AP3456
The Central Flying School (CFS) Manual of Flying

Volume 10 – Meteorology AP3456Met

10-1-THE ATMOSPHERE

Introduction

1. Weather can be described as the state of the atmosphere at a given time and place, with respect to temperature, moisture, visibility, pressure and wind velocity. It can have a significant effect on aircraft performance and flight safety.

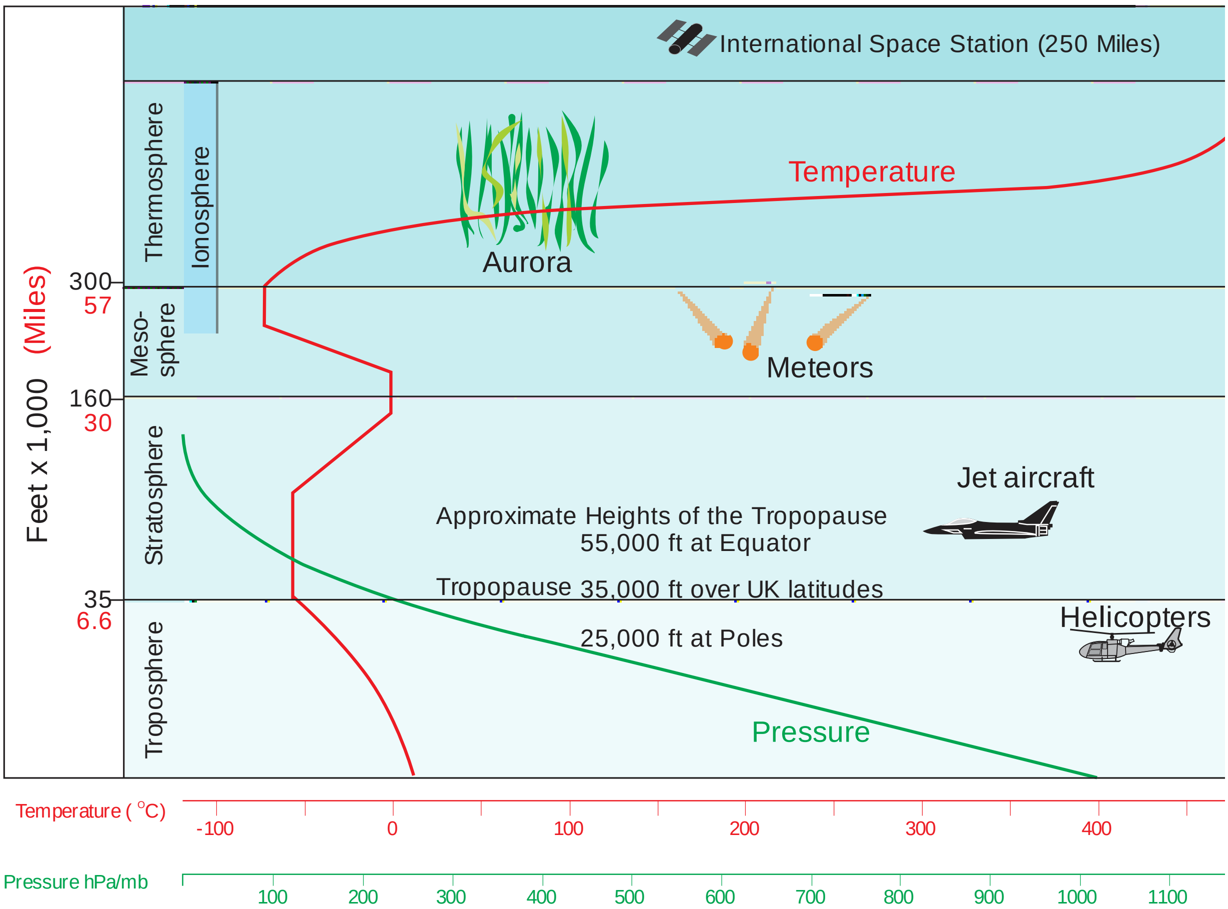
The Atmosphere

2. The atmosphere is the term given to the layer of air which surrounds the Earth and extends upwards from the surface to about 500 miles and can be considered as four concentric gaseous layers (Fig 1). The flight of all objects using fixed or moving wings to sustain them, or air-breathing engines to propel them, is confined to the lower layers of the atmosphere. Most flying occurs in the troposphere but high-flying jets cruise in the stratosphere and so the properties of the atmosphere are of great importance to all forms of flight.

10CD-1 Fig 1 - Gaseous Layers of the Atmosphere

EXOSPHERE where the atmosphere merges into SPACE		
THERMOSPHERE		Upper limit not defined. Temperature increases above the Mesopause.
------------------------	**Mesopause**	**---**
MESOSPHERE		Extends to between 260,000 and 295,000 ft. Temperature falls with height to the Mesopause.
------------------------	**Stratopause**	**---**
STRATOSPHERE		Extends to about 164,000 ft. Negligible water content. Temperature overall increases. Contains the Ozone layer.
------------------------	**Tropopause**	**---**
TROPOSPHERE		The Troposphere contains almost all atmospheric water and therefore most of the weather, clouds, storms and temperature variances. Temperature falls with height. The Tropopause varies in height from about 25,000 ft at the poles, 35,000 ft over UK latitudes, to about 55,000 ft over the equator; thus being elliptical in shape. The height varies from day to day and is higher in summer than in winter.
SURFACE		

10CD-1 Fig 2 - Structure of the Atmosphere

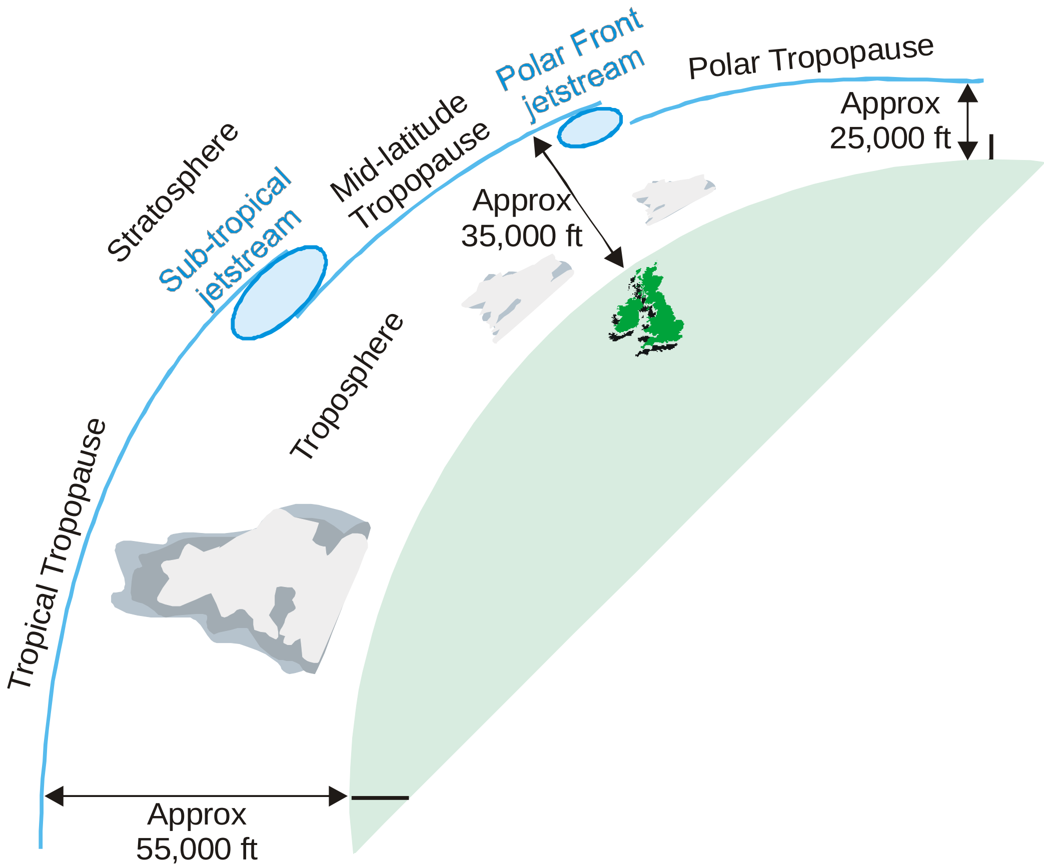


Pressure falls steadily with height, but temperature falls steadily to the tropopause, where it remains constant through the stratosphere, and then increases for a while in the warm upper layers. Temperature falls again in the mesosphere and eventually increases rapidly in the thermosphere. The fall in temperature in the tropopause is known as the Environmental Lapse Rate (ELR) or Temperature Lapse Rate (TLR) (See Fig 2).

Troposphere and Tropopause

3. Most weather occurs in the Troposphere. The Tropopause is important in aviation as clouds are rare above it, maximum wind speeds are often found just below it, condensation trails occur just below but not above it and severe turbulence may be encountered close to it. A simplified diagram of the troposphere is at Fig 3. There may be multiple overlapping mid-latitude tropopauses separated by jetstreams. Air masses tend to ‘keep’ their Tropopause, so in the northern hemisphere, with a moving air mass from the south, the Tropopause will rise with the air mass. The tropopause is higher in each region in the summer than in winter.

10CD-1 Fig 3 - The Troposphere and Tropopause



Stratosphere

4. The lower portion of the stratosphere is an isothermal layer where the temperature remains constant (approximately -57° C) with increasing height, and then in its upper layers the temperature increases to around 0° C at the stratopause. This layer of the atmosphere, where high flying jets cruise, contains the Ozone Layer. Ozone is an efficient absorber of ultraviolet radiation.

Significant Differences between the Troposphere and the Stratosphere

	Troposphere	**Stratosphere**
Temperature	Decreases with altitude with an abrupt change in the ELR at the tropopause.	Steady in the lower region but increases in the higher layers.
Air movement	Marked vertical movement with warm air rising and cool air descending.	Little vertical movement.
Water content	Contains almost all atmospheric water vapour.	Clouds rare.

Properties and Composition of Air

5. Air is a compressible fluid and as such it is able to flow or change its shape when subjected even to minute pressures. In fluids the degree of cohesion of its molecules is so small that very small forces suffice to move them in relation to each other. At any point in a fluid the pressure is the same in all directions, and if a body is immersed in a stationary fluid, the pressure on any point of the body acts at right angles to the surface at that point irrespective of the shape or position of the body.

6. Air is a mixture of a number of separate gases, the proportions of which are:

Element	By Volume %	By Weight %
Nitrogen	78.08	75.5
Oxygen	20.94	23.1
Argon	0.93	1.3
Carbon dioxide	0.03	0.05

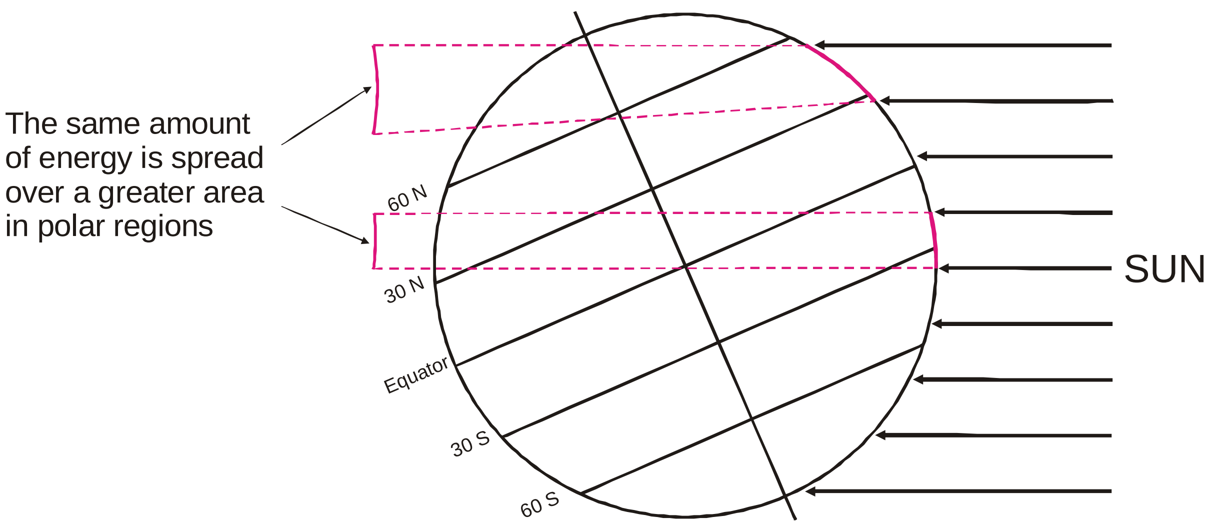
Plus trace quantities of other gases

7. For all practical purposes the atmosphere can be regarded as consisting of 21% oxygen and 78% nitrogen by volume. From the Surface up to a height of between 26,000 to 30,000 ft water vapour is found in varying quantities from almost zero to 5% by volume. The amount of water vapour in a given mass of air depends on the temperature and whether the air is, or has recently been, over large areas of water. The higher the temperature the greater the amount of water vapour that the air can hold. A water molecule is relatively light and the presence of large numbers in an air mass decreases the overall density of that air mass. As a result, aircraft and engine performance will be degraded on a humid day as compared to a dry day.

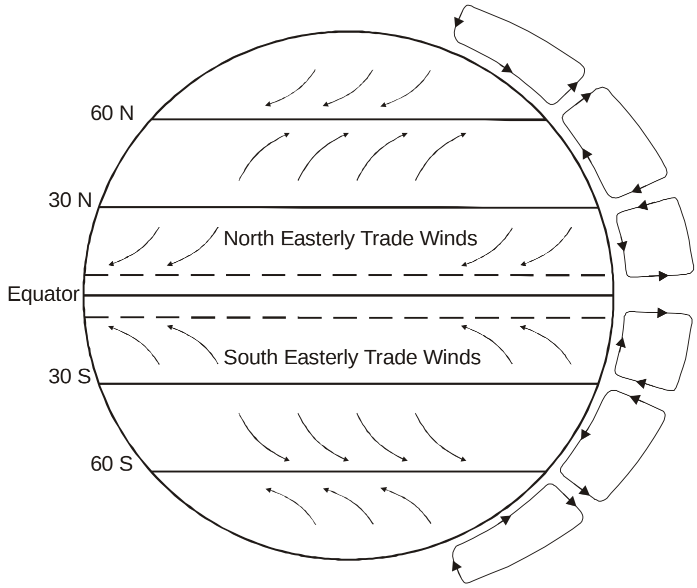
Atmospheric Circulation

8. The combination of the earth's tilt and its curved surface means that the equatorial regions get more direct sunlight, and hence more surface heating from the Sun. This heating causes convection within the atmosphere, resulting in a circular motion of the air with warm, less dense air rising and being replaced by cooler, denser air. The warm air flows towards the poles where it cools, becoming denser, and sinks back towards the surface.

10CD-1 Fig 4 - Comparing the Sun's Energy Over Polar and Equatorial Regions



10CD-1 Fig 5 - Atmospheric Circulation



Coriolis Force

9. In the general atmospheric circulation theory, warm, less dense air exists in equatorial regions creating areas of low pressure while in polar regions, areas of high pressure exist due to cooler, denser air. In simple terms, high pressure at the poles causes air to flow along the surface towards the equator. This simplified pattern of air circulation is correct in theory, but the circulation of air is modified by several forces, the most important of which is the rotation of the Earth.

10. The force created by the rotation of the Earth is known as the Coriolis force. To a person standing on the Earth the effect of Coriolis is imperceptible because humans move slowly and travel relatively short distances compared to the size of the Earth and its speed of rotation. However, the Coriolis force significantly affects bodies that move over great distances, such as air masses or bodies of water.

11. In the Northern Hemisphere, the Coriolis force deflects air to the right causing it to follow a curved path instead of a straight line (Fig 6). The degree of deflection depends on the latitude. It is greatest at the poles and diminishes to zero at the equator.

12. The speed of the Earth's rotation causes the general flow to break up into three distinct cells in each hemisphere. In the Northern Hemisphere, the warm air at the equator rises upward from the surface, travels northward, and is deflected eastward by the rotation of the Earth. By the time it has travelled one-third of the distance from the equator to the North Pole, it is no longer moving northward, but eastward. This air cools and sinks in a belt-like area at about 30° latitude, creating an area of high pressure as it sinks toward the surface. Then, it flows southward along the surface back toward the equator. Coriolis force bends the flow to the right, thus creating the north-easterly trade winds that prevail from 30° latitude to the equator. Similar forces create circulation cells that encircle the Earth between 30° and 60° latitude, and between 60° and the poles. This circulation pattern results in the prevailing westerly winds over the United Kingdom.

13. Circulation patterns are further complicated by seasonal changes, differences between the surfaces of continents and oceans, and other factors such as frictional forces caused by the topography of the Earth's surface which modify the movement of the air in the atmosphere. For example,

within 2,000 feet of the ground, the friction between the surface and the atmosphere slows the moving air. The wind is diverted from its path because the frictional force reduces the Coriolis force. Thus, the wind direction at the surface varies somewhat from the wind direction just a few thousand feet above the Earth.

International Standard Atmosphere (ISA)

14. To provide a common reference, the International Standard Atmosphere (ISA) has been established. These standard conditions are a model which allows for the calibration of certain flight instruments and most aircraft performance data. The ISA seldom applies to actual conditions. The assumed characteristics of ISA are:

a. The air is dry, and its chemical composition is the same at all altitudes.

b. The value of g is constant at 980.665 cm/sec^2.

c. At mean sea level:

(i) The temperature is 15º C
(ii) The pressure is 1013.25 hPa (29.92 inches Hg).
(iii) The density is 1.225 kg/m^3.

d. The temperature lapse rate is 1.98 ºC per 1,000 ft up to a height of the theoretical tropopause at 36,090 ft. Above this height the temperature is assumed to remain constant at –56.5 ºC until 65,617 ft where is then rises at a rate of 0.3° C per 1,000 ft.

Table 1 ICAO Standard Atmosphere

Altitude (ft)	Temperature (º C)	Pressure (hPa / mb)	Pressure (psi)	Density (kg/m^3)	Relative Density (%)
50,000	–56.5	116.0	1.68	0.186	15.2
45,000	–56.5	147.5	2.15	0.237	19.4
40,000	–56.5	187.6	2.72	0.302	24.6
35,000	–54.3	238.4	3.46	0.386	31.0
30,000	–44.4	300.9	4.36	0.458	37.4
25,000	–34.5	376.0	5.45	0.549	44.8
20,000	–24.6	465.6	6.75	0.653	53.3
15,000	–14.7	571.8	8.29	0.771	62.9
10,000	–4.8	696.8	10.11	0.905	73.8
5,000	+5.1	843.1	12.22	1.056	86.2
0	+15.0	1013.25	14.7	1.225	100.0

Measurement of Temperature

15. Temperature can be measured against various scales:

a. The Celsius scale (symbol º C) is normally used for recording atmospheric temperatures and the working temperatures of engines and other equipment. On this scale, water freezes at 0º C and boils at 100º C, at sea level.

b. On the Kelvin thermodynamic scale, temperatures are measured in kelvins (symbol K - note there is no degree sign) relative to absolute zero. In the scientific measurement of temperature, 'absolute zero' has a special significance; at this temperature a body is said to have no heat whatsoever. Kelvin zero occurs at –273.15º C.

c. On the Fahrenheit scale (symbol º F), water freezes at 32º F and boils at 212º F, at sea level. This scale is still used, particularly in the USA.

16. **Conversion Factors**. A kelvin unit equates to one degree C, therefore to convert º C to kelvins, add 273.15. To convert º F to º C, subtract 32 and multiply by $\frac{5}{9}$; to convert º C to º F, multiply by $\frac{9}{5}$ and add 32.

17. In ISA conditions, the temperature lapse rate is 1.98 ºC per 1,000 ft up to a height of the theoretical tropopause at 36,090 ft. For practical purposes, it is accepted that the ELR is 2° C per 1,000 ft up to the tropopause at which point the temperature is constant at -57° C per 1,000 ft.

Temperature Deviation from ISA

18. The temperature at height may not be the same as the ISA value for that level. Actual temperatures may be referred to in terms of a deviation from the ISA value which is of more use when determining aircraft performance than an actual temperature might be.

The determination of the deviation from ISA:

Example What is the temperature (ISA) deviation at 8,500 ft if the actual temperature is +5° C?

ISA temperature at 8,500 ft =	ISA temperature at sea level – (ELR x height (in 1,000) ft)
=	15 – (2 x 8.5)
=	15 - 17
=	-2° C
Actual temperature at 8,500 ft =	=+5° C
The temperature deviation =	The difference between ISA and actual temperature is 7°

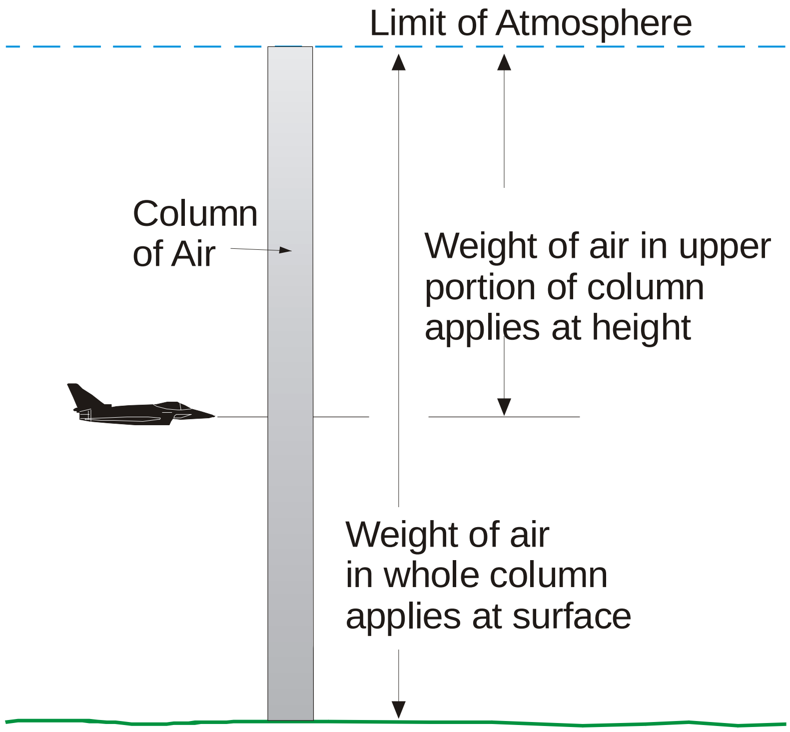
This is written as ISA +7 because the actual temperature is warmer than ISA

Atmospheric Pressure

19. Air molecules are invisible to the naked eye but still have mass and take up space. Atmospheric pressure is a measure of the weight (force) of a column of air above the Earth's surface in a unit area.

The circulation of the atmosphere results in there being areas of warm ascending air and cooler descending air. The warm less dense air contains fewer molecules per unit volume than the cooler denser air. As distance increases from the Earth, the weight of the air above will be less, therefore atmospheric pressure decreases (Fig 7).

10CD-1 Fig 6 - Decrease in Atmospheric Pressure with Height



20. Atmospheric pressure is measured in the following ways:

a. **Hectopascal**. The hectopascal (hPa) is the unit of measurement of pressure in common use. At mean sea level (MSL), the atmospheric pressure is of the order of 1,000 hPa (see also the next paragraph); at 50,000 ft it is of the order of 100 hPa.

b. **Inches of Mercury**. Some countries (notably the USA), measure pressure in inches of mercury (Hg). At MSL, atmospheric pressure is 29.92 inches Hg.

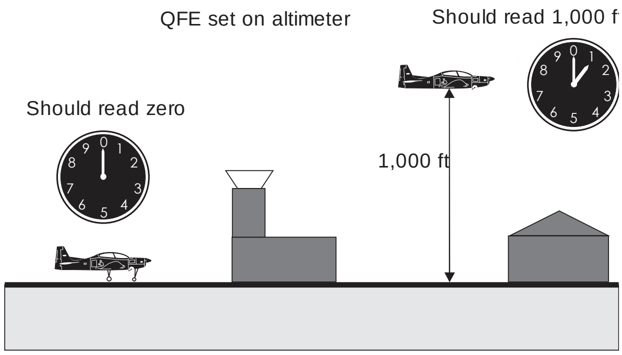
c. **Millibar**. Although the hPa is now in common usage, the millibar (mb) is still used in aviation. The hPa and the mb have equivalent values and so can be considered to be identical for all practical purposes. At mean sea level (MSL), the atmospheric pressure is of the order of 1,000 mb (see also the next paragraph); at 50,000 ft it is of the order of 100 hPa.

Altimeter Pressure Settings

21. The most obvious application of atmospheric pressure is its use in the altimeter. There are four pressure settings that are generally used on the altimeter.

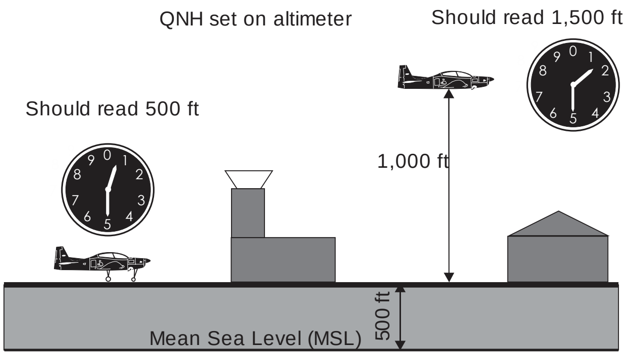
a. **QFE**. QFE is the corrected pressure for a specific datum, usually an airfield. With QFE set, the altimeter will read zero at touchdown and will indicate height above touchdown when in the circuit.

10CD-1 Fig 7 - QFE Pressure Setting



b. **QNH**. QNH is the observed pressure of the airfield elevation, corrected for temperature and reduced to mean sea level (MSL). With QNH set, the altimeter will read altitude above mean sea level (AMSL). At touchdown, with QNH set, the altimeter will read touchdown elevation.

10CD-1 Fig 8 - QNH Pressure Setting



c. **Regional Pressure Setting (RPS)**. The RPS is the lowest forecast value of mean sea level pressure in a geographical region for a specified hour. The UK is divided into Altimeter Setting Regions (ASRs) with an associated RPS for the current hour and forecast RPS for the next hour.

d. **Standard Altimeter Setting**. The standard altimeter setting is used when flying above Transition Altitude (TA). It assumes a MSL pressure of 1013.2 hPa.

Altitude and Atmospheric Pressure

22. As altitude increases, atmospheric pressure decreases. At sea level, 1 hPa difference in pressure is equivalent to approximately 27 ft of height change; at 20,000 ft, 1 hPa equates to approximately 50 ft. Thus, close to sea level, it can be assumed that 1 hPa equates to 30 ft.

Pressure Altitude

23. Pressure altitude can be defined as the vertical distance from the 1013.25 hPa pressure level. When the term 'altitude' appears in Operating Data Manuals (ODMs) and performance charts, it refers strictly to pressure altitude. Therefore, when the sea level pressure is other than 1013.25 hPa, aerodrome and obstacle elevations must be converted to pressure altitude before use in performance calculations. ODMs normally contain a conversion graph. Pressure altitude can be obtained by setting

the sub-scale of an ICAO calibrated altimeter to 1013.25 hPa and reading altitude directly from the instrument. Alternatively, the approximate pressure altitude can be calculated.

$$\text{Pressure altitude} \doteq \text{Elevation} + 30p,$$

where p is 1013 minus the sea level pressure (QNH) at that point.

Example 1: To determine the pressure altitude of an airfield, elevation 1,700 ft, if sea level pressure (QNH) is 1003 hPa:

$$p = 1013 – 1003 = 10 \text{ hPa}$$

$$\therefore \text{airfield pressure altitude} \doteq 1{,}700 + (30 \times 10) \text{ ft} \doteq 2{,}000 \text{ ft}$$

Example 2: To determine the pressure altitude of an airfield, elevation 1,700 ft, if sea level pressure (QNH) is 1026 hPa:

$$p = 1013 – 1026 = -13 \text{ hPa}$$

$$\therefore \text{airfield pressure altitude} \doteq 1{,}700 + (30 \times (-13)) \text{ ft}$$

$$\therefore \text{airfield pressure altitude} \doteq 1{,}700 + (-390) \text{ ft} \doteq 1310 \text{ ft}$$

When 1013 is greater than the QNH, pressure altitude is greater than the airfield elevation.

When 1013 is less than the QNH, pressure altitude is less than the airfield elevation.

Density Altitude

24. Aircraft and engine performance depend upon air density. For aircraft operations, air density is usually expressed as a density altitude. Density altitude is the pressure altitude adjusted to take into consideration the actual temperature of the air. For ISA conditions of temperature and pressure, density altitude is the same as pressure altitude. Density altitude can be determined by the formula:

$$\text{density altitude} = \text{pressure altitude} + 120t$$

where t is the actual air temperature minus the standard (ISA) temperature for that pressure altitude. Continuing the Example 1 pressure altitude calculation above, if the actual air temperature at the airfield elevation is +13 ºC (ISA temp for 2,000 ft is +11 ºC), then the density altitude will be:

$$2{,}000 \text{ ft} + 120\,(13^{\circ}\text{C} – 11\,^{\circ}\text{C})$$

$$2{,}000 \text{ ft} + (120 \times 2) = 2{,}240 \text{ ft}$$

Continuing the Example 2 pressure altitude calculation above, if the actual air temperature at the airfield elevation is +5 ºC (ISA temp for 1,700 ft is approximately +11.5 ºC), then the density altitude will be:

$$1{,}700 \text{ ft} + 120\,(+5^{\circ}\text{C} – 11.5\,^{\circ}\text{C})$$

$$1{,}700 \text{ ft} + (120 \times (-6.5)) = 920 \text{ ft}$$

25. It is evident from Example 1 that a pressure altitude exceeding the airfield altitude, combined with a higher temperature than ISA can result in a significant increase in density altitude and hence a decrease in aircraft performance. Example 2 shows that the converse is true.

Density

26. Air density is important to aircraft operations because:

a. Lift is generated by the flow of air around the wing and if the air is denser the lift force can be generated at a lower airspeed.

b. Engine power is generated by burning fuel with air (oxygen) and greater engine power is available due to the greater mass of air passing through the engine.

27. Density (symbol rho (ρ)) is the ratio of mass to volume and is expressed in kilograms per cubic metre (kg/m^3). The relationship of density to temperature and pressure can be expressed thus:

$$\frac{p}{T\rho} = \text{constant}$$

where p = Pressure in hectopascals
and T = Absolute temperature (i.e. measured on the Kelvin scale)

28. **Effects of Pressure on Density**. When air is compressed, a greater amount can occupy a given volume; i.e. the mass, and therefore the density, has increased. Conversely, when air is expanded less mass occupies the original volume and the density decreases. From the formula in the previous paragraph it can be seen that, provided the temperature remains constant, density is directly proportional to pressure, i.e. if the pressure is halved, so is the density, and vice versa.

29. **Effect of Temperature on Density**. When air is heated it expands so that a smaller mass will occupy a given volume, therefore the density will have decreased, assuming that the pressure remains constant. The converse will also apply. Thus, the density of the air will vary inversely as the absolute temperature: this is borne out by the formula in para 27. In the atmosphere, the fairly rapid drop in pressure as altitude is increased has the dominating effect on density, as against the effect of the fall in temperature which tends to increase the density.

30. **Effect of Humidity on Density**. The preceding paragraphs have assumed that the air is perfectly dry. In the atmosphere some water vapour is invariably present; this may be almost negligible in certain conditions, but in others the humidity may become an important factor in the performance of an aircraft. The density of water vapour under standard sea level conditions is 0.760 kg/m^3. Therefore, water vapour can be seen to weigh 0.760/1.225 as much as air, roughly ⅝ as much as air at sea level. This means that under standard sea level conditions the portion of a mass of air which holds water vapour weighs (1 – ⅝), or ⅜ less than it would if it were dry. Therefore, air is least dense when it contains a maximum amount of water vapour and most dense when it is perfectly dry.

Dynamic Pressure

31. Because it possesses density, air in motion must possess energy and therefore exerts a pressure on any object in its path. This dynamic pressure is proportional to the density and the square of the

speed. The energy due to movement (the kinetic energy (KE)) of one cubic metre of air at a stated speed is given by the following formula:

$$KE = ½\rho V^2 \text{ joules}$$

where ρ is the local air density in kg/m^3 and V is the speed in metres per second (m/s)

If this volume of moving air is completely trapped and brought to rest by means of an open-ended tube the total energy remains constant. In being brought to rest, the kinetic energy becomes pressure energy (small losses are incurred because air is not an ideal fluid) which, for all practical purposes, is equal to $½\rho V^2$ newtons/m^2, or if the area of the tube is S m^2, then:

$$\text{total pressure (dynamic + static)} = ½\rho V^2 S \text{ newtons.}$$

32. The term $½\rho V^2$ is common to all aerodynamic forces and fundamentally determines the air loads imposed on an object moving through the air. It is often modified to include a correction factor or coefficient. The term stands for the dynamic pressure imposed by air of a certain density moving at a given speed, which is brought completely to rest. The abbreviation for the term $½\rho V^2$ is the symbol 'q'. Note that dynamic pressure cannot be measured on its own, as the ambient pressure of the atmosphere (known as static) is always present. The total pressure (dynamic + static) is also known as stagnation or pitot pressure. It can be seen that:

$$\text{total pressure} - \text{static pressure} = \text{dynamic pressure}$$

10-2-STABILITY

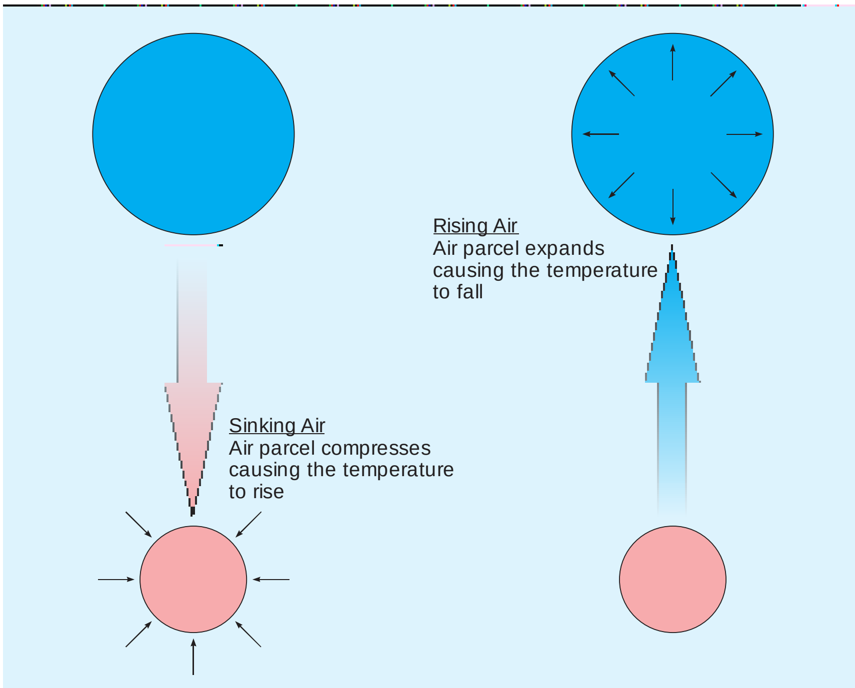
Introduction

1. Stability in the atmosphere can be better understood if one has an appreciation of the process of adiabatic cooling and warming of air.

2. It is a property of all gases that when compressed their temperature rises and when allowed to expand their temperature falls. Energy is required to compress a gas but in accordance with the principle of conservation of energy [1], as the gas is compressed, the energy is not lost but transferred to the gas molecules, which increases their motion and hence their temperature. Similarly, as a gas expands its temperature falls.

3. A parcel of air can be affected by the processes of conduction or mixing which may result in a temperature change. When these effects are eliminated such that the air is thermally insulated from its surroundings, any change in temperature is said to be adiabatic [2].

10CD-2 Fig 1 - Adiabatic Temperature Change of a Parcel of Air



Dry Adiabatic Lapse Rate

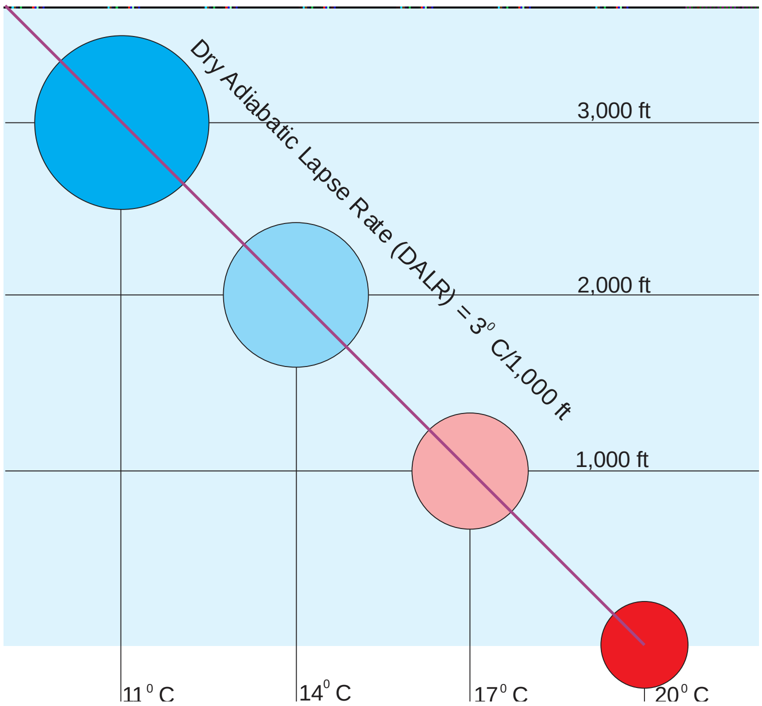
4. If a small mass of air is moved rapidly upwards or downwards, the change in pressure will cause a change in the temperature of the air. The rapid vertical movement of the air parcel will not allow there to be a transfer of heat by conduction, mixing or radiation, thus any temperature change will be just

[1] In physics, the law of conservation of energy states that the total energy of an isolated system remains constant—it is said to be conserved over time. Energy can neither be created nor destroyed; rather, it transforms from one form to another.

[2] An adiabatic process changes the temperature of a gas within a defined system without any transfer of heat energy across the boundaries of the system.

adiabatic. As long as the air remains unsaturated [3], it can be shown that the displaced air changes temperature at a rate of 3° C per1,000 ft; the Dry Adiabatic Lapse Rate (DALR).

10CD-2 Fig 2 - The Dry Adiabatic Lapse Rate



Saturated Adiabatic Lapse Rate

5. Water can exist in one of three forms in the atmosphere, solid, liquid and vapour. Each form can readily change to another, and during such a transformation latent heat is exchanged. Latent heat is the energy released or absorbed during a constant temperature process. The moisture content of the air is affected by its temperature where warm air can hold more than cold air. As moist air is cooled it reaches its saturation point, where further cooling will result in the moisture condensing. If the air is cooled further, below its saturation point, cloud, mist or fog will form.

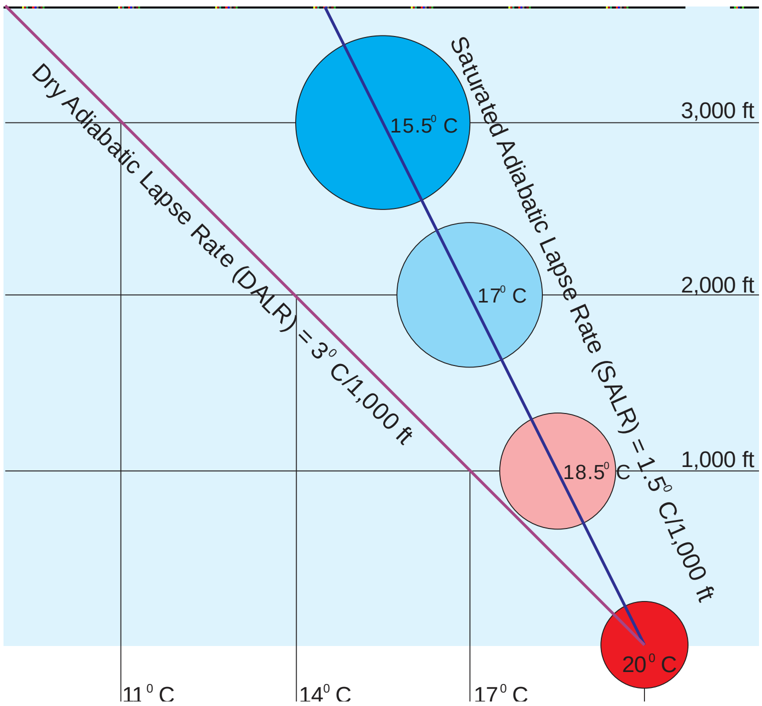
6. When saturated air rises, adiabatic cooling occurs as with dry air, however, the cooling causes condensation and is part offset by the latent heat liberated. The rate of cooling is termed the Saturated Adiabatic Lapse Rate (SALR) and is less than the DALR. Unlike the DALR, the SALR is not constant and at low levels in temperate latitudes is about 1.5° C per 1,000 ft. In tropical warm saturated air the SALR may fall to about 1° C per 1,000 ft and may exceed 2° C per 1,000 ft in freezing air, eventually approaching the DALR.

7. When saturated air falls the process is a little more complicated. Provided little or no condensed water is held in suspension, adiabatic warming causes the air to become unsaturated almost immediately and it warms at the DALR. If however, all of the condensed water were to be retained, the effect of the descent would be to gradually evaporate the droplets so that the air would remain saturated, thus the air would warm at the SALR. In practice, larger droplets tend to fall as precipitation,

[3] Saturated air contains the maximum amount of water vapour that is possible at the given temperature and pressure, i.e. air in which the relative humidity is 100%. Air that is not saturated is unsaturated.

while the smaller droplets evaporate, so that descending cloudy air generally clears and warms at the DALR.

10CD-2 Fig 3 - The Saturated Adiabatic Lapse Rate



Environmental Lapse Rate

8. In the International Standard Atmosphere (ISA) the temperature lapse rate is 1.98 ºC per 1,000 ft up to a height of the theoretical tropopause at 36,090 ft. Above this height the temperature is assumed to remain constant (isothermal) at –56.5 ºC until 65,617 ft where is then rises at a rate of 0.3° C per 1,000 ft. For practical purposes, the lapse rate which can be termed as the Environmental Lapse Rate (ELR) is assumed to be 2 ºC per 1,000 ft. It must be noted that the ELR can vary significantly from the ISA standard due to varying conditions within the atmosphere, especially in the lower troposphere and this will affect the stability of the air.

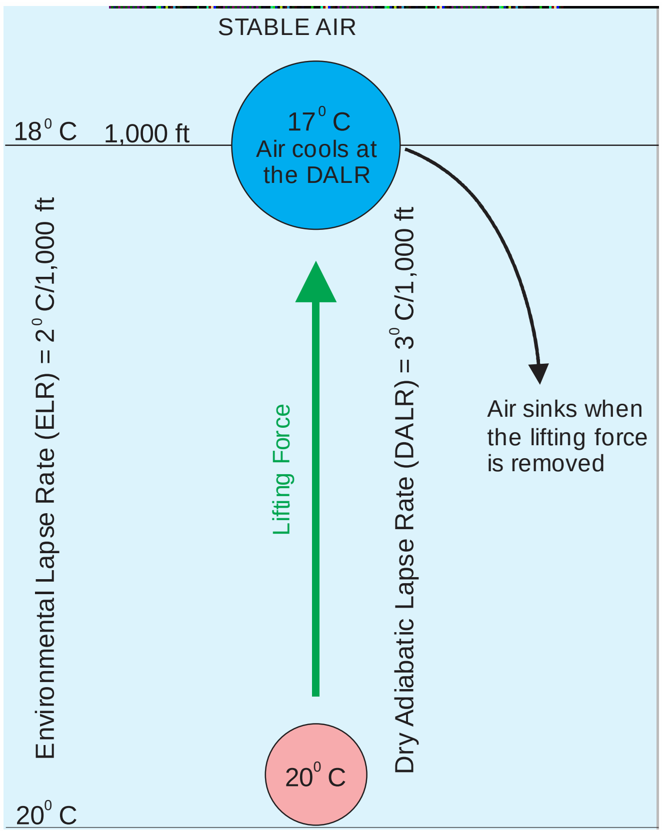
Stability

9. Atmospheric stability is an important factor in the process of cloud formation and can help to make predictions about the weather.

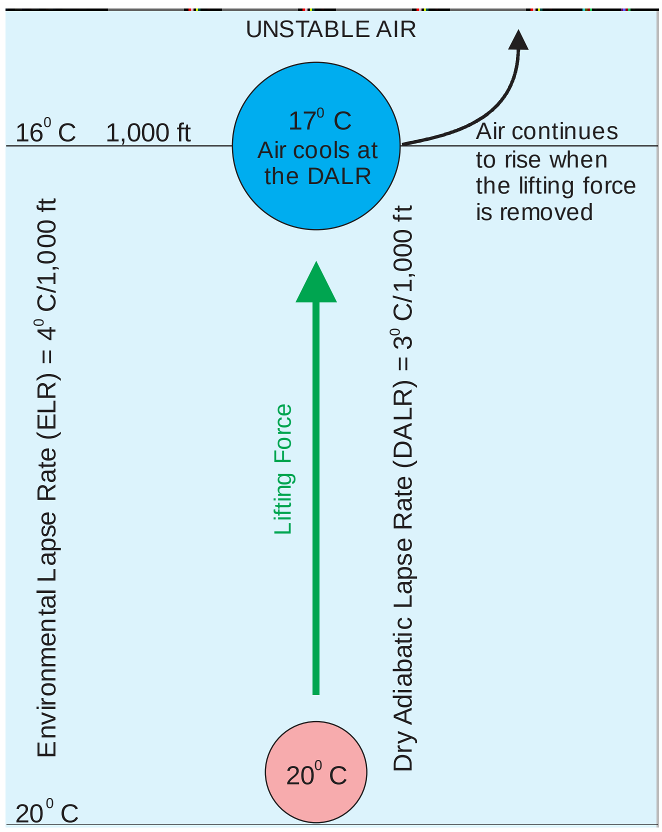
10. If air that is displaced has a tendency to return to its original position once the displacing force is removed, the atmosphere is said to be stable (Fig 4).

11. In an unstable atmosphere, displaced air tends to be further displaced even when the displacement force is removed (Fig 5).

10CD-2 Fig 4 - Displaced Air in a Stable Atmosphere



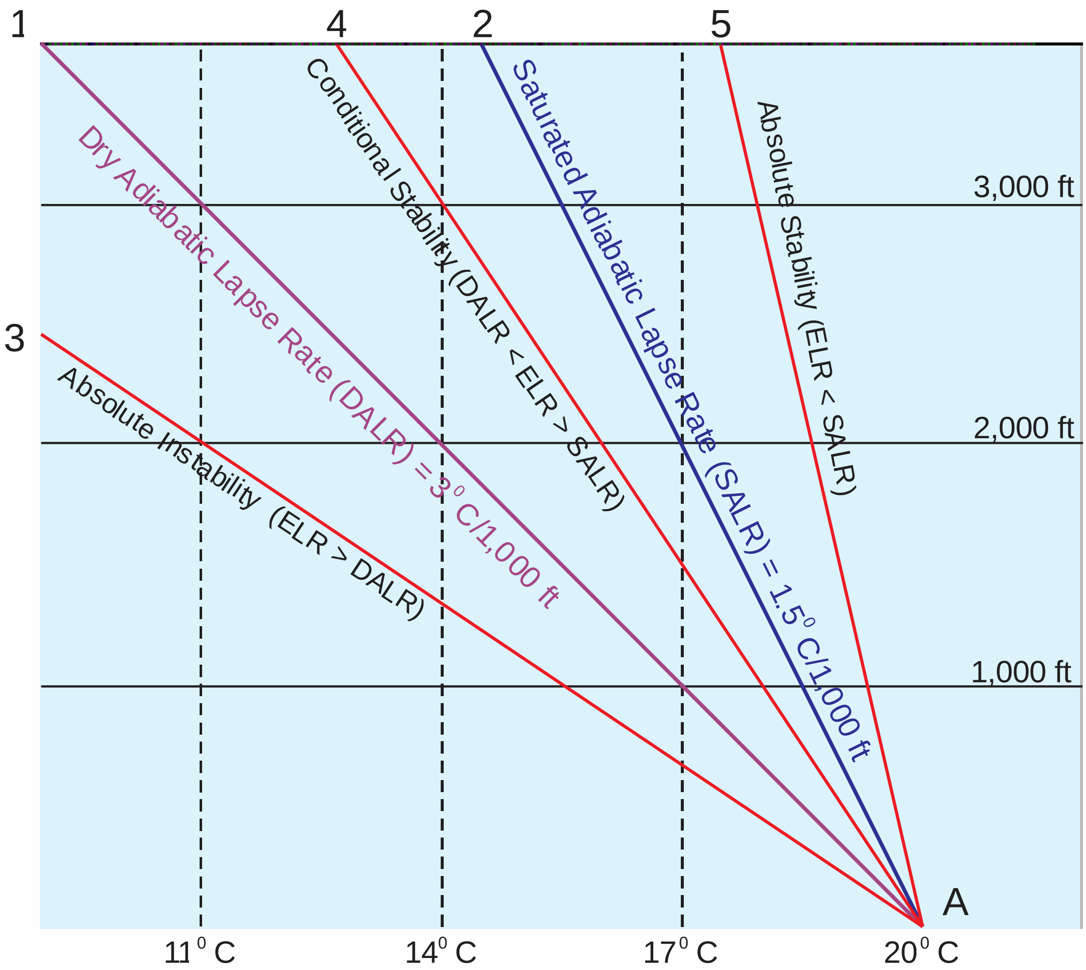
10CD-2 Fig 5 - Displaced Air in an Unstable Atmosphere



12. It can be deduced from Figs 4 and 5 that basic adiabatic processes within the atmosphere are governed by the variable ELR. If the actual ELR for a particular day is known, then an assessment of the atmospheric stability can be made.

13. Consider air at point A in Fig 6 that is lifted adiabatically. If the air is saturated it will follow the SALR line and if it is unsaturated it will follow the DALR line. If the path of the air is compared to the ELR prevailing on the day, three cases may be distinguished.

10CD-2 Fig 6 – Stability and Instability in Relation to Lapse Rate



Absolute Instability

14. When the ELR is greater than the DALR, i.e. when the rate of change in temperature with height is greater than 3° C per 1,000 ft, a condition of absolute instability is said to exist. If a parcel of unsaturated air at point A in Fig 6 were forced to rise, at 1,000 ft its temperature would have fallen at the DALR to 17° C (line 1 in Fig 6). With an ELR of 4.5° C per 1,000 ft, for example, as depicted by line 3 in Fig 6, it can be seen that the parcel of air will be warmer than its surroundings. As a result it will be less dense and lighter than its surroundings and so, if the displacement force were to be removed it would continue to rise. On reaching 2,000 ft, the temperature difference would be even greater, increasing the tendency to rise. In the case of saturated air in the same conditions, i.e. the ELR is greater than the SALR, the result will be the same.

Absolute Stability

15. When the ELR is less than the SALR, i.e. when the rate of change in temperature with height is less than 1.5° C per 1,000 ft, a condition of absolute stability is said to exist. Line 5 in Fig 6 represents an ELR of less than 1.5° C per 1,000 ft, and so rising saturated or unsaturated air will always be cooler than the surrounding air. Thus, it will be more dense and heavier so there will be a tendency for it to return to the surface.

Conditional Stability

16. Line 4 in Fig 6 depicts the conditions where the ELR is less than the DALR but greater than the SALR. If a parcel of unsaturated air rises from point A at the DALR, at 1,000 ft its temperature will be less than the ELR (line 4) and so when the lifting force is removed it will sink back to the surface. Thus in this case the atmosphere will be stable. On the other hand, a parcel of saturated air rising from point A at the SALR will be warmer than its surroundings at 1,000 ft and thus will have a tendency to continue rising. In this case the atmosphere will be unstable. In this case a state of conditional stability exists. It is evident that humidity affects the stability of the atmosphere.

Neutral Stability

17. In a neutrally stable atmosphere, a parcel of air that is disturbed tends to remain at the level to which it is displaced. This condition only occurs when the ELR equals the DALR, in the case of unsaturated air, or the ELR equals the SALR in the case of saturated air.

Characteristics of an Unstable Atmosphere

18. Air that is displaced vertically in an unstable atmosphere will accelerate upwards into the atmosphere generating significant vertical currents. Cloud formed will be cumuliform and may develop into cumulonimbus cloud. With strong up currents pollution at lower levels will be drawn upwards giving excellent visibility below. On warm, clear sunny days, the surface temperature can rise rapidly, increasing the ELR to create an unstable atmosphere with active cumuliform clouds.

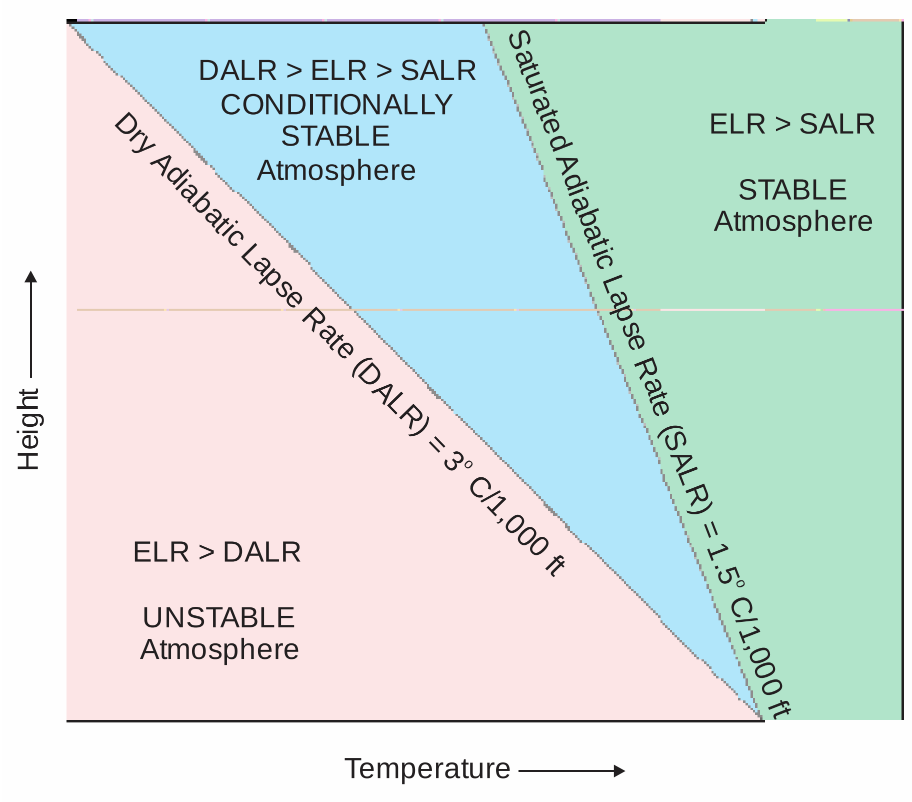
Characteristics of a Stable Atmosphere

19. Vertical movement of air is suppressed in a stable atmosphere even when convection is present. Cloud that is produced will be mainly stratiform and while some cumulus cloud can form it will not be of any great vertical extent. Without any significant vertical motion of the air, pollutants will be trapped in the lower layers of the atmosphere creating hazy conditions and poor visibility.

Summary

20. Fig 7 shows that the stability of the atmosphere depends upon in which coloured area the ELR on a particular day lies.

10CD-2 Fig 7 – Atmospheric Stability in Relation to the ELR



21. In the conditional stability area (Fig 7) humidity is a determining factor on whether the atmosphere is stable or unstable.

22. For the atmosphere to be neutrally stable:

ELR = DALR if the air is unsaturated

ELR = SALR if the air is saturated.

10-3-ATMOSPHERIC HEATING AND TEMPERATURE

General

1. Atmospheric temperature is fundamental to weather as every process can be linked to an exchange of heat.

Heating Processes in the Atmosphere

2. The Sun provides the energy that heats the Earth and its atmosphere by a process of insolation (**in**coming **sol**ar radi**ation**). The mainly short-wave electromagnetic energy radiated by the Sun is concentrated in the infrared and near infrared (46%), visible light (45%) and ultra-violet (9%) bands. Approximately half of the total radiation reaches, and is absorbed by, the Earth's surface with the rest being absorbed by the atmosphere or re-radiated into space by scattering and reflection. Some radiation is absorbed by gases (mainly oxygen and ozone) in the high atmosphere. Some is absorbed by water vapour and clouds in the lower atmosphere. Clouds will also reflect radiation, possibly as much as 70%. Most of the remaining radiation is absorbed by the surface but some will be reflected due to the nature of the surface or when the Sun is low in the sky and the striking angle of incidence is small. Air is effectively transparent to solar radiation and so the atmosphere is not directly heated by the Sun. Absorption of solar radiation takes place mainly at the earth's surface with the result that the atmosphere is heated indirectly from the heated earth by processes explained in the following paragraphs. The result of this activity is very important in meteorology.

Insolation

3. If the atmosphere were to be ignored when considering the amount of energy reaching the Earth's surface, there are two factors that govern this process.

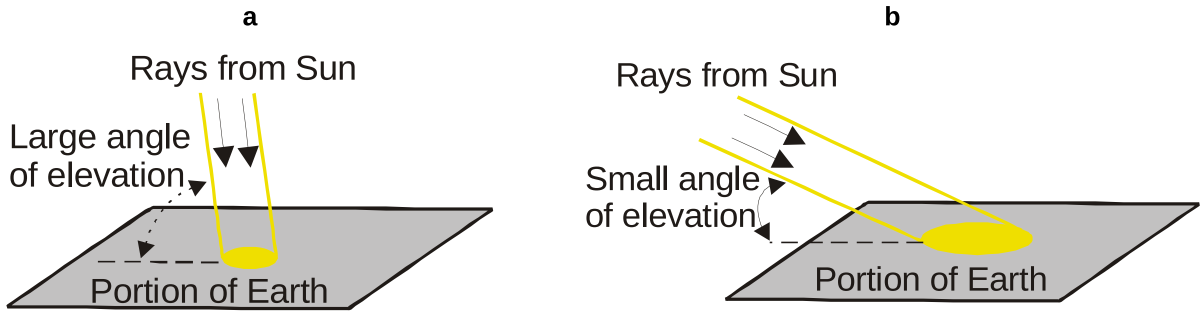
a. The angle that the Sun's rays strike the Earth's surface.

b. The length of exposure.

Angle of Elevation or Incidence

4. In Fig 1 the same amount of radiation reaches the earth's surface on each occasion. Where the angle of elevation is large, the rays are concentrated on to a small area on the earth's surface. With a small angle the given amount of solar energy is spread over a larger area. Therefore, large angle of elevation result in large rises in the surface temperature whereas small angles result in small rises in temperature. Not all solar energy will be absorbed as some will be reflected. The amount that is reflected will depend upon the nature of the surface, for example, with the sun's rays striking water at an angle of 45° approximately 2% of the radiation is reflected while at an angle of 5° as much as 75% is reflected.

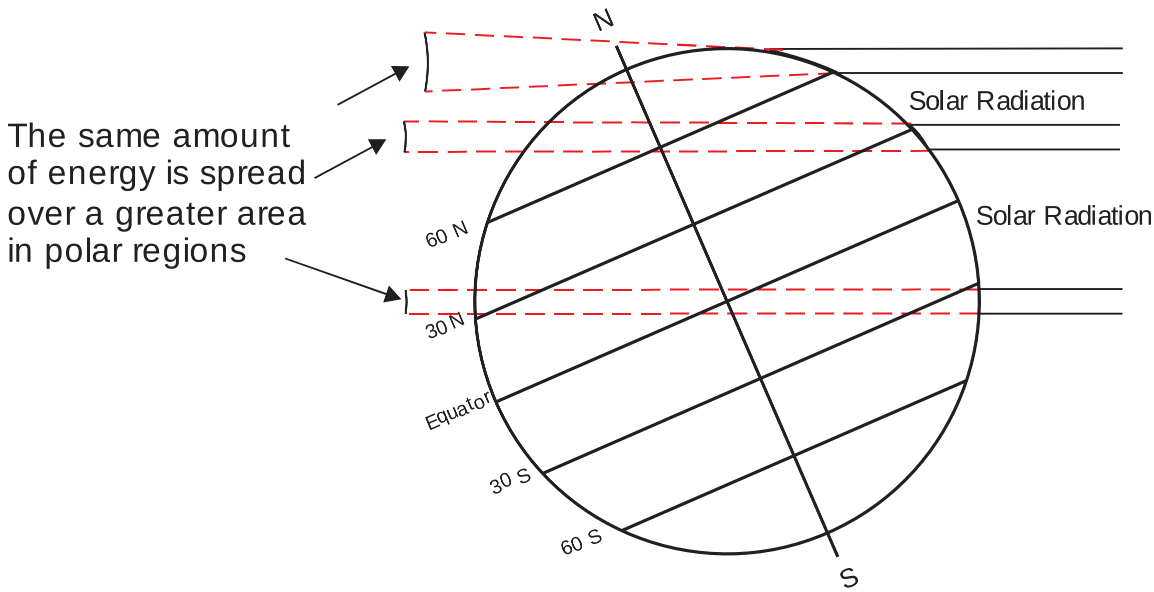
10CD-3 Fig 1 - Angle of Incidence of the Sun's Rays



Duration of Insolation

5. The surface of the Earth will only receive solar radiation when it is facing the Sun. The duration of exposure will depend upon the rotation of the Earth on its axis and the season as the Earth travels around the Sun. Latitude will also affect the amount of insolation.

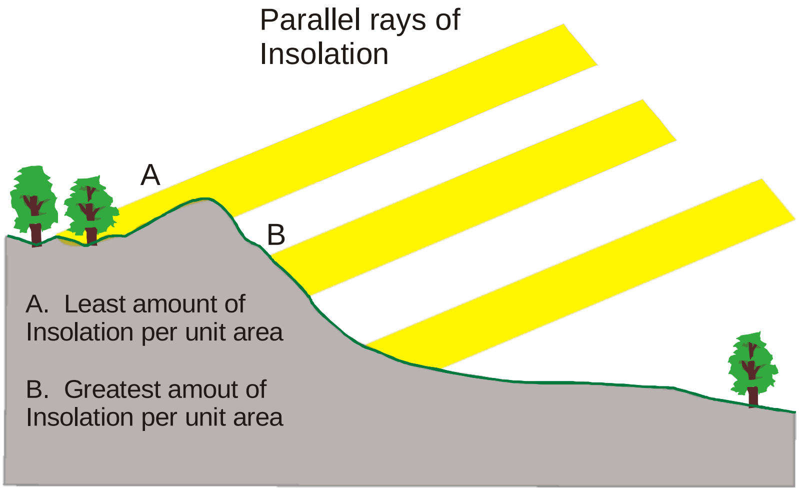
10CD-3 Fig 2 - The Effect of Latitude and Angle of Incidence on Insolation



Topography

6. Topography will also affect the amount of radiation received per unit area. Fig 7 illustrates the effects of varying slopes on the amount of insolation received. These variations in the amount and duration of insolation are mainly responsible for the differing temperatures experienced over the earth's surface.

10CD-3 Fig 3 Insolation



7. The Nature of the Surface. The nature of the surface will affect the amount of heat that is absorbed which in turn will govern the rise in temperature. Land will absorb more heat than water for a given amount of solar energy, and bare earth more than snow covered ground. Water requires more energy to raise its temperature by 1° C than land and so the land will heat more rapidly than the sea by day, and also cool more rapidly by night.

Specific Heat

8. The amount of heat required to raise the temperature of the substance by 1 C is called the thermal capacity of that substance. Assuming the thermal capacity of water to be unity, any substance can be expressed as a ratio of its thermal capacity to that of water; this ratio is known as the specific heat. This is significant as the specific heat of water is higher than that of dry land and so water will heat and cool more slowly than dry land given the same radiation conditions.

Latent Heat of Evaporation

9. Evaporation is the process of a liquid (e.g. water) changing into a gas (water vapour). For this to happen heat energy is required, known as latent heat. The significance of latent heat is that it does not change the temperature of the substance but does change the state of the substance; i.e. water to water vapour. Comparing the same amount of heat supplied to equal areas of land and water, evaporation of the water will use much of the heat without raising its temperature.

10. **The Reflectivity of the Surface.** Solar radiation that is reflected by a surface will not be absorbed and so reflective surfaces such as snow and water will reflect more energy than ploughed fields for example. The following figures represent typical levels of reflected solar energy.

Surface	% Energy Reflected
Snow	70-90
Rock	10-15
Grass	15-30
Forest	10-20
Sand	15-20
City areas	10

Good reflectors of solar energy tend to be poor absorbers and heating will occur slowly on those surfaces with a high reflective index, with a corresponding poor transfer of heat to the atmosphere.

Opacity

11. Water is transparent and some solar radiation penetrates to a considerable depth before being entirely absorbed. The result is that a significant layer of water shares the radiation resulting in an overall small temperature change. The opaque nature of land surfaces leads to a rapid heating of a layer a few inches deep as all the solar radiation remains at the surface.

12. **The Conductivity of the Surface**. Heat energy does not penetrate readily into the lower layers of soil but ocean currents transport heat energy to the lower layers of the sea. As a result the sea is heated to a greater depth than the land for a given area and amount of solar energy.

13. **The Effect of Cloud Cover**. Cloud cover by day will reduce the amount of solar radiation reaching the Earth's surface, due to reflection and scattering, resulting in lower temperatures on cloudy days as opposed to sunny days. Cloudy nights however prevent some heat energy from escaping from the Earth's surface and so the atmosphere below cloud will experience less cooling than that below clear skies.

Terrestrial Radiation

14. The Earth radiates energy into the atmosphere in the form of terrestrial radiation. It is more readily absorbed by the atmosphere especially by clouds, water vapour and carbon dioxide that solar radiation due to its longer wavelength. The absorption of heat by the atmosphere from the Earth is the main heat exchange mechanism that causes weather.

15. Any terrestrial radiation not absorbed or reflected by the atmosphere escapes back into space. Clouds play an important role in this process; by reflection they cut off a substantial proportion of incoming radiation and by absorption and re-radiation they reduce the loss of outgoing radiation.

Radiation

16. Apart from the radiation absorbed by gases (mainly oxygen and ozone) in the high atmosphere, the atmosphere gains little or no heat by absorption of radiation directly. Radiation involves the flow of heat from one material to another without heating the intervening space.

Absorption

17. Any body in the path of radiation will absorb some of the energy. The amount of energy absorbed will depend upon the nature of both the body and radiation.

Conduction

18. Conduction is the process by which heat is transferred from one body to another through direct physical contact between the two bodies. The earth's surface absorbs radiation very readily and so is heated. Heat may be passed from one body to another that is in direct contact with it by conduction. Only a layer of air very close to the surface is heated by conduction, but because air is a poor conductor it will not transfer its heat to the air above it. It will however carry heat with it if it moves and mixes with higher air layers. While water and air are poor conductors because of the loose nature of their molecular structure, solids generally will conduct heat more readily. Land materials are usually

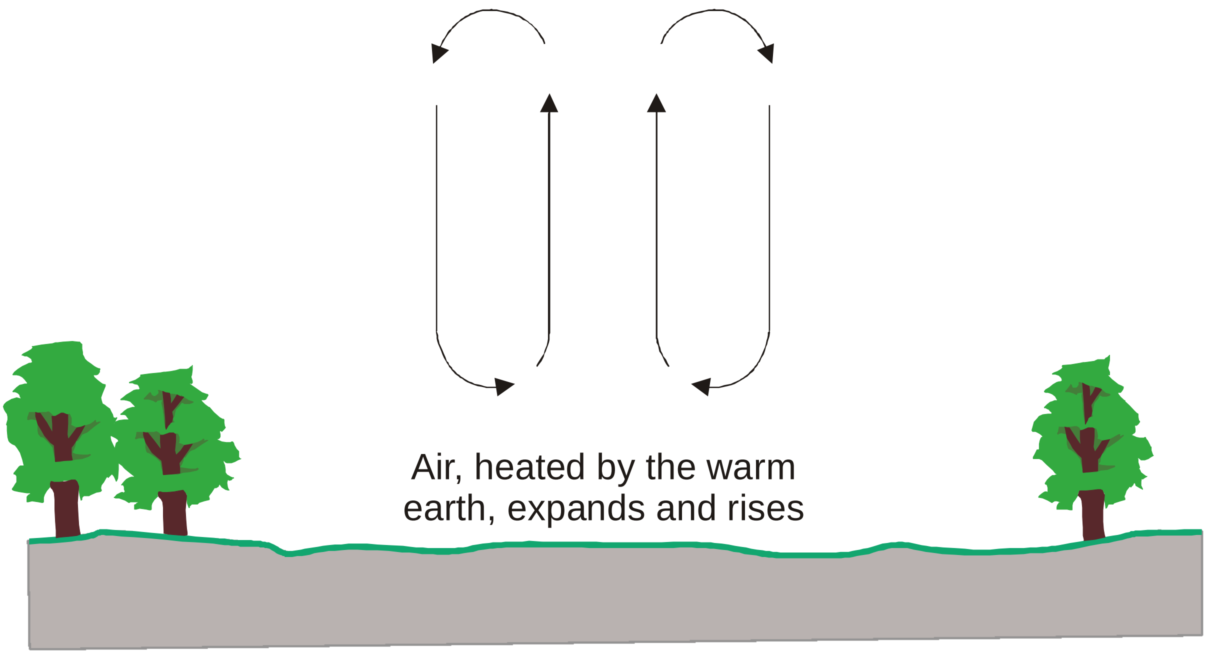
better conductors than water, but even so changes in ground temperature over a 24 hour period will only affect the first few centimetres of depth. Snow is a very poor conductor because it contains a large proportion of trapped air pockets.

Convection

19. Convection is the process by which heat is carried from one place to another by the bodily transfer of the air. Air that is heated at the Earth's surface will expand, become less dense and rise. This process of thermal convection will carry heat higher into the atmosphere. Vertical air currents (Fig 4) are formed and heat is spread through the layers in the lower atmosphere that are affected by these currents. Convection is the more important method of atmospheric heating.

20. It must be noted that convection takes place in water also and results in temperature changes through a considerable depth. The dispersal, or loss, of heat energy through a large volume results in small changes of surface temperature in the oceans.

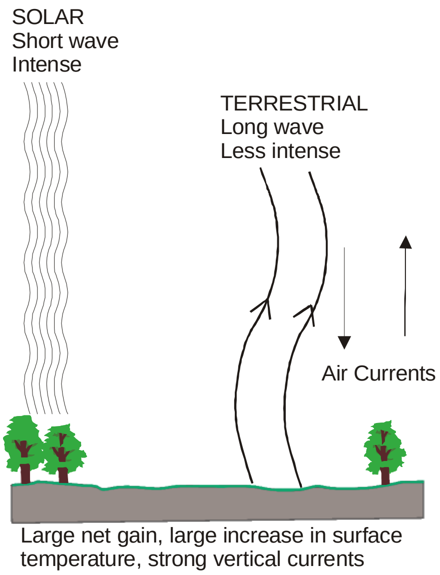
10CD-3 Fig 4 - Convection Heating



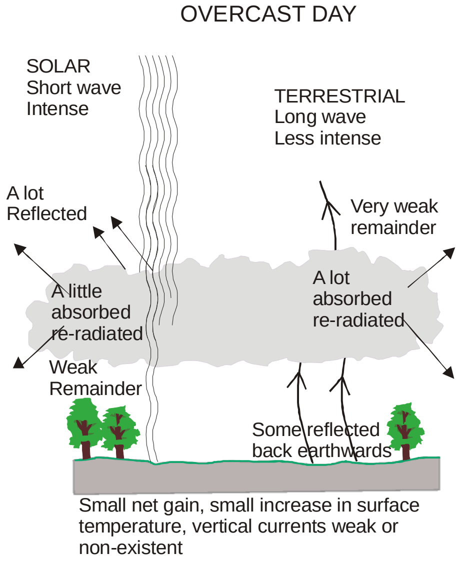
21. The following diagrams (Figs 5 and 6) show a rough balance for 4 extreme cases.

10CD-3 Fig 5 - Heating Process – Day

Heating Process on a Clear Day

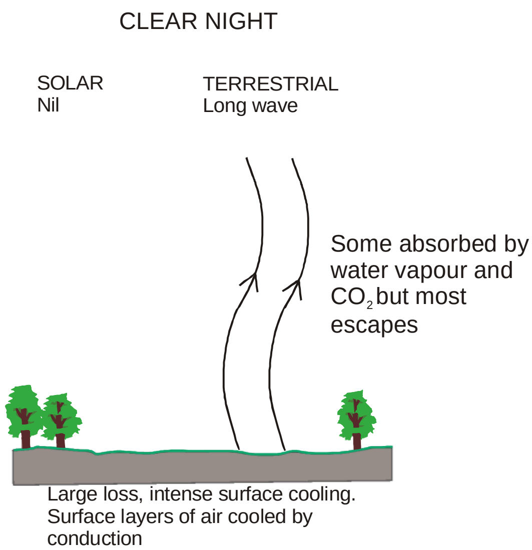


Heating Process on an Overcast Day

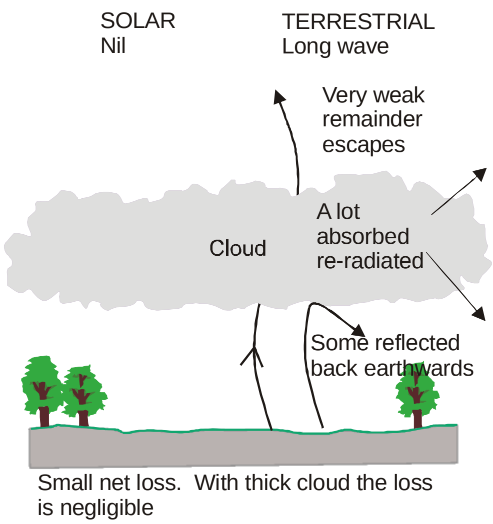


10CD-3 Fig 6 - Heating Process – Night

Heating Process on a Clear Night



Heating Process on an Overcast Night



Diurnal Variation of Surface Air Temperature

22. In meteorological terms the surface air temperature refers to the temperature of free air recorded in the shade and at a height of 1.25 metres (4 ft).

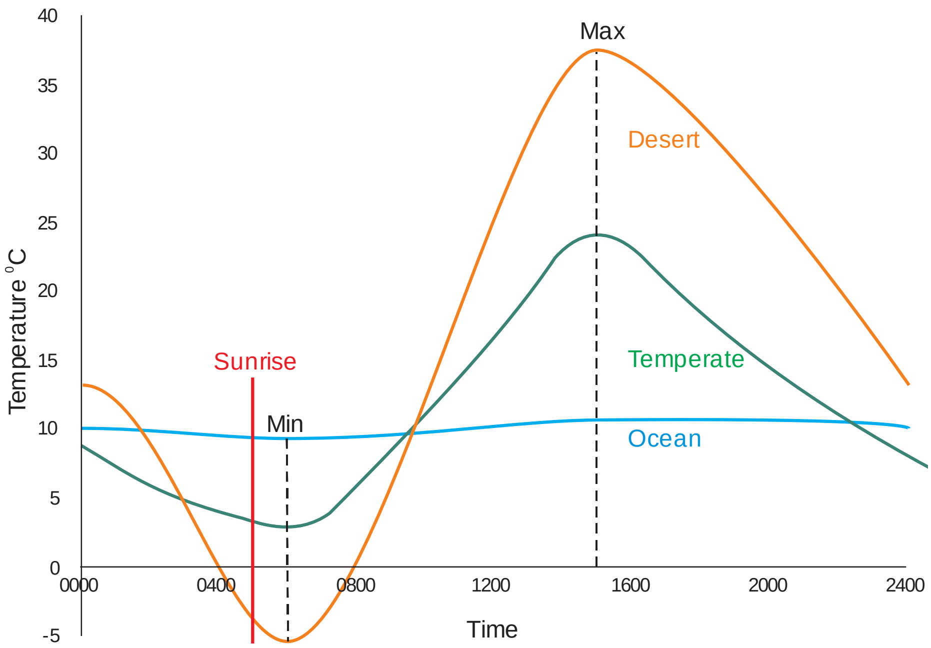
23. Solar heating only occurs on the Earth's surface facing the Sun, i.e. during daytime. Radiation of heat from the Earth's surface however happens continually by day and night. As a consequence, the surface of the Earth heats up by day, reaching a maximum temperature at about 1500 local time, and cools by night, typically reaching a minimum temperature about one hour after sunrise. The

temperature lags behind the elevation of the Sun due to the air being heated indirectly. The 24 hour cycle of heating and cooling is called the Diurnal Variation of Temperature. The extremes of high and low temperatures can be large in desert areas while over the ocean they can be very small or even non-existent. The differing diurnal variations in coastal areas can set up a temperature gradient between the two surfaces causing land and sea breezes.

24. Overcast conditions will affect the diurnal variation resulting in a lower maximum and a higher minimum temperature. Generally, the diurnal variation is greatest when the wind is calm. Wind causes the surface air to mix with the air above so that the gain of heat by day and the loss of heat by night is spread through a layer of air which may be 2,000 ft thick. In windy conditions the daytime maximum temperature will be lower and the night time minimum temperature higher than the temperatures experienced in calm conditions.

25. With clear skies overnight coupled with calm conditions, the ground temperature may be as much as 5° C below the air temperature. It may be that the air temperature is above freezing but the ground temperature is below freezing giving a 'ground frost' and possibly icy airfield surfaces.

10CD-3 Fig 7 - Illustration of the Diurnal Variation in Temperature



Summary of the Heating and Cooling Characteristics of Land and Water

26. If the same amount of solar energy falls on the same area of land and water:

a. The land will warm more quickly than the water.

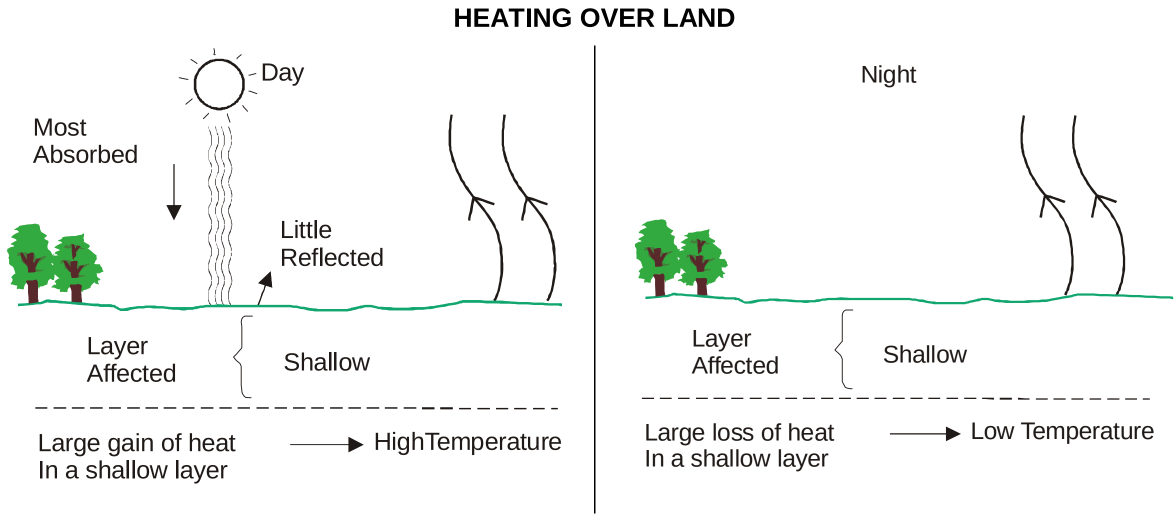
b. At night, the land will cool more quickly than the water.

c. Continental land areas will see large diurnal and seasonal ranges of temperature.

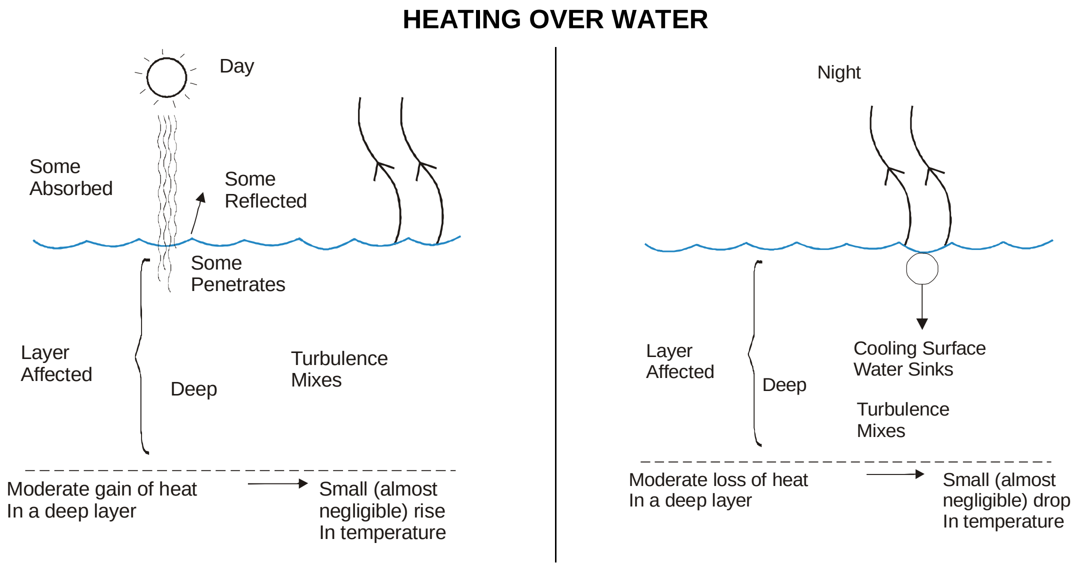
d. Oceans and seas will see small diurnal and seasonal ranges of temperature.

27. Figs 8 and 9 illustrate the differential heating over land and water, by day and by night.

10CD-3 Fig 8 - Heating Over Land



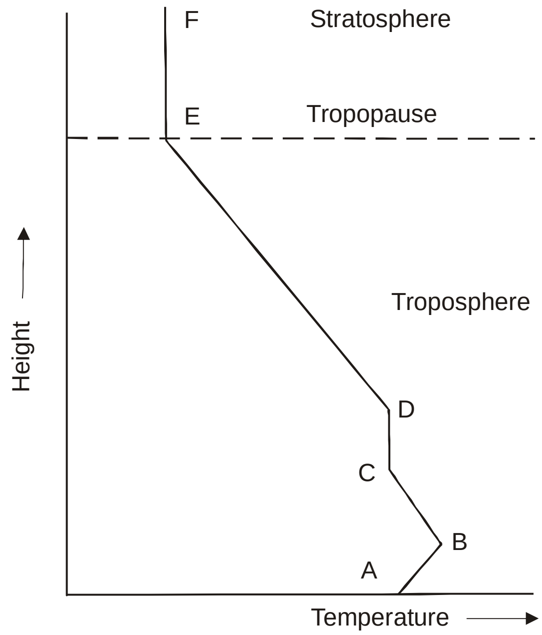
10CD-3 Fig 9 - Heating Over Water



Environmental Lapse Rate

28. Most of the atmosphere is heated as a result of terrestrial heating. It follows that air temperature normally decreases with height. In Fig 10 line ABCDEF represents readings of a thermometer lifted vertically through the atmosphere. In the troposphere the temperature normally decreases with height. This rate of change of temperature with height is called the Environmental Lapse Rate (ELR) and varies with place and time. The average value is around 2°C per 1000 ft. The ELR is the temperature change one would observe on an aircraft's outside air temperature gauge as it climbed away from ground level. The lapse rate may differ considerably from this average value. Line AB shows a rise in temperature with height. This is called an Inversion (of lapse rate). Along line CD the temperature remains the same through a considerable vertical layer. Such a layer is called an Isothermal layer.

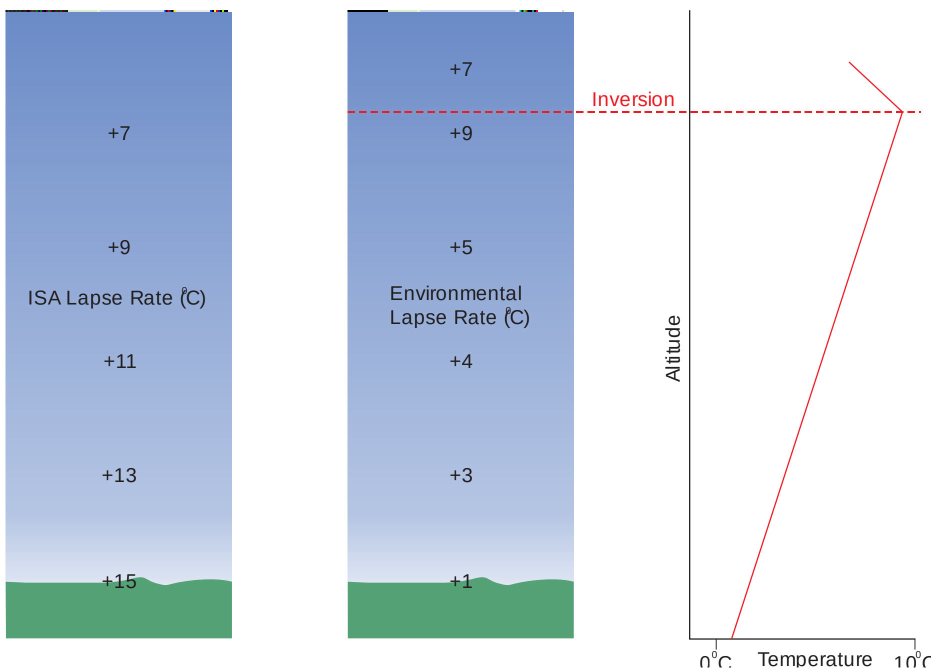
10CD-3 Fig 10 - Environmental Lapse Rate



Temperature Inversions

29. In the International Standard Atmosphere the ELR is 1.98° C/1,000 ft (but generally assumed to be 2° C/1,000 ft). In some layers of the atmosphere there may be a relatively shallow band where the temperature increases. This is called a Temperature Inversion.

10CD-3 Fig 11 - Temperature Inversion



30. Inversions are significant to pilots because:

a. The atmosphere will be stable and vertical movement of air will be resisted.

b. The vertical development of clouds may be limited.

c. Warmer air overlying colder air will reduce the normal mixing of air with lower levels and an aircraft climbing through an inversion may experience sudden wind increases and weak turbulence.

Types of Inversion

31. **Surface Inversion**. A surface inversion is caused by radiation cooling of the ground. As the ground radiates heat to the atmosphere, the lowest layers immediately above the surface are cooled by conduction to the ground. With air being a poor conductor the cooling is restricted to a shallow layer and a strong surface inversion can be formed which can be just a few tens of feet deep. The cooling can be quite intense with a rise in temperature of as much as 10° C. Surface inversions tend to form on clear nights with no surface wind and are most noticeable around sunrise.

32. **Turbulence Inversion**. Two types of turbulence inversions may occur, one at the surface and the other in the upper air.

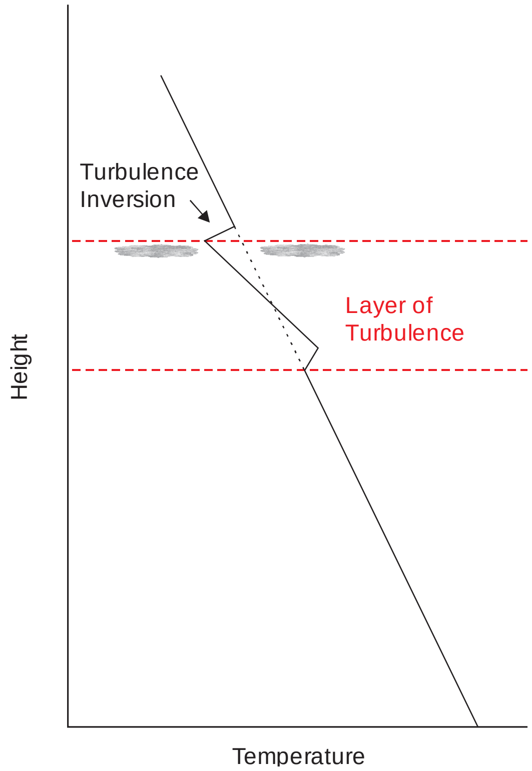
a. **Surface Turbulence Inversion**. This type is really an extension of the surface inversion. The surface inversion requires calm conditions to form but if a light wind is introduced, the cool surface air is mixed with the warmer air aloft. The depth of the inversion increases to a few hundred feet (probably no more than 300 ft) and the temperature rise is reduced to as little as 1° C. This type of inversion is important because it is a necessary requirement for fog to form. An increase in wind speed to over 5 kt will cause the inversion to dissipate.

b. **Upper Air Turbulence Inversion**. This type occurs at the top of the layer of air containing turbulence and a weak temperature lapse rate. Air that is lifted by turbulence cools at the Dry Adiabatic Lapse Rate (DALR)[1] and air caused to descend by the turbulence will warm at the DALR. The combined effect of these movements is to increase the ELR through the layer. Assuming that the temperature above and below the turbulence layer is not affected; a weak inversion will develop just above the top of the layer. With sufficient moisture in the air a layer of cloud can form just under the inversion.

---

[1] Unsaturated air will cool adiabatically at 3° C/1,000 ft as it rises and expands. This is known as the Dry Adiabatic Lapse Rate (DALR).

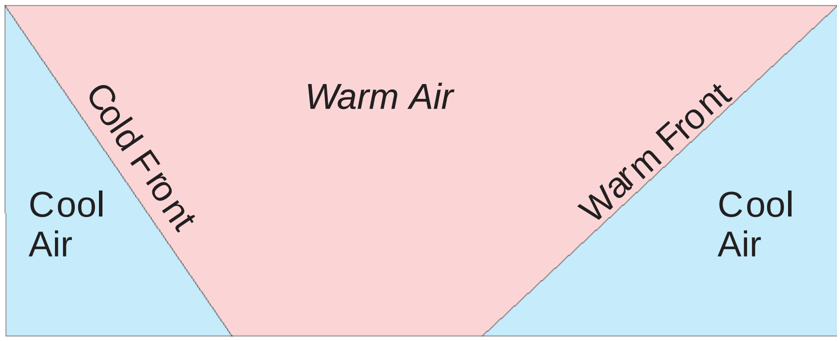
10CD-3 Fig 12 - Upper Air Turbulence Inversion



33. **Subsidence Inversion**. Subsidence of air[2] is part of the formation process of anticyclones (areas of high pressure). The air in the top layers of the troposphere tends to subside more, with greater adiabatic warming due to compression, than air in the lower levels. The result is relatively warmer air overlying the lower layer. Typically subsidence inversions occur between 4,000 ft and 6,000 ft and are quite strong with up to a 15° C temperature rise. They are generally up to 500 ft deep and provide a lid to haze and smoke layers which causes a reduction in visibility during descents through them. Also, they tend to inhibit thermal development so that low level convective cloud has limited vertical development if the inversion is strong enough.

34. **Frontal Inversion**. A front is the boundary between two air masses with the most significant feature being the temperature difference between them.

10CD-3 Fig 13 - Fronts

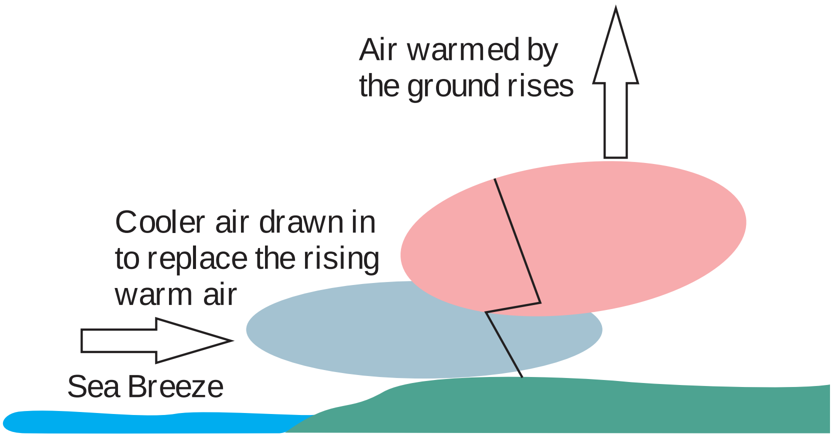


[2] Subsidence is the downward movement of air in the atmosphere. It is most commonly applied to the slow sinking of air within an anticyclone, but can apply to any downward motion of air.

The colder, more dense air will lie under the warmer less dense air mass. An inversion will exist along the boundary where the warm air overlies the cooler air. The strength of the inversion depends upon the width of the boundary zone and the physical temperature difference. The boundary of a cold front is usually quite sharp and may only be a few hundred feet deep.

35. **Sea Breeze Inversion**. A sea breeze inversion is very similar to a frontal inversion as it occurs at the boundary of a warm body of air and a cooler body; the sea breeze itself.

10CD-3 Fig 14 - A Sea Breeze Inversion



As the sea breeze is usually close to the surface, the inversion will also occur there, between 100 ft and 1,000 ft above the ground. The strength of the inversion will depend upon the temperature difference between the sea breeze and the warmer air ahead of it. The rising warm air will be cooled adiabatically so the temperature above the inversion might be slightly less than expected, but still could be about 10° C through a couple of hundred feet.

36. **Tropopause Inversion**. It is possible for an inversion to exist at the tropopause. If ozone is present immediately above the tropopause, because the gas absorbs UV radiation from the Sun and is warmed by it, there may be a rise in temperature forming a tropopause inversion. If one exists it may not be strong and might only result in a temperature rise of between 1° C and 5° C but it might extent through a depth of several thousand feet.

Flying Conditions in Inversions

37. There is nearly always a sudden change in wind vector when passing through an inversion. Wind speed will increase when climbing through an inversion and decrease when descending. Turbulence may also be encountered. Because of the windshear and density change in the vicinity of an inversion, an aircraft may experience turbulence of varying severity.

38. An inversion marks the boundary between layers of air having differing temperatures and to some extent density. This will result in an aircraft gaining lift, thrust and power when descending through an inversion with the reverse conditions when climbing. Changes may or may not be noticeable to the pilot depending on the strength of the inversion and its vertical depth. A strong inversion in the vicinity of an airfield may affect climb performance after take-off as a sudden reduction in lift, thrust and power coupled with windshear resulting in a tailwind, could lead to a hazardous situation.

39. Visibility below an inversion is generally worse than that above it because the inversion can trap impurities in the air. Greater moisture below an inversion may lead to cloud formation below it but the

reduced tendency of air to lifting above it inhibits the formation of clouds. Exceptions to this general rule is with inversions formed by fronts and sea breezes.

10-4-PRECIPITATION

Introduction

1. By definition, precipitation is any aqueous deposit in liquid or solid form (rain, drizzle, snow, hail, etc.) derived from the atmosphere. Depending on the form of precipitation, it can reduce visibility, create icing situations, and affect the landing and take-off performance of aircraft. It occurs when water or ice particles in clouds grow in size until the atmosphere can no longer support them.

Rain

2. Water drops larger than 0.5 mm in diameter are classified as rain with smaller drops termed as drizzle. The difference between rain and drizzle is purely the size of the water drop rather than the intensity of the precipitation. Drizzle will usually fall from sheets of low shallow cloud whereas rain generally originates from deeper clouds. Drizzle, consisting of many small drops, will reduce visibility more than the equivalent amount of water falling as rain and is also more wetting than slight rain.

Drizzle

3. Drizzle is liquid precipitation in the form of water drops of very small size (by convention, with diameters between about 200 and 500 µm) and usually accompanies fog or low stratus clouds. Drizzle forms by the collision of water droplets in stratus cloud. Large droplets have a greater fall speed that small droplets and it is the difference in fall speed that allows the collisions to happen. The turbulent motion of air within clouds also leads to collisions taking place as small drop are carried upwards faster than large drops. For drizzle to fall there also needs to be relatively high humidity values below the cloud to prevent the drops from evaporating before they reach the ground.

Hail

4. If rain falls through a temperature inversion it may freeze as it passes through the underlying cold air and fall to the ground in the form of ice pellets. Ice pellets are an indication of a temperature inversion and that freezing rain exists at a higher altitude. Hail is associated with cumulonimbus (Cb) clouds where much of the cloud is composed of supercooled water droplets [1]. Hail stones are carried up and down within the cloud by up-draughts and down-draughts, growing larger in size as they come in contact with supercooled water droplets. Once the updrafts can no longer support the hailstone it falls to Earth. A hail stone generally has a diameter of between 5 and 50 mm but can be much larger. If a hail stone is cut open a layered structure similar to that of an onion is apparent. A large hail stone may consist of several layers of clear and opaque ice.

5. Hail showers are common in the UK in westerly and northerly airstreams during spring but large hail stones tend to be associated with hot continental air. While hail stones in the UK tend to be on the smaller size they can still cause damage to structures and aircraft. Hail stones in other parts of the globe can be much larger; for example, in 1986 hail stones weighing up to 1 kg fell in Bangladesh killing over 90 people. Such large hail stones falling from a Cb cloud will cause severe damage to an airframe, which reinforces the advice to pilots to avoid Cb cloud.

---

[1] Water inside a cloud freezes at a temperature below 0° C. At -40° C all the water will turn to ice but between about -10° C and -40° C, the cloud consists of supercooled liquid water droplets and ice crystals.

Snow

6. Snow is solid precipitation in the form of ice crystals that fall at a steady rate or in snow showers. Falling snow also varies in size, falling as very small grains at temperatures well below 0° C or as large flakes at temperatures near to 0° C. Snow grains are the equivalent of drizzle in size. Thirty centimetres of snow equates to about 25 mm of rainfall.

7. Precipitation falls as snow when the air temperature is below 2° C. Logically the snow should melt when above freezing but as the melting process begins, the air around the snowflake is cooled. However, above 2° C the snowflake will melt to become sleet [2] or rain. In the UK the heaviest snowfall tends to be when the temperature is between 0° C and 2° C.

Virga

8. Precipitation that falls from a cloud but evaporates before reaching the ground is known as virga. An important aspect in this process is that the rain absorbs latent heat from the air, causing the air to cool and sink, sometimes rapidly, towards the ground. This can produce a dry microburst which can be hazardous to aircraft. Virga is common in deserts and temperate regions.

Intensity of Precipitation

9. The intensity of precipitation is classified as SLIGHT, MODERATE or HEAVY (see Table 1), and it depends on:

a. **Vertical Thickness of the Cloud**. Development of the cloud to a depth several thousand feet above the 0 °C isotherm aids the growth of ice crystals. These crystals can further increase in size by collision with supercooled water droplets and eventually fall out of the base of the cloud as snow or rain depending on the temperature.

b. **Water Content of the Cloud**. This is dependent on the temperature of the cloud base. The higher the temperature the more water vapour the air can hold, and therefore the more liquid water that is produced when the air is cooled below its dew point.

c. **Strength of Updraughts within the Cloud**. Strong up draughts within a cloud can support larger water droplets or ice crystals, and so the larger the droplets/crystals that fall from the cloud. Updraughts in Cumulonimbus clouds can exceed 5000 ft/min in the tropics, but in temperate latitudes 3000 ft/min is more likely.

d. **Topography**. When air flows over hills and mountains the vertical velocity of the air increases and this leads to deep clouds with large droplets and heavier precipitation.

[2] Sleet has no agreed international meaning but in the UK it is used to describe precipitation of snow and rain/drizzle together or of snow melting as it falls.

Table 1 - Precipitation Intensity

Classification	Rainfall Rate (mm/hr) Rain	Rainfall Rate (mm/hr) Rain/Hail Showers	Snow Accumulation (cm/hr)	Drizzle (mm/hr)
Slight	< 0.5	< 2	< 0.5	Negligible runoff from roofs
Moderate	0.5 to 4	2 to 10	0.5 to 4	
Heavy	> 4	10 to 50	> 4	> 1
Violent	N/A	>50	N/A	N/A

10. **Continuity of Precipitation**. There is a clear distinction between showers and general precipitation:

a. **Showers**. Showers are local outbreaks of precipitation from detached heap cloud, i.e. Cumulus or Cumulonimbus, no matter how prolonged the precipitation may be.

b. **General Precipitation**. General precipitation falls from an extensive layer of cloud and affects a larger area, it is reported as:

(1) **Intermittent**. Where each spell of precipitation lasts for less than one hour.

(2) **Continuous**. Where it is prolonged i.e. lasting for one hour or more.

Intensity of Precipitation and Method of Uplift

11. **Convection**. Convection produces showers and the intensity varies from light to heavy.

12. **Orographic Uplift**. In an unstable atmosphere orographic uplift starts convection which often results in increased intensity. In a stable atmosphere where air is forced to ascend, the precipitation is usually light but occasionally moderate and may be sustained.

13. **Mass Ascent**. Mass ascent can produce clouds of considerable depth with precipitation varying in intensity from light to heavy.

14. **Turbulence**. Usually turbulence produces fairly shallow cloud and only light drizzle if any at all.

The Effects of Precipitation on Flying Conditions

15. Because precipitation is intimately associated with clouds, it is useful to summarize the effects of major cloud types on flying conditions. The effects of major cloud types on flying conditions resulting from icing, turbulence and precipitation are shown in Table 2.

Table 2 - The Effect of Major Cloud Types on Flying Conditions

CLOUD TYPE		ICING	TURBULENCE	PRECIPITATION
Cumulonimbus	Cb	Severe	Severe	Heavy showers of rain, snow and hail
Cumulus	Cu	Moderate or Severe	Moderate or Severe	Light to heavy showers of rain or snow
Cirrus Cirrostratus Cirrocumulus	Ci Cs Cc	Nil	Nil	Nil
Altostratus	As	Light	Nil or Light	Nil or light rain or snow
Altocumulus	Ac	Light or Moderate	Light or Moderate	Nil or rain or snow
Stratus	St	Light during prolonged flight	Nil	Nil or drizzle
Stratocumulus	Sc	Light or Moderate	Light	Nil or light rain, drizzle or snow flurries
Nimbostratus	Ns	Moderate or Severe	Moderate	Periods of rain or snow

16. Cloud types which are most likely to affect flying conditions in terms of icing, turbulence and precipitation are Cumulus, Cumulonimbus and to a lesser extent Nimbostratus.

17. The effects of cloud on air operations are as follows:

a. Reduced visibility from air to ground (sometimes obscuring high ground) and air to air.

b. Turbulence (some clouds are more turbulent than others).

c. Icing (ice accretion varies with type of cloud).

d. Interference with communications (lightning, static, icing).

e. Increased airframe fatigue (turbulence stresses).

f. Instrument approaches required (cloud base).

18. The effects of precipitation may be summarized as follows:

a. Lowering of cloud base (saturation of air below cloud).

b. Stronger down-currents of air (air sinks as it is cooled by evaporation of precipitation and is dragged downwards by the precipitation) known as down draughts, gust fronts and micro bursts.

c. Reduced visibility (greatest with snow, then drizzle, then rain).

d. Hail damage to airframes (especially at high speed).

10-5-WIND PATTERNS, AIR CURRENTS AND STABILITY

Introduction

1. The term wind refers to the flow of air over the earth's surface. This flow is almost completely horizontal, with only about 0.1% of the total flow being vertical. Despite only a small proportion of the overall flow of air in the atmosphere, vertical airflow is extremely important to weather and to aviation, since it leads to the formation of clouds and turbulence. In general, the term wind is used in reference to the horizontal flow of air. It is a pressure difference in the atmosphere (usually resulting from temperature differences) that initiates a wind.

2. Air flows from high pressure to low pressure. Air pressure, temperature changes, and the Coriolis force work in combination to create two kinds of motion in the atmosphere. Vertical movement of ascending and descending currents, and horizontal movement in the form of wind. In the Northern Hemisphere, the flow of air is deflected to the right and produces a clockwise circulation around an area of high pressure (anticyclonic circulation). The opposite is true of low-pressure areas; the air flows toward a low and is deflected to create an anticlockwise or cyclonic circulation.

3. High pressure systems are generally associated with good weather as they are areas of dry, stable, descending air. Conversely, air flows into a low-pressure area to replace rising air. This air tends to be unstable, and usually brings increasing cloudiness and precipitation.

Unstable Air

4. A rising parcel of air that is warmer than its surroundings will continue to rise. Such air is unstable and can produce vertical air currents known as thermals. These conditions often result in turbulence (especially in thermals) and the formation of cumuliform (heaped) clouds giving showery rain and good visibility between showers.

Stable Air

5. An unstable parcel of air will stabilize when it reaches the same temperature as its surroundings and will stop rising, becoming stable. Stable air results in the formation of stratiform clouds with steady precipitation. Visibility will generally be poor but with smooth flying conditions, i.e. little turbulence. Inversions may form along with fog.

6. The circulation theory is accurate on a global scale, but local conditions, geological features and other factors can affect the weather and wind conditions close to the Earth's surface.

Buys Ballot's Law

7. There is a relationship between the direction of the wind and the air pressure (and hence the isobars shown on a synoptic chart) known as Buys Ballot's Law which states:

> **If an observer stands with their back to the wind in the northern hemisphere, then the lower pressure is on the left-hand side. The opposite is true in the southern hemisphere**.

Convective Currents

8. Ploughed land, rocks, sand, and barren land radiate a large amount of heat. Water, trees, and other areas of vegetation tend to absorb and retain heat which results in uneven heating of the air close to the Earth's surface generating small areas of local circulation called convective currents.

9. Convective currents can cause turbulent air in the lower layers of the atmosphere and updrafts are likely to occur over pavement or barren places with downdrafts over water or expansive areas of vegetation. Convective currents may be noticeable in areas with a land mass directly adjacent to a large body of water. During the day, land heats faster than water, and the air over the land becomes warmer and less dense. This air rises and is replaced by cooler, more dense air from over the water causing an onshore wind (Sea Breeze). Conversely, at night land cools faster than water along with the corresponding air, causing the warmer air over the water to rise and be replaced by the cooler, denser air from the land, creating an offshore wind (Land Breeze).

Effect of Obstructions on Local Wind

10. Structures on the ground may affect the flow of the local wind. Ground topography and large buildings can break up the flow of the wind and create wind gusts that change rapidly in direction and speed. Structures may be manmade, such as hangars and buildings, or large natural obstructions, such as mountains.

11. Local winds in mountainous regions can cause difficult flying conditions. Wind generally flows smoothly up the windward side of the mountain whereas the wind on the leeward side tends to follow the contour of the terrain and is increasingly turbulent.

Windshear

12. Windshear may be defined as a sudden change of wind velocity and/or direction which may be in the vertical or horizontal plane, or a mixture of both. Windshear can occur at altitude but it becomes particularly significant and potentially hazardous at low level especially during the take-off, approach and landing phases of flight. It is important that pilots should recognise when and where to expect windshear so that it can be avoided or countered in accordance with the recognised flying techniques associated with their particular aircraft.

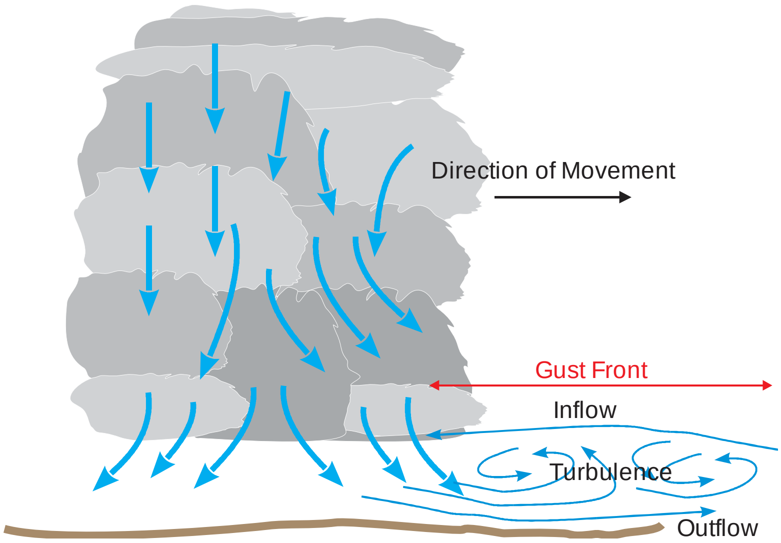
Low-Level Windshear

13. Low-level windshear is commonly associated with passing frontal systems, thunderstorms, and temperature inversions with strong upper level winds (greater than 25 knots).

a. Frontal Passage. Windshear is likely on active fronts with narrow frontal zones and a marked temperature difference. Fronts with sharp changes in wind direction across the front, temperature differences of 5° C or more, or a speed of movement of 30 kt or more may indicate a potential for windshear.

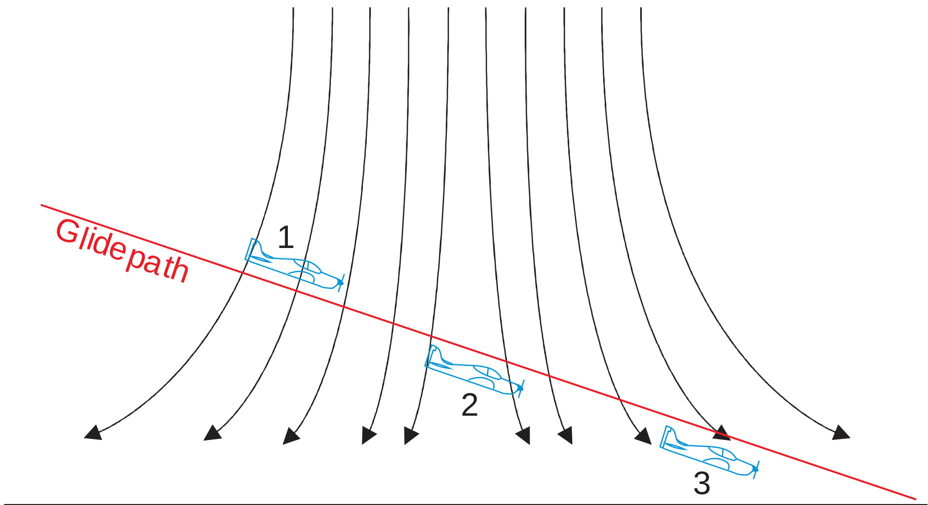
b. Thunderstorms. Thunderstorms are associated with severe updraughts and downdraughts which will produce significant windshear. Some thunderstorms have a well-defined area of cold air flowing out ahead of the storm, known as a gust front. These are areas of significant turbulence and give little warning of their approach.

10CD-5 Fig 1 Thunderstorm Gust Front



c. Microbursts. A microburst is a particularly intense downdraught of air within a thunderstorm. It is typically less than 2 nm across and is short lived. With a downdraught speed of up to 6,000 feet per minute and very rapid wind direction changes of 45 degrees or more, this is perhaps the most lethal form of windshear. Fig 2 shows a small aircraft flying through a microburst. At position 1 it will experience an increasing headwind and hence a rising airspeed. The rate of descent will reduce resulting in a tendency to rise above the glidepath. At position 2, the headwind will reduce, thus reducing the airspeed. The aircraft will descend below the glidepath with an increased rate of descent. At position 3 there will be an increased tailwind and a still falling airspeed along with an increasing rate of descent. A successful recovery from this extremely hazardous condition will depend on the pilot recognising the situation and the power, height and speed reserves available to them.

10CD-5 Fig 2 Windshear Caused by a Microburst



d. Temperature Inversion. A temperature inversion at low level can separate stronger airflow above it from weaker airflow below the inversion causing turbulence, and hence windshear, at the inversion boundary.

Atmospheric Stability

14. A stable atmosphere resists vertical movement and small vertical disturbances dampen out, whereas in an unstable atmosphere, small vertical air movements tend to become larger, resulting in turbulent airflow and convective activity. Instability can lead to significant turbulence, extensive vertical clouds, and severe weather.

15. When a gas expands its temperature falls and conversely, when a gas is compressed its temperature rises. Rising air expands and cools due to the decrease in air pressure with altitude. The opposite is true of descending air; as atmospheric pressure increases, the temperature of descending air increases as it is compressed. Adiabatic heating and adiabatic cooling are terms used to describe this temperature change.

16. The adiabatic process takes place in all upward and downward moving air. The rate at which temperature decreases with altitude is referred to as its lapse rate. In the Standard Atmosphere, the temperature lapse rate is 1.98 ºC per 1,000 ft up to a height of 36,090 ft above which the temperature is assumed to remain constant at –56.5 ºC. Moisture in the air will affect its lapse rate. Since water vapour is lighter than air, moisture decreases air density, causing it to rise. Conversely, as moisture decreases, air becomes denser and tends to sink. Since moist air cools at a slower rate, it is generally less stable than dry air since the moist air must rise higher before its temperature cools to that of the surrounding air. The dry adiabatic lapse rate (unsaturated air) is 3 °C per 1,000 feet. The moist adiabatic lapse rate varies from 1.1 °C to 2.8 °C per 1,000 feet.

17. Moisture and temperature determine the stability of the air and hence the resulting weather. Cool, dry air is very stable and resists vertical movement, which leads to good and generally clear weather. The greatest instability occurs when the air is moist and warm, as it is in the tropical regions in the summer, resulting in daily thunderstorms.

Inversion

18. Under normal circumstances rising air expands and its temperature decreases. An inversion is an atmospheric anomaly where the air temperature increases with altitude. Inversion layers are shallow layers of smooth stable air close to the ground where the temperature increases to a certain altitude which is the top of the inversion. The air at the top of the inversion traps weather and pollutants below it. Where the relative humidity is high, it can lead to the formation of clouds, fog and haze and in combination with pollutants can significantly affect visibility.

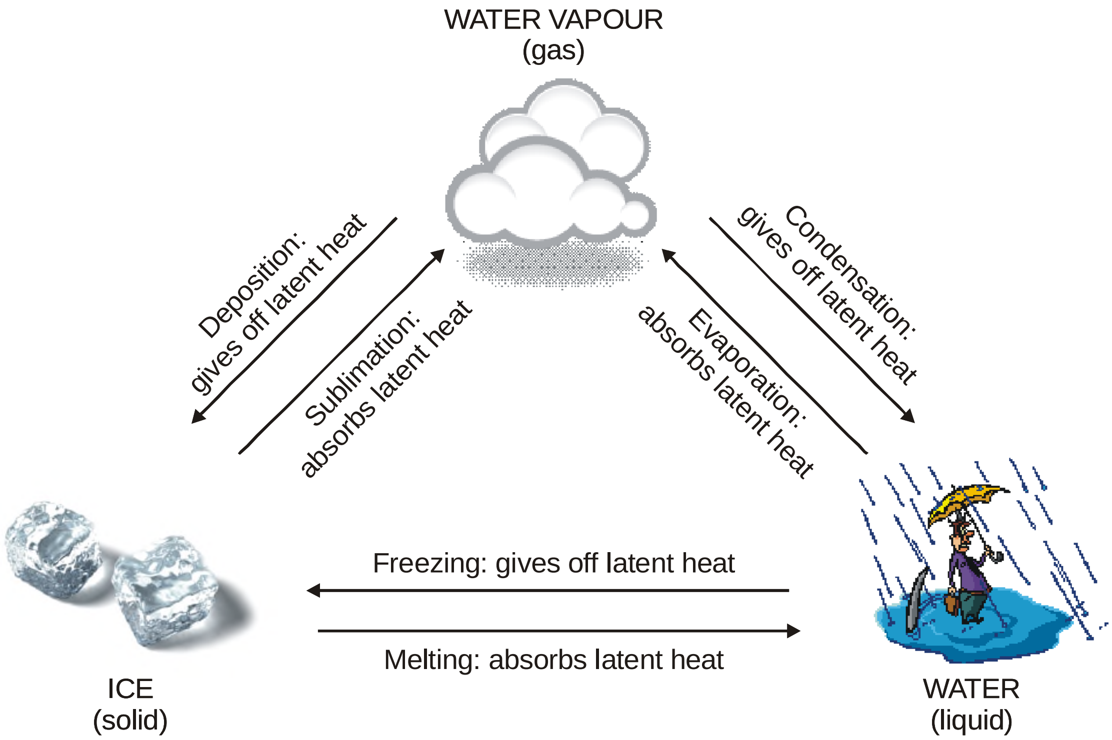
19. Surface based temperature inversions occur on clear, cool nights when the air close to the ground is cooled by the falling temperature of the ground. The air within a few hundred feet of the surface becomes cooler than the air above it. Frontal inversions occur when warm air spreads over a layer of cooler air, or cooler air is forced under a layer of warmer air.

Moisture and Temperature

20. Water can exist in one of three forms in the atmosphere, solid, liquid and vapour. Each form can readily change to another, and during such a transformation latent heat is exchanged (Fig 3). Latent heat is the energy released or absorbed during a constant temperature process. The moisture content of the air is affected by its temperature where warm air can hold more than cold air. As moist air is

cooled it reaches its saturation point, where further cooling will result in the moisture condensing. If the air is cooled further, below its saturation point, cloud, mist or fog will form.

10CD-5 Fig 3 The Three States of Water



Definitions

21. **Sublimation**: The transition of a substance directly from a solid to its gaseous form without passing through a liquid phase.

22. **Deposition**: The reverse process of sublimation.

23. **Evaporation**: The vaporization of a liquid that occurs from its surface into a gaseous state that is not saturated with the evaporating substance.

24. **Condensation**: The change of a vapour into its liquid form commonly caused when a vapour is cooled and/or compressed to its saturation limit. Condensation requires a surface to condense onto. Within the air, the surfaces are provided by microscopic solid particles (condensation nuclei) such as dust, smoke, sea salt, bacteria and pollens.

25. **Freezing**: When the temperature of a liquid is lowered below its freezing point.

26. **Melting**: The reverse of freezing.

Relative Humidity

27. Humidity refers to the amount of water vapour present in the atmosphere at a given time. Relative humidity is the actual amount of moisture in the air compared to the total amount of moisture the air could hold at that temperature expressed as a percentage. For example, if the current relative humidity

is 65%, the air is holding 65% of the total amount of moisture that it is capable of holding at that temperature and pressure.

Temperature and Dew Point

28. The dew point, given in degrees, is the temperature at which a sample of air becomes saturated if cooled at a constant pressure. When the temperature of the air is reduced to the dew point moisture begins to condense in the form of fog, dew, frost, clouds, rain, hail, or snow.

29. There are four methods by which air can reach the saturation point.

a. When warm air moves over a cold surface, the air temperature drops and reaches the saturation point.

b. The saturation point may be reached when cold air and warm air mix.

c. When air cools at night through contact with cooler ground, air reaches its saturation point.

d. When air is lifted or is forced upward in the atmosphere.

Dew and Frost

30. On cool, calm nights, the temperature of the ground and objects can cause the surrounding air temperature to drop below the dew point. When this occurs, the moisture in the air condenses and deposits itself on the ground, buildings, and other objects such as aircraft. This moisture is known as dew. If the temperature is below freezing, the moisture is deposited in the form of frost.

Fog and Mist

31. Fog forms when very small water droplets are suspended in the air, reducing the horizontal visibility at the Earth's surface to less than 1000 m. Where ice crystals are held in suspension, ice fog forms. Mist is defined as for fog, but the visibility does not fall below 1000 m. Fog can be taken as a cloud on the surface. Fog typically occurs when air near the ground is cooled to its dew point.

32. **Radiation Fog**. Radiation fog occurs when the ground cools rapidly due to terrestrial radiation, and the surrounding air temperature reaches its dew point. As the Sun rises and the temperature increases, radiation fog usually lifts and burns off.

33. **Advection Fog**. Advection fog is caused by the movement of moist air over a relatively colder surface. Unlike radiation fog, wind is required to form advection fog. Winds of up to 15 knots allow the fog to form and intensify; above a speed of 15 knots, the fog usually lifts and forms low stratus clouds. Advection fog is common in coastal areas where sea breezes can blow the air over cooler landmasses. Advection fog, unlike radiation fog, may not burn off with the morning sun, but instead can persist.

34. **Steam Fog**. Steam fog, or sea smoke, forms when cold, dry air moves over warmer water. As the water evaporates, it rises and resembles smoke. This type of fog is common over bodies of water during the coldest times of the year. Low-level turbulence and icing are commonly associated with steam fog.

10-6-VISIBILITY AND FOG

Introduction

1. Meteorological visibility is the greatest horizontal distance at which a defined object can be recognised, against a contrasting background, by an observer with normal eyesight during daylight. At night, visibility is defined as the distance over which the lights of a specified candlepower can be distinguished by the naked eye. Many synoptic weather stations in the UK use automatic sensors to determine the visibility. Where there are also human observers (e.g. at airfields) the sensors are used as an aid in the estimation of visibility.

2. In-flight visibility is defined as the forward visibility from the cockpit of an aircraft in flight.

Prevailing Visibility

3. Depending upon the weather, the prevailing visibility may not be the same in all directions. In the UK the Met Office has adopted the concept of prevailing visibility for aerodrome weather reports. Prevailing visibility is the visibility value which is either reached or exceeded around at least half of 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 1500 m, or less that 50% of the prevailing visibility, the lowest visibility observed, and its general direction should also be reported.

4. Within aviation there is more than one meaning of the term 'visibility'. One is Meteorological Optical Range (MOR) and is usually referred to as 'Met Vis', while another is the Runway Visual Range (RVR).

a. The MOR or Met Vis is the greatest horizontal distance at which suitable objects can be recognised for what they are in daylight, or at which lights of a specified candlepower can be seen at night, by a person of normal sight. Where the visibility varies depending on the direction of view, it is usual to report the lowest visibility.

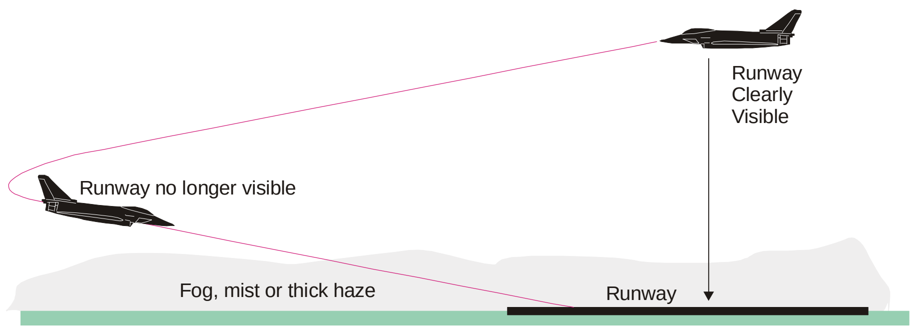
b. The RVR is the maximum distance in the direction of take off or landing at which the runway or specified lights delineating the runway can be seen from a position on the centreline at a height corresponding to the average eye level of the pilot at touchdown.

c. Because the RVR is determined directionally while the met visibility is determined omni-directionally, if there is, for example, fog away from the runway, this may affect the met visibility but not the RVR. At night the met visibility is measured using lights of a set candlepower whereas RVR may use high intensity lighting to maximize the visual range.

5. The above measures of visibility are made horizontally at ground level and do not cater for the air to ground (slant range) condition. The slant range visibility will depend upon the angle of slant, the thickness of any low cloud or haze layer and the aircraft height. Figs 1 and 2 illustrate this.

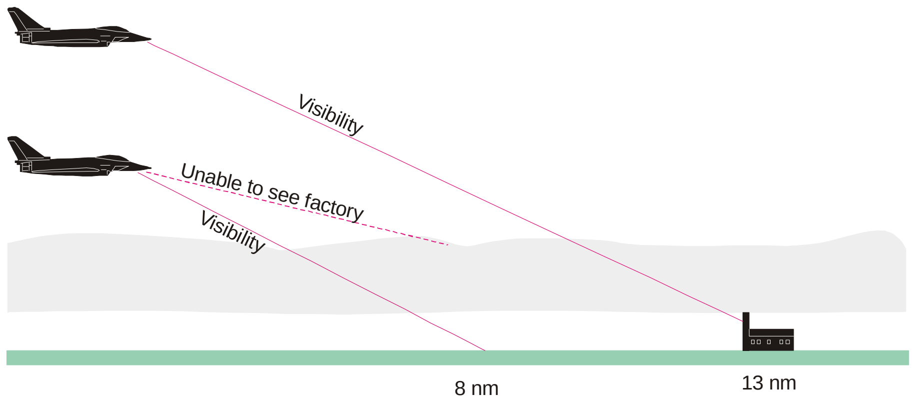
6. Although the airfield may be visible from the overhead, once the aircraft is on the final approach the runway may no longer be visible. Descending into shallow fog from air where the visibility is good may give a visual illusion that the aircraft has a pitched-up attitude causing disorientation and leading to a dangerous situation.

10CD-6 Fig 1 - Reduced Visibility on the Final Approach



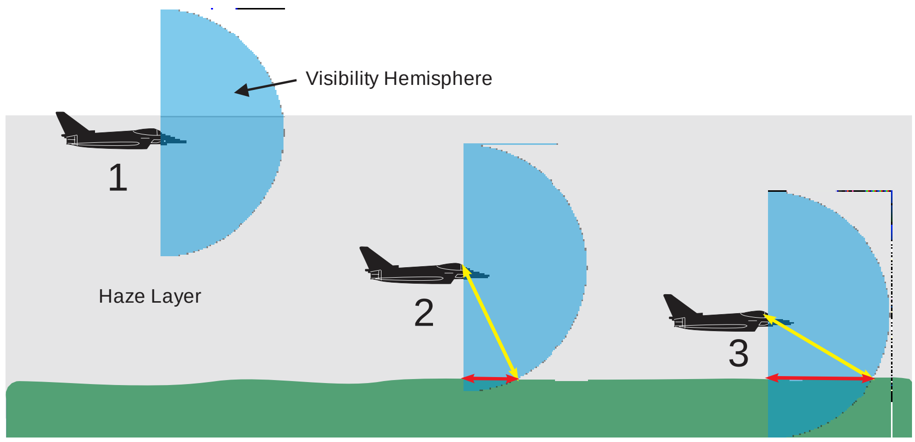
7. Fig 2 illustrates the reduced visibility for an aircraft flying over a layer of haze as compared to a higher-flying aircraft. The visibility under the haze layer may be unlimited while visibility through the haze will be reduced and will be affected by the aircraft height.

10CD-6 Fig 2 - Slant Range Affected by Aircraft Height



8. Slant visibility is the distance a pilot can see along the ground at a given height. Flying within a haze layer will reduce visibility, especially when heading into sun. Fig 3 depicts the distance a pilot can see when flying within a haze layer using the concept of a visibility hemisphere. At position 1 the pilot cannot see the ground and therefore the slant visibility is zero. At position 2 the pilot can see the ground, but the slant visibility is poor. When flying still lower at position 3, the slant visibility is improved, and the pilot can see more of the ground ahead of the aircraft. In summary, when operating in a haze layer, descending will improve the slant visibility BUT depending on the actual conditions it may be unsafe to do so.

10CD-6 Fig 3 – Slant Visibility



Factors Affecting Visibility (Obscurations)

9. Reduced visibility can be caused by several atmospheric phenomena known as obscurations.

a. **Airborne Water and Precipitation**. Fog, mist and cloud are water droplets or ice particles that are suspended in the air and will reduce visibility to varying degrees. Rain Drizzle, hail and snow will affect visibility to varying degrees. Rain will reduce visibility depending upon the size and number of the rain drops. Heavy rain may reduce visibility to between 50 m and 500 m whereas light rain may reduce visibility to 5 or 6 nm. Heavy rain may also collect on the windscreen, further reducing the visibility. Drizzle will normally reduce visibility to about 1.5 nm, but heavy drizzle can reduce it to 500 m. Hail has little effect on visibility. Snow may reduce visibility to less than 1000 m but heavy snow, especially if it is blowing in the wind can reduce visibility to less than 100 m.

b. **Sea Spray**. When low flying over the sea or operating from an airfield very close to the sea, visibility may be reduced due to sea spray. Another hazard associated with sea spray is the build-up of salt deposits on windscreens as the spray evaporates rapidly in the airflow.

c. **Smoke, Dust and Sand**. Smoke and industrial pollution can affect visibility to varying degrees and can encourage fog to form as there is likely to be an abundance of condensation nuclei in the air. When combined with an inversion, where the layer of pollution is trapped under the inversion, visibility can be severely reduced. In rural areas visibility may be affected by pollen or dust trapped below an inversion. In desert areas sand can be blown to heights of several thousand feet but is seldom carried far from its source. Close to the source of the sandstorm, and immediately downwind, visibility can be reduced to a few metres.

d. **Fog, Mist and Haze**.

i. Fog is defined as a visibility of less than 1000 m with a relative humidity near to 100%.

ii. Mist is defined as the visibility of between 1000 m and 5000 m providing that the relative humidity is 95% or more. The upper limit of visibility for mist may vary.

iii. Haze or smoke is reported when the visibility is below 5000 m and when the humidity is not high enough for the obscuration to be classified as mist or fog. Haze or smoke is cause by solid particles suspended in the atmosphere. In haze the humidity will be less that 95% and will often be in the order of 50% to 60%.

Fog

10. There are five main types of fog, which are, radiation fog, hill fog, advection fog, frontal fog and arctic smoke or steam fog.

Radiation Fog

11. Radiation fog forms inland at night when air in contact by the ground is cooled by conduction. If

the air is cooled to below its dew point [1], the water vapour in the air will condense into water droplets and fog will form. There are three conditions required for radiation fog to form:

a. **Clear Skies**. There must be clear skies as clouds trap warm air near the Earth's surface.

b. **High Relative Humidity**. There must be sufficient moisture so that the air will become saturated when cooled.

c. **Light Wind**. A light wind of around 2 to 8 kt is required. If there is no wind there will be no condensation nuclei suspended in the air for the water vapour to condense onto. With no wind dew will form on the ground instead. With a wind of above about 8 kt, the cool surface air will mix with the higher warmer air and radiation fog will not form.

12. The above conditions are usually present in anticyclonic conditions, especially in autumn and winter, when long nights allow for a significant cooling period, and around sunrise and sunset. Radiation fog is most prevalent just after dawn when the surface temperature is at its lowest. Once the Sun rises and starts to heat the ground the fog will thin and disperse through evaporation. Also, as the ground heats, convection will become established, mixing ground level air with warmer upper air to aid the dispersal process. If the wind increases, thus causing further mixing of the air layers, the radiation fog may lift to form low stratus cloud.

Valley Fog (Radiation Fog)

13. Valley fog is a form of radiation fog, which as the name suggests, forms in valleys. It is the result of heavier cold air settling into a valley with warmer air passing over the valley sides above. It is radiation fog confined by the local topography and can last for several days in calm conditions.

Hill Fog

14. Hill fog forms when moist stable air is forced upwards over high ground. The air will condense to form low cloud which covers the high ground which will pose a serious hazard to aviators.

Advection Fog (Sea Fog)

15. Advection fog forms when warm moist air moves over a cold surface which cools the air to below its dew point. It is mainly associated with cool sea areas, particularly in spring and summer, and may affect coastal areas too, hence it being also known as sea fog. The fog may also form in winter over land when the ground is frozen or snow covered. For the fog to form the wind speed must be around 15 kt and the air must have a relatively high humidity.

16. Advection fog is usually dispersed when drier air moves into the area to replace the fog or with a wind increase that lifts it to become low stratus.

Frontal Fog

17. As the name suggests, frontal fog is associated with a frontal system. It is formed when precipitation from warm falling air into colder air below causes the colder air to become saturated, forming fog. Frontal fog can extend up to 200 nm ahead of a front and will clear as the front passes.

---

[1] The dew point is the temperature to which the air must be cooled at constant pressure in order for it become saturated, i.e., the relative humidity becomes 100%.

Arctic Smoke or Steam Fog

18. Arctic Smoke or Steam Fog can be referred to by many names, but the process is the same for all. It is formed by evaporation of relatively warm water into cool air and results in a shallow layer of fog. Arctic Smoke is rare in the UK and is more common in high latitudes when very stable cold air moves over relatively warm water in sea inlets, over newly formed holes in pack ice, over lakes and streams on calm clear nights and over damp ground heated by bright sunlight in cool conditions. Although rare in the UK it can be seen in the winter months, mostly in Scotland.

10-7-PRESSURE SYSTEMS, FRONTS AND AIR MASSES

Pressure Systems - Introduction

1. Pressure systems play an important role in determining the Earth's weather. In low pressure areas, air is rising while in high pressure areas air is descending. It is the vertical movement of the air that determines the distinction between high- and low-pressure areas not the numerical value of the prevailing atmospheric pressure. There are two main types of pressure system; low pressure systems (depressions or cyclones) and high-pressure systems (anticyclones). Subsidiary pressure systems may be classified as cols, ridges or troughs.

Low Pressure Systems

2. Low pressure systems may be small or large low-pressure areas with significant differences between them.

Small-Scale Low-Pressure Systems

3. Small scale lows are created when there is unequal heating of the Earth's surface and can be found almost anywhere. Air at the surface is heated by conduction and rises until it reaches a height where it has cooled to the same temperature of the surrounding air. During this process the total weight of the column of air above the warm surface reduces as the air spreads out causing the atmospheric pressure to fall at the surface. As the warm air rises, air surrounding the low-pressure area will be drawn inwards. This air will be slowed due to friction with the Earth's surface but the air at the top of the column will not be affected and will diverge more quickly. As a result, the incoming air will not be able to return the pressure to equilibrium and the low pressure will be maintained or continue to fall over time.

4. Air pressure decreases with increasing altitude and so as the air in the centre of the depression rises its volume will expand. The expansion will cause the air to cool due to adiabatic cooling[1] Condensation takes place when the air temperature has fallen to its dew point [2] and clouds form. Clouds which form in small scale lows develop vertically as cumuliform or cumulus clouds. A great deal of energy can be associated with small scale lows resulting in turbulence, precipitation, icing and poor visibility.

Large-Scale Low-Pressure Systems (Depressions)

5. Polar frontal depressions are large-scale low-pressure areas and are formed differently to small scale lows. The polar front[3] typically lies between the 40° and 60° north and south latitudes, depending upon the season, which is the area where polar frontal depressions form. The polar front boundary will not be a straight line and at points along it, the warm tropical air will intrude into the cold polar air (Fig 1).

---

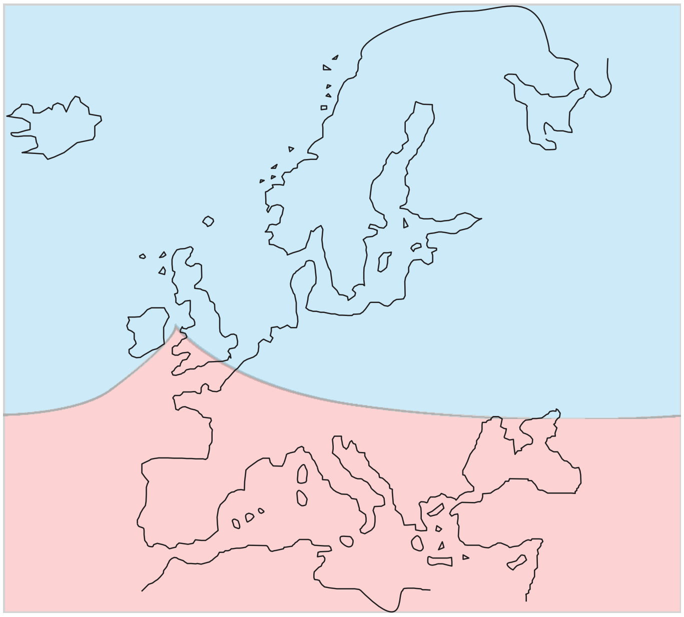
[1] An adiabatic process changes the temperature of a gas within a defined system without any transfer of heat energy across the boundaries of the system.

[2] The dew point is the temperature to which air must be cooled, at a constant barometric pressure, for the water vapour contained in the air to condense.

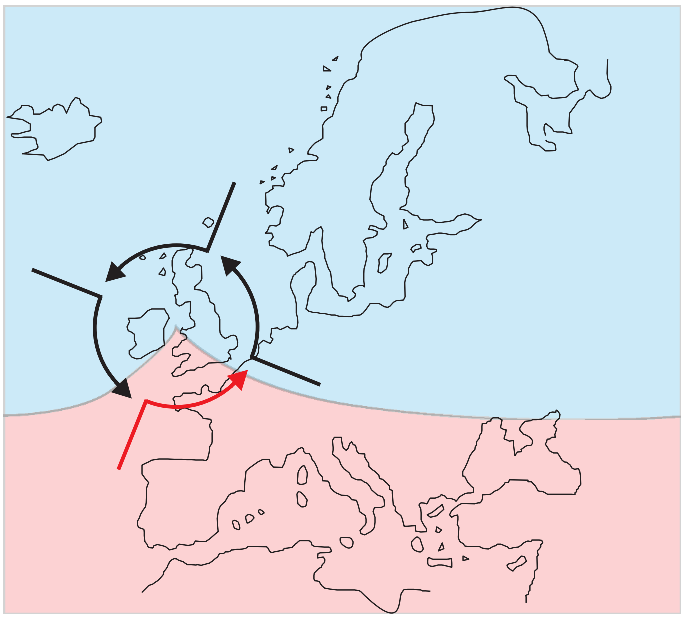
[3] The polar front is the boundary where warm tropical air meets cold polar air.

6. The intruding warmer air replaces the cold air and as it is lighter (less dense) the weight of the overlying air is reduced leading to a reduction of surface air pressure. As the surface pressure falls, more air is drawn into the low-pressure area and as this process is happening on a large scale, the flow of the air is deflected by the Earth's rotation (Fig 2). In the northern hemisphere the air mass is deflected to the right causing an anti-clockwise flow around the depression. In the southern hemisphere the opposite is true.

10CD-7 Fig 1 – Formation of a Polar Front Depression



10CD-7 Fig 2 – Air Flow around a Northern Hemisphere Polar Front Depression

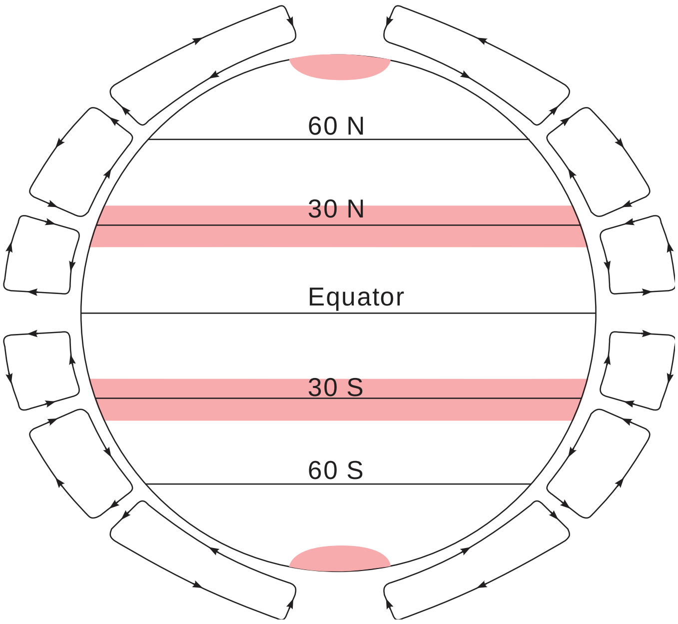


7. There are two types of interaction between cold and warm air masses which are the cold front and the warm front.

High Pressure Systems

8. An area of high pressure (anticyclone) is formed when the weight of a column of air is increased causing subsidence [4] of the air mass. A common cause of the increase in weight is the convergence of air in the upper atmosphere leading to a band of high pressure over the tropics and at the poles (Fig 3). The upper atmosphere convergence increases the mass of air at that location over the Earth's surface and so the surface air pressure will rise. At the surface there will be a tendency for the air to flow outwards, but this outward flow will be slowed by friction with the Earth's surface. The convergence at high level will be unaffected by this hence it will inflow faster than the outflow at the surface thus sustaining the high-pressure area.

10CD-7 Fig 3 – Atmospheric Air Flow



9. As the air descends it is compressed by the increase in pressure in the lower atmosphere. This compression will cause an increase in temperature by adiabatic warming [5] which will inhibit condensation and the forming of clouds. In general, there is little significant cloud within high pressure areas but contaminants within the atmosphere, such as dust and smoke, are trapped in the lower areas and will reduce visibility. Haze is a common feature especially in summer while in winter the air near the Earth's surface cools significantly without cloud cover to give fog as a prevalent feature and surface temperature inversions.

10. **Anti-cyclonic Winds**. Air descends at the centre of an anti-cyclone and then diverges outwards. As anti-cyclones are large scale events, the diverging air is deflected by the rotation of the Earth. The deflection is to the right in the northern hemisphere giving a clockwise flow while the flow is anticlockwise in the southern hemisphere. Unlike a low-pressure area, the anti-cyclonic isobar spacing is a lot wider giving light winds.

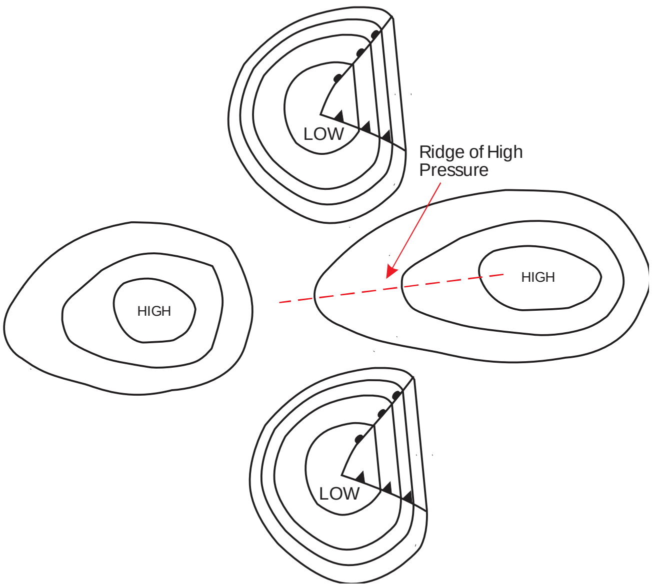
[4] Subsidence is the downward movement of air in the atmosphere. It is most commonly applied to the slow sinking of air within an anticyclone but can apply to any downward motion of air.

[5] An adiabatic process changes the temperature of a gas within a defined system without any transfer of heat energy across the boundaries of the system.

Ridge of High Pressure (Isobaric Ridge)

11. The isobars around the high-pressure area at the bottom of Fig 4 extend to form a protrusion from the centre of the anti-cyclone creating a ridge of high pressure. A ridge of high pressure is usually interposed between two depressions and is of short duration. The weather characteristics are the same as for the main high-pressure area but the subsidence is not as pronounced which allows for greater convection producing cumulus cloud and improved visibility. Ridges often result in excellent flying weather.

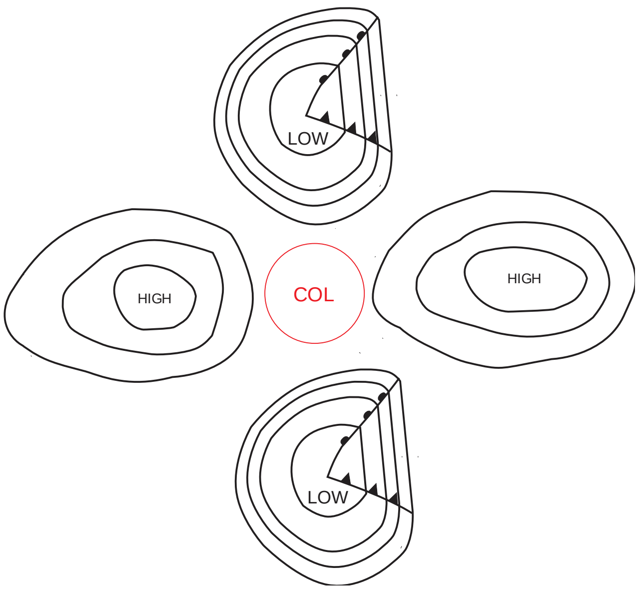
10CD-7 Fig 4 – A Ridge of High Pressure



Cols

12. A col is an area in between two high and two low pressure systems which is not influenced by the high- or low-pressure areas. The isobars within the col are widely spaced resulting in very light and variable winds. The weather within a col is season dependent. Generally over land areas is summer typical col weather will be thundery whilst in winter fog is likely to be prevalent.

10CD-7 Fig 5 – A Col



Summary of Pressure Systems

13. Each type of pressure system has its own weather characteristics which should allow the weather in each area to be predicted.

14. **Low Pressure Areas**. Low pressure weather is generally dominated by cloud and precipitation.

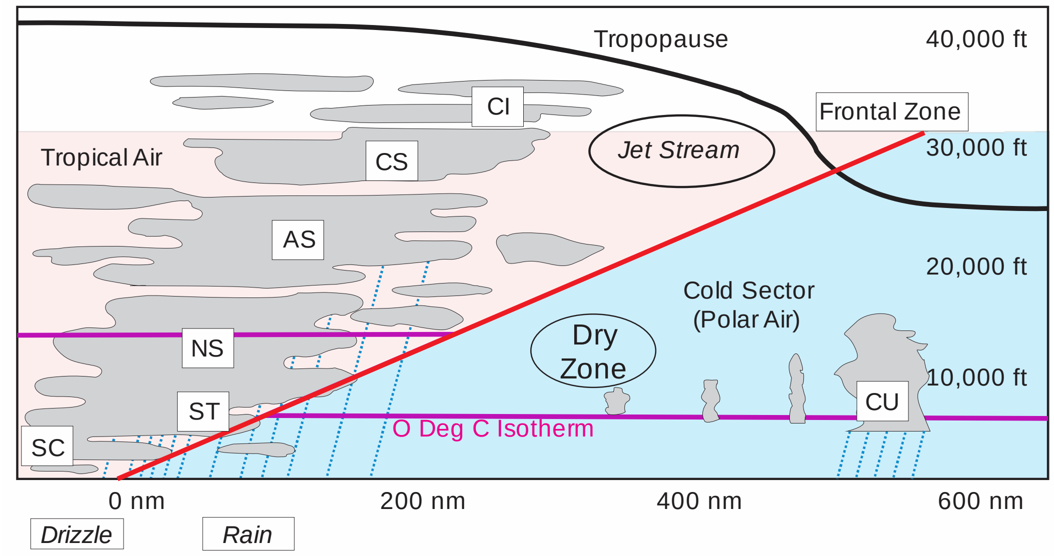
15. **High Pressure Areas**. High pressure weather generally has clear skies with poor visibility in fog or haze. Ridges of high pressure generally produce good flying weather.

Fronts

16. As an air mass moves it will eventually come into contact with another air mass with different characteristics. The boundary between two types of air masses is known as a front. A front of any type will change the weather in a geographical area. Any change will never be absolutely abrupt, and the weather will change gradually. While a front is represented on a synoptic chart by a discrete line (see Fig 15), it is more realistic to picture it as a 'frontal zone' where one air mass is replaced by another. No two fronts are the same but generalized weather conditions can be associated with specific types of front.

Warm Front

10CD-7 Fig 6 – Cross Section Through a Warm Front



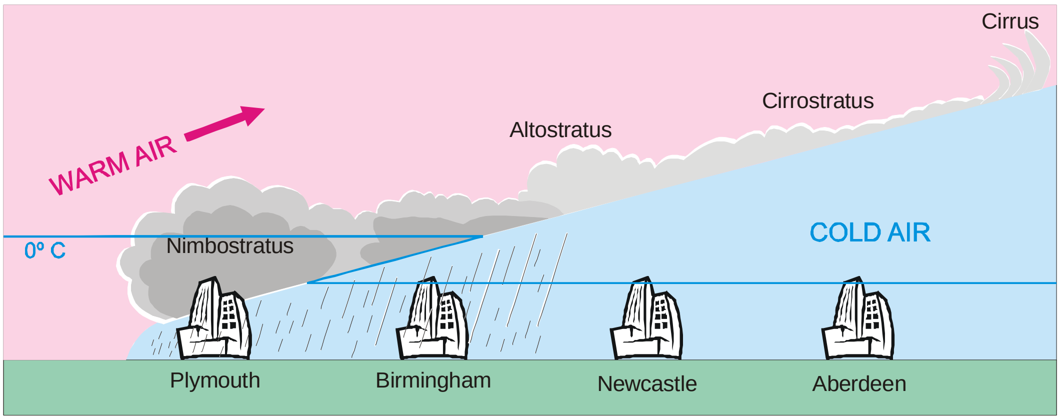
17. **General Conditions of a Warm Front**. A warm front occurs where a warm mass of air advances and replaces a body of colder air. Warm fronts move slowly, typically 10 to 25 mph. The slope of the advancing front moves up and over the top of the cooler air and gradually pushes it out of the area. Warm fronts contain warm air that often has very high humidity. As the warm air is lifted, the temperature drops, and condensation occurs.

18. **Conditions of an Approaching Warm Front**. As a warm front approaches, cirriform or stratiform clouds, along with fog, can form along the frontal boundary. In summer, Cbs are likely to develop. Light to moderate precipitation is probable, usually in the form of rain, sleet, snow, or drizzle, with poor visibility. The outside temperature is cool or cold, with an increasing dew point. The barometric pressure falls until the front passes completely.

19. **Conditions in a Passing Warm Front**. During the passage of a warm front, stratiform clouds are visible and drizzle may be falling. The visibility is generally poor but improves with variable winds. The temperature rises steadily. For the most part, the dew point remains steady and the barometric pressure stabilizes. An aircraft flying through a front which is moving in the opposite direction will experience the wind veering. Conversely, if the aircraft is moving in the same direction as the front, the wind will back.

20. **Conditions When the Warm Front has Passed**. After the passage of a warm front, stratocumulus clouds predominate, and rain showers are possible. The visibility eventually improves, but hazy conditions may exist for a short period after passage. The temperature rises, and the dew point rises and then levels off. There is generally a slight rise in barometric pressure, followed by a decrease.

10CD-7 Fig 7 - Structure of a Warm Front



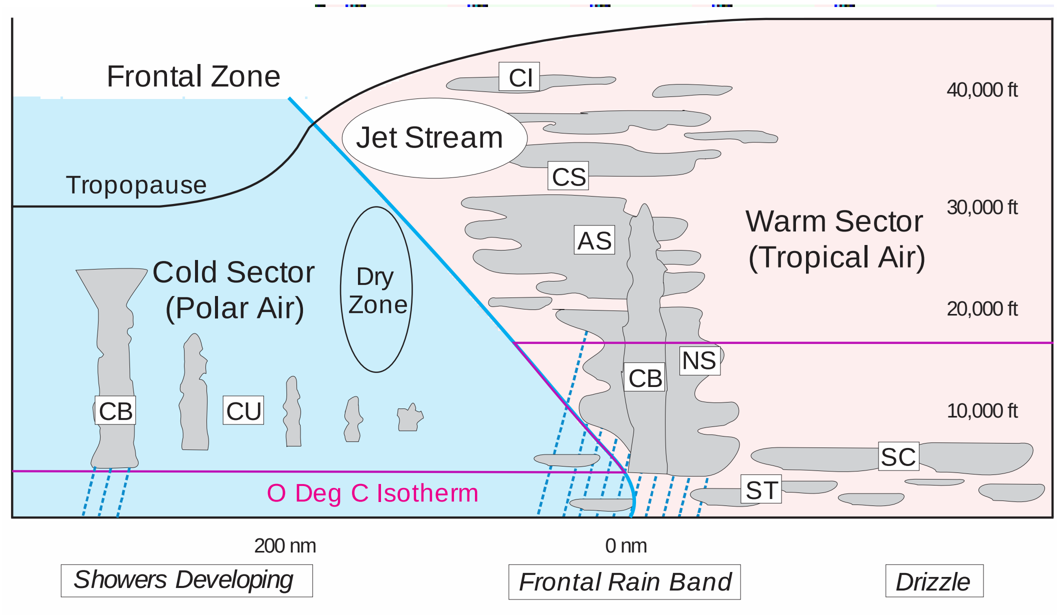
Flight Towards an Approaching Warm Front

21. Fig 7 depicts a warm front moving north east through the UK. Imagine an aircraft flying from Aberdeen to Plymouth.

22. Departing from Aberdeen, the weather is good with a scattered layer of Ci and SC clouds. Progressing towards Newcastle the clouds deepen and become increasingly stratiform in appearance with a lowering ceiling. The visibility decreases in haze with a falling barometric pressure. Approaching Birmingham, the weather deteriorates to low level broken clouds with reducing visibility and rain. With a similar air temperature and dew point fog is likely. At Plymouth, the sky is overcast with low clouds, drizzle and poor visibility.

Cold Front

10CD-7 Fig 8 – Cross section Through a Cold Front



23. **General Conditions of a Cold Front**. A cold front occurs when a mass of cold, dense, and stable air advances and replaces a body of warmer air. Cold fronts move more rapidly than warm fronts, progressing at a rate of 25 to 30 mph. However, extreme cold fronts have been recorded moving at speeds of up to 60 mph. A typical cold front moves in a manner opposite that of a warm front. The air is denser and so it stays close to the ground and slides under the warmer air forcing it to rise. The rapidly ascending air causes the temperature to decrease suddenly, forcing the creation of clouds. The type of clouds that form depends on the stability of the warmer air mass. A cold front in the Northern Hemisphere is normally oriented in a northeast to southwest manner and can be several hundred miles long.

24. **Conditions of an Approaching Cold Front**. Prior to the passage of a typical cold front, cirriform or towering cumulus clouds are present, and cumulonimbus clouds are possible. Rain showers and haze are possible due to the rapid development of clouds. A high dew point and falling barometric pressure are indicative of imminent cold front passage.

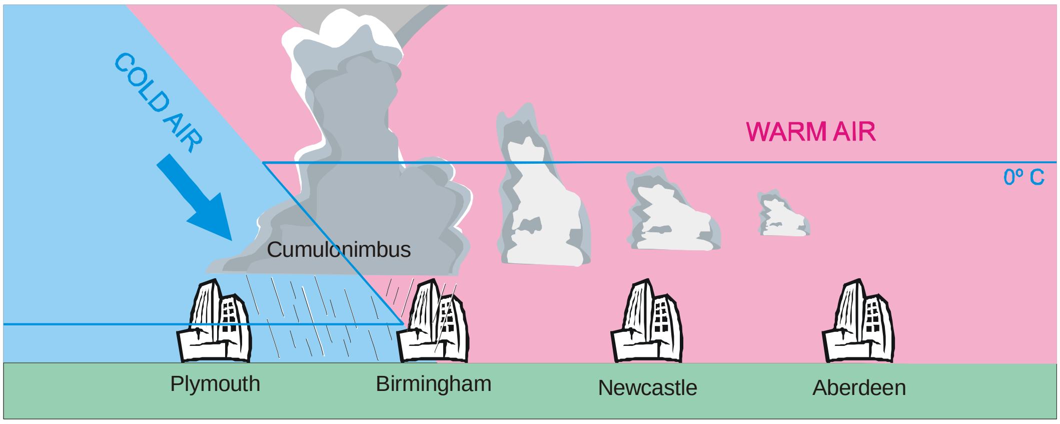
25. **Conditions in a Passing Cold Front**. As the cold front passes, towering cumulus or cumulonimbus clouds are present. Depending on the intensity of the cold front, heavy rain showers form and might be accompanied by lightning, thunder, and/or hail. During cold front passage, the visibility is poor, with winds variable and gusty, and the temperature and dew point drop rapidly. A quickly falling barometric pressure steadies during frontal passage and then begins a gradual increase. An aircraft flying through a front which is moving in the opposite direction will experience the wind veering. Conversely, if the aircraft is moving in the same direction as the front, the wind will back.

26. **Conditions When the Cold Front has Passed**. After the frontal passage, the towering cumulus and cumulonimbus clouds begin to dissipate to cumulus clouds with a corresponding decrease in precipitation. Good visibility eventually prevails, temperatures remain cooler and the barometric pressure continues to rise.

27. **Fast-Moving Cold Front**. Fast-moving cold fronts are pushed by intense pressure systems far behind the actual front. Where the front moves over land, the friction between the ground and the cold

front retards its movement and creates a steeper frontal surface. This results in a very narrow band of weather, concentrated along the leading edge of the front. If the warm air being overtaken by the cold front is relatively stable, overcast skies and rain may occur for some distance ahead of the front. If the warm air is unstable, scattered thunderstorms and rain showers may form. A continuous line of thunderstorms, or squall line, may form along or ahead of the front. Squall lines present a serious hazard to pilots as squall type thunderstorms are intense and move quickly. Behind a fast-moving cold front, the skies usually clear rapidly and the front leaves behind gusty, turbulent winds and colder temperatures.

10CD-7 Fig 9 - Structure of a Cold Front



Flight Towards an Approaching Cold Front

28. Fig 9 depicts a cold front moving north east through the UK. Imagine an aircraft flying from Aberdeen to Plymouth.

29. Departing from Aberdeen, the weather is good with reasonable visibility and scattered low level clouds. As the flight progresses towards Newcastle the clouds show signs of vertical development with a broken layer at low level. The visibility has improved, and the barometric pressure is falling. Approaching Birmingham, the weather has deteriorated to overcast clouds with a low ceiling, and poorer visibility in thunderstorms and heavy rain showers. At Plymouth, the weather improves with scattered low-level clouds and a much-improved visibility.

Wind Shifts

30. Wind around a high-pressure system rotates in a clockwise fashion, while low pressure winds rotate in an anticlockwise direction. When two pressure systems are adjacent, the winds are almost in direct opposition to each other at the point of contact. Fronts are the boundaries between two areas of pressure, and therefore, wind shifts are continually occurring within a front. Shifting wind direction is most pronounced in conjunction with cold fronts.

Comparison of Cold and Warm Fronts

31. Warm and cold fronts are very different in nature as are the hazards associated with each. They vary in speed, composition, weather phenomenon, and prediction.

Table 1 - A Comparison Between Cold and Warm Fronts

Cold Front	Warm Front
Move at 20 to 35 mph but can be much faster.	Slower than a cold front at 10 to 25 mph
Provide little warning and can move through an area and change the weather in a few hours.	Provides advance warning and can take days to pass through an area.
Steeper frontal slope.	Shallower frontal slope.
Violent weather activity, usually in the frontal zone close to the frontal boundary. In summer, squall lines can advance up to 200 miles ahead of a severe front.	Weather activity much less violent.
Sudden storms, gusty winds, turbulence, hail.	Low ceilings, poor visibility and rain.
Weather clears rapidly after passage with drier air and very good visibility.	Weather improves more slowly.
Aircraft moving in the same direction as the front, wind backs at the frontal boundary.	Aircraft moving in the same direction as the front, wind backs at the frontal boundary.
Aircraft moving in the opposite direction to the front, wind veers at the frontal boundary.	Aircraft moving in the opposite direction to the front, wind veers at the frontal boundary.

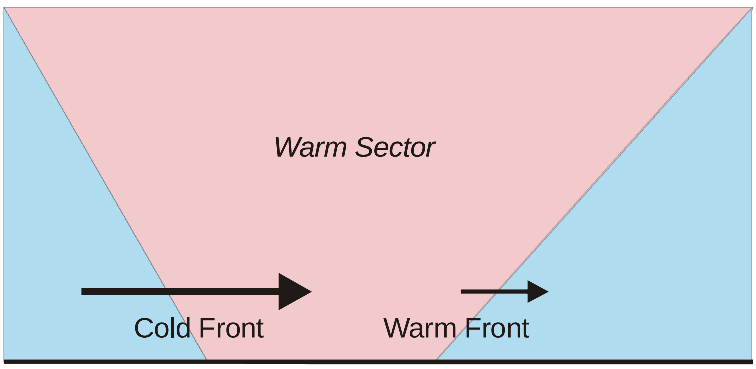
Stationary Front

32. A stationary front occurs when the forces of two air masses are relatively equal. The front that separates them remains stationary and influences the local weather for days. The weather associated with a stationary front is typically a mixture that can be found in both warm and cold fronts.

Occluded Front

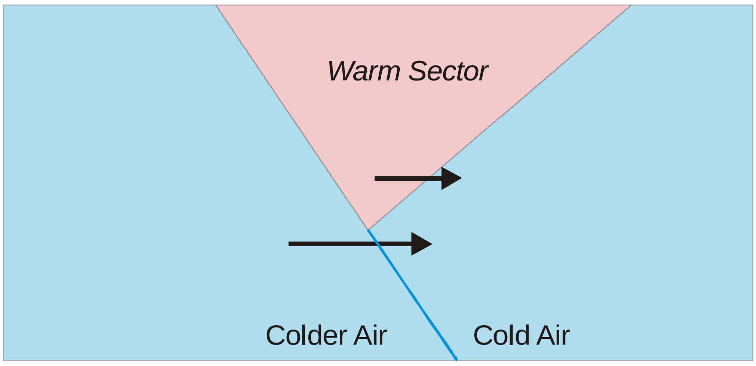
33. An occluded front occurs when a faster moving cold front catches up with a slower moving warm front. As the occluded front approaches, warm front weather prevails, but is immediately followed by cold front weather.

10CD-7 Fig 10 - The Development of an Occlusion



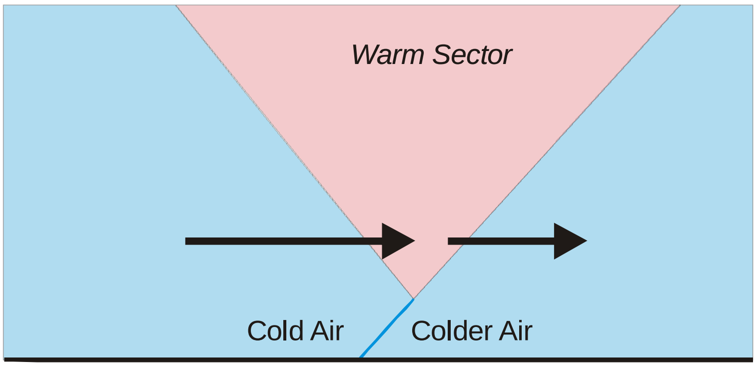
34. Two types of occluded fronts can occur, and the temperatures of the colliding frontal systems play a large part in defining the type of front and the resulting weather. A cold front occlusion occurs when a fast-moving cold front is colder than the air ahead of the slow moving warm front. When this occurs, the cold air replaces the cool air and forces the warm front aloft into the atmosphere. Typically, the cold front occlusion creates a mixture of weather found in both warm and cold fronts, providing the air is relatively stable.

10CD-7 Fig 11 - Cold Occlusion



35. A warm front occlusion occurs when the air ahead of the warm front is colder than the air of the cold front. Here the cold front rides up and over the warm front. If the air forced aloft by the warm front occlusion is unstable, the weather is more severe than the weather found in a cold front occlusion and embedded thunderstorms, rain, and fog are likely to occur.

10CD-7 Fig 12 - Warm Occlusion



36. Prior to the passage of the typical occluded front, cirriform and stratiform clouds prevail, light to heavy precipitation falls with poor visibility. The dew point is steady, and the barometric pressure falls. During the passage of the front, nimbostratus and cumulonimbus clouds predominate, and towering cumulus may also be possible. Light to heavy precipitation falls and visibility is poor, winds are variable, and the barometric pressure levels. After the passage of the front, nimbostratus and altostratus clouds are visible, precipitation reduces, and visibility improves.

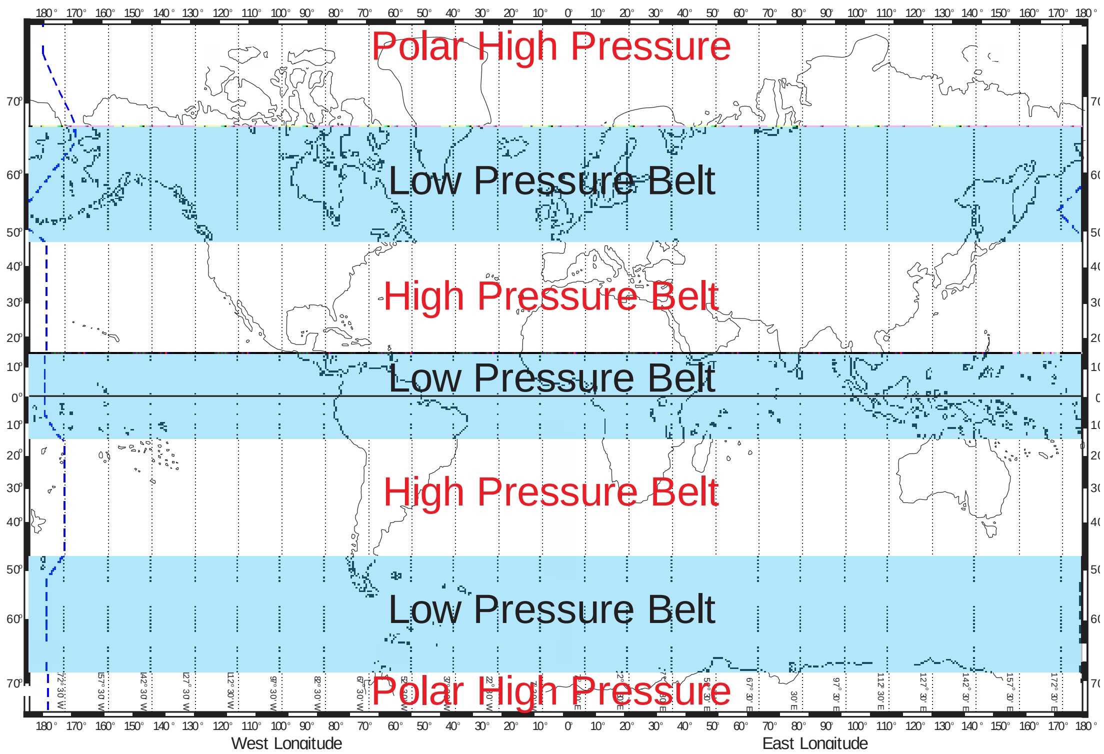
Air Masses

37. Air masses are bodies of air, covering a very large area where the temperature, lapse rate and humidity characteristics are almost uniform. They are classified according to the regions where they originate and the track that they follow over the Earth's surface.

Air Mass Source Regions

38. A source region is typically an area in which the air remains relatively stagnant for a period of days or longer and typically will be either the sub-tropical belts of high pressure, polar anticyclones or areas of high pressure over continental land masses (Fig 11). During this time of stagnation, the air mass takes on the temperature and moisture characteristics of the source region. Air masses are generally identified as polar (cold air) or tropical (warm air) and maritime (moist air) or continental (dry air). A combination of these terms is used to describe the source and track of the air mass and will define the weather characteristics resulting from it. As the air mass moves, the terrain/sea that it moves over will slowly modify the weather within it due to surface heating or cooling and evaporation or condensation.

10CD-7 Fig 13 – Air Mass Source Regions



39. An air mass will slowly take on the characteristics of its source region but will need to be virtually stagnant for a time to do this, for example it may take up to a week for an air mass to warm by 10° C right through to the troposphere. The initial properties of an air mass can be logically deduced from its origin, for example:

Tropical or sub-tropical land mass – Warm, dry and unstable - e.g. Sahara Desert
Tropical or sub-tropical oceans - Warm, moist and unstable
Arctic and Southern oceans – Cold, moist and stable
High latitude land mass - Cold, dry and stable - e.g. Siberia, Northern Canada, Antarctica

Tropical air is unstable because it is heated from below and polar air is stable because it is cooled from below.

40. As an air mass moves from its source region it will be modified by the surface over which it travels. An air mass with a maritime track will increase its moisture content, especially in its lower layers, through evaporation from the sea. An air mass with a long land track will remain dry. A cold air mass moving over a warmer surface will be warmed from below and become more unstable in its lower layers. Conversely, a warm air mass moving over a colder surface will be cooled from below and become more stable in its lower layers.

Air Masses Affecting the UK

41. Fig 12 shows the general air masses affecting the UK and Table 2 gives some general conditions that may be applied to them. The general properties of an air mass may be deduced from its source region and track, but it must be stressed that in practice no two air masses are exactly alike. The character of an air mass undergoes a process of continuous transition due to a combination of many variables which can be surmised from knowledge of the processes that affect the weather.

10CD-7 Fig 14 – Air Masses Affecting the UK

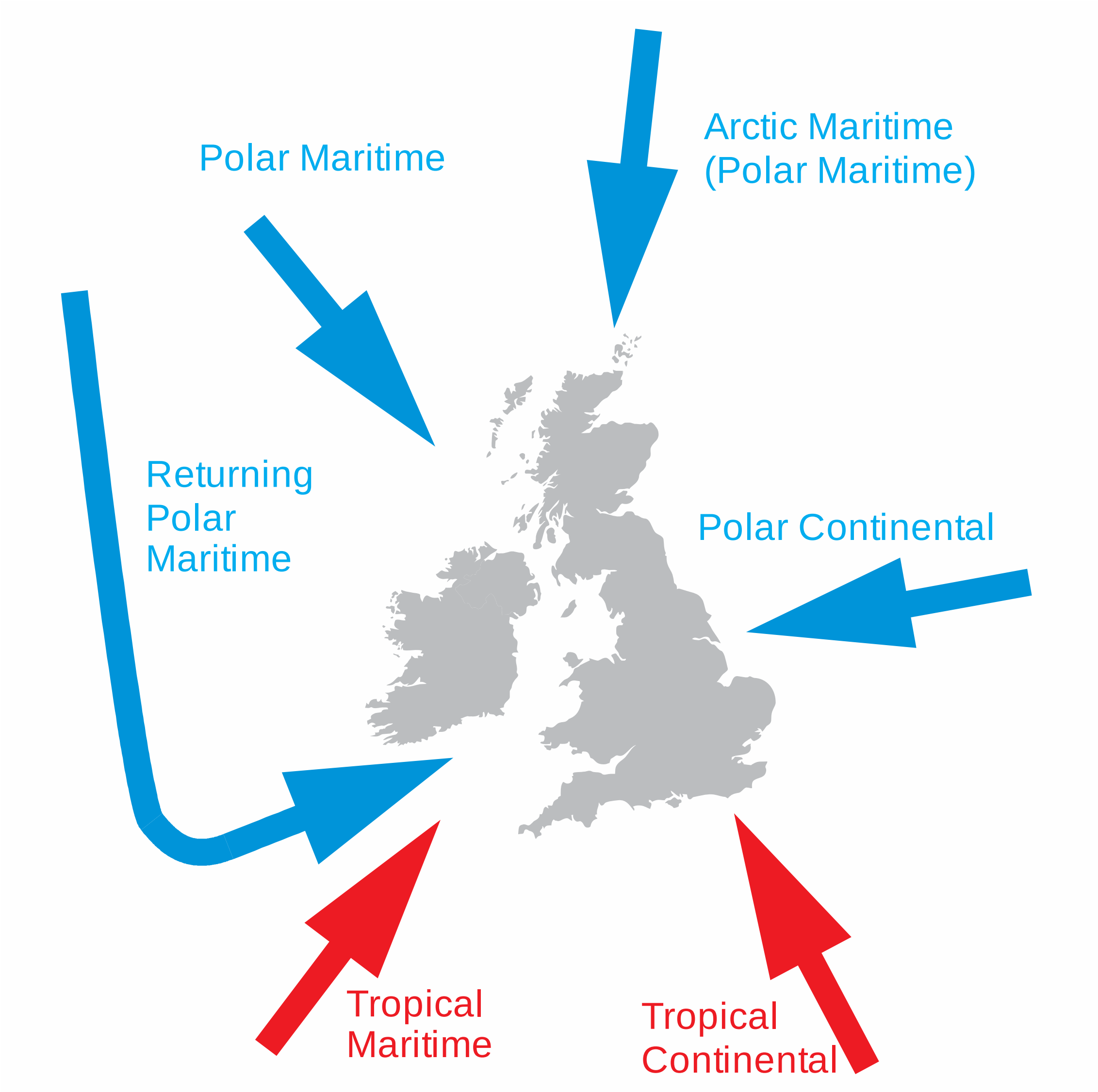
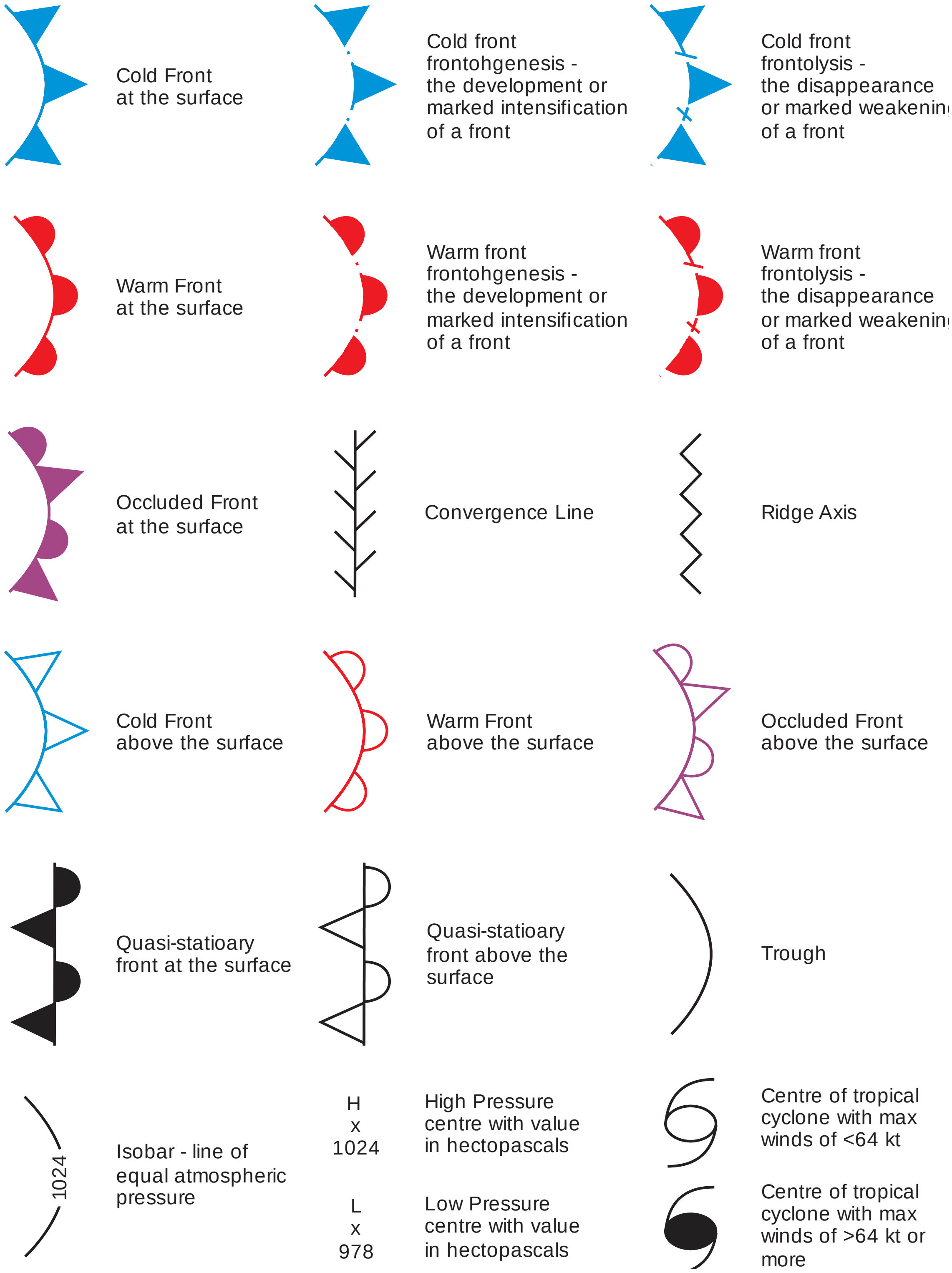


Table 2 - Air Mass Effects on the UK

Air Mass	Source	Start conditions	Track
Tropical Maritime	Sub-tropical anticyclones	High temperature High relative humidity High Dew Point	Sea
Modified conditions	Cooled from below. With light winds becomes more stable and possible inversion. Stronger winds, inversion is lifted. High relative humidity is maintained or increased to give low stratus, fog, drizzle and orographic cloud. Visibility usually moderate to poor.		
Tropical Continental	North Africa Southern Europe	Warm Air with low humidity	Land
Modified conditions	Lower layers cool, humidity remains low (except where there is some sea track). With a long sea track, process is changed to Maritime. Dryness and cooling of the air prevents cloud formation giving high temperatures. Visibility reduced due to haze.		
Polar Maritime	Arctic	Low temperature, low Dew Point, high relative humidity	Sea
Modified conditions	Heated from below but temperature remains lower than sea surface. Thermal instability gives conditions for convective cloud development and can lead to large Cu and Cb. Showers, thunderstorms, strong gusts or squalls. Can stabilize to give fair-weather Cu or Sc. Visibility good except in showers. On reaching land, air dries and cloud formation more difficult. In winter, air relatively mild but affected by surface cooling, becoming stabilized in lower layers but can be cold enough to produce hail showers and snow. Shower intensity decreases, clouds tend to be layer types and fog readily forms under a clear sky. A **Returning Polar Maritime** air mass, which moves south and then turns northwards back towards the UK will give similar conditions. An **Arctic Maritime** air mass has similar characteristics to a Polar maritime air mass but with a shorter sea track, the air is colder and less moist.		
Polar Continental	Northern continental land mass	Cold air, low Dew Point	Land
Modified conditions	Air absorbs heat and possibly moisture after travelling over warmer surface. In winter, over land, low humidity gives clear skies. If sea track develops, evaporation and heating produce cumuliform cloud and wintry showers and the air mass may transform to Polar Maritime. In the UK, with track over the North Sea, showers develop on east coast but die out further west. In summer, air starts dry and cloudless but moves over warmer land. Air becomes warm and if a track develops over a cooler sea, fog and low stratiform cloud may form.		

10CD-7 Fig 15 – Synoptic Chart Symbols



10-8-CLOUDS AND THUNDERSTORMS

Introduction

1. In meteorology, a cloud is an aerosol comprising a visible mass of minute liquid droplets or frozen crystals, both of which are made of water or various chemicals. The droplets or particles are suspended in the atmosphere and clouds are formed by the saturation of air. The air may be cooled to its dew point [1] by a variety of atmospheric processes or it may gain moisture (usually in the form of water vapour) from an adjacent source.

Cloud Formation

2. For clouds to form there must be adequate water vapour and condensation nuclei, which are miniscule particles of matter such as dust, salt, and smoke. There must also be a method by which the air can be cooled below its dew point. When air cools and reaches its saturation point invisible water vapour changes into a visible state. Through the processes of sublimation and condensation, moisture condenses or sublimates onto condensation nuclei. The nuclei are important because they provide a means for the moisture to change from one state to another.

Trigger Actions

3. The cooling of air is usually achieved by lifting and there are four trigger actions that facilitate this lifting process.

Turbulence

a. Turbulence formation is caused by mechanical lifting which forms layers of St and Sc clouds.

Convection

b. Convection formation is caused by heating from below which forms Cu and Cb clouds.

Orographic

c. Orographic formation is caused where air rises over hills and forms St, Cu, Cb and lenticular Ac clouds.

Mass Ascent

d. Mass ascent formation is associated with depressions and fronts forming Cs, Ci, As, Ns and Cb clouds.

---

[1] The dew point is the temperature to which the air must be cooled at constant pressure in order for it become saturated, i.e., the relative humidity becomes 100%.

Cloud Types

4. Cloud type is determined by its height, shape, and behaviour.

High Clouds

a. High clouds form above 16,500 feet AGL and usually form only in stable air. Typical high-level clouds are cirrus, cirrostratus, and cirrocumulus. They are made up of ice crystals and pose no real threat of turbulence or aircraft icing.

Middle Clouds

b. Middle clouds form around 6,500 feet above ground level (AGL) and extend up to around 23,000 feet AGL. They are composed of water, ice crystals, and super cooled water droplets. Typical middle-level clouds include altostratus and altocumulus. These types of clouds may also be encountered at higher altitudes. Altostratus clouds can produce turbulence and may contain moderate icing. Altocumulus clouds, which usually form when altostratus clouds are breaking apart, also may produce light turbulence and icing.

Low Clouds

c. Low clouds are those that form near the Earth's surface and extend up to 6,500 feet AGL. They are made primarily of water droplets but can include super cooled water droplets that cause aircraft icing. Typical low clouds are stratus, stratocumulus, and nimbostratus. Fog may also classified as a type of low cloud formation. Clouds in this family create low ceilings, hamper visibility, and can change rapidly.

Heap Cloud

d. Although the high clouds discussed above do not significantly affect aircraft operations, cumulus clouds with extensive vertical development build into towering cumulus or cumulonimbus clouds. The bases of these clouds form in the low to middle cloud base region and their tops can extend into the high-altitude cloud levels. Towering cumulus clouds indicate areas of instability in the atmosphere, and the air around and inside them is turbulent. These types of clouds often develop into cumulonimbus clouds or thunderstorms. Cumulonimbus clouds contain large amounts of moisture and unstable air, and generally produce hazardous weather phenomena, such as lightning, hail, strong gusty winds, and wind shear. These extensive vertical clouds can be obscured by other cloud formations and are not always visible from the ground or while in flight. In this situation these clouds are said to be embedded, hence the term, embedded thunderstorms.

Table 1 – Cloud Types

Cloud	Nature	Height Band	Moisture Content
Cirrus (Ci) Cirrostratus (Cs) Cirrocumulus (Cc)	High Layer Cloud	45,000 ft to 16,500 ft	Relatively low (Ice crystals)
Altostratus (As) Altocumulus (Ac)	Medium Layer Cloud	23,000 ft to 6,500 ft	Moderate (ice and/or water)
Stratus (St) Stratocumulus (Sc) Nimbostratus (Ns)	Low Layer Cloud	6,500 ft to Surface (possibly to the Tropopause)	Relatively large concentration (Water and/or Ice)
Cumulus (Cu) Cumulonimbus (Cb)	Heap Cloud	Tropopause to Low-level	Often large concentration (Water drops, Ice crystals, hail in Cb)

Cloud Appearance

5. Clouds can be described by type according to the outward appearance and composition.

Cloud Type	Appearance
Cirrus	Ringlets, fibrous clouds, also high-level clouds
Alto	Meaning high, also middle level clouds
Stratus	Formed in layers
Cumulus	Heaped or piled clouds
Nimbus	Rain-bearing clouds
Castellanus	Common base with separate vertical development, castle-like
Lenticularus	Lens shaped, formed over mountains in strong winds
Fracto	Ragged or broken

Cloud Amount and Ceiling

6. Cloud amounts are reported as a fraction in eights, termed Oktas where;

FEW (few)	1 to 2 oktas
SCT (scattered)	3 to 4 oktas
BKN (broken)	5 to 7 oktas
OVC (overcast)	8 oktas

7. For aviation purposes, the ceiling is the lowest layer of clouds reported as being broken or overcast, or the vertical visibility into an obscuration such as fog or haze.

Thunderstorms (Cumulonimbus Cloud)

8. There are three conditions necessary for a thunderstorm to develop.

a. **Instability**. Instability must be present so that once the air begins to rise it will continue to rise (e.g. a steep lapse rate with warm air in lower layers of the atmosphere and cold air in the upper layers).

b. **High Humidity**. There must be abundant humidity over a considerable depth in the atmosphere such that unsaturated air cools through lifting sufficiently to cause condensation. Latent heat is released which increases instability.

c. **Trigger Action**. There must be a trigger action or lifting mechanism to start the air rising. The trigger may be a cold front forcing air aloft, orographic ascent and convective heating from the surface,

9. A cumulonimbus cloud is perhaps the most dangerous cloud type with respect to aircraft. It can appear individually or in groups and is known as either an air mass or orographic thunderstorm. Heating of the air near the Earth's surface creates an air mass thunderstorm; the upslope motion of air in mountainous regions causes orographic thunderstorms. Cumulonimbus clouds that form in a continuous line are non-frontal bands of thunderstorms or squall lines.

10. Since rising air currents cause cumulonimbus clouds, they are extremely turbulent and pose a significant hazard to flight safety. An aircraft entering a thunderstorm can experience updraughts and downdraughts exceeding 3,000 fpm. Thunderstorms can also produce large hailstones, lightning, and significant precipitation, all of which are potentially hazardous to aircraft.

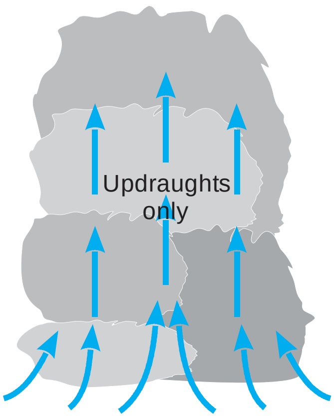
The Stages of Thunderstorm Development

11. A thunderstorm develops through three distinct stages.

Cumulus or Building Stage

a. A cumulonimbus cloud develops from one or more cumulus clouds which starts to grow larger with a base up to 5 nm (10 km) across and a lifting action of the air begins. Where there is sufficient moisture and instability, the cloud continues to increase in vertical height and continuous, strong updrafts prohibit moisture from falling. Updrafts are generally 16 to 32 ft/sec but can be as high as 100 ft/sec. This stage lasts for 15 to 20 min.

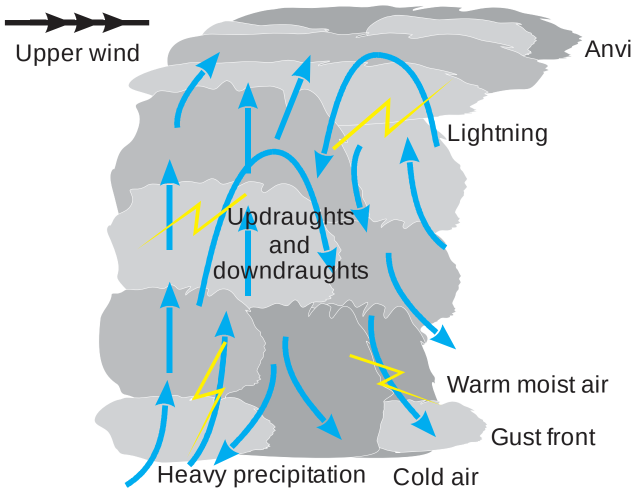
10CD-8 Fig 1 – Thunderstorm Building Stage



Mature Stage

b. Within approximately 15 minutes, the thunderstorm reaches the mature stage, which is the most violent period of the thunderstorm's life cycle. At this point drops of rain and/or ice are too heavy for the cloud to support and begin falling creating a downward motion of the air. Warm, rising air; cool precipitation-induced descending air; and violent turbulence all exist within and near the cloud. Below the cloud, evaporation of the rain results in further cooling and an acceleration of the downdraught. The down-rushing air forms a gust front spreading out from the storm increasing surface winds and reducing the temperature.

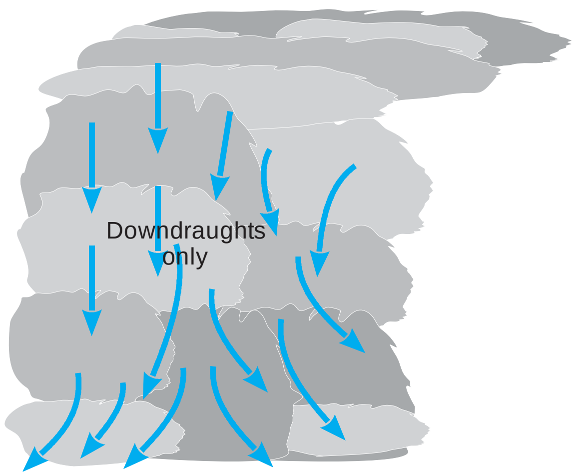
10CD-8 Fig 2 – Thunderstorm Mature Stage



Dissipating Stage

c. This stage begins when the storm has used the local supply of moisture. Once the vertical motion near the top of the cloud slows down, the top of the cloud spreads out and takes on a characteristic anvil-like shape. At this point, the storm enters the dissipating stage where the downdrafts spread out and replace the updrafts needed to sustain the storm.

10CD-8 Fig 3 – Thunderstorm Dissipating Stage



12. Severe thunderstorms can penetrate the tropopause and extend into the stratosphere reaching heights of 50,000 to 60,000 ft depending on latitude.

Air Mass Thunderstorms

13. Air mass thunderstorms are generally the result of surface heating. Some occur at random in unstable air, are short in duration and produce only moderate wind gusts and rainfall.

Steady-state Thunderstorms

14. Steady-state thunderstorms are associated with weather systems. Fronts, converging winds and troughs aloft force air upwards producing storms which often form into squall lines. In the mature stage, updrafts become stronger and last much longer than in air mass storms, hence the name steady state.

Hazards Associated with Thunderstorms

15. Thunderstorms present several different weather hazards with respect to aviation which occur individually or in combination. Many of the hazards associated with thunderstorms can be encountered outside of the cloud itself, therefore, light aircraft in particular should avoid the storm by at least 10 nm horizontally and 5,000 ft vertically.

Squall Line

16. A squall line is a narrow band of active thunderstorms which often develop on or ahead of a cold front in moist, unstable air, but may develop in unstable air far removed from any front. The line may be extensive making a detour around it difficult and the severe weather may make it too hazardous to penetrate. The squall often contains steady-state thunderstorms and presents the single most intense weather hazard to aircraft. The Squall Line usually forms rapidly, generally reaching maximum intensity during the late afternoon and the first few hours of darkness.

Turbulence

17. Potentially hazardous turbulence is present in all thunderstorms and a severe thunderstorm can severely damage an aircraft, even to destruction. The strongest turbulence within the cloud is associated with the shear forces between updraft and downdraft boundaries. Outside the cloud, shear turbulence may be encountered several thousand feet above and 20 miles laterally from a severe storm. A low-level turbulent area is the shear zone associated with the gust front. Often, a "roll cloud" on the leading edge of a storm marks the top of the eddies in this shear and it signifies an extremely turbulent zone. Gust fronts often move far ahead (up to 15 miles) of associated precipitation. The gust front causes a rapid and sometimes drastic change in surface wind ahead of an approaching storm. See also Volume 8, Chapter 17, Flying in Turbulence.

Microbursts

18. A significant hazard associated with thunderstorms is the microburst. These are created when strong cold downdraughts under the cloud spread out as they reach the surface. Microbursts can be extremely dangerous to aviation because the sink rate of the air can exceed the climb performance of an aircraft, thus forcing the aircraft into the ground. The presence of virga [2] is a good visual indication of microburst activity.

Icing

18. Strong updrafts in a thunderstorm are capable of supporting abundant liquid water with relatively large droplet sizes. When carried above the freezing level, the water becomes super cooled and when the temperature in the upward current cools to about –15 °C, much of the remaining water vapour sublimates as ice crystals. Above this level, at lower temperatures, the amount of super cooled water decreases. Super cooled water freezes on impact with an aircraft. Clear icing can occur at any altitude above the freezing level, but at high levels, icing from smaller droplets may be rime or mixed rime and clear ice. The abundance of large, super cooled water droplets within thunderstorms causes the rapid accretion of clear ice between 0 °C and –15 °C.

---

[2] Virga is precipitation that is falling but not reaching the ground. It looks like tendrils hanging beneath the cloud.

Hail

19. Hail perhaps presents as great a hazard to aircraft as the turbulence associated with a thunderstorm. Super cooled raindrops above the freezing level begin to freeze. Once a raindrop has frozen, forming a hailstone, other drops can freeze to it, significantly increasing its size. Large hailstones can be present within severe thunderstorms which have a large vertical extent coupled with strong updrafts. Eventually, the hailstones fall, possibly some distance from the storm core and may be encountered in clear air several miles from thunderstorm clouds. As hailstones fall through air whose temperature is above 0 °C, they begin to melt, and precipitation may reach the ground as either hail or rain. Rain at the surface does not mean the absence of hail aloft. Hail should be anticipated with any thunderstorm, especially beneath the anvil of a large cumulonimbus.

Ceiling and Visibility

20. Generally, visibility is close to zero within a thunderstorm cloud and may be reduced in precipitation and dust between the cloud base and the ground. The hazards to aviation presented by low visibility are multiplied when associated with the other thunderstorm hazards of turbulence, hail, and lightning.

Lightning

21. Lightning can damage the structure of an aircraft along with communication, electronic and navigation equipment. Composite material is especially vulnerable unless it is protected. Magnetic compasses in particular are vulnerable to lightning discharges which can also disrupt radio communications on low and medium frequencies. Although lightning intensity and frequency have no simple relationship to other storm parameters, severe storms, as a rule, have a high frequency of lightning. Lightning is most likely to be present within 5,000 ft of the freezing level within cloud that has a temperature of between -10° C and +20° C.

Effect on Altimeters

22. Pressure usually falls rapidly with the approach of a thunderstorm, rises sharply with the onset of the first gust and arrival of the cold downdraft and heavy rain showers, and then falls back to normal as the storm moves on. This cycle of pressure change may occur over 15 minutes and can lead to significant errors in indicated altitude; possibly up to 1,000 ft. If a pilot ‘chases’ the altimeter to maintain level flight, there is a danger of overstressing the airframe. It is more important to maintain the aircraft attitude rather than altitude within a storm.

Table 2 – Summary of Cloud Types

Type	Definition	Trigger	Composition
Cirrus (Ci)	Detached clouds-white, delicate filaments or white (or mostly white) patches or narrow bands. Fibrous (hair-like) appearance or silky sheen or both.	Mass Ascent	Ice crystals
Cirrostratus (Cs)	Transparent, whitish of fibrous or smooth appearance. Totally or partially covering sky generally with a halo phenomenon.	Mass Ascent	Ice crystals
Cirrocumulus (Cc)	Thin white layer, sheet or patch of cloud without shading. Small grains or ripples.	Turbulence	Ice crystals
Altostratus (As)	Greyish or bluish cloud sheet or layer. Striated fibrous or uniform appearance. Total or partial sky cover with Sun visible as though looking through clouded glass. No halo phenomena.	Mass Ascent	Supercooled Water droplets
Altocumulus (Ac)	White or grey - patch, sheet or layer cloud. Composed of laminae, rounded masses or rolls-sometimes partially fibrous or diffuse.	Turbulence Convection Orographic	Supercooled Water droplets
Nimbostratus (Ns)	Grey layer, often dark and rendered diffuse by continually falling rain/snow, most of which reaches the ground. Thick enough to obscure the Sun.	Mass Ascent	Water drops/droplets Supercooled Water droplets above freezing level
Stratocumulus (Sc)	Grey or whitish or both. Patch, sheet or layer cloud which almost always has dark parts.	Turbulence Orographic	Water droplets
Stratus (St)	Generally grey layer with uniform base. May give drizzle, ice prisms or snow grains. Outline of Sun clear when visible. Sometimes appears as ragged patches.	Convection with Turbulence Orographic	Water drops/droplets Supercooled Water droplets above freezing level
Cumulus (Cu)	Detached clouds, generally dense with sharp outlines. Vertically developed with rising mounds, domes or towers. Sunlit parts brilliant white. Base relatively dark and horizontal. Sometimes ragged.	Convection	Water drops/droplets Supercooled Water drops and droplets above freezing level
Cumulonimbus (Cb)	Heavy dense cloud with considerable vertical extent. Part of upper portion usually smooth, fibrous or striated and nearly always flattened. May form classic anvil shape.	Moderate to Strong Convection	Water drops and droplets below freezing level. Supercooled Water drops and droplets above freezing level. Ice crystals and pellets

Cloud Photographs

Cirrus (Ci) – (Return to text)

Cirrostratus (Cs) – (Return to text)

Cirrocumulus (Cc) – (Return to text)

Altostratus (As) – (Return to text)

Altocumulus (Ac) – (Return to text)

Nimbostratus (Ns) – (Return to text)

Stratocumulus (Sc) – (Return to text)

Stratus (St) – (Return to text)

Cumulus (Cu) – (Return to text)

Cumulonimbus (Cb) – (Return to text)

10-9-WEATHER REPORTS AND DOCUMENTATION

METAR, SPECI, TREND, TAF Codes

1. Although aerodrome weather codes may seem confusing, with practice they can be read quickly and easily. METARs should be consulted for departure and arrival airfields along with others on the planned route. Forecasts for aerodromes upwind of a destination can give a picture of the weather that is approaching the destination.

2. More detailed information concerning METAR, SPECI, TREND, TAF codes can be found in the Flight Information Handbook (FIH).

Meteorological Aerodrome Report (METAR)

3. A METAR contains coded information relating to a particular airfield at a stated time. Military stations issue METARs hourly on the hour. Civil airfields issue them hourly and half-hourly. Both are prepared ten minutes before issue. An AUTO METAR is a fully automated report, generated without human intervention and as a result is inherently less accurate than a METAR.

Special Aerodrome Report (SPECI)

4. A SPECI is issued following a significant change from the previous report. Civil stations do not issue SPECIs due to their half-hourly cycle.

TREND

5. A TREND is a forecast showing significant changes expected in the 2 hours following a METAR or SPECI.

Terminal Aerodrome Forecast (TAF)

6. A TAF is a forecast of conditions and significant changes expected during a specified period, normally 9 hours but may be for up to 30 hours. A 9-hour TAF is issued every 3 hours until the airfield closes.

The Format of METAR, SPECI and TREND, Codes

7. The coded elements of these messages are normally given in the order shown below. Some elements may be omitted when they are not needed or do not apply.

a	b	c	d	e	f	g	h	i	j	k	l	m
Code Name	Location	Date/time of report	AUTO	Surface Wind	Visibility	RVR	Weather	Cloud		Temp	QNH	Aerodrome Colour State

a. METAR, SPECI or TREND.

b. ICAO indicator of the reporting station.

c. Day of the month and time in UTC.

d. AUTO. An automated report. If any element cannot be reported it will be replaced by a number of slashes, e.g. four //// for a missing visibility group and nine ///////// for a missing cloud group.

e. The mean wind direction in degrees true to the nearest 10°, from which the wind is blowing and the mean wind speed in kt over the 10-minute period immediately preceding the observation. E.g. 35015KT = 350° T/15 kt; VRB05KT = variable at 5 kt; 00000 = Calm. If gusts exceed the mean wind speed by 10 kt or more in the 10 minutes preceding the report a letter G and two more figures are added to indicate the maximum wind speed, e.g. 23018G30KT = 230° T/18 kt with a maximum of 30 kt. Reports from non-UK stations may express the wind speed in meters per second (MPS) or kilometres per hour (KMH).

f. Visibility is expressed as a four-figure group, e.g. 0400 = 400 metres; 8000 = 8 km up to but not exceeding 10 km; 9999 = 10 km or more; 0000 = less than 50 metres. Greater detail on the visibility group is given in the FIH.

g. The Runway Visual Range (RVR) is included when the horizontal visibility or the RVR itself is less than 1500 metres. The group starts with an R then the runway in use followed by the threshold visibility in metres. E.g. R30/1100 = the RVR on runway 30 is 1100 metres. If the airfield has parallel runways, further letters can be included to differentiate them. E.g. R30L/1100 = the RVR on runway 30 Left is 1100 metres R30R/1200 = the RVR on runway 30 Right is 1200 metres.

h. The weather group indicates the weather present at, or near to, the airfield at the time of observation. A decode of the weather codes is given at Table 1.

i. Cloud is reported as FEW (1 to 2 oktas), scattered SCT (3 to 4 oktas), broken BKN (5 to 7 oktas), overcast OVC (8 oktas). The cloud amount is measured in oktas, meaning 'eighths of the sky', thus if half the sky is covered in cloud, the amount will be reported as 4 oktas (see Fig 1).

j. CAVOK. The visibility, cloud and weather groups are replaced with the term CAVOK (cloud and visibility OK) when the following conditions exist simultaneously:

a. Prevailing visibility is 10 km or more.
b. No cloud below 5000 ft or below the Minimum Sector Altitude (whichever is greater).
c. No CB or TCU at any height.
d. No significant weather in the vicinity of the airfield.

k. The air temperature and dew point are reported in whole degrees Celsius, e.g. 10/07 means air temperature 10° C and dew point 7° C. Temperatures below 0° C are indicated by M, e.g. M01/M07 means air temperature minus 1° C and dew point minus 7° C.

l. QNH is stated to the nearest whole hectopascal, rounded down and preceded by the letter Q.

m. UK military airfields will include an aerodrome colour state at the end of the message and a forecast colour state after a TREND. See Table 1.

n. Significant recent weather observed since the last routine observation will be reported using the weather codes preceded by RE.

o. Civil aerodromes may include wind shear (WS) along the take-off and landing paths in the lowest 1600 ft with reference to the runway. E.g. WS TKOF RWY20; or WS LDG RWY20; or WS ALL RWY.

10CD-9 Fig 1 – Example of Cloud Report

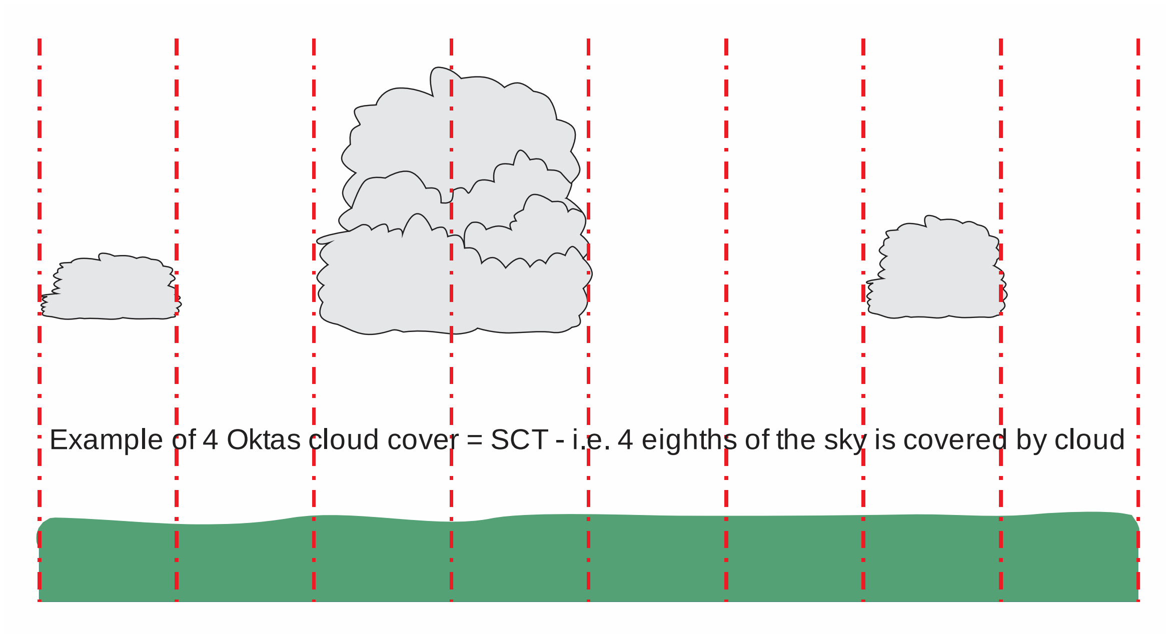


Table 2 – Aerodrome Colour Codes

Surface Visibility			Base of Lowest Cloud Layer 3/8 (SCT) or More	Colour Code
RN/RAF USAFE				
km	nm	st		
8.0	4.3	5.0	2500 ft agl	Blue (BLU)
5.0	2.7	3.0	1500 ft agl	White (WHT)
3.7	2.0	2.3	700 ft agl	Green (GRN)
2.5	1.4	1.6	500 ft agl	Yellow 1 (YLO1)
1.6	0.9	1.0	300 ft agl	Yellow 2 (YLO2)
0.8	0.4	0.5	200 ft agl	Amber (AMB)
Less than 0.8	0.4	0.5	Below 200 ft agl or sky obscured	Red (RED)
Aerodrome not usable for reasons other than cloud or visibility minima will use the term Black (BLACK). This will precede the actual colour code.				

8. **TREND**. Trend forecasts are indicated by **BECMG** (becoming) or **TEMPO** (temporary) which may be followed by a time group (hours and minutes UTC) preceded by one of the letter indicators **FM** (from), **TL** (until), **AT** (at). E.g. BECMG FM1030 TL1130. NOSIG replaces the TREND group when no significant changes are forecast to occur during the 2-hour forecast period. To indicate the end of significant weather the abbreviation **NSW** (No Significant Weather) is used. Only those elements for which a significant change is expected should be included in a TREND. In TRENDs for civil airfields, significant changes in prevailing visibility shall be forecast but at military airfields only significant changes in lowest visibility shall be forecast. In respect of cloud, all cloud groups below 2500 FT, including layers or masses not expected to change, are included.

9. METAR, SPECI, TREND, TAF codes in some NATO countries may have differences to the information specified above. Users should refer to the FIH for details.

Table 1 – Significant Weather Codes

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 the airfield)	**DZ** – Drizzle **RA** – Rain **SN** – Snow **IC** – Ice Crystals **PL** – Ice Pellets **GR** – Hail **GS** – Small Hail (< 5mm 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 **SQ** – Squall **FC** – Funnel Cloud(s) (Tornado or Water Spout) **SS** – Sandstorm / Duststorm

Format of TAFs in the UK

10. The format of a TAF in the UK differs from a METAR in the following respects:

a. **Date/time of report**. The date/hour of beginning and end of the period of validity of the forecast, e.g. 1906/1915 means 19th day of month from 0600 to1500 UTC. The validity start time of a TAF will be determined by the time the aerodrome opens (at remote airfields the start time will be determined by the availability of the first observation). A TAF cancellation message will be issued when the airfield closes e.g. TAF EGZZ 022330Z 0218/0303 CNL indicates the 1803 TAF was cancelled at 2330Z.

b. **Surface Wind**. Refers to the mean wind direction and speed throughout the relevant period in the TAF.

c. **Visibility**. The conditions shown in the first groups of a TAF are those which are expected to predominate at the beginning of the TAF period. The visibility shown following a **BECMG** or **TEMPO** where the phenomenon causing the change is of a transitory nature, notably showers, thunderstorms or fog patches, will be the forecasters best estimate of the horizontal visibility within the phenomenon. The visibilities subsequently observed will depend on the extent of the phenomenon, the proportion of the observer's view it takes up and the distance of the phenomenon from the observer. As these variations are very difficult for a forecaster to predict, the visibility within the phenomenon will be forecast to err on the side of safety.

d. **Weather**. If no weather is expected the weather group is omitted. If the weather ceases to be significant after a change group, the abbreviation 'NSW' (No Significant Weather) is used.

e. **Cloud**. Cloud forecasts in a TAF will be limited to clouds of operational significance i.e. cloud below 5000ft or the highest minimum sector altitude (whichever is greater) and **CB** and **TCU** at any height. If the abbreviation **CAVOK** is not appropriate and there are no clouds of operational significance and no **CB** or **TCU** expected, **NSC** (No Significant Cloud) will be used; e.g. a forecast of 4 oktas at 5000ft and 8 oktas at 12000ft will appear as NSC; 1 okta of TCU at 5000ft and 3 oktas at 25000ft will appear as FEW050TCU.

f. **Temperature**. Not forecast.

g. **QNH, Recent Weather, Wind Shear, Aerodrome Colour State, Runway State Group**. Not forecast.

h. **Turbulence**. A TAF may include a 6-figure turbulence group e.g. **520002**

5 - Turbulence group indicator.

2 - Degree of turbulence on the scale 0-9 as follows:

0 = Nil. 1 = Light. 2 = Moderate, clear air, occasional.
3 = Moderate, clear air, frequent. 4 = Moderate, in cloud, occasional.
5 = Moderate, in cloud, frequent. 6 = Severe, clear air, occasional.
7 = Severe, clear air, frequent. 8 = Severe, in cloud, occasional.
9 = Severe, in cloud, frequent.

000 -Base of the turbulence in hundreds of feet.

2 - Thickness of the turbulent layer in thousands of feet.

The example means: Moderate occasional clear air turbulence from the surface to 2000 feet.

i. **Change groups**:

i. **BECMG** is used to indicate that a change is expected to take place at either a regular or irregular rate during a specified part of the TAF. BECMG marks a permanent change in the forecast but which will establish itself gradually.

ii. **TEMPO** is used to indicate a period of temporary fluctuations to the forecast conditions during a specified part of the TAF. The fluctuations are expected to last less than one hour in each instance and in aggregate less than half the specified period.

iii. **PROB** followed by 30 or 40 to indicate the percentage probability of the conditions becoming as given in subsequent groups.

iv. **BECMG** and **TEMPO** (also **PROB** when used without **TEMPO**) are followed by a 9-figure group to indicate the specified period. The format of the group is ddhh/ddhh indicating the start and end of the period in hours UTC e.g.: 'BECMG 0222/0301' means becoming during the period 022200 UTC to 030100 UTC.

v. **FM** followed by the date/time UTC is used to indicate the beginning of a self-contained part in the TAF. All conditions given before this group are superseded by those indicated after the group. FM introduces what is effectively a new forecast.

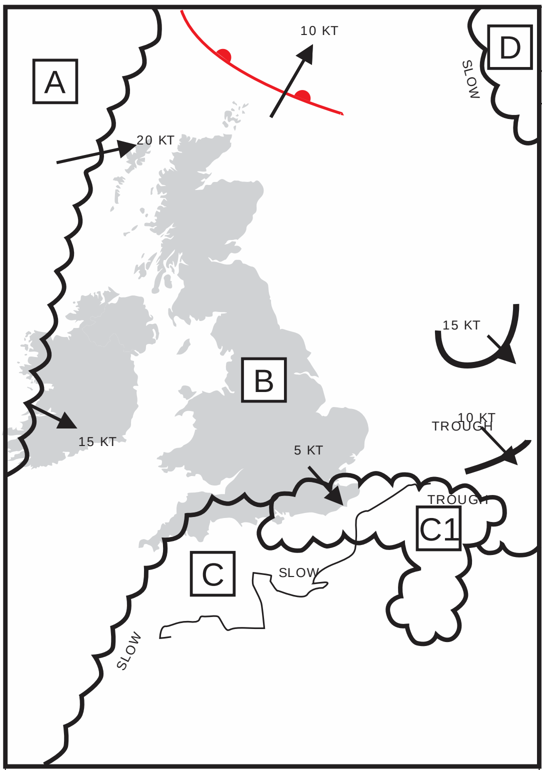
j. **Change Group Criteria**. Significant changes in military and civil TAFs requiring the use of change groups are listed in the FIH.

11. **Format of TAFs in NATO Countries.** The format of TAFs in other countries may differ from those in the UK and are detailed in the FIH.

Low Level Forecast Charts

12. Low level significant weather charts indicate the meteorological phenomena, below 10,000 ft, which are anticipated during a specified time period.

10CD-9 Fig 3 - Example of a Low-Level Significant Weather Chart



Forecast Weather below 10000 FT

Valid (DTG) to (DTG) (Date) Fronts/zones valid at (DTG)

AREA	SURFACE VIS AND WX	CLOUD	0 C
A	25 KM OCNL 7 KM RA W FM 13Z OCNL (OCNL W FM 11Z) ISOL HILL FG	AREAS BKN ACAS 080/XXX… …MAINLY W SCT/BKN CU SC … …015-030 / 040-(080 W FM 13Z) ISOL SCT/BKN ST 010/015 W FM 14Z	030-040… …FAR NE 070 SUB-… …ZERO… …030-050 E
B	20 KM NIL AREAS 7 KM HZ ISOL 6 KM SHRA MAINLY NEAR… …TROUGHS ISOL (OCNL S) 3000 M BR LAN ISOL 1000 M SN MON ISOL (OCNL FAR S TL 11Z) 200M… …FG/FZFG LAN ISOL (OCNL S TL 11Z) HILL FG	AREAS (WDSPR NEAR TROUGHS)… …BKN CU SC 015-030/050-070 ISOL (OCNL LAN S TL 11 Z)… …SCT/BKN ST… …004-010/015 (BASE 000 FG/FZFG)	020-035 … …LCA… …010-015… LAN
C	15 KM NIL OCNL (WDSPR NE) 7 KM HZ ISOL (OCNL NE) 3000M BR … … MAINLY LAN ISOL (OCNL **C1** TL 11 Z) 200 M … … FG/FZFG LAN ISOL (OCNL **C1**) HILL FG	ISOL SCT/BKN SC … … 030-040 / 050 ISOL (OCNL **C1**) SCT/BKN ST … … 002-008/010-015 **C1** AND LAN … … (BASE 000 FG/FZFG)	020-040 … … LCA 000 … CONTINENT
D	20 KM NIL OCNL 6 KM SHRA OCNL 1000 M SN MON OCNL HILL FG	BKN CU SC 015-030/070-090 ISOL SCT/BKN ST 006-012/015	015/030

All heights in 100s of feet above airfield level
XXX means above chart upper limit
Speed of movement in KT
HILL FG implies VIS<200 m

Cloud amount (Oktas)
FEW: 1-2 SCT: 3-4
BKN: 5-7 OVC: 8

MOD/SEV ICE
MOD/SEV TURB
TS/CB Implies GR
FZ precipitation implies

13. The chart will show the time period for which it is valid and the time at which the depicted frontal systems are predicted to be.

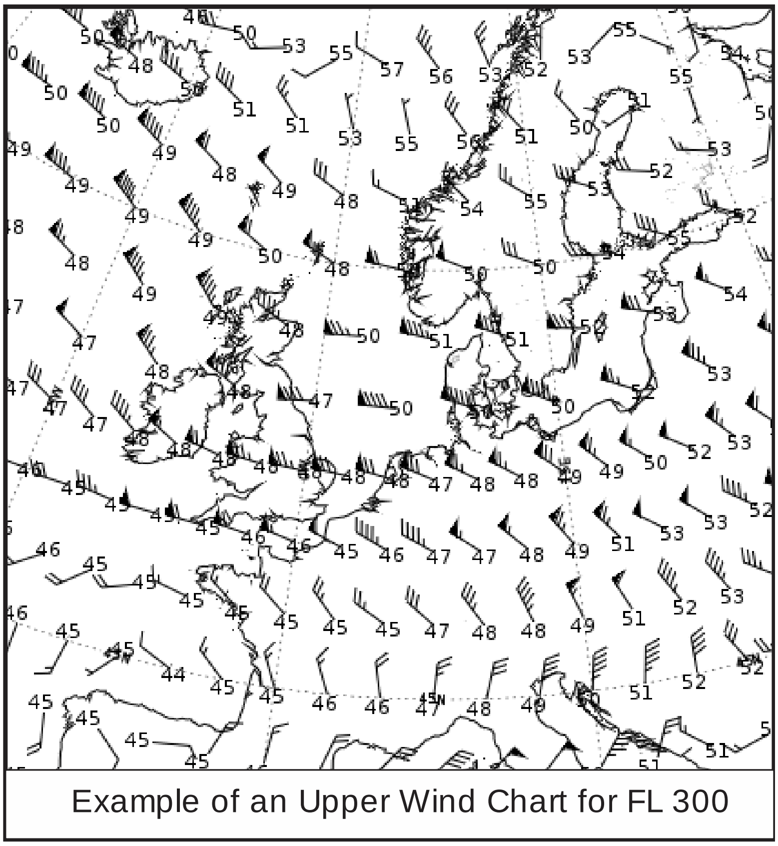
14. The left-hand side will feature a schematic map showing fronts and weather phenomena divided into areas delineated by scalloped lines and identified by letters of the alphabet. The map will use standard symbols and terminology. Arrows and associated numbers will depict the direction and speed of movement of a feature. Where a feature is moving at less than 5 kt, the word SLOW will be used.

15. The right-hand text boxes contain information regarding the conditions in the lettered areas of the chart. The codes used are as for Terminal Area Forecasts (TAFs) with information appearing in the same order, i.e. surface visibility, weather, cloud. When Cb cloud is indicated, it is implicit that there will be associated severe icing, severe turbulence and hail. The extreme right-hand column contains details of the forecast freezing levels.

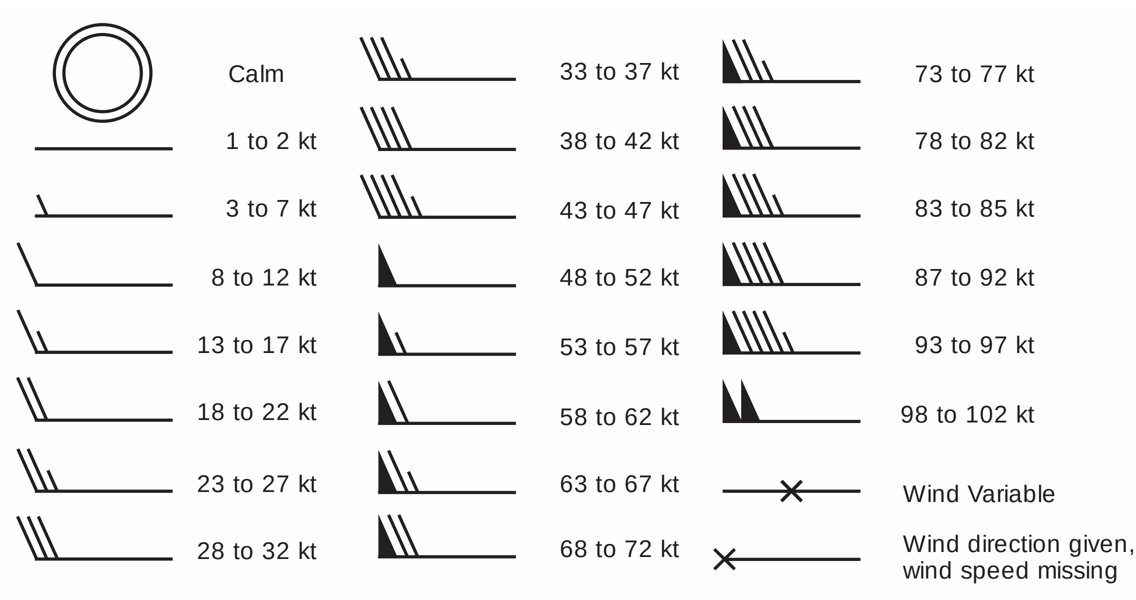
Upper Wind and Temperature Charts

16. Upper wind charts are produced for various pressure levels. The wind arrows indicate the direction and strength of the wind and spot temperatures are shown. Depending upon the organization that produces the chart, temperatures may be depicted with a + or – sign or a letter, M or PS, to indicate negative or positive values. In the example at Fig 2, there are no indicators and it is assumed that the temperatures are negative unless otherwise stated. Each wind chart should indicate the system in use in its key.

10CD-9 Fig 4 – Example of an Upper Wind Chart



10CD-9 Fig 5 – Wind Arrow Decode



Significant Meteorological Information (SIGMET)

17. A SIGMET is an abbreviated plain language message concerning the occurrence or expected occurrence of significant weather (generally thunderstorms, severe turbulence and icing) which may affect the safety of aircraft. It is valid for a period of 4 hours. Convective SIGMETs are concerned with the occurrence of thunderstorms and non-convective SIGMETs are concerned with the occurrence of severe turbulence and/or icing.

18. Many of the abbreviations used in SIGMETs are also used on low level forecast charts. A list is given in Table 3.

Table 2 – SIGMET Abbreviations

At subsonic cruising 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 with a 10-minute mean surface wind speed of 34 kt or more		TC (+ cyclone name)
Severe Turbulence		SEV TURB
Severe Icing		SEV ICE
Severe Icing due to freezing rain		SEV ICE (FZRA)
Severe Mountain Waves		SEV MTW
Heavy Duststorm		HVY DS
Heavy Sandstorm		HVY SS
Volcanic Ash		VA (+volcano name if known)
At transonic levels and supersonic cruising levels		
Moderate Turbulence		MOD TURB
Severe Turbulence		SEV TURB
Cumulonimbus		
Isolated cumulonimbus		ISOL CB
Occasional cumulonimbus		OCNL CB
Frequent cumulonimbus		FRQ CB
Hail		GR
Volcanic ash		VA (+volcano name if known)

19. The following is an example of a SIGMET with decodes.

a	**b**	**c**	**d**	**e**
EGTT	*SIGMET*	*03*	*VALID 071200/071600*	*EGRR-*

	f	**g**	**h**	**i**
EGTT	*LONDON FIR*	*SEV TURB*	*FCST*	*BLW FL070*

j	**k**	**l**
S OF A LINE N5030 W00600 TO N5400 E00100	*STNR*	*WKN=*

a. The location indicator of the Air Traffic Services Unit (ATSU) serving the Flight Information Region (FIR) or Control Area to which the SIGMET refers. (EGTT – London FIR)

b. The message identifier, i.e. SIGMET.

c. The sequence number of the SIGMET; i.e. the third SIGMET for the London FIR since 0001Z on the day of issue.

d. The period of validity of the SIGMET in UTC.

e. The location of the Met Office issuing the SIGMET. (EGRR – UK Met Office) This is followed by a hyphen to separate the SIGMET preamble from the next line of text.

f. The FIR or Control Area for which the SIGMET is issued.

g. The weather phenomena associated with the SIGMET using the abbreviations from Table 3.

h. This field tells whether the weather phenomena is forecast, FCST, or observed, OBS.

i. The altitude of the phenomena.

j. The location of the phenomena.

k. Indicates the movement of the phenomena, using one of eight compass points and a speed in km/h or kt. Where STNR is used, the movement is stationary.

l. This last group indicates whether the phenomena is weakening (WKN), intensifying (INTSF) or is not changing (NC). The group ends with an equal sign to denote the end of the message.

10-10-AIRCRAFT ICING

Introduction

1. It is important that all aircrew are aware of the hazards of aircraft icing. The possibility of ice accretion on the airframe of an aircraft should always be considered:

a. Whenever ground temperatures are at or below 0 °C.

b. Whenever flights take place through cloud or rain at temperatures below 0 °C. The most severe icing is usually present in the temperature range 0 °C to about -10 °C.

c. At heights where the temperature is between 0 °C and -20 °C, the rate of icing may be severe over a substantial depth of cloud for a wide range of cloud-base temperatures.

d. At heights where temperatures are between about -20 °C and -40 °C, the chance of moderate or severe icing reduces, except in newly developed convective cloud, but light icing is possible.

e. At temperature below -40 °C the chance of icing is small.

Table 1 (at the end of this chapter) summarizes the various types of aircraft icing. Engine icing may occur even in clear air at temperatures above 0 °C.

2. Frost, ice or snow on aircraft will adversely affect performance and even small amounts can have disastrous consequences. Accidents and incidents have been caused by:

a. Ice build-up on engine inlet pressure probes causing erroneous indications of engine power.

b. A thin layer of ice on control surfaces inducing flutter with subsequent structural damage.

c. Severe tail plane icing leading to loss of control when the flaps were selected down.

d. Very small deposits on wing leading edges dangerously eroding performance.

e. Attempting to take-off with wet snow on the wings and tail plane which had accumulated after earlier de-icing with diluted fluid.

The problems of aircraft icing are not limited to in-flight conditions as many icing problems occur on the ground. Two physical processes may cause a deposit of ice on objects exposed to the atmosphere. Ice may form directly from water vapour by sublimation, or by the freezing of liquid water drops. At ground level, these processes produce two familiar forms of ice deposit known as Hoar Frost and Rime. Glazed ice may also form when raindrops freeze on striking sub-zero surfaces.

Pre-flight Preparation

3. Pre-flight, the whole aircraft should be free from deposits of frost, ice and snow. If a de-icing fluid has been used to remove any frost or ice, it should be remembered that the efficiency of the fluid under varying atmospheric conditions is dependent upon the correct mixture strength. For example, using fluid diluted with water will effectively remove ice; however, its ability to prevent further formation will be significantly reduced. The Flight Information Handbook contains advice on aircraft de-icing and anti-icing fluids. Under certain circumstances the fact that the aircraft surfaces have been wetted may actually enhance the accumulation of wet snow, particularly if there is any significant delay between de-

icing and take-off. The temptation to become airborne because of any time control should be resisted if there is any doubt about the icing condition of the aircraft.

4. Particular attention should be paid to leading edges, control surfaces, flaps, slats and their associated mechanisms, hinges and gaps. All orifices and guards (e.g. generator cooling inlets, fuel vents, APU inlet, pressurization inlet and outlet valves, static plates) and exposed operating mechanisms, such as nosewheel steering and oleos, should be cleared of snow or slush, and de-iced when so recommended. Snow and ice should be cleared from boots before entering an aircraft.

Start-up, Taxiing and Take-off Precautions

5. **Start Up**. On some types of engine, the icing of probes can cause over-reading of power gauges. To prevent this, and also to prevent damage to, or flame-out of the engine, engine anti-icing should be switched on, in accordance with any recommendations within the Aircrew Manual. If the OAT is less than 10 ºC, and there is either precipitation, standing water, or the RVR is less than 1,000 metres then a possibility of engine icing must be considered. Use of carburettor heat and propeller de-icing may be recommended.

6. **Taxiing**. During taxiing in icing conditions, the use of reverse thrust on podded engines should be avoided, as this can result in ice contamination on the wing leading edges, slats and flaps. For the same reason, a reasonable distance should be maintained from aircraft taxiing ahead. In no circumstances should an attempt be made to de-ice an aircraft by placing it in the wake of the engine exhaust of another aircraft. It should always be remembered that stopping distances on snow and ice are increased. Painted areas are particularly slippery, especially when covered with de-icing fluid or snow.

7. **Take-off**. Just before take-off a final check should be made to ensure that the wings are not contaminated by ice and snow, and that fuel, propeller, airframe and engine icing controls are appropriately set as recommended in the Aircrew Manual. Take-off power should be monitored closely, if possible by cross-reference to all the engine instruments. Take-off direction should be selected by using the driest part of the runway and pilots should be aware of their abort speed. Water and snow will seriously affect stopping distances and if heavy rain has saturated the runway pilots should be aware of the aircraft's aquaplaning speed and the associated hazards.

In-flight Precautions

8. The build-up of ice in flight, particularly in cloud and freezing rain, may be very rapid and aircrew should avoid icing conditions for which their aircraft has not been cleared. The various parts of the airframe are affected in different ways by ice formation, both with regard to the types of ice likely to form and to the effect of ice accretion on their performance.

9. **Aerodynamic Effects**. When ice formation occurs on the leading edges of the aircraft wings and tail plane, the pattern of the airflow becomes modified round the affected part. This leads to an increase in drag, a decrease in lift, an increase in stalling speed (by as much as 30% in some cases), and perhaps to buffeting. Ice accretion on the leading edges of the fin and rudder and other moveable parts may interfere with the airflow to such an extent that control is seriously affected. To appreciate how this accretion forms, consider an object moving through air which contains many water droplets. As it moves, it catches only a fraction of the water which is present in its path; this fraction varies with the shape of the object and is found to be greater for a thin wing than for a thick wing, other things being equal. It does not follow that a greater total weight of ice is collected by the thin wing, since the path swept out has a smaller cross-section. On the other hand, a small deposit on a thin wing may cause greater aerodynamic disturbance than a similar deposit on a thick wing. This dependence on shape

explains why thin objects such as aerials, struts, the leading edges of propellers etc., are more likely to ice up than the bluffer parts of the airframe such as the blunt nose of the fuselage. The extremities of propeller blades have a much higher speed than other parts of aircraft and for this reason one might expect this component to be susceptible to icing, but there is some protection through kinetic heating. The aerodynamic effects of ice accretion are of course not confined to disturbances at the leading edges; ice forming on other parts of the wing or fuselage may lead to a considerable increase of drag. Ice formation under the wing may be particularly dangerous in that it is normally out of sight and its existence may be inferred only from a change in the performance of the aircraft.

10. **Weight and Vibration**. The effect of an accumulated weight of ice will obviously reduce aircraft performance. An unequal distribution of ice may have serious effects, particularly when it occurs on a propeller, for with this component the lack of balance when parts of the ice break away may lead to serious vibration. This type of hazard may also occur in connection with aerial masts, exposed balance weights and control surface links, and may in extreme circumstances lead to fracture. An uneven increase of weight through ice accumulation might also alter the centre of gravity.

11. **Effect on Instruments**. Any small extension or orifice is liable to gather ice and, if these include the pitot tube or static vents, it could seriously affect the indications of flight or engine instruments.

12. **Effect on Control Surfaces**. Normally there is a gap between the forward edge of a control surface and the fixed surface ahead of it. In some positions of the controls, sufficient ice may form in the gap to jam the control. The risk is greater on small aircraft than on larger ones, since on the former the gap is smaller and the movable part thinner, leading to a greater rate of accumulation. However, it is dependent chiefly on the design of an aircraft rather than on its size.

13. **Miscellaneous Effects**. A well-known effect is the formation of an ice coating on windscreens and canopies so that vision is restricted. This is often due to hoar frost formation in clear air when there is a rapid change of temperature.

14. **Communication**. Ice and frost covering aerials can reduce their effectiveness, and vibration and an increase in weight could damage them.

15. **Undercarriage**. Undercarriage lowering/retraction may be hindered by ice accumulation.

16. **Engines**. Engine air intakes may be blocked or restricted by ice, hindering fuel vapour and air flow.

17. **Descending**. If an aircraft has been operating for a long period at high altitude in cold conditions, a rapid descent into warmer air temperatures, and the higher humidity at lower levels, will cause frosting or misting up of the cockpit windows, and even the faces of instruments. Full use should be made of the defrosting and demisting devices fitted. It may also be necessary to allow time for the aircraft to warm up at lower altitude to disperse this misting before attempting to land. In addition, clear ice may occur on the airframe when a rapid descent is made as the aircraft temperature lags behind the ambient air temperature. If rain is encountered whilst the temperature of the aircraft is below 0 °C, the relatively large water drops form clear ice over a large part of the aircraft, with considerable spreading over the wings. When the runway is covered with snow and ice or is slippery, a positive landing should be made, without drift, on the centre-line. The aircraft should not be turned off the runway until the speed of the aircraft is suitably low. The friction of a wet runway will be greatly reduced from its dry value depending on the degree of wetness and the type of surface. When the runway is wet, braking distances can be significantly increased. Aquaplaning may occur when there is a layer of water on the landing surface and the tyre is no longer in contact with the surface. Advice on Equivalent Braking Action is given in the Flight Information Handbook.

Airframe Icing Factors

18. **Freezing of Supercooled Water Droplets**. The most important factor for the build-up of ice on aircraft is the freezing of supercooled drops - either cloud particles or raindrops - following impact with a cold aircraft. A certain amount of heat is required to melt a given mass of ice without a change in temperature and the same amount of heat is liberated when freezing takes place. This is known as the latent heat of fusion and its value is approximately 80 calories per gram of water or ice. Only 1/80th of a drop can freeze for every degree Celsius by which the temperature is below 0 ºC. Once the temperature of the partly frozen drop is raised, it begins to lose heat by evaporation and conduction to the object in contact with it, so that the remainder of the drop freezes more gradually while assuming the temperature of its surroundings. The higher the temperature of the supercooled drop, the smaller the fraction which will freeze instantly, and the greater the amount of liquid which will freeze progressively.

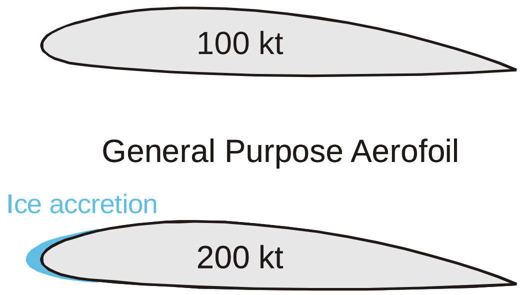
19. **Temperature of the Free Air**. Spontaneous freezing of supercooled drops in the free atmosphere is determined partly by the temperature and size of the drop and partly by other factors. As the temperature falls, the larger drops are likely to freeze first, while at lower temperatures only the smallest drops will remain liquid until a temperature of minus 40 ºC. The higher the temperature of a supercooled drop, the greater the fraction of the drop which remains liquid. The liquid portion then starts to flow over the aircraft thus favouring the formation of clear ice. At lower temperatures, there is a tendency towards the formation of rime ice concentrated near the leading edges.

20. **Size of Supercooled Drops**. The smallest supercooled drops tend to freeze immediately on striking a cold aircraft; the latent heat of fusion is quickly removed by the airflow and there is little or no spreading of the drop before freezing is complete. At the same time, air is enclosed between the particles, so that accretion takes the form of rime concentrated near the leading edge. On the other hand, large drops are accompanied by spreading of water over the airframe while the latent heat is being dissipated, so that freezing takes place more slowly and tends to be in the form of clear ice. Drops of moderate size can produce results intermediate between these two.

21. **Severity of Ice Accretion**. The severity of icing is defined as the rate of accumulation of ice by weight per unit area per unit time. Among the meteorological factors determining this rate are the amount of liquid water present and the size of the droplets. These characteristics are not the same throughout a particular cloud, even at one level. A cloud containing both liquid water and ice crystals may have large patches where one or the other predominate and icing will tend to be severe when the temperature is not far below 0 °C. An analysis of reports on ice accretion shows a preponderance of occasions at temperatures above about minus 10 °C and indicates that the frequency diminishes rapidly when the temperature falls below minus 20 °C, although occasional icing has been reported at temperatures below minus 40 °C. The severity of ice accretion is also dependent on:

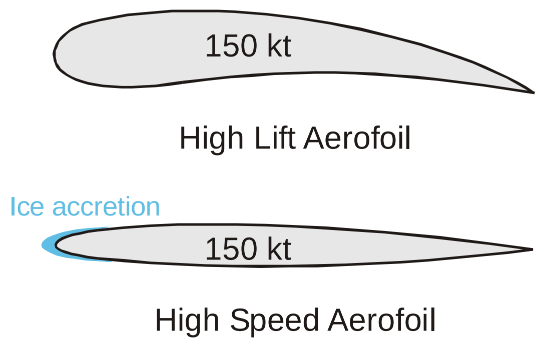
a. **Aircraft speed**. An aircraft will pick up more icing when travelling faster (see Fig 1).

10CD-Fig 1 - The Effect of Speed on Airframe Icing



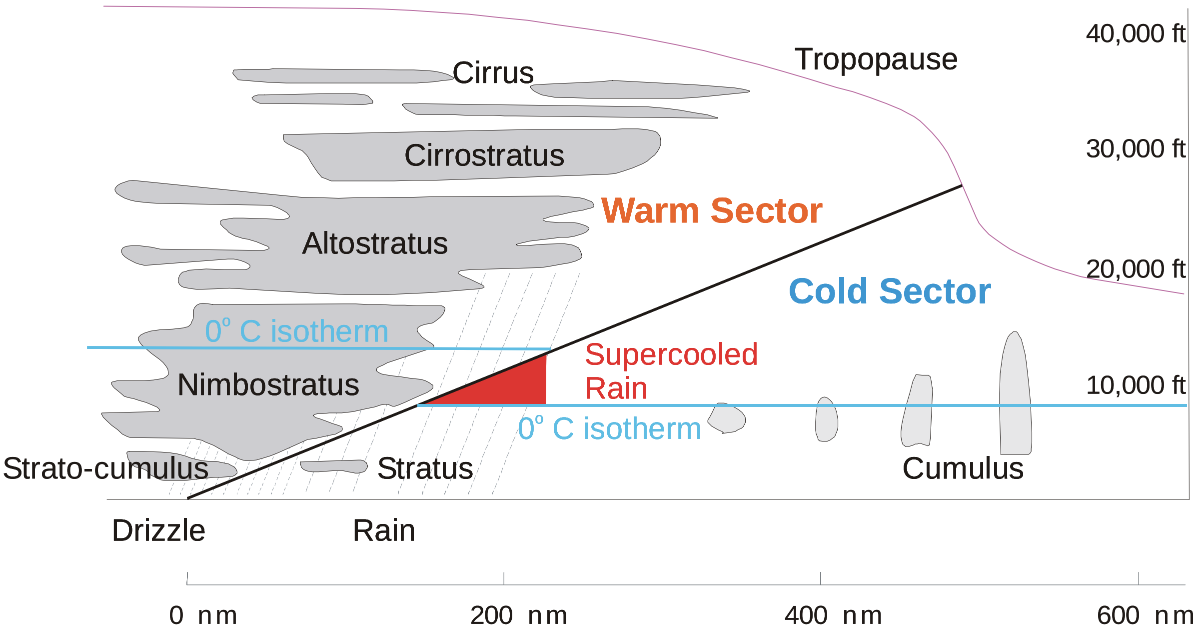
b. **Wing shape**. A thin, fast-jet type wing will pick up icing quicker than a thick, high-lift wing shape (see Fig 2).

10CD-Fig 2 - The Effect of Wing Shape on Aircraft Icing



c. **Supercooled Rain**. Supercooled rain occurs beneath warm fronts and occlusions and occasionally beneath cold fronts (see Fig 3). When present, there is necessarily a warmer layer above, in which the temperature exceeds 0 °C. When flying beneath this type of meteorological condition the best procedure is to climb into the warmer layer of air. The belt of frontal cloud and rain should if possible be crossed at right angles so as to give the shortest traverse through the icing region. A particularly dangerous procedure is to fly parallel to the front in the freezing rain, since a heavy accumulation of clear ice could form rapidly.

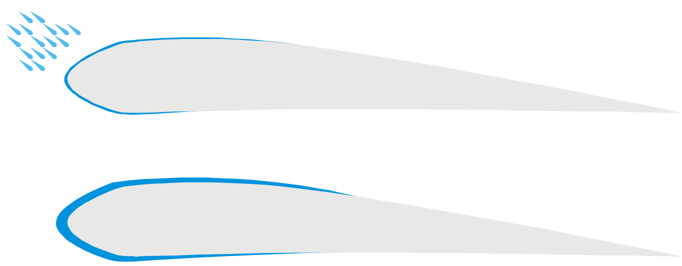
10CD-Fig 3 - A Cross-section of a Warm Front where Supercooled Rain may Occur



Clear Ice

22. Clear ice is the most hazardous form of airframe icing. It is most likely to be encountered in freezing rain where the raindrops spread and freeze on contact with a cold airframe. Liquid water drops, known as supercooled drops, can exist in the atmosphere below 0 °C. One situation where supercooled drops can form is when rain falls from air whose temperature is above 0 °C into a below freezing layer of air beneath. Supercooled drops are unstable and will freeze on contact with a below 0 °C surface, such as an airframe. When the supercooled drop hits the airframe, it freezes relatively slowly due to the latent heat released in the freezing process. This allows part of the drop to spread backwards before it too freezes. The spread back is greatest when the temperature is just at 0 °C. Clear ice forms a sheet of solid, clear, glazed ice with very little air trapped in it which can dramatically alter the aerodynamic properties of an aerofoil. There may also be a significant increased weight penalty associated with clear ice. Click here for an image of clear ice.

10CD-Fig 4 - The Formation of Clear Ice

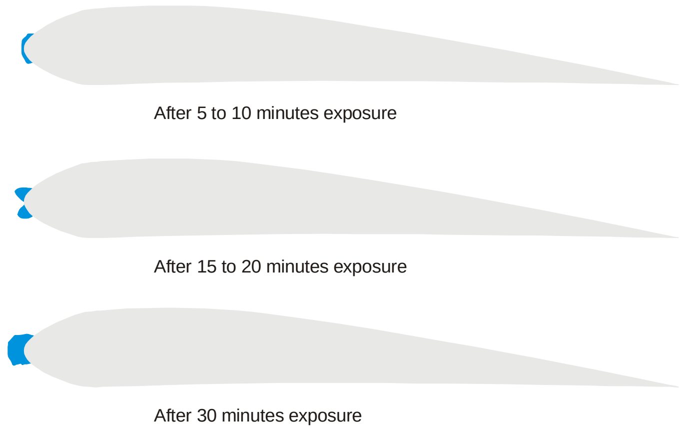


Rime Ice

23. Rime ice occurs when small, supercooled liquid water droplets freeze on contact with a surface that is below freezing. Due to the small size of the water drops, there is little latent heat released to slow the freezing of the water and the airflow also removes some of the latent heat. The small size of the drops also means that there is little water remaining after the initial freezing to coalesce into a

sheet of ice, as in the case of clear ice. The result is a mixture of tiny ice particles and trapped air, giving a rough, opaque deposit that is crystalline and fairly brittle. Rime ice usually forms on leading edges and can affect engine intake airflow. Usually there is little weight penalty and the ice is slow to accumulate. Although rime ice can form in the temperature range 0 °C to -40 °C, it is most commonly found in the range -10 °C to -40 °C. Click here for an rime of clear ice.

10CD-Fig 5 - The Formation of Rime Ice



Mixed Ice

24. Rain within or falling from clouds can consist of many different sized drops which may result in the formation of a mixture of clear and rime ice, known as Mixed Ice. Most icing encounters are likely to be mixed ice, especially when flying in cloud. Only rarely will just pure rime ice or clear ice form.
Click here for an mixed of clear ice.

Hoar Frost

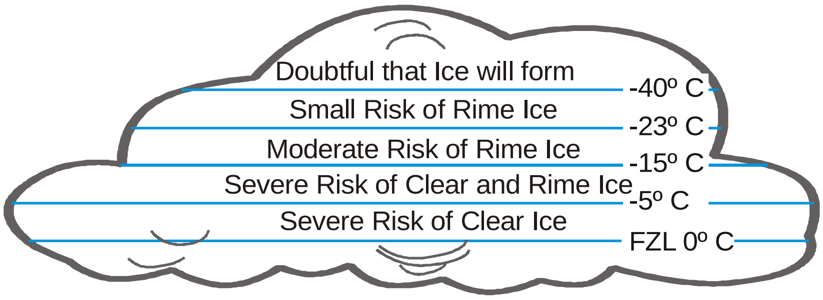
25. When moist humid air comes into contact with a surface below 0 °C frost forms on the surface. The water vapour changes directly into ice and deposits as frost without going through the liquid water stage. Favourable conditions for frost to form are a clear night (making it cool), a calm wind and high humidity. While frost does not alter the basic aerodynamic shape of a wing it can disrupt the smooth airflow over it, causing early separation. As such, frost should be removed from an aircraft before flight. Frost can also form in flight when a cold airframe descends from height into warm moist air. It can also form when climbing through an inversion where warm air overlays cold air.
Click here for an image of hoar frost.

Airframe Icing and Cloud Type

10CD-Fig 6 - Airframe Icing and Associated Cloud Type

Cloud Type	Composition
Cumulus	Predominantly liquid water droplets down to about -23 ºC. Below -23 ºC either liquid drops or ice crystals may predominate. The temperature profile of the cloud will determine the severity and type of icing present in it. (Fig 19). Convective clouds possess considerable vertical motion therefore the risk of icing may be present though out a wide altitude band.

10CD-Fig 7 - Potential Icing Temperature Bands in Cumulus Clouds



Stratiform	Predominately liquid water drops down to about -15 ºC with a risk of icing. Stratiform clouds associated with an active front or orographic uplift present a greater risk of icing at lower temperatures than normal.
Precipitation	Rain and drizzle will freeze on an airframe below -0 ºC, with the risk of clear ice increasing with the size of the drops. This may occur when flying in cool air under the warmer air of a warm front from which rain is falling.
Orographic Lifting	The uplift of air enables it to support more moisture. This increases the risk of icing, particularly clear ice, and lowers the freezing layer.
Cloud Base Temperature	Warm air can hold more moisture than cold air. Icing potential in a convective cloud, at a given level, is likely to be greater in tropical latitudes than temperate ones, and greater in summer than winter.
High-level Clouds	High clouds with bases above 20,000 ft are usually composed of ice crystals and so the risk of airframe icing is minimal.

Piston Engine Icing

26. Piston engine induction system icing is commonly referred to as carburettor icing but this is only one form of engine icing. Such icing can occur at any time, even on warm humid days. It can be so severe that unless the correct action is taken the engine may stop, especially at low power settings during descent, approach or during helicopter autorotation.

27. Considerable cooling of the air in the carburettor of piston engines can occur when the OAT is above 0 ºC. This cooling is the result of two factors:

a. The latent heat of evaporation of the petrol.

b. The pressure drop passing the throttle butterfly valve.

The combined effect can reduce the temperature of air by as much as 25 ºC. To counter carburettor icing, an alternative hot air supply needs to be selected to maintain the internal temperature above 0 ºC. The direct injection type of carburettor is rarely subject to internal icing; however, the air intakes and filters can be seriously affected by external icing.

28. The aircraft document set such as aircraft manuals and the release to service are the primary source of information for individual aircraft and the advice given in them should be followed.

Types of Icing

29. There are three main types of induction system icing:

a. **Carburettor Icing.** The most common form of icing, the earliest to show and the most serious, is carburettor icing. It is caused by a combination of a sudden temperature drop due to fuel vaporisation and pressure reduction as the mixture passes through the carburettor venturi and past the throttle valve. If the temperature drop brings the air below its dew point condensation forms and if the mixture temperature reduces to below freezing, the condensed water will form ice on the surfaces of the carburettor. The ice gradually blocks the venturi, which upsets the fuel/air ratio causing a progressively smooth and slow loss of power. Conventional float type carburettors are more prone to icing than pressure jet types.

b. **Fuel Icing**. Less common than carburettor icing is fuel icing which is the result of water, held in suspension in the fuel, precipitating and freezing in the induction piping, especially in the elbows formed by bends.

c. **Impact Ice**. Impact ice builds up on air intakes, filters, alternate air valves etc. It forms on the aircraft in snow, sleet, sub-zero cloud and rain if either the rain or the aircraft is below 0 °C. This type of icing can affect fuel injection systems as well as carburettors. In general, impact ice is the main hazard for turbocharged engines.

Engine Factors

30. **Use of MOGAS (MOtor GASolene)**. MOGAS has a greater and seasonally variable volatility and higher water content than aviation fuels and as a result carburettor icing is more likely when MOGAS is used. MOGAS may be used in some aircraft that have been specifically cleared to use it. The CAA Safety Sense Leaflet 4 – 'Use of MOGAS' gives advice and guidance on the use of MOGAS.

31. **Reduced Power Settings**. Engines at reduced power settings are more prone to icing because engine induction temperatures are lower. Also, the partially closed butterfly can more easily be restricted by the ice build-up. This is a particular problem if the engine is de-rated as in many piston-engined helicopters and some aeroplanes.

32. **Carburettor Surfaces**. A rough carburettor venturi surface is likely to increase carburettor icing severity.

33. **The Effect of Engine Cooling**. Water-cooled engine bodies tend to cool less quickly when power is reduced, reducing the carburettor icing severity. Coolant directed around the carburettor body may maintain the venturi temperature above freezing.

Atmospheric Conditions

34. Carburettor icing is not restricted to cold weather and will occur on warm days if the humidity is high, especially at low power settings.

35. Serious icing can occur at descent power with the ambient temperature above 25 °C, even with relative humidity as low as 30%. It can also occur at cruise power with an ambient temperature of 20 °C and relative humidity at 60% or more. Cold, clear winter days are less of a hazard than humid summer days because cold air holds less moisture than warm air.

36. Carburettor icing can occur in clear air with the absence of any visual warning.

37. Pilots should be alert to the possibility of carburettor icing when:

a. In cloud and fog where the relative humidity should be assumed to be 100%.

b. In clear air where cloud or fog may have just dispersed, or just below the top of a haze layer.

c. Just below a cloud base or between cloud layers.

d. In precipitation, especially if persistent.

e. The surface and low-level visibility is poor, especially in early morning and late evening, and particularly near a large body of water.

f. The ground is wet (even with dew) and the wind is light.

Recognition of Engine Icing

38. **Fixed Pitch Propeller**. With a fixed pitch propeller, a slight drop in rpm and performance (airspeed and/or altitude) are the most likely indications of the onset of carburettor icing. The loss of rpm can be smooth and gradual, and the usual reaction is to open the throttle slightly to compensate. However, whilst restoring power, this hides the loss. As icing builds up, rough running, vibration, further loss of performance and ultimately engine stoppage may follow.

For a fixed pitch propeller, the primary instrument for detecting engine icing is the rpm gauge in conjunction with ASI and altimeter.

39. **Constant Speed Propeller**. With a constant speed propeller, and in a piston-engine helicopter, the loss of power would have to be large before a reduction in rpm occurs. The onset of icing is more insidious but there will be a drop in manifold pressure and a performance reduction.

For a constant speed propeller, the primary instrument for detecting engine icing is the manifold pressure gauge.

40. In steady level flight, an exhaust gas temperature gauge, if fitted, may show a decrease in temperature before any significant decrease in engine and aircraft performance.

Piston Engine Icing Summary.

41. The main considerations with regard to piston engine icing can be summarised as:

a. Engine icing forms stealthily but can be anticipated.

b. Icing may occur in warm humid conditions at any time of the year in the UK.

c. The use of MOGAS makes carburettor icing more likely.

d. Low power settings, such as in a descent or in the circuit, are more likely to produce carburettor icing.

e. Warming up the engine before take-off improves the effectiveness of any carburettor body heat.

f. Use full carburettor hot air often when flying in conditions where carburettor icing is likely.

g. The RPM gauge is the primary indication of carburettor icing for a fixed pitch propeller.

h. Manifold pressure is the primary indication of carburettor icing for a variable pitch propeller.

i. Treat the carburettor hot air as an ON/OFF control; either full hot or full cold.

j. It takes time for the heat to work and the engine may run roughly while ice is clearing.

k. Timely use of appropriate procedures can prevent carburettor icing.

42. In the event of carburettor heat system failure in flight:

a. Avoid likely carburettor icing conditions.

b. Maintain high throttle settings; full throttle if possible.

c. Weaken the mixture slightly.

d. Land as soon as is reasonably possible.

Turboprop and Jet Engine Icing

43. **Turboprop and Jet Engines***.* The intakes of turboprop and jet engines are subject to icing in the same way as the airframe when flight is taking place in supercooled water droplets. The susceptible parts are the rim of the intake where the radius of curvature may be small, any struts across the intake, and the vanes in the early stages of the compressor. Thereafter, air temperatures are usually too high for icing to be a problem, although ice breaking away from the inlet may cause damage to the engine. Generally speaking, engine icing will be directly proportional to the rate of airflow through the engine and thus to the engine rpm - it is frequently found that the rate of icing may be reduced by decreasing the rpm. When a jet engine is operating at high rpm during flight at low speeds, as when taking off and landing, or whilst stationary, as in running up, the pressure within the intake is much less than the pressure outside. The consequent adiabatic expansion in the intake causes a drop-in temperature as much as 5 ºC. If the clear indrawn air is moist and the temperature is near 0 ºC, prolonged operation may result in condensation and ice formation when this would not occur on the airframe. This effect may accentuate the icing which would normally be expected when the flight is in icing cloud, or when the aircraft is taking off or landing in freezing fog. Usually jet engines ice up in flight only under conditions which might be expected to produce airframe icing. The intensities of icing on the airframe and in the engine may be different since the airframe icing rate depends on the airspeed, whilst engine icing depends on the rpm. At high speeds, the engine tends to be supplied with more air than it needs and there is a ram effect, whereas at lower speeds, below about 250 kt, air is sucked in. Because of the ram effect at higher speeds some of the air is deflected round the intake, but the inertia of the water droplets results in a higher water concentration within the intake, and the icing rate increases markedly with increases of airspeed above 250 kt. At speeds where the air is sucked in (below 250 kt) the water concentration of the air entering the intake remains virtually the same as free air so that engine icing rates tend to be constant with decreasing speed, whereas the airframe is likely to show a marked decrease of icing rate with decreasing speed.

Summary

44. Aircraft encounter a greater variety of icing conditions in flight than on the ground, resulting in a wider variety of ice deposits. Snow, ice and frost, in all their forms, produce a flight safety risk. Being

aware of the physical process and conditions which produce airframe and engine icing will help to avoid the dangers associated with this phenomenon.

Table 1 Types of Icing and their Properties

Reference: The Handbook of Aviation Meteorology – HMSO - 1994

Type	Occurs	Appearance	Effect	Action
Hoar-frost	Occurs in clear air on a surface whose temperature is reduced below the frost-point (1) of the air in contact with it. Occurs on clear nights when there is a fall in temperature to a value below 0 °C. May occur in flight when moving rapidly from air well below 0 °C to warmer and more humid air. Should soon disappear as the aircraft warms up. May affect radio reception and may cause frost on the windscreen and instruments.	White crystalline coating, normally of a feathery nature.	Weight of the deposit is unlikely to be serious. It can interfere with the airflow over the wing and thus the attainment of flying speed during take-off. Can also affect vision through the windscreen, the free working of control surfaces and radio reception.	Should be removed before take-off.
Rime Ice	Occurs when small supercooled water drops freeze on contact with a surface at a temperature below 0 °C. At ground level it forms in freezing fog. In flight it may form in clouds of low water content composed of small droplets, comparable with those of freezing fog. Most liable to occur at low temperatures where small, unfrozen cloud droplets freeze almost instantaneously.	Tiny ice particles between which air is entrapped to give a rough crystalline deposit. Forms and accumulates on leading edges with no spreading back. Trapped air gives a white opaque appearance.	Usually breaks away quite easily. Usually little weight. Alters the aerodynamic characteristics of the wings and may block air intakes.	If present, it should be removed before take-off.
Clear Ice (Glaze Ice)	Occurs in dense cloud of convective or orographic type. Forms when large water drops, not far below 0 °C, are encountered in flight. Results from water flowing over a cold airframe before freezing. Drop unite while liquid and little air is trapped. May also occur when an airframe, below 0 °C, descends rapidly through large raindrops. May also occur where there is an inversion where rain falls from a level above 0 °C to a layer where it is below 0 °C. Typically associated with warm fronts where the icing layer occupies a narrow range of altitude below the frontal surface (see Fig 3).	Transparent or Translucent coating with a glassy surface. Ice surface is smooth but may have bumps and undulations.	Tough and sticks closely to the surface of the aircraft and cannot be broken away easily. If it breaks away, it sheds in large pieces which may be dangerous. Will affect the aerodynamics and increase weight. May cause unequal loading of the wings, struts and propeller/rotor blades.	Avoid if possible. Use aircraft anti-icing/de-icing systems. Try to avoid the danger area associated with warm fronts (Fig 3). Cross the front at right angles if possible.
Cloudy (Mixed Ice)	Rime and Clear ice are the extreme forms of ice accretion experienced by aircraft in flight through cloud and rain. As a large range of drop sizes may be encountered at any temperature between 0 °C and -40 °C, a wide range of icing exists between the two extremes. These varieties are usually described as Cloudy or Mixed ice.	The smaller the drops and the lower the temperature, the rougher and cloudier will be the build-up on the leading edges. A smoother and more glassy ice formation, spreading back over the airframe will occur with large drops and a temperature closer to 0° C.	Effects as above depending on droplet size and temperature. Where ice crystals are present in a cloud, these may stick to a wet airframe and freeze, along with the cloud drops, to give a formation of rough cloudy ice. If snowflakes are present they are trapped in the ice as it forms, producing an opaque deposit with the appearance of tightly packed snow.	Avoid if possible. Use aircraft anti-icing/de-icing systems.

(1) Frost-point is the temperature to which moist air must be cooled in order to just reach the condition of saturation with respect to a plane ice surface. Further cooling induces deposition of ice in the form of hoar-frost on solid surfaces, including other ice surfaces.

10CD-Fig 8 - Icing Images

Hoar-frost		Return to Text.
Rime Ice		
Clear Ice (Glaze Ice)		
Cloudy (Mixed Ice)