In this chapter

- Atmosphere
- Global Winds
- Air Pressure
- Local Winds
- Air Masses
- Fronts
- Weather Maps

CHAPTER 2

The story of weather starts with the sun. Its energy travels 150 million kilometres to the outer edge of the earth's atmosphere. Some of that energy is reflected back into space by the tops of the clouds and some is scattered by the dust and the water vapour in the atmosphere. About half of the sun's energy reaches the earth. Here it is converted to heat to warm the earth and the air above it as well as melt snow and evaporate water.

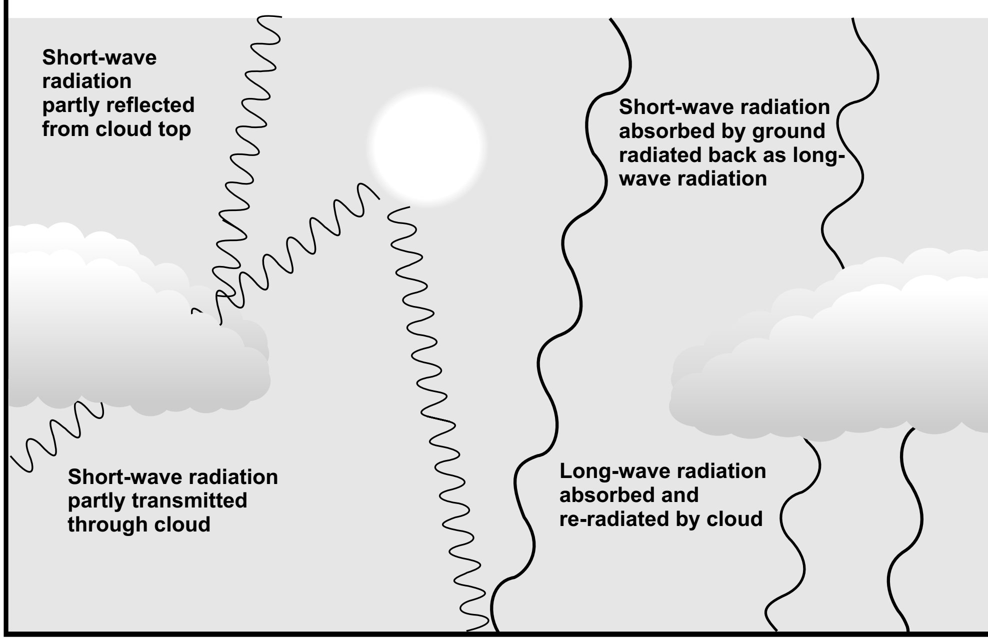
All areas of the earth do not receive the same amount of the sun's energy at the same time. There are 3 reasons for this.

First, the earth rotates on its axis every 24 hours creating night and day.

Second, the earth revolves around the sun every year. During the earth's orbit, some regions receive more of the sun's energy than others.

Third, the earth is tilted on its axis at an angle of 23 ½ degrees. Without that tilt, the sun would shine directly over the equator all year and there would be no seasons. Instead, the sun's energy hits different parts of the earth at different angles affecting the amount of heat any one part of the earth receives. This unequal heating also sets the air in motion creating global wind belts.

SOLAR RADIATION

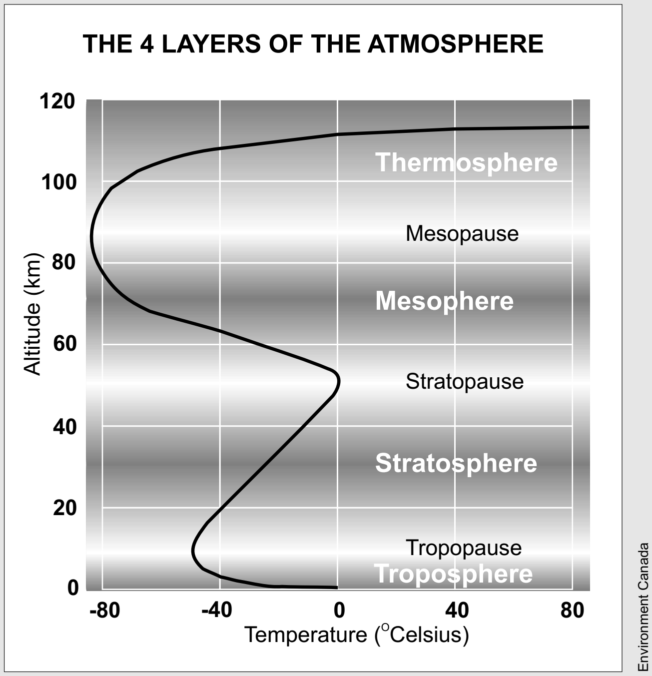


To help your students see the effect of the earth's tilt, try Activity number I on page 8-1 of the Activities Section at the back of the guide.

The Atmosphere

The earth is surrounded by an ocean of air. Meteorologists, the men and women who study weather, refer to this ocean of air as the atmosphere. Scientists have divided it into 4 layers, using temperature and the way it rises or falls with height as one of the criteria.

1. Troposphere is the layer closest to earth. The troposphere is thinner than the other layers. It ranges from 6 to 7 kilometres thick over the north and south poles to 20 kilometres in the tropics. Normally, temperatures in this layer decrease with height to about -50°C at the outer limits. The troposphere is the layer that produces weather.



The dark line shows how temperatures change with height in the different layers of the atmosphere

2. Stratosphere is about 11 to 50 kilometres above the earth. Temperatures here increase with height starting at about -50°C and rising to 0°C. Ozone gas which absorbs most of the sun's harmful ultraviolet rays is in this layer. Some aircraft fly in the stratosphere.

3. Mesosphere is 50 to 80 kilometres above the earth. As in the troposphere, temperatures in the mesosphere decrease with height starting at about 0°C and falling to -80°C in the outer regions of the layer.

4. Thermosphere is the layer which is farthest away from the earth's surface. This layer begins at about 80 kilometres above the earth where the temperature is about -80°C. This increases to about 2,000°C at the outer edges of the thermosphere.

There are transition zones between the layers of the atmosphere. The transition zone between the troposphere and the stratosphere is called the tropopause; between the stratosphere and mesosphere, the stratopause; and, between the mesosphere and thermosphere, the mesopause.

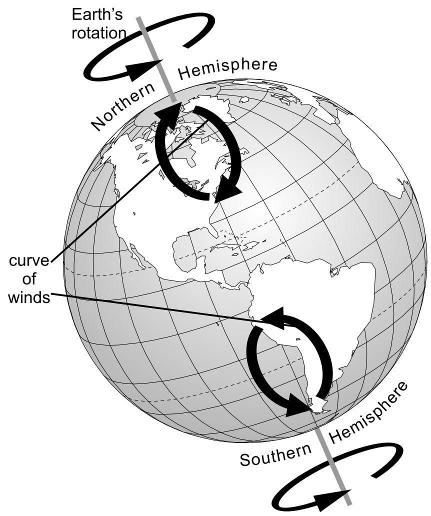
GLOBAL WINDS

The earth's tilt of 23 ½ degrees results in the sun's energy striking some areas of the world more directly than other areas. As a result, some parts of the earth such as the tropics are hotter than others. In the warm areas, the air rises as it heats up and is replaced by the colder and heavier air from the north and south poles. In the meantime, the rising warm air fans out towards the north and south poles where it cools, sinks, and moves back towards the equator. And so the cycle continues.

This movement of air from the poles to the equator would take an orderly course if the earth did not rotate on its axis from west to east every 24 hours. But it does and that gives the winds a curve. In the Northern Hemisphere, the rotation of the earth deflects the winds to the right and in the Southern Hemisphere to the left. The effect of the earth's rotation on the winds is called the Coriolis force.

Over the centuries, the sailors and merchants who plied the oceans exploring or trading named some of these winds. For example, the men sailing the east-

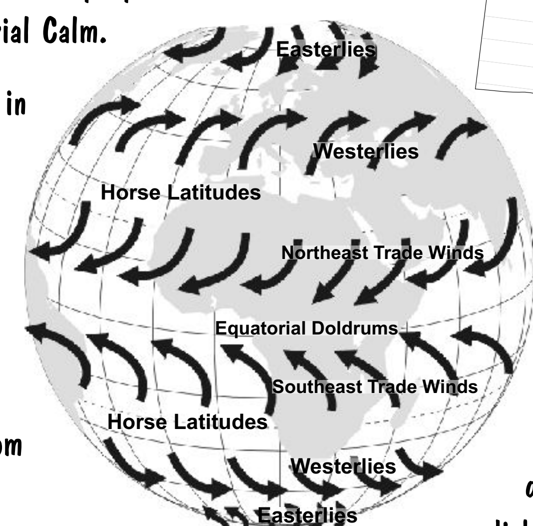
CORIOLIS FORCE



The Coriolis force is named after Gaspard-Gustave de Coriolis, the French scientist, who in 1835 described what happens to any object which has been set in motion on a spinning surface. For example, in the Northern Hemisphere the earth's rotation deflects winds to the right.

west trade routes near the equator called the main east-west winds the trade winds because they were consistent and carried the cargo ships to port on time. Generally speaking, though, the prevailing winds are named after the direction from which they flow. In the Northern Hemisphere, the Polar Easterlies blow from the northeast and the Westerlies blow from the southwest. The Trade Winds in the Northern Hemisphere blow from the northeast towards the equator. Then there are the doldrums, an area of light shifting winds on both sides of the equator. Some people call the doldrums areas of Equatorial Calm.

This pattern repeats itself in the Southern Hemisphere because of the Coriolis force. Here, though, the trade winds flow from the southeast. The Westerlies flow from the northwest and the Easterlies blow from the southeast.



Global pattern of winds

FACT Between the trade winds and the Westerlies lies another area of light, variable winds called the Horse Latitudes. This area got its name when sailing ships carrying horses to the West Indies were becalmed here, and ran short of water. The sailors had to throw the animals overboard so they would not die slowly of thirst.

AIR PRESSURE

To understand pressure of any kind, we first need to look at forces. A force is anything that causes a push or a pull; for example, gravity is a force that pulls you against the surface of the earth. This gives you weight. Another example is the floor pushing up against you when you walk on it.

Pressure is the amount of force spread over a surface. If a force is spread over a large area, the pressure it exerts is smaller. If the same force is spread over a smaller area, the resulting pressure is greater.

Activity

Bring in a piece of wood with a single nail driven through it so that the sharp end protrudes out the bottom. A small piece of 2 X 4 is ideal. Ask your students if they would rather have the wood balanced on their foot with the nail pointing up or pointing down. But why? It weighs the same either way! With the sharp end of the nail pointing down, the weight of the wood is applied at a single point giving BIG pressure while with the piece of wood flipped over, the same weight is spread over a larger surface giving less pressure. (For the same reason, if you're in a lineup and the lady ahead of you steps back onto your foot, you'd much rather she were wearing sneakers than spike heels!)

An Italian scientist named Evangelista Torricelli discovered that air has weight in 1644 when he turned a tube full of mercury upside down and put it into a dish of mercury. The mercury in the tube did not rush down and completely spill out into the dish. Torricelli reasoned that the air above the dish of mercury was pushing down on it so the level of mercury in the bowl was unable to rise. From that experiment, he deduced that air pushes down on everything.

To show your students that air indeed has weight, try Activity number 2 on page 8-2 of the Activity Section.

The weight of all the air above you is called air pressure. Air doesn't seem to weigh very much to us because it is a gas. Remember, though, that the atmosphere is many kilometres thick over your head. The average pressure exerted by the air is about 1 kilogram per square centimetre at sea level--or, in kilopascals, 101.325.

FACT The atmosphere presses down with the weight of 16 tonnes on the body of the average adult.

Activity

Have your students draw a 1 cm by 1 cm square on a piece of paper. How many square centimetres would fit on top of their heads? That adds up to a lot of force. Each 1 centimetre square patch on top of your head feels 1 kg of force. If the radius of your head is 8 cm, you have 200 kg of force pushing down on top of your head alone!

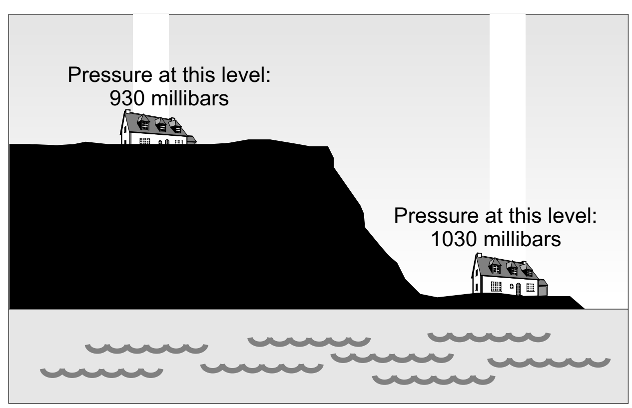
Fortunately, air doesn't just push down on us from above, or we might flatten like a balloon does when you step on it. The atmosphere is composed of a mixture of gases that exert pressure in all directions, pushing equally on all sides of our bodies.

The higher you go in the atmosphere, the lower the air pressure, which makes sense as there is less air above you, pressing down. In the lower levels of the atmosphere close to the earth's surface, the weight of all the air above squeezes the air molecules together, making it denser and heavier. By contrast, in the higher levels, there is less weight above to force the air to compress, and the air molecules can spread out more, making it lighter and less dense.

Activity

To demonstrate that air pushes up as well as down, fill a paper cup or glass right to the brim with water. Now place a piece of cardboard over the top of the cup and hold it in place while you quickly invert the cup. Take your hand away. If atmospheric pressure were not pushing up against the cardboard, the weight of the water would push the cardboard off, causing the water to spill out. Because the air does push up, though, and with a greater force than the water exerts, the cardboard stays in place, appearing to "stick" to the cup.

For example, the air pressure is lower at the top of a mountain than it is at the base. At an altitude of 5,400 metres or 18,000 feet, the air pressure is about half that at sea level. This is the reason you were asked to set your barometer to the mean sea level pressure in Chapter 1. That allows you to compare your readings with those of other schools because all the barometers are using the same reference point — the elevation of zero.



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Air pressure decreases with altitude.

If your students are interested in making a barometer try Activity number 3 on page 8-3 of the Activity Section.

Although you cannot see or hear air pressure, you do feel it, especially when it changes rapidly. For example, if you have ever flown in an aircraft, ridden in the elevator to the top of the CN Tower or taken a chairlift to the top of a ski mountain, there is a good chance your ears popped at some point during the journey. That pop signaled a rapid change in air pressure.

To show your students that air exerts pressure, try Activity number 4 on page 8-4 of the Activities Section.

The air pressure also changes when the air heats up or cools down. When heat, a form of energy, is added to a parcel of air, the air molecules move faster and tend to move farther apart from each other. Consequently, when air warms up, it expands and becomes lighter. Conversely, cold air is heavier and denser because the air molecules are less active and closer together. As the atmosphere strives to create a balance, the air moves from areas of high pressure, which are often associated with cool air, to areas of lower pressure, which are often areas of warmer air. This creates wind. The greater the contrast or difference in air pressure between the two areas, the stronger the winds.

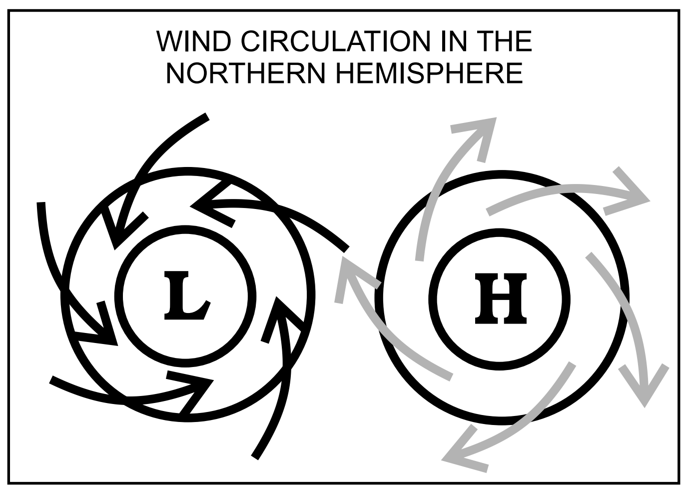
LOCAL WINDS

The global pattern of winds establishes the prevailing winds over large regions. In Canada, for instance, the prevailing winds are from the west. But local differences in air pressure and air temperature as well as lakes, hills and valleys also affect the direction and strength of the winds.

If your students are interested in making an anemometer and wind streamer, try Activity number 5 on page 8-5 and Activity number 6 on page 8-6.

The atmosphere behaves like a liquid. If you scoop a cup of water out of a bucket of water, what remains quickly flows in to fill the hole and restore the balance. So it is with air. The atmosphere tries to create a balance by flowing from areas of high pressure to areas of low pressure.

Here, too, the Coriolis force affects the direction of the winds. They blow clockwise around and out of a high pressure area and counter-clockwise into a low pressure area. The greater the difference in air pressure between the two areas, the harder the winds blow. In Canada the wind speed is given in kilometres per hour and the direction is named for the direction from which it blows. For example, a north wind comes from the north.

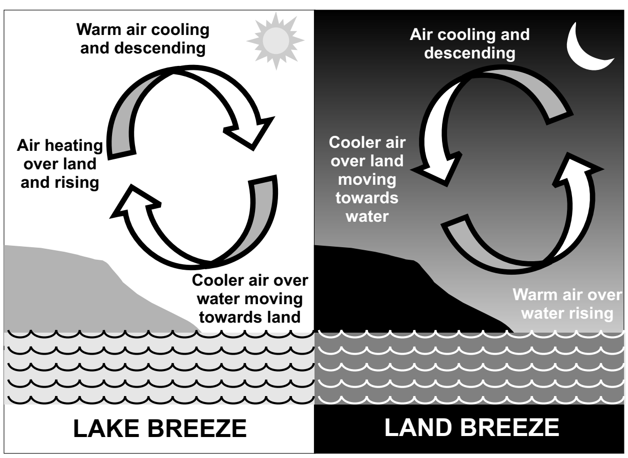


Winds blow counter-clockwise into an area of low pressure and clockwise around and out of an area of high pressure.

FACT If you stand with your back to the wind in the Northern Hemisphere, the area of lower pressure will be on your left. Check it out using the diagram of pressure centres and winds.

Local differences in temperature also help to create local winds, particularly around large lakes such as the Great Lakes. For instance, since land heats up more quickly than water, the difference in temperature between the two creates a breeze. What happens is this. On a warm, sunny day the land near a lake heats the air above which then rises. Cooler air from the lake blows in to replace the rising air, which travels out over the water where it cools and sinks to replace the cooler air blowing on shore. In this cycle, the winds blowing on shore are called Lake Breezes.

In the evening when the sun has gone down, the cycle reverses itself. Since land also cools more quickly than water, the air over the water is now warmer than the air over the land. The air heated by the water rises and is replaced by cool air from the land. At the same time, the warm air from the water moves over the land where it cools and sinks. In this cycle, the winds blowing off shore are called Land Breezes.



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A similar process occurs between hills and valleys, where the valleys are normally cooler than the hills during the day. Cities and natural features of the landscape such as forests also affect winds.

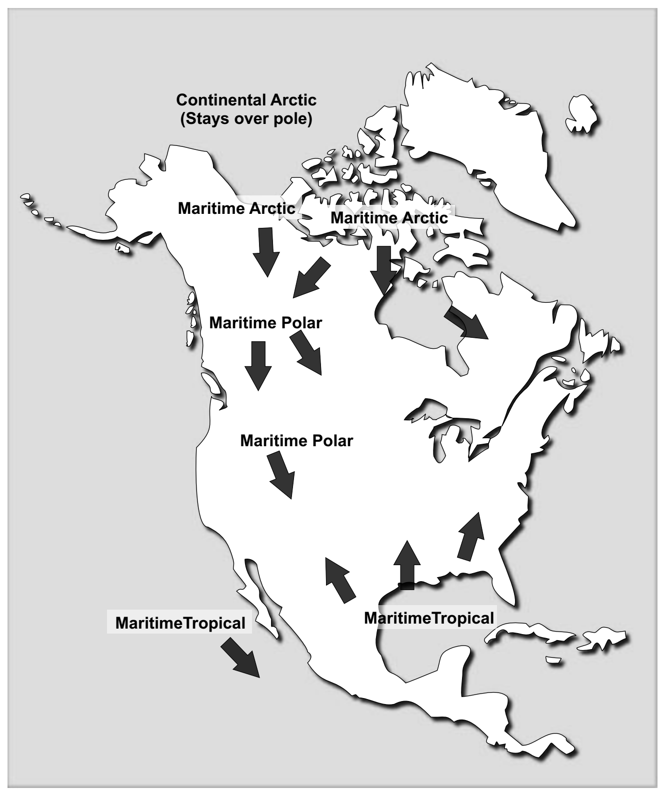
FACT

In the glossary of Canadian winds a Barber does not cut your hair. A Barber is a strong wind which brings precipitation that freezes on contact, especially if the contact is with hair or beard. A Flaw is not a mistake but another name for a Scud or sudden gust of wind.

AIR MASSES

The water and land heat or cool the air above them. This creates large masses of air with roughly the same temperature and moisture content. These air masses extend for hundreds of kilometres and are often classified according to the region that produced them.

For example, air which sits in the Arctic for a few months during the dark days of the polar winter turns cold and dry like the snow and ice below. Meteorologists may call this an Arctic air mass. Similarly, air which sits above the Gulf of Mexico or the Caribbean Sea during the summer months becomes warm and moist. This type of air mass is often called tropical.



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Air masses over North America in the summer.

Air masses over North America in the winter.

The weather would be easy to forecast if these air masses stayed put. But they do not. They move, pushed by the circulation of air in the upper reaches of the troposphere. As air masses move, their temperature and moisture content change. For example, an air mass travelling down from the Arctic may warm up as it moves over southern Canada. If the air mass also passes over a large body of water such as Great Slave Lake or Lake Superior, then the air mass may pick up moisture too. Conversely, an air mass may also dry out as it moves inland from the Pacific Ocean. In this case, the air mass may lose its moisture in the form of rain or snow as it rises and crosses over the Coast and Rocky mountains.

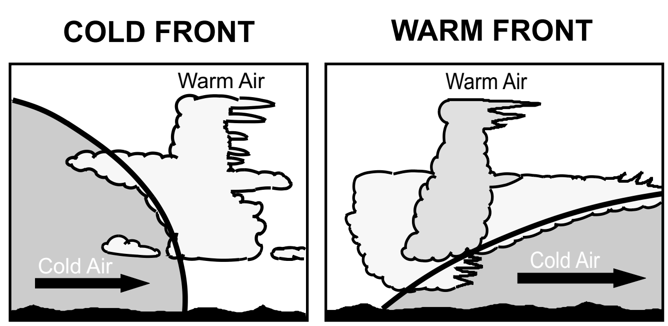
There is one other point about air masses, which you have probably noticed. They do not always enter or leave quietly.

FRONTS

A front is the boundary or transition zone between an air mass, which is entering a region, and the air mass, which is leaving it. Usually the two air masses have originated in quite different places, such as the Arctic and the Caribbean. Consequently, they possess different characteristics of temperature and moisture. The interaction between the two air masses may produce dramatic changes in weather, and sometimes, violent weather itself, such as high winds and thunderstorms.

Meteorologists name fronts after the air mass that is entering the region. If cold air is pushing in from the Arctic, displacing the warm air, then the leading edge of the Arctic air mass is called a cold front. If cold air is retreating, allowing warm air to move in, then the leading edge of the warmer air mass is called a warm front. A warm air mass will never push a cold air mass out of a region because cold air is heavier and denser.

Interestingly, the slope of a cold front is, on average, 4 times steeper than the slope of a warm front. That is because when a cold air mass pushes into an area, there is friction, called surface friction, between the advancing air and the land. This friction causes the leading edge to buckle somewhat. Thunderstorms often develop more quickly along a cold front, because its steeper slope lifts the warm air ahead of it up rapidly, creating ideal conditions for the quick formation of thunderclouds or cumulonimbus clouds.



The slope of a cold front is steeper than that of a warm front because of the friction between the cold air and surface.

Activity

To show your students why a cold front has a steep slope, ask them to rest their hands flat on their desks with their palms down. Then ask your students to slide their hands forward toward the front edge of the desk, pause, and pull them backward to the original position. What happened to your students' fingers as they pushed their hands forward? Was there a difference when they pulled their hands back? The students' fingers probably buckled when they pushed their hands forward, as advancing air does, and then flattened when they were drawn back. This is similar to retreating air.

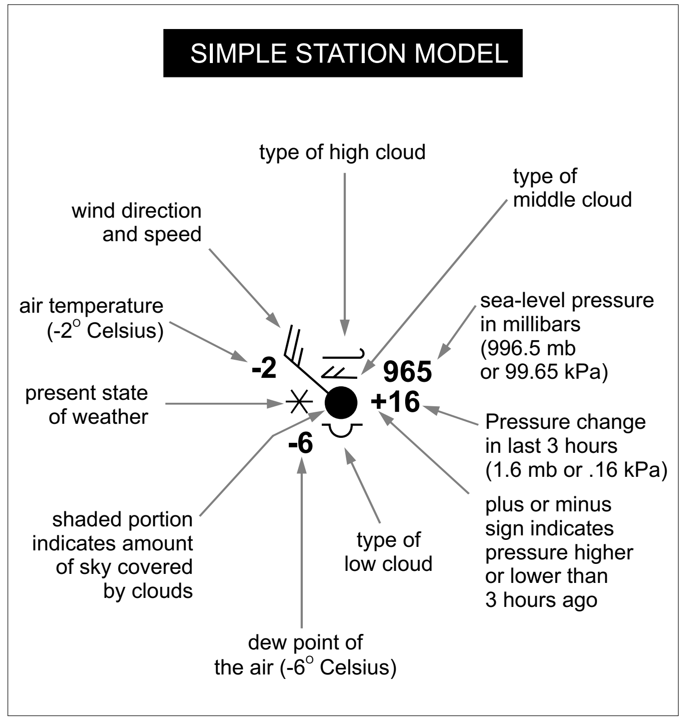
WEATHER MAPS

One of the tools that forecasters use to identify and locate air masses, pressure systems, and fronts is the weather map. These maps are normally prepared at 3- or 6-hour intervals.

Weather observations from hundreds of places in North America are plotted on a weather map like the one on the next page. As there isn't enough room to write out all the observed information and still have the map readable, a code was developed to condense the information into a smaller space. This code is called the station model. The station model uses a graphical format to fit all of the following information into a space about the size of a dime:

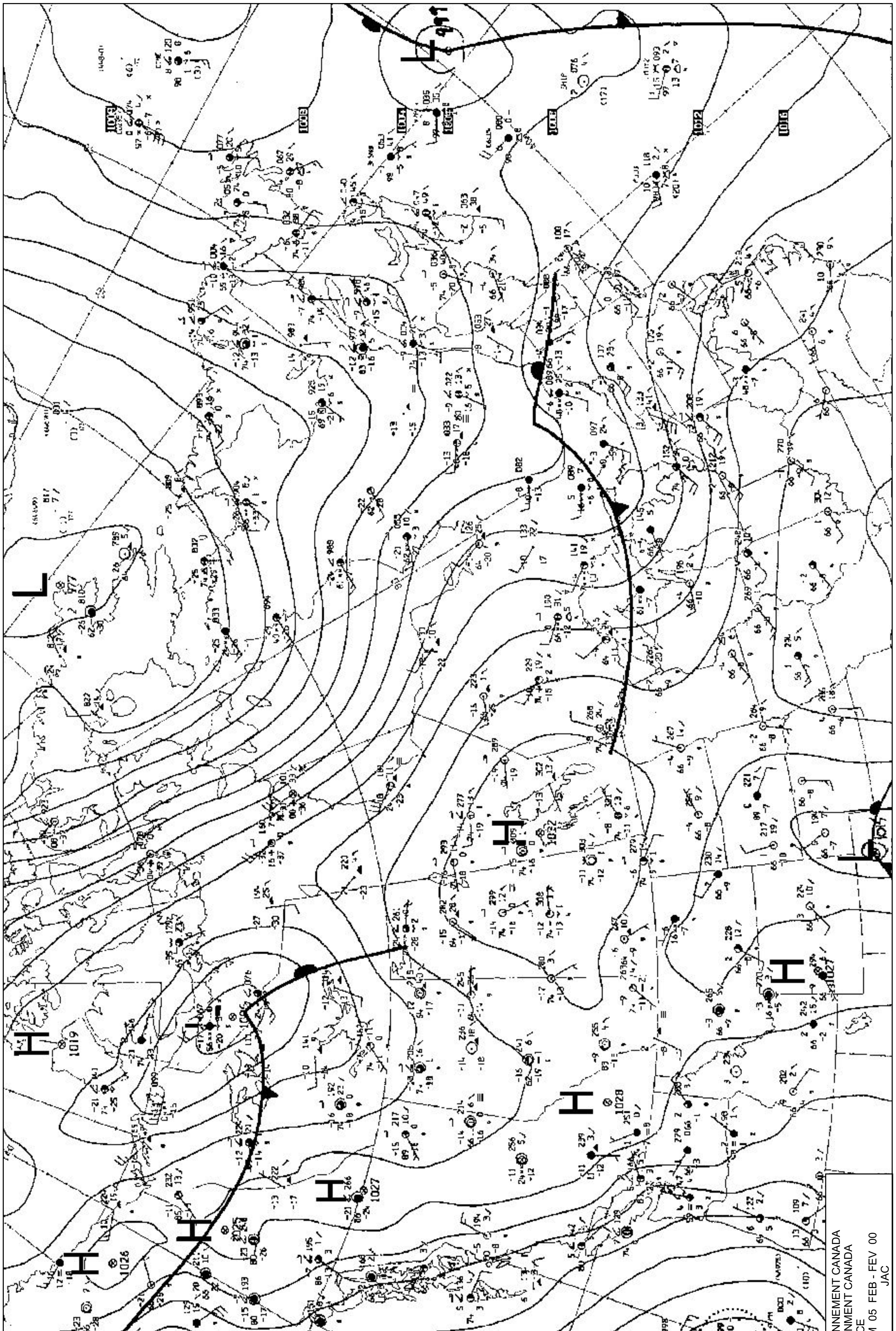
- Temperature and dew point
- Wind speed and direction
- Amount of the sky covered
- Visibility and present weather conditions
- Types of clouds present
- Air pressure
- Change in pressure over the last 3 hours and whether it's rising or falling

Here's how a simple station model looks.



Most weather maps are analysed at least in part by computer but forecasters sometimes do the analysis by hand. They begin by sketching in isobars, which are curved lines joining places with the same atmospheric pressure. They look much like the contour lines that show elevation on a topographical map. In Canada, isobars are drawn at 4-millibar (0.4 kPa) intervals. Normally, the forecaster looks for values close to 1000 millibars (mb) and draws that isobar first. For example, if the pressure at one station is 1001.3 millibars and a neighbouring station is 998.7 millibars, then at some point between the 2, the pressure must be 1000. Once the 1000 mb isobar is drawn, the forecaster works up to 1004, 1008, etc., and down to 996, 992, and so on until isobars have been drawn to include all of the pressures on the map.

Once the isobars have been drawn, pressure centres will appear. The forecaster will label them as areas of high pressure (H) or low pressure (L), depending on whether the central pressure is higher or lower than the values around it.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CMC ENVIRONMENT CANADA
ANAL SURFACE
18Z SAT - 5AM 05 FEB - FEV 00
G3PLJAC 18 JAC

The forecaster also marks fronts on the weather map. Sometimes, the transition from one airmass to another is so gradual and takes place over such an extended distance that no clear front is identifiable. However where 2 air masses meet and the temperature and humidity change significantly within a short distance, the forecaster will draw either a cold front or a warm front, depending on which type of airmass is moving in. The forecaster may also choose to shade in areas of cloud and areas of precipitation.

The map is then compared to the previous one to determine how the weather systems have moved and whether they have intensified or weakened. The information gleaned from this map analysis is combined with information from other sources such as radar and satellite imagery to give the forecaster a composite picture of what's happening in the atmosphere.

Activity

Using the weather map provided, have your students study the surface winds near high and low pressure systems. Ask them to describe the difference in pattern of wind circulation around highs and lows. Their findings should reinforce what they learned earlier in this chapter.