WEATHER and WATER

READINGS
Table of Contents

Naming Hurricanes 3
Weather Tools 5
What's in the Air? 6
A Thin Blue Veil 8
Wendy and Her Worldwide Weather Watchers 12
Seasons 17
Thermometer: A Device to Measure Temperature 20
Heating the Atmosphere 22
Density 27
Convection 32
Dragon's Breath 34
Observing Clouds 37
Weather Balloons and Upper-Air Soundings 43
Earth: The Water Planet 45
What Is Air Pressure? 48
Where the Wild Wind Blows 53
Laura's Big Day 57
Is Earth Getting Warmer? 63
Mr. Tornado 67
Severe Weather 69

Observing Clouds

Fluffy, puffy white clouds in a bright blue sky. This is one of the first memories of clouds that many of us have. You might remember a peaceful time lying on your back looking at the sky above, imagining shapes coming to life in the clouds. Ducks, people, trucks, houses, and horses might have paraded by as the puffs of bright cloud slowly changed.

You've already learned that clouds form when water vapor condenses on tiny particles of smoke, salt, and other condensation nuclei. But why do some clouds appear puffy and white and others grow to towering mountains? And what about those clouds that cover the sky as a gray, gloomy mass? Why are some clouds close to the ground and others faint streaks high above?

Clouds appear as one of two basic types—**cumuliform** and **stratiform.** *Cumuliform* describes the puffy, sometimes fast-moving and rapidly growing kind of cloud. *Cumulus* comes from the Latin word that means "heap." To grow a cumuliform cloud, air must be moving upward. As air rises, it cools. If water vapor and condensation nuclei are present, you've got the ingredients for a cumuliform cloud. When you see cumuliform clouds, you can infer that the weather conditions are unstable, and change may be in the works.

Stratiform clouds are flat and layered. *Stratus* is a Latin word meaning "layer." Stratiform clouds form when weather conditions are fairly stable. They result from the lifting of a large, moist air mass.

Meteorologists also observe where in the troposphere clouds form. High-level clouds form above 5000 meters (m) and are given the *cirro-* prefix. Middle-level clouds form between 2000 and 5000 m and are given the *alto-* prefix. Low-level clouds form below 2000 m. There is no special prefix for low-level clouds.

Some clouds may extend from low to high levels. They are nimbus clouds. *Nimbus* means "rain-bearing."

Luke Howard, the Cloud Father?

Luke Howard is sometimes called the godfather of the clouds.

Howard was never trained as a scientist, but he loved nature, especially weather, from an early age. For more than 30 years of his life, he kept a record of his weather observations. He presented his first system for classifying clouds in 1802. It is the same system meteorologists all over the world use today.

Howard also discovered that the air over cities is warmer at night than air over the countryside. We call this an urban heat island today.

You can describe just about any cloud you observe by its shape and altitude. For example,

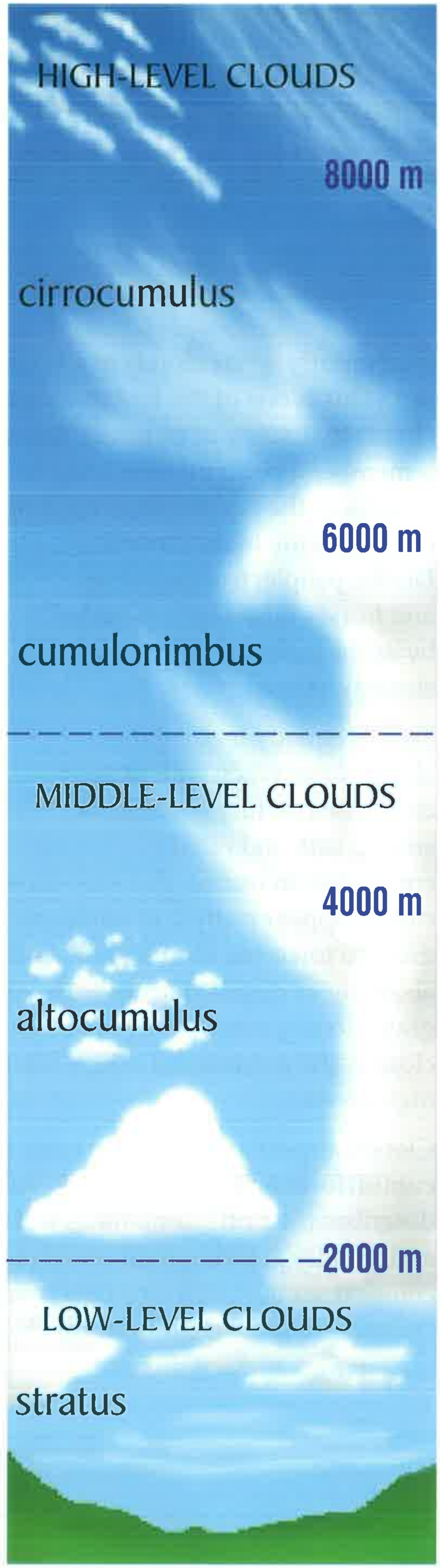
- An altostratus cloud is a middle-level-layer cloud.
- A cirrocumulus cloud is a high-level puffy cloud.
- A cumulonimbus cloud is a heaped cloud growing from low to high levels, bringing rain.

Some low-level clouds have no prefix and are just known as stratus or cumulus clouds.

The words that describe clouds are very useful when you're recording weather observations and want to tell someone else what you have observed. Knowing why different clouds form gives you a good idea of weather conditions in your area.

That which no hand can reach, no hand can clasp.

A description of clouds in a poem
by Johann Wolfgang von Goethe (1749–1832)



LOW-LEVEL CLOUDS

Stratus

The base of stratus clouds is often around 600 m. Stratus clouds form in stable air. They appear flat and layered, with no lumps or bumps.

STRATUS

Stratocumulus

Stratocumulus clouds form when warm, moist air mixes with drier, cooler air. When this mixture moves beneath warmer, lighter air, it starts to form rolls or waves. It looks thick. It may bring drizzle or light precipitation.

STRATOCUMULUS

Cumulus

Puffy white clouds at low levels are called cumulus clouds. When they are small and scattered, it means good weather. These are sometimes called fair-weather cumulus.

CUMULUS

Cumulonimbus

Cumulonimbus clouds form on hot summer days. The sky may start clear, with little wind. Air heated by the ground rises. Convection cells form. Warm air rises through the cell center; cooler air sinks down the sides. A cumulonimbus cloud forms. It is taller than a cumulus cloud, with a base between 300 and 1500 m. Rain starts to fall. Thunderstorms may develop.

CUMULONIMBUS

MEDIUM-LEVEL CLOUDS

Nimbostratus

Nimbostratus clouds are sheet clouds carrying rain. Rain or snow falls almost continuously. There is usually little turbulence.

NIMBOSTRATUS

Altostratus

Altostratus clouds appear white or slightly blue. They can form a continuous sheet or look fibrous. They form between 2000 and 5000 m. Rain or snow may fall. Sometimes you can see the Sun through an altostratus cloud.

ALTOSTRATUS

Altocumulus

Altocumulus clouds form between 2500 and 5500 m. They look like small, loose cotton balls floating across the sky.

ALTOCUMULUS

Altocumulus mammatus

Altocumulus mammatus clouds look threatening, but actually indicate that the rainy weather is almost over. The clouds droop because the air is cooling and sinking.

ALTOCUMULUS MAMMATUS

Altocumulus lenticularis

Altocumulus lenticularis clouds are lens-shaped. Sometimes they look like flying saucers. They form at the top of a wave of air flowing over a mountain peak or ridge.

ALTOCUMULUS LENTICULARIS

HIGH-LEVEL CLOUDS

Cirrus

Cirrus clouds are made of falling ice crystals. The wind blows them into fine strands. The longer the strands, the stronger the wind. Cirrus clouds indicate that the air is dry. Good weather should continue.

CIRRUS

Cirrocumulus

Clouds composed of many smaller clouds at a high level are called cirrocumulus. Some people think these clouds look like fish scales. It is sometimes known as a mackerel sky. It may mean that unsettled weather is on its way.

CIRROCUMULUS

Cirrostratus

Cirrostratus clouds are high-level clouds that cover the sky. The cloud is thin and transparent. You can see the Sun or the Moon through cirrostratus clouds.

CIRROSTRATUS

Jet Contrail

This jet is flying among some cirrus clouds. This could be called a human-made cloud. The jet's contrail is formed by condensation of water vapor from its exhaust.

JET CONTRAIL

Think Questions

1. Look at the weather observations your class has recorded on the class weather chart.
   - If you included cloud observations, what were the most common types of clouds?
   - Try to identify any relationships between the types of clouds and other weather observations. For example, when air pressure decreased, did a certain kind of cloud appear?
2. If stratus clouds fill the sky for several days, what does that tell you about the stability of the air? What kind of weather might you expect?
3. Cumulonimbus clouds often form in the afternoon. What weather and land conditions might contribute to their forming later in the day? (Hint: Think about solar heating of Earth and heat transfer.)
4. Read the quote by Goethe on page 38. What do you think he means?
5. Write and illustrate a short poem about clouds.

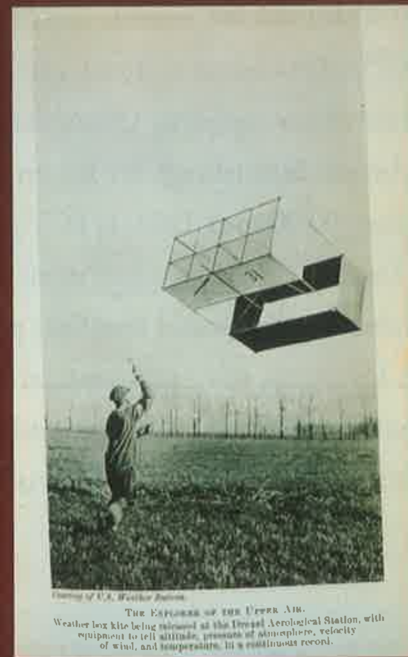
WEATHER BALLOONS AND UPPER-AIR SOUNDINGS

In the late 19th century, meteorologists used kites to gather data about the air above them. Kites could fly up to 3 kilometers into the air. Temperature, pressure, and humidity data were gathered. Kites worked well when the wind cooperated.

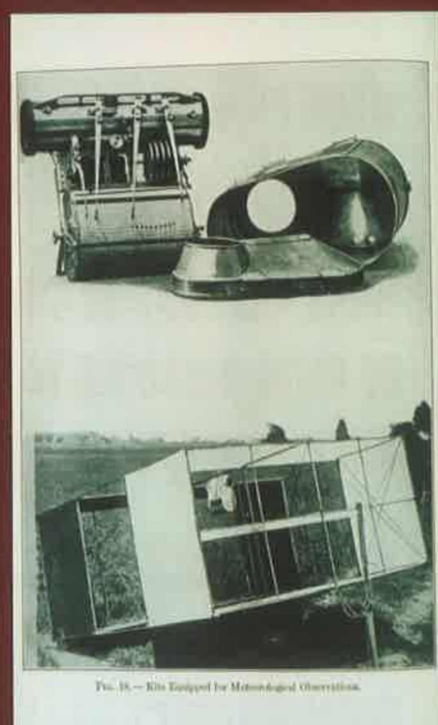
The **radiosonde** was developed in 1943. A radiosonde is a weather-instrument package that can be carried into the stratosphere by a balloon. It has sensors for measuring temperature, relative humidity, and air pressure. Measurements are taken continuously as the balloon rises. A radio transmitter sends the data to a ground receiver. A tracking device monitors the location of the radiosonde during its flight. Wind speed and direction are calculated from the tracking data.

A weather balloon is made of a thin membrane of natural or synthetic rubber. It is inflated with either hydrogen or helium. A biodegradable plastic parachute is attached to the radiosonde. The balloon expands as it rises. When the balloon bursts, the radiosonde is carried to Earth by the parachute.

A radiosonde can be used as many as seven times. About one-third of the radiosondes launched by the National Weather Service (NWS) are recovered. Instructions are printed on each radiosonde, explaining how to return the device to the NWS. It goes to the NWS Instrument Reconditioning Branch in Kansas City, Missouri, where it is made ready for another flight.



Weather kites were used to take recording instruments to high levels. Temperature, pressure, humidity, and winds were observed from kites.



Recording instruments traveled with the kites. They were brought back to the ground, where the observations could be read.

There are more than 900 upper-air observation stations around the world, 108 of them in the United States. Most stations are located in the Northern Hemisphere. Observations are called soundings. Soundings are taken at the same times each day, 00:00 and 12:00 UTC (Universal Time Coordinated), 365 days per year. The data are used for global and regional weather prediction, severe-storm forecasts, general aviation and maritime navigation, ground truth for satellite data, weather research, and climate-change studies.

THINK QUESTIONS

1. WHAT IS A RADIOSONDE?
2. WHEN DO METEOROLOGISTS LAUNCH WEATHER BALLOONS?
3. WHAT ARE SOME OF THE ADVANTAGES OF USING BALLOONS TO GATHER WEATHER INFORMATION?
4. WHY DO WEATHER BALLOONS EXPAND AS THEY RISE THROUGH THE TROPOSPHERE?

The weather-balloon assembly includes the balloon, radiosonde, and parachute.

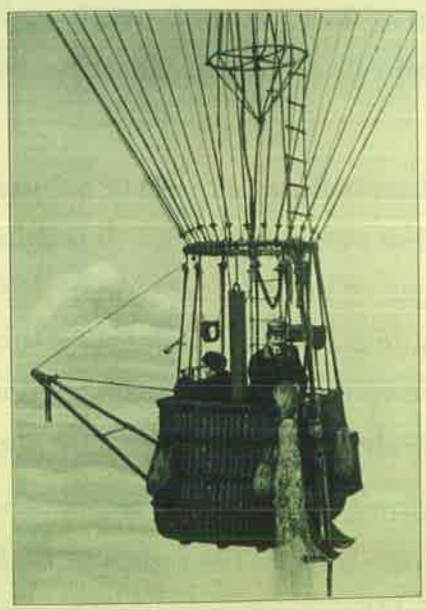


Fig. 17. — Balloon Equipped for Meteorological Observations.
(From Assmann's *Wissenschaftliche Luftfahrten.*)

Hot-air balloons have been used to carry human observers and weather instruments into the atmosphere.

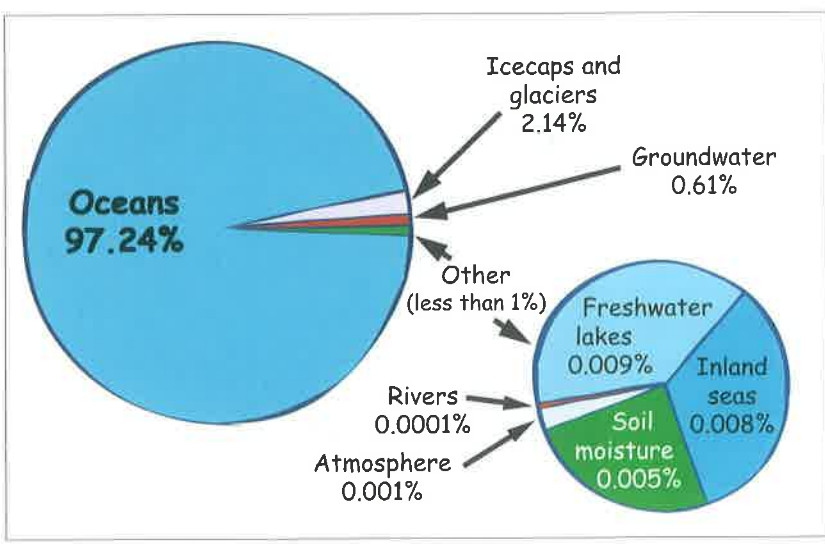
EARTH: THE WATER PLANET

Earth is known as the water planet. Of all the planets in the Solar System, Earth is the only one that has vast oceans of water. If your first view of Earth from space was of the Pacific Ocean, you might think Earth was completely covered with water.

Earth is a closed system (almost). That means almost no material comes to Earth from space, and, on the flip side, no material is lost. This includes the water. All the water that is here now has been here for billions of years. The good news is that Earth's water is going to stay here for the next several billion years, but the probability of getting any more water from some outside source is essentially zero. What you see is what we've got.

Where Is Earth's Water?

By now, you know water is almost everywhere—in the oceans, in and on the land, and in the atmosphere. The pie charts show how water is distributed on Earth. A quick glance shows that just about all Earth's water is in the oceans. All that water and not a drop to drink, because to humans, seawater is poisonous. To acquire the water we need for survival and to support civilization, we need access to the small portion of Earth's water that is fresh. After subtracting the amount of fresh water frozen as icecaps and glaciers and as groundwater, that small portion is less than 1% of the water. Even this small percentage is still a pretty impressive volume of water—about 13 million cubic kilometers. This water is in lakes, rivers, swamps, soil, snow, clouds, water vapor, and organisms. It is known as free water because it is free-moving and constantly being refreshed and recycled on and over the land.



Source: *The Hydrologic Cycle* (pamphlet), U.S. Geological Survey, 1984.

Most of the water we can easily use comes from rivers and lakes. Water in rivers and lakes is known as surface water. Water that falls as precipitation can either remain as surface water or seep into the ground, where it is stored in soil or porous rock. Underground water is known as groundwater. You can see from the pie charts on the previous page that there is much more water stored underground than at the surface. It's water that is close at hand, but water that we can't see.

Water Use

Americans place high demands on water sources. Think about this. In 1995, people in the United States used about 1204 billion liters of surface water a day. They also used about 289 billion liters of groundwater a day. That's a total of nearly 1500 billion liters every day. Over the course of a year that adds up to more than 500,000 billion liters! That translates into half a million cubic kilometers per year. This is a significant percentage of the 13 million cubic kilometers of free water available on Earth—about 4%.


Flooded farm in the Midwest.

People use water in many different ways. Most important, water is essential for life. Without water to drink, we wouldn't survive. You can probably think of many nonessential ways you use water at home. You wash clothes, brush your teeth, and cook food with water. Swimming pools are filled with water, and lawns are watered. Humans also use water for navigation, for creating electricity, in manufacturing, and for agriculture. Many of these activities require good water quality. And, unfortunately, many of these activities create pollutants that can lower water quality.

Water Distribution

Water is distributed on Earth's landmasses by weather. If weather did not continually resupply the land with water in the form of rain and snow, all land would be arid and lifeless. Weather does not, however, distribute water equally around the planet. Some places, like the Midwest, have variable water supplies, getting very little precipitation one year and too much the next. During droughts there may be severe water shortages, followed by floods. The deserts of the world are always parched, while the tropical rain forests are continually soaked. Adding to the problem of water distribution is the pattern of human-population distribution. Some densely populated areas, like Los Angeles, Phoenix, and New York City, need more water than is available locally. They have to import water from faraway places.


Photo taken by space-shuttle astronauts of Valley of the Kings, southern Egypt, October 1988. Water from the Nile River is used to water crops. The land is arid outside of the agricultural area.

Scientists are concerned about the warming trend on Earth. Global warming could affect both evaporation and precipitation in the United States. If more evaporation happens than precipitation, the land will dry, lake levels will drop, and rivers will run at lower levels. Other regions may receive more precipitation than usual,

A middle school field trip to Kings Landing on the Patuxent River, Maryland. Biologists are dragging a seine net to determine kinds and variety of organisms present in the river at this time of year. Photo by Mary Hollinger, NODC biologist, NOAA.

creating floods and affecting vegetation. It will take worldwide planning and cooperation to adjust to the impact of global warming.

Earth is the water planet. Fortunately, water is one of our renewable resources. It is constantly being recycled among the atmosphere, land, and oceans. Humans can't change how much water there is. But we can make smart decisions about how much of it we remove from natural systems, how it is distributed, how it is used, and what happens to it after we use it. As the demand for water increases worldwide due to population increase and a rising standard of living (which requires water), everyone will have to participate in water conservation. Industries will need to be more efficient with water use and careful not to introduce pollutants into water sources. Agriculture will have to develop more conservative crop-watering practices. And every citizen will have to become more aware of the value of water and treat it as the most precious substance on Earth.

References

Environmental Protection Agency/Water, Resources Site

www.epa.gov/globalwarming/impacts/water/index.html

U.S. Geological Survey, Water Science for Schools

ga.water.usgs.gov/edu/

America's Water Supply

www.gcrio.org/CONSEQUENCES/spring95/Water.html

What Is Air Pressure?

The atmosphere is composed of air. Air has mass. In fact, a column of air 1 centimeter square (cm^2) extending up to the top of the atmosphere has a mass of 1.2 kilograms (kg). If the top of your head has a surface area of 150 cm^2, that means every time you go out and stand under the open sky, you have the pressure of 180 kg of air pushing down on your head! That's like wearing a hat with a refrigerator on it. Is it safe to go outside?

Don't worry, it's safe. The force applied by the air above you is called **atmospheric pressure.** Life on Earth has evolved in this high-pressure environment, so we are able to handle the pressure just fine. In fact, most of the time we are totally unaware of the pressure, except...

We do feel the air pressure when it changes quickly. Have you ever traveled to the mountains and noticed an interesting sensation in your ears as you go up or down the mountain? It's called popping your ears. Sometimes this happens in an airplane when it changes altitude rapidly or in a car going up and down a mountain road. If you have had that experience, keep it in mind as you think more about atmospheric pressure.

Sometimes you can see evidence of change in pressure even if you can't feel it. In an airplane, you might notice that packets of peanuts or chips are puffed up like balloons.

Or if you drain a plastic water bottle up in the mountains and screw the cap on tightly, it might get squashed a little as you drive down the mountain. These are examples of air pressure.

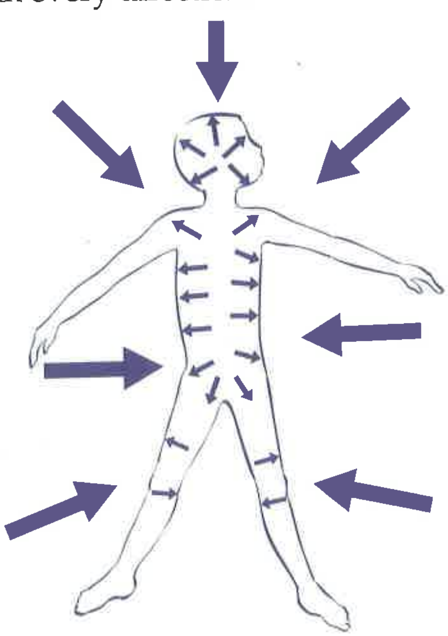
What Causes Air Pressure?

Molecules have mass, so they are pulled to Earth by gravity. The air surrounding Earth has weight. Atmospheric pressure is the weight of the air pushing on Earth's surface.

Remember, air molecules are zipping around individually. So what prevents gravity from attracting them all to the ground? Why aren't we walking around knee deep in a soup of oxygen and nitrogen molecules?

The answer is kinetic energy. The gas molecules have so much energy of motion that they are pushing each other away in all directions. They resist being crowded together by this constant banging into one another.

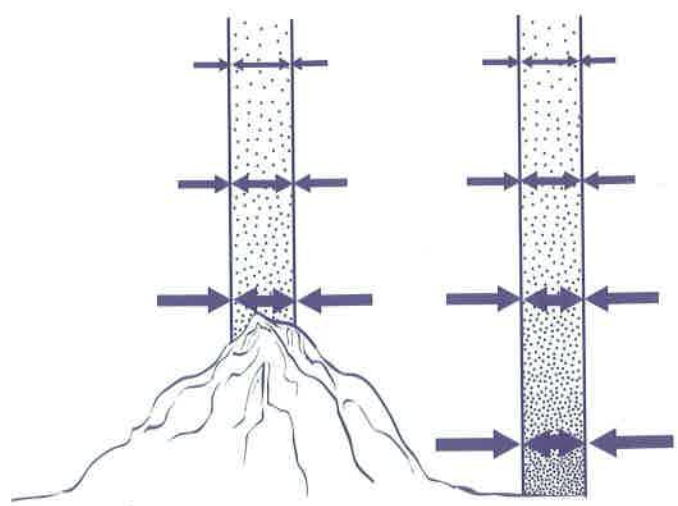
Here's an important point: The pressure is not only pushing down on Earth; the molecular banging is also pushing back with equal force on the air molecules above. Also, molecules are pushing back with equal force on the molecules trying to crowd in from the sides. Atmospheric pressure acts with equal force in every direction.



Atmospheric pressure is not the same everywhere. Air pressure is caused by the mass of air being pulled to Earth. But what happens if you go up into the atmosphere, high above Earth's surface?

If you have the good luck to go for a hot-air-balloon ride, you might find yourself 2 kilometers (km) above the land. Up there, 2 km of air is below you, so that 2 km of air is not applying pressure up where you are. The atmospheric pressure is less up in the balloon.

The greater the amount of air overhead, the greater the pressure. Also, the greater the pressure, the closer together the molecules are pushed. Remember, gases can be compressed. Pressure (force) drives gas molecules closer together. When more molecules are present in a given volume, the gas is denser. Because we live at the bottom of a sea of compressible air, the atmosphere is densest at Earth's surface. It becomes less and less dense as you go higher in the atmosphere.



As you go up in the atmosphere, pressure goes down. As pressure goes down, the air expands (less force pushes the molecules together). As air expands, it gets less dense.

Mount Everest is over 8 km high. Up on top the atmospheric pressure is only one-third the pressure at sea level. Consequently, the air is one-third the density of air at sea level. Have you ever seen pictures of climbers laboring up the highest reaches of the mountain? Most of them are using oxygen supplies. Why? Because there is only one-third as much oxygen in each breath of air at that elevation. It takes an exceptional climber to reach the summit without extra oxygen.

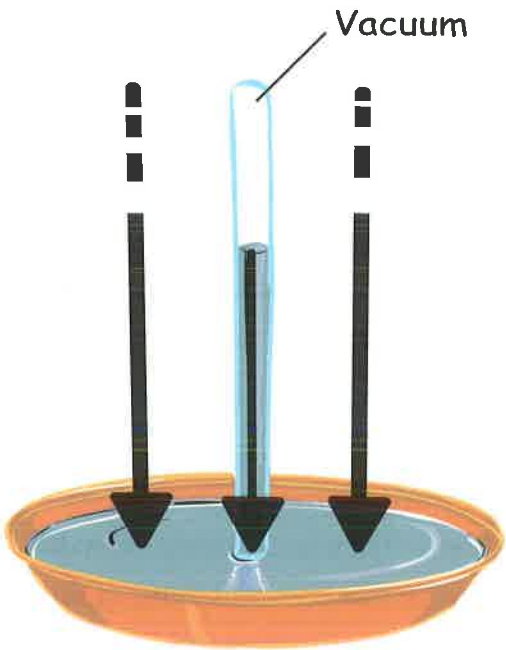
Now, about those ears popping when you travel through the mountains. Does it have anything to do with atmospheric pressure?

MEASURING AIR PRESSURE

The air pressure that meteorologists talk about on the evening news is the pressure exerted by the mass of air pushing down on a certain point on Earth's surface. Elevation is one factor that causes pressure to vary, but there are a number of other factors as well. These factors, and the resulting pressure, are of interest to weather forecasters.

Meteorologists use a **barometer** to measure air pressure. An Italian naturalist named Evangelista Torricelli invented the first barometer in 1643. He filled a long glass tube with mercury and turned it upside down in a dish also filled with mercury. A small amount of the mercury (not all of it) ran out of the tube and into the dish, leaving an empty space above the mercury.

This space was a vacuum. A vacuum is a space containing almost no matter, not even air.

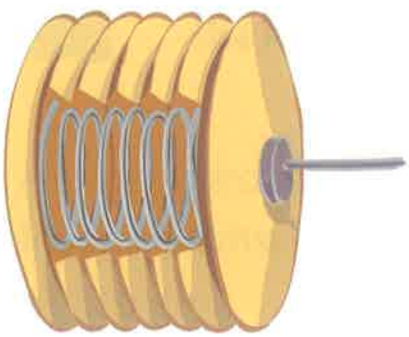


What was holding the heavy column of mercury up in the tube? Atmospheric pressure. Air pressure pushes down on the mercury in the dish. The pressure is distributed throughout the mercury, including the mercury in the tube. Remember, a column of atmosphere 1 cm^2 has a mass of 1.2 kg. If the column of mercury is 1 cm^2 in cross section, it will have a mass of...that's right, 1.2 kg. So, the air pressure is exactly balanced by the mercury pressure.

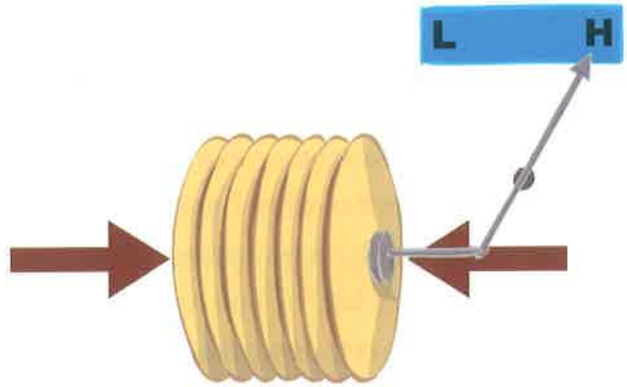
Because mercury is very dense, a column of mercury exactly 76 cm high will balance a column of atmosphere 600 km high at sea level. As Torricelli observed his new invention closely, he noted that the level of mercury moved up and down a little from day to day. He reasoned that the changing level of mercury was due to changes in the atmospheric pressure. Torricelli had invented the first barometer—an instrument for observing and measuring changes in atmospheric pressure.

Today, meteorologists often use another type of barometer called an **aneroid barometer.** Aneroid barometers are much smaller and more versatile than mercury barometers.

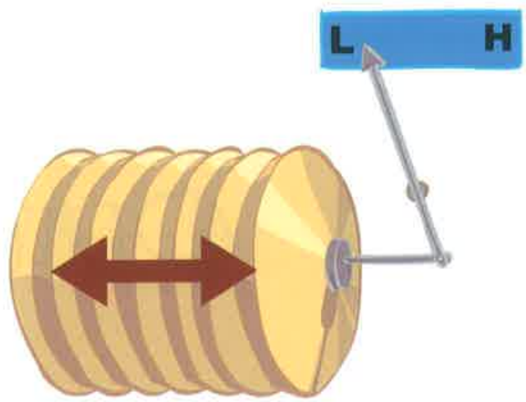
At the heart of an aneroid barometer is a sealed bellowslike chamber with a spring inside. All the air is removed from inside the bellows. Air pressure tries to squash the bellows flat, but the spring inside pushes back to keep that from happening. The force of atmospheric pressure and the force exerted by the spring are balanced.



If the atmospheric pressure increases, it will push on the bellows. The ends of the bellows will be pushed closer together until the force pushing back by the spring is equal to the increased air pressure. A pointer attached to the bellows moves along a scale to show the change in pressure.



Lower pressure allows the spring inside the bellows to push the ends of the bellows farther apart.



Sometimes a pen is attached to the bellows. The pen records the air pressure on a rotating cylinder to obtain a continuous record of pressure changes. If an electronic sensor and a transmitter are attached to a barometer, pressure information can be radioed from a weather balloon back to a receiving unit on Earth.

Because pressure changes with elevation, airplanes use a type of barometer to monitor how high the plane is. This application of a barometer is called an **altimeter.**

Scientists and meteorologists use several different units to report pressure. For historical reasons, inches or centimeters of mercury are used in science experiments. Meteorologists, on the other hand, look at the average atmospheric pressure at sea level and call that 1 bar. If you are relaxing at the beach (sea level), the pressure around you will be 1 bar (or close to it).

The bar has been subdivided into 1000 equal parts called **millibars (mb).** Standard atmospheric pressure is 1000 mb. These are the units you used to record your local atmospheric pressure on the class weather chart.

In practice, standard pressure is actually 1013 mb. Any pressure below 1013 mb is lower than normal pressure, and over 1013 mb is higher than normal.

Think Questions

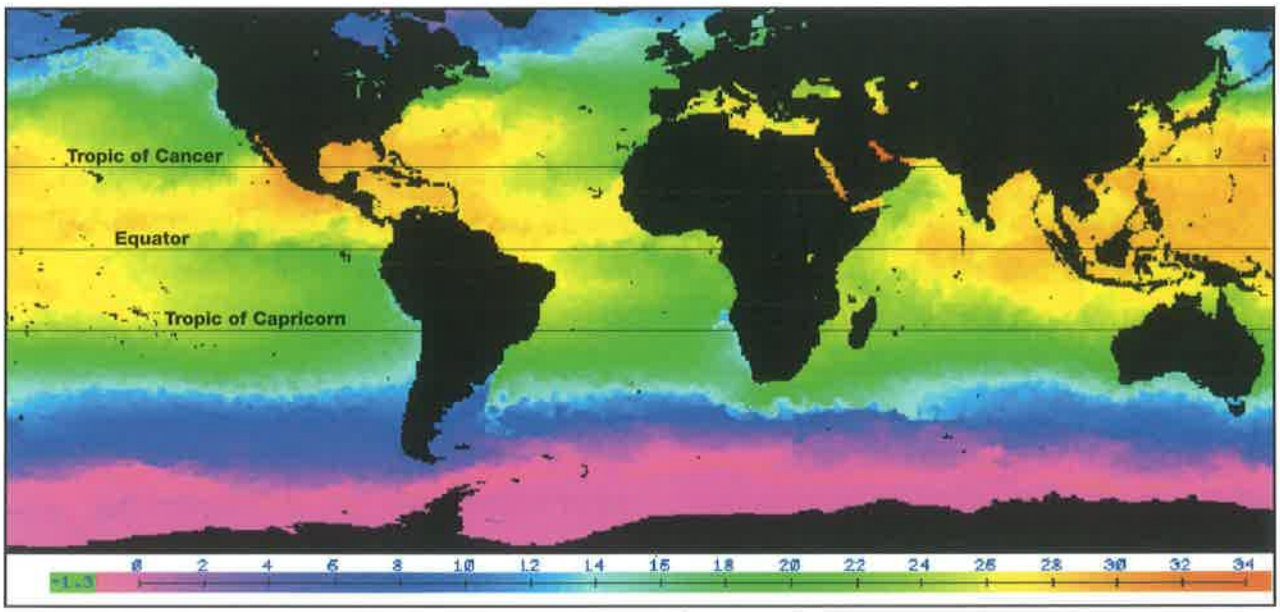
1. *When you drive down a mountain, what makes your ears experience those interesting and sometimes uncomfortable sensations?*
2. *Why doesn't air pressure crush an empty soda can sitting on a table?*
3. *If a meteorologist says that the air pressure is getting lower, what would you expect to see happen to Torricelli's mercury barometer?*
4. *If Torricelli had drilled a little hole at the top of the glass tube holding his mercury column, what would have happened to his barometer?*

Where the Wild Wind Blows

All renewable energy (except tidal and geothermal) comes from the Sun. The Sun radiates 100,000,000,000,000 kilowatts of energy to Earth every hour. About 1–2% of that energy is converted into wind energy.

The region near the equator, extending about 20° north and south, is known as the tropics. The Sun's rays hit Earth with the greatest intensity here. The tropics, which are predominantly oceanic, absorb a lot of heat.

As the air rises, it cools. At about 10 kilometers (km) altitude, the warm air has cooled to the same temperature as the surrounding air. The cool air begins to fall back to Earth. But, because the wall of warm air is rising from the tropics, it can't return directly back. The cool air, still at about 10 km, flows north and south, like two gigantic sheets. When it reaches about 30° north and 30° south, it descends back toward Earth.

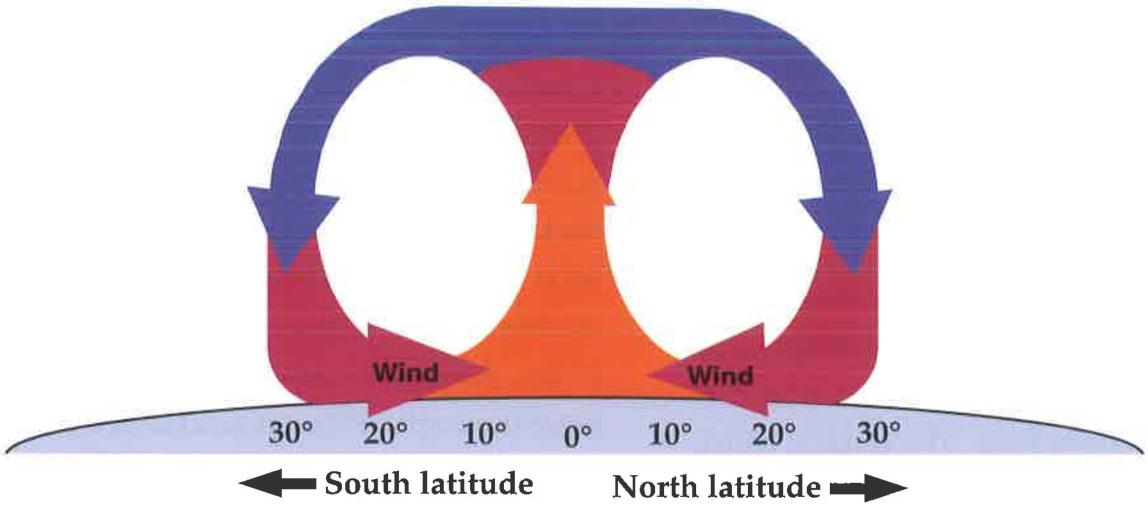


This infrared satellite image of the world shows the temperatures of the seas. The lightest areas are the warmest.

Warm tropical water transfers energy to the air. The air warms and expands. Hot air is less dense and rises into the atmosphere. Warm air does not rise in only one place, like smoke from a fire. Air rises like the smoke from thousands of fires all the way around the world in the tropics.

Meanwhile, the warm, low-density, rising air in the tropics creates a low-pressure area. Cooler, denser air that is descending from the upper atmosphere flows into the area of low pressure to replace the rising air. This creates a huge **convection cell.** The bottom of the cell flows across the surface of the planet, from about 30° north and south to the tropics, producing wind.

Generalized model of a convection cell in Earth's atmosphere



Wind is the movement of air from the high-pressure region north and south of the tropics rushing to balance the low-pressure region created by air rising from the tropics.

Differential heating creates high- and low-pressure areas, creating wind. Winds always move from a high-pressure area to a low-pressure area. Earth rotates under the moving atmosphere, and this easterly movement keeps the winds from going straight north or south, bending them to the east or west. This Coriolis effect gives us the **prevailing wind direction.**

Prevailing winds are global winds. They are predictable for different latitudes on Earth. The prevailing wind directions are important to people sailing ships, flying balloons around Earth, and building windmill farms to generate electricity. These global winds are not greatly influenced by structures on Earth's surface, like forests, cities, and mountains.

Local Winds

Local winds change with the season and even with the time of day. They are the direct result of local differential heating. Local winds are affected by land structures and bodies of water near landmasses.

A typical Chicago weather forecast in the summertime might go something like this.

Sunny skies today with a high of 85°F inland; temperatures in the low 70s lakeside.

A similar weather forecast is likely in Los Angeles and San Diego, with temperatures being cooler at the beaches than inland.

The climates of Los Angeles and Chicago are affected by large bodies of water. Landmasses near oceans or the Great Lakes will feel the effects of the nearby water. Here's how.

Landmasses get hotter faster than water when the Sun shines. The hot land transfers heat to the air above it, and the air expands. The warmer, less-dense air creates a low-pressure area over the land.

Even though the sea also absorbs energy, its temperature does not change much at all. The sea stays cooler than the land. Less energy transfers to the air over the water, so it is cooler and denser. The air pressure over the water is higher than it is over the land.

Pressure always tries to equalize, so air from the high-pressure area over the water flows into the area of low pressure. Wind blows from the sea onto the land. This is called a **sea breeze.**

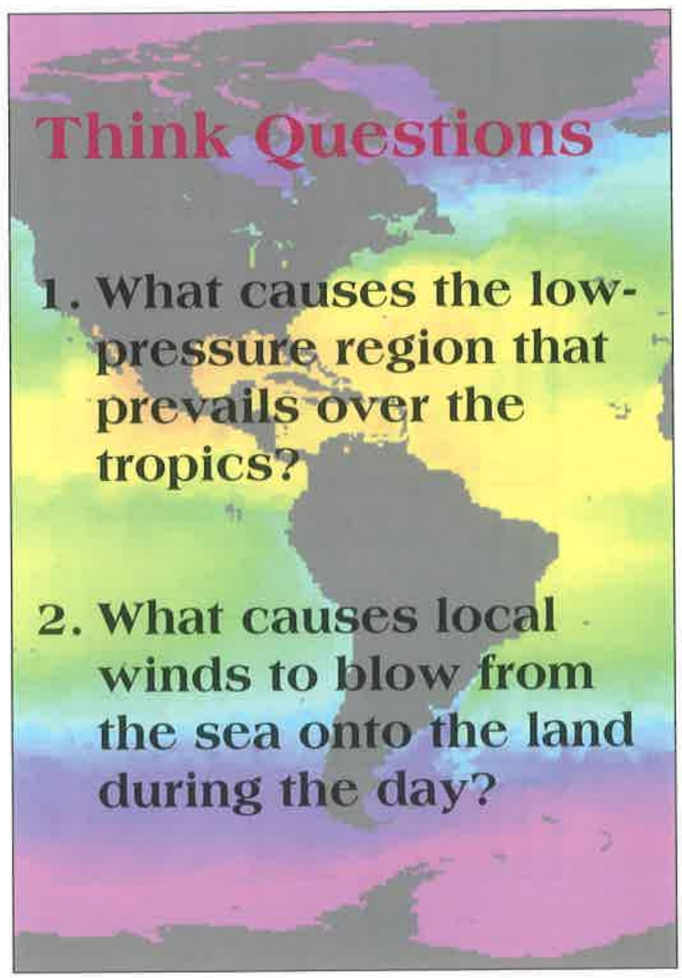
At sunset, there may be a period of calm when land and sea temperatures are about equal. After sunset, the land cools off quickly. The air over the land cools and contracts, becoming denser. Now the local high-pressure area is over the land. Meanwhile, the sea temperature is still about the same as it was during the day, so the air pressure is about the same. Even though the pressure is the same, it is lower than the local pressure over the land. Now the local high pressure over the land moves into the lower-pressure area over the water. Wind blows from the land out to sea. This is called a **land breeze.**

Measuring the Wind

A lot of people want to know how fast the wind is blowing—hot-air balloonists, airplane pilots, sailors, hang-glider pilots, and kite fliers, to mention a few. Before ships were powered by steam, most international maritime travel, trade, and war was conducted in ships driven by wind. Understanding wind was a critically important part of life on the sea.

In 1805, Sir Francis Beaufort, commander of a British naval ship, developed a simple scale for comparing winds. Beaufort was born in Ireland in 1744, and he entered the Royal Navy when he was only 13!

Beaufort's scale was a wind *force* scale, not a wind *speed* scale. Beaufort described 13 levels of wind force that he could recognize from the deck of his ship. His descriptions related to how a ship was pushed or hindered by the wind, how many sails could be flown, how full the sails would be, and, at the extremes of his scale, the chances of survival. By 1838, the Beaufort scale was the mandatory system for reporting wind force in the official log in all ships of the British Royal Navy.



The Beaufort Scale

Beaufort number	Wind (km/h)	Wind (mph)	Wind classification	Wind effects on land	Wind effects on water
0	1	<1	Calm	Smoke rises vertically	Water calm, mirrorlike
1	1–5	1–3	Light air	Smoke drift indicates wind direction; still wind vanes	Scalelike ripples with no foam crests
2	6–11	4–7	Light breeze	Leaves rustle; wind felt on face; wind vanes moved by wind	Small wavelets; crests have a glassy appearance and do not break
3	12–19	8–12	Gentle breeze	Leaves and twigs constantly moving; light flags extended	Large wavelets; crests begin to break; scattered whitecaps
4	20–29	13–18	Moderate breeze	Dust and loose paper raised; small branches move	Small waves 1–4′ becoming longer; many whitecaps
5	30–38	19–24	Fresh breeze	Small trees with leaves begin to sway	Moderate, longer waves 4–8′; whitecaps common; some spray
6	39–50	25–31	Strong breeze	Larger tree branches moving; phone lines whistle	Larger waves 8–13′; whitecaps common; more spray
7	51–61	32–38	Near gale	Whole trees moving; difficult to walk against wind	Sea heaps up; waves 13–20′; crests break; white foam streaking off breakers
8	62–74	39–46	Gale	Twigs break off trees; difficult to walk against wind	Moderately high waves (13–20′) with greater lengths; crests beginning to break into foam that is blown in white streaks
9	75–86	47–54	Strong gale	Slight damage to buildings; shingles and slates torn off roofs	High waves of 20′; rolling seas; dense streaks of foam; spray may reduce visibility
10	87–101	55–63	Storm	Trees uprooted; considerable structural damage to buildings	Very high waves (20–30′) with overhanging crests; sea white with blown foam
11	102–115	64–72	Violent storm	Widespread damage	Huge waves (30–45′); foam patches cover sea; air filled with spray; visibility reduced
12	> 115	> 72	Hurricane	Widespread damage	Huge waves (over 45′); air filled with foam; sea completely white with driving spray; little visibility

LAURA'S BIG DAY

Laura opened her eyes with a start. She checked her alarm clock. Only 6:30 a.m. Laura got out of bed and went to the window. All she could see was the dim outline of the tree in the front yard. Fog blocked out everything else on her street.

It was her birthday. How could the weather be so lousy? Laura really wanted the fog to go away. After all, she had something very special to do today. Uncle Ken was taking her hang gliding for her 13th birthday.

They had been planning the event for 6 months, about the time Laura reached 5 feet tall. Ever since she could remember, Laura had wanted to fly like a bird. She had stood on the tops of rocks with her arms stretched out, while her parents called to her to come down. She had flown in an airplane when she visited her grandparents, but that just wasn't the same. Laura peered into the fog, hoping to see the mountains beyond.

Laura was dejected and wide awake. When she went into the kitchen, she found her mom making coffee. "The weather is lousy!" Laura pouted.

"It will probably clear up by noon," her mother offered. "I saw the weather forecast last night. The meteorologist said that it was really hot out in the desert yesterday. A high-pressure area pushed ocean air over our town all day yesterday. When the humid sea cools off at night, the water vapor condenses, forming fog. I think the Sun will come up and warm the ground and the air. The fog will evaporate again, leaving us with a nice day."

Laura wasn't convinced. She ate her cereal and stared out of the window.

"I'm going to the nursery later. Want to come along?" her mother asked.

Laura was tempted, but decided she would wait to see what the weather would do. "No, thanks," she replied.

At 9:00 it started getting lighter. Laura called Uncle Ken on the phone.

"Hi, Laura," Uncle Ken said. "You looking forward to your lesson today?"

Laura could hardly believe her ears. "Are we really going to be able to fly?" she blurted out.

"Sure," Uncle Ken said. "It's really gorgeous up here on the mountain, and I can see that the fog down your way is burning off."

"What do you mean, burning off?" Laura asked.

"The Sun just warms up the air and the fog evaporates," Uncle Ken replied.

"Oh," said Laura, "that's just what Mom said."

"Get your mom to drive you up here and we'll get the equipment ready. I'm already working on our flight plan."

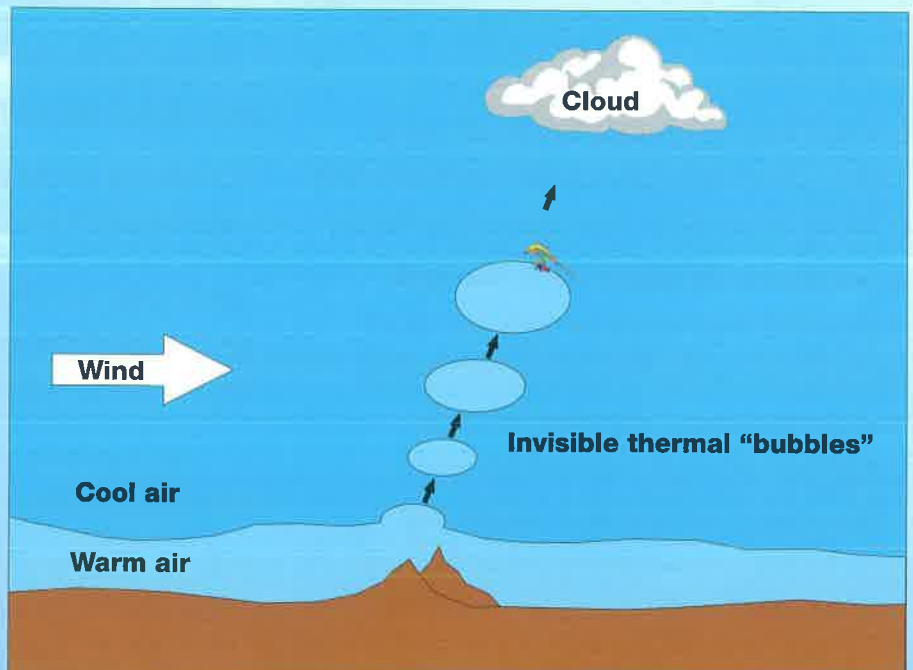
Uncle Ken lived in a cabin on a mountain ranch where he worked when he wasn't teaching hang gliding or building new equipment. When Laura arrived at the cabin, she trotted down to the storage garage where Uncle Ken was working.

"What are we going to do?" she asked.

"Well, your first lesson will be a tandem flight so I can show you what hang gliding is all about," Uncle Ken answered. "We'll fly together on a glider like this Falcon here in this picture. Right now it's packaged for the road on top of my truck. I have to check on the weather now."

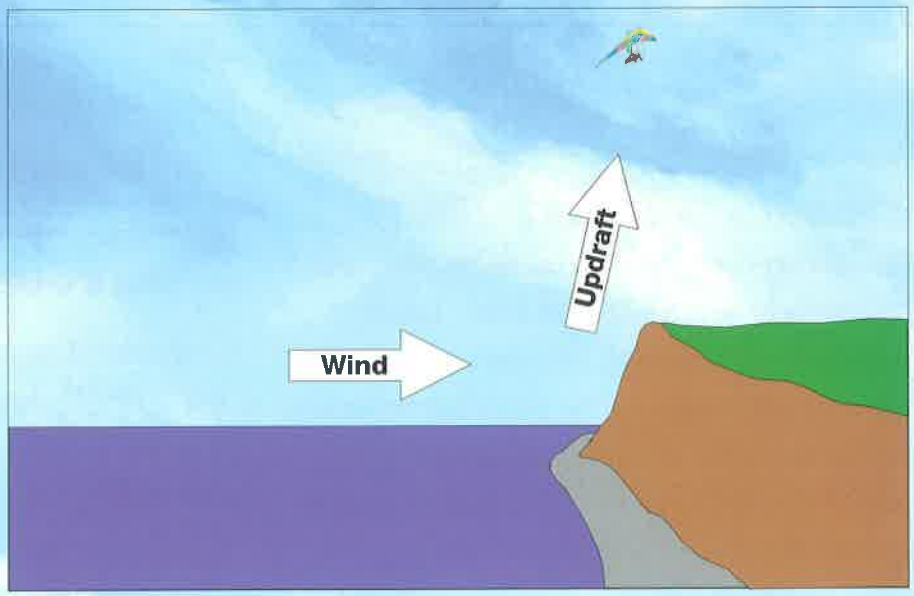
Uncle Ken had taken Laura with him in the spring when he taught hang gliding. She knew the names of the parts of the glider and had tried to balance one on her shoulders. She had listened to Uncle Ken talk about mature decisions and safety. Laura already knew about helmets, reserve parachutes, and harnesses. She had been at the landing zone with Uncle Ken, watching his friends land their gliders after long flights riding the thermals. She saw them look at the wind sock for wind direction, so they could land into the wind.

Uncle Ken had explained that the summer was a good time for thermals. A thermal is the name given to a bubble or column of warm, rising air, common on sunny days. The Sun heats the ground and the air near



the ground. The air expands, making it less dense than the air above it. The warm air rises like bubbles rising in a glass of soda. An important skill in flying a hang glider is to spend as much time as possible in the strongest part of the thermal (usually the center).

Laura had seen Uncle Ken's weather station behind his cabin and how it was hooked up to an old computer. He recorded wind speed, wind direction, temperature, humidity, and barometric pressure. She also knew that he contacted a weather station near the landing zone to get current temperature and wind speed.



Uncle Ken used the temperature difference between his cabin on the mountain and the landing zone to figure out how strong the thermals would be. As you go higher in the atmosphere, the air cools off. It cools off at a rate of about 6°F per 1000 feet. Because the difference from the top to the bottom of the mountain was almost 5000 feet, the air should cool about 30°F. If the difference in temperature was more than that, it meant good thermals, because the warmer air at the bottom rises more quickly through the cooler air near the top of the mountain.

"Conditions look great. Let's go."

Laura tossed her duffle into the back of Uncle Ken's truck. She and her mom jumped in, and they were off.

On the road Laura asked, "Uncle Ken, how long will we be up in the air?"

"No telling," he responded. "I was up over 2 hours on Wednesday, but I don't think we'll push it that far. Maybe we'll fly for 15 or 20 minutes. But it all depends on the wind."

Uncle Ken talked about how this site had both ridge and thermal lifts, and that promised a great ride. "Ridge lift means that the wind gets forced straight up when it runs into a cliff or hill. Hang gliders don't have motors to gain altitude, you know, so the only energy we use for going higher in the air is an updraft—currents going upward. Any time that a steady wind blows directly against a wide slope, ridge lift will probably result."

They pulled into the launch site and parked near several other trucks and vans. Uncle Ken pointed to a wind sock about half extended by the gentle, steady breeze. "It's a little old-fashioned, but we like it. It's a pretty straightforward tool for estimating wind direction and speed. Looks like we have a breeze of about 15 miles per hour."

Uncle Ken set about assembling the glider. It was surprisingly big, but he handled the lightweight materials with ease. Laura watched with interest, but she could feel a little anxiety rising in the pit of her stomach as the assembly neared completion. The moment when they would launch into thin air was drawing uncomfortably close.

Laura zipped up her warm parka and strapped on her harness.

"Is it tight enough? Does it feel right?" asked Laura's mother.

"Mom, please, I'm all right. Uncle Ken showed me how...I can do it by myself."

Uncle Ken checked and double-checked Laura's preparation. She was dressed in warm, rugged clothes, helmet, goggles, and a properly tightened harness. Ready.

Uncle Ken and Laura reviewed the procedure for getting into the air safely, the flying position, and the landing procedure. Uncle Ken could see how excited she was, and he reminded her that this was a lesson, not a ride, and that she had to be mature and follow his instructions in the air.

Uncle Ken hooked onto the hang glider and carried it to the launch area. Following his instructions exactly, Laura hooked her harness onto the glider right next to her uncle. She practiced lying out prone—just like she would in the air.

"Ready?" asked Uncle Ken.

"I think so. It's a little scary, but I want to see what it is like to fly."

Laura stood next to Uncle Ken on the edge of the gentle slope. The breeze was blowing in their faces. Laura felt the hang glider lift up as it caught the wind.

"Now! Run!"

Down the slope they dashed. Amazingly, in just a moment Laura's feet barely touched the ground. She felt as light as a leaf on the autumn wind. Then she wasn't touching the ground at all. She was in the air, and the ground was moving away with alarming speed.

"Uncle Ken, it worked! We're flying!"

Uncle Ken shifted his weight to bank the glider so they swooped over the launch area and Laura's mother. Laura waved at the amazed figure of her mother with her hands clamped over her mouth. Then her mother waved back and remembered to snap a few pictures.

"Let's use this nice ridge lift to climb a little, and then let's look for a thermal." They flew back and forth along the ridge twice, and then Uncle Ken turned away from the ridge to look for thermals. It was so quiet and peaceful. The hang glider just floated. As they headed over the valley, the land fell away and Laura realized she was thousands of feet above the ground. This was real flying.

"Look, there's a thermal just a quarter mile to the left," announced Uncle Ken after a couple of minutes. "Can you see it?"

She looked where he indicated, but could see nothing.

"Those two red-tailed hawks, spiraling up, have pointed out the invisible thermal for us. Let's join them."

In a minute, Laura could feel the turbulence in the air and the definite lift provided by the thermal. Uncle Ken skillfully banked the glider to keep it in the thermal, and they spiraled up, just like the hawks above them.

In a few minutes, the thermal lift died out, and they glided off toward the site where they would land, making large, lazy circles in the sky. When they passed through a region of turbulence, Laura asked with wide eyes, "Uncle Ken, was that a thermal? Could it take us higher again?"

Pleased by her close observation, Uncle Ken responded, "I'm not sure. Let's go see."

He banked sharply and entered the thermal. The glider was once again lifted several hundred feet in a minute.

"Excellent lift. That was a nice little elevator you spotted. Let's head for home."

Uncle Ken turned the glider away from the mountain and began to fly a circular route that took him lower and closer to the landing area. As they got closer to the landing zone, Uncle Ken asked Laura to watch the wind sock and the streamers to see which way the wind was blowing. They slowly glided lower and lower until the ground was just below them. Uncle Ken pushed the down tube forward, and the glider made an easy dive toward the landing target. They skimmed just above the ground. Uncle Ken pushed out hard on the down tube. The front of the glider rose up and they settled easily to the ground.

It was over. They were back on the ground. She had flown. Laura was dazed. "Uncle Ken, that was great! I never knew anything could be so exciting. Can we go again?"

"Well, the first hang-gliding trip is a ride. If you go up again, you will have to do some of the driving, you know."

"Can I? Can I really do the flying?"

Laura saw her father coming across the field as she and Uncle Ken carried the marvelous flying machine to the parking lot.

"Dad, I was flying and it was the greatest thing. It's like flying a kite, except we were on the kite! And you won't believe it, Dad, we followed red-tailed hawks. We flew with red-tailed hawks right to the top of a thermal!"

Laura couldn't get the idea of flying with birds out of her mind. She knew that she would continue her lessons and become a pilot. She'd have her own glider one day. But before that, there was a lot to learn about seeing, feeling, and imagining what's going on in the air, and learning about the weather, and what makes a good day for hang gliding.

Think Questions

1. **Why is the weather forecast so important for hang gliders?**
2. **How does a hang-glider pilot rise higher in the atmosphere?**

IS EARTH GETTING WARMER?

Global warming is in the news and on the scientific agenda worldwide. And there are a lot of questions about it. Is it real? Is it happening fast? Is it serious? Is it natural or caused by humans? What can we do to stop it? What will happen if we don't stop it?

The answer to the first question is yes, global warming is real. The scientific community of climatologists has evidence that Earth is heating up. Here is a sampling of what has been confirmed.

Atmosphere temperature. Earth's lower atmosphere (troposphere) has warmed by about 0.6°C over the past 100 years. This may not seem like a lot, but it is significant, and some weather effects result from even slight temperature changes.

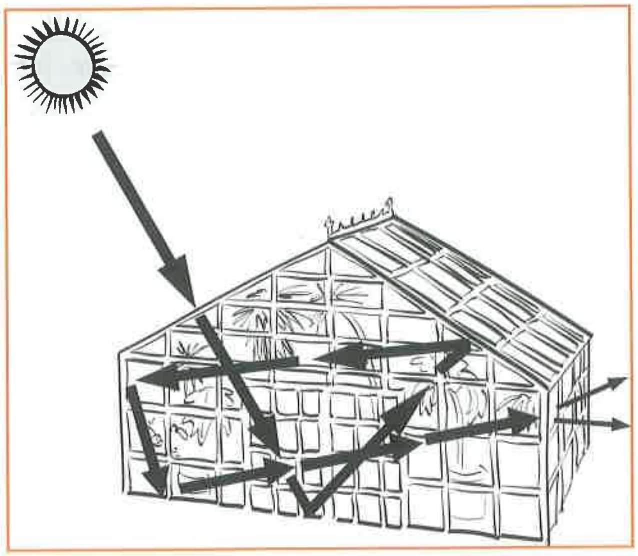
Glaciers. A glacier is a large sheet of ice that moves very slowly. Many glaciers in the world are getting smaller. Glaciers are melting in Montana's Glacier National Park. At the present rate of melting, they will be gone in 50 years. Large chunks of ice are breaking off the Antarctic ice sheets. There isn't as much ice at the North Pole. Ice melting could be the result of global warming.

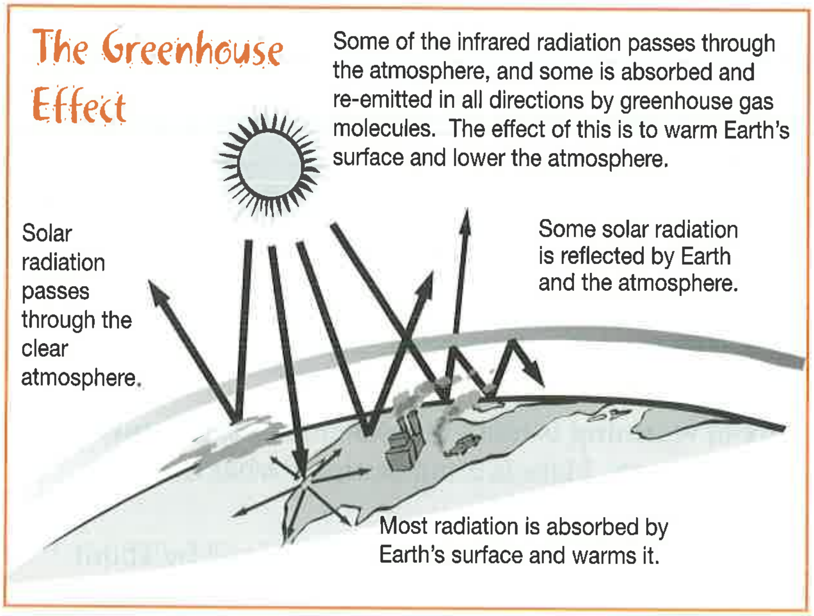
Ocean temperature. The temperature of the upper ocean layer (top 300 meters) has increased by more than 0.3°C in the past 40 years. As we know, a small increase in water temperature represents a lot of heat energy. Increased oceanic temperature can influence global weather patterns and hasten the melting of oceanic ice.

Sea level. The level of the sea is rising the world over. Over the last 100 years, the level of the sea has risen 15–21 centimeters. When the sea level rises, the tide goes farther up the beach and submerges low coastal areas. Scientists think the sea has risen because there is more liquid water in the world today. This water came from melted glaciers and sea ice. Also, heat makes water expand. When the ocean expands, it takes up more space.

What Is Causing Earth to Warm?

Earth's atmosphere produces what is often popularly called the greenhouse effect. The name suggests that Earth operates like the little glass houses used by gardeners to grow plants in cold climates. Greenhouses work by trapping heat from the Sun. The glass panels of the greenhouse let in light. The light is absorbed by plants, soil, and water in the greenhouse and reradiated as infrared rays. Infrared is also known as heat rays. The glass doesn't let the infrared escape, so the heat builds up inside the greenhouse.





Earth is not surrounded by glass, but it is wrapped in atmosphere. Two of the important gases in the atmosphere are water vapor (H_2O) and carbon dioxide (CO_2). Because these two gases can absorb solar energy, they are called greenhouse gases. The action is not exactly like a greenhouse, because the atmospheric gases don't reflect heat back to Earth. They absorb heat, but the effect is the same. The air heats up.

CO_2 is a by-product of combustion. Whenever someone starts up a car, lights a barbecue grill, burns a field, or takes off in a plane, CO_2 is released into the atmosphere. The amount of CO_2 in the atmosphere has jumped in the last 100 years. Not coincidentally, the increase of CO_2 corresponds with the explosive use of fossil fuels worldwide and the massive burning of the rain forests.

The greenhouse effect is not all bad, however. The protective blanket of greenhouse gases prevents Earth from losing too much heat to space. Without these gases, Earth's average temperature would be about 33°C colder. The problem that needs attention is excessive greenhouse gases that may contribute to global warming.

What Do We Know about the History of Global Climate Change?

Climate is the long-term average of a region's weather patterns. Earth's climate has been changing constantly over its 4.5-billion-year history. The geological evidence indicates that during some periods the climate was so warm that sea level was 20 m higher than it is today. This would suggest that no water was locked up in ice. At other times, Earth cooled, water was trapped as ice, and sea level dropped as much as 122 m. Each of the changes may seem extreme, but they probably occurred slowly over many thousands of years.

The first people arrived in America between 15,000 and 30,000 years ago. During that time, much of North America was covered by great ice sheets called continental glaciers. Sea level was so low that people could walk to North America on a land bridge between Asia and Alaska. Some 14,000 years ago, the vast ice sheet began to melt very quickly. By 7000 years ago, the ice was gone.

In the 14th century, Europeans lived through what is known as the Little Ice Age. The Little Ice Age lasted for several hundred years. During it, glaciers advanced down mountain valleys, and hard winters and famines caused great hardship for people.

Clearly, humans didn't influence these climate changes. They occurred naturally, probably as a result of variations in energy output of the Sun. But the Sun's energy output has been steady for the last hundred years, and still the heat is building up.

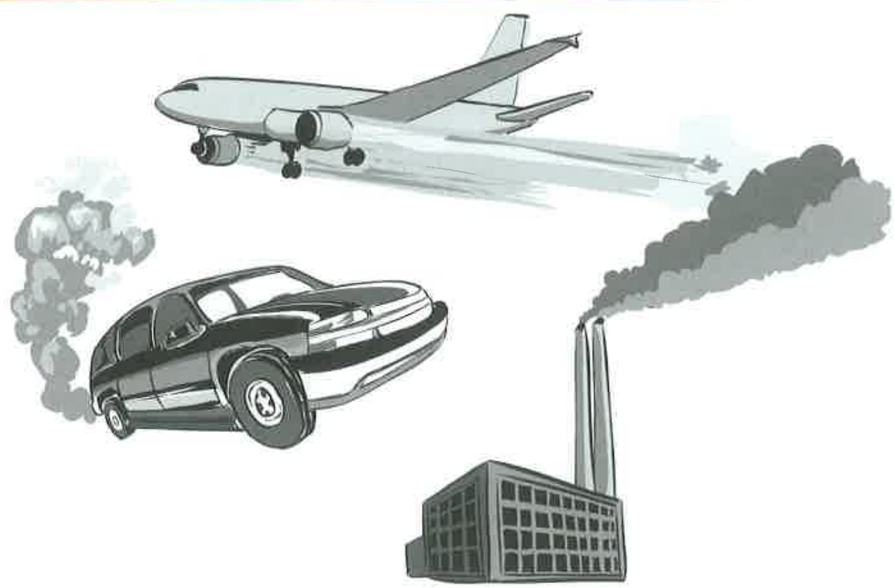
What's in the Future?

Scientists are not fortune-tellers, so they don't claim to know exactly what will happen in the future. But they can use computers to model some of the possible outcomes. The computer models tell us that Earth may continue to get warmer. The information suggests that Earth's temperature will probably continue to rise as long as the concentration of greenhouse gases in the atmosphere continues to increase.

The key to halting a runaway greenhouse effect is reversing greenhouse gas emissions. There are two ways to do that: stop adding new greenhouse gases to the atmosphere, and take measures to remove greenhouse gases currently in the atmosphere. Neither is easy, but steps must be taken.

One of the most powerful ways to reduce greenhouse gas emissions is the action of individuals. The first action is understanding when you are contributing to the greenhouse load. It's obvious that CO_2 is being released when you start a gasoline engine or burn a fire. But you also contribute to CO_2 emission when you

- Watch TV
- Use the air conditioner
- Turn on a light
- Use a hair dryer
- Ride in a car
- Play a video game
- Listen to a stereo
- Wash or dry clothes
- Use a dishwasher
- Microwave a meal



We need energy to do things like drive a car, fly a plane, or make things in factories. But we need to use energy wisely if we want to help slow global warming.

How? To do most of these things, you need to use electricity. Most electricity is generated in power plants that use coal, gas, and oil. Burning fossil fuels produces greenhouse gases. As an individual, you can conserve electricity, use public transportation, support alternative technologies that replace internal combustion engines, and produce some of your own food in a garden.

Oh, and gardening has a second benefit to the environment. Plants use CO_2 in photosynthesis. In the process, CO_2 is removed from the atmosphere. So grow plants, particularly trees. They take up a lot of CO_2 and hold it in the form of cellulose for a very long time.

Adapted from: The Environmental Protection Agency's (EPA) Global Warming Kids Page. www.epa.gov/globalwarming/kids/index.html

MR. TORNADO

"GRABBING A PENCIL AND PAPER, I RUSHED TO THE ROOFTOP WHERE I BEGAN RECORDING THE DIRECTION OF CLOUD-TO-GROUND LIGHTNING AND THE TIME BETWEEN THE FLASH AND SUBSEQUENT THUNDER."

That's how Professor Tetsuya Theodore Fujita described the beginning of his lifelong fascination with severe weather. He was 27 years old when he made those first observations. After completing his degree in meteorology at the University of Tokyo, Fujita joined the faculty at the University of Chicago. Some of the most powerful storms in the world occur in the stretch of land that runs from Texas, north and east through Oklahoma and Kansas, and into the Midwest. This corridor, known as Tornado Alley, was where Professor Fujita focused much of his study over the next several decades.

Shortly after his arrival in Chicago, Ted, as he was popularly known, began analyzing individual thunderstorms in detail. He observed and recorded temperature, pressure, and wind data and related them to the development of the huge, dark clouds that form during thunderstorms. His interest in thunderstorms led directly to tornadoes. It was in the area of tornado study that Ted established his reputation as a pioneer researcher. Among his peers he was nicknamed Mr. Tornado, in recognition of his great contributions.

Ted introduced the concept of tornado families, a group of individual tornadoes, each with a unique path, spawned by the same massive thunderstorm. Prior to this, long damage paths were thought to be made

by a single tornado. Ted discovered that, as a thunderstorm advanced, two, three, or more funnels might form, touch down, dissipate, and re-form later to create more destruction on the ground. On occasion, two or more funnels might extend from the storm front at the same time. He introduced new concepts of thunderstorm architecture and developed terms like "wall cloud" and "tail cloud."

In the late 1960s, Ted's analysis of the Palm Sunday outbreak of 1965 changed the course of how we view a tornado outbreak. For the first time, he mapped the entire outbreak in terms of tornado families. While multiple-vortex tornadoes are well known today, he was the first to identify their existence, based on damage patterns.

In the 1970s, he again revolutionized tornado climatology by giving us a system that linked damage and wind speed. Previously, all tornadoes were counted as equals. Ted quantified their force on a five-level scale, with force 5 (F5) being the most powerful and potentially destructive storms. For the Super Outbreak of 1974, Ted was able to develop Fujita scale-intensity contour maps for the entire path of many of the 148 tornadoes that raged that year. After 25 years, we still use his ideas and terminology.

In the late 1970s, Ted turned his attention to weather-related aircraft disasters. He identified two phenomena that had not been described before, the **downburst** and the **microburst.** Before this, meteorologists had been confused by a bewildering array of gusty winds in and around thunderstorms. By the 1980s, the downburst and microburst were understood as separate winds. They were known to be caused by events such as dry air moving into a thunderstorm.

In Ted's later years, he applied his knowledge to hurricanes and typhoons, which are the kind of weather that he had originally focused on in Japan, where he was born.

SEVERE WEATHER

Weather is fairly predictable most of the time. During the summer months in the San Francisco Bay area, you can expect foggy mornings and late afternoons, with the possibility of sunshine midday. In the southeast United States, summer days are often hot and humid. In the Midwest and East, winters are usually cold, cloudy, and snowy. These are the normal conditions that people come to expect where they live.

It's the change from normal that catches people's attention, whether they see it on TV or experience it for themselves. Tornadoes, thunderstorms, windstorms, hurricanes, and floods are examples of what is known as **severe weather.** Severe weather is weather out-of-the-ordinary. It usually causes dangerous conditions that can damage property and threaten lives.

FLOOD

Floods occur when water overflows the natural or artificial banks of a stream or other body of water. The water moves over normally dry land or accumulates in low-lying areas. Floods often happen with heavy rainfall over short periods of time or when a large quantity of snow melts quickly.

Johnstown, Pennsylvania, 1889

In 1889, a flood of disastrous proportions hit the city of Johnstown, Pennsylvania. An earthen dam collapsed after heavy rains. A great wall of water rushed down the Conemaugh River valley at speeds up to 64 kilometers (km) an hour. The 10-meter-high wall of water devastated the town, washing away most of the northern half of the city, killing 2209 people, and destroying 1600 homes.

Floods may also occur behind ice dams on rivers, during very high tides, or following tsunamis (huge waves) caused by earthquakes under water. **Flash floods** are short, rapid, unexpected flows of muddy water rushing down a canyon. They are often caused by thunderstorms occurring over mountains, during which large quantities of water flow down a single canyon.

DROUGHT

Droughts are less than normal precipitation over a long period of time. They usually cause water shortages, including low flow or no flow in streams. Soil moisture and groundwater levels decrease. Droughts are especially disastrous to agriculture.

The Dust Bowl, 1930s

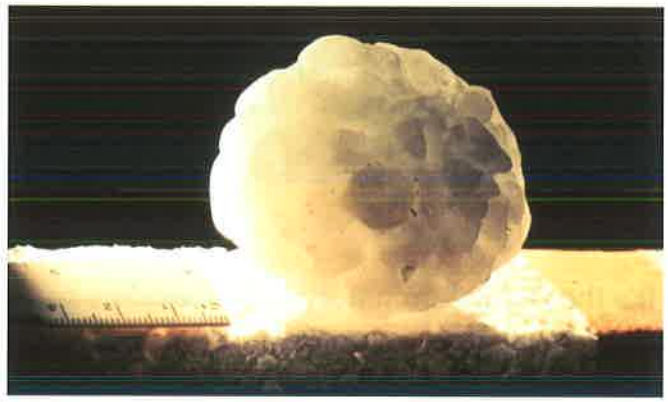
During the early 1930s, an area of the United States that includes parts of Colorado, Kansas, New Mexico, and the panhandles of Texas and Oklahoma was named the Dust Bowl. A severe drought occurred after years of poor land management. The native grasses had been removed, exposing the topsoil. Strong spring winds blew away the topsoil, causing "black blizzards." Thousands of families left the area at the height of the Great Depression.

Pakistan, 2000

Large parts of Pakistan were hit by drought in 2000. No rain fell in the Baluchistan area for more than 3 years. Many people were forced to leave some of the more remote villages. They migrated to cities in search of food and water. This required a major support effort by the Pakistani government and several international relief agencies.

HAIL

Hail is frozen precipitation in the form of balls of ice. The diameter of hailstones ranges from 0.5 to 10 centimeters (cm). Hail usually forms during thunderstorms when strong updrafts (vertical winds) move through cumulonimbus clouds in which temperatures are near or below freezing.



Northwest Missouri, September 5, 1898

A huge hailstorm assaulted Nodaway County in northwest Missouri on September 5, 1898. The hail remained on the ground for 52 days and left the fields unworkable for 2 weeks. On October 27, there was still enough hail left in ravines for the local residents to make ice cream.

Selden, Kansas, June 3, 1959

On June 3, 1959, a severe hailstorm struck the town of Selden in northwest Kansas. Hail fell for 85 minutes. The storm covered an area 10 km by 14.4 km with hailstones to a depth of 46 cm. The storm caused $500,000 worth of damage. That was a lot of money in 1959.

HURRICANE

Hurricanes are cyclones, moving wind systems that rotate around an eye, or center of low atmospheric pressure. Hurricanes form over warm tropical seas. Wind speeds are more than 64 knots (119 km/h) in a hurricane. The term *hurricane* is used for Northern Hemisphere cyclones east of the International Dateline to the Greenwich Meridian. The term **typhoon** is used for Pacific cyclones north of the equator west of the International Dateline. Hurricanes produce dangerous winds, heavy rains, and flooding. They can cause great property damage and loss of life in coastal areas.

Galveston, Texas, September 8, 1900

The hurricane that struck Galveston, Texas, on September 8, 1900, is considered one of the worst natural disasters in U.S. history. More than 6000 men, women, and children lost their lives during the Great Storm. It is estimated that the winds reached 250 to 333 km/h. The tidal surge was probably 4.6 to 6.2 m. The highest elevation on Galveston Island in 1900 was 2.7 m. More than 3600 homes were destroyed, with whole blocks of homes totally wiped out, leaving only a few bricks behind.

Southern Florida, August 1992

Hurricane Andrew was a relatively small, but ferocious, hurricane that devastated areas in the northwest Bahamas, southern Florida, and south central Louisiana during August 1992. Hurricane Andrew was the most expensive natural disaster in U.S. history at that time, causing nearly $25 billion worth of damage. Forty lives were lost, and almost 250,000 people were left homeless.

LIGHTNING AND THUNDER

Lightning is a visible electric discharge produced by thunderstorms. Not everyone agrees why lightning happens, but what happens is pretty well understood. Lightning travels from a cloud to the ground. The electric charge moves downward in approximately 46-m steps called **step leaders.** This flow continues until the charge reaches something on the ground that is a good conductor. The circuit is completed.

The whole event usually takes less than half a second, and a lightning bolt can reach 200 million volts.

Since 1989, U.S. meteorologists have been able to detect lightning with a network of antennas. An average of 20 million cloud-to-ground strikes happen every year over the continental United States.

Thunder is the explosive sound that usually accompanies lightning. The sound is caused by the rapidly expanding gases in the atmosphere along the path of the lightning. How loud and what type of sound you hear depends on atmospheric conditions and how far away you are from the flash.

Perth, Australia, December 16, 1998

An apprentice jockey, Damion Beckett, and champion gelding Brave Buck died instantly when lightning struck them. They were training at Ascot racecourse in Perth about 5 a.m. on December 16, 1998.

Durham, North Carolina, July 7, 1995

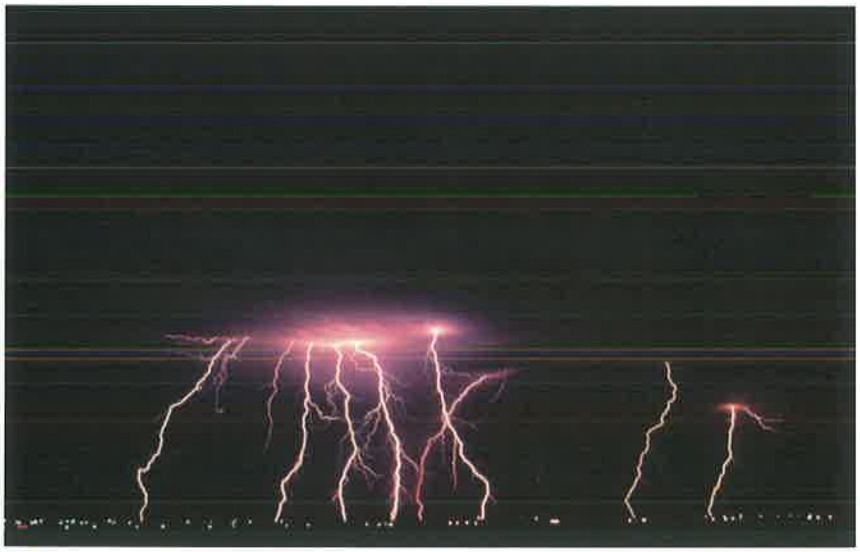
Lightning during an early-evening thunderstorm killed a golfer. The man took cover from the storm in a wooden shed at a golf course. Witnesses say the lightning first struck a tree and then bounced to the shed. Other golfers sustained scrapes and burns from the accident. All were dazed and in shock. Later they said that the lightning was the brightest they had ever seen and that the thunder came immediately.

TORNADO

Tornadoes are rapidly rotating columns of air that extend from a thunderstorm to the ground. Wind speeds in a tornado can reach 417 km/h or more. The path of a tornado can be more than 1 km wide and 83 km long.

Xenia, Ohio, April 3, 1974

On April 3 and 4, 1974, a super tornado outbreak struck the states of Alabama, Georgia, Illinois, Indiana, Kentucky, Michigan, Mississippi, North Carolina, Ohio, South Carolina, Tennessee, Virginia, and West Virginia. Especially devastating tornadoes struck Ohio during the afternoon and early evening of April 3. The town of Xenia was hardest hit. Thirty people died, more than 1100 were injured, and more than 1000 homes were destroyed. The path of damage ranged from 0.4 to 0.83 km wide.



Oklahoma City, Oklahoma, May 3, 1999

Eight supercell thunderstorms produced at least 59 different tornadoes in central Oklahoma alone on May 3, 1999. Many of these tornadoes were very violent and long-lasting. They made direct hits on several populated areas, including Oklahoma City. At least 40 people died in Oklahoma because of the twisters, and 675 were injured. Total damage was as much as $1.2 billion. Tornadoes also caused extensive damage to the Wichita, Kansas, metro area.

Salt Lake City, Utah, August 11, 1999

The largest tornado ever to strike Salt Lake City happened on August 11, 1999. Tornadoes are rare in Utah. Winds from this tornado reached 188 to 262 km/h. One person died, 99 people were hurt, and 387 homes were damaged. Damage estimates reached $3.2 million.

This is the oldest known photo of a tornado. It was taken 35 km southwest of Howard, South Dakota, on August 28, 1884.

THUNDERSTORM

Thunderstorms produce rapidly rising air currents, usually resulting in heavy rain or hail along with thunder and lightning. A thunderstorm is classified as severe when it produces one or more of the following:

- Hail 1.9 cm or greater in diameter
- Winds gusting in excess of 96 km/h
- A tornado

West Central Texas, October 22, 1996

On October 22, 1996, surface temperatures dropped from 10°C to around 0°C in an area of west central Texas. Bands of convection developed. The storm increased in intensity very quickly. Dime- to egg-sized hail fell, as well as large amounts of sleet and light snow.

Fort Worth, Texas, May 5, 1995

An isolated severe storm became the costliest thunderstorm in U.S. history when it devastated the area in and around Fort Worth, Texas, on May 5, 1995. More than 100 people were injured, mostly by softball-sized hail that pelted people attending an outdoor Mayfest. Winds reached 100 to 117 km/h (60 to 70 mph), driving hail the size of grapefruit in some areas. The large hail and high winds damaged hundreds of homes, businesses, and vehicles. Damage totals reached more than $2 billion.

BLIZZARD

Blizzards are severe storms with low temperatures, strong winds, and large quantities of snow. Blizzards have winds of more than 51 km/h and enough snow to limit visibility to 150 m or less. A severe blizzard has winds of more than 72 kph, near zero visibility, and temperatures of –12°C or lower.

East Coast, United States, February 1–14, 1899

A cold wave hit the East Coast during February 1–14, 1899, causing a huge blizzard and bitter-cold temperatures from the Rockies to the Atlantic Ocean. Snow fell from Louisiana to Georgia and extended northeast into New England. Florida experienced its first blizzard. Temperatures fell below freezing there for the first time. Up to 61 cm of snow fell across much of the Northeast. Winds gusted to 58 km/h. Jacksonville, Florida, measured its greatest snowfall ever at just over 4 cm. Tampa received its first measurable snow on record.

Chicago, January 26–27, 1967

The city of Chicago set records on January 26 and 27 with the worst blizzard ever recorded there. More than 52 cm of snow fell in 29 hours and 8 minutes. Trains froze and couldn't move. Buses were stranded. O'Hare Airport was closed for 3 days.

Washington, DC, February 22, 1979

Known as the Presidents' Day Storm, this blizzard covered much of the Northeast, closing down Washington, DC. Ice formed on the Potomac. Some mid-Atlantic areas received more than 44 cm of snow. Observers in Baltimore reported snow falling at a rate of 11 cm per hour.

Super Storm, March 12–15, 1993

Twenty-six states were affected by a low-pressure system during March 12–15, 1993. The system brought heavy snow and strong winds. Birmingham, Alabama, received 28.6 cm of snow, while Chattanooga, Tennessee, measured 44 cm by the time the storm passed. Winds gusted up to 83 km/h as temperatures fell rapidly. Parts of Long Island, New York, recorded wind gusts of 155 km/h. Over 50 tornadoes hit Florida. The storm took more than 200 lives.

WINDSTORM

Sometimes strong winds that are not directly connected with thunderstorms, tornadoes, or hurricanes occur. **Straight-line winds** are strong winds that have no rotation. The winds can travel at speeds of more than 167 km/h. If no one is around to observe what happens, it can be difficult to tell if damage came from a straight-line wind or a tornado.

Microbursts are small, very intense downdrafts. They affect areas less than 4 km wide. Microbursts can produce winds of more than 280 km/h. They typically last less than 10 minutes. They are often associated with thunderstorms. Microbursts often cause significant ground damage and are a threat to aviation.

Dust devils are small rotating winds not associated with a thunderstorm. They become visible when they collect dust or debris. Dust devils form when air is heated by a hot surface during fair, hot weather. You are most likely to see a dust devil in arid or semiarid regions.

Dust storms are rare conditions in which strong winds carry dust over a large area. They occur when there are drought conditions. In desert areas, sandstorms occur.

China, April 1998

Parts of China and Mongolia experienced a major dust storm in April 1998. Twelve people were reported missing after the storm, whose winds reached gale force. The storm blanketed ten cities and districts. Power and water supplies were cut. A trace of yellow dust carried by the winds was deposited on nearby deserts. Some of the dust was blown all the way to the United States.

Mars, August 9, 1999

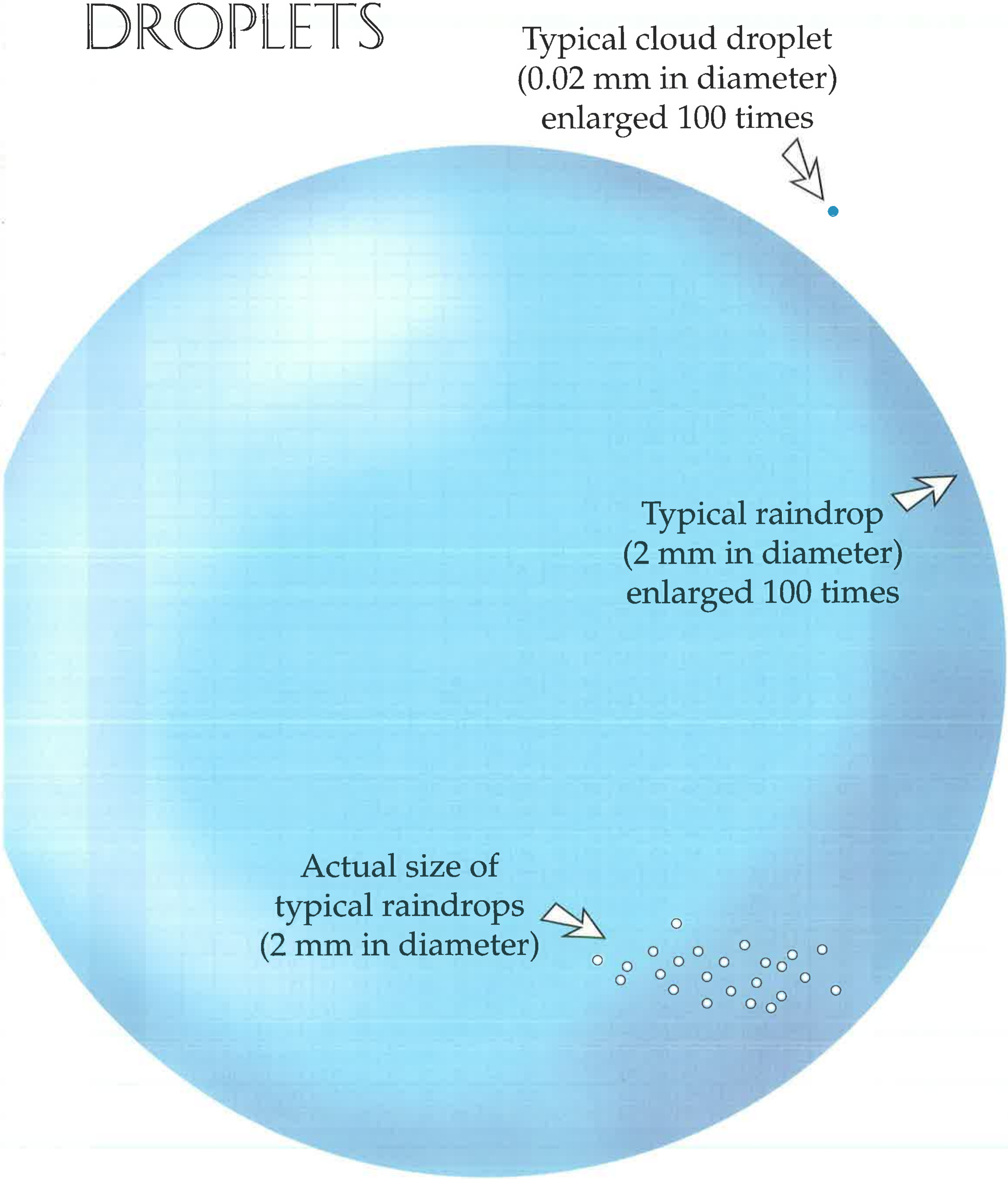
The Mars Global Surveyor *photographed a dust storm blowing across Mars's northern plains. A Martian dust storm can cover most of the planet. Scientists have also identified dust devils on Mars photographs. This dust devil has a diameter of 8 km.*

For more information about severe weather, visit this National Weather Service website: www.nws.noaa.gov/om/severeweather/index.shtml

Humidity Calculator

Dry-bulb temp. (°C)	Relative humidity (%)																			
	Difference between wet- and dry-bulb temperature (°C)																			
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°	20°
–10	67	35																		
–9	69	39	9																	
–8	71	43	15																	
–7	73	48	20																	
–6	74	49	25																	
–5	76	52	29	7																
–4	77	55	33	12																
–3	78	57	37	17																
–2	79	60	40	22																
–1	81	62	43	26	8															
0	81	64	46	29	13															
1	83	66	49	33	17															
2	84	68	52	37	22	7														
3	84	70	55	40	26	12														
4	85	71	57	43	29	16														
5	86	72	58	45	33	20	7													
6	86	73	60	48	35	24	11													
7	87	74	62	50	38	26	15													
8	87	75	63	51	40	29	19	8												
9	88	76	64	53	42	32	22	12												
10	88	77	66	55	44	34	24	15	6											
11	89	78	67	56	46	36	27	18	9											
12	89	78	68	58	48	39	29	21	12											
13	89	79	69	59	50	41	32	23	15	7										
14	90	79	70	60	51	42	34	26	18	10										
15	90	80	71	61	53	44	36	27	20	13	6									
16	90	81	71	63	54	46	38	30	23	15	8									
17	90	81	72	64	55	47	40	32	25	18	11									
18	91	82	73	65	57	49	41	34	27	20	14	7								
19	91	82	74	65	58	50	43	36	29	22	16	10								
20	91	83	74	66	59	51	44	37	31	24	18	12	6							
21	91	83	75	67	60	53	46	39	32	26	20	14	9							
22	92	83	76	68	61	54	47	40	34	28	22	17	11	6						
23	92	84	76	69	62	55	48	42	36	30	24	19	13	8						
24	92	84	77	69	62	56	49	43	37	31	26	20	15	10	5					
25	92	84	77	70	63	57	50	44	39	33	28	22	17	12	8					
26	92	85	78	71	64	58	51	45	40	34	29	24	19	14	10	5				
27	92	85	78	71	65	58	52	47	41	36	31	26	21	16	12	7				
28	93	85	78	72	65	59	53	48	42	37	32	27	22	18	13	9	5			
29	93	86	79	72	66	60	54	49	43	38	33	28	24	19	15	11	7			
30	93	86	79	73	67	61	55	50	44	39	35	30	25	21	17	13	9	5		
31	93	86	80	73	67	61	56	51	45	40	36	31	27	22	18	14	11	7		
32	93	86	80	74	68	62	57	51	46	41	37	32	28	24	20	16	12	9	5	
33	93	87	80	74	68	63	57	52	47	42	38	33	29	25	21	17	14	10	7	
34	93	87	81	75	69	63	58	53	48	43	39	35	30	28	23	19	15	12	8	5
35	93	87	81	75	69	64	59	54	49	44	40	36	32	28	24	20	17	13	10	7

RAINDROPS AND CLOUD DROPLETS



Weather-Balloon Sounding Data
May 9, 2000

Phoenix, Arizona

Altitude (m)	Air temp. (°C)	Dew point (°C)
75	33	8
300	31	6
550	28	5
800	26	5
1000	24	5
1250	21	4
1500	19	3
1750	17	2
2000	15	0
3000	9	–14
4400	4	–22
5800	–7	–26
8500	–28	–43
12,000	–59	–66

Chicago, Illinois

Altitude (m)	Air temp. (°C)	Dew point (°C)
40	16	14
250	14	13
500	13	12
700	13	12
900	12	12
1200	12	11
1400	11	10
1900	9	8
2400	6	5
3000	3	3
3600	0	–2
5000	–9	–9
8300	–30	–32
12,000	–60	–68

Boston, Massachusetts

Altitude (m)	Air temp. (°C)	Dew point (°C)
16	10	9
150	9	5
600	8	6
800	9	9
1200	9	9
1500	9	9
1700	9	9
2100	8	7
4000	–4	–5
4900	–8	–9
5300	–10	–12
6100	–17	–17
7000	–22	–24
9100	–38	–42

San Francisco, California

Altitude (m)	Air temp. (°C)	Dew point (°C)
10	12	9
170	12	9
400	10	9
600	9	7
800	9	4
1000	10	0
1300	10	–3
1500	9	–3
2000	8	–2
2600	6	–3
5000	–6	–21
7500	–22	–33
9500	–38	–44
12,000	–60	–64

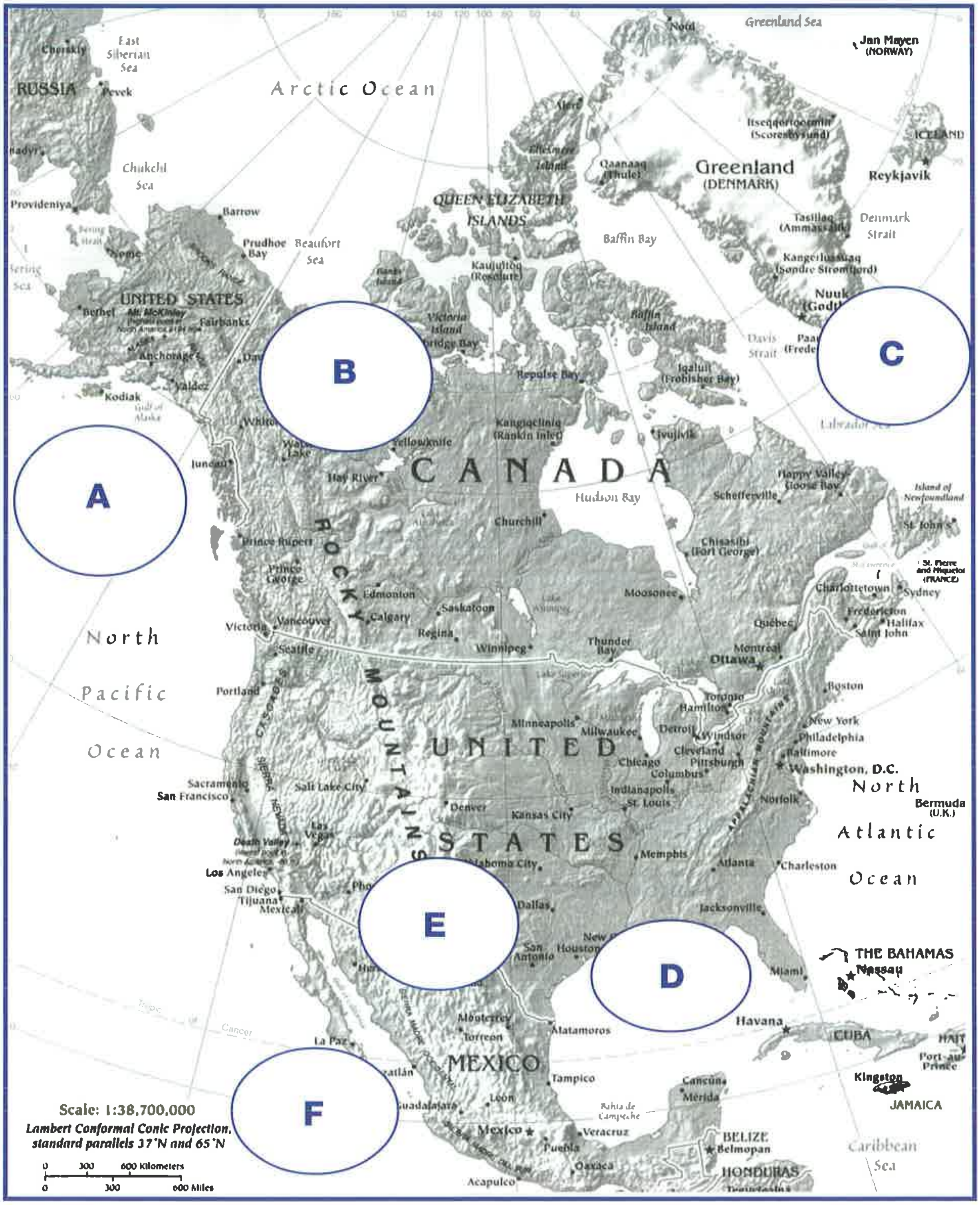
Water-Cycle Game Rules: Plain Version

WHAT YOU ROLL	WHAT HAPPENS TO YOU	WHERE YOU GO
GROUNDWATER		
1	Water filters into a river.	River
2 or 3	Water filters into a lake.	Lake
4, 5, or 6	Water stays underground in an aquifer. Roll again.	Groundwater
RIVER		
1	Water flows into a lake.	Lake
2	Water filters into the soil.	Soil
3	Water flows into the ocean.	Ocean
4	An animal drinks water.	Animal
5	Water heats up and evaporates.	Atmosphere
6	Water remains in the river. Roll again.	River
ANIMAL		
1 or 2	Water is excreted through feces and urine.	Soil
3, 4, or 5	Water is respired or evaporated from the body.	Atmosphere
6	Water is incorporated into the body. Roll again.	Animal
SOIL		
1	Water is absorbed by plant roots.	Plant
2	Soil is saturated, so water runs into a river.	River
3	Water filters into the soil.	Soil
4 or 5	Heat evaporates the water.	Atmosphere
6	Water remains on the surface, in a puddle, or on a soil particle. Roll again.	Soil
ATMOSPHERE		
1	Water condenses and falls on soil.	Soil
2	Water condenses and falls as snow on a glacier.	Glacier
3	Water condenses and falls on a lake.	Lake
4 or 5	Water condenses and falls on an ocean.	Ocean
6	Water remains as vapor in the atmosphere. Roll again.	Atmosphere
GLACIER		
1	Ice melts and water filters into the ground.	Groundwater
2	Ice sublimates (turns directly from ice into water vapor) and goes into the atmosphere.	Atmosphere
3	Ice melts and water flows into a river.	River
4	Ice melts and water flows into the ocean.	Ocean
5 or 6	Ice stays frozen in the glacier. Roll again.	Glacier
LAKE		
1	Water filters into the soil.	Soil
2	An animal drinks water.	Animal
3	Water flows into a river.	River
4	Water heats up and evaporates.	Atmosphere
5 or 6	Water remains within a lake or estuary. Roll again.	Lake
OCEAN		
1 or 2	Water heats up and evaporates.	Atmosphere
3, 4, 5, or 6	Water remains in the ocean. Roll again.	Ocean
PLANT		
1, 2, 3, or 4	Water leaves a plant through the process of transpiration.	Atmosphere
5 or 6	Water is used by a plant and stays in cells. Roll again.	Plant

Water-Cycle Game Rules: Global-Warming Version

WHAT YOU ROLL	WHAT HAPPENS TO YOU	WHERE YOU GO
GROUNDWATER		
1 or 2	Water filters into a river.	River
3, 4, 5, or 6	Water filters into a lake.	Lake
7, 8, 9, 10, 11, or 12	Water stays underground in an aquifer. Roll again.	Groundwater
RIVER		
1 or 2	Water flows into a lake.	Lake
3 or 4	Water filters into the soil.	Soil
5 or 6	Water flows into the ocean.	Ocean
7 or 8	An animal drinks water.	Animal
9 or 10	Water heats up and evaporates.	Atmosphere
11 or 12	Water remains in the river. Roll again.	River
ANIMAL		
1, 2, 3, or 4	Water is excreted through feces and urine.	Soil
5, 6, 7, 8, 9, or 10	Water is respired or evaporated from the body.	Atmosphere
11 or 12	Water is incorporated into the body. Roll again.	Animal
SOIL		
1 or 2	Water is absorbed by plant roots.	Plant
3 or 4	Soil is saturated, so water runs into a river.	River
5 or 6	Water filters into the soil.	Soil
7, 8, 9, or 10	Water heats up and evaporates.	Atmosphere
11 or 12	Water remains on the surface, in a puddle, or on a soil particle. Roll again.	Soil
ATMOSPHERE		
1 or 2	Water condenses and falls on soil.	Soil
3 or 4	Water condenses and falls as snow on a glacier.	Glacier
5 or 6	Water condenses and falls on a lake.	Lake
7, 8, 9, or 10	Water condenses and falls on an ocean.	Ocean
11 or 12	Water remains as vapor in the atmosphere. Roll again.	Atmosphere
GLACIER		
1 or 2	Ice melts and water filters into the ground.	Groundwater
3, 4, or 5	Ice sublimates (turns directly from ice into water vapor) and goes into the atmosphere.	Atmosphere
6, 7, or 8	Ice melts and water flows into a river.	River
9, 10, or 11	Ice melts and water flows into the ocean.	Ocean
12	Ice stays frozen in the glacier. Roll again.	Glacier
LAKE		
1 or 2	Water filters into the soil.	Soil
3 or 4	An animal drinks water.	Animal
5 or 6	Water flows into a river.	River
7, 8, or 9	Water heats up and evaporates.	Atmosphere
10, 11, or 12	Water remains within a lake or estuary. Roll again.	Lake
OCEAN		
1, 2, 3, 4, or 5	Water heats up and evaporates.	Atmosphere
6, 7, 8, 9, 10, 11, or 12	Water remains in the ocean. Roll again.	Ocean
PLANT		
1, 2, 3, 4, 5, 6, 7, 8, or 9	Water leaves a plant through the process of transpiration.	Atmosphere
10, 11, or 12	Water is used by a plant and stays in cells. Roll again.	Plant

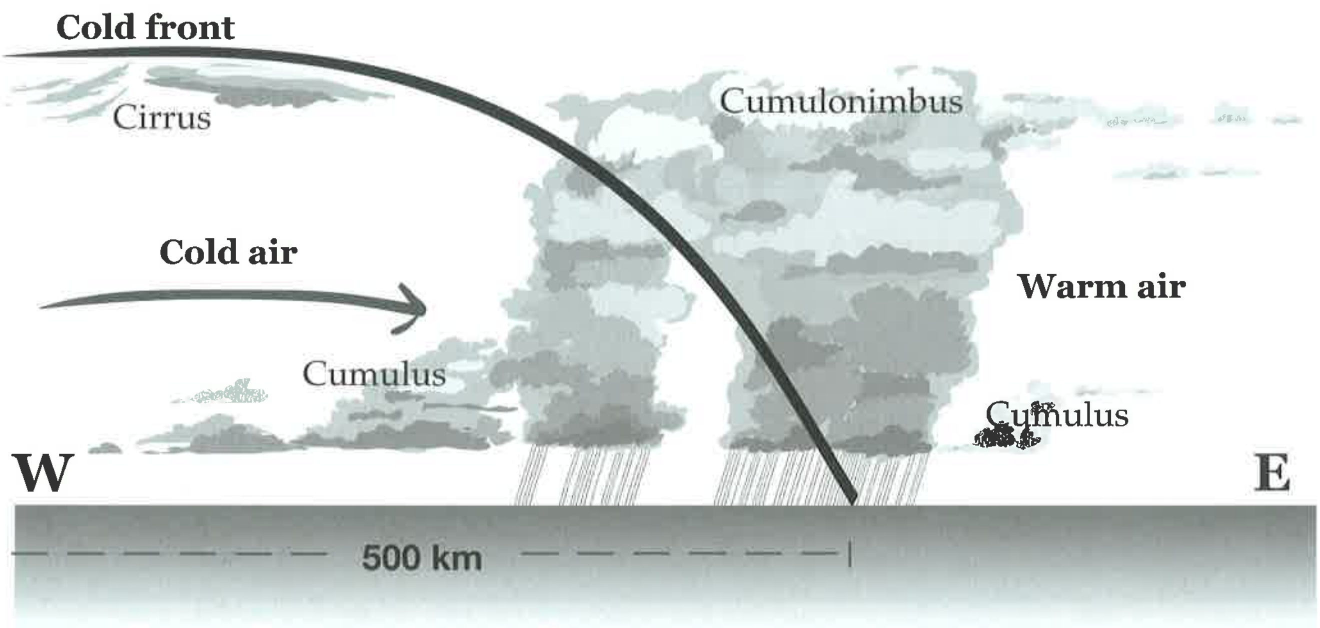
NORTH AMERICAN AIR MASSES



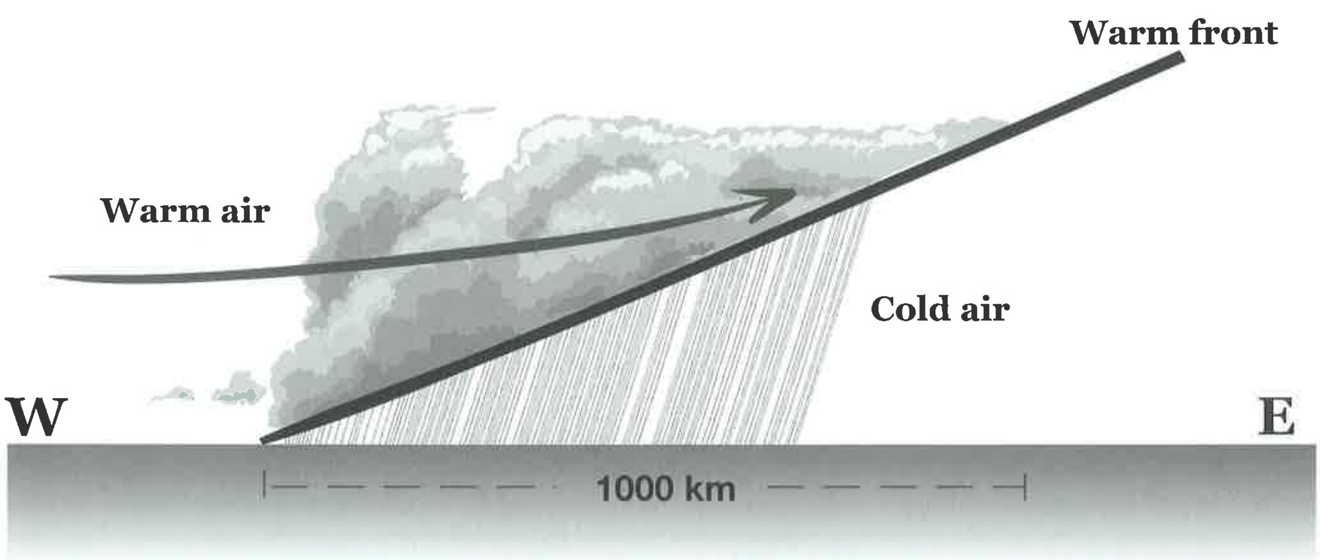
Continental (c): related to the land
Maritime (m): related to the ocean or sea
Polar (P): areas near the poles, including Canada and the Arctic Ocean
Tropical (T): areas in the tropics, Gulf of Mexico, Mexico, and southwestern United States

FRONTS

COLD FRONT



WARM FRONT



WEATHER AND FRONTS

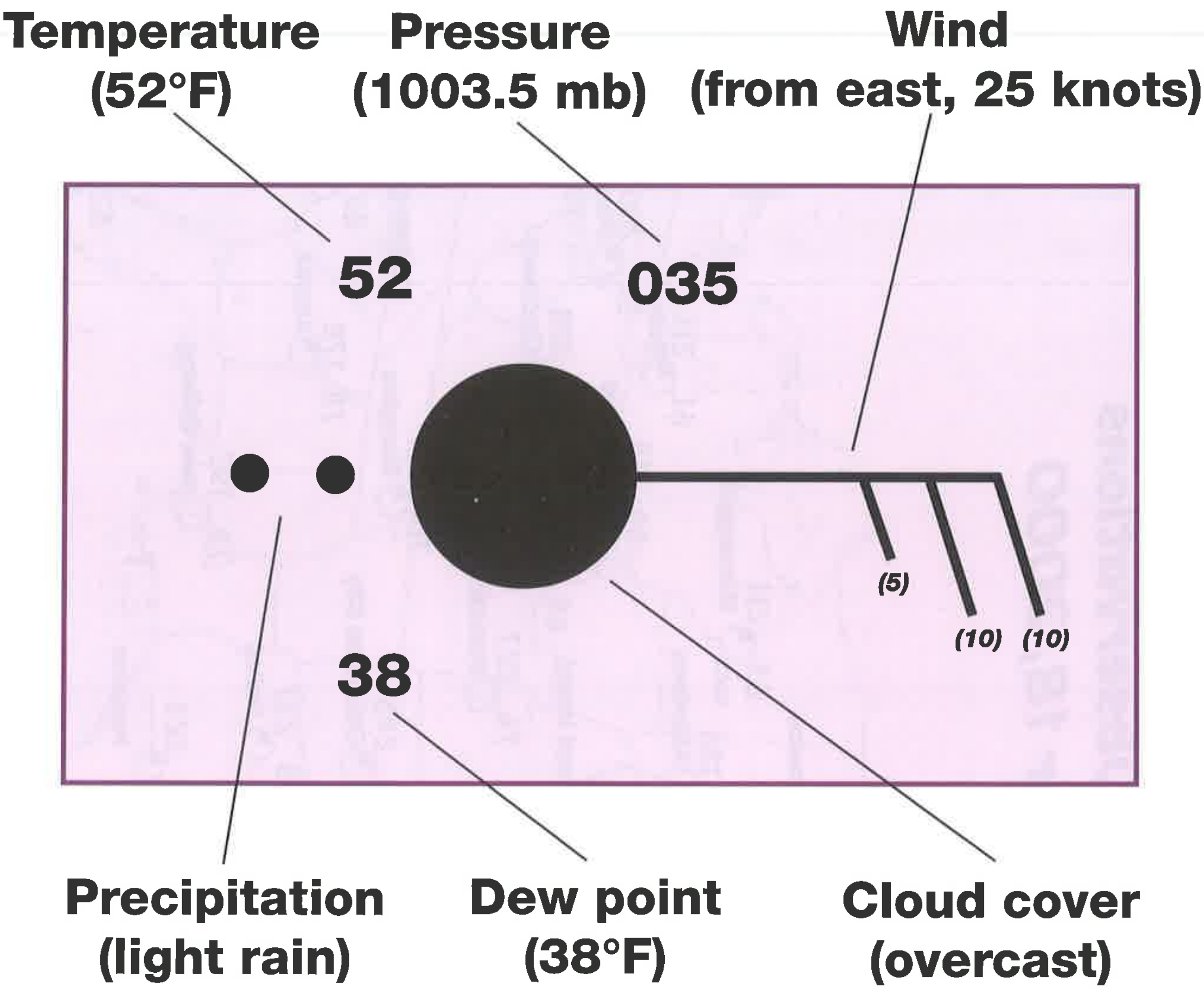
COLD FRONT

WEATHER OBSERVATION	BEFORE FRONT PASSES	WHILE FRONT PASSES	AFTER FRONT PASSES
Winds	South to southwest	Gusty, shifting	West to northwest
Temperature	Warm	Sudden drop	Drops steadily
Pressure	Falls steadily	Small drop, then sharp rise	Rises steadily
Clouds	Cloud cover increases: cirrus, cirrostratus, cumulonimbus	Cumulonimbus	Cumulus
Precipitation	Short period of showers	Heavy rain, sometimes with thunderstorms, including hail	Showers followed by clearing
Visibility	Fair to poor, hazy	Poor, then improving	Good, unless there are showers
Dew point	High and steady	Drops sharply	Continues to lower

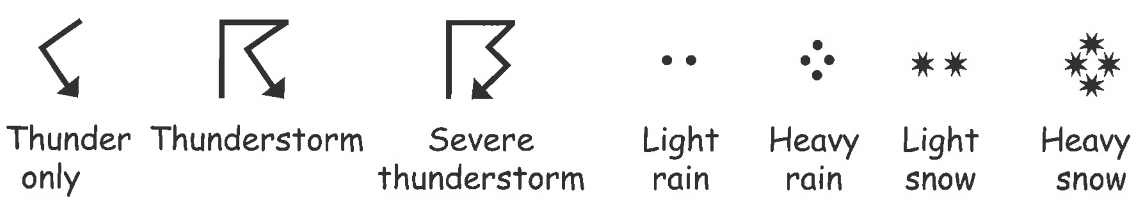
WARM FRONT

WEATHER OBSERVATION	BEFORE FRONT PASSES	WHILE FRONT PASSES	AFTER FRONT PASSES
Winds	South to southeast	Variable	South to southwest
Temperature	Cool/cold, slowly warming	Steadily rising	Warming, then steady
Pressure	Usually falling	Leveling off	Rises slightly, then falls
Clouds	Clouds usually in this order: cirrus, cumulostratus, altostratus, nimbostratus, stratus, then fog; sometimes cumulonimbus also possible in summer	Stratus and variations of stratus	Clearing followed by stratocumulus; sometimes cumulonimbus appear in summer
Precipitation	Light to moderate rain or drizzle	Drizzle or none	Usually none, but sometimes light rain or showers
Visibility	Poor	Poor, but improving	Hazy or fair
Dew point	Steady rise	Steady	Rising, then steady

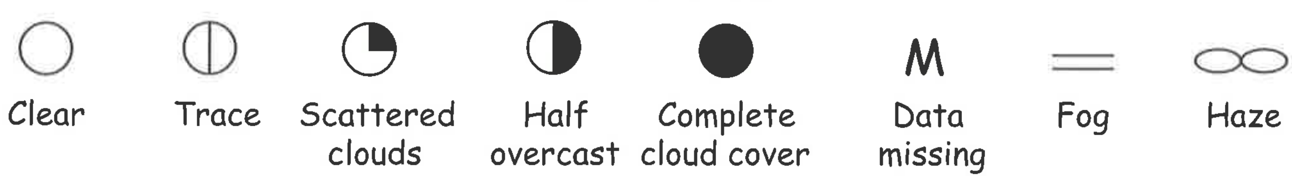
Sample Weather-Map Symbol



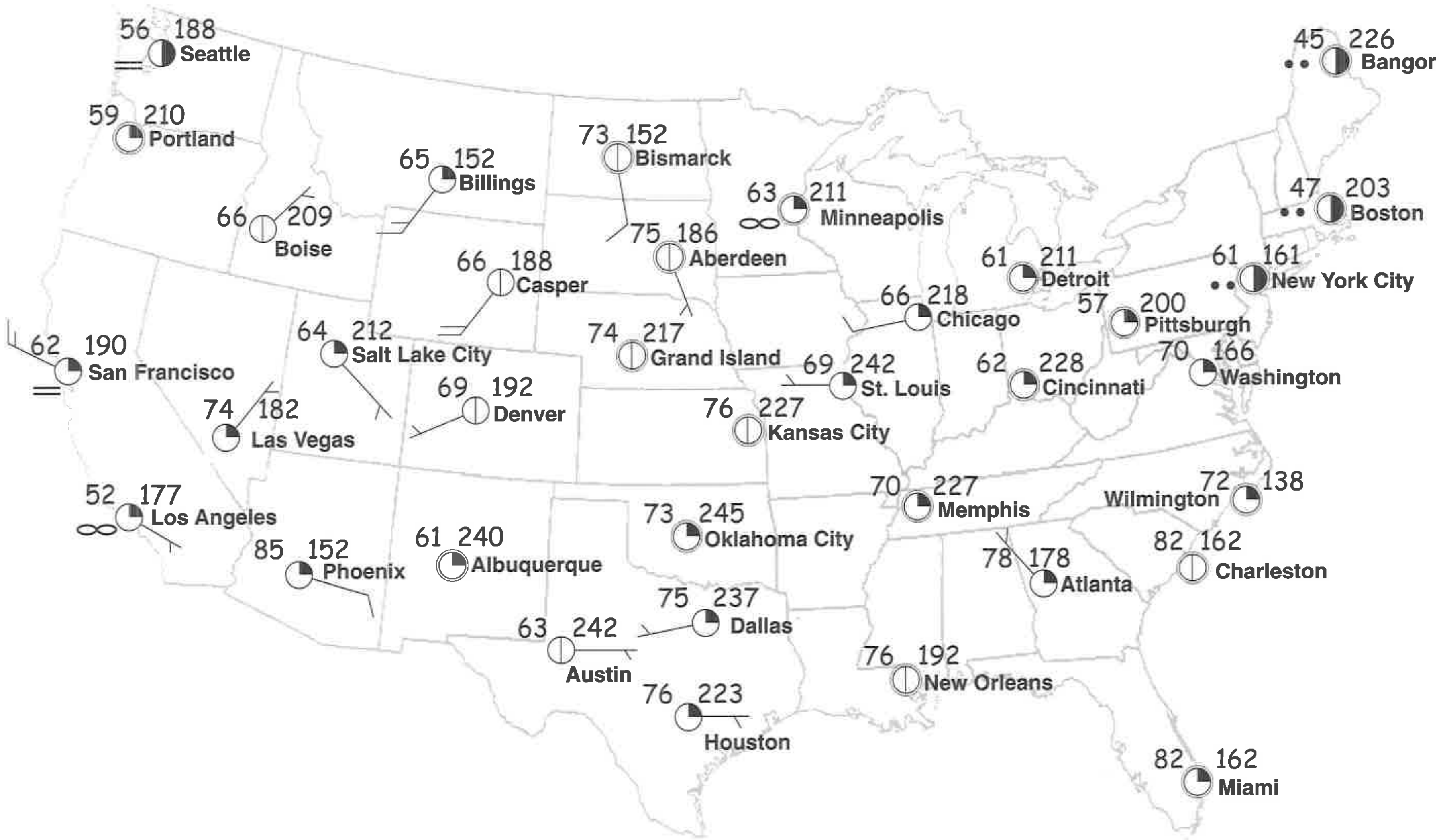
Other weather-map symbols



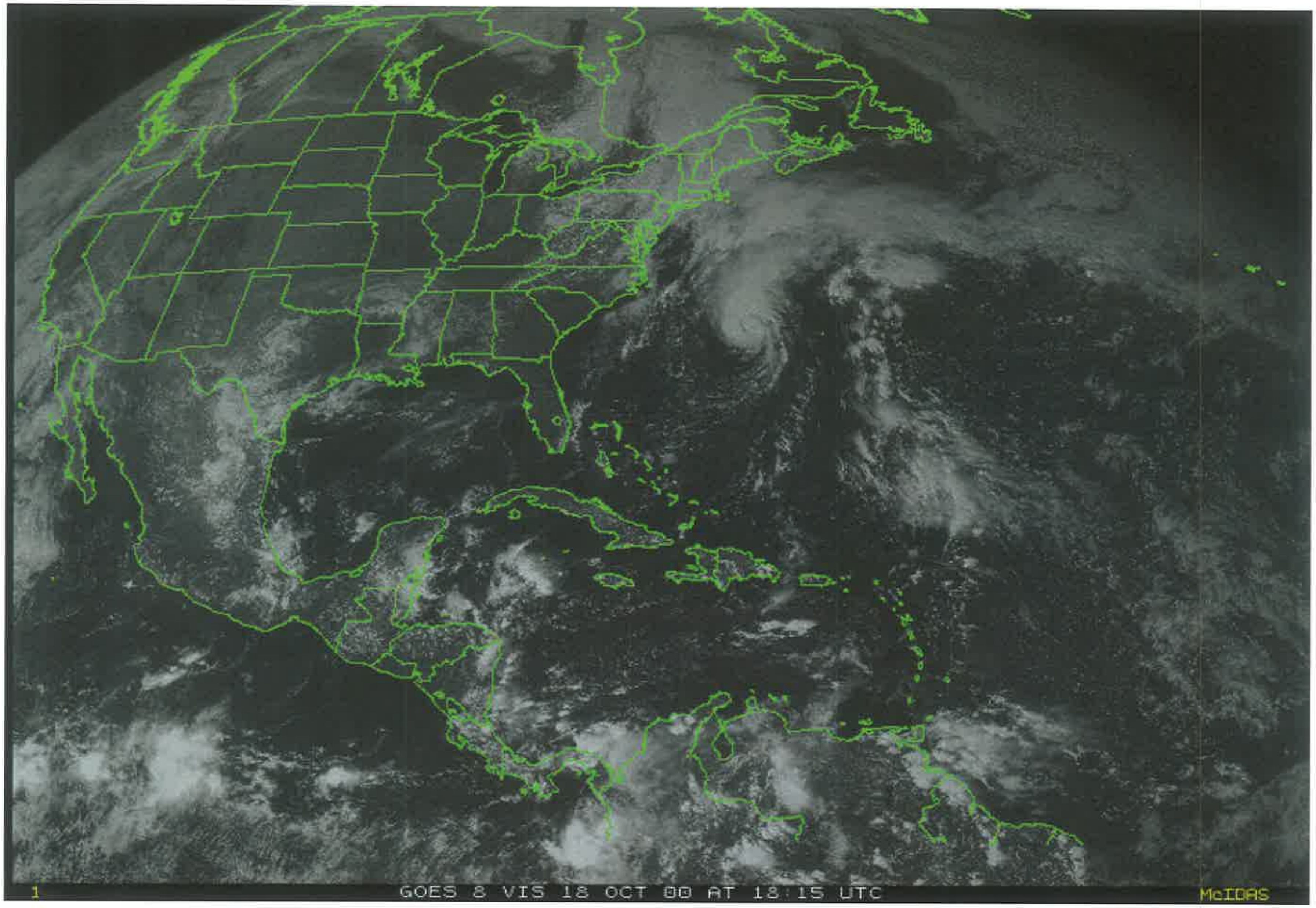
Cloud cover



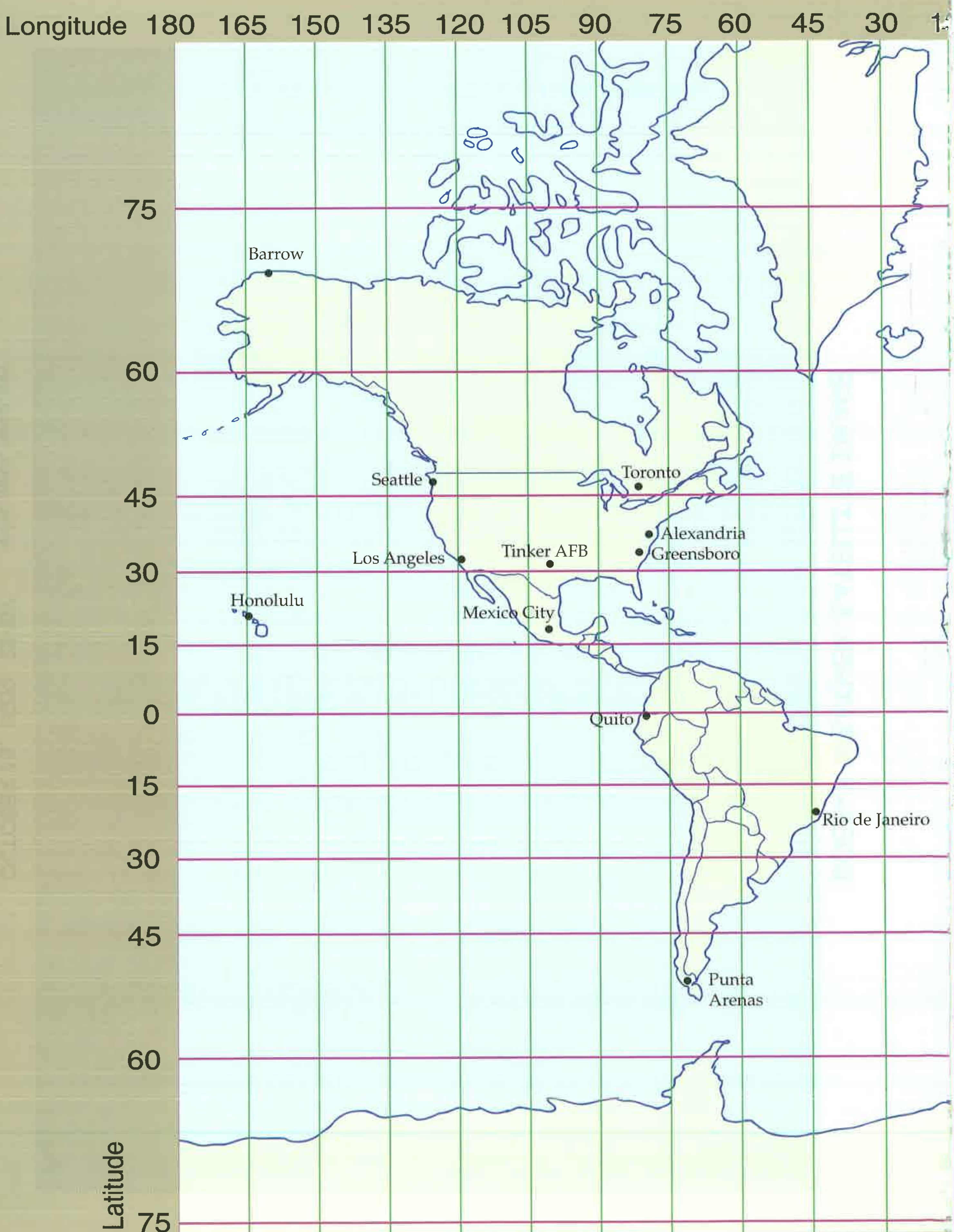
Surface Observations
October 18, 2000



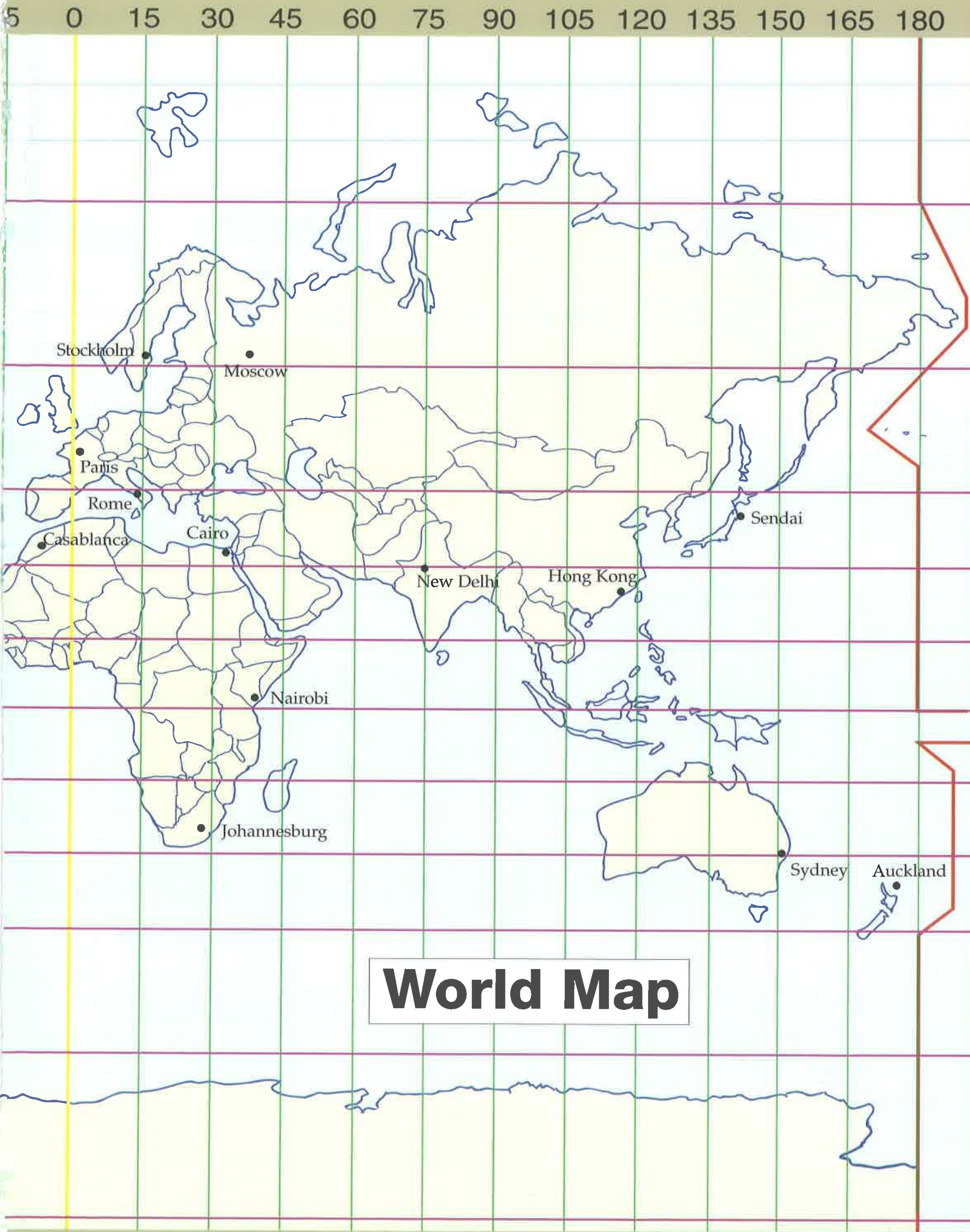
GOES-8 WEATHER-SATELLITE IMAGE



OCTOBER 18, 2000 2345Z www.goes.noaa.gov



Longitude 180 165 150 135 120 105 90 75 60 45 30
Latitude
75
60
45
30
15
0
15
30
45
60
75
Barrow
Seattle
Toronto
Alexandria
Greensboro
Tinker AFB
Los Angeles
Honolulu
Mexico City
Quito
Rio de Janeiro
Punta Arenas


5
0
15
30
45
60
75
90
105
120
135
150
165
180
Stockholm
Moscow
Paris
Rome
Casablanca
Cairo
New Delhi
Hong Kong
Sendai
Nairobi
Johannesburg
Sydney
Auckland
World Map