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Book Contents

CHAPTER ONE

THE ATMOSPHERE

Contents

A DEFINITION OF METEOROLOGY

"The branch of science dealing with the earth's atmosphere and the physical processes occurring in it."

REASONS FOR STUDYING METEOROLOGY

- To gain a better understanding of meteorologists' deductions.
- To gain a better understanding of meteorologists' documentation.
- To gain a better understanding of in-flight hazards.
- To gain a better understanding of data and its collection.
- To gain a better understanding of self-forecasting.

Weather is the one factor in modern aviation over which man has no control, knowledge of meteorology will at least enable the aviator to anticipate some of the difficulties which weather may cause.

Weather - influenced accidents to UK transport aircraft

Table 1 Transport aircraft accidents, 1975 – 94

All accidents

	Aeroplanes			Rotorcraft			All aircraft		
Year	Total	WI	Per cent	Total	WI	Per cent	Total	WI	Per cent
1975-79	52	17	32.69	9	4	44.44	61	21	34.43
1980-84	67	20	29.85	20	7	35.00	87	27	31.03
1985-89	95	22	23.16	20	3	15.00	115	25	21.74
1990-94	216*	25	11.58*	20	6	30.00	236*	31	13.13*
1975-94	430	84	19.53	69	20	28.98	499	104	20.84

* Includes ramp and other minor ground accidents, hence low percentage figures.
WI: Weather-influenced

Accidents excluding selected ramp and other occurrences

	Aeroplanes			Rotorcraft			All aircraft		
Year	Total	WI	Per cent	Total	WI	Per cent	Total	WI	Per cent
1975-79	52	17	32.69	9	4	44.44	61	21	34.43
1980-84	67	20	29.85	20	7	35.00	87	27	31.03
1985-89	78	22	28.20	20	3	15.00	98	25	25.51
1990-94	101	25	24.75	20	6	30.00	121	31	25.62
1975-94	298	84	28.18	69	20	28.98	367	104	28.34

WI: Weather-influenced

Table 2 Weather -influence accidents to transport aircraft by element of weather, 1975 -94

	All accidents		Fatal accidents	
Element	No.	Percentage of total	No.	Percentage of total
Visibility	22	21.1	10	66.7
Icing/snow	22	21.1	3	20.0
Wind and turbulence	45	43.3	2	13.3
Rain/wet runway	12	11.5	0	0
Lightning	3	2.9	0	0
All cases	104	100	15	100

Note: *For this course, knowledge of advanced physics is not required, but a knowledge of the elementary laws of motion, heating, cooling, condensation and evaporation will be useful.*

A DEFINITION OF THE ATMOSPHERE

"The spheroidal gaseous envelope surrounding a heavenly body."

The majority of the gases in our atmosphere have been produced by internal process on the earth, such as volcanic eruptions and photosynthesis from plants. The gases, once produced, become trapped by gravity and are therefore held against the surface of the earth.

THE CONSTITUENTS OF THE ATMOSPHERE (BY VOLUME)

Nitrogen	78 %	Argon	0.95%
Oxygen	21 %	Carbon Dioxide	0.05%

Plus traces of:

Neon	Nitrous Oxide	Helium	Nitrogen Dioxide
Krypton	Carbon Monoxide	Xenon	Sulphur Dioxide
Hydrogen	Ammonia	Methane	Iodine and Ozone
Water Vapour			

Of all the trace gases, water vapour is by the far the most significant. Without it there would be no weather.

The proportions of the constituent gases remain constant up to a height of at least 60 km (except for Ozone), but by 70 km the force of gravity, being less, causes the proportions to change. Although the trace of ozone in the atmosphere is important as a shield against ultra violet radiation, if the whole of the layer of ozone were brought down to sea level it would only be 3 mm thick.

PROPERTIES OF THE EARTH'S ATMOSPHERE

The earth's atmosphere varies vertically and horizontally in:

- Pressure
- Temperature
- Density
- Humidity

The earth's atmosphere is a poor conductor. The earth's atmosphere is fluid.

THE STRUCTURE OF THE ATMOSPHERE

The organisation of the atmosphere into different layers is determined by the temperature lapse rate. Each layer of the atmosphere has a unique temperature profile. There are several layers in the atmosphere, but only the lower ones will be discussed here.

The Troposphere

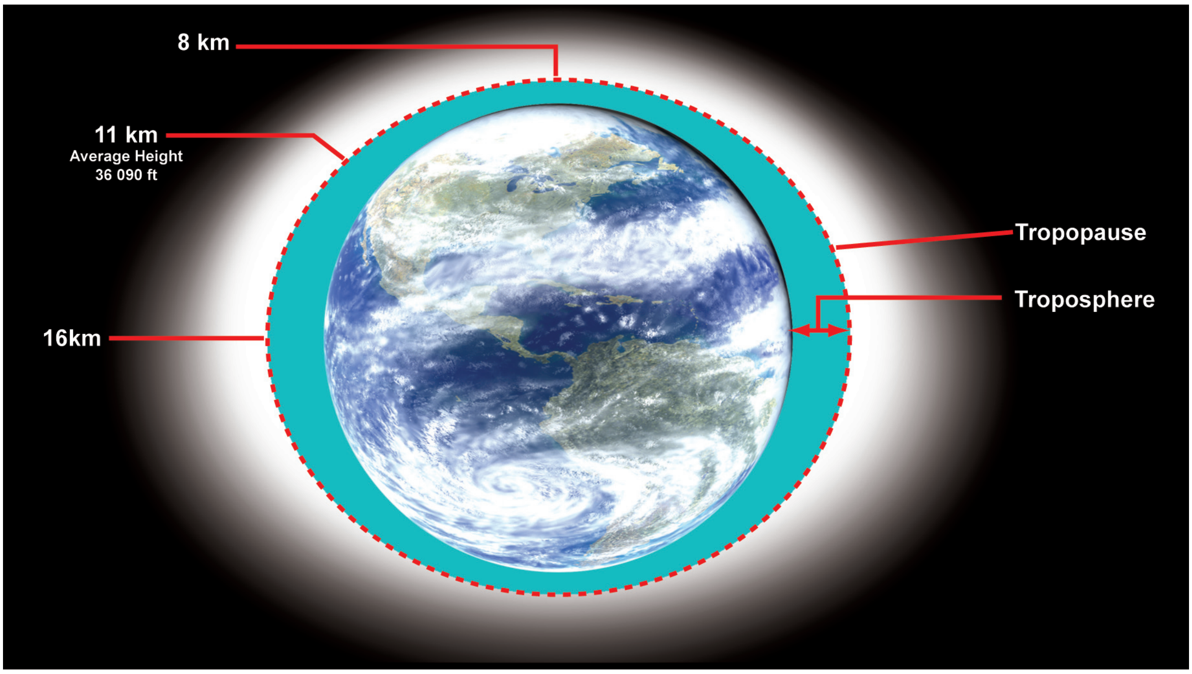
This is layer in the atmosphere closest to the earth's surface and it is defined by the fact that temperature decreases with height by approximately 0.65°C/100 m (1.98°C/1000 ft). It consists of ¾ of the total atmosphere in weight and contains almost all the weather. On average this layer extends from the surface to a 11 km.

The Tropopause

The Tropopause is at the top of the troposphere. It marks the boundary between the troposphere and the next atmospheric layer, the stratosphere. The tropopause is defined as being that part of the atmosphere where temperature no longer decreases with height. (Practically taken as the height where the temperature fall is less than 0.65° per 100m (1.98°C per 1,000 ft.). There are two important points about the tropopause you need to be familiar with, these are it's height and it's temperature.

- The height of the tropopause is controlled by the temperature of the air near the surface. The warmer the air, the higher the tropopause. The colder the air, the lower the tropopause. Generally over the poles, the tropopause can be between 8 -10 km and over the equator 16 - 18 km. Surface temperature variations due to latitude, season, land and sea, will all cause varying heights of the tropopause. For example in winter the tropopause is lower than in the summer.

- Since temperature decreases with height it goes to follow that the temperature at the tropopause is controlled by its height. The higher it is, the colder the temperature at the tropopause. The lower it is, the warmer the temperature at the tropopause. The temperature at the tropopause can be as high as -40°C over the poles and as low as -80°C over the equator. However, on average the tropopause is at about 11 km where its temperature is -56.5°C.



An illustration showing the troposphere and tropopause

The significance of the tropopause height is that it usually marks;-

- the maximum height of the cloud
- the presence of Jetstreams
- the presence of Clear Air Turbulence (CAT)
- the maximum wind speed

The Stratosphere

This layer of the atmosphere is defined as that layer above the troposphere where the temperature (more or less) remains constant with an increase in height. (In fact temperature shows a gradual increase with height, especially at the top, where the temperature is zero at 50 km. This is due to the absorption of the sun's ultra violet radiation by the concentration of ozone at higher levels). The upper boundary to the stratosphere is called the Stratopause. On average the stratosphere layer extends from 11 km to about 50 km.

The Mesosphere

This layer of the atmosphere is found above the stratosphere and below the thermosphere. It is characterised by a decrease in temperature with height. In fact the Mesosphere is the coldest layer in the atmosphere with temperatures in the upper mesosphere as low as 200K or -73°C. The mesosphere is located from approximately 50 to 80/85 km above Earth's surface. Noctilucent clouds are located in the mesosphere. The upper boundary to the Mesosphere is called the Mesopause.

ATMOSPHERIC HAZARDS

As aircraft operating altitudes increase, so concentrations of OZONE and COSMIC RADIATION become of greater importance to the aviator.

Above 50,000ft, normal concentrations of ozone exceed tolerable limits and air needs to be filtered before entering the cabin. The heat of the compressor system will assist in the breaking down of the ozone to an acceptable level.

Cosmic radiation is not normally hazardous, but at times of solar flare activity a lower flight level may be necessary.
Advances in meteorological forecasting and communications should result in pilots receiving prompt and accurate information regarding high altitude hazards, but it is important that they should be aware of these hazards and prepared to take the necessary re-planning action.

THE ICAO STANDARD ATMOSPHERE (ISA)

For a variety of reasons it is necessary to establish a standard average atmosphere, describing variations in temperature, pressure and density throughout altitude.

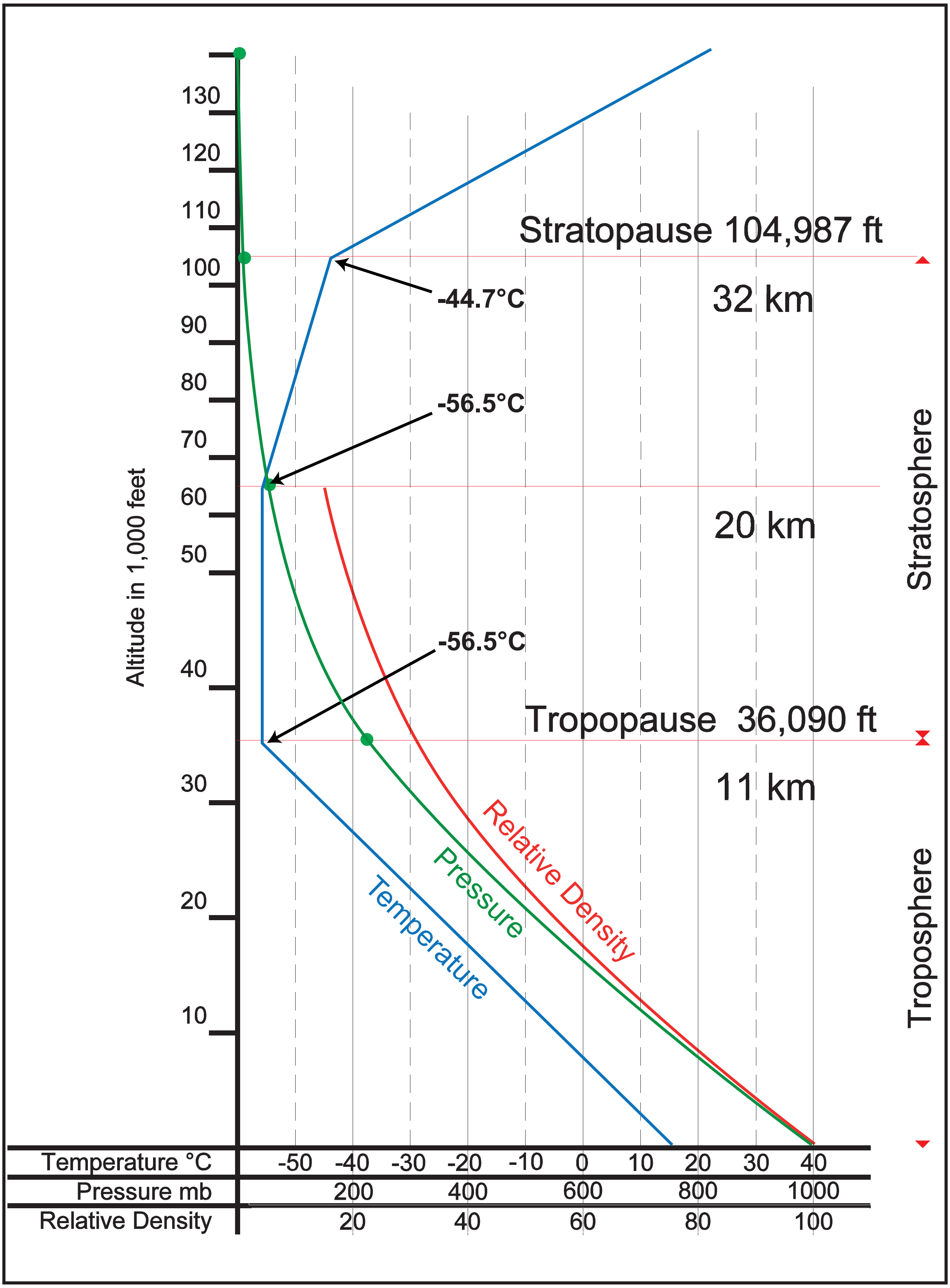
There have been several different Standard Atmospheres, but the one in general use now is the 'ICAO Standard Atmosphere', dated 1964 which covers an atmosphere from -0.5 km to 32 km.

The ISA is needed for;-

- the calibration of aircraft instruments
- the design and testing of aircraft

The ICAO ISA is defined as follows:-

- a MSL temperature of +15°C
- a MSL pressure of 1013.25 hPa
- a MSL density of 1225 g/m^3
- a lapse rate of 0.65°C/100m (1.98° C /1000 ft) up to 11 km (36,090 ft)
- a constant temperature of -56.5°C from 11 km (36,090ft) to 20 km (65,617 ft)
- an increase of temperature 0.1°C/100m (0.3°C /1000 ft), from 20 km (65,617ft) to 32 km (104,987 ft)



The International Standard Atmosphere (ISA)

ISA DEVIATION

Although meteorological observations are made in absolute figures, it is usual, when making calculations involving aircraft performance or corrections to instruments, to consider them relative to the ISA. These are known as “ISA deviations”.

If for instance, the observed temperature were 5°C warmer than that expected in the ISA, then the deviation would be described as ISA + 5.

For the temperatures below, calculate the ISA deviations;-

Height (ft)	Temperature (°C)	ISA Temperature	ISA Deviation
1,500	+28		
17,500	-18		
24,000	-35		
37,000	-45		
9,500	-5		
5,000	+15		
31,000	-50		
57,000	-67		

Q1: If the limiting deviation for your aircraft at an airfield 5,000 ft AMSL is ISA +10, what is the maximum temp at which you can operate?

Q2: If the deviation at 3,500 ft is ISA + 12, what is the ambient temperature?

THE ICAO STANDARD ATMOSPHERE

Height (km)	Height (ft)	Temp (°C)	Pressure (hPa)	Change of Height per hPa	Density (%)
32.00	104,987	-44.7	8.9		1.1
30.48	100,000	-46.2	11.1		1.4
27.43	90,000	-49.2	17.3		2.2
24.38	80,000	-52.2	28.0		3.6
21.34	70,000	-55.2	44.9		5.8
20.00	65,620	-56.5	56.7		7.2
15.24	50,000	-56.5	116.6		15.3
13.71	45,000	-56.5	148.2		19.5
11.78	38,662	-56.5	200	103 ft	26.3
11.00	36,090	-56.5	228.2	91 ft	29.7
9.16	30,065	-44.4	300	73 ft	36.8
5.51	18,289	-21.2	500	48 ft	56.4
3.05	10,000	-4.8	696.8	37 ft	73.8
3.01	9,882	-4.6	700	36 ft	74.1
1.46	4,781	+5.5	850	31 ft	87.3
0	0	+15	1013.25	27 ft	100

You will notice that parts of the Height Change per hPa are left blank. You may fill these in using the formula below.

$$H = \frac{96T}{P}$$

Where:

H = height change (in feet) per hPa
T = Actual Absolute Temperature at that level (Kelvin)
P = Actual Pressure in hPa
K = 96 (the equation constant)

The 4% Rule:

The 4% rule is an extension of the above which states that when the ELR temperature is 10°C away from ISA a 4% height error is generated at or through any given altitude change.

QUESTIONS

1. Which one of the following statements applies to the tropopause?

   a. It is, by definition, an isothermal layer
   b. It indicates a strong temperature lapse rate
   c. It is, by definition, a temperature inversion
   d. It separates the troposphere from the stratosphere

2. At a certain position, the temperature on the 300 hPa chart is -48°C; according to the tropopause chart, the tropopause is at FL 330. What is the most likely temperature at FL 350?

   a. -54°C
   b. -50°C
   c. -56.5°C
   d. -58°C

3. The tropopause is lower

   a. south of the equator than north of it
   b. over the equator than over the South Pole
   c. over the North Pole than over the equator
   d. in summer than winter in moderate latitudes

4. What is the most likely temperature at the tropical tropopause?

   a. -55°C
   b. -35°C
   c. -25°C
   d. -75°C

5. Which statement is correct regarding the International Standard Atmosphere?

   a. At MSL temperature is 15°C and the decrease in temperature with height is 1°C per 100m
   b. At MSL temperature is 10°C and the decrease in temperature with height is 1°C per 100m
   c. At MSL pressure is 1013.25 hPa and the decrease of temperature with height is 1°C per 100m
   d. At MSL temperature is 15°C and pressure is 1013.25hPa

6. The tropopause is a level at which

   a. water vapour content is greatest
   b. pressure remains constant
   c. vertical currents are strongest
   d. temperature ceases to fall with increasing height

7. The 0°C isotherm is forecast to be at FL 50.
   At what FL would you expect a temperature of -6°C?

   a. FL 80
   b. FL 20
   c. FL 100
   d. FL 110

8. How does temperature vary with increasing altitude in the ICAO standard atmosphere below the tropopause?

a. Increases
b. At first it increases and higher up it decreases
c. Remains constant
d. Decreases

9. Which is true of the temperature at the tropopause?

a. It is higher in polar regions than in equatorial regions
b. It is higher in equatorial regions than in Polar Regions
c. It is highest in middle latitudes
d. There is no significant difference with change of latitude

10. What is the boundary layer between troposphere and stratosphere called?

a. Tropopause.
b. Ionosphere.
c. Stratosphere.
d. Atmosphere.

11. How would you characterise an air temperature of -15°C at the 700 hPa level over Western Europe?

a. Low
b. High
c. Within +/-5°C of ISA
d. 20°C below standard

12. The temperature at FL 110 is -5°C. What will the temperature be at FL 50 if the ICAO standard lapse rate is applied?

a. +3°C
b. 0°C
c. -3°C
d. +7°C

13. How does the height of the tropopause normally vary with latitude in the northern hemisphere?

a. It remains constant throughout the year.
b. It decreases from south to north.
c. It remains constant from north to south.
d. It increases from south to north.

14. The temperature at FL 80 is +6°C. What will the temperature be at FL 130 if the ICAO standard lapse rate is applied?

a. +2°C
b. -4°C
c. -6°C
d. 0°C

15. The lowest assumed temperature in the ICAO Standard Atmosphere is :

a. -273°C
b. -44.7°C
c. -100°C
d. -56.5°C

16. The troposphere is the:

a. part of the atmosphere below the tropopause
b. part of the atmosphere above the stratosphere
c. boundary between the mesosphere and thermosphere
d. boundary between the stratosphere and the mesosphere

17. How would you characterise an air temperature of -55°C at the 200 hPa level over Western Europe?

a. Within +/-5°C of ISA
b. High
c. Low
d. Very high

18. The height and the temperature of the tropopause are respectively in the order of

a. 8 km and -40°C over the equator
b. 8 km and - 75°C over the poles
c. 16 km and -40°C over the poles
d. 16 km and -75°C over the equator

19. What of the following is the most important constituent in the atmosphere from a weather stand-point?

a. Nitrogen
b. Oxygen
c. Hydrogen
d. Water vapour

20. What is the vertical temperature lapse rate, up to 11 km, in the ICAO standard atmosphere?

a. 6.5°C per 1000 m
b. 4.5°C per 1000 m
c. 3°C per 1000 m
d. 2°C per 1000 m

21. An outside air temperature of -35°C is measured while cruising at FL 200. What is the temperature deviation from the ISA at this level?

a. 10°C warmer than ISA.
b. 5°C warmer than ISA.
c. 5°C colder than ISA.
d. 10°C colder than ISA.

22. How would you characterise an air temperature of -30°C at the 300 hPa level over Western Europe?

a. Within +/-5°C of ISA
b. Low
c. Very low
d. High

23. The rate of decrease of temperature with height per 100 m in the International Standard Atmosphere is:

a. 0.65°C
b. 1°C
c. 0.5°C
d. variable

24. What is the approximate composition of the dry air by volume in the troposphere?

a. 50 % oxygen, 40 % nitrogen, and the rest other gasses
b. 21 % oxygen, 78 % nitrogen, and the rest other gasses
c. 10 % oxygen, 89 % nitrogen, and the rest other gasses
d. 88 % oxygen, 9 % nitrogen, and the rest other gasses

25. If you are flying at FL 300 in an air mass that is 15°C warmer than a standard atmosphere, what is the outside temperature likely to be?

a. -15°C
b. -30°C
c. -45°C
d. -60°C

26. A temperature of +15°C is recorded at an altitude of 500 metres above sea level. If the vertical temperature gradient is that of a standard atmosphere, what will the temperature be at the summit of a mountain, 2500 metres above sea level?

a. +4°C
b. 0°C
c. -2°C
d. +2°C

27. The temperature at FL 140 is -12°C. What will the temperature be at FL 110 if the ICAO standard lapse rate is applied?

a. -15°C.
b. -6°C.
c. -18°C.
d. -9°C.

28. If you are flying at FL 120 and the outside temperature is -2°C, at what altitude will the "freezing level" be?

a. FL 150
b. FL 90
c. FL 110
d. FL 130

29. The troposphere:

    a. reaches the same height at all latitudes
    b. has a greater vertical extent above the equator than above the poles
    c. contains all oxygen of the stratosphere
    d. is the separation layer between the stratosphere and atmosphere

30. The thickness of the troposphere varies with:

    a. rotation of the earth
    b. the wind
    c. latitude
    d. longitude

31. What, approximately, is the average height of the tropopause over the equator?

    a. 16 km
    b. 8 km
    c. 11 km
    d. 40 km

32. Going from the equator to the North Pole, the altitude of the tropopause

    a. decreases and its temperature increases
    b. increases and its temperature increases
    c. increases and its temperature decreases
    d. decreases and its temperature decreases

33. The temperature at 10,000 FT in the International Standard Atmosphere is :

    a. -20°C
    b. -35°C
    c. -5°C
    d. 0°C

34. The average height of the tropopause at 50°N is about:

    a. 14 km
    b. 16 km
    c. 11 km
    d. 8 km

35. In the lower part of the stratosphere the temperature

    a. increases with altitude
    b. increases at first and decreases afterward
    c. is almost constant
    d. decreases with altitude

36. Which layer of the atmosphere contains more than 90% of all water vapour?

    a. Troposphere
    b. Lower stratosphere
    c. Upper stratosphere
    d. Ionosphere

37. In the mid-latitudes the stratosphere extends on an average from:

a. 85 to more than 200 km
b. 11 to 50 km
c. 0 to 11 km
d. 50 to 85 km

ANSWERS TO ISA DEVIATION QUESTIONS

Height (ft)	Temperature (°C)	ISA Temperature	ISA Deviation
1,500	+28	+12°C	+16
17,500	-18	-20°C	+2
24,000	-35	-33°C	-2
37,000	-45	-56.5°C	+11.5
9,500	-5	-4°C	-1
5,000	+15	+5°C	+10
31,000	-50	-47°C	-3
57,000	-67	-56.5°C	-10.5

Q1: Max temperature +15°C

Q2: Ambient temperature +20°C

ANSWERS TO ICAO STANDARD ATMOSPHERE TABLE

Height (km)	Height (ft)	Temp (°C)	Pressure (hPa)	Change of Height per hPa	Density (%)
32.00	104,987	-44.7	8.9	2463 ft	1.1
30.48	100,000	-46.2	11.1	1962 ft	1.4
27.43	90,000	-49.2	17.3	1242 ft	2.2
24.38	80,000	-52.2	28.0	757 ft	3.6
21.34	70,000	-55.2	44.9	466 ft	5.8
20.00	65,620	-56.5	56.7	367 ft	7.2
15.24	50,000	-56.5	116.6	178 ft	15.3
13.71	45,000	-56.5	148.2	140 ft	19.5
11.78	38,662	-56.5	200	103 ft	26.3
11.00	36,090	-56.5	228.2	91 ft	29.7
9.16	30,065	-44.4	300	73 ft	36.8
5.51	18,289	-21.2	500	48 ft	56.4
3.05	10,000	-4.8	696.8	37 ft	73.8
3.01	9,882	-4.6	700	36 ft	74.1
1.46	4,781	+5.5	850	31 ft	87.3
0	0	+15	1013.25	27 ft	100

ANSWERS

1.	D	11.	A	21.	D	31.	A
2.	A	12.	D	22.	D	32.	A
3.	C	13.	B	23.	A	33.	C
4.	D	14.	B	24.	B	34.	C
5.	D	15.	D	25.	B	35.	C
6.	D	16.	A	26.	D	36.	A
7.	A	17.	A	27.	B	37.	B
8.	D	18.	D	28.	C		
9.	A	19.	D	29.	B		
10.	A	20.	A	30.	C		

CHAPTER TWO

PRESSURE

Contents

INTRODUCTION

Understanding the variations in atmospheric pressure across the Earth's surface is fundamental to an understanding of the weather, itself. But what is the fundamental cause of atmospheric pressure? Expressed simply, atmospheric pressure, which acts on any object immersed in the atmosphere, is caused by the weight of air above that object. Atmospheric pressure acts in all directions.

The forces generated by horizontal pressure differences across the Earth's surface give rise to both horizontal, and vertical air movement, creating winds and clouds. The variation of atmospheric pressure with altitude allows us to measure the vertical separation of an aircraft from the Earth's surface, using an instrument called an altimeter.

The Fundamental Cause of Atmospheric Pressure

The air which constitutes our atmosphere is made up of billions of molecules. The atmosphere, therefore, has mass, and, as a result of the Earth's gravitational field pulling the mass of the atmosphere towards the centre of the Earth, air possesses weight. The pressure of the atmosphere at any point is caused by the weight of the column of air overlying that point. Atmospheric pressure (sometimes, in other branches of aeronautics, called static pressure) acts in all directions on any object contained within the atmosphere.

Most of the mass of the atmosphere is contained in its lower layers near the Earth's surface. This is because of the action of the Earth's gravitational field on the air molecules (the force of gravity being greater near the surface), combined with the fact that air is compressible. The air in the lower layers of the atmosphere is compressed by the weight of the air above it. Consequently, air is denser, and atmospheric pressure is greater, at the Earth's surface than at altitude.

Figure 2.1 represents the relative distribution of molecules within the atmosphere, with more molecules in the lower part of the atmosphere than at altitude. The red arrows within the column of air illustrate that the atmosphere exerts its pressure equally, in all directions.

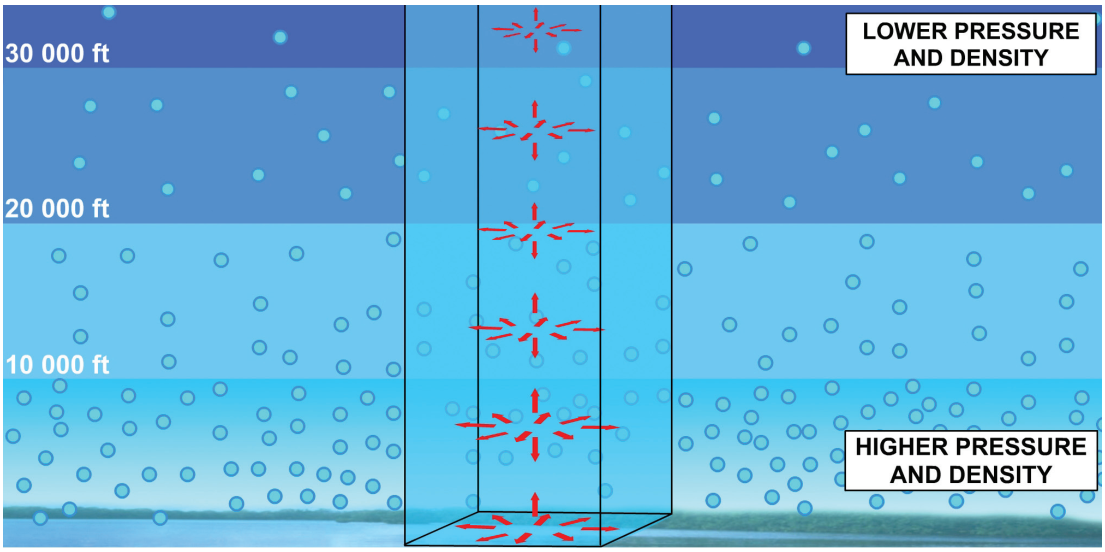


Figure 2.1 Atmospheric Pressure

Atmospheric Pressure is the force or weight exerted on any object by the column of air above that object. Atmospheric (or static) pressure acts in all directions and reduces with increasing altitude.

UNITS OF ATMOSPHERIC PRESSURE

In meteorology, the units commonly used to represent atmospheric pressure are inches of mercury, and millibars or hectopascals. The ICAO Standard Atmosphere (ISA) unit of pressure is the hectopascal, but, currently, the millibar is still used in the United Kingdom. The millibar and the hectopascal are identical in value. For instance, ISA sea-level pressure can be expressed as 1013.25 millibars or 1013.25 hectopascals. In the United States of America, atmospheric pressure is expressed in inches of Mercury. In inches of Mercury, ISA sea-level pressure is 29.92 inches Hg.

The instrument used to measure atmospheric pressure is the barometer (from Greek “baros” meaning weight and “metron” meaning measure). A barometer can be one of two distinct types: the aneroid barometer or the mercury barometer.

The Mercury Barometer
The mercury barometer consists of a glass tube, sealed at one end, containing Mercury, with the open end immersed in an open mercury reservoir, in the form of a dish.

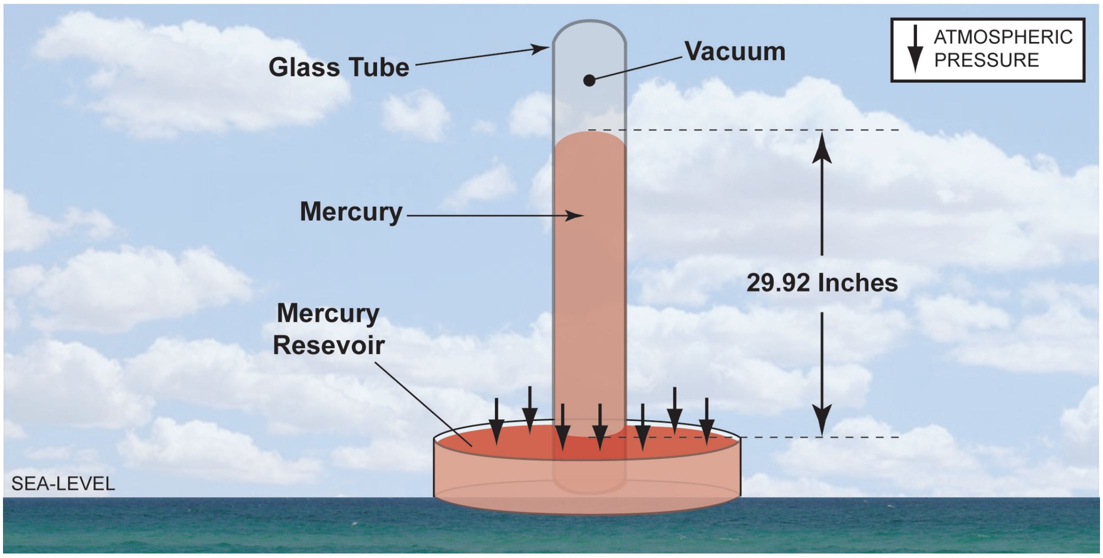


Figure 2.2 A simple Mercury Barometer

The weight of the column of Mercury in the glass tube is balanced by atmospheric pressure exerted on the Mercury in the dish. In ISA sea-level conditions, the height of the Mercury column would be 29.92 inches. Changes in atmospheric pressure will either depress the Mercury in the open reservoir, forcing more of the Mercury up into the tube, or will allow the level of Mercury in the reservoir to rise, permitting the height of the Mercury in the glass tube to fall. The space above the column of Mercury in the tube is almost a vacuum.

The Aneroid Barometer

The aneroid barometer does not contain mercury or liquid, but measures the effect of air pressure on a partially evacuated metal capsule. The aneroid barometer (from Greek "a" meaning not and "neros" meaning water) is less accurate overall than the mercury barometer, but is more sensitive to small changes in air pressure. Changes in air pressure cause the metal capsule to expand or contract; a mechanism connected to the capsule causes a needle or pointer to move around a calibrated scale.

An aneroid barometer may be calibrated in inches of mercury or in millibars. However, an aneroid barometer can also be calibrated in feet or metres to indicate height above the Earth's surface; the instrument is then known as an altimeter.

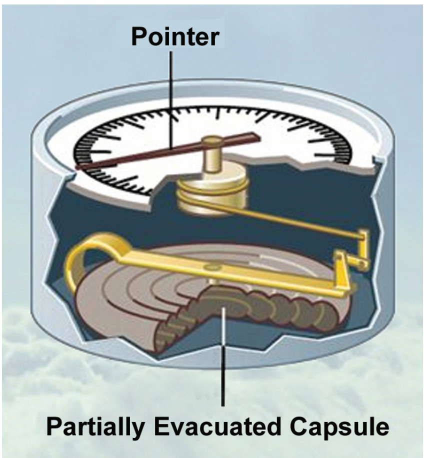


Figure 2.3 Aneroid Barometer

An example of a portable aneroid barometer used widely by Air Traffic Service Units to measure pressure at the Earth's surface is shown in Figure 2.4.

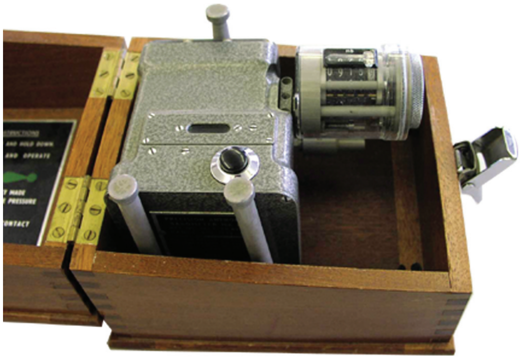


Figure 2.4 Aneroid Barometer

Figure 2.5 Barograph

A barograph is an aneroid barometer which records pressure against time on a cylindrical chart. The barograph is usually driven by clockwork.

PRESSURE VARIATIONS AT THE EARTH'S SURFACE

Horizontal variations in surface pressure arise because of the differences in weight of different columns of air overlying different locations on the Earth's surface.

Comparatively speaking, if there is a greater mass of air above a given area on the Earth's surface, then the atmosphere will be exerting more pressure on that area. If, in another location, there is less air above the Earth's surface, the atmosphere will be exerting less pressure on the surface. Therefore, high or low surface pressures are a direct consequence of the weight of the mass of the air overlying a given locality, as depicted in Figure 2.6.

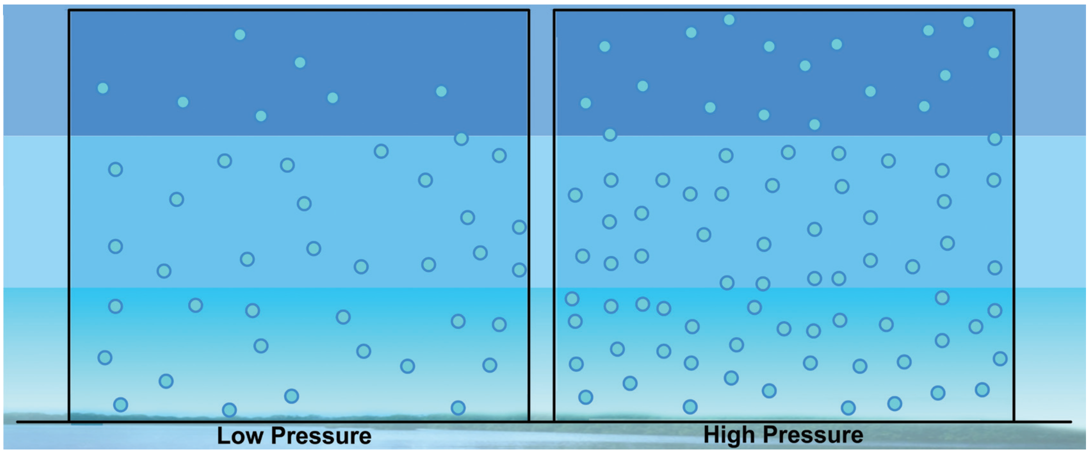


Figure 2.6

The mechanisms which give rise to these differences in surface pressure are described below. Diagrammatic representations of variations in surface pressure allow us to identify areas of high and low pressure on the Earth's surface. By mapping these pressure variations, it is possible to analyse and, therefore, predict the weather. Diagrams of variations in surface pressure are called surface pressure charts, or, sometimes, synoptic charts (from synopsis meaning a general view).

MEAN SEA-LEVEL SURFACE PRESSURE CHARTS

Figure 2.7 shows a typical surface pressure chart. Its interpretation and main features will be explained in the following paragraphs.

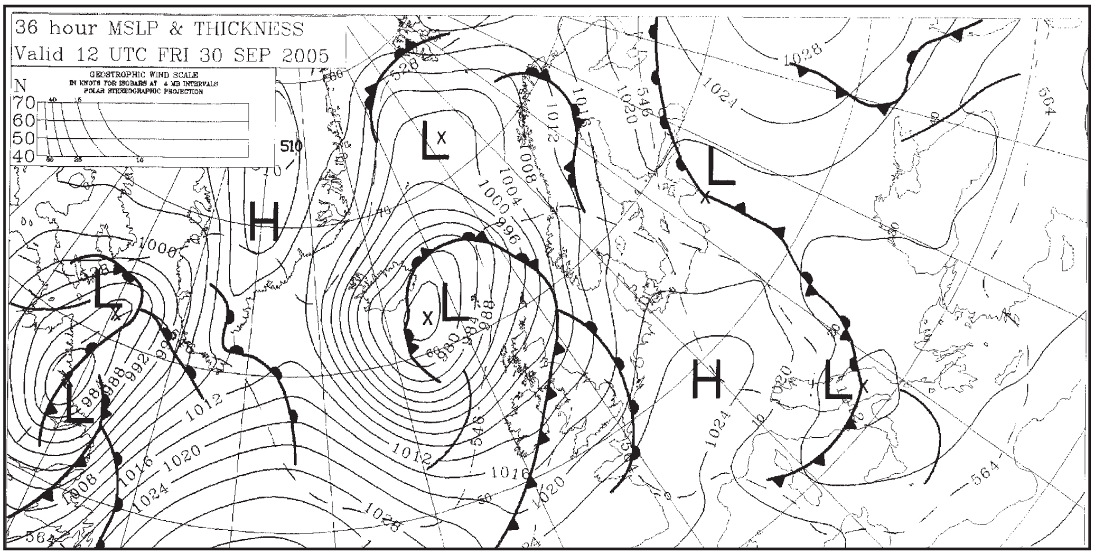


Figure 2.7 Surface Pressure Chart

The Earth's surface is made up of plains, mountains, lakes and oceans, and, so, over the Earth's surface, there are wide variations in the elevation of terrain. Consequently, in order to obtain an accurate surface pressure chart, surface pressure readings need to be made with respect to a common vertical datum. Mean sea-level is the usual datum from which pressures are measured.

The chart at Figure 2.7 shows the actual horizontal variation in pressure on a given day (30 Sep 2005). The chart is made up of the individual observations taken at different reporting stations.

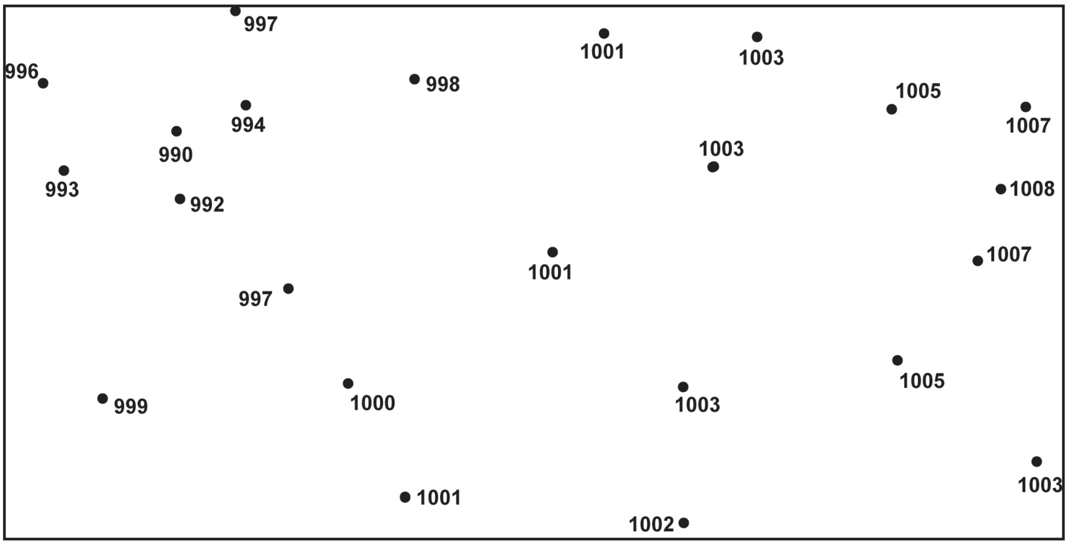


Figure 2.8 Pressure Readings

Figure 2.8, on the other hand, shows a fictional example of reported mean sea level pressures from meteorological stations across the Earth's surface. To produce a Mean Sea Level Pressure Chart from the figures given in Figure 2.8, lines are drawn connecting all the stations with the same pressure readings. These lines are called isobars (from Greek isos meaning equal and baros meaning weight).

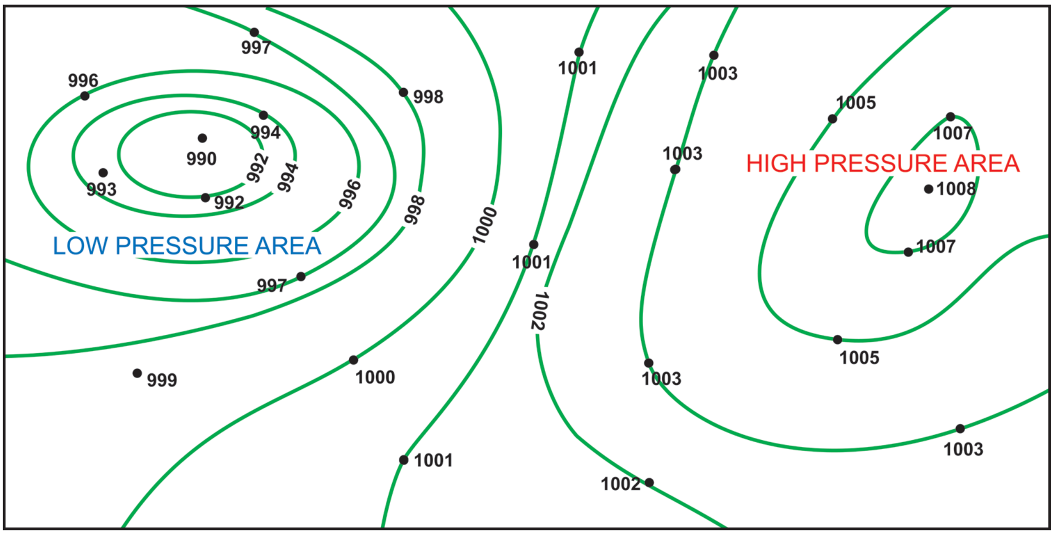


Figure 2.9 Mean Sea Level Pressure Chart

From the pressure values and isobars, relative areas of low and high atmospheric pressure can be identified. Isobars centred on an area of low pressure values indicate a low pressure area, and isobars centred on an area of relatively higher pressure values indicate an area of high pressure. The dimensions of these high and low pressure area systems can range from tens of nautical miles wide to hundreds, and sometimes a thousand miles wide.

Low pressure areas are known as depressions. High pressure areas are known as anticyclones.

Around the British Isles, the pressure at mean sea-level fluctuates between extremes of 950 millibars and 1050 millibars, but is usually around 1 000 millibars.

THE PRESSURE GRADIENT FORCE

The isobars themselves can reveal a great deal of useful information. Air will always tend to move from an area of high pressure to an area of low pressure. Consequently, a force exists which acts from the high pressure regions to the low pressure regions. This force is called the pressure gradient force. The direction of action of the pressure gradient force is shown in Figure 2.10.

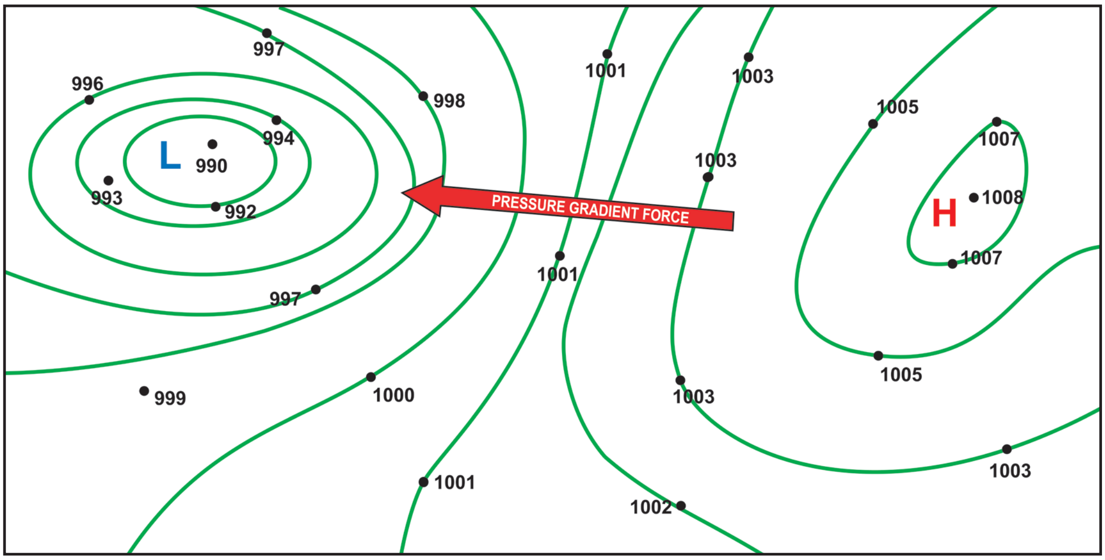


Figure 2.10

The force acting from the high pressure area (H) to the low pressure area (L) is called the Pressure Gradient Force. The spacing between isobars is indicative of the relative strength of the pressure gradient force.

Isobars may be compared to contour lines on a topographical map, where the contour line spacing indicates the gradient of a slope. Closely spaced isobars show a large change in the pressure over a short distance, indicating the presence of a large pressure gradient force; this is common within low pressure areas. Widely spaced isobars show a small change in the pressure over a large distance, indicating a small pressure gradient force; this is common within high pressure areas. Wind speed and direction will be discussed in greater detail later.

VERTICAL PRESSURE VARIATION

The relative number and distribution of air molecules shown in Figure 2.11 indicates that the higher an aircraft climbs in the atmosphere, the smaller will be the mass of air above the aircraft, and, therefore, the lower will be the atmospheric pressure exerted on the aircraft. So, as we have already mentioned, atmospheric pressure decreases with increasing altitude.

Atmospheric pressure falls very quickly with altitude near the Earth's surface, but, at high altitude, the rate of pressure reduction with height is much less marked. This is because most of the air is located close to the Earth's surface.

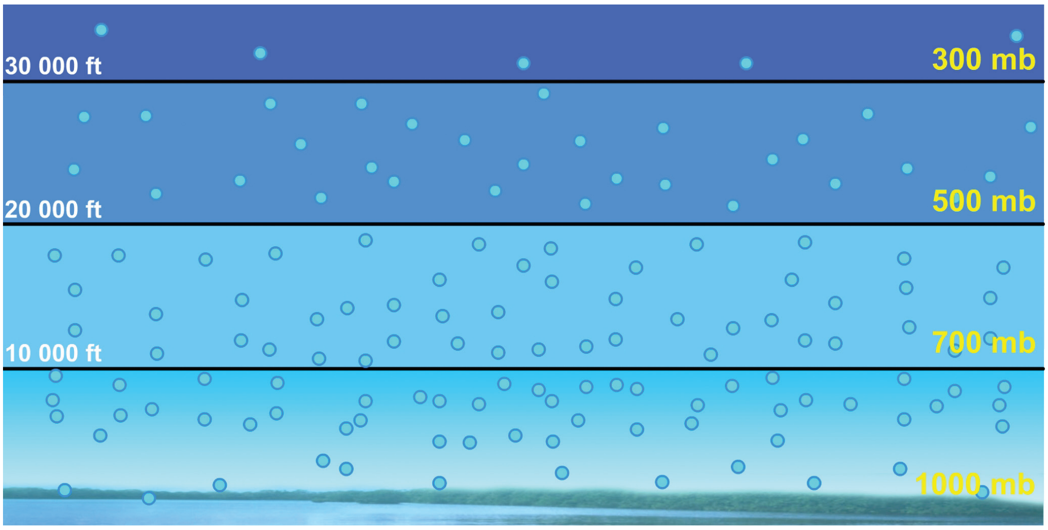


Figure 2.11

The rate at which pressure decreases with altitude also falls as altitude increases. In the ICAO Standard Atmosphere (ISA), the fall in pressure with height, close to sea-level, is approximately 1 millibar for every 27 feet. However, at 10 000 feet the rate of pressure decrease with altitude is less, being approximately 1 millibar for every 36 feet gain of height.

For the purposes of pressure versus height calculations, it is assumed that the average change of pressure with height, below the Tropopause, is 1 millibar for every 27 feet.

THE EFFECT OF TEMPERATURE ON VERTICAL PRESSURE VARIATION

However, even in identical atmospheric layers, the rate of pressure change with altitude is not always constant. Sometimes, pressure falls more rapidly with increasing altitude than at other times. The reason for this is the variations in temperature over the Earth's surface. In Figure 2.12 you will see three different columns of air. For simplicity, we have included only six molecules of air per column.

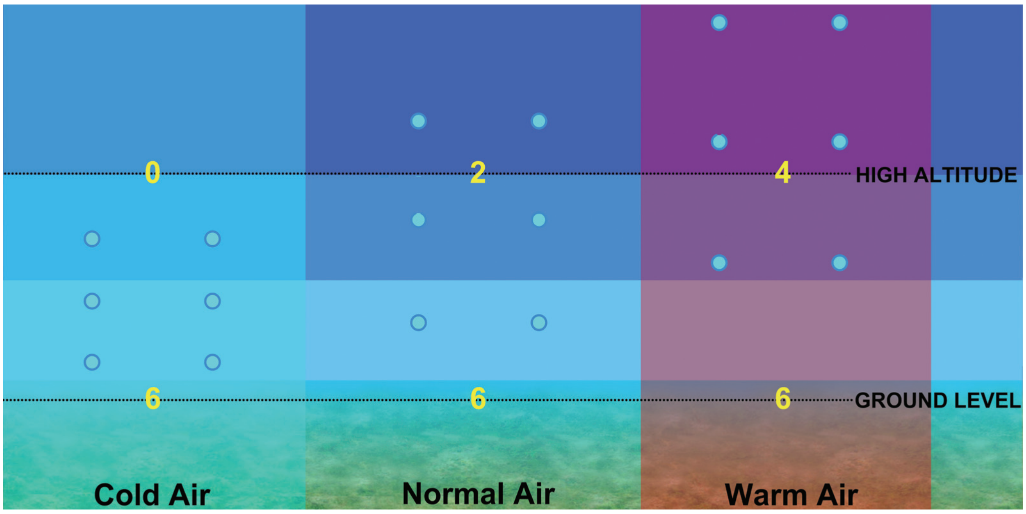


Figure 2.12

Cold air causes pressure to fall more rapidly with height. Warm air causes pressure to fall more slowly with height.

Examine the column in the middle of Figure 2.12, which we will assume represents a "normal" atmosphere. As there are six molecules represented in each column, we will express the pressure at the Earth's surface, caused by the column of air, as six units. However, at high altitude, there are only two molecules, so we will express the atmospheric pressure at high altitude, in this column, as two units.

Now, look at the left hand column of air in Figure 2.12. Here, the air is colder, and, as a result, the air has become denser, with the air molecules collecting at the bottom of the column. Surface pressure is still six units, because there are still six molecules bearing down on the surface. However, because the air in this column is cold, there are no molecules at all at altitude; so pressure at altitude in this column, is approaching zero units. You can now see that cold air has caused the pressure to decrease much more rapidly with height than in the warmer air of the "normal" atmosphere. You will not be surprised to find that the opposite is true when the air is warmer than normal.

Examine the column of air on the right. Since this column represents warmer than normal air, the molecules have risen to the top of the column. There are still six molecules above the surface, so the pressure at the surface is still six units, but at altitude there are now four molecules; so pressure at altitude, in this column is 'four units'.

Note: *The warm air has caused the pressure to decrease with altitude much more slowly than normal.*

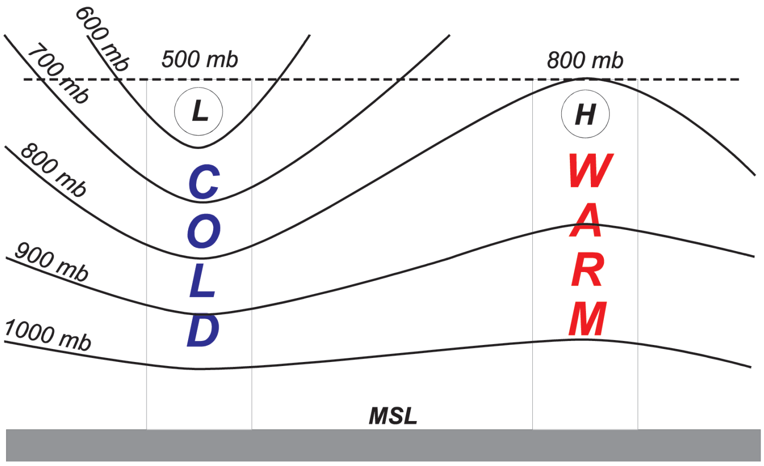


Figure 2.13

The effect that temperature has on pressure change with height can also be shown in another way. Figure 2.13 depicts a column of cold air on the left, and a column of warm air on the right. Notice that, since cold air causes pressure to fall more rapidly with height, the pressure levels in the cold air column are compressed towards the Earth's surface, whereas, in the warm air column, they expand away from the surface. Cold air compacts pressure levels and warm air expands pressure levels.

The Effect of Temperature on Altimeter Readings

The altimeter is calibrated in ISA conditions, so, if the temperature is other than the ISA value, the altimeter indication will be in error. You have already learnt that pressure changes with altitude at different rates, depending on the temperature of the air. Therefore, an altimeter is subject to temperature error. The altimeter will read correctly only when ISA conditions prevail, which is almost never. However, altimeter temperature errors are not excessive.

Temperature Error in an Altimeter

In the ISA, if the atmospheric pressure were to be 300 millibars (or hectopascals), an altimeter would register a height of 30,000 ft. (See Figure 2.14.) However, if the atmosphere were to be colder than ISA, as shown on the left of Figure 2.14, the 300 millibar pressure level would be at a lower true altitude than 30,000 ft. But, because the altimeter has been calibrated to ISA, it would still read 30,000 ft at the 300 millibar level. The altimeter is, however, clearly in error, as the true altitude of the altimeter in the column of cold air is less than 30,000 ft. In the column of cold air, therefore, the altimeter is over-reading.

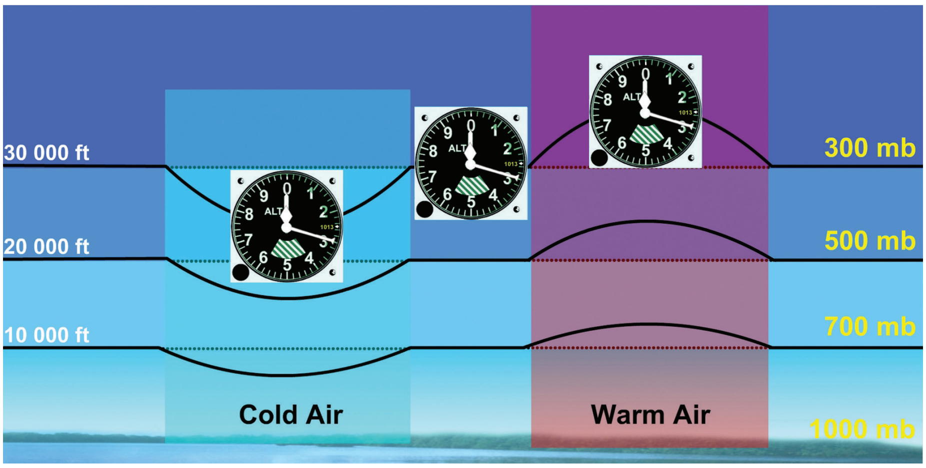


Figure 2.14

If the air were to be warmer than ISA, as shown on the right of Figure 2.14, the 300 millibar pressure level would be higher than its 30,000 ft level in ISA. Nevertheless, in warmer air, an altimeter calibrated to ISA would continue to read 30,000 ft at the 300 millibar level, even though the altimeter was clearly higher than the true altitude of 30,000 ft. Here, then, in the column of warm air, the altimeter is under-reading.

A useful phrase to recall in order to remember what you have just learnt is: "from warm to cold, don't be bold". This phrase refers to the fact that when flying from warm air into cold air, the altimeter will over-read, giving the impression that you are at a higher altitude than you actually are. This situation obviously has inherent risks. For example, if you were at an altitude of 2 000 feet, with an outside temperature of -10°C, well below the ISA value for that altitude, your altimeter would be over-reading by about 200 feet.

The concept of temperature changing the pressure lapse rate can be seen mathematically by using the formula below. This simple formula can help work out the pressure lapse rate. Notice "T" which is temperature forms part of the formula. Varying the value of "T" will change the pressure lapse rate. The values shown below the formula are based on ISA.

$$H = \frac{96T}{P}$$

Where:

H = height change (in feet) per hPa
T = Actual Absolute Temperature at that level (Kelvin)
P = Actual Pressure in hPa
K = 96 (the equation constant)

ISA

27 feet at MSL
50 feet at 20,000 ft
100 feet at 40,000 ft

DIURNAL VARIATION

There is a change in pressure during the day which although small (about 1 mb) in temperate latitudes, can be as much as 3 mb in the tropics and would need to be taken into account when considering pressure tendency as an indication of changing weather. The variation is shown in the figure on the next page.

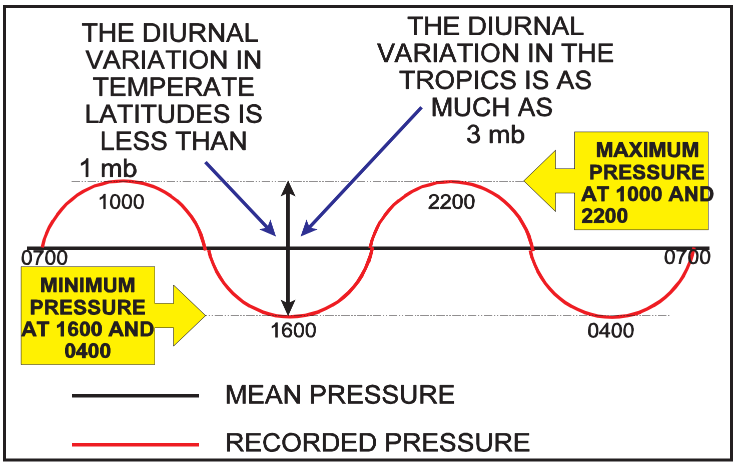


Figure 2.15 Diurnal Variation.

The variation is difficult to explain, but is probably due to a natural oscillation of the atmosphere having a period of about 12 hours, this oscillation being maintained by the 24 hour variation of temperature.

TYPES OF PRESSURE

QFE
The atmospheric pressure read from a barometer on an airfield will give the aerodrome pressure, otherwise known as QFE.

QFF
This is the barometric pressure at the surface reduced to MSL using the observed temperature at the surface and it's corresponding pressure lapse rate (this assumes an isothermal layer from MSL to that surface). QFF accounts for the effect that temperature has on the pressure lapse rate and therefore the resultant calculated pressure. From Figure 2.7 it can be seen that although the pressure at the airfield was 980 hPa, if the airfield was taken to Mean Sea Level, the pressure would be greater, but an account must also be made of the effect that the temperature has had on the pressure lapse rate. This allows us to accurately draw surface pressure charts. The correction to be made to the surface pressure will depend on the height of the surface (or airfield) AMSL and the actual temperature prevailing at the time.

The range of QFF so far recorded, low pressure to high pressure, is from 856 to 1083 hPa, but meteorologically the range is taken from 950 to 1050 hPa.

QNH
This is the barometric pressure at the airfield (QFE), reduced to MSL using the ISA temperature at the airfield and the ISA pressure lapse rate. This will provide a pressure which does not account for any temperature deviation away from ISA and the result this may have on the actual pressure lapse rate. The correction to be made to the surface pressure will depend solely upon the height of the airfield AMSL. QNH is always rounded down to a whole number without any decimal places.

In order to get QNH and QFF from a barometric reading at a surface we must use a formula, which is not required, but it is vital to know the difference that the temperature deviation will have when being asked to analyse QNH and QFF. We are required to relate QNH to QFF or visa versa as a relative not an absolute value.

SUMMARY OF QNH/QFF RELATIONSHIP

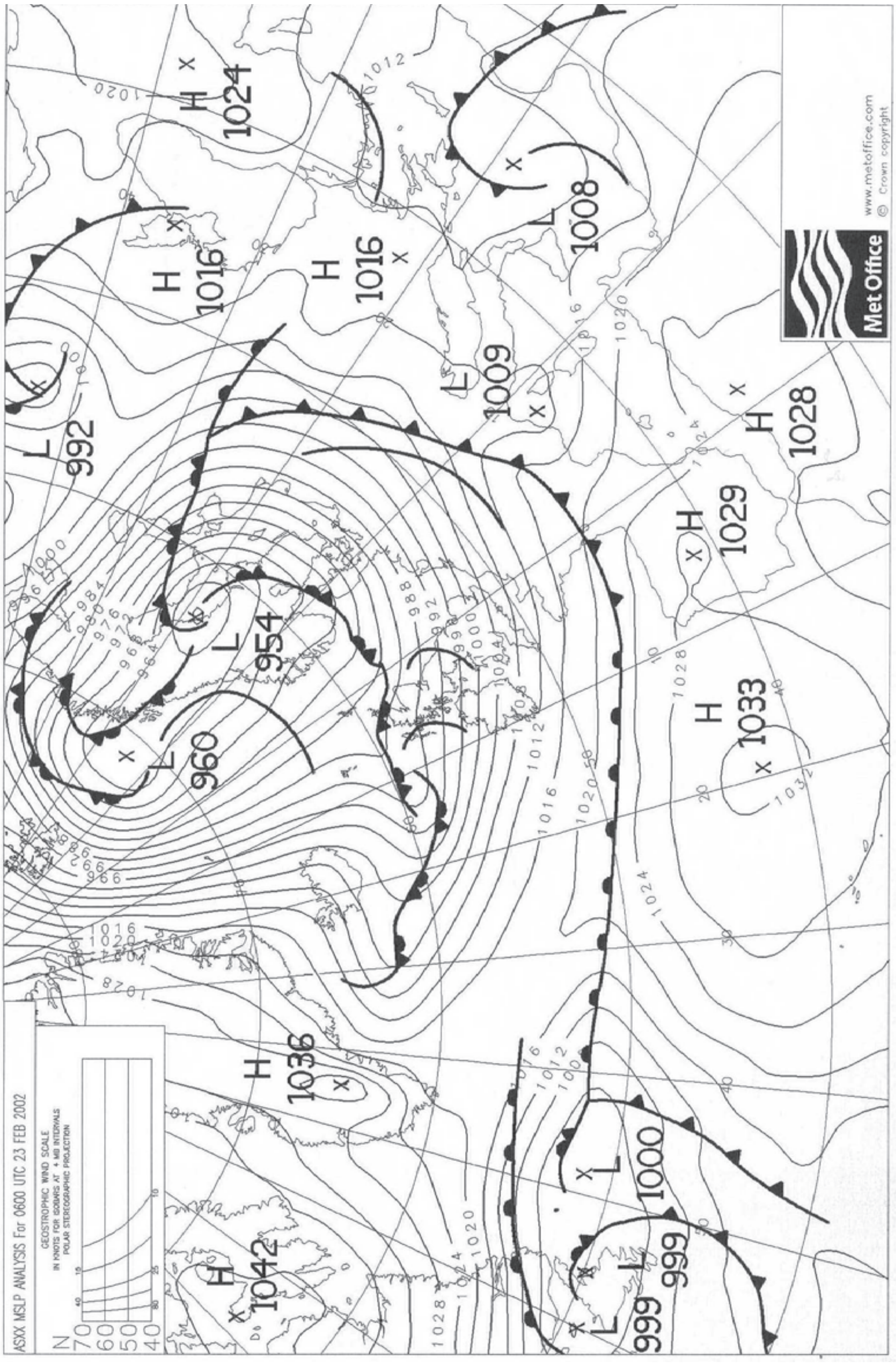
Stations ABOVE MSL	ISA+	QFF < QNH
	ISA-	QFF > QNH
Stations BELOW MSL	ISA+	QFF > QNH
	ISA-	QFF < QNH
Stations AT MSL	Regardless of temperature	QFF = QNH

PRESSURE DEFINITIONS

QFE	The value of pressure, for a particular aerodrome and time, corrected to the official elevation.
QFF	The value of pressure reduced to MSL in accordance with isothermal conditions.
QNH	The value of pressure, for a particular aerodrome and time, corrected to the MSL in accordance with the ICAO standard.
FORECAST QNH	Also known as Regional Pressure Setting (RPS). A forecast, valid for one hour, of the lowest QNH expected in any part of the Altimeter Setting Region (ASR).
QNE	The height indicated on landing at an airfield when the altimeter sub-scale is set to 1013.25 hPa.
ISOBAR	A line joining places of the same atmospheric pressure (usually MSL pressure QFF).
ISALLOBAR	A line joining places of the same pressure tendency.

MEAN SEA LEVEL PRESSURE CHARTS

Isobars on normal surface pressure charts are Mean Sea Level Isobars (QFF) and are normally drawn for every even whole millibar, (i.e. 1000, 1002, etc.). Figure 2.16 illustrates the isobars on a synoptic chart. On larger area maps the spacing may be expanded to 4 or more hectopascals but this will be stated on the chart.



Atlantic ASXX Analysis for 0000UTC 23 Feb 2002

Figure 2.16 A typical surface pressure chart

QUESTIONS

1. The 850 hPa pressure level can vary in height. In temperate regions which of the following average heights is applicable?

   a. FL100
   b. FL 300
   c. FL 390
   d. FL 50

2. Which constant pressure altitude chart is standard for 18,289 FT pressure level (FL 180)?

   a. 300 hPa
   b. 200 hPa
   c. 700 hPa
   d. 500 hPa

3. If you are planning a flight at FL 170, which of these upper wind and temperature charts would be nearest your flight level?

   a. 850 hPa
   b. 700 hPa
   c. 500 hPa
   d. 300 hPa

4. Which constant pressure altitude chart is standard for a 38,662 FT pressure level (FL 390)?

   a. 500 hPa
   b. 700 hPa
   c. 200 hPa
   d. 300 hPa

5. The station pressure used in surface weather charts is

   a. QNE
   b. QFF
   c. QFE
   d. QNH

6. Half the mass of the atmosphere is found in the first

   a. 8 km
   b. 6 km
   c. 3 km
   d. 11 km

7. A 500 hPa pressure level can vary in height. In temperate regions which of the following average heights is applicable?

   a. FL 160
   b. FL 100
   c. FL 390
   d. FL 180

8. Which constant pressure altitude chart is standard for a 4781 FT pressure level (FL50)?

   a. 300 hPa.
   b. 850 hPa.
   c. 700 hPa.
   d. 500 hPa.

9. The QNH at an airfield located 200 metres above sea level is 1022 hPa. The air temperature is not available. What is the QFF?

   a. It is not possible to give a definitive answer
   b. More than 1022 hPa
   c. 1022 hPa
   d. Less than 1022 hPa

10. A 700 hPa pressure level can vary in height. In temperate regions which of the following average heights is applicable?

   a. FL 180
   b. FL 300
   c. FL 390
   d. FL 100

11. When planning a flight at FL 60, which upper wind and temperature chart would be nearest your flight level?

   a. 300 hPa
   b. 850 hPa
   c. 700 hPa
   d. 500 hPa

12. The QFF at an airfield located 400 metres above sea level is 1016 hPa. The air temperature is 10°C higher than a standard atmosphere. What is the QNH?

   a. More than 1016 hPa
   b. 1016 hPa
   c. Less than 1016 hPa
   d. It is not possible to give a definitive answer

13. Which of the following is true concerning atmospheric pressure?

   a. It always decreases with height at a rate of 1 hPa per 8m
   b. It decreases with height
   c. It is higher in winter than in summer
   d. It is higher at night than during the day

14. The upper wind and temperature chart of 250 hPa corresponds, in a standard atmosphere, to about

   a. 32 000 FT
   b. 34 000 FT
   c. 39 000 FT
   d. 30,000 FT

15. What positions are connected by isobars on the surface weather chart?

    a. Positions with the same relative pressure heights
    b. Positions with the same air pressure at a given level
    c. Positions with the same temperature at a given level
    d. Positions with the same wind velocity at a given level

16. How would you characterise an air temperature of -30°C at the 300 hPa level over Western Europe?

    a. Within +/-5°C of ISA
    b. Low
    c. Very low
    d. High

17. The QFF at an airfield in California located 69 meters below sea level is 1030 hPa. The air temperature is 10°C lower than a standard atmosphere. What is the QNH?

    a. 1030 hPa
    b. It is not possible to give a definitive answer
    c. More than 1030 hPa
    d. Less than 1030 hPa

18. What is the approximate vertical interval which is equal to a pressure change of 1 hPa at an altitude of 5500m?

    a. 8 m (27 FT).
    b. 32 m (105 FT).
    c. 64 m (210 FT).
    d. 15 m (50 FT).

19. The greater the pressure gradient the

    a. closer the isobars and the lower the temperatures
    b. further the isobars will be apart and the higher the temperature
    c. closer the isobars and the stronger the wind
    d. further the isobars will be apart and the weaker the wind

20. When planning a flight at FL 110, which upper wind and temperature chart would be nearest your flight level?

    a. 700 hPa
    b. 850 hPa
    c. 300 hPa
    d. 500 hPa

21. The QNH at an airfield in California located 69 meters below sea level is 1018 hPa. The air temperature is 10°C higher than a standard atmosphere. What is the QFF?

    a. 1018 hPa
    b. It is not possible to give a definitive answer
    c. More than 1018 hPa
    d. Less than 1018 hPa

22. The QNH at an airfield located 0 meters above sea level is 1022 hPa. The air temperature is not available. What is the QFF?

a. It is not possible to give a definitive answer
b. 1022 hPa
c. Less than 1022 hPa
d. More than 1022 hPa

23. In what hPa range is an upper weather chart for FL 340 situated?

a. 400 - 300 hPa
b. 500 - 400 hPa
c. 600 - 500 hPa
d. 300 - 200 hPa

24. If you are flying at FL 100 in an air mass that is 10°C warmer than a standard atmosphere, what is the outside temperature likely to be?

a. -10°C
b. -15°C
c. +5°C
d. +15°C

25. In the troposphere the decrease of pressure per 100 m increase in height

a. is smaller at higher levels than at lower levels.
b. remains constant at all levels.
c. is greater at higher levels than at lower levels.
d. is in the order of 27 hPa near MSL.

26. The QFF at an airfield located 400 meters above sea level is 1016 hPa. The air temperature is 10°C lower than a standard atmosphere. What is the QNH?

a. More than 1016 hPa
b. 1016 hPa
c. It is not possible to give a definitive answer
d. Less than 1016 hPa

27. Isobars on a surface chart are lines of equal

a. QFF
b. QFE
c. QNE
d. QNH

28. A 200 hPa pressure altitude level can vary in height. In temperate regions which of the following average heights is applicable?

a. FL 100.
b. FL 50.
c. FL 390.
d. FL 300.

29. If you are planning a flight at FL 290, which of these upper wind and temperature charts would be nearest your flight level?

a. 850 hPa
b. 300 hPa
c. 500 hPa
d. 700 hPa

30. A 300 hPa pressure level can vary in height. In temperate regions which of the following average heights is applicable?

a. FL 100
b. FL 50
c. FL 300
d. FL 390

31. The QNH at an airfield located 200 metres above sea level is 1009 hPa. The air temperature is 10°C lower than a standard atmosphere. What is the QFF?

a. Less than 1009 hPa
b. It is not possible to give a definitive answer
c. More than 1009 hPa
d. 1009 hPa

32. Which constant pressure altitude chart is standard for a 30,065 FT pressure level (FL 300)?

a. 200 hPa
b. 700 hPa
c. 500 hPa
d. 300 hPa

33. Which constant pressure altitude chart is standard for a 9,882 FT pressure level (FL 100)?

a. 700 hPa
b. 850 hPa
c. 500 hPa
d. 300 hPa

34. The isobars drawn on a surface weather chart represent lines of equal pressure

a. at flight level
b. at height of observatory
c. at a determined density altitude
d. reduced to sea level

35. If the pressure surfaces bulge upwards in all levels then the pressure system is a

a. cold low
b. cold high
c. warm low
d. warm high

ANSWERS

1. D	11. B	21. C	31. C
2. D	12. A	22. B	32. D
3. C	13. B	23. D	33. A
4. C	14. B	24. C	34. D
5. B	15. B	25. A	35. D
6. B	16. D	26. D	
7. D	17. C	27. A	
8. B	18. D	28. C	
9. A	19. C	29. B	
10. D	20. A	30. C	

CHAPTER THREE

DENSITY

Contents

INTRODUCTION

Density may be defined as mass per unit volume and may be expressed in three main ways:

- Grammes per cubic metre. (g/m^3)
- A percentage of the standard surface density - relative density.
- The altitude in the standard atmosphere to which the observed density corresponds - density altitude.

DENSITY EXPRESSIONS

Relative Density
Relative density is the prevailing density, expressed as a percentage of mean sea level density in ISA. For example, if the prevailing density is 1000 g/m^3, then comparing this to the ISA mean sea level density of 1225 g/m^3 we can say that the prevailing density is 82% of ISA mean sea level density. To put it another way, if the relative density is 50%, then this would mean that the prevailing density is half that of mean sea level density is ISA. Therefore the prevailing density is 612 g/m^3.

Density Altitude
Density altitude is the altitude in the ISA at which the current observed density would occur. For example, if the prevailing or observed density is 612 g/m^3 then this represents a density that is found at approximately 20,000 ft in ISA. Therefore, the location of the observed density is described as having a density altitude of 20,000 ft.

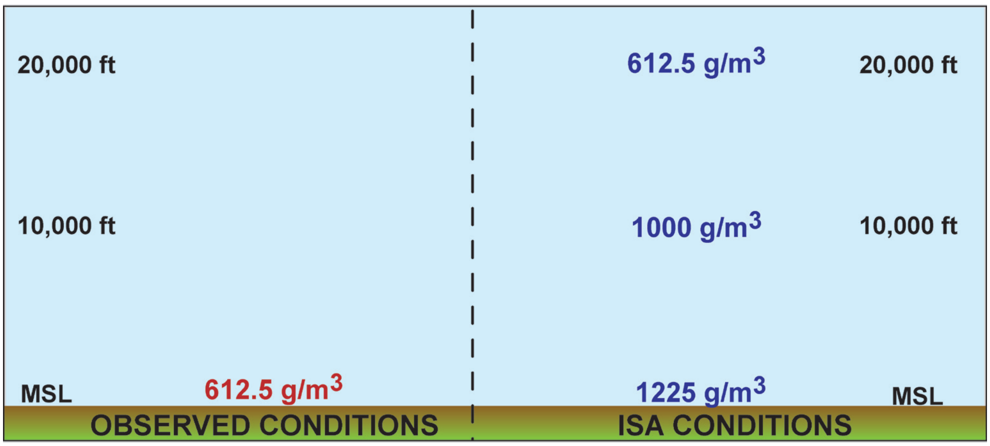


Figure 3.1 Comparing observed density to ISA density

"Density Altitude" can be calculated by adjusting the pressure altitude for non-standard temperature.

DENSITY ALTITUDE = PRESSURE ALTITUDE +/- (ISA DEVIATION X 118.8)

An increase in temperature and an increase in humidity cause a reduction in air density. Thus in hot and humid conditions the density altitude at a particular location may be significantly higher than the actual altitude.

EFFECT OF CHANGES OF PRESSURE ON DENSITY

As pressure is increased, the air will be compressed which reduces the volume and increases the density. Likewise, if pressure is decreased, the air will expand which will increase the volume and decrease the density. We can therefore say that:

DENSITY IS DIRECTLY PROPORTIONAL TO PRESSURE

In the atmosphere density can be decreased by raising the volume of air to a greater height since we know that pressure decreases with an increase in altitude. Similarly, density can be increased by lowering the volume of air to a lower height.

EFFECT OF CHANGE OF TEMPERATURE ON DENSITY

If a volume of air is heated it will expand and the mass of air contained in unit volume will be less. Thus density will decrease with an increase in temperature and we can say:

DENSITY IS INVERSELY PROPORTIONAL TO TEMPERATURE

EFFECT OF CHANGE OF HUMIDITY ON DENSITY

Humidity is a measure of the water vapour content of the air. Humid air is lighter, or less dense, than dry air. This is due to the fact that a molecule of water, H_2O, weighs less than molecules of Nitrogen (N_2) and Oxygen (O_2). Therefore, an atmosphere with very high humidity will have a lower total mass than a dry atmosphere. Thus density will decrease with an increase in humidity and we can say:

DENSITY IS INVERSELY PROPORTIONAL TO HUMIDITY

EFFECT OF CHANGE OF ALTITUDE ON DENSITY

As altitude increases, the effect of pressure decreasing causes density to fall despite the fact that temperature decreases. Therefore, the effect is for the density to decrease with an increase of height. You can appreciate this because at high altitudes, pilots and mountaineers require supplemental oxygen to breathe simply because there isn't much air in the upper atmosphere. The information below simply shows you that at 20,000 ft the density of the air is almost half of what is at mean sea level. Mean sea level density is approximately 1225g/m^3 therefore at 20,000 ft density is 612 g/m^3.

(ρ = 100% at sea level, 50% at 20,000 ft, 25% at 40,000 ft and 10% at 60,000 ft)

Density will change by 1% for a 3°C change in temperature or a 10 hPa change in pressure.

EFFECT OF CHANGE OF LATITUDE ON DENSITY

Along the surface of the earth density will be higher at the poles than at the equator. This is because the surface pressure at the poles is relatively higher than the equator and because the temperature is much colder than at the equator. Therefore, along the surface of the earth density increases with increasing latitude.

Above 26,000 ft the effect is reversed. At high altitudes above the equator the temperature is relatively low and the pressure relatively high, therefore at high altitudes above the equator density is higher than at high altitudes above the poles. Therefore, density increases with decreasing latitude.

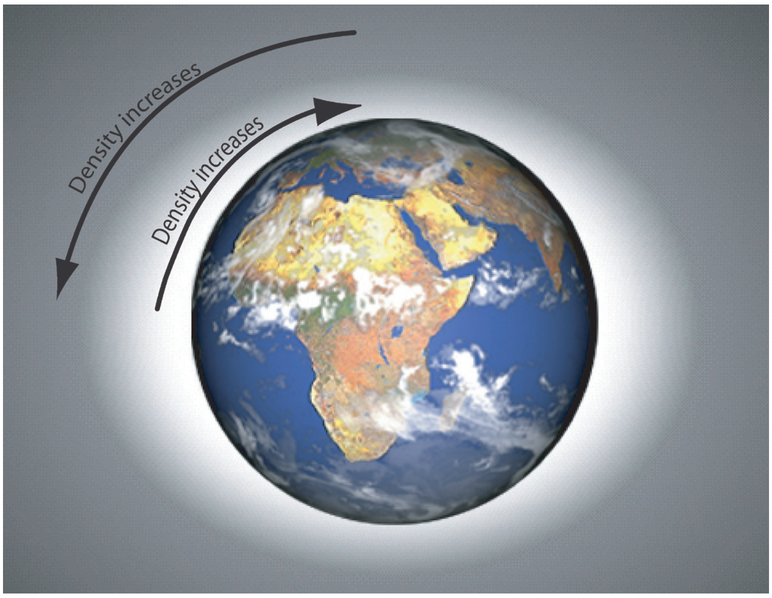


Figure 3.2 The Effect of Latitude on Density.

EFFECT OF CHANGES IN DENSITY ON AIRCRAFT OPERATIONS

- Accuracy of aircraft instruments - Mach meters, ASIs.
- Aircraft and engine performance - low density will reduce lift, increase take off run, reduce maximum take off weight.

$$(L = C_L \tfrac{1}{2} \rho V^2 S)$$

Where

Where	L	=	Lift
	C_L	=	Coefficient of Lift
	ρ	=	Density
	V	=	TAS
	S	=	Wing area

Airfields affected would be:

High	Denver	Nairobi	Saana
Hot	Bahrain	Khartoum	Singapore

Humidity generally has a small effect on density (humidity reduces density), but must be taken into account at moist tropical airfields, e.g. Bahrain, Singapore.

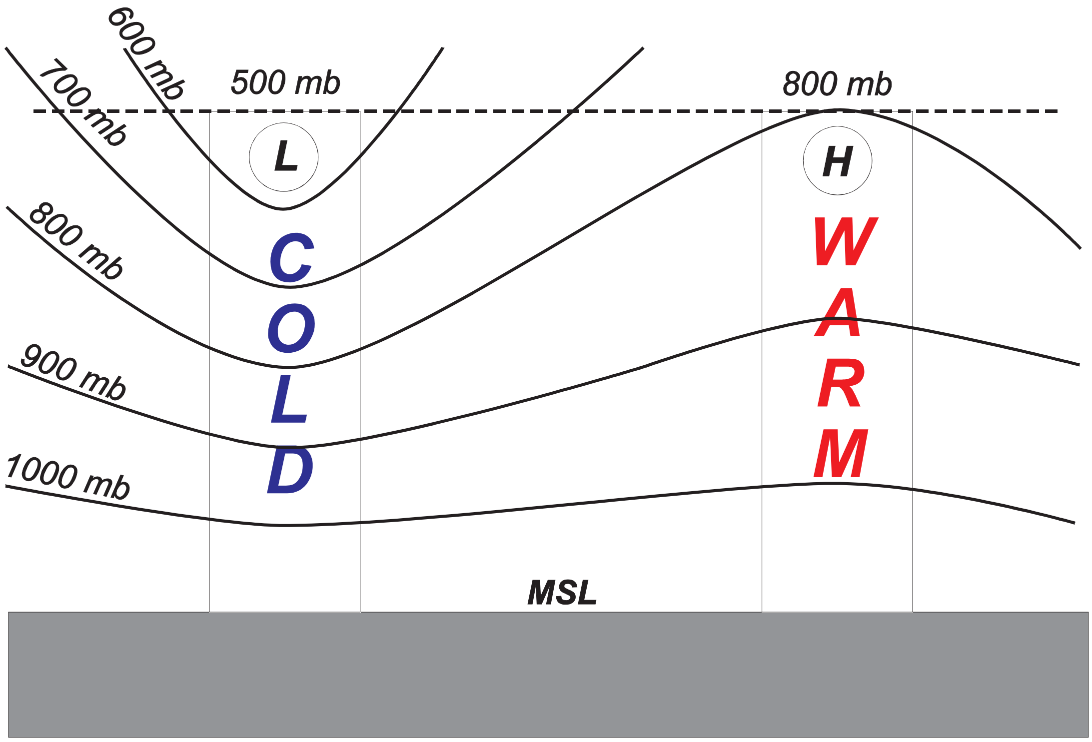


Figure 3.3 An Illustration of Pressure Decreasing with Height in Airmasses with Different Temperatures and therefore Different Densities

QUESTIONS

1. Consider the following statements relative to Air Density and select the one which is correct:

   a. Because air density increases with decrease of temperature, air density must increase with increase of height in the International Standard Atmosphere (ISA..
   b. At any given surface temperature the air density will be greater in anticyclonic conditions than it will be when the MSL pressure is lower.
   c. Air density increases with increase of relative humidity.
   d. The effect of change of temperature on the air density is much greater than the effect of change of atmospheric pressure.

2. The tropopause in mid latitudes is:

   a. Lower in summer with a lower temperature.
   b. Lower in winter with a higher temperature.
   c. Lower in summer with a higher temperature.
   d. Lower in winter with a lower temperature.

3. Generally as altitude increases:

   a. temperature decreases and density increases
   b. temperature, pressure and density decreases
   c. temperature and pressure increase and density decreases
   d. temperature decreases and pressure density increases

4. In the troposphere:

   a. over cold air, the pressure is higher at upper levels than at similar levels over warm air
   b. over cold air, the pressure is lower at upper levels than at similar levels over warm air
   c. over warm air, the pressure is lower at upper levels than at similar levels over warm air
   d. the upper level pressure depends solely on the relative humidity below

5. Density at the surface will be low when:

   a. Pressure is high and temperature is high.
   b. Pressure is high and temperature is low.
   c. Pressure is low and temperature is low.
   d. Pressure is low and temperature is high.

6. At FL 180, the air temperature is -35°C.The air density at this level is:

   a. Equal to the density of the ISA atmosphere at FL 180.
   b. Unable to be determined without knowing the QNH.
   c. Greater than the density of the ISA atmosphere at FL 180.
   d. Less than the density of the ISA atmosphere at FL 180

7. Under what condition does pressure altitude have the same value as density altitude?

   a. At sea level when the temperature is 0°C.
   b. When the altimeter has no position error.
   c. When the altimeter setting is 1013,2 hPa.
   d. At standard temperature.

ANSWERS

1.	B
2.	B
3.	B
4.	B
5.	D
6.	C
7.	D

CHAPTER FOUR

PRESSURE SYSTEMS

Contents

INTRODUCTION

The different pressure systems found across the surface of the Earth play a primary role in determining the Earth's weather. Understanding pressure systems is central to the understanding of weather, itself.

It is important to note, from the outset, that in low pressure areas, air is rising, while in high pressure areas, air is descending. This general vertical movement of air constitutes the primary distinction between high and low pressure systems. Pressure systems are not defined by the numerical value of the prevailing atmospheric pressure within the systems, themselves, but by the relative pressures.

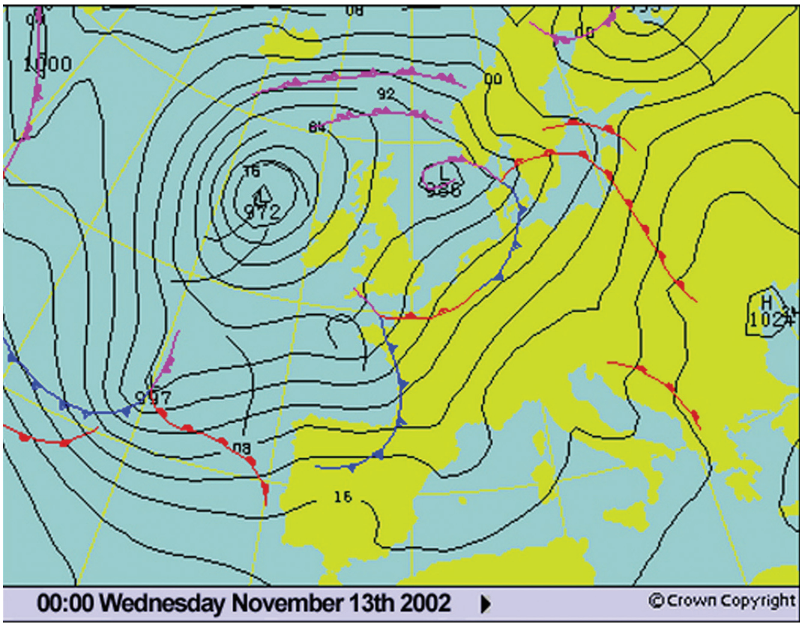


Figure 4.1 Lows, Highs and Cols

The two principal types of pressure system, are low pressure systems (also called depressions or cyclones) and high pressure systems (also called anticyclones). There are also a number of subsidiary pressure systems called cols, ridges and troughs.

LOW PRESSURE SYSTEMS

There are two forms of low pressure system: small scale low pressure areas and large scale low pressure areas.

SMALL SCALE LOWS

Small scale lows, or depressions, can be found almost anywhere on the Earth's surface. They are created when there is unequal heating of the Earth's surface.

As you have learnt, an increase in temperature leads to a decrease in air density. Air lying above a warm surface will be heated by that surface through conduction. The heating process and the associated reduction in air density will cause air to rise. The rising air travels up through the atmosphere and eventually, when it reaches high altitudes and has cooled again to the temperature of the surrounding air, diverges, or spreads out. The total weight of the column of air above the warm surface of the Earth reduces as the air diverges, causing the atmospheric pressure to fall at the surface.

As air rises, the air surrounding the low pressure area will be drawn inwards in an attempt to fill the low, and return the air pressure to equilibrium. However, the inward-moving air will experience friction as it moves over the Earth's surface, slowing it down. Consequently, more air leaves the divergence area in the upper atmosphere than can be replaced at the surface. Therefore, low pressure above the warm surface is maintained, and air pressure may continue to fall over time as this process evolves. The development of a small scale low is depicted in Figure 4.2.

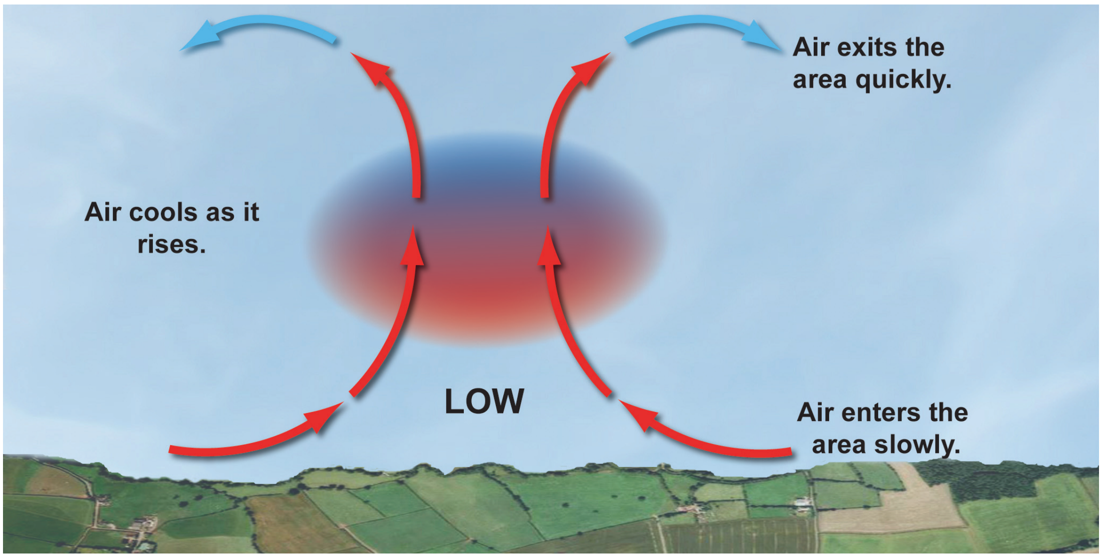


Figure 4.2 Rising Air in a Small Scale Low

As the air in the centre of the depression rises, the volume of air will expand, because pressure decreases with increasing altitude. This expansion will cause the rising air to cool as it ascends by a process called adiabatic cooling. Adiabatic cooling will be covered in detail in Chapter 8. Condensation will take place when the air temperature has fallen to its dew point. The dew point is the temperature to which the air must be cooled, at constant barometric pressure, for the water vapour contained in the air to condense. As water vapour changes state to become liquid water droplets, cloud is formed. The clouds which are created within a small scale low develop vertically, and are called cumuliform clouds, or, more simply, cumulus clouds.

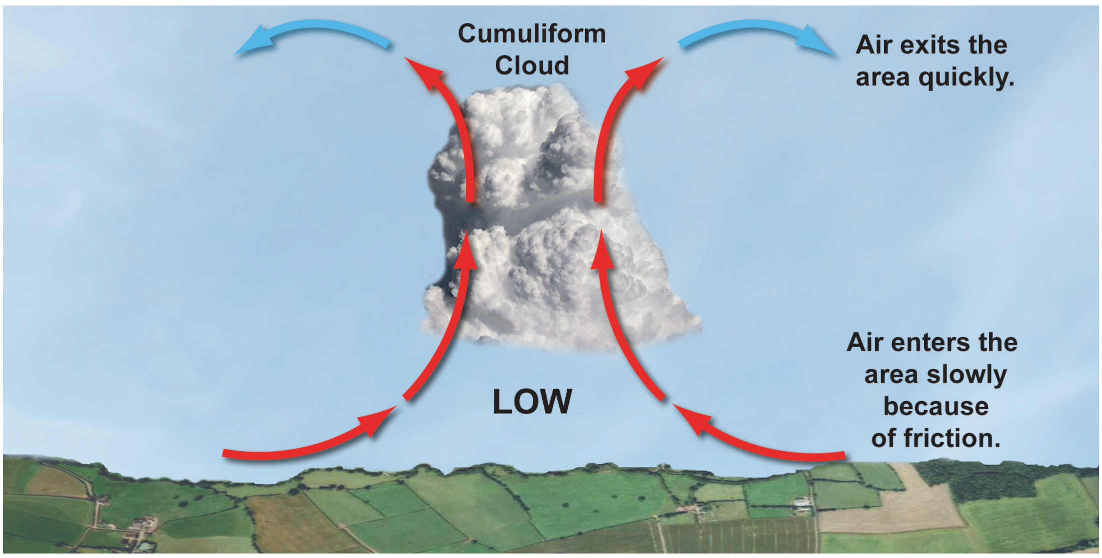


Figure 4.3 Cumiliform Clouds Caused by Adiabatic Cooling

HAZARDS TO AVIATION FROM SMALL SCALE LOWS

Small scale low pressure areas can set in motion large amounts of energy, and may present some serious hazards to the general aviation pilot. Hazards associated with small-scale low pressure areas include:

- Turbulence
- Precipitation
- Icing
- Poor visibility

Turbulence and Precipitation
The velocity of the rising air can be very significant inside a vigorously developing cumuliform cloud. In some cases, hail stones up to 2 lbs (1 kg) in weight may be suspended inside the cloud by strong upcurrents. When the weight of the water droplets or hail stones suspended within the cloud exceeds the force of the rising air, they will fall to the Earth as precipitation. The onset of precipitation associated with small scale lows is generally both rapid and intense, resulting in air being forced downwards toward the Earth's surface, creating very active down draughts. The strong updraughts and downdraughts within small scale lows generate moderate to severe turbulence.

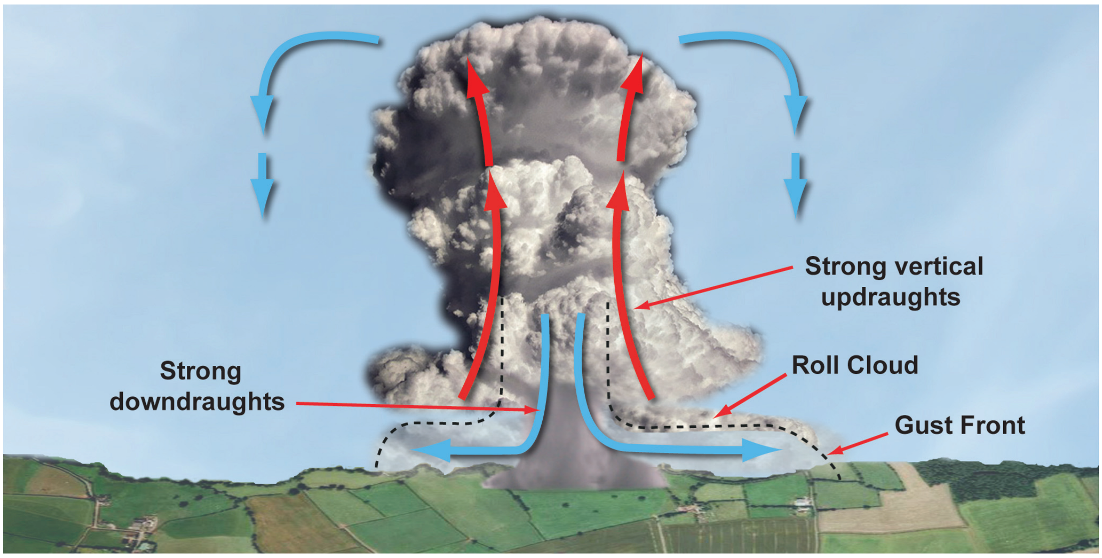


Figure 4.4 Turbulence and precipitation hazards in small scale lows

Icing

Another phenomenon associated with small scale lows and of significance to aircraft is icing. Icing occurs when liquid or super cooled water, held within the cloud, freezes onto an aircraft's surfaces. The formation of ice dramatically affects the aircraft's performance and ability to remain airborne.

Aircraft Icing will be covered in detail in a later chapter; for the moment, it is important that you should note that the icing risk can be moderate to severe in weather phenomena associated with intense small-scale low pressure areas

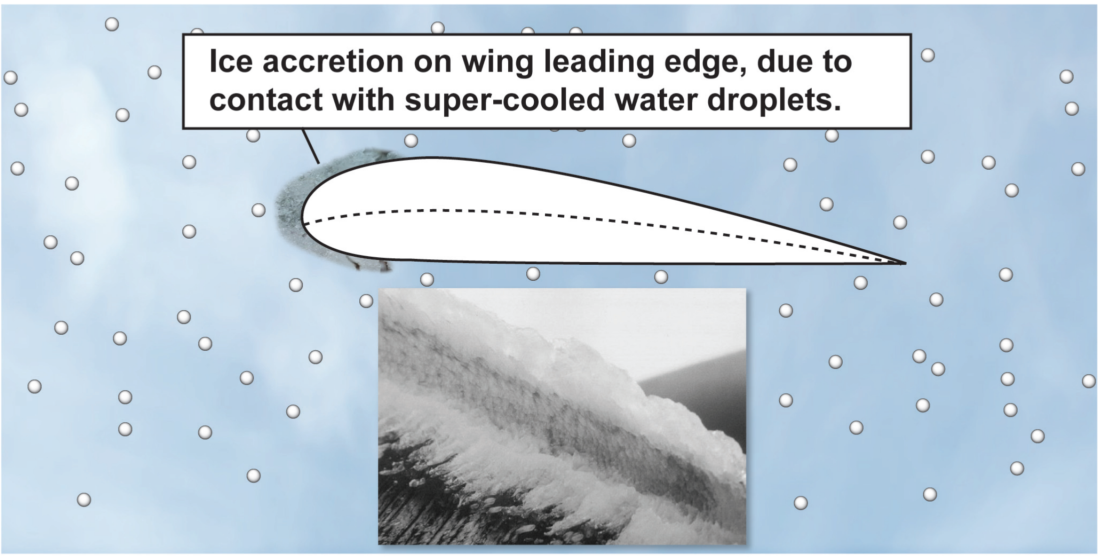


Figure 4.5 Icing in a Cumiliform Cloud

Visibility

One other concern for pilots, connected with small scale low pressure areas, is the horizontal visibility near the Earth's surface. When air is converging and rising, any impurities near the Earth's surface will be drawn up into the upper atmosphere leaving much clearer air at the surface. Nevertheless, although surface visibility may be good, in precipitation, visibility can be very poor, reducing to almost zero in heavy precipitation.

THE EQUATORIAL LOW PRESSURE BELT

Small scale lows commonly form over land masses in the summer months, especially in Asia, Central Europe and the USA. However, the most frequent occurrence of small scale low pressure areas is around the Equator. Figure 4.6, depicts bands or belts of low pressure systems centred on the Equator, created by warm rising air. The central belt is the Equatorial Low Pressure Belt where very extensive cumuliform cloud developments occur.

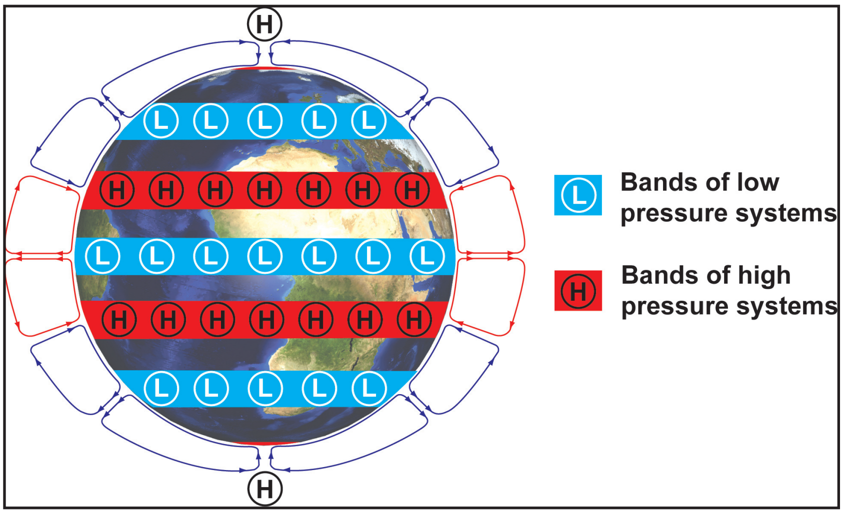


Figure 4.6 A Global Pressule Distribution Model

Under certain circumstances, the small scale depressions around the Equator can evolve into some of the most violent weather phenomena on the surface of the Earth, called Tropical Revolving Storms, or, as they are more commonly known, Hurricanes, Cyclones or Typhoons. Storm systems of this type can expand to over 700 nautical miles in diameter. As these storm systems expand to this much larger scale, the action of the Earth's rotation becomes significant, and, unlike in the small scale low, the airflow is deflected as it is drawn towards the centre of the depression. This deflection of the airflow can result in rotational wind speeds of up to 200 miles per hour. Such storms are generally found only over the tropical oceans and require specific environmental conditions for them to develop.

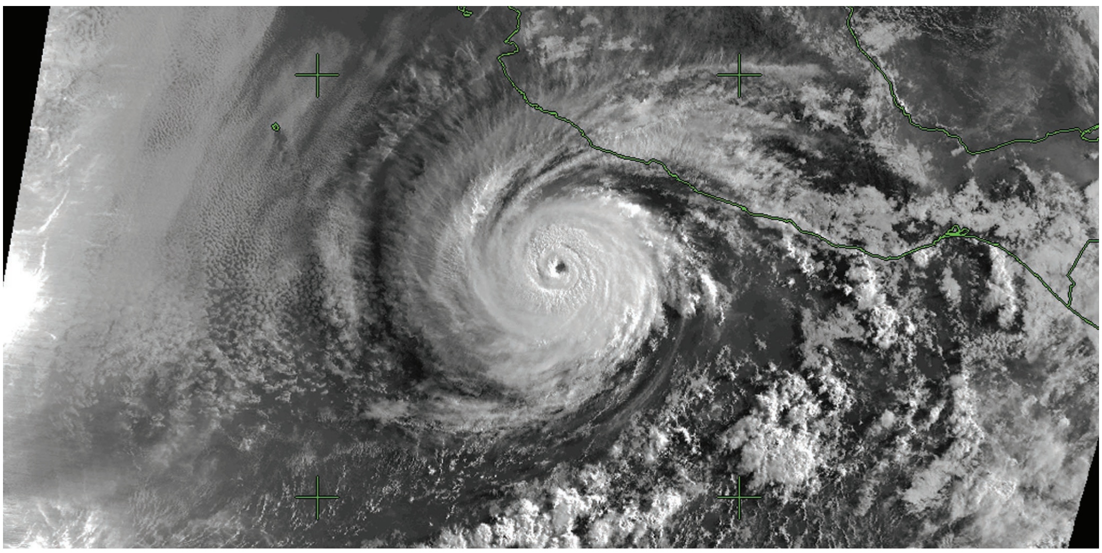


Figure 4.7 Satellite photograph of a Tropical Revolving Storm off the coast of Central America.

LARGE SCALE LOW PRESSURE AREAS (DEPRESSIONS)

Polar frontal depressions are large scale low pressure areas, which are created in a very different manner to the small scale heat lows. Polar front depressions are found along the polar front which lies principally in the higher latitudes at about 40º to 60°, North (see Figure 4.9) and South, depending upon the season. You can see these two bands of low pressure in Figure 4.6, near the top and bottom of the globe. The depressions typically move from West to East across the Earth's surface, and the process of their formation is complex. Figure 4.8, shows a typical polar front depression over the British Isles.

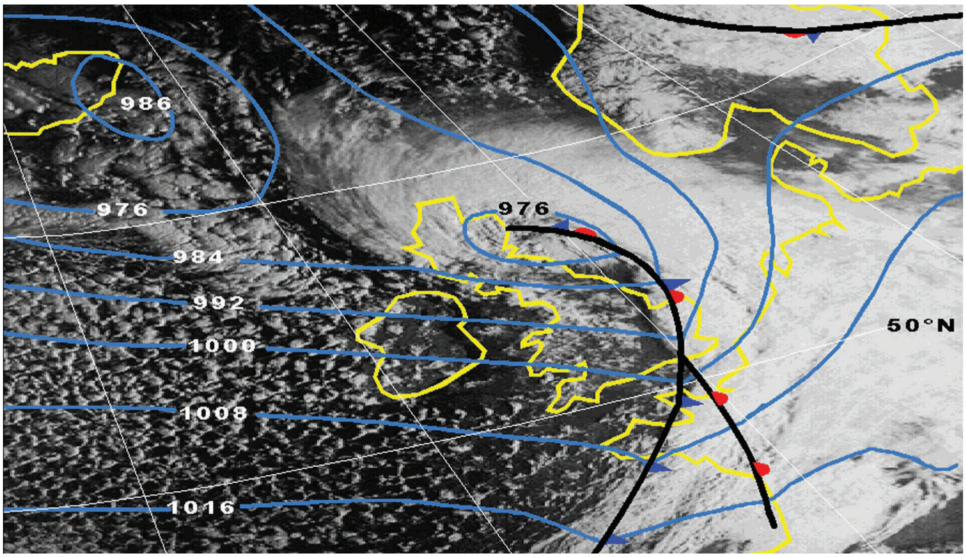


Figure 4.8 Polar Front Depression

FORMATION OF POLAR FRONT DEPRESSIONS

In the temperate latitudes (between the tropics and the polar circles), warm tropical air meets cold polar air. The boundary between warm and cold air masses is called the polar front. As with any boundary between two air masses of different densities, the boundary will not be a straight line. At some points along the front there will be "kinks" or small irregularities. In these kinks, the warm tropical air intrudes into the cooler polar air, as depicted in Figure 4.9.

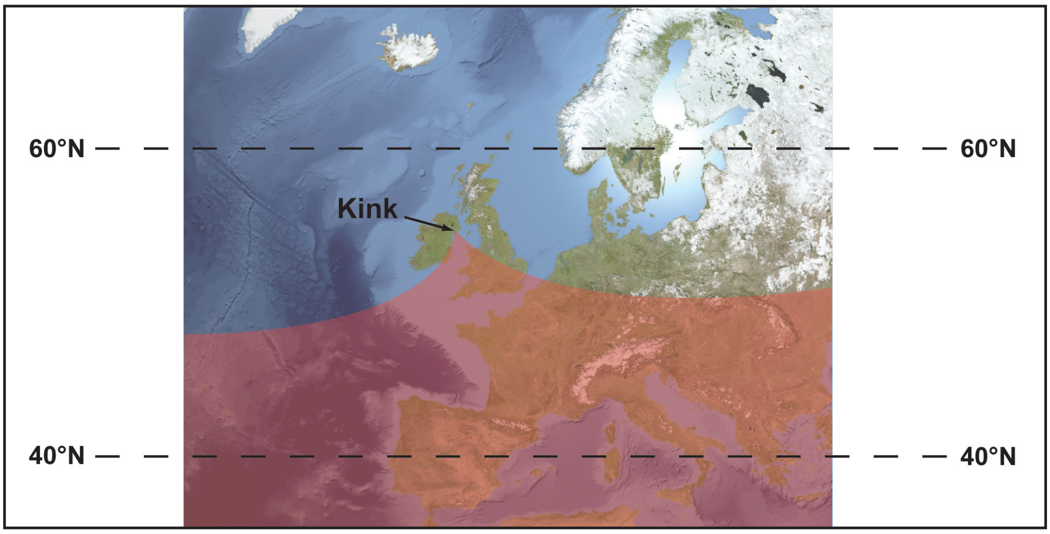


Figure 4.9 Along the Polar Front

The lighter, warmer air in the kink replaces the colder, heavier air, so the weight of the overlying air is reduced, leading to a fall in the surface pressure.

As the surface pressure falls, air will be drawn in towards the area of low pressure. However, because the air movement is on a large scale, this displacement of air is deflected by the rotation of the Earth.

In the Northern Hemisphere, the deflection of the moving air mass, as shown in Figure 4.10, is to the right, causing winds to blow anti-clockwise around the depression. In the Southern Hemisphere the deflection is to the left, and so, South of the Equator, the wind blows clockwise around a depression. This deflection of the moving air mass is caused by a force known as the Coriolis Force. Coriolis Force will be covered in more detail later.

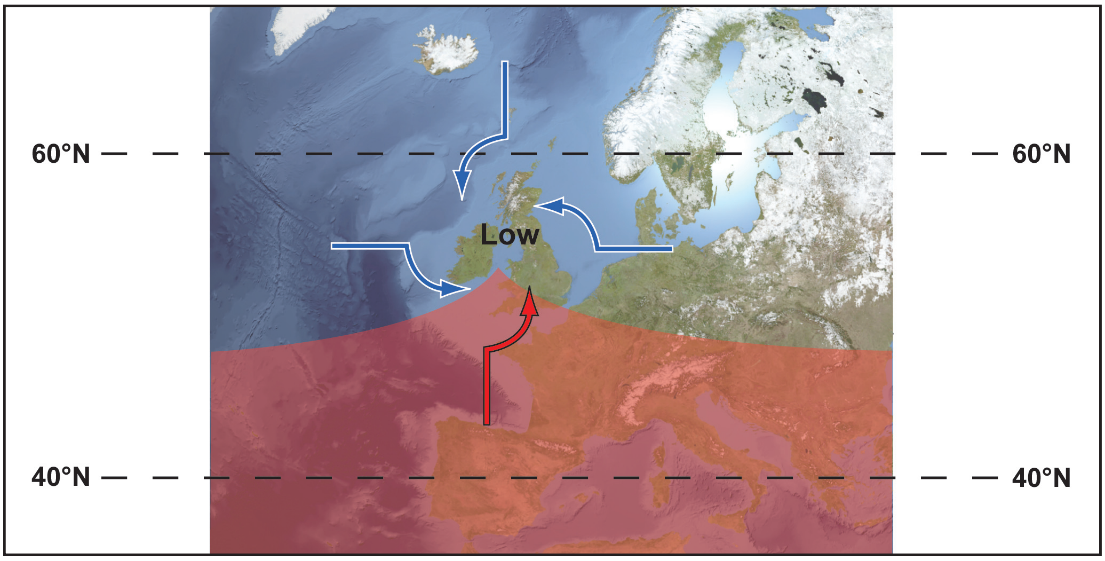


Figure 4.10 Corriolis Force

There are two types of interaction between the warm and cold air masses which are fundamental to the understanding of frontal weather systems.

The Warm Front
Along the section of the front depicted by the red semi-circular symbols in Figure 4.11, warm air is being forced against the cooler air.

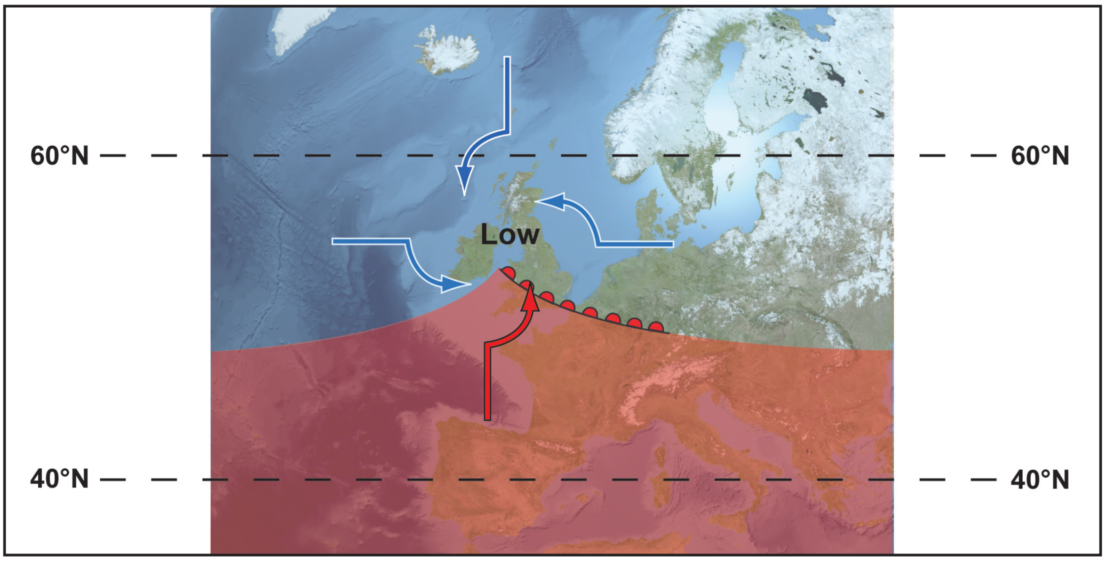


Figure 4.11

The warmer air, being less dense, will ride up and over the colder air. The weather feature created in this way, and depicted in Figure 4.12, in cross section, is called a warm front.

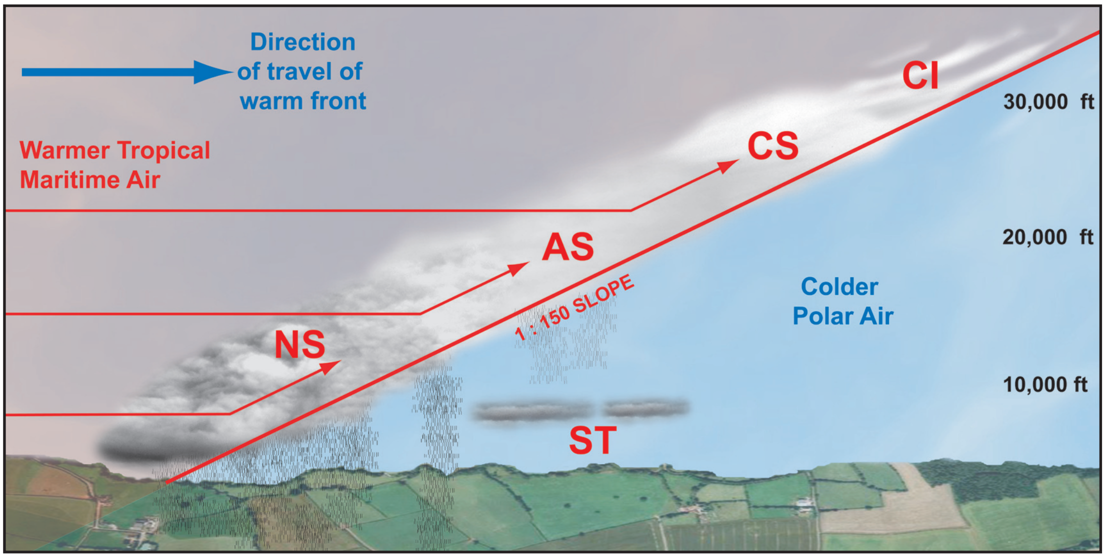


Figure 4.12 The Warm Front

Because the warm air is being forced upwards into lowering atmospheric pressure, the air expands and cools. Water vapour in the air, therefore, condenses, creating cloud along the frontal boundary. The cloud takes on a horizontal, layered appearance since the slope of the warm front is about one in one hundred and fifty, much shallower than the slope indicated in the diagram at Figure 4.12. This layer-type cloud is called stratiform cloud.

The Cold Front

The other main feature of the polar front is depicted in Figure 4.13. Along the line marked by the blue triangles, the blue colder air is being forced against the red warmer air. The colder, heavier air will undercut the warmer, lighter air in the form of a wedge creating a cold front (see Figure 4.14). The blue triangles, in Figure 4.13 are the standard symbols denoting a cold front.

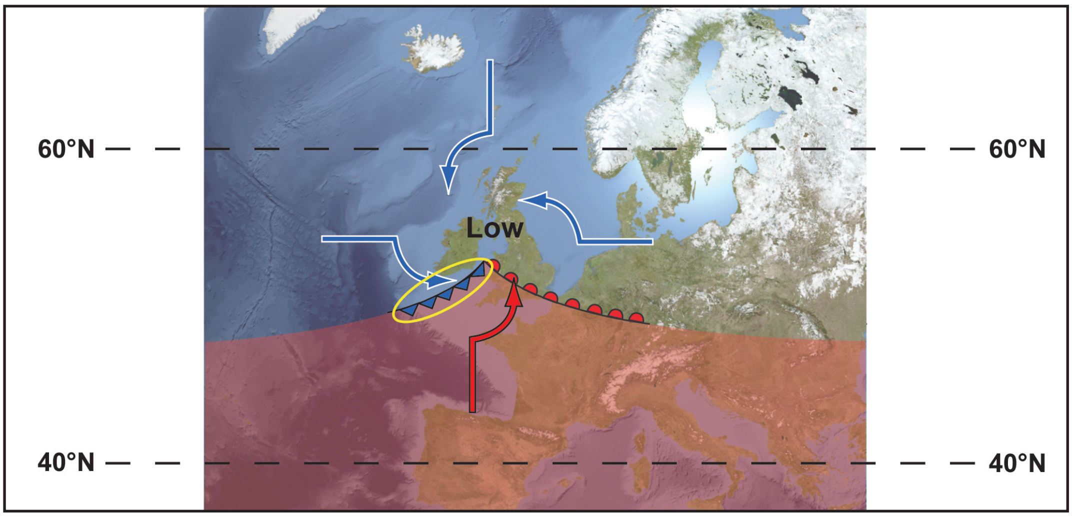


Figure 4.13 The Cold Front

As the cold air advances, it forces the warm air upwards causing the warm air to cool. The water vapour in the warm air mass, consequently, condenses, and clouds are created. The slope of the cold front boundary is steeper than that of the warm front, with a gradient of approximately one in fifty. If we consider the whole extent of the cold front, cloud will still take on a general stratiform appearance.

However, there is a fundamental difference along the cold front compared to the warm front. Notice that the cold front slopes forwards first, then slopes backwards creating a wedge shape. The wedge shape is formed because the portion of the front in contact with the ground will slow down due to friction as the front advances, and, as a result, will lag behind the air immediately above it. This phenomenon creates instability in the warm air which is in direct contact with the wedge.

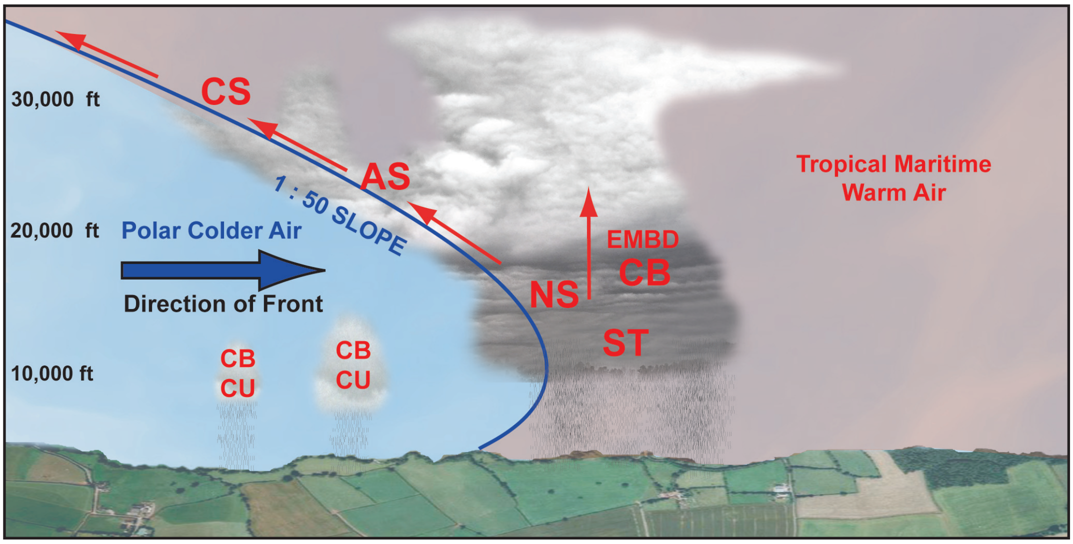


Figure 4.14 Cross Section Through the Cold Front

The unstable air just ahead of the cold front is, therefore, forced to rise vigorously. This vigorous vertical ascent creates vertically developed cumuliform cloud. The cumuliform clouds formed in advance of the cold front are potentially hazardous, often becoming storm clouds, called cumulonimbus which may often be embedded or concealed within the stratiform cloud.

Note that the cold and warm fronts, depicted on weather charts by the semi-circular and triangular symbols, mark the surface position of each of the fronts.

Isobars

Isobars on typical weather charts are lines of equal surface pressure. A typical pattern of isobars around a polar front depression is shown in Figure 4.15. You should note that Polar Front Depressions move from West to East, so that, in a typical frontal system, the warm front precedes the cold front. Therefore, as the warm front approaches from the West, pressure falls. Between the fronts, the pressure falls slightly, but after the cold front has passed, pressure will start to rise again.

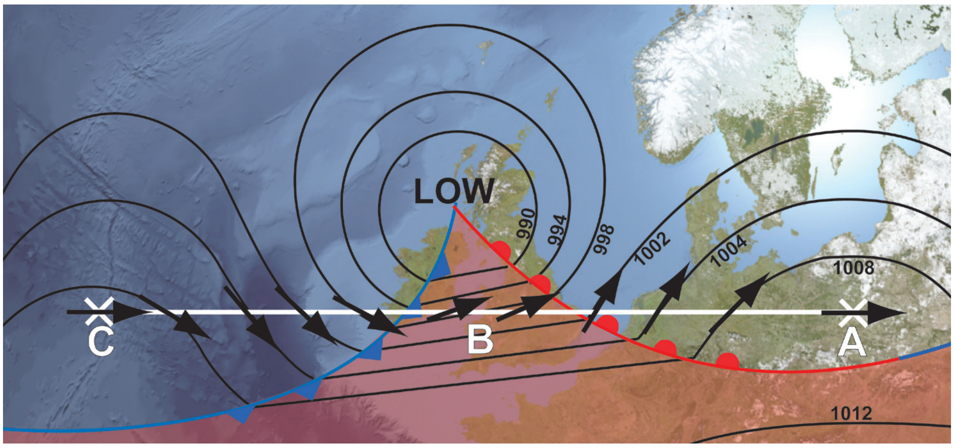


Figure 4.15 Isobars on a Weather Chart

Figure 4.16 is a typical UK Met Office chart showing Polar Front Depressions with their associated cold and warm fronts and isobars. In Figure 4.16, there is, however, a feature that we have not yet mentioned. That is the occluded front.

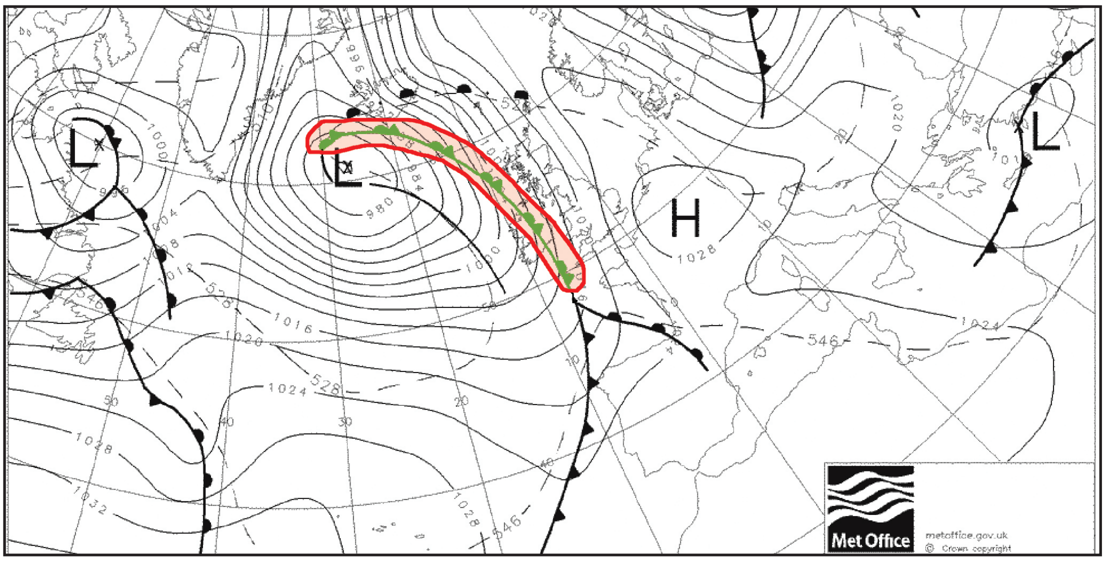


Figure 4.16 An Occluded Front

The Occluded Front
If you examine the highlighted area in Figure 4.16 you will notice that the warm and cold front symbols are found together along one line. When the symbols are arranged in this manner, they indicate the presence of an occluded front. Occluded fronts are created when the cold and warm fronts merge. Occluded fronts will be explained in more detail later on in this book.

ISOBARIC TROUGHS

Depressions of any kind will change over time, and can be a variety of shapes and sizes. By analysing the pattern of the isobars it is possible to identify the shape of the depression. If the isobars form a finger-like protrusion away from the centre of the depression an isobaric trough of low pressure is present.

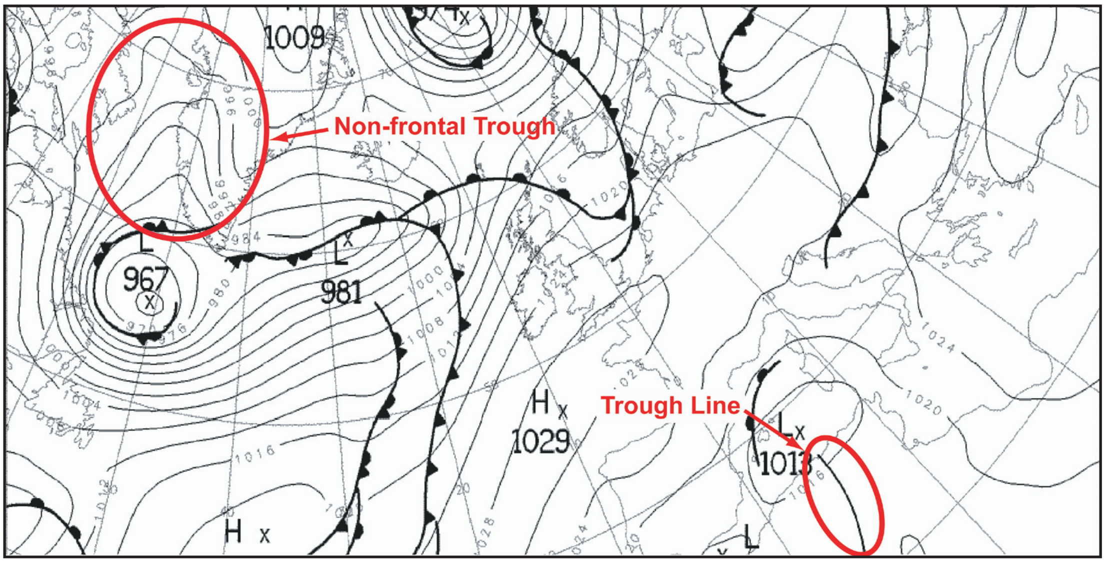


Figure 4.17 Isobaric Trough

Weather in an isobaric trough can be as active as that of a main depression.

There is another type of surface trough, also shown in Figure 4.17, which is caused by processes higher up in the atmosphere. These are known as trough lines, and are represented on surface pressure charts with a solid black line. Significant formations of cumuliform storm cloud can occur along these trough lines.

Troughs can be associated with fronts, or may be non-frontal. Both types can be seen in Figure 4.17. A non-frontal trough is usually U-shaped, such as the trough highlighted in Figure 4.17. Non-frontal troughs are characterised by convergence of air at the Earth's surface, causing air to rise over a large area, producing extensive cloud with associated rain and showers

ANTICYCLONES

An anticyclone or high is a region of relatively high surface pressure shown by more or less circular isobars similar to a depression but with higher pressure at the centre. Isobars are more widely spaced than with depressions. There are three types of surface anticyclone, warm, cold and temporary cold. All anticyclones are formed when the there is a net gain of the air above a particular location.

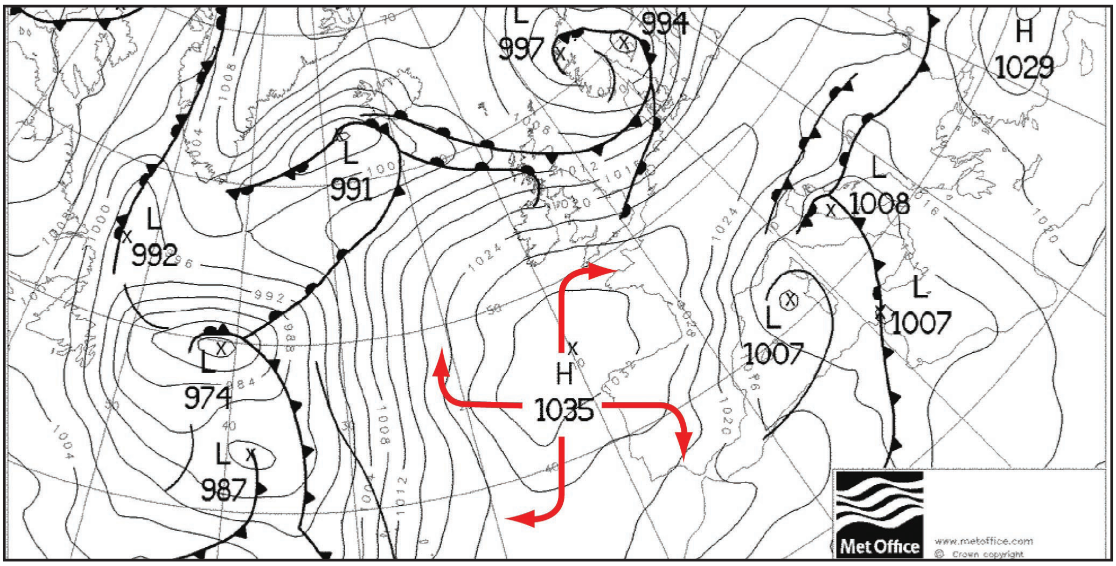


Figure 4.18 A surface anticyclone in the Northern Hemisphere showing surface outflow in with red arrows

An anticyclone or high pressure is created when, for whatever reason, the air converges at the top of atmosphere, descends or subsides and then diverges once it reaches the surface. The reason this type of air flow creates a high pressure is because the air converging at the top of the atmosphere enters the area quicker than it can leave by the surface divergence. This is because the surface divergence is slowed due to friction with the earth.

As the air descends in a high pressure system it becomes compressed. This compression causes the air to warm and thus prevents any significant cloud from forming (because to make clouds, air must cool). The other effect of this warming is to create a "foot" of abnormally warm air at the bottom of the high pressure system. This foot of warm air sits a few thousand feet above the surface and creates a temperature inversion commonly called a subsidence inversion. The only clouds that can develop in a high pressure sit between this foot and the surface, or at very high altitudes near the top of the troposphere.

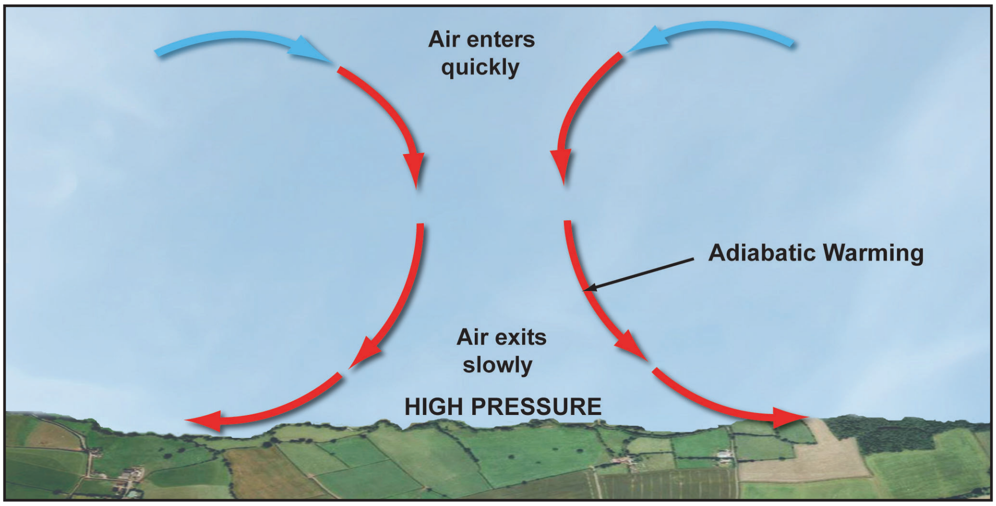


Figure 4.19 A cross section of a surface anticyclone.

At the surface, the air diverges away from the region of higher pressure and this air flow will eventually be turned right in the Northern Hemisphere or left in the Southern Hemisphere by the corriolis force. This causes the air to flow outwards and clockwise in the Northern Hemisphere and outwards and anticlockwise in the Southern Hemisphere. In both cases the surface air will blow across the isobars away from the high.

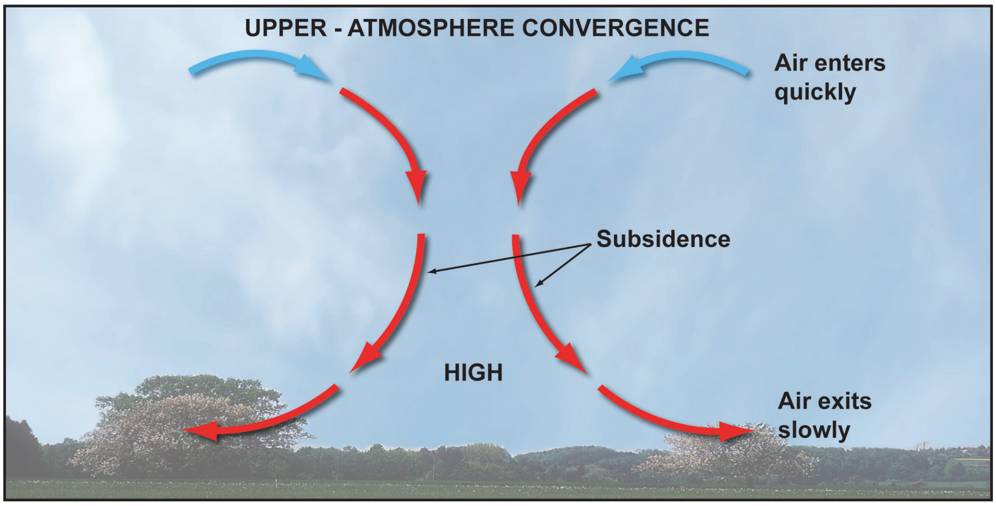


Figure 4.20 High Pressures

Warm Anticyclones

Warm anticyclones are caused by an excess of air at high level. The descending air will be heated by compression and surface temperatures will rise as a result. These anticyclones form a belt of high pressure which is normally found between the 20° and 40° latitude. The high pressures within this area are called the Sub Tropical Highs and two examples of such in the Atlantic Ocean are the Azores and Bermuda Highs. This belt of high pressure will move with the passage of the overhead sun through the seasons, moving slightly north up to June and slightly south up to December.

Cold Anticyclones

These are caused by low surface temperatures. The decreasing surface temperatures of large land masses in winter cause a slow but progressive sinking of the atmosphere. This will eventually create the airflow required to form a high pressure. Cold anticyclones only occur over large land masses in the winter months. An example is the Siberian High over northern Asia and the North American High or Canadian High.

Temporary Cold Anticyclones Or Travelling Anticyclones

A temporary cold anticyclone is found along the polar front between the polar front depressions. It is not actual a high pressure with concentric isobars, it is more akin to a ridge of high pressure. Cold temporary anticyclones are produced in the cold air between depressions on the polar front.

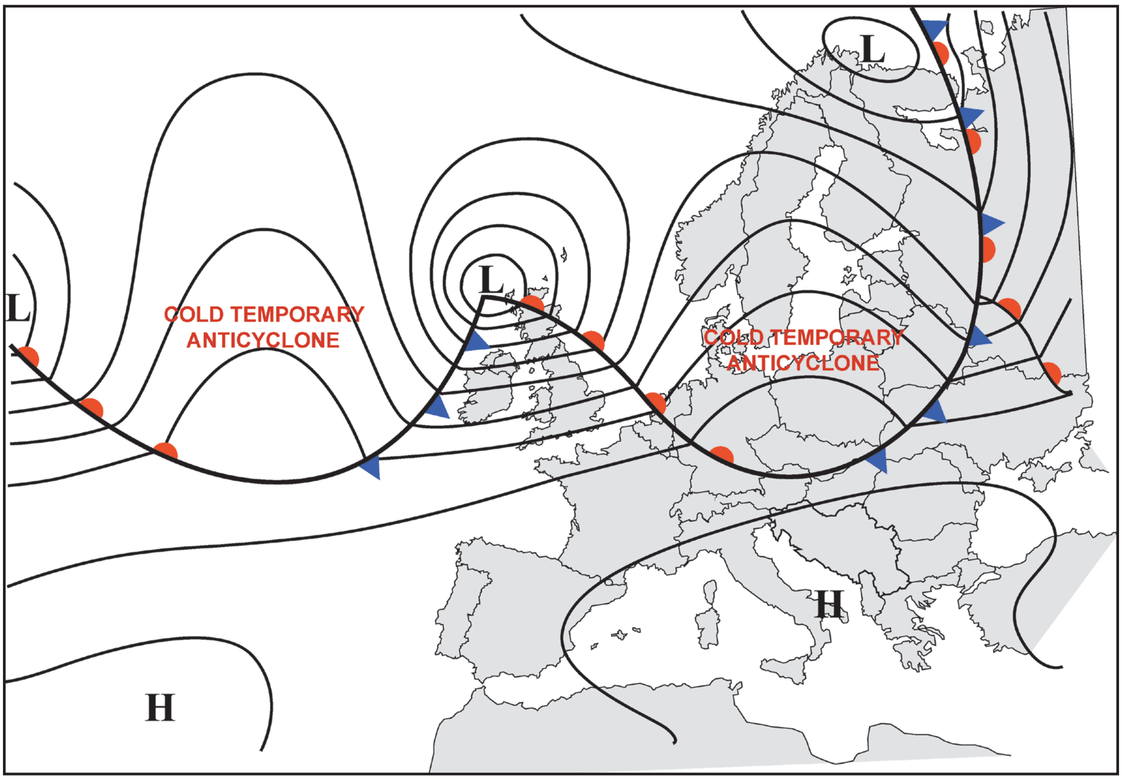


Figure 4.21 A Temporary Cold Anticyclone

Blocking Anticyclones

Blocking anticyclones are warm anticyclones formed from an extensions of high pressure areas developed in the sub- tropical regions, may hold up or divert the normal west-east passage of polar front depressions and persist for several days. The diagram shows how the usual west-east flow becomes more north-south, or meridional as the effect of the extension of the Azores High affects the air flow. In order for the anticyclone to block the passage of polar fronts it must be at higher latitudes than its parent sub tropical high. Usually, the blocking anticyclone must persist at latitudes between 45° to 65° for it to be effective at blocking the polar front.

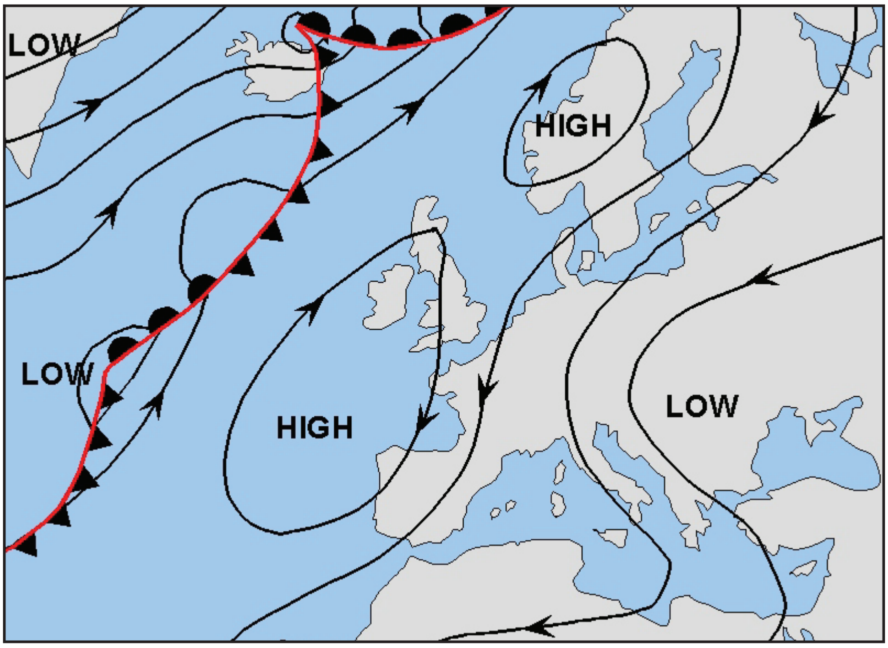


Figure 4.22 Blocking Anticyclones from Azores to Scandinavia

Weather

Cloud	Very little cloud. Some low stratus and fog in winter and over night but never any cumuliform clouds
Precipitation	None.
Visibility	Generally poorer than with a depression. Autumn/Winter - fog early morning and night. Summer - haze is possible, especially around industrial areas.
Temperature	Dependent on type of anticyclone.
Winds	Light and variable

RIDGES

Ridges of high pressure are indicated by isobars extending outwards from an anticyclone. They are also sometimes referred to as 'wedges'. Ridges are essentially extensions of a high pressure system. Since they are formed from a parent high pressure, their weather and characteristics are similar to a high pressure.

A ridge like the cold temporary anticyclone often brings a period of good weather between two depressions. An example of a ridge of high pressure is shown below

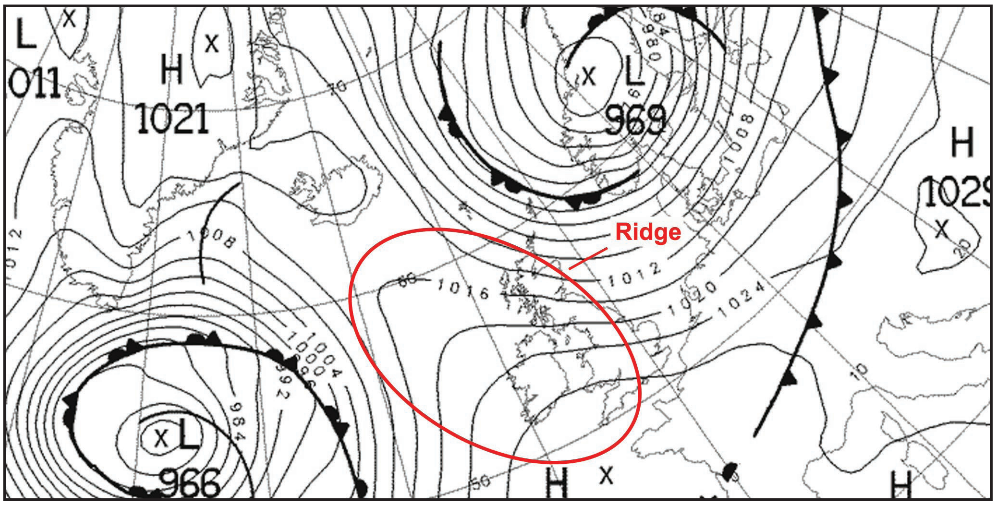


Figure 4.23 A Ridge of High Pressure

COLS

Cols are regions of almost level pressure between two highs and two lows. It is an area of stagnation. This is illustrated in the figure below.

Weather
Col weather is normally settled, but is dependent on changing pressure. They always have very light and variable winds but their weather depends on the season. In autumn and winter cols produce poor visibility and fog, whilst in summer thunderstorms are common.

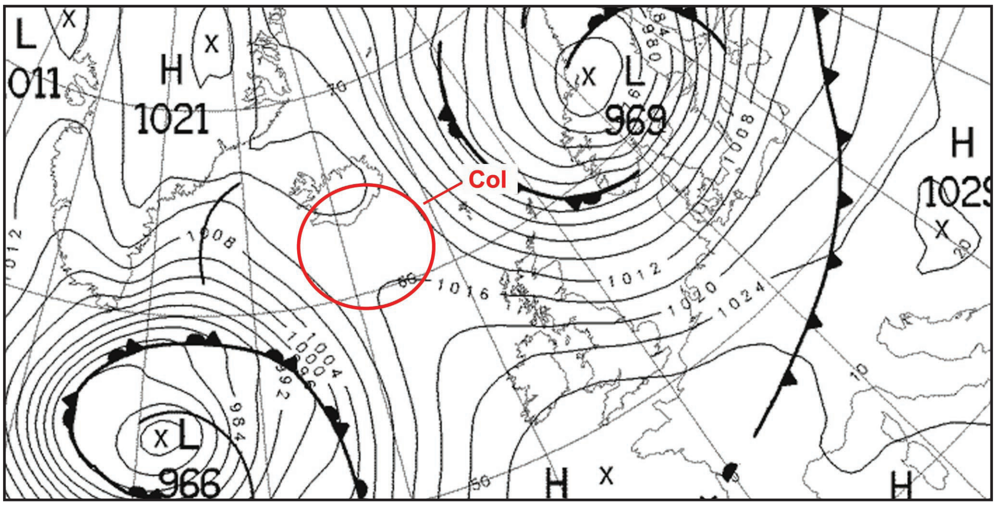


Figure 4.24 A typical Col

PRESSURE SYSTEMS MOVEMENT

Weather patterns (pressure systems) vary across the globe. They are mobile in high latitudes while slow moving in equatorial latitudes. Patterns of isobars which indicate weather will retain their general shape while moving, but change their numerical value, either weakening or intensifying. Movement of the systems is the key to accurate forecasting.

As a general rule, pressure systems outside of the equatorial regions move from west to east, whereas within the equatorial region they move from east to west.

TERMINOLOGY

Depressions will fill up or decay as pressure rises.

Depressions will deepen as pressure falls.

Depressions move rapidly, their average lifetime is 14 days.

Anticyclones will build up as pressure rises.

Anticyclones will weaken or collapse as pressure falls.

Anticyclones are very slow moving, they can last for a lengthy period, even up to 6 months.

Cols last a few days only and are then absorbed into other systems.

Changes of shape and intensity are slight in tropical regions where pressure is generally low, but in temperate and polar latitudes changes are much more varied and rapid.

BUYS BALLOT'S LAW

In the 19th century the Dutch meteorologist Buys Ballot produced a law based on the observation of wind direction and pressure systems.

Buys Ballot's Law states that: If an observer stands with his back to the wind, the lower pressure is on his left in the northern hemisphere, and on his right in the southern hemisphere.

A corollary of this law is that if an aircraft is experiencing starboard drift in the northern hemisphere the aircraft is heading towards low pressure. This is illustrated below.

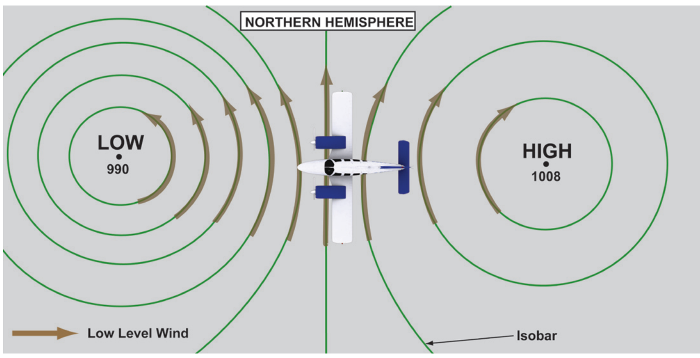


Figure 4.25 A Corollary of Buys Ballot's Law

PRESSURE GRADIENT

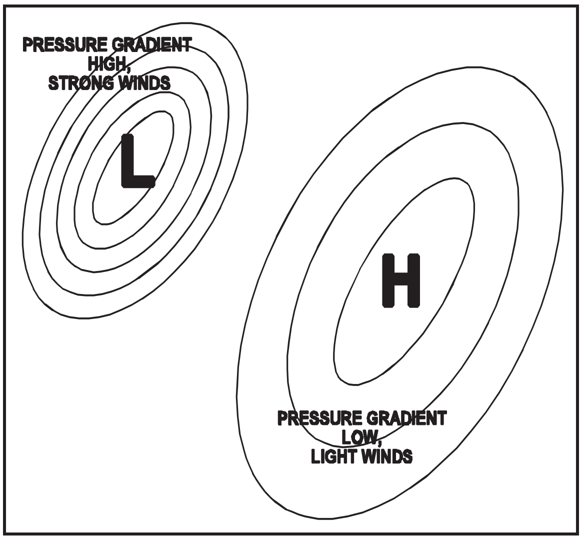
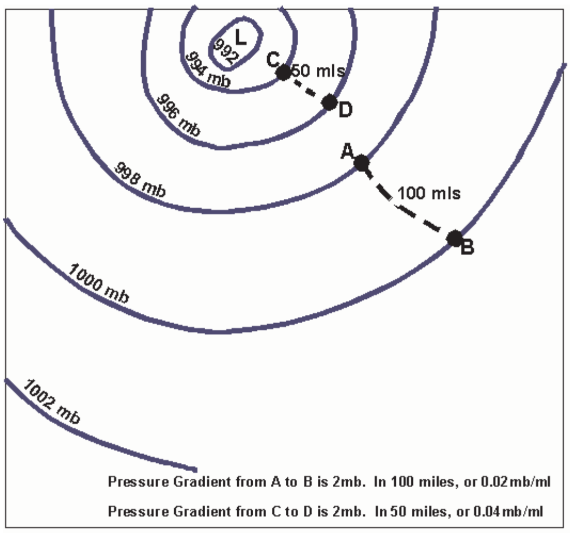


Figure 4.26 Pressure Gradient

The pressure gradient is the difference in pressure between consecutive isobars divided by the distance between them, this is illustrated in the figure below. Closely spaced isobars imply a steep pressure gradient (common in low pressure systems) and widely spaced isobars imply a shallow pressure gradient (common in high pressure systems). The pressure gradient produces an attractive force that will tend to pull molecules of air towards lower pressure areas. The greater the pressure change and the greater the pressure gradient force for a given distance the faster the wind velocity.



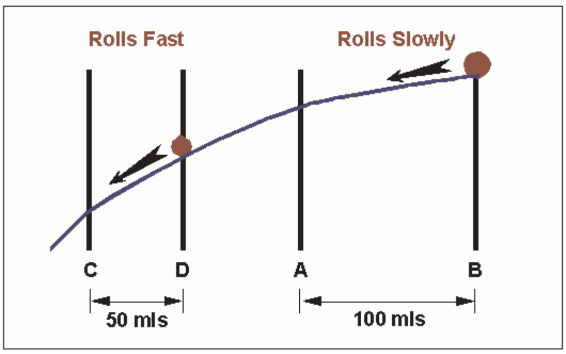


Figure 4.27 Wind speed and pressure gradient

Air tries to move from high to low pressure and this will generate a pressure gradient force which develops into the wind velocity that we feel. This will be discussed fully in Chapter 11.

QUESTIONS

1. (For this question use annex B)
A ridge is indicated by letters:

a. D
b. A & C
c. B & C
d. C & D

2. When isobars, for an area in the mid-latitudes on a weather map, are close together, the wind is most likely to be

a. changing direction rapidly
b. light
c. strong
d. blowing perpendicular to the isobars

3. Subsidence is:

a. vertically upwards motion of air
b. the same as convection
c. vertically downwards motion of air
d. horizontal motion of air

4. The isobars drawn on a surface weather chart represent lines of equal pressure

a. at flight level
b. at height of observatory
c. at a determined density altitude
d. reduced to sea level

5. Areas of sinking air are generally cloudless because as air sinks it

a. loses water vapour
b. is heated by compression
c. reaches warmer layers
d. is heated by expansion

6. What type of air movement is associated with the centre line of a trough?

a. Divergence with descending air.
b. Divergence with lifting.
c. Convergence with descending air.
d. Convergence with lifting.

7. Extensive cloud and precipitation is often associated with a non frontal thermal depression because of :

   a. surface divergence and upper level convergence causing widespread descent of air in the depression
   b. surface divergence and upper level convergence causing widespread ascent of air in the depression
   c. surface convergence and upper level divergence causing widespread ascent of air in the depression
   d. surface convergence and upper level divergence causing widespread descent of air in the depression

8. A trough of low pressure on a surface synoptic chart is an area of

   a. convergence and subsidence
   b. convergence and widespread ascent
   c. divergence and subsidence
   d. divergence and widespread ascent

9. How do air masses move at a warm front?

   a. Cold air overrides a warm air mass
   b. Cold air undercuts a warm air mass
   c. Warm air undercuts a cold air mass
   d. Warm air overrides a cold air mass

10. In temperate latitudes what weather conditions may be expected over land during the summer in the centre of a stationary high pressure zone?
   a. thick low level cloud.
   b. Calm winds, haze.
   c. showers and thunderstorms.
   d. cumulus clouds and thunderstorms

11. What surface weather is associated with a stationary high pressure region over land in the winter?

   a. thick stratus with continuous rain.
   b. The possibility of snow showers.
   c. A tendency for fog and low stratus
   d. Thunderstorms.

12. (For this question use annex A)
   Which of the following best describes Zone D?

   a. Ridge of high pressure
   b. Anticyclone
   c. Trough of low pressure
   d. Col

13. (For this question use annex A)
Which of the following best describes Zone C?

a. Trough of low pressure
b. Depression
c. Ridge of high pressure
d. Anticyclone

14. (For this question use annex B)
Which of the following best describes Zone A?

a. Col
b. Ridge of high pressure
c. Depression
d. Trough of low pressure

15. What is the correct term for the descending air flow in a large high pressure area?

a. Convection.
b. Subsidence.
c. Convergence.
d. Advection.

16. Which of the following is a common result of subsidence?

a. Clear air turbulence at higher altitudes.
b. An inversion over a large area with poor visibility.
c. CB-clouds and thunderstorms over a large area.
d. Wide spread NS and AS clouds and intense precipitation.

17. What is the most likely cause of a lack of clouds at higher levels in a stationary high?

a. Divergence at higher levels
b. Sinking air
c. Rising air
d. Instability

18. (For this question use annex B)
Which of the following best describes Zone B?

a. Ridge of high pressure
b. Depression
c. Anticyclone
d. Col

19. (For this question annex C)
The pressure system at position "A" is a

a. trough of low pressure
b. Anticyclone
c. col
d. secondary low

20. Divergence in the upper air results, near the surface, in

    a. falling pressure and likely dissipation of clouds
    b. falling pressure and likely formation of clouds
    c. rising pressure and likely formation of clouds
    d. rising pressure and likely dissipation of clouds

21. Where are you likely to find the strongest winds close to the ground?

    a. Where there is little variation in pressure over a large area during the winter months
    b. In the transition zone between two air masses
    c. At the centre of a low-pressure system
    d. At the centre of a high-pressure system

22. A blocking anticyclone on the northern hemisphere is

    a. a warm anticyclone/quasi stationary/situated between 50°N and 70°N
    b. quasi stationary/situated between 50°N and 70°N,/a cold anticyclone
    c. situated between 50° and 70°N/a cold anticyclone/steering depressions
    d. a cold anticyclone/steering depressions/situated over Scandinavia

23. In an area of converging air

    a. clouds can not be formed
    b. clouds can be formed
    c. convective clouds can be dissolved
    d. stratified clouds can be dissolved

24. (For this question use annex C)
    The pressure system located in area "B"

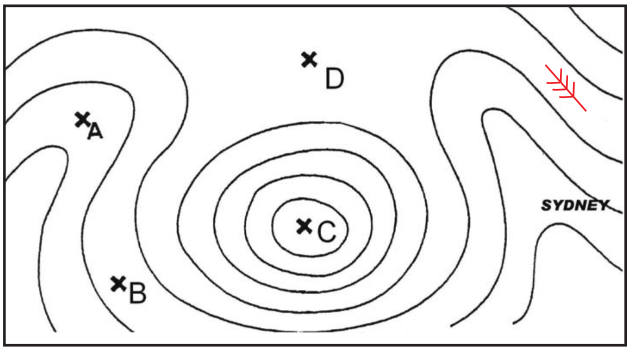
    a. ridge of high pressure
    b. col
    c. trough of low pressure
    d. depression

25. (For this question use annex B)
    Which location is most likely to have fog in the coming night?

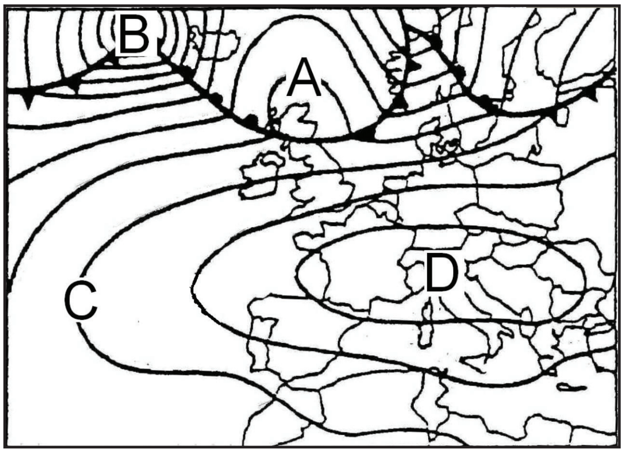
    a. D
    b. C
    c. B
    d. A

ANNEXES

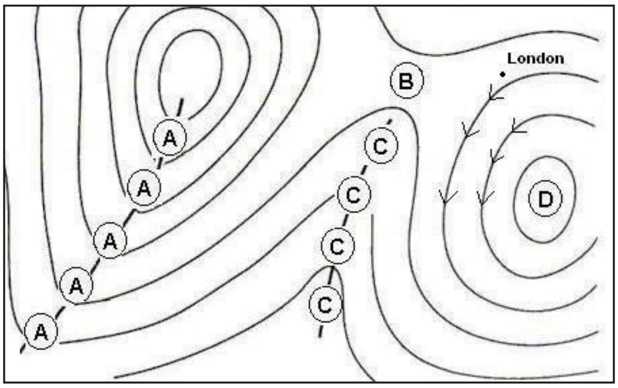
ANNEX A



ANNEX B



ANNEX C



ANSWERS

1.	C	11.	C	21.	C
2.	C	12.	D	22.	A
3.	C	13.	D	23.	B
4.	D	14.	B	24.	B
5.	B	15.	B	25.	A
6.	D	16.	B		
7.	C	17.	B		
8.	B	18.	B		
9.	D	19.	A		
10.	B	20.	B		

CHAPTER FIVE

ALTIMETRY

CONTENTS

THE ALTIMETER

Because air pressure varies with altitude, a pilot is able directly to read his aircraft's vertical separation from the Earth's surface, using an instrument called the altimeter.

The altimeter is a form of aneroid barometer. Any change in air pressure will cause the partially evacuated metal capsule of the aneroid barometer, to expand or contract. In the altimeter, this capsule is linked to a pointer which moves over a scale, calibrated in feet or metres, so that the pilot can read his altitude or height.

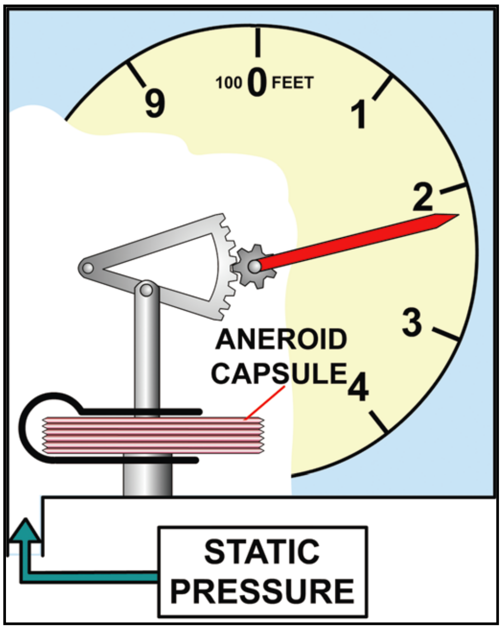


Figure 5.1 A Simple Altimeter

As an aircraft climbs, the atmospheric pressure surrounding the aircraft decreases causing the capsule within the altimeter to expand, and the altimeter pointer to move clockwise over the scale to indicate an increase in height. Conversely, when the aircraft descends, atmospheric pressure increases, compressing the capsule, causing the altimeter pointer to move anticlockwise, over the scale to indicate a decrease in height.

The aircraft's altimeter is basically an instrument which measures atmospheric pressure and, in doing so, is calibrated so as to indicate the vertical separation of the aircraft from a defined pressure datum level.

It is important to note that the altimeter is unable to measure vertical separation above any datum level other than a pressure datum.

We must consider, therefore, where the altimeter reading is measured from, in other words, where is the altimeter assuming the datum level to be?

ALTIMETER SUB-SCALE SETTINGS

The datum with respect to which the altimeter's scale is calibrated is neither a physical, nor geographical level; it is a pressure value. It follows, then, that the altimeter must be given a pressure value to begin measuring from, before it can indicate a vertical separation of any use to the pilot. This pressure value is selected by means of an adjustable sub-scale. The altimeter sub-scale takes the form of a small window in the face of the altimeter; which shows the selected datum pressure value, either in millibars, hectopascals or inches of mercury. (See Figure 5.3.)

Figure 5.2 Sub Scale Setting

The pressure value set in the altimeter's sub-scale window, is the pressure level that the altimeter will start measuring from; in other words, the pressure level that the altimeter will assume to be zero feet. So, if a pilot wishes the altimeter to read height above mean sea level, the atmospheric pressure at mean sea level must be determined and selected on the altimeter's subscale.

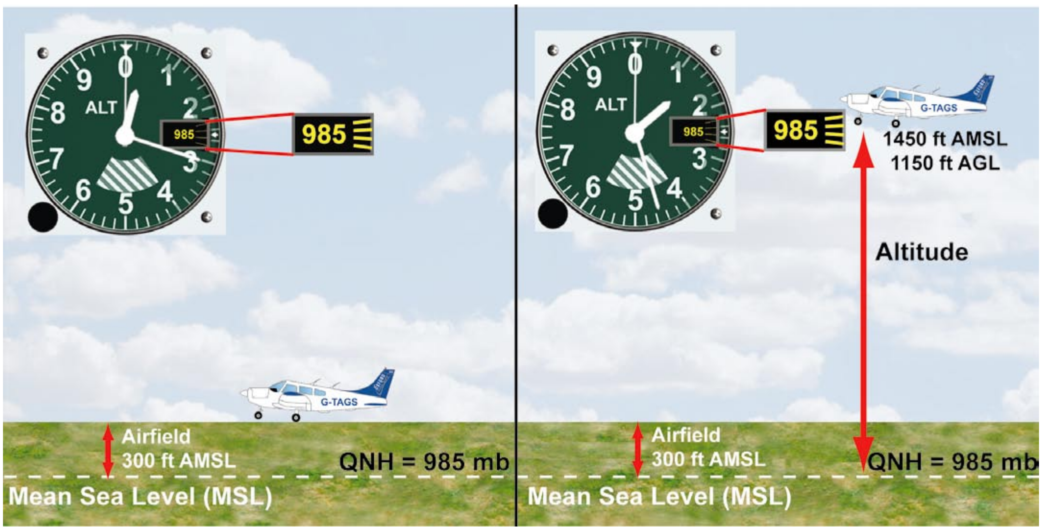


Figure 5.3 Setting QNH

The altimeter now has its zero datum point set at a pressure which equates to the pressure at mean sea level; this pressure value is commonly referred to as the QNH. The QNH is passed to a pilot by an Air Traffic Service Unit. If the aircraft were then to take-off and climb, the altimeter would show the aircraft's height above mean sea level.

Elevation figures given for terrain, and obstacles, on aeronautical charts, are given in feet above sea-level. So, if the altimeter is set to indicate vertical distance above sea-level, the task of maintaining safe separation from the terrain becomes much simpler for the pilot; he simply subtracts the elevation of the terrain over which he is flying from his altitude above sea-level to obtain his vertical separation from the ground beneath him.

With QNH set on the altimeter subscale, the indication on the altimeter is referred to as "altitude". Altitude is defined as vertical distance above mean sea-level. Figure 5.3 shows an aircraft, in flight, with the altimeter indicating 1,450 feet above mean sea-level (AMSL), with a QNH of 985 millibars set on its sub-scale. The altimeter of the same aircraft, when on the ground, reads 300 feet AMSL, the airfields elevation.

QNH is determined by Air Traffic Control using a special barometer such as the one shown in Figure 2.4 of Chapter 2.

If a pilot wishes to determine his height above an airfield, then he can set the airfield pressure as a datum in the sub-scale window. This airfield pressure setting is defined as QFE.

The formal definition of QFE is:
The value of pressure, for a particular aerodrome and time, corrected to the official elevation.

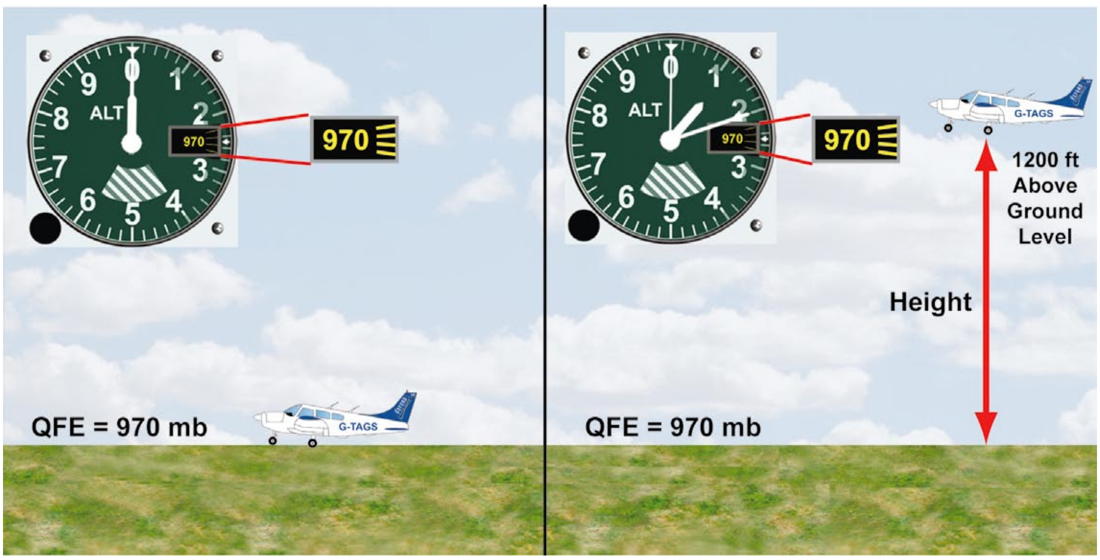


Figure 5.4 Setting QFE

HORIZONTAL PRESSURE VARIATION

As explained in Chapter 4, atmospheric pressure varies horizontally as well as vertically. This phenomenon can lead to problems for the pilot, because the atmospheric pressure at any given level in the atmosphere will rarely remain constant. So if a pilot flies at a constant indicated altitude, his true altitude will usually vary over time and distance.

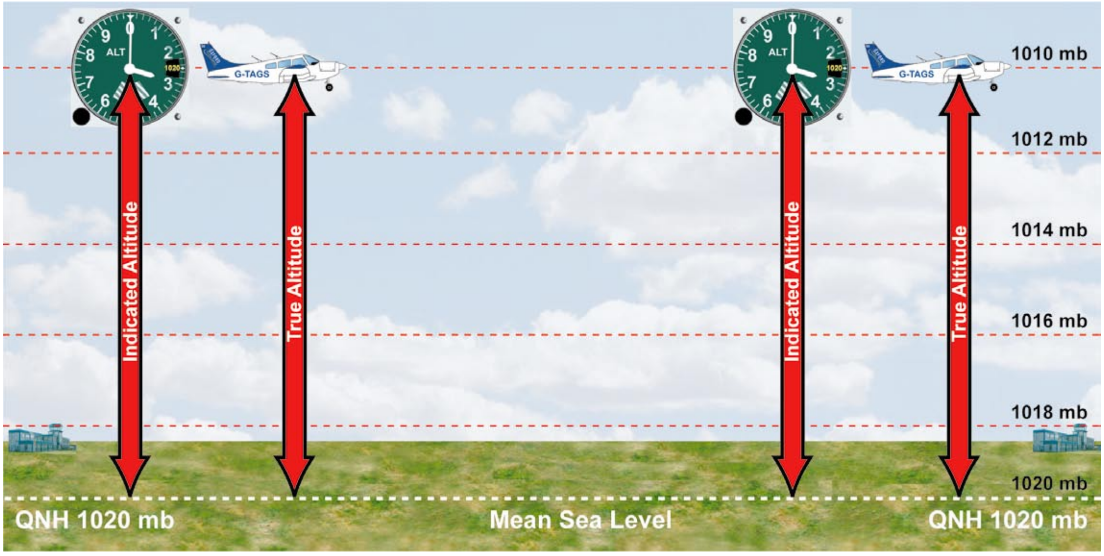


Figure 5.5 Constant QNH

However, if, as in Figure 5.5, the atmospheric pressure at both departure and destination airfields were to be the same, the lines of equal pressure, or isobars, at all levels between the two airfields would be horizontal. In these circumstances, as the aircraft flew along the route between the airfields, the indicated altitude, and the true altitude above sea-level would be the same.

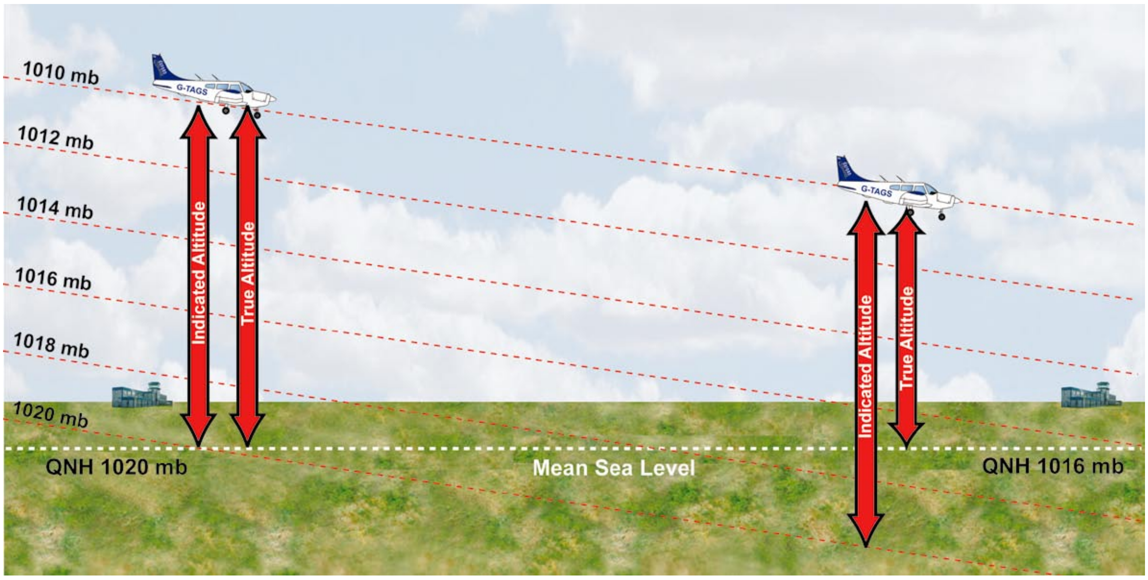


Figure 5.6 High to Low QNH

In Figure 5.6, atmospheric pressure at the destination airfield is lower than at the departure airfield. Notice that, now, the isobars slope downwards.

Consequently, by flying at a constant indicated altitude, say at 3,000 feet, the aircraft would be following the isobar marking the pressure which causes the altimeter to read 3,000 feet. In reality, therefore, the aircraft would be descending.

So, when flying from a high pressure area to an area of lower pressure, true altitude is reducing whilst the indicated altitude remains the same. You will doubtless realise immediately that this is a potentially hazardous situation. There is, however, a saying to help you remember this fact. "From High to Low, Look out Below."

In Figure 5.7, the situation is reversed, the QNH at the destination airfield being higher than at the departure airfield. The isobars, therefore, now slope upwards. So, if an aircraft were to fly from the departure airfield to the destination airfield, while maintaining a constant indicated altitude, the aircraft would climb, following the upwards-sloping isobars. This time true altitude is increasing, while the indicated altitude remains constant. This situation is not as dangerous as the former, since the aircraft's true altitude is increasing, but, nevertheless, the altitude indication is not accurate, so the altimeter subscale setting would not be suitable for landing.

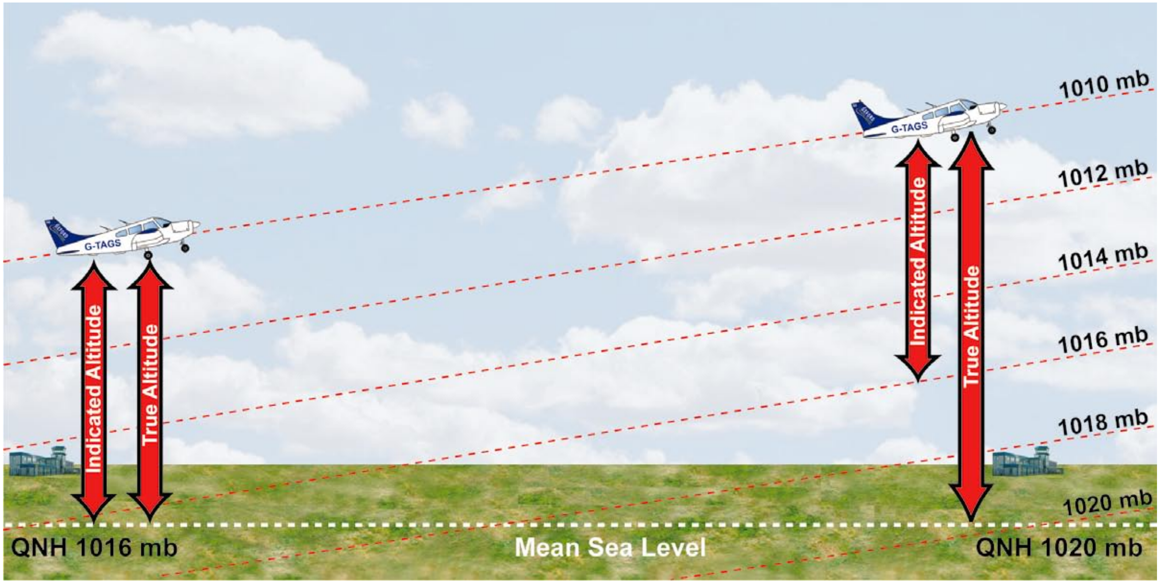


Figure 5.7 Low to High QNH

The above examples illustrate why pilots need to adjust the pressure setting on the altimeter subscale in order to take into account horizontal variation in pressure. Resetting the altimeter subscale, when required, is, therefore, a vital part of aircraft operations. When taking off or landing at an airfield with an Air Traffic Control Unit, the controller will normally give the pilot the airfield QNH, which must be read back to confirm that it has been received correctly. The pilot must then set QNH on the altimeter's subscale. This essential practice ensures that the altimeter is not only reading correctly, but is reading the same as the altimeters in other aircraft, operating in the vicinity of the aerodrome.

The procedure of setting airfield QNH gives an appropriate altimeter subscale setting for departure or arrival at an airfield, only. A different pressure setting will be required as the aircraft progresses en-route.

Note: *Most civilian Air Traffic Service Units at aerodromes operate exclusively on QNH. Controllers at military aerodromes, however, will invariably pass the QFE to a pilot who is arriving at, taking off from the aerodrome or transiting their Zone.*

REGIONAL PRESSURE SETTINGS

With an airfield QNH set on the altimeter, its indications may be inaccurate when the aircraft is flying cross-country at considerable distances from the departure aerodrome. In the United Kingdom, this problem is solved by the provision of Regional Pressure Settings. Regional Pressure Settings (RPS) may be obtained from any Air Traffic Service Unit providing a Flight Information Service.

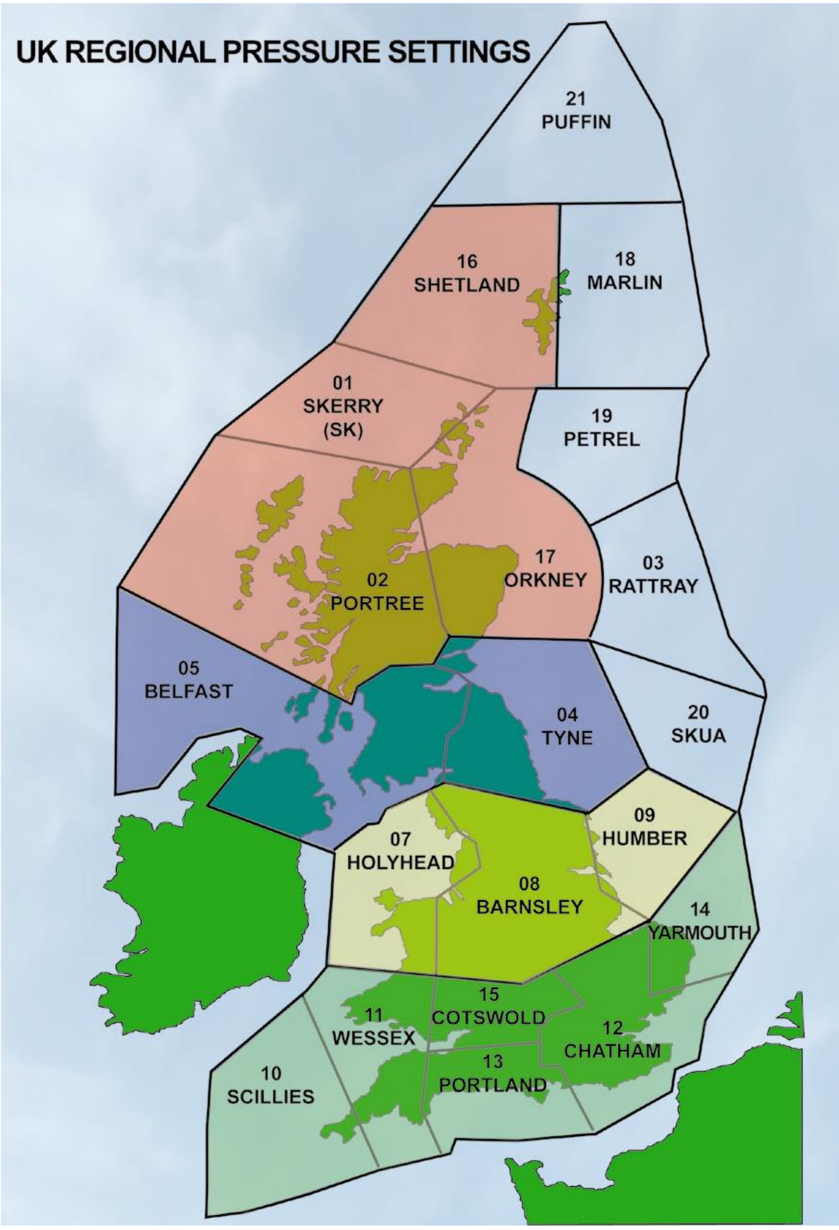


Figure 5.8

Figure 5.8 shows the regions of the United Kingdom for which Regional Pressure Settings (RPS) values are issued. These regions are known as Altimeter Setting Regions (ASRs). When flying in these regions, below the transition altitude, the altimeter should be set to the appropriate RPS which will be passed to pilots by the Air Traffic Service Unit with which they are in contact. Selecting the correct RPS will ensure a reasonably accurate, but more importantly, safe, altimeter reading.

On the approach to an airfield, the Air Traffic Service Unit will pass pilots the airfield's QNH. Generally, the aerodrome QNH will differ only little from the RPS. The RPS value is based on the lowest forecast pressure within the whole of the Altimeter Setting Region, and is valid for one hour. An individual airfield may have a slightly higher value of pressure, but will certainly be more up to date than the RPS value.

The Standard Pressure Setting of 1013.2 millibars
Flight below a set transition altitude is conducted with the altimeter sub-scale set to an aerodrome QNH or RPS, as these sub-scale settings allow a pilot to determine the vertical separation of his aircraft from the terrain beneath.

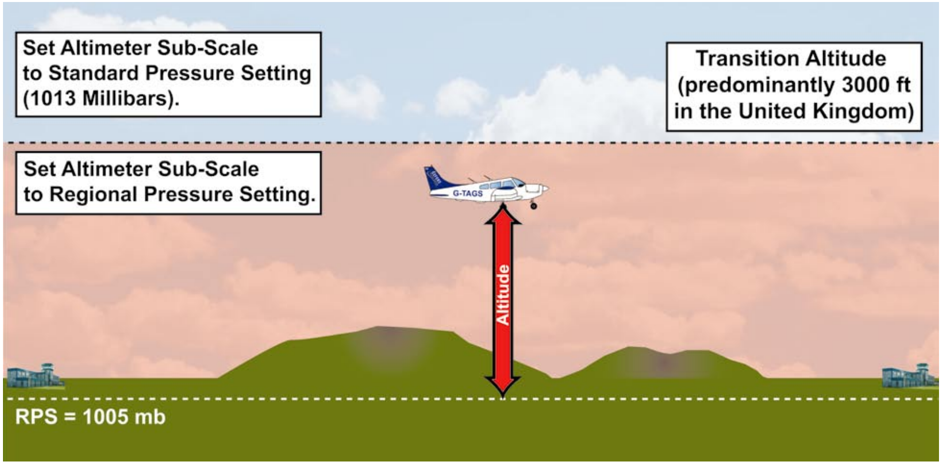


Figure 5.9 Transition Altitude

However, when the aircraft climbs through the transition altitude it is necessary to change to the Standard Pressure Setting (SPS). For flight at these higher altitudes, where variations in pressure are less likely to endanger the aircraft, flight at a constant altimeter pressure setting is more convenient for the pilot, and for Air Traffic Control Units.

Above the Transition Altitude, vertical distance above the SPS of 1013.2 millibars is referred to as a Flight Level or a Pressure Altitude. Air Traffic Control Units (ATCU) will always refer to Flight Levels, above the Transition Altitude. With all aircraft which are flying above the Transition Altitude having the SPS set on their altimeters, ATCUs are able to maintain vertical separation between aircraft more easily.

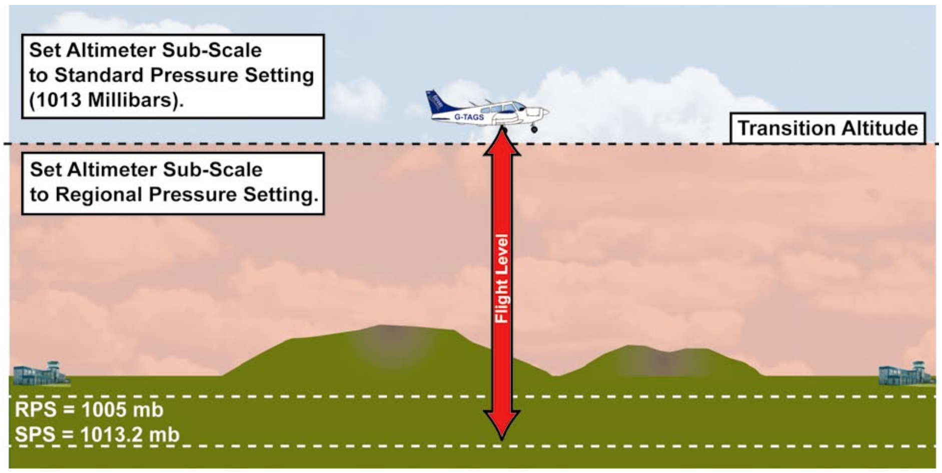


Figure 5.10 Transition Altitude

You should note that the Transition Altitude is not a constant altitude. For low-lying countries the Transition Altitude will usually be 3,000ft, but in many countries the elevation of airfields can be greater than 3,000 feet. In such cases, the Transition Altitude will be much higher. In the United States, for instance, the Transition Altitude is 18,000 feet. Always be sure to check the Transition Altitude at unfamiliar aerodromes.

When descending to an aerodrome, the pilot must re-set the altimeter to airfield QNH. The level during the descent at which this adjustment take place is known as the Transition Level. The Transition Level (which is the lowest Flight Level available for use by pilots) is not a fixed level. The Transition Level depends on the prevailing atmospheric pressure.

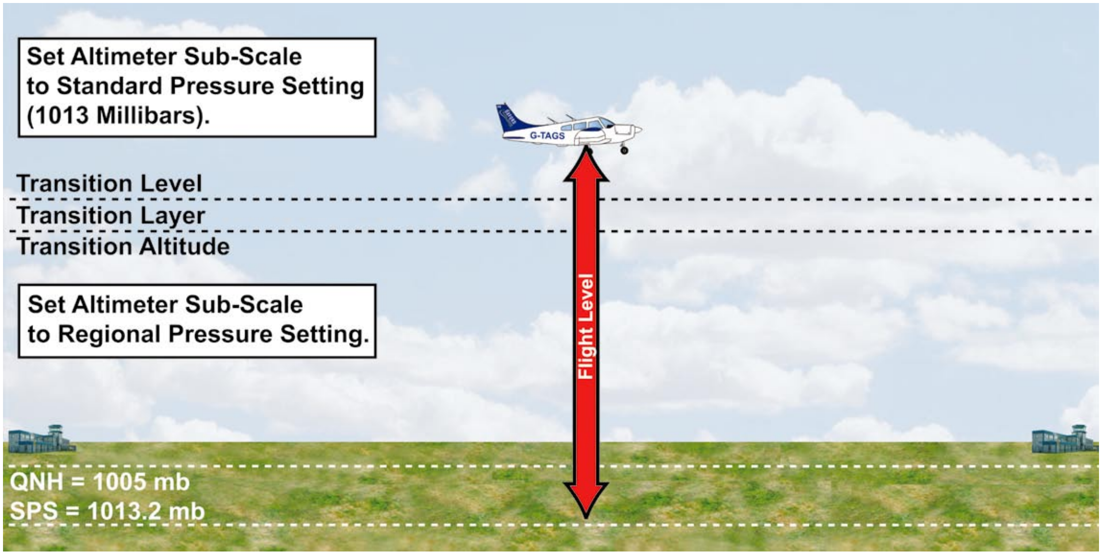


Figure 5.11 Transition Layer

The Transition Level is always higher than the Transition Altitude. The layer between these two levels is known as the Transition Layer. Air Traffic Control determine the Transition Level. The relationship between Transition Altitude and Transition Level and the relevant altimeter sub-scale settings, is covered in detail in Book 10 of this series - General Navigation.

QNE

Finally, we must mention a special use of the SPS which is referred to as QNE. QNE is seldom used, and, then, only at high-altitude airfields, although it is theoretically possible for it to be needed at low-altitude airfields with extremely low atmospheric pressures.

On rare occasions, QFE or QNH cannot be selected on the altimeter subscale when atmospheric pressure values are outside the range of the subscale. At these times the pilot will be instructed by the ATCU to set 1013.2 millibars on his altimeter subscale. The pilot will then be passed the elevation of the airfield above the 1013.2 millibar pressure datum. QNE is defined as the pressure altitude indicated on landing at an aerodrome, when the altimeter sub scale is set to 1013.2 millibars.

TEMPERATURE ERROR

In Chapter 2, Pressure, you learnt how the temperature of the air affects the rate at which pressure decreases with altitude. There is, however, no altimeter setting which will compensate for temperature error. The altimeter is calibrated against the ISA temperature and pressure lapse rate profile and is unable to compensate for the effect on its indications of any deviations from ISA.

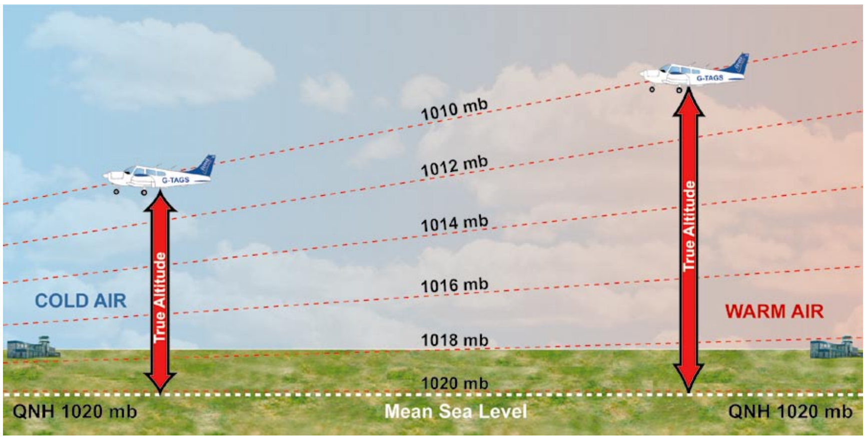


Figure 5.12 Warm to Cold Air

Figure 5.12 shows a typical horizontal pressure variation caused by temperature differences within the atmosphere. If air cools, the isobars become closer together, causing an increase in the pressure lapse rate; in other words, the pressure change with height is greater. However, a rise in air temperature has the opposite effect, causing the pressure lapse rate with height to decrease. If an aircraft were to fly from the area on the right of Figure 5.11 (warm air) to the area on the left (cold air), at a constant indicated altitude, the aircraft would be following a pressure level or isobar, and, as you can see from the diagram, would descend.

This is a potentially hazardous situation. To help the pilot remember the danger involved in flying from an area of high temperature to an area of low temperature he should recall the saying: "When flying from hot to cold, don't be bold" or, even more dramatically, "cold kills". So, never forget that, in cold air, the altimeter will over-read.

Conversely, if an aircraft is flown from cold air into warm air, true altitude will increase while indicated altitude remains constant, and, therefore, the aircraft will climb. In warm air, the altimeter will under-read.

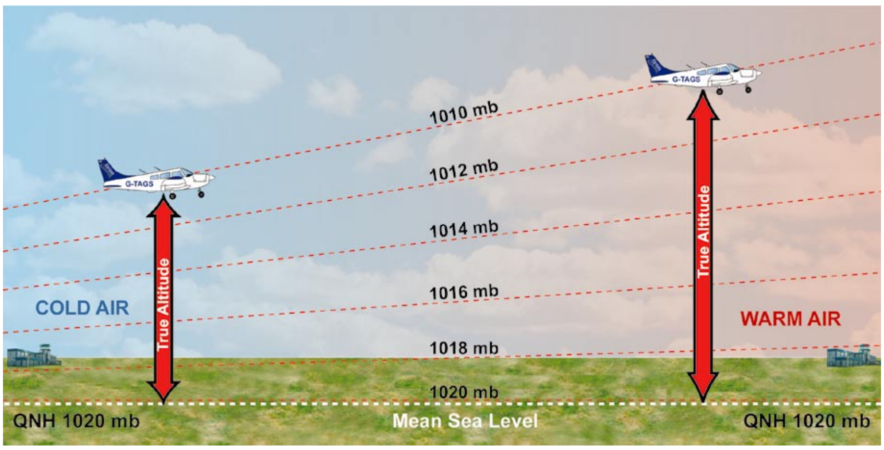
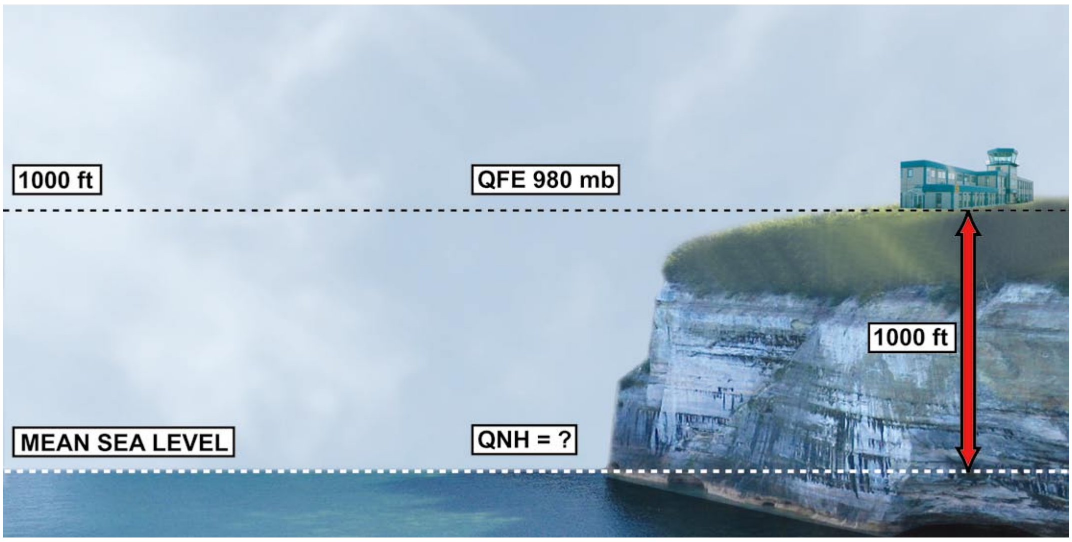


Figure 5.13 Cold to Warm Air

ALTIMETER PROBLEMS

Having completed the theory of the altimeter it may be useful to work through some typical altimetry problems and solutions. For simple calculations below 5,000 feet above mean sea-level, you should assume a height change of 30 feet per millibar. This means that for every one millibar change in pressure, the altimeter will show a height change of 30 feet.

Problem 1
Let us assume that an airfield is 1,000 feet above mean sea-level. If the observed QFE at the airfield is 980 millibars, what is the QNH?



At sea-level, pressure is obviously higher than that at the airfield, but by how much?

We are assuming that pressure changes by approximately 30 feet per millibar. Therefore, 1,000 feet divided by 30 feet tells us that the pressure change in 1,000 feet is approximately 33 millibars. So we simply add this pressure value to the airfield QFE to find the QNH. In this example, the QNH will be 980 plus 33, which equals 1013 millibars.

Problem 2
An airfield is 2,100 feet above mean sea-level and, on a particular day, has a QNH of 1005 millibars. What is the airfield's QFE?

Since the QFE is the airfield pressure, and the airfield is above mean sea-level, the QFE will have a lower value than the QNH. But, by how much?

Well, over an altitude of 2 100 feet there is a pressure change of approximately 70 millibars (2 100 divided by 30). Therefore, the airfield QFE will be 1 005 millibars minus 70 millibars, giving a QFE of 935 millibars.

Problem 3
An aircraft flies from Aerodrome A, at which the QNH is 1020 millibars (hectopascals), and whose elevation is 1,000 feet above mean sea-level, to Aerodrome B, at which the QNH is 1010 millibars, and whose elevation is 500 feet above mean sea-level.

The pilot has a QNH of 1020 millibars set on his altimeter. If he does not change the altimeter sub-scale setting, what will be the altimeter indication on landing at Aerodrome B?

Firstly, draw a diagram using the information provided in the question. Such a diagram might look like the image shown below. When drawing the QNH pressure levels, remember that pressure decreases with altitude; therefore, the 1010 millibar pressure level will be found above the 1020 millibar pressure level.

As the pilot has Aerodrome A's QNH set on his altimeter's sub scale, his altimeter will indicate 1,000 ft, the elevation of Aerodrome A, when the pilot is still on the ground at Aerodrome A.

From the image, then, you should be able to deduce that the question is essentially asking for the vertical distance of Aerodrome B above the pressure level 1020 millibars.

To find this out, you must first of all calculate the vertical distance between the two pressure levels of 1020 millibars and 1010 millibars. The pressure difference between these two pressure levels is 10 millibars. Now, you have learnt that for every 1 millibar change of pressure, the height difference is approximately 27 feet, and 10 × 27 feet gives us 270 feet.

So, the 1020 millibar pressure level is 300 feet lower than the 1010 millibar pressure level. Consequently, when the aircraft lands at Aerodrome B, whose elevation is 500 feet, it will be (500 + 270) feet above the 1020 millibar pressure datum level to which the altimeter is set.

On landing at Aerodrome B, then, the aircraft's altimeter will read 770 feet.

TRUE ALTITUDE

True altitude is the actual physical altitude of the aircraft above sea level. This can only be directly measured by a Radio Altimeter. However, an Aneroid Altimeter can read true altitude, but only if the atmosphere exactly matches ISA conditions. If ISA conditions do not prevail, then the aneroid altimeter will be suffer errors. The amount of error suffered by the instrument is a function of the ISA deviation, surface pressure and the altitude of the instrument.

A simple rule is that for every 1°C deviation, the aneroid altimeter is in error by 4 ft for every 1000 ft of pressure altitude (an alternative to the 4% rule). If the atmosphere is hotter than ISA then the aneroid altimeter set to QNH will read less than the true altitude, whereas if the atmosphere is colder than ISA the aneroid altimeter set to QNH will read higher than the true altitude. This is a fundamental concept and we have seen it already in the previous concepts.

Formulas to help you more accurately solve the mathematical type true altitude questions are shown below.

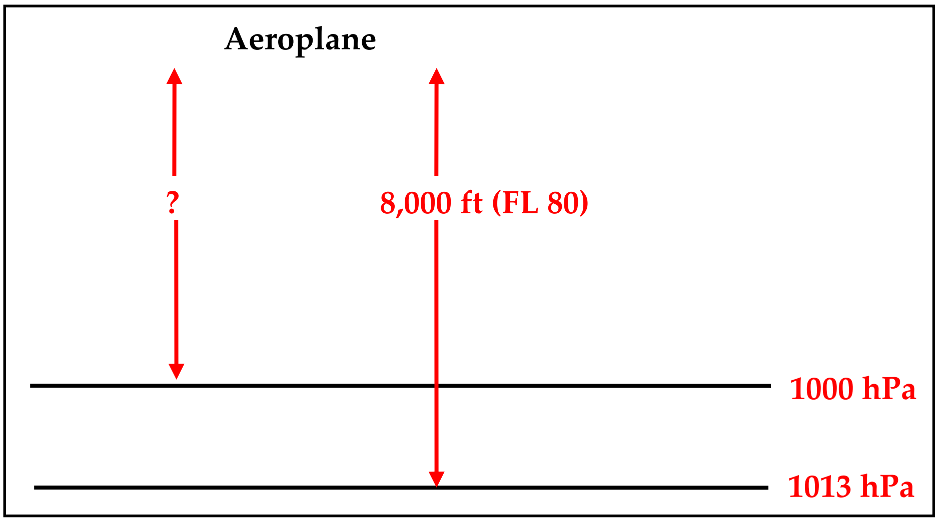
TRUE ALTITUDE = ALTITUDE ON QNH + (ISA DEVIATION x 4 x PRESSURE ALTITUDE ÷ 1000)

ALTITUDE ON QNH = TRUE ALTITUDE - (ISA DEVIATION x 4 x PRESSURE ALTITUDE ÷ 1000)

Example Mathematical Type Problems

1. An aircraft is flying at FL 80. The local QNH is 1000 hPa. After the altimeter has been adjusted to the local QNH, the reading will be approximately: (assume 27 ft per 1 hPa)

For this example we need to work out the altimeter reading with 1000 hPa set in the subscale based on the current altimeter reading of 8,000 ft with 1013 set in the subscale (FL 80). The diagram below will help. The distance between 1000 hPa and 1013 hPa is 351 ft because for every 1 hPa we assume 27 ft. Therefore to find out the answer, subtract 351 ft from 8,000 ft.



2. An aircraft is flying at FL100, the temperature is 10°C colder than ISA and local QNH is 1003 hPa. What is the aircrafts true altitude?

In this case we will use the top formula from the section on True Altitude. The information you lack in order to complete the formula is the altitude on QNH. You must work this out first. If you are reading 10,000 ft with 1013 hPa set in the subscale (FL100) then with 1003 hPa set in the subscale your altitude will be 9,730 ft. If you were not sure how we did this, please example the previous example problem. Now insert the relevant data into the formula.

True altitude = 9,730 + (-10 x 4 x 10,000 ÷ 1000)

True altitude = 9,330 ft

CALCULATION QUESTIONS

FOR ALL OF THE FOLLOWING QUESTIONS ASSUME THAT 1 HPA=27 FT.

1. An aircraft is at an airfield with an elevation of 350 ft. The altimeter setting is 1002, but the actual QNH is 993. What is the altimeter reading?

2. An aircraft is on an airfield, elevation 190 ft and has an altimeter reading of 70 ft with a setting of 1005. What is the actual QNH?.

3. What is the altimeter reading if the setting is 978, the QNH 993 and the airfield elevation 770 ft?

4. The regional pressure setting is 1012, the altimeter setting is 1022 and the indicated altitude is 4100 ft. Ahead is some high ground shown on the map as being at 3700 ft. Will the aircraft clear the high ground, and if so, by how much?

FILL IN THE BLANK SPACES IN THE FOLLOWING EXAMPLES.
ASSUME 1 MB = 27FT

QNH	ALTIMETER SETTING	TRUE ALTITUDE	ALTIMETER READING
1012	1010	4,060	
1015	1010		5000
	1010	650	560
1020	1013		10,500
999	1013		8,500
1015		35	125
1017	1027	3,300	
1012		330	0
	993	415	0
1025	1015	4,760	

ANSWERS TO CALCULATIONS

1. 593 ft
2. 1010 hPa
3. 365 ft
4. Yes, by 130 ft

QNH	ALTIMETER SETTING	TRUE ALTITUDE	ALTIMETER READING
1012	1010	4060	4006
1015	1010	5135	5000
1014	1010	650	560
1020	1013	10689	10500
999	1013	8122	8500
1015	1018	35	125
1017	1027	3300	3570
1012	1000	330	0
1009	993	415	0
1025	1015	4760	4490

QUESTIONS

1. MSA given as 12,000 ft, flying over mountains in temperatures +9°C, QNH set as 1023 (obtained from a nearby airfield. What will the true altitude be when 12,000 ft is reached?

   a. 11,940
   b. 11,148
   c. 12,210
   d. 12,864

2. When flying at FL180 in the Southern Hemisphere you experience a left crosswind. What is happening to your true altitude if indicated altitude is constant?

   a. Remains the same
   b. Increasing
   c. Decreasing
   d. Impossible to tell

3. Flying from Marseilles (QNH 1012) to Palma (QNH 1015) at FL100. You do not reset the altimeter, why would true altitude be the same throughout the flight?

   a. Not possible to tell
   b. Air at Palma is warmer than air at Marseilles
   c. Air at Marseilles is warmer than air at Palma
   d. Blocked static vent

4. Which of these would cause your true altitude to decrease with a constant indicated altitude?

   a. Cold air/Low pressure
   b. Hot air/Low pressure
   c. Cold air/High pressure
   d. Hot air/High pressure

5. An aircraft flying in the Alps on a very cold day, RPS 1013 set in the altimeter, flies level with the summit of the mountains. Altitude from aneroid altimeter reads:

   a. Same as mountain elevation
   b. Lower than mountain elevation
   c. Higher than mountain elevation
   d. Impossible to determine

6. You are flying in an atmosphere which is warmer than ISA, what might you expect?

   a. True altitude to be the same as Indicated altitude
   b. True altitude to be lower than Indicated altitude
   c. True altitude to be the decreasing
   d. True altitude to be higher than Indicated altitude

7. The QNH is 1030 hPa and at the Transition Level you set the SPS. What happens to your indicated altitude (assume 27 ft per 1 hPa)?

    a. Drops by 459 ft
    b. Rises by 459 ft
    c. No change
    d. Rises

8. You are flying from Madrid (QNH 1012) to Paris (QNH 1015) at FL 80. If your true altitude and indicated altitude remain the same then

    a. The air at Madrid is warmer than Paris
    b. The air at Paris is warmer than Madrid
    c. The altimeters are incorrect
    d. Your indicated altitude must be changing

9. If you are flying on a QNH 1009 on very cold day and you circle the top of a peak in the Alps, your altimeter will read

    a. The same as the elevation of the peak
    b. Lower than the elevation of the peak
    c. Higher than the elevation of the peak
    d. Not enough information to tell

10. How do you calculate the lowest useable flight level?

    a. Lowest QNH and lowest negative temperature below ISA
    b. Lowest QNH and highest negative temperature below ISA
    c. Highest QNH and highest temperature above ISA
    d. Highest QNH and lowest temperature

11. QNH is 1003. At FL100 true altitude is 10,000ft. Is it

    a. Warmer than ISA
    b. Colder than ISA
    c. Same as ISA
    d. Cannot tell

12. How is QNH determined from QFE?

    a. Using the temperature of the airfield and the elevation of the airfield
    b. Using the temperature
    c. Using the elevation
    d. Using the temperature at MSL and the elevation of the airfield

13. Use Annexe A
    You are on a flight from A to B at 1500 ft. Which statement is true?

    a. True altitude at A is greater than B
    b. True altitude at B is greater than A
    c. True altitude is the same
    d. Cannot tell

14. QFE is 1000 hPa with an airfield elevation of 200 m AMSL. What is QNH? (use 8 m per hPa)

    a. 975 HPa
    b. 1025 HPa
    c. 1008 HPa
    d. 992 HPa

15. Which of the following is true?
    QNH is:

    a. Always more than 1013.25 hPa
    b. Always less than 1013.25 hPa
    c. Never 1013.25 hPa
    d. Can never be above or below 1013 hPa

16. Flying from Marseilles to Palma you discover your true altitude is increasing, but oddly the QNH is identical at both places. What could be the reason?

    a. Re-check the QNH
    b. Re-check the radio altimeter
    c. The air at Palma is warmer
    d. Palma is lower than Marseilles

17. QNH is 1030. Aerodrome is 200m AMSL. What is QFF?

    a. Higher than 1030
    b. Lower than 1030
    c. Same
    d. Not enough info

18. If an Aerodrome is 1500ft AMSL on QNH 1038, what will the actual height AGL to get to FL75?

    a. 6675 ft
    b. 8175 ft
    c. 8325 ft
    d. 5325 ft

19. Altimeter set to 1023 at aerodrome. On climb to altitude the SPS is set at transition altitude. What will indication on altimeter do on resetting to QNH?

    a. Dependent on temperature
    b. Decrease
    c. Increase
    d. Same

20. What temperature and pressure conditions would be safest to ensure that your flight level clears all the obstacles by the greatest margin?

    a. Cold temp/low pressure
    b. Warm temp/high pressure
    c. Temp less than or equal to ISA and a QNH less than 1013
    d. Temp more than or equal to ISA and a QNH greater than 1013

21. You are flying from Marseilles (QNH 1012 hPa) to Palma de Mallorca (QNH 1012 hPa) at FL100. You notice that the effective height above MSL (Radio Altitude) increases constantly. Hence...

a. One of the QNH values must be wrong.
b. You have the altimeters checked, as their indications are obviously wrong.
c. The air mass above Palma is warmer than that above Marseilles
d. You have to adjust for a crosswind from the right.

22. Flying at FL 135 above the sea, the Radio Altimeter indicates a true altitude of 13500 ft. The local QNH is 1019 hPa. Hence the crossed air mass is, on average,

a. At ISA standard temperature
b. Colder than ISA
c. Warmer than ISA
d. There is insufficient information to determine the average temperature deviation

23. You are flying in the Alps at the same level as the summits on a hot day. What does the altimeter read?

a. Same altitude as the summit
b. Higher altitude as the summit
c. Lower altitude as the summit
d. Impossible to tell

24. An airfield has an elevation of 540ft with a QNH of 993mb. An aircraft descends and lands at the airfield with 1013mb set. What will its altimeter read on landing?

a. 380ft
b. 1080ft
c. 0ft
d. 540ft

25. When is pressure altitude equal to true altitude?

a. In standard conditions
b. When surface pressure is 1013.25mb
c. When the temperature is standard
d. When the indicated altitude is equal to the pressure altitude

26. What is the relationship between QFE and QNH at an airport 50ft below MSL?

a. QFE = QNH
b. QFE < QNH
c. QFE > QNH
d. There is no clear relationship

27. You are flying at FL160 with an OAT of -27°C. QNH is 1003 hPa. What is your true altitude?

a. 15,540 ft
b. 15,090 ft
c. 16,330 ft
d. 15,730 ft

28. Use Annexe B.
Flying from D to C at a constant indicated altitude in the northern hemisphere.

a. True altitude increases
b. Wind is northerly
c. True altitude decreases
d. Wind is southerly

29. Up to FL 180 ISA Deviation is ISA +10°C. What is the actual depth of the layer between FL 60 and FL 120?

a. 6000 ft
b. 6240 ft
c. 5760 ft
d. 5700 ft

30. Up to FL 180 ISA Deviation is ISA -10°C.What is the actual depth of the layer between FL 60 and FL 120?

a. 6000 ft
b. 6240 ft
c. 5760 ft
d. 5700 ft

31. What condition would cause your indicated altitude to be lower than that being actually flown?

a. Pressure lower than standard
b. Pressure is standard
c. temperature lower than standard
d. temperature higher than standard

32. You fly over the sea at FL 90, your true altitude is 9100 ft and QNH is unknown. What can be said about the atmosphere temperature?

a. QNH is lower than standard
b. It is colder than ISA
c. It is warmer than ISA
d. Nothing, insufficient information.

33. You are flying at FL 100 in an air mass that is 15°C colder than ISA. Local QNH is 983 hPa. What would the true altitude be?

a. 8590 ft
b. 11410 ft
c. 10000 ft
d. 10210 ft

34. Which statement is true?

a. QFE is always lower than QNH
b. QNH is always lower than QFE
c. QNH can be equal to QFE
d. QFE can be equal to QFF only

35. You fly from east to west at the 500 hPa level in the Northern Hemisphere;

a. if the wind is from the north there will be a gain in altitude
b. if the wind is from the south there is again in altitude
c. if you encounter northerly drift, there is a gain in altitude
d. you fly towards an area of lower pressure, and therefore, experience a loss in altitude.

36. You have landed on an airport elevation 1240 ft and QNH 1008 hPa. Your altimeter subscale is erroneously ser to 1013 hPa. The indication on the altimeter will be?

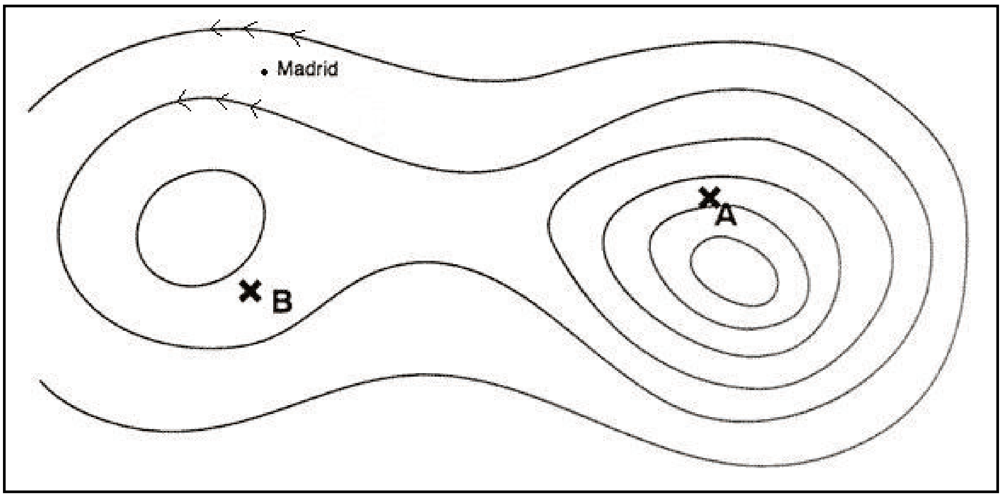
a. 1200 ft
b. 1375 ft
c. 1105 ft
d. 1280 ft

37. You are cruising at FL 200, OAT is -40°C, sea level pressure is 1033 hPa. Calculate the true altitude?

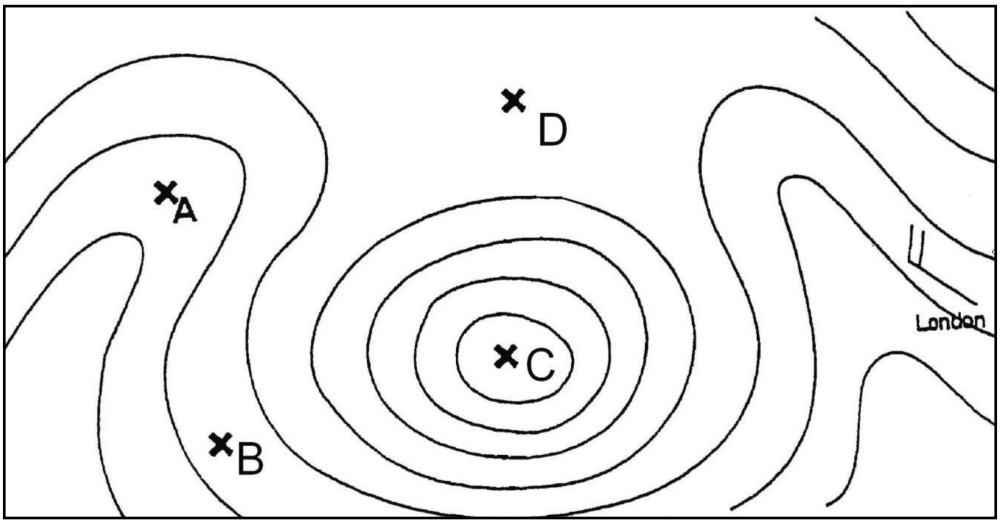
a. 20660 ft
b. 21740 ft
c. 18260 ft
d. 19340 ft

ANNEXES

Annex A



Annex B



ANSWERS

1. D	11. A	21. C	31. D
2. B	12. C	22. B	32. D
3. C	13. B	23. C	33. A
4. A	14. B	24. B	34. C
5. C	15. C	25. A	35. A
6. D	16. C	26. C	36. B
7. A	17. D	27. B	37. D
8. A	18. A	28. C	
9. C	19. C	29. B	
10. A	20. D	30. C	

CHAPTER SIX

TEMPERATURE

Contents

INTRODUCTION

One of the important variables in the atmosphere is temperature. The study of temperature variation, both horizontally and vertically has considerable significance in the study of meteorology. For example, without temperature variations there would be no pressure variations, therefore no wind and no weather.

MEASUREMENT

There are three scales which may be used to measure temperature though only Celsius and Kelvin are used in meteorology. The figures show the melting point of ice and the boiling point of water at standard pressure in each scale. In the exam you may of course use the conversion scale on your Navigation Computer instead.

- The FAHRENHEIT scale: +32 to +212 degrees.
- The CELSIUS (or Centigrade) scale: 0 to +100 degrees.
- The KELVIN (or Absolute) scale: +273 to +373 degrees.

Conversion factors:

$$°C = \frac{5°F - 32}{9} \quad (.56)$$

$$°F = \frac{9°C}{5} + 32 \quad (1.8)$$

$$K = °C + 273$$

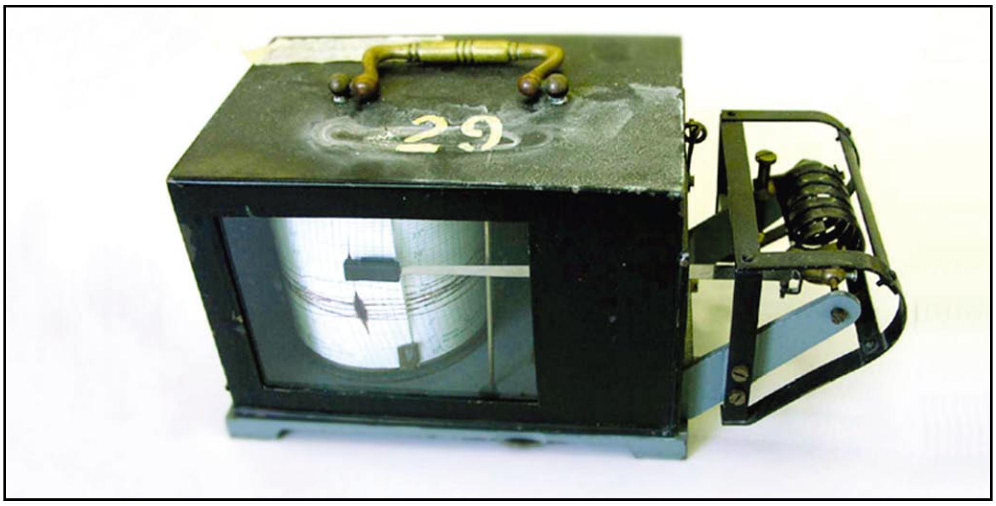
INSTRUMENTS

The standard means of measurement on the ground is a mercury thermometer placed in a Stevenson Screen. Electrical resistance thermometers may be used where the Screen is not readily accessible to the observer.

A Stevenson Screen

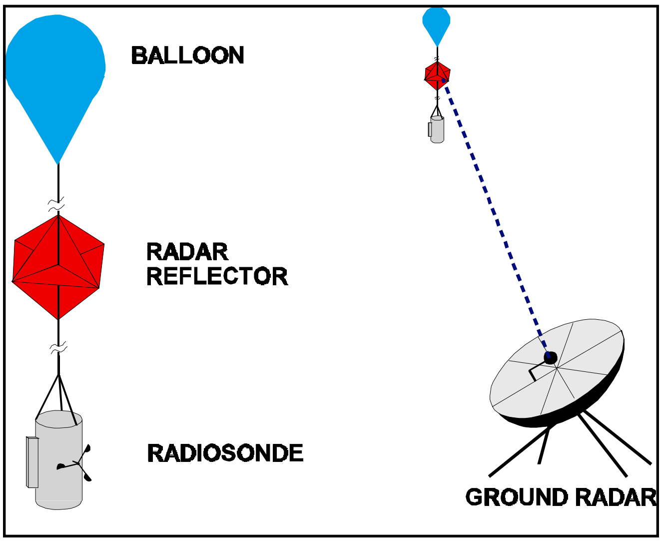
The Stevenson Screen is a louvred box 4 feet (1.22m) above the ground. This screen, shown in the figure above, is used worldwide.

A Thermograph (similar in its output to a Barograph) will also be found inside the screen.



A Thermograph

Upper air temperatures are taken using a Radiosonde, as shown below. Radiosondes are devices transmitting continuous readings of temperature, pressure, humidity and wind speed whilst being carried aloft beneath a balloon. Rate of climb is 1200 fpm and maximum ceiling between 65,000 and 115,000 ft. The data is then plotted on a graph with height on one axis and either temperature, pressure or dew point on the other axis.



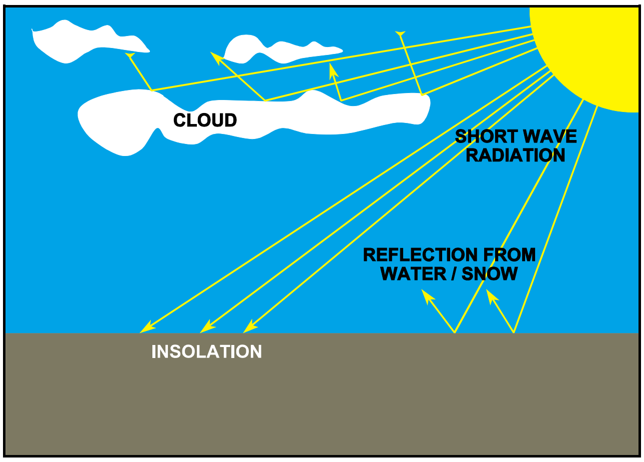
A Radiosonde

Aircraft readings, though often the only way in which atmospheric temperature may be measured over the oceans and other areas far away from meteorological stations, are not as accurate as they are affected by compressibility and lag. The electrical thermometer will give a digital readout of temperature and this can be automatically calibrated and transmitted on some modern aircraft.

HEATING OF THE ATMOSPHERE

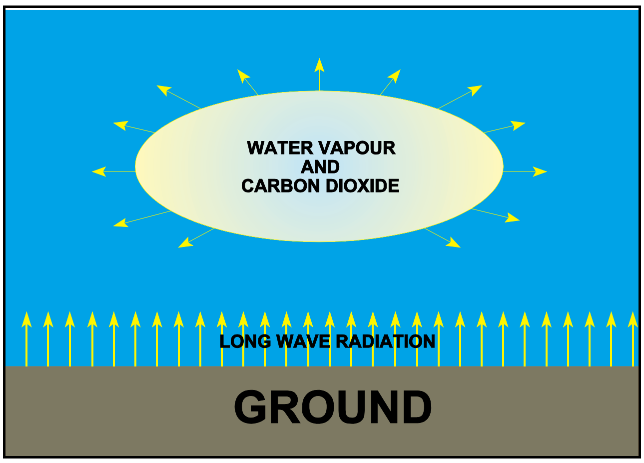
The atmosphere is heated by 5 different processes:

Solar Radiation
Radiation from the sun is of Short wave-length and of high intensity. It passes through the atmosphere almost without heating it at all. Some solar radiation is reflected back to the upper air from cloud tops and from water surfaces on the earth. The rest of this radiation heats the earth's surface. The process whereby the surface is heated by solar radiation is called insolation.



SolarRadiation

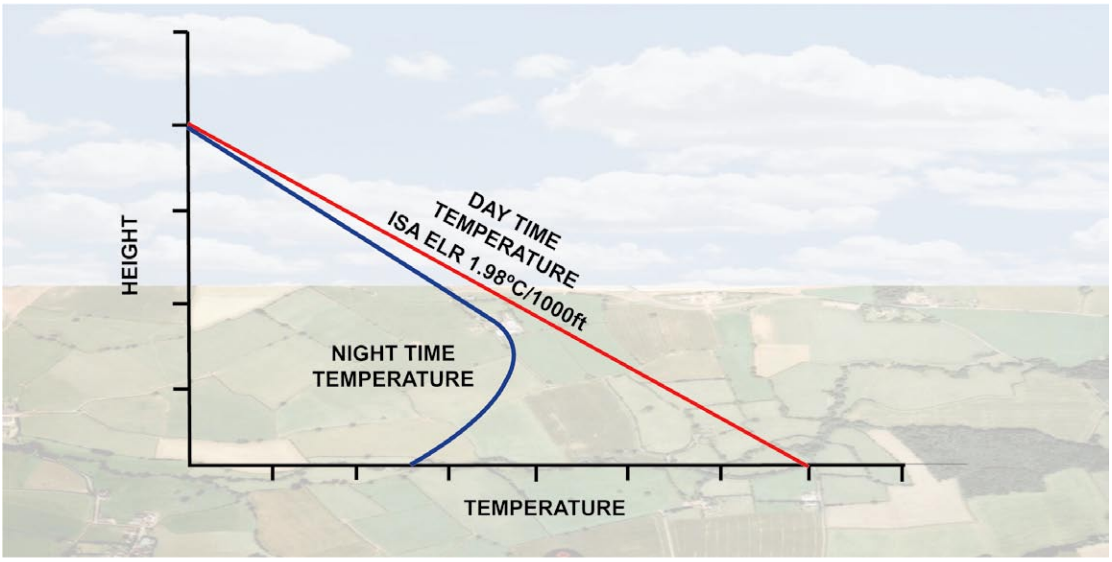
Terrestrial Radiation
When sunlight reaches the Earth's surface, it is absorbed and warms the earth. Because the earth is much cooler than the sun, it radiates its energy at much longer wavelengths than the sun. Some of these longer wavelengths are absorbed and then re-transmitted as heat by gases such water vapour and CO2 in the atmosphere. This re-transmission of heat to the surrounding air is the main method by which the atmosphere is heated. Since there is more water vapour and CO2 in the lower atmosphere than in the upper atmosphere, then there will be more warming taking place within the lower atmosphere. This explains why the atmosphere reduces in temperature with an increase in height. It is heated from below - hence there is an environmental lapse rate which is on average 0.65°C per 100 m.



Terrestrial Radiation

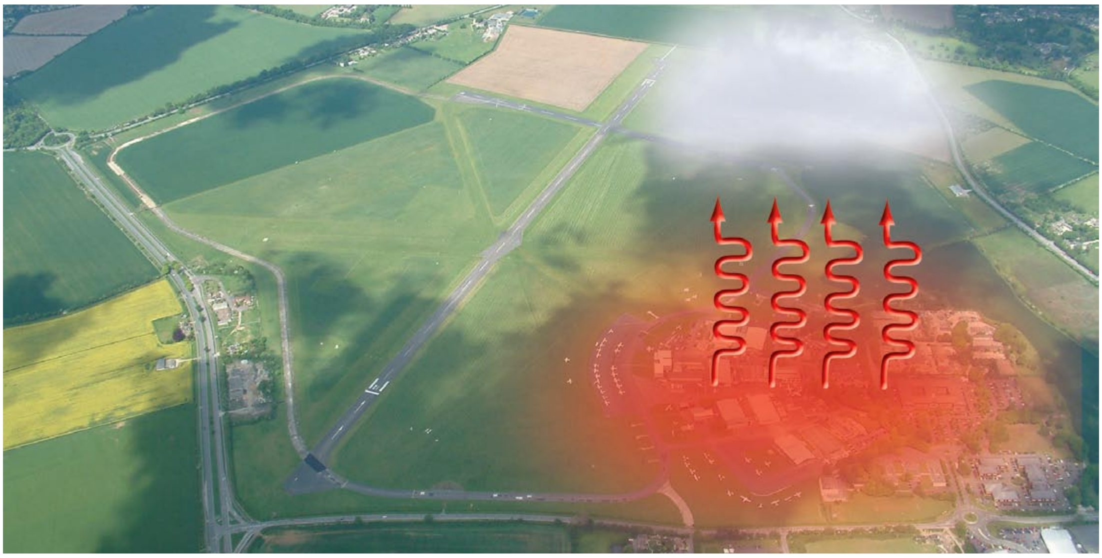
Greenhouse Effect
There are other gases other than water vapour and CO2, namely methane and nitrous oxide which are also effective at absorbing the terrestrial radiation and re-transmitting it as heat. Because of the way these gases behave in warming our atmosphere they have been collectively called the "Greenhouse gases" and they create the "Greenhouse Effect". The term is in fact a misnomer, as this process is not the primary mechanism that warms greenhouses. The major natural greenhouse gas is water vapor, which causes about 36-70% of the "greenhouse effect" on Earth. Certain human activities, such as Aviation, add to the levels of most of the naturally occurring greenhouse gases.

Conduction
Air lying in contact with the earth's surface by day will be heated by conduction. At night air in contact with the earth's surface will be cooled by conduction. At night, because of the air's poor conductivity, the air at a higher level will remain at the same temperature as during the day and an inversion will result. This is sometimes called a nocturnal inversion or radiation inversion.

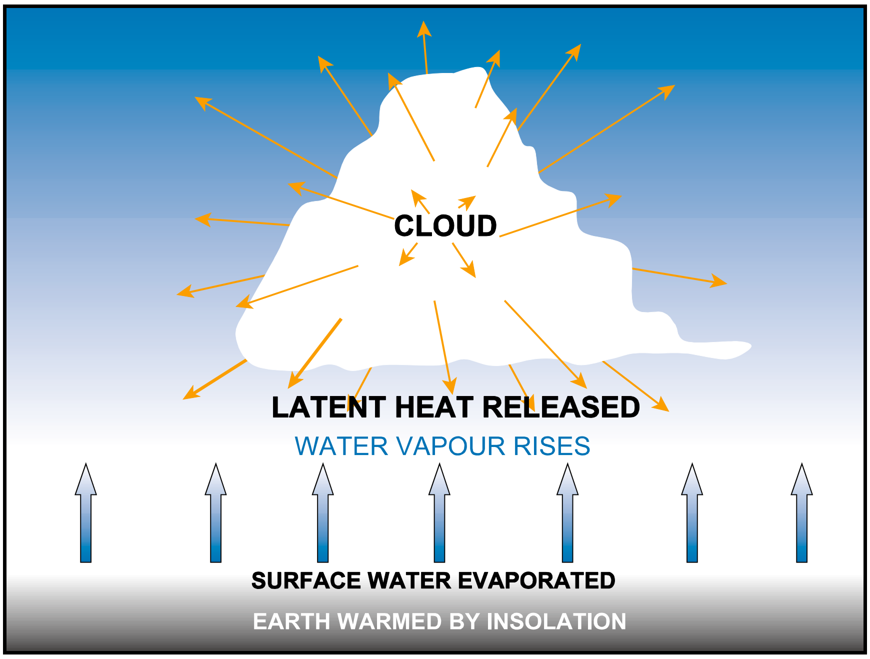


Environmental lapse rates during the day and night

Convection
Air heated by conduction will be less dense and will therefore rise. This will produce up currents called thermals or convection currents. These currents will help to transfer heat to different parts of the atmosphere. For example, warm air will rise to the upper levels, thus helping to heat the upper atmosphere.


Convection currents or thermal rising from a warm surface during the day

Condensation
As the air is lifted it will cool adiabatically and the water vapour in the air will condense out as visible droplets forming cloud. As this occurs latent heat will be released by the water vapour and this will heat the atmosphere. The release of latent heat into the surrounding air as condensation takes place is an important explanation as to why cumuliform clouds have such strong up draughts. In tropical revolving storms, the source of power is from the release of latent heat as water vapour condenses. A typical hurricane, or cyclone, releases enough energy to power the whole earth for a day!



Latent heat released from condensation within a cloud

TEMPERATURE VARIATION WITH HEIGHT

We have seen that although our source of heat is the sun, because of the atmosphere's virtual transparency to solar radiation, the atmosphere is in fact heated from the surface upwards. Thus, as we move further and further from the surface we would expect the heating effects to diminish.

Lapse Rate
The rate at which temperature falls with an increase in height is called the Environmental Lapse Rate (ELR). The average rate of cooling within a static atmosphere would be 0.65°C/100m (1.98°C per 1000ft.) However, in reality the environmental lapse rate varies significantly from day to day and season to season, especially in the lower layers of the atmosphere. It is this variation in the ELR that determines the stability of the atmosphere. This concept will be made clear in the chapter on stability. There are other lapse rates, namely the adiabatic lapse rates, but these will be discussed in later chapters.

Isotherms
Because the ELR varies significantly, there will be parts of the atmosphere where temperature remains constant with height, for example, just above the tropopause. When temperature is constant with height is it called an isothermal layer.

Inversions
Where the temperature increases with an increase in height, then we have what is called an inversion. We have already seen that at night we can expect an inversion above the surface, but this can occur in many different ways.

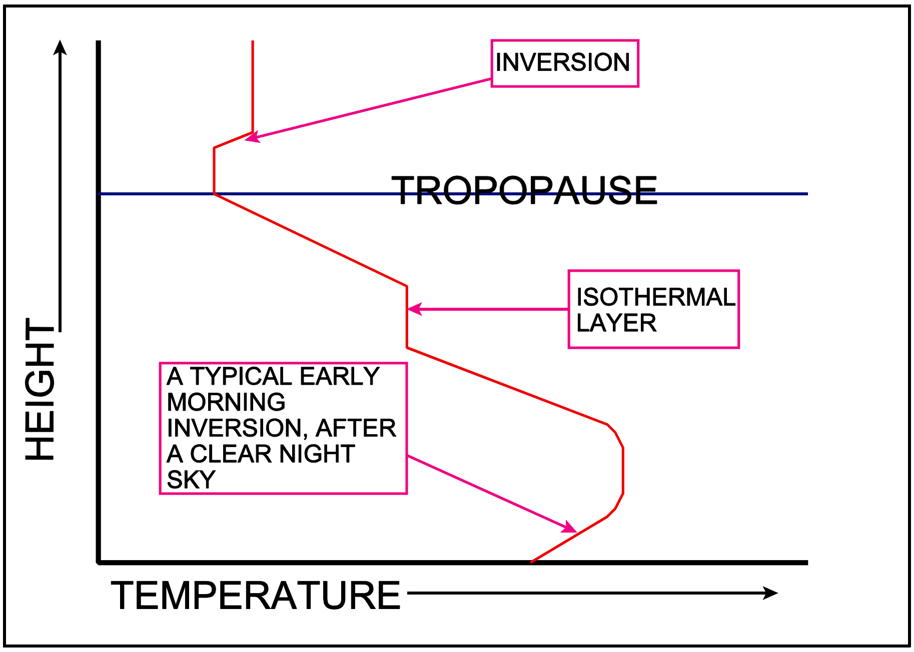
Radiation, on a night of clear skies, will also result in a temperature inversion above the surface. This is called a Radiation Inversion.

When we look at cloud formation, we shall see that because of turbulence in the layer closest to the surface we can have an inversion at a height of 2 or 3 thousand feet. This is called a turbulence inversion.

Quite often, at the tropopause instead of the temp. remaining constant, it may show a slight rise for a few thousand feet.

At the higher levels of the stratosphere, temperature will show an increase with height (in ISA from 65,617ft temperature increases at a rate of 0.3°/1000ft).

In a high pressure system, air descends at the centre. As the air descends it will be heated adiabatically (more of this later) and will be warmer than the air at a lower level adjacent to the surface. This is called a Subsidence Inversion.



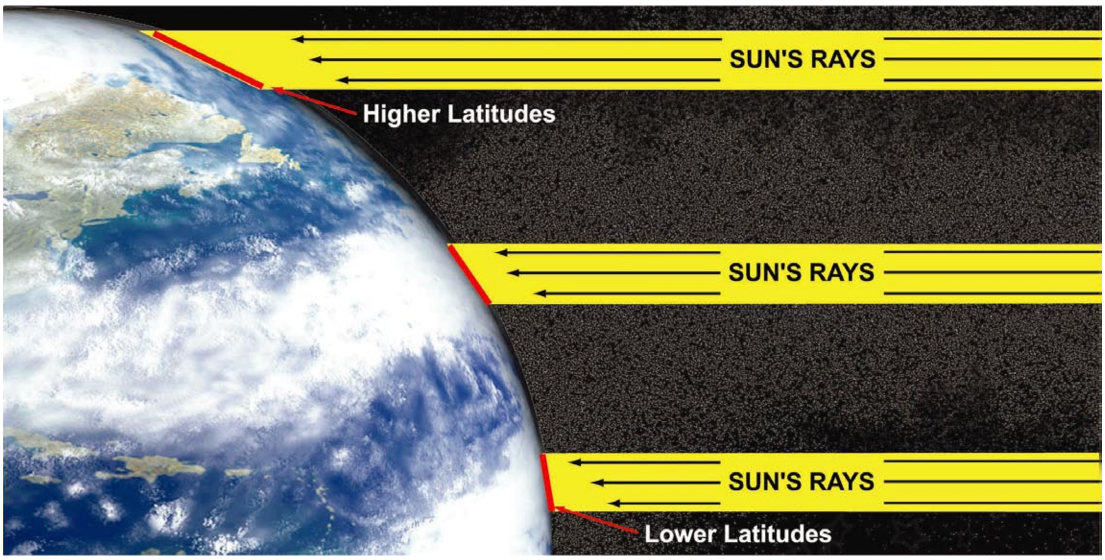
An ELR showing an early morning surface inversion, an isothermal layer and an inversion.

SURFACE TEMPERATURE

The surface air temperature measured in a Stevenson Screen is subject to considerable variations: Latitude Effect, Seasonal Effect, Diurnal Variation and multiple effects due to cloud and wind.

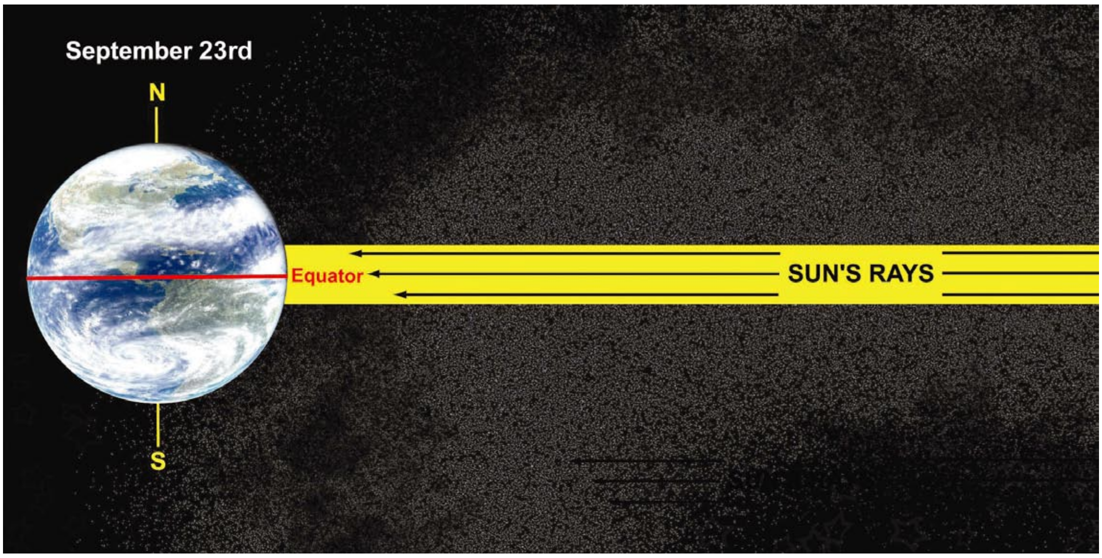
The angular elevation of the sun

Latitude Effect. At the equator only a small area is affected by the suns rays and therefore will be subject to the greatest heat per unit area. At the poles the suns rays will cover a larger area and there will be the least heat per unit area. The actual distance of polar regions from the sun is only fractionally more than that from the equator, and therefore the distance from the sun is an effect which is ignored.



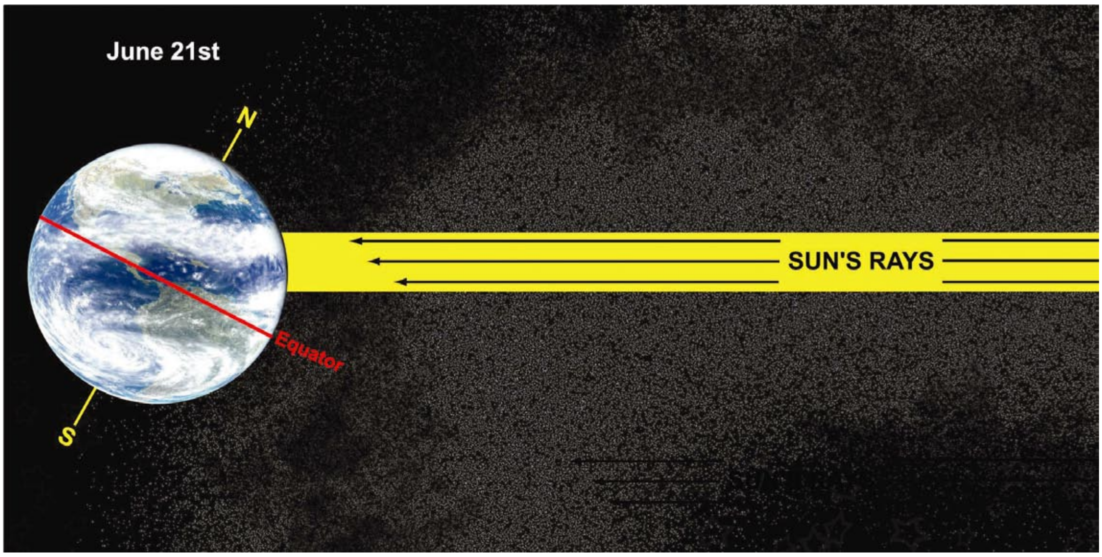
The Effect of Latitude.

Seasonal Effect. On around the 20/21st of March and 22/23rd of September (the Spring and Autumn Equinoxes) the sun is directly overhead the equator and maximum heating occurs at the equator.



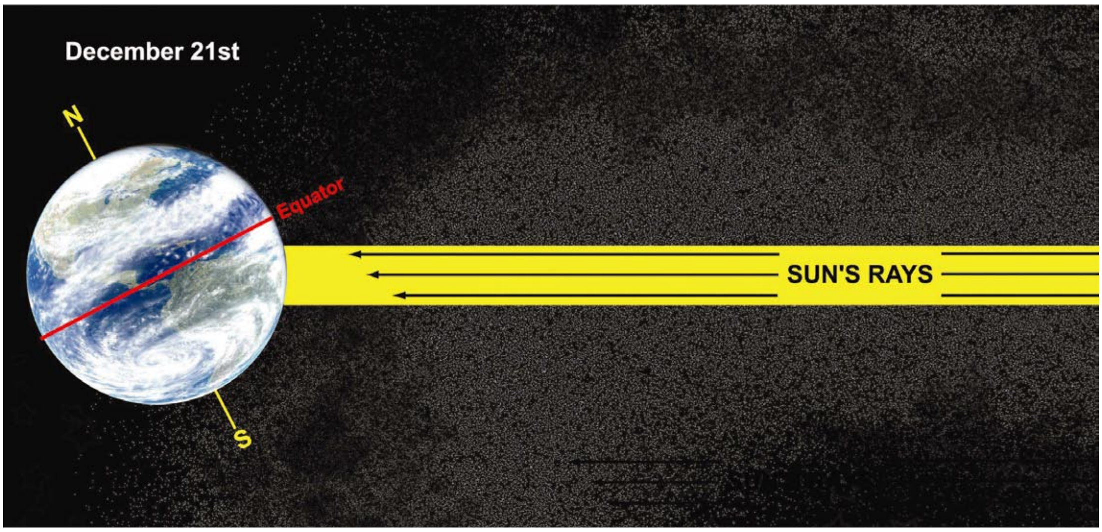
The suns position at the Equinox.

On the 20/21st of June, the sun is overhead the Tropic of Cancer and maximum heating will occur at 23.5°N. In the Northern hemisphere the temperature will increase as the sun moves north. This will be the summer season in the Northern Hemisphere.



The suns position at the 21st of June. Summer solstice in the Northern Hemisphere.

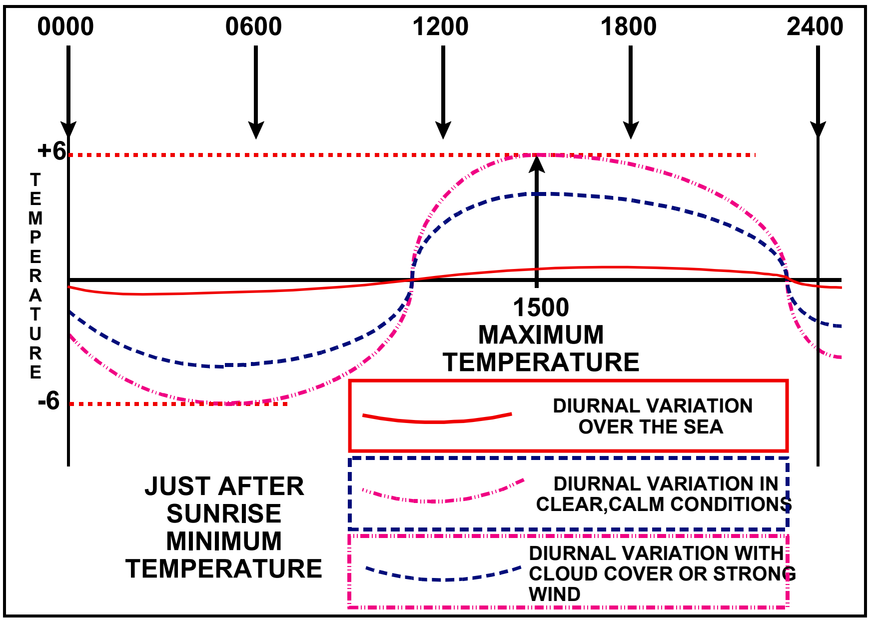
On the 21/22nd of December the sun is overhead the Tropic of Capricorn and maximum heating will occur at 23.5°S. This will be the summer season in the Southern Hemisphere.



The suns position at the 21st of December. Summer solstice in the Southern Hemisphere

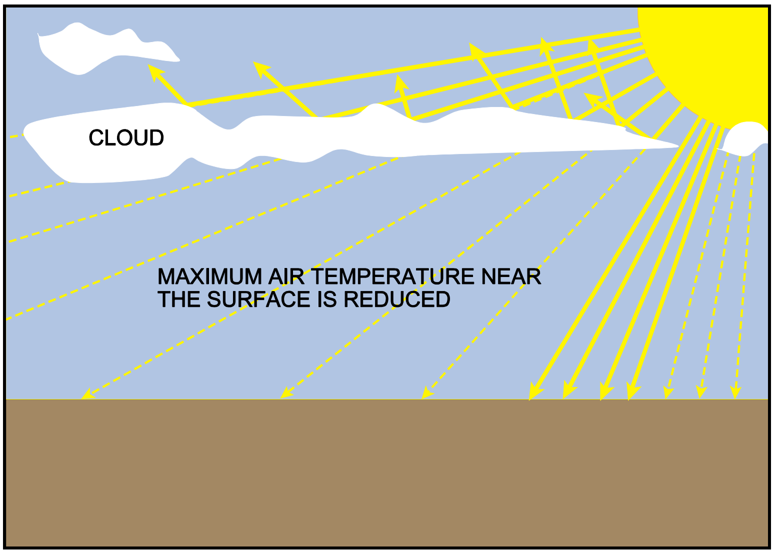
Time of Day (Diurnal Variation)

- The sun is at its highest elevation at noon, but for two to three hours after this time, the earth is receiving more solar radiation than it is giving up as terrestrial radiation (Thermal Inertia). As a result temperature is highest at about 15:00 LMT (TMAX).
- From 15:00 LMT onwards, the temperature falls continuously until a little after sunrise. The lowest temperature occurs at about sunrise plus 30 minutes. (TMIN)
- Diurnal Variation (the temperature variation between TMAX and TMIN) is greatest with clear skies and little wind. Diurnal Variation varies with a number of factors, but in temperate latitudes is about +/- 6 °C about the mean.



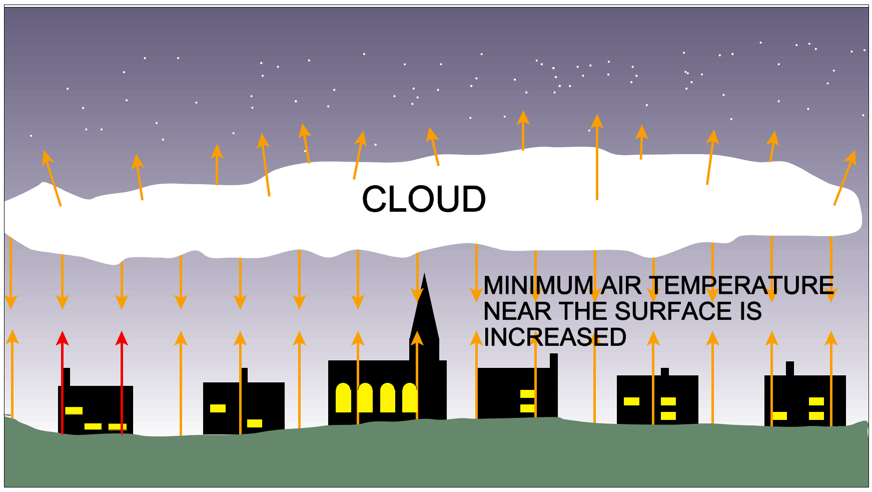
Diurnal Variation

Cloud cover by day. By day some of the solar radiation is reflected back by the cloud tops and T Max is decreased.



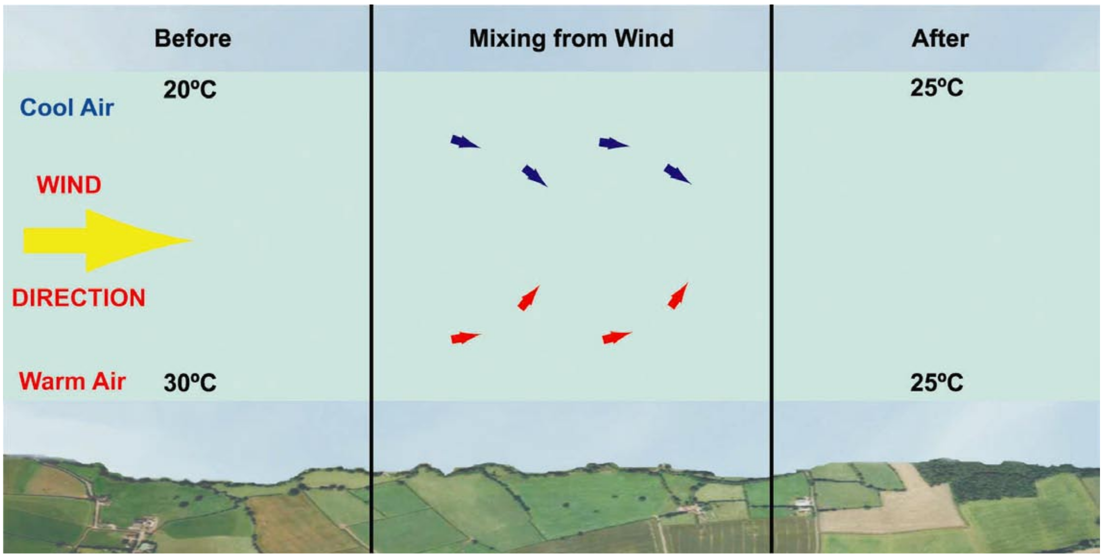
Cloud Cover by day

Cloud cover by night. By night terrestrial radiation is absorbed and radiated back to the earth's surface from the clouds. T min is increased.



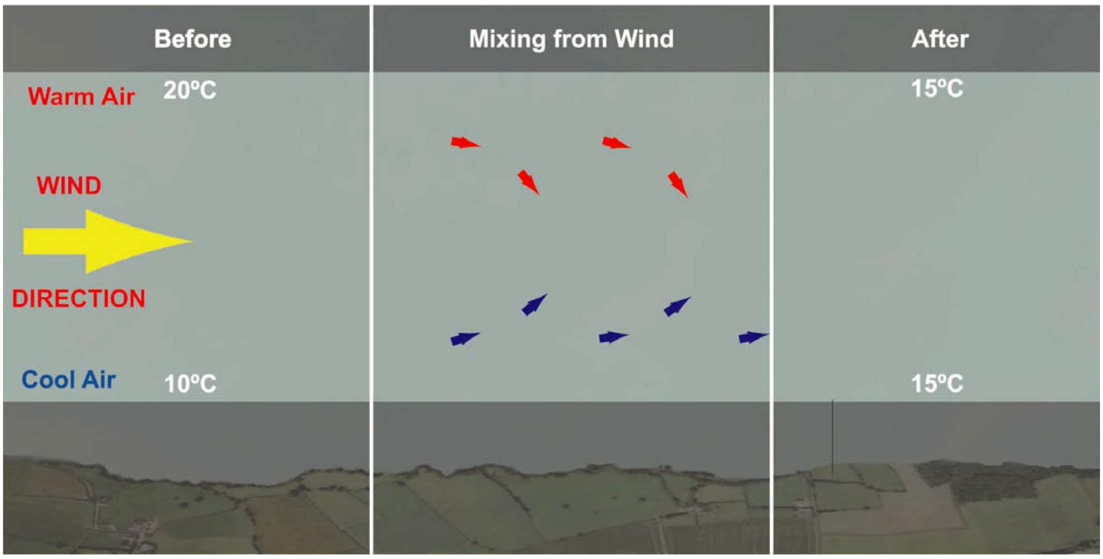
Cloud Cover by night

Effect of wind by day. By day wind will cause turbulent mixing of the warm air at the surface with cold air above, reducing T max. Wind will also reduce the time the air is in contact with the warm ground.



The effect of wind by day

Effect of wind by night. By night there will normally be an inversion above the surface and wind will cause cold air to be turbulently mixed with warm air above thus increasing T min.



The effect of wind by night

In summary, wind and cloud cover will cause T max to be reduced and T min to be increased. Therefore diurnal variation will be reduced.

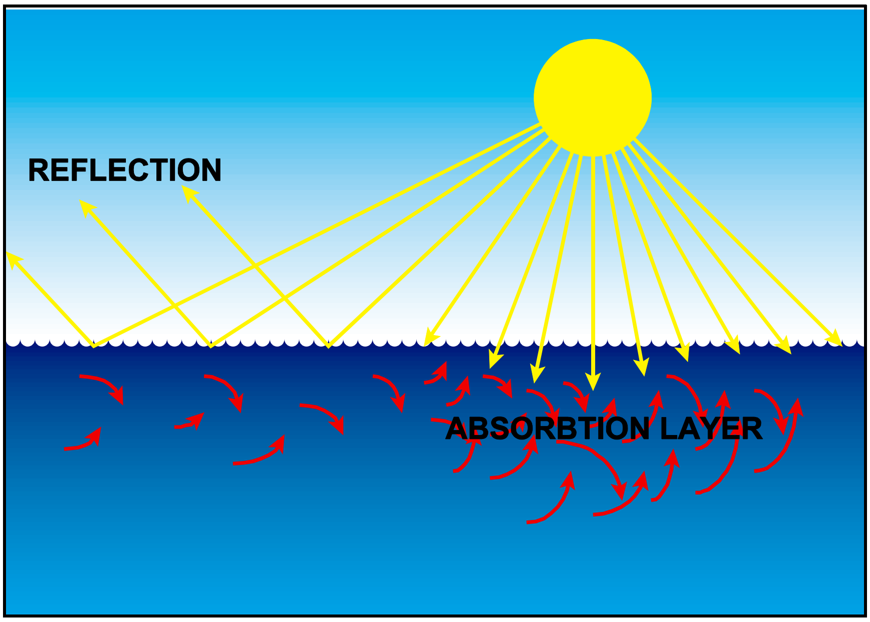
Diurnal Variation over the sea. As the Specific Heat (SH) of water is unity (i.e. 1), compared to other substances whose SH is much less, and as the temperature rise is inversely proportional to the Specific Heat , the temperature rise and fall over the sea is small, generally less than 1°C.

Nature of the Surface
Albedo is a measure of the ratio of scattered to incident light or radiation. A substance with a high albedo is a substance that scatters or reflects a large proportion of the radiation or light it receives. The nature of the surface, being dark or light will affect it albedo.

- **Sea.** The sea takes a long time to heat (and cool) and as we have seen has a very small DV.

The difference in DV values between land and sea is the cause of sea breezes. The minimal DV of sea temperature is the reason why the most common form of fog, radiation fog, never forms over the sea.

When the angular elevation of the sun is low, much solar radiation is reflected back to the atmosphere.



The effect of sun on the sea

- **Land.** Bare rock, sand, dry soil, tarred roads and concrete runways attain a higher temperature by insolation than woods, lakes, grasslands and wet soil.

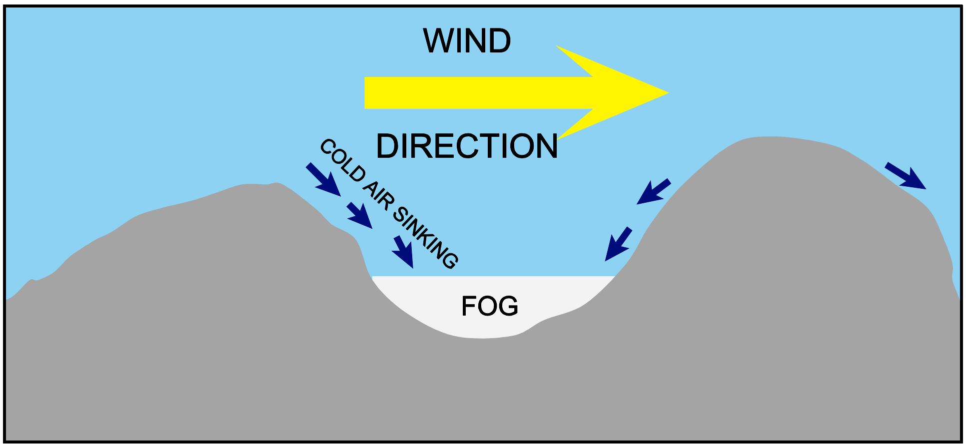
The temperature difference between air above concrete runways and adjacent grass can be as much as 4 degrees. Higher temperature surfaces provide strong up currents called thermals or convection currents. Air over snow covered surfaces is very cold. 80% of solar radiation is reflected from snow surfaces.

Snow does not prevent the earth from radiating its heat. Hence surface air temperatures over snow will become colder day by day. Temperatures in Siberia can reach -72°C after a long cold winter. This very cold air results in high density and the development of anticyclones.

Albedos of typical materials range from up to 90% for fresh snow, to about 4% for charcoal, one of the darkest substances. When seen from a distance, the ocean surface has a low albedo, as do most forests, while desert areas have some of the highest albedos. The average albedo of the Earth is about 30%. This is far higher than for the ocean primarily because of the contribution of clouds.

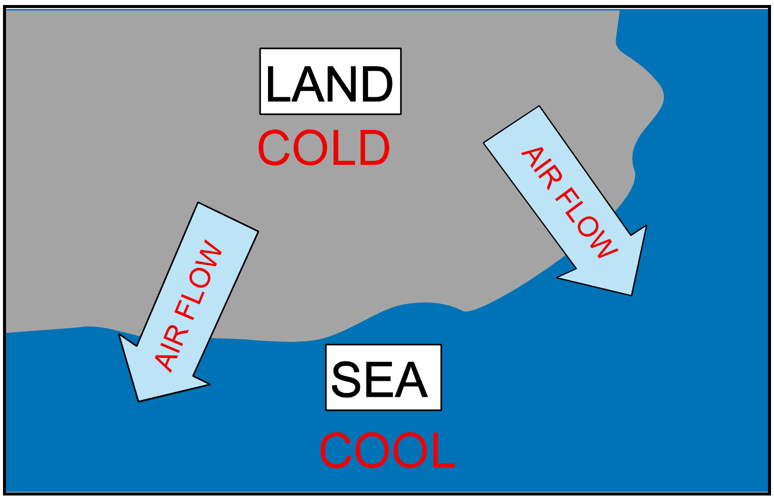
Location

- Over Land. Air in a valley will tend to be more static than air in an exposed position. Therefore by night the air is in contact with the ground for a longer time and the air temperature is lower than on a hill. Additionally, in a valley, cold air tends to sink from the hills above at night, again causing lower temperatures. It is for these reasons that mist and fog tend to form firstly in valleys.



The effect of location on temperature

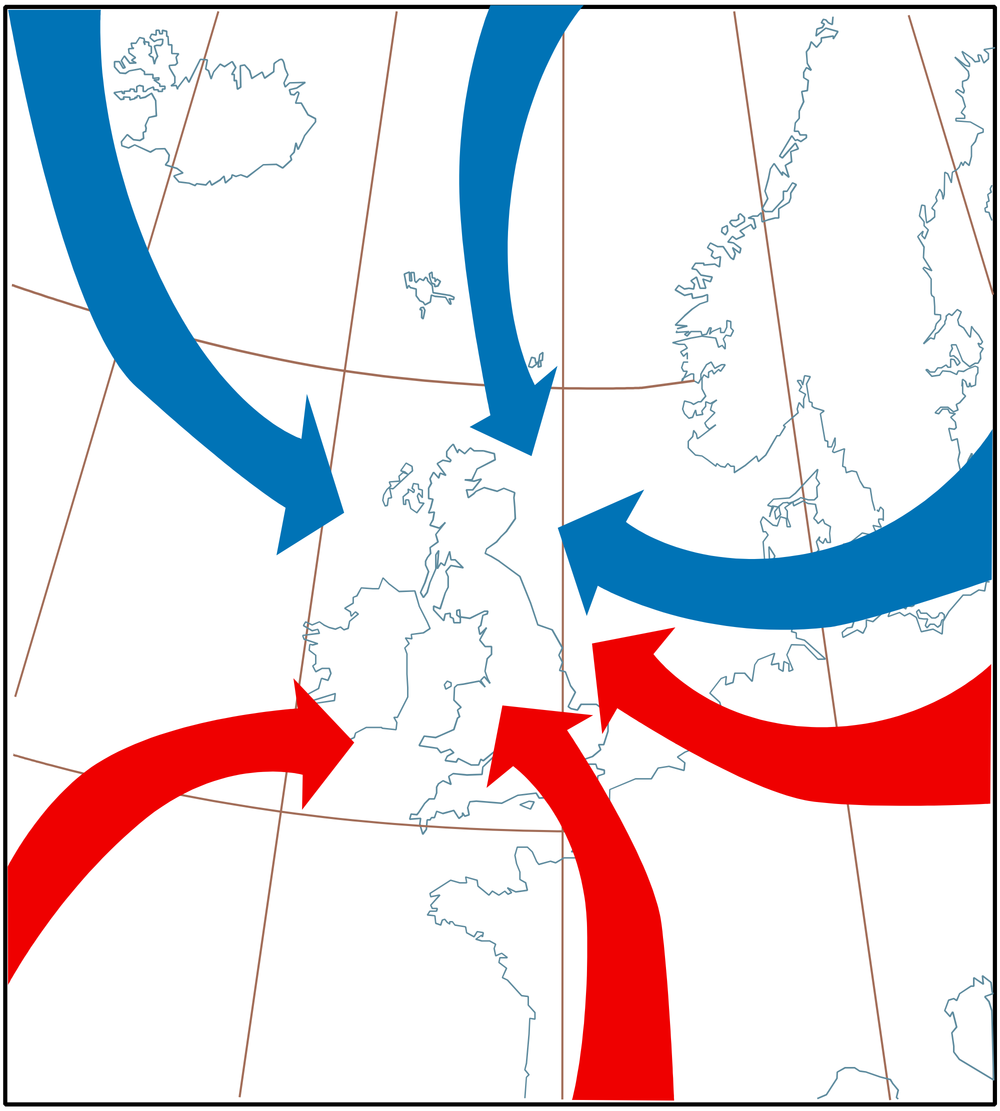
- Over Oceans. The fact that seas tend to have a very small DV of temperature has been stated above. On a wide scale this means that in winter the sea is warmer than the land and thus there is a widespread movement of air from land to sea (monsoon effect). There is an opposite tendency in summer.



The winter monsoon

Origin of air supply

Air tends to retain its temperature and humidity for a considerable time, therefore air from high latitudes will bring lower temperatures to UK for example. A southerly wind, however, will normally provide an increase in temperature.



The origin of the air supply will also modify the temperature

QUESTIONS

1. Convective activity over land in mid-latitudes is greatest in

    a. summer during the night and early morning.
    b. winter in the afternoon.
    c. summer in the afternoon.
    d. winter during the night and early morning.

2. Several physical processes contribute to atmospheric warming. Which of the following contribute the most?

    a. Absorption and vaporization.
    b. Absorption and evaporation.
    c. Convection and condensation.
    d. Solar radiation and conduction.

3. The temperature at FL 160 is -22°C. What will the temperature be at FL 90 if the ICAO standard lapse rate is applied?

    a. +4°C
    b. -8°C
    c. -4°C
    d. 0°C

4. The morning following a clear, calm night when the temperature has dropped to the dew point, is likely to produce

    a. a cold front
    b. haze
    c. good clear weather
    d. radiation fog

5. The environmental lapse rate in an actual atmosphere

    a. has a fixed value of 2°C/1000 FT
    b. varies with time
    c. has a fixed value of 1°C/100m
    d. has a fixed value of 0.65°C/100m

6. An isothermal layer is a layer of air in which the temperature

    a. decreases with height at a constant rate
    b. increases with height at a constant rate
    c. remains constant with height
    d. increases with height

7. Around Paris on January 3rd at 1800 UTC, the surface temperature, under shelter, is 3°C. The sky is covered by 8 oktas of stratus. QNH is 1033 hPa. If the sky is covered all night, the minimum temperature of the night of January 3rd to January 4th should be

    a. slightly below +3°C.
    b. significantly below 0°C.
    c. slightly above +3°C.
    d. significantly above +3°C.

8. An inversion is a layer of air in which the temperature

   a. remains constant with height
   b. increases with height more than 1°C/100m
   c. decreases with height more than 1°C/100m
   d. increases with height

9. An inversion is

   a. a decrease of pressure with height
   b. a decrease of temperature with height
   c. an increase of temperature with height
   d. an increase of pressure with height

10. On a clear sky, continental ground surface, wind calm, the minimum temperature is reached approximately

   a. one hour before sunrise
   b. half an hour after sunrise
   c. half an hour before sunrise
   d. at the moment the sun rises

11. The radiation of the sun heats

   a. the air in the troposphere only directly if no clouds are present
   b. the surface of the earth, which heats the air in the troposphere
   c. the air in the troposphere directly
   d. the water vapour in the air of the troposphere

12. Which of the following is a common cause of ground or surface temperature inversion?

   a. Terrestrial radiation on a clear night with no or very light winds.
   b. Warm air being lifted rapidly aloft, in the vicinity of mountainous terrain.
   c. The movement of colder air under warm air, or the movement of warm air over cold air.
   d. Heating of the air by subsidence

13. The diurnal variation in temperature is least when the sky is

   a. clear and winds are weak
   b. clear and winds are strong
   c. overcast and winds are weak
   d. overcast and winds are strong

14. What is the technical term for an increase in temperature with altitude?

   a. Advection
   b. Inversion
   c. Subsidence
   d. Adiabatic

15. The diurnal variation in temperature is largest when the sky is

a. clear and winds are weak
b. clear and winds are strong
c. overcast and winds are weak
d. overcast and winds are strong

16. If you are flying at FL 100 in an air mass that is 10°C warmer than a standard atmosphere, what is the outside temperature likely to be?

a. -10°C
b. -15°C
c. +5°C
d. +15°C

17. In the International Standard Atmosphere the decrease in temperature with height below 11 km is

a. 0.6°C per 100m
b. 0.65°C per 100m
c. 1°C per 100m
d. 0.5°C per 100m

ANSWERS

1. C
2. C
3. B
4. D
5. B
6. C
7. A
8. D
9. C
10. B
11. B
12. A
13. D
14. B
15. A
16. C
17. B

CHAPTER SEVEN

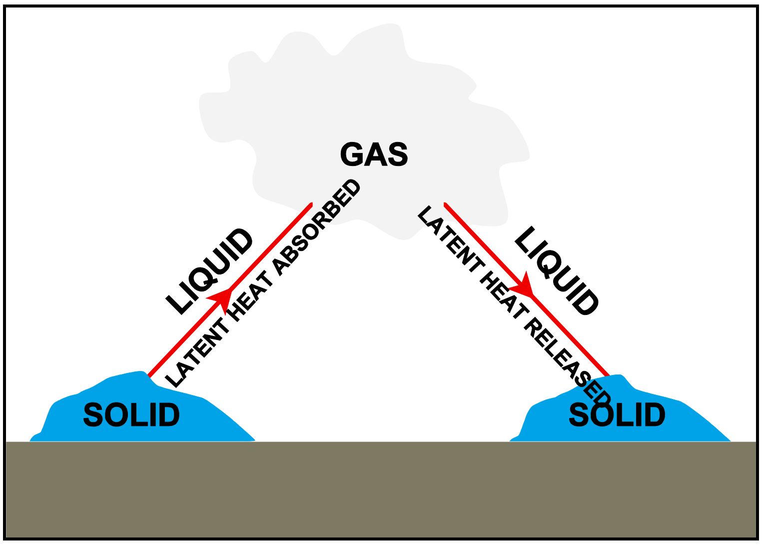
HUMIDITY

Contents

DEFINITION OF LATENT HEAT

Latent heat describes the amount of energy in the form of heat that is required for a material to undergo a change of state or phase. Latent heat differs according to the state of the substance.

When ice changes to water, or water changes to water vapour, latent heat is absorbed.
When water vapour changes to liquid water, or water changes to ice, latent heat is released.



The Change of State from Solid to Liquid to Gas and Back Again.

CHANGE OF STATE

Evaporation
Evaporation is the change of state from liquid to vapour. Latent heat is absorbed. Evaporation can occur at any temperature, even from ice. For a particular temperature there is a particular amount of water per unit volume that the air can hold. When this maximum is reached, evaporation will cease.

Saturation
Air becomes saturated by adding more water vapour to it. Alternatively, as warm air can hold more water vapour than cold, saturation can be achieved by cooling the air.

Air is saturated if it contains the maximum amount of water vapour that it can hold at that temperature. If saturated air is cooled, condensation will occur.

Condensation
Condensation is the change of state from vapour to liquid. Latent heat is released. If the water vapour is returned to a liquid or solid phase (by condensation or deposition), the stored energy is released as sensible heat onto the surface where condensation (or sublimation) has occurred. Condensation causes cloud and fog to form. Condensation will require minute impurities or particles called condensation nuclei; without these nuclei, the vapour would become super-saturated which is 100% Humidity but still in gas form.

Freezing
If the water droplet is cooled below zero, then it may change state again to ice. The process is called freezing (the droplet may cool to considerably below zero - called supercooling). Freezing may also require the existence of freezing nuclei.

Melting
The opposite change of state, from solid to liquid, is called melting. (There is no superfrozen state).

Sublimation/Deposition
Sublimation is the change of state directly from water vapour to ice without water droplets being formed. Latent heat is released. This process is also known as deposition.

The change of state from ice directly to water vapour is also called sublimation.

HUMIDITY MEASUREMENT

Absolute Humidity is the weight of water vapour in unit volume of air. Absolute Humidity is usually expressed in gm/m3. Warm air can "hold" more vapour than cold air. Therefore, a cold saturated air mass will contain less grams of water vapour per volume than a warm saturated air mass. This can be seen in the diagram opposite.

Humidity Mixing Ratio (HMR) is the weight of water vapour contained in unit mass of dry air. The Humidity Mixing Ratio is usually expressed in gm/kg and in temperate latitudes it is usually between 5 & 50 gm/kg. In unsaturated air, HMR remains constant during ascent while temperature and pressure decreases.

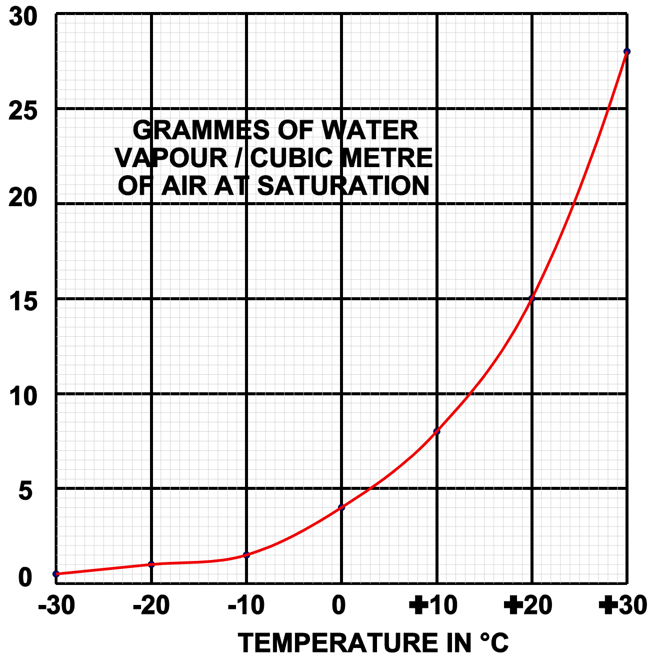
Saturation Mixing Ratio is the HMR when the parcel of air is saturated.

Relative Humidity is a term used to describe the quantity of water vapour that exists in a gaseous mixture of air and water. Relative humidity is expressed as a percentage and is calculated using the formula below. More simply, the relative humidity is the amount of water vapour present in a volume of air divided by the maximum amount of water vapour which that volume could hold at that temperature expressed as a percentage. Although this is an over simplification, it is sufficient for the ATPL requirements.

The ratio $\frac{\text{HMR}}{\text{Saturation mixing ratio}} \times 100\%$,

When the relative humidity is 100%, the air is holding as much water vapour as it can, although under exceptional circumstances it may exceed 100%.

NOTE: If the RH is less than 100% then the air is considered to be dry.
For example: RH = 99.9%, the air is dry.
RH = 20%, the air is dry.

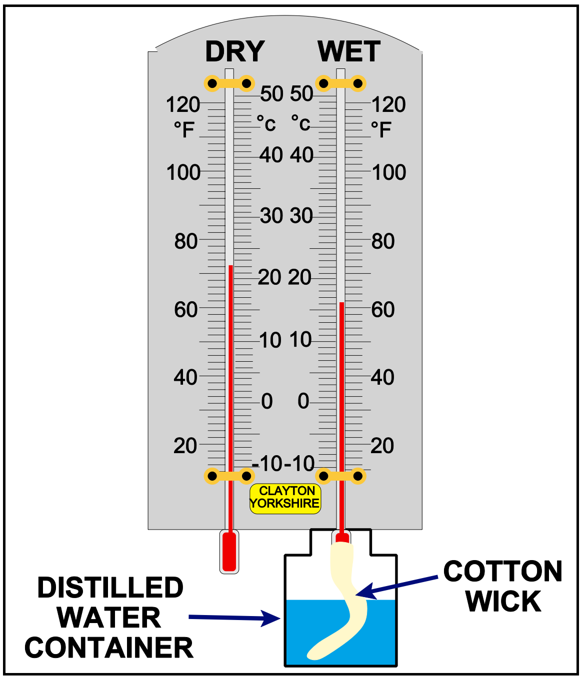


The Amount of Water Vapour the Air can Hold, when Saturated, at Different Temperatures.

HYGROMETER OR PSYCHROMETER

This instrument consists of two thermometers, one of which has its bulb constantly kept wet which measures the wet-bulb temperature and the other thermometer is simply open to the free air and thus called the dry bulb thermometer.

Evaporation from the wet bulb lowers the temperature (because evaporation absorbs latent heat from the surroundings) so that the wet bulb thermometer usually shows a lower temperature than that of the dry bulb thermometer. The lowest temperature to which air may be cooled by the evaporation of water is known as the wet bulb temperature. In conjunction with the dry bulb temperature, this forms the standard method of measuring humidity at the earth's surface. If air is saturated, no evaporation will occur and thermometers will read the same.



Dry-Bulb and Wet-Bulb Hygrometer
or Psychrometer

Dewpoint, relative humidity and HMR can be read from tables or a slide rule by entering the values that the two temperatures obtained.

DEWPOINT TEMPERATURE

The dew point or dewpoint of a given parcel of air is the temperature to which the parcel must be cooled, at constant barometric pressure, for the water vapour component to condense into water. The dew point of unsaturated air decreases by approximately 0.5°C per 1,000 ft

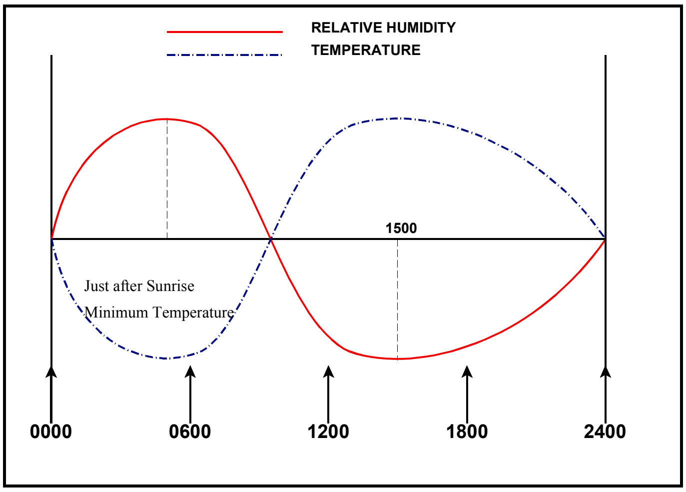
The dew point is associated with the relative humidity. A high relative humidity indicates that the dew point is closer to the current air temperature. If the relative humidity is 100%, the dew point will be equal to the current temperature. The dew point can never be more than the ambient temperature. By knowing the temperature and dew point we can calculate the approximate cloudbase of convective cloud.

$$T - DP \times 400 = \text{Cloud Base} \quad \text{(in feet)}$$

DIURNAL VARIATION OF HUMIDITY

By day, as the temperature increases, the relative humidity will decrease because the maximum amount of water vapour air can hold increases as the temperature rises.

After 1500 hrs, the temperature will start to fall and the maximum amount of water vapour the air can hold will fall and thus the relative humidity will increase. The higher relative humidity at night is the reason for the formation of mist and fog after dark in autumn and winter. This type of fog that is very common over land at night in autumn and winter is called radiation fog.



Diurnal Variation of Humidity.

RH is maximum at dawn when the temperature is minimum.

QUESTIONS

1. Relative humidity depends on

    a. moisture content of the air only
    b. temperature of the air only
    c. moisture content and temperature of the air
    d. moisture content and pressure of the air

2. When a given mass of air descends, what effect will it have on relative humidity?

    a. It increases.
    b. It remains constant.
    c. It increases up to 100%, and then remains stable.
    d. It decreases.

3. What does dewpoint mean?

    a. The freezing level (danger of icing).
    b. The temperature at which the relative humidity and saturation vapour pressure are the same.
    c. The temperature to which a mass of air must be cooled in order to reach saturation.
    d. The temperature at which ice melts.

4. Relative humidity at a given temperature is the relation between:

    a. water vapour weight and humid air volume
    b. dew point and air temperature
    c. actual water vapour content and saturated water vapour content
    d. water vapour weight and dry air weight

5. The maximum amount of water vapour that the air can contain depends on the:

    a. air temperature
    b. relative humidity
    c. stability of the air
    d. dewpoint

6. Which of the following changes of state is known as sublimation?

    a. Solid direct to liquid
    b. Liquid direct to solid
    c. Liquid direct to vapour
    d. Solid direct to vapour

7. When water evaporates into unsaturated air:

    a. heat is absorbed
    b. heat is released
    c. relative humidity is not changed
    d. relative humidity is decreased

8. Which of the following statements is true of the dew point of an air mass?

a. It can only be equal to, or lower, than the temperature of the air mass
b. It can be higher than the temperature of the air mass
c. It can be used together with the air pressure to estimate the air mass's relative humidity
d. It can be used to estimate the air mass's relative humidity even if the air temperature is unknown

9. The process by which water vapour is transformed directly into ice is known as:

a. sublimation
b. supercooling
c. supersaturation
d. radiation cooling

10. During the late afternoon an air temperature of +12°C and a dew point of +5°C were measured. What temperature change must occur during the night in order to induce saturation?

a. It must decrease to +7°C.
b. It must decrease to +5°C.
c. It must decrease by 5°C.
d. It must decrease to +6°C.

11. Dew point is defined as:

a. the temperature below which the change of state in a given volume of air will result in the absorption of latent heat
b. the temperature to which moist air must be cooled to become saturated at a given pressure
c. the lowest temperature at which evaporation will occur for a given pressure
d. the lowest temperature to which air must be cooled in order to reduce the relative humidity

12. How, if at all, is the relative humidity of an unsaturated air mass influenced by temperature changes?

a. It increases with increasing temperature.
b. It is only influenced by the amount of water vapour.
c. It decreases with increasing temperature.
d. It is not influenced by temperature changes.

13. Relative humidity:

a. increases if the air is cooled whilst maintaining the vapour pressure constant
b. is higher in warm air than in cool air
c. is higher in cool air than in warm air
d. decreases if the air is cooled whilst maintaining the vapour pressure constant

14. In which of the following changes of state is latent heat released?

a. Gas to liquid
b. Solid to liquid
c. Solid to gas
d. Liquid to gas

15. The dewpoint temperature:

a. can be reached by cooling the air whilst keeping pressure constant
b. can be reached by lowering the pressure whilst keeping temperature constant
c. can not be equal to the air temperature
d. can not be lower than the air temperature

16. Which of the following is the definition of relative humidity?

a. Ratio between water vapour pressure and atmospheric pressure X 100
b. Ratio between water vapour (g) and air (kg) X 100
c. Ratio between the actual mixing ratio and the saturation mixing ratio X 100
d. Ratio between air temperature and dewpoint temperature X100

17. The difference between temperature and dewpoint is greater in:

a. moist air
b. air with high temperature
c. air with low temperature
d. dry air

18. A parcel of moist but not saturated air rises due to adiabatic effects. Which of the following changes?

a. Mixing ratio
b. Specific humidity
c. Relative humidity
d. Absolute humidity

19. Relative humidity:

a. does not change when water vapour is added provided the temperature of the air remains constant.
b. changes when water vapour is added, even though the temperature remains constant.
c. is not affected when air is ascending or descending.
d. is not affected by temperature changes of the air.

20. The relative humidity of a sample air mass is 50%. How is the relative humidity of this air mass influenced by changes of the amount of water vapour in it?

a. It decreases with increasing water vapour.
b. It is only influenced by temperature.
c. It increases with increasing water vapour.
d. It is not influenced by changing water vapour.

21. How does relative humidity and the dewpoint in an unsaturated air mass change with varying temperature?

    a. When temperature increases, the relative humidity decreases, and the dewpoint remains constant.
    b. When temperature increases, the relative humidity increases, and the dewpoint decreases.
    c. When temperature decreases, the relative humidity decreases, and the dewpoint increases.
    d. When temperature decreases, the relative humidity and the dewpoint remain constant.

22. In which layer is most of the atmospheric humidity concentrated?

    a. Stratosphere.
    b. Stratopause.
    c. Troposphere.
    d. Tropopause.

23. The dewpoint temperature

    a. can not be equal to the air temperature
    b. can be equal to the air temperature
    c. is always lower than the air temperature
    d. is always higher than the air temperature

ANSWERS

1. C
2. D
3. C
4. C
5. A
6. D
7. A
8. A
9. A
10. B
11. B
12. C
13. A
14. A
15. A
16. C
17. D
18. C
19. B
20. C
21. A
22. C
23. B

CHAPTER EIGHT

ADIABATICS AND STABILITY

Contents

ADIABATIC TEMPERATURE CHANGES

Introduction

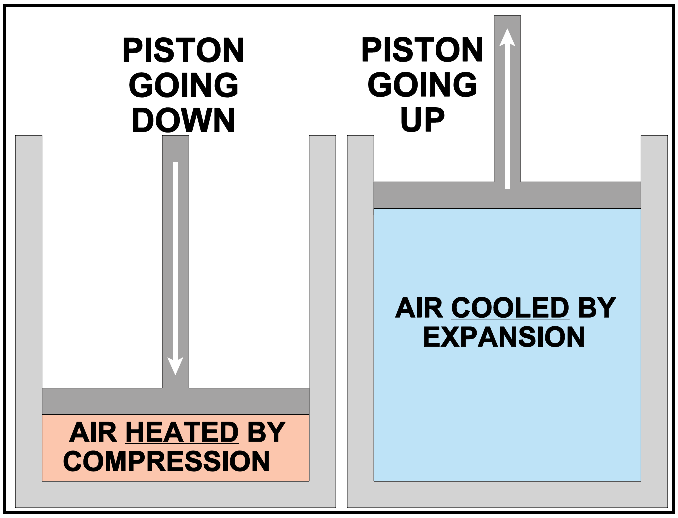
We mentioned in the chapter on temperature that because the earth heats our atmosphere and not the sun, in a stationary or static atmosphere under ISA conditions the temperature decreases with height at approximately 0.65°C per 100m. We called this lapse rate the environmental lapse rate (ELR). It is important because this variable lapse rate controls the stability of the air. We also mentioned that the ELR changed from day to day and season to season, sometimes temperature increased with height (inversions) sometimes is was constant with height (isotherms). However, there is another type of temperature change that occurs in our atmosphere that takes place when air is moved.

Concept

In thermodynamics, an adiabatic process is a process in which no heat is transferred to or from a working fluid. The term "adiabatic" literally means an absence of heat transfer. What this essentially means is that it is possible to change the temperature of a fluid without adding or subtracting heat from it. This seems strange, but it is possible if the fluid is either compressed or expanded.

If air is compressed, the molecular movement or energy of the molecules is confined into a smaller and smaller volume. This makes the molecules hit each other more often, creating friction and generating more heat. Therefore, if air compressed, it warms up. This is called "Adiabatic Warming". You can appreciate this when you pump up a bicycle tyre with a hand pump, you'll notice the pump gets warm.

The reverse will take place if air is expanded. If air is expanded, the molecules will have a larger volume to move around in. Now the molecules are less likely to hit each other, and consequently they will not generate as much heat. Therefore, if air expands, it cools. This process is called "Adiabatic Cooling".



The temperature change of air by compression or expansion

Adiabatic processes in the atmosphere

Compressing or expanding air through natural processes in the atmosphere does not seem likely. However, if a parcel of air was forced to rise in the atmosphere, the decreasing ambient pressure would cause the parcel to expand, much like an air bubble does when it rises through a champagne glass. As the air rises and expands, it will cool adiabatically. Rising air is characteristic of low pressure systems, and as a result of the rising air cooling, it will condense and form cloud.

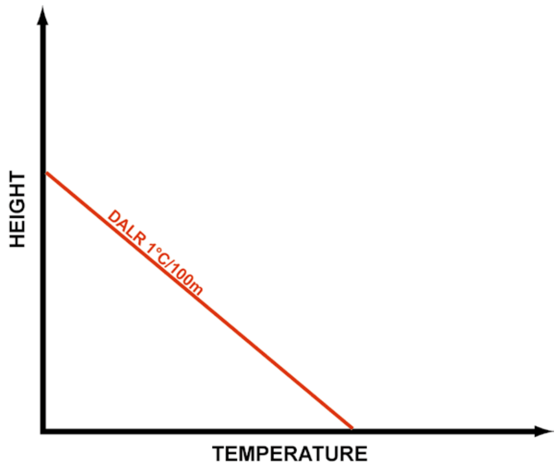
Conversely, if air is forced to descend within the atmosphere, the increasing ambient pressure will cause the air parcel to compress, much like the experience of compression when deep sea diving. As the air compresses it warms adiabatically. You may recall that in high pressure systems, the air was descending. This descent warms the air and prevents the formation of cloud.

ADIABTIC LAPSE RATES

As we have just discussed, as air either rises or descends its temperature will either increase or decrease. The question to ask is: "by how much the temperature is changing by this adiabatic process?" In essence then, what is the adiabatic lapse rate? The answer depends on the humidity of the air concerned.

Dry Adiabatic Lapse Rate (DALR)

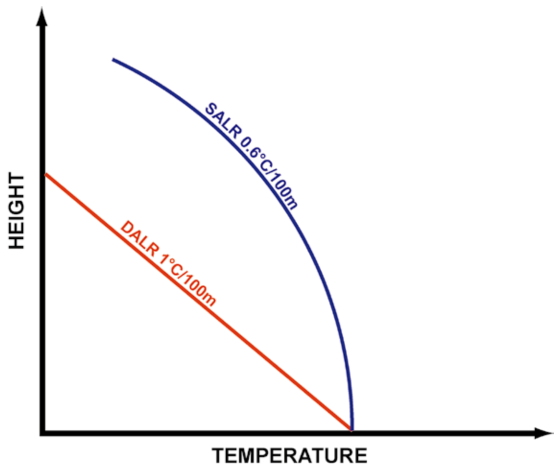
"Dry" air is air with a relative humidity of less than 100%. Therefore, a relative humidity of 99.9% is considered as dry. A more correct word to describe this situation for stability and adiabatic purposes is "unsaturated". Dry or unsaturated air that is either forced to rise or descend within the atmosphere will change its temperature by 1°C per 100 m (3°C/1000 ft). This change of temperature is called the Dry Adiabatic Lapse Rate, (DALR) and it is fixed.



The Dry Adiabatic Lapse Rate

Saturated Adiabatic Lapse Rate (SALR)

Saturated air that is either forced to rise or descend within the atmosphere will change its temperature, on average by 0.6°C per 100 m (1.8°C/1000 ft). This change of temperature is called the Saturated or Moist Adiabatic Lapse Rate, (SALR). The SALR varies strongly with the moisture content, which when saturated, depends on temperature, and pressure of the air parcel.



The Dry Adiabatic Lapse Rate and Saturated Adiabatic Lapse Rate

The reason for the difference between DALR and SALR
The reason for the difference between the SALR and DALR is that when saturated air either warms or cools, latent heat is either released or absorbed. For example, when saturated air rises, it cools, but as it cools, condensation takes place which releases latent heat to the air parcel. This slows down the rate of cooling of that air parcel from 1°C/100m to 0.6°C/100 m.

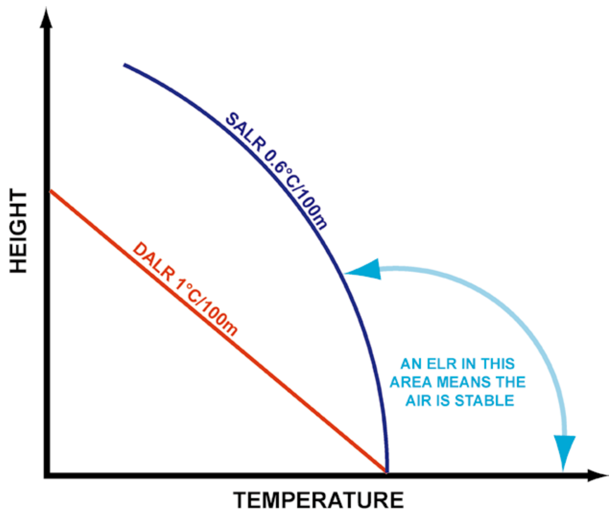
The reason for the SALR variation with temperature
The warmer the saturated air, the more moisture is contains and therefore the more condensation occurs when it rises and cools. Therefore, more latent heat is released to the air parcel. As a result, warm saturated air cools at a slower rate than 0.6°C/100m and cold saturated air cools at a faster than 0.6°C/100m. At high altitudes (and latitudes) temperatures are low, little latent heat is released and thus DALR and SALR are nearly the same. Conversely, at low latitudes and altitudes, temperatures are higher and consequently SALR is shallow.

STABILITY

Atmospheric stability describes the tendency of a parcel of air to either continue to move or return to its original position after an applied displacement force. If, once disturbed, a parcel of air returns to its original position it is described as being stable, whereas if it continued to move it would be described as unstable. Neutral stability is when the air neither returns or continues to move. These three states of stability will be described next

Absolute Stability/Stable Air
The atmosphere is described as stable when a displacement force (such the prevailing wind causing air to be forced up the side of a mountain) causes air to be lifted, and then, if this lifting force is removed, the air returns to its original position. The greater the displacement, the greater the tendency for it to return to its original position. The air is resistant to vertical motion.

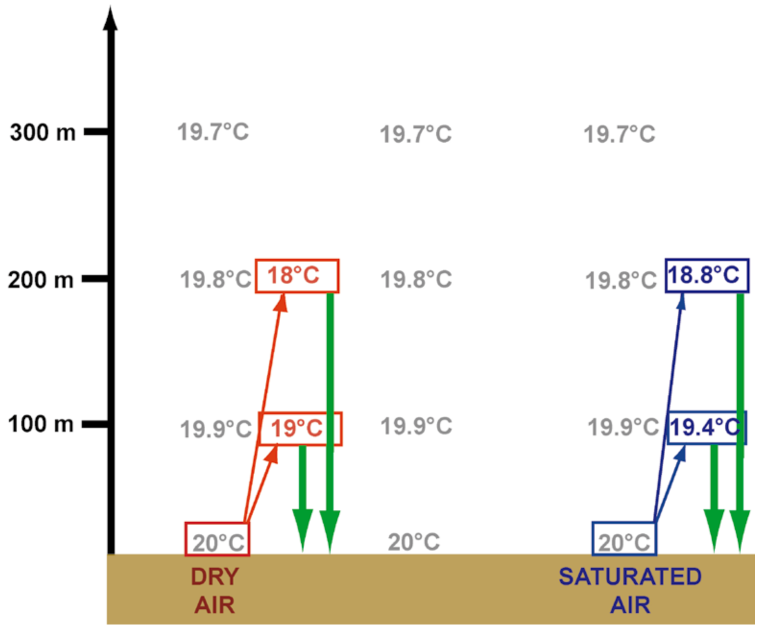
The reason the displaced air returns is because it has become colder and therefore denser than its surroundings. In other words, the lifted air parcel has cooled down more rapidly than the surrounding environment, or the surrounding environment has cooled more slowly than the lifted air parcel. This can easily be seen by comparing the temperature change with height of the lifted air and the temperature change with height of the surrounding environmental air. Lifted air will either change its temperature by the DALR or SALR (depending on whether is dry or saturated) and these rates need to be compared with the ELR.



If the ELR is less than the SALR the atmosphere is stable

Air is stable whenever the ELR is less than 0.6°C/100m. In other words, anytime the ELR is less than the SALR and DALR as shown in the image in the figure above.

Let's work through an example. Let us assume the ELR is 0.1°C/100m which IS less than the SALR and the DALR. Looking at the figure below you can see the environmental change of temperature with height (ELR = 0.1°C/100m) as the black temperatures. Notice that if dry air is disturbed it will rise and cool at the DALR of 1°C/100m and therefore the disturbed air will be colder at 100m than the surroundings. As a result, once the displacement force is removed, the air will want to return to its original position as shown by the downward green arrows. The same can be seen if the saturated air were to be displaced. If saturated air was lifted it would cool at the SALR of 0.6°C/100m and it too would be colder than environment and tend to return to its original position. As you can see from the figure below, it makes no difference whether the air in the atmosphere is saturated or not, the air is stable, period. As such the stability is described as Absolute Stability.



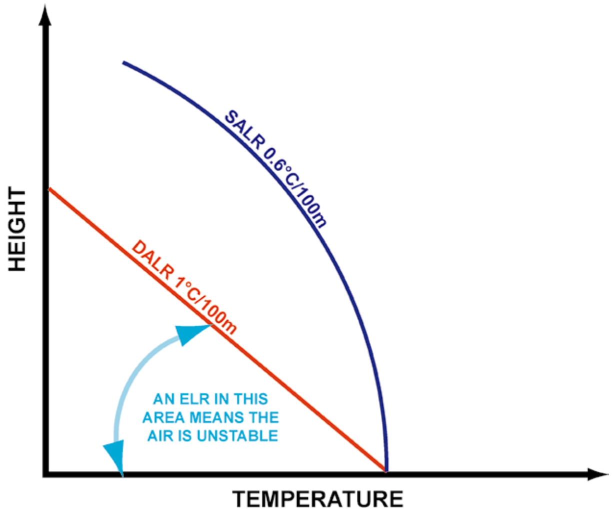
Absolute stability

In summary then, anytime there is little environmental change of temperature with height, expect stable conditions in the atmosphere. The atmosphere will be even more stable in isothermal conditions or in an inversion. For example, when warm air is found on top of cold air, such as is the case at night or in high pressure systems. If you plot an isotherm or an inversion on the figure on the previous page, you will draw the ELR either straight upwards or sloping up and to the right. In either case the ELR will be plotted in the stable area of the graph.

Absolute Instability/Unstable Air

The atmosphere is described as unstable when a displacement force (such the prevailing wind causing air to be forced up the side of a mountain) causes air to be lifted, and then, if this lifting force is removed, the air continues to rise. The greater the displacement, the greater the tendency for the air to rise. The air is very susceptible to vertical motion.
The reason the displaced air continues to rise is because it has become warmer and therefore lighter than its surroundings. In other words, the lifted air parcel has cooled down more slowly than the surrounding environment, or the surrounding environment has cooled more quickly than the lifted air parcel. This can easily be seen by comparing the temperature change with height of the lifted air and the temperature change with height of the surrounding environmental air.

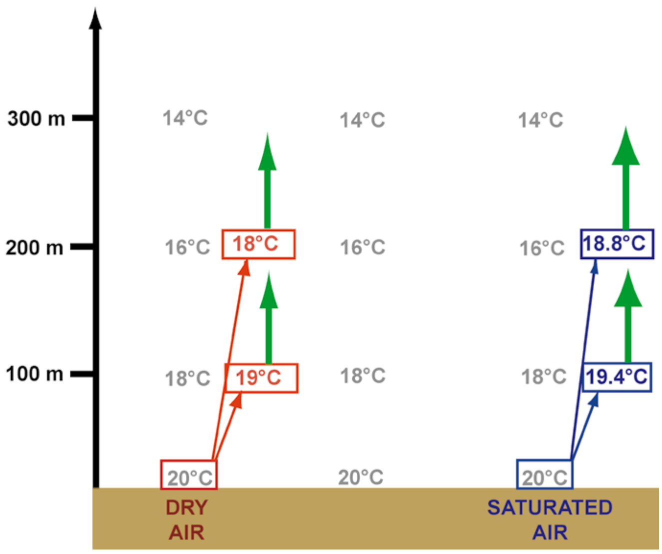
Air is unstable when the whenever the ELR is more than 1°C/100m. In other words, anytime the ELR is more than the DALR and SALR as shown in the image in the figure below.



If the ELR is more than the DALR the atmosphere is unstable

Let's work through an example. Let us assume the ELR is 2°C/100m which IS more than the DALR and the SALR. Looking at the figure on the next page you can see the environmental change of temperature with height (ELR = 2°C/100m) as the black temperatures. Notice that if dry air is disturbed it will rise and cool at the DALR of 1°C/100m and therefore the disturbed air will be warmer at 100m than the surroundings. As a result, once the displacement force is removed, the air will want to rise as shown by the upward green arrows. The same can be seen if the saturated air were to be displaced. If saturated air was lifted it would cool at the SALR of 0.6°C/100m and it too would be warmer than environment and tend to return to rise. Saturated air will tend to rise more than the dry air in an unstable atmosphere which explains why up the currents inside thunderstorms are far more powerful and far faster than the up currents outside of the storm.

As you can see from the figure below it makes no difference whether the air in the atmosphere is saturated or not, the air is unstable, period. As such it is described as Absolute Instability.

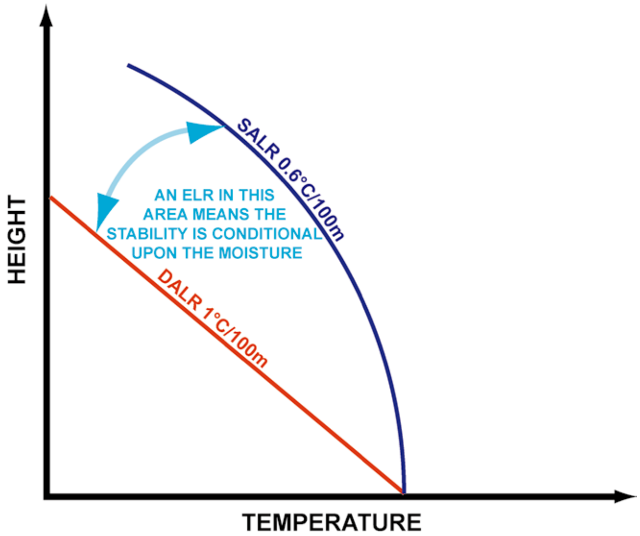


Absolute instability

In summary then, anytime the environmental temperature falls rapidly with height, such as when cold air is found above warm air, expect unstable conditions and strong up currents.

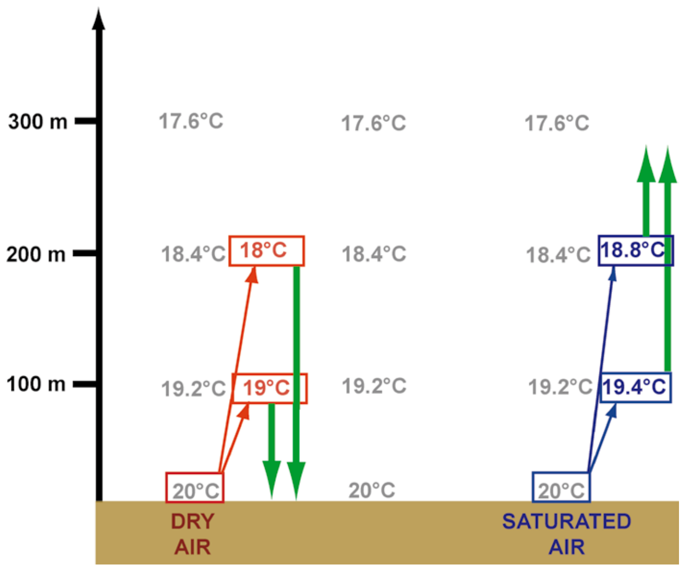
Conditional Stability/Instability

The atmosphere is described as being in a conditional state when the ELR is between the DALR and SALR as shown in the figure below.



If the ELR is between the DALR and SALR the atmospheric stability is conditional.

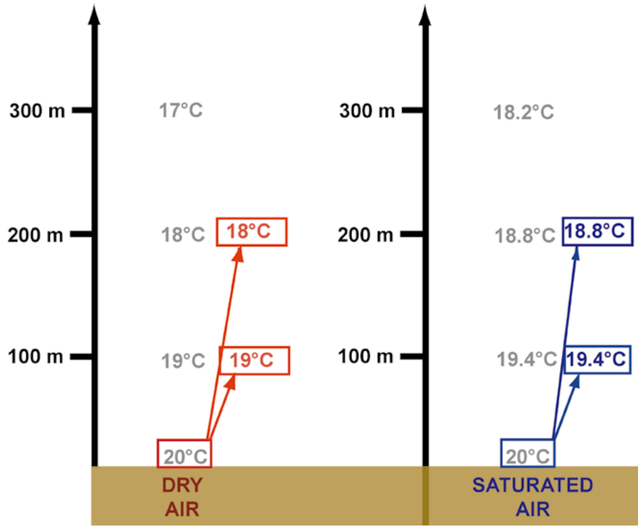
In such a case, if dry air is disturbed it will return to is original position, in other words the air is stable, however, when saturated air is disturbed it will continue to rise and it is unstable. You can see this in the figure on the next page. Notice that the stability of the atmosphere is now conditional upon its moisture content and not just the value of the ELR.



Absolute instability

In summary then, when the atmospheric stability is in a conditional state, the air is stable if it's dry and unstable if it's saturated.

Neutral Stability
If the lifted air's lapse rate (either dry or saturated) is the same as the environmental lapse rate then we have neutral stability. This is because the temperature change of the lifted air will be the same temperature change as the environmental air. Therefore, at every level the air is forced to rise, it will have the same temperature as the surrounding air and therefore the same density. As a result the air will remain where it is displaced to.



Absolute instability

STABILITY SUMMARY

- THE ELR CONTROLS STABILITY.
- If the ELR is less than 0.6°C / 100 m, the air is stable - absolute stability.

  Stable weather — Bad visibility
  Nil to Light turbulence
  Stratiform cloud
  Intermittent to continuous precipitation
  DZ, -RA, RA, SN

- If the ELR is greater than 1°C/100 m, the air is unstable - absolute instability.

  Unstable weather — Good visibility (poor in showers)
  Moderate to severe turbulence
  Cumuliform cloud
  Showery precipitation
  SHRA, +SHRA, GR, GS

- If the ELR is between 0.6°C and 1°C/100 m, the air is stable if dry and unstable if saturated - conditional instability.
- The clouds which form in stable air tend to be small in vertical extent and large in horizontal extent - layer clouds / stratiform cloud.
- The clouds which form in unstable air tend to be large in vertical extent and small in horizontal extent - heap clouds.

QUESTIONS

1. If the ELR is 0.65°C/100m

   a. Atmosphere is conditionally stable
   b. Atmosphere is absolutely stable
   c. Atmosphere is absolutely unstable
   d. Atmosphere is stable when dry

2. ELR is 1°C/100m

   a. Neutral when dry
   b. Absolute stability
   c. Absolute instability
   d. Conditional stability

3. Why does air cool as it rises?

   a. It expands
   b. It contracts
   c. The air is colder at higher latitudes
   d. The air is colder at higher altitudes

4. From which of the following can the stability of the atmosphere be determined?

   a. surface pressure
   b. surface temperature
   c. DALR
   d. ELR

5. The rate of cooling of ascending saturated air is less than the rate of cooling of ascending unsaturated air because:

   a. water vapour doesn't cool as rapidly as dry air
   b. water vapour absorbs the incoming heat from the sun
   c. heat is released during the condensation process
   d. moist air is heavier than dry air

6. The temperature at the surface is 15°C, the temperature at 1000m is 13°C. Is the atmosphere

   a. Unstable
   b. Conditionally unstable
   c. Stable
   d. Cannot tell

7. Which of the following gives conditionally unstable conditions when saturated?

   a. 1°C/100m
   b. 0.65°C/100m
   c. 0.49°C/100m
   d. None of the above

8. A mass of unsaturated air is forced to rise till just under the condensation level. It then settles back to its original position

   a. Temp. is greater than before
   b. Temp. stays the same
   c. Temp. is less than before
   d. It depends on QFE

9. What happens to the stability of the atmosphere in an inversion? (Temp increasing with height)

   a. Absolutely stable
   b. Unstable
   c. Conditionally stable
   d. Conditionally unstable

10. What happens to stability of the atmosphere in an isothermal layer? (Temp constant with height)

   a. Absolutely stable
   b. Unstable
   c. Conditionally stable
   d. Conditionally unstable

11. What is the effect of a strong low level inversion?

   a. Good visibility
   b. Calm conditions
   c. Windshear
   d. Unstable conditions

12. A layer of air can be

   a. Conditional; unstable when unsaturated and stable when saturated
   b. Conditional; unstable when saturated and stable when unsaturated
   c. Neutrally stable when saturated and unstable when unsaturated
   d. All of the above

13. What happens to the temperature of a saturated air mass when forced to descend?

   a. it heats up more than dry because of expansion
   b. it heats up less than dry because of evaporation
   c. it heats up more than dry because of sublimation
   d. it heats up less than dry because of latent heat released during condensation

14. In still air a lapse rate of 1.2°C/100m refers to:

   a. DALR
   b. SALR
   c. ELR
   d. ALR

15. What happens to the temperature of a saturated air mass when descending?

    a. it heats up more than dry because of expansion
    b. it heats up less than dry because of evaporation
    c. it heats up more than dry because of compression
    d. it heats up less than dry because of latent heat released during condensation

16. The DALR is

    a. Variable with time
    b. Fixed
    c. Variable with latitude
    d. Variable with temperature

17. A parcel of air cooling by more than 1°C/100m is said to be?

    a. Conditionally stable
    b. Conditionally unstable
    c. Unstable
    d. Stable

18. During an adiabatic process heat is

    a. lost
    b. added but the result is an overall loss
    c. neither added nor lost
    d. added

19. In unstable air, surface visibility is most likely to be restricted by

    a. haze
    b. drizzle
    c. low stratus
    d. showers of rain or snow

20. In an unstable layer there are cumuliform clouds. The vertical extent of these clouds depends on the

    a. thickness of the unstable layer
    b. wind direction
    c. air pressure at the surface
    d. pressure at different levels

21. In an air mass with no clouds the surface temperature is 15°C and 13°C at 1000m. This layer of air is:

    a. stable
    b. unstable
    c. a layer of heavy turbulence
    d. conditionally unstable

22. The stability in a layer is increasing if

a. warm air is advected in the upper part and cold air in the lower part
b. warm air is advected in the lower part and cold air in the upper part
c. warm and moist air is advected in the lower part
d. cold and dry air is advected in the upper part

23. When warm air is advected in the lower part of a cold layer of air:

a. stability increases in the layer
b. stability decreases in the layer
c. stability will remain the same
d. stability will be conditional

ANSWERS

1.	D	9.	A	17.	C
2.	A	10.	A	18.	C
3.	A	11.	C	19.	D
4.	D	12.	B	20.	A
5.	C	13.	B	21.	A
6.	C	14.	C	22.	A
7.	B	15.	B	23.	B
8.	B	16.	B		

CHAPTER NINE

TURBULENCE

Contents

INTRODUCTION

A dictionary definition of turbulence is a 'disturbed state' and so from the aviation point of view this would mean disturbed or rough air. There are different ways in which this turbulence is caused and also different parts of the atmosphere where it occurs.

CAUSES

Turbulence is caused by up and down currents which interfere with the normal horizontal flow of air. The two types of turbulence are:

- Thermal
- Frictional or mechanical

GUSTS AND SQUALLS

A gust is a rapid increase in wind strength, of short duration (less than 1 minute).

A squall is a sudden increase of windspeed of at least 16 kt rising to 22 kt or more and lasting at LEAST 1 minute. A squall may be accompanied by a marked drop in temperature, cloud and precipitation.

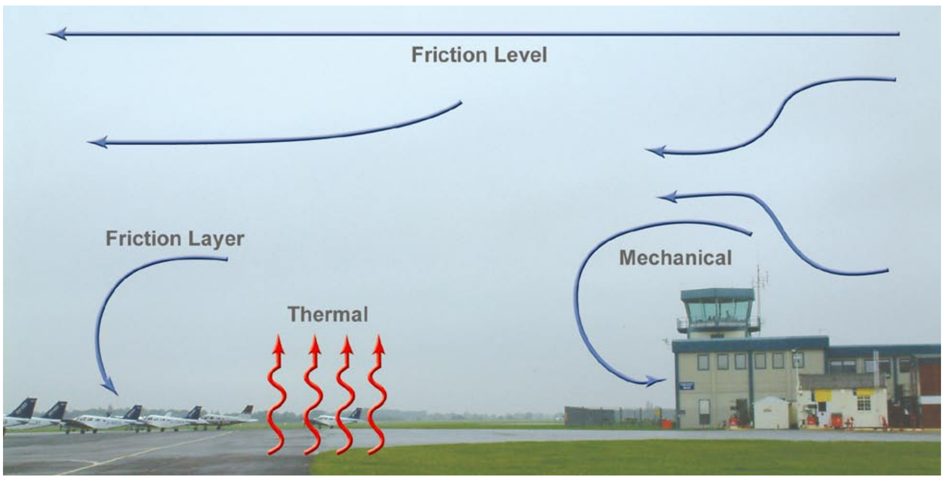
AREAS

Turbulence occurs:

- In the Friction Layer
- In Clouds
- In Clear Air

IN THE FRICTION LAYER

The friction layer is a layer of air on the earth's surface 2000 to 3000 ft (1 km) thick where the horizontal flow of air is disturbed by both thermal and mechanical turbulence.



Turbulence within the friction layer

Thermal Turbulence
This is caused by convection currents resulting from insolation. The convection will obstruct the normal flow of air and this effect can be increased by variable convection.

Thermal turbulence is greatest around 1500 hrs on clear sunny days. There is no thermal turbulence over the sea.

Mechanical Turbulence
This is caused by physical obstructions to the normal flow of air such as hills, mountains, coasts, trees and buildings.

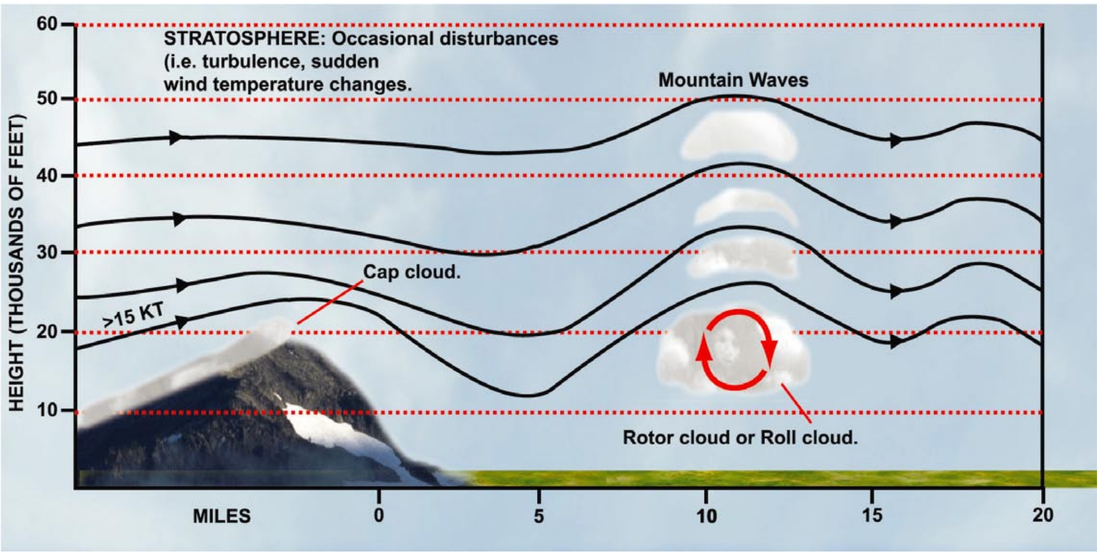
IN CLEAR AIR

Turbulence can occur in clear air, particularly near the Tropopause. Clear Air Turbulence (CAT) is associated with Jet Streams, Standing Waves, air surrounding Cumulo Nimbus (CB) cloud, Upper Level Troughs, and sometimes Upper Level Ridges.

It is caused by horizontal or vertical windshear and can lead to Stalling, Loss of Control and Airframe Damage.

STANDING (OR MOUNTAIN/LEE) WAVES (MTW)

These are turbulent waves of air which can form above and downwind of a mountain range to an average distance of 50 to 100 nm at all heights up to, and even above, the tropopause. Vertical currents may be quite strong: up to 2000 fpm have occurred in the UK, whilst in western USA, currents of 5,000 fpm have been recorded.



A well developed mountain wave or lee wave

CONDITIONS NECESSARY FOR FORMATION OF STANDING WAVES

- Windspeed at mountain height must be at least 15 kt (often more than 20 kt is required) increasing with height.
- The wind must blow within 30 degrees of the perpendicular to the range of hills/mountains.
- There must be a region of marked stability such as an inversion or isothermal layer at mountain top height with less stable air above and below.

TURBULENCE EFFECTS OF STANDING WAVES

The most severe turbulence occurs in the Rotor Zone lying beneath the crests of lee waves and is often marked by Roll Clouds. The most powerful rotor lies beneath the first wave crest. Flight in waves can be smooth, but severe turbulence may occur. Occasionally violent turbulence will occur, due to wave 'breaking'.

Normal turbulence associated with flight across jet streams is frequently greatly increased when the jet passes over mountainous areas, particularly when mountain waves are present.

It has been found that turbulence caused in the troposphere due to mountain waves may continue well into the stratosphere. An aircraft flying close to its ceiling on these occasions might find itself in serious difficulty.

VISUAL RECOGNITION FEATURES OF STANDING WAVES

Providing there is sufficient moisture in the atmosphere, distinctive clouds are formed with mountain waves and these provide useful warning of the presence of such waves. The clouds are:

- Lenticular, or lens shaped clouds which form on the crests of standing waves. They appear a few thousand feet above the mountain tops and at any level up to the tropopause, and sometimes above. Ragged edges indicate turbulence.
- Rotor, or roll-clouds occur under the crests of strong waves down wind of the ridge. The strongest rotor is normally formed in the first wave downwind and will be level or slightly above the ridge crest.
- Cap clouds form on the ridge and strong winds may sweep the cloud down the lee slopes.

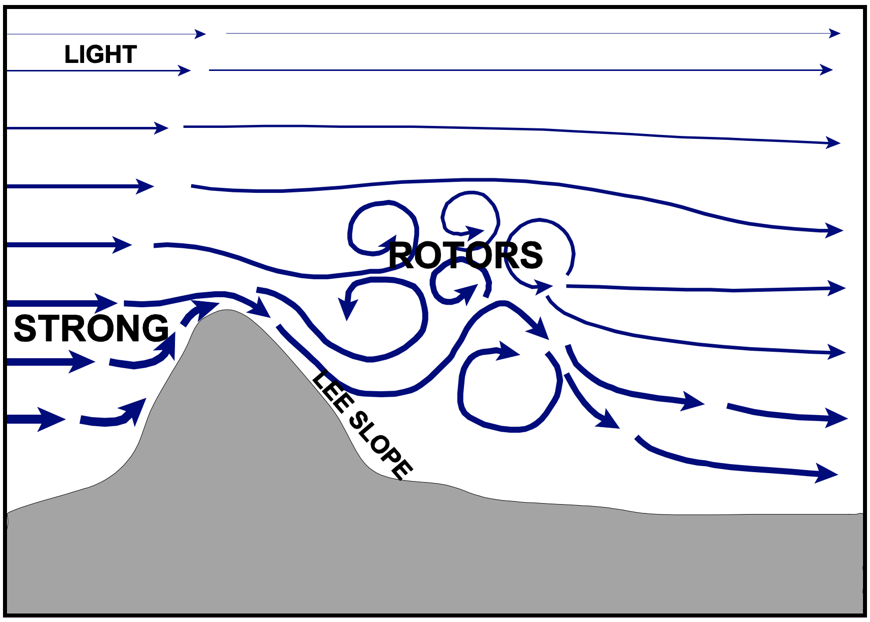
Note: The characteristic clouds above may be obscured by other clouds and the presence of standing waves may thus not be evidenced.
If the air is dry, clouds may not form at all, even though standing waves are present.

ACTION TO AVOID THE WORST EFFECTS OF STANDING WAVES

- Read the Met. Forecast
- Arrange to cross mountain ranges at 90 degrees.
- Fly at the recommended turbulence speed.
- Do not fly parallel to and just downwind of the range.
- Avoid flight through or near the rotor zone.
- Avoid flight levels within 5000 ft of stable layer where severe turbulence is most likely.
- Allow a height clearance above highest ground at least equal to the height of that ground above local terrain.
- Avoid low altitude flight towards the mountain range from the Lee side. Aircraft height variations will be out of phase with waves and downdraughts will be hazardous.
- Avoid high altitude flight on the lee side of the mountain range downwind. Buffet margin at high level may be small, and speed of approaching standing waves will be high, with subsequently greater loads applied to the airframe.
- Be prepared for icing in cloud.

ROTOR STREAMING

If the winds approaching a mountain range are strong only at lower levels and fall off or reverse direction at higher levels, Rotor Streaming may result. This comprises violent rotors moving downwind from the ridge. Unlike the stationary rotors described above, these rotors travel downwind after forming on the lee slopes.

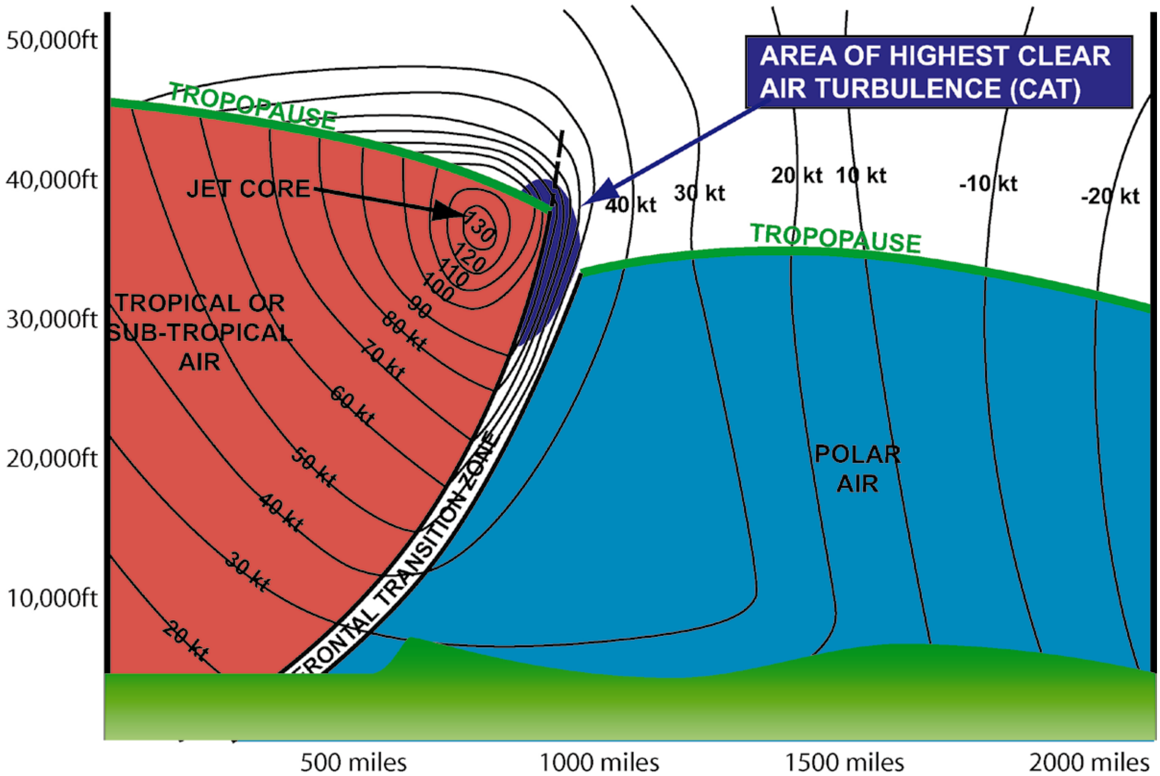


Rotor streaming

JET STREAMS

Jet streams are narrow bands of fast moving air commonly found beneath the tropopause. These air currents can be very fast, especially over South East Asia in winter where the highest recorded velocity was 407 kt. Around these fast currents of air are eddies and shear lines, just like around the edge of powerful river. The shear lines are created when there is marked change in wind speed and direction. This is commonly called Wind shear and is creates very dangerous Clear Air Turbulence (CAT). Turbulence in jet streams is most severe:

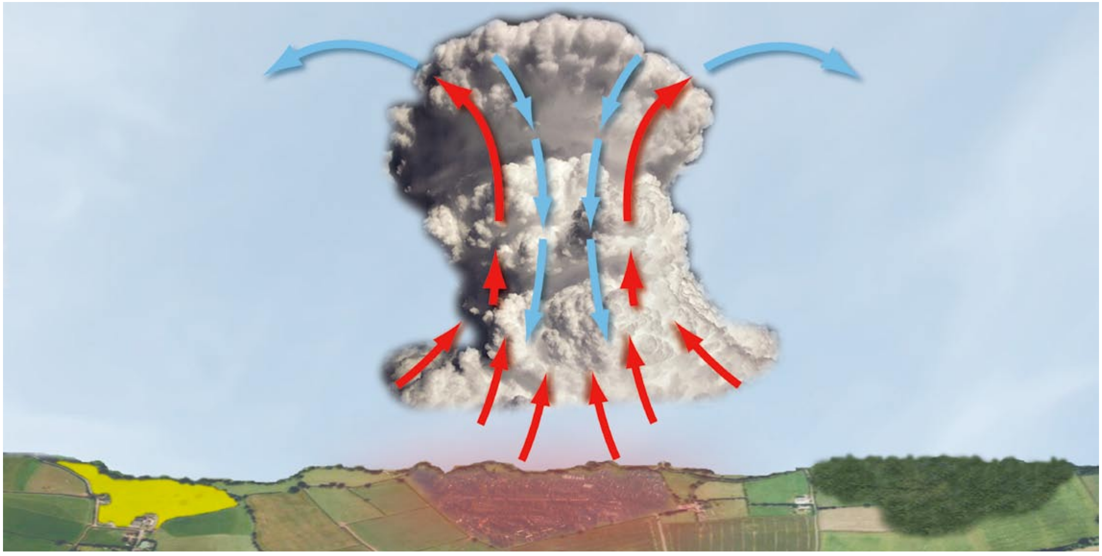
- With stronger winds.
- With curved jet streams.
- Above and to the lee of mountain ranges.
- In the primary area for Maximum CAT associated with a jet stream which is near to or below the jet axis on the cold air (low pressure) side. In the Northern Hemisphere this will be found by looking downstream to the left hand side; in the Southern Hemisphere looking downstream to the right hand side of the jet core.
- With developing and rapidly moving jets.



A vertical cross section through a jet stream

TURBULENCE WITHIN CLOUDS

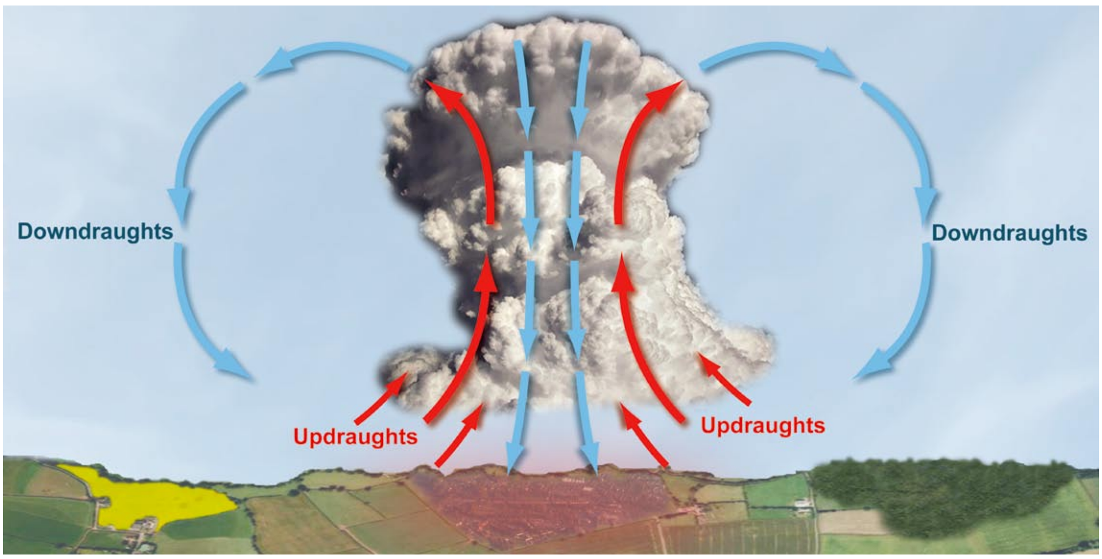
Turbulence is also found in and around significant cloud developments, especially in cumuliform cloud, which are convective clouds created by rising air currents.



The vertical extent of a cumulus cloud is therefore a very good indication of the intensity of the vertical air flow beneath and within the cloud, and, consequently, the intensity of the turbulence in and around the cloud. For this reason, pilots must treat large cumuliform clouds with caution. Cumulonimbus clouds generate the most violent turbulence. In cumulonimbus clouds, and well developed cumulus cloud, both upcurrents and downdraughts are present within the cloud, itself.

TURBULENCE SURROUNDING CLOUDS

Around well developed cumulus cloud, (cumulus congestus), and cumulonimbus, downdraughts are active at some distance from the cloud itself. These downdraughts cause severe turbulence.

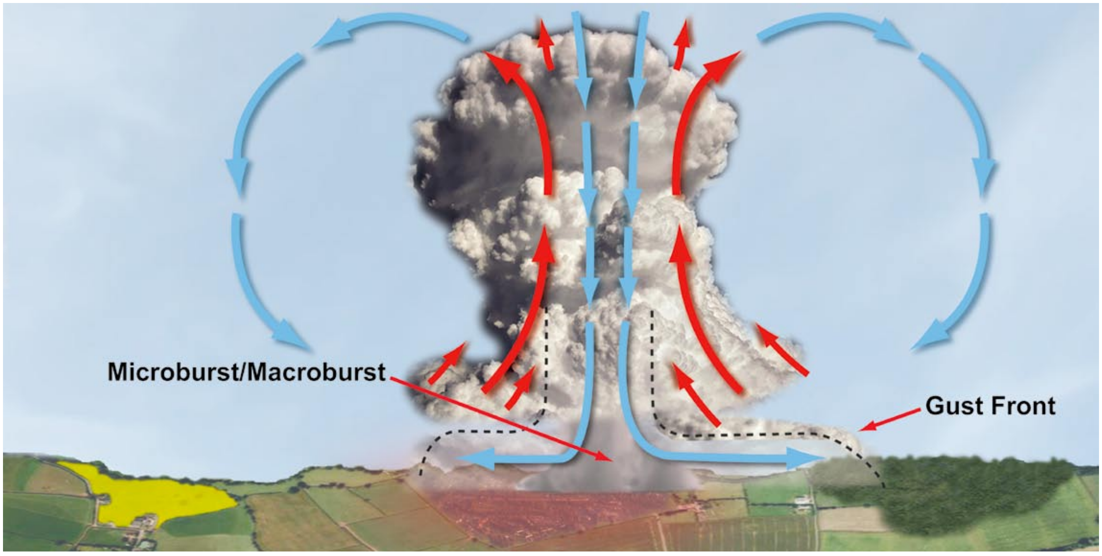


TURBULENCE BENEATH CLOUDS

Beneath the base of cumulus congestus and cumulonimbus, convective upcurrents are also very strong. Downdraughts can be met beneath cloud base, too.

The most severe downdraughts occur in precipitation.

When precipitation falls from clouds, it tends to drag air down with it, creating downdraughts within, and underneath the cloud.



If the mass of air descending from the cloud is significant enough, a phenomenon known as a microburst, or, on a larger scale, a macroburst, is created.

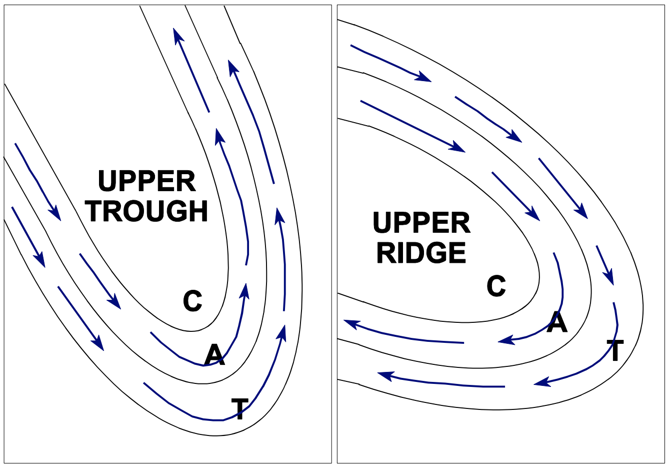
If the downdraught descends from beneath a cumulonimbus or cumulus congestus, it may come into contact with the ground, and then spread out, from the cloud itself, sometimes up to distances from the cloud of 15 - 20 miles. This type of phenomenon causes large changes in the direction and speed of the wind in the vicinity of the cloud, both vertically and horizontally, and may, thus, give rise to dangerous low level wind shear.

Because of the weather phenomena such as microbursts and windshear associated with them, cumulonimbus clouds are extremely hazardous to aircraft. Flight below, and in the immediate vicinity of, large cumuliform clouds, especially cumulonimbus, should be avoided.

TURBULENCE AROUND UPPER LEVEL TROUGHS AND RIDGES

Since upper level winds are stronger than those at the surface, the sharp changes in wind direction at upper level troughs are likely to produce considerable horizontal windshear and consequent disturbance which may be experienced as Clear Air Turbulence (CAT).

As upper level ridges tend to be more gently curved than troughs, the direction changes and consequent turbulence will be less severe.



Turbulence Produced at Upper Troughs and Ridges

TURBULENCE REPORTING CRITERIA

Turbulence remains an important operational factor at all levels but particularly above FL 150. The best information on turbulence is obtained from pilots' Special Aircraft Observations; all pilots encountering turbulence are requested to report time, location, level, intensity and aircraft type to the ATS Unit with whom they are in radio contact. High level turbulence (normally above FL 150 not associated with cumuliform cloud, including thunderstorms) should be reported as guided in table below. You will be asked questions on this table so be sure to try and remember it.

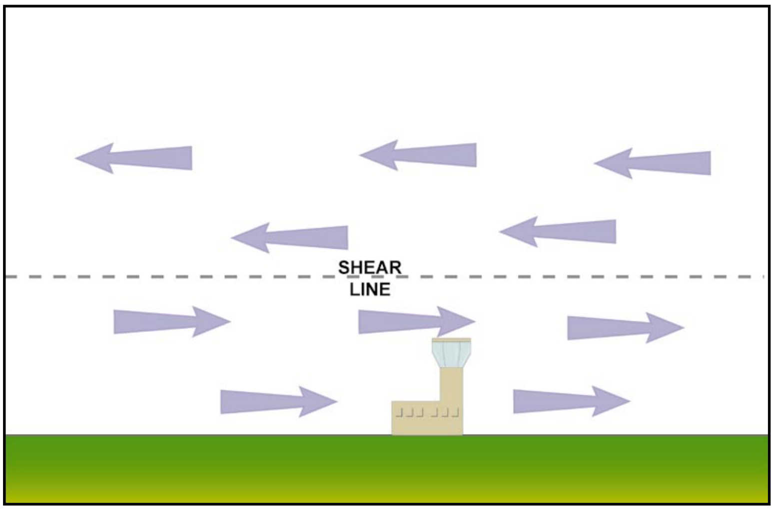
TURB and other Turbulence Criteria Table		
Incidence: **Occasional** - less than 1/3 to 2/3 **Intermittent** - 1/3 to 2/3 **Continuous** - more than 2/3		
Intensity	Aircraft Reaction (transport size aircraft)	Reaction Inside Aircraft
Light (not shown on Sig. WX charts)	Turbulence that momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw). IAS fluctuates 5 - 15 kt. (< 0.5 g at the aircraft's centre of gravity) Report as 'Light Turbulence'. or; turbulence that causes slight, rapid and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude. No IAS fluctuations. Report as 'Light Chop'.	Occupants may feel a slight strain against seat belts or shoulder straps. Unsecured objects may be displaced slightly. Food service may be conducted and little or no difficulty is encountered in walking.
Mo**d**erate	Turbulence that is similar to light Turbulence but of greater intensity. Changes in altitude and/or attitude occur but the aircraft remains in positive control at all times. IAS fluctuates **15 - 25 kt. (0.5-1.0g** at the aircraft's centre of gravity). Report as 'Moderate Turbulence'. or; turbulence that is similar to Light Chop but of greater intensity. It causes rapid bumps or jolts without appreciable changes in altitude or attitude. IAS may fluctuate slightly. Report as 'Moderate Chop'.	Occupants feel **d**efinite strains against seat belts or shoulder straps. Unsecured objects are **d**islodged. Food service and walking are **d**ifficult.
Severe	Turbulence that causes large, abrupt changes in altitude and/or attitude. Aircraft may be momentarily out of control. IAS fluctuates more than 25 kt. (>1.0 g at the aircraft's centre of gravity). Report as 'Severe Turbulence'.	Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about. Food service and walking impossible.
Note 1: Pilots should report location(s), time(s) (UTC), incidence, intensity, whether in or near clouds, altitude(s) and type of aircraft. All locations should be readily identifiable. Turbulence reports should be made on request, or in accordance with paragraph 2. Example: (a) Over Pole hill 1230 intermittent Severe Turbulence in cloud, FL 310, B747. (b) From 50 miles north of Glasgow to 30 miles west of Heathrow 1210, occasional moderate Chop TURB, FL 330, MD80. Note 2: The UK does not use the term 'Extreme' in relation to turbulence.		

The turbulence reporting criteria

LOW ALTITUDE WINDSHEAR

Vertical Windshear

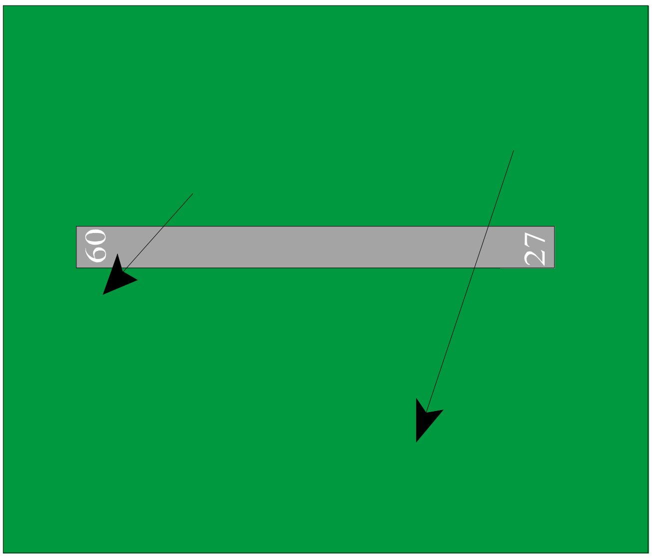
Vertical windshear is change in wind velocity with height. It is typically measured in knots per 100ft. This type of windshear is very common during an inversion, therefore expect them at night and in well developed high pressure systems such as those found under the sub tropical high pressure belt. As an aeroplane fly's through an inversion, not only will the change of temperature cause the engine performance to change, but the abrupt change in wind speed and direction may significantly alter the flight path.



Vertical Windshear.

Horizontal Windshear

Horizontal windshear is change in wind velocity with horizontal distance and is common with the passage of fronts. It is typically measured in knots per 1000ft.



Horizontal Windshear.

QUESTIONS

1. The vertical extent of the friction layer depends primarily on

    a. roughness of surface, temperature, local time
    b. temperature, local time, environmental lapse rate
    c. stability, wind speed, roughness of surface
    d. wind speed, roughness of surface, temperature

2. Low level wind shear is likely to be greatest

    a. at the top of a marked surface-based inversion.
    b. at the condensation level when there is no night radiation.
    c. at the condensation level when there is strong surface friction.
    d. at the top of the friction layer.

3. Which cloud type may indicate the presence of severe turbulence?

    a. Cirrocumulus
    b. Nimbostratus
    c. Altocumulus lenticularis
    d. Stratocumulus

4. Low level vertical wind shear can be expected during the night

    a. in association with radiation inversions
    b. in unstable atmospheres
    c. and early morning only in winter
    d. and early morning only in summer

5. What is the effect of a strong low level inversion?

    a. It results in good visual conditions.
    b. It promotes vertical windshear.
    c. It promotes extensive vertical movement of air.
    d. It prevents vertical windshear.

6. A wide body aircraft takes off on a clear night in Dhahran, Saudi Arabia. Shortly after take off the aircraft's rate of climb drops to zero. This can be due to

    a. very pronounced downdrafts
    b. low relative humidity
    c. a very strong temperature inversion
    d. sand/dust in the engines

7. Vertical wind shear is

    a. vertical variation in the horizontal wind
    b. vertical variation in the vertical wind
    c. horizontal variation in the horizontal wind
    d. horizontal variation in the vertical wind

8. What is normally the most effective measure to reduce or avoid CAT effects?

   a. Change of flight level.
   b. Change of course.
   c. Increase of speed.
   d. Decrease of speed.

9. How does moderate turbulence affect an aircraft?

   a. Large, abrupt changes in altitude or attitude occur but the aircraft may only be out of control momentarily.
   b. Continued flight in this environment will result in structural damage.
   c. Changes in altitude or attitude occur but the aircraft remains in positive control at all times.
   d. Rapid and somewhat rhythmic bumpiness is experienced without appreciable changes in altitude or attitude

10. In which zone of a jet stream is the strongest CAT to be expected?

   a. The warm air side of the core.
   b. Exactly in the centre of the core.
   c. About 12000 FT above the core.
   d. The cold air side of the core.

11. On a clear summer day, turbulence caused by solar heating is most pronounced

   a. during early morning hours before sunrise
   b. about midmorning
   c. during the early afternoon
   d. immediately after sunset

12. What units are used to report vertical wind shear?

   a. kt.
   b. m/100 FT.
   c. m/sec.
   d. kt/100 FT.

13. Which degree of aircraft turbulence is determined by the following ICAO description?
“There may be moderate changes in aircraft attitude and/or altitude but the aircraft remains in positive control at all times. Usually, small variations in air speed. Changes in accelerometer readings of 0.5 to 1.0 g at the aircraft’s enter of gravity. Occupants feel strain against seat belts. Loose objects move about. Food service and walking is difficult.”

   a. Severe.
   b. Violent.
   c. Moderate.
   d. Light.

14. At the top of orographic waves, in mountainous regions, the cloud most likely to be encountered is

a. cirrus.
b. cumulus mediocris.
c. altocumulus lenticularis.
d. cirrostratus.

15. A zone of strong convection currents is encountered during a flight. In spite of moderate gust you decide to continue the flight. What are your precautionary measures?

a. Increase the speed / try to climb above the zone of convective currents if aircraft performance parameters allow.
b. Decrease the speed / try to descend below the zone of convective currents.
c. Increase the speed / try to descend below the zone of convective currents.
d. Decrease the speed / try to climb above the zone of convective currents if aircraft performance parameters allow

16. All pilots encountering Clear Air Turbulence are requested to report it. You experience CAT which causes passengers and crew to feel definite strain against their seat belt or shoulders straps. Unsecured objects are dislodged. Food service and walking are difficult. This intensity of CAT should be reported as

a. severe
b. extreme
c. moderate
d. light

17. Which of the following conditions are most favourable to the formation of mountain waves?

a. Unstable air at mountain top altitude and a wind at least 20 knots blowing across the mountain ridge.
b. Either stable or unstable air at mountain top and a wind of at least 30 knots blowing parallel to the mountain ridge.
c. Moist unstable air at mountain top and wind of less than 5 knots blowing across the mountain ridge.
d. Stable air at mountain top altitude and a wind at least 20 knots blowing across the mountain ridge.

18. Under which of the following conditions is the most severe CAT likely to be experienced?

a. A westerly jet stream at low latitudes in the summer
b. A straight jet stream near a low pressure area
c. A curved jet stream near a deep trough
d. A jet stream, with great spacing between the isotherms

19. You intend to carry out a VFR flight over the Alps, on a hot summer day, when the weather is unstable. What is the best time of day to conduct this flight?

a. Mid-day.
b. Afternoon.
c. Early evening.
d. Morning.

20. The most dangerous low level wind shears are encountered

a. when strong ground inversions are present and near thunderstorms
b. in areas with layered clouds and wind speeds higher than 35 kt
c. during any period when wind speed is greater than 35 kt and near valleys
d. near valleys and at the windward side of mountains.

21. The turbulence which occurs at high flight levels (above FL 250) is mainly of the type Clear Air Turbulence. In what way can moderate to severe Clear Air Turbulence affect an aircraft, the flight and the passengers?

a. The turbulence is wave like which makes the flight unpleasant for the passengers but the manoeuvring will not be affected essentially.
b. The turbulence is a small scale one and can cause damage of worn out type. The manoeuvring of the aircraft will be made more difficult or even impossible. For the passengers the flight will be unpleasant.
c. The turbulence is a large scale one (waving) so that the aircraft will be difficult to manoeuvre. The passengers will feel some discomfort.
d. The turbulence can be resembled with the roughness of a washing-board (small scale) and will not have influence on the aircraft and its solidity, but will make flight a little more difficult. The passengers will seldom notice anything of this turbulence.

22. The degree of clear air turbulence experienced by an aircraft is proportional to the

a. intensity of the solar radiation
b. intensity of vertical and horizontal windshear
c. height of the aircraft
d. stability of the air

23. Which cloud type may indicate the presence of severe turbulence?

a. Cirrocumulus
b. Nimbostratus
c. Altocumulus lenticularis
d. Stratocumulus

24. Fallstreaks or virga are?

a. strong katabatic winds in mountainous areas and accompanied by heavy precipitation
b. water or ice particles falling out of a cloud that evaporate before reaching the ground
c. strong downdraughts in the polar jet stream, associated with jet streaks
d. gusts associated with a well developed Bora

25. The presence of altocumulus lenticularis is an indication of the

a. development of thermal lows
b. presence of valley winds
c. presence of mountain waves
d. risk of orographic thunderstorms

26. Above and below a low level inversion the wind is likely to

a. experience little or no change in speed and direction
b. change significantly in speed and direction
c. change in speed but not in direction
d. change in direction but not in speed

27. At the top of orographic waves, in mountainous regions, the cloud most likely to be encountered is

a. cirrus.
b. cumulus mediocris.
c. altocumulus lenticularis.
d. cirrostratus.

28. A flight is to depart from an airport with runways 09 and 27. Surface wind is 270/05; an inversion is reported at 300 feet with turbulence and wind shear. The wind just above the inversion is 090/30. What is the safest departure procedure?

a. Take-off is not possible under these conditions.
b. Depart on runway 09 with a tailwind.
c. Depart runway 27 with maximum throttle during the passage through the inversion.
d. Depart runway 27 with as steep an ascent as possible.

ANSWERS

1.	C
2.	A
3.	C
4.	A
5.	B
6.	C
7.	A
8.	A
9.	C
10.	D
11.	C
12.	D
13.	C
14.	C
15.	D
16.	C
17.	D
18.	C
19.	D
20.	A
21.	B
22.	B
23.	C
24.	B
25.	C
26.	B
27.	C
28.	B

CHAPTER TEN

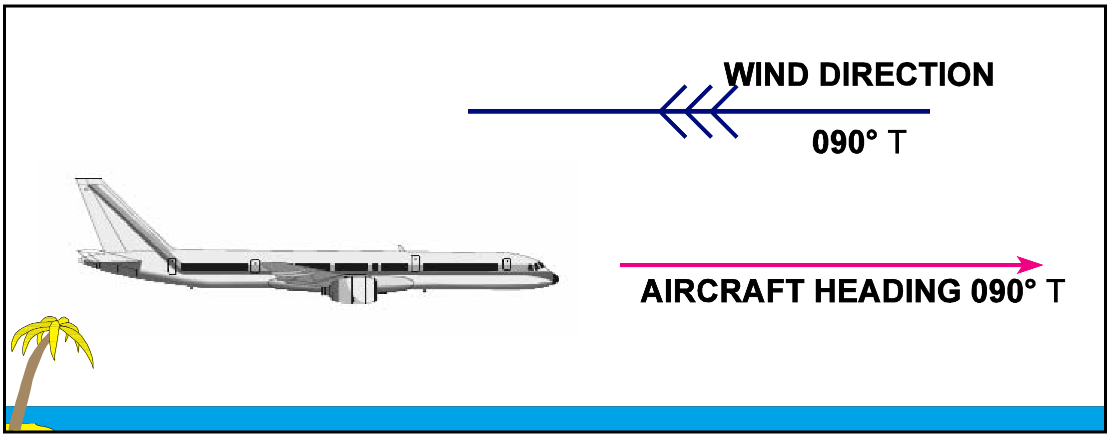
WINDS

Contents

INTRODUCTION

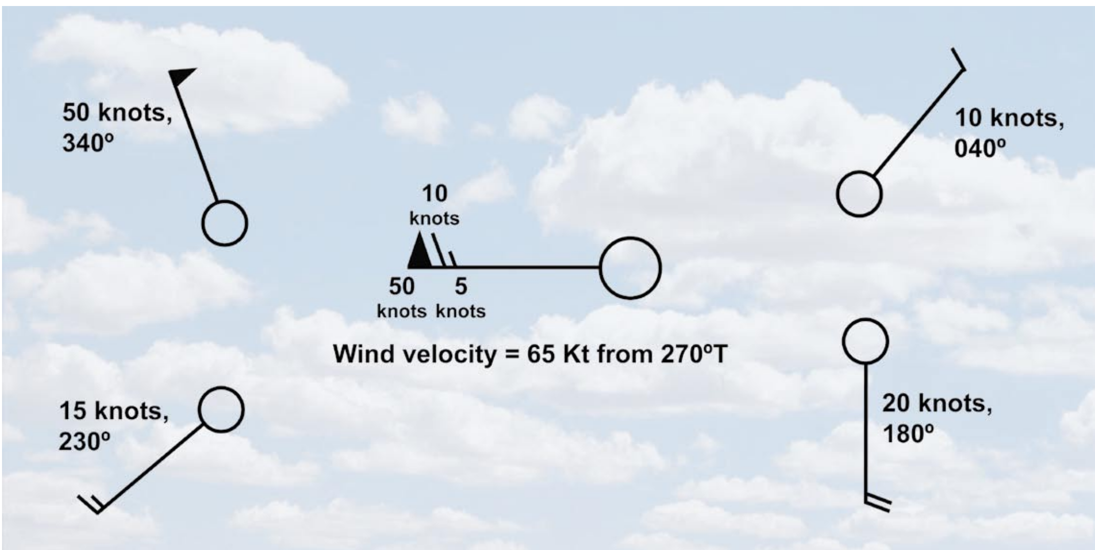
Wind is air in horizontal motion. Wind Velocity (W/V) has both direction and speed.

Wind direction is always given as the direction from which the wind is blowing. It is normally given in degrees true, but wind direction given to a pilot by ATC or in an ATIS will be given in degrees magnetic.



Wind Direction.

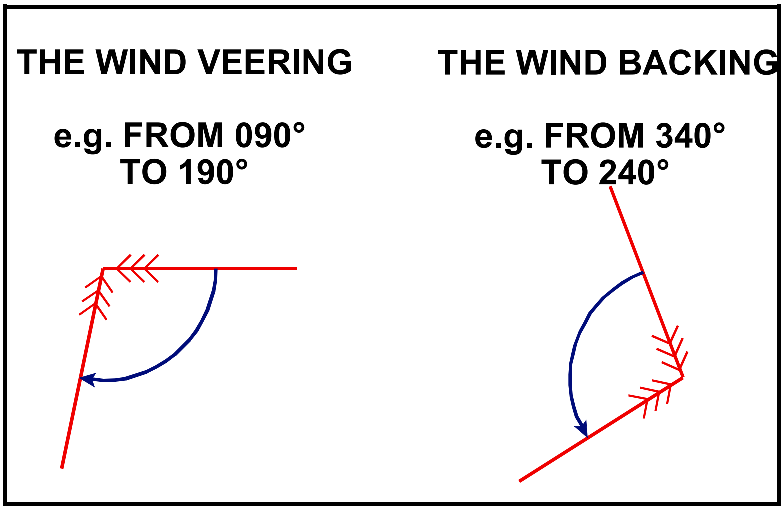
Wind speed is usually given in knots, but some countries give the speed in metres per second and the Met. Office often work internally in kilometres per hour.



Surface Wind Indications on the Station Circle.

A veer is a change in wind direction in a clockwise direction. Here the direction values are getting higher, for example, the wind direction goes from 090° to 120°.

A back is a change in wind direction in an anti-clockwise direction. This applies in both hemispheres. Here the direction values are getting smaller, for example, the wind direction goes from 290° to 220°.



The Wind Veering and Backing.

GUSTS AND LULLS

A gust is a sudden increase in wind speed, often with a change in direction. It lasts only for a few seconds and is very local.

A lull is a sudden decrease in windspeed.

SQUALLS

A squall is a sudden increase in wind speed, often with a change in direction. It lasts for some minutes and can cover a wide area. It is often associated with cumulonimbus cloud and cold fronts.

GALES

A gale is a condition where the wind speed exceeds 33 kt, or if the wind gusts exceed 42 kt.

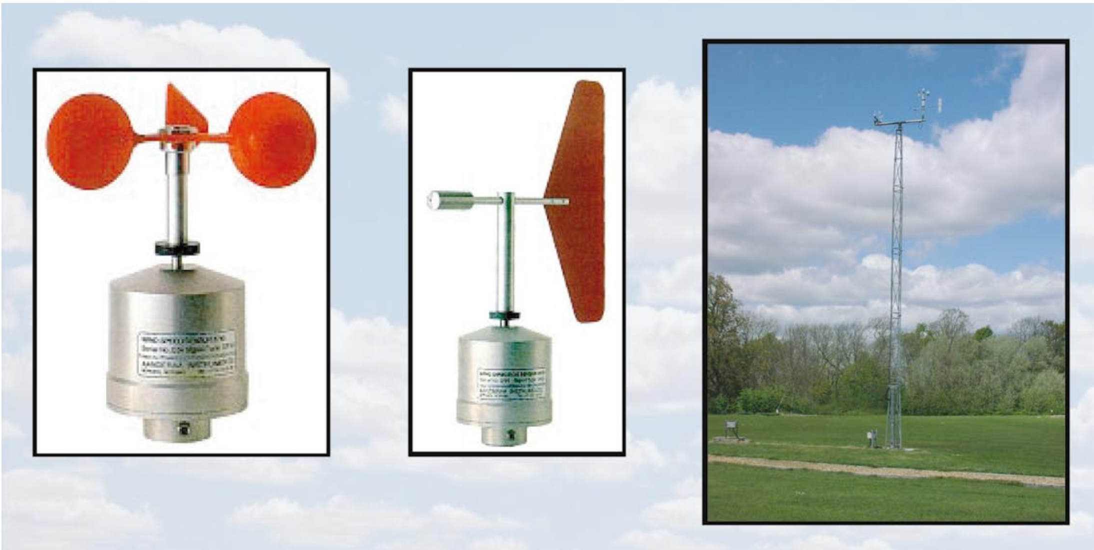
HURRICANES

A Hurricane (Typhoon, Cyclone) means a wind speed exceeding 63 kt.

MEASUREMENT OF WINDS

Surface wind is measured by a wind vane which aligns itself with the wind direction, and an anemometer which measures the speed. An anemometer is a set of 3 hemispherical cups which rotate on a shaft with the effect of the wind. The speed of rotation of the shaft is directly proportional to the windspeed. The rotation is used to drive a small generator, the output of which is then displayed on a gauge which is calibrated in knots.

Both vane and anemometer are positioned 33 ft (10 m) AGL and they are located clear of buildings and obstructions which could affect the airflow and hence accuracy. An anemograph records windspeed and sometimes direction.



A Wind Vane and Anemometer

Upper winds are measured by radar tracking of a radio sonde and by aircraft reports.

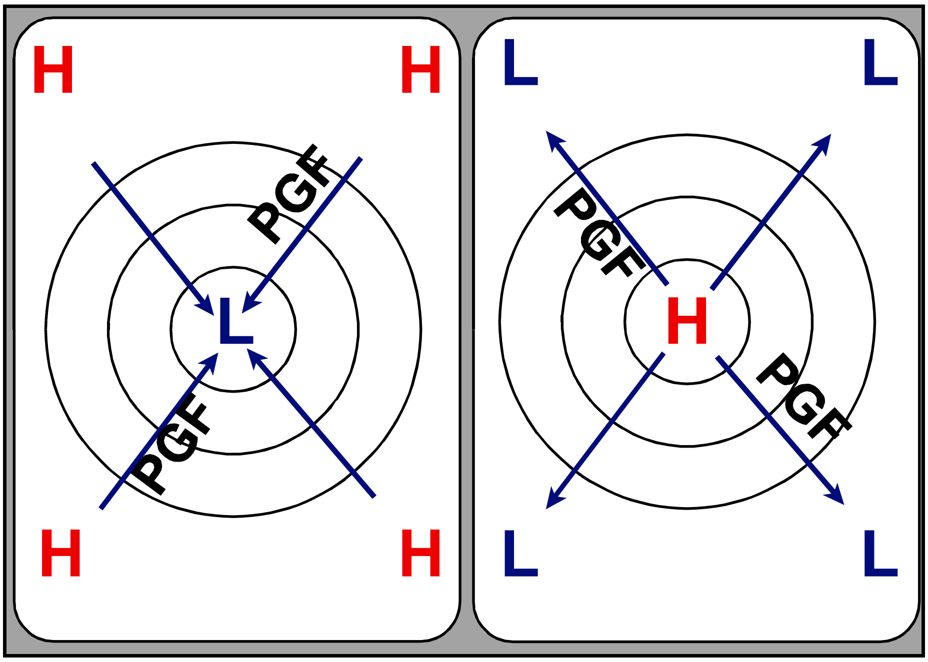
THE GEOSTROPHIC WIND

As with any theorised wind or model wind, a number of assumptions must be used to reduce the complexity of reality and make the model more simplistic. These are as follows:

1. The Geostrophic Wind is said to have only two forces. These must be working opposite from each other and in balance. These two forces are:

Pressure Gradient Force (Pgf)

- Pressure Gradient Force, (PGF), is the force that acts from a high pressure to a low pressure.

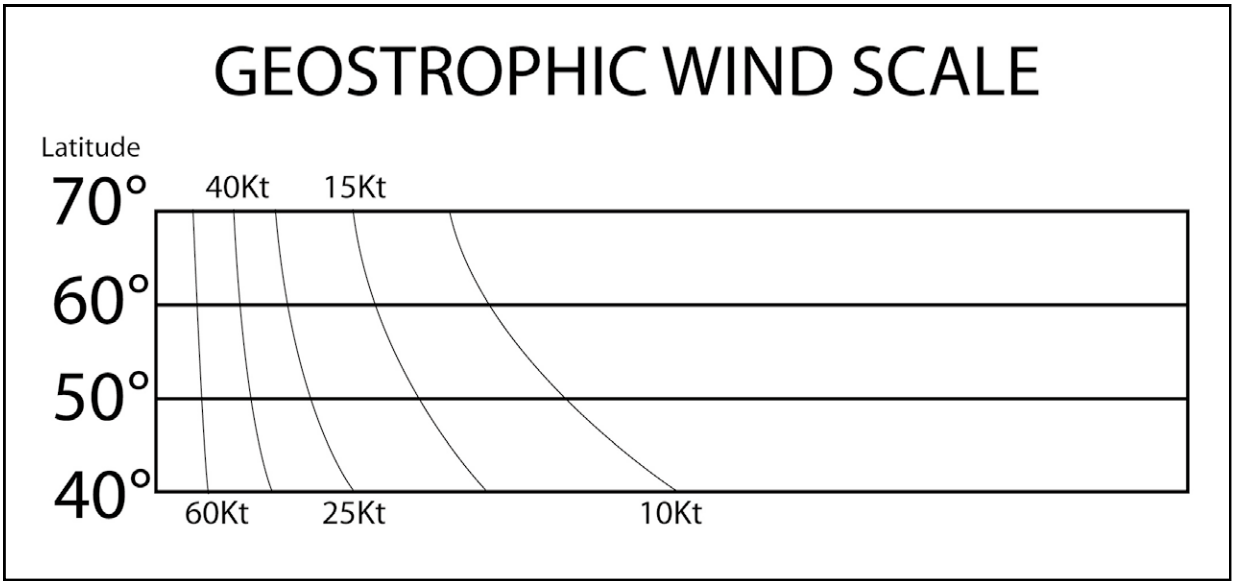


Pressure Gradient Force (P.G.F.).

- We can see the strength of this force by studying the spacing between isobars. Closely spaced isobars would indicate a large pressure gradient force. This is common in low pressure systems. Widely spaced isobars indicate a small pressure gradient force. This is common in high pressure systems.

- The Pressure Gradient Force, (PGF), controls the windspeed. A large pressure gradient force would create strong winds, whereas a small pressure gradient force would create light winds. Windspeed is directly proportional to the pressure gradient force.

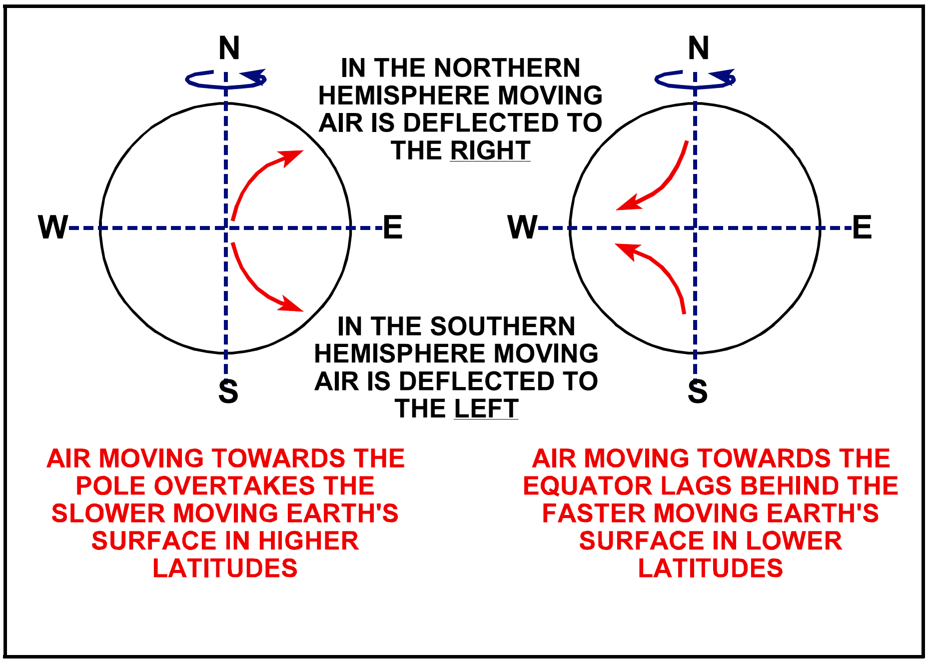
- The relationship between the isobar spacing, the pressure gradient force and the windspeed can be seen in the Geostrophic Wind Scale (GWS). Using the Geostrophic Wind Scale, on the next page, take the distance between two isobars and reading from left to right, measure the geostrophic windspeed. You will notice the wider the spacing of the isobars, the lighter the wind.



Geostrophic Wind Scale

Coriolis Force (Cf)

- Coriolis Force, (CF), is the force caused by the rotation of the earth.
- It acts 90° to the wind direction causing air to turn to the right in the northern hemisphere and to the left in the Southern hemisphere. CF is maximum at the poles and minimum at the equator.



An Illustration of the Coriolis Force.

- Looking at the formula for the Coriolis Force shown below, it is evident that an increase in latitude causes an increase in the Corilolis Force. Therefore this force is maximum at the poles and nil at the equator. However, for theoretical purposes, within 15° either side of the equator the Coriolis Force is so small that we consider it to be nil.

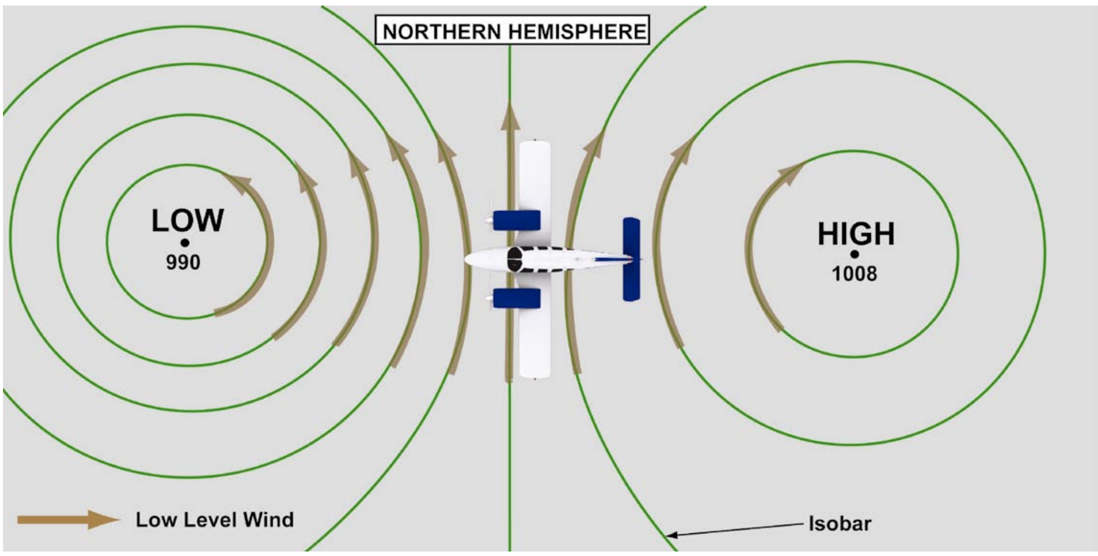
$$CF = 2\,\Omega\,\rho\,V\sin\theta$$

where Ω = angular rotation of the earth
ρ = density
V = wind speed
θ = latitude

- Again, looking at the formula, we can see that an increase in wind speed will cause an increase in the Coriolis Force. Therefore the Coriolis Force is proportional to the wind speed.

2. The Geostrophic Wind blows parallel to straight isobars. Therefore the Geostrophic Wind can only blow in a straight line. If the wind were to follow a curved path, it cannot be considered as a Geostrophic Wind because there will be additional forces involved, namely the centrifugal or centripetal forces. The Gradient Wind (which will be discussed later) uses the Pressure Gradient Force, the Coriolis Force and the Centrifugal Force. This is the model for wind which follows a curved path.

How can we know the direction of the Geostrophic Wind along the isobar? If you remember from earlier lessons, Buys Ballot's Law told us that in the northern hemisphere with your back to the wind, the low pressure is to your left. In the southern hemisphere with your back to the wind, the low pressure is on your right. Looking at the diagram below and by using Buys Ballot's Law, we can see a geostrophic wind direction of 180°.



Geostrophic Wind Direction in the Northern Hemisphere

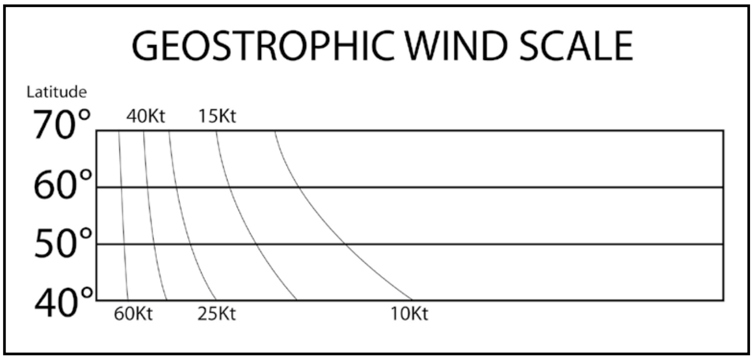
How can we know the speed of the Geostrophic Wind? If you remember from earlier, there was a correlation between the isobar spacing, the pressure gradient force and the wind speed. The Geostrophic Wind Scale allowed us to quantify this relationship. Measure the distance perpendicular between the isobars and use that distance on the Geostrophic Wind Scale, reading from left to right.

3. The Geostrophic Wind only blows above the friction layer. Within the friction layer the wind speed is reduced because of surface friction. Therefore the Coriolis Force will reduce, causing the two forces to be out of balance. Remember that the friction layer varies depending upon the nature of the surface and the time of the day. Therefore, the height of the Geostrophic Wind will vary. Generally though it is considered to be between 2,000 - 3,000ft.

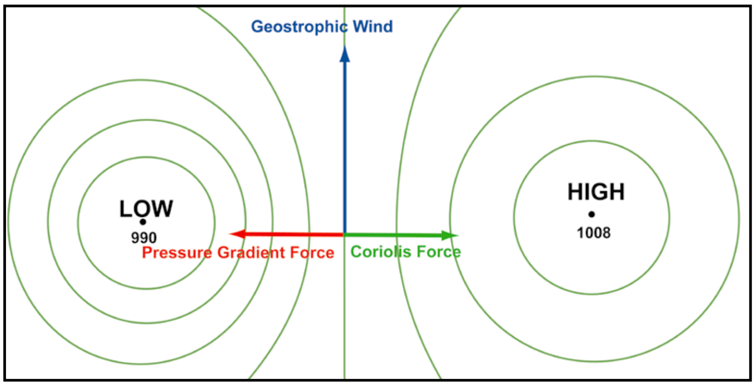
4. For a particular pressure gradient force, the Geostrophic Wind Speed will increase as latitude reduces.

$$v = \frac{PGF}{2\,\Omega\,\rho\,\sin\theta}$$

So the effect of latitude must be accounted for when using the Geostrophic Wind Scale. The diagram below shows the Geostrophic Wind Scale for latitude between 40° and 70°. Notice that the same spacing between the isobars at high latitude gives a slower wind speed when compared to lower latitude. Within 5 degrees of the equator the CF is zero. Within 15 degrees the CF is very small, so that the geostrophic formula no longer applies.



Latitude Corrected Geostrophic Wind Scale

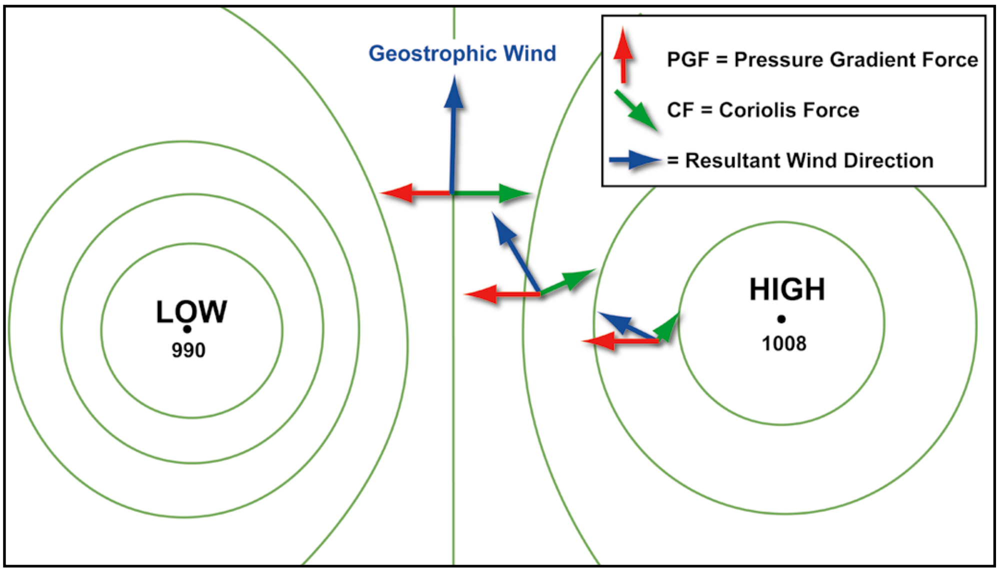


Geostrophic Wind

The above diagram illustrates the Geostrophic Wind and emphasises the points made so far. The wind blows parallel to the isobars with the two forces in balance and opposing one another.

Construction Of The Geostrophic Wind

Look at the diagram below for the northern hemisphere. Air is being accelerated towards the low pressure but in doing so, the strength of the Coriolis Force is increasing. The wind is being deflected to the right until the two forces are acting opposite from each other and the wind now blows parallel to the isobar. With your back to the wind, the low pressure is on your left.



The Geostrophic Wind.

Conditions Necessary For The Wind To Be Geostrophic

For the wind to be geostrophic, it has to occur:

- Above the friction layer.
- At a latitude greater than 15 degrees.
- When the pressure situation is not changing rapidly.
- With the isobars straight and parallel.

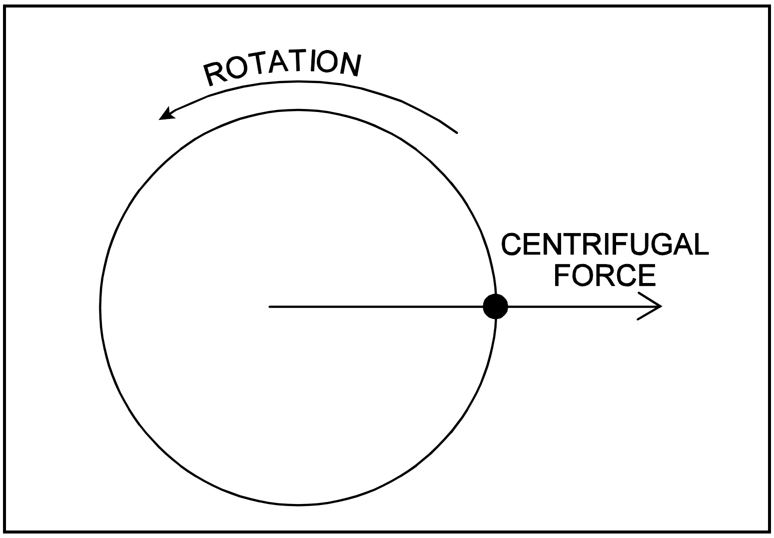
The geostrophic wind can apply at all heights above the friction layer. However, with an increase in height, the wind speed should increase due to the reduction in density.

THE GRADIENT WIND

The gradient wind occurs when the isobars are curved. This brings into play a force which makes the wind follow a curved path parallel to the isobars. The gradient wind then is the wind which blows parallel to curved isobars due to a combination of 3 forces:

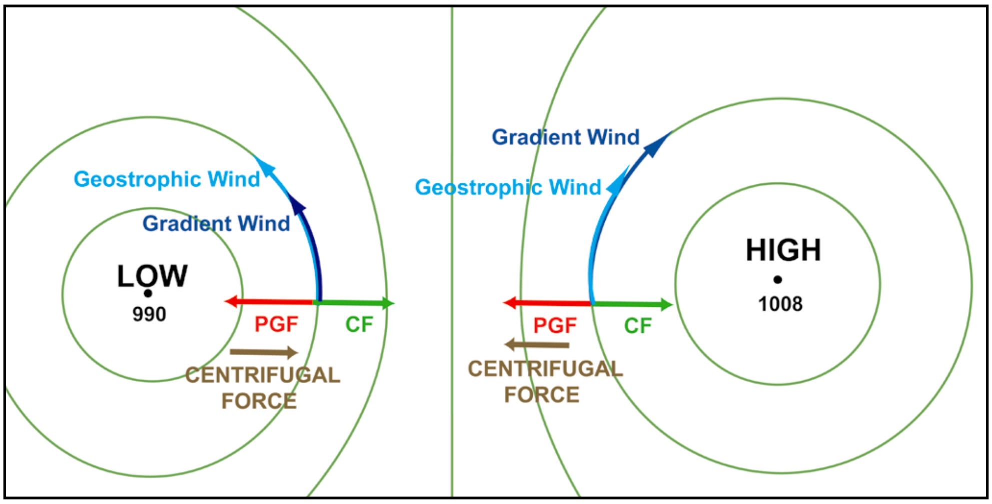
- PGF
- CF
- Centrifugal Force

Centrifugal Force
Centrifugal force is the force acting away from a rotating body.



Centrifugal Force

Gradient Wind In A Depression
If air is moving steadily around a depression, then the centrifugal force opposes the PGF and therefore reduces the wind speed. You can see this on the left hand side of the image shown below.



Gradient Wind Compared to Geostrophic Wind Around a High and a Low

The gradient wind speed around a depression is less than the geostrophic wind for the same isobar interval. Hence if the Geostrophic Wind Scale (GWS) is used, it will overread.

Gradient Wind In A High
Looking to the right of the iagram, if air is moving steadily around a high, then the centrifugal force acts with the Pressure Gradient Force (PGF), increasing the velocity of the wind.

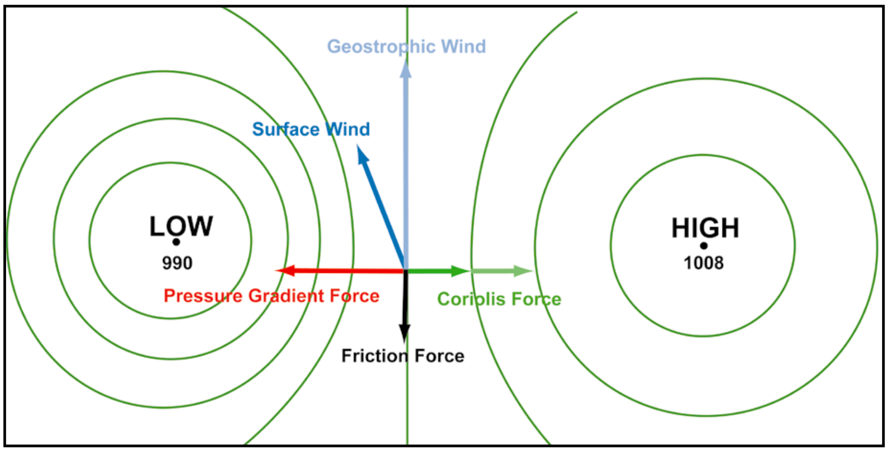
The gradient wind speed around an anticyclone is greater than the geostrophic wind for the same isobar interval. Hence if the Geostrophic Wind Scale (GWS) is used, it will underread.

THE ANTITRIPTIC WIND

The wind which blows in low latitudes (within 15°) where the Corriolis Force (CF) is very small is called the antitriptic wind.

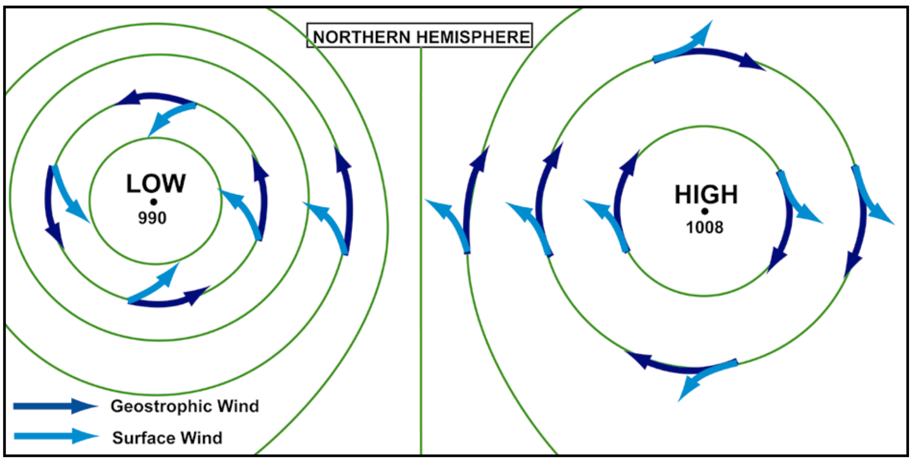
WINDS BELOW 2000 - 3000ft (1 Km)

Friction between moving air and the land surface will reduce wind speed near the ground. This reduction also reduces the CF. This will cause the two forces in the Geostrophic Wind to be out of balance since now CF is less than PGF. The wind is now called a surface wind.



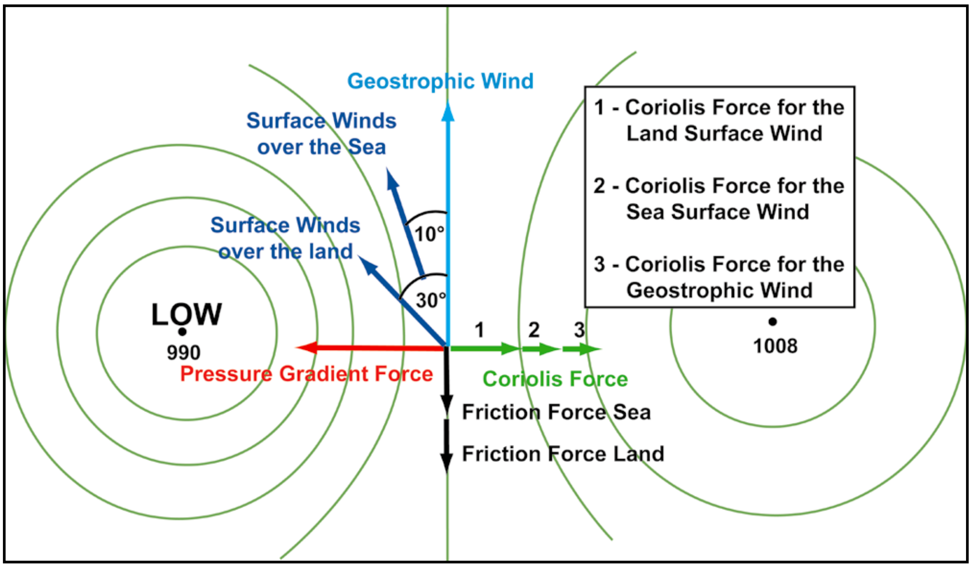
The Surface Winds in the Northern Hemisphere.

Since surface friction has reduced the wind velocity, resulting in a reduction in the Coriolis Force, the PGF is now more dominating. This causes the wind to blow across the isobars towards the low.



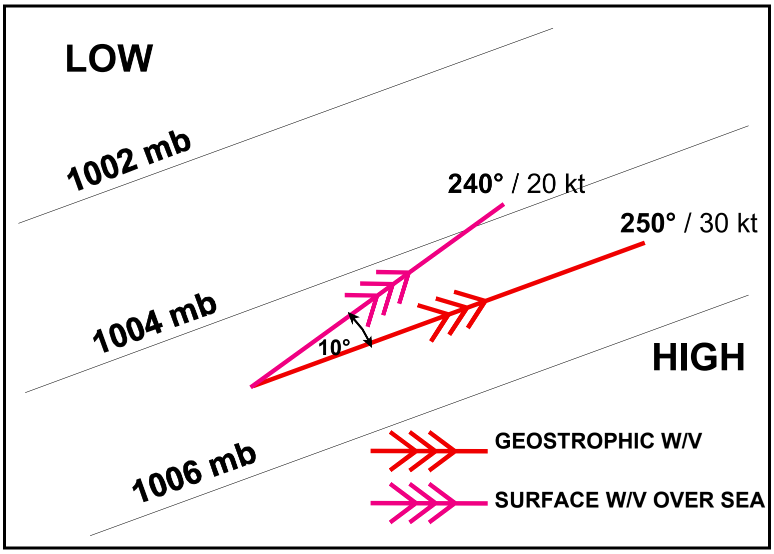
Surface Wind Over Sea and Land

- The surface wind over land is backed by 30 degrees from the geostrophic wind and its speed is reduced by 50%.



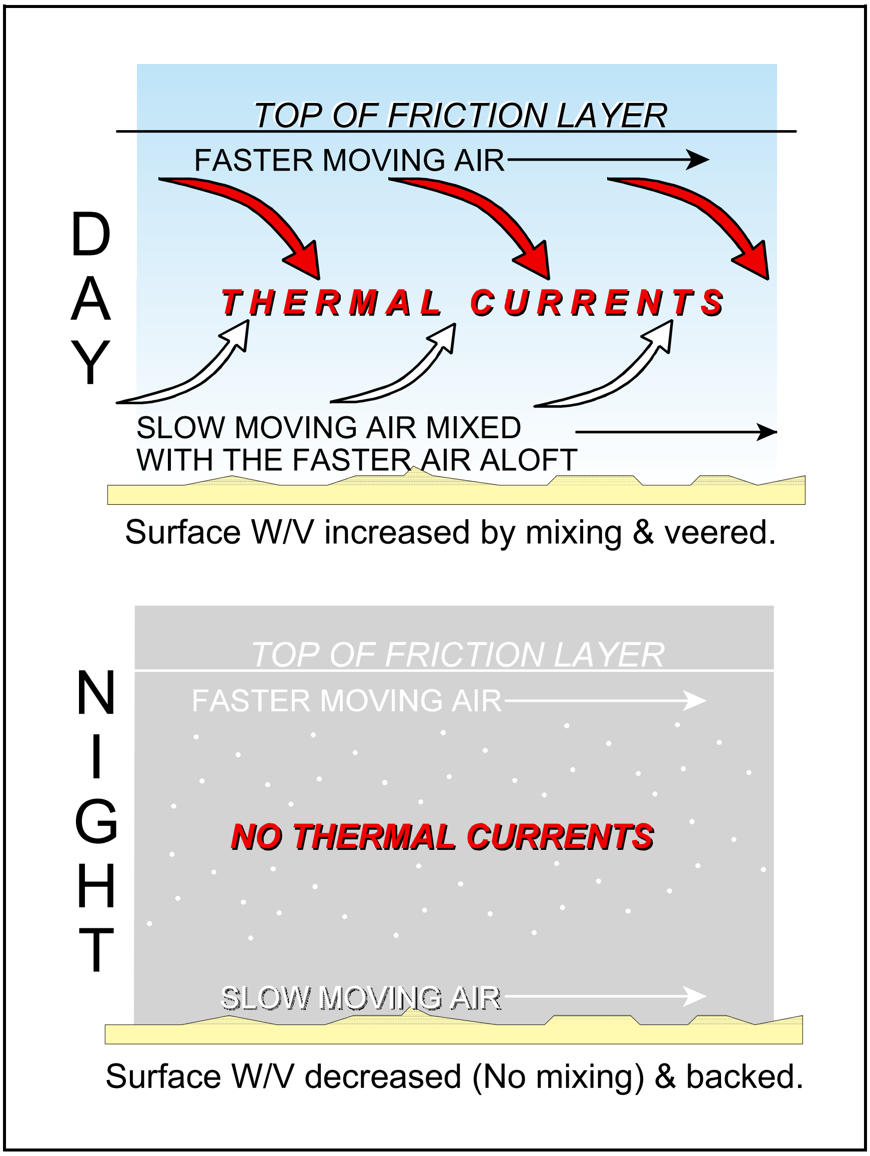
An Example of Rough Rules Over Land in the Northern Hemisphere.

- Over the sea friction is very much less and the surface winds are closer to geostrophic values. Surface wind over the sea is backed by 10 degrees from the geostrophic wind and speed reduced to 70% (surface winds will veer in the southern hemisphere).



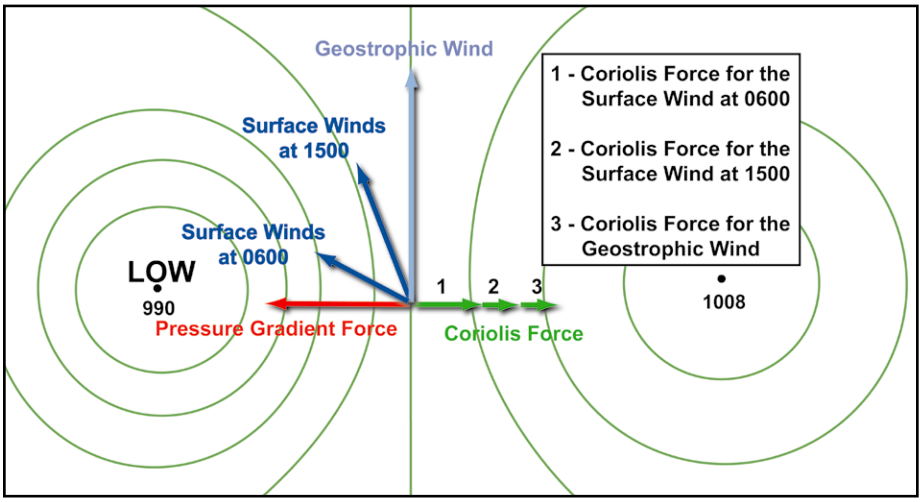
An Example of Rough Rules Over Sea in the Northern Hemisphere.

Diurnal Variation Of The Surface Wind
Diurnal variation of surface winds are due to thermal turbulence which mixes the air at the surface with air moving freely above. During the day thermal currents mix the faster air at altitude with the surface wind. This increases the surface wind speed. However, at night there is no thermal mixing and therefore the surface wind stays slow.



Diurnal Variation of the Surface Wind

As a result of the effect of thermal mixing, there can be a regular change in the surface wind in each 24 hr period. It veers and increases by day reaching maximum strength about 1500 hrs. It backs and decreases thereafter with minimum strength around dawn.



LAND AND SEA BREEZES

Sea Breezes

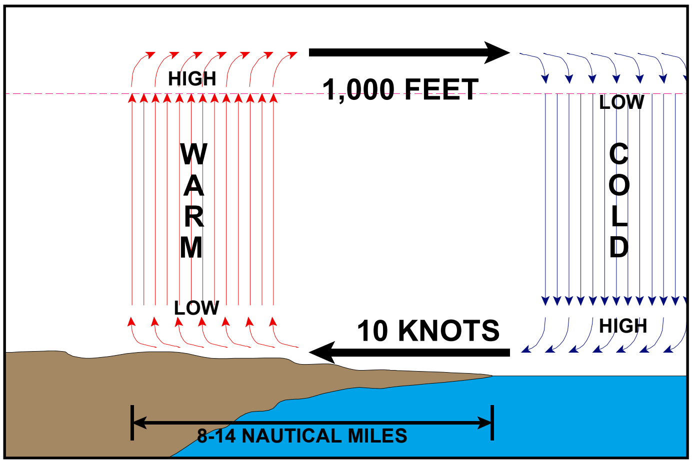
On a sunny day, particularly in an anticyclone with a slack pressure gradient, the land will heat quickly.

The air in contact will be warmed and will rise and expand so that pressure at about 1000 ft will be higher than pressure at the same level over the sea. This will cause a drift of air from over the land to over the sea at about 1000 ft. The drift of air will cause the surface pressure over the land to fall, and the surface pressure over the sea to rise.

As a result there will be a flow of air over the surface from sea to land - a sea breeze.

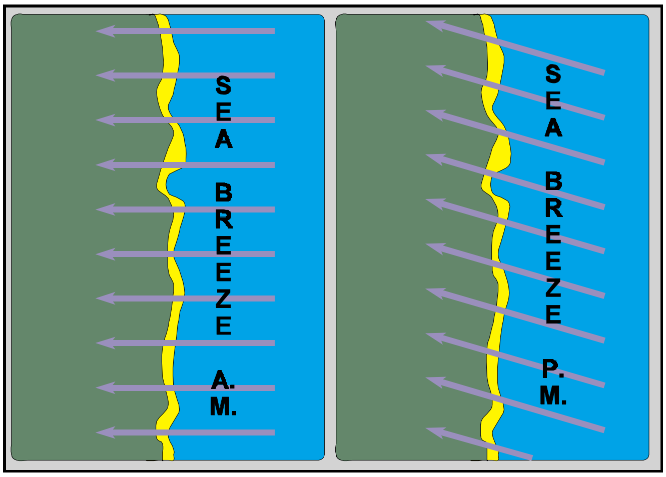
On average, sea breezes extend 8 to 14 nm either side of the coast and the speed is about 10 kts. In the tropics speed is 15 kts or more and the inland extent is greater.

An illustration of the formation of a sea breeze is shown below.



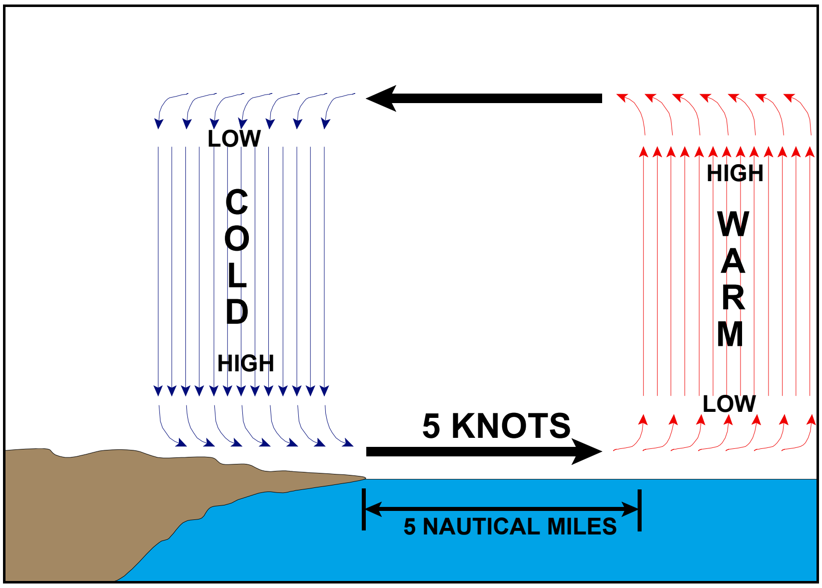
The Sea Breeze.

The direction of the sea breeze is more or less at right angles to the coast, but after some time it will veer under the influence of the coriolis force in the northern hemisphere.



The Influence of the Coriolis Force on Sea Breezes over time

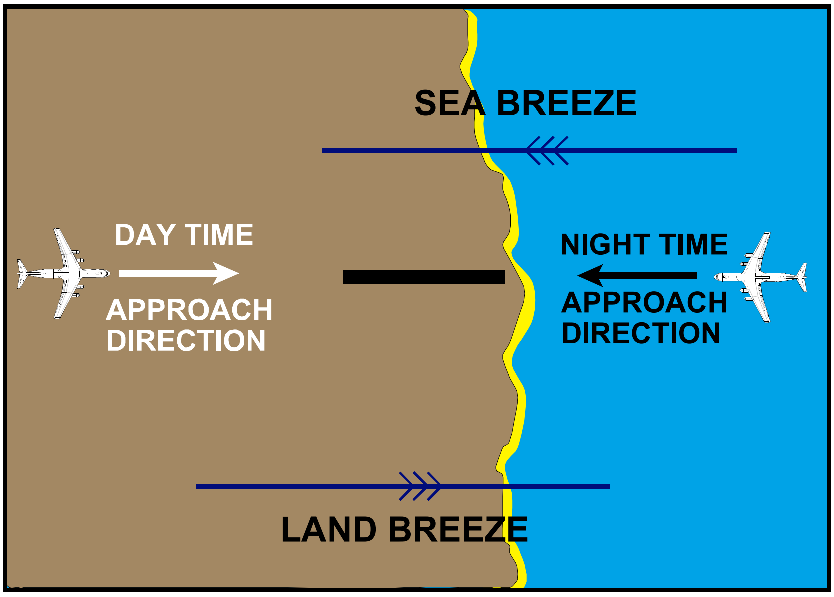
Land Breezes
After sunset the situation will reverse. The land will cool rapidly whilst the sea will retain its heat. There will be an increase in pressure at the surface over the land whilst the pressure over the sea will fall - there will be a land breeze. The speed will be about 5 kts and the breeze will extend about 5 nms out to sea. This effect is shown below.



The Land Breeze

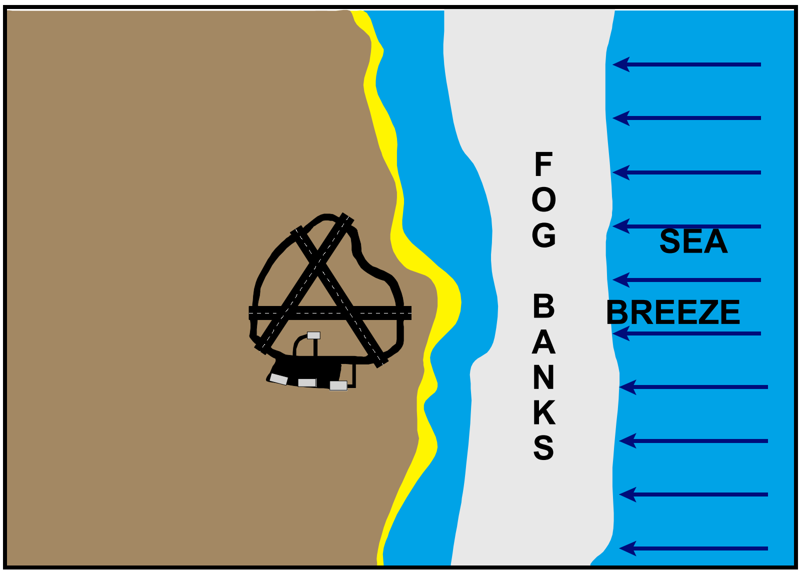
PRACTICAL COASTAL EFFECTS

The direction of take-off and landing can be reversed with the change from sea to land breeze. This is shown below:



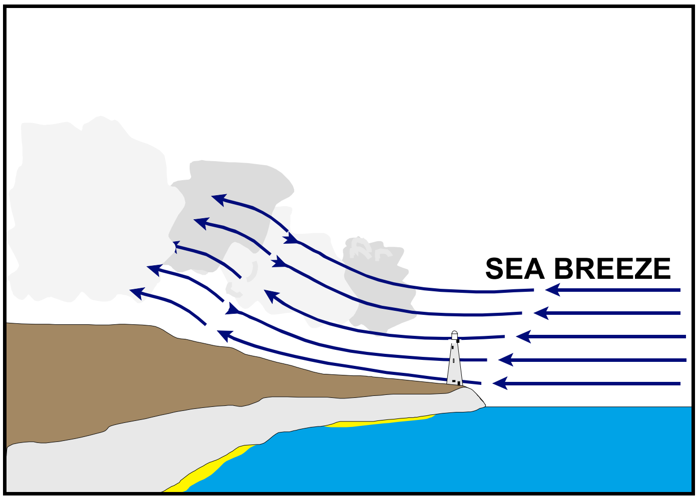
Reversal of Direction of Take off and Landing

Fog at sea can be blown inland by day to affect coastal airfields.



Fog Being Blown Inland by the Sea Breeze

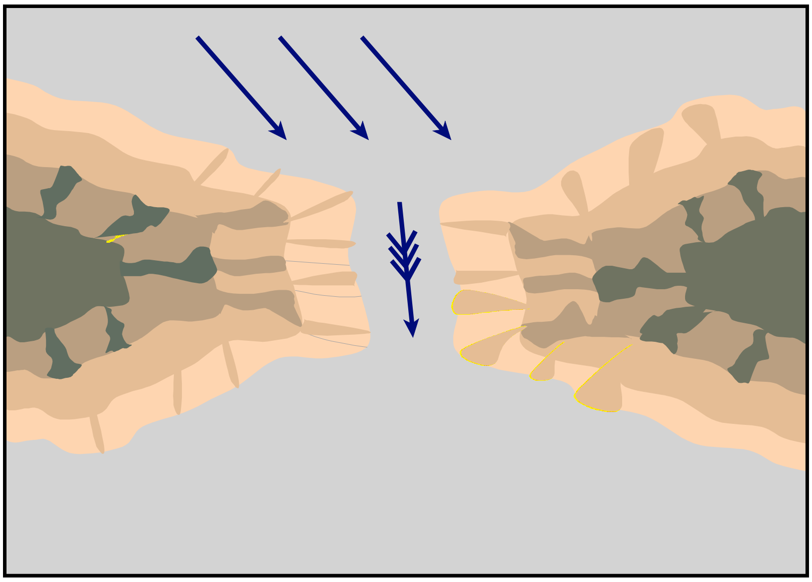
The lifting of air over land with the sea breeze can cause small clouds to form as shown below. These are a good navigational features of a coastline.



Cloud Formation Over a Coastline.

VALLEY OR RAVINE WINDS

A wind blowing against a mountain is impeded. If the barrier is broken by a gap or valley, the wind will blow along the valley at an increased speed due to the restriction.



A Valley or Ravine Wind.

The above example is typical in a wind system known as the Mistral. The Mistral is a strong wind which is mainly found around the southeast of France in the Gulf of Lion for up to 100 days of the year. A famous author once described the Mistral as a "brutal, exhausting wind that can blow the ears off a donkey". In the case of the Mistral, air is cooled above the Massif

Central, the central mountains of France and the Alps. Since the air is colder and denser than the surrounding air, it flows down slope feeding into the Rhône valley. The presence of the Rhône valley creates a funnel or venture effect, speeding up the current towards the Gulf. These winds may affect the weather in North Africa, Sicily and Malta or throughout the Mediterranean, particularly when low pressure systems form in the Gulf of Genoa.

Valley winds may also be considered in another way. During the night, or in the in the winter months, the mountain sides and slopes will cool. This cools the adjacent air increasing its density. Because of the slope, this denser and heavier air will start to descend from the mountain sides towards the valley. Such a wind is termed a Mountain Wind since the airflow is from the mountain. On the following pages you will also see that this wind is also known as a Katabatic Wind.

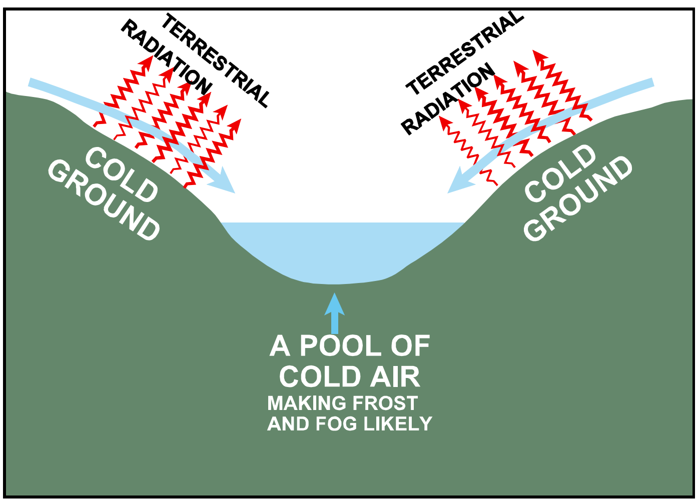
The reverse of the above wind pattern is true during the day and in the summer months especially. As the mountain sides and slopes start to warm from insolation, the air will become less dense and start to rise creating a flow of air from the valley to the top of the mountain. Such a wind is termed a Valley wind. On the following pages you will read that such a wind is also called an Anabatic Wind.

Examples of valley winds are the Mistral (Rhone Valley), (see Chapter 24) Genovese (Po Valley), Kosava (Danube) and Vardarac (Thessalonika). Valley winds also occur in fjords.

KATABATIC WINDS

A katabatic wind (which simply means "going downhill"), is a wind that blows down-slope, for example, down hills or mountains. However, there is a difference between winds that feel warmer than their surroundings and those that are cooler than their surroundings. The more commonly used reference of a katabatic wind usually refers to the cold down-slope wind and is the reference that will be used in here. Examples of cold katabatic winds include the Mistral and the Bora which you will study later and examples of warm Katabatic winds are the Föhn, Chinook, Bergwind and Diablo.

The cold form of katabatic wind originates in a cooling of the air adjacent to the slope usually at night or in winter. Since the density of air increases as the air temperature falls, the air will flow downwards, warming adiabatically as it descends, but still remaining relatively colder than the surrounding.



Katabatic Wind Formation

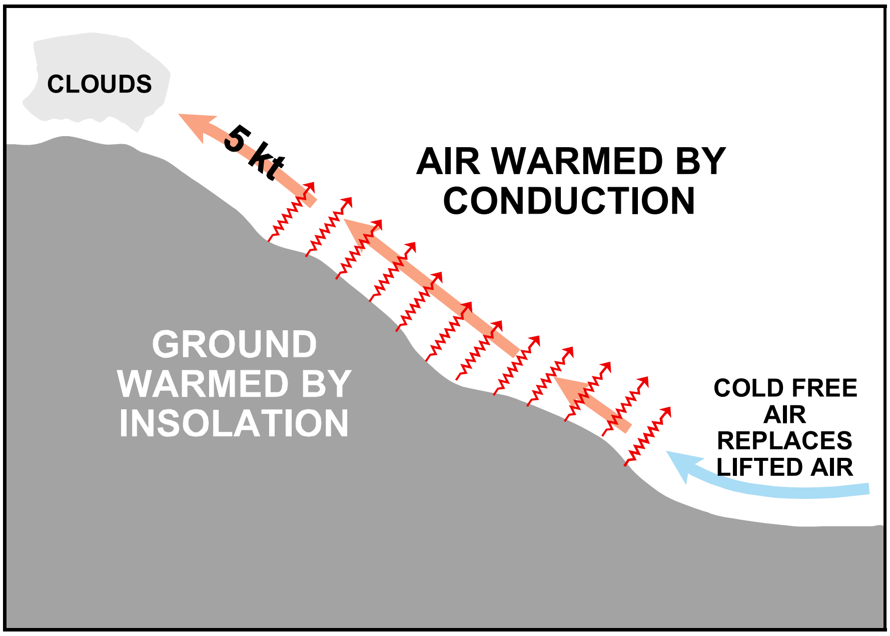
Cold katabatic winds are frequently found on slopes or valleys in the early hours of the night when the ground cools from the release of terrestrial radiation. Such an example is clearly shown in the diagram above.

Over Antarctica and Greenland, extensive cold katabatic winds exist especially in winter. These winds slip off the large ice masses and push towards the sea. On their journey they are deflected by Coriolis force and form the Polar Easterlies. These easterlies are some of the fastest sustained wind speeds on the planet often reaching 100 miles per hour for days or weeks on end. Combine this with temperatures as low as -50°C and you get to realise why the Antarctic peninsular is so perilous.

ANABATIC WINDS

On a warm sunny day, the slope of a hill will become heated by insolation, particularly if it is a south facing slope.

The air in contact with the ground will be heated by conduction and will rise up the hill. Free cold air will replace the lifted air and so a light wind will blow up the hillside. An anabatic wind is a light wind of around 5 kts which blows up a hill or mountain by day.



Anabatic Wind Formation.

FÖHN WINDS

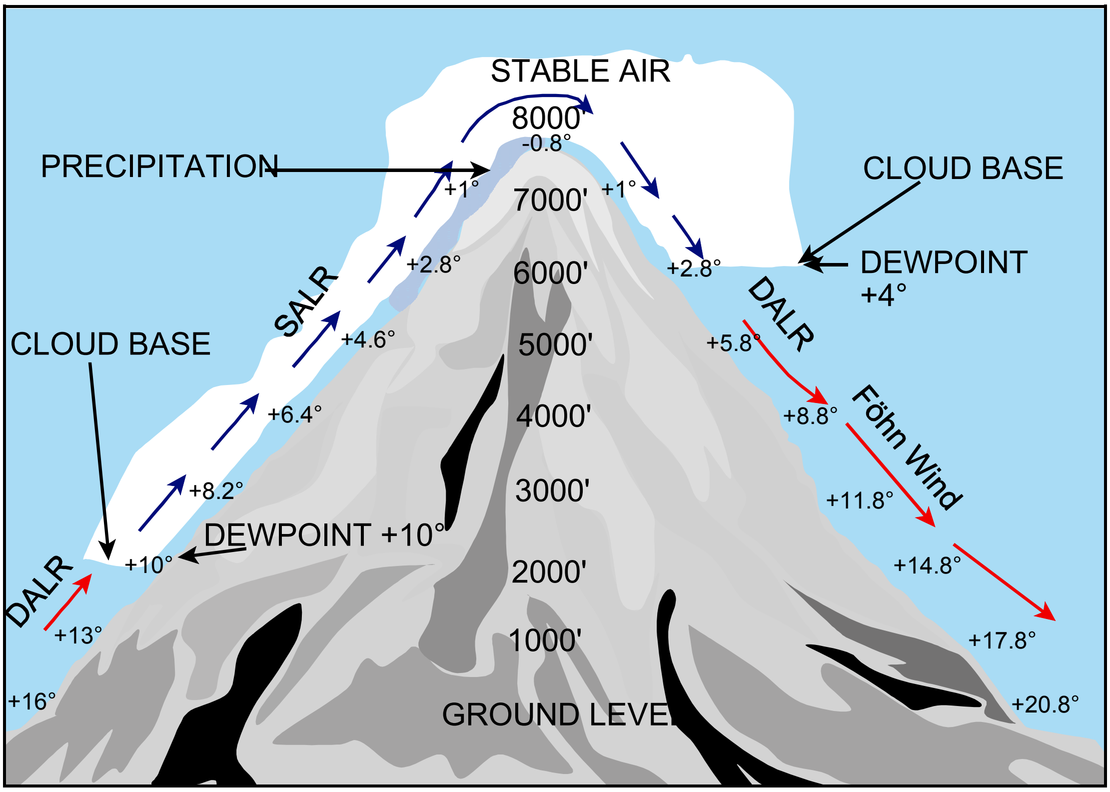
The Föhn Wind is a warm dry wind which blows on the downwind side of a mountain range. It is a local wind in the Alps. A similar wind on the east of the Rocky Mountains in Canada is called the Chinook. There is also the Santa Anna to the east of the Andes in South America, and to the east of the High Sierras in California.

If moist air is forced to rise up a mountain side, it will quickly become saturated and will cool adiabatically as it rises. After reaching the condensation level, cloud will form and the air will cool at the SALR.

If the air is stable, it will follow the line of the mountain on the downwind side and descend. Some moisture may be lost at the top of the climb through precipitation (this is now thought to be a secondary effect) and air descending the lee slope will warm at the DALR.

The result is a warm, dry wind blowing on the downwind side of the mountain. Temperature increases of 10°C can occur. The drying and warming of air in this way creates many dangerous mountain fires, and are most notable along the coast of California.

Föhn winds can occur over the east coast of Scotland with a south west wind over the Highlands.



The Föhn Effect

QUESTIONS

1. In central Europe, where are the greatest wind speeds?

    a. Tropopause level
    b. 5500m
    c. Where the air converges
    d. Above the Alps

2. Standing in the Northern Hemisphere, north of a polar frontal depression travelling west to east, the wind will

    a. Continually veer
    b. Continually back
    c. Back then veer
    d. Veer then back

3. ATC will only report wind as gusting if:

    a. Gust speeds exceeds mean speed by >15kts
    b. Gusts to over 25kts
    c. Gusts exceeds mean speed by 10kts
    d. Gusts to over 25kts

4. What is a land breeze?

    a. From land over water at night
    b. From land over sea by day
    c. From sea over land by night
    d. From sea over land by day

5. When heading South in the Southern Hemisphere you experience Starboard drift:

    a. You are flying towards a lower temperature
    b. You are flying away from a lower temperature
    c. You are flying towards a low pressure
    d. You are flying out of a high

6. The gradient wind is more than geostrophic wind around an anticyclone because the:

    a. centrifugal force is added to the pressure gradient
    b. centrifugal force opposes the pressure gradient
    c. effect of coriolis is added to friction
    d. coriolis effect opposes the centrifugal force

7. What is the Bora?

    a. Cold katabatic wind over the Adriatic
    b. Northerly wind blowing from the Mediterranean
    c. Warm anabatic wind blowing to the Mediterranean
    d. An anabatic wind in the Rockies

8. Flying from an area of low pressure in the Southern Hemisphere at low altitudes, where is the wind coming from?

   a. Right and slightly on the nose
   b. Left and slightly on the tail
   c. Left and slightly on the nose
   d. Right and slightly on the tail

9. What causes the Geostrophic wind to be stronger than the gradient wind around a low?

   a. Centrifugal force adds to the gradient force
   b. Centrifugal force opposes the gradient force
   c. Coriolis force adds to the gradient force
   d. Coriolis force opposes the centrifugal force

10. A METAR for Paris gave the surface wind at 260°/20. Wind at 2000ft is most likely to be:

   a. 260°/15
   b. 210°/30
   c. 290°/40
   d. 175°/15

11. A large pressure gradient is shown by:

   a. Closely spaced isobars - low temperature
   b. Distant spaced isobars - high temperature
   c. Close spaced isobars - strong winds
   d. Close spaced isobars - light winds

12. Where would you expect to find the strongest wind on the ground in temperate latitudes?

   a. In an area of Low pressure
   b. In an area of High pressure
   c. In the warm air between two fronts
   d. In a weak anticyclone

13. At a coastal airfield, with the runway parallel to the coastline. You are downwind over the sea with the runway to your right. On a warm summer afternoon, what would you expect the wind to be on finals?

   a. Crosswind from the right
   b. Headwind
   c. Tailwind
   d. Crosswind from the left

14. What causes wind?

   a. Difference in pressure
   b. Rotation of the earth
   c. Frontal systems
   d. Difference in temperature

15. If flying in the Alps with a Foehn effect from the south

a. Clouds will be covering the southern passes of the Alps
b. CAT on the northern side
c. Wind veering and gusting on the northern side
d. Convective weather on the southern passes of the Alps

16. Comparing the surface wind to the 3000ft wind

a. Surface wind veers and is less then the 3000ft wind
b. Surface wind blows along the isobars and is less than the 3000ft wind
c. Surface wind blows across the isobars and is less than the 3000ft wind
d. Both are the same

17. 90km/hr wind in kts is:

a. 70
b. 60
c. 50
d. 30

18. The Geostrophic Wind blows at your flight level in Northern Hemisphere the true altitude and indicated altitude remain constant, is the crosswind

a. From the left
b. From the right
c. No crosswind
d. Impossible to determine

19. With all other things being equal with a high and a low having constantly spaced circular isobars. Where is the wind the fastest?

a. Anticyclonic
b. Cyclonic
c. Where the isobars are closest together
d. Wherever the PGF is greatest.

20. Foehn winds are

a. Cold fall wind
b. Cold katabatic
c. Warm descending winds
d. Warm anabatic

21. What is the effect of a mountain valley wind?

a. it blows down a mountain to a valley at night
b. it blows down a mountain to a valley during the day
c. it blows from a valley up a mountain by day
d. it blows from a valley up a mountain at night

22. What is the difference between Gradient and Geostrophic winds?

a. Difference in temperatures
b. A lot of friction
c. Curved isobars and straight isobars
d. Different latitudes and densities

23. What prevents air from flowing directly from a high to a low pressure

a. Centripetal force
b. Centrifugal force
c. Pressure force
d. Coriolis force

24. What is the relationship between the 5000 ft wind and the surface wind in the southern hemisphere

a. surface winds are veered from the 5000ft and have the same speed
b. surface winds are backed from the 5000ft and have a slower speed
c. surface winds are veered from the 5000ft and have a slower speed
d. surface winds are backed from the 5000ft and have a faster speed

25. What is the relationship between the 2000 ft wind and the surface wind in the Northern Hemisphere

a. surface winds blow across isobars towards a high
b. surface winds blow parallel to isobars
c. surface winds blow across isobars towards a low
d. surface winds have laminar flow

26. Wind is caused by?

a. Mixing of fronts
b. Horizontal pressure difference
c. Earth rotation
d. Surface friction

27. For the same pressure gradient at 50°N, 60°N and 40°N, the geostrophic wind speed is?

a. Greatest at 60N
b. Least at 50N
c. Greatest at 40N
d. The same at all latitudes

28. The wind in the Northern Hemisphere at the surface and above the friction layer at 2000 ft would be?

a. Veered at the surface, veered above the friction layer
b. Backed at the surface, veered above the friction layer
c. Veered at the surface, backed above the friction layer
d. Backed at the surface, backed above the friction layer

29. Where are easterly and westerly jets found?

    a. Northern hemisphere only
    b. Southern hemisphere only
    c. Northern and southern hemisphere
    d. There are no easterly jets.

30. In a high pressure systems

    a. The winds tend to be stronger in the morning.
    b. The angle between the isobars and the wind direction is greatest in the afternoon.
    c. The winds tend to be stronger at night.
    d. The winds tend to be stronger in early afternoon.

31. An aircraft is flying East to West in the Northern Hemisphere. What is happening to his altitude?

    a. Flying into a headwind will decrease altitude
    b. If the wind is from the south, he will gain altitude
    c. If the wind is from the north, he will gain altitude
    d. Tailwind will increase altitude.

32. Where would an anemometer be placed?

    a. close to station, 2m above ground
    b. on the roof of the station
    c. 10m above aerodrome elevation on a mast
    d. next to the runway, 1m above ground

33. Which of the following is an example of a Foehn wind?

    a. Bora
    b. Harmattan
    c. Chinook
    d. Ghibli

34. Wind at altitude is usually given as …….. in ……..

    a. True, m/s
    b. Magnetic, m/s
    c. True, KT
    d. Magnetic, KT

35. If you fly with left drift in the Northern Hemisphere, what is happening to surface pressure?

    a. Increases
    b. Decreases
    c. Stays the same
    d. Cannot tell

ANSWERS

1.	A	11.	C	21.	A	31.	C
2.	B	12.	A	22.	C	32.	C
3.	C	13.	A	23.	D	33.	C
4.	A	14.	A	24.	C	34.	C
5.	B	15.	A	25.	C	35.	A
6.	A	16.	C	26.	B		
7.	A	17.	C	27.	C		
8.	C	18.	C	28.	B		
9.	B	19.	A	29.	A		
10.	C	20.	C	30.	D		

CHAPTER ELEVEN

UPPER WINDS

Contents

INTRODUCTION

Upper winds are caused by Pressure Gradient Force (PGF), Coriolis Force (CF) and Cyclostrophic Forces in the same way as the wind immediately above the friction layer.

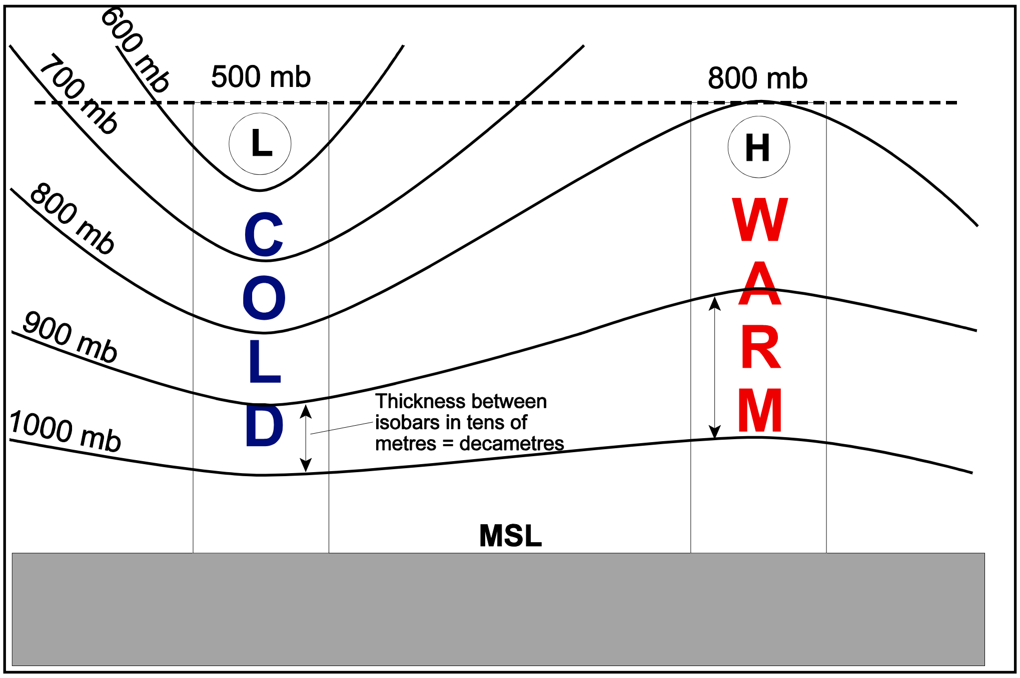
The winds are stronger because the density is less -

$$V = \frac{PGF}{2\,\Omega\,\varrho\,\sin\theta}$$

At 20,000 ft, for the same PGF, the wind speed is double the surface wind speed, since density is half that at the surface.

THERMAL WIND

The pressure changes that exist in the upper atmosphere that control our upper winds are directly related to the temperature differences between air masses. The figure below shows that the temperature difference between two air masses dictates the pressure we find in the upper atmosphere.



Pressure Changes at Height in Airmasses of Different Temperature

Pressure charts for heights above mean sea level could be drawn to find the upper winds, but it would be a labourious task and there are advantages in using a different system.

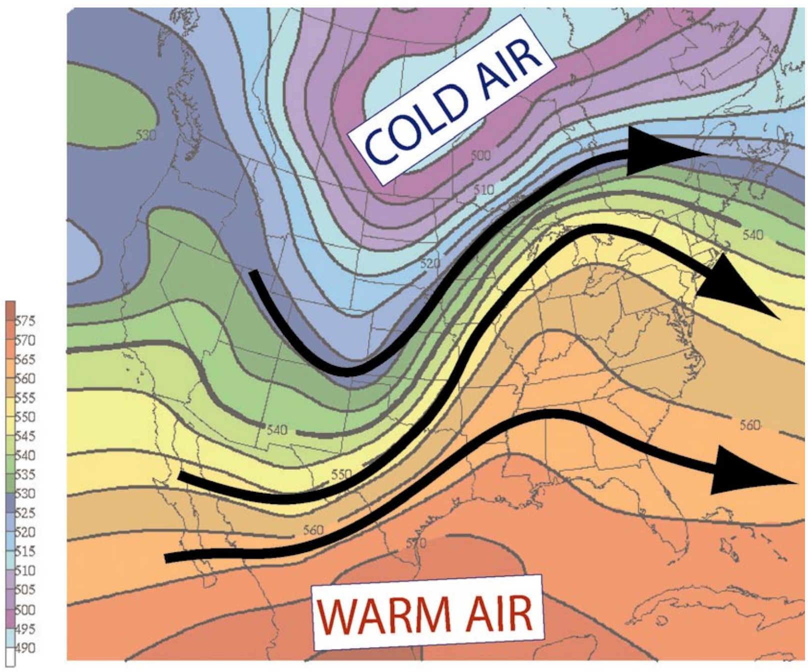
CONTOUR AND THICKNESS CHARTS

A Constant Pressure or Contour Chart is a chart where the pressure is constant everywhere. For example, as shown on the previous page we can see that the 800 mb pressure level varies with height. These heights are plotted as contour lines with the reference being MSL. The heights give us an indication of the distance that a pressure level is from MSL. If the pressure level is higher (as shown on the right hand side of the diagram) then we can assume a high pressure exists aloft. Conversely if the pressure level is much lower and the contour line shows a lower height (as shown on the left hand side of the diagram) then we can assume a low pressure is aloft.

A more useful chart that is similar in principle to the contour chart is the thickness chart. From the image at the beginning of the chapter you can see that a correlation exists between the thickness between two pressure levels, the temperature and upper air pressure. For example, warm air changes the pressure lapse rate such that it forces the pressure levels apart, increasing the thickness between the pressure levels and eventually increasing the pressure at any given height. Thus we can assume that the greater the thickness (vertical spacing) between the pressure levels, the higher the upper air pressure, and conversely, the smaller the thickness, the lower the upper air pressure.

Hopefully, having understood the concept, lets now look at a sample chart shown below. This chart is simply a plot of the vertical spacing between the 1000 hPa and the 500 hPa pressure levels. The thickness is measured in decametres or dams. These are tens of metres, so 530 dams is 5300 metres. Lines of equal thickness are then plotted on the chart. These lines are in fact contour lines but are more specially they are referred to as isohypses.

Notice that to the south, the warmer temperatures have made the thickness between the pressure levels greater, and the thickness is about 5,700 m between the 1000 hPa level and the 500 hPa level. This means that a higher upper air pressure is located to the south. Towards the north, where temperatures are lower, the thickness is less, at about 5000 m. This means that lower upper air pressure is located to the north. As a result of the pressure variation, the upper air will try to move north towards the lower pressure but it will be deflected to the right in the northern hemisphere, much like surface winds were.



Therefore, the upper winds blow parallel to the isohypses or contour lines such that in the northern hemisphere the cold air is on the left and in the southern hemisphere the cold air is to the right. The spacing of the thickness lines or contours will determine the wind speed, much like isobar spacing determined surface wind speed. Therefore, the closer together the lines are, the greater the pressure gradient will be and the faster the wind will become.

On most thickness charts the 540 line is highlighted as a thicker black line since this line is often used as a rule of thumb to indicate the division between rain and snow for low terrain. When there is precipitation expected in the area where the thickness is below 540 dams, it is generally likely to be snow. If the thickness is above 540 dam, it is usually rain (or sleet if the air next to the surface is below freezing).

By using contour charts and thickness charts, and by using computer models, the responsible meteorological authority can produce upper wind and temperature charts for various altitudes and these are shown below.

Charts are drawn for the following pressure levels:

700 hPa - 10,000 ft
500 hPa - 18,000 ft
300 hPa - 30,000 ft
250 hPa - 34,000 ft
200 hPa - 39,000 ft
100 hPa - 53,000 ft

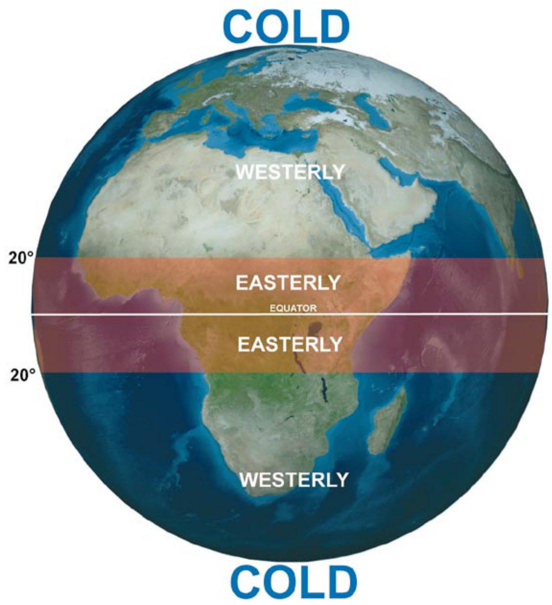
GENERAL UPPER WINDS

So far we have learnt a fundamental principle for understanding upper wind direction in relation to cold and warm air. This principle is actually a slight adaptation of Buys Ballots law. This upper wind principal states that:

"With your back to the upper wind, the cold air is to your left in the northern hemisphere and to your right in the southern hemisphere."

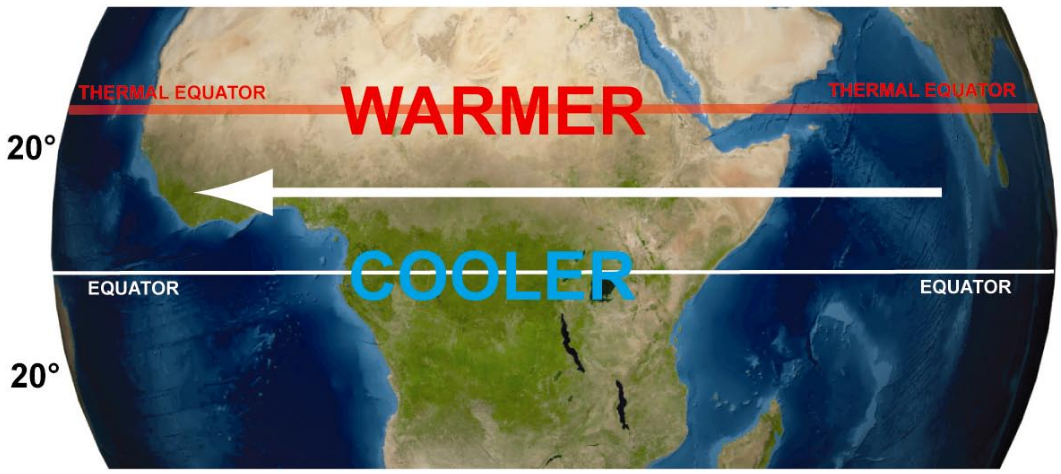
You can see this rule working in the previous diagram. In the Northern Hemisphere, with you back to the wind the cold air is to your left and the warmer air is to your right. We can use the principle we have just learnt to help create a simple model of the general upper wind patterns of the world.

Using the image below and focusing on the Northern Hemisphere you can see the cold air at the North Pole. As a result of the cold surface conditions we should expect a low pressure zone appearing at high altitude over the pole. This means that at high altitudes, air will be drawn pole-wards, but in the northern hemisphere this will be deflected to the right by coriolis force and the resultant wind will be westerly. Or more simply, just use the upper wind principle, with you back to the wind, the cold air is to your left.



The same exercise can be done in the Southern Hemisphere. Use the principle to help you see the general upper wind direction. Using the cold South Pole, with your back to the wind, the cold air is on the right. To make the cold air on the right, the upper wind must be westerly.

However, there is a band of easterlies around the equator which do not seem to follow the upper wind principle we have just studied. In actual fact, these winds do observe the principle, but to understand why, we must look more carefully at the temperature around the equator. Using the image below, this is for June & July, notice that the hottest place on the earth is theoretically at 23.5°N. This means that the equator, by comparison, is a little cooler. Use the upper wind principle in the region between the real equator and the heat equator. Here, with your back to the wind, the cooler air must be on the left. For that to occur the wind must be an easterly.

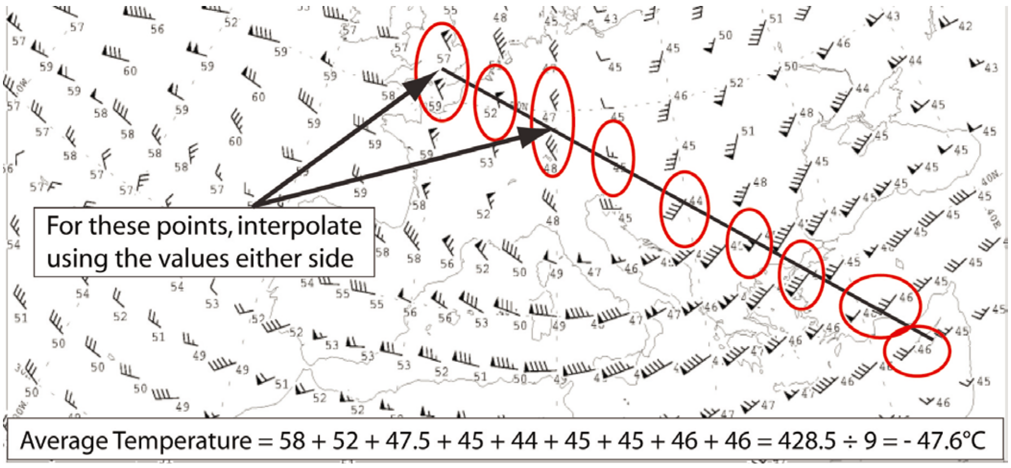


Repeat the exercise but for December using the image below. In the southern hemisphere, with your back to the wind the cooler air is to your right. For this to be true the wind must be easterly.

In summary then, most of the upper winds are westerly, except for a narrow band around the equator which are easterly. These tropical easterlies exist between the real equator and the thermal equator.

CALCULATING AVERAGE UPPER WIND ALONG ROUTE

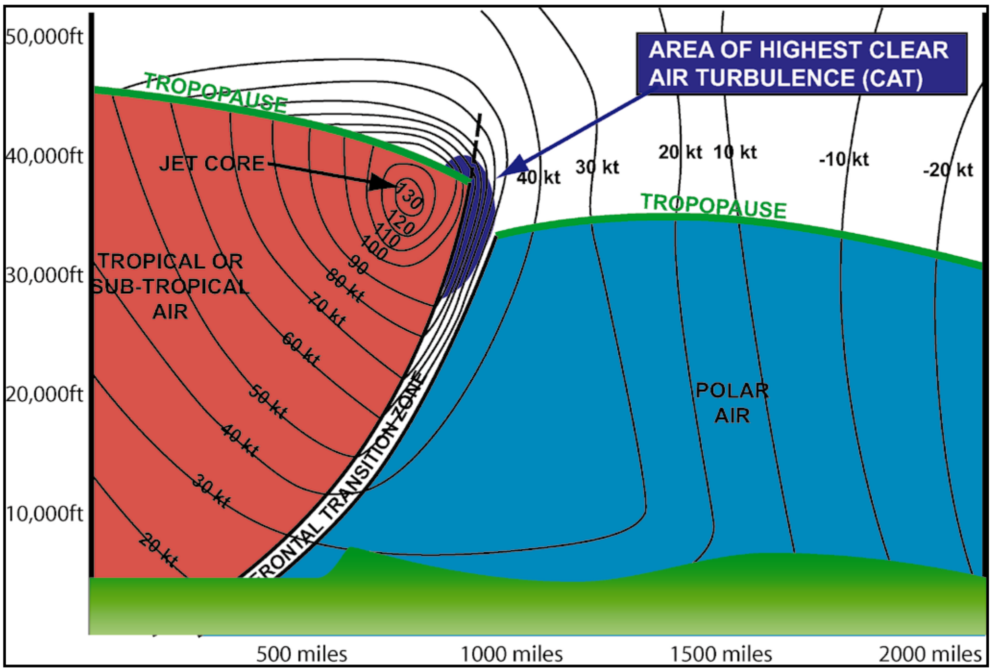
The image shown below is a typical upper wind and temperature chart, in the case below, this is for FL390, although there are many others for different levels. Looking at the image you can see the wind direction and speed is coded using the standard coding which you learnt at the start of the wind chapter. Next to each wind symbol you will see an air temperature. This is the temperature in negative values. If the temperature is above zero the value will be preceded buy a plus sign (+).



You can use such charts for various planning purposes, namely to find the average wind and temperature along your route, like the example route shown. To do this, take the closest points of the wind and temperature information along your track (or even either side of track if there is none directly on your track), interpolating if you have to. Examples of such points are shown by the red circles. To find the average temperature, simply add up the temperatures at each of your sample points and divide by the number of samples you chose. You can repeat this exercise for the wind speed and wind direction. A word of caution. There will be occasions where your flight level does not have a corresponding chart, in such cases, use the nearest chart to your level and adjust the values as required, for example, make the temperature warmer if your flight level is less than the level of the chart.

JET STREAMS

As we go higher in the troposphere, the density decreases and the temperature effect overwhelms the pressure effect, hence winds become progressively westerly with height. The strongest winds are to be found just below the tropopause and where these winds exceed 60 kts they are termed jet streams. For examination purposes we assume a jet stream to be about 2000 miles long, 200 miles wide and 2 miles deep. This gives a width to length ratio of 1:10 and a depth to width ratio of 1:100. Speeds of over 300 kts have been recorded, though these are rare.



A Vertical Cross Section Through a Jetstream.

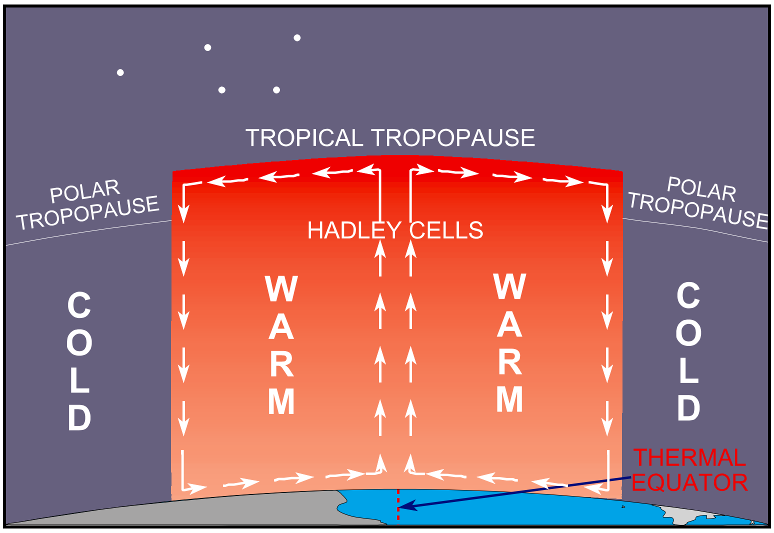
CAUSES

Jetstreams are caused by large mean temperature differences in the horizontal, i.e. large thermal components.

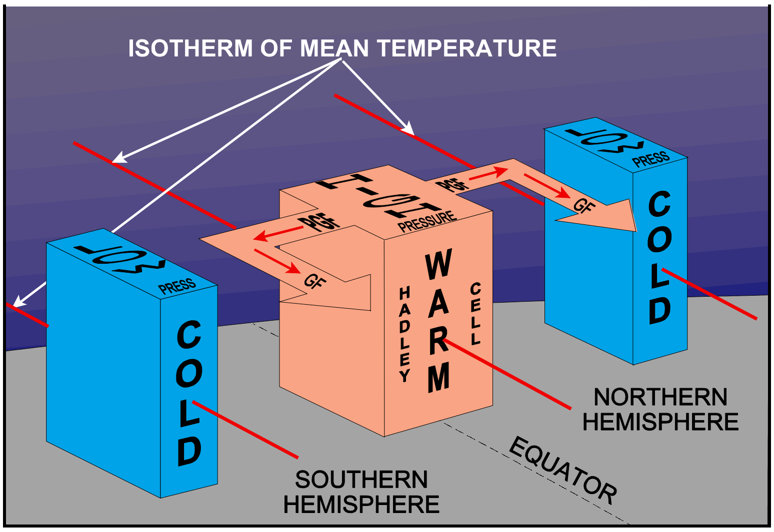
LOCATIONS

There are two main locations:

- Sub tropical jetsteams form in the area of the sub-tropical anti-cyclones. They are more or less permanent but move seasonally with the sub-tropical highs. They occur in the latitude bands 25° to 40° in winter and 40° to 45° in summer. The jet core is at the 200 hPa level.

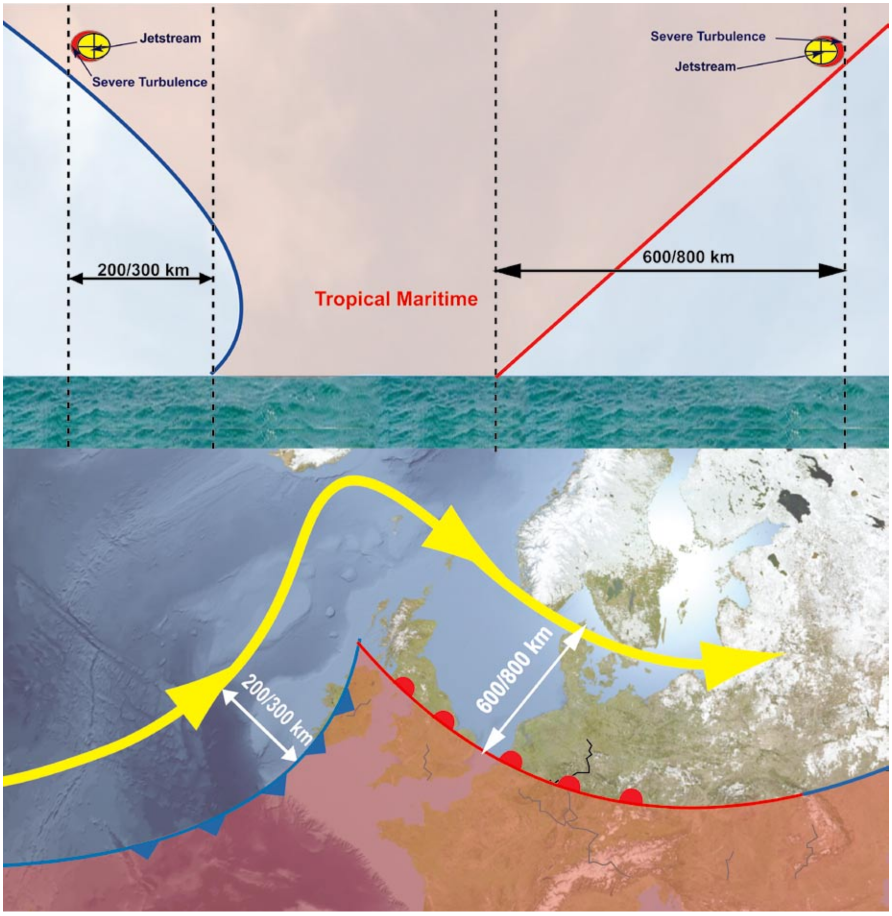


Sub-Tropical Jetstreams.



Sub-Tropical Jetstreams.

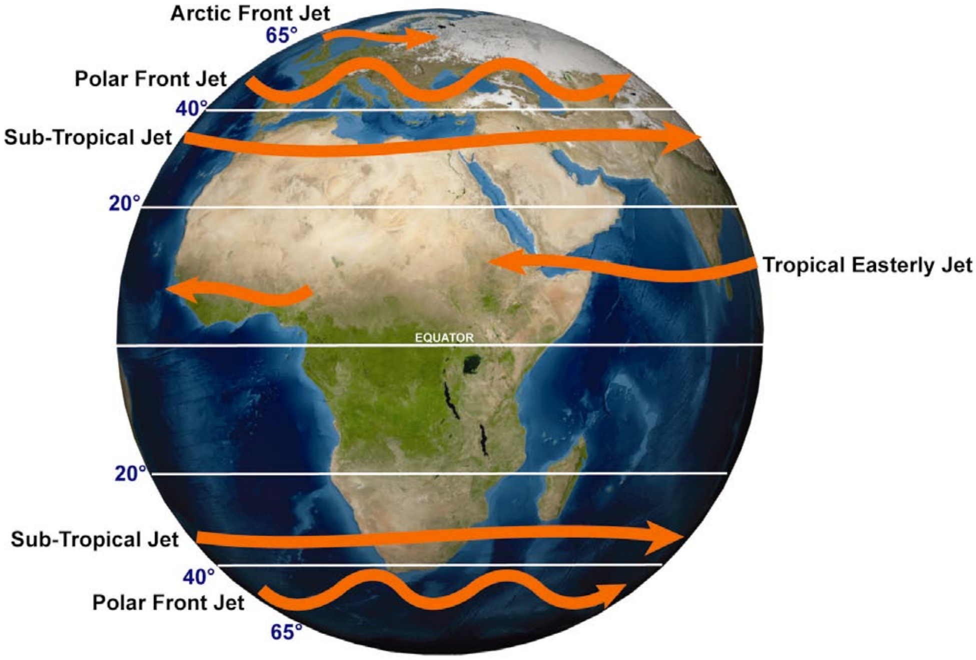
- Polar front jetstreams form in the polar front region in both hemispheres 40° to 65° N and around 50° S and near any front which is separate from the polar front. The jetstreams in a polar front depression lie parallel to the fronts. They are located in the warm air.



Polar Front Jetstream

- Tropical Easterly Jet (Equatorial Easterly Jet). Strong easterlies that occur in the northern hemisphere's summer between 10° and 20° north, where the contrast between intensely heated central Asian plateaux and upper air further south is greatest. It runs from South China Sea westwards across Southern India, Ethiopia and the sub Sahara. Typically heights circa 150hPa (13-14 km; 45,000 ft).

- Arctic Jet Stream found between the boundary of arctic air and polar air. Typically in winter at around 60° north but in the USA around 45° to 50° north. The core varies between 300 and 400hPa. It is a transient feature found over large continents during arctic air outbreaks.



Location of Jetstreams

Note: *This general disposition of winds will move some 15° South in January and some 15° North in July.*

- Local Jets may arise due to local thermal or dynamic circumstances e.g. the Somali.
- Other Jets. 'Jets' as opposed to Jet Streams may exist as narrow, fast currents of air at low level.

DIRECTION AND SPEED

The direction of jet streams is generally westerly, maximum speeds occur near the tropopause, 200 kts have been recorded in Europe/N Atlantic and 300 kts in Asia.

In equatorial regions there are however some easterly jets.

CLEAR AIR TURBULENCE

Clear air turbulence (CAT). occurs around the boundaries of jet streams because of the large horizontal and vertical windshears. It is strongest near to, or just below, the jet axis on the cold air (low pressure) side with a secondary area above the axis.

MOVEMENT

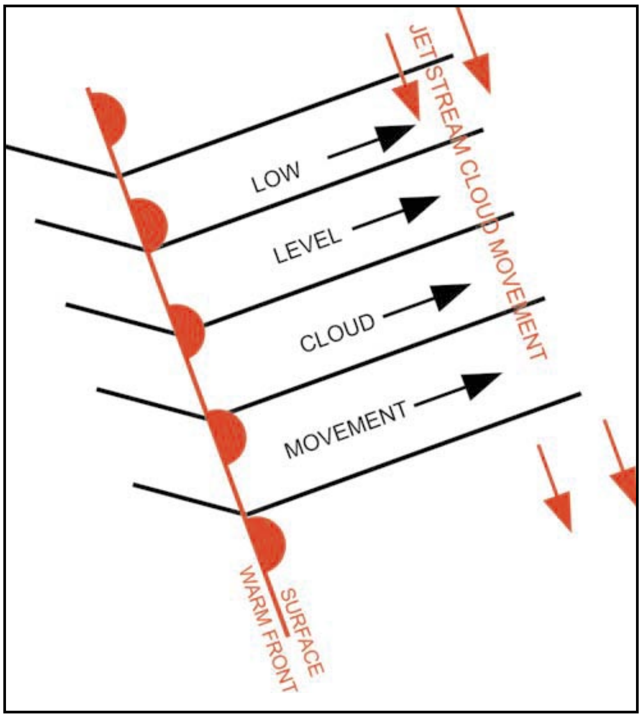
As with most other weather phenomena, Jet streams move with the sun.

Sub-tropical jets, based on Hadley Cells, will move north in the northern summer as the heat equator moves north and then south in the northern winter.

Polar Front Jets in the northern hemisphere will move north (and decrease in speed) as the Polar Front moves north in summer. During the winter the Polar Front moves south and because of the greater temperature difference, the speed will increase.

RECOGNITION

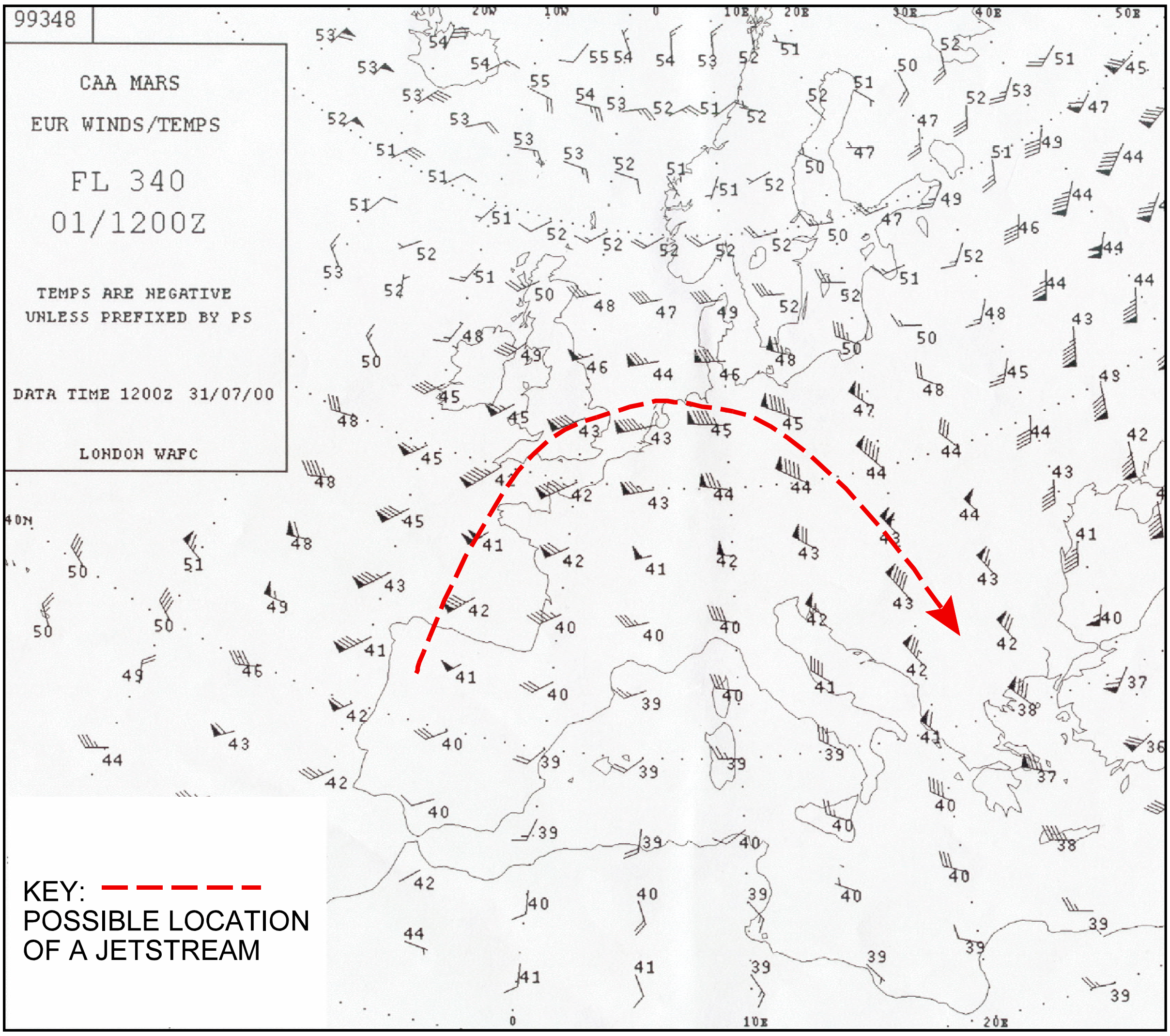
- From the ground, when the cloud amounts allow, jets may be recognised by wind blown wisps of CIRRUS cloud blowing at right angles to the clouds at lower levels.



Recognition by Clouds

- In the Air, the presence of a jet will be difficult to SEE, but temperature differences, increases in windspeed, drift and clear air turbulence are all evidence of jet streams.

- On Charts, jets may be picked out quite easily by inspection of Upperwind Charts and more graphically perhaps by looking at a Significant Weather Chart.

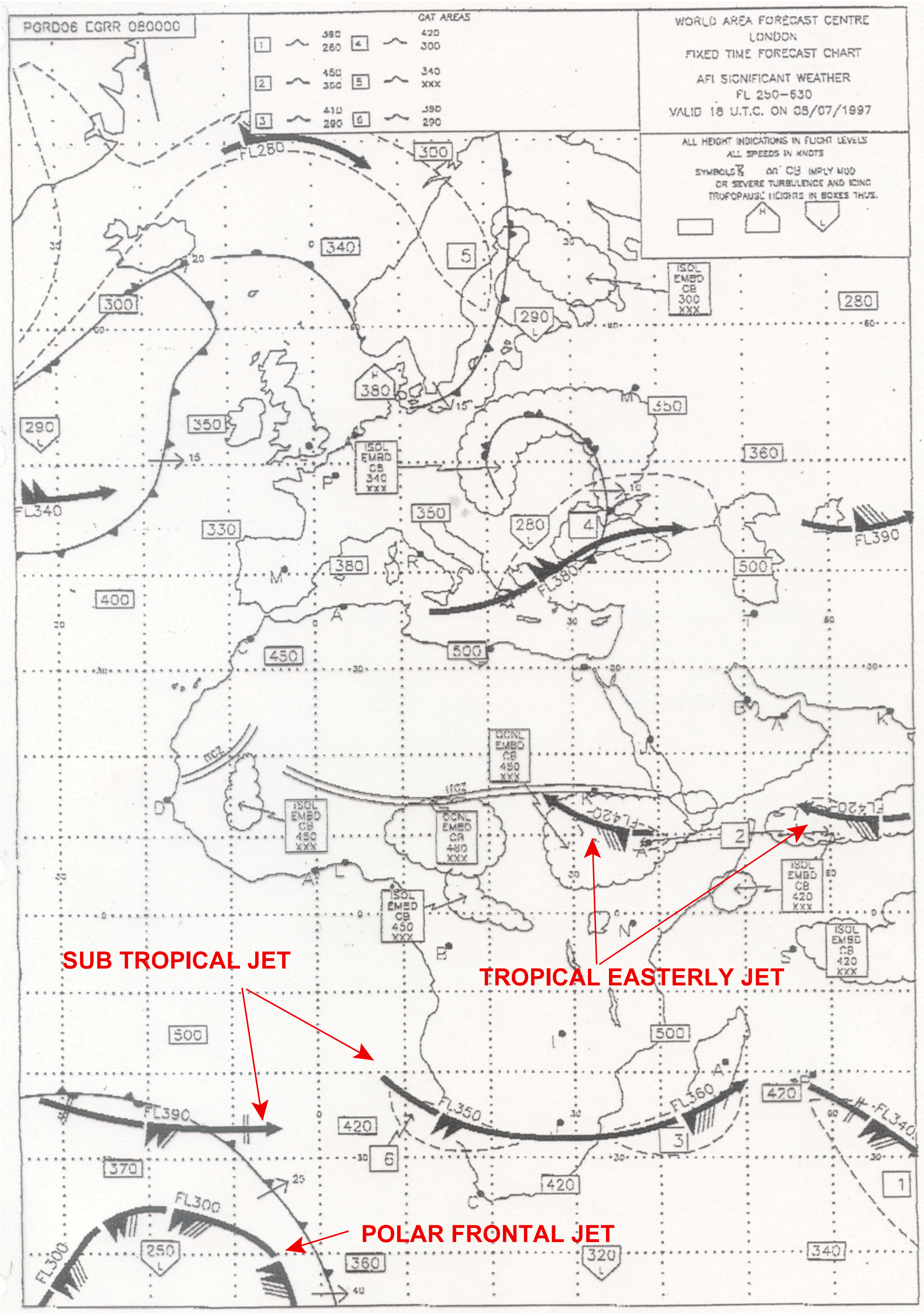


An upper wind and temperature chart for FL340

FORECASTING

The forecasting of jet streams is largely a matter of producing charts from upper air soundings by Radio Sonde. Thickness charts were mentioned earlier as a means of establishing thermal wind patterns, but for forecasting, meteorologists use contour charts.

In-flight reports of temperature and wind velocities are a useful confirmation of upper air soundings and over oceans (and deserts) are vital supplements.



Jet Streams on Sig/Wx Chart

QUESTIONS

1. How do you recognise high level jet streams and associated CAT?

    a. High pressure centre at high level
    b. Streaks of Cirrus
    c. High level dust
    d. Lenticularis

2. What type of jet stream blows constantly through the northern hemisphere?

    a. Arctic
    b. Equatorial
    c. Polar night
    d. Sub tropical

3. In central Europe, where are the greatest wind speeds?

    a. Tropopause level
    b. 5500m
    c. Where the air converges
    d. Above the Alps

4. The Arctic Jet core is at:

    a. 20,000ft
    b. 30,000ft
    c. 40,000ft
    d. 50,000ft

5. FL180, Northern Hemisphere with a wind from the left, what can you say about temperature with a heading of 360°?

    a. Not possible to tell without a pressure
    b. Increases from South to North
    c. Increases from North to South
    d. Nothing

6. When heading South in the Southern Hemisphere you experience Starboard drift:

    a. You are flying towards a lower temperature
    b. You are flying away from a lower temperature
    c. You are flying towards a low pressure
    d. You are flying out of a high

7. With a polar front jet stream (PFJ), the area with the highest probability of turbulence in the Southern Hemisphere is:

    a. In the jet core
    b. Above the jet core in the boundary of the warm and cold air
    c. Looking downstream, on your left hand side
    d. Looking downstream, on your right hand side

8. Contours on a weather chart indicate:

   a. Heights of pressure levels
   b. Distance between pressure levels
   c. Thickness between pressure levels
   d. Height of ground

9. If an Isohypse on a surface pressure chart of 500hPa shows a figure of 522, this indicates

   a. Topography of 522m above MSL
   b. Topography of 522 decametres above MSL
   c. Pressure is 522mb
   d. A low surface pressure

10. The polar front jet stream in summer compared to winter in the Northern Hemisphere moves

   a. North and decreases in strength
   b. North and increases in strength
   c. South and decreases in strength
   d. South and increases in strength

11. A jet stream with a wind speed of 350kts is

   a. Impossible
   b. Possible but very rare
   c. Possible in polar areas
   d. Common

12. If you fly at right angles to a jet stream in Europe with a decreasing outside air temperature, you will experience

   a. Increasing headwind
   b. Increasing tailwind
   c. Wind from the left
   d. Wind from the right

13. On a particular day the PFJ runs north to south in the Northern Hemisphere.

   a. The temperature gradient runs north to south below the jet core
   b. The temperature gradient runs north to south above the jet core
   c. The polar air is east of the jet above the core
   d. The polar air is below the jet to the east

14. Flying 2500 ft below core of jet, with temperature increasing in the Southern Hemisphere, where does the wind come from?

   a. Head
   b. Tail
   c. Left
   d. Right

15. When flying from south to north in the Southern Hemisphere, you cross over the Polar Front Jet. What happens to the temperature?

a. it increases
b. it decreases
c. it remains the same
d. impossible to determine

16. The core of a jet stream is located

a. at the level where temperature change with altitude becomes little or nil and the pressure surface is at maximum slope
b. in the warm air where the pressure surface is horizontal
c. in the warm air and directly beneath at the surface
d. in cold air

17. What is the ratio of height to width in a typical jet stream?

a. 1:10
b. 1:100
c. 1:1000
d. 1:10000

18. When and where does an Easterly jet stream occur?

a. All year through the Equator
b. In summer from SE Asia through S. India to Central Africa
c. In summer from the Middle East through N. Africa and the Mediterranean to S. Spain
d. In winter in Arctic Russia

19. From the pre-flight briefing you know a jet stream is at 31,000 ft whilst you are at FL270. You experience moderate C.A.T. What would be the best course of action?

a. Stay level
b. Descend
c. Climb
d. Reduce speed

20. What is most different about the Equatorial Easterly jet stream?

a. Its height
b. Its length
c. Its direction
d. Its speed

21. Where are easterly and westerly jets found?

a. Northern hemisphere only
b. Southern hemisphere only
c. Northern and southern hemisphere
d. There are no easterly jets

22. Wind at altitude is usually given as .... in ....

a. True, m/s
b. Magnetic, m/s
c. True, Kts
d. Magnetic, Kts

23. Under which of the following circumstances is the most severe CAT likely to be experienced?

a. A westerly jet stream at low altitude in the summer
b. A curved jet stream near a deep trough
c. A straight jet stream near a low pressure area
d. A jet stream where there is a large spacing between the isotherms

ANSWERS

1	B	11	B	21	A
2	D	12	C	22	C
3	A	13	D	23	B
4	A	14	C		
5	C	15	A		
6	B	16	A		
7	D	17	B		
8	A	18	B		
9	B	19	B		
10	A	20	C		

CHAPTER TWELVE

CLOUDS

Contents

INTRODUCTION

Clouds are signposts in the sky which indicate to the pilot possible weather problems, such as:

- Turbulence
- Poor Visibility
- Precipitation
- Icing

CLOUD AMOUNT

Cloud amounts are reported in OKTAS (eigths). It is assumed that the sky is divided into 8 equal parts and the total cloud amount is reported by an assessment of the number of eighths of the sky covered by cloud.

FEW	1 to 2 OKTAS
SCT	3 to 4 OKTAS
BKN	5 to 7 OKTAS
OVC	8 OKTAS

CLOUD BASE

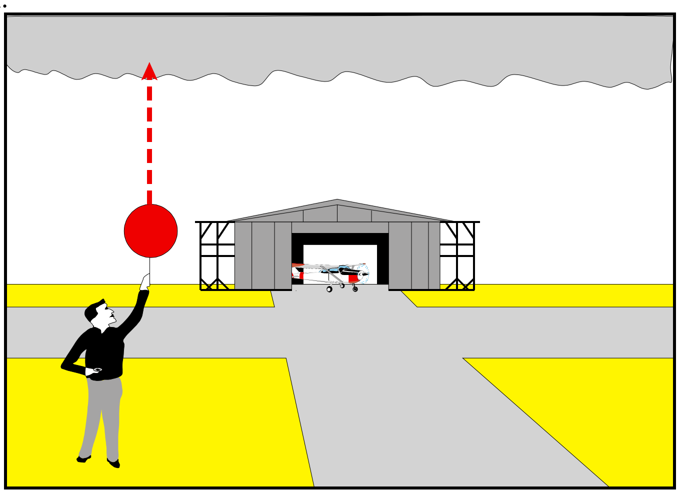
"That lowest zone in which the type of obscuration perceptibly changes from that corresponding to clear air haze to that corresponding to water droplets or ice crystals." The cloud base is the height of the base of the cloud above ground - above official aerodrome level.

CLOUD CEILING

"The height above aerodrome level of the lowest layer of cloud of more than 4 oktas" .

MEASUREMENT OF CLOUD BASE

- By day a balloon with a known rate of ascent is released and the time between release and the disappearance of the balloon into cloud is noted. From this cloud base can be calculated.



Finding the Cloudbase by Releasing a Balloon with a Known Rate of Ascent.

➢ By night: An Alidade is positioned a known distance from a searchlight and is used to measure the angle above the horizontal of the searchlight glow on the base of the cloud. The height of the cloud base is then calculated by trigonometry.


Finding the Height of the Cloud Base.

THE CLOUD BASE RECORDER

A cloud base recorder or ceilometer is a device that uses a laser or other light source to determine the height of a cloud base. There are several types of ceilometers depending on whether a normal light source or a laser light source is used.

➢ The first type of ceilometer uses a normal light source. There a several versions of such ceilometers. The optical drum ceilometer consists essentially of a projector, a detector, and a recorder. The projector emits an intense beam of light into the sky. The detector, located at a fixed distance from the projector, uses a photoelectric cell to detect the projected light when it is reflected from clouds. In the fixed-beam ceilometer, the light is beamed vertically into the sky by the projector and the detector is aligned at various angles to intercept the reflected light; in the rotating-beam ceilometer, the detector is positioned vertically and the light projected at various angles. In either case, trigonometry is used to determine the altitude of the clouds reflecting the light from a knowledge of the angle at which the light is detected and the distance between the projector and detector. The recorder is calibrated to indicate cloud height directly.

A Laser Ceilometer

- A laser ceilometer consists of a vertically pointing laser and a receiver house in the same instrument assembly, as shown above. It determines the height by measuring the time required for a pulse of light to be scattered back from the cloud base. The laser ceilometer is more accurate and more reliable than the other types of recorders and as such it is the main type of recorder currently in use.

MEASUREMENT OF CLOUD TOPS

The height of cloud tops is obviously not as easy to measure as that of the cloud base. Meteorologists may be able to make a visual assessment, if conditions permit, but more usually they will use RADAR or employ aircraft observation.

CLOUD MOVEMENT

Meteorological stations measure the movement of clouds by means of a Nephoscope. This measures the angular speed of movement of cloud and if the base height is known, the speed of movement may be calculated. A Besson Nephoscope is shown below.

CLOUD CLASSIFICATION

Classification of cloud type is based, primarily, on the shape, or form of the cloud. The basic forms of cloud are stratiform, cumuliform and cirriform.

Stratiform cloud is a layered type of cloud of considerable horizontal extent, but little vertical extent.

Stratiform Cloud

Cumuliform cloud is heaped cloud, displaying a marked vertical extent, of greater or lesser degree.

Cumuliform Cloud

Cirriform cloud is a cloud which is fibrous, wispy or hair-like in appearance. This type of cloud is found only at high levels in the Troposphere.

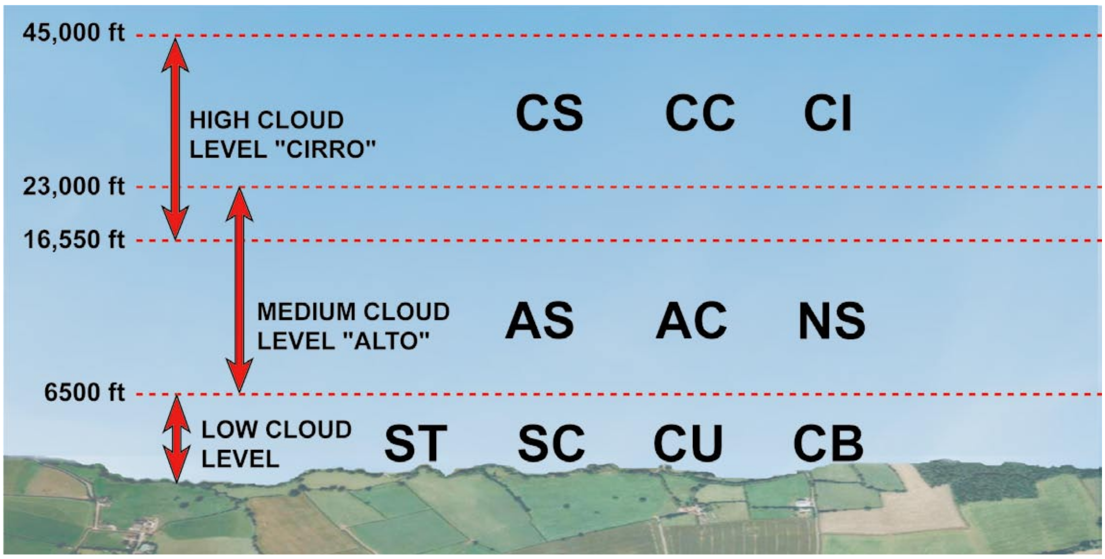
Clouds are also identified by reference to the height at which they occur. There are 3 distinct cloud levels within the troposphere.

- **Low-level clouds** are those which are found between the surface and 6,500 ft. These clouds may be stratus, stratocumulus, cumulus and cumulonimbus. (The suffix nimbus implies "rain bearing".) However, cumulus and cumulonimbus will have significant vertical development and will extend from low-level to higher levels. Cumulonimbus clouds may even extend up to the Tropopause.

- **Medium-level clouds** are found between 6,500 feet and 23,000 feet.

  The names of medium-level clouds are characterised by the prefix "alto-": such as altostratus and altocumulus. Nimbostratus is also a medium-level cloud, but it may also extend into both the lower and upper levels of the atmosphere.

- **High-level clouds** are generally found between 16,500 feet and the Tropopause. The names of high-level clouds are prefixed by "cirro-": cirrostratus, cirrocumulus, and cirrus. (Latin cirrus means curl.)



Cloud Classification

Stratus (St)
Stratus (from Latin stratum, meaning strewn) is generally a grey, layered cloud with a fairly uniform base, which may produce drizzle, or light snow. Stratus cloud is no more than 1,000 - 1 500 ft thick, and is often much thinner. Stratus is usually the lowest of all cloud types. The main hazard associated with stratus is that it often covers high ground, concealing hill tops from pilots and producing hill fog for hikers. When stratus is at its thinnest, the sun can be clearly seen through the stratus layer. Usually the cloud base is between the surface and 2,000 ft above ground level.

Nimbostratus (Ns)
Nimbostratus is a dense, dark-grey, rain-bearing, stratiform cloud, producing extensive and long-lasting continuous precipitation. Usually the cloud base is between the surface and 10,000ft above ground level.

Cumulus (Cu)
Cumulus cloud is the most common form of convective cloud, being classified as heaped cloud, from Latin cumulare meaning to heap up. For glider pilots, a developing cumulus is regarded as a reliable indication of the presence of thermal upcurrents which, if skilfully exploited, can enable the glider to gain height. Pilots of light aircraft, on the other hand, will note that, on a day when the sky is peppered with fine-weather cumulus flight below cloud base is turbulent, whereas, above the cloud tops, the air is likely to be very smooth.

A developed cumulus cloud is generally dense, with sharp outlines. As it continues to develop vertically, a cumulus cloud forms mounds, domes or towers, of which the upper parts often resemble the head of a cauliflower. The sunlit parts of cumulus clouds are brilliant white, but their bases are relatively dark.

Cumulus clouds of small vertical development can appear benign, but they can grow rapidly, when the atmosphere is unstable, with no upper-air inversion, and may develop into cumulonimbus clouds, with their tops reaching the Tropopause. Usually the cloud base is between 1,000 ft and 5,000 ft but this increases as the surface temperature increases.

Stratocumulus (Sc)

Stratocumulus cloud is probably the most common form of cloud in the skies of the United Kingdom. It appears grey, or whitish, but usually always has distinct dark parts. Stratocumulus can be seen as patches, or in a continuous layer. Stratocumulus is usually no more than 2,000 to 3,000 feet thick, but may become 5,000 to 6,000 ft deep in certain conditions. Usually the cloud base is between 1,000 ft and 4,500 ft.

Cumulonimbus (Cb)

Cumulonimbus clouds are clouds that the aviator should avoid. Cumulonimbus clouds consist of vigorous convective cloud cells of great vertical extent. In the later stages of their development, cumulonimbus clouds display a characteristic anvil top, as the upper part of the cloud hits the Tropopause. The upper parts of a cumulonimbus cloud often consist of super-cooled water droplets and ice crystals. The base of cumulonimbus clouds is often very dark, with ragged cloud appearing beneath the main cloud cell. Usually the cloud base is between 2,000 ft and 5,000 ft.

The risk of icing and turbulence associated with cumulonimbus is always severe. Within cumulonimbus, very strong upcurrents and downdraughts are continually at play, producing severe precipitation in the form of heavy showers of rain and hail. Other hazards associated with cumulonimbus are lightning and static discharge, which may lead to airframe damage, erroneous instrument readings and squally winds.

Moist unstable air throughout a deep layer of the atmosphere is necessary for the formation of cumulonimbus cloud. A trigger mechanism is also required to kick off the convection process associated with isolated, heat-type cumulonimbus.

Altocumulus (Ac)

Altocumulus takes the form of speckled white or grey cloud. The patches of cloud appear as rounded masses of fibrous or diffuse aspect. Altocumulus usually occur between 8,000 and 15,000 ft with tops on some occasions as high as 23,000 ft. Usually the cloud base is between 6,500 ft and 20,000 ft.

There are two forms of altocumulus which are of particular significance, namely: altocumulus lenticularis and altocumulus castellanus.

Altocumulus Lenticularis

Altocumulus Castellanus

Altocumulus lenticularis, also known as lenticular cloud, is found downwind of mountainous or hilly areas, and is indicative of the presence of mountain wave activity. Because of its position downwind of high ground, moderate or even severe turbulence may be found beneath altocumulus lenticularis. However, the air in the lenticular clouds, themselves, is always smooth.

Altocumulus castellanus is a "bubbly" form of normal altocumulus. The "towers" that form in altocumulus castellanus are like battlements on castles, hence the name. These clouds are significant because they often herald a change to showery, thundery weather and are a feature of summer weather in temperate latitudes.

Cumulonimbus clouds sometimes develop from altocumulus castellanus, when instability is present at medium levels of the Troposphere.

Altostratus (As)
Altostratus is a grey or bluish sheet, or layer of cloud, which can be fibrous or uniform in appearance. Sometimes, altostratus covers the whole sky, giving a "ground glass" effect around the Sun or Moon.

Altostratus is usually found between 8,000 and 15,000 feet and can be from around 2,000 to 8,000 feet thick. But despite its thickness, altostratus is not a dense cloud, and the sun is usually perceptible through the cloud layer.

Cirrus (Ci)
Cirrus (from Latin cirrus, meaning curl) is the highest of all the cloud types and is composed entirely of ice crystals. Cirrus clouds take the form of white delicate filaments, in patches or narrow bands. They may also be described as fibrous or hair-like. Cirrus clouds can be found between 16,500 and 45,000 ft. They often herald the approach of a warm front.

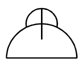
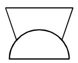
Cirrostratus (Cs)
Cirrostratus is a transparent, whitish cloud-veil of fibrous or smooth appearance, totally or partially covering the sky.

Cirrostratus is made up of ice crystals, and lies between 18,000 and 45,000 ft. Cirrostratus is a further warning of an approaching frontal system, and, like altostratus, may cause the Sun and Moon to appear with a halo.

Cirrocumulus (Cc)
Cirrocumulus is probably the cloud which is least often seen in the sky. Cirrocumulus is a thin, white and patchy layer of cloud, with ripples, more or less regularly arranged. Cirrocumulus consists of ice crystals and is generally found between 20,000 and 30,000 feet.

NAME & SYMBOL	HEIGHT RANGE (TEMPERATURE)	COMPOSITION	TURBULENCE	ICING	VISIBILITY	SIGNIFICANCE
CIRRUS Ci	16,500 to 45,000 FT (5 - 13Kms+)	Ice Crystals	NIL	NIL	QUITE GOOD (1000mtrs+)	400 to 600nm Ahead of Warm Front
CIRRO- STRATUS Cs	16,500 to 45,000 FT (5 - 13Kms+)	Ice Crystals	NIL	NIL	QUITE GOOD (1000mtrs+)	300 to 500nm Ahead of Warm Front
CIRRO- CUMULUS Cc	16,500 to 45,000 FT (5 - 13Kms+)	Ice Crystals	NIL	NIL	QUITE GOOD (1000mtrs+)	300 to 500nm Ahead of Warm Front

NAME & SYMBOL	HEIGHT RANGE (TEMPERATURE LATITUDE)	COMPOSITION	TURBULENCE	ICING	VISIBILITY	SIGNIFICANCE
ALTO-CUMULUS Ac	6,500 to 23,000FT (2 - 7kms)	Water Droplets and Ice Crystals	Light to Moderate	Light to Moderate	FAIR (20 - 1000mtrs)	Sometimes indicates the approach of a Warm Front
ALTO-STRATUS As	6,500 to 23,000 FT (2 - 7kms)	Water Droplets and Ice Crystals	Light to Moderate	Light to Moderate	FAIR (20 - 1000mtrs)	200nm ahead of a Warm Front often merges into Nimbo-stratus behind and below
NIMBO-STRATUS Ns	Base Ground Level to 6,500 Ft - Maybe 10,000 to 15,000 Ft Thick, Merging Into As above	Mainly Water Droplets, but Ice Crystals at Medium Levels	Moderate to Severe	Moderate to Severe	POOR (10 - 20mtrs)	Warm Front adjacent

NAME & SYMBOL	HEIGHT RANGE (TEMPERATURE LATITUDES)	COMPOSITION	TURBULENCE	ICING	VISIBILITY	SIGNIFICANCE
STRATO-CUMULUS 	Ground Level to 6,500 FT (0 - 5Kms)	Water Droplets	Light to Moderate	Light to Moderate	Moderate to Poor (10 - 30mtrs)	Turbulence Cloud. Often Associated with Cu Cloud
STRATUS	Ground Level to 6,500FT (0 - 5Kms)	Water Droplets	Nil	Occasional Light to Moderate	Moderate to Poor (10 - 30mtrs)	Turbulence Cloud. Warm Sector, Risen Fog. Light Pptn
CUMULUS Cu FAIR WEATHER   LARGE	Ground Level to 25,000FT (0 - 7Kms+)	Water Droplets and Ice Crystals	Moderate to Severe	Moderate to Severe	Poor (< 20mtrs, Occ. < 10mtrs)	Instability Cloud. Cold Front, Large Cu May develop Into Cb
CUMULO NIMBUS Cb  WITHOUT ANVIL  WITH ANVIL	Ground Level to 45,000 FT (0 - 13Kms+)	Water Droplets and Ice Crystals	Moderate to Severe Occ. Very Severe	Moderate to Severe	Poor (< 20mtrs, Occ. < 10mtrs)	Instability Cloud. Thunderstorms, Lightning, Hail

NAME & SYMBOL	HEIGHT RANGE	COMPOSITION	SIGNIFICANCE
ALTOCUMULUS CASTELLANUS Acc	6,500 to 23,000 FT (2 - 7Kms)	Water Droplets and Ice Crystals	Indicate **Unstable** Air At Higher Levels, possibly developing Cb. Returning Polar Maritime Airmass
ALTOCUMULUS LENTICULARIS	6,500 TO 23,000 FT (2 - 7Kms)	Water Droplets and Ice Crystals	Indication of Standing (Mountain) Waves. May indicate Severe Turbulence
NACREOUS CLOUD	70,000 TO 100,000FT	Probably Ice Crystals and Dust	Otherwise known as 'Mother of Pearl' Cloud. Occasionally seen in High Latitudes in Winter around Sunset.
NOCTILUCENT CLOUD	75-90Km (ABOVE 200,00 FT)	Probably Minute Ice Crystals	Mostly observed between 50° & 65° Latitude during Summer Months with the Sun between 6° & 10° below the horizon. Looks Rather Like Ci Cloud. A **Mesosphere** Cloud

CHAPTER THIRTEEN

CLOUD FORMATION and PRECIPITATION

Contents

VERTICAL MOTION

Cloud is formed by air being lifted and cooled adiabatically until the water vapour condenses out as water droplets. The height at which this occurs is called the condensation level. It is also the height of the cloud base.

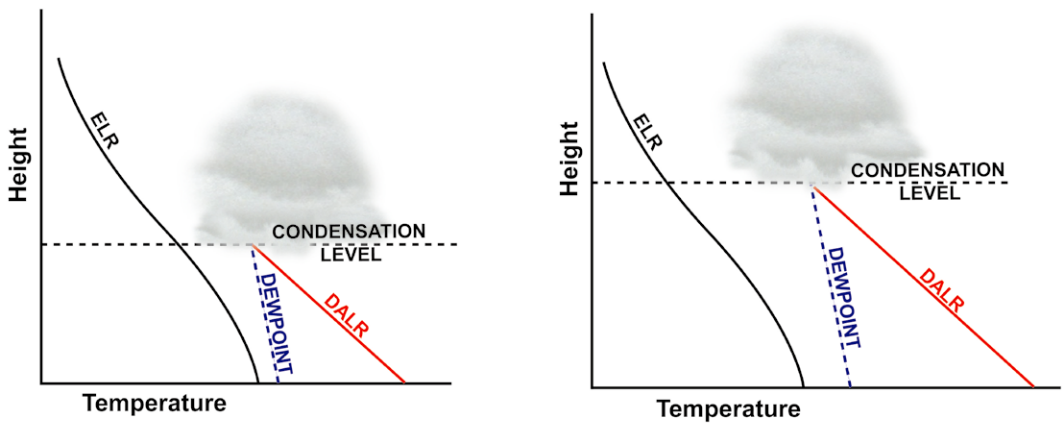
The means whereby the initial lifting of the air occurs are as follows:

- Turbulence.
- Orographic Uplift.
- Convection.
- Slow, widespread ascent (frontal uplift).
- Convergence

Note: The lifting processes above are strictly all 'convection'; process c.is free convection, the rest are forced convection.

CONDENSATION LEVEL

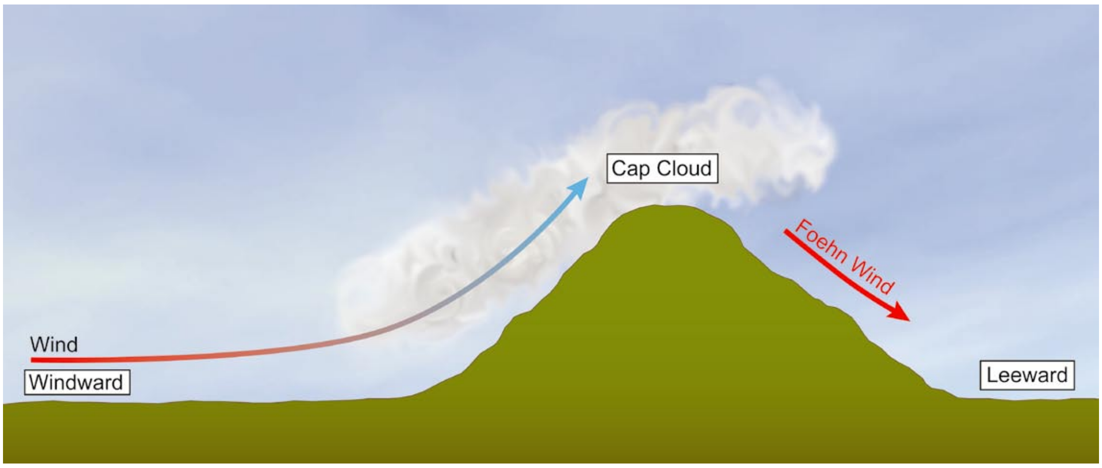
If an unsaturated parcel of air rises (either because it's buoyant or it is forced to do so) it will cool adiabatically. This cooling increases the relative humidity of the parcel of air until eventually the temperature of parcel has reached dew point temperature and the relative humidity will be 100%. At this point the air parcel is saturated and further ascent and cooling will cause condensation and cloud to form. The level in the atmosphere at which this happens is called the condensation level. It usually marks the base of any cloud formations.



Looking at the above diagram you can see that greater the different between the initial temperature and the dew point, the higher the condensation level or cloud base. The diagrams also show that the rising parcel of air is much warmer than the surrounding air. You can tell this because the rising air parcel follows the red line (DALR), which is, in our example anyway, always at a higher temperature than the surrounding environmental air (ELR). This is a classic example of convection. The air rises because it is warmer and lighter than the surroundings. You will find out a little later on in the discussion on Convective Cloud that the rising air parcel may not always be warmer than the surrounding air, and hence, may not continue to rise.

OROGRAPHIC CLOUD

Air meeting a ridge of high ground will be forced to rise. If the air is sufficiently humid the condensation level will appear below the crest of the ridge & cloud will form.



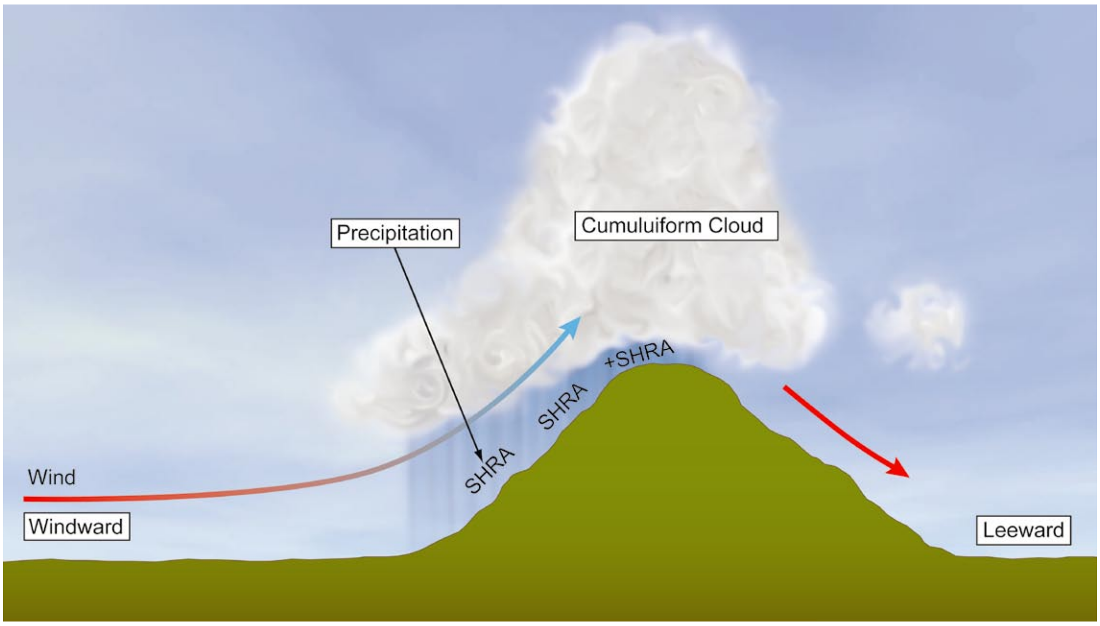
Orographic Cloud – Stable Conditions

If the air is stable and precipitation occurs, the air will descend on the LEE side and the cloud base will be higher than on the windward side and this will generate warmer surface temperature - the Fohn effect.

If the air is dryer, then the cloud base will be above the ridge and lenticular cloud would result.

Lifting in unstable conditions can produce Cu or Cb clouds and also thunderstorms if there is enough water vapour present.

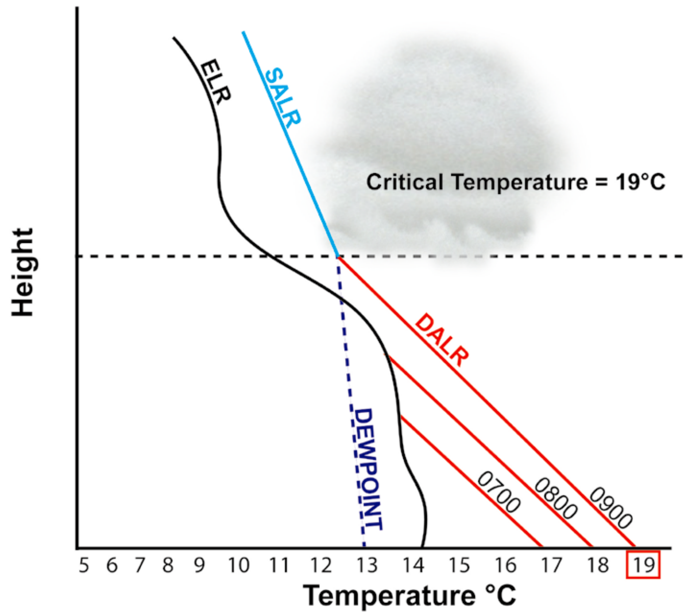
Strong winds with moist air can cause convective instability and Cb and thunderstorms. The Cb can be embedded in other cloud types, eg frontal or Turbulence cloud.



Orographic Cloud Forming in Unstable Conditions.

CONVECTION CLOUD

Critical Temperature. Before dealing with the formation of convection cloud we must consider the critical, or convective temperature. The image below shows air rising and cooling at the DALR at 0700,0800 & 0900 hrs. The first two ascents result in the air reaching the same temperature as the environment which stops any further ascent. However, at 0900 the rising air reaches the Dew Point line, cloud forms and the air now cools at the SALR & continues rising, but it importantly stays warmer then the surroundings and the cloud formation continues.



Critical Temperature

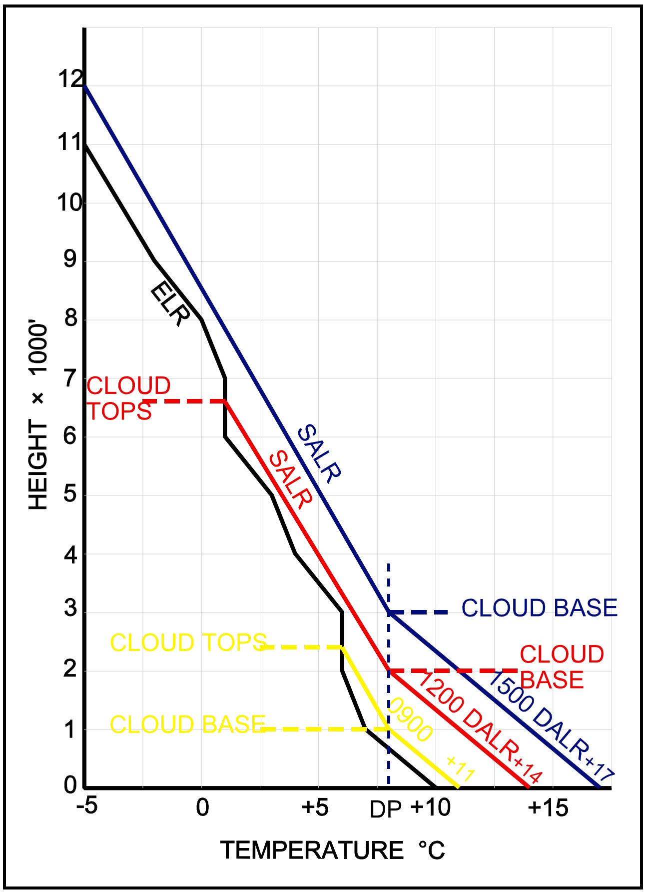
There are two particular cases:

- Fair weather Cu, which often forms early in the morning
- Large Cu/Cb, which often occur later in the day.

Convection cloud is heap type,Cu or Cb.. It is isolated, often forming over a place, then being blown away by the wind and further clouds forming over the same place.

The surface air temperature required for the air to be lifted to the condensation level and for cloud to form is called the critical temperature.

A characteristic of convection cloud is that as the temperature generally rises during the day, the the cloud base is found at higher altitudes and the cloud depths increase. However, once temperature falls the cloud dissipates.



The Formation of Convection Cloud

If there is turbulence with the convection, then Sc can form, the Cu being spread out to form the layer cloud.

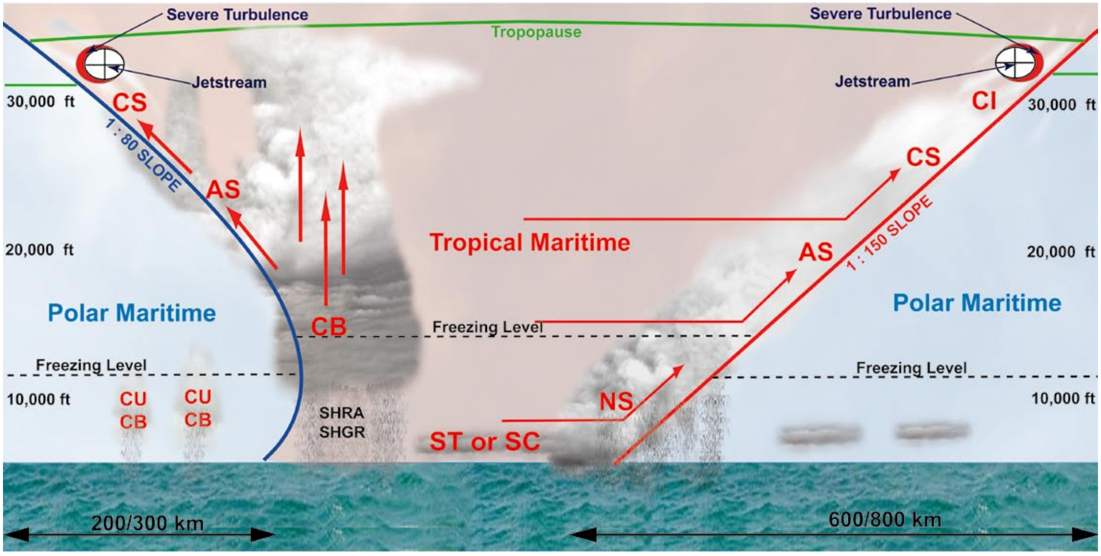
Pure convection cloud cannot form over the sea but where there is cold air moving over a warm surface the air will become unstable and convection type cloud can form.

Convection cloud formed over land by surface heating soon dissipates at night because insolation stops and the cloud droplets evaporate.

Convective cloud may progress through various cumulus types from humilis, to mediocris, through congestus to calvus. A fully developed Cb may appear as Cumulus Capilatus.

WIDESPREAD ASCENT (FRONTAL UPLIFT)

At a front there is widespread lifting of air as warm air comes into contact with colder air. Layer type clouds form in the stable air at a warm front and heap clouds in the unstable air at a cold front.



The Formation of Frontal Cloud.

CONVERGENCE CLOUD

When there is low pressure there is always convergence at the surface which leads to air being lifted. Thus in depressions and troughs, where there are no actual fronts, cloud formation occurs.

With strong convergence at a trough, lifting can cause instability to develop so that the cloud type is Cu or Cb with possible thunderstorms.

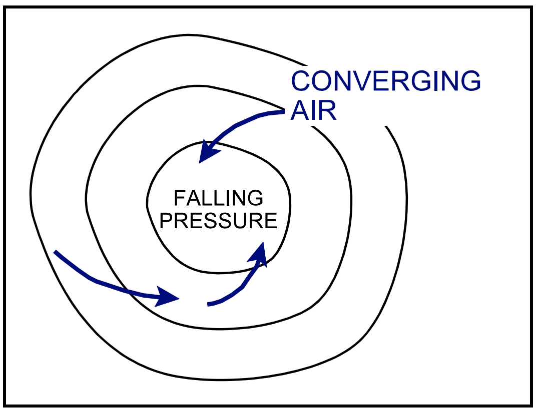
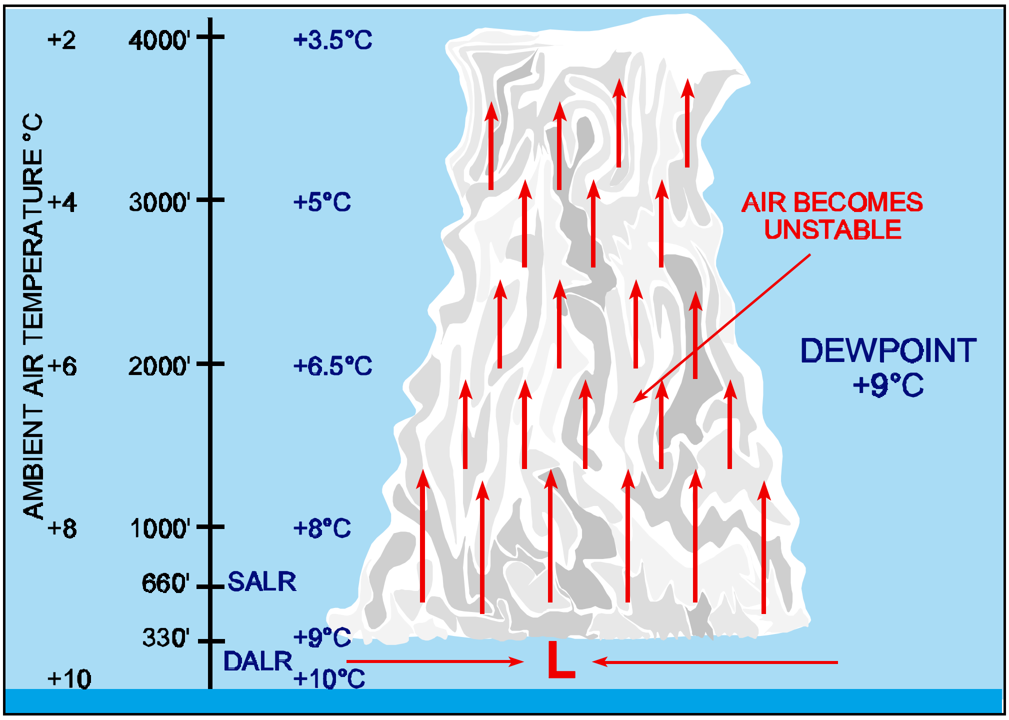


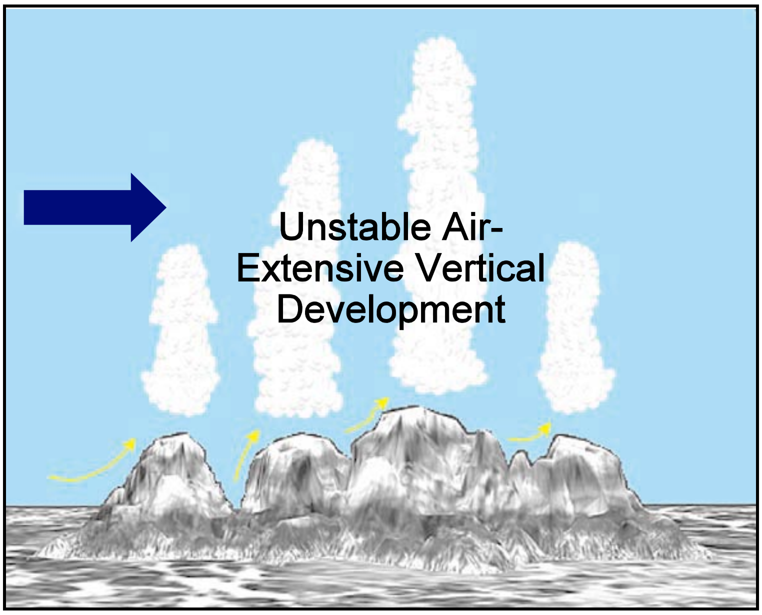
Figure 13.9 Convergence



Cloud Formation through Convergence.

MOUNTAINOUS AREAS

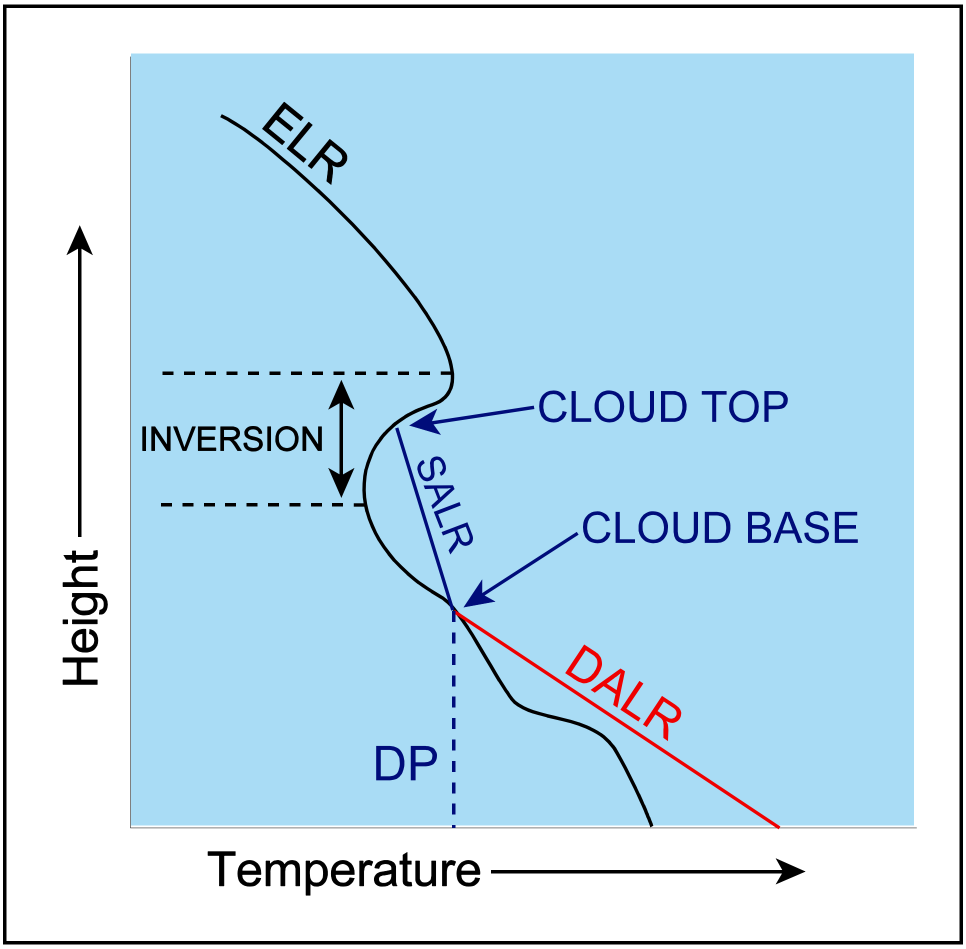
We have seen how orographic lifting produces cloud; in mountainous areas this may be very active and produce extensive cloud and vertical development due to Convective Instability. Additionally, this may increase the intensity of precipitation.



Mountainous terrain

INVERSIONS

An inversion in the atmosphere is where temperature rises with an increase in height. This produces extreme stability and inhibits the formation of cloud. An inversion always exists above turbulence cloud and inversions have a similar effect at ANY altitude.

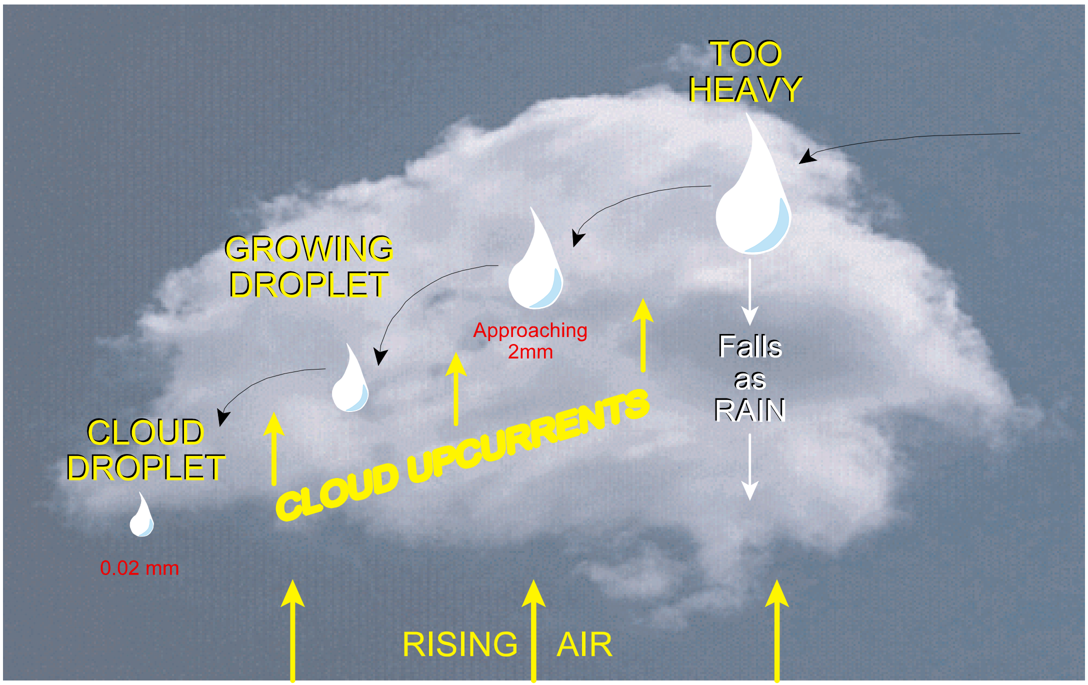


Effect of Inversions

PRECIPITATION

Clouds consist of water droplets averaging 0.02 mm in diameter and the rate of fall is negligible. By colliding with other droplets they may increase in size until they are too heavy to be supported by the up currents in the cloud and they drop out as precipitation.

There are currently two theories governing the formation of these precipitation drops.



Precipitation

BERGERON THEORY

The Bergeron theory presumes that at high levels in the cloud, some of the water droplets will turn to ice and will grow in size by sublimation of water vapour and collision with supercooled water droplets. The frozen droplets will be much heavier than the existing water droplets and drop out at the bottom of the cloud, either as Snow or Raindrops, depending on the temperature.

COALESCENCE THEORY

It is difficult to see how the above can account for summer precipitation where the whole of the cloud is at a temperature above zero and the coalescence theory may provide a better answer. This assumes the presence of a range of droplet sizes, the larger falling faster and uniting with the smaller until eventually the overweight drop falls out as drizzle or rain.

PARTIAL PRESSURE OF WATER VAPOUR OVER ICE AND SUPERCOOLED WATER

Over ice, water vapour will condense as ice crystals at subzero temperatures at less than 100% relative humidity. However over supercooled water the RH remains at 100%, hence ice crystals can form at a much lower pressure over ice than over supercooled water.

PRECIPITATION TYPES

,	Drizzle. DZ	Diameter: Visibility: Imperceptible impact.	0.2 to 0.5mm 500 to 3,000m
●	Rain. RA	Diameter: Visibility: Perceptible impact.	0.5 to 5.5mm 3,000 to 5.5km (1,000m in heavy rain)
✳	Snow. SN	Grains/Needles: Pellets: Flakes:	Diameter <1mm Diameter 2-5mm A collection of crystals greater than 4mm in diameter. (The lower the temperature, the smaller the size.)
△	Hail: GR	Diameter: Weight: Growth:	5 to 50mm+ Up to 1 kg Collision with supercooled water droplets and sublimination/ deposition.
	Soft Hail or Graupel:	Small rounded pellets, only a few mm in diameter. Fall from wintry, showery cloud. Early stage of hail growth.	
	Ice Pellets	Transparent pellets, spherical or irregular. Fall from layered cloud.	 Diameter <5mm.

PRECIPITATION SUMMARY

DURATION

	DESCRIPTION
SHOWERS	Always associated with CONVECTION or HEAP type cloud. Of short duration.
INTERMITTENT	Associated with LAYER cloud. Falling 'from time to time', with no marked clearance.
CONTINUOUS	Associated with LAYER cloud. No breaks for 60 minutes +.

INTENSITY

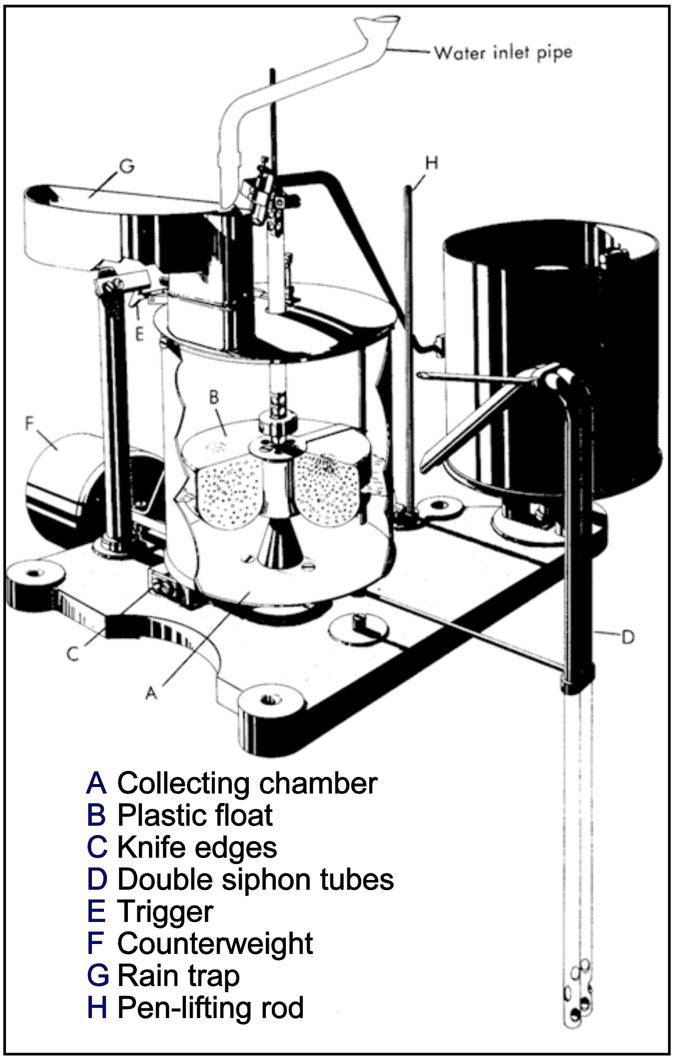
	RAIN (mm/hr)	Snow (Cm/hr)	Showers (mm/hr)
SLIGHT	< 0.5	< 0.5	< 2
MODERATE	0.5 TO 4	0.5 TO 4	2 - 10
HEAVY	> 4	> 4	10 - 50

CLOUD

		TYPE	INTENSITY
HEAP (Instability)	Cu Cb Ac	Rain/Snow showers Rain/Snow/Hail showers	Light to moderate Moderate to heavy
LAYER C: (stability)	Cc Cs	N I L	
	As, St, Sc,	Rain/Snow	Slight
	Ns	Rain/Snow	Moderate to heavy

RECORDING

Rainfall recorders are used at some Met. Offices. They will indicate rate of fall (intensity) of precipitation.



Rainfall Recorder

Rain GAUGES merely measure the amount of precipitation falling at the station. The intensity would have to be estimated, and where visibility is measured a table may be used.

QUESTIONS

1. What cloud does hail fall from?

   a. Cb
   b. Ns
   c. Cu
   d. Ci

2. Flying conditions in Ci cloud and horizontal visibility

   a. Less than 500m vis, light/mod clear icing
   b. Greater than 1000m vis, light/mod rime ice
   c. Less then 500m vis, no icing
   d. Greater than 1000m vis, no icing

3. What is the composition of Ci cloud?

   a. Super cooled water droplets
   b. Ice crystals
   c. Water droplets
   d. Smoke particles

4. What cloud types are classified as medium cloud?

   a. Ns + Sc
   b. Ac + As
   c. Cb + St
   d. Ci + Cs

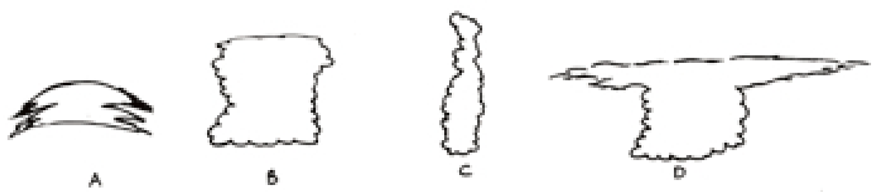
5. What type of cloud is associated with drizzle?

   a. St
   b. Cb
   c. Ci
   d. Ac

6. Fair weather cumulus gives an indication of

   a. Poor visibility
   b. Thunderstorms
   c. Turbulence
   d. Smooth flying below

7. What best shows Altocumulus Lenticularis?



8. What are Lenticularis clouds a possible indication of?

   a. Mountain waves
   b. Instability
   c. Developing Cu and Cb
   d. Horizontal wind shear in the upper atmosphere

9. In what cloud is icing and turbulence most severe?

   a. Cb
   b. Ns
   c. Sc
   d. Ci

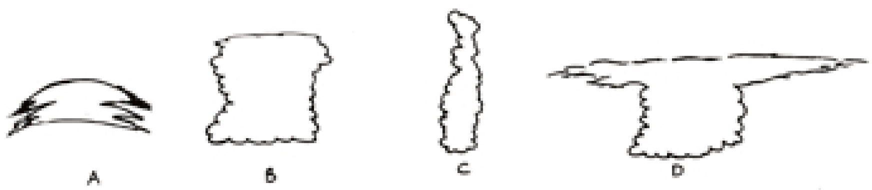
10. What will snow most likely fall from?

    a. Ns
    b. Ci
    c. Cs
    d. Ac

11. A plain in Western Europe at 500m (1600ft) AMSL is covered with a uniform alto - cumulus cloud during summer months. At what height AGL is the base of the cloud expected?

    a. 100 - 1500ft
    b. 15000 - 25000ft
    c. 7000 - 15000ft
    d. 1500 - 7000ft

12. Cumulus Capillatus



13. Clouds classified as low level are considered to have a base height of:

    a. 500 - 1000ft
    b. 1000 - 2000ft
    c. the surface - 6500ft
    d. 100 - 200ft

14. In a Tropical Downpour the visibility is sometimes reduced to:

    a. 1000m
    b. 500m
    c. 200m
    d. less than 100m

15. What type of cloud is usually found at high level?

a. St
b. Ac
c. Cc
d. Ns

16. What diagram, below, best shows Acc?

a. b. c. d.

17. Altostratus is

a. A low level cloud
b. A medium level cloud
c. A high level cloud
d. A heap type cloud

18. What would be reflected to radar?

a. Fog
b. Hail
c. Cloud
d. Mist

19. Which of the following clouds may extend into more than one layer?

a. Stratus.
b. Altocumulus.
c. Cirrus.
d. Nimbostratus.

20. Which cloud would you encounter the most intensive rain?

a. Ci
b. Ns
c. St
d. Sc

21. CB cloud in summer contains

a. Water droplets
b. Ice crystals
c. Water droplets, ice crystals and super cooled water droplets
d. Water droplets and ice crystals

22. Which cloud would produce showers?

    a. NS
    b. AS
    c. CS
    d. CB

23. When would you mostly likely get fair weather Cu?

    a. 15:00
    b. 12:00
    c. 17:00
    d. 07:00

24. What type of cloud extends into another level?

    a. As
    b. Acc
    c. Ns
    d. Ci

25. Ceilometers measure

    a. RVR
    b. Cloud height
    c. Met Vis
    d. Turbulence

26. Which of the following will indicate medium level instability, possibly leading to thunderstorms?

    a. Halo
    b. Altocumulus Castellanus
    c. Altocumulus Capillatus
    d. Red Cirrus

27. What is the base of alto cumulus in summer?

    a. 0 - 1500′
    b. 1500 - 7000′
    c. 7000′ - 15000′
    d. 7000′ - 16500′

28. When a CC layer lies over a West European plane in summer, with a mean terrain height of 500 m above sea level, the average cloud base could be expected

    a. 0- 100 ft above ground level
    b. 5000 - 15000 ft above ground level
    c. 15 000 - 25 000 ft above ground level
    d. 15 000 - 35 000 ft above ground level

29. Which of the following cloud types can stretch across all three cloud levels (low, medium and high level)?

    a. CI
    b. ST
    c. AC
    d. CB

30. Which of the following cloud types can stretch across at least two cloud levels?

    a. ST
    b. NS
    c. CI
    d. SC

31. From which cloud do you get hail?

    a. Sc
    b. Cb
    c. Ns
    d. Ts

32. If you see Alto Cu Castellanus what does it indicate?

    a. The upper atmosphere is stable
    b. Subsistence
    c. Instability in the lower atmosphere
    d. Middle level instability

33. To dissipate cloud

    a. Subsidence
    b. Decrease in temperature
    c. Increase pressure
    d. Convection

34. Cu is an indication of

    a. vertical movement of air
    b. stability
    c. the approach of a warm front
    d. the approach of a cold front

35. Which clouds are evidence of stable air?

    a. St, As
    b. Cb, Cc
    c. Cu, Ns
    d. Cu, Cb

36. Lack of cloud at low level in a stationary high is due to:

    a. instability
    b. rising air
    c. sinking air
    d. divergence at high level

37. What is the most common freezing precipitation?

    a. Freezing pellets
    b. Freezing rain and freezing drizzle
    c. Freezing graupel
    d. Freezing hail and freezing snow

38. From which of the following clouds are you least likely to get precipitation in summer?
    a. CS/NS
    b. CS/AS
    c. CB/CU
    d. CU/ST

39. A layer of air cooling at the SALR compared to the DALR would give what kind of cloud?

    a. Stratus if saturated
    b. Cumulus if saturated
    c. No cloud if saturated
    d. Convective cloud

40. Over flat dry land what would cause cloud?

    a. Orographic uplift.
    b. Convective uplift during the day.
    c. Release of latent heat.
    d. Advection.

ANSWERS

1.	A	11.	C	21.	C	31.	B
2.	D	12.	D	22.	D	32.	D
3.	B	13.	C	23.	D	33.	A
4.	B	14.	D	24.	C	34.	A
5.	A	15.	C	25.	B	35.	A
6.	C	16.	C	26.	B	36.	C
7.	A	17.	B	27.	D	37.	B
8.	A	18.	B	28.	D	38.	B
9.	A	19.	D	29.	D	39.	A
10.	A	20.	B	30.	B	40.	B

CHAPTER FOURTEEN

THUNDERSTORMS

Contents

CONDITIONS

Thunderstorms occur in well developed Cumulonimbus (Cb), though not all Cb's produce thunderstorms. They are most likely to occur when there is:

- A lapse rate greater than the SALR (unstable conditions) through a layer at least 10,000 ft thick and extending above the freezing level.
- Sufficient water vapour to form and maintain the cloud.
- Trigger action to produce early saturation, thus enhancing instability.

The so-called triggers or lifting forces are:

- Convection
- Orographic uplift
- Convergence
- Frontal uplift

Thunderstorms are classified as:

- Heat, or airmass type (more common in summer time).
- Frontal type (more common in winter time).

HEAT TYPE THUNDERSTORMS

Heat type thunderstorms are:

- Isolated - all triggers except frontal.
- Most frequent over land in summer.
- Formed by day, clear by night.
- Formed in cols or weak lows.

Note: Thunderstorms formed by advection can occur day or night, over land or sea or at any time of the year.

FRONTAL TYPE THUNDERSTORMS

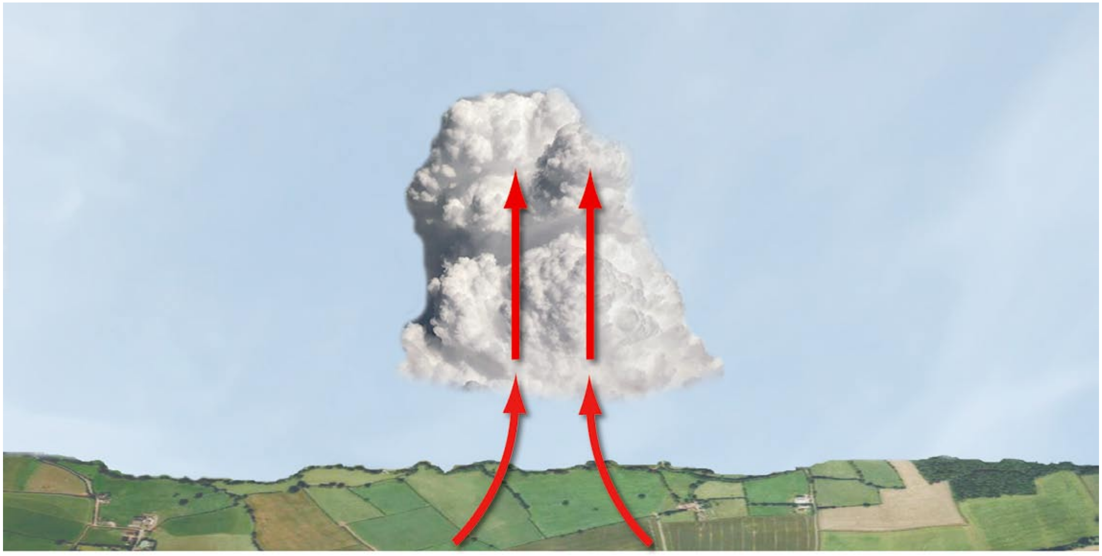
Frontal thunderstorms are;

- most frequent in winter.
- formed over land or sea, day or night.
- usually formed in a line at a cold front or occlusion.
- found in active depressions or troughs.
- often accompanied by a line squall.

THUNDERSTORM DEVELOPMENT (SINGLE CELL)

Initial stage

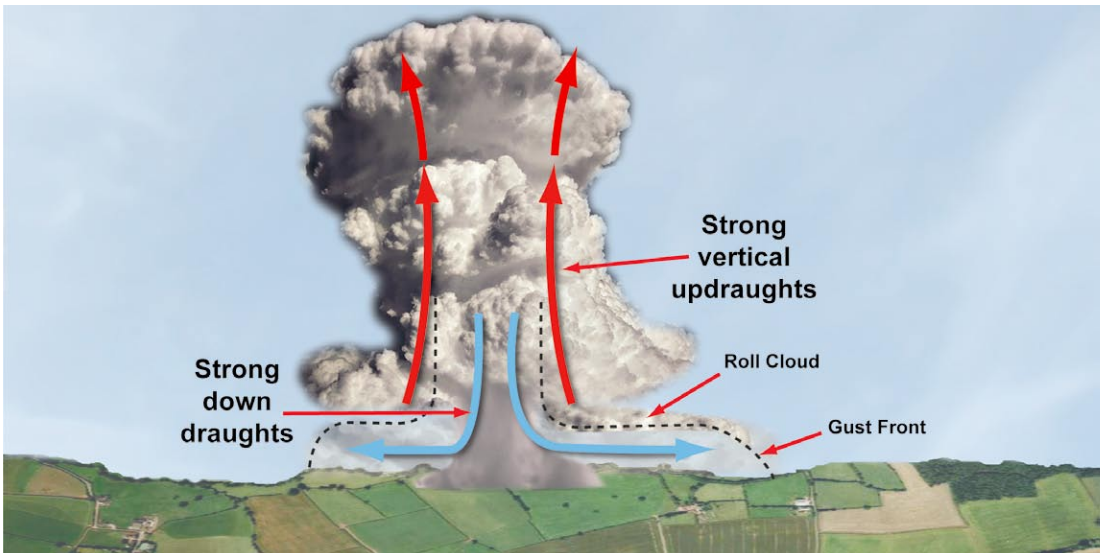
Several small Cu combine to form a large Cu cell about 5 nm across. There are strong upcurrents of 1000 to 2000 fpm (exceptionally 6,000 ft). Air from the sides and below is drawn in to replace the lifted air, thus causing turbulence. The initial stage lasts about 15 to 20 minutes and is characterised by only having updraughts.



The Building Stage of a Thunderstorm.

Mature stage

When precipitation occurs, the storm has reached the mature stage. The rain or hail will cause strong down currents of up to 2400 fpm and will also bring cold air to lower levels. These down drafts will warm initially at the SALR causing the air to warm very slowly, thereby staying colder than the surrounding air causing it to sink faster. Another factor aiding these down drafts is that some of the rain will evaporate which will absorb latent heat from the air making it even colder and more dense. As the cold air reaches the surface it spreads out and leads to the formation of the GUST FRONT.



The Mature Stage of Thunderstorm Development

Up currents remain strong and can be up to 10,000 fpm. Tops may rise at 5,000 fpm or more. There can be extreme turbulence in, under and all around the cloud.

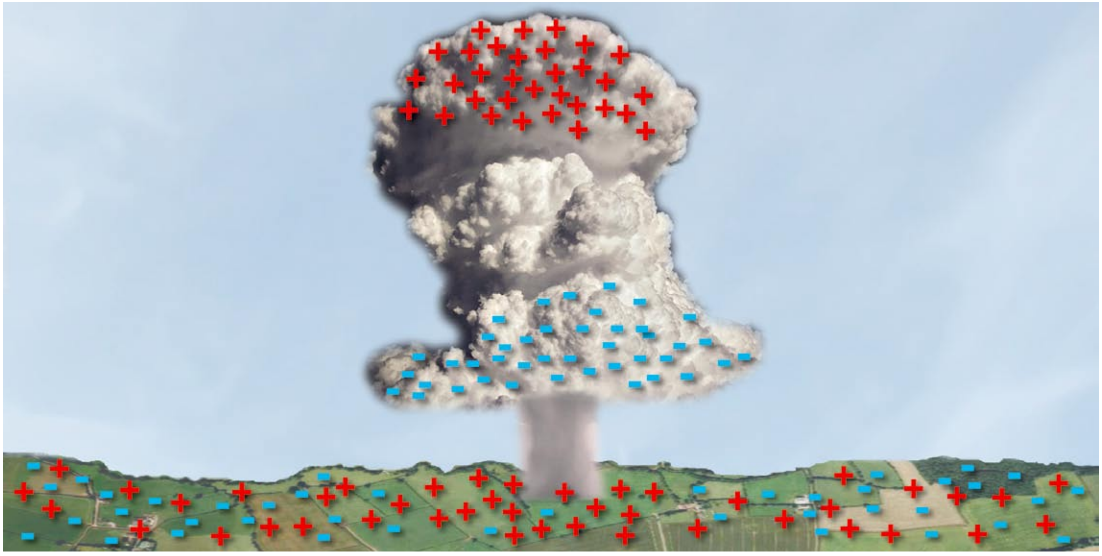
At the bottom leading edge of the storm there can be a roll of Sc and a strong gust front can be experienced up to 13 to17 nm (24 to 32km) ahead of the storm and be up to 6,000 feet in depth. Below the cloud a squall and associated wind shear can be expected.

Microbursts are possible where the down currents are very strong and are confined to a region in the cloud no more than 3nm (5km) across and a duration of less than 5 minutes.

Macrobursts are slightly larger in area than microbursts and are said to affect an area between 3 and 5miles across as the entire cold air outflow leaves the thunderstorm or group of thunderstorms (classification Dr. Ted Fujita.). These are typically of more than 5 minutes duration.

Rising and falling water droplets will produce a considerable build-up of **static electricity**, usually of positive charge at the top of the cloud and negative at the bottom. The build-ups eventually lead to **lightning** discharge and **thunder**.

The mature stage lasts for a further 15 to 20 mins and this stage is characterised by both up and down draughts.



Electrostatic Charge on a Thundercloud

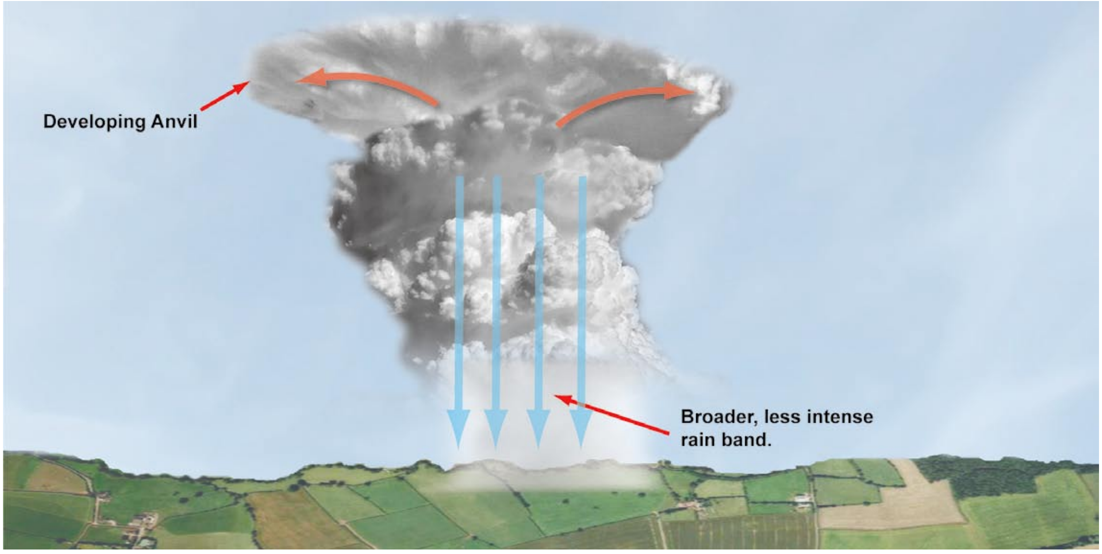
Dissipating stage

At this stage there is a wider distribution of **precipitation**, which is heavy, and extreme turbulence. Thunder and lightning may possibly occur at this stage. This stage is characterised by predominantly downdraughts.

The cloud extends to the tropopause, where it is spread out by the upper wind to form an anvil. At these levels the cloud thins to form Ci.

Large variations in static charge in and around the cloud cause discharge in the form of lightning which can appear in the cloud, from the cloud to the ground, or from the cloud to the air alongside.

The dissipating stage lasts for a further 1½ to 2½ hours.



The Dissipating Stage of a Thunderstorm.

MOVEMENT OF THUNDERSTORMS

Thunderstorms usually move in the direction of the 10,000 ft (700 mb) wind, though large storms and newly developed ones may differ from this.

ALIGNMENT

Frontal thunderstorms will often appear along a **squall line**. This is usually an indication of severe weather. The thunderstorm cells will be in varying stages of development.

FORECASTING

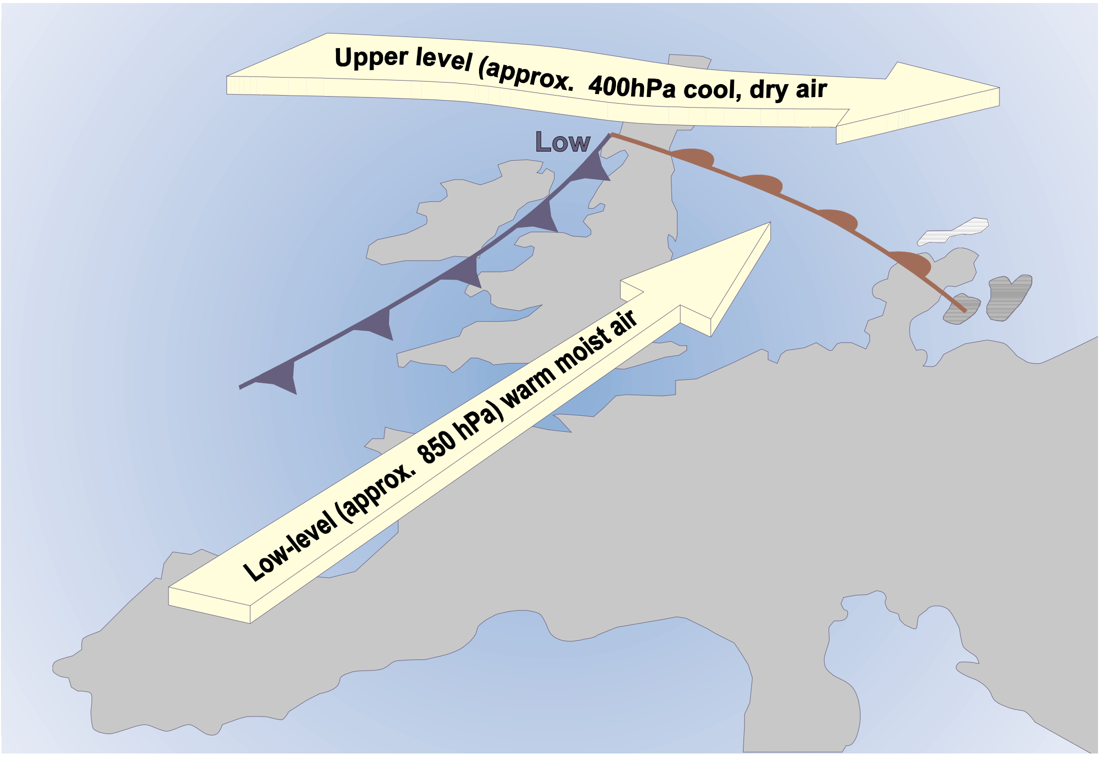
Forecasting the occurrence of thunderstorms will be largely a matter of assembling the conditions necessary for the formation and the triggers. A combination of these two groups will indicate the probability of thunderstorms. **Satellite photography** and **computer modelling** are used to predict this occurrence.

SUPERCELL THUNDERSTORMS (Severe local storms)

Initial Stage

Conditions necessary to initiate these thunderstorms are:

- Great depth of instability
- Strong vertical windshear
- Stable layer between warm (lower) and cool (upper) air which is eventually broken down by insolation.



Conditions for Supercell Thunderstorm.

Mature Stage

Characteristics of the mature stage are:

- Very strong up and down draughts produced in the one large (super) cell give rise to violent weather and even tornadoes (an average of 33 tornadoes per year have occurred in Britain over recent years reminding us that they are not a phenomena restricted to the USA).

- The mature stage may last several hours.

Movement

In the Northern hemisphere movement is usually about 20° to the right of the 18,000 ft (500mb) W/V.

Location

Supercell thunderstorms are more common over continental land masses than over maritime areas. Thunderstorms over the mid-west states of the USA producing tornadoes are good examples.

AVOIDANCE

The CAA has produced recommended avoidance distances when using weather radar. It should be noted that the significance of a radar return of given intensity usually increases with altitude. The principle underlying use of airborne weather radar is that strong up currents (which will support strong turbulence) will support large water droplets, which will show a stronger radar return. The diagram below shows a display that can be found on a typical /generic EFIS display.

Typical Weather Mode Display

RECOMMENDED THUNDERSTORM AVOIDANCE RANGES USING AIRBORNE RADAR

FLIGHT LEVEL	AVOIDANCE RANGE
0 - 200	5nm (10 nm if growing rapidly)
200 - 250	10 nm
250 - 300	15 nm
300 +	20 nm
Visually - avoid by 10 nm any storm that is TALL, GROWING RAPIDLY or has an ANVIL TOP.	

RADAR

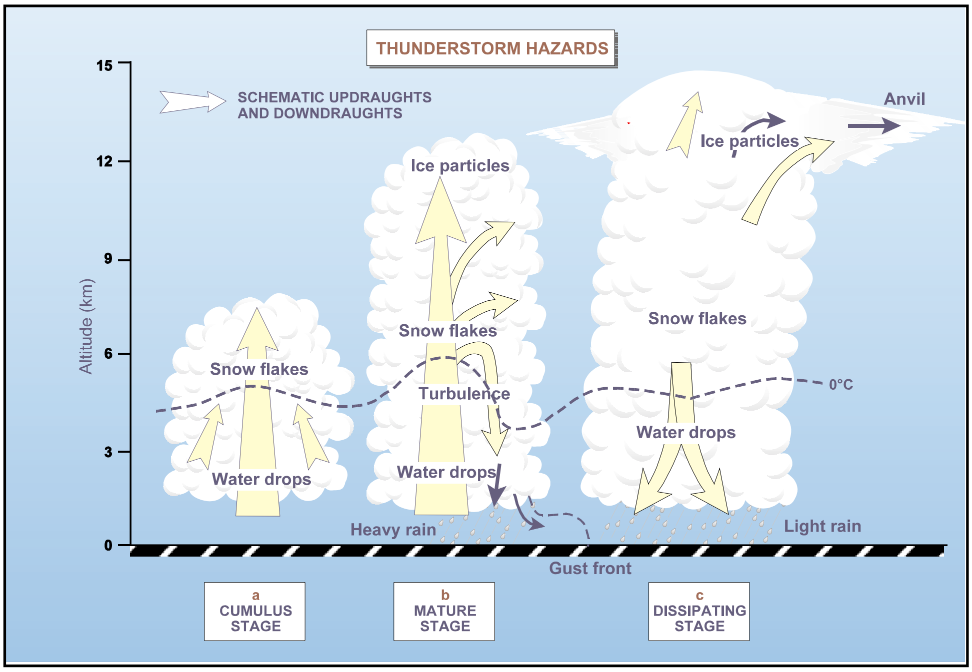
Airorne Weather Radar (CCWR) is Plan Position Indicator (PPI) radar, but ground radar, though mostly PPI, may also use RHI (range-height indicator). CCWR is explained elsewhere in this course, but the returns from many radars are combined to produce an area display which will be multicoloured to identify different precipitation intensities.

A **Stormscope** is a highly sophisticated system that detects, locates and maps areas of electrical discharge activity contained within thunderstorms permitting avoidance of the associated hazards.

SUMMARY OF THUNDERSTORM HAZARDS

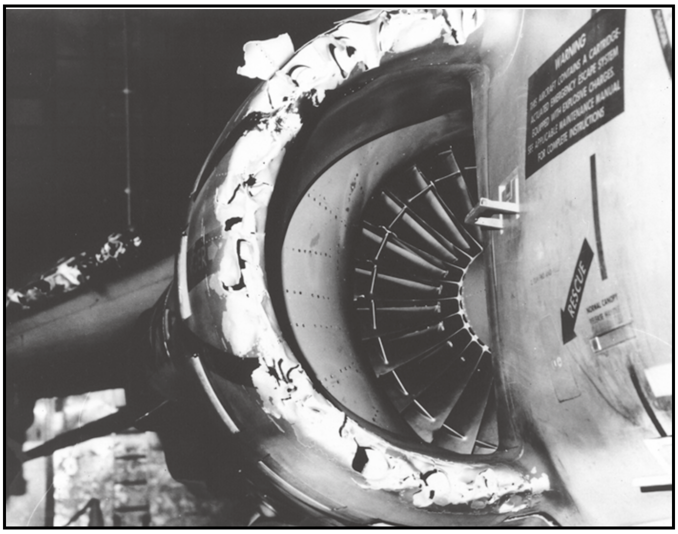
- **Turbulence**. Turbulence can be violent both within cloud and at their sides. Below the cloud, turbulence can be dangerous during take-off and landing and there can be wind shear. It is possible for a pilot to overstress the airframe in these conditions.

  Loose articles being thrown about inside the aircraft cabin can injure passengers. Pressure instruments can be in error due to lag.



Turbulence

- **Hail**. Hail can be met at any height in the cloud, also below the cloud and below the anvil. Severe skin damage to the airframe can occur when the hail is large. Damaging hail can occur up to a height of 45,000 feet.



Thunderstorm Hazards

- **Icing**. This can occur at all heights in the cloud where the temperature is between 0°C and -45°C. Heavy concentrations of droplets and large droplet size result in severe clear icing.

  Carburettor icing can occur at temperatures between -10°C and +30°C and it can be particularly severe between -2°C and +15°C.

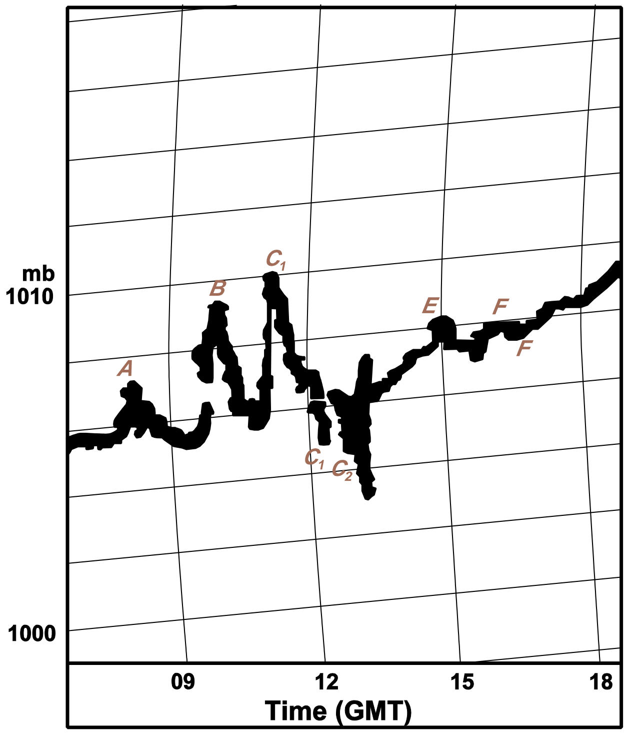
- **Lightning**. Lightning is most likely to occur within 5,000 ft of the freezing level. Temperature between 20°C and -10°C. There are 3 effects which can be expected:

  - It can cause a pilot to be temporarily blinded.
  - Compasses can become totally unreliable.
  - Some airframe damage can be caused, particularly with composite aircraft.

- **Static**. This causes interference on radio equipment in the LF, MF, HF and VHF frequencies. St Elmo's fire can be caused by static and it results in purple rings of light around the nose, wing tips and propellers. This is not a hazard, but it indicates that the air is electrically charged and lightning is probable.

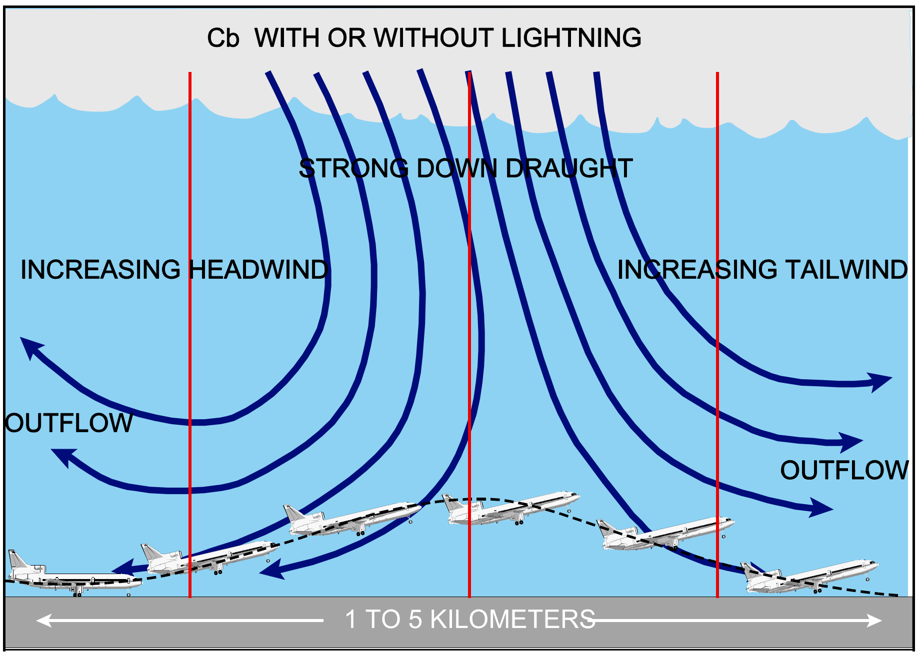
- **Pressure variations**. Local pressure variations covering only a very small region, in or close to, a storm can occur causing QFE/QNH to be in error, so that altimeter readings can be inaccurate by as much as ±1000 ft at all heights. These, together with gust effects, can cause height errors at low level which can be dangerous.

- VSI's will also be subject to errors. The aircraft should be flown for ATTITUDE rather than altitude, though some attitude indicators may not be able to cope with the changes of attitude produced but the severe turbulence likely to be encountered.



Barogram during a Thunderstorm Pressure Variations

- **Microbursts**. These are down currents in the cloud which also move outwards by reaction from the ground, having speeds considerably in excess of 1000 feet per minute downwards (up to 6000 fpm) and 50 kts horizontally. The windshear (headwind to tailwind) may be between 50 & 90 kts. They are largely caused by descending raindrops which cool the surrounding air by evaporation, the higher density accelerating the down draught still further.



Microbursts

They are concentrated in a burst which is up to 3nm (5km) in horizontal length and have a lifetime of about 5 minutes. (A Macroburst is a similar event but over a bigger area.)

Microbursts are most likely to occur in summer air mass thunder-storms in low latitude regions where surface conditions are dry. They cause extreme turbulence and severe wind shear conditions.

A warning sign is virga, which is streaks of precipitation from below the cloud which do not reach the ground.

- **Water ingestion**. If up draught speed approaches or exceeds the terminal velocity of the falling raindrops, the resulting high concentrations of water can exceed the design limits for water ingestion in some turbine engines. The result can be engine flame-out and/or engine structural failure. Water ingestion may also affect pitot heads, even though heaters have been switched on.

- **Tornados**. These are usually associated with severe thunderstorms and Tropical Revolving Storms (TRS), particularly in the mid-west of the United States of America although they do occur in Europe albeit of a lower intensity.

They take the form of a violent whirlwind extending up from the ground into the base of the Cumulonimbus cloud.

The speed of the air in the vortex has been known to exceed 200 knots.

The width of the vortex is typically less than 300 metres horizontally, (average diameter 100m to 150m).

Further discussion on tornadoes will be given in the syllabus topic of “OTHER DEPRESSIONS” later in the Meteorology Theory lectures.

QUESTIONS

1. What is the approximate maximum diameter of a microburst?

   a. 20 km
   b. 50 km
   c. 4 km
   d. 400 m

2. Which of the following causes echoes on meteorological radar screens?

   a. Water vapour
   b. Fog
   c. Any cloud
   d. Hail

3. What are the requirements for the formation of a thunderstorm?

   a. A stratocumulus cloud with sufficient moisture
   b. A cumulus cloud with sufficient moisture associated with an inversion
   c. An adequate supply of moisture, conditional instability and a lifting action
   d. Water vapour and high pressure

4. A microburst

   a. occurs only in tropical areas
   b. has a diameter up to 4 km
   c. has a life time of more than 30 minutes
   d. is always associated with thunderstorms

5. In Central Europe when is the greatest likelihood for thunderstorms due to warm updrafts?

   a. Late morning.
   b. Mid - afternoon.
   c. Around midnight.
   d. Early morning.

6. Which of the following statements describes a microburst ?

   a. A high speed downdraft of air with a higher temperature than its surroundings
   b. An extremely strong wind gust associated with a tropical revolving storm
   c. A small low pressure system where the wind circulates at high speed
   d. A high speed downburst of air with a generally lower temperature than its surroundings

7. Which thunderstorms move forward the fastest?

   a. Thunderstorms formed by lifting processes.
   b. Thermal thunderstorms.
   c. Orographic thunderstorms.
   d. Frontal thunderstorms.

8. In addition to a lifting action, what are two other conditions necessary for thunderstorm formation?

   a. Stable conditions and low atmospheric pressure
   b. Unstable conditions and low atmospheric pressure
   c. Unstable conditions and high moisture content
   d. Stable conditions and high moisture content

9. Aircraft struck by lightning may sometimes get considerable damage and at least temporarily the manoeuvring of the aircraft will be made more difficult. Which one of the following statements is correct?

   a. Aircraft made by composite material may get severe damage, the crew may be blinded and temporarily lose the hearing.
   b. An aircraft made by metal has a certain capacity to attract a lightning, but the lightning will follow the surface and therefore no damage will be caused.
   c. An aircraft has in the atmosphere the same qualities as a "Faradays cage", which means that struck of lightning seldom occurs. But if it happens, the result will be an occasional engine failure. The crew may get a shock.
   d. Aircraft made by composite material can't conduct a lightning and will therefore very seldom be struck.

10. Which thunderstorms generally develop in the afternoon in summer over land in moderate latitudes?

   a. Airmass thunderstorms
   b. Warm front thunderstorms
   c. Cold mass thunderstorms
   d. Occlusion thunderstorms

11. How long does a typical microburst last?

   a. 1 to 2 hours.
   b. About 30 minutes.
   c. 1 to 5 minutes.
   d. Less than 1 minute.

12. An airborne weather radar installation makes it possible to detect the location of

   a. all clouds
   b. cumulonimbus, but provided that cloud of this type is accompanied by falls of hail
   c. stratocumulus and its vertical development
   d. zones of precipitation, particularly liquid-state precipitation, and also their intensity

13. Which of the statements is true concerning squall lines?

   a. Severe squall lines always move from northwest to southeast
   b. For severe squall lines a SIGMET is issued
   c. Severe squall lines only occur in the tropics
   d. For severe squall lines a TAF is issued

14. What are the meteorological prerequisites, at low level, for thunderstorms formed by lifting processes, over land?

    a. High air pressure (> 1013 hPa), high temperatures.
    b. Low temperatures, low humidity.
    c. Subsidence, inversion.
    d. High temperatures, high humidity.

15. What is a microburst?

    a. A small low pressure system where the wind circulates with very high speeds.
    b. A concentrated downdraft with high speeds and a lower temperature than the surrounding air.
    c. A concentrated downdraft with high speeds and a higher temperature than the surrounding air.
    d. An extremely strong wind gust in a tropical revolving storm.

16. The initial phase of a thunderstorm is characterized by

    a. continuous up draughts
    b. continuous downdraughts
    c. frequent lightning
    d. rain starting at surface

17. In which stage of the life cycle of a single thunderstorm cell occur both up- and downdrafts simultaneously?

    a. Cumulus stage
    b. Dissipating stage
    c. In all stages
    d. Mature stage

18. What weather condition would you expect at a squall line?

    a. Fog
    b. Strong whirlwinds reaching up to higher levels
    c. Thunderstorms
    d. Strong steady rain

19. Thunderstorms reach their greatest intensity during the

    a. period in which precipitation is not falling.
    b. mature stage.
    c. cumulus stage.
    d. dissipating stage.

20. A microburst phenomenon can arise in the

    a. up draught of a cumulonimbus at the mature stage.
    b. downdraught of a cumulonimbus at the formation stage.
    c. up draught of a cumulonimbus at the growth stage.
    d. downdraught of a cumulonimbus at the mature stage.

21. During the life cycle of a thunderstorm, which stage is characterized predominantly by downdrafts?

    a. Anvil stage
    b. Dissipating stage
    c. Cumulus stage
    d. Mature stage

22. Continuous up draughts occur in a thunderstorm during the

    a. period in which precipitation is falling.
    b. cumulus stage.
    c. mature stage.
    d. dissipating stage.

23. Where is a squall line to be expected?

    a. In front of a cold front occlusion at higher levels.
    b. At the surface position of a warm front.
    c. In front of an active cold front.
    d. Behind a cold front.

24. What feature is normally associated with the cumulus stage of a thunderstorm?

    a. Continuous updraft
    b. Roll cloud
    c. Frequent lightning
    d. Rain or hail at the surface

25. A gust front is

    a. normally encountered directly below a thunderstorm
    b. characterized by heavy lightning
    c. another name for a cold front
    d. formed by the cold air outflow from a thunderstorm

26. The diameter and the life time of a typical microburst are in the order of

    a. 8 km and 5-15 minutes
    b. 12 km and 5-10 minutes
    c. 4 km and 1-5 minutes
    d. 4 km and 30-40 minutes

27. During which stage of thunderstorm development are rotor winds characterized by roll clouds most likely to occur?

    a. Cumulus stage and mature stage.
    b. Mature stage.
    c. Cumulus stage.
    d. Dissipating stage.

28. Large hail stones

    a. only occur in frontal thunderstorms
    b. are typically associated with severe thunderstorms
    c. only occur in thunderstorms of mid-latitudes
    d. are entirely composed of clear ice

29. In which of the following areas is the highest frequency of thunderstorms encountered?

    a. Temperate
    b. Tropical
    c. Polar
    d. Subtropical

30. Isolated thunderstorms of a local nature are generally caused by

    a. frontal lifting (warm front).
    b. frontal lifting (cold front).
    c. frontal occlusion.
    d. thermal triggering.

ANSWERS

1.	C	11.	C	21.	B
2.	D	12.	D	22.	B
3.	C	13.	B	23.	C
4.	B	14.	D	24.	A
5.	B	15.	B	25.	D
6.	D	16.	A	26.	C
7.	D	17.	D	27.	B
8.	C	18.	C	28.	B
9.	A	19.	B	29.	B
10.	A	20.	D	30.	D

CHAPTER FIFTEEN

VISIBILITY

Contents

INTRODUCTION

Meteorological Optical Range (MOR), or more simply 'met vis' is the greatest horizontal distance at which a dark object can be recognised by an observer with normal eyesight, or at which lights of specified candlepower can be seen by night.

Ground visibility is the visibility of an aerodrome as reported by an accredited observer.

Up to the 25th of November 2004 'minimum visibility' has been reported as part of the METAR, TAF and SPECI coding. 'Prevailing visibility' has now been implemented in the METAR and TAF coding as from 25th November 2004 and has replaced the reporting of 'minimum visibility'.

Prevailing visibility is defined as the visibility value, which is reached or exceeded within at least half the horizon circle or within at least half of the surface of the aerodrome. These areas could comprise contiguous or non-contiguous sectors.

The lowest or 'minimum visibility' will also be reported in the METAR, after the prevailing visibility, if the visibility in one direction, which is not the prevailing visibility, is less than 1500 metres or less than 50% of the prevailing visibility. A direction will also be appended to this minimum visibility as one of the eight points of the compass. If the lowest visibility is observed in more than one direction, then the most operationally significant direction should be reported. (No direction is required for the prevailing visibility.) When the visibility is fluctuating rapidly and the prevailing visibility cannot be determined, only the lowest visibility should be reported, with no indication of direction.

In SYNOPTIC visibility reporting, the lowest visibility will be still be used.

OBSCURITY

In effect, visibility is a measure of **atmospheric clarity**, or **obscurity**. This obscurity can be caused by **water droplets** - cloud, fog, rain, or **solid particles**-sand, dust or smoke, or by a mixture of the two - smog (fog and smoke). Ice, in the form of crystals, hail or snow will also reduce visibility. Poor visibility is usually associated with **stable** conditions, an inversion and light winds.

Visibility is generally better upwind of towns and industrial areas.

The various types of reduction in visibility are:

➢ **Mist**. There is mist if the visibility is 1000m or more and the relative humidity is greater than 95% with very small water droplets.

➢ **Fog**. There is fog if the visibility is less than 1000m and the obscuring agent is water droplets. Relative Humidity (RH) will be near 100%.

➢ **Haze**. There is haze if the visibility is reduced by extremely small solid particles - sand, dust or smoke. If the visibility is reduced below 1000m. Again, haze is not reported when the visibility is more than 5000m.

Descriptor	Lower Limit of visibility (metres)	Upper Limit of visibility (metres)	Relative Humidity
HAZE or SMOKE	1000	5000	Less than 95%
MIST	1000	5000	95% or more
FOG	Zero	<1000	100%

RADIATION FOG

Radiation fog is caused by radiation of the earth's heat at night, and the subsequent conductive cooling of the air in contact with the ground to below dew point.

If there is a light wind, then fog will form, in calm conditions the result will be the formation of dew. The fog is not usually more than a few hundred feet thick.

Conditions necessary for radiation fog to form.

- **Clear sky** - to increase the rate of terrestrial radiation.
- **High relative humidity** - so that a little cooling will be enough to cause saturation and condensation.
- **Light wind** - of 2 - 8 kts to mix the layers of air causing turbulence so that droplets will be kept in suspension and so that warmer air from above can be brought into contact with the cold ground to thicken the fog.

Figure 15.1: Radiation Fog.

A natural result of the radiative cooling at the surface will be an inversion above the fog layer (usually the friction layer).

Times of occurrence

- **Autumn** and **winter**.
- **Night** and **early morning**. The lowest temperatures are early morning. Additionally, the first insolation provides thermal turbulence and light winds.

Location

- **Over land** - not over sea because there is little DV of temperature.
- **Firstly in valleys** because of the katabatic effect.
- In anticyclones, ridges and cols.

Dispersal

- By insolation causing convection which will lift the fog. It will also help to evaporate the lower layers.
- By a strong wind lifting the fog to form stratus cloud.

Note: *In the UK, radiation fog usually clears by 1000 - 1100 hours.*

HILL / OROGRAPHIC FOG

Hill fog is cloud on the sides of or the top of a hill or mountain which has been generated by the movement of humid air up the hillside (orographic lifting). Visibility will be 200 metres or less.

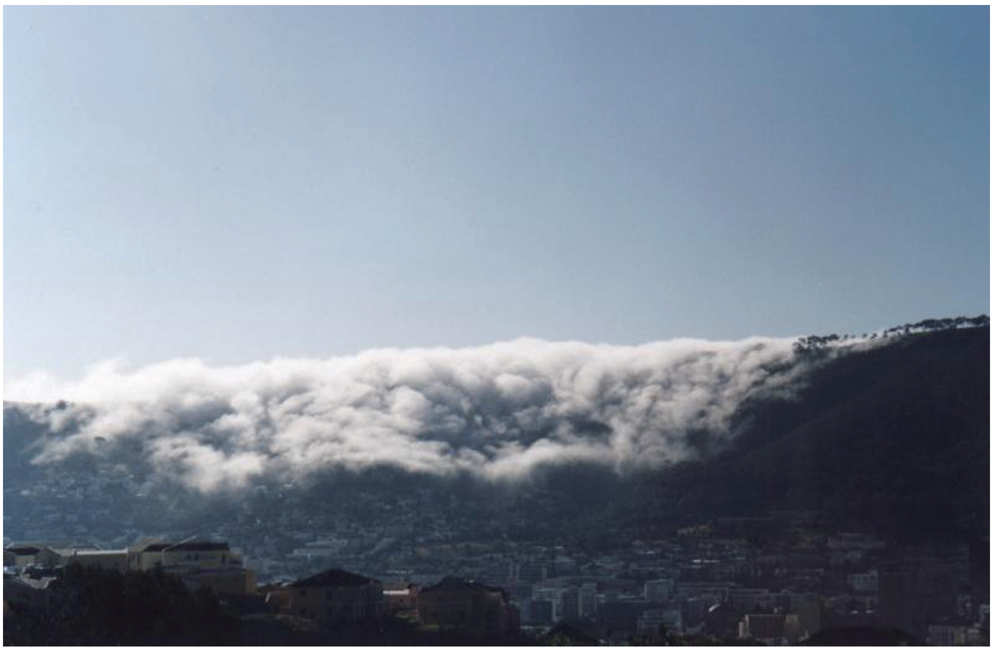


Figure 15.2: Hill Fog.

ADVECTION FOG

Advection fog is formed by the movement of **warm, moist** air over a **cold surface**. The surface can be land or sea.

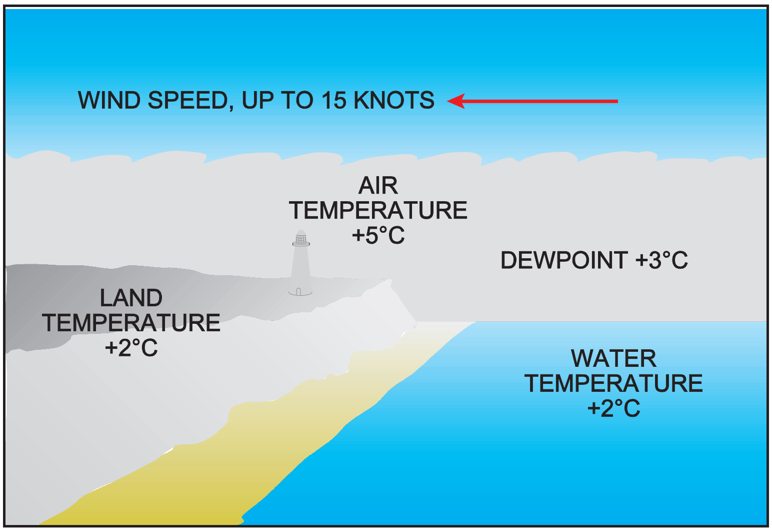


Figure 15.3: The conditions necessary for advection fog to form.

Conditions necessary for advection fog to form

- Winds up to 15kts to move the air. (May be stronger over sea areas)
- A high RH so that relatively little cooling is required to produce saturation and subsequent condensation.
- A cold surface with a temperature lower than the Dew Point (DP) of the moving air to ensure condensation.

Times of occurrence and location

- Over **land** areas in **winter** and **early spring**.
- Over **sea** areas in **late spring** and **early summer**.
- Occurs particularly when a SW wind brings tropical maritime air to the UK.

Dispersal

- By a **change of airmass**. (Wind change).
- By a windspeed **greater than 15kts** which will lift the fog to form stratus cloud.

SPECIAL AREAS

Nearly all sea fogs are caused by advection. Good examples are the extensive and persistent sea fogs which occur in the region of the **Grand Banks of Newfoundland** and around the **Kamchatka Peninsula** in the North Pacific.

In both cases warm air from the south moves over a cold sea current flowing down from the north.

Figure 15.4: Advection fog.

STEAMING FOG (ARCTIC SMOKE)

Steaming fog, or as it is sometimes called, Arctic Smoke, occurs over sea in polar regions, eg the fjords of Greenland, Iceland and the sea areas of high latitudes. It is caused by **cold air** from a land mass moving over a **warmer moist surface or sea**. The small amount of evaporation from the sea is enough to cause saturation and condensation but the air itself must be **very stable**.

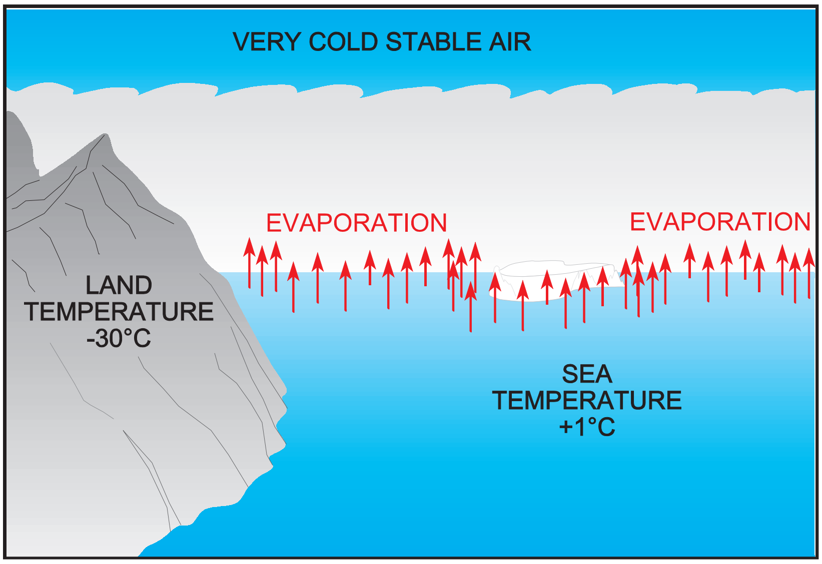


Figure 15.5: The conditions necessary for steaming fog (Arctic smoke).

The fog can be persistent and up to 500 ft thick - may drift inland. Will be dispersed by an increase in windspeed or change of direction. Usually only significant in Arctic regions, but the ‘steam’ may be seen at any latitude when cold air moves over a wet surface. ‘Steam’ rising from a wet road after a very heavy summer shower is a good example.

Figure 15.6: Steaming fog.

FRONTAL FOG

Frontal fog occurs at a warm front or occlusion. The main cause is **precipitation lowering the cloud base to the ground.**

Subsidiary causes are:

- Evaporation of standing water on the ground.
- Mixing of saturated air with non-saturated air below.

The fog can form along a belt up to 200 nm wide which then travels with the front. Can be increased by orographic lifting. Will be dispersed by the passing of the front.

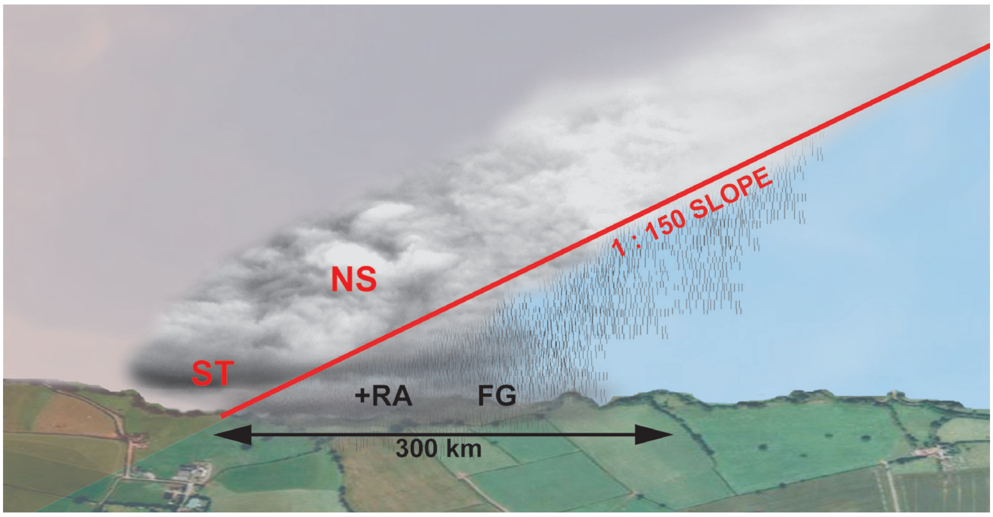


Figure 15.7: Frontal fog.

VISIBILITY REDUCERS

Apart from very small water droplets, visibility may be reduced by solid particles or precipitation.

Smoke
Smoke consists of solid particles produced by combustion. Conditions will be worse under STABLE (subsiding air) conditions. Smoke may cause widespread visibility reductions.

The reduction will depend upon:

- Rate of production
- Rate of dispersal by wind
- Distance from the smoke source

The particles provide ample H**ygroscopic Nuclei** for vapour to condense on to, thus increasing the severity of **Radiation Fog**.

Dust
Dust is a particle less than 0.08mm in diameter. Because of its lightness, it may be carried high into the atmosphere. The surface wind speed is likely to exceed 15kts and as the speed increases, so will the height to which the dust will rise.

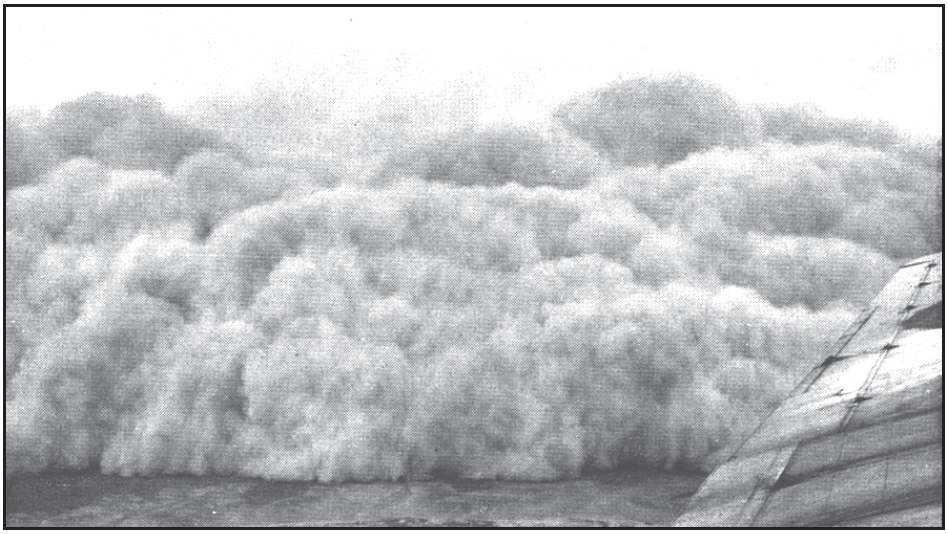


Figure 15.8: Dust storm rising to 11,000 ft (75miles SSE of Damascus)

Dust storms mainly occur in daylight due to the diurnal variation of wind, but simple dust is very small, it may stay in suspension and visibility may not improve for a day or so. Examples are the **Khamsin** and **Haboobs**, which will be covered later.

Sand: Sand consists of particles between 0.08 and 0.3mm in diameter. Wind speed will be 20kts or more. The greater weight of sand particles means that they will only be carried a few feet above the surface. Again, more a daylight event, due to the diurnal variation of wind.

Dust or sandstorms imply a visibility below 1000m.

Precipitation
Reductions in visibility caused by precipitation have already been covered under Cloud Formation, but to recap, they are:

Drizzle	500 to 3000m	
Rain	Moderate:	3000m to 10km
	Heavy:	< 1000 m
	Tropical:	Downpour < 100m
Snow	Moderate:	1000m
	Heavy:	50 to 200m
	Drifting:	(< 2m above the surface) will reduce the above.
	Blowing:	(2m above the surface) will GREATLY reduce the above.

As an example, moderate rain compared to moderate drizzle, the visibility will be worse in moderate drizzle.

VISIBILITY MEASUREMENT

- **By day.** Measurements are made by reference to suitable objects at known distances from an observing position.

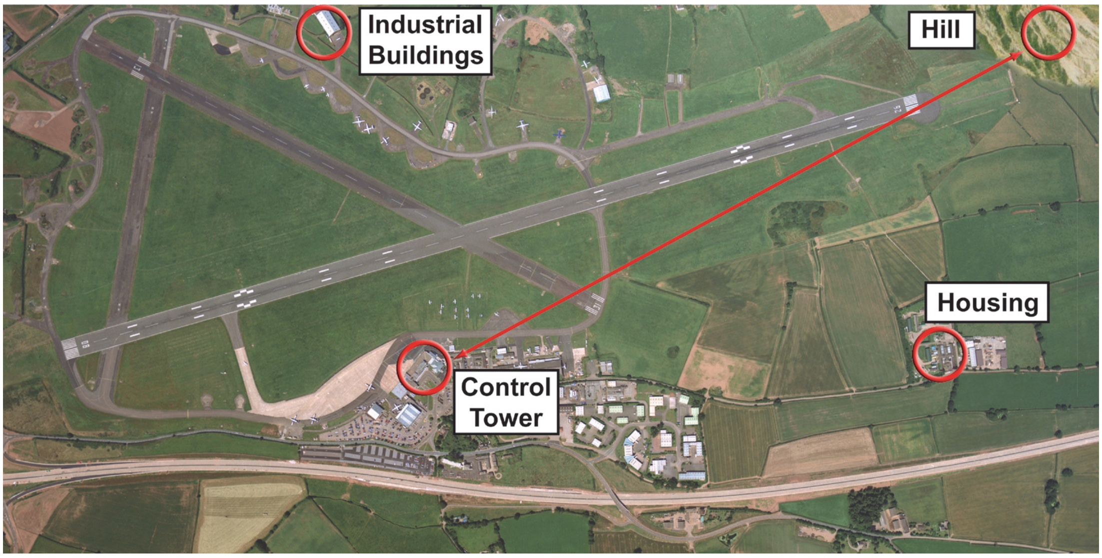


Figure 15.9: Visibility measurement: Day.

- **By night**. If a suitable arrangement of lights of known candlepower is not available the visibility value obtained has to be the daytime equivalent in terms of atmospheric obscurity. This is achieved by viewing lights of known candlepower from a known distance through a variable filter in an instrument called a **Gold's Visibility Meter.** The filter is varied until the light is no longer visible and the reading will give an equivalent of daylight visibility.

Figure 15.10: Gold's Visibility Meter, Visiometer and Transmissometer.

RUNWAY VISUAL RANGE (RVR)

RVR is the maximum distance that a pilot 15 ft above the runway in the touchdown area can see marker boards by day or runway lights by night when looking in the direction of take-off or landing. The RVR can be assessed by positioning an observer 76 metres from the centre line of the runway in the touchdown area to sight the number of marker board or lights in the appropriate direction. RVR is reported when normal visibility is 1500 m or less, or when shallow fog is reported or forecast. RVR values are usually greater than reported visibility.

The United Kingdom standard RVR reporting incremental scale is 25m between 0 and 200m, 50m between 200 and 800m, and 100m above 800m. If traffic is more or less continuous, readings are taken every 30 minutes, or when a significant change in the normal visibility occurs.

If traffic is light, readings are taken 15 minutes before a take-off or landing. RVR is never forecast. There is no connection between RVR and Meteorological Observations and Reports (MOR), but there are factors which may be applied for regulatory purposes (see Air Law Notes).

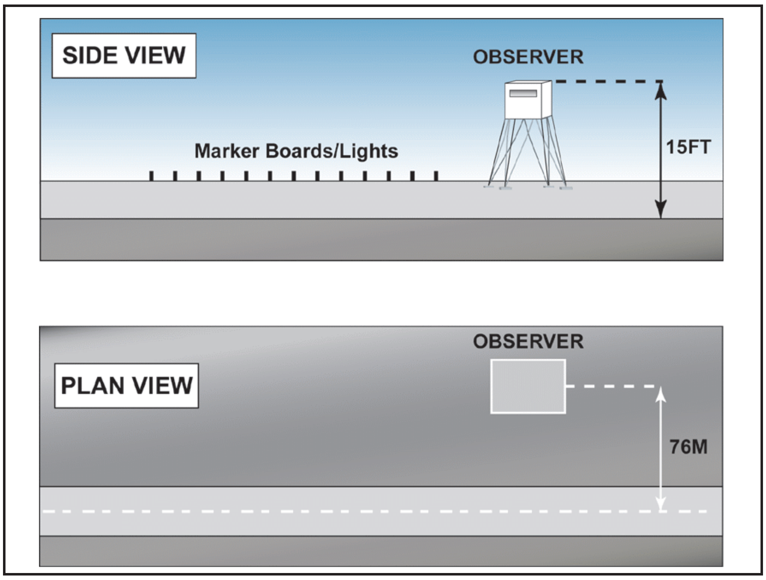


Figure 15.11: Runway visual range.

TRANSMISSOMETER

This is an electronic device where the intensity of a light a distance from a photo Electric cell gives an indication of the equivalent daytime visibility. This has the advantage of a constant measurement of visibility, but the disadvantage, as with the Gold Meter, is that only a small portion of the atmosphere is being sampled.

INSTRUMENTED RUNWAY VISUAL RANGE (IRVR)

Three **Transmissometers** are positioned alongside the runway.

A transmissometer comprises a light source transmitter and photo-electric cell receiver which are separated from each other.

The strength of current in the receiver is dependant on the clarity of the air between the transmitter and the receiver.

IRVR is reported when the normal visibility is 1500 metres or less, or when shallow fog is reported or forecast.

Readings are sent to ATC. Three readings can be given, one each for touch-down zone, mid-point and stop-end.

For example: R28L / 600 400 550.

RVR values less than 50 metres are reported as RBLW50 or M0050.
RVR values greater than 1500 metres are reported as P1500.
A trend over the preceding 10 minutes may be added to the end of the RVR value as an indication of the RVR increasing (U), decreasing (D) or remain the same (N).

For example: R26L/1100U.

Extremes in RVR are reported with "V" between the extreme values.

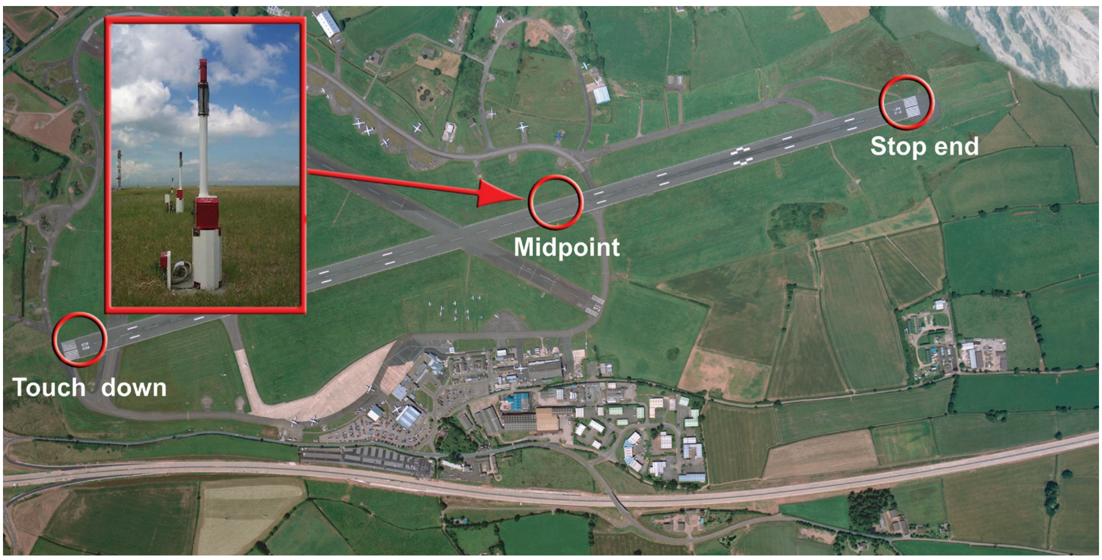


Figure 15.12: Instrumented runway visual range (IRVR).

SUMMARY OF VISIBILITY EFFECTS

- **By day** visibility is generally poor looking **up sun**.

- **By night** visibility is usually better looking **up moon**, because of light reflections from water surfaces, railway lines etc.

- In precipitation visibility is usually worst in **driving snow** and very poor in **drizzle** (because of the large number of small droplets).

- Night visibility is improved if the pilot does not look at bright cockpit lights.

QUESTIONS

1. What is the relationship between meteorological visibility and RVR in homogeneous fog?

    a. The met. vis. is generally less than the RVR.
    b. The met. vis. generally is greater than the RVR.
    c. The met. vis. generally is the same as the RVR.
    d. There is no specific relationship between the two.

2. Visibility is reduced by haze when:

    a. small water droplets are present.
    b. dust particles are trapped below an inversion.
    c. a light drizzle falls.
    d. a cold front just passed.

3. What is the average vertical extent of radiation fog?

    a. 2,000 ft.
    b. 5,000 ft.
    c. 10,000 ft.
    d. 500 ft.

4. When is the RVR reported at most airports?

    a. When the RVR decreases below 800m.
    b. When the RVR decreases below 2000m.
    c. When the meteorological visibility decreases below 1500m.
    d. When the meteorological visibility decreases below 800m.

5. Under which of these conditions is radiation fog most likely to form?

    a. Little or no cloud.
    b. Very dry air.
    c. Strong surface winds.
    d. Very low temperatures.

6. Which of the following conditions is most likely to lead to the formation of advection fog ?

    a. Dry cold air moving over a warm surface.
    b. Moist warm air moving over a cold surface.
    c. Moist cold air moving over a warm surface.
    d. Dry warm air moving over a cold surface.

7. When does frontal fog, also known as mixing fog, occur?

    a. When very humid warm air meets with very humid cold air.
    b. When very humid warm air meets with dry cold air.
    c. When very humid cold air meets with dry warm air.
    d. When very dry cold air meets with very dry warm air.

8. Flight visibility from the cockpit during approach in a tropical downpour can decrease to minimal:

a. about 500m.
b. about 1000m.
c. tens of metres.
d. about 200m.

9. The most likely reason for radiation fog to dissipate or become low stratus is:

a. an increasingly stable atmosphere.
b. surface cooling.
c. a low level temperature inversion.
d. increasing surface wind speed.

10. Advection fog can be formed when:

a. warm moist air flows over a warmer surface.
b. cold moist air flows over warmer water.
c. warm moist air flows over a colder surface.
d. cold moist air flows over a warmer surface.

11. Below a low level inversion visibility is often:

a. moderate or poor because there is no vertical exchange.
b. very good at night.
c. very good in the early morning.
d. moderate or poor due to heavy snow showers.

12. Which of the following conditions is most likely to lead to the formation of steam fog (arctic smoke)?

a. Warm air moving over cold water.
b. The sea is warmed by strong radiation from the sun.
c. The coastal region of the sea cools at night.
d. Cold air moving over warm water.

13. Which of the following circumstances most favour the development of radiation fog?

a. Moist air over land during clear night with little wind.
b. Warm moist air at the windward side of a mountain.
c. Maritime tropical air flowing over cold sea.
d. Advection of very cold air over much warmer sea.

14. (For this question use annex A)
Of the four radio soundings, select the one that indicates ground fog:

a. 1
b. 3
c. 4
d. 2

15. Which of the following statements is true concerning advection fog?

a. It forms when unstable air is cooled adiabatically.
b. It forms slowly and disappears rapidly.
c. It can be formed suddenly by day or night.
d. It forms at night or the early morning.

16. What wind conditions, occurring just before dawn, favour the formation of fog at an airport where the temperature is 15°C and the dew point is 14°C?

a. Westerly, 10kt variable.
b. Easterly, 10kt.
c. Calm.
d. Northerly, 10kt.

17. Advection is:

a. the same as convection.
b. horizontal motion of air.
c. vertical motion of air.
d. the same as subsidence.

18. Which of the following weather conditions favour the formation of radiation fog?

a. Light wind, extensive cloud, dry air.
b. Light wind, extensive cloud, moist air.
c. Strong wind, little or no cloud, moist air.
d. Light wind, little or no cloud, moist air.

19. At what time of day, or night, is radiation fog most likely to occur?

a. Shortly after midnight.
b. Shortly after sunrise.
c. At sunset.
d. Late evening.

20. What conditions are most likely to lead to the formation of hill fog?

a High relative humidity and an unstable air mass.
b. Clear skies, calm or light winds, with relatively low humidity.
c. Precipitation which is lifted by the action of moderate winds striking the range.
d. Humid stable air mass, wind blowing towards the hills.

21. Which of the following is most likely to lead to the dissipation of radiation fog ?

a. A build up of a high pressure area resulting in adiabatic warming associated with a sinking air mass.
b. A marked increase in wind velocity near the ground.
c. A marked decrease in wind velocity close to the ground.
d. Ground cooling caused by radiation during the night.

22. What are the differences between radiation fog and advection fog ?

    a. Radiation fog forms only on the ground, advection fog only on the sea.
    b. Radiation fog forms due to night cooling and advection fog due to daytime cooling.
    c. Radiation fog is formed by surface cooling in a calm wind. Advection fog is formed by evaporation over the sea.
    d. Radiation fog forms due to surface cooling at night in a light wind. Advection fog forms when warm humid air flows over a cold surface.

23. Frontal fog is most likely to occur:

    a. in winter in the early morning.
    b. in advance of a warm front.
    c. in rear of a warm front.
    d. in summer in the early morning.

24. While approaching your target aerodrome you receive the following message:
    RVR runway 23: 400m. This information indicates the:

    a. length of runway which a pilot in an aircraft on the ground would see, on the threshold of runway 23.
    b. meteorological visibility on runway 23.
    c. portion of runway which a pilot on the threshold of any of the runways would see, with runway 23 in service.
    d. minimum visibility at this aerodrome, with runway 23 being the one in service.

25. Which of the following is most likely to lead to the formation of radiation fog?

    a. Cold air passing over warm ground.
    b. Heat loss from the ground on clear nights.
    c. Dry, warm air passing over warm ground.
    d. The passage of fronts.

26. What type of fog is most likely to form over flat land during a clear night, with calm or light wind conditions?

    a. Orographic.
    b. Radiation.
    c. Advection.
    d. Steam.

27. In general, the meteorological visibility during rainfall compared to during drizzle is:

    a. greater.
    b. the same.
    c. less.
    d. in rain - below 1 km, in drizzle - more than 2 km.

28. Which type of fog is likely to form when air having temperature of 15°C and dew point of 12°C blows at 10 knots over a sea surface having temperatures of 5°C?

    a. Steam fog.
    b. Frontal fog.
    c. Advection fog.
    d. Radiation fog.

29. Steaming fog (arctic sea smoke) occurs in air:

a. with warm mass properties.
b. that is absolutely stable.
c. that is stable.
d. with cold mass properties.

30. The range of wind speed in which radiation fog is most likely to form is:

a. between 5 and 10kt.
b. above 15kt.
c. below 5kt.
d. between 10 and 15kt.

31. In the vicinity of industrial areas, smoke is most likely to affect surface visibility when:

a. there is a low level inversion.
b. the surface wind is strong and gusty.
c. cumulus clouds have developed in the afternoon.
d. a rapid moving cold front has just passed the area.

32. A significant inversion at low height is a characteristic of:

a. cumulus clouds.
b. terrestrial radiation.
c. the passage of cold front.
d. advection fog.

33. In unstable air, surface visibility is most likely to be restricted by:

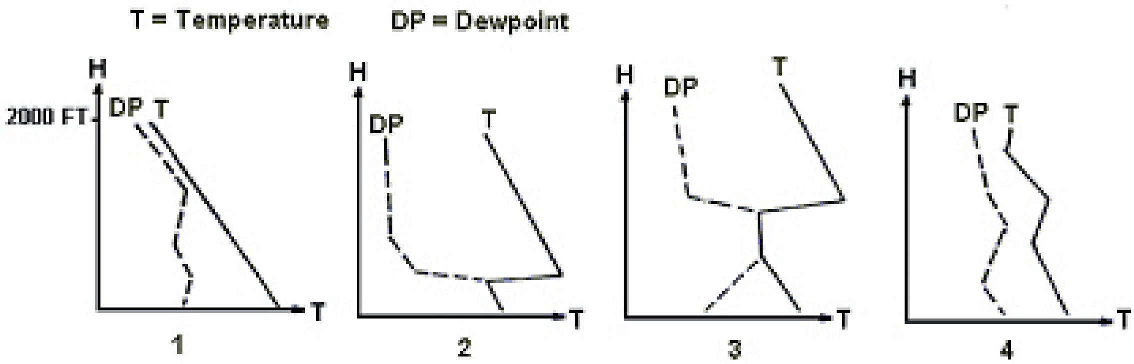
a. haze.
b. drizzle.
c. low stratus.
d. showers of rain or snow.

34. When the temperature and dew point are less than one degree apart the weather conditions are most likely to be:

a. clear and cool.
b. high scattered clouds.
c. unlimited visibility.
d. fog or low cloud.

ANNEX

A



ANSWERS

1. A	11. A	21. B	31. A
2. B	12. D	22. D	32. D
3. D	13. A	23. B	33. D
4. C	14. D	24. A	34. D
5. A	15. C	25. B	
6. B	16. C	26. B	
7. A	17. B	27. A	
8. C	18. D	28. C	
9. D	19. B	29. D	
10. C	20. D	30. C	

CHAPTER SIXTEEN

ICING

Contents

AN INTRODUCTION TO ICING AND ITS BASIC CAUSES

Airframe icing can cause a serious loss of aircraft performance and this will frequently result in a large increase in fuel consumption and some difficulty with aircraft control.
Icing is difficult to forecast and therefore there is a need for a full understanding of the processes involved.

Ice will form on an airframe if there is:

- Water in a super cooled liquid state.
- Ambient air temperature below 0°C (but see later).
- Airframe temperature below 0°C.

SUPERCOOLED WATER DROPLETS (SWD).

A supercooled water droplet is a droplet of water still in the liquid state although its temperature is below 0°C. If the SWD contains a **freezing nucleus** then the droplet will start to freeze. Mention was made in humidity chapter of **condensation nuclei**, but as the number of freezing nuclei in the atmosphere is considerably less than these, the state of supercooling is a frequent occurrence. Supercooled water droplets can exist in clouds at temperatures as low as -40°C. However, when an aircraft strikes a supercooled water droplet, it will start to freeze. Supercooled water droplet size is dependant on the size of the basic cloud droplet, (controlled by cloud type) and the temperature.

Sizes will be:

- **0°C to -20°C**; both large and small supercooled water droplets can exist. The cloud type will govern the size or droplet supported. For example Stratiform cloud will only support small droplets even through the temperature may allow for both sizes. Cumuliform cloud can hold both types, but large droplets will be predominant.

- **-20°C to -40°C**; small supercooled water droplets can exist. At these temperatures large supercooled water droplets will have become ice.

- **Below -40°C**; only very small supercooled water droplets can exist. All others will have become ice. Freezing will occur without the aid of nuclei.

THE EFFECTS OF ICING

- **Aerodynamic.** Ice tends to form on leading edges, thereby spoiling the aerodynamic shape. The result is **reduced lift, increased drag, increased weight, increased stalling speed** and **increased fuel consumption.**

  - Ice, frost or snow of a thickness and roughness similar to coarse sandpaper can reduce lift by 30% and increase drag by 40%.

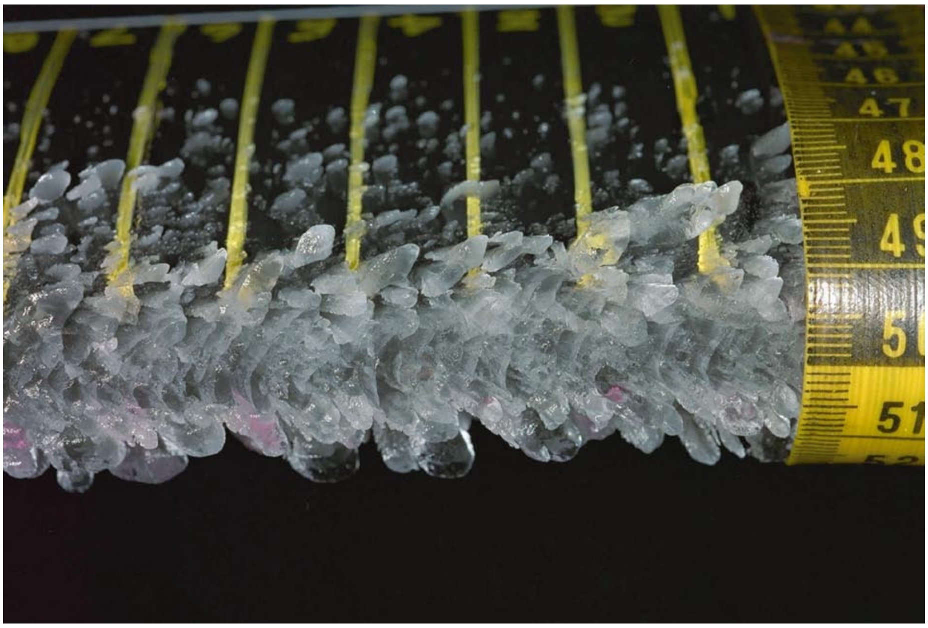
  - It is also possible for pieces of ice to break off other surfaces and to jam between the control surfaces and wings and tail.

- **Weight.** In severe conditions, ice can form at a rate of 1 inch in 2 minutes.
    - There will be a loss of stability due to the weight of ice not being uniform across the airframe.
    - This can lead to a displaced C of G. Similar uneven weight of ice on propeller blades can cause severe engine vibration.
    - Ice breaking off propellers can cause skin damage.
- **Instrument effects.** Ice can block pressure heads and the readings of ASIs, VSI, altimeters and mach meters can be in error as a result.
- **General.** Windscreens and canopies can be obscured.
    - A thin film of ice/frost can cause skin friction.
    - Ice in landing gear wells can affect retraction.
    - Ice on aerials can cause static interference.

CLEAR (OR GLAZE) ICE

If a large supercooled water droplet strikes an aircraft, it will start to freeze and this will release **latent heat** . This will delay the freezing process whilst part of the supercooled water droplet will flow back over the impact surface forming **clear ice**. The amount of a supercooled water droplet that freezes on impact is 1/80th of the droplet for each degree below freezing.

Clear or glaze ice is a transparent form of ice formed by **large** supercooled water droplets, it can be very dangerous. There can be much flowback and the ice appears transparent because there is no air trapped under the flowback icing. The lamination of the ice into layers increases its strength and because it has less air in it this type of ice is much stronger and much harder to remove.



Clear Ice

The ice will destroy aerofoil shapes and its weight can cause problems of control because the build-up can be uneven.

Propeller icing can cause severe vibrations and as the ice adheres strongly, when it breaks off, the pieces can be large and cause skin damage.

Clear ice forms in Ns (especially when orographically intensified), Cu and Cb at temperatures from 0 to -20°C.

It should be noted that clear ice often forms with another form of ice called rime ice, the latter being formed from the smaller supercooled water droplets in the cloud. When the two types of ice occur together it is usually described as mixed ice. This is most common in Ns cloud and in the middle level of cumuliform clouds.

RIME ICE

When the super cooled water droplets are small (at very low temperatures) or when cloud droplets are small, the whole droplet freezes instantly on impact, each droplet sticking to the surface it strikes and becoming solid almost at once.

Air becomes trapped between each frozen droplet, which makes the ice white. Rime ice is characterised by being a **white opaque** deposit with a granular or flake like texture. It is caused by **small**, super cooled water droplets freezing instantly. This types of ice is weak and very brittle. There is little or no flowback. The ice grows out from the leading edges and is compacted by the airstream.

Some loss of aerofoil shape can occur and **air intakes** can be affected.

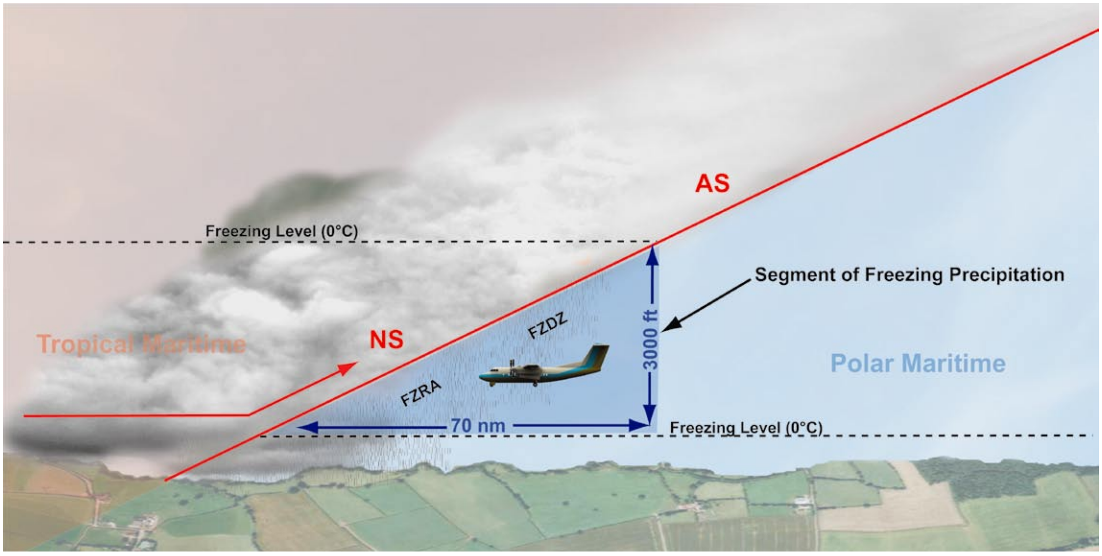
Rime ice can occur in any cloud where there are small super cooled water droplets; Ns, As, Ac, SC, St and the parts of heap clouds where super cooled water droplets are small which mainly near the top of the cloud.

RAIN ICE

Rain ice is the most dangerous form of icing and it occurs in **rain** which becomes **supercooled** by falling through an **inversion** into air below 0°C. The supercooled water droplets are now rain sized. The rain does not freeze in the air but once it impacts the aerofoil it freezes to form **clear ice** with significant flowback.

Rain ice builds up very quickly and a pilot's action should be to turn onto a reciprocal heading immediately. If the pilot perceives the rain ice very late, then the course of action would be to climb into the warmers layers above. Turning at a late stage into the icing conditions will increase the stall speed and the return journey back out of the rain ice zone will double the ice on the aircraft from when the pilot first elected to turn around.

Rain ice occurs in a narrow range of altitudes at low level, about 1000 ft, ahead of a **warm front** or **occlusion** and is associated particularly with the moderate continuous rain which often falls from **Nimbo Stratus** cloud, this is illustrated on the next page.



Factors Affecting the Formation of Rain Ice.

Rain ice is rare over the UK, but is common in winter over North America and Central Europe.

PACK SNOW

Pack snow is icing which is due to a mixture of super cooled water droplets and **snow**. It can block air intakes and other aircraft openings. Normally the effects are **slight**.

HOAR FROST

Hoar frost is a **white crystal deposit** which appears similar to frost on the ground. It occurs in **clear air**. Hoar frost will form if the airframe temperature is **below** 0°C and the ambient temperature is lowered to saturation level. Water vapour in contact with the airframe is converted to ice crystals without becoming liquid, i.e. **sublimating**. This process requires the presence of another type of ice nucleus, the **sublimation nucleus**. Their composition is usually inorganic, e.g. volcanic dust, clay or soil particles.

There are two situations where hoar frost can occur:

- **On the ground.**

  This usually occurs at night and is similar to the frost which forms on a car. It must be cleared before take-off because:

  - Skin friction will increase the take-off run.
  - Windscreens will be obscured.
  - Radio interference will be caused by ice on aerials.

- **In flight**
  Hoar frost can occur in flight in the following cases:

  - If a **rapid descent** is made from a **very cold** region to a **warm moist** layer.
  - If a climb is made from a temperature **below 0°c** through an **inversion.**

The icing is not severe. The effects can be overcome by flying in a region where the temperature is above 0°C or by flying faster to increase the kinetic heating. It should quickly disappear once the aeroplane starts to warm up.

FACTORS AFFECTING THE SEVERITY OF ICING

- **Size of the super cooled water droplets.** This is dependant on cloud type and temperature as follows:

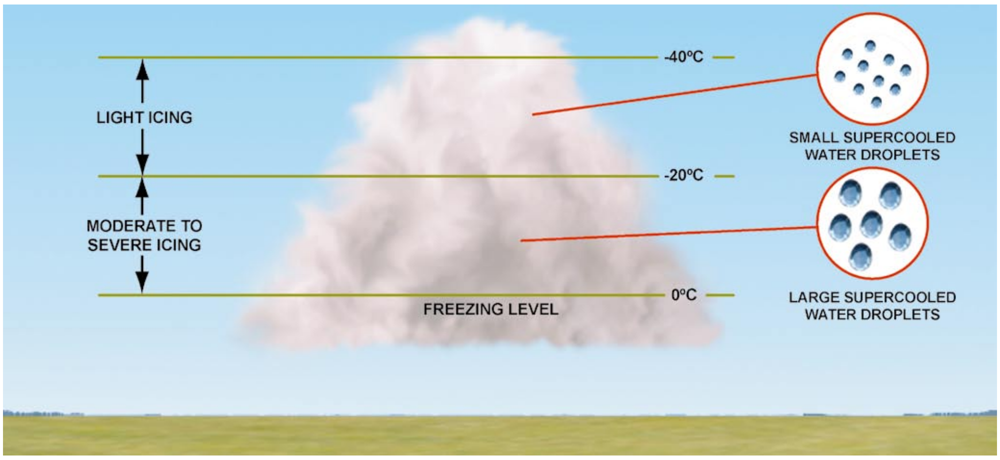
TYPE	DETAILS
MODERATE /HEAVY CLEAR ICE	Super cooled water droplets can only be large in Cu, Cb, Ns and then only when temperatures are in the general range 0°C to -20°C.
LIGHT/MODERATE RIME ICE	For layer clouds small super cooled water droplets are present from 0°C to -10°C
LIGHT RIME ICE	For layer clouds super cooled water droplets are smaller below -10°C.
RIME ICE	Super cooled water droplets are also small in Cu, Cb and Ns from -20°C to -40°C.

At -40°C and below, super cooled water droplets are very small and icing is usually negligible.

- **Concentration of super cooled water droplets.** The concentration of water droplets is **higher** in **heap** clouds because the up currents are stronger. Hence Cu and Cb clouds have a high concentration of super cooled water droplets and this causes the icing to be **severe**.

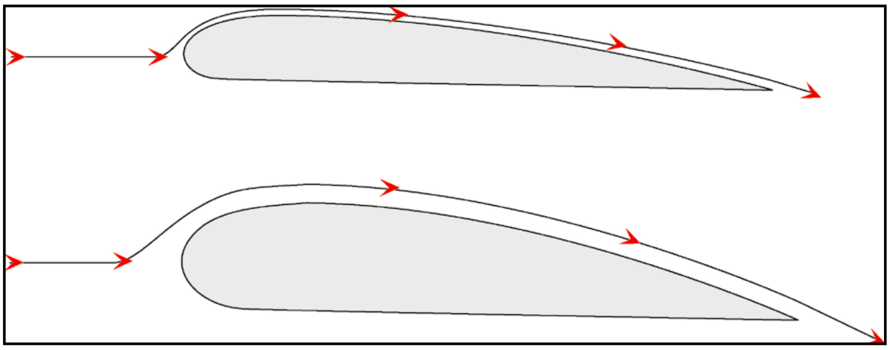
  There is always a **greater** concentration of droplets near the base of the cloud where it is warmest. Icing severity (by cloud types) tends to be:

  - Cu, Cb - Severe.
  - Ns- Moderate to severe.
  - Sc- Light to moderate.
  - Others - Light. (except Ci, Cs, Cc)



The Concentration of Super Cooled Water Droplets

- **Shape of the aircraft.** **Thin** shapes collect ice more rapidly than **high drag** ones. On of thin wings the airflow separation point is closer to the leading edge and therefore droplets are more likely to strike and freeze. Thin wings and pressure heads are therefore liable to rapid icing. High speeds also result in a greater ice hazard because the airframe strikes a greater number of super cooled water droplets in unit time. Kinetic heating may cancel this effect.



Thin Wing Collect Ice More Rapidly than Thick Wings

- **Orographic Intensification**. The undulation of hills and mountains forces air to rise. This has two effects. Firstly this vertical deflection of air increases the capability of the cloud to hold larger supercooled water droplets and also more of them. This will undoubtedly increase the intensity of the icing. The second effect of the orography is that the rising air may have a temperature lapse rate faster than the ambient air and therefore the freezing level around the mountain will fall. Therefore, a pilot may feel that flying just below the freezing level in the cloud is safe from icing. However with the approach of a mountain, the freezing level will drop putting the aeroplane in the zone of temperature between 0°C and -15°C, which is the zone of large supercooled water droplets.

- **Cloud base temperature.** The higher the temperature, the greater the water vapour content.

  Condensation first occurs at the base, and there is therefore a greater amount of free water to become ice on an airframe. The free water content at any level in the cloud increases with base temperature.

  Concentration of drops will increase and so will icing severity.

- **Kinetic heating.** Although a rise of temperature due to kinetic heating to above 0°C may prevent ice acretion, a rise to below 0°C may increase the risk and the severity .

$$\text{Skin Temp} = \text{OAT} + \left(\frac{\text{TAS}}{100}\right)^2$$

ICING FORECASTS

Forecasting airframe icing is a matter of forecasting clouds, both by type and vertical extent. The degree of airframe icing is classed as **light, moderate** , or **severe .**

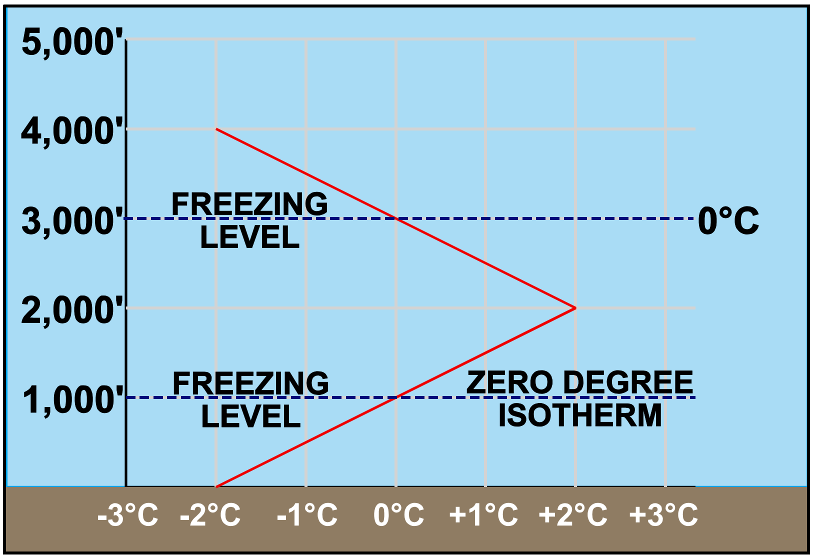
When rain ice is expected, it will be mentioned specifically in the forecast. Forecasts of engine icing are not normally provided.

FREEZING LEVEL

The height where ambient temperature is zero is called the freezing level.

It is usually given in forecasts on an area basis by reference to the height of the **Zero Degree Isotherm**.

With an inversion, two freezing levels are possible.



Two freezing levels in an inversion

Freezing levels in the south of the United Kingdom average 11,000 ft in August and 3,000 ft in February.

REPORTING OF ICING

The following extract from the UK Air Pilot is a useful description of the degree of icing encountered in flight.

Airframe Icing

All pilots encountering un-forecast icing are requested to report time, location, level, intensity, icing type- and aircraft type to the ATS unit with whom they are in radio contact. It should be noted that the following icing intensity criteria are reporting definitions; they are not necessarily the same as forecasting definitions because reporting definitions are related to aircraft type and to the ice protection equipment installed, and do not involve cloud characteristics. For similar reasons, aircraft icing certification criteria might differ from reporting and/or forecasting criteria.

Airframe Icing Intensity Criteria	
Intensity	Ice Accumulation
Trace	Ice becomes perceptible. Rate of accumulation slightly greater than rate of sublimation. It is not hazardous even though de-icing/anti-icing equipment is not utilised, unless encountered for more than one hour
Light	The rate of accumulation might create a problem if flight in this environment exceeds 1 hour. Occasional use of de-icing/anti-icing equipment removes/prevents accumulation. It does not present a problem if de-icing/anti-icing equipment is used.
Moderate	The rate of accumulation is such that even short encounters become potentially hazardous and use of de-icing/anti-icing equipment, or diversion, is necessary.
Severe	The rate of accumulation is such that de-icing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.
*Rime Ice: Rough, milky, opaque ice formed by the instantaneous freezing of small supercooled water droplets. *Clear Ice: A glossy, clear, or transparent ice formed by the relatively slow freezing of large supercooled water droplets.	

Icing reporting advice

PISTON ENGINE INDUCTION ICING

- **Impact icing.** Ice in intake areas caused by **snow, snow** and **rain** mixed or **super cooled water droplets**.
  For turbo-charged (fuel injection) engines, this is the only icing hazard.

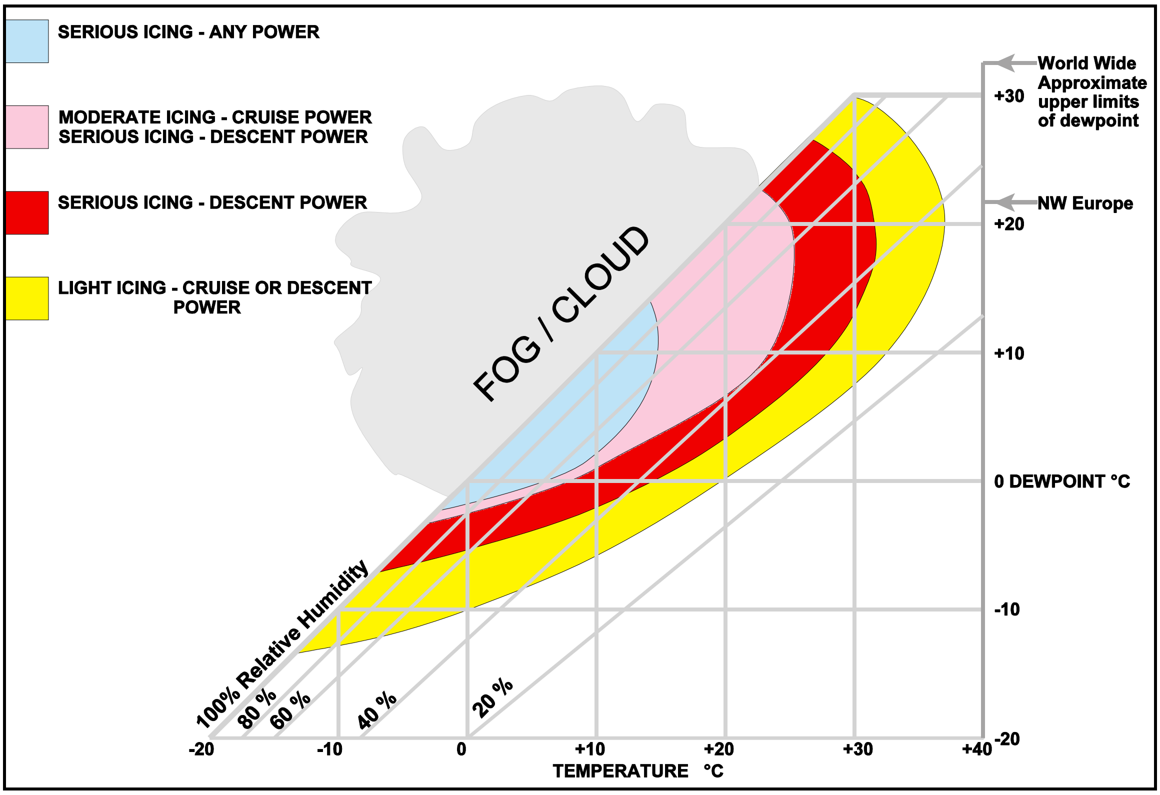
- **Fuel icing.** This is caused by water in the fuel freezing in bends in the induction piping.

- **Carburettor icing.** This is caused by:

  - The sudden temperature drop as **latent heat** is absorbed when fuel evaporates.

  - The temperature drop due to the **adiabatic expansion** of the air as it passes through the venturi.

Carburettor icing is most dangerous within a temperature range of -10 °C to +25°C, in cloud, fog or precipitation **at any power setting**.



The Wide Range of Ambient Conditions Conducive to the Formation of Carburettor Icing.

JET ENGINE ICING

Ice may form on intake lips or inlet guide vanes, if this breaks away and enters the engine, blade damage may occur.

Some icing may occur in the early inlet stages, particularly at high engine speeds and low aircraft forward speeds (eg during the approach), where much adiabatic cooling may occur and temperature reductions of 5°C and more can result.

This icing is particularly prevalent in freezing conditions which are associated with any form of precipitation; as a consequence of this, engine anti-icing **must be selected "ON" when there is precipitation and the indicated outside air temperature is +10°C and below.**

JET ENGINE OPERATION IN ICING CONDITIONS

- Engine power indications may be in error if there is ice on engine inlet (P1) pressure probes.

- Engine igniters should be used in potential icing conditions, otherwise engine failure is possible.

- Long flights at very low temperatures may cause fuel freezing and fuel freezing point specification for the aircraft type should be known.

- Clear ice can occur at ambient temperatures above zero when water droplets come into contact with an aircraft whose upper surfaces are at or below zero.

    - This low skin temperature can be caused by a very low fuel temperature conducting through the skin.

    - This icing can also occur on the ground in high humidity, rain, drizzle or fog. It could then be snow covered and difficult to detect.

    - Break up of this ice on take-off can be particularly hazardous to rear engined aircraft.

- Operation of anti-icing or deicing equipment usually implies a performance penalty.

QUESTIONS

1. Large supercooled water drops, which freeze on impact on an aircraft, form

   a. rime ice
   b. hoar frost
   c. cloudy ice
   d. clear ice

2. Two aircraft, one with a sharp wing profile (S), and the other with a thick profile (T), are flying through the same cloud with same true airspeed. The cloud consists of small supercooled droplets. Which of the following statements is most correct concerning ice accretion?

   a. Aircraft T experiences more icing than S.
   b. Aircraft S and T experience the same amount of icing
   c. Neither of the aircraft accumulate ice due to the small size of droplets.
   d. Aircraft S experiences more icing than T.

3. Supercooled droplets can be encountered

   a. only in winter above 10000 FT
   b. only in winter at high altitude
   c. at any time of the year
   d. in winter only in high clouds

4. Freezing precipitation occurs

   a. only in the precipitation of a cold front
   b. only in the precipitation of a warm front
   c. mainly in the form of freezing hail or freezing snow
   d. mainly in the form of freezing rain or freezing drizzle

5. You have been flying for some time in dense layered cloud. The outside air temperature is -25°C. Which of the following statements is true?

   a. Severe airframe icing is quite likely under these conditions
   b. If you do not have weather radar on board there is no need to worry as CB is unlikely to form in such cloud
   c. In a dense layered cloud icing is unlikely
   d. Severe airframe icing is unlikely under these conditions

6. A vertical temperature profile indicates the possibility of severe icing when the temperature profile

   a. intersects the 0°C isotherm twice
   b. coincides with a dry adiabatic lapse rate
   c. indicates temperatures below -40°C
   d. indicates temperatures above 3°C

7. In which of these cloud types can icing be virtually ruled out?

   a. NS
   b. CU
   c. CI
   d. SC

8. Glaze or clear ice is formed when supercooled droplets are

a. large and at a temperature just below freezing
b. small and at a temperature just below freezing
c. small and freeze rapidly
d. of any size at temperatures below -35°C.

9. A small supercooled cloud droplet that collides with an airfoil will most likely

a. freeze immediately and create clear ice.
b. travel back over the wing, creating rime ice.
c. travel back over the wing, creating clear ice.
d. freeze immediately and create rime ice.

10. How does a pilot react to heavy freezing rain at 2000 FT/AGL, when he is unable to deice, nor land?

a. He ascends to the cold air layer above.
b. He continues to fly at the same altitude.
c. He turns back before the aircraft loses maneuverability.
d. He descends to the warm air layer below.

11. In which of these cloud types can icing be virtually ruled out?

a. SC
b. NS
c. CS
d. AS

12. Hoar frost forms on an aircraft as a result of

a. droplets forming on the aircraft and then freezing
b. small super-cooled droplets striking the aircraft
c. water vapour turning directly into ice crystals on the aircraft surface
d. freezing rain striking the aircraft

13. While descending through a cloud cover at high level, a small amount of a white and rough powder-like contamination is detected along the leading edge of the wing. This contamination is called:

a. Rime ice.
b. Clear ice.
c. Mixed ice.
d. Frost.

14. Supercooled droplets are always

a. at a temperature below -60°C
b. at a temperature below freezing
c. small and at a temperature below freezing
d. large and at a temperature below freezing

15. How does freezing rain develop?

a. Rain falls through a layer where temperatures are below 0°C
b. Rain falls on cold ground and then freezes
c. Through melting of sleet grains
d. Through melting of ice crystals

16. Freezing rain occurs when

a. snow falls into an above-freezing layer of air
b. rain falls into a layer of air with temperatures below 0°C
c. ice pellets melt
d. water vapour first turns into water droplets

17. During the formation of rime ice in flight, water droplets freeze

a. slowly and do not spread out
b. slowly and spread out
c. rapidly and spread out
d. rapidly and do not spread out

18. Under which conditions would you expect the heaviest clear ice accretion to occur in a CB?

a. Between -30°C and -40°C
b. Between -2°C and -15°C
c. Between -20°C and -30°C
d. Close to the freezing level

19. Clear ice is dangerous because it:

a. is not translucent and forms at the leading edges
b. spreads out and contains many air particles
c. is heavy and is difficult to remove from the aircraft surfaces
d. is translucent and only forms at the leading edges

20. At what degree of icing should ICAO's "Change of course and/or altitude desirable" recommendation be followed?

a. Extreme
b. Moderate
c. Light
d. Severe

21. Hoar frost is most likely to form when

a. taking off from an airfield with a significant ground inversion.
b. flying inside convective clouds.
c. flying inside stratiform clouds.
d. flying in supercooled drizzle.

22. The most dangerous form of airframe icing is

a. clear ice.
b. hoar frost.
c. dry ice.
d. rime ice.

23. Freezing fog exists if fog droplets

a. are supercooled
b. are frozen
c. are freezing very rapidly
d. freeze when temperature falls below zero

24. Supercooled droplets can occur in

a. clouds but not in precipitation
b. precipitation but not in clouds
c. clouds but not in fog
d. clouds, fog and precipitation

25. What type of fronts are most likely to be present during the winter in Central Europe when temperatures close to the ground are below 0°C, and freezing rain starts to fall?

a. Warm fronts, warm occlusions.
b. Cold occlusions.
c. High level cold fronts.
d. Cold fronts.

26. In which environment is aircraft structural ice most likely to have the highest rate of accretion?

a. Stratus clouds.
b. Snow.
c. Freezing rain.
d. Cirrus clouds.

27. Which of the following conditions is most likely to cause airframe icing?

a. SHSN
b. PE
c. +FZRA
d. GR

28. In which of the following situations can freezing rain be encountered?

a. Ahead of a warm front in the winter
b. Ahead of a cold front in the winter
c. Behind a warm front in the summer
d. Ahead of a cold front in the summer

29. Which of the following statements is true regarding moderate-to-severe airframe icing?

    a. It may occur in the uppermost levels of a cumulonimbus capillatus formation
    b. It always occurs in altostratus cloud
    c. It is likely to occur in nimbostratus cloud
    d. It will occur in clear-sky conditions

30. On the approach, the surface temperature is given as -5°C. The freezing level is at 3000 FT/AGL. At 4000 FT/AGL, there is a solid cloud layer from which rain is falling. According to the weather briefing, the clouds are due to an inversion caused by warm air sliding up and over an inclined front. Would you expect icing?

    a. Yes, between ground level and 3000 FT/AGL.
    b. Yes, but only between 3000 and 4000 FT/AGL.
    c. No, flights clear of cloud experience no icing.
    d. No, absolutely no icing will occur.

ANSWERS

1.	D	11.	C	21.	A
2.	D	12.	C	22.	A
3.	C	13.	A	23.	A
4.	D	14.	B	24.	D
5.	D	15.	A	25.	A
6.	A	16.	B	26.	C
7.	C	17.	D	27.	C
8.	A	18.	B	28.	A
9.	D	19.	C	29.	C
10.	C	20.	B	30.	A

CHAPTER SEVENTEEN

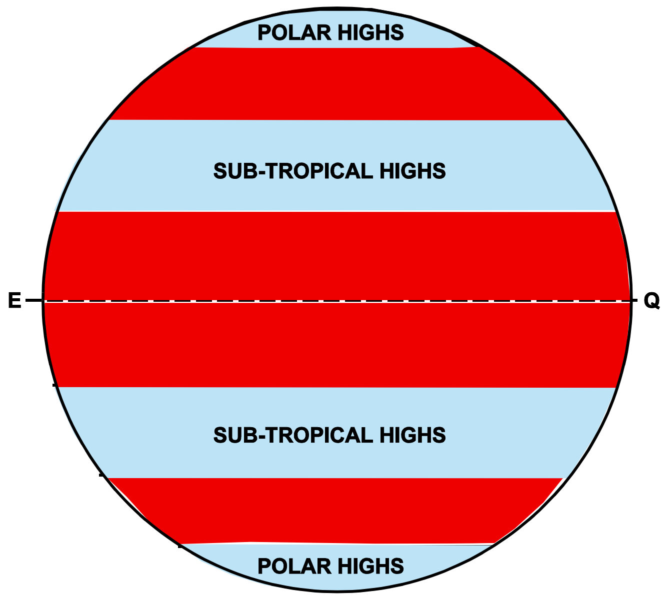
AIR MASSES

Contents

AIRMASS INTRODUCTION

An air mass is a large volume of air where the humidity and temperature in the horizontal are more or less constant.

The temperature and humidity properties are obtained by the air remaining roughly stationary over a surface where conditions are generally constant for some length of time - a high pressure area. Therefore at source, all air masses must be **stable**.



General Source Regions

The basic properties of stability, temperature and humidity can change as an air mass moves over surfaces with different properties.

An air mass moving to a warmer area will become heated in the lower layers and should become:

- Unstable.
- Warmer.
- Lower relative humidity.

An air mass moving to a colder region should become:

- More stable.
- Colder in the lower layers.
- Have an increased relative humidity.

AIRMASS IDENTIFICATION

Air masses are identified by temperature/latitude:

- Tropical.
- Polar.
- Arctic

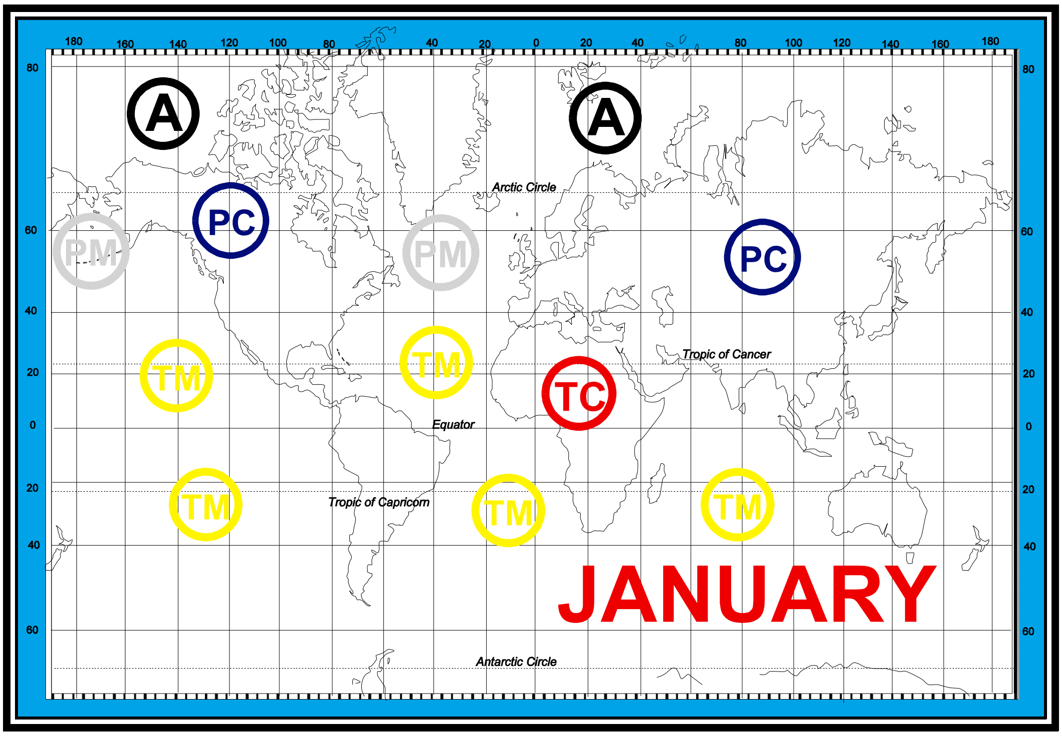
and by humidity or sea/land source:

- Maritime.
- Continental.

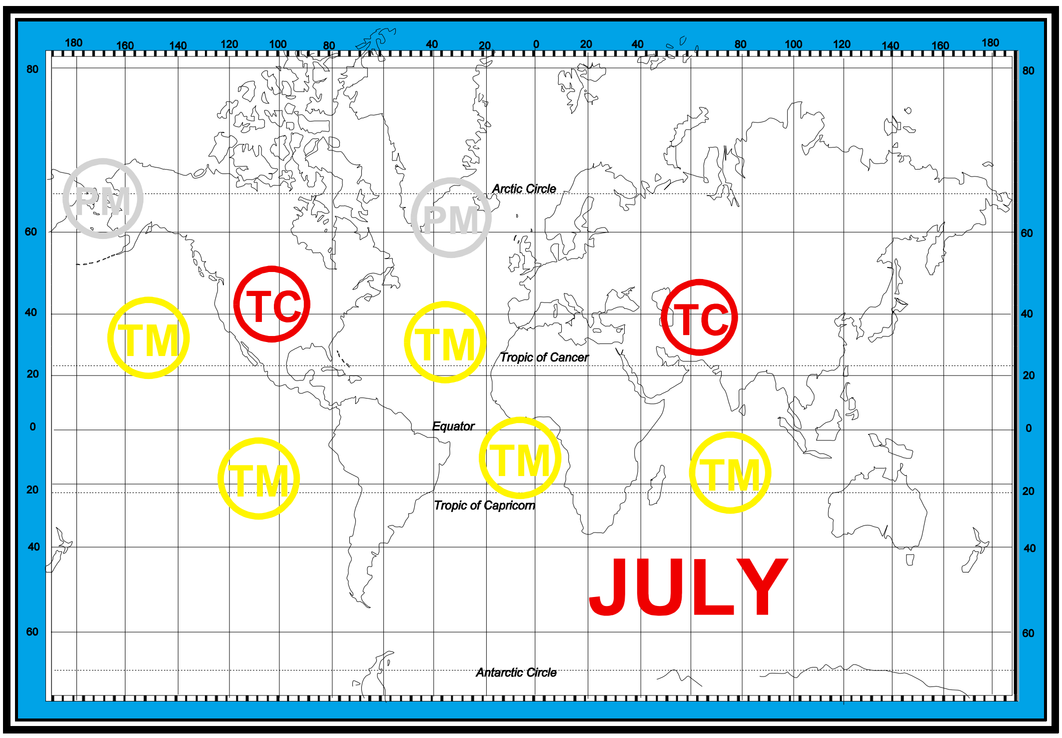
Hence the main air masses are named:

- Arctic (not usually sub-divided.
- Polar Maritime (PM).
- Polar Continental (PC).
- Tropical Maritime (TM).
- Tropical Continental (TC).

It is usually a straightforward exercise to name an airmass. If the airmass is lying over a warm tropical ocean, the airmass is classified as Tropical Maritime (TM). If the airmass lies over a cold continent in winter, the airmass is classified as Polar Continental (PC).



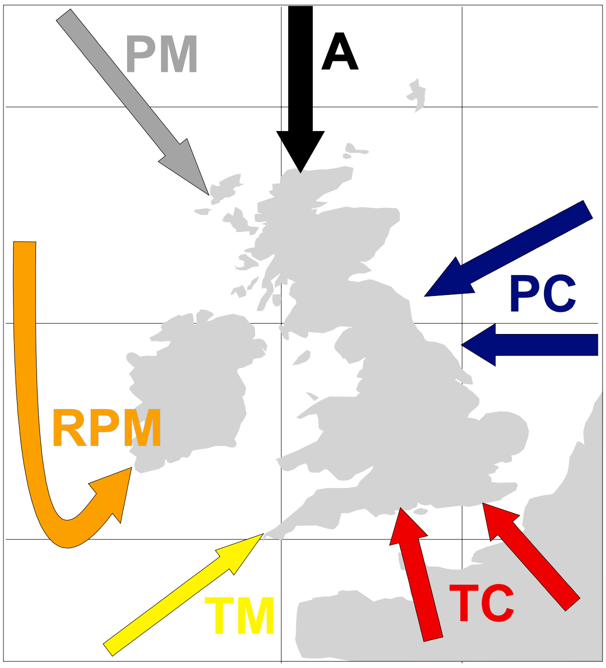
Air Mass Source Regions in January



Air Mass Source Regions in July.

AIR MASSES AROUND NW EUROPE

(Air masses affecting this area affect other parts of the world in a similar fashion.)



Air Masses Affecting the British Isles.

- **Polar Maritime**.

  Source: North Atlantic: stable, cold, absolute humidity **low**, relative humidity **high**.

  Weather: Cold, moist, NW airflow. On approaching UK becomes unstable giving Cu, Cb, heavy showers, sometimes hail and thunderstorms. Cu, Cb most likely over NW coasts. Visibility good except in showers. Bumpy flying. At night inland the cloud dissipates, the clearing skies causing a low level inversion with stable air below - ideal conditions for radiation fog.

- **Polar Continental**.

  Source: Siberia (winter only). Stable, very cold and dry.

  Weather:

  - If the airflow is mainly from the E via continental Europe, then very cold, very dry, no cloud, no precipitation. Remains stable - good visibility but smoke possible.

  - If the airflow is mainly from over the North Sea from the NE, the air will become unstable, with large Cu and snow showers on the E coast of UK. Remains very cold. Visibility good except in showers.

- In summer the air mass virtually disappears. However, with high pressure over Scandinavia in early to mid summer, there will be a NE flow over the North Sea to E UK. The air originates as dry, warm and stable. Over the North Sea it becomes moist and cool. This results in **Haar** conditions over E coast of N England and Scotland - very low St, drizzle, advection fog, poor visibility.

➢ **Tropical Continental**.

Source: N Africa, SE Europe and the Balkans. Mainly summer, warm, dry, stable.

Weather: A warm, dry S or SE flow. No cloud or precipitation, warm or very warm. Visibility good except in dust haze which can occur.

➢ **Tropical Maritime.**

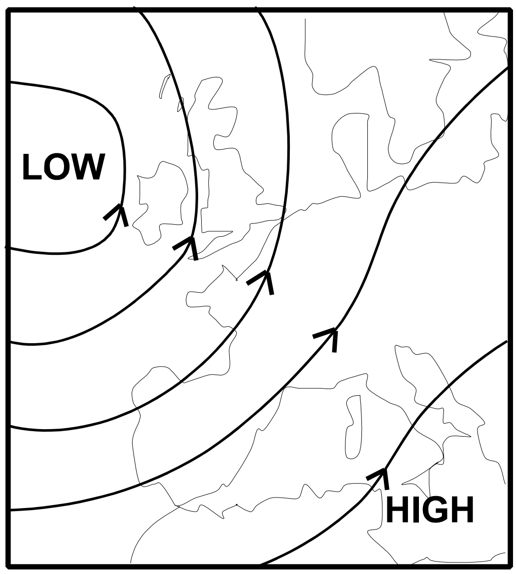
Source: The Azores. Warm, stable, absolute humidity **high**, RH **moderate**.

Weather: A warm, moist SW air flow. As the air moves North, the temperature reduces (but remains warm). Stability and RH increase. Low cloud, St and Sc. Drizzle or light precipitation. Visibility poor. Advection fog over sea area late spring, early summer, over land winter, early spring. In high summer insolation and convection break down the stability resulting in clear skies or possibly a few small Cu.

➢ **Arctic**: The source is the polar ice cap, where it is stable, very cold with low absolute humidity. The humidity increases as it approaches N Scotland and it becomes unstable from the warmer sea. It gives a cold N airflow with large Cu, heavy snow falls, blizzards and very low temperatures in the extreme N of Scotland. It occurs only infrequently in winter.

➢ **Returning Polar Maritime.**

This is Polar Maritime air which has moved to the S of the North Atlantic and approaches from the W or SW. In its lower layers tropical maritime conditions are acquired and retained. It will still be unstable at higher levels. It can quickly become unstable giving Cu, Cb and Ts.



Returning Polar Maritime

- **Equatorial**
  This does not affect the UK or Northern Europe. The weather patterns associated with the equatorial sources include; **Trade Winds, Monsoons, The Inter Tropical Convergence Zone** and **Tropical Revolving Storms**. The main properties are high temperatures and high humidity (both absolute and relative).

OTHER AREAS

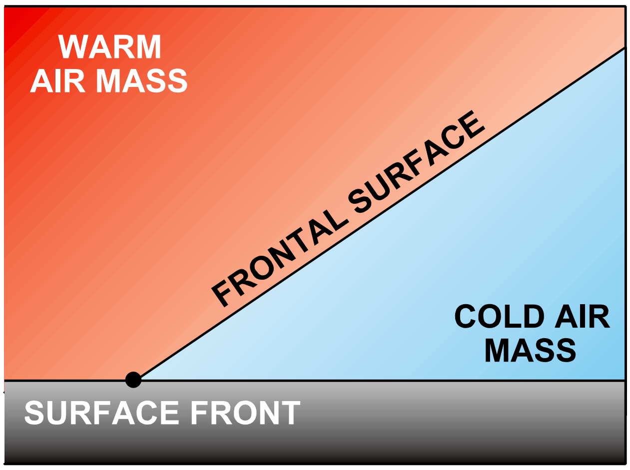
Polar Maritime (PM) air also has a source in the N Pacific. Tropical Maritime (TM) air has sources in the Pacific and the sub-tropics. Polar Continental (PC) air has a source in N America which considerably affects N American weather.

INTRODUCTION FRONTS

A front is a boundary zone or surface of interaction between two air masses of different temperature.

When the two air masses meet, the warmer will rise over the top of the colder because of the difference in density. The frontal surface where they meet is frequently, but not always, active with much cloud and precipitation. The ground position of the frontal surface is shown on synoptic charts.

A front is usually only a few miles wide. If the term ZONE is used, then the region of interaction is much wider (up to 300 nm).



Front

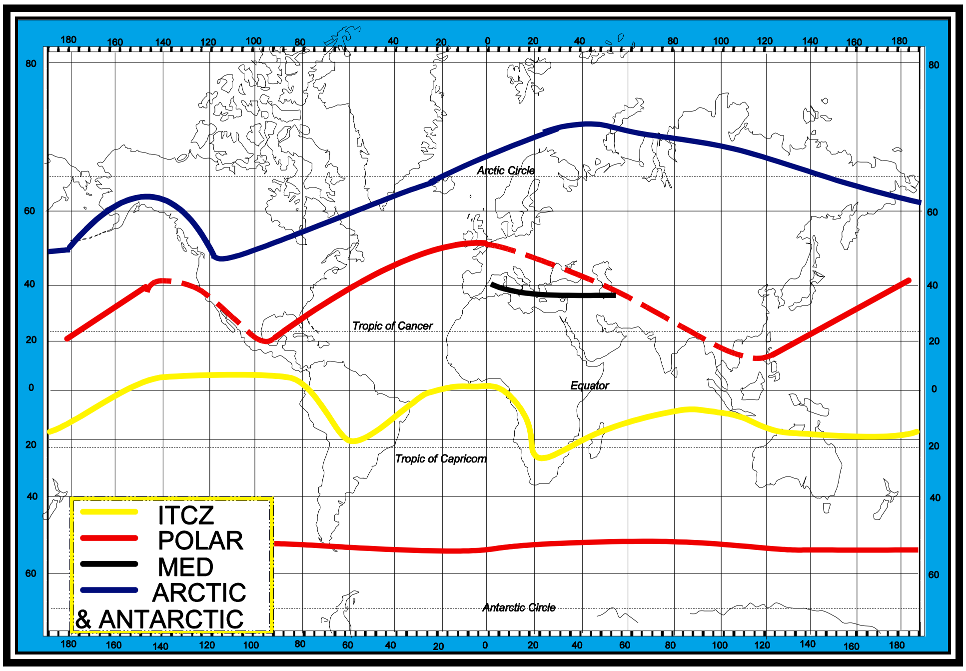
The main global fronts are:

- The Polar Front.
- The Arctic Front.
- The Mediterranean Front.
- The Inter Tropical Convergence Zone (ITCZ).

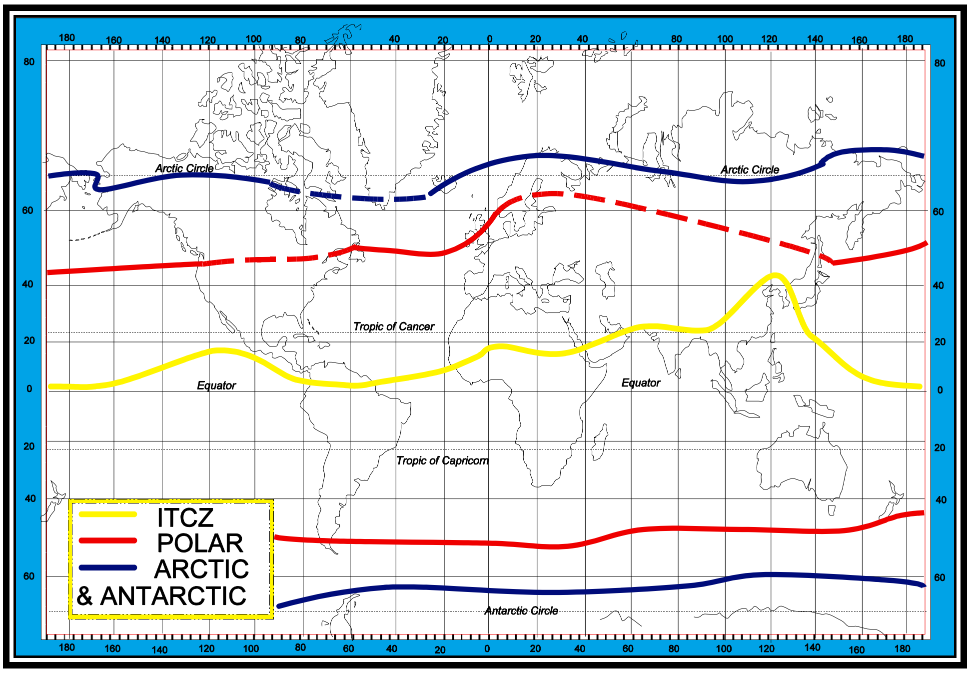
THE POLAR FRONT

The Polar Front is the boundary between polar and tropical air masses. It extends across the Atlantic and Pacific from 35N to 65N and in the southern hemisphere around 50S.

There are numerous waves on the front which cause depressions which contain their own portions of the polar front. NW Europe is almost always within the origin of the Polar Front.



Frontal Positions in January.



Frontal Positions in July.

THE ARCTIC FRONT

The Arctic Front is the boundary between the Arctic and the Polar air masses and may have an associated Jet Stream. It lies at higher latitudes than the Polar Front but sometimes moves into temperate latitudes (south Greenland to north of Norway) in winter and spring. (See Figures opposite).

THE MEDITERRANEAN FRONT

The Mediterranean Front is the boundary between Polar Continental or Maritime air from Europe and Tropical Continental air from North Africa. It extends west to east across the middle of the Mediterranean Sea as far as the Caspian. The front disappears in Summer.

THE INTERTROPICAL CONVERGENCE ZONE (ITCZ)

The Intertropical Convergence Zone is the broad zone of separation between the air masses either side of the heat equator. The air is conveyed by the Trade Winds north east and south east. Subject to large seasonal movement overland, but much less over the sea. Sometimes known as the **Thermal Equator** or **Equatorial Trough.**

FRONTAL FACTORS

Fronts in a locality are named warm or cold, dependant upon whether warm or cold air is replacing the other. All fronts have a slope with height so that in side view the front is a sloping surface. Whilst fronts are normally associated with convergence and ascending air, giving much cloud and bad weather, it is possible for air masses to flow side by side with little interaction, such front is termed quazi stationary. Fronts will remain in this manner unless factors come into play that disturb them.

The factors concerned are:

Equilibrium
The Pressure Gradient Force (PGF) is towards the front from both the cold and the warm side then under these conditions the wind would be Geostrophic, blowing parallel to the front. The frontal surfaces would be in equilibrium with no tendency for the cold air to undercut the warm.

It can be concluded that if the wind is Geostrophic, there is equilibrium and little weather.

Convergence
There is always convergence in any depression but this will normally be small and give light precipitation and thin cloud only. It follows therefore that there must be unbalancing of the equilibrium, causing lifting and undercutting of the warm air, for extensive cloud to occur together with heavy precipitation.

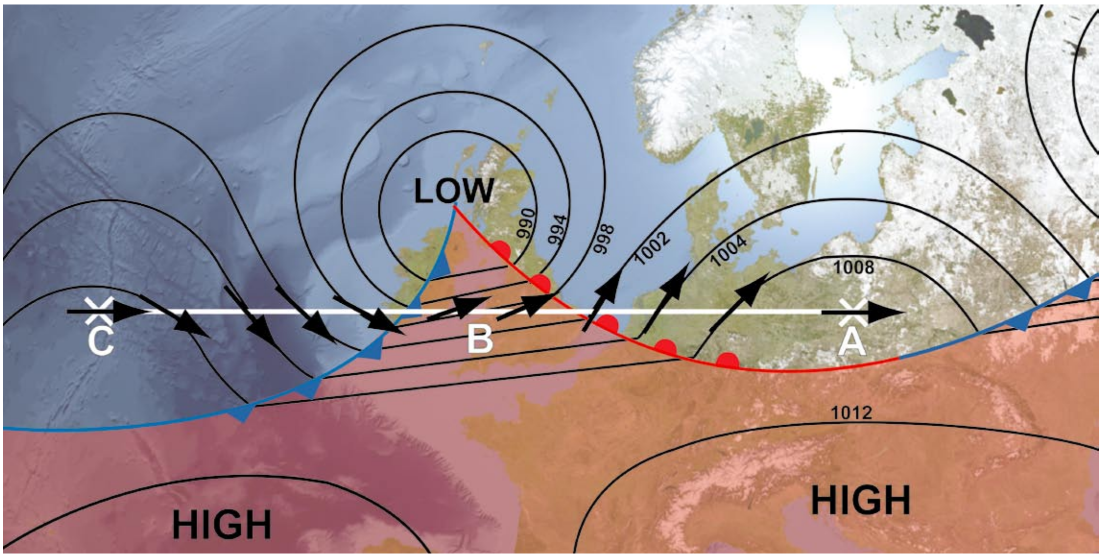
Unbalancing can be caused by the pressure falling in the depression. This will cause the winds to no longer be geostrophic and there will be a flow of air across the isobars towards the deepening centre.

THE POLAR FRONT AND POLAR FRONT DEPRESSIONS

Although we have already briefly described the polar front and it's depressions in the chapter on pressure systems, in this chapter there will be more detail.

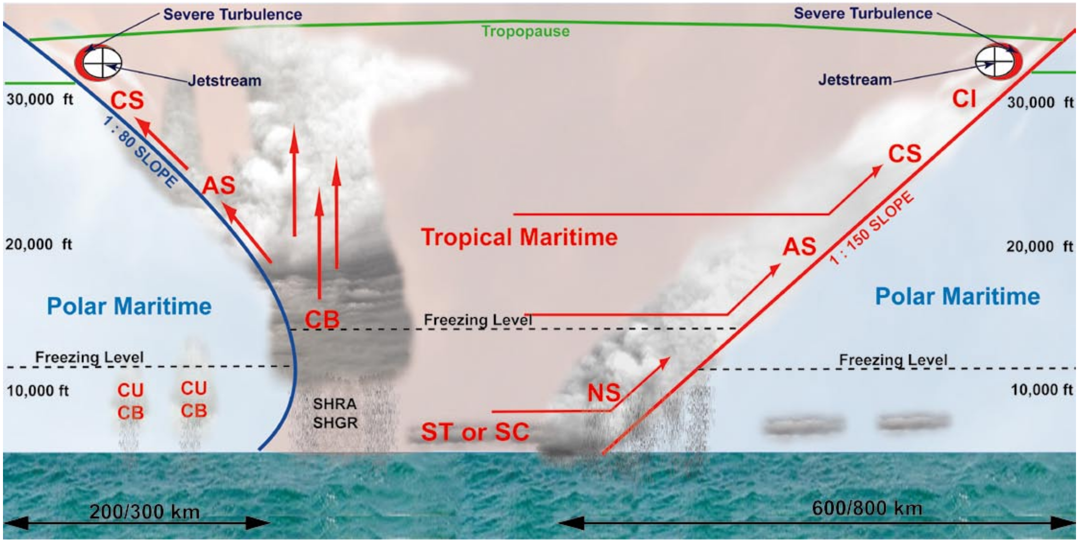
The polar front is a boundary between warm Tropical Maritime and cooler Polar Maritime air. As a result of the different densities these airmasses do not mix well and form a "frontal zone". The polar front zone affects the temperate latitudes at an average latitude of 50°N, but it does move with the seasons, moving to higher latitudes in summer and lower latitudes in winter especially so in the Northern Hemisphere.

The polar front usually has irregularities or kinks along it that are created by complex process. Suffice to say these irregularities create a series of depressions along the polar front where the warm tropical maritime air intrudes into the colder polar maritime air and the surface pressure is lowered. These depressions are called the Polar Front Depressions or Warm Sector Depressions and they move west to east along the polar front with the general westerly upper winds, reaching NW Europe from the Atlantic Ocean. Occasionally these depressions are called the "temperate depressions" or "travelling depressions".



Looking at the above plan view you can see a typical polar front depression on the polar front. Notice the intrusion of the tropical maritime air creating the characteristic wedge shape which we call the warm sector. To the right of the warm sector, you can see the warm front. This part of the polar front is marked with red semicircles to signify that warm air is overriding and replacing cold air. To the left of the warm sector you can see the cold front. This part of the polar front is marked with blue triangles to signify that cold air is undercutting and replacing warm.

You will notice a white line through the depression. This white line represents the track an observer would follow if a polar front depression was to approach from west to east and pass over the observer. This track starts at position A, which in front of the warm front, and then goes through the warm sector and the cold front, ending at point C. The cross sectional diagram of this track is shown in the following image - over the page.



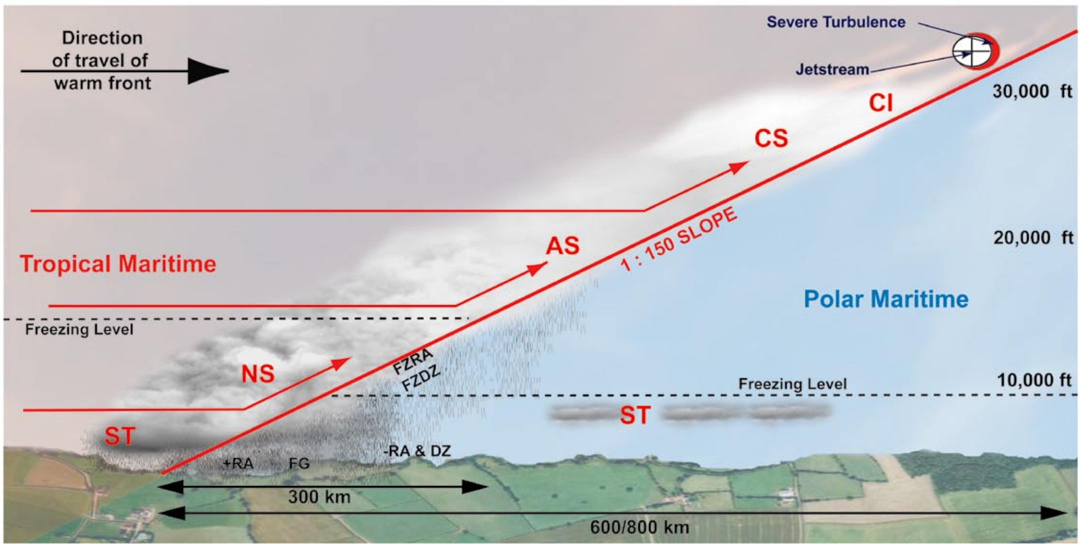
Using the cross section picture you can easily see the associated weather of each front, such as the cloud, precipitation and temperature. However, to understand the variation in the pressure and wind pattern as the polar front passes, you must consult the first image which shows the plan view. The black arrows on the plan view are representations of the surface wind.

It is important you remember the associated conditions of each front as they form not only a vital part of the exam, but they will be an almost daily occurrence when operating in Europe.

WARM FRONTS

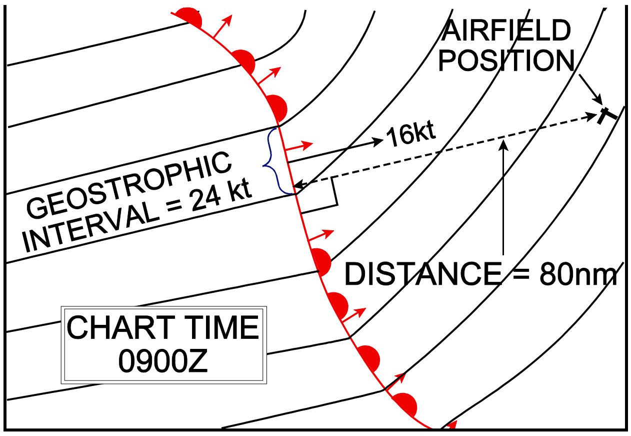
If warm air is replacing cold air, then the front is called warm.

A warm front has an approximate slope of 1:150 and a side view is as shown below. Generally as the warm front approaches the cloud will lower and thicken. Precipitation will start and gradually increase in intensity until the front passes. Visibility will also decrease and eventually fog may appear when the surface front arrives.



Cross section through a warm front

The front moves parallel to the isobars behind the front at a speed equal to 2/3 of the speed given by the Geostrophic wind scale.



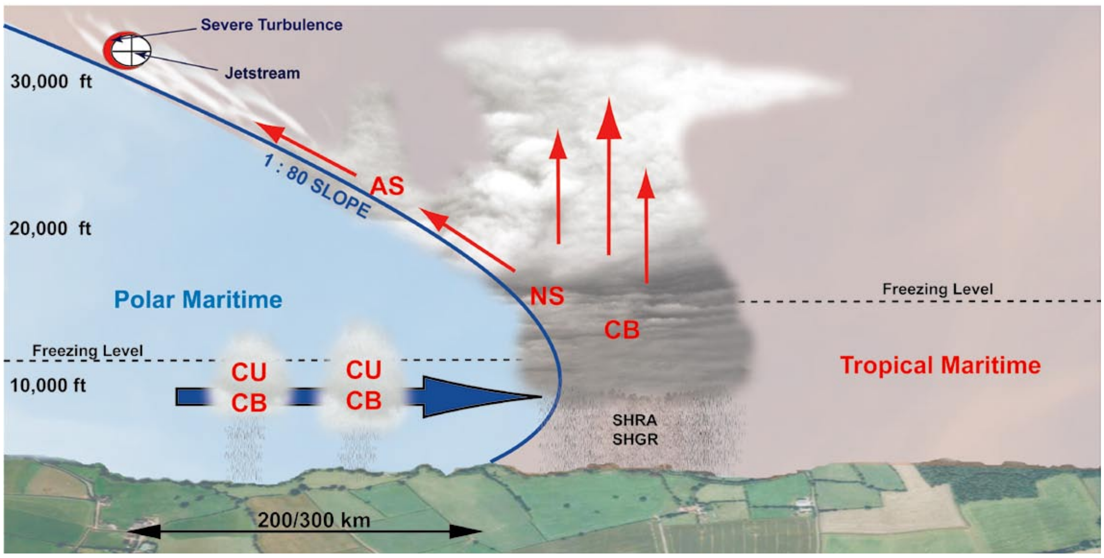
Warm front speed

COLD FRONTS

If cold air is replacing warm air, then the front is called a cold front.

The slope of a cold front is approximately 1:80 and a side view is shown on the next page. A Winter cold front in Europe will usually produce more intense weather and precipitation.

Cold fronts are marked by a sudden approach of cloud with embedded cumulonimbus. This gives precipitation in the form of showers of rain or even hail. After the cold front passes the weather should improve markedly but the temperature will be much lower.



A cross section through a cold front

The front moves parallel to the isobars behind the front at a speed equal to the geostrophic interval (full) measured along the front.

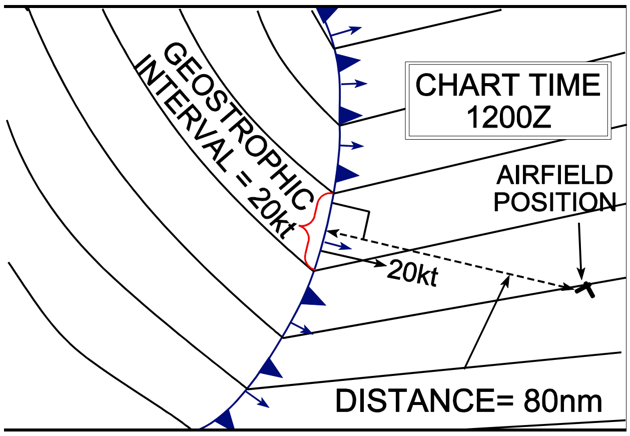
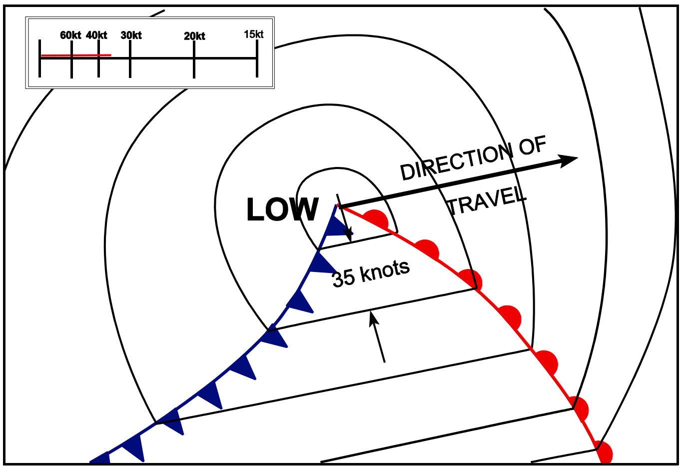


Figure 17.16 Speed of the cold front

THE WARM SECTOR

The area lying between the two fronts is known, since it is covered by tropical air, as the warm sector.

The warm sector and the whole of the polar front depression will move as the warm front and cold fronts move and will in fact narrow, as the cold front moves faster than the warm. The depression at the tip of the warm sector will move parallel to the isobars in the warm sector at a speed given by the distance between the first and second isobars.

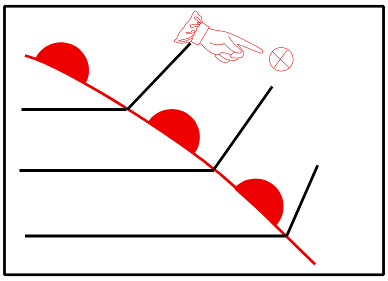


Speed of the warm sector and the whole depression

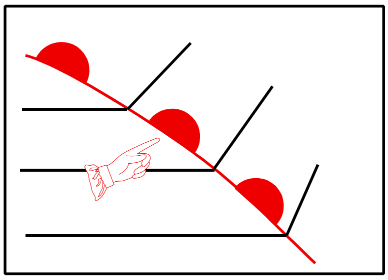
WEATHER WITH THE PASSAGE OF A POLAR FRONT DEPRESSION

➢ **Ahead of a warm front**

Surface W/V	-	Speed increasing, slight backing, usually southerly.
Temperature	-	Steady low.
Dew Point	-	Steady low.
Pressure	-	Steady fall.
Cloud	-	Increasing to 8/8, base lowering. Initially cloud changes from Ci to Cs to As, then very close to the front Ns.
Precipitation	-	Light continuous from As becoming moderate continuous from Ns.
Visibility	-	Reducing to poor.



Ahead of a Warm Front



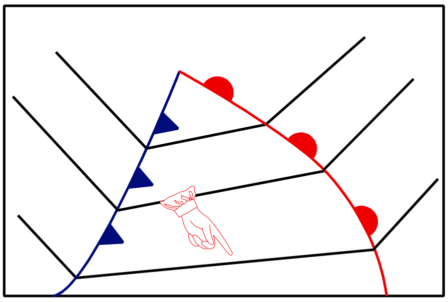
At the Warm Front

➢ **At the warm front.**

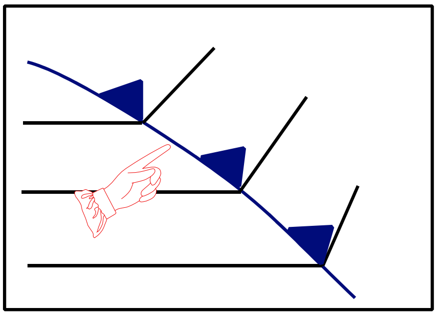
Surface W/V	-	Sharp veer.
Temperature	-	Sudden rise.
Dew Point	-	Sudden rise.
Pressure	-	Stops falling as rapidly.
Cloud	-	8/8, base very low, Ns, St.
Precipitation	-	Moderate or heavy continuous.
Visibility	-	Very poor, fog can occur.

➢ **In the warm sector.**

Surface W/V	-	Steady, usually from the SW.
Temperature	-	Steady.
Dew Point	-	Steady.
Pressure	-	Steadily decreasing.
Cloud	-	Uniform 6/8 to 8/8, some large breaks may occur, base low, St, Sc. In summer over land - fair weather cumulus
Precipitation	-	Light rain, drizzle
Visibility	-	Poor.



In the Warm Sector



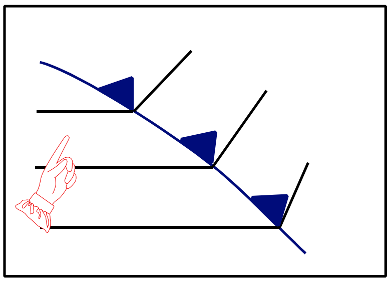
At the Cold Front

➢ **At the cold front**

Surface W/V	-	Sharp veer, gusts and squalls likely.
Temperature	-	Sudden fall.
Dew Point	-	Sudden fall.
Pressure	-	Starts to rise.
Cloud	-	6/8 to 8/8, base low but rising, Cu, CB, sometimes Ns.
Precipitation	-	Heavy rain showers, thunder and hail possible.
Visibility	-	Good, except in precipitation.

➢ **Behind the cold front**

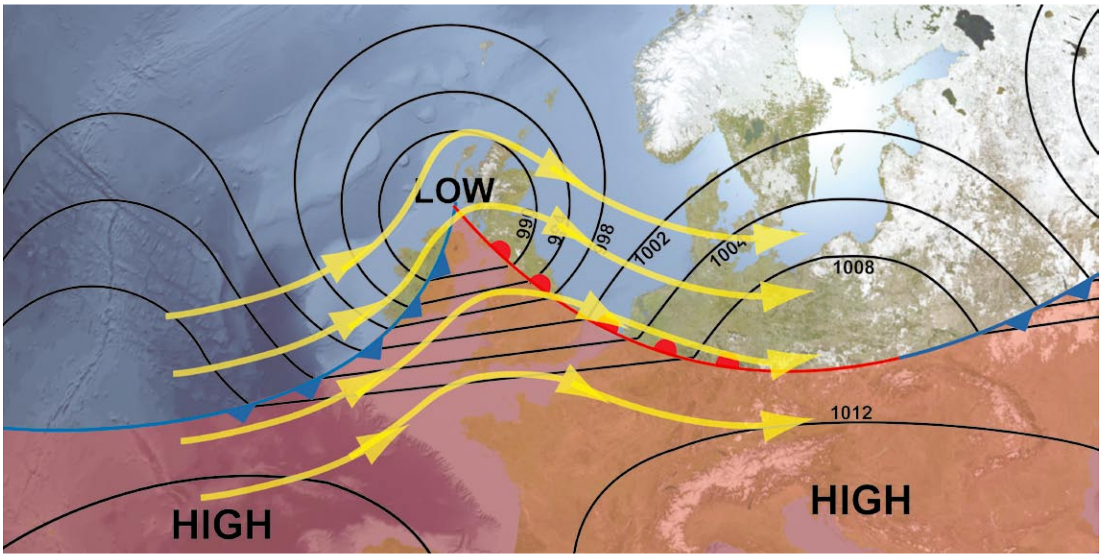
Surface W/V	-	Steady or slight veer to NW.
Temperature	-	Steady low.
Dew Point	-	Steady low.
Pressure	-	Rises slowly.
Cloud	-	6/8, base lifting, isolated Cu, Cb.
Precipitation	-	Showers, heavy at times, hail and Ts possible.
Visibility	-	Very good, except in showers.



Behind the Cold Front

UPPER WINDS IN A POLAR FRONT DEPRESSION

The upper winds will blow such that looking downstream the cold air will be to the left hand side in northern hemisphere and to the right hand side in the southern hemisphere. Therefore the upper winds often blow parallel to the surface fronts.



The Upper Winds in a Polar Front Depression.

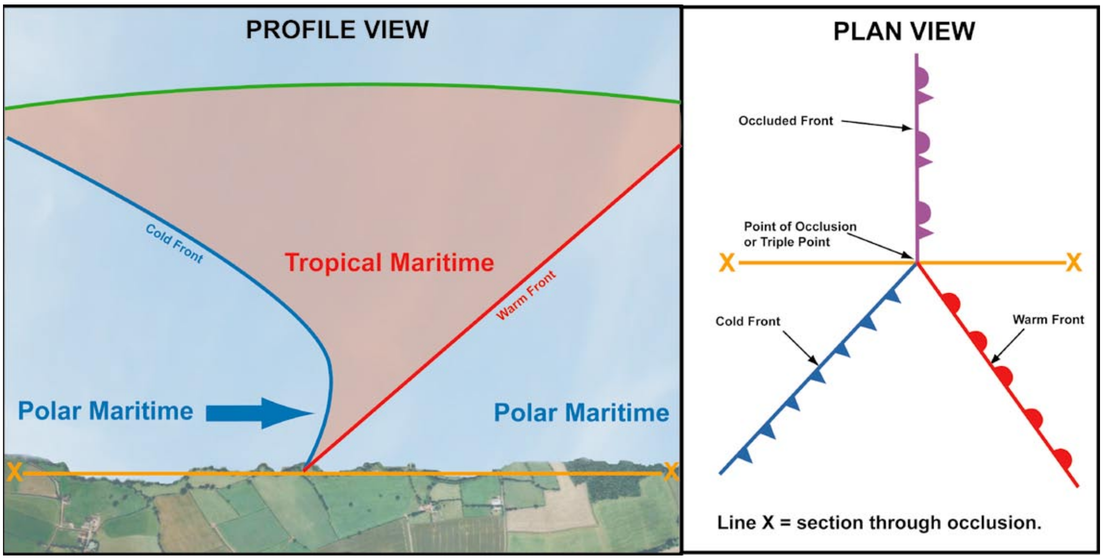
- **Ahead of a warm front.** NW (rapid movement of Ci from the NW is a good indication of a jet stream above) The jet stream will be near the tropopause, parallel to and about 400nm **ahead** of the surface position of the front in the **warm air.**

- **Above the warm sector**. There will be little change from the geostrophic wind near the surface as regards direction, but the speed will be greater.

- **Behind the cold front**. SW. The jet stream will be near the tropopause, parallel to and about 200nm **behind** the surface position of the cold front in the **warm air**.

OCCLUDED FRONTS/OCCLUSIONS

An occlusion occurs when the **cold front** in a depression catches up with or over takes the **warm front**. An occlusion forms because the cold front normally moves faster than the warm front. It usually forms when the **pressure in the depression stops falling (frontolysis).**

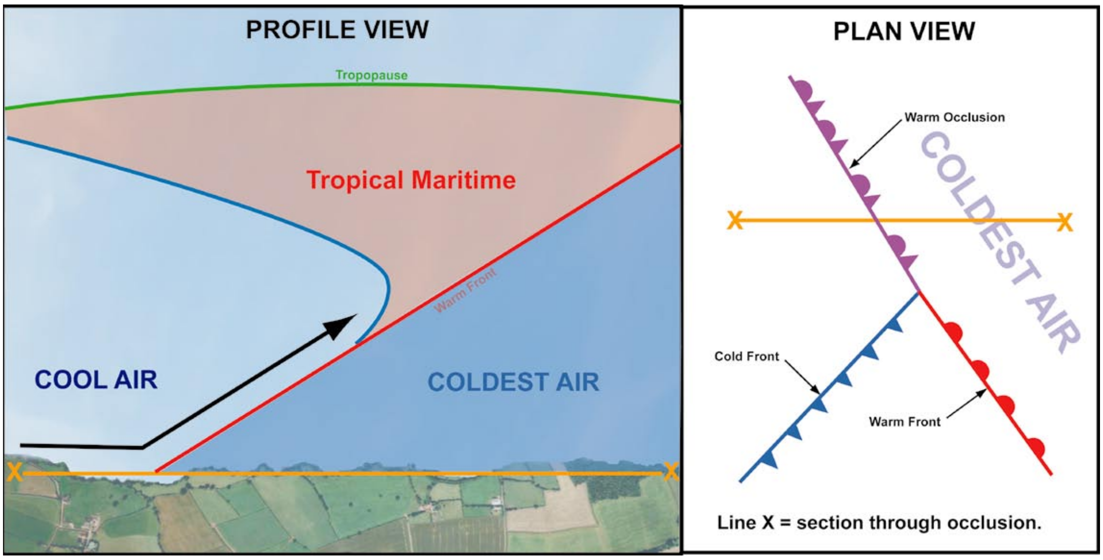


An Occlusion

WARM TYPE OCCLUSION

If the air ahead of the warm front is **colder** than the air behind the cold front, then a **warm** type occlusion will be formed. This type of occlusion is more common in winter.

The warm sector will be lifted above the surface and only a **warm front** will be apparent on the ground. There will be a wide rain belt, with mainly stability type precipitation. For the purposes of the exam the shape of the warm occlusion as seen in profile view will be an extension of the warm front. Therefore the warm occlusion front axis is a continuation of the warm front.

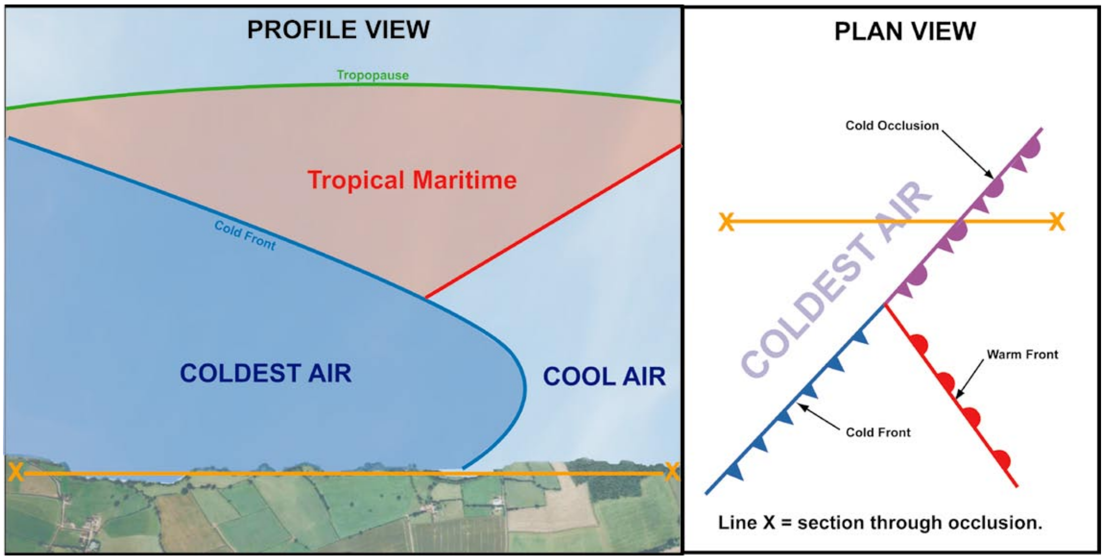


A Warm Occlusion as seen front a cross section and profile view

COLD TYPE OCCLUSION

If the air behind the cold front is **colder** than the air ahead of the warm front, then a **cold** type occlusion will be formed. This type of occlusion is more common in summer.

The warm sector will be lifted above the surface and only a **cold front** will be apparent on the ground. There will be a narrow rain belt, with Cb and Ns the most likely cloud. For the purposes of the exam the shape of the cold occlusion as seen in profile view will be an extension of the cold front. Therefore the cold occlusion front axis is a continuation of the cold front.



A Cold Occlusion as seen front a cross section and profile view

OCCLUSION WEATHER

Weather is usually bad because the normal frontal depression weather is concentrated into a smaller horizontal band and therefore a mixture of clouds can occur, e.g. Cb embedded in Ns. Furthermore, an occlusion forms towards the end of the life cycle of a depression, when it is slow moving and hence the weather can last for a lengthy period of time.

The above situation applies more particularly to the **warm** type occlusion because of the wider precipitation belt and the fact that this type of occlusion is more frequent in European winters because of the effect of Polar Continental air from the east (rain ice is a particular hazard..

Occlusions can become non-active and then produce a little cloud and nothing more as the depression dies.

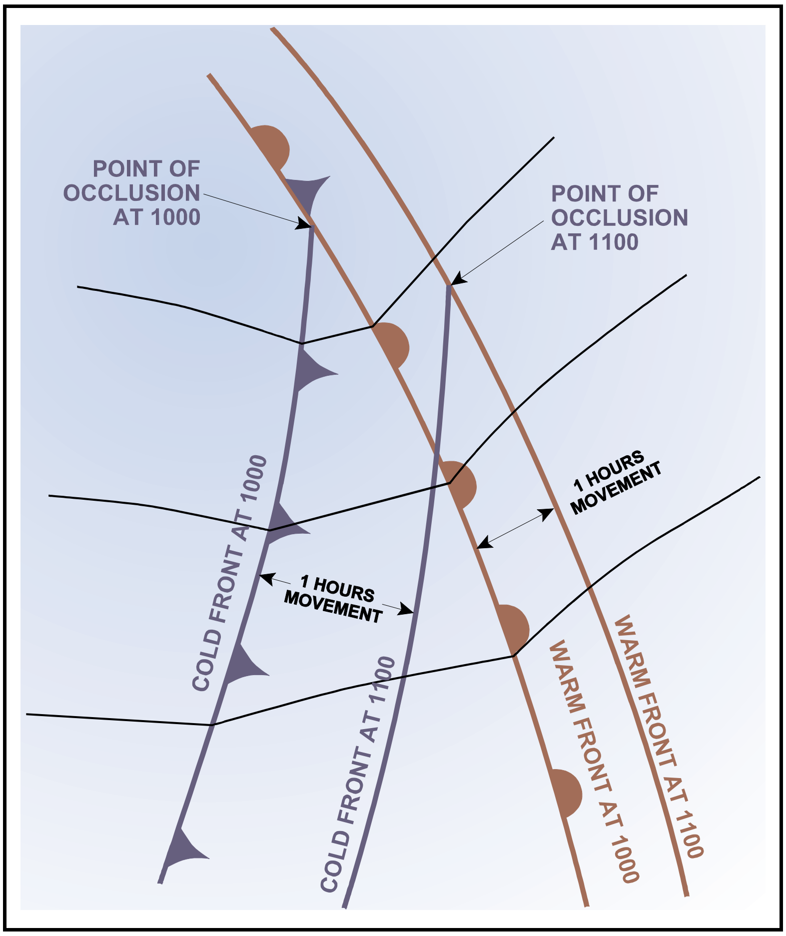
Occlusions usually move at about the same speed as cold fronts.

BACK BENT OCCLUSIONS

As the occlusion forms, the first point of occlusion is at the depression centre. It gradually moves S and W forming a **back bent** occlusion rather like a loop through the depression centre. This back bent portion is usually some 100 - 200 nm long and gives a belt of rain in the cold air behind the cold front, often of a thundery nature.

MOVEMENT OF OCCLUSIONS

The precise forecasting of weather and movement of the occlusion is difficult. The **point of occlusion** may be plotted for some time ahead by moving the **warm front** and **cold front** of a warm sector depression as described in the last chapter. Where the fronts meet will be the new point of occlusion. Generally the point of occlusion will move southward as the cold and warm front meet and merge, much like a zip closing. However, the whole system will also move eastwards as the upper winds drive the system.



Movement of the Point of Occlusion

Movement of the **depression** itself is much more difficult to predict, but it will curve in an anticlockwise direction (Northern Hemisphere) at a speed dependent upon isobar spacing.

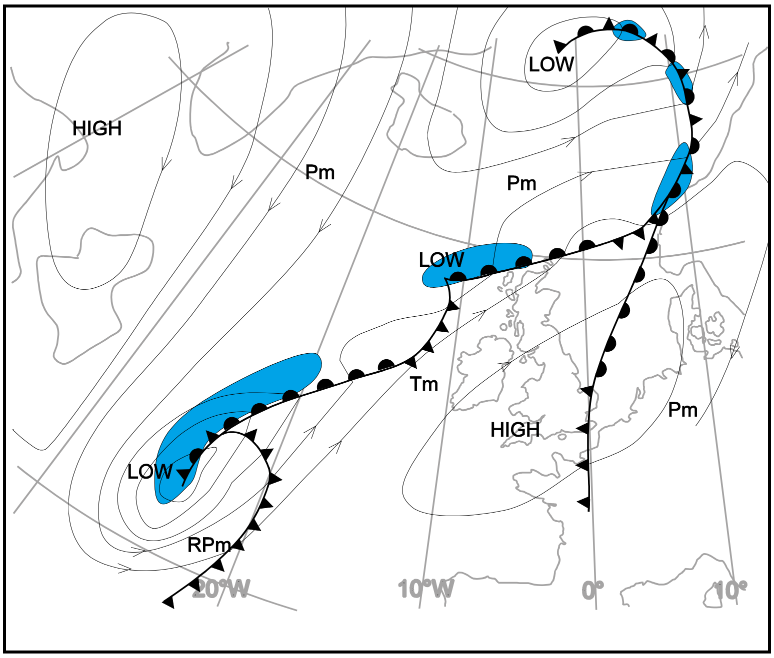
GROWTH AND DECAY

Growth of a depression to the time of producing the lowest pressure at the centre is about 4 days. The dying away as the depression fills can take 10 days or more and eventually the depression is absorbed by some other pressure feature.

For the British Isles, the time sequence typically involves:

- Formation and growth near the Eastern seaboard of USA or mid-Atlantic.
- Lowest pressure over the UK and occlusion of front.
- Depression filling over N Sea/Norway/Europe/Russia- frontolysis.

Families of depressions form along the Polar Front and most frequently the new members form as secondary depressions at an occlusion point or at the end of a trailing cold front. This latter position particularly applies later in the life of a depression as the cold front crosses a coastline (e.g. the coast of Brittany) or a range of mountains.



A North Atlantic Polar Front.

CONCLUSION

The Handbook of Aviation Meteorology sums up the matter of occlusions thus:

> 'The characteristics of the occlusion are variable. They may be similar to those of either the warm or cold front (according to type) but are often ill defined'.

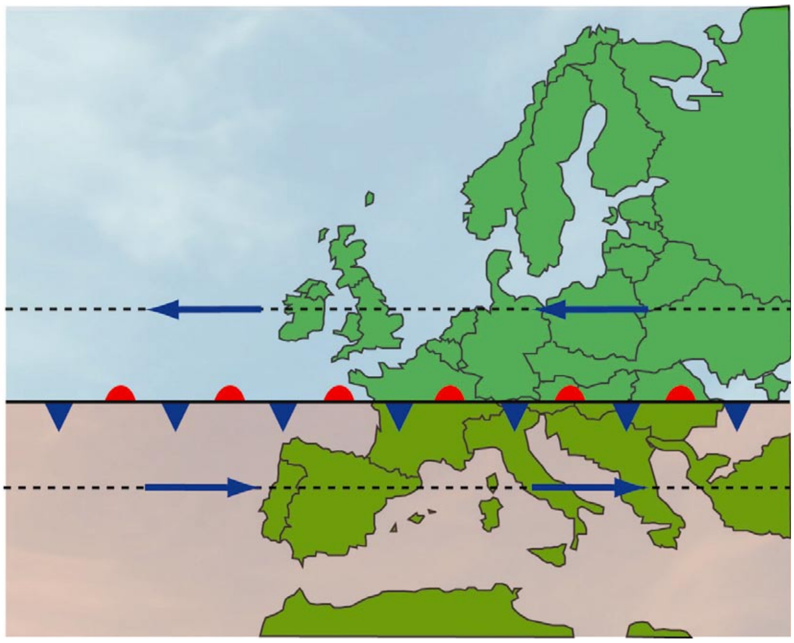
ANA - AND KATAFRONTS

A sub-classification of fronts depends upon the vertical motion of air at the front. If the air in the warm sector (between the two fronts) is **rising** relative to the front it is called an **ANA** front. The front will be **active** with **heavy** precipitation and a **deep** layer of cloud, especially near the **surface position** of the front.

With the **KATA** front however, where the warm sector air is **descending**, the weather is less intense, with a much shallower cloud belt. This usually occurs when the depression is **filling**.

QUASI STATIONARY FRONTS

When the polar front has little or no movement it is known as a **quasi stationary** front. The image below shows such a front on a synoptic chart. Since there is little frontal movement, weather conditions are likely to be comparatively quiet, though longer lasting.



A Quasi-Stationary Front

QUESTIONS

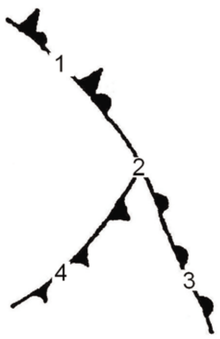
1. What will be the effect on the reading of an altimeter of an aircraft parked on the ground shortly before an active cold front passes?

    a. It will be increasing.
    b. It will remain unchanged.
    c. It will be decreasing.
    d. It will fluctuate up and down by about +/- 50 feet.

2. In which approximate direction does the centre of a frontal depression move?

    a. In the direction of the warm sector isobars.
    b. In the direction of the isobars ahead of the warm front.
    c. In the direction of the sharpest pressure increase.
    d. In the direction of the isobars behind the cold front.

3. The cold front is indicated with a number at position:



    a. 2
    b. 1
    c. 3
    d. 4

4. In a polar front depression, an occlusion is called a warm occlusion when the cold air

    a. behind is colder than the cold air in front.
    b. behind is colder than the cold air in front, with the warm air being at a high altitude.
    c. behind is less cold than the cold air in front, with the warm air at a high altitude.
    d. in front of the surface position of front is only at a high altitude.

5. The main factor which contributes to the formation of very low clouds ahead of a warm front is the

    a. saturation of the cold air by rain falling into it and evaporating
    b. saturation of the warm air by rain falling into it and evaporating
    c. reduction of outgoing radiation due to clouds
    d. warm air moving over a cold surface

6. A squall line usually is most likely to be encountered

    a. at an occluded front
    b. in an air mass with cold mass properties
    c. behind of a stationary front
    d. ahead of a cold front

7. When do cold occlusions occur most frequently in Europe?

   a. Summer
   b. Winter
   c. Autumn and winter
   d. Winter and spring

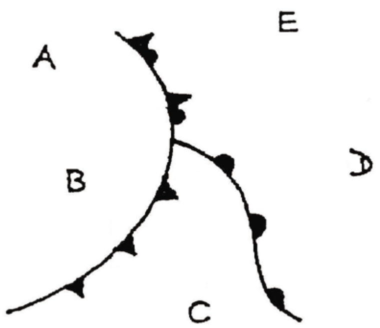
8. The polar front is the boundary between:

   a. polar air and tropical air.
   b. arctic air and polar air.
   c. arctic air and tropical air.
   d. maritime polar air and continental polar air.

9. Which of the following is typical for the passage of a cold front in the summer ?

   a. Rapid increase in temperature once the front has passed
   b. Mainly towering clouds
   c. Mainly layered clouds
   d. Rapid drop in pressure once the front has passed

10. The warm sector is indicated by letter:



   a. A
   b. C
   c. B
   d. D

11. In which air mass are extremely low temperatures encountered?

   a. Arctic maritime air.
   b. Polar continental air.
   c. Polar maritime air.
   d. Tropical continental air.

12. What characterizes a stationary front?

   a. The warm air moves at approximately half the speed of the cold air
   b. The weather conditions that it originates is a combination between those of an intense cold front and those of a warm and very active front
   c. The surface wind usually has its direction parallel to the front
   d. The surface wind usually has its direction perpendicular to the front

13. What type of front / occlusion usually moves the fastest?

   a. Warm occlusion.
   b. Cold front.
   c. Warm front.
   d. Cold occlusion.

14. What will be the effect on the reading of an altimeter of an aircraft parked on the ground during the period following the passage of an active cold front?

    a. It will show a small increase or decrease.
    b. It will have decreased.
    c. It will remain unchanged.
    d. It will have increased.

15. Where does polar continental air originate?

    a. Siberian landmass.
    b. Areas of arctic water.
    c. The region of the Baltic sea.
    d. The region of Greenland.

16. After passing at right angles through a very active cold front in the direction of the cold air, what will you encounter, in the northern hemisphere immediately after a marked change in temperature?

    a. A veering in the wind direction.
    b. A backing in the wind direction.
    c. An increase in tailwind.
    d. A decrease in headwind.

17. In which of the following regions does polar maritime air originate?

    a. Baltic Sea
    b. Black Sea
    c. East of Greenland
    d. Region of British Isles

18. How do air masses move at a warm front?

    a. Cold air overrides a warm air mass
    b. Cold air undercuts a warm air mass
    c. Warm air undercuts a cold air mass
    d. Warm air overrides a cold air mass

19. What types of cloud will you meet flying towards a warm front?

    a. At some 500 km from the front, groups of CB, later at some 250 km thickening AS
    b. At some 800 km CS, later AS, and at some 300 km NS until the front
    c. Extensive areas of fog. At some 100 km from the front NS begin
    d. At some 500 km AS, later CS and at some 80 km before the front CB

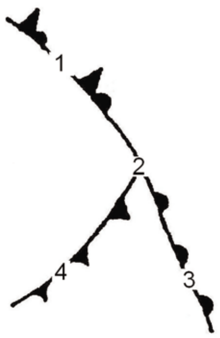
20. (For this question use annex A)
    Refer to the diagram. Assuming the usual direction of movement, to which position will the polar frontal wave have moved?

    a. Position 1
    b. Position 4
    c. Position 3
    d. Position 2

21. In which main direction does a polar front depression move?

a. Across the front towards the north
b. Across the front towards the south
c. Along the front towards the east
d. Along the front towards the west

22. The front labeled "1" is a:



a. Warm front
b. Cold front
c. Warm front occlusion
d. Cold front occlusion

23. How are the air masses distributed in a cold occlusion ?

a. The coldest air mass behind and the less cold air in front of the occlusion; the warm air mass is above ground level.
b. The coldest air in front of and the less cold air is behind the occlusion; the warm air mass is above ground level.
c. The coldest air in front of and the warm air behind the occlusion; the less cold air is above ground level.
d. The coldest air behind and the warm air in front of the occlusion; the less cold air mass is above ground level.

24. (For this question use annex F)
Which typical weather situation is shown on the weather chart? (Spacing of the isobars: 5 hPa)

a. Cutting wind.
b. West wind condition.
c. Warm south wind condition (Foehn).
d. Uniform pressure pattern.

25. (For this question use annex B)
Refer to the diagram. Assuming the usual direction of movement, where will this polar frontal wave have moved?

a. Position 2
b. Position 4
c. Position 3
d. Position 1

26. Where is the coldest air to be found, in an occlusion with cold front characteristics?

a. At the surface position of the front.
b. At the junction of the occlusion.
c. Behind the front.
d. Ahead of the front.

27. What cloud cover is typical for a wide warm sector of a polar front depression over Central Europe in the summer ?

a. Fair weather CU
b. BKN CU and CB
c. Sky clear
d. ST with drizzle

28. A frontal depression passes through the airport. What form of precipitation do you expect?

a. Rain or snow during about 12 hours until the warm front arrives. Within the warm sector the rain increases. Improvement on the passage of the cold front.
b. Continuous rain or snow during 6 hours until the warm front arrives. The precipitation stops for several hours within the warm sector. On the arrival of the cold front, showers within a couple of hours.
c. Continous rain or snow while the frontal wave passes for a period of some 24 hours.
d. Showers during some 2 hours until the warm front arrives. Drizzle in the warm sector within 12 hours. Rain or snow on the passage of the cold front.

29. At the approach of a warm front (northern hemisphere) the wind direction changes from the surface up to the tropopause. The effect of this change is that the wind

a. backs in the friction layer and and backs above the friction layer
b. veers in the friction layer and veers above the friction layer
c. backs in the friction layer and veers above the friction layer
d. veers in the friction layer and backs above the friction layer

30. (For this question use annex C)
Which cross-section of air mass and cloud presentation is applicable to the straight line A-B?

a. 4
b. 3
c. 1
d. 2

31. What is the surface visibility most likely to be, in a warm sector of tropical maritime air, during the summer?

a. Very good (greater than 50 km).
b. Moderate (several km).
c. Very poor (less than 1 km).
d. Good (greater than 10 km).

32. On an aerodrome, when a warm front is approaching

a. QFE increases and QNH decreases.
b. QFE decreases and QNH increases.
c. QFE and QNH decrease.
d. QFE and QNH increase.

33. During a cross-country flight at FL 50, you observe the following sequence of clouds: Nimbostratus, Altostratus, Cirrostratus, Cirrus. Which of the following are you most likely to encounter?

a. Strong, gusty winds.
b. A strong downdraught.
c. Increasing temperatures.
d. Decreasing temperatures.

34. How do you recognize a cold air pool?

a. A cold air pool may only be recognized on the surface chart as a high pressure area.
b. As a low pressure area aloft (e.g. on the 500 hPa chart).
c. As a high pressure area aloft (e.g. on the 500 hPa chart).
d. A cold air pool may only be recognized on the surface chart as a low pressure area.

35. What is encountered during the summer, over land, in the centre of a cold air pool?

a. Nothing (CAVOK).
b. Showers and thunderstorms.
c. Strong westerly winds.
d. Fine weather CU.

36. Which of the following describes a warm occlusion?

a. The warmer air mass is ahead of the original warm front
b. The coldest air mass is ahead of the original warm front
c. The air mass behind the front is more unstable than the air mass ahead of the front
d. The air mass ahead of the front is drier than the air mass behind the front

37. Thunderstorms can occur on a warm front if the

a. warm air is moist and the environmental lapse rate exceeds the saturated adiabatic lapse rate
b. cold air is moist and the environmental lapse rate is less than the dry adiabatic lapse rate
c. warm air is moist and the environmental lapse rate is less than the saturated adiabatic lapse rate
d. cold air is moist and the environmental lapse rate exceeds the saturated adiabatic lapse rate

38. What is the relative movement of the two air masses along a cold front?

a. Cold air slides over a warm air mass
b. Warm air pushes under a cold air mass
c. Cold air pushes under a warm air mass
d. Warm air pushes over a cold air mass

39. What type of precipitation would you expect at an active unstable cold front?

a. Freezing rain
b. Light to moderate continuous rain
c. Drizzle
d. Showers associated with thunderstorms

40. Frontal depressions can be assumed to move in the direction of the 2000 feet wind

a. behind the cold front
b. at the apex of the wave
c. in the warm sector
d. in front of the warm front

41. Read this description: "After such a fine day, the ring around the moon was a bad sign yesterday evening for the weather today. And, sure enough, it is pouring down outside. The clouds are making an oppressively low ceiling of uniform grey; but at least it has become a little bit warmer." Which of these weather phenomena is being described?

a. A blizzard
b. Weather at the back of a the cold front
c. A cold front
d. A warm front

42. What are the typical differences between the temperature and humidity between an air mass with its origin in the Azores and an air mass with its origin over northern Russia?

a. The North-Russian air is colder and more humid than the air of the Azores.
b. The air of the Azores is warmer and dryer than the North- Russian air.
c. The North-Russian air is warmer and dryer than the air of the Azores.
d. The air of the Azores is warmer and more humid than the North-Russian air.

43. (For this question use annex D)
Examining the pictures, on which one of the tracks (dashed lines) is this cross-section to be expected?

a. Track A-D
b. Track A-E
c. Track B-D
d. Track B-C

44. (For this question use annex E)
Under the weather conditions depicted, which of the following statements is likely to apply?

a. Moderate to strong Foehn in the Alps.
b. Radiation fog is unlikely in Central Europe in the winter.
c. Thunderstorms may occur in the summer months over South West Europe.
d. Severe gradient wind likely over Central Europe.

45. What cloud formation is most likely to occur at low levels when a warm air mass overrides a cold air mass?

a. Nimbostratus.
b. Cumulus.
c. Altostratus.
d. Cumulonimbus.

46. Which of the following conditions are you most likely to encounter when approaching an active warm front at medium to low level ?

a. Severe thunderstorms at low altitude.
b. Extreme turbulence and severe lightning striking the ground.
c. High cloud base, good surface visibility, and isolated thunderstorms.
d. Low cloud base and poor visibility.

47. The approximate inclined plane of a warm front is:

a. 1/150
b. 1/50
c. 1/300
d. 1/500

48. Thunderstorms in exceptional circumstances can occur in a warm front if

a. the cold air is convectively stable.
b. the warm air is convectively stable.
c. the warm air is convectively unstable.
d. the cold air is convectively unstable.

49. Which of the following zones is most likely to encounter little or no precipitation?

a. Frontal zones.
b. Occlusions.
c. The north side of the alps with a prevailing Foehn from the south.
d. The north side of the alps with a prevailing Foehn from the north.

50. What will be the effect on the reading of an altimeter of an aircraft parked on the ground as an active cold front is passing?

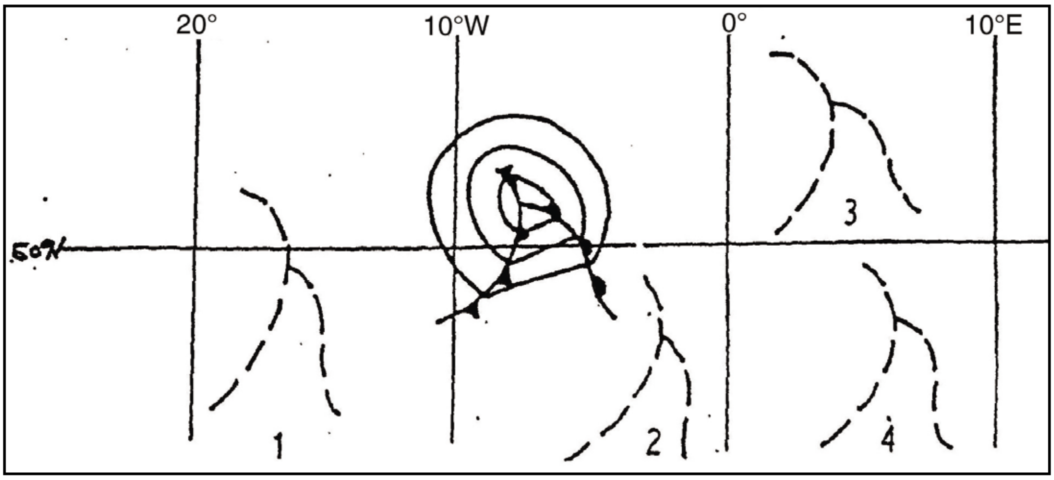
a. It will remain unchanged.
b. It will first decrease then increase.
c. It will fluctuate up and down by about +/- 50 feet.
d. It will first increase then decrease.

51. Which of the following statements concerning the core of a polar front jet stream is correct?

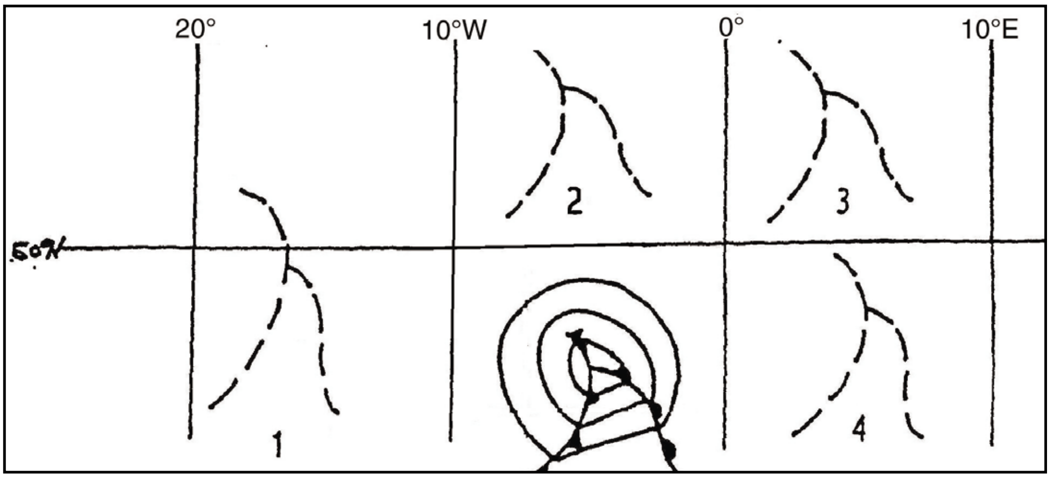
a. It and its surface projection lie in the warm air
b. It lies in the warm air; its pressure surfaces are horizontal at the height of the core
c. It lies in the cold air; the thermal wind reverses direction at the height of the core
d. It lies at a height where there is no horizontal temperature gradient; the slope of the pressure surfaces at the height of the core is at its maximum

ANNEXES to QUESTIONS

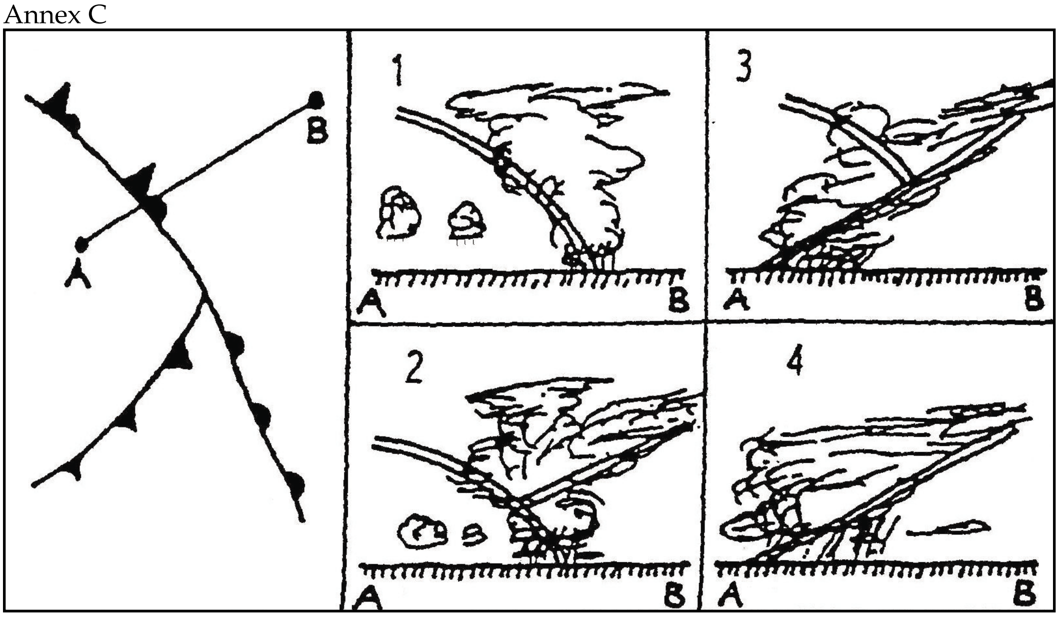
Annex A



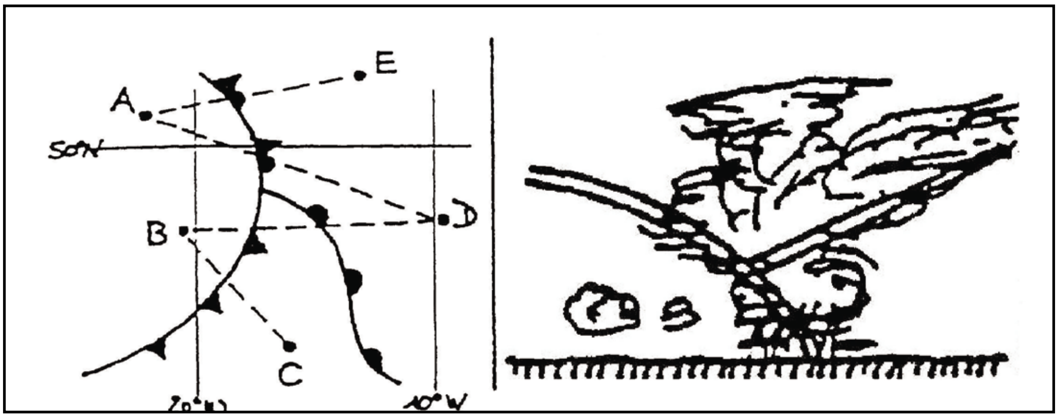
Annex B



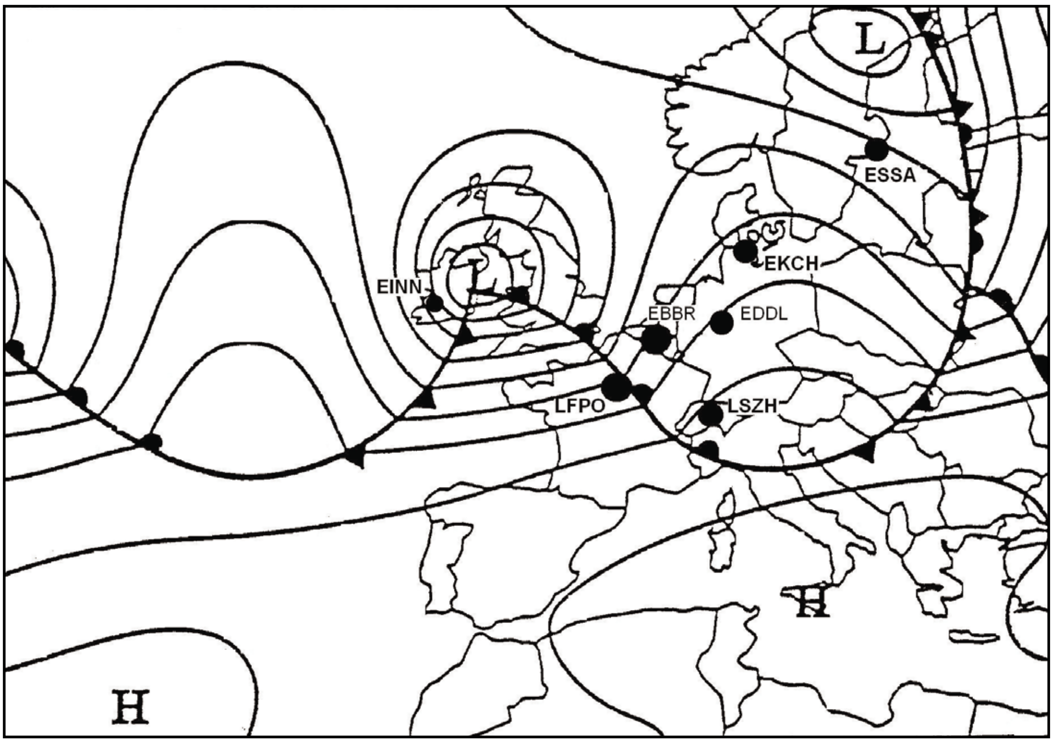
Annex C



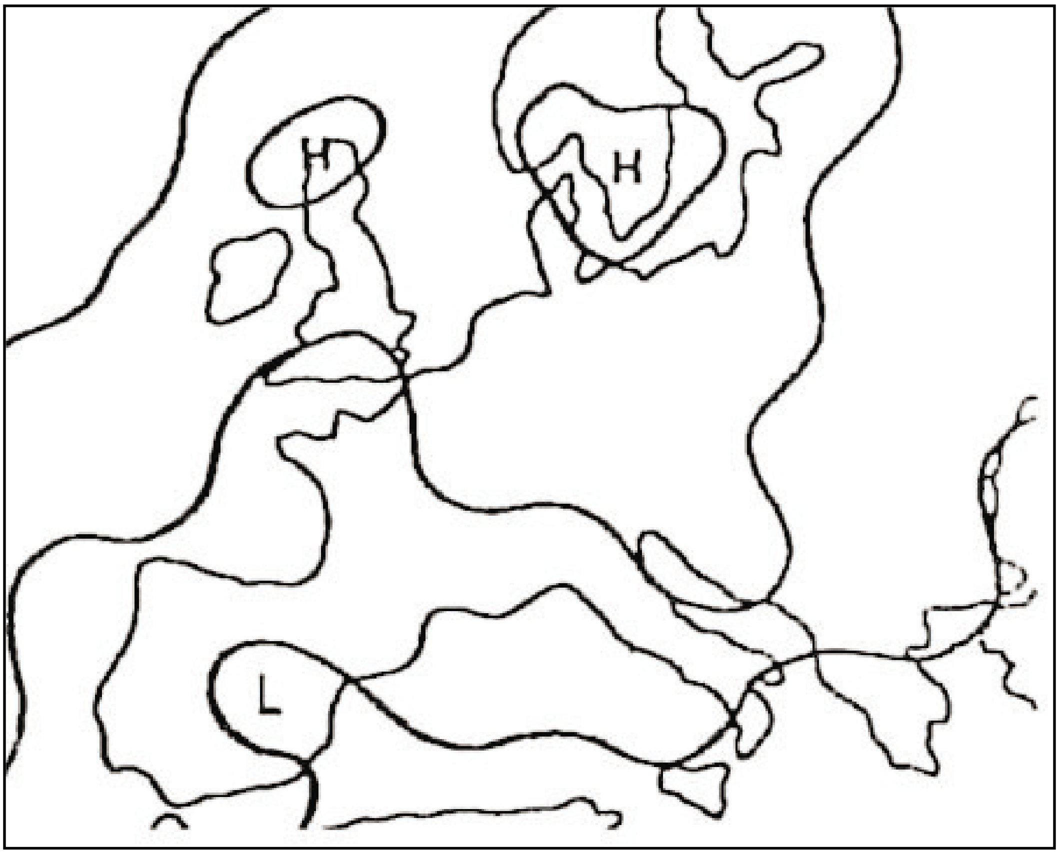
Annex D



Annex E



Annex F



ANSWERS

1. A	11. B	21. C	31. B	41. D
2. A	12. C	22. C	32. C	42. D
3. D	13. B	23. A	33. D	43. C
4. C	14. B	24. D	34. B	44. C
5. A	15. A	25. B	35. B	45. A
6. D	16. A	26. C	36. B	46. D
7. A	17. C	27. A	37. A	47. A
8. A	18. D	28. B	38. C	48. C
9. B	19. B	29. B	39. D	49. C
10. B	20. C	30. B	40. C	50. D
				51. D

CHAPTER EIGHTEEN

OTHER DEPRESSIONS

Contents

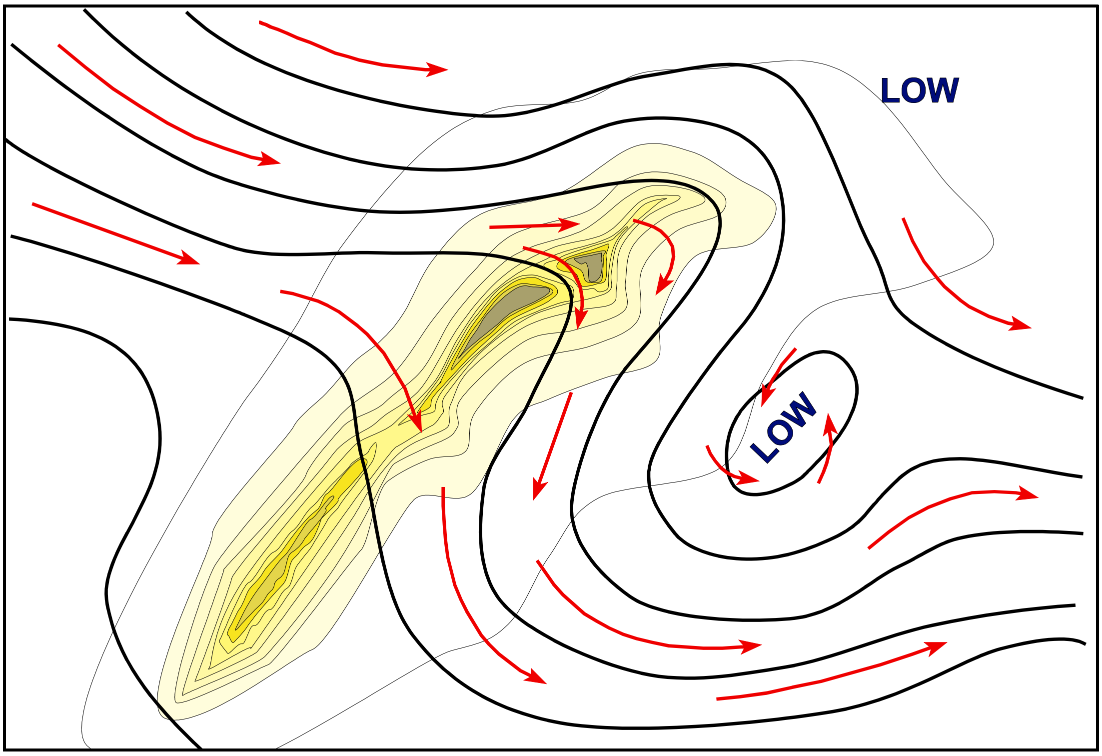
INTRODUCTION

Polar Front depressions predominate in temperate latitudes but other types of depression also exist, in temperate and other regions. These include:

- Orographic depressions.
- Thermal depressions.
- Secondary depressions.

OROGRAPHIC (LEE) DEPRESSIONS

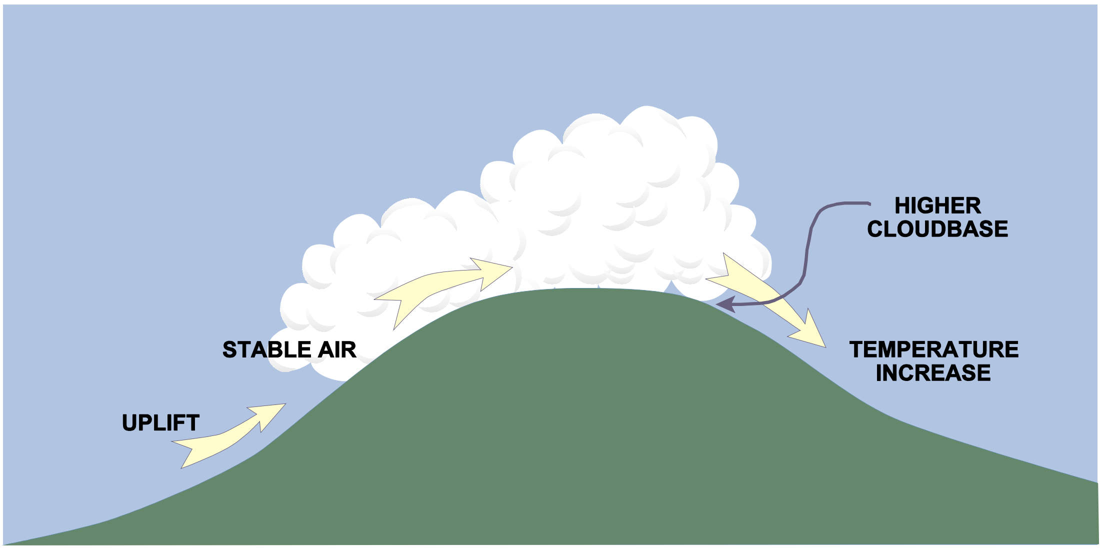
When a flow of air meets a mountain range at a large angle, there is a marked tendency for much of the air to flow around the end of the range instead of flowing over the top. This can cause a comparative lack of air on the downwind (lee) side of the mountains so that low pressure occurs.



Orographic Depressions.

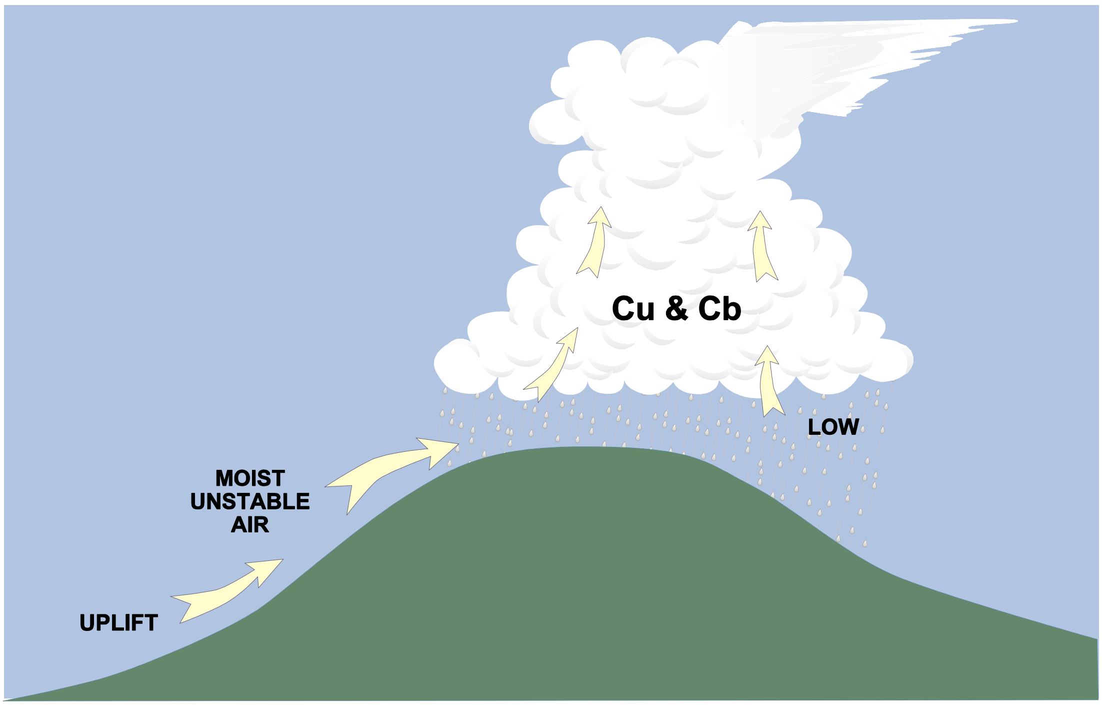
There are three weather situations:

- If the air is **dry** and **stable**, then any uplift caused by the depression will have little effect and the weather will be **warm, clear** and **dry**. This is the Föhn effect.



Föhn effect

- If the air is **moist and unstable**, then the uplift caused as it passes over the depression can ensure that Cu and Cb with **showers** and possibly **thunderstorms** and **hail** may develop.

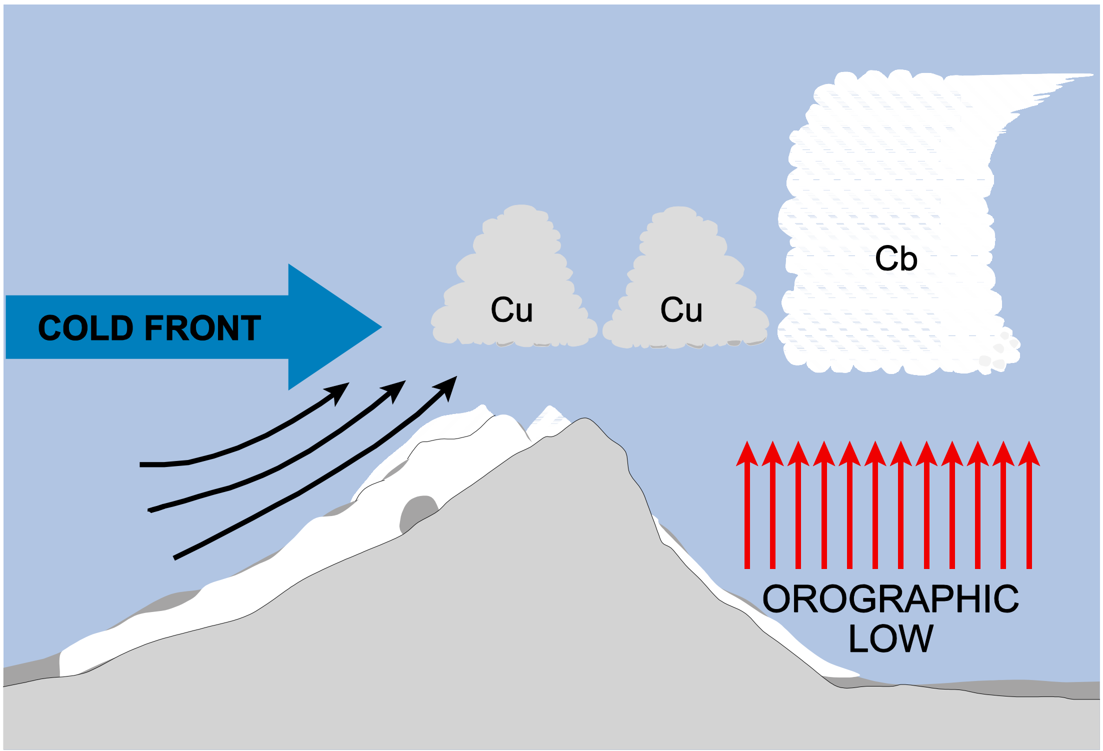


Moist, Unstable

➢ Sometimes a **cold front** will approach the mountain range and then much of the cold air will initially be held back by the range. When this unstable air finally breaks over the mountains, lifting will occur with additional lifting from the orographic low.

- The result can be **heavy banks** of Cb, with **line squalls, very heavy showers, thunderstorms, hail** and **poor visibility**.

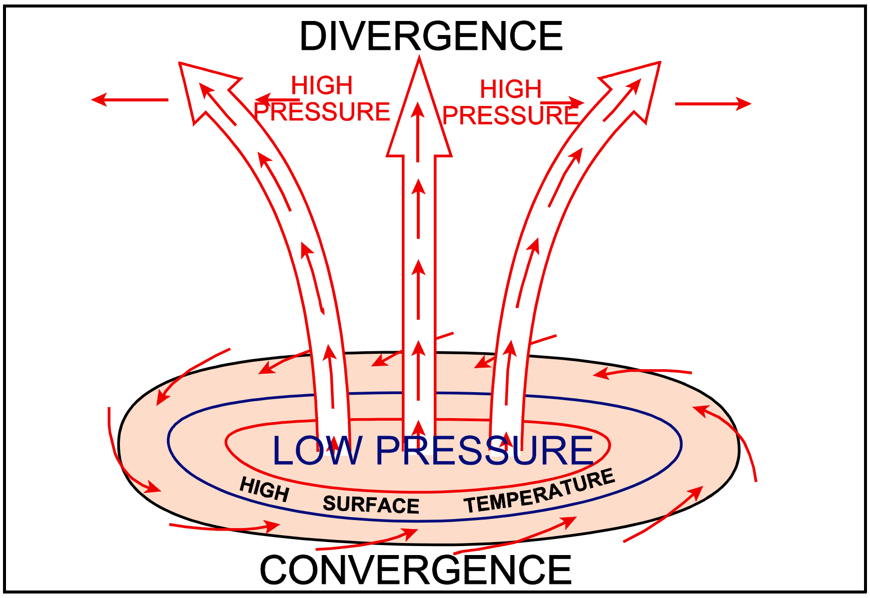
- A good example of this occurs over the **Alps** in **Northern Italy** in winter, the cold front being part of a polar front depression.



The Result of a Cold Front Approaching a Mountain Range.

THERMAL DEPRESSIONS

Basic Theory
As the air at the surface is heated, it will expand, causing the pressure surface to be lifted. This higher pressure at height will result in an outflow of air. In turn this will cause a fall in surface pressure and the air will move cyclonically.



Thermal Depression Theory

The thermal depression often weakens with height because pressure tends to be higher. This can cause upper winds to reverse, but development of a thermal depression in unstable air can be active up to tropopause heights.

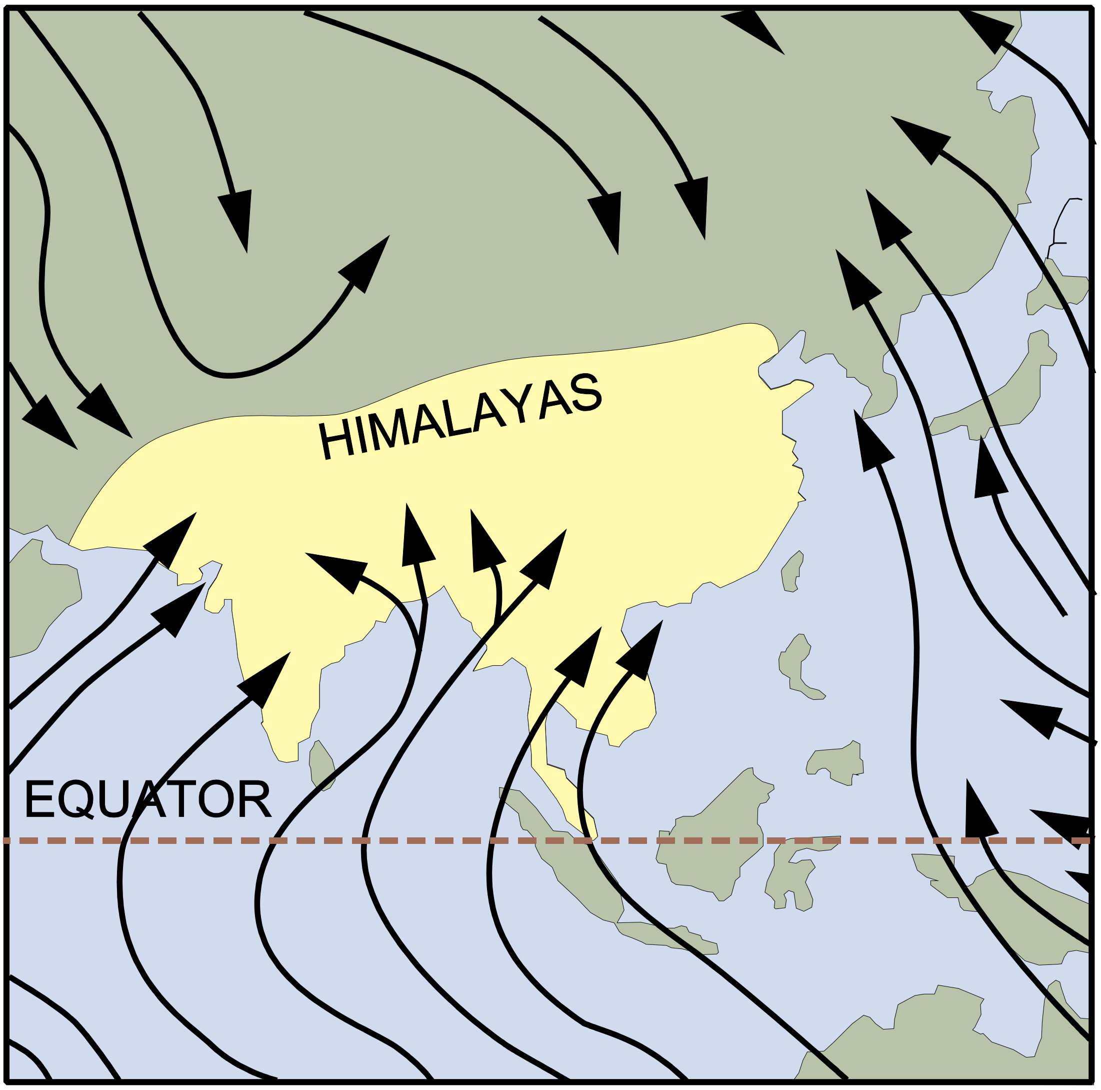
Thermal depressions are most frequent over land masses in summer, but they are found over inland lakes and seas in winter. The Polar Air Depression can be classified as a thermal depression because it is essentially created by warming its lower layers.

Weather

- Cu, Cb (perhaps hail and thunderstorms)
- Heavy showers
- Good visibility except in showers
- Moderate or severe turbulence.

THE MONSOON LOW

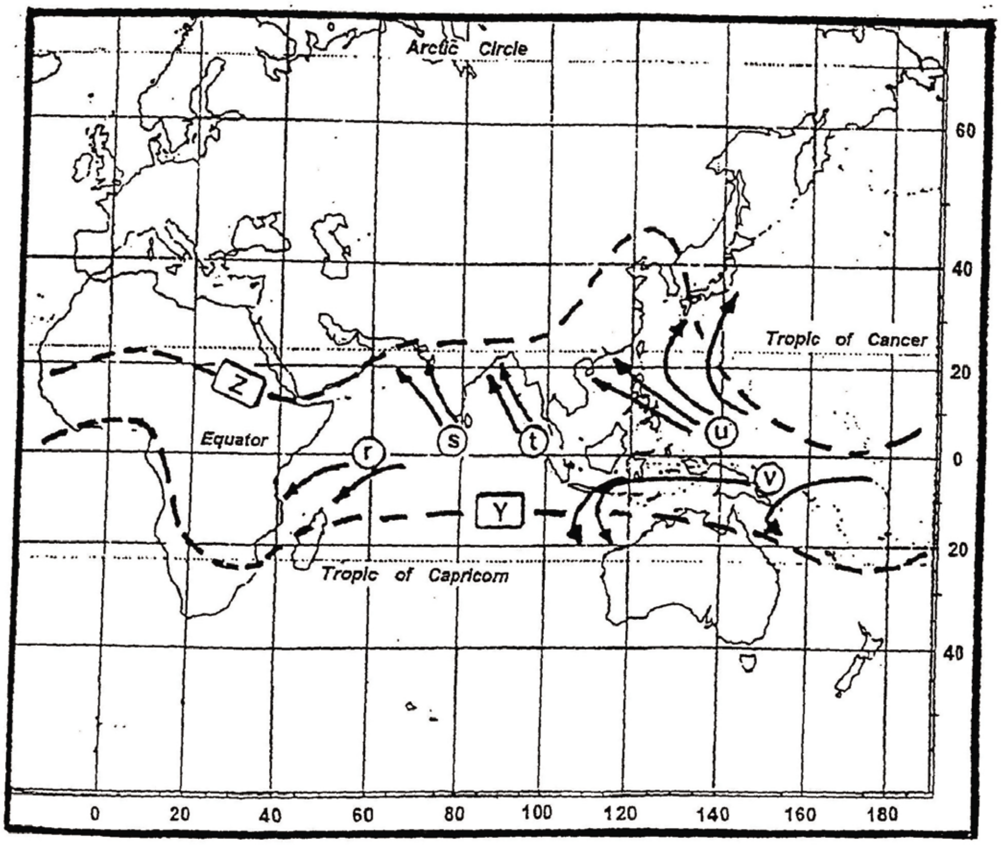
Over large continents in summer a large thermal low develops which controls the circulation of air. The weather pattern is variable, being affected by topography, e.g. the Himalayas, and by the air masses drawn into the circulation.



Monsoon Low

THE EQUATORIAL LOW PRESSURE BELT

The sun moves between the tropics of Cancer (23°27′N) and Capricorn (23°27′S) during the course of the year and a permanent low pressure belt produced by the sun's heating results, together with much instability. Because of the different land masses and oceanic areas the North and South boundaries of this belt do not follow the parallels of latitude, but are as shown below.



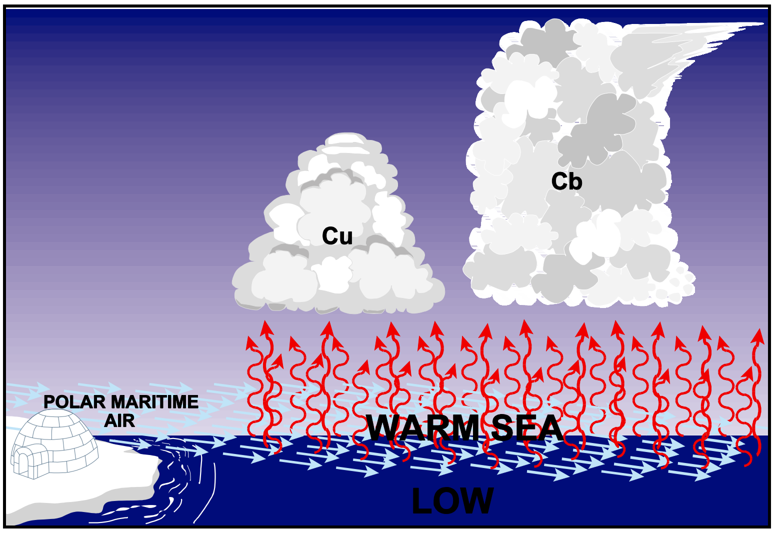
The dashed Z and Y lines mark the most northerly and southerly limits of the ITCZ

Also known as:

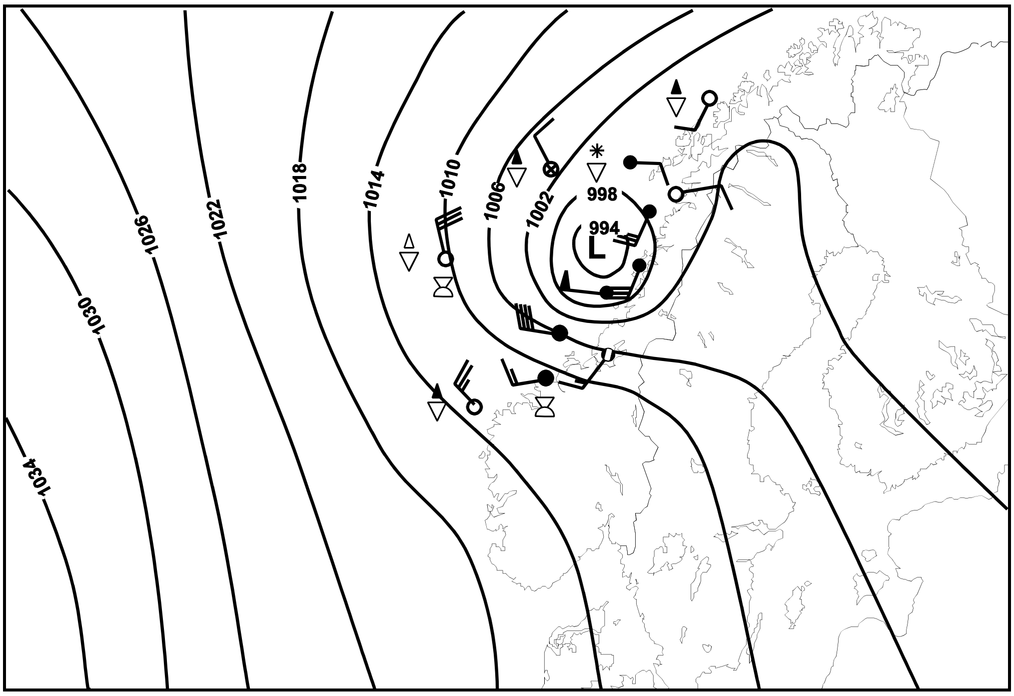
- Equatorial trough
- Intertropical Convergence Zone. (ITCZ) or (sometimes) Intertropical Front (ITF)
- Heat Equator.

POLAR AIR DEPRESSIONS

These thermal lows form when Polar Maritime air is subject to lifting on a large scale. This usually occurs due to the PM air moving south over a warmer sea in winter. It gives Cu, Cb, **heavy showers** and sometimes **secondary cold fronts** develop. Do not confuse with Polar Front Depressions which are at the joining point of the Tropical Maritime and Polar Air Masses.



The Formation of a Polar Air Depression.



A Polar Air Depression off the Norwegian Coast in November

INLAND WATERS

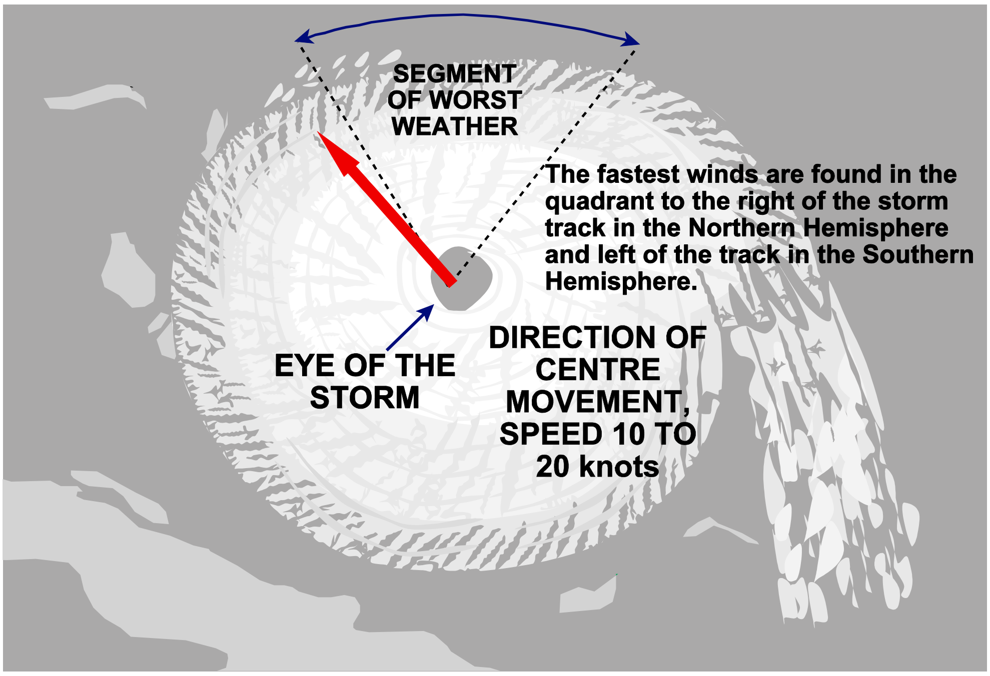
In winter, thermal lows develop over the **Caspian, Black** and **Mediterranean** Seas. A cold outflow of PC air from the **Siberian high** flows over the warmer seas. Convection and the development of depressions result. Similar lows develop over the **Great Lakes of North America.**

THERMAL LOWS OVER LAND (SUMMER)

During SUMMER, shallow lows will appear over land due to surface heating. If the air is already UNSTABLE or there are OLD FRONTAL ZONES in the area, thunderstorms, widespread rain or squalls may result. They also occur regularly in Summer over the American mid-west, giving heavy thunderstorms.

TROPICAL REVOLVING STORMS (TRS)

Description
These are cyclones that develop over the warm tropical oceans and have sustained wind speeds in excess of 64 knots. They are the most destructive and extensive weather phenomenon which affects our planet. Winds in a tornado may momentarily exceed those of a TRS, but the life cycle of a tornado is primarily measured in minutes. The life cycle of a TRS, however, is measured in weeks and its extraordinary size exceeds any other meteorological phenomenon.



The Segment of Worst Weather in a Tropical Revolving Storm,
in the Northern Hemisphere

Formation
Hurricanes are formed from complexes of thunderstorms, (usually starting on the eastern side of the oceans). However, these thunderstorms can only grow to hurricane strength with the right conditions of the ocean and the atmosphere. These thunderstorms are most commonly formed in one of two ways.

The main way being from the InterTropical Convergence Zone (I.T.C.Z) where the easterly trade winds converge at the equator creating a band of storms circumnavigating the globe. The second way is from the equatorial easterly atmospheric waves, otherwise known as easterly waves.

The storms generate their power and energy from the release of large amounts of latent heat from the moisture they have gained over the warm seas. This release of heat causes the air to expand and rise, further reducing the surface pressure. This creates even stronger convergence, which in turn causes more moist air to rise and cool to condensation, aiding the release of greater amounts of latent heat. Since the warm ocean provides the energy it goes to follow that these storms occur when the sea is warmest. However, because of thermal inertia, the sea surface temperatures and therefore storm activity only reaches a maximum during late summer and autumn.

Requirements

- Must be within 5 and 25 latitude. Below 5 coriolis force is too small, above 25 latitude the sea is usually too cold.
- Ocean temperatures must be greater than 26 C. The higher the ocean temperature the greater the pressure drop within the core. This is the reason why we have no TRS forming in the southern Atlantic because the sea surface temperatures are too low.
- There must be a sufficient depth of warm water (200-300ft) in the ocean to provide a continual energy source. If the depth of warm water is too shallow the storm would quickly drain the energy from the ocean and cease to develop.
- Very little shear must exist within the atmosphere, otherwise the storm would topple. This also has the effect of increasing the area over which the latent heat is released, thereby reducing the effect it will have on intensifying the storm.

Movement

The path of a TRS greatly depends upon the wind belt in which it is located. Since most originate from the tropics, it follows then that the TRS will initially be driven westwards by the easterly upper winds at around 10 - 20 knots. Eventually the storms will move away from the equator and increase in strength as a result of increasing Coriolis Force. The subtropical highs and prevailing westerlies at these latitudes drive the TRS eastwards. At this stage the TRS have moved to higher latitudes where the seas are now too cold to feed energy into the storm and they will eventually die. If at any time the storm goes over land, the influx of moisture is ceased and again, the storm will die.

Stages of Development

TRS evolve through a life cycle, from birth to death much like that of a thunderstorm. The stages are based upon the organisation of the storm and the sustained wind speeds which they create. Not all of the stages will eventually evolve in to a TRS.

Stage 1 **Tropical Depression**
This is designated when the first appearance of a lowered pressure and organized circulation in the centre of the thunderstorm complex occurs. A surface pressure chart will reveal at least one closed isobar. Winds constantly between 20 - 34 knots.

Stage 2 **Tropical Storm**
This is when the storm becomes more organized, taking on a circular rotating appearance, with sustained wind speeds between 35 - 63 knots. It is at this stage when it is assigned a name.

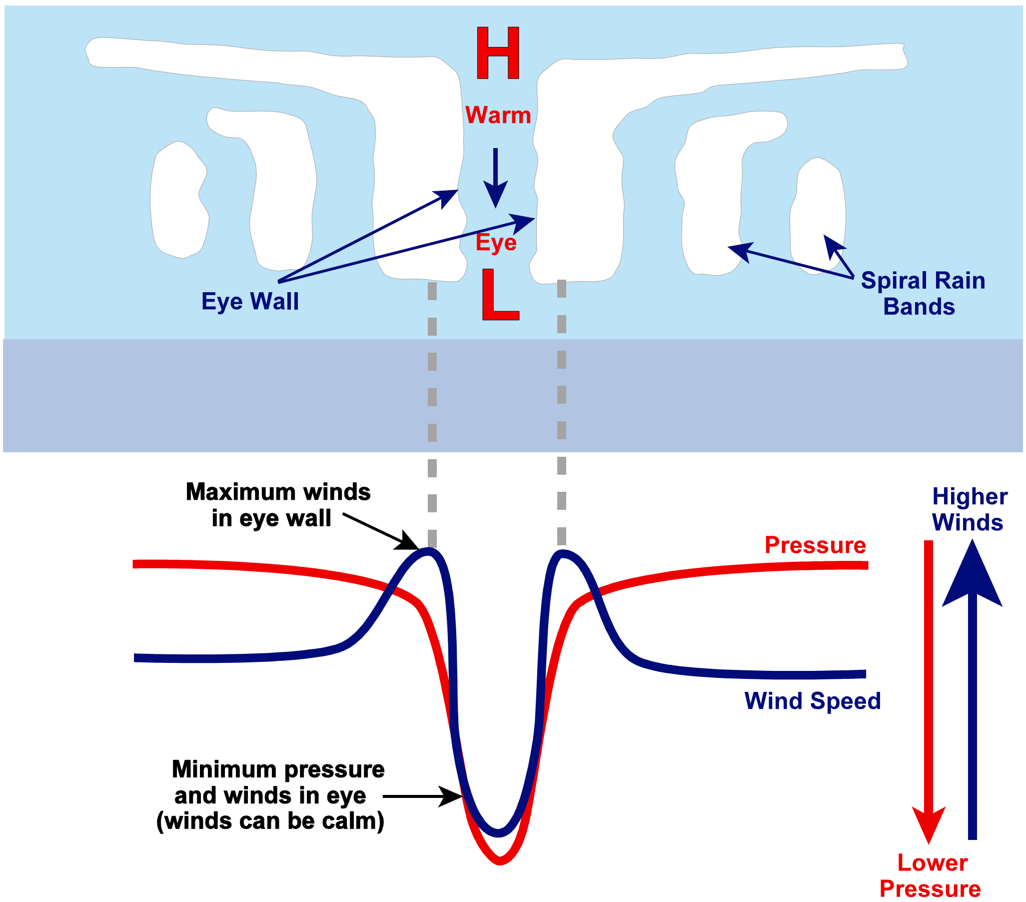
Stage 3 **Tropical Cyclone / Hurricane / Typhoon**
Surface pressure continues to drop and it is designated this stage when sustained wind speeds are greater than 63 knots. There is a pronounced rotation around a central core which will eventually form the "eye".

The eye

The of the most recognizable features found within a TRS is the eye. They are found within the centre having a typical diameter of 20 - 50km. The tightening of the eye is a useful guide that the storm is increasing in strength. It is within the eye that we find the lowest surface pressures, and the calmest conditions. As air is forced up and outward from the storm some of it returns down the centre causing adiabatic heating which evaporates clouds creating the familiar clear column of air which distinguishes the eye itself.

The eye wall

This is the vertical wall of cloud enclosing the eye and is the most devastating region with intense winds and rainfall. From the wall itself large bands of cloud and precipitation spiral out from the storm and are called "spiral rain bands".



Cross Section of a TRS

Names and Nicknames:

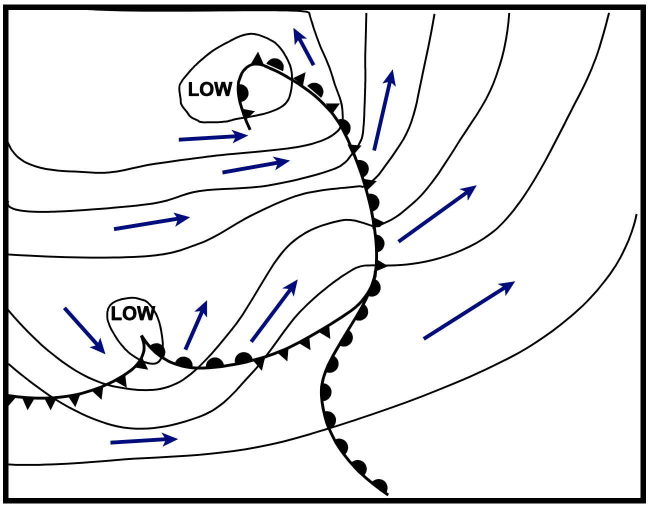
TRS are given different names in different parts of the world. Either side of North America these storms are called Hurricanes. In the Indian Ocean and around Australia they are called Cyclones and around the far east, they called Typhoons. Typhoons are the most violent and have the longest season of any TRS.

Within each region, and for each storm season, a series of nicknames in alphabetical order is devised, alternating male and female names, e.g. the first storm in this year's season in the Caribbean might be called 'Arthur', the next one 'Betty' and the third one 'Charlie'. Next year the series may start with 'Annie' followed by 'Brian' and so on.

SECONDARY DEPRESSIONS

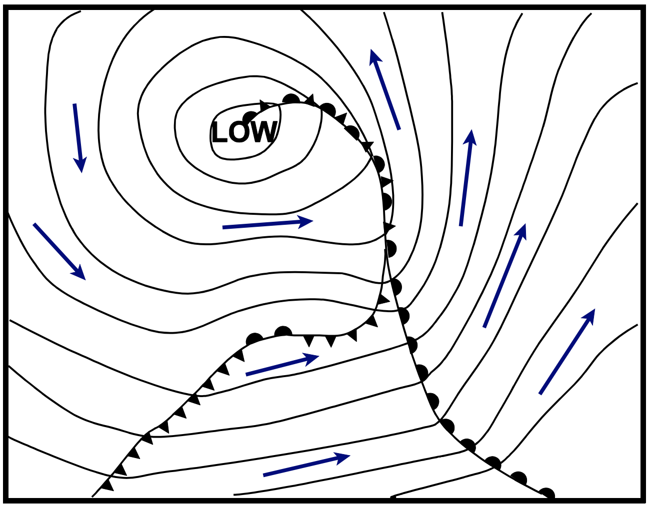
When a small depression is enclosed within the circulation of a larger depression it is called a **secondary.** The isobars need not show a closed centre. Secondaries are particularly associated with frontal depressions and form:

- **On a trailing front from an occluded primary**. This secondary may deepen and form the next depression along the PF and equal the size of the primary. At this stage, the depressions tend to rotate around each other, until eventually the primary and the secondary has become the new primary.



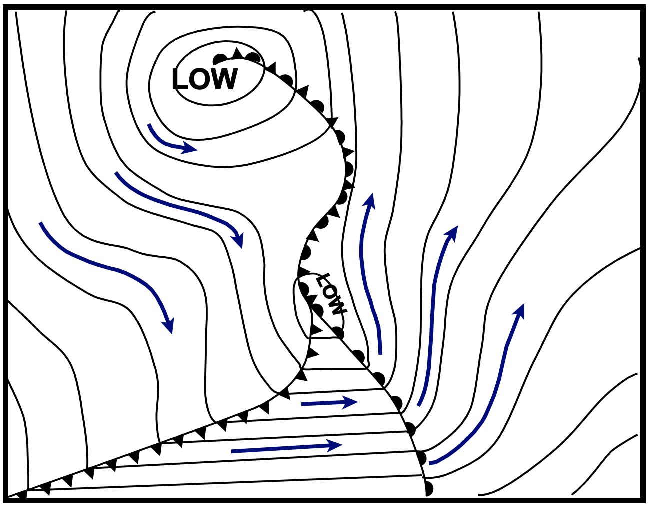
A Secondary Depression on the End of a Cold Front

- **On a trailing cold front well within the primary circulation**. In this case, it appears only as a disturbance on the front, it moves along it without much development until it eventually becomes absorbed. Although producing little weather of its own, it may delay the movement of the CF and make forecasting of frontal passage difficult.



A Secondary Depression Within the Primary Circulation

- **Tip of warm sector of partly occluded depression.** Formed at the Point of Origin or Triple Point, while the primary fills up. Often formed when primary and occluded fronts are held up by a mountain barrier as in **Southern Greenland** or **Norway**.



A Secondary Front Formed at the Tip of a Warm Sector
Where Fronts Have Occluded

COLD AIR POOLS

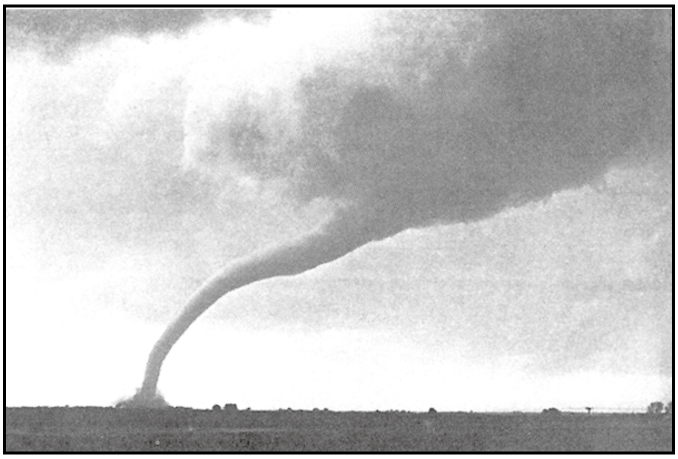
These are outbreaks of cold air from near the poles. These outbreaks are usually characterized by a cold front at their leading edge. In fact they are common just behind the polar front depressions behind the cold front itself. Typically the air is unstable and therefore expect cumuliform activity with showers and even thunderstorms.

Although surface temperature anomalies such as cold pools are not evident on surface pressure charts, they can be found most notably by looking at pressure charts in the middle to upper atmosphere. You may remember that cold air causes pressure to fall more rapidly with height, reducing the pressure in the upper atmosphere. Therefore by analyzing a pressure chart in the middle to upper atmosphere you can identify cold air pools by the low pressure they create.

TORNADOES

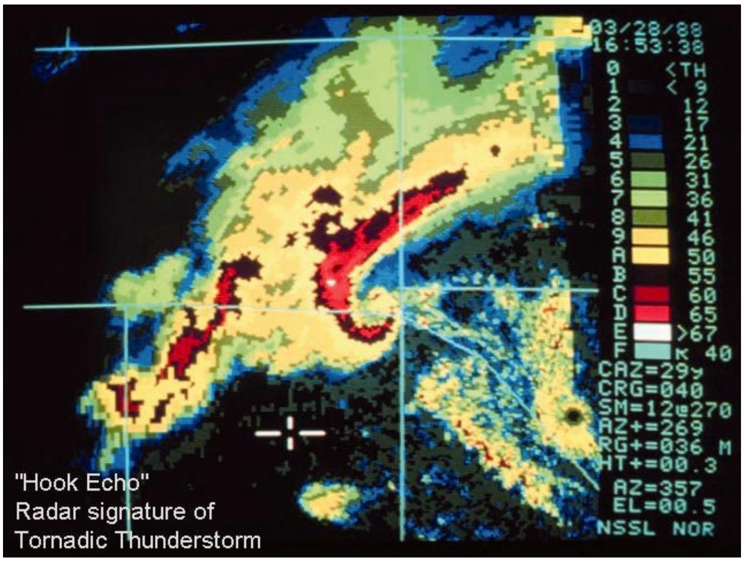
A tornado is a violently rotating column of air which is in contact with both a cumulonimbus (or, in rare cases, cumulus) cloud base and the surface of the earth. Tornadoes can come in many shapes, but are typically in the form of a visible condensation funnel, with the narrow end touching the earth. Often, a cloud of debris encircles the lower portion of the funnel.

Tornadoes can be very destructive. Most have winds of 110 mph or less, are approximately 100m to 150 m, and travel a few miles before dissipating. However, some tornadoes can have winds of more than 300 mph be more than a mile across, and stay on the ground for dozens of miles. They are most common in “Tornado Alley” in the mid-west of North America during late spring and early summer. They reach peak occurrence at about 1700 LMT.



A Tornado

Increasing use of Doppler Radars which will also measure particle speeds within the vortex is making local tornado warnings more reliable, but still not more than 30 mins ahead.
Tornadoes develop a typical ‘hook’ pattern on the radar screen.



Radar Scope Picture

West African Tornado. West African Tornadoes are associated with the passage of the ITCZ through countries bordering the Gulf of Guinea. They are thundersqualls which form in a line North-South and move from East to West in March to May and October to November.

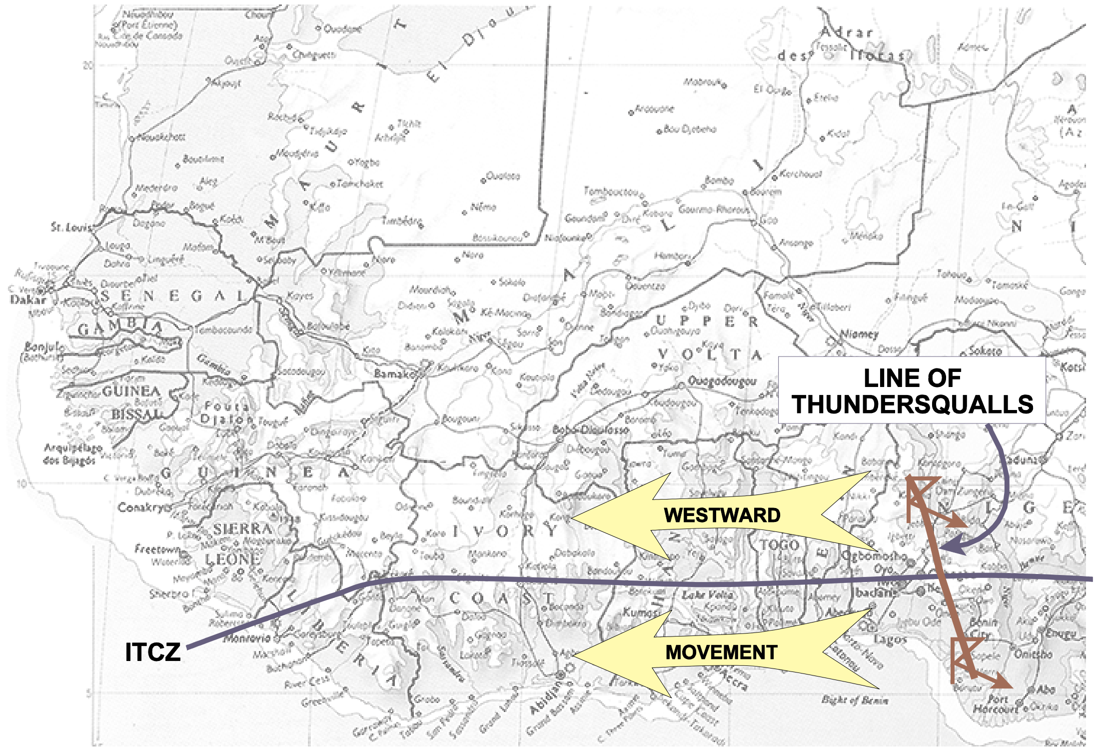


Figure 18.19 West African Tornadoes

Whilst the two above are the main tornadoes, lesser tornadoes occur in the UK and Europe and in the USA weak tornadoes called 'gustadoes' occur in association with Gust Fronts and 'landspouts' are waterspouts which have come ashore. An example of this occurs in the film 'Hurricane' shown as part of the course.

QUESTIONS

1. A thermal depression is likely to form:

   a. over the Iberian peninsular during the summer
   b. in the lee of the Alps over Northern Italy in winter
   c. in association with a marked trough of low pressure over the USA
   d. on the trailing edge of a warm sector mid latitude depression

2. Tropical revolving storms usually:

   a. form close to one side of the equator and while moving slowly in a westerly direction, cross over to the other hemisphere
   b. move in a westerly direction before re-curving towards the equator
   c. move in an easterly direction before re-curving towards the nearest pole
   d. do not form within 5° of the equator

3. With reference to tropical revolving storms, which of the following statements is correct:

   a. typhoons are found in the South China sea in January
   b. cyclones, occur in the Bay of Bengal in winter
   c. hurricanes, in the South Atlantic sometimes affect the east coast of Brazil
   d. hurricanes affect the south east of the USA in late summer

4. Which of the following statements accurately describes the "West African Tornado":

   a. the West African Tornado is similar to the North American and European tornadoes
   b. it is a line of thunderstorms producing a line squall aligned roughly north/south
   c. it is another name for the cyclones that affect the West African coast in summer
   d. it is the name given to a line of thunderstorms that lie along the ITCZ but some 200 miles to the south

5. Extensive cloud and precipitation is often associated with a non-frontal thermal depression because of:

   a. Surface divergence and upper level convergence causing widespread descent of air in the depression.
   b. Surface convergence and upper level divergence causing widespread descent of air in the depression.
   c. Surface convergence and upper level divergence causing widespread ascent of air in the depression.
   d. Surface divergence and upper level convergence causing widespread ascent of air in the depression.

6. In comparison with a primary depression a secondary depression is:

   a. Always more active.
   b. Sometimes more active.
   c. Never more active.
   d. Unlikely to produce gale force winds.

7. A Secondary Depression would form in association with:

   a. A Polar Depression.
   b. A Col.
   c. A Summer Thermal Depression over the Mediterranean or Caspian Sea.
   d. A Polar Front Low.

8. Tropical Revolving Storms:

   a. Are always given a male first name beginning with "A" for the first of the season and thereafter named in alphabetical order of occurrence.
   b. Have internal wind speeds of 10-20 knots rotating cyclonically round a subsiding clear air core known as the eye.
   c. Usually have the most severe weather in the quadrant to the right of the track in a Hurricane.
   d. Regenerate after crossing the coast from sea to land

9. Which of the following are Thermal Depressions:

   a. Tropical revolving storms, polar air depressions, tornadoes.
   b. The equatorial trough, monsoon lows, some depressions over the central and eastern Mediterranean sea in summer.
   c. The equatorial trough, polar air depressions, monsoon lows, orographic lows.
   d. The lows forming over flat land in summer, polar air depressions, tropical revolving storms, some of the lows which form over inland seas in winter

10. A Secondary low pressure system rotates around a Primary low:

   a. Cyclonically.
   b. Anticyclonically.
   c. Into the primary.
   d. At a constant distance.

11. Flying conditions in a Secondary low pressure system are:

   a. Always more severe than in a Primary low.
   b. Sometimes more severe than in a Primary low.
   c. Less severe than in a Primary low.
   d. Relatively calm.

12. Tropical Revolving Storms:

   a. Do not occur in the South Atlantic.
   b. Generally move from east to west before turning towards the equator.
   c. Intensify after crossing coasts.
   d. Occur principally in spring and early summer.

ANSWERS

1	A
2	D
3	D
4	B
5	C
6	B
7	D
8	C
9	D
10	A
11	B
12	A

CHAPTER NINETEEN

GLOBAL CLIMATOLOGY

Contents

INTRODUCTION

We have studied how the individual elements of weather occur, how winds occur, the precipitation that falls from the clouds and so on. We now need to look at how all these elements come together to form **weather** and how this weather varies from place to place. The weather at a place makes its **climate;** the study of this climate is called **climatology.**

The elements of climatology are **precipitation, temperature, humidity, sunshine** and **wind velocity.**

These elements will be affected differently across the globe by; **latitude, location** (maritime or continental), the circulation of **pressure systems, altitude** and **geography.**

Over the years climatological data has been accumulated to such a degree that weather forecasting on an area basis has become quite accurate and communications have improved to such a degree that weather expected on arrival at a destination (and the weather en-route) may easily be obtained. This chapter will deal with climatology on a global basis and its regional and seasonal variations.

IDEALIZED AIR CIRCULATION

The general air circulation is a very complicated system of air movements. These movements, while based on the passage of air from high pressure to low and the effect of the rotation of the earth, are complicated by:

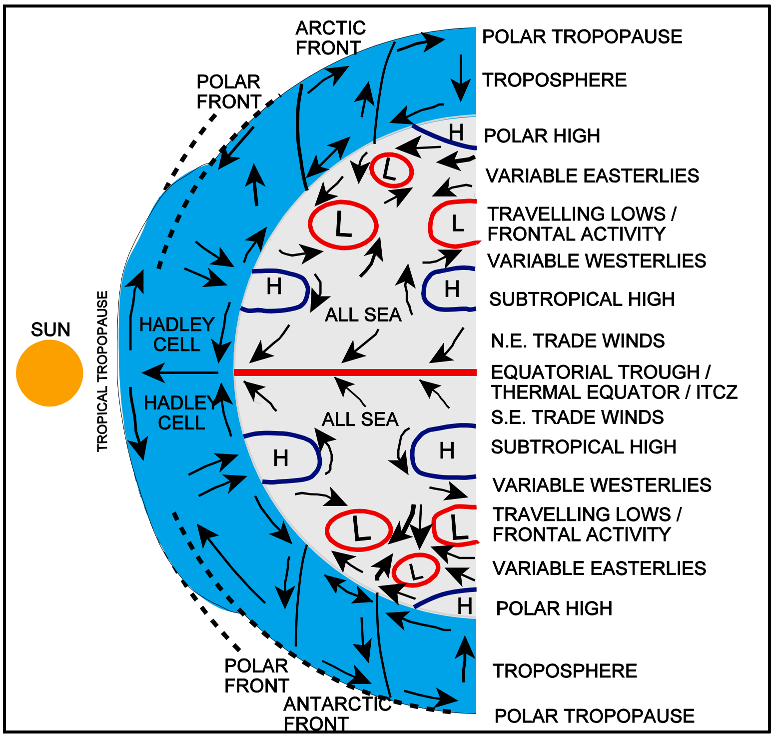
- The unequal heating of land and sea together with land and sea disposition.
- Variation in land heating caused by different surfaces.
- The 23½° inclination of the earth's axis which causes movement of the thermal equator.

It is therefore useful to consider an air circulation which ignores these main complications and to use this as a basis for understanding the conditions which actually prevail. The idealized circulation assumes that the earth's surface is covered with sea and that the geographic and thermal equators are coincident. In fact, since the surface of the southern hemisphere is largely covered by sea, climatology in that hemisphere very closely follows the idealized case.

IDEALIZED CIRCULATION WEATHER

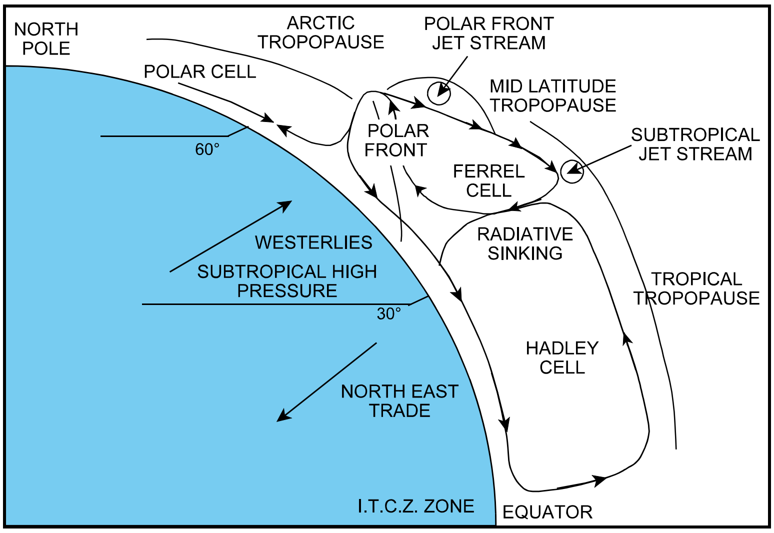
With a uniform spherical earth, the temperature would only vary with latitude. Pressure at any given height over the equator would then be greater than that at any height over the poles. Thus air would drift at height from the equator to the poles, helping to produce high latitude anticyclones and causing a movement on the surface of air from poles to equator.

However, this cyclic movement of air would be affected by the rotation of the earth, and the circulation would be modified to that shown below.



Idealised Distribution of Surface Pressure over the Earth.

Anticyclones, formed by Hadley Cells around 30° N and S, and known as sub-tropical anticyclones, would provide a surface outflow of warm air, some of which would move towards the nearer pole. This air would meet the cold anticyclonic flow from the polar regions, thus providing areas of frontal activity.



Hadley Cell, Polar Front and Associated Wind-Flows.

The Hadley Cell and Polar Front, with the vertical airflows that cause them, are shown above. From the sub tropical anticyclones in each hemisphere, surface outflow also occurs towards the equator. This convergence causes rising air and much instability in the Equatorial Zone, and is known as the Inter Tropical Convergence Zone (ITCZ).

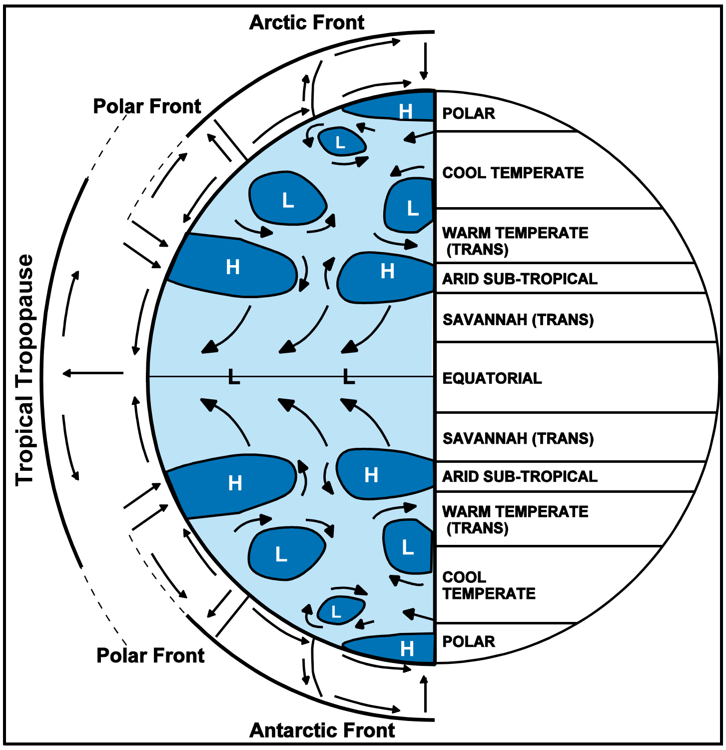
The Earth's climatic engine, the airflow pathways of the world, clearly demonstrate how the climatic zones of earth are interrelated. Moisture laden air rises along the ITCZ causing masses of cumulonimbus thunderclouds to develop giving rise to the heavy rains in the tropical regions. Upper air from the Hadley and Ferrel cells meet and are cooled and undergo radiative sinking to produce the Sub Tropical High Pressure zones at the Earth's surface giving settled weather.

The air streams separate here in the northern hemisphere , one flows South as the NE Trade Winds whilst the other flows North to become temperate latitude Westerlies. The flow is mirrored in the southern hemisphere.

The Polar Front is caused by cold air of the Polar Cell forming a wedge beneath the warmer Ferrel Cell. Complex airflow patterns associated with the Polar Front are responsible for the vagaries in the weather of mid latitudes.

BASIC CLIMATIC ZONES

Adiabatic cooling of the air by ascent, producing cloud and much precipitation, will occur in the equatorial region and in the temperate frontal zones. Conversely, mainly arid conditions will apply in the anticyclonic polar and sub-tropical regions because of subsidence. The Globe therefore may be conveniently divided into a number of climatic zones as shown below.



World Climatic Zones

CLIMATIC ZONES (BY LATITUDE)

Equatorial 0 - 10 degrees. Two main wet seasons - at the Equinoxes. Never dry. Much convection cloud and heavy rain showers and thunderstorms. Temperature and humidity high. Light surface winds (the Doldrums).

Savannah/tropical transitional 10 - 20 degrees. Dry Trade Wind conditions in winter. Equatorial rains in summer. Duration of wet period decreases as latitude increases towards 20°

Arid sub-tropical/steppe 20 - 35 degrees. Typical sub-tropical anticyclonic weather. Descending air - warm & dry. Produces typical desert climate with short wet season at the desert edge - at the low latitude edge in summer from the ITCZ, and at the high latitude edge in winter from temperate zone activity. Deserts include Sahara, Kalahari, Gibson, Arabian, Arizona & South America. The zone includes the Trade Wind belt.

The semi-arid Steppe type climate borders the desert regions and has a short rainfall season. Weather gives grassy, treeless plains. Examples are the Russian Steppes and the South American Pampas.

Warm temperate 35 - 40 degrees. Mediterranean type climate. Disturbed temperate conditions in winter with frontal and thermal depressions. In summer, warm and dry as thermal equator moves towards the pole.

Cool temperate 40 - 65 degrees. Weather is controlled mainly by travelling polar front depressions. Winds are westerly; gales are frequent in winter. There is no dry season.

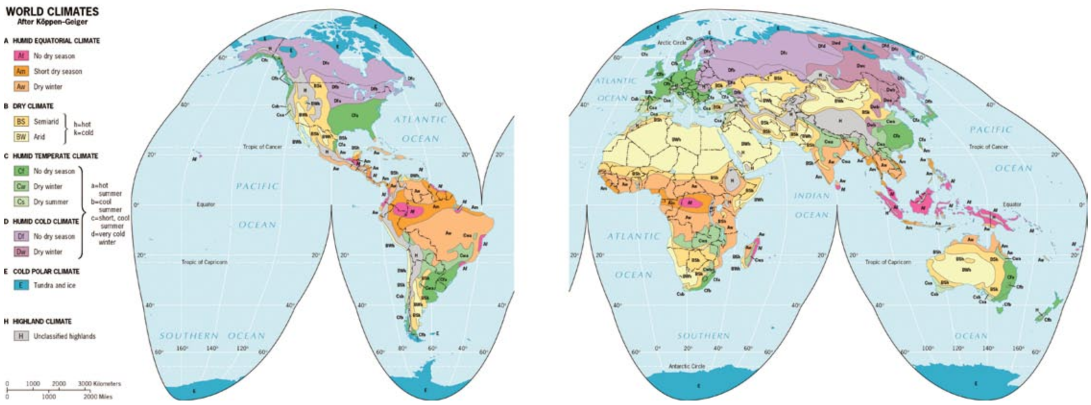
Boreal zone 40-60N. Between the Cool Temperate and Polar zones in the Northern Hemisphere lies the Boreal Zone. Occurs over the land masses of northern North America, Scandinavia and north Russia. Characterised by warm, moist summers and very cold winters.

Polar 65 - 90 degrees. For much of the time, anticyclonic weather - very cold and dry, but modified by depressions penetrating the peripheral region in summer to bring unsettled weather and precipitation.

In some areas, temperatures can rise above zero for a month or so, giving a Tundra Climate of sparse vegetation, e.g. Lichen and Moss. Subsoil remains permanently frozen - Permafrost.

SUMMARY

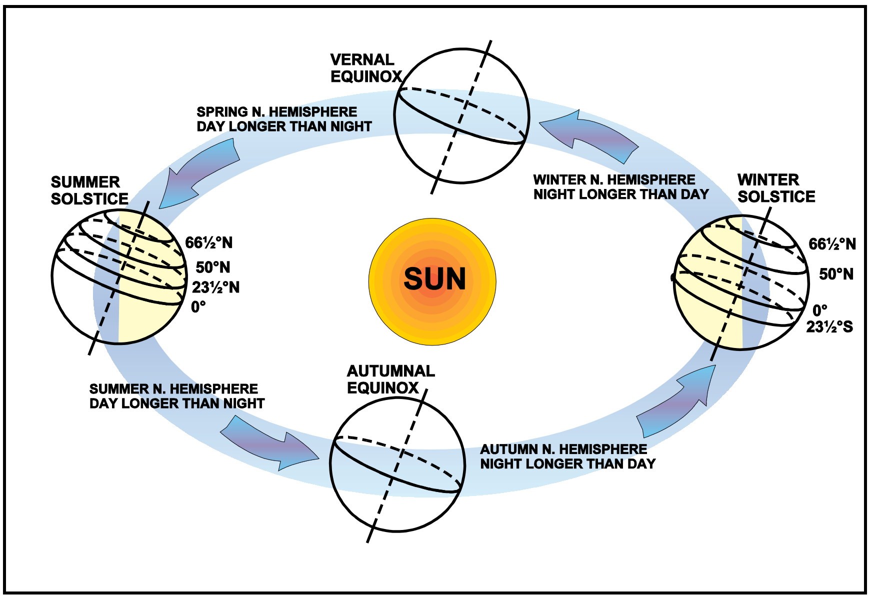
The idealized weather described above will be modified by local topography and by the proximity of sea areas. The effect of these on temperature, density and pressure can have a marked effect on local climatology.



SEASONAL EFFECT

The previous images have assumed that the sun's sub point encircles the globe along the equator in all seasons.

In practice, the earth's polar axis is inclined at an angle of 23½° to the plane of the path that the earth travels through space during the year. This path is shown below and it may be seen that, while the sun's sub point is on the equator at the Equinoxes on 20/21 March and 20/21 September, it is on the Tropic of Cancer (23½°N) at the Solstice of 21 June and on the Tropic of Capricorn (23½°S) at the Solstice of 21 December.



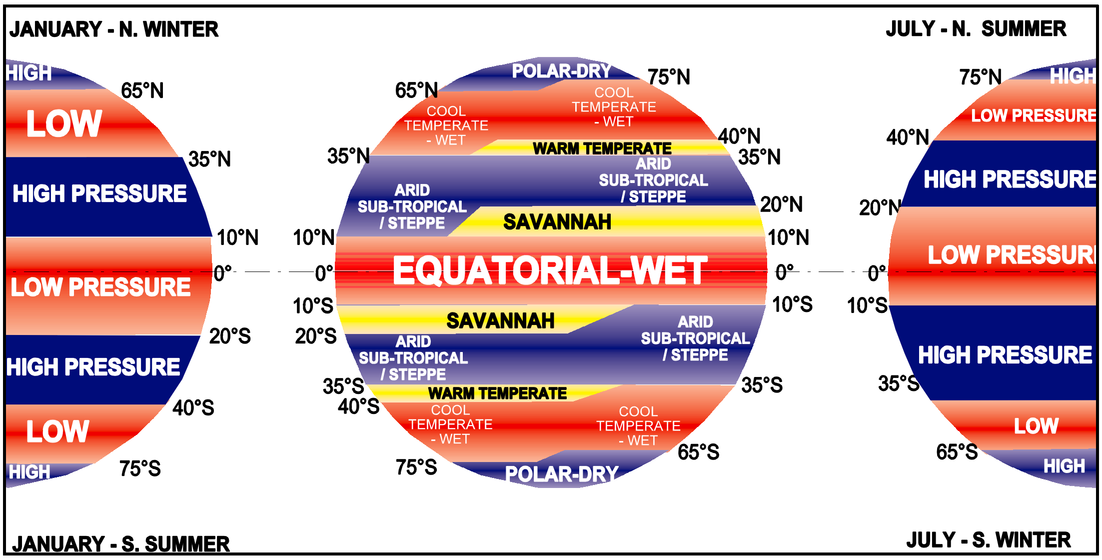
The Orbital Motion of the Earth around the Sun.

Hence when viewed from the earth the sun's sub latitude appears to move southwards from the Tropic of Cancer on 21 June to the Tropic of Capricorn on 21 December then northwards again returning to 23½°N the next June.

It may be noted that above 66½° N (the Arctic Circle) the sun is above the horizon 24 hours a day on 21 June and below the horizon 24 hours a day on 21 December. The reverse is true in the Antarctic.

In the actual world the seasonal movement of the thermal equator can produce tropical rains moving into the summer hemisphere; that is, North in July or South in January. We thus have a transitional region in each hemisphere between the sub-tropical highs and the equatorial low. Each will be subject to tropical rain in summer and to dry trade wind weather in winter. Near the equator there will be rain nearly all the time, with maximum rainfall about the time of the equinoxes and minimum at the solstices.

The hottest band around the equator or "Heat Equator", will move North and South some 10° of latitude in sympathy with the sun's movement, albeit about a month later and indeed all climatic zones will so move. This gives rise to the Northern and Southern climatic extremes in the all-sea world as shown below.



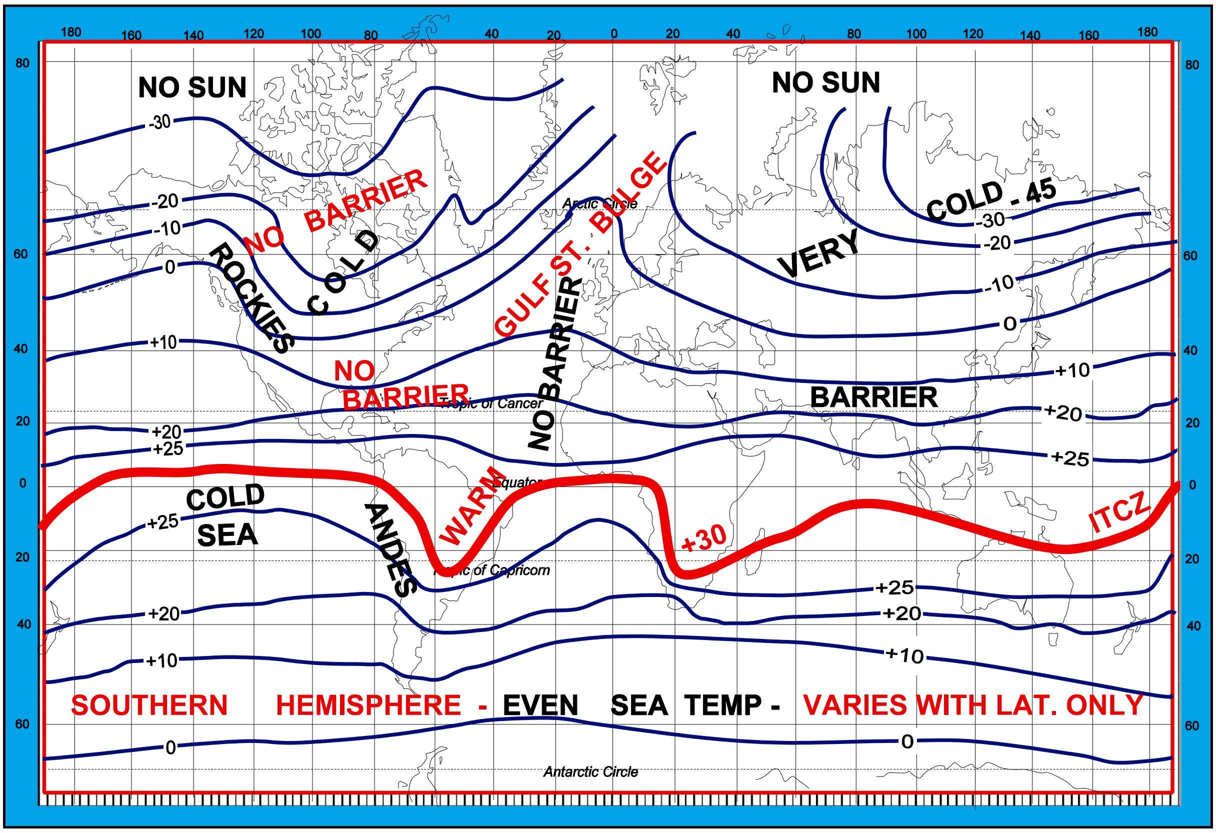
Seasonal movement of the World Climatic Zones

Similarly, the disturbances of the temperate zone extend towards the equator in winter and away again in summer so that areas on the polar side of the sub-tropical highs have winter cyclonic rains and dry summers.

TEMPERATURE AND TOPOGRAPHICAL EFFECTS

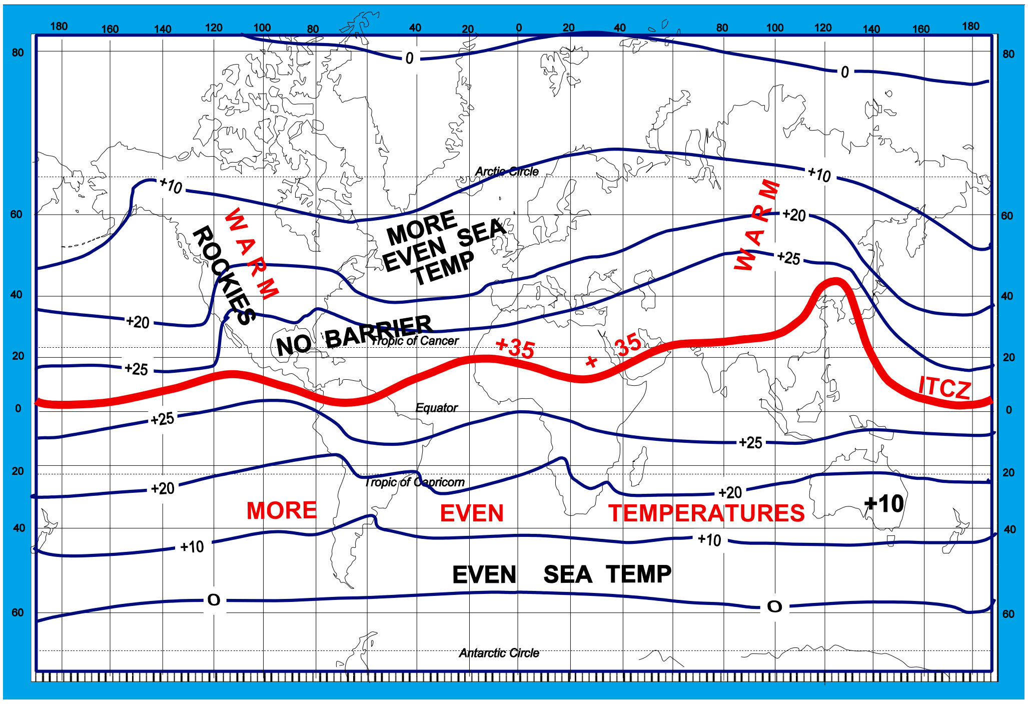
The surface temperature of an idealized all sea world would cool evenly with latitude increase because the sun's elevation would reduce. In practice this even cooling will be much modified by the presence of land masses, especially in the Northern Hemisphere where the continents of Asia and North America are vast. One effect is that the sub tropical anticyclones do sometimes break down due to summertime land heating which lowers pressure. Conversely, continents **outside** the sub-tropical high belt can experience wintertime land cooling which raises pressure.

In **January** the temperature in **Asia** is exceptionally cold as shown below. The winter cold air over central Asia is due to its distance from the sea, long nights and winter long terrestrial radiation. It will be held back from India and Pakistan to the south by the Himalayas. In **North America** the cold is further enhanced by the Rocky Mountains which block warm Pacific air while the absence of a barrier to the North allows Arctic air to move south. **North Atlantic** temperatures will remain comparatively high due to the warm water sea current from the Gulf of Mexico. Hence prevailing westerly winds from the Atlantic will warm the adjacent land masses of UK and Western France. **Southern Hemisphere** isotherms will be near the ideal due to the greater sea areas.



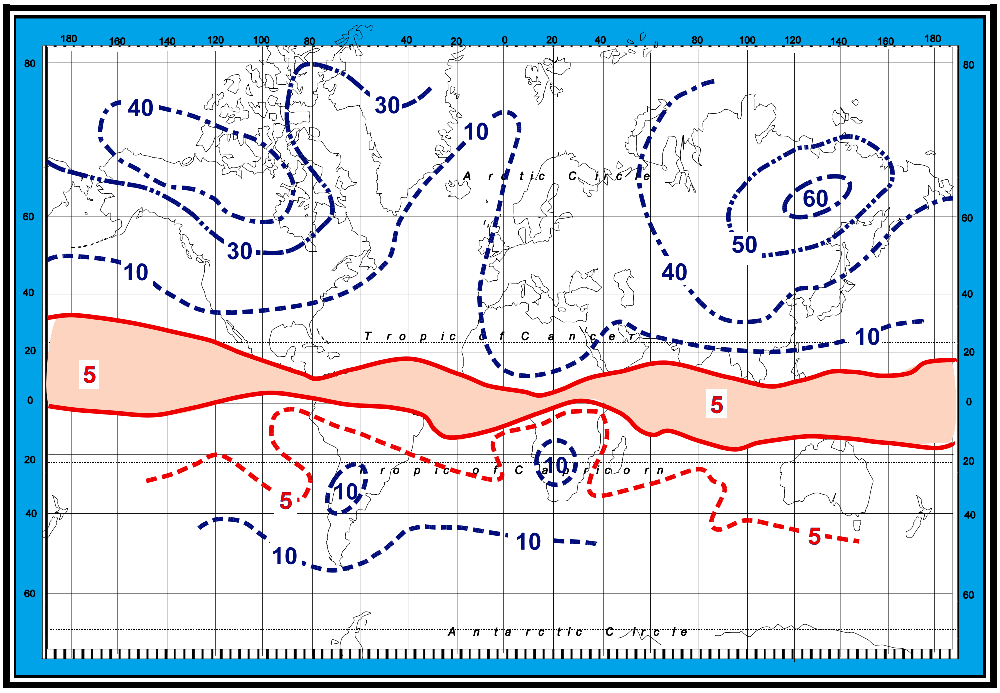
Average mean sea level temperatures in January

In **July,** Central **North America** is warmed by air free to move north from the Gulf of Mexico; the vast area of Asia is warmed by the sun. These continents are now warmer than the Gulf stream-warmed-**Atlantic** so that isotherms are reversed, although contrasts are less than in January. In the **Southern Hemisphere** the July winter reflects some seasonal ocean cooling but isotherms still equate approximately with latitude.



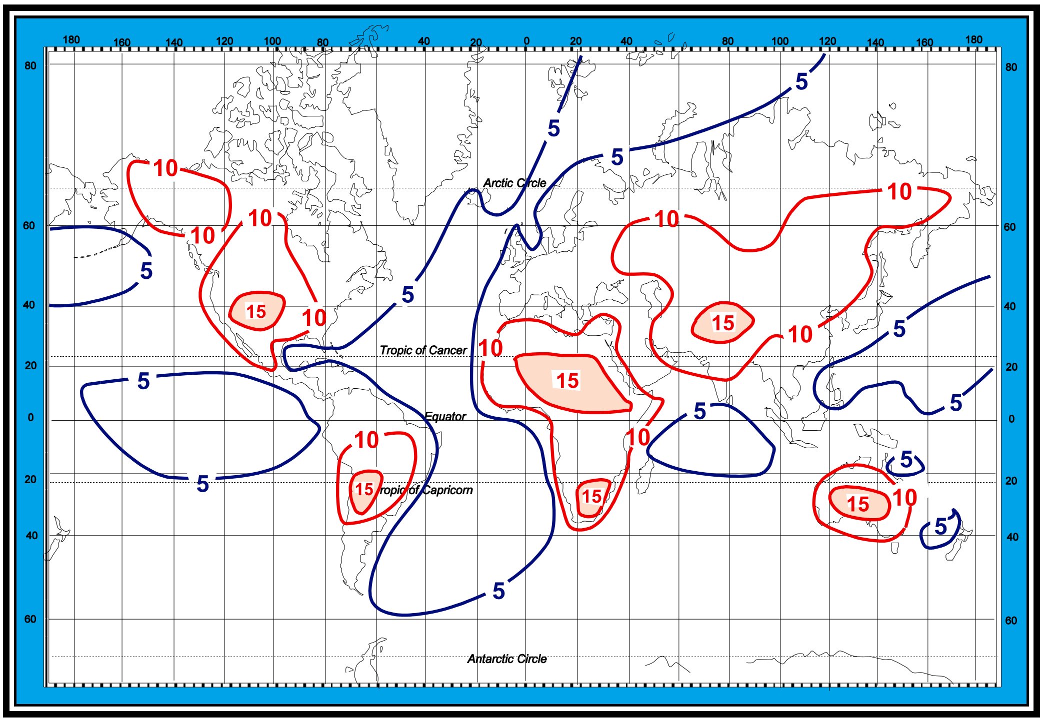
Average mean sea level temperatures in July

By comparing the January and July diagrams it can be seen that in **high latitudes,** annual surface continental land temperatures will have wide extremes, whereas sea temperatures will vary much less during the year. This has implication for instance on the location of polar fronts and the strength of jetstreams. At the **Equator** temperatures vary little. Typical Winter and Summer differences are shown below.



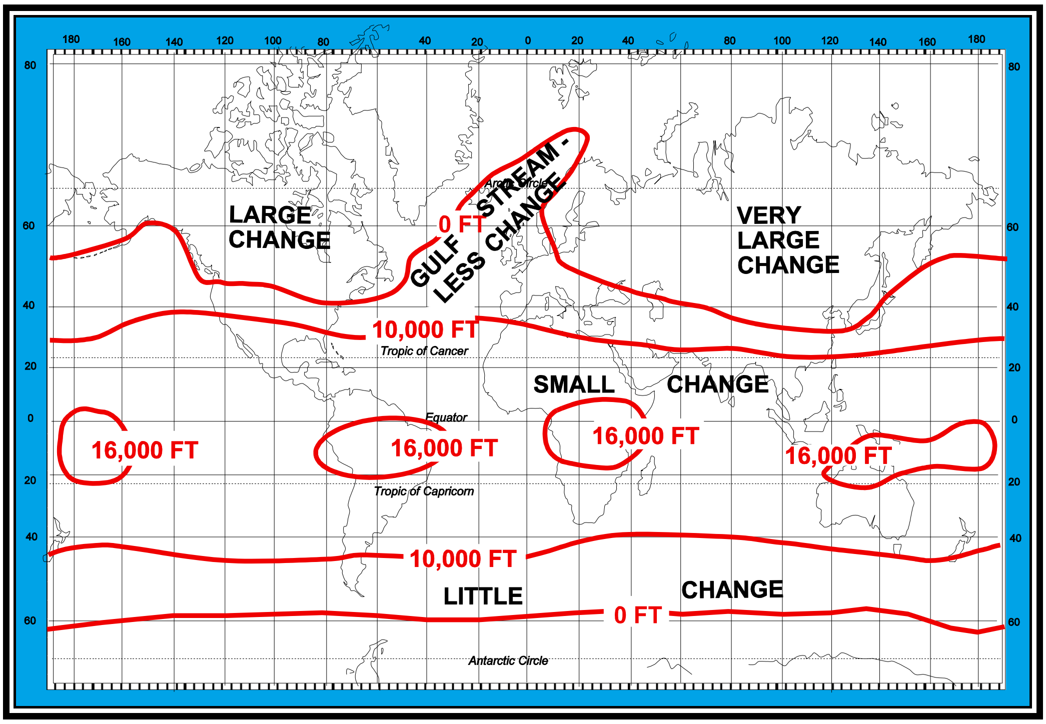
Annual range of temperature (Annual Variation)

As distinct from seasonal variation, temperatures will also change daily, but diurnal change will be most in areas over land masses since it is in this circumstance that the sun's heating effect is greatest. The chart below shows the diurnal differences.

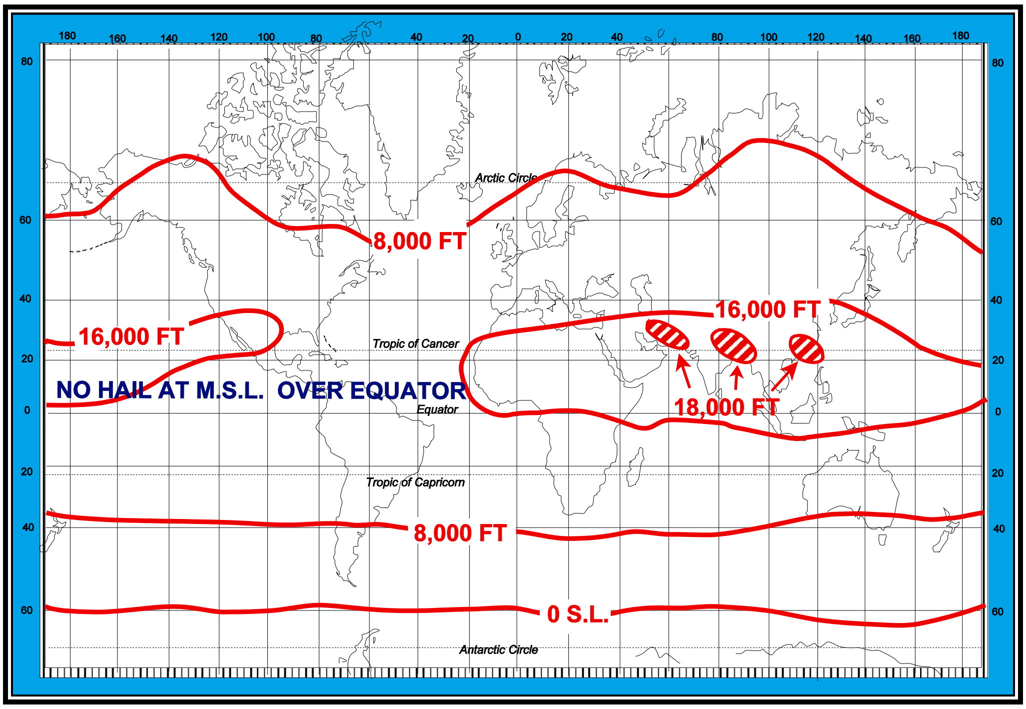


Diurnal range of temperature (Diurnal Variation)

Just as **surface** temperatures change more with departure from the equator, so will temperatures aloft. At the geographical equator the freezing level is 16000′, although locally as high as 18000′ in July when the heat equator lies overland in SE Asia; because of this hail in thunderstorms would melt before reaching Mean Sea Level. Elsewhere in both hemispheres the freezing level change will be seasonally wider but especially so over land areas. The following diagrams show the freezing levels in January and July.



Height in Feet of Freezing Level in January



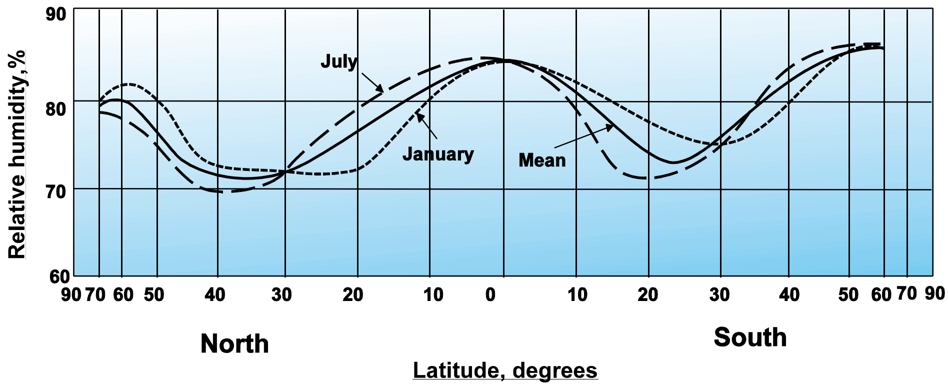
Height in Feet of Freezing Level in July

Summary

Topographical temperature variations will affect surface pressure and distort the idealized distribution shown earlier, so that whereas the climatic pressure zones will be maintained over the **oceans**, the pressure patterns **overland**, and hence the winds and weather, will be governed much more by surface temperature changes. This will apply especially to the Northern Hemisphere, where two-thirds of the world's land masses lie.

Relative Humidity

This chart shows how relative humidity varies with latitude and season.



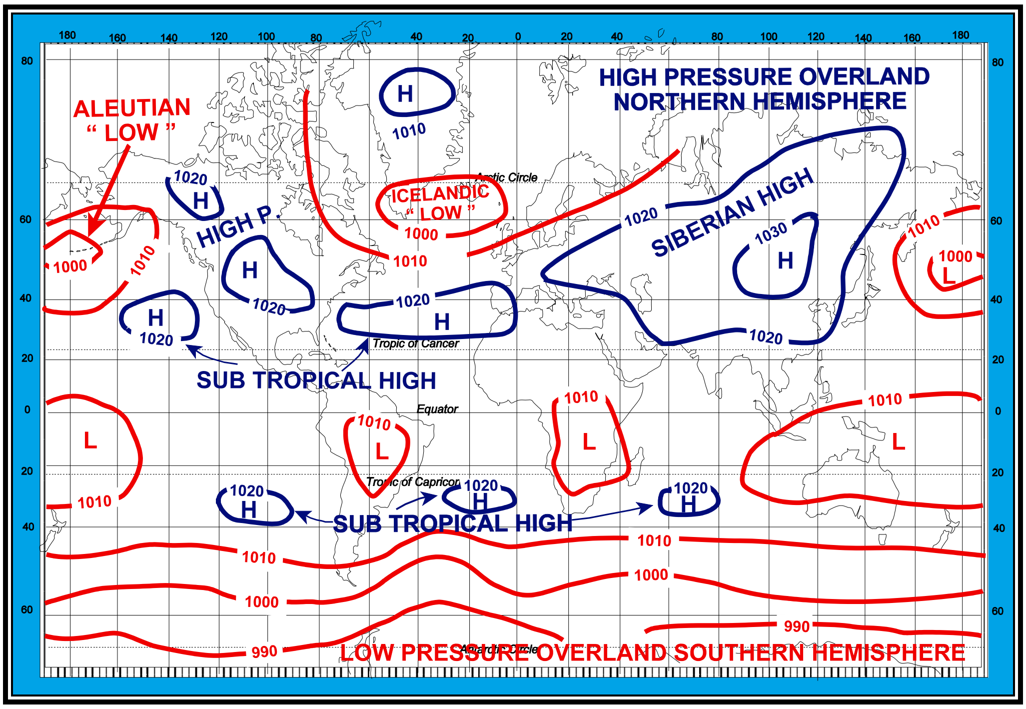
Zonal distribution of the relative humidity

PRESSURE

➢ JANUARY

- In the southern hemisphere the pattern is close to the idealized circulation.
- The **Equatorial Low Pressure zone** lies to the **south** of the equator.
- **Sub-tropical highs** are established over **oceanic areas**.
- **Cold weather highs** are established over Northern hemisphere **land masses**.
- There are significant pressure areas in the region of:

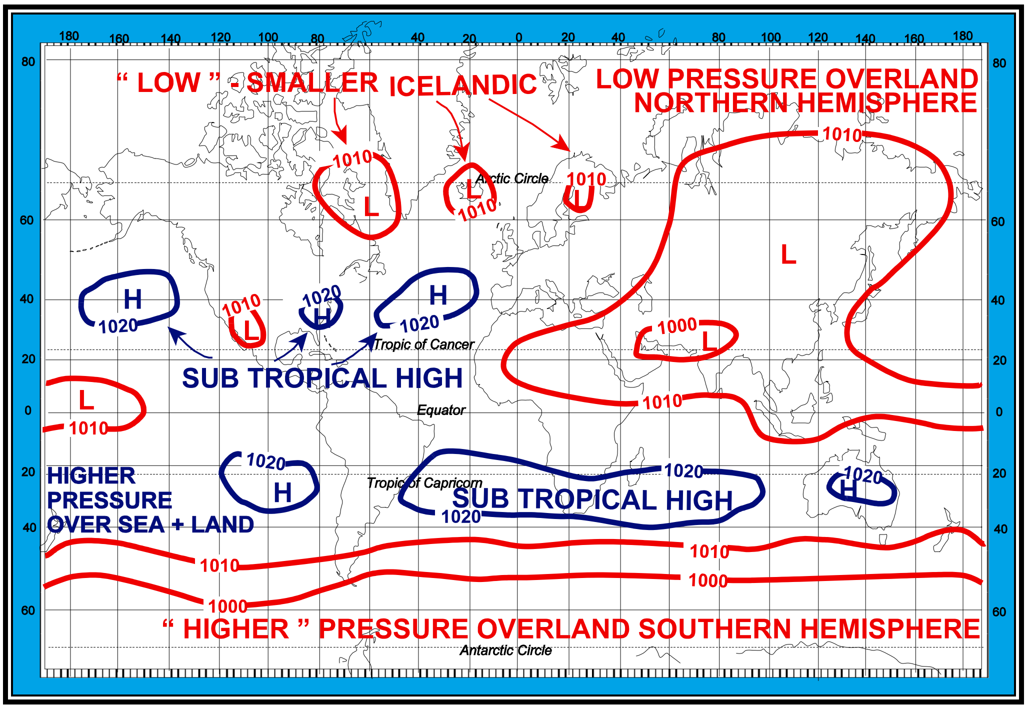
Iceland (**Low**)	1000 hPa	(statistical low)
Aleutians (**Low**)	1000 hPa	(statistical low)
N. Australia (**Low**)	1005 hPa	
Siberia (**High**)	1035 hPa	
N. America (**High**)	1020 hPa	
Azores (**High**)	1020 hPa	
Pacific (**High**)	1020 hPa	



Average Mean Sea Level Pressures in Millibars in January.

➢ **JULY**

- In the southern hemisphere the pattern remains close to the ideal. Overland temperatures are colder thus the subtropical high is generally unbroken.
- The **Equatorial low pressure zone** lies to the **north** of the equator.
- Where sub-tropical highs would be expected in the Northern Hemisphere, low pressure areas now form over land masses due to solar heating. Thus the **Siberian High** of January is replaced by the **Baluchistan Low**, centred over Pakistan but affecting all of **Asia. N America** also has low pressure.
- The **Aleutian** and **N Australia lows** disappear.
- **Icelandic statistical low** pressure is less deep and is now dispersed into three small areas:
- **Off Greenland, the Baltic and Iceland** - 1010 hPa
- The **Azores & Pacific Highs** are dominant at 1025 hPa

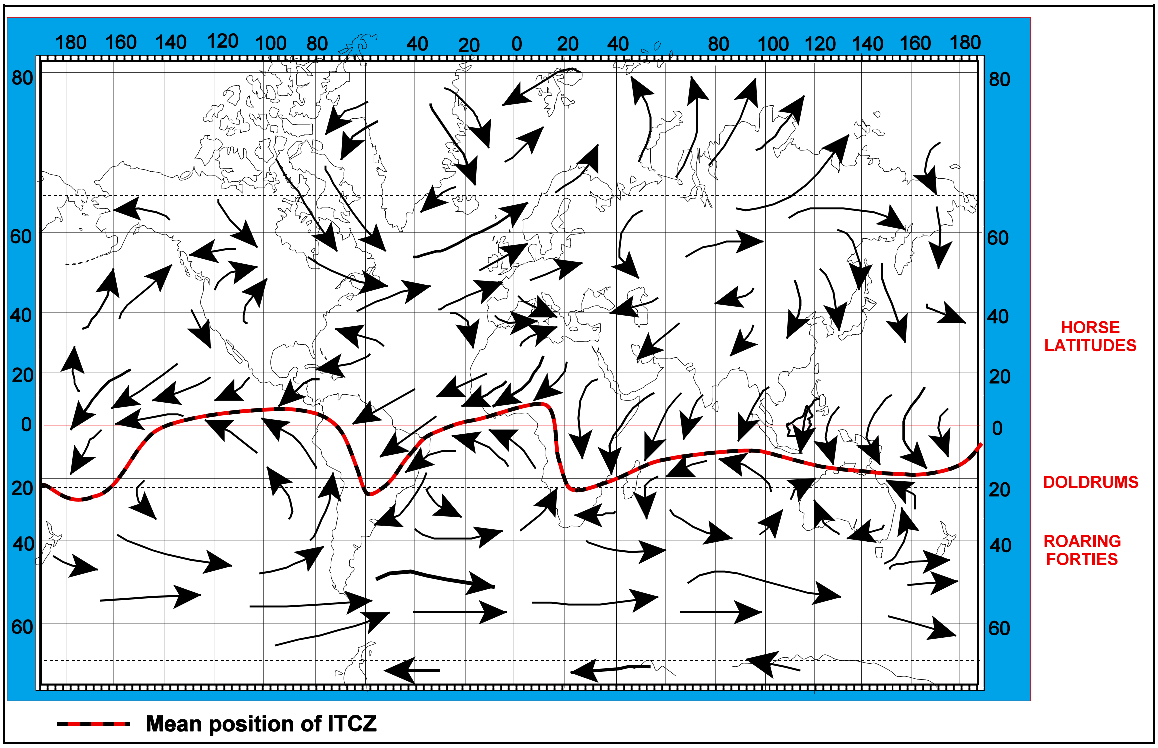


Average Mean Sea Level Pressures in Millibars in July

SURFACE WINDS

The westerlies of temperate latitudes

Westerly winds exist in the region between sub-tropical highs and temperate lows. (40 - 60 degrees latitude). These are caused by the turning effect of Coriolis Force on the **Poleward** outflow from those sub-tropical highs. In the northern hemisphere the westerlies apply mainly over the oceans, with frequent winter gales. During the summer months these westerlies are less constant and less strong. In the southern hemisphere these winds are largely uninterrupted by land masses and are consequently strong. They are called **The Roaring Forties** - so called because they blow principally between latitudes Forty and Fifty South. Weather in this belt comes from rapidly moving depressions; wild weather, strong westerly winds and gales, overcast skies and heavy rain.

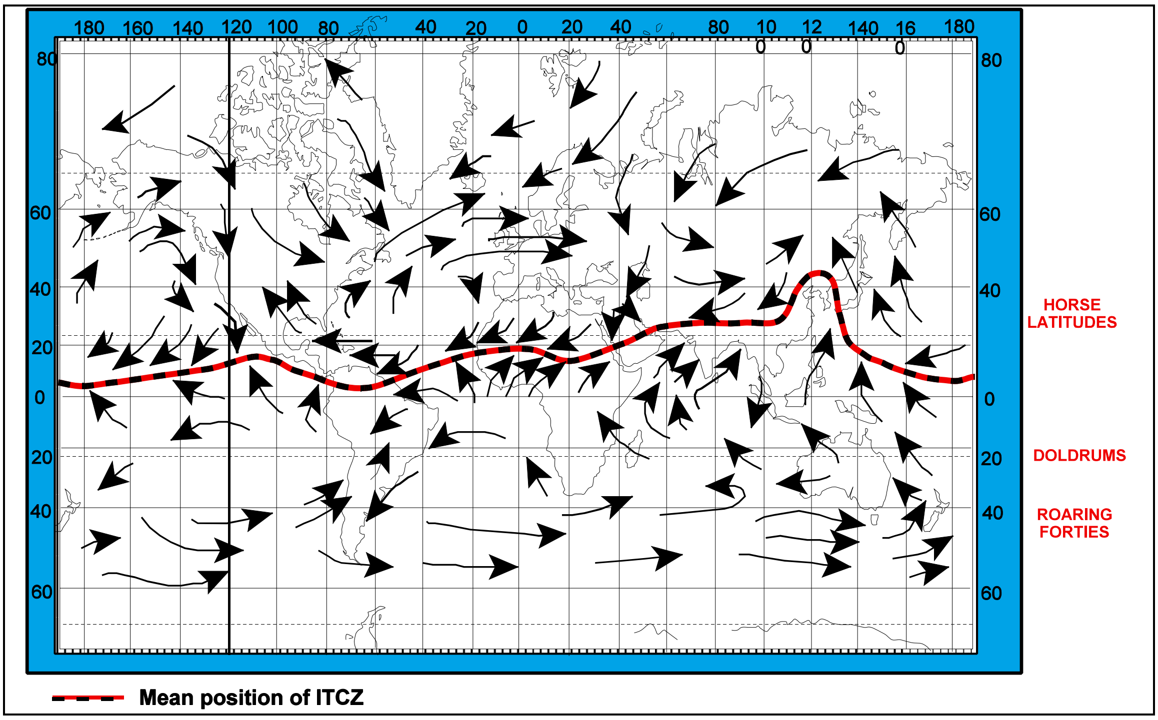


Prevailing Surface Winds in January

Underneath the sub-tropical high pressure zones the wind speed is relatively slow and sometimes nonexistent. The areas (between 30 - 40N) have become known as the "Horse Latitudes" from the time when sailors en-route to the Americas disposed of their horses off the ships rather than have to feed them when the sailing ships were becalmed.

Trade winds (Tropical Easterlies)

Trade winds are consistent winds converging to the equatorial trough from the sub-tropical high belt on each side of it. The turning effect of Coriolis Force causes **north east trades** in the northern hemisphere and **south east trades** in the southern. The trade winds blow towards the **thermal equator** and will therefore **change direction** when crossing the **geographic equator**. NE trades will **back**; SE trades will **veer**. Fine weather prevails in the poleward and eastern parts of the tropical oceans while towards the west and the equator unstable conditions will dominate, with cloudy, showery weather.



Prevailing Surface Winds in July

Monsoons
These are seasonal winds due to the winter high pressure, or summer low pressure, which develops over large continents. They are particularly marked in **South** and **South East Asia** and also occur in **West Africa.** They blow in concert with the trade winds.

Weather will depend very much on the track followed. NE monsoons over central India will be dry with little cloud, whilst the SW monsoon will be warm and moist with much convective cloud and heavy rain. NE monsoon over the Far East will be relatively dry whilst the SW monsoon, with its long sea track over the tropical oceans will produce very wet conditions.

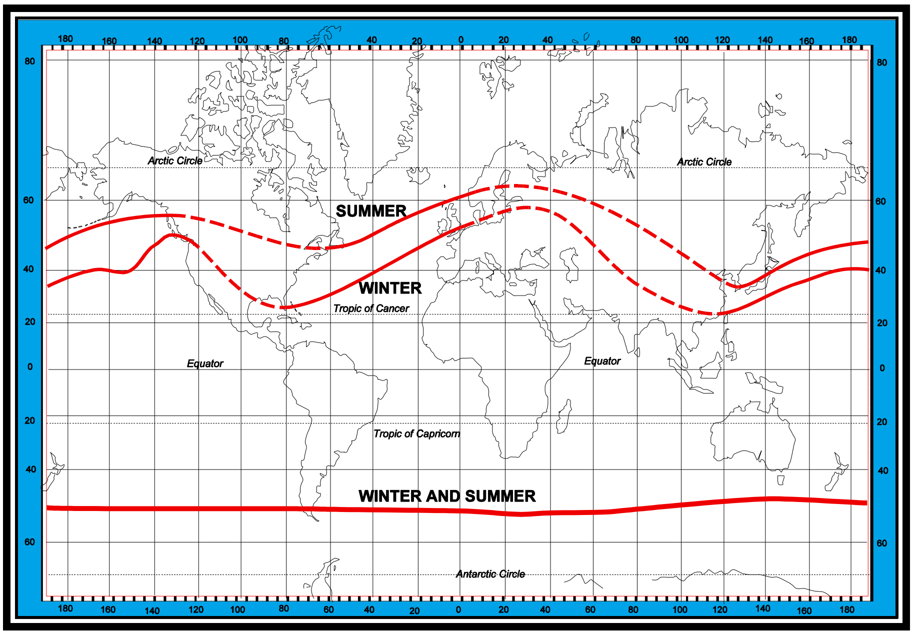
Monsoons will be discussed in more detail later in this chapter.

Other winds
Outside the main currents there are:

- Winds applicable to the local pressure system prevailing at the time.
- Strong **Polar Easterlies** near the **North and South Pole**, especially in winter as the katabtic wind flows towards the sea.

WEATHER

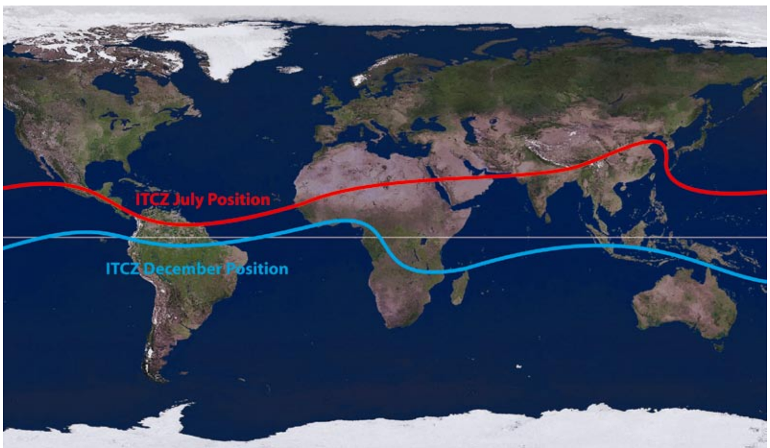
Temperate latitude depressions. Frontal depressions will breed along the polar front where this lies over wide ocean areas. In the **Northern Hemisphere** this will occur between 35°N and 65°N across the **Atlantic between N America and Europe**, and a similar pattern will exist across the **North Pacific** to affect the West Coast of N America. In the **Southern Hemisphere** Polar front depressions will centre around **50°S in all seasons** with fronts affecting the west coast of South America also New Zealand and the South Coast of Australia.
Polar Air Outbreaks. Found generally in wintertime, these are depressions affecting Central and North China as well as Central and Southern United States. Behind the cold front fresh outbreaks of very cold continental polar air greatly reduce mean temperatures. These winter mean temperatures are considerably below those of equivalent latitudes.



Alignment of Polar Front - Winter and Summer

The Equatorial Trough / ITCZ

The trough is centred on the thermal equator. High temperatures cause low pressure, particularly over land, with widespread lifting of air from the Trade Winds which converge below at the surface. This area is known as the ITCZ.



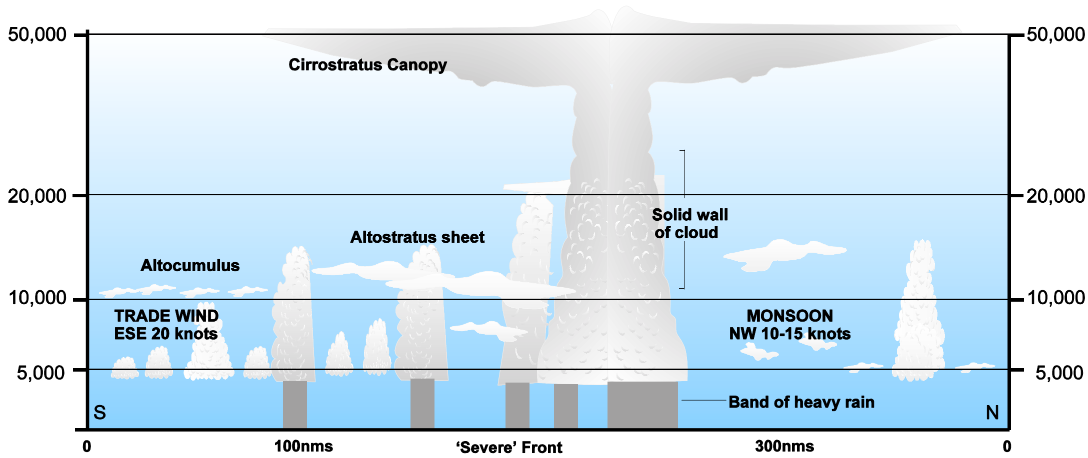
The Approximate Position of the Equatorial Trough

- The main feature of the **ITCZ** is **extensive Cu, Cb & thunderstorms.** When stable air exists, there will be extensive sheets of **As** & **Ns** cloud and more continuous type rain.

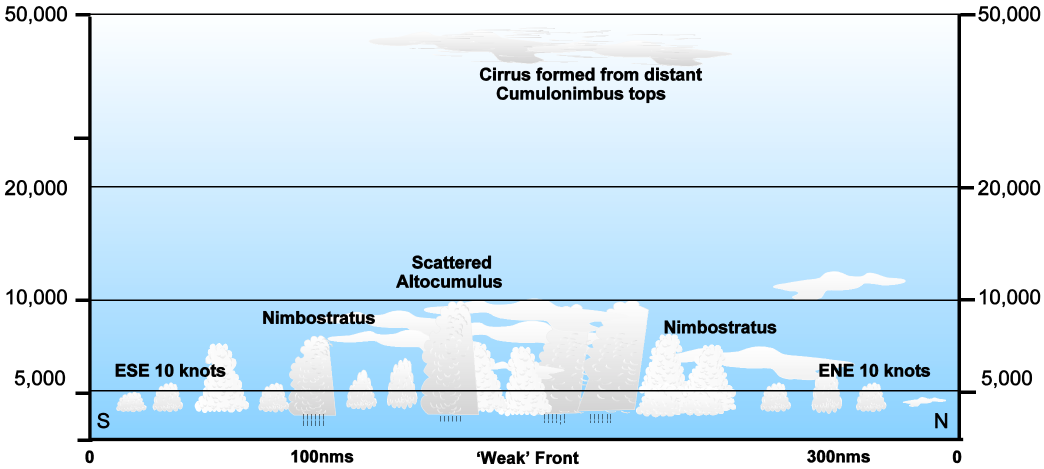
- The **ITCZ** can vary from 25 nms to 300 nms in width and there is no well defined frontal surface. Cloud is **not** caused by air mass temperature differences as at the polar front, but by **convergence** of the NE and SE trade winds which are normally the same temperature. The cloud tops are sometimes as low as 20,000 ft but more frequently 50,000 ft or more.

- Turbulence is usually severe, as is icing, which can be from 16,000 ft upwards.

- Vigorous and quiet **ITCZ** cross sections are shown below.



Cross section through a vigorous ITCZ

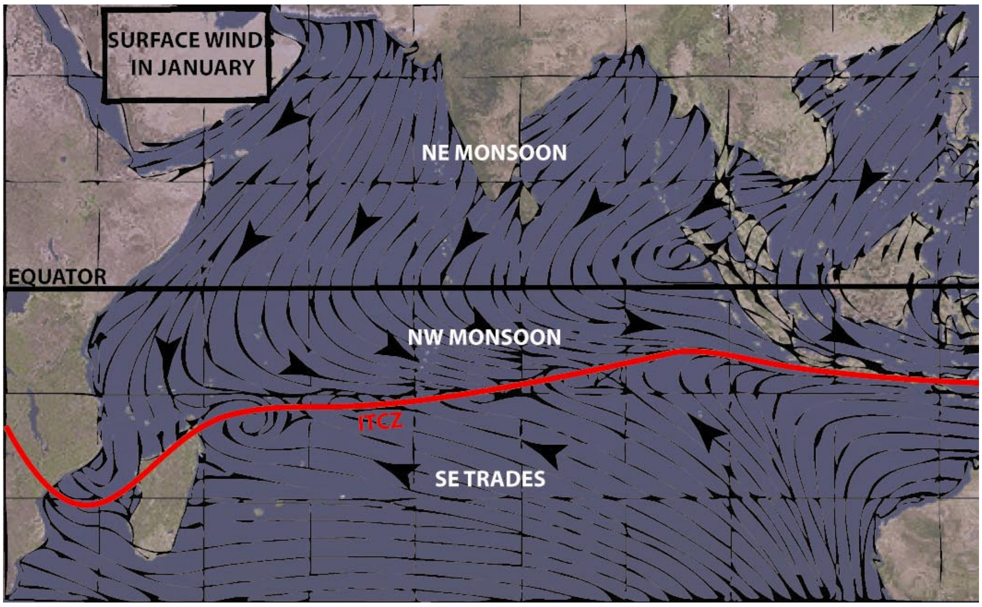


Cross section through a quiet ITCZ

MONSOONS

- When **trade winds** blow ***to*** continental low pressure or ***from*** continental high pressure the associated weather is known as a **monsoon**. There are three monsoon flows; the **NE, NW & SW.**

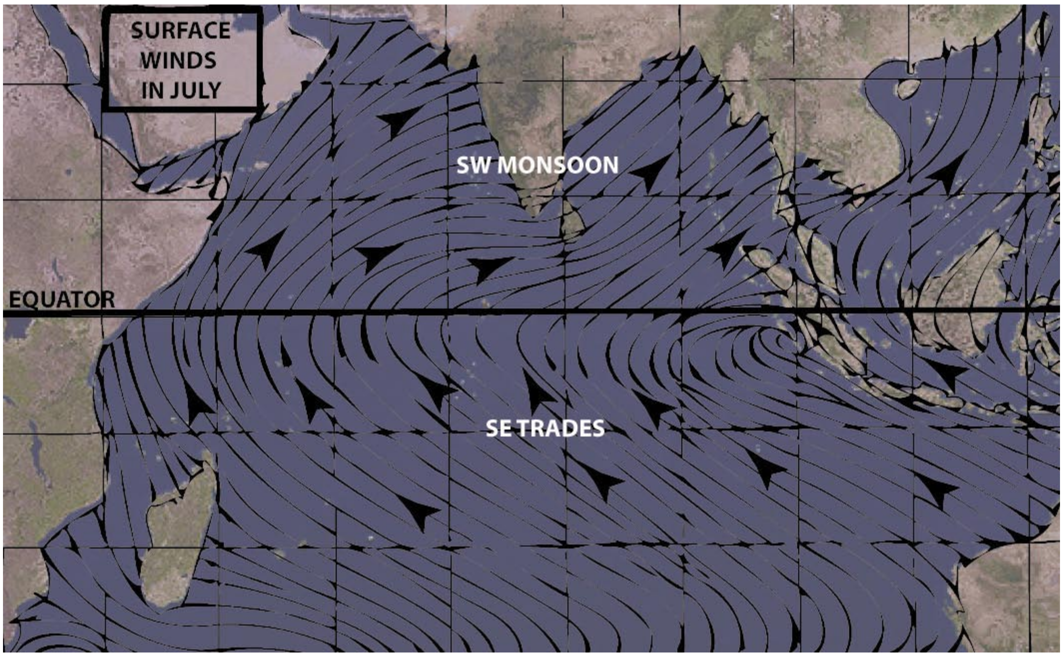
- The NE MONSOON of Asia blows from the winter siberian high and is consequently cool & comparatively dry giving clear weather over Bangladesh, Burma and Thailand. SE India, Sri Lanka & East Coast of West Malaysia are also affected by this monsoon, but here the over-sea track picks up moisture and produces heap type clouds and thunderstorms and heavy precipitation when crossing coastal mountain ranges.



North East Monsoon and North West Monsoon

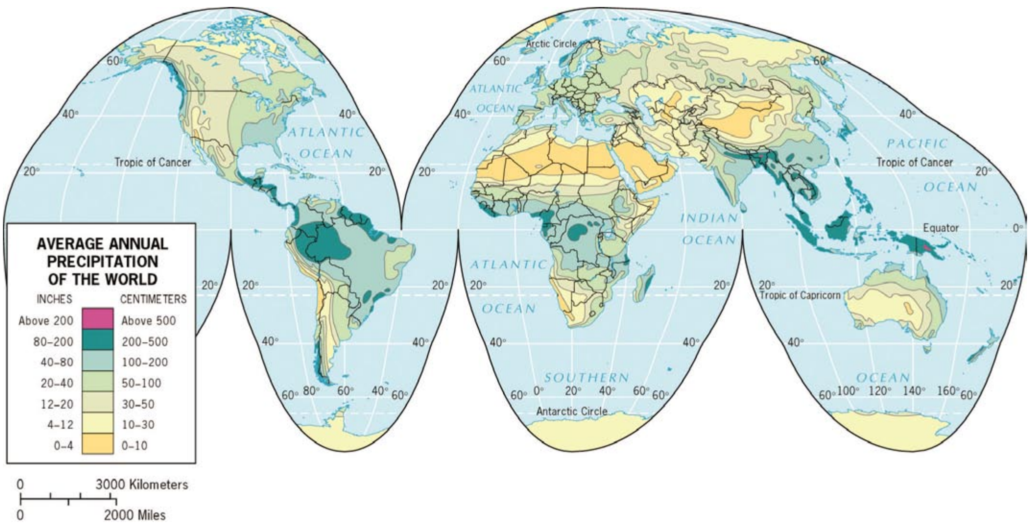
- The **NW MONSOON** is really an extension of the NE Monsoon which backs on crossing the equator southbound and brings **Cu**, **Cb** and **thunderstorms to North Australia & New Guinea.**

- The **SW MONSOON** is produced by the SE Trade Wind crossing the equator and veering to SW and thence to the summer Baluchistan Low. Having a long sea track, this monsoon is very moist and produces much **heavy Cu & Cb with large scale thunderstorms**. It affects **all of India, Sri Lanka, Burma** and exposed coasts of **West Malaysia.** It has a more serious effect on flying than the NE Monsoon, with **heavy thunderstorms, low cloud base & severe turbulence.** The SW Monsoon also affects the **West African coast**, notably **Guinea, Ghana & North Nigeria**.



South West Monsoon

- In **summary**. The worlds rainfall is produced principally by the weather from the ITCZ and associated monsoons, also from the two Cool Temperate zones. The two subtropical high belts and two polar highs will usually be dry. Nevertheless these patterns may be altered significantly by local topographical features.



Mean Annual Precipitation Showing Extreme Wet and Dry Areas

UPPER WINDS

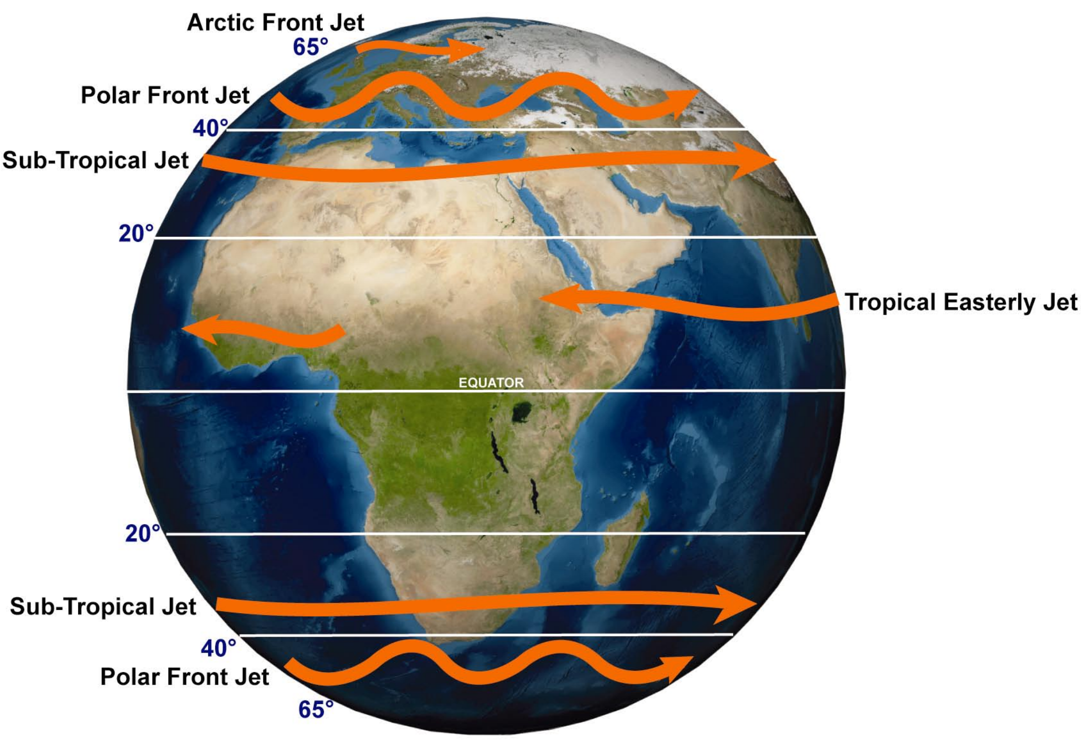
- **Sub Tropical Jets.** These jets blow at the **200 hPa level** in each hemisphere between 25° and 40° latitude in winter and 40° and 45° in summer. The **cause** is the upper pressure gradient between the descending warm and cold air on either side of the sub tropical high pressure belt. Speeds can be in excess of 100 kt. (Up to 300 kt near Japan).

- **Polar Front Jets.** The Polar Front jets in the northern hemisphere are of a transient nature and move with the Polar Front as it moves south in winter and north in summer. Polar Front Jets are caused by the upper pressure gradient between the Tm warm and Pm cold air masses on either side of the polar front.

In the southern hemisphere they are more constant and blow around the 50th parallel. They are less strong than those in the northern hemisphere.

- **Tropical Easterly Jet (Equatorial Easterly Jet).** Strong easterlies that occur in the northern hemisphere's summer between 10° and 20° north, where the contrast between intensely heated central Asian plateaux and upper air further south is greatest. It runs from South China Sea westwards across Southern India, Ethiopia and the sub Sahara. Typically heights circa 150hPa (13-14 km; 45,000 ft). These easterlies can give way to westerlies especially in January as the ITCZ moves south.

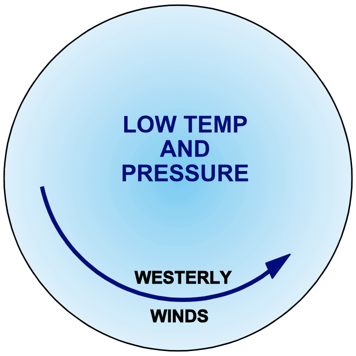
- **Arctic Jet Stream** found between the boundary of arctic air and polar air. Typically in winter at around 60° north but in the USA around 45° to 50° north. The core varies between 300 and 400hPa. It is a transient feature found over large continents during arctic air outbreaks.



- **High Level Winds Over India.** With the onset of the SW Monsoon (May to June), large changes occur over India at the 200 hPa level. The axis of the westerly sub-tropical jet moves north of the Himalayas and the high level winds across India become **easterly**.

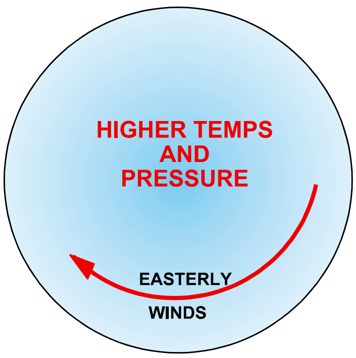
- **Eastern Mediterranean.** In the eastern Mediterranean in winter, sub-tropical jet stream winds occur particularly at the **200 hPa level**. They are normally in the Cyprus/Egyptian Coast area with westerlies in excess of 100 kts. 225 kts has been recorded.

- **Polar Winds.** Near the poles there are strong **westerlies** in **winter** because the polar tropopause temperature is lower than that at temperate latitude. Remember - back to the wind - Northern Hemisphere -**low temperature on the left**).



Polar Upper Winds - Winter

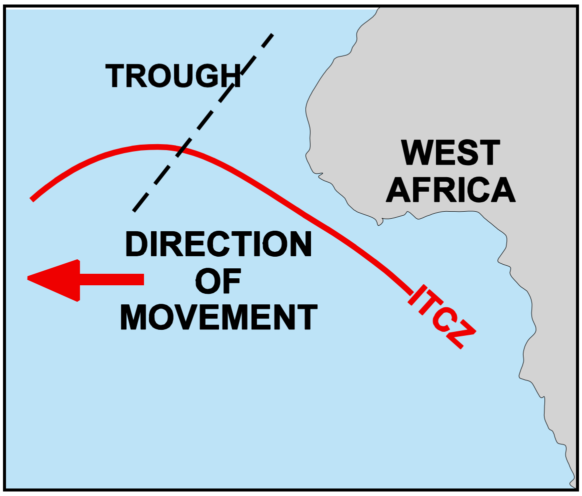
In **Summer**, as the polar tropopause temperature rises and exceeds that at Temperate Latitudes, the Westerlies reduce and become **Easterlies**.



Polar Upper Winds - Summer

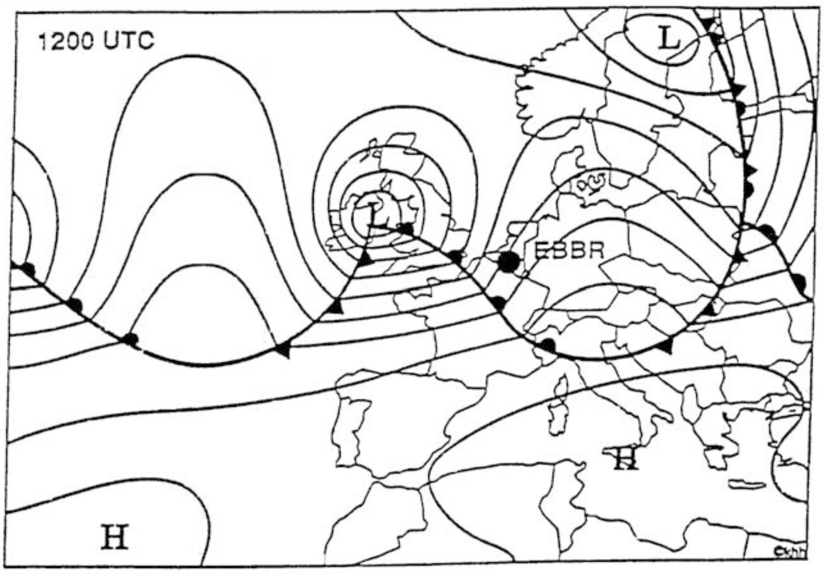
WAVES

- **Easterly Waves**. An easterly wave is a wave or trough of low pressure, originating over West Africa between latitude 5° North and 20° North and moving towards the **Caribbean**. Some of the waves proceed beyond the Caribbean and into the Pacific. They occur during the summer and autumn, usually numbering about 50 each year. Weather produced will be like that associated with **tropical revolving storms**, though to a much lesser extent in severity. They may develop into tropical revolving storms themselves.

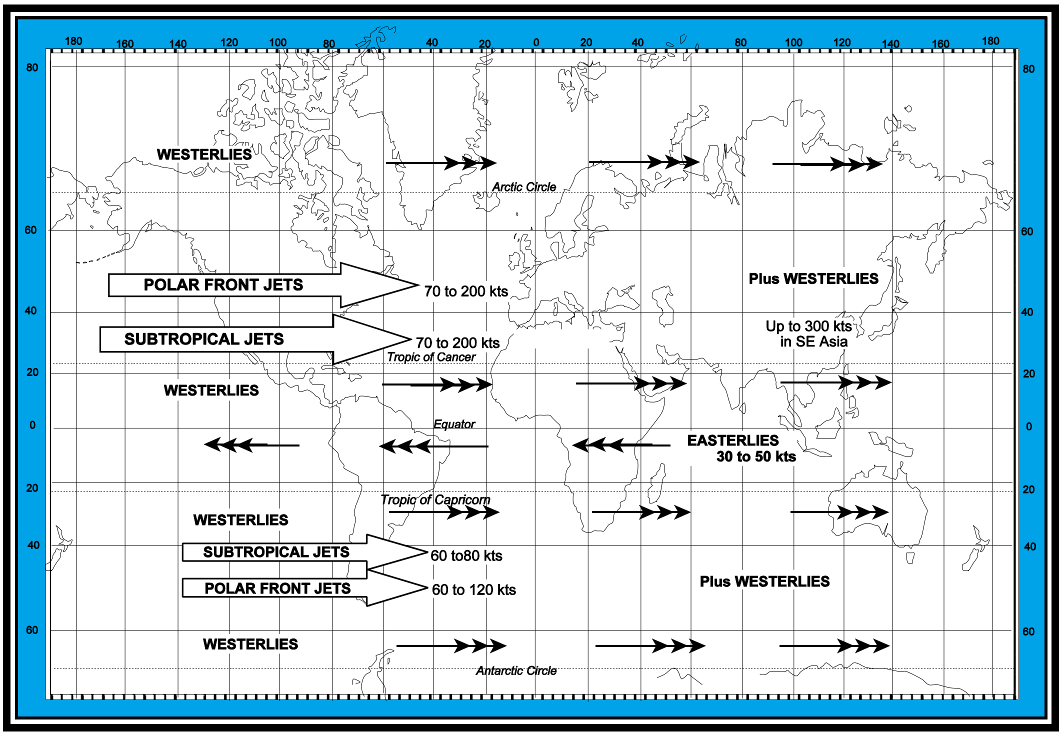


An Easterly Wave.

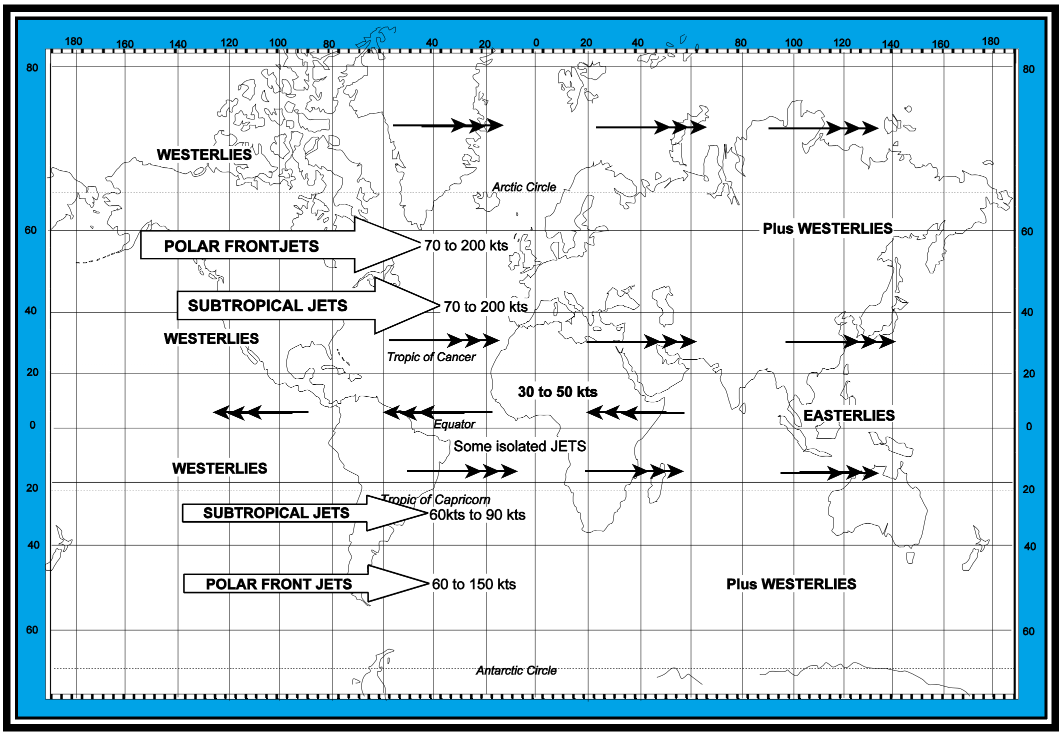
- **Westerly Waves**. These are very similar to easterly waves but are simply interconnecting warm front and cold front bands of weather (associated with a polar frontal depression) that move from the west to the east creating a pattern that is very similar to that of a wave.



A Westerly Wave



A Simplified Upper Wind Diagram for January.



A Simplified Upper Wind Diagram for July.

QUESTIONS

1. The Savannah climatic zone is:

   a. approximately 20° - 30° of latitude and provides very dry desert conditions throughout the year.
   b. approximately 10°- 20° of latitude and provides dry trade wind conditions in winter and a wet summer season.
   c. approximately 10° - 20° of latitude and provides a wet winter season and a dry hot summer.
   d. approximately 10° - 30° of latitude and has a period of long rains in spring and autumn, but is never dry.

2. The warm temperature climatic zone is:

   a. approximately 20° - 35° of latitude and covers the high pressure desert regions of the world.
   b. approximately 35° - 40° of latitude and is under the influence of polar front depressions throughout the year.
   c. approximately 35° - 40° of latitude and provides a warm dry summer with a cool wet winter.
   d. approximately 35° - 40° of latitude and provides a wet summer season and a dry cold winter.

3. Northern hemisphere summers tend to be:

   a. warmer than the southern hemisphere and winters are warmer too.
   b. colder than the southern hemisphere due to the smaller amount of solar radiation.
   c. colder than the southern hemisphere because of the large land masses.
   d. warmer than the southern hemisphere and the winters are colder.

4. The effect of mountain barriers on temperature is exemplified by the following:

   a. European temperatures are low in winter because there is no barrier to prevent cold Atlantic air crossing the area.
   b. the Rocky mountains of North America prevent cold Pacific air reaching inland, so summer temperatures to the east of the mountains are high.
   c. the Himalayas prevent warm dry air from Russia reaching India and Pakistan.
   d. the Ural mountains of West Russia prevent most of the cold Siberian air reaching Europe in summer.

5. The Tropopause is:

   a. more or less constant for any latitude.
   b. is a boundary layer between the troposphere and the stratosphere.
   c. normally the upper limit of weather.
   d. the upper limit for jet streams and mountain waves.

6. Statistical pressure values tend to be:

   a. on average parallel to the lines of latitude.
   b. on average parallel to the lines of latitude in the southern hemisphere and much more variable in the northern hemisphere.
   c. much lower in winter in the northern hemisphere than in the southern hemisphere.
   d. higher over the oceans in winter.

7. The heat equator is:

   a. another name for the geographic equator.
   b. coincident with the equatorial trough and ITCZ.
   c. a line over the land joining places where the summer temperatures are highest.
   d. a line over the land joining places where the winter temperatures are highest.

8. The average temperature around the equatorial regions:

   a. is always above +40° C.
   b. is higher over the sea areas.
   c. varies on average from winter to summer by only some 5° C.
   d. has a very high range of temperatures throughout the year.

9. Trade winds:

   a. blow towards the sub tropical anticyclones.
   b. are caused by lifting over the heat equator and the subsequent air movements from the sub tropical anticyclones.
   c. only blow in the winter months.
   d. blow from the equatorial low pressure systems throughout the year.

10. Trade winds in the southern hemisphere are:

   a. southeasterly.
   b. southeast at first becoming southwest.
   c. in opposition to the monsoons.
   d. usually from the northeast.

11. The Hadley cell is the name given to:

   a. the CU cells which continue to form a CB.
   b. an initial bubble of air which is lifted by convection.
   c. the centre portion of a jet stream.
   d. a cell formed by lifted air over the heat equator descending to the sub tropical highs.

12. The large change in the direction of trade winds is caused by:

   a. local pressure differences.
   b. an excess of air at height in association with the Hadley cells.
   c. the change in geostrophic force when crossing the geographic equator.
   d. the cyclostrophic force in the equatorial regions.

13. Monsoons are seasonal winds which:

   a. develop due to the high pressure over continents in winter and the subsequent low pressure which develops over the same areas in summer.
   b. are never in combination with trade winds.
   c. blow only in the southeast Asia region.
   d. are from the southeasterly direction over the Indian sub continent in summer.

14. The outflow from the Siberian High:

    a. is northwesterly over Japan, northerly and northeasterly over China and northerly over the whole of India.
    b. is the source of Polar Maritime air.
    c. is northwesterly over Japan, northeasterly over southeast Asia and easterly over Europe.
    d. is evident throughout the year.

15. The upper winds tend to be westerly outside the tropics because:

    a. the rotation of the earth is west to east.
    b. the thermal winds are westerly on average.
    c. surface winds are nearly always westerly.
    d. jet streams are usually westerly.

16. Jet stream main locations are:

    a. in the warm air some 400 nm ahead of a warm or cold front and near the subtropical highs.
    b. in the warm air some 400 nm ahead of a warm front and some 200 nm behind a cold front and near the sub tropical highs.
    c. only in association with the polar front.
    d. in association with the polar front and with mountain waves.

17. Jet streams:

    a. only occur in the troposphere.
    b. have a speed in excess of 80 kt.
    c. are located above the tropopause.
    d. are caused by a large difference in mean temperature in the horizontal.

18. Near the equator upper winds tend to be:

    a. easterly.
    b. westerly.
    c. at speeds greater than 60 kt.
    d. calm.

19. The Polar Front is:

    a. the boundary surface between polar continental and tropical continental air.
    b. near the poles.
    c. only apparent over the Atlantic ocean.
    d. the region where warm sector depressions develop.

20. The ITCZ is:

    a. the region between the two trade wind systems centred on the heat equator.
    b. the boundary region between the two monsoons.
    c. the boundary between polar air and equatorial air.
    d. a region of calm winds and layer type clouds with much haze.

21. Tropical Revolving Storms are:

a. a summer weather feature.
b. easily predictable.
c. can be very active well inland.
d. can travel at speeds of 100 kt.

22. The areas of greatest rainfall are:

a. those where there is much polar front depression activity.
b. in the equatorial regions.
c. in the polar regions.
d. in central North America in summer due to the large convective cloud formations.

23. The most numerous and frequent thunderstorms occur:

a. in association with the ITCZ over north Africa.
b. over the east Indies area (Java) due to the intense surface heating.
c. in regions affected by cold fronts.
d. in association with tropical revolving storms.

24. Dust storms and haze are most common:

a. in association with the sub tropical anticyclones over land.
b. with the Haboobs in winter.
c. in unstable air with low pressure.
d. in temperate latitudes.

25. The most notorious advection fogs occur:

a. over southwest UK.
b. over the sea in the region of Newfoundland and the Kamchatka peninsula.
c. over Europe with high pressure to the north.
d. over central North America in autumn and winter.

26. The cloud to be expected along the front at A3 in Appendix A is:

a. CU CB
b. ST SC
c. ST NS
d. AS NS

27. The cloud to be expected at B2 between the fronts in Appendix A is:

a. AS
b. ST SC
c. NS
d. NIL

28. The cloud to be expected at C2 along the front in Appendix A is:

a. CU CB
b. AS NS
c. ST SC
d. AC

29. The cloud to be expected along the front at A2 in Appendix A is:

a. CI
b. AS NS
c. ST
d. CU

30. The average surface level winds at A3, B3 and C3 in Appendix A are respectively:

a. easterly, westerly, southwesterly.
b. westerly, westerly, southwesterly.
c. southwesterly, westerly, northwesterly.
d. southwesterly, westerly, northerly.

31. The average upper winds at A1, B1 and C1 in Appendix A are respectively:

a. easterly, westerly, northwesterly.
b. northwesterly, westerly, southwesterly.
c. southwesterly, westerly, northwesterly.
d. southwesterly, westerly, northerly.

32. The names of the air masses indicated A, B, C and D at Appendix B are respectively:

a. Polar Maritime, Polar Continental, Tropical Maritime, Tropical Continental.
b. Returning Polar Maritime, Arctic, Tropical Continental, Tropical Maritime.
c. Polar Maritime, Arctic, Tropical Continental, Tropical Maritime.
d. Polar Maritime, Arctic, Polar Continental, Tropical Maritime.

33. The names of the air masses indicated E, F, G and H at Appendix B are respectively:

a. Tropical Maritime, Polar Continental, Tropical Continental, Arctic.
b. Polar Continental, Tropical Maritime, Tropical Continental, Arctic.
c. Polar Continental, Tropical Continental, Tropical Maritime, Arctic.
d. Tropical Maritime, Polar Maritime, Tropical Continental, Polar Maritime.

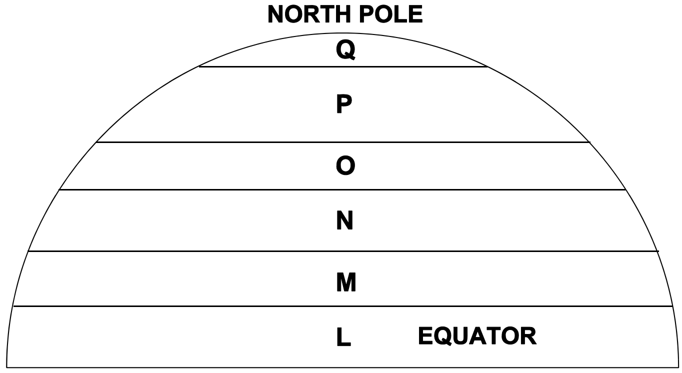


Figure 1
REFER TO THE ABOVE DIAGRAM FOR QUESTIONS 34 - 39.

34. In area L the main wet seasons will be:

a. at the equinoxes.
b. in January/February.
c. in July/August.
d. in November/December.

35. In area M in winter there will be:

a. equatorial rains.
b. extensive low cloud.
c. the Doldrums.
d. dry trade wind conditions.

36. In area N there will be:

a. extensive winter rains.
b. anticyclonic desert areas.
c. dry summers and wet winters.
d. polar front weather.

37. In area O the climate will include:

a. the trade winds.
b. dry warm summers and a wet winter season.
c. steppe type with grassy plains.
d. a wet summer and dry cold winters.

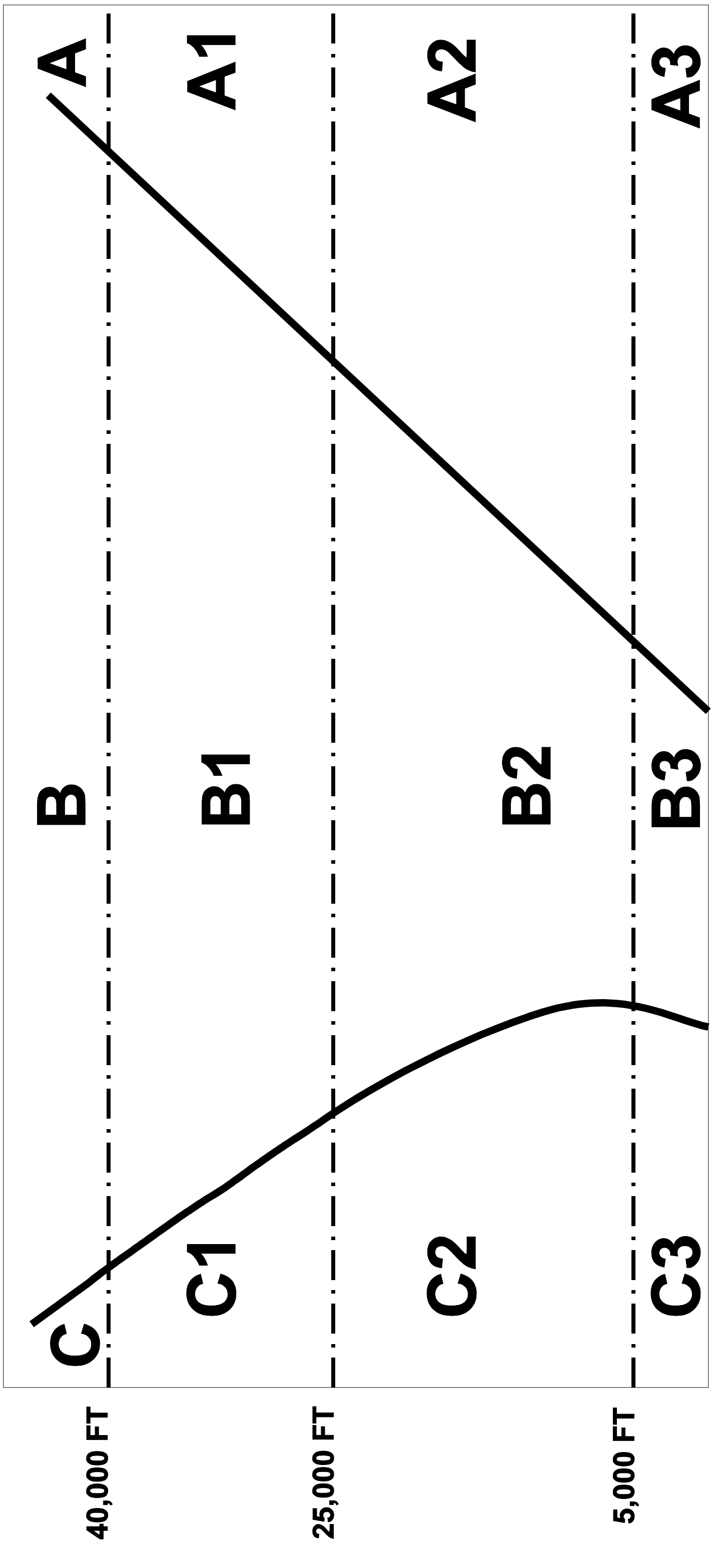
38. In area P the main weather factor will be:

a. polar front depressions.
b. depressions in winter, anticyclones in summer.
c. extensive low cloud throughout the year.
d. monsoon weather.

39. In area Q the climate will include:

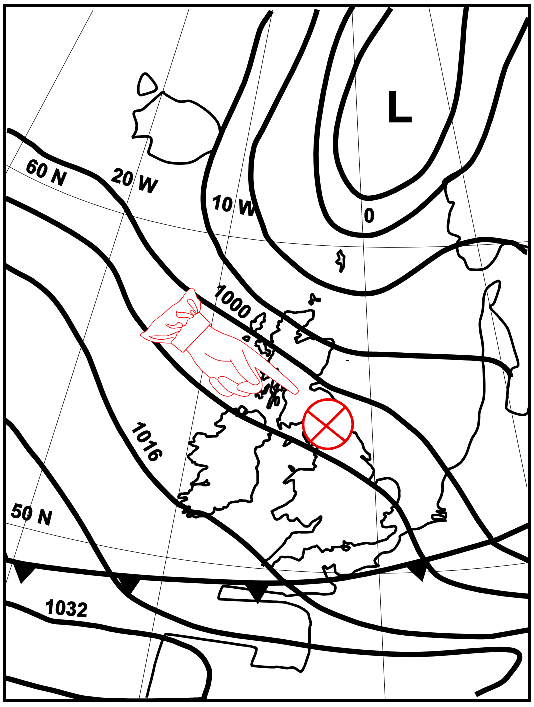
a. polar front depressions.
b. cold anticyclonic weather.
c. temperatures above zero for 3 months of the year.
d. good visibility throughout the year.

APPENDIX A



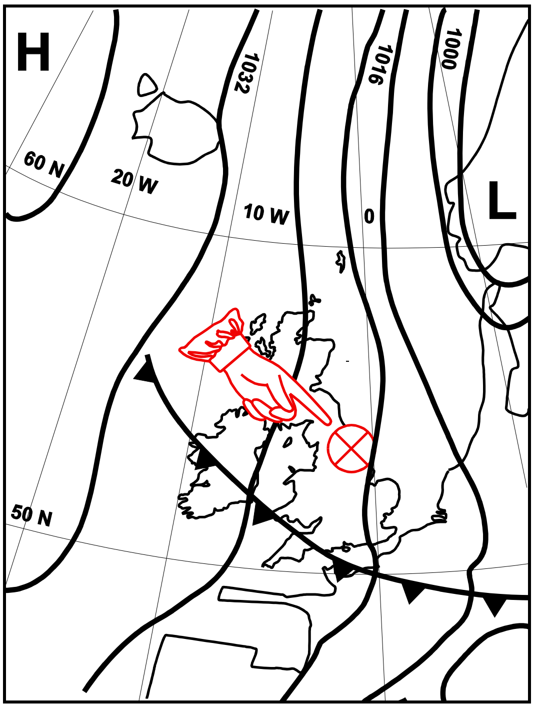
Cross Section Through a Polar Front Depression

APPENDIX B



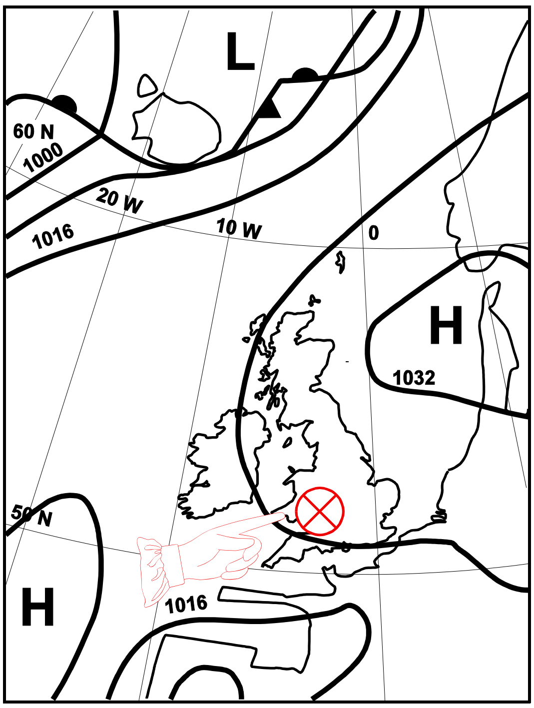
February

A



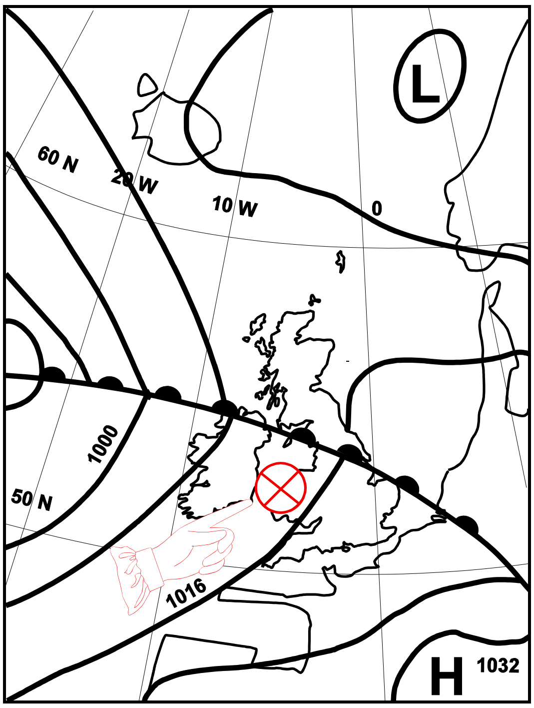
May

B



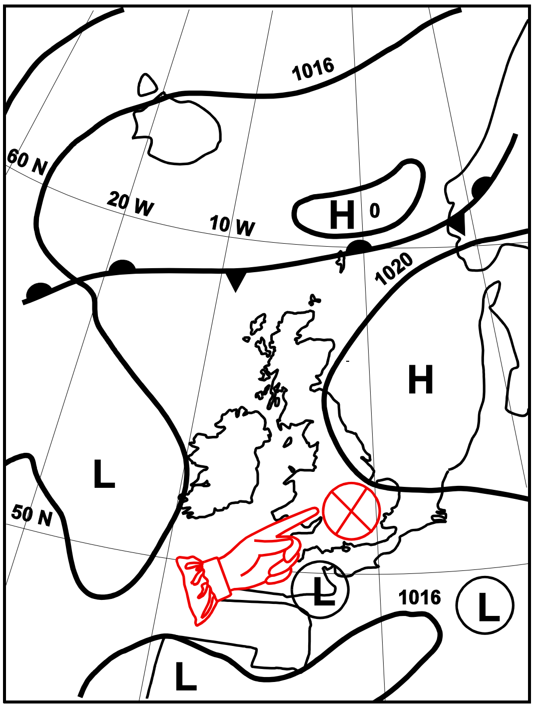
August

C



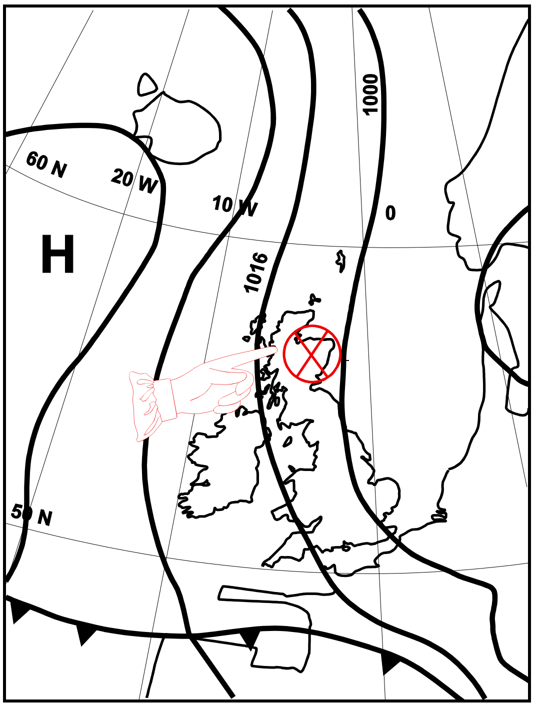
November

D



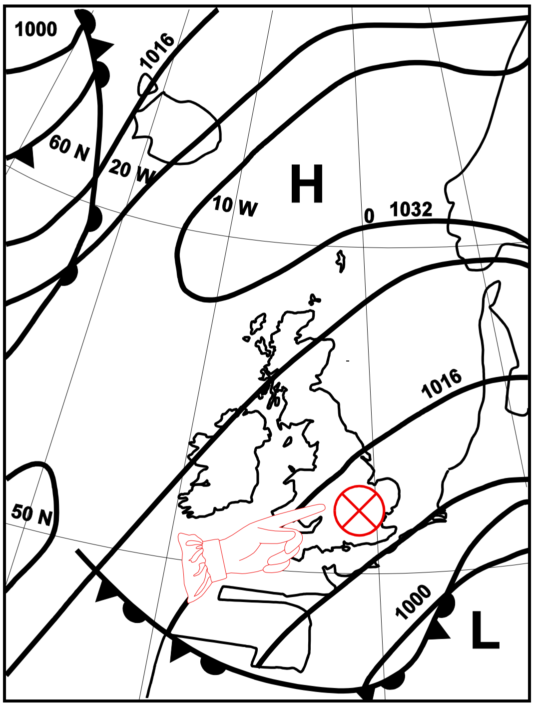
July

G



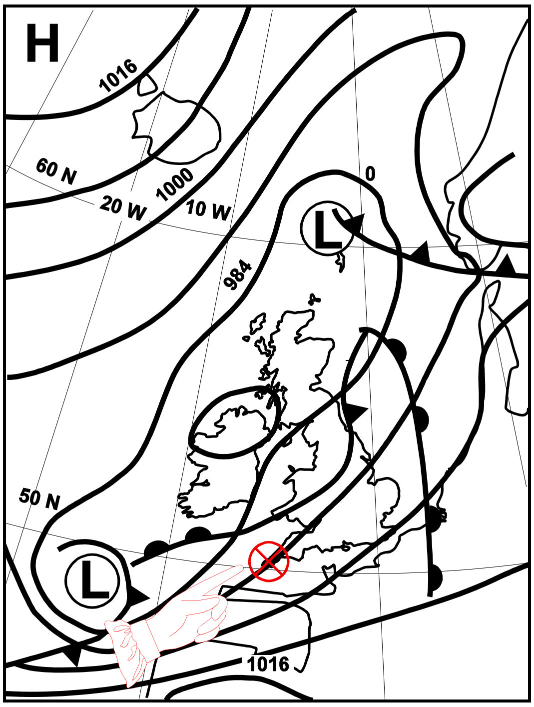
November

H



February

E



March

F

ANSWERS

1	B	11	D	21	A	31	B
2	C	12	C	22	B	32	C
3	D	13	A	23	B	33	B
4	B	14	C	24	A	34	A
5	C	15	B	25	B	35	D
6	B	16	B	26	C	36	B
7	B	17	D	27	D	37	B
8	C	18	A	28	A	38	A
9	B	19	D	29	B	39	B
10	A	20	A	30	C		

CHAPTER TWENTY

LOCAL WINDS and WEATHER

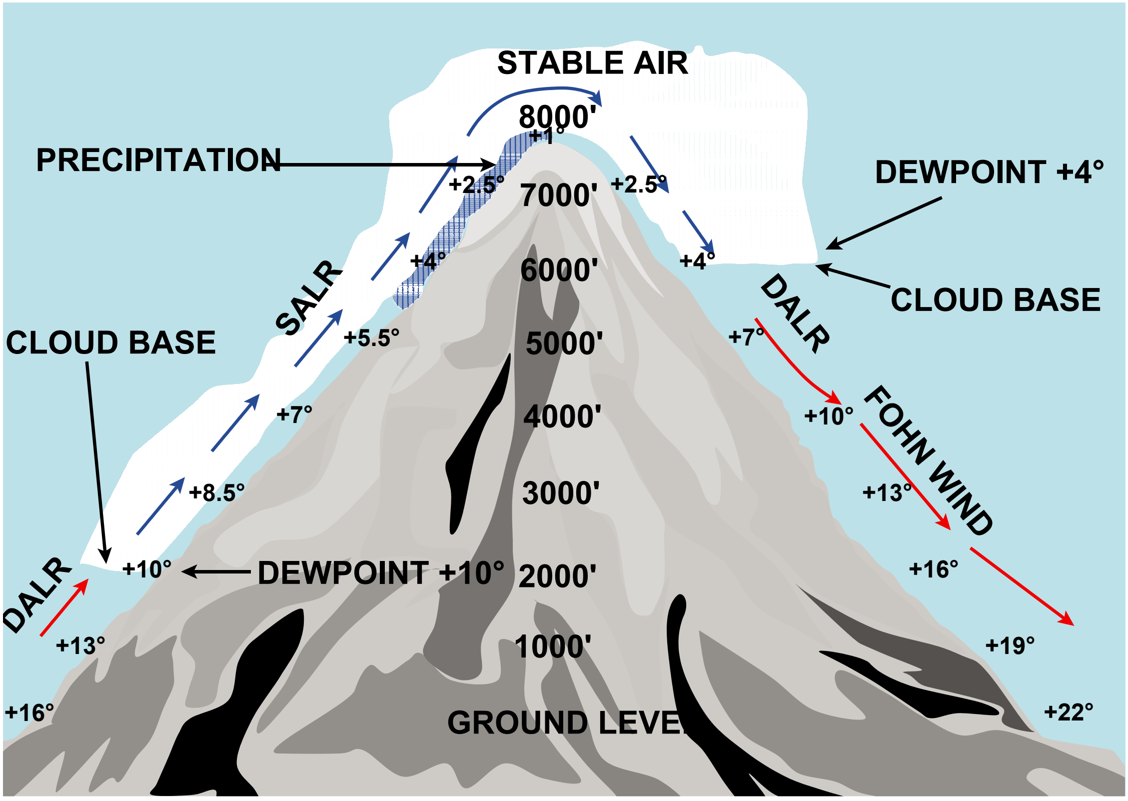
Contents

INTRODUCTION

The last chapter dealt with the general theory of climatology: this chapter seals with a number of winds around the world and the weather patterns associated with them. The winds are in five sections, **Föhn** type, **Valley**, some **Mediterranean**, **Storm squalls** and a **West African** wind.

FÖHN WINDS

Föhn Winds were dealt with in Chapter 10 and the diagram explaining the resultant increase in temperature on the lee side of the mountain range is shown below.



The Föhn Effect.

Although Föhn winds blow in the Alps, the name is used generically to describe winds which blow with similar effect in other parts of the world.
One such wind is the **Chinook** which blows on the Eastern side of the Rocky mountains of North America.

The Chinook usually blows during the winter months and produces a rapid and considerable rise in temperature. A rise of 20° in 15 minutes is not unusual. The wind may blow for several days and snow on the eastern side of the Rockies may clear completely. The area covered runs from **Southern Colorado** up to the **Mackenzie Basin**.

Chinook Wind

VALLEY WINDS

Mistral. Valley winds are caused by air funnelling through a mountain gap or down a valley. The Mistral, which is a good example of such a wind, blows down the **Rhône Valley** between the Massif Central and the Alps to the French Mediterranean coast and beyond. It is usually a winter wind with **high pressure** over **Central France** and **low pressure** over the **Gulf of Genoa.** Temperatures are **low** with winter Mistral temperatures well below zero, flying conditions are **turbulent** and the winds are **strong**, 40 to 75 kts.

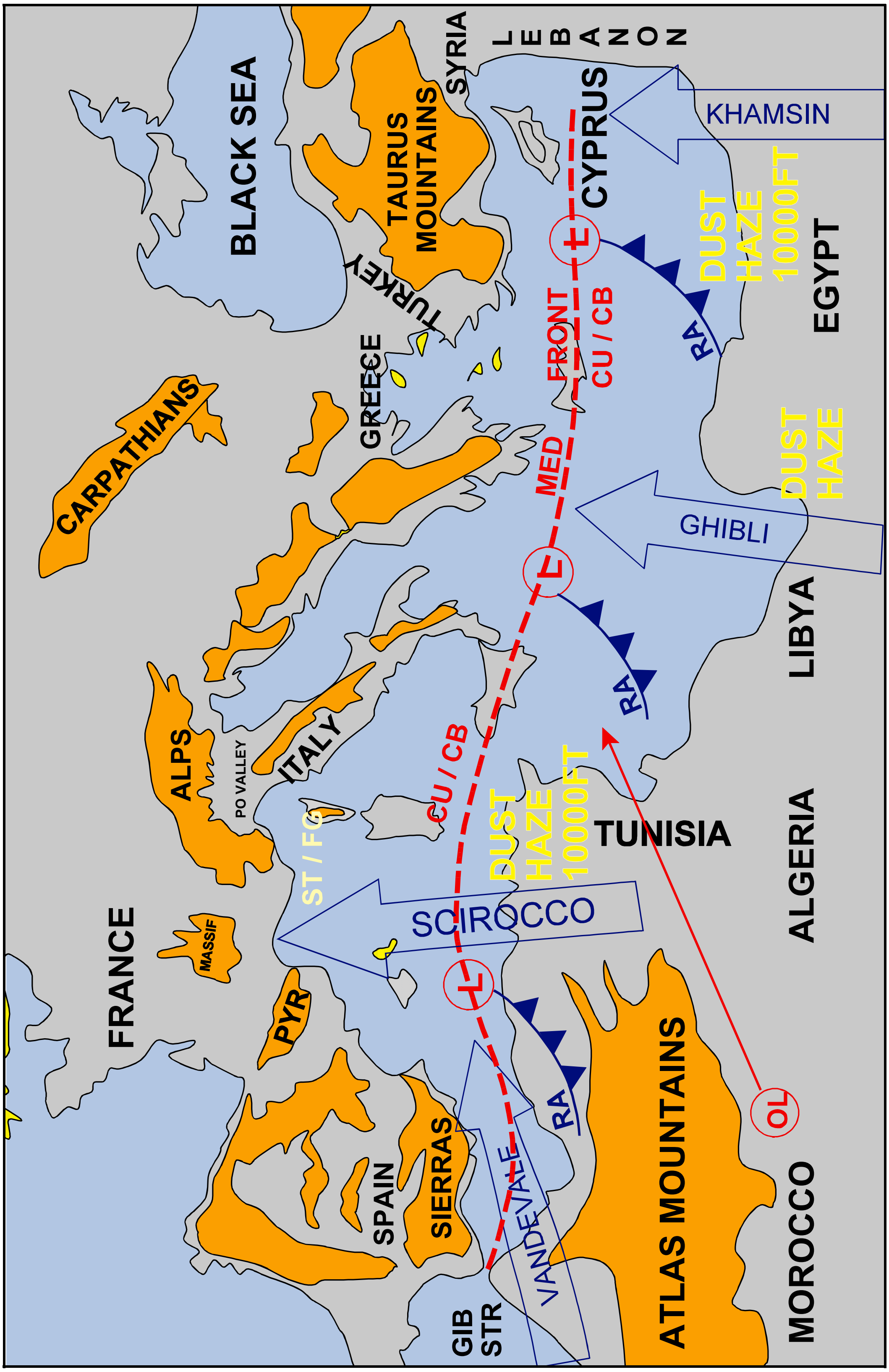
The Bora. This wind is part valley and part katabatic. It blows down the north **Adriatic** with high pressure over **Central Europe** and the **Balkans** and a **low** over the **Adriatic.** The wind speed is around **70 kts** with great gusts **exceeding 100 kts** in places. The Bora is strongest and most frequent in winter.

MEDITERRANEAN WINDS

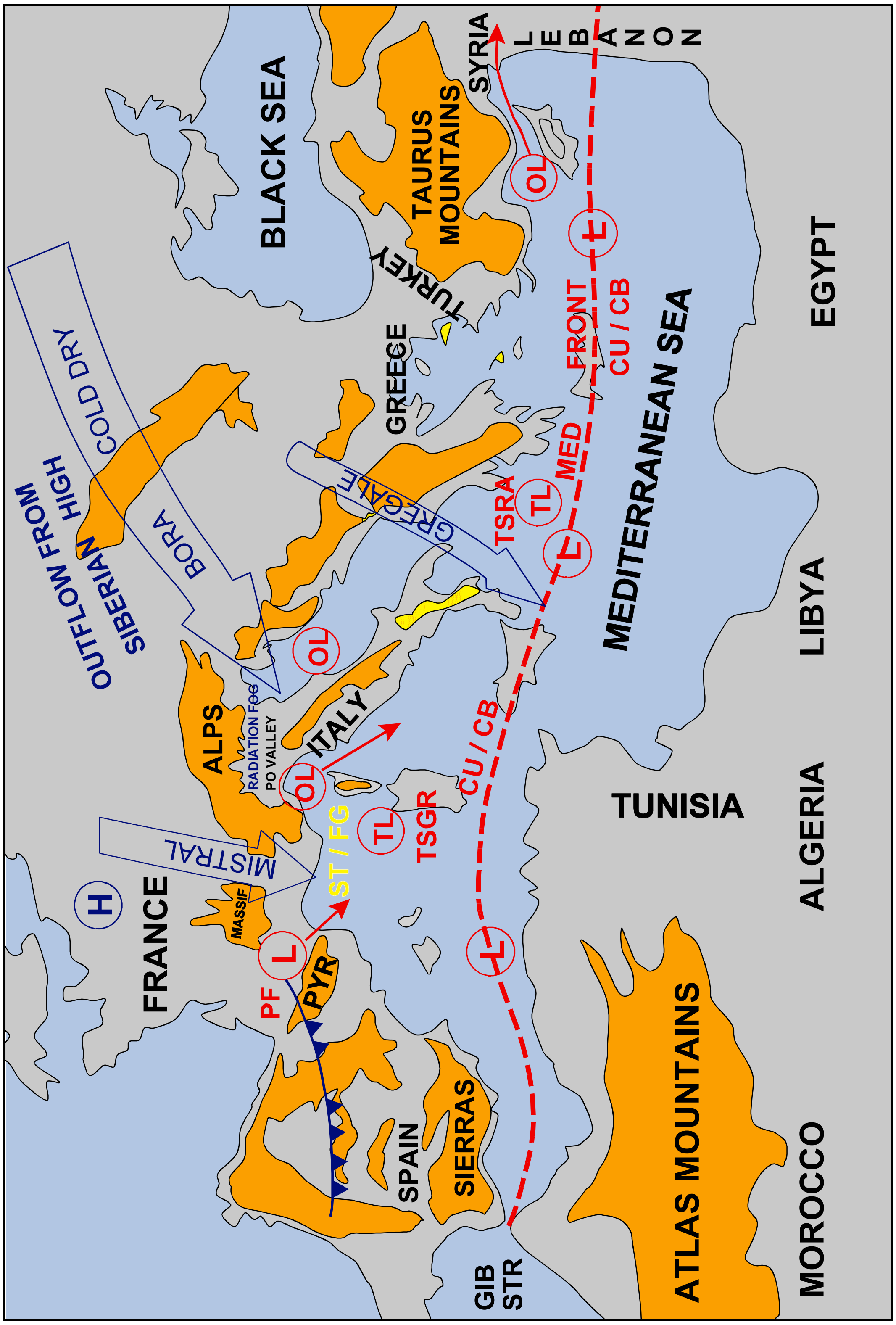
The Sirocco. All three of the major Mediterranean winds we are dealing with are similar in that they blow ahead of frontal depressions tracking along the North African coastline. The Sirocco, which blows over Algeria is a **hot** and **dusty** southerly wind blowing out of the desert. This wind is usually a **springtime** wind and may last a day or so. **Visibility** may be reduced to **below fog limits** (1000m). The Sirocco may travel as far as the **French coast** and in the process it may pick up moisture and produce low **stratus, drizzle** and **fog**.

The Ghibli. This is a similar wind which blows over Libya.

The Khamsin. Blows ahead of depressions tracking along the Mediterranean coast of **Egypt.** Conditions are similar to the Sirocco and the Ghibli. The name is also given to south or south west gales blowing in the **Red Sea.**



Winter pressure systems and surface winds southern parts



Winter pressure systems and surface winds northern parts

SQUALLS

The Pampero. This is a **severe windstorm** blowing around the estuary of the **River Plate** (Uruguay and Argentina.. It is a **cold dusty south** to **south west** wind blowing behind a cold frontal depression. Stormy, gusty conditions prevail, with a considerable **temperature fall** after the storm passes. The squall is **short lived**, but the strong, steady wind may last for **some hours**. Pamperos usually blow in **spring and summer**

The Pampero

Sumatras. These occur in the **Straits of Malacca** blowing between south west and north west, most frequently between **April** and **November** during the time of the south west monsoon. During the day thunderstorms build up over the high ground of Sumatra, assisted by the **sea breeze**, but at night the subsiding cumulo nimbus clouds drift eastward under the influence of the **land breeze** and the **Katabatic** effect. The storms are rejuvenated over the warm sea and **violent storms** result late at night and in the early morning. There is a sudden **temperature drop** as the squall passes through. Sumatras take on a pronounced **arched shape** as the Cb anvils spread out at the tops of the clouds.

Sumatras

THE HARMATTAN

The last of the major local winds is the **Harmattan**. This blows mostly during the winter from the **high pressure** desert areas of North Africa as a **North Easterly** wind towards the ITCZ. (North east trade winds). The Harmattan is a cool dusty wind that may reduce visibility to below 1000m, especially in areas bordering desert regions, such as Kano, Nigeria. The dust layer may extend to 7,000 or 10,000 ft or more, visibility improves towards the coast. The Harmattan blows from **November** through to **April**, though by this time the winds will be light, especially in the south.

CHAPTER TWENTY ONE

AREA CLIMATOLOGY

Contents

NORTH WEST AFRICA

INTRODUCTION

The region includes the area between the Mediterranean in the North, and the Nigeria - Ghana - Senegal coast in the South, that is between 35°N and 5°N and west of 10°E. It also includes parts of Ivory Coast, Guinea, Liberia, Mauritania, Morocco, Mali and Algeria.

GEOGRAPHICAL CONSIDERATIONS

The area is bounded to the east by the Sahara desert, centred near 23°N, which is a source of Tropical Continental air and brings much dust to the region. The cold Canaries sea current running south close to the Atlantic Coast helps advection fog to form.

PRESSURE SYSTEMS

The **ITCZ** (Equatorial Trough) traverses the **southern half** of the region bringing **rain and a change of surface W/V as it passes**. It is south of the coastal regions of Ghana and Nigeria in January, then pushes north to 18° - 20°N in July, thereafter moving south again, to clear the south coast by the next January. North of the ITCZ lies the **Sub Tropical High**. In Winter it extends from the West across the Sahara desert and the surface outflow brings **dry dusty conditions** to all parts especially the South and West. Towards Summer, the sub tropical high and associated dry dusty conditions will be increasingly restricted northwards as the ITCZ advances from the South.

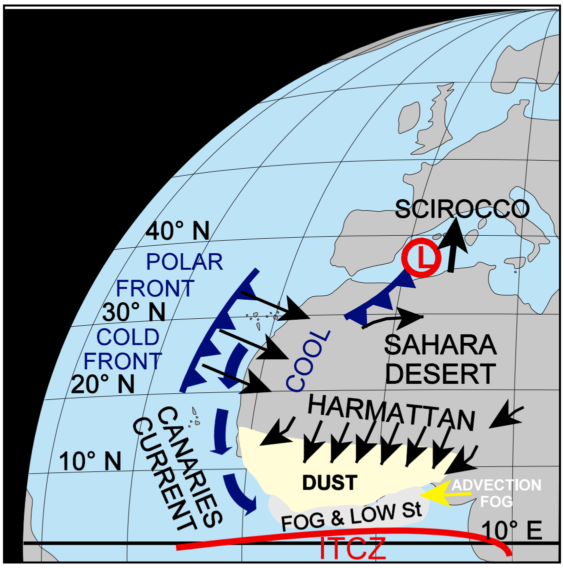
WEATHER AND SURFACE WINDS

It is convenient to divide the region into two areas split at the mid latitude of 20°N. The southern region includes **Dakar** on the West Coast at 15°N.

South of 20°N - Winter Season

The **ITCZ** is **south** of the area. **High pressure** is dominant over the **Sahara** and there is no cloud or precipitation. The **NE** tradewind outflow from the Sahara to the ITCZ is extremely dusty and is known as the **Harmattan**. The **duration** of the **Harmattan** period decreases southwards because the ITCZ recedes southwards in Autumn then advances north in the Spring. **Visibility** in the dust is frequently down to **4000 metres** and occasionally down to the **fog limits**. Outflow over the cold canaries sea current favours **advection sea fog**, which can then drift inland when there is a sea breeze.

North of 20°N - Winter Season



North West Africa in January
Weather Details at the Surface

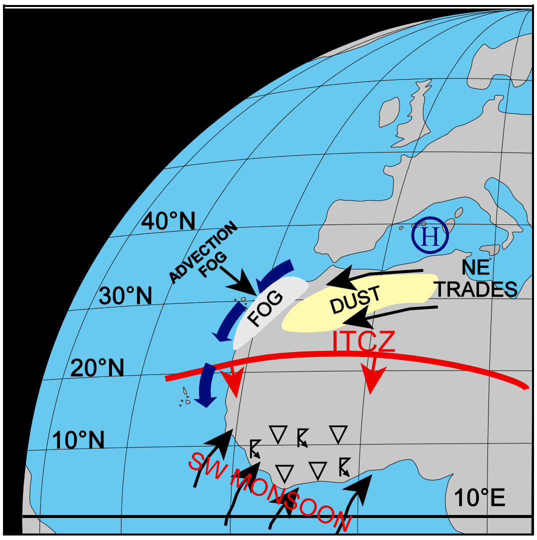
High pressure over the **Sahara** and to the **West** can be modified by encroaching polar front Lows and their associated cold fronts, which in turn bring onshore Westerlies or North Westerlies to the coasts of Mauritania and Morocco. Passing over the cold canaries current this wind can bring cold fronts with low cloud and precipitation - **the wet season**. Cold fronts from the Mediterranean can also affect Northern Algeria but are prevented from moving further south by the Atlas mountains. Elsewhere the prevailing NE **Harmattan** wind will traverse the area bringing **dry dusty conditions**.

At times outflow to the North will produce the dusty but dry **Scirocco** wind to the Mediterranean

South of 20°N - Summer Season

The ITCZ will advance northwards across the region during the Spring and **with its passage** the **NE Harmattan** will **veer through East** to become the **SW Monsoon wind**. The SW direction results from the SE trades which have crossed the equator and have therefore veered. The **SW Monsoon** brings the wet season with much CU, CB, heavy rain showers and Thunderstorms. In the Autumn the ITCZ will recede southwards and **with its passage** the SW monsoon will **back through East** to become the dry dusty NE Harmattan once more. Note the **SW/V** is **easterly** at each **ITCZ passage**.

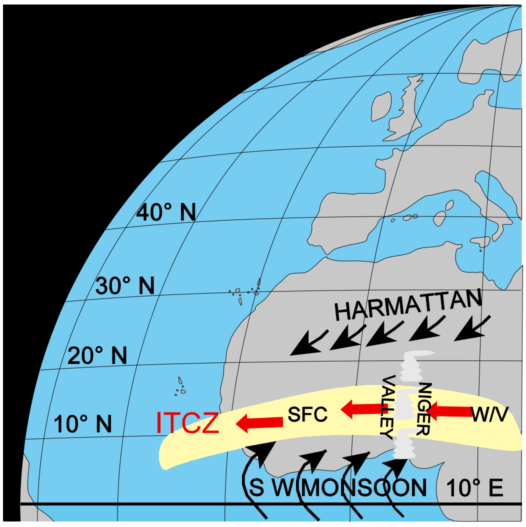
North of 20°N - Summer Season



North West Africa in July
Weather Details at the Surface

The winter Sahara High has moved n o r th to the Mediterranean. The outflow gives **NE dusty winds** flowing to the ITCZ to the south, and to beyond the West Coast where **advection sea fog** can form over the cold canaries current. This fog can then be drawn **inland** by sea breezes.

West African Tornadoes

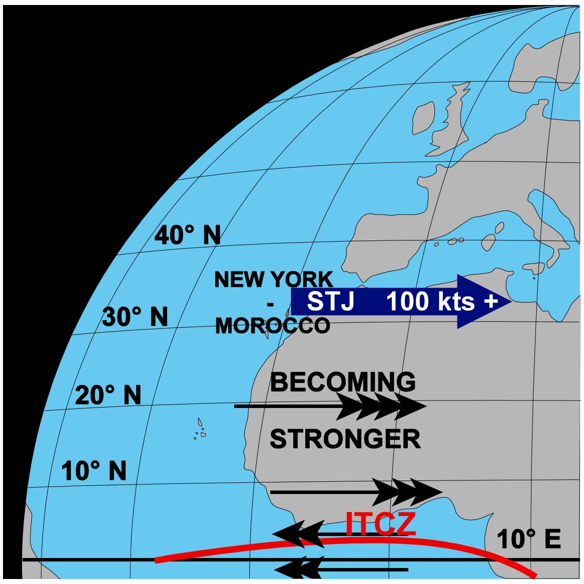


North West Africa, in Spring and Autumn
The Formation and Movement of West African Tornadoes

Tornadoes occur in the **SE** of the area over the **Southern Nigerian Valleys**, where the air is moist and the surface heating strong. They are **thunderstorms** which form in a **North/South line** above the valleys **as the ITCZ passes** Northbound in March/April, and Southbound in September/October. The **wind** is **temporarily from the East** at these times and the storms are therefore carried westwards to affect other coastal countries before passing out to the Atlantic.

UPPER WINDS

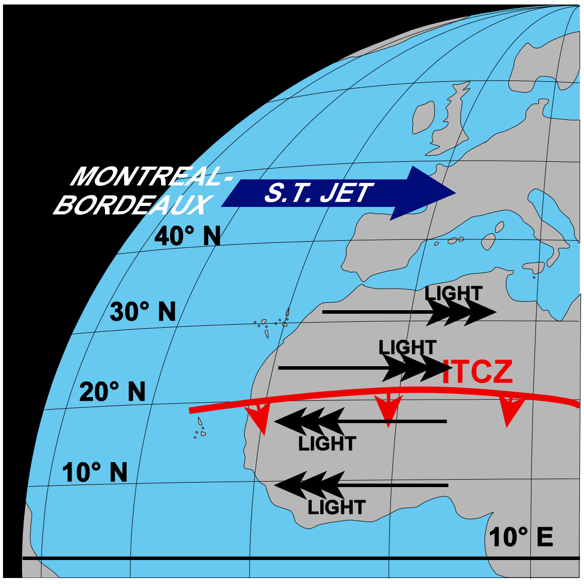
Winter



North West Africa, Upper Winds in January

The ITCZ with light Easterlies aloft lies well south. Overland **light westerlies** will occur in the **south** increasing to the **westerly sub tropical jet** of **100 knots or more** over **Morocco**.

Summer



North West Africa, Upper Winds in July

The ITCZ with **light easterlies** aloft affects the **south** of the region. In the **north** the wind will become light westerly only. Note that the sub tropical jet has moved out of the area to Bordeaux.

Tropopause and Freezing Level

The tropopause averages 54000 ft and the Freezing level 15000 ft throughout the year.

NORTH ATLANTIC REGION

GEOGRAPHICAL AREA

The area considered reaches from **10°N** to **70°N** latitude and from the **Caribbean** and **New York** in the West to **London** and the **Norwegian Sea** in the North-East. The area lies across the **Disturbed Temperate** and **Sub-tropical High** climatic belts.

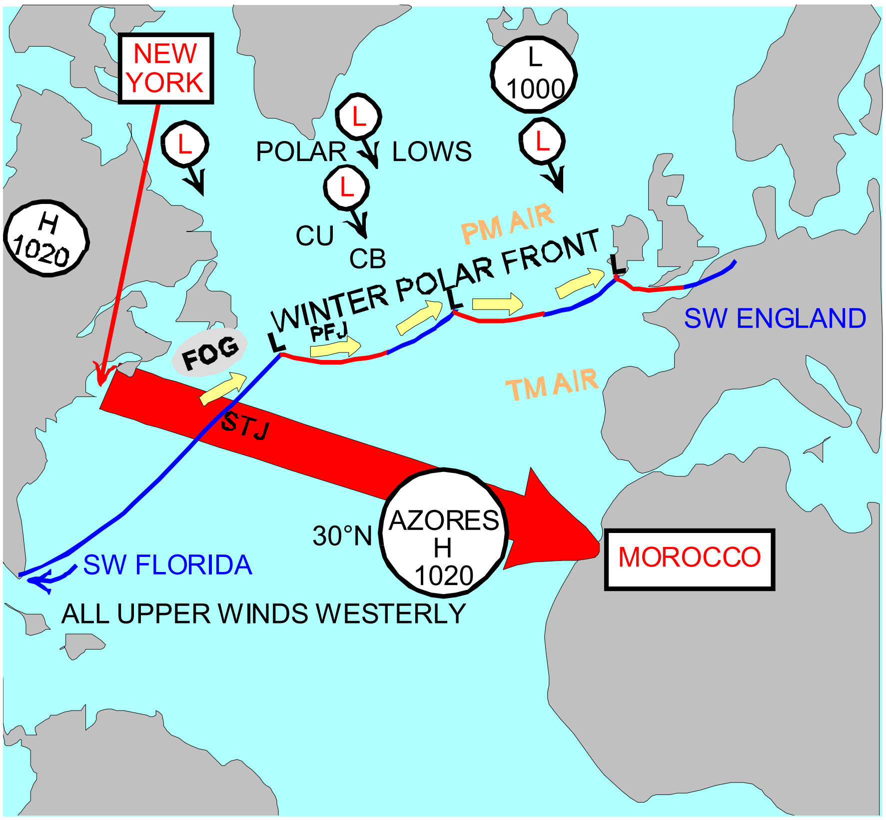
WINTER

Pressure Systems	North American High	1020 hPa
	Icelandic "Statistical" Low	1000 hP
	Azores High 30°N	1020 hPa
	Polar Air Depressions	65°N - 55°N

Polar Front Activity is dominant across the disturbed temperate region. In the West, diverging air from the North American High moves SE over the sea to meet warm Tm air overlying the warm gulfstream waters flowing northbound off the N.American East Coast. This convergence causes much instability and the formation of depressions where the two air masses meet. This well-defined but erratic frontal line forms the Western end of the **polar front** which in **Winter** lies near **SW Florida** and stretches across the Atlantic. These depressions will be driven east/north-eastwards by the thermal mid latitude winds and will track along the polar front towards the UK and Norwegian Sea. Some of the Lows will become slow moving and/or occluded between S Greenland and Norway, giving rise to the **"Statistical" Low** near **Iceland** as the depressions pass by.

In the Eastern Atlantic the north-eastward outflow from the sub-tropical **Azores High** will ensure that the travelling frontal depressions track to the North-East, a typical **Winter** landfall being **SW England**.

Over the Atlantic, the **polar front** will remain the **boundary** between **Pm air to the north and Tm air to the south**. As the travelling depressions develop, a portion of the **Tm air** will be increasingly **trapped between** areas of **Pm air** either side, forming warm and cold fronts. North of the Polar Front, **Polar Air depressions** are formed by **arctic air moving south** 65°N - 55°N over relatively warmer seas causing **instability** weather.



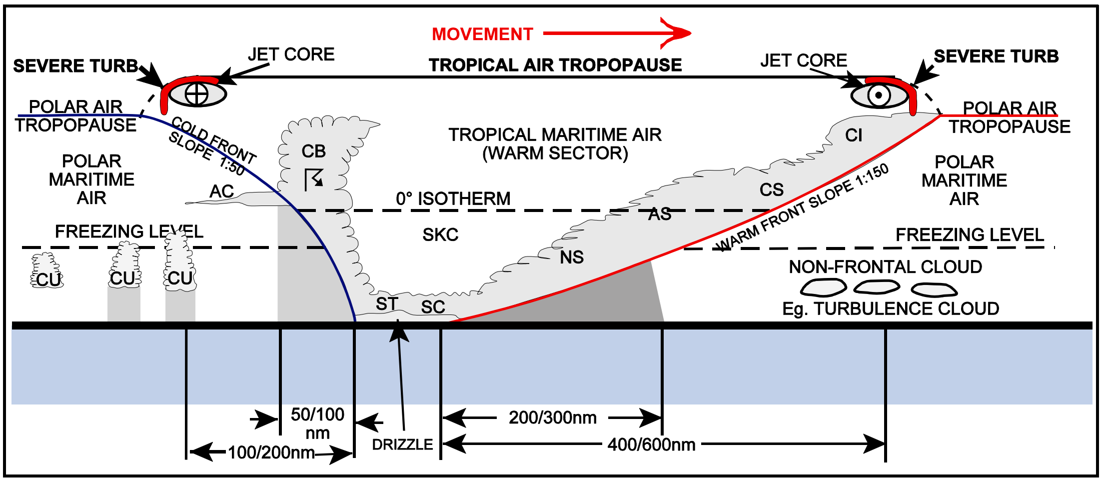
North Atlantic Weather details in January

Weather. The contrast between London and New York. Although New York is 40°N and London 52°N the winter weather is worse in New York. Why?

Cold continental outflow from the North American High becomes unstable over the adjacent but warmer sea forming low pressure. The resultant instability can then swing inland bringing snow to the New York area.

London in Winter can also be affected by cold continental outflow - from the Siberian High. The difference is that such air will have a long land track and therefore will remain dry. Secondly, if the wind in London is from the prevailing west, it will be flowing off the Atlantic and therefore will be relatively warm, possibly giving rain but not snow.

Cloud. In the North of the region, cloud averages 6 Oktas, mostly associated with travelling depressions and a cross section is shown below. Cirrus and Stratoform cloud below the tropopause will thicken down to near the surface preceding a warm front. Extensive Stratus/Strato cumulus will occur as Tm air moves north over colder seas to the polar front and especially while trapped in the warm sector of polar front depressions. Cumulus and Cumulo-Nimbus will occur on cold fronts with cumulus forming in the following unstable northwesterly air. In the Caribbean the moist NE trade winds will produce orographic cloud and rainfall on windward slopes.



A typical cross section through a Polar Front Depression

Flying west through a polar front depression the pilot should find:

CI **400 - 600 nm ahead** of the warm front surface position
CS **300 - 500 nm ahead** of the warm front surface position
AS **200 - 400 nm ahead** of the warm front surface position
ST/NS **200 - 300 nm ahead** of the warm front surface position.
ST/SC Above **Warm Sector** at Low Level.
CU/CB At **Cold Front** surface position and 100 - 200 nm beyond.
Behind Cold Front region, the same but smaller amounts.

Icing. Icing occurs widely and through great depth in Convective and Frontal Cloud and is frequently moderate to severe. Rain Ice/Freezing rain, in cold air below warm frontal air, can cause severe clear ice affecting airfields near Washington and New York.

Visibility.

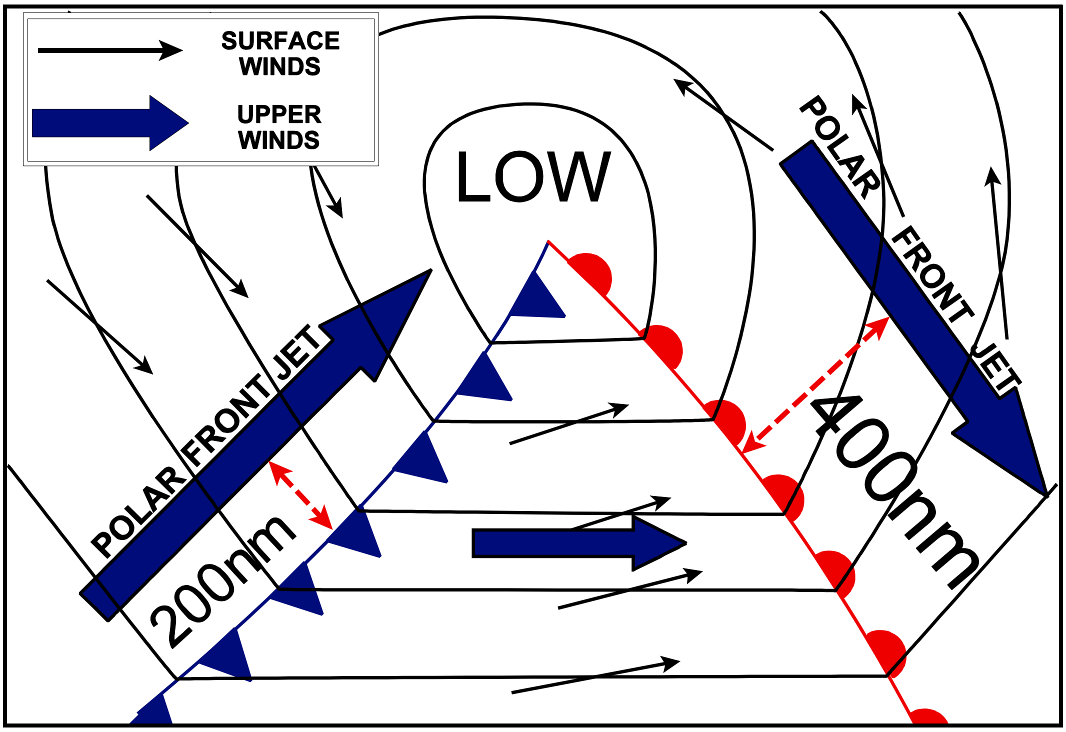
Radiation Fog can occur inland especially in **Autumn** and **Winter** when **pressure is high.**

Advection Fog can occur when moist Tm air overruns previously cold-soaked inland areas especially in **late Winter/early Spring**.

Surface Winds. North of the subtropical Bermuda-Azores High, winds are generally westerly but locally easterly on the north side of depressions. There are frequent gales. In the South, NE trade winds prevail all year.

Upper Winds. These are generally westerly because their direction is governed by the thermal wind which blows with **Low Temperature on the left.** The average winter wind component from **London** to **New York** is **minus 50 knots** - locally winds can be stronger and if greater than 60 knots are known as jetstreams. Over the Atlantic there are two distinct jetstream patterns – the **Polar front Jet** and the **Subtropical Jet.** Each may reach **200 knots.**

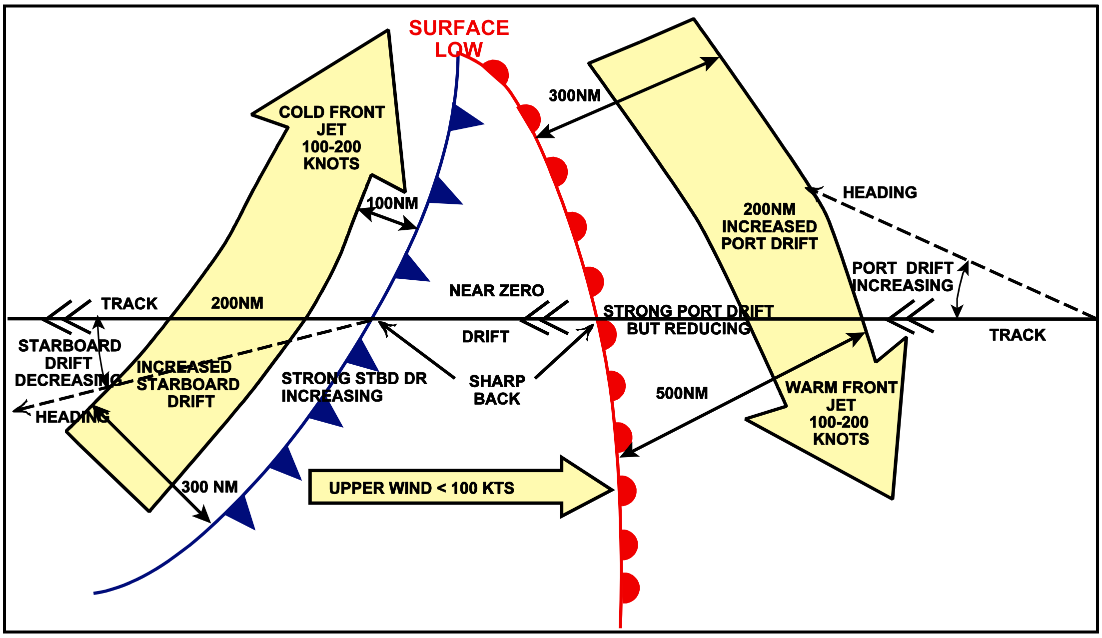
Polar Front Jet. This will normally blow from between NW and SW and occasionally outside this range, depending on the **surface orientation of the polar front**. With low temperature on the left, the **Warm Front Jet** will normally be **from the NW** and **ahead of a warm front** and due to the slope of the front, some **400 nm ahead** of its surface position. Similarly the Cold Front jet will normally blow from the **South-West** and some 200 nm behind the surface position of the front. The level is around 300 hPa (30000′) and its average location is **SW Florida to SW England** is shown on the opposite page.



The Upper Winds over a North Atlantic Polar Front Depression.

A pilot flying at **high level** from **East to West across a polar frontal depression** would experience **wind and drift** as follows and as shown below.

- Initially winds will be North Westerly giving strong **port drift**.
- Some 500 nm ahead of the warm front, jet axis speeds of 100-200 knots give **increased port drift**. This will last for 200 nm.
- Winds remain strong NW until crossing **the surface position of warm front** when winds will **back** sharply to West or South-West giving **near-zero drift.**
- Above **surface position of cold front** winds will **back again** sharply to South West giving **starboard drift.**
- After 100 nm enter the jet axis, speeds 100-200 knots, giving **increased starboard drift**. This will last for 200 nm.
- Passing out of the Jet stream SW winds, **starboard drift decreases**.



Upper Wind Changes Crossing Polar Front Depression East To West

Sub Tropical Jet. This will be located close to the surface position of the Subtropical High (in the North Atlantic, the Azores High) and is caused by the temperature difference between the adjacent columns of descending air from the warmer Hadley cell to the South and the cooler Ferrel cell to the North. The wind will be westerly, blow at 200 hPa (39000') and in Winter be located between 25°N-40°N. Over the **N.Atlantic in Winter** it blows from **New York to Morocco** as shown on page 410.

SUMMER

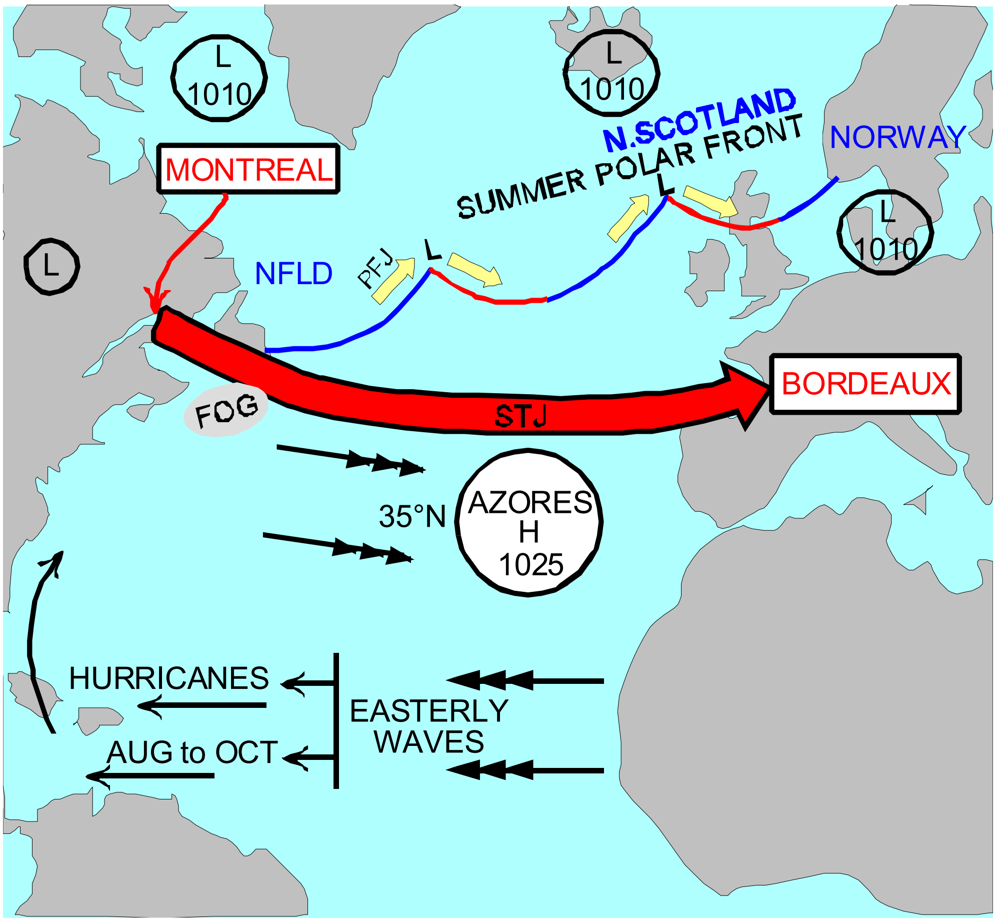
Pressure Systems. North American Low replaces Winter High. Icelandic "Statistical" Low 1010 mbs. Less deep and split. Azores High 1025 hPa intensified. Further North at 35°N. Hurricanes in Caribbean and Florida area.

The **polar front** is still present but **less active**. The North American Winter High has disappeared and with it the east coast temperature contrast between land and sea. This part of the polar front therefore disappears in Summer and the western end starts at Labrador, Newfoundland, E. Canada where the advanced warm Gulf Stream sea current now meets the receded cold Labrador Sea current.

In the East, the Azores High is intensified and further North, thus pushing the Polar Front northwards to Scotland.

In **Summer** the **Polar Front** average position thus lies from **Labrador/Newfoundland** to **North of Scotland** to **Norway.**

Temperature differences across the front are less, so frontal activity is less intense and less frequent. The weakened Icelandic "statistical" low is now split with average 1010 hPa centred West of Greenland, over Iceland and in the Baltic.



North Atlantic Weather details in July

Weather and Cloud

The New York Winter snows are gone. London temperatures remain moderated by air flow from the Atlantic**.** Polar air is less cold and the reduced temperature contrasts mean less convection cloud over the sea. From the **Azores High** warm moist **Tm outflow northwards** over cooler seas causes **advection fog/stratus/stratocumulus** and this can widely affect SW English coasts in late Spring/early Summer.

In the **Caribbean** the NE trade winds will continue to cause **orographic cloud and rain** on windward slopes. Additionally in Summer, rainfall will be increased by **convection**.

Visibility. Inland radiation fog is less likely in Spring and Summer and if formed, early morning insolation will cause quick clearance**. Advection Fog** can form over the **cooler seas** and near **SW facing coasts of UK and France** in **late Spring/early Summer** by **Tm air** from the Azores moving northeast. Near **Newfoundland** widespread advection fog can form over the Grand Banks (approx 45°N 50°W) in **May/June** by advancing warm moist air from the Mexican Gulf overrunning the very cold Labrador sea current.

Winds. In mid latitude, surface winds are still generally westerly but less strong than in Winter, as are upper winds because the temperature differences are less. In the Caribbean, NE trade winds prevail at the surface.

Jetstreams. The **Polar Front** jet streams will still be around the 300 hPa level and be positioned in relation to the Polar warm and cold fronts as in Winter but will be less frequent, less strong, and displaced further north with the Summer alignment of the Polar Front. The **Sub- Tropical Jet** at 200 hPa will also be further north and in the latitude band 40°N-45°N.

Specifically across the Atlantic in **Summer**, it will blow from **Montreal to Bordeaux,** as shown on the opposite page.

Easterly Waves. Easterly waves are similar to shallow troughs extending North from the Equatorial Low Pressure belt. They move slowly East to West under the influence of the anticyclonic wind around the subtropical High pressure. In the North Atlantic autumn, West African Tornadoes, which form over Nigeria, drift westwards with these waves and can become seedlings of Caribbean Hurricanes.

Hurricanes. Hurricane is the name given to Tropical Revolving Storms in the Caribbean/Gulf of Mexico Area. Frequency of developed Hurricanes is average 3 per year. They occur from **August to October**, tracking **westwards** across the Atlantic near 10°N-15°N latitude and at **10-15 knots**. Internal **windspeeds** can exceed **100 knots**. They then cross the Bay of Mexico or turn right around the sub tropical high to track NW, N, NE up the USA East Coast. They are energised by the latent heat of condensation and are therefore **more active over the sea**. Each season they are **named alphabetically** in order of occurrence using alternate male/female first names.

Tropopause Heights	70°N	30000ft	
	20°N	50000ft	
Freezing Level Height		January	July
	70°N	Surface	5000ft
	20°N	12000ft	16000ft
	47°N - 65°N and 4°W - 20°E		

CONTINENTAL NORTH WEST EUROPE

GEOGRAPHICAL CONSIDERATIONS

The **mountains of Norway** lie to the **North** while to the **South** there are many mountain ranges dominated by the **Alps. Between** the two regions lies the **North European Plain** with no mountain barrier against the Atlantic winds from the West nor to the cold winter winds from the East.

WINTER

Polar Front Depressions. These move **from the Atlantic towards Russia** and principally between the mountain barriers to North and South although tracks are variable. Areas to the **South of each Low** will experience **frontal weather.**

The **Alps** often block and delay cold fronts, causing **frontal and orographical cloud** to persist on the northern side. An active **secondary depression** may develop on such a front, tending to run **east-north-east** along the front until the cyclonic circulation around it eventually drives the front into the Mediterranean.

Thermal Depressions. Thermal lows can form in **Winter** to the East of the Alps over the low lying **Danube** area which is **moist and comparatively warm.** Associated cyclonic circulation on the east side will bring warm air North from the Mediterranean forming **active warm fronts.** These can bring extensive **low stratus** to Germany and **snowfall** as far north as SE England.

Polar Air Depressions. These can sometimes affect the extreme NW sea areas of the region in Winter.

Siberian High Extension. Pc air gives cold dry weather. Steaming fog or Low Stratus may be produced locally over water near German and Dutch coasts as the cold air reacts with the warmer water.

Temporary Highs. Ridges or transient anticyclones may exist in the N/NW in between travelling polar front lows.

Cloud and Precipitation.

Cloud amount exceeds **six octas** on average. Cloud is frontal from the many polar front depressions also from warm fronts moving North from the Mediterranean although cloud amounts decrease from West to East.
There is much precipitation, in the East mainly of snow.

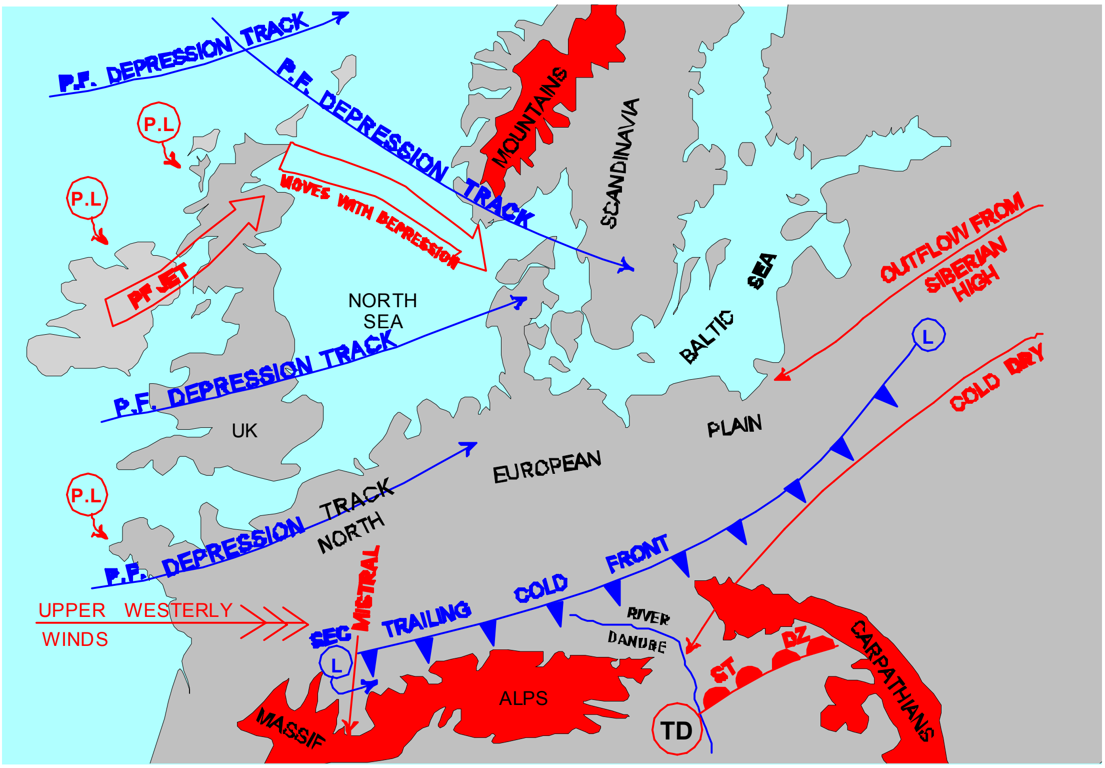
Visibility.

Radiation Fog can form **inland** with a slack pressure gradient, principally in Autumn and Winter. With a SW warm moist wind from the Atlantic, **advection fog** can form over previously **cold soaked inland** areas. **Smoke haze** may reduce visibility to the **lee of industrial areas. Frontal fog** can occur on the **warm fronts** of deep active **Polar Front depressions.**

Winds.

Surface Winds are generally **westerly** although easterly on the north side of depressions.
E or NE winds can occur as an outflow from the **Siberian High.**

Upper Winds become increasingly westerly with ascent, due to the increasing westerly thermal component. **Polar Front Jets,** located in relation to the moving **warm** and **cold front** surface positions, and centred around **300 hPa / 30000'** are common and often exceed **100 knots.** The Subtropical Jet is to the South near Morocco and therefore does not affect the region.



January Weather

Icing. As over the North Atlantic, **icing** occurs widely and through great depth in Frontal Cloud and is frequently **moderate** to **severe**. **Freezing Rain (Rain Ice)** can cause severe **clear ice** in cold air under a warm front or warm occlusion. A rare occurrence in UK, it is more common over **Central Europe** where the ground is generally much colder, indeed the freezing level may frequently be on the surface especially in the East.

SUMMER

Pressure Systems

Polar Front Depressions. These will track eastwards as in Winter but **further North** (seasonal movement is with the Sun). They will also be **less intense** because of the smaller Polar/Tropical temperature difference that forms them.

Thermal Depressions. Strong insolation can cause active thermal depressions over France and Southern Germany. Thunderstorms are common when moist unstable conditions exist. **Azores High.** This is well established west of Africa at 35°N. An associated ridge across Europe often gives a limited period of fine dry weather.

Temporary Highs. Temporary ridges or transient anticyclones to the NW are more dominant in Summer, in between weaker Polar Front Lows.

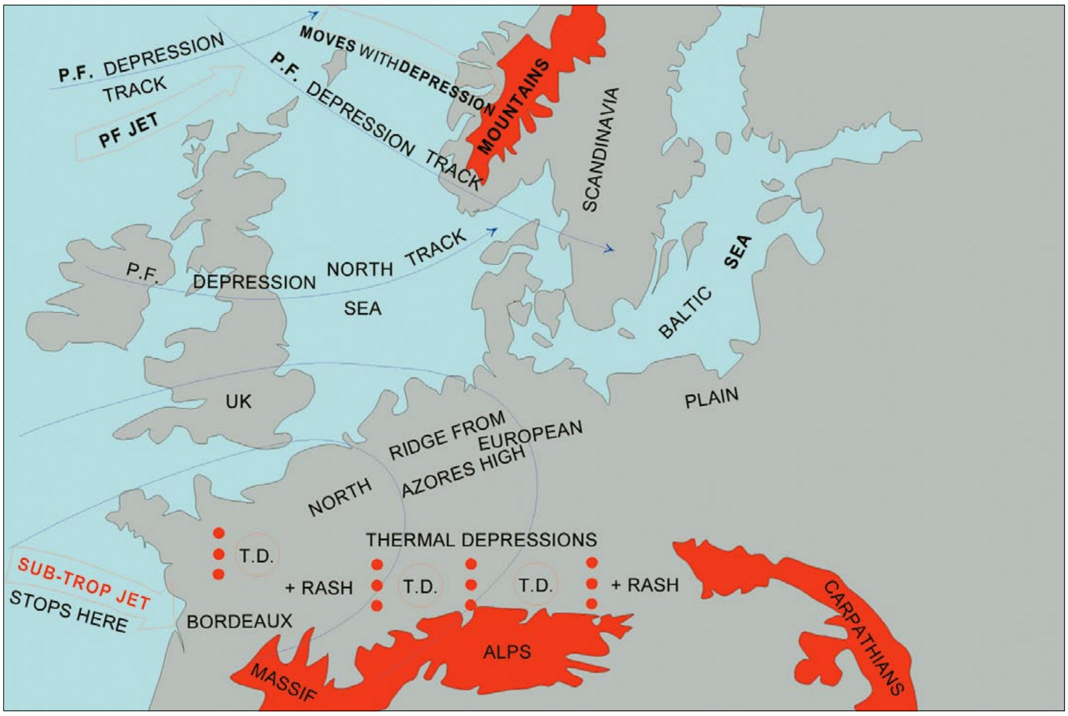
Scandinavian Highs. These can persist for a few days drawing air across the North Sea from western Russia.

Cloud and Precipitation

Frontal cloud amounts and rain will be much less than in Winter because the associated polar front depressions are fewer, less intense, and further north, and by Summer the Mediterranean warm fronts are gone. Cloud is mainly **convective** in **thunderstorms** produced by **thermal lows**. **Rainfall** is therefore mainly in the form of **heavy showers** but the effect may be increased by orographic lifting in the southern mountains.

Visibility

Radiation Fog is much **less likely.** It can occur in early Spring but morning insolation will normally ensure quick clearance. In Late Spring/Early Summer an easterly wind round a Scandinavian High blowing over the North Sea can often result in extensive **advection sea fog** along the **UK East Coast.** In Scotland this is known as **haar.** It can travel inland some distance.



July Weather.

Winds

Surface winds are generally **westerly** but **lighter** than in Winter. Winds may be modified by **sea breezes** along coasts.

Upper Winds become increasingly westerly with ascent but the thermal wind component is less than in Winter and upper winds will therefore be less strong. **Reduced Speed Polar Front Jets** will occur but **further North** with the Summer movement of the polar fronts. The Atlantic **sub-tropical jet** will reach the coast near Bordeaux but due to mountain interference will not extend overland at Jet Speeds. It therefore **does not affect the region.**

Icing. The freezing level will be higher in Summer and frontal activity is less, but icing in thunderstorms and orographical cloud may still be severe.

Average Tropopause and Freezing Level Heights over Central France

	January	July
Tropopause	35000ft	39000ft
Freezing Level	4000ft	12000ft

MEDITERRANEAN SEA and ADJACENT LANDS

GEOGRAPHICAL CONSIDERATIONS

The Mediterranean sea is almost entirely surrounded by land. **Compared with the land**, the sea will be **relatively warmer in winter** (giving unstable conditions above) and **relatively cooler in summer** (giving stable conditions above). Therefore during the **winter** surface air will tend to **flow in** from surrounding land areas and during **summer** it will tend to **flow out**.

There are significant **mountain areas** to the **North** and to the **West.** In winter, the **mountains** to the **North** will **hold back** much of the **cold air** from Europe/Asia. The **high ground** to the **West** will **resist** the **advance** of **Polar Front Depressions except** via the mountain gaps in **SW France** and at the **Straits of Gibraltar** between Spain and Morocco.

To the **South** there is **no mountain barrier** to prevent **dry dusty air** from the **Sahara** desert spreading north, except the Atlas mountains in the extreme SW.

WINTER

Pressure Systems

Mediterranean Front Depressions. The Mediterranean front lies **east/west** along the **centre** of the **Mediterranean**, and is formed by inflowing cold **Pc air** from the North and inflowing less cold **Tc air** from the South. Air will be forced to rise along the convergence line forming **frontal depressions** in the West which **move eastwards** along the frontal divide driven by the westerly upper airflow. Because of the **dryness** of the desert Tc air, warm front and warm sector cloud does not form, thus there is **cold front weather only**.

Orographic or Lee Depressions. These can form **south of the Alps** over the **Northern Adriatic** and over the **Gulf of Genoa**. The Genoa Low can move south along the Italian coast giving **unstable weather**. Lee Lows can form **South of the Atlas mountains** in Morocco with a cold W/NW airstream and then move NE to enter the Mediterranean east of Tunisia. They can also form **South of the Turkish Taurus mountains** to form the **Cyprus Low** between Cyprus and Turkey. The **Cyprus Low** gives not only instability but is accompanied by **NE gales**. Weak depressions moving into the area can become **deepened** and reactivated. These lows can then move **eastwards into Lebanon and Arabia.**

Siberian High. The Siberian High is well **north of the region** but its **cold outflow** can reach the warm Mediterranean and cause **instability**.

Thermal Depressions. When **cold** air from the **Siberian High** flows **over** a relatively **warm landlocked sea area** such as the **Mediterranean**, instability or **Thermal Lows** are created. Over the Mediterranean, these form particularly in Central and Eastern areas and move eastwards to Arabia, the Arabian Gulf, Iran and Afghanistan.

Polar Front Depressions. Polar Front Lows and sometimes secondary Lows can enter the region via **SW France** or **Gibraltar**, after which they tend to **become absorbed** by other Depressions.

Cloud and Precipitation

Cold fronts associated with Mediterranean front Depressions, also orographic and thermal depressions, produce **CU and CB** with attendant **heavy rain** or **hail showers** and **thunderstorms.** There is some layer type cloud and more continuous rain in association with the few Polar Front depressions in the West.

Visibility

Radiation Fog is **less common** than in NW Europe **but** can be persistent in the **Po Valley** in North Italy. Otherwise visibility is excellent between showers except when air blows from the south bringing dust laden air from the Sahara desert. These **southerly winds**, called the **Sirocco in Algeria**, the Chili in Tunisia, the Ghibli in Libya and the **Khamsin in Egypt** blow **ahead of depressions** travelling east over the sea.

Surface Winds

Surface winds will blow in accord with the location of depressions but there are some **named winds** blowing **into** the **Mediterranean** from surrounding land areas that should be noted:

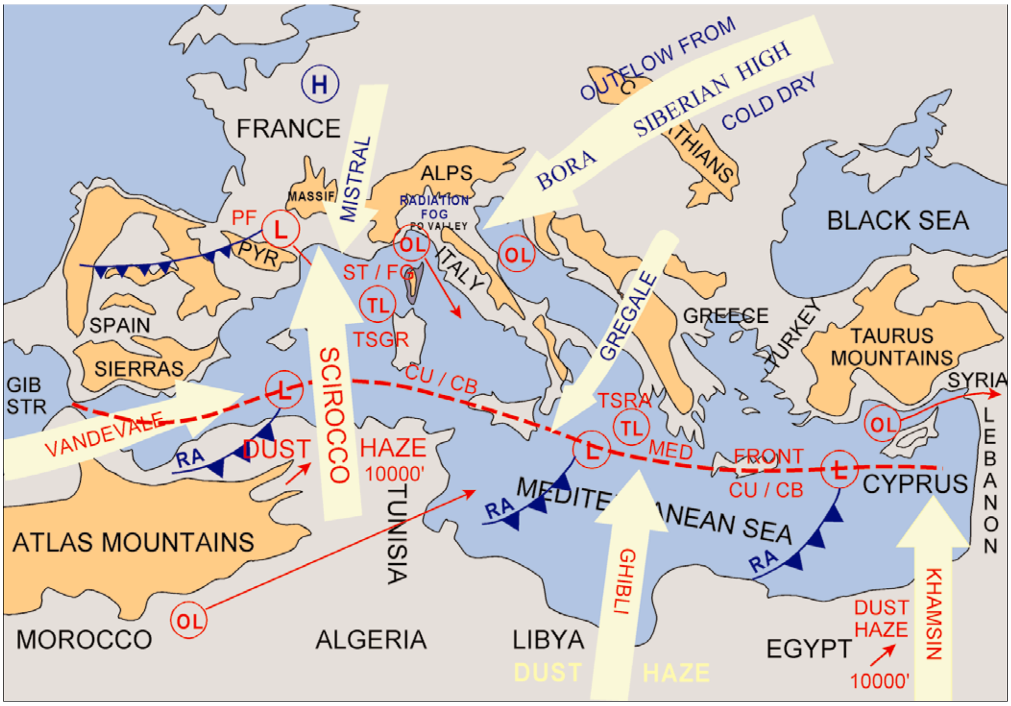
Mistral. This is a strong **northerly** wind up to **70 kts** blowing down the **Rhône valley** in SE France, especially when High pressure is to the North. It is a **valley/katabatic** wind, normally **stronger at night and in Winter**, which brings **cold air** from the North. It helps form the Genoa orographic Low.

Bora. This is a stronger dry gusty **NE** wind up to **100 kts** which is **part valley/part katabatic**. The wind blows through the mountain passes into the **Northern Adriatic** and can be reinforced by High Pressure to the NE. It can bring snow and is **strongest at night**.

It can set in suddenly and is therefore dangerous. It can help form the Adriatic orographic Low. **Gregale**. This is similar to the **Bora** but **less strong**, **further south** and more **moist**. It blows from the **NE** near Southern Italy and Malta and is due to continental relatively high pressure to the North, and low pressure over the Mediterranean Sea. It occurs in 1-2 day spells in association with Mediterranean depressions to the South which are moving eastwards.

Sirocco (or **Scirocco**). Blows out of **Algeria** and the Sahara Desert into the **western Mediterranean** ahead of travelling Mediterranean lows, and can carry dust up to 10000′. The Sirocco can **sometimes continue northwards to France**; while in transit it will be cooled and humidified by the sea and can thus cause **advection fog and/or low stratus** along the **South French Coast**.

Khamsin. Similar to the sirocco, but **further east**, the Khamsin originates in Northern **Sudan**, blows **from the South** through **Egypt** and can affect Jordan, Syria and Cyprus. Dust can be carried to 10,000ft.



Winter Pressure Systems and Surface Winds.

Vandevale. Strong **SW** to **W** wind in the **Straits of Gibraltar**. Blows ahead of a polar front cold front approaching from the Atlantic. It is very squally with much low cloud.

Upper Winds

In the **extreme west** a **few Polar Front Jet Streams** occur in association with PF Lows. The **Sub Tropical Jet** over **Morocco** does not affect the West of the sea area but can affect the Eastern Mediterranean in the Cyprus and Egypt region. It is centred at the 200 hPa level with maximum westerly winds at over 100kts.

Winter Upper Winds.

Icing

Clear ice can occur in convective cloud and thunderstorms. Freezing rain/rain ice can occur over N Italy where the freezing level may occasionally be on the surface.

SUMMER

Pressure Systems

Azores High. The Azores sub tropical high at 35°N extends eastwards across the Mediterranean. **Thermal Lows**. Pressure over Egypt, Lebanon, and lands to the East is relatively low due to intense insolation.

Cloud and Precipitation

There is little cloud aside from **fair weather CU**. **Local CU/CB** can occur over the high ground of Greece, Italy and Turkey due to **convective** and **orographic uplift**, possibly resulting in local thunderstorms.

Visibility

Trapped near the surface by generally descending air, **dust** can reduce visibility **across the region**. In the straits of **Gibraltar**, warm moist air **flowing out** over the cooler Atlantic can produce **advection fog** or **low ST/SC**.

Surface Winds

Levanter. Summer **outflow** from the Mediterranean occurs at Gibraltar and is called the Levanter. It blows from the East (the Levant) during **July-October** and **March** and can reach gale force. The axis of the Rock of Gibraltar is North/South and **orographic uplift** on the east side through some 1100ft can produce a **banner of ST/SC** which then **streams westward** from the top of the Rock. In stable air **standing waves** can occur over the rock. Considerable **turbulence** up to 5000ft can exist above the adjacent airfield.

Etesian. This **moderate persistent** wind blows **from the North** across the Greek Islands of the **Aegean sea** towards the island of Rhodes then southwards. It is caused by the pressure gradient between the Azores ridge, extending across the Western and Central Mediterranean, and heat induced low pressure overland to the East. The wind is dry and brings **clear skies** and **good visibility**. Strong Etesians can bring gales and affect the area from W Greece to W Turkey and as far south as the N African coast when CU may develop after the long sea track.

Sea Breezes. These can be strong at this time of the year and will **locally modify** surface wind direction.

Upper Winds

Light westerly in the **West**. **Westerly** average **40-50 knots** in the **East**. Both **Jetstreams** are **out of the region** to the North.

Icing

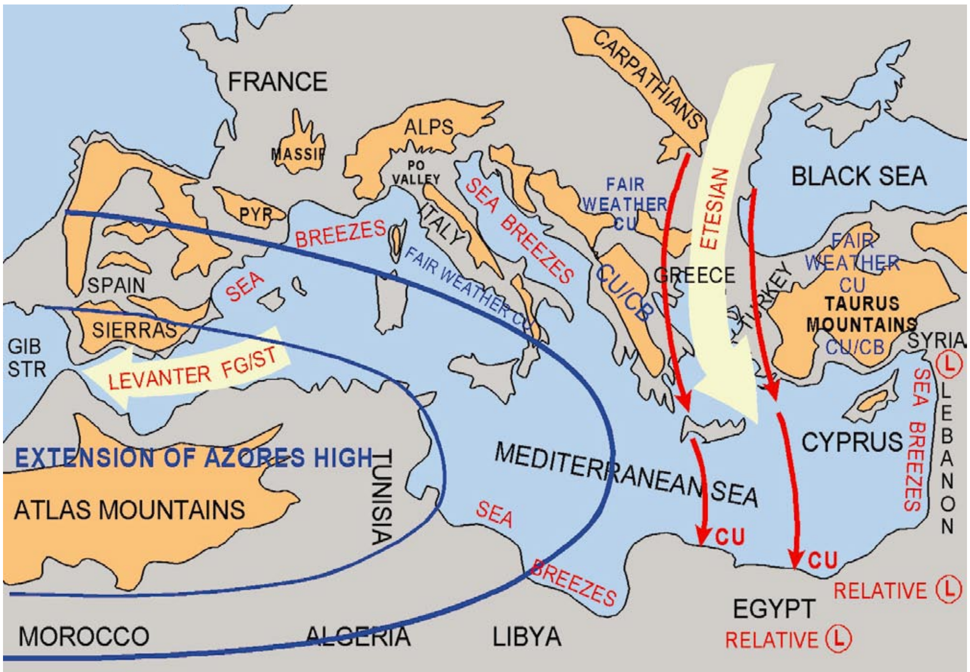
The freezing level is high and icing is not normally a problem in summer.

Average Tropopause

South Region 53000ft North Region 40000ft

Average Freezing Levels

Winter 6000ft Summer 14000ft



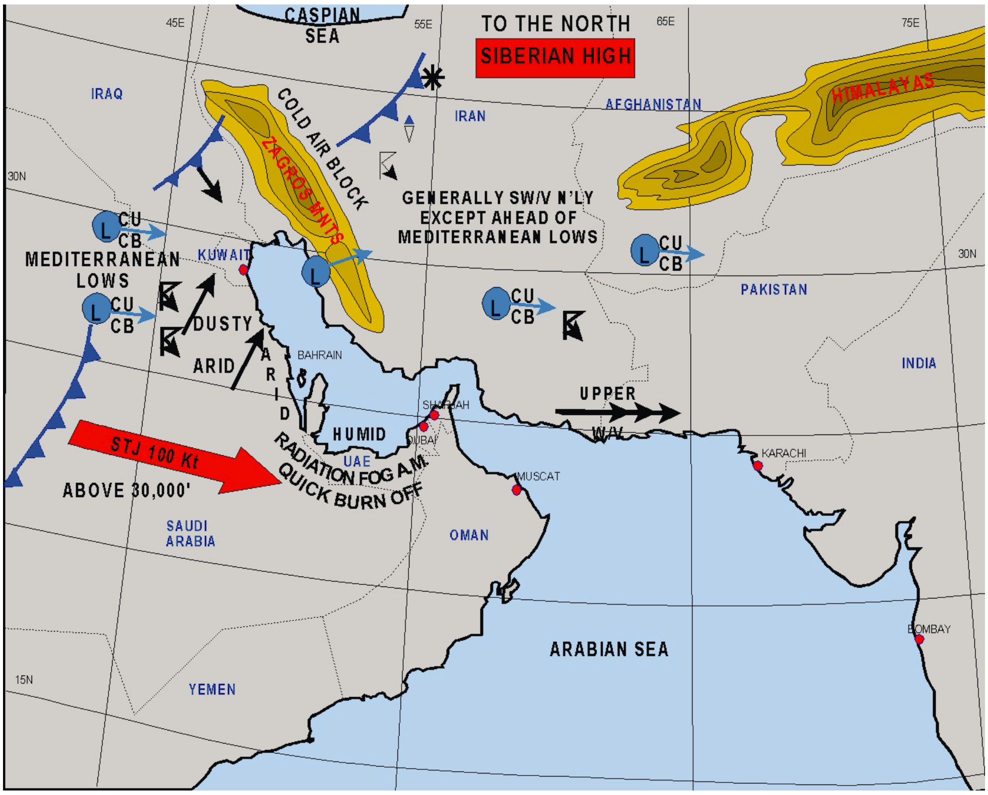
Summer Pressure, Surface Wind Velocity and Cloud.

Summer Upper Winds.

ARABIA, THE GULF AREA, ARABIAN SEA and BORDERS ENCLOSED WITHIN 15°N-35°N and 35°E-75°E

GEOGRAPHICAL CONSIDERATIONS.

Inland areas of Iraq, Saudi Arabia and Oman are largely desert. The Tropic of Cancer at 23½° N almost bisects the region so that in summer the noon sun is virtually overhead. The daytime interior is extremely dry and hot. The warm Gulf waters cause oppressive humidity along coasts. Surface wind direction is generally governed in the West by the NW/SE axis of the Zagros mountains in W. Iran and in the East by the Himalayas.



Arabian Weather - Winter

WINTER

Pressure Systems

The Siberian High is established over Asia to the NE but its surface outflow affects the region. **Thermal Lows**, often with associated cold fronts, travel eastward from the Mediterranean across Arabia into Iran and Afghanistan.

Siberian dry cold frontal air passing over the relatively warm Caspian Sea to the North can initiate considerable thermal instability.

Cloud and Precipitation is restricted to the North and West only. **Travelling Lows** from the **Mediterranean** will produce **CU/CB, heavy showers** and **thunderstorms**, and their associated cold fronts may bring some weather and **duststorms** to the more southern interior of Arabia. **Thermal instability** over the **Caspian Sea** can bring **thunderstorms**, **hail** and possibly **snow** to high ground to the north.

Surface Winds. In the west the **Zagros mountain range** and parallel ridges are **oriented NW/ SE**. These **block** and **deflect** the cold Siberian outflow so that the **surface winds** become **North** or **Northwesterly**. In the East, the Siberian outflow escaping round the western end of the Himalayan air block will again be **northerly**. The exception is the **temporary southerly** wind which occurs **ahead** of the travelling depressions from the Mediterranean.

Visibility. Winter visibility is generally much better than in the summer convection currents, but in the NW of the region rising **dust** can occur with any wind direction and especially in the **southerly** winds **ahead of** the travelling ex Mediterranean **Lows**. Violent but short lived **duststorms** may accompany the **passage** of associated **cold fronts**. Overland near coasts where humidity is high, **radiation fog** may form, but **dispersal** is quick after sunrise.

Upper Winds are westerly. The **200 hPa Subtropical Jet** covers the west of the region and may extend as low as 300 hPa (30000 ft). Core speeds frequently exceed 100 knots.

Icing is not a problem except when climbing or descending through large CU/CB.

SUMMER

Pressure Systems.

The Baluchistan Low is the lowest pressure point of general warm weather low pressure over the Asian continent. It centres on the area of Baluchistan, lying across the Iran/Pakistan border, due to the mainly south-facing rocky nature of the surface, and intense solar heating from the high noonday sun.

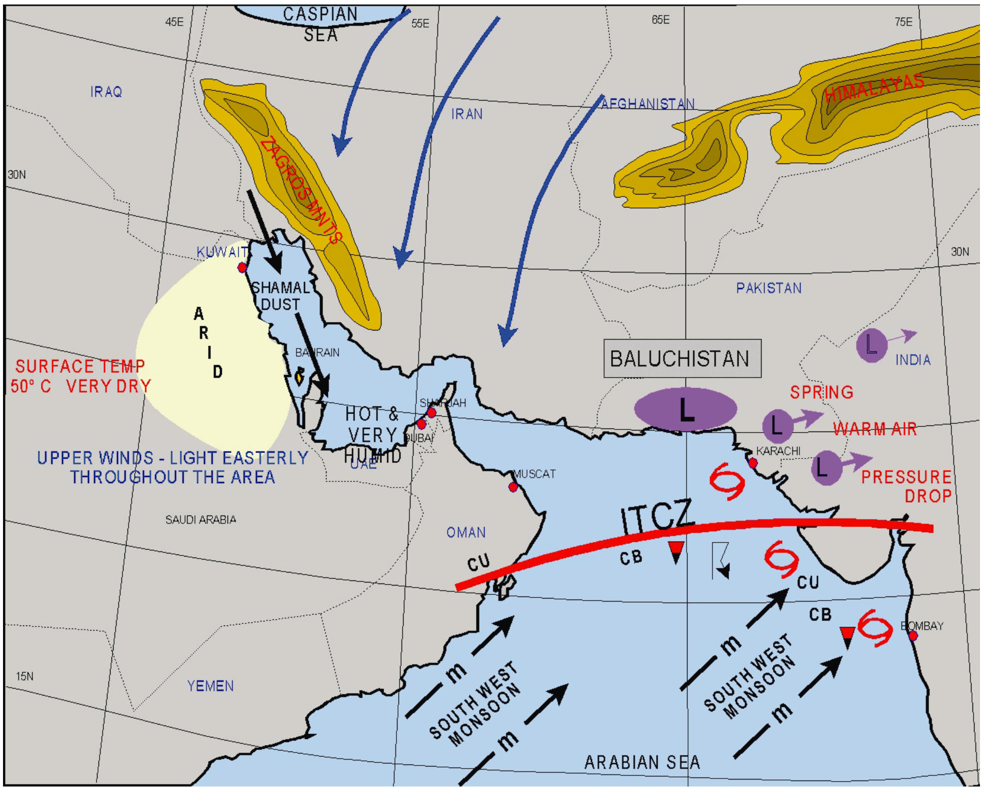
The ITCZ just reaches Oman in the west. In the east it traverses the N. Arabian Sea northwards in June/July and southwards during September.

Thermal Low Pressure. Over Eastern Pakistan and NW India, March to June is dry. With advancing Spring, the land mass begins to warm, thus pressure begins to fall, drawing in warm moist air from the Arabian Sea in response to the pressure gradient; first at lower latitudes then progressively further north. The ITCZ follows.

Cyclones occur over the **Arabian Sea** during the advance and retreat of the ITCZ between **June** and **September**.

Surface Winds

In the west there will be anticlockwise rotation around the Baluchistan Low, as modified by the Zagros mountains with a NW/SE orientation, gives a Northerly or Northwesterly winds. In particular the Shamal wind originates as dry and dusty convection currents from Iraq. It is northwesterly and blows the length of the Gulf picking up moisture and bringing a dusty humid wind to facing coasts around Bahraina and Dubai.



Arabian Summer

Cloud and Precipitation.

Most of the region is almost rainless and temperatures can exceed 50°C. Inland areas are very dry but Gulf coastal regions facing the N/NW onshore winds can be oppressively humid. An exception is the **SE of Oman**. The **ITCZ** reaches the **coast** where the desert terrain temporarily "bursts into bloom". Further East towards the Indian coast, the ITCZ northward movement is followed by the onset of the SW monsoon. The monsoon is very moist and convectively unstable. Orographic and convection cloud and heavy rain are widespread.

Visibility.

The **north/northwesterly winds** can cause much **dust** in the desert regions. The **shamal** will bring **dusty moist air** to coastal areas.. Visibility will also be reduced in regions affected by the ITCZ.

Upper Winds. Above 20000ft winds are light Easterly.

Icing. Icing should not be a problem in Summer.

Average Tropopause and Freezing Level Heights

	Tropopause		Freezing Level
January	38,000ft		11,000ft
	>	56,000ft	
July	45,000ft		16,000ft

CHAPTER TWENTY TWO

ROUTE CLIMATOLOGY

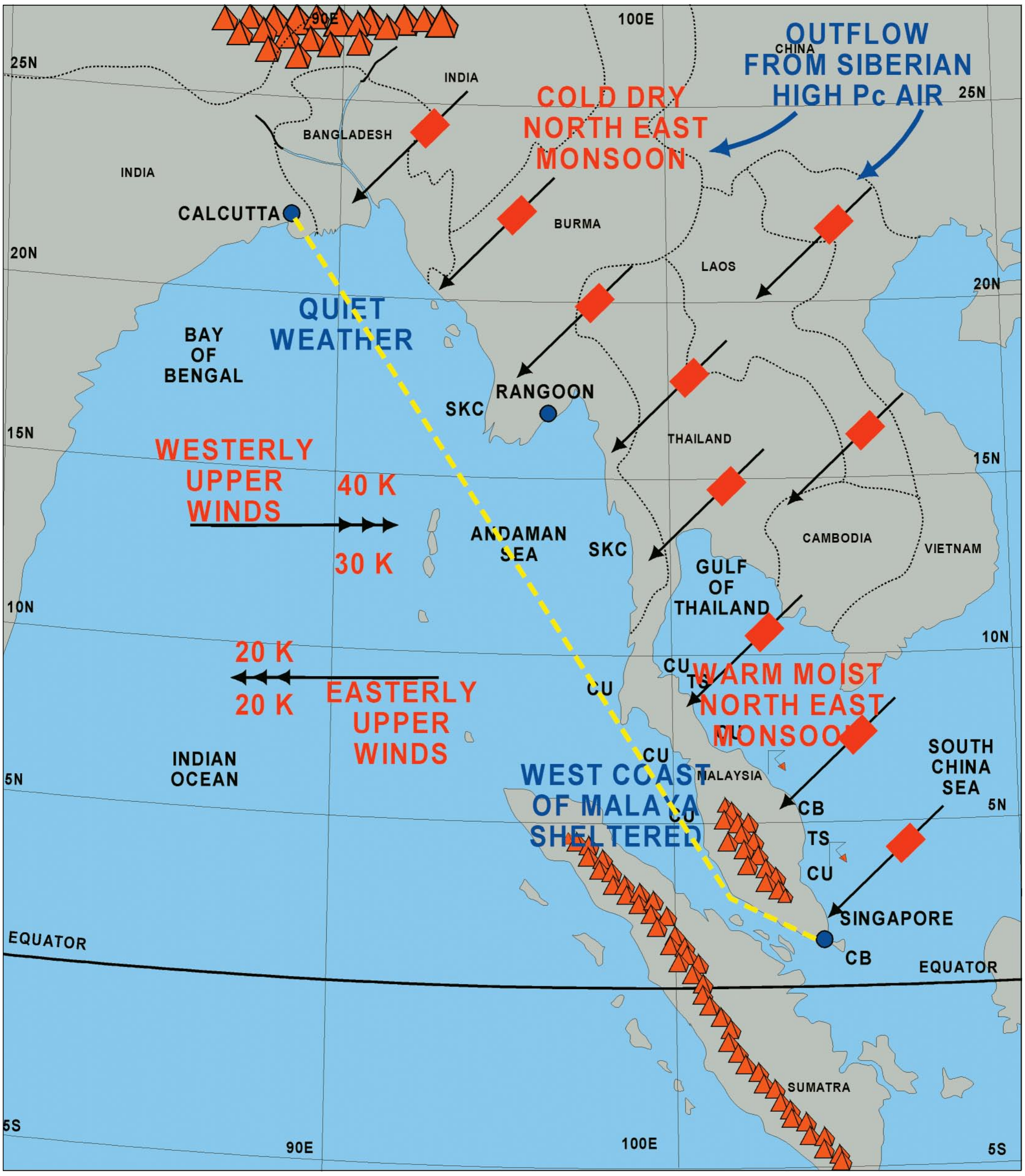
Contents

CALCUTTA to SINGAPORE

GEOGRAPHICAL CONSIDERATIONS

The route is located between Latitudes 23°N and 01°N. It overflies the eastern Bay of Bengal and is just off the west coast of Bangladesh, Burma, Thailand and W. Malaysia. The Himalayas lie to the north of low lying Bangladesh. The Cameron Highlands form a spine the length of West Malaysia, and Sumatra Island to the SW also has a mountain backbone.

WINTER (JANUARY)



Weather and Winds in January.

Pressure Systems.

Continental outflow from the **Siberian High** establishes the **NE Monsoon** over the whole route as shown above. The **ITCZ** is **south** of the route.

Weather.

In Winter the route weather is generally very good. Calcutta and Bangladesh are protected from the North by the Himalayas. Abeam Burma, the NE monsoon will have had a long land track and, although isolated convective cumulus are possible, the dry cold air will in general ensure clear skies.

Further south the monsoon will cross the Gulf of Thailand picking up warmth and moisture encouraging some CU and CB to form over the isthmus of Southern Thailand.

On the last section of the route the NE Monsoon arrives warm and moist from the expanse of the South China Sea giving large scale orographic cumulus and thunderstorms over the East Coasts and Central highlands of West Malaysia and Sumatra.

The West Coasts are more sheltered and generally less wet although all equatorial land areas including Singapore have considerable convective heating resulting in almost daily thunderstorms.

Visibility.

Early morning mist can occur in the moist river delta regions of Bangladesh and Burma. Otherwise visibility is very good outside showers and thunderstorms.

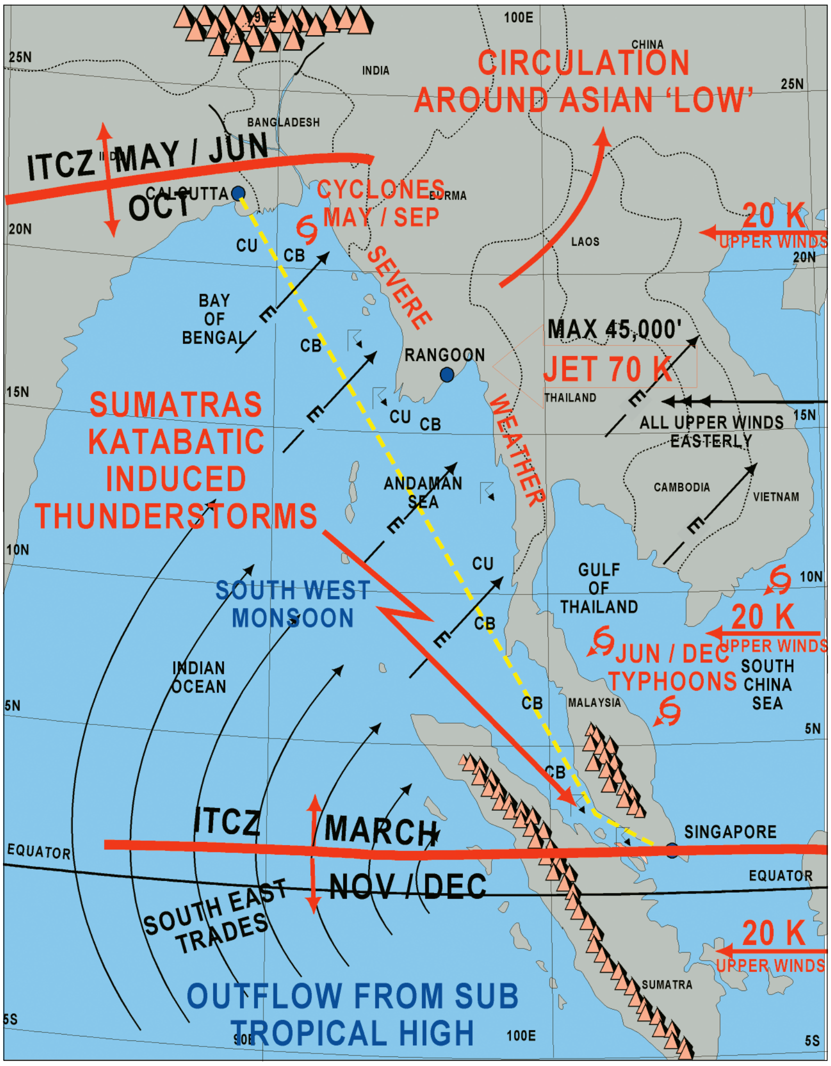
Winds.

Low level winds are north-easterly over the whole route under the influence of the NE monsoon. Above 20,000′ upper winds overrun the monsoon. The 200 mb subtropical jet lies just south of the Himalayas and is therefore north of the route; decreasing westerlies of around 40 knots over Calcutta reduce to zero near 10°N thereafter becoming the normal light equatorial easterlies.

Icing.

Icing can occur above 16,000′ but is a lesser problem in January than July as skies are generally clear on the route.

SUMMER (JULY)



Weather and Winds in July.

Pressure Systems.

The Siberian High of Winter has been replaced by the **Asian Low** centred over **Baluchistan**. The **ITCZ** rapidly traverses the route northbound in Spring to be by Singapore in March and Calcutta in May, then again southbound in the Autumn to be by Calcutta in October and Singapore again in November/December. In **July** it is therefore located well to the **North**. The inflow to the ITCZ cyclonically round the Asian Low establishes the **SW**. The monsoon is supplied from the Southern Hemisphere SE trade winds which veer to SW on crossing the equator.

The lengthy equatorial sea track of these winds ensures high temperatures and high humidity so that wherever they landfall, the orographic uplift will trigger intense instability with thunderstorms and severe weather.

Weather.

In Summer, flying conditions are poor. The whole route lies on the windward side of the Bangladeshi, Burmese, Thai and West Malaysian coasts. Thunderstorms and severe weather will occur throughout except over the extreme south of the route, where in the Straits of Malacca there will be some protection by the mountains of Sumatra from the SW Monsoon. Nevertheless the high mountains on either side of the straits can cause a new hazard.

At **Night**, the **katabatic winds from each side**, aided by the land breeze effect, will meet in the middle of the straits causing a convergence line with consequent uplift. Along the straits this double sided uplift can cause a line of **night time thunderstorms arched** in the middle, known as **Sumatras**. (Jingle: **S**umatras occur in **S**ummer)

Cyclones.

Tropical revolving storms are known as **cyclones** in the Bay of Bengal. To form they need a summer **warm sea** (evidence suggests in excess of +27°C. and the close **instability** of the **ITCZ**. In July the ITCZ is north, over the land, so that in this area they form only in early and late summer when the ITCZ is over the sea, that is in **June** or **October**. Tropical revolving storms also occur in the Gulf of Thailand and occasionally move west to affect the route.

Visibility.

Visibility is generally impaired by much cloud and frequent rainfall. Reduction in tropical rainstorms can be considerable.

Winds.

Surface winds are **SW** over the whole route. Aloft, the 200 hPa subtropical jet is now located North of the Himalayas thus above 20,000′ the equatorial mostly light **upper easterlies** apply over the **whole route**. Also in this region, summer high temperatures in the land mass of Asia cause a reversal of the South-North temperature gradient. Aloft, with warm air to the north, the upper pressure gradient movement is southward, which Coriolis/GF will turn to the right, giving a pronounced **Easterly Jet** over **Rangoon** of **70 knots** centred near the 150 hPa level (45,000′).

Icing. Icing can be a problem on this route during the Summer, when descending through cumulo-form clouds.

Tropopause Heights average 56,000′ all year.

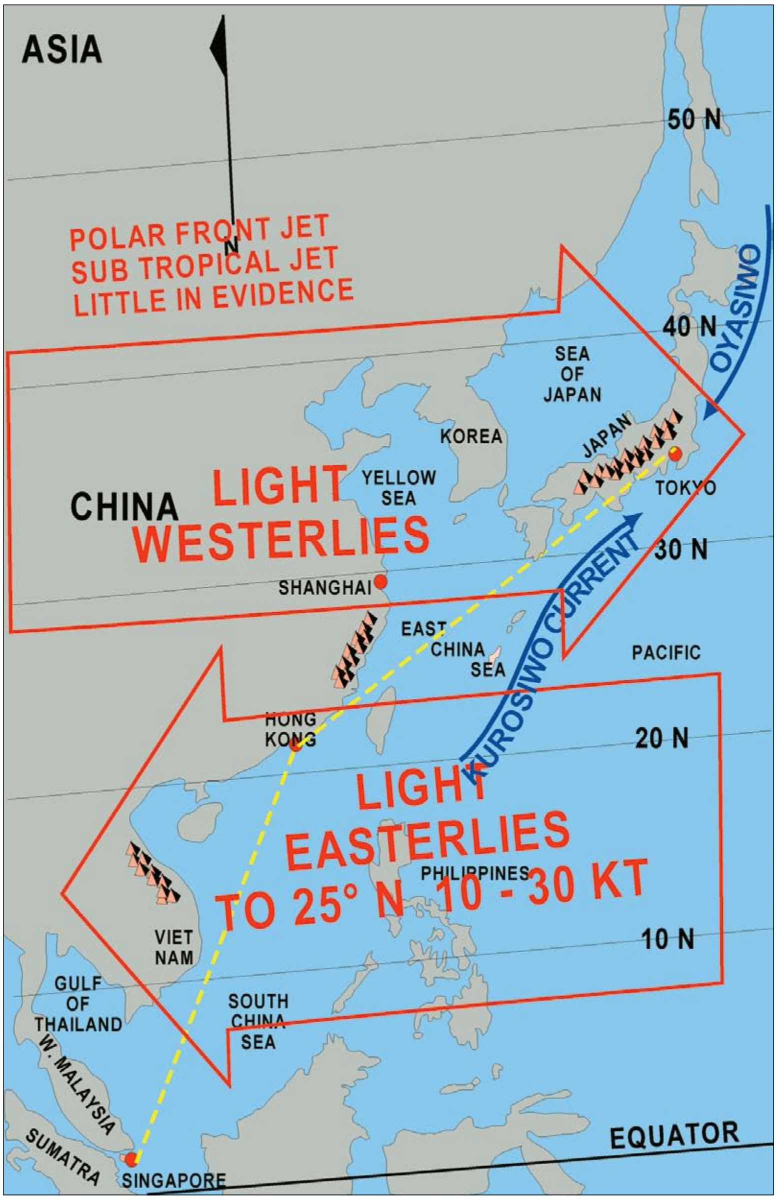
Freezing Level Heights average 16,000′ all year.

SINGAPORE to TOKYO via HONG KONG

GEOGRAPHICAL CONSIDERATIONS

The route traverses the "Western Pacific Rim" from Latitude 01°N to 35°N. It passes close to the east coasts of W. Malaysia, Vietnam and China. The en route weather is dominated by the **changing seasonal pressure over Asia** and the temperature differences between continent and ocean and between sea currents. East of Japan, the cold Oyasiwo sea current sweeps down from the Russian Kamchatka peninsula, and is countered by the warm Kurosiwo sea current flowing northeastward from the Northern Philippines. Much of the area, including Japan, has a mountainous interior.

WINTER



Surface Conditions in January.

Pressure Systems

- The **ITCZ** lies well south of the route.
- The **Siberian High** is well established to the west over Asia.
- Some **Polar Front Lows** traverse the extreme north of the region.

Surface Winds.

Clockwise outflow from the **Siberian High** establishes the wind flow over the route as shown in Fig. 22.3. From **Singapore to Vietnam** the **NE monsoon** blows. From **Vietnam to China** the wind remains **north or north east**. Near **Japan** the wind is **north or north west**.

Weather.

In the south of the route, the NE monsoon sweeps down from the warm expanse of the South China Sea producing intense convective instability. This will produce CU, CB, heavy showers and thunderstorms along any windward coast in its path, for example the East/NE coasts of W. Malaysia and Vietnam. Inland areas, sheltered by mountains, will remain drier aside from convective weather.

Towards Hong Kong, after the ITCZ has passed southbound in September,some shelter will be afforded from north/NE winds by the Chinese mountainous landmass; from October to December the weather in Hong Kong is fine and dry. A change occurs in January as the wind veers and the source area is over the warm Kurosiwo sea current. These new warm moist winds form, over seasonally cooled coastal **Hong Kong** waters, **advection fog**, **low stratus drizzle and gloomy conditions**. This coastal condition is known as the **Crachin** and lasts in Hong Kong from **January to April** after which the northward movement of the ITCZ will dispel it.

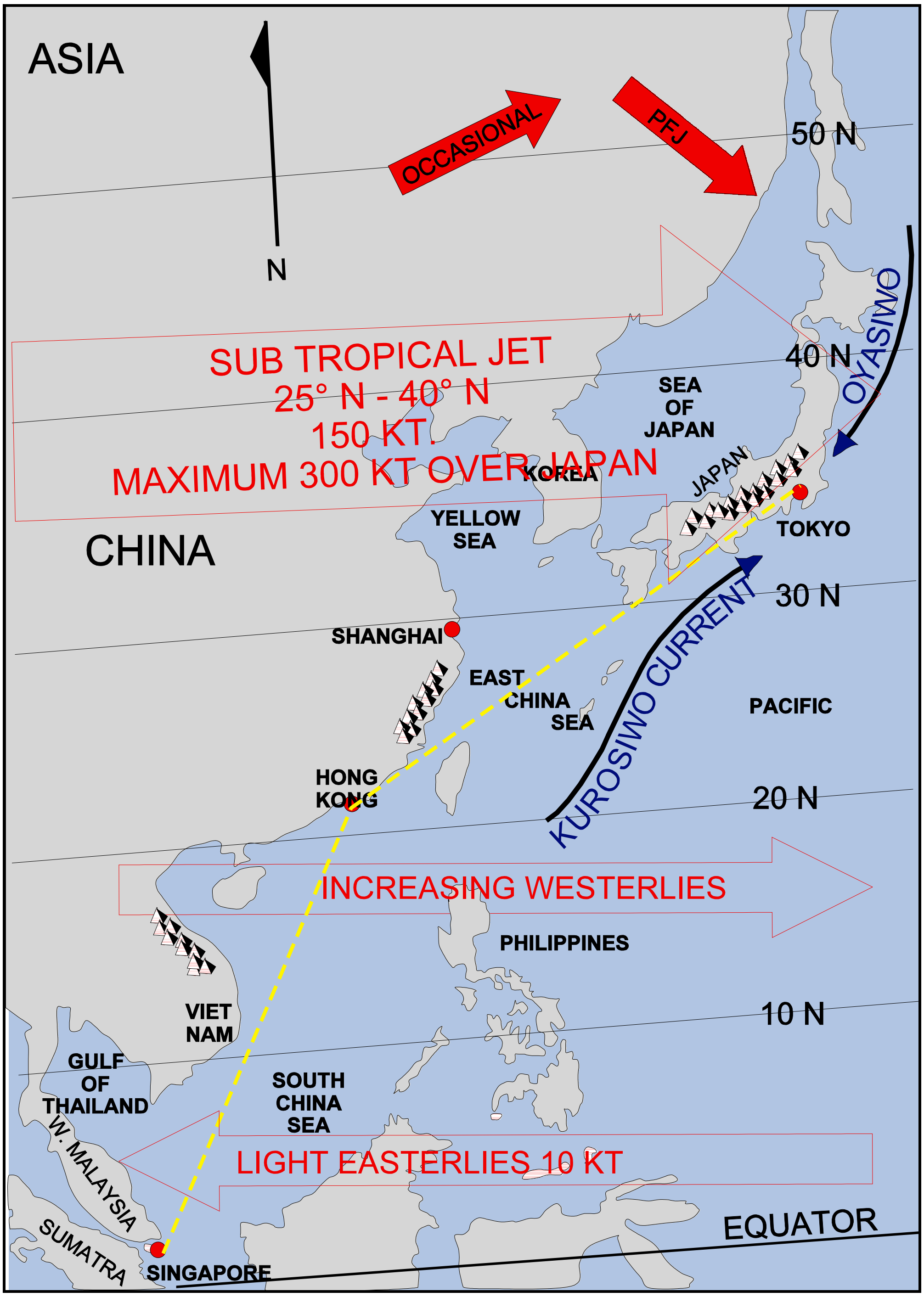
In the north of the route very cold dry S E ward outflow from Siberia crosses the comparatively warm Sea of Japan. Moderate instability generated is orographically enhanced over the **Japanese NW coast** and **central mountains** causing **CU** and **heavy snow showers**. Eastern lee areas, such as Tokyo, will be drier and less cold due to the F◎hn effect and warming from the Kurosiwo sea current.

Visibility.

In the south of the route, visibility is good between showers. At Hong Kong visibility is **excellent October-December**, but **abysmal** from **January-April** in the **Crachin** conditions discussed above. Near Tokyo and other big Japanese cities visibility can be reduced to near fog limits by industrial smoke.

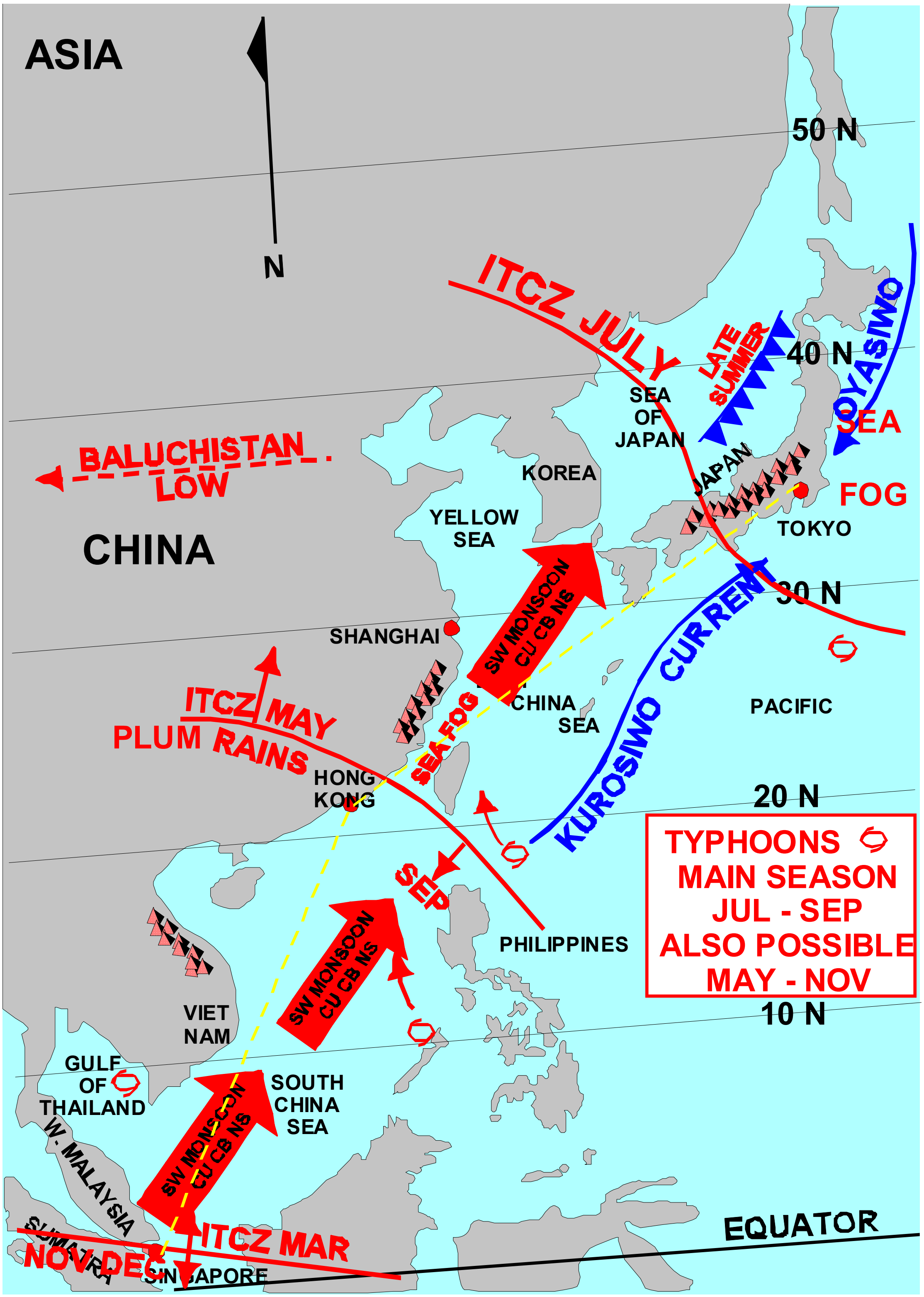
Upper Winds.

Equatorial 10 -30 kt Easterlies blow from Singapore to 10°N. Further north, winds become westerly increasing in speed towards 25°N-40°N where the 200 mb subtropical jet blows, frequently up to 150 knots, and occasionally to 300 knots near Japan. This exceptional speed is due to a combination of the strong low level geostrophic South Eastward Siberian outflow and the extreme thermal wind component generated by the marked Siberia/Pacific temperature difference. Further north, there are some occasional westerly jets in association with polar front lows.



Upper winds in January.

SUMMER



Surface Conditions in July.

Pressure Systems

Baluchistan Low. The Winter Siberian High is replaced by the Summer Asian Low centred over Baluchistan. Its **anticlockwise inflow** produces the **SW monsoon** over the route as far north as Central Japan - the Northern limit of the ITCZ.

ITCZ/Equatorial Trough. The SW monsoon will follow northwards the ITCZ which will be over Singapore in March, China in May and Japan in July. The northern extent of the SW monsoon will then recede southwards again driven before the ITCZ, which passes Hong Kong in September and Singapore again in November/December.

Typhoons. In the North Pacific, tropical revolving storms are known as typhoons. Evidence suggests that to form, requirements include a sea temperature greater than +27°C, a proximity to ITCZ instability, plus a displacement away from the equator where coriolis is zero, and location south of the Jet stream belts which would destroy their vertical continuity. They form in the Central pacific, at around 10°-15°N then drift westward at 10-15 knots with the clockwise wind direction around the N. Pacific sub tropical High. Nearing the Philippines they will generally track near the seasonal ITCZ but can curl northwards extending the season in some locations. Up to 12 per year can effect Southern Japan, principally in July - September and in Hong Kong occurrence is commonly in September. The overall season may extend from May to November depending on Latitude. The southern limit is the Gulf of Thailand.

Surface Winds

In July the south west monsoon extends over the whole route as far North as Central Japan where the ITCZ then lies. By late Summer, the cold Northwesterlies will re-establish behind the retreating ITCZ as the Siberian High begins to rebuild. Where Typhoons occur, winds of varying direction may exceed 100 knots. Sea breezes will effect coastal wind direction in sunny conditions especially in the South.

Weather

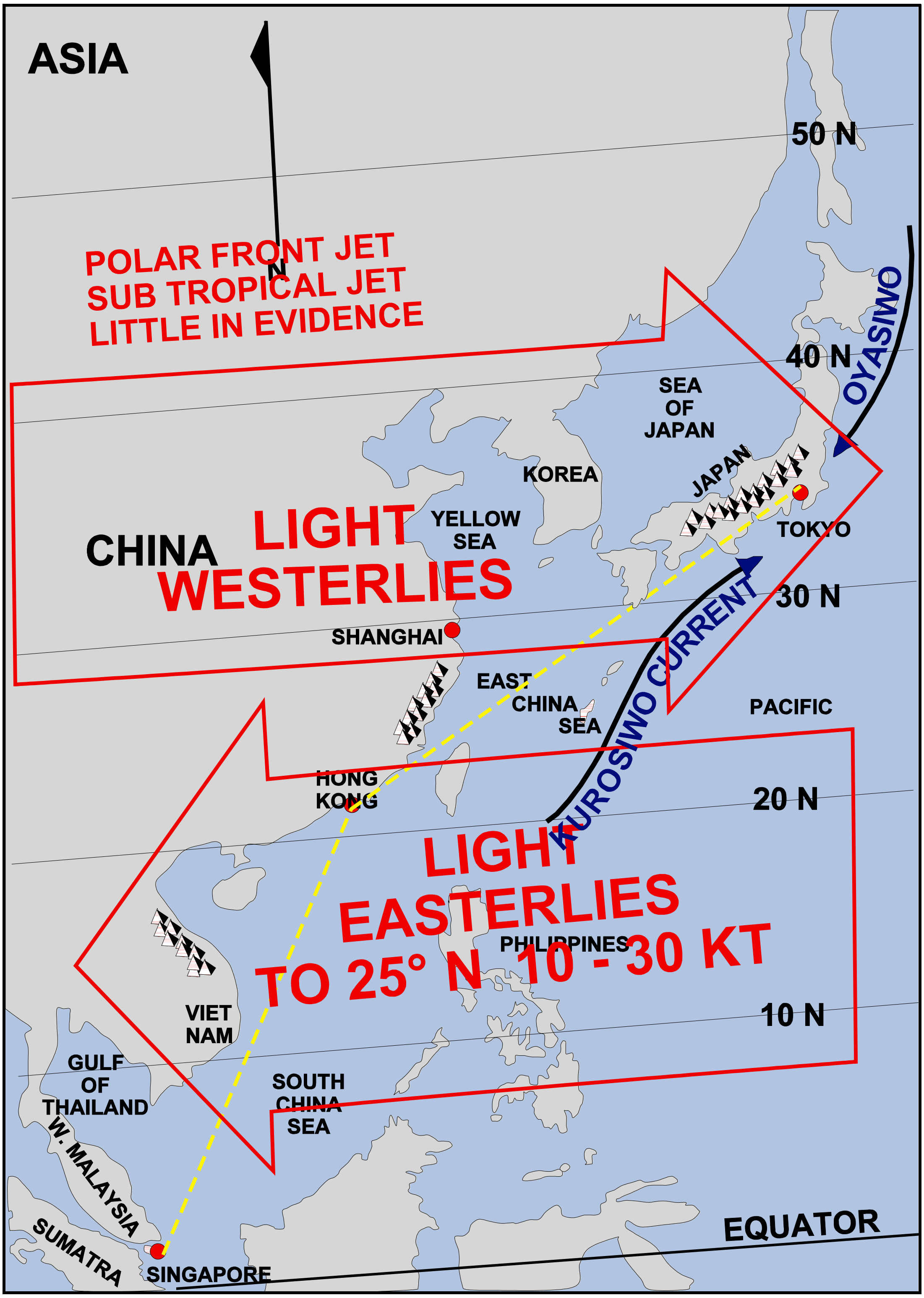
To the west of Singapore in the Malacca Straits, the Katabatic thunderstorm **Sumatras** will form overnight. The SW monsoon will bring Orographic CU CB to SW facing coasts, while east coasts will be more sheltered.

Nevertheless in these equatorial regions including Singapore purely convective cloud will be heavy, often giving daily thunderstorms.

Most route weather arises on the ITCZ as it travels from **Singapore** in **March** to **Tokyo** in **July** and back to **Singapore** in **November/December**. The **northbound ITCZ** will pass **China** in **May** where associated precipitation is known as the **Plum Rains**.

High typhoon internal wind speeds, coupled with intense rain and thunderstorms, can locally bring much structural damage and flooding.

Over Japan in Late Summer some frontal rain occurs as PC air spreading south from Siberia meets retreating tropical air.



Upper Winds in July.

Visibility

In early summer, warm moist SW monsoon winds, advancing north, can bring sea fog to cooler Chinese coastal waters and extensive blanket advection sea fog over the cold Oyasiwo sea current between eastern Japan and the mainland Kamchatka peninsula further to the northeast. Some industrial smoke can occur near cities in Japan.

Upper Winds

Equatorial **light easterlies** of 10-30 knots extend to 25°N, beyond which winds become **light westerly**. Sub tropical and Polar Front Jets are little in evidence over the summer North Pacific.

Tropopause Heights

Singapore	Japan
56,000′	38,000′

Freezing Levels

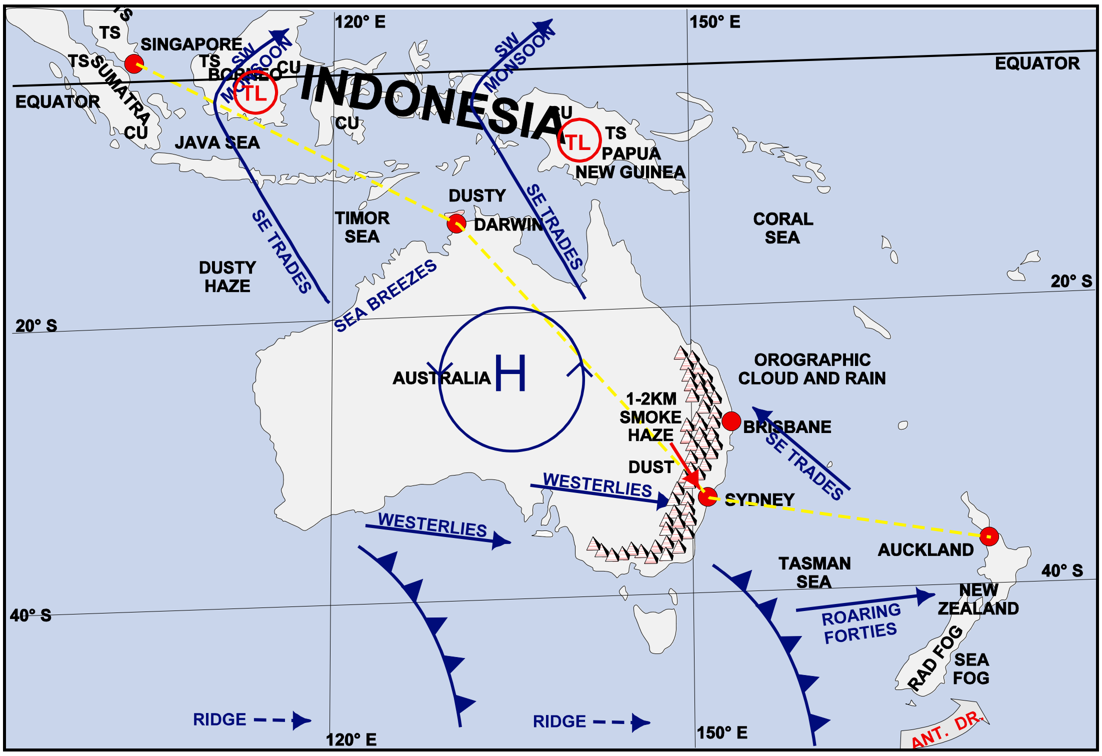
Singapore	Japan
16,000′	3,000′ -15,000′

SINGAPORE to AUCKLAND via DARWIN and SYDNEY
01°N – 37°S 105° - 175°E

GEOGRAPHICAL CONSIDERATIONS

The route crosses the equator just south of Singapore then over overflies the Java sea and many of the Indonesian islands. Next is the Timor Sea followed by the Central North Australian coast at Darwin, at latitude 12°S. From Darwin the route crosses the dusty largely flat Australian interior to the mountainous SE coast at Sydney, latitude 34°S. The last leg then heads across the Tasman sea to New Zealand's low lying Auckland airport at 37°S.

WINTER (JULY)



Surface pressure and weather - July (Winter)

Pressure Systems

ITCZ. The ITCZ is in the northern hemisphere **well clear** of the route.

Thermal Lows. Convective thermal lows will occur over the Indonesian islands. These are formed by a combination of island insolation and high humidity from the surrounding sea.

Sub tropical High. The Australian interior in winter lies in the southern hemisphere Sub Tropical High belt. Relatively **cool** seasonal temperature overland will **reinforce high pressure** within the continent.

Polar Front Depressions. Travelling Polar Front Lows in the Southern Hemisphere's disturbed temperate zone will themselves be located **well south** of the route; but associated troughs, and secondary lows, can bring **frontal weather** as far north as the **Australian South Coast** and to **New Zealand**. As in the northern hemisphere, these eastward-travelling fronts will alternate with temporary ridges and anticyclones. Cold frontal activity can be quite severe from Sydney to Auckland.

Surface Winds.

The **SW Monsoon Wind** at **Singapore** will soon back to **SE** (Coriolis change), as the route crosses the equator. These SE "trade" winds will remain as far as Darwin and beyond although at Darwin itself **strong local sea breezes** may blow from the North. On the **Darwin to Sydney** sector the **SE** trade winds gradually veer to **Southwesterly** to conform with the anticlockwise rotation round the Central Australian winter high.

Towards **Sydney,** and beyond **to Auckland**, the wind direction will locally be governed by the location of the travelling polar front depressions to the South but be generally **westerly.** South of the Australian land mass, these westerlies will encircle the globe largely unimpeded by land and will therefore strengthen. Here they are known as the **'Roaring Forties'** from the principal latitude band in which they blow.

Sea breezes can affect **Sydney** even in winter.

Visibility.

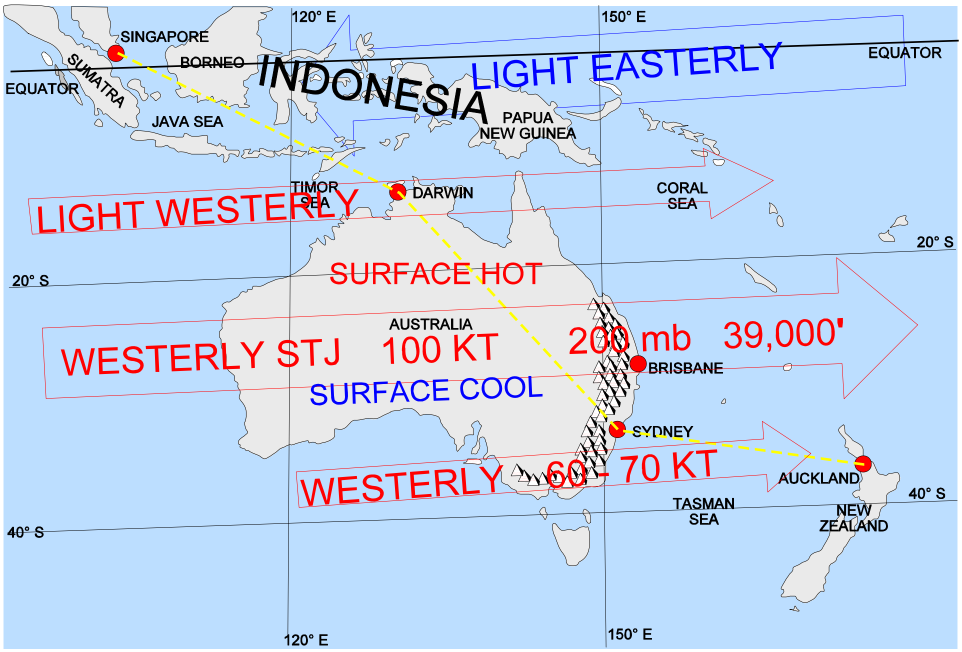
Between frequent equatorial showers over Singapore and the Indonesian islands, visibility will be **good until near 05°S** beyond which there will be **haze** caused by the dry dust laden SE trade wind blowing from Australia.

Beyond Darwin, the dusty outflow from the interior will maintain haze. Near large cities visibility may be reduced to 1-2 Km by **industrial smoke haze**.

Over the two islands of New Zealand, the clear air gives good visibility in between cold frontal precipitation. **Radiation fog** can occur inland, especially over the colder South Island. **Advection/ sea fog** can occur off the South Island east coast over the cold Antarctic Drift sea current.

Cloud and Precipitation.

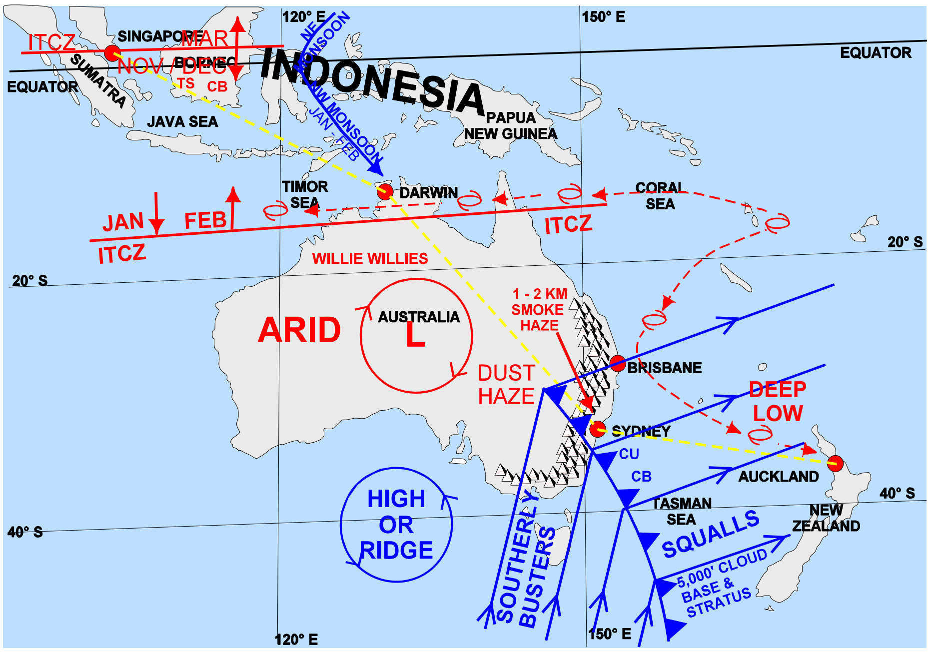
Daily convective CU with showers over Singapore and the Indonesian Islands will give way to quieter weather towards Darwin. The anticyclonic Australian interior will be dry but, rising over the mountainous east coast, the onshore SE trade winds can give orographic cloud and rain. The Sydney area and Tasman Sea route are affected by the disturbed temperate region Lows to the South. They are thus crossed by fronts which bring moderate to heavy precipitation interspersed with Highs giving several days of cool fine weather.



Upper Winds - July (Winter)

Upper Winds. Above Singapore the **upper equatorial easterlies** will blow until 10°S after which the winds will increase from the west. In the southern winter, tropical North Australia remains hot whereas the South is comparatively cool. The temperature difference over the intervening sub tropical and continental high will produce the westerly **sub-tropical jetstream** at the **200 mbs** level across the **centre of the continent** around 25°S. Speeds may reach **100 knots**. From Sydney to Auckland, the westerly wind will moderate to 60-70 knots.
Icing. Icing is not a special problem on this route.

SUMMER (JANUARY)



Surface pressure and weather - January (Summer)

Pressure Systems.
ITCZ. Over Singapore the ITCZ is southbound in November/December and northbound in March. Its southerly extreme is just **south of Darwin** at the end of **January**. Thus it affects the **Singapore - Darwin** section of the route from **November to March**.

Continental Low. The Australian sub tropical high belt of Winter has moved south with the sun. Over **Australia** itself intense insolation brings **low pressure** to the interior.

Cyclones. Tropical cyclones and associated weather form adjacent to the ITCZ over the **Coral** and **Timor Seas.** They move at 10-15 knots in one of two general directions:

- Westwards, close to the North Australian Coast, or
- Curve to the left from the Coral Sea around the South Pacific High to affect the Australian East coast at Brisbane.

Occasionally they travel further southeastwards degrading to a deep depression as they cross the Tasman Sea to New Zealand's North Island.

Surface Winds.
The Northeast monsoon wind blowing from the South China Sea to Singapore will continue across the equator to become now the **Northwest monsoon** (Coriolis change) as far as the ITCZ; which in late January is just south of Darwin. Beyond the ITCZ there will be **Southeast trade winds** although overland they will be modified around thermal low pressure centres.

At Sydney the SE trades can give way to a strong **E/NE sea breeze**, or **southerly** winds after the passage of a polar front cold front. The latter are known locally as **Southerly Busters** (see 'cloud and precipitation' below).

Cyclones from the Coral Sea via Brisbane occasionally continue South eastwards over the Tasman Sea to produce very deep lows with **strong variable winds** but otherwise winds between Sydney and Auckland are generally **westerly**.

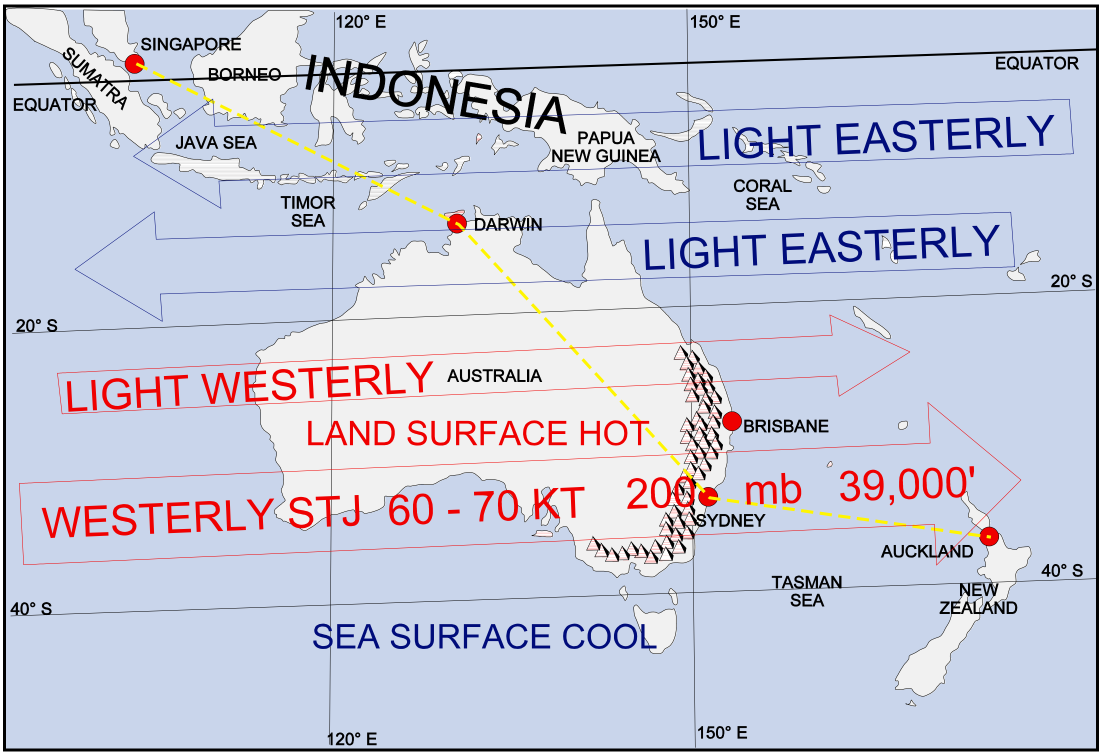
Visibility.
Visibility over Darwin and to the North is good except in precipitation from CB/TS. Between Darwin and Sydney, clockwise rotation around continental low pressure carries dust to the centre and south of the route and occasional dust storms will occur sometimes known in the NW as "Willy-Willies". **Industrial haze** near cities may reduce visibility to **1 - 2 Kms**. Visibility over the Tasman sea is good except in precipitation.

Cloud and Precipitation.
The Singapore and Indonesia region is one of the most **active daily thunderstorm** areas in the world. This is due to high ambient temperature, strong overland insolation coupled possibly with orographic uplift, and and high humidity from the abundant supply of sea water. At no time of the year is this region free from daily convective cloud, but the presence of the **ITCZ enhances instability** even further. Therefore in the southern summer, thunderstorms may be present all the way from Singapore to Darwin, and are reinforced by the ITCZ near Singapore in November/December and March, and near Darwin in January/February.

South of the ITCZ , the Australian **interior** is mainly **arid**. Towards Sydney, the weather is mainly subtropical excepting cyclones, but occasional cold troughs or fronts give squally wet weather.

The passage of these **fronts** causes a marked drop in temperature, CU CB, and squalls and a **sharp back** in the wind to South known in Sydney as **"Southerly Busters"**. Indeed the Sydney weather can be worst in Summer.

From Sydney to Auckland, Eastward travelling High cells, in the subtropical High belt, are interspersed with troughs and associated cold fronts.



Upper Winds - January (Summer)

Upper Winds. Light upper equatorial easterlies blow from Singapore to approximately 20°S after which winds will increase from the West. In summer the whole continent of Australia is hot with cooler sea to the south. Thus the **200 mb sub-tropical westerly jet** is now along the **south coast** at around **70 knots** reducing to 40 knots towards Auckland.

Icing. Icing can be severe above 16000′ in CB's.

Tropopause and Freezing Levels

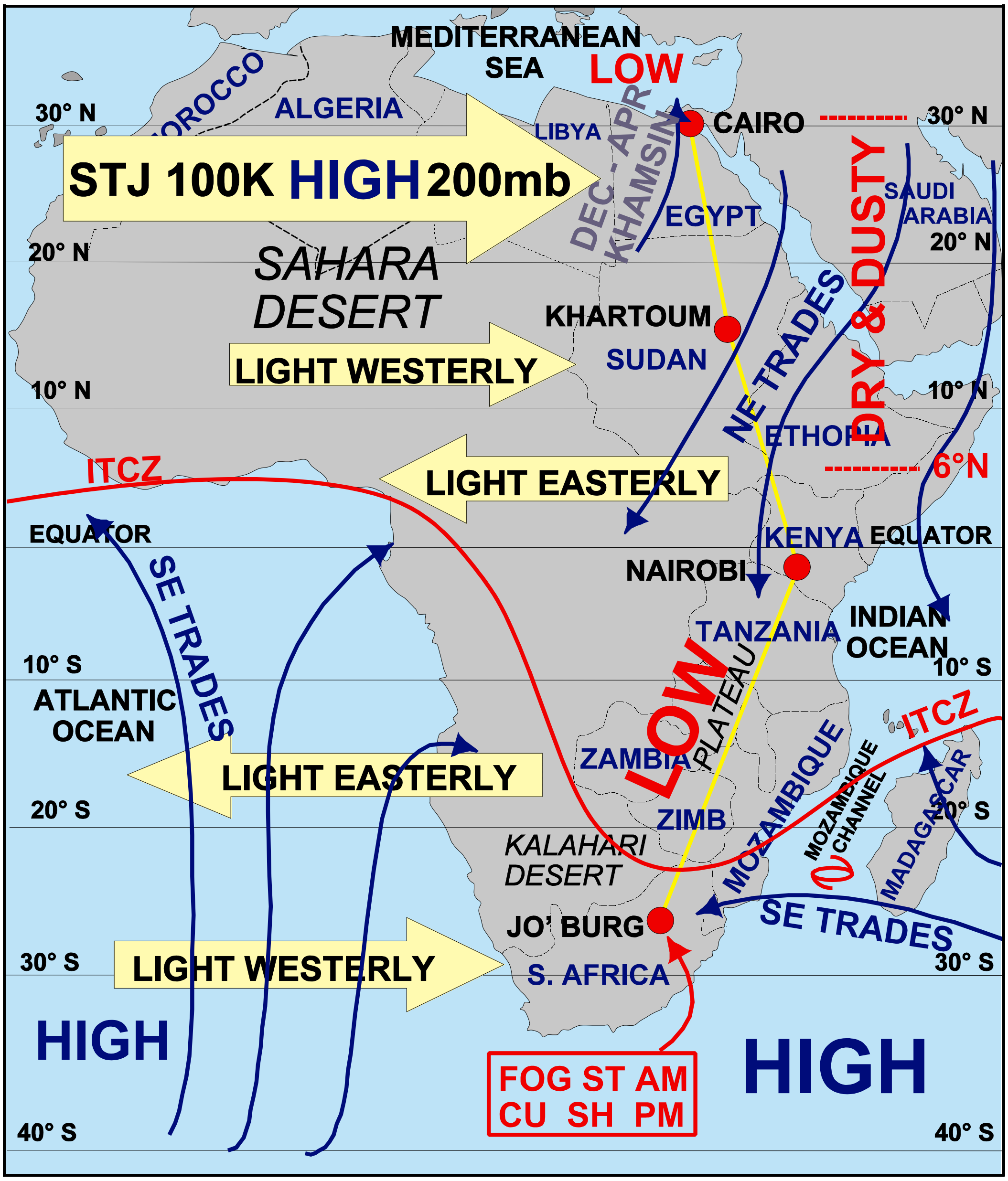
	North	South
Tropopause	56,000′	51,000′ (tropical air) – 36,000′ (polar air)
Freezing Level	16,000′	10,000′ (summer) – 5,000′ (winter)

CAIRO to JOHANNESBURG via NAIROBI
30°N – 27°S 28° - 37°E

GEOGRAPHICAL CONSIDERATIONS.

The route over Egypt and Sudan is almost all over low lying Sahara desert. At the Kenya border latitude 06°N, the land rises, at the beginning of the equatorial vegetation belt, to over 5,000' by 02°S at Nairobi. The route then traverses the eastern edge of the Kalahari plateau to the high veld of Johannesburg.

JANUARY (Northern Winter/Southern Summer)



January Surface Weather and Wind Velocity, upper wind velocity in yellow.

Pressure Systems

In the northern winter, **pressure** will be **high** over the comparatively cool **Sahara desert.** The **ITCZ** will be at its southern extreme over Zimbabwe. This will lead to overland **low pressure** extending south from **Nairobi to Johannesburg**.

Weather.

The northern section from **Cairo to 06°N** will be **dry and dusty**.

Convective CU/CB and some **NS** will form near **Nairobi**, and further south instability will be further enhanced by the ITCZ.

At Johannesburg, orographic **low cloud and fog** can occur early morning, but this clears quickly to give way to **convective CU** and showers in the afternoon. It is the **wet season**.

Cyclones originating in the Mozambique Channel can sometimes move west to affect Zimbabwe and Northern South Africa.

Surface Winds.

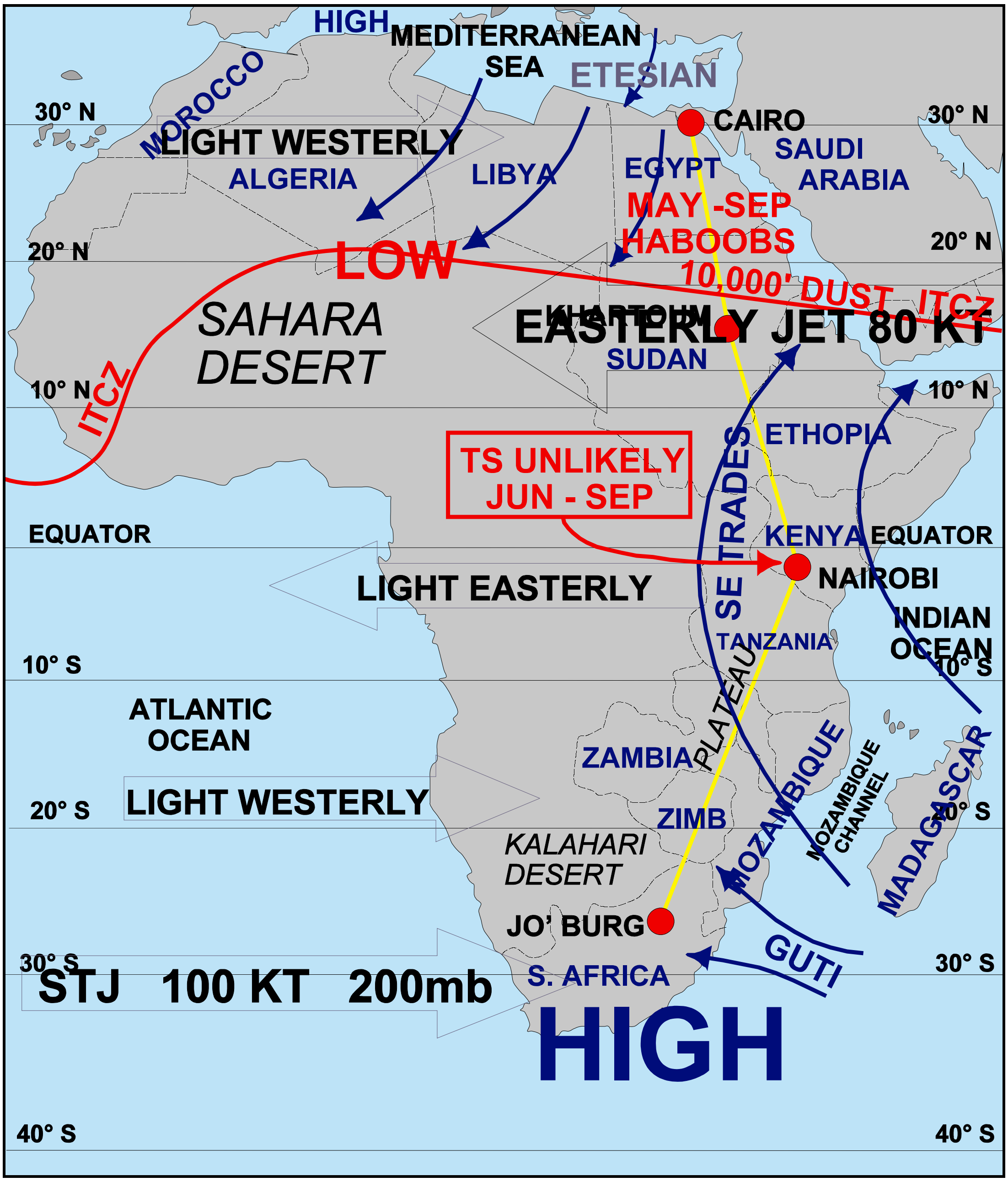
The southerly **Khamsin** wind to the Mediterranean blows from Egypt between **December and April.**

Further south over Sudan and Kenya, clockwise outflow from the Sahara High will become first northerly then north easterly to become the trade winds blowing from dry Saudi Arabia.

South of the Equator they will back again northerly (coriolis change) to blow **clockwise** around **southern Africa's summer low** pressure of some 1005 mbs; and for this reason, become **easterly** again near Johannesburg.

Visibility. Visibility is poor over the dusty Sahara but good towards Nairobi except in showery precipitation. At Johannesburg early morning fog can be caused by the easterly surface winds from the Indian Ocean orographically rising to the Kalahari plateau.
Icing. Icing can be severe above 16000′ in CB near the ITCZ.

JULY (Northern Summer/Southern Winter)



July Surface weather and Wind Velocity, upper wind velocities in yellow.

The ITCZ equatorial trough has moved north with the sun to approximately 18°N, thus pushing the winter Sahara anticyclone northwards to the Mediterranean.

Behind and south of the ITCZ, cooler winter temperatures over the **Southern African landmass** will build pressure.

Weather

The ITCZ northern extreme is just north of Khartoum in July. This is therefore normally that city's only wet month of the year. The ITCZ brings a tropical rain belt, line squalls and dust storms known as **Haboobs** which often appear as walls of dust lifted to 10,000'. Haboobs can appear in Northern Sudan from May to September as the ITCZ sweeps north then south. They form during the day when convection is strong.

It is winter in Johannesburg. Continental high pressure prevails and it is the **dry season** although ST and SC turbulence cloud may form in air rising orographically from the Indian Ocean to the Johannesburg high veld.

Surface Winds

High pressure over the Mediterranean, and low pressure over Arabia will give northerly surface winds (an extension of the Mediterranean Etesian) over the route from Cairo to the ITCZ which in July is near 18°N.

South of the ITCZ and north of the Equator, winds will be from the SW (Coriolis effect), reverting to the SE trade winds south of the Equator. Over southeastern Africa these SE trades are known as the **Guti**. The southeasterly Guti blows anti-clockwise around the overland winter high, often being in place for five days or so at a time. It can bring the orographically formed ST & SC to Johannesburg.

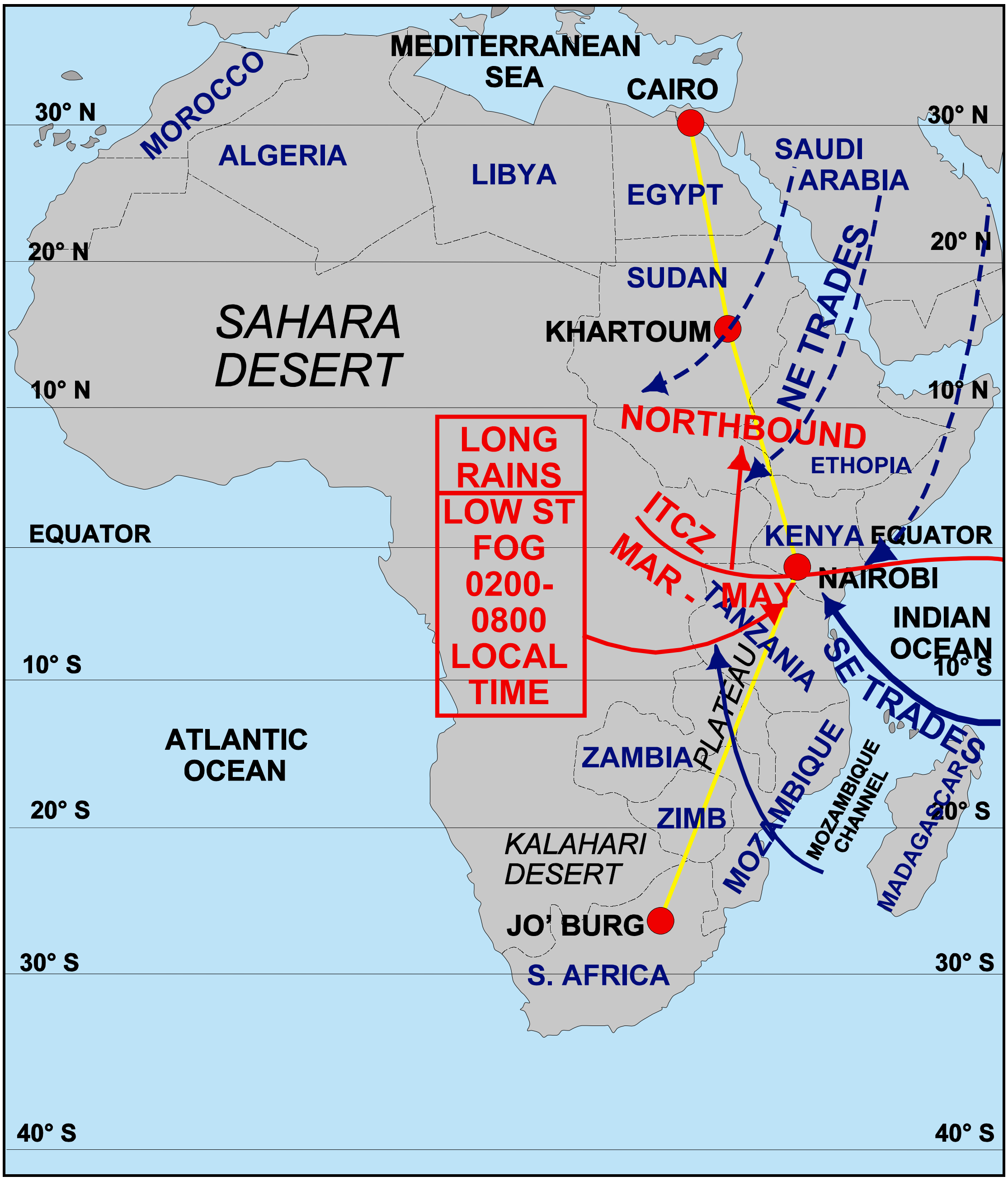
Visibility

Visibility over the Sahara will be appalling in Haboobs, and poor elsewhere in Sahara dust. Near Nairobi it will be good except in showers. At Johannesburg visibility may be reduced below low ST/SC formed by the Guti SE wind.

Icing. As in winter, icing can be severe above 16,000' in CB.

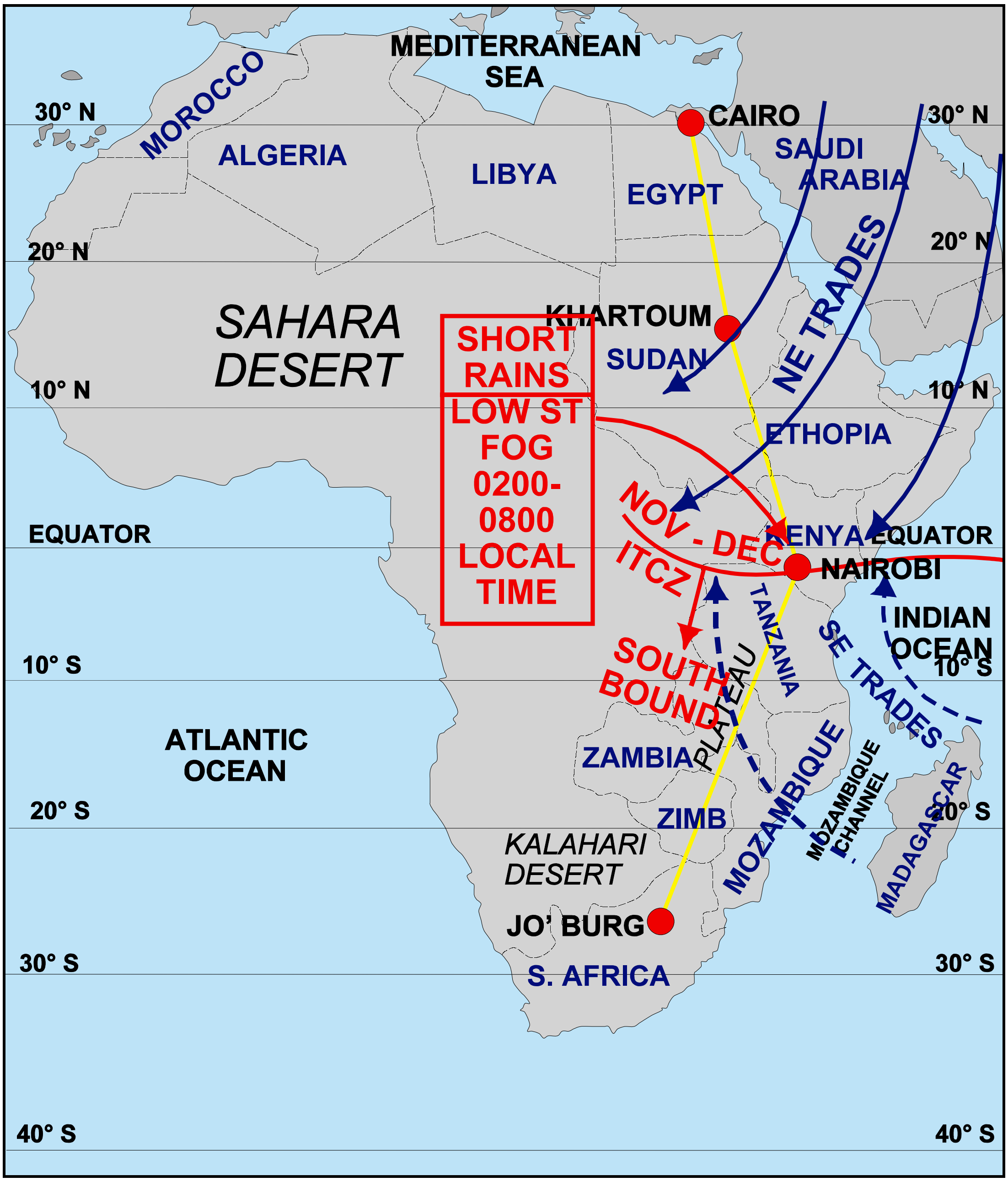
NAIROBI REGION

This region is of special interest because the **two ITCZ transits** in the **year** each give their own instability rainfall pattern.



Nairobi Weather March - May.

Northern hemisphere Spring. ITCZ passage will be **northbound** (March/May) and will be followed by the **moist** SE trade winds from the Indian Ocean. Rainfall will be extensive and is known as the **Long Rains**.



Nairobi Weather November - December.

Northern hemisphere Autumn. ITCZ passage will be **southbound** (November/December) and will be followed by the **dry** NE trade winds from Saudi Arabia. Rainfall will still occur but will be less and is known as the **Short Rains**.

Orographic Uplift. At each ITCZ passage the surface w/v will be alternating between NE and SE. Nairobi has an elevation of over 5,000′ and is only 200 nm from the east coast. **Especially during the long and short rains** at ITCZ passage, and between **0200 and 0800 local time**, orographic uplift in the generally easterly winds can frequently produce Low Stratus, often lowering to the undulating surface as **fog**.

Thunderstorms. Convective thunderstorms can occur at any time but are very infrequent from June to September when the ITCZ is well north.

Tropopause and Freezing Levels.

Tropopause heights average 56,000′ all year.

Freezing level heights are 16,000′ in equatorial regions and average 14,000′ in the higher latitudes in Winter.

CHAPTER TWENTY THREE

SATELLITE OBSERVATIONS

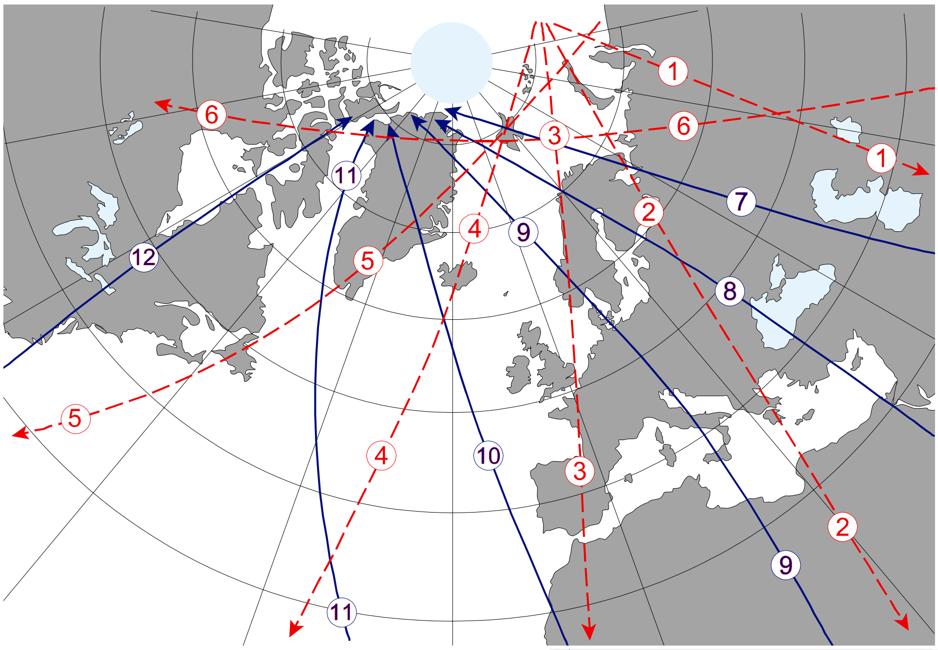
Contents

INTRODUCTION

Meteorology has benefited considerably by the use of satellites in recent years. Apart from the obvious advantages of satellite communications over the old land-based systems, providing prompt and trouble free communication of meteorological data, satellite photography has provided weather images that were impossible to produce in the past and were often merely 'artist's impressions' of the weather.
There are two types of satellite; the polar orbiting and the geostationary and two methods of producing the weather picture; visual photography and infra red.

POLAR ORBITING SATELLITES

The so-called polar orbiting satellites have been put up principally by Russia (Meteor) and USA (NOAA). The NOAA orbit is inclined at an angle of 99° to the equator, takes 1 hr 42 min to orbit the earth, is between 820 and 870 km above the surface and covers a band 1500 nm wide. Each successive orbit is a little further west and there will be an overlap, greatest at the poles and small near the equator. Any spot on the globe will experience a southbound pass of the satellite in the morning and a northbound pass in the afternoon or evening. Although picture definition is good, polar orbiting satellites do not give a continuous view of the weather.



Successive Tracks of A Polar Orbiting Satellite

GEOSTATIONARY SATELLITES

Geostationary satellites are put into orbit over the equator and since they take 24 hours to complete the orbit, they will appear to be stationary over a selected longitude. In 1987 there were 5 geostationary satellites in orbit; meteosat 2 over the Greenwich meridian, GOES E over longitude 75W, GOES W over longitude 135W, GMS 2 over longitude 140E and INSAT over longitude 70E.

These satellites are considerably higher than the polar orbiting satellites (36 000 km) and picture definition may not be as good, but the advantage of a continuous picture outweighs this disadvantage. Because of the equatorial orbit the picture become somewhat distorted towards the poles, but this may be corrected by computer processing. Meteosat covers about 1/3 of the earth's surface from 70° west to 70° east. The satellite transmits a picture every 4 minutes and a useful feature is the time lapse sequence showing movement of weather over a period of time.

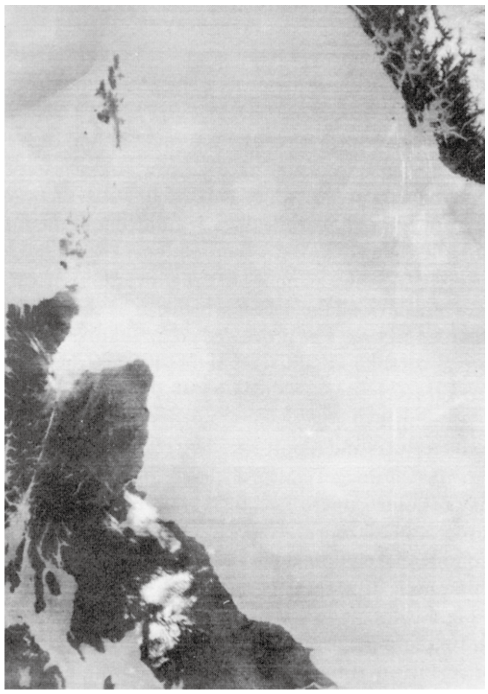
VISUAL IMAGES

Although visual photography may be easy to interpret, it suffers the disadvantage of not being available continuously, due to lack of sunlight at night. Clouds will appear white, the land grey and the sea black.

INFRA RED (IR)

Infra red images have the advantage of being available for 24 hours a day and the shading of the picture will be more or less the same by day and by night. Cold (high) cloud will give a white image, lower cloud a somewhat darker one, whilst warm land will give a dark image. There are 9 IR temperature bands, black normally denoting cloud free areas. IR may not be able to distinguish between a sea surface and fog, which may have a similar temperature. In this case, a visual picture would be able to show the position of fog more precisely.

Visual Picture of North Sea Fog



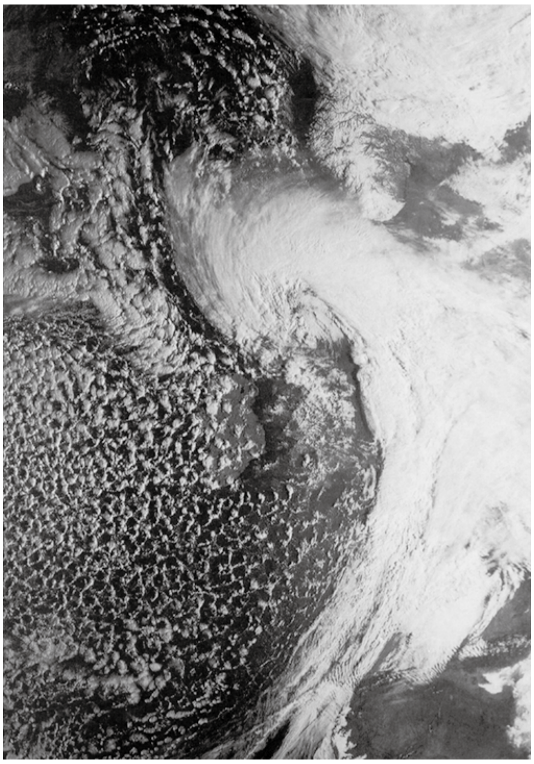
Infra-red Picture of North Sea Fog

FALSE COLOUR PICTURES

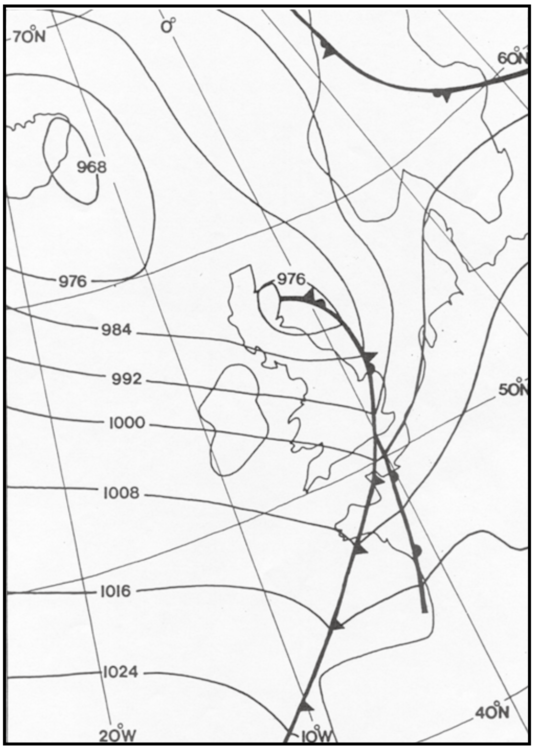
To help differentiate between the various shades of grey produced by both visual and IR photography, the shades may be converted by computer into various colours. This is used particularly with IR systems.

LOCATION OF THE IMAGE

It is often difficult to pick out geographical features, especially when there is thick cloud and of course, areas of oceans are completely featureless. Satellite images are therefore presented with a computer produced graticule of numbered parallels and meridians superimposed. Coastlines may be enhanced as well.



Satellite Visible Image, 0909 GMT

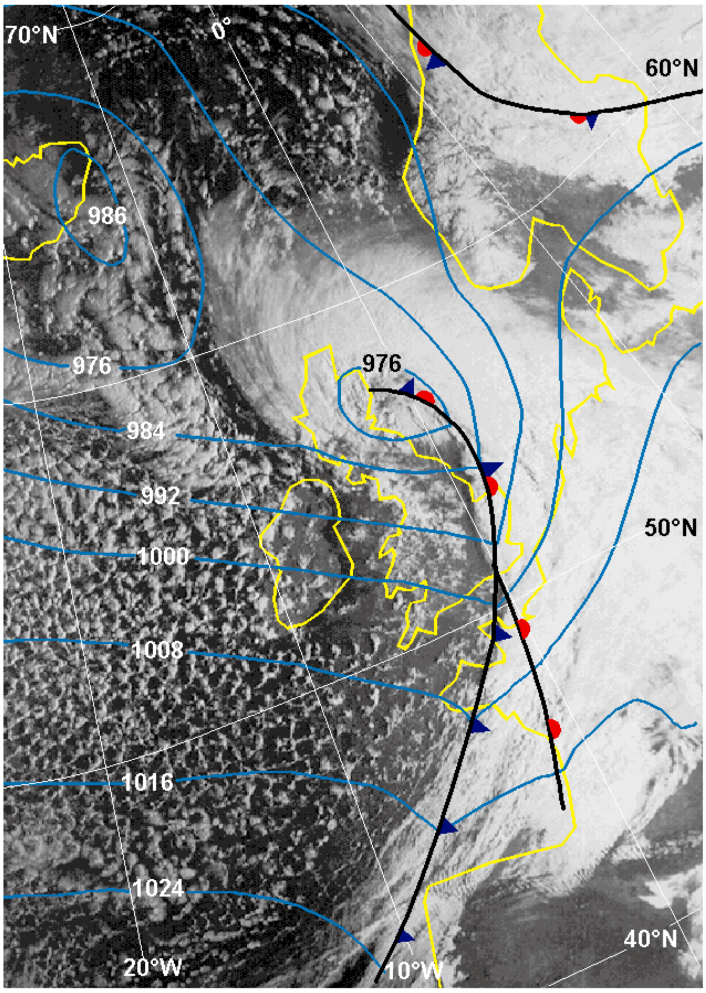


Surface Weather Map for the same time

Interpretation of Satellite Photography

Whilst violent weather such as tropical revolving storms may produce an easily identifiable picture, normal weather pictures are best used in conjunction with synoptic charts. The time-lapse sequences can be used to confirm existing and forecast weather before setting off on a flight. Figures 23.4 & 23.5 show a surface analysis and a satellite picture for the same times.

The picture below shows the visual image with the surface analysis superimposed.



Weather map and visual image

CHAPTER TWENTY FOUR

METEOROLOGICAL AERODROME REPORT (METAR)

Contents

INTRODUCTION

The letters **METAR** stand for **METeorological Aerodrome Report**. **METARs** contain coded messages pertaining to the **actual weather conditions** at a **given aerodrome**, at a **stated time**. Typical **METARs** for United Kingdom aerodromes, extracted from the **United Kingdom Met Office** website, are shown below.

```
ZCZC ZKA498 031428
GG EGTKZGZX
031428 EGGYYBYA
SAUK34 EGYY 031420
METAR EGDG NIL=
METAR EGHD 031420Z 00000KT 9999 SCT025 13/08 Q1032=

METAR EGHE NIL=
METAR EGHK 031420Z 34005KT 9999 SCT020 BKN040 15/08 Q1031 NOSIG=
METAR EGJA 031420Z 05008KT 020V100 9999 FEW030 SCT050 15/09 Q1031=
METAR EGJB 031420Z 04008KT 9999 FEW028 BKN250 15/08 Q1031
METAR EGJJ 031420Z 04010KT 010V100 9999 FEW030 16/08 Q1030 NOSIG=
METAR EGTE 031420Z 02005KT 040V050 9999 FEW024 BKN045 15/07 Q1031=
METAR EGTG 031420Z 00000KT 9999 BKN036 14/06 Q1032=
```

METARs are usually issued **every half hour** during aerodrome operating hours. The aim of this chapter is to explain the **METAR** coding, group by group.

DECODING THE METAR

This example reproduces the first eight code-groups normally found in a **METAR**.

METAR EGTK 231020Z 26012G25KT 220V300

For clarity the METAR has been split into its significant parts - (a) to (h):

METAR	EGTK	231020Z	260	12	G	25KT	220 V 300
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)

Report Type
The first code, **(a)**, is the identification of the **type** of report; in this case a **METAR**.

Aerodrome
The four-letter **ICAO designator** of the **issuing aerodrome** is shown next, **(b)**; this example is for **Oxford/Kidlington**, **EGTK**.

Date-Time Groups
The third group, **(c)**, is the **date/time group**, which simply gives the date of the actual weather observation. The first **two digits represent the day of the month**, followed by the **time in hours and minutes**. Time is always given as **Coordinated Universal Time (UTC)**, which is, for all practical purposes, the same as **Greenwich Mean Time (GMT)**: the **local time** at **Greenwich**, **London**. In the **METAR**, itself, **UTC** is indicated by the code **Z**, pronounced **"Zulu"**.

WIND INFORMATION

The next items in the **METAR** (**d**, **e** ,**f** and **g**) are the **observed wind information**. Firstly, the **direction** of the wind given in **degrees true**, rounded up or down to the **nearest 10 degrees, (d)**, and then the **wind speed in knots, (e),** which is a **mean speed** taken over a **10 minute period**. However, if a **gust** is observed which is at least **10 knots** more than the **mean wind speed**, then a **gust figure**, **(g)**, comes after the **mean wind**; this **gust figure** is preceded by the letter **G, (f)**.

The next **code-group**, **(h)**, may or may not appear depending on the directional **variability** of the wind. **Variability** is shown after the main wind group and signifies the **extremes in the direction of the wind** during the previous **10 minutes**. The letter **V** will appear between these two extremes. If there is no wind, the coding, **00000KT**, will be used.

VISIBILITY

Visibility in the **METAR** is represented by the next group, depicted in **red** in the example. In the **METAR**, the reported **visibility** is the **prevailing visibility** and, may, under certain conditions, include the **minimum visibility**. Here, the **prevailing visibility** is reported as **1,400 metres**.

Prevailing visibility is the **visibility** value which is either **reached, or exceeded, around at least half the horizon circle**, or **within at least half of the surface of the aerodrome**. If the **visibility** in one direction, which is **not** the **prevailing visibility**, is less than **1,500 m**, or **less than 50% of the prevailing visibility**, the **lowest visibility observed**, and its **general direction**, should also be reported.

Up to **10 km**, the **visibility** is measured in **metres**. For example, **6000** means that the **prevailing visibility** is **6,000 metres**. Once the visibility reaches **10 km** or more, the code figure used is **9999**.

Visibility of **less than 50 metres** is indicated by the code **0000**. In this example the **prevailing visibility** is **1,400** metres.

METAR EGTK 231020Z 26012G25KT 220V300 1400

In some instances, **runway visibility** information is given in a **METAR**; this is known as **Runway Visual Range** (**RVR**.) **RVR** is given only when either the **horizontal visibility** or the **RVR**, itself, is less than **1,500 metres**. The **RVR group** starts with the letter **R**, and then goes on to give the **runway in use**, followed by the **threshold visibility in metres**.

In the following example, for **Oxford Kidlington**, we have a **prevailing visibility** of **1,400 metres**, with an **RVR**, on **Runway 30**, of **1,100 metres**.

METAR EGTK 211020Z 26012G25KT 1400 R30/1100

If the **RVR** is more than the **maximum reportable value of 1,500 metres**, the code **P** is used in front of the visibility value, **R30/P1500**.

A letter can sometimes come after the **RVR** to indicate any trends that the **RVR** has shown. A **U** means that the visibility has increased by **100 m** or more in the last **10 minutes**, e.g. **R30/1100U**. A **D** shows that visibility has **decreased** in that same time period, **R30/1100D.** An **N** added to the visibility group shows that there is no distinct trend observed, **R30/1100N**.

THE WEATHER GROUP

The next section of the **METAR** is the **weather group**. The **weather group** gives information on the **present weather** at, or near, the aerodrome **at the time of the observation**. The weather group **+SHRA** added to our example **METAR** means **"heavy showers of rain"**.

METAR EGTK 211020Z 26012G25KT 1400 R30/1100 +SHRA

The following table lists the various **codes** which may be used in the **METAR weather group** to describe **different weather phenomena**.

Significant Present and Forecast Weather Codes				
Qualifier		**Weather Phenomena**		
Intensity or Proximity	**Descriptor**	**Precipitation**	**Obscuration**	**Other**
- Light Moderate (no Qualifier) + Heavy (well developed in the case of FC and PO) VC - In the vicinity	MI - Shallow BC - Patches BL - Blowing SH - Shower(s) TS - Thunderstorms FZ - Freezing (Super - Cooled) PR - Partial (covering part of aerodrome)	DZ - Drizzle RA - Rain SN - Snow IC - Ice Crystals (Diamond Dust) PL - Ice Pellets GR - Hail GS - Small hail - (<5 mm in diameter and/or snow pellets) UP - Unknown Precipitation PY - Spray	BR - Mist FG - Fog FU - Smoke VA - Volcanic Ash DU - Widespread Dust SA - Sand HZ - Haze	PO - Dust/Sand Whirls (Dust Devils) SQ - Squall FC - Funnel Cloud(s) (tornado or water spout) SS - Sandstorm/ Duststorm

The first column represents the **intensity** or **proximity** of a **weather phenomenon**. These have the following meaning:

- \- meaning light
- \+ meaning heavy
- VC meaning in the vicinity of, but not at, the observation point
- If there is no qualifier (no + or -) in front of precipitation, then the precipitation is moderate

The second column in the table, bearing the title **Descriptor**, contains letters which add **detail** to each **weather phenomenon**; for example, **BC** means **patches**, and is frequently used to describe **fog**, **SH** means **showers**, and **TS** means **thunderstorm**.

The last three columns in the table contain **codes** which describe the **weather phenomena** themselves.

The column headed **Precipitation** contains **codes** for **drizzle**, **rain**, **snow**, **hail** etc. The next column covers those **weather phenomena** which are classified as **Obscurations**; these include **mist**, **fog**, **smoke**, and **ash**.

The last column in the table contains those **weather phenomena** which have not already been mentioned in the table. This group mainly consists of the more unusual weather events that are rarely reported in the United Kingdom.

Referring to the **weather group** of the partially complete **METAR** which indicated **heavy showers of rain**, **+SHRA**, we see that **+** means **heavy**, **SH** indicates **showers** and **RA** stands for **rain**.

THUNDERSTORMS

A **Thunderstorm** report will appear in a **METAR** if **thunder has been heard within the last 10 minutes**.

A **thunderstorm** is represented by the letters **TS**. If there is **no precipitation**, the letters **TS** will appear on their own. However, if there **is precipitation**, a further two letters, which signify the type of precipitation, are inserted after the **TS**. For example, if there is **rain** observed from the **thunderstorm**, **TSRA** will appear in the **METAR**. If **hail** were to be observed, the code would read **TSGR,** or **TSGS**, with **GS** meaning **small hail**.

CLOUD COVERAGE

The next **code-group** to appear in the **METAR** gives detail of **cloud coverage**, as highlighted in red below. In this case the highlighted code means: overcast sky, base 2,000 feet, with cumulonimbus.

METAR EGTK 211020Z 26012G25KT 1400 R30/1100 +SHRA OVC020CB

There are several prefixes which are used to describe **cloud amount**, at any given **level**. **Cloud coverage** is reported in the **METAR** using the following three-letter codes:

- **FEW (FEW)** meaning **one to two eighths** of cloud coverage.
- **SCATTERED (SCT)** meaning **three to four eighths** of cloud coverage.
- **BROKEN (BKN)** meaning **five to seven eighths** of cloud coverage.
- **OVERCAST (OVC)** meaning **complete cloud coverage**, or **eight eighths.**

Cloud base is given as a **three-digit figure** showing **hundreds of feet**. **Cloud base** in a **METAR** is always measured as **height above aerodrome level**, using the current aerodrome **QFE**.

For example, **6 eighths of cloud (6 oktas)** at **1 900 feet** above aerodrome level would appear in the **METAR** as **BKN019**. **8 oktas** at **five hundred feet** would be abbreviated to **OVC005**.

The only **cloud types** that are specified in the **METAR** are the **significant convective clouds**. These are **cumulonimbus (CB)** and **towering cumulus (TCU)**.

Looking back to the **cloud group** we see the code **OVC020CB**. This refers to an **overcast sky** covered by **convective cumulonimbus cloud** whose **base** is **2,000 ft above aerodrome level**. The previous **weather group, +SHRA,** indicates that the **cloud** detailed in the **cloud group** is producing a **heavy shower of rain**. If there is **no cloud** observed at the airfield, the code **SKC**, meaning **sky clear**, is used.

OBSCURATION

If the sky at an aerodrome is **obscured** for reasons other than **cloud cover**, and **cloud coverage** cannot easily be determined, the code **VV** is used in place of the cloud information. **VV** is followed by the **vertical visibility** in hundreds of feet.

METAR EGTK 231020Z 26005KT 300FG OVC VV002
(a) (b) (c)

The highlighted codes in this METAR indicate that:
Visibility is 300m in fog (a), the sky is overcast (b), and the vertical visibility is 200ft (c).

ThIS **METAR** decodes as follows:

METAR for **Oxford/Kidlington**, observed at **1020 UTC** on **23rd** of the month; the **surface wind** is **260º True**, at **5 knots**; the visibility is **300 m** in **fog (a)**; the sky is **overcast (b)**, and a **vertical visibility of 200 ft** has been reported **(c)**.

If the **vertical visibility** cannot be assessed, **three forward slashes** will replace the **cloud height figures**, e.g. **VV///**.

The code **CAVOK** is frequently used in the **METAR code**, being the abbreviation for "**cloud, ceiling** and **visibility** are **OK**." If **CAVOK** is used, it will replace the **visibility**, **RVR**, **weather** and **cloud groups**. There are four criteria which must be met in order for **CAVOK** to appear in the **METAR**. These are:

- the visibility must be **10 kilometres** or more.
- the **height of the lowest cloud** must be **no less than 5 000 feet**, or the level of highest minimum sector altitude, whichever is the greater.
- there must be **no cumulonimbus** present.
- there must be **no significant weather**.

METAR EGTK 231020Z 26012G25KT 220V300 CAVOK

TEMPERATURE AND DEW POINT

The **temperature** and **dew point** constitute the next group in the **METAR code**. The **temperature** and **dew point code** is simply a **two-digit number** giving the **air temperature**, with a **forward slash**, followed by another **two-digit number** which indicates the **dew point**. Both **temperatures** are measured in **degrees Celsius**. For example, the **code 10/02** indicates that the **air temperature** is **plus 10° C**, and the **dew point** is **plus 2° C**. If either figure is **negative**, the prefix **M** will be used, as in **10/M02**. The **dew point** in the example just given is **minus 2° C**.

METAR EGTK 231020Z 26012G25KT 220V300 CAVOK 10/M02

This **METAR** decodes as follows:

METAR for **Oxford/Kidlington**, observed at **1020 UTC** on **23rd** of the month; the surface wind is **260° (True)** at **12 knots**, **gusting to 25 knots** and varying in direction from **220° (T) to 300° (T)**; the **visibility is 10 km** or more, with **no cloud below 5,000 ft**; there are **no cumulonimbus** and there is **no significant weather** at, or in the vicinity of, the aerodrome; the air temperature is **+10° C** and the dew point is **-2° C**.

QNH

The next **METAR code** is the **QNH**. The **QNH** will be represented by the letter **Q**, followed by a **four digit number representing the actual pressure value**. If the **QNH** is less than **1000 millibars**, the value will be preceded by a **zero**. For example, a **QNH** of **991 millibars** would appear as **Q0991**.

METAR EGTK 231020Z 26012G25KT 220V300 9999 -RA FEW060 SCT120 10/M02 Q0991

It is important to note that the only **pressure value** given in a **METAR** is the **QNH**. The **QNH** is always rounded **down for safety reasons**, if there are digits after the decimal point; for instance, if the **QNH** were **991.7 millibars**, the **QNH** would be reported as **Q0991**.

The above **METAR** decodes as follows:

METAR for Oxford/Kidlington observed at **1020 UTC** on **23rd** of the month; the **surface wind** is **260° (T) at 12 knots, gusting to 25 knots,** and **variable in direction from 220° (T) to 300° (T)**; the **prevailing visibility is 10 km** or more with **light rain**; there are **1 to 2 oktas of cloud at 6,000 ft** and **3 to 4 oktas at 12,000 ft**; the air temperature is **+10° C** and the dew point is **-2° C**; the **QNH is 991 millibars**.

RECENT WEATHER

If there has been **recent significant weather**, either **in the past hour**, or since the last **METAR** was issued, and if the **significant weather** has ceased, or reduced in intensity, a **METAR code group** beginning with **RE** will appear. **RE** stands for **recent**. If there has been a **thunderstorm** during the hour, but which has now abated, giving only light rain, the **present weather** is reported as **light rain**, **–RA**; the fact that there have been **thunderstorms in the past hour** is reported by the three-letter code **RETS**:

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS

WINDSHEAR

Although not currently issued at **United Kingdom** airfields, **windshear** information may be reported in the **METAR**. This will simply be denoted by the letters **WS**, followed by the necessary details, such as **WS ALL RWY**, meaning **windshear on all runways**, or **WS 30**, meaning **windshear present on Runway 30**.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY

TREND, BECMG, TEMPO

A **TREND** forecast is valid for **2 hours** after the time of the observation of the **METAR**, and constitutes the final section of the **METAR**. The change in weather conditions indicated by the code, **TREND**, can be further qualified by the codes, **BECMG,** meaning **becoming**, or **TEMPO** meaning **temporarily**.

BECMG indicates that the change in the present weather will be long-lasting. **TEMPO**, on the other hand, means that the change is **temporary**, and that the different conditions will prevail for periods of **less than one hour**, only, and **no more than half the time period**, in aggregate. The codes may be followed by a time period in hours and minutes. The time periods given may be preceded by **FM** meaning **from**, **TL** meaning **until**, or **AT** meaning **at**.

For example, **TEMPO FM1020 TL 1220 1000 +SHRA** translates as: **temporarily**, from **1020Z** to **1220Z**, the **visibility** will reduce to **1,000 metres**, in **heavy showers of rain**.

If there is no expected change in the meteorological conditions being forecast by the **METAR**, the code **NOSIG** is used to indicate that **no significant change** is expected in the next two hours.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY NOSIG

SNOWTAM

An additional **eight-figure runway-state code** will be added after any **TREND** information, when there is **snow** or other **runway contamination**. This code is sometimes referred to as a **SNOWTAM**.

The **SNOWTAM** takes the form;

- runway designator.
- runway deposits.
- extent of runway contamination.
- depth of deposit.
- the braking action.

In order to decode a **SNOWTAM**, a pilot should consult the **UK AIP**, **GEN 3.5.10**, **Meteorological Codes**.

SPECIAL REPORTS

A variation on the **METAR** is the **Special Report**. A **Special Report**, which is denoted by the abbreviation, **SPECI**, has the same format as a **METAR** except that the code **SPECI** will replace **METAR** at the beginning of the report. A **SPECI** will be issued when the **weather conditions significantly change** in the period between routine observations. A **SPECI** can be issued to indicate either an **improvement** or a **deterioration** in the weather.

SPECI EGTK 231025Z 26012G25KT 220V300 2000 +RA OVC010 5/M02 Q0991 RETS WS ALL RWY NOSIG

END OF MESSAGE

An equals sign **(=)** appears at the end of the **METAR** to denote that the **message is complete**.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY NOSIG =

SUMMARY

Although **METARs** may appear confusing to the uninitiated, with practice, it is quite a simple task to decode a **METAR** accurately and speedily. Pilots should consult **METARs** for **departure and destination aerodromes** and also for other **aerodromes along the planned route**, and, in particular, for aerodromes **upwind** of a destination aerodrome, in order to get a picture of the **weather which is approaching** the destination.

If the **aerodrome of destination** does not issue a **METAR**, consult a **METAR** from an aerodrome **in the vicinity** of your destination.

QUESTIONS

1. When a TREND is included at the end of a METAR, the trend is a forecast valid for:

   a. 1 hour after the time of observation
   b. 2 hours after the time of observation
   c. 2 hours after it was issued
   d. 1 hour after it was issued

2. A METAR may be defined as being:

   a. A routine weather report for a large area
   b. An aerodrome forecast containing a TREND for the next 2 hours
   c. A routine weather report concerning a specific aerodrome
   d. A forecast weather report concerning a specific aerodrome

3. In the METAR shown below, the cloud base has been omitted. At what height might you expect the cloud-base to be?

   28005KT 9999 ?????? 12/11 Q1020 NOSIG

   a. SCT042
   b. OVC090
   c. SCT280
   d. OVC005

4. Which of the following correctly decodes the METAR shown below?

   METAR EGKL 130350Z 32005KT 0400N DZ BCFG VV002

   a. Observed on the 13th day of the month at 0350Z, surface wind 320° True, 05kt, minimum visibility 400 metres to the north, moderate drizzle, with fog patches and a vertical visibility of 200 ft

   b. Reported on the 13th day of the month at 0350Z, surface wind 320° magnetic, 05kt, minimum visibility 400 metres to the north, moderate drizzle, with fog patches and a vertical visibility of 200 ft

   c. Valid on the 13th day of the month between 0300 and 1500Z, surface wind 320°T/05kt, minimum visibility 400 metres, drizzle, with fog patches and a vertical visibility of 200 ft

   d. Valid between 1300 and 1350Z, surface wind 320°T/05kt, minimum visibility 400 metres to the north, moderate drizzle, with fog patches and a vertical visibility of 200 ft

5. A temperature group of 28/24 in a METAR means that:

   a. The temperature is 28° C at the time of reporting, but it is expected to become 24° C by the end of the TREND report
   b. The dry bulb is 28° C and the wet bulb temperature is 24° C
   c. The dew point is 28° C and the temperature is 24° C
   d. The temperature is 28° C and the dew point is 24° C

6. Providing the minimum sector altitude is not a factor, CAVOK in a TAF or METAR:

   a. Means visibility 10 km or more, and no cloud below 5,000 ft
   b. Means visibility 10 km or more, and few cloud below 5,000 ft
   c. Means visibility 10 nm or more, and no cloud below 5,000 ft
   d. Means visibility 10 nm or more, and no scattered cloud below 5,000 ft.

7. The visibility group R20/0050 in a METAR means:

   a. As measured by runway measuring equipment for runway 20, a current visibility of 50 metres
   b. For runway 20, a current visibility of 500 metres measured by runway visual range equipment
   c. The runway visibility reported is 50 metres as measured by runway visual range equipment in the last 20 minutes
   d. On runway 20 the current viability is less than 5 000 metres

8. The code "BECMG FM 1100 –RASH" in a METAR means:

   a. From 1100UTC, the cessation of rain showers
   b. Becoming from 1100UTC slight rain showers
   c. Becoming from 1100UTC rain showers
   d. Becoming from 1100UTC till 0000UTC slight rain showers

ANSWERS

1	2	3	4	5	6	7	8
B	C	D	A	D	A	A	B

CHAPTER TWENTY FIVE

TERMINAL AERODROME FORECASTS (TAFs)

Contents

INTRODUCTION

Terminal Aerodrome Forecasts (TAFs) are **forecasts** of **meteorological conditions** at an **aerodrome**, as opposed to the report of actual, present conditions as given in a **METAR**. The format of the **TAF** is similar, however, to that of a **METAR**, with many of the coding groups identical in both the **METAR** and **TAF**. **TAFs** usually cover a period of between **9** and **24 hours**. **9-hour TAFs** are issued every **3 hours**, and **12 to 24-hour TAFS** every **6 hours**.

9 Hour TAFs	
KIRKWALL	TAF EGPA 160602Z 1607/1616 15010 9999 SCT012 BKN030 PROB320 TEMPO 1607/1613 7000 -RADZ SCT008 BKN012=
ABERDEEN	TAF EGPD 160656Z 1607/1616 13008KT 4000HZ TEMPO 1609/1612 5000 HZ BKN007=
INVERNESS	TAF EGPE 160656Z 1607/1616 VRB03KT 9999 FEW035=
SANTIAGO	TAF LEST 160800Z 1610/1619 24007KT 9999 SCT040=
VALENCIA	TAF LEVC 160800Z 1610/1619 12008KT CAVOK TEMPO 1614/1619 05006KT=

DECODING TAFS

The first code which appears in the **TAF** is the identifier, **TAF**. The next code is the **ICAO location indicator of the aerodrome** for which the report is issued. The example given below is for **EGTK**, Oxford, Kidlington, airport.

TAF **EGTK 130600Z 1307/1316 31015KT 8000 -SHRA SCT010 BKN018=**

THE DATE-TIME INFORMATION

As we have established, the **TAF** gives a **forecast for a period of time**. Consequently, the date-time information in **TAFs** is slightly different from that given in a **METAR**. In the **TAF**, there are two items of **date-time information.**

The first **date-time group**, highlighted in red below, indicates the date and time at which the **TAF** was issued.

TAF EGTK 130600Z 1307/1316 31015KT 8000 -SHRA SCT010 BKN018=

The digits **13** identify the day of the month; this information is followed by the time in **hours and minutes UTC**. The above **TAF**, then, was issued on **13th of the month**, at **0600 hours**, **UTC**. In the **TAF**, **Coordinated Universal Time, UTC**, is indicated by the letter, **Z**.

The next **code-group** identifies the **period of validity** of the **TAF.** The format for this was changed as recently as November 2008. The information here uses this new eight-digit format instead of the six-digit format. The first four digits show the start date and time, so 1307 indicates that the TAF's validity period starts on the 13th at 0700Z. The next four digits are the end date and time of the validity period.

So, in the example given below, the date and time of the origin of the report is **0600 UTC** on **13th** of the month, and the **validity period**, highlighted in red, is from the 13th at **0700 UTC** to **1600 UTC** on the same day. This example, then, is a **nine hour TAF**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

WIND

The **wind codes** in the **TAF** are the same as in the **METAR**. Our example **TAF** shows a **mean wind direction** of **310° (True),** at a **wind speed** of **15 knots**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Weather.
The weather coding in the **TAF** is also the same as in the **METAR**. In our example, the visibility is **8 000m** with **light showers of rain**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

CLOUD

Cloud coding in the **TAF** can be slightly different from the **METAR**.

If there is no **cloud below 5 000 ft**, or **cloud cover below the minimum sector altitude**, whichever is the lower, and if the codes **CAVOK** or **SKC** are not appropriate, the code **NSC** is used, which stands for **no significant cloud**.

You should note, too, that while **cloud-coverage** is reported in the **TAF**, in the same way as in a **METAR**, only **cumulonimbus clouds** are reported in **TAFs**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Our example **TAF,** above, is forecasting **scattered cloud at 1 000 feet**, with **broken cloud at 1 800 feet**.

The main **TAF** information ends with the cloud group. **TAFs** do not contain information on **temperature and dew point, QNH, recent weather, wind-shear or runway state information**.

Only significant changes of weather follow the cloud group. These **significant changes** are introduced by **codes** classified as **forecast change indicators**.

FORECAST CHANGE INDICATORS

There are distinctive **TAF codes** which indicate that a **change** is expected in some or all of the **forecast meteorological conditions**. The nature of the change can vary: it may, for instance, be a **rapid**, **gradual** or **temporary change**. These codes are **FM** (meaning **FROM)**, **BECMG** (meaning **BECOMING**), **TEMPO (**meaning **TEMPORARILY)**, and **PROB** (meaning **PROBABILITY**)**.**

THE FROM (FM) GROUP

The **FROM** group in a **TAF** is introduced by the code **FM** and marks the fact that a **rapid change in the forecast conditions is expected**, which will lead to the appearance of a new set of prevailing conditions becoming established at the aerodrome.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 FM 131220 27017KT 4000 BKN010=

The **change indicator FM** is followed by a **six-digit date and time group.** The first two digits are the day of the month followed by the hours and minutes to indicate the time at which the change is expected to begin. In our example **FM 131220** means that certain weather changes will occur from the 13th at **1220 UTC**. **This weather forecast** following the code **FM supersedes the TAF forecast, prior to 1220 UTC**.

The **FM** indicator, therefore, introduces what is effectively a new forecast, associated with a new weather situation, and which supersedes the previous forecast. The **FM** group contains all the elements of a complete **TAF** forecast: **wind**, **visibility**, **weather** and **cloud**.

In the example below, highlighted in red, we read that from the 13th at **1220Z** until the **end of the TAF period**, the **wind** will change to be **270° (T) at 17 knots**, with a **prevailing visibility of 4 000 metres**, and **broken cloud at 1 000 feet**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 FM 131220 27017KT 4000 BKN010=

The forecast following the **FM indicator** continues either to the end of the current **TAF**, or until another change indicator occurs in the **TAF**.

THE BECOMING (BECMG) GROUP

The change group **BECMG,** meaning **becoming,** is followed by an **eight-figure date and time group** which indicates the period during which there will be a **permanent change in the forecast conditions**. However, **BECMG** marks a **more gradual change in conditions** than **FM**.

The **forecast gradual change,** introduced by **BECMG,** will occur at an **unspecified time** within the time period stated.

The following example **TAF** indicates that, at some time on the 13th between the **0900 UTC** and **1100 UTC,** but definitely by **1100 UTC**, the prevailing conditions will give **5 000 metres visibility**, in **light rain**. There is no new **wind information** after **BECMG**, so the inference is that the wind will be as **previously forecast**: **310° (T) at 15 knots**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 BECMG 1309/1311 5000 –RA=

THE TEMPORARY (TEMPO) GROUP

"**TEMPO**", meaning **temporarily,** indicates that a change in **meteorological conditions** will occur **at any time within the specified time period**, but is expected to last **less than one hour** each time, and, in aggregate, will last no longer than half the time period of the complete forecast. The **TEMPO indicator** is followed by an **8-digit date and time group** indicating the hours between which the **temporary conditions** are expected to begin and end.

The example **TAF**, which follows, tells us that sometime on the 13th between **1200 UTC and 1400 UTC**, the **visibility** will fall to **4 000 metres**, with the weather being **thunderstorms** and **moderate rain**. There will be **5 - 7 oktas** of **cumulonimbus cloud** at **1 000 ft**. **However, after 1400 UTC, the weather will return to the conditions specified in the first part of the message.**

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 TEMPO 1312/1314 4000 TSRA BKN010CB=

The Probability (PROB) Indicator.
The code **PROB** (meaning **probability**) in a **TAF** indicates the **probability** of the occurrence of specified weather phenomena.

The **probability indication** is a **percentage probability** of the occurrence of **significant weather events** such as **thunderstorms** and associated **precipitation**. A **30% probability is considered low**, while a **40% probability** indicates that it is **highly likely** that the weather being forecast will actually occur. The code **PROB** can be followed by a **time group of its own**, and/or by an indicator, such as **BECMG** or **TEMPO**.

The example **TAF** below tells us that there is a **high probability** that, between **1000 UTC and 1400 UTC**, there will be **thunderstorms** with **heavy rain** and **hail**, and from **3 to 4 oktas** of **cumulonimbus clouds** at **500 ft**.

The storms will not last longer than one hour at a time and no more than two hours in total, which is one half of the period to which the TAF applies.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 PROB40 TEMPO 1310/1314 +TSRAGR SCT005CB=

AMENDMENT

When a **TAF** requires an **amendment**, the amended forecast may be indicated by the code **AMD**, highlighted in red, after the **TAF identifier**, as shown below:

TAF AMD EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 PROB40 TEMPO 1310/1314 +TSRAGR SCT005CB=

Used correctly, **TAFs** will enable a pilot to make accurate and informed decisions about a planned flight, including the expected conditions en-route, and at destination and alternate aerodromes.

END OF MESSAGE

An equals sign **(=)** appears at the end of the **TAF** to denote that the message is complete.

QUESTIONS

1. The weather group RERA in a TAF means:

   a. Rain in retreat
   b. Recent rain
   c. Returning rain
   d. Retreating rain

2. TEMPO in a TAF means:

   a. A temporary variation to the main forecast that will last for less than one hour, or if recurring, for less than half the period indicated
   b. A temporary variation to the main forecast lasting less than an hour
   c. The development of unpredictable conditions that may be a hazard to aviation
   d. A variation to the base line conditions laid down in the main forecast that will continue to prevail until the end of the main forecast

3. The weather group SHSNRA in a TAF means:

   a. Slight showers of snow and rain
   b. Moderate showers of snow and rain
   c. Heavy showers of snow and rain
   d. Showers of snow and rain

4. A TAF time group 0202/0220 means that the TAF:

   a. Is a short range forecast only, at 0220 UTC
   b. Was observed at 0220 UTC
   c. Was issued at 0220 UTC
   d. Is a long range forecast for the 18 hour period from the 2nd at 0200 UTC to the 2nd at 2000 UTC

5. BECMG 1618/1620 BKN030 in a TAF means:

   a. Becoming between 1800 UTC and 2000 UTC 3-4 oktas of cloud at 300 ft agl
   b. Becoming from 1820 UTC 5-7 oktas of cloud at 3,000 ft agl
   c. Becoming from 1820 UTC 3-4 oktas of cloud at 3,000 ft agl
   d. Becoming between 1800 UTC and 2000 UTC 5-7 oktas of cloud at 3,000 ft agl

6. Which of the following correctly decodes a TAF that reads:

   EGLL 1306/1315 VRB08KT 9999 SCT025=

   a. Valid from 0600 UTC to 1500 UTC; surface wind variable at 8 kts; visibility 10 nm or more; with a cloud base of 2500 ft above mean sea level
   b. Observed at 0615 UTC; the surface wind was variable in direction and speed; averaging 8 kts; with a visibility of 10 km or more, and a cloud base of 2500 ft above aerodrome level
   c. Valid from the 13th at 0600 UTC to the 13th at 1500 UTC; surface wind will be variable at 8 kts, with a visibility 10 km or more; 3-4 oktas of cloud with a base of 2500 ft above aerodrome level
   d. Observed at 0600 UTC; the surface wind was variable in direction and speed; with a visibility of 10 km and a cloud base of 2500 ft above ground level

7. The correct decode for a TAF 1206/1215 14025G40KT 1200 BR would be:

a. The forecast is for a nine hour period from 0615 UTC with a surface wind of 140° M at 25 kts gusting 40 kts, visibility 1,200 metres in mist
b. The forecast is for a nine hour period from 0615 UTC with a surface wind of 140° T at 25, visibility 1,200 metres in fog
c. The forecast is for a nine hour period from 0600 to 1500 UTC with a surface wind of 140° M at 25 kts gusting 40 kts, visibility 1,200 metres in broken patches
d. The forecast is for a nine hour period from the 12th at 0600 to 1500 UTC on the same day with a surface wind of 140° T at 25 kts gusting 40 kts, visibility 1,200 metres in mist

ANSWERS

1	2	3	4	5	6	7
B	A	B	D	D	C	D

CHAPTER TWENTY SIX

SIGMET

Contents

INTRODUCTION

The code **SIGMET** stands for **Significant Meteorological Information**. A **SIGMET** is an **abbreviated, plain language message**, which concerns the occurrence, and/or expected occurrence, of **significant weather** which may affect the operational safety of aircraft.

There are two classifications of basic **SIGMETS**: **convective** and **non-convective**. **Convective SIGMETS** concern the occurrence of **thunderstorms**, and **non-convective SIGMETS** warn of **severe turbulence and/or icing**. A **SIGMET** is valid for **4 hours**.

SIGMETs are issued from designated **meteorological watch offices** each of which has a responsibility to the many **Flight Information Regions** around the world.

A full list of the abbreviations used is shown below.

Abbreviated plain language commonly used in SIGMETs

a) at subsonic crusing levels:

thunderstorm
- obscured OBSC TS
- embedded EMBD TS
- frequent FRQ TS
- squall line SQL TS
- obscured with heavy hail OBSC TS HVYGR
- embedded with heavy hail EMBD TS HVYGR
- frequent, with heavy hail FRQ TS HVYGR
- squall line with heavy hail SQL TS HVYGR

tropical cyclone
- tropical cyclone with 10-minute mean surface wind speed of 63 km/h (34kt) or more TC (+ cyclone name)

turbulence
- severe turbulence SEV TURB

icing
- severe icing SEV ICE
- severe icing due to freezing rain SEV ICE (FZRA)

mountain wave
- severe mountain wave SEV MTW

duststorm
- heavy duststorm HVY DS

sandstorm
- heavy sandstorm HVY SS

volcanic ash
- volcanic ash VA (+ volcano name, if known)

b) at transonic levels and supersonic cruising levels:

turbulence
- moderate turbulence MOD TURB
- severe turbulence SEV TURB

cumulonimbus
- isolated cumulonimbus ISOL CB
- occasional cumulonimbus OCNL CB
- frequent cumulonimbus FRQ CB

hail
- hail GR

volcanic ash
- volcanic ash VA (+ volcano name, if known)

DECODING THE SIGMET

Below is shown an example of a **SIGMET** message.

```
 (a)   (b)   (c)        (d)          (e)
EGTT SIGMET 02 VALID 281400/281900 EGRR-

 (f)             (g)                 (h)     (i)     (j)
EGTT LONDON FIR SEV MTW VSP 600FPM FCST FL060/120 S OF A LINE FROM

                                 (k)  (l)(m)
N5220 W00530 TO N5300 E00300 STNR NC=
```

The first item is the location indicator of the Air Traffic Services Unit (ATSU) serving the Flight Information Region (FIR) or Control Area to which the SIGMET message refers. The ATSU which issued our example SIGMET is EGTT, (a), which is the London FIR. EGTT is followed by the code SIGMET, (b), which is the message identifier.

After the identifier, the sequence number is given next, (c). In this example, the sequence number is 02, which corresponds to the number of SIGMET messages issued for the London FIR since 0001 UTC on the day of issue.

The next item is the **date and time groups, (d),** indicating the **period of validity** of the **SIGMET** message in **UTC**. In this example, the **SIGMET** is valid on the **28th** of the month from **1400 UTC** to **1900 UTC**.

The first line of the **SIGMET** ends with the **location indicator** of the **meteorological watch office** which issued the **SIGMET**. Here, it is **EGRR**, **(e)**, which is the **UK Met Office**. **EGRR** is followed by **a hyphen** which separates the **SIGMET preamble** from the next line of text.

At the beginning of the second line, is the **name of the FIR or control area** for which the **SIGMET** is issued; so the code **EGTT** is repeated, **(f)**, but now is also decoded as the **London FIR**.

Next comes the **name** and **description** of the **weather phenomenon** which is the reason for the issuing of the **SIGMET**. The **weather phenomenon** is given in **abbreviated plain language**, using the **abbreviations** given on the previous page. In our example, the warning is of **severe mountain waves, (g),** with a **vertical speed of 600 feet per minute**.

Following the **weather phenomenon,** there is an indication of whether the information is **observed** or **forecast**, using the abbreviation "**OBS**", or "**FCST**", **(h)**. If relevant, the time of observation in **UTC** will also be given.

The next group of information relates to the **location** and **altitude** of the **observed** or **forecast phenomenon**, in this instance between **Flight Levels 60** and **120**, **(i)**.

Where possible, reference is made to **latitude** and **longitude**, **locations** or **well-known geographical features**. In our example **SIGMET**, the location of the **mountain waves** is given as: **South of a line** from a position at **52° 20′ N, 5° 30′ W** to a position at **53° N, 3° E**, **(j)**. This is a line from a point on the **FIR boundary in Cardigan Bay** to a **point in the North Sea, some miles North East of Yarmouth**.

Movement or the **forecast movement of the weather phenomenon** is normally indicated by reference to one of the **eight points of the compass**; however, this **SIGMET** does not contain such a reference.

The **speed of displacement** of the **weather phenomenon** is given in **kilometres per hour** or **knots**. But if the **weather phenomenon** is **stationary,** as in this example, the code **STNR, (k)**, is used. Finally, an indication is made of any **change in intensity** of the **weather phenomenon**, using the abbreviation **INTSF** for **intensifying**, **WKN** for **weakening** or **NC** for **no change,** as in this example, **(l)**.

The **SIGMET** is ended, as with the **METAR**, with an equals sign **(m)**.

COMPLETE SIGMET MESSAGE.

The complete **SIGMET message**:

```
EGTT SIGMET 02 VALID 281400/281900 EGRR-
EGTT LONDON FIR SEV MTW VSP 600FPM FCST FL060/120 S OF A LINE FROM
N5220 W00530 TO N5300 E00300 STNR NC=
```

Decodes as follows:

The message is for the **London FIR, EGTT**; the message is a **SIGMET**, the **second** to be issued for the **FIR since 0001 UTC**. It is valid for the **28th of the month** from **1400 UTC** until **1900 UTC** and was issued by the **UK Met Office, EGRR**. In the **London FIR, severe mountain waves**, whose vertical speed is **600 feet per minute, are forecast from FL60 to FL120**, **South of a line from 52° 20′ N 5° 30′ W to 53° N 3° E**; the phenomenon is **stationary** and **no change** is expected.

A further **SIGMET** is shown below.

```
EGPX SIGMET 01 VALID 280900/281300 EGRR-
EGPX SCOTTISH FIR SEV TURB FCST BLW FL070 S OF A LINE N5800 W01000
TO N5700 W00500 TO N5500 E00000 MOV NNE AT 35KT NC=
```

This **SIGMET** decodes as follows:

The message is for the **Scottish FIR, EGPX**; it is the **first SIGMET issued since 0001 UTC**, and is valid for the **28th of the month from 0900 UTC to 1300 UTC,** being issued by **the UK Met Office, EGRR**. In the **Scottish FIR, severe turbulence is forecast below FL70, South of a line from 58° N, 10° W to 57° N, 5° W to 55° N, 0° E/W**; it is **moving North North East at 35 knots**, and **no change is expected**.

SPECIAL SIGMETS

There are two other specialised types of **SIGMET** valid for up to **6 hours.** These are the **VOLCANIC SIGMET,** issued to notify pilots of **volcanic ash**, due to **volcanic eruptions**, and the **TROPICAL CYCLONE SIGMET**, used to notify pilots of **hurricane** or **cyclone activity**.

SIGMETs for **volcanic ash clouds** or **tropical cyclones** include an additional line of text. This line contains a **brief outlook forecast** beyond the **period of validity** specified earlier in the message. In a **Volcanic SIGMET**, the outlook will include a direction of travel for the **ash cloud**. For a **Tropical Cyclone SIGMET**, the position of the **tropical cyclone centre** is included.

QUESTIONS
METARs, TAFs and SIGMETs

1. Given the following METAR: EDDM 250850Z 33005KT 2000 R26R/P1500N R26L/1500N BR SCT002 OVC003 05/05 Q1025 NOSIG

   a. Runway 26R and runway 26L have the same RVR
   b. RVR on runway 26R is increasing
   c. Visibility is reduced by water droplets
   d. There is a distinct change in RVR observed

2. What does the abbreviation “nosig” mean?

   a. Not signed by the meteorologist
   b. No significant changes
   c. No report received
   d. No weather related problems

3. Refer to TAF below.
   EGBB 261812 28015G25KT 9999 SCT025 TEMPO 1822 29018G35KT 5000 SHRASN BKN010CB PROB30 TEMPO 1821 1500 TSGR BKN008CB BECMG 2124 26010KT
   From the TAF above you can assume that visibility at 2055Z in Birmingham (EGBB) will be:

   a. more than 10 km
   b. not less than 1,5 km but could be in excess of 10 km.
   c. a maximum 5 km.
   d. a minimum of 1,5 km and a maximum of 5 km.

4. Refer to the following TAF for Zurich.
   LSZH 261019 20018G30KT 9999 -RA SCT050 BKN080 TEMPO 23012KT 6000 -DZ BKN015 BKN030 BECMG 1518 23020G35KT 4000 RA OVC010=
   The lowest visibility forecast at ETA Zurich 1430 UTC is:

   a. 6 km.
   b. 6 NM.
   c. 4 km.
   d. 10 km.

5. Which of the following statements is an interpretation of the SIGMET?

   SIGMET VALID 121420/121820 embd ts obs and fcst in w part of athinai fir / mov e / intst nc =

   a. Athens Airport is closed due to thunderstorms. The thunderstorm zone should be east of Athens by 1820 UTC
   b. The thunderstorms in the Athens FIR are increasing in intensity, but are stationary above the western part of the Athens FIR
   c. Thunderstorms must be expected in the western part of the Athens FIR. The thunderstorm zone is moving east. Intensity is constant
   d. Thunderstorms have formed in the eastern part of the Athens FIR and are slowly moving west

6. In the weather briefing room during the pre-flight phase of a passenger flight from Zurich to Rome, you examine the following weather reports of pressing importance at the time:

EINN SHANNON 2808 sigmet 2 valid 0800/1100 loc sev turb fcst einn fir blw fl 050 south of 53n wkn =

LIMM MILANO 2809 sigmet 2 valid 0900/1500 mod sev cat btn fl 250 and fl 430 fcst limm fir stnr nc =

EGLL LONDON 2808 sigmet nr01 valid 0800/1200 for london fir isol cb embd in lyr cloud fcst tops fl 300 btn 52n and 54n east of 002e sev ice sev turb ts also fcst mov e wkn =

Which decision is correct?

a. Because of the expected turbulence you select a flight level below FL 250.
b. You show no further interest in these reports, since they do not concern the route to be flown.
c. Owing to these reports and taking into account the presence of heavy thunderstorms at planned FL 310 you select a higher flight level (FL 370).
d. You cancel the flight since the expected dangerous weather conditions along the route would demand too much of the passengers.

7. Refer to the TAF for Bordeaux airport.

FCFR31 281400
LFBD 1524 26015KT 9999 SHRA BKN020 TEMPO 1620 26020G30KT 8000 +SHRA BKN015CB PROB30 TSRA =

Flight Lisbon to Bordeaux, ETA 1800 UTC. What type of precipitation is forecast on the approach to Bordeaux ?

a. Continuous moderate rain
b. Light drizzle and fog
c. Moderate snow showers
d. Heavy rain showers

8. What does the term TREND signify?

a. It is a flight forecast, issued by the meteorological station several times daily
b. It is a brief landing forecast added to the actual weather report
c. It is the actual weather report at an aerodrome and is generally issued at half-hourly intervals
d. It is a warning of dangerous meteorological conditions

9. Compare the following TAF and VOLMET reports for Nice:
TAF 240716 VRB02KT CAVOK = 0920Z 13012KT 8000 SCT040CB BKN100 20/18
Q1015 TEMPO TS =
What can be concluded from the differences between the two reports ?

a. That the weather at Nice is clearly more volatile than the TAF could have predicted earlier in the morning
b. That the weather conditions at 0920 were actually predicted in the TAF
c. That the weather in Nice after 0920 is also likely to be as predicted in the TAF
d. That the VOLMET speaker has got his locations mixed up, because there is no way the latest VOLMET report could be so different from the TAF

10. Which statement is true?

    a. QNH can be 1013.25 only for a station at MSL
    b. QNH can be only lower than 1013.25 hPa
    c. QNH can not be 1013.25 hPa
    d. QNH is lower than 1013.25 hPa at any time

11. Which of the following statements is an interpretation of the SIGMET?

    LSAW SWITZERLAND 0307 SIGMET 2 VALID 030700/031100 LSSW mod to sev cat fcst north of alps btn fl 260 and fl 380 / stnr / intsf =

    a. Severe turbulence observed below FL 260 north of the Alps. Pilots advised to cross this area above FL 380
    b. Moderate to strong clear air turbulence of constant intensity to be expected north of the Alps
    c. Moderate to severe clear air turbulence to be expected north of the Alps. Intensity increasing. Danger zone between FL260 and FL 380
    d. Zone of moderate to severe turbulence moving towards the area north of the Alps. Intensity increasing. Pilots advised to cross this area above FL 260

12. Refer to the TAF for Amsterdam airport:

    FCNL31 281500
    EHAM 281601 14010KT 6000 -RA SCT025 BECMG 1618 12015G25KT SCT008 BKN013 TEMPO 1823 3000 RA BKN005 OVC010 BECMG 2301 25020KT 8000 NSW BKN020 =
    Flight from Bordeaux to Amsterdam, ETA 2100 UTC.

    What is the minimum visibility forecast for ETA Amsterdam ?

    a. 5 NM
    b. 6 km
    c. 3 km
    d. 5 km

13. At a weather station, at 0600 UTC, the air temperature and dew point are respectively:
    T = - 0,5°C,Td = -1,5°C.

    In the METAR message transmitted by this station, the “temperature group” will be:

    a. M00/M01
    b. M01/M02
    c. 00/M01
    d. M01/M01

14. Refer to the TAF for Zurich Airport
    TAF LSZH 250716 00000KT 0100 FG VV001 BECMG 0810 0800 VV002 BECMG 1012 23005KT 2500 BKN005 TEMPO 1316 6000 SCT007 =

    Which of these statements best describes the weather that can be expected at 1200 UTC?

    a. Meteorological visibility 6 kilometres, cloudbase 500 feet, windspeed 5 knots
    b. Meteorological visibility 2,5 kilometres, cloudbase 500 feet, windspeed 5 knots
    c. Meteorological visibility 800 metres, wind from 230°, cloudbase 500 feet
    d. Meteorological visibility 800 metres, vertical visibility 200 feet, calm

15. In which of the following METAR reports, is the probability of fog formation in the coming night the highest?

a. 1850Z 21003KT 8000 SCT250 12/m08 Q1028 NOSIG =
b. 1850Z 06018G30KT 5000 OVC010 04/01 Q1024 NOSIG =
c. 1850Z 25010KT 4000 RA BKN012 OVC030 12/10 Q1006 TEMPO 1500 =
d. 1850Z 15003KT 6000 SCT120 05/04 Q1032 BECMG 1600 =

16. In which of the following circumstances is a SIGMET issued ?

a. Marked mountain waves.
b. Fog or a thunderstorm at an aerodrome.
c. Clear ice on the runways of an aerodrome.
d. A sudden change in the weather conditions contained in the METAR.

17. What is the wind speed given in a METAR report based on?

a. The average speed of the previous 30 minutes
b. The strongest gust in the previous hour
c. The actual speed at the time of recording
d. The average speed of the previous 10 minutes

18. Which of the following weather reports could be, in accordance with the regulations, abbreviated to "CAVOK"?
(MSA above ground : LSZB 10000 FT, LSZH 8000 FT, LSGG 12000 FT, LFSB 6000 FT)

a. LFSB 24008KT 9999 SCT050 18/11 Q1017 RERA NOSIG =
b. LSZH VRB02KT 9000 BKN080 21/14 Q1022 NOSIG =
c. LSGG 22006KT 9999 BKN090 17/15 Q1008 RERA NOSIG =
d. LSZB 28012KT 9999 OVC100 16/12 Q1012 BECMG 5000 =

19. What does the term METAR signify?

a. A METAR is a flight forecast, issued by the meteorological station several times daily.
b. A METAR is a landing forecast added to the actual weather report as a brief prognostic report.
c. A METAR signifies the actual weather report at an aerodrome and is generally issued in half-hourly intervals.
d. A METAR is a warning of dangerous meteorological conditions within a FIR.

20. Does the following report make sense?
LSZH VRB02KT 5000 MIFG 02/02 Q1015 NOSIG

a. The report would never be seen, because shallow fog is not reported when the meteorological visibility is more than 2km.
b. The report is nonsense, because it is impossible to observe a meteorological visibility of 5 km if shallow fog is reported.
c. The report is not possible, because, with a temperature of 2°C and a dew point of 2°C there must be uniform fog.
d. The report is possible, because shallow fog is defined as a thin layer of fog below eye level.

21. Runway Visual Range (RVR) is

    a. measured with ceilometers alongside the runway
    b. usually better than meteorological visibility
    c. reported when meteorological visibility is less than 2000m
    d. reported in TAF and METAR

22. When will the surface wind in a METAR record a gust factor?

    a. With gusts of at least 25 knots
    b. With gusts of at least 35 knots
    c. When gusts are at least 10 knots above the mean wind speed
    d. When gusts are at least 15 knots above the mean wind speed

23. What does the term SIGMET signify?

    a. A SIGMET is a brief landing forecast added to the actual weather report
    b. A SIGMET is an actual weather report at an aerodrome and is generally issued at half-hourly intervals
    c. A SIGMET is a warning of dangerous meteorological conditions
    d. A SIGMET is a flight forecast, issued by the meteorological station several times daily

24. In which weather report would you expect to find information about icing conditions on the runway?

    a. GAFOR
    b. TAF
    c. METAR
    d. SIGMET

25. A SPECI is

    a. an aviation routine weather report
    b. a warning for special weather phenomena
    c. a forecast for special weather phenomena
    d. an aviation selected special weather report

26. Refer to the following TAF for Zurich.
    LSZH 061019 20018G30KT 9999 -RA SCT050 BKN080 TEMPO 23012KT 6000 -DZ BKN015 BKN030 BECMG 1518 23020G35KT 4000 RA OVC010=

    The lowest cloud base forecast at ETA Zurich (1200 UTC) is:

    a. 1000 FT.
    b. 1500 m.
    c. 5000 FT.
    d. 1500 FT.

27. Refer to the TAF for Bordeaux airport.
FCFR31 281400
LFBD 1524 26015KT 9999 SHRA BKN020 TEMPO 1620 26020G30KT 8000 +SHRA BKN015CB PROB30 TSRA =

Flight Lisbon to Bordeaux, ETA 1800 UTC. At ETA Bordeaux what is the lowest quoted visibility forecast?

a. 10 or more km
b. 8 km
c. 8 NM
d. 10 NM

28. Which of the following weather reports could be, in accordance with the regulations, abbreviated to "CAVOK"?

a. 26012KT 8000 SHRA BKN025 16/12 Q1018 NOSIG =
b. 27019G37KT 9999 BKN050 18/14 Q1016 NOSIG =
c. 34004KT 7000 MIFG SCT260 09/08 Q1029 BECMG 1600 =
d. 00000KT 0100 FG VV001 11/11 Q1025 BECMG 0500 =

29. Which of the following weather reports is a warning of conditions that could be potentially hazardous to aircraft in flight ?

a. SIGMET.
b. ATIS.
c. SPECI.
d. TAF.

30. Refer to the TAF for Amsterdam airport.
FCNL31 281500
EHAM 281601 14010KT 6000 -RA SCT025 BECMG 1618 12015G25KT SCT008 BKN013 TEMPO 1823 3000 RA BKN005 OVC010 BECMG 2301 25020KT 8000 NSW BKN020 =

Flight from Bordeaux to Amsterdam, ETA 2100 UTC. At ETA Amsterdam what surface wind is forecast ?

a. 120° / 15 kt gusts 25 kt
b. 140° / 10 kt
c. 300° / 15 kt maximum wind 25 kt
d. 250° / 20 kt

31. Within a short interval, several flight crews report that they have experienced strong clear air turbulence in certain airspace. What is the consequence of these reports?

a. The airspace in question, will be temporarily closed
b. The competent aviation weather office will issue a SPECI
c. The competent aviation weather office will issue a storm warning
d. The competent aviation weather office will issue a SIGMET

32. In Zurich during a summer day the following weather observations were taken:

160450Z 23015KT 3000 +RA SCT008 SCT020 OVC030 13/12 Q1010 NOSIG =
160650Z 25008KT 6000 SCT040 BKN090 18/14 Q1010 RERA NOSIG =
160850Z 25006KT 8000 SCT040 SCT100 19/15 Q1009 NOSIG =
161050Z 24008KT 9999 SCT040 SCT100 21/15 Q1008 NOSIG =
161250Z 23012KT CAVOK 23/16 Q1005 NOSIG =
161450Z 23016KT 9999 SCT040 BKN090 24/17 Q1003 BECMG 25020G40KT TS =
161650Z 24018G35KT 3000 +TSRA SCT006 BKN015CB 18/16 Q1002 NOSIG =
161850Z 28012KT 9999 SCT030 SCT100 13/11 Q1005 NOSIG =

What do you conclude based on these observations?

a. A cold front passed the station early in the morning and a warm front during late afternoon
b. A trough line passed the station early in the morning and a warm front during late afternoon
c. Storm clouds due to warm air came close to and grazed the station
d. A warm front passed the station early in the morning and a cold front during late afternoon

33. Refer to the following TAF extract:

BECMG 1821 2000 BKN004 PROB30 BECMG 2124 0500 FG VV001
What does the abbreviation "PROB30" mean?

a. Change expected in less than 30 minutes.
b. Probability of 30%.
c. Conditions will last for at least 30 minutes.
d. The cloud ceiling should lift to 3000 FT.

34. Refer to the following TAF extract:
BECMG 1821 2000 BKN004 PROB30 BECMG 2124 0500 FG VV001
What visibility is forecast for 2400 UTC?

a. 500 m.
b. 2000 m.
c. Between 500 m and 2000 m.
d. Between 0 m and 1000 m.

35. What is a trend forecast?

a. An aerodrome forecast valid for 9 hours
b. A route forecast valid for 24 hours
c. A routine report
d. A landing forecast appended to METAR/SPECI, valid for 2 Hours

36. SIGMET information is issued as a warning for significant weather to

a. VFR operations only
b. heavy aircraft only
c. all aircraft
d. light aircraft only

37. Which of the following phenomena can produce a risk of aquaplaning?

a. SA
b. +RA
c. FG
d. BCFG

38. In which of the following 1850 UTC METAR reports, is the probability of fog formation, in the coming night, the highest?

a. 00000KT 9999 SCT300 21/01 Q1032 NOSIG =
b. VRB01KT 8000 SCT250 11/10 Q1028 BECMG 3000 =
c. 22004KT 6000 -RA SCT012 OVC030 17/14 Q1009 NOSIG =
d. VRB02KT 2500 SCT120 14/M08 Q1035 NOSIG =

39. How long from the time of observation is a TREND in a METAR valid?

a. 1 hour.
b. 30 minutes.
c. 2 hours.
d. 9 hours.

40. Refer to the following TAF extract:
BECMG 1821 2000 BKN004 PROB30 BECMG 2124 0500 FG VV001

What does the abbreviation "BKN004" mean?

a. 4 - 8 oktas, ceiling 400 m.
b. 1 - 4 oktas, ceiling 400 m.
c. 5 - 7 oktas, ceiling 400 FT.
d. 1 - 4 oktas, ceiling 400 FT.

41. What is a SPECI?

a. A warning of meteorological dangers at an aerodrome, issued only when required.
b. An aerodrome forecast issued every 9 hours.
c. A selected special aerodrome weather report, issued when a significant change of the weather conditions have been observed.
d. A routine aerodrome weather report issued every 3 hours.

42. Which of these four METAR reports suggests that rain is most likely in the next few hours?

a. 05016G33KT 8000 OVC015 08/06 Q1028 NOSIG =
b. 23015KT 8000 BKN030 OVC070 17/14 Q1009 BECMG 4000 =
c. 34004KT 9999 SCT040 SCT100 m05/m08 Q1014 NOSIG =
d. 16002KT 0100 FG SCT300 06/06 Q1022 BECMG 1000 =

43. Refer to the following TAF extract:
BECMG 1821 2000 BKN004 PROB30 BECMG 2124 0500 FG VV001

What does the abbreviation "VV001" mean?

a. Vertical visibility 100 m.
b. Vertical visibility 100 FT.
c. RVR less than 100 m.
d. RVR greater than 100 m.

44. If CAVOK is reported then

a. low level windshear has not been reported
b. any CB's have a base above 5000 FT
c. no low drifting snow is present
d. no clouds are present

45. The following weather report
EDDM 241322 VRB03KT 1500 HZ OVC004 BECMG 1517 00000KT 0500 FG VV002 TEMPO 2022 0400 FG VV001
is a :

a. 24 hour TAF.
b. SPECI.
c. METAR.
d. 9 hour TAF.

46. Which of the following statements is an interpretation of the METAR?
25020G38KT 1200 +TSGR BKN006 BKN015CB 23/18 Q1016 BECMG NSW =

a. Mean wind speed 20-38 knots, meteorological visibility 1200 metres, temperature 23°C
b. Broken, cloudbase 600 feet and 1500 feet, temperature 18°C
c. Wind 250°, thunderstorm with moderate hail, QNH 1016 hPa
d. Gusts of 38 knots, thunderstorm with heavy hail, dew point 18°C

47. Which of the following weather reports could be, in accordance with the regulations, abbreviated to "CAVOK"?
(MSA above ground: LSZB 10000 FT, LSZH 8000 FT, LSGG 12000 FT, LFSB 6000 FT)

a. LSZH 26024G52KT 9999 BKN060 17/14 Q1012 RETS TEMPO 5000 TSRA =
b. LSZB 30004KT 9999 SCT090 10/09 Q1006 NOSIG =
c. LFSB 00000KT 9000 SCT080 22/15 Q1022 NOSIG =
d. LSGG 22003KT 9999 SCT120 BKN280 09/08 Q1026 BECMG 5000 =

48. On the European continent METARs of main airports are compiled and distributed with intervals of

a. 0.5 hour
b. 1 hour
c. 2 hours
d. 3 hours

49. The RVR, as reported in a METAR, is always the

a. highest value of the A-, B- and C-position
b. lowest value of the A-, B- and C-position
c. value representative of the touchdown zone
d. average value of the A-, B- and C-position

50. In the TAF for Dehli (India), during the summer, for the time of your landing you note: TEMPO TS. What is the maximum time this deterioration in weather can last in anyone instance ?

a. 60 minutes.
b. 120 minutes.
c. 10 minutes.
d. 20 minutes.

51. Refer to the following TAF extract:
BECMG 1821 2000 BKN004 PROB30 BECMG 2124 0500 FG VV001
What does the "BECMG" data indicate for the 18 to 21 hour time frame?

a. A quick change to new conditions between 1800 UTC and 1900 UTC.
b. Many short term changes in the original weather.
c. Many long term changes in the original weather.
d. The new conditions are achieved between 1800 and 2100 UTC

52. The cloud base, reported in the METAR, is the height above

a. airfield level
b. mean sea level
c. the pressure altitude of the observation station at the time of observation
d. the highest terrain within a radius of 8 km from the observation station

53. Appended to a METAR you get the following runway report: 01650428
What must you consider when making performance calculations?

a. The braking action will be medium to good.
b. The runway will be wet.
c. Aquaplaning conditions.
d. The friction coefficient is 0.28.

54. Which of these four METAR reports suggests that a thunderstorm is likely in the next few hours?

a. 1350Z 16004KT 8000 SCT110 OVC220 02/m02 Q1008 NOSIG =
b. 1350Z 34003KT 0800 SN VV002 m02/m04 Q1014 NOSIG =
c. 1350Z 04012KT 3000 OVC012 04/03 Q1022 BECMG 5000 =
d. 1350Z 21005KT 9999 SCT040CB SCT100 26/18 Q1016 TEMPO 24018G30 TS =

55. The wind direction in a METAR is measured relative to

a. magnetic north
b. the 0-meridian
c. grid north
d. true north

56. Which of the following weather reports could be, in accordance with the regulations, abbreviated to "CAVOK"?

a. 04012G26KT 9999 BKN030 11/07 Q1024 NOSIG =
b. 15003KT 9999 BKN100 17/11 Q1024 NOSIG =
c. 24009KT 6000 RA SCT010 OVC030 12/11 Q1007 TEMPO 4000 =
d. 29010KT 9999 SCT045TCU 16/12 Q1015 RESHRA NOSIG =

57. Marseille Information gives you the following meteorological information for Ajaccio and Calvi for 1600 UTC :
Ajaccio: wind 360°/2 kt, visibility 2000 m, rain, BKN stratocumulus at 1000 FT, OVC altostratus at 8000 FT, QNH 1023 hPa.
Calvi: wind 040°/2 kt, visibility 3000 m, mist, FEW stratus at 500 FT, SCT stratocumulus at 2000 FT, OVC altostratus at 9000 FT, QNH 1023 hPa.

The ceilings (more than 4 oktas) are therefore:

a. 1000 FT at Ajaccio and 9000 FT at Calvi
b. 1000 FT at Ajaccio and 500 FT at Calvi
c. 8000 FT at Ajaccio and 9000 FT at Calvi
d. 1000 FT at Ajaccio and 2000 FT at Calvi

58. Which of the four answers is a correct interpretation of data from the following METAR ?
16003KT 0400 R14/P1500 R16/1000N FZFG VV003 M02/M02 Q1026 BECMG 2000 =

a. Meteorological visibility 400 m, RVR for runway 16 1000 m, dew point -2°C, freezing fog.
b. RVR for runway 16 1000 m, meteorological visibility increasing in the next 2 hours to 2000 m, vertical visibility 300 m, temperature -2°C.
c. RVR for runway 14 1500 m, meteorological visibility 400 m, QNH 1026 hPa, wind 160° at 3 kt.
d. Meteorological visibility 1000 m, RVR 400 m, freezing level at 300 m, variable winds, temperature 2°C.

59. You receive the following METAR :
LSGG 0750Z 00000KT 0300 R05/0700N FG VV001 M02/M02 Q1014 NOSIG =
What will be the RVR at 0900 UTC?

a. 900 m.
b. The RVR is unknown, because the "NOSIG" does not refer to RVR.
c. 300 m.
d. 700 m.

60. Which of the following statements is an interpretation of the METAR ?
00000KT 0200 R14/0800U R16/P1500U FZFG VV001 m03/m03 Q1022 BECMG 0800 =

a. Meteorological visibility 200 metres, RVR for runway 16 1500 metres, temperature -3°C, vertical visibility 100 metres
b. Meteorological visibility 200 feet, RVR for runway 16 more than 1500 metres, vertical visibility 100 feet, fog with hoar frost
c. Meteorological visibility for runway 14 800 metres, fog with hoar frost, RVR for runway 16 more than 1500 metres
d. RVR for runway 14 800 metres, vertical visibility 100 feet, calm, meteorological visibility improving to 800 metres in the next 2 hours

61. Look at this TAF for Zurich Airport
TAF LSZH 211322 22018G35KT 9999 SCT012 BKN030 BECMG 1315 25025G45KT TEMPO 1720 4000 +SHRA BKN025TCU BECMG 2022 25015KT T1815Z T1618Z =

Which of these statements best describes the weather most likely to be experienced at 1500 UTC?

a. Meteorological visibility 10 kilometres or more, main cloudbase 3000 feet, wind 250°, temperature 18°C.
b. Meteorological visibility 4000 metres, gusts up to 25 knots, temperature 18°C.
c. Meteorological visibility 10 kilometres or more, main cloudbase 1200 feet, gusts up to 45 knots.
d. Severe rain showers, meteorological visibility 4000 metres, temperature 15°C, gusts up to 35 knots.

62. The validity of a TAF is
a. 2 hours
b. between 6 and 9 hours
c. 9 hours from the time of issue
d. stated in the TAF

63. Runway visual range can be reported in

a. a METAR
b. a TAF
c. a SIGMET
d. both a TAF and a METAR

64. Refer to the TAF for Amsterdam airport.
FCNL31 281500
EHAM 281601 14010KT 6000 -RA SCT025 BECMG 1618 12015G25KT SCT008 BKN013 TEMPO 1823 3000 RA BKN005 OVC010 BECMG 2301 25020KT 8000 NSW BKN020 =

Flight from Bordeaux to Amsterdam, ETA 2100 UTC.
What lowest cloud base is forecast for arrival at Amsterdam?

a. 250 FT
b. 500 m
c. 800 FT
d. 500 FT

65. ATIS information contains

a. only operational information
b. meteorological and operational information
c. only meteorological information
d. operational information and if necessary meteorological information

66. In METAR messages, the pressure group represents the

a. QFE rounded to the nearest hPa.
b. QNH rounded down to the nearest hPa.
c. QFE rounded down to the nearest hPa.
d. QNH rounded up to the nearest hPa

67. What do the first four letters of the SIGMET message identify?

a. The issue number
b. The ICAO identifier for the relevant airport
c. The name of the air traffic services controlling unit
d. The validity time

68. What is the expected change in the weather intensity indicated by this SIGMET?

EGTT SIGMET 1 VALID 310730/311130 EGRR LONDON FIR ISOL CB FCST TOPS FL370 ROUTES W OF W00400 NC=

a. Weakening
b. Strengthening
c. Dissipating
d. No change

69. How would a severe mountain wave be coded in a SIGMET message?

a. + MTW
b. SEV MTW
c. SEV MNTW
d. SEVERE MNTW

70. In the following SIGMET message, what is the hazard forecast?

LFFF SIGMET 1 VALID 310600/311100 LFPW- UIR FRANCE MOD TURB
FCST BLW FL420 W of 04W MOVE E 30KT NC=

a. Moderate turbulence at 42 000 ft west of 4 degrees west and moving eastwards
b. Moderate turbulence below 42 000 ft west of 4 degrees west and moving from the east
c. Turbulence at 42 000 ft west of 4 degrees west and moving at 30 kts
d. Moderate turbulence below 42 000 ft west of 4 degrees west and moving eastwards

ANSWERS

1	C	21	B	41	C	61	A
2	B	22	C	42	B	62	D
3	B	23	C	43	B	63	A
4	A	24	C	44	C	64	D
5	C	25	D	45	D	65	B
6	A	26	D	46	D	66	B
7	D	27	B	47	D	67	C
8	B	28	B	48	A	68	D
9	A	29	A	49	C	69	B
10	C	30	A	50	A	70	D
11	C	31	D	51	D		
12	C	32	D	52	A		
13	A	33	B	53	D		
14	B	34	A	54	D		
15	D	35	D	55	D		
16	A	36	C	56	B		
17	D	37	B	57	A		
18	D	38	B	58	A		
19	C	39	C	59	D		
20	D	40	C	60	D		

CHAPTER TWENTY SEVEN

METEOROLOGICAL INFORMATION FOR AIRCRAFT IN FLIGHT (VOLMET)

Contents

INTRODUCTION

The weather-briefing material and services that you have read about in this book, so far, enable a pilot to obtain information on **forecast or actual weather conditions**, **prior to getting airborne**, during **flight planning**. However, pilots are also able to obtain **weather information** when they are in the air, by tuning into appropriate **frequencies** on the aircraft's **radio**.

One of these **in-flight weather briefing services** is the **VOLMET**. The first element of the code **VOLMET**, **vol**, is the French word for **flight**. **VOLMET**, therefore, is a term signifying **meteorological information for aircraft in flight**.

VOLMET broadcasts are **ground-to-air radio transmissions** of **meteorological reports** and **forecasts** made on the **High Frequency (HF)** and **Very High Frequency (VHF)** bands. These transmissions are broadcast in plain language, and give the latest weather **reports** and **forecasts**, in the form of spoken **METARs**, **TAFs** and **SIGMETs**. **VOLMET** broadcasts transmit weather information **for a number of different aerodromes**, sequentially. As a result, the pilot may have to wait for the forecast for the aerodrome pertinent to his flight to come around.

VOLMET OPERATION

The following table is an extract from the **United Kingdom Aeronautical Information Publication** (**GEN** Section), containing a list of **VHF VOLMET** services and their associated **radio frequencies** for the **United Kingdom** and the **near continent**.

UK AIP (11 Jul 02) GEN 3-5-21

GEN 3.5.7 — VOLMET SERVICES

Table 3.5.7.1 — Meteorological Radio Broadcasts (VOLMET)

Call Sign/ID	EM	Frequency MHz	Operating Hours	Stations	Contents	Remarks
1	2	3	4	5	6	7
London Volmet (Main)	A3E	135.375	H24 continuous	Amsterdam Brussels Dublin Glasgow London Gatwick London Heathrow London Stansted Manchester Paris/Charles de Gaulle	(1) Half hourly reports (METAR) (2) The elements of each report broadcast in the following order: (a) Surface wind (b) Visibility (or CAVOK) (c) RVR if applicable (d) Weather (e) Cloud (or CAVOK) (f) Temperature (g) Dewpoint (h) QNH (i) Recent Weather if applicable (j) Windshear if applicable (k) TREND if applicable (l) Runway Contamination Warning if applicable (3) Non-essential words such as 'surface wind', 'visibility' etc are not spoken. (4) Except for 'SNOCLO' (see Column 7), the Runway State Group is not broadcast. (5) All broadcasts are in English.	The spoken word 'SNOCLO' will be added to the end of the aerodrome report when that aerodrome is unusable for take-offs and landings due to heavy snow on runways or runway snow clearance.
London Volmet (South)	A3E	128.600	H24 continuous	Birmingham Bournemouth Bristol Cardiff Jersey London Luton Norwich Southampton Southend		
London Volmet (North) **(Note 1)**	A3E	126.600	H24 continuous	Blackpool East Midlands Isle of Man Leeds Bradford Liverpool London Gatwick Manchester Newcastle Teesside		
Scottish Volmet	A3E	125.725	H24 continuous	Aberdeen/Dyce Belfast Aldergrove Edinburgh Glasgow Inverness London/Heathrow Prestwick Stornoway Sumburgh		

Note 1: Broadcasting range extended to cover Southeast England and English Channel.

Note 2: An HF VOLMET broadcast for North Atlantic flights (Shannon VOLMET) is operated by the Republic of Ireland.

Individual **VOLMET stations**, in each region, broadcast weather reports and forecasts for a **group of major aerodromes** in their region of responsibility.

From the table below you can see that there are four **UK VOLMET** stations: **LONDON VOLMET MAIN, LONDON VOLMET NORTH, LONDON VOLMET SOUTH** and the **SCOTTISH VOLMET.** Next to each of these **stations**, is the **frequency** on which the **VOLMET** transmission is broadcast, the operating hours, and the list of aerodromes covered by the broadcast. The **LONDON VOLMET MAIN** broadcast, for example, is transmitted on the **VHF frequency** of **135.375 MHz, continuously, over a 24 hour period**.

The content of each **VOLMET broadcast** is a set of pre-recorded weather elements. **VOLMET broadcasts** are updated every **half hour**.

You will also see from *Figure 23.1* that the **LONDON VOLMET MAIN** broadcast contains weather information for aerodromes in **France** and the **Republic of Ireland**, as well as in the **United Kingdom**. The **LONDON VOLMET SOUTH** broadcast contains **weather information** for major airfields between **Birmingham**, in the **Midlands**, and the island of **Jersey**, in the **English Channel**.

Column 6 of *Figure 23.1* details the **specific weather elements** which are included in the **VOLMET broadcasts**. You will notice that the **broadcast content** has the same format as that of a **METAR**; however, in *Figure 23.2* which contains examples of actual **VOLMET broadcasts**, you will notice that **TAF**-terminology **(BECMG, TEMPO)** is also used, giving the broadcast a **forecast element**, too.

LONDON VOLMET MAIN

The following table shows sample **LONDON VOLMET MAIN** broadcasts. Six of the **major aerodromes** from the broadcast are included, with associated weather information.

THIS IS LONDON VOLMET MAIN AMSTERDAM AT 1125 WIND 160 DEGREES 16 KNOTS VARIABLE BETWEEN 130 AND 190 DEGREES VISIBILITY 7 KILOMETRES LIGHT RAIN SHOWERS CLOUD FEW 2 THOUSAND FEET FEW CUMULONIMBUS 2 THOUSAND 5 HUNDRED FEET BROKEN 4 THOUSAND FEET TEMPERATURE 14 DEWPOINT 9 QNH 1004 BECOMING VISIBILITY 10 KILOMETRES OR MORE NIL SIGNIFICANT WEATHER	BRUSSELS AT 1120 WIND 190 DEGRESS 14 KNOTS MAXIMUM 24 KNOTS VISIBILITY 10 KILOMETRES OR MORE LIGHT RAIN SHOWERS CLOUD SCATTERED 2 THOUSAND 3 HUNDRED FEET SCATTERED 5 THOUSAND FEET BROKEN 10 THOUSAND FEET TEMPERATURE 13 DEWPOINT 10 QNH 1006 NOSIG
GLASGOW AT 1120 WIND 070 DEGREES 5 KNOTS VARIABLE BETWEEN 030 AND 110 DEGREES VISIBILITY 10 KILOMETRES OR MORE CLOUD FEW 1 THOUSAND 8 HUNDRED FEET SCATTERED 4 THOUSAND 5 HUNDRED FEET TEMPERATURE 14 DEWPOINT 8 QNH 997	DUBLIN AT 1130 WIND 260 DEGREES 6 KNOTS VARIABLE BETWEEN 240 AND 300 DEGREES VISIBILITY 10 KILOMETRES OR MORE CLOUD SCATTERED 2 THOUSAND 4 HUNDRED FEET SCATTERED 20 THOUSAND FEET TEMPERATURE 13 DEWPOINT 6 QNH 997 NOSIG

LONDON/GATWICK AT 1120 WIND 190 DEGREES 10 KNOTS VARIABLE BETWEEN 150 AND 220 DEGREES VISIBILITY 10 KILOMETRES OR MORE SHOWERS IN VICINITY FEW CUMULONIMBUS 2 THOUSAND 4 HUNDRED FEET SCATTERED 4 THOUSAND FEET TEMPERATURE 11 DEWPOINT 9 QNH 999	LONDON/HEATHROW AT 1120 WIND 220 DEGREES 12 KNOTS VARIABLE BETWEEN 190 AND 250 DEGREES VISIBILITY 10 KILOMETRES OR MORE LIGHT RAIN SHOWERS FEW CUMULONIMBUS 2 THOUSAND 5 HUNDRED FEET BROKEN 11 THOUSAND FEET TEMPERATURE 11 DEWPOINT 8 QNH 997 TEMPO VISIILITY 4 THOUSAND 5 HUNDRED FEET RAIN SHOWERS

VOLMET BROADCASTS IN THE HIGH FREQUENCY BAND

The **VOLMET** broadcasts that we have spoken of, so far, are transmitted in the **VHF band**. However, **VOLMETS** are also broadcast, all over the world, in the **High Frequency (HF) band**, typically between **3** to **20 MHz**.

ATIS	**Automatic Terminal Information Service**
VOLMET	**Routine Broadcast of Meteorological Information for Aircraft In Flight (INTL)**
VOLMET	**Routine Broadcast of Meteorological Information for Aircraft In Flight (NATL)**
WX	**Weather Broadcast**
	Inactive or Planned Service

EUR-MET Europe

Freq (Mhz)	Type	BCH +	Call Sign	State	Station Name	Latitude (N)	Longitude (E/W)	Remarks
2.998	VOLMET							unassigned
3.413	VOLMET	00,30	EIP	IRL	Shannon	52 34 N	09 12 W	1800-0530Z
4.540	WX	15,45	MLD	GBR	Architect (Kinloss)	57 39 N	03 34 W	
4.645	ATIS	Cont	ES..	EST	Tallinn	59 25 N	24 50 E	ex-RPH 6
4.742	WX	00,30	MLP	GBR	Architect (Brize Norton)	51 45 N	01 35W	
	VOLMET	.., 35	GFG	GIB	Gibraltar	36 09 N	05 21 W	
	VOLMET	15, ..	GFW	CYP	Cyprus (Akrotiri)	34 35 N	32 58 E	Mo-Fr 0215-1815Z
5.450	VOLMET	00, 30	MPL 2	GBR	West Drayton (London)			"RAF"
5.505	VOLMET	00, 30	EIP	IRL	Shannon	52 34 N	09 12 W	
5.714	WX	00, 30	MLP	GBR	Architect (Brize Norton)	51 45 N	01 35 W	
6.580	VOLMET							unassigned

The **Shannon VOLMET** is a vital source of weather information for **North Atlantic flight routes**.

The types of **VOLMETs** shown contain the same information as the **VOLMETs** for mainland **United Kingdom**, although they are more likely also to contain additional weather forecast details, such as **SIGMETS** for en-route weather.

VOLMET transmissions are designed to be simple and easily understood, so that fast, efficient weather briefing can be obtained by pilots, in-flight.

During **pre-flight planning**, note down the **VOLMET frequencies** for the areas that you will be flying in, so that, en-route, you can listen to broadcasts for aerodromes in the vicinity of your **destination**, as well as for **alternate aerodromes**.

Access to **VOLMET** broadcasts enables the pilot to confirm that **weather conditions** at his **destination airfield** are favourable. If a **diversion** becomes necessary, the current suitability of the planned **diversion airfield** can also be rapidly determined.

QUESTIONS

1. An aerodrome VOLMET report for 0450 UTC, during the autumn in the United Kingdom is:

Surface wind	150/05 kts
Visibility	2000 m
Weather	Nil
Temperature	9° C
Dew point	8° C
QNH	1029 mb
Trend	NOSIG

From the information above, what type of pressure system, do you deduce, is dominating the region?

a. An anti-cyclone
b. A cyclone
c. A low pressure
d. A trough

2. A VOLMET is defined as:

a. A radio broadcast of selected aerodrome forecasts
b. A continuous telephone message of selected aerodrome METARs
c. A continuous radio broadcast of selected aerodrome actual weather observations and forecasts
d. A teleprinter message of selected aerodrome TAFs and METARs

3. VOLMETs are updated:

a. Every hour
b. 4 times a day
c. 2 times a day
d. Every half hour

4. VOLMETs are:

a. Air to ground radio transmissions on HF and VHF
b. Air to ground radio transmissions on HF and SVHF
c. Ground to air radio transmissions on LF and VHF
d. Ground to air radio transmissions on HF and VHF

5. An aerodrome VOLMET report for 0450 UTC, during the autumn in the United Kingdom is:

Surface wind	150/05 kts
Visibility	2000 m
Weather	Nil
Temperature	9º C
Dew point	8º C
QNH	1029 mb
Trend	NOSIG

Given that sunrise is at 0600 UTC, what might you expect during the 2 hours following this report?

a. CAVOK
b. Radiation Fog
c. Low Stratus
d. Advection Fog

ANSWERS

1	2	3	4	5
A	C	D	D	B

CHAPTER TWENTY EIGHT

AUTOMATIC TERMINAL INFORMATION SERVICE
(ATIS)

Contents

INTRODUCTION

The **Automatic Terminal Information Service (ATIS)** *is a continuous broadcast of* **current aerodrome weather** *and* **other aerodrome information**.

The purpose of the **ATIS** is to **improve controller effectiveness** and to **reduce congestion** on busy **ground, tower** and **approach frequencies** by automatically transmitting on a discrete **VHF radio frequency**.

Pilots **departing from** or **arriving at** aerodromes which offer **ATIS** are encouraged to listen to the **ATIS broadcast** and to **notify air traffic control**, on **initial contact**, that they have received the **ATIS broadcast**, by passing the **phonetic alphabet code letter** by which all **ATIS broadcasts** are identified.

At some aerodromes there will be a separate **ATIS broadcast** for **departure** and **arrival**.

In order to free up **air traffic VHF communication frequencies**, some aerodromes transmit the **ATIS** information on the voice channel of a **VOR** beacon located at the aerodrome.

Shown below, is an extract from the **Aerodrome** section of the **United Kingdom Aeronautical Information Publication (UK AIP)** illustrating that both an **arrival** and **departure ATIS** is available, on different frequencies, at **Manchester Airport**.

EGCC AD 2.18 – ATS COMMUNICATION FACILITIES					
Service Designation	Callsign	Frequency MHz	Hours of Operation Winter	Summer	Remarks
1	2	3	4		5
APP	Manchester Radar	119.525 †	H24	H24	ATZ hours coincident with Approach hours. † Serves Manchester and Manchester Woodford.
	Manchester Radar	118.575	As directed by ATC	As directed by ATC	
	Manchester Director	121.350			
TWR	Manchester Tower	118.625 121.500 ‡ 119.400	H24	H24	
	Manchester Ground	121.850 121.700 § 125.375	0630-2200 2200-0630 As directed by ATC	0530-2100 2100-0530 As directed by ATC	‡ Emergency Ch O/R.
	Manchester Delivery	121.700 §	0630-2200	0530-2100	§ Departing aircraft are to make initial call on 121.700 MHz to 'Manchester Delivery' or 'Manchester Ground' as appropriate.
Arrival ATIS[Ø]	Manchester Information	128.175	H24	H24	[Ø]Also available by telephone: 0161-499 2324
Departure ATIS[Ø]	Manchester Departure Information	121.975	0520-2220	0420-2120	
FIRE	Manchester Fire	121.600	Available when Fire vehicle attending aircraft on the ground in an emergency.		Non-ATS frequency.

This extract shows that, at **Southampton Airport**, the **ATIS broadcast** is made on the **Southampton VOR frequency**.

EGHI AD 2.18 – ATS COMMUNICATION FACILITIES					
Service Designation	Callsign	Frequency MHz	Hours of Operation Winter	 Summer	Remarks
1	2	3	4		5
APP	Southampton Approach	128.850	As directed by ATC	As directed by ATC	ATZ hours coincident with Tower hours (but not by arrangement).
TWR	Southampton Tower	118.200	† Mon-Fri 0625-2100 Sat 0625-2000 Sun 0735-2100 and by arrangement	† Mon-Thu 0545-2030 Fri 0545-2115 Sat 0630-1915 Sun 0800-2000 and by arrangement	† Hours subject to change, consult latest NOTAM.
	Southampton Ground	121.775	As directed by ATC	As directed by ATC	
RAD	Southampton Radar	128.850	As directed by ATC	As directed by ATC	
ATIS	Southampton Information	113.350	HO	HO	Broadcast on Southampton VOR.
FIRE	Southampton Fire	121.600	Available when Fire vehicle attending aircraft on the ground in an emergency.		Non-ATS frequency.

ATIS OPERATION

If the **current aerodrome weather conditions** change, or if there is any change in other **pertinent aerodrome information,** the **ATIS broadcast** is immediately updated to reflect these changes. The updated **ATIS broadcast** is then given a new, sequential **alphabetical code**. For example, **ATIS broadcast BRAVO** will have replaced the previous **ATIS broadcast ALPHA**.

On initial contact with **Air Traffic Control (ATC)**, a pilot is required to state the **identifying letter code** of the **ATIS information last received**, in order that **ATC** may know that the pilot has the most recent information.

ATIS will be broadcast in plain language and will contain some or all of the following information, if applicable.

- Aerodrome name.
- ATIS sequence designator or information code.
- Time of observation.
- Runway in use and status.
- Surface wind in knots and referenced to magnetic north.
- Visibility and RVR
- Present weather
- Significant cloud.
- Temperature and dew point.
- Altimeter setting.
- Transition level.
- Type of approach expected.
- And finally any warnings pertinent to flight operations.

USE OF ATIS

On **departure** from an aerodrome, **ATIS information** should be obtained by the pilot **before initial contact with Air Traffic Control**. When initial contact is made with **Air Traffic Control**, the pilot must mention the **identifying letter** of the ATIS broadcast obtained, in order to confirm to the controller that the latest airfield information has been received.

A pilot **arriving** at an aerodrome should also listen to the **ATIS broadcast before transmitting on the aerodrome's initial contact frequency**. On hearing that a pilot has the latest **ATIS information,** an approach controller may omit, in his reply to the pilot, certain details contained in the **ATIS broadcast**. Normally, however, the **aerodrome QNH** will always be confirmed by the controller.

If a pilot does not acknowledge receipt of the latest **ATIS broadcast** on initial contact with an aerodrome controller, the controller will pass the **essential aerodrome information** to the pilot.

Obtaining the latest **ATIS information** helps ensure that radio transmissions between **Air Traffic Control** and the pilot are kept to a minimum. This is especially important in **busy airspace** where radio transmissions must be kept short to allow for effective communication between controllers and all the aircraft to which they are giving a service.

QUESTIONS

1. When are ATIS broadcasts updated?

    a. Any time the aerodrome or weather information changes
    b. Only when the aerodrome information changes
    c. Every 30 minutes
    d. Every hour

2. To minimise VHF frequency use, the ATIS can be broadcast on the voice frequency of which navigation aid?

    a. ILS
    b. NDB
    c. VOR
    d. GPS

3. In an ATIS broadcast, what is used to identify the current report?

    a. An alphabetical code
    b. A number
    c. A validity number
    d. An issue time

4. What is the ATIS?

    a. A chart of current aerodrome and weather information
    b. A continuous broadcast of current aerodrome and weather information
    c. A continuous broadcast of weather information
    d. A printed text report of current aerodrome and weather information

5. In what frequency band is the ATIS normally broadcast?

    a. LF
    b. HF
    c. ADF
    d. VHF

ANSWERS

1	2	3	4	5
A	C	A	B	D

CHAPTER TWENTY NINE

WORLD AREA FORCAST SYSTEM
SIGNIFICANT WEATHER CHARTS

Contents

1. Symbols for significant weather

	Thunderstorms	,	Drizzle
	Tropical cyclone	/// ///	Rain
	Severe squall line*	*	Snow
	Moderate turbulence		Shower / Hail
	Severe turbulence		Widespread blowing snow
	Mountain waves		Severe sand or dust haze
	Moderate aircraft icing		Widespread sandstorm or dust storm
	Severe aircraft icing	∞	Widespread haze
	Widespread fog	=	Widespread mist
	Radioactive materials in the atmosphere**		Widespread smoke
	Volcanic eruption***		Freezing precipitation ****
	Mountain obscuration	■	Visible ash cloud *****

* In flight documentation for flights operating up to FL100. This symbol refers to "squall line".

** The following information should be included at the side of the chart: radioactive materials symbol; latitude/longitude of accident site; date and time of accident; check NOTAM for further information.

*** The following information should be included at the side of the chart: volcanic eruption symbol; name and international number of volcano (if known); latitude/longitude; date and time of the first eruption (if known);
Check SIGMETs and NOTAM or ASHTAM for volcanic ash.

**** This symbol does not refer to icing due to precipitation coming into contact with an aircraft which is at a very low temperature.

***** Visible ash cloud symbol applies only to model VAG not to SIGWX charts.

NOTE: Height indications between which phenomena are expected, top above base as per chart legend.

2. Fronts and convergence zones and other symbols used

	Cold front at the surface	FL 270	Position, speed and level of max. wind
	Warm front at the surface		Convergence line
	Occluded front at the surface	0°:100	Freezing level
	Quasi-stationary front at the surface		Intertropical convergence zone
H 460	Tropopause High	10	State of the sea
270 L	Tropopause Low	18	Sea-surface temperature
380	Tropopause Level	40	Widespread Strong surface wind *

FL 300 — FL 340

Wind arrows indicate the maximum wind in jet and the flight level at which it occurs. Significant changes (speed of 20 knots or more, 3 000 ft (less if practicable) in flight level) are marked by the double bar. In the example, at the double bar the wind speed is 225 km/h (120 kt).

The heavy line delineating the jet axis begins/ends at the points where a wind speed of 150 km/h (80 kt) is forecast.

* This symbol refers to widespread surface wind speeds exceeding 60 km/h (30 kt).

3. Abbreviations used to describe clouds

3.1 Type

CI = Cirrus
CC = Cirrocumulus
CS = Cirrostratus
AC = Altocumulus
AS = Altostratus
NS = Nimbostratus
SC = Stratocumulus
ST = Stratus
CU = Cumulus
CB = Cumulonimbus

3.2 Amount

Clouds except CB

SKC = sky clear (0/8)
FEW = few (1/8 to 2/8)
SCT = scattered (3/8 to 4/8)
BKN = broken (5/8 to 7/8)
OVC = overcast (8/8)

CB only

ISOL = individual CBs (isolated)
OCNL = well-separated CBs (occasional)
FRQ = CBs with little or no separation (frequent)
EMBD = CBs embedded in layers of other clouds or concealed by haze (embedded)

3.3 Heights

Heights are indicated on SWH and SWM charts in flight levels (FL), top over base. When XXX is used, tops or bases are outside the layer of the atmosphere to which the chart applies.
In SWL charts:
i) Heights are indicated as altitudes above mean sea level;
ii) The abbreviation SFC is used to indicate ground level.

4. Depicting of lines and systems on specific charts

4.1 Models SWH and SWM — Significant weather charts (high and medium)

Scalloped line = demarcation of areas of significant weather
Heavy broken line = delineation of area of CAT
Heavy solid line interrupted by wind arrow and flight level = position of jet stream axis with indication of wind direction, speed in kt or km/h and height in flight levels. The vertical extent of the jet stream is indicated (in flight levels) below the flight level, e.g. FL270 accompanied by +20/–30 indicates that the height of the jet extends from FL240 to FL290.
Figures on arrows = speed in kt or km/h of movements of frontal system
Flight levels inside small rectangles = height in flight levels of tropopause at spot locations, e.g. [340]. Low and high points of the tropopause topography are indicated by the letters L or H, respectively, inside a pentagon with the height in flight levels.

4.2 Model SWL — Significant weather charts (low level)

X = position of pressure centres given in hectopascals
L = centre of low pressure
H = centre of high pressure
Scalloped lines = demarcation of area of significant weather
Dashed lines = altitude of 0°C isotherm in feet (hectofeet) or metres
NOTE: 0°C level may also be indicated by [0° : 060], i.e. 0°C level is at an altitude of 6 000 ft
Figures on arrows = speed in kt or km/h of movement of frontal systems, depressions or anticyclones
Figure inside the state of the sea symbol = total wave height in feet or metres
Figure inside the sea-surface temperature symbol = sea-surface temperature in °C
Figures inside the strong surface wind symbol = wind in kt or km/h

4.3 Arrows, feathers and pennants

Arrows indicate direction. Number of pennants and/or feathers correspond to speed.
Example:

270°/115 kt (equivalent to 213 km/h)
Pennants correspond to 50 kt or 93 km/h
Feathers correspond to 10 kt or 18 km/h
Half-feathers correspond to 5 kt or 9 km/h

SIGNIFICANT WEATHER CHARTS - DECODE

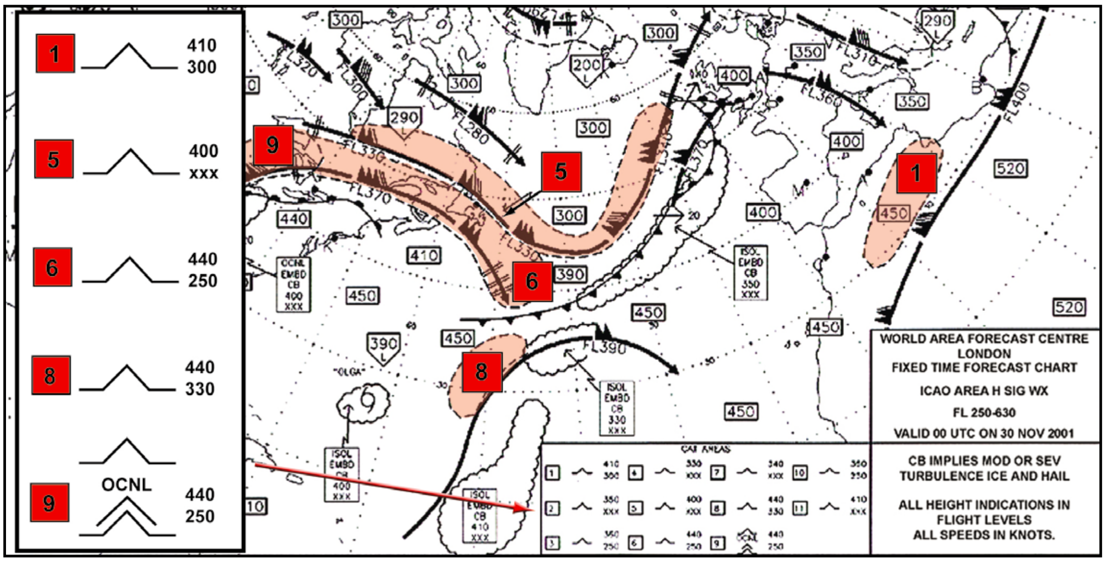
INTRODUCTION

World Area Forecast System Significant Weather (WAF SIGWX) Charts apply to pressure altitudes between **10,000** and **63,000 feet (Flight Levels 100 to 630)** provide information about **significant weather** at **medium** and **high altitudes**. **Significant weather phenomena** include the forecast locations of **embedded cumulonimbus clouds**, **medium and severe clear air turbulence**, **moderate and severe icing**, **jet streams**, and other important **meteorological occurrences**.

HIGH LEVEL WAFS SIGWX CHARTS

High level **WAF SIGWX charts** cover the **atmospheric** level bounded by **Flight Level 250 and Flight Level 630.**

Shown below is an example of a **high level WAFS SIGWX chart**. The chart has a clearly defined **legend** which contains the following information: the name of the **World Area Forecast Centre (WAFC)** which produced the chart, (either **London** or **Washington)**, a reminder that the forecast is for a **single, fixed time**; the **ICAO-designated letter** used to identify the area covered by the chart; the range of **flight levels** through which the chart is valid; the **time** in **UTC**, and the **date** on which the chart is valid.



Clear Air Turbulence (CAT) Legends. This displays the degree of turbulence and forecast flight levels for specific numbered areas on the chart. The areas visible on this chart, and their corresponding numbers have been highlighted in red, for clarity.

WAFS SIGWX charts are produced, daily, **every 6 hours**, and are valid for **0000**, **0600**, **1200**, and **1800 UTC**. Since each chart is valid for **one single fixed time only**, it is the responsibility of the user to interpolate between charts to establish what weather conditions can be expected at intermediate times. **WAFS SIGWX charts** which are produced by the **UK Met Office** (**WAFC London)** have an additional legend, which highlights the **flight levels** between which **Clear Air Turbulence** can be expected.

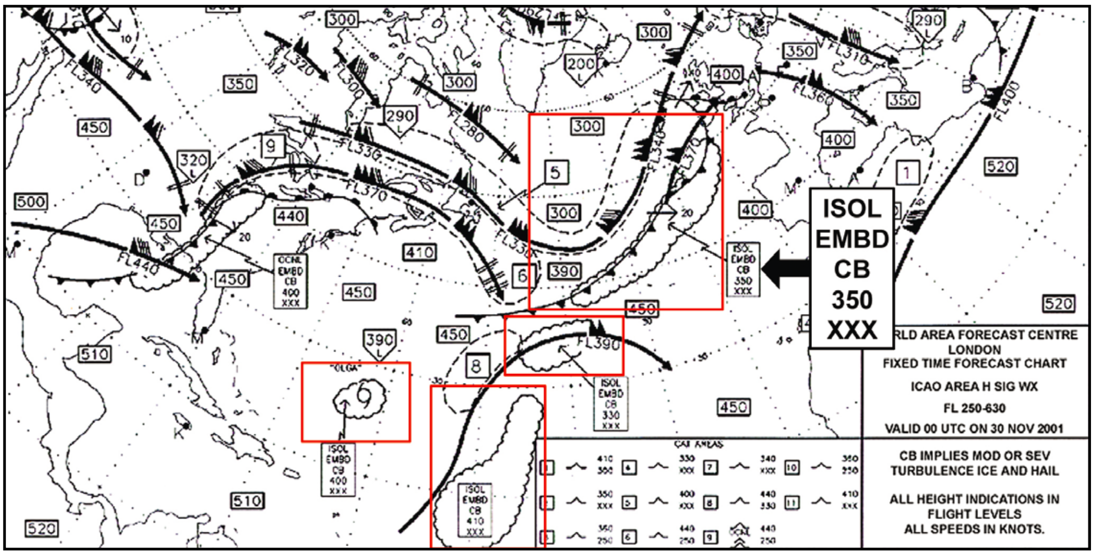
In the legend each **Clear Air Turbulence (CAT)** symbol has a **number** assigned to it. This **number** corresponds to the **number** attached to an **area of CAT on the chart**; these areas have been **highlighted in red**, and are enclosed by a dashed line.

MEDIUM LEVEL WAF SIGWX CHARTS

The **legends** which are assigned to the **medium level WAF SIGWX charts** are similar to those on the **high level charts,** except for the text line which clearly highlights that the **medium level charts** are valid between **FL 100** and **FL 450**.

THUNDERSTORMS

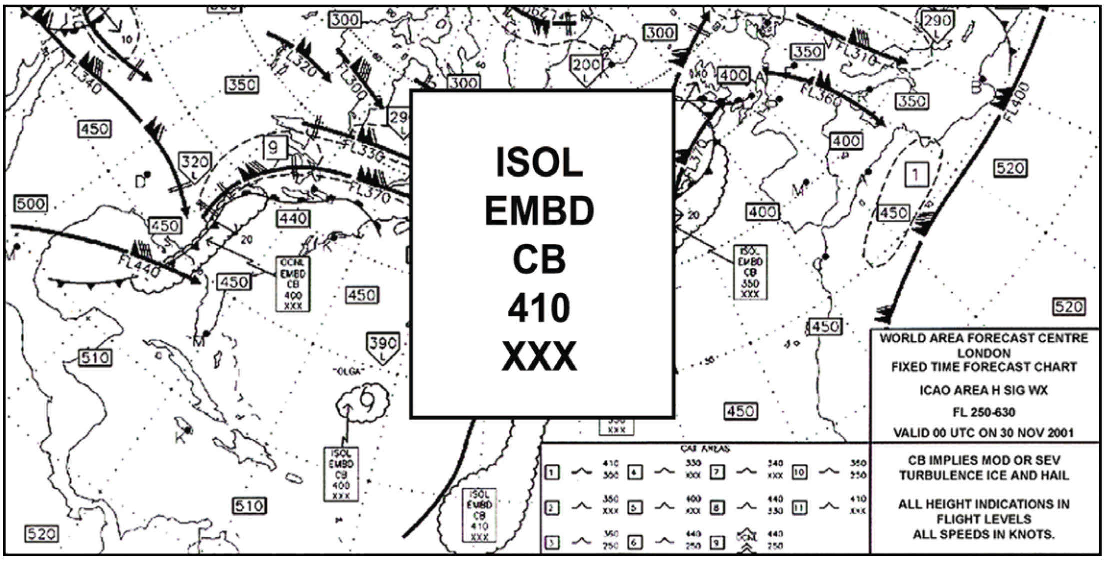
Thunderstorms are not explicitly displayed on the charts as such; however, **thunderstorm activity** is assumed whenever **cumulonimbus cloud** is forecast. Thus, wherever the code **CB** is seen on the chart, it must be assumed that **thunderstorm activity** is present in those areas. These areas on the chart are delineated using a **scalloped line**, as shown in *Figure 20.3*. However, it is important to remember that only **embedded cumulonimbus** clouds are displayed on **WAFS charts**.



Included in the information about the **cumulonimbus** activity is an indication of the **flight level** at which the **cumulonimbus cloud** will be present. This information is included either adjacent to the chart, or within the **scalloped area** on the chart.

In the examples shown "**ISOL**" is used to indicate that any occurrences of cumulonimbus will be **isolated** within the scalloped area shown on the chart. Other abbreviations that may be used on the **WAFS significant weather charts** are: "**OCNL,**" indicating that cumulonimbus may be **occasionally** encountered within the area; "**WDSPD**" implies that cumulonimbus are forecast to be **widespread** within the scalloped area on the chart; and, finally, "**FRQ**" is used to imply that cumulonimbus are expected to be **frequen**t within that area.

In the boxes next to the areas denoting **cumulonimbus** activity, are indications of the **flight levels** between which **cumulonimbus cloud** can be expected. If any of these **flight levels** are **outside the height range of the chart**, the symbol **XXX** is used. In *Figure 20.4*, the top of the **cumulonimbus** activity is forecast for **Flight level 410**, but the bottom of the **cumulonimbus** activity is below the **lowest level** of the **chart forecast**. This is **flight level 250** for the **high level chart shown in** *Figure 20.4*. In the example shown, the **medium level WAFS SIGWX chart** must be consulted, in order to discover the **base** of the **cumulonimbus activity**.



ISOL - **Individual CBs**

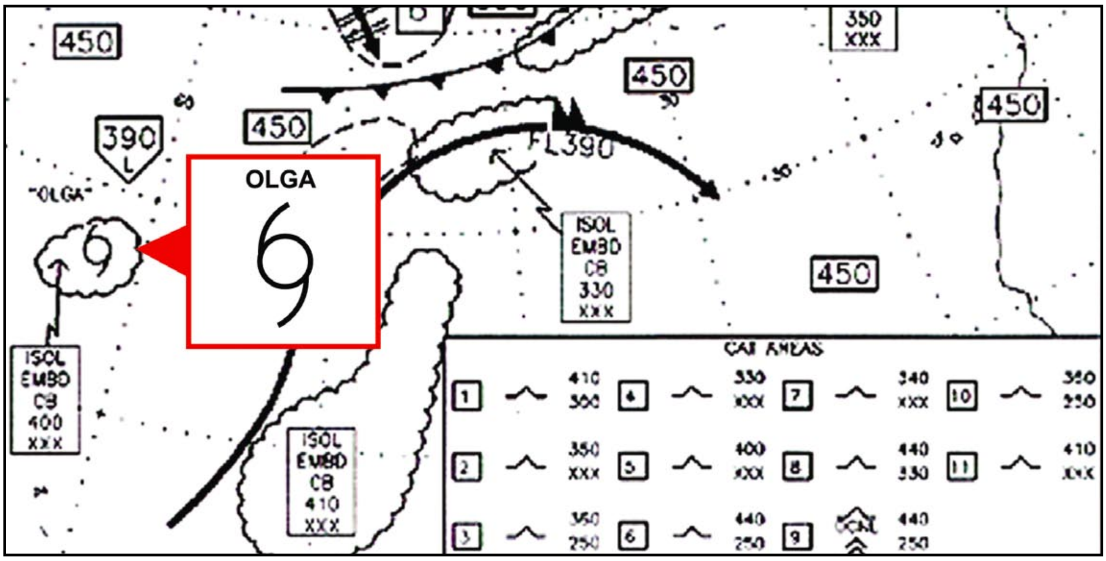
OCNL - **Well separated**

FRQ - **Little or no separation**

EMBD - **Embedded within other cloud layers or concealed by haze**

TROPICAL CYCLONES AND HURRICANES

Tropical cyclones are referred by a variety of names; however, if they become particularly severe, they are called **hurricanes,** in the **Atlantic Ocean**. **Hurricanes** are easily recognisable on significant weather charts by the symbol highlighted on the chart below.

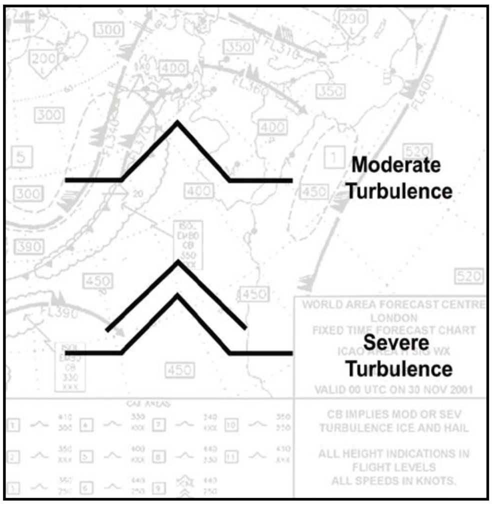


The symbol is always accompanied by the **World Meteorological Organisation name of the storm**. **Hurricanes** used to be given exclusively women's names, but, for reasons that have never been revealed, are now given men's names too. On the chart the **hurricane** has been named **"Olga"**.

Tropical cyclones are associated with **intense areas of cumulonimbus activity**, and they need to be very carefully monitored.

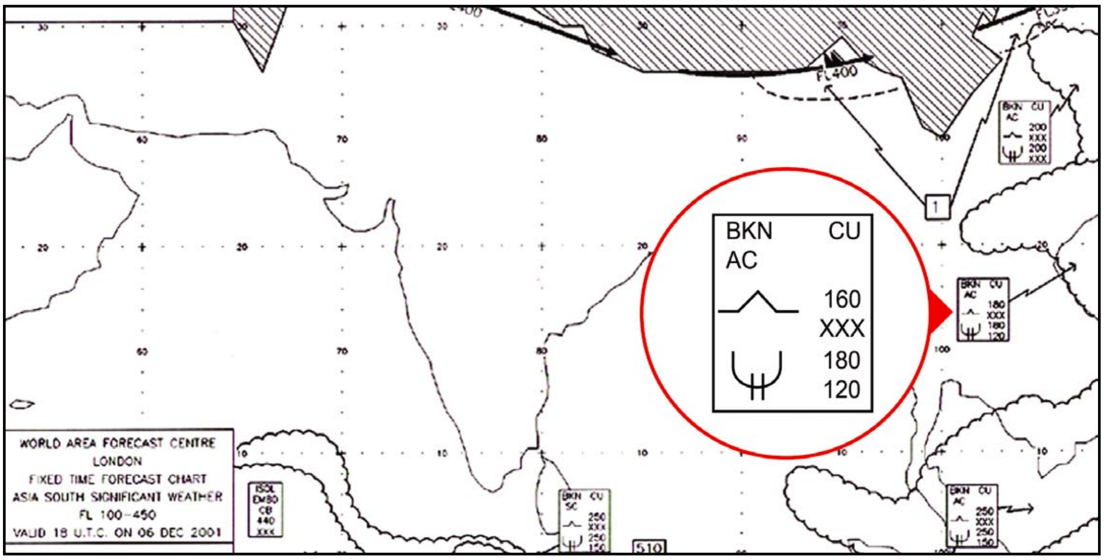
TURBULENCE

Moderate, or **severe turbulence** is displayed on the **WAF SIGWX chart** using the symbols shown.



The symbol for **turbulence**, as for other **weather phenomena,** are the same as the symbols used on the **low-level forecast charts.**

Wherever **cumulonimbus** is forecast, **moderate to severe turbulence** must be assumed to be active in the area. On the **medium level significant weather charts**, areas of **moderate and severe turbulence** are also associated with other types of medium level cloud. The example from a medium - level chart, below, shows turbulence around **broken cumulus** and **altocumulus**.

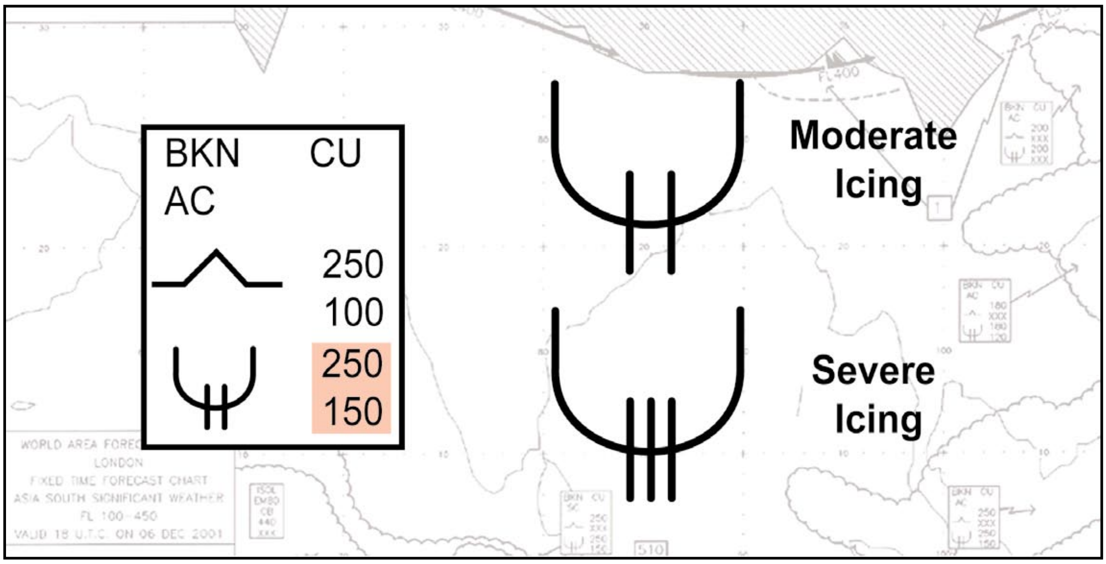


The turbulence symbols are included within the "cloud" boxes assigned to every **scalloped cloud area**.

These areas are highlighted by way of the turbulence symbols which are included within the cloud boxes assigned to every scalloped cloud area as shown.

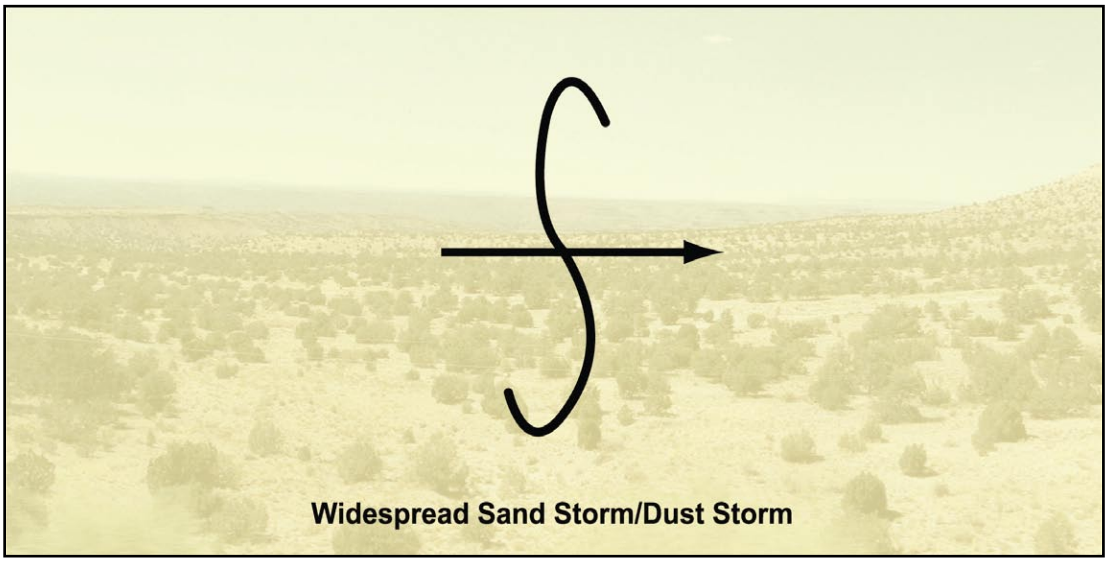
ICING

As previously described, the only cloud type shown by **high level WAF SIGWX charts**, is **cumulonimbus clouds.** You may also recall that **moderate** or **severe icing** is also automatically assumed to be prevail in the vicinity of these clouds. However, on **medium level charts**, other cloud types are shown. As **icing conditions** are not **only** confined to **cumulonimbus clouds**, symbols are used on the **medium level WAFC significant weather charts** to denote **moderate** or **severe icing conditions**. These symbols are shown on the chart below. Within this example, the red highlighted area shows the range of flight levels between which the **icing risk** is forecast.



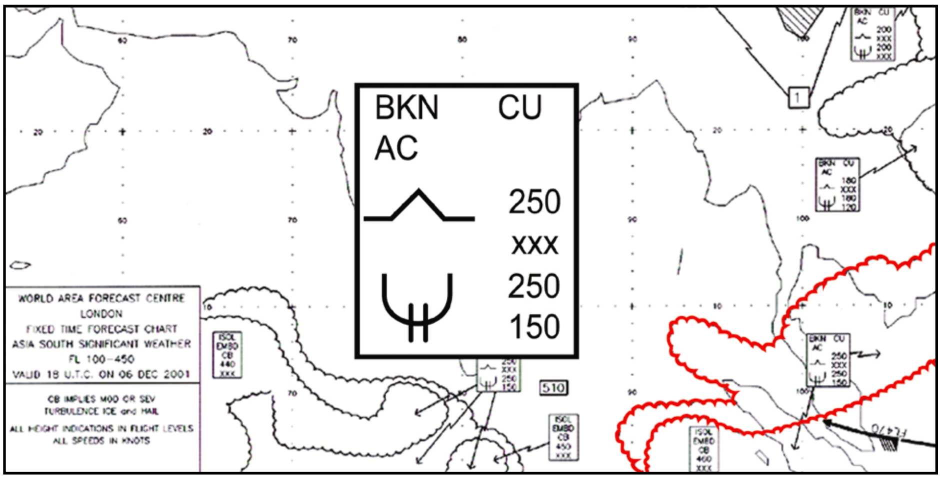
SAND AND DUST STORMS

Widespread sandstorms or dust storms are highlighted on the significant weather charts only when these phenomena are forecast to significantly obscure visibility between the flight-levels for which the chart is valid. The symbol which is used on the chart is identical for both phenomena and is shown below.



CLOUD AREAS

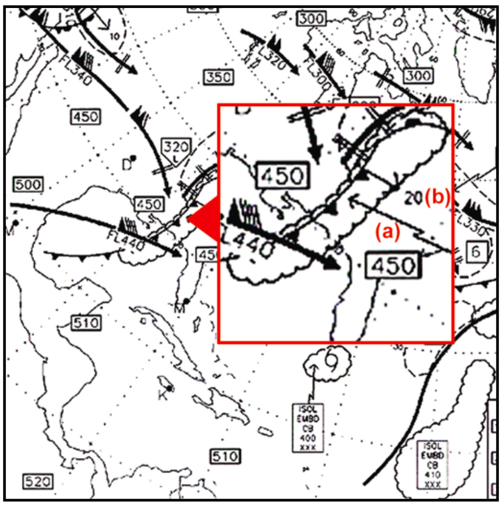
The only clouds which are displayed on **high level charts** are **embedded cumulonimbus**; however, on the **medium level charts**, rather more cloud information is displayed. Whereas **high level charts** show only **embedded cumulous clouds**, **medium level charts** show more detail on the types of cloud that may be encountered. Any cloud types which are likely to have a **significant icing or turbulence risk** are clearly highlighted. In the following example the cloud box refers to the scalloped cloud areas highlighted in red. From the symbols within the box, it can be seen that **broken amounts of cumulus and altocumulus** may be present; **moderate turbulence** can be expected between **Flight Levels 250** and **XXX**, which is less than **FL 100**; **moderate icing** can be expected between **Flight Levels 250** and **150**.



FRONTAL SYSTEMS

Although frontal systems have been officially removed from **WAF SIGWX** charts, the information remains and some examinations may use old charts.

Standard frontal coding is used to indicate the **surface positions** of the fronts. The **direction of travel** of the front is shown by **arrows**, with the **speed of movement** of the front shown by **small numbers** next to the front. On the chart below there is a **cold front** moving **eastwards (a)** at a speed of 20 knots **(b)**.

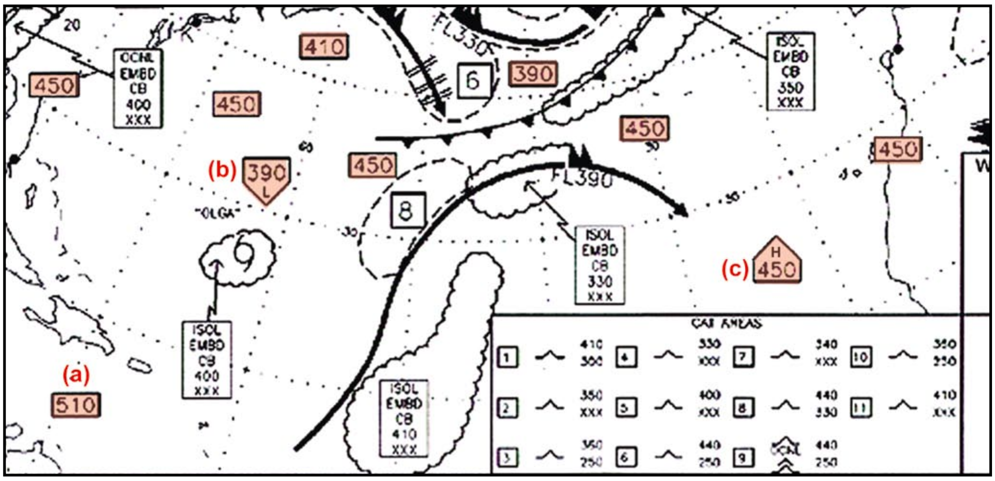


Only significant fronts are shown. Standard front coding is used to denote frontal type. Direction of movement is shown by small arrows, (a), with numbers next to them, giving speed in knots (b).

TROPOPAUSE LEVELS

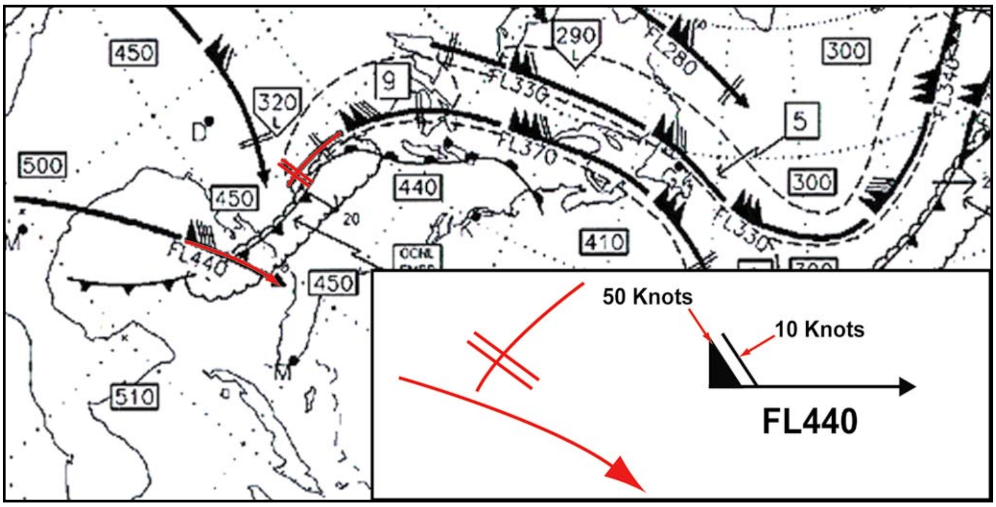
Tropopause levels are included on the **high level significant weather charts**. The levels shown indicate the start of the **Tropopause**, and are calculated by finding the **coldest temperature in the Troposphere**. The height of the **Tropopause,** therefore, is defined by the height in the **atmosphere** at which the **temperature becomes constant, rather than declining with altitude**. These **Tropopause levels** are indicated at a number of spot locations across the **high level charts**. **Tropopause levels** are presented as **flight levels** in a rectangular box, marked as **(a) on the chart below**.

When more than one **Tropopause level** is present in the atmosphere, either an **"H"** or an **"L"** is added to the **Tropopause box**, to indicate whether the **uppermost** or **lowest Tropopause height** is displayed. In these cases, the rectangular box is expanded to include the additional symbol, and the box looks more like an arrow head pointing up or down. On the chart below the lowest **Tropopause level** is marked **(b)**, and the highest **Tropopause level** is marked **(c)**.



JET STREAMS

Jet streams are identifiable on the charts by **black solid lines**, which have **wind "barbs",** indicating **jet stream speeds** at various **spot points**, with the **flight level** at which the maximum speed occurs written underneath. The **arrow head** on the end of each **jet stream line** indicates the **direction of movement of the flow**. Any **changes in speed** along the length of the **jet stream** of **20 knots or more** are indicated by either an additional set of **wind "barbs"**, or, if there is little space on the chart, two parallel lines perpendicular to the direction of flow of the **Jet Stream**.



Usually, the Jet Stream has an associated Clear Air Turbulence region indicated by a dashed line with an identifying number in it.

QUESTIONS

1. (For this question use annex A)
You are flying from Munich to Amsterdam. Which of the following flight levels would you choose in order to avoid turbulence and icing?

    a. FL 320
    b. FL 180
    c. FL 140
    d. FL 260

2. Which weather chart gives information about icing and the height of the freezing level?

    a. 700 hPa chart
    b. Surface chart
    c. Low Level Significant weather chart
    d. 500 hPa chart

3. (For this question use annex B)
On which of these routes would you not have to worry about turbulence at FL 340?

    a. Zurich - Rome
    b. Zurich - Athens
    c. Rome - Berlin
    d. Shannon - Hamburg

4. (For this question use annex C)
Select from the map the average temperature for the route Athens - Geneva at FL 150.

    a. -14°C
    b. -21°C
    c. -11°C
    d. -27°C

5. (For this question use annex D)
Which one of the tracks (dashed lines) is represented by the cross-section shown on the right?

    a. Track C-A
    b. Track B-A
    c. Track B-C
    d. Track D-A

6. How are well separated CB clouds described on the Significant Weather Chart?

    a. EMBD CB.
    b. FREQ CB.
    c. ISOL CB.
    d. OCNL CB.

7. (For this question use annex C)
Look at the chart. Assuming a normal vertical temperature gradient, at what altitude will the freezing level above Shannon be found?

a. FL 120
b. FL 60
c. FL 20
d. FL 140

8. (For this question use annex E)
The dotted line labelled “Y” represents the

a. mean position of the temperate/tropical front during July
b. mean position of the intertropical convergence zone (ITCZ) during January
c. axis of the subtropical jet stream during January
d. mean position of the intertropical convergence zone (ITCZ) during July

9. (For this question use annex F)
Select from the map the average temperature for the route Geneva -Stockholm at FL 260.

a. -51°C
b. -55°C
c. -63°C
d. -47°C

10. (For this question use annex E)
The arrows labeled “u” represents the tracks of tropical revolving storms which occur mainly from

a. December to April and are called tornadoes
b. July to October and are called typhoons
c. January to March and are called willy-willies
d. May to July and are called cyclones

11. (For this question use annex G)
What change in pressure, will occur at point A, during the next hour?

a. A drop in pressure
b. Irregular fluctuations
c. Approximately constant pressure
d. A rise in pressure

12. (For this question use annex H)
Assuming a generalised zonal system of world climatic and wind circulation, zone “t” is an area of

a. subtropical high pressure systems
b. SE trade winds
c. travelling low pressure systems
d. NE trade winds

13. (For this question use annex I)
At which airport is the following weather development taking place?
TAF 231322 24014G32KT 4000 +TSRA SCT005 BKN015 BKN020CB BECMG 1416 29012KT 9999 BKN030TCU SCT100 TEMPO 8000 SHRA BKN025TCU BECMG 1922 27012KT 9999 SCT030 OVC220 =

a. EKCH
b. EINN
c. ENFB
d. LSZH

14. (For this question use annex J)
Assuming a normal vertical temperature gradient, at what altitude will the freezing level above Tunis be found?

a. FL 20
b. FL 180
c. FL 260
d. FL 100

15. (For this question use annex G)
Which typical weather condition is shown by the design for northern Italy, area D?

a. High pressure
b. Warm southerly wind
c. Westerly wind
d. Easterly wind

16. (For this question use annex B)
In what height range and at what intensity could you encounter turbulence in CAT area n°2?

a. From FL 250 to FL 320, moderate
b. From FL 310 to FL 400, moderate
c. From FL 220 to FL 350, moderate/severe
d. From below FL 130 to FL 270, light

17. Which of the following symbols represents a squall line?

a. Symbol b)
b. Symbol c)
c. Symbol d)
d. Symbol a)

18. (For this question use annex F)
Select from the map the average wind for the route Zurich - Hamburg at FL 300.

a. 200/53
b. 360/60
c. 185/60
d. 360/55

19. (For this question use annex A)
Over Paris at what height would you expect to find the tropopause according to the map?

a. 34000 FT
b. 30000 FT
c. 27000 FT
d. 40000 FT

20. (For this question use I)
What weather conditions are expected at Paris airport (LFPO) around 0550 UTC?

a. 23014KT 3000 +RA SCT008 OVC025 15/13 Q1004 NOSIG =
b. 26012KT 9999 SCT025 SCT040 14/09 Q1018 TEMPO 5000 SHRA =
c. 22020G36KT 1500 TSGR SCT004 BKN007 BKN025CB 18/13 Q1009 BECMG NSW =
d. 20004KT 8000 SCT110 SCT250 22/08 Q1016 NOSIG =

21. (For this question use annex K)
If you are flying from Zurich to Shannon at FL 340, where will your cruising altitude be?

a. Constantly in the stratosphere
b. Constantly in the troposphere
c. First in the troposphere and later in the stratosphere
d. In the stratosphere for part of time

22. In which meteorological forecast chart is information about CAT regions found?

a. 300 hPa chart.
b. Significant Weather Chart.
c. 24 hour surface forecast.
d. 500 hPa chart.

23. (For this question use annex B)
Which of the following statements is true?

a. The front to the north of Frankfurt is moving north-east at about 5 kt
b. The jet stream above Italy has a maximum speed of 120 km/h
c. Thunderclouds have formed over the Iberian peninsula extending to some 25000 meters
d. There is no significant cloud above Rome

24. (For this question use annex L)
At what flight level is the jet stream core that is situated over northern Scandinavia?

a. FL 330
b. FL 360
c. FL 300
d. FL 320

25. (For this question use annex B)
On which of these routes would you not need to worry about icing at FL 180?

a. Zurich - Rome
b. Hamburg - Stockholm
c. Zurich - Madrid
d. Zurich - Hamburg

26. (For this question use annex C)
Select from the map the average wind for the route Athens - Geneva at FL 160.

a. 210/50
b. 260/40
c. 050/35
d. 225/47

27. (For this question use annex B)
At which position could you encounter thunderstorms, and what is the maximum height of the CB clouds?

a. London, FL 300.
b. Frankfurt, FL 150.
c. Madrid, FL 250.
d. Rome, FL 310.

28. (For this question use annex M)
What name is given to the jet stream lying across India (A) ?

a. Sub-tropical jet stream.
b. Equatorial jet stream.
c. Polar front jet stream.
d. Arctic jet stream.

29. (For this question use annex C)
Select from the map the average wind for the route Frankfurt - Rome at FL 170.

a. 050/40
b. 030/35
c. 230/35
d. 200/50

30. (For this question use annex C)
What OAT would you expect at FL 200 over Geneva?

a. -38°C
b. -34°C
c. -40°C
d. 36°C

31. (For this question use annex A)
What is the speed of the front located north of Ireland?

a. 30 kt
b. 15 kt
c. 5 kt
d. < 5 kt

32. (For this question use annex A)
Flight Munich to London. What is the direction and maximum speed of the jet stream affecting the route between Munich and London ?

a. 050° / 120 km/h
b. 050° / 120 kt
c. 230° / 120 m/sec
d. 220° / 120 kt

33. Why are indications about the height of the tropopause not essential for flight documentation in the tropics?

a. Tropopause information is of no value.
b. The tropopause is generally well above the flight level actually flown.
c. The meteorological services are unable to provide such a chart.
d. The temperatures of the tropical tropopause are always very cold and therefore not important.

34. (For this question use annex A)
At what approximate flight level is the tropopause over Frankfurt?

a. FL 330
b. FL 300
c. FL 350
d. FL 240

35. (For this question use annex I)
To which aerodrome is the following TAF most applicable?
TAF 231019 24014KT 6000 SCT030 BKN100 TEMPO 1113 25020G38KT 2500 +TSRA SCT008 BKN025CB BECMG 1315 28012KT 9999 SCT025 TEMPO 5000 SHRA BKN020 BECMG 1719 27008KT 9999 SCT030

a. EKCH
b. ESSA
c. LFPG
d. ENFB

36. (For this question use annex I)
What is the classification of the air mass affecting position "Q" at 0600 UTC?

a. Polar maritime.
b. Polar continental.
c. Tropical continental.
d. Tropical maritime.

37. (For this question use annex L)
Looking at the chart, at what altitude above Frankfurt would you expect the tropopause to be located?

a. FL 250
b. FL 280
c. FL 300
d. FL 350

38. Which of the following symbols represents a tropical revolving storm?

a. Symbol b)
b. Symbol c)
c. Symbol d)
d. Symbol a)

39. (For this question use annex I)
Which airport, at 1200 UTC, has the lowest probability of precipitation?

a. EFHK
b. LSZH
c. ESSA
d. ENFB

40. (For this question use annex N)
This chart shows the weather conditions on the ground. Which of the following reports reflects weather development at Brussels Airport?

a. TAF EBBR 230716 23016KT 8000 -RA BKN030 OVC070 BECMG 0810 5000 RA BKN020 OVC050 TEMPO 3000 +RA BKN010 OVC030 BECMG 1215 25014KT 8000 SCT030 BKN090 =
b. TAF EBBR 230716 05014KT 5000 OVC015 BECMG 0810 8000 BKN018 BECMG 1013 05015G30KT 9999 SCT025 =
c. TAF EBBR 230716 26012KT 9999 SCT030 BKN080 TEMPO 1013 25020G35KT 3000 TSRA or +SHRA BKN030CB BECMG 1316 VRB02KT 3000 BCFG SCT100 =
d. TAF EBBR 230716 VRB03KT 6000 BR SCT020 BECMG 0811 23005KT 9999 SCT025TCU PROB 40 TEMPO 1216 34012G30KT 3000 TSRA BKN020CB =

41. (For this question use annex C)
What is the temperature deviation in degrees Celsius, from the International Standard Atmosphere overhead Frankfurt ?

a. ISA +12°C
b. ISA +4°C
c. ISA -4°C
d. ISA -12°C

42. (For this question use annex O)
Judging by the chart, what wind speeds can you expect at FL 340 above Rome?

a. 95 kt
b. 140 km/h
c. 145 kt
d. 340 kt

43. (For this question use annex A)
Flight Shannon to London. What amount and type of cloud is forecast for the eastern sector of the route between Shannon and London at FL 220 ?

a. Very well separated cumulonimbus
b. Overcast nimbo layered cumulonimbus
c. Scattered towering cumulus
d. Scattered castellanus

44. (For this question use annex N)
Which typical weather condition is shown by the design for the area of Central Europe ?

a. Easterly waves
b. Westerly waves
c. Uniform pressure pattern
d. Cutting wind

45. (For this question use annex G)
The weather most likely to be experienced at position "D" in summer

a. increasing high and medium cloud cover and generally good visibility
b. mainly overcast with anticyclonic gloom
c. fine and warm with little or no cloud
d. early morning fog lifting to low stratus

46. (For this question use annex N)
At which airport, is the following weather development taking place?
TAF 060716 25006KT 8000 BKN240 BECMG 0710 OVC200 BECMG 1013 23010KT 8000 OVC100 BECMG 1316 23014KT 6000 RA SCT030 OVC050 =

a. LFPO
b. LOWW
c. LEMD
d. EDDL

47. (For this question use annex O)
Over Amsterdam, what amount and general type of cloud would you expect at FL 160 ?

a. 4 oktas broken cumulus
b. Isolated cumulonimbus only
c. 5 to 7 oktas towering cumuliform cloud and with moderate turbulence
d. Mainly 5 to 8 oktas of stratiform cloud in layers

48. (For this question use annex E)
The arrows labeled "r" represents the mean tracks of tropical revolving storms which occur mainly from

a. June to October and are called hurricanes
b. December to April and are called cyclones
c. December to April and are called tornadoes
d. June to October and are called typhoons

49. (For this question use annex A)
Flight Zurich to Rome, ETD 1600 UTC, ETA 1800 UTC. At what flight level would you first expect to encounter clear air turbulence on the climb out from Zurich?

a. FL 180
b. FL 320
c. FL 280
d. FL 220

50. (For this question use annex C)
What is the mean temperature deviation from ISA for the Frankfurt - Rome route at FL160?

a. 12°C warmer than ISA
b. 4°C colder than ISA
c. 4°C warmer than ISA
d. 12°C colder than ISA

51. A pilot is warned of severe icing at certain flight levels by information supplied in

a. SWC and SIGMET
b. TAF and METAR
c. METAR and SIGMET
d. TAF and SIGMET

52. What does the symbol with an "H 450" inside it indicate on a significant weather chart?

a. The upper limit of significant weather at FL 450.
b. The lower limit of the tropopause.
c. The center of a tropopause "high", where the tropopause is at FL 450.
d. The center of a high pressure area at 450 hPa.

53. What information is given on a Significant Weather Chart?

a. The significant weather forecast for the time given on the chart
b. The significant weather that is observed at the time given on the chart
c. The significant weather in a period 3 hours before and 3 hours after the time given on the chart
d. The significant weather forecast for a period 6 hours after the time given on the chart

54. (For this question use annex I)
The attached chart shows the weather conditions on the ground at 1200 UTC on October 10. Which of the following reports reflects weather development at LSZH?

a. TAF LSZH 101601 05020G35KT 8000 BKN015 TEMPO 1720 05018KT 0300 +SHSN VV002 =
b. TAF LSZH 101601 23012KT 6000 RA BKN012 OVC030 TEMPO 2023 22025G40KT 1600 +SNRA BKN003 OVC015 =
c. TAF LSZH 101601 32008KT 9999 SCT030TCU TEMPO 2201 32020G32KT 3000 TSRA BKN020CB =
d. TAF LSZH 101601 VRB02KT 8000 SCT280 BECMG 1618 00000KT 3500 MIFG BECMG 1820 1500 BCFG BECMG 2022 0100 FG VV001 =

55. On WAFC significant weather charts, jet streams are given flight levels. To what does this flight level refer?

a. The flight level of the mean wind in the jet stream
b. The flight level of the maximum wind in the jet stream
c. The highest flight level where the winds are more than 60 knots
d. The average height of the jet stream

56. At what times are WAFC significant weather charts produced?

a. At 0000, 0600, 1200, 1800 UTC
b. At 0000, 0600, 1200, 1800 LMT
c. At 0000 and 1200Z
d. At midnight and midday only

57. What is the validity time for a WAFC significant weather chart?

a. 6 hours
b. 3 hours
c. 30 minutes
d. For a fixed single time only

58. When are WAFC significant weather charts produced?

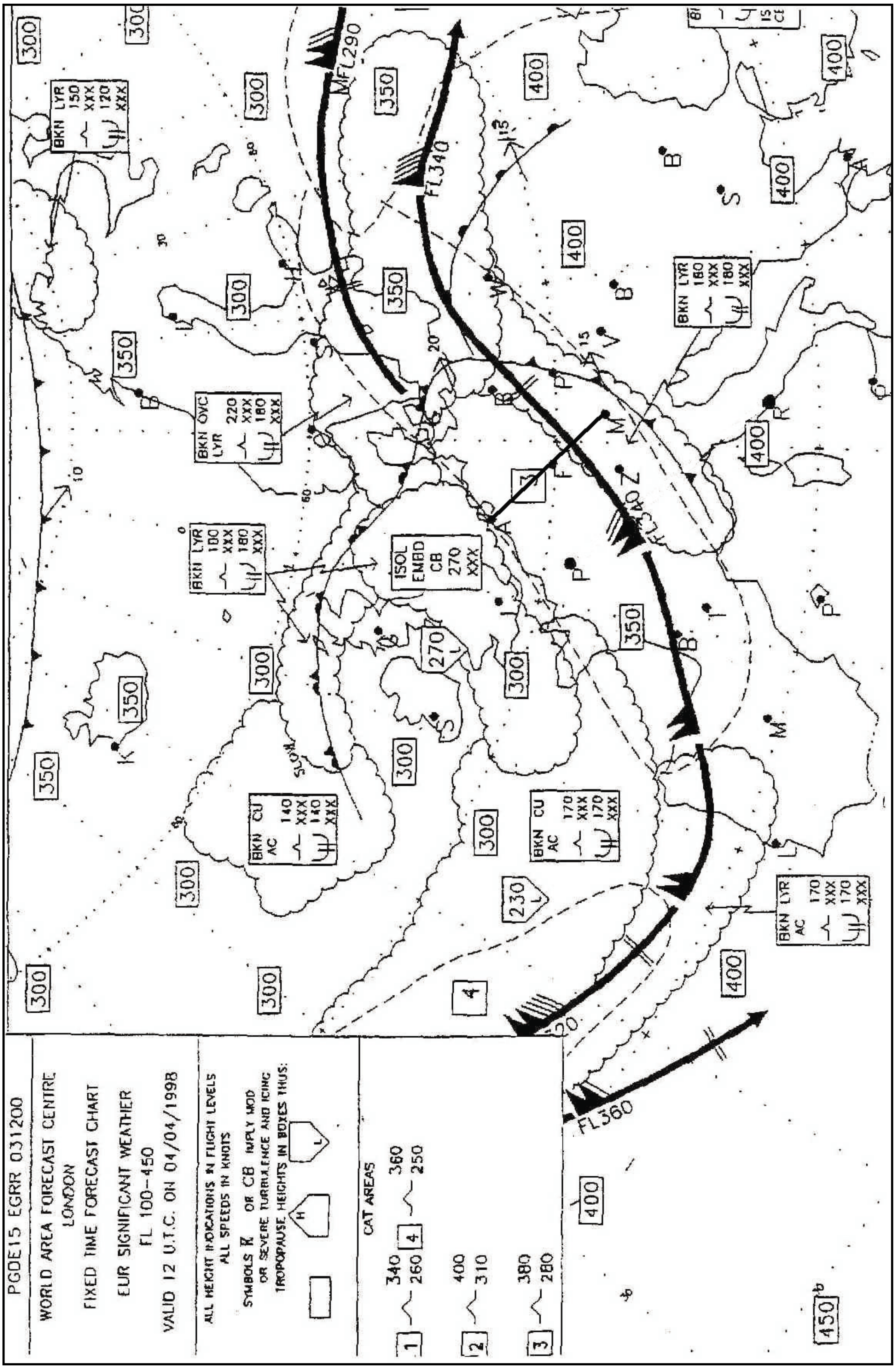
a. Every 3 hours
b. Every 6 hours
c. Every 12 hours
d. At midnight and midday only

59. On WAFC significant weather charts what do the letters CB imply?

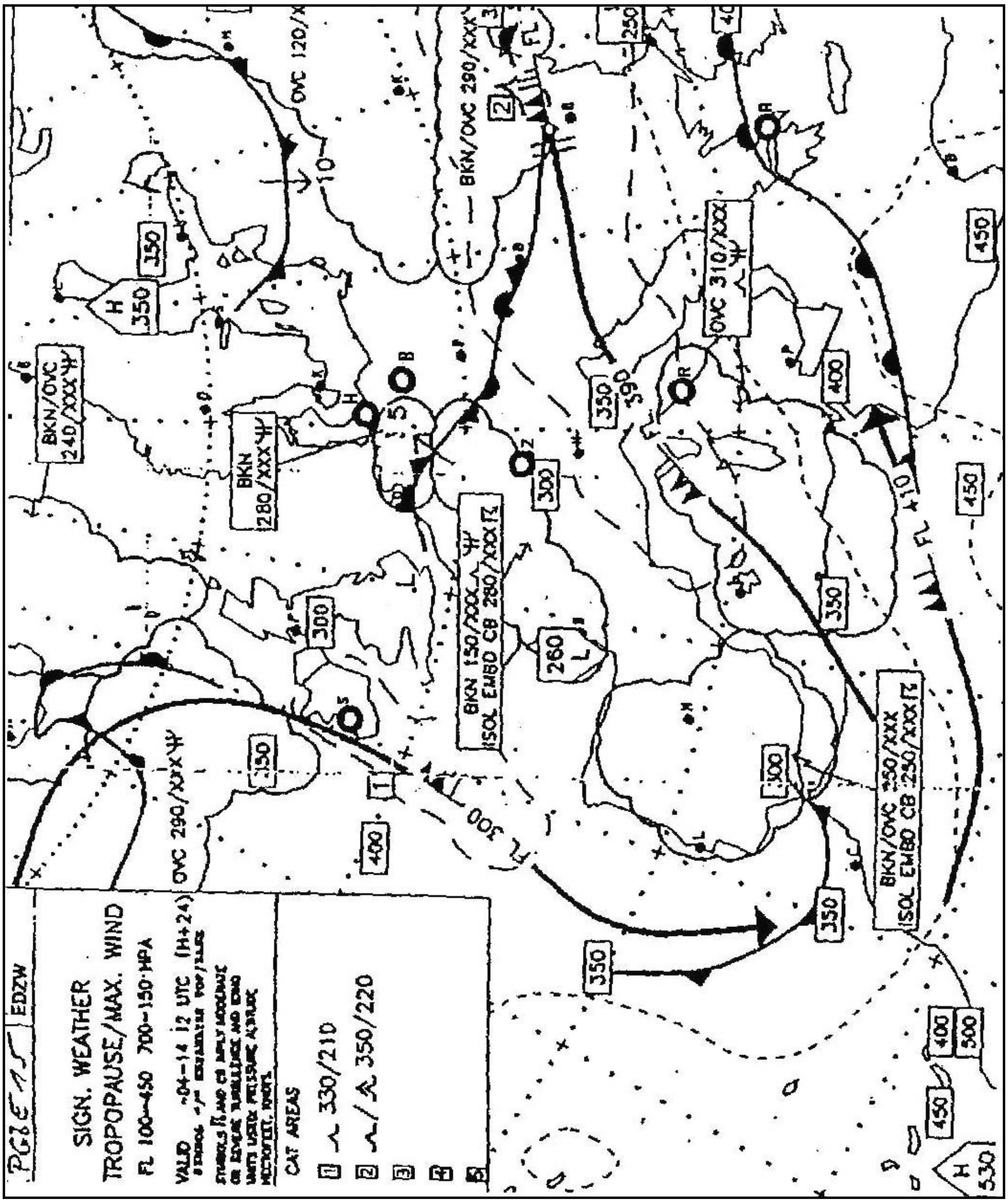
a. Moderate icing and turbulence
b. Moderate to severe icing and turbulence
c. Moderate to severe icing and turbulence and hail
d. Severe icing and turbulence and hail

ANNEXES

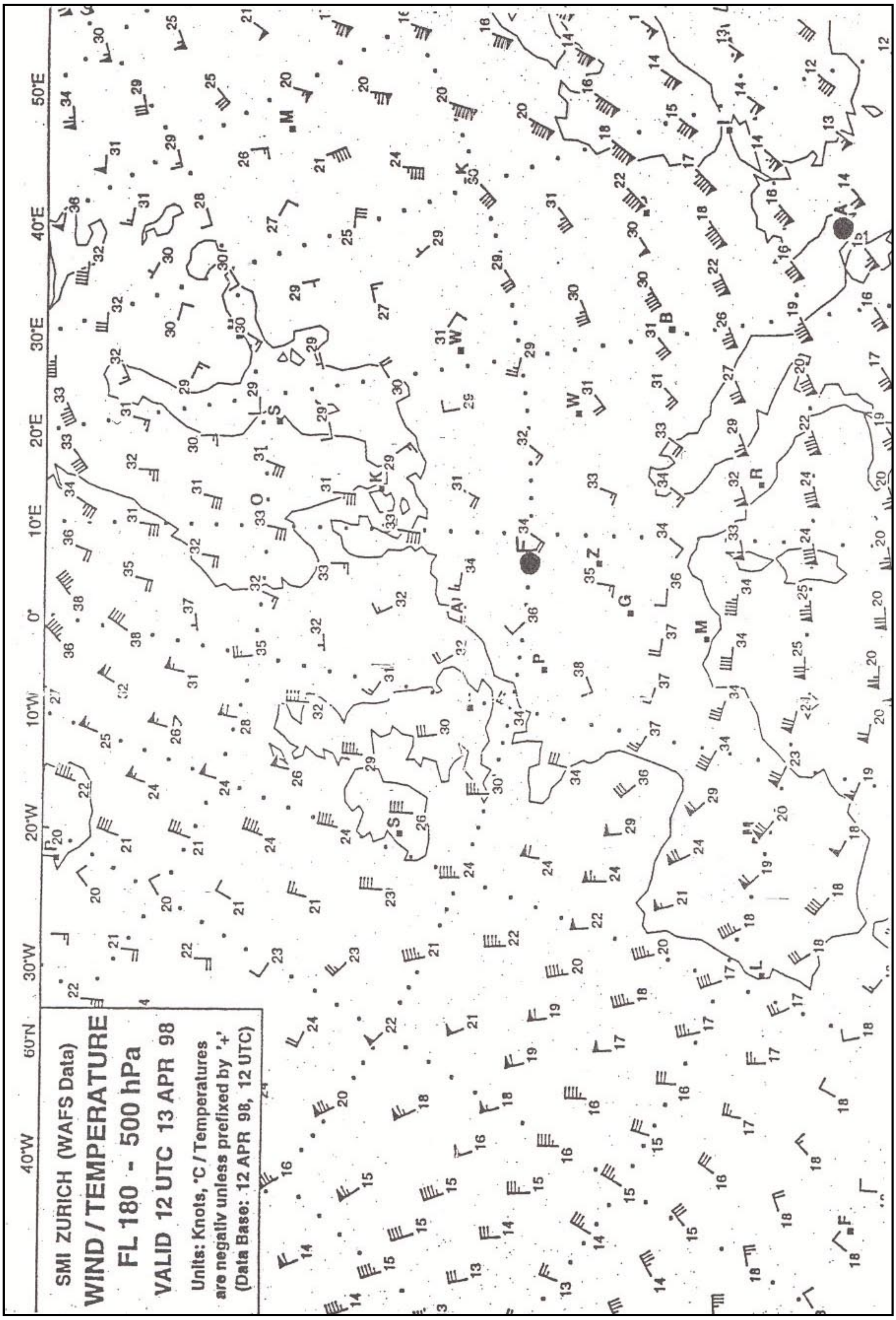
A


PGDE15 EGRR 031200
WORLD AREA FORECAST CENTRE
LONDON
FIXED TIME FORECAST CHART
EUR SIGNIFICANT WEATHER
FL 100-450
VALID 12 U.T.C. ON 04/04/1998
ALL HEIGHT INDICATIONS IN FLIGHT LEVELS
ALL SPEEDS IN KNOTS
OR CB IMPLY MOD OR SEVERE TURBULENCE AND ICING
TROPOPAUSE HEIGHTS IN BOXES THUS:
CAT AREAS
FL290
FL340
FL360
ISOL EMBD CB 270 XXX
BKN OVC LYR 220 XXX 180 XXX
BKN CU AC 140 XXX 140 XXX
BKN CU AC 170 XXX 170 XXX

B


EDZW
SIGN. WEATHER
TROPOPAUSE/MAX. WIND
CAT AREAS
330/210
350/220
BKN/OVC 240/XXX
BKN 280/XXX
OVC 290/XXX
OVC 310/XXX
BKN 150/XXX
ISOL EMBD CB 280/XXX
BKN/OVC 350/XXX
ISOL EMBD CB 250/XXX
FL 300
FL 410

C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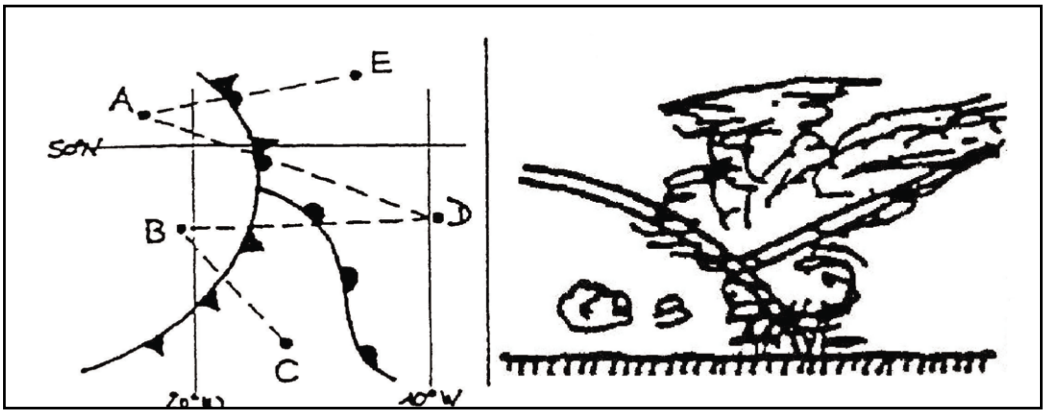
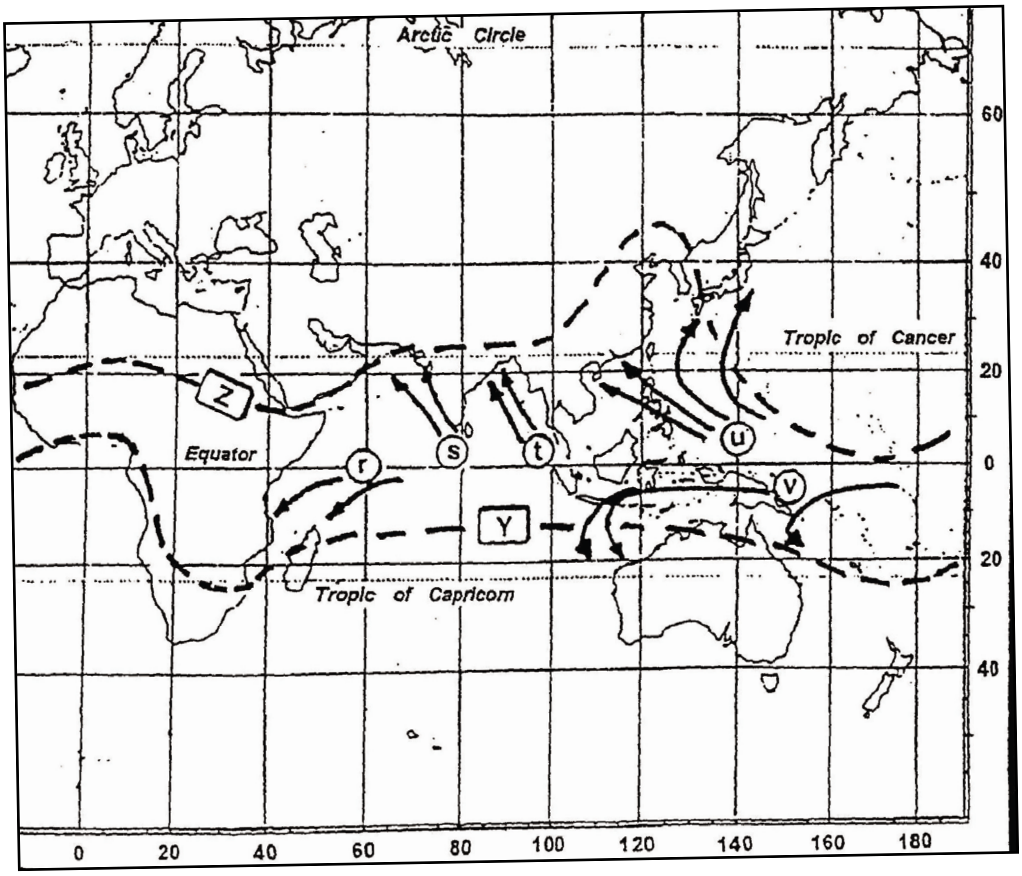
WIND / TEMPERATURE
FL 180 - 500 hPa
VALID 12 UTC 13 APR 98
Units: Knots, °C / Temperatures are negativ unless prefixed by '+'
(Data Base: 12 APR 98, 12 UTC)

D


A
E
50°N
B
D
C
10°W

E


Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Z
Y
r
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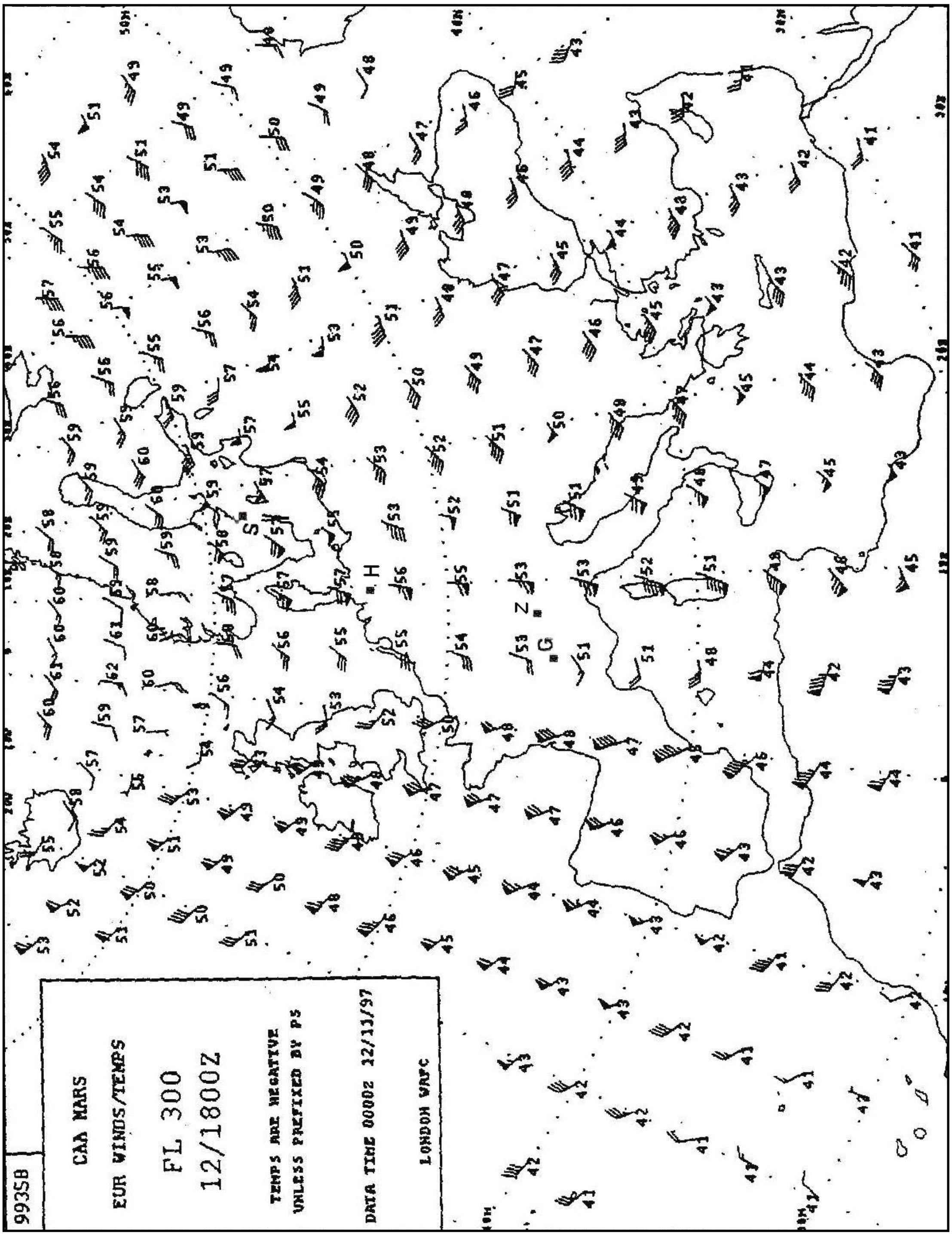
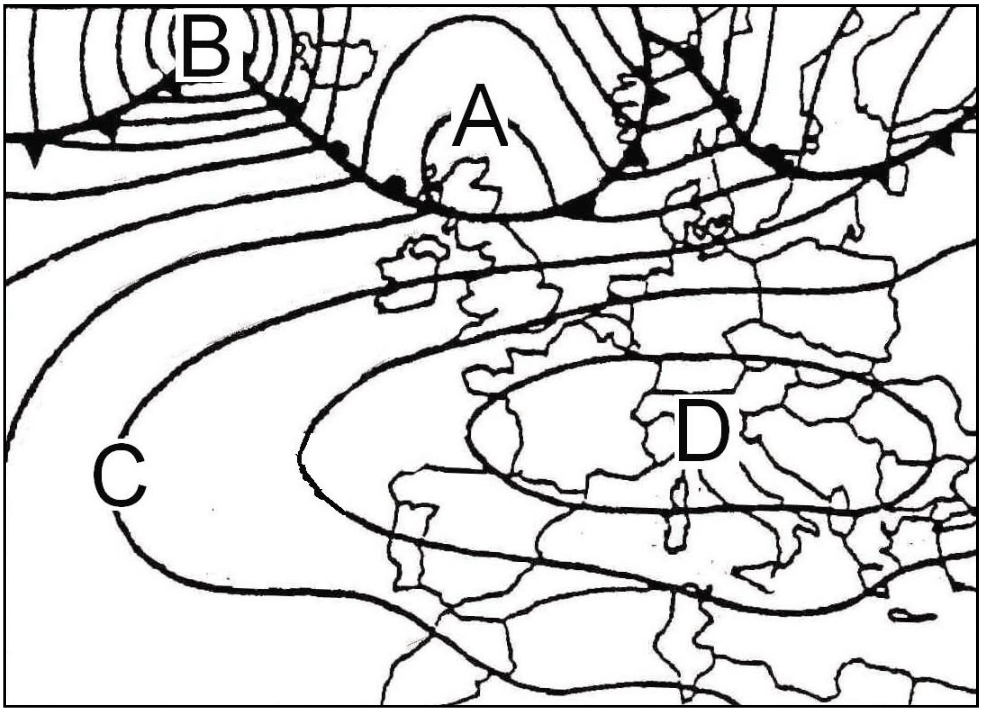
40
20
0
20
40
0
20
40
60
80
100
120
140
160
180

F


9935B
CAA MARS
EUR WINDS/TEMPS
FL 300
12/1800Z
TEMPS ARE NEGATIVE
UNLESS PREFIXED BY PS
DATA TIME 0000Z 12/11/97
LONDON WAFC

G



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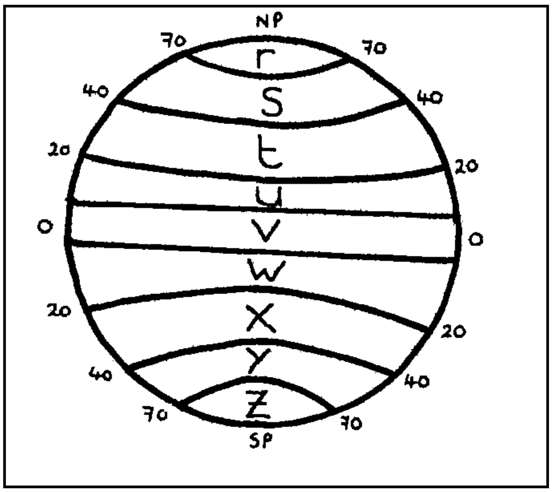

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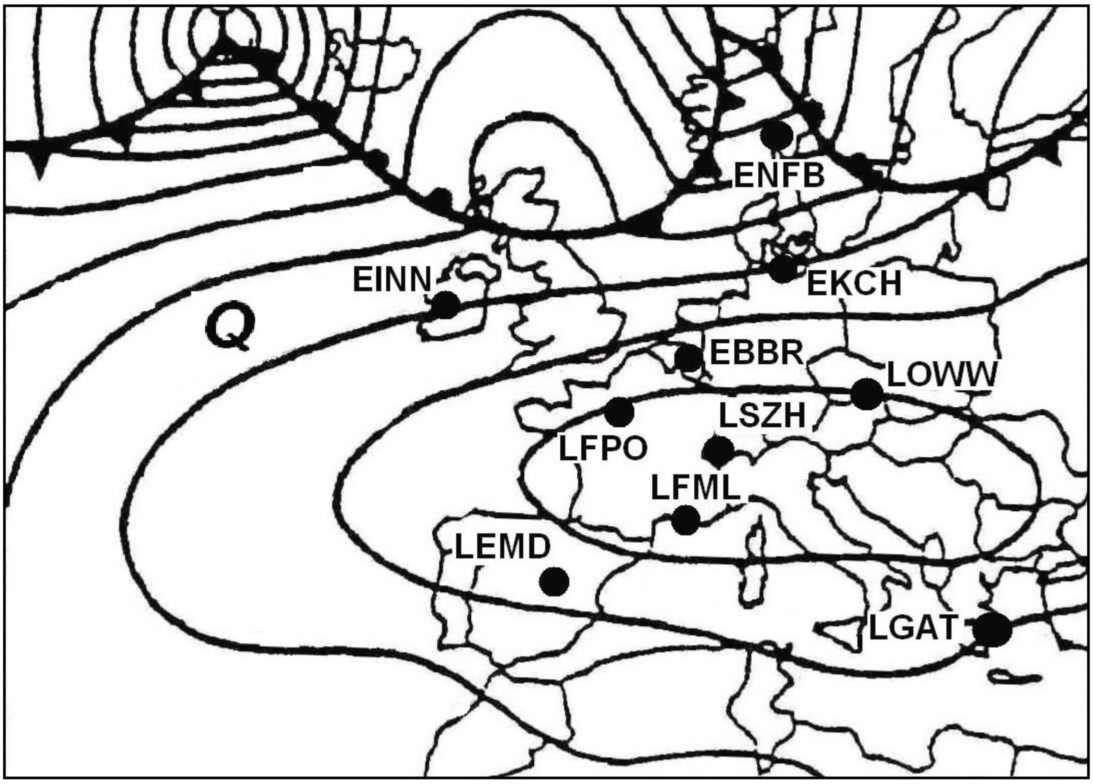

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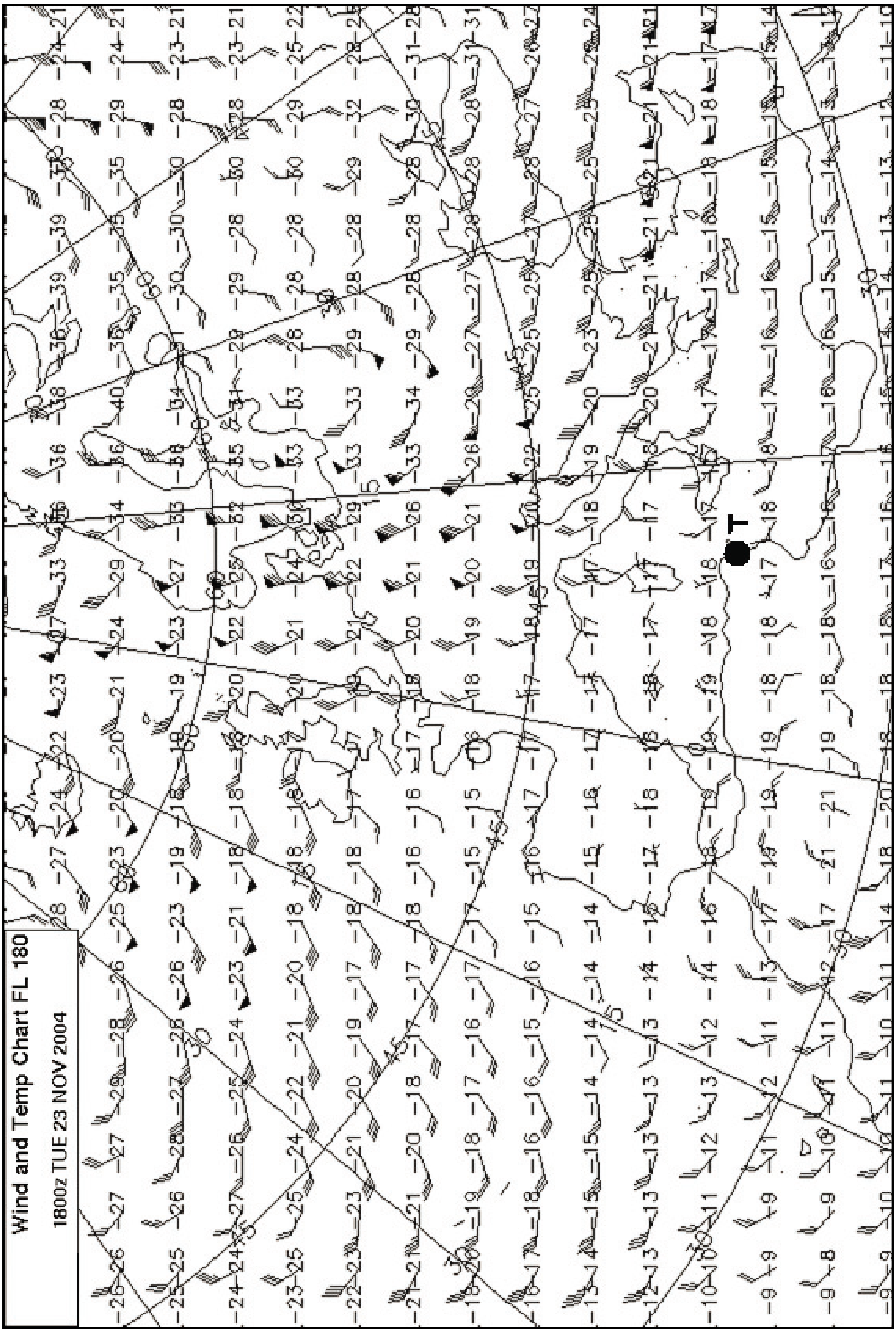

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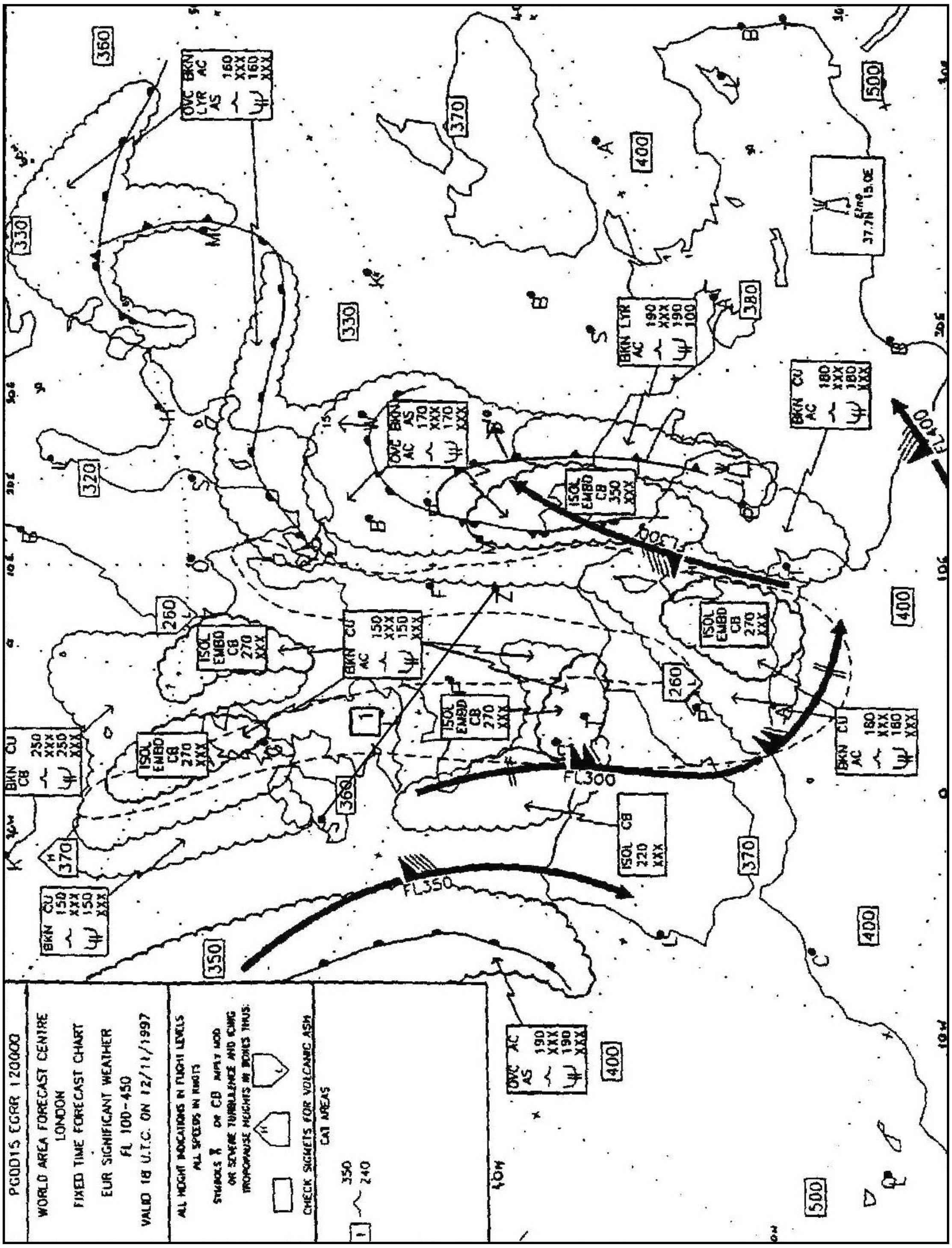
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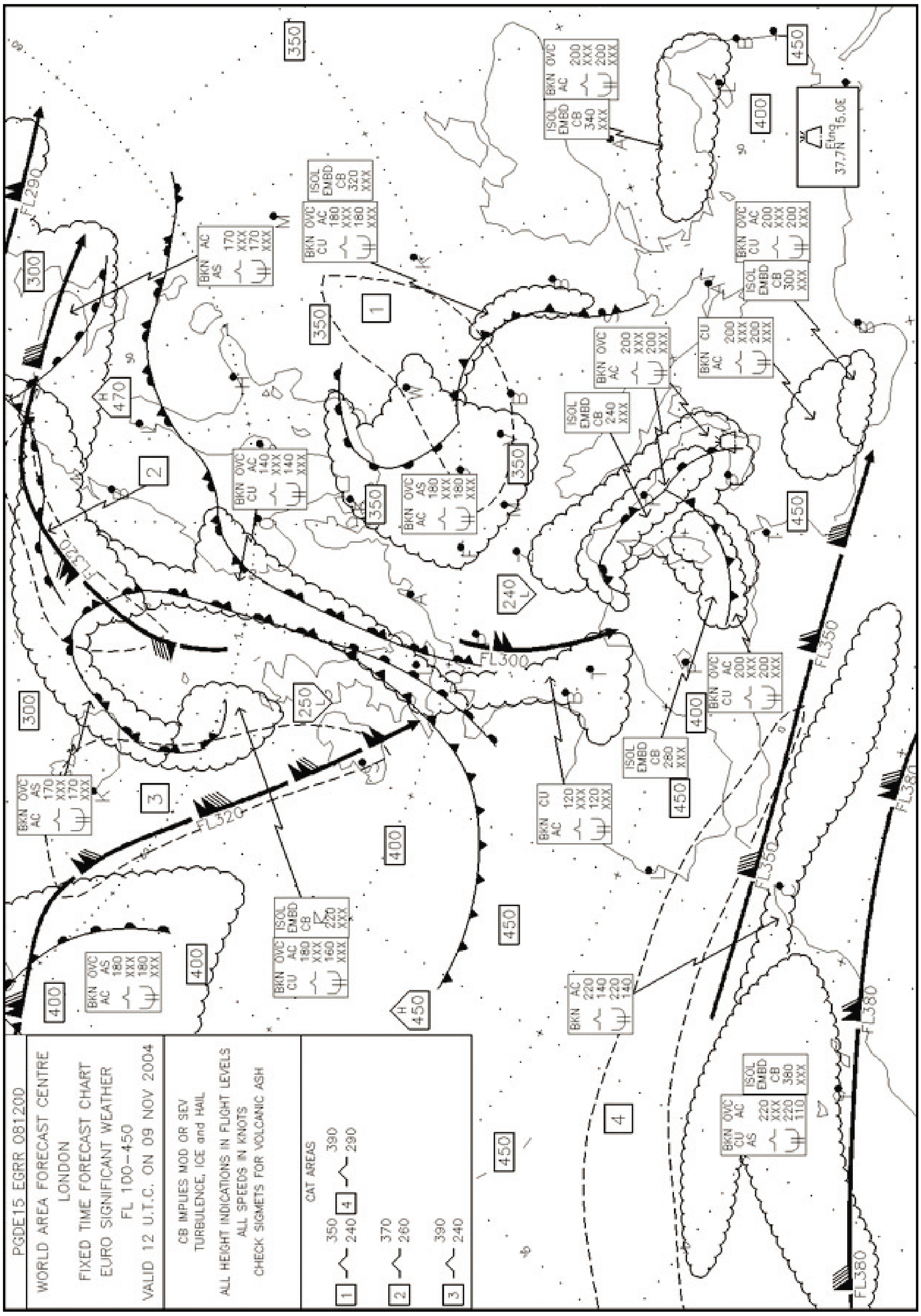
WORLD AREA FORECAST CENTRE
LONDON
FIXED TIME FORECAST CHART
EUR SIGNIFICANT WEATHER
FL 100-450
VALID 18 U.T.C. ON 12/11/1997
CHECK SIGMETS FOR VOLCANIC ASH
FL350
FL300
FL400

L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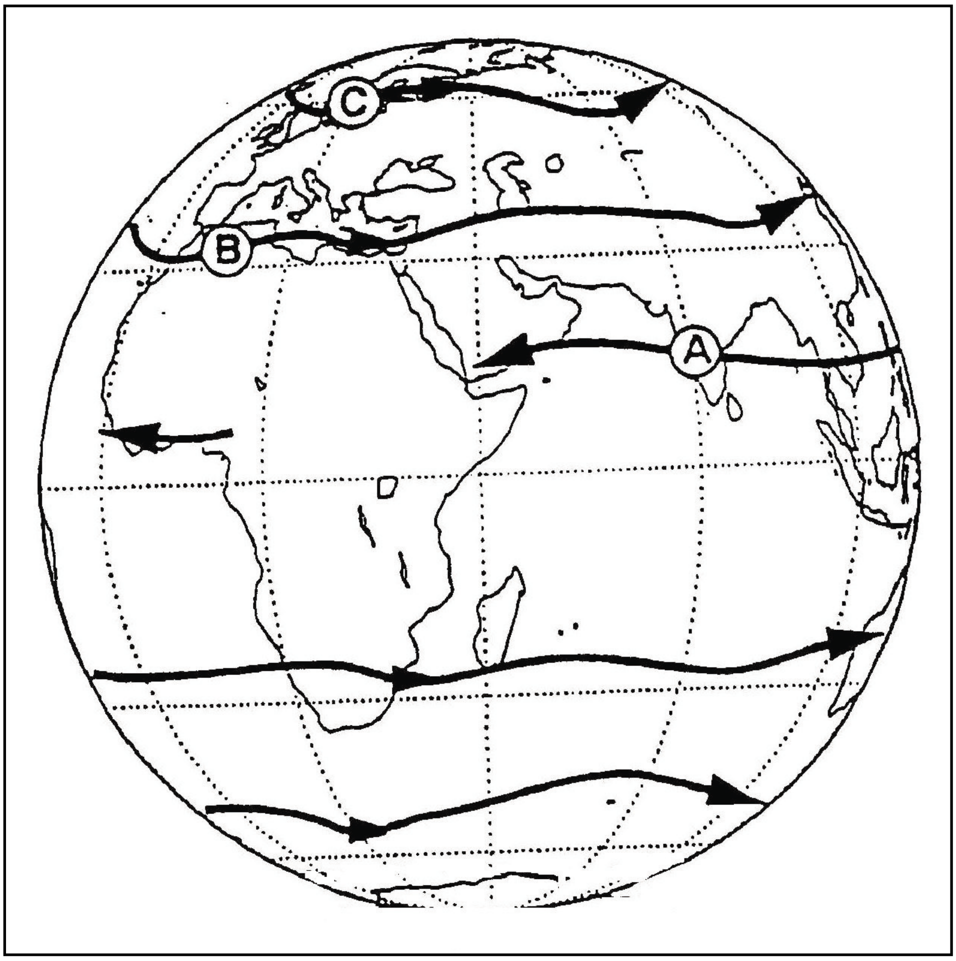
WORLD AREA FORECAST CENTRE
LONDON
FIXED TIME FORECAST CHART
EURO SIGNIFICANT WEATHER
FL 100-450
VALID 12 U.T.C. ON 09 NOV 2004
CB IMPLIES MOD OR SEV
TURBULENCE, ICE and HAIL
ALL HEIGHT INDICATIONS IN FLIGHT LEVELS
ALL SPEEDS IN KNOTS
CHECK SIGMETS FOR VOLCANIC ASH
CAT AREAS

M



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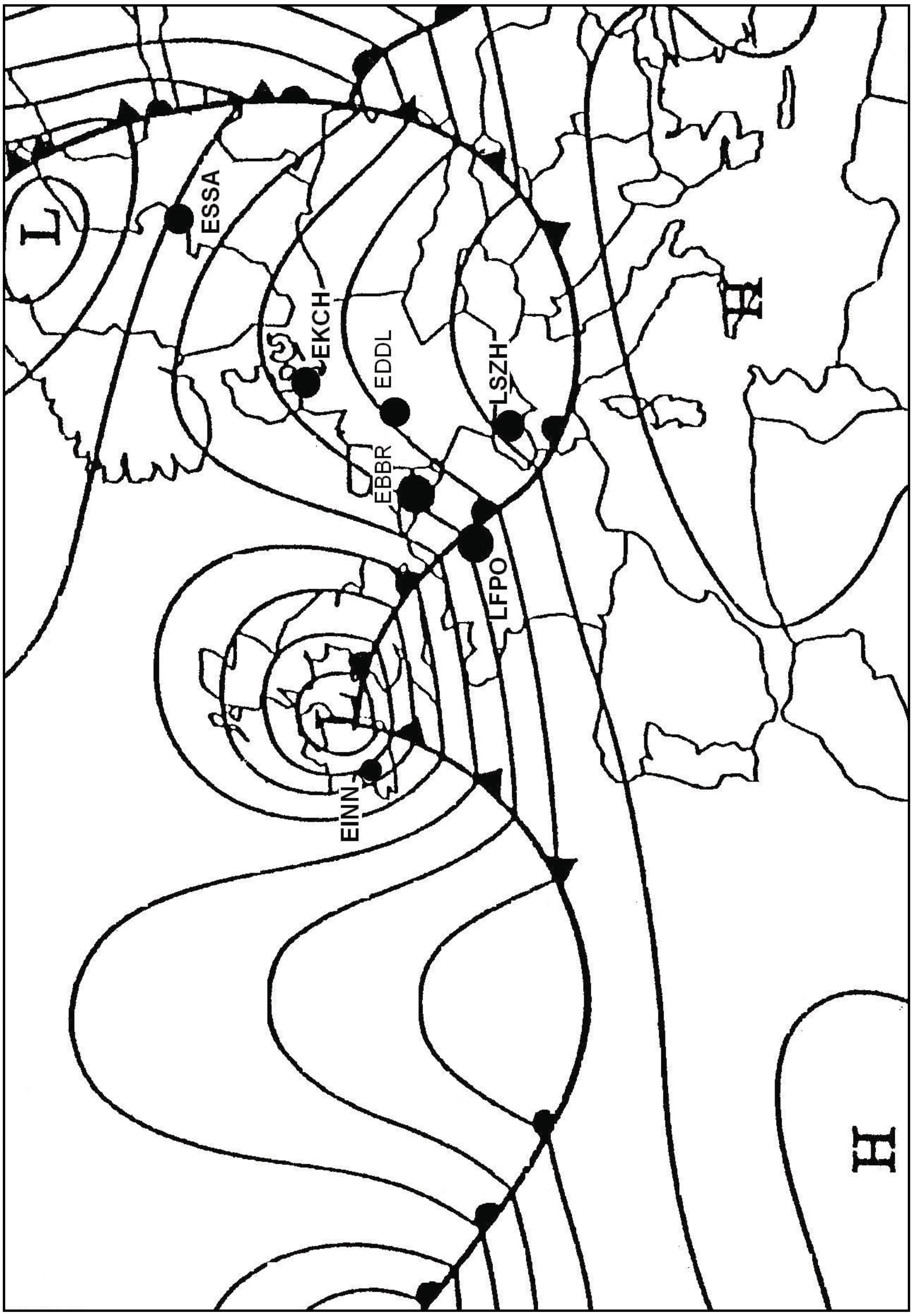

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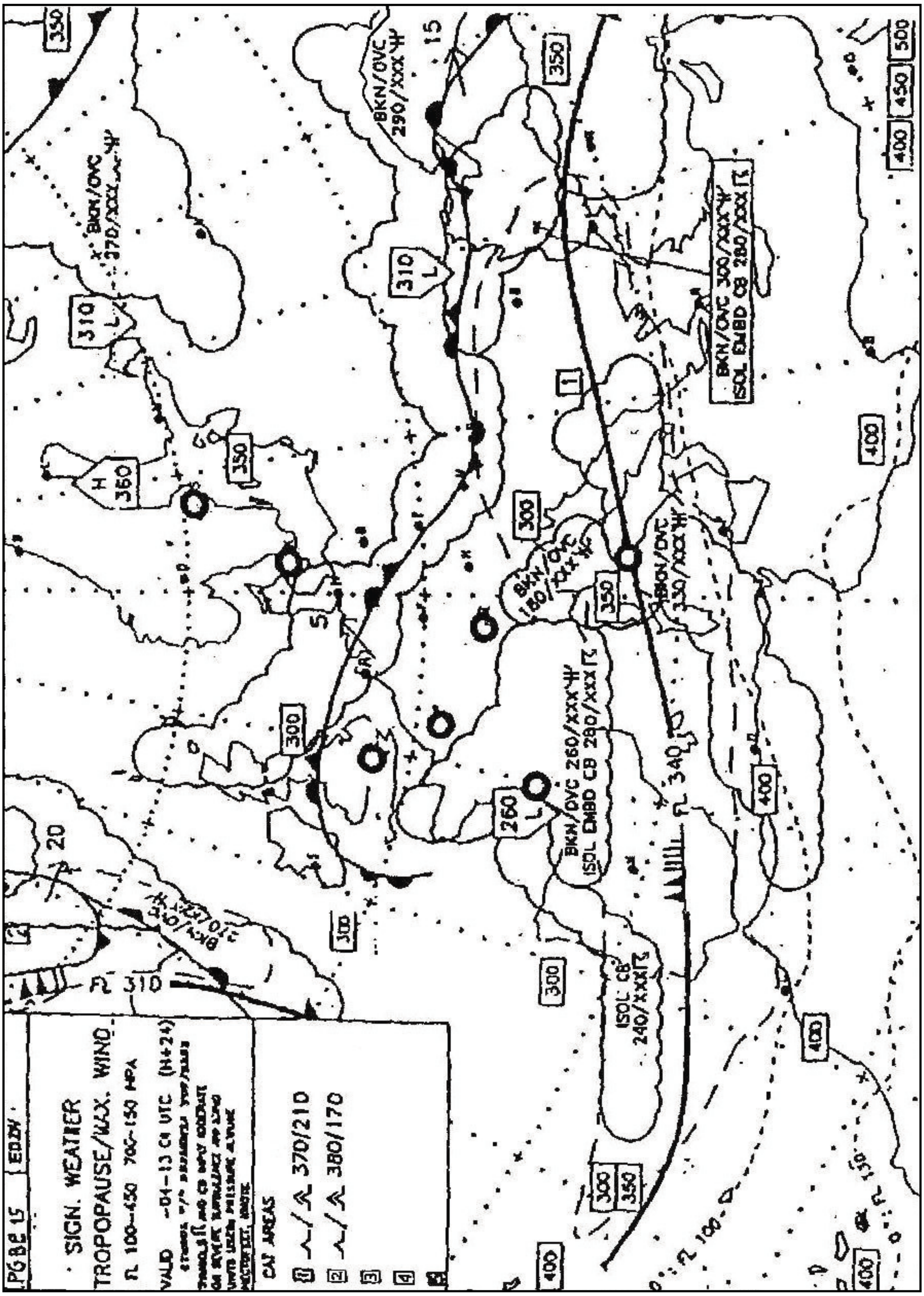

SIGN. WEATHER
TROPOPAUSE/MAX. WIND
CAT AREAS
FL 310
FL 340
BKN/OVC 260/XXX
ISOL EMBD CB 280/XXX
ISOL CB 240/XXX

ANSWERS

1.	D	21.	D	41.	D
2.	C	22.	B	42.	C
3.	D	23.	A	43.	A
4.	B	24.	D	44.	B
5.	D	25.	B	45.	C
6.	D	26.	D	46.	D
7.	B	27.	C	47.	D
8.	B	28.	B	48.	B
9.	D	29.	C	49.	C
10.	B	30.	C	50.	D
11.	A	31.	D	51.	A
12.	A	32.	D	52.	C
13.	C	33.	B	53.	A
14.	D	34.	C	54.	D
15.	A	35.	D	55.	B
16.	C	36.	D	56.	A
17.	A	37.	C	57.	D
18.	C	38.	D	58.	A
19.	A	39.	B	59.	C
20.	D	40.	A		

CHAPTER THIRTY

REVISION QUESTIONS

Contents

QUESTIONS

1 MSA given as 12,000ft, flying over mountains in temperatures +9°C, QNH set as 1023 (obtained from a nearby airfield). What will the true altitude be when 12,000ft is reached?

a. 11,940
b. 11,148
c. 12,210
d. 12,864

2 Why do TRS not occur in the SE Pacific and South Atlantic?

a. Low water temperatures
b. No Coriolis effect
c. SE trade crosses equator
d. SE trade winds blow there

3 In the Northern Hemisphere a man observes a low pressure system passing him to the south, from west to east. What wind will he experience?

a. Backs the Veers
b. Constantly Backs
c. Veers then Backs
d. Backs then steady

4 When would a rotor cloud be ahead of a Cb?

a. Mature stage
b. Cumulus stage
c. Dissipating stage
d. Initial stage

5 What are the conditions under which advection fog will be formed?

a. Warm moist air over cold surface
b. Cold dry air over warm surface
c. Warm dry air over cold surface
d. Cold moist air over warm surface

6 What cloud does hail fall from?

a. Cb
b. Ns
c. Cu
d. Ci

7 What is a cold pool, in the northern hemisphere?

a. Cold air found on the lee side of the Alps in winter in a cold north westerly air stream
b. Cold air brought down from the North behind frontal systems
c. Air from tropical continental origin
d. Air from Polar maritime origin only

8 What is Relative Humidity dependent upon?

a. Moisture content and temperature of the air
b. Temperature of the air
c. Temperature and pressure
d. Moisture content of the air

9 If the ELR is 0.65°C/100m

a. Atmosphere is conditionally stable
b. Atmosphere is stable
c. Atmosphere is unstable
d. Atmosphere is stable when dry

10 Where are you most likely to find moderate to severe icing?

a. In upper levels of Cumulonimbus Capillatus
b. Nimbostratus
c. Stratus
d. Cirrus

11 Height of the tropopause at 50°N

a. 11 km
b. 16 km
c. 5 km
d. 20 km

12 What are the indications of a TRS from a great distance?

a. Thick Ci
b. Thick Cb's
c. Ns
d. Sc

13 Flying form London to Bombay in January, what average wind might you expect?

a. Light easterly
b. Light westerly
c. Westerly polar front jet stream
d. Tropical Easterly jet

14 What pressure systems affect the North Atlantic in summer?

a. Azores low, Scandinavian high
b. Azores low, North Canadian low
c. North Canadian low, Azores High
d. Azores high, Scandinavian High

15 A characteristic of a stable air mass

a. Lapse rate of 1°C/100m
b. Rising air slows down and dissipates
c. Lapse rate of 0.3°C/100m
d. Good visibility and showers

16 How do you recognise high level jet streams and associated CAT?

a. High pressure centre at high level
b. Streaks of Cirrus
c. High level dust
d. Lenticularis

17 Which conditions lead to mountain waves?

a. Unstable moist air, speeds <5 kts across the ridge
b. Stable air, speed, >20 kts across the ridge
c. Unstable air, speed >20 kts across the ridge
d. Stable air, speed >30kts, parallel to the ridge

18 Where is the coldest air in a cold occlusion?

a. Behind the cold front
b. At the junction of the occlusion
c. In front of the occlusion
d. Behind the warm front

19 What causes low level cloud in front of the warm front?

a. Rain falling into the cold air
b. Rain falling into warm air
c. Warm air passing over cold surface
d. Cold air passing over warm surface

20 Where is the largest chance of squalls occurring?

a. In front of an active cold front
b. Above the occlusion along the cold front
c. Behind the cold front
d. Above the occlusion along the warm front

21 ELR is 1°C/100m

a. Neutral when dry
b. Absolute stability
c. Absolute instability
d. Conditional stability

22 Typical tornado diameter

a. Less than 100m
b. 100 - 150m
c. 2 - 6 km
d. More than 10 km

23 In the areas of the ITCZ why are the heights of the tropopause not reported?

a. Because it's too cold
b. Because it cannot be measured
c. Because it is likely to be above your FL
d. Because it is in the stratosphere

24 Flying conditions in Ci cloud and horizontal visibility

a. Less than 500m vis, light/mod clear icing
b. Greater than 1000m vis, light/mod rime ice
c. Less then 500m vis, no icing
d. Greater than 1000m vis, no icing

25 Description of radiation fog

a. Marked increase in ground wind speed
b. Marked increase in wind speed close to the ground
c. Ground cooling due to radiation
d. Warm air over warm surface

26 Flying over an airfield, at the surface the temp. is -5°C, freezing level is at 3000ft, rain is falling from clouds with a base of 4000ft caused by warm air rising above cold air. Where would you experience icing?

a. Never
b. No icing because your not in cloud
c. Between 3000 - 4000ft
d. Below 3000ft

27 Climbing out of Dhahran, Saudi Arabia on a clear night you suddenly lose your rate of climb. Why?

a. Engine full of sand
b. Downdraft
c. Marked temperature inversion
d. VSI blocked

28 What is the composition of Ci cloud?

a. Super cooled water droplets
b. Ice crystals
c. Water droplets
d. Smoke particles

29 What cloud types are classified as medium cloud?

a. Ns + Sc
b. Ac + As
c. Cb + St
d. Ci + Cs

30 What is the approximate height of the tropopause at 50°N?

a. 14 km
b. 13 km
c. 11 km
d. 16 km

31 Isolated TS occur mostly due to

a. Warm frontal uplift
b. Cold front uplift
c. Insolation
d. Convection

32 What type of cloud is associated with drizzle?

a. St
b. Cb
c. Ci
d. Ac

33 Fair weather cumulus gives an indication of

a. Poor visibility
b. Thunderstorms
c. Turbulence
d. Smooth flying below

34 What cloud type are you least likely to get icing from?

a. Ci
b. Cu
c. St
d. Ns

35 When flying from South to North in the Southern Hemisphere crossing over and above a polar frontal jet at FL 400, what might happen to the OAT?

a. initially fall then rise
b. initially rise then fall
c. rise
d. fall

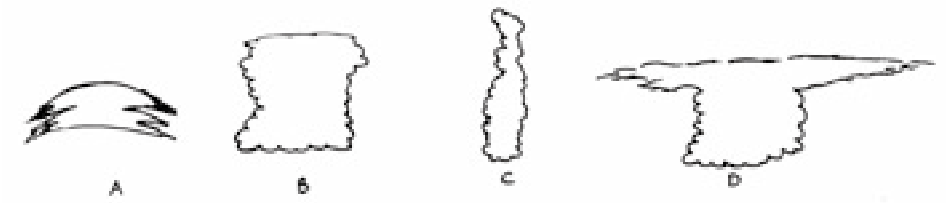
36 What type of jet stream blows constantly through the northern hemisphere?

a. Arctic jet
b. Equatorial jet
c. Polar night jet
d. Sub tropical jet

37 Why is clear ice such a problem?

a. Translucent and forms along leading edges
b. Not translucent and forms along leading edges
c. Very heavy and can affect aircraft controls and surfaces
d. Forms in clear air

38 What best shows Altocumulus Lenticularis?

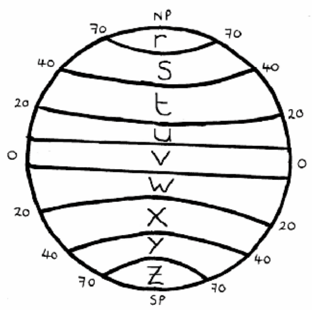


39 A steep pressure gradient is characterised by

a. Isobars close together, strengthened wind
b. Isobars far apart, decreased wind
c. Isobars close together, temperature increasing
d. Isobars far apart, temperature decreasing

40 Assuming a generalised zonal distribution of winds, which zones on the diagram contain the temperate lows?

a. t
b. t + x
c. s + y
d. u + w



41 If you fly with left drift in the Northern Hemisphere, what is happening to your true altitude?

a. Increases
b. Decreases
c. Stays the same
d. Cannot tell

42 What type of icing requires immediate diversion?

a. Light
b. Moderate
c. Severe
d. extreme

43 What is the weather inside the warm sector in a frontal depression in central Europe?

a. Fair weather Cu
b. Low stratus and drizzle
c. Cb and thunderstorms
d. As with light rain

44 Flying from Dakar to Rio de Janeiro, where is the ITCZ in winter?

a. >8°S
b. 0 - 7°N
c. 8 - 12°N
d. 12 - 16°N

45 At a stationary front

a. Winds blow parallel to the isobars and front
b. Winds blow perpendicular to the isobars
c. Winds are always very strong
d. Winds are usually gusty and variable

46 In central Europe, where are the greatest wind speeds?

a. Tropopause level
b. 5500m
c. Where the air converges
d. Above the Alps

47 Sublimation is

a. Solid to vapour
b. Vapour to liquid
c. Liquid to vapour
d. Liquid to solid

48 Standing in the Northern Hemisphere, north of a polar frontal depression travelling west to east, the wind will

a. Continually veer
b. Continually back
c. Back then veer
d. Veer then back

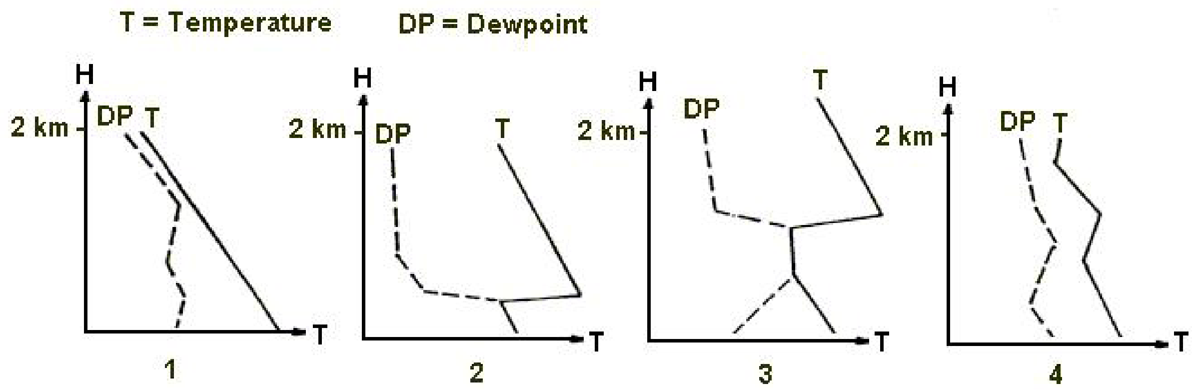
49 What is the coldest time of the day?

a. 1hr before sunrise
b. 30 min before sunrise
c. at exact moment of sunrise
d. 30 min after sunrise

50. Which of the following would lead to the formation of Advection fog

a. warm moist air over cold surface, clear night and light winds
b. cold dry air over warm surface, clear night and light winds
c. cold moist air over warm surface, cloud night with strong winds
d. warm dry air over cold surface, cloudy night with moderate winds

51 Using the radiosonde diagrams, which would most likely show ground fog?



a. 1
b. 2
c. 3
d. 4

52 Which of the following would lead to the formation of Steaming fog

a. cold air over warm sea
b. warm air over cold sea
c. cold sea near coast
d. warm air over land

53 When is diurnal variation a maximum?

a. Clear sky, still wind
b. Clear sky, strong wind
c. OVC, still
d. OVC, windy

54 QNH at Timbuktu (200m AMSL) is 1015 hPa. What is the QFE? (Assume 1 hPa = 8m)

a. 1000
b. 990
c. 1020
d. 995

55 The Arctic Jet core is at:

a. 20,000ft
b. 30,000ft
c. 40,000ft
d. 50,000ft

56 If flying cross country at FL50 you first see NS, AS, CC then CI, you can expect:

a. Increasing temperature
b. Decreasing temperature
c. A veer in the wind
d. Increase in pressure

57 Which is likely to cause aquaplaning?

a. +RA
b. SA
c. FG
d. DS

58 Prevailing winds in North West. Africa will be

a. SW monsoon in summer, NE trade winds in winter
b. SE monsoon in summer, NW trade winds in winter
c. SE trade wind in summer, NE monsoon in winter
d. SE trade wind in winter, NE monsoon in summer

59 ATC will only report wind as gusting if:

a. Gust speeds exceeds mean by >15kts
b. Gusts to over 25kts
c. Gusts exceed mean by 10kts
d. Gusts to over 25kts

60 Hill fog will be most likely when:

a. Clear sky, little wind, dry air
b. Humid, stable, blowing onto a range of hills
c. Precipitation is lifted by air blowing over the hills
d. High RH, unstable

61 In temperate latitudes in summer what conditions would you expect in the centre of a high pressure system?

a. TS, CB
b. calm winds, haze
c. TS, SH
d. NS

62 Above a stable layer in the lower troposphere in an old high pressure system is called:

a. radiation inversion
b. subsidence inversion
c. frontal inversion
d. terrestrial inversion

63 If the pressure level surface bulges upwards, the pressure system is a:

a. cold, low
b. warm, low
c. cold, high
d. warm, high

64 What is a land breeze?

a. From land over water at night
b. From land over sea by day
c. From sea over land by night
d. From sea over land by day

65 When travelling from Stockholm (55N 18E) to Rio de Janeiro (22S 80W), do you encounter:

a. Polar Front jet stream then sub tropical jet then polar jet
b. Polar Front jet then 1 or 2 sub tropical jets
c. One Sub tropical jet stream
d. One sub tropical jet stream then one polar front jet

66 Why does air cool as it rises?

a. It expands
b. It contracts
c. The air is colder at higher latitudes
d. The air is colder at higher altitudes

67 When flying at FL180 in the Southern Hemisphere you experience a left crosswind. What is happening to your true altitude if indicated altitude is constant?

a. Remains the same
b. Increasing
c. Decreasing
d. Impossible to tell

68 In a polar front jet stream in the Northern Hemisphere, where is there likely to be the greatest probability of turbulence?

a. above the jet core in the boundary between warm and cold air
b. looking downstream, to the right
c. in the core
d. looking downstream, to the left

69 Dew point is defined as:

a. The lowest temperature at which evaporation will occur for a given pressure
b. The lowest temperature to which air must be cooled in order to reduce the relative humidity
c. The temperature below which the change of state for a given volume of air will result in absorption of latent heat
d. The temperature to which moist air must be cooled to reach saturation

70 Flying from Marseilles (QNH 1012) to Palma (QNH 1015) at FL100. You dont reset the altimeter, why would true altitude be the same throughout the flight?

a. Not possible to tell
b. Air at Palma is warmer than air at Marseilles
c. Air at Marseilles is warmer than air at Palma
d. Blocked static vent

71 FL180, Northern Hemisphere with a wind from the left, what can you say about temperature with a heading of 360°?

a. Not possible to tell without a pressure
b. Increases from South to North
c. Increases from North to South
d. Nothing

72 From which of the following can the stability of the atmosphere be determined?

a. surface pressure
b. surface temperature
c. DALR
d. ELR

73 How do you define convection?

a. Horizontal movement of air
b. Vertical movement of air
c. Same as advection
d. Same as conduction

74 In a class A aircraft if you encounter freezing rain, do you:

a. Climb to the cooler air above
b. Climb to the warmer air above
c. Accelerate
d. Descend

75 When heading South in the Southern Hemisphere you experience Starboard drift:

a. You are flying towards a lower temperature
b. You are flying away from a lower temperature
c. You are flying towards a low pressure
d. You are flying out of a high

76 When is the latest time radiation fog is most likely?

a. Just after dawn
b. Late afternoon
c. Midday
d. Midnight

77 When are thunderstorms most likely in Europe?

a. Just after dawn
b. Late afternoon
c. Midday
d. Midnight

78 How does the level of the tropopause vary with latitude in the Northern Hemisphere?

a. Decreases North - South
b. Decreases South - North
c. Constant
d. It varies with longitude not latitude

79 What is the tropopause?

a. The layer between the troposphere and stratosphere
b. The boundary between the troposphere and stratosphere
c. Where temperature increases with height
d. Upper boundary to C.A.T.

80 Where do you find the majority of the air within atmosphere?

a. Troposphere
b. Stratosphere
c. Tropopause
d. Mesosphere

81 What are Lenticularis clouds a possible indication of?

a. Mountain waves
b. Instability
c. Developing Cu and Cb
d. Horizontal wind shear in the upper atmosphere

82 What are the factors affecting the Geostrophic wind?

a. PGF, θ, Ω, ρ
b. θ, Ω, ρ
c. Ω, ρ
d. ρ

83 What is the Bora?

a. Cold katabatic wind over the Adriatic
b. Northerly wind blowing from the Mediterranean
c. Warm anabatic wind blowing to the Mediterranean
d. An anabatic wind in the Rockies

84 Where is the 300mb level approx. in ISA?

a. 30,000ft
b. 39,000ft
c. 18,000ft
d. 10,000ft

85 What is the usual procedure when encountering CAT en-route?

a. Request climb to get out of it
b. Turn around immediately
c. Descend immediately to clear it
d. Accelerate through it and stay level

86 When are cyclones most likely?

a. Mid Winter
b. Late Autumn
c. Late Summer
d. Late Spring

87 At a certain position the temperature on the 300 hPa chart is -48°C. According to the chart the tropopause is at FL330. The most likely temperature at FL350 is:

a. -54°C
b. -50°C
c. -56.5°C
d. 58°C

88 When are the rains most likely in Equatorial Africa?

a. March to May, August to October
b. March to May, October to November
c. June to July
d. December to January

89 What is the likely hazard association with the Harmattan?

a. Poor visibility from dust and sand
b. Sand up to FL150
c. Thunderstorms
d. Dense fog

90 General surface winds in West Africa with ITCZ to the north:

a. NE trade wind to the north, SW monsoon to the south
b. East - West
c. SE trade winds to the north, NE trade winds to the south
d. West - East

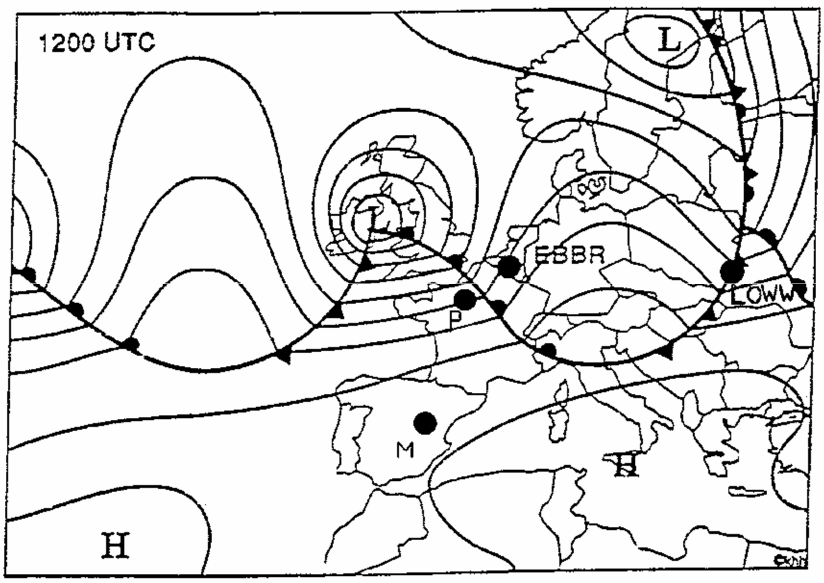
91 In what cloud is icing and turbulence most severe?

a. Cb
b. Ns
c. Sc
d. Ci

92 What will snow most likely fall from?

a. Ns
b. Ci
c. Cs
d. Ac

93 Referring to the diagram below the TAF applies best to which aerodrome
19010KT 8000 RA BKN014 TEMPO 1518 4000 RADZ BKN010



a. EBBR
b. Madrid
c. Paris
d. LOWW

94 Rime ice is caused by:

a. Large Super cooled water droplets
b. Small Super cooled water droplets
c. Slow freezing of water droplets onto the wing
d. Rapid re-freezing of large water droplets

95 What is the most severe form of icing?

a. Dry Ice
b. Hoar frost
c. Clear ice
d. Rime ice

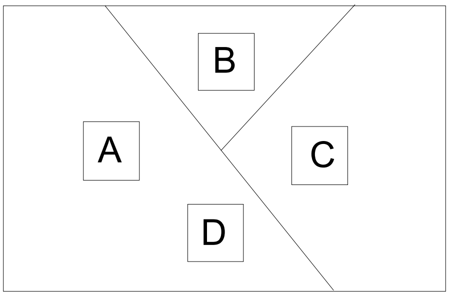
96 Cold occlusion is:

a. Cold air undercutting warm air
b. Warm air overriding cold air
c. Air ahead of the warm front undercutting the air behind the cold front
d. Air behind the cold front undercutting the air in front of the warm front

97 Warm occlusion is:

a. Warm air undercutting cold air
b. Warm air overriding cold air
c. Air ahead of the warm front over riding the air behind the cold front
d. Air behind the cold front over riding the air in front of the warm front

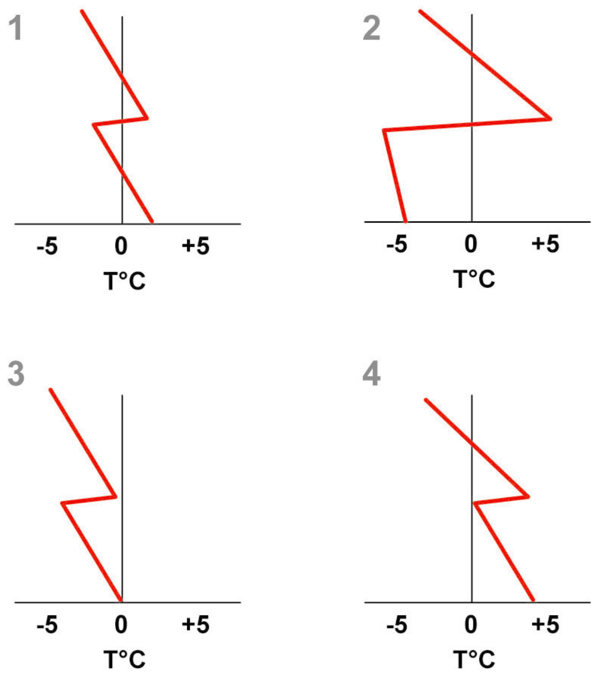
98 Where is the warmest air?



99 What happens to the polar front jet stream in NH winter compared to summer?

a. Moves south, speed increases
b. Moves North, speed increases
c. Moves South, speed decreases
d. Moves North, speed decreases

100 Which is likely to give freezing rain?



a. 1
b. 2
c. 3
d. 4

101 Duration of a microburst:

a. 5 mins, 5 km
b. 20 mins, 5 km
c. 15 mins, 25 km
d. 45 mins, 25 km

102 Where is the surface wind usually westerly in a Northern Hemisphere polar front depression?

a. In front of the warm front
b. In front of the cold front
c. Behind the cold front
d. To the north of centre of the depression

103 Flying from an area of low pressure in the Southern Hemisphere at low altitudes, where is the wind coming from?

a. Right and slightly on the nose
b. Left and slightly on the tail
c. Left and slightly on the nose
d. Right and slightly on the tail

104 What causes the Geostrophic wind to be stronger than the gradient wind around a low?

a. Centrifugal force adds to the gradient force
b. Centrifugal force opposes the gradient force
c. Coriolis force adds to the gradient force
d. Coriolis force opposes the centrifugal force

105 The subtropical high pressure belt is at which latitude?

a. 25° - 35°
b. 10° - 15°
c. 55° - 75°
d. 40° - 55°

106 A METAR for Paris gave the surface wind at 260/20. Wind at 2000ft is most likely to be:

a. 260/15
b. 210/30
c. 290/40
d. 175/15

107 When the upper part of a layer of warm air is advected:

a. Stability increases within the layer
b. Stability decreases within the layer
c. Wind speed will always decrease with increase in height in the Northern Hemisphere.
d. Wind will back with increase in height in the Northern Hemisphere.

108 The QNH at an airfield 200m AMSL is 1009 hPa; air temperature is 10°C lower than standard. What is the QFF?

a. Not possible to give a definite answer
b. Less than 1009
c. 1009
d. More than 1009

109 A plain in Western Europe at 500m (1600ft) AMSL is covered with a uniform alto - cumulus cloud during summer months. At what height AGL is the base of the cloud expected?

a. 100 - 1500ft
b. 15000 - 25000ft
c. 7000 - 15000ft
d. 1500 - 7000ft

110 With the passage of a Polar frontal depression what would be most likely?

a. Showers for 2hrs, Drizzle for 12hrs, then snow and rain
b. Continuous snow and rain, then it stops to be followed by showers of rain and snow.
c. Continual backing of the wind
d. Heavy showers of rains and possible hail, followed by drizzle and light rain

111 A pilot experiences severe turbulence and icing. A competent met. man would issue:

a. SPECI
b. METAR
c. TEMPO
d. SIGMET

112 Which of these would cause your true altitude to decrease with a constant indicated altitude?

a. Cold/Low
b. Hot/Low
c. Cold/High
d. Hot/High

113 Flying from Bangkok to Bombay, why does the wind at 30,000ft change from 15kts headwind in winter to a 20kt tailwind in summer?

a. Freak weather conditions experienced on route
b. The Equatorial Easterly jet changes direction through 180 degrees
c. This is due to local changes in the upper winds due to the movement of the ITCZ
d. The Subtropical jet changes direction through 180 degrees

114 ITCZ weather is:

a. Thundery strong convergence
b. Clear Wx
c. Showers
d. Light winds

115 Where is the ITCZ during the year?

a. Doesn’t move
b. Always north of the equator
c. Always south of the equator
d. Moves in accordance with the heat equator

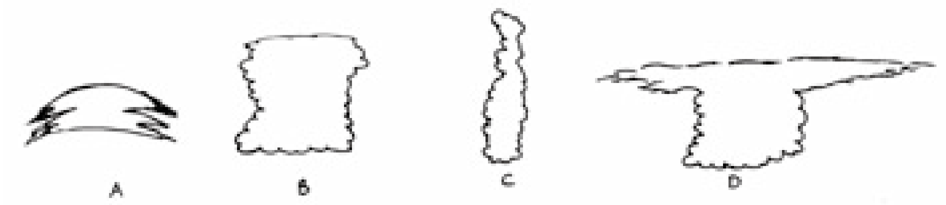
116 Flying from Marseilles to Dakar in summer where is the ITCZ?

a. Canaries
b. Algeria
c. Gibraltar
d. Near Dakar

117 Where is the ozone layer?

a. ionosphere
b. Stratosphere
c. Tropopause
d. Troposphere

118 Which of the following diagrams depicts Cumulus Capillatus:



119 What wind would you expect between the equator and 20° south?

a. NE monsoon
b. Trade wind
c. Strong westerlies
d. Roaring forties

120 Where are TRS not likely to form?

a. South China sea
b. South Pacific
c. South Atlantic
d. South Indian Ocean

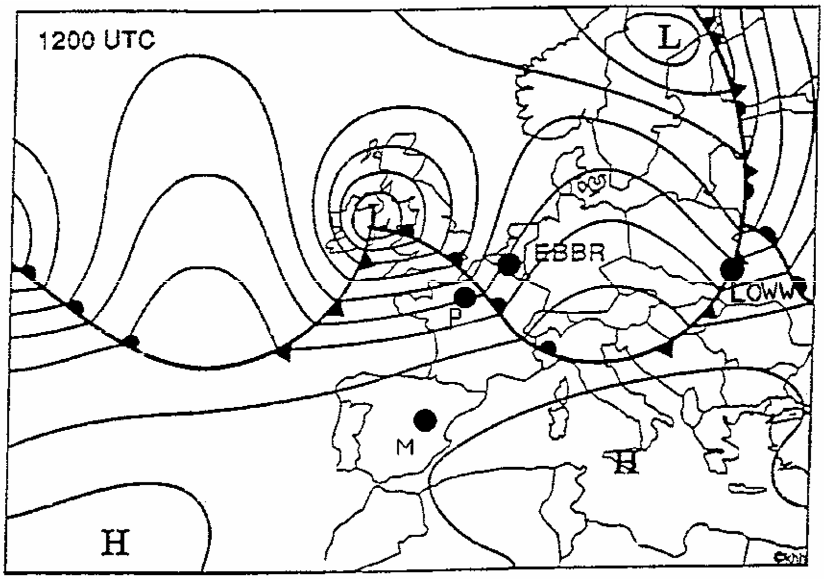
121 Where is the most severe weather in a TRS?

a. in the centre of the eye
b. in the wall of cloud surrounding the eye
c. within the eye
d. 300km from the eye

122 Satellite images are used to:

a. locate fronts in areas with few ground stations
b. to achieve 14 day forecasts
c. locate precipitation zones
d. locate wind currents on the ground

123 What best describes the diagram below?



a. Cutting winds
b. Westerly wave
c. Easterly wave
d. Uniform pressure gradient

124 A large pressure gradient is shown by:

a. Closely spaced isobars - low temperature
b. Distant spaced isobars - high temperature
c. Close spaced isobars - strong winds
d. Close spaced isobars - light winds

125 The degree of CAT experienced by an aircraft is proportional to:

a. Intensity of vertical and horizontal wind shear
b. Intensity of solar radiation
c. Stability of the air
d. Height of the aircraft

126 Squall lines are encountered:

a. In an air mass with cold air properties
b. Ahead of a cold front
c. Behind a stationary front
d. At an occluded front

127 Microbursts:

a. Only affect tropical areas
b. Average lifespan 30mins
c. Typical horizontal dimensions 1 - 3km
d. Always associated with CB clouds

128 Which of the following are described as precipitation?

a. TS
b. SQ
c. SA
d. DZ

129 An aircraft flying in the Alps on a very cold day, RPS 1013 set in the altimeter, flies level with the summit of the mountains. Altitude from aneroid altimeter reads:

a. Same as mountain elevation
b. Lower than mountain elevation
c. Higher than mountain elevation
d. Impossible to determine

130 Clouds classified as low level are considered to have a base height of:

a. 500 - 1000ft
b. 1000 - 2000ft
c. the surface - 6500ft
d. 100 - 200ft

131 With a polar front jet stream (PFJ), the area with the highest probability of turbulence in the Southern Hemisphere is:

a. In the jet core
b. Above the jet core in the boundary of the warm and cold air
c. Looking downstream, on your left hand side
d. looking downstream, on your right hand side

132 A after such a fine day yesterday, the ring around the moon indicated bad weather today. Sure enough, it is pouring down rain, with a very low cloud base of uniform grey. It is a little warmer though.
This describes:

a. A warm front
b. A cold front
c. The weather behind a cold front
d. Poetic licence

133 On a flight from London to New York in summer, where would you cross the ITCZ?

a. Newfoundland, Grand Banks
b. New York
c. Azores
d. You wouldn't

134 What type of low is usually associated with frontal activity?

a. Polar front low
b. Mountain lee low
c. Warm low
d. Cold low

135 When would you encounter hoar frost?

a. Climbing through an inversion
b. Ns
c. Cb
d. Ac

136 What is the temperature decrease with height below 11km?

a. 1°C - 100m
b. 0.5°C - 100m
c. 0.65°C - 100m
d. 0.6°C - 100m

137 Contours on a weather chart indicate:

a. Heights of pressure levels
b. Distance between pressure levels
c. Thickness between pressure levels
d. Height of ground

138 When do you get TRS at Darwin?

a. July - October
b. Never
c. November - April
d. In the winter

139 Sub tropical highs are found:

a. 5 - 15°
b. 25 - 35°
c. 40 - 60°
d. Between the Polar and Ferrell cells

140 Equatorial easterly jets

a. Northern Hemisphere in summer
b. Northern Hemisphere all year
c. Southern Hemisphere all year
d. Southern Hemisphere

141 What causes 'echoes' on airborne weather radar screens?

a. Water vapour
b. All cloud
c. Fog
d. Hail

142. In a Tropical Downpour the visibility is sometimes reduced to:

a. 1000m
b. 500m
c. 200m
d. less than 100m

143. Aircraft with thick wing (T) and thin wing (S) fly at the same TAS and altitude through cloud containing small super cooled water droplets. What extent of icing will be experienced?

a. S and T same icing
b. Nothing as its super cooled water droplets
c. S more, T less
d. T more, S less

144 What surface weather is associated with a stationary high pressure region, over land, in the winter?

a. Ns and continuous rain
b. A tendency for fog and low Stratus
c. The possibility of snow showers
d. Thunderstorms

145 QNH is defined as:

a. The pressure at MSL obtained using the standard atmosphere
b. The pressure at MSL obtained using the actual conditions
c. QFE reduced to MSL using the actual conditions
d. QFE reduced to MSL using the standard atmosphere

146 Where would you expect to find the strongest wind on the ground in temperate latitudes?

a. In an area of Low pressure
b. In an area of High pressure
c. In the warm air between two fronts
d. In a weak anticyclone

147 Landing at an airfield with QNH set the pressure altimeter reads:

a. Zero feet on landing only if ISA conditions prevail
b. Zero
c. The elevation of the airfield if ISA conditions prevail
d. The elevation of the airfield

148 The fastest moving thunderstorms are:

a. Orographic
b. Thermal
c. Frontal
d. Lifting

149 Where are the fastest winds in a Tropical Revolving Storm?

a. Near the eye
b. In the wall of cloud surrounding the eye
c. To the right of the track
d. To the right of the track in Hurricanes and Cyclones

150 What type of cloud is usually found at high level?

a. St
b. Ac
c. Cc
d. Ns

151 You are flying in an atmosphere which is warmer than ISA, what might you expect?

a. True altitude to be the same as Indicated altitude
b. True altitude to be lower than Indicated altitude
c. True altitude to be the decreasing
d. True altitude to be higher than Indicated altitude

152 The environmental lapse rate in the real atmosphere:

a. Has a fixed value of 2^0C / 1000ft
b. Has a fixed value of 0.65^0C / 100Mtrs
c. Varies with time
d. Has a fixed value of 1^0C / 100Mtrs

153 Airfield is 69 metres below sea level, QFF is 1030 hPa, temperature is ISA -10^0C. What is the QNH?

a. Impossible to tell
b. Less than 1030Hpa
c. 1030Hpa
d. More than 1030Hpa

154 The QNH is 1030Hpa and at the Transition Level you set the SPS. What happens to your indicated altitude?

a. Drops by 510ft
b. Rises by 510ft
c. Rises
d. Drops

155 What is the movement of air relating to a trough?

a. Descending and diverging
b. Ascending and diverging
c. Descending and converging
d. Converging and ascending

156 What is the movement of air relating to a ridge?

a. Descending and diverging
b. Ascending and diverging
c. Descending and converging
d. Ascending and converging

157 What would the code 01650428 tell you about the condition of the runway?

a. Its raining
b. its snowing
c. braking co-efficient of 0.28
d. its broken

158 What time of year is the tornado season in N. America?

a. Spring to summer
b. Summer and autumn
c. Spring
d. Summer

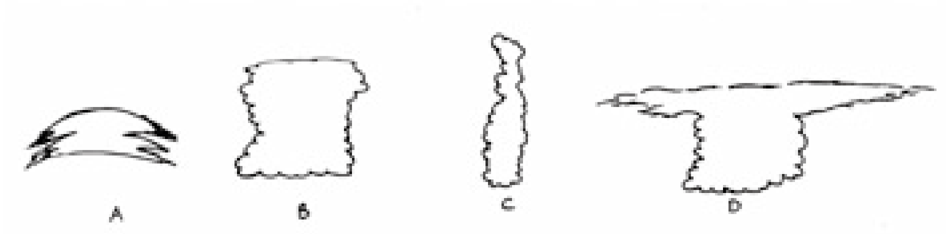
159 What is the min. temperature according to ISA?

a. -56.5°C
b. -273°C
c. -100°C
d. 215.6°K

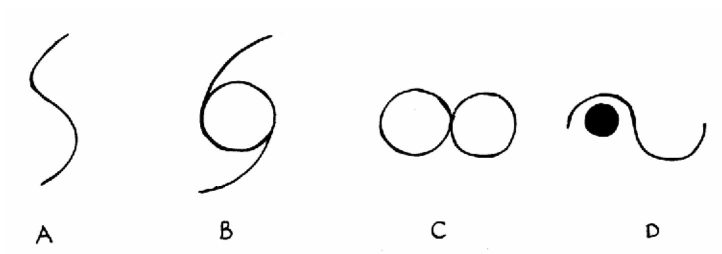
160 At a coastal airfield, with the runway parallel to the coastline. You are downwind over the sea with the runway to your right. On a warm summer afternoon, what would you expect the wind to be on finals?

a. crosswind from the right
b. Headwind
c. Tailwind
d. Crosswind from the left

161 What diagram best shows Acc?



For questions 162 to 164, use the diagram below



162 What symbol is used to describe wide spread haze?

163 What symbol is used to describe a TRS?

164 What symbol is used to describe freezing rain?

165 The temperature at the surface is 15°C, the temperature at 1000m is 13°C. Is the atmosphere

a. Unstable
b. Conditionally unstable
c. Stable
d. Cannot tell

166 Altostratus is

a. A low level cloud
b. A medium level cloud
c. A high level cloud
d. A heap type cloud

167 Which of the following would give you the worst airframe icing?

a. GR
b. SN
c. FZFG
d. +FZRA

168 Small super cooled water droplets hit the aerofoil, will it

a. Freeze on impact giving clear ice
b. Partially freezing and running back giving clear ice
c. Freeze on impact giving rime ice
d. Partially freezing and running back giving a cloudy rime ice

169 In a METAR you see the coding R16/P1300. What does this imply?

a. RVR assessed to be more than 1300 meters
b. RVR equipment is problematic
c. RVR is improving
d. RVR is varying

170 If at 0600 the temperature and dew point were recorded as T= - 0.5 and Td = - 1.5, how would a METAR record this?

a. M01, M02
b. M01, M01
c. M00, M01
d. 00, M01

171 What causes wind?

a. Difference in pressure
b. Rotation of the earth
c. Frontal systems
d. Difference in temperature

172 What is the approximate height of the 250hPa level?

a. 30,000ft
b. 32,000ft
c. 39,000ft
d. 34,000ft

173 Several aircraft report clear air turbulence in a certain area en route

a. ATC should issue a storm warning
b. ATC should close the specified area
c. A competent ATC should issue a SPECI
d. A competent ATC should issue a SIGMET

174 What is the flight hazard associated with the Harmattan?

a. Sand up to FL150
b. Wind shear
c. Dust and poor visibility
d. Dense fog

175 Where are icing conditions on a runway specified?

a. TAF
b. METAR
c. SIGMET
d. GAFFO

176 Where are icing conditions on route specified?

a. TAF and METAR
b. METAR and SIGMET
c. SWC (**s**ig. **w**eather. **c**hart) and SIGMET
d. SPECI and TREND

177 If flying in the Alps with a Foehn effect from the south

a. Clouds will be covering the southern passes of the Alps
b. CAT on the northern side
c. Wind veering and gusting on the northern side
d. Convective weather on the southern passes of the Alps

178 If flying en route and you encounter moderate turbulence with convective clouds and you decide to continue, you should

a. Decrease power and climb above the clouds if flight parameters allow
b. Decrease power and fly below the clouds
c. Increase power and climb above the clouds if flight parameters allow
d. Increase power and fly below the clouds

179 You are flying from Madrid (QNH 1012) to Paris (QNH 1015) at FL 80. If your true altitude and indicated altitude remain the same then

a. The air at Madrid is warmer than Paris
b. The air at Paris is warmer than Madrid
c. The altimeters are incorrect
d. Your indicated altitude must be changing

180 If you are flying on a QNH 1009 on very cold day and you circle the top of a peak in the Alps, your altimeter will read

a. The same as the elevation of the peak
b. Lower than the elevation of the peak
c. Higher than the elevation of the peak
d. Not enough information to tell

181 ICAO statement no diversion necessary, de-icing is not required or is effective; the icing in this case is

a. Light
b. Moderate
c. Severe
d. Extreme

182 Aircraft A has a sharp leading edge and a thin aerofoil. Aircraft B has a thick cambered wing aerofoil. If they are flying at the same TAS into clouds with small super cooled water droplets then

a. Depends upon the differential kinetic heating
b. B gets more icing than A
c. Both get the same
d. A gets more icing than B

183 What is subsidence?

a. Horizontal motion of air
b. Vertical down draught of air
c. Vertical up draught of air
d. Adiabatic cooling

184 If an Isohypse on a surface pressure chart of 500hPa shows a figure of 522, this indicates

a. Topography of 522m above MSL
b. Topography of 522 decametres above MSL
c. Pressure is 522mb
d. A low surface pressure

185 Moderate turbulence can be expected in

a. Alto-cumulus Lenticularis
b. Cirrocumulus
c. Nimbostratus
d. Stratus

186 The polar front jet stream in summer compared to winter in the Northern Hemisphere moves

a. North and decreases in strength
b. North and increases in strength
c. South and decreases in strength
d. South and increases in strength

187 The Bora is a

a. Cold katabatic wind with a air mass of maritime origin
b. Cold katabatic wind with a air mass of arctic origin
c. Cold katabatic wind that may produce violent gusts
d. Warm squally katabatic wind

188 RVR is

a. Measured using ceilometers along the runway
b. Displayed in TAF=s and METAR=s
c. Usually greater than met visibility
d. Given when the met visibility is below 2000m

189 Comparing the surface wind to the 3000ft wind

a. Surface wind veers and is less then the 3000ft wind
b. Surface wind blows along the isobars and is less than the 3000ft wind
c. Surface wind blows across the isobars and is less than the 3000ft wind
d. Both are the same

190 In which air mass can extreme cold temperatures be found?

a. Polar continental
b. Arctic maritime
c. Polar maritime
d. Tropical maritime

191 Up and down going draughts in a thunderstorm occur in which stage?

a. Cumulus stage
b. Mature stage
c. Dissipating stage
d. Precipitation stage

192 Relative humidity increases in

a. Warmer air compared to colder air
b. Warm air at a constant vapour pressure
c. Cold air at a constant vapour pressure
d. Colder air compared to warmer air

193 Super cooled water droplets are found in

a. Clouds only
b. Clouds, fog and precipitation
c. Precipitation and clouds
d. Precipitation

194 Which of the following, with no Orographic intensification, will give rise to light to moderate icing conditions?

a. Ns and Cs
b. As and Ac
c. Cb and Ns
d. Ns and Cc

195 If an active cold front is approaching what will the altimeter read on a parked aircraft shortly before the front arrives?

a. Decrease
b. Increase
c. fluctuates -50ft to +50ft
d. stays the same

196 Which of the following METARs at 1850UTC will most likely give fog formation over the coming night?

a. 240/04 6000 -RA SCT012 OVC 3000 17/14 Q1002 NOSIG=
b. VRB002 9999 SCT150 17/M08 Q1012 NOSIG=
c. VRB001 8000 SCT280 11/10 Q1028 BECMG 3000
d. VRB002 8000 FEW100 12/09 Q1025 BECMG 0800

197 The lowest temperature in the international standard atmosphere (ISA)is?

a. -50.6°C
b. -56.5°F
c. 216.5°K
d. 56.5°C

198 What would be reflected to radar?

a. Fog
b. Hail
c. Cloud
d. Mist

199 A jet stream with a wind speed of 350kts

a. Impossible
b. Possible but very rare
c. Possible in polar areas
d. Common

200 Turbulence is worst in a Jet stream

a. In the core
b. Along the axis of the core to the right
c. Along the axis of the core to the left
d. Between the boundaries of the cold and warm air

201 If you fly at right angles to a jet stream in Europe with a decreasing outside air temperature, you will experience

a. Increasing headwind
b. Increasing tailwind
c. Wind from the left
d. Wind from the right

202 Low level wind shear is likely to be greatest

a. At the condensation level when there is a strong surface friction
b. At the condensation level when there is no night radiation
c. At the top of the friction layer during strong solar radiation
d. At the top of a surface based inversion during strong night radiation

203 The North African rains occur

a. March to May and August to October
b. March to May and October to November
c. December to April
d. June to August

204 TEMPO TS indicates

a. TS that will last for the entire period indicated
b. TS that will last for a max of 1hr in each instance
c. TS that will last for at least 30 mins
d. TS that will last for less than 30 mins

205 What happens in a warm occlusion?

a. Warm air behind the cold front overrides the cold air in front of the warm front
b. Cold air under rides the warm air
c. Cold air behind the cold front undercuts the warm air ahead of the warm front
d. Warm air undercuts the cold air

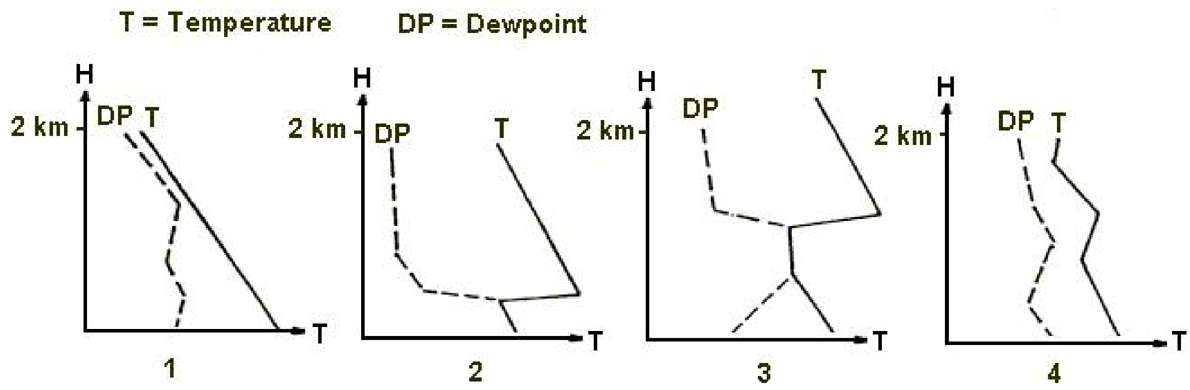
206 Which of the following gives conditionally unstable conditions?

a. 1°C/100m
b. 0.65°C/100m
c. 0.49°C/100m
d. None of the above

207 A mass of unsaturated air is forced to rise till just under the condensation level. It then settles back to its original position

a. Temp. is greater than before
b. Temp. stays the same
c. Temp. is less than before
d. It depends on QFE

208 Which of the radiosonde diagrams below will show low stratus?



a. 4
b. 2
c. 3
d. 1

209 What is a microburst?

a. Air descending at high speed, the air is colder than the surrounding air
b. Air is descending at high speed; the air is warmer than the surrounding air
c. A small Tropical Revolving Storm
d. A small depression with high wind speeds

210 The high bringing tropical continental air masses to Europe in summer

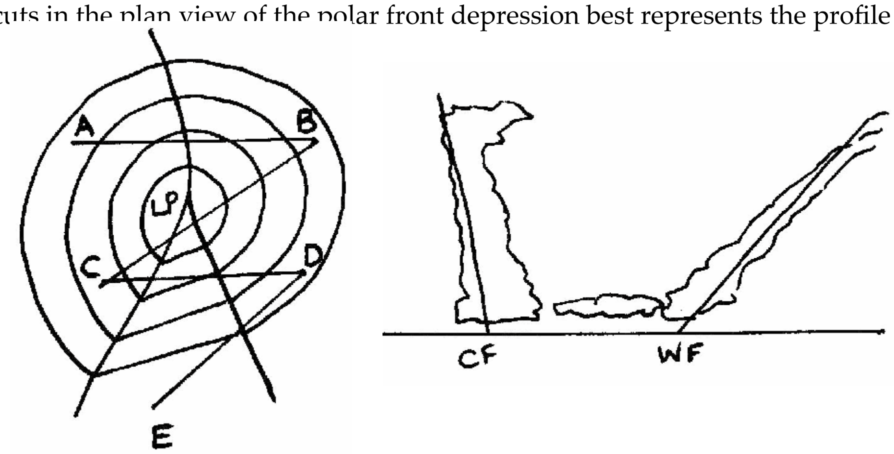
a. Southern Italy
b. Southern France
c. Balkans
d. Azores

211 What most likely gives freezing rain over Central Europe?

a. Warm occlusion
b. Cold occlusion
c. Warm front
d. Cold front

212 Which of the cuts in the plan view of the polar front depression best represents the profile view?

a. A, B
b. B, C
c. C, D
d. D, E



213 On a polar front depression, the point of occlusion moves mainly in which direction in the Northern Hemisphere?

a. Along the front to the west
b. Across the front to the north
c. Across the front to the south
d. Along the front to the east

214 In the Northern Hemisphere between lat. 35°N - 65°N in the north Atlantic during winter, the principle land based depression affecting the region is located at

a. USA high
b. Siberia high
c. Greenland/Icelandic low
d. Azores high

215 The ITCZ is best described as

a. where the trade winds of the north and southern hemisphere meet
b. where the west winds meet the sub-tropical high pressure belt
c. where cold fronts are formed in the tropics
d. where the Harmattan meets the NE trades in Africa

216 When would you most likely find cold occlusions across central Europe?

a. Winter and spring
b. Summer
c. Winter and autumn
d. Winter

217 Clear ice is most likely to form

a. -10°C to -17°C
b. -30°C to -40°C
c. -20°C to -30°C
d. -40°C to -60°C

218 How do you calculate the lowest flight level?

a. Lowest QNH and lowest negative temperature below ISA
b. Lowest QNH and highest negative temperature below ISA
c. Highest QNH and highest temperature above ISA
d. Highest QNH and lowest temperature

219 TRS off Somalia are called

a. Hurricanes
b. Typhoons
c. Cyclones
d. Tornadoes

220 Which cloud would you encounter the most intensive rain?

a. Ci
b. Ns
c. St
d. Sc

221 What height is the tropopause and at what temperature?

a. At the poles 8km and -16°C
b. At the pole 18km and -75°C
c. At the equator 8km and -40°C
d. At the equator 18km and -76°C

222 Where do you get freezing rain?

a. Rain hitting the ground and freezing on impact
b. Rain falling into warmer air
c. Rain falling from an inversion into an area below 0°C
d. Rain falling into colder air and freezing into pellets

223 Flying from Dakar to Rio de Janeiro in winter where would you cross the ITCZ?

a. 0 to 7°N
b. 7°N to 12°N
c. 7°S to 12°S
d. 12°S to 18°S

224 Where are polar front depressions located?

a. 10 to 15°N
b. 25 to 35°N
c. 35 to 55°N
d. 55 to 75°N

225 Which of the following is worst for icing?

a. -2°C to -15°C
b. -15°C to -20°C
c. -25°C to -30°C
d. Near freezing level

226 Which of the following is worst for icing?

a. Speed and shape of aerofoil
b. Relative humidity and temperature
c. Size of droplet and temperature
d. Freezing levels

227 With low pressures dominating the Med, which of the following would likely be found in central Europe?

a. Thunderstorms and snow
b. Thermal depressions
c. Northerly Foehn wind over the Alps
d. Warm clear sunny spells

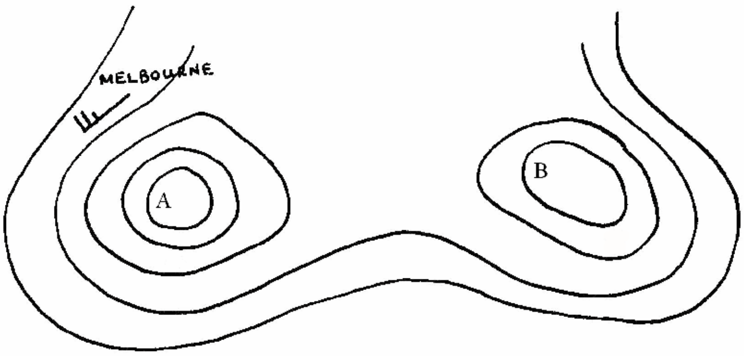
228 Which of the following will give the greatest difference between temperature and dew point?

a. Dry air
b. Moist air
c. Cold air
d. Warm air

229 CB cloud in summer contains

a. Water droplets
b. Ice crystals
c. Water droplets, ice crystals and super cooled water droplets
d. Water droplets and ice crystals

230 Using the diagram below you are on a flight from A to B at 1500 ft. Which statement is true?



a. True altitude at A is greater than B
b. True altitude at B is greater than A
c. True altitude is the same
d. Cannot tell

231 Solar radiation heats the atmosphere by

a. Heating the air directly
b. Heating the surface, this then heats the air in the atmosphere
c. Heating the water vapour in the atmosphere directly
d. Heating the water vapour directly unless there are clouds present

232 How are CBs that are not close to other CBs described on a SIGMET?

a. Isolated
b. Embedded
c. Frequent
d. Occasional

233 When do you mainly get cold occlusions?

a. Summer
b. Autumn and winter
c. Winter
d. Winter and spring

234 A coded SIGMET message for Athens reads
"TS W Athenia MOV E"

a. there will be TS coming from the east
b. there will be TS coming from the west
c. there will be TS coming from the west, moving east
d. there will be TS coming from the east, moving west

235 In a very deep depression in Iceland, the likely weather is

a. convection causing snow
b. high wind, clear vis
c. high wind, rain, snow
d. high wind shear

236 What affects how much water vapour the air can hold?

a. RH
b. Temperature
c. Dew point
d. Pressure

237 In a METAR/TAF what is VV?

a. RVR in metres
b. Vertical visibility
c. Horizontal visibility in metres
d. Vertical visibility in feet

238 In an METAR the cloud height is above

a. MSL
b. Aerodrome level
c. The measuring station
d. The highest point within 5Km

239 Aerodrome at MSL, QNH is 1022. QFF is

a. Greater than 1022
b. Less than 1022
c. Same as QNH
d. Cannot tell without temperature information

240 Air at the upper levels of the atmosphere is diverging. What would you expect at the surface?

a. Rise in pressure with clouds dissipating
b. Rise in pressure with clouds forming
c. Fall in pressure with cloud dissipating
d. Fall in pressure with cloud forming

241 What happens to the stability of the atmosphere in an inversion? (Temp increasing with height)

a. Absolutely stable
b. Unstable
c. Conditionally stable
d. Conditionally unstable

242 What happens to stability of the atmosphere in an isothermal layer? (Temp constant with height)

a. Absolutely stable
b. Unstable
c. Conditionally stable
d. Conditionally unstable

243 Air temperature in the afternoon is +12°C with a dew point of +5°C. What temperature change must happen for saturation to occur?

a. cool to +5°C
b. cool by 5°C
c. cool to +6°C
d. cool to +7°C

244 What is the gradient of a warm front?

a. 1:50
b. 1:150
c. 1:300
d. 1:500

245 Subsidence would be described as

a. Vertical ascension of air
b. Horizontal movement of air
c. The same as convection
d. Vertical down flow of air

246 What is the technical term for an increase in temperature with altitude?

a. Inversion
b. Advection
c. Adiabatic
d. Subsidence

247 What units are used to measure vertical wind shear?

a. m/sec
b. kts
c. kts/100ft
d. kms/100ft

248 The Pampero is

a. Marked movement of cold polar air in North America
b. Marked movement of cold air in South America
c. Foehn type wind in North America
d. Polar air over the Spanish Pyrenees

249 If you fly from Bombay to Karachi in summer you might experience a 70kt tailwind and the same flight in winter experiences a headwind. This is due to

a. The normal local changes in the winds at that time of the year
b. The route happens to be in a region of the STJ=s
c. In winter you unusually unfavourable conditions
d. In summer you had unusually good weather conditions

250 Why is the "Icelandic low" more intense in winter?

a. The temperature contrast between arctic/polar air and equatorial areas are much greater in winter.
b. The developments of lows over the North Atlantic Sea, east of Canada are stronger in winter
c. The winds over the North Atlantic are more favourable for lows during winter.
d. In winter, strong winds favour the developments of lows.

251 What causes the formation of aircraft contrails at certain altitudes?

a. Water vapour that condenses behind the engines
b. Soot particles from the engine exhaust
c. Water vapour that condenses in the wing tips due to pressure changes in the relative warm air
d. Un burnt fuel

.

252 QNH is 1003. At FL100 true altitude is 10,000ft. Is it

a. Warmer than ISA
b. Colder than ISA
c. Same as ISA
d. Cannot tell

253 Winds in western India

a. SW monsoon in summer, NE monsoon in winter
b. NE monsoon in summer and SW monsoon in winter
c. SE monsoon in summer and SW monsoon in winter
d. SE monsoon in summer and NE monsoon in winter

254 Ice pellets on the ground are evident that

a. A warm front has past
b. A cold front has passed
c. There are thunderstorms in the area
d. There maybe freezing rain at a higher level

255 You have to fly through a warm front. The freezing level in the warm air is at 10,000ft and the freezing layer in the cold air is at 2,000ft. Where are you least likely to encounter freezing rain?

a. 12,000ft
b. 9,000ft
c. 5,000ft
d. 3,000ft

256 You are flying at FL170. The pressure level which is closest to you is the

a. 300mb
a. 700mb
c. 500mb
d. 850mb

257 When you have icing conditions forecast on-route, on what chart would you find this information?

a. 500hPa
b. 300hPa
c. Surface charts
d. Significant weather charts

258 The average duration of a microburst

a. 1-5 mins
b. 10mins
c. 15mins
d. less than 2mins

259 How is QFE determined from QNH?

a. Using the temperature of the airfield and the elevation of the airfield
b. Using the temperature
c. Using the elevation
d. Using the temperature at MSL and the elevation of the airfield

260 Which cloud would produce showers?

a. NS
b. AS
c. CS
d. CB

261 What clears radiation fog?

a. Temperature drop
b. Wind speed decreases
c. Wind speed increases
d. Mixing

262 QFE is 1000hPa with an airfield elevation of 200m AMSL. What is QNH?

a. 976 hPa
b. 1024 hPa
c. 1008 hPa
d. 992 hPa

263 With the approach of a warm front

a. QNH/QFE decreases
b. QNH/QFE increases
c. QNH decreases and QFE increases
d. QNH increases and QFE decreases

264 With the approach of a cold front, temperature will

a. Decrease
b. Remain the same
c. Increase
d. Decrease then increase

265 On a surface weather chart, isobars are lines of

a. QNH
b. QFE
c. QFF
d. QNE

266 What is the effect of a strong low level inversion?

a. Good visibility
b. Calm conditions
c. Turbulence
d. Unstable conditions

267 A moist stable air mass is forced to rise against a mountain range. What might you expect?

a. Large Cu clouds and turbulence
b. Altocumulus Lenticularis
c. Cap clouds and standing waves
d. Clear skies

268 Air temperature is 12°C, Dew point is 10°C and the sea temperature is 8°C. What might you expect if the air is blown over the sea?

a. Steaming fog
b. Radiation fog
c. Arctic smoke
d. Advection fog

269 A cold pool over land in summer would give rise to:

a. Clear skies
b. Low stratus with intermittent rain
c. A potentially very unstable atmosphere
d. Extensive industrial haze

270 Near industrial areas with lots of smoke what the worst situation is for met vis:

a. Low level inversion
b. Strong winds
c. Fast moving cold fronts
d. Cb's in the area

271 Upper level winds are forecast in significant weather charts as:

a. True/knots
b. Magnetic/knots
c. Magnetic/km/h
d. True/km/h2

272 Melbourne in July will experience:

a. The equatorial low pressure belt
b. Sub-tropical high
c. Continuous waves of troughs and ridges
d. The Antarctic high

273 How often are METAR's issued at Main European Airfields?

a. 1 hr
b. 30 mins
c. 3 hrs
d. 1 hr 30 mins

274 METAR winds are meaned over the.............. period immediately preceding the time of observation.

a. 10 minute
b. 30 minute
c. 1 hour
d. 1 minute

275 Main TAF's at large aerodromes are valid for approximately:

a. 1 hour
b. 2 hours
c. 6 hours
d. 24 hours

276 What are the TRS of the west coast of Africa called?

a. Typhoons
b. Cyclones
c. Easterly waves
d. Hurricanes

277 The most severe in-flight icing occurs in:

a. Cb
b. Cu
c. Ns
d. FZRA

278 Which of the following constituents in the atmosphere has the greatest effect on the weather?

a. Nitrogen
b. Oxygen
c. Hydrogen
d. Water Vapour

279 When would you mostly likely get fair weather Cu?

a. 15:00
b. 12:00
c. 17:00
d. 07:00

280 RVR is defined as being

a. The maximum distance an observer on the runway can see marker boards by day and runway lights by night
b. The maximum distance a pilot in the threshold area at 15ft above the runway can see marker boards by day or runway lights by night, when looking in the direction of take-off or landing.
c. The maximum distance in metres a pilot 15ft above the touchdown zone can see marker boards by day and runway lights by night in the direction of take-off
d. The distance it would be possible to see an observer 15ft above the runway when standing in the direction of take-off or landing.

281 What type of cloud extends into another level?

a. As
b. Acc
c. Ns
d. Ci

282 Ceilometers measure

a. RVR
b. Cloud height
c. Met Vis
d. Turbulence

283. In a METAR, the pressure group represents

a. QFE rounded up to the nearest hectopascal
b. QFE rounded down to the nearest hectopascal
c. QNH rounded up to the nearest hectopascal
d. QNH rounded down to the nearest hectopascal

284 On a Station circle decode, the cloud cover is divided into

a. 8 parts
b. 6 parts
c. 4 parts
d. 10 parts

285 Which of the following is true?
QNH is:

a. Always more than 1013.25 hPa
b. Always less than 1013.25 hPa
c. Never 1013.25 hPa
d. Can never be above or below 1013 hPa

286 When does Darwin (Australia. experience TRS?

a. June and July
b. December to March
c. Early summer
d. Not at all

287 Radiation fog extends from the surface to:

a. 5000ft
b. 2000ft
c. 10,000ft
d. 800ft

288 Flying from Marseilles to Palma you discover your true altitude is increasing, but oddly the QNH is identical at both places. What could be the reason?

a. Re-check the QNH
b. Re-check the radio altimeter
c. The air at Palma is warmer
d. Palma is lower than Marseilles

289 Hurricanes in the Caribbean generally move

a. West, then NE
b. East, then SE
c. West, then SE
d. East, the NE

290 Low level inversions

a. Good vis at night
b. Good vis in the morning
c. Poor vis due to the lack of vertical moving air
d. Poor vis because of the lack of horizontal movement of air

291 What are the TRS off the coast of Madagascar called and when would you expect to find them?

a. Cyclones, in December and January
b. Hurricanes, in July and August
c. Typhoons, in May to November
d. Cyclones, in June and July

292 A forecast trend

a. Aerodrome and valid for 9 hours
b. Route and valid for 24 hours
c. SPECI and valid for 2 hours
d. Landing and valid for 2 hour

293 On rare occasions TS can be found along the warm front. What conditions could lead to this?

a. The warm sector being stable
b. The warm sector being unstable
c. The cold air being stable
d. The cold air being unstable

294 QNH is 1030. Aerodrome is 200m AMSL. What is QFF?

a. Higher than 1030
b. Lower than 1030
c. Same
d. Not enough info

295 Where are down draughts predominant in a thunderstorm?

a. Mature
b. Dissipating
c. Initial
d. Cumulus

296 If an Aerodrome is 1500ft AMSL on QNH 1038, what will the actual height AGL to get to FL75?

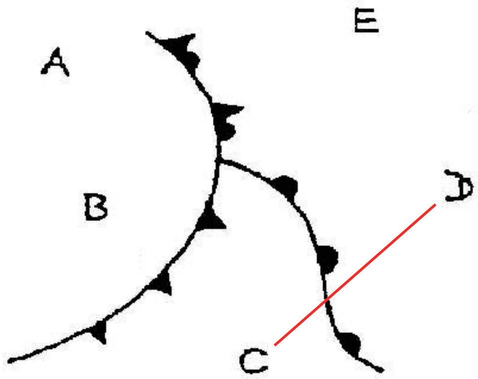
a. 6670 ft
b. 8170 ft
c. 8330 ft
d. 2330 ft

297 What is FG VV100?

a. RVR less than 100m
b. RVR less than 100ft
c. Vertical visibility is 100m
d. Vertical visibility is 100ft

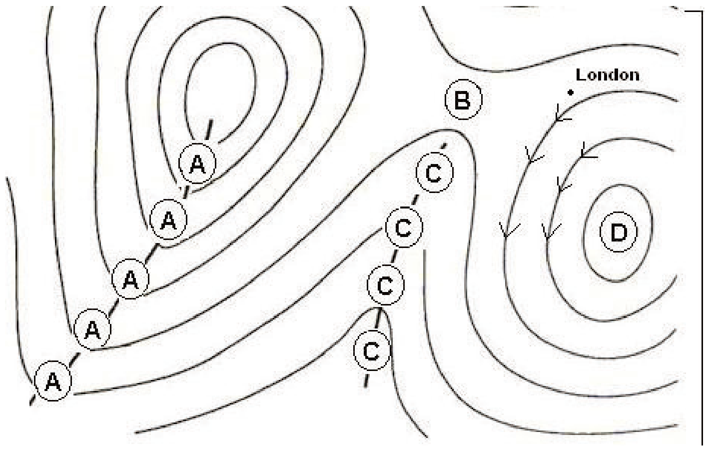
298 The line connecting C to D crosses which type of front?

a. Cold front
b. Warm front
c. Warm occlusion
d. Cold occlusion



299 What is B?

a. A trough of high pressure
b. Col
c. A ridge of low pressure
d. A low



300 On a particular day the PFJ runs north to south in the Northern Hemisphere.

a. The temperature gradient runs north to south below the jet core
b. The temperature gradient runs north to south above the jet core
c. The polar air is east of the jet above the core
d. The polar air is below the jet to the east

301 A 350 kt jet stream is

a. Impossible
b. Common near equator
c. Possible but rare
d. Common in the Southern Hemisphere over the oceans

302 Why do TRS tend to form in the western side of tropical oceans?

a. Because the land temperature and sea temperature provide unstable gradient for formation
b. Because the coastal gulf provides a strong rotational force
c. Because the areas tend to have high >shear= in the atmosphere
d. Because the air humidity is high, due to long passage of trade winds over ocean

303 Where would an anemometer be placed?

a. close to station, 2m above ground
b. on the roof of the station
c. 10m above aerodrome elevation on a mast
d. next to the runway, 1m above ground

304 Altimeter set to 1023 at aerodrome. On climb to altitude the SPS is set at transition altitude. What will indication on altimeter do on resetting to QNH?

a. Dependent on temperature
b. Decrease
c. Increase
d. Same

305 90km/hr wind in kts is:

a. 70
b. 60
c. 50
d. 30

306 The ITCZ is best described as:

a. The area where trade winds from the Northern Hemisphere meets those from the Southern Hemisphere
b. Where west winds meet subtropical high pressure zone
c. Where Harmattan meets the N.E. Trade winds
d. Where cold fronts form in the tropics

307 When landing at Dakar in July, the weather to be expected is:

a. Clear and dry
b. Wet and stormy, due to proximity of the ITCZ
c. settled/warm/clear skies due to influence of the Azores High
d. Low visibility/dust storms due to the Harmattan

308 When is the Hurricane season in the Caribbean?

a. July to November
b. October to January
c. January to April
d. April to July

309 An aircraft is stationary on the ground. With the passage of an active cold front its altimeter will show:

a. An increase then a decrease
b. Will fluctuate ± 50ft
c. A decrease then an increase
d. Remain constant

310 What is the average vertical extent of radiation fog?

a. 2,000 ft
b. 500 ft
c. 5,000 ft
d. 10,000 ft

311 Where is clear ice most likely in a Cb?

a. Near the freezing level
b. -2°C to -15°C
c. -20°C to -40°C
d. Below -40°C

312 You have to make an emergency ditch at sea. The QNH of a nearby island airfield is 1025mb, airfield elevation 4000ft. The temp is -20°C. With 1025 set on your sub-scale, on ditching the altimeter will read:

a. 0 ft
b. Less than 0 ft
c. > 0 ft but less than 4000 ft
d. 4000 ft

313 Which of the following will indicate medium level instability, possibly leading to thunderstorms?

a. Halo
b. Altocumulus Castellanus
c. Altocumulus Capillatus
d. Red Cirrus

314 Radiation fog extends to:

a. 8,000 ft
b. 4,000 ft
c. 2,000 ft
d. 500 ft

315 What is reported as precipitation?

a. FZFG
b. FG
c. TS
d. SN

316 At FL60 what pressure chart would you use?

a. 700 hPa
b. 850 hPa
c. 800 hPa
d. 900 hPa

317 On a descent through cloud cover at high level you notice a white, cloudy or opaque, rough powder like substance on the leading edge of the wing. This contamination is likely to be:

a. Frost
b. Clear ice
c. Mixed ice
d. Rime ice

318 In association with CB in temperate latitudes, at about what levels can hail be anticipated?

a. Ground to FL100
b. Ground to FL200
c. Cloud base to FL200
d. Ground to FL450

319 Moderate Turbulence

a. Changes in altitude and/or attitude occur but the aircraft remains in positive control at all times.
b. Slight erratic changes in altitude and/or attitude
c. Large, abrupt changes in altitude and/or attitude. Aircraft maybe momentarily out of control.
d. Slight, rapid and somewhat rhythmic bumpiness.

320 ATIS reports:

a. Aerodrome operational and meteorological information
b. Met only
c. Operational only
d. None of the above

321 +TSRA come from what sort of cloud?

a. Cb
b. Ns
c. Cc
d. Cu

322 Flying 2500 ft below core of jet, with temperature increasing in the Southern Hemisphere, where does the wind come from?

a. Head
b. Tail
c. Left
d. Right

323 Secondary depressions move

a. Around the primary in a cyclonic fashion
b. Around the primary in an anticyclonic fashion
c. Eastwards
d. Westwards

324 What temperature and pressure conditions would be safest to ensure that your flight level clears all the obstacles by the greatest margin?

a. Cold temp/low pressure
b. Warm temp/high pressure
c. Temp less than or equal to ISA and a QNH less than 1013
d. Temp more than or equal to ISA and a QNH greater than 1013

325 In which part of the world are TRS most frequent?

a. Caribbean
b. Madagascar, Eastern Indian Ocean
c. NW Pacific i.e. Japan, Korea
d. Northern Indian Oceans around India, Sri Lanka

326 As an active cold front passes, the altimeter of an a/c parked on the apron

a. Increases then decreases
b. Fluctuates by ± 50 ft
c. Decreases then increases
d. Remains unchanged

327 Where does a TRS gain its energy from?

a. Energy gained directly from the sun
b. Latent heat from water in oceans
c. The very fast winds
d. The very low pressures inside the storm

328 What is the height and temperature of Tropopause?

a. 8km and -40°C at Equator
b. 16km and -75°C at Equator
c. 16km and -40°C at Pole
d. 8 km and -75°C at Pole

329 What is the Easterly wave?

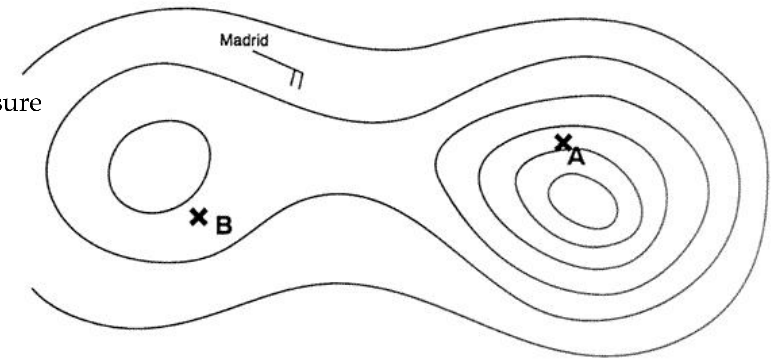
a. a wave of weather travelling east-west
b. a wave of weather travelling west-east
c. a wave of weather travelling north-south
d. a wave of weather travelling south-north

330 Where is icing worst?

a. Near condensation level
b. Near freezing level
c. -2°C to -15 °C
d. -16°C to -30°C etc

331 What is in position A?

a. col
b. Ridge of high pressure
c. A low
d. A high



332 The Geostrophic Wind blows at your flight level in Northern Hemisphere, true altitude and indicated altitude remain constant, is the crosswind

a. From the left
b. From the right
c. No crosswind
d. Impossible to determine

333 What is the base of alto cumulus in summer?

a. 0 - 1500′
b. 1500 - 7000′
c. 7000′ - 15000′
d. 7000′ - 16500′

334 What is the general height of radiation fog?

a. 500′
b. 2000′
c. 3000′
d. 1500

335 When a CC layer lies over a West European plane in summer, with a mean terrain height of 500 m above sea level, the average cloud base could be expected

a. 0- 100 ft above ground level
b. 5000 - 15000 ft above ground level
c. 15 000 - 25 000 ft above ground level
d. 15 000 - 35 000 ft above ground level

336 Which of the following cloud types can stretch across all three cloud levels (low, medium and high level)?

a. CI
b. ST
c. AC
d. CB

337 Which of the following cloud types can stretch across at least two cloud levels?

a. ST
b. NS
c. CI
d. SC

338 Shortly after the passage of an active cold front you observe the aneroid altimeter of a parked aircraft. The indication of the instrument will...

a. Decrease
b. Not be influenced by the air pressure
c. Increase
d. Show no appreciable change due to such minor pressure fluctuation

339 In a shallow pressure distribution (widely spaced Isobars or low pressure gradients) you observe the aneroid altimeter of a parked aircraft for 10 minutes (no thunderstorms observed). The reading of the instrument will...

a. Not be influenced by the air pressure
b. Increase greatly
c. Show no appreciable change due to such a minor pressure fluctuation
d. Experience great changes

340 You are flying from Marseilles (QNH 1012 hPa. to Palma de Mallorca (QNH 1012 hPa. at FL100. You notice that the effective height above MSL (Radio Altitude) increases constantly. Hence...

a. One of the QNH values must be wrong.
b. You have the altimeters checked, as their indications are obviously wrong.
c. The air mass above Palma is warmer than that above Marseilles
d. You have to adjust for a crosswind from the right.

341 You are flying from Marseilles (QNH 1026 hPa. to Palma de Mallorca (QNH 1026 hPa. at FL100. You notice that the effective height above MSL (Radio Altitude) decreases constantly. Hence...

a. One of the QNH values must be wrong.
b. The air mass above Marseilles is warmer than that above Palma
c. You have the altimeters checked, as their indications are obviously wrong.
d. You have to adjust for a crosswind from the right.

342 Flying at FL 135 above the sea, the Radio Altimeter indicates a true altitude of 13500 ft. The local QNH is 1019 hPa. Hence the crossed air mass is, on average,

a. At ISA standard temperature
b. Colder than ISA
c. Warmer than ISA
d. There is insufficient information to determine the average temperature deviation

343 Which air mass has the coldest temperature?

a. AM
b. PM
c. PC
d. TM

344 What happens to an aircraft altimeter on the ground once a cold front has passed?

a. increases
b. decreases
c. increases then decreases
d. remains the same

345 What happens to an aircrafts altimeter on the ground at the approach of a cold front?

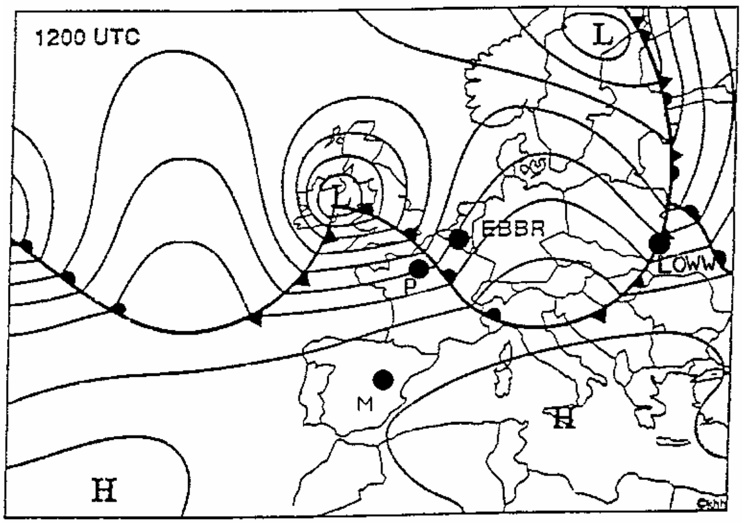
a. increases then decreases
b. decreases then increases
c. remains the same
d. increases

346 Even pressure system, no CB - what would you notice the altimeter in an aircraft on the ground to do during a 10 min period

a. remains the same as any fluctuations are small
b. increases
c. rapidly fluctuates
d. impossible to tell

347 What weather phenomenon is over Northern Italy?

a. a high
b. easterly wind
c. cloud and rain
d. a col



348 You are flying in the Alps at the same level as the summits on a hot day. What does the altimeter read?

a. Same altitude as the summit
b. Higher altitude as the summit
c. Lower altitude as the summit
d. Impossible to tell

349 What cloud is between a warm and cold front?

a. St with drizzle
b. Cs
c. Ns
d. St with showers

350 From which cloud do you get hail?

a. Sc
b. Cb
c. Ns
d. Ts

351 When flying from south to north in the Southern Hemisphere, you cross over the Polar Front Jet. What happens to the temperature?

a. it increases
b. it decreases
c. it remains the same
d. impossible to determine

352 If you see Alto Castellanus what does it indicate?

a. The upper atmosphere is stable
b. Subsistence
c. Instability in the lower atmosphere
d. Middle level instability

353 To dissipate cloud

a. Subsidence
b. Decrease in temperature
c. Increase pressure
d. Convection

354 When would a SIGMET be issued for subsonic flights

a. Thunderstorms and fog
b. Severe Mountain Waves
c. Solar Flare activity
d. Moderate turbulence

355 Which of these statements about icing is correct?

a. Ice will occur going through cirrus cloud
b. Large amounts of icing if temperature is way below -12°C
c. Icing increases if dry snow starts to fall from cloud
d. Icing will occur if super-cooled water and ice are present

356 You will get least amount of icing in which cloud?

a. NS
b. SC
c. CS
d. AS

357 The core of a jet stream is located

a. at the level where temperature change with altitude becomes little or nil and the pressure surface is at maximum slope
b. in the warm air where the pressure surface is horizontal
c. in the warm air and directly beneath at the surface
d. in cold air

358 Isolated TS in summer are because of

a. Convection
b. Cold fronts
c. Warm front occlusions
d. Cold front occlusions

359 Trade winds are most prominent or strongest

a. Upper troposphere over sea
b. Lower troposphere over ocean
c. Lower troposphere over land
d. Upper troposphere over land

360 A layer of air can be

a. Conditional; unstable when unsaturated and stable when saturated
b. Conditional; unstable when saturated and stable when unsaturated
c. Neutrally stable when saturated and unstable when unsaturated
d. all of the above

361 On a significant weather chart you notice a surface weather front with an arrow labelled with the no. 5 pointing outward perpendicular from the front. This would indicate

a. Front speed is 5kts
b. Front movement is 5nm
c. Front thickness is 5km
d. front is 5000ft AMSL

362 With all other things being equal with a high and a low having constantly spaced circular isobars. Where is the wind the fastest?

a. Anticyclonic
b. Cyclonic
c. Where the isobars are closest together
d. Wherever the PGF is greatest.

363 Blocking Anticyclones prevent the polar front from arriving over the UK and originate from?

a. Warm anticyclones over the Azores
b. Warm anticyclones over Siberia
c. Cold anticyclones over the Azores
d. Cold anticyclones over Siberia

364 Foehn winds are

a. Warm katabatic
b. Cold katabatic
c. Warm descending winds
d. Warm anabatic

365 The Gust Front is

a. Characterised by frequent lightning
b. Formed by the cold outflow from beneath TS
c. another name for a cold front
d. Directly below a TS

366 Cu is an indication of

a. vertical movement of air
b. stability
c. the approach of a warm front
d. the approach of a cold front

367 Which clouds are evidence of stable air?

a. St, As
b. Cb, Cc
c. Cu, Ns
d. Cu, Cb

368 Lack of cloud at low level in a stationary high is due to:

a. instability
b. rising air
c. sinking air
d. divergence at high level

369 What is the ratio of height to width in a typical Jet stream:

a. 1:10
b. 1:100
c. 1:1000
d. 1:10000

370 When and where does an Easterly Jet stream occur:

a. All year through the Equator
b. In Summer from SE Asia through S. India to Central Africa
c. In Summer from the Middle East through N. Africa and the Mediterranean to S. Spain
d. In Winter in Arctic Russia

371 What degree of turbulence, if any, is likely to be encountered while flying through a cold front in the summer over central Europe at FL100?

a. light turbulence in ST cloud
b. moderate turbulence in NS cloud
c. light turbulence in Cb cloud
d. severe turbulence in Cb cloud

372 An easterly wave is a:

a. wave in a trade wind belt, moving from east to west with severe convective activity in rear of its trough
b. small scale wave disturbance in the tropics, moving from east to west with severe convective activity ahead of its trough
c. wave-like disturbance in the monsoon regime of indices moving from east to west with severe convective activity ahead of its trough
d. disturbance in the higher levels associated with the equatorial easterly jets, moving from east to west, with severe convective activity in rear of its trough

373 What is the most common freezing precipitation?

a. Freezing pellets
b. Freezing rain and freezing drizzle
c. Freezing graupel
d. Freezing hail and freezing snow

374 Which of the following is an example of a Foehn wind?

a. Bora
b. Harmattan
c. Chinook
d. Ghibli

375 From which of the following clouds are you least likely to get precipitation in summer?

a. CS/NS
b. CS/AS
c. CB/CU
d. CU/ST

376 What is a cold pool?

a. Found south of the Alps if there is NW airflow
b. Cool area of weather which disappears at night
c. Cold pool is most evident behind polar frontal weather in mid temperate areas with little or no sign on significant weather charts
d. Air trapped on the leeward side of mountain ranges

377 Where do you find information on ICING and CAT?

a. 300mb chart
b. 700mb chart
c. Sig. WX chart
d. Analysis chart

378 Which of these statements is true about Hurricanes?

a. They are 400-500m wide
b. They pick up in force when they hit land
c. The air inside is warmer than outside and can reach up to tropopause
d. They are never found more than 25° latitude

379 Relative humidity:

a. Is not affected by temperature
b. Is not affected by air expanding and contracting
c. Does not change when water is added
d. changes when water is added, even if the temperature is the same

380 What happens to the temperature of a saturated air mass when forced to descend?

a. it heats up more than dry because of expansion
b. it heats up less than dry because of evaporation
c. it heats up more than dry because of sublimation
d. it heats up less than dry because of latent heat released during condensation

381 A warm front occlusion is approaching the east coast of the UK.
What WX would you expect in the North Sea during summer?

a. High level Ci
b. TS/showers/CB
c. Medium level cloud 3/8 oktas, isolated showers
d. Low level stratus

382 What is the average height of the Tropopause at the equator?

a. 16km
b. 11km
c. 5km
d. 3km

383 The Tropopause is lower:

a. in summer in mid latitudes
b. at the North Pole than at the Equator
c. in summer at the Equator
d. at the Equator than at the South Pole

384 An airfield has an elevation of 540ft with a QNH of 993mb. An aircraft descends and lands at the airfield with 1013mb set. What will its altimeter read on landing?

a. 380ft
b. 1080ft
c. 0ft
d. 540ft

385 In a METAR a gust is reported when:

a. it is 10 kts greater than the mean wind speed
b. it is 15 kts greater than the mean wind speed
c. it is 20 kts greater than the mean wind speed
d. it is 5 kts greater than the mean wind speed

386 When is pressure altitude equal to true altitude?

a. In standard conditions
b. When surface pressure is 1013.25mb
c. When the temperature is standard
d. When the indicated altitude is equal to the pressure altitude

387 What is the relationship between QFE and QNH at an airport 50ft below MSL?

a. QFE = QNH
b. QFE < QNH
c. QFE > QNH
d. There is no clear relationship

388 Where would a pilot find information about the presence of a jet stream?

a. On an Upper Air chart
b. On a Significant Weather chart
c. On a Surface Analysis chart
d. On a Wind/Temperature chart

389 Up to FL180 ISA Deviation is ISA +10°C. What is the actual depth of the layer between FL60 and FL120?

a. 6000ft
b. 6240ft
c. 5760ft
d. 5700ft

390 Thunderstorms will occur on a warm front:

a. When air is cold moist and cools quicker than SALR
b. When air is warm moist and cools quicker than SALR
c. When air is cold moist and cools slower than SALR
d. When air is warm moist and cools slower than DALR

391 What is the effect of a mountain valley wind?

a. it blows down a mountain to a valley at night
b. it blows down a mountain to a valley during the day
c. it blows from a valley up a mountain by day
d. it blows from a valley up a mountain at night

392 What is the name of the dry, dusty wind blowing in North West Africa from the North East?

a. Pampero
b. Khamsin
c. Harmattan
d. Ghibli

393 What is the difference between Gradient and Geostrophic winds?

a. Difference in temperatures
b. A lot of friction
c. Curved isobars and straight isobars
d. Different latitudes and densities

394 In still air a lapse rate of 1.2°C/100m refers to:

a. DALR
b. SALR
c. ELR
d. ALR

395 What happens to the temperature of a saturated air mass when descending

a. heats up more than dry because of expansion
b. heats up less than dry because of evaporation
c. heats up more than dry because of compression
d. heats up less than dry because of latent heat released during condensation

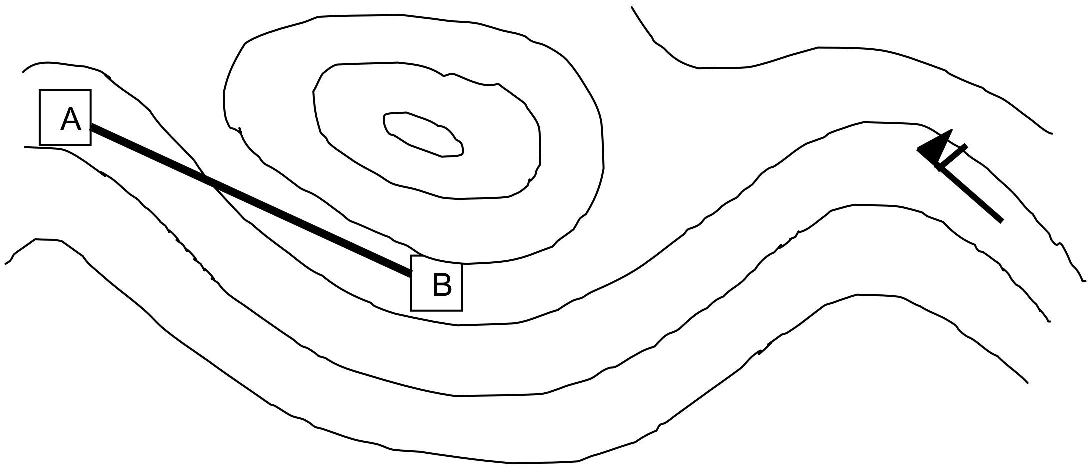
396 What prevents air from flowing directly from a high to a low pressure

a. Centripetal force
b. Centrifugal force
c. Pressure force
d. Coriolis force

397 You are flying at FL160 with an OAT of -27°C. QNH is 1003 hPa. What is your true altitude?

a. 15,540 ft
b. 15,090 ft
c. 16,330 ft
d. 15,730 ft

398 Flying from A to B at a constant indicated altitude in the northern hemisphere.



a. True altitude increases
b. Wind is northerly
c. True altitude decreases
d. Wind is southerly

399 What is the relationship between the 5000 ft wind and the surface wind in the southern hemisphere

a. surface winds are veered from the 5000ft and have the same speed
b. surface winds are backed from the 5000ft and have a slower speed
c. surface winds are veered from the 5000ft and have a slower speed
d. surface winds are backed from the 5000ft and have a faster speed

400 What is the relationship between the 2000 ft wind and the surface wind in the Northern Hemisphere

a. surface winds blow across isobars towards a high
b. surface winds blow parallel to isobars
c. surface winds blow across isobars towards a low
d. surface winds have laminar flow

401 The DALR is

a. Variable with time
b. Fixed
c. Variable with latitude
d. Variable with temperature

402 Which frontal or occlusion system is the fastest moving?

a. Warm front
b. Cold front
c. Cold occlusion
d. Warm occlusion

403 From the pre-flight briefing you know a jet stream is at 31000 ft whilst you are at FL270. You experience moderate C.A.T, what would be the best course of action?

a. Stay level
b. Descend
c. Climb
d. Reduce speed

404 On a significant weather chart you notice a symbol with the letter "H" and the number "400" inside. What does this imply?

a. The height of the significant weather chart
b. Tropopause "low"
c. Tropopause "high"
d. Tropopause "middle"

405 You are at 12,000 ft (FL120) with an outside air temperature is -2°C. Where would you find the freezing level?

a. FL110
b. FL100
c. FL090
d. FL140

406 How does a polar front depression normally move?

a. Same direction as the isobars behind the cold front
b. Same direction as the isobars in the warm sector
c. Same direction as isobars in front of the warm front
d. Same direction as the isobars north of the centre of the low.

407 Flying away from a low pressure at low levels in the Southern Hemisphere, where is the wind coming from?

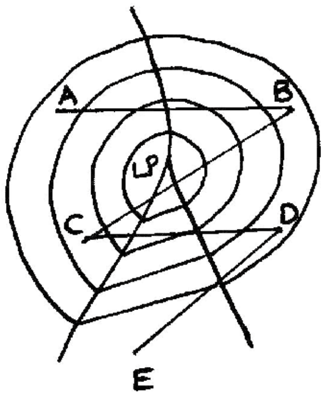
a. From the left and slightly on the nose
b. From the right and slightly on the nose
c. From the rear and slightly on the left
d. From the rear and slightly on the right

408 The ITCZ in July is?

a. Over West Africa at 25°N and stretches up to the north of the Arabian sea
b. 20°N over west Africa
c. Near the Canaries
d. Passing through Freetown

409 Using the diagram shown, what cross section is through an occluded front?

a. DE
b. CD
c. CB
d. AB



410 What is true about the dew point temperature?

a. Can be higher or lower than the air mass temperature
b. Can be higher than the temperature of the air mass only
c. Can be only lower than the temperature of the air mass
d. Can be equal to or lower than the temperature of the air mass

411 What kind of weather system might you typically find between the 45° - 70°N?

a. Sub tropical highs
b. Polar highs
c. Polar front depressions
d. Arctic front depressions

412. What is true regarding super cooled water droplets?

a. Always below -60°C
b. All large
c. All small
d. All below 0°C

413 What is most different about the Equatorial Easterly jet stream?

a. It's height
b. It's length
c. It's direction
d. It's speed

414 Flying towards a warm front, at what distances might you expect the following cloud types from the surface position of the front?

a. CS 600km; AS 400km: NS 200km
b. CS 200km: AS 400 km: NS 600km
c. CS 800km: AS 200km: NS 400km
d. CS 400km: AS 600km: NS 800km

415 Wind is caused by?

a. Mixing of fronts
b. Horizontal pressure difference
c. Earth rotation
d. Surface friction

416 What weather might you expect behind a fast moving cold front?

a. 8 oktas of layered cloud
b. Scattered ST
c. Isolated CB's and showers
d. Continuous rain

417 How would an unstable atmosphere likely reduce the visibility?

a. By mist
b. By haze
c. By rain and or snow
d. Low stratus

418 Which is true regarding a polar front jet stream?

a. It is found in the warm air and so does it's plan projection show this
b. It is located where there is little vertical temperature gradient but the horizontal pressure gradient is at it's steepest
c. It is located where there is significant horizontal temperature difference but the pressure gradient is flat
d. It is always in the colder of the air masses

419 Which of the following indicates upper level instability and possible the formation of TS?

a. Halo
b. Red cirrus
c. Altocumulus Lenticularis
d. Altocumulus castalanus

420 When are the north Atlantic lows at their most southerly position?

a. Spring
b. Summer
c. Autumn
d. Winter

421 A layer of air cooling at the SALR compared to the DALR would give what kind of cloud?

a. Stratus if saturated
b. Cumulus if saturated
c. No cloud if saturated
d. Convective cloud

422 For the same pressure gradient at 50N, 60N and 40N, the geostrophic wind speed is?

a. Greatest at 60N
b. Least at 50N
c. Greatest at 40N
d. The same at al latitudes

423 What is a SPECI?

a. A forecast valid for 3 hours
b. A report produced when significant changes have occurred
c. A forecast and valid for 6 hours
d. A landing forecast

424 A parcel of air cooling by more than 1°C/100m is said to be?

a. Conditionally stable
b. Conditionally unstable
c. Unstable
d. Stable

425 The wind in the Northern Hemisphere at the surface and above the friction layer at 2000 ft would be?

a. Veered at the surface, veered above the friction layer
b. Backed at the surface, veered above the friction layer
c. Veered at the surface, backed above the friction layer
d. Backed at the surface, backed above the friction layer

426 Where are easterly and westerly jets found?

a. Northern hemisphere only
b. Southern hemisphere only
c. Northern and southern hemisphere
d. There are no easterly jets.

427 Which weather phenomena are typical for the north side of the alps with stormy winds from the south (Foěhn?)

a. Drop in temperature, moderate to severe icing
b. Icing, huge mass of cloud
c. Good visibility, turbulence
d. Continuous precipitation and moderate turbulence

428 At 15,000ft in nimbostratus cloud with an outside air temperature of -12°C, what icing might you expect?

a. Moderate rain ice.
b. Moderate to severe mixed ice.
c. Moderate to severe ice if orographicaly intensified.
d. Light rime ice.

429 Comparing rain to drizzle, visibility will generally…?

a. Rain has a visibility of 1 km, drizzle has 2 km.
b. Remains the same
c. Deteriorate
d. Improve

430 What statement is true regarding the tropopause?

a. It is higher over the equator with a higher temperature.
b. It is lower over the equator with a lower temperature.
c. It is higher over the poles with a lower temperature.
d. It is lower over the poles with a higher temperature.

431 Please refer to Appendix F (attached on the next page)
What is the temperature deviation, in degrees Celsius, from the International Standard Atmosphere overhead Frankfurt (50N 08E) at FL 180 ?

a. ISA +2°C
b. ISA -13°C
c. ISA +13°C
d. ISA -2°C

432 Polar front depression normally move

a. In the direction of the isobars behind the cold front
b. In the direction of the isobars in front of the warm front
c. In the direction on the isobars ahead of the depression
d. In the direction of the isobars inside the warm sector

433 QNH in a METAR is

a. Rounded up to the nearest whole hectopascal
b. Rounded down to the nearest even hectopascal.
c. Rounded up to the nearest even hectopascal.
d. Rounded down to the nearest whole hectopascal.

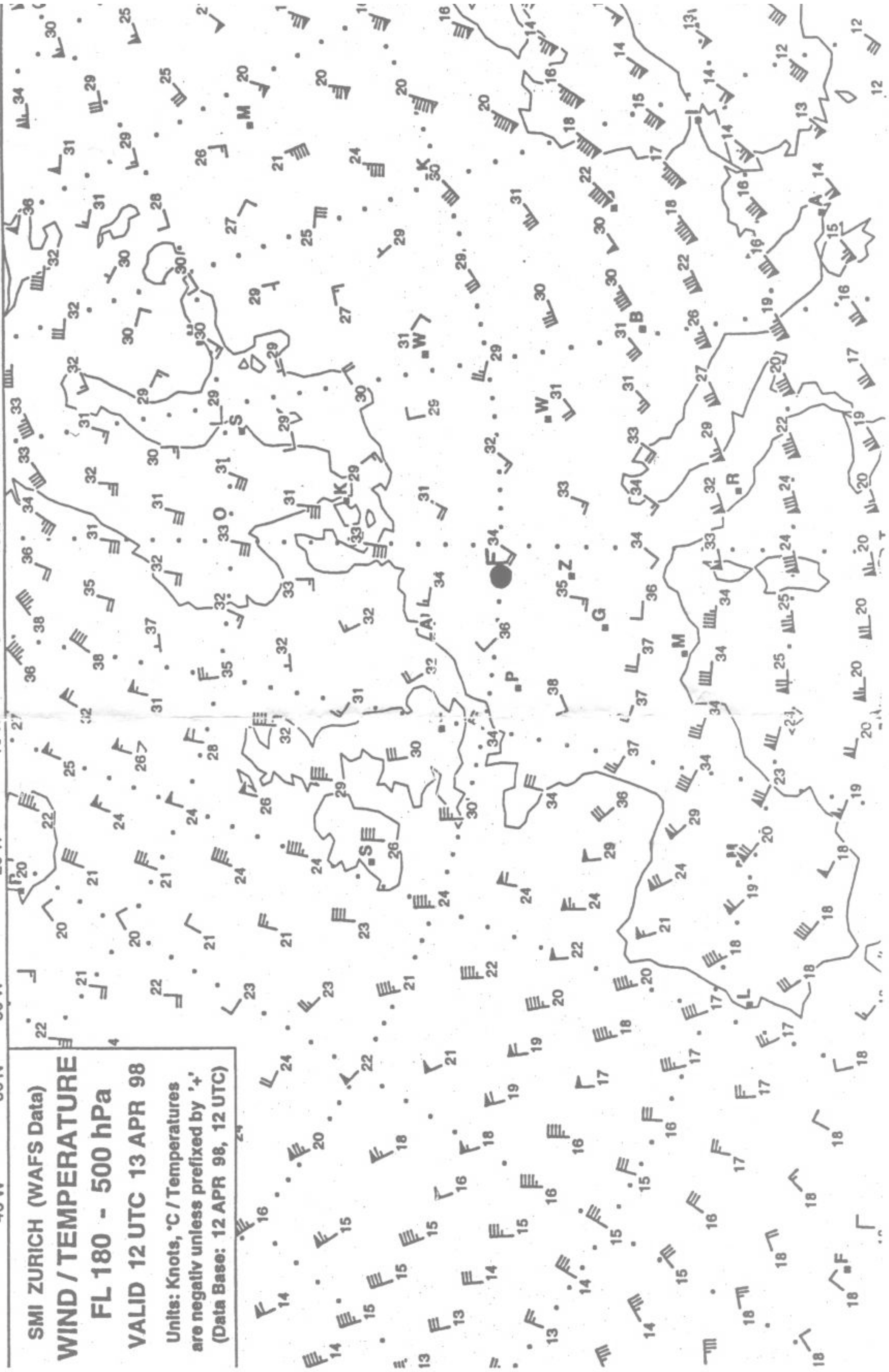
434 Thermal lows usually develop

a. Over the sea in summer.
b. Over the sea in winter.
c. Over the land in summer.
d. Over the land in winter.

435 TAF's are usually valid for

a. For the period indicated in the TAF itself
b. For 18 hours
c. For 24 hours.
d. For 8 hours.

ANNEX F


SMI ZURICH (WAFS Data)
WIND / TEMPERATURE
FL 180 - 500 hPa
VALID 12 UTC 13 APR 98
Units: Knots, °C / Temperatures are negativ unless prefixed by '+'
(Data Base: 12 APR 98, 12 UTC)

436 Tornadoes are usually associated with which cloud type

a. Ns
b. Cu
c. Cb
d. Ts

437 Wind at altitude is usually given as …….. in ……..

a. True, m/s
b. Magnetic, m/s
c. True, KT
d. Magnetic, KT

438 The surface wind circulation found between the sub tropical highs and the equatorial lows are called?

a. The doldrums
b. The trade winds
c. The easterlies
d. The westerlies

439 An occlusion is mimicking a cold front, where would the coldest air be found?

a. Behind the original cold front.
b. Behind the original warm front
c. In front of the occlusion.
d. In front of the original warm front.

440 In a high pressure systems

a. The winds tend to be stronger in the morning.
b. The angle between the isobars and the wind direction is greatest in the afternoon.
c. The winds tend to be stronger at night.
d. The winds tend to be stronger in early afternoon.

441 Over flat dry land what would cause cloud?

a. Orographic uplift.
b. Convective uplift during the day.
c. Release of latent heat.
d. Advection.

442 Where does freezing rain come from?

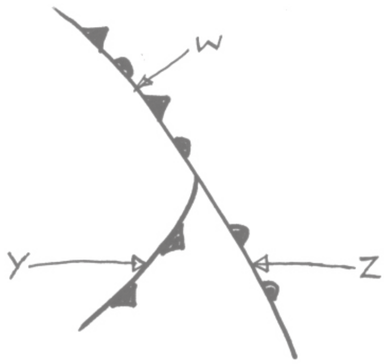
a. Cold hail falling into a warm layer.
b. Cold rain falling into a warmer layer.
c. Warmer rain falling into a colder layer.
d. Cold rain falling into cold layer.

443 Without the ability to de-ice or land immediately, what should you do if you encounter rain ice at about 2,000ft?

a. Turn around immediately before loss of controllability.
b. Descend immediately to stop the rain ice
c. Climb into the warm air found above.
d. Fly faster.

444 What is the feature W?

a. Warm occlusion.
b. Cold occlusion.
c. Quasi stationary front.
d. Warm front.



445 Using the picture shown above, what will be expected to happen to the surface pressure after the feature Y has passed?

a. Increase.
b. Decrease.
c. Remain the same.
d. Increase, then decrease.

446 A man is flying East to West in the Northern Hemisphere. What is happening to his altitude?

a. Flying into a headwind will decrease altitude
b. If the wind is from the south, he will gain altitude
c. If the wind is from the north, he will gain altitude
d. Tailwind will increase altitude.

447 Up to FL180 ISA Deviation is ISA -10°C. What is the actual depth of the layer between FL60 and FL120?

a. 6000ft
b. 6240ft
c. 5760ft
d. 5700ft

448 In central Europe in summer, under the influence of a polar depression in a wide warm sector, you would expect the following wx:

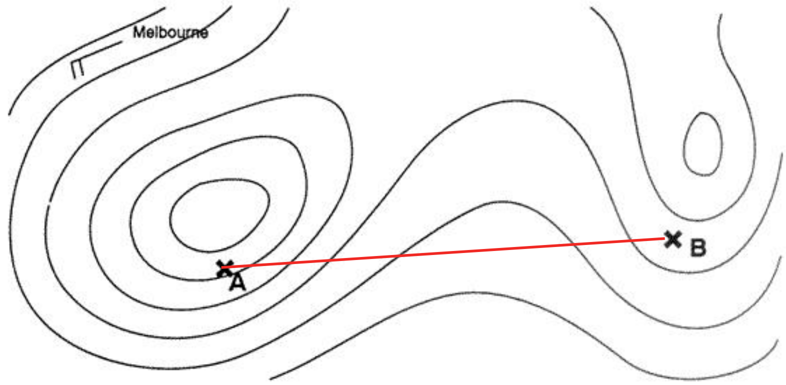
a. Thunderstorms and rain showers
b. Low stratus and drizzle
c. Fair weather Cu
d. Clear skies

449 An Easterly wave will produce:

a. Frontal weather
b. Thunderstorms and rain
c. Low stratus
d. Clear skies

450 The line connecting A to B crosses what pressure system:

a. A trough
b. A ridge
c. A front
d. An occlusion



451 Which coast of the USA is affected by the most frequent hurricanes:

a. NE
b. NW
c. SE
d. SW

452 Flying over France at dawn, with 8/8 St at 200ft, QNH 1026, wind Var3, what will be the most likely conditions at mid-day in winter and summer:

a. OVC 2000ft St OVC 200ft St
b. OVC 500ft AGL St SCT 3000ft St
c. OVC 2000ft AGL St OVC 200ft St
d. Clear skies CB's

453 What do the following one hour interval METARS indicate the passage of:

22010KT 9999 SCT200 14/08 Q1012=
22010KT 9999 OVC200 13/08 Q1011=
23012KT 9KM SCT 060 OVC120 13/08 Q1010=
24012KT 8KM -RA BKN040 OVC090 12/08 Q1009=
25015KT 2000 +RA SCT002 OVC008 12/08 Q1008=
27015KT 0800 DZ BKN002 OVC010 17/16 Q1008=
27015KT 0800 DZ BKN002 OVC010 17/16 Q1008=
27015G30KT 1000 +SHRA TS OVC010 17/16 Q1008=
29020KT 9000 SHRA BKN020 14/07 Q1010=
31020KT 9999 SCTO30 13/07 Q1012=

a. Cold occlusion
b. Polar front
c. Ridge
d. Warm front

454 Paris reports OVC 8/8 St at +3 ° C during the day. What will happen on the night of 3/4 Jan

a. slightly above +3°
b. sligltly below +3°
c. stays at +3°
d. well below 0°

455 With a cold front over the North Sea, what weather would you expect 300km behind the front?

a. Stratus with drizzle
b. Thunderstoms and heavy showers
c. Scattered Cu and showers
d. Clear skies

456 Surface wind is 320/12 what is the wind at 2000ftin the Northern hemisphere?

a. 330/25
b. 220/20
c. 270/20
d. 210/12

457 Lucarno airfield elv 1735 ft altimeter indicates 1310 ft with 1013hPa set what is the QNH?

a. 990hPa
b. 980hPa
c. 1028hPa
d. 998hPa

458 Where is the ITCZ in July?

a. 25 N over the Atlantic
b. 10 - 20 N over East Africa and the Arabian sea
c. 10 - 30 N over West Africa
d. 20 - 30 N over East Africa

459 The letters NC used at the end of a SIGMET, mean:

a. No cloud
b. No change
c. No cumulus
d. Not clear

460 On the route London to Bombay, which feature would you most likely encounter between 30E and 50E.

a. Polar front jet in excess of 90kts
b. Sub tropical jet in excess of 90kts
c. Variable winds less than 30kts
d. Easterly winds

461 When would the strongest convection occur?

a. Land in summer
b. Land in winter
c. Sea in summer
d. Sea in winter

462 Which way does a depression move?

a. Direction of the isobars in the warm sector
b. 90 degrees to the plane of the warm front
c. Towards the east
d. Direction of the isobars behind the cold front

463 Freezing rain is most likely from

a. Warm front in summer
b. Cold front in summer
c. Warm front in winter
d. cold front in winter

464 With regard to RVR and Met vis

a. Met vis is usually less than RVR
b. Met vis is usually greater than RVR
c. RVR is usually less than met vis
d. Met vis and RVR are usually the same

465 When are thermal lows most likely

a. Land in summer
b. Land in winter
c. Sea in summer
d. Sea in winter

466 What is the validity of a significant weather chart

a. 3 hrs
b. 6 hrs
c. 9 hrs
d. 12 hrs

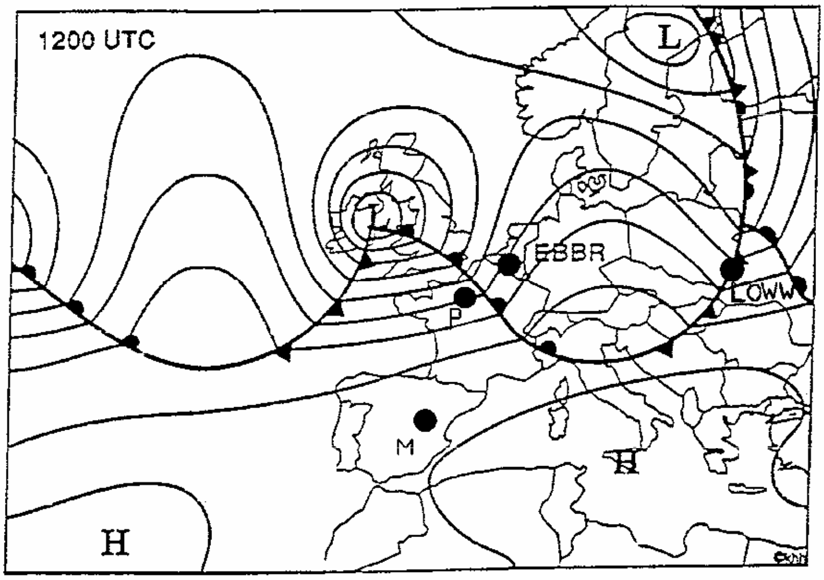
467 What is the main feature of the initial stage of a thunderstorm

a. Downdrafts
b. up currents
c. rain
d. rotor cloud

468 What is haze?

a. poor visibility due to drizzle
b. poor visibility due to rain
c. poor visibility due to dust or sand
d. all of the above

469 On the chart below, where is rain least likely



a. EBBR
b. Madrid
c. Paris
d. LOWW

470 On a flight from Zurich to Rome, which of the following METARS would be applicable?

a. London
b. Shannon
c. Madrid
d. Milan

471 Which of the following is true about freezing precipitation?

a. It only falls from a Warm front
b. It is either rain or drizzle
c. It only falls from a cold front
d. It only falls from an occlusion

472 What do the letters NO SIG mean at the end of a METAR

a. No significant change
b. No significant weather
c. No significant cloud
d. No signature on report

473 What is a trend forecast

a. An aerodrome forecast valid for 9 hours
b. A routine report
c. A landing forecast appended to a METAR/SPECI valid for 2 hours.
d. A route forecast, valid for 24 hours.

474 How does clear ice form?

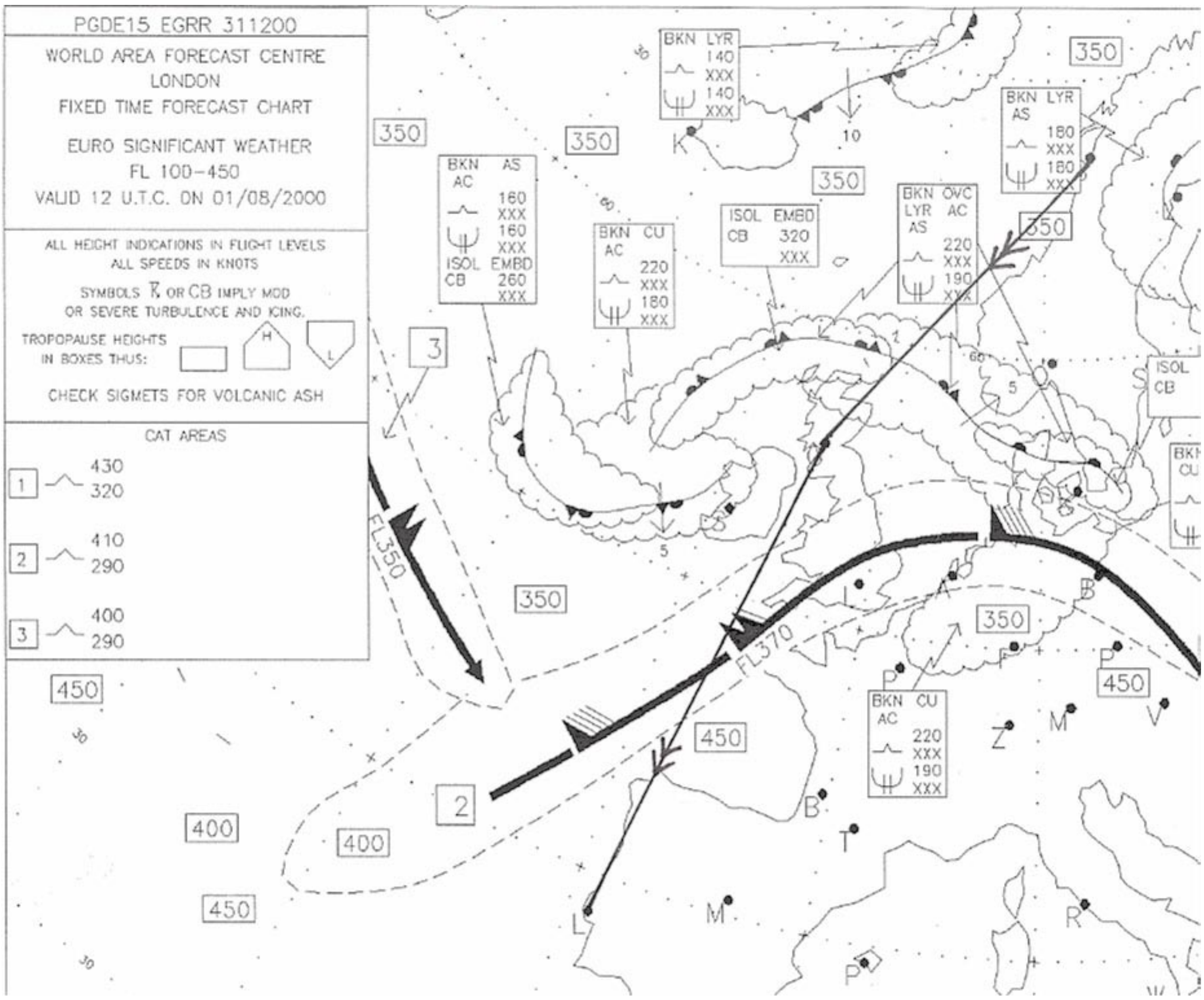
a. SWD's speading on impact
b. Ice pellets shattering on impact
c. Frost on the wing
d. Water vapour freezing on the aircraft surface.

475 Where is windshear the greatest?

a. Near a strong low level inversion and in the region of a thunderstorm
b. Near a valley with wind speeds greater than 35kts
c. On the windward side of a mountain
d. When the wind is greater than 35kts

477 On the chart below, for the route Edinburgh to Zurich, state the optimum flight level.

a. FL220
b. FL240
c. FL370
d. FL390



476 Where do you find squall lines

a. Where there are thunderstorms
b. Ahead of a fast moving cold front
c. Foggy areas
d. Regions of snow

478 A Fohn wind occurs

a. On the windward side caused by surface heating
b. On the leeward side, because the condensation level is higher
c. On the windward side, caused by surface cooling and wind flow reversal
d. On the leeward side, caused by precipitation

479 The Harmattan is

a. A SE monsoon wind
b. NE wind over NW Africa between Nov - April reducing visibility with dust
c. A local depression wind
d. SE wind over NW Africa between Nov - April reducing visibility with dust

480 Icing is most likely

a. -20 to --35 C
b. +10 to 0 C
c. 0 to -10C
d. below - 35 C

481 At what height is half the mass of the atmosphere

a. 5km
b. 11km
c. 8km
d. 3km

482 How can you determine QNH from QFE

a. Temperature and elevation
b. Elevation
c. Pressure and temperature
d. Temperature

483 What is true about moderate to severe airframe icing

a. It will occur in clear sky conditions
b. Always occurs in AS cloud
c. May occur in the uppermost levels of CB capillatus formation
d. Most likely in NS

484 A winter day in N Europe with a thick layer of SC and surface temperature zero degrees C. You can expect

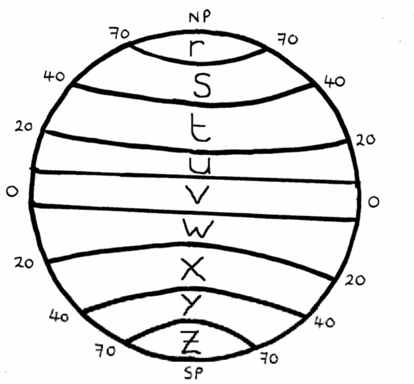
a. Decreasing visibility due to snow below the cloud base and light icing in cloud
b. High probability of icing in clouds, Severe icing in the upper levels due to large droplets
c. Turbulence due to a strong inversion, but no icing due to clouds being formed from ice crystals
d. Reduced visibility and light icing in cloud

485 An aircraft flies into an area of supercooled rain with a temperature below zero, what kind of icing is most likely

a. Clear
b. Rime
c. Hoar frost
d. Granular frost

486 With regard to the idealized globe below, where are traveling lows located

a. V
b. S + Y
c. T + W
d. U + W



487 If Paris has a surface wind of 160/40, what is the wind at 2000 ft

a. 180/60
b. 120/40
c. 160/60
d. 160/40

488 What causes convection in a low pressure system

a. Height
b. Latitude
c. Centripetal force
d. Friction

489 What is the cause of the formation of the polar front jet

a. Pressure
b. Azores High
c. Temperature
d. Tropopause height

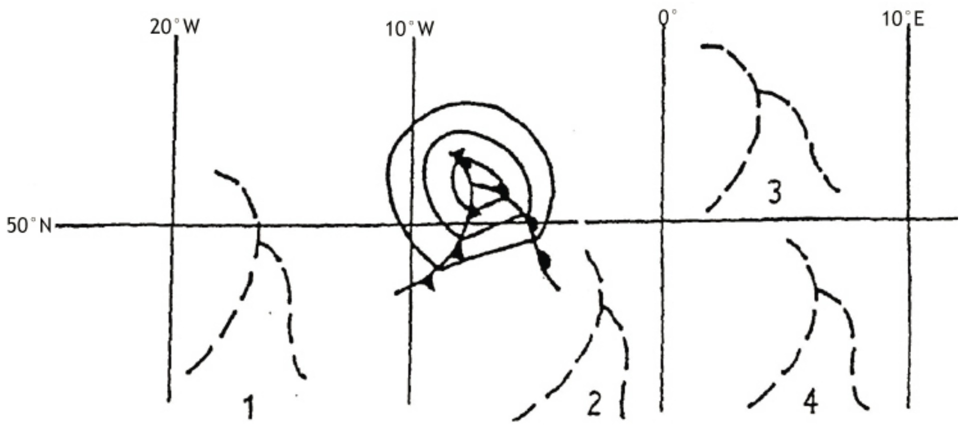
490 You are flying at FL120 with a true altitude of 12,000ft, why would this be

a. ISA conditions prevail
b. Temperature higher than ISA
c. Temperature lower than ISA
d. An altimeter fault

491 TAF 130600Z 130716 VRB02 CAVOK =
Volmet 0920 28020G40KT BKN050CB OVC090 TEMPO TS =

a. TAF is correct Volmet is wrong
b. TAF & Volmet match
c. Volmet speaker surely must have mixed up airports because there is no way that TAF & Volmet can differ by that much.
d. Conditions just turned out to be much more volatile than originally forecast.

492 What will be the position of the Polar Front in 24 hours time, assuming the usual path of movement of the PF.



493 Considering the North Atlantic area at 60 N in winter, the mean height of the tropopause is approximately

a. 56,000 ft
b. 37,000 ft
c. 29,000 ft
d. 70,000 ft

494 An unsaturated parcel of air is forced to rise through an isothermal layer. As long as it stays unsaturated the temperature of the parcel will

a. Remain the same
b. Become equal to the temperature of the isothermal layer
c. Decrease at 1.0 deg C per 100m
d. Decrease at 0.65 deg C per 100m

ANSWERS

1	D	41	A	81	A	121	B	161	C	201	C	241	A
2	A	42	C	82	A	122	A	162	C	202	D	242	A
3	B	43	B	83	A	123	B	163	B	203	D	243	A
4	A	44	B	84	A	124	C	164	D	204	B	244	B
5	A	45	A	85	C	125	A	165	C	205	A	245	D
6	A	46	A	86	C	126	B	166	B	206	B	246	A
7	B	47	A	87	A	127	C	167	D	207	B	247	C
8	A	48	B	88	B	128	D	168	C	208	C	248	B
9	D	49	D	89	A	129	C	169	A	209	A	249	A
10	B	50	A	90	A	130	C	170	C	210	C	250	A
11	A	51	B	91	A	131	D	171	A	211	C	251	A
12	A	52	A	92	A	132	A	172	D	212	C	252	A
13	B	53	A	93	A	133	D	173	D	213	D	253	A
14	C	54	B	94	B	134	A	174	C	214	C	254	D
15	C	55	A	95	C	135	A	175	B	215	A	255	A
16	B	56	B	96	D	136	C	176	C	216	B	256	C
17	B	57	A	97	D	137	A	177	A	217	A	257	D
18	A	58	A	98	B	138	C	178	A	218	C	258	A
19	A	59	C	99	A	139	B	179	A	219	C	259	C
20	A	60	B	100	B	140	A	180	C	220	B	260	D
21	A	61	B	101	A	141	D	181	A	221	D	261	C
22	B	62	B	102	B	142	D	182	D	222	C	262	B
23	C	63	D	103	C	143	C	183	B	223	A	263	A
24	D	64	A	104	B	144	B	184	B	224	C	264	B
25	C	65	B	105	A	145	D	185	C	225	A	265	C
26	D	66	A	106	C	146	A	186	A	226	C	266	C
27	C	67	B	107	B	147	D	187	C	227	C	267	C
28	B	68	D	108	D	148	C	188	C	228	A	268	D
29	B	69	D	109	C	149	B	189	C	229	C	269	C
30	C	70	C	110	B	150	C	190	A	230	B	270	A
31	D	71	C	111	D	151	D	191	B	231	B	271	A
32	A	72	D	112	A	152	C	192	C	232	A	272	C
33	C	73	B	113	C	153	D	193	B	233	A	273	B
34	A	74	B	114	A	154	A	194	B	234	C	274	A
35	C	75	B	115	D	155	D	195	B	235	C	275	D
36	D	76	A	116	D	156	A	196	D	236	B	276	D
37	C	77	B	117	B	157	C	197	C	237	D	277	D
38	A	78	B	118	D	158	A	198	B	238	B	278	D
39	A	79	B	119	B	159	A	199	B	239	C	279	D
40	C	80	A	120	C	160	A	200	D	240	D	280	B

281	C	321	A	361	A	401	B	441	B	481	A
282	B	322	C	362	A	402	B	442	C	482	B
283	D	323	A	363	A	403	B	443	A	483	D
284	A	324	D	364	C	404	C	444	A	484	D
285	C	325	C	365	B	405	A	445	A	485	A
286	B	326	A	366	A	406	B	446	C	486	B
287	D	327	B	367	A	407	A	447	C	487	A
288	C	328	B	368	C	408	B	448	B	488	D
289	A	329	A	369	B	409	D	449	B	489	C
290	C	330	C	370	B	410	D	450	B	490	A
291	A	331	C	371	D	411	C	451	C	491	D
292	D	332	C	372	A	412	D	452	B	492	C
293	B	333	D	373	B	413	C	453	B	493	C
294	D	334	A	374	C	414	A	454	B	494	C
295	B	335	D	375	B	415	B	455	C		
296	A	336	D	376	C	416	C	456	C		
297	D	337	B	377	C	417	C	457	A		
298	B	338	A	378	C	418	B	458	B		
299	B	339	C	379	D	419	D	459	B		
300	D	340	C	380	B	420	D	460	B		
301	C	341	B	381	D	421	A	461	A		
302	D	342	B	382	A	422	C	462	A		
303	C	343	C	383	B	423	B	463	C		
304	C	344	B	384	B	424	C	464	A		
305	C	345	D	385	A	425	B	465	A		
306	A	346	A	386	A	426	A	466	C		
307	B	347	C	387	C	427	C	467	B		
308	A	348	C	388	B	428	C	468	C		
309	A	349	A	389	B	429	D	469	B		
310	B	350	B	390	B	430	D	470	D		
311	B	351	A	391	A	431	B	471	B		
312	B	352	D	392	C	432	D	472	A		
313	B	353	A	393	C	433	D	473	C		
314	D	354	B	394	C	434	C	474	A		
315	D	355	D	395	B	435	A	475	A		
316	C	356	C	396	D	436	C	476	B		
317	D	357	A	397	B	437	C	477	B		
318	D	358	A	398	C	438	B	478	B		
319	A	359	B	399	C	439	A	479	B		
320	A	360	B	400	C	440	D	480	C		

JAA FINAL EXAMINATION

1 MSA given as 12,000ft, flying over mountains in temperatures +9°C, QNH set as 1023 (obtained from a nearby airfield). What will the true altitude be when 12,000ft is reached?

a. 11,940
b. 11,148
c. 12,210
d. 12,864

2 In the Northern Hemisphere a man observes a low pressure system passing him to the south, from west to east. What wind will he experience?

a. Backs then Veers
b. Constantly Backs
c. Veers then Backs
d. Backs then steady

3 What is Relative Humidity dependent upon?

a. Moisture content and temperature of the air
b. Temperature of the air
c. Temperature and pressure
d. Moisture content of the air

4 If the ELR is 0.65°C/100m

a. Atmosphere is conditionally stable
b. Atmosphere is stable
c. Atmosphere is unstable
d. Atmosphere is stable when dry

5 Height of the tropopause at 50°N

a. 11 km
b. 16 km
c. 5 km
d. 20 km

6 ELR is 1°C/100m

a. Neutral when dry
b. Absolute stability
c. Absolute instability
d. Conditional stability

7 A steep pressure gradient is characterised by

a. Isobars close together, strengthened wind
b. Isobars far apart, decreased wind
c. Isobars close together, temperature increasing
d. Isobars far apart, temperature decreasing

8 If you fly with left drift in the Northern Hemisphere, what is happening to your true altitude?

a. Increases
b. Decreases
c. Stays the same
d. Cannot tell

9 Sublimation

a. Solid to vapour
b. Vapour to liquid
c. Liquid to vapour
d. Liquid to solid

10 What is the coldest time of the day?

a. 1hr before sunrise
b. 1/2 hr before sunrise
c. at exact moment of sunrise
d. 1/2 hr after sunrise

11 When is diurnal variation a maximum?

a. Clear sky, still wind
b. Clear sky, strong wind
c. OVC, still
d. OVC, windy

12 QNH at Timbuktu (200m AMSL) is 1015 hPa. What is the QFE? (Assume 1 hPa = 8m)

a. 1000
b. 990
c. 1020
d. 995

13 Above a stable layer in the lower troposphere in an old high pressure system is called:

a. radiation inversion
b. subsidence inversion
c. frontal inversion
d. terrestrial inversion

14 Why does air cool as it rises?

a. It expands
b. It contracts
c. The air is colder at higher latitudes
d. The air is colder at higher altitudes

15 When flying at FL180 in the Southern Hemisphere you experience a left crosswind. What is happening to your true altitude if indicated altitude is constant?

a. Remains the same
b. Increasing
c. Decreasing
d. Impossible to tell

16 Dew point is defined as:

a. The lowest temperature at which evaporation will occur for a given pressure
b. The lowest temperature to which air must be cooled in order to reduce the relative humidity
c. The temperature below which the change of state for a given volume of air will result in absorption of latent heat
d. The temperature to which moist air must be cooled to reach saturation

17 Flying from Marseilles (QNH 1012) to Palma (QNH 1015) at FL100. You dont reset the altimeter, why would true altitude be the same throughout the flight?

a. Not possible to tell
b. Air at Palma is warmer than air at Marseilles
c. Air at Marseilles is warmer than air at Palma
d. Blocked static vent

18 From which of the following can the stability of the atmosphere be determined?

a. surface pressure
b. surface temperature
c. DALR
d. ELR

19 When heading South in the Southern Hemisphere you experience Starboard drift:

a. You are flying towards a lower temperature
b. You are flying away from a lower temperature
c. You are flying towards a low pressure
d. You are flying out of a high

20 How does the level of the tropopause vary with latitude in the Northern Hemisphere?

a. Decreases North - South
b. Decreases South - North
c. Constant
d. It varies with longitude not latitude

21 What is the tropopause?

a. The layer between the troposphere and stratosphere
b. The boundary between the troposphere and stratosphere
c. Where temperature increases with height
d. Upper boundary to C.A.T.

22 Where do you find the majority of the air within atmosphere?

a. Troposphere
b. Stratosphere
c. Tropopause
d. Mesosphere

23 Flying from an area of low pressure in the Southern Hemisphere at low altitudes, where is the wind coming from?

a. Right and slightly on the nose
b. Left and slightly on the tail
c. Left and slightly on the nose
d. Right and slightly on the tail

24 The QNH at an airfield 200m AMSL is 1009 hPa; air temperature is 10°C lower than standard. What is the QFF?

a. Not possible to give a definite answer
b. Less than 1009
c. 1009
d. More than 1009

25 Which of these would cause your true altitude to decrease with a constant indicated altitude?

a. Cold/Low
b. Hot/Low
c. Cold/High
d. Hot/High

26 Where is the ozone layer?

a. ionosphere
b. Stratosphere
c. Tropopause
d. Troposphere

27 An aircraft flying in the Alps on a very cold day, RPS 1013 set on the altimeter, flies level with the summit of the mountains. Altitude from aneroid altimeter reads:

a. Same as mountain elevation
b. Lower than mountain elevation
c. Higher than mountain elevation
d. Impossible to determine

28 QNH is defined as:

a. The pressure at MSL obtained using the standard atmosphere
b. The pressure at MSL obtained using the actual conditions
c. QFE reduced to MSL using the actual conditions
d. QFE reduced to MSL using the standard atmosphere

29 Where would you expect to find the strongest wind on the ground in temperate latitudes?

a. In an area of Low pressure
b. In an area of High pressure
c. In the warm air between two fronts
d. In a weak anticyclone

30 Landing at an airfield with QNH set the pressure altimeter reads:

a. Zero feet on landing only if ISA conditions prevail
b. Zero
c. The elevation of the airfield if ISA conditions prevail
d. The elevation of the airfield

31 You are flying in an atmosphere which is warmer than ISA, what might you expect?

a. True altitude to be the same as Indicated altitude
b. True altitude to be lower than Indicated altitude
c. True altitude to be the decreasing
d. True altitude to be higher than Indicated altitude

32 The environmental lapse rate in the real atmosphere:

a. Has a fixed value of 2^0C / 1000ft
b. Has a fixed value of 0.65^0C / 100Mtrs
c. Varies with time
d. Has a fixed value of 1^0C / 100Mtrs

33 Airfield is 69 metres below sea level, QFF is 1030 hPa, temperature is ISA -10^0C. What is the QNH?

a. Impossible to tell
b. Less than 1030Hpa
c. 1030Hpa
d. More than 1030Hpa

34 The QNH is 1030Hpa and at the Transition Level you set the SPS. What happens to your indicated altitude?

a. Drops by 510ft
b. Rises by 510ft
c. Rises
d. Drops

35 What is the movement of air relating to a trough?

a. Descending and diverging
b. Ascending and diverging
c. Descending and converging
d. Converging and ascending

36 What is the movement of air relating to a ridge?

a. Descending and diverging
b. Ascending and diverging
c. Descending and converging
d. Ascending and converging

37 What is the min. temperature according to ISA?

a. -56.5°C
b. -273°C
c. -100°C
d. 215.6°K

38 The temperature at the surface is 15°C, the temperature at 1000m is 13°C. Is the atmosphere

a. Unstable
b. Conditionally unstable
c. Stable
d. Cannot tell

39 You are flying from Madrid (QNH 1012) to Paris (QNH 1015) at FL 80. If your true altitude and indicated altitude remain the same then

a. The air at Madrid is warmer than Paris
b. The air at Paris is warmer than Madrid
c. The altimeters are incorrect
d. Your indicated altitude must be changing

40 If you are flying on a QNH 1009 on very cold day and you circle the top of a peak in the Alps, your altimeter will read

a. The same as the elevation of the peak
b. Lower than the elevation of the peak
c. Higher than the elevation of the peak
d. Not enough information to tell

41 What is subsidence?

a. Horizontal motion of air
b. Vertical down draught of air
c. Vertical up draught of air
d. Adiabatic cooling

42 Relative humidity increases in

a. Warmer air compared to colder air
b. Warm air at a constant vapour pressure
c. Cold air at a constant vapour pressure
d. Colder air compared to warmer air

43 Which of the following gives conditionally unstable conditions?

a. 1°C/100m
b. 0.65°C/100m
c. 0.49°C/100m
d. None of the above

44 A mass of unsaturated air is forced to rise till just under the condensation level. It then settles back to its original position

a. Temp. is greater than before
b. Temp. stays the same
c. Temp. is less than before
d. It depends on QFE

45 What height is the tropopause and at what temperature?

a. At the poles 8km and -16°C
b. At the pole 18km and -75°C
c. At the equator 8km and -40°C
d. At the equator 18km and -76°C

46 Which of the following will give the greatest difference between temperature and dew point?

a. Dry air
b. Moist air
c. Cold air
d. Warm air

47 Solar radiation heats the atmosphere by

a. Heating the air directly
b. Heating the surface, this then heats the air in the atmosphere
c. Heating the water vapour in the atmosphere directly
d. Heating the water vapour directly unless there are clouds present

48 What affects how much water vapour the air can hold?

a. RH
b. Temperature
c. Dew point
d. Pressure

49 Aerodrome at MSL, QNH is 1022. QFF is

a. Greater than 1022
b. Less than 1022
c. Same as QNH
d. Cannot tell without temperature information

50 What is the technical term for an increase in temperature with altitude?

a. Inversion
b. Advection
c. Adiabatic
d. Subsidence

51 On a surface weather chart, isobars are lines of

a. QNH
b. QFE
c. QFF
d. QNE

52 Which of the following constituents in the atmosphere has the greatest effect on the weather?

a. Nitrogen
b. Oxygen
c. Hydrogen
d. Water Vapour

53 Which of the following is true?
QNH is:

a. Always more than 1013.25 hPa
b. Always less than 1013.25 hPa
c. Never 1013.25 hPa
d. Can never be above or below 1013 hPa

54 If an Aerodrome is 1500ft AMSL on QNH 1038, what will the actual height AGL to get to FL75? (27ft = 1 hPa).

a. 6675 ft
b. 8170 ft
c. 8330 ft
d. 2330 ft

55 Altimeter set to 1023 at aerodrome. On climb to altitude the SPS is set at transition altitude. What will indication on altimeter do on resetting to QNH?

a. Dependent on temperature
b. Decrease
c. Increase
d. Same

56 Secondary depressions move

a. Around the primary in a cyclonic fashion
b. Around the primary in an anticyclonic fashion
c. Eastwards
d. Westwards

57 What temperature and pressure conditions would be safest to ensure that your flight level clears all the obstacles by the greatest margin?

a. Cold temp/low pressure
b. Warm temp/high pressure
c. Temp less than or equal to ISA and a QNH less than 1013
d. Temp more than or equal to ISA and a QNH greater than 1013

58 In a shallow pressure distribution (widely spaced Isobars or low pressure gradients) you observe the aneroid altimeter of a parked aircraft for 10 minutes (no thunderstorms observed). The reading of the instrument will...

a. Not be influenced by the air pressure
b. Increase greatly
c. Show no appreciable change due to such a minor pressure fluctuation
d. Experience great changes

59 You are flying from Marseilles (QNH 1012 hPa. to Palma de Mallorca (QNH 1012 hPa. a t FL100. You notice that the effective height above MSL (Radio Altitude) increases constantly. Hence...

a. One of the QNH values must be wrong.
b. You have the altimeters checked, as their indications are obviously wrong.
c. The air mass above Palma is warmer than that above Marseilles
d. You have to adjust for a crosswind from the right.

60 You are flying from Marseilles (QNH 1026 hPa. to Palma de Mallorca (QNH 1026 hPa. a t FL100. You notice that the effective height above MSL (Radio Altitude) decreases constantly. Hence...

a. One of the QNH values must be wrong.
b. The air mass above Marseilles is warmer than that above Palma
c. You have the altimeters checked, as their indications are obviously wrong.
d. You have to adjust for a crosswind from the right.

61 Flying at FL 135 above the sea, the Radio Altimeter indicates a true altitude of 13500 ft. The local QNH is 1019 hPa. Hence the crossed air mass is, on average,

a. At ISA standard temperature
b. Colder than ISA
c. Warmer than ISA
d. There is insufficient information to determine the average temperature deviation

62 You are flying in the Alps at the same level as the summits on a hot day. What does the altimeter read?

a. Same altitude as the summit
b. Higher altitude as the summit
c. Lower altitude as the summit
d. Impossible to tell

63 To dissipate cloud

a. Subsidence
b. Decrease in temperature
c. Increase pressure
d. Convection

64 A layer of air can be

a. Conditional; unstable when unsaturated and stable when saturated
b. Conditional; unstable when saturated and stable when unsaturated
c. Neutrally stable when saturated and unstable when unsaturated
d. all of the above

65 Relative humidity:

a. Is not affected by temperature
b. Is not affected by air expanding and contracting
c. Does not change when water is added
d. changes when water is added, even if the temperature is the same

66 What happens to the temperature of a saturated air mass when forced to descend?

a. it heats up more than dry because of expansion
b. it heats up less than dry because of evaporation
c. it heats up more than dry because of sublimation
d. it heats up less than dry because of latent heat released during condensation

67 An airfield has an elevation of 540ft with a QNH of 993mb. An aircraft descends and lands at the airfield with 1013mb set. What will its altimeter read on landing?

a. 380ft
b. 1080ft
c. 0ft
d. 540ft

68 When is pressure altitude equal to true altitude?

a. In standard conditions
b. When surface pressure is 1013.25mb
c. When the temperature is standard
d. When the indicated altitude is equal to the pressure altitude

69 What happens to the temperature of a saturated air mass when descending

a. heats up more than dry because of expansion
b. heats up less than dry because of evaporation
c. heats up more than dry because of compression
d. heats up less than dry because of latent heat released during condensation

70. The DALR is

a. Variable with time
b. Fixed
c. Variable with latitude
d. Variable with temperature

71. Which of the following defines RH

a. HMR/ Satuaration mixing ratio x 100
b. Absolute humidity/ mixing ratio x 100
c. Saturation mixing ratio/ HMR x 100
d. Amount of water held/ amount of water air could hold x 100

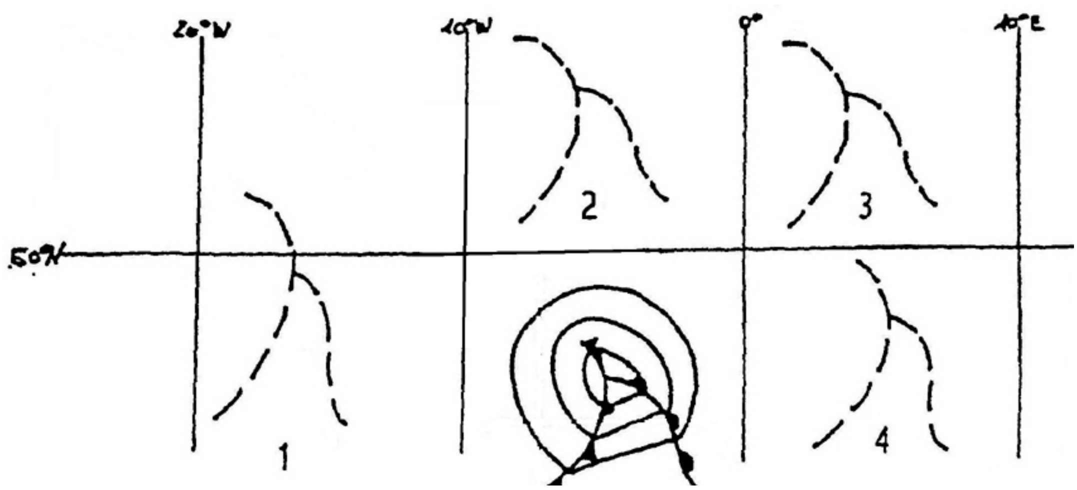
72 A winter day in N Europe with a thick layer of SC and surface temperature zero degrees C. You can expect

a. Decreasing visibility due to snow below the cloud base and light icing in cloud
b. High probability of icing in clouds, Severe icing in the upper levels due to large droplets
c. Turbulence due to a strong inversion, but no icing due to clouds being formed from ice crystals
d. Reduced visibility and light icing in cloud

73 TAF 130600Z 130716 VRB02 CAVOK =
Volmet 0920 28020G40KT BKN050CB OVC090 TEMPO TS =

a. TAF is correct Volmet is wrong
b. TAF & Volmet match
c. Volmet speaker surely must have mixed up airports because there is no way that TAF & Volmet can differ by that much.
d. Conditions just turned out to be much more volatile than originally forecast.

74 What will be the position of the Polar Front in 24 hours time, assuming the usual path of movement of the PF.



a. 1
b. 2
c. 3
d. 4

75 The Harmattan is

a. A SE monsoon wind
b. NE wind over NW Africa between Nov - April reducing visibility with dust
c. A local depression wind
d. SE wind over NW Africa between Nov - April reducing visibility with dust

76. Which of the following factors have the greatest effect on aircraft icing?

a. Aircraft speed and curvature of the airfoil
b. RH inside the cloud
c. Cloud temperature and droplet size
d. Aircraft speed and size of cloud droplets

77 In which of the following regions does polar maritime air originate?

a. British Isles
b. Baltic sea
c. Black sea
d. East of Greenland

78 What is the validity of a significant weather chart

a. 3 hrs
b. 6 hrs
c. 9 hrs
d. 12 hrs

79 On the route London to Bombay, which feature would you most likely encounter between 30E and 50E.

a. Polar front jet in excess of 90kts
b. Sub tropical jet in excess of 90kts
c. Variable winds less than 30kts
d. Easterly winds

80 Where is the ITCZ in July?

a. 25 N over the Atlantic
b. 10 - 20 N over East Africa and the Arabian sea
c. 10 - 30 N over West Africa
d. 20 - 30 N over East Africa

ANSWERS

1	D	21	B	41	B	61	B
2	B	22	A	42	C	62	C
3	A	23	C	43	B	63	A
4	D	24	D	44	B	64	B
5	A	25	A	45	D	65	D
6	A	26	B	46	A	66	B
7	A	27	C	47	B	67	B
8	A	28	D	48	B	68	A
9	A	29	A	49	C	69	B
10	D	30	D	50	A	70	B
11	A	31	D	51	C	71	A
12	B	32	C	52	D	72	D
13	B	33	D	53	C	73	D
14	A	34	A	54	A	74	D
15	C	35	D	55	C	75	B
16	D	36	A	56	A	76	C
17	C	37	A	57	D	77	D
18	D	38	C	58	C	78	B
19	B	39	A	59	C	79	C
20	B	40	C	60	B	80	C