AVIATION WEATHER

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A DISSERTATION REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

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CERTIFICATE

This is to certify that **Mr. Dhanraj Munnalal Mistry**,
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under my Supervision.

Further, I certify that the work is based on the investigation made, data collected & analyzed by him and it has not been submitted in any other University or Institution for award of any degree.

In my opinion, it is fully adequate, in scope and utility, as a Dissertation towards partial fulfillment for the award of Degree of B. B. A.

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DISSERTATION

TOPIC:- AVIATION WEATHER

A DEFINITION OF METEOROLOGY

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

REASONS FOR STUDYING METEOROLOGY

¾¾ To gain a better understanding of meteorologists' deductions.
¾¾ To gain a better understanding of meteorologists' documentation.
¾¾ To gain a better understanding of in-flight hazards.
¾¾ To gain a better understanding of data and its collection.
¾¾ To gain a better understanding of self-forecasting.

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

ABSTRACT:-

A DEFINITION OF THE ATMOSPHERE

"The spheroidal gaseous envelope surrounding a heavenly body."

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

THE CONSTITUENTS OF THE ATMOSPHERE (BY VOLUME)

Nitrogen 78 % Argon 0.95%
Oxygen 21 % Carbon Dioxide 0.05%
Plus traces of:
Neon Nitrous Oxide Helium Nitrogen Dioxide
Krypton Carbon Monoxide Xenon Sulphur Dioxide
Hydrogen Ammonia Methane Iodine and Ozone
Water Vapour

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

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

PROPERTIES OF THE EARTH'S ATMOSPHERE

The earth’s atmosphere varies vertically and horizontally in:
¾¾ Pressure
¾¾ Temperature
¾¾ Density
¾¾ Humidity
The earth’s atmosphere is a poor conductor. The earth’s atmosphere is fluid.

THE STRUCTURE OF THE ATMOSPHERE

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

The Troposphere

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

The Tropopause

The Tropopause is at the top of the troposphere. It marks the boundary between the troposphere and the next atmospheric layer, the stratosphere. The tropopause is defined as being that part of the atmosphere where temperature no longer decreases with height. (Practically taken as the height where the temperature fall is less than 0.65° per 100m (1.98°C per 1,000 ft.). There are two important points about the tropopause you need to be familiar with, these are it’s height and it’s temperature.
¾¾ The height of the tropopause is controlled by the temperature of the air near the surface. The warmer the air, the higher the tropopause. The colder the air, the lower the tropopause. Generally over the poles, the tropopause can be between 8 -10 km and over the equator 16 - 18 km. Surface temperature variations due to latitude, season, land and sea, will all cause varying heights of the tropopause. For example in winter the tropopause is lower than in the summer.
¾¾ Since temperature decreases with height it goes to follow that the temperature at the tropopause is controlled by its height. The higher it is, the colder the temperature at the tropopause. The lower it is, the warmer the temperature at the tropopause. The temperature at the tropopause can be as high as -40°C over the poles and as low as -80°C over the equator. However, on average the tropopause is at about 11 km where its temperature is -56.5°C.
The significance of the tropopause height is that it usually marks;-
¾¾ the maximum height of the cloud
¾¾ the presence of Jetstreams
¾¾ the presence of Clear Air Turbulence (CAT)
¾¾ the maximum wind speed

The Stratosphere

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

The Mesosphere

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

RATIONALE / PURPOSE AND IMPORTANCE OF DISSERTATION:-

ATMOSPHERIC HAZARDS

As aircraft operating altitudes increase, so concentrations of OZONE and COSMIC RADIATION become of greater importance to the aviator.
Above 50,000ft, normal concentrations of ozone exceed tolerable limits and air needs to be filtered before entering the cabin. The heat of the compressor system will assist in the breaking down of the ozone to an acceptable level.
Cosmic radiation is not normally hazardous, but at times of solar flare activity a lower flight level may be necessary.
Advances in meteorological forecasting and communications should result in pilots receiving prompt and accurate information regarding high altitude hazards, but it is important that they should be aware of these hazards and prepared to take the necessary re-planning action.

THE ICAO STANDARD ATMOSPHERE (ISA)

For a variety of reasons it is necessary to establish a standard average atmosphere, describing variations in temperature, pressure and density throughout altitude.
There have been several different Standard Atmospheres, but the one in general use now is the 'ICAO Standard Atmosphere', dated 1964 which covers an atmosphere from -0.5 km to 32 km.
The ISA is needed for;-
¾¾ the calibration of aircraft instruments
¾¾ the design and testing of aircraft
The ICAO ISA is defined as follows:-
¾¾ a MSL temperature of +15°C
¾¾ a MSL pressure of 1013.25 hPa
¾¾ a MSL density of 1225 g/m3
¾¾ a lapse rate of 0.65°C/100m (1.98° C /1000 ft) up to 11 km (36,090 ft)
¾¾ a constant temperature of -56.5°C from 11 km (36,090ft) to 20 km (65,617 ft)
¾¾ an increase of temperature 0.1°C/100m (0.3°C /1000 ft), from 20 km (65,617ft) to 32 km

(104,987 ft)

ISA DEVIATION

Although meteorological observations are made in absolute figures, it is usual, when making calculations involving aircraft performance or corrections to instruments, to consider them relative to the ISA. These are known as “ISA deviations”.
If for instance, the observed temperature were 5°C warmer than that expected in the ISA, then the deviation would be described as ISA + 5.

Understanding the variations in atmospheric pressure across the Earth’s surface is fundamental to an understanding of the weather, itself. But what is the fundamental cause of atmospheric pressure? Expressed simply, atmospheric pressure, which acts on any object immersed in the atmosphere, is caused by the weight of air above that object. Atmospheric pressure acts in all directions.
The forces generated by horizontal pressure differences across the Earth’s surface give rise to both horizontal, and vertical air movement, creating winds and clouds. The variation of atmospheric pressure with altitude allows us to measure the vertical separation of an aircraft from the Earth’s surface, using an instrument called an altimeter.

The Fundamental Cause of Atmospheric Pressure

The air which constitutes our atmosphere is made up of billions of molecules. The atmosphere, therefore, has mass, and, as a result of the Earth’s gravitational field pulling the mass of the atmosphere towards the centre of the Earth, air possesses weight. The pressure of the atmosphere at any point is caused by the weight of the column of air overlying that point. Atmospheric pressure (sometimes, in other branches of aeronautics, called static pressure) acts in all directions on any object contained within the atmosphere.
Most of the mass of the atmosphere is contained in its lower layers near the Earth’s surface. This is because of the action of the Earth’s gravitational field on the air molecules (the force of gravity being greater near the surface), combined with the fact that air is compressible. The air in thelower layers of the atmosphere is compressed by the weight of the air above it. Consequently, air is denser, and atmospheric pressure is greater, at the Earth’s surface than at altitude.
Figure 2.1 represents the relative distribution of molecules within the atmosphere, with more molecules in the lower part of the atmosphere than at altitude. The red arrows within the column of air illustrate that the atmosphere exerts its pressure equally, in all directions.
Atmospheric Pressure is the force or weight exerted on any object by the column of air above that object. Atmospheric (or static) pressure acts in all directions and reduces with increasing altitude.

UNITS OF ATMOSPHERIC PRESSURE

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

inches Hg.

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

REVIEW OF LITERATURE:-

The Mercury Barometer

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

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

The Aneroid Barometer

The aneroid barometer does not contain mercury or liquid, but measures the effect of air pressure on a partially evacuated metal capsule. The aneroid barometer (from Greek "a" meaning not and "neros" meaning water) is less accurate overall than the mercury barometer, but is more sensitive to small changes in air pressure. Changes in air pressure cause the metal capsule to expand or contract; a mechanism connected to the capsule causes a needle or pointer to move around a calibrated scale. An aneroid barometer may be calibrated in inches of mercury or in millibars. However, an aneroid barometer can also be calibrated in feet or metres to indicate height above the Earth's surface; the instrument is then known as an altimeter.

PRESSURE VARIATIONS AT THE EARTH'S SURFACE

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

Comparatively speaking, if there is a greater mass of air above a given area on the Earth's surface, then the atmosphere will be exerting more pressure on that area. If, in another location, there is less air above the Earth's surface, the atmosphere will be exerting less pressure on the surface.

Therefore, high or low surface pressures are a direct consequence of the weight of the mass of the air overlying a given locality

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

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

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

THE PRESSURE GRADIENT FORCE

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

Figure 2.10

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

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

VERTICAL PRESSURE VARIATION

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

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

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

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

THE EFFECT OF TEMPERATURE ON VERTICAL PRESSURE VARIATION

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

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

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

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

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

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

The Effect of Temperature on Altimeter Readings

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

Temperature Error in an Altimeter

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

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

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

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

$H = 96T$

P

Where:

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

ISA

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

DIURNAL VARIATION

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

TYPES OF PRESSURE

QFE

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

QFF

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

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

QNH

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

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

PRESSURE DEFINITIONS

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

QFF The value of pressure reduced to MSL in accordance with isothermal conditions.

QNH The value of pressure, for a particular aerodrome and time, corrected to the MSL in accordance with the ICAO standard.

FORECAST QNH Also known as Regional Pressure Setting (RPS). A forecast, valid for one hour, of the lowest QNH expected in any part of the Altimeter Setting Region (ASR).

QNE The height indicated on landing at an airfield when the altimeter subscale is set to 1013.25 hPa.

ISOBAR A line joining places of the same atmospheric pressure (usually MSL pressure QFF).

ISALLOBAR A line joining places of the same pressure tendency.

MEAN SEA LEVEL PRESSURE CHARTS

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

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

☐ Grammes per cubic metre. (g/m3)

☐ A percentage of the standard surface density - relative density.

☐ The altitude in the standard atmosphere to which the observed density corresponds - density altitude.

DENSITY EXPRESSIONS

Relative Density

Relative density is the prevailing density, expressed as a percentage of mean sea level density in ISA. For example, if the prevailing density is 1000 g/m3, then comparing this to the ISA mean sea level density of 1225 g/m3 we can say that the prevailing density is 82% of ISA mean sea level density. To put it another way, if the relative density is 50%, then this would mean that the prevailing density is half that of mean sea level density is ISA. Therefore the prevailing density is 612 g/m3.

Density Altitude

Density altitude is the altitude in the ISA at which the current observed density would occur. For example, if the prevailing or observed density is 612 g/m3 then this represents a density that is found at approximately 20,000 ft in ISA. Therefore, the location of the observed density is described as having a density altitude of 20,000 ft

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

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

EFFECT OF CHANGES OF PRESSURE ON DENSITY

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

DENSITY IS DIRECTLY PROPORTIONAL TO PRESSURE

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

EFFECT OF CHANGE OF TEMPERATURE ON DENSITY

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

DENSITY IS INVERSELY PROPORTIONAL TO TEMPERATURE

EFFECT OF CHANGE OF HUMIDITY ON DENSITY

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

DENSITY IS INVERSELY PROPORTIONAL TO HUMIDITY

EFFECT OF CHANGE OF ALTITUDE ON DENSITY

As altitude increases, the effect of pressure decreasing causes density to fall despite the fact that temperature decreases. Therefore, the effect is for the density to decrease with an increase of height. You can appreciate this because at high altitudes, pilots and mountaineers require supplemental oxygen to breathe simply because there isn't much air in the upper atmosphere. The information below simply shows you that at 20,000 ft the density of the air is almost half of what is at mean sea level. Mean sea level density is approximately 1225g/m3 therefore at 20,000 ft density is 612 g/m3.

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

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

EFFECT OF CHANGE OF LATITUDE ON DENSITY

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

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

EFFECT OF CHANGES IN DENSITY ON AIRCRAFT OPERATIONS

☐ Accuracy of aircraft instruments - Mach meters, ASIs.

☐ Aircraft and engine performance - low density will reduce lift, increase take off run, reduce maximum take off weight.

(L = CL ½ ρ V2 S)
Where L = Lift
CL =
Coefficient of Lift
ρ = Density
V = TAS
S = Wing area

Airfields affected would be:
High Denver Nairobi Saana
Hot Bahrain Khartoum Singapore

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

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

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

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

LOW PRESSURE SYSTEMS

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

SMALL SCALE LOWS

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

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

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

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

Statement of Dissertation Objectives/ Questions / Hypotheses:-

HAZARDS TO AVIATION FROM SMALL SCALE LOWS

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

¾¾ Turbulence
¾¾ Precipitation
¾¾ Icing
¾¾ Poor visibility

Turbulence and Precipitation

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

Icing

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

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

Visibility

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

THE EQUATORIAL LOW PRESSURE BELT

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

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

LARGE SCALE LOW PRESSURE AREAS (DEPRESSIONS)

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

FORMATION OF POLAR FRONT DEPRESSIONS

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

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

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

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

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

The Warm Front

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

The Cold Front

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

Figure 4.13 The Cold Front

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

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

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

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

Isobars

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

The Occluded Front

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

ISOBARIC TROUGHS

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

ANTICYCLONES

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

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

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

Cold Anticyclones

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

Asia and the North American High or Canadian High.

Temporary Cold Anticyclones Or Travelling Anticyclones

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

Blocking Anticyclones

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

RIDGES

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

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

COLS

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

Weather

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

TERMINOLOGY

Depressions will fill up or decay as pressure rises.
Depressions will deepen as pressure falls.
Depressions move rapidly, their average lifetime is 14 days.
Anticyclones will build up as pressure rises.
Anticyclones will weaken or collapse as pressure falls.
Anticyclones are very slow moving, they can last for a lengthy period, even up to 6 months.
Cols last a few days only and are then absorbed into other systems.
Changes of shape and intensity are slight in tropical regions where pressure is generally low, but in temperate and polar latitudes changes are much more varied and rapid.

BUYS BALLOT’S LAW

In the 19th century the Dutch meteorologist Buys Ballot produced a law based on the observation

of wind direction and pressure systems.
Buys Ballot's Law states that: If an observer stands with his back to the wind, the lower pressure is on his left in the northern hemisphere, and on his right in the southern hemisphere.
A corollary of this law is that if an aircraft is experiencing starboard drift in the northern hemisphere the aircraft is heading towards low pressure. This is illustrated below.

PRESSURE GRADIENT

The pressure gradient is the difference in pressure between consecutive isobars divided by the distance between them, this is illustrated in the figure below.
Closely spaced isobars imply a steep pressure gradient (common in low pressure systems) and widely spaced isobars imply a shallow pressure gradient (common in high pressure systems). The pressure gradient produces an attractive force that will tend to pull molecules of air towards lower pressure areas. The greater the pressure change and the greater the pressure gradient force for a given distance the faster the wind velocity.
Consequently, by flying at a constant indicated altitude, say at 3,000 feet, the aircraft would be following the isobar marking the pressure which causes the altimeter to read 3,000 feet. In reality, therefore, the aircraft would be descending.
So, when flying from a high pressure area to an area of lower pressure, true altitude is reducing whilst the indicated altitude remains the same. You will doubtless realise immediately that this is a potentially hazardous situation. There is, however, a saying to help you remember this fact. "From High to Low, Look out Below."
In Figure 5.7, the situation is reversed, the QNH at the destination airfield being higher than at the departure airfield. The isobars, therefore, now slope upwards. So, if an aircraft were to fly from the departure airfield to the destination airfield, while maintaining a constant indicated altitude, the aircraft would climb, following the upwards-sloping isobars. This time true altitude is increasing, while the indicated altitude remains constant. This situation is not as dangerous as the former, since the aircraft's true altitude is increasing, but, nevertheless, the altitude indication is not accurate, so the altimeter subscale setting would not be suitable for landing.

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

The Standard Pressure Setting of 1013.2 millibars

Flight below a set transition altitude is conducted with the altimeter sub-scale set to an aerodrome
QNH or RPS, as these sub-scale settings allow a pilot to determine the vertical separation of his aircraft from the terrain beneath.
However, when the aircraft climbs through the transition altitude it is necessary to change to the Standard Pressure Setting (SPS). For flight at these higher altitudes, where variations in pressure are less likely to endanger the aircraft, flight at a constant altimeter pressure setting is

more convenient for the pilot, and for Air Traffic Control Units.

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

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

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

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

QNE

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

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

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

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

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

ALTIMETER PROBLEMS

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

True Altitude

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

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

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

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

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

MEASUREMENT

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

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

INSTRUMENTS

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

The Stevenson Screen is a louvred box 4 feet (1.22m) above the ground.

When sunlight reaches the Earth's surface, it is absorbed and warms the earth. Because the earth is much cooler than the sun, it radiates its energy at much longer wavelengths than the sun. Some of these longer wavelengths are absorbed and then re-transmitted as heat by gases such water vapour and CO2 in the atmosphere. This re-transmission of heat to the surrounding air is the main method by which the atmosphere is heated. Since there is more water vapour and CO2 in the lower atmosphere than in the upper atmosphere, then there will be more warming taking place within the lower atmosphere. This explains why the atmosphere reduces in temperature

with an increase in height. It is heated from below - hence there is an environmental lapse rate which is on average 0.65°C per 100 m.
The temperature difference between air above concrete runways and adjacent grass can be as much as 4 degrees. Higher temperature surfaces provide strong up currents called thermals or convection currents. Air over snow covered surfaces is very cold. 80% of solar radiation is reflected from snow surfaces.
Snow does not prevent the earth from radiating its heat. Hence surface air temperatures over snow will become colder day by day. Temperatures in Siberia can reach -72°C after a long cold winter. This very cold air results in high density and the development of anticyclones.

Latent heat describes the amount of energy in the form of heat that is required for a material to undergo a change of state or phase. Latent heat differs according to the state of the substance.
When ice changes to water, or water changes to water vapour, latent heat is absorbed.
When water vapour changes to liquid water, or water changes to ice, latent heat is released.
Figure 8.1. The Change of State from Solid to Liquid to Gas and Back Again.
The Change of State from Solid to Liquid to Gas and Back Again.

CHANGE OF STATE

Evaporation

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

Saturation

Air becomes saturated by adding more water vapour to it. Alternatively, as warm air can hold more water vapour than cold, saturation can be achieved by cooling the air.
Air is saturated if it contains the maximum amount of water vapour that it can hold at that temperature. If saturated air is cooled, condensation will occur.

Condensation

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

Freezing

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

Melting

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

Sublimation/Deposition

Sublimation is the change of state directly from water vapour to ice without water droplets

being formed. Latent heat is released. This process is also known as deposition.
The change of state from ice directly to water vapour is also called sublimation.

DIURNAL VARIATION OF HUMIDITY

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

We called this lapse rate the environmental lapse rate (ELR). It is important because this variable lapse rate controls the stability of the air. We also mentioned that the ELR changed from day to day and season to season, sometimes temperature increased with height (inversions) sometimes is was constant with height (isotherms). However, there is another type of temperature change that occurs in our atmosphere that takes place when air is moved.

Concept

In thermodynamics, an adiabatic process is a process in which no heat is transferred to or from a working fluid. The term "adiabatic" literally means an absence of heat transfer. What this essentially means is that it is possible to change the temperature of a fluid without adding or subtracting heat from it. This seems strange, but it is possible if the fluid is either compressed or expanded.
If air is compressed, the molecular movement or energy of the molecules is confined into a smaller and smaller volume. This makes the molecules hit each other more often, creating friction and generating more heat. Therefore, if air compressed, it warms up. This is called "Adiabatic Warming". You can appreciate this when you pump up a bicycle tyre with a hand pump, you'll notice the pump gets warm.
The reverse will take place if air is expanded. If air is expanded, the molecules will have a larger volume to move around in. Now the molecules are less likely to hit each other, and consequently they will not generate as much heat. Therefore, if air expands, it cools. This process is called "Adiabatic Cooling".

Adiabatic processes in the atmosphere

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

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

The reason for the difference between DALR and SALR

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

The reason for the SALR variation with temperature

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

STABILITY

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

Absolute Stability/Stable Air

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

Absolute Instability/Unstable Air

The atmosphere is described as unstable when a displacement force (such the prevailing wind causing air to be forced up the side of a mountain) causes air to be lifted, and then, if this lifting force is removed, the air continues to rise. The greater the displacement, the greater the tendency for the air to rise. The air is very susceptible to vertical motion.

The reason the displaced air continues to rise is because it has become warmer and therefore lighter than its surroundings. In other words, the lifted air parcel has cooled down more slowly than the surrounding environment, or the surrounding environment has cooled more quickly than the lifted air parcel. This can easily be seen by comparing the temperature change with height of the lifted air and the temperature change with height of the surrounding environmental air.

Neutral Stability

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

INTRODUCTION

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

CAUSES

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

☐ Thermal
☐ Frictional or mechanical

GUSTS AND SQUALLS

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

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

AREAS

The Turbulence occurs:

☐ In the Friction Layer
☐ In Clouds
☐ In Clear Air

IN THE FRICTION LAYER

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

CONDITIONS NECESSARY FOR FORMATION OF STANDING WAVES

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

TURBULENCE EFFECTS OF STANDING WAVES

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

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

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

VISUAL RECOGNITION FEATURES OF STANDING WAVES

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

☐ Lenticular, or lens shaped clouds which form on the crests of standing waves. They appear a few thousand feet above the mountain tops and at any level up to the tropopause, and sometimes above. Ragged edges indicate turbulence.
☐ Rotor, or roll-clouds occur under the crests of strong waves down wind of the ridge. The strongest rotor is normally formed in the first wave downwind and will be level or slightly above the ridge crest.
☐ Cap clouds form on the ridge and strong winds may sweep the cloud down the lee slopes.
Note: The characteristic clouds above may be obscured by other clouds and the presence of standing waves may thus not be evidenced.
If the air is dry, clouds may not form at all, even though standing waves are present.

JET STREAMS

Jet streams are narrow bands of fast moving air commonly found beneath the tropopause. These air currents can be very fast, especially over South East Asia in winter where the highest recorded velocity was 407 kt. Around these fast currents of air are eddies and shear lines, just like around the edge of powerful river. The shear lines are created when there is marked change in wind speed and direction. This is commonly called Wind shear and is creates very dangerous Clear Air Turbulence (CAT). Turbulence in jet streams is most severe:
☐ With stronger winds.
☐ With curved jet streams.
☐ Above and to the lee of mountain ranges.
☐ In the primary area for Maximum CAT associated with a jet stream which is near to or below the jet axis on the cold air (low pressure) side. In the Northern Hemisphere this will be found by looking downstream to the left hand side; in the Southern Hemisphere looking downstream to the right hand side of the jet core.
☐ With developing and rapidly moving jets.

TURBULENCE BENEATH CLOUDS

Beneath the base of cumulus congestus and cumulonimbus, convective upcurrents are also very strong. Downdraughts can be met beneath cloud base, too.
The most severe downdraughts occur in precipitation.
When precipitation falls from clouds, it tends to drag air down with it, creating downdraughts within, and underneath the cloud.

If the mass of air descending from the cloud is significant enough, a phenomenon known as a microburst, or, on a larger scale, a macroburst, is created.
If the downdraught descends from beneath a cumulonimbus or cumulus congestus, it may come into contact with the ground, and then spread out, from the cloud itself, sometimes up to distances from the cloud of 15 - 20 miles. This type of phenomenon causes large changes in the direction and speed of the wind in the vicinity of the cloud, both vertically and horizontally, and may, thus, give rise to dangerous low level wind shear.
Because of the weather phenomena such as microbursts and windshear associated with them, cumulonimbus clouds are extremely hazardous to aircraft. Flight below, and in the immediate vicinity of, large cumuliform clouds, especially cumulonimbus, should be avoided.

TURBULENCE REPORTING CRITERIA

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

LOW ALTITUDE WINDSHEAR

Vertical Windshear

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

Wind is air in horizontal motion. Wind Velocity (W/V) has both direction and speed.

Wind direction is always given as the direction from which the wind is blowing. It is normally given in degrees true, but wind direction given to a pilot by ATC or in an ATIS will be given in degrees magnetic.

A veer is a change in wind direction in a clockwise direction. Here the direction values are getting higher, for example, the wind direction goes from 090° to 120°.

A back is a change in wind direction in an anti-clockwise direction. This applies in both hemispheres. Here the direction values are getting smaller, for example, the wind direction goes from 290° to 220°.

GUSTS AND LULLS

A gust is a sudden increase in wind speed, often with a change in direction. It lasts only for a few seconds and is very local.

A lull is a sudden decrease in windspeed.

SQUALLS

A squall is a sudden increase in wind speed, often with a change in direction. It lasts for some minutes and can cover a wide area. It is often associated with cumulonimbus cloud and cold fronts.

GALES

A gale is a condition where the wind speed exceeds 33 kt, or if the wind gusts exceed 42 kt.

HURRICANES

A Hurricane (Typhoon, Cyclone) means a wind speed exceeding 63 kt.

Coriolis Force (Cf)

☐ Coriolis Force, (CF), is the force caused by the rotation of the earth.
☐ It acts 90° to the wind direction causing air to turn to the right in the northern hemisphere and to the left in the Southern hemisphere. CF is maximum at the poles and minimum at the equator.

Construction Of The Geostrophic Wind

Conditions Necessary For The Wind To Be Geostrophic

For the wind to be geostrophic, it has to occur:
☐ Above the friction layer.
☐ At a latitude greater than 15 degrees.
☐ When the pressure situation is not changing rapidly.
☐ With the isobars straight and parallel.

The geostrophic wind can apply at all heights above the friction layer. However, with an increase in height, the wind speed should increase due to the reduction in density.

THE GRADIENT WIND

The gradient wind occurs when the isobars are curved. This brings into play a force which makes the wind follow a curved path parallel to the isobars. The gradient wind then is the wind which blows parallel to curved isobars due to a combination of 3 forces:
☐ PGF
☐ CF
☐ Centrifugal Force

Centrifugal Force

Centrifugal force is the force acting away from a rotating body.
Figure 11.11 Centrifugal Force
Centrifugal Force

Gradient Wind In A Depression

If air is moving steadily around a depression, then the centrifugal force opposes the PGF and therefore reduces the wind speed. You can see this on the left hand side of the image shown below.

The gradient wind speed around a depression is less than the geostrophic wind for the same isobar interval. Hence if the Geostrophic Wind Scale (GWS) is used, it will overread.

Gradient Wind In A High

Looking to the right of the iagram, if air is moving steadily around a high, then the centrifugal force acts with the Pressure Gradient Force (PGF), increasing the velocity of the wind.

The gradient wind speed around an anticyclone is greater than the geostrophic wind for the same isobar interval. Hence if the Geostrophic Wind Scale (GWS) is used, it will underread.

THE ANTITRIPTIC WIND

The wind which blows in low latitudes (within 15°) where the Corriolis Force (CF) is very small is called the antitriptic wind.

WINDS BELOW 2000 - 3000ft (1 Km)

Friction between moving air and the land surface will reduce wind speed near the ground. This reduction also reduces the CF. This will cause the two forces in the Geostrophic Wind to be out of balance since now CF is less than PGF. The wind is now called a surface wind.

LAND AND SEA BREEZES

Sea Breezes

On a sunny day, particularly in an anticyclone with a slack pressure gradient, the land will heat quickly.

The air in contact will be warmed and will rise and expand so that pressure at about 1000 ft will be higher than pressure at the same level over the sea. This will cause a drift of air from over the land to over the sea at about 1000 ft. The drift of air will cause the surface pressure over the land to fall, and the surface pressure over the sea to rise.

As a result there will be a flow of air over the surface from sea to land - a sea breeze.

On average, sea breezes extend 8 to 14 nm either side of the coast and the speed is about 10 kts. In the tropics speed is 15 kts or more and the inland extent is greater.

An illustration of the formation of a sea breeze is shown below.

Land Breezes

After sunset the situation will reverse. The land will cool rapidly whilst the sea will retain its heat. There will be an increase in pressure at the surface over the land whilst the pressure over the sea will fall - there will be a land breeze. The speed will be about 5 kts and the breeze will extend about 5 nms out to sea.

The above example is typical in a wind system known as the Mistral. The Mistral is a strong wind which is mainly found around the southeast of France in the Gulf of Lion for up to 100 days of the year. A famous author once described the Mistral as a “brutal, exhausting wind that can blow the ears off a donkey”. In the case of the Mistral, air is cooled above the Massif

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Winds

Central, the central mountains of France and the Alps. Since the air is colder and denser than the surrounding air, it flows down slope feeding into the Rhône valley. The presence of the Rhône valley creates a funnel or venture effect, speeding up the current towards the Gulf. These winds may affect the weather in North Africa, Sicily and Malta or throughout the Mediterranean, particularly when low pressure systems form in the Gulf of Genoa.

Valley winds may also be considered in another way. During the night, or in the in the winter months, the mountain sides and slopes will cool. This cools the adjacent air increasing its density. Because of the slope, this denser and heavier air will start to descend from the mountain sides towards the valley. Such a wind is termed a Mountain Wind since the airflow is from the mountain. On the following pages you will also see that this wind is also known as a Katabatic Wind.

The reverse of the above wind pattern is true during the day and in the summer months especially. As the mountain sides and slopes start to warm from insolation, the air will become less dense and start to rise creating a flow of air from the valley to the top of the mountain. Such a wind is termed a Valley wind. On the following pages you will read that such a wind is also called an Anabatic Wind.

Examples of valley winds are the Mistral (Rhone Valley), (see Chapter 24) Genovese (Po Valley),
Kosava (Danube) and Vardarac (Thessalonika). Valley winds also occur in fjords.

KATABATIC WINDS

A katabatic wind (which simply means "going downhill"), is a wind that blows down-slope, for example, down hills or mountains. However, there is a difference between winds that feel warmer than their surroundings and those that are cooler than their surroundings. The more commonly used reference of a katabatic wind usually refers to the cold down-slope wind and is the reference that will be used in here. Examples of cold katabatic winds include the Mistral and the Bora which you will study later and examples of warm Katabatic winds are the Föhn, Chinook, Bergwind and Diablo.

The cold form of katabatic wind originates in a cooling of the air adjacent to the slope usually at night or in winter. Since the density of air increases as the air temperature falls, the air will flow downwards, warming adiabatically as it descends, but still remaining relatively colder than the surrounding.

Cold katabatic winds are frequently found on slopes or valleys in the early hours of the night when the ground cools from the release of terrestrial radiation. Such an example is clearly shown in the diagram above.

Over Antarctica and Greenland, extensive cold katabatic winds exist especially in winter. These winds slip off the large ice masses and push towards the sea. On their journey they are deflected by Coriolis force and form the Polar Easterlies. These easterlies are some of the fastest sustained wind speeds on the planet often reaching 100 miles per hour for days or weeks on end. Combine this with temperatures as low as -50°C and you get to realise why the Antarctic peninsular is so perilous.

ANABATIC WINDS

On a warm sunny day, the slope of a hill will become heated by insolation, particularly if it is a south facing slope.

The air in contact with the ground will be heated by conduction and will rise up the hill. Free cold air will replace the lifted air and so a light wind will blow up the hillside. An anabatic wind is a light wind of around 5 kts which blows up a hill or mountain by day.

FÖHN WINDS

The Föhn Wind is a warm dry wind which blows on the downwind side of a mountain range. It is a local wind in the Alps. A similar wind on the east of the Rocky Mountains in Canada is called the Chinook. There is also the Santa Anna to the east of the Andes in South America, and to the east of the High Sierras in California.

If moist air is forced to rise up a mountain side, it will quickly become saturated and will cool adiabatically as it rises. After reaching the condensation level, cloud will form and the air will cool at the SALR.

If the air is stable, it will follow the line of the mountain on the downwind side and descend. Some moisture may be lost at the top of the climb through precipitation (this is now thought to be a secondary effect) and air descending the lee slope will warm at the DALR.

The result is a warm, dry wind blowing on the downwind side of the mountain. Temperature increases of 10°C can occur. The drying and warming of air in this way creates many dangerous mountain fires, and are most notable along the coast of California.

Föhn winds can occur over the east coast of Scotland with a south west wind over the Highlands.

THERMAL WIND

The pressure changes that exist in the upper atmosphere that control our upper winds are directly related to the temperature differences between air masses. The figure below shows that the temperature difference between two air masses dictates the pressure we find in the upper atmosphere.

CONTOUR AND THICKNESS CHARTS

A Constant Pressure or Contour Chart is a chart where the pressure is constant everywhere. For example, as shown on the previous page we can see that the 800 mb pressure level varies with height. These heights are plotted as contour lines with the reference being MSL. The heights give us an indication of the distance that a pressure level is from MSL. If the pressure level is higher (as shown on the right hand side of the diagram) then we can assume a high pressure exists aloft. Conversely if the pressure level is much lower and the contour line shows a lower height (as shown on the left hand side of the diagram) then we can assume a low pressure is aloft.
A more useful chart that is similar in principle to the contour chart is the thickness chart. From the image at the beginning of the chapter you can see that a correlation exists between the thickness between two pressure levels, the temperature and upper air pressure. For example, warm air changes the pressure lapse rate such that it forces the pressure levels apart, increasing the thickness between the pressure levels and eventually increasing the pressure at any given height. Thus we can assume that the greater the thickness (vertical spacing) between the pressure levels, the higher the upper air pressure, and conversely, the smaller the thickness, the lower the upper air pressure.
Hopefully, having understood the concept, lets now look at a sample chart shown below. This chart is simply a plot of the vertical spacing between the 1000 hPa and the 500 hPa pressure levels. The thickness is measured in decametres or dams. These are tens of metres, so 530 dams is 5300 metres. Lines of equal thickness are then plotted on the chart. These lines are in fact contour lines but are more specially they are referred to as isohypses.
Notice that to the south, the warmer temperatures have made the thickness between the pressure levels greater, and the thickness is about 5,700 m between the 1000 hPa level and the 500 hPa level. This means that a higher upper air pressure is located to the south. Towards the north, where temperatures are lower, the thickness is less, at about 5000 m. This means that lower upper air pressure is located to the north. As a result of the pressure variation, the upper air will try to move north towards the lower pressure but it will be deflected to the right in the northern hemisphere, much like surface winds were.

GENERAL UPPER WINDS

So far we have learnt a fundamental principle for understanding upper wind direction in relation to cold and warm air. This principle is actually a slight adaptation of Buys Ballots law. This upper wind principal states that:
"With your back to the upper wind, the cold air is to your left in the northern hemisphere and to your right in the southern hemisphere."
You can see this rule working in the previous diagram. In the Northern Hemisphere, with you back to the wind the cold air is to your left and the warmer air is to your right. We can use the principle we have just learnt to help create a simple model of the general upper wind patterns of the world.
Using the image below and focusing on the Northern Hemisphere you can see the cold air at the North Pole. As a result of the cold surface conditions we should expect a low pressure zone

appearing at high altitude over the pole. This means that at high altitudes, air will be drawn pole-wards, but in the northern hemisphere this will be deflected to the right by coriolis force and the resultant wind will be westerly. Or more simply, just use the upper wind principle, with you back to the wind, the cold air is to your left.

The same exercise can be done in the Southern Hemisphere. Use the principle to help you see the general upper wind direction. Using the cold South Pole, with your back to the wind, the cold air is on the right. To make the cold air on the right, the upper wind must be westerly. However, there is a band of easterlies around the equator which do not seem to follow the upper wind principle we have just studied. In actual fact, these winds do observe the principle, but to understand why, we must look more carefully at the temperature around the equator. Using the image below, this is for June & July, notice that the hottest place on the earth is theoretically at 23.5°N. This means that the equator, by comparison, is a little cooler. Use the upper wind principle in the region between the real equator and the heat equator. Here, with your back to the wind, the cooler air must be on the left. For that to occur the wind must be an easterly

JET STREAMS

As we go higher in the troposphere, the density decreases and the temperature effect overwhelms the pressure effect, hence winds become progressively westerly with height. The strongest winds are to be found just below the tropopause and where these winds exceed 60 kts they are termed jet streams. For examination purposes we assume a jet stream to be about 2000 miles long, 200 miles wide and 2 miles deep. This gives a width to length ratio of 1:10 and a depth to width ratio of 1:100. Speeds of over 300 kts have been recorded, though these are rare.

CAUSES

Jetstreams are caused by large mean temperature differences in the horizontal, i.e. large thermal components

LOCATIONS

There are two main locations:

☐ Sub tropical jetsteams form in the area of the sub-tropical anti-cyclones. They are more or less permanent but move seasonally with the sub-tropical highs. They occur in the latitude bands 25° to 40° in winter and 40° to 45° in summer. The jet core is at the 200 hPa level.

DIRECTION AND SPEED

The direction of jet streams is generally westerly, maximum speeds occur near the tropopause, 200 kts have been recorded in Europe/N Atlantic and 300 kts in Asia.
In equatorial regions there are however some easterly jets.

CLEAR AIR TURBULENCE

Clear air turbulence (CAT). occurs around the boundaries of jet streams because of the large horizontal and vertical windshears. It is strongest near to, or just below, the jet axis on the cold air (low pressure) side with a secondary area above the axis.

MOVEMENT

As with most other weather phenomena, Jet streams move with the sun.
Sub-tropical jets, based on Hadley Cells, will move north in the northern summer as the heat

equator moves north and then south in the northern winter.
Polar Front Jets in the northern hemisphere will move north (and decrease in speed) as the Polar Front moves north in summer. During the winter the Polar Front moves south and because of the greater temperature difference, the speed will increase.

RECOGNITION

☐ From the ground, when the cloud amounts allow, jets may be recognised by wind blown wisps of CIRRUS cloud blowing at right angles to the clouds at lower levels.

Clouds are signposts in the sky which indicate to the pilot possible weather problems, such as:
¾¾ Turbulence
¾¾ Poor Visibility
¾¾ Precipitation
¾¾ Icing

CLOUD AMOUNT

Cloud amounts are reported in OKTAS (eigths). It is assumed that the sky is divided into 8 equal parts and the total cloud amount is reported by an assessment of the number of eighths of the sky covered by cloud.
FEW 1 to 2 OKTAS
SCT 3 to 4 OKTAS
BKN 5 to 7 OKTAS
OVC 8 OKTAS

CLOUD BASE

"That lowest zone in which the type of obscuration perceptibly changes from that corresponding to clear air haze to that corresponding to water droplets or ice crystals." The cloud base is the height of the base of the cloud above ground - above official aerodrome level.

CLOUD CEILING

"The height above aerodrome level of the lowest layer of cloud of more than 4 oktas" .

MEASUREMENT OF CLOUD BASE

¾¾ By day a balloon with a known rate of ascent is released and the time between release and the disappearance of the balloon into cloud is noted. From this cloud base can be calculated.

THE CLOUD BASE RECORDER

A cloud base recorder or ceilometer is a device that uses a laser or other light source to determine the height of a cloud base. There are several types of ceilometers depending on whether a normal light source or a laser light source is used.

¾¾ The first type of ceilometer uses a normal light source. There a several versions of such ceilometers. The optical drum ceilometer consists essentially of a projector, a detector, and a recorder. The projector emits an intense beam of light into the sky. The detector, located at a fixed distance from the projector, uses a photoelectric cell to detect the projected light when it is reflected from clouds. In the fixed-beam ceilometer, the light is beamed vertically into the sky by the projector and the detector is aligned at various angles to intercept the reflected light; in the rotating-beam ceilometer, the detector is positioned vertically and the light projected at various angles. In either case, trigonometry is used to determine the altitude of the clouds reflecting the light from a knowledge of the angle at which the light is detected and the distance between the projector and detector. The recorder is calibrated to indicate cloud height directly.

¾¾ A laser ceilometer consists of a vertically pointing laser and a receiver house in the same instrument assembly, as shown above. It determines the height by measuring the time required for a pulse of light to be scattered back from the cloud base. The laser ceilometer is more accurate and more reliable than the other types of recorders and as such it is the main type of recorder currently in use.

MEASUREMENT OF CLOUD TOPS

The height of cloud tops is obviously not as easy to measure as that of the cloud base. Meteorologists may be able to make a visual assessment, if conditions permit, but more usually they will use RADAR or employ aircraft observation.

CLOUD MOVEMENT

Meteorological stations measure the movement of clouds by means of a Nephoscope. This measures the angular speed of movement of cloud and if the base height is known, the speed of movement may be calculated. A Besson Nephoscope is shown below.

CLOUD CLASSIFICATION

Classification of cloud type is based, primarily, on the shape, or form of the cloud. The basic forms of cloud are stratiform, cumuliform and cirriform.

Stratiform cloud is a layered type of cloud of considerable horizontal extent, but little vertical extent.

Cirriform cloud is a cloud which is fibrous, wispy or hair-like in appearance. This type of cloud is found only at high levels in the Troposphere.

Clouds are also identified by reference to the height at which they occur. There are 3 distinct cloud levels within the troposphere.

¾¾ **Low-level clouds** are those which are found between the surface and 6,500 ft. These clouds may be stratus, stratocumulus, cumulus and cumulonimbus. (The suffix nimbus implies "rain bearing".) However, cumulus and cumulonimbus will have significant vertical development and will extend from low-level to higher levels. Cumulonimbus clouds may even extend up to the Tropopause.

¾¾ **Medium-level clouds** are found between 6,500 feet and 23,000 feet.

The names of medium-level clouds are characterised by the prefix "alto-": such as altostratus and altocumulus. Nimbostratus is also a medium-level cloud, but it may also extend into both the lower and upper levels of the atmosphere.

¾¾ **High-level clouds** are generally found between 16,500 feet and the Tropopause. The names of high-level clouds are prefixed by "cirro-": cirrostratus, cirrocumulus, and cirrus. (Latin cirrus means curl.)

Stratus (St)

Stratus (from Latin stratum, meaning strewn) is generally a grey, layered cloud with a fairly uniform base, which may produce drizzle, or light snow. Stratus cloud is no more than 1,000 - 1 500 ft thick, and is often much thinner. Stratus is usually the lowest of all cloud types. The main hazard associated with stratus is that it often covers high ground, concealing hill tops from pilots and producing hill fog for hikers. When stratus is at its thinnest, the sun can be clearly seen through the stratus layer. Usually the cloud base is between the surface and 2,000 ft above ground level.

Nimbostratus (Ns)

Nimbostratus is a dense, dark-grey, rain-bearing, stratiform cloud, producing extensive and long-lasting continuous precipitation. Usually the cloud base is between the surface and 10,000ft above ground level.

Cumulus (Cu)

Cumulus cloud is the most common form of convective cloud, being classified as heaped cloud, from Latin cumulare meaning to heap up. For glider pilots, a developing cumulus is regarded as a reliable indication of the presence of thermal upcurrents which, if skilfully exploited, can enable the glider to gain height. Pilots of light aircraft, on the other hand, will note that, on a day when the sky is peppered with fine-weather cumulus flight below cloud base is turbulent, whereas, above the cloud tops, the air is likely to be very smooth

Stratocumulus (Sc)

Stratocumulus cloud is probably the most common form of cloud in the skies of the United Kingdom. It appears grey, or whitish, but usually always has distinct dark parts. Stratocumulus can be seen as patches, or in a continuous layer. Stratocumulus is usually no more than 2,000 to 3,000 feet thick, but may become 5,000 to 6,000 ft deep in certain conditions. Usually the cloud base is between 1,000 ft and 4,500 ft.

Cirrus (Ci)

Cirrus (from Latin cirrus, meaning curl) is the highest of all the cloud types and is composed entirely of ice crystals. Cirrus clouds take the form of white delicate filaments, in patches or narrow bands. They may also be described as fibrous or hair-like. Cirrus clouds can be found between 16,500 and 45,000 ft. They often herald the approach of a warm front.

Cirrostratus (Cs)

Cirrostratus is a transparent, whitish cloud-veil of fibrous or smooth appearance, totally or partially covering the sky.

Cirrostratus is made up of ice crystals, and lies between 18,000 and 45,000 ft. Cirrostratus is a further warning of an approaching frontal system, and, like altostratus, may cause the Sun and Moon to appear with a halo.

Cirrocumulus (Cc)

Cirrocumulus is probably the cloud which is least often seen in the sky. Cirrocumulus is a thin, white and patchy layer of cloud, with ripples, more or less regularly arranged. Cirrocumulus consists of ice crystals and is generally found between 20,000 and 30,000 feet.

VERTICAL MOTION

Cloud is formed by air being lifted and cooled adiabatically until the water vapour condenses out as water droplets. The height at which this occurs is called the condensation level. It is also the height of the cloud base.

The means whereby the initial lifting of the air occurs are as follows:

☐ Turbulence.
☐ Orographic Uplift.
☐ Convection.

☐ Slow, widespread ascent (frontal uplift).
☐ Convergence

Note: The lifting processes above are strictly all 'convection'; process c.is free convection, the rest are forced convection.

CONDENSATION LEVEL

If an unsaturated parcel of air rises (either because it's buoyant or it is forced to do so) it will cool adiabatically. This cooling increases the relative humidity of the parcel of air until eventually the temperature of parcel has reached dew point temperature and the relative humidity will be 100%. At this point the air parcel is saturated and further ascent and cooling will cause condensation and cloud to form. The level in the atmosphere at which this happens is called the condensation level. It usually marks the base of any cloud formations.

OROGRAPHIC CLOUD

Air meeting a ridge of high ground will be forced to rise. If the air is sufficiently humid the condensation level will appear below the crest of the ridge & cloud will form.

Orographic Cloud – Stable Conditions

If the air is stable and precipitation occurs, the air will descend on the LEE side and the cloud base will be higher than on the windward side and this will generate warmer surface temperature - the Fohn effect.

If the air is dryer, then the cloud base will be above the ridge and lenticular cloud would result.

Lifting in unstable conditions can produce Cu or Cb clouds and also thunderstorms if there is enough water vapour present.

Strong winds with moist air can cause convective instability and Cb and thunderstorms. The Cb can be embedded in other cloud types, eg frontal or Turbulence cloud.

CONVECTION CLOUD

Critical Temperature. Before dealing with the formation of convection cloud we must consider the critical, or convective temperature. The image below shows air rising and cooling at the DALR at 0700,0800 & 0900 hrs. The first two ascents result in the air reaching the same temperature as the environment which stops any further ascent. However, at 0900 the rising air reaches the Dew Point line, cloud forms and the air now cools at the SALR & continues rising, but it importantly stays warmer then the surroundings and the cloud formation continues

WIDESPREAD ASCENT (FRONTAL UPLIFT)

At a front there is widespread lifting of air as warm air comes into contact with colder air. Layer type clouds form in the stable air at a warm front and heap clouds in the unstable air at a cold front..

CONVERGENCE CLOUD

When there is low pressure there is always convergence at the surface which leads to air being lifted. Thus in depressions and troughs, where there are no actual fronts, cloud formation occurs.

With strong convergence at a trough, lifting can cause instability to develop so that the cloud type is Cu or Cb with possible thunderstorms.

MOUNTAINOUS AREAS

We have seen how orographic lifting produces cloud; in mountainous areas this may be very active and produce extensive cloud and vertical development due to Convective Instability. Additionally, this may increase the intensity of precipitation.

Figure 14.14 Mountainous terrain

Mountainous terrain

INVERSIONS

An inversion in the atmosphere is where temperature rises with an increase in height. This produces extreme stability and inhibits the formation of cloud. An inversion always exists above turbulence cloud and inversions have a similar effect at ANY altitude.

PRECIPITATION

Clouds consist of water droplets averaging 0.02 mm in diameter and the rate of fall is negligible. By colliding with other droplets they may increase in size until they are too heavy to be supported

by the up currents in the cloud and they drop out as precipitation.

There are currently two theories governing the formation of these precipitation drops.

BERGERON THEORY

The Bergeron theory presumes that at high levels in the cloud, some of the water droplets will turn

to ice and will grow in size by sublimation of water vapour and collision with supercooled water droplets. The frozen droplets will be much heavier than the existing water droplets and drop out at the bottom of the cloud, either as Snow or Raindrops, depending on the temperature.

COALESCENCE THEORY

It is difficult to see how the above can account for summer precipitation where the whole of the cloud is at a temperature above zero and the coalescence theory may provide a better answer. This assumes the presence of a range of droplet sizes, the larger falling faster and uniting with the smaller until eventually the overweight drop falls out as drizzle or rain.

PARTIAL PRESSURE OF WATER VAPOUR OVER ICE AND SUPERCOOLED WATER

Over ice, water vapour will condense as ice crystals at subzero temperatures at less than 100% relative humidity. However over supercooled water the RH remains at 100%, hence ice crystals can form at a much lower pressure over ice than over supercooled water.

CONDITIONS

Thunderstorms occur in well developed Cumulonimbus (Cb), though not all Cb's produce thunderstorms. They are most likely to occur when there is:

☐ A lapse rate greater than the SALR (unstable conditions) through a layer at least 10,000 ft thick and extending above the freezing level.

☐ Sufficient water vapour to form and maintain the cloud.

☐ Trigger action to produce early saturation, thus enhancing instability.

The so-called triggers or lifting forces are:

☐ Convection

☐ Orographic uplift
☐ Convergence
☐ Frontal uplift

Thunderstorms are classified as:

☐ Heat, or airmass type (more common in summer time).
☐ Frontal type (more common in winter time).

HEAT TYPE THUNDERSTORMS

Heat type thunderstorms are:

☐ Isolated - all triggers except frontal.
☐ Most frequent over land in summer.
☐ Formed by day, clear by night.
☐ Formed in cols or weak lows.

Note: Thunderstorms formed by advection can occur day or night, over land or sea or at any time of the year.

FRONTAL TYPE THUNDERSTORMS

Frontal thunderstorms are;

☐ most frequent in winter.
☐ formed over land or sea, day or night.
☐ usually formed in a line at a cold front or occlusion.
☐ found in active depressions or troughs.
☐ often accompanied by a line squall.

Up currents remain strong and can be up to 10,000 fpm. Tops may rise at 5,000 fpm or more. There can be extreme turbulence in, under and all around the cloud.

At the bottom leading edge of the storm there can be a roll of Sc and a strong gust front can be experienced up to 13 to17 nm (24 to 32km) ahead of the storm and be up to 6,000 feet in depth. Below the cloud a squall and associated wind shear can be expected.

Microbursts are possible where the down currents are very strong and are confined to a region in the cloud no more than 3nm (5km) across and a duration of less than 5 minutes.

Macrobursts are slightly larger in area than microbursts and are said to affect an area between 3 and 5miles across as the entire cold air outflow leaves the thunderstorm or group of thunderstorms (classification Dr. Ted Fujita.). These are typically of more than 5 minutes duration.

Rising and falling water droplets will produce a considerable build-up of **static electricity**, usually of positive charge at the top of the cloud and negative at the bottom. The build-ups eventually lead to **lightning** discharge and **thunder**.

The mature stage lasts for a further 15 to 20 mins and this stage is characterised by both up and down draughts.

Electrostatic Charge on a Thundercloud

Dissipating stage

At this stage there is a wider distribution of **precipitation**, which is heavy, and extreme turbulence. Thunder and lightning may possibly occur at this stage. This stage is characterised by predominantly downdraughts.

The cloud extends to the tropopause, where it is spread out by the upper wind to form an anvil. At these levels the cloud thins to form Ci.

Large variations in static charge in and around the cloud cause discharge in the form of lightning which can appear in the cloud, from the cloud to the ground, or from the cloud to the air alongside.

The dissipating stage lasts for a further 1½ to 2½ hours. **MOVEMENT OF THUNDERSTORMS** Thunderstorms usually move in the direction of the 10,000 ft (700 mb) wind, though large storms and newly developed ones may differ from this.

ALIGNMENT

Frontal thunderstorms will often appear along a **squall line**. This is usually an indication of severe weather. The thunderstorm cells will be in varying stages of development.

FORECASTING

Forecasting the occurrence of thunderstorms will be largely a matter of assembling the conditions

necessary for the formation and the triggers. A combination of these two groups will indicate the probability of thunderstorms. **Satellite photography** and **computer modelling** are used to predict this occurrence.

Mature Stage

Characteristics of the mature stage are:

☐ _Very strong up and down draughts produced in the one large (super) cell give rise to violent weather and even tornadoes (an average of 33 tornadoes per year have occurred in Britain over recent years reminding us that they are not a phenomena restricted to the USA).

☐ _The mature stage may last several hours.

Movement

In the Northern hemisphere movement is usually about 20° to the right of the 18,000 ft (500mb) W/V.

Location

Supercell thunderstorms are more common over continental land masses than over maritime areas. Thunderstorms over the mid-west states of the USA producing tornadoes are good examples.

RADAR

Airone Weather Radar (CCWR) is Plan Position Indicator (PPI) radar, but ground radar, though

mostly PPI, may also use RHI (range-height indicator). CCWR is explained elsewhere in this course, but the returns from many radars are combined to produce an area display which will be multicoloured to identify different precipitation intensities.

A **Stormscope** is a highly sophisticated system that detects, locates and maps areas of electrical discharge activity contained within thunderstorms permitting avoidance of the associated hazards.

SUMMARY OF THUNDERSTORM HAZARDS

☐ **Turbulence**. Turbulence can be violent both within cloud and at their sides. Below the cloud, turbulence can be dangerous during take-off and landing and there can be wind shear. It is possible for a pilot to overstress the airframe in these conditions.

Loose articles being thrown about inside the aircraft cabin can injure passengers. Pressure instruments can be in error due to lag.

☐ **Icing**. This can occur at all heights in the cloud where the temperature is between 0°C and -45°C. Heavy concentrations of droplets and large droplet size result in severe clear icing.

Carburettor icing can occur at temperatures between -10°C and +30°C and it can be particularly severe between -2°C and +15°C.

☐ **Lightning**. Lightning is most likely to occur within 5,000 ft of the freezing level. Temperature between 20°C and -10°C. There are 3 effects which can be expected:

yy It can cause a pilot to be temporarily blinded.

yy Compasses can become totally unreliable.

yy Some airframe damage can be caused, particularly with composite aircraft.

☐ **Static**. This causes interference on radio equipment in the LF, MF, HF and VHF frequencies. St Elmo's fire can be caused by static and it results in purple rings of light around the nose, wing tips and propellers. This is not a hazard, but it indicates that the air is electrically charged and lightning is probable.

☐ **Pressure variations**. Local pressure variations covering only a very small region, in or close to, a storm can occur causing QFE/QNH to be in error, so that altimeter readings can be inaccurate by as much as ±1000 ft at all heights. These, together with gust effects, can cause height errors at low level which can be dangerous.

☐ VSI's will also be subject to errors. The aircraft should be flown for ATTITUDE rather than altitude, though some attitude indicators may not be able to cope with the changes of attitude produced but the severe turbulence likely to be encountered.

☐ **Microbursts**. These are down currents in the cloud which also move outwards by reaction from the ground, having speeds considerably in excess of 1000 feet per minute downwards (up to 6000 fpm) and 50 kts horizontally. The windshear (headwind to tailwind) may be between 50 & 90 kts. They are largely caused by descending raindrops which cool the surrounding air by evaporation, the higher density accelerating the down draught still further.

☐ **Water ingestion**. If up draught speed approaches or exceeds the terminal velocity of the falling raindrops, the resulting high concentrations of water can exceed the design limits for water ingestion in some turbine engines. The result can be engine flameout and/or engine structural failure. Water ingestion may also affect pitot heads, even though heaters have been switched on.

☐ **Tornados**. These are usually associated with severe thunderstorms and Tropical Revolving Storms (TRS), particularly in the mid-west of the United States of America although they do occur in Europe albeit of a lower intensity.

They take the form of a violent whirlwind extending up from the ground into the base of the Cumulonimbus cloud.

The speed of the air in the vortex has been known to exceed 200 knots.

The width of the vortex is typically less than 300 metres horizontally, (average diameter 100m to 150m).

Further discussion on tornadoes will be given in the syllabus topic of "OTHER DEPRESSIONS" later in the Meteorology Theory lectures.

INTRODUCTION

Meteorological Optical Range (MOR), or more simply 'met vis' is the greatest horizontal distance at which a dark object can be recognised by an observer with normal eyesight, or at which lights of specified candlepower can be seen by night.

Ground visibility is the visibility of an aerodrome as reported by an accredited observer.

Up to the 25th of November 2004 'minimum visibility' has been reported as part of the METAR, TAF and SPECI coding. 'Prevailing visibility' has now been implemented in the METAR and TAF coding as from 25th November 2004 and has replaced the reporting of 'minimum visibility'.

Prevailing visibility is defined as the visibility value, which is reached or exceeded within at least half the horizon circle or within at least half of the surface of the aerodrome. These areas could comprise contiguous or non-contiguous sectors.

The lowest or 'minimum visibility' will also be reported in the METAR, after the prevailing visibility, if the visibility in one direction, which is not the prevailing visibility, is less than 1500 metres or less than 50% of the prevailing visibility. A direction will also be appended to this minimum visibility as one of the eight points of the compass. If the lowest visibility is observed in more than one direction, then the most operationally significant direction should be reported. (No direction is required for the prevailing visibility.) When the visibility is fluctuating rapidly and the prevailing visibility cannot be determined, only the lowest visibility should be reported, with no indication of direction.

In SYNOPTIC visibility reporting, the lowest visibility will be still be used.

OBSCURITY

In effect, visibility is a measure of **atmospheric clarity**, or **obscurity**. This obscurity can be caused by **water droplets** - cloud, fog, rain, or **solid particles**-sand, dust or smoke, or by a mixture of the two - smog (fog and smoke). Ice, in the form of crystals, hail or snow will also reduce visibility.

Poor visibility is usually associated with **stable** conditions, an inversion and light winds.

Visibility is generally better upwind of towns and industrial areas.

The various types of reduction in visibility are:

☐ **Mist**. There is mist if the visibility is 1000m or more and the relative humidity is greater than 95% with very small water droplets.

☐ **Fog**. There is fog if the visibility is less than 1000m and the obscuring agent is water droplets. Relative Humidity (RH) will be near 100%.

☐ **Haze**. There is haze if the visibility is reduced by extremely small solid particles - sand, dust or smoke. If the visibility is reduced below 1000m. Again, haze is not reported when the visibility is more than 5000m.

RADIATION FOG

Radiation fog is caused by radiation of the earth's heat at night, and the subsequent conductive cooling of the air in contact with the ground to below dew point.

If there is a light wind, then fog will form, in calm conditions the result will be the formation of dew. The fog is not usually more than a few hundred feet thick.

Conditions necessary for radiation fog to form.

☐ **Clear sky** - to increase the rate of terrestrial radiation.

☐ **High relative humidity** - so that a little cooling will be enough to cause saturation and condensation.

☐ **Light wind** - of 2 - 8 kts to mix the layers of air causing turbulence so that droplets will be kept in suspension and so that warmer air from above can be brought into contact with the cold ground to thicken the fog.

Conditions necessary for advection fog to form

- Winds up to 15kts to move the air. (May be stronger over sea areas)
- A high RH so that relatively little cooling is required to produce saturation and subsequent condensation.
- A cold surface with a temperature lower than the Dew Point (DP) of the moving air to ensure condensation.

Times of occurrence and location

- Over **land** areas in **winter** and **early spring**.
- Over **sea** areas in **late spring** and **early summer**.
- Occurs particularly when a SW wind brings tropical maritime air to the UK.

Dispersal

- By a **change of airmass**. (Wind change).
- By a windspeed **greater than 15kts** which will lift the fog to form stratus cloud.

SPECIAL AREAS

Nearly all sea fogs are caused by advection. Good examples are the extensive and persistent sea fogs which occur in the region of the **Grand Banks of Newfoundland** and around the **Kamchatka Peninsula** in the North Pacific.

In both cases warm air from the south moves over a cold sea current flowing down from the north.

FRONTAL FOG

Frontal fog occurs at a warm front or occlusion. The main cause is **precipitation lowering the cloud base to the ground.**

Subsidiary causes are:

- Evaporation of standing water on the ground.
- Mixing of saturated air with non-saturated air below.

The fog can form along a belt up to 200 nm wide which then travels with the front. Can be increased by orographic lifting. Will be dispersed by the passing of the front.

Airframe icing can cause a serious loss of aircraft performance and this will frequently result in a large increase in fuel consumption and some difficulty with aircraft control.

Icing is difficult to forecast and therefore there is a need for a full understanding of the processes involved.

Ice will form on an airframe if there is:

- Water in a super cooled liquid state.
- Ambient air temperature below 0°C (but see later).
- Airframe temperature below 0°C.

SUPERCOOLED WATER DROPLETS (SWD).

A supercooled water droplet is a droplet of water still in the liquid state although its temperature is below 0°C. If the SWD contains a **freezing nucleus** then the droplet will start to freeze. Mention was made in humidity chapter of **condensation nuclei**, but as the number of freezing nuclei in the atmosphere is considerably less than these, the state of supercooling is a frequent occurrence. Supercooled water droplets can exist in clouds at temperatures as low as -40°C. However, when an aircraft strikes a supercooled water droplet, it will start to freeze. Supercooled water droplet size is dependant on the size of the basic cloud droplet, (controlled by cloud type) and the temperature.

Sizes will be:

□ **0°C to -20°C**; both large and small supercooled water droplets can exist. The cloud type will govern the size or droplet supported. For example Stratiform cloud will only support small droplets even through the temperature may allow for both sizes. Cumuliform cloud can hold both types, but large droplets will be predominant.

□ **-20°C to -40°C**; small supercooled water droplets can exist. At these temperatures large supercooled water droplets will have become ice.

□ **Below -40°C**; only very small supercooled water droplets can exist. All others will have become ice. Freezing will occur without the aid of nuclei.

THE EFFECTS OF ICING

□ **Aerodynamic.** Ice tends to form on leading edges, thereby spoiling the aerodynamic shape. The result is **reduced lift, increased drag, increased weight, increased stalling speed** and **increased fuel consumption.**

- Ice, frost or snow of a thickness and roughness similar to coarse sandpaper can reduce lift by 30% and increase drag by 40%.
- It is also possible for pieces of ice to break off other surfaces and to jam between the control surfaces and wings and tail.

□ **Weight.** In severe conditions, ice can form at a rate of 1 inch in 2 minutes.

- There will be a loss of stability due to the weight of ice not being uniform across the airframe.
- This can lead to a displaced C of G. Similar uneven weight of ice on propeller blades can cause severe engine vibration.
- Ice breaking off propellers can cause skin damage.

□ **Instrument effects.** Ice can block pressure heads and the readings of ASIs, VSI, altimeters and mach meters can be in error as a result.

□ **General.** Windscreens and canopies can be obscured.

- A thin film of ice/frost can cause skin friction.
- Ice in landing gear wells can affect retraction.
- Ice on aerials can cause static interference.

CLEAR (OR GLAZE) ICE

If a large supercooled water droplet strikes an aircraft, it will start to freeze and this will release **latent heat** . This will delay the freezing process whilst part of the supercooled water droplet will flow back over the impact surface forming **clear ice**. The amount of a supercooled water droplet that freezes on impact is 1/80th of the droplet for each degree below freezing.

Clear or glaze ice is a transparent form of ice formed by **large** supercooled water droplets, it can be very dangerous. There can be much flowback and the ice appears transparent because there is no air trapped under the flowback icing. The lamination of the ice into layers increases its strength and because it has less air in it this type of ice is much stronger and much harder to remove.

RIME ICE

When the super cooled water droplets are small (at very low temperatures) or when cloud droplets are small, the whole droplet freezes instantly on impact, each droplet sticking to the surface it strikes and becoming solid almost at once.

Air becomes trapped between each frozen droplet, which makes the ice white. Rime ice is characterised by being a **white opaque** deposit with a granular or flake like texture. It is caused by **small**, super cooled water droplets freezing instantly. This types of ice is weak and very brittle. There is little or no flowback. The ice grows out from the leading edges and is compacted by the airstream.

Some loss of aerofoil shape can occur and **air intakes** can be affected.

Rime ice can occur in any cloud where there are small super cooled water droplets; Ns, As, Ac, SC, St and the parts of heap clouds where super cooled water droplets are small which mainly near the top of the cloud.

PACK SNOW

Pack snow is icing which is due to a mixture of super cooled water droplets and **snow**. It can block air intakes and other aircraft openings. Normally the effects are **slight**.

HOAR FROST

Hoar frost is a **white crystal deposit** which appears similar to frost on the ground. It occurs in **clear air**. Hoar frost will form if the airframe temperature is **below** 0°C and the ambient temperature is lowered to saturation level. Water vapour in contact with the airframe is converted to ice crystals without becoming liquid, i.e. **sublimating**. This process requires the presence of another type of ice nucleus, the **sublimation nucleus**. Their composition is usually inorganic, e.g. volcanic dust, clay or soil particles.

ICING FORECASTS

Forecasting airframe icing is a matter of forecasting clouds, both by type and vertical extent. The degree of airframe icing is classed as **light, moderate** , or **severe .**

When rain ice is expected, it will be mentioned specifically in the forecast. Forecasts of engine icing are not normally provided.

FREEZING LEVEL

The height where ambient temperature is zero is called the freezing level.

It is usually given in forecasts on an area basis by reference to the height of the **Zero Degree Isotherm**.

With an inversion, two freezing levels are possible.

JET ENGINE ICING

Ice may form on intake lips or inlet guide vanes, if this breaks away and enters the engine, blade damage may occur.

Some icing may occur in the early inlet stages, particularly at high engine speeds and low aircraft forward speeds (eg during the approach), where much adiabatic cooling may occur and temperature reductions of 5°C and more can result.

This icing is particularly prevalent in freezing conditions which are associated with any form of precipitation; as a consequence of this, engine anti-icing **must be selected "ON" when there is precipitation and the indicated outside air temperature is +10°C and below.**

JET ENGINE OPERATION IN ICING CONDITIONS

☐ Engine power indications may be in error if there is ice on engine inlet (P1) pressure probes.

☐ Engine igniters should be used in potential icing conditions, otherwise engine failure is possible.

☐ Long flights at very low temperatures may cause fuel freezing and fuel freezing point specification for the aircraft type should be known.

☐ Clear ice can occur at ambient temperatures above zero when water droplets come into contact with an aircraft whose upper surfaces are at or below zero.

- This low skin temperature can be caused by a very low fuel temperature conducting through the skin.
- This icing can also occur on the ground in high humidity, rain, drizzle or fog. It could then be snow covered and difficult to detect.
- Break up of this ice on take-off can be particularly hazardous to rear engined aircraft.

☐ Operation of anti-icing or deicing equipment usually implies a performance penalty.

AIRMASS INTRODUCTION

An air mass is a large volume of air where the humidity and temperature in the horizontal are more or less constant.

The temperature and humidity properties are obtained by the air remaining roughly stationary over a surface where conditions are generally constant for some length of time - a high pressure area. Therefore at source, all air masses must be **stable**.

Figure 2G0e.n1e Grael Snoeurarcl eS Roeugricoen sRegions

The basic properties of stability, temperature and humidity can change as an air mass moves over surfaces with different properties.

An air mass moving to a warmer area will become heated in the lower layers and should become:

☐ Unstable.

☐ Warmer.

☐ Lower relative humidity.

An air mass moving to a colder region should become:

☐ More stable.

☐ Colder in the lower layers.

☐ Have an increased relative humidity.

☐ **Polar Maritime**.

Source: North Atlantic: stable, cold, absolute humidity **low**, relative humidity **high**.

Weather: Cold, moist, NW airflow. On approaching UK becomes unstable giving Cu, Cb, heavy showers, sometimes hail and thunderstorms. Cu, Cb most likely over NW coasts. Visibility good except in showers. Bumpy flying. At night inland the cloud dissipates, the clearing skies causing a low level inversion with stable air below - ideal conditions for radiation fog.

☐ **Polar Continental**.

Source: Siberia (winter only). Stable, very cold and dry.

Weather:

- If the airflow is mainly from the E via continental Europe, then very cold, very dry, no cloud, no precipitation. Remains stable - good visibility but smoke possible.

- If the airflow is mainly from over the North Sea from the NE, the air will become unstable, with large Cu and snow showers on the E coast of UK. Remains very cold. Visibility good except in showers.
- In summer the air mass virtually disappears. However, with high pressure over Scandinavia in early to mid summer, there will be a NE flow over the North Sea to E UK. The air originates as dry, warm and stable. Over the North Sea it becomes moist and cool. This results in **Haar** conditions over E coast of N England and Scotland - very low St, drizzle, advection fog, poor visibility.

☐ **Tropical Continental**.

Source: N Africa, SE Europe and the Balkans. Mainly summer, warm, dry, stable.

Weather: A warm, dry S or SE flow. No cloud or precipitation, warm or very warm. Visibility good except in dust haze which can occur.

☐ **Tropical Maritime.**

Source: The Azores. Warm, stable, absolute humidity **high**, RH **moderate**.

Weather: A warm, moist SW air flow. As the air moves North, the temperature reduces (but remains warm). Stability and RH increase. Low cloud, St and Sc. Drizzle or light precipitation. Visibility poor. Advection fog over sea area late spring, early summer, over land winter, early spring. In high summer insolation and convection break down the stability resulting in clear skies or possibly a few small Cu.

☐ **Arctic**: The source is the polar ice cap, where it is stable, very cold with low absolute humidity. The humidity increases as it approaches N Scotland and it becomes unstable from the warmer sea. It gives a cold N airflow with large Cu, heavy snow falls, blizzards and very low temperatures in the extreme N of Scotland. It occurs only infrequently in winter.

☐ **Returning Polar Maritime.**

This is Polar Maritime air which has moved to the S of the North Atlantic and approaches from the W or SW. In its lower layers tropical maritime conditions are acquired and retained. It will still be unstable at higher levels. It can quickly become unstable giving Cu, Cb and Ts.

OTHER AREAS

Polar Maritime (PM) air also has a source in the N Pacific. Tropical Maritime (TM) air has sources in the Pacific and the sub-tropics. Polar Continental (PC) air has a source in N America which considerably affects N American weather.

INTRODUCTION FRONTS

A front is a boundary zone or surface of interaction between two air masses of different temperature.

When the two air masses meet, the warmer will rise over the top of the colder because of the difference in density. The frontal surface where they meet is frequently, but not always, active with much cloud and precipitation. The ground position of the frontal surface is shown on synoptic charts.

A front is usually only a few miles wide. If the term ZONE is used, then the region of interaction is much wider (up to 300 nm).

THE POLAR FRONT

The Polar Front is the boundary between polar and tropical air masses. It extends across the Atlantic and Pacific from 35N to 65N and in the southern hemisphere around 50S.
There are numerous waves on the front which cause depressions which contain their own portions of the polar front. NW Europe is almost always within the origin of the Polar Front.

THE ARCTIC FRONT

The Arctic Front is the boundary between the Arctic and the Polar air masses and may have an associated Jet Stream. It lies at higher latitudes than the Polar Front but sometimes moves into temperate latitudes (south Greenland to north of Norway) in winter and spring. (See Figures opposite).

THE MEDITERRANEAN FRONT

The Mediterranean Front is the boundary between Polar Continental or Maritime air from Europe and Tropical Continental air from North Africa. It extends west to east across the middle of the Mediterranean Sea as far as the Caspian. The front disappears in Summer.

THE INTERTROPICAL CONVERGENCE ZONE (ITCZ)

The Intertropical Convergence Zone is the broad zone of separation between the air masses either side of the heat equator. The air is conveyed by the Trade Winds north east and south east. Subject to large seasonal movement overland, but much less over the sea. Sometimes known as the **Thermal Equator** or **Equatorial Trough.**

FRONTAL FACTORS

Fronts in a locality are named warm or cold, dependant upon whether warm or cold air is replacing the other. All fronts have a slope with height so that in side view the front is a sloping surface. Whilst fronts are normally associated with convergence and ascending air, giving much cloud and bad weather, it is possible for air masses to flow side by side with little interaction, such front is termed quazi stationary. Fronts will remain in this manner unless factors come into play that disturb them.
The factors concerned are:

Equilibrium

The Pressure Gradient Force (PGF) is towards the front from both the cold and the warm side then under these conditions the wind would be Geostrophic, blowing parallel to the front.
The frontal surfaces would be in equilibrium with no tendency for the cold air to undercut the warm.

It can be concluded that if the wind is Geostrophic, there is equilibrium and little weather.

Convergence

There is always convergence in any depression but this will normally be small and give light precipitation and thin cloud only. It follows therefore that there must be unbalancing of the equilibrium, causing lifting and undercutting of the warm air, for extensive cloud to occur together with heavy precipitation.

Unbalancing can be caused by the pressure falling in the depression. This will cause the winds to no longer be geostrophic and there will be a flow of air across the isobars towards the deepening centre.

THE POLAR FRONT AND POLAR FRONT DEPRESSIONS

Although we have already briefly described the polar front and it's depressions in the chapter on pressure systems, in this chapter there will be more detail.

The polar front is a boundary between warm Tropical Maritime and cooler Polar Maritime air. As a result of the different densities these airmasses do not mix well and form a "frontal zone". The polar front zone affects the temperate latitudes at an average latitude of 50°N, but it does move with the seasons, moving to higher latitudes in summer and lower latitudes in winter especially so in the Northern Hemisphere.

The polar front usually has irregularities or kinks along it that are created by complex process. Suffice to say these irregularities create a series of depressions along the polar front where the warm tropical maritime air intrudes into the colder polar maritime air and the surface pressure is lowered. These depressions are called the Polar Front Depressions or Warm Sector Depressions and they move west to east along the polar front with the general westerly upper winds, reaching NW Europe from the Atlantic Ocean. Occasionally these depressions are called the "temperate depressions" or "travelling depressions".

COLD FRONTS

If cold air is replacing warm air, then the front is called a cold front.

The slope of a cold front is approximately 1:80 and a side view is shown on the next page. A Winter cold front in Europe will usually produce more intense weather and precipitation.

Cold fronts are marked by a sudden approach of cloud with embedded cumulonimbus. This gives precipitation in the form of showers of rain or even hail. After the cold front passes the weather should improve markedly but the temperature will be much lower.

THE WARM SECTOR

The area lying between the two fronts is known, since it is covered by tropical air, as the warm sector.

The warm sector and the whole of the polar front depression will move as the warm front and cold fronts move and will in fact narrow, as the cold front moves faster than the warm. The depression at the tip of the warm sector will move parallel to the isobars in the warm sector at a speed given by the distance between the first and second isobars.

UPPER WINDS IN A POLAR FRONT DEPRESSION

The upper winds will blow such that looking downstream the cold air will be to the left hand side in northern hemisphere and to the right hand side in the southern hemisphere. Therefore the upper winds often blow parallel to the surface fronts.

The Upper Winds in a Polar Front Depression.

☐ **Ahead of a warm front.** NW (rapid movement of Ci from the NW is a good indication of a jet stream above) The jet stream will be near the tropopause, parallel to and about 400nm **ahead** of the surface position of the front in the **warm air.**

☐ **Above the warm sector**. There will be little change from the geostrophic wind near the surface as regards direction, but the speed will be greater.

☐ **Behind the cold front**. SW. The jet stream will be near the tropopause, parallel to and about 200nm **behind** the surface position of the cold front in the **warm air**.

WARM TYPE OCCLUSION

If the air ahead of the warm front is **colder** than the air behind the cold front, then a **warm** type occlusion will be formed. This type of occlusion is more common in winter.
The warm sector will be lifted above the surface and only a **warm front** will be apparent on the ground. There will be a wide rain belt, with mainly stability type precipitation. For the purposes of the exam the shape of the warm occlusion as seen in profile view will be an extension of the warm front. Therefore the warm occlusion front axis is a continuation of the warm front.

COLD TYPE OCCLUSION

If the air behind the cold front is **colder** than the air ahead of the warm front, then a **cold** type occlusion will be formed. This type of occlusion is more common in summer.
The warm sector will be lifted above the surface and only a **cold front** will be apparent on the ground. There will be a narrow rain belt, with Cb and Ns the most likely cloud. For the purposes of the exam the shape of the cold occlusion as seen in profile view will be an extension of the cold front. Therefore the cold occlusion front axis is a continuation of the cold front

OCCLUSION WEATHER

Weather is usually bad because the normal frontal depression weather is concentrated into a smaller horizontal band and therefore a mixture of clouds can occur, e.g. Cb embedded in Ns. Furthermore, an occlusion forms towards the end of the life cycle of a depression, when it is slow moving and hence the weather can last for a lengthy period of time.
The above situation applies more particularly to the **warm** type occlusion because of the wider precipitation belt and the fact that this type of occlusion is more frequent in European winters because of the effect of Polar Continental air from the east (rain ice is a particular hazard..
Occlusions can become non-active and then produce a little cloud and nothing more as the depression dies.
Occlusions usually move at about the same speed as cold fronts.

BACK BENT OCCLUSIONS

As the occlusion forms, the first point of occlusion is at the depression centre. It gradually moves S and W forming a **back bent** occlusion rather like a loop through the depression centre. This back bent portion is usually some 100 - 200 nm long and gives a belt of rain in the cold air behind the cold front, often of a thundery nature.

MOVEMENT OF OCCLUSIONS

The precise forecasting of weather and movement of the occlusion is difficult. The **point of occlusion** may be plotted for some time ahead by moving the **warm front** and **cold front** of a warm sector depression as described in the last chapter. Where the fronts meet will be the new point of occlusion. Generally the point of occlusion will move southward as the cold and warm front meet and merge, much like a zip closing. However, the whole system will also move eastwards as the upper winds drive the system.

CONCLUSION

The Handbook of Aviation Meteorology sums up the matter of occlusions thus:
'The characteristics of the occlusion are variable. They may be similar to those of either the warm or cold front (according to type) but are often ill defined'.

OROGRAPHIC (LEE) DEPRESSIONS

When a flow of air meets a mountain range at a large angle, there is a marked tendency for much of the air to flow around the end of the range instead of flowing over the top. This can cause a comparative lack of air on the downwind (lee) side of the mountains so that low pressure occurs.

There are three weather situations:

☐ If the air is **dry** and **stable**, then any uplift caused by the depression will have little effect and the weather will be **warm, clear** and **dry**.

☐ If the air is **moist and unstable**, then the uplift caused as it passes over the depression can ensure that Cu and Cb with **showers** and possibly **thunderstorms** and **hail** may develop.

Sometimes a **cold front** will approach the mountain range and then much of the cold air will initially be held back by the range. When this unstable air finally breaks over the mountains, lifting will occur with additional lifting from the orographic low.

- The result can be **heavy banks** of Cb, with **line squalls, very heavy showers, thunderstorms, hail** and **poor visibility**.
- A good example of this occurs over the **Alps** in **Northern Italy** in winter, the cold front being part of a polar front depression.

THE MONSOON LOW

Over large continents in summer a large thermal low develops which controls the circulation of air. The weather pattern is variable, being affected by topography, e.g. the Himalayas, and by the air masses drawn into the circulation.

INLAND WATERS

In winter, thermal lows develop over the **Caspian, Black** and **Mediterranean** Seas. A cold outflow of PC air from the **Siberian high** flows over the warmer seas. Convection and the development of depressions result. Similar lows develop over the **Great Lakes of North America.**

THERMAL LOWS OVER LAND (SUMMER)

During SUMMER, shallow lows will appear over land due to surface heating. If the air is already UNSTABLE or there are OLD FRONTAL ZONES in the area, thunderstorms, widespread rain or squalls may result. They also occur regularly in Summer over the American mid-west, giving heavy thunderstorms.

TROPICAL REVOLVING STORMS (TRS)

Description

These are cyclones that develop over the warm tropical oceans and have sustained wind speeds in excess of 64 knots. They are the most destructive and extensive weather phenomenon which affects our planet. Winds in a tornado may momentarily exceed those of a TRS, but the life cycle of a tornado is primarily measured in minutes. The life cycle of a TRS, however, is measured in weeks and its extraordinary size exceeds any other meteorological phenomenon.

Stages of Development

TRS evolve through a life cycle, from birth to death much like that of a thunderstorm. The stages are based upon the organisation of the storm and the sustained wind speeds which they create. Not all of the stages will eventually evolve in to a TRS.

Stage 1 Tropical Depression

This is designated when the first appearance of a lowered pressure and organized circulation in the centre of the thunderstorm complex occurs. A surface pressure chart will reveal at least one closed isobar. Winds constantly between 20 - 34 knots.

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This is when the storm becomes more organized, taking on a circular rotating appearance, with sustained wind speeds between 35 - 63 knots. It is at this stage when it is assigned a name.

Stage 3 Tropical Cyclone / Hurricane / Typhoon

Surface pressure continues to drop and it is designated this stage when sustained wind speeds are greater than 63 knots. There is a pronounced rotation around a central core which will eventually form the "eye".

The eye

The of the most recognizable features found within a TRS is the eye. They are found within the centre having a typical diameter of 20 - 50km. The tightening of the eye is a useful guide that the storm is increasing in strength. It is within the eye that we find the lowest surface pressures. and the calmest conditions. As air is forced up and outward from the storm some of it returns down the centre causing adiabatic heating which evaporates clouds creating the familiar clear column of air which distinguishes the eye itself.

The eye wall

This is the vertical wall of cloud enclosing the eye and is the most devastating region with intense winds and rainfall. From the wall itself large bands of cloud and precipitation spiral out from the storm and are called "spiral rain bands".

COLD AIR POOLS

These are outbreaks of cold air from near the poles. These outbreaks are usually characterized by a cold front at their leading edge. In fact they are common just behind the polar front depressions behind the cold front itself. Typically the air is unstable and therefore expect cumuliform activity with showers and even thunderstorms.

Although surface temperature anomalies such as cold pools are not evident on surface pressure charts, they can be found most notably by looking at pressure charts in the middle to upper atmosphere. You may remember that cold air causes pressure to fall more rapidly with height, reducing the pressure in the upper atmosphere. Therefore by analyzing a pressure chart in the middle to upper atmosphere you can identify cold air pools by the low pressure they create.

TORNADOES

A tornado is a violently rotating column of air which is in contact with both a cumulonimbus (or, in rare cases, cumulus) cloud base and the surface of the earth. Tornadoes can come in man shapes, but are typically in the form of a visible condensation funnel, with the narrow end touching the earth. Often, a cloud of debris encircles the lower portion of the funnel. Tornadoes can be very destructive. Most have winds of 110 mph or less, are approximately 100m to 150 m, and travel a few miles before dissipating. However, some tornadoes can have winds of more than 300 mph be more than a mile across, and stay on the ground for dozens of

miles. They are most common in "Tornado Alley" in the mid-west of North America during late spring and early summer. They reach peak occurrence at about 1700 LMT.
The elements of climatology are **precipitation, temperature, humidity, sunshine** and **wind velocity.**
These elements will be affected differently across the globe by; **latitude, location** (maritime or continental), the circulation of **pressure systems, altitude** and **geography.**
Over the years climatological data has been accumulated to such a degree that weather forecasting on an area basis has become quite accurate and communications have improved to such a degree that weather expected on arrival at a destination (and the weather en-route) may easily be obtained. This chapter will deal with climatology on a global basis and its regional and seasonal variations.

Research Design, Tools and Methodology:-

IDEALIZED AIR CIRCULATION

The general air circulation is a very complicated system of air movements. These movements, while based on the passage of air from high pressure to low and the effect of the rotation of the earth, are complicated by:

☐ The unequal heating of land and sea together with land and sea disposition.
☐ Variation in land heating caused by different surfaces.
☐ The 23½° inclination of the earth's axis which causes movement of the thermal equator.

It is therefore useful to consider an air circulation which ignores these main complications and to use this as a basis for understanding the conditions which actually prevail. The idealized circulation assumes that the earth's surface is covered with sea and that the geographic and thermal equators are coincident. In fact, since the surface of the southern hemisphere is largely covered by sea, climatology in that hemisphere very closely follows the idealized case.

IDEALIZED CIRCULATION WEATHER

With a uniform spherical earth, the temperature would only vary with latitude. Pressure at any given height over the equator would then be greater than that at any height over the poles. Thus air would drift at height from the equator to the poles, helping to produce high latitude anticyclones and causing a movement on the surface of air from poles to equator.
However, this cyclic movement of air would be affected by the rotation of the earth, and the circulation would be modified to that shown below.

BASIC CLIMATIC ZONES

Adiabatic cooling of the air by ascent, producing cloud and much precipitation, will occur in the equatorial region and in the temperate frontal zones. Conversely, mainly arid conditions will apply in the anticyclonic polar and sub-tropical regions because of subsidence. The Globe therefore may be conveniently divided into a number of climatic zones.

CLIMATIC ZONES (BY LATITUDE)

Equatorial 0 - 10 degrees. Two main wet seasons - at the Equinoxes. Never dry. Much convection cloud and heavy rain showers and thunderstorms. Temperature and humidity high. Light surface winds (the Doldrums).

Savannah/tropical transitional 10 - 20 degrees. Dry Trade Wind conditions in winter. Equatorial rains in summer. Duration of wet period decreases as latitude increases towards 20°

Arid sub-tropical/steppe 20 - 35 degrees. Typical sub-tropical anticyclonic weather. Descending air - warm & dry. Produces typical desert climate with short wet season at the desert edge - at the low latitude edge in summer from the ITCZ, and at the high latitude edge in winter from temperate zone activity. Deserts include Sahara, Kalahari, Gibson, Arabian, Arizona & South America. The zone includes the Trade Wind belt.

The semi-arid Steppe type climate borders the desert regions and has a short rainfall season. Weather gives grassy, treeless plains. Examples are the Russian Steppes and the South American Pampas.

Warm temperate 35 - 40 degrees. Mediterranean type climate. Disturbed temperate conditions in winter with frontal and thermal depressions. In summer, warm and dry as thermal equator moves towards the pole.

Cool temperate 40 - 65 degrees. Weather is controlled mainly by travelling polar front depressions. Winds are westerly; gales are frequent in winter. There is no dry season.

Boreal zone 40-60N. Between the Cool Temperate and Polar zones in the Northern Hemisphere lies the Boreal Zone. Occurs over the land masses of northern North America, Scandinavia and north Russia. Characterised by warm, moist summers and very cold winters.

Polar 65 - 90 degrees. For much of the time, anticyclonic weather - very cold and dry, but modified by depressions penetrating the peripheral region in summer to bring unsettled weather and precipitation.

In some areas, temperatures can rise above zero for a month or so, giving a Tundra Climate of sparse vegetation, e.g. Lichen and Moss. Subsoil remains permanently frozen - Permafrost.

TEMPERATURE AND TOPOGRAPHICAL EFFECTS

The surface temperature of an idealized all sea world would cool evenly with latitude increase because the sun's elevation would reduce. In practice this even cooling will be much modified by the presence of land masses, especially in the Northern Hemisphere where the continents of Asia and North America are vast. One effect is that the sub tropical anticyclones do sometimes break down due to summertime land heating which lowers pressure. Conversely, continents **outside** the sub-tropical high belt can experience wintertime land cooling which raises pressure.

In **January** the temperature in **Asia** is exceptionally cold as shown below. The winter cold air over central Asia is due to its distance from the sea, long nights and winter long terrestrial radiation. It will be held back from India and Pakistan to the south by the Himalayas. In **North America** the cold is further enhanced by the Rocky Mountains which block warm Pacific air while the absence of a barrier to the North allows Arctic air to move south. **North Atlantic** temperatures will remain comparatively high due to the warm water sea current from the Gulf of Mexico. Hence prevailing westerly winds from the Atlantic will warm the adjacent land masses of UK and Western France. **Southern Hemisphere** isotherms will be near the ideal due to the greater sea areas.

Summary

Topographical temperature variations will affect surface pressure and distort the idealized distribution shown earlier, so that whereas the climatic pressure zones will be maintained over the **oceans**, the pressure patterns **overland**, and hence the winds and weather, will be governed much more by surface temperature changes. This will apply especially to the Northern Hemisphere, where two-thirds of the world's land masses lie.

Relative Humidity

This chart shows how relative humidity varies with latitude and season.

PRESSURE

□ JANUARY

- In the southern hemisphere the pattern is close to the idealized circulation.
- The **Equatorial Low Pressure zone** lies to the **south** of the equator.
- **Sub-tropical highs** are established over **oceanic areas.**
- **Cold weather highs** are established over Northern hemisphere **land masses.**
- There are significant pressure areas in the region of:

Iceland **(Low)** 1000 hPa (statistical low)
Aleutians **(Low)** 1000 hPa (statistical low)
N. Australia **(Low)** 1005 hPa
Siberia **(High)** 1035 hPa
N. America **(High)** 1020 hPa
Azores **(High)** 1020 hPa
Pacific **(High)** 1020 hPa

□ JULY

- In the southern hemisphere the pattern remains close to the ideal. Overland temperatures are colder thus the subtropical high is generally unbroken.
- The **Equatorial low pressure zone** lies to the **north** of the equator.
- Where sub-tropical highs would be expected in the Northern Hemisphere, low pressure areas now form over land masses due to solar heating. Thus the **Siberian High** of January is replaced by the **Baluchistan Low**, centred over Pakistan but affecting all of **Asia. N America** also has low pressure.
- The **Aleutian** and **N Australia lows** disappear.
- **Icelandic statistical low** pressure is less deep and is now dispersed into three small areas:
- **Off Greenland, the Baltic and Iceland** - 1010 hPa
- The **Azores & Pacific Highs** are dominant at 1025 hPa

SURFACE WINDS

The westerlies of temperate latitudes

Westerly winds exist in the region between sub-tropical highs and temperate lows. (40 - 60 degrees latitude). These are caused by the turning effect of Coriolis Force on the **Poleward** outflow from those sub-tropical highs. In the northern hemisphere the westerlies apply mainly over the oceans, with frequent winter gales. During the summer months these westerlies are less constant and less strong. In the southern hemisphere these winds are largely uninterrupted by land masses and are consequently strong. They are called **The Roaring Forties** - so called because they blow principally between latitudes Forty and Fifty South. Weather in this belt comes from rapidly moving depressions; wild weather, strong westerly winds and gales, overcast skies and heavy rain.

Monsoons

These are seasonal winds due to the winter high pressure, or summer low pressure, which develops over large continents. They are particularly marked in **South** and **South East Asia** and also occur in **West Africa.** They blow in concert with the trade winds.
Weather will depend very much on the track followed. NE monsoons over central India will be dry with little cloud, whilst the SW monsoon will be warm and moist with much convective cloud and heavy rain. NE monsoon over the Far East will be relatively dry whilst the SW monsoon, with its long sea track over the tropical oceans will produce very wet conditions. Monsoons will be discussed in more detail later in this chapter.

Other winds

Outside the main currents there are:

☐ Winds applicable to the local pressure system prevailing at the time.

☐ Strong **Polar Easterlies** near the **North and South Pole**, especially in winter as the katabtic wind flows towards the sea.

MONSOONS

☐ When **trade winds** blow ***to*** continental low pressure or ***from*** continental high pressure the associated weather is known as a **monsoon**. There are three monsoon flows; the **NE, NW & SW.**

☐ The NE MONSOON of Asia blows from the winter siberian high and ~~is~~ consequently cool & comparatively dry giving clear weather over Bangladesh, Burma and Thailand. SE India, Sri Lanka & East Coast of West Malaysia are also affected by this monsoon, but here the over-sea track picks up moisture and produces heap type clouds and thunderstorms and heavy precipitation when crossing coastal mountain ranges.

☐ The **NW MONSOON** is really an extension of the NE Monsoon which backs on crossing the equator southbound and brings **Cu**, **Cb** and **thunderstorms to North Australia & New Guinea.**

☐ The **SW MONSOON** is produced by the SE Trade Wind crossing the equator and veering to SW and thence to the summer Baluchistan Low. Having a long sea track, this monsoon is very moist and produces much **heavy Cu & Cb with large scale thunderstorms**. It affects **all of India, Sri Lanka, Burma** and exposed coasts of **West Malaysia.** It has a more serious effect on flying than the NE Monsoon, with **heavy thunderstorms, low cloud base & severe turbulence.** The SW Monsoon also affects the **West African coast**, notably **Guinea, Ghana & North Nigeria**.

UPPER WINDS

☐ **Sub Tropical Jets.** These jets blow at the **200 hPa level** in each hemisphere between 25° and 40° latitude in winter and 40° and 45° in summer. The **cause** is the upper pressure gradient between the descending warm and cold air on either side of the sub tropical high pressure belt. Speeds can be in excess of 100 kt. (Up to 300 kt near Japan).

☐ **Polar Front Jets.** The Polar Front jets in the northern hemisphere are of a transient nature and move with the Polar Front as it moves south in winter and north in summer.

Polar Front Jets are caused by the upper pressure gradient between the Tm warm and Pm cold air masses on either side of the polar front.

In the southern hemisphere they are more constant and blow around the 50th parallel. They are less strong than those in the northern hemisphere.

☐ **Tropical Easterly Jet (Equatorial Easterly Jet).** Strong easterlies that occur in the northern hemisphere's summer between 10° and 20° north, where the contrast between intensely heated central Asian plateaux and upper air further south is greatest. It runs from South China Sea westwards across Southern India, Ethiopia and the sub Sahara. Typically heights circa 150hPa (13-14 km; 45,000 ft). These easterlies can give way to westerlies especially in January as the ITCZ moves south.

☐ **Arctic Jet Stream** found between the boundary of arctic air and polar air. Typically in winter at around 60° north but in the USA around 45° to 50° north. The core varies between 300 and 400hPa. It is a transient feature found over large continents during arctic air outbreaks.

WAVES

☐ **Easterly Waves**. An easterly wave is a wave or trough of low pressure, originating over West Africa between latitude 5° North and 20° North and moving towards the **Caribbean**. Some of the waves proceed beyond the Caribbean and into the Pacific. They occur during the summer and autumn, usually numbering about 50 each year. Weather produced will be like that associated with **tropical revolving storms**, though to a much lesser extent in severity. They may develop into tropical revolving storms themselves.

Figure 23.35 An Easterly Wave.

An Easterly Wave.

☐ **Westerly Waves**. These are very similar to easterly waves but are simply interconnecting warm front and cold front bands of weather (associated with a polar frontal depression) that move from the west to the east creating a pattern that is very similar to that of a wave.

VALLEY WINDS

Mistral. Valley winds are caused by air funnelling through a mountain gap or down a valley. The Mistral, which is a good example of such a wind, blows down the **Rhône Valley** between the Massif Central and the Alps to the French Mediterranean coast and beyond. It is usually a winter wind with **high pressure** over **Central France** and **low pressure** over the **Gulf of Genoa.**

Temperatures are **low** with winter Mistral temperatures well below zero, flying conditions are **turbulent** and the winds are **strong**, 40 to 75 kts.

The Bora. This wind is part valley and part katabatic. It blows down the north **Adriatic** with high pressure over **Central Europe** and the **Balkans** and a **low** over the **Adriatic.** The wind speed is around **70 kts** with great gusts **exceeding 100 kts** in places. The Bora is strongest and most frequent in winter.

MEDITERRANEAN WINDS

The Sirocco. All three of the major Mediterranean winds we are dealing with are similar in that they blow ahead of frontal depressions tracking along the North African coastline. The

Sirocco, which blows over Algeria is a **hot** and **dusty** southerly wind blowing out of the desert. This wind is usually a **springtime** wind and may last a day or so. **Visibility** may be reduced to **below fog limits** (1000m). The Sirocco may travel as far as the **French coast** and in the process it may pick up moisture and produce low **stratus, drizzle** and **fog**.

The Ghibli. This is a similar wind which blows over Libya.

The Khamsin. Blows ahead of depressions tracking along the Mediterranean coast of **Egypt.** Conditions are similar to the Sirocco and the Ghibli. The name is also given to south or south west gales blowing in the **Red Sea.**

SQUALLS

The Pampero. This is a **severe windstorm** blowing around the estuary of the **River Plate** (Uruguay and Argentina.. It is a **cold dusty south** to **south west** wind blowing behind a cold frontal depression. Stormy, gusty conditions prevail, with a considerable **temperature fall** after the storm passes. The squall is **short lived**, but the strong, steady wind may last for **some hours.** Pamperos usually blow in **spring and summer**

Sumatras. These occur in the **Straits of Malacca** blowing between south west and north west, most frequently between **April** and **November** during the time of the south west monsoon. During the day thunderstorms build up over the high ground of Sumatra, assisted by the **sea breeze**, but at night the subsiding cumulo nimbus clouds drift eastward under the influence of the **land breeze** and the **Katabatic** effect. The storms are rejuvenated over the warm sea and **violent storms** result late at night and in the early morning. There is a sudden **temperature drop** as the squall passes through. Sumatras take on a pronounced **arched shape** as the Cb anvils spread out at the tops of the clouds.

THE HARMATTAN

The last of the major local winds is the **Harmattan**. This blows mostly during the winter from the **high pressure** desert areas of North Africa as a **North Easterly** wind towards the ITCZ. (North east trade winds). The Harmattan is a cool dusty wind that may reduce visibility to below 1000m, especially in areas bordering desert regions, such as Kano, Nigeria. The dust layer may extend to 7,000 or 10,000 ft or more, visibility improves towards the coast. The Harmattan blows from **November** through to **April**, though by this time the winds will be light, especially in the south. The region includes the area between the Mediterranean in the North, and the Nigeria - Ghana - Senegal coast in the South, that is between 35°N and 5°N and west of 10°E. It also includes parts of Ivory Coast, Guinea, Liberia, Mauritania, Morocco, Mali and Algeria.

GEOGRAPHICAL CONSIDERATIONS

The area is bounded to the east by the Sahara desert, centred near 23°N, which is a source of Tropical Continental air and brings much dust to the region. The cold Canaries sea current running south close to the Atlantic Coast helps advection fog to form.

PRESSURE SYSTEMS

The **ITCZ** (Equatorial Trough) traverses the **southern half** of the region bringing **rain and a change of surface W/V as it passes**. It is south of the coastal regions of Ghana and Nigeria in January, then pushes north to 18° - 20°N in July, thereafter moving south again, to clear the south
coast by the next January. North of the ITCZ lies the **Sub Tropical High**. In Winter it extends

from the West across the Sahara desert and the surface outflow brings **dry dusty conditions** to all parts especially the South and West. Towards Summer, the sub tropical high and associated dry dusty conditions will be increasingly restricted northwards as the ITCZ advances from the South.

WEATHER AND SURFACE WINDS

It is convenient to divide the region into two areas split at the mid latitude of 20°N. The southern region includes **Dakar** on the West Coast at 15°N.

South of 20°N - Winter Season

The **ITCZ** is **south** of the area. **High pressure** is dominant over the **Sahara** and there is no cloud or precipitation. The **NE** tradewind outflow from the Sahara to the ITCZ is extremely dusty and is known as the **Harmattan**. The **duration** of the **Harmattan** period decreases southwards because the ITCZ recedes southwards in Autumn then advances north in the Spring.

Visibility

in the dust is frequently down to **4000 metres** and occasionally down to the **fog limits**. Outflow over the cold canaries sea current favours **advection sea fog**, which can then drift inland when there is a sea breeze.

GEOGRAPHICAL AREA

The area considered reaches from **10°N** to **70°N** latitude and from the **Caribbean** and **New York** in the West to **London** and the **Norwegian Sea** in the North-East. The area lies across the **Disturbed Temperate** and **Sub-tropical High** climatic belts.

WINTER

Pressure Systems North American High 1020 hPa
Icelandic "Statistical" Low 1000 hP
Azores High 30°N 1020 hPa
Polar Air Depressions 65°N - 55°N

Polar Front Activity is dominant across the disturbed temperate region. In the West, diverging air from the North American High moves SE over the sea to meet warm Tm air overlying the warm gulfstream waters flowing northbound off the N.American East Coast. This convergence causes much instability and the formation of depressions where the two air masses meet. This well-defined but erratic frontal line forms the Western end of the **polar front** which in **Winter** lies
near **SW Florida** and stretches across the Atlantic. These depressions will be driven east/northeastwards
by the thermal mid latitude winds and will track along the polar front towards the
UK and Norwegian Sea. Some of the Lows will become slow moving and/or occluded between S Greenland and Norway, giving rise to the **"Statistical" Low** near **Iceland** as the depressions pass by.

In the Eastern Atlantic the north-eastward outflow from the sub-tropical **Azores High** will ensure that the travelling frontal depressions track to the North-East, a typical **Winter** landfall being **SW England**.

Over the Atlantic, the **polar front** will remain the **boundary** between **Pm air to the north and Tm air to the south**. As the travelling depressions develop, a portion of the **Tm air** will be increasingly **trapped between** areas of **Pm air** either side, forming warm and cold fronts. North of the Polar Front, **Polar Air depressions** are formed by **arctic air moving south** 65°N - 55°N over relatively warmer seas causing **instability** weather.

Weather. The contrast between London and New York. Although New York is 40°N and London 52°N the winter weather is worse in New York. Why?
Cold continental outflow from the North American High becomes unstable over the adjacent but warmer sea forming low pressure. The resultant instability can then swing inland bringing snow to the New York area.
London in Winter can also be affected by cold continental outflow - from the Siberian High. The difference is that such air will have a long land track and therefore will remain dry. Secondly, if the wind in London is from the prevailing west, it will be flowing off the Atlantic and therefore will be relatively warm, possibly giving rain but not snow.
Cloud. In the North of the region, cloud averages 6 Oktas, mostly associated with travelling depressions and a cross section is shown below. Cirrus and Stratoform cloud below the tropopause will thicken down to near the surface preceding a warm front. Extensive Stratus/Strato cumulus will occur as Tm air moves north over colder seas to the polar front and especially while trapped in the warm sector of polar front depressions. Cumulus and Cumulo-Nimbus will occur on cold fronts with cumulus forming in the following unstable northwesterly air. In the Caribbean the moist NE trade winds will produce orographic cloud and rainfall on windward slopes.
Flying west through a polar front depression the pilot should find:
CI 400 - 600 nm ahead of the warm front surface position
CS 300 - 500 nm ahead of the warm front surface position
AS 200 - 400 nm ahead of the warm front surface position
ST/NS 200 - 300 nm ahead of the warm front surface position.
ST/SC Above **Warm Sector** at Low Level.
CU/CB At **Cold Front** surface position and 100 - 200 nm beyond.
Behind Cold Front region, the same but smaller amounts.
Icing. Icing occurs widely and through great depth in Convective and Frontal Cloud and is frequently moderate to severe. Rain Ice/Freezing rain, in cold air below warm frontal air, can cause severe clear ice affecting airfields near Washington and New York.
Visibility.
Radiation Fog can occur inland especially in **Autumn** and **Winter** when **pressure is high.**
Advection Fog can occur when moist Tm air overruns previously cold-soaked inland areas especially in **late Winter/early Spring**.
Surface Winds. North of the subtropical Bermuda-Azores High, winds are generally westerly but locally easterly on the north side of depressions. There are frequent gales. In the South, NE trade winds prevail all year.
Upper Winds. These are generally westerly because their direction is governed by the thermal wind which blows with **Low Temperature on the left.** The average winter wind component from **London** to **New York** is **minus 50 knots** - locally winds can be stronger and if greater than 60 knots are known as jetstreams. Over the Atlantic there are two distinct jetstream patterns – the **Polar front Jet** and the **Subtropical Jet.** Each may reach **200 knots.**
Polar Front Jet. This will normally blow from between NW and SW and occasionally outside this range, depending on the **surface orientation of the polar front**. With low temperature on

the left, the **Warm Front Jet** will normally be **from the NW** and **ahead of a warm front** and due to the slope of the front, some **400 nm ahead** of its surface position. Similarly the Cold Front jet will normally blow from the **South-West** and some 200 nm behind the surface position of the front.

A pilot flying at **high level** from **East to West across a polar frontal depression** would experience **wind and drift** as follows and as shown below.

☐ Initially winds will be North Westerly giving strong **port drift.**

☐ Some 500 nm ahead of the warm front, jet axis speeds of 100-200 knots give **increased port drift**. This will last for 200 nm.

☐ Winds remain strong NW until crossing **the surface position of warm front** when winds will **back** sharply to West or South-West giving **near-zero drift.**

☐ Above **surface position of cold front** winds will **back again** sharply to South West giving **starboard drift.**

☐ After 100 nm enter the jet axis, speeds 100-200 knots, giving **increased starboard drift**. This will last for 200 nm.

☐ Passing out of the Jet stream SW winds, **starboard drift decreases.**

SUMMER

Pressure Systems. North American Low replaces Winter High. Icelandic "Statistical" Low 1010 mbs. Less deep and split. Azores High 1025 hPa intensified. Further North at 35°N. Hurricanes in Caribbean and Florida area.

The **polar front** is still present but **less active**. The North American Winter High has disappeared and with it the east coast temperature contrast between land and sea. This part of the polar front therefore disappears in Summer and the western end starts at Labrador, Newfoundland, E. Canada where the advanced warm Gulf Stream sea current now meets the receded cold Labrador Sea current.

In the East, the Azores High is intensified and further North, thus pushing the Polar Front northwards to Scotland.

In **Summer** the **Polar Front** average position thus lies from **Labrador/Newfoundland** to **North of Scotland** to **Norway.**

Temperature differences across the front are less, so frontal activity is less intense and less frequent. The weakened Icelandic "statistical" low is now split with average 1010 hPa centred West of Greenland, over Iceland and in the Baltic.

Weather and Cloud

The New York Winter snows are gone. London temperatures remain moderated by air flow from the Atlantic. Polar air is less cold and the reduced temperature contrasts mean less convection cloud over the sea. From the **Azores High** warm moist **Tm outflow northwards** over cooler seas causes **advection fog/stratus/stratocumulus** and this can widely affect SW English coasts in late Spring/early Summer.

In the **Caribbean** the NE trade winds will continue to cause **orographic cloud and rain** on windward slopes. Additionally in Summer, rainfall will be increased by **convection.**

Visibility. Inland radiation fog is less likely in Spring and Summer and if formed, early morning insolation will cause quick clearance. **Advection Fog** can form over the **cooler seas** and near **SW facing coasts of UK and France** in **late Spring/early Summer** by **Tm air** from the Azores moving northeast. Near **Newfoundland** widespread advection fog can form over the Grand Banks (approx 45°N 50°W) in **May/June** by advancing warm moist air from the Mexican Gulf overrunning the very cold Labrador sea current.

Winds. In mid latitude, surface winds are still generally westerly but less strong than in Winter, as are upper winds because the temperature differences are less. In the Caribbean, NE trade winds prevail at the surface.

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Jetstreams. The **Polar Front** jet streams will still be around the 300 hPa level and be positioned in relation to the Polar warm and cold fronts as in Winter but will be less frequent, less strong, and displaced further north with the Summer alignment of the Polar Front. The **Sub- Tropical Jet** at 200 hPa will also be further north and in the latitude band 40°N-45°N. Specifically across the Atlantic in **Summer**, it will blow from **Montreal to Bordeaux,** as shown on the opposite page.

Easterly Waves. Easterly waves are similar to shallow troughs extending North from the Equatorial Low Pressure belt. They move slowly East to West under the influence of the anticyclonic wind around the subtropical High pressure. In the North Atlantic autumn, West African Tornadoes, which form over Nigeria, drift westwards with these waves and can become seedlings of Caribbean Hurricanes.

Hurricanes. Hurricane is the name given to Tropical Revolving Storms in the Caribbean/Gulf of Mexico Area. Frequency of developed Hurricanes is average 3 per year. They occur from **August to October**, tracking **westwards** across the Atlantic near 10°N-15°N latitude and at **10-15 knots**. Internal **windspeeds** can exceed **100 knots**. They then cross the Bay of Mexico or turn right around the sub tropical high to track NW, N, NE up the USA East Coast. They are energised by the latent heat of condensation and are therefore **more active over the sea**. Each season they are **named alphabetically** in order of occurrence using alternate male/female first names.

GEOGRAPHICAL CONSIDERATIONS

The **mountains of Norway** lie to the **North** while to the **South** there are many mountain ranges dominated by the **Alps. Between** the two regions lies the **North European Plain** with no mountain barrier against the Atlantic winds from the West nor to the cold winter winds from the East.

WINTER

Polar Front Depressions. These move **from the Atlantic towards Russia** and principally between the mountain barriers to North and South although tracks are variable. Areas to the **South of each Low** will experience **frontal weather.**

The **Alps** often block and delay cold fronts, causing **frontal and orographical cloud** to persist on the northern side. An active **secondary depression** may develop on such a front, tending to run **east-north-east** along the front until the cyclonic circulation around it eventually drives the front into the Mediterranean.

Thermal Depressions. Thermal lows can form in **Winter** to the East of the Alps over the low lying **Danube** area which is **moist and comparatively warm.** Associated cyclonic circulation on

the east side will bring warm air North from the Mediterranean forming **active warm fronts.** These can bring extensive **low stratus** to Germany and **snowfall** as far north as SE England.
Polar Air Depressions. These can sometimes affect the extreme NW sea areas of the region in Winter.
Siberian High Extension. Pc air gives cold dry weather. Steaming fog or Low Stratus may be produced locally over water near German and Dutch coasts as the cold air reacts with the warmer water.
Temporary Highs. Ridges or transient anticyclones may exist in the N/NW in between travelling
polar front lows.

Cloud and Precipitation.
Cloud amount exceeds **six octas** on average. Cloud is frontal from the many polar front depressions also from warm fronts moving North from the Mediterranean although cloud amounts decrease from West to East.
There is much precipitation, in the East mainly of snow.

Visibility.
Radiation Fog can form **inland** with a slack pressure gradient, principally in Autumn and Winter. With a SW warm moist wind from the Atlantic, **advection fog** can form over previously **cold soaked inland** areas. **Smoke haze** may reduce visibility to the **lee of industrial areas.**
Frontal fog can occur on the **warm fronts** of deep active **Polar Front depressions.**

Winds.
Surface Winds are generally **westerly** although easterly on the north side of depressions.
E or NE winds can occur as an outflow from the **Siberian High.**

Upper Winds become increasingly westerly with ascent, due to the increasing westerly thermal component. **Polar Front Jets,** located in relation to the moving **warm** and **cold front** surface positions, and centred around **300 hPa / 30000'** are common and often exceed **100 knots.** The Subtropical Jet is to the South near Morocco and therefore does not affect the region.

SUMMER
Pressure Systems
Polar Front Depressions. These will track eastwards as in Winter but **further North** (seasonal movement is with the Sun). They will also be **less intense** because of the smaller Polar/Tropical temperature difference that forms them.
Thermal Depressions. Strong insolation can cause active thermal depressions over France and Southern Germany. Thunderstorms are common when moist unstable conditions exist. **Azores High.** This is well established west of Africa at 35°N. An associated ridge across Europe often gives a limited period of fine dry weather.
Temporary Highs. Temporary ridges or transient anticyclones to the NW are more dominant in Summer, in between weaker Polar Front Lows. **Scandinavian Highs.** These can persist for a few days drawing air across the North Sea from
western Russia.

Cloud and Precipitation
Frontal cloud amounts and rain will be much less than in Winter because the associated polar front depressions are fewer, less intense, and further north, and by Summer the Mediterranean warm fronts are gone. Cloud is mainly **convective** in **thunderstorms** produced by **thermal**

lows. Rainfall is therefore mainly in the form of **heavy showers** but the effect may be increased by orographic lifting in the southern mountains.

Visibility

Radiation Fog is much **less likely.** It can occur in early Spring but morning insolation will normally ensure quick clearance. In Late Spring/Early Summer an easterly wind round a Scandinavian High blowing over the North Sea can often result in extensive **advection sea fog** along the **UK East Coast.** In Scotland this is known as **haar.** It can travel inland some distance.

Winds

Surface winds are generally **westerly** but **lighter** than in Winter. Winds may be modified by **sea breezes** along coasts.

Upper Winds become increasingly westerly with ascent but the thermal wind component is less than in Winter and upper winds will therefore be less strong. **Reduced Speed Polar Front Jets** will occur but **further North** with the Summer movement of the polar fronts. The Atlantic **subtropical jet** will reach the coast near Bordeaux but due to mountain interference will not extend overland at Jet Speeds. It therefore **does not affect the region.**

Icing. The freezing level will be higher in Summer and frontal activity is less, but icing in thunderstorms and orographical cloud may still be severe.

MEDITERRANEAN SEA and ADJACENT LANDS

GEOGRAPHICAL CONSIDERATIONS

The Mediterranean sea is almost entirely surrounded by land. **Compared with the land**, the sea will be **relatively warmer in winter** (giving unstable conditions above) and **relatively cooler in summer** (giving stable conditions above). Therefore during the **winter** surface air will tend to **flow in** from surrounding land areas and during **summer** it will tend to **flow out**.

There are significant **mountain areas** to the **North** and to the **West.** In winter, the **mountains** to the **North** will **hold back** much of the **cold air** from Europe/Asia. The **high ground** to the **West** will **resist** the **advance** of **Polar Front Depressions except** via the mountain gaps in **SW France** and at the **Straits of Gibraltar** between Spain and Morocco.

To the **South** there is **no mountain barrier** to prevent **dry dusty air** from the **Sahara** desert spreading north, except the Atlas mountains in the extreme SW.

WINTER

Pressure Systems

Mediterranean Front Depressions. The Mediterranean front lies **east/west** along the **centre** of the **Mediterranean,** and is formed by inflowing cold **Pc air** from the North and inflowing less cold **Tc air** from the South. Air will be forced to rise along the convergence line forming **frontal depressions** in the West which **move eastwards** along the frontal divide driven by the westerly upper airflow. Because of the **dryness** of the desert Tc air, warm front and warm sector cloud does not form, thus there is **cold front weather only**.

Orographic or Lee Depressions. These can form **south of the Alps** over the **Northern Adriatic** and over the **Gulf of Genoa**. The Genoa Low can move south along the Italian coast giving **unstable weather**. Lee Lows can form **South of the Atlas mountains** in Morocco with a cold

W/NW airstream and then move NE to enter the Mediterranean east of Tunisia. They can also form **South of the Turkish Taurus mountains** to form the **Cyprus Low** between Cyprus and Turkey. The **Cyprus Low** gives not only instability but is accompanied by **NE gales**. Weak depressions moving into the area can become **deepened** and reactivated. These lows can then move **eastwards into Lebanon and Arabia.**

Siberian High. The Siberian High is well **north of the region** but its **cold outflow** can reach the warm Mediterranean and cause **instability**.

Thermal Depressions. When **cold** air from the **Siberian High** flows **over** a relatively **warm landlocked sea area** such as the **Mediterranean**, instability or **Thermal Lows** are created. Over the Mediterranean, these form particularly in Central and Eastern areas and move eastwards to Arabia, the Arabian Gulf, Iran and Afghanistan.

Polar Front Depressions. Polar Front Lows and sometimes secondary Lows can enter the region via **SW France** or **Gibraltar**, after which they tend to **become absorbed** by other Depressions.

Cloud and Precipitation

Cold fronts associated with Mediterranean front Depressions, also orographic and thermal depressions, produce **CU and CB** with attendant **heavy rain** or **hail showers** and **thunderstorms.**

There is some layer type cloud and more continuous rain in association with the few Polar Front depressions in the West.

Visibility

Radiation Fog is **less common** than in NW Europe **but** can be persistent in the **Po Valley** in North Italy. Otherwise visibility is excellent between showers except when air blows from the south bringing dust laden air from the Sahara desert. These **southerly winds**, called the **Sirocco in Algeria**, the Chili in Tunisia, the Ghibli in Libya and the **Khamsin in Egypt** blow **ahead of depressions** travelling east over the sea.

Surface Winds

Surface winds will blow in accord with the location of depressions but there are some **named winds** blowing **into** the **Mediterranean** from surrounding land areas that should be noted:

Mistral. This is a strong **northerly** wind up to **70 kts** blowing down the **Rhône valley** in SE France, especially when High pressure is to the North. It is a **valley/katabatic** wind, normally **stronger at night and in Winter**, which brings **cold air** from the North. It helps form the Genoa orographic Low.

Bora. This is a stronger dry gusty **NE** wind up to **100 kts** which is **part valley/part katabatic**. The wind blows through the mountain passes into the **Northern Adriatic** and can be reinforced by High Pressure to the NE. It can bring snow and is **strongest at night**.

It can set in suddenly and is therefore dangerous. It can help form the Adriatic orographic Low.

Gregale. This is similar to the **Bora** but **less strong, further south** and more **moist**. It blows from the **NE** near Southern Italy and Malta and is due to continental relatively high pressure to the North, and low pressure over the Mediterranean Sea. It occurs in 1-2 day spells in association with Mediterranean depressions to the South which are moving eastwards.

Sirocco (or **Scirocco**). Blows out of **Algeria** and the Sahara Desert into the **western Mediterranean**

ahead of travelling Mediterranean lows, and can carry dust up to 10000'. The Sirocco can **sometimes continue northwards to France**; while in transit it will be cooled and humidified by the sea and can thus cause **advection fog and/or low stratus** along the **South French Coast**.
Khamsin. Similar to the sirocco, but **further east**, the Khamsin originates in Northern **Sudan**, blows **from the South** through **Egypt** and can affect Jordan, Syria and Cyprus. Dust can be carried to 10,000ft.

Vandevale. Strong **SW** to **W** wind in the **Straits of Gibraltar**. Blows ahead of a polar front cold front approaching from the Atlantic. It is very squally with much low cloud.

Upper Winds

In the **extreme west** a **few Polar Front Jet Streams** occur in association with PF Lows. The **Sub Tropical Jet** over **Morocco** does not affect the West of the sea area but can affect the Eastern Mediterranean in the Cyprus and Egypt region. It is centred at the 200 hPa level with maximum westerly winds at over 100kts.

Icing

Clear ice can occur in convective cloud and thunderstorms. Freezing rain/rain ice can occur over N Italy where the freezing level may occasionally be on the surface.

SUMMER

Pressure Systems

Azores High. The Azores sub tropical high at 35°N extends eastwards across the Mediterranean.
Thermal Lows. Pressure over Egypt, Lebanon, and lands to the East is relatively low due to intense insolation.

Cloud and Precipitation

There is little cloud aside from **fair weather CU. Local CU/CB** can occur over the high ground of Greece, Italy and Turkey due to **convective** and **orographic uplift**, possibly resulting in local thunderstorms.

Visibility

Trapped near the surface by generally descending air, **dust** can reduce visibility **across the region**. In the straits of **Gibraltar**, warm moist air **flowing out** over the cooler Atlantic can produce **advection fog** or **low ST/SC**.

Surface Winds

Levanter. Summer **outflow** from the Mediterranean occurs at Gibraltar and is called the Levanter.
It blows from the East (the Levant) during **July-October** and **March** and can reach gale force. The axis of the Rock of Gibraltar is North/South and **orographic uplift** on the east side through some 1100ft can produce a **banner of ST/SC** which then **streams westward** from the top of the Rock. In stable air **standing waves** can occur over the rock. Considerable **turbulence** up to 5000ft can exist above the adjacent airfield.
Etesian. This **moderate persistent** wind blows **from the North** across the Greek Islands of the **Aegean sea** towards the island of Rhodes then southwards. It is caused by the pressure gradient between the Azores ridge, extending across the Western and Central Mediterranean, and heat induced low pressure overland to the East. The wind is dry and brings **clear skies** and **good**

visibility. Strong Etesians can bring gales and affect the area from W Greece to W Turkey and as far south as the N African coast when CU may develop after the long sea track.

Sea Breezes. These can be strong at this time of the year and will **locally modify** surface wind direction.

Upper Winds

Light westerly in the **West**. **Westerly** average **40-50 knots** in the **East**. Both **Jetstreams** are **out of the region** to the North.

Icing

The freezing level is high and icing is not normally a problem in summer.

GEOGRAPHICAL CONSIDERATIONS.

Inland areas of Iraq, Saudi Arabia and Oman are largely desert. The Tropic of Cancer at 23½° N almost bisects the region so that in summer the noon sun is virtually overhead. The daytime interior is extremely dry and hot. The warm Gulf waters cause oppressive humidity along coasts. Surface wind direction is generally governed in the West by the NW/SE axis of the Zagros mountains in W. Iran and in the East by the Himalayas.

WINTER

Pressure Systems

The Siberian High is established over Asia to the NE but its surface outflow affects the region.

Thermal Lows, often with associated cold fronts, travel eastward from the Mediterranean across Arabia into Iran and Afghanistan.

Siberian dry cold frontal air passing over the relatively warm Caspian Sea to the North can initiate considerable thermal instability.

Cloud and Precipitation is restricted to the North and West only. **Travelling Lows** from the **Mediterranean** will produce **CU/CB, heavy showers** and **thunderstorms**, and their associated cold fronts may bring some weather and **duststorms** to the more southern interior of Arabia.

Thermal instability over the **Caspian Sea** can bring **thunderstorms**, **hail** and possibly **snow** to high ground to the north.

SUMMER

Pressure Systems.

The Baluchistan Low is the lowest pressure point of general warm weather low pressure over the Asian continent. It centres on the area of Baluchistan, lying across the Iran/Pakistan border, due to the mainly south-facing rocky nature of the surface, and intense solar heating from the high noonday sun.

The ITCZ just reaches Oman in the west. In the east it traverses the N. Arabian Sea northwards in June/July and southwards during September.

Surface Winds

In the west there will be anticlockwise rotation around the Baluchistan Low, as modified by the Zagros mountains with a NW/SE orientation, gives a Northerly or Northwesterly winds. In particular the Shamal wind originates as dry and dusty convection currents from Iraq. It is northwesterly and blows the length of the Gulf picking up moisture and bringing a dusty humid wind to facing coasts around Bahraina and Dubai.

Cloud and Precipitation.

Most of the region is almost rainless and temperatures can exceed 50°C. Inland areas are very dry but Gulf coastal regions facing the N/NW onshore winds can be oppressively humid. An exception is the **SE of Oman**. The **ITCZ** reaches the **coast** where the desert terrain temporarily "bursts into bloom". Further East towards the Indian coast, the ITCZ northward movement is followed by the onset of the SW monsoon. The monsoon is very moist and convectively unstable.

Orographic and convection cloud and heavy rain are widespread.

Visibility.

The **north/northwesterly winds** can cause much **dust** in the desert regions. The **shamal** will bring **dusty moist air** to coastal areas.. Visibility will also be reduced in regions affected by the ITCZ.

CALCUTTA to SINGAPORE

GEOGRAPHICAL CONSIDERATIONS

The route is located between Latitudes 23°N and 01°N. It overflies the eastern Bay of Bengal and

is just off the west coast of Bangladesh, Burma, Thailand and W. Malaysia. The Himalayas lie to the north of low lying Bangladesh. The Cameron Highlands form a spine the length of West Malaysia, and Sumatra Island to the SW also has a mountain backbone.

Pressure Systems.

Continental outflow from the **Siberian High** establishes the **NE Monsoon** over the whole route as shown above. The **ITCZ** is **south** of the route.

Weather.

In Winter the route weather is generally very good. Calcutta and Bangladesh are protected from the North by the Himalayas. Abeam Burma, the NE monsoon will have had a long land track and, although isolated convective cumulus are possible, the dry cold air will in general ensure clear skies.

Further south the monsoon will cross the Gulf of Thailand picking up warmth and moisture encouraging some CU and CB to form over the isthmus of Southern Thailand.

On the last section of the route the NE Monsoon arrives warm and moist from the expanse of the South China Sea giving large scale orographic cumulus and thunderstorms over the East Coasts and Central highlands of West Malaysia and Sumatra.

The West Coasts are more sheltered and generally less wet although all equatorial land areas including Singapore have considerable convective heating resulting in almost daily thunderstorms.

Visibility.

Early morning mist can occur in the moist river delta regions of Bangladesh and Burma. Otherwise visibility is very good outside showers and thunderstorms.

Winds.

Low level winds are north-easterly over the whole route under the influence of the NE monsoon. Above 20,000' upper winds overrun the monsoon. The 200 mb subtropical jet lies just south of the Himalayas and is therefore north of the route; decreasing westerlies of around 40 knots over Calcutta reduce to zero near 10°N thereafter becoming the normal light equatorial easterlies.

Icing.

Icing can occur above 16,000' but is a lesser problem in January than July as skies are generally clear on the route.

Weather.

In Summer, flying conditions are poor. The whole route lies on the windward side of the Bangladeshi, Burmese, Thai and West Malaysian coasts. Thunderstorms and severe weather will occur throughout except over the extreme south of the route, where in the Straits of Malacca there will be some protection by the mountains of Sumatra from the SW Monsoon. Nevertheless the high mountains on either side of the straits can cause a new hazard.

At **Night**, the **katabatic winds from each side**, aided by the land breeze effect, will meet in the middle of the straits causing a convergence line with consequent uplift. Along the straits this double sided uplift can cause a line of **night time thunderstorms arched** in the middle, known as **Sumatras**. (Jingle: Sumatras occur in Summer)

Cyclones.

Tropical revolving storms are known as **cyclones** in the Bay of Bengal. To form they need a summer **warm sea** (evidence suggests in excess of +27°C. and the close **instability** of the **ITCZ.** In July the ITCZ is north, over the land, so that in this area they form only in early and late summer when the ITCZ is over the sea, that is in **June** or **October**. Tropical revolving storms also occur in the Gulf of Thailand and occasionally move west to affect the route.

Visibility.

Visibility is generally impaired by much cloud and frequent rainfall. Reduction in tropical rainstorms can be considerable.

Winds.

Surface winds are **SW** over the whole route. Aloft, the 200 hPa subtropical jet is now located North of the Himalayas thus above 20,000' the equatorial mostly light **upper easterlies** apply over the **whole route**. Also in this region, summer high temperatures in the land mass of Asia cause a reversal of the South-North temperature gradient. Aloft, with warm air to the north, the upper pressure gradient movement is southward, which Coriolis/GF will turn to the right, giving a pronounced **Easterly Jet** over **Rangoon** of **70 knots** centred near the 150 hPa level (45,000').

Icing. Icing can be a problem on this route during the Summer, when descending through cumulo-form clouds.

SINGAPORE to TOKYO via HONG KONG

GEOGRAPHICAL CONSIDERATIONS

The route traverses the "Western Pacific Rim" from Latitude 01°N to 35°N. It passes close to the east coasts of W. Malaysia, Vietnam and China. The en route weather is dominated by the **changing seasonal pressure over Asia** and the temperature differences between continent and ocean and between sea currents. East of Japan, the cold Oyasiwo sea current sweeps down from the Russian Kamchatka peninsula, and is countered by the warm Kurosiwo sea current flowing northeastward from the Northern Philippines. Much of the area, including Japan, has a mountainous interior.

Pressure Systems

☐ The **ITCZ** lies well south of the route.
☐ The **Siberian High** is well established to the west over Asia.
☐ Some **Polar Front Lows** traverse the extreme north of the region.

Surface Winds.

Clockwise outflow from the **Siberian High** establishes the wind flow over the route as shown in Fig. 22.3. From **Singapore to Vietnam** the **NE monsoon** blows. From **Vietnam to China** the wind remains **north or north east**. Near **Japan** the wind is **north or north west**.

Weather.

In the south of the route, the NE monsoon sweeps down from the warm expanse of the South China Sea producing intense convective instability. This will produce CU, CB, heavy showers and thunderstorms along any windward coast in its path, for example the East/NE coasts of W. Malaysia and Vietnam. Inland areas, sheltered by mountains, will remain drier aside from convective weather.

Towards Hong Kong, after the ITCZ has passed southbound in September,some shelter will be afforded from north/NE winds by the Chinese mountainous landmass; from October to December the weather in Hong Kong is fine and dry. A change occurs in January as the wind veers and the source area is over the warm Kurosiwo sea current. These new warm moist winds form, over seasonally cooled coastal **Hong Kong** waters, **advection fog, low stratus drizzle and gloomy conditions**. This coastal condition is known as the **Crachin** and lasts in Hong Kong from **January to April** after which the northward movement of the ITCZ will dispel it.

In the north of the route very cold dry S E ward outflow from Siberia crosses the comparatively warm Sea of Japan. Moderate instability generated is orographically enhanced over the **Japanese NW coast** and **central mountains** causing **CU** and **heavy snow showers**. Eastern lee areas, such as Tokyo, will be drier and less cold due to the Föhn effect and warming from the Kurosiwo sea current.

Visibility.

In the south of the route, visibility is good between showers. At Hong Kong visibility is **excellent October-December**, but **abysmal** from **January-April** in the **Crachin** conditions discussed above. Near Tokyo and other big Japanese cities visibility can be reduced to near fog limits by industrial smoke.

Upper Winds.

Equatorial 10 -30 kt Easterlies blow from Singapore to 10°N. Further north, winds become westerly increasing in speed towards 25°N-40°N where the 200 mb subtropical jet blows, frequently up to 150 knots, and occasionally to 300 knots near Japan. This exceptional speed is due to a combination of the strong low level geostrophic South Eastward Siberian outflow and the extreme thermal wind component generated by the marked Siberia/Pacific temperature difference. Further north, there are some occasional westerly jets in association with polar front lows.

Pressure Systems

Baluchistan Low. The Winter Siberian High is replaced by the Summer Asian Low centred over Baluchistan. Its **anticlockwise inflow** produces the **SW monsoon** over the route as far north as Central Japan - the Northern limit of the ITCZ.

ITCZ/Equatorial Trough. The SW monsoon will follow northwards the ITCZ which will be over Singapore in March, China in May and Japan in July. The northern extent of the SW monsoon will then recede southwards again driven before the ITCZ, which passes Hong Kong in September and Singapore again in November/December.

Typhoons. In the North Pacific, tropical revolving storms are known as typhoons. Evidence suggests that to form, requirements include a sea temperature greater than +27°C, a proximity to

ITCZ instability, plus a displacement away from the equator where coriolis is zero, and location south of the Jet stream belts which would destroy their vertical continuity. They form in the Central pacific, at around 10°-15°N then drift westward at 10-15 knots with the clockwise wind direction around the N. Pacific sub tropical High. Nearing the Philippines they will generally track near the seasonal ITCZ but can curl northwards extending the season in some locations. Up to 12 per year can effect Southern Japan, principally in July - September and in Hong Kong occurrence is commonly in September. The overall season may extend from May to November depending on Latitude. The southern limit is the Gulf of Thailand.

Surface Winds

In July the south west monsoon extends over the whole route as far North as Central Japan where the ITCZ then lies. By late Summer, the cold Northwesterlies will re-establish behind the retreating ITCZ as the Siberian High begins to rebuild. Where Typhoons occur, winds of varying direction may exceed 100 knots. Sea breezes will effect coastal wind direction in sunny conditions especially in the South.

Weather

To the west of Singapore in the Malacca Straits, the Katabatic thunderstorm **Sumatras** will form overnight. The SW monsoon will bring Orographic CU CB to SW facing coasts, while east coasts will be more sheltered.

Nevertheless in these equatorial regions including Singapore purely convective cloud will be heavy, often giving daily thunderstorms.

Most route weather arises on the ITCZ as it travels from **Singapore** in **March** to **Tokyo** in **July** and back to **Singapore** in **November/December**. The **northbound ITCZ** will pass **China** in

May

where associated precipitation is known as the **Plum Rains**.

High typhoon internal wind speeds, coupled with intense rain and thunderstorms, can locally bring much structural damage and flooding.

Over Japan in Late Summer some frontal rain occurs as PC air spreading south from Siberia meets retreating tropical air.

Visibility

In early summer, warm moist SW monsoon winds, advancing north, can bring sea fog to cooler Chinese coastal waters and extensive blanket advection sea fog over the cold Oyasiwo sea current between eastern Japan and the mainland Kamchatka peninsula further to the northeast. Some industrial smoke can occur near cities in Japan.

Upper Winds

Equatorial **light easterlies** of 10-30 knots extend to 25°N, beyond which winds become **light westerly**. Sub tropical and Polar Front Jets are little in evidence over the summer North Pacific.

Tropopause Heights

Singapore	Japan
56,000’	38,000’

Freezing Levels
Singapore Japan
16,000’ 3,000’ -15,000’

SINGAPORE to AUCKLAND via DARWIN and SYDNEY
01°N – 37°S 105° - 175°E

GEOGRAPHICAL CONSIDERATIONS

The route crosses the equator just south of Singapore then over overflies the Java sea and many of the Indonesian islands. Next is the Timor Sea followed by the Central North Australian coast at Darwin, at latitude 12°S. From Darwin the route crosses the dusty largely flat Australian interior to the mountainous SE coast at Sydney, latitude 34°S. The last leg then heads across the Tasman sea to New Zealand’s low lying Auckland airport at 37°S.

WINTER (JULY)

?

Figure 26.7: Surface pressure and weather – July (Winter)

ITCZ. The ITCZ is in the northern hemisphere **well clear** of the route.
Thermal Lows. Convective thermal lows will occur over the Indonesian islands. These are formed by a combination of island insolation and high humidity from the surrounding sea.

Sub tropical High. The Australian interior in winter lies in the southern hemisphere Sub Tropical High belt. Relatively **cool** seasonal temperature overland will **reinforce high pressure** within the continent.

Polar Front Depressions. Travelling Polar Front Lows in the Southern Hemisphere’s disturbed temperate zone will themselves be located **well south** of the route; but associated troughs, and secondary lows, can bring **frontal weather** as far north as the **Australian South Coast** and to **New Zealand**. As in the northern hemisphere, these eastward-travelling fronts will alternate with temporary ridges and anticyclones. Cold frontal activity can be quite severe from Sydney to Auckland.

Surface Winds.
The **SW Monsoon Wind** at **Singapore** will soon back to **SE** (Coriolis change), as the route crosses the equator. These SE “trade” winds will remain as far as Darwin and beyond although at Darwin itself **strong local sea breezes** may blow from the North. On the **Darwin to Sydney** sector the **SE** trade winds gradually veer to **Southwesterly** to conform with the anticlockwise rotation round the Central Australian winter high.
Towards **Sydney,** and beyond **to Auckland**, the wind direction will locally be governed by the location of the travelling polar front depressions to the South but be generally **westerly.** South of the Australian land mass, these westerlies will encircle the globe largely unimpeded by land and will therefore strengthen. Here they are known as the **‘Roaring Forties’** from the principal latitude band in which they blow.
Sea breezes can affect **Sydney** even in winter.

Visibility.

Between frequent equatorial showers over Singapore and the Indonesian islands, visibility will be **good until near 05°S** beyond which there will be **haze** caused by the dry dust laden SE trade wind blowing from Australia.
Beyond Darwin, the dusty outflow from the interior will maintain haze. Near large cities visibility may be reduced to 1-2 Km by **industrial smoke haze**.
Over the two islands of New Zealand, the clear air gives good visibility in between cold frontal precipitation. **Radiation fog** can occur inland, especially over the colder South Island. **Advection/sea fog** can occur off the South Island east coast over the cold Antarctic Drift sea current.

Cloud and Precipitation.
Daily convective CU with showers over Singapore and the Indonesian Islands will give way to quieter weather towards Darwin. The anticyclonic Australian interior will be dry but, rising over the mountainous east coast, the onshore SE trade winds can give orographic cloud and rain. The Sydney area and Tasman Sea route are affected by the disturbed temperate region Lows to the South. They are thus crossed by fronts which bring moderate to heavy precipitation interspersed with Highs giving several days of cool fine weather.

Upper Winds. Above Singapore the **upper equatorial easterlies** will blow until 10°S after which the winds will increase from the west. In the southern winter, tropical North Australia remains hot whereas the South is comparatively cool. The temperature difference over the intervening sub tropical and continental high will produce the westerly **sub-tropical jetstream** at the **200 mbs** level across the **centre of the continent** around 25°S. Speeds may reach **100 knots**. From Sydney to Auckland, the westerly wind will moderate to 60-70 knots.
Icing. Icing is not a special problem on this route.

Pressure Systems.
ITCZ. Over Singapore the ITCZ is southbound in November/December and northbound in March. Its southerly extreme is just **south of Darwin** at the end of **January**. Thus it affects the **Singapore - Darwin** section of the route from **November to March.**
Continental Low. The Australian sub tropical high belt of Winter has moved south with the sun. Over **Australia** itself intense insolation brings **low pressure** to the interior.
Cyclones. Tropical cyclones and associated weather form adjacent to the ITCZ over the **Coral** and **Timor Seas.** They move at 10-15 knots in one of two general directions:
☐ Westwards, close to the North Australian Coast, or
☐ Curve to the left from the Coral Sea around the South Pacific High to affect the Australian East coast at Brisbane.
Occasionally they travel further southeastwards degrading to a deep depression as they cross the Tasman Sea to New Zealand's North Island.

Surface Winds.
The Northeast monsoon wind blowing from the South China Sea to Singapore will continue across the equator to become now the **Northwest monsoon** (Coriolis change) as far as the ITCZ; which in late January is just south of Darwin. Beyond the ITCZ there will be **Southeast trade winds** although overland they will be modified around thermal low pressure centres.

At Sydney the SE trades can give way to a strong **E/NE sea breeze**, or **southerly** winds after the passage of a polar front cold front. The latter are known locally as **Southerly Busters** (see 'cloud and precipitation' below).

Cyclones from the Coral Sea via Brisbane occasionally continue South eastwards over the Tasman Sea to produce very deep lows with **strong variable winds** but otherwise winds between Sydney and Auckland are generally **westerly**.

Visibility.

Visibility over Darwin and to the North is good except in precipitation from CB/TS. Between Darwin and Sydney, clockwise rotation around continental low pressure carries dust to the centre and south of the route and occasional dust storms will occur sometimes known in the NW as "Willy-Willies". **Industrial haze** near cities may reduce visibility to **1 - 2 Kms**. Visibility over the Tasman sea is good except in precipitation.

Cloud and Precipitation.

The Singapore and Indonesia region is one of the most **active daily thunderstorm** areas in the world. This is due to high ambient temperature, strong overland insolation coupled possibly with orographic uplift, and and high humidity from the abundant supply of sea water. At no time of the year is this region free from daily convective cloud, but the presence of the **ITCZ enhances instability** even further. Therefore in the southern summer, thunderstorms may be present all the way from Singapore to Darwin, and are reinforced by the ITCZ near Singapore in November/December and March, and near Darwin in January/February.

South of the ITCZ , the Australian **interior** is mainly **arid**. Towards Sydney, the weather is mainly subtropical excepting cyclones, but occasional cold troughs or fronts give squally wet weather. The passage of these **fronts** causes a marked drop in temperature, CU CB, and squalls and a **sharp back** in the wind to South known in Sydney as **"Southerly Busters"**. Indeed the Sydney weather can be worst in Summer.

Pressure Systems

In the northern winter, **pressure** will be **high** over the comparatively cool **Sahara desert.**
The **ITCZ** will be at its southern extreme over Zimbabwe. This will lead to overland **low pressure** extending south from **Nairobi to Johannesburg**.

Weather.

The northern section from **Cairo to 06°N** will be **dry and dusty**.

Convective CU/CB and some **NS** will form near **Nairobi**, and further south instability will be further enhanced by the ITCZ.

At Johannesburg, orographic **low cloud and fog** can occur early morning, but this clears quickly to give way to **convective CU** and showers in the afternoon. It is the **wet season.**

Cyclones originating in the Mozambique Channel can sometimes move west to affect Zimbabwe and Northern South Africa.

Surface Winds.

The southerly **Khamsin** wind to the Mediterranean blows from Egypt between **December and**

April.
Further south over Sudan and Kenya, clockwise outflow from the Sahara High will become first northerly then north easterly to become the trade winds blowing from dry Saudi Arabia.
South of the Equator they will back again northerly (coriolis change) to blow **clockwise** around **southern Africa's summer low** pressure of some 1005 mbs; and for this reason, become **easterly** again near Johannesburg.

Visibility. Visibility is poor over the dusty Sahara but good towards Nairobi except in showery precipitation. At Johannesburg early morning fog can be caused by the easterly surface winds from the Indian Ocean orographically rising to the Kalahari plateau.
Icing. Icing can be severe above 16000' in CB near the ITCZ.**CAIRO to JOHANNESBURG via NAIROBI**
30°N – 27°S 28° - 37°E

GEOGRAPHICAL CONSIDERATIONS.
The route over Egypt and Sudan is almost all over low lying Sahara desert. At the Kenya border latitude 06°N, the land rises, at the beginning of the equatorial vegetation belt, to over 5,000' by 02°S at Nairobi. The route then traverses the eastern edge of the Kalahari plateau to the high veld of Johannesburg.
JANUARY (Northern Winter/Southern Summer)

Weather
The ITCZ northern extreme is just north of Khartoum in July. This is therefore normally that city's only wet month of the year. The ITCZ brings a tropical rain belt, line squalls and dust storms known as **Haboobs** which often appear as walls of dust lifted to 10,000'. Haboobs can appear in Northern Sudan from May to September as the ITCZ sweeps north then south. They form during the day when convection is strong.
It is winter in Johannesburg. Continental high pressure prevails and it is the **dry season** although ST and SC turbulence cloud may form in air rising orographically from the Indian Ocean to the Johannesburg high veld.

Surface Winds
High pressure over the Mediterranean, and low pressure over Arabia will give northerly surface winds (an extension of the Mediterranean Etesian) over the route from Cairo to the ITCZ which in July is near 18°N.
South of the ITCZ and north of the Equator, winds will be from the SW (Coriolis effect), reverting to the SE trade winds south of the Equator. Over southeastern Africa these SE trades are known as the **Guti**. The southeasterly Guti blows anti-clockwise around the overland winter high, often being in place for five days or so at a time. It can bring the orographically formed ST & SC to Johannesburg.

Visibility

Visibility over the Sahara will be appalling in Haboobs, and poor elsewhere in Sahara dust. Near Nairobi it will be good except in showers. At Johannesburg visibility may be reduced below low ST/SC formed by the Guti SE wind.

Icing. As in winter, icing can be severe above 16,000' in CB.
Northern hemisphere Autumn. ITCZ passage will be **southbound** (November/December) and will be followed by the **dry** NE trade winds from Saudi Arabia. Rainfall will still occur but will be less and is known as the **Short Rains.**
Orographic Uplift. At each ITCZ passage the surface w/v will be alternating between NE and SE.
Nairobi has an elevation of over 5,000' and is only 200 nm from the east coast. **Especially during the long and short rains** at ITCZ passage, and between **0200 and 0800 local time**, orographic uplift in the generally easterly winds can frequently produce Low Stratus, often lowering to the undulating surface as **fog**.
Thunderstorms. Convective thunderstorms can occur at any time but are very infrequent from June to September when the ITCZ is well north.
Tropopause and Freezing Levels.
Tropopause heights average 56,000' all year.
Freezing level heights are 16,000' in equatorial regions and average 14,000' in the higher latitudes in Winter.

Limitations and Delimitations of the Study:-

INTRODUCTION

Meteorology has benefited considerably by the use of satellites in recent years. Apart from the obvious advantages of satellite communications over the old land-based systems, providing prompt and trouble free communication of meteorological data, satellite photography has provided weather images that were impossible to produce in the past and were often merely 'artist's impressions' of the weather.
There are two types of satellite; the polar orbiting and the geostationary and two methods of producing the weather picture; visual photography and infra red.

POLAR ORBITING SATELLITES

The so-called polar orbiting satellites have been put up principally by Russia (Meteor) and USA (NOAA). The NOAA orbit is inclined at an angle of 99° to the equator, takes 1 hr 42 min to orbit the earth, is between 820 and 870 km above the surface and covers a band 1500 nm wide. Each successive orbit is a little further west and there will be an overlap, greatest at the poles and small near the equator. Any spot on the globe will experience a southbound pass of the satellite in the morning and a northbound pass in the afternoon or evening. Although picture definition is good, polar orbiting satellites do not give a continuous view of the weather.

GEOSTATIONARY SATELLITES

Geostationary satellites are put into orbit over the equator and since they take 24 hours to complete the orbit, they will appear to be stationary over a selected longitude. In 1987 there were 5 geostationary satellites in orbit; meteosat 2 over the Greenwich meridian, GOES E over longitude 75W, GOES W over longitude 135W, GMS 2 over longitude 140E and INSAT over longitude 70E.

These satellites are considerably higher than the polar orbiting satellites (36 000 km) and picture definition may not be as good, but the advantage of a continuous picture outweighs this disadvantage. Because of the equatorial orbit the picture become somewhat distorted towards the poles, but this may be corrected by computer processing. Meteosat covers about 1/3 of the earth's surface from 70° west to 70° east. The satellite transmits a picture every 4 minutes and a useful feature is the time lapse sequence showing movement of weather over a period of time.

VISUAL IMAGES

Although visual photography may be easy to interpret, it suffers the disadvantage of not being available continuously, due to lack of sunlight at night. Clouds will appear white, the land grey and the sea black.

INFRA RED (IR)

Infra red images have the advantage of being available for 24 hours a day and the shading of the picture will be more or less the same by day and by night. Cold (high) cloud will give a white image, lower cloud a somewhat darker one, whilst warm land will give a dark image. There are 9 IR temperature bands, black normally denoting cloud free areas. IR may not be able to distinguish between a sea surface and fog, which may have a similar temperature. In this case, a visual picture would be able to show the position of fog more precisely.

FALSE COLOUR PICTURES

To help differentiate between the various shades of grey produced by both visual and IR photography, the shades may be converted by computer into various colours. This is used particularly with IR systems.

LOCATION OF THE IMAGE

It is often difficult to pick out geographical features, especially when there is thick cloud and of course, areas of oceans are completely featureless. Satellite images are therefore presented with a computer produced graticule of numbered parallels and meridians superimposed. Coastlines may be enhanced as well.

Interpretation of Satellite Photography

Whilst violent weather such as tropical revolving storms may produce an easily identifiable picture, normal weather pictures are best used in conjunction with synoptic charts. The timelapse sequences can be used to confirm existing and forecast weather before setting off on a flight. Figures 23.4 & 23.5 show a surface analysis and a satellite picture for the same times. The picture below shows the visual image with the surface analysis superimposed

DECODING THE METAR

This example reproduces the first eight code-groups normally found in a **METAR**.

METAR EGTK 231020Z 26012G25KT 220V300

For clarity the METAR has been split into its significant parts - (a) to (h):
METAR EGTK 231020Z 260 12 G 25KT 220 V 300
(a) (b) (c) (d) (e) (f) (g) (h)

Report Type

The first code, **(a)**, is the identification of the **type** of report; in this case a **METAR**.

Aerodrome

The four-letter **ICAO designator** of the **issuing aerodrome** is shown next, **(b)**; this example is for **Oxford/Kidlington, EGTK**.

Date-Time Groups

The third group, **(c)**, is the **date/time group**, which simply gives the date of the actual weather observation. The first **two digits represent the day of the month**, followed by the **time in hours and minutes**. Time is always given as **Coordinated Universal Time (UTC)**, which is, for all practical purposes, the same as **Greenwich Mean Time (GMT)**: the **local time** at **Greenwich, London**. In the **METAR**, itself, **UTC** is indicated by the code **Z**, pronounced **"Zulu"**.

WIND INFORMATION

The next items in the **METAR** (**d**, **e** ,**f** and **g**) are the **observed wind information**. Firstly, the **direction** of the wind given in **degrees true**, rounded up or down to the **nearest 10 degrees, (d)**, and then the **wind speed in knots, (e),** which is a **mean speed** taken over a **10 minute period**. However, if a **gust** is observed which is at least **10 knots** more than the **mean wind speed**, then a **gust figure**, **(g)**, comes after the **mean wind**; this **gust figure** is preceded by the letter **G, (f)**. The next **code-group**, **(h)**, may or may not appear depending on the directional **variability** of the wind. **Variability** is shown after the main wind-group and signifies the **extremes in the direction of the wind** during the previous **10 minutes**. The letter **V** will appear between these two extremes. If there is no wind, the coding, **00000KT**, will be used.

VISIBILITY

Visibility in the **METAR** is represented by the next group, depicted in **red** in the example. In the **METAR**, the reported **visibility** is the **prevailing visibility** and, may, under certain conditions, include the **minimum visibility**. Here, the **prevailing visibility** is reported as **1,400 metres**. **Prevailing visibility** is the **visibility** value which is either **reached, or exceeded, around at least half the horizon circle**, or **within at least half of the surface of the aerodrome**. If the **visibility** in one direction, which is **not** the **prevailing visibility**, is less than **1,500 m**, or **less than 50% of the prevailing visibility**, the **lowest visibility observed**, and its **general direction**, should also be reported.

Up to **10 km**, the **visibility** is measured in **metres**. For example, **6000** means that the **prevailing visibility** is **6,000 metres**. Once the visibility reaches **10 km** or more, the code figure used is 9999.

Visibility of **less than 50 metres** is indicated by the code **0000**. In this example the **prevailing visibility** is **1,400** metres.

METAR EGTK 231020Z 26012G25KT 220V300 1400

In some instances, **runway visibility** information is given in a **METAR**; this is known as

Runway Visual Range (RVR.) RVR is given only when either the **horizontal visibility** or the **RVR**, itself, is less than **1,500 metres**. The **RVR group** starts with the letter **R**, and then goes on to give the **runway in use**, followed by the **threshold visibility in metres**.

In the following example, for **Oxford Kidlington**, we have a **prevailing visibility** of **1,400 metres**, with an **RVR**, on **Runway 30**, of **1,100 metres**.

METAR EGTK 211020Z 26012G25KT 1400 R30/1100

If the **RVR** is more than the **maximum reportable value of 1,500 metres**, the code **P** is used in front of the visibility value, **R30/P1500**.

A letter can sometimes come after the **RVR** to indicate any trends that the **RVR** has shown. A **U** means that the visibility has increased by **100 m** or more in the last **10 minutes**, e.g. **R30/1100U**. A **D** shows that visibility has **decreased** in that same time period, **R30/1100D.** An **N** added to the visibility group shows that there is no distinct trend observed, **R30/1100N**.

THUNDERSTORMS

A **Thunderstorm** report will appear in a **METAR** if **thunder has been heard within the last 10 minutes.**

A **thunderstorm** is represented by the letters **TS**. If there is **no precipitation**, the letters **TS** will appear on their own. However, if there **is precipitation**, a further two letters, which signify the type of precipitation, are inserted after the **TS**. For example, if there is **rain** observed from the **thunderstorm, TSRA** will appear in the **METAR**. If **hail** were to be observed, the code would read **TSGR**, or **TSGS**, with **GS** meaning **small hail.**

CLOUD COVERAGE

The next **code-group** to appear in the **METAR** gives detail of **cloud coverage**, as highlighted in red below. In this case the highlighted code means: overcast sky, base 2,000 feet, with cumulonimbus.

METAR EGTK 211020Z 26012G25KT 1400 R30/1100 +SHRA OVC020CB

There are several prefixes which are used to describe **cloud amount**, at any given **level. Cloud coverage** is reported in the **METAR** using the following three-letter codes:

¾¾ **FEW (FEW)** meaning **one to two eighths** of cloud coverage.
¾¾ **SCATTERED (SCT)** meaning **three to four eighths** of cloud coverage.
¾¾ **BROKEN (BKN)** meaning **five to seven eighths** of cloud coverage.
¾¾ **OVERCAST (OVC)** meaning **complete cloud coverage**, or **eight eighths.**

Cloud base is given as a **three-digit figure** showing **hundreds of feet. Cloud base** in a **METAR** is always measured as **height above aerodrome level**, using the current aerodrome **QFE**.

For example, **6 eighths of cloud (6 oktas)** at **1 900 feet** above aerodrome level would appear in the **METAR** as **BKN019. 8 oktas** at **five hundred feet** would be abbreviated to **OVC005**.

The only **cloud types** that are specified in the **METAR** are the **significant convective clouds**. These are **cumulonimbus (CB)** and **towering cumulus (TCU)**.

Looking back to the **cloud group** we see the code **OVC020CB**. This refers to an **overcast sky** covered by **convective cumulonimbus cloud** whose **base** is **2,000 ft above aerodrome level**. The previous **weather group, +SHRA**, indicates that the **cloud** detailed in the **cloud group** is producing a **heavy shower of rain**. If there is **no cloud** observed at the airfield, the code **SKC**, meaning **sky clear**, is used.

OBSCURATION

If the sky at an aerodrome is **obscured** for reasons other than **cloud cover**, and **cloud coverage** cannot easily be determined, the code **VV** is used in place of the cloud information. **VV** is followed by the **vertical visibility** in hundreds of feet.

METAR EGTK 231020Z 26005KT 300FG OVC VV002

(a) (b) (c)

The highlighted codes in this METAR indicate that:

Visibility is 300m in fog (a), the sky is overcast (b), and the vertical visibility is 200ft (c).

ThIS **METAR** decodes as follows:

METAR for **Oxford/Kidlington**, observed at **1020 UTC** on **23rd** of the month; the **surface wind** is **260° True**, at **5 knots**; the visibility is **300 m** in **fog (a)**; the sky is **overcast (b)**, and a **vertical visibility of 200 ft** has been reported **(c)**.

If the **vertical visibility** cannot be assessed, **three forward slashes** will replace the **cloud height figures**, e.g. **VV///**.

The code **CAVOK** is frequently used in the **METAR code**, being the abbreviation for "**cloud, ceiling** and **visibility** are **OK**." If **CAVOK** is used, it will replace the **visibility**, **RVR**, **weather** and **cloud groups**. There are four criteria which must be met in order for **CAVOK** to appear in the **METAR**. These are:

¾¾ the visibility must be **10 kilometres** or more.

¾¾ the **height of the lowest cloud** must be **no less than 5 000 feet**, or the level of highest minimum sector altitude, whichever is the greater.

¾¾ there must be **no cumulonimbus** present.

¾¾ there must be **no significant weather**.

METAR EGTK 231020Z 26012G25KT 220V300 CAVOK

TEMPERATURE AND DEW POINT

The **temperature** and **dew point** constitute the next group in the **METAR code**. The **temperature** and **dew point code** is simply a **two-digit number** giving the **air temperature**, with a **forward slash**, followed by another **two-digit number** which indicates the **dew point**. Both **temperatures** are measured in **degrees Celsius**. For example, the **code 10/02** indicates that the **air temperature** is **plus 10° C**, and the **dew point** is **plus 2° C**. If either figure is **negative**, the prefix **M** will be used, as in **10/M02**. The **dew point** in the example just given is **minus 2° C**.

METAR EGTK 231020Z 26012G25KT 220V300 CAVOK 10/M02

This **METAR** decodes as follows:

METAR for **Oxford/Kidlington**, observed at **1020 UTC** on **23rd** of the month; the surface wind is **260° (True)** at **12 knots**, **gusting to 25 knots** and varying in direction from **220° (T) to 300° (T)**; the **visibility is 10 km** or more, with **no cloud below 5,000 ft**; there are **no cumulonimbus** and there is **no significant weather** at, or in the vicinity of, the aerodrome; the air temperature is **+10° C** and the dew point is **-2° C**.

QNH

The next **METAR code** is the **QNH**. The **QNH** will be represented by the letter **Q**, followed by a **four digit number representing the actual pressure value**. If the **QNH** is less than **1000 millibars**, the value will be preceded by a **zero**. For example, a **QNH** of **991 millibars** would appear as **Q0991**.

METAR EGTK 231020Z 26012G25KT 220V300 9999 -RA FEW060 SCT120 10/M02 Q0991

It is important to note that the only **pressure value** given in a **METAR** is the **QNH**. The **QNH** is always rounded **down for safety reasons**, if there are digits after the decimal point; for instance, if the **QNH** were **991.7 millibars**, the **QNH** would be reported as **Q0991**.

The above **METAR** decodes as follows:

METAR for Oxford/Kidlington observed at **1020 UTC** on **23rd** of the month; the **surface wind** is **260° (T) at 12 knots, gusting to 25 knots**, and **variable in direction from 220° (T) to 300° (T)**; the **prevailing visibility is 10 km** or more with **light rain**; there are **1 to 2 oktas of cloud at 6,000 ft** and **3 to 4 oktas at 12,000 ft**; the air temperature is **+10° C** and the dew point is **-2° C**; the **QNH is 991 millibars.**

RECENT WEATHER

If there has been **recent significant weather**, either **in the past hour**, or since the last **METAR** was issued, and if the **significant weather** has ceased, or reduced in intensity, a **METAR code group** beginning with **RE** will appear. **RE** stands for **recent**. If there has been a **thunderstorm** during the hour, but which has now abated, giving only light rain, the **present weather** is reported as **light rain, –RA**; the fact that there have been **thunderstorms in the past hour** is reported by the three-letter code **RETS**:

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS

WINDSHEAR

Although not currently issued at **United Kingdom** airfields, **windshear** information may be reported in the **METAR**. This will simply be denoted by the letters **WS**, followed by the necessary details, such as **WS ALL RWY**, meaning **windshear on all runways**, or **WS 30**, meaning **windshear present on Runway 30**.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY

TREND, BECMG, TEMPO

A **TREND** forecast is valid for **2 hours** after the time of the observation of the **METAR**, and constitutes the final section of the **METAR**. The change in weather conditions indicated by the code, **TREND**, can be further qualified by the codes, **BECMG,** meaning **becoming**, or **TEMPO** meaning **temporarily**.

BECMG indicates that the change in the present weather will be long-lasting. **TEMPO**, on the other hand, means that the change is **temporary**, and that the different conditions will prevail for periods of **less than one hour**, only, and **no more than half the time period**, in aggregate. The codes may be followed by a time period in hours and minutes. The time periods given

may be preceded by **FM** meaning **from**, **TL** meaning **until**, or **AT** meaning **at**.
For example, **TEMPO FM1020 TL 1220 1000 +SHRA** translates as: **temporarily**, from **1020Z** to **1220Z**, the **visibility** will reduce to **1,000 metres**, in **heavy showers of rain**.
If there is no expected change in the meteorological conditions being forecast by the **METAR**, the code **NOSIG** is used to indicate that **no significant change** is expected in the next two hours.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY NOSIG

SNOWTAM

An additional **eight-figure runway-state code** will be added after any **TREND** information, when there is **snow** or other **runway contamination**. This code is sometimes referred to as a **SNOWTAM**.
The **SNOWTAM** takes the form;

¾¾ runway designator.
¾¾ runway deposits.
¾¾ extent of runway contamination.
¾¾ depth of deposit.
¾¾ the braking action.

In order to decode a **SNOWTAM**, a pilot should consult the **UK AIP**, **GEN 3.5.10, Meteorological Codes**.

SPECIAL REPORTS

A variation on the **METAR** is the **Special Report**. A **Special Report**, which is denoted by the abbreviation, **SPECI**, has the same format as a **METAR** except that the code **SPECI** will replace **METAR** at the beginning of the report. A **SPECI** will be issued when the **weather conditions significantly change** in the period between routine observations. A **SPECI** can be issued to indicate either an **improvement** or a **deterioration** in the weather.

SPECI EGTK 231025Z 26012G25KT 220V300 2000 +RA OVC010 5/M02 Q0991 RETS WS ALL RWY NOSIG

END OF MESSAGE

An equals sign (=) appears at the end of the **METAR** to denote that the **message is complete**.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY NOSIG =

SUMMARY

Although **METARs** may appear confusing to the uninitiated, with practice, it is quite a simple task to decode a **METAR** accurately and speedily. Pilots should consult **METARs** for **departure and destination aerodromes** and also for other **aerodromes along the planned route**, and, in particular, for aerodromes **upwind** of a destination aerodrome, in order to get a picture of the **weather which is approaching** the destination.

If the **aerodrome of destination** does not issue a **METAR**, consult a **METAR** from an aerodrome **in the vicinity** of your destination.

DECODING TAFS

The first code which appears in the **TAF** is the identifier, **TAF**. The next code is the **ICAO location indicator of the aerodrome** for which the report is issued. The example given below is for **EGTK**, Oxford, Kidlington, airport.

TAF EGTK 130600Z 1307/1316 31015KT 8000 -SHRA SCT010 BKN018=

THE DATE-TIME INFORMATION

As we have established, the **TAF** gives a **forecast for a period of time**. Consequently, the datetime information in **TAFs** is slightly different from that given in a **METAR**. In the **TAF**, there are two items of **date-time information.**

The first **date-time group**, highlighted in red below, indicates the date and time at which the **TAF** was issued.

TAF EGTK 130600Z 1307/1316 31015KT 8000 -SHRA SCT010 BKN018=

The digits **13** identify the day of the month; this information is followed by the time in **hours and minutes** UTC. The above **TAF**, then, was issued on **13th of the month**, at **0600 hours**, **UTC**. In the **TAF**, **Coordinated Universal Time, UTC**, is indicated by the letter, **Z**.

The next **code-group** identifies the **period of validity** of the **TAF.** The format for this was changed as recently as November 2008. The information here uses this new eight-digit format instead of the six-digit format. The first four digits show the start date and time, so 1307 indicates that the TAF's validity period starts on the 13th at 0700Z. The next four digits are the end date and time of the validity period.

So, in the example given below, the date and time of the origin of the report is **0600 UTC** on **13th** of the month, and the **validity period**, highlighted in red, is from the 13th at **0700 UTC** to **1600 UTC** on the same day. This example, then, is a **nine hour TAF**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

WIND

The **wind codes** in the **TAF** are the same as in the **METAR**. Our example **TAF** shows a **mean wind direction** of **310° (True)**, at a **wind speed** of **15 knots**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Weather.

The weather coding in the **TAF** is also the same as in the **METAR**. In our example, the visibility is **8 000m** with **light showers of rain**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

CLOUD

Cloud coding in the **TAF** can be slightly different from the **METAR**.

If there is no **cloud below 5 000 ft**, or **cloud cover below the minimum sector altitude**, whichever is the lower, and if the codes **CAVOK** or **SKC** are not appropriate, the code **NSC** is used, which stands for **no significant cloud.**

You should note, too, that while **cloud-coverage** is reported in the **TAF**, in the same way as in a **METAR**, only **cumulonimbus clouds** are reported in **TAFs**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Our example TAF, above, is forecasting **scattered cloud at 1 000 feet**, with **broken cloud at 1 800 feet.**

The main **TAF** information ends with the cloud group. **TAFs** do not contain information on **temperature and dew point, QNH, recent weather, wind-shear or runway state information.**

Only significant changes of weather follow the cloud group. These **significant changes** are introduced by **codes** classified as **forecast change indicators.**

FORECAST CHANGE INDICATORS

There are distinctive **TAF codes** which indicate that a **change** is expected in some or all of the **forecast meteorological conditions**. The nature of the change can vary: it may, for instance, be a **rapid, gradual** or **temporary change**. These codes are **FM** (meaning **FROM), BECMG** (meaning **BECOMING), TEMPO** (meaning **TEMPORARILY**), and **PROB** (meaning **PROBABILITY)**

THE FROM (FM) GROUP

The **FROM** group in a **TAF** is introduced by the code **FM** and marks the fact that a **rapid change in the forecast conditions is expected**, which will lead to the appearance of a new set of prevailing conditions becoming established at the aerodrome.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 FM 131220 27017KT 4000 BKN010=

The **change indicator FM** is followed by a **six-digit date and time group.** The first two digits are the day of the month followed by the hours and minutes to indicate the time at which the change is expected to begin. In our example **FM 131220** means that certain weather changes will occur from the 13th at **1220 UTC. This weather forecast** following the code **FM supersedes the TAF forecast, prior to 1220 UTC.**

The **FM** indicator, therefore, introduces what is effectively a new forecast, associated with a new weather situation, and which supersedes the previous forecast. The **FM** group contains all the elements of a complete **TAF** forecast: **wind, visibility, weather** and **cloud.**

In the example below, highlighted in red, we read that from the 13th at **1220Z** until the **end of the TAF period**, the **wind** will change to be **270° (T) at 17 knots**, with a **prevailing visibility of 4 000 metres**, and **broken cloud at 1 000 feet.**

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 FM 131220 27017KT 4000 BKN010=

The forecast following the **FM indicator** continues either to the end of the current **TAF**, or until another change indicator occurs in the **TAF**.

THE BECOMING (BECMG) GROUP

The change group **BECMG,** meaning **becoming,** is followed by an **eight-figure date and time**

group which indicates the period during which there will be a **permanent change in the forecast conditions**. However, **BECMG** marks a **more gradual change in conditions** than **FM**.

The **forecast gradual change,** introduced by **BECMG,** will occur at an **unspecified time** within the time period stated.

The following example **TAF** indicates that, at some time on the 13th between the **0900 UTC** and **1100 UTC,** but definitely by **1100 UTC,** the prevailing conditions will give **5 000 metres visibility**, in **light rain**. There is no new **wind information** after **BECMG,** so the inference is that the wind will be as **previously forecast**: **310° (T) at 15 knots**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 BECMG 1309/1311 5000 –RA=

THE TEMPORARY (TEMPO) GROUP

"TEMPO", meaning **temporarily,** indicates that a change in **meteorological conditions** will occur **at any time within the specified time period**, but is expected to last **less than one hour** each time, and, in aggregate, will last no longer than half the time period of the complete forecast. The **TEMPO indicator** is followed by an **8-digit date and time group** indicating the hours between which the **temporary conditions** are expected to begin and end.

The example **TAF**, which follows, tells us that sometime on the 13th between **1200 UTC and 1400 UTC**, the **visibility** will fall to **4 000 metres**, with the weather being **thunderstorms** and **moderate rain**. There will be **5 - 7 oktas** of **cumulonimbus cloud** at **1 000 ft. However, after 1400 UTC, the weather will return to the conditions specified in the first part of the message.**

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 TEMPO 1312/1314 4000 TSRA BKN010CB=

The Probability (PROB) Indicator.

The code **PROB** (meaning **probability**) in a **TAF** indicates the **probability** of the occurrence of specified weather phenomena.

The **probability indication** is a **percentage probability** of the occurrence of **significant weather events** such as **thunderstorms** and associated **precipitation**. A **30% probability is considered low**, while a **40% probability** indicates that it is **highly likely** that the weather being forecast will actually occur. The code **PROB** can be followed by a **time group of its own**, and/or by an indicator, such as **BECMG** or **TEMPO**.

The example **TAF** below tells us that there is a **high probability** that, between **1000 UTC and 1400 UTC**, there will be **thunderstorms** with **heavy rain** and **hail**, and from **3 to 4 oktas** of **cumulonimbus clouds** at **500 ft**.

The storms will not last longer than one hour at a time and no more than two hours in total, which is one half of the period to which the TAF applies.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 PROB40 TEMPO 1310/1314 +TSRAGR SCT005CB=

AMENDMENT

When a **TAF** requires an **amendment**, the amended forecast may be indicated by the code **AMD**, highlighted in red, after the **TAF identifier**, as shown below:

TAF AMD EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 PROB40 TEMPO 1310/1314 +TSRAGR SCT005CB=

Used correctly, **TAFs** will enable a pilot to make accurate and informed decisions about a planned flight, including the expected conditions en-route, and at destination and alternate aerodromes.

END OF MESSAGE

An equals sign (=) appears at the end of the **TAF** to denote that the message is complete.

DECODING THE SIGMET

Below is shown an example of a **SIGMET** message.

(a) (b) (c) (d) (e)
EGTT SIGMET 02 VALID 281400/281900 EGRR-
(f) (g) (h) (i) (j)
EGTT LONDON FIR SEV MTW VSP 600FPM FCST FL060/120 S OF A LINE FROM
(k) (l)(m)
N5220 W00530 TO N5300 E00300 STNR NC=

The first item is the location indicator of the Air Traffic Services Unit (ATSU) serving the Flight Information Region (FIR) or Control Area to which the SIGMET message refers. The ATSU which issued our example SIGMET is EGTT, (a), which is the London FIR. EGTT is followed by the code SIGMET, (b), which is the message identifier.

After the identifier, the sequence number is given next, (c). In this example, the sequence number is 02, which corresponds to the number of SIGMET messages issued for the London FIR since 0001 UTC on the day of issue.

The next item is the **date and time groups, (d),** indicating the **period of validity** of the **SIGMET** message in **UTC**. In this example, the **SIGMET** is valid on the **28th** of the month from **1400 UTC** to **1900 UTC**.

The first line of the **SIGMET** ends with the **location indicator** of the **meteorological watch office** which issued the **SIGMET**. Here, it is **EGRR, (e)**, which is the **UK Met Office. EGRR** is followed by **a hyphen** which separates the **SIGMET preamble** from the next line of text.

At the beginning of the second line, is the **name of the FIR or control area** for which the **SIGMET** is issued; so the code **EGTT** is repeated, **(f)**, but now is also decoded as the **London FIR**.

Next comes the **name** and **description** of the **weather phenomenon** which is the reason for the issuing of the **SIGMET**. The **weather phenomenon** is given in **abbreviated plain language**, using the **abbreviations** given on the previous page. In our example, the warning is of **severe mountain waves, (g),** with a **vertical speed of 600 feet per minute**.

Following the **weather phenomenon,** there is an indication of whether the information is **observed** or **forecast**, using the abbreviation **"OBS"**, or **"FCST"**, **(h)**. If relevant, the time of observation in **UTC** will also be given.

The next group of information relates to the **location** and **altitude** of the **observed** or **forecast phenomenon**, in this instance between **Flight Levels 60** and **120, (i).**

Where possible, reference is made to **latitude** and **longitude**, **locations** or **well-known geographical features**. In our example **SIGMET**, the location of the **mountain waves** is given as: **South of a line** from a position at **52° 20' N, 5° 30' W** to a position at **53° N, 3° E, (j)**. This is a
line from a point on the **FIR boundary in Cardigan Bay** to a **point in the North Sea, some miles**
North East of Yarmouth.

Movement or the **forecast movement of the weather phenomenon** is normally indicated by reference to one of the **eight points of the compass**; however, this **SIGMET** does not contain such a reference.

The **speed of displacement** of the **weather phenomenon** is given in **kilometres per hour** or **knots**. But if the **weather phenomenon** is **stationary,** as in this example, the code **STNR, (k)**, is used. Finally, an indication is made of any **change in intensity** of the **weather phenomenon,** using the abbreviation **INTSF** for **intensifying, WKN** for **weakening** or **NC** for **no change,** as in this example, **(l).**

The **SIGMET** is ended, as with the **METAR**, with an equals sign **(m).**

COMPLETE SIGMET MESSAGE.

The complete **SIGMET message**:

EGTT SIGMET 02 VALID 281400/281900 EGRREGTT
LONDON FIR SEV MTW VSP 600FPM FCST FL060/120 S OF A LINE FROM
N5220 W00530 TO N5300 E00300 STNR NC=

Decodes as follows:

The message is for the **London FIR, EGTT**; the message is a **SIGMET**, the **second** to be issued for
the **FIR since 0001** UTC. It is valid for the **28th of the month** from **1400 UTC** until **1900 UTC** and
was issued by the **UK Met Office, EGRR**. In the **London FIR, severe mountain waves,** whose vertical speed is **600 feet per minute, are forecast from FL60 to FL120, South of a line from 52° 20' N 5° 30' W to 53° N 3° E**; the phenomenon is **stationary** and **no change** is expected.

A further **SIGMET** is shown below.

EGPX SIGMET 01 VALID 280900/281300 EGRREGPX
SCOTTISH FIR SEV TURB FCST BLW FL070 S OF A LINE N5800 W01000
TO N5700 W00500 TO N5500 E00000 MOV NNE AT 35KT NC=

This **SIGMET** decodes as follows:

The message is for the **Scottish FIR, EGPX**; it is the **first SIGMET issued since 0001 UTC,** and
is valid for the **28th of the month from 0900 UTC to 1300 UTC,** being issued by **the UK Met Office, EGRR**. In the **Scottish FIR, severe turbulence is forecast below FL70, South of a line from 58° N, 10° W to 57° N, 5° W to 55° N, 0° E/W**; it is **moving North North East at 35 knots,**
and **no change is expected.**

SPECIAL SIGMETS

There are two other specialised types of **SIGMET** valid for up to **6 hours.** These are the **VOLCANIC SIGMET,** issued to notify pilots of **volcanic ash,** due to **volcanic eruptions,** and the **TROPICAL CYCLONE SIGMET,** used to notify pilots of **hurricane** or **cyclone activity. SIGMETs** for **volcanic ash clouds** or **tropical cyclones** include an additional line of text. This line contains a **brief outlook forecast** beyond the **period of validity** specified earlier in the message. In a **Volcanic SIGMET,** the outlook will include a direction of travel for the **ash cloud.**

For a **Tropical Cyclone SIGMET,** the position of the **tropical cyclone centre** is included.

VOLMET OPERATION

The following table is an extract from the **United Kingdom Aeronautical Information Publication** (GEN Section), containing a list of **VHF VOLMET** services and their associated **radio frequencies** for the **United Kingdom** and the **near continent**

Individual **VOLMET stations,** in each region, broadcast weather reports and forecasts for a **group of major aerodromes** in their region of responsibility.

From the table below you can see that there are four **UK VOLMET** stations: **LONDON VOLMET MAIN, LONDON VOLMET NORTH, LONDON VOLMET SOUTH** and the **SCOTTISH VOLMET.** Next to each of these **stations,** is the **frequency** on which the **VOLMET** transmission is broadcast, the operating hours, and the list of aerodromes covered by the broadcast. The **LONDON VOLMET MAIN** broadcast, for example, is transmitted on the **VHF frequency** of **135.375 MHz, continuously, over a 24 hour period.**

The content of each **VOLMET broadcast** is a set of pre-recorded weather elements. **VOLMET broadcasts** are updated every **half hour.**

You will also see from *Figure 23.1* that the **LONDON VOLMET MAIN** broadcast contains weather information for aerodromes in **France** and the **Republic of Ireland,** as well as in the **United Kingdom.** The **LONDON VOLMET SOUTH** broadcast contains **weather information** for major airfields between **Birmingham,** in the **Midlands,** and the island of **Jersey,** in the **English Channel.**

Column 6 of *Figure 23.1* details the **specific weather elements** which are included in the **VOLMET broadcasts.** You will notice that the **broadcast content** has the same format as that of a **METAR;** however, in *Figure 23.2* which contains examples of actual **VOLMET broadcasts,** you will notice that **TAF**-terminology **(BECMG, TEMPO)** is also used, giving the broadcast a **forecast element,** too.

LONDON VOLMET MAIN

The following table shows sample **LONDON VOLMET MAIN** broadcasts. Six of the **major aerodromes** from the broadcast are included, with associated weather information.

The **Shannon VOLMET** is a vital source of weather information for **North Atlantic flight routes.**

The types of **VOLMETs** shown contain the same information as the **VOLMETs** for mainland **United Kingdom,** although they are more likely also to contain additional weather forecast details, such as **SIGMETS** for en-route weather.

VOLMET transmissions are designed to be simple and easily understood, so that fast, efficient weather briefing can be obtained by pilots, in-flight.

During **pre-flight planning**, note down the **VOLMET frequencies** for the areas that you will be flying in, so that, en-route, you can listen to broadcasts for aerodromes in the vicinity of your **destination**, as well as for **alternate aerodromes**.

Access to **VOLMET** broadcasts enables the pilot to confirm that **weather conditions** at his **destination airfield** are favourable. If a **diversion** becomes necessary, the current suitability of the planned **diversion airfield** can also be rapidly determined.

ATIS OPERATION

If the **current aerodrome weather conditions** change, or if there is any change in other **pertinent aerodrome information,** the **ATIS broadcast** is immediately updated to reflect these changes. The updated **ATIS broadcast** is then given a new, sequential **alphabetical code**. For example, **ATIS broadcast BRAVO** will have replaced the previous **ATIS broadcast ALPHA**.

On initial contact with **Air Traffic Control (ATC)**, a pilot is required to state the **identifying letter code** of the **ATIS information last received**, in order that **ATC** may know that the pilot has the most recent information.

ATIS will be broadcast in plain language and will contain some or all of the following information, if applicable.

USE OF ATIS

On **departure** from an aerodrome, **ATIS information** should be obtained by the pilot **before initial contact with Air Traffic Control**. When initial contact is made with **Air Traffic Control,** the pilot must mention the **identifying letter** of the ATIS broadcast obtained, in order to confirm to the controller that the latest airfield information has been received.

A pilot **arriving** at an aerodrome should also listen to the **ATIS broadcast before transmitting on the aerodrome's initial contact frequency**. On hearing that a pilot has the latest **ATIS information,** an approach controller may omit, in his reply to the pilot, certain details contained in the **ATIS broadcast**. Normally, however, the **aerodrome QNH** will always be confirmed by the controller.

If a pilot does not acknowledge receipt of the latest **ATIS broadcast** on initial contact with an aerodrome controller, the controller will pass the **essential aerodrome information** to the pilot.

Obtaining the latest **ATIS information** helps ensure that radio transmissions between **Air Traffic Control** and the pilot are kept to a minimum. This is especially important in **busy airspace** where radio transmissions must be kept short to allow for effective communication between controllers and all the aircraft to which they are giving a service.

HIGH LEVEL WAFS SIGWX CHARTS

High level **WAF SIGWX charts** cover the **atmospheric** level bounded by **Flight Level 250 and Flight Level 630.**

Shown below is an example of a **high level WAFS SIGWX chart**. The chart has a clearly defined **legend** which contains the following information: the name of the **World Area Forecast Centre (WAFC)** which produced the chart, (either **London** or **Washington)**, a reminder that the forecast is for a **single, fixed time**; the **ICAO-designated letter** used to identify the area covered by the chart; the range of **flight levels** through which the chart is valid; the **time** in **UTC**, and the **date** on which the chart is valid.

WAFS SIGWX charts are produced, daily, **every 6 hours**, and are valid for **0000, 0600, 1200,** and **1800 UTC**. Since each chart is valid for **one single fixed time only**, it is the responsibility of the user to interpolate between charts to establish what weather conditions can be expected at intermediate times. **WAFS SIGWX charts** which are produced by the **UK Met Office** (**WAFC London)** have an additional legend, which highlights the **flight levels** between which **Clear Air Turbulence** can be expected.

In the legend each **Clear Air Turbulence (CAT)** symbol has a **number** assigned to it. This **number** corresponds to the **number** attached to an **area of CAT on the chart**; these areas have been **highlighted in red**, and are enclosed by a dashed line.

MEDIUM LEVEL WAF SIGWX CHARTS

The **legends** which are assigned to the **medium level WAF SIGWX charts** are similar to those on the **high level charts,** except for the text line which clearly highlights that the **medium level charts** are valid between **FL 100** and **FL 450**.

THUNDERSTORMS

Thunderstorms are not explicitly displayed on the charts as such; however, **thunderstorm activity** is assumed whenever **cumulonimbus cloud** is forecast. Thus, wherever the code **CB** is seen on the chart, it must be assumed that **thunderstorm activity** is present in those areas. These areas on the chart are delineated using a **scalloped line**, as shown in *Figure 20.3.* However, it is important to remember that only **embedded cumulonimbus** clouds are displayed on **WAFS charts**.

In the examples shown "**ISOL**" is used to indicate that any occurrences of cumulonimbus will be **isolated** within the scalloped area shown on the chart. Other abbreviations that may be used on the **WAFS significant weather charts** are: "**OCNL,**" indicating that cumulonimbus may be **occasionally** encountered within the area; "**WDSPD**" implies that cumulonimbus are forecast to be **widespread** within the scalloped area on the chart; and, finally, "**FRQ**" is used to imply that cumulonimbus are expected to be **frequent** within that area.

In the boxes next to the areas denoting **cumulonimbus** activity, are indications of the **flight levels** between which **cumulonimbus cloud** can be expected. If any of these **flight levels** are **outside the height range of the chart**, the symbol XXX is used. In *Figure 20.4,* the top of the **cumulonimbus** activity is forecast for **Flight level 410**, but the bottom of the **cumulonimbus** activity is below the **lowest level** of the **chart forecast**. This is **flight level 250** for the **high level chart shown in** *Figure 20.4.* In the example shown, the **medium level WAFS SIGWX chart** must be consulted, in order to discover the **base** of the **cumulonimbus activity**.

TROPICAL CYCLONES AND HURRICANES

Tropical cyclones are referred by a variety of names; however, if they become particularly severe, they are called **hurricanes,** in the **Atlantic Ocean**. **Hurricanes** are easily recognisable on significant weather charts by the symbol highlighted on the chart below.
The symbol is always accompanied by the **World Meteorological Organisation name of the storm**. **Hurricanes** used to be given exclusively women's names, but, for reasons that have never been revealed, are now given men's names too. On the chart the **hurricane** has been named **"Olga"**.
Tropical cyclones are associated with **intense areas of cumulonimbus activity**, and they need to be very carefully monitored.

TURBULENCE

Moderate, or **severe turbulence** is displayed on the **WAF SIGWX chart** using the symbols shown.
The symbol for **turbulence**, as for other **weather phenomena,** are the same as the symbols used on the **low-level forecast charts.**
Wherever **cumulonimbus** is forecast, **moderate to severe turbulence** must be assumed to be active in the area. On the **medium level significant weather charts**, areas of **moderate and severe turbulence** are also associated with other types of medium level cloud. The example from a medium - level chart, below, shows turbulence around **broken cumulus** and **altocumulus**.

The turbulence symbols are included within the "cloud" boxes assigned to every **scalloped cloud area**.
These areas are highlighted by way of the turbulence symbols which are included within the cloud boxes assigned to every scalloped cloud area as shown.

ICING

As previously described, the only cloud type shown by **high level WAF SIGWX charts**, is **cumulonimbus clouds.** You may also recall that **moderate** or **severe icing** is also automatically assumed to be prevail in the vicinity of these clouds. However, on **medium level charts**, other cloud types are shown. As **icing conditions** are not **only** confined to **cumulonimbus clouds**, symbols are used on the **medium level WAFC significant weather charts** to denote **moderate** or **severe icing conditions**. These symbols are shown on the chart below. Within this example, the red highlighted area shows the range of flight levels between which the **icing risk** is forecast.

SAND AND DUST STORMS

Widespread sandstorms or dust storms are highlighted on the significant weather charts only when these phenomena are forecast to significantly obscure visibility between the flight-levels for which the chart is valid. The symbol which is used on the chart is identical for both phenomena and is shown below.

CLOUD AREAS

The only clouds which are displayed on **high level charts** are **embedded cumulonimbus**; however, on the **medium level charts**, rather more cloud information is displayed. Whereas

high level charts show only **embedded cumulous clouds, medium level charts** show more detail on the types of cloud that may be encountered. Any cloud types which are likely to have a **significant icing or turbulence risk** are clearly highlighted. In the following example the cloud box refers to the scalloped cloud areas highlighted in red. From the symbols within the box, it can be seen that **broken amounts of cumulus and altocumulus** may be present; **moderate turbulence** can be expected between **Flight Levels 250** and **XXX**, which is less than **FL 100**; **moderate icing** can be expected between **Flight Levels 250** and **150**.