Environment Canada / Environnement Canada

AWARE: The atmosphere, the weather and flying

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Canada

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Welcome

AWARE is an educational manual directed towards aircraft pilots and produced by a collaborative initiative of Search and Rescue and Environment Canada. This manual is designed to contribute to aviation safety with an effort towards improving communication between pilots and weather forecasters.

Table of Contents

CHAPTER 1
THE ATMOSPHERE

Meteorology is the science of the atmosphere and the changes that take place within it.

1.1 Composition of the Atmosphere

The atmosphere is a mixture of invisible gases, completely surrounding the Earth. The most important of these gases are:

nitrogen	78.09%
oxygen	20.95%

nitrogen	78.09%
water vapour	0 to 3%
carbon dioxide	0.03%
ozone	0.000003%

Although nitrogen and oxygen are the most significant in terms of quantity, it is actually the very small proportions of water vapour and carbon dioxide that most influence the behaviour of the atmosphere.

Carbon dioxide has a strong impact on climate, but water vapour determines weather conditions.

Water vapour causes clouds, fog and precipitation, simply because of its inherent instability. Depending on temperature and pressure, it varies between a vapour, liquid and solid.

Obviously, the atmosphere is more than just water vapour. Indeed, it also contains billions of tonnes of gas and various particles from human activities and natural phenomena.

In the lower levels, especially in the troposphere, which is the atmospheric layer in which we live and move about, there are considerable quantities of liquid or solid particles in suspension, known as aerosols.

Water vapour condenses on aerosols of liquid particles to form droplets, clouds and fog.

Ice crystals form mainly around aerosols of solid particles, consisting mostly of dust, pollen, ash, smoke, sea salt and sand, to form clouds or ice fog.

Aerosols are also responsible for haze and smog, and are the main triggers of changes in state of water vapour.

1.2 Extent of the Atmosphere

The farther we travel from the Earth's surface, the thinner the air becomes, until it almost disappears. In fact, 99% of the total mass of the atmosphere lies within 30 km (100,000 feet) of the ground, while fully half of it is within the first 5.5 km (18,000 feet).

But the trails left by some satellites tell us that it extends up to some 1600 km above the Earth. Indeed, the aurora borealis can often be seen at an altitude of over 1000 km.

Although data collected at very high altitudes are not used in the preparation of day-to-day forecasts, their study is important for an overall understanding of weather.

1.3 Properties of the Atmosphere

Air is inert, fluid, viscous, expansible and compressible, and as such is subject to the laws of thermodynamics.

Inertia

Since air is inert and has mass, some force is necessary to set it in motion, accelerate or stop it.

The density of air varies considerably from one point to another. At sea level, it is about 1.125 grams per litre, whereas at 10 km (33,000 feet), it is only about 0.414 grams per litre.

Fluidity

The atmosphere is also highly fluid; it tends to take up all available space and to exert pressure on all the bodies it surrounds.

Viscosity

The air's viscosity is an important property. Although it allows the air to move and to influence the movements of neighbouring layers, this same property prevents excessive wind shear.

The movement caused by this viscosity is always slowed by a much more inert body, however: the obstacles making up the Earth's surface and the friction they exert.

Expansibility and compressibility

As soon as the pressure of an air mass at some point increases in relation to the surrounding pressure, the air in question expands and tends to take up more room.

If the surrounding pressure increases, however, the air mass will decrease in volume as it is compressed.

Thermodynamics

Air is as thermodynamic as all other gases, under the effects of pressure and temperature.

In absolute terms, we know that as soon as a small quantity of air rises above the surface, its pressure and temperature fall and its volume increases.

On the other hand, air descending toward the surface obviously undergoes the opposite changes: it is compressed, its volume shrinks and its temperature rises.

This phenomenon is not the main cause of atmospheric warming or cooling, but does play a crucial role in cloud formation due to vertical air movements.

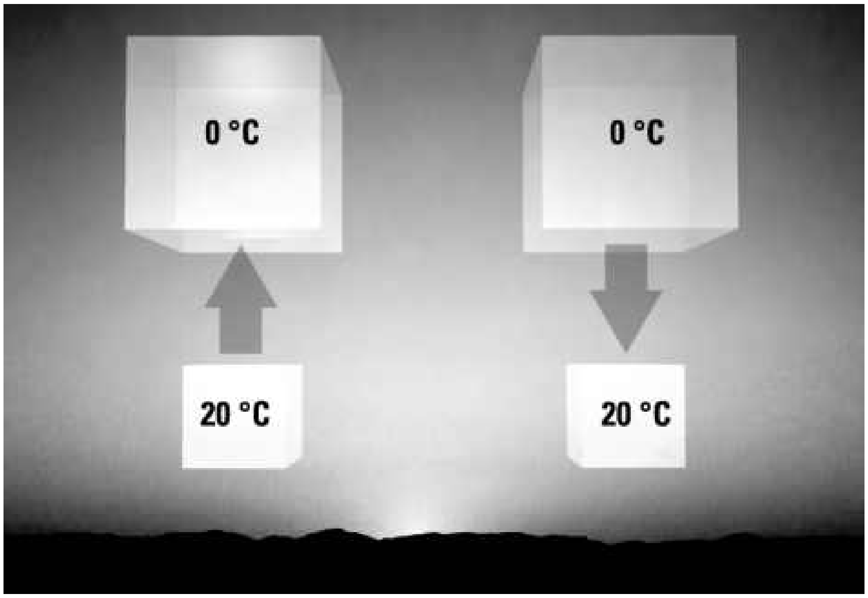


Figure 1-1 On the left, rising air expands and cools as its pressure falls.

On the right, descending air is compressed and warms, which increases its pressure.

1.4 Divisions of the Atmosphere

Scientists agree on major divisions of the atmosphere, but the exact dividing lines and characteristics vary with different disciplines and purposes.

We will discuss two classifications: those of the International Union of Geodesy and Geophysics (IUGG) and that of Goody, based on temperature and ionization.

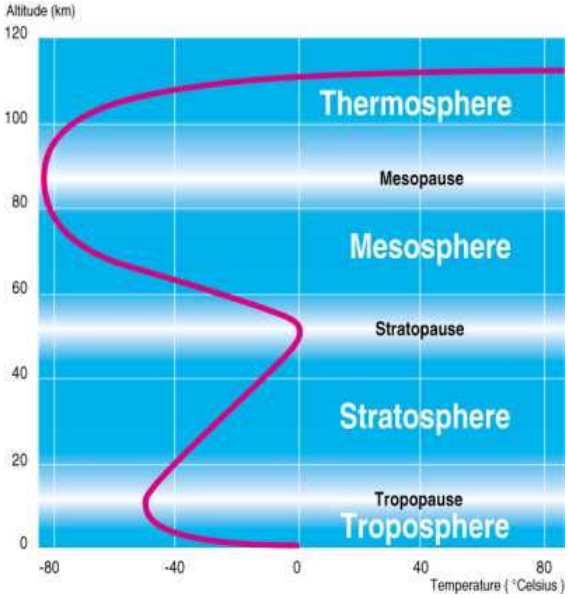


Figure 1-2 Systems for dividing the atmosphere into layers

In meteorology, the IUGG system is used, because it divides the atmosphere into layers according to their thermal structures.

The IUGG system consists of the following layers, by distance from the surface:
troposphere
stratosphere
mesosphere
thermosphere

To identify each of the transition zones, the suffix sphere is simply replaced with pause, to give:

tropopause
stratopause
mesopause
thermopause

Troposphere

It is in this first layer that the atmosphere, in contact with the Earth, is the warmest. The Earth's surface captures the Sun's rays and becomes a radiating body that warms the air, setting it in motion by simple thermodynamic action.

This produces large-scale rising air currents that warm the upper levels, while moving gigantic volumes of air horizontally. These movements are what we call weather systems.

As a result, most weather activity occurs in this lowermost layer of the atmosphere, the great variety of phenomena that affect us from day to day all around the world.

The intense concentration of water vapour, associated with strong rising air currents, leads to clouds and precipitation, thunderstorms, hurricanes and tornadoes.

Just below the tropopause, the shear caused by the strong contrast between the troposphere and stratosphere generate the very powerful winds called jet streams, and gives them their sometimes complex structures.

These narrow and powerful streams of air, which originate only in the north of the Northern Hemisphere, are so influential that they are part of what is called the general circulation, that is the trajectory of the Earth's air masses.

Tropopause

The first thermal boundary. The tropopause marks the end of the biosphere and is the coldest part of the lower atmosphere.

The average altitude of this layer is about 11 km (36,000 feet). Above the poles, it is about 8 km (26,000 feet) from the surface, while at the equator is at about 18 km (59,000 feet).

The tropopause shifts according to temperature and is highest in summer. It changes altitude abruptly near the jet streams.

Stratosphere

The stratosphere is a 15 km, 50 000 feet layer where the temperature increases gradually to 0 C or even as much as 10 C.

In this layer there is almost no water vapour, and no major vertical air currents. Occasionally some mother-of-pearl clouds formed from the rare ice crystals at this level can be seen.

The main characteristic of the stratosphere is the ultraviolet shield it contains-the ozone layer. Stratospheric warming occurs as this layer absorbs part of the ultraviolet rays from the Sun.

Stratopause

At the top of the stratosphere lies the stratopause. Past this level, the temperature begins falling again as the ozone becomes increasingly thinner with height.

Mesosphere

The only significant characteristic of this layer is the rarity of ozone and consequently its absolute minimum temperature of about -80 C, recorded at a distance of 80 to 90 km from the Earth's surface. This is the lowest temperature ever recorded in the atmosphere.

It is also in this layer that meteorites burn up as they come into contact with the atmosphere.

Mesopause

The mesopause is another thermal transition layer; after this point the atmosphere again begins warming with altitude.

Thermosphere

Air molecules are rare in this layer, which is why the Sun's rays strike with such force and temperatures can theoretically rise to enormous levels.

Exosphere

According to the GOODY classification, this upper part of the atmosphere is where particles begin escaping from the Earth's pull, and are subject to atomic and molecular exchanges with solar and cosmic particles. The exosphere is where the aurora borealis occur.

The bottom of the exosphere is not very clearly defined, but is estimated to lie 500 to 800 km from the Earth's surface.

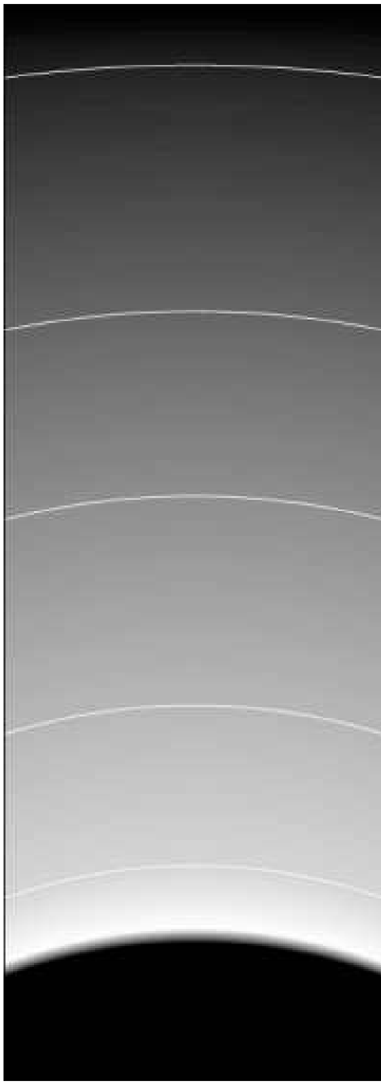
1.5 The International Civil Aviation Organization (ICAO) Standard Atmosphere

The wealth of direct observational data available for the first 20 km of the atmosphere make it possible to prepare detailed descriptions of average conditions within this layer.

These data are organized into standard atmospheres, defined on the basis of average altitude, pressure and temperature conditions at 40 north latitude.

Some of the values of particular significance are:

- mean sea level (MSL) pressure: 1013.25 hectopascals (hPa or mb)
- mean sea level temperature: 15ºC
- rate of decrease of temperature with height (lapse rate) in the troposphere: 6.5ºC per kilometre (1.98ºC per 1000 feet)
- height of the tropopause: 11 kilometres (36,000 feet) above mean sea level
- temperature of the tropopause: -56.5ºC
- temperature is constant from the tropopause to the top of the standard atmosphere.



ALTITUDE		PRESSION		TEMPERATURE
THOUSANDS OF FEET	KILOMETRES	INCHES OF MERCURY	HECTO-PASCALS	DEGREES CELSIUS
70	21.3	1.3	44.0	-55.2
50	15.2	3.4	115.1	-56.5
35	10.7	7.0	237.1	-54.0
18	5.5	14.9	504.6	-20.6
10	3.0	20.6	707.8	-4.8
5	1.5	24.9	843.2	5.1
Sea level		29.92	1013.2	15.0

Figure 1-3 ICAO standard atmosphere. Pressure falls with height, particularly in the lower altitudes.

1.6 Exercises

1. What do we call the layer of invisible gases surrounding the Earth?
2. Name five gases in the atmosphere.
3. What is the most important gas in the atmosphere, where weather is concerned? Why?
4. What is an aerosol?
5. Why are solid particles important for aviation meteorology?
6. How high does the atmosphere extend?
7. Half the total mass of the atmosphere lies below what altitude?
8. Name the physical properties of the atmosphere.
9. What is the physical property of the atmosphere that limits wind shear?
10. What happens to a small air mass as it descends toward the surface?
11. What atmospheric layer lies next to the Earth's surface?
12. What are the atmospheric layers on either side of the tropopause?
13. Describe the thermal profile of the troposphere and explain it.
14. What is the defining characteristic of the tropopause?

1. What is the average altitude of the tropopause?
2. Is the tropopause higher or lower at the Equator than at the poles?
3. In what atmospheric layer are jet streams normally found?
4. Why do temperatures rise in the stratopause?
5. What is the ICAO standard atmosphere?
6. According to the ICAO standard atmosphere, what are the pressure and temperature at mean sea level?

CHAPTER 2 THERMODYNAMICS

Thermodynamics deals with the energy transfer processes that occur in all the thermal and mechanical relations affecting air masses.

Heat is a form of energy that we measure in terms of temperature. The hotter it is, the more energy is present. This energy is always diffused toward bodies with a lower temperature.

Where the atmosphere is concerned, warming and cooling are very simple processes. The Sun warms the Earth, which in turn diffuses heat into the atmosphere. When the Earth cools, the atmosphere is immediately affected. These thermodynamic transfers can take many different forms.

2.1 Radiation

A warm body such as the Sun transmits its energy by radiation, even in a vacuum. However, the body exposed to the radiation must be able to absorb it, for its absorption rate determines the amount of energy that can be stored.

In the atmosphere, although part of the heat is absorbed by the ozone layer and part by the troposphere, solar radiation is strong enough to reach the Earth's surface and warm it considerably, depending on cloudiness and the nature of the surface-water, sand, vegetation, snow, ice, etc.

The Earth warms and acts as a radiator, emitting heat into the air in the form of infrared radiation. It is the densest layers of the atmosphere-the lowest-that absorb most of this radiation.

At night, the Earth continues to emit the warmth it has received during the day, but as its surface cools this radiation gradually decreases.

Clouds play an important role in the radiative warming process, since they prevent part of the solar radiation from reaching the Earth.

At night, clouds reflect part of the long-wave terrestrial radiation, thereby helping to delay the cooling of the lower atmosphere. This energy remains trapped between the Earth's surface and the clouds.

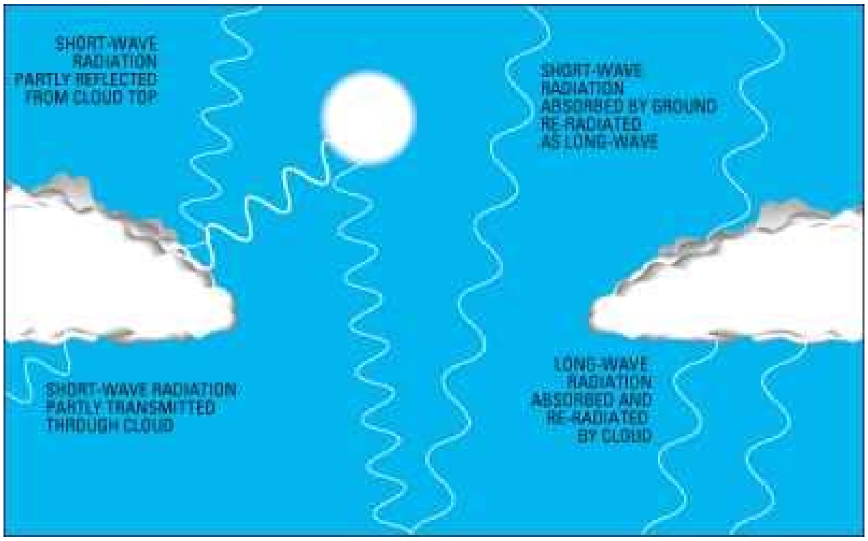


Figure 2-1 Solar radiation

2.2 Conduction

Thermal conductivity is a phenomenon that tends to distribute heat throughout a body. The heat from the warm parts of an object will gradually spread to its cold parts.

For instance, if one end of a metal rod is placed in a fire, the other end will gradually heat up because of thermal conduction, as the heat moves along the length of the rod.

As air is a poor thermal conductor, there is almost no conductive effect except near the surface, the phenomenon is more marked under turbulent conditions.

2.3 Convection and Mechanical Turbulence

When air is heated from underneath and begins to rise into colder surrounding air, convection occurs. Some types of home heating, such as baseboard heaters, work on this principle.

The heat transmitted to the lowest layers of the atmosphere is carried aloft by convection and mechanical turbulence, that is mixing by means of wind in the air closest to the ground.

The vertical movement of the air, or convection, is a small-scale phenomenon that occurs between the surface and the atmosphere or between superposed atmospheric layers.

It takes place when the surface is unevenly heated and the lapse rate aloft reaches a critical threshold.

Convection also occurs when the air rising along a slope, for example, continues rising when it reaches the top of the slope and is replaced on the surface by the surrounding, cooler air.

This movement begun by the air systematically creates mechanical turbulence resulting from the friction of the air on the ground. The rougher the surface, the more turbulence is caused by these eddies.

Such turbulence plays an important part in warming the lower tropospheric layers, since it literally draws heat from the ground. Its intensity varies directly with the strength of convection.

2.4 Advection

The effects of radiation vary considerably depending on the type of surface, but also with latitude and the season. Thus the upper-air temperature profile must constantly be updated.

Surface and upper-air charts are used for this purpose, on which lines are drawn to delimit areas at the same temperature every 4 or 5 degrees. These lines are called isotherms.

The lapse rate, giving the change in temperature according to distance, is expressed in ºC/km and is generally represented by an arrow pointing toward the warmer isotherms.

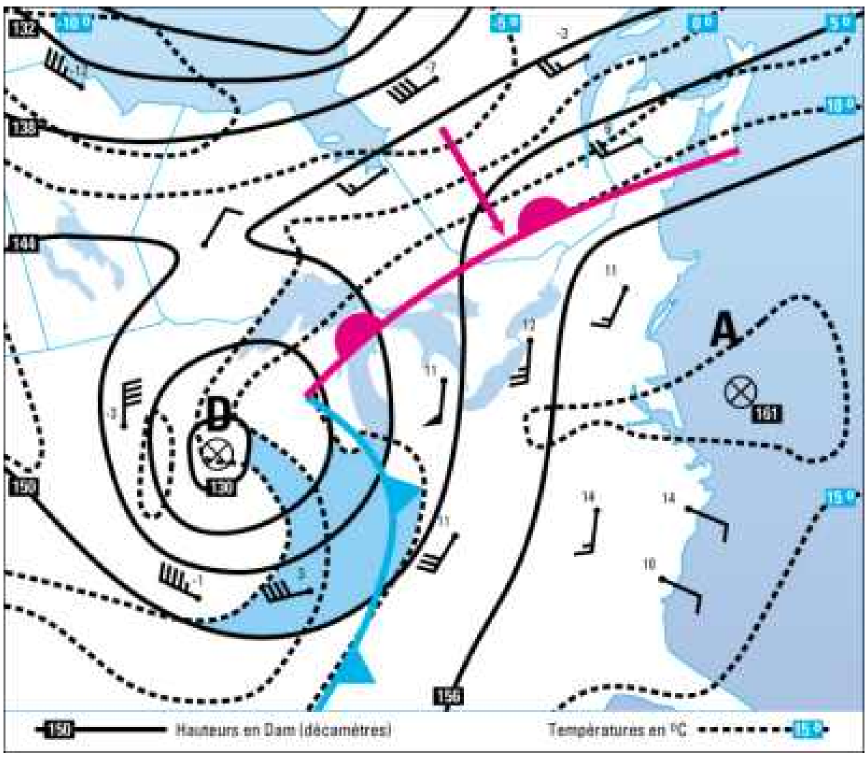


Figure 2-2 Isotherms and lapse rate, on an 850 hPa chart. The isotherms, 5 ºC apart, are shown in green. The purple arrow indicates the lapse rate. The blue section represents the cold air advection behind the cold front.

Advection means that there is horizontal movement of an air mass toward a colder or warmer region. It indicates warming or cooling.

The steeper the horizontal thermal gradient with a strong wind reaching its maximum speed as it blows parallel to the gradient, the greater the advection.

Figure 2-2 illustrates cold-air advection. Behind the cold front, in blue, is a west wind pushing the isotherms eastward.

2.5 Latent heat

In the atmosphere, water is simultaneously and successively present in all its three states, but there must be some transfer of energy for it to pass from one state to another.

To be transformed from liquid to vapour, and from ice to liquid, water must absorb a certain quantity of energy, and must release just as much to pass to a state requiring less energy. The energy released or absorbed in this way is called latent heat. For transitions to a more solid state, the energy used is already stored in the phase to be transformed.

For example, the concept of latent heat applies throughout this process: the Sun warms the sea surface; the water on the surface evaporates; this vapour, which stores its own heat, condenses upon reaching the colder regions of the atmosphere, and warms them as it releases its latent heat.

2.6 Adiabatic changes

Another very important aspect of thermal energy concerns the effects of air pressure.

When a gas is compressed or expands for any reason, it warms or cools.

When a tire is inflated, for example, the valve and the rubber become warm because of the pressure increase and air friction.

A cylinder of compressed gas, on the other hand, cools as it is emptied, because the remaining gas it contains is expanding.

In the atmosphere, much the same phenomena occur as the air is constantly subject to changes in temperature owing to compression or expansion. The most common of these phenomena is linked to rising or descending motion.

Since atmospheric pressure is greatest at sea level, rising air expands and cools, while descending air is compressed and warms.

Whenever air warms or cools simply because of changing pressure, this is called an adiabatic change.

We know that air warmed by the surface naturally rises and cold air descends and replaces the rising air; but it also happens that cold air already aloft may be compressed by subsidence (the phenomenon of sinking air) caused by an anticyclone, and may warm as it descends toward the surface.

Warm, dry winds from the mountains, including the Chinook that flows into Alberta from the Rockies, are good illustrations of this phenomenon.

Under adiabatic conditions, dry air warms or cools at a rate of approximately 1 ºC per 100 m (3 ºC per 1000 feet). If it is saturated, its cooling rate depends on the surface temperature. At 15 ºC this rate will be about 0.5 ºC per 100 m (1.5 ºC per 1000 feet). The colder the air, the higher this rate will be.

2.7 Vertical Temperature Distribution

Temperature falls with height in the atmosphere. The rate of decline is called the lapse rate.

In the ICAO Standard Atmosphere, designed according to the adiabatic process, the temperature lapse rate is 6.5 ºC per 1000 m (1.98 ºC per 1000 feet).

But things are quite different in reality. There are often discrepancies between this standard atmosphere and actual conditions. It also exists for horizontal thermal advection at different altitudes.

An isothermic layer, with a lapse rate of zero, may extend over several hundreds of metres.

In other cases, rather than falling, temperature climbs with altitude. This is an inversion caused by a negative thermal lapse rate.

Sometimes such inversions are caused by energy that has been stored near the surface during the day and rises during a cloudless night, reducing the surface temperature.

Inversions are more frequent in winter than in summer. In the Arctic, they can reach up to 3 km (10,000 feet) in mid-winter.

2.8 Scales used to measure temperature

In Canada, the Celsius scale is used almost exclusively to express temperatures at the surface and aloft. On a Celsius thermometer, water freezes at 0º and boils at 100º.

The Kelvin, or absolute, scale is more useful for scientific applications. It is divided in exactly the same way as the Celsius scale, but with zero indicating the lowest temperature theoretically obtainable. This absolute zero is so low that the freezing point of water on the scale is 273.15º, with the boiling point at 373.15º .

In some countries, aircrews must be able to convert temperatures from one scale to another, using these formulas:

a. from Fahrenheit to Celsius:

   (ºF - 32) / 180 = ºC / 100

b. from Celsius to Kelvin

   ºC + 273.15 = ºK

c. from Fahrenheit to Kelvin

   (ºF - 32) / 180 = (ºK - 273.15) / 100

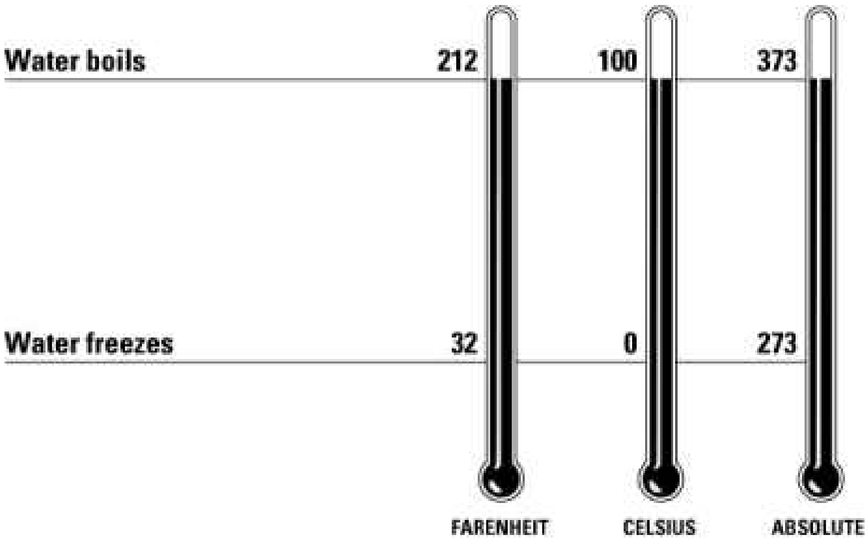


Figure 2-3 Temperature scales

2.9 Exercises

1. Define thermodynamics.
2. Name the ways in which heat is transmitted in the atmosphere.
3. Why do clouds prevent the air from cooling off quickly overnight?
4. What is convection? What conditions promote convection?
5. What is a horizontal thermal gradient?
6. What is strong warm air advection?
7. Define latent heat.
8. What do we mean when we say that an air mass is compressed adiabatically?
9. The dry adiabatic lapse rate is ____ ºC per 100 m.
10. Saturated air cools more slowly as it rises than does dry air. True or false?
11. If the surface temperature is 12ºC, what is the temperature of a rising column of saturated air at 600 m (2000 feet)?
12. If the surface temperature is 20ºC, what is the temperature of a rising column of dry air at 1000 m (3300 feet)?

CHAPTER 3 MOISTURE

Anything that is "moist" contains water, by definition. The moisture content of the air determines how much water vapour it holds.

This moisture content has a great influence on meteorological phenomena, including cloud formation and all events related to clouds.

3.1 Water Vapour and Saturation

Water vapour is of great significance to meteorology, because of its instability and the influence of this characteristic.

Water vapour is the only gas that slight fluctuations in ordinary atmospheric conditions can transform into a liquid or a solid.

Clouds form as a result of water vapour turning into droplets or ice crystals; other developments within the cloud may lead to rain, hail, snow or, near the surface, fog or mist.

The amount of water vapour present in the air varies considerably, and its saturation point depends only on the temperature-pressure ratio. Under constant pressure, the moisture content will rise if the temperature falls, and fall if the temperature rises.

At a given temperature, the quantity of water vapour is inversely proportional to changes in pressure: falling pressure will increase the moisture content.

In any case, as soon as the maximum amount of water vapour is reached and the saturated air begins to cool, the excess water vapour liquefies or solidifies to form clouds, fog, dew, hoarfrost or ice crystals.

3.2 Condensation Nuclei

Everything in the troposphere contributes to weather in some way. For instance, there is a specific link between water vapour and the billions of tons of microscopic particles carried in air masses.

These particles may be pollen, volcanic or other ash, smoke, sea salt, sand, rock dust, etc.-in short, waste from human activities and natural materials carried off by the wind.

Some of these particles, called "hygroscopic," are excellent catalysts; they act as nuclei for the condensation of water vapour.

Without these condensation nuclei (mostly sea salt, it is thought), the dynamics of precipitation would likely be quite different.

Water vapour condenses around these nuclei, creating an accumulation of liquid or frozen particles. In fact, such particles can remain in their liquid state even at temperatures far below freezing.

3.3 Changes of Phase or state

Water interacts with the atmosphere in many ways, changing state, or phase, as it evaporates, condenses, freezes, melts and sublimates.

Evaporation From liquid water to water vapour.

Condensation From water vapour to liquid water.

Freezing From liquid water to ice.

Fusion, or melting From ice to liquid water.

Sublimation Directly from a solid, i.e. ice, to water vapour, or vice versa; this is the case for snow and ice crystals.

For condensation to occur, or sublimation if the air is very cold, the saturated air must be cooled or must become supersaturated while there are condensation nuclei present.

Rainwater is not as pure or fresh snow as clean as we like to think!

3.3.1 Cooling

For water vapour to turn into water or ice, it must cool in order to condense.

Air can cool by means of condensation in various ways:

- adiabatic expansion -- expansion as air rises
- radiation from a colder surface -- mostly at night
- conduction -- contact with a colder surface.

3.3.2 Increase in Water Vapour

The quantity of water vapour changes constantly, but several factors contribute to keeping it high or even increasing it:

- water evaporation, particularly when it is warmer than the surrounding air
- evaporation of warm rain
- evapotranspiration from plants
- combustion of organic materials.

3.4 Dew-point temperature and moisture

Although water changes state depending on variations in temperature and pressure, the fact remains that there is a key moment when saturation and condensation will occur, and that it is possible to predict this moment.

For this one simply needs to know the temperature, pressure and moisture content, and insert them in a very well-known formula.

For example, we know that at constant pressure of 1013 hPa at mean sea level, an air mass has to cool from 13 ºC to 3 ºC to be saturated with water vapour, since 3 ºC is the dew point, i.e. the point when condensation occurs.

This type of cooling under constant pressure, with no addition of water vapour, is called isobaric cooling.

But if this cooling occurs adiabatically (with no exchange of heat or moisture with the surrounding environment), as pressure decreases and the air expands, the dew point will fall.

For instance, if the air at the surface, with a dew point of 10 ºC, is lifted to a height where the pressure is only 700 hPa rather than 1000 hPa, its dew point will fall to 4.8 ºC.

3.4.1 Specific Humidity

There are other ways of expressing the concept of moisture. The ratio of the mass of water vapour to a unit mass of moist air is one.

For example, a given volume of air could contain 12 g of water vapour per kg of moist air.

At constant pressure, so long as there is no condensation or sublimation, the specific humidity is assumed to remain constant.

3.4.2 Mixing Ratio

The mixing ratio compares the mass of water vapour with the mass of dry air.

This ratio also remains the same as long as there is no condensation or sublimation.

In short, the mixing ratio is the number of grams of water vapour per kilogram of dry air.

3.4.3 Relative Humidity

Finally, relative humidity is the ratio of the actual water vapour content to the quantity necessary to reach saturation.

For example, if the temperature is 13 ºC, the dew point is 3 ºC and there are 4.7 g of water vapour per kilogram of dry air, when the saturation point should be 9.4 g, the ratio is 0.5, or 50% of relative humidity.

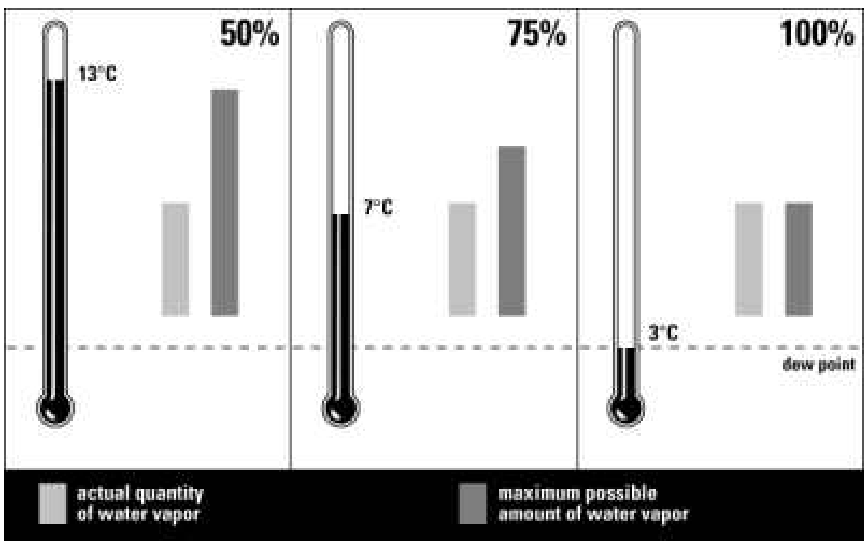


Figure 3-1 Relative humidity and dew-point temperature

Relative humidity depends on the temperature and the quantity of water vapour.

In Figure 3-1, in all cases, the water vapour is constant even though the air temperature changes.

On the right, the air and dew-point temperature are both at 3 C, which gives relative humidity of 100%.

On the left, however, the diagram shows that if the temperature increased to 13 ºC while the dew point remained at 3 ºC, the relative humidity would be 50%.

At this temperature, the air contains twice as much water vapour as at 3 ºC. However, the quantity measured is the same as if the temperature had been 3 ºC.

3.5 Exercises

1. Why is water vapour so important?
2. What determines the quantity of water vapour?
3. What is saturated air?
4. What is sublimation?
5. Name three processes involving the cooling of air.
6. Name four processes that lead to an increase in water vapour.
7. What is the dew-point temperature?
8. When an air mass rises, its pressure and its temperature both fall, while the dew point remains the same. True or false?
9. What is the mixing ratio?
10. At constant pressure, if unsaturated air cools, the dew point will fall. True or false?
11. Ice crystals result from what thermodynamic process?

CHAPTER 4 PRESSURE

Atmospheric pressure is a crucial subject for aviators, if only because aircraft altimeters must be properly set.

More important, however, is that pressure distribution in the atmosphere controls the winds and, to a considerable extent, weather phenomena such as cloud and precipitation.

Consequently, some knowledge of the nature of atmospheric pressure, the units in which it is expressed and the way in which it varies both horizontally and vertically under different conditions is necessary.

4.1 Characteristics

The atmosphere, through the bombardment of air molecules on exposed surfaces, exerts pressure on the bodies it surrounds.

This pressure depends on the density of the air and the speed of movement of the molecules, itself determined by temperature.

Since air has weight, each particle is compressed by the ones above it. Density and hence pressure increase with proximity to the Earth's surface.

Similarly, when air is cooled, its mass increases, since molecules do not move as quickly.

This means that at constant pressure, cold air is denser than warm air.

Atmospheric pressure is exerted in all directions. The pressure on a surface is at right angles to the exposed plane.

Unlike gravitational force, which is always exerted vertically and toward the Earth's centre, pressure can also be horizontal or upward.

4.2 Units

Atmospheric pressure is measured with a barometer. The simplest barometer consists of a vertical tube full of mercury, since we know the specific mass of mercury.

Mercury being 13.6 times denser than water, a column of mercury will be 76 cm (2.5 feet) high, rather than 10 m (33 feet)!

In addition, we can easily determine its hydrostatic pressure, simply by comparing atmospheric pressure to the pressure of mercury.

This method is so widespread that pressure values are still expressed in terms of inches of mercury.

But with the adoption of the international system of measurement, the pascal became the unit used for measuring the pressure of fluids.

In the world of aviation it is the hectopascal (hPa) that is used to express atmospheric pressure. This unit has the same value as the millibar, the former unit still used by some meteorologists in Canada and elsewhere.

4.3 Station Pressure and Mean Sea Level Pressure

Station pressure is the atmospheric pressure at the elevation of the station, measured with a barometer.

To determine the pressure field at a given level, we must compare the pressure with data from different stations, but taking their respective elevations into account, since pressure decreases with increasing altitude.

But how can we determine the pressure at different elevations? Meteorologists have solved this problem by basing their calculations on sea-level pressure, since pressure reaches its maximum at this level.

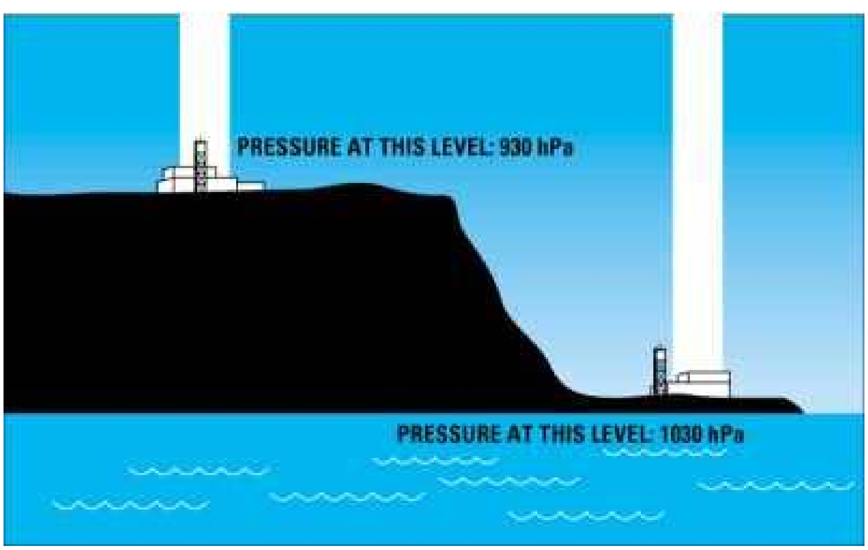


Figure 4-1 Differences in station pressure owing to differences in elevation

To determine the station pressure with reference to mean sea level we need to know its exact elevation and to determine the mean temperature between this elevation and sea level.

But to make proper use of the latest meteorological information, we need to make a clear distinction between station pressure, the altimeter setting and mean sea level (MSL) pressure.

4.4 Horizontal Pressure Differences

In meteorological terms, the Earth's atmosphere is a single unit. This is why weather observations are taken simultaneously around the globe.

These observations are immediately sent via the global meteorological network to computerized centres and then redirected from there to forecasting centres.

The vast observation network built up over the years now makes it possible to obtain an accurate profile of prevailing conditions all over the world in just a few minutes.

Of course, these conditions vary as widely as do the type of surface, the topography, climate, season, time of day and sky cover.

All these many distinctions, as different as seas of sand and seas of water, rain forests and polar ice caps, prevent uniform warming. As a result, pressure fluctuates over space and time.

These fluctuations are obvious as soon as one consults a weather chart, regardless of the number of observation points or their distance from one another.

Curves linking points of equal pressure, or "isobars," are normally plotted at 4-hPa intervals from the main isobar at 1000 hPa, and clearly illustrate changing pressure.

Isobars varying from 980 to 1012 hPa can commonly be found on a single chart.

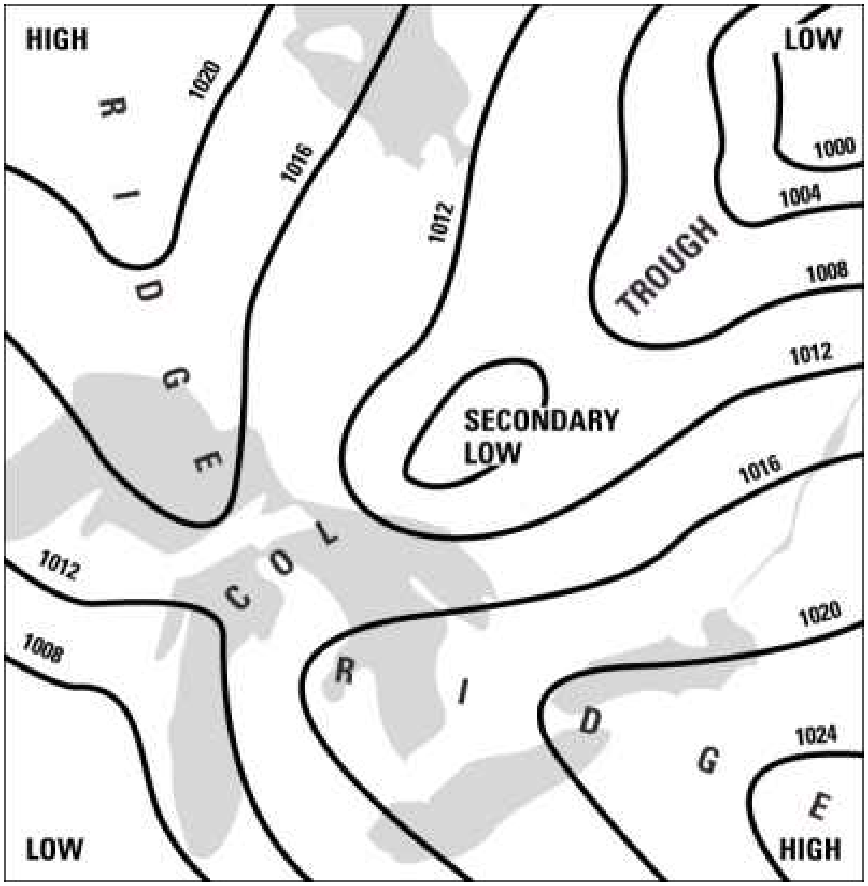


Figure 4-2 Pressure field on a surface chart

Figure 4-2 shows that the isobars on a surface chart never cross, but form relatively concentric curves.

These lines identify the five phenomena, or systems, directly related to pressure fields: lows, troughs, highs, ridges and cols.

4.4.1 Lows

Wherever pressure is at its lowest in a given area is the centre of a low.

Lows, or depressions, may be from less then one kilometre (3,300 feet)wide in the case of tornadoes, to several hundred kilometres, for large-scale lows.

Among the largest and most devastating are hurricanes, known as typhoons in Asia, which generate surface winds of 64 knots or more.

The lower the central pressure, the stronger the depression. When the central pressure is falling, the low is said to be deepening.

When the reverse occurs, and the lowest pressure increases and rises above the surrounding pressure, we say that the low is filling. The winds fall and precipitation decreases with time.

In addition to generating very strong winds, lows cause heavy precipitation. In our part of the world they are more common in winter, as a result of strong large-scale temperature gradients.

4.4.2 Troughs

One of the abstract concepts popularized by the media is the barometric trough. This trough is actually a straight or curved line of minimum pressure, which can extend over several hundred kilometres.

The line of the trough often falls right between the isobars of a front that corresponds exactly to the trough of the low.

At lower levels, the air revolving around the low converges in the centre, as if it had been sucked in by the low centre.

Another phenomenon directly associated with the trough is the abrupt change in the direction of the wind, called a windshift. The wind is often from the south ahead of the trough, and gradually turns to blow from the northwest behind the trough.

It is precisely this strong convergence that causes temperature gradients to tighten up and creates fronts in troughs.

4.4.3 Highs

A high, or anticyclone, is the opposite of a low. In this case, the central area is a zone of maximum high pressure.

Isobars are generally wider apart near the centre of a high than near the centre of a low.

A high forms when its central pressure rises, and is strong when its central value is significantly higher than the surrounding values.

In our latitudes, highs are strongest in winter of the cold air. Pressure can sometimes exceed 1040 hPa.

Fine weather is generally associated with highs, because the dry cold air of the high is systematically pushed down toward the ground.

A high weakens when its central pressure falls.

4.4.4 Ridges

A ridge, or wedge of high pressure, is the opposite of a trough. Pressure is higher along its top than on its sides. It may also form a curve or run in a straight line.

Ridges are generally found in the wake of highs. A high may be surrounded by several ridges, with isobars generally more rounded than those of troughs.

4.4.5 Cols

A col is an area between two highs or two lows; however, this term is rarely used in messages and weather bulletins for users.

Because cols are small, only the systems on either side of a col are considered.

4.5 Pressure Gradient

The expression "pressure gradient," or simply "gradient," refers to a horizontal difference in pressure over a specific distance, measured at right angles to isobars.

The pressure gradient at mean sea level can be calculated directly on the weather map, since isobars represent the pressure pattern at this level.

The gradient is simply the ratio of the difference in pressure between two points to the distance between them.

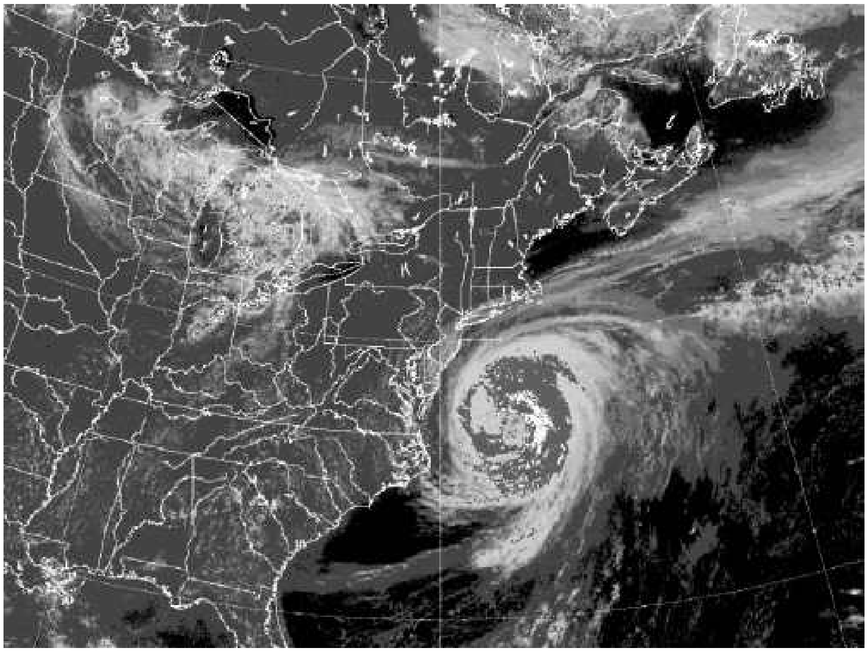


Figure 4-3 Determining the pressure gradient at MSL

The closer the isobars, the stronger the gradient.

4.6 Barometric Tendency

The barograph makes a permanent recording of barometric variations. As a low approaches, for example, the barograph records a regular drop in pressure.

Once the centre of the low has passed, the pressure begins to rise again. These variations make up what is called the barometric tendency, or pressure tendency.

The tendency consists only of the last three hours of observations.

4.7 Constant Pressure Charts

Constant pressure charts are analyses based on constant pressure fields. These charts are generally prepared for the 850, 700, 500 and 250 hPa fields.

Lines linking points at the same altitude are called isohypses.

Variations in height depend on the temperature and pressure fluctuations of the underlying layer.

Since the coldest air in the lower layers is near the poles, pressure levels are generally lower there than over the equator.

There may be very marked temperature differences at a given latitude. These variations will also influence heights.

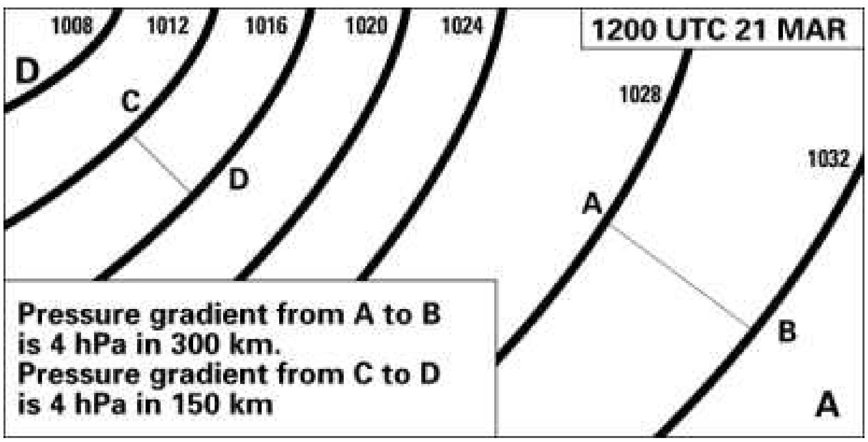


Figure 4-4 Effect of temperature on heights of pressure levels

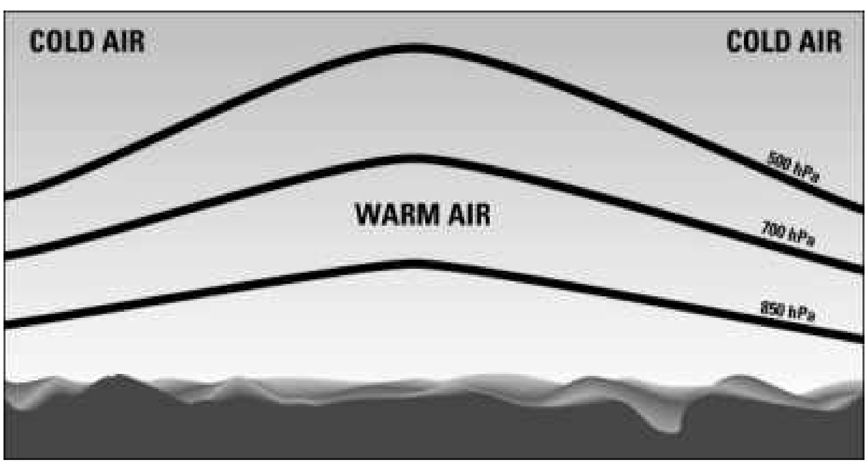


Figure 4-5 Constant pressure chart for 700 hPa

4.8 Altimeter

The altimeter is an aneroid barometer whose scale is marked to register altitude rather than pressure.

When pressure drops, the altimeter indicates a rise in altitude rather than a decrease in pressure (since the air associated with a low is warmer).

It is important to remember that the relationship between temperature, pressure and altitude is much more direct at higher altitudes than at the surface.

Since altimeters are not designed to identify these deviations, they are calibrated on the basis of the ICAO standard atmosphere, which sets mean sea level pressure at 1,013.25 hPa.

The temperature at this level is 15 ºC, and the vertical temperature gradient up to 11 km (36,000 feet) is 6.5 ºC/km (1.98 ºC/1,000 feet).

Under these conditions, a drop in pressure of 1 hPa is equivalent to a change in altitude of 8.4 m (27.5 feet) near the surface, and one inch of mercury corresponds to 283.7 metres (931 feet).

4.8.1 Altimeter Error

When the atmosphere corresponds to the standard atmosphere in all respects, which is very rarely the case, the altitude indicated is the same as the actual altitude.

Otherwise, there is a difference because mean sea level pressure or temperature, or both, differ from the standard values.

4.8.2 Pressure Error

Since pressure at mean sea level varies constantly from one place and time to another, an altimeter can indicate the altitude accurately only if it is equipped with some kind of compensation device.

For instance, the altimeter of an aircraft on the ground at mean sea level would indicate 111 m (384 feet), if the actual pressure were 1,000 hPa rather than 1,013.25 hPa.

Consequently, altimeters come with a subscale device that allows the user to adjust the reading to the desired value.

This adjustment can be made in two ways. One way is to obtain the exact altitude of the aircraft. This is simple to do when the aircraft is on the ground, but not so easy when it is already in flight.

The other method is to obtain the exact pressure reading at ground level of a weather station and then calculate a value that the pilot should display in the subscale window to determine the aircraft height.

If the aircraft is on the ground, either method can be used. If it is in flight and is preparing to land, however, only the second method is appropriate, for obvious reasons.

The altimetric adjustment is calculated from station pressure. The value obtained corresponds to the pressure reduced to mean sea level, calculated from standard atmospheric values.

The more actual conditions depart from those of the standard atmosphere, the greater the discrepancy between the altimetric adjustment and mean sea level pressure. The exception is the specific case where a station is exactly at mean sea level.

When making this adjustment on the ground it is possible to correct the error when the pressure differs from standard value; in flight, the altitude indicated will no longer necessarily be accurate and there will be no means of compensating for it.

Suppose that a high of 1025 hPa passes over an aerodrome, followed by a low of 975 hPa.

By carefully examining the vertical structure of the standard atmosphere we can see that the difference in altitude between two neighbouring pressure levels is not quite the same at 1025 and 975 hPa.

More specifically, the difference between two pressure levels 1 hPa apart is 8.3 m (27.1 feet) at 1025 hPa and increases gradually to reach 8.6 m (28.2 feet) at 975 hPa.

If the aircraft takes off from an airport where pressure is relatively high, its altimeter will tend to overestimate the altitude, and the aircraft will be flying below the indicated altitude. If the pressure is relatively low, the instrument will underestimate the altitude.

4.8.3 Temperature Error

Altimeter adjustment is not enough to eliminate errors due to differences in pressure, but these errors are usually not drastic.

The situation is very different when it comes to errors caused by temperature differences, as they are more difficult to adjust for.

The colder the air, the greater its density and the steeper the vertical gradient.

Thus, according to the standard atmosphere, for a pressure of 1013 hPa at a temperature of 30 ºC, the gradient will be 0.11 hPa/m or 8.6 m/hPa (28.7 feet/hPa).

At a temperature of 15 ºC, the gradient will be approximately 0.12 hPa/m or 8.3 m/hPa (27.1 feet/hPa).

Still for the same pressure, if the temperature is -30 ºC, the gradient will reach 0.14 hPa/m or 7.1 m/hPa (23.3 feet/hPa).

When it is very cold, the altimeter will overestimate the altitude, and underestimate it when it is very hot.

The above examples show how serious the error can be.

These examples assume that the aircraft is flying at an altitude higher than its point of departure; if the arrival point is lower than the departure point, the altimetric error will have the reverse effect.

It is essential to remember that during very cold weather or in conditions of relatively low pressure, the altimeter will overestimate the actual altitude. The aircraft will actually be flying lower than the indicated altitude.

4.8.4 Altimeter Adjustments

At any aerodrome equipped with observation instruments, it is possible to adjust the altimeter according to the pressure recorded at the point of arrival.

By setting the altimeter correctly, the pilot should normally be able to obtain the exact altitude of the runway.

In flight, however, the indicated altitude is not necessarily correct. Minimal altitudes for flight paths take this into consideration, particularly for IFR flight.

A pilot who maintains the same altitude, relying only on the altimeter, will be following an isohypse.

At an altitude of 3 km (10,000 feet), a difference of 300 m (1000 feet) over a distance of 1000 km (540 nautical miles) is nothing unusual.

If a pilot flies toward a depression without changing the altimetric setting, he can expect the altimeter to indicate a higher altitude than the actual altitude when he lands. In other words, caution is necessary when flying into a low, particularly for IFR flights. In flying toward a high, the reverse occurs.

Flying from a hot region to a cold one also calls for caution, at least if the destination airport is at a higher elevation than the departure airport.

Pilots must also be wary of mountains, where strong winds have a great influence on pressure. The errors can be fairly serious.

Errors of close to 900 m (3000 feet) have been recorded when flying at low levels in a narrow valley where there are strong winds.

In mountainous areas, orographic waves (the waves created in the atmosphere by strong currents crossing over mountains) are also a source of major errors, as well as the eddies they generate at lower levels.

4.9 Exercises

1. What is atmospheric pressure?
2. What is mean sea level pressure according to the ICAO standard atmosphere, for each of the three standard pressure measurements?
3. What does "station pressure" mean?
4. What factor must be taken into consideration when comparing pressure readings from different stations, and why?
5. What is the normal level used when reducing pressure from different stations to a common level?
6. On a surface weather chart, what do we call the lines joining points of equal pressure at mean sea level and defining areas of high and low pressure?
7. Connect the words in the first column to those in the second. There may be more than one link per word.

   a. depression   1. area of high pressure

a. depression 1. area of high pressure
b. high 2. area of low pressure
c. low 3. neither of the above
d. tornado
e. hurricane
f. barometric col
g. ridge
h. trough

8.
9. Depressions are often associated with cloudy weather, whereas highs are normally associated with clear weather. True or false?
10. On a surface chart, a ridge is an area where pressure is low in comparison to the pressure field. True or false?
11. What is the barometric tendency?
12. What is a pressure gradient?
13. On a 700 hPa constant pressure chart, it can be seen that the pressure is much lower in Cape Dorset, Northwest Territories, YTE, than at Brandon, Manitoba, YBR. What does this tell us about the temperatures at these two places?
14. An aircraft's altimeter indicates the correct elevation at the destination point. Twelve hours later, the pressure there has risen. If the pilot does not correct the altimeter setting, what will the instrument indicate?

CHAPTER 5
WINDS AND GENERAL CIRCULATION

Wind is moving air. Forecasts of wind are used to guide pilots and navigators in preparing their flight plans and for take-offs and landings.

With proper knowledge of the wind you can not only save considerable time and fuel, but also interpret weather developments during flight.

5.1 Wind Direction

In any discussion of winds it is important to understand that wind direction means the direction from which it is blowing. A south wind, for instance, is blowing toward the north.

A clockwise change in direction is known as a veer; a counterclockwise change as a back. Accordingly, a change in direction from south to southwest and then to west would be described as a veer from south to west.

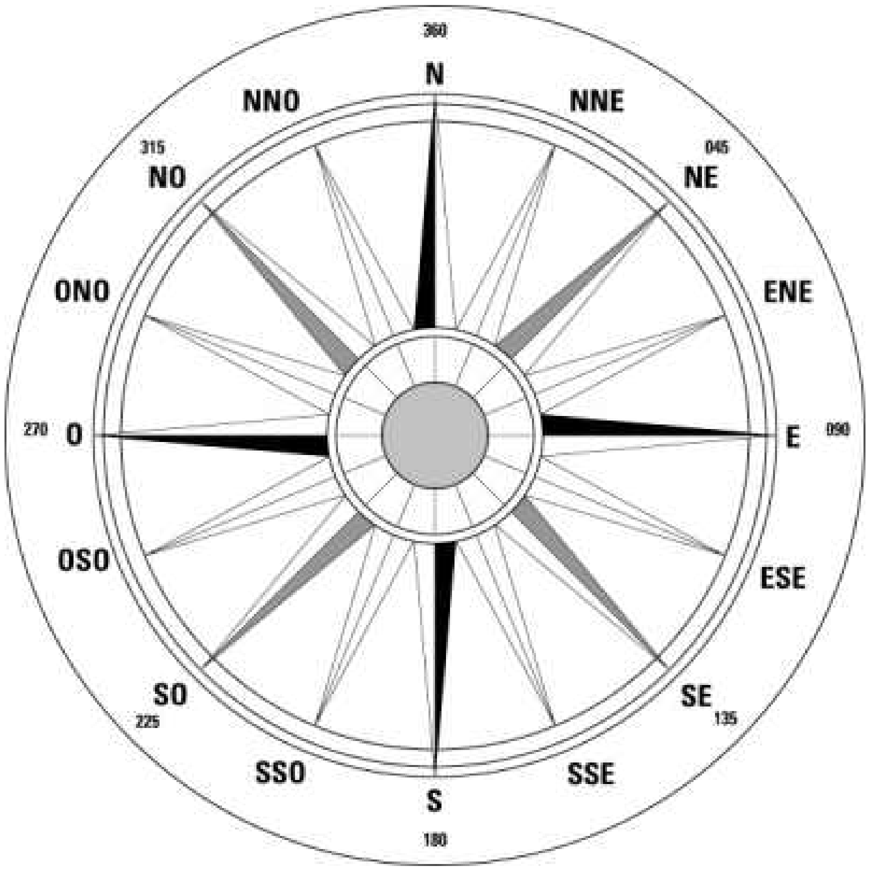


Figure 5-1 Wind rose

5.2 Forces Acting on the Air

The air consists of a collection of particles subject to different forces. These variable forces apply at all atmospheric levels, and it is they that cause the wind.

5.2.1 Pressure Gradient Force

The force that results from a difference in pressure between two points is the pressure gradient.

This force always pushes the air from a region of high pressure to one of low pressure. It varies directly with the weight of the air.

The closer together the isobars, the greater this force.

5.2.2 Coriolis Force

The Earth's rotation exerts a constant force that deflects the air slightly to the right in the northern hemisphere. This is called the Coriolis force.

The Coriolis force balances the pressure gradient force when the two are equal.

The result is that the wind, if the Coriolis force and the gradient force are in balance, blows parallel to the isobars around a centre of low pressure, meaning that it veers, whereas it backs around a centre of high pressure.

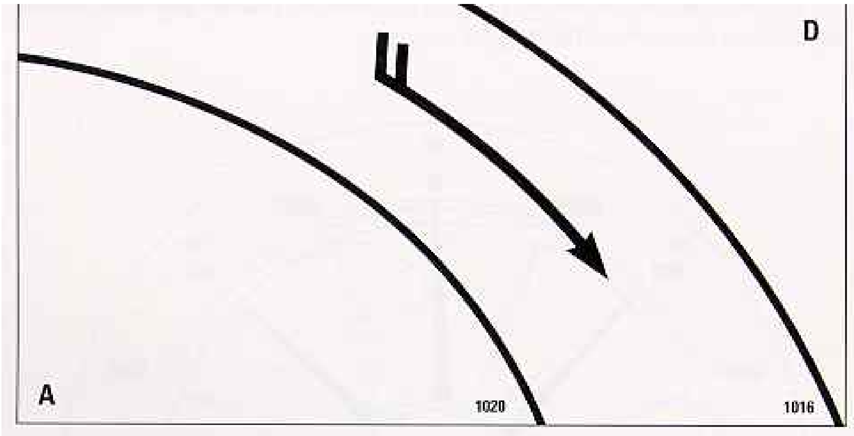


Figure 5-2 Relationship between wind direction and isobars related to the high, A, in a frictionless atmosphere.

5.2.3 Centripetal Force

Centripetal force occurs when the air flow curves in. This force acts perpendicularly, in the direction of the centre of rotation.

Since centripetal force is added to the gradient, the wind blows a bit more strongly around high-pressure centres.

This force is weaker than the Coriolis and pressure gradient forces, however.

5.2.4 Friction

An important surface force, friction, slows the wind and can affect its path. It also reduces the influence of the Coriolis force.

Since the gradient force remains the same, the air is generally shifted toward low-pressure regions. See Figure 5-3.

How much it is shifted depends on the nature of the surface. In areas where the terrain is very rough, the impact of friction will be greater.

Above normal terrain, the wind could be diverted by about 30º , but over bodies of water it often ranges from 0 to15º .

At heights of more than 1000 m (3000 feet) above the ground, this effect dies out and the winds blow parallel to the isobars.

Pilots will note, after take-off, that the wind veers and strengthens; as they land, the opposite occurs.

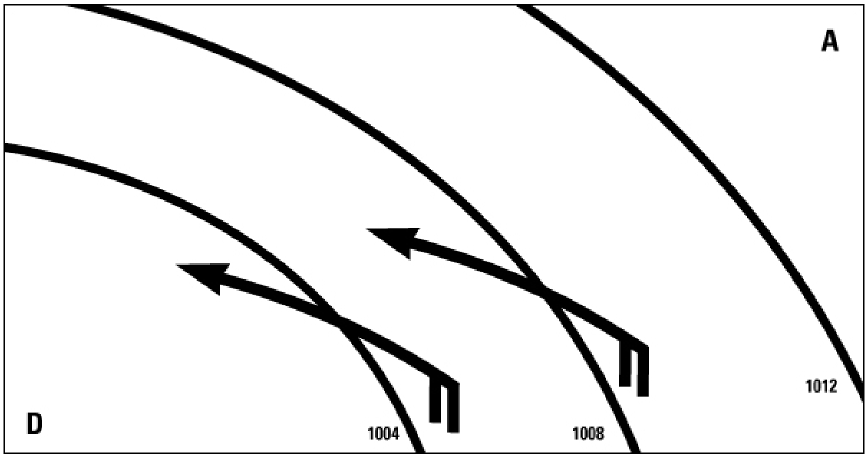


Figure 5-3 Relationship between wind direction and isobars related to the depression, D, in an environment with friction.

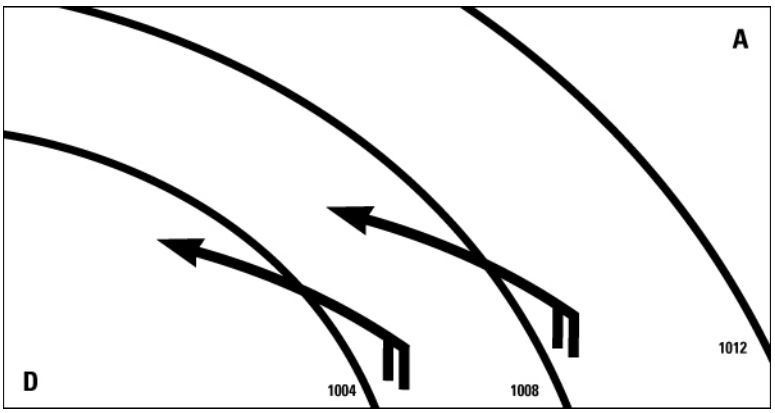


Figure 5-4 Comparison of surface wind and wind at 1000 m above a flat surface.

As weather maps show, it is pressure that controls winds.

Winds at the surface and at mean sea level are sometimes quite different from those at higher altitudes.

For instance, there may be light and variable winds at ground level, and winds of 280 km/h (150 knots) or more at 6000 m (20,000 feet).

5.3 Gusts and Squalls

Gusts are rapid and short-lived changes in wind speed and direction and its main components.

They may be caused by instability or by natural or artificial obstacles, such as high buildings.

If the wind is strong enough and the instability lasts, gusts can sometimes persist for several hours.

Squalls produce sudden and significant increases in wind speed, and are usually accompanied by showers or thunderstorms.

They appear suddenly, last only a few minutes and die out just as quickly. They often result from the passage of a cold front.

Behind the front, if there is one, there may be strong gusts.

Squalls may also be caused by a line of thunderstorms. Consecutive thunderstorms may produce a series of squalls at fairly long intervals.

5.3.1 Instability

Although wind speed and direction are largely determined by the pressure gradient, the time of day has an equally strong influence.

During the diurnal cycle, the air warmed by the ground rises as the warming increases.

Since this air mass moves more slowly than the air aloft, the mixing of air masses slows the upper-level winds.

The air is replaced at ground level by the colder air from the upper layers, leading to gusts that are simply rapid and brief variations in the wind, for all practical purposes.

At night, surface cooling considerably slows such vertical exchanges, weakening the wind and gusts near the surface and strengthening the winds aloft.

Although the temperature gradients are still strong enough to maintain medium-speed winds overnight, the gusts may disappear.

In addition to the diurnal and nocturnal thermal variations that influence winds, other phenomena are directly associated with the instability caused by alternating warming and cooling:

- Both the SEA BREEZE AND LAND BREEZE result from unequal heating of land and bodies of water.

  Sea breeze On sunny days, the air above the land warms more quickly than the air over water.

  Because of the difference in density, the sea air pushes the warm air off the coast, often forcefully, which gives a sea breeze.

  Land breeze At night, heat loss through radiation means that the coastal air becomes heavier, and in turn pushes the warmer sea air off the coast, giving a land breeze.

  The strength of these breezes depends on the difference in temperature over land and water, the instability of the warmer air, the upper-air wind, friction, the shape of the shore and the size of the body of water.

  These are very local phenomena that occur only when prevailing winds are weak.

  Land breezes are generally much weaker than sea breezes, since the temperature of the air varies more slowly during nighttime, thereby ensuring some stability.

  Sea breezes can reach as much as 50 km/h (25 knots), and can blow as far as 25 km inland.

- Anabatic and katabatic winds also result from unequal heating.

  Anabatic winds occur when the slopes of a valley exposed to the sun warm more quickly than the bottom of the valley.

This heating releases rising air, which causes the cooler air from the valley to climb the slopes, creating localized circulation restricted to the valley.

Katabatic winds are a nighttime phenomenon, and blow down the slopes of valleys that are still warm from the day.

Katabatic winds are generally stronger than anabatic winds, particularly in the mountains, where the valley sides may be covered with ice.

5.3.2 Obstacles to the Wind

The surface wind is affected by many obstacles, which create gusts whose strength depends on the wind direction and speed and on the topography itself.

Outside of mountainous regions, their influence is quite limited. Nevertheless, they must be taken into account by pilots, particularly during take-off and landing.

There are many obstacles that act on the wind's behaviour, and create different effects:

- **BARRIER EFFECT** A cliff, mountain or mountain range can form a wall that deflects the wind with varying force, depending on the strength and direction of the air flow. If the wind is flowing almost at right angles to a mountain range and the air is sufficiently moist, this phenomenon may create lens-shaped clouds in the upper atmosphere on the lee side.

  The presence of such clouds indicates that the area is sprinkled with areas of strong turbulence, making it dangerous.

- **VALLEY EFFECT** Any well-defined valley channels the wind.

  Depending on the valley's orientation, the wind may be channelled in a much different direction from the unconstrained upper-air winds, called "prevailing" winds.

  The St. Lawrence Valley is an excellent example. The winds are frequently forced into northeast or southwest paths, following the direction of the St. Lawrence.

- **FUNNEL EFFECT** When steep sides of a valley, or cliffs, hills or mountains suddenly narrow, this produces a funnel effect.

  Since the wind is too strong for the volume of air to change, the natural bottleneck causes it to accelerate, and its speed may even double.

  This effect is common in bays, straits or wherever a body of water suddenly narrows. Over the St. Lawrence it is very evident around the Île d'Orléans, where the funnel effect considerably reinforces any wind from the northeast.

- **SHEAR** A sort of rip in the atmosphere occurs at the junction of horizontal air layers of different speed or direction, producing a vertical wind motion, or shear.

  Depending on the direction of the air layers, the result may be divergent or convergent; horizontal divergence aloft produces rising motion in the lower levels, while convergence aloft creates subsidence in the lower levels.

  Shear may be caused by an obstacle on the ground or simply by a windshift in the upper air; this is frequently the case in the Saguenay Valley as a winter low approaches.

  In this valley the wind will blow from the east, whereas just above, it will be from the southwest.

5.4 Upper-air Winds

Upper-air conditions are represented on constant-pressure charts, on which solid lines called isohypses indicate changes in altitude, in decametres, at each pressure level.

Isohypses are similar to isobars on surface charts.

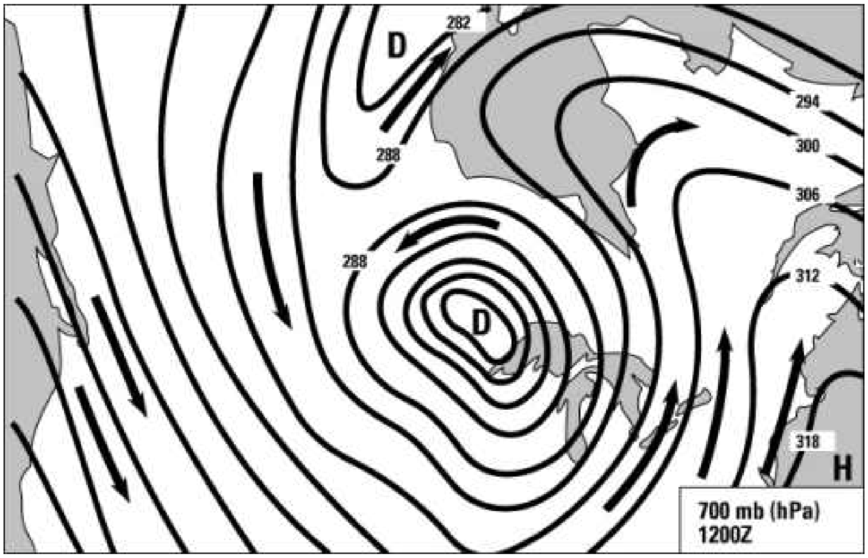


Figure 5-5 Example of air movements at 700 hPa. The altitude of the pressure level is indicated by isohypses. Simply add a zero to obtain the height in metres; for instance 294 equals 2940 metres.

The wind blows parallel to the isohypses in high-pressure regions, and vice-versa in lower-pressure regions.

Wind strength is proportional to the horizontal gradient of the isohypses; the closer together the lines, the stronger the wind.

If the Earth had a uniform surface and no winds to mix the air from the equator and the poles its temperature would gradually and uniformly decrease toward the poles. Because pressure surfaces aloft are lower in regions of cold air than in regions of warm air, upper-air maps should show pressure surfaces much lower over the pole than over the equator.

This would result in a westerly flow aloft, since winds at a given pressure level blow parallel to the isohypses, counterclockwise around lows and clockwise around highs.

The fact that the surface of the Earth is not uniform causes considerable variation in temperature along a given latitude.

Pressure levels will show marked variations along a specific latitude, being higher over warm areas than over cold areas.

Some lower-level pressure systems affect even the 250 mb pressure surface.

In many cases, closed isohypses appear on the upper-level charts, showing that the westerly flow has been completely disrupted and that easterly winds are present aloft, over part of the continent.

5.5 Winds and Altimeters

Since the wind blows constantly, it has an inescapable influence on altimeter readings, for both are affected by variations in and the configuration of the pressure field, generally different at higher levels and sea level.

If you are flying at 600 m (2000 ft) with a direct headwind or tailwind, then you must be flying parallel to the isohypses. No pressure change will affect the accuracy of your altimeter.

At constant pressure, you must remember that with a tailwind, the aircraft will automatically drift strongly to port and will gradually gain height.

If you have to climb to remain at the same pressure level, you must be heading into an upper-air ridge. The isohypses show a rising air mass. To continue flying at the same pressure level, you must climb.

Drifting to starboard while experiencing a tailwind indicates that the aircraft is gradually losing height and heading toward a high-pressure zone.

The air becomes denser because of subsidence, a sign of high pressure zones. While the altimeter reading is unchanged, your altitude will be lower if there is an upper low.

As you can see, the winds as determined during flight can be of great value in assessing altimeter errors due to pressure.

On the other hand, there are other ways to find exactly what the altimeter error is during flight- for example by comparing altimeter readings with data from a radio altimeter, to give you the wind component blowing at right angles to your aircraft.

5.6 General Circulation

All meteorological data confirm that air circulation around the planet is highly variable, but also that some of these variations are in fact quite foreseeable, given the extreme sensitivity of air flows to the nature of the land surface.

To illustrate the general profile throughout the days and seasons, we must examine the mean distribution of pressure.

In the northern part of the northern hemisphere, this circulation flows from west to east, following the uneven path created by the meeting of arctic and continental air.

5.6.1 At Sea Level

The average distribution of pressure in Figure 5-6 clearly shows that the troposphere is broken up into key currents:

- the polar high

- the subpolar low at 60 ºN
- the subtropical high at 30 ºN
- intertropical convergence near the equator.

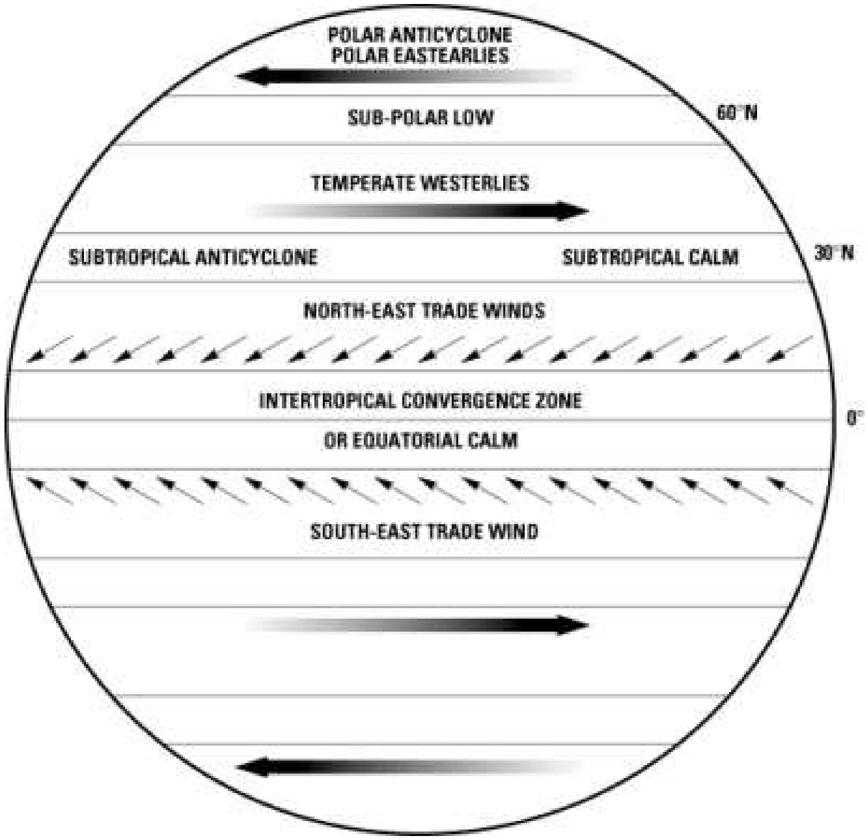


Figure 5-6 General circulation at sea level

The general surface circulation corresponds to these upper-air phenomena:

- polar easterlies, from the pole to 60 ºN
- temperate westerlies, from 60 ºN to 30 ºN;
- easterlies, between 30 ºN and the equator, called the trade winds; they blow from the northeast in the northern hemisphere, and from the southeast south of the equator.

Interzonal areas, when the winds are weak, are just as well defined:

- near the North Pole;
- subtropical calms, or horse latitudes;
- equatorial calms, or doldrums, characterized by thick clouds and abundant rain.

5.6.2 Upper-air Winds

Figure 5-7 also shows:

- the cold polar high weakens aloft to become a low at 700 hPa and intensifies gradually;
- the warm subtropical high does the same;
- the result is a zonal cyclonic circulation from the west around the upper-air polar low.

Near the equator, south of the subtropical high, this circulation is transformed into an easterly current.

The temperate westerlies also intensify as far as the tropopause, and then weaken in the stratosphere.

To conclude, in regions subject to circulation from the west, the westerlies reach their maximum speed in the tropopause.

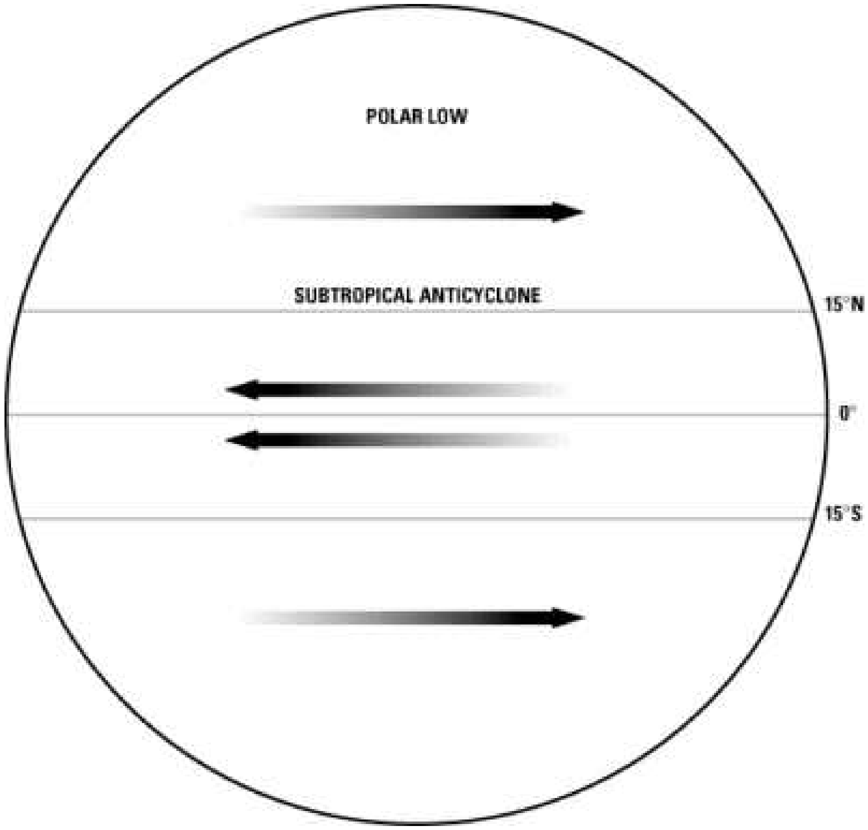


Figure 5-7 General upper-air circulation, from 700 hPa to the tropopause

5.7 Tropical Regime

5.7.1 Characteristics

The Hadley cells between 30 N and 30 S are what is called the tropical regime. At sea level, this regime includes the trade winds and equatorial calms.

The main characteristics of tropical circulation, illustrated in Figure 5-8, are as follows:

- At sea level, the trade winds blow toward the highly unstable intertropical convergence zone. On their way toward the equator they absorb heat and moisture.
- Under the combined effect of this convergence and the many convective currents in this region, the moist and unstable air of the intertropical zone is pushed upward.

The result is huge cumulonimbus clouds, their tops sometimes pushing through the tropopause and reaching 18 km (70,000 feet).

These cloud tops lose heat through radiation, maintaining the instability necessary to support this convective-type circulation.

Latent heat released when condensation occurs also contributes directly to the lifting.

- In the upper troposphere, the air flows toward the poles and takes on a predominantly easterly flow, albeit weak, influenced by the subtropical high;
- this weak easterly current in the upper troposphere cools by radiation and gradually descends.

As it sinks, it warms at the dry adiabatic rate and absorbs the latent heat released during its previous rise in the intertropical convergence zone.

This phenomenon tends to smooth out temperature fluctuations between 25 ºN and 25 ºS, but creates a powerful and lasting inversion.

The inversion of descending warm air, almost cloudless, contrasts enormously with events in the lower layer, where the contribution of the moist and unstable trade winds gives rise to clouds of vertical development.

- This air arrives at ground level between 30 ºN and 30 ºS, and there it splits in two, with part of it flowing back toward the equator and the subtropical high, while part flows toward the poles.

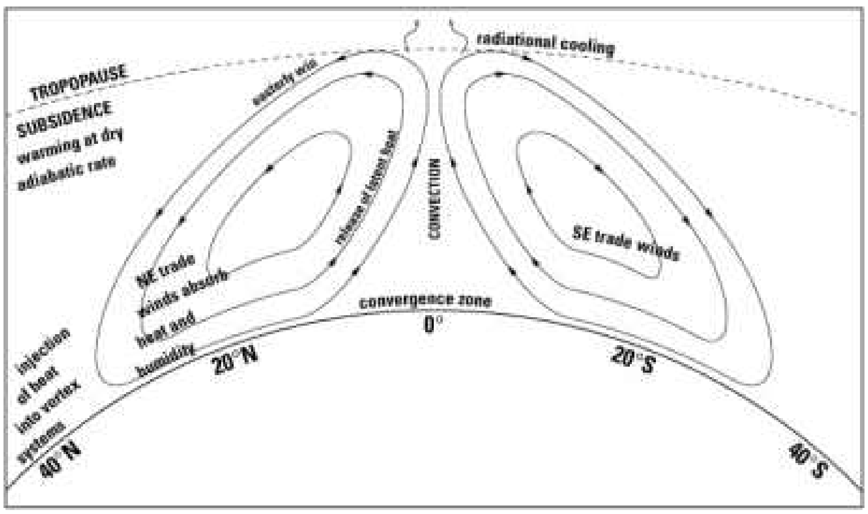


Figure 5-8 Tropical circulation

5.7.2 Intertropical Convergence Zone

The clouds associated with the intertropical convergence zone are convective. There are many clouds, but they do not form an unbroken belt around the globe.

Although the weather in this zone resembles frontal-type weather, it cannot be considered an immense front. The air masses converging here are thermally similar, but do not form a truly monolithic whole.

The intertropical convergence zone is located 10º on either side of the equator, on average, and shifts northward in summer and southward in winter. This shift is more noticeable over the continents, where temperatures vary more widely than over the oceans.

The thermal low in Asia known as the summer monsoon lifts warm and moist air from the continent and eliminates the convergence zone. The winter monsoon, on the other hand, which is a continental high, expels cold dry air and pushes the convergence zone back toward the southern hemisphere.

5.7.3 Heat Exchanges in the Tropical Regime

Tropical circulation is maintained by many heat exchange processes:

- absorption of sensible heat and latent heat by the trade winds;
- release of latent heat by the current rising from the intertropical convergence zone;
- radiational cooling of the upper levels;
- divergence in the upper troposphere above the convergence zone, which results in air warmed at the dry adiabatic rate descending into the subtropical regions;
- injection of heat into vortex systems in the temperate latitudes.

These heat exchanges produce a thermally homogenous tropical air mass.

The effect of the Earth's rotation, that is the Coriolis force, must be weak for this circulation to persist.

This is another characteristic of the Hadley cell. It is nil at the equator and remains fairly weak up to 30º N and 30º S.

5.7.4 Extratropical Regimes

By contrast with the tropical regime, the extratropical regimes are characterized by strong horizontal temperature gradients and significant Coriolis effects.

In addition, since these regions are generally heat-deficient, they draw heat away from the tropical regions.

In the middle latitudes, the current from the subtropical high that flows toward the poles is diverted at sea level to become a westerly current in the northern hemisphere, under the influence of the Coriolis force.

When this current meets the cold-air current from the North Pole, it is diverted and transformed, this time, into an easterly current.

The polar front forms where these two currents meet, in the subpolar low zone.

In this sector, the wave circulation in the upper atmosphere is reflected in lows and highs on the surface.

5.8 Geographic Influences

5.8.1 Continents and Oceans

The annual variation in temperature is weaker over the oceans than over the continents, since the loss or gain by radiation is weaker there; it increases with latitude and is much more evident at the poles than at the equator.

In summer, the continents warm much more quickly than do the oceans. Consequently, as soon as a thermal low forms over the continent, it increases pressure over the ocean. The inverse occurs in winter.

Because of the great thermal mass represented by the oceans, with the exception of the polar regions, the temperature difference between the oceans and continents is much more marked in winter than in summer.

Over the continent, lows tend to move southward, where warming is more intense, whereas highs act in the opposite fashion.

5.8.2 Influence of Mountain Ranges

Large mountain ranges have a considerable effect on weather over the continents and oceans. The Rockies, for instance, inhibit heat exchanges between the Pacific and the east of the continent.

This natural wall causes winter highs and summer lows to the east of the Rockies.

Over the Eurasian content, it is the southern and eastern ranges that prevent such heat exchanges between the Pacific and the southern parts of the continent.

Over North America, similar circumstances keep the winter high in the east, and let the summer low occupy the entire continent.

5.9 Tropopause

The tropopause is the transition zone between the troposphere and stratosphere, where winds and temperatures vary considerably.

This phenomenon can have a direct impact on comfort and safety, since it is here that the wind reaches maximum velocity. (See Figure 5-9.)

These strong winds create narrow wind shear zones that often generate dangerous turbulence.

Accordingly, it is important to make sure that you always have the latest information on the current and forecast wind and wind shear.

The height of the tropopause varies. It is about 20 km (60,000 feet) at the equator, and some 6 km (20,000 feet) or less over the poles.

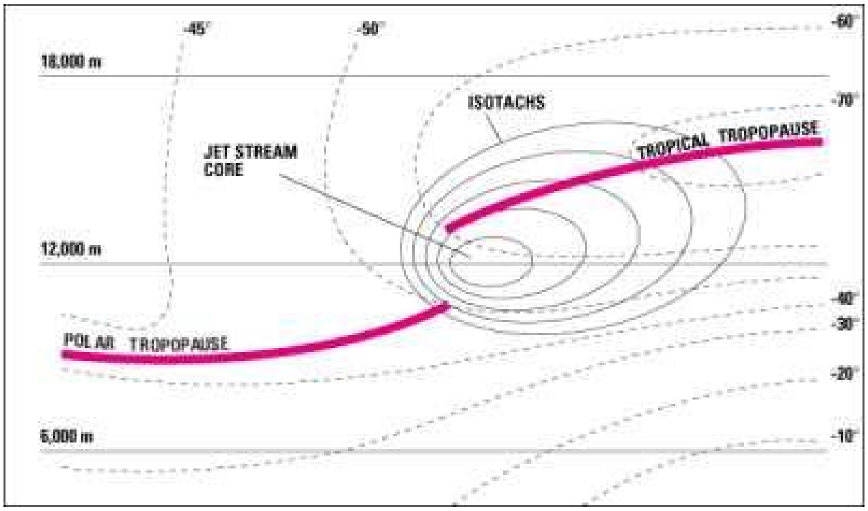


Figure 5-9 Cross-section of the upper troposphere and the tropopause

5.10 Jet Streams

A jet stream is a narrow, shallow and twisting river of maximum winds extending almost everywhere around the globe. (See Figure 5-10.)

A jet stream may reach as far as the northern tropics, but at that point it will be travelling much more slowly than in the middle latitudes, where it is moving at its maximum.

It is the abrupt variation in the altitude of the tropopause that creates the jet stream.

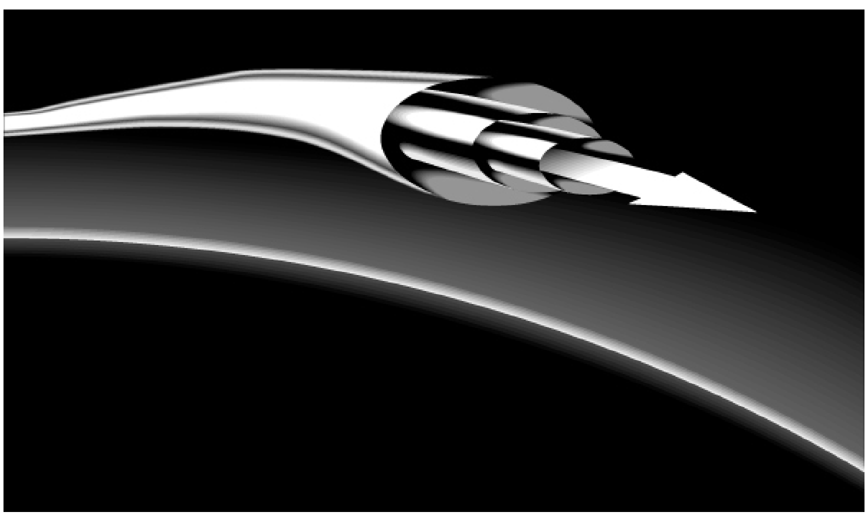


Figure 5-10 Artist's conception of the jet stream. The arrow indicates the direction.

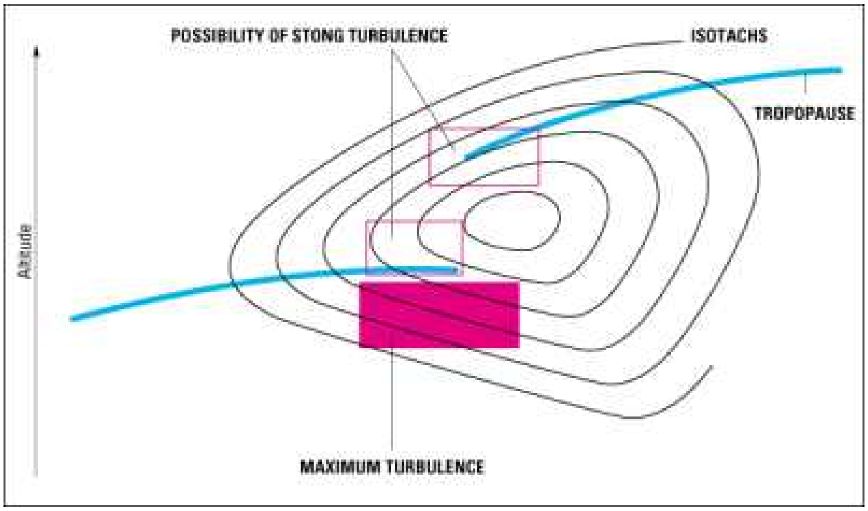


Figure 5-11 A segment of the jet stream. Isotachs link points of equal speed.

By definition, a jet stream is a stream of air flowing at a minimum of 110 km/h (60 knots).

Jet streams do not always have the same configuration. They generally resemble a boomerang. (See Figure 5-12.)

Jet stream segments move with underlying pressure ridges and troughs in the upper atmosphere. In general they travel faster than the underlying pressure systems.

In the middle latitudes, the average speed of the jet stream is highest in winter. In the summer they tend more to the south.

The core of the jet stream is the part where the wind reaches its greatest speed.

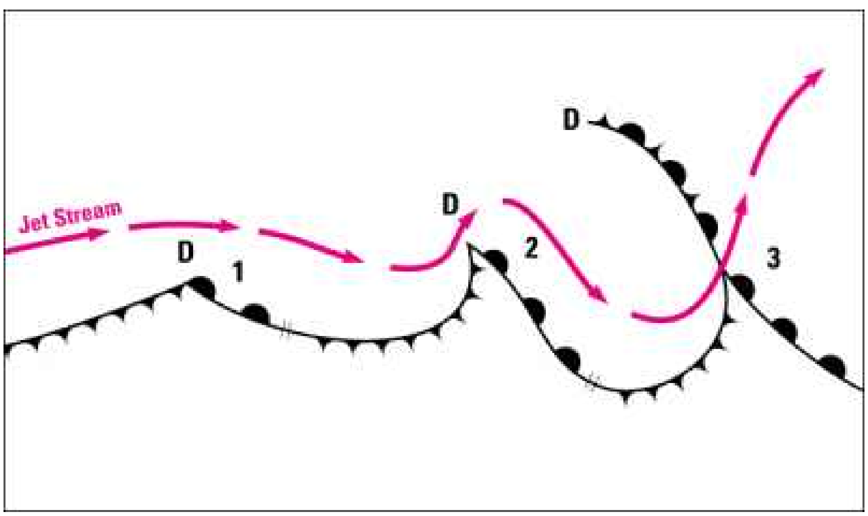


Figure 5-12 Analysis of the jet stream at 250 hPa.

Windspeed falls with distance from the core of the jet stream, particularly on the polar (cold) side. (See Figure 5-9.)

A comparison of two jet streams shows that their paths conform approximately to the shape of the isohypses. (See Figure 5-12.)

The northerly jet stream has three segments of maximum velocity, while the more southerly stream has two.

Isohypses are tighter in areas where the speeds are highest, both in the area of jet streams and on either side, where wind shear is generally stronger.

Strong, long-trajectory jet streams are usually associated with well-developed surface lows and frontal systems beneath deep upper troughs. The occluding low moves north of the jet stream, and the jet stream crosses the frontal system near the point of occlusion.

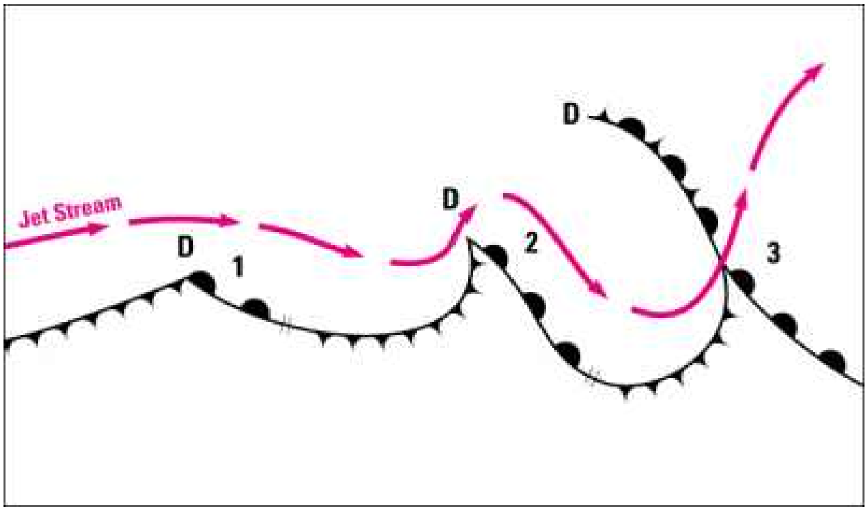


Figure 5-13 Mean jet positions relative to surface systems (1). Cyclogenesis (development) of a surface low is generally south of the jet (2). The deepening low moves nearer the jet(3) . As it occludes, the low moves north of the jet; the jet crosses the frontal system near the point of occlusion.

5.11 Exercises

1. What is wind?
2. How is wind direction indicated?
3. Name four forces that act on the air.
4. Why does the surface wind veer to the right in the northern hemisphere and end up blowing parallel to the isobars?
5. If, in the northern hemisphere, you turn your back to the wind after the Coriolis force has acted on it, where will the low-pressure zone be with respect to you?
6. The tighter the isobars, the stronger the pressure gradient and, consequently, the higher the wind speed. True or false?
7. In the northern hemisphere, air blows clockwise around a low. True or false?
8. Windspeed at 1 km (3000 feet) can generally be determined from:

    - the temperature lapse rate
    - the pressure gradient at mean sea level
    - the mean sea level pressure

9. What is the effect of surface friction on wind direction?
10. If there is a great deal of friction, the wind will be stronger and will flow more toward low-pressure zones. True or false?

11. The angle of the wind direction with respect to the isobars is stronger when the wind is blowing over water than when it is blowing over rough terrain. True or false?
12. Name two of the main causes of gusts.
13. How does a land breeze behave, and at what time of day is this phenomenon most likely to occur?
14. Katabatic winds flow down slopes during the night. True or false?
15. Name four effects caused by obstacles to surface wind.
16. What is an isohypse?
17. The closer isohypses are together, the faster the wind blows. True or false?
18. Upper-air winds always blow parallel to isohypses. True or false?
19. Where is the low if the wind is blowing from the north?
20. What is the difference between a gust and a squall?
21. When flying at a constant pressure level, you note that you are drifting strongly to the left, meaning that the aircraft's true altitude is too low. Is the altimeter reading too high or too low?
22. You are flying from east to west at 500 hPa. For each of the wind directions observed during the flight, indicate whether you would gain or lose height.
    - from the south
    - from the north
    - headwind
    - tailwind
23. What is a temperate westerly?
24. What does "the doldrums" mean?
25. Upper-air circulation is from the west near the poles and from the east near the equator. True or false?
26. What is the profile of the general circulation between the equator and latitudes 30 ºN and 30 ºS called?
27. By contrast with the tropical regime, the extratropical regimes are characterized by marked horizontal temperature gradients and strong Coriolis force. True or false?
28. Continents and oceans have a thermal influence on the general circulation. True or false?
29. In the tropopause, the temperature and wind regime is fairly stable. True or false?
30. What is a jet stream?
31. Where are jet streams found?
32. The segment of a jet stream where the winds reach their maximum is called the "core." True or false?
33. What do we call the lines that join points of equal wind speed?
34. When you turn your back to a jet stream, is the tropopause on your left or your right?
35. The edge of cirroform clouds is often cut off abruptly near the north side of the jet stream. True or false?

CHAPTER 6 AIR STABILITY

The most important cooling process is expansion associated with rising air.

However, there are great variations in the vigour and extent of vertical motion in situations that appear to be otherwise identical. For example, in the course of a flight over an area of small hills, you may encounter violent vertical motion at some points and none in other places. This difference is attributable to a difference in the stability of the air. Although this property plays an important role in determining the strength and extent of vertical motion, it does not initiate the motion.

6.1 Definition of Terms

"Stability" and "instability," when referring to the atmosphere, have much the same meaning as when applied to ordinary objects.

For instance, a ship with its weight unevenly distributed is unstable, particularly if it is top-heavy. If the ship rolls to one side, its structure is farther from the vertical. In a rough sea, it may capsize rather than righting itself.

Figure 6-1 shows the case of a ball in a bowl.

If the ball is lifted up the side of the bowl and then released, it returns to its original position. However, if the bowl is turned over and the ball is placed on the bottom, a slight push sends it rolling off, unable to return to its original position by itself.

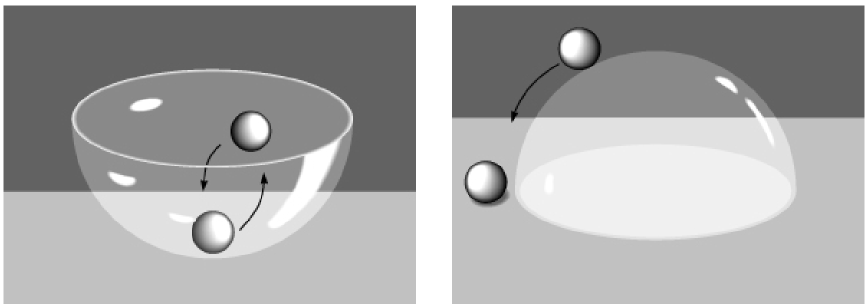


Figure 6.1 A case of a ball in a bowl

A balloon is an even better illustration of the concepts of atmospheric stability and instability.

In the three situations in Figure 6-2, a balloon is inflated with dry air at a temperature of 31 ºC, the ambient temperature at ground level, and released at 1.5 km (5,000 feet) above the surface.

In each situation, the dry air in the balloon expands and cools at the dry adiabatic lapse rate of 1 ºC per 100 m (330 feet), to reach the temperature of 16 ºC at the selected ceiling.

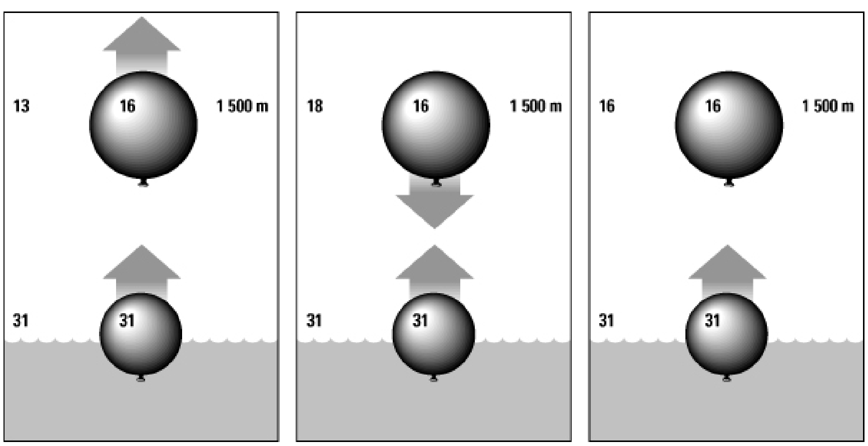


Figure 6.2 Stability is linked to the temperature aloft and adiabatic cooling.

On the left, even if the air in the balloon cools adiabatically, it remains warmer than the ambient air, which is at 13 ºC. This balloon will rise and cool, until its temperature is the same as that of the surrounding air or until it bursts.

In the atmosphere, particles behave in the same way, creating instability and generating convective-type rising currents.

The ambient air is warmer than the air inside the balloon in the centre, so the weight of its cold air will make it sink back to its initial position. Since the air in the balloon will warm as it descends at the same lapse rate as the surrounding air, it will nevertheless always remain cooler, which will keep it sinking.

When a colder particle sinks, this is an indication that the air is stable, and that consequently convection is not possible.

In the last situation, the temperature of the balloon and that of the surrounding air are identical. The balloon will remain in place. This condition is neutrally stable; that is, the air is neither stable nor unstable.

In all three cases, the air in the balloon cools at a fixed rate, since it is expanding at the same time.

The differences between the forces acting on this balloon are attributable to the differences in temperature measured between the ground and at 1.5 km, in other words the lapse rates in the atmosphere.

6.2 Variations in intensity

The range of variation extends from absolute stability to absolute instability, and gives rise to the never-ending quest for equilibrium that characterizes the atmosphere.

As soon as the atmosphere reaches equilibrium, a minor change in the lapse rate of an air mass can tip the balance.

Simple surface warming or cooling in the upper atmosphere can produce instability, whereas cooling at the surface or warming in the upper air can induce or strengthen stability.

6.3 Stratiform Clouds

Since stable air resists convection, the clouds that form under these conditions are stratiform, meaning that they are horizontal, long and flat.

For them to maintain this shape, the layer of stable air must not be affected by condensation.

6.4 Cumuliform or Convective Clouds

Unstable air promotes convection, and hence the formation of cumulus clouds caused by rising air currents.

The vertical extent of cumulus clouds is proportional to the moisture content of such currents and the instability of this layer.

The lifting process that encourages the formation of cumulus clouds may be identical to the process that lifts a layer of stable air, but is commonly set off by surface heating.

For cumulus clouds to develop, the air must be unstable following saturation; the rising air current cools at the saturated adiabatic rate, so cooling occurs less quickly because of the release of heat due to condensation.

The temperature in the saturated updraft is naturally higher than the surrounding temperature, and this produces spontaneous convection.

The result is acceleration in the rising currents, as long as the temperature of the cloud is greater than the ambient temperature. When the temperature of the cloud becomes equal to or less than the air temperature, the resulting inversion slows convection.

The vertical extension of clouds ranges from shallow fair-weather cumulus to gigantic thunderstorm cumulonimbus.

Generally speaking, the height of the base of a cumulus cloud can be estimated by multiplying the difference between the surface temperature and the dew point by 120 m (400 feet).

This method works only for cumulus clouds, and only at the warmest time of day.

In the reverse situation, when unstable air lies above stable air, convective currents aloft sometimes form middle and high-level cumuliform clouds. In relatively shallow layers they occur as altocumulus and cirrocumulus clouds. Altocumulus castellanus clouds develop in deeper mid-level unstable layers.

6.5 Cumulus and Stratus Clouds

A layer of stratiform clouds may sometimes form in a relatively stable layer, although they are associated with instability, while a few convective clouds may penetrate the layer from below and mix with the stratus. Convective clouds may be entirely embedded in a massive stratiform layer and pose an unseen threat to instrument flight.

6.6 Reading Stability

The usual convection in unstable air gives a "bumpy" ride, depending on the degree of instability; only at times is it violent enough to be hazardous. In stable air, flying is usually smooth, but sometimes can be plagued by low ceiling and visibility.

The following are some clues to help detect whether the air is stable or unstable.

- Cumulonimbus clouds are a sure sign that the air is violently unstable, with very strong turbulence. It is best not only to avoid this area but to give it a very wide berth.
- Showers and clouds swelling upward indicate strong updrafts and possible marked turbulence inside and near such clouds.
- Fair-weather cumulus generally indicate a zone of fairly weak turbulence inside the clouds and below them. The cloud tops indicate the approximate upper limit of convection.
- Thunderstorms may be embedded in a layer of stratiform clouds.

A clear sky does not necessarily mean, however, that the air is stable. Meteorological data give the best indications of the state of the atmosphere.

A rapidly falling temperature, i.e. by 2 to 3 ºC/300 m while climbing, indicates that the air is unstable.

If the temperature remains constant or rises or falls only very slowly with height, however, the air is stable.

Finally, warm and moist air at the surface is a strong indicator of instability.

6.7 Lapse Rate and Air Stability

One of the most important factors in stability is the temperature lapse rate in the air that is not rising.

Because the weight of the air per unit volume depends on the pressure as well as the temperature, stable conditions will prevail even if temperatures decrease slightly with height.

In a nut shell, unstable air is indicated by a steep negative lapse rate, while stable air is indicated by a shallow negative lapse rate, an isothermal layer, or an inversion.

Since the lapse rate in non-rising air is rarely constant with altitude, there may be considerable differences in the degree of stability or instability.

In some cases, a slight initial push may result in updrafts reaching as high as 6 to 9 km. In other cases, the current will rise no more than 1.2 to 1.5 km.

There are also times when very stable air in the first 300 metres becomes so unstable aloft that it continues to climb to great altitudes.

More often, however, the air will be unstable in the first 300 metres and then stable above; in this case there may be strong vertical motion in the lower levels and none in the upper air. In this situation, the lapse rate shows that there is an inversion or an isothermal layer at the top of the turbulent layer.

6.8 Changing Stability

Since stability depends primarily on the lapse rate, most changes in stability are due to changes in this gradient.

If the lapse rate becomes steeper, the air becomes more unstable; if it becomes shallower, the air stabilizes. (See Figure 6-3.)

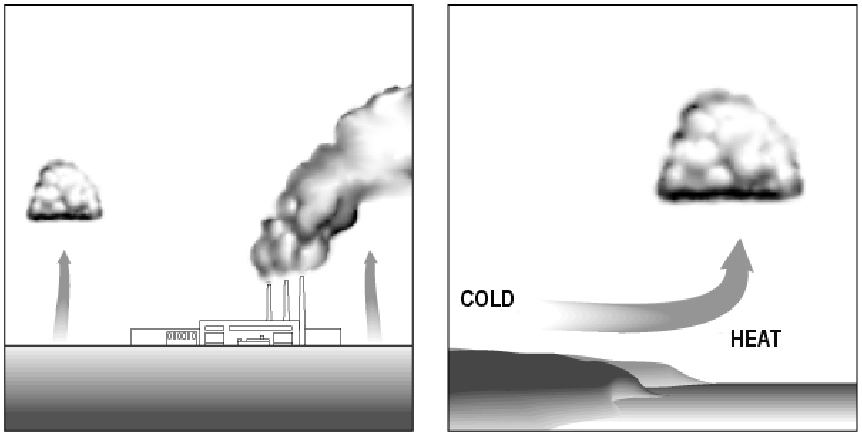


Figure 6.3 Warming from below creates instability

A negative lapse rate strengthens when the temperature climbs in the lower levels, or when it falls in the upper atmosphere. The first phenomenon is more common; it results from warming from underneath, which in turn is a result of solar radiation or of air passing over a warm surface.

Cold air carried aloft can also cause instability. In fact, the lapse rate weakens when the temperature falls in the lower levels, or when it climbs in the upper atmosphere.

It is in the lower levels that changes in the lapse rate are most frequent.

At night, for instance, the cooling of the surface by radiation causes the air to cool, which weakens the lapse rate, stabilizes the air or may even create an inversion.

Warm air moving over a cold surface acts in the same way.

In the upper air, the movement of warm air weakens the thermal lapse rate, which also tends to promote stability. (See Figure 6-4.)

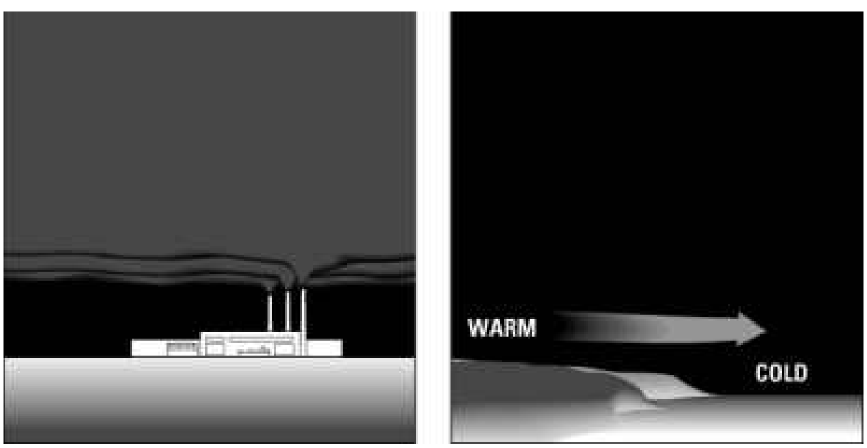


Figure 6.4 Cooling from below stabilizes the air.

6.9 Weather Conditions in Stable and Unstable Air

Table 6-1 gives a summary of weather conditions in stable and unstable air. Only general characteristics are shown, for the weather depends on other factors, in addition to the stability of the air.

Table 6-1 Weather relate to air stability.

	Stable	Unstable
Lapse rate	shallow	steep
Cloud	layer type; fog	cumuliform (heap type)
Precipitation	of uniform intensity	showers
Visibility	Often poor, because impurities not carried aloft.	Impurities are carried aloft and dispersed; visibility good, except in showers, blowing snow or blowing dust.
Turbulence	weak	strong

6.10 Lifting Processes

Many thermal phenomena initiate upward vertical motion. This type of motion is indispensable for the formation of large-scale clouds.

6.10.1 Convection

Convection is marked by local rising currents separated by wide areas of gradually sinking air. It is the result of unequal heating of the Earth's surface.

Coasts and shores create the most pronounced temperature differences, but there may also be marked thermal contrasts between different types of terrain.

Convection also develops in cold air that has moved over a warm surface for some time.

6.10.2 Friction

Friction between the air and ground disrupts the lower part of the airflow into a series of eddies. This condition is called mechanical turbulence. Although its effects are usually confined to the lowest 1.5 km of the atmosphere, the vertical extent of the disturbance will depend upon the stability of the air, the strength of the surface wind and the nature of the surface.

Of these three factors, the most important is the stability of the air.

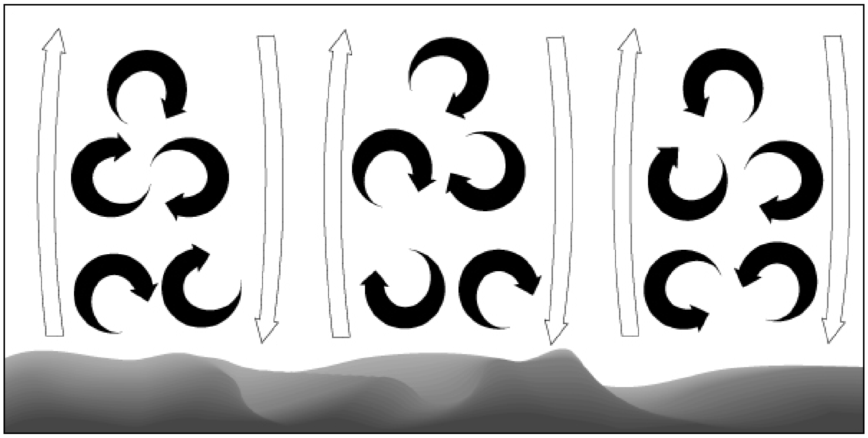


Figure 6.5 Mechanical turbulence

6.10.3 Orographic lifting

Orographic lifting is caused by some prominent topographical feature, such as a range of mountains, or a sloping plain. Here again, the extent of the disturbance depends not only on the height of the obstruction, but also the degree of stability of the air. (See Figure 6-6.)

Mechanical turbulence may be associated with the general upward motion. A downdraft of considerable strength is generally found on the leeward side of the crest of the obstruction-a good example is the Chinook wind in Alberta. (See Figure 6-7.)

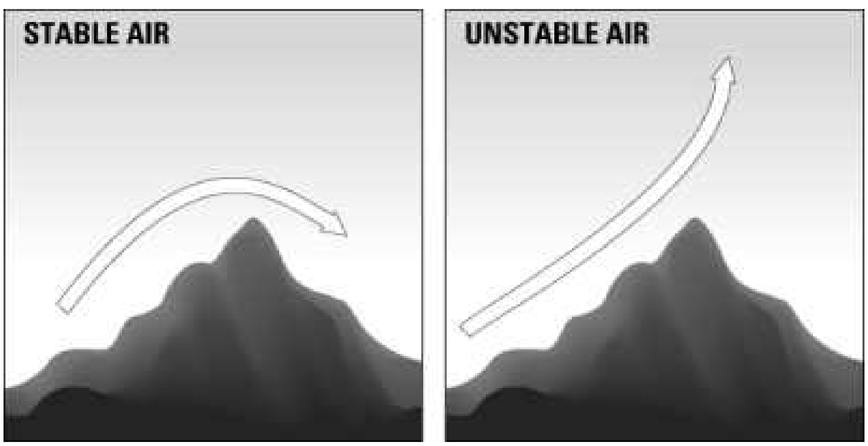


Figure 6.6 Orographic lifting

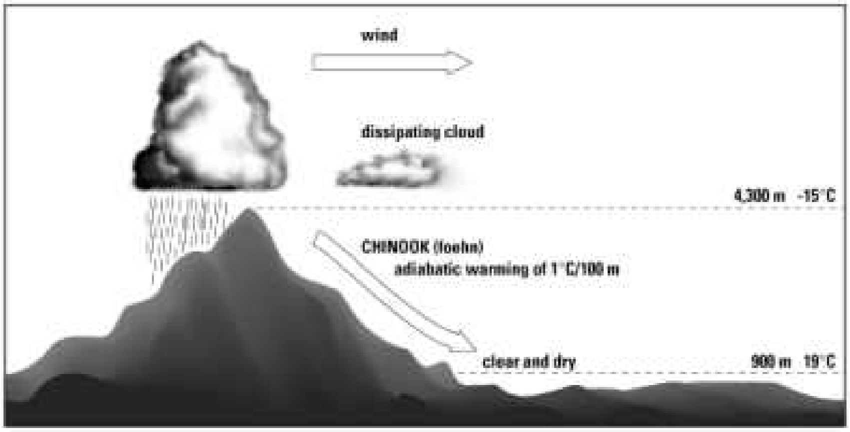


Figure 6.7 The Chinook

6.10.4 Frontal lifting

Frontal lifting is identical to orographic lifting, but in this case the obstruction is a wedge of colder air.

Obviously, there is a front between the two air masses.

6.10.5 Convergence

In the vicinity of a low-pressure area, the surface wind blows across the isobars into the centre of the low. The accumulation of air in the lower levels of the system results in vertical motion, as the air pushes into the region and forces the excess air to rise.

EXERCISES

1. What is stable air?
2. What does the word "neutral" mean when referring to stability?
3. If we place a balloon containing air at a temperature of 10 C in an environment with no vertical motion, at 1 km off the ground, where the temperature is 15 C, what will happen to the balloon?
4. Rising air causes cooling that promotes cloud formation. True or false?
5. What is the name of the lifting process caused by differential warming of the Earth's surface?
6. The vertical push caused by convection continues farther up into the altitude than does lifting due to mechanical turbulence. True or false?
7. What is the name of the type of lifting caused by a mountain range?
8. What is frontal lifting?
9. In the following list, specify whether each phenomenon is associated with stable or unstable air:
    - Cold air moving over a warm surface
    - Thunderstorms
    - Fog
    - Low stratus
    - Blowing dust
    - Warm air moving over a cold surface
    - Showers
    - In-flight turbulence
    - Steep lapse rate
    - Inversion
10. Underline the words or expressions in parentheses that correctly complete the sentence.

- o Vertical currents form easily when the air is (stable/unstable).
- o A shallow lapse rate means (stable/unstable) air.
- o An inversion (inhibits/promotes) vertical currents.
- o Air can become stable through (warming/cooling) from below.
- o Lifting caused by the slope of the ground is referred to as (orographic/ frontal).
- o Blowing snow indicates (stable/unstable) air.
- o A layer of fog is a sign of a (steep/shallow) lapse rate.
- o Differential warming of the ground produces (mechanical turbulence/ convection).
- o Thunderstorms indicate a (steep/shallow) lapse rate.

11. Early in the morning, visibility is reduced to less than one mile because of smoke, but the sky is clear. Visibility may improve in a few hours if there is no change in wind direction. Explain.
12. Most of the Great Lake waters do not freeze in winter. A cold air current from the northwest brings swelling cumulus, snow showers and blowing snow over the southeast shores of Lake Huron. A south wind blowing over Lake Ontario can cause stratocumulus and light snow over the north shore of that Lake. Compare the air stability in the two cases, and explain why the difference is to be expected.

CHAPTER 7 AIR MASSES

The troposphere is divided into separate horizontal sections known as air masses. In most cases these air masses do not merge with each other, but are clearly separated by relatively narrow transition zones, or fronts.

7.1 Definition

The troposphere is not a single entity with uniform physical characteristics, as its horizontal segmentation shows. An air mass may be defined as a large section of the troposphere with uniform properties of temperature and moisture in the horizontal. They are separated by fronts, which form transition zones between two air masses, zones in which horizontal temperature and moisture fields undergo significant and rapid changes.

7.2 Formation and Classification of Air Masses

An air mass is defined as a large section of the troposphere whose characteristics are influenced by the large regions it has crossed in its lifetime.

Air masses are often several thousands of kilometres across.

In winter, cold dry arctic air can cover more than half of North America and extend large fingers down into the warm and moist tropical air masses.

Although the cold air is gradually warmed as it moves southward, there is still a marked difference between the two air masses, when they are side by side in the temperate zone.

Since air masses generally do not merge, the transition zone between the warm air and the cold air is relatively narrow. This is the polar front.

If the earth's surface were uniform, there could be just two air masses, one cold and the other warm, separated by a polar front.

In reality, the behaviour of the air, under the influence of the continents and oceans, is much more complex. Heat and moisture exchanges between the atmosphere and the surface are quite different, and lead to the formation of other air masses.

To the south of the polar front, the tropical air mass is constantly fed by the water vapour from the equatorial oceans.

To the north, there is polar air and glacial arctic air, from the snow and ice fields. The polar air, between the arctic and tropical air masses, is made up partly of the arctic air that has warmed as it moved southward.

In short, there are three kinds of major air masses surrounding the planet: ; arctic, polar and tropical.

Air masses are divided not only according to temperature, but also by moisture content. If an air mass is dry, it is called "continental," meaning that it must have passed over a continental surface from which it could draw only limited moisture.

Air masses that draw a great deal of moisture from various sources, such as water surfaces or great expanses of vegetation, are called "maritime" air masses.

Combining the two types of classification gives a total of six air masses:

- continental arctic
- continental polar
- continental tropical
- maritime arctic
- maritime polar
- maritime tropical.

To apply this classification to North America and the adjacent oceans, we must first discuss the importance of the shape of the continent. North America is shaped like a huge triangle, with the widest part to the north.

In winter, the northern part is covered with snow and ice, while in summer the snow and ice withdraw to a region near the pole, leaving behind an abundance of small lakes, which have important effects on air masses.

The adjacent oceans are very warm in the south, particularly at the narrowest section of the continent, near the Gulf of Mexico, but cold in the north.

These oceans are always an excellence source of moisture for changing air masses.

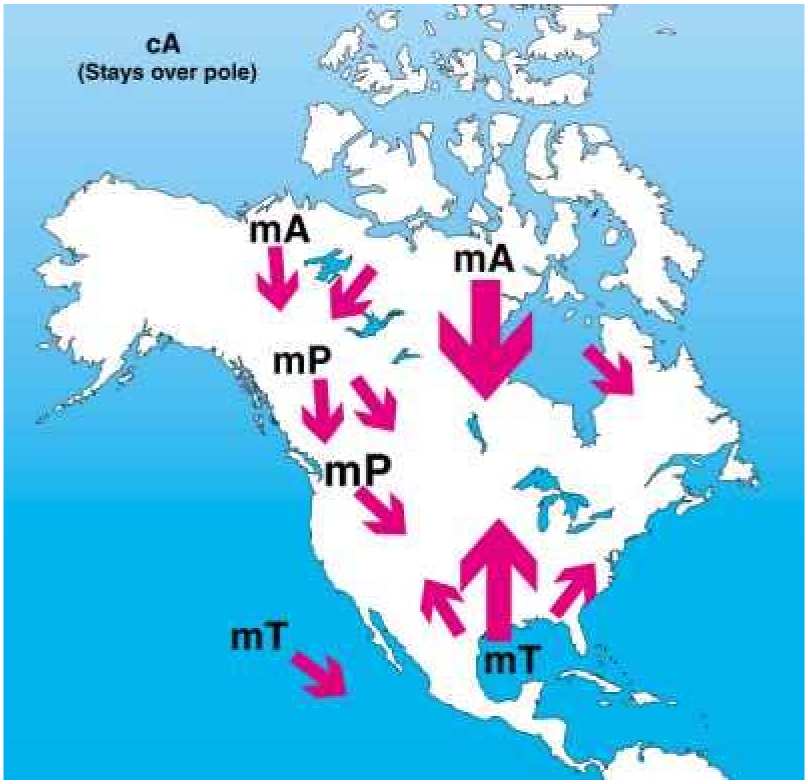


Figure 7-1 Origin of air masses in summer

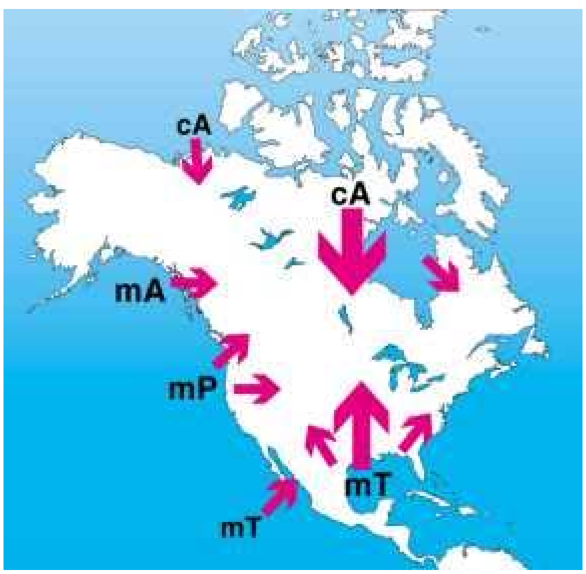


Figure 7-2 Origin of air masses in winter

7.2.1 Continental Arctic Air, cA

This air mass originated over a snow- and ice-covered region. The air temperature in the troposphere rises or remains nearly stable with altitude, so this air is subject to intense cooling from below, with the result that deep inversions, called arctic inversions, occur in its lower layers.

The specific moisture of this air mass is low, since sources of water vapour are limited. In addition, the low temperature restricts the amount of water vapour that the air mass can contain. The water vapour content remains low, even if the air is saturated.

In winter, this air mass can take different routes to descend from the glacial Arctic regions toward the temperate latitudes. If it moves down the ice-covered parts of the continent, it remains very cold and dry. This is continental arctic air. The Canadian Prairies often come under the influence of this air mass, which brings them morning temperatures of close to -40 C. Intense cold spells and record low temperatures are often associated with this air mass, the coldest of all.

If the air moves over a wide expanse of water, such as the Great Lakes, it is considerably warmed from below, and its lapse rate strengthens in the lower layers. At the same time, the air mass gains some moisture and this, associated with its instability, produces cumuliform clouds and snow showers. Eddies, gusty winds and blowing snow associated with the resulting turbulence often reduce visibility. Once the air has moved across the water and pursues its journey over a cold, snow-covered surface, it is stabilized by cooling from below. The cumuliform clouds and snow showers gradually fall off and finally disappear, as the air moves farther away from the water.

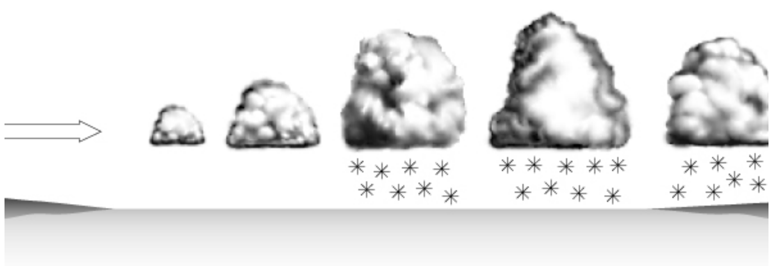


Figure 7-3 Arctic air over the Great Lakes in winter

During the summer, with the exception of a narrow region near the pole, this air mass has no effect over North America, and remains over the North Pole.

7.2.2 Maritime Arctic Air, mA

In winter, this air mass consists of continental arctic air that reaches the Pacific coast from Alaska or Siberia, after a relatively short trip over the northern Pacific. As it moves over the water, the air gains some heat and moisture, and becomes unstable all the way up to high altitudes. Stratocumulus and cumulus form and, if the air is very cold and is moving quickly, there are small cumulonimbus. When the air mass is lifted by coastal mountains, storms may result, as well as snow pellets, snow, rain or a combination of all of them. Strong winds, in particular over rough terrain, may cause low-level turbulence. A similar air mass forms over the North Atlantic, but its effects do not reach any farther than the eastern seaboard of North America.

In summer, the maritime arctic air mass forms when cold air descends southward from the polar regions, passing over many lakes. The lakes supply the air mass with moisture and turn it into a maritime arctic air mass. Warming during the day destabilizes the air and encourages the formation of cumuliform clouds. At night, radiational cooling dissipates the clouds.

The extent and nature of clouds and precipitation that are caused by an arctic air flow over warmer water surfaces depend on the water temperature as compared with the air temperature, and the length of time the air spends over the water. For example, the weather situation would be quite different if arctic air moved the length of Lake Ontario, rather than across it. Consequently, relatively minor changes in wind direction often bring substantial changes in atmospheric conditions at airports located near lakes.

Generally speaking, the maritime arctic air mass is not quite as cold as the continental arctic, but it is still colder than continental polar air.

7.2.3 Continental Polar Air, cP

A continental polar air mass rarely forms over North America, since the cold arctic air has to move straight south for this to occur, warming as it goes. The air also has to remain dry. This is uncommon in winter, since arctic air tends to remain as it is.

In summer, the many lakes in the far north provide it with moisture, producing a maritime polar air mass.

In other words, a continental polar air mass is almost impossible in any season except winter.

7.2.4 Maritime Polar Air, mP

In winter, this air mass reaches the Pacific coast after a long trip from the west, over areas where the Pacific Ocean is relatively warm. It undergoes more changes than the maritime arctic air mass, and warms up to the water temperature at its lower levels. Although it is more stable than the maritime arctic air mass, stratocumulus and cumulus are frequent phenomena. Orographic lifting along the mountains causes extensive cloud formations and heavy rain.

When the arctic cold penetrates as far as the warm waters of the temperate latitudes, this air gains more heat and moisture than maritime arctic air, and it is then called maritime polar air.

The effects of this air mass from the Arctic, associated with the Atlantic Ocean, are normally restricted to the eastern coast of Canada and the United States.

In summer, the air mass moves over mountains and is subject to lifting, resulting in cumulonimbus and thunderstorms.

In winter, the loss of water vapour in the form of precipitation along the western slopes dries out the air mass before it reaches the Prairies. Diurnal warming tends to produce cumuliform cloud, which disappears in the evening as radiational cooling stabilizes the air.

7.2.5 Continental Tropical Air, cT

This type of air mass is rather rare, since the tropical regions are made up of the large expanses of water: the Pacific, the Atlantic and the Gulf of Mexico.

Since these waters supply the air masses with moisture, the tropics only rarely experience very dry and hot conditions.

Maritime tropical air masses are much more common.

7.2.6 Maritime Tropical Air, mT

This type of air mass originates in the Gulf of Mexico, the Caribbean and the Atlantic and Pacific Oceans, to the south of 30 N.

Since the southern part of the continent is narrow, most of the tropical air has been in contact with the very warm surface of the oceans in the southern latitudes. The major highs in the subtropical latitudes provide ideal conditions for producing a warm, moist air mass. Consequently, warm and moist maritime tropical air predominates to the south of the polar front.

In winter, maritime tropical air rarely reaches the north of the Great Lakes on the surface, but often does so at upper altitudes. It becomes unstable when it is subjected to frontal lifting, and produces heavy snow, rain, freezing rain or turbulence, accompanied by a strong possibility of icing.

As this air heads north over the cold continent in winter, radiational cooling often leads to extensive fog banks. Fog also forms within the air mass in both summer and winter, when it climbs northward over the cold waters of the North Atlantic, including the dense fog that covers the Maritimes and Newfoundland.

In the early summer, similar conditions occur when the air mass moves over the Great Lakes. Over the continent, maritime tropical air gives showers and thunderstorms when it is warmed from below.

This very warm and moist air mass usually produces heavy rain and is associated with heat waves.

7.3 Factors That Determine Weather within an Air Mass

To understand why an air mass causes certain conditions, the reader must take into account the combined effects of the factors that determine weather. Three factors lead to the formation or dissipation of the clouds that bring precipitation: moisture, the cooling processes and the stability of the air mass.

Some air masses may be quite dry, and consequently little cloud is encountered. Maritime tropical air, on the other hand, has a high moisture content, and often produces cloud, precipitation and fog.

Clouds form and precipitation occurs when the moisture content of the air mass reaches saturation. This may occur because of the addition of water vapour or because the temperature of the air mass falls.

There are three well-defined processes for cooling an air mass:

- contact with a surface that cools it through radiation;
- advection over a colder surface
- expansion resulting from large-scale rising air.

Since most clouds and precipitation result from cooling due to expansion associated with rising air, stability is clearly a crucial factor.

The moisture content and stability of the air will be determined partly by the source region of the air mass, and partly by the nature of the surface over which the air mass has passed since leaving its source.

7.4 Changes in Air Masses

Although the definition of the term "air mass" specifies that temperature and moisture are horizontally almost uniform, there may be major local variations in those properties. These variations are not extensive enough to cause the formation of fronts.

Surface charts for a given air mass regularly show that stations record temperatures or dew points quite different from the surrounding data. This is due to local variations in topography which create microclimates specific to a lake, mountain, valley, etc.

If the air passes over lakes, forests, wetlands or melting snow, the moisture it absorbs causes the dew point of the lower levels to rise.

These differences are less visible at 850 hPa, however, where the air mass is clearly dominant.

If the modification is very large, horizontally or vertically speaking, the air that is modified in this way takes on a new name. In North America, it is not uncommon for continental arctic air to become maritime polar or maritime arctic air in the space of a few days.

When moist air from the west, on the Pacific coast, is pushed toward a mountain range, it loses a large part of its moisture in the form of precipitation as it climbs the western slopes, and is much dryer once it reaches the Prairies.

In fact, one of the fundamental differences between the North American and Western European climates is that westerly winds can penetrate far over the European continent without meeting any major mountain chains, which is impossible over the west coast of North America. This explains why these air masses, even far over the continent, are often moister than over North America.

Since stability is one of the major factors governing the extent and strength of vertical air motion, variations in stability have a considerable effect on weather conditions. Remember that if the air mass is being warmed from below, instability will result, while cooling from below will induce stability.

7.5 Weather Associated with Air Masses

The name of an air mass is not sufficient to predict what kind of weather will prevail in that air mass except in very general terms. Forecasters must look particularly closely at the upper-air data provided by radiosondes, pilot observations and satellite photos.

It is the many data plotted on a tephigram that provide the best indications of air stability and moisture conditions.

Continental arctic air, for example, may produce clear and cold weather in one region, snow showers and cumuliform clouds in another.

Neither is it enough that the air mass has been clearly identified. You must be in possession of all the data in order to identify the type, number and extent of air masses present over the continent at a given time.

7.6 EXERCISES

1. What is an air mass?
2. What is a front?
3. Can an air mass change from one type to another? Explain your answer.
4. What word in the name of an air mass indicates that it formed over a body of water?
5. At what latitude does a polar air mass form?
6. What do we call an air mass that forms over the Gulf of Mexico?
7. A mP air mass moves over the Prairies on an afternoon in June. The air is very likely to be warmed from underneath and to become unstable. True or false?
8. Edmonton is covered by mA air on a winter day. The mA air is replaced by cA air. As a result, what will happen to the maximum quantity of water vapour that the air can hold?
9. What conditions can be expected in December over Lake Ontario, when a maritime arctic air mass is dominating in the region?
10. What is an arctic inversion, and in what air mass does this normally occur?
11. What are the four major air masses in North America?
12. Name three factors that influence the weather.
13. What are the three factors that act in cooling the lower levels?
14. What air masses match the following descriptions?
    - results from arctic air moving briefly over the cold oceans in the northern latitudes.
    - results from the lengthy movement of cold arctic air over the warm oceans of the temperate latitudes.
    - forms over North America in winter, but rarely in summer.
    - moves from the Arctic down over the North American continent in summer.
    - generally has a strong inversion in its lower layers in the beginning.
    - originates in the Gulf of Mexico.
15. Compare the moisture of mP and mT air masses in winter, and explain the difference.
16. Explain the differences in the following conditions between mP and mA air masses.
    - average surface temperature
    - moisture content

CHAPTER 8
FRONTAL SYSTEMS

The transition zones between two separate air masses, called frontal or baroclinic zones, are divided into fronts. Fronts are as large as real weather systems, and can be several thousand kilometres long and wide. They move at different speeds, since each air mass pushes them along at its own rate.

By definition, a frontal system includes its own low, bringing foul weather: low cloud, precipitation, icing, turbulence, storms and tornadoes.

8.1 Classification

Four of the six types of air masses that surround the Earth influence the weather in North America. Depending on the season, then, meteorologists daily deal with up to four types of baroclinic zones, with strong thermal and moisture gradients.

Generally speaking, each of these zones is identified according to the colder air mass, which is almost always on the north side.

8.1.1 Arctic, Arctic 2 or A2 Front

An arctic front separates a continental arctic air mass from a maritime arctic air mass, to the south. It is a clear separation between dry and very cold air and less cold, less dry air.

This main front is found on all analysis charts, and is more common in winter, because of the invasion of continental arctic air.

In summer, on the other hand, this air remains over the pole, not even reaching as far south as the far north of Canada.

In Canada we make a slight distinction, however: whenever continental polar air reaches south of maritime arctic air, it is called arctic 2 air, or A2 air. This distinction is necessary because of the presence of the arctic front that divides maritime arctic and continental polar air.

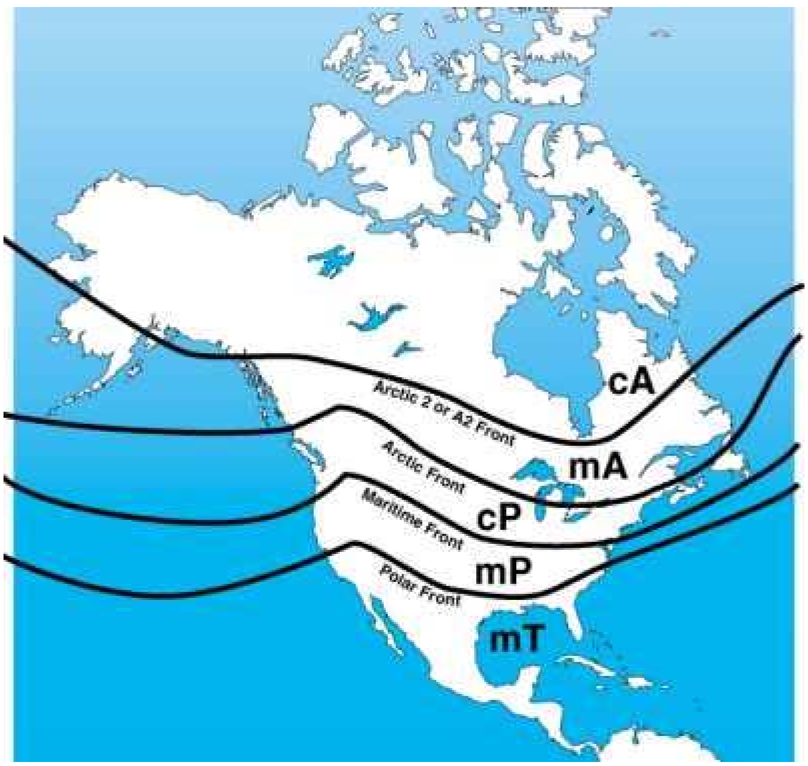


Figure 8-1 Arrangement of fronts and air masses on the weather chart

8.1.2 Maritime Front

Since there is no continental polar air mass, this front actually divides the maritime arctic and maritime polar air masses, the main difference between the two being in their temperature and moisture content.

In winter, the transition zone from snow to rain or from freezing rain to rain is often near this front, a fact that simplifies meteorologists' work, in particular when it comes to pinpointing icing zones associated with freezing rain.

8.1.3 Polar Front

In three-dimensional terms, the combination of cold air masses forms an enormous dome of cold air, with the outer part made up of maritime polar air, covering the top of the globe. This dome is surrounded on all sides by warmer tropical air; in the far northern latitudes, the tropical air is much colder than in the lower latitudes.

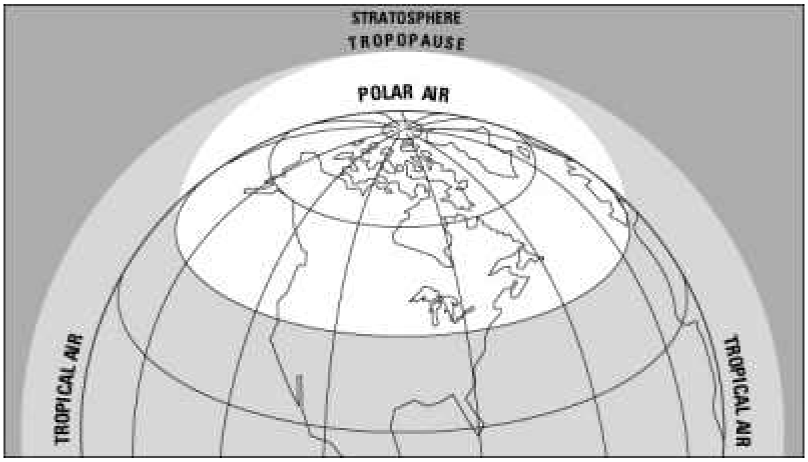


Figure 8-2 Idealized arrangement of polar and tropical air masses in the northern hemisphere

The polar front, which sits north of the maritime tropical air, thus essentially separates the polar and tropical air masses.

Given the strong temperature and moisture contrasts in winter between these masses, the polar front generates heavy precipitation and sometimes violent storms.

8.2 Types and Structures

The direction of transition zones between two air masses is clearly illustrated on weather charts.

The chart in Figure 8-3 shows the symbols used in Canada.

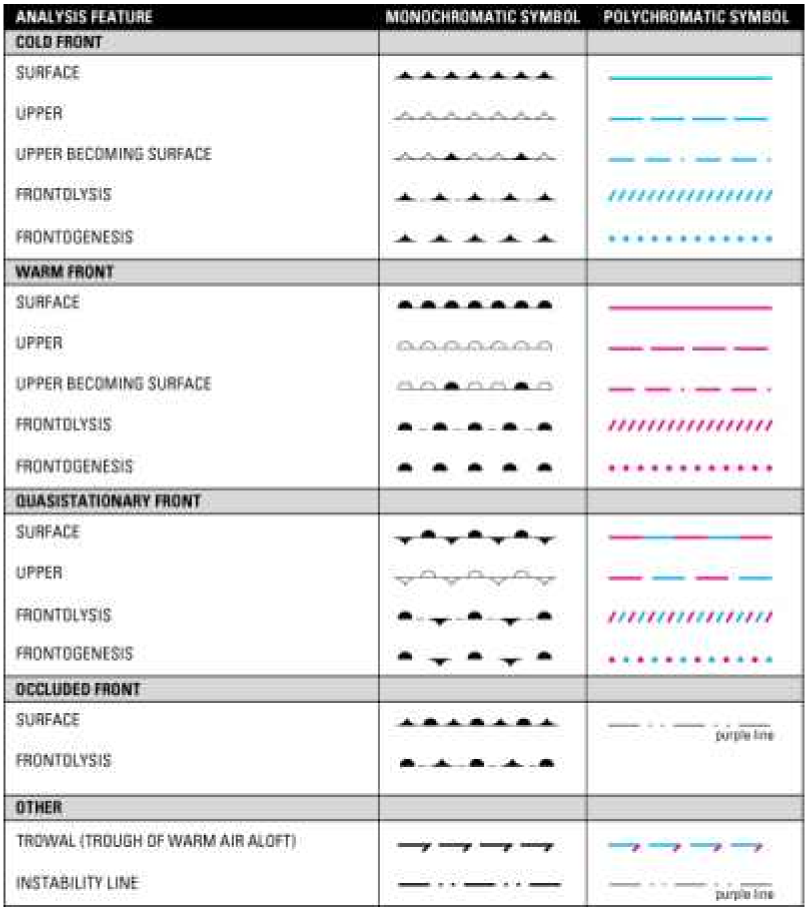


Figure 8-3 Standard symbols used to represent frontal phenomena on weather charts

8.2.1 Stationary Front

A stationary front occurs when the cold and warm air are moving parallel to one another.

Only an upper-air disturbance, caused by a short wave, vortex effect or a trough can initiate movement.

The cold air that descends southward will push beneath the warm air and lift it, creating a low with its own cold and warm fronts.

The resulting rising movement generates clouds and precipitation.

Synoptic-scale (large-scale) systems are in fact the product of stationary fronts.

8.2.2 Cold Front

A cold front is that section of a frontal system where the cold air is moving more quickly than the warm air. It is represented on charts by a blue line or a line of small triangles pointing in the direction of movement. (See Figure 8-3.)

A frontal zone is not a perfectly straight wall. When cold air pushes horizontally against warm air, the warm air is automatically lifted.

This phenomenon creates a "scraper" effect, as the cold air pushes under the warm air.

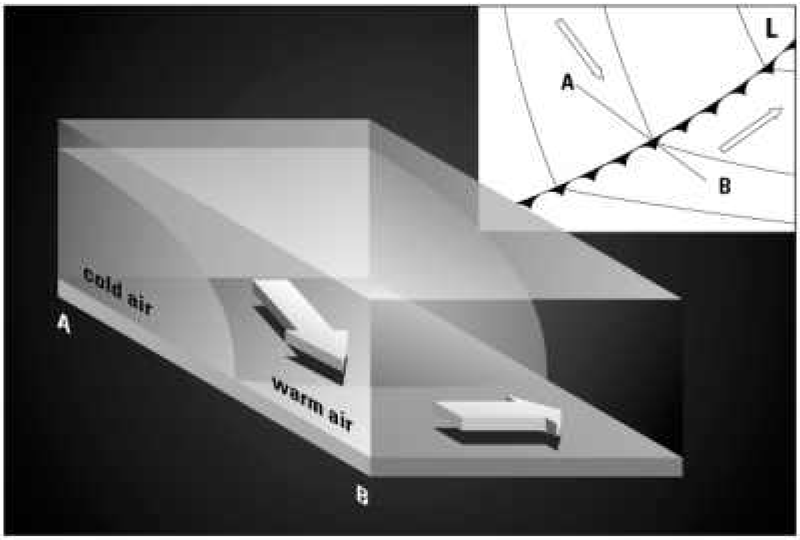


Figure 8-4 Three-dimensional cross-section of a cold front

The wedge of cold air becomes progressively thicker as the cold front pushes into the warm air mass. Because of the frictional drag on the lower levels of the advancing cold air, the cold air dome tends to be relatively steep in this region, with a slope generally of about 1:50.

Since the resistance of the warm air near the ground depends directly on surface friction, the weaker the friction the steeper the slope.

As the cold front advances, it systematically initiates condensation, and clouds and precipitation can be seen along its length.

The greater the moisture and instability, the greater the risk of storms, even violent ones... but clouds are not always signs of frontal activity.

Both the entire transition zone and the sloping frontal surface are referred to as the "front."

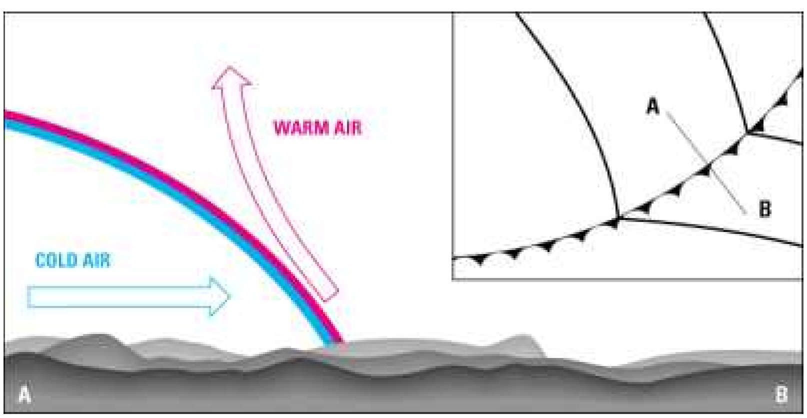


Figure 8-5 Effects of a cold front

8.2.3 Warm Front

A warm front is that part of a frontal system that moves so that the warmer air mass pushes against the colder air mass.

In this situation, as the warm air climbs over the cold air, the slope of the frontal surface is inverted.

Since the surface friction is much stronger, the slope is considerably shallower, about 1 in 200 km.

Warm fronts are always indicated by a red line, or by half-circles indicating the direction of movement. (See Figure 8-3.)

Figure 8-6 shows the warm front as it appears on the weather chart, and illustrates the three-dimensional arrangement of the air masses.

The isobars show that the cold air is pushed northward, while the warm air from the southwest, which pushes into the gap, rapidly slides or climbs over the cold air.

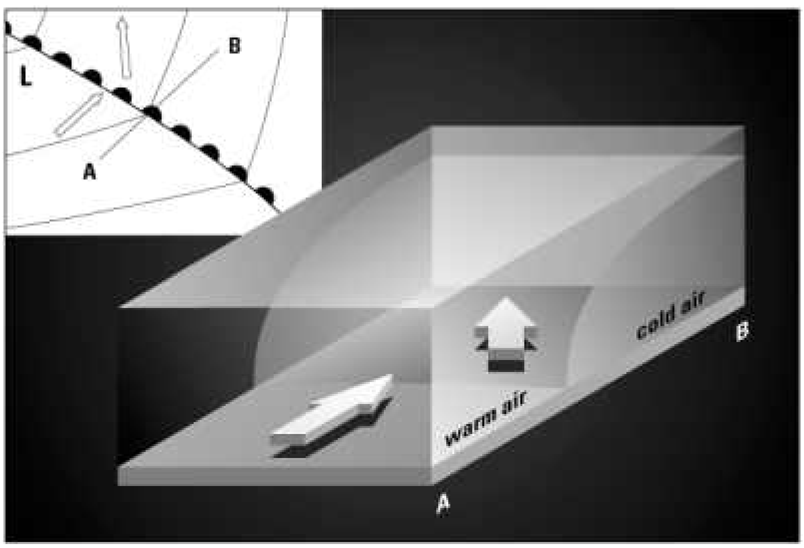


Figure 8-6 Three-dimensional cross-section of a warm front

8.2.4 Occluded Front and Trowal

The cold front of an intensifying weather system picks up speed and catches up with the warm front. When the cold front reaches the warm front, the warm air is caught and squeezed more and more between the two fronts. It will be lifted and the system becomes occluded, producing what is known as a trowal ("trough of warm air aloft"). Figures 8-7 and 8-8 illustrate the occlusion process and how a trowal is formed

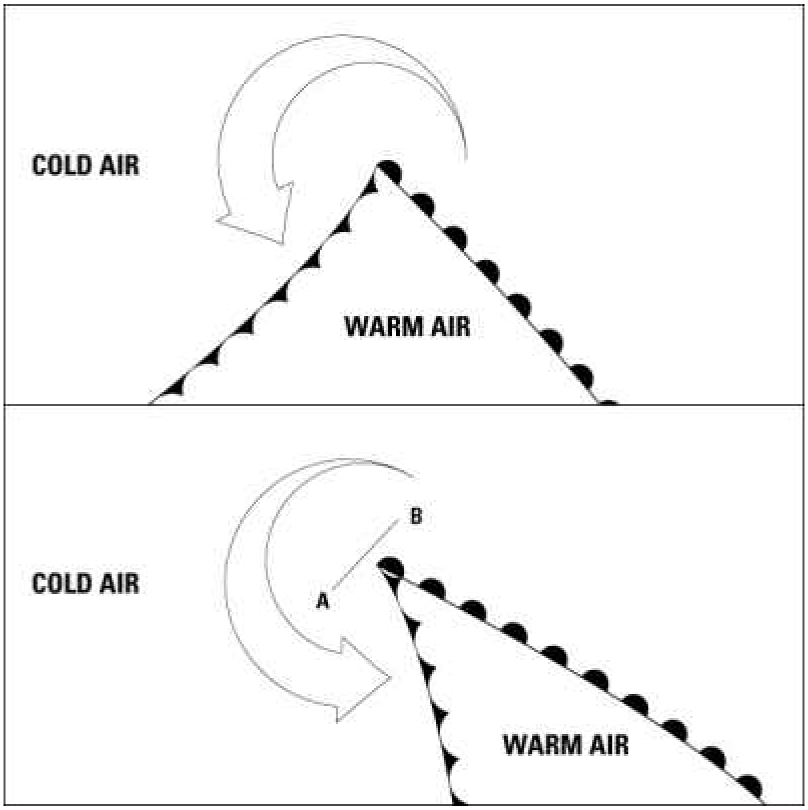


Figure 8-7 Occlusion process

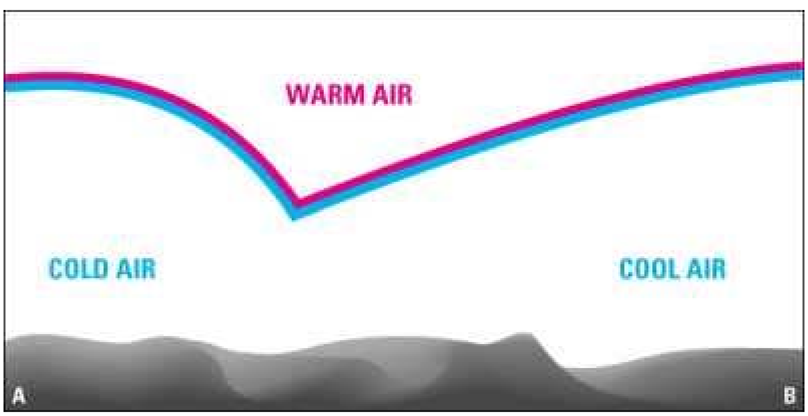


Figure 8-8 Vertical cross-section showing the trowal, along line AB

In the cold air underlying the trowal, a weak front may form, stretching from its base to the surface. This is called an occluded front.

This front is a narrow transition zone between the two cold air masses that have created the occlusion.

In North America, occlusions are marked with the trowal symbol. (See Figure 8-3.)

There are two kinds of occluded fronts. If the advancing part of the cold air is colder than the retreating part and lifts the warm front, this is called a cold-front type occlusion. In the reverse situation, when the cold front climbs all along the warm frontal surface, the term warm-front type is used. Note that in a cold-front type occlusion, the base of the upper-air warm air trough is located behind the surface occlusion, while in a warm-front type occlusion, the base is ahead of the surface front.

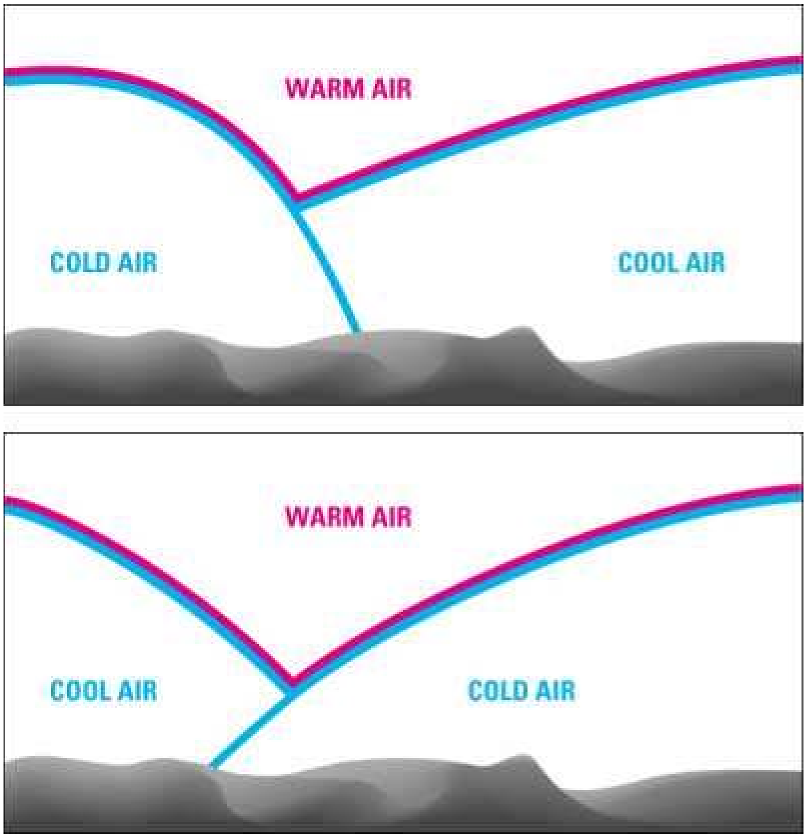


Figure 8-9 Top: a cold-front type occlusion; bottom: a warm-front type occlusion

In countries where the term "upper front" is used instead of trowal, the upper front may be called a cold or warm front.

8.2.5 Upper Cold Front

As cold air moves it may encounter pools of cold air trapped in hollows or ride over a shallow layer of colder air on the surface. The leading edge of the advancing cold air is called an upper cold front.

There is another type of upper cold front, when cold air advances much more rapidly in the lower levels than it does aloft and causes a shallow layer of cold air to spread out along the ground for some distance ahead of the main dome of cold air. The line along which the surface of the cold air abruptly steepens is called an upper cold front.

8.2.6 Upper Warm Front

The basic concept of the upper warm front is similar to that of the upper cold front, except that a station located in the colder air does not experience a change of air mass, since the cold air retreats and the warm air advances overhead.

There are cases in which the frontal surface of the retreating cold air is almost flat for some distance ahead of the surface front and then abruptly steepens. The line along which the surface of the retreating cold air abruptly steepens is also called an upper warm front.

8.3 Frontogenesis and Frontolysis

Sometimes a transition zone is too wide or its isotherms too far apart for it to be considered a true frontal structure. For this zone to intensify, the lapse rate must become steeper and the moisture rate higher; this is termed frontogenesis.

Just as transition zones may sharpen, so they may become weak and even disappear, in which case the phenomenon is called frontolysis.

Frontogenesis and frontolysis are directly related to thermal or dynamic processes, in particular those caused by advection or radiation.

The influence of the narrow strip of warm water off the east coast of North America, the Gulf Stream, is crucial. Since it warms any cold air mass from below as the air arrives from the east of the continent, this current is the main cause of frontogenesis in this area, for in doing so it creates a temperature and moisture gradient. The Gulf Stream is responsible for major winter storms.

As for frontolysis, gradients become shallower whenever the southern part of a frontal zone advances over the icy waters of the Labrador Sea. The consequent gradual cooling reduces the temperature contrast between its northern and southern parts.

As a result, the isotherms spread wider apart, the moisture content evens out, and the frontal zone weakens or disappears altogether.

8.4 Frontal Depressions and the Norwegian Theory of Cyclones

The most important aspects of frontal activity are in fact intimately linked to the intense rising and descending air movements associated with lows. When air is rising, a low or a trough occurs on the surface; at upper levels, when air is drawn upward from the lower levels, the heights rise, producing high pressure or a ridge.

Over the continent, fronts are often associated with troughs or lows and are called frontal depressions; the most vigorous ones often comprise more than one frontal system.

But the strongest depressions, in fact, are not preceded by any front. Here were are talking about hurricanes.

8.4.1 Step 1 - Disturbance of the Stationary Front

According to the so-called Norwegian theory, frontal depressions originate on a portion of either a slowly moving cold front or a stationary front.

When a short wave or an upper trough passes over the stationary front, a frontal depression forms along the baroclinic zone. The front always occurs at the point of lowest pressure.

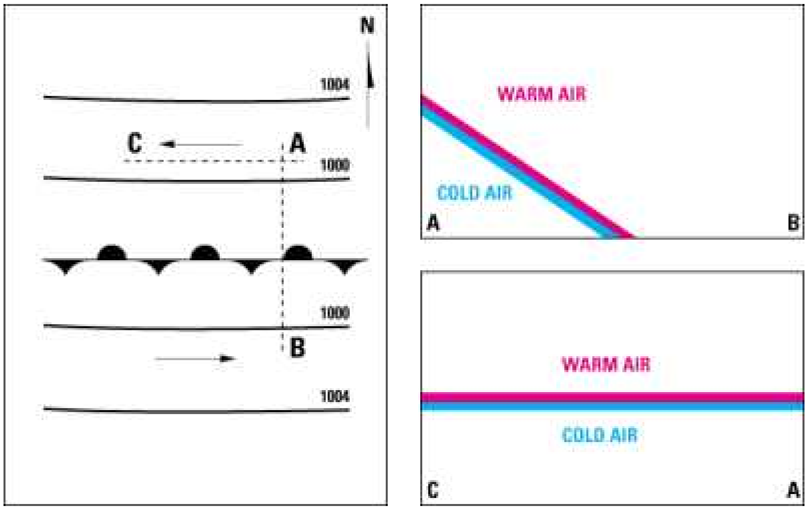


Figure 8-10 Cross-sections of a stationary front

8.4.2 Step 2 - Birth of a Depression in the Baroclinic Zone

The first sign of a developing depression is a local fall in pressure at some point on the front. The result is a weak cyclonic circulation about the point. The cold air begins to advance southward on the west side of the centre, and to retreat northward on the east side. The stationary front becomes a cold front just west of the centre of the new low, and a warm front just east of the centre. The warm air is forced to rise along the sloping cold air surface. The structure of the stationary front has been modified as shown in Figure 8-11.

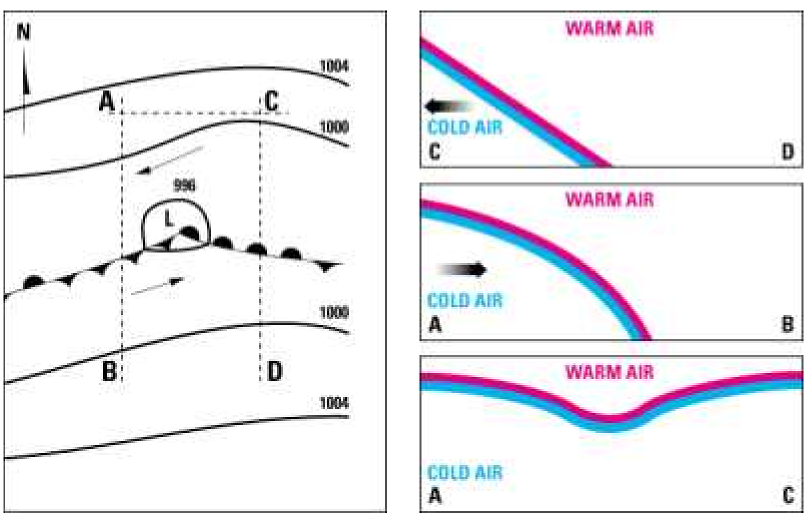


Figure 8-11 Birth of a depression in a baroclinic zone

8.4.3 Step 3 - Mature Depression

At this stage the wave has reached maturity. It has moved east of the position indicated in Step 2, and appears on the surface chart as indicated in Figure 8-12. The accompanying diagrams and vertical cross-sections illustrate the three-dimensional view.

The low has deepened considerably since Step I. In addition, both fronts are curved in the direction toward which they are moving, like sails on a ship. The portion of the depression located between the warm and cold air fronts is called the warm sector; this is the warmest part of the low system.

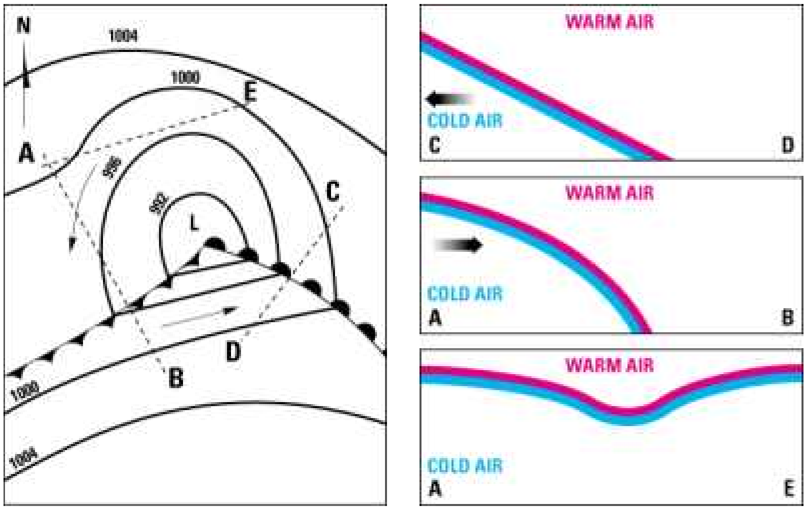


Figure 8-12 Mature depression

8.4.4 Step 4 - Beginning Occlusion

The low is still moving, but begins to slow down. This stage marks the beginning of the occlusion. The cold front, moving more quickly than the warm front, catches up and compresses the air. Part of this air is lifted, creating a trowal and occluded front.

If there were no occluded surface front, cross-sections C and D should show the cold air and the cool air joining, as do vertical cross-sections E and F.

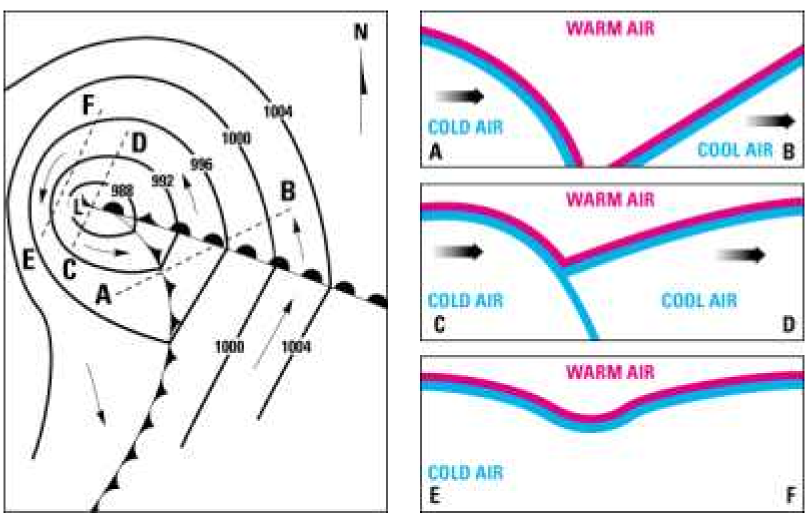


Figure 8-13 Beginning of an occlusion

8.4.5 Step 5 - Occlusion

By this point, the warm air has been almost completely cut off from the surface, and frontolysis is causing cyclonic circulation in the cold air beneath the overlying trough of warm air. The pressure is rising at the centre of the low and the system is weakening. In many cases, the low will become stationary.

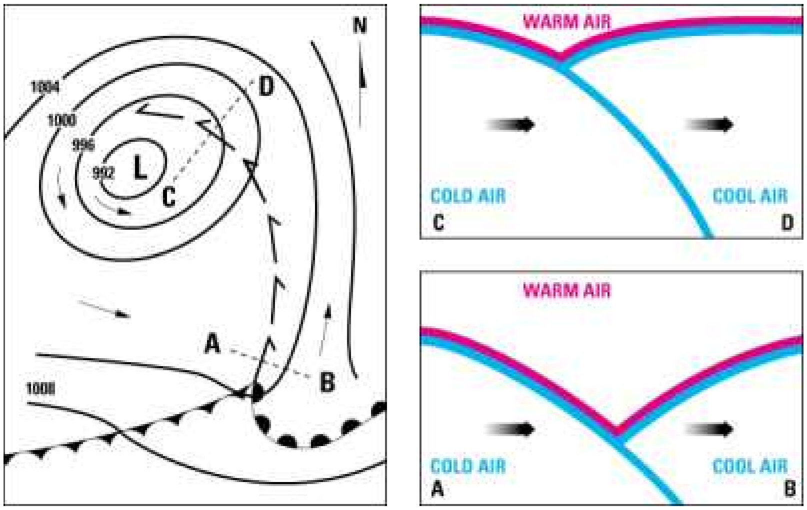


Figure 8-14 Occlusion of a frontal system

8.4.6 Step 6 - Dissipation

Figure 8-15 shows a rapidly filling low in which there are no surface fronts. On the surface, the warm air associated with this low is now far to the southeast, while low-level weak cyclonic circulation persists in the presence of a trough.

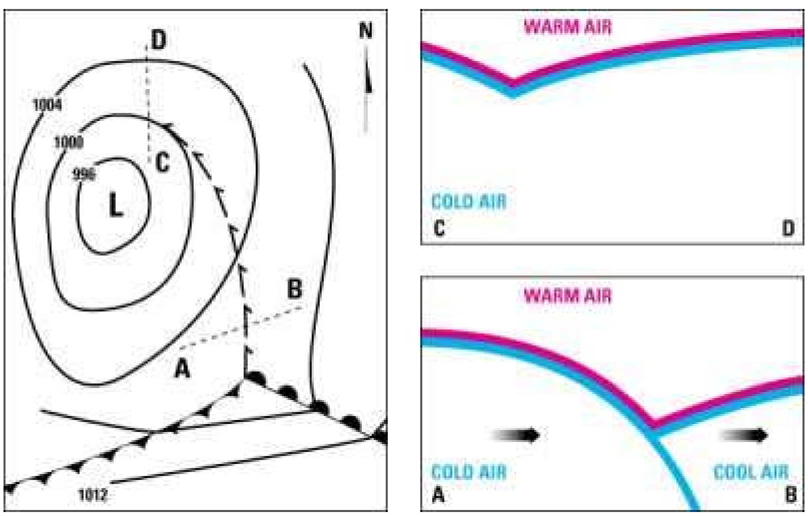


Figure 8-15 Dissipation

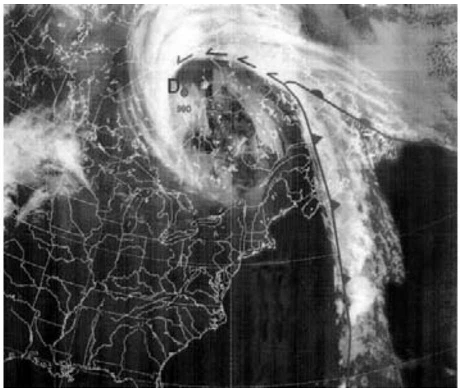


Figure 8-16 Infrared photo taken by GOES-8 on October 22, 1995, at 23:15 UTC, illustrating how the warm air far to the southeast of the low is associated with a trowal.

8.5 Exercises

1. What is a frontal or baroclinic zone?
2. What is the front separating mA and mP air masses called?
3. What are the two air masses separated by a maritime arctic front?
4. What is the zone separating a warm air mass and a cold air mass at upper levels called?
5. If the slope of a cold front is 1 kilometre in 50, and the station is located 200 kilometres inside the cold air mass, what will be the height of the frontal surface above the station?
6. A slowly moving cold front has a steeper than average slope. True or false?
7. The temperature change associated with the front can start before a warm front arrives. True or false?
8. When a front passes a station, the wind backs. True or false?
9. When a cold front passes a station, the pressure increases, because of the arrival of heavier air. True or false?
10. When passing from cold air to warm air, the dew-point temperature rises. True or false?
11. In the cold sector of a front, the cold air:
    - always forms a wedge that lifts the warm air.
    - precedes and spreads over the warm air.
    - rises vertically from the ground.
    - None of the above.
12. The part of a surface front coloured alternately red and blue represents:
    - a weakening front.
    - a warm air occlusion.
    - a stationary front.
    - frontogenesis.
13. What is a trowal?
14. In what isobaric configuration are fronts usually located?
15. What is frontolysis?
16. Name a geographic location that promotes frontogenesis, and explain the process involved.
17. Name four types of depression not associated with a frontal zone.
18. What is the warm sector of a low system?
19. What is an occlusion?

CHAPITRE 9
WEATHER AND FRONTAL SYSTEMS

Aside from super-phenomena that arrive unannounced by any front--cyclones, hurricanes and typhoons of the tropical latitudes, although they can nevertheless be easily forecast--day-to-day weather is shaped entirely by the wide range of sometimes pleasant and sometimes dangerous phenomena, such as tornadoes or micro-gusts, generated by the development of fronts.

9.1 Weather at cold fronts

An advancing cold front has drastic effects on the weather. As it lifts and cools the warm air it gives rise to clouds and precipitation, windshifts, heavy storms, violent winds, gusts and sometimes even squalls, when the upper section of the front pushes ahead of its line on the surface and literally sinks toward the ground.

9.1.1 Surface Winds

The first sign of an arriving cold front is the windshift marking the passage from warm air to cold air, with the two air masses sharply separated by the trough line. The isobars on either side of the trough line run in different directions.

Figure 9-1 shows cold air from the northwest undercutting warm air from the southwest, strengthening the veer in the wind. The greater the contrast between the two air masses, the higher the risk of squalls and gusts.

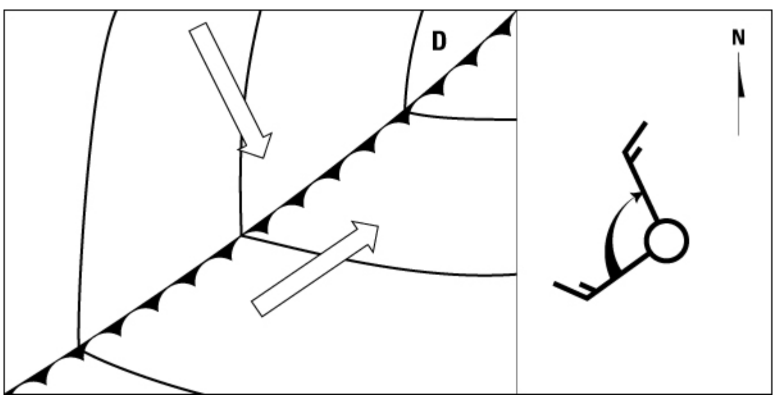


Figure 9-1 Example of surface windshift with cold frontal passage

Windshifts at a cold frontal surface can be abrupt, particularly in the lower levels. In any case, they oblige the pilot to correct to the right, regardless of the direction in which he crosses the front. (See Figure 9-2.) They are also marked by a drastic change in temperature.

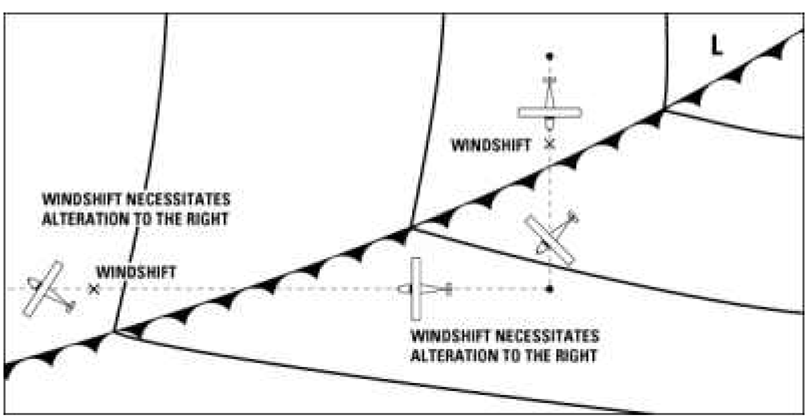


Figure 9-2 Example of windshift aloft with cold frontal passage

9.1.2 Temperature

In winter, the temperature decrease associated with the passage of a cold front is sometimes both sharp and substantial. The leading edge of the front will be warmed as it passes over warmer surfaces, however, so it may take several hours for the lower layers to cool.

There are occasional cases in which the surface temperature shows a slight increase after the frontal passage, normally accompanied by a drop in the dew point. This effect will be noticeable for only a few hours, and occurs in the late afternoon or evening, when the cold air is cloudless and the warm air ahead of the front is cloudy. For a short period the cold air warms up and its moisture content drops.

9.1.3 Moisture Content

The moisture content is a key indication of the type of air mass and how it will develop. Fluctuations in the dew point are the best clue to moisture content.

The arrival of cold air generally results in a drop in the dew point temperature. This is particularly noticeable if the cold air mass is the dry continental arctic type, since it cannot hold as much water vapour as warm air.

9.1.4 Clouds and Precipitation

Cloud development at a cold front will depend upon the nature of the warm air mass, the nature and speed of the advancing cold air wedge and the type of surface.

If the warm air is stable and moist, layer clouds form and precipitation will be either intermittent or steady.

If however, the frontal surface is steep and the cold air is advancing rapidly, the warm air may be lifted so vigorously that heap clouds form regardless of the fact that the air is stable.

Whether or not the cold front is active, its frontal zone of rain or snow is usually fairly narrow, particularly if it is giving showery precipitation.

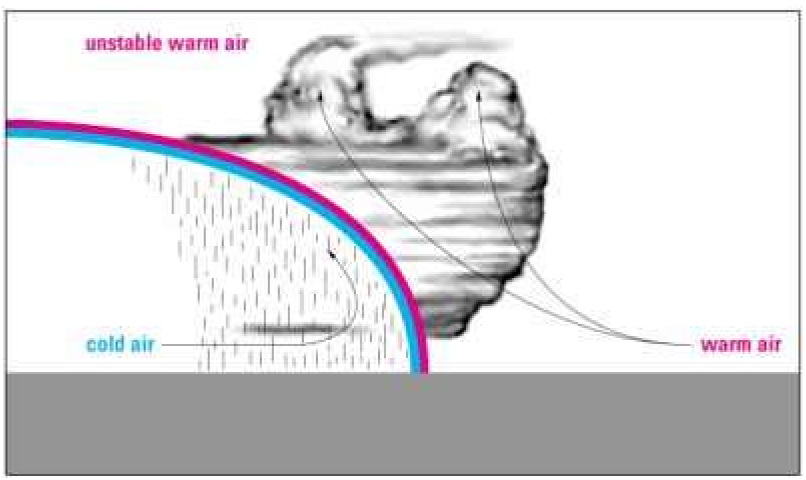


Figure 9-3 Lifting of moist and unstable warm air as a cold front passes

A moist and unstable warm air mass gives heap clouds and showers. If the warm air is dry there will be little cloud, unless the air is lifted far aloft.

In many cases, an advancing surface front produces a layer of altocumulus over a certain distance. The slower the front is moving, the steeper it is and the larger the zone of cloud and precipitation ahead of it.

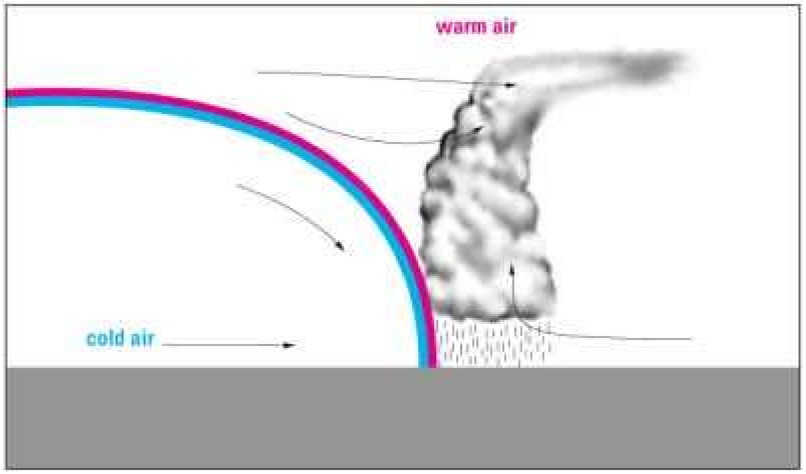


Figure 9-4

9.1.5 Visibility

When a cold front is moving at moderate or high speed, its frontal zone is generally less than 80 km wide. With a slowly moving front, this zone can be much wider and have a considerable effect on flying conditions for several hours.

Visibility usually increases after the front has passed, although the vertical motion caused by its passage over a warm surface lift pollutants and smoke from factories into the relatively clean polar and arctic air.

9.1.6 Pressure

A drop in barometric pressure is generally the most common indication of an approaching cold front. This decrease is obviously because surface fronts very often lie in troughs. The pressure climbs again after the front has passed.

9.1.7 Frontal Turbulence

Many cold fronts are accompanied by turbulence, even at great heights, although there will not necessarily be any clouds or storms; obviously, the turbulence is strongest where there are storms.

9.1.8 Icing

Icing occurs vertically in cumulonimbus, rather than horizontally as in the cloud layers that characterize warm fronts.

9.2 Recognizing Cold Fronts in Flight

When flying at high altitudes, if you see a long line of heap clouds on the horizon, often preceded by a bank of altocumulus, this is a sure indication of an approaching cold front. These clouds may conceal the lower section of the frontal cloud.

Banks of stratus or stratocumulus for several kilometres ahead of the front may also mask substantial low-level cloud.

Thunderstorms are indicated by a main line of cirrus and cumulonimbus.

In cloudless skies, turbulence, windshifts and temperature variations will tell you that you are flying through the frontal surface. These changes are most marked in the lower levels.

9.3 Weather at warm fronts

Warm frontal changes are usually less abrupt than cold frontal changes. That is why there are not many cases of a long spell of cold weather ending suddenly, except with the arrival of a chinook.

The change is usually too gradual to be immediately noticeable, but the weather at the warm front is more extensive and may take the form of a cloud system and precipitation covering many thousands of square kilometres and generating a great variety of phenomena.

For example, one warm front may create a vast zone of clouds so dense, and with such heavy precipitation, that all visual flight is impossible; nearby there may be another zone with no limits on ceiling and visibility. An inactive front that intensifies will quickly lead to lower ceilings and visibility.

In any case, the behaviour of the warm front will be determined specifically by its moisture content and stability, along with the amount and angle of lift imparted to the overrunning warm air by the cold air mass.

9.3.1 Surface Winds

On the surface, the wind changes direction where the cold air and warm air meet, that is exactly at the trough line, which is the dividing line between the isobars running in different directions on either side.

In Figure 9-5, the warm front is a zone in which the warm air from the southwest meets and overruns a stream of colder air from the south. With the passage of the warm front, the wind starts to veer.

This change is much more gradual than in the case of a cold front, for warm frontal zones are generally much wider.

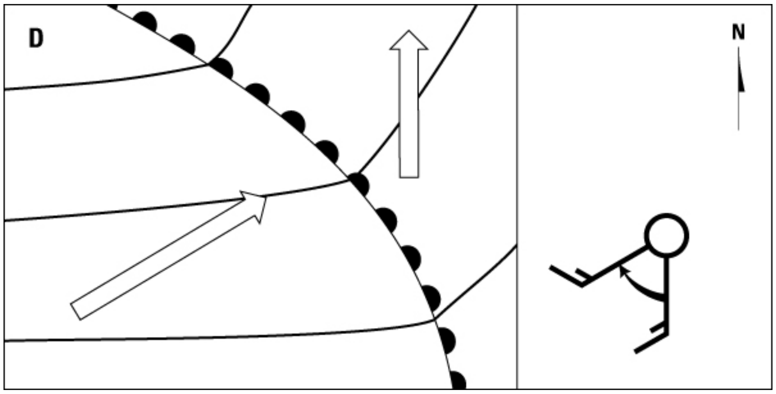


Figure 9-5 Example of surface windshift with warm frontal passage

Local relief may influence the direction of the winds associated with a warm front. The St. Lawrence valley in Quebec is a very good example of this effect.

In winter, as soon as an intense low from the central United States approaches Lake Ontario and combines with a low to the north of Sept-Îles, the St. Lawrence valley channels the winds toward Lake Ontario. Strong northeast winds then bring the cold surface air toward southwestern Quebec, while the warm air flows above, in the opposite direction.

At the warm front, the windshift is very sharp, and sometimes reaches 180 in the lower levels, where it produces shear that can make landings or take-offs risky.

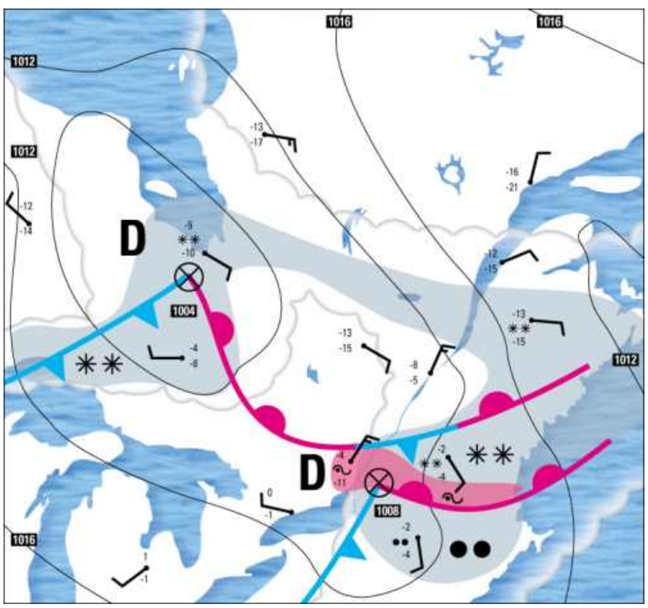


Figure 9-6 Warm front to the west of Montréal, giving surface winds from the northeast downstream and creating a zone of freezing rain, along the St. Lawrence. In its warm sector the winds from this 1008 hPa low are from the south to southwest. This zone is characterized by cold air at the surface, from the Lower St. Lawrence, and warm air at 1.5 km brought by the southwest winds. This analysis was done on December 4, 1995, at 00:00 UT.

The windshift occurs at the frontal surface, rather than at the front. A rise in temperature tells you that you are flying toward its warm sector. In all cases, you will have to alter your course to the right, particularly in the lower levels.

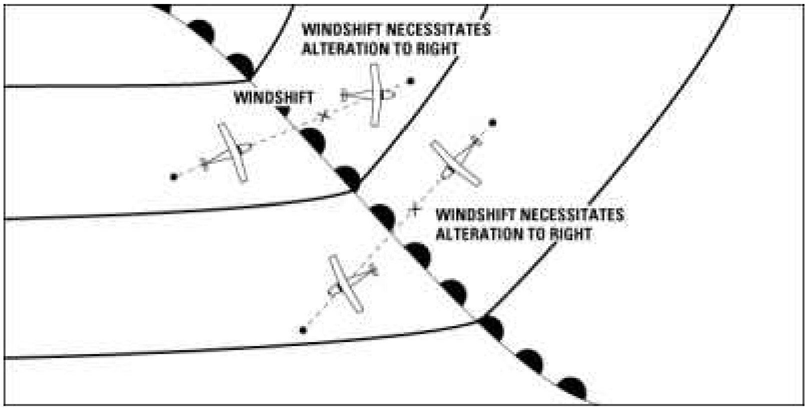


Figure 9-7 Windshifts aloft, associated with the warm front

9.3.2 Temperature

The passage of a warm front will result in a gradual increase in temperature, and the depth of the cold air will decrease. Depending on the proximity of the warm air to the surface, there may be a slight rise in temperature even before the warm front arrives.

Owing to their dynamics, air masses are not the same temperature throughout; in fact temperatures may vary widely. Consequently, any rise in temperature is not necessarily associated with the passage of a warm front.

On the weather map, the red line indicates the trailing edge of a retreating cold air mass, directly associated with the warm frontal surface.

9.3.3 Moisture Content

Particularly when the warm air mass is tropical in origin, the passage of the warm front will result in a marked rise in the dew point temperature. The warmer the air, the higher the water vapour saturation point.

9.3.4 Clouds and Precipitation

As the warm air sweeps up the cold wedge, it reaches regions of lower pressure, expands and cools, causing condensation.

There may be clouds in the cold air mass as well, owing to lifting within this cold air by mechanical turbulence, topographical features, or convergence. Any rain will contribute to the moisture in the cold air, facilitating cloud formation.

A moist stable overrunning warm air mass will produce an extensive area of layer clouds from which light to moderate steady precipitation will fall for a considerable distance ahead of the surface front.

In order of appearance ahead of the surface front, there may be cirrus, cirrostratus, altostratus or altocumulus and nimbostratus. Stratus, stratocumulus and even stratus fractus may be found in the cold air beneath the frontal surface, and may merge with the nimbostratus just ahead of the surface front.

If the overrunning warm air is unstable, cumulonimbus clouds will be found embedded in the main cloud bank, producing heavier precipitation. Dry overrunning warm air will result in only high or middle clouds with no precipitation.

If the retreating side of the cold air dome is fairly flat, there may be no clouds, meaning that the moisture content of the cold air mass will stabilize. Any clouds beneath the frontal surface will be the same as elsewhere in the cold air, and will have no connection with frontal activity. Figures 9-8, 9-9 and 9-10 illustrate the types of clouds and precipitation that occur with warm fronts.

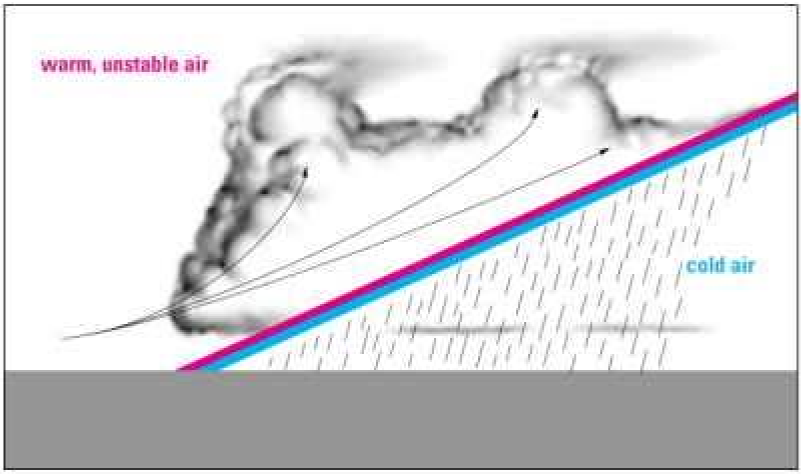


Figure 9-8 Warm front with overrunning moist, unstable warm air

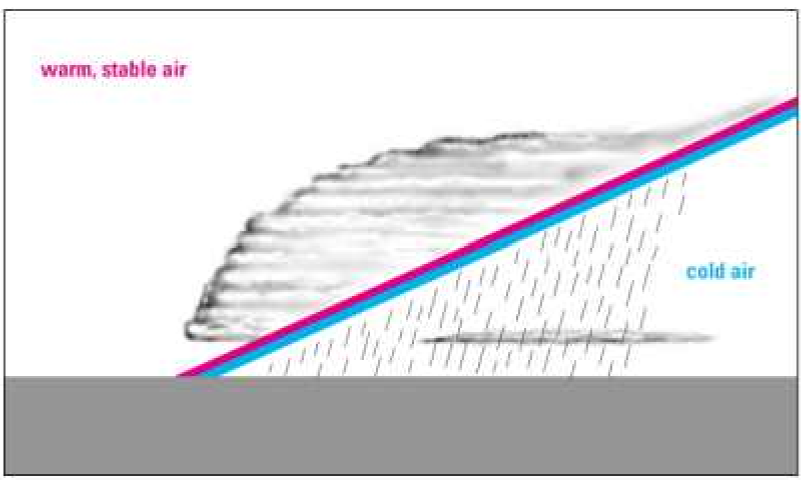


Figure 9-9 Warm front with overrunning stable warm air

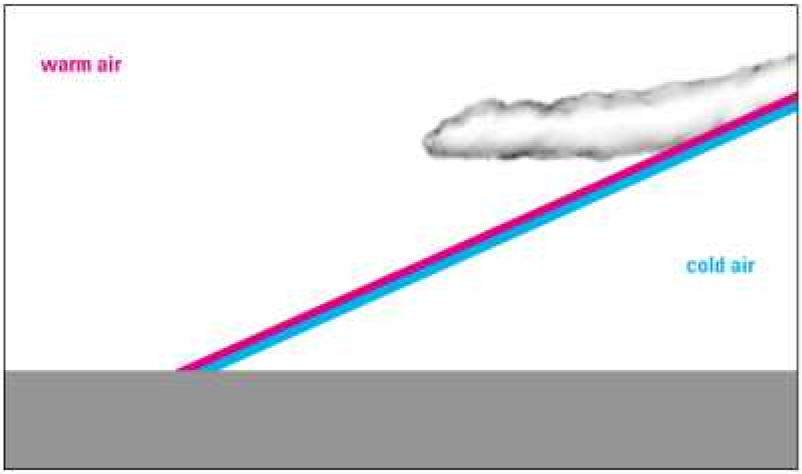


Figure 9-10 Warm front with dryer warm air

Flying through an active warm front is complicated by the presence of a vast area of low ceilings and limited visibility. Since the front moves slowly, these conditions can persist for long periods.

When rain begins to fall in the warm air, masses of irregular cloud can form in cold air, considerably reducing ceilings.

For 80 to 160 km ahead of the front, the cold air will not be very thick, and the cloud bases often reach the ground in the form of fog.

9.3.5 Visibility

Fronts separating maritime polar air and tropical air are generally characterized by poor visibility; conditions are worse, with even zero visibility, in the fog and precipitation ahead of the front.

In summer, however, and particularly in the afternoon, visibility and ceilings often improve with the arrival of the warm part of the low, albeit long after the front has passed. This is noted in forecasts.

9.3.6 Pressure

The pressure change will depend largely on the nature of the trough in which the warm front is located. Ahead of the warm front, pressure usually falls rapidly, while behind it the decline becomes more gradual, or there may even be a slight rise, depending on the direction of the isobars in the warm air.

The pressure will fall again as the cold front behind the warm sector approaches.

9.3.7 Frontal Turbulence and Storms

The pressure change will depend largely on the nature of the trough in which the warm front is located. Ahead of the warm front, pressure usually falls rapidly, while behind it the decline becomes more gradual, or there may even be a slight rise, depending on the direction of the isobars in the warm air.

The pressure will fall again as the cold front behind the warm sector approaches.

9.3.8 Icing

As you approach an active warm front from the cold air side, precipitation will begin in the region where the altostratus cloud bank is from 2400 to 3500 m, 8200 to 11500 ft above the surface; the precipitation may evaporate before it reaches the ground. This is known as virga.

As you approach the front, precipitation gradually becomes heavier and steadier. If you encounter occasional heavy precipitation in the cold air beneath the frontal surface, it is an indication of thunderstorms in the warm air aloft.

During winter, temperatures in the cold air are generally below freezing and temperatures in the lower 300 m or so in the warm air are above freezing. This gives rise to a variety of precipitation that is of considerable significance for flight planning.

Figure 9-11 shows snow falling from the part of the warm air clouds that are at below-freezing temperatures. Rain is falling from the portion of the clouds that are at above-freezing temperatures, but as it falls through the cold air, it becomes slightly supercooled and will freeze on contact with any cold object. This is called freezing rain. If the cold air is sufficiently deep, the drops of freezing rain will freeze and form ice pellets.

Between the snow and the freezing rain area there is a relatively narrow transition zone. The upper portion of this zone is characterized by a mixture of freezing rain and snow, while in the lower levels there is a mixture of snow and ice pellets.

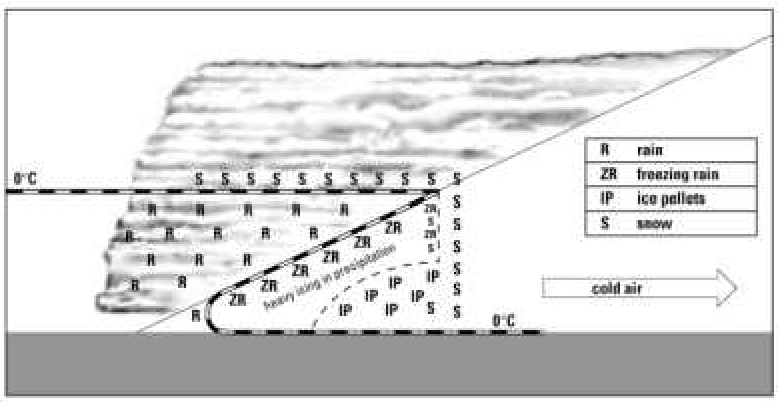


Figure 9-11 Icing conditions at the warm front

As you fly toward the front in the lower levels of the cold air mass, you may meet snow, mixed snow and ice pellets, and freezing rain. At higher levels, but still in the cold air, there are no ice pellets, and the precipitation changes from snow to freezing rain.

Snow falling in cold air does not present an icing problem unless it is wet. If it sticks to the fuselage it forms ice, but much more slowly than freezing rain.

Ice pellets have no effect on aircraft performance; but since they are frozen raindrops, they indicate freezing rain aloft. Reports of ice pellets must be taken to mean that there will be freezing rain as well.

If the temperature beneath the frontal surface is below 0 C, icing may occur in the cloud layers, although this risk is smaller if it is snowing. In the warm air mass, icing sometimes occurs even in the part of a cloud where the temperature is above freezing.

In normal weather, however, the layer clouds predominating at the warm front cause less icing than the more turbulent cumuliform clouds associated with the cold front. There may be considerable icing in a bank of warm front clouds of vertical development.

When you fly through warm air clouds, snow or ice crystals increase in volume at the expense of water drops. The main part of the altostratus bank at the warm front, where this situation occurs, generally contains fairly little liquid and so there is little likelihood of icing.

Given the extent of layer clouds at warm fronts, icing regions are generally more extensive than at most cold fronts.

9.4 Recognizing Active warm Fronts in Flight

As you approach an active warm front from the cold air side, the first sign of the front is cirrus clouds, followed by a layer of cirrostratus that does not obscure the stars, but often causes a halo around the Sun or moon.

The clouds may merge with altostratus and altocumulus, which will gradually descend from 6.5 km to 2 km. At first the Sun or moon will be seen dimly through the thin leading clouds of the altostratus bank, but it will soon disappear. Intermittent light precipitation may fall from the thick altostratus, but if the altostratus bank is still quite high, this precipitation may not reach the ground.

As the altostratus-altocumulus bank continues to descend and precipitation increases in intensity, low clouds will appear beneath you. The upper bank will descend to become nimbostratus from near the surface to 8000 m or more.

Passage into the warm air will be indicated by a rise in temperature and a windshift, although this windshift will be very small above 3000 m, 10000 ft.

9.5 Weather and Trowals

The weather with a trowal varies a great deal, but generally represents a combination of cold front and warm front conditions. The nature of this weather depends mainly on the nature of the air masses involved and the height of the trowal.

A trowal normally originates at the junction of the warm and cold fronts, and extends as far as the low; conditions vary considerably in this zone, but it is at the point it meets the fronts that conditions are worst.

Figure 9-12 gives an example of the type of weather in a trowal. This is a specific case but nevertheless shows common features.

When flying toward an approaching trowal, the cloud pattern is very similar to that of a warm front. However, the weather is more complex, since part of the trowal weather is characteristic of cold fronts.

When approaching a trowal from behind, it resembles a cold front, but the effects on flight are different. In addition to the problems associated with the cold front, there are the problems posed by the extensive cloud bank that may lie ahead of the trough of warm air.

During a flight through the system below the base of the trough, a windshift will occur. At higher levels, there will be two windshifts, since you must pass through two frontal surfaces.

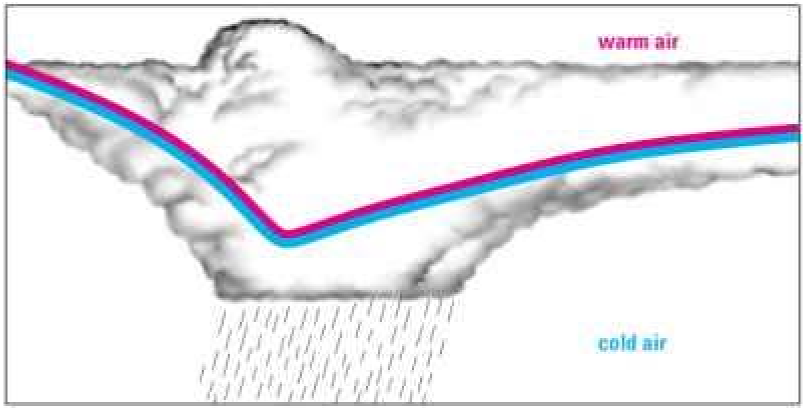


Figure 9-12 Trowal without surface occlusion

If the trowal includes a surface occlusion, the general weather picture will not change substantially. Figures 9-13 and 9-14 give examples of weather at a cold-front type occlusion and a warm-front type occlusion. In each case, it can be seen that the trowal is an important part of the system.

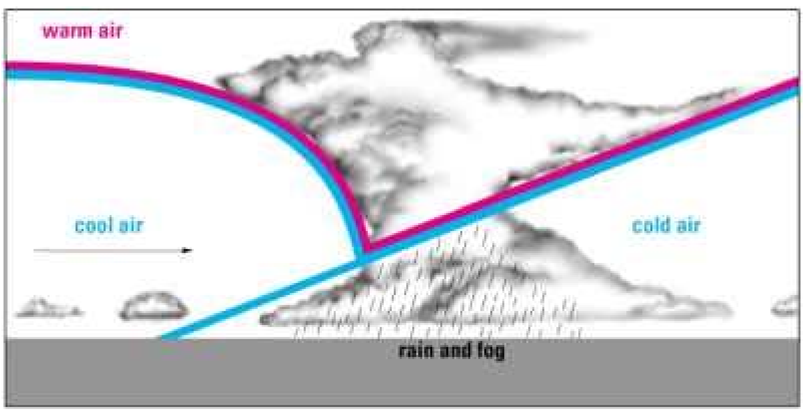


Figure 9-13 Warm-front type occlusion, lifting warm air

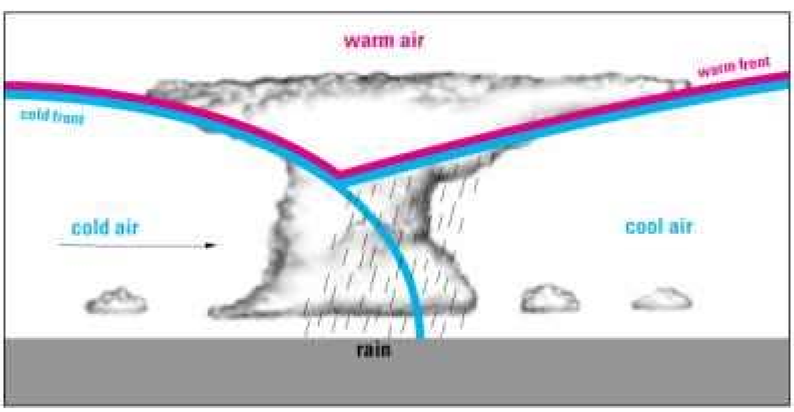


Figure 9-14 Cold-front type occlusion, lifting stable moist air

9.6 Upper cold Fronts

In the case of a cold front riding up over a pool of colder air, a station in the cold air will experience most of the changes associated with a cold frontal passage, except for the windshift and temperature change. Although there will be clouds moving overhead, the station will not experience a change in air mass.

In the case of cold air spreading out in the lower levels more rapidly than it does aloft, the passage of the front may give a noticeable temperature change and a windshift; clouds and precipitation will move in some time later.

9.7 Upper Warm Fronts

If the warm front rides up over a colder air mass, the cloud system will still be present, although there will be no change in the lower levels of the air mass. If a great deal of rain falls from the warm air into the cool air and then into the cold air at the surface, clouds may form.

When the warm frontal surface is flat for some distance ahead of the front and then abruptly steepens, the rainy zone associated with the front will also be found some distance ahead of the surface front.

If the shallow layer of cold air mixes with the warm air, and the front reforms at the surface as an extension of the steepest portion of the retreating cold air, then the front appears to jump ahead a considerable distance.

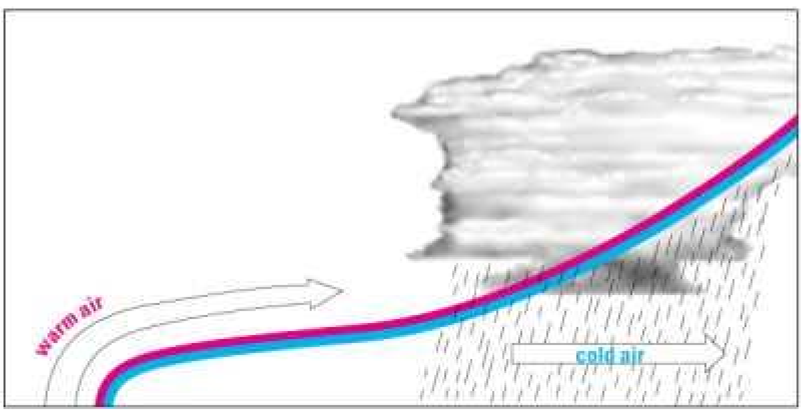


Figure 9-15 Upper warm front

9.8 Exercises

1. Generally speaking, what happens to the temperature when a cold front passes?
2. What changes can be seen in the pressure as a cold front approaches and passes?
3. Why is cold air generally unstable behind a cold front?
4. Is the horizontal extent of clouds and precipitation associated with a slow-moving cold front generally greater or smaller than in the case of a rapidly moving cold front?
5. If air and dew point temperatures are 7 C and 4 C, respectively, in a cold air mass and 24 C and 16 C in a warm air mass, which one contains more water vapour?
6. When a cold front passes, the wind generally veers. True or false?
7. Name seven problems encountered in flying across a cold front.
8. One of the factors determining the type of clouds and precipitation ahead of a cold front is:

    - the pressure of the warm air.
    - the moisture of the warm air.
    - the temperature of the cold air.

- the moisture in the cold air.

9. Clouds and precipitation at a cold front are generally caused by warm air underrunning the cold air. True or false?
10. Cumuliform clouds and showers occur at a cold front when:
    - the front is moving slowly and the warm air is stable.
    - the warm air is moist and unstable.
    - the cold air is moist and has a steep thermal gradient.
    - the air masses in contact are moist and stable.
11. When crossing a cold front, the windshift occurs:
    - where the front meets the surface.
    - where the cold air slope steepens.
    - at 700 hPa.
    - when crossing the frontal surface.
12. Underline the term that describes conditions when a warm front passes:
    - wind (veers, backs);
    - temperature (rises, falls);
    - moisture (increases, decreases).
13. What is the effect on a station's altimeter setting as a warm front approaches and passes over?
14. Name two factors that determine to what extent warm air will overrun cold air.
15. What are the results of warm air overrunning cold air?
16. Give the sequence of clouds generally associated with the approach of a warm front.
17. Draw the cross-section of a warm front, showing the 0 C isotherm that is likely to cause freezing rain and ice pellets; colour the air layers above the 0 C isotherm; with hourly observation symbols, mark the zones of snow, ice pellets, freezing rain and rain.
18. Compare the position of the thunderstorms associated with cold and warm fronts, respectively.
19. The main cause of the very low clouds forming ahead of a warm front is
    - saturation of cold air
    - saturation of warm air by rain evaporating as it falls.
20. When crossing a warm front, the wind changes direction
    - ahead of the frontal surface.
    - behind the frontal surface.
    - at the frontal surface.
21. The weather associated with a trowal is generally worst
    - where the trowal is at a high altitude.
    - after the total occlusion of the warm sector.
    - at the time of occlusion of the cA air.
    - near the frontal wave.

CHAPTER 10
CLOUDS, FOG AND PRECIPITATION

Clouds are a visible accumulation of fine droplets and/or ice crystals suspended in the atmosphere.

Fog is also composed of droplets and/or crystals, but reaches the ground and reduces visibility to less than 1 km (5/8 mile); otherwise it is referred to as mist.

When haze or mist is present, visibility can be reduced not only by water droplets or ice crystals, but also by solid hygroscopic particles. These particles may be moist or dry, depending on the moisture content; if they are dry, we speak of haze.

10.1 Classification of clouds

Clouds are classified according to appearance, shape and altitude. Their appearance and shape depend in part on how they are formed and the ambient temperature.

Clouds may be divided into three families, according to height:

- high, based above 6 km (20,000 ft);
- middle, based between 2 and 6 km (6500 to 20,000 ft);
- low, from the surface to 2 km (6500 ft).

There are ten main types, which can be further subdivided into secondary types. Only the most important secondary types have been considered in this guide. The following table presents the ten main types and four most important secondary types.

Table 10.1 Classification of clouds

Family	Main type	Secondary type
High	Cirrus	
	Cirrocumulus	
	Cirrostratus	
Middle	Altocumulus	
	Altocumulus	Castellanus
	Altostratus	
	Nimbostratus	
Low	Stratocumulus	
	Stratus	
	Stratus	Fractus
	Cumulus	
	Cumulus	Fractus
	Cumulus	Congestus

Table 10.1 Classification of clouds		
Family	Main type	Secondary type
	Cumulonimbus	

10.1.1 High Clouds

High clouds occur at an altitude of over 6 km (20,000 ft); in North America, the temperature at this level is always below 0ºC.

- **Cirrus** Detached or discontinuous clouds, in the form of delicate white filaments, patches or narrow white bands. Fibrous, hair-like, silky in appearance. Often described as looking like "mare's tails."
- **Cirrocumulus** Thin, white cloud patch, sheet or layer, without shading, composed of very small elements in the form of grains or ripples, merged or separate, more or less regularly arranged. Most of the elements have an apparent width of less than a finger viewed at arm's length.
- **Cirrostratus** More or less transparent, whitish cloud veil of fibrous or smooth appearance, totally or partly covering the sky, and often producing halo phenomena, e.g. halos and parhelia.

10.1.2 Middle Clouds

The bases of middle clouds are from 2 to 6 km (6500 to 20,000 ft). While the temperature at this level is often below freezing, in summer it may climb above 0ºC, in which case the clouds will not always consist only of ice crystals, but may also include supercooled water droplets.

- **Altocumulus** White or grey cloud patch, sheet or layer, generally with shading; may be composed of thin layers, rounded masses or rolls, which are sometimes partly fibrous or diffuse and may be separate or merged. Most of the regularly arranged small elements have an apparent width of from one to three fingers viewed at arm's length.
- **Altocumulus castellanus** Altocumulus with heaped protuberances in at least part of the upper section; small towers, some of them taller than they are wide, are linked by a common base and seem to be arranged in lines.
- **Altostratus** Greyish or bluish cloud sheet or layer of striped, fibrous or uniform appearance, totally or partly covering the sky, thin enough in parts to reveal the Sun at least vaguely, as if through ground glass.
- **Nimbostratus Grey**, often dark cloud layer, whose appearance is diffused by more or less continuously falling rain or snow, which in most cases reaches the ground. Thick enough to blot out the Sun at all points.

10.1.3 Low Clouds

The bases of the following clouds all extend from the surface to 2 km (6500 ft). However, the bases of cumulus or cumulonimbus can sometimes reach 3 km (10,000 ft) or even more, particularly when the weather is very dry. Depending on the height of the freezing level, which varies with the season, these clouds consist of droplets, possibly supercooled, and/or ice crystals.

- **Stratocumulus** Grey or whitish bank, patch or sheet of cloud, almost always with dark parts, made up of rounded masses, rolls or cloudlets which are non-fibrous, except for the virga, and may be separate or merged. Most of the regularly arranged cloudlets have an apparent width of more than three fingers viewed at arm's length.

- **Stratus** Generally grey cloud layer with a fairly uniform base, often fairly close to the ground; the Sun's outline is clearly discernible when it is visible through the cloud. Produces halos only in very cold weather.
- **Stratus fractus** Made up of the same components as stratus, but more ragged.
- **Cumulus** Detached clouds, generally dense and with sharp outlines, developing vertically in the form of rising mounds, domes or towers. Sunlit parts are mostly brilliant white; the base is relatively dark and nearly horizontal.
- **Cumulus fractus** Ragged cumulus, consisting of the same components as cumulus clouds.
- **Cumulus congestus** Very puffy and swelling cumulus, with domes or towers that often resemble sections of a cauliflower.
- **Cumulonimbus** Heavy dense cloud with a large vertical extent, in the form of a mountain or huge tower. Part of its upper portion is usually smooth, fibrous, or streaked and nearly always flattened; this part often spreads out in the shape of an anvil or plume. This type of cloud is composed of water droplets, sometimes supercooled, and ice crystals, and usually produces heavy icing.

10.2 Cloud Formation

Since clouds are composed of water droplets or solid particles suspended in the atmosphere, condensation or sublimation must occur for them to form.

10.2.1 Formation by cooling

- Orographic lifting

As the air rises along a slope, it expands and cools adiabatically. If the air is sufficiently moist, it can reach saturation as it continues to cool.

The type of clouds formed in this way depends on the temperature and stability. The most common are altocumulus, stratocumulus and cumulus. Figures 10-1, 10-2 and 10-3 give examples of clouds formed by orographic lifting.

Since such clouds are associated with the topography, they tend to remain stationary. Under some conditions, the combination of wind and relief can create waves extending well downstream of the mountaintops, and associated lenticular (lens-shaped) clouds.

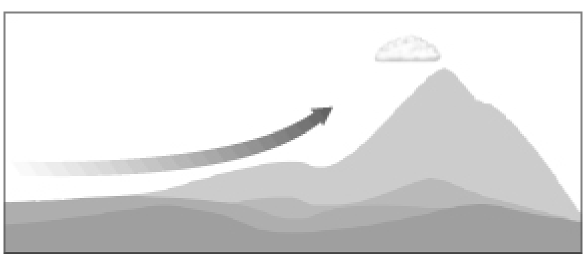


Figure 10-1 Relatively dry air

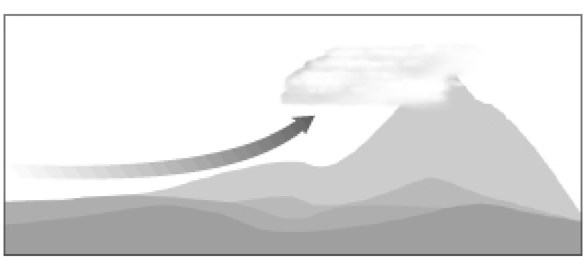


Figure 10-2 Moist stable air

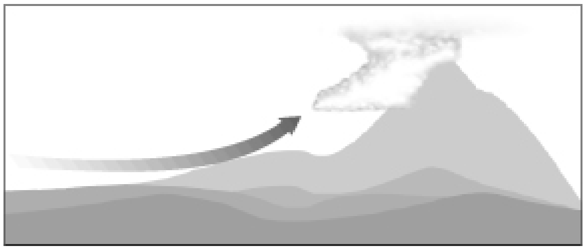


Figure 10-3 Moist unstable air

- Frontal lifting

Warm air is lifted over cold air as a front passes. The lifting process is somewhat similar to orographic lifting. The type of cloud depends on whether the front is cold or warm, as well as the moisture and stability of the warm air mass.

- Lifting by mechanical turbulence

The Earth's surface is marked by many irregularities of varying size and extent, called "roughness." Roughness is considered highest in a range of high mountains, and minimal over the sea.

This roughness affects circulation near the land surface, causing it to become turbulent and producing eddies when there are small-scale areas of rising and descending air currents next to each other at more or less regular intervals. The atmospheric layer in which this turbulence and eddies occur is called the "friction layer."

The thickness of the friction layer depends on the wind speed and the degree of roughness and stability. It is very thin over the sea and in stable air, of course, but may reach several hundred metres in mountainous areas and in unstable air.

If the air is very stable and dry, this layer will be too thin for clouds to form. In highly stable and relatively moist air, stratiform clouds will appear.

When the air is unstable, the friction layer will be thicker and mechanical turbulence will create relatively well-organized convective clouds, such as streets of cumulus. If the layer of unstable air is at all thick, convective clouds will develop regardless of mechanical turbulence.

- Lifting associated with convection

Convective movements in unsaturated air can give rise to cumulus, if they reach sufficient height for condensation to occur. If the upper layer is still unstable, these cumulus will develop further and become cumulus congestus or possibly cumulonimbus.

Convection can also occur within other clouds, if the air is unstable enough. Cumulus congestus or cumulonimbus may then be embedded in a nimbostratus or develop from a stratocumulus base.

These vertical developments can sometimes be observed in banks of altocumulus, in which case they are castellanus; in exceptional cases they may produce small cumulonimbus.

- Surface convergence

When air piles up over a region and cannot escape on any side, the "surplus" air is forced to rise. This phenomenon occurs on a large scale mainly when there are lows present, since winds near the ground converge toward the centre of the low. Smaller-scale convergence may be caused by relief.

- Divergence aloft

Upper-air circulation produces horizontal divergence and convergence zones, in turn creating compensating vertical movements.

Accordingly, if there is a horizontal divergence zone aloft, the "vacuum" created will likely be filled by air from the lower levels and, to a lesser extent, from the upper levels. Thus there will be rising air movements beneath this zone.

These upper-air divergence zones form what are called troughs, while convergence zones form ridges. Upper-air troughs and ridges occur and move in a series of wave-like movements called short waves.

There may be many short waves over the continent at the same time, but only two or three of the longer, so-called planetary waves, Rossby waves or long waves, in which divergence or convergence is not as powerful.

On an upper-air chart, the difference in configuration between long and short waves can be identified by following the wave-like path of isohypses; they can easily be picked out on satellite photos of the associated cloud formations.

Altocumulus are typical of short-wave troughs. When the air is very unstable in the middle levels, altocumulus castellanus and even small cumulonimbus may form, accompanied by showers or thunderstorms.

10.3 Precipitation

Because precipitation is intimately linked with clouds, it may be considered another valuable source of information for pilots.

Looking up at a solid layer of cloud, it is often difficult to visualize its vertical structure. The nature or type of any precipitation, in particular the size of droplets, is the best indication of the presence of another cloud bank aloft.

There is a definite upper limit to the size of a water droplet that forms solely by condensation. In stable air clouds, such as stratus, there is very little vertical motion to sustain the cloud droplets and they drift slowly to the earth as drizzle.

When upward motion is stronger, the droplets grow to considerable size before they are heavy enough to overcome the vertical currents and fall as precipitation. Raindrops are so large, however, that other mechanisms must be involved in their growth.

When the temperature of a cloud is below freezing, there may be both ice crystals and supercooled droplets present. Since the vapour pressure is lower for ice than for supercooled water, and since the moist air has already reached its saturation point, in this case it is already supersaturated with respect to the ice.

This property of water vapour means that as soon as ice crystals form in a cloud, they begin to grow, often at the expense of water droplets. This is known as the Bergeron effect. Once they are large enough, they fall from the cloud, and melt during the descent as they pass through layers where the temperature is above freezing.

But the Bergeron effect alone produces ice crystals rather slowly: it takes four hours to form a raindrop measuring only 2 mm. Since cumulonimbus often generate much larger drops in the space of just a few minutes, there must be another process involved.

Droplets and ice crystals of widely varying size and mass coexist in clouds, suggesting that all these parts of the cloud are moving at very different speeds, frequently colliding and merging. These combinations produce what is known as growth by coalescence.

The greater the turbulence within the cloud, as is the case for large cumulus and cumulonimbus, for example, the greater the coalescence. This is why larger snowflakes or raindrops generally fall from convective clouds.

The type of precipitation therefore depends on the main or secondary type of cloud. Steady or intermittent precipitation comes mostly from stratiform clouds, while showers and flurries are characteristic of convective clouds.

10.3.1. Classification and Definition of Precipitation Types

Table 10.2 Clouds and the precipitation associated with them

Precipitation	Cloud
Drizzle, freezing drizzle, granular snow	Stratus
Snow, rain - steady or intermittent	Nimbostratus, altostratus, altocumulus, stratocumulus
Snow flurries, rain showers	Cumulonimbus, cumulus congestus, altocumulus castellanus
Snow pellets, sleet showers	Cumulonimbus, cumulus congestus
Steady sleet	Nimbostratus, altostratus, altocumulus, stratocumulus
Hail	Cumulonimbus
Ice crystals	Clear sky

Drizzle

Precipitation in the form of very small drops of water, fairly uniform, with a maximum diameter of 0.5 mm; they fall very slowly, appearing to float down, and form no rings on puddles.

Supercooled or freezing drizzle

Drizzle consisting of supercooled droplets that freeze on contact with solid objects at temperatures below freezing.

Rain

Larger drops than drizzle, with a diameter of over 0.5 mm, that form rings on puddles.

Supercooled or freezing rain

Supercooled droplets that freeze on contact with solid objects at temperatures below freezing.

Snow

Ice crystals, usually of branched hexagonal or star-like form, frequently interlaced to form large flakes when the temperature is near freezing.

Snow pellets

White, opaque ice particles, that may be spherical or conical, measuring 2 to 5 mm in diameter; always fall in showers and break up easily.

Granular snow

Tiny grains of ice, white and opaque, fairly flat or elongated, generally less than 1 mm in diameter.

Sleet or ice pellets

Transparent or translucent grains of ice, spherical or irregular in shape, no more than 5 mm in diameter, that fall as frozen raindrops or snowflakes that have melted substantially and then re-frozen, generally close to the surface. In this form sleet does not fall in showers; or
snow pellets with a thin layer of ice formed by the freezing of tiny drops intercepted by pellets or the re-freezing of water released by the pellet as it melts. This type of precipitation falls in showers.

Hail

Balls or lumps of ice, called "hailstones," from 5 to 50 mm in diameter or sometimes even more, separate or melted into irregular blocks. Hailstones are formed almost solely of clear ice or alternate layers of clear and opaque ice. Hail falls in showers, often during violent thunderstorms.

Ice crystals

Fine needles or platelets of ice that can fall from a cloudless sky. Often so small that they seem to hang in the air.

10.4 Fog

Fog is a collection of fine droplets or tiny ice crystals accompanied by often-microscopic saturated hygroscopic particles, and reduces surface visibility. In fact, it is identical to a cloud with its base resting on the ground.

By convention, horizontal visibility is limited to less than 1 km (5/8 mile) in fog. Otherwise it is referred to as haze or mist. Since mist generally occurs in very moist air, any mist in a relatively dry atmosphere is probably haze, consisting of dry particles.

Fog forms in almost exactly the same way as clouds, as air cooled to supersaturation collects around a sufficient quantity of condensation nuclei. Water vapour is added by evaporation from the ground or sea, or by precipitation.

Near the coast, these nuclei consist mainly of sea salt; farther inland, they consist mostly of dust, smoke or automobile and industrial pollution. Even in the Arctic, fog may form around combustion particles from engines.

The physical processes that act to dissipate and move fog can only be effective once the phenomena that created and maintained the fog no longer apply.

Over the land, the first of these processes is the Sun's radiation, which dissipates the fog by warming it from below and all around, provided that the rays are not blocked by clouds.

Over the sea, fog dissipates in a different manner. Since the Sun cannot warm the water enough, the fog dissipates only when the wind changes direction or if the downstream water surface is warmer and the wind picks up; however, the fog will persist if it is blown toward a colder water surface.

10.4.1 Radiation Fog

Radiation fog forms overnight or early in the morning, when the air holds enough moisture to allow condensation as a result of radiation cooling. The cooling necessary to reach the dew point must persist or be strengthened by a clear sky or a cloudy sky in combination with light winds.

This type of fog generally dissipates early in the morning, as soon as the Sun's rays warm the ground.

If a layer of cloud prevents the Sun's rays from reaching the ground, such fog may persist for much of the morning and even thicken; alternatively, but not usually, it may lift and form a low-level layer of stratus, which in turn can persist for several hours.

Topography has an important influence on the formation of radiation fog. It frequently flows into valleys or low-lying areas, and is rarer on plateaus, hills or mountainsides. It almost never occurs over large bodies of water.

10.4.2 Advection Fog

When a moist warm air mass is pushed over a relatively cold surface, the air is cooled by contact with the surface and its temperature falls to that of the surface.

If the air temperature reaches the dew point as it falls, the air will become saturated and fog will form. In some cases, the air temperature and the dew point will fall still further under the influence of the cold surface, producing advection fog.

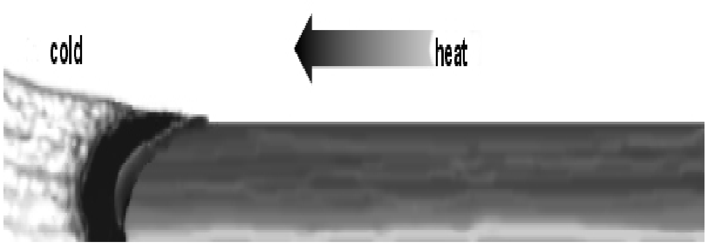


Figure 10-4 Formation of advection fog

This fog may be accompanied by winds of 12 knots or more. Strong winds may result in mechanical turbulence lifting the fog and forming stratus cloud. This is not always the case, however, as advection fog has been observed over Hudson Bay when there were 30-knot winds.

Advection fog may form over water when moist air moves from a warm surface to an area where the water is colder. In this case, the fog will spread out and persist until the wind changes direction. Since diurnal warming has little effect on the water surface, the fog can last all day.

Over land, this type of fog forms when the air blows in from the sea. In some cases it extends well inland, although a range of hills will hold it near the coast.

If there is sufficient warming, advection fog over land will thin out or lift during the day, only to form again at night. An overlying cloud layer may prevent the fog from lifting or thinning out, in which case it may persist until the wind changes direction.

The warm sector of a frontal depression moving northward over colder ground will obviously produce advection fog.

10.4.3 Upslope Fog

This type of fog is formed by air cooling owing to expansion as it moves up a slope. Upslope fog often forms with moderate winds. Strong winds will create stratus or stratocumulus cloud (owing to mechanical turbulence), rather than fog.

Near a mountain, an observer in a valley might report cloud, while another observer near the mountain top would consider it fog.

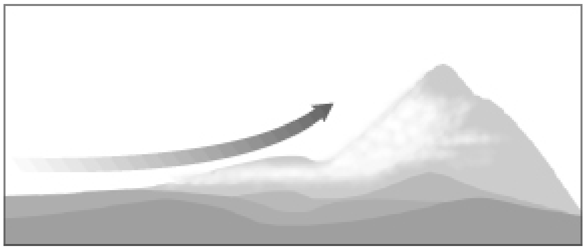


Figure 10-5 Formation of upslope fog

10.4.4 Fog on Snowy Surfaces

Warm spring air is cooled as it flows over a snow-covered surface. If the temperature falls to the dew point, the resulting saturation will create persistent fog, since the cooling effect is maintained by the snow.

10.4.5 Steam Fog or Arctic Sea Smoke

In the early morning, particularly in spring or autumn, rivers or small lakes seem to be steaming, because the water is warmer than the air moving over it. The water vapour escaping from the water surface saturates the colder air and produces curling wisps of fog, caused by the minor vertical currents developing in the air as a result of the heating from below.

Should there be sufficient heating to cause instability up to great heights, cumulus-type cloud will form. This situation may be observed in winter, when cold arctic air moves over an extensive area of warm water.

When the cold air first moves over the water, steam fog will appear, followed by heap clouds. In arctic areas, where it is known as arctic sea smoke, this fog forms as the air moves from the ice surfaces to vast open areas of water.

This is an example of fog forming when the dew point rises to the air temperature, owing to an increase in water vapour because of evaporation.

10.4.6 Pre-Frontal and Frontal Fog

Fronts are often preceded by fog. Prefrontal fog is associated with warm fronts and is caused by the saturation of cold air as rain falling from the warm air evaporates.

The fog that often follows warm fronts is due to advection cooling as the warmer air moves over a colder surface.

The other types of fog associated with fronts are called frontal fog.

10.4.7 Rime Fog

Rime fog is very common in cold weather, when the air temperature near the surface is below freezing and the air is fairly moist. This type of fog consists mostly of supercooled droplets that turn into rime frost on contact with freezing objects.

This situation occurs on cold mornings, often when the sky is clear. Aircraft must then be de-iced before takeoff. This type of fog is similar to radiation fog.

10.4.8 Ice-Crystal Fog

At very low temperatures, in a continental arctic air mass for example, the air may become full of ice crystals, seriously limiting visibility. In this case, the ice crystals have formed by sublimation.

In very cold weather, ice crystals may suddenly appear when an aircraft engine is started, since the exhaust gases contain water vapour and suitable nuclei for sublimation. In addition, the turbulence from the propeller constitutes a perfect mixing agent.

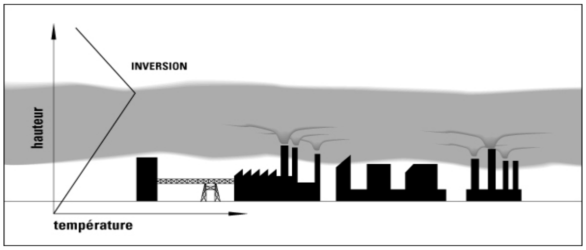


Figure 10-6 Smoke and pollutants blocked by inversion in a stable air mass

10.4.9 High Inversion Fog

A stratus layer over the land is often an indication of an inversion. If it extends downward as far as the ground, it can create what is called high inversion fog.

Such fog may be accompanied by light rain. If there is heavy rain, the fog will lift but the cloud will remain.

10.5 Exercises

1. What kind of cloud produces a halo around the Sun?
2. What kind of cloud can produce hail?
3. What kind of cloud resembles a "mare's tail"?
4. What kind of cloud gives steady rain?
5. What kind of cloud produces lighting?
6. What low clouds, in an unbroken layer, resemble fog and sometimes produce drizzle?
7. What is the name of the layer or patches of round, flattish clouds with a base between 2 and 6 km, 6500 and 20,000 ft?
8. What do we call a cloud of vertical development with a nearly flat base, a rounded top and sharp edges?
9. What do we call a cloud that seems to consist of small round masses or white flakes, without shading, separated or merged, with ripples like the sand on a beach?
10. What cloud gives the sky a "ground-glass" appearance?
11. What is the type of cloud of vertical development that sometimes has a white, fibrous top?
12. What is the cloud that often occurs in layers, resembling rounded masses with strong shading, and with its base between 6 and 12 km, 20,000 and 40,000 ft?
13. What is the layer cloud with a relatively flat top and a base generally above 2000 m, 6500 ft, and a top that often extends beyond 6 km, 20,000 ft?
14. What are the three conditions necessary for condensation to occur?
15. Name three cooling mechanisms that cause condensation.
16. What is the cooling mechanism responsible for the formation of most clouds?
17. Name five lifting process that cause clouds. What do they have in common?
18. What is the weather element that determines the maximum quantity of water vapour in the air?
19. A volume of air condenses by cooling. What changes will there be in:
20. the dew point temperature?
21. the relative humidity?

22. Suppose that a volume of air with constant moisture is warmed. What changes will there be in:
23. the dew point temperature?
24. the relative humidity?

25. Name two circumstances favourable to convection.
26. Why do cumulus clouds over land generally extend farther upward on a summer afternoon?
27. Why do convective clouds generally dissipate at night?
28. Why do vast layers of low cloud form in a moist air flow crossing the Prairies from east to west?
29. What is the cause of the heap or stratiform structure of clouds formed over a mountain range?
30. A layer of low stratus covers the Maritimes and swelling cumulus are observed over southern Ontario. What low-level turbulence conditions can be expected in each region?
31. There is drizzle at point A and heavy showers at point B. Compare the air stability at the two points.
32. What type of precipitation can occur when there are no clouds?
33. Explain the phenomenon of "radiation cooling" in the lower atmosphere.
34. Name three conditions necessary for the formation of radiation fog.
35. Why does radiation fog occur only rarely over the sea?
36. Why does radiation fog generally dissipate in the morning?
37. Why does radiation fog first form in valleys?
38. Under what circumstances does advection fog form?
39. How does an overlying cloud layer affect the dissipation of advection fog
    - over land?
    - over water?

CHAPTER 11
VISIBILITY

Visibility is one of the most important weather elements from the standpoint of aircraft take-off and landing. In conjunction with ceiling, it determines whether or not to close the airport.

Visibility is decisive for pilots and crews. They must determine the nature and horizontal and vertical extent of any serious obstacle to visibility that may affect their route or destination, each time they take off.

11.1 Definition

Most people define visibility as the greatest distance at which an object can normally be identified. As used in observations and weather forecasts, however, the word has a different meaning, in that it is prevailing visibility that is measured and forecast.

To measure the prevailing visibility at an airport, the horizontal ground visibility at a height of 1.8 m is estimated in all directions. The maximum visibility that applies for at least half the horizon is considered the prevailing visibility. This usually, although not always, gives a clear indication of conditions affecting take-off and landing.

During flight or while landing, however, it is the slant visual range that is most important, that is visibility from the aircraft. The reference used is the distance to the farthest identifiable point on the ground. Weather forecasts and bulletins give only an indirect indication of the slant visual range.

The term "vertical visibility," associated with ceilings, means the vertical visibility through a layer of obstructing cloud based on the ground. Only from an aircraft in flight can one determine whether actual visibility is better or poorer than the forecast, depending on lighting, contrast, the nature of the surroundings and other factors.

The prevailing visibility may be quite different from the slant visual range at relatively low altitudes.

- A thin layer of fog can greatly reduce surface visibility, although from the aircraft, the slant visual range of 1,500 m is unchanged. The final moments of the actual landing may be somewhat difficult.

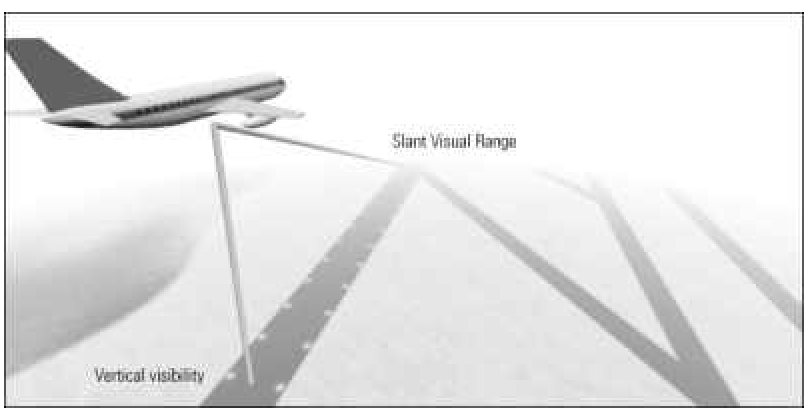


Figure 11-1 Vertical visibility and slant visual range

- Ground visibility may be fairly good if there are only layers of haze, but in flight such conditions make it difficult for the crew to identify features on the ground.

Experience also indicates that in case of smoke or haze, visibility is better down sun than up sun, since the smoke and haze cause intense glare. At night, objects can be seen more easily against the moon.

11.2 Restrictions

Aside from ceilings and haze, there are many phenomena that affect visibility. Experienced pilots never take off without consulting the latest weather information, even for short flights.

11.2.1 Cloud

Within cloud there is a very wide range of visibility. In thin clouds, visibility may be as high as 1 km, while in heavy rain clouds it may be only a few metres.

Stratus clouds are a particular case. Once inside these low clouds, pilots will often find that visibility falls to zero. Taking off and landing present serious risks if these clouds extend right to the ground.

11.2.2 Precipitation

Although rain on the windshield can be a serious irritation for the pilot, it does not seriously limit visibility. Even very heavy rain does not usually limit visibility to under 2 km. If the rain is associated with fog, however, it is a different matter.

For helicopters, the flow of heavy rain down the windshield can cause serious difficulties, as it distorts the pilot's vision. Since it makes objects seem farther away, there is a serious risk of collision.

Drizzle is also a serious problem, owing to the numerous droplets. It is often associated with fog and consists mainly of industrial pollution.

Even a very light snowfall can reduce visibility considerably. If the snowfall becomes heavy, visibility may drop to a few metres.

Freezing precipitation affects visibility in the same way as other types of precipitation, but is even more dangerous, since the forming on the windshield adds to the distortion.

11.2.3 Fog

Fog occurs only at the surface, and is formed of water droplets or ice crystals. It reduces visibility to less than 1 km (5/8 mile).

11.2.4 Mist or Haze

Mist or haze consists of particles so small that they cannot be felt and cannot be individually distinguished. They generally form a continuous veil. Visibility in mist or haze is always greater than 1 km (5/8 mile).

11.2.5 Smoke and Volcanic Ash

Near industrial areas and forest fires, smoke pollution may be a major concern. If the air is stable, as is the case with a low-level inversion, impurities accumulate in the lower levels, greatly reducing visibility.

Vertical currents will serve to thin the pollution out and improve surface visibility. In addition, strong winds and strong turbulence will concentrate the pollution on the leeward side of the smoke source and improve visibility at low levels.

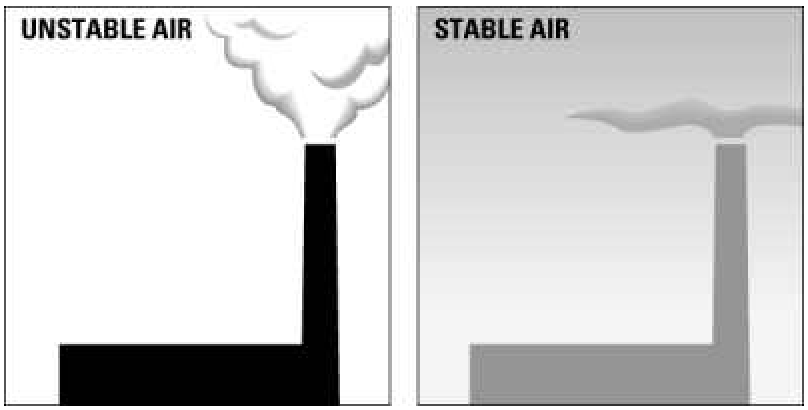


Figure 11-2 Visibility in stable and unstable air

If the smoke particles near the surface act as condensation nuclei that promote the formation of fog, the dense smoke from forest fires may carried for long distances at great heights and reduce visibility, even if the sky is clear in the lower levels.

The same occurs with volcanic ash, although such ash is even more dangerous than smoke. It not only reduces visibility, but can be sucked in by the engines and clog them.

11.2.6 Blowing Dust

Blowing dust is a feature of unstable air moving over semi-arid regions. The rotating action of the vertical currents serves to lift the soil, often to considerable height.

If the air is stable, even moderate winds will blow the dust, but will not lift it any higher than about 1 m; such drifting dust does not affect visibility at eye level.

Blowing dust is common behind cold fronts moving rapidly across the Prairies in early spring, because of the strong lower-level instability that develops in the cold air as it moves from snow-covered surfaces across the warmer snow-free ground. The resulting eddies may cause blowing dust that will reduce visibility over an extensive area.

11.2.7 Blowing Snow

Blowing snow is to be expected in a strong flow of unstable air over loose snow. As in the case of blowing dust, the limited visibility may extend to a considerable height. This problem is of special significance in arctic regions.

11.2.8 Drifting Snow

Drifting snow is confined to the lower levels, and does not affect visibility at eye level. It can temporarily make runways hard to see, however.

11.3 exercises

1. What is the difference between "horizontal ground visibility" and "slant visual range"?
2. The forecaster informs a pilot about to leave on a night flight that the sky is clear, with visibility of 15 km, but that visibility will gradually fall during the night owing to haze and smoke. Explain how visibility can be good during the day and deteriorate during the night.
3. In the winter, a front is approaching quickly, and visibility is greatly reduced by gusting snow up to 80 km behind the front. What causes this gusting snow?
4. Give three reasons why the hourly observed visibility can be different from that observed by a pilot in the final approach.
5. Ground visibility, in unstable air, can be reduced by:
    - fog.
    - drizzle.
    - showers.
    - low stratus.
6. Low visibility persists in:
    - hail.
    - drizzle.
    - showers.
7. Low ground visibility because of smoke is exacerbated at the edges of an industrial zone when:
    - there is a strong wind and gusts at ground level.
    - there is an inversion in the lower 300 m.
    - cumulus form in the afternoon.
    - a cold front has just passed quickly.
8. The presence of a thin fog bank can make landing dangerous, because it reduces:
    - vertical visibility.
    - slant visual range above 100 m.
    - reported ground visibility at 150 m.
    - ground visibility.

CHAPTER 12
ICING

No satisfactory solution has yet been found to the problem of aircraft icing. Since even the simplest icing prevention system imposes significant constraints on aircraft design, no aircraft can be equipped with total protection, and existing systems merely limit the extent of icing.

The severity of an icing situation depends not only on weather conditions, but also on the type of aircraft, the flight techniques used by the pilot, the anti-icing system and the de-icers used. No specific rule can accordingly be applied in the preparation of flight plans and in flights through icing regions. Moreover, the criteria used to define such regions can be misleading.

12.1 Formation

Ice forms on the airframe when the aircraft meets water droplets at below freezing temperatures. The extent of the icing depends on the air temperature and that of the aircraft's skin, and the amount of water that comes in contact with the aircraft, which in turn depends partially on the size of the droplets and the aircraft's cruising speed.

12.1.1 Supercooled Water Droplets

Water droplets that remain in the liquid state at temperatures below freezing are said to be supercooled. As they cool, the drops do not necessarily freeze as soon as the temperature reaches 0ºC. Nevertheless, there is a limit to the possible cooling before the droplet freezes, and that depends mostly on the size of the droplets.

The largest droplets freeze at temperatures just below 0ºC while the smallest ones can remain liquid to temperatures as low as 40ºC. Below that temperature, liquid droplets are rare.

A supercooled water droplet freezes at the slightest jar. When it strikes an aircraft, the droplet gives off heat, so that its temperature immediately rises. Provided the initial temperature of the droplet was not too cold, it increases until it reaches 0ºC.

The freezing caused by the impact obviously stops when the temperature moves slightly above 0ºC and the remaining, liquid portion of the droplet begins to freeze more slowly as it evaporates in the surrounding cold air. The amount of water available in the droplet which freezes by evaporation is greater at temperatures closer to 0ºC.

After the initial freezing by contact, the speed at which the remaining water freezes depends primarily on the temperature of the aircraft's skin. The higher the temperature, the slower the water freezes and, as a result, the farther it moves from the point of impact before freezing completely.

The size of the droplets and the frequency with which they strike the aircraft are also crucial. The type of icing depends on the degree to which a droplet is frozen before another droplet strikes the same place. If the droplet accumulates rapidly without being completely frozen, the parts that are still liquid cool and spread before freezing.

12.1.2 Collection Efficiency

The amount of water intercepted by an aircraft in a given period is called the collection efficiency. It varies with the liquid water content of clouds, the size of the droplets, the speed of the aircraft and its wing type. If the temperature is conducive to icing, the ice accumulates more quickly as the aircraft's collection efficiency increases.

The amount of water in the form of droplets in a cloud is referred to as the liquid water content of the cloud. This depends on the size of the droplets in the cloud as much as their number per square kilometre, but does not include the weight of the ice crystals that may be present. A cloud made up entirely of ice crystals thus contains no liquid water.

The water content of a cloud varies with altitude. At constant temperatures slightly below freezing, it generally increases with altitude, hence the fact that the icing rate is often greater in the highest clouds.

At lower temperatures, however, the number of frozen droplets increases considerably with altitude, while at the same time, the liquid content falls. It is low at temperatures below 25ºC, and generally disappears at 40ºC.

The liquid water content of a cloud also varies over time, meaning that icing conditions within a cloud can change substantially in the space of a few minutes. This variation results from a number of factors, including the behaviour of water droplets and ice crystals.

When ice crystals appear in a zone of water droplets, they grow by absorbing the droplets, which decrease until they ultimately disappear. That is because when ice crystals are present, the evaporating droplets produce water vapour that sticks to the crystals by sublimation.

When a cloud cools sufficiently for ice crystals to appear, or when ice crystals fall through a cloud, the droplets suddenly begin shrinking.

The behaviour is responsible for much of the precipitation that occurs in the temperate zone, so that the onset of precipitation often indicates that the cloud's water content is decreasing (see Figure 12 1). The same does not apply, however, if precipitation is caused mostly by droplets combining.

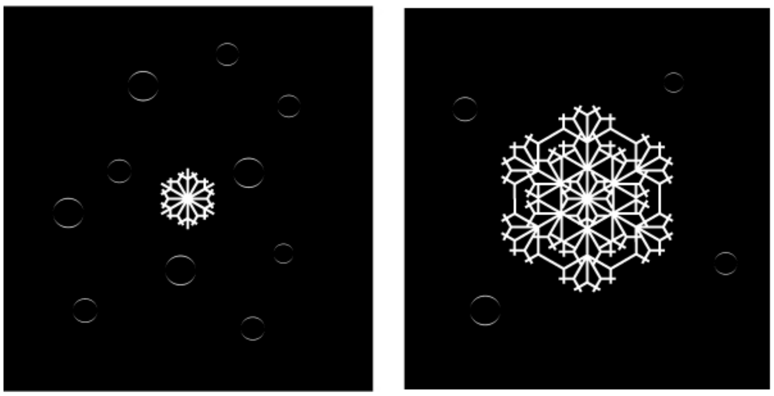


Figure 12-1 Interaction of water droplets and ice crystals

An aircraft's collection efficiency also depends on the size of the droplets. At a given speed, small droplets tend to follow the air flow, and to slip over the wing profile, while heavier droplets tend to cross the air flow and strike the wing.

Since large droplets cannot be supercooled to the same extent as small ones, they are highly likely to be found in lower layers, where the clouds are less cold than in the upper levels. In addition, since strong vertical currents are necessary to hold them up, they are more frequent in clouds that have formed in unstable air, such as large cumulus.

The relationship between the speed of the aircraft and the collection efficiency is obvious, if one considers that, the higher the speed, the greater the number of droplets intercepted in a given period. In addition, there is a direct correlation between the radius of curvature of the leading edge of a wing and its collection efficiency.

Thin wings intercept more droplets per square inch of leading edge than do thick wings. In short, collection efficiency can be said to be highest when an aircraft has thin wings and flies at high speed through a cloud containing many large droplets of liquid water. Furthermore, if the temperature is just at the freezing point and the cloud is at high altitude, there will be substantial icing.

12.1.3 Role of the Temperature of the Aircraft Skin

For icing to occur, the temperature of the aircraft skin must be at or below freezing. If the skin is at the same temperature as the surrounding air, icing will occur as soon as the aircraft comes into contact with supercooled water.

Because of friction and compression effects, however, the temperature of the aircraft skin is warmer than the air or droplets in the cloud. In addition, at temperatures below freezing, the heat given off by the supercooled drops striking the leading edge increases the temperature of the wing surface.

Figure 12-2 shows the variation in skin temperature as a function of speed in flight in a supercooled cloud. At speeds of less than A or A', when the temperature of the aircraft surface is less than 0ºC, rime ice forms.

At speeds between A and B or A' and B', the temperature of the surface is 0ºC and clear ice forms. At speeds greater than B or B', no ice forms, since the surface is then at temperatures greater than 0ºC. The critical values here depend on the liquid water content, the size of the droplets and the air temperature.

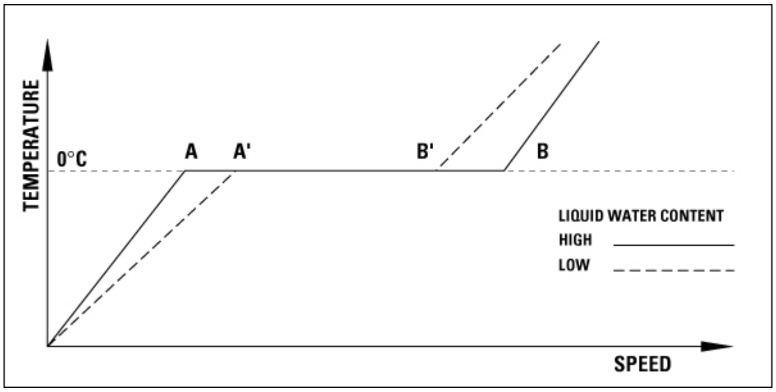


Figure 12-2 Relationship between speed and surface temperature

12.2 Types

There are several types of icing, just as there are several ways of producing it. The crystallization of water vapour and supercooled droplets is a process which depends on air pressure and temperature, humidity and the length of the transformation process.

12.2.1 Hoarfrost

This term is used for a white, feather-like crystalline formation which settles on objects after the water vapour in the air has frozen. It can cover the entire surface of the aircraft. It resembles the white ice which forms on metal surfaces such as car roofs on clear, cold winter nights.

It forms by sublimation, ie, the direct passage of the water vapour into a solid state, without passing through a liquid state. Sublimation occurs when humid air comes into contact with an object whose temperature is sufficiently far below freezing for crystals to form. The less humidity there is in the air, the lower the temperature has to be in order to create this deposit.

Aircraft parked outside on a clear, cold winter night are exposed to hoarfrost. The aircraft's metal surfaces come into contact with the outside air and cool down through radiation. Since metal is a highly effective conductor, it will cool down more rapidly than the ambient air. The water vapour in the air crystallizes on contact and forms hoarfrost.

Hoarfrost is also formed in flight, eg, when an aircraft which is flying at temperatures below the freezing point suddenly descends into warmer humid air. This condition persists until the temperature of the aircraft skin is the same as that of the ambient air. It frequently happens that frost forms sooner and lasts longer around structural tanks, because the fuel heats more slowly than the aircraft.

Hoarfrost also forms when an aircraft climbs quickly inside an inversion. In such cases, the variation between temperatures from one level to another must be sufficiently large to cause sublimation. Such a situation is uncommon in practice, as temperature variations inside an inversion are relatively small.

12.2.2 White Dew

Aircraft parked outside overnight when the temperature is just below freezing may be covered by a deposit which differs slightly from hoarfrost. As the aircraft cools down, a covering of dew may freeze and form an icy deposit. Its appearance distinguishes it from hoarfrost, which results from sublimation, in that it is opaque, with crystalline reflections.

12.2.3 Rime Ice

Rime ice is opaque, whitish, crystalline, rough and granular, and often resembles the hard crust of a snow bank. It accumulates on the leading edges, windshields, propeller blades, aerials, pitot tubes, static ports and any other opening or projection.

Rime does not normally spread on the wings. It is generally brittle, and can be broken off or dislodged from the aircraft. If allowed to accumulate to a sufficient thickness, it usually forms a sharp knife edge facing the air flow.

In order for it to form, the aircraft skin must remain below 0ºC, while supercooled droplets freeze on it. This allows the droplets to freeze quickly and completely, without spreading out behind the point of impact.

When rime ice forms, the collection efficiency is low enough for each droplet to freeze completely before another droplet strikes the same place. The air thus trapped in the ice makes it brittle and porous. The most favourable conditions for the formation of rime ice, then, occur when the aircraft surface is below freezing and there is a low collection efficiency of small supercooled droplets.

12.2.4 Clear Ice

This is a clear, glassy, hard type of ice spread often irregularly, over the surfaces of wings, propeller blades, aerials, windshields, canopies and other projections. It blocks static ports, pitot tubes, etc. It is difficult to break off or dislodge from the aircraft. If it accumulates, it can produce a blunt-edged formation along the leading edge of the wing and reduce its aerodynamic efficiency.

This type of ice forms when the surface temperature of the aircraft rises to 0ºC as droplets freeze on the surface. Under such circumstances, only part of each supercooled droplet freezes on impact, leaving a large part of the water to spread out and mix with other droplets before freezing completely.

The result is a solid layer of transparent ice, containing no air bubbles to weaken its structure. When the cloud also includes ice crystals, the ice often takes on a milky appearance.

The most favourable condition for the formation of clear ice occurs when the temperature of the aircraft's surface reaches 0ºC while the droplets are freezing, with a high collection efficiency of large supercooled droplets.

12.2.5 Mixed Ice

Mixed ice is a mix of white and transparent ice. In flight, ice often presents characteristics somewhere between those described for rime and clear ice. If the ice is clear in some spots and white in others, and is spread irregularly over the wings, it is described as mixed ice (see Figure 12-3).

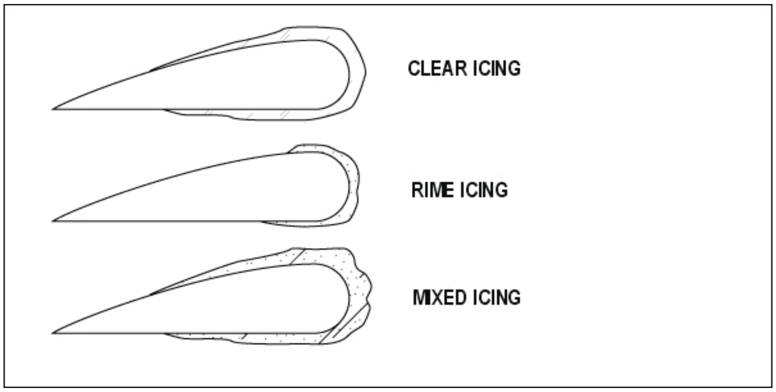


Figure 12-3 Clear, white and mixed ice

12.3 Icing Intensity

Icing intensity may be termed light, moderate or severe. It is difficult to define these terms with precision, since the intensity of icing on a given flight depends on the type of aircraft, its speed, the pilot's manoeuvres and its anti-icing system, as well as atmospheric conditions.

As far as forecasting is concerned, reported icing intensity cannot correspond to these definitions, because forecasts are aimed at all types of aircraft. The forecaster will use these terms in their general sense, to indicate the relative severity of the situation.

ICAO defines icing intensity in terms of ice accretion on aircraft. The following definitions are taken from the Environment Canada publication MANAIR.

- Light icing - The rate of ice accretion is such that prolonged flight (over 1 hour) without using de-icing equipment may create a problem. Occasional use of de-icing/anti-icing equipment removes or prevents ice accretion. If de-icing/anti-icing equipment is used, no problem occurs.
- Moderate icing - The rate of ice accretion is such that even short encounters become potentially hazardous. De-icing/anti-icing equipment must be used or a diversion is necessary.
- Severe icing - The rate of ice accretion is such that de-icing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.

There is a direct correlation between icing intensity and type, since clear ice forms when there is a high collection efficiency, and so the icing will generally be more severe than in cases of rime icing. Hoarfrost is always considered a light deposit, and the concept of intensity does not apply.

At low speeds, the surface heats up by only a few degrees, and the effects of the warming are mitigated by normal variations in temperature. Nevertheless, the icing on such aircraft is usually less severe when the air temperature is close to 0ºC than at temperatures several degrees below freezing.

The increase in the surface temperature associated with the normal cruising speed of jet aircraft inhibits ice formation at temperatures where the water content of clouds should be highest. Severe icing of jet aircraft is consequently rare, although not unheard of in cumulonimbus clouds, even though the speed and wing structure of jet aircraft gives them a high collection efficiency. When the aircraft has to reduce speed, however, for a descent or final approach, for example, icing in clouds or icy precipitation can create problems.

Icing intensity depends on other factors. If, for example, an aircraft enters an icy region bearing small amounts of rime or hoarfrost on its surface, the areas already affected will be the first to be covered with clear ice. The altitude at which an aircraft is flying can also have an impact on the nature and location of ice formation.

Since collection efficiency depends on the water content of the clouds and the size of the droplets, it is possible for two aircraft of the same type to experience different icing intensities within the space of a few minutes, even if they are flying at the same speed, along the same route and at the same altitude.

When icing is involved, every situation, as well as every type of aircraft, requires special attention. An aircraft equipped with rubber de-icing pulsating boots, for example, may experience difficulties in moderate icing conditions, whereas another aircraft equipped with a thermal de-icing system can cope with most situations, provided the system is working at full capacity.

A light aircraft without anti-icing equipment will have difficulty flying even in light icing conditions. A jet aircraft, owing to its high speed and the corresponding rise in the temperature of its skin, can fly in a severe icing region, provided it maintains sufficient speed to prevent any icing.

12.4 Types of Cloud and Icing

Icing situations are not limited to a few types of cloud. They are related both to their nature and composition, if not to the changes they undergo, both in space and in time. Each situation must therefore be studied on its own merits, depending also on the types of aircraft involved.

12.4.1 Cumulus Clouds

Icing is quite variable and, on occasion, very severe in turbulent cumulus clouds, although such clouds rarely extend far horizontally. Nevertheless, there are situations when these clouds are very close together, or even touching.

The severe icing encountered in these clouds occurs in the upper half of cumulonimbus approaching the advanced stage. Once precipitation has begun, the water content begins to shrink, so that there are few supercooled droplets left when the cumulus reaches the dissipation stage.

The probability of severe icing is consequently limited. Generally speaking, the clouds contain little liquid water at temperatures below 25ºC, although cumulonimbus are an exception, since strong vertical currents rapidly carry large liquid droplets upward into low temperature regions.

12.4.2 Layer Clouds

On the average, icing conditions are less serious in layer clouds than in cumulus clouds. Unlike cumulus clouds, icing regions in layer clouds are very widespread horizontally, but not vertically.

Stratus and stratocumulus layers can produce severe icing if their water content is high, which is the case mostly when such clouds have formed over water. The situation is exacerbated when the layer contains cumulus-type clouds.

When thick stratus and stratocumulus clouds form as a result of turbulence, it is to be expected that icing will increase with altitude, reaching its maximum just below the cloud top. Just as with other types of cloud, the beginning of a snowfall is an indication that icing is decreasing.

Under suitable conditions, ie, when the liquid water content, temperature and turbulence are favourable, alto-cumulus and alto-stratus can produce heavy icing. Heavy precipitation is not likely to pose serious icing problems, however, except near the edge of a cloud bank.

12.5 Precipitation Types and Icing

Some kinds of precipitation produce severe icing, while others, although in themselves harmless, are indicative of severe icing conditions nearby.

12.5.1 Freezing Rain

For there to be freezing rain, the rain must fall from a layer above the freezing point into a layer below freezing point. This situation is found almost exclusively ahead of warm fronts in cold weather (see Figure 9 11). Valleys are particularly susceptible, since cold air tends to accumulate there.

The most severe icing resulting from freezing rain occurs when flying near the top of a cold layer below a thick layer of warm air, where the raindrops are much larger than the cloud droplets. The raindrops can produce a very high collection efficiency, producing an extremely heavy formation of clear ice.

12.5.2 Ice Pellets, Sleet

Ice pellets do not stick to an aircraft with a cold surface. This type of sleet does not fall as a shower, and consists of drops of freezing rain which have frozen through long exposure to cold air.

In other words, ice pellets are a positive indication that the layer of cold air with a temperature below the freezing point is deep enough to allow drops of freezing rain to freeze before touching the ground. This type of precipitation accordingly indicates the presence of freezing rain aloft.

12.5.3 Freezing Drizzle

Freezing drizzle, like drizzle itself, is associated with lower layer clouds with a stable thermal profile, such as stratus. When the stratus is trapped under a thermal inversion where the temperature is slightly below freezing, small supercooled droplets are produced.

These droplets will freeze when they strike objects which are colder than 0ºC, and freezing drizzle is produced, followed by clear ice.

It is not necessary to have a warm layer above 0ºC, as in the case of freezing rain, to get freezing drizzle. The temperature of the air mass can be under 0ºC at every level.

When they fall from the clouds, the droplets lose some of their volume through evaporation. Icing in freezing drizzle is thus usually worse near the base of the cloud, where the droplets are largest. Icing can be severe when the base of the cloud layer is at ground level, especially if it remains stationary.

12.5.4 Snow Grain

Snow grains consist of small crystals of white, opaque hoarfrost. They are generally elongated and flat, with a diameter under 1 mm. When droplets of freezing drizzle spend too long in cold air, they can freeze.

In this case, snow grain forms. The presence of snow grain indicates the presence of freezing drizzle in the air mass, probably at a higher level. Snow grains do not of themselves produce icing.

12.5.5 Snow and Ice Crystals

Dry snow and ice crystals do not stick to an aircraft whose surface is cold and so are not an icing hazard. If, however, part of the aircraft is warm, snow or ice crystals may partially melt on contact and produce icing. If the snow includes supercooled droplets, ice may accumulate rapidly.

12.6 Impact on Performance

Before discussing the overall impact of icing on specific parts of an aircraft, we should emphasize one basic difference between fast aircraft and slow aircraft. Fast aircraft accumulate ice more quickly than slow aircraft, because of their thin wings.

Nevertheless, since jets fly at altitudes above most icing regions, they are only rarely affected, except when taking off and landing. In the latter case, icing poses few problems if the aircraft descends quickly and the pilot increases the approach and landing speed to counteract any ice accretion. If icing occurs near the ground, any aborted approach may expose the aircraft to severe icing.

Icing usually affects an aircraft as a result of its shape and angles of exposure to supercooled droplets. More importantly, however, is the location at which icing forms. For example, icing on the fuselage will not affect performance in the same ways as on the wings.

12.6.1 Airframe

The primary impact of icing on the airframe is the deterioration of its aerodynamic qualities due to a disruption of the air flow, thereby reducing lift and increasing drag (see Figure 12 4). These effects increase the stalling speed and reduce air speed.

Even a light accretion of clear ice, freezing precipitation or snow sticking to the wings may make takeoff dangerous. Icing on the wings is especially dangerous when the ice spreads in irregular formation behind the wing leading edges.

The increased tendency of some aircraft to go into a spin under such circumstances is all the more serious, in that the controls are less effective. Additional complications occur if pieces of ice break off from the forward section and stick in the rear elevators. In addition, ice which forms on the wings may interfere with or even block the high-lift flaps.

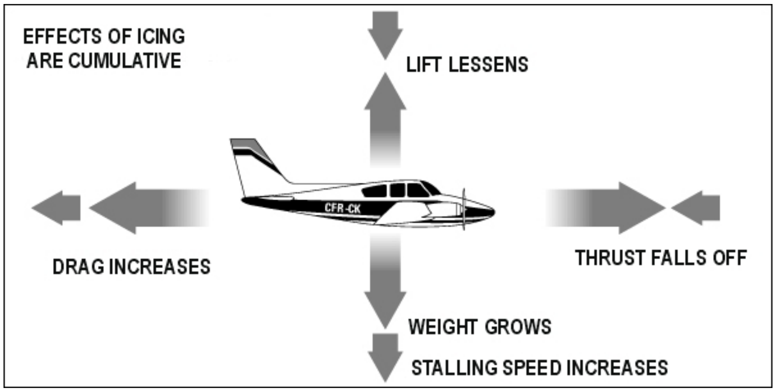


Figure 12-4 Results of icing on the airframe

Under normal flight conditions, the weight of the ice accretion on the aircraft has no serious effects. If, however, the aircraft is heavily laden or an engine malfunction occurs, the excess weight will cause a major problem. The lift of the aircraft will be reduced, which in turn will increase drag.

12.6.2 Propellers

Thrust is reduced when ice builds up on the propellers. This loss of thrust, combined with a reduction in the aerodynamic efficiency of ice-covered wings, makes flying even more difficult under icing conditions.

In addition, pieces of ice breaking off the blades pose a further problem, since they upset the balance of the propeller and make it vibrate heavily, necessitating a reduction in power. Ice chunks can damage the airframe and even the engine.

12.6.3 Windshields and Canopies

Ice build-up on windshields and canopies seriously interferes with the pilot's view. Even a thin layer of ice can pose a serious problem during takeoff and landing.

12.6.4 Radio Aerials

Radio aerials are generally quite small, which makes them fragile as well as susceptible to rapid ice accretion. When aerials become too heavy, they start to vibrate heavily and eventually break. This can result in an interruption in communication.

12.6.5 Pitot Tubes and Static Intakes

Ice obstructing pitot tubes and static intakes can put anemometers, altimeters and other related instruments out of action in a few seconds. Furthermore, the static intakes of some aircraft are located in places where ice accretion can disrupt the air flow, which falsifies the instrument readings.

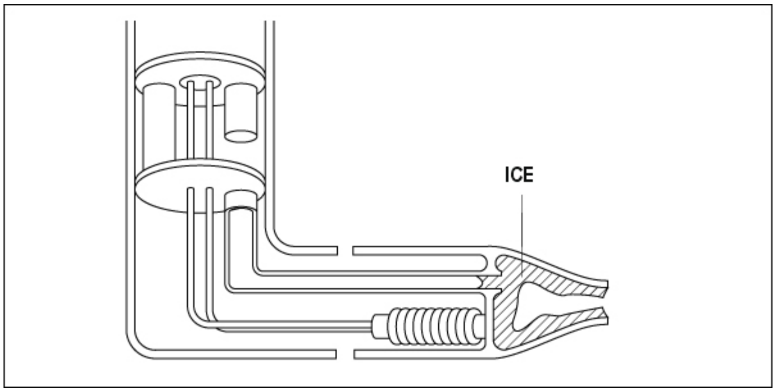


Figure 12-5 Icing of a pitot tube and static intakes

12.6.6 Carburetors and Air Intakes

Icing in the carburetor and air intakes (see Figure 12-6) can obstruct the intake of air into the engine. This results in a drop in power, which can be severe enough to produce total engine failure. What is worse, there is a danger of icing on these parts under clear, moist skies, even if the air temperature is slightly above freezing.

The air which feeds the carburetor normally undergoes a slight drop in pressure. Combined with the evaporation of fuel in the carburetor, this will create a sufficient cooling to drop the air temperature in the carburetor below freezing.

This can occur, even if the ambient air temperature is significantly above freezing, even as high as 30ºC. If the specific humidity of the air entering the carburetor is high, the cooling can form icing, which is harmful to the carburetor and related parts.

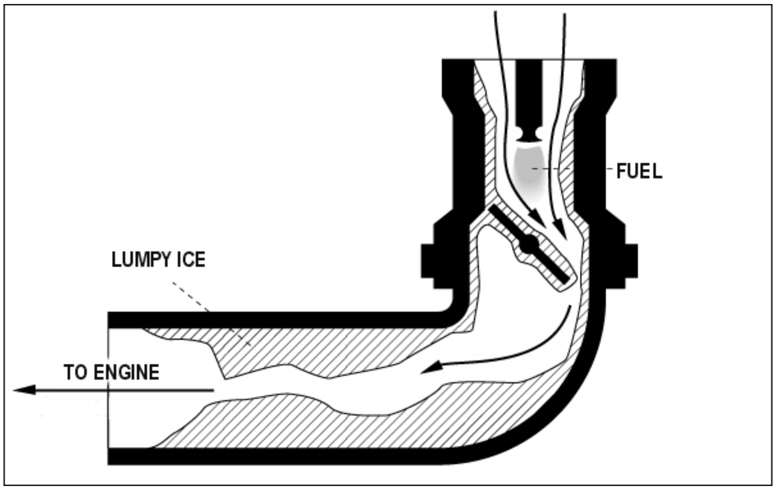


Figure 12-6 Carburetor icing

12.6.7 Turbines

Ice can form on air intake fairings and rotor and stator blades in turbine engines. Chunks of ice break loose from the forward part and get into the air intake, which can damage the aircraft.

Ice sticking to rotor and stator blades reduces their aerodynamic qualities and can cause vibrations, loss of power and even stalling. Air intake blockage is another common difficulty in the case of severe icing and, if equipped with a screen, the jet can stop functioning in a few seconds.

Generally speaking, centrifugal-type engines are less susceptible to icing than axial-flow engines, in which engine failure can occur quickly.

12.6.8 Piston Engines

Most of the problems associated with the icing of piston engines concern icing in the carburetor and on air intakes. The nature and effects of this icing depend on the type of engine as much as the weather.

Carburetor icing happens when flying through a cloud or precipitation, whenever icing of the airframe occurs, and for the same reasons. The problem is exacerbated, however, by the fact that the temperature inside the carburetor may be different from that of the outside air; cooling by expansion, fuel evaporation and water evaporation explain this difference.

12.6.9 Turbine Engines

Axial-flow engines are more subject to engine failure due to icing than are centrifugal-type engines. The icing of air intakes and rotor and stator blades occurs for the same reasons as the icing of the airframe.

Icing is increased, however, by the fact that at the run-up, while taxiing on the ground or climbing at low speed and full power, air sucked in by the air intake is cooled and can form ice at temperatures even slightly above freezing, particularly in clouds and rain, but also in clear air, if it is very moist.

12.10 Icing on Helicopters

Icing can cause serious problems for helicopters, because of the altitude at which they fly. The parts generally affected by icing are the forward surfaces, the windshields, the engines, the main rotor (including the pitch control mechanism and droop restrainers) and the tail rotor.

The effects of icing on the first three areas mentioned are similar to those on fixed wing aircraft, the only difference being that the thinness of the blades and the speed at which they turn mean that rotor blades can very quickly be covered with a thick layer of ice.

In addition, even limited amounts of ice can reduce the blades' aerodynamic qualities. The weight of ice on the main blade, moreover, can cause their ends to droop.

Depending on the model, the blades can strike the tail of the helicopter, causing serious damage. Violent vibrations are felt when the ice breaks off in sheets, unbalancing the rotors. Small helicopters with no anti-icing system can be forced down in the space of a few minutes.

12.7 Anti-Icing Protection

Aeronautical technology has designed two effective systems to protect aircraft from icing. There is the anti-icing system which prevents ice formation on the aircraft, and de-icers which dislodge ice accretion on the surfaces.

The difference is important as, if some anti-icing systems are used as de-icers, they can exacerbate rather than reduce the effects of icing; the water produced by ice being melted by a thermal anti-icing system will flow until it refreezes on a colder part out of reach of the heaters.

The protection systems include liquids, membranes, de-icing boots and heaters.

12.7.1 Liquids

Certain liquids, when applied to the surface of an aircraft, prevent ice from forming. Propeller blades and windshields are often protected in this way, as are leading edges in some cases. The liquids are considered anti-icing devices, as they are used when ice begins to build up.

12.7.2 Membranes

Membranes made of rubber or some similar material can be attached to the leading edges. Air pumped in to them intermittently expands them, which in turn cracks and dislodges any ice accretion. These are de icing devices, as they operate only once ice is formed.

12.7.3 Heaters

Heating vulnerable areas is a very common method of icing prevention. Hot air from the engines or from small, powerful, specially installed heaters is aimed at the wing leading edges, stabilizers and vulnerable parts, and coverings or heating elements are used to protect pitot tubes, propellers and other parts.

12.8 Icing Prevention

The purpose of this section is to help pilots prevent icing, although the list of suggestions does not cover all cases. More detailed information can be obtained from the aviation industry.

- Pilots' reports (PIREPs) are an important source of information on atmospheric conditions. Any air crews who note icing during flight should issue a report of this type. These messages are required, even if the icing was forecast or omitted by the meteorologist.
  A PIREP which confirms the presence of icing is always useful, both for other pilots who are preparing to fly and for meteorologists who are preparing forecasts. Prior to takeoff, pilots should always inform themselves whether there is a risk of icing, or if a PIREP exists which indicates the occurrence of icing.
- It is best to avoid icing zones, even if the aircraft is equipped with anti-icing and de-icing equipment. Since forecasts are based only on atmospheric conditions, and there are thousands of different types of aircraft, it is crucial to consult the manufacturer's instructions. One aircraft may be subject to moderate clear icing, while another may be subject to severe icing.
  Icing is present whenever the ice accretion is such that the de-icing or anti-icing systems are unable to reduce or avoid the danger. If this occurs, divert immediately.
- Prior to takeoff, always inspect the airframe and remove any ice or frost. Ice may disrupt air flow and affect performance.
- In cold weather, avoid where possible taxiing or taking off on muddy ground, puddles or slush; if you have taxied through any of these conditions, make a visual check of the aircraft. Mud can freeze in flight and interfere with some equipment.
- To avoid stalling when climbing through an icing zone, it is important to climb at a true, ie, corrected speed, and to fly slightly faster than normal.
- Use your de-icing equipment before the ice accretion has become too thick. As soon as the equipment becomes less effective, however, change your course or altitude to leave the icing zone as quickly as possible.

- If your aircraft is not equipped with a pitot-static port de-icing system, be on the lookout for false readings on anemometer, variometer and the altimeter.
- It is a good idea to avoid cumuliform clouds wherever possible. Clear ice can form above freezing. The ice normally builds up fastest at temperatures between 0 and 15ºC. Large cumulus and cumulo-nimbus clouds are good producers of clear ice: avoid them.
- In stratiform clouds, you can easily avoid icing by changing altitude, either to a level where temperatures are above 0ºC or where they are below 10ºC. There is often little likelihood of icing at these levels. Rime icing in stratiform clouds can be extensive horizontally.
- In frontal conditions of freezing rain, you should try to climb to a level where temperatures are above freezing. Once you have decided to climb, do so quickly: hesitation can result in additional dangerous ice accretion.
  If you are forced to descend, however, it is imperative that you be aware of the temperature and topography below. Furthermore, if the layer of cold air is fairly thick, 1.5 to 2 km or 5,000 to 7,000 ft, it is highly likely that there will be drizzle underneath the layer of freezing rain.
  While drizzle does not produce icing, if the layer of cold air is thin, the freezing rain will fall as far as the ground and there will be no drizzle. This situation will result in continuous clear ice down to ground level.
- Avoid abrupt manoeuvres when your aircraft is covered with a thick layer of ice, since it has inevitably lost some of its aerodynamic efficiency.
- When your aircraft is iced up, use more power in your approach manoeuvres.

12.8.1 The Worst Icing Conditions

The worst icing conditions occur when an aircraft, whose airframe temperature is at or slightly below freezing, is flying in clouds with a high moisture content containing large supercooled droplets.

Such conditions are normally found in cumulus-type clouds, such as cumulo-nimbus, or at the bottom of layered clouds. The higher the base of the cloud and the closer it is to being just below freezing, the greater the quantity of supercooled droplets.

In addition, the severity of icing depends on the flight time in an icing zone and the type of aircraft. Aircraft with thin wings are more susceptible to icing than those with thicker wings.

12.9 Exercises

1. droplet is said to be supercooled when it:
    - o has frozen to form an ice pellet
    - o is in liquid form at a temperature below 0ºC
    - o forms an ice envelope containing water
    - o is at a temperature of greater than 0ºC, in air at a temperature below freezing
2. Hoarfrost forms on an aircraft:
    - o on contact with freezing rain
    - o if drops formed on the aircraft freeze
    - o on contact with tiny droplets of supercooled water
    - o if water vapour is transformed into ice crystals on the aircraft itself
3. Clear ice forms on an aircraft when:
    - o water vapour freezes on the aircraft
    - o ice pellets strike the aircraft
    - o snow particles strike the aircraft
    - o supercooled water droplets mix and spread out over the aircraft and freeze
4. Large supercooled water droplets are particularly common in
    - o non-turbulent clouds
    - o turbulent clouds

- fog banks

5. Rime forms when:
    - each droplet of supercooled water freezes only partially upon striking the aircraft, and the rest spreads out
    - supercooled water droplets freeze almost instantly on the aircraft, without mixing or spreading out
    - water vapour turns into water on the aircraft, and then freezes
    - water vapour turns directly into ice
6. Turbulent clouds present the greatest risk of icing, because they can contain:
    - large droplets of supercooled water
    - tiny supercooled droplets
    - ice pellets that stick to the aircraft
    - ice crystals
7. An aircraft is flying in clear conditions, and its surfaces are at less than 0ºC. Hoarfrost may form if it enters:
    - a colder zone
    - a moist, warmer zone
    - a cloud with a temperature of less than 0ºC
    - a cloud that is warmer than the surrounding air
8. Freezing rain occurs when:
    - ice crystals melt
    - water vapour has first condensed into water droplets
    - rain falls through a layer of air where the temperature is below 0ºC
    - rain falls through a layer of air where the temperature is above 0ºC
9. An aircraft flies in a layer of stratus through which the ground can be seen. A layer of white crystalline ice forms on the windshield and the wing leading edges:
    - what kind of ice is this?
    - why is this more frequent than the other types in thin stratus?
10. Name four factors determining the icing efficiency on an aircraft in flight.
11. Explain why the water content of a cloud can vary at any time.
12. As far as icing is concerned, what happens when an aircraft's speed is increased in a clear ice zone?
13. At what stage in the formation of a storm cell is the risk of icing greatest?
14. Explain why the risk of icing is low in an area of strato-cumulus from which snow has been falling for some time.
15. An aircraft is flying through a layer of stratocumulus on a hot day in May, and the carburetor ices up. The aircraft climbs above the clouds and the icing stops. Explain why the carburetor ices up below the clouds and not above them.
16. An aircraft is flying in the clouds 3,000 m above an airport. The observations radioed by the airport indicate moderate ice crystal precipitation. What sort of icing should you expect during your descent?
17. Describe the vertical temperature distribution associated with:
    - freezing rain;
    - freezing drizzle.

CHAPTER 13
THUNDERSTORMS AND TORNADOES

Thunderstorms are one of the most dramatic of atmospheric phenomena. From an aeronautical point of view, they present flight conditions that must be studied carefully. Even though experienced instrument pilots who are thoroughly familiar with the structure and life history of a thunderstorm are able to fly successfully through one, it is best to avoid thunderstorms as far as possible.

13.1 Conditions

In all major thunderstorm situations, unstable air stretches from the surface to high levels. The following conditions must be present: high relative humidity at low levels, drier air at high altitude and, very often, some lifting agency, such as a mountain or a cold front.

13.2 Structure and Development

A thunderstorm cloud is made up of separate cells in various stages of development. Horizontally, the cloud mass may cover between 30 and 500 km. Generally speaking, the cells are connected by considerable cloud.

Some thunderstorms may consist of a single cell, but it will not take on the scale of a cell in a multi-cell system. As a thunderstorm develops, each cell grows and reaches a higher altitude than its predecessor.

13.2.1 Cumulus Stage

In its initial stage, every thunderstorm is a cumulus cloud. At this stage, a rising current predominates throughout the cell. The vertical current normally attains its maximum speed in the upper part of the cell and it is not uncommon for the current to reach a speed of 16 m/s. At every level within the current, temperatures are higher than at the same level in the surrounding air. The cell may grow from 2 to 10 km in diameter.

13.2.2 Mature Stage

As the updrafts penetrate to greater heights, the presence of an abundance of ice crystals and water droplets leads to the formation of precipitation. The appearance of precipitation at the surface is the identifying factor that marks the transition from the cumulus to the mature stage of development, for the drag of the precipitation is one of the factors that causes a downdraft to appear.

At first, the downdraft is found only in the middle and lower levels of the cell, but gradually it increases in horizontal and vertical extent, although it never reaches the summit of the cloud.

The downflow of air spreads out along the ground, producing marked changes in surface weather conditions. During this stage, the cell may build to 9 to 12 m (30,000 to 40,000 ft) and, in certain areas, to 20 km (65,000 ft).

Occasionally, the friction between the downdraft and the updraft causes a roll of cloud (scud roll) to form at the leading portion of the storm. The mature phase normally lasts 15 to 30 minutes.

13.2.3 Dissipation Stage

The downdraft gradually spreads throughout the cell, until it occupies the entire cell, except for a portion of the top, where the updraft persists. At this stage, the thunderstorm is said to have reached the dissipation stage. This results in a gradual cessation of rainfall, and the top of the cell frays out into the anvil structure.

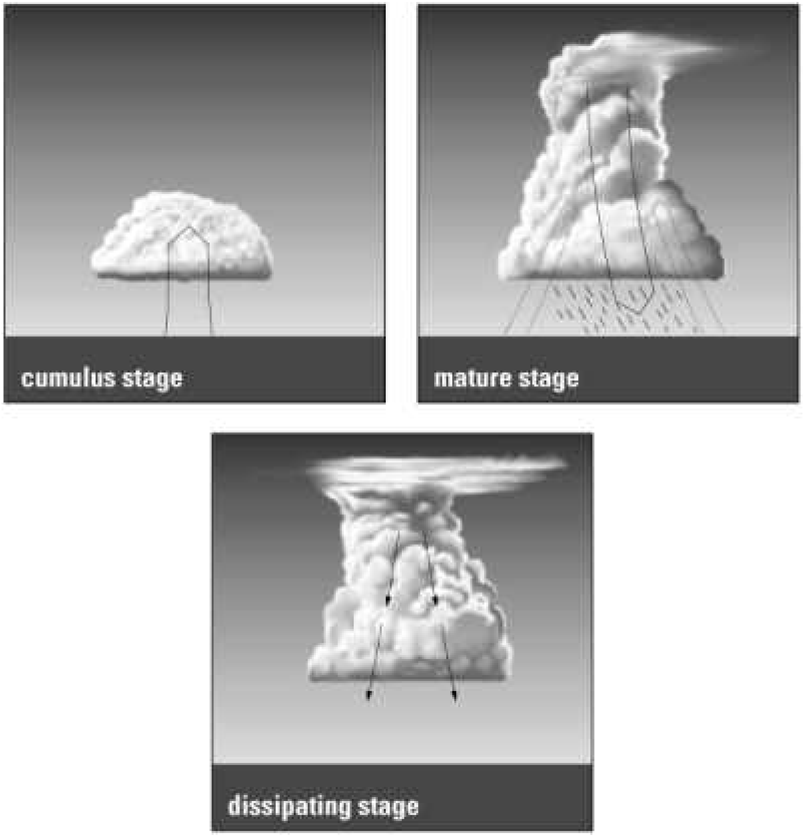


Figure 13-1 Development of a thunderstorm cell

13.3 Types

Thunderstorms are classified on the basis of their process of development. There are air mass thunderstorms and those associated with fronts. In either case, such storms may be highly destructive. But the movement of a front which generates storms is easily detected by satellite photographs or radar. It is therefore easier to forecast frontal thunderstorms than air mass thunderstorms.

13.3.1 Air Mass Thunderstorms

Thunderstorms may form as a result of daytime heating, cold moist air moving over a warmer surface or lifting at mountains. Topography is therefore an extremely important factor.

Even if an air mass displays relatively uniform horizontal temperature and moisture properties, these can be altered locally by topography. For example, the air near the surface of a lake is moister than that inland.

As a result, it is not uncommon during the summer for thunderstorms to form near a slightly sloping bank. Thousands of lakes make it difficult to predict in which area the thunderstorms will develop.

The movement of thunderstorms depends exclusively on high altitude winds. If there is no wind, thunderstorms remain virtually stationary.

- Daytime heating of moist air. As the heading suggests, these thunderstorms form during the afternoon and early evening on hot spring and summer days. They tend to be isolated. At night, as the ground cools, the air is stabilized at lower levels and thunderstorm activity ceases.
- Cold moist air passing over a warm land surface. These thunderstorms have the same properties as those described above. They are common near coastal areas, when onshore winds prevail.
- Cold moist air passing over a warm water surface. In this case, thunderstorms are more common in the early morning during autumn and winter. They are not as large as those that form over land, but are more tightly packed.
- Lifting at mountains. Thunderstorms may form if an unstable flow of air is lifted at a mountain range. In such cases, the storms will be found along the windward side of the range, and will persist as long as the airflow is maintained.

13.3.2 Frontal Thunderstorms

See Chapter 9.

13.4 Weather Conditions

Figures 13-2 and 13-5 illustrate the main characteristics of a mature cell. The cold air pouring out of the cell and along the ground is clearly shown. Normally, the structure of a thunderstorm is more complex and contains several storm cells.

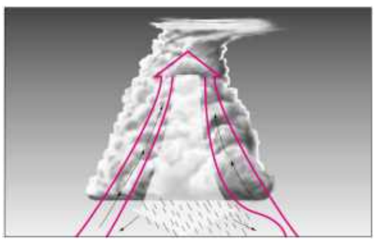


Figure 13-2 Mature thunderstorm cell

13.4.1 Low Ceiling and Poor Visibility

Visibility inside a thunderstorm cloud is often zero. Ceiling and visibility can also be reduced by precipitation and in the vertical space between the base of the cloud and the ground. The resulting restrictions cause the same problems in all similar cases.

The dangers in such cases are greatly increased when combined with those of hail, turbulence and lightning; this makes precision instrument flying virtually impossible.

13.4.2 Rain

At first, the rain associated with a cell covers only a few square kilometres. As the cold air spreads out, the rain initially follows, but, as the cold air spreads further, the rain area lags behind and the rain-free area of cold air increases. As the cell dissipates, the rain area shrinks, while the cold air continues to spread.

13.4.3 Temperature

The temperature near the surface will drop quickly when a thunderstorm passes in the area. The air immediately below the storm comes from cumulonimbus clouds, and is colder than the surface air.

Even though the air from the cloud heats up somewhat as it descends towards the surface, it does not heat sufficiently for its temperature to become as warm as the surface air.

As a result, when a storm passes, there is in most cases a significant drop in surface temperature. Figures 13-2 and 13-5 show downdrafts from cumulonimbus clouds.

13.4.4 Pressure

During the initial stage of a thunderstorm, the dominant updraft causes the pressure at the surface to fall. As the cell passes into the mature stage, the outflow of cold air causes a sudden rise in pressure, followed by a drop when the cell has passed. Changes in surface pressure are frequent and difficult to predict when a storm passes.

13.4.5 Lightning

The electricity generated by thunderstorms rarely poses a danger to aircraft, although it may cause damage which interferes with the work of the pilot and crew. Lightning is the most spectacular element of electrical discharges.

Even though lightning normally occurs in areas where the temperature is between 0º and -4.9ºC, lightning frequently strikes places where the temperatures are quite different. For example, lightning generated by a cloud may hit the ground, even though the ground is much warmer than the zone in which it originates.

A lightning strike may damage the fuselage by perforating it and, most importantly, it may damage electrical navigation and communications equipment. It is advisable to retract the antennas in order to protect radio equipment at the least sign of lightning.

Lightning can also produce persistent false readings on a magnetic compass, and has been suspected of igniting fuel vapours and thereby causing an explosion. It should nonetheless be noted that serious accidents due to lightning are extremely rare.

Pilots may, moreover, be temporarily blinded by lightning, to the point where they are incapable of navigating by sight or by instruments for a brief period. We suggest that this problem be avoided by switching on the aircraft's interior lights.

Lastly, the increase in the frequency of lightning can be said to be proportional to the increase in a storm's intensity. The reverse is also true. Frequent lightning at night over much of the horizon is a sign of a squall line.

13.4.6 Hail

Hail can occur during the mature stage of cells having updrafts of higher than usual intensity. If the cell is built up diagonally, there is also a possibility that the hail near its peak may be cast out into the clear surrounding air. In such cases, the hail appears to come from overhanging shelves. Hail occurs most frequently at altitudes of between approximately 3,000 and 4,500 m (10,000 and 15,000 ft).

Figure 13-3 Damage caused by hail

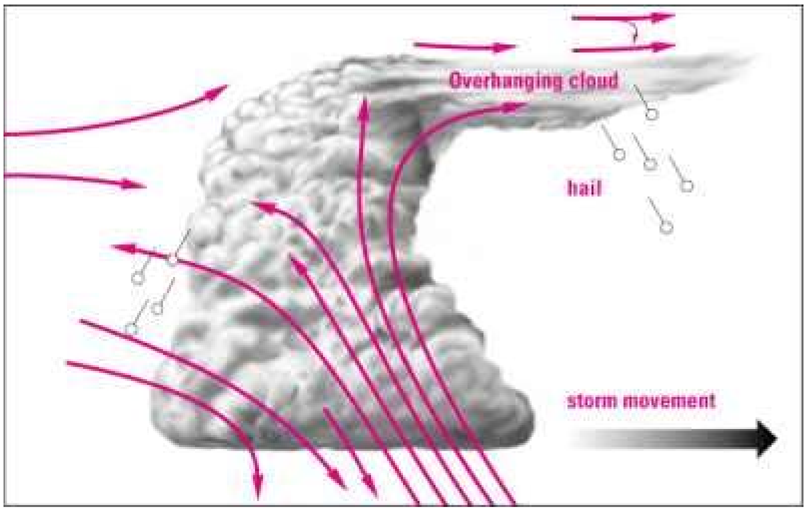


Figure 13-4 Position of hail in a mature thunderstorm

13.4.7 Icing

Storm clouds comprise fairly strong vertical currents that carry large droplets aloft with such speed that, even with temperatures below -25º C, the cloud water content can be relatively high.

The probability of icing is probably greatest in the upper portion of cells that have just reached maturity. The concentration of droplets diminishes as the cell passes through the mature phase, so that in the dissipation stage, the upper part of the cell consists mainly of ice crystals; at that point, icing problems are much less severe.

13.4.8 Wind

When a cell is in its cumulus stage, a gentle inflow towards the cell takes place. As the downdraft develops, the air it contains spreads out along the surface, undercutting the warm air, so that it resembles a miniature cold front.

This is called a gust front. When the leading edge of the cold air is accompanied by an abrupt windshift, this wind, especially on the surface, is accompanied by strong and occasionally destructive gusts.

13.4.9 Gusts

Gusts are momentary and irregular variations in wind speed, caused by small eddies embedded in the general airflow. In a thunderstorm, they result from the shear movements between currents.

Once such an eddy has formed, it can travel some distance from its point of origin. Gusts are the cause of pitching, rolling, yawing and acceleration, with no systematic change in altitude.

Like other flight conditions in the eddies forming gusts, the stress applied to the aircraft increases with its speed. Gusts experienced during flights as part of the "Thunderstorm" project had a diameter of 8 to 250 m, although the most frequent diameter was 45 m.

Within the cloud, gusts intensify with altitude, as far as 1,500 to 3,000 m (5,000 to 10,000 ft) above the cloud top. In general, gusts are weaker near or beneath the cloud base, although even there they can appear quite strong to some pilots.

In the lowest 30 m above the ground, strong turbulence caused by the friction of cold air spreading over the ground has some impact on low-altitude flight, take offs and landings.

The extent of such turbulence depends on the wind speed in the cold air and the nature of the ground. When strong downdrafts spread out over rough terrain, the gusts can be as strong as in the cloud.

At lower levels, gusts are strongest when the downdraft reaches the ground, ie, shortly after the rainfall begins. A ring of strong gusts spreads out toward the edges of the rain zone, travelling fastest in the direction of the prevailing wind.

Although gusts appear to be most intense at the leading edge of the cold air, it is very important to note that taking off into the wind, after the arrival of the cold air, will point the aircraft into the zone of downdrafts from the cloud cell.

13.4.10 Microbursts

Microbursts are intense downdrafts which are produced on a small scale underneath a violent thunderstorm; when they reach ground level, they blow outwards from the centre of the base of the thunderstorm. They are the cause of horizontal and vertical shearing, which can be extremely dangerous for all types and categories of aircraft, particularly at low and critical altitudes.

They can also overturn small aircraft parked on the ground. Because of their small size, short duration and the fact that they can occur where there is no precipitation, microbursts are difficult to detect without the proper equipment.

They can be detected by meteorological radars or conventional wind-shear detection systems; all turbulent clouds at medium or low levels can produce microbursts.

During take off and landing, the shearing effect of microbursts may affect performance sufficiently to pose a serious risk of contact with the ground. It is therefore advisable to avoid flying in an area where the presence of microbursts is suspected.

Characteristics of microbursts

- Aloft, they have an approximate diameter of 2 km (6,500 ft), while on the surface they blow approximately 4 km or 13,000 ft from their axis.
- They change from vertical draughts as strong as 30 m/s (58 knots) aloft to horizontal winds as high as 150 km/h (80 knots) on the surface. The vertical downdrafts can reach right down to ground level.
- They can be either dry or moist. In wet areas, microbursts are normally accompanied by heavy rain. In dry areas, the precipitation dissipates before it reaches the ground and virga occurs.
- Microbursts rarely last more than 10 minutes, and their maximum intensity lasts approximately 2 minutes. Several microbursts can be expected in the same area.
- Dry microbursts generate surface dust eddies. Winds from the opposite direction over a short distance, accompanied by turbulent cells, are also an indication of the presence of microbursts.

13.4.11 Turbulence

In a cloud, turbulence consists of sustained, non-horizontal air currents; during a thunderstorm, such currents are continuous above the entire area. In addition to buffeting aircraft in flight, the primary effect of turbulence is to cause changes in altitude.

During the active stage of the cell, the cloud is almost entirely shot through with such turbulence. In Section 2, we stressed that an updraft predominates in the early stages, while downdrafts are predominant during the final stage of a thunderstorm.

The updraft associated with the development of cumulus is generally less than 7.5 km (24,000 ft) wide, although it can occasionally extend to 12 km (39,000 ft). During the final stage, the updraft is almost entirely confined to the zone between 3 and 4.5 km (10,000 to 14,000 ft).

Downdrafts are slower and narrower than updrafts. Downdrafts pierce the base of the cloud and stop near the ground, where the cold air spreads out horizontally. The current reaches its maximum speed during the mature phase, and decreases in intensity during the dissipation stage.

Aircraft participating in the "Thunderstorm" project experienced changes in altitude of more than 150 m (500 ft) in half the currents encountered in a cloud. If a pilot tries to maintain course by flying into a cloud, he will have to engage in corrective manoeuvres for half the currents he meets. Under such circumstances, the airframe will be subject to additional stress, and changes in altitude can cause the engine to stall or die.

Underneath the cloud, the main current is the cold downdraft associated with the precipitation zone. Although it begins to spread out and slow down before reaching the ground, it can have a significant effect at altitudes of less than 300 m (1000 ft) in the precipitation zone.

Generally speaking, currents of this type do not extend more than 5 km horizontally. Pilots may encounter more than one current of this type by flying across several rain zones.

It is nonetheless highly unlikely that two downdrafts will be closer than 5 km (16,000 ft) apart. In a rain zone, downdrafts can reach speeds of 6 m/s (12 knots) or more.

The drop in altitude experienced during flight through a downdraft under a cloud cell depends on the extent and speed of the current and the speed of the aircraft.

It is, however, unlikely that larger and faster aircraft will lose more than 450 to 600 m (1,400 to 2,000 ft) as a result of the current alone. At heights of under 600 m (2,000 ft), the current normally reaches its maximum width, but its speed is low, and so the pilot has time to make the necessary corrections.

Watch out for cumulonimbus, however: all cumulonimbus contains hazardous turbulence, which can easily damage an airframe during a severe thunderstorm. The strongest turbulence occurs with shear between updrafts and downdrafts.

Shear turbulence is encountered up to thousands of metres above the summit and up to 30 km (9,800 ft) laterally from a severe storm. A low level turbulent area is the shear zone between the downdraft that races toward the ground and the surrounding air.

Often a roll cloud on the leading edge of a storm marks the eddies in this shear. The roll cloud is most prevalent with cold frontal or squall line thunderstorms, and signifies an extremely turbulent zone.

The first gust causes a rapid and sometimes drastic change in surface wind ahead of an approaching storm.

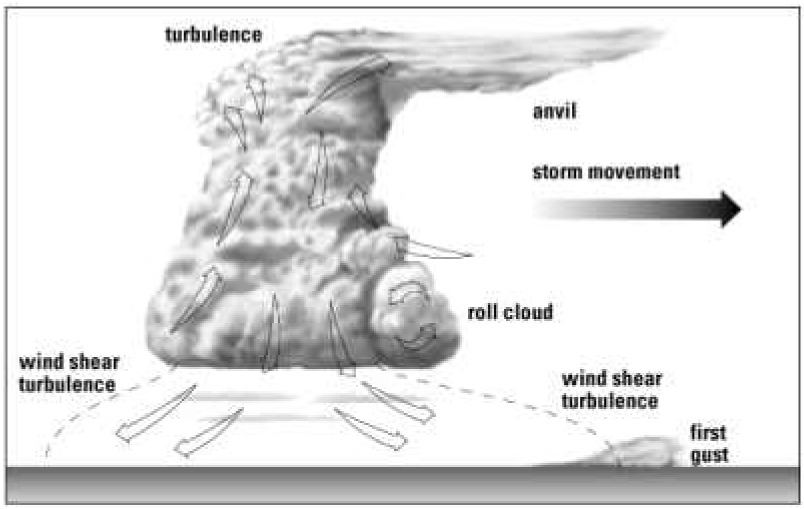


Figure 13-5 Diagram of a thunderstorm cloud showing the location of areas of turbulence


Figure 13-6 Cumulonimbus

13.4.12 Squall Lines

A squall is a violent variation of the wind which occurs along a narrow, mobile line. This line is very often accompanied by downpours or thunderstorms. It often develops ahead of a cold front in moist, unstable air, but it may also develop in unstable air far removed from any front.

A line may be too long for aircraft to easily detour and the resulting conditions may be too severe to penetrate. It often contains severe multi-cell thunderstorms, and therefore presents some of the most hazardous weather for aircraft.

A line may form rapidly, reaching maximum intensity during the late afternoon and the first few hours of darkness.

13.4.13 Funnel Clouds, Tornadoes and Waterspouts

The most violent thunderstorms draw air into their cloud bases with great vigour. If the incoming air has any initial rotating motion, it often forms an extremely concentrated vortex from the surface well into the cloud.

Meteorologists have estimated that wind in such a vortex can exceed 375 km/h; pressure inside the vortex is accordingly very low. The strong winds gather dust and debris, and the low pressure generates a funnel-shaped cloud extending downward from the cumulonimbus base as far as the ground. If the cloud does not reach the surface, it is a funnel cloud.

Funnel clouds are very dangerous, although they are a valuable indicator of a strong wind shear at ground level, where neither dust nor debris provides a visual indication of the powerful vortex sweeping the ground.

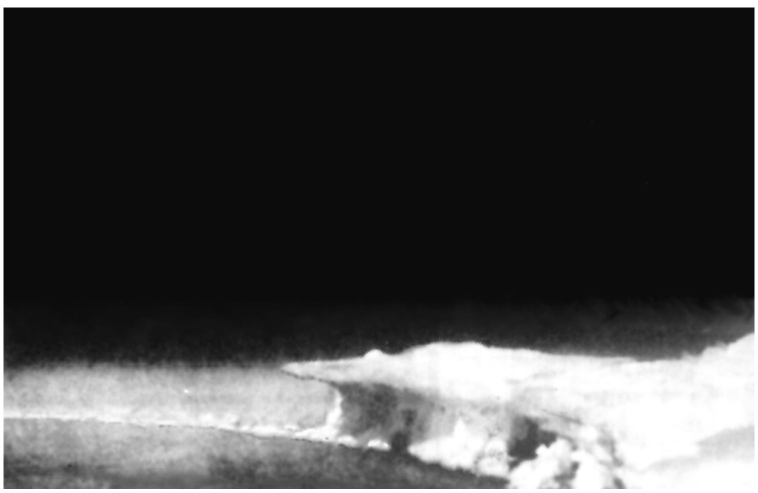


Figure 13-7 Funnel cloud

A funnel cloud which touches a land surface is a tornado: this is extremely destructive, both to aircraft on the ground and in flight.

Figure 13-8 Tornadoes

Tornadoes are sometimes produced by isolated thunderstorms, but they most often result from multi-cell thunderstorms associated with cold fronts or squall lines.

An aircraft entering the vortex of a tornado will in all likelihood sustain structural damage. Since the vortex is hidden by the cloud, it is advisable to be suspicious of all thunderstorms.

Figure 13-9 Tornado

Figure 13-10 shows the internal and external currents of a thunderstorm cell which includes a tornado. In this figure, point (1) indicates the location where the hot, moist air gradually rises.

In (2), the resulting updraft is reinforced by the air from the south sector. If strong enough, it will reach the coldest layers of the atmosphere, where the vapour it contains (3) condenses and creates the cloud known as cumulonimbus.

In rising, the hot air cuts across winds of varying directions and speeds, and causes a spiral movement (4). Since the shape of the funnel gradually narrows at higher altitudes, it creates an increase in the rotation speed, resulting in a twist similar to that of a skater.

The cumulonimbus grows to such a size that the winds aloft are systematically diverted up, down and to the side (5). It can happen that the rotation movement causes a further gyration (6): this time, that of the downdrafts. Finally, under certain conditions, the downdrafts combine to form this intense, always dangerous vortex, which touches the ground and is known as a tornado (7).

If the funnel touches water, it is called a "waterspout".

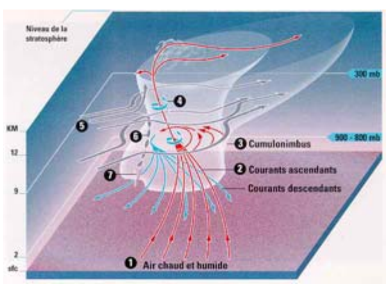


Figure 13-10 Waterspout

Violent thunderstorms and tornadoes often produce cumulonimbus mamma clouds. The cloud displays rounded forms resembling udders along its base, which are a sign of violent turbulence. Surface aviation reports specifically mention this type of hazardous cloud.

Figure 13-11 Cumulonimbus mamma clouds indicating extremely unstable conditions

13.5 Recommendations

13.5.1 Avoid Thunderstorms

- Don't land or take off in the face of an approaching thunderstorm. A sudden wind shift or low-level turbulence could cause a loss of control.
- Don't attempt to fly under a thunderstorm, even if you have good visibility. Turbulence under the storm could be disastrous.
- Detour around thunderstorms covering more than half of an area, either visually or by airborne radar.
- Don't fly without weather radar into a cloud mass containing scattered embedded cumulonimbus.
- Give a wide berth (at least 30 km) to any thunderstorm identified as severe or which produces an intense radar echo. This is especially true under the anvil of a large cumulonimbus.
- If you have to overfly a violent thunderstorm, clear the top by at least 300 m altitude for every 10 knots an hour of wind speed at the cloud top. This would far exceed the altitude capability of most aircraft.
- Do remember that vivid and frequent lightning indicates a severe thunderstorm.
- Do regard as severe any thunderstorm which tops 10 km or higher, whether the top is visually sighted or determined by radar.

13.5.2 Inside a Thunderstorm

If you can't avoid entering a thunderstorm, the following are some dos and don'ts:

- Fasten safety belts and secure all lose objects.
- Plan your course to take you through the storm in minimum time.
- To avoid the most critical icing conditions, establish a penetration altitude below the freezing level or at a level colder than -15 C.
- Turn on heating for the pitot tube and carburetor. Icing can be rapid at any altitude and cause almost instantaneous power failure or loss of air speed indication.
- Reduce your air speed before penetrating areas of turbulence - turn up cockpit lights to lessen the danger of being temporarily blinded by lightning.
- Do keep your eyes on your instruments - don't change power setting; maintain settings for reduced airspeed.
- Let the aircraft "ride the waves".
- Corrective manoeuvres to maintain constant altitude just increase structural stresses on the aircraft.
- Don't turn back once you are in a thunderstorm.

13.6 Exercises

1. Name three prerequisite conditions for the formation of a thunderstorm.
2. Draw a thunderstorm cell in the three stages of its development.
3. Why do isolated thunderstorms not associated with a front dissipate during the evening?
4. Why does thunderstorm activity associated with a cold front frequently persist during the night, even if it is no longer isolated?
5. Name four hazards which pilots may face during thunderstorms.
6. Why is it dangerous to land during a thunderstorm?
7. A violent thunderstorm is approaching. What damage may parked aircraft suffer as the storm passes over the aerodrome?
8. Some weather elements undergo variations when a storm becomes mature. Describe the changes that are to be expected in:
    - ground speed and wind direction
    - ceiling
    - visibility
    - temperature

  - precipitation
  - pressure
9. What is a microburst?
10. Microbursts can be produced underneath a storm where there is no precipitation. True or false?
11. Dangerous turbulence is present in every cumulonimbus cloud. True or false?
12. What is a squall line?
13. Tornadoes, funnel clouds and waterspouts are formed from cumulonimbus clouds in which a vortex causes severe windshear. True or false?

CHAPTER 14
TURBULENCE AND MOUNTAIN WAVES

Everyone who flies encounters turbulence at some time or other. Atmospheric turbulence occurs when air currents vary greatly over short distances. These currents range from mild eddies to powerful vortices.

Turbulence can be defined as a disordered, persistent agitation in air flow. An aircraft passing through zones of turbulence experiences changes in acceleration from all directions, which jostle it from its smooth flight path. Turbulence ranges from bumpiness (which is annoying to passengers), to severe jolts that can structurally damage the aircraft or injure its passengers.

Aircraft reaction to turbulence varies with the difference in wind speed in adjacent currents, aircraft size, wing loading, air speed and altitude. When an aircraft moves rapidly from one current to another, it undergoes rapid changes in acceleration. If the aircraft moves more slowly, the changes in acceleration are more gradual.

If two different aircraft enter the same turbulence zone, it is possible that the pilots will report different intensities of turbulence in their PIREPs.

Rule number 1 of flying through turbulence is to reduce airspeed in line with the manufacturer's recommendations.

14.1 Intensity of Turbulence

The intensity of turbulence can be defined in terms of its impact on flight.

- **Light turbulence (LGT)** causes slight momentary irregular changes in altitude, trim, pitch, roll, yaw, etc.
- **Moderate turbulence (MDT)** Similar to light turbulence, but of greater intensity. It involves changes in altitude or trim, but the aircraft still remains under control. It normally causes variations in indicated air speed.
- **Severe turbulence (SEV)** Causes significant, abrupt changes in altitude or trim. It normally involves large variations in indicated air speed, and the pilot may lose control of the aircraft momentarily. A SIGMET must be issued when such turbulence is encountered.

Knowing where to expect turbulence helps a pilot avoid or minimize passenger discomfort. The main causes of turbulence are:

- convective currents
- obstructions to windflow and
- windshear

Turbulence also occurs in the wake of moving aircraft, whenever the airfoils exert lift. This is called lift-wake turbulence.

14.2 Convective Currents

Convective currents are a common cause of turbulence, especially at low altitude. Such currents are highly localized vertical air movements, both ascending and descending. For every rising current, there is a compensating downward current. Downward currents frequently occur over broader areas than do upward currents, and therefore have a slower vertical speed than do rising currents.

Convective currents are most active on warm summer afternoons, when winds are light. Heated air near the surface creates a shallow unstable layer, and the warm air is forced upward. This convection increases in strength as surface heating increases.

Convective currents can extend several thousand metres above the surface, resulting in rough, choppy turbulence. This condition can occur in any season after the passage of a cold front.

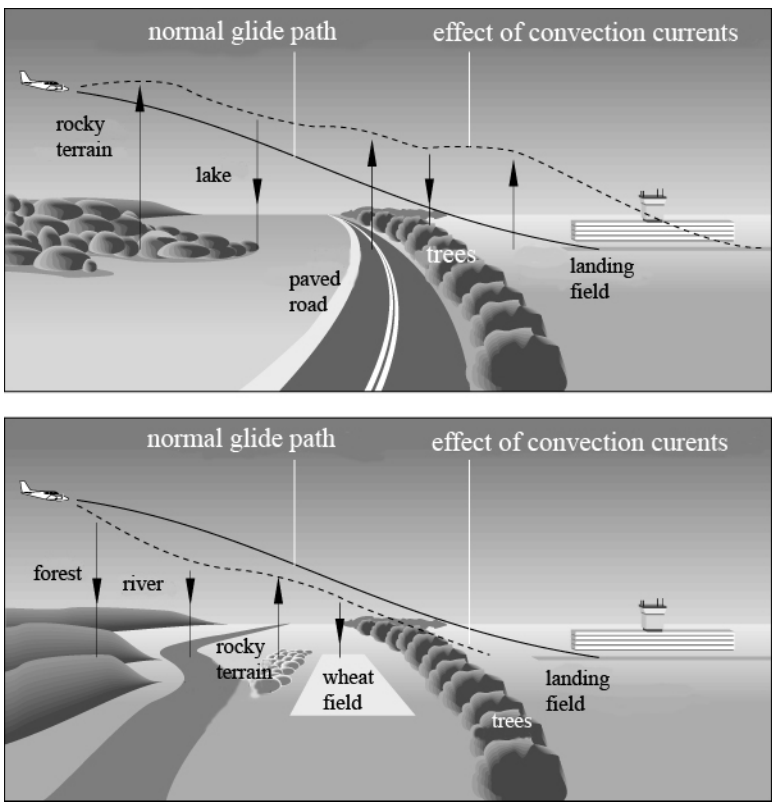


Figure 14-1 During final approach, predominately upward currents tend to cause the aircraft to overshoot, while predominantly downward currents tend to cause the aircraft to undershoot

Figure 14-1 illustrates the effect convective currents have on aircraft approaching to land. Turbulence on approach can cause abrupt changes in air speed and may even result in a stall or hazardous deceleration at a critically low altitude.

To avoid this danger, increase airspeed slightly over normal approach speed, even if this procedure may appear to conflict with the rule of reducing airspeed for turbulence penetration.

Fair weather cumulus clouds, seen on sunny afternoons, are signposts in the sky indicating convective turbulence. This turbulence originates in a convective current which, after stabilizing itself at an altitude of equivalent temperature and cooling to saturation point, has created a cloud, whose peak generally indicates the upper limit.

Pilots can expect to encounter turbulence beneath or in the clouds, while the air is generally smooth above the clouds. You will find it most comfortable to fly well above the cumulus.

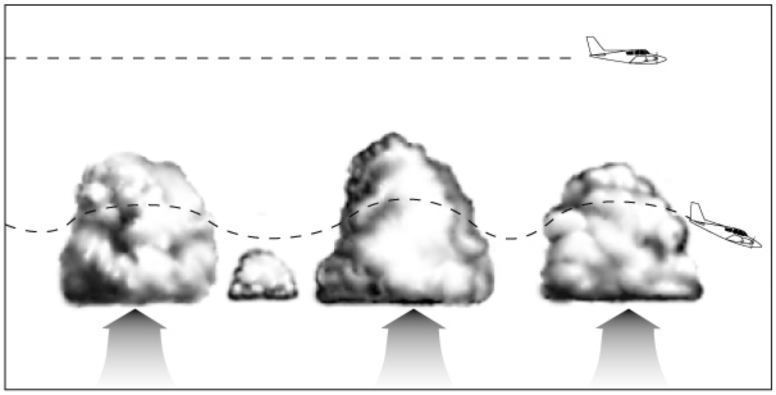


Figure 14-2 Avoiding turbulence by flying above convective clouds

When convection extends to very great heights, it develops large cumulus congestus (TCU) cloud and cumulonimbus (CB) with anvil-shaped tops. The cumulonimbus gives visual warning of violent rising and descending convective turbulence.

When the air is too dry for cumulus to form, convective currents can still be present and active. The pilot has little visual warning of their presence until he encounters turbulence.

14.3 Obstacles to Wind Flow

Obstructions such as buildings, trees and rough terrain disrupt smooth windflow into a complex snarl of eddies, as illustrated in Figure 14-3. An aircraft flying through these eddies experiences mechanical turbulence.

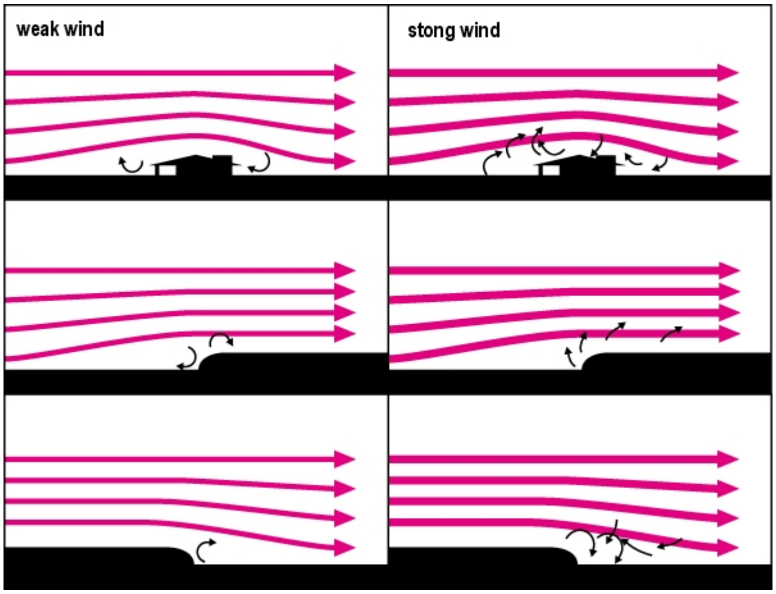


Figure 14-3 Turbulence caused by wind blowing over rough terrain or a building

The degree of mechanical turbulence depends on wind speed and the roughness of the obstructions. The higher the speed and/or the rougher the surface, the greater the turbulence.

A feature of this type of turbulence is the fact that the wind carries the turbulent eddies downstream - how far depends on wind speed and the stability of the air. The more unstable the air, the larger the eddies. Instability accentuates the eddies, while stable air causes them to dissipate slowly.

Mechanical turbulence can also cause cloudiness near the top of the unstable layer. However, the type of cloudiness tells you whether it is from mechanical mixing or convection.

Mechanical mixing produces stratocumulus clouds in rows or bands, while convective clouds form at random. The cloud rows developed by mechanical mixing may be parallel or perpendicular to the wind, depending on meteorological factors.

The immediate airport area is especially vulnerable to mechanical turbulence, which invariably causes gusty surface winds. When an aircraft is in a low-level approach or a climb, airspeed fluctuates in the gusts, and the aircraft may even stall.

During extremely gusty conditions, maintain a margin of airspeed above normal to allow for changes in airspeed caused by gusts. Airport structures upwind can cause control problems, even when the aircraft is taxiing on the runway.

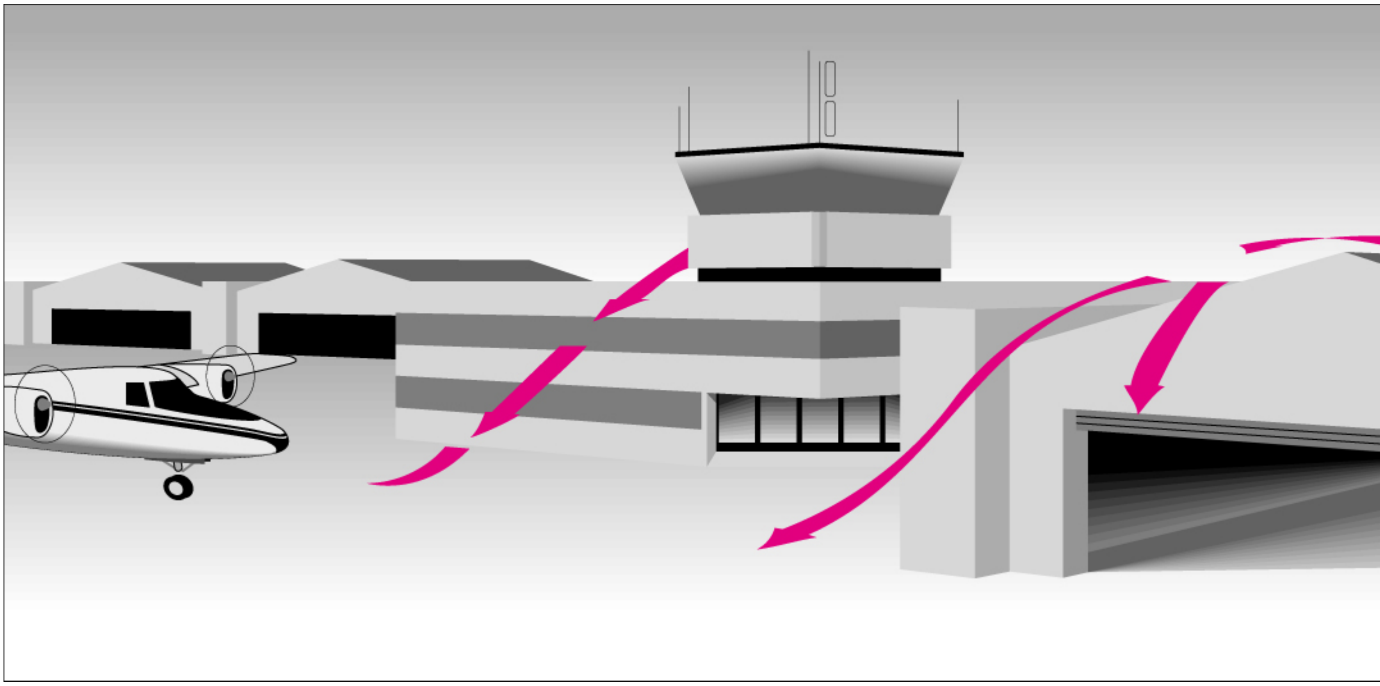


Figure 14-4 Turbulent air in the landing area

Mechanical turbulence can affect low-level flight almost anywhere, and is even present at altitudes higher than mountain tops.

14.3.1 Flying Over Mountainous Terrain

The mechanical turbulence caused by a succession of rolling hills is not generally hazardous, merely uncomfortable; climbing to higher altitude should reduce its effects. When flying over rugged hills or mountains, however, you may have some real turbulence problems and dangers.

When wind speed across mountains exceeds 75 km/h (40 knots) there is a strong probability of turbulence. Where and to what extent vertically and horizontally depends largely on stability.

Unstable air crossing a mountain chain is conducive to turbulence on the windward side. If sufficient moisture is present, convective clouds form, intensifying the turbulence on the leeward side and below the crest.

When the unstable air moves over a mountain peak, which acts as a barrier, it then flows downward often in the form of relatively violent downdrafts. The speed of the descending air can sometimes exceed an aircraft's climbing ability, and cause a collision with the underfeature.

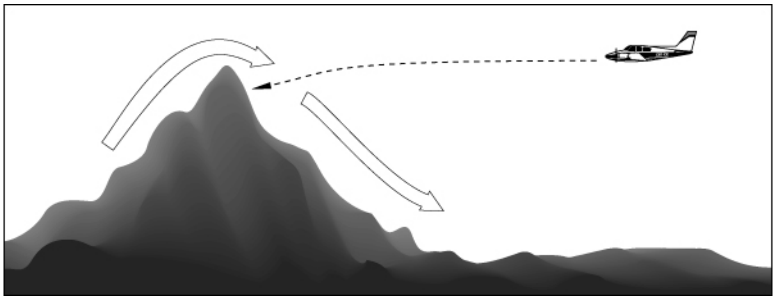


Figure 14-5 Windflow in mountainous areas; dangerous downdrafts may be encountered on the lee side

In the process of crossing a mountain chain, mixing reduces the instability of an air mass considerably. This is reflected in particular in the formation of stratiform clouds. The hazardous turbulence associated with it is accordingly limited to the area around the summit.

When approaching mountains from the leeward side during strong winds, begin to climb well away (50 to 80 km) from the mountains. Climb to an altitude of 1,000 to 1,500 m above the mountain tops before attempting to cross. The best procedure is to approach a ridge at a 45 angle to allow you to beat a rapid retreat to calmer air although you may have to choose between turning back or detouring around the obstacle.

Flying above mountain passes and valleys is not a safe procedure during high winds, and the mountains have the effect of increasing wind speed and turbulence significantly. If winds at mountain top level are strong, go high or go around.

Surface wind may be relatively light in a valley surrounded by mountains when the wind aloft is strong. If you are taking off in the valley, climb above mountaintop level before changing course and maintain sufficient lateral clearance from the mountains to allow for a safe recovery if you are caught in a dangerous downdraft.

14.3.2 Mountain Waves

When stable air crosses a mountain barrier the size of the Rockies, the flow across the barrier is "laminar" and forms superimposed layers marked by waves, comparable to waves on a water surface, which creates exactly the configuration of the summits.

Since these waves merely emulate this configuration, they are tantamount to a corridor though which wind flows rapidly. They are called "standing" or "mountain" waves because of their association with mountains. The wave pattern may extend 150 km (100 miles) or more downwind.

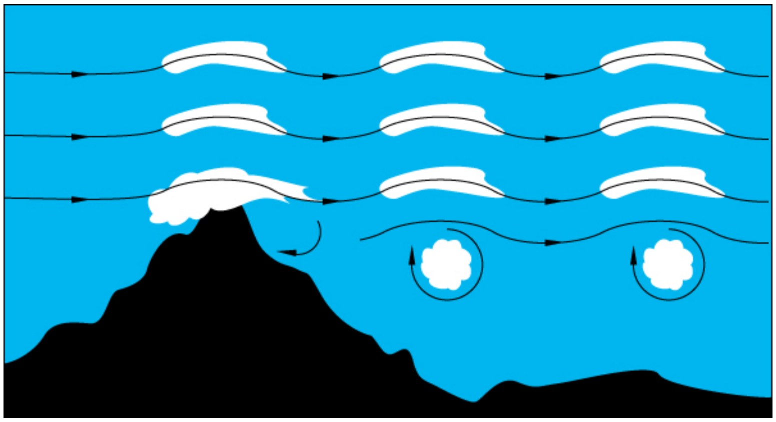


Figure 14-6 Schematic cross section of a mountain wave

Wave crests extend well above the highest mountains, sometimes as far as the lower stratosphere. A rotary circulation is also produced below each wave crest, as shown in Figure 14-6.

The "rotor downstream vortex cloud" forms, as its name implies, downstream and below the mountain peaks. The turbulence it generates can be violent, but the updrafts and downdrafts which develop in the waves can also be violent.

Figure 14-7 Standing lenticular clouds and rotor clouds associated with a mountain wave

Figure 14-7 depicts standing lenticular clouds and rotor clouds. These clouds form along and in the updraft and dissipate along and in the downdraft, and channel the wind, while remaining as stationary as the mountain waves.

The rotor may also be marked by a rotor cloud, indicating the presence of this type of eddying and rotating current. Figure 14-8 shows a series of rotor clouds, each under the crest of the wave. Remember that clouds are not always present to mark the mountain wave: sometimes the air is too dry.

Figure 14-8 Rotor clouds associated with a stationary wave

Always anticipate possible mountain wave turbulence, when winds of at least 75 km/h (40 knots) are perpendicular to a mountain peak.

In mountain waves, the turbulence is sufficiently violent to damage an aircraft. SIGMET are required when mountain waves are encountered.

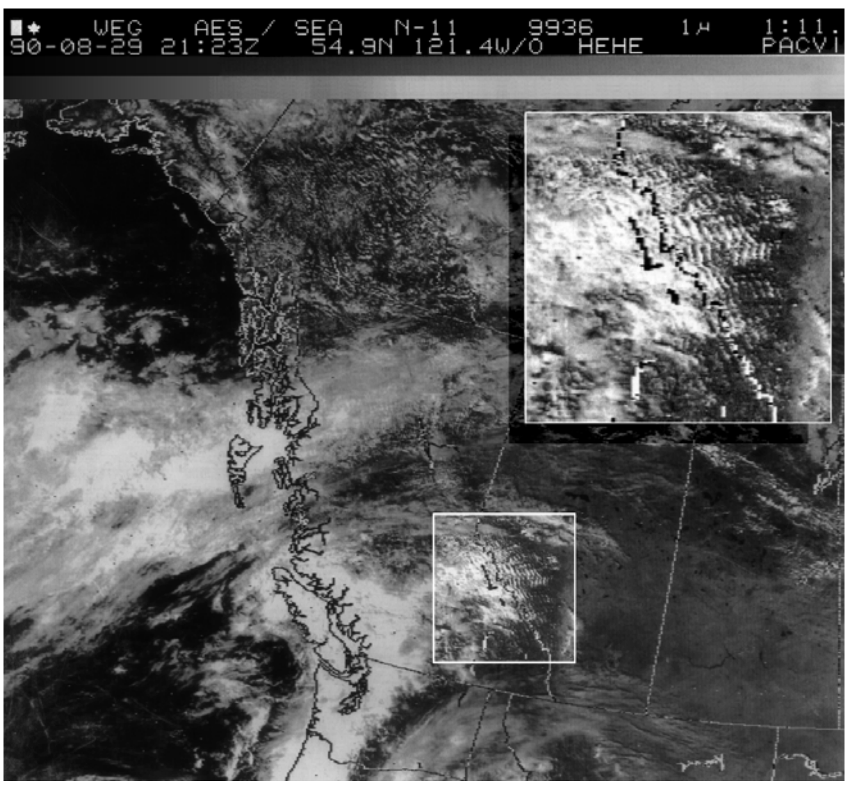


Figure 14-9 Satellite image showing mountain wave clouds in Alberta

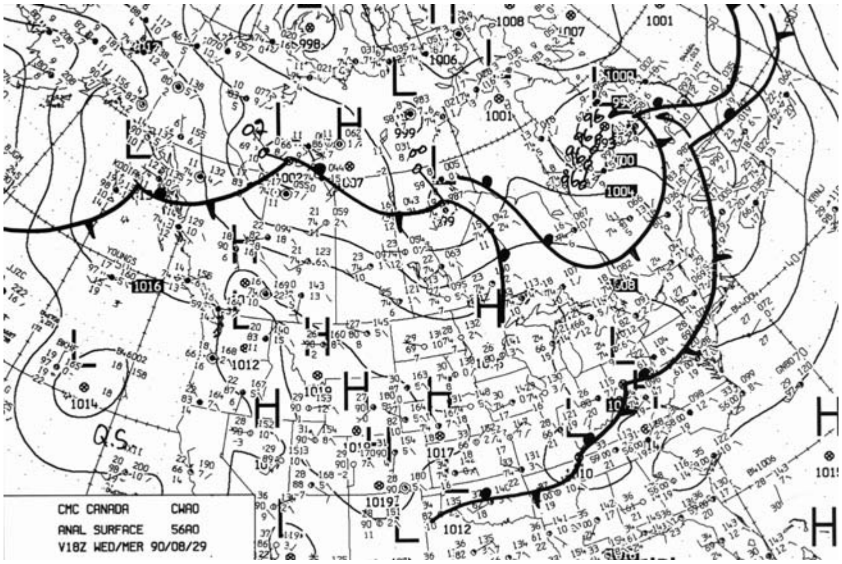


Figure 14-10 Surface map corresponding to the meteorological situation shown in Figure 14-9

14.4 Windshear

In a way, windshear is a spatial variation of the wind vector. It generates eddies between two wind currents of different velocities or direction, or both. Windshear may be associated with either a wind shift or the wind speed gradient at any level in the atmosphere.

14.4.1 Windshear with a Low-Level Temperature Inversion

Above the top of an inversion, often produced by an approaching depression, is a windshear zone created at the confluence of light and relatively strong winds. The eddies generated in the shear zone cause air speed fluctuations as an aircraft climbs or descends.

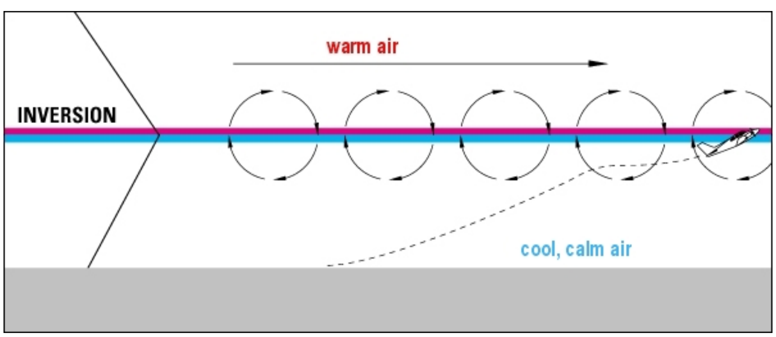


Figure 14-11 Windshear between light and strong winds above an inversion

A similar situation is produced when a depression above the Great Lakes moves towards Quebec; the surface winds often blow from the northeast in the St Lawrence Valley, while the wind at 600 m (2,000 ft) often blows from the south or southwest: this creates a low-level windshear.

This type of phenomenon is most important in winter, as depressions are at their most intense at that time of year. The difference between turbulence, which mainly involves erratic changes in height and trim, and low-level shear is not always apparent below 450 m (1,500 ft).

Low-level windshear (LLWS) results in a rapid loss or gain of air speed. Consequently, in forecasts, all cases of moderate or strong windshear, limited to 450 m (1,500 ft) above ground level, will be identified by the acronym LLWS.

LLWS is virtually impossible to detect from the ground. Its presence can be confirmed only by the observations of pilots in flight. The following principles, however, provide a guide for determining whether a dangerous LLWS exists:

- under 150 m (500 ft), vector over 25 knots
- under 300 m (1,000 ft), vector over 40 knots
- under 450 m (1,500 ft), vector over 50 knots
- under 450 m (1,500 ft), PIREPs report a loss or gain of at least 20 knots of indicated airspeed

If these LLWS conditions are present or forecast with at least four hours notice, a SIGMET must be issued.

14.4.2 Turbulence and Windshear in a Frontal Zone

A front can conceal many dangers. A front can be located between two dry, stable air masses and can be devoid of clouds. Even so, wind changes abruptly in the frontal zone and can induce windshear turbulence. The degree of turbulence depends on the magnitude of the windshear (the size of the angle between the difference in wind directions).

Since winter is the season with the strongest thermal contrasts, it is normal that fronts should be more vigorous then than in summer, despite the occurrence of violent summer thunderstorms.

Be that as it may, turbulence must always be suspected when there is a front. The turbulence may occur at any altitude along the front, or at times even well ahead of a surface cold front. Valleys and mountains can intensify the turbulence associated with a passage of a front.

14.4.3 Turbulence Associated with Windshear in Clear Air (CAT)

High altitude clear air turbulence, in the presence of strong airflow or a jetstream, as described in Chapter 5.

Exercises

1. What is turbulence?
2. Why can two aircraft flying in the same area report different turbulence intensities?
3. Name the three degrees of turbulence.
4. What are the three main phenomena which cause turbulence?
5. How does an aircraft behave when it is approaching a landing in a downdraft?
6. Where should you fly to avoid convective turbulence when you encounter convective clouds?
7. A glider will gain altitude by flying just below a convective cloud. True or false?
8. What is mechanical turbulence?
9. What are the two main factors which affect the degree of mechanical turbulence?
10. When approaching a mountain chain, what should you suspect and what should you do if you encounter convective clouds?
11. What is a mountain wave?
12. Mountain waves occur just above the mountain tops. True or false?
13. What is windshear?
14. What does the acronym LLWS mean?

15. What wind changes are observed above 150 m (500 ft) to indicate the presence of strong LLWS?
16. Is there always turbulence near a front?

CHAPTER 15
FLIGHT PLANNING INFORMATION

Environment Canada provides air crews with all the meteorological information required for safety, much of it transmitted to pilots and air crews by NAV CANADA flight information specialists.

Environment Canada's national meteorological network comprises the Canadian Meteorological Centre (CMC), in Dorval, and two Canadian Meteorological Aeronautical Centres (CMACs) one located in Montreal and one in Edmonton. Each observing station transmits its weather data to the CMC, where the data are analyzed with all the data from the global network to produce forecasts on a global and hemispheric scale.

These analyses and forecasts are subsequently communicated to the CMACs in the form of charts, from which regional and local forecasts are prepared for distribution to a variety of users.

Observation stations.......>	Canadian Meteorological.......> Centre	Weather Environmental Services.......> offices	Users

Weather Briefings

One of the special services commissioned by NAV CANADA and offered to air crews is the preparation of everything that requires a verbal briefing in the context of flight planning, including documentation and all the computer imaging related to radar and satellite charts and data.

The information assembled in this way is intended not only to inform users, but also to provide them with a basis for interpreting subsequent observations and updated forecasts; the material therefore includes a complete analysis of current weather charts and forecasts.

For briefings to be as complete as possible, it is important to provide crucial information at least several hours in advance:

- the specific conditions of the flight
- the point of departure
- the destination
- the flight path
- the intended altitude
- the type of aircraft
- ETD
- ETA
- type of flight: instrument (IFR) or visual (VFR)

Although the weather specialist provides the pilot with information, only the pilot can decide whether or not the weather is suitable for flying, based on his own skills, the aircraft and its equipment.

15.2 Weather Products

The two types of meteorological information of interest to air crews deal with current weather and forecast weather, and take a variety of forms:

Current weather

- hourly reports
- pilot's reports
- surface charts
- charts of data aloft
- radar data
- satellite data

Weather forecast

- Graphic area forecast
- upper-air wind and temperature forecast
- aerodrome forecast
- SIGMET
- AIRMET
- surface weather chart
- upper-air forecast chart
- significant weather chart

15.2.1 Information on Current Weather

- Reports
    - Hourly (METAR) and special (SPECI) reports

      Based on surface data, describe the current weather at a specific time and place, provide frequent, regular information on current weather developments and on the weather observed above the observation point.

        - Pilot's report (PIREP)

      In-flight observation by pilots of current conditions. These may include: cloud types and amount, upper-air winds, turbulence, icing and temperature at specific altitudes.

    - Radar data

      Remote mapping of precipitation zones by means of sweeps at several altitudes

    - Satellite data

      Remote mapping of cloud areas shown on satellite images

- Charts
    - Surface

      Analysis of MSL pressure configuration, location of fronts, precipitation and obstacles to visibility on the surface, based on reports.

- Aloft

  Represents atmospheric conditions reported at standard pressure levels: wind speed and direction, temperature, water vapour content, frontal systems and pressure systems at 850, 700, 500, 250 mb (hPa).

15.2.2 Information on weather forecast

- Reports
  - Graphic area forecasts (GFA)

    All weather elements affecting flight for a specific time period over a specific area up to an altitude of 24,000 ft (7300 m).
  - Upper-air wind and temperature forecasts - FD

    Winds and temperatures aloft at standard pressure levels for a specific time and place up to an altitude of 53,000 ft (16 km).
  - Aerodrome forecast (TAF)

    Forecast conditions affecting takeoff and landing at a specific location up to an altitude of 24,000 feet (7,300m).
  - Amended forecast (AMD)

    Significant change in previous forecast.
  - Flight forecast

    Special briefing for a specific flight, requiring additional information not covered by regular forecasts.
  - SIGMET

    Warning to air crews of existing or forecast dangerous conditions up to a maximum altitude of 45,000 feet (13.7 km).
  - AIRMET

    Warning of potentially dangerous conditions, other than those which generate a SIGMET.
- Charts
  - Surface forecast

    Represents forecast surface pressure patterns and surface front locations at a specific time and predicts weather developments.
  - Upper-air wind and temperature forecasts

    One chart for each of the following levels:

    FL240, FL340 and FL450, above a variety of geographic points.

    - Significant weather charts

    For the layers between either two pressure levels or two flight levels: thunderstorms, cloud layers or significant clouds, height of the tropopause, of jetstreams, turbulence, strong squalls, icing and hail, tropical storms and cyclones, of the position of frontal systems on the surface and, in some cases, the position of the 0 C isotherm at 10,000 ft, and the position on the surface of highs and lows, presented by charts covering the surface at 400 hPa (24,000 ft), from 700 to 400 hPa (10,000 to 24,000 ft) and from 375 to 50 hPa (25,000 to 60,000 ft).

15.3 Universal Time Coordinated (UTC)

Weather information is Universal Time Coordinated (UTC), indicated by the letter Z following the time, expressed using the 24 hour system. When the time zone is not shown, it is assumed that the time is UTC. To interpret local weather effects properly, UTC time must be converted into local time, by subtracting the proper number of hours, as follows:

UTC Subtract	Pacific 8	Mountain 7	Central 6	Eastern 5	Atlantic 4	Newfoundland 3.5

To convert from Daylight Saving time to UTC, subtract one hour less than is shown in the table. For example, Eastern Daylight Saving time = UTC - 4 hours.

Example: to convert 1100Z to Central Standard time you must subtract 6 hours from 1100Z, to obtain 0500 Central Standard time.

15.4 Surface Weather Charts - Their Use and Function

As the name implies, a surface weather chart is a symbolic representation of the weather at the surface for a specific region at a specific time. These charts are prepared using simultaneous observations from weather stations around the world.

The observation data are then analyzed on the basis of pressure distribution, air masses, fronts, precipitation and obstacles to visibility. Once completed, a surface weather chart gives a bird's-eye view of the weather at the time of the observations, ie, 2 or 3 hours before they are issued.

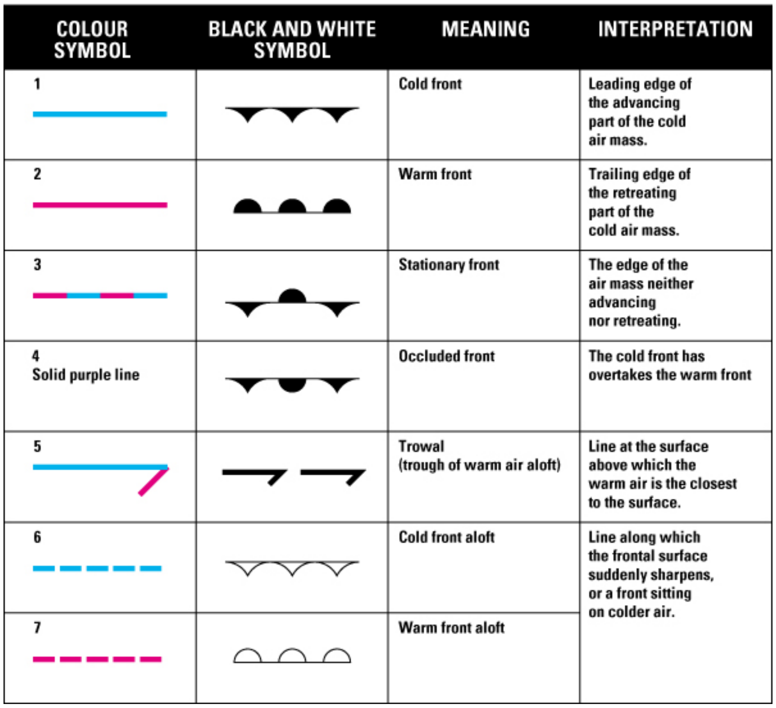
15.5 Pressure Distribution

Pressure distribution as shown on surface weather charts is that at mean sea level (MSL). The analysis is conducted by linking all points of equal pressure, called isobars, with a black line. In Canada, isobars are drawn at 4-hPa intervals on either side of 1,000 hPa, ie, at 992, 996, 1000, 1004, 1008, etc.

15.6 Air Masses and Fronts

Fronts are narrow transition zones between air masses. The presence of four air masses means that there are three major frontal systems.

On a surface chart, the type of front is indicated by a specific symbol, as shown in Figure 15-1.



COLOUR SYMBOL	BLACK AND WHITE SYMBOL	MEANING	INTERPRETATION
1		Cold front	Leading edge of the advancing part of the cold air mass.
2		Warm front	Trailing edge of the retreating part of the cold air mass.
3		Stationary front	The edge of the air mass neither advancing nor retreating.
4 Solid purple line		Occluded front	The cold front has overtakes the warm front
5		Trowal (trough of warm air aloft)	Line at the surface above which the warm air is the closest to the surface.
6		Cold front aloft	Line along which the frontal surface suddenly sharpens, or a front sitting on colder air.
7		Warm front aloft	

Figure 15.1

15.7 Precipitation and Obstacles to Visibility

Surface weather charts, if they are to give an accurate picture of current conditions at the surface, must show, not only pressure configurations, air masses and frontal systems, but also the types and extent of precipitation and obstacles to visibility. These characteristics are also portrayed by means of symbols.

SYMBOL	DESCRIPTION	INTERPRETATION
1 	Green shading	Continuous rain
2 	Green hatching	Intermittent rain
3 	Green period	Rain
4 	Green comma	Drizzle
5 	Green period in the middle of a green triangle	Ice pellets
6 	Green star	Snow
7 	Curved green line (used with period or comma)	Freezing rain (with period); freezing drizzle (with comma)
8 	Green period above an inverted green triangle	Rain shower
9 	Green star above an inverted green triangle	Snow shower
10 	Green "T" with a green lightning symbol	Thunderstorm
11 	Yellow shading	Fog

Figure 15.2

15.8 Observation Times

The main surface weather charts are analyzed using observation data obtained every six hours, starting at 0000Z, and transmitted over the Environment Canada network. The intermediate charts prepared by the CMACs are based on conditions observed at certain specific times.

In all cases, the data supplied on these charts are valid only for the time the observations were made, and are invariably "history" by the time they are available to users.

15.9 Upper-Air Charts - Their Use and Purpose

Upper-air charts complement surface weather charts, by providing information on upper levels. They give an overview of weather conditions aloft.

When used in combination with surface charts, they allow meteorologists to provide a three-dimensional image of weather conditions. Obviously, analyses of surface weather charts and upper-air charts must agree.

The information on these charts is obtained by radiosondes, as compared with the observations from ground or sea level used to draw up surface charts.

Surface and upper-air charts also differ in that the data apply to different kinds of levels; ie, conditions on upper-air charts correspond to specific pressure levels rather than elevations.

15.10 Observation Times

Upper-air observations are made twice a day worldwide, at 0000Z and 1200Z. Each series of charts is therefore issued at 12-hour intervals.

15.11 Content

Upper-air charts tell you more than the changes in altitude of the various pressure levels. For example, studying one of these charts will tell you the wind speed and direction, temperature distribution, and areas with strong temperature gradients. Occasionally, a supplementary analysis will show you, among other things, the areas where the air is near saturation, and areas of significant instability.

Variations in altitude shown for a pressure level are directly related to the general circulation at the pressure level represented on the chart. These variations are shown by joining points where the pressure level above MSL is at the same altitude.

On surface charts, the letters H and L designate high and low pressure areas. Similarly, H and L are used to mark areas where a pressure level is at a high altitude and areas where it is at a low altitude, respectively.

15.12 Determining Wind Direction and Speed

Contour lines can be used to determine the wind direction at a specific time. Air flows parallel to the contours, so that when pressure levels are lower to the left than to the right, you will have the wind at your back.

In other words, if you turn your back to the wind, pressure levels will be lower on your left than on your right. Winds move in a clockwise direction around a high-altitude pressure-level area, and inversely around a low-altitude pressure-level area.

In addition to indicating the altitude of a pressure level and the wind direction, the configurations formed by the contour lines provide a good indication of the wind speed. The closer the contour lines, the higher the wind speed.

Isotachs join points of equal wind speed. Wind speed is accordingly determined by studying both contour lines and isotachs.

15.13 Pressure Levels and Charts

The following table reviews the pressure levels for which upper-air charts are prepared, and their average altitudes.

PRESSURE LEVELS	ALTITUDE in feet (average)	ALTITUDE in metres (average)
850 hPa (mb)	5,000	1,500
700 hPa (mb)	10,000	3,000
500 hPa (mb)	18,000	5,500
250 hPa (mb)	34,000	10,400

The following table summarizes the symbols used on the various upper-air charts, and their meaning.

CHART **All pressure levels**	**SYMBOL** **Solid line**	**INTERPRETATION** **Isohypses: lines that join points of equal altitude of a pressure level above MSL.**
850 and 700 hPa	Dotted red or black line	Isotherms: lines that join points of equal temperature (5ºC) intervals.
500 hPa (preliminary)	Dotted black line	Vortex: a measurement of rotation of the air used by forecasters.
500 hPa (complete)	Dotted black line	The thickness of the 1,000-500 hPa layer indicates the average temperature in this layer.
250 hPa	Dotted black line	Isotachs: lines that join points of equal wind speed (regardless of direction).
250 hPa	Dotted areas	Indicate areas of maximum wind speed at the 250 hPa level. The zones are 60 to 90, 120 to 150 and 180 to 210 knots.

15.4 Weather Forecast Charts

Surface and upper-air weather charts, although they give a picture of the weather at a specific place and time, are of rather limited usefulness, since they represent conditions at the time of observation, and so are quickly outdated.

For two major reasons, that delay is a critical factor in flight planning, even though it is inevitable in view of the constant, often rapid, change and movement in systems and the resulting sometimes major changes in conditions.

For example, a system which produces considerable cloud and abundant precipitation may lose its intensity in a few hours. While an unexpected improvement in conditions is normally gratefully received, the reverse - an unexpected deterioration - is also possible and may have more serious consequences.

It is essential to anticipate the changes that are likely to occur after analysis of observations on a surface weather chart, surface and upper-air forecast charts is prepared. These charts indicate the conditions expected in a specific area at a specific time.

When used in conjunction with analyses, forecast charts are extremely useful for flight planning, since they describe the anticipated weather changes over a period of up to 48 hours. Briefing officers, as well as pilots, frequently use charts which combine surface and upper-air forecasts.

15.5 Exercises

- What Department provides weather information across Canada?
- Weather services are available to air crews only. True or false?
- List two ways of obtaining a briefing prior to takeoff.
- Why is it necessary that pilots understand some of the causes of forecast weather?

- Mark the information formats that relate to present or past conditions with a "P", and those that relate to forecast conditions with an "F".
    - o radar
    - o report to graphic area forecast
    - o upper-air chart
    - o upper-air forecast chart
    - o significant weather forecast chart
    - o hourly report
    - o forecast surface chart
    - o flight forecast
    - o surface weather chart
- Which in-flight message a pilot should request from the airport to know if there is severe icing on his way?
- What is the main difference between the scope of an area forecast and that of a flight forecast?
- What do you add to or subtract from universal time (UTC) to obtain Pacific time in July?
- Convert:
    - o 0000Z to Eastern Standard time
    - o 1700Z to Newfoundland Standard time
    - o 2300Z, to Mountain Daylight time
    - o noon at Central Standard time to UTC
- On the surface weather chart in Figure 15-3, which symbols represent the following conditions?
    - o continuous freezing rain
    - o snow flurries
    - o cold front
    - o intermittent drizzle
    - o continuous snow
    - o thunderstorm
    - o warm front
    - o continuous rain
    - o intermittent snow
    - o warm trough
    - o continuous drizzle
    - o rain shower
    - o fog

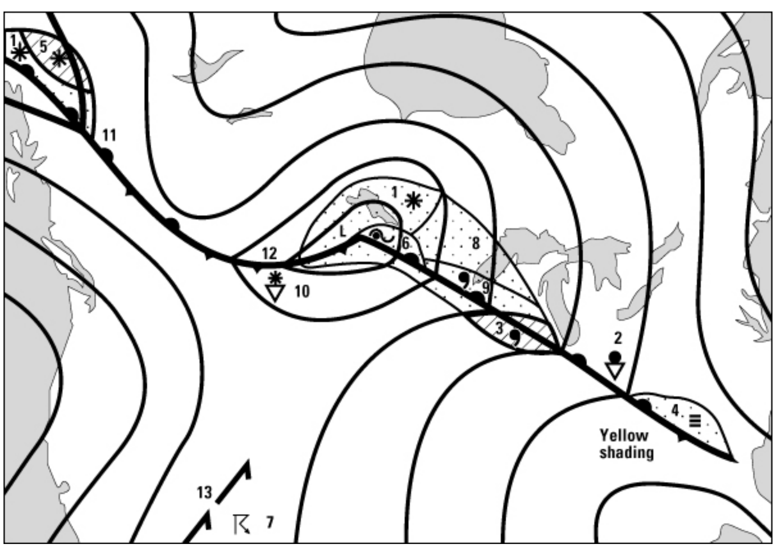


Figure 15-3

- A pilot is preparing for a low-level flight, to last about 50 minutes. He checks only the surface weather chart, which shows a low-pressure zone some distance to the north of his flight path. On the basis of that information, he assumes that he will not encounter any significant weather. During his flight, however, he meets with strong winds and precipitation. How do you explain this difference?
- What would each of the symbols in Figure 15-4 represent, if they appeared on a surface weather chart?

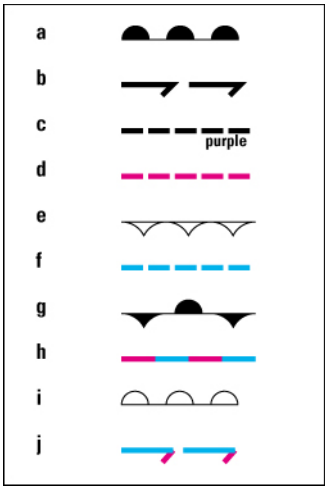


Figure 15-4

- What would each of the symbols in Figure 15-5 represent?

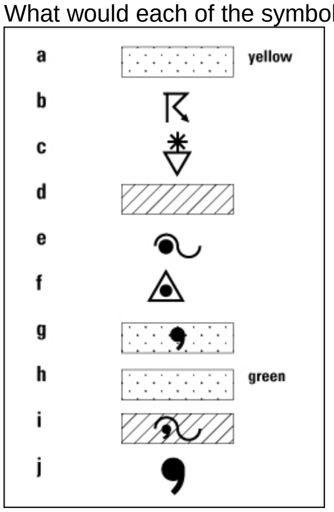


Figure 15-5

- Which of the following charts would give the most useful information for planning a flight at about 5,500 m (18,000 ft)?
    - o the 850 hPa chart
    - o the 750 hPa chart
    - o the 500 hPa chart
    - o the 250 hPa chart
- On the 250 hPa charts, what is the slowest wind speed range indicated by a dotted area?
- An isotach indicates:
    - o the core of a jet-stream
    - o the direction of the wind at a given pressure level
    - o points where the wind reaches its maximum speed
    - o points of equal wind speed.
- On a surface weather chart, an alternating red and blue solid line represents a trowal. True or false?

- Lines that join points of equal altitude are called?
- The average altitude of the 500 hPa pressure level is _______ ft or __________ m.
- The average altitude of the 700 hPa pressure level is _______ ft or __________ m.

CHAPTER 16
Weather Observation

Weather observations are coded messages which contain either visual or instrument observations of the weather at a specific point on the surface, generally at an observation station.

16.1 METAR Reports

METAR is the international code for standard aviation weather reports. METAR code reports are produced by software using the same base data as SA reports.

METAR reports are normally transmitted every hour on the hour. Significant changes in weather conditions result in the issuance of a special observation report, bearing the heading SPECI instead of METAR.

Both the METAR and SPECI reports consist of a number of groups, which always appear in the same order. When a weather element or phenomenon is not present, the corresponding group or its extension is omitted from the report. Some groups may be repeated for coding reasons.

METAR reports are coded to facilitate transmission and archiving.

METAR CYWG 172000Z 30015G25KT 3/4SM R36/4000FT/D -SN BLSN BKN008 0VC040 M05/M08 A2992 REFZRA WS RWY36 RMK36 SF5NS3 SLP134

Code: METAR
Meaning: report type identification

- METAR indicates a report of conditions observed on the hour.

- SPECI indicates a special observation report at any time.

Code: CYWG
Meaning: Winnipeg, Manitoba

- International 4-letter call sign of the originating station

Code: 172000Z
Meaning: 17th of the month, 2000 hours, time of observation

- The letter Z indicates Universal Coordinated Time (UTC).

- If the word AUTO appears after the time, the report originates from an automatic observation station.

Code: 30015G25KT
Meaning: wind from 300º West-North-West, at an average speed of 15 knots, gusting to 25 knots.

- The first 3 digits indicate the wind direction to the nearest 10º from true North.

- The following 2 digits indicate wind speed: average 2 minutes.

- G indicates the presence of gusts, and the digits which follow indicate maximum speed.

- KT indicates that wind speeds are given in knots. Outside North America, KPH is used for km/h and MPS for m/s.

- The code 00000KT indicates a calm wind; if the speed is 100 knots or over, 3 digits are used.

- VRB means that wind direction is variable.

Code: 3/4SM
Meaning: dominant visibility 3/4 of a mile.

- Dominant visibility is the highest visibility for at least half the horizon, as measured by an observer on the ground. This is reported in statute*, with values from 0 to 15 miles.

- Fractions of a mile are reported when visibility is reduced.

- When visibility in an area is low, eg, half the dominant value or less, this is noted in the "Remarks" at the end of the report.

*SM indicates statute miles; outside North America, visibility is reported in metres.

Code: R36/4000FT/D
Meaning: visibility from runway 36: 4,000 feet, downward.

- When dominant visibility is one mile or less, or visibility from the runway is 6,000 feet or less, this group is added to the report to indicate average visibility during the past 10 minutes.

- R is the group indicator.

The following 2 digits indicate the runway. If there are several parallel runways, the letters L are added for left, C for centre or R for right.

- Runway visual range (RVR) is given by 3 or 4 digits followed by FT for feet, hundreds of feet.

- If the value is below the recording capability of the instrument, the minimum measurable value is reported, preceded by an M (less than), when the range is lower, or a P (more than) when the range is greater.

- If the letter U (upward), D (downward) or N (no change) is added to the end of the group, this indicates the nature of the change observed during the past 5 minutes.

Code: -SN BLSN
Meaning: low-intensity or light snow, and high blowing snow.

- This group reports existing conditions, ie, phenomena occurring at the time of the observation, or immediately prior to it.

- Existing weather includes violent weather phenomena, precipitation, obstacles to visibility and other weather elements.

- Where necessary, intensity is indicated, and other characteristics, eg, proximity to the station, may be included.

The following table lists the phenomena which can be reported, together with the current adjectives.

Code 4678 Table Including Canadian differences w'w' - Significant current weather				
ADJECTIVE		PHENOMENON		
INTENSITY AND PROXIMITY 1	**DESCRIPTION 2**	**PRECIPITATION 3**	**OBSTACLES TO VISION 4**	**OTHER 5**
- Light	MI Shallow	DZ Drizzle	BR Mist VVVV > 5/8 SM	PO Dust or sand devils
No sign	BC Patches	RA Rain		
			FG Fog VVVV < 5/8 SM	
Moderate	PR Partial	SN Snow		SQ Squalls
+ Heavy			FU Smoke VVVV <= 6 SM	
NB: for precipitation , the intensity adjective applies to all forms combined	DR Low Drifiting	SG Snow grains		+FC Funnel cloud tornado or waterspout
			VA Volcanic ash	
	BL Blowing	IC Ice crystals VVVV<= 6 SM	regardless of visibility	
	SH Shower(s)			FC Funnel cloud
			DU Dust VVVV <= 6 SM	
VC means in the immediate area	TS Thunderstorm	PL Ice pellets		
				SS Sand storm VVVV < 5/8 SM +SS: VVVV<5/16
	FZ freezing		SA Sand VVVV <= 6 SM	
		GR Hail		
			HZ Haze VVVV = 6 SM<5/16	DS Dust storm VVVV < 5/8 SM +DS: VVVV
		GS Snow pellets or small hail		
		UP Unknown precipitation		

16.2 Details Regarding Qualifiers

Intensity

- Light	no sign	Moderate	+ Heavy

- The sign before the phenomenon code indicates its intensity.

- When several types of precipitation occur simultaneously, the predominant type is indicated first. Only the overall intensity of precipitation is recorded, however.

Proximity

- The proximity qualifier VC is used when certain phenomena are less than 8 km (5 miles) from the station:

SH	Shower. NB: Neither the type nor the intensity of precipitation is shown here.
FG	Fog
BLSN	Blizzard or high blowing snow
BLDU	Blowing dust
BLSA	Blowing sand
PO	Dust or sand devils
DS	Dust storm
SS	Sand storm
TS	Thunderstorm
FC	Funnel Cloud
VA	Volcanic Ash

Descriptive Adjectives

MI.....Shallow	DR.....Low Drifting	TS.....Thunderstorm
BC.....Patches	BL.....Blowing	FZ.....Freezing
PR.....Partial	SH.....Shower	

- Only one descriptive qualifier per ww group is reported.

- The adjectives MI, BC and PR are used only with FG; eg, MIFG.

- The adjectives DR and BL are used only with SN snow, DU dust and SA sand. DR drifting indicates that the phenomenon is no higher than 2 m from the ground. If the vertical extent is greater than 2 m, BL blowing is used.

- When SN snow and BLSN high blowing snow occur together, the 2 phenomena are described by separate ww groups: SN, BLSN.

- The SH shower is used only with RA rain, SN snow, PL ice pellets, GS snow pellets and GR hail: -SHRAGR.

- A storm may be reported alone or with precipitation. However, TS and SH cannot be reported together, as a WW group cannot have more than one qualifier.

- The FZ may be used only with RA rain, DZ drizzle or FG fog.

16.3 Details of Phenomena

PRECIPITATION	
RA.....Rain	DZ.....Drizzle
SN.....Snow	SG.....Snow grains
PL.....Ice pellets	GR.....Hail
GS.....Snow pellets	IC.....Ice crystals
UP.....Unknown precipitation From automated stations only	

OBSTACLES TO VISIBILITY	
BR.....Mist	FU.....Smoke
FG.....Fog	HZ.....Haze
SA.....Sand	DU.....Dust
VA.....Volcanic ash	
UP.....Unknown precipitation From automated stations only	

OTHER PHENOMENA	
PO.....Dust/sand devils	SQ.....Squalls
SS.....Sand storm	DS.....Dust storm
+FC......Tornado, waterspout	FC.....Funnel cloud
VA.....Volcanic ash	
Exact type of phenomenon indicated in "Remarks"	Exact type of phenomenon indicated in "Remarks"

- When a variety of forms of precipitation occur simultaneously and are reported by a single ww group, the dominant precipitation is reported first, and the overall intensity of precipitation is indicated subsequently. There are exceptions to this rule, however: FZRA freezing rain, and FZDZ freezing drizzle, are reported in separate groups.

- With few exceptions, obstacles to visibility are indicated when dominant visibility is 6 miles or less. When an obscuring phenomenon occurs at the same time as precipitation, this is reported by a separate ww group.

Code: BKN008 OVC040
Meaning: broken cloud layer at 800 ft, cloud cover at 4,000 ft

- Each layer of cloud is reported by a group which indicates the cumulative extent (3 letters), and height of the base (3 digits).

- Extent is indicated by:

SKC	clear sky	no clouds
FEW	a few clouds	cumulative extent 1/8 to 2/8
SCT	scattered	cumulative extent 3/8 to 4/8
BKN	broken	cumulative extent 5/8 to less than 8/8
OVC	overcast	cumulative extent 8/8

Observations from automatic stations only:

CLR BLO 100 - no clouds observed under 10,000 feet

CLR BLO 250 – no clouds observed under 25,000 feet

- METAR reports do not report thin layers.

- The height of the layer is shown in hundreds of feet above ground level

001 = 100 ft (30 m)
027 = 2,700 ft (810 m)
130 = 13,000 ft (3,900 m)
- The METAR code does not identify the ceiling. However, if it is assumed to be at the level of the first layer, the symbol BKN or OVC is used.

- The presence of TCU or CB is reported by the cloud abbreviation after the group; eg, SCT025TCU.

- A surface layer is reported when it completely covers the sky. In such cases, the letters VV replace the code for the extent of cloud and indicate that the following three digits give the vertical visibility in the surface layer; eg, VV005 means vertical visibility of 500 ft (160 m).

- The METAR code does not allow for reporting of partially obscured conditions. If there is no cloud above a surface layer, even if it covers 7/8 of the sky, the sky condition is SKC. If, however, there is a layer of cloud, the extent of the surface layer is included in the cumulative extent of the first upper-air layer.

Code: M05/M08
Meaning: air temperature: -5ºC
dew point: -8ºC

- These temperatures are given to the nearest degree. The M indicates below freezing.

Code: A2992
Meaning: altimeter reading 29.92 inches of mercury

- The A indicates that the value shown is in inches of mercury, which is customary in North America. International usage is to give the reading in millibars (hPa), indicated by the letter Q.

Code: REFZRA
Meaning: recent weather since the last regular observation: freezing rain

- This group is identified by the letters RE. This is included when:

- one of the following phenomena has occurred since the last observation, but was not present at the time of the observation;

- the phenomenon is present at the time of the current observation, and has also occurred since the last observation, but with greater intensity at this time:
  - freezing precipitation;
  - rain, drizzle or snow of high or moderate intensity;
  - ice pellets, snow pellets or moderate or heavy hail;
  - high, moderate or heavy blowing snow;
  - sand or dust storms;
  - tornadoes, waterspouts or funnel clouds;
  - thunderstorms;
  - volcanic ash.

Code: WS RWY36
Meaning: Vertical shear reported on approach to or takeoff from runway 36.

- The code WS wind shear means that a vertical shear has been reported at low altitude - by definition, under 1,600 ft from the ground - on the approach or takeoff path to or from one or more runways.

Code: RMK SF5NS3 SLP 134
Meaning: Remarks: types of cloud and opacity of layers reported earlier in the sky condition: stratus fractus, 5/8; nimbostratus, 3/8; sea level atmospheric pressure, 1013.4 mb or hPa.

- The data on cloud layers with regard to type and opacity are always included in the sky condition. The order of the entries corresponds to the order of the layers in the sky condition portion.

- Pressure at sea level is shown at the end of the METAR hourly report.

- When additional remarks on overall conditions are included, these are given between the cloud and atmospheric pressure data

16.4 METAR Examples

16.4.1 Example 1

METAR CYOW 160800Z 21004KT 8SM -TSRA BKN020 OVC100 20/18 A2966 RMK SC5AC3 CB EMBDD LTGCG SE SLP044=

Meaning

STATION:	OTTAWA
DATE/HOUR:	THE 16th AT 0800 Z
WIND:	210º TRUE AT 4 KNOTS
VISIBILITY:	8 STATUTE MILES
ATMOSPHERIC CONDITIONS:	THUNDERSTORM AND LIGHT RAIN
STATE OF SKY:	BROKEN AT 2,000 ft; COVERED AT 10,000 ft
TEMPERATURE:	20ºC
DEW POINT:	18ºC
ALTIMETER READING:	29.66 INCHES OF MERCURY

STATION:	OTTAWA
REMARKS:	STRATOCUMULUS 5 OKTAS, ALTOCUMULUS 3 OKTAS, CUMULONIMBUS EMBEDDED, LIGHTNING CLOUD TO GROUND IN THE SOUTHEAST
MSL PRESSURE:	1004.4 hPa

16.4.2 Example 2

METAR CYQX 141200Z CCB 32008KT 1/4SM FG VV002 09/08 A2963 RMK F8 SLP040=

Meaning

STATION:	GANDER
DATE/HOUR:	THE 14th AT 1200 Z 2nd CORRECTION*
WIND:	320º TRUE AT 8 KNOTS
VISIBILITY:	1/4 STATUTE MILE
ATMOSPHERIC CONDITIONS:	FOG
STATE OF SKY:	INDEFINITE CEILING
VERTICAL VISIBILITY:	200 ft
TEMPERATURE:	9ºC
DEW POINT:	8ºC
ALTIMETER READING:	29.63 INCHES OF MERCURY
REMARKS:	FOG 8 OKTAS
MSL PRESSURE:	1004.0 hPa

* - When a METAR or SPECI report is corrected, the letters CCx are added after the date/time group. CCA indicates the first correction, CCB the second, and so on.

16.4.3 Example 3

METAR CYYQ 241700Z 34011KT 2SM -DZ BR OVC004 05/05 A2994 RMK F4SF3 VSBY NE QUAD 1 SLP140=

Meaning

STATION:	CHURCHILL
DATE/HOUR:	THE 24th AT 1700 Z
WIND:	340º TRUE AT 11 KNOTS
VISIBILITY:	2 STATUTE MILES
ATMOSPHERIC CONDITIONS:	LIGHT DRIZZLE AND FOG
STATE OF SKY:	COVERED AT 400 ft
TEMPERATURE:	5ºC
DEW POINT:	5ºC
ALTIMETER READING:	29.94 INCHES OF MERCURY
REMARKS:	MIST 4 OKTAS, STRATUS FRACTUS 3 OKTAS, VISIBILITY IN

STATION:	CHURCHILL
	THE NORTHEAST QUADRANT 1 MILE
MSL PRESSURE:	1014.0 hPa

16.4.4 Example 4

METAR CYYQ 301300Z 35011KT 1/8SM FG VV001 02/02 A2991 RMK F8 SLP131=

Meaning

STATION:	CHURCHILL
DATE/HOUR:	THE 30th AT 1300 Z
WIND:	350º TRUE AT 11 KNOTS
VISIBILITY:	1/8 STATUTE MILE
ATMOSPHERIC CONDITIONS:	FOG
STATE OF SKY:	CLOUDED OVER, VERTICAL VISIBILITY 100 ft
TEMPERATURE:	2ºC
DEW POINT:	2ºC
ALTIMETER READING:	29.91 INCHES OF MERCURY
REMARKS:	FOG 8 OKTAS
MSL PRESSURE:	1013.1 hPa

16.4.5 Example 5 - Report in SPECI Format

SPECI CYVR 061843Z 09008KT 4SM -SHRA BR BKN006 BKN015 OVC040 RMK CF5SC2SC1 TCU EMBDD=

Meaning

STATION:	VANCOUVER
DATE/HOUR:	THE 6th AT 1843 Z
WIND:	090º TRUE AT 8 KNOTS
VISIBILITY:	4 STATUTE MILES
ATMOSPHERIC CONDITIONS:	LIGHT RAIN SHOWERS AND MIST
STATE OF SKY:	BROKEN AT 600 ft; BROKEN AT 1,500 ft, COVERED AT 4,000 ft
REMARKS:	CUMULUS FRACTUS 5 OKTAS, STRATOCUMULUS 2 OKTAS, STRATOCUMULUS 1 OKTAS; TCU EMBEDDED

NB:

- The altimeter reading Axxxx and the atmospheric pressure SLPxxx are not included in the report, because the observation was not made on the hour.
- For some locations, temperature is included in the SPECI and is included immediately after the state of the sky and is immediately followed by a "/". (e.g. BKN006 BKN015 OVC040 10/)

16.4.6 Example 6

METAR CYQB 201900Z 00000KT 3/4SM -SHRA BR BKN004 OVC020 19/18 A2962 RMK SF6SC2 SLP032=

Meaning

STATION:	QUEBEC CITY
DATE/HOUR:	THE 20th AT 1900 Z
WIND:	CALM
VISIBILITY:	3/4 STATUTE MILE
ATMOSPHERIC CONDITIONS:	LIGHT RAIN SHOWERS AND MIST
STATE OF SKY:	BROKEN AT 400 ft; COVERED AT 2,000 ft
TEMPERATURE:	19ºC
DEW POINT:	18ºC
ALTIMETER READING:	29.62 INCHES OF MERCURY
REMARKS:	STRATUS FRACTUS 6 OKTAS, STRATOCUMULUS 2 OKTAS
MSL PRESSURE:	1003.2 hPa

16.5 Decoding Exercise

Answer the questions using the Canadian METAR reports shown below.

CYVR 151100Z VRB03KT 1/4SM FG VV002 09/08 A2963 RMK F8 SLP998=

CYYC 151100Z 09005KT 1 1/2SM -SN BR OVC003 00/00 A2990 RMK F6SF2 SLP009=

CYEG 151100Z 00000KT 15SM FEW018 BKN040 OVC095 M00/MO2 A2996 RMK CF2SC3AC3 SLP141=

CYZF 151100Z 28005KT 12SM -SN FEW015 OVC025 M11/M13 A2988 RMK SF1SC7 SLP105=

CYYQ 151100Z 34015G30KT 1/2SM -SN BLSN VV005 M05/M07 A2975 RMK S8 SLP002=

CYUL 151100Z AUTO 04002KT 9SM BKN050 BKN090 00/M01 A3032 RMK SLP 244=

CYHZ 151100Z 00000KT 15SM BCFG FEW020 SCT100 SCT250 M00/M02 A3038 RMK CU1AS2CI0 SLP299=

CYYT 151100Z 00000KT 0SM FG VV000 07/07 A3019 RMK F8 SLP212=

CYAW 151100Z 03006KT 1 1/4SM -RADZ BR OVC003 10/10 A2976 WS ALL RWY RMK SF7 CIG RGD SLP001=

CYQX 151100Z 30007KT 1/8SM FZFG VV001 M02/M03 A2998 RMK F8 SLP146=

1. What is the altimeter reading at Calgary CYYC?
   What is the temperature at Churchill CYYQ?
   What is the dew point at Gander CYQX?
   What is the wind speed and direction at Churchill CYYQ?

What is the wind speed and direction at Vancouver CYVR?
What clouds are observed at Montreal CYUL?
What clouds are observed at Halifax CYHZ?

2. What is the condition of the sky at Vancouver CYVR?
3. What is the visibility observed at Calgary CYYC?
4. What stations report the best visibility?
5. What stations report the lowest cloud layer, and what is its elevation?
6. What is the present weather at Churchill CYYQ?
7. What is the present weather observed at Shearwater CYAW?

CHAPTER 17
AVIATION FORECASTS

17.1 Introduction

This chapter provides a description and decoding of five types of aviation forecasts:

- Graphic Area Forecast (GFA)
- AIRMET
- Aerodrome forecast in TAF code
- SIGMET; and
- Wind and upper-air temperature forecasts.

17.1.1 Graphic area forecasts (GFA)

The Graphical Area Forecast (GFA) is a weather forecast for a defined area in graphic format covering a 12-hour period depicted in three frames spaced at 6 hours apart. Each frame consists of two charts: one showing the clouds and weather conditions, the other showing icing, turbulence and freezing level over the same area and for the same time. The concept may be considered as a 3-frame movie where, to compensate for the small number of frames (course temporal resolution), intermediate frames are supplied by alphanumeric comments (either on the charts themselves or inside a comments box) to complement and thus render the entire picture more complete (adding the missing pieces of the jigsaw puzzle).

In dealing with weather, it is highly unlikely that one will find all the jigsaw pieces required to complete the puzzle, chances are that some of them will almost always be missing. What is important is to find those that are of vital importance to aviation operations. GFA forecast areas or domains are shown in Figure 17-1.

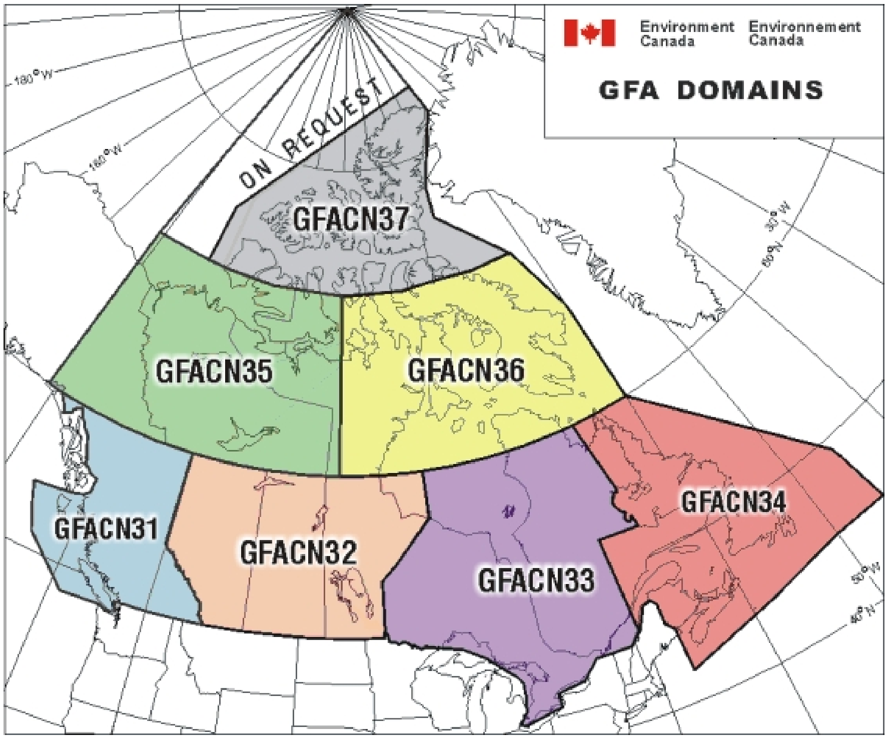


Figure 17.1.1 Graphic area forecasts domains

The names of the GFA domains indicated above are the following:
GFACN31 - PACIFIC REGION
GFACN32 - PRAIRIE REGION
GFACN33 - ONTARIO-QUÉBEC REGION
GFACN34 - ATLANTIC REGION
GFACN35 - YUKON-NORTHWEST TERRITORIES REGION
GFACN36 - NUNAVUT REGION
GFACN37 - ARCTIC REGION

17.1.2 Issue and valid time

The Canadian Meteorological Centre (CMC) transmits a GFA (all six panels) at least 15 minutes prior to its period of coverage. The actual window within which a GFA is transmitted is 30-minute wide and runs from as much as 45 minutes to as little as 15 minutes before the beginning of its period of coverage (T_0).

More specifically, a GFA is transmitted through the following windows:

2315-2345Z, 0515-0545Z, 1115-1145Z, and 1715-1745Z with a corresponding period of coverage of 00-12Z, 06-18Z, 12-24Z, and 18-06Z respectively. In addition, the last (T_0 + 12hr) CLOUDS AND WEATHER MAP carries an IFR outlook for the next 12 hours; i.e., for 12-24Z, 18-06Z, 00-12Z, and 06-18Z respectively.

The GFA is valid at the time specified in the Title Box of each depiction, regardless of the time it is transmitted or received.

The word abbreviations used in GFAs are the same as those used in hourly weather reports and aerodrome forecasts and are found in the Manual of Abbreviation (MANAB). See chapter 21.

17.1.3 Clouds and weather forecast map

This map depicts the followings:

- Main synoptic features
- Organized areas of clouds
- Organized areas of precipitation
- Organized areas of obstruction to vision
- Visibility
- Speed and direction of motion of main synoptic features, when known
- Speed and direction of motion of organized areas of clouds, organized areas of precipitation, and organized areas of obstruction to vision, when known and not tied to any other features for which the speed and direction of motion are already indicated
- Isobars (entered by CMC)
- Strong surface winds and gusts
- The IFR outlook on the T+12hr chart.

17.1.4 Outlook

The comment box on the T_0+ 12hr clouds and weather forecast includes an IFR outlook for the next 12 hours. It consists of a general statement, reduced to the pertinent terms associated to the following categories:

Category	Ceiling - feet	Visibility - statute miles
IFR instrument flight rules	Less than 1,000 ft or	Less than 3 miles

The cause(s) of an IFR restriction on flight conditions is noted as follows:

The term "CIG" is specified when the ceiling is the only reason

When the visibility is the only reason, the standard abbreviation (without intensity symbols) used to denote the atmospheric condition(s) and/or obstacle(s) to visibility is stated (e.g. IFR VIS SHSN);

When both the ceiling and visibility are the cause of IFR conditions, the standard abbreviations for ceiling "CIG" and the visibility (VIS) are indicated.

If a change from VFR to IFR or vice-versa is expected during the period covered by the outlook, that change is indicated by the abbreviation BECMG (becoming), followed by the time at which the change is anticipated.

Example of an outlook included in the T_0 + 12hr clouds and weather panel.

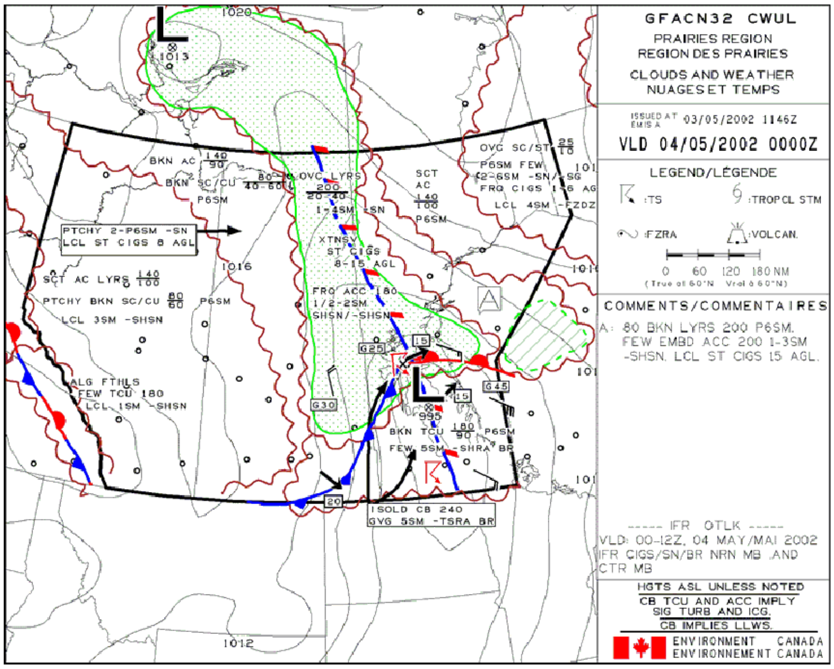


Figure 17.1.4

17.1.5 Icing-turbulence and freezing level depiction

The icing, turbulence and freezing level depiction includes the following information:

- Title, Legend, and Comments Box
- Main synoptic features
- Areas of turbulence
- Areas of icing
- Freezing level contours
- Speed and direction of motion of main synoptic features, when known.

17.1.5.1 Areas of icing

Areas of moderate or severe icing are depicted enclosed in a continuous blue line and coarse stippled in blue. The intensity (moderate or severe) is indicated by means of their corresponding symbols currently in usage and well known by users. The base and the top of the icing layer are indicated immediately after the icing symbol in the form of a fraction, where the denominator represents the base and the numerator the top of the icing layer in hundreds of feet ASL. The types of icing are: RIME, CLR and MXD.

NOTE: When icing is expected to be light , is indicated it in the comments box rather than on the depiction itself.

17.1.5.2 Area of turbulence (TURB)

Areas of moderate or severe turbulence are indicated enclosed in a continuous red line with coarse positive cross-hatching. The intensity (moderate or severe) is indicated by means of their corresponding symbols currently in usage and well known by users. Again, the base and the top of the turbulent layer are indicated in the same fashion described for icing.

Types of turbulence in a GFA are as follows:

- Clear air turbulence (CAT)
- Mechanical (MECH)
- Low level wind shear (LLWS)
- Lee waves (LEEWV)
- Low-level jet (LLJ).

NOTE: When turbulence is expected to be light, is indicated it in the comments box rather than on the chart itself.

In the special case where two areas of moderate and/or severe turbulence overlay, totally or in part, one on top of the other, the lower area of turbulence is indicated using hatches with the conventional positive slope and the area above it using hatches with a negative slope.

The following example illustrates the point:

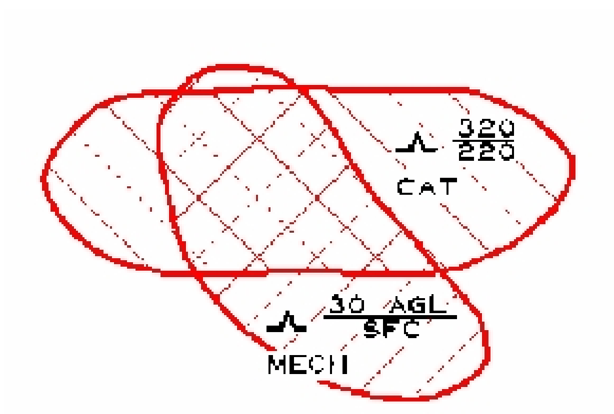


Figure 17-26

17.1.5.3 Freezing level contours

Freezing level contours are included only on the ICG-TURB-FZLVL CHART. These are indicated as dashed red lines at 2500-foot intervals and labeled in hundreds of feet ASL. Above freezing layers (AFL) are indicated as close areas as shown below:

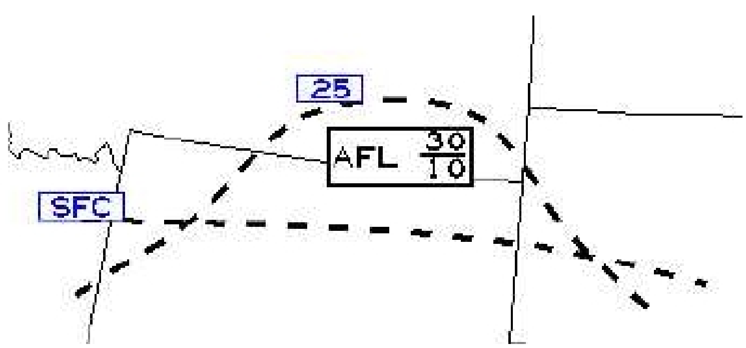


Figure 17.1.5.3a

NOTE: Discontinuous AFL structures are indicated in the comments box.

Example of Icing-turbulence & freezing level panel

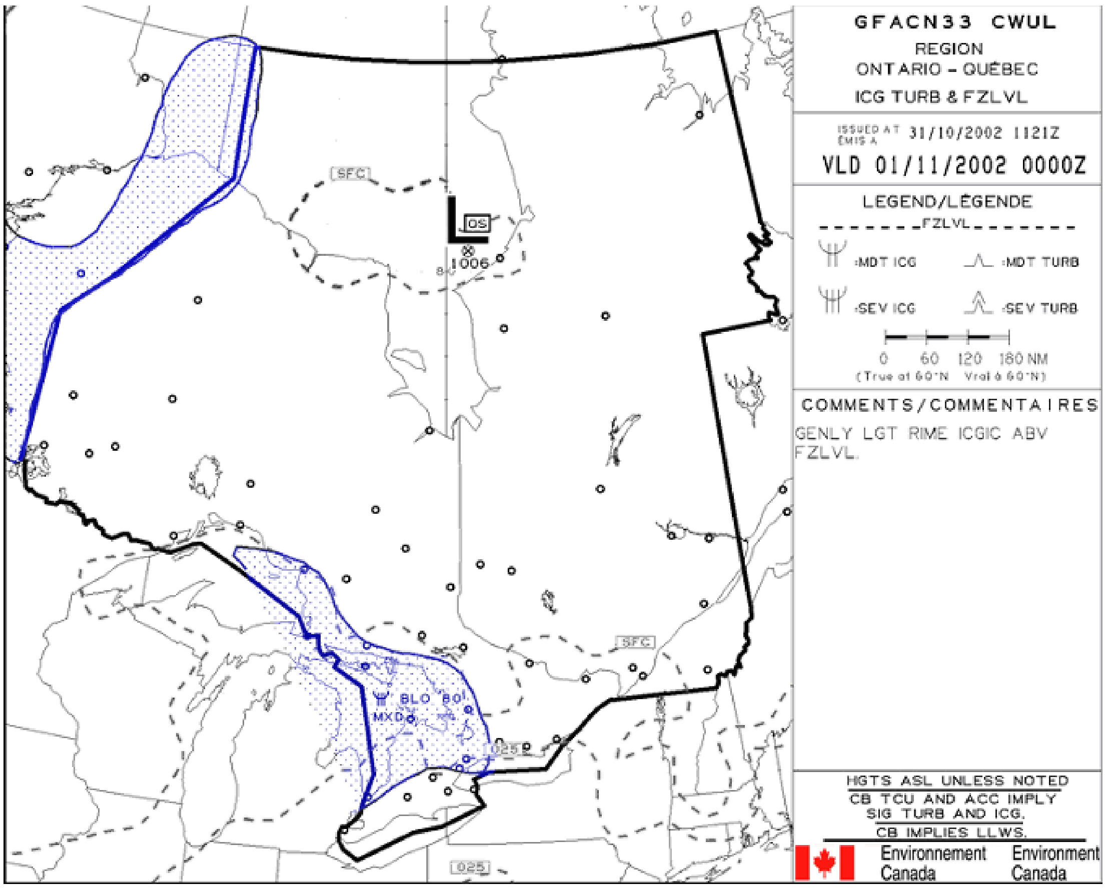


Figure 17.1.5.3b

17.2 SIGMET

A SIGMET bulletin is mainly a short-term weather warning intended for aircraft in flight to notify pilots of hazardous weather conditions. These messages describe specific weather hazards extending all the way up to and including the 60,000-foot level, i.e., FL600 or 70 hPa, regardless of the height of the base of the weather phenomenon for which the SIGMET is issued.

17.2.1 Issuing office

Each Meteorological Watch Office (MWO) is responsible for issuing SIGMET messages over its own designated area of responsibility. In Canada there are two MWOs which issue SIGMET messages, Montreal (CWUL) and Edmonton (CWEG).

17.2.2 Weather phenomena for which SIGMET messages are issued

The list of weather phenomena for which SIGMETs are issued is limited by international agreement to include only the most serious weather hazards that are considered to be of vital importance to all types of aircraft.

The list is the following:

- Area of active thunderstorms
- Line of thunderstorms
- Severe squall line
- Hurricance or Tropical cyclones

- Moderate or heavy hail
- Severe turbulence (not associated with convective clouds)
- Severe icing (not associated with convective clouds)
- Marked mountain waves
- Widespread sand or dust storm

- Radioactive Cloud

- Volcanic ash
- Tornado or Waterspout

- Low-level wind shear

17.2.3 Lead-time

Normally, SIGMET messages are issued for weather phenomena that are already occurring or are expected to occur in the very near future. However, a SIGMET can be issued as far as four hours prior to the expected onset of the weather phenomenon. In other words, if freezing rain is expected to move into a certain area by 12Z, a SIGMET covering that event could be issued at 08Z. Furthermore, in case of a volcanic ash SIGMET, such a message could and should be issued as much as **12 hours** prior to the onset of the phenomenon.

17.2.4 Period of coverage or period of validity

In Canada, all SIGMET messages cover a period of four hours. This is also true for volcanic ash and tropical cyclone SIGMETs. In the special case of volcanic ash and tropical cyclone SIGMETs, however, they also include an outlook providing information about the weather phenomenon for a period up to 12 hours beyond the regular period of coverage.

17.2.5 Format

SIGMETs are issued over Canada according to the format described below:
W(y)CN3(#) C(ZZZ) ddGGgg (SIGMET telecommunication header)
SIGMET (XY) VALID d1d1G1G1g1g1 CZZZ- (first part of the SIGMET's heading)
(TEXT) (body of the SIGMET)
END/GFA3(#)/FORECASTER'S INITIALS (last line of the SIGMET)

SIGMETs are issued over the Gander Oceanic FIR according to the format described below:
W(y)CN0(#) C(ZZZ) ddGGgg (SIGMET telecommunication header)
CZQX SIGMET (XY) VALID d1d1G1G1g1g1/d2d2G2G2g2g2 CZZZ- (first part of the SIGMET's heading)
GANDER OCEANIC FIR.

(TEXT) (body of the SIGMET)
END/GANDER OCEANIC FIR/FORECASTER'S INITIALS (last line of the SIGMET)

17.2.5.1 Telecommunication header

The first line of a SIGMETis called the telecommunication header and contains the following information:
W(y)CN(##) C(ZZZ) ddGGgg (e.g. WCCN31 CWEG 121045).

Where:
W(y)CN(#) - stands for SIGMETS issued by Canada; where: the number "##" is the telecommunication header series for aviation weather products required by WMO (e.g. WSCN32 or WVCN02). The symbol (##) is a two-digit number (02, 31, 32, 33, 34, 35,36, 37) that differs from MWO to MWO. For SIGMETs over Canada this number is identical to the number in the title box of the GFA that the SIGMET amends.

y – designates the type of SIGMET being issued (e.g. V = volcanic ash, C – Tropical Cyclone and S – Significant Weather)
ddGGgg - is the six-figure group representing the date and time (UTC) of issue (201520);
C(ZZZ) - the four-letter identifier of the MWO issuing the SIGMET (e.g. CWUL).
For example: **WSCN33 201430 CWUL**.

17.2.5.2 SIGMET's heading

The second line of an SIGMET is the first line of the SIGMET's heading and contains the following information:

(CXXX) SIGMET (XY) VALID d1d1G1G1g1g1/d2d2G2G2g2g2 CZZZ -

Where:

CXXX – FIR affected by the SIGMET (included only in those SIGMETs for the Gander Oceanic FIR CZQX)
SIGMET (XY) - is the message identifier and (XY) is the sequence number (e.g. SIGMET B1);
d1d1G1G1g1g1/d2d2G2G2g2g2 - is the valid period of the SIGMET in UTC (e.g. 1725Z); and
C(ZZZ) - is the four-letter identifier of the MWO issuing the message, followed immediately by a hyphen (e.g. CWUL -).

For example: SIGMET A1 VALID 201415/291815 CWUL-.

17.2.6 Description of meteorological phenomena

Because of the way SIGMET messages are disseminated, they are phrased clearly and concisely to indicate where the phenomenon is occurring, what flight altitudes are affected, the direction the phenonenon is moving and any changes that may take place during the valid period of the SIGMET.

17.2.7 Outlook period

In the special case of volcanic ash or tropical cyclone SIGMETs, an outlook stretching as much as 12 hours beyond the regular period of validity of the SIGMET is included in the message.

In the case of a tropical cyclone, the position of the centre of the cyclone at the end of the outlook period is stated. In case the tropical cyclone will no longer affect the area by 8- hours beyond the regular period of validity of the SIGMET, the outlook will be for an 8-hour period rather than 12. For example, if the period of validity of the SIGMET was 101020/101420, then an outlook could be " OTLK TC CNTRD AT 4500N05000W BY 110220", or "TC MOVG OUT OF AREA BY 2200Z".

In the case of volcanic ash, the leading edge of the volcanic ash cloud at the end of the outlook period is indicated. Again, if the volcanic ash cloud will no longer affect the area by 10 hours into the outlook period, then the outlook period will extend only 10 hours after the end of the regular period of coverage of the SIGMET.

For example, if the regular period of validity of your SIGMET was 101325/101725, the outlook could be "OTLK VA CLD WILL MOV OUT OF FCST AREA BY 110300".

17.2.8 Relationship to GFA

A GFA is not amended by issuing another GFA. When a GFA needs to be amended, it is done by issuing an AIRMET or a SIGMET, whatever is required.

A SIGMET message automatically amends the corresponding GFA without explicitly stating it in the body of the SIGMET.

Domestic SIGMETs have a one-to-one correspondence with GFA domains. For example, WSCN31, WVCN31 and WCCN31 correspond to GFACN31.

SIGMETs issued over the Gander Oceanic Flight Information Region (FIR) have no relationship to the GFA and are issued using the headers WSCN02 WVCN02 and WCCN02.

17.2.9 Examples of SIGMETs

17.2.9.1 For a line of CBs issued by Edmonton

WSCN32 CWEG 050518
SIGMET C5 VALID 050520/050920 CWEG-
WTN 20 NM OF LN /5950N10745W/25 SW DUNVAGEN LAKE - /5832N10810W/35 N DUNNING LAKE - /5741N11107W/65 S FORT CHIPEWYAN - /5639N11207W/30 W FORT MCMURRAY. BKN LN CB MOVG EWD AT 10KT. FCST CB TOPS 350 MAX TOPS 430. CB XPCD TO GRDLY WKN AFT 06Z.
END/AKY

17.2.9.2 SIGMET for Gander Oceanic FIR

WSCN02 CWUL 081511
CZQX SIGMET F6 VALID 081515/081915 CWUL-
GANDER OCEANIC FIR.
WTN 30 NM OF LN 5800N03000W - 5700N04000W.
MODERATE TO SEVERE TURBULENCE REPORTED AT 1303Z BY B757 AND FORECAST BETWEEN FL340 AND FL380. LINE STATIONARY. WEAKENING.
END/BS/ML

> NOTE: Volcanic ash SIGMETs over the North Atlantic airspace are issued using the header WVCN02 CWEG.

17.2.9.3 SIGMET for tropical cyclone issued by Montreal

WCCN35 CWUL 111000
SIGMET A1 VALID 111000/111400 CWUL-
WTN 120 NM OF 4030N7030W.
TC FRED OBSD AT 10Z IS FCST TO MOV NEWD TO 4330N6700W BY 14Z. MAX TOPS 380
WTN 120 NM OF CNTR.OTLK...TC CNTR AT 4400N6430W BY112000 AND AT 4630N5800W
BY120200.
END/AF

17.2.9.4 SIGMET for volcanic ash issued by Edmonton

WVCN31 CWEG 171535
SIGMET A1 VALID 171535/171935 CWEG-
WTN 60 NM OF /5030N12324W/ 30 NW WHISTLER.
VA BLO FL350 FCST DUE ERUPTION MT MEAGHER 171350-171420Z.
PIREP 171455Z VA FL330. FCST VA MOVG NWD 15 KT.
OTLK 180735Z.. VA FL100-400 WTN 60 NM OF LN /5330N12330W/QUESNEL -
/5100N12330W/60 NW WHISTLER. NO CHG.
END/TDF

17.3 AIRMET

An AIRMET message is mainly a short term weather alert intended to notify pilots either en-route or in the flight planning phase of potentially hazardous weather conditions not described in the current GFA and not serious enough to require a SIGMET.

These messages describe, in abbreviated English, potentially hazardous weather conditions below 24,000feet. As with GFAs, however, when the top of a weather phenomenon is above 24,000 feet, you must state it, if known, provided that the base of such a phenomenon is below 24,000 feet.

17.3.1 Issuing office

Each Meteorological Watch Office (MWO) is responsible for issuing AIRMET messages over its own designated area of responsibility. In Canada there are two MWOs which issue AIRMET messages, Montreal (CWUL) and Edmonton (CWEG).

17.3.2 Weather phenomena for which AIRMETs are issued

AIRMET messages are used to amend the GFA and are issued for certain weather phenomena based below 24,000 feet and only when those phenomena were not forecast in the current corresponding GFA or were forecast in the current corresponding GFA and are no longer expected to occur.

NOTE: When the top of a weather phenomenon for which an AIRMET must be issued is above 24,000 feet, the top of the weather phenomenon must be indicated if known.

The list of weather phenomena for which AIRMETs are issued is limited by international agreement to those weather conditions considered important, but not extremely hazardous, to all types of aircraft:

- **IFR conditions** (ceiling less than 1,000 feet and/or visibility less than 3 miles).
- **Moderate icing** (not associated with convective clouds). This includes icing in clouds or in light freezing precipitation, such as -FZDZ, for which a SIGMET is not required.

- **Moderate turbulence** (not associated with convective clouds).
- **Moderate mountain waves** (defined by ICAO as indicated below)
- **Moderate -** when is accompanied by downdrafts of 1.75-3.00 m/s (350-600 ft/min) and/or moderate turbulence is observed or forecast.
- **Thunderstorms** (scattered or unorganized).
- **Surface Winds**. When the following unforecast changes in the wind occur or are expected to occur:
    - Mean surface wind speed over a significantly large area increases to 20 KT or more or gusts increase to 30 KT or more when lighter winds were originally forecast.
    - The difference between observed and forecast wind speed is greater than 20 KT if winds were mentioned in the original forecast.
    - The difference between the forecast and the observed wind direction is greater than 60 degrees.

17.3.3 Issuing procedures

AIRMET bulletins are issued according to the following standards and procedures:

17.3.3.1 Lead time

Normally, AIRMETs are issued for weather phenomena listed in section 17.3.2 when they are already occurring or are expected to occur in the near future and were not forecast in the current GFA.

17.3.3.2 Period of validity

In Canada, all AIRMETs are valid until the next corresponding GFA is issued or until it is updated or cancelled.

17.3.4 Format

AIRMETs are issued according to the format described below:
WACN3(#) C(ZZZ) ddGGgg (AIRMET telecommunication header)
AIRMET (XY) VALID d1d1G1G1g1g1 CZZZ- (first part of the AIRMET's heading)
AMEND GFACN3(#) C(ZZZ) $d_2d_2G_2G_2g_2g_2$ ISSUE (second part of the AIRMET's heading)
(TEXT) (body of the AIRMET)
END/FORECASTER'S INITIALS (last line of the AIRMET)

17.3.4.1 Telecommunication header

The first line of an AIRMET is called the telecommunication header and contains the following information:
WACN3(#) C(ZZZ) ddGGgg (e.g. WACN31 CWEG 121045).

Where:
WACN3(#) - stands for Canadian AIRMETs; where: the number "3" is the telecommunication header series for aviation weather products required by WMO (e.g. WACN32). The symbol (#) is a one-digit number ranging from 0 to 7 that differs from MWO to MWO. This number is identical to the number in the title box of the GFA that the AIRMET amends. This is stated in the third line of the bulletin (e.g. GFACN32).
ddGGgg - is the six-figure group representing the date and time (UTC) of issue (201520);
C(ZZZ) - the four-letter identifier of the MWO issuing the AIRMET (e.g. CWUL).
For example: **WACN33 201430 CWUL**.

17.3.4.2 AIRMET's heading

The second line of an AIRMET is the first line of the AIRMET's heading and contains the following information:

AIRMET (XY) ISSUED AT GGggZ CZZZ -

Where:
AIRMET (XY) - is the message identifier and (XY) is the sequence number (e.g. AIRMET B1);
GGggZ - is the issue time in UTC (e.g. 1725Z); and
C(ZZZ) - is the four-letter identifier of the MWO issuing the message, followed immediately by a hyphen (e.g. CWUL -).
For example: AIRMET A1 ISSUED AT 1415Z CWUL-.

17.3.5 Numbering AIRMETs

Every AIRMET is numbered. In Canada, the convention for numbering AIRMETs is to use a combination of letters and numbers (e.g. A1) in the same fashion in vigor for SIGMETs. AIRMETs issued by the same MWO for different weather phenomena are labeled with different letters (e.g. A1, B1, C1, etc.).

- When two or more separate weather phenomena requiring separate AIRMETs occur or are expected to occur simultaneously within the same area of responsibility, AIRMET messages are issued to deal with individual weather phenomenon separately. This means that separate AIRMETs identified by different alphanumeric signatures (e.g. A1. B1, C1, etc.) are issued.
- When two or more criteria requiring the issuance of an AIRMET are met and they are produced by the same weather phenomenon (e.g. freezing drizzle and widespread stratus) and occurring over the same area, only one single AIRMET summarizing the whole situation is issued.
- When a single weather phenomenon meeting AIRMET criteria occurs or is expected to occur simultaneously over parts of two different GFA domains (e.g. GFACN32 and GFACN33), two separate AIRMETs are issued, one by each MWO involved. These separate AIRMETs are identified by a different telecommunication header (e.g. WACN32 and WACN33) each amending its corresponding GFA area (in this case GFACN32 and GFACN33) and different alphanumeric signature (e.g. A1, B1, etc.). Furthermore, these AIRMETs will be updated and canceled, when necessary, within their corresponding GFA areas.
- When a weather phenomenon for which an AIRMET was issued moves out of its original GFA area into another prior to the issuance of the next regular GFA, an AIRMET for the new GFA domain being affected is issued, provided that such weather phenomenon was not forecast in the corresponding GFA. In this case, the telecommunication header of the new AIRMET matches the new GFA area affected and bears a different signature. For example, if WACN31 affecting GFACN31 is issued with signature A1, a new AIRMET affecting GFACN33 is labeled WACN33 with signature B1 or any other letter in use by the new MWO involved.

17.3.6 Updating AIRMETs

AIRMETs messages are not updated on a regular basis as SIGMETs are. Under normal circumstances, AIRMETs are updated automatically with the issuance of a new regular GFA. However, in special circumstances, AIRMETs could be updated. This may occurs in the following situations:

- When the original AIRMET indicates that a weather condition, for which it was issued, was expected to end significantly before the T_0 panel of the next regular issue of the corresponding GFA and subsequently is anticipated to last at least up to T_0.

- When an AIRMET indicates that a weather condition is expected to last at least up to the T0 panel of the next regular issue of the corresponding GFA and subsequently ends, or is expected to end significantly sooner, the AIRMET is canceled.

This implies that, AIRMETs are not updated or canceled in the same fashion as SIGMETs are, but they are updated or canceled only if and when they require.

17.3.7 Canceling AIRMETs

Under normal circumstances, all AIRMETs are automatically canceled when the next regular GFA is issued. However, when a weather condition as described in an AIRMET does not occur, or ends significantly earlier than forecast and significantly before the issue of the next regular GFA, the AIRMET is canceled.

When an AIRMET must be canceled, one must do it ensuring that a statement of explanation provides the reason for the cancellation. This statement must also be very brief and to the point (e.g. -FZDZ CHGD TO -DZ).

In addition, an AIRMET is also canceled when the same weather situation that triggered its issuance becomes hazardous enough to warrant a SIGMET. In this situation, the AIRMET is canceled by providing a brief explanation for canceling it.

17.3.8 GFA reference

The third line of an AIRMET provides reference to which GFA the AIRMET amends. This line includes the following information:

AMEND GFACN3(#) C(ZZZ) $d_1d_1G_1G_1g_1g_1$ ISSUE (e.g. AMEND GFACN33 CWUL 251730 ISSUE).

Where:
GFACN3(#) - is the specific GFA that is amended by the AIRMET and the symbol (#) is a one-digit number that differs from MWO to MWO and it ranges from 1 to 7 (e.g. GFACN32 CWUL);
C(ZZZ) - is the four-letter location identifier of the MWO issuing the AIRMET (e.g. CWUL);
$d_1d_1G_1G_1g_1g_1$ - is the date and time of issue of the original GFA that is now amended by your AIRMET (e.g. 201010).

17.3.9 Examples of AIRMET

17.3.9.1

WACN34 CWUL 200720
AIRMET A1 ISSUED AT 0720Z CWUL-
AMEND GFACN34 CWUL 200530 ISSUE
WTN AREA /4607N06441W/MONCTON - /4428N06831W/BANGOR -
/4459N06455W/GREENWOOD - /4607N06441W/MONCTON. DC9 RPRTD MDT CLR ICG IN
FZDZ ALG THE S CST OF NB AT 07Z. FZDZ EXPD TO CONT UNCHGD.
END/FU

17.3.9.2

WACN33 CWUL 181915
AIRMET A1 ISSUED AT 1915Z CWUL -
AMEND GFACN33 CWUL 181730 ISSUE
WTN AREA /4300N08106W/LONDON - /4342N07936W/KINKARDINE -
/4448N08106W/WIARTON - /4300N08106W/LONDON. SCT TS EXPD TO DVLP BY 20Z. TS

WILL DSIPT BY 23Z.
END/FI

17.4 Aerodrome Forecasts (TAF)

Figure 17.4 - Canadian aerodromes for which TAF are prepared.

17.4.1 Definition

A TAF is a "forecaster's best judgment of the most probable weather conditions expected to occur at an aerodrome together with their most probable time of occurrence." In other words, it isn't every possible weather element.

17.4.2 Purpose

A TAF is intended for use mostly in pre-flight and to a much lesser extent in in-flight operations. This makes pilots, flight dispatchers, and FSS personnel the primary users of TAFs. Also, although it is not officially acknowledged, TAFs are also used for other purposes, e.g. to help ATC make decisions on which runways to designate as the active runways, and to aid in snow removal operations.

17.4.3 Issue and valid time

Under normal circumstances, TAFs are issued at least 20 minutes prior to the beginning of their period of coverage. For example, if a TAF covers a period from 1100 to 2300Z, it is normally issued by 1040Z. For sites with less than 24-hour observational coverage or for which a part time TAF is provided, two consecutive hourly observations are required from that site immediately prior to the issue time to issue a TAF. This is true unless some regional authority approves some other arrangement (e.g. for sites which are close to other observing sites and are deemed to experience a weather representative of the weather at nearby sites, one observation might be enough to issue a TAF.)

For example, some aerodromes start issuing weather observations at 1200Z and require the first TAF of the day by 1330Z. This requirement is normally taken care of by issuing the first TAF shortly after receiving the second observation, i.e., by 1315Z. In such a case, the beginning of the period of coverage is backdated to 1300Z. It must be remembered, however, that a TAF is valid at the time is issued and not at the beginning of its period of coverage.

Example: TAF CYHA 201315Z 2014/2021...

If two consecutive hourly observations immediately prior to the issue time of a TAF, are not available, a nil TAF is issued.

Example: TAF CYTS 201735Z 2018/2106 NOT AVBL DUE INSUFFICIENT OBS=

17.4.4 Forecast elements and overall structure

The main forecast elements that make up a TAF are wind, visibility and sky condition. They appear in all part periods of a TAF. Two additional elements, wind shear and weather, are inserted only when they are expected to occur. Forecast elements appear in the following order:

- Wind
- Wind shear (when necessary)
- Visibility
- Weather or obstructions to vision (when necessary)
- Sky condition.

Additional groupings of the above elements may appear as well. For example, the TEMPO (temporary) group is used to describe transient phenomena (temporary fluctuations from the main weather conditions). The PROB (probability) group is used to describe phenomena with a lower probability of occurrence. PROB30 and PROB40 are the only ones allowed.

Transition or change groups also appear in the form of FM (from) or BECMG (becoming). These indicate when the weather condition is expected to permanently change, and at what time or over what time period the change is expected to occur. The use of BECMG is restricted to changes occurring over a two-hour period or less.

Finally, additional remarks are included at the very end of the TAF indicating the type of weather observations used to prepare the TAF.

17.4.4.1 Content

The following is a regular TAF for Saskatoon:

TAF CYXE 291045Z 2911/3011 24010G25KT WS011/27050KT 3SM -SN BKN010 OVC040 TEMPO 2918/3001 11/2SM -SN BLSN BKN008 PROB30 2920/2922 1/2SM SN VV005

FM300130 28010KT 5SM -SN BKN020 BECMG 3006/3008 00000KT P6SM SKC RMK FCST BASED ON AUTO OBS NXT FCST BY 281700Z

Code	Meaning
TAF	Message type indicator. The aerodrome forecast is in TAF code
CYXE	The international four-letter aerodrome designator. CYXE is the aerodrome designator for Saskatoon J.G. Diefenbaker's Airport
291045Z	The TAF was issued on the 29th of the month at 1045 UTC
2911/3011	The TAF is valid from 1100 UTC on the 29th of the month until 1100 UTC on the 30th
24010G25KT	The wind is forecast to blow from 240 degrees at 10 knots with gusts to 25

Code	Meaning
WS011/27050KT	Wind-shear in the layer between the surface and 1100 feet and the wind at 1100 feet is from 270 degrees at 50 knots
3SM	The visibility is 3 statute miles
-SN	Light snow
BKN010 OVC040	This is a broken ceiling at 1000 feet with an overcast layer at 4000 feet
TEMPO 2918/3001	Temporary fluctuation between 1800 on the 29th and 0100 UTC on the 30th of the following elements
11/2SM	Visibility 1 ½ statute miles
-SM BLSN	Light snow and blowing snow
BKN008	Broken ceiling at 8oo feet
PROB30 2920/2922	There is a possibility between 2000 and 2200 UTC on the 29th the following
1/2SM	Visibility ½ statute mile
SN	Moderate snow
VVOO5	Vertical visibility 500 feet
FM300130	From 0130 UTC on the 30th
28010KT	Wind from 280 degrees at 10 knots
5SM	Visibility 5 statute miles
-SN	Light snow
BKN020	Broken ceiling at 2000 feet
BECMG 3006/3008	Becoming between 0600 and 0800 UTC on the 30th
00000KT	Wind calm
P6SM	Visibility greater than 6 statute miles
SKC	Sky clear
RMK	Remarks
FCST BASED ON AUTO OBS	The weather observations available to the forecaster in the preparation of the TAF were from an automated weather station
NXT FCST BY 291700Z	Next regular forecast is scheduled to be issued by 1700 UTC on the 29th

17.4.4.2 Temporary change group (TEMPO)

TEMPO stands for temporary. It begins a section of the TAF that indicates transitory changes in one or more forecast elements from the main condition. The changes indicated by the TEMPO group should in each instance last less than one hour, and if expected to recur, should not, in the aggregate, cover more than half the forecast period for which the TEMPO group applies.

As a general rule of thumb, only those elements (wind, visibility, weather, cloud) that are expected to change are mentioned in the TEMPO group. When these elements are not mentioned, they are assumed to be the same as those stated in the main condition. The only exception is the visibility and the weather group that are treated as one entity. This will be explained later.

The wind-shear group is not mentioned in the TEMPO group. When expected, the wind-shear group is stated in the main condition. If the wind-shear is expected to end at a certain time, a new FM group starting at that time is introduced. What this means is that wind-shear is not a fluctuating phenomenon.

17.4.4.3 Permanent change group (BECMG)

The "BECMG" (becoming) group is used to indicate a permanent but gradual change in a weather element. It takes the form:

BECMG	Transition Period	Changing Element(s)

The transition period is the period during which the elements in question change from the main condition to those mentioned in the BECMG group. Only those elements mentioned in the BECMG group are assumed to be changing; all other elements remain the same. Again, the only exception is for visibility and weather. When one changes, the other must also be stated even though it remains the same after the transition period.

17.4.4.4 Permanent and more complete change group (FM)

The FM or "from" group also indicates a permanent change. This group chops up the TAF into separate periods in which each part period has all the required forecast elements. Each part period completely supersedes all part periods indicated before it. The FM group has the following form:

FM Change Time	Required Elements (a fresh start)

The change time appended to "FM" is a six-digit group indicating the date and time at which conditions are forecast to change.

17.4.4.5 Probability group (PROB)

The PROB group is used to indicate cases where there is a probability of occurrence of a conditions that is hazardous to aviation. This is true, however, only in cases where the probability is near 30 or 40 percent. PROB30 and PROB40 are the only allowed values. If the likelihood is less than 30 percent then it is not considered significant. On the other hand, if the likelihood is 50 percent or more, it is indicated as part of a TEMPO group or any other allowed method of inclusion.

The PROB statement follows the form:

PROB Probability	Valid Period	Hazard/Weather

17.4.4.6 Remarks (RMK)

A TAF ends with a remark section indicated by the abbreviation "RMK". What follows "RMK" depends on the circumstances affecting the TAF, but one of its primary functions is to indicate the following:

17.4.4.6.1 TAFs for aerodrome not operating 24 hours a day

If a TAF is for an aerodrome that does not operate 24 hours a day, the following remarks may be included as applicable:

NXT FCST WILL BE ISSUED AT 151345Z;
NO FCST COVERAGE 180000 - 181100Z;
NO FCST ISSUED UNTIL FURTHER NOTICE.

17.4.4.6.2 TAFs for aerodrome operating 24 hours a DAY

If a TAF is for an aerodrome that operates 24 hours a day, the following remark may be included as applicable:

FCST BASED ON AUTO OBS.

17.4.4.6.3 Remarks indicating when the next regular forecast will be issued:

NXT FCST BY DDXXMMZ (where DDXXMM is the date and time of the beginning of the period of coverage of the next scheduled forecast. For example, NEXT FCST BY 071200Z.

17.4.4.6.4 Remarks explaining possible discrepancies between AWOS observations and aerodrome forecast

When there is a reason to believe that AWOS observations are non-representative of the actual weather at the aerodrome, the following remarks will be included as requires:

AUTO OBS RPRTG NON-REPRESENTATIVE WND SPD;
AUTO OBS RPRTG NON-REPRESENTATIVE WND DRCTN;
AUTO OBS RPRTG NON-REPRESENTATIVE VSBY;
AUTO OBS RPRTG NON-REPRESENTATIVE CLD HGT;
AUTO OBS RPRTG NON-REPRESENTATIVE PCPN TYPE;
AUTO OBS RPRTG NON-REPRESENTATIVE PCPN INTSTY;
AUTO OBS NON-REPRESENTATIVE OF CURRENT WEATHER;

17.4.4.6.4 Remarks indicating that one or more AWOS sensors are inoperative

For aerodromes where there are AWOS observations and one (or more) of the AWOS sensors is inoperative but the forecaster is still able through alternative means to determine representative weather conditions for elements normally reported by the inoperative sensor then the forecaster will include one or more of the following remarks when issuing the TAF:

WND SPEED SENSOR INOPV

WND DRCTN SENSOR INOPV

WND SENSORS INOPV

VIS SENSOR INOPV

CLD SENSOR INOPV

PCPN TYPE SENSOR INOPV

PCPN INTSTY SENSOR INOPV

PCPN SENSOR INOPV

17.4.5 Aerodrome advisories

Aerodrome advisories are issued in place of aerodrome forecasts for the following reasons:

17.4.5.1 Offsite (OFFSITE):

The term OFFSITE is used when a forecast is based on observations that are not always considered to be representative of weather conditions at that aerodrome. In normal situations, an observation is considered representative of the weather conditions at the aerodrome if it is taken within 1.6 NM (3 km) of the geometric centre of the runway complex.

The word ADVISORY appears after the period of coverage. The word OFFSITE appears, followed by one space, after the word ADVISORY (e.g. TAF CCCC 151040Z 1511/1523 ADVISORY OFFSITE ...). This is intended to indicate to the users that the observations do not necessarily reflect the actual conditions at the aerodrome.

17.4.5.2 Observation incomplete (OBS INCOMPLETE)

The term "OBS INCOMPLETE" is used when the forecast is based on observations with missing or incomplete data on a regular basis (e.g. MSL pressure not reported).

The word ADVISORY appears after the period of coverage. The words OBS INCOMPLETE appears, followed by one space, after the word ADVISORY (e.g. TAF CCCC 201640Z 2017/2105 ADVISORY OBS INCOMPLETE ...).

17.4.5.3 No specials (NO SPECI)

The term "NO SPECI" is used when the forecast is based on observations from a station with a limited observing program that does not issue special weather observations.

The word ADVISORY appears after the period of coverage. The words NO SPECI appears, after one space, after the word ADVISORY (e.g. TAF CCCC 252240Z 2523/2612 ADVISORY NO SPECI ...).

17.4.6 TAF Updates

Certain TAF sites, usually high-traffic aerodromes, are designated for frequent TAF updates. These are forecasts issued between the normally scheduled TAF issue times, but which do not extend the valid period of the original TAF. They are mainly used to allow for greater accuracy in the short range since they are updated every three hours.

The second TAF for CYYZ, (Pearson International) below is an updated TAF.

TAF CYYZ 041130Z 0412/0518 36010KT P6SM BKN020 BKN200 TEMPO 0412/0414 SCT020

FM041400 04013G23KT P6SM SCT020 BKN220 BECMG 0500/0502 04012KT RMK NXT FCST BY 041500Z=

TAF CYYZ 041330Z 0414/0518 02008KT P6SM SCT020 BKN180 BECMG 0415/0417

04012G22KT BECMG 0501/0503 04010KT RMK NXT FCST BY 041800Z=

17.4.7 Canceling TAFs

Canceling a TAF is sometimes necessary, but is not done lightly as users depend on it. If, canceling a TAF become necessary, forecasters in charge will call the FSS nearest to the site or at the site itself to discuss the reasons why a cancellation is planned.

17.4.8 TAF amendment procedure

The requirement for issuing TAF amendments is driven by customers needing to know when significant weather conditions, liable to affect their operations, are expected. This means that TAF amendment criteria are based on specific thresholds that are significant to aviation operations.

A number of changes in the occurrences/non-occurrences of forecast and actual weather elements can prompt the need for an amendment. They are explained in depth in this section.

As in a regular TAF, the time in the telecommunication header of an amended TAF indicates the whole hour (UTC) that precedes the time of entry to the collection circuit.

The date/time group YYGGggZ in the bulletin, however, shall indicate the date and time of origin of the amended TAF. For example, a first amendment of a regular TAF for CYYZ issued at 1845Z on the 21 of the month shall be issued as:

FT 211800 AAA
TAF AMD CYYZ 211845Z 2118/2217...

17.4.9 Example of TAFs

17.4.9.1

TAF CYTL 101140Z 1012/10 24 24010KT P6SM BKN030 TEMPO 1018/1020 5SM -SHRA BR

FM202000 24005KT P6SM SKC
RMK FCST BASED ON AUTO OBS. NXT FCST BY 101800Z=

17.4.9.2

TAF CYWG 011740Z 0118/0218 28015KT P6SM -SNRA SCT015 OVC040 TEMPO 0118/0124 2SM -SNRA BR OVC015

FM020000Z 28015KT P6SM BKN030 BKN250 TEMPO 0200/0203 P6SM -SHRA
FM021000Z 30015KT P6SM SKC
RMK NXT FCST BY 012400Z=

NOTE: If an updated TAF was scheduled, the remark in the above example would say: NXT FCST BY 012100Z.

17.5 Upper Wind and Temperature Forecasts (FDs)

Forecasts in digital form of the winds and the temperatures aloft (FDs) are prepared to meet aeronautical requirements for flight planning and to prepare documentation for flights in Canada and between Canada and the United States, Greenland, Mexico and the Caribbean.

17.5.1 Content and issuing offices

The Canadian Meteorological Centre (CMC) issues objective forecasts of upper wind and temperature for 170 locations. These locations are listed in Appendix D of MANAIR.

The CMC, in Montreal, issues the FDCN01, FDCN02 and FDCN03 CWAO messages for the 3,000, 6,000, 9,000, 12,000 and 18,000-foot levels above sea level (ASL). The 3000-foot level is omitted when the terrain elevation is greater than 1,500 feet. In addition, temperatures are not forecast for the 3,000-foot level.

The National Weather Service (NWS), in Washington, issues objective forecasts of upper winds and temperatures for, to a few exceptions, the same locations as the CMC, but for the 24,000; 30,000; 34,000; 39,000; 45,000 and 53,000-foot levels. These forecasts are transmitted under the headers FDCN01, FDCN02 and FDCN03 KWBC.

Each group contains the following information:

- Wind direction are stated in tens of degrees with reference to true north. To decode it, one zero must be added to the wind direction. For example, a wind direction stated as 27 implies that the wind is blowing from 270 degrees.
- Wind speed are indicated in knots. A wind speed of less than 5 knots is indicated by 9900 and a wind between 5 and 9 knots is indicated with a zero in front of the value (e.g. a wind of 8 knots is indicated as 08). Wind speeds between 100 and 199 knots are decoded by subtracting 50 from the direction and adding 100 to the speed. For example, a value of 7430 represents a wind blowing from 240 (74 minus 50) degrees at 130 (30 + 100) knots.
- The temperature at 3,000 ft is not given. Temperatures at the other levels are given in degrees Celsius. Data for 3,000 ft are omitted when the height of the terrain is greater than 1,500 ft.

17.5.2 Issue time and period of use

Wind and temperature forecasts in digital form (FDs) are prepared twice daily and are based on 00Z (UTC) and 12Z data, respectively.

When FDs are generated, 6, 12, 18, 24, 30, 36 and 48-hour forecasts are created. The 6, 12 and 24-hour forecasts become respectively the FDCN01, FDCN02 and FDCN03 messages, and are transmitted via the EC telecommunications network.

Each of the 6, 12 and 24-hour forecasts, though for a particular time, applies to a specific period, called "Period of Use".

The following table gives the times of issue, the valid times and the periods of use of each forecast.

HEADER	OBSERVATION TIME	HEADER TIME	VALID TIME	PERIOD OF USE
FDCN01 CWAO	0000Z(UTC)	0320Z	0600Z	0500-0900Z
FDCN02 CWAO	0000Z	0330Z	1200Z	0900-1800Z
FDCN03 CWAO	0000Z	0720Z	0000Z	1800-0500Z
FDCN01 CWAO	1200Z	1520Z	1800Z	1700-2100Z
FDCN02	1200Z	1530Z	0000Z	2100-0600Z

CWAO				
FDCN03 CWAO	1200Z	1920Z	1200Z	0600-1700Z

NOTE 1: Although their headers indicate a later time, the FDCN01, FDCN02 and FDCN03 CWAO forecasts are normally available on AES circuits towards 0230 UTC (forecasts based on 0000Z data) and 1430 UTC (forecasts based on 1200Z data).

NOTE 2: The FDCN01, FDCN02 and FDCN03 KWBC forecasts (from the NWS) that are based on 0000Z observations are normally issued towards 0330Z and their headers show 0440Z. Forecasts based on 1200Z observations are normally issued towards 1530Z and their headers show 1640Z.

17.5.3 Format

The symbolic form of the forecast is ddfftt where dd is the wind direction in tens of degrees with respect to true north, ff is the wind speed in knots, and tt is the temperature in degrees Celsius.

Wind speeds from 100-199 knots are indicated in the same manner as those issued by the NWS and described in section 17.5.1, b. Speeds in excess of 199 knots are coded as if they were of 199 knots (e.g. winds from 90 degrees at 210 knots are coded 5999, as would winds of 199 knots). Finally, wind speeds less than 5 knots are indicated by 9900.

The sign of the temperature is not indicated for levels above 24,000 feet.

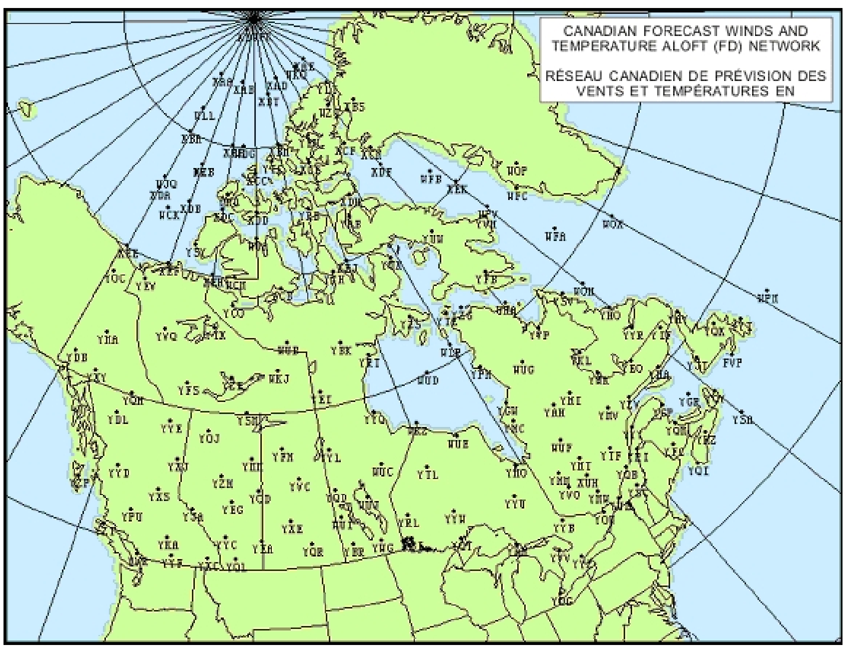


Figure 17.5.3 - Map of Sites for which FDs Are Issued

The following is a regular FDCN bulletin of a forecast of winds and temperatures aloft (FD) issued by the Canadian Meteorological Centre (CMC):

FDCN02 CWAO 242015
FCST BASED ON 241800 DATA VALID 250000 FOR USE 21-06

3000	6000	9000	12000	18000	
YSA	2828	2729+15	2734+12	2737+08	2742-02
YVR	2706	2709+12	2814+08	2817+03	2722-08
YYZ	2610	2712+12	2714+08	2615+03	2618-07

The above forecasts are based on data available at 1800 UTC on the 24th of the current month and valid at 0000 UTC on the 25th of the current month. For practical purpose, it is assumed that the forecasts can be used for the period between 2100 UTC on the 24th of the current month and 0600 UTC on the 25th of the current month.

From the set of upper wind and temperature forecasts above, the upper wind and temperature forecasts for Vancouver (YVR) is the following:

At 3,000 feet, the wind is blowing from 270 degrees true at 6 knots.
At 6,000 feet, the wind is blowing from 270 degrees at 9 knots and the temperature is +12 degrees Celsius.
At 9,000 feet, the wind is blowing from 280 degrees at 14 knots and the temperature is +8 degrees Celsius.
At 12,000 feet, the wind is blowing from 280 degrees at 17 knots and the temperature is 3 degrees Celsius.
At 18,000 feet, the wind is blowing from 270 degrees at 22 knots and the temperature is -8 degrees Celsius.

17.6 Practical Questions

17.6.1 Practical questions on TAFs

TAF CYQX 020540Z 0206/0306 13005KT 1SM -DZ BR OVC005 TEMPO 0206/0210 1/4SM DZ FG VV002

FM021300 31005KT 4SM BR SKC TEMPO 0302/0305 3/4SM BR SCT005 RMK NXT FCST BY 021200Z=

- What does the group 020540Z mean?
- What does the group 4SM BR mean?
- What does the group 0206/0306 mean?
- What does the identifier CYQX stand for?
- What does the group TEMPO 0302/0305 mean?
- What does the group SCT005 mean?

17.6.2 Practical questions on SIGMET

WSCN33 CWUL 061729
SIGMET A1 VALID **061730/062130** CWUL-
WTN 20 NM OF LN /5220N09430W/60 SW SANDY LAKE - /5324N09355W/30 NW SANDY LAKE.
BKN LN CB MAX TOPS 400 ON LTNG DTCTR AND ON SAT PIX. PSBL WIND GUSTS TO 40 KT. SVR ICG AND TURBC ASOCTD. LN MOVG EWD AT 35 KTS AND INTSFYG.
END/LB

- What is a SIGMET message (**WSCN**)?
- What is the valid period of the above SIGMET?
- Who is the issuing office of the above SIGMET?
- When do you expect the above SIGMET to be updated?
- What is the reason for issuing the above SIGMET?

17.6.3 Practical questions on AIRMETs

WACN34 CWUL 200720
AIRMET A1 ISSUED AT 0720Z CWUL-
AMEND GFACN34 CWUL 200530 ISSUE
WTN AREA /4607N06441W/MONCTON - /4428N06831W/BANGOR -
/4459N06455W/GREENWOOD - /4607N06441W/MONCTON. DC9 RPRTD MDT CLR ICG IN
FZDZ ALG THE S CST OF NB AT 07Z. FZDZ EXPD TO CONT UNCHGD.
END/FU

- What is an AIRMET message (WACN)?
- What is the valid period of the above SIGMET?
- Who is the issuing office of the above SIGMET?
- When do you expect the above SIGMET to be updated?
- What is the reason for issuing the above SIGMET?

17.6.4 Practical questions on the GFA clouds and weather panel

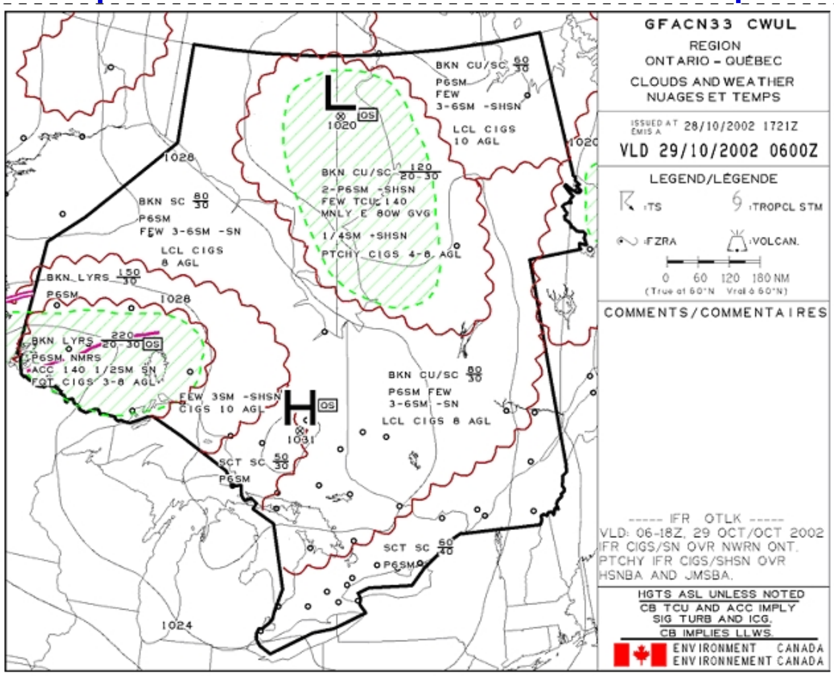


Figure 17.6.4

- What is the valid period of the outlook of the above GFA?
- What is the issue and valid time of the above GFA?
- What kind of weather is expected over Hudson and James Bays at that time?
- What are the weather symbols described in the Legend Box?
- What is the weather expected just north of lake superior at that time?

17.6.5 Practical questions on the GFA icing-turbulence and freezing level panel

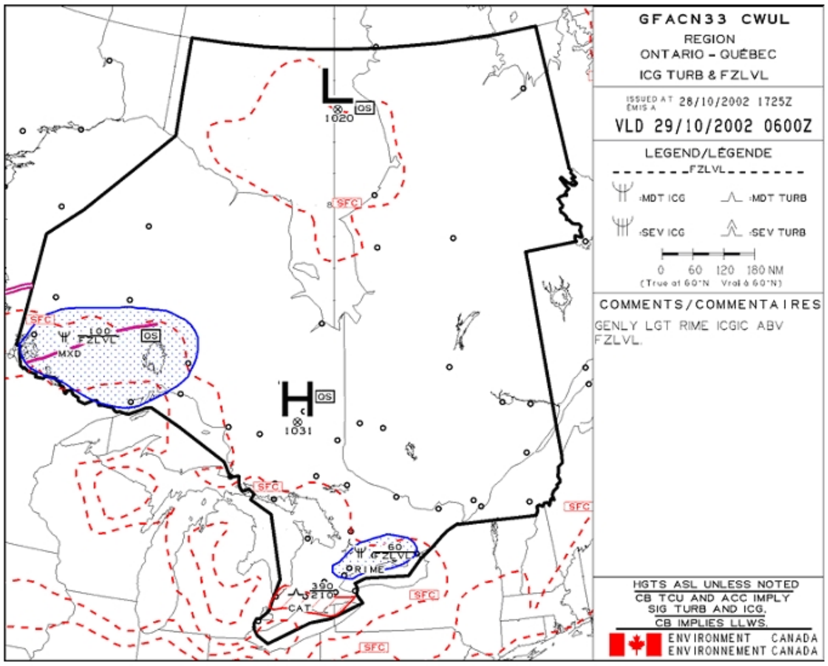


Figure 17.6.5

- Why is the map called an ICG-TURB & FZLVL Map?
- What is the valid time of the map?
- Where are the areas of icing forecast?
- Is there any area of turbulence indicated on the map?
- What are the dashed red lines?

17.6.6 Practical questions on an FD issued by CMC

FDCN01 CWAO 090320
BASED ON 090000 DATA VALID 090600 FOR USE 05-09
3000 6000 9000 12000 18000
FCST YVR 2118 2322+04 2435+01 2447-08 2456-18
YYF 1818 2125+03 2136+01 2129-07 2134-19

- What is the wind speed over Vancouver at 9,000 feet?
- What is the wind direction over Vancouver at 18,000 feet?
- What is the temperature over Penticton at 6,000 feet?
- Why is there no temperature forecast over Penticton and Vancouver at 3,000 feet?

17.6.7 Practical questions on an FD issued by NWS

FDCN01 KWBC 240440
DATA BASED ON 240000Z
VALID 240600Z FOR USE 0500-0900Z. TEMPS NEG ABV 24000 FT
24000 30000 34000 39000 45000 53000
YVR 0815-28 092043 081848 051249 331449 340653
YYF 1315-27 132043 132050 121151 280750 280652

- What is the date and time of issue of the FDCN01 KWBC?
- What is the temperature over Vancouver at 34,000 feet?

- What is the wind speed and direction over Penticton at 30,000 feet?

CHAPTER 18
PILOT REPORT - PIREP

18.1 Introduction

PIREPs are reports of observations made by pilots in flight. Such observations are crucial for other pilots, navigators, air traffic controllers and meteorologists preparing forecasts, as well as for the computer network which automatically generates some forecasts.

Regardless of the weather, every pilot should produce a PIREP every time he gives his position, in addition to producing them systematically whenever an expected or unexpected phenomenon occurs.

PIREPs received by flight information service points are immediately transmitted to other points and to all weather offices.

18.2 Format

The outlook of the PIREP is as follows:

- heading
- position
- altitude
- type of aircraft
- sky condition
- temperature
- wind speed
- turbulence
- icing
- remarks

The general format of a PIREP is shown below. The length of the report may vary where elements are omitted.

(U) UA/OV	NAVAID (*3) Direction (*3) Distance (*3) Time (UTC) (*4)
FL	Altitude (*3)
/TP	Type of aircraft (*3 or *4)
/SK	Base (*3) Extent (*3) Top (*3)
/TA	Temperature in degrees Celsius [ºC] (*2 or *3)
/WV	Direction (3) Speed (*3)
/TB	Intensity (3) Intensity (*3 or *4) CAT only Altitude (*3) Altitude (*3)
/IC	Intensity (*2 or *3) Intensity (*2 or *3) Type (*3 or *4) Altitude (*3) Altitude (*3)
/RM	Remarks

Notes:

- The elements for which no data are reported are omitted.
- All codes, with the exception of FL (flight level) are always preceded by a space and an oblique line, and followed by another space.
- FL is always preceded by a space only, and followed immediately by the flight level or altitude (3 digits).
- If turbulence and/or icing is reported at the same altitude as that given for the aircraft's location, no altitude is shown after /TB and/or /IC. A single altitude can be indicated, or a layer can be defined by giving the altitude of both the base and the top.

18.3 Codes

The codes used in PIREPs are as follows:

UA	Identifies the message as a PIREP.
UUA	Identifies the message as an urgent PIREP and tells the computer to give the message a higher priority for distribution.
/OV	Data on the location to follow.
FL	Flight level or altitude. The unit used by pilots in North America is the foot. If the flight level is unknown, UNK may be indicated.
/SK	Sky conditions. Several layers may be indicated, separated by oblique line.
/TA	Ambient temperature in degrees Celsius.
/TP	Type of aircraft. If the type is unknown UNK may be indicated.
/WV	Wind velocity.
/TB	Turbulence.
/IC	Icing.
/RM	Remarks.

Dashes are used to show variations in the intensity, the upper and lower limits of a layer, and the two ends of a route segment. A dash is also used to indicate negative temperatures.

When the number of digits is less than the number required, the data will be preceded by one or more zeros. A message on the position of an aircraft at "45 miles from London VOR, heading 005º, at 0030 Z, at 5000 ft" would be coded: /OV YXU 005045 0030 FL050.

18.4 Heading

Each PIREP or groups of PIREPs distributed over telecommunications networks must include:

- an identification code for the type of message
- a 4-letter circuit code
- a 6-digit date/time group (the 4 final digits giving the UTC time).

The usual message type code is UACN10. Urgent PIREPs, however, are transmitted with the code UACN01. Two examples are shown below:

- Normal PIREP: UACN10 CYUL 020922

- Urgent PIREP: UACN01 CYYZ 232037

18.5 Urgent PIREPs

An urgent PIREP must be transmitted when a pilot reports dangerous or potentially dangerous flight conditions.

Each of the following weather conditions reported by a pilot is sufficient cause for transmitting an urgent PIREP.

- tornado, funnel cloud, waterspout
- severe or violent turbulence
- severe icing
- hail
- low level wind shear (less than 2,000 ft from ground level)

18.6 Examples

- UACN10 CYYZ 131348

  UA/OV VQC 045043 1342 FL090 /TP BE80 /SK OVC 075 /TA-18 /IC LGT RIME BLO 075 /RM WIND COMP HEAD 010 MH 065 TAS 210

  Meaning:
  Location: Stirling VORTAC, direction 045º, 43 nautical miles, 1342Z at 9,000 ft
  Type: Beech Queen Air
  Sky conditions: overcast, top at 7,500 ft
  Air temperature: minus 18ºC
  Icing: light rime below 7,500 ft
  Remarks: head wind component 10 kt, magnetic heading 065; true airspeed: 210 kt

  Note: If the pilot is unable to determine the precise wind direction or velocity, the wind components on a specific part of the flight may be reported in the remarks section. In such cases, the wind component is coded WIND COMP, followed by a space and the qualifier HEAD or TAIL.

- UACN10 CYEG 070122 UA/OV YNY-YRM 0116 FL270 /TP DC8 /SK 180 BKN 230 /TA -36 /WV 280045 /TB LGT CAT ABV 250

  Meaning:
  Location: Enderby to Rocky Mountain House, 0116 Z, at 27,000 ft
  Type: DC-8
  Sky conditions: Cloud base 18,000 ft, broken, top 23,000 ft
  Air temperature: minus 36ºC
  Wind: 280º at 45 kt
  Turbulence: Light CAT above 25,000 ft

- UACN01 CYYZ 072137 UUA/OV YXU 099015 2133 FL040 /TP CV64 /SK 005 OVC /TB MDT-SVR ABV 050 /RM TORNADO TOUCHING SURFACE 8 N

  Meaning:
  Location: London VORTAC, heading 099º, 15 nautical miles, at 2133Z, at 40,000 ft
  Type: Convair 640
  Sky conditions: Cloud base at 500 ft, overcast
  Turbulence: Moderate to severe at 5,000 ft
  Remarks: Tornado touching the surface at 8 nautical miles north

18.7 Examples of Coded Elements

- Location, including the time and flight level
    - /OV YQT 115055 0040 FL090
    - /OV YEG-YYC 2125 FL230
- Type of aircraft
    - TP DH6 DeHavilland Twin Otter
    - /TP L101 Lockheed Tri-Star (1011)
- Sky conditions
    - /SK 045 SCT Scattered cloud, based at 4,500 ft
    - /SK BKN 074 Broken layer topped at 7,400 ft
    - /SK 160 OVC 240 Overcast, layer based at 16,000 ft, topped at 24,000 ft. When a number of layers are reported, they are separated by an oblique line; eg, /SK 120 SCT 140/180 BKN 210
- Air temperature (amended)
    - /TA 04 Temperature is 4ºC
    - /TA -35 Temperature minus 35ºC
- Wind velocity
    - /WV 005110: wind is 5º true at 110 kt
    - /WV 310010: wind is 310º true at 10 kt
- Turbulence
    - /TB MD moderate turbulence at flight level
    - /TB LGT-MDT BLO 050 light to moderate turbulence below 5,000 ft
    - /TB LGT-MDT CAT 230-270 light to moderate clear-air turbulence between flight levels 23,000 and 27,000 ft

Note: A dash is used (without spaces) to separate intensity symbols when describing variations in intensity. Similarly, when describing a layer, a dash is placed between the 2 flight levels representing the top and base of the layer.

- Icing
    - /IC TR RIME BLO 040 /MDT CLR 100-140 trace rime icing below 4,000 ft; moderate clear icing between 10,000 and 14,000 ft

Note: Oblique lines are used to separate layers of icing.

18.8 Exercises

1. What is a PIREP?
2. When can PIREPs be issued?
3. Who uses PIREPs?

CHAPTER 19 WEATHER RADAR

The term "radar", which has been in use since the 1940s, is an acronym formed from the English term "RAdio Detection And Ranging". It defines a system of spatial location which uses energy from the HF, VHF, SHF and microwave portion of the electromagnetic spectrum.

Weather radar systems generally use a paraboloidal antenna and, much like a searchlight, reveal objects caught in their beam. Radar detects and locates objects equally well by day or night, under clear or overcast sky conditions.

By selecting an appropriate frequency for weather radar operation, it is possible to penetrate through light precipitation and see beyond showers and small-scale meteorological events. Meteorologists use radar primarily to detect and locate precipitation, both suspended in clouds and falling, and to measure its intensity.

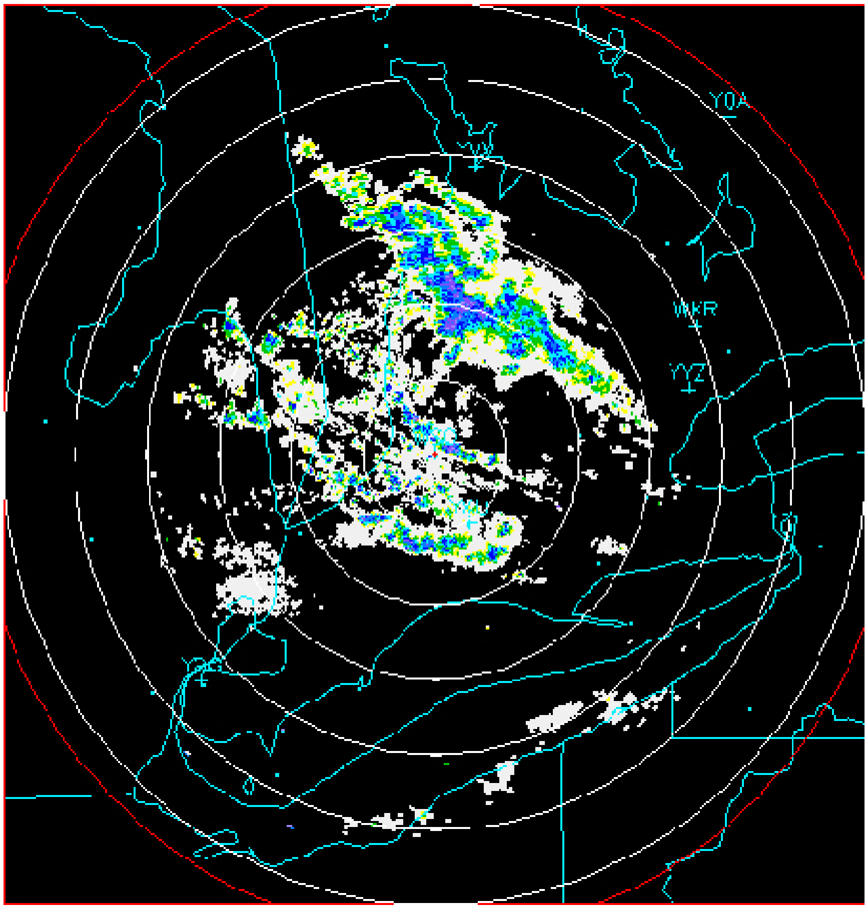
19.1 Operation

Microwave pulses from the transmitter, focused into a narrow beam by the antenna, sweep the sky as the antenna slowly rotates while pointing at different elevation angles. When the energy emitted by the radar antenna strikes particles of precipitation, such as drops of water, snowflakes, sleet or hail, it is reflected with intensity proportional to the number and size of the particles.

When operating in conventional mode, Environment Canada's radars transmit bursts of 2 microsecond duration at a repetition rate of 1200 Hz. Two Doppler modes are used, where the pulse duration is 0.8 micro-second and the repetition rate is either 890 or 1100 Hz. Using a combination of both repetition rates enables the use of Doppler data at longer ranges than would otherwise be possible.

The intensity of the returned signal is digitized along with the antenna position information for each transmitted pulse. It is subsequently processed and portrayed to the meteorologist on a 16-colour geographically-referenced CAPPI display showing precipitation intensity levels in dBz and as rain or snow rates (mm or cm per hour). A CAPPI (Constant Altitude Plan Position Indicator) is a horizontal radar projection showing reflectivity data at a specified altitude.

The returned-echo intensity signal is digitized along with the antenna position information for each pulse. It is subsequently processed and portrayed to the meteorologist on a 16-colour geographically-referenced CAPPI display showing precipitation intensity levels in dBz and as rain or snow rates (mm or cm per hour). A CAPPI (Constant Altitude Plan Position Indicator) is a horizontal radar projection showing reflectivity data at a specified altitude.

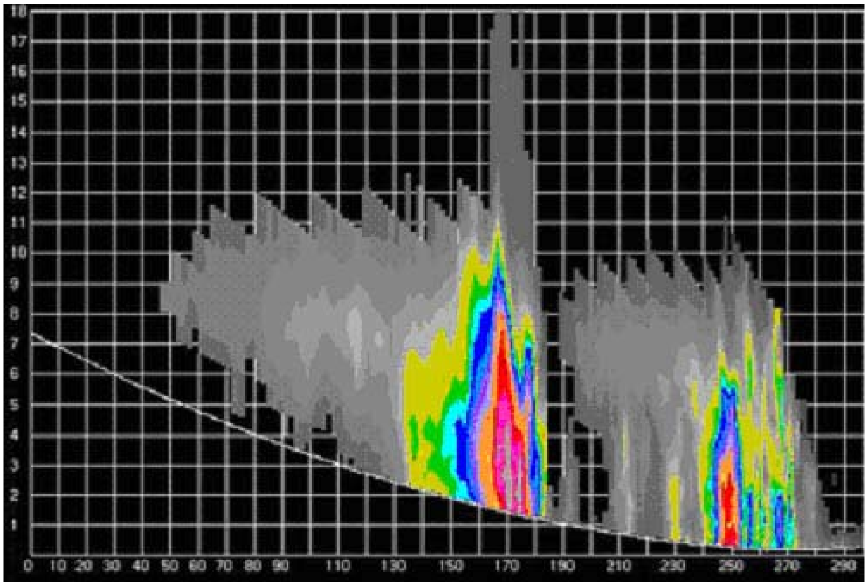


1 km CAPPI, Exeter radar, Nov 17, 2000

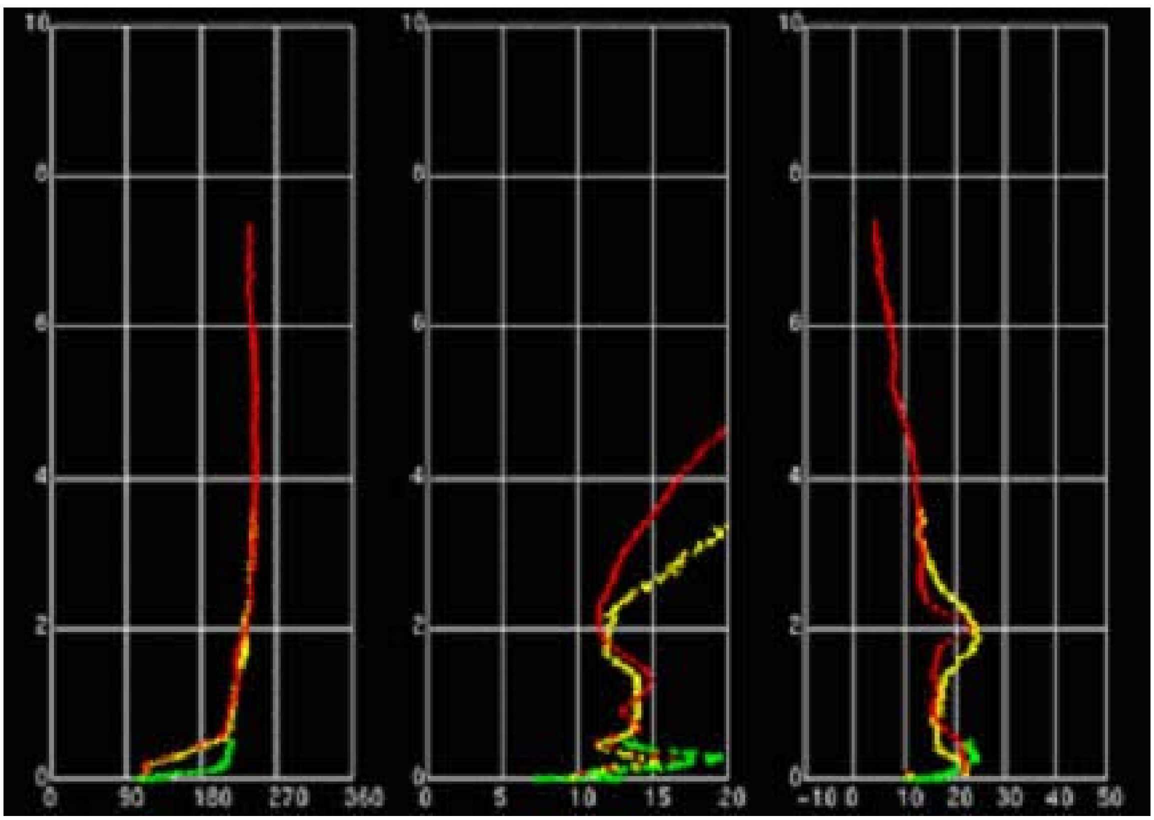
This 1 km CAPPI from the Exeter radar Nov 17 2000 shows bands of snow squalls coming in off Lake Huron, typical of when a cold northwesterly flow crosses the relatively warm waters of the Great Lakes, particularly in late November and December. The squalls nearly always form in lines in the direction of the low level winds.

We can see the cells of stronger radar returns embedded in the lines. The snowfall accumulation rate estimated from radar is up to 2 cm per hour in the squall 80 km (2 rings) north of the radar. Radar typically underestimates this snowfall. Accumulations of 5-10 cm per hour are not uncommon in these squalls.

Some radars use software which can target a portion of the sky and compile a vertical profile of precipitation. This is true of all of the radars which form the National Radar Program network operated by Environment Canada. Using the cross-section tool, it is possible to analyse precipitation inside a thunderstorm, among other things, this gives the vertical precipitation rate, on the basis of which violent storms can be identified quickly.



Arbitrary Cross-Section, Exeter Radar, 000Z 13 Aug, 2003



VAD, Exeter radar, 1350Z 12 Jan 2005.

The frame on the left is height versus direction, the middle is height versus wind speed in m/s, and the right graph is reflectivity. The values are averages around the radar circle at the various heights. These are calculated by 3 separate radar scans as indicated by the 3 colours.

19.2 Doppler Radar

Doppler radars not only detect the intensity and location of precipitation at several levels, but also measure its speed and direction of movement within the area swept, whether it is moving towards the site or away from it.

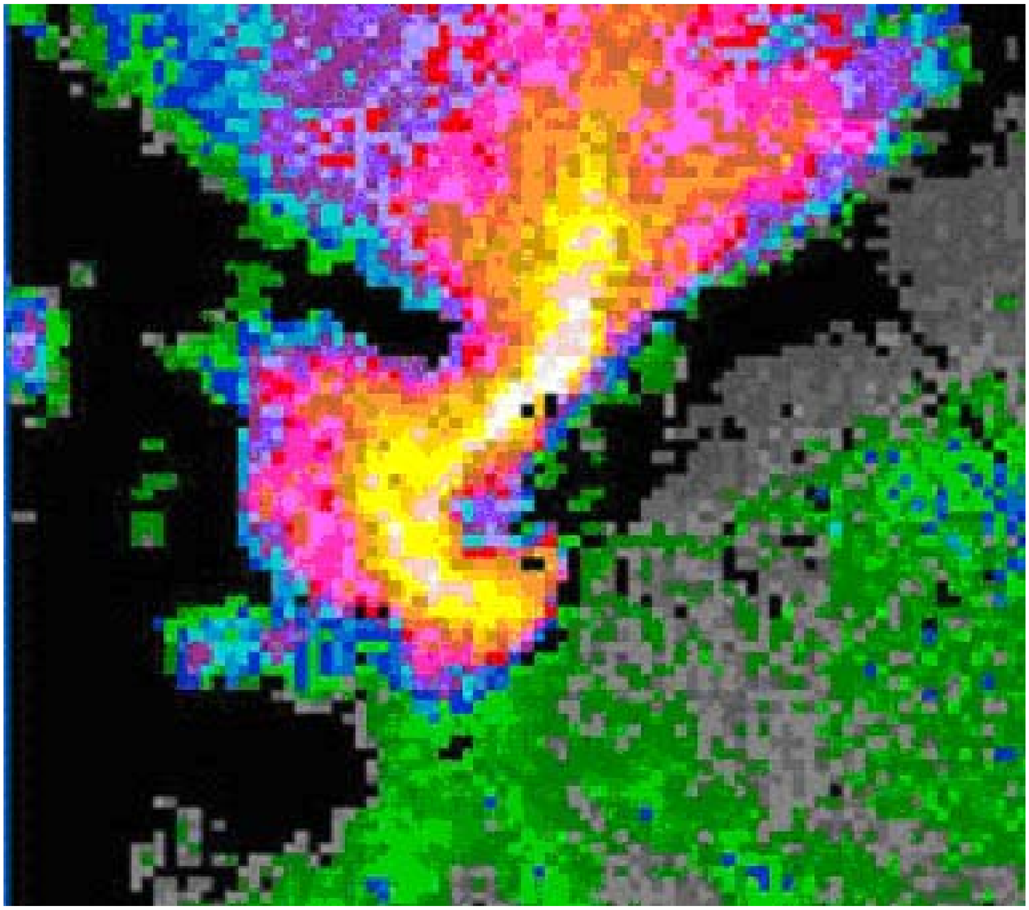
Doppler radars accordingly make it possible to detect the rotation of precipitation, called mesocyclonic movement, which is one of the signs associated with the development of tornadoes.

Although the resolution of MSC's radar is 1km, tornadoes are generally too small and too ephemeral to be detected.

The images below, however, show characteristic reflectivity and Doppler versions of a tornadic event.

Tornadoes which occur in Canada average approximately 10 to 100 m in diameter. They normally occur close to the ground and last for no more than a few tens of seconds to a few minutes. Since they emerge from the base of the clouds and because of the curvature of the Earth, they are almost always below the radar beam.

Doppler radar data are useful in assisting research into the initial conditions conducive to the formation of tornadoes. Doppler data can be used to systematically predict their arrival and assist in the issuance of warnings defining their trajectory.

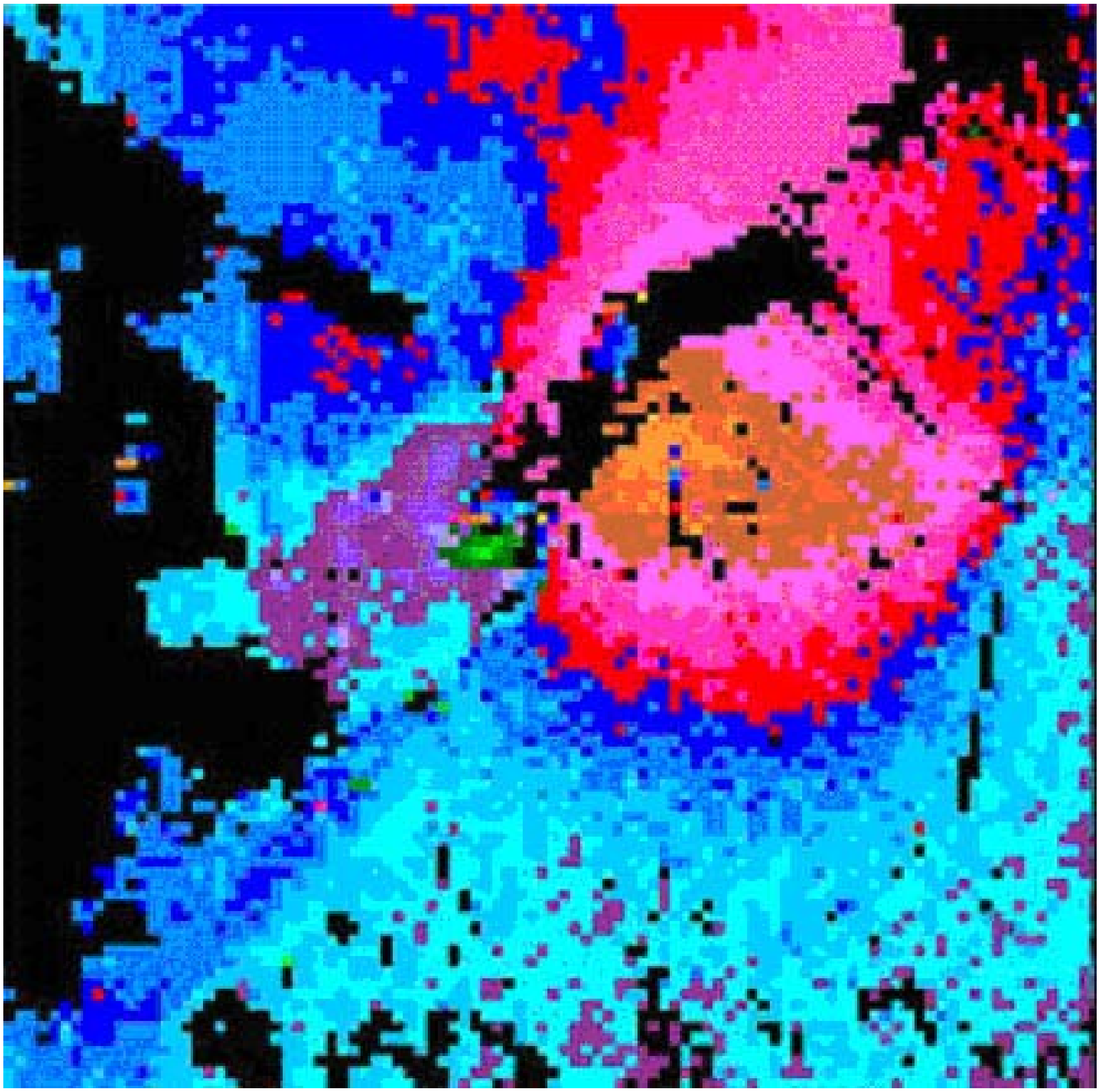


The image above and below are from the Carvel radar, and were captured on Aug 12 2003.

At the time a small tornado is reported to have touched down with this cell. This is quite unique because the storm was only about 20 km away from the radar. These radar pictures are zoomed in on the storm. The upper image shows reflectivity. We see the dramatic hook shape associated with this cell, typical of a tornadic storm.

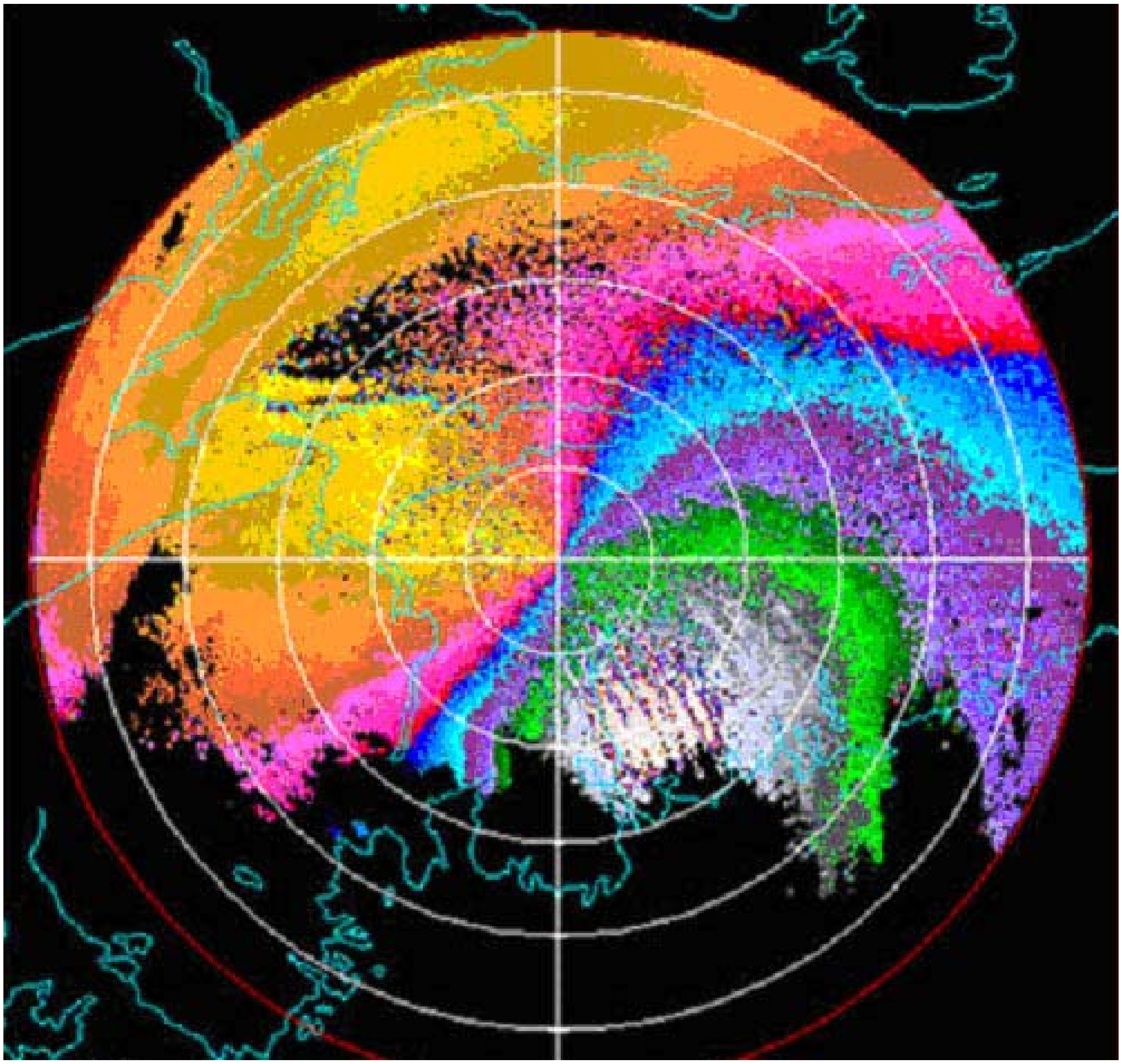
In the Dopplerized image shown below, we see a small area of bright green indicating radial velocities towards the radar up to 36 m/s. The velocities just to the north are near zero. This "velocity couplet" indicates the cyclonic (counter-clockwise) circulation located on the southeastern edge of our reflectivity hook. This is a classic example of what a tornado looks like on Doppler radar.

Doppler radar is highly effective in the case of major thunderstorms and mesocyclones several kilometres in diameter, since it measures rotation inside convection cells, determines the violence of the phenomena and issues increasingly accurate warning messages.



Data generated by Doppler radar about precipitation can also identify wind swings, gust fronts and sometimes even low level wind shear (LLWS), when this does not occur too close to the ground.

Below is a Doppler image captured by the Halifax radar during hurricane Juan.



The beige area to the southeast of the radar indicates winds at the height of the radar beam well in excess of 50 m/s (180 km/hr) that were crossing the Halifax area at this time.

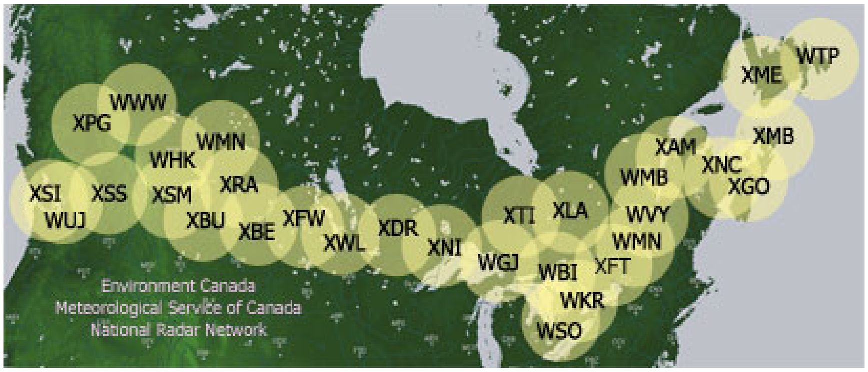
19.3 Mathematical Algorithms

In addition to the capability of directly measuring the intensity of precipitation, radar data can be used to detect other phenomena, such as the structure of violent thunderstorms and associated gusts, or to compile short-term forecasts on the movement of precipitation.

The use of mathematical algorithms on Doppler data makes it possible to determine the speed of thunderstorm gusts; this helps meteorologists to rapidly issue warning messages.

19.4 Environment Canada's Radar Network

Environment Canada 's radars are installed close to the most populated areas and those most affected by violent weather . Their primary purpose is the early detection of developing precipitation and thunderstorms. They have a range of 256 km radius around the site in conventional mode and a Doppler range of 128 km radius from the site.



By comparing a series of radar images of the same type at precise intervals, forecasters can observe the development of a disturbance, follow its trajectory, determine the intensity of precipitation, issue alerts or warnings, and fine-tune their forecasts.

Radar is also used in research to study the development process of precipitation in clouds, specifically heavy rain, hail and violent thunderstorms.

Site Location	Area covered	Province	ID	Band	Type
Aldergrove	Vancouver	BC	WUJ	C	98E
Bethune	Regina	SN	XBU	C	98A
Britt	Georgian Bay	ON	WBI	C	98A
Carvel	Edmonton	AB	WHK	C	98E
Chipman	Fredricton	NB	XNC	C	98E
Dryden	Western Ontario	ON	XDR	C	98E
Exeter	Southwestern Ontario	ON	WSO	C	98A
Foxwarren	Eastern Saskatchawan/Western Manitoba	MB	XFW	C	98E
Franktown	Eastern Ontario	ON	XFT	C	98A
Gore	Halifax	NS	XGO	C	98A
Holyrood	Eastern Newfoundland and Labrador	NF&L	WTP	C	98R
Jimmy Lake	NW Saskatchewan/NE Alberta	SN	WHN	C	98E
King City	Southern Ontario	ON	WKR	C	98A
Lac Castor	Saguenay	QC	WMB	C	98E
Landrienne	Val d'Or	QC	XLA	C	98R
Marble Mountain	Western Newfoundland and Labrador	NF&L	XME	C	98A
Marion Bridge	Cape Breton	NS	XMB	C	98E
McGill	Montréal	QC	WMN	S	
Montreal River Harbour	The Soo	ON	WGJ	C	98E
Mt. Sicker	Victoria	BC	XSI	C	98A
Mt. Silver Star	Eastern B.C.	BC	XSS	C	98A
Nipigon	Superior West	ON	XNI	C	98E

Site Location	Area covered	Province	ID	Band	Type
Prince George	Northern B.C.	BC	XPG	C	98R
Radisson	Saskatoon	SN	XRA	C	98E
Schuler	Medicine Hat	AB	XBU	C	98E
Spirit River	Grand Prarie	AB	WWW	C	98E
Strathmore	Calgary	AB	XSM	C	98A
Timmins	Norhteastern Ontario	ON	XTI	C	98E
Val d'irène	Lower St. Lawrence	QC	XAM	C	98A
Villeroy	Québec	QC	WVY	C	98R
Woodlands	Winnipeg	MB	XWL	C	98A

19.5 Exercises

1. Explain briefly how a weather radar works.
2. What can be observed using radar?
3. What is the range of Environment Canada's radar?
4. Explain why Environment Canada's radars cannot directly detect a tornado.
5. What is a 1.5 km CAPPI?
6. What can you measure with Doppler radar?
7. What conditions will enable you to detect low-level wind shear (LLWS) using Doppler radar?
8. Indicate (yes or no) if the following objects and phenomena can be detected with conventional or Doppler radar:

    - tornadoes
    - lightning
    - hail in the clouds
    - wind shear
    - thunderstorms
    - aircraft in flight
    - aurora borealis
    - snow showers
    - blowing snow
    - ceiling

CHAPTER 20
WEATHER SATELLITES

20.1 Introduction

Our everyday view of the atmosphere is from the bottom looking up and around. Our field of view is limited since most of us can see only a few kilometres in any direction. At the same time, the systems that dominate our weather can be hundreds or even thousands of kilometres across.

Weather maps and radar have extended our views, but it is the weather satellite that gives us a completely different perspective on weather.

By looking down on weather, we can see that fair and stormy weather are somehow related. Clear areas and giant swirls of clouds fit together. In the continually changing atmosphere we can observe evidence of predictability through the order and evolution of weather systems.

Weather satellites now provide a continuous atmospheric observation system which goes beyond the capture of images of cloud cover and the phenomena which disrupt it.

20.2 Historical Background

On April 1, 1960, the first US satellite in the TIROS (Television and Infrared Observational Satellite) series took photographs of the Earth. The United States has subsequently launched some 45 weather satellites, each more modern than its predecessor. In December 1963, Environment Canada received its first images transmitted by satellite.

With the launch of TIROS-1 in 1960, we gained our first total views of the cloud patterns that accompany low pressure systems and fronts. Areas of high pressure and fair weather also became apparent by their general lack of clouds.

Since then, Environment Canada has made a major contribution to the development of weather satellites by helping to develop and verify their instruments for observing the atmosphere, oceans and ice. This experience has optimized the use of satellites in the daily process of forecast preparation.

Today, the Department's research into satellite technology is concentrated primarily in the area of computer modelling and image processing.

20.3 Current Operational Weather Satellite Systems

We now have two basic types of satellite systems. The descendants of TIROS known as polar-orbiting satellites, and geostationary orbiters known as Geostationary Observational Environmental Satellites (GOES).

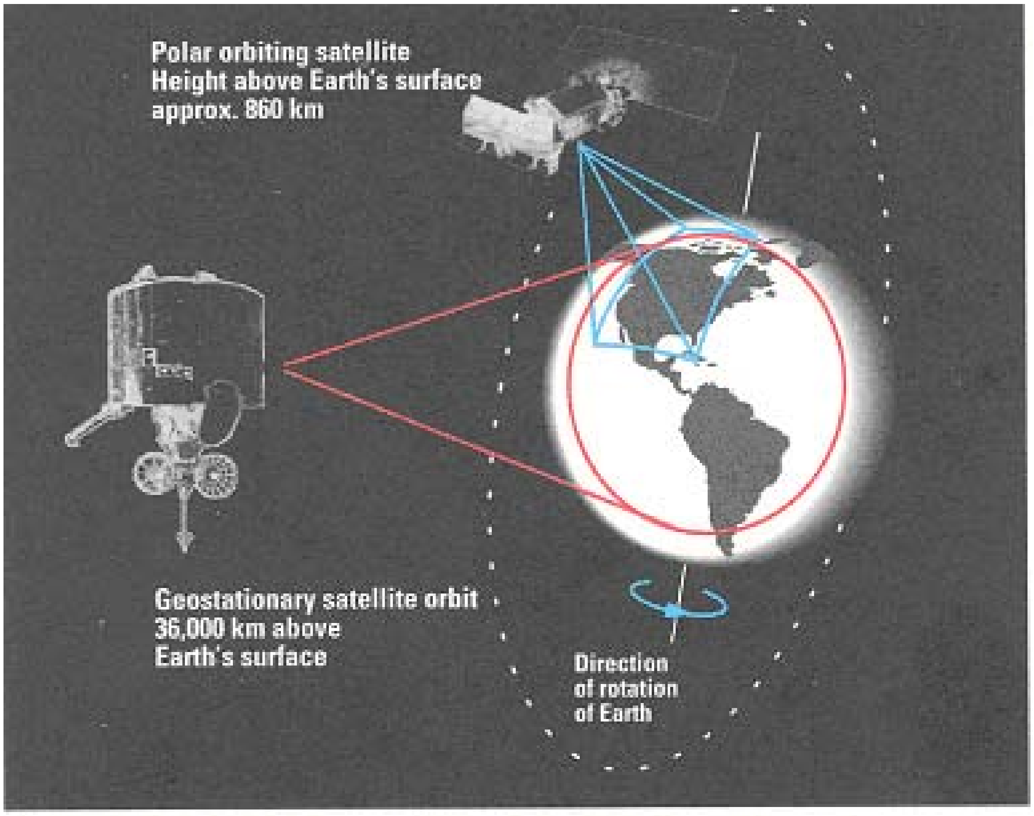


Figure 20-1 The Earth, seen from a NOAA satellite in polar orbit and a GOES geostationary satellite.

Weather satellites are orbiting platforms from which onboard instruments can sense light and heat energy from the atmosphere and underlying surfaces. Because weather satellites can view a large area at one time, anywhere on Earth, they provide meteorological information over the oceans and sparsely populated land regions.

The launch of TIROS culminated a long march of technological advance in electronics and space exploration. The use of electronics for the sensors, information storage, and transmissions to Earth depended upon the newest transistor technology.

The sensors themselves depended upon television research for their images. Later sensors were outgrowths of this and went on to solid-state extensions where heat radiation, as well as light, from the Earth could be measured.

Weather satellite pictures are received as composites of tiny blocks (called pixels) of varying energy intensities, often shown in shades of grey or in colour. The area each block covers determines how detailed the image can be. The smaller that block is, the greater the detail in a satellite image will be.

In addition to sending back pictures of Earth, weather satellites can determine the temperature and water vapour content at different heights in the atmosphere. They can also monitor the ozone layer and detect energetic particles in the space environment.

Finally, the signals that are measured electrically are converted to digital values for storage and are later transmitted down to Earth. There, the visual images with which we are familiar are produced. This last step is highly dependent on computer technology for the assembly, organization, and interpretation of the data.

20.3.1 Polar Orbiting Satellites

Polar orbiting satellites revolve around the Earth at relatively low altitudes, approximately 800 kilometres passing over the Polar Regions, as the Earth rotates underneath. Such an orbit takes about 100 minutes to complete. Most places are scanned twice a day, once in daylight and once in darkness.

With each pass, they survey a strip approximately 1900 km wide that is further west because of the Earth's eastward rotation. Many hours elapse between passes over the same mid or low latitude location. Large-scale views are made from composites of several orbital strips that are about 1,900 kilometres in width.

With 2 satellites to provide the same service, at an interval of 6 hours, they provide only 4 images of a given area every 24 hours. Since they are very close to the Earth, their images have a higher resolution than those from geostationary satellites. Furthermore, when they pass over the North Pole, provided there are no clouds, they provide clear, accurate images of ice conditions in the Arctic.

These satellites provide us with information on the condition of the ozone "hole" and composite pictures of snow cover and ocean surface temperatures.

20.3.2 Geostationary Satellites

A second type of weather satellite orbit is located 35,800 kilometres directly over the equator. These satellites make one revolution, moving in the same direction as the Earth's rotation, in the time it takes Earth to make one rotation. This keeps them above the same spot on the equator, making them appear stationary, hence their name, Geostationary Operational Environmental Satellites (GOES).

They do not picture details as well as the loser polar-orbiting type of satellite, but they do provide more frequent views, every half hour, of the same Earth surfaces.

Ordinarily, there are two geostationary satellites covering Canada and the United States, one for the eastern part and one for the west coast and Pacific Ocean. Each one has a field of view covering about one-third of the Earth's surface.

Because of their angle in relation to the poles, these satellites do not provide accurate information above 60ºN. Image distortion prevents their use in the Arctic.

20.4 Visual Satellite Images

Visual satellite images are views produced from reflected sunlight. Thus, these pictures look similar to pictures made with an ordinary camera.

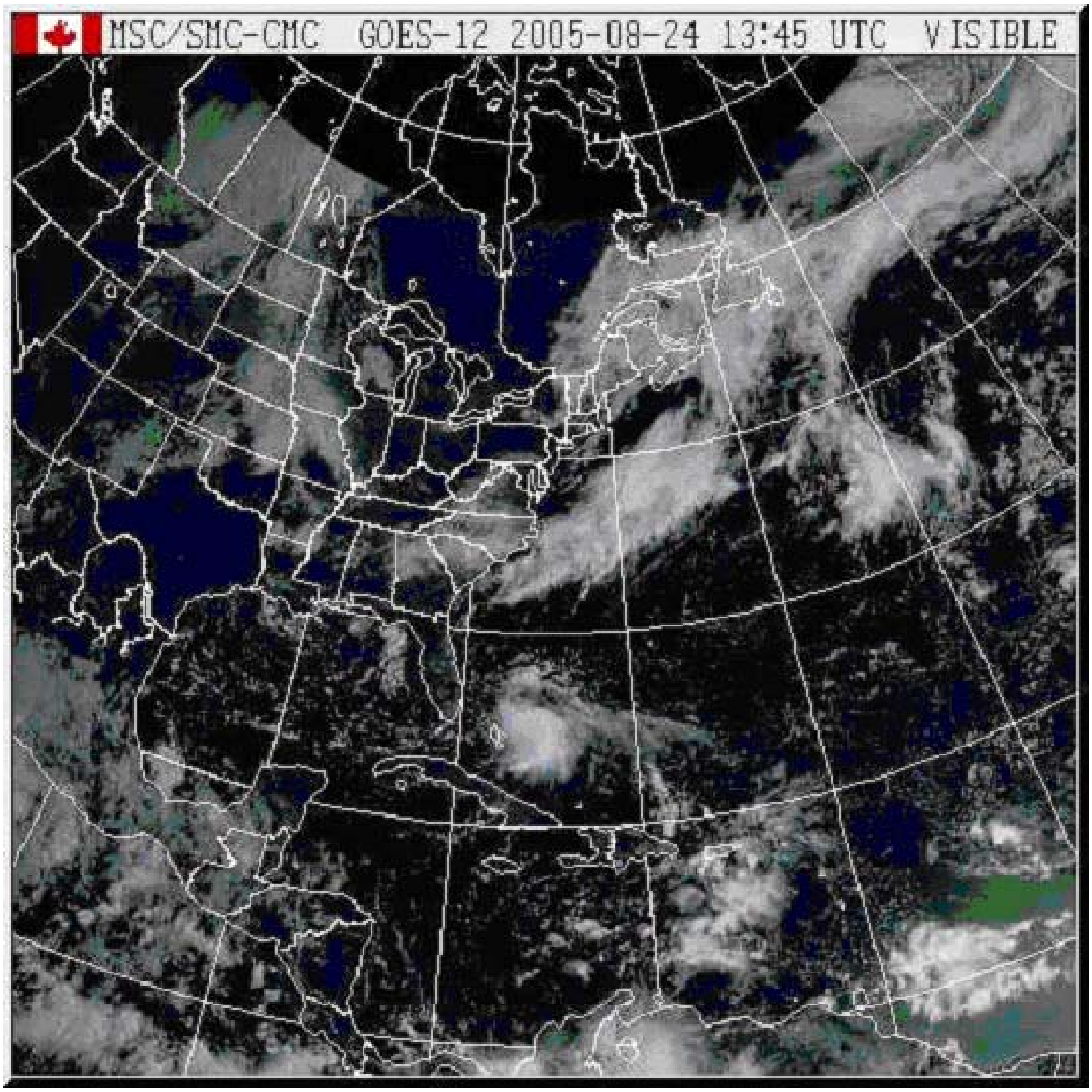


Figure 20-2. GOES-east visual satellite image taken on 24 August 2005 at 1345 UTC.

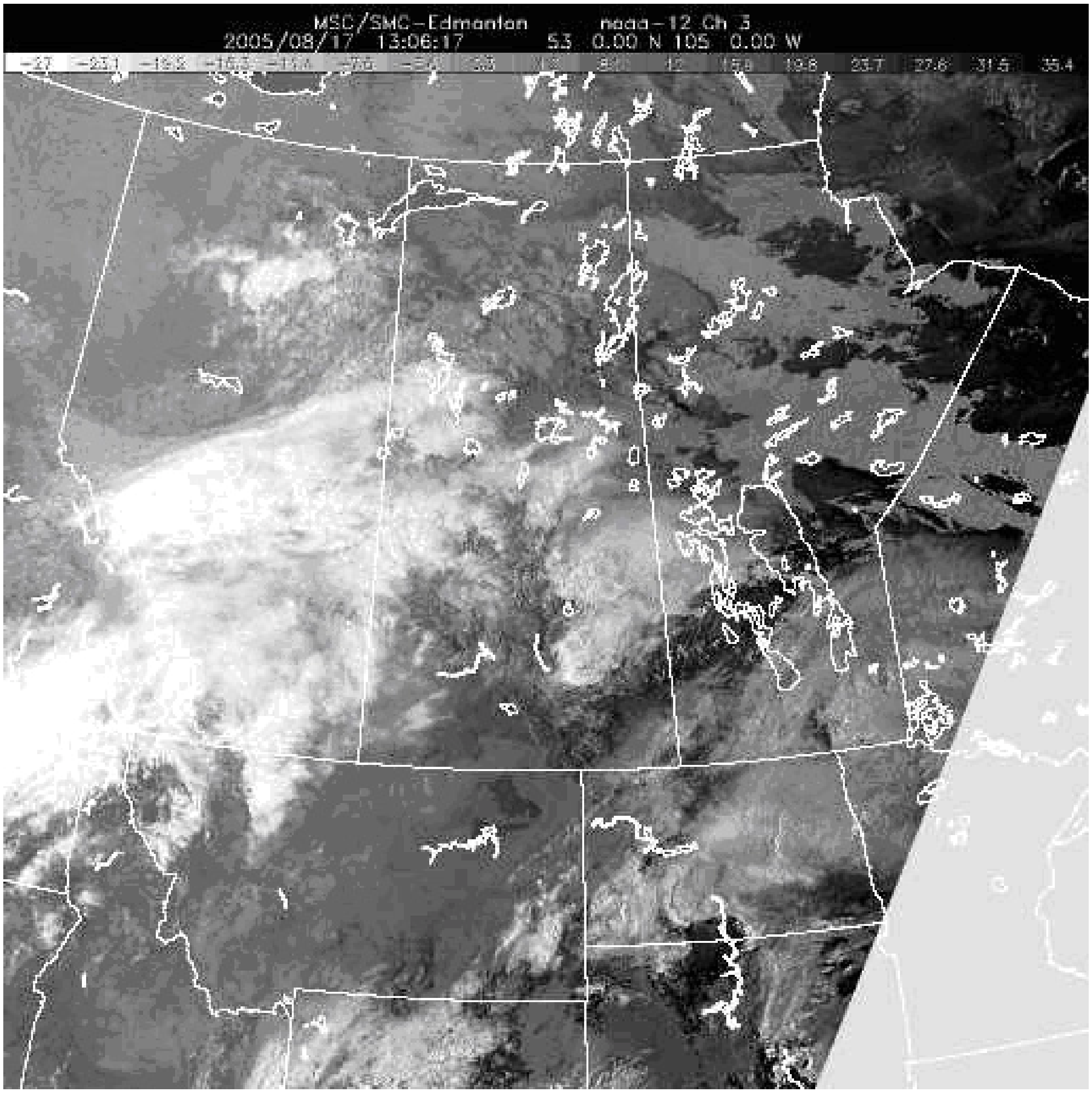


Figure 20-3. NOAA polar orbiting visual satellite image taken on 17 August 2005 at 1306 UTC.

On visual satellite imagery, clouds appear white and the ground and water surfaces are dark grey or black. Since this imagery is produced by sunlight, it is only available during daylight hours. Low clouds and fog are usually distinguishable from nearby land surfaces. In addition, the hazy conditions associated with air pollution can be tracked.

The shadows of thunderstorm clouds can be seen cast on lower clouds in the late afternoon. Snow cover can be monitored because it does not move as clouds do. Land features, such as streams, can be visible.

20.5 Infrared Satellite Images

Infrared satellite images are produced by the infrared (heat) energy Earth radiates to space. Since Earth is always radiating heat, infrared images are available day and night.

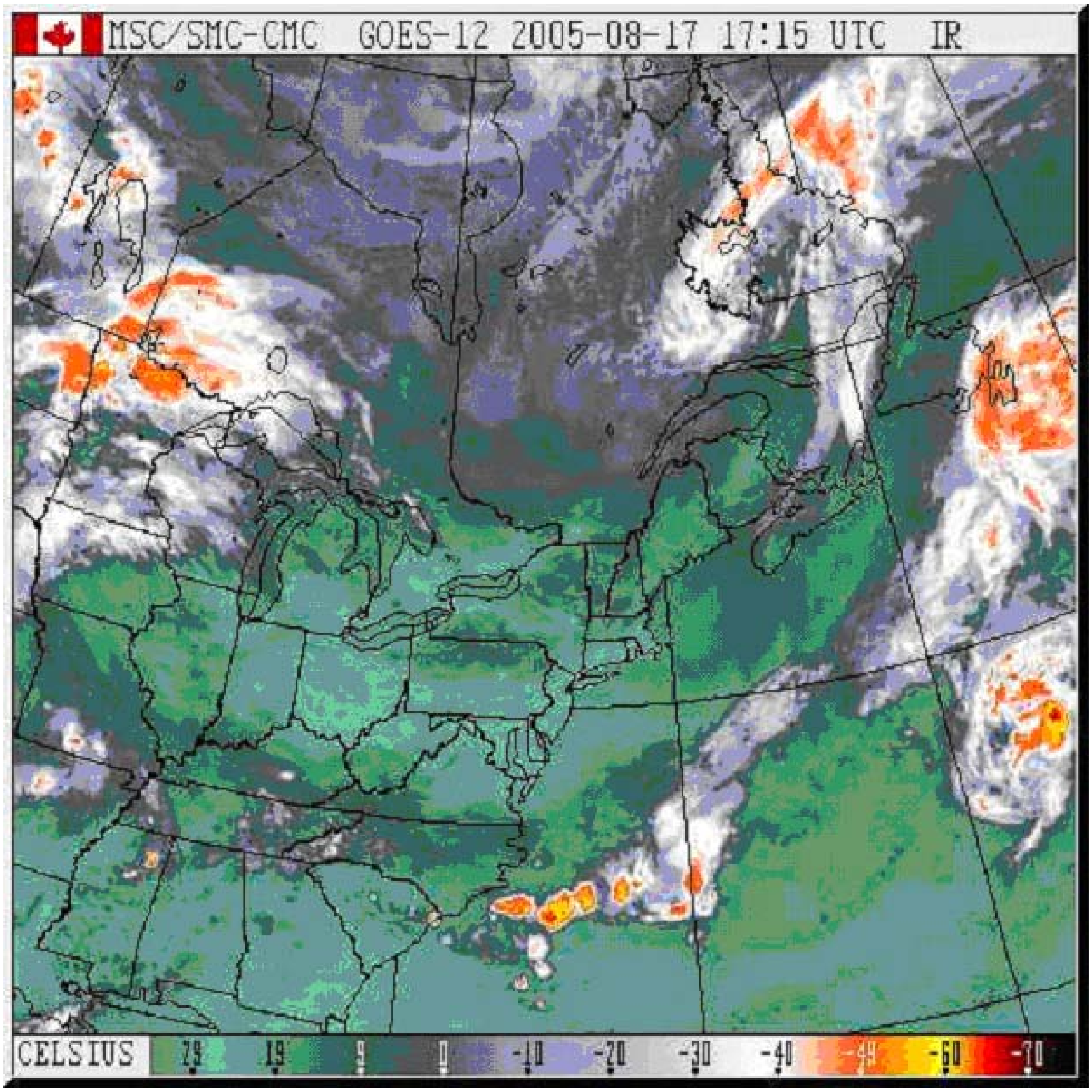


Figure 20-4 GOES-east infrared satellite image taken on 17 August 2005 at 1715 UTC.

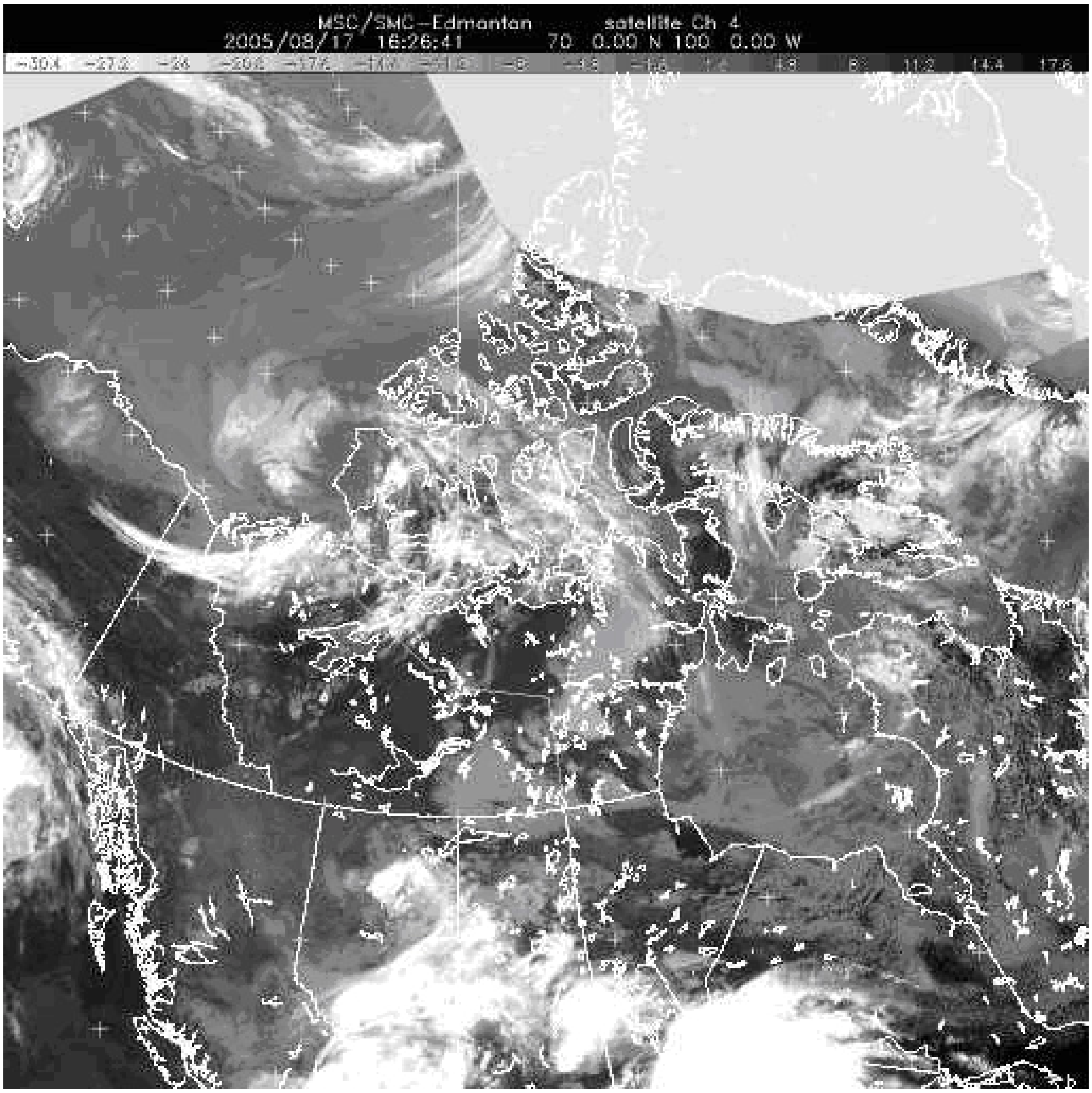


Figure 20-5 NOAA polar orbiting infrared satellite image taken on 17 August 2005 at 1626 UTC.

On infrared images, warm land and water surfaces appear dark grey or black. The cold tops of high clouds are white and lower-level clouds, being warmer, are grey. Low clouds and fog are difficult to detect in the infrared when their temperatures are nearly the same as the nearby Earth surfaces.

An additional advantage of infrared imagery is that it can be processed to produce enhanced views. The data from the usual infrared pictures are specially treated to emphasize temperature details or structure by assigning contrasting shades of grey or colour to narrow temperature ranges.

The enhanced images make it possible to keep track of land and oceanic surface temperatures. These surface temperatures play major roles in making and modifying weather. The high, cold clouds associated with severe weather are also easily monitored. Enhanced imagery can be interpreted to produce rainfall rate estimates. This information is used in flash flood forecasting.

20.6 Combination of Visual Plus Infraded satellite Image

Visual and infrared imagery complement each other. There are weather features that can be clearly seen in one kind of image that are difficult to see in the others.

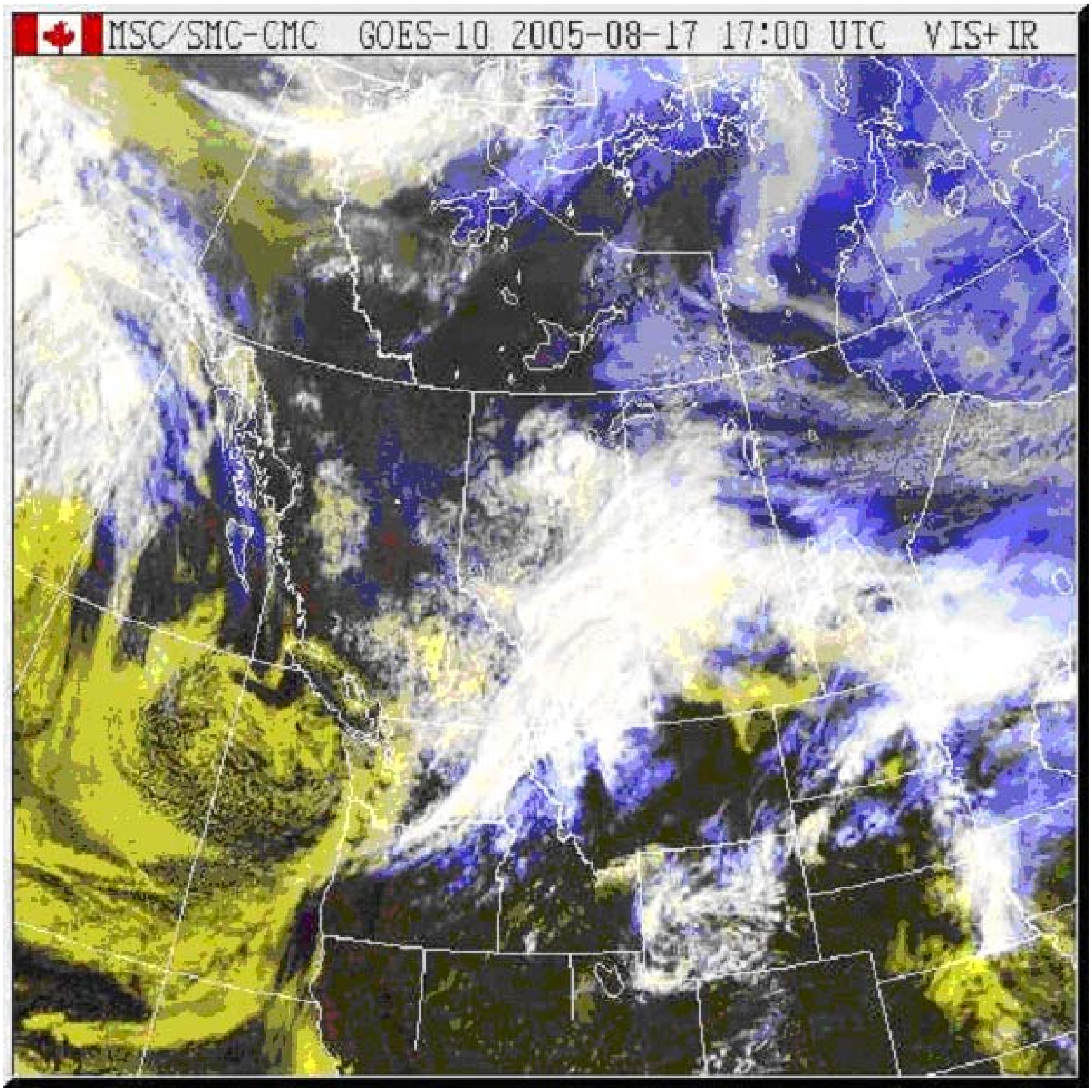


Figure 20-6. GOES-west visual plus infrared satellite image taken on 17 August 2005 at 1700 UTC.

20.7 Water Vapour Satellite Images

Solid, liquid and vapour forms of water interact with specific ranges of infrared energy. Specially tuned geostationary weather satellite sensors can detect water vapour in the atmosphere, in addition to clouds.

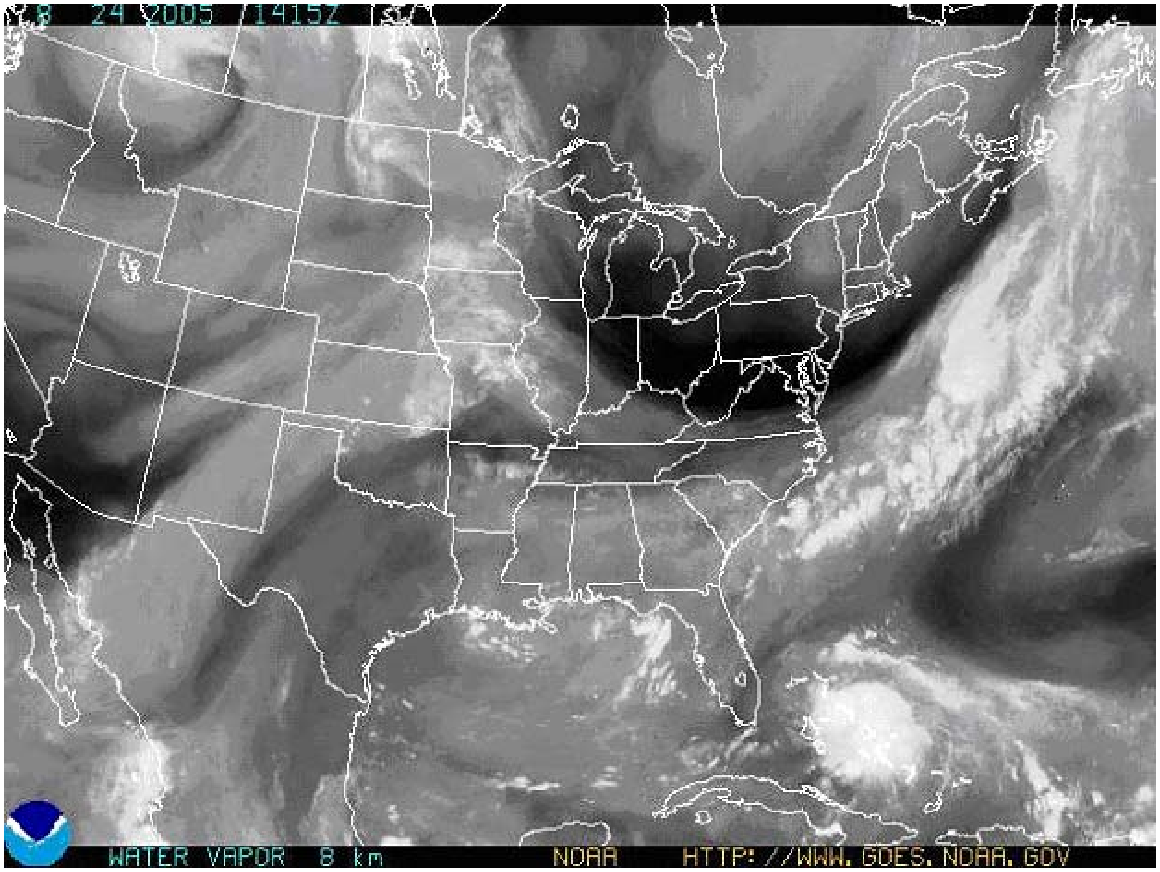


Figure 20-7. NOAA water vapour satellite image taken by a polar orbiting satellite on 24 August 2005 at 1415 UTC.

The water vapour sensors aboard weather satellites reveal regions of high atmospheric water vapour concentration in the troposphere between altitudes of 3 and 7 km. These regions, sometimes resembling gigantic swirls or plumes, can be seen to flow within and through broad scale weather patterns. Recent studies suggest that, at any one time, atmospheric water vapour may be found concentrated in several large flowing streams forming the equivalent of "rivers in the sky".

20.8 Advantages of Weather Satellites in Weather Forecasting

In the past, meteorologists based their forecasts on measurements of temperature, air pressure, moisture, precipitation, cloud cover and wind speed and direction. They laboriously compiled charts and analysed their observations 2 to 4 times a day to assess the direction and speed at which systems were moving.

The advent of satellites completely transformed meteorologists' daily work, by enabling them to observe the formation of clouds anywhere in the world, virtually as they form, and to locate with greater accuracy such major phenomena as weather systems, hurricanes, or a thunderstorm zone beyond the range of surface observation.

The relatively long distances between weather observing stations make it difficult to locate these systems and to follow their movements accurately. The problem is especially acute above oceans, deserts and Polar Regions, where conventional observation posts are rare.

Where surface observations aim at determining as accurately as possible the type and nature of air masses and atmospheric phenomena, satellite imaging is both a valuable complement and a unique source of information on what is going on over all forecasting areas.

Movements of cloud patterns detected by viewing sequential satellite images, indicate the circulations of broad-scale weather systems. Wind speeds can be estimated at different levels and even upper-air jet streams can be identified.

Meteorologists use satellite images to determine cloud shapes, heights, and type. Changes in these cloud properties, along with cloud movement, provide valuable information to weather forecasters to determine what is happening and what is likely to happen to weather in the hours and days ahead.

Hurricanes look like pinwheels of clouds. More often than not, the beginnings of hurricanes are detected from satellite views, because they occur over broad expanses of oceans.

Large comma-shaped cloud shields give shape and form to mid-latitude low-pressure systems. Clouds from which showers fall can look like grains of sand, especially on visible satellite pictures.

Thunderstorms appear as "blobs" or "chains of blobs". Their high tops spread downwind from them as wispy cirrus clouds. They may have neighbouring lower clouds appearing as tiny curved "tails" to the southwest. Such "tails" can also be indicators of the possibility of tornadoes.

Since satellite observation enables the development and path of hurricanes and storms to be tracked, warning services are now significantly more efficient; this efficiency is also matched in the marine sphere, since the best information about icebergs is also used for safety purposes with regard to oil and gas field operations in the Arctic.

At the same time, climatologists also use their data to study seasonal changes in snow cover, in order to facilitate water management and improve flood forecasting.

20.9 Weather Satellites Contribution to Science

Both geostationary and polar orbit satellites compile data day and night on the basis of which we can measure temperature, cloud elevation, atmospheric temperature profiles and moisture, and the temperature of the ocean surface.

In the absence of rain, the "sounder" (a hyper-frequency sensor) in the latest GOES satellite can see through the clouds and thus produce temperature profiles. In addition, by capturing the infrared radiation of the Earth and the clouds, satellites produce nocturnal images which reflect both the cloud cover and temperatures of large areas of the ocean surface.

Taken together, their data are used to fine-tune the surface and upper air charts produced by the forecasting centres, to enhance the accuracy of forecasts, or to depict the entire situation for a flight preparation briefing.

While the quality of forecasting has improved substantially in recent decades, new generation satellites will, in all likelihood, further enhance both accuracy and range, while providing even more information on the environment and our use of it.

20.10 Exercises

1. What are the two basic weather satellite systems currently in operation?
2. What are the main differences between the two?
3. What type of pictures can these satellites take?
4. What are the advantages of satellites in weather forecasting?
5. How do thunderstorms appear on satellite images?
6. How frequently are GOES satellite images transmitted from the satellite to earth receiving stations?
7. How many GOES satellites are operating over North America and adjacent ocean water?

CHAPTER 21
DECODING STANDARD ABBREVIATIONS

Aviation forecasts are often written in abbreviated language, in order to shorten texts for faster transmission. Forecasts in North America are written in English, and the abbreviations accordingly correspond to English words. Words which have no abbreviation are written out in full.

A B C D E F G H I J K L M N O P Q R S T U V W Y

21.1 Letter A

English	Abbr.	French
ABOUT	ABT	À PEU-PRÈS
ABOVE	ABV	AU-DESSUS
ABOVE FREEZING LAYER	AFL	AU-DESSUS NIV. CONGÉLATION
ABOVE GROUND	AG	AU-DESSUS DU SOL
ABOVE GROUND LEVEL	AGL	AU-DESSUS DU NIVEAU DU SOL
ABOVE MEAN SEA LEVEL	AMSL	AU-DESSUS DU NIV. MOYEN DE LA MER
ABOVE SEA LEVEL	ASL	AU-DESSUS DU NIV. DE LA MER
ACCELERATE	ACLT	ACCÉLÉRER
ACCEPT	ACPT	ACCEPTER
ACCOMPANY	ACPY	ACCOMPAGNER
ACCORDING	ACRDG	SELON
ACROSS	ACRS	À TRAVERS
ACTIVE	ACT	ACTIF
ADDITION	ADDN	ADDITION
ADJACENT	ADJ	ADJACENT
ADVANCE	ADVN	AVANCER
ADVECTION	ADVCTN	ADVECTION
ADVISE	ADZ	CONSEILLER
ADVISORY	ADZRY	AVIS
AERODROME	AD	AÉRODROME
AERODROME FORECAST	TAF	PRÉVISION D'AÉRODROME

English	Abbr.	French
AFFECT	AFCT	AFFECTER
AFTER	AFT	APRÈS
AFTERNOON	AFTN	APRÈS-MIDI
AGAIN	AGN	ENCORE
AGREE	AGR	EN ACCORD, ÊTRE D'ACCORD
AGREEMENT	AGRMT	ACCORD
AHEAD	AHD	EN AVANT
AIR-TO-AIR	A/A	AIR-AIR
AIR-TO-GROUND	A/G	AIR-SOL
AIR MASS	AIRMS	MASSE D'AIR
AIR REPORT	AIREP	COMPTE RENDU EN VOL
AIRCRAFT	ACFT	AÉRONEF, AVION
AIRPORT	ARPT	AÉROPORT
ALABAMA	AL	ALABAMA
ALASKA	AK	ALASKA
ALASKA PANHANDLE	ALSK PNHDL	EXTRÊME SUD DE L'ALASKA
ALBERTA	AB	ALBERTA
ALEUTIAN	ALUTN	ALÉOUTIENNES
ALL QUADRANTS	ALQDS	TOUS LES QUADRANTS
ALOFT	ALF	EN ALTITUDE
ALONG	ALG	LE LONG DE
ALTERNATE	ALTN	AÉROPORT DE DÉGAGEMENT
ALTHOUGH	ALTHO	BIEN QUE
ALTIMETER	ALTM	ALTIMETRE
ALTITUDE	ALT	ALTITUDE
ALTOCUMULUS	AC	ALTOCUMULUS
ALTOCUMULUS CASTELLANUS	ACC	ALTOCUMULUS CASTELLANUS
ALTOSTRATUS	AS	ALTOSTRATUS
AMEND	AMD	MODIFIER
AMOUNT	AMT	NÉBULOSITÉ, ÉTENDUE DES NUAGES
AMPLIFY	AMP	AMPLIFIER
AMPLITUDE	AMPLTD	AMPLITUDE
ANALYSE, ANALYSIS	ANAL	ANALYSE, ANALYSER
ANOMALOUS PROPAGATION	AP	PROPAGATION ANORMALE
ANTICIPATE	ANTCPT	ANTICIPER
ANTICYCLONIC	ACYC	ANTICYCLONIQUE
APPARENT	APRNT	APPARENT

English	Abbr.	French
APPEAR	APPR	SEMBLER
APPROACH	APCH	APPROCHE/APPROCHER
APPROXIMATE	APRX	APPROXIMATIF
APRIL	APR	AVRIL
ARCTIC	ARTC	ARCTIQUE
ARIZONA	AZ	ARIZONA
ARKANSAS	AR	ARKANSAS
AROUND	ARND	AUTOUR
ARRANGE	ARNG	PRENEZ DES DISPOSITIONS POUR
ARRIVE	ARR	ARRIVER
AS SOON AS POSSIBLE	ASAP	DÈS QUE POSSIBLE
ASCEND	ASND	MONTER, S'ÉLEVER
ASCENT	ASNT	ASCENSION
ASSOCIATE	ASOCT	ASSOCIER
AT THIS TIME	ATTM	À CE MOMENT
ATLANTIC	ATLC	ATLANTIQUE
ATMOSPHERE	ATMOS	ATMOSPHÈRE
ATTEND	ATND	ASSISTER À
AUGUST	AUG	AOÛT
AURORA BOREALIS	AURBO	AURORE BORÉALE
AUTOMATIC	AUTO	AUTOMATIQUE
AVAILABLE	AVBL	DISPONIBLE
AVERAGE	AVG	MOYEN(NE)
AVIATION	AVTN	AVIATION
AVIATION ROUTINE WEATHER REPORT	METAR	MESSAGE MÉTÉOROLOGIQUE RÉGULIER POUR L'AVIATION
AVIATION WEATHER ADVISORY	AIRMET	AVIS MÉTÉOROLOGIQUE POUR L'AVIATION

21.2 Letter B

English	Abbr.	French
BACK	BCK	RECULER
BAFFIN BAY	BAFBA	BAIE DE BAFFIN
BAFFIN ISLAND	BAFISLD	ÎLE DE BAFFIN
BALLOON	BLN	BALLON
BAND	BND	BANDE
BAROCLINIC	BACLIN	BAROCLINE
BAROMETER	BARO	BAROMÈTRE

English	Abbr.	French
BAROTROPIC	BATROP	BAROTROPE
BASE OF OVERCAST	BOVC	BASE DU CIEL COUVERT
BAY OF FUNDY	BAFDY	BAIE DE FUNDY
BEACON	BCN	RADIOPHARE
BEAUFORT SEA	BFRTS	MER DE BEAUFORT
BECAUSE	BCS	PARCE QUE
BECOME	BECM	DEVENIR
BECOMING	BECMG	DEVENANT
BEFORE	BFR	AVANT
BEGIN, BEGAN	BGN	COMMENCER, À COMMENCÉ
BEHIND	BHND	DERRIÈRE
BELOW	BLO	AU-DESSOUS
BENEATH	BNTH	SOUS
BERMUDA	BDA	BERMUDES
BETTER	BTR	MEILLEUR
BETWEEN	BTN	ENTRE
BETWEEN LAYERS	BTL	ENTRE LES COUCHES
BEYOND	BYD	AU-DELÀ
BLOCK	BLK	BLOC
BLOWING	BL	SOUFFLER
BLOWING DUST	BLDU	CHASSE-POUSSIÈRE ÉLEVÉE
BLOWING DUST IN THE VICINITY	VCBLDU	CHASSE-POUSSIÈRE ÉLEVÉE DANS LES ENVIRONS
BLOWING SAND	BLSA	CHASSE-SABLE ÉLEVÉE
BLOWING SAND IN VICINITY	VCBLSA	CHASSE-SABLE ÉLEVÉE DANS LES ENVIRONS
BLOWING SNOW	BLSN	CHASSE-NEIGE ÉLEVÉE
BLOWING SNOW IN VICINITY	VCBLSN	CHASSE-NEIGE ÉLEVÉE DANS LES ENVIRONS
BORDER	BDR	FRONTIÈRE
BOUNDARY	BDRY	LIMITE
BREAK	BRK	ÉCLAIRCIE
BRIEF	BRF	BREF
BRITISH COLUMBIA	BC	COLOMBIE BRITANNIQUE
BROAD	BRD	LARGE, ÉVASÉ
BROADCAST	BCST	ÉMISSION RADIO/TÉLÉ
BROKEN	BKN	FRAGMENTÉ
BUILD	BLD	DÉVELOPPER
BUILDUP	BLDUP	SE DEVELOPPER, AUGMENTER
BUILT	BLT	DÉVELOPPER

English	Abbr.	French
BULLETIN	BULL	BULLETIN
BY WAY OF, VIA	VIA	VIA, PASSANT PAR

21.3 Letter C

English	Abbr.	French
CALIFORNIA	CA	CALIFORNIE
CANADA	CAN	CANADA
CANADIAN	CDN	CANADIEN(NE)
CANCEL	CNCL	ANNULER
CARIBBEAN	CARIB	ANTILLES
CASCADES	CASCDS	CASCADES
CATEGORY	CTGY	CATÉGORIE
CAUTION	CAUTN	PRUDENCE
CEILING	CIG	PLAFOND
CELSIUS (DEGREES)	C	CELSIUS (DEGRÉS)
CENTIMETRE(S)	CM	CENTIMÈTRE(S)
CENTRAL	CNTRL	CENTRAL
CENTRE	CNTR	CENTRE
CHANCE	CHNC	CHANCE
CHANGE	CHG	CHANGE
CHANNEL	CH	CANAL
CIRCUIT	CCT	CIRCUIT
CIRCULATE	CRCLT	CIRCULER
CIRROCUMULUS	CC	CIRROCUMULUS
CIRROSTRATUS	CS	CIRROSTRATUS
CIRRUS	CI	CIRRUS
CIVIL	CIV	CIVIL
CLEAR	CLR	CLAIR,DEGAGÉ
CLEAR AIR TURBULENCE	CAT	TURBULENCE EN ATMOSPHÈRE CLAIRE
CLOSE	CLS	PRÈS, FERMER
CLOUD	CLD	NUAGES
CLOUDS AND WEATHER	CLDS AND WX	NUAGES ET TEMPS
COAST	CST	CÔTE
COASTAL MOUNTAINS	CSTLMTNS	CHAINE CÔTIÈRE
COASTAL PASSES	CSTLPSS	COLS CÔTIERS
COLD AIR ADVECTION	CAA	ADVECTION D'AIR FROID
COLD FRONT PASSAGE	FROPA	PASSAGE D'UN FRONT FROID

English	Abbr.	French
COLORADO	CO	COLORADO
COMMA	CMA	VIRGULE
COMMA HEAD	CMAH	TÊTE DE LA VIRGULE NUAGEUSE
COMMA SHAPE CLOUD	CMASC	VIRGULE NUAGEUSE
COMMENCE	CMNC	COMMENCE
COMMUNICATIONS	COM	COMMUNICATIONS
COMPLETE	CMPL	COMPLÉTER, COMPLET
COMPLEX	CMPLX	COMPLEXE
COMPUTER	CMPTR	ORDINATEUR
CONCLUSION	CNCLSN	CONCLUSION
CONDENSATION TRAILS	CONTRAILS	TRAINNÉES DE CONDENSATION
CONDITION	COND	CONDITION
CONFIDENT,CONFIDENCE	CONFID	CONFIANT,CONFIANCE
CONFLUENCE	CNFLNC	CONFLUENCE
CONFLUENT	CNFLNT	CONFLUENT
CONNECTICUT	CT	CONNECTICUT
CONSIDERABLE	CSDRBL	CONSIDÉRABLE
CONTACT	CTC	CONTACT
CONTINUE	CONT	CONTINUER
CONTINUOUS	CONTUS	CONTINU
CONTOUR	CONTR	CONTOUR, ISOLIGNE
CONTROL	CTL	CONTRÔLE
CONVECTION	CVCTN	CONVECTION
CONVECTIVE	CVCTV	CONVECTIF
CONVERGE	CONVRG	CONVERGER
CONVERGENCE	CONVRGNC	CONVERGENCE
CORRECT, CORRECTION	COR	CORRECT(E), CORRECTION
CORRESPOND	CRSPND	CORRESPONDRE
COVER	COV	COUVERT
CROSSING	XNG	CROISEMENT
CUMULONIMBUS	CB	CUMULONIMBUS
CUMULUS	CU	CUMULUS
CUMULUS FRACTUS	CUFRA	CUMULUS FRACTUS
CURRENT	CRNT	COURANT
CURVE	CRV	COURBE
CYCLOGENESIS	CYCGNS	CYCLOGÉNÈSE
CYCLOLYSIS	CYCLYS	CYCLOLYSE
CYCLONIC	CYC	CYCLONIQUE

21.4 Letter D

English	Abbr.	French
DAILY	DLY	QUOTIDIEN
DAKOTAS	DKTS	DAKOTAS
DANGER, DANGEROUS	DNG	DANGER, DANGEREUX
DAVIS STRAIT	DVSST	DÉTROIT DE DAVIS
DAYBREAK	DABRK	AUBE
DAYLIGHT	DALGT	LUMIÈRE DU JOUR
DAYTIME	DATM	JOUR
DECAMETRE	DAM	DECAMÉTRE
DECELERATE	DCLRT	RALENTIR
DECEMBER	DEC	DÉCEMBRE
DECIDE	DECID	DÉCIDER
DEEP	DP	PROFOND
DEEPEN	DPN	CREUSER (SE)
DEFINITE	DFNT	DÉFINI, PRÉCIS
DEFORMATION ZONE	DFZN	ZONE DE DÉFORMATION
DEGREE	DEG	DEGRÉ
DELAWARE	DE	DELAWARE
DELAY	RTD	DÉLAI, RETARD
DELETE	DLT	RAYER
DENSE	DNS	DENSE
DEPICTION	DPCTN	REPRÉSENTATION
DEPTH	DPT	PROFONDEUR
DESCEND	DSND	DESCENDRE
DESCENT	DSNT	DESCENTE
DESCRIBE	DSCRB	DÉCRIRE
DETECTOR	DTCTR	DÉTECTEUR
DETERIORATE	DTRT	DÉTERIORER
DETERMINE	DTRM	DÉTERMINER
DEVELOP	DVLP	DÉVELOPPER
DEVIATION	DEV	DÉVIATION
DEW POINT	TD	POINT DE ROSÉE
DIAGNOSIS	DIAG	DIAGNOSTIC
DIFFICULT	DFCLT	DIFFICILE
DIFFLUENCE	DIFLNC	DIFFLUENCE
DIFFLUENT	DIFLNT	DIFFLUENT
DIFFUSE	DFUS	DIFFUS

English	Abbr.	French
DIMINISH	DMSH	DIMINUER
DIRECT	DCT	DIRECT
DIRECTION	DCTN	DIRECTION
DISAPPEAR	DSAPR	DISPARAÎTRE
DISCUSS	DSCS	DISCUTER
DISPERSAL	DSPRL	DISPERSION
DISPLACE	DSPLC	DÉPLACER
DISSEMINATE	DISEM	DISSÉMINER
DISSIPATE	DSIPT	DISSIPER
DISTANT/DISTANCE	DIST	DISTANT/DISTANCE, ÉLOIGNÉ
DISTRIBUTE	DISTR	DISTRIBUER
DISTRICT OF COLUMBIA	DC	DISTRICT DE COLUMBIA
DISTURBANCE	DSTBNC	PERTURBATION
DIVERGE	DIVRG	DIVERGER
DIVERGENCE	DIVRGNC	DIVERGENCE
DIVIDE	DVD	SÉPARER, PARTAGER
DODGING	DDG	ÉVITANT
DOMESTIC	DOM	INTÉRIEUR
DOMINANT	DMNT	DOMINANT
DOPPLER (RADAR)	DPLR	DOPPLER (RADAR)
DOUBLE	DBL	DOUBLE
DOUBTFUL	DBTFL	DOUTEUX
DOWN	DN	SOUS
DOWNDRAFT	DNDFT	COURANT D'AIR DESCENDANT
DOWNSLOPE	DNSLP	DESCENDANT LA PENTE
DOWNSTREAM	DNSTRM	AVAL, DESCENDRE LE
DOWNWIND	DNWND	SOUS LE VENT
DRAFT	DFT	ÉBAUCHE, COURANT (D'AIR)
DRIFT	DRFT	DÉRIVER,DÉRIVE
DRIFTING DUST	DRDU	CHASSE-POUSSIÈRE
DRIFTING SNOW	DRSN	CHASSE NEIGE
DRIZZLE	DZ	BRUINE
DRY BULB	DB	THERMOMÈTRE SEC
DUPLICATE	DUPLCT	COPIE
DURATION	DUR	DURÉE
DURING	DURG	DURANT, PENDANT
DURING CLIMB	DURC	EN MONTÉE
DURING DESCENT	DURD	EN DESCENTE
DUST	DU	POUSSIÈRE

English	Abbr.	French
DUST STORM	DS	TEMPÊTE DE POUSSIÈRE
DUST STORM IN VICINITY	VCDS	TEMPÊTE DE POUSSIÈRE DANS LES ENVIRONS
DUST WHIRLS	PO	TOURBILLON DE POUSSIÈRE
DUST WHIRLS IN VICINITY	VCPO	TOURBILLON DE POUSSIÈRE DANS LES ENVIRONS

21.5 Letter E

English	Abbr.	French
EARLY	ERLY	TÔT
EAST	E	EST
EAST-NORTHEAST	ENE	EST-NORD-EST
EAST-SOUTHEAST	ESE	EST-SUD-EST
ECHO TOP	ECTP	SOMMET DE L'ÉCHO
EFFECT	EFCT	EFFET, RÉSULTAT, EN VIGEUR
ELEVATION	ELEV	ÉLÉVATION
ELLESMERE ISLAND	ELISL	ÎLE ELLESMERE
ELSEWHERE	ELSW	AILLEURS
EMBEDDED	EMBD	ENCASTRÉ, IMBRIQUÉ
EMISSION	EM	ÉMISSION
EN-ROUTE	ENRT	EN ROUTE
ENDING	ENDG	SE TERMINANT
ENHANCE, ENHANCEMENT	ENHNC	REHAUSSER, REHAUSSEMENT
ENOUGH	ENUF	ASSEZ
ENTIRE	ENTR	ENTIER
EQUIPMENT	EQPT	ÉQUIPEMENT
ESPECIALLY	ESPLY	SPÉCIALEMENT
ESTIMATE	EST	ESTIMER
EVAPORATION	EVAP	ÉVAPORATION
EVENING	EVE	SOIR
EVERY	EVRY	CHAQUE
EVIDENCE	EVDNC	ÉVIDENCE
EXCEPT	EXC	EXCEPTÉ
EXPAND	XPND	AUGMENTER, AUGMENTATION
EXPECT	EXP	ATTENDRE, S'ATTENDRE À
EXPOSED	XPOSD	EXPOSÉ
EXTEND	XTND	ÉTENDRE,PROLONGER
EXTENSIVE	XTNSV	VASTE

English	Abbr.	French
EXTRAPOLATION	XTRAP	EXTRAPOLATION
EXTREME	XTRM	EXTRÊME

21.6 Letter F

English	Abbr.	French
FACILITIES	FAC	INSTALLATIONS ET SERVICES
FACSIMILE	FAX	FAC-SIMILE
FALLING	FALG	À LA BAISSE
FARTHER, FURTHER	FRTHR	PLUS LOIN, DAVANTAGE
FEATURE	FEAT	CARACTÉRISTIQUE
FEBRUARY	FEB	FÉVRIER
FEET, FOOT	FT	PIED(S)
FEW	FEW	QUELQUES
FIELD	FLD	CHAMP, TERRAIN
FILL	FIL	COMBLER, REMPLIR
FIRST	FST	PREMIER
FLIGHT	FLT	VOL, ENVOLÉE
FLIGHT INFORMATION CENTRE	FIC	CENTRE D'INFORMATION DE VOL
FLIGHT INFORMATION REGION	FIR	RÉGION D'INFORMATION DE VOL
FLIGHT INFORMATION SERVICE	FIS	SERVICE D'INFORMATION DE VOL
FLIGHT LEVEL (PIREP)	FL	NIVEAU DE VOL (PIREP)
FLIGHT PLAN	PLN	PLAN DE VOL
FLIGHT SERVICE STATION	FSS	STATION D'INFORMATION DE VOL
FLORIDA	FL	FLORIDE
FLOW	FLO	ÉCOULEMENT
FLUCTUATE	FLUC	FLUCTUER
FLURRY	FLRY	AVERSE DE NEIGE
FLY	FLY	VOLER
FOG	FG	BROUILLARD
FOG (ANY TYPE) IN VICINITY	VCFG	BROUILLARD DANS LES ENVIRONS
FOG COVERING PART OF AERODROME	PRFG	BROUILLARD SUR UNE PARTIE DE L'AÉRODROME
FOG PATCHES	BCFG	BANCS DE BROUILLARD
FOLLOW	FLW	SUIVRE
FOOTHILLS	FTHLS	CONTREFORTS DES ROCHEUSES
FOR YOUR INFORMATION	FYI	À TITRE DE RENSEIGNEMENT
FORECAST	FCST	PRÉVISION, PRÉVU
FORM	FRM	FORME

English	Abbr.	French
FORMAT	FRMT	FORMAT
FORWARD	FWD	DEVANT, VERS L'AVANT
FOX BASIN	FXBSN	BASIN DE FOX
FREEZE, FREEZING	FZ	GELER, GELANT
FREEZING DRIZZLE	FZDZ	BRUINE SE CONGELANT
FREEZING LEVEL	FZLVL	NIVEAU DE CONGÉLATION
FREEZING RAIN	FZRA	PLUIE VERGLAÇANTE
FREQUENCY	FREQ	FRÉQUENCE
FREQUENT	FRQ	FRÉQUENT
FRIDAY	FRI	VENDREDI
FROM	FM	DE (VENANT DE)
FRONT	FNT	FRONT
FRONTAL PASSAGE	FROPA	PASSAGE FRONTAL
FRONTOGENESIS	FNTGNS	FRONTOGÉNÈSE
FRONTOLYSIS	FNTLYS	FRONTOLYSE
FROST ON THE INDICATOR	FROIN	GIVRE SUR L'INDICATEUR
FROZEN	FZN	GELÉ
FUNCTION	FUNC	FONCTION
FUNNEL CLOUD	FC	NUAGE EN ENTONNOIR
FUTURE	FUTR	FUTUR

21.7 Letter G

English	Abbr.	French
GARBLE	GRBL	BROUILLÉ
GENERAL	GEN	GÉNÉRAL
GENERAL NOTICE	GENOT	AVIS GÉNÉRAL
GEORGIA	GA	GEORGIE
GEORGIA STRAIT	GASTR	DÉTROIT DE GÉORGIE
GEORGIAN BAY	GGNBA	BAIE GEORGIENNE
GIVE	GV	DONNER
GLIDE PATH	GP	ALIGNMENT DE DESCENTE
GOOD	GUD	BON
GRADIENT	GRAD	GRADIENT
GRADUAL	GRDL	GRADUEL
GRAND BANKS	GRBNKS	GRAND BANCS
GRAPHIC AREA FORECAST	GFA	PRÉVISION DE ZONE EN FORMAT GRAPHIQUE
GREAT	GRT	GRAND

English	Abbr.	French
GREAT BEAR LAKE	GBRLK	GRAND LAC DE L'OURS
GREAT LAKES	GRTLKS	GRANDS LACS
GREAT SLAVE LAKE	GSVLK	GRAND LAC DES ESCLAVES
GREENLAND	GRNLD	GROENLAND
GROUND	GND	SOL
GROUND-TO-AIR	G/A	SOL-AIR
GROUP	GRP	GROUPE
GUIDANCE	GDNC	CONSEIL
GULF	GLF	GOLFE
GULF OF ALASKA	GLFALSK	GOLFE DE L'ALASKA
GULF OF MEXICO	GLFMEX	GOLFE DU MEXIQUE
GULF OF ST. LAWRENCE	GLFSTLAWR	GOLFE DU SAINT-LAURENT
GUST(METAR, TAF)	G	RAFALE(METAR, TAF)
GUSTY	GSTY	EN RAFALE

21.8 Letter H

English	Abbr.	French
HAIL	GR	GRÊLE
HAIL SHOWER	SHGR	AVERSE DE GRÊLE
HAILSTONE	HLSTO	GRÊLON
HALF	HLF	DEMI,MOITIÉ
HARBOUR	HBR	PORT
HAZE	HZ	BRUME SÈCHE
HEADING	HDG	EN-TÊTE
HEATING	HTG	CHALEUR
HEAVY	HVY	LOURD, FORT
HECTOPASCAL	HPA	HECTOPASCAL
HEIGHT	HGT	HAUTEUR
HEMISPHERE	HEMIS	HÉMISPHÈRE
HENCE	HNC	PAR CONSÉQUENT
HERE	ER	ICI
HIGH	HI	HAUT,ANTICYCLONE
HIGHER	HIER	PLUS HAUT
HILL TOP	HLTP	SOMMET DE COLLINE
HISTORY	HIST	HISTOIRE
HODOGRAPH	HODO	HODOGRAPHE
HOLIDAY	HOL	CONGÉ, VACANCES

English	Abbr.	French
HORIZON	HRZN	HORIZON
HORIZONTAL	HRZNTL	HORIZONTAL
HOUR	HR	HEURE
HOWEVER	HWVR	CEPENDANT
HUDSON BAY	HSNBA	BAIE D'HUDSON
HUNDRED	HND	CENT,CENTAINE
HURRICANE	HURCN	OURAGAN

21.9 Letter I

English	Abbr.	French
ICE CRYSTALS	IC	CRISTAUX DE GLACE
ICE FOG	FZFG	BROUILLARD GLACÉ
ICE PELLET SHOWER	SHPL	AVERSE DE GRANULES DE GLACE
ICE PELLETS	PL	GRANULES DE GLACE
ICING	ICG	GIVRAGE
ICING IN CLOUD	ICGIC	GIVRAGE DANS LES NUAGES
ICING IN PRECIPITATION	ICGIP	GIVRAGE DANS LES PRÉCIPITATIONS
IDAHO	ID	IDAHO
IDENTIFIER	ID	IDENTIFICATEUR
IDENTIFY, IDENTIFICATION	IDENT	IDENTIFIER,IDENTITÉ
ILLINOIS	IL	ILINOIS
IMMEDIATE	IMDT	IMMÉDIAT
IMPORTANT	IMPT	IMPORTANT
IMPROVE	IMPR	AMÉLIORER
IN CLOUD	INC	DANS LES NUAGES
IN VICINITY OF	INVOF	DANS LES ENVIRONS
INCLUDE	INCL	INCLURE
INCOMPLETE	INCOMP	INCOMPLET
INCREASE	INCR	AUGMENTER, AUGMENTATION
INDEFINITE	INDEF	INDÉFINI
INDIANA	IN	INDIANA
INDICATE	INDC	INDIQUER
INFERIOR	INFR	INFÉRIEUR
INFLUENCE	INFLNC	INFLUENCE
INFORMATION	INFO	INFORMATION, RENSEIGNEMENTS
INFORMATION CONCERNING EN-ROUTE WEATHER PHENOMENA WHICH MAY AFFECT THE SAFETY	SIGMET	RENSEIGNEMENTS RELATIFS AUX PHÉNOMENES MÉTÉOROLOGIQUES EN ROUTE QUI PEUVENT AFFECTER

English	Abbr.	French
OF AIRCRAFT OPERATIONS		LA SÉCURITÉ DE VOL
INFRARED	IR	INFRAROUGE
INLAND	INLD	INTÉRIEUR DES TERRES
INOPERATIVE	INOP	INOPÉRANT, DÉFECTUEUX
INSTABILITY	INSTBY	INSTABILITÉ
INSTEAD	INSTD	PLUTÔT, AU LIEU DE
INSTRUMENT	INSTR	INSTRUMENT
INSTRUMENT FLIGHT RULES	IFR	RÈGLES DE VOL AUX INSTRUMENTS
INTENSE	INTS	INTENSE
INTENSIFY	INTSFY	INTENSIFIER
INTENSITY	INTSTY	INTENSITÉ
INTERIOR	INTR	INTÉRIEUR
INTERMITTENT	INTMT	INTERMITTENT
INTERNATIONAL	INTL	INTERNATIONAL
INTERRUPT, INTERRUPTION	INTRP	INTERROMPRE, INTERRUPTION
INTERSECTION	INTSCN	INTERSECTION
INVADE	INVD	ENVAHIR
INVERSION	INVRN	INVERSION
IOWA	IA	IOWA
ISLAND	ISLD	ÎLE
ISOBAR	ISBR	ISOBARE
ISOLATE	ISOL	ISOLER
ISOTHERM	ISOTRM	ISOTHERME

21.10 Letter J

English	Abbr.	French
JAMES BAY	JMSBA	BAIE JAMES
JANUARY	JAN	JANVIER
JETSTREAM	JTSTR	COURANT-JET
JUAN DE FUCA STRAIT	JDFSTR	DÉTROIT JUAN DE FUCA
JULY	JUL	JUILLET
JUNCTION	JCTN	JONCTION
JUNE	JUN	JUIN

21.11 Letter K

English	Abbr.	French

English	Abbr.	French
KANSAS	KS	KANSAS
KEEWATIN	KWTN	KEEWATIN
KENTUCKY	KY	KENTUCKY
KILOGRAMS	KG	KILOGRAMMES
KILOHERTZ	KHZ	KILOHERTZ
KILOMETRE	KM	KILOMÈTRE
KILOMETRE PER HOUR	KMH	KILOMÈTRE À L'HEURE
KILOPASCAL	KPA	KILOPASCAL
KNOT	KT	NOEUD

21.12 Letter L

English	Abbr.	French
LABRADOR	LABRDR	LABRADOR
LAKE	LK	LAC
LAKE WINNIPEG	LKWPG	LAC WINNIPEG
LAND	LD	TERRE,ATTERRIR
LANDING	LDG	ATTERRISSAGE
LARGE	LRG	GRAND
LATER	LTR	PLUS TARD
LATITUDE	LAT	LATITUDE
LAYER	LYR	COUCHE
LEAVING	LVG	LAISSANT, PARTANT DE
LEE	LEE	SOUS LE VENT
LENGTH	LEN	LONGEUR
LENTICULAR	LENT	LENTICULAIRE
LEVEL	LVL	NIVEAU, UNI
LIFT	LFT	SOULÈVEMENT
LIFTED INDEX	LI	INDICE DE SOULÈVEMENT
LIGHT	LGT	LÉGER,LUMIÈRE
LIGHT AND VARIABLE	L/V	LÉGER ET VARIABLE
LIGHTNING	LTNG	ÉCLAIR,FOUDRE
LIGHTNING CLOUD TO CLOUD	LTGCC	ÉCLAIR DE NUAGE À NUAGE
LIGHTNING CLOUD TO GROUND	LTGCG	ÉCLAIR DE NUAGE AU SOL
LIGHTNING IN CLOUD	LTGIC	ÉCLAIR DANS LES NUAGES
LIKELY	LKLY	PROBABLEMENT
LIMIT	LT	LIMITE
LIMITED	LTD	LIMITÉ

English	Abbr.	French
LINE	LN	LIGNE
LITTLE	LTL	PEU, PETIT
LOCAL	LCL	LOCAL
LONG	LG	LONG
LONG RANGE	LGRG	À LONG TERME
LONGITUDE	LONG	LONGITUDE
LONGWAVE	LGWV	GRANDE ONDE
LOUISIANA	LA	LOUSIANE
LOW	LO	DÉPRESSION, BAS
LOW IFR	LIFR	IFR INFÉRIEUR
LOW LEVEL JET	LLJ	JET À BAS NIVEAU
LOW LEVEL WIND SHEAR	LLWS	CISAILLEMENT DU VENT À BAS NIVEAUX
LOWER	LWR	PLUS BAS, INFÉRIEUR

21.13 Letter M

English	Abbr.	French
MACKENZIE	MCKNZ	MACKENZIE
MAGNETIC	MAG	MAGNÉTIQUE
MAINE	ME	MAINE
MAINLY	MNLY	PRINCIPALEMENT
MAINTAIN	MAINT	MAINTENIR
MANITOBA	MB	MANITOBA
MANUAL	MANL	MANUEL
MARCH	MAR	MARS
MARGINAL	MRGL	MARGINAL
MARGINAL VFR	MVFR	VFR MARGINAL
MARITIME	MRTM	MARITIME
MARYLAND	MD	MARYLAND
MASSACHUSETTS	MA	MASSACHUSETTS
MAXIMUM	MAX	MAXIMUM
MAY	MAY	MAI
MEAN SEA LEVEL	MSL	NIVEAU MOYEN DE LA MER
MEASURE	MSR	MESURE
MECHANICAL	MECH	MÉCANIQUE
MEGAHERTZ	MHZ	MÉGAHERTZ
MERGE	MRG	JOINDRE,RÉUNIR
MESOSCALE	MESO	MOYENNE ÉCHELLE

English	Abbr.	French
MESSAGE	MSG	MESSAGE
METEOROLOGICAL	MET	MÉTÉOROLOGIQUE
METEOROLOGICAL WATCH OFFICE	MWO	CENTRE DE VEILLE MÉTÉOROLOGIQUE
METRE PER SECOND	MPS	MÈTRES PAR SECONDE
METRES	M	MÉTRES
METRIC UNITS	MTU	UNITÉS MÉTRIQUES
MICHIGAN	MI	MICHIGAN
MIDDLE	MID	MILIEU
MIDNIGHT	MIDNGT	MINUIT
MILES PER HOUR	MPH	MILLES À L'HEURE
MILLIBAR	MB	MILLIBAR
MINIMUM	MIN	MINIMUM
MINNESOTA	MN	MINNESOTA
MISSING	MISG	MANQUANT, ABSENT
MISSISSIPPI	MS	MISSISSIPPI
MISSISSIPPI RIVER	MISSIRVR	RIVIÈRE MISSISSIPPI
MISSOURI	MO	MISSOURI
MIST	BR	BRUME
MIXED	MXD	MÉLANGÉ
MIXING	MXG	MÉLANGEANT, DE MÉLANGE
MODERATE	MDT	MODÉRÉ
MODIFY	MDFY	MODIFIER
MOIST	MST	HUMIDE
MOISTURE	MSTR	HUMIDITÉ
MONDAY	MON	LUNDI
MONITOR, MONITORED	MNT	CONTRÔLE, CONTRÔLÉ
MONTANA	MT	MONTANA
MORNING	MRNG	MATIN, MATINÉE
MOSTLY	MSTLY	GÉNÉRALEMENT
MOTION	MOTN	MOUVEMENT
MOUNTAIN	MT	MONTAGNE
MOUNTAIN WAVES	MTW	ONDE OROGRAPHIQUES
MOVE	MOV	MOUVOIR, DÉPLACER

21.14 Letter N

English	Abbr.	French
NARROW	NRW	ÉTROIT

English	Abbr.	French
NAUTICAL MILE	NM	MILLE MARIN
NAVIGATION	NAV	NAVIGATION
NEAR	NR	PRÈS
NEBRASKA	NE	NEBRASKA
NECESSARY	NEC	NÉCESSAIRE
NEGATIVE	NEG	NÉGATIF
NEGATIVE VORTICITY ADVECTION	NVA	ADVECTION NÉGATIVE DE TOURBILLON
NEVADA	NV	NEVADA
NEW BRUNSWICK	NB	NOUVEAU-BRUNSWICK
NEW ENGLAND	NEWENG	NOUVELLE-ANGLETERRE
NEW HAMPSHIRE	NH	NEW HAMPSHIRE
NEW JERSEY	NJ	NEW JERSEY
NEW MEXICO	NM	NOUVEAU MEXIQUE
NEW YORK	NY	NEW YORK
NEWFOUNDLAND	NF	TERRE-NEUVE
NEXT	NXT	SUIVANT
NIGHT	NGT	NUIT
NIGHTTIME	NGTM	DURANT LA NUIT
NIL SIG WEATHER	NSW	PAS DE TEMPS SIGNIFICATIF
NIMBOSTRATUS	NS	NIMBOSTRATUS
NO CHANGE	NC	PAS DE CHANGEMENT
NONE	NIL	AUCUN
NORMAL	NML	NORMAL
NORTH	N	NORD
NORTH-NORTHEAST	NNE	NORD-NORD-EST
NORTH-NORTHWEST	NNW	NORD-NORD-OUEST
NORTH AMERICA	NAM	AMÉRIQUE DU NORD
NORTH ATLANTIC	NAT	NORD ATLANTIQUE
NORTH CAROLINA	NC	CAROLINE DU NORD
NORTH DAKOTA	ND	DAKOTA DU NORD
NORTH POLE	NP	PÔLE NORD
NORTHEAST	NE	NORD-EST
NORTHWEST	NW	NORD-OUEST
NORTHWEST TERRITORIES	NT	TERRITOIRES DU NORD-OUEST
NOTIFY	NTFY	NOTIFIER
NOVA SCOTIA	NS	NOUVELLE-ÉCOSSE
NOVEMBER	NOV	NOVEMBRE
NUMBER	NMBR	NOMBRE

English	Abbr.	French
NUMERICAL	NUMCL	NUMÉRIQUE
NUMEROUS	NMRS	NOMBREUX
NUNAVUT	NU	NUNAVUT

21.15 Letter O

English	Abbr.	French
OBSCURE	OBSC	OBSCURCIR
OBSERVE, OBSERVATION	OBS	OBSERVER, OBSERVATION
OBSTRUCT, OBSTACLE	OBST	OBSTRUER, OBSTACLE
OCCASIONAL	OCNL	OCCASIONNEL
OCCLUDE	OCLD	OCCLURE
OCCLUSION	OCLN	OCCLUSION
OCCUR	OCR	SE PRODUIRE
OCEAN	OCN	OCÉAN
OCTOBER	OCT	OCTOBRE
OFFSHORE	OFSHR	AU LARGE
OHIO	OH	OHIO
OKLAHOMA	OK	OLKLAHOMA
ON REQUEST	O/R	SUR DEMANDE
ON TOP	OTP	AU-DESSUS
ONSHORE	ONSHR	DU LARGE (vent)
ONTARIO	ON	ONTARIO
OPEN	OPN	OUVRIR
OPERATION	OPS	EXPLOITATION OU VOLS
OPERATOR	OPR	EXPLOITANT
OREGON	OR	OREGON
ORGANISE	ORGZ	ORGANISER
ORIENT	ORNT	ORIENTER
ORIGINAL	ORIG	ORIGINAL
OROGRAPHIC	ORGPHC	OROGRAPHIQUE
OTHERWISE	OTWZ	AUTREMENT
OUTLOOK	OTLK	APERÇU
OVER	OVR	AU-DESSUS
OVER THE LAND	OVRLD	SUR LA TERRE
OVER THE SEA	OVRSEA	SUR LA MER
OVER THE STRAITS	OVRSTRS	SUR LES DÉTROITS
OVERCAST	OVC	COUVERT

English	Abbr.	French
OVERHEAD	OVRHD	AU-DESSUS, DANS LE CIEL
OVERLAP	OVRLP	RECOUVREMENT
OVERNIGHT	OVRNGT	PENDANT LA NUIT
OVERRUN	OVRN	ENVAHIR, DÉBORDER

21.16 Letter P

English	Abbr.	French
PACIFIC	PAC	PACIFIQUE
PANHANDLE	PNHNDL	BANDE DE TERRE
PARAGRAPH	PARA	PARAGRAPHE
PARALLEL	PRLL	PARALLÈLE
PARTLY	PTLY	PARTIELLEMENT
PASSAGE, PASSING	PSG	PASSAGE, PASSANT
PATCH	PTCH	NAPPES, BANCS
PATTERN	PATN	CONFIGURATION
PENNSYLVANIA	PA	PENNSYLVANIE
PERFORMANCE	PER	PERFORMANCE
PERIOD	PD	PÉRIODE
PERMANENT	PERM	PERMANENT
PERSIST	PRST	PERSISTER
PHASE	PHS	PHASE
PICTURE	PIX	IMAGE, PHOTO
PILOT BALLOON OBS	PIBAL	OBSERVATION BALLON PILOTE
PILOT REPORT	PIREP	MESSAGE DE PILOTE
PLEASE	PLS	S'IL VOUS PLAÎT
POINT	PT	POINT
POLAR	P	POLAIRE
PORTION	PTN	PORTION
POSITION	PSN	POSITION
POSITIVE	POS	POSITIF
POSITIVE VORTICITY ADVECTION	PVA	ADVECTION POSITIVE DE TOURBILLON
POSSIBLE	PSBL	POSSIBLE
POTENTIAL	PTNL	POTENTIEL
POWER	PWR	PUISSANCE
PRECAUTION	PRCTN	PRÉCAUTION
PRECEDE	PRECD	PRÉCÉDER
PRECIPITATIONS	PCPN	PRÉCIPITATIONS

English	Abbr.	French
PREDOMINATE, PREDOMINANT	PDMT	PRÉDOMINER, PRÉDOMINANT
PREFER	PRFR	PRÉFÉRER
PRELIMINARY	PRELIM	PRÉLIMINAIRE
PREPARE	PREP	PRÉPARER
PRESENT	PRSNT	PRÉSENT, PRÉSENTER
PRESSURE	PRES	PRESSION
PRESSURE FALLING RAPIDLY	PRESFR	PRESSION EN BAISSE RAPIDE
PRESSURE RISING RAPIDLY	PRESRR	PRESSION EN HAUSSE RAPIDE
PREVAIL	PVL	PRÉVALOIR
PREVALENT	PVLT	COURANT, RÉPANDU
PREVIOUS	PREV	PRÉCÉDENT, ANTÉRIEUR
PRIMARY	PRIM	PRIMAIRE
PRINCE EDWARD ISLAND	PE	ÎLE DU PRINCE ÉDOUARD
PRINCIPAL	PRCPL	PRINCIPAL
PROBABILITY	PROB	PROBABILITÉ
PROCEDURE	PROC	PROCÉDURE
PROCEED	PCD	PROCÉDER
PROGNOSIS, PROGNOSTIC	PROG	PRONOSTIC, PRONOSTIQUE
PROVIDE	PRVD	FOURNIR
PROVISIONAL	PROV	PROVISOIR
PUBLIC	PUB	PUBLIQUE
PUGET SOUND	PGTSND	PUGET SOUND

21.17 Letter Q

English	Abbr.	French
QUADRANT	QUAD	QUADRANT
QUANTITATIVE PRECIPITATION FORECAST	QPF	PRÉVISION DES QUANTITÉS DE PRÉCIPITATIONS
QUANTITY	QNTY	QUANTITÉ
QUARTER	QTR	QUART
QUASI-STATIONARY	QS	QUASI-STATIONNAIRE
QUEBEC	QC	QUÉBEC
QUEEN CHARLOTTE ISLANDS	CHRLTS	ÎLES DE LA REINE CHARLOTTE

21.18 Letter R

English	Abbr.	French

English	Abbr.	French
RADAR	RDR	RADAR
RADAR REPORT	RAREP	MESSAGE DE RADAR
RADIAL	RDL	RADIAL
RADIATION	RADN	RAYONNEMENT
RADIO	RDO	RADIO
RADIOSONDE OBS.	RAOB	RADIOSONDAGE
RADIUS	RAD	RAYON
RAGGED	RAG	DÉCHIQUETÉ
RAIN	RA	PLUIE
RAIN SHOWER	SHRA	AVERSE DE PLUIE
RAINFALL RATE	RRT	TAUX DE CHUTE DE PLUIE
RANGE	RG	PORTÉE ÉTENDUE
RAPID	RPD	RAPIDE
RATHER	RTHR	PLUTÔT
REACH	RCH	ATTEINDRE
REASON	RSN	RAISON
RECEIVE	RCV	RECEVOIR
RECENT	RE	RÉCENT
RECOMMEND	RCMD	RECOMMANDER
REFERENCE	REF	RÉFÉRENCE
REFLECTION	RFCN	RÉFLEXION
REFORM	RFRM	RÉFORMER
REGION	RGN	RÉGION
REGULAR	REG	RÉGULIER
RELATIVE	RLTV	RELATIF
RELATIVE HUMUDITY	RH	HUMIDITÉ RELATIVE
RELAY	RLA	RELAYER
RELEASE	RLS	LIBÉRER, LÂCHER
RELIABLE	RLBL	FIABLE
REMAIN	RMN	DEMEURER, RESTER
REMARK	RMK	REMARQUE
REPEAT	RPT	RÉPÉTER
REPLACE	RPLC	REMPLACER
REPORT	REP	RAPPORTER, RAPPORT, MESSAGE
REQUEST	REQ	DEMANDER
REQUIRE	RQR	NÉCESSITER
RESTRICT	RSTR	RESTREINDRE
RETARD, LATE	RTD	RETARDER, EN RETARD
RETURN	RTRN	RETOUR,RETOURNER

English	Abbr.	French
REVISE	RVS	RÉVISER
RHODE ISLAND	RI	RHODE ISLAND
RIDGE	RDG	CRÊTE
RISING	RSG	MONTANT, À LA HAUSSE
ROCKIES	RCKY	ROCHEUSES
ROTATE	ROT	TOURNER, PIVOTER
ROTATION	ROTN	ROTATION
ROUGH	RUF	RUDE, RUGEUX
ROUTE	RT	ROUTE
ROUTE FORECAST	ROFOR	PRÉVISION DE ROUTE
ROUTINE PIREP	UA	PIREP RÉGULER
RUNWAY	RWY	PISTE D'AÉRODROME
RUNWAY VISUAL RANGE	RVR	PORTÉE VISUELLE DE PISTE

21.19 Letter S

English	Abbr.	French
SAND WHIRLS	PO	TOURBILLON DE SABLE
SAND WHIRLS IN VICINITY	VCPO	TOURBILLON DE SABLE DANS LES ENVIRONS
SANDSTORM	SS	TEMPÊTE DE SABLE
SANDSTORM IN VICINITY	VCSS	TEMPÊTE DE SABLE DANS LES ENVIRONS
SASKATCHEWAN	SK	SASKATCHEWAN
SATELLITE	SAT	SATELLITE
SATELLITE COMMUNICATION	SATCOM	COMMUNICATION PAR SATELLITE
SCATTERED, SCATTER	SCT	ÉPARS, DISPERSER
SCHEDULE	SKED	HORAIRE
SEA LEVEL PRESSURE	SLP	PRESSION AU NIVEAU DE LA MER
SEARCH AND RESCUE	SAR	RECHERCHES ET SAUVETAGE
SECOND (next)	SCND	DEUXIÈME, SECOND
SECOND (time)	SEC	SECONDE
SECTION	SXN	SECTION
SECTOR	SECT	SECTEUR
SELECT	SEL	SÉLECTIONNER
SELKIRKS	SLKRS	MONTS SELKIRKS
SEPTEMBER	SEP	SEPTEMBRE
SEQUENCE	SQNC	SÉQUENCE
SERVICE	SER	SERVICE

English	Abbr.	French
SETTING	SETG	RÉGLAGE, CALAGE (altimètre)
SETTLE	SETL	AJUSTER
SEVERAL	SVRL	PLUSIEURS
SEVERE	SEV	FORT, VIOLENT
SHALLOW	SHLW	PEU PROFOND, PEU ÉPAIS
SHALLOW FOG	MIFG	COUCHE MINCE DE BROUILLARD
SHIFT	SHFT	CHANGEMENT, SAUTE
SHORE	SHR	RIVE
SHORT	SHRT	PETIT, COURT
SHORT RANGE	SRG	COURT TERME
SHORTWAVE	SWV	ONDE COURTE
SHOULD	SHUD	DEVRAIT
SHOWER	SH	AVERSE
SHOWER (ANY TYPE) IN VICINITY	VCSH	AVERSE DANS LES ENVIRONS
SHUTDOWN	SHTDN	ARRÊT
SIGNAL	SGL	SIGNAL
SIGNATURE	SIGNTR	SIGNATURE
SIGNIFICANT	SIG	SIGNIFICATIF
SIGNIFICANT WEATHER	SIGWX	TEMPS SIGNIFICATIF
SIMULTANEOUS	SIMUL	SIMULTANÉ
SITUATION	SITU	SITUATION
SKY CLEAR	SKC	CIEL DÉGAGÉ
SKY CONDITION (pirep)	SK	ÉTAT DU CIEL (pirep)
SLIGHT	SLGT	LÉGER, PEU
SLOPE	SLP	PENTE
SLOW	SLO	LENT
SMALL	SML	PETIT
SMOKE	FU	FUMÉE
SMOOTH	SMTH	DOUX
SNOW	SN	NEIGE
SNOW GRAINS	SG	NEIGE EN GRAINS
SNOW PELLET SHOWER	SHGS	AVERSE DE NEIGE ROULÉE
SNOW PELLETS	GS	NEIGE ROULEE
SNOW SHOWER	SHSN	AVERSE DE NEIGE
SNOW SQUALL	SNSQ	BOURRASQUE DE NEIGE
SNOWFALL	SNFL	CHUTE DE NEIGE
SOMETIMES	SMTM	PARFOIS
SOMEWHAT	SMWHT	QUELQUE PEU

English	Abbr.	French
SOURCE	SRC	SOURCE
SOUTH	S	SUD
SOUTH-SOUTHEAST	SSE	SUD-SUD-EST
SOUTH-SOUTHWEST	SSW	SUD-SUD-OUEST
SOUTH CAROLINA	SC	CAROLINE DU SUD
SOUTH DAKOTA	SD	DAKOTA DU SUD
SOUTHEAST	SE	SUD-EST
SOUTHWEST	SW	SUD-OUEST
SPECIAL	SPECI	SPÉCIAL
SPEED	SPD	VITESSE
SPIRAL	SPRL	SPIRALE
SPREAD	SPRD	RÉPANDRE
SPRINKLE	SPKL	ARROSER
SQUALL LINE	SQLN	LIGNE DE GRAINS
SQUALLS	SQ	GRAINS
ST. LAWRENCE	STLAWR	ST-LAURENT
STABILITY INDEX	SI	INDICE DE STABILITÉ
STABLE	STBL	STABLE
STAGNANT	STAG	STAGNANT, INACTIF
STANDARD	STD	STANDARD, NORME
STATION	STN	STATION
STATISTICS	STATS	STATISTIQUES
STEADY	STDY	CONSTANT
STOP	STP	ARRÊTER, ARRÊT
STORM	STM	TEMPÊTE
STRAIT	STR	DÉTROIT
STRAIT OF BELLE ISLE	STRBI	DÉTROIT DE BELLE ÎLE
STRATIFORM	STFRM	STRATIFORME
STRATOCUMULUS	SC	STRATOCUMULUS
STRATUS	ST	STRATUS
STRATUS FRACTUS	SF	STRATUS FRACTUS
STREAM	STRM	COURANT
STRENGTHEN	STGTN	RENFORCER
STRONG	STG	FORT
SUBJECTIVE	SBJV	SUBJECTIF
SUBSIDE	SBSD	APAISER, EN SUBSIDENCE
SUBSIDENCE	SBSDNC	SUBSIDENCE
SUGGEST	SUG	SUGGÉRER
SUMMARY	SMRY	SOMMAIRE

English	Abbr.	French
SUMMER SEVERE WEATHER	SSWX	TEMPS VIOLENT D'ÉTÉ
SUNDAY	SUN	DIMANCHE
SUNRISE	SNRS	LEVER DU SOLEIL
SUNSET	SNST	COUCHER DU SOLEIL
SUPERIOR	SUPR	SUPÉRIEUR
SUPERSEDE	SUPSD	REMPLACER
SUPPLEMENT	SUPPL	SUPPLÉMENT
SUPPORT	SUPRT	APPUI, SOUTIEN
SURFACE	SFC	SURFACE
SYNOPSIS, SYNOPTIC	SYNO	SYNOPTIQUE, SITUATION
SYSTEM	SYS	SYSTÈME

21.20 Letter T

English	Abbr.	French
TAKE-OFF	TKOF	DÉCOLLAGE
TECHNICAL	TECHL	TECHNIQUE
TECHNICAL REASON	TECR	RAISONS TECHNIQUES
TECHNICIAN	TECH	TECHNICIEN
TELECOMMUNICATION	TELECOM	TÉLÉCOMMUNICATION
TELEPHONE	TEL	TÉLÉPHONE
TELETYPE	TLTP	TÉLÉSCRIPTEUR
TEMPERATURE	T	TEMPÉRATURE
TEMPORARY	TEMPO	TEMPORAIRE
TENDENCY	TNDCY	TENDANCE
TENNESSEE	TN	TENNESSEE
TEPHIGRAM	TEPHI	TÉPHIGRAMME
TERMINAL	TRML	AÉROGARE, AÉRODROME
TERRAIN	TRRN	TERRAIN
TEXAS	TX	TEXAS
THENCE	THNC	DE LÀ
THEREAFTER	THRFTR	PAR LA SUITE
THERMAL	THRML	THERMIQUE
THICK	THK	ÉPAIS
THIN	THN	MINCE
THOUSAND	THSD	MILLE, MILLIER
THROUGH	THRU	À TRAVERS
THROUGHOUT	THRUT	PARTOUT, POUR TOUTE LA DURÉE

English	Abbr.	French
THUNDERSTORM	TS	ORAGE
THURSDAY	THU	JEUDI
TILL	TILL	JUSQU'À
TODAY	TDA	AUJOURD'HUI
TOMORROW	TMW	DEMAIN
TONIGHT	TNGT	CE SOIR ET CETTE NUIT
TOPPING	TPG	SURMONTANT
TORNADO	+FC	TORNADE
TOWARD	TWD	VERS
TOWERING	TWRG	BOURGEONNANT
TOWERING CUMULUS	TCU	CUMULUS BOURGEONNANT
TRACE	TR	TRACE
TRACK	TRK	VOIE,ROUTE, SILLAGE
TRAFFIC	TRFC	TRAFIC
TRAJECTORY	TRAJ	TRAJECTOIRE
TRANSCRIBED WEATHER BROADCAST	TWB	ÉMISSION RADIO TRANSCRITE
TRANSFER	TSFR	TRANSFÉRER
TRANSMIT	XMIT	TRANSMETTRE
TROPICAL	TROPCL	TROPICAL
TROPICAL CYCLONE	TC	CYCLONE TROPICAL
TROPOPAUSE	TROP	TROPOPAUSE
TROUGH	TROF	CREUX, DÉPRESSION
TROUGH OF WARM AIR ALOFT	TROWAL	LANGUE D'AIR CHAUD EN ALTITUDE
TUESDAY	TUE	MARDI
TUKTOYAKTUK PENINSULA	TUKPEN	PÉNINSULE DE TUKTOYAKTUK
TURBULENCE	TURB	TURBULENCE
TWILIGHT	TWLGT	PÉNOMBRE
TYPE OF AIRCRAFT	TYP	TYPE D'AÉRONEF
TYPHOON	TYPH	TYPHON

21.21 Letter U

English	Abbr.	French
UNABLE	UNA	INCAPABLE, DANS L'IMPOSSIBILITÉ
UNAVAILABLE	UNAVBL	NON DISPONIBLE
UNIVERSAL TIME COORDINATED	UTC	TEMPS UNIVERSEL COORDONNÉ
UNKNOWN	UNKN	INCONNU

English	Abbr.	French
UNLESS	UNLS	À MOINS QUE
UNLIKELY	UNLKLY	IMPROBABLE
UNLIMITED	UNLTD	ILLIMITÉ
UNRELIABLE	UNREL	DOUTEUX, PEU FIABLE
UNSCHEDULED	UNSKED	IMPRÉVU, SPÉCIAL
UNSETTLE	UNSETL	PERTURBER, INCERTAIN
UNSTABLE	UNSTBL	INSTABLE
UNSTEADY	UNSTDY	IRRÉGULIER, NON CONSTANT
UNTIL	TILL	JUSQU'À
UNTIL FURTHER NOTICE	UFN	JUSQU'À NOUVEL AVIS
UPDRAFT	UPDFT	COURANT D'AIR ASCENDANT
UPPER	UPR	SUPÉRIEUR, PLUS ÉLEVÉ
UPPER AIR	UA	EN ALTITUDE
UPPER WIND FROM RAOB	RAWIN	VENTS PAR RADIOSONDAGE
UPSLOPE	UPSLP	MONTANT LA PENTE
UPSTREAM	UPSTRM	EN AMONT
UPWIND	UPWND	ENAMONT
URGENT	URG	URGENT
URGENT PIREP	UUA	PIREP URGENT
USABLE	USBL	UTILISABLE
UTAH	UT	UTAH
UTC (UNIVERSAL TIME COORDINATED)	Z	UTC (TEMPS UNIVERSEL COORDONNE)

21.22 Letter V

English	Abbr.	French
VALID	VLD	VALIDE, VALABLE
VALLEY	VLY	VALLÉE
VANCOUVER ISLAND	VRISL	ÎLE DE VANCOUVER
VAPOUR	VPR	VAPEUR
VARIABLE	VRB	VARIABLE
VARIATION	VRTN	VARIATION
VEER	VR	VIRER (mouvement dextrogyre)
VERIFY	VFY	VÉRIFIER
VERMONT	VT	VERMONT
VERTICAL	VERT	VERTICAL
VERTICAL VELOCITY	VV	VITESSE VERTICALE
VERY	VRY	TRÈS

English	Abbr.	French
VICINITY	VC	ENVIRONS
VICTORIA ISLAND	VICISL	ÎLE DE VICTORIA
VIOLENT	VLNT	VIOLENT
VIRGINIA	VA	VIRGINIE
VISIBILITY	VIS	VISIBILITÉ
VISIBLE	VISBL	VISIBLE
VISUAL	VISL	VISUEL
VISUAL FLIGHT RULES	VFR	RÈGLES DE VOL À VUE
VOLCANIC ASH	VA	CENDRE VOLCANIQUES
VORTICITY	VORT	TOURBILLON
	W	
WARM	WRM	CHAUD
WARM AIR ADVECTION	WAA	ADVECTION D'AIR CHAUD
WARNING	WRNG	AVERTISSEMENT
WASHINGTON	WA	WASHINGTON
WATER	WTR	EAU
WATERSPOUT	WTSPT	TROMBE MARINE
WATERSPOUT (METAR)	+FC	TROMBE MARINE (METAR)
WAVE	WV	VAGUE, ONDE
WEAK	WK	FAIBLE
WEAKEN	WKN	FAIBLIR, S'AFFAIBLIR
WEATHER	WX	CONDITIONS DU TEMPS
WEDNESDAY	WED	MERCREDI
WEIGHT	WT	POIDS

21.23 Letter W

English	Abbr.	French
WEST-NORTHWEST	WNW	OUEST-NORD-OUEST
WEST-SOUTHWEST	WSW	OUEST-SUD-OUEST
WEST VIRGINIA	WV	VIRGINIE OCCIDENTALE
WET BULB	WB	THERMOMÈTRE MOUILLÉ
WIDELY	WDLY	TRÈS, GRANDEMENT
WIDESPREAD	WDSPRD	ÉTENDU
WIDTH	WID	LARGEUR
WIND	WND	VENT
WIND SHEAR	WS	CISAILLEMENT DU VENT
WIND SHIFT	WSHFT	CHANGEMENT DE DIRECTION DU VENT

English	Abbr.	French
WINTER SEVERE WEATHER	WSWX	TEMPS D'HIVER RIGOUREUX
WISCONSIN	WI	WISCONSIN
WITHIN	WTN	DANS
WITHOUT	WO	SANS
WORSE	WRS	PIRE
WYOMING	WY	WYOMING

21.24 Letter Y

English	Abbr.	French
YESTERDAY	YDA	HIER
YUKON	YK	YUKON

CHAPTER 22 SOLUTIONS

Chapter: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

22.1 Chapter 1

1. The atmosphere.
2. Nitrogen, oxygen, water vapour, carbon dioxide and ozone.
3. Water vapour; it becomes visible under certain atmospheric conditions, producing clouds and fog.
4. Aerosols are liquid or solid particles in suspension in the air.
5. They serve as condensation nuclei necessary for water vapour to change phase. In addition, high concentrations of solid aerosols can considerably limit visibility.
6. Several hundred kilometres.
7. 5,500 m.
8. Inertia, fluidity, viscosity, expansibility and compressibility.
9. Viscosity.
10. The air will be compressed. It will shrink in volume but its temperature will rise.
11. The troposphere.
12. The troposphere and the stratosphere.
13. The air temperature in the troposphere decreases with altitude. The Sun warms the Earth's surface, which in turn warms the air from the ground up.
14. Temperature abruptly stops falling with height.
15. 11 km.
16. Higher.
17. The tropopause.
18. The ozone layer plays a key role. Ozone absorbs ultraviolet rays from the Sun; this explains the rising temperatures.

19. It is an average representation of the temperature profile with respect to pressure in the first 20 kilometres of altitude, at 40 ºN latitude.
20. 1013.25 hPa and 15 ºC.

22.2 Chapter 2

1. The study of relationships between thermal and mechanical phenomena.
2. By radiation, conduction, convection, mechanical turbulence, thermal advection and exchanges related to latent heat.
3. Clouds form a shield that reflects terrestrial long-wave radiation back to Earth. This energy remains trapped between the ground and the clouds, and slows the drop in the air temperature, even though the Sun is not shining.
4. Convection is an internal air movement triggered by warming of the Earth's surface. It generates vertical heat transfers and considerable movement in the troposphere. Convection occurs when the temperature, falling with altitude, reaches a critical threshold, and while the Earth's surface is unevenly heated. It may also occur when air is lifted.
5. The horizontal temperature gradient is a vector perpendicular to the isotherms and indicates the direction of the warmest isotherms. It is an indication of the intensity of the thermal field.
6. There is strong warm-air advection when the temperature above a fixed point climbs rapidly.
7. The energy required to allow a substance--solid, liquid or gas-- to change phase with no variation in temperature. In meteorology, the substance used is water.
8. For a small volume of air, the thermodynamic compression process will be adiabatic if there is no heat exchange (i.e. loss or gain) with its surroundings. The air will be warmed only by the compression it undergoes.
9. 1.
10. True.
11. 9 ºC.
12. 10 ºC.

22.3 Chapter 3

1. Water vapour is the only gas that can change phase depending on the temperature regime of the atmosphere. In addition, these phase changes cause the formation and dissipation of clouds and precipitation.
2. Air temperature and pressure.
3. It is air that contains the maximum quantity of water vapour, depending on its temperature and pressure.
4. It is a direct change in phase, from a solid state to a gaseous one, without passing through the liquid phase.
5. Adiabatic expansion, expansion when the air is lifted, radiation and conduction.
6. Evaporation of water at the ground or water surface, particularly when it is warmer than the ambient air; evaporation of warm rain; evapotranspiration from plants; and combustion of organic materials.
7. At constant pressure, this is the temperature that the air mass must reach for saturation to occur in terms of water.
8. False. The dew point will also fall.
9. It is the measurement of the number of grams of water vapour per kilogram of dry air in an air mass.

10. False.
11. Sublimation of water vapour.

22.4 Chapter 4

1. The force per unit surface area exerted by the air at a given level.
2. 1013.25 hPa (mb), 101.3 kPa, 29.92 inches of mercury.
3. Actual atmospheric pressure at the altitude of the observing station.
4. Differences in altitude, because atmospheric pressure falls with height and increases as one approaches the ground.
5. Mean sea level.
6. Isobars.
    a) 2, b) 1, c) 2, d) 2, e) 2, f) 3, g) 1, h) 2
7. True.
8. False.
9. The variation in station pressure at mean sea level, over the three hours preceding the observation.
10. The rate of variation in pressure with horizontal distance.
11. Colder at YTE than at YBR.
12. Since the pressure has risen the altimeter setting has also risen; if it is not corrected, the altimeter will show an altitude lower than that of the station.

22.5 Chapter 5

1. Wind is the movement of air.
2. By giving its point of origin.
3. The force of the pressure gradient, the Coriolis force, the centripetal force and friction.
4. The Earth's rotation exerts force on the air, called the Coriolis force. This opposes the force of the pressure gradient and causes the air to blow along the isobars, by forcing the air to veer to the right along its trajectory.
5. On the left.
6. True.
7. False.
8. b)
9. The surface wind will blow across the lowest isobars.
10. False. The wind will not blow as strongly, but will blow more toward the low-pressure zones.
11. False.
12. Instability of the air and obstacles to the wind.
13. On the surface, the wind blows from the coast toward the body of water when the land surface temperature is colder than the water temperature. The wind aloft blows in the opposite direction to the surface wind. The land breeze is more common at night.
14. True.
15. The barrier, valley and funnel effects and wind shear.
16. An isohypse is a line linking points of equal altitude on a constant pressure chart.
17. True.
18. True.
19. The low is to the east of the point.
20. A squall lasts longer than a gust. In addition, a squall lasts several minutes.
    - Too low
      you lose height.
    - you gain height.
    - no change.

- o no change.

21. Low-level winds from the west between 30 °N and 60 ºN.
22. The intertropical convergence zone where there is thick cloud and heavy rain. This region is also sometimes called the equatorial calms.
23. True.
24. Hadley cells.
25. True.
26. True.
27. False.
28. A jet stream is a shallow, twisting river of maximum winds, near the tropopause.
29. Jet streams occur where there is an abrupt change in the height of the tropopause.
30. True.
31. Isotachs.
32. On the left.
33. True.

22.6 Chapter 6

1. Air is stable if it returns to its original location after being lifted.
2. Air is neutral if it is neither stable nor unstable.
3. The balloon will fall gently to earth, since the air it contains is colder than the surrounding air.
4. True.
5. Convection.
6. True.
7. Orographic lifting.
   - o Lifting of an air mass by a front.
     Unstable.
   - o Unstable.
   - o Stable.
   - o Stable.
   - o Unstable.
   - o Stable.
   - o Unstable.
   - o Unstable.
   - o Unstable.
   - o Stable.
8.
   - o Unstable.
   - o Stable.
   - o Inhibits.
   - o Cooling.
   - o Orographic.
   - o Unstable.
   - o Shallow.
   - o Convection.
   - o Steep.

9. Diurnal warming strengthens the temperature gradient and produces vertical currents that will draw the smoke upward.
10. The cold air from the northwest current will be unstable over the water because of its temperature regime. This air is actually much colder than the water of the Great Lakes. Consequently, heavy convective cloud will form and give snow showers over the southeast shore of Lake Huron. The air in the southern current is more stable because the temperature regime of the air is warmer. The difference in temperature between the lake water and the air mass is smaller in this case than in

the case of an air mass from the northwest. A smaller temperature difference will produce a more stable regime. In this case, the snow showers will be less pronounced over the north shore of Lake Ontario.

22.7 Chapter 7

1. An air mass is a large section of the troposphere with uniform properties of temperature and moisture in the horizontal.
2. A front is a transition zone separating two air masses.
3. Yes. An air mass may change and take another name if it remains long enough over a surface for its temperature and moisture regimes to change.
4. Maritime.
5. Mean latitude.
6. Maritime tropical.
7. True.
8. It will decrease.
9. Cumulus or towering cumulus, even isolated cumulonimbus.
10. An arctic inversion is an abnormal distribution of the temperature in the troposphere, with the result that the temperature rises or remains nearly stable with altitude. It is characteristic of the continental arctic air mass.
11. mT, mP, mA, cA.
12. Stability, moisture, type of cooling.
13. Radiation, advection and expansion cooling during large-scale lifting.

    - mA
    - mP
    - cA
    - mA
    - cA
    - mT

14. Both are relatively moist; the mP air, because it has spent a long time over the ocean; the mT air because it has remained in the lower latitudes. However, the warm mT air is moister than the mP air, because of its higher saturation point.
15.

    - The mP air is warmer than the mA air, because its route takes it farther south, over the warmer waters of the temperate latitudes, before it reaches the continent.
    - The mP air is moister than the mA air, because it remains longer over the ocean, which warms the air and adds to its moisture content.

22.8 Chapter 8

1. It is a transition zone separating two clearly distinct air masses.
2. A maritime front.
3. A continental arctic (cA) air mass and a maritime arctic (mA) air mass.
4. The frontal surface.
5. 4 km.
6. False.
7. True.
8. False.
9. True.
10. False.
11. a)

12. c)
13. A trowal is a trough of warm air aloft.
14. In troughs.
15. The weakening or dissipation of a frontal or baroclinic zone.
16. The Gulf Stream. When a cold air mass over the east of the continent moves over the Gulf Stream, the air layer next to the water surface is affected. The water in the Gulf Stream is considerably warmer than the cold air mass. This produces a temperature and moisture gradient, with an attendant strengthening of the baroclinic zone and frontogenesis.
17. Hurricanes, tornadoes, orographic lows and thermal lows.
18. The warm sector is that part of a frontal system located between the warm and cold fronts. This part contains warm air, hence its name.
19. An occlusion is one of the steps in the evolution of a frontal low, where the warm sector at the surface between the warm and cold fronts separates from the system as the cold front reaches the warm front.

22.9 Chapter 9

1. It falls.
2. It falls continuously as the front approaches, and rises quickly after the front has passed.
3. It is warmed from beneath as it crosses relatively warm regions.
4. Greater.
5. The warmer one.
6. True.
7.
    - Icing.
    - Precipitation.
    - Turbulence.
    - Thunderstorms.
    - Windshifts.
    - Low ceiling.
    - Low visibility.

1. b)
2. False.
3. b)
4. d)
5.
    - veers.
    - rises.
    - increases.

1. As the warm front approaches, the thickness of the cold air over the station falls; consequently, the mean sea level pressure and the altimeter setting also fall. After the warm front has passed, the thickness and characteristics of the homogenous warm air front are uniform.
2. The pressure gradient of the warm air and the angle between the warm current and the frontal surface.
3. Rising air causes cooling by expansion, condensation and cloud formation.
4. Cirrus, cirrostratus, altostratus, nimbostratus and stratus.
5. See Figure 9-11.
6. Cold front storms generally form at the front, whereas warm front storms are embedded in a thick cloud layer ahead of the front.
7. a)
8. c)

9. d)

22.10 Chapter 10

1. Cirrostratus.
2. Cumulonimbus.
3. Cirrus.
4. Nimbostratus.
5. Cumulonimbus.
6. Stratus.
7. Altocumulus.
8. Cumulus.
9. Cirrocumulus.
10. Altostratus.
11. Cumulonimbus.
12. Stratocumulus.
13. Altostratus.
14. High relative humidity, cooling of the air and the presence of condensation nuclei.
15. Cooling by radiation, advection and expansion.
16. Adiabatic expansion of the air.
17. Orographic lifting, frontal lifting, mechanical turbulence, convection and convergence. All these phenomena cause cooling by expansion.
18. Temperature.
    - It remains constant.
    - It increases.
19. Diurnal warming and cold air advection above a warm surface.
20. Warming from underneath strengthens the temperature gradient, producing strong vertical currents during the day.
21. Cooling from underneath at night stabilizes the air and prevents the formation of vertical currents.
22. Cooling by expansion occurs when the eastern current is lifted by the rising slope: orographic lifting.
23. Stability or instability of the rising air.
24. The presence of stratus in the Maritimes is indicative of stable air, meaning little turbulence, whereas the cumulus in southern Ontario indicate that the air is unstable with updrafts causing convective turbulence.
25. The air is stable at station A, while the showers reported at station B show that the air there is unstable.
26. Ice crystals.
27. At night, the ground loses warmth through radiation. The ground becomes colder and the air cools on contact.
28. Clear sky, light winds and high humidity.
29. Mixing of water limits the loss of heat by radiation, preventing it from cooling much overnight. As a result, the air temperature will remain almost stable.
30. The Sun warms the surface where there is no fog, and the top layer of the fog. The ground, in turn, warms the surrounding air and the edges of the fog. This warming evaporates the fog droplets, and the fog dissipates.
31. Denser cold air flows down into the valleys.
32. When warm moist air flows over a relatively cold surface.
    - The clouds slow the diurnal warming of the ground, which explains the persistent fog. However, the warming may produce weak vertical currents that lift the fog and give a low-level stratus layer.
    - Over the water, clouds do not affect advection fog, because the water temperature rises little with diurnal warming.

22.11 Chapter 11

1. Prevailing horizontal visibility, on the ground, is measured at eye level, and is the greatest distance at which an object can be identified. The slant visual range is the greatest distance that a pilot in flight can see when he looks down at the ground.
2. Nocturnal cooling stabilizes the air at lower levels, limiting the rising currents that normally carry off and disperse smoke and dust particles aloft. The stable nighttime air allows the particles to collect at low altitude, thereby reducing visibility.
3. Unstable air and strong surface winds, behind the cold front, cause mechanical turbulence. Powdery snow is lifted well above eye level, reducing surface visibility.
4. The hourly observation reports the prevailing horizontal visibility at the surface, and not the slant visual range observed by the aircraft. The hourly observation indicates the visibility observed at the station, and not at the beginning of the runway in use. Abrupt and frequent fluctuations in visibility often mean a difference between actual conditions and those reported in the latest hourly observation.
5. c)
6. b)
7. b)
8. d)

22.12 Chapter 12

1. b
2. d
3. d
4. b
5. b
6. a
7. b
8. c
9.
    - Rime.
    - The absence of strong updrafts explains the small supercooled droplets present in strataform clouds. Because of their small size, the droplets have a tendency to freeze immediately on contact with the aircraft, forming this type of fragile, crystalline ice.
10. The size of the supercooled droplets, their number, the shape of the aircraft's wing and its airspeed.
11. When ice crystals and supercooled droplets coexist in a cloud, the droplets have a tendency to evaporate and coalesce into ice crystals. The crystals accordingly multiply at the expense of the supercooled droplets, and the water content of the cloud diminishes.
12. When an aircraft's speed is increased, the collection efficiency also increases. The quantity of supercooled droplets collected from a given volume within a given time increases and, as a result, the quantity of clear ice accretion also increases.
13. Immediately prior to the maturity stage and the onset of precipitation, when the cell's water content is greatest.
14. Snowfall reduces the water content in a cloud by crystallizing super-cooled droplets.
15. If the relative humidity is high, there is a danger that the carburetor will ice up under clear skies at relatively high temperatures. Relative humidity close to saturation is very high immediately under the cloud, but low above its top.
16. Ice pellets on the surface indicate freezing rain aloft, resulting in a moderate or high probability of clear icing in the course of the descent.

- A layer in which the temperature is above 0 C, located above a layer in which the air is below 0 C.
- A temperature at or slightly lower than 0 C in or under a cloud. Normally, the temperature profile is stable and often corresponds to an isotherm.

22.13 Chapter 13

1. High humidity, unstable air up to upper levels and updrafts.
2. See Figure 13-1.
3. Nighttime cooling stabilizes air at low altitude and blocks updrafts, thereby preventing the development of thunderstorms.
4. In this case, the process which generates the thunderstorm is a rising front, which continues despite nighttime cooling; updrafts continue to sustain thunderstorms day and night.
5. Turbulence, hail, icing and lightning.
6. Strong gusts produce abrupt variations in wind direction at ground level.
7. Damage caused by hail and wind.
8.
    - Sudden variations in the wind and increase in wind speed with the arrival of the cold downdraft.
    - Lowering followed by an increase of the ceiling after the thunderstorm has passed.
    - Temporary reduction in visibility in the precipitation, as the thunderstorm passes.
    - Sudden drop in temperature during the thunderstorm, followed by a gradual rise after it has passed.
    - Showers which begin and stop abruptly with the passing of the thunderstorm.
    - A drop in air pressure as the thunderstorm passes, followed by an increase as it moves away.
9. Microgusts are intense downdrafts, on a small scale, underneath a violent thunderstorm which, on reaching the ground, blow from the centre of the base of the thunderstorm towards the outside.
10. True.
11. True.
12. A narrow, moving line, along which violent variations in wind occur: squall. This line is frequently accompanied by showers or thunderstorms. They frequently develop in advance of a cold front in moist, unstable air, but can also develop in unstable air far away from any front.
13. True.

22.14 Chapter 14

1. Turbulence can be defined as a disorganized, persistent agitation in air flow.
2. The intensity of turbulence depends on the difference in speed between adjacent currents, the size of the aircraft, its wing surface, airspeed, flight altitude and the pilot's assessment of the intensity.
3. Light, moderate and severe turbulence.
4. Convective currents, obstacles to wind and windshear.
5. Aircraft will have a tendency to descend lower than the expected flight path. This must be compensated by increasing the aircraft's approach speed.
6. Avoid flying in convective clouds. Turbulence is less severe far above them.
7. True.
8. Turbulence resulting from mechanical disturbances in the ambient flow of the wind due to obstacles.
9. Wind speed and the roughness of obstacles on the ground.
10. The presence of convective clouds indicates that the air is unstable and that there is probably turbulence on the windward side, as well as above the top. In addition, the air subsides on the leeward side. To avoid a crash, you must climb 1,000 to 1,500 m (3,200 to 5,000 ft) above the mountain top when you reach a point between 50 and 80 km from the mountain.
11. A wave-like disruption of the direction of the wind above a mountain chain. The waves are virtually stationary above the mountains and produce moderate or severe turbulence.
12. False. Because of the wind, mountain waves frequently spill over the mountains by several dozen kilometres.
13. A spatial variation in the wind vector at a definite time and place.
14. Low Level Wind Shear.

15. Variations in the wind vector of more than 25 kt.
16. Turbulence almost always occurs near a front.

22.15 Chapter 15

1. Environment Canada.
2. False.
3.

- o By telephone.
- o By a briefing from a weather specialist.

4. So they can make better use of observations, forecasts and amendments.

5.

- o P
- o F
- o P
- o F
- o F
- o P
- o F
- o F
- o P

5. A SIGMET.
6. An area forecast covers a specific area and not a flight path.
7. Subtract 7 hours.
8.

    - o 1900 h Eastern Standard time.
    - o 1330 h Newfoundland Standard time.
    - o 1700 h Mountain Daylight time.
    - o 1800Z.

9.

    - o Continuous freezing rain.
    - o Snow showers.
    - o Cold front.
    - o Intermittent drizzle.
    - o Continuous snow.
    - o Thunderstorm.
    - o Warm front.
    - o Continuous rain.
    - o Intermittent snow.
    - o Warm trough.
    - o Continuous drizzle.
    - o Rain shower.
    - o Fog.

10.The pilot's assumptions are based solely on the surface weather chart. Because of the variation between the time of observation and the time the chart was issued, it did not give a complete weather picture. The low-pressure zone probably moved towards the pilot's flight path, bringing bad weather. The pilot should have consulted the forecasts.

11.

- Warm front.
- Warm trough.
- Occluded front.
- Upper-air warm front.
- Upper-air cold front.
- Upper-air cold front.
- Stationary front.
- Stationary front.
- Upper-air warm front.
- Warm trough.

12.

- Fog.
- Thunderstorm.
- Snow shower.
- Intermittent rain.
- Freezing rain.
- Ice pellets.
- Continuous drizzle.
- Continuous rain.
- Intermittent freezing drizzle.
- Drizzle.

14. c.
15. 60 to 90 kt.
16. d.
17. False.
18. Isohypses.
19. 18,000 ft or 5,500 m.
20. 10,000 ft or 3,000 m.

22.16 Chapter 16

Hourly reports (SA) Section

YUL	Station identifier: Montreal International Airport, DORVAL
SA	Normal message classification
2300	Time of observation: 2300Z
-X	Sky partially obscured by a layer based at the surface
4 SCT	Scattered layer based at 400 ft above ground level
M40 0VC	Sky overcast, ceiling measured at 4,000 ft above ground level
4FK	Visibility four miles in smog

YUL	Station identifier: Montreal International Airport, DORVAL
243	Pressure at MSL 1024.3 hPa
16	Temperature: 16 C
15	Dewpoint: 15 C
0410	Wind direction: 40 true, wind speed: 10 kt
025	Altimeter setting: 30.25 inches of mercury
F2SF3SC5	Fog: opacity 2/10; stratus fractus: opacity 3/10; stratocumulus: opacity 5/10.

METAR Section

1. 29.90 inches of mercury
2. 5 C
3. 3 C
4. 340 at 15 kt, gusting to 30
5. Direction variable, 3 kt
6. Data not available
7. CU1AS2C10 (oktas)
8. Sky obscured, vertical visibility 200 ft
9. 1.5 miles
10. CYEG and CYHZ
11. CYYC and CYAW
12. 300 ft
13. Light snow and blowing snow
14. Light rain, light drizzle and mist.

22.17 Chapter 17

1. Section 17.6.1

- Issue time of the TAF.
- Visibility = 6 statute miles in mist.
- It the date and valid time of the TAF. In this case the TAF is valid from the second of the current month at 0600Z to 0600Z the following day.
- Is the station identifier for Montreal, the office that issued the TAF.
- There is a scattered layer of cloud based at 2,000 ft with a top at 3,000 ft. There is also another broken layer above the first, based at 4,000 ft with a top at 6,000 ft MSL.
- The sky is broken with a layer of cloud based at 3,000 ft MSL, with a top at 6,000 ft. There is a cloud-covered area above the first layer, based at 10,000 ft, with a top at 15,000 ft. These clouds occasionally result in visibility reduced to 6 miles in the rain. After 1900Z, clouds will cover the sky, based at 2,000 ft with a top at 15,000 ft MSL. In addition, visibility will be 3 miles in light rain and mist.

2. Section 17.6.2

- It means that the bulletin is a SIGMET for a weather hazard other than volcanic ash or a tropical cyclone.
- The SIGMET is valid on the sixth day of the current month from 1730Z to 2130Z
- The SIGMET was isued by Montreal.
- It means that from 0200Z to 0500Z the wather indicated prior to the TEMPO group will cange to the one indicated by the TEMPO group.l
- he reason for issuing the SIGMET was the presence of a broken line of cumulonembus clouds

3. Section 17.6.3

- It means that the bulletin is an AIRMET message.
- The AIRMET is valid from 0720Z on the 20 of the current month until the next GFA will be issued or until the AIRMET needs to be updated, whichever comes first.
- The office that issued the AIRMET was Montreal.
- Most likely the AIRMET will be automatically updated by the next regular issue of the GFA. If the weather situation will change significantly prior to the issue time of the next regular GFA, the AIRMET will be updated then.
- The reason for issuing the AIRMET was the presence of freezing drizzle that was not forecast in the valid GFA.

4. Section 17.6.4

- The outlook period of the GFA is 12 hours, from 0600Z to 1800Z on 29 October 2002.
- The issue time of the GFA is 28 October 2002 at 1721Z and the GFA is valid at 0600Z on 29 October 2002.
- An area of snow with visibility as low as 3 of a statute mile.
- The weather symbols described in the legend box are : Thunderstorm (TS), Tropical cyclone STM), freezing rain (FZRA) and volcanic eruption (VOLCAN).
- An area of multiple layers of clouds with some altocumulus castellanus (ACC) producing snow showers with visibility near 2 statute mile and frequent stratus ceilings 3 to 6 hundred feet above ground.

5. Section 17.6.5

- The map is called ICG-TURB & FZLVL because it depits areas where moderate or severe turbulence or moderate to severe icing are to be found, as well as the freezing level lines.
- The valid time of the map is 29 October 2002 at 0600Z.
- There are no area of icing forecast.
- There are two areas of turbulence indicated on the map : they are the hatched areas enclosed with a blue line.
- The dashed red lines are freezing level lines.

6. Section 17.6.6

- The wind speed over Vancouver (YVR) at 9,000 feet is 35 knots.
- The wind direction over Vancouver at 18,000 feet is 240 degrees true.
- The temperature over Penticton (YYF) at 6,000 feet is 01 degree Celsus.
- The temperature is not forecast at 3,000 feet.

7. Section 17.6.7

- The FDCN1 KWBC was issued on the 24 of the month at 0440 Z.
- The temperature over Vancouver at 34,000 feet is -48 degrees Celsus.
- The wind over Penticton at 30,000 feet is from 130 degrees and its speed is 20 knots.

22.18 Chapter 18

1. A PIREP is a message concerning weather conditions observed and transmitted by a pilot in flight.
2. PIREPs must be issued when significant conditions for air navigation occur, whether or not they were forecasted. However, a PIREP may also be issued to confirm that the weather observed is favourable.
3. Pilots or navigators preparing their flight plans and those already in flight. Meteorologists and technicians preparing and transmitting weather forecasts. Control Tower and aides to navigation personnel. The computer networks which generate some forecasts automatically.

22.19 Chapter 19

1. A radar antenna emits a very high frequency electromagnetic wave in the form of impulses, which sweeps the sky. When the wave strikes an obstacle, such as particles of precipitation, part of it is reflected towards the radar. The data thus collected are used to produce images which illustrate the position and scale of the precipitation.
2. Particles of precipitation, such as raindrops, snowflakes, ice pellets and hail.
3. 220 km.
4. Tornadoes occur close to the ground, while radar sweeps the sky at higher altitude. The size of a tornado, furthermore, is smaller than the radar's resolution, hence it is impossible for radar to detect them.
5. A 1.5 km Cappi is a horizontal radar projection at a height 1.5 km. In other words, it is an image which illustrates all the echoes received by the radar at that height.
6. Doppler radar can detect the intensity, location, direction and speed of movement of particles of precipitation.
7. LLWS can be detected provided it is not too close to the ground and there is precipitation.

1.

- No, no. They are too small and too close to the ground.
- No, no. Lightning is not solid matter.
- Yes, yes.
- No, yes.
- Yes, yes.
- No, no. The resolution of weather radar is not good enough.
- No, no. It occurs too high up.
- Yes, yes. Provided they are within radar range and at a height that is detectable by radar.
- No, no. Blowing snow occurs underneath the radar sweep.
- No, no. Radar cannot detect clouds, only precipitation.

22.20 Chapter 20

1. The descendants of TIROS known as polar-orbiting satellites, launched by the National Oceanic and Atmospheric Administration (NOAA) and Geostationary satellites known as Geostationary Observational Environmental Satellites (GOES).
2. Polar orbiting (NOAA) satellites revolve around the Earth at an altitude of approximately 800 kilometres passing over the Polar Regions, as the Earth rotates underneath. With each pass, they survey a strip approximately 1900 km wide that is further west because of the Earth's eastward rotation. Since they are very close to the Earth, their images have a higher resolution than those from geostationary satellites. Furthermore, when they pass over the North Pole, provided there are no clouds, they provide clear, accurate images of ice conditions in the Arctic.
   Geostationary (GOES) satellites are located 35,800 kilometers directly over the equator. These satellites make one revolution, moving in the same direction as the Earth's rotation in the time it takes the Earth to make one rotation. This keeps them above the same spot on the equator, making them appear stationary. Because such a satellite remains over the same equatorial surface location, successive views from the same geostationary satellite can be provided to observe development of storm systems. They do not picture details as well as the polar-orbiting type of satellite, but they do provide more frequent views, every half hour, of the same Earth surfaces. Because of their angle in relation to the poles, these satellites do not provide accurate information above 60ºN. Image distortion prevents their use in the Arctic.
3. Satellites can take the following images:
4. visual;
5. infrared;
6. a combination of visual & infrared;
7. water vapour.
8. Movements of cloud patterns detected by viewing sequential satellite images, indicate the circulations of broad-scale weather systems. Wind speeds can be estimated at different levels and

even upper-air jet streams can be identified. Meteorologists use satellite images to determine cloud shapes, heights, and type. Changes in these cloud properties, along with cloud movement, provide valuable information to weather forecasters to determine what is happening and what is likely to happen to weather in the hours and days ahead.

9. Thunderstorms appear as "blobs" or "chains of blobs".
10. GOES satellites provide images every half hour of the same Earth surfaces.
11. Ordinarily, there are two geostationary satellites covering Canada and the United States, one for the eastern part and one for the west coast and Pacific Ocean. Each one has a field of view covering about one-third of the Earth's surface.