7.4.3 WEATHER[M13]

Weather is the term given to the natural events that occur in the atmosphere of a planet. Weather generally refers to the activity of these events over a short period of time, usually no more than a few days—the period over which the behaviour of these natural phenomena can currently be predicted with any degree of accuracy.

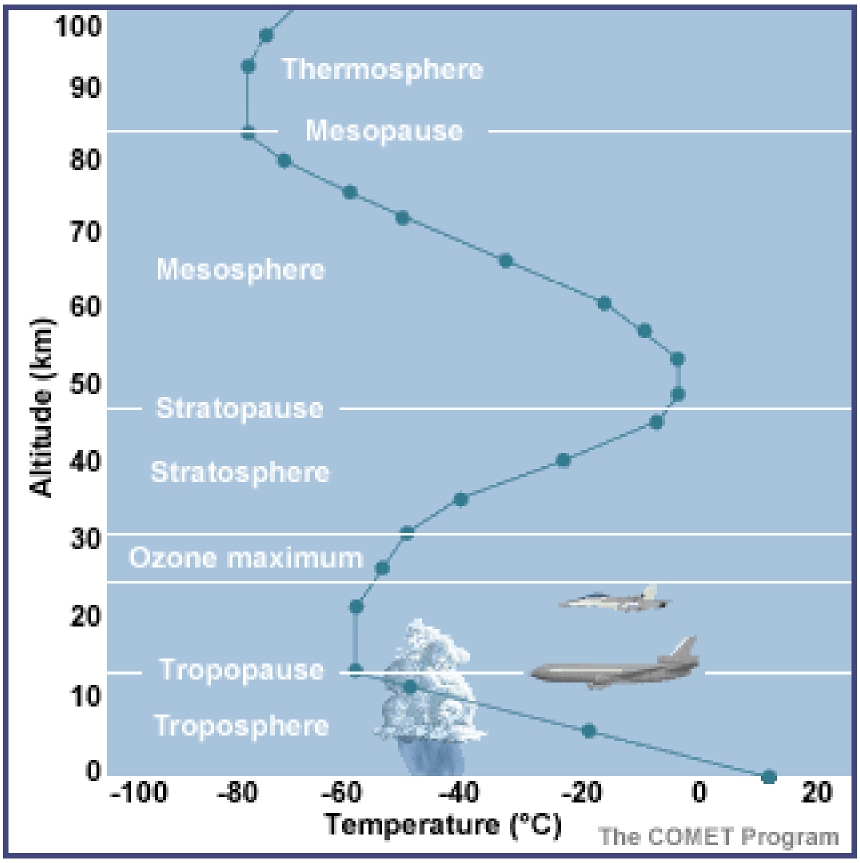
While individual weather events are difficult to predict, the underlying pattern of atmospheric circulation and associated weather events is fairly constant over periods or a year or more. This longer-term pattern of weather events is generally referred to as the *climate*.

7.4.3.1 Solar Energy

While the sun radiates energy across a broad region of the electromagnetic spectrum, it is the **infrared radiation** that most affects the weather. This solar radiation warms the ground, the sea and the air, providing the force that drives Earth's weather.

7.4.3.2 Structure of the Atmosphere

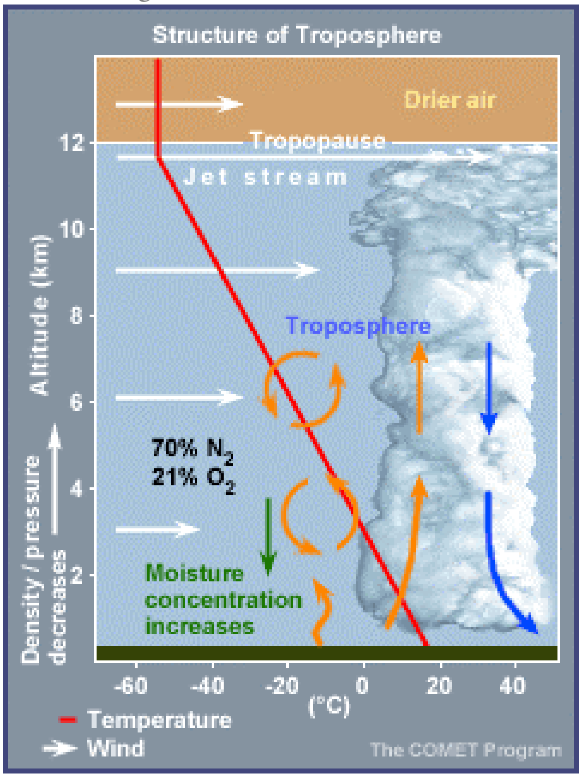
Earth's atmosphere is divided vertically into four layers, based on temperature: the troposphere, stratosphere, mesosphere, and thermosphere.



7.4.3.2.1 Troposphere

The word troposphere comes from **tropein**, meaning to turn or change. All of the earth's weather occurs in the troposphere.

The troposphere has the following characteristics:



- It extends from the earth's surface to an average of 12 km;
- The pressure ranges from 1000 to 200 hectopascals (hPa) or millibars (1hPa = 1mb);
- The temperature generally decreases with increasing height up to the tropopause (top of the troposphere); this is near 200 hPa or 36,000 ft.;
- The temperature averages 15°C near the surface and -57°C at the tropopause;
- It ends at the point where temperature no longer varies with height. This area, known as the tropopause, marks the transition to the stratosphere;
- Winds increase with height up to the jet stream;
- The moisture concentration decreases with height up to the tropopause;
- The air is much drier above the tropopause, in the stratosphere;
- The sun's heat that warms the earth's surface is transported upwards largely by convection and is mixed by updrafts and downdrafts;
- The troposphere is 70% $\mathbf{N_2}$ and 21% $\mathbf{O_2}$. The lower density of molecules higher up would not give us enough $\mathbf{O_2}$ to survive.

7.4.3.3 Atmospheric Processes

7.4.3.3.1 Interactions - Atmosphere and Ocean

Water is an essential part of the earth's ecosystem. The oceans cover nearly three-quarters of the earth's surface and play an important role in exchanging and transporting heat and moisture in the atmosphere. Most of the water vapor in the atmosphere comes from the oceans, and most of the precipitation falling over land finds its way back to the oceans. Indeed, the oceans and atmosphere interact extensively.

Oceans not only act as an abundant moisture source for the atmosphere but also as a heat source and sink (storage medium). **Ocean currents** play a significant role in transferring this heat towards the poles. Major currents, such as the northward flowing Gulf Stream, transport tremendous amounts of heat toward the north pole and contribute to the development of many types of weather phenomena. They also warm the climate of nearby locations. Conversely, cold southward flowing currents, such as the California current, cool the climate of nearby locations.

7.4.3.3.2 Convection in the Atmosphere

Within the atmosphere, warm air rises and cool air moves in to take its place resulting in the formation of wind. For example, air over the land becomes warmer during the day than air over the sea so the air moves from sea to land as a sea breeze. The reverse happens at night.

During the day, the sun warms both land and sea. Since water has a greater specific heat, however, the land warms up more than the sea. As the air over the land is warmed, it rises and the cooler air from over the sea moves in to replace it. This air movement is known as a **sea breeze**. Sea breezes are usually quite local and confined to coastal areas. They may, however, carry cool air several hundred kilometres inland on a hot day.

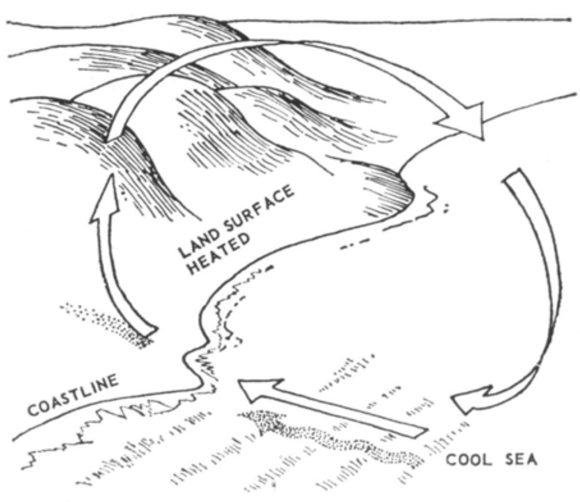


Figure 13.2 A sea breeze

At night, the land surface radiates its heat energy (in the form of infrared radiation) more rapidly than the sea. As a result, the land can become cooler than the sea and it is common late at night and in the early morning to experience offshore winds as air moves from the cooler land to the warmer sea.

Monsoons are caused in a similar way, though on a larger scale and seasonally rather than daily. During the summer the air over continents in tropical regions becomes hotter than that over the oceans, it rises, and cool moist air moves in from the oceans, bringing heavy rain.

7.4.3.3.3 Coriolis Effect

The slow rotation of the earth toward the east also causes the air to move toward the right in the northern hemisphere and toward the left in the southern hemisphere. This apparent deflection of the wind by the earth's rotation is known as the **Coriolis effect**, after the French engineer-mathematician Gaspard-Gustave Coriolis (1792–1843) who first described the effect in 1835.

The Coriolis effect is an inertial force described by French engineer-mathematician Gaspard-Gustave Coriolis in 1835. Coriolis showed that, if the ordinary Newtonian laws of motion of bodies are to be used in a rotating frame of reference, an inertial force—acting to the right of the direction of body motion for counterclockwise rotation of the reference frame or to the left for a clockwise rotation—must be included in the equations of motion.

The effect of the Corilois force is an apparent deflection of the path of an object that moves within a rotating coordinate system. The object [The air] does not actually deviate from its path—it just appears to do so because of the motion of the coordinate system [the Earth].

7.4.3.4 Latitudinal Circulation Features[1]

To understand the convection cells that distribute heat over the surface of the earth, consider a simplified, smooth earth with no land/sea interactions and a slow rotation. Under these conditions, air at the equator is warmed by the sun more than that at the poles. The warm, light air at the equator rises and spreads northward and southward, and the cool dense air at the poles sinks and spreads toward the equator—air tends to

[1] http://en.wikipedia.org/wiki/Atmospheric_circulation

move from poles to equator at low altitudes and from equator to poles at high altitude. In reality, however, the rotation of the earth [from west to east] causes the resultant winds to be turned towards the west in the southern hemisphere, producing easterly winds—wind direction is defined by stating the direction *from which* the wind blows. At high latitudes, the air flowing towards the poles turns towards the east and becomes a westerly wind. Because these air flows are constant for much of the year, they were of great value to early sailing vessels and became known as the Trade Winds.

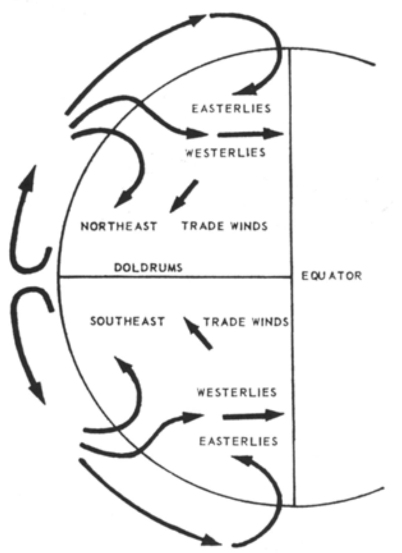
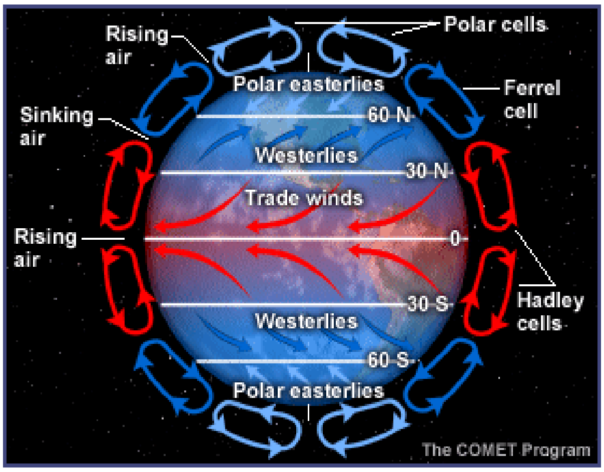


Figure 13.4 Effect of earth's rotation on wind circulation



Further complications in the global wind patterns arise from eddies set up at the boundary of two air streams. These swirls may vary in size from small willy willies to enormous cyclones—a system of winds flowing around region of low atmospheric pressure—many hundreds of kilometres across.

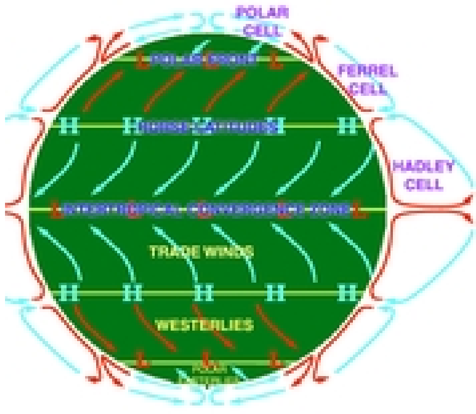
The circulation of winds in a cyclone can be understood if one remembers that the rotation of the earth tends to make winds turn towards the left in the southern hemisphere. Consider what happens if the pressure in the atmosphere in a given region becomes lower than that in surrounding regions. This may happen as a result of heating and consequent rising of air causing a low pressure area. The surrounding air, being denser and at higher pressure, immediately begins to move in towards the low pressure area. But winds turn towards the left in the southern hemisphere, and to the right in the northern hemisphere. The result is a circulation of air that is clockwise in the southern hemisphere and anti-clockwise in the northern hemisphere.

An **anticyclone** is a region of high pressure, from which winds tend to blow outward, and, being turned towards the left, form a circulation system that is anti-clockwise in the southern hemisphere, and clockwise in the northern hemisphere.

In the upper atmosphere, just below the tropopause (around 11 km or 36,000 ft), the low level winds are balanced, to some extent, by fast flowing but relatively narrow air currents known as jet streams. These form at the boundaries of adjacent air masses that differ significantly in temperature (*e.g.* those of the polar region and the warmer air nearer to the equator).

The wind belts and the jet streams girdling the planet are steered by three convection cells: the Hadley cell, the Ferrel cell, and the Polar cell. In reality, things are not quite as simple as this. For example, there is not one discrete Hadley cell, but several within the equatorial zone which shift, merge, and decouple in a complicated process over time.

7.4.3.4.1 Hadley Cell



The Hadley cell mechanism is, nonetheless, well understood. The atmospheric circulation pattern that George Hadley (1685–1768) described to provide an explanation for the trade winds matches observations very well. It is a closed circulation loop, which begins at the equator with warm, moist air lifted aloft in equatorial low pressure areas to the tropopause and carried toward the poles. At about 30°N/S latitude, it descends in a cooler high pressure area. Some of the descending air travels back toward the equator, along the surface, closing the loop of the Hadley cell and creating the Trade Winds.

Though the Hadley cell is described as lying on the equator, it should be noted that it is more accurate to describe it as following the sun's zenith point, or what is termed the *thermal equator*, which undergoes a semiannual north-south migration.

7.4.3.4.2 Polar cell

The Polar cell is likewise a simple system. Though cool and dry relative to equatorial air, air masses at the 60th parallel are still sufficiently warm and moist to undergo convection and drive a thermal loop. Air circulates within the troposphere, limited vertically by the tropopause at about 8 km. Warm air rises at lower latitudes and moves toward the poles through the upper troposphere—this happens at both the north and south poles. When the air reaches the polar areas, it has cooled considerably, and descends as a cold, dry high pressure mass, moving away from the pole along the surface, but twisting westward as a result of the Coriolis effect, to produce the Polar easterlies.

The outflow from the Polar cell creates harmonic waves in the atmosphere known as Rossby waves. These ultra-long waves play an important role in determining the path of the jet stream, which travels within the transitional zone between the tropopause and the Ferrel cell. By acting as a heat sink, the Polar cell also balances the Hadley cell in the Earth's energy equation.

It can be argued that the Polar cell is the primary weather maker for regions above the middle northern latitudes. While Canadians and Europeans may have to deal with occasional heavy summer storms, there is nothing like the arrival of a winter visit from a Siberian high to give one a true appreciation of real cold. In fact, it is the polar high that is responsible for generating the coldest temperature recorded on Earth: -89.2°C at Vostok II Station in 1983 in Antarctica.

The Hadley cell and the Polar cell are similar in that they are thermally direct—they exist as a direct consequence of surface temperatures and their thermal characteristics override the effects of weather in their domain. The sheer volume of energy supported by the Hadley cell, and the depth of the heat sink that is the Polar cell, ensures that the effects of transient weather phenomena are not only not felt by the system as a whole, but—except under unusual circumstances—are not even permitted to form. The endless chain of passing highs and lows that is part of everyday life for mid-latitude dwellers is unknown above the 60th and below the 30th parallels.

These atmospheric features are also stable, so even though they may strengthen or weaken regionally or over time, they do not vanish entirely.

7.4.3.4.3 Ferrel cell

The Ferrel cell, theorised by William Ferrel (1817–1891), is a secondary circulation feature, dependent for its existence upon the Hadley and Polar cells. It behaves much as an atmospheric ball bearing between the Hadley cell and the Polar cell, and comes about as a result of the eddy circulations (the high and low pressure areas) of the mid-latitudes. For this reason it is sometimes known as the *zone of mixing*. In the southern hemisphere, at its northern extent, the Ferrel cell overrides the Hadley cell, and at its southern extent, it overrides the Polar cell. Just as the Trade Winds can be found below the Hadley cell, the Westerlies can be found beneath the Ferrel cell.

While the Hadley and Polar cells are truly closed loops, the Ferrel cell is not, and the telling point is in the Westerlies, which are more formally known as *the Prevailing Westerlies*. While the Trade Winds and the Polar Easterlies have nothing over which to prevail, their parent circulation cells having taken care of any competition they might have to face, the Westerlies are at the mercy of passing weather systems. While upper-level winds are essentially westerly, surface winds can vary sharply and abruptly in direction. A low passing to the south or a high passing to the north (from a Southern Hemisphere frame of reference) maintains or even accelerates a westerly flow; the local passage of a cold front may change that in a matter of minutes, and frequently does. A strong high passing to the north may bring easterly winds for days.

The base of the Ferrel cell is characterised by the movement of air masses, and the location of these air masses is influenced in part by the location of the jet stream, which acts as a collector for the air carried aloft by surface lows (a look at a weather map will show that surface lows follow the jet stream). The overall movement of surface air is from the 30th parallel to the 60th. However, the upper flow of the Ferrel cell is not well defined. This is in part because it is intermediary between the Hadley and Polar cells, with neither a strong heat source nor a strong cold source to drive convection, and in part because of the effects on the upper atmosphere of surface eddies, which act as destabilising influences.

In addition, the Coriolis effect is strongest in the region of the Ferrel cell.

7.4.3.5 Longitudinal Circulation Features

While the Hadley, Ferrel, and Polar cells are major components of the global heat transport process, they do not act alone. Disparities in temperature also drive a set of longitudinal circulation cells, and the overall atmospheric motion is known as the *zonal overturning circulation*.

Latitudinal circulation occurs because incident solar radiation per unit area is highest at the equator, and decreases as the latitude increases, reaching its minimum at the poles. Longitudinal circulation, on the other hand, comes about because water has a higher specific heat than land and thereby absorbs and releases heat less readily than land. Even on a microscale, this effect is noticeable—it is what brings the sea breeze ashore in the day, and carries the land breeze out to sea during the night.

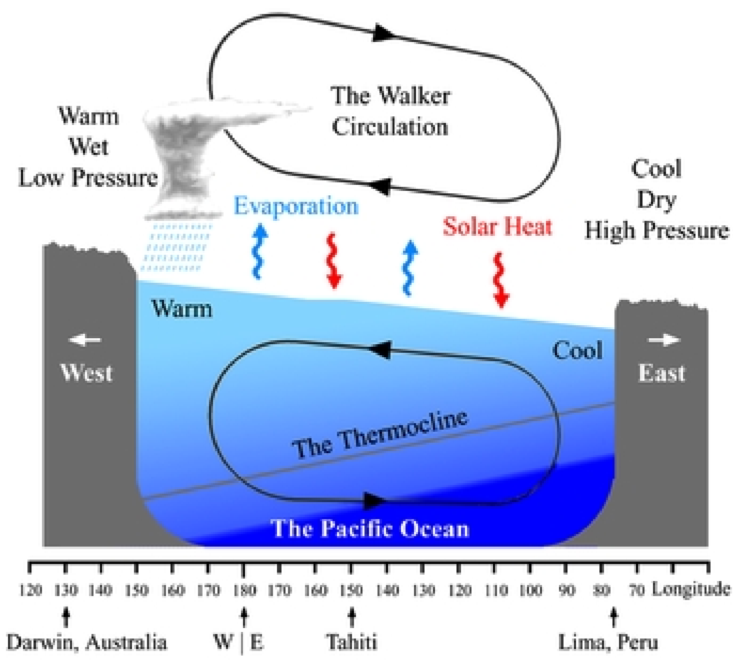
On a larger scale, this effect ceases to be diurnal (daily), and instead is seasonal or even decadal in its effects. Warm air rises over the equatorial continental and western Pacific Ocean regions, flows eastward or westward, depending on its location, when it reaches the tropopause, and subsides in the Atlantic and Indian Oceans, and in the eastern Pacific.

The Pacific Ocean cell plays a particularly important role in Earth's weather. This entirely ocean-based cell comes about as the result of a marked difference in the surface temperatures of the western and eastern Pacific. Under ordinary circumstances, the western Pacific waters are warm and the eastern waters are cool. The process begins when strong convective activity over equatorial East Asia and subsiding cool air off South America's west coast creates a wind pattern which pushes Pacific water westward and piles it up in the western Pacific.

7.4.3.5.1 Walker Circulation

The Pacific Ocean cell is of such importance that it has been named the Walker Circulation after Sir Gilbert Walker (1868–1958), an early-20th-century director of British observatories in India, who sought a means of predicting when the monsoon winds would fail. While he was never successful in doing so, his work led him to the discovery of an indisputable link between periodic pressure variations in the Indian and Pacific Oceans, which he termed the *Southern Oscillation*.

The Walker circulation is an atmospheric circulation of air over the equatorial Pacific Ocean, responsible for creating ocean upwelling off the coasts of Peru and Ecuador. It is driven by the pressure gradient that results from a high pressure system over the eastern pacific ocean, and a low pressure system over Indonesia. When the Walker Circulation weakens or reverses, an El Niño results, causing above-average temperatures in the ocean surface, as upwelling of cold water occurs less or not at all. An especially strong Walker Circulation causes a La Niña, resulting in below-average ocean temperatures due to increased upwelling.



A thermocline is a characteristic of bodies of water, ranging in size from lakes to oceans, which exhibit a change in water temperature with depth. It is defined as the depth at which the rate of decrease of temperature with increase of depth is the largest. In general the sea water temperature decreases from the surface to the deepest levels, except in high latitudes where the configuration can be more complex. There exists in most ocean areas (apart from polar and sub-polar oceans) a zone where the rate of decrease of temperature is much larger compared with that above and below, hence the definition. Depending on the geographical location, the thermocline depth ranges from about 50m to 1000m. A simplified view is to consider the thermocline as the separation zone between the mixed-layer above, much influenced by atmospheric fluxes, and the deep ocean. In the tropics, the thermocline can be quite shallow on average, as in the eastern Pacific (50m), or deeper as in the western part (160-200m). In extra-tropical regions a permanent (or main) thermocline is found between 200m and 1000m. However the thermocline depth varies seasonally, especially in the mid-latitude regions where a secondary and much shallower thermocline (above 50m) occurs in summer. In high latitudes, a thermocline may appear only seasonally. Thermocline can also vary from one year to the next, as in the tropical Pacific where thermocline vertical displacements play a fundamental role during ENSO. As the pycnocline (a layer across which there is a rapid change in water density with depth), the thermocline is a prominent feature of the ocean that conditions many physical, chemical and biological processes occurring in the oceanic upper layers. In many situations, the thermocline can be identified with the pycnocline when the vertical contrasts of salinity are small[2].

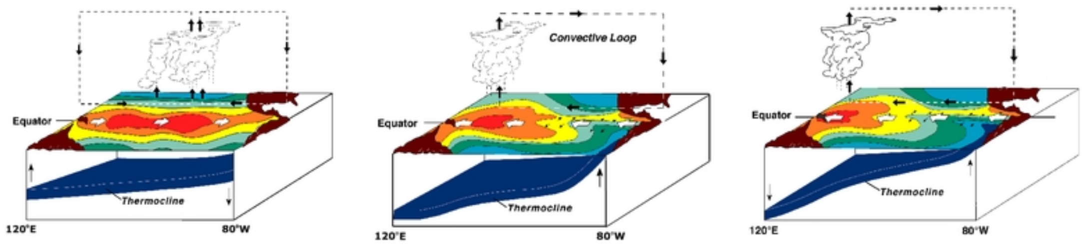
7.4.3.5.2 El Niño - Southern Oscillation

El Niño - Southern Oscillation (ENSO) is a global coupled ocean-atmosphere phenomenon. The Pacific ocean signatures, El Niño and La Niña are major temperature fluctuations in surface waters of the tropical Eastern Pacific Ocean. The names, from the Spanish for "the little boy" and "the little girl", refer to the Christ child, because the phenomenon is usually noticed around Christmas time in the Pacific Ocean off the west coast of South America. Their effect on climate in the southern hemisphere is profound. The atmospheric signature, the Southern Oscillation (SO) reflects the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. El Niño affects Australia by drought. As of September 2006, El Niño is currently active, and is expected to continue into 2007.

ENSO is the most prominent known source of inter-annual variability in weather and climate around the world. Although not all areas on Earth are affected, ENSO has signatures in the Pacific, Atlantic and Indian Oceans.

In the Pacific, during major warm events El Niño warming extends over much of the tropical Pacific and becomes clearly linked to the SO intensity. While ENSO events are basically in phase between the Pacific and Indian Oceans, ENSO events in the Atlantic Ocean lag behind those in the Pacific by 12 to 18 months. While ENSO is a global and natural part of the Earth's climate, whether its intensity or frequency may change as a result of global warming is an important concern. Low-frequency variability has been evidenced. Inter-decadal modulation of ENSO might exist.

El Niño and La Niña are officially defined as sustained sea surface temperature anomalies of magnitude greater than 0.5 °C across the central tropical Pacific Ocean. El Niño is associated with a positive anomaly, and La Niña with a negative anomaly. When the condition is met for a period of less than five months, it is classified as El Niño or La Niña conditions; if the anomaly persists for five months or longer, it is classified as an El Niño or La Niña episode. Historically, El Niño events occur at irregular intervals of 2–7 years, usually last one or two years and are followed by La Niña events.



El Niño **Normal** **La Niña**

2 http://www.esr.org/outreach/glossary/thermocline.html

The first signs of an El Niño are:

- Rise in air pressure over the Indian Ocean, Indonesia, and Australia
- Fall in air pressure over Tahiti and the rest of the central and eastern Pacific Ocean
- Trade winds in the south Pacific weaken or head east
- Warm air rises near Peru, causing rain in the deserts there
- Warm water spreads from the west Pacific and the Indian Ocean to the east Pacific. It takes the rain with it, causing rainfall in normally dry areas and extensive drought in eastern areas.

El Niño's warm current of nutrient-poor tropical water, heated by its eastward passage in the Equatorial Current, replaces the cold, nutrient-rich surface water of the Humboldt Current, also known as the Peru Current, which support great populations of food fish. In most years the warming lasts only a few weeks or a month, after which the weather patterns return to normal and fishing improves. However, when El Niño conditions last for many months, more extensive ocean warming occurs and its economic impact to local fishing for an international market can be serious.

During non-El Niño conditions, the Walker circulation is seen at the surface as easterly trade winds that move water and air warmed by the sun towards the west. This also creates ocean upwelling off the coasts of Peru and Ecuador and brings nutrient-rich cold water to the surface, increasing fishing stocks. The western side of the equatorial Pacific is characterised by warm, wet low pressure weather as the collected moisture is dumped in the form of typhoons and thunderstorms. The ocean is some 60 cm higher in the western Pacific as the result of this motion.

If convective activity slows in the Western Pacific (the reason for which is not currently known), an El Niño event develops. First, the upper-level westerly winds fail. This cuts off the source of cool subsiding air, and the surface Easterlies cease.

The consequence of this is twofold. In the eastern Pacific, warm water surges in from the west since there is no longer a surface wind to constrain it. This and the corresponding effects of the Southern Oscillation result in long-term unseasonable temperatures and precipitation patterns in North and South America, Australia, and Southeast Africa, and disruption of ocean currents.

Meanwhile in the Atlantic, high-level, fast-blowing Westerlies that would ordinarily be blocked by the Walker circulation, and unable to reach such intensities, form. These winds tear apart the tops of nascent hurricanes and greatly diminish the number that are able to reach full strength.

The opposite of an El Niño event is known as a La Niña. In this case, the convective cell over the western Pacific strengthens inordinately, resulting in colder than normal winters in North America, and a more robust hurricane season in South-East Asia and Eastern Australia. There is increased upwelling of deep cold ocean waters and more intense uprise of surface air near South America, resulting in increasing numbers of drought occurrences, although it is often argued that fishermen reap benefits from the more nutrient-filled eastern Pacific waters.

The La Niña condition often follows the El Niño, especially when the latter is strong.

7.4.3.5.3 Wider effects of El Niño conditions

Because El Niño's warm pool feeds thunderstorms above, it creates increased rainfall across the east-central and eastern Pacific Ocean.

In South America, the effects of El Niño are direct and stronger than in North America. An El Niño is associated with warm and very wet summers (December-February) along the coasts of northern Peru and Ecuador, causing major flooding whenever the event is strong or extreme. The effects during the months of February, March and April may become critical. Southern Brazil and northern Argentina also experience wetter than normal conditions but mainly during the spring and early summer. Central Chile receives a mild winter with large rainfall, and the Peruvian-Bolivian Altiplano is sometimes exposed to unusual winter snowfall events. Drier and hotter weather occurs in parts of the Amazon River Basin, Colombia and Central America.

Direct effects of El Niño resulting in drier conditions occur in parts of southeast Asia and Northern Australia, increasing forest fires and worsening haze and decreasing air quality dramatically. Drier than normal conditions are also generally observed in Queensland, inland Victoria, inland New South Wales and eastern Tasmania from June to August.

West of the Antarctic Peninsula, the Ross, Bellingshausen, and Amundsen Sea sectors have more sea ice during El Niño. The latter two and the Weddell Sea also become warmer and have higher atmospheric pressure.

In North America, typically, winters are warmer than normal in the upper Midwest states, the Northeast, and Canada, while central and southern California, northwest Mexico and the southeastern U.S., are wetter than normal. Summer is wetter in the intermountain regions of the U.S. The Pacific Northwest states, on the other hand, tend to be drier during an El Niño. During a La Niña, by contrast, the Midwestern U.S. tends to be drier than normal. El Niño is associated with decreased hurricane activity in the Atlantic, especially south of 25º N; this reduction is largely due to stronger wind shear over the tropics.

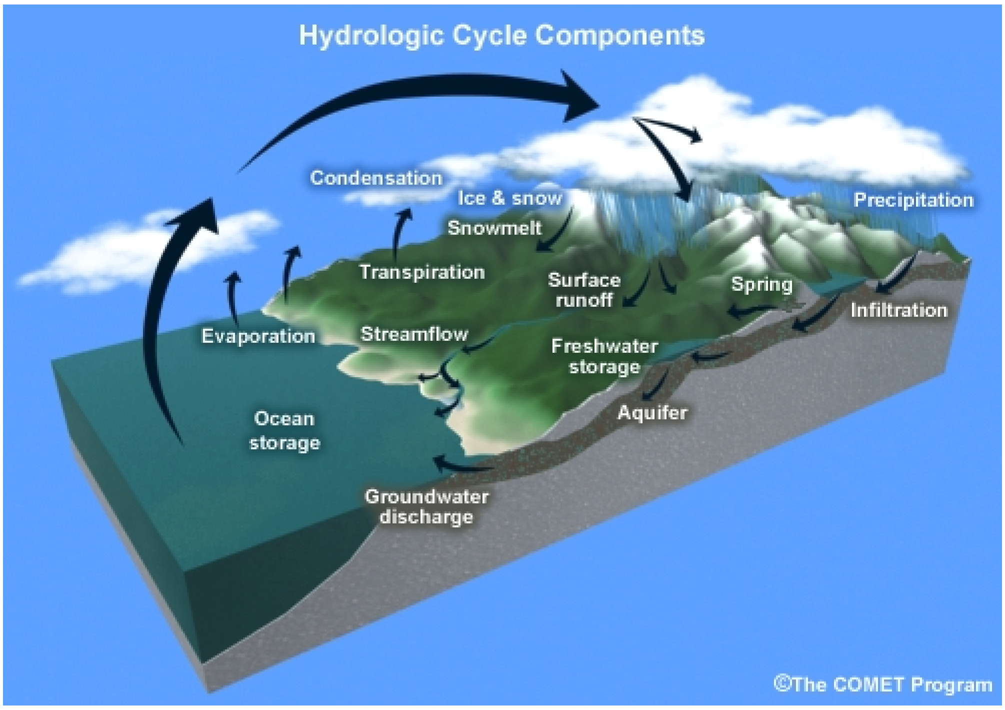
Finally, East Africa, including Kenya, Tanzania and the White Nile basin experiences, in the long rains from March to May, wetter than normal conditions. There also are drier than normal conditions from December to February in south-central Africa, mainly in Zambia, Zimbabwe, Mozambique and Botswana.

7.4.3.5.4 Southern Oscillation Index

The strength of the Southern Oscillation is measured by the Southern Oscillation Index (SOI), which is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. Sustained negative values of the SOI often indicate El Niño episodes, while positive values generally indicate La Niña episodes.

7.4.3.6 The Hydrologic Cycle

The hydrologic cycle is often called the water cycle. It is the vertical and horizontal movement of water as vapour, liquid or solid between the earth's surface, atmosphere and oceans.



7.4.3.6.1 Precipitation and the Formation of Cloud

The amount of water vapour present in the air is called **humidity**. Air is said to be **saturated** when it can hold no more water vapour at any given temperature. **Relative humidity** is the amount of water vapour present in the air expressed as a percentage of the amount needed to saturate it.

If air with a high relative humidity is cooled, the amount of water vapour it can contain is reduced and if cooled sufficiently some of the water vapour will condense, to form either water or ice.

The cooling of humid air in the atmosphere results in the condensation of water as tiny droplets, so small that they float in the air. If enough of these droplets form, they become visible as clouds. Causes of cooling include:

Convection, when low-level, generally warmer air rises, which may be caused through air mass instability. It may be initiated by warming of low-level air, forced ascent over mountainous country, or dynamic causes associated with severe weather systems. Cumulus clouds often form as a result of convection. The most exceptional forms are often associated with severe thunderstorms and occasionally, tornadoes. Cumulonimbus, for instance, may reach altitudes above 15,000 metres;

Systematic ascent of moist air over large areas linked with large-scale weather systems such as low pressure systems, including tropical cyclones. In mid-latitudes this systematic ascent often occurs ahead of active fronts, or with 'cut off' lows. This type of rain may be persistent and heavy and cause floods, especially if enhanced by forced (orographic) ascent over mountains;

Orographic ascent, which occurs when air is forced upwards by a barrier of mountains or hills. Cloud formation and rainfall is often the result. Australia's heaviest rainfall occurs on the Queensland coast and in western Tasmania, where prevailing maritime airstreams are forced to lift over mountain ranges;

Cold and warm fronts, which also cause systematic ascent. A cold front is the boundary where cold air moves to replace, and undercut, warmer and less dense air. Associated cloud and weather may vary enormously according to the properties of the air masses, but tends to be concentrated near the front. As a typical cold front approaches, winds freshen from the north or northwest, and pressure falls. After the front passes, winds shift direction anticlockwise ('backing' to the west or southwest) and pressure rises. Cold fronts are much more frequent and vigorous over southern Australia than elsewhere. Warm fronts, relatively infrequent over Australia, are usually found in high latitudes where they can occasionally cause significant weather. They are often shown on weather charts over the Southern Ocean. Warm fronts progressively displace cool air by warmer air;

Convergence lifting, which occurs when more air flows into an area at low levels than flows out, leading to forced rising of large air masses. Convergence is often associated with wave-like disturbances in tropical easterlies and may also occur with broad tropical air masses flowing to the south. Given sufficient atmospheric moisture and instability, it may cause large cloud clusters and rain.

If the condensation forms sufficiently large droplets, these will fall as rain. When the air temperature is below 0 °C, the water can condense as ice, in the form of either sleet ('wet' ice) or snow.

When the sun sets, the earth's surface radiates energy and cools down. The air above the ground also cools, and if cooled sufficiently water will condense as dew. If the temperature falls below 0 °C, water may condense out of the air as fog or frost.

7.4.3.6.2 Cold Fronts

A cold front is the front edge of a mass of cold air moving towards, and underneath, a mass of warm air. It causes uplift of the warm air, with resulting condensation, cloud formation, and rain.

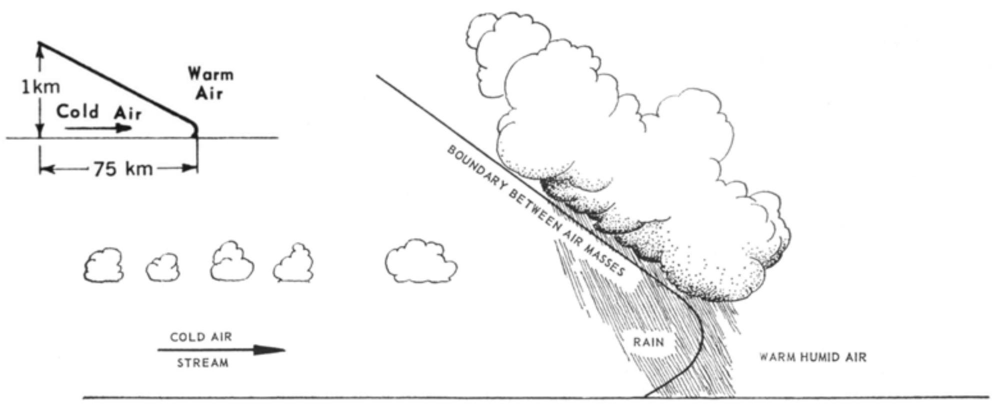


Figure 13.7 A cold front

7.4.3.6.3 Warm Fronts

A warm front is the edge of a mass of warm air that moves towards, and rises over, a mass of cold air.

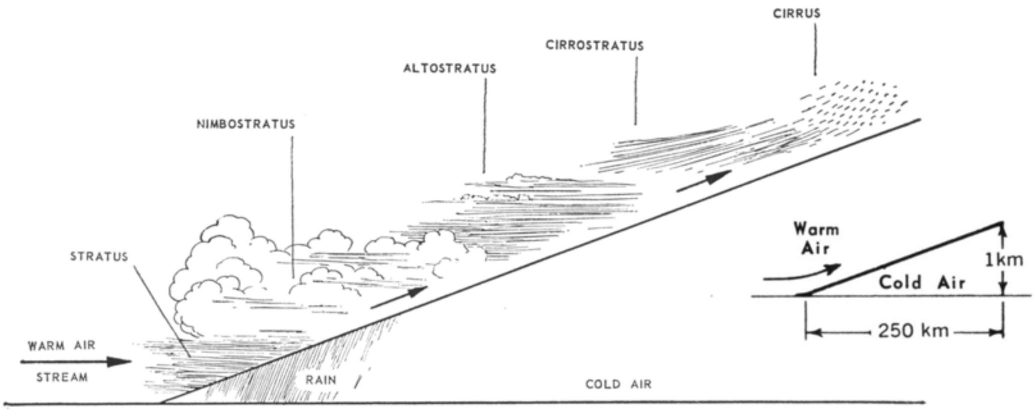


Figure 13.8 A warm front

7.4.3.7 Cloud Classification

7.4.3.7.1 Cloud Names

There are two main types of clouds: *cumuliform* and *stratiform*. Cumuliform clouds comprise cumulous-type formations in which the clouds are usually separated from each other by clear spaces. By contrast, stratiform clouds form sheets or layers covering large areas of the sky.

The names of clouds are descriptive of their type and form. A number of Latin words are used to indicate certain characteristics of clouds. The word *nimbus* (a shower) is added to the names of clouds that produce precipitation. The prefix *fracto* (broken) appears at the beginning of the names of broken, wind-blown clouds. The word *cirrus* (a hair) is used to describe a cloud with hair-like appearance.

7.4.3.7.2 Cloud Genera

Ten main groups of clouds, listed below, can be distinguished. Each is called a *genus* (plural form: *genera*). Each genus may be further subdivided into species and varieties.

1. Cirrus (Ci) Detached clouds in the form of white, delicate filaments or white or mostly white patches or narrow bands. These clouds have fibrous (hair-like) appearance, or a silky sheen, or both.	 Cirrus originating in tufts progressively invading the sky

2. Cirrocumulus (Cc) Thin, white patch, sheet or layer of cloud without shading, composed of very small elements in the form of grains, ripples, etc., merged or separate, and more or less regularly arranged; most of the elements have an apparent width of less than one degree.	 Cirrocumulus
3. Cirrostratus (Cs) Transparent, whitish cloud veil of fibrous (hair-like) or smooth appearance, totally or partly covering the sky, and generally producing halo phenomena.	 Veil of Cirrostratus covering the whole sky, with accompanying halo phenomena.
4. Altocumulus (Ac) White or grey, or both white and grey, patch, sheet or layer of cloud, generally with shading, composed of laminae, rounded masses, rolls, etc., which are sometimes partly fibrous or diffuse and which may or may not be merged. Most of the regularly arranged small elements usually have an apparent width of between one and five degrees.	 Altocumulus in the form of waves. Some small globular elements of Altocumulus also present. Patches of Stratocumulus below.
5. Altostratus (As) Greyish or bluish cloud sheet or layer of striated, fibrous or uniform appearance, totally or partly covering the sky, and having parts thin enough to reveal the sun at least vaguely, as through ground glass. Altostratus does not show halo phenomena.	 Altostratus (thin). Sun appears as through ground glass. Fractocumulus below.

6. Nimbostratus (Ns) Grey cloud layer, often dark, the appearance of which is rendered diffuse by more or less continuously falling rain or snow, which in most cases reaches the ground. It is thick enough throughout to blot out the sun. Low, ragged clouds frequently occur below the layer, with which they may or may not merge.	 Nimbostratus with Fractocumulus below.
7. Stratocumulus (Sc) Grey or whitish, or both grey and whitish, patch, sheet or layer of cloud that almost always has dark parts, composed of tessellations, rounded masses, rolls, etc., which are non-fibrous (except for virga) and which may or may not be merged. Most of the regularly arranged small elements have an apparent width of more than five degrees.	 Stratocumulus not formed from Cumulus.
8. Stratus (St) Generally grey cloud layer with a fairly uniform base, which may give drizzle, ice prisms or snow grains. When the sun is visible through the cloud, its outline is clearly discernible. Stratus does not produce halo phenomena except, possibly, at very low temperatures. Sometimes stratus appears in the form of ragged patches.	 Layer of Stratus
9. Cumulus (Cu) Detached clouds, generally dense and with sharp outlines, developing vertically in the form of rising mounds, domes or towers, of which the bulging upper part often resembles a cauliflower. The sunlit parts of these clouds are mostly brilliant white; their base is relatively dark and nearly horizontal. Sometimes cumulus is ragged.	 Cumulus of moderate vertical development.

<table>
<tr>
<td>10. Cumulonimbus (Cb)
Heavy and dense cloud, with a considerable vertical extent, in the form of a mountain or huge towers. At least part of its upper portion is usually smooth, or fibrous or striated, and nearly always flattened; this part often spreads out in the shape of an anvil or vast plume. Under the base if this cloud, which is often very dark, there are frequently low ragged clouds either merged with it or not, and precipitation sometimes in the form of virga.</td>
<td>
Cumulonimbus with anvil top. Cumulus also present.</td>
</tr>
</table>

7.4.3.7.3 Height, Altitude & Vertical Extent

It is often important to refer to the level at which certain parts of a cloud occur. Two concepts are used to identify such a level, namely height and altitude.

The height of a point (*e.g.* the base of a cloud) is the vertical distance from the point of observation to the level of that point. Note that the point of observation may sometimes be on a hill or mountain.

The altitude of a point is the vertical distance measured from mean sea level to the level of that point.

Surface observers generally use the concept of height. Observers on aircraft, however, usually refer to altitude.

The vertical extent of a cloud is the vertical distance between the level of it base and that of its top.

7.4.3.7.4 Etages

Most clouds are generally encountered over a range of altitudes varying from sea level to the level of the tropopause. The altitude of the tropopause also varies in time and space. As a result, the tops of the clouds are higher in the tropics than in middle and high latitudes.

By convention, the part of the atmosphere in which clouds are usually present has been vertically divided into three étages or intervals—high, middle and low.

Each étage is defined by the range of levels at which clouds of certain genera occur most frequently. The étages overlap and their limits vary with latitude. The approximate heights of the limits in kilometres are as follows:

Etage	Polar Regions	Temperate Regions	Tropical Regions	Australia
High	3–8 km	5–13 km	6–18 km	Above 6 km
Middle	2–4 km	2–7 km	2–8 km	2.5–6 km
Low	From the earth's surface to 2 km	From the earth's surface to 2 km	From the earth's surface to 2 km	From the earth's surface to 2.5 km

The étages in which six of the genera are found are as follows:

High Etage	Cirrus, cirrocumulus and cirrostratus (high level clouds);
Middle Etage	Altocumulus (middle level clouds);
Low Etage	Stratocumulus and stratus (low level clouds).

With regard to the other four genera, the following remarks may be made:

Altostratus is usually found in the middle étage, but often extends to higher levels;

Nimbostratus is almost invariably found in the middle étage, but it usually extends both downwards into the low étage and upwards into the upper étage;

Cumulus and cumulonimbus usually have their bases in the low étage, but their vertical extent is often so great that their tops may reach into the middle and high étages.

When the height of a particular cloud is known, the concept of étages may be of some help to the observer in identifying it. Its genus can then be determined, by making a choice from among the genera normally encountered in the étage corresponding to its height.

7.4.3.7.5 Cloud Recognition

Although the classification of clouds into typical forms is of great use, the problem of identifying cloud forms is not always an easy one. It does not overcome the difficulties that arise from the gradual transition between the various types of clouds. Natural cloud does not always conform to the types described in the artificial classification outlined above. At times, the clouds may be intermediate between two types. In these cases, the experience and judgement of the observer becomes important.

Reliable observations of cloud can best be made by keeping a close and continuous watch on their development. It is not always sufficient merely to make a brief examination of the sky at the observation hour.

7.4.3.8 Atmospheric Pressure[3]

Atmospheric pressure is the result of the atmosphere's pressing down on the earth's surface. The atmospheric pressure will be lower under a column of warm, less dense air, and higher under a column of cool, more dense air. Thus a barometer can be used to detect areas of rising and descending air.

The air pressure at any point is the total weight of air above that point. At the surface of the earth, this is about 10,000 kg (10 tonnes) per square metre, or 14 lb/in^2. For many years pressure was expressed as the height, in inches or millimetres, of a column of mercury needed to balance the weight of the air in a mercury barometer. In more recent times, one bar has been defined as a near average total atmospheric pressure, divided, for convenience, into 1000 millibars (mb).

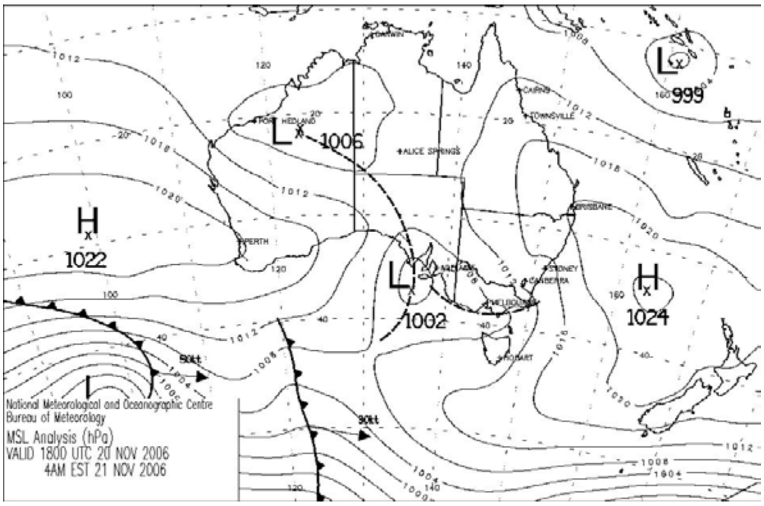
Following the adoption of the Pascal as the SI unit of pressure, meteorologists chose the hectopascal as the international unit for measuring atmospheric pressure (1 hPa = 100 pascals = 1 mb). The millibar is still occasionally used in weather reports and forecasts.

The measurement of air pressure plays a vital role in meteorological analysis and weather forecasting. Since weather stations are invariably located at different altitudes, official pressure readings are adjusted to a datum of Mean Sea Level. These readings form the basis of the isobaric charts (also called synoptic charts or simply weather

[3] http://www.franksingleton.clara.net/hectopascals.html

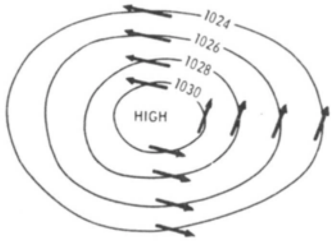
maps) generally provided with weather reports. Isobars are usually drawn either side of 1000 hPa at equal intervals, typically 2, 4 or 8 hPa, depending on the chart scale.

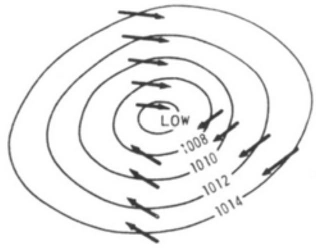
7.4.3.8.1 The Weather Map



The most common weather map is the Mean Sea Level Pressure Analysis, dominated by the smooth, curving patterns of sea level isobars—lines of equal atmospheric pressure—that show the central elements of our weather systems: highs, lows and frontal systems.

In the southern hemisphere, the earth's rotation causes air to flow clockwise around low pressure systems and anticlockwise around high pressure systems. (The opposite applies in the northern hemisphere.)





This rule does not apply in the tropics where the effect of the earth's rotation is weak. For this reason, tropical meteorologists usually replace isobars with streamline arrows that indicate wind and direction without directly relating to the pressure gradient. Wind strength is inversely proportional to the distance between isobars—the closer the lines, the stronger the winds.

Barbed lines indicate the leading edge of travelling cold (and occasionally warm) fronts, the boundaries between different types of air. The term 'front' was applied during World War 1 by European meteorologists who saw similarities between atmospheric structures and the large-scale conflict along battle fronts.

Cold Front

Warm Front

The strongest winds are usually experienced near cold fronts, low pressure systems and in westerly airstreams south of the continent. Winds are normally light near high pressure systems where the isobars are widely spaced. In general, highs tend to be associated with subsiding (sinking) air and generally fine weather, while lows are associated with ascending (rising) air and usually produce rain or showers.

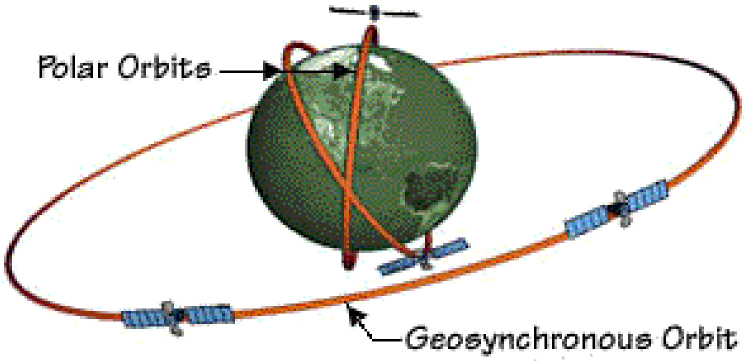
Shaded areas on weather maps show where there has been rain in the previous 24 hours, and wind direction is shown with arrows that have a series of barbs on their tails to indicate speed.

7.4.3.9 Weather Satellites[4,5]

The field of meteorology entered the space age on April 1, 1960 with the launch of TIROS 1 (Television and Infra-Red Observation Satellite). Since that time, numerous satellites with ever increasing capabilities and sophistication have been deployed.

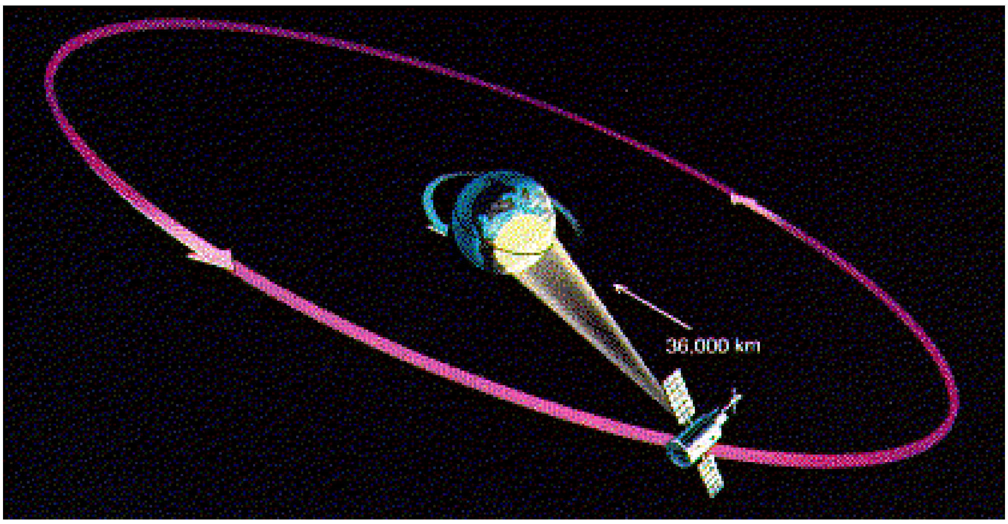
Weather satellites provide valuable cloud photographs of the earth. Most importantly, coverage includes the 70 percent of the earth's surface covered by water where few surface observations can be made. Before the deployment of weather satellites, many areas had no advance warning of impending severe storms. Today satellites can spot and accurately track hurricanes and typhoons while they are still far out in the ocean.

Modern satellites also carry many instruments used to measure various environmental variables, providing vital information to not only meteorologists, but farmers, geologists, fishermen, foresters and others.



7.4.3.9.1 Geostationary Satellites

Geostationary satellites (or *geosynchronous* satellites) orbit the equator at the same rate the earth spins, once per day. They orbit at a distance of 36,000 km above a fixed spot on the earth's surface. This positioning allows continuous monitoring of a specific region.

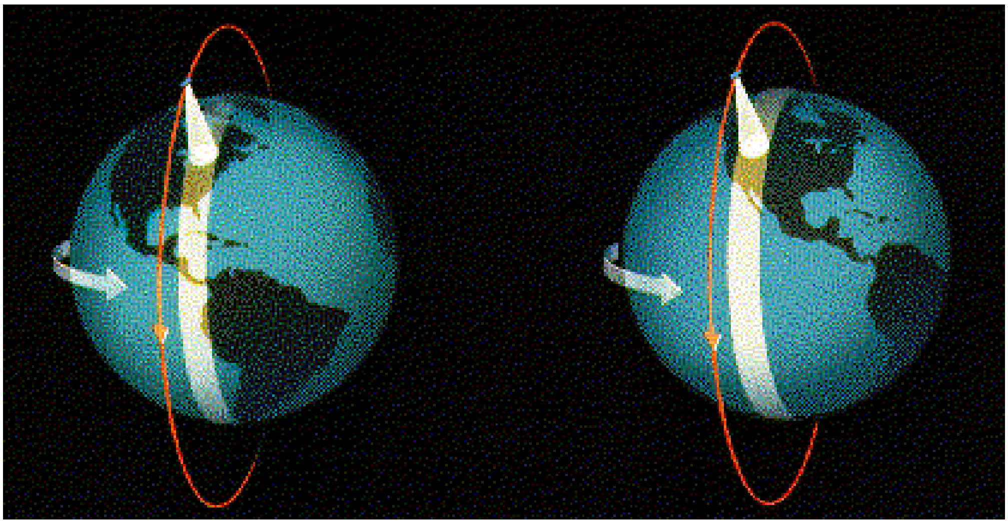


4 http://thetech.org/exhibits/online/satellite/
5 http://physics.uwstout.edu/WX/wxsat/types.htm

Geostationary satellites measure in *real time*, meaning they transmit photographs to the receiving system on the ground as soon as the camera takes the picture. A succession of photographs from these satellites can be displayed in sequence to produce a movie showing cloud movement. This allows forecasters to monitor the progress of large weather systems such as fronts, storms and hurricanes. Wind direction and speed can also be determined by monitoring cloud movement.

7.4.3.9.2 Polar Orbiting Satellites

Polar orbiting satellites closely parallel the earth's meridian lines. They pass over the north and south poles each revolution. As the earth rotates to the east beneath the satellite, each pass monitors an area to the west of the previous pass. These 'strips' can be pieced together to produce a picture of a larger area.



Geostationary satellite images of the polar regions are distorted because of the low angle at which the satellite sees the region. This is not a problem with polar orbiting satellites, which have the advantage of photographing clouds directly beneath them and also circle at a much lower altitude (about 850 km) providing more detailed information about violent storms and cloud systems.

7.4.3.9.3 Satellite Measurements

The following are some of the uses of weather satellites.

- Radiation measurements from the earth's surface and atmosphere give information on the earth-atmosphere energy budget;
- Measurements from the ocean surface are translated into sea-surface temperatures - information valuable to the fishing industry as well as meteorologists;
- Satellites can monitor snow cover in winter, ice fields in the Arctic and Antarctic, and the height of the ocean's surface;
- Infrared sensors on satellites can assess conditions of crops, areas of deforestation and regions of drought;
- Some satellites are equipped with a water vapor sensor that can profile the distribution of water vapor in the atmosphere;
- Volcanic eruptions and the motion of ash clouds can be detected;
- During the winter, satellites monitor the southward progress of freezing air in Florida and Texas, allowing forecasters to warn growers of impending low temperatures;

- Satellites can receive environmental information from remote data collection platforms on the surface. These include instrumented buoys, river gauges, automatic weather stations, seismic and tsunami stations, and ships. This information is then relayed to a central receiving station at Wallop's Island, Virginia.

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