Senior 2

Appendix 4:
Weather Dynamics

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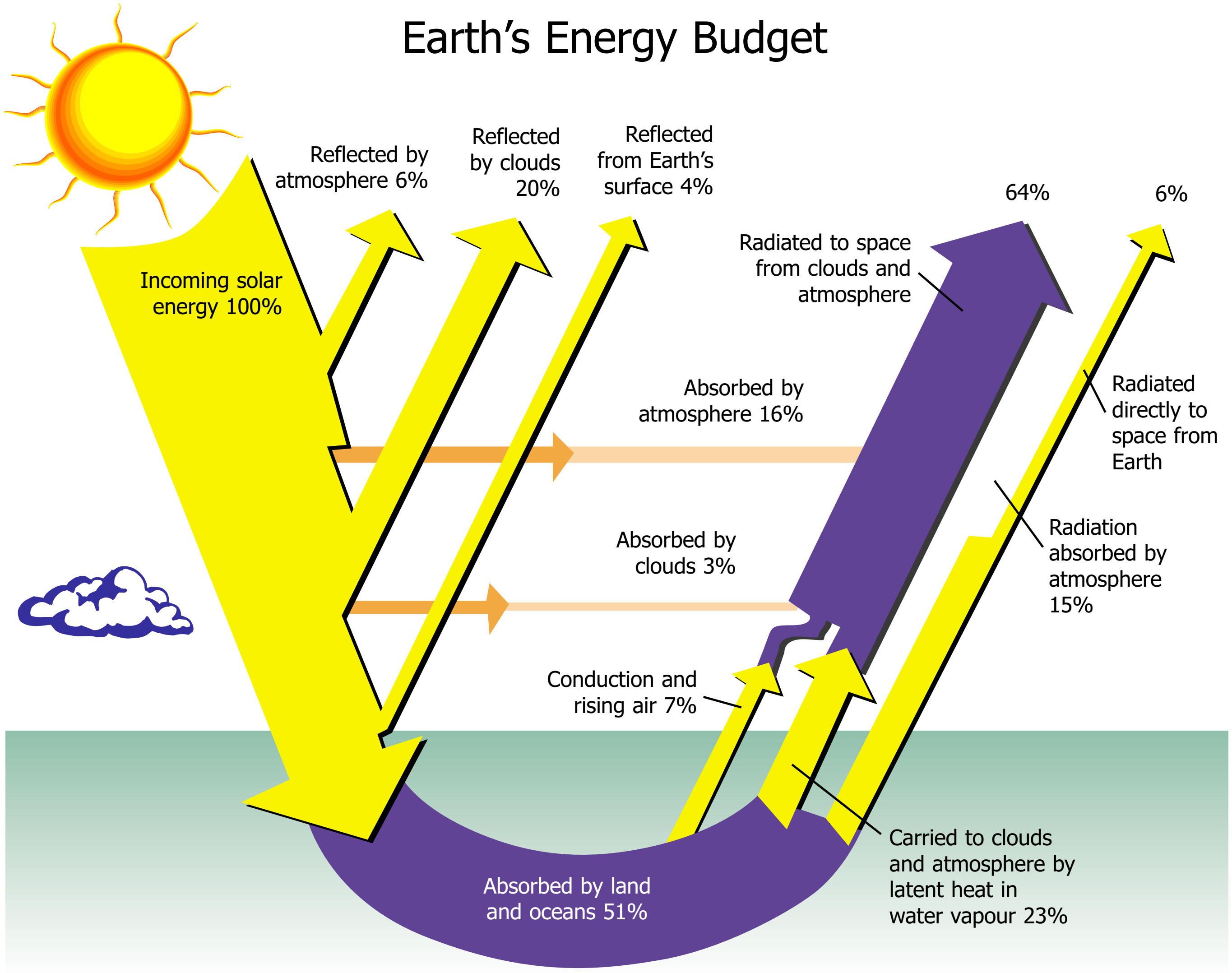
Earth's Energy Budget*



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Sunlight and Seasonal Variations

Introduction

Weather, the current state of the atmosphere, generally varies from day to day, and more so over the seasons. Climate, the long-term summary of weather conditions, follows patterns that remain nearly constant from year to year. Astronomical factors that govern the amount of sunlight Earth receives play a major role in determining these weather and climate patterns.

Our solar system consists of the Sun and a series of planets orbiting at varying distances from the Sun. We can see other stars and we are fairly certain other planets exist, however, Earth is the only world on which we are sure life exists. It is the Sun's energy that makes all life on Earth possible. The variations in the amounts of solar energy received at different locations on Earth are also fundamental to the seasonal changes of weather and climate.

Essentially, all the energy received by the Earth originates from thermonuclear reactions within the Sun. Energy from the Sun travels outward through the near-vacuum of space. The concentration of the Sun's emissions decreases rapidly as they spread in all directions. By the time they reach the Earth, some 150 million kilometres (93 million miles) from the Sun, only about 1 / 2,000,000,000 of the Sun's electromagnetic and particle emissions are intercepted by the Earth. This tiny fraction of solar energy is still significant with about 1,365 watts per square metre of solar power falling on a surface oriented perpendicular to the Sun's rays at the top of the Earth's atmosphere. To the Earth system, this important life-giving amount of energy is called the "solar constant," even though it does vary slightly with solar activity and the position of Earth in its elliptical orbit. For most purposes, the delivery of the Sun's energy can be considered essentially constant at the average distance of the Earth from the Sun. About 31 percent of the solar energy reaching the top of the Earth's atmosphere is scattered back into space.

Because of Earth's nearly spherical form, the incoming energy at any one instant strikes only one point on the Earth's surface at a 90-degree angle (called the sub-solar point). All other locations on the sunlit half of the Earth receive the Sun's rays at lower angles, causing the same energy to be spread over larger areas of horizontal surface. The lower the Sun in the sky, the less intense the sunlight received.

As shown in the accompanying **Sunlight and Seasons diagram, Fig. 1**, the Earth has two planetary motions that affect the receipt of solar energy at the surface: its once-per-day rotation and its once-per-year revolution about the Sun. These combined motions cause daily changes in the receipt of sunlight at individual locations. As the Earth rotates and revolves about the Sun, its axis of rotation always remains in the same alignment with respect to the distant "fixed stars." Because of this, throughout the year, the North Pole points toward Polaris, also called the North

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Star or, astronomically speaking, *alpha Ursae Minoris*. This axis orientation is a steady 23.5-degree inclination from the perpendicular to the plane of the orbit. While the inclination remains the same relative to the Earth's orbital plane, the Earth's axis is continuously changing position relative to the Sun's rays.

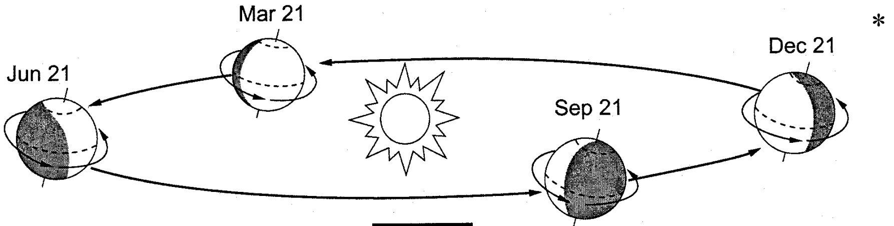

Figure 1

Figs. 2(a), 2(b), and 2(c) show the effects of rotation, revolution, and orientation of the Earth's axis on the path of the Sun through the sky at equatorial, mid-latitude, and polar locations at different times of the year.

SKY VIEWS OF THE SUN *

Daylight hours depicted for Brockport, NY (43.5°N)

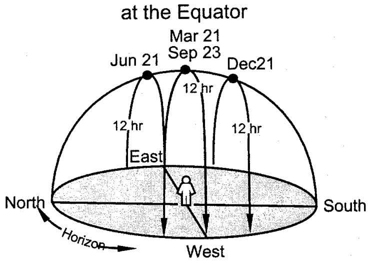

Figure 2a

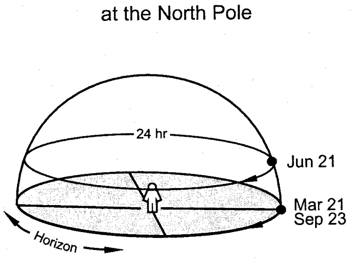

Figure 2b

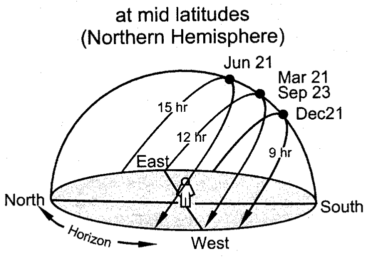

Figure 2c

Twice each year, as the Earth makes its journey around the centre of the solar system, the Earth's axis is oriented perpendicular to the Sun's rays. This happens on the Spring (or Vernal) Equinox—on or about March 21, and the Fall (or Autumnal) Equinox—on or about September 23 (terminology being a Northern Hemisphere bias!).

On these days (i.e., on or about March 21 and September 23), the sub-solar point is over the equator. Exactly one-half of both the Northern and Southern Hemispheres

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are illuminated and everywhere (except the pole itself) receives 12 hours of daylight in the absence of atmospheric effects. From the perspective of a surface observer located anywhere except at the poles, the Sun would rise in the due east position and set due west. At the equator, the Sun would be directly overhead at local noon.

At the North Pole, the Spring Equinox marks the beginning of the transition period from 24 hours of darkness to 24 hours of daylight and vice versa from 24 hours of daylight to 24 hours of darkness for the Fall Equinox. In the Northern Hemisphere, this transition to 24-hour daylight, which begins on the Spring Equinox at the North Pole, progresses southward to reach 66.5 degrees north latitude (the Arctic Circle) at the Summer Solstice on or about June 21.

There are two times when the Earth's axis is inclined the most from the perpendicular to the Sun's rays. These are the solstices, approximately midway between the equinoxes. For the Summer Solstice, on or about June 21, the North Pole is inclined 23.5-degrees from the perpendicular and tipped towards the Sun. The sub-solar point is at 23.5 degrees north latitude, which is also referred to as the Tropic of Cancer. At this time, more than half of the Northern Hemisphere is illuminated at any instant and, thus, has daylight lengths greater than 12 hours. The day length increases with increasing latitude until above 66.5 degrees north (the Arctic Circle) there is 24 hours of sunlight.

Conversely, for the Winter Solstice, on or about December 21, the Earth's axis is also inclined 23.5 degrees from the perpendicular to the Sun's rays. However, at this time of the year the sub-solar point is at 23.5 degrees south latitude, which is also referred to as the Tropic of Capricorn. The North Pole tips away from the Sun and no sunlight reaches above the Arctic Circle (66.5 degrees N). Less than half of the Northern Hemisphere is illuminated and experiences daylight periods shorter than 12 hours.

Sunlight variability due to astronomical factors in the Southern Hemisphere is the reverse of the Northern Hemisphere pattern. The seasons are also reversed.

Together, the path of the Sun through the local sky and the length of daylight combine to produce varying amounts of solar energy reaching Earth's surface. The energy received is one of the major factors in determining the character of weather conditions and, in total, the climate of a location. Generally, the higher the latitude, the greater the range (difference between maximum and minimum) in solar radiation received over the year, and the greater the difference from season to season.

Astronomical factors do not tell the whole story about sunlight and seasons. The daily changes of solar energy received at the Earth's surface within each season come primarily from the interaction of the radiation with the atmosphere through which it is passing. Gases within the atmosphere scatter, reflect, and absorb energy. Scattering of visible light produces the blue sky, white clouds, and hazy gray days. Ozone formation and dissociation absorb harmful ultraviolet radiation while water vapour absorbs infrared. Clouds strongly reflect and scatter solar energy as well as absorb light, depending on their thickness. Haze, dust, smoke, and other atmospheric pollutants also scatter solar radiation.

Basic Understandings for the Seasonal Variations

Solar Energy

Practically all the energy that makes the Earth hospitable to life and determines weather and climate comes from the Sun. The Sun, because of its high surface temperatures, emits radiant energy throughout the electromagnetic spectrum, most in the form of visible light and infrared (heat) radiation. The Earth, on average some 150 million kilometres away, intercepts a tiny fraction (1 / 2,000,000,000) of the Sun's radiation.

The rate at which solar energy is received outside the Earth's atmosphere on a flat surface placed perpendicular to the Sun's rays, and at the average distance of the Earth from the Sun, is called the solar constant. The value of the solar constant is about 2 calories per square centimetre per minute (1370 watts per square metre). Solar radiation is not received the same everywhere at the Earth's surface, due primarily to astronomical and atmospheric factors.

Astronomical Factors—The Spherical Earth

At any instant of time, one-half of the nearly spherical Earth is in sunlight and one-half is in darkness. The total amount of solar energy received by Earth is limited to the amount intercepted by a circular area with a radius equal to the radius of the Earth.

In the absence of atmospheric effects, sunlight is most intense at the place on Earth where the Sun is directly overhead (i.e., at the zenith for that location). As the Sun's position in the sky lowers, the sunlight received on a horizontal surface decreases. Due to our planet's rotation and revolution, the place on Earth where the Sun's position is directly overhead is constantly changing.

Astronomical Factors—The Inclination of the Earth's Axis

Throughout Earth's annual journey around the Sun, the planet's rotational axis remains in the same position relative to the background stars. Throughout the year, the North Pole points in the same direction towards Polaris, also called the North Star or *alpha Ursae Minoris*. The Earth's rotational axis is inclined 23.5 degrees from the perpendicular to the plane of the Earth's orbit. The orientation of the Earth's axis relative to the Sun and its rays changes continuously as our planet speeds along its orbital path.

Twice a year the Earth's axis is positioned perpendicular to the Sun's rays. In the absence of atmospheric effects, all places on Earth except the poles experience equal periods of daylight and darkness. These times are the equinoxes, the first days of spring and fall, and they occur on or about March 21 and September 23, respectively.

The Earth's rotational axis is positioned at the greatest angle from its perpendicular equinox orientation to the Sun's rays on the solstices. On or about June 21, our Northern Hemisphere is most tipped towards the Sun on its first day of summer. On or about December 21, the Northern Hemisphere is most tipped away from the Sun on its first day of winter.

As the Earth orbits the Sun, the inclined axis causes the Northern Hemisphere to tilt towards the Sun for half of the year (i.e., the spring and summer seasons in North America). During this time, more than half of the Northern Hemisphere is in sunlight at any instant of time. During the other half of the year (i.e., the fall and winter seasons in North America), the axis tilts away and less than half of the Northern Hemisphere is in sunlight.

The tilting of the Southern Hemisphere relative to the Sun's rays progresses in opposite fashion, reversing its seasons relative to those in the Northern Hemisphere. The changing orientation of the Earth's axis to the Sun's rays determines the length of daylight and the path of the Sun as it passes through the sky at every location on Earth. The continuous change in the angular relationship between the Earth's axis and the Sun's rays causes the daily length of daylight to vary throughout the year everywhere on Earth except at the equator.

From day to day in a perpetually repeating annual cycle, the path of the Sun through the sunlit sky changes everywhere on Earth, including at the equator. In the latitudes between 23.5 degrees north and 23.5 degrees south, the Sun passes directly overhead twice each year. At latitudes greater than 23.5 degrees, the maximum altitude the Sun ever reaches in the local sky during the year decreases as latitude increases. At either pole, the maximum altitude is 23.5 degrees above the horizon, occurring on the first day of that hemisphere's summer.

Solar Energy Received

In the absence of atmospheric effects, the length of the daylight period and the path of the Sun through the local sky determine the amount of solar radiation received at the Earth's surface. Ignoring atmospheric effects, the variation in the amount of sunlight received over the period of a year at the equator is determined by the path of the Sun. The Sun's path is highest in the sky on the equinoxes and lowest on the solstices. This results in two periods of maximum sunlight centring on the equinoxes and two periods of minimum sunlight at solstice times each year.

The Four Seasons

At the equator, the daily period of daylight is the same day after day. The changing path of the Sun through the sky over the year produces a cyclical variation in the amounts of solar radiation received that exhibit maxima near the equinoxes and minima near the solstices. The relatively little variation in the amounts of solar energy received over the year produces seasons quite different from those experienced at higher latitudes.

Away from the tropics, the variations in the amounts of solar radiation received over the year increase as latitude increases. The amounts of sunlight received exhibit one minimum and one maximum in their annual swings. The poles have the greatest range, since the Sun is in their skies continuously for six months and then below the horizon for the other half-year.

In general, the variations in solar radiation received at the surface over the year at higher latitudes create greater seasonal differences. While the receipt of solar energy is the major cause of seasonal swings of weather and climate at middle and high latitudes, other factors such as nearness to bodies of water, topographical features, and migrations of weather systems play significant roles as well.

Atmospheric Factors

The atmosphere reflects, scatters, and absorbs solar radiation, reducing the amount of sunlight that reaches the Earth's surface. Some atmospheric gases absorb specific wavelengths of solar radiation. Water vapour is a strong absorber of incoming infrared energy, causing a significant reduction in the amount of solar radiation reaching the ground during humid conditions. Ozone, during its formation and dissociation, absorbs harmful ultraviolet radiation that can lead to sunburn and skin cancer.

To some extent, haze, dust, smoke, and other general air pollutants block incoming solar energy wherever present. Clouds strongly reflect, scatter, and absorb incoming sunlight. High, thin cirrus absorbs some sunlight while dense clouds, if thick enough, can produce almost nighttime conditions.

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Exploring Albedo

Guiding Question—What effect does albedo have on surface temperature?

Concepts

Albedo is the fraction of incoming sunlight that is reflected, rather than absorbed.

Principles

1. Albedo is represented as a percent of Earth's total incoming energy. Thus, an albedo of 50 percent would indicate that half of all incoming radiation is reflected. In general, the more radiation that is reflected, the lower the overall surface temperatures.
2. Albedo represents an important aspect of the radiation budget.
3. Earth's Radiation Budget is a model that depicts the amount of energy the Earth gets from the Sun and the amount of energy Earth sends back to space. If Earth receives more solar energy than it sends back to space, we expect it to warm up. If Earth sends more energy than it receives from the Sun, we expect Earth to cool down.
4. In general, more lightly coloured surfaces (e.g., snow and ice) have a higher albedo than dark-coloured ones (e.g., trees, blacktop, and so on).

Facts

1. The overall albedo of Earth is thought to be about 30 percent.
2. NASA satellite instruments collect data concerning Earth's albedo.
3. The concept of albedo explains, for example, why white robes are favoured in desert regions.

Skills

1. Experimenting and making measurements
2. Drawing conclusions

Preparation

Materials

1. Thermometers (three per lab team)
2. Black- and white-coloured paper (one sheet each per lab team)
3. One paper cup of water per lab team
4. Earth's Radiation Budget graphic from this or other learning resources or websites, such as: <http://asd-www.larc.nasa.gov/erbe/components2.gif>

Room Preparation

As most of the lesson will take place outside, no room preparation is necessary. In the absence of warm, sunny weather, the room can be set up with a number of high-intensity lamps as "suns."

Note: The number of sun lamps will depend on how many students and how many groups are working on the activity. It is suggested that there should be one lamp per group.

Safety Precautions

1. Students should report broken thermometers immediately. Both broken glass and mercury have a high hazard potential.
2. If lamps are used, make sure students are careful not to let clothes or skin touch the bulb or metal shade (if any).

Procedures and Activity

Prelab discussions

1. Introduce the Earth's Radiation Budget so students will understand the concept, and how their learning resources (such as the text) explain albedo.
2. Ask students if they would be hotter on a sunny day wearing black- or white-coloured clothes. Guide them into realizing that because white is "brighter" (it has a higher albedo), it is correspondingly cooler; black garments reflect little sunlight and thus are warmer.
3. Review variables—independent and dependent. Which variables are involved here?

Activity

1. Distribute materials among students. Each lab team should wrap one thermometer tightly in black paper. A second thermometer should be wrapped tightly in white paper, and the third thermometer should be submerged in the cup of water. All three thermometers should then be put in the Sun (or underneath the lamp).
2. The temperature readings for all three thermometers should be checked and recorded every five minutes, for a total of 10 minutes. At the end of the first five-minute waiting period, students should rank the three materials (white paper, black paper, and water) in order, from the highest to the lowest albedo, as a working hypothesis.
3. Each of the three materials (white paper, black paper, and water) should be rated for albedo again at the end of the final five-minute waiting period, this time using the idea that a higher albedo will yield a lower final temperature.

Discussion

1. Which final temperature was the highest? Which was the lowest? Did your results turn out the way you expected?
2. Just in case: If the final temperature for the water proves to exceed that for the black paper, help students to understand the fact that the black paper "shields" its thermometer and thus might have influenced the results. Ask for suggestions on how to redesign the experiment to account for this (an example of a more accurate method is given under "Extension Ideas" below).

Closing

Ask students "What effect does albedo have on surface temperature?"

Assessment

1. Completion of a lab activity sheet or formal lab report.
2. Did each student contribute equally to the group effort? You may wish to add a question to each activity sheet, along the lines of "How did you divide up the work?"

Extension Ideas to Challenge Students

1. Have students graph temperature versus time for all three thermometers, and ask if all three warmed up at the same rate.
2. A more accurate method of determining albedo-temperature-colour relationships would be to put each thermometer in a cup filled with either cola, milk, or plain water. Make sure that the starting temperatures of all three liquids are identical, and that the volumes of the three are more or less equivalent. You might wish to run the experiment this way after completing it as described above, and allow students to compare results.
3. Assume (for the sake of this experiment) that the black paper (or cola) has an albedo of 0 percent. Further assume that the albedo of the white paper (or milk) is 100 percent. Have students interpolate the temperature for Earth in general (30 percent albedo) under similar light conditions, based on the two end-point temperatures.

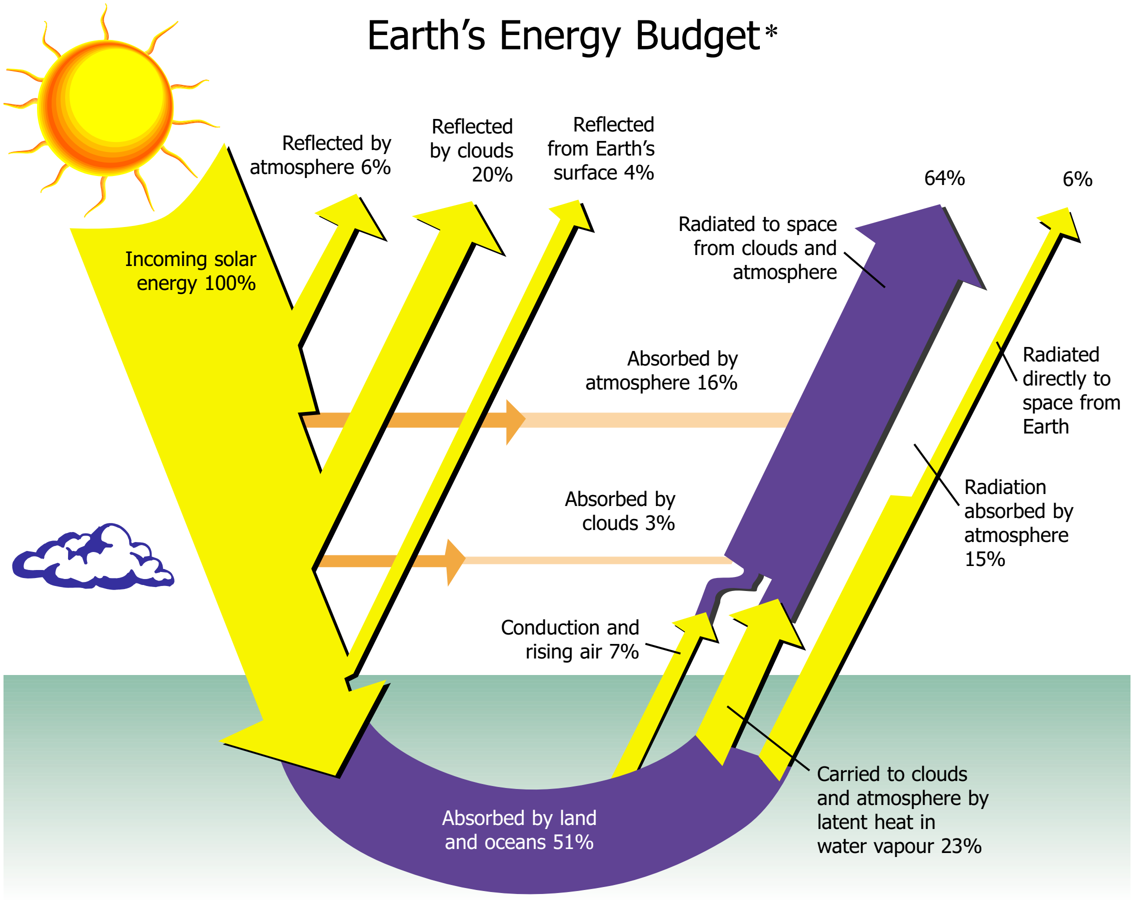
   Interpolated Temperature (30%) = 100% albedo temperature +
   (0.3) x (0% temperature–100% temperature)

Careers Related to the Lesson Topics

1. Atmospheric scientist
2. Land-use management
3. Climatologist
4. Optical physicist

Students could explore the above careers in some detail to see how their science can be directly connected to interesting career options.

Earth's Energy Budget*



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SLA
Student
Learning
Activity

Connecting Mathematics to the Atmosphere
(For Further Exploration)

Purpose

Develop and apply a variety of strategies to solve problems, with emphasis on multistep and nonroutine problems.

Instructional Delivery

Co-operative Groups/Flexible Groups/Independent

Materials

Appendix 4.1: Earth's Energy Budget

Activity

Students solve the suggested mathematical word problems by looking at the Earth's Energy Budget. Students use their Earth's Energy Budget graphic to assist with answering the questions. After answering the questions, use a self-assessment or peer-assessment strategy to have students follow up on the class responses.

Assessment

Have students (independently, or in co-operative or flexible groups) create and solve an original mathematical word problem by using the information on the Earth's Energy Budget handout.

Extension Ideas

When introducing the information to the class about the long and short waves, have the students estimate and predict wavelengths. Use a piece of yarn or a coil spring toy to represent and simulate wavelength. The students can manipulate the piece of yarn or spring toy after making their predictions. This activity may be altered to predict measurement in inches, centimetres, yards, feet, and so on. There are particular unit conversion skills involved here, and students of *Applied Mathematics (20S)* could use this as reinforcement.

Student Activity Questions

1. Determine the radiation budget by looking at the Earth’s Energy Budget. (Subtract the amount of solar energy from the total amount of reflected energy from the Earth in order to determine the radiation budget.)

2. What is the total percentage of the incoming solar energy reflected from the Earth by the atmosphere, clouds, and Earth’s surface?

   Total Reflected: (% atmosphere + % clouds + % Earth’s surface) = ________%

3. Is the total percentage of the incoming solar energy reflected from the atmosphere, clouds, and Earth’s surface less than or greater than the incoming solar energy absorbed by the land and oceans?

   (% atmosphere + % clouds + % Earth’s surface) < or > (% land + % ocean)

4. If the amount of incoming solar energy reflected from the Earth’s surface tripled, how much energy would be reflected?

   (% incoming solar energy) x 3 = ______%

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The Coriolis Effect*

The Coriolis effect (sometimes erroneously called a force) results from Earth's rotation and our perspective as residents who are more or less fixed to the surface. Because the Earth is big (relative to us), and everything around us (including us) is moving at the same speed as the Earth's surface, we don't really notice this constant rotation. The atmosphere, however, is not attached rigidly to the Earth's surface, and is therefore not constrained to move at the same speed or direction as the Earth's surface. Because of this, objects (such as air, ocean currents, airplanes) not rigidly attached to the Earth will appear to us to move along a curved path even though they may actually be traveling in a straight line.

Consider the following example. Suppose that an airplane takes off from the North Pole (see sketches on the following page) and is traveling in a straight line due south (of course). After one hour of flying, the plane is headed straight toward Montreal and New York City. If the plane continues to fly in a perfectly straight line, after a second hour, the Earth will have rotated through an angle of about 15 degrees underneath the airplane, which is now somewhere over Hudson Bay. By hour three, another 15 degrees of Earth rotation puts the plane in the centre of the continent, at about the Canada-U.S. Border. After four hours of flight, the airplane is somewhere over northern California. Notice that the plane flew in a straight line while the apparent path on the ground is curved. Work through the sketches a few times until it starts to make sense. Where would the plane be after another hour of flight?

As viewed from the North Pole, the plane, which was headed directly toward New York City, has drifted severely off its course, curving to the right. In the Northern Hemisphere, the Coriolis effect makes objects appear to curve to the right. This would also be the case if the plane took off at the equator and headed toward the North Pole. In the Southern Hemisphere, the direction of the effect is reversed and there is an apparent deflection to the left (from the perspective of the starting point). For further information, see your textbook or visit some Coriolis effect websites that you may find on the Internet.

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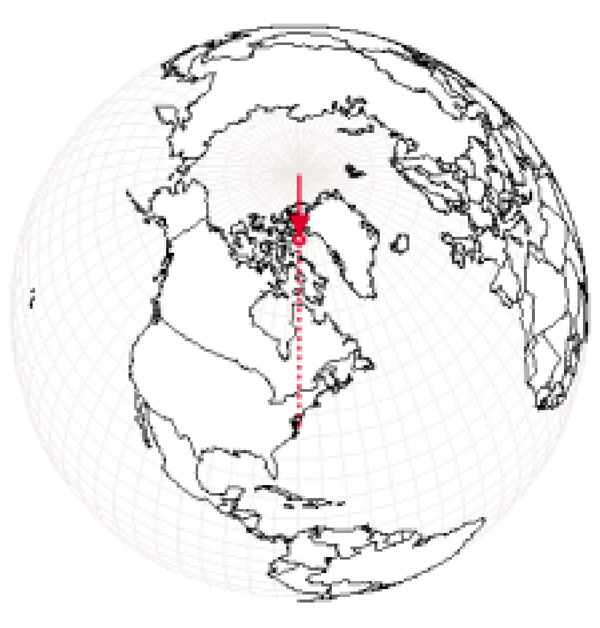
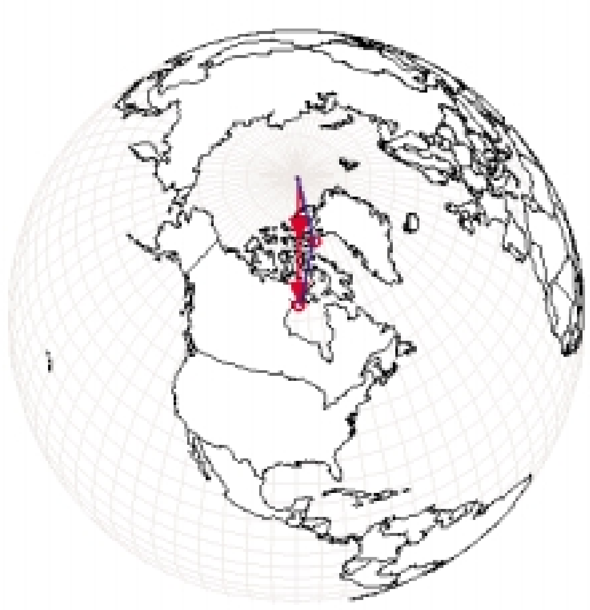
Position of Aircraft (Looking North)*

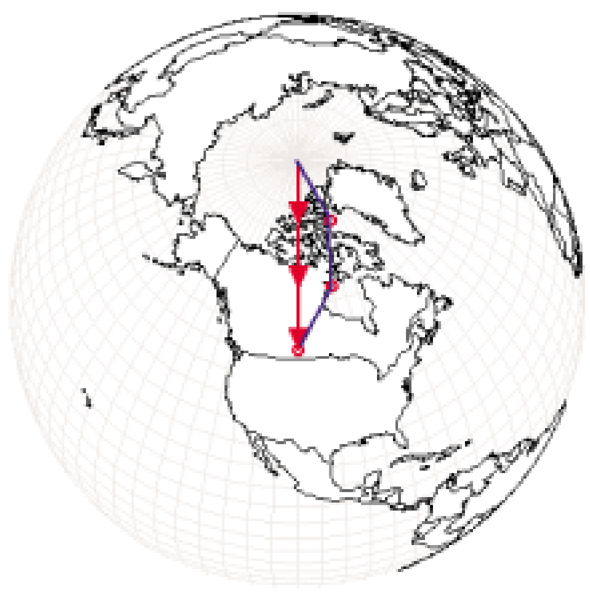
After 1 hour:



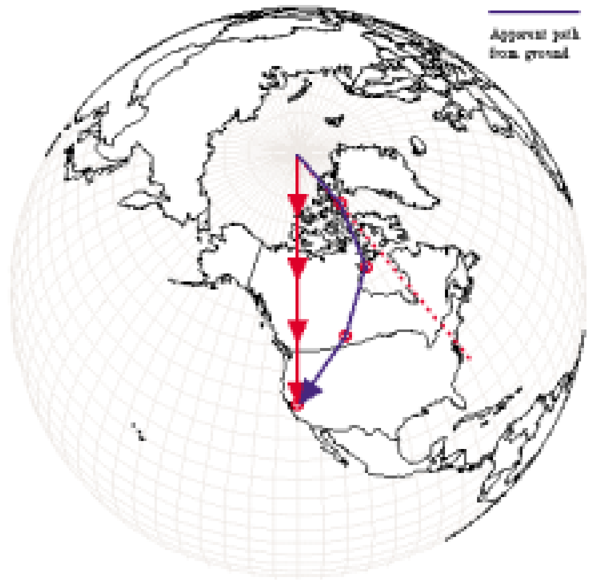
After 2 hours:



After 3 hours:



After 4 hours:



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Understanding the Link Between Coriolis and Weather

Why Do Objects Follow a Curved Path as Earth Rotates?

Most of us know that the Earth rotates in an easterly direction, but few appreciate that the surface of the Earth rotates at different speeds at different latitudes. This phenomenon is best illustrated at the extremes. Both the poles and the equator have to make a full rotation in 24 hours, but the circumference of Earth near the poles is much smaller than that of the equator; therefore, the equator has to spin much "faster" relative to regions near the poles. In fact, a point on the equator travels at ~1,640 kph, while a point 100 kilometres south of the North Pole travels at only ~6 kph. For a typical Manitoba student, the ground has a rotational velocity of ~1,000 kph in an easterly direction. This rotational speed decreases as one travels further north toward the pole, and is zero at the North Pole.

Earth's atmosphere and ocean exhibit numerous instances of horizontal motions along curved paths. Near-surface winds spiral into low-pressure areas and out of high-pressure areas. Ocean currents flow in huge almost circular gyres thousands of kilometres across. Other objects, including planes and boats, freely moving horizontally almost everywhere on Earth (except at the equator) turn right or left. The turning of these moving object's paths, as seen from our vantage point on Earth, is the **Coriolis effect**.

Why does this curved motion occur? Aren't objects that are moving 'freely" (not held down) in horizontal directions supposed to move in straight paths? As described by Sir Isaac Newton's First Law of Motion, an object in motion should remain in motion in a straight line, unless acted upon by an external force. But, there is no horizontal force acting on an object moving freely across the Earth's surface to cause it to turn right or left. Yet, except at the equator, the moving object is apparently deflected. If there is no horizontal force acting to make this happen, there must be another explanation. There is! The Earth is turning underneath the moving object; that is, the Earth rotates.

All motion must be measured with respect to something, and the Earth is our frame of reference. The Earth is so immense that we usually think of it as being unmoving. That is why objects that are moving horizontally and freely appear to turn to the right or left. Actually, it is the Earth that is turning underneath as the objects move forward.

The effect of the Earth's rotation on horizontally moving objects is greatest at the poles. The Coriolis deflection decreases as latitude decreases, until it is zero at the equator. In the Northern Hemisphere, the sense of the Earth's rotation is counterclockwise as seen from above the North Pole. Consequently, moving objects always appear to turn rightward in the Northern Hemisphere. The reverse happens in

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the Southern Hemisphere because of the clockwise sense of our planet's rotation when looking down from above the South Pole. There, horizontally moving objects appear to turn toward the left.

Scientists account for the Coriolis effect by inventing an imaginary force called the **Coriolis "force."** This imaginary Coriolis "force" is applied in combination with real forces, such as the air pressure gradient force and friction, to explain motions of objects in terms of Newton's laws. The Coriolis "force" is defined as always acting perpendicular to the direction of motion: to the right in the Northern Hemisphere to explain rightward turning, and to the left in the Southern Hemisphere to describe leftward turning. It is all necessary because the Earth turns!

Basic Understandings About Earth to Appreciate the Coriolis Effect

Motion or Objects (Revisiting "In Motion" from Cluster 3)

1. Motion describes the continuous change of location of an object.
2. All motion is relative; that is, motion must be measured from a frame of reference. Most of the time we use the Earth as our frame of reference, such as when we measure the speed of a car. But persons walking in a traveling airliner, ship, or train car use the airliner, ship, or train as their frame of reference.
3. The term "speed" describes how fast an object is moving. Speed is the magnitude of motion. Motion can be described fully by indicating both speed and direction. Such fully described motion is called velocity, and was described as a **vector quantity** in Cluster 3, In Motion.
4. Motion results from forces (pushes or pulls) acting on an object. Sir lsaac Newton studied motion and devised basic laws to describe his findings. His First Law indicates that an object at rest tends to stay at rest and a moving object moves in a straight line at a constant speed, unless acted upon by an outside force. Another of his laws describes how an outside force can speed up or slow down the object, or it can change the direction of the object's motion.

Horizontal Motions Near Earth's Surface

5. Objects moving horizontally and freely (unconstrained and not being acted upon by an outside horizontal force) across the surface of the Earth at the equator follow paths that are straight relative to the Earth's surface, as described by Newton's First Law of Motion.
6. Objects moving horizontally and freely across the surface of the Earth everywhere except at the equator follow paths that are curved as measured from Earth. In the Northern Hemisphere, they turn towards the right of the direction of motion and in the Southern Hemisphere they turn left. This deflection is called the Coriolis effect, after Gustave-Gaspard de Coriolis.

7. The observed Coriolis effect arises because the Earth is rotating and, in locations not on the equator, is actually turning underneath as a horizontally and freely moving object travels forward. Because the motion is being measured relative to the Earth, the motion appears to be along a curved path.
8. Anywhere in the Northern Hemisphere, the sense of the Earth's rotation is counterclockwise as seen from above the North Pole. Consequently, the observed curved motion is always to the right of the direction of motion.
9. Anywhere in the Southern Hemisphere, the sense of the Earth's rotation is clockwise as seen from above the South Pole. Consequently, the observed curved motion is always to the left of the direction of motion.
10. Because there is no turning of the surface of the Earth (sense of rotation) underneath a horizontally and freely moving object at the equator, there is no curving of the object's path as measured relative to the Earth's surface. The object's path is straight; that is, there is no Coriolis effect.
11. The Earth's rotational effects on horizontally and freely moving objects are greatest at the poles; therefore, the Coriolis effect is greatest at the poles.
12. As the latitude at which horizontally and freely moving objects are located decreases, the twisting of the underlying Earth's surface due to the planet's rotation decreases. That is, the Coriolis effect decreases as the latitude decreases. It is maximum at the poles and absent at the equator.

The Coriolis "Force"

13. The Coriolis effect arises because motion is being measured from a rotating frame of reference. There are no outside forces acting on a horizontally moving object that causes the observed curved motion.
14. Scientists have invented an imaginary force, called the Coriolis force, to account for the Coriolis effect. This has been done so that Newton's Laws of Motion can be applied to movements measured relative to the Earth's surface.
15. The Coriolis force is defined as always acting perpendicular to the direction of motion. Because the sense of the Earth's rotation as seen from above in the Northern Hemisphere is opposite to that in the Southern Hemisphere, it is further defined as always acting to the right in the Northern Hemisphere and always to the left in the Southern Hemisphere.

Mathematics Connection

16. The Coriolis force is also defined as being directly proportional to the sine of the latitude to account for the increasing curvature of paths as latitude increases. The trigonometric function sine is zero at an angle of 0 degrees (equatorial latitude) and 1 (maximum) at an angle of 90 degrees (polar latitude).

SLA
Student
Learning
Activity

It Bends Because the Earth Turns

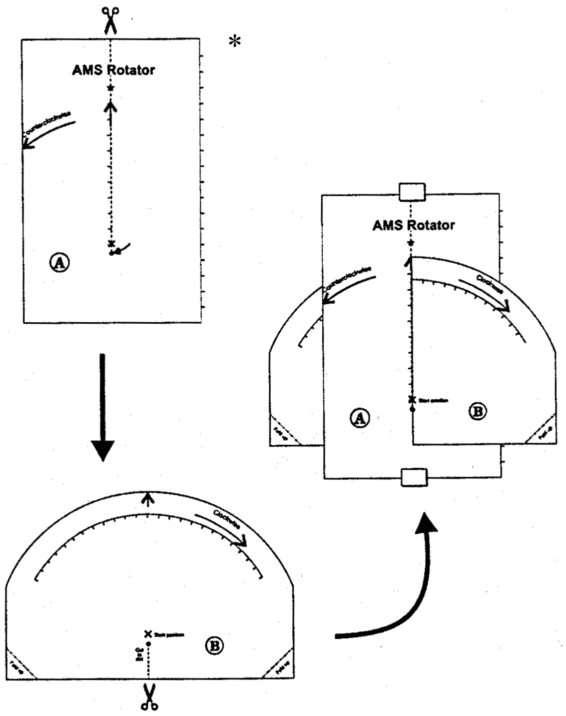
Introduction

Almost everywhere on Earth (except at the equator), objects moving horizontally and freely (unconstrained) across the Earth's surface travel in curved paths. Objects, such as planes, boats, bullets, air parcels, and water parcels, turn right or left as seen from our vantage point on Earth. This activity investigates the reason for this turning, a phenomenon known as the Coriolis effect.

Directions

First construct the **AMS Rotator** device that appears on page A84. As outlined in the diagrams, cut out the two large pieces, labeled "A" and "B," plus the "straight-edge." Cut along the dashed lines on "A" and "B" only as far as the dots. Fit "A" and "B" together as shown in the drawing, making sure that the dot on "A" coincides with the dot on "B." Lay the device flat on the desk in front of you with the cut end of "A" positioned away from you. Now tape "A" to your desk at the two places indicated at the midpoints of the far and near edges of "A," making sure that "B" can rotate freely. Fold up the bottom two corners of "B" as shown. Gripping these tabs, practise rotating "B" so that the two dots always coincide. Note that a straight scale is drawn on "A" along the cut edge and a curved scale is drawn on "B."

The following diagrams should assist you in constructing the **AMS Rotator**....



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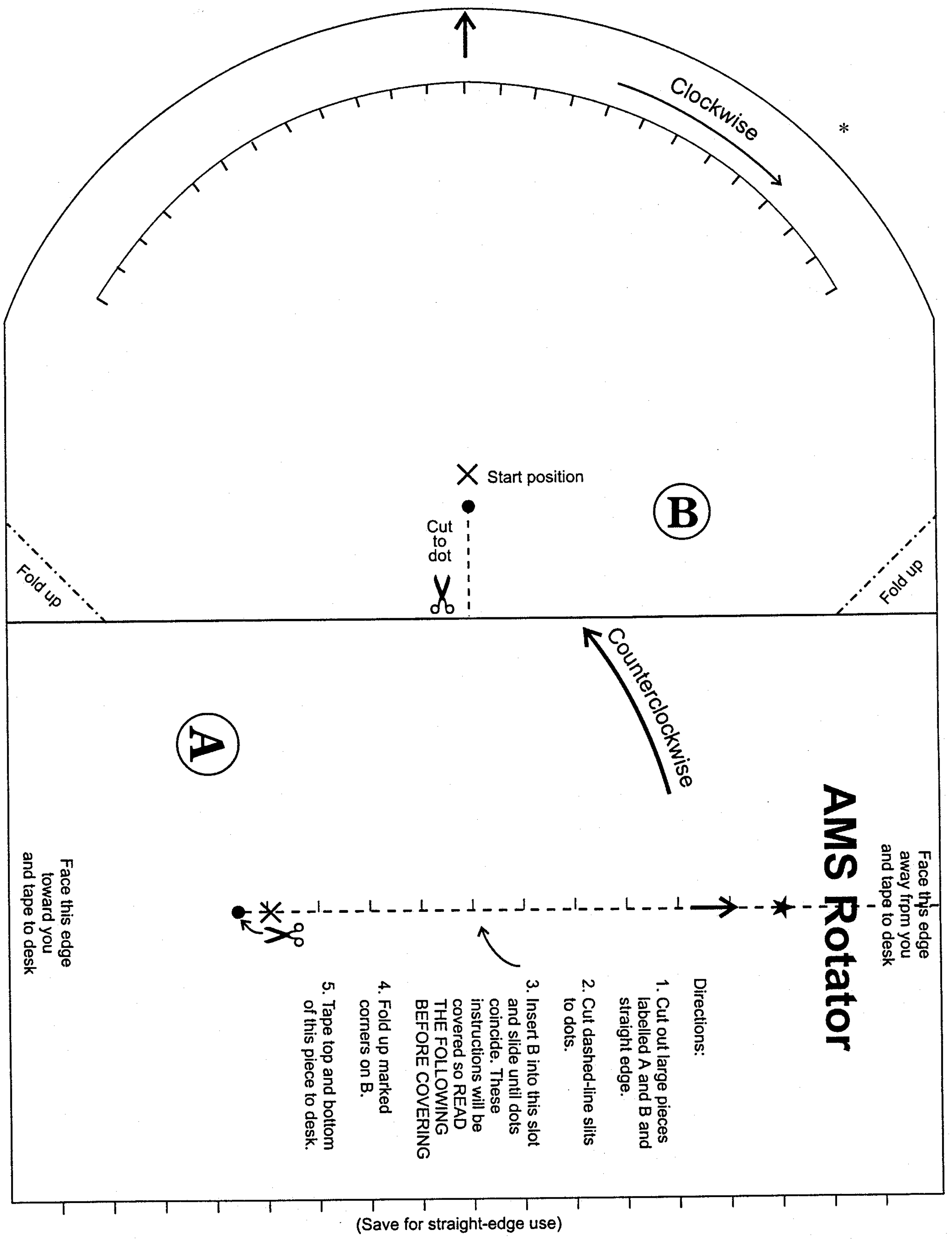

AMS Rotator

Directions:

1. Cut out large pieces labelled A and B and straight edge.
2. Cut dashed-line slits to dots.
3. Insert B into this slot and slide until dots coincide. These instructions will be covered so READ THE FOLLOWING BEFORE COVERING
4. Fold up marked corners on B.
5. Tape top and bottom of this piece to desk.

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Student Investigations

Where options are contained in [brackets], students CIRCLE the response that they believe is the correct one

1. Orient B in the “cross” position as shown in the drawing. If positioned properly, a straight arrow should point towards the ★. Place your pencil point at the centre of the Start Position X. Carefully draw a line on B along the cut edge and directly towards the ★. The line you drew represents a path that is **[(straight) (curved)]**.
2. Now investigate how rotation affects the path of your pencil lines. Again, begin with B in the “cross” position with the direction arrow pointing towards the ★. Pulling the lower left tab towards you, rotate B counterclockwise through one division of the curved scale (on B). Make a pencil dot on B along the straight scale at one scale division above the Start Position X. Continue rotating B counterclockwise one division at a time along the curved scale, stopping each time to mark a pencil dot on B at each successive division along the straight scale. Repeat these steps until you reach the curved scale. Starting at X, connect the dots with a smooth curve. Place an arrowhead at the end of the line to show the direction of the motion. The line you drew on B is [**(straight) (curved)**].
3. You actually moved the pencil point along a path that was both straight and curved at the same time! This is possible because motion is measured relative to a frame of reference. (A familiar frame of reference is east-west, north-south, up-down.) In this activity, you were using two different frames of reference: one fixed and the other rotating. When the pencil-point motion was observed relative to the fixed A and ★, its path was **[(straight) (curved)]**. When the pencil motion was measured relative to B, which was rotating, the path was **[(straight) (curved)]**.
4. Begin again with B in the “cross” position and the arrow pointing towards the ★. Pulling the lower right tab towards you, rotate B clockwise one division of the curved scale and make a pencil dot on B along the straight scale at one scale division above the Start Position X. Continue in similar fashion as you did in Item 2 to determine the path of the moving pencil point. The path was straight when the pencil-point motion was observed relative to **[(A) (B)]**. The path was curved when the pencil motion was measured relative to **[(A) (B)]**.
5. Imagine yourself shrunk down in size, located at X, and looking towards the ★. You observe all three situations described above (i.e., no motion of B, counterclockwise rotation, and clockwise rotation). From your perspective at the X starting position, in all three cases the pencil point moved towards the ★ along a **[(straight) (curved)]** path.
6. Watching the same motion on B, the pencil path was straight in the absence of any rotation. However, the pencil path curved to the **[(right) (left)]** when B rotated counterclockwise. When the rotation was clockwise, the pencil path curved to the **[(right) (left)]**.

   This apparent deflection of motion from a straight line in a rotating co-ordinate system is called the Coriolis effect for Gustave-Gaspard de Coriolis (1792–1843) who first explained it mathematically. Because the Earth rotates, objects moving freely above its surface, except at the equator, exhibit curved paths.

7. Imagine yourself far above the North Pole, looking down on the Earth below. Think of B in the AMS Rotator as representing Earth. As seen against the background stars, the Earth rotates in a counterclockwise direction. From your perspective, an object moving freely across the Earth's surface would move along a **[(straight) (curved)]** path relative to the background stars (depicted by the ★ on the AMS Rotator). Now think of yourself on the Earth's surface at the North Pole at the dot position while watching the same motion. From this perspective, you observe the object's motion relative to the Earth's surface. You see the object moving along a path that **[(is straight) (curves to the right) (curves to the left)]**.
8. Imagine yourself located far above the South Pole. As seen against the background stars, the Earth rotates in a clockwise direction. The sense of rotation is reversed from the North Pole because you are now looking at the Earth from the opposite direction. An object moving freely across the Earth's surface is observed to move along a **[(straight) (curved)]** path relative to the background stars. Now think of yourself on the Earth's surface at the South Pole while watching the same motion. From this perspective, you observe the object's motion relative to the Earth's surface. You see the object moving along a path that **[(is straight) (curves to the right) (curves to the left)]**.
9. In summary, the Coriolis effect causes objects freely moving horizontally over Earth's surface to curve to the **[(right) (left)]** in the Northern Hemisphere and to curve to the **[(right) (left)]** in the Southern Hemisphere.

Further Investigations

1. Again, begin with B in the "cross" position. Create paths that originate on the straight scale at one division below the curved scale and move toward the original Start Position (X). Do this for B rotating clockwise and then counterclockwise. Earlier we found that curvature to the right was associated with counterclockwise rotation and curvature to the left was associated with clockwise rotation. In these cases, the same associations between curvature and direction of rotation **[(apply) (do not apply)]**.
2. Try moving across B while it rotates by using the straight edge as a pencil guide. Orient the straight edge at a right angle to the cut edge in A, about halfway between X and the ★, and tape its ends so that B rotates freely. While rotating B counterclockwise, draw a line several scale units long from left to right beginning at the cut edge. Repeat the process for B rotating clockwise. Curvature was to the **[(right) (left)]** with counterclockwise rotation and to the **[(right) (left)]** with clockwise rotation.
3. Investigate changes in the relative speed of rotation and the curvature by moving one division along the straight scale for every two divisions of the curved scale, or two divisions of the straight scale for every one of the curved scale. Does the direction of curvature change? Does the amount of curvature change?

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SLA
Student
Learning
Activity

Coriolis Deflection and Earth Latitude

Introduction

The Coriolis deflection is greatest at the North and South Poles and is absent at the equator. What happens to the Coriolis deflection at latitudes in between? The purpose of this activity is to investigate how the Coriolis effect changes with latitude. You may recall from earlier discussions that the significance of the Coriolis depends upon where you are on Earth. In this activity, you will construct your own generalizations concerning the influence of the Coriolis effect on objects moving horizontally and freely over different latitudes. It assists in understanding why there are no rotating storms near the equator, but they are common at higher latitudes such as where Manitoba is located.

Materials

- Transparent plastic in a hemispheric shape, 10 to 15 cm (4 to 6 inches) in diameter
- Scissors
- Tape
- Washable overhead-projection pen or other washable-ink pen that writes on plastic
- **AMS Rotator**

Directions

The plastic hemisphere represents the Earth's Northern Hemisphere surface. Place the hemisphere on the AMS Rotator (taped flat on your desk) so that the pole position of the hemisphere is directly above the rotational axis (dot location) of the **AMS Rotator**.

1. With your eyes about one-half metre above the hemisphere, look down at the curved line you drew on B in Item 2 of the *Because the Earth Turns* activity in Appendix 4.7. Using the overhead-projection pen, draw on the hemisphere surface the path of the curved line as viewed from your perspective. Examine the curve that you drew on the hemisphere's surface. The curvature of the path **[(decreases) (increases)]** as the latitude decreases. This happens because the effect of the Earth's rotation on freely moving objects is greatest in a plane (flat surface) oriented perpendicular to Earth's rotational axis (i.e., at one of the poles). As the plane representing the surface of the Earth tilts more and more from this perpendicular position, the effects of the rotation on motion along that plane decreases. This activity visually depicts this change.
2. Consequently, the effect of the Earth's rotation on horizontally moving objects becomes less and less with decreasing latitude. At the equator, an object moving freely across the Earth's surface would exhibit no deflection due to the Earth's rotation. Stating it another way, the Coriolis deflection increases with increasing latitude. The change in deflection varies as the sine of the latitude. The sine of 0 degrees (equator) is 0, no Coriolis deflection; the sine of 90 degrees (poles) is 1, the maximum Coriolis deflection. The sine of 45 degrees is 0.707, so at 45 degrees latitude the Coriolis deflection is 0.707 of what it is at 90 degrees latitude.

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SLA
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Activity

Convection Currents

Purpose

To model convection currents generated by temperature differences in a fluid.

Materials

- Hot water
- Cold water
- Red and blue food colouring
- Five polystyrene cups
- Eyedropper
- Clear plastic or glass tray (e.g., 8 x 8 or 8 x 12 baking dish)

Procedure

1. Fill the clear tray with cold water. Place the tray on top of four inverted polystyrene cups. Be sure the tray is well supported and stable.
2. Fill the fifth cup with hot water. Slide it under the centre of the tray.
3. Gently add a few drops of red food colouring to the bottom of the tray, directly above the heat source (hot water).
4. Add a few drops of blue food colouring to the bottom, outside edge of the tray.
5. Observe for 5–10 minutes.

Questions

1. Which way does the warm water move?
2. Which way does the cold water move?
3. Sketch a diagram of your observations.
4. a. Is warm water more or less dense than cold water?
   b. Do warm water molecules move faster or slower than cold water molecules?
5. Where can we find convection currents?
6. Predict what would happen if the tray held hot water and a cup of ice water was placed under the tray. Sketch a diagram to explain your prediction.

Explanation

The heat source warms the water directly above it. Warm water molecules are less dense and move faster than cold water molecules. The warm water molecules rise to the surface and are pushed to the edges of the tray by the molecules that follow. As they reach the edge of the tray, they cool, become more dense, and sink to the bottom. As cool water molecules, they now are drawn to the centre and heated. The cycle continues as long as there is a temperature difference.

SLA
Student
Learning
Activity

The Atmosphere-Ocean Connection: El Niño and La Niña
(For Further Exploration)

After completing this set of activities, you will be able to:

- Describe the characteristics of an El Niño event (the Southern Oscillation), such as sea-surface temperatures and trade wind circulation
- Contrast an El Niño event with a contrasting event known as a La Niña
- Describe, on a global scale, the environmental effects—particularly weather changes—that result from an El Niño event in the Pacific Ocean
- Conduct an Internet "webquest" in order to learn more about how El Niño and La Niña events alter Canadian climate in the short-term

Key Words

- El Niño/La Niña
- El Niño and Southern Oscillation (ENSO)
- Wind and ocean currents in tropical Pacific Ocean
- Sea-surface temperature
- Thermocline

Introduction

The term El Niño originally described a weak warming of the ocean water that ran southward along the coast of Peru and Ecuador around the time of the Winter Solstice each year, resulting in poor fishing. Today, El Niño refers to a large-scale disturbance of the ocean and atmosphere in the tropical Pacific. A persistent El Niño can be accompanied by major shifts in planetary-scale atmospheric and oceanic circulations and weather extremes that bring major ecological, social, and economic disruptions world-wide.

Most of the time, westward-blowing trade winds drive warm surface water westward, away from the west coast of South America. In the western tropical Pacific, this pool of transported warm surface water results in low air pressure and abundant rainfall. In the eastern tropical Pacific, the warm surface water is replaced by colder water that wells up from below, a process known as upwelling. Relatively cold surface water favours high air pressure and meagre precipitation. Upwelling also exposes nutrient-rich water from below to sunlight, stimulating the growth of phytoplankton, which supports fisheries.

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The first sign of El Niño in progress is a weakening of the trade winds. Normally, the contrast between relatively high air pressure over the eastern tropical Pacific and low air pressure over the western tropical Pacific drives the trade winds. With the onset of El Niño, air pressure falls over the eastern tropical Pacific and rises in the west, with the greatest pressure drop over the central Pacific. As the air pressure gradient across the tropical Pacific weakens, trade winds slacken and may even reverse in the west. The see-saw variation in air pressure between the western and central tropical Pacific is known as the Southern Oscillation. El Niño and Southern Oscillation are abbreviated as **ENSO**.

During El Niño, changes in atmospheric circulation over the tropical Pacific are accompanied by changes in ocean currents and **sea-surface temperature** (SST) patterns. The pool of warm surface water normally driven westward by the trade winds now drifts eastward. At the same time, changes take place in the thermocline, the zone of transition between relatively warm surface water and cold deep water. The thermocline sinks in the east, greatly weakening or even cutting off cold-water upwelling along the west coast of South America. Changes in the trade wind circulation alter tropical weather patterns. In turn, these changes shift the planetary-scale winds, including jet streams, that steer storms and air masses at higher latitudes, causing weather extremes in many areas of the globe outside of the tropics.

El Niño, lasting an average 12 to 18 months, occurs about once every two to seven years. Ten El Niños occurred during a recent 42-year period, with one of the most intense of the century in 1997-98. Sometimes, but not always, El Niño alternates with La Niña, a period of unusually strong trade winds and vigorous upwelling over the eastern tropical Pacific. During La Niña, changes in SSTs and extremes in weather are essentially opposite those observed during El Niño.

Basic Understandings—El Niño

El Niño, the Southern Oscillation, ENSO, and La Niña

Originally, El Niño was the name given by Peruvian fishermen to a period of warm waters and poor fishing that often occurred in late December.

Today, El Niño refers to a significant departure from the average state of the ocean-atmosphere system in the tropical Pacific that has important consequences, including those for weather and climate in the tropics and other regions of the globe.

The Southern Oscillation is a see-saw variation in air pressure between the central and western tropical Pacific. These pressure changes alter the strength of the trade winds and affect surface ocean currents as parts of El Niño. Scientists often combine El Niño and the Southern Oscillation as the acronym, ENSO.

The occurrence of ocean/atmosphere conditions essentially opposite those of El Niño is called La Niña. La Niña sometimes, but not always, alternates with El Niño.

Long-Term Average Conditions in the Tropical Pacific

Normally, strong trade winds drive warm surface water westward and away from the west coast of South America.

In the tropical eastern Pacific, colder water rising up from the depths replaces the warm surface water that is driven westward from the area, a process called upwelling.

Upwelling delivers cold nutrient-rich water from below into sunlit surface regions, greatly enhancing biological productivity. Most of the important commercial fisheries are located in areas of upwelling.

In the tropical eastern Pacific, offshore transport of warm surface water results in a locally lower sea level, a rise in the thermocline (the transition zone separating warmer surface water from colder deep water), and a drop in sea-surface temperature. Cooler surface waters are responsible for relatively high air pressure and mostly fair weather. Low precipitation amounts over adjacent land areas give rise to desert conditions.

Piling up of wind-driven warm surface water in the western tropical Pacific causes a higher sea level, a deeper thermocline, and higher sea-surface temperatures than in the central and eastern tropical Pacific. Warm surface waters produce relatively low air pressure and spur atmospheric convection that is responsible for heavy rainfall.

El Niño Conditions in the Tropical Pacific

During El Niño, the trade winds are weaker than average over the tropical Pacific and may even reverse direction, especially in the west.

In the tropical western Pacific, weakening or reversal of the trade winds causes the pool of warm surface water in the western tropical Pacific to drift eastward along the equator toward the coast of South America.

In the tropical western Pacific, an eastward transport of warm surface water is accompanied by a drop in sea level and a rise in the thermocline. Slightly cooler surface waters produce higher than usual air pressure, weaker atmospheric convection, and reduced rainfall.

Arrival of the pool of warm surface water along the coast of South America greatly diminishes or eliminates upwelling of nutrient-rich cold bottom water so that biological productivity declines sharply.

In the tropical eastern Pacific, the piling up of warm surface water results in a local rise in sea level, a deeper **thermocline**, and higher sea-surface temperatures. Warm surface waters produce relatively low air pressure and enhance atmospheric convection that brings higher than usual amounts of rainfall.

The concurrent rise in air pressure over the western tropical Pacific and fall in air pressure over the central tropical Pacific (which weakens the trade winds) is part of a regular see-saw variation in surface air pressure known as the Southern Oscillation.

Global El Niño and La Niña Conditions

Changes in oceanic and atmospheric circulation in the tropical Pacific affect weather and climate in the tropics and well beyond.

Temperature governs the rate at which water molecules escape a water surface and enter the atmosphere; that is, warm water evaporates more readily than cool water. Regions of relatively warm surface waters heat and add moisture to the atmosphere. Thunderstorms more readily develop in this warm, humid air. Towering thunderstorms help shape the planetary-scale atmospheric circulation, altering the course of jet streams and moisture transport at higher latitudes.

Changes in the planetary-scale atmospheric circulation during El Niño and La Niña often give rise to weather extremes, including drought and excessive rainfall, in many areas of the globe outside the tropics.

No two El Niño or La Niña events are exactly the same, so that in some areas weather extremes may or may not accompany a particular El Niño or La Niña.

In Canada, El Niño winters tend to be mild and less wet than normal. The exceptions are the Atlantic provinces and the territory of Nunavut in the Canadian Arctic, which are usually milder but wetter than normal. La Niña, on the other hand, usually results in colder temperatures in Canada in winter. La Niña winters are usually also wetter than normal in western Canada, southern Ontario and Quebec, and the Atlantic provinces, while being drier than normal elsewhere.

Ecological, Social, and Environmental Impacts

Many aspects of the environment and global economy are affected by variations in the ocean/atmosphere system of the tropical Pacific. These impacts also have human and social consequences. Some of the larger impacts of El Niño and La Niña are experienced by developing countries in the tropical and subtropical regions that are most vulnerable to climate catastrophes.

Too little or too much precipitation can have devastating effects. In some areas, drought, especially when accompanied by high temperatures, causes crops to wither and die, reduces the public water supply, and increases the likelihood of wildfire. In other areas, exceptionally heavy rains trigger flash flooding that drowns crops, washes away motor vehicles, destroys houses and other buildings, and disrupts public utilities.

Weather extremes associated with El Niño and La Niña have implications for public health by creating conditions that increase the incidence of diseases such as malaria, dengue fever, encephalitis, cholera, and plague. Also, smoke from wildfires in drought-stricken regions can cause respiratory problems for people living up to 1,500 kilometres from the fires.

Advance warning of El Niño and La Niña and their accompanying weather extremes could save lives and billions of dollars in property and crop damage by allowing adequate time for preparedness and development of appropriate response strategies.

More details on how El Niño can affect Canadian temperature and precipitation patterns can be found at:
<http://www.msc-smc.ec.gc.ca/elNiño/index_e.cfm>

Similarly, Canadian La Niña effects can be found at:
<http://www.msc-smc.ec.gc.ca/laNiña/index_e.cfm>

El Niño and La Niña Research

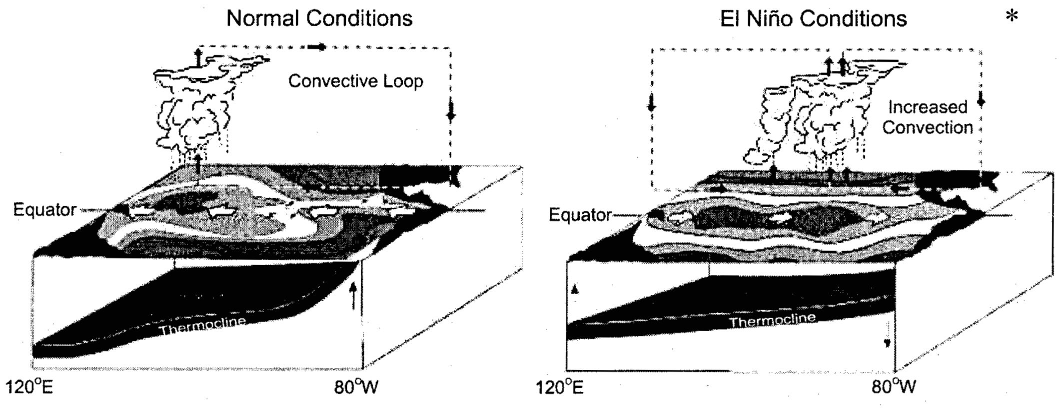
Scientists are actively investigating the tropical Pacific ocean/atmosphere system for answers to many questions including: What gets El Niño and La Niña started? Why do they stop? Why do regional impacts differ from one El Niño (or La Niña) to the next? When will scientists be able to reliably predict the duration and impact of El Niño and La Niña?

Observations of conditions in the tropical Pacific are essential for the investigation and prediction of short-term climate variations like El Niño. A wide variety of sensors are used to obtain ocean and atmospheric data from this vast and remote region of the ocean.

Satellite-borne temperature sensors and altimeters are being used to track the movement of warm surface water across the tropical Pacific. Additional information is provided by a network of buoys that directly measures temperature, currents, and winds along the equatorial band.

Predicting the onset and duration of El Niño and La Niña is critical in helping water, energy, and transportation managers, and farmers plan for, mitigate, or avoid potential losses.

Advances in El Niño and La Niña prediction are expected to significantly enhance economic opportunities, particularly for the agriculture, fishing, forestry, and energy sectors, as well as provide opportunities for social benefits.



Three-dimensional view depicting the atmospheric and oceanographic circulations over the tropical Pacific during normal conditions and then during El Niño conditions.

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Student Activity—El Niño and La Niña Web-Based Activities (“Theme Pages”)

MSC Issues and Topics <http://www.msc-smc.ec.gc.ca/contents_e.html>

Canadian El Niño page <http://www.msc-smc.ec.gc.ca/elNiño/index_e.cfm>

Canadian La Niña page <http://www.msc-smc.ec.gc.ca/laNiña/index_e.cfm>

NOAA El Niño page <http://www.pmel.noaa.gov/tao/elNiño/Niño-home.html>

The El Niño Theme Pages will help you explore the workings of the tropical Pacific marine environment. Stretching nearly one-third of the way around the globe and covering a fifth of the Earth’s surface, the tropical Pacific is a coupled ocean/atmosphere system that makes its presence known far beyond its boundaries. Its influence on world-wide weather and climate can lead to major ecological, societal, and economic disruptions. Occurrences of El Niño every two to seven years, and the less frequent occurrences of La Niña, demonstrate that there are swings in ocean/atmosphere conditions, weather, and climate that operate on other than annual timetables.

With the El Niño Theme Pages, you can investigate and compare ocean and atmospheric conditions that occur during El Niño and La Niña with long-term average conditions.

The Tropical Pacific During Long-Term Average Conditions

Examine the Basic Understandings pages, or the web-based “Theme Pages” listed above, where you will find information on “What is El Niño?” and “What is La Niña?” Click on the links found there (or consult the text earlier in this activity) to help you identify the correct answers in the statements below that have solutions contained in **[brackets]**. Circle your answers for later discussion with classmates.

The winds in the equatorial Pacific Ocean during long-term average conditions blow toward the **[(east) (west)]** and the wind speed is **[(higher) (lower)]** in the eastern Pacific than in the western Pacific.

During long-term average conditions in the equatorial Pacific Ocean, surface water flows towards the **[(east) (west)]**.

The highest sea surface temperatures (SSTs) during long-term average conditions occur in the **[(eastern) (western)]** tropical Pacific. This SST pattern is caused by relatively strong trade winds pushing Sun-warmed surface water **[(eastward) (westward)]** as evidenced by the direction of surface currents.

Strong trade winds also cause the warm surface waters to pile up in the western tropical Pacific so that the sea surface height in the western Pacific is **[(lower) (higher)]** than in the eastern Pacific. Transport of surface water to the west also causes the thermocline (the transition zone between warm surface water and cold deep water) to be **[(deeper) (shallower)]** in the eastern Pacific than in the western Pacific.

Warm surface water transported by the wind away from the South American coast is replaced by cold water rising from below in a process called upwelling. Upwelling of cold deeper water results in relatively **[(high) (low)]** SSTs in the eastern Pacific compared to the western Pacific.

Cold surface water cools the air above it, which leads to increases in the surface air pressure. Warm surface water adds heat and water vapour to the atmosphere, lowering surface air pressure. These effects result in tropical surface air pressure being **[(highest) (lowest)]** in the eastern Pacific and **[(highest) (lowest)]** in the western Pacific.

Whenever air pressure changes over distance, a force will act on air to move it from where the pressure is relatively high to where pressure is relatively low. The trade winds blow from east to the west because from east to west the surface air pressure **[(increases) (decreases)]**.

Rainfall in the tropical Pacific is also related to SST patterns. There are reasons for this relationship. The higher the SST, the greater the rate of evaporation of seawater and the more vigorous is atmospheric convention. Consequently, during long-term average conditions, rainfall is greatest in the **[(western) (eastern)]** Pacific where SSTs are **[(highest) (lowest)]**.

The Tropical Pacific During El Niño and La Niña

While no two El Niño or La Niña episodes are exactly alike, all of them exhibit most of the characteristics described in the El Niño Theme Pages. Click on the links found there (or consult the text earlier in this activity) to help you identify the correct answers in the statements below that have solutions contained in **[brackets]**.

During long-term average conditions, the surface air pressure in the central Pacific is higher than to the west. During El Niño, the surface air pressure to the west is **[(higher) (lower)]** than in the central Pacific. During La Niña, the surface air pressure to the west is **[(higher) (lower)]** than in the central Pacific. This see-saw pattern of pressure variation is called the Southern Oscillation.

In response to changes in the air pressure pattern across the tropical Pacific, the speed of the trade winds decreases (and wind directions can reverse, especially in the western Pacific). No longer being pushed toward and piled up in the western Pacific, the warm surface water reverses flow direction. This causes SSTs in the eastern tropical Pacific to be **[(higher) (lower)]** than long-term average values. Conversely, the surface water currents during La Niña flow toward the **[(east) (west)]**.

In response to surface currents, sea surface heights in the eastern tropical Pacific are **[(higher) (lower)]** than long-term average levels during El Niño events. At the same time, the arrival of the warmer water causes the surface warm-water layer to thicken during El Niño. Evidence of this is the **[(shallower) (deeper)]** depth of the thermocline compared to long-term average conditions.

In response to surface currents, sea surface heights in the eastern tropical Pacific are **[(higher) (lower)]** than long-term average levels during La Niña events. At the same time, the arrival of the warmer water causes the surface warm-water layer to thicken during La Niña. Evidence of this is the **[(shallower) (deeper)]** depth of the thermocline compared to long-term average conditions.

Differences between existing conditions and long-term average conditions are called anomalies. If readings are higher than the respective long-term averages, the anomalies are positive. If values are lower, the anomalies are negative. In the eastern tropical Pacific during El Niño, the SST anomaly is **[(negative) (positive)]**, the sea-surface height anomaly is **[(negative) (positive)]**, the surface air pressure anomaly is **[(negative) (positive)]**, and the rainfall anomaly is **[(negative) (positive)]**.

Differences between existing conditions and long-term average conditions are called anomalies. If readings are higher than the respective long-term averages, the anomalies are positive. If values are lower, the anomalies are negative. In the eastern tropical Pacific during La Niña, the SST anomaly is **[(negative) (positive)]**, the sea-surface height anomaly is **[(negative) (positive)]**, the surface air pressure anomaly is **[(negative) (positive)]**, and the rainfall anomaly is **[(negative) (positive)]**.

Continue your investigations of the tropical Pacific Ocean/atmosphere system by predicting how the changes shown by the El Niño Theme Page might affect people living along the Peruvian coast and on the island nations of the western tropical Pacific. Return back to the El Niño Theme Page to study the potential impacts of El Niño in those areas and elsewhere, including Canada.

Canadian Winter Climate Prediction

Using the Canadian El Niño or La Niña web pages or the maps at the end of this section that show average temperature and precipitation changes that occur during El Niño and La Niña conditions, give a forecast for the winter for the following Canadian cities **assuming that a La Niña will be occurring in the tropical Pacific.**

> **Example:** If a La Niña occurs this winter, Churchill, Manitoba should experience temperatures about two degrees colder than normal but with less snowfall than normal.

Write a forecast for your hometown for the upcoming winter. First, using the Canadian El Niño or La Niña web pages, find out if one of these tropical events is expected to be occurring in the upcoming winter. Second, using the maps at the end of this activity that show average temperature and precipitation changes that occur during El Niño and La Niña conditions, give a forecast for the winter for your hometown. Try **one** other Canadian city listed below—perhaps a place you would like to travel to one day—to see if there are any differences across the Canadian experience.

1. Vancouver
2. Victoria
3. Edmonton
4. Calgary
5. Regina
6. Winnipeg
7. Thunder Bay
8. Toronto
9. Ottawa
10. Quebec City
11. Montreal
12. Fredericton
13. Halifax
14. St. John’s
15. Yellowknife
16. Whitehorse
17. Iqaluit
18. Prince George
19. Kelowna

My Forecast (hometown)

Temperature Predictions:

Precipitation Predictions:

Overall Weather Picture for My Hometown in Manitoba:

My Forecast (alternate location to visit)

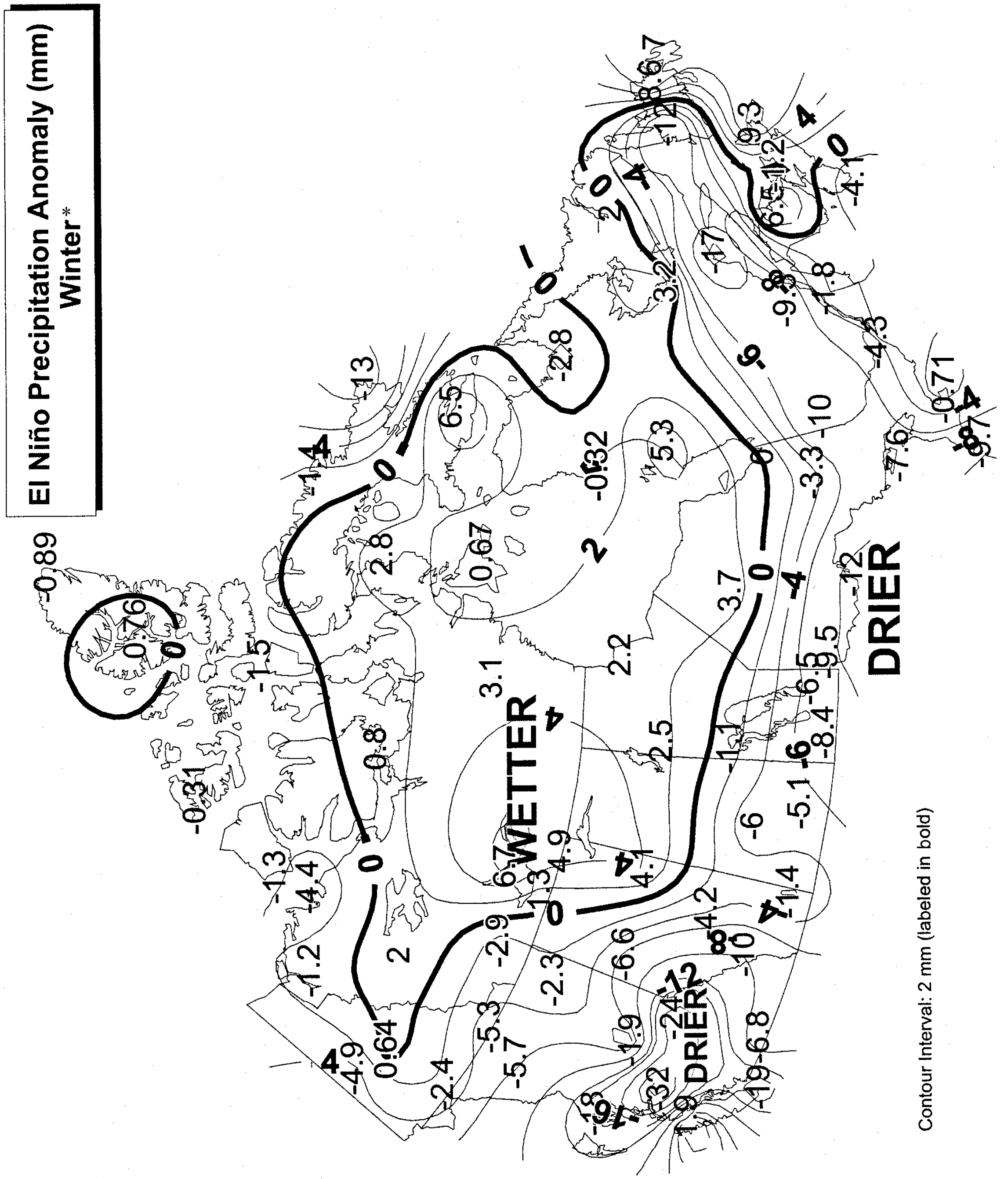
Temperature Predictions:

Precipitation Predictions:

Overall Weather Picture for City Elsewhere in Canada:

Weather Maps

Note: There are two maps for each type of event—two for El Niño and two for a La Niña. One map is for expected changes in temperature (temperature anomaly map), and the other is for expected changes in precipitation amounts (precipitation anomaly map).



El Niño Precipitation Anomaly (mm) Winter*

Contour Interval: 2 mm (labeled in bold)

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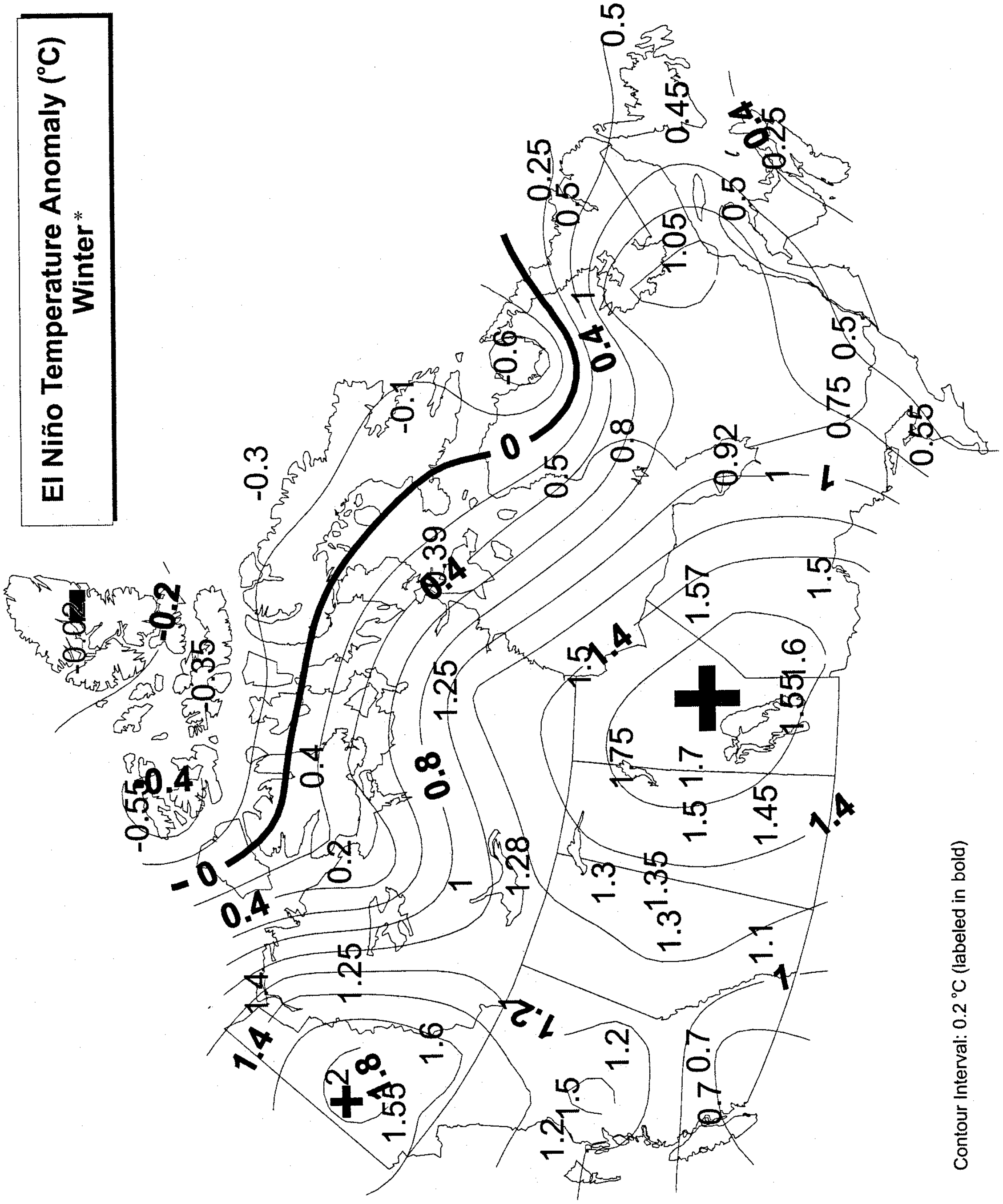

El Niño Temperature Anomaly (°C) Winter*

Contour Interval: 0.2 °C (labeled in bold)

---

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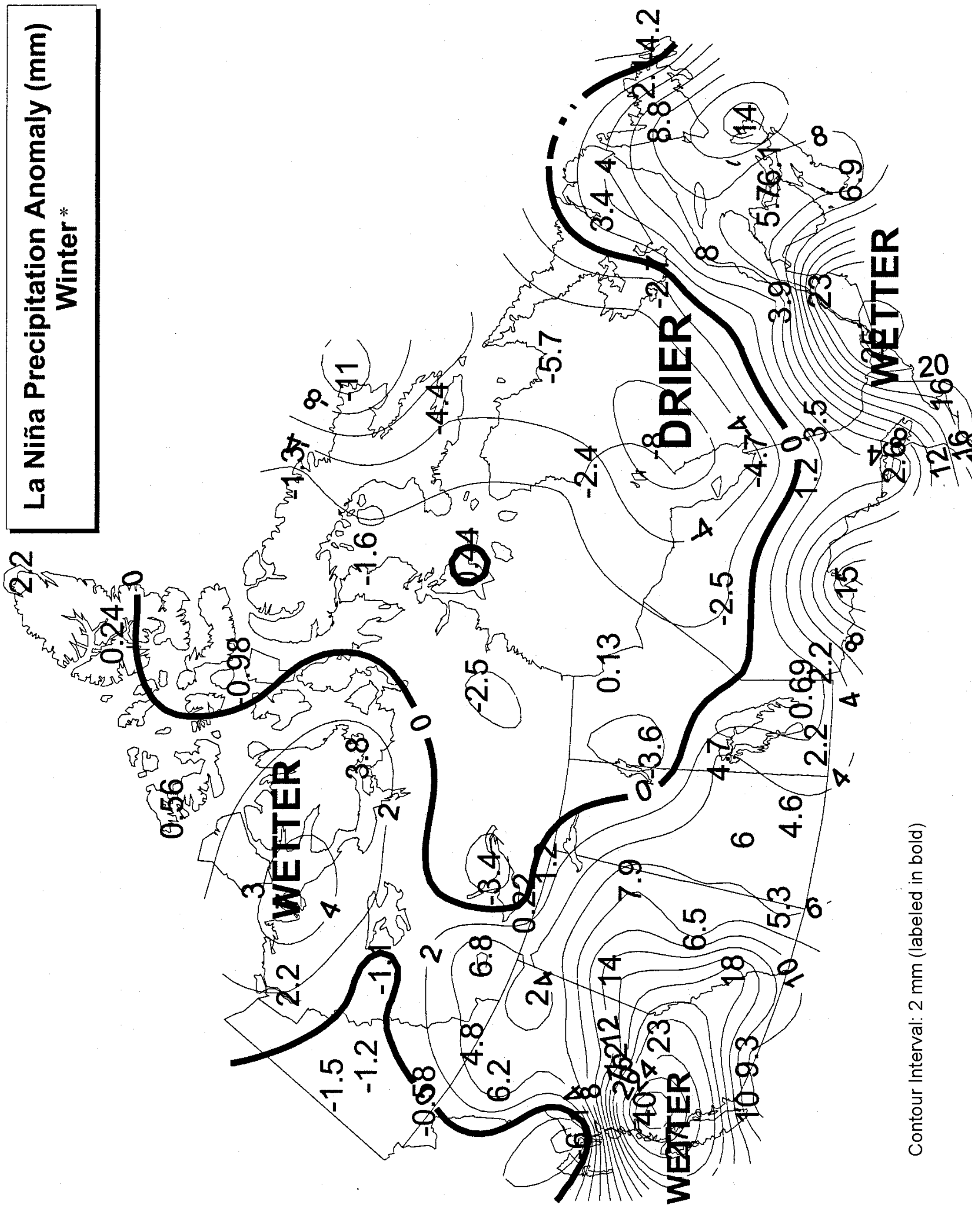

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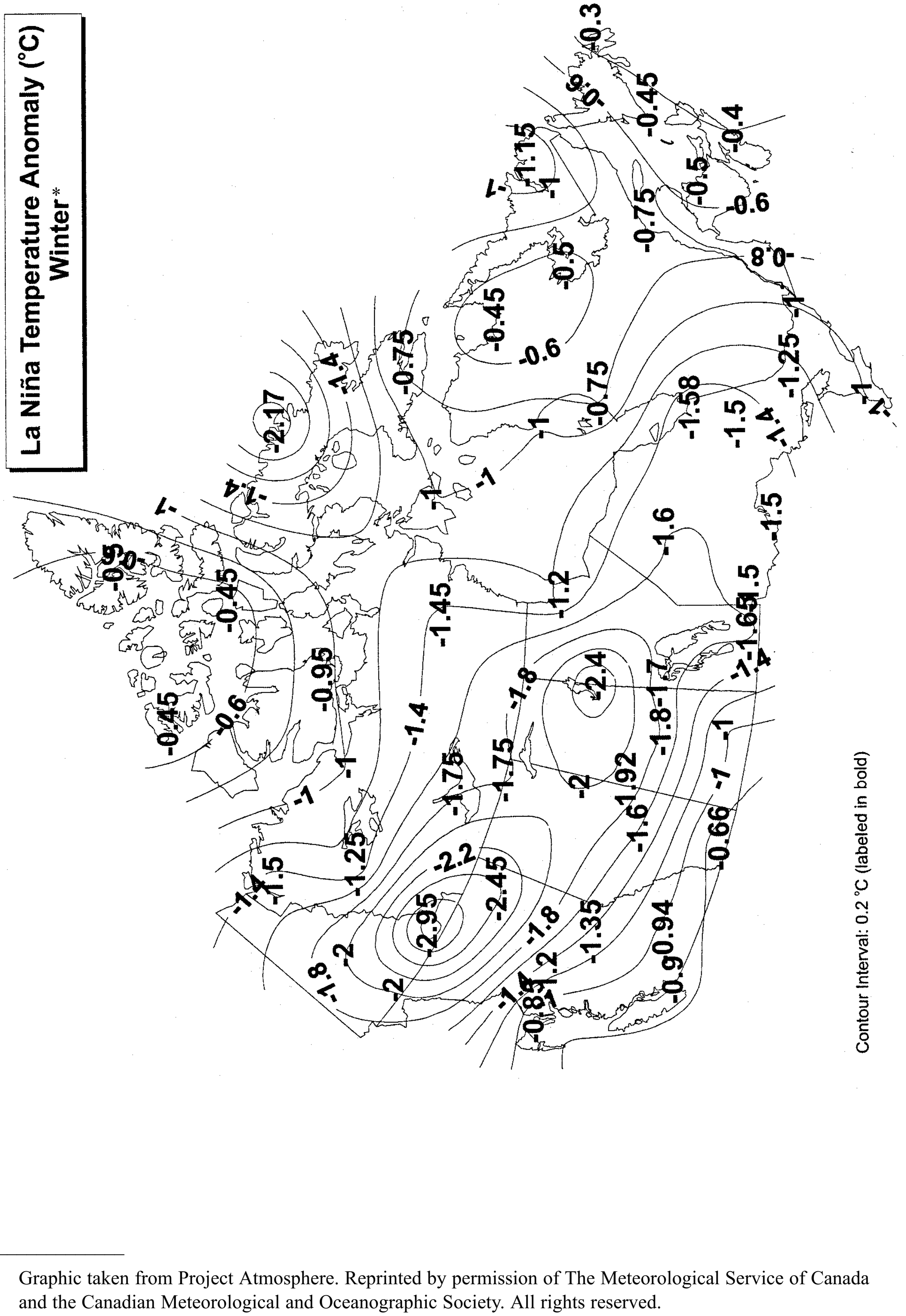
La Niña Temperature Anomaly (°C)
Winter*



Contour Interval: 0.2 °C (labeled in bold)

---

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BLM
Blackline
Master

World Map (Globe Projection)*

---

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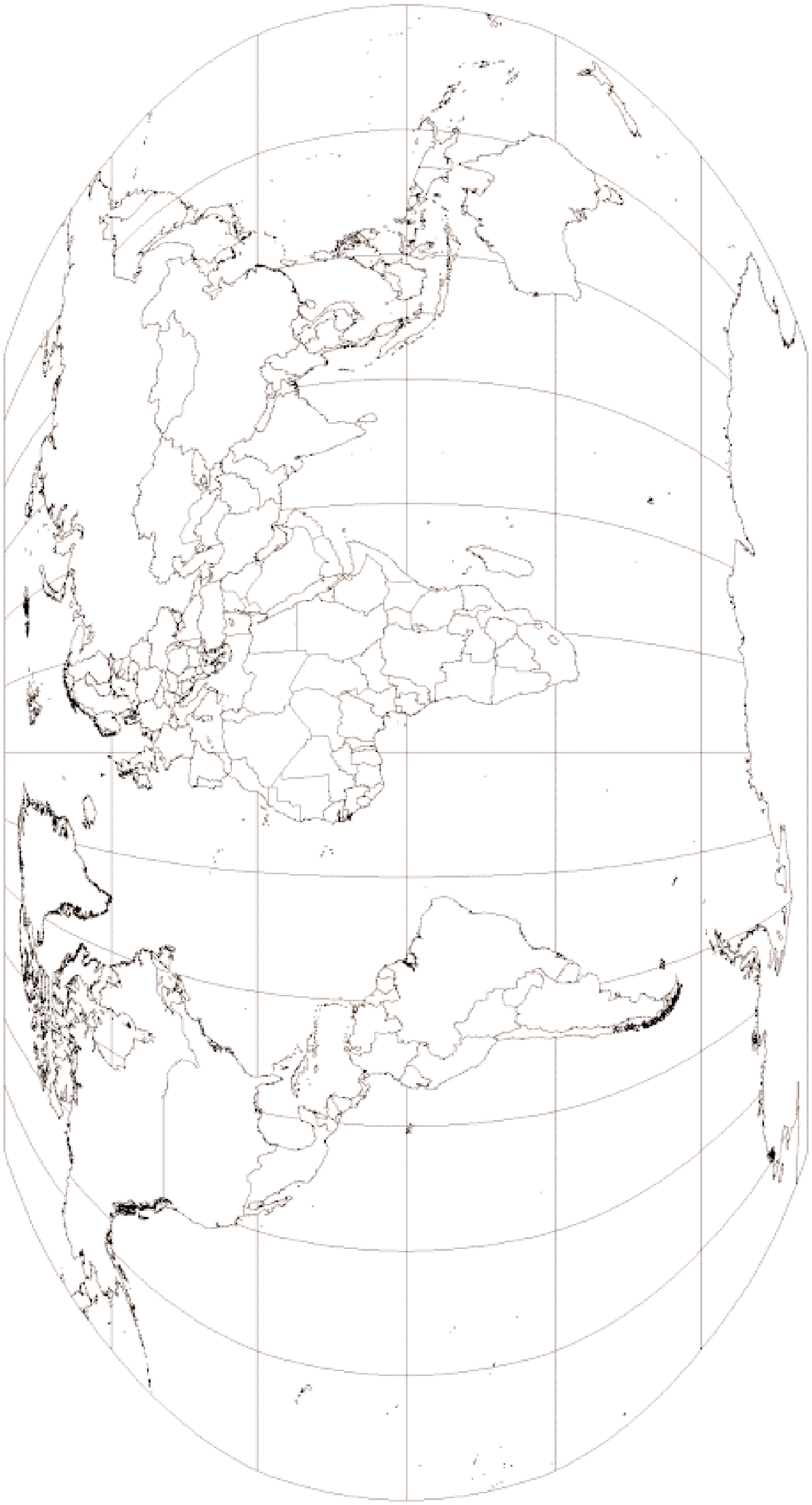
BLM
Blackline
Master

World Map*



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BLM
Blackline Master

Map of North America*

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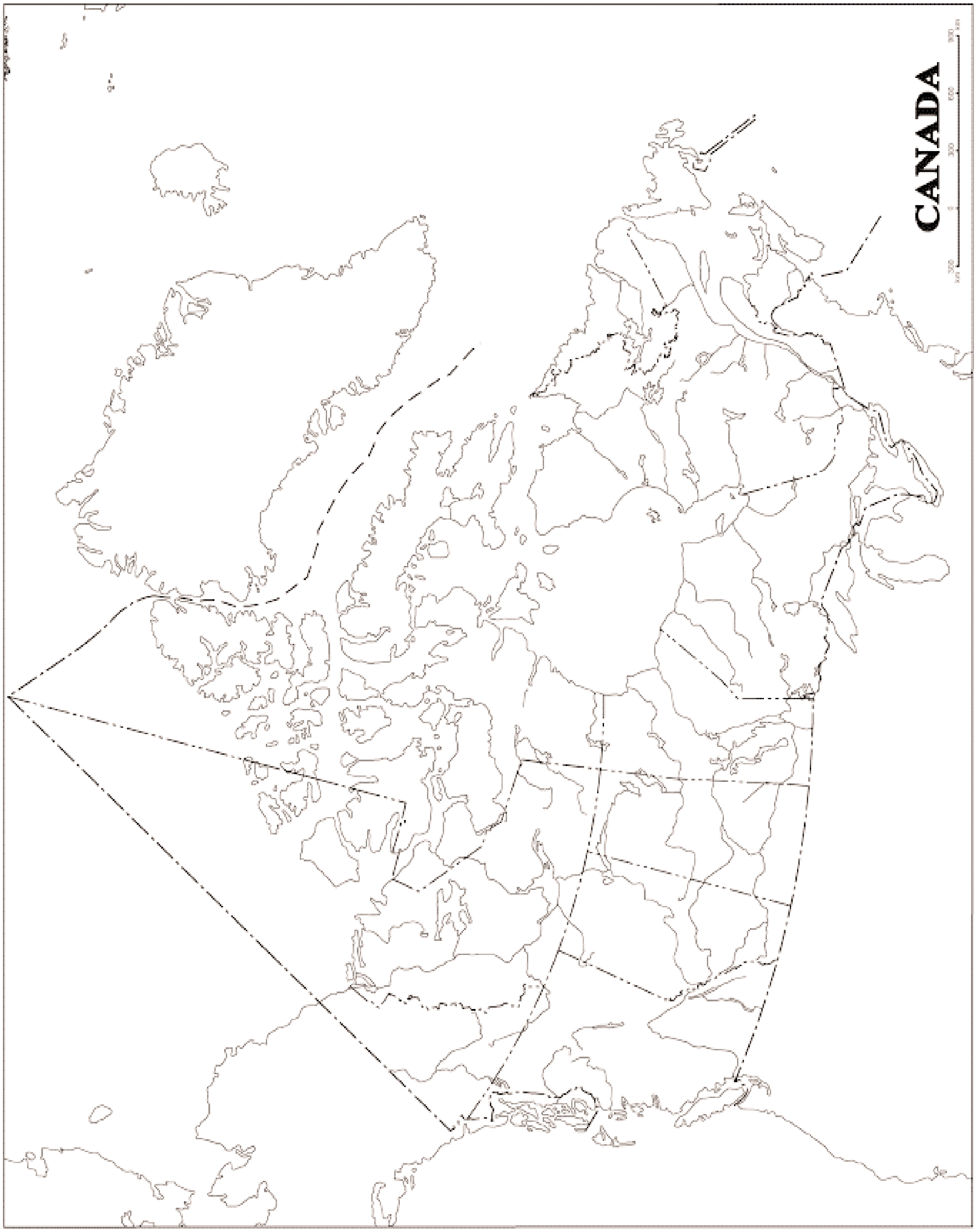
BLM Blackline Master

Map of Canada with Major Rivers*



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BLM
Blackline
Master

Circumpolar Map*

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The Beaufort Wind Scale

The Beaufort Scale was long in use as a system for estimating wind speeds. It was introduced in 1806 by Admiral Sir Francis Beaufort (1774–1857) of the British navy to describe wind effects on a fully rigged man-of-war sailing vessel, and it was later extended to include descriptions of effects on land features as well. Today the accepted international practice is to report wind speed in knots (1 knot equals a wind speed of about 1.85 km/hour).

The Beaufort scale is divided into a series of values, from 0 for calm winds to 12 and above for hurricanes. Each value represents a specific range and classification of wind speeds with accompanying descriptions of the effects on surface features, as follows:

Beaufort	Average km/h	Knots	Surroundings
0 (calm)	0	0–1	Smoke rises vertically and the sea is mirror smooth.
1 (light air)	2–5	1–3	Smoke moves slightly with breeze and shows direction of wind.
2 (light breeze)	6–12	4–6	You can feel wind on your face and hear the leaves start to rustle.
3 (gentle breeze)	13–20	7–10	Smoke will move horizontally and small branches will sway. Wind extends a light flag.
4 (moderate breeze)	21–30	11–16	Loose dust or sand on the ground will move and larger branches will sway, loose paper blows around, and fairly frequent whitecaps occur.
5 (fresh breeze)	31–40	17–21	Surface waves form on water and small trees sway.
6 (strong breeze)	41–50	22–27	Trees bend with the force of the wind, and wind causes whistling in telephone wires and some spray on the sea surface.
7 (moderate gale)	51–61	28–33	Large trees sway.
8 (fresh gale)	62–74	34–40	Twigs break from trees, and long streaks of foam appear on the ocean.
9 (strong gale)	75–89	41–47	Branches break from trees.
10 (whole gale)	90–103	48–55	Trees are uprooted, and the sea takes on a white appearance.
11 (storm)	104–119	56–63	There is widespread damage.
12 (hurricane)	120+	64+	There is structural damage on land, and there are storm waves at sea.

SLA
Student
Learning
Activity

Understanding Highs and Lows
(For Further Exploration)

After completing this activity, you will be able to:

- Draw lines of equal pressure (isobars) to show the pattern of surface air pressures on a weather map
- Locate regions of relatively high and low air pressure on a surface weather map
- Locate regions on a surface weather map exhibiting relatively large air pressure changes over short horizontal distances and broad areas with gradually varying air pressure

Key Words

- High pressure centre
- Low pressure centre
- Surface analysis maps
- Spacing of isobars
- Kilopascal, hectopascal, millibar

Introduction

The Earth's atmosphere and oceans are in continual motion. This motion results from an unequal distribution of energy within the earth-atmosphere system. Forces arise from this non-uniform distribution and work to move heat and energy from where it is warmer to where it is colder (e.g., from the tropics to mid and high latitudes). Motion is initiated by differences in pressure (pressure is the amount of force acting on a unit surface area). Atmospheric pressure is the force exerted on an object or person by the weight of the air above. Atmospheric scientists and oceanographers monitor pressure as part of their investigation of Earth's dynamic atmosphere and ocean.

The force of gravity pulls molecules and particles in the atmosphere toward the centre of the Earth. The resulting weight of the air pushing down on itself and on the surface of the planet creates atmospheric pressure. Air is treated as a fluid in the study of the dynamics of the atmosphere. Although it's common to refer to the atmosphere pressing "down," we know that pressure acts in all directions in a fluid. All sides of an object, then, are subjected to practically the same pressure. For example, atmospheric pressure pushing down on the surface of a bucket of water is transmitted equally through the liquid to the walls of the bucket and is balanced by the same atmospheric pressure acting on the outside walls of the bucket.

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In Canada, the unit of atmospheric pressure most often heard on weather broadcasts is the **kilopascal (kPa)**. The average pressure exerted by the atmosphere at sea level is one kilogram per square centimetre or 101.325 kPa. A **pascal (Pa)** is defined as "a pressure of one newton (the basic unit of force) per square metre" and is named after the 17th-century mathematician and physicist Blaise Pascal, who demonstrated that air pressure decreased with altitude. Because a pascal is such a small pressure unit, the kilopascal, which is equal to 1000 newtons per square metre, is more commonly used.

When one studies the concepts of pressure in the upper atmosphere, the common unit becomes the **hectopascal (hPa)** which is simply the kilopascal times 10 or 10,000 Pa. Scientists involved in the measurement and analysis of atmospheric pressure may also use the term **millibar** as the unit of atmospheric pressure. One millibar is equal to one hectopascal.

Atmospheric pressure can also be expressed in other units such as "pounds per square inch" and "inches of mercury," which refers back to the historical use of the mercury barometer in measuring air pressure.

Mathematics Connection

For conversion purposes, one pound per square inch equals 6.895 kPa and one inch of mercury equals 3.386389 kPa.

The analysis of the distribution of pressure on a surface weather map consists of drawing a series of lines called isobars, which connect points of equal pressure. After the isobaric analysis is completed, the familiar weather map with its highs and lows takes form.

Highs and Lows

"What's the weather?" and "What's the weather going to be?" are questions people frequently ask because weather and its changes strongly influence our activities and lives. When we are aware of current and anticipated weather, we can make informed choices that range from selecting appropriate clothing for the day to those that might be related to work and recreation. Less frequently, but by no means less importantly, the decisions and actions we take can reduce the amount of property damage and the number of injuries and fatalities due to hazardous weather.

Adequate answers to our questions about the weather can often be found on the daily weather map. Prominently featured on television and newspaper maps are the words "high" and "low" or the letters H and L. These are the symbols for centres of broad-scale pressure systems. They and their locations are key to describing and understanding probable weather conditions throughout the map area.

The highs and lows or the Hs and Ls on maps represent centres of broad regions of relatively high or low surface air pressure. They also provide information that enables meteorologists to predict possible atmospheric conditions up to a day or more in advance. Highs and lows govern atmospheric conditions throughout their expanses. Highs are generally fair weather systems. Widespread cloud and stormy weather conditions are generally associated with lows.

Mid-latitude highs and lows tend to move from west to east, changing the weather at locations along their paths. In the Northern Hemisphere, the mid- or middle latitude is the zone between the Tropic of Cancer, at latitude 23.5 degrees North, and the Arctic Circle latitude, 66.5 degrees North. Highs follow lows and lows follow highs in an endless procession. No two highs or two lows are exactly alike, but they share enough common characteristics that descriptive models of each can be employed to make sense of the weather.

One purpose of this activity is to introduce you to atmospheric pressure and the descriptive models of highs and lows. As a result of successfully completing this activity, you will be able to summarize in general terms the descriptive models of highs and lows, and the weather associated with each. You will also be able to apply these models to interpret weather maps and to describe probable current and future weather at different locations on a weather map.

Surface Air Pressure Patterns

Upon completing this activity, you should be able to:

- Draw lines of equal pressure (isobars) to show the pattern of surface air pressures on a weather map
- Locate regions of relatively high and low air pressure on a surface weather map
- Locate regions on a surface weather map exhibiting relatively large air pressure changes over short horizontal distances and broad areas with gradually varying air pressure

Materials

- Pencil

Introduction

Air pressure is determined by the weight of the overlying air, and it varies from place to place and over time. Surface air pressure is the force exerted per unit area on an object at the Earth's surface by the air above, approximately 100,000 newtons per square metre or 100 kilopascals (100 kPa). Pressure variations bring about atmospheric motions that set the stage for much of the weather we experience. Knowing the patterns of pressure is basic to understanding what the weather is and what it is likely to be where you live.

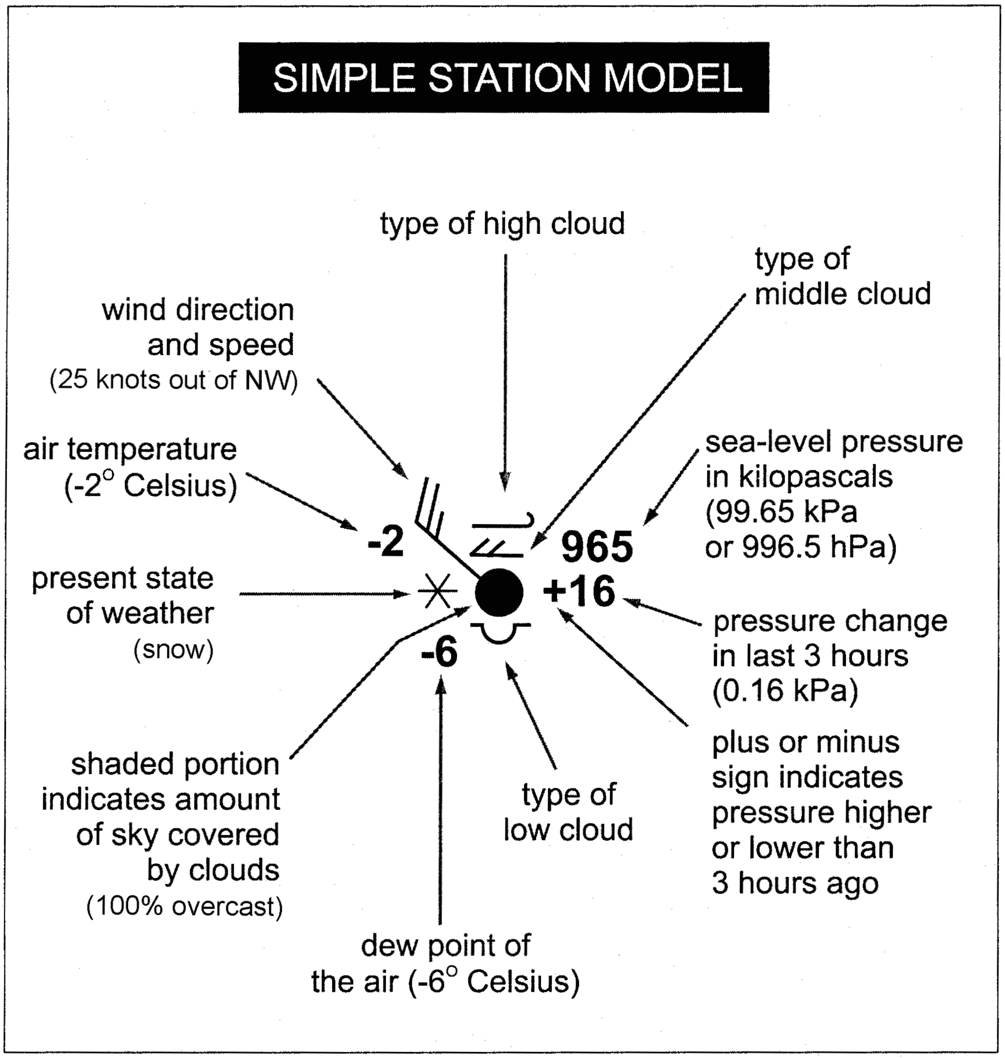
Air pressures routinely reported on surface weather maps are values "corrected" to sea level. That is, air pressure readings are adjusted to what they would be if the reporting stations were actually located at sea level. Adjustment of air pressure readings to a common elevation (sea level) removes the influences of the Earth's relief (topography) on air pressure readings. This adjustment allows comparisons of horizontal pressure differences that can lead to the recognition of weather patterns.

Horizontal air pressure patterns on a weather map are revealed by drawing lines joining points of **equal pressure**, or representing equal pressure, on the map. These lines are called **isobars** because every point on a given line has the same air pressure value. Each isobar separates stations reporting pressure values higher than that of a particular isobar's value from stations reporting pressure values lower than that isobar.

Station Pressure Plotting and Analysis on Weather Maps

The standard unit of atmospheric pressure at the surface of the Earth is the kilopascal (kPa). Today's barometers read the station pressure accurately to the second decimal point (e.g., 101.25 kPa). In the plotting of weather maps, it is common practice to **drop the decimal points** from the map to facilitate legibility and to avoid confusion with station symbols. The plot on a weather map thus shows the station pressure of 101.25 kPa simply as "125" (or the last three digits of the pressure value) as depicted in the station plot model shown on the following page.

The initial 10, or 9 in case the pressure is below 100 kPa, is also dropped for convenience on most maps. Since most sea-level pressures fall between 970 and 1050 hPa, there is little chance for confusion. By convention, isobars on surface weather maps are usually drawn using standard intervals. Remembering that 100.0 kilopascals is the approximate force exerted per unit area on an object at the Earth's surface by the air above, a pressure value of 100.0 kilopascals (kPa) or 1000 hectopascals (hPa) becomes an easily recognized reference value. Again, remembering that the use of the decimal point in map plotting is avoided whenever possible, the **1000 hectopascal (hPa) value becomes a reference for isobaric analysis.** See the graphic (next page) for details of a surface station weather glyph.



Activity 1—Practice Drawing of Isobars

Figure 1 below represents a surface map plot which shows air pressure in hectopascals (hPa) at various locations. (The example uses whole numbers and not the traditional station plot format for the purpose of this exercise only.) Each pressure measurement is placed on the location it represents. A 1012-hPa isobar, which encircles one station on this map, has been drawn. Complete the 1008-hPa isobar that has already been started. Finally, draw the 1004-hPa isobar. **Label each isobar by writing the appropriate pressure value at its end point.**

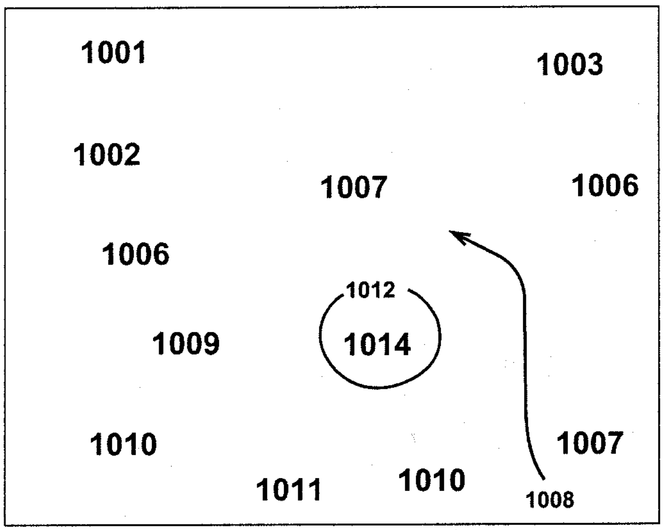


Figure 1—Sample plot of surface pressure values in hectopascals (hPa) at various stations. (For the purpose of this exercise only, this example uses whole numbers and not the traditional station plot format.)

Tips for Drawing Isobars

A. Always draw an isobar so that air pressure readings greater than the isobar's value are consistently on one side of the isobar and lower values are on the other side.

B. When positioning isobars, assume a steady pressure change with distance between neighbouring stations. For example, a 1012-hPa isobar would be drawn between the observations of 1013 hPa and 1010 hPa, about one-third the way from the 1013 hPa reading.

C. Adjacent isobars tend to follow a similar pattern. The isobar that you are drawing will generally parallel the curves of its neighbours because horizontal changes in air pressure from place to place are usually gradual.

D. Continue drawing an isobar until it reaches the boundary of the plotted data or "closes" to form a loop by making its way back to its starting point.

E. Isobars never stop or end within a data field, and they never fork, touch, or cross one another.

F. Isobars cannot be skipped if their values fall within the range of air pressure reported on the map. Isobars must always appear in sequence; for example, there must always be a 1000-hPa isobar between a 996-hPa and 1004-hPa isobar.

G. Always label isobars with a number (e.g., 996, 1000, 1004).

Some Sample Surface Analysis Maps from Environment Canada*

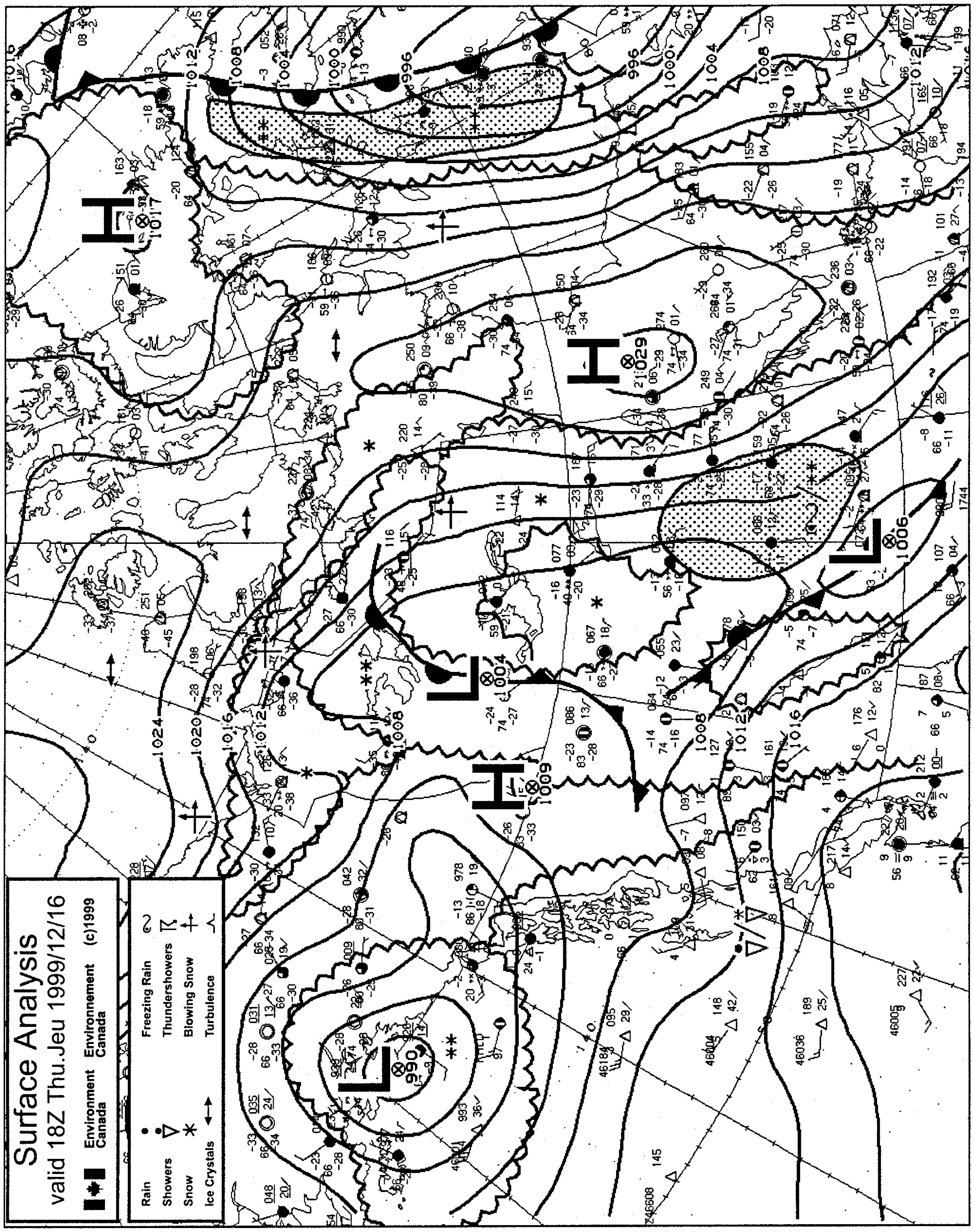


Figure 2—An example of a regional surface map analysis showing isobars, highs, lows, fronts, clouds, and precipitation.

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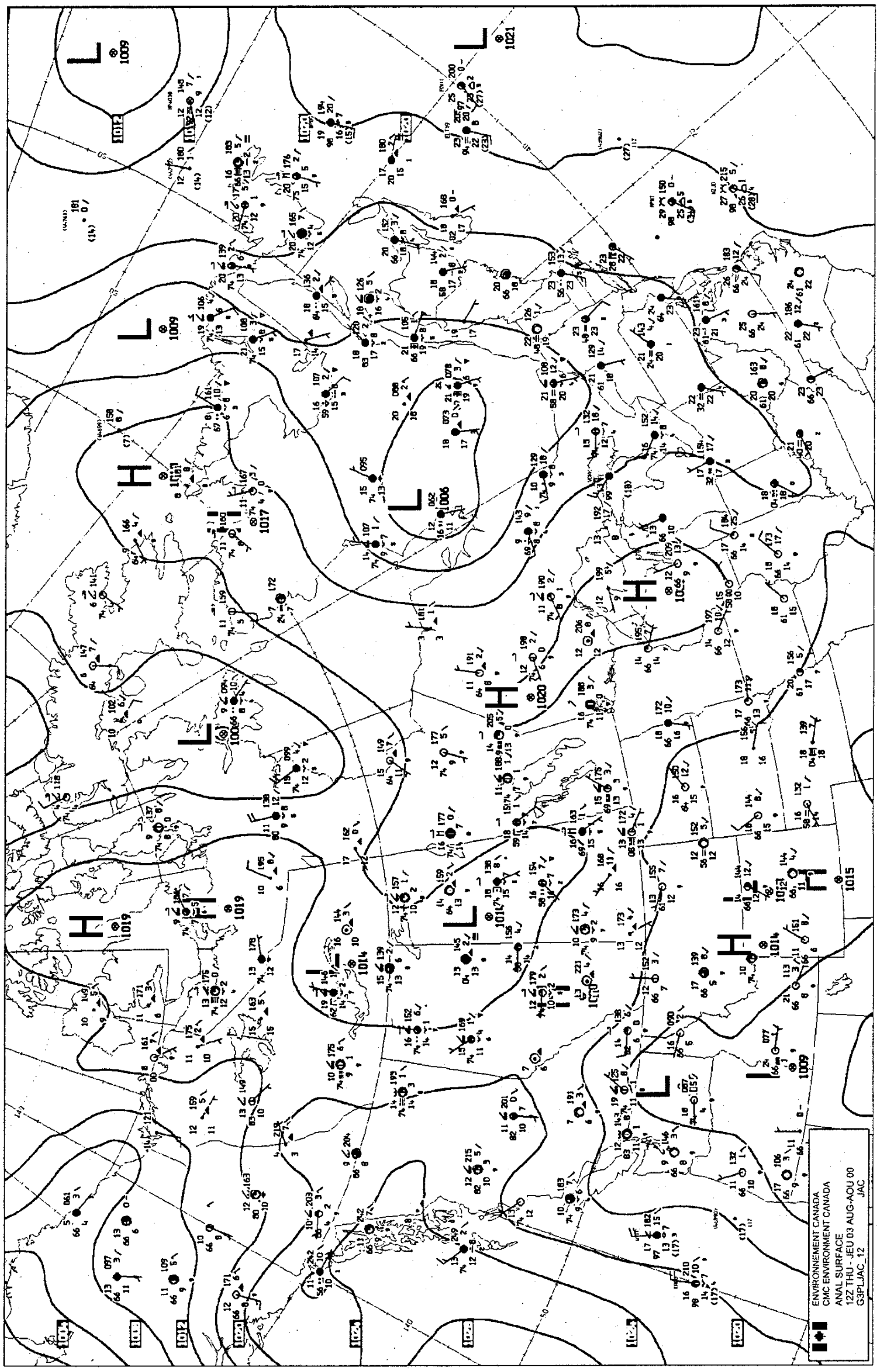

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Figure 3—An example of a computerized national surface analysis map showing isobars, highs, and lows. The time is 0700 CDT.

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SLA
Student
Learning
Activity

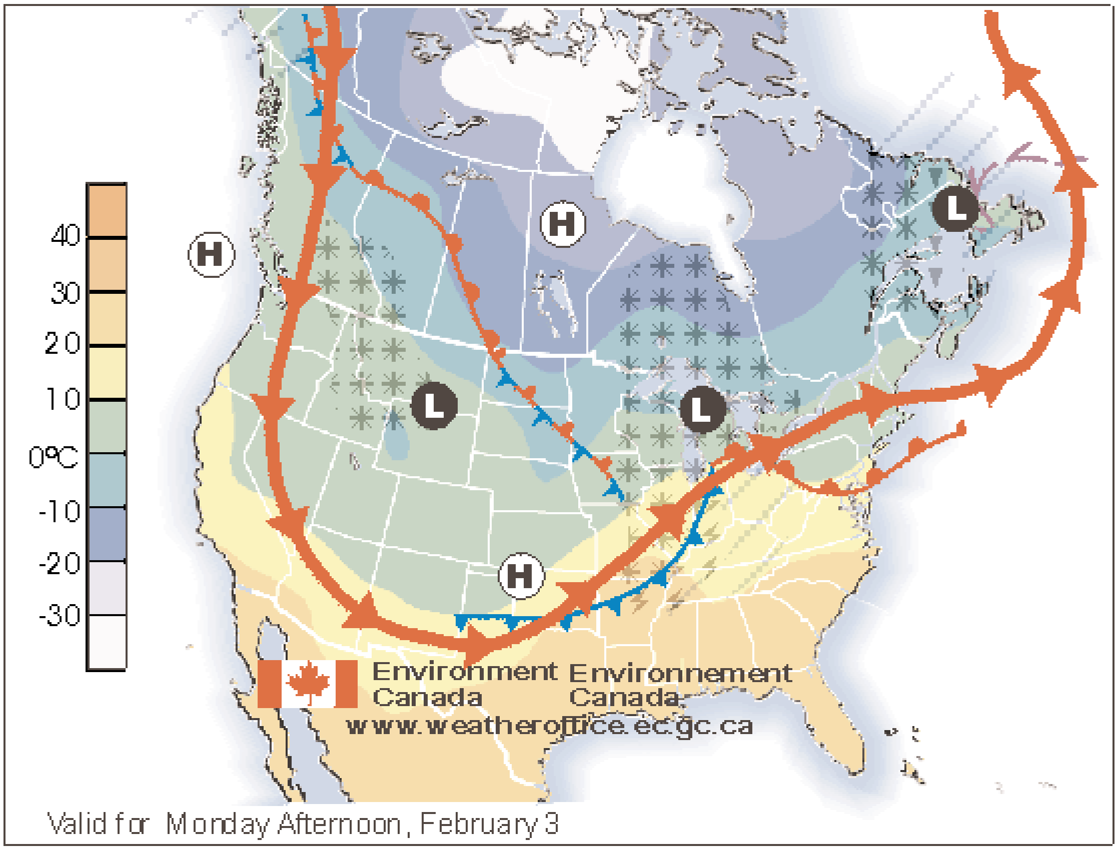
Introduction to Weather Maps and Symbols

Introduction

This sequence of weather maps and associated questions are designed to give you an introduction into effectively reading information from a weather map. By the end of this activity sequence, you will be able to go significantly beyond a typical "weather channel" approach to the features on a weather map.

Begin by looking at what you would typically see on a weather-related website or TV station forecast image. The ones that follow are available through Environment Canada's weather chart website found at:
<http://weatheroffice.ec.gc.ca/charts/index_e.html>.

What follows is a legend that allows you to interpret the features of these types of simplified "at-a-glance" weather maps.



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*

Legend

Ⓗ	**High Pressure**	➝	**Jet Stream**
🅛	**Low Pressure**	▨	**Rain**
⌓⌓⌓	**Warm Front**	▦	**Freezing Rain**
▲▲▲	**Cold Front**	▩	**Snow**
∠∠∠	**Trowal - Trough of Warm Air Aloft**	▩	**Thunder Showers**

The series of maps that follow have been prepared to assist you in becoming familiar with weather mapping techniques and symbols. In order to fully appreciate events such as severe storms, winter blizzards, hurricanes, thunderstorms, and tornadoes, it is important to have a working knowledge of maps. That knowledge puts you in a position to analyze the atmospheric conditions before, during, and after a significant weather event has occurred. The approach we will take is to introduce the weather map components in a sequence, rather than all at once. The maps, however, will still have plenty of other information, so be patient with the process. Most importantly, do not let yourself be overwhelmed with the amount of information contained on each map. Simply focus on the **"guiding questions"** that accompany each map panel.

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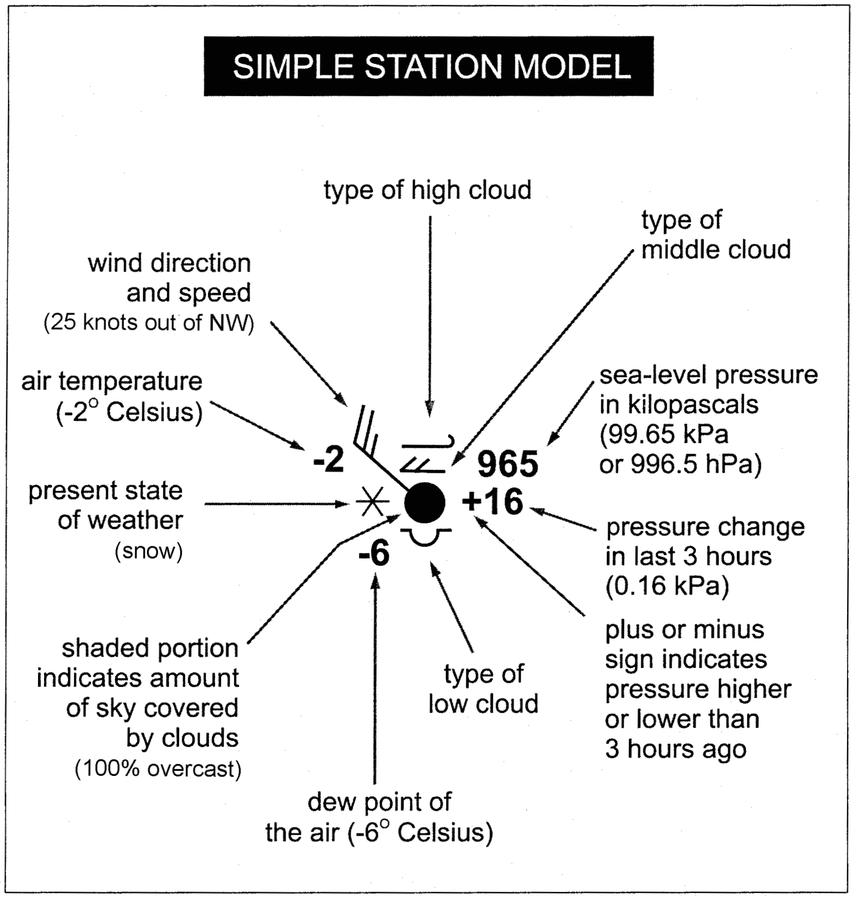
Elements of a Surface Weather Station Glyph

In the graphic that follows, the weather station glyph has each symbol described in detail. Familiarity with these features helps us understand what the weather is doing at a location.



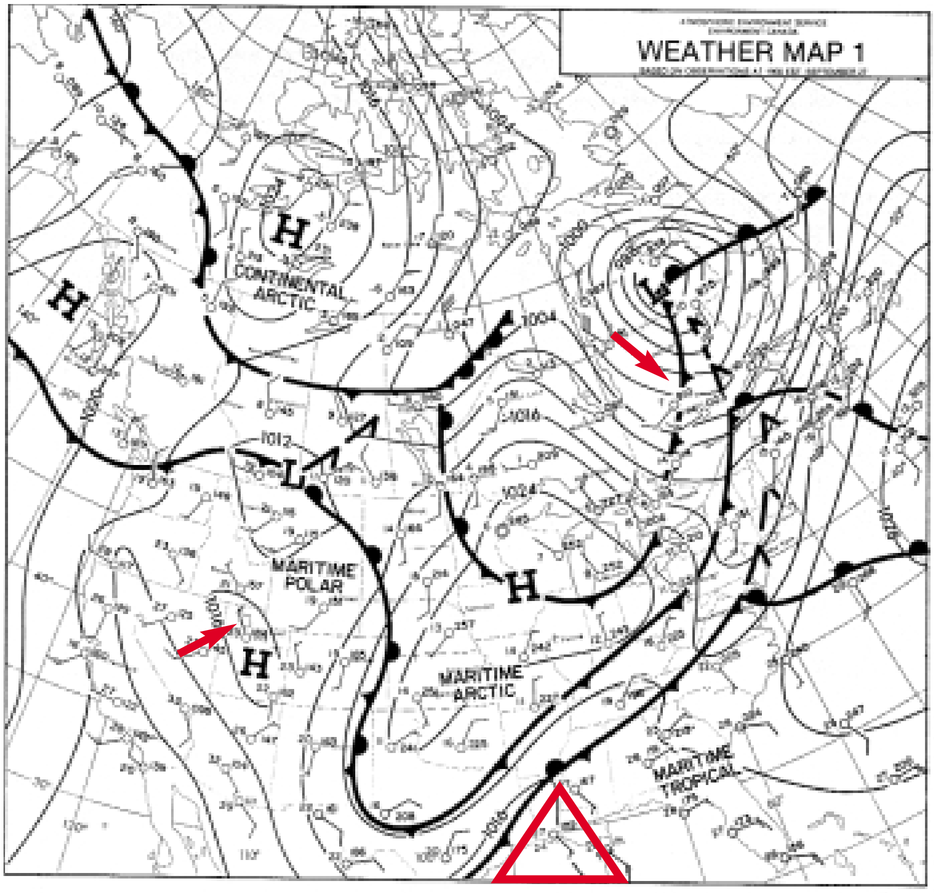
From Where Do the Maps Originate…Are They Real?

The map series covers a 60-hour time period, during the month of September. The time goes from 1900 EST (that is 7 p.m. EST, or 6:00 p.m. CST for Manitobans) on September 27th to 0700 EST (0600 CST) on September 30th of the same month.

The series also gives us a look at a typical early fall pattern of weather across North America. Try to see the following features on Surface Analysis Chart 1:

- a well-developed storm over northern Quebec
- fresh, cold arctic air covering the Northwest Territories
- warm “Chinook” winds keeping temperatures warm in southern Alberta and Montana in the USA
- extremely warm conditions in the U.S. southwest in the deserts of California, Nevada, Arizona, and New Mexico
- very windy conditions in Nova Scotia and northern Quebec

Surface Analysis Chart 1—September 27, 1900 EST



*

Some Questions

1. Were temperatures above or below freezing at this time where you live?

   Location: ____________________________

   Freezing? ____________________________

2. Take note of the time of this map (1900 EST). What time is it in Manitoba?

   ____

3. Will the air temperature drop below 0º C this night anywhere in the southern Prairies? If your answer is "yes," give the name of the town or city.

   ____

4. Take a close look at the direction of the surface winds around the **LOW-pressure system** centred on northern Quebec. Take a pencil and, for as many stations as you can, draw ~2-cm-long arrows that show the direction the winds are blowing. One is done for you on the map.

---

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5. Is there a pattern to the wind directions as you look at the region around the big low-pressure system?

____

____

____

6. Now, take a close look at the direction of the surface winds around the **HIGH-pressure system** centred on southwestern United States. Take a pencil and, for as many stations as you can, draw ~2-cm-long arrows that show the direction the winds are blowing. One is done for you on the map.

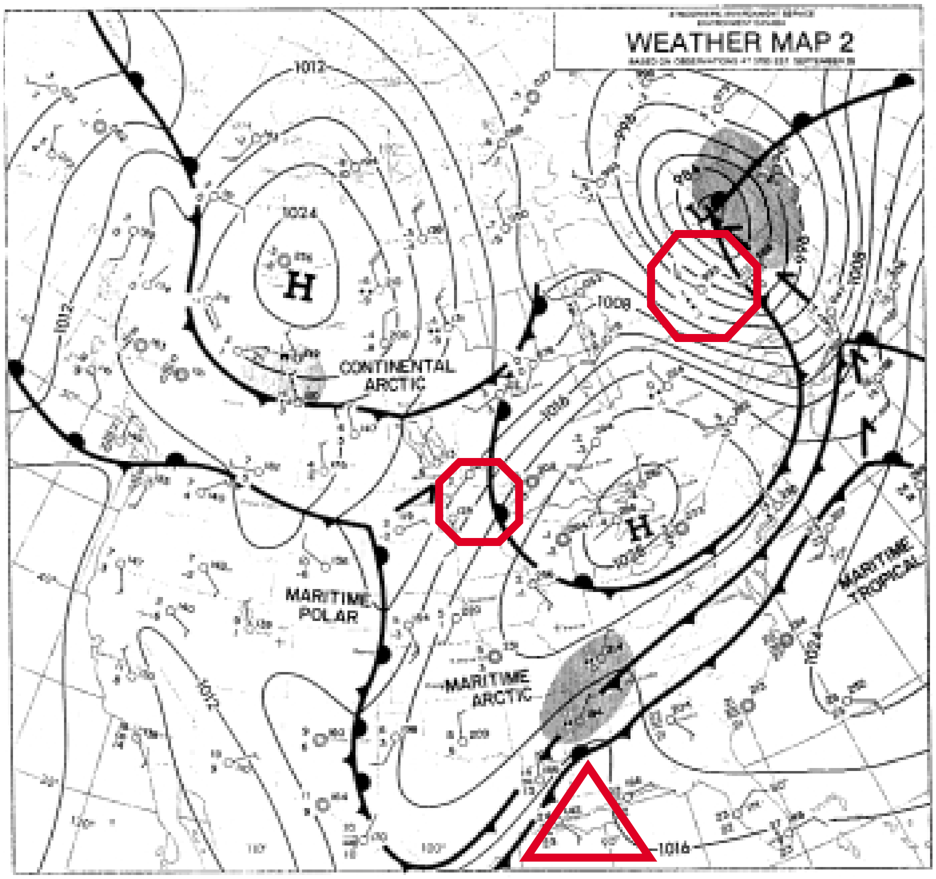
7. Is there a pattern to the wind directions as you look at the region around the big high-pressure system?

____

____

____

Surface Analysis Chart 2—September 28, 0700 EST



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Some Questions

1. Note that the surface winds are blowing around the H and the L centres, as you found out with your work on Surface Analysis Map 1. Are there any areas that seem to have wind directions that disregard the general rules?

   ____

   ____

   ____

2. What temperature change has occurred during the last 12 hours at Schefferville, Quebec? ________________________________

   Kenora, Ontario? ________________________________

   These two localities are CIRCLED on your map to make them easier to find.

---

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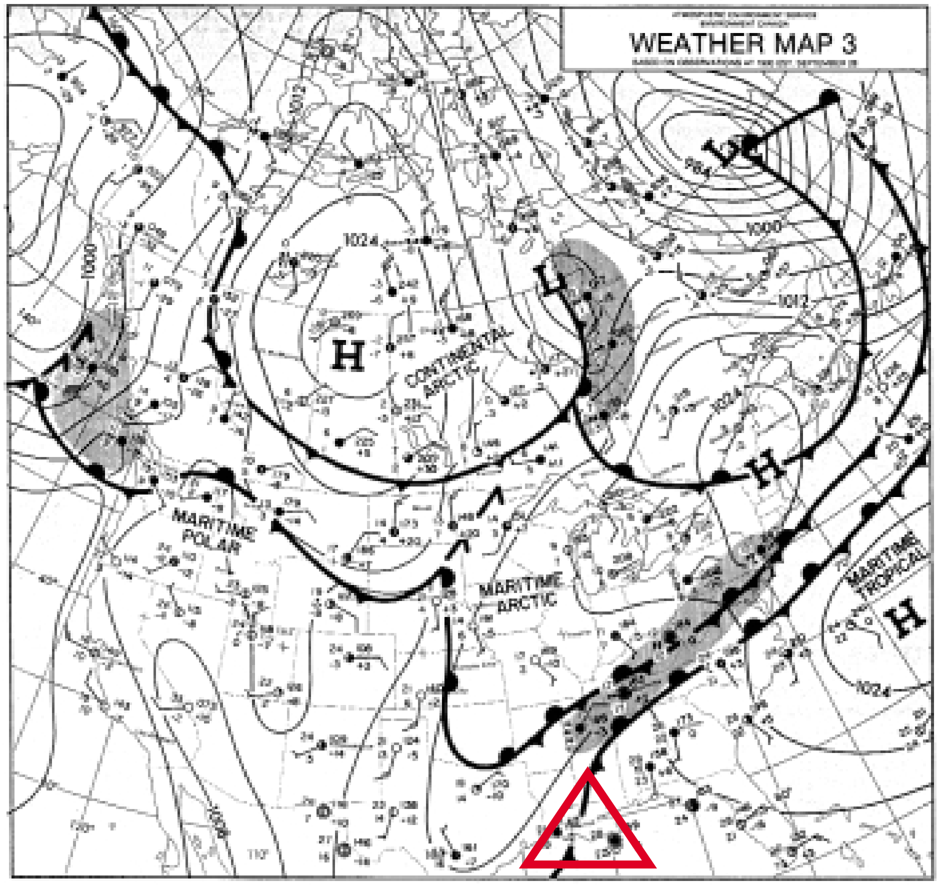
Surface Analysis Chart 3—September 28, 1900 EST



*

Some Questions

1 The isobars (lines on the map joining points having equal air pressure) mark out two types of pressure systems, high- and low-pressure areas. Do these highs and lows move?

Find the point or area of highest pressure in northwestern Canada on September 27 at 1900 EST (on Map 1). Mark this point on the chart for 1900 EST September 28 (the map on this page). Similarly, locate the high of September 28 at 0700 EST (from Map 2) and mark its position on Map 3 for September 28 (this page).

In what direction is the high moving?

About how fast is it going on a 24-hour basis?

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For measuring distances, remember that a **degree of latitude is about 100 km**. Therefore, Sept-Iles is almost 480 km south of Schefferville in Quebec.

About how far is Churchill, MB from Baker Lake, NU?

Or Winnipeg, MB from Regina, SK?

2. Follow the same procedures with the low-pressure area near northern Quebec, beginning on September 27th (Map 1) and ending with its position on this map (Map 3).

   How fast is it moving?

   In what direction is this low-pressure system moving?

3. Symbols for sky cover have also been included in this activity, prior to Map 3.

   In general, do you find cloudy or clear skies in low-pressure areas?

   In high-pressure areas, what occurs with cloud cover?

   What are the skies like in areas where precipitation is falling?

   What happened to the **temperature** and **dew point** at Lake Charles (in Louisiana), when the cold front passed east of this station from Map 1 to Map 3? A triangle appears on maps 1–3 to help you find Lake Charles.

   Compare this report with the previous map of September 27th. What happened to the wind at this station over this 24-hour period? What sort of FRONT passed through this station over the same time period?

4. What changes occurred at The Pas, MB in the preceding 24 hours? Why?

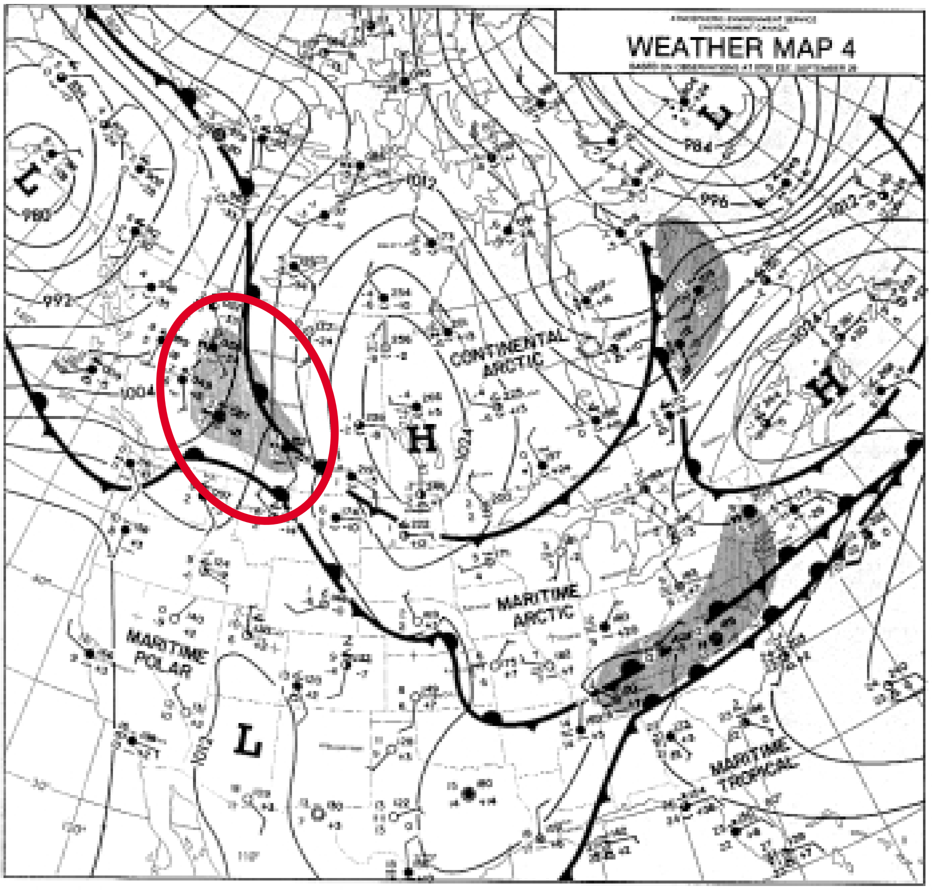
____

____

____

____

Surface Analysis Chart 4—September 29, 0700 EST



*

Some Questions

1. Take note of the large area of precipitation in eastern British Columbia and western Alberta (outlined by the shaded oval shape). How far has this moved in the last 24 hours (since Map 2)? Where would you expect to find this rain 24 hours from now on September 30th?

____

____

____

____

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2. Have you been watching the large area of high pressure that is now sitting over Manitoba's Interlake region on this map? Where will it likely be in 24 hours? In 48 hours?

   ____

   ____

   ____

   ____

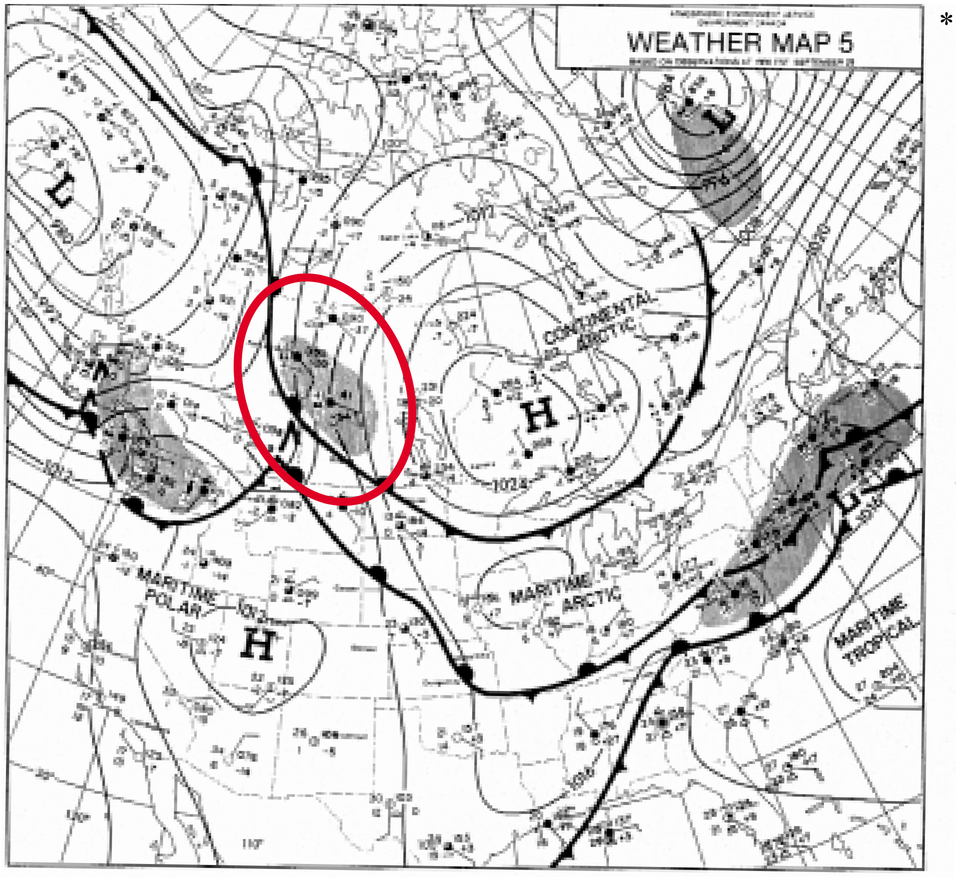
3. Using the symbols on this map, attempt to identify what the weather is like in these three Manitoba centres (include % **cloud cover, temperature, wind speed/direction**):

   a. Winnipeg: ______________________________

   b. The Pas: ______________________________

   c. Churchill: ______________________________

Surface Analysis Chart 5—September 29, 1900 EST



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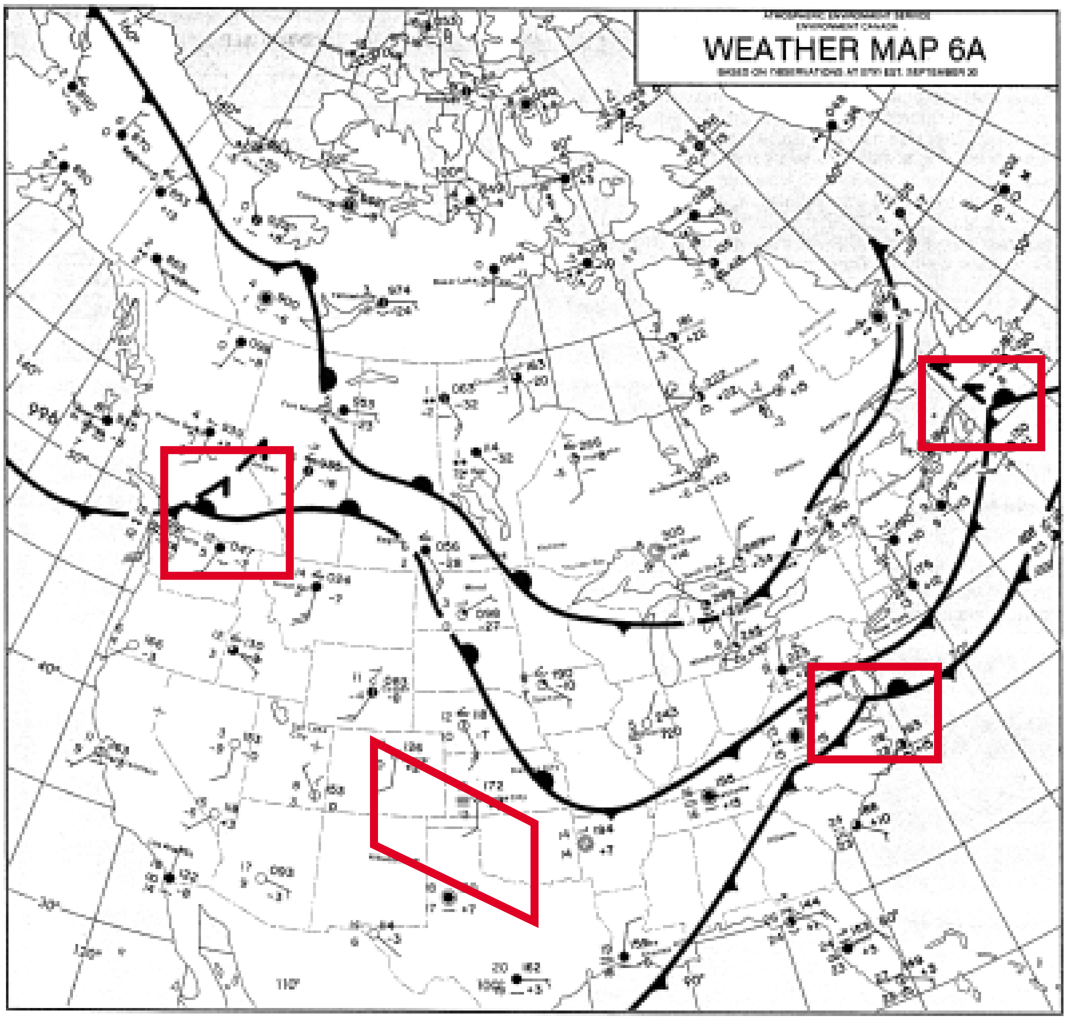
Some Questions

1. Take a close look at the relationship between the location of large precipitation areas and **pressure systems**. What kind of systems, **high** or **low**, seem to be regularly associated with rain or snow?

2. Did the area of **high pressure** that was over Manitoba on the previous day move as you expected it?

   Where will it be in another 24 hours (i.e., who will have fine weather tomorrow)?

Surface Analysis Chart 6a—September 30, 0700 EST



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Some Final Questions

1. What would you expect to find happening with the weather in the three areas outlined with boxes on Map 6a?

   ____

   ____

   ____

2. What do these three areas have in common in terms of weather map symbols or features?

   ____

   ____

   ____

3. Note the two cities inside the parallelogram on the map—Dodge City, Kansas and Denver, Colorado.
   a. What can you say about the **relative humidity** at Dodge City? (Hint: look at the air temperature and dew point readings.)

      ____

   b. Account for the fact that Denver reports no fog whereas Dodge City does.

      ____

      ____

      ____

4. Examine the temperatures of the stations under the influence of the Arctic air mass that is behind the **cold front** in eastern Ontario and Quebec. Now, look back 48 hours to Map 2 when the large region of high pressure was centred over Great Slave Lake in the Northwest Territories.
   a. Have there been any temperature changes at these stations in the last 48 hours? If so, could you explain briefly what has occurred?

      ____

      ____

      ____

   b. The cold, Arctic-origin cold front that is approaching Toronto has been moving steadily southeastward in the period covered by maps 1–6a.
      1. How far has the front moved since 0700 EST on September 28th when we started this process?

         ____

      2. What was its average velocity (in kilometres per hour) over this period?

         ____

      3. Has this cold front changed its velocity over the three-day period (either sped up or slowed down)?

         ____

TSM
Teacher
Support
Material

Using Satellites to Track Weather

In this activity, students will:

- Describe how information is acquired by satellites, sent to Earth, and interpreted to construct images
- Explain how pixel size influences the detail (resolution) on weather satellite images
- Utilize different types of satellite imagery to understand a particular weather system or event that is occurring, or has happened in the past

Key Words

- Visible and infrared wavelengths
- Geostationary and polar orbiting satellites
- Water vapour images

Introduction

Our everyday view of the atmosphere is from the bottom looking up and around. Our field of view is limited since most of us can see only a few kilometres in any direction. At the same time, the systems that dominate our weather can be hundreds or even thousands of kilometres across. Weather maps and radar have extended our views, but it is the weather satellite that gives us a completely different perspective on weather. Orbiting satellites are platforms from which the atmosphere and surfaces below can be observed from the outside.

By looking down on weather, we can see that fair and stormy weather are somehow related. Clear areas and giant swirls of clouds fit together. In the continually changing atmosphere, we can observe evidence of predictability through the order and evolution of weather systems.

With the launch of TIROS-1 (Television Infra-red Observational Satellite) in 1960, we gained our first total views of the cloud patterns that accompany low-pressure systems and fronts. Areas of high pressure and fair weather also became apparent by their general lack of clouds. The launch of TIROS culminated a long march of technological advance in electronics and space exploration. The use of electronics for the sensors, information storage, and transmissions to Earth depended upon the newest transistor technology.

The sensors themselves depended upon television research for their images. Later sensors were outgrowths of this and went on to solid-state extensions where heat radiation, as well as light, from the Earth could be measured.

Finally, the signals that are measured electrically are converted to digital values for storage and are later transmitted down to Earth. There, the visual images we are familiar with are produced. This last step is highly dependent on computer technology for the assembly, organization, and interpretation of the data.

We now have two basic types of satellite systems. The descendants of TIROS are known as polar-orbiting satellites. They revolve around the Earth at relatively low altitudes, 800 kilometres or so, passing over the polar regions as the Earth rotates underneath. Such an orbit takes about 100 minutes to complete. Most places are scanned twice a day, once in daylight and once in darkness. Large-scale views are made from composites of several orbital strips that are about 1900 kilometres in width.

The satellite pictures most often displayed on television and in the newspapers are taken by geostationary orbiters known as Geostationary Operational Environmental Satellites (GOES). Today's images are commonly from GOES-8 and GOES-10 and on May 17, 2000, the first images from GOES-11 were received. At 35,800 kilometres above the equator, such satellites will make one revolution in 24 hours. Because this is the same time as one Earth rotation, and the satellite revolves in the same direction the Earth is turning, such a satellite remains over the same equatorial surface location. Successive views from the same geostationary satellite can be provided to observe development of storm systems. They do not picture details as well as the closer polar-orbiting type of satellite, but they do provide more frequent views, every half hour, of the same Earth surfaces.

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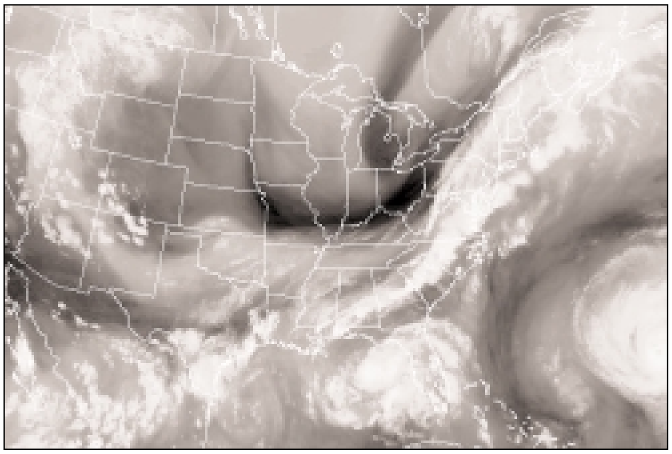

The sensors on-board the satellites react to two basic types of radiant energy. Visible light is produced by the Sun and reflected off Earth surfaces and clouds back up to the satellite. These images look like black-and-white television pictures. All clouds look white to the sensor as they do to our eyes. Darker ground surfaces and water bodies in clear areas reflect little sunlight back up to space and therefore appear dark gray or black. Visible images from the current geostationary weather satellites can resolve objects such as clouds that are as small as one kilometre in width.

The second main type of sensor detects infrared or heat energy given off by surfaces with temperatures in the range of the Earth's land and water surfaces and cloud tops. The intensity of the infrared energy is related to the specific temperature of the emitting surface. In this way, infrared (IR) images are temperature maps of the Earth view. Because the Earth and atmosphere emit heat day and night, infrared images are always available. The infrared sensor on the geostationary weather satellites can distinguish areas as small as four kilometres in width.

Visible light images, when containing a portion of the daylight half of the globe, show clouds to be uniformly white whether they are at low, middle, or high levels in the atmosphere. Earth surface details are usually dark. In contrast, infrared images

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can provide continuous information, day and night, because heat is constantly being emitted from all surfaces, day and night. Land and water surfaces are usually warm and therefore shown as dark. Cooler surfaces are typically displayed as gray with decreasing temperatures having lighter shading. In this way, low, warm clouds will be contrasted with high, cold ones. Temperature variations between warmer land and cooler water surfaces can be seen, as can the temperature cycle on land where daytime warming changes to nighttime cooling.

The variation in temperature across land and water surfaces is a major factor in the development of weather systems. These temperature variations are also displayed in cloud features associated with severe weather situations. Therefore, it has been useful to enhance or process infrared images to accentuate the temperature variations by displaying differing shades of gray or by using colour coding. The 24-hour availability and the colour coding make the enhanced infrared imagery ideally suited to display on television weathercasts, as successive views are looped into movies of cloud motions.

The solid and liquid water found in clouds is very well monitored by the visible and infrared images of weather satellites. The existence of water vapour in the atmosphere is much more difficult to detect. A knowledge of water vapour patterns is very important to understanding weather systems. Water vapour is the supply material for the creation of clouds and precipitation, but it is invisible to the eye and only measured by instruments at widely separated locations. Fortunately, a specific range of infrared energy wavelengths interacts with water vapour. This finely tuned infrared sensor on the geostationary satellites can provide images, and sequences, of cloud locations and the regions of large water vapour content in cloud-free areas at altitudes between 3 and 7 km. Current water vapour imagery can resolve areas down to widths of eight kilometres. Water vapour images are especially helpful in detecting the atmospheric circulation patterns that lead to later cyclone formation and their associated cloud shapes.

The combination of satellite types provides much valuable information about the Earth below. In addition to monitoring weather systems, the satellites provide other data, including vertical temperature profiles and moisture measurements.

To view the latest satellite imagery, you can go to the Environment Canada website: <http://weatheroffice.ec.gc.ca>.

Navigate to the **Satellite page**. The menu offers a number of choices, such as:

GOES-East Eastern Canada
IR (infra-red: 10.7 µm)
Visible & Topography
IR + Visible

Note: 10.70 µm (micron) is an infrared (IR) image where 10.70 microns simply refers to the infrared wavelength being used for this specific image. 1 µm (micron) = 10^{-6} metres

Basic Understandings About Satellite Imagery

Weather Satellite Characteristics

1. Weather satellites are orbiting platforms from which onboard instruments can sense light and heat energy from the atmosphere and underlying surfaces.
2. Because weather satellites can view a large area at one time anywhere on Earth, they provide meteorological information over the oceans and sparsely populated land regions.
3. Weather satellite pictures are received as composites of tiny blocks (called pixels) of varying energy intensities, often shown in shades of gray or in colour. The area each block covers determines how detailed the image can be. The smaller the block, the greater the detail in a satellite image.
4. In addition to sending back pictures of Earth, weather satellites can determine the temperature and water vapour content at different heights in the atmosphere. They can also monitor the ozone layer and detect energetic particles in the space environment.

Polar Orbiting Weather Satellites

5. One type of weather satellite orbit passes near the Earth's poles, making north and south journeys at an altitude of about 800 kilometres.
6. Polar-orbiting satellites scan a strip of Earth, taking less than two hours to complete an orbit. With each pass, they survey a strip approximately 1900 km wide that is further west because of the Earth's eastward rotation. Many hours elapse between passes over the same mid- or low-latitude location.
7. These satellites provide us with information on the condition of the ozone "hole" and composite pictures of snow cover and ocean surface temperatures.

Geostationary Weather Satellites

8. A second type of weather satellite orbit is located 35,800 kilometres directly over the equator. These satellites make one revolution, moving in the same direction as the Earth's rotation, in the time it takes Earth to make one rotation. This keeps them above the same spot on the equator, making them appear stationary, hence their name, Geostationary Operational Environmental Satellites (GOES).
9. Ordinarily, there are two geostationary satellites covering Canada and the United States, one for the eastern part, and one for the west coast and Pacific Ocean. Each one has a field of view covering about one-third of the Earth's surface.
10. Each satellite's view remains the same, so sequential images may be viewed in rapid succession to show development and movement of weather systems.

Visible Satellite Images

11. Visible satellite images are views produced from reflected sunlight. Thus, these pictures look similar to pictures made with an ordinary camera.
12. On visible satellite imagery, clouds appear white, and the ground and water surfaces are dark gray or black. Since this imagery is produced by sunlight, it is only available during daylight hours.
13. Low clouds and fog are usually distinguishable from nearby land surfaces. In addition, the hazy conditions associated with air pollution can be tracked.
14. The shadows of thunderstorm clouds can be seen on lower clouds in the late afternoon. Snow cover can be monitored because it does not move as clouds do. Land features, such as streams, can be visible.

Below is a sample image from a satellite using **visible wavelengths**:

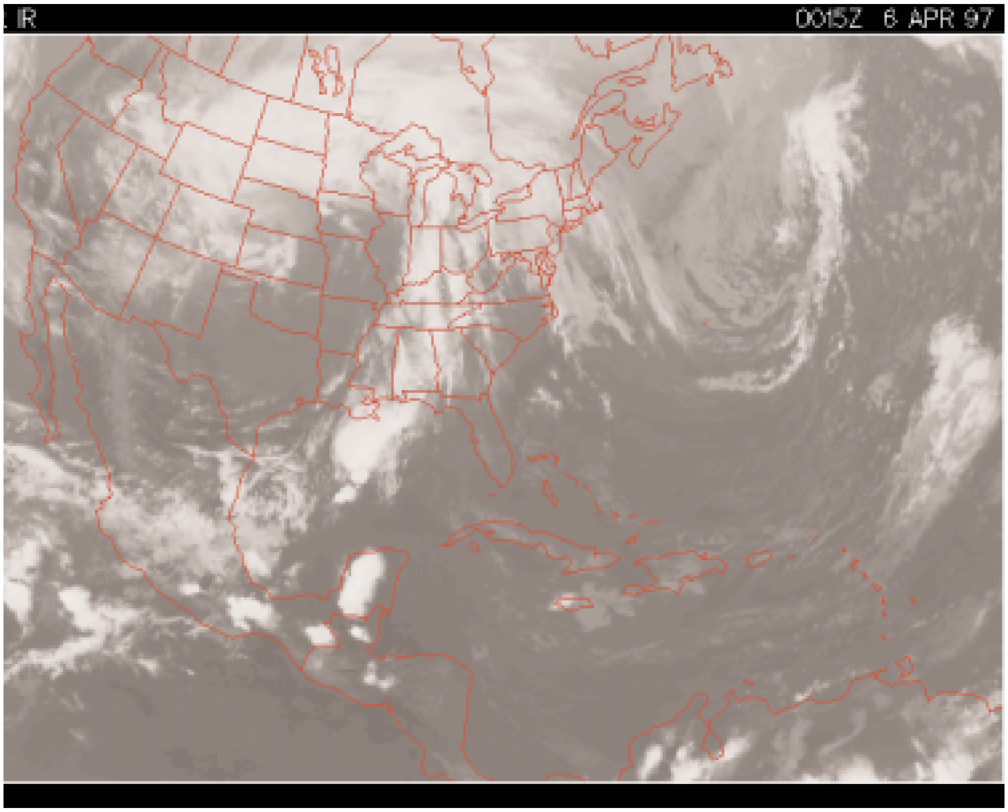

Figure 1: The above image happens to be from the April 6, 1997, Spring blizzard that just preceded the great Red River "Flood of the Century." Note the well-developed, comma-shaped form of the clouds making up this very large mid-latitude cyclone.

Infrared Satellite Images

15. Infrared satellite images are produced by the infrared (heat) energy Earth radiates to space. Since Earth is always radiating heat, infrared images are available day and night.

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* Image courtesy of NOAA. Used with permission.

16. On infrared images, warm land and water surfaces appear dark gray or black. The cold tops of high clouds are white and lower-level clouds, being warmer, are gray. Low clouds and fog are difficult to detect in the infrared when their temperatures are nearly the same as the nearby Earth surfaces.
17. An additional advantage of infrared imagery is that it can be processed to produce enhanced views. The data from the usual infrared pictures are specially treated to emphasize temperature details or structure by assigning contrasting shades of gray or colour to narrow temperature ranges. Such imagery, often seen colour-coded, appears regularly on television weathercasts and computer displays.
18. The enhanced images make it possible to keep track of land and oceanic surface temperatures. These surface temperatures play major roles in making and modifying weather. The high, cold clouds associated with severe weather are also easily monitored.
19. Enhanced imagery can be interpreted to produce rainfall rate estimates. This information is used in flash-flood forecasting.

Below is a sample image from a satellite using **infrared wavelengths**:

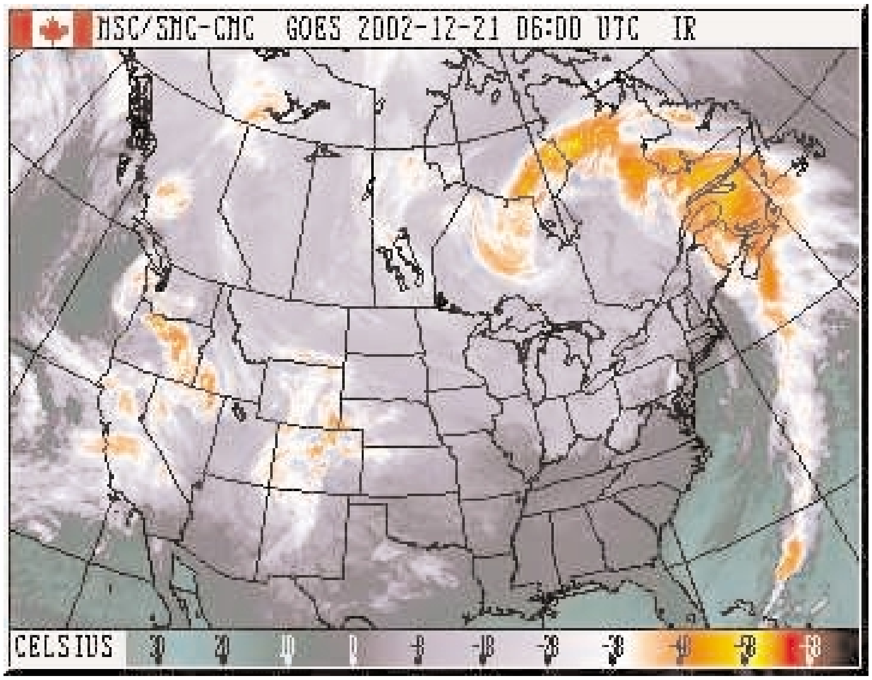

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Figure 2: Infrared image of North America on December 21, 2002. Note the large winter storm in eastern Canada, with classic "comma-shaped" cloud structure.

Water Vapour Images

20. Solid, liquid, and vapour forms of water interact with specific ranges of infrared energy. Specially tuned geostationary weather satellite sensors can detect water vapour in the atmosphere, in addition to clouds.

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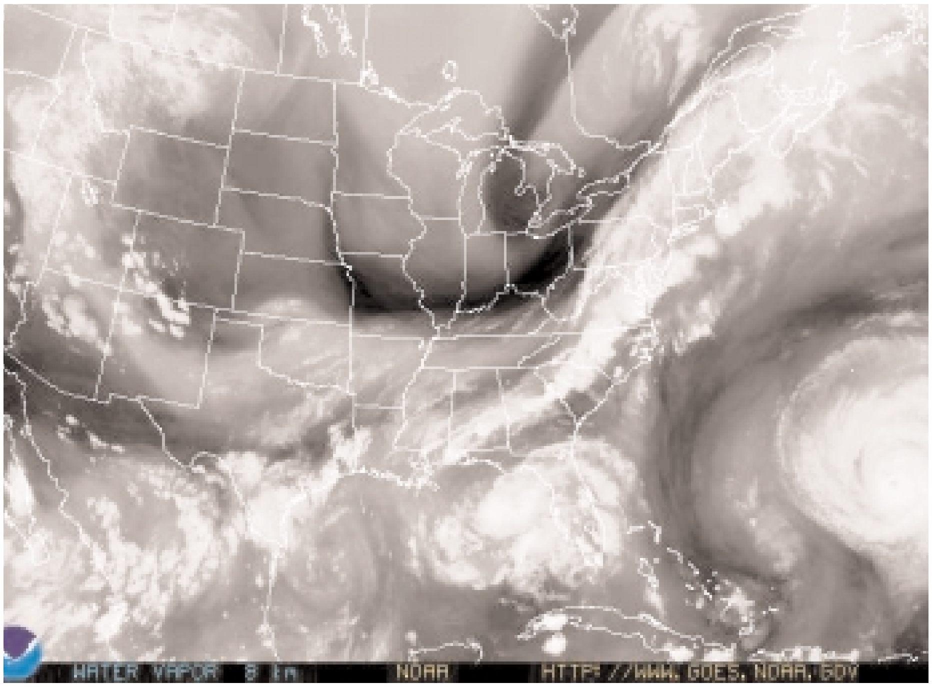
21. The water vapour sensors aboard weather satellites reveal regions of high atmospheric water vapour concentration in the troposphere between altitudes of 3 and 7 km. These regions, sometimes resembling gigantic swirls or plumes, can be seen to flow within and through broad-scale weather patterns.
22. Recent studies suggest that, at any one time, atmospheric water vapour may be found concentrated in several large flowing streams, forming the equivalent of "rivers in the sky."



*

Figure 3: Water vapour image of the western Atlantic/Caribbean region. Dark areas represent dry (low humidity) air, and white areas are areas of moisture saturation (e.g., clouds). The fluid nature of Earth's atmosphere is well represented in water vapour images. Note the very dry air adjacent to the hurricane on the right side of the image.

Weather Features in Satellite Imagery

23. Hurricanes look like pinwheels of clouds. More often than not, the beginnings of hurricanes are detected from satellite views, because they occur over broad expanses of oceans.
24. Large comma-shaped cloud shields give shape and form to mid-latitude low-pressure systems.
25. Clouds from which showers fall can look like grains of sand, especially on visible satellite pictures. Thunderstorms appear as "blobs" or "chains of blobs." Their high tops spread downwind from them as wispy cirrus clouds. They may have neighbouring lower clouds appearing as tiny curved "tails" to the southwest. Such "tails" can also be indicators of the possibility of tornadoes.

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* Image courtesy of NOAA. Used with permission.

26. Movements of cloud patterns detected by viewing sequential satellite images indicate the circulations of broad-scale weather systems. Wind speeds can be estimated at different levels and even upper-air jet streams can be identified.
27. Meteorologists use satellite images to determine cloud shapes, heights, and type. Changes in these cloud properties, along with cloud movement, provide valuable information to weather forecasters to determine what is happening and what is likely to happen to weather in the hours and days ahead.
28. Visible, infrared, and water vapour satellite imagery complement one another. There are weather features that can be clearly seen in one kind of image that are difficult to see in the others.

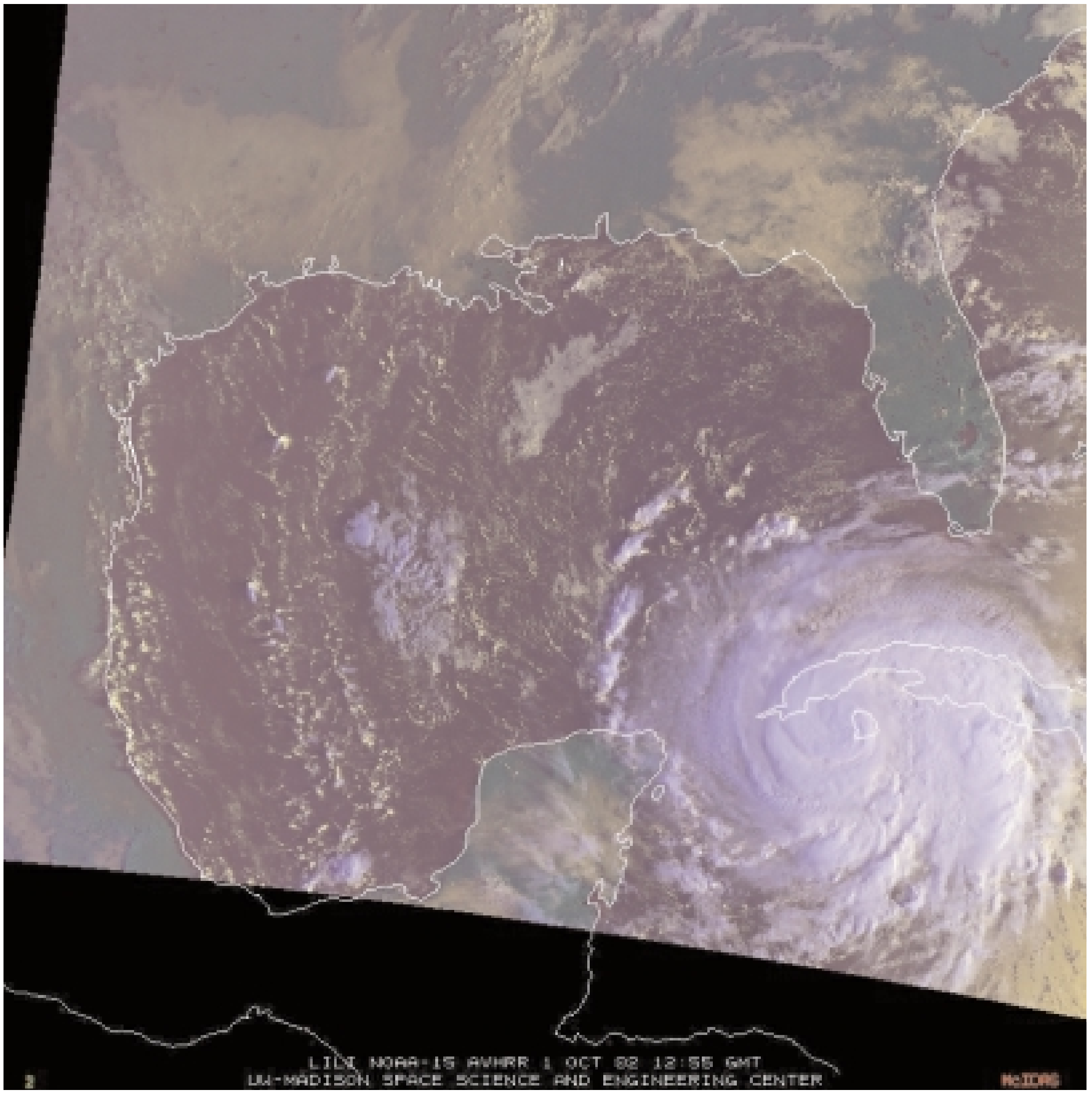

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Figure 4: The image above is of Hurricane Lili (with the storm eye in western Cuba) from October 2002.

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* Image courtesy of NOAA. Used with permission.

Blackline Master

The Fujita Scale of Tornado Intensity

The Fujita Tornado Scale, usually referred to as the F-Scale, classifies tornadoes based on the resulting damage. This scale was developed by Dr. T. Theodore Fujita (University of Chicago) in 1971.

F-Scale	Winds	Type of Damage	Frequency
F0	40–72 mph 64–116 km/h	MINIMAL DAMAGE: Some damage to chimneys, TV antennas, roof shingles, trees, and windows.	29%
F1	73–112 mph 117–180 km/h	MODERATE DAMAGE: Automobiles overturned, carports destroyed, trees uprooted.	40%
F2	113–157 mph 181–253 km/h	MAJOR DAMAGE: Roofs blown off homes, sheds and outbuildings demolished, mobile homes overturned.	24%
F3	158–206 mph 254–332 km/h	SEVERE DAMAGE: Exterior walls and roofs blown off homes. Metal buildings collapsed or severely damaged. Forests and farmland flattened.	6%
F4	207–260 mph 333–418 km/h	DEVASTATING DAMAGE: Few walls, if any, standing in well-built homes. Large steel and concrete missiles thrown far distances.	2%
F5	261–318 mph 419–512 km/h	INCREDIBLE DAMAGE: Homes leveled with all debris removed. Schools, motels, and other larger structures have considerable damage with exterior walls and roofs gone. Top storeys demolished.	less than 1%

SLA
Student
Learning
Activity

Canadian Tornado Frequency Data—An Applied Mathematics (20S) Approach

The Data*

Year	Number of Recorded Tornadoes in Canada	Year	Number of Recorded Tornadoes in Canada
1950	10	1974	28
1951	10	1975	68
1952	15	1976	45
1953	31	1977	54
1954	16	1978	95
1955	14	1979	58
1956	23	1980	61
1957	22	1981	39
1958	15	1982	55
1959	19	1983	61
1960	27	1984	76
1961	20	1985	42
1962	29	1986	71
1963	27	1987	72
1964	45	1988	68
1965	26	1989	86
1966	36	1990	52
1967	22	1991	69
1968	58	1992	39
1969	61	1993	57
1970	42	1994	96
1971	40	1995	40
1972	28	1996	59
1973	59	1997	46

Working with the Data

1. The table of data represents an approximately 50-year baseline of tornado sightings that are considered reliable. The data come from every region of Canada where tornado funnel clouds have been spotted.
2. Load these data into a spreadsheet program of your choice, a graphics calculator, or a plotting program such as *Curve Expert*© or *Graphical Analysis*™.
3. Produce a scatter plot of the data, paying attention to the axes on which the "year" and "number of tornadoes" should be placed.
4. As an alternative, use plotting technology to produce a histogram (vertical bar graph) of the same data.
5. On the grid below, reproduce a rough sketch of the scatter plot, label the axes, and comment briefly on any patterns that appear in the data plot (e.g., are there any unusual years of many tornadoes?).

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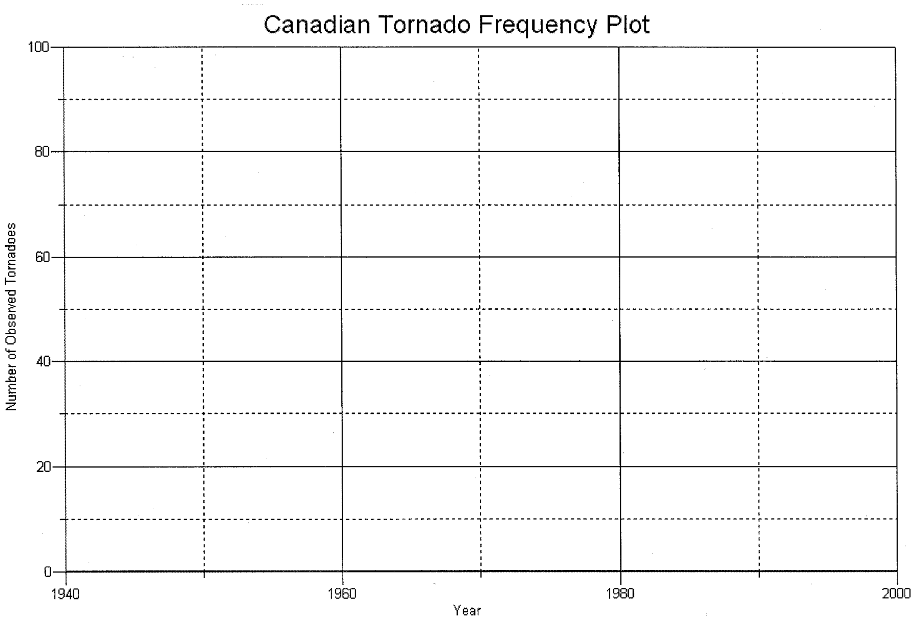


Comments on the Appearance of the Scatter Plot:

- ____________________
- ____________________
- ____________________

6. Using your graphics calculator or plotting software, produce the **linear regression** (least squares line of best fit) for the data, and record the following (to two decimal places):
   a. Equation of the line in the form y = mx + b

      ____

   b. Determine the value of the **slope**:

      ____

c. Determine the **significance** of the slope (state in words, and point out whether the slope is positive or negative):

____

____

d. Determine the value of the correlation coefficient, “r”, to three (3) decimal places:

r = ______________________________

e. Does the value of “r” give you confidence that there is indeed a correlation between the calendar year and the frequency of tornadoes in Canada? State clearly the evidence for your decision.

____

____

f. What other factors could be affecting these data? Is there a possibility that the data or your “best fit” line are biased in some way?

____

____

g. According to your model, how many tornadoes can we expect in the year 2051?

____

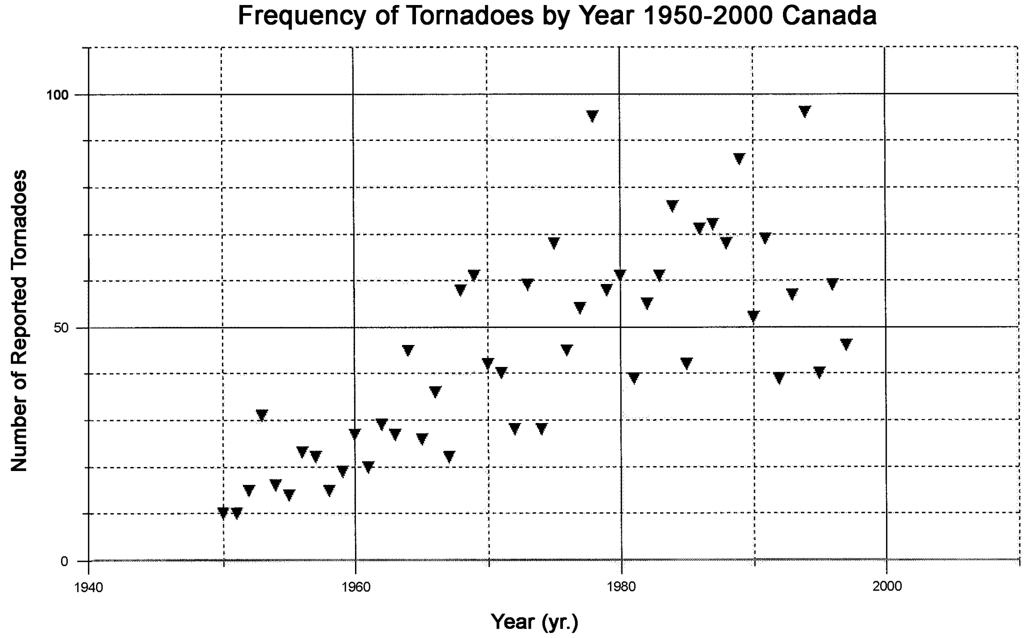
Is this a realistic projection into Canada’s severe weather future? How far back in time does your model indicate no Canadian tornadoes?

____

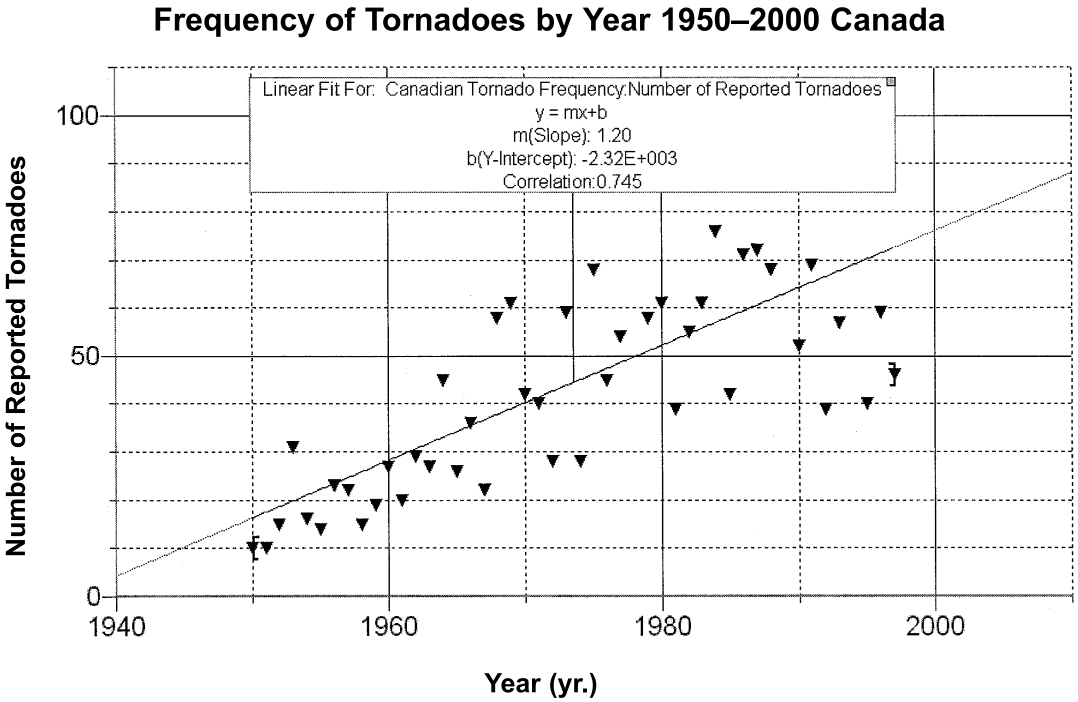
____

Some Possible Plots

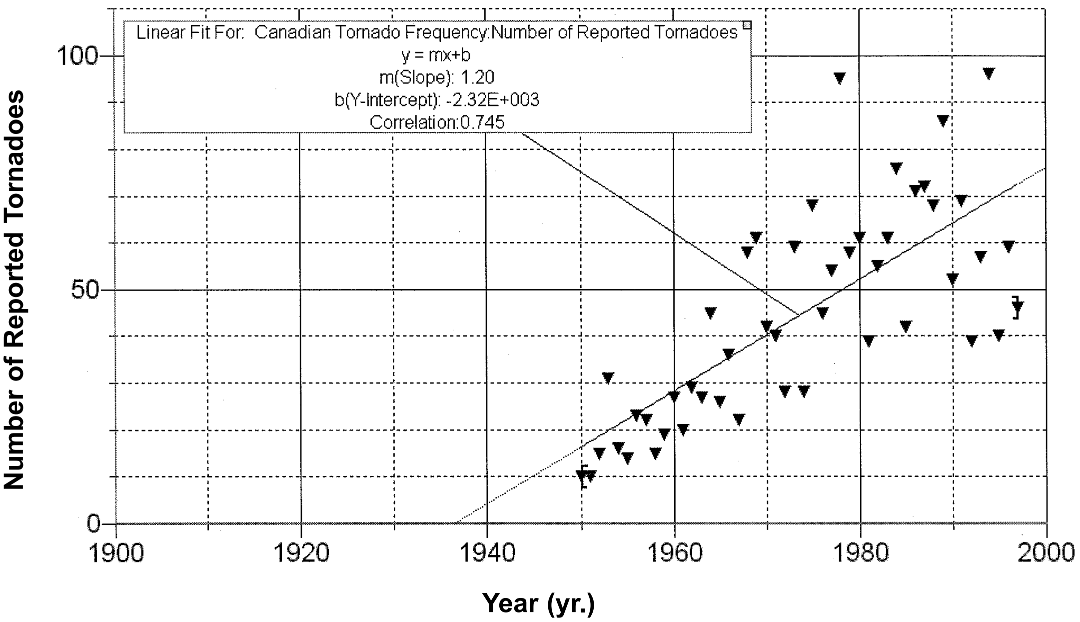
Scatter Plot



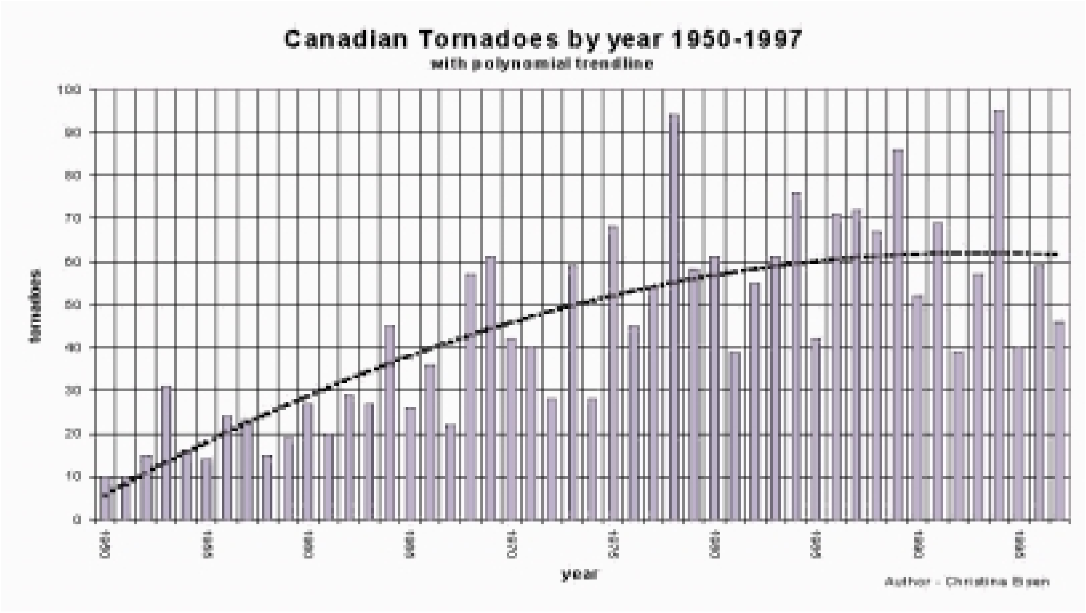
Scatter Plot and "Line of Best Fit" for a Linear Model



Linear Model for Years 1900–2000 Canada



Histogram with “Polynomial Best Fit”*



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SLA
Student
Learning
Activity

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A Consumer Mathematics (20S) Approach

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1973	59	1997	46

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2. Load these data into a spreadsheet program of your choice, a graphics calculator, or a plotting program such as *Curve Expert*© or *Graphical Analysis*™.
3. Produce a scatter plot of the data, paying attention to the axes on which the independent and dependent variables should be placed.
4. As an alternative, use plotting technology to produce a histogram (vertical bar graph) of the same data.
5. On the grid below, reproduce a rough sketch of the scatter plot by plotting one point every 10 years. Label the axes, and comment briefly on any patterns that appear in the data plot (e.g., are there any unusual years of many tornadoes?)
6. Now, plot a detailed scatter plot, using technology.

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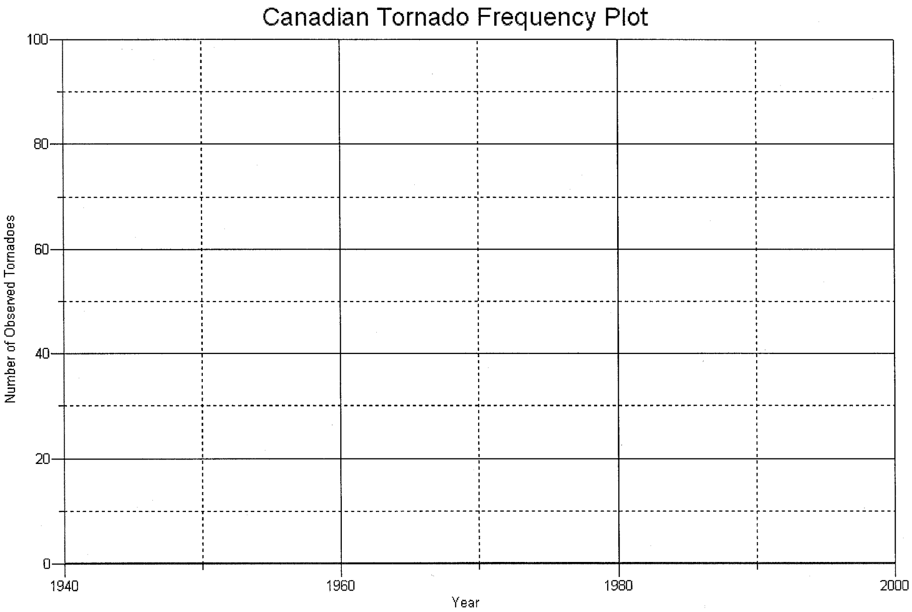


Comments on the Appearance of the Scatter Plot:

- ____
- ____
- ____

6. Construct a LINE that passes through the middle of most of the points on your plot.
   - Have you chosen to draw a **straight line** or a **curved line** through your data points? Write a statement to explain why you chose your particular line type.

7. Do the points indicate any of the following conclusions? Explain briefly why you think the following statements either apply to the data or why they are false.

    - The number of tornadoes is increasing every year in Canada.

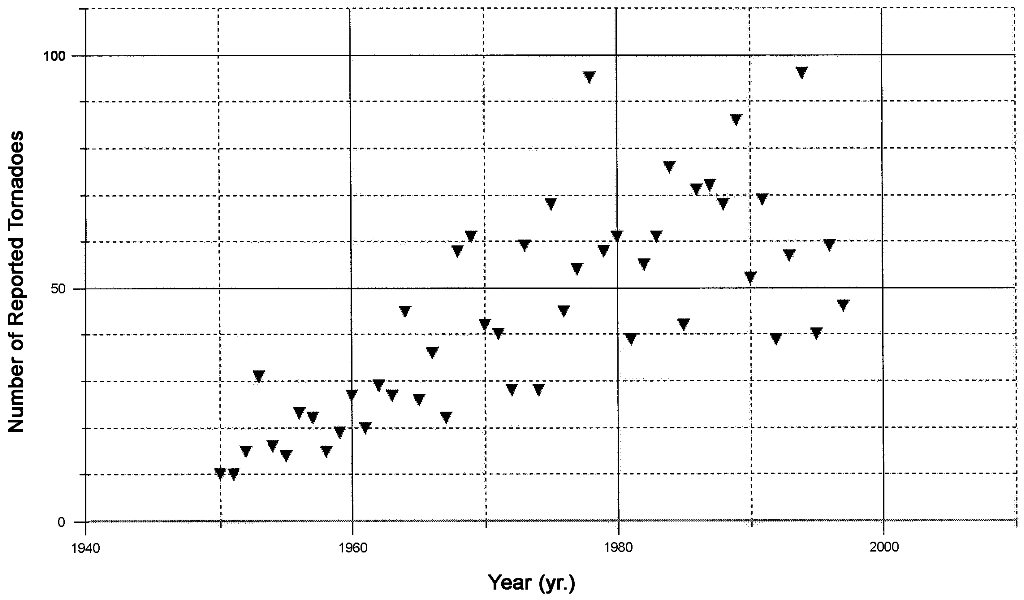
    - The number of tornadoes **sighted** in Canada each year is increasing.

    - New technologies for detecting tornadoes in Canada are allowing more and more to be sighted each year.

Some Possible Plots

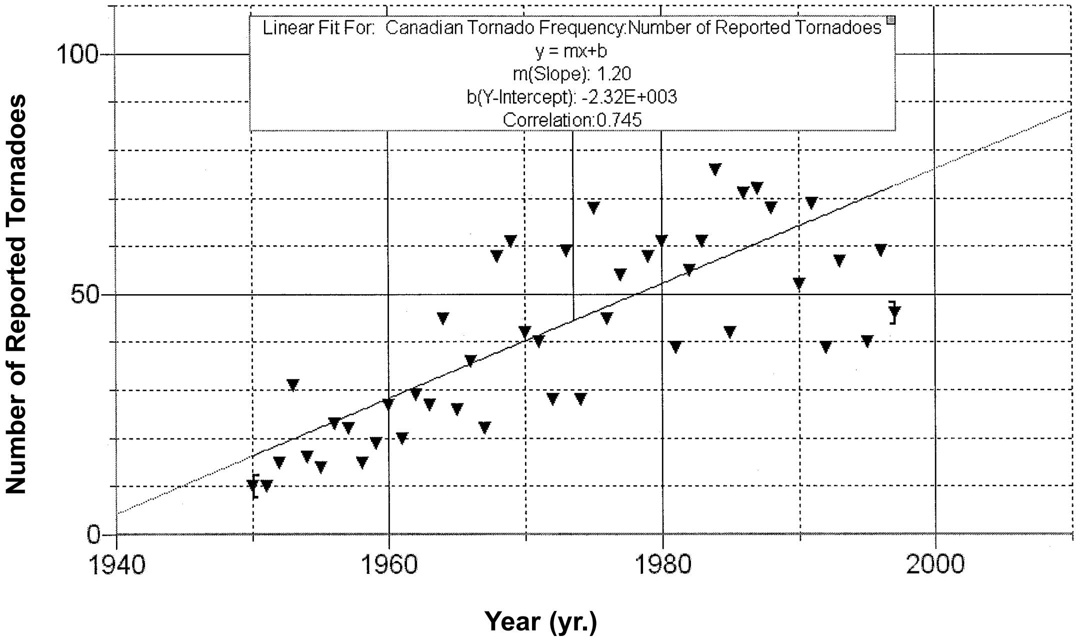
Scatter Plot

Frequency of Tornadoes by Year 1950-2000 Canada

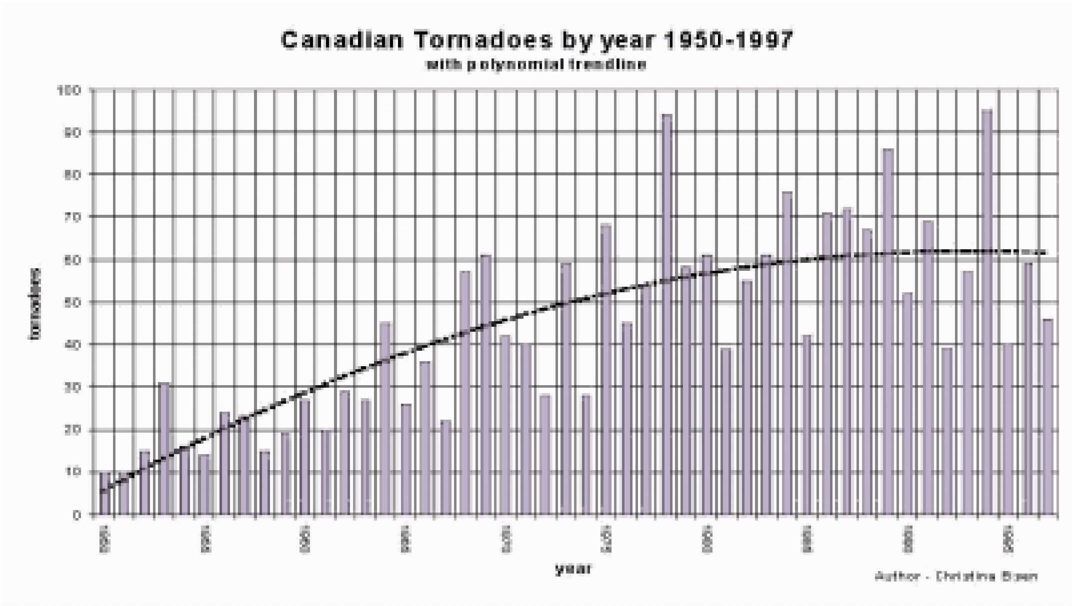


Scatter Plot and "Line of Best Fit" for a Straight Line

Frequency of Tornadoes by Year 1950–2000 Canada



Bar Graph (Histogram) with a Curved Line of Best Fit*



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8. Using the histogram appearing above, determine the following:
   - In what two years were there more than 90 tornadoes?
   - How many tornadoes were sighted in the year you were born?

     Year: ____________________ Number of Tornadoes: ___________________

   - For what years is the curved line exactly predicting the number of tornadoes that were observed?

     ______________ _______________ _______________ _______________

   - Which time span contains the higher probability that a tornado will occur in Canada?

     1965–1975? 1975–1985? 1985–1995?

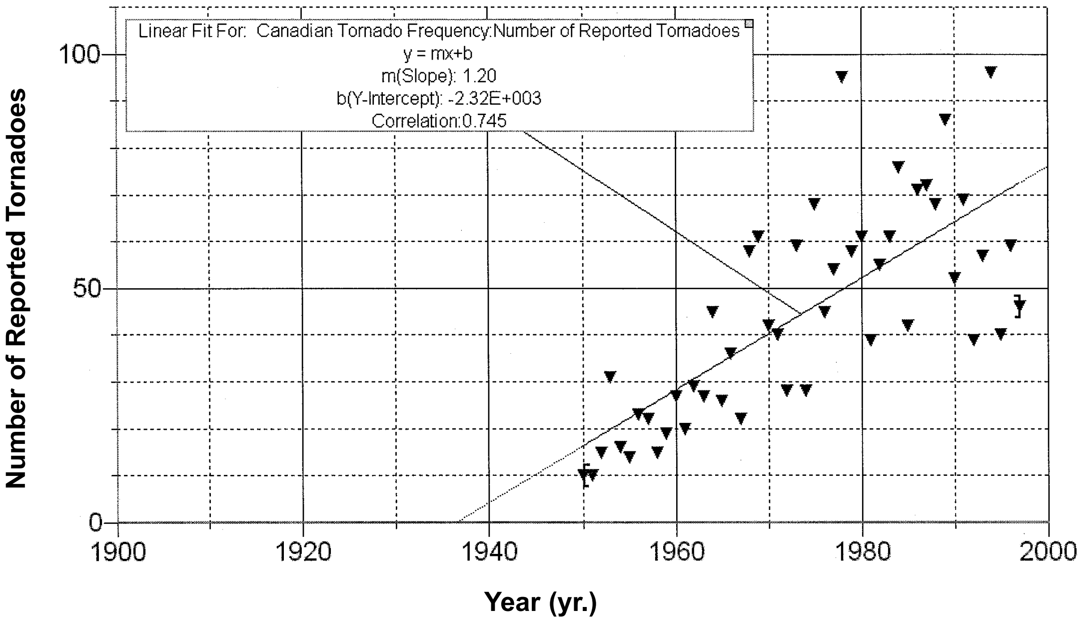
   - What possible biases could occur in these data to give a misleading picture of what is taking place?

     ____

     ____

     ____

     ____



Linear Model for Years 1900–2000 Canada

9. The above plot is using a “best fit” line that is a straight line. In comparing this to an earlier plot, what effect does extending the timeline to 1900–2050 have on the story?

   ____

   ____

10. The plot appearing above in #8 uses what we call a **linear** (straight line) of “best fit.” If the line is actually predicting what is happening with Canadian severe storms (such as tornadoes), does it make sense?

    For example, according to the line, how many tornadoes would you have expected in the year 1945?

    ____

    ____

    ____

    ____

    ____

SLA
Student
Learning
Activity

Canadian Tornado Frequency Data—A Pre-Calculus (20S) Approach

The Data*

Year	Number of Recorded Tornadoes in Canada	Year	Number of Recorded Tornadoes in Canada
1950	10	1974	28
1951	10	1975	68
1952	15	1976	45
1953	31	1977	54
1954	16	1978	95
1955	14	1979	58
1956	23	1980	61
1957	22	1981	39
1958	15	1982	55
1959	19	1983	61
1960	27	1984	76
1961	20	1985	42
1962	29	1986	71
1963	27	1987	72
1964	45	1988	68
1965	26	1989	86
1966	36	1990	52
1967	22	1991	69
1968	58	1992	39
1969	61	1993	57
1970	42	1994	96
1971	40	1995	40
1972	28	1996	59
1973	59	1997	46

Working with the Data

1. The table of data represents an approximately 50-year baseline of tornado sightings that are considered reliable. The data come from every region of Canada where tornado funnel clouds have been spotted.
2. Load these data into a spreadsheet program of your choice, a graphics calculator, or a plotting program such as *Curve Expert*© or *Graphical Analysis*™.
3. Produce a scatter plot of the data, paying attention to the axes on which the independent and dependent variables should be placed.
4. As an alternative, use plotting technology to produce a histogram (vertical bar graph) of the same data.
5. On the grid below, reproduce a rough sketch of the scatter plot, label the axes, and comment briefly on any patterns that appear in the data plot (e.g., are there any unusual years of many tornadoes?). Plot one point for every five years.

---

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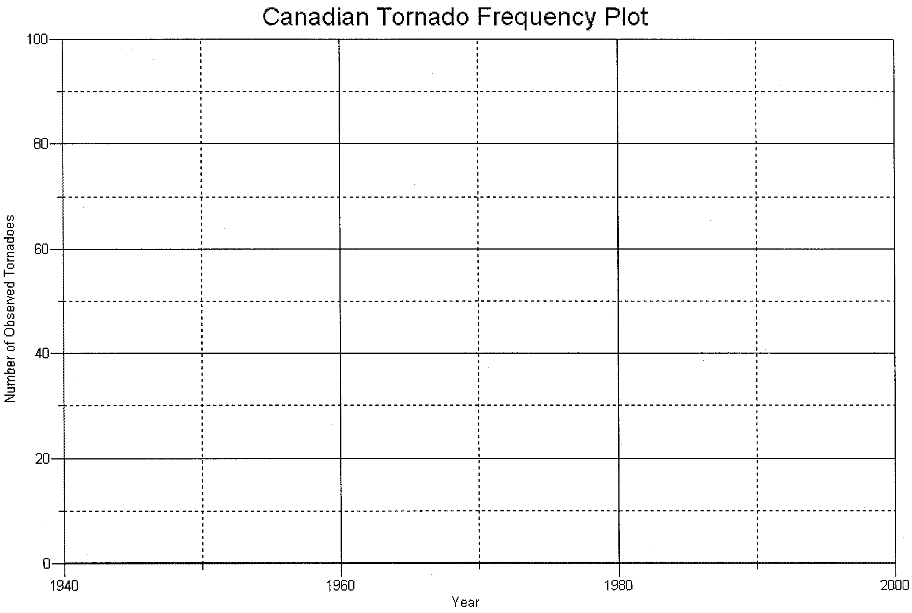


Comments on the Appearance of the Scatter Plot:

- ____

  ____

  ____
- ____

  ____

  ____
- ____

  ____

  ____

6. Using your graphics calculator or plotting software, produce the **linear regression** (least squares line of best fit) for the data, and record the following (to two decimal places):

   a. Equation of the line in the form y = mx + b and Ax + By = C

   ______________________ ___________________

   b. Determine the value of the **slope** using the values of "A" and "B," and then compare with the value given by technology:

   ____

   ____

c. Determine the slope directly from the line of best fit, using the following definition, and compare to earlier results in (a) and (b). What rate of change does the slope represent?

$m = Dy/Dx$

d. Using your slope from part (c) above, and one point from the data, write an equation in **standard form** for the line of best fit, using the **point-slope** method. Compare results with those in part (a).

$y–y_1 = m\ (x–x_1)$

e. Using **function notation**, rewrite the equation of the line of best fit, with "N(t)" and "t" as your variables

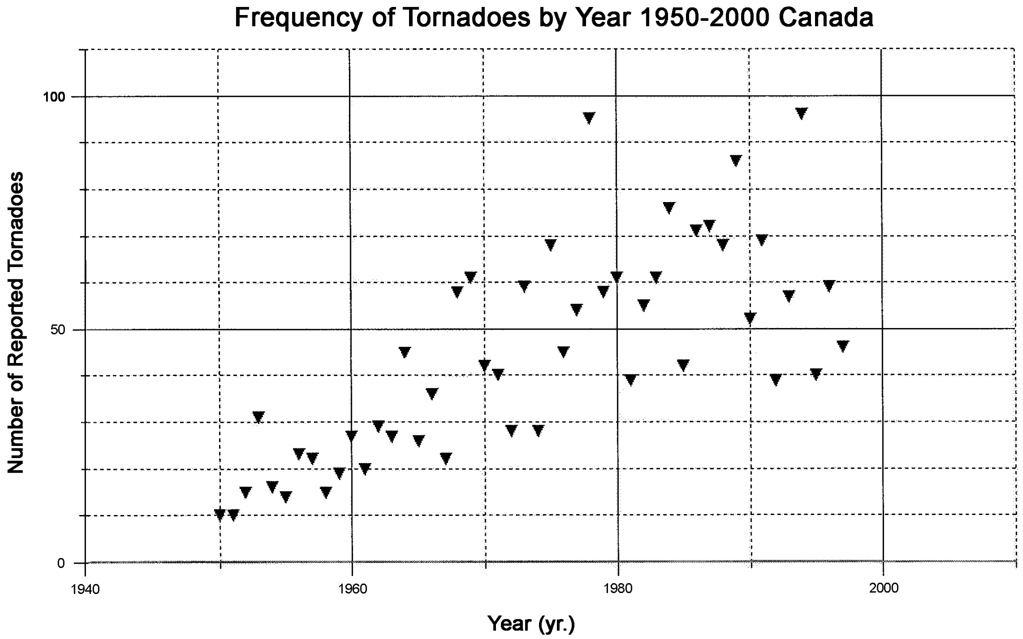
f. According to your model, how many tornadoes can we expect in the year 2050?

N(2050) = ____________

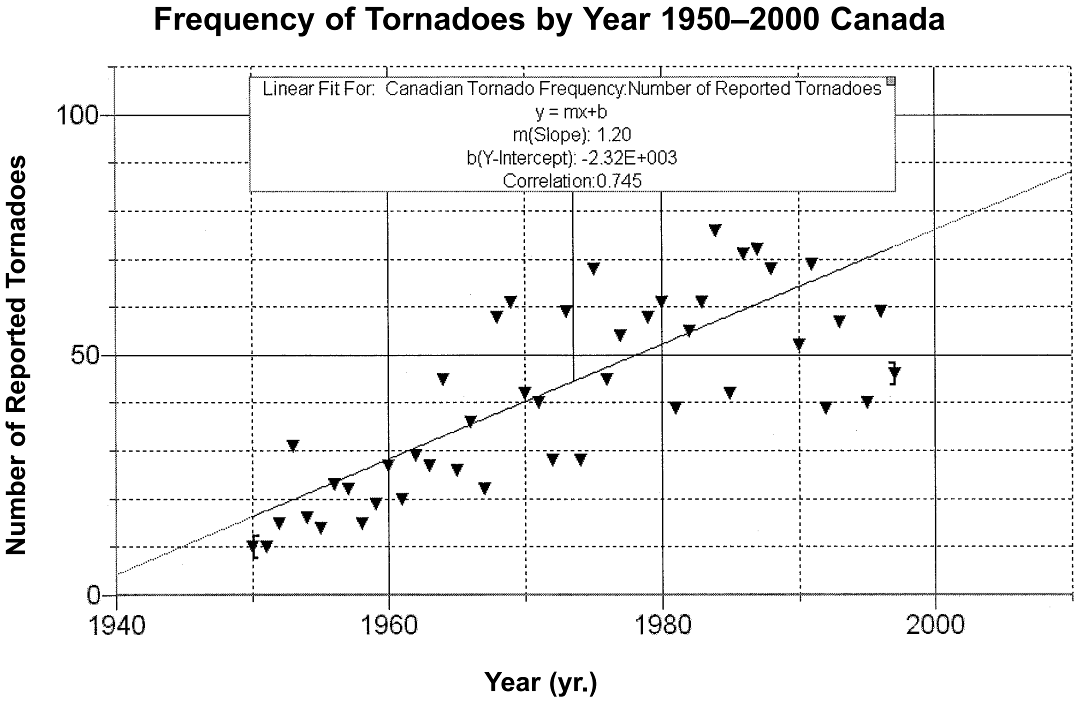
Is this a realistic projection into Canada's severe weather future? How far back in time does your model indicate no Canadian tornadoes (e.g., for what value of "t" does N(t) = 0)?

Some Possible Plots

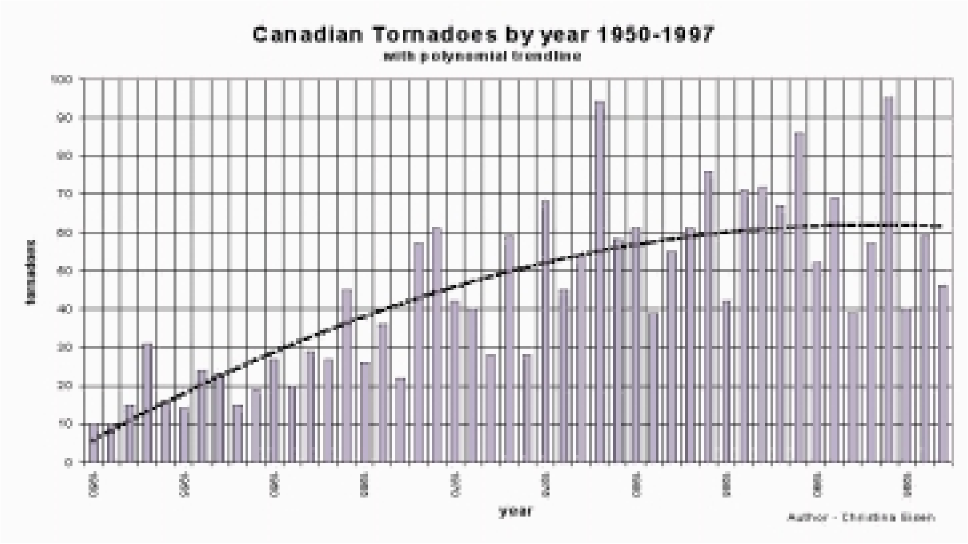
Scatter Plot



Scatter Plot and “Line of Best Fit” for a Straight Line



Histogram with “Polynomial Best Fit”*



g. Using the histogram appearing above, determine the following:

- For what two years does N(t) = 55? ___________ & __________
- For what year(s) does N(t) = 95? ___________ & __________
- What are the values of: N(1950) ___________ N(1980) ___________
- Which time span contains the greater probability that a tornado will occur in Canada?

  1965–1975? 1975–1985? 1985–1995?
- What possible **biases** could occur in these data to give a misleading picture of what is taking place?

  ____

  ____

  ____

7. The following plot is using a “best fit” line that is a polynomial function. In comparing this to earlier plots, what effect does extending the **domain** and **range** beyond the 1950–1997 data have on how the past and future of Canadian tornadoes is interpreted?

   ____

   ____

---

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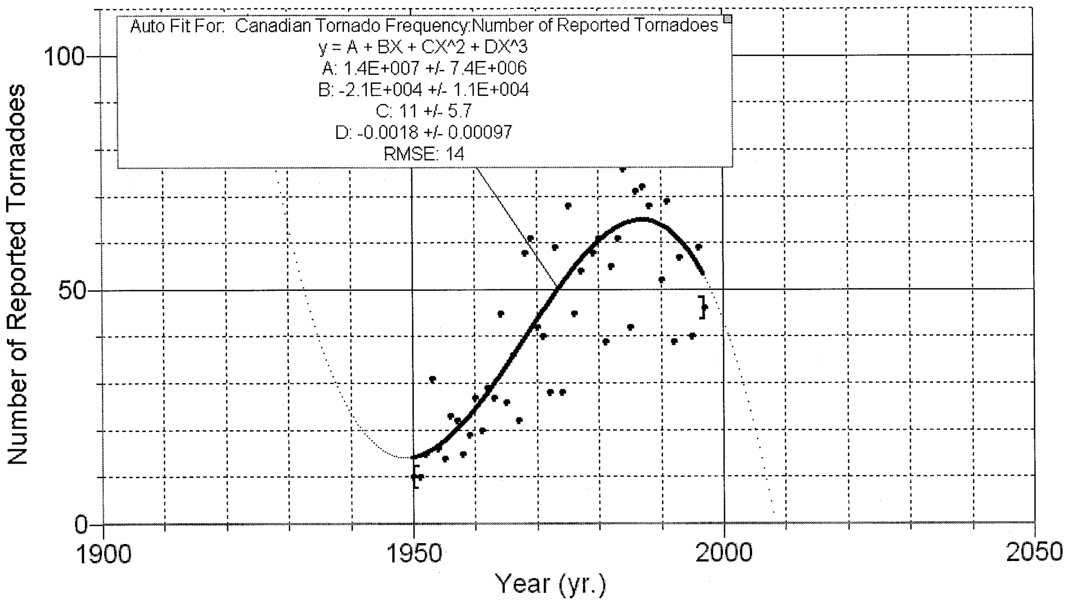
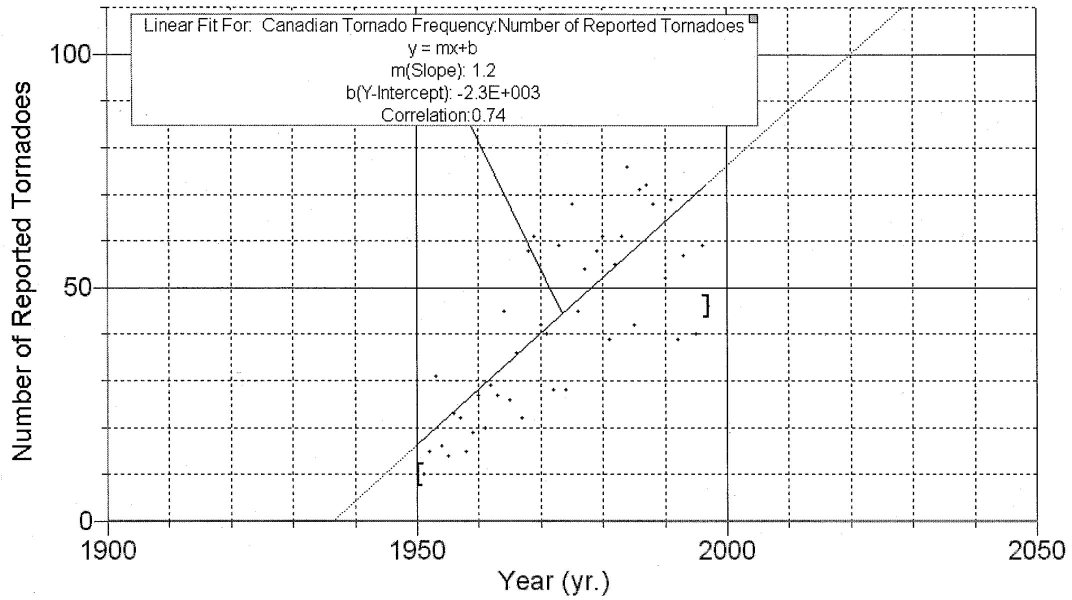
Polynomial Model for Years 1950–2050 Canada



8. The plot appearing below uses a **linear** “best fit.” Does this graph suffer the same potential faults as the previous example? Explain in detail.

Linear Model for Years 1950–2050 Canada



TSM
Teacher
Support
Material

Watch Out! There May Be a Tornado in Your Backyard!!

A **histogram** showing tornado frequency by province provides the information students need to define tornado risk regions. Because the average number of tornadoes changes gradually from one province to another, the decision on where to draw the outline of each of the regions is more subjective than what students may prefer. The intent of the activity is to initially encourage students to provide a "rough sketch" based on their own interpretations of the data.

Teacher Notes

Provide each student with a copy of the Tornado Plotting Map of Canada, found at the end of this activity.

Expectations

Students will

- Use or construct a wide variety of graphs, charts, diagrams, maps, and models to organize information
- Demonstrate an understanding of the regions theme as applied to tornadic activity frequency in Canada
- Identify and describe regions where natural hazards such as tornadoes exist

Assessment

- Formative self-assessment of the final map (see Appendix 6.9; Rubric for Map Drawing).
- Formative assessment by teacher of the explanation of the method used in drawing up the three regions (see Appendix 6.6: Assessing Region Explanations).

Teaching/Learning Strategies

1. Using the Tornado Plotting Map of Canada, and the Canadian Tornado Distribution Graph, students outline three regions on the blank map of Canada according to tornado risk. Teachers may wish to include the density map of Canadian tornadoes for student use, or clip it off for later discussion and/or assessment of student results. The three regions could be colour coded.

   1 — high risk of tornadoes

   2 — moderate risk of tornadoes

   3 — little or no risk of tornadoes

2. Students describe the method used to outline their regions (how they went about drawing the lines on their map).

3. Display the maps to enable students to see the similarities and differences from one map to another.

4. Conduct a general discussion on why all the maps are not exactly the same and whether or not this is what should have happened (i.e., as long as each region has a similar range of tornadoes throughout and is different from the other two regions, then it is acceptable that slightly different interpretations could result).

5. Point out the position of Manitoba (or the student's province of origin, if applicable) within the tornado regions of Canada, and ask if any students have had personal experiences with, or seen, an actual tornado or the damage one can cause.

Modifications/Expanded Opportunities

- Vary this activity by using a variety of natural phenomena (cyclonic storms, storm tracks, forest fires, severe weather-related events) or human phenomena connected to severe natural events (such as population density, income per person) that are shown using dot maps or maps similar to the one showing tornadoes. It is important to emphasize STSE connections where climate and weather phenomena are in operation.

- Students with advanced mathematical or algorithmic experiences (such as computer modeling, use of mapping or GIS software systems) may wish to approach the data representation in a more symbolic manner.

- Use the datasets to plot histograms, scatter plots, or frequency distributions. Presentation of graphs from manual drawing, spreadsheet applications, and graphics calculators are to be encouraged where mathematics development makes this feasible. Sample graphs are included in the teacher version of this activity for reference.

Resources

- Tornado Plotting Map of Canada

- Atlas, particularly the world or regional distribution maps of physical and human activities that are often found in the front or back sections, or within the regional sections of the atlas

- Textbooks with maps of this type

- Internet information from tornado sites (e.g., The Tornado Project at <www.tornadoproject.com/index.html>)

- Data sets found in this activity: Canadian Tornado Occurrence (Table 1) and Canadian Tornado Distribution by Province/Region 1950–1997 (Table 2)

Activity Data Sets*

Table 1: Canadian Tornado Occurrence as Percentage by Month (30-year avg.)

Month	Percent of Total Annual Tornadoes Occurring
January	0.5%
February	0.4%
March	0.4%
April	2.2%
May	11.0%
June	32.5%
July	30.8%
August	14.0%
September	6.0%
October	2.0%
November	0.2%
December	0.0%

Table 2: Canadian Tornado Distribution by Province/Region 1950–1997

Province/Region	Percentage of Annual Tornadic Activity
Interior British Columbia	1.4%
Alberta	23.1%
Saskatchewan	22.4%
Manitoba	13.2%
Central/Southern Ontario	31.9%
Quebec	6.6%
Maritimes/Newfoundland and Labrador	1.5%

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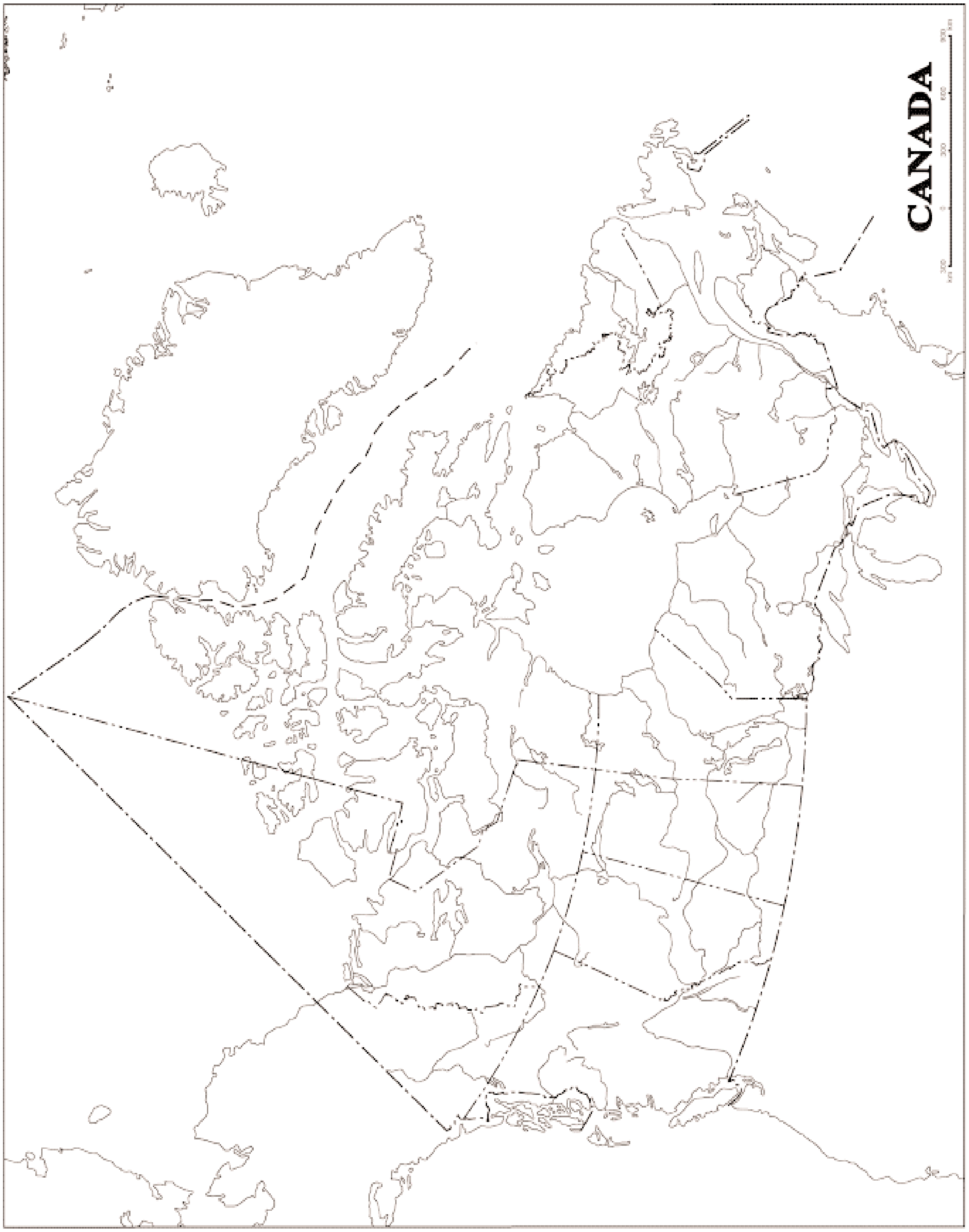
BLM
Blackline Master

Tornado Plotting Map of Canada*



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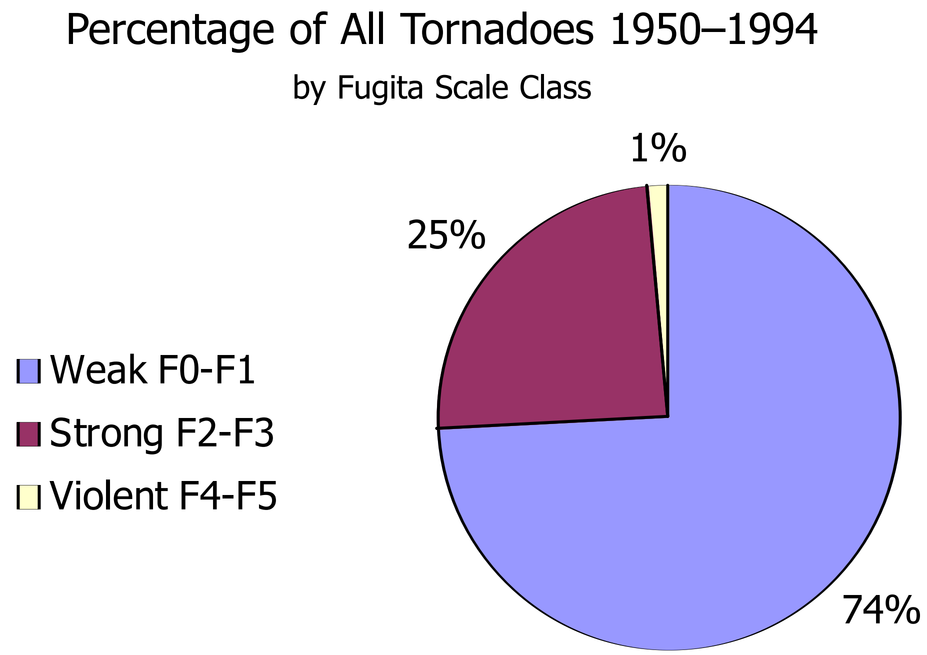
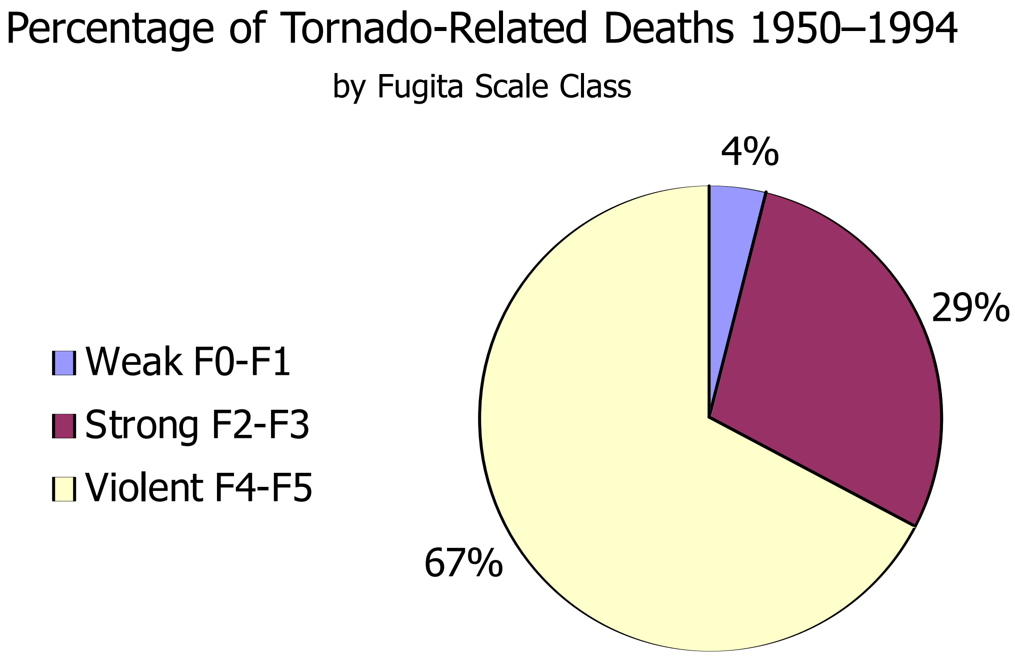
SLA
Student
Learning
Activity

Tornado-Related Statistics and Graphing*


Percentage of All Tornadoes 1950–1994
by Fugita Scale Class


Percentage of Tornado-Related Deaths 1950–1994
by Fugita Scale Class

---

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Table 1: Tornado Funnel Cloud Dimensions and the Fujita Intensity Scale

F Scale Intensity	Length of Tornado Path (km)	Width of Funnel Cloud (km)	Area Covered by Ground Contact (km^2)	Average Wind Speeds (kph)
0	1.77	0.04	0.08	90
1	4.18	0.10	0.36	149
2	9.14	0.15	1.40	217
3	19.49	0.27	5.17	293
4	36.16	0.40	14.29	375

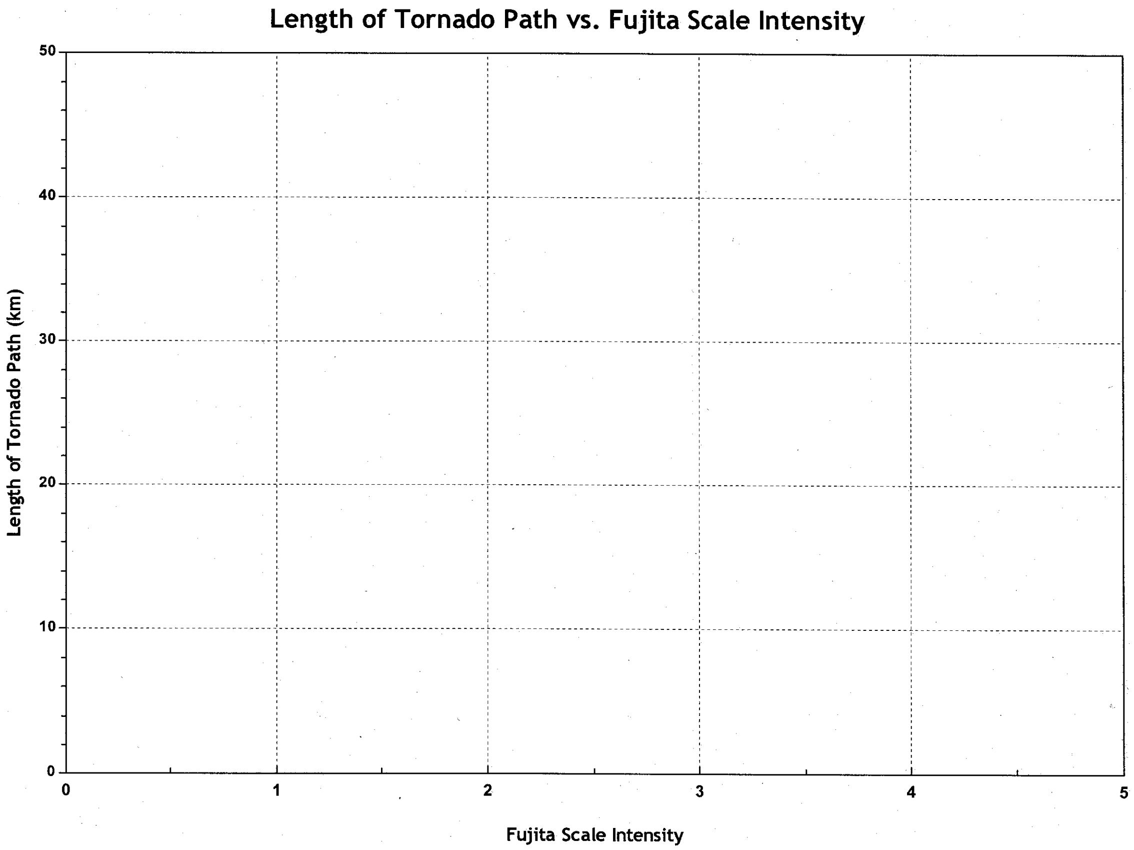
Working with the Data

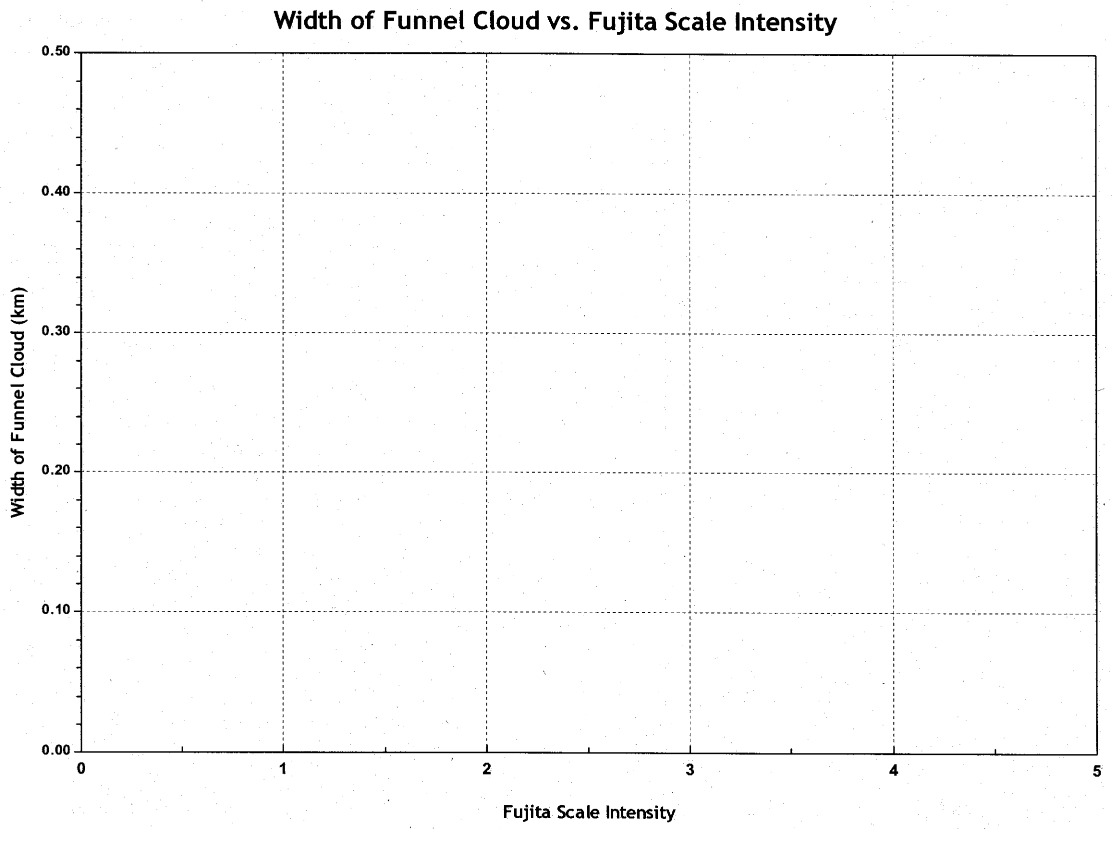
1. Plot a graph of LENGTH OF TORNADO PATH versus F SCALE INTENSITY.
2. Plot a graph of WIDTH OF FUNNEL CLOUD versus F SCALE INTENSITY.
3. Plot a graph of AREA versus F SCALE INTENSITY.
4. Plot a graph of LENGTH OF TORNADO PATH versus WIDTH OF FUNNEL CLOUD.
5. Plot a graph of AREA OF GROUND CONTACT versus (LENGTH x WIDTH). What do you notice?
6. Plot a graph of AVERAGE WIND SPEEDS versus F SCALE INTENSITY.

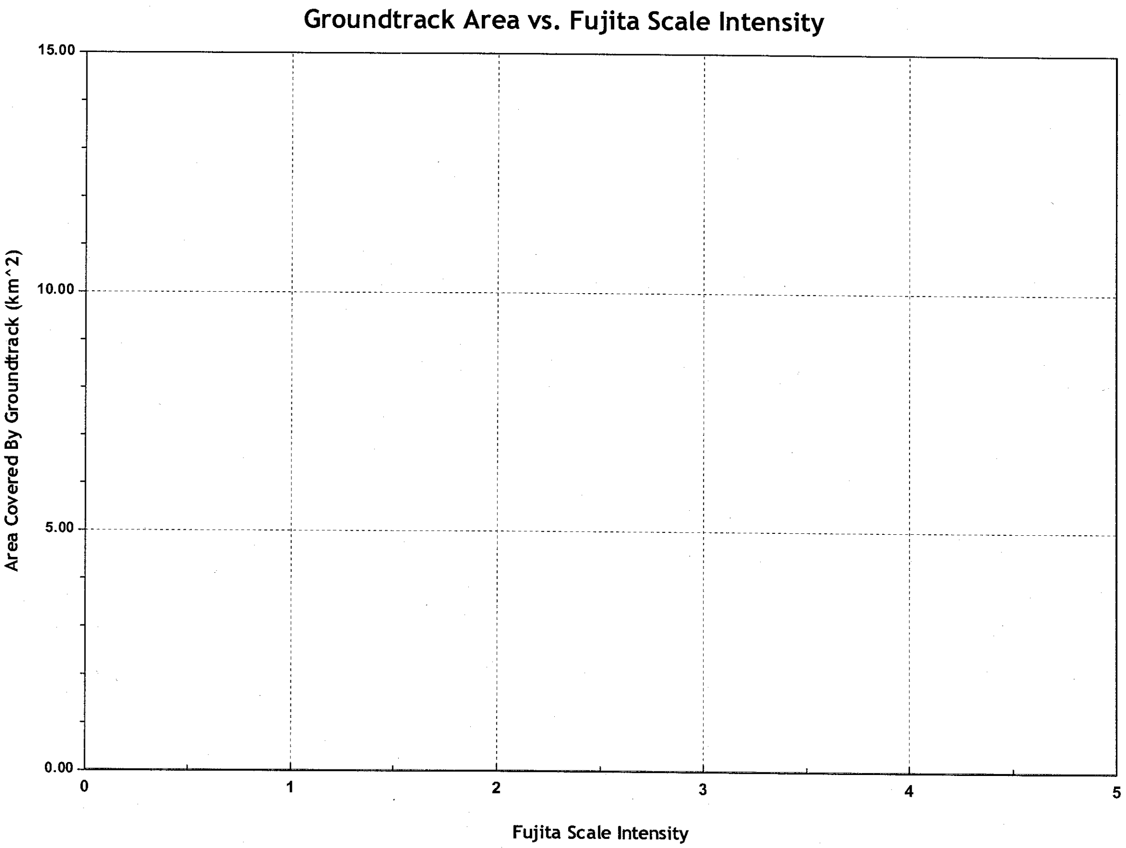
Follow-up Questions

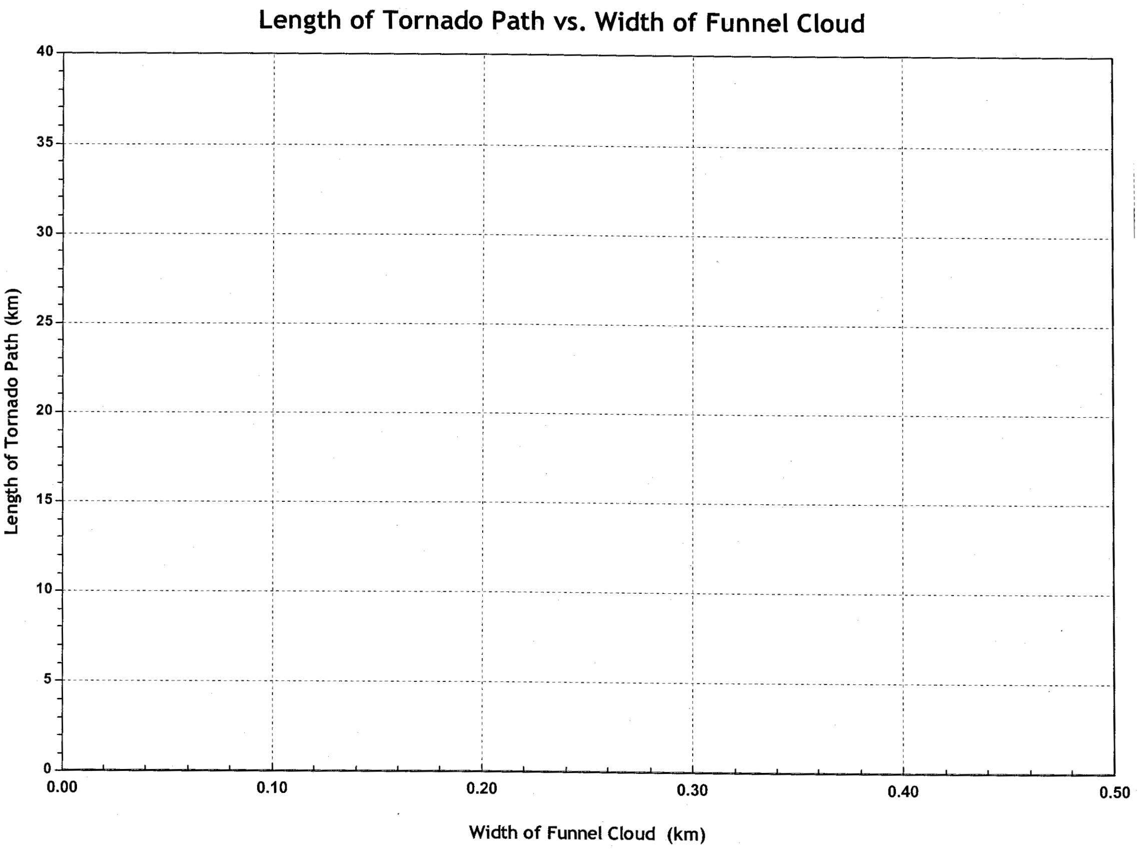
1. Of the six (6) plots that you have completed, which of the relationships seem to be LINEAR (the points form an almost straight line)?
2. Of the graphs that were plotted, are there any that are curved?
3. Could there be a mathematical explanation for why Graph #3 (Area of Funnel Cloud versus Fujita Intensity) curves in the manner that it does? Hint: Think about exponents.
4. By looking at your last graph—Graph #6 (Average Tornado Speeds versus Fujita Intensity Scale), is the Fujita Tornado Intensity Scale a LINEAR SCALE? Justify your answer with some evidence.

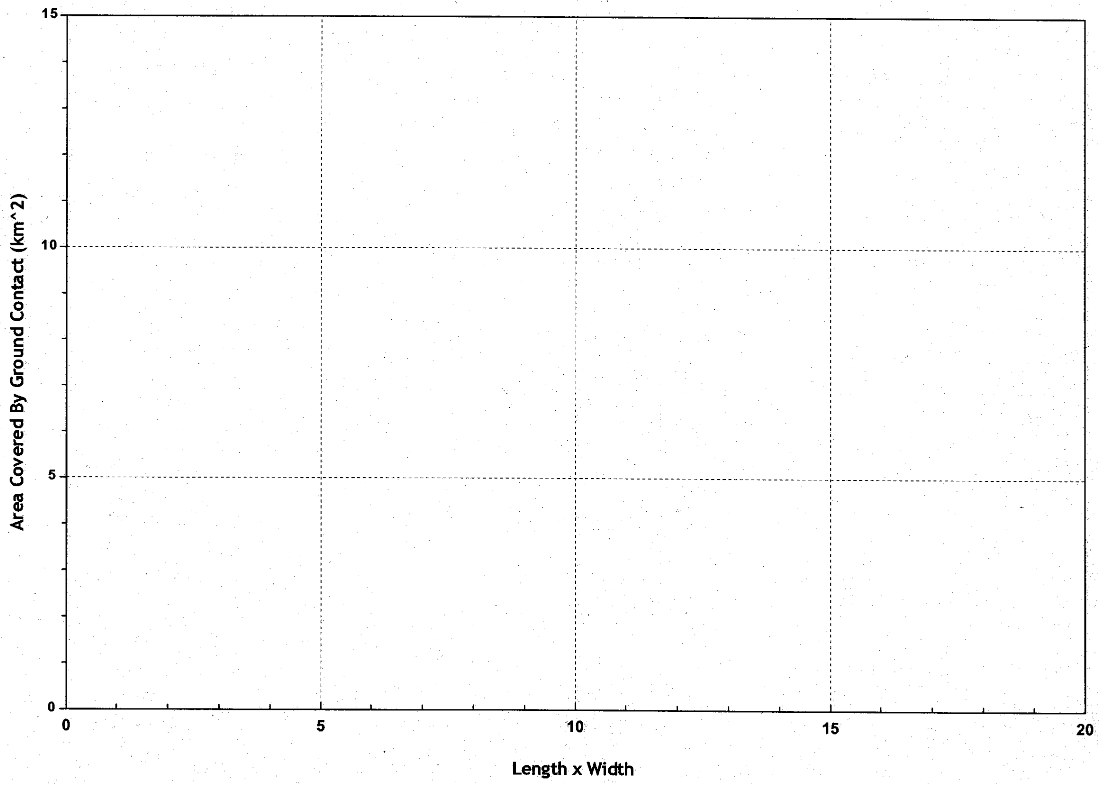
   If a tornado was an F5, what would be the average wind speeds be?
   _____________ kph

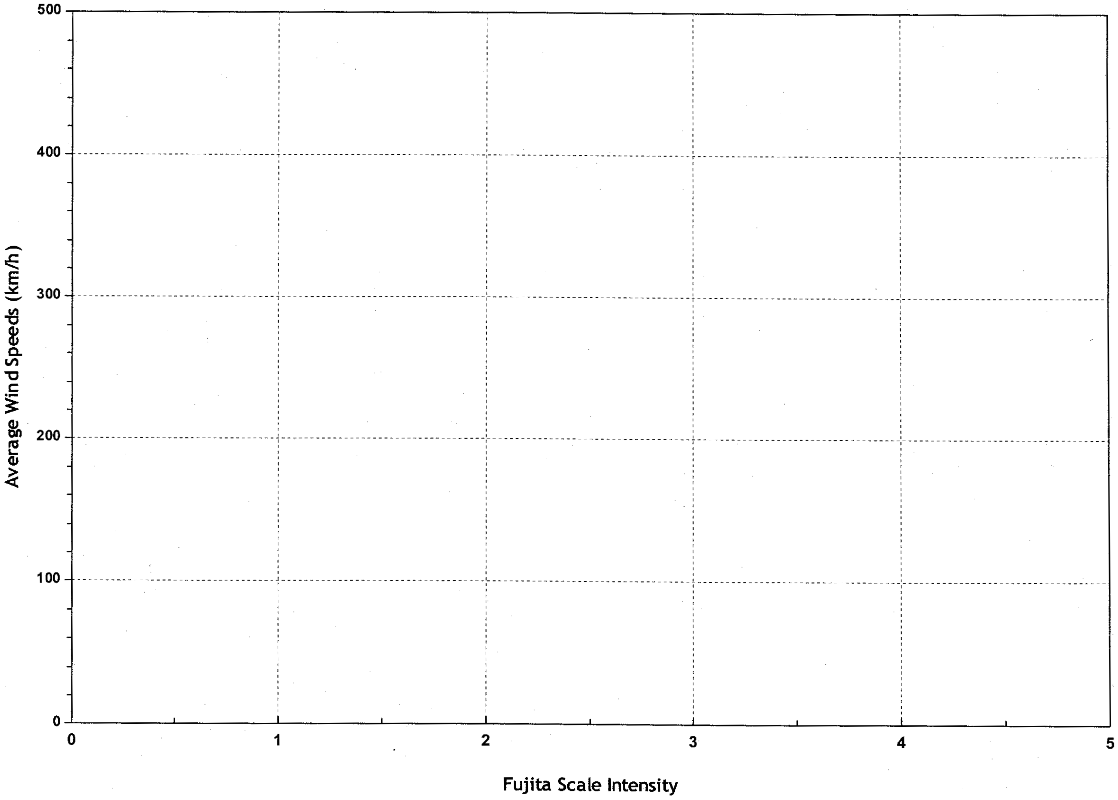

Length of Tornado Path vs. Fujita Scale Intensity
Length of Tornado Path (km)
0
10
20
30
40
50
Fujita Scale Intensity
0
1
2
3
4
5


Width of Funnel Cloud vs. Fujita Scale Intensity
Width of Funnel Cloud (km)
0.00
0.10
0.20
0.30
0.40
0.50
Fujita Scale Intensity
0
1
2
3
4
5


Groundtrack Area vs. Fujita Scale Intensity
15.00
10.00
5.00
0.00
Area Covered By Groundtrack (km^2)
0
1
2
3
4
5
Fujita Scale Intensity


Length of Tornado Path vs. Width of Funnel Cloud
40
35
30
25
20
15
10
5
0
Length of Tornado Path (km)
0.00
0.10
0.20
0.30
0.40
0.50
Width of Funnel Cloud (km)


Area of Ground Contact vs. (Length)x(Width) of Funnel Cloud


Area of Ground Contact vs. (Length)x(Width) of Funnel Cloud

TSM
Teacher
Support
Material

Location/Place—Where in the World Can Severe Storm Events Happen?

Students first map and describe the locations of sports or other events of interest to them and explain why the organizers decided on these locations to stage such events. Students then research a weather-related natural disaster of their choice and prepare a TV news report to explain where they expect such a disaster to strike in the future.

Teacher Note

Book time in the library/resource centre for student research on the locations of sports or other events and then natural disasters. If the Internet is to be used, bookmark useful sites (see suggestions in the Resources section below). Students may bring in any magazines or other sources of information on these topics. If CD-ROMs on natural disasters are available in the school, have them on hand for students to use. Atlases and textbooks with information on natural weather disasters should be available to each group of students. Designate two or three students per class as evaluators for oral presentations. The remaining students are part of the audience listening to the presentations. Provide students with copies of Appendix 6.8: Rubric for Map Drawing, and Appendix 6.10: Rubric for Student Presentation.

Expectations

Students will

- Demonstrate an understanding of the location/place theme in geographic inquiry
- Locate relevant information from a variety of primary and secondary sources
- Analyze, synthesize, and evaluate data
- Construct a wide variety of graphs, charts, diagrams, maps, and models to organize information
- Communicate the results of inquiries, stating different points of view on an issue, using media works, oral presentations, written notes, descriptions, drawings, tables, charts, and graphs
- Produce a report on current environmental events (weather-related) in the news

Assessment

- Formative assessment by teacher of student ability to locate relevant information from primary and secondary sources, and to analyze, synthesize, and evaluate data (Appendix 6.10: Rubric for Research Skills)
- Formative self-assessment of the map produced in Appendix 6.9: Rubric for Map Drawing
- Peer assessment of the oral presentations from Appendix 6.8: Rubric for Student Presentation
- Formative assessment by teacher of the oral presentation for accuracy in describing the place/location of the natural event, using absolute and relative locations, valid reasons for their predictions, the accuracy of their location map and graphics, and their decision-making steps (see Appendix 6.3: Rubric for the Assessment of a Decision-Making Process Activity and Appendix 6.9: Rubric for Map Drawing)

Teaching/Learning Strategies

1. In groups of two to four, students map the locations of at least three to four events of interest to them on a world map (see Appendix 4.12). Suggestions include the sites of the Winter Olympic Games, World Cup Soccer finals, the Summer Olympics, various entertainment award ceremonies (such as the Oscars, Junos, or Golden Globes), or the performance sites of their favourite music group(s). Their research could be done in the library/resource centre, on the Internet, magazines and books on the topic, or with their own resources at home. Students look for ideas on why these locations/places were chosen for such sites. What unique characteristics did they have? How did their absolute or relative locations influence people to choose them over others?

2. Before students start their research on this activity, outline the features that make an effective and complete map by reviewing with the class Appendix 6.9: Rubric for Map Drawing.

3. Upon completing their research, students draw their maps, describe where their chosen activity occurred in the world in both absolute and relative terms, and suggest what unique features might have been considered in choosing such places.

4. Review Appendix 6.8: Rubric for Student Presentation so students know how they will be evaluated.

5. Each group makes a brief oral presentation to the class, describing the place(s) or location(s) for their event(s) and their explanation(s) for the choice of these locations.

6. Collect, assess, and evaluate the maps and reasons for the choices of locations of the researched event(s).

7. Groups of two to four students choose to research one of the following natural weather-related events that interests them most (or they are chosen "out of a hat").
   - hurricane
   - earthquake
   - blizzard
   - tornado
   - avalanche
   - volcanic eruption
   - forest fire (lightning-caused)
   - ice storm
   - waterspouts over Lake Winnipegosis
   - or other natural event

8. Using an atlas, Internet sites, or textbooks, students find out where their type of event has occurred most frequently in the past and mark this information on a map of the world, or one of the continents. You may wish to restrict the area of research to one continent rather than the whole world. Students would then decide which continent to use to map their event.

9. After the research is completed, review the criteria that will be used to assess a five-minute TV news report using a TV news report rubric generated by the class with teacher assistance (see Appendix 5 for details).

10. Each group prepares a five-minute TV news report on their event describing the place/location (absolute and relative) where it is most likely to occur in the future. They include valid reasons for their prediction, backed up by a map, graphics, and a three- to four-step diagram outlining the steps used in reaching their conclusion (the decision-making model could be used as a guide).

11. Each group presents its five-minute report to the class.

12. Students peer-assess the map, showing the areas where the chosen natural disaster often occurs and the place/location predicted for a similar disaster.

13. Assess the research skills using Appendix 6.10: Rubric for Research Skills, and the content of the oral presentation, using the class-generated TV news report rubric.

Extension Ideas

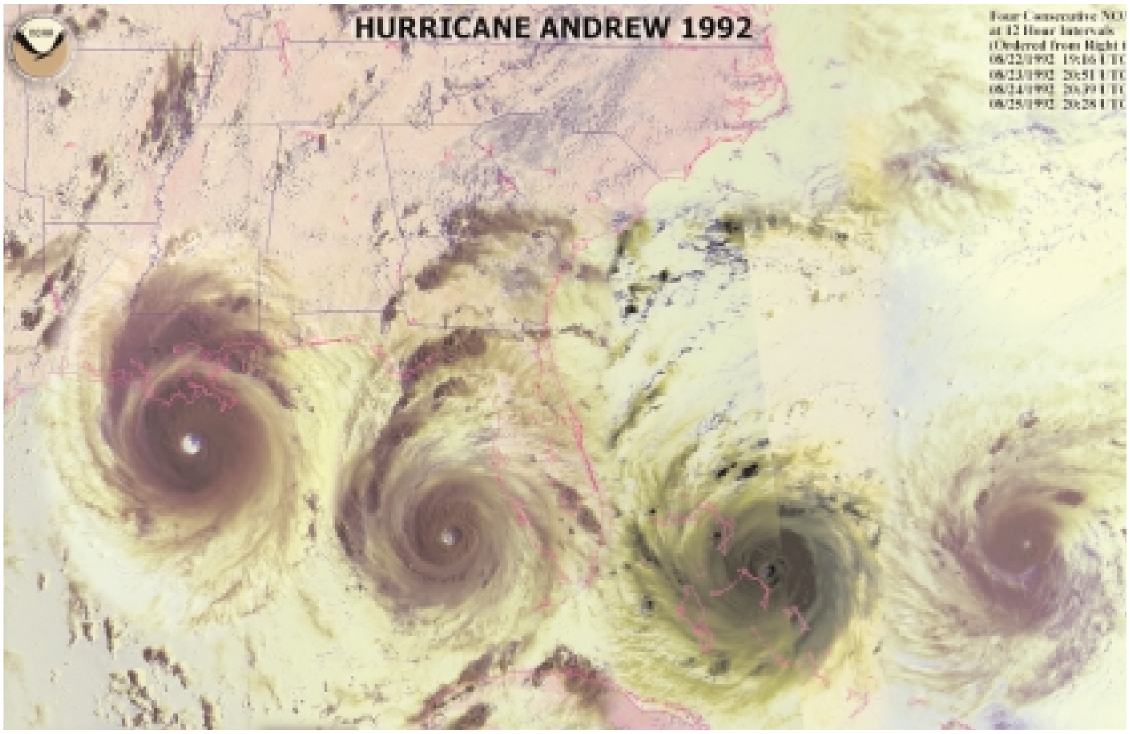
- Provide the sites of various types of events or have students do research in the classroom, library/resource centre, or at home. Depending on the level of group skills of the students, this activity might be done individually, rather than in groups.
- A less challenging variation: provide the locations of the events for mapping. In small groups, students then discuss the reasons for choosing such places or locations. Groups share ideas in a whole-class discussion session. Summarize ideas into a note for students.
- Show a portion of a live newscast (such as CBC Newsworld or CNN) as a model of what is expected in this activity. Try <www.cbc.ca> for streaming news video.
- Have students produce a poster or display board to present their findings instead of the TV news report.
- Students prepare maps of locations using computer mapping, paint/draw programs, or storm-tracking software.

Resources

- World Outline Map or Globe Map (see Appendices 4.11-4.15)
- Access to library/resource centre, atlases, magazines and encyclopedias, home materials
- Internet browser software or the special sections devoted to severe weather events found at the Lycos, AltaVista, Infoseek, and Excite search sites
- Internet sites for volcanoes, earthquakes, cyclones, hurricanes, tornadoes, thunderstorms, and related natural weather-related events suggested in the pre-planning section of this unit
- Local newspaper articles or maps that identify significant natural events (past copies of maps can be found on the Internet at <www.earthweek.com> or its new address at <www.discovery.com/news/earthalert/earthalert.html>, or at the NASA Earth Observatory site at <http://earthobservatory.nasa.gov>)
- Textbooks on physical geography written for this level (Senior Years)

SLA
Student
Learning
Activity

Tracking a Killer Hurricane*



The Background

On August 16, 1992, Hurricane Andrew first became a tropical depression. On August 17, it became the first tropical storm of the season. The storm moved rapidly west and northwest during the next few days and on August 22 it had reached hurricane strength. Landfall was made in southern Florida on August 24th at approximately 5:00 a.m. Having become a Category 4 storm, the central pressure fell to 922 millibars (92.2 kPa) and wind gusts were estimated in excess of 280 kph (175 mph). Andrew moved west at 29 kph (18 mph).

Once over the open waters of the Gulf of Mexico, a moderate intensification ensued as the storm turned northwestward. August 26, Andrew made landfall again, this time in south central Louisiana, with a central pressure of 956 millibars (95.6 kPa) and sustained winds approaching 190 kph (120 mph). The hurricane quickly weakened and became a depression 24 hours later, as it was turned sharply northeastward and merged with a frontal system over the eastern United States.

When all was said and done, Andrew was by far the most expensive natural disaster in history (up to that date), with estimated damages exceeding $20 billion. More than 60 people were killed and approximately 2 million people were evacuated from their homes.

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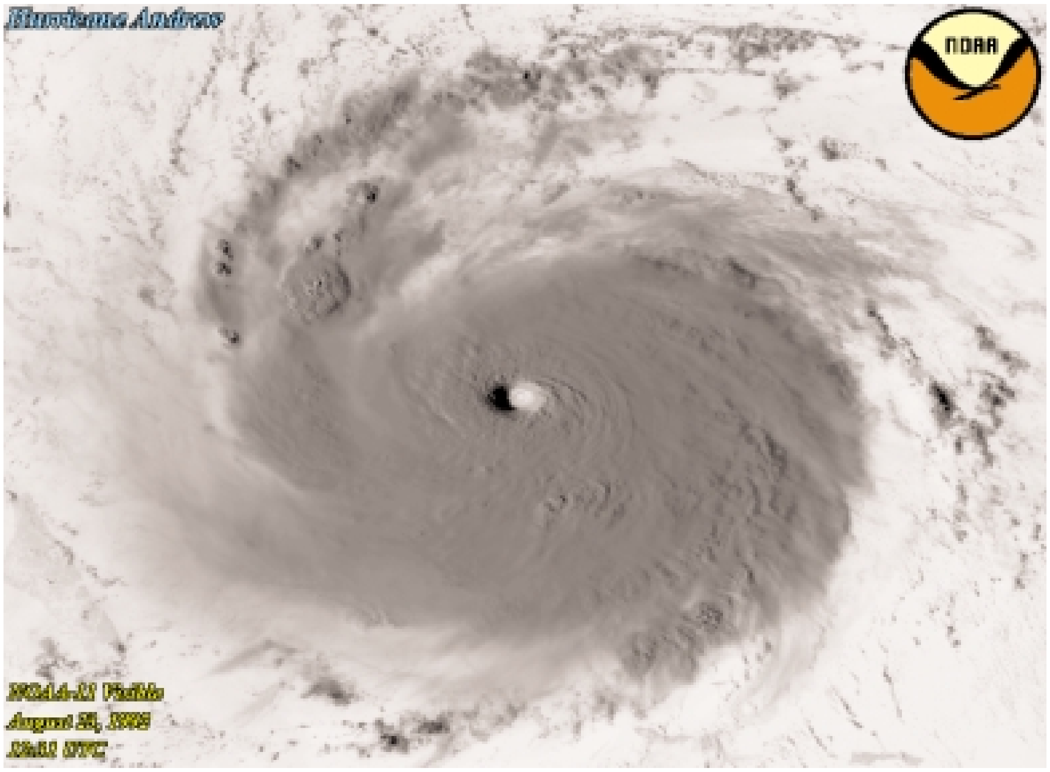
* Satellite image courtesy of NOAA. All rights reserved.

Procedure for the Activity

- Observe the location of Hurricane Andrew on a set of satellite images that can be used with this activity. Download from <http://lwf.ncdc.noaa.gov/servlets/GoesBrowser>.
- Using the *Hurricane Tracking Map* provided in Appendix 4.26b, carefully plot the location of Hurricane Andrew as it approaches landfall in Florida. Create an appropriate symbol for the storm, and be consistent in its use. The chart below should provide information on location and the time for each plot. Plot 12 points on the tracking chart—one for each full day.

Note: Meteorologists use UNIVERSAL TIME (UT) (often referred to as Greenwich Mean Time, or GMT) for all observations. For instance, a time recorded as 1600z on a satellite image represents 1600–500, or 11:00 a.m. Manitoba time. The "500" represents the five-hour time difference between GMT and local Central Daylight Time (CDT). When we are on Standard Time (CST), the time difference increases to six hours.

Sample Satellite Image of Hurricane Andrew*



Note: The time of the image, "12:31 UTC," appearing in the lower-left corner of this image means "August 23, 1992 at 1231z, Coordinated Universal Time (UTC)." For Manitobans, the time would be 1231–500 or 731 = 7:31 a.m. CDT.

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* Satellite image courtesy of NOAA. All rights reserved.

Hurricane Andrew—Tracking Information

The chart that follows contains information that will allow you to track Andrew's progress as it began as a tropical low-pressure system (a "depression" in weather terms) far out in the eastern Atlantic ocean. The chart includes information such as:

- Adv = Advisory Number
- Latitude and longitude of the centre of the storm (negative values for longitude indicate west of Greenwich, England)
- Date and time (the time is in "zulu" format, which is equivalent to Greenwich Mean Time). For instance, 18Z = 1800 GMT = 13:00 CDT here in Manitoba.
- Maximum sustained winds (measured in "nautical miles per hour (knots)"), where 1 knot = 2 km/hr). For example, 150 kt = 300 km/hr.
- Minimum air pressure in the "eye" of the storm (in millibars (mb), where 10 mb = 1.0 kPa). For instance, 1000 mb = 100.0 kPa.
- Classification of the storm

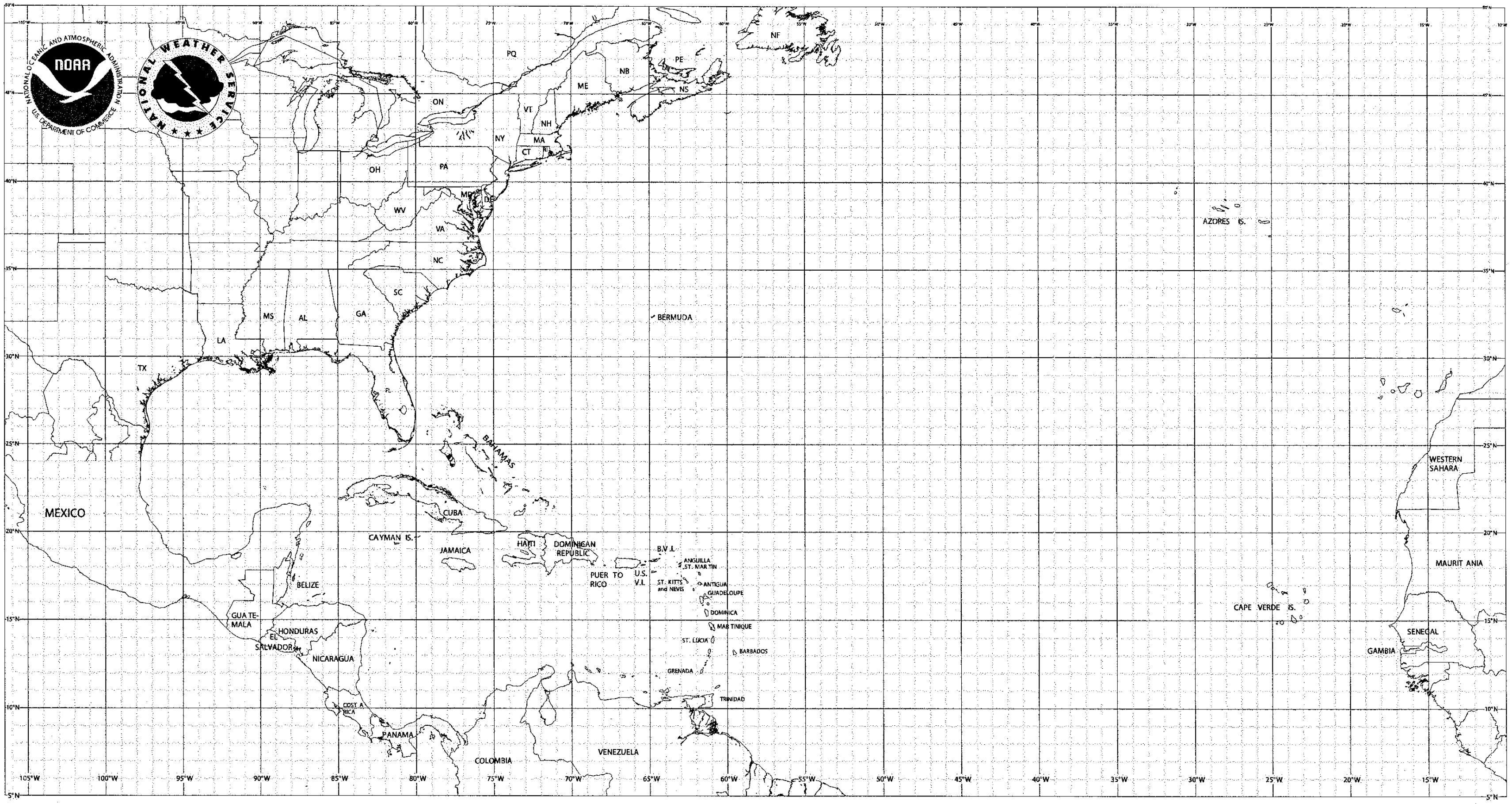
Dates: 16-28 AUG 1992

Adv	Latitude	Longitude	Time	Wind	Pressure	Status
1	10.80	–35.50	08/16/18Z	25	1010	Tropical Depression
2	11.20	–37.40	08/17/00Z	30	1009	Tropical Depression
3	11.70	–39.60	08/17/06Z	30	1008	Tropical Depression
4	12.30	–42.00	08/17/12Z	35	1006	Tropical Storm
5	13.10	–44.20	08/17/18Z	35	1003	Tropical Storm
6	13.60	–46.20	08/18/00Z	40	1002	Tropical Storm
7	14.10	–48.00	08/18/06Z	45	1001	Tropical Storm
8	14.60	–49.90	08/18/12Z	45	1000	Tropical Storm
9	15.40	–51.80	08/18/18Z	45	1000	Tropical Storm
10	16.30	–53.50	08/19/00Z	45	1001	Tropical Storm
11	17.20	–55.30	08/19/06Z	45	1002	Tropical Storm
12	18.00	–56.90	08/19/12Z	45	1005	Tropical Storm
13	18.80	–58.30	08/19/18Z	45	1007	Tropical Storm
14	19.80	–59.30	08/20/00Z	40	1011	Tropical Storm
15	20.70	–60.00	08/20/06Z	40	1013	Tropical Storm
16	21.70	–60.70	08/20/12Z	40	1015	Tropical Storm
17	22.50	–61.50	08/20/18Z	40	1014	Tropical Storm
18	23.20	–62.40	08/21/00Z	45	1014	Tropical Storm
19	23.90	–63.30	08/21/06Z	45	1010	Tropical Storm
20	24.40	–64.20	08/21/12Z	50	1007	Tropical Storm
21	24.80	–64.90	08/21/18Z	50	1004	Tropical Storm
22	25.30	–65.90	08/22/00Z	55	1000	Tropical Storm

23	25.60	–67.00	08/22/06Z	65	994	Hurricane—1
24	25.80	–68.30	08/22/12Z	80	981	Hurricane—1
25	25.70	–69.70	08/22/18Z	95	969	Hurricane—2
26	25.60	–71.10	08/23/00Z	110	961	Hurricane—3
27	25.50	–72.50	08/23/06Z	130	947	Hurricane—4
28	25.40	–74.20	08/23/12Z	145	933	Hurricane—5
29	25.40	–75.80	08/23/18Z	150	922	Hurricane—5
30	25.40	–77.50	08/24/00Z	125	930	Hurricane—4
31	25.40	–79.30	08/24/06Z	130	937	Hurricane—4
32	25.60	–81.20	08/24/12Z	115	951	Hurricane—4
33	25.80	–83.10	08/24/18Z	115	947	Hurricane—4
34	26.20	–85.00	08/25/00Z	115	943	Hurricane—4
35	26.60	–86.70	08/25/06Z	115	948	Hurricane—4
36	27.20	–88.20	08/25/12Z	120	946	Hurricane—4
37	27.80	–89.60	08/25/18Z	125	941	Hurricane—4
38	28.50	–90.50	08/26/00Z	125	937	Hurricane—4
39	29.20	–91.30	08/26/06Z	120	955	Hurricane—4
40	30.10	–91.70	08/26/12Z	80	973	Hurricane—1
41	30.90	–91.60	08/26/18Z	50	991	Tropical Storm
42	31.50	–91.10	08/27/00Z	35	995	Tropical Storm
43	32.10	–90.50	08/27/06Z	30	997	Tropical Depression
44	32.80	–89.60	08/27/12Z	30	998	Tropical Depression
45	33.60	–88.40	08/27/18Z	25	999	Tropical Depression
46	34.40	–86.70	08/28/00Z	20	1000	Tropical Depression
47	35.40	–84.00	08/28/06Z	20	1000	Tropical Depression

Atlantic Basin Hurricane Tracking Chart*

National Hurricane Center, Miami, Florida



* Tracking chart courtesy of NOAA. All rights reserved.
A larger (11 x 17 inch) version of this chart is available at the National Hurricane Centre. <http://www.nhc.noaa.gov/>

Follow-up Responses

Use the Atlantic Basin Hurricane Tracking Chart provided for you on page A172.

1. Carefully trace the path of Hurricane Andrew by joining each of your plotted positions. Then, attempt to trace eastward out into the Atlantic to where you believe this storm first became hurricane-class. Then, verify your projections by looking over a 1992 Hurricane Tracking Map provided by a relevant website such as the National Hurricane Center <http://www.nhc.noaa.gov/>.

2. By determining how long the time span is between each plotted position, you can work out the average speed of the storm for a 72-hour period.

   AVERAGE SPEED = DISTANCE TRAVELED ÷ TIME

   Work out the speed of the storm, first in miles per day, then convert to kilometres per hour using an appropriate conversion that you can look up in tables of measurement. Do this for each of the following 72-hour periods:

   i. August 16th to August 18th

   ____

   ____

   ____

   ii. August 21st to August 23rd

   ____

   ____

   ____

   iii. August 24th to August 26th

   ____

   ____

   ____

   iv. August 26th to August 28th

   ____

   ____

   ____

3. Describe the nature of any changes in average speed over a 72-hour period for the hurricane, and link these to changes in direction observed on the tracking chart.

4. After landfall, did Andrew "join forces" with any continental weather systems moving eastward across the southern United States? You will need to consult a satellite image from the archive listed at the beginning of this activity.

East Pacific Hurricane Tracking Chart

BLM
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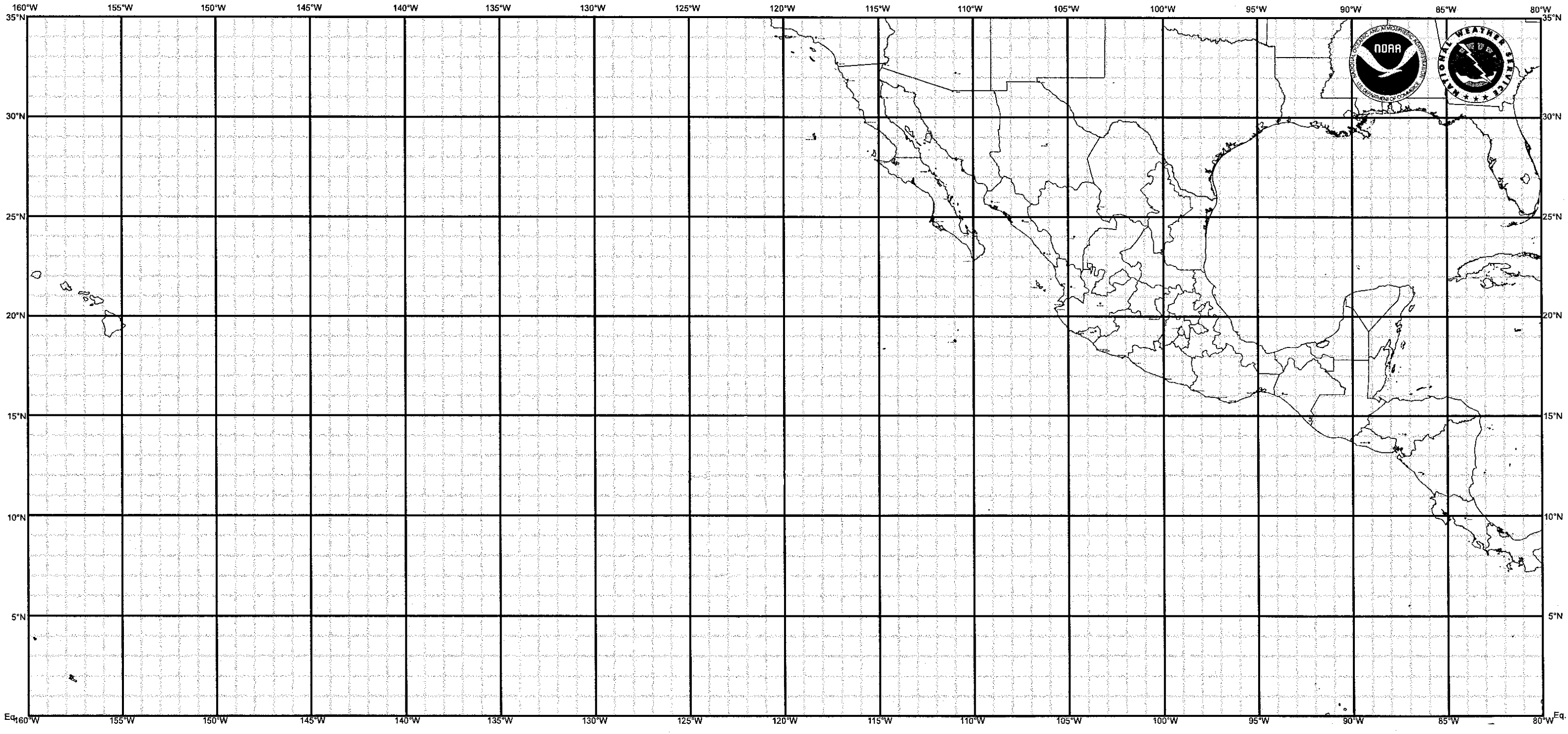
East Pacific Hurricane Tracking Chart *
National Hurricane Center, Miami, Florida



This is a reduced version of the chart used to track hurricanes at the National Hurricane Center

* Tracking chart courtesy of NOAA. All rights reserved.
A larger (11 x 17 inch) version of this chart is available at the National Hurricane Centre. <http://www.nhc.noaa.gov/>

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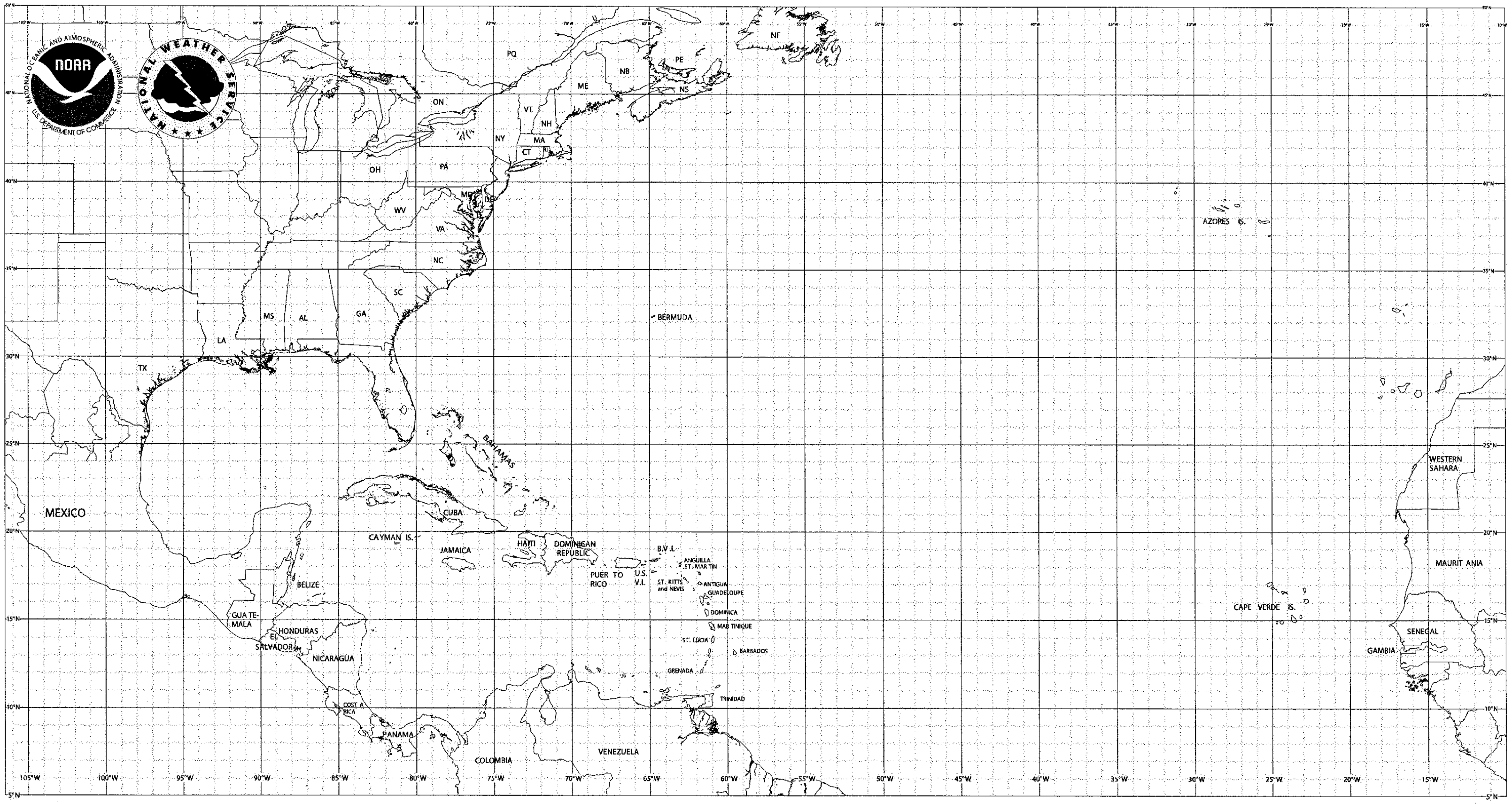
Atlantic Hurricane Track Chart

Atlantic Basin Hurricane Tracking Chart*

National Hurricane Center, Miami, Florida



* Tracking chart courtesy of NOAA. All rights reserved.
A larger (11 x 17 inch) version of this chart is available at the National Hurricane Centre. <http://www.nhc.noaa.gov/>

The Saffir-Simpson Hurricane Scale and Fujita Tornado Scale

The Saffir-Simpson Hurricane Scale

The Saffir-Simpson Hurricane Scale is a 1–5 rating based on a hurricane's present intensity. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf in the landfall region. Note that all winds are using the U.S. one–minute average.

Category One Hurricane

Winds 119–153 km/h (64–82 kt or 74–95 mph). Storm surge generally 4–5 feet above normal. No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage. Hurricanes Allison of 1995 and Danny of 1997 were Category One hurricanes at peak intensity.

Category Two Hurricane

Winds 154–177 km/h (83–95 kt or 96–110 mph). Storm surge generally 6–8 feet above normal. Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2–4 hours before arrival of the hurricane centre. Small craft in unprotected anchorages break moorings. Hurricane Bonnie of 1998 was a Category Two hurricane when it hit the North Carolina coast, while Hurricane Georges of 1998 was a Category Two Hurricane when it hit the Florida Keys and the Mississippi Gulf Coast.

Category Three Hurricane

Winds 178–209 km/h (96–113 kt or 111–130 mph). Storm surge generally 9–12 feet above normal. Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Damage to shrubbery and trees with foliage blown off trees and large trees blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3–5 hours before arrival of the hurricane centre. Flooding near the coast destroys smaller structures with larger structures damaged by battering of floating debris. Terrain continuously lower than 5 feet above mean sea level may be flooded inland 8 miles (13 km) or more. Evacuation of low-lying residences within several blocks of the shoreline may be required. Hurricanes Roxanne of 1995 and Fran of 1996 were Category Three hurricanes at landfall on the Yucatan Peninsula of Mexico and in North Carolina, respectively.

Category Four Hurricane

Winds 131–155 mph (114–135 kt or 210–249 km/hr). Storm surge generally 13–18 feet above normal. More extensive curtainwall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3–5 hours before arrival of the hurricane centre. Major damage to lower floors of structures near the shore. Terrain lower than 10 feet above sea level may be flooded, requiring massive evacuation of residential areas as far inland as 6 miles (10 km). Hurricane Luis of 1995 was a Category Four hurricane while moving over the Leeward Islands. Hurricanes Felix and Opal of 1995 also reached Category Four status at peak intensity.

Category Five Hurricane

Winds greater than 155 mph (135 kt or 249 km/hr). Storm surge generally greater than 18 feet above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3–5 hours before arrival of the hurricane centre. Major damage to lower floors of all structures located less than 15 feet above sea level and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5–10 miles (8–16 km) of the shoreline may be required. Hurricane Mitch of 1998 was a Category Five hurricane at peak intensity over the western Caribbean. Hurricane Gilbert of 1988 was a Category Five hurricane at peak intensity and is the strongest Atlantic tropical cyclone of record. Hurricane Andrew (1992) made landfall as a Category Five storm (not known until 2002).

Fujita Scale of Tornado Force

The Fujita Tornado Scale, usually referred to as the F-Scale, classifies tornadoes based on the resulting damage. This scale was developed by Dr. T. Theodore Fujita (University of Chicago) in 1971.

F-Scale	Winds	Type of Damage	Frequency
F0	40–72 mph 64–116 km/h	MINIMAL DAMAGE: Some damage to chimneys, TV antennas, roof shingles, trees, and windows.	29%
F1	73–112 mph 117–180 km/h	MODERATE DAMAGE: Automobiles overturned, carports destroyed, trees uprooted.	40%
F2	113–157 mph 181–253 km/h	MAJOR DAMAGE: Roofs blown off homes, sheds and outbuildings demolished, mobile homes overturned.	24%
F3	158–206 mph 254–332 km/h	SEVERE DAMAGE: Exterior walls and roofs blown off homes. Metal buildings collapsed or severely damaged. Forests and farmland flattened.	6%
F4	207–260 mph 333–418 km/h	DEVASTATING DAMAGE: Few walls, if any, standing in well-built homes. Large steel and concrete missiles thrown far distances.	2%
F5	261–318 mph 419–512 km/h	INCREDIBLE DAMAGE: Homes leveled with all debris removed. Schools, motels, and other larger structures have considerable damage with exterior walls and roofs gone. Top storeys demolished.	less than 1%

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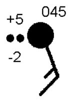
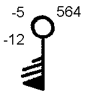
Weather Map Symbols*

Selected Weather Map Symbols

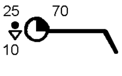
Surface Station Model

	Temp (F) Weather Dewpoint (F)	Pressure (mb) Sky Cover Wind (kts)	Data at Surface Station: Temp 5°C, dewpoint –2°C, overcast, wind from SE at 15 knots, weather light rain, pressure 1004.5 mb

Upper Station Model

	Height (m) Wind (kts)	Data at Pressure Level: Temp –5°C, dewpoint –12°C, wind from S at 75 knots, height of level 1564 m

Forecast Station Model

	PoP (%) Sky Cover Wind (kts)	Forecast at Valid Time Temp 25°C, dewpoint 10°C, scattered clouds, wind from E at 10 knots, probability of precipitation 70% with rain showers

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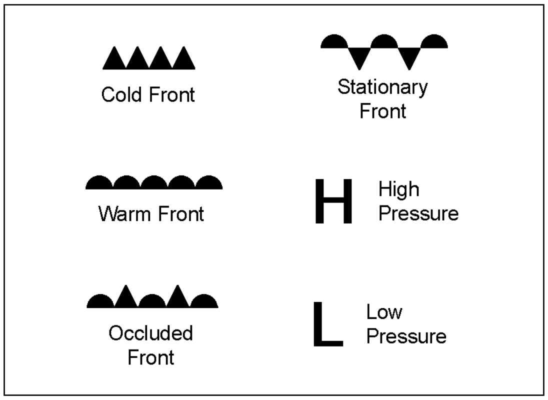
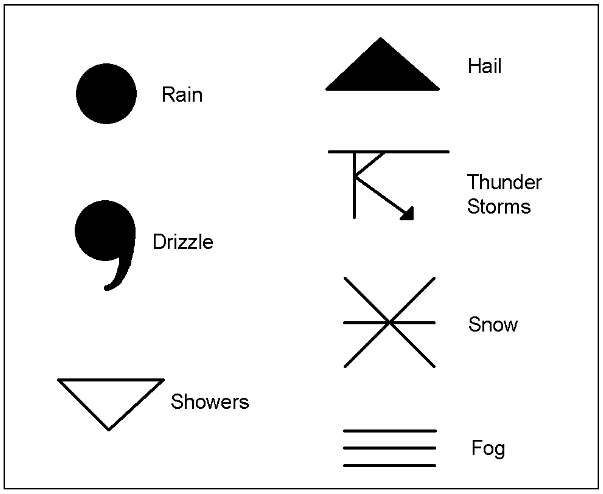
Weather Map Symbols—A Student’s Guide*

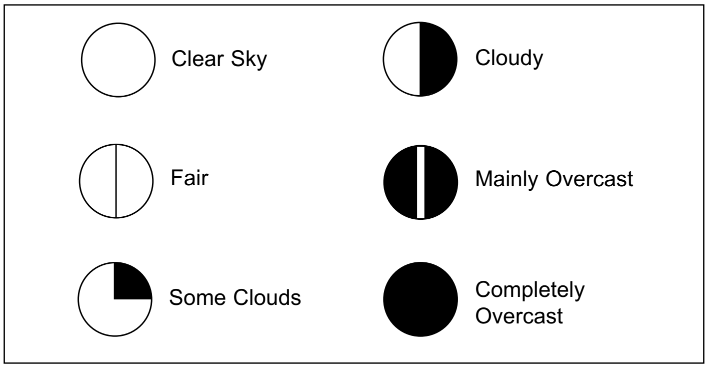
Fronts and Pressure



Precipitation Types



Cloud Cover



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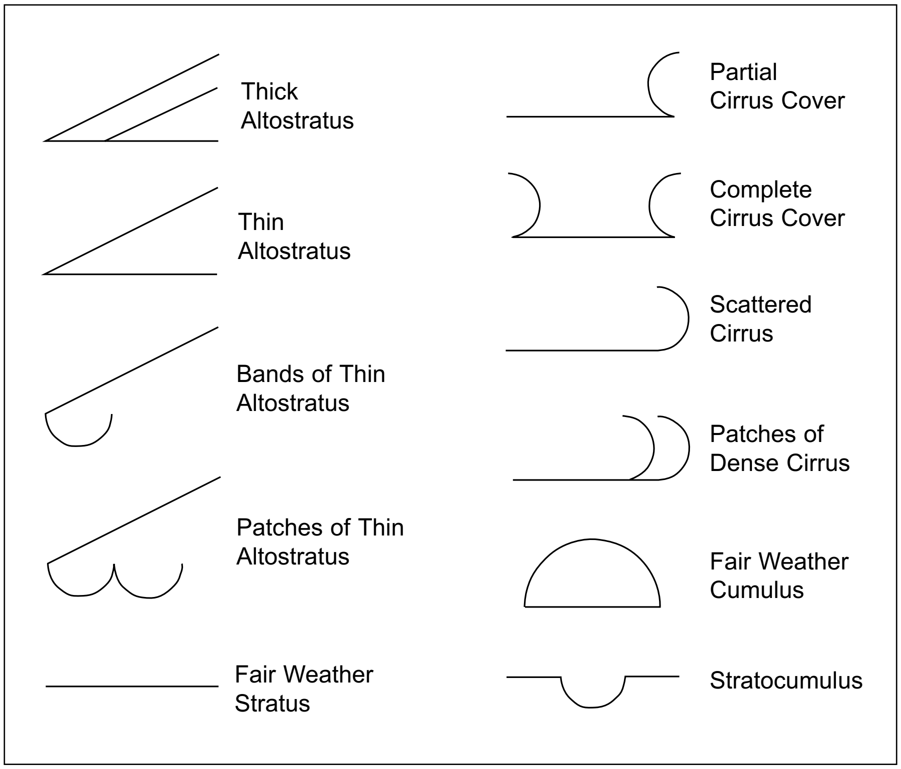
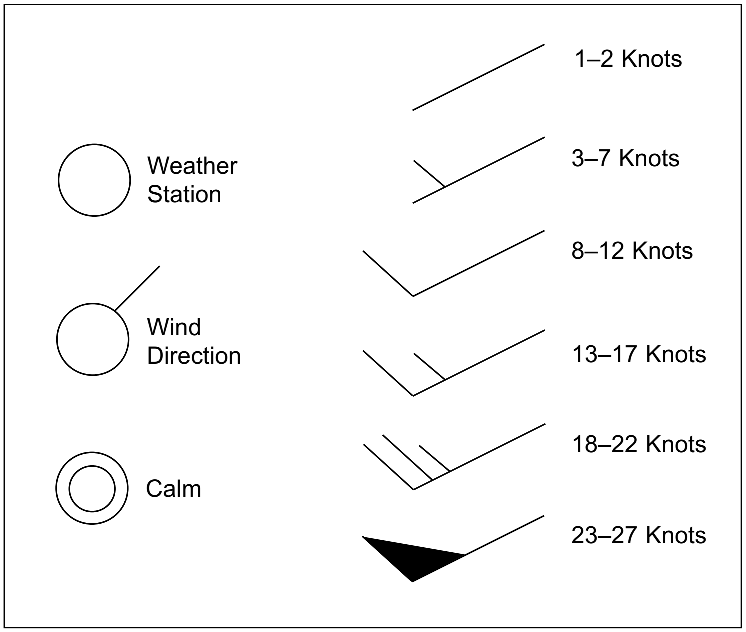
Cloud Types



Wind Direction and Speed



SLA
Student
Learning
Activity

Tracking a Severe Winter Storm: The 1997 Manitoba Blizzard

In this activity, you will:

- Analyze the early conditions as a winter storm system develops
- Track the path of the cyclone as it moves into Manitoba
- Determine the relationship between the major storm and corresponding hazardous weather it produced
- Connect your knowledge of storm systems to the spring blizzard of 1997 in Manitoba, the year of the "Flood of the Century"

Key Words

- Warm moist air/cool dry air
- Frontal boundary
- Cyclogenesis
- Jet stream flow
- Low pressure system

Introduction

During the period December 1996 to March 1997, the southern prairies in Canada and the northern plains in the United States (i.e., North and South Dakota) received almost record levels of snowfall. The sidewalks in Fargo, North Dakota, for instance, were piled high with three-metre-high snowbanks such that a pedestrian on the sidewalk could not even see the road. It was apparent that, as this snow melted in the spring of 1997, the risk of flooding along the Red River Basin was going to be significant. In the first week of April 1997, a major winter storm developed over Colorado (we often call these systems **"Colorado Lows"**) and began to track northeastward, heading directly for southern Manitoba. This particular storm was among the largest ever seen, spanning almost the entire North American continent from the Arctic to the Gulf of Mexico.

Between November 1996 and April 1997, the Red River Valley received almost double its average precipitation. Then on April 4, a blizzard struck the region, dumping 50 centimetres of snow over three days. Cold weather after the blizzard in April delayed the snow melt until the last week of April. The subsequent spring melt turned the Red River turned into the "Red Sea," covering some 2000 square kilometres, an area equivalent to the size of Prince Edward Island. More than 28,000 people had been evacuated from southern Manitoba by the time the Red River crested in Winnipeg on May 1, reaching its highest peak since 1826. Undertaking its largest military operation since the Korean War, 8500 Canadian soldiers participated in the sandbagging and evacuating. Total damages have been estimated at more than $150 million.

Major snowstorms are generally associated with winter storm systems that move across the central plains like this one did. The purpose of this lesson is to demonstrate the relationship between the track of the winter cyclone and areas of heavy snowfall and strong winds—real blizzard conditions!

Activity—Tracking the Blizzard of April 1997

In this activity, you will examine a sequence of satellite images that come from the period April 3–8, 1997. Your task is as follows:

1. Look very carefully at each image, beginning with the first one from April 3, 1997.
2. Use your prior knowledge about **storm fronts** and **low pressure systems** to locate the centre of the LOW as it moves across North America.
3. On the map of North America that appears after the images, track the storm **every two days**; draw the following for each of the three days that you plot (the first one will already be done for you):
    a. Label the centre of the LOW with a large "L."
    b. Draw the trailing **cold front** (look for the "comma-shaped" cloud pattern) that advances with the storm.
    c. With large arrows, draw in the direction of flow for the following air masses colliding—**cold, dry air** and **warm, moist air**. Do this only ONCE for April 6, 1997.
    d. Label these locations: Colorado (state) and Winnipeg (city).
4. What seems to be forming in the southern United States on April 8th, just after the conclusion of the blizzard event? Answer in the space below:

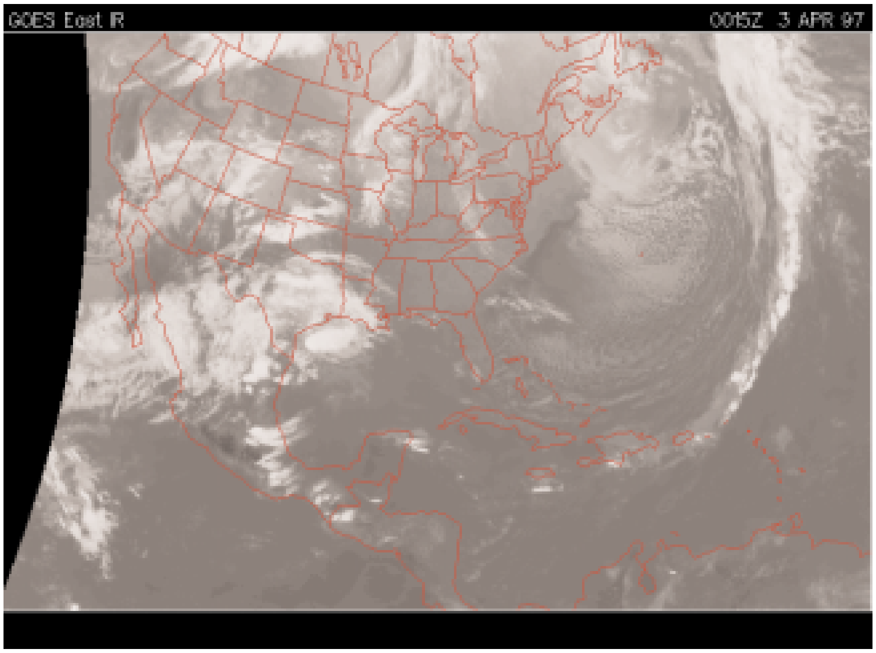
____

____

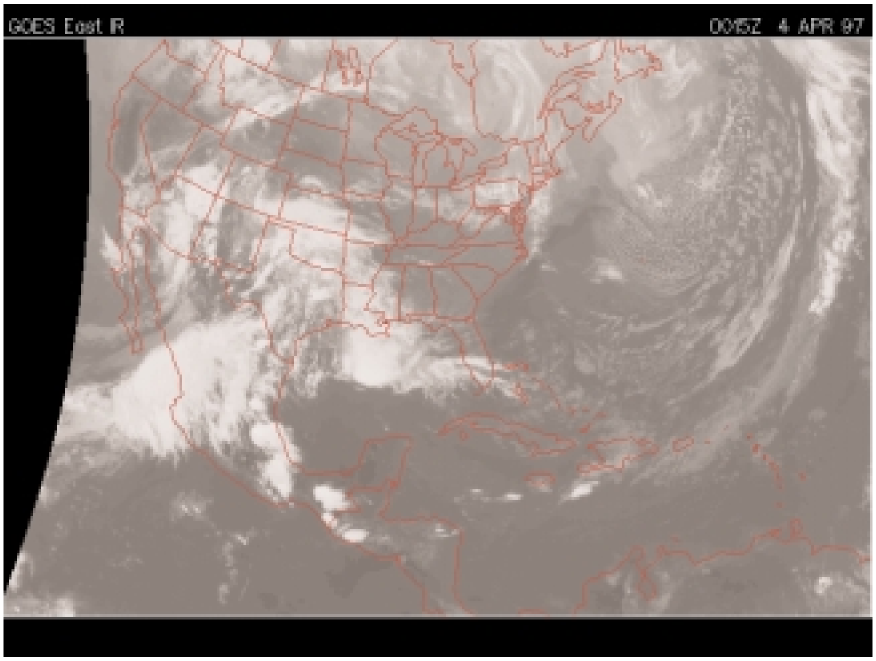
____

Satellite Images—April, 1997 Blizzard*

April 2nd, 6 p.m.



April 3rd, 6 p.m.



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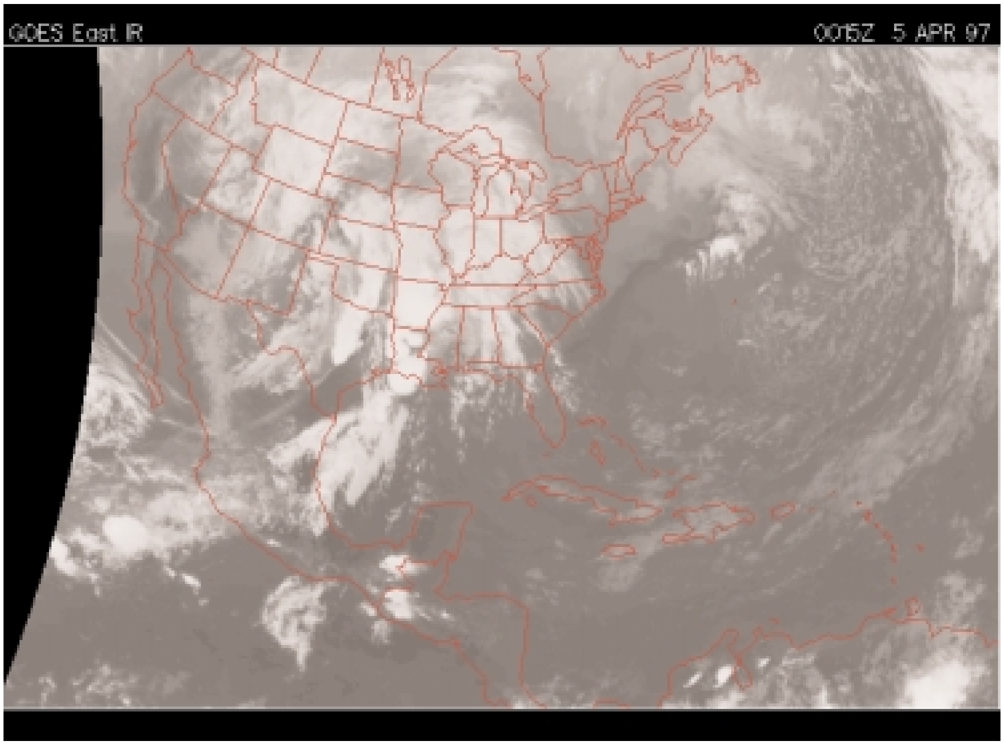
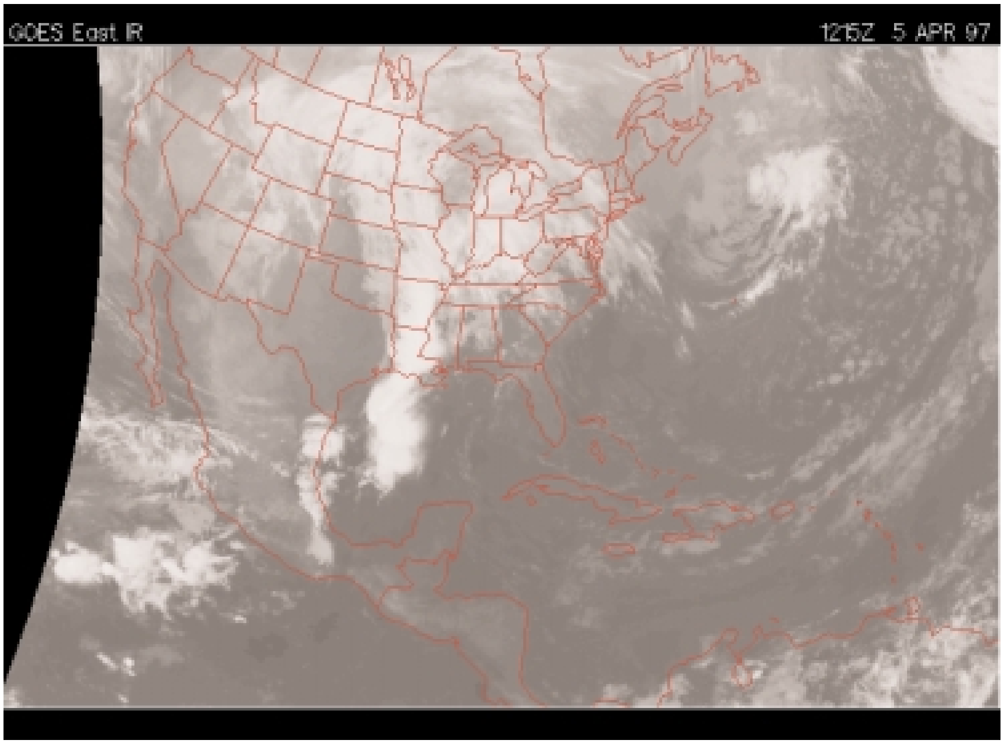
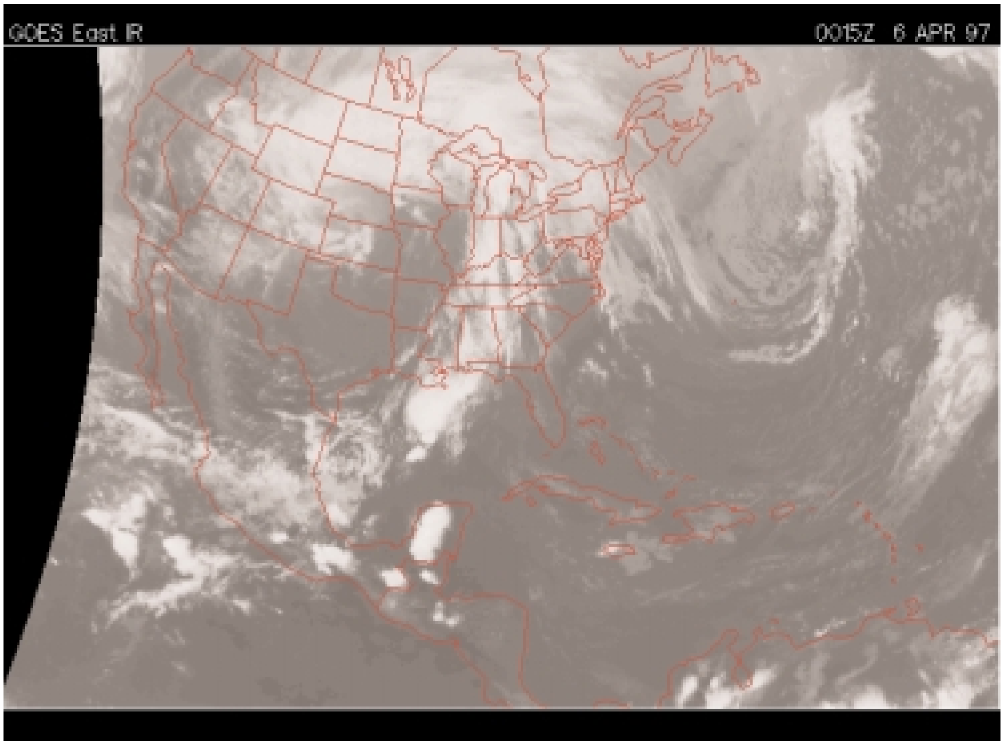
April 4th, 6 p.m.



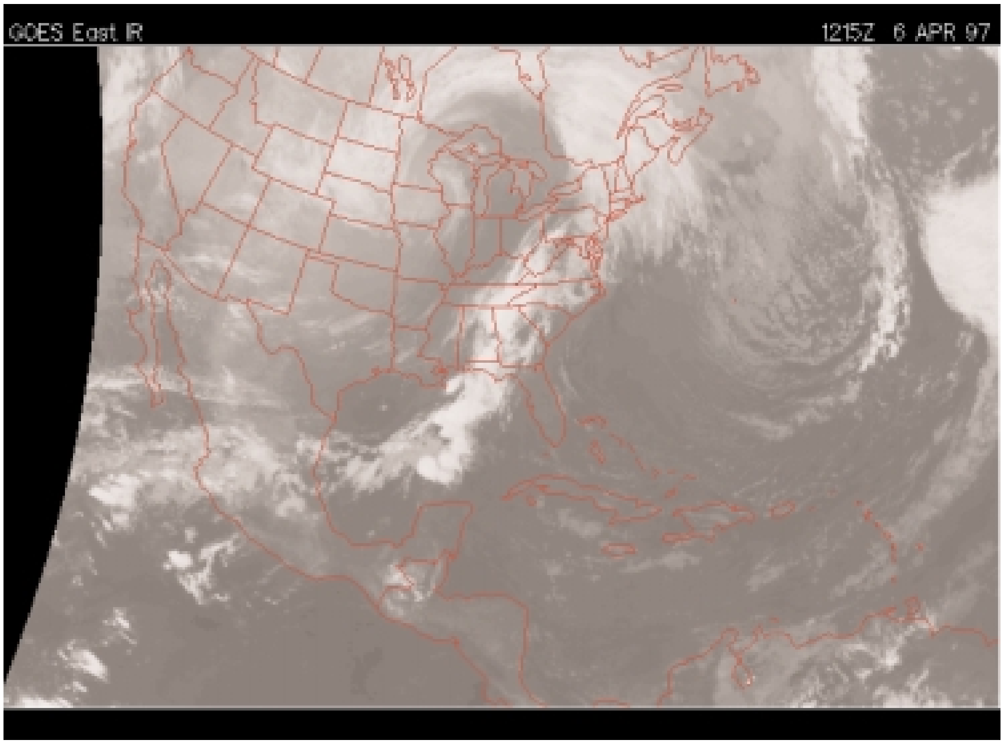
April 5th, 6 a.m.



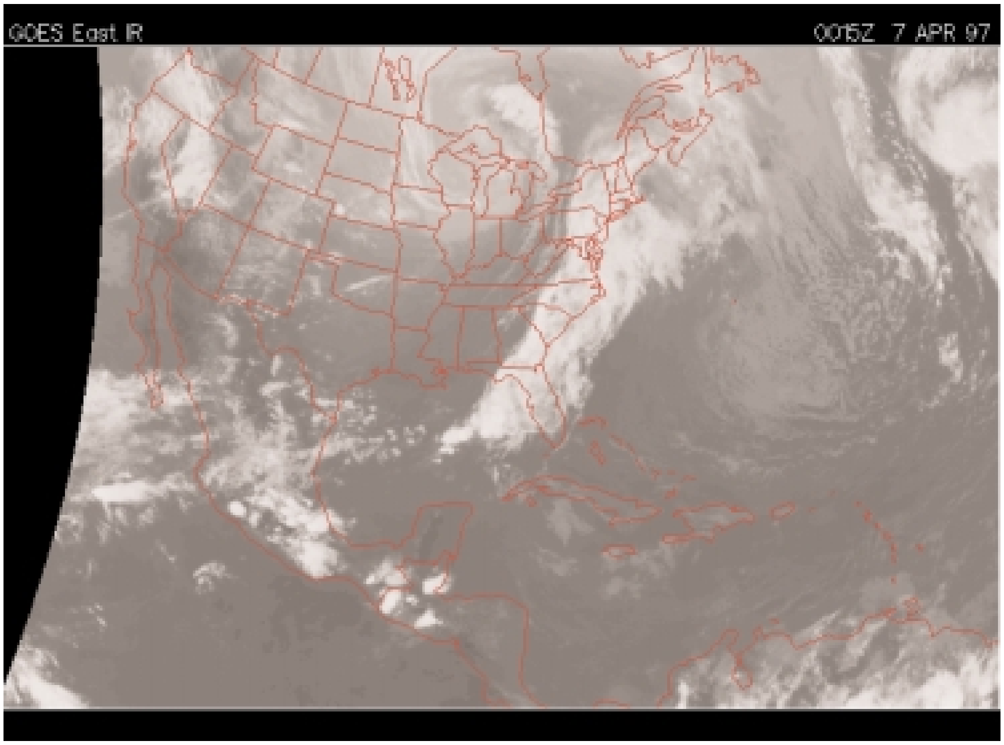
April 5th, 6 p.m.



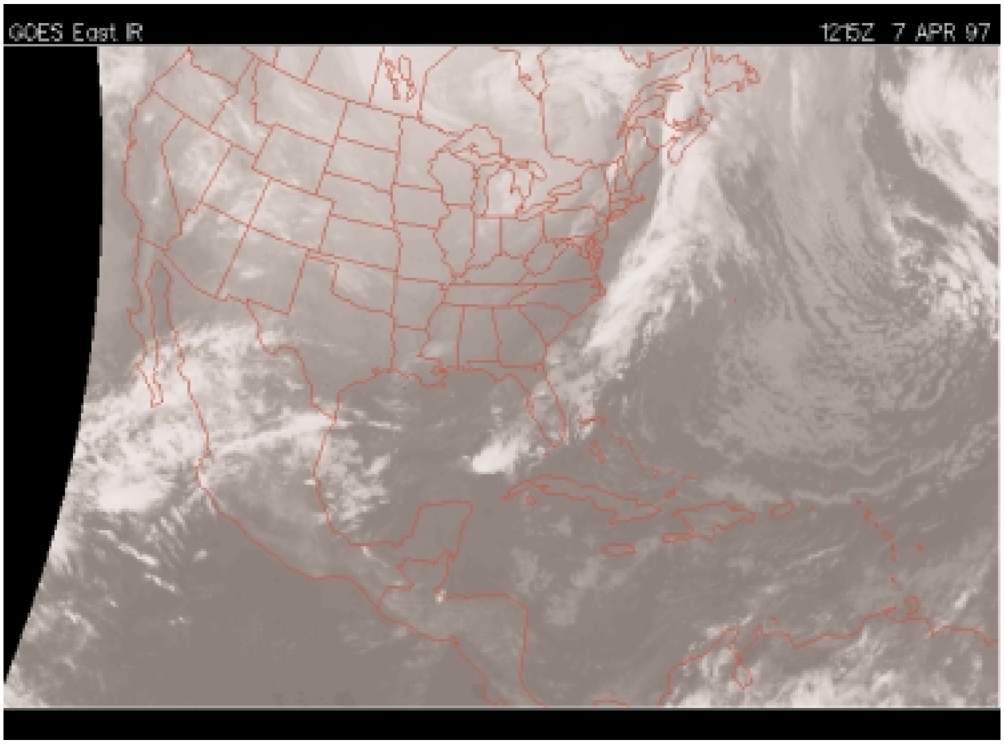
April 6th, 6 a.m.



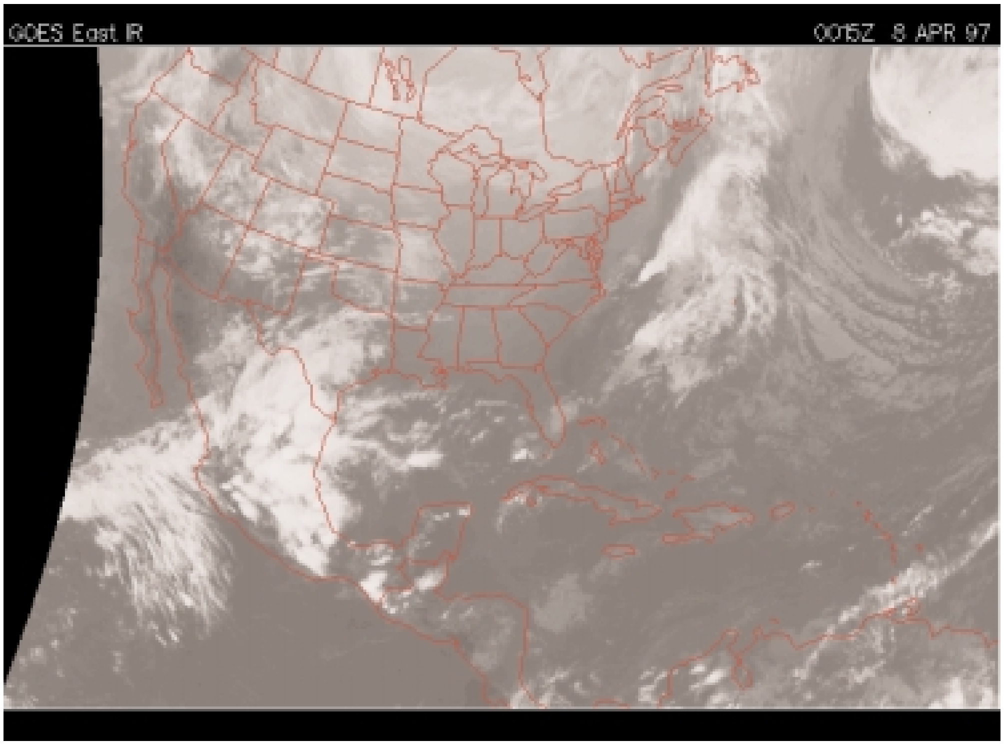
April 6th, 6 p.m.



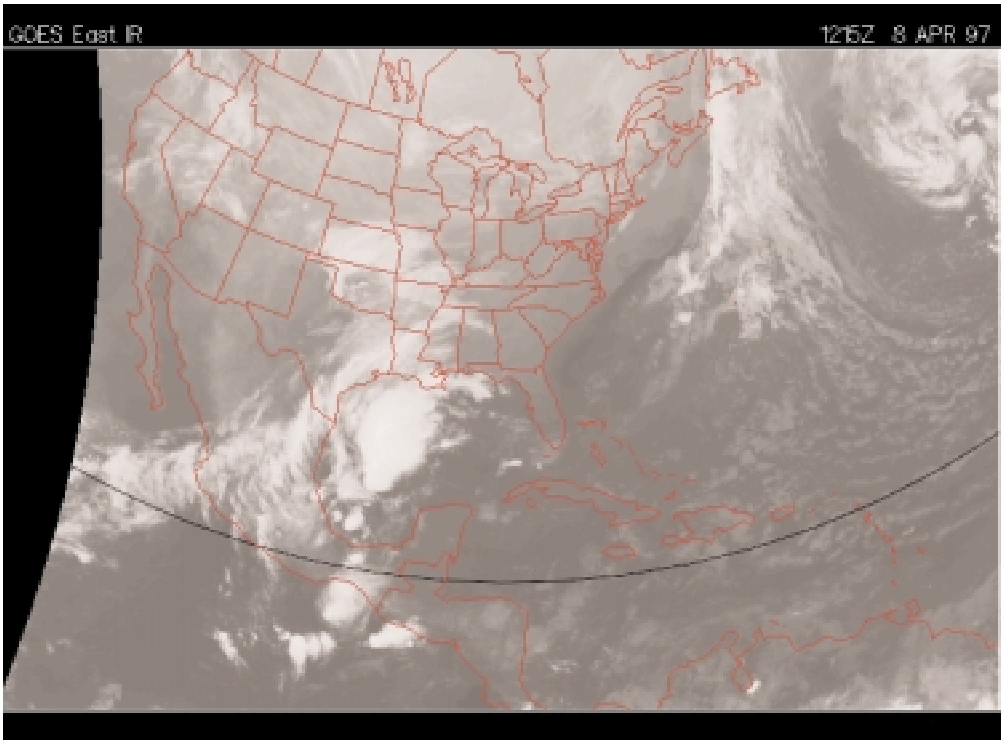
April 7th, 6 a.m.



April 7th, 6 p.m.



April 8th, 6 a.m.



Tracking the Storm—North American Weather Map*

As indicated earlier in this activity, use the map blank below to chart the progress of the storm over the period April 3–8, 1997.

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SLA
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Activity

Climates Do Change Naturally*

After completing this activity, you will be able to:

- Understand that climate change is a naturally occurring, long-term set of processes
- Describe how changing climates may have influenced the development of stable populations and then modern civilization as we know it
- Describe how the polar ice caps have allowed science to better understand past climates and atmospheric conditions through ice core research
- Interpret data sets that indicate past, current, and possible future trends in global temperatures

Key Words

- Weather and climate
- Long-term climate change
- Temperature profiles
- Ice cores

Introduction

If you don't like the climate, just wait a while…a long while.

Warming and cooling trends are part of the Earth's normal climatic cycles. Temperatures vary within a given year, from one year to the next, and, on longer time scales, over decades, centuries, and millennia. In fact, there have been frequent changes in climate, with repeated swings from colder to warmer conditions. Past changes in climate have had a significant impact on human development. At the peak of the last ice age (about 16,000 years ago), most of Canada was covered with ice.

Question: How might climate stability, or instability, have influenced the early development of human civilization here in North America?

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* Source: Natural Resources Canada: The Winds of Change—Climate Change on the Prairies Poster. Used with permission. Available online at <http://www.adaptation.nrcan.gc.ca/posters/>.

What Has Happened over the Last 500,000 Years?

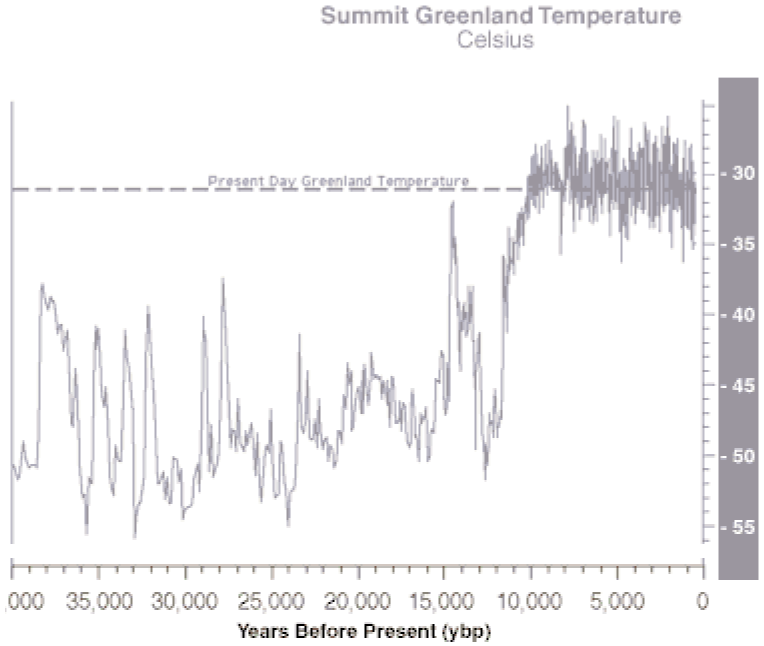
Since the 1980s, a great effort has taken place to search for evidence of weather and climate change on Earth. We have a unique "library" or database available to us where that information has been stored—the polar ice caps. You see, when snow falls at the poles, it rarely ever melts. Year after year, for thousands of years, snowfalls are eventually packed down into a set of layers called **firn**. Eventually, firn becomes solid ice. As this happens, all the air bubbles in the ice become forever trapped—locked up in ice—and become a sample of ancient atmosphere.

We have drilled deep into the ice caps on Greenland and in Antarctica for a number of years, and the ice cores that are taken out are examined carefully by scientists who are interested in what they contain. In addition to the air bubbles that can be extracted, each thin layer of the ice core can be sampled to see how much airborne dust fell with the snow. Volcanic eruptions are very good at leaving behind dust in the atmosphere that eventually gets "cleaned up" by snowflakes falling. We can determine how much volcanic activity occurred in the past 500,000 years or so simply by finding out what kind of dust, and how much of it, can be found in each layer of a four-kilometre-long tube of ice from Greenland.

Dr. Eric Wolff, a British Antarctic researcher, examining a section of ice core drilled out of the ice cap near the South Pole.

http://www.antarctica.ac.uk/BAS_Science/Highlights/2001/drilling.html

The graph presented here shows the average temperature above the Greenland ice sheet over the past 40,000 years or so.

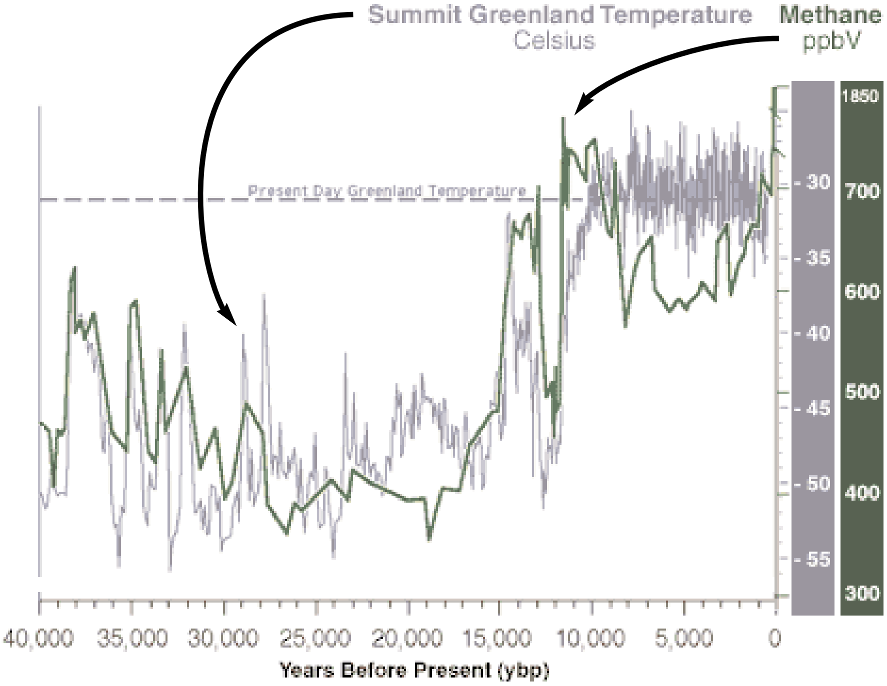


Question: Look carefully at the shape of the temperature profile above. What conclusions can you make about the following aspects of climate?

Has it become generally warmer or cooler in the last 40,000 years according to the graph?

How have temperatures fluctuated (gone up and down) during the period 10,000 to 40,000 years ago when compared to the period 0–10,000 years ago?

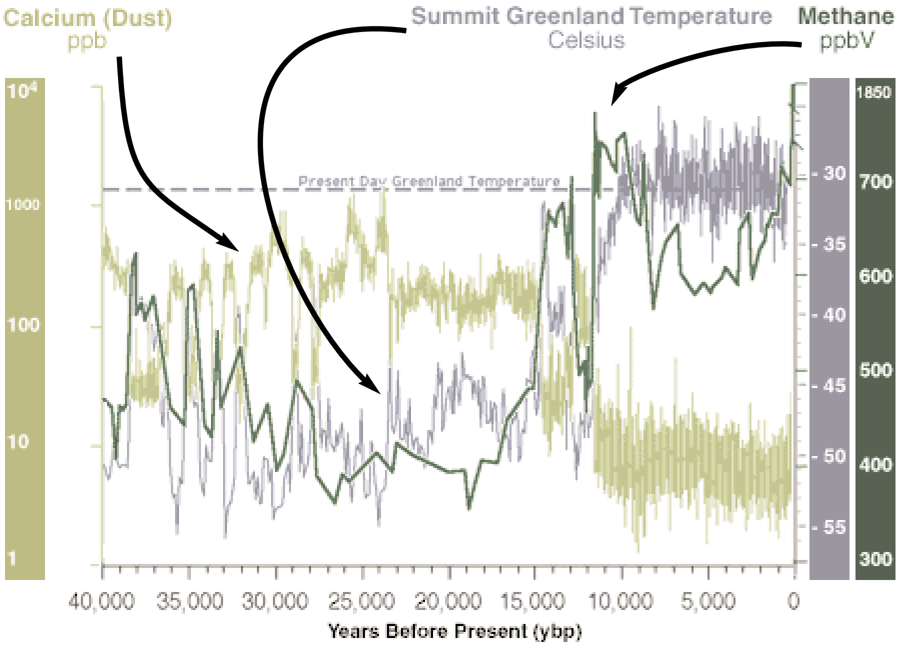
Below is the same temperature graph, but this time we have included a second graph that shows the amount of **methane** (CH_4)—a so-called "greenhouse gas"—in the atmosphere as measured from small bubbles of air trapped in the ice core from Greenland.



Question: How is the amount of methane in the atmosphere connected to the temperature that existed at a particular time?

Question: What parts of the graph **do not** seem to show the relationship that you noticed from the previous question? Express these as periods of years (e.g. 30,000 to 35,000 years ago, et cetera).

We will now add a third piece of information to the graph—the effect of dust in the atmosphere. The calcium dust found in ice cores (such as those drilled in Greenland or Antarctica) was blown by the wind from areas with little or no vegetation, falling to Earth with rain or snow. Calcium dust originates from continental shelves that are exposed to the atmosphere as the sea level drops around the world during an ice age.



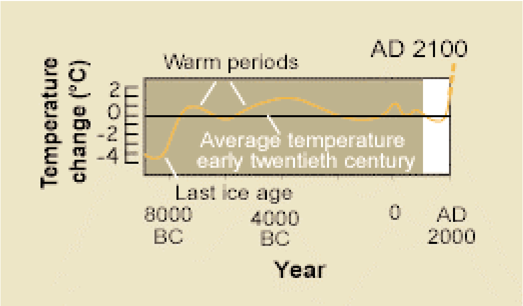
Question: When there is very little calcium dust in the ice core record, what does that seem to predict about temperature during that same period of time (e.g., from 0–10,000 years ago)?

Question: From the calcium dust information given on the graph, identify the following two periods of time:

1. A period when worldwide sea levels were probably much **lower** than they are now.

2. A short period when there was a sharp rise in global temperatures and an increase of methane in the atmosphere in the last 15,000 years.

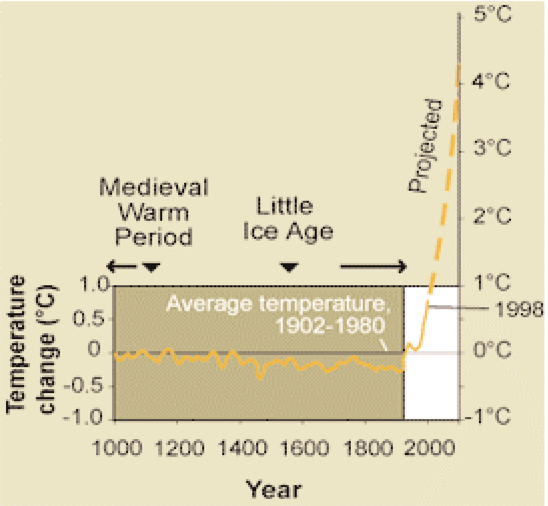
After the Ice Age: The Last 10,000 Years



*

The global climate warmed rapidly at the end of the last ice age. By about 4000 BCE, the Prairies were warm and dry, and prairie grasslands probably extended more than 80 kilometres farther north than they do today. Later, increased moisture and cooler temperatures caused renewed glacial ice accumulation to the west of us in the Rockies.

Warmer—Cooler—Hotter in the Last 1000 Years?



*

During the Medieval Warm Period, between about AD 1000 and AD 1200, temperatures were comparatively warm—this is the time when Vikings traveled to Greenland and Newfoundland. During a subsequent cooling trend called the Little Ice Age, the Vikings abandoned their settlements, Europe experienced colder weather, and the glaciers in the Canadian Rockies expanded. By AD 1860, temperatures began to rise again.

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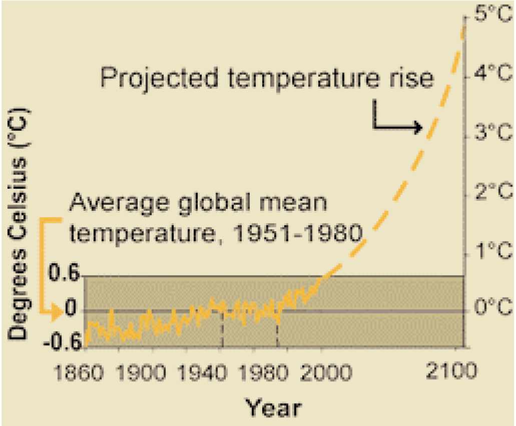
* Source: Natural Resources Canada: The Winds of Change—Climate Change on the Prairies Poster. Used with permission. Available online at <http://www.adaptation.nrcan.gc.ca/posters/>.

Turning Up the Heat in the 1980s and 1990s



*

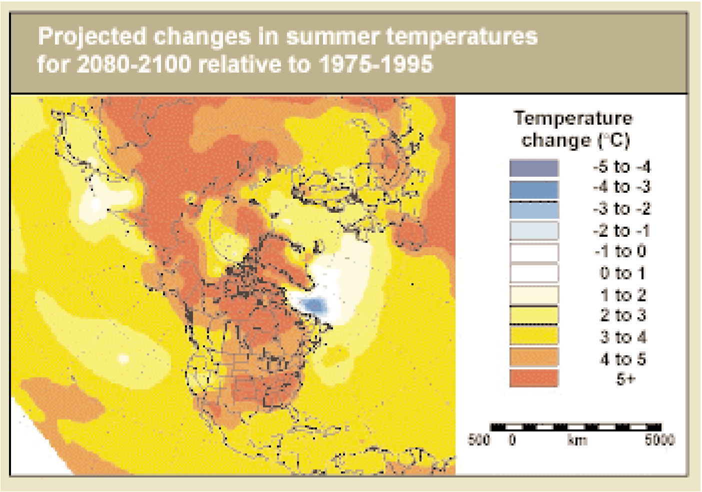
Over the past 140 years, Earth's atmosphere has warmed. Since the 1980s, the rate of this warming trend has increased. Scientists are concerned that we are entering a period of unprecedented global warming that will be caused, in part, by human activity—particularly, as we will see later on, by the tremendous increase in the burning of carbon-based fuels such as coal, oil, and natural gases like propane and methane.

Did you know?

The 20th century was the warmest century of the last 1000 years, and the 1990s was the warmest decade of the 20th century.

A Much Different Future…

This map shows a predicted summer surface air temperature change for the northern hemisphere that could occur in the next century. The greatest differences are predicted to occur in the Arctic and the interior of North America.



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* Graphic reproduced from <www.ec.gc.ca> (Government of Canada with permission from Natural Resources Canada), © 2001. Reproduced by permission.

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Canadian Climatology Datasets*

Table 1: Winter national temperature departures, warmest/coolest 10 years in the period 1948–2001

	10 Warmest		10 Coolest	
Rank	Year	Departure °C	Year	Departure °C
1	1987	3.0	1972	–3.2
2	1998	2.8	1950	–2.6
3	1960	2.6	1965	–1.9
4	2000	2.5	1957	–1.7
5	1999	2.5	1949	–1.6
6	1981	2.4	1979	–1.5
7	1953	2.4	1971	–1.3
8	1980	1.8	1962	–1.2
9	1995	1.7	1994	–1.2
10	1986	1.7	1952	–1.1

Note: “Departure” refers to the percentage above (10.0) or below (–10.0) the 30-year normals for the data.

Table 2: Winter national precipitation departures, wettest/driest 10 years in the period 1948–2001

	10 Wettest		10 Driest	
Rank	Year	Departure %	Year	Departure %
1	1965	19.4	1978	–20.1
2	1997	14.6	1966	–17.6
3	1963	14.4	1957	–14.6
4	1958	11.7	1979	–14.5
5	1956	11.0	1961	–12.7
6	1968	9.2	1970	–12.2
7	1977	9.0	1994	–12.1
8	1996	8.2	1998	–11.4
9	1981	6.5	1983	–10.4
10	1969	6.0	**2001**	**–10.3**

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Table 3: Winter regional temperature departures: trend, extremes and current season ranking, 1948–2001 (54 years)

		Extreme years				Winter 2001	
Region	Trend °C	Coldest	Depart. °C	Warmest	Depart. °C	Rank*	Depart. °C
Atlantic Canada	–1.2	1959	–2.8	1958	3.2	33	-0.6
Great Lakes/St. Lawrence Lowlands	0.3	1994	–2.9	1998	3.7	37	-0.3
Northeastern Forest	0.3	1994	–2.5	1998	4.1	26	0.0
Northwestern Forest	3.6	1950	–5.5	1987	7.6	17	2.5
Prairies	2.9	1950	–5.8	1987	7.0	32	0.0
South British Columbia Mountains	2.3	1950	–5.0	1992	5.0	29	0.7
Pacific Coast	1.6	1950	–3.8	1992	2.6	19	0.8
North British Columbia/ Yukon	3.9	1969	–6.9	1977	8.7	4	5.7
Mackenzie District	3.8	1965	–3.8	1987	6.7	8	3.7
Arctic Tundra	1.3	1972	–3.2	1999	3.6	13	1.6
Arctic Mountains and Fjords	0.0	1949	–4.4	1969	3.4	20	0.4
Canada	**1.6**	**1972**	**–3.2**	**1987**	**3.0**	**14**	**1.3**

Table 4: Winter regional precipitation departures: extremes and current season ranking, 1948–2001 (54 years)

	Extreme years				Winter 2001	
Region	Driest	Depart. %	Wettest	Depart. %	Rank*	Depart. %
Atlantic Canada	1949	–26.1	1982	29.9	38	–9.9
Great Lakes/St. Lawrence Lowlands	1961	–33.3	1997	47.3	16	8.0
Northeastern Forest	1987	–29.6	1969	19.9	48	–20.1
Northwestern Forest	1978	–43.1	1956	44.5	52	–41.8
Prairies	1988	–48.0	1956	40.6	49	–39.0
South British Columbia/ Mountains	2001	–51.0	1972	44.1	54	–51.0
Pacific Coast	2001	–41.2	1999	31.2	54	–41.2
North British Columbia/ Yukon	1978	–58.0	1955	46.3	44	–21.3
Mackenzie District	1979	–53.3	1962	70.1	41	–19.4
Arctic Tundra	1967	–47.6	1980	50.6	18	17.1
Arctic Mountains and Fjords	1966	–48.9	1951	78.5	7	37.8
Canada	**1978**	**–20.1**	**1965**	**19.4**	**45**	**–10.3**

Table 5: Annual national temperature departures, warmest/coolest 10 years in the period 1948–2000

	10 Warmest		10 Coolest	
Rank	Year	Departure °C	Year	Departure °C
1	1998	2.5	1972	–1.8
2	1981	2.0	1950	–1.0
3	1999	1.7	1982	–0.9
4	1987	1.4	1974	–0.8
5	1953	1.0	1965	–0.6
6	1952	1.0	1956	–0.6
7	**2000**	**0.9**	1964	–0.5
8	1977	0.9	1978	–0.4
9	1988	0.8	1951	–0.4
10	1958	0.7	1967	–0.3

Table 6: Annual national precipitation departures, wettest/driest 10 years in the period 1948–2000

	10 Wettest		10 Driest	
Rank	Year	Departure %	Year	Departure %
1	1996	10.2	1956	–7.3
2	1981	8.8	1957	–6.8
3	1982	7.5	1958	–6.0
4	1973	6.8	1948	–4.4
5	1980	6.6	1961	–4.2
6	1979	6.5	1967	–4.0
7	1988	6.3	1955	–3.4
8	1991	5.7	1952	–3.4
9	1999	5.6	1950	–2.4
10	1984	5.5	1969	–2.3

Table 7: Annual regional temperature departures: trend, extremes, and current season ranking, 1948–2000 (53 years)

		Extreme years				**Winter 2001**	
Region	Trend °C	Coldest	Depart. °C	Warmest	Depart. °C	Rank*	Depart. °C
Atlantic Canada	–0.2	1972	–1.4	1999	2.0	11	0.7
Great Lakes/St. Lawrence Lowlands	0.2	1978	–1.0	1998	2.3	13	0.4
Northeastern Forest	0.3	1972	–1.9	1998	2.1	10	0.8
Northwestern Forest	1.6	1950	–2.1	1987	3.0	19	0.6
Prairies	1.3	1950	–2.1	1987	3.1	25	0.3
South British Columbia Mountains	1.3	1955	–1.8	1998	2.0	27	0.2
Pacific Coast	1.1	1955	–1.2	1958	1.6	21	0.4
North British Columbia/ Yukon	1.8	1972	–2.1	1981	2.8	5	1.7
Mackenzie District	1.9	1982	–1.5	1998	3.9	8	1.3
Arctic Tundra	1.0	1972	–2.4	1998	3.3	5	1.3
Arctic Mountains and Fjords	0.3	1972	–1.9	1981	2.2	8	0.9
Canada	**0.9**	**1972**	**–1.8**	**1998**	**2.5**	**7**	**0.9**

Table 8: Annual regional precipitation departures: extremes and current season ranking, 1948–2000 (53 years)

	Extreme years				**Winter 2001**	
Region	Driest	Depart. %	Wettest	Depart. %	Rank*	Depart. %
Atlantic Canada	1966	–15.5	1990	19.2	22	3.6
Great Lakes/St. Lawrence Lowlands	1963	–16.0	1996	22.4	15	6.9
Northeastern Forest	1962	–10.3	1979	13.2	43	–4.8
Northwestern Forest	1981	–21.8	1973	16.5	45	–9.7
Prairies	1961	–29.1	1951	26.8	26	–2.4
South British Columbia/ Mountains	2000	–21.7	1996	30.4	53	–21.7
Pacific Coast	2000	–26.3	1997	21.5	53	–26.3
North British Columbia/ Yukon	1998	–51.4	1974	22.7	10	10.2
Mackenzie District	1995	–29.7	1974	27.6	30	–3.2
Arctic Tundra	1954	–19.8	1996	24.2	19	8.8
Arctic Mountains and Fjords	1948	–46.4	1953	44.2	13	16.6
Canada	**1956**	**–7.3**	**1996**	**10.2**	**32**	**0.4**

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Annual Regional Temperature and Precipitation Datasets

Table 1: Annual regional temperature departures: trend, extremes, and current season ranking, 1948–2000 (53 years)*

		Extreme years				Annual 2000	
Region	**Trend °C**	**Coldest**	**Depart. °C**	**Warmest**	**Depart. °C**	**Rank***	**Depart. °C**
Atlantic Canada	–0.2	1972	–1.4	1999	2.0	11	0.7
Great Lakes/St. Lawrence Lowlands	0.2	1978	–1.0	1998	2.3	13	0.4
Northeastern Forest	0.3	1972	–1.9	1998	2.1	10	0.8
Northwestern Forest	1.6	1950	–2.1	1987	3.0	19	0.6
Prairies	1.3	1950	–2.1	1987	3.1	25	0.3
South British Columbia Mountains	1.3	1955	–1.8	1998	2.0	27	0.2
Pacific Coast	1.1	1955	–1.2	1958	1.6	21	0.4
North British Columbia Mountains/Yukon	1.8	1972	–2.1	1981	2.8	5	1.7
Mackenzie District	1.9	1982	–1.5	1998	3.9	8	1.3
Arctic Tundra	1.0	1972	–2.4	1998	3.3	5	1.3
Arctic Mountains and Fiords	0.3	1972	–1.9	1981	2.2	8	0.9
Canada	0.9	1972	–1.8	1998	2.5	7	0.9

The rank for the most recent value in the series (the 2000 annual value for each region in this case) is calculated on series data arranged in descending order, from warmest to coolest values. Note: the 2000 data are preliminary.

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* Chart reproduced from Environment Canada (2003). Used with permission. <http://www.msc-smc.ec.ca/ccrm/bulletin/annual00/ttabsumm_e.html>.

Table 2: Annual national temperature departures ranked from warmest to coolest, for the period 1948–2000*

Rank	Year	Dep. °C	Rank	Year	Dep. °C	Rank	Year	Dep. °C	Rank	Year	Dep. °C
01	1998	2.5	15	1993	0.5	29	1949	0	43	1959	–0.3
02	1981	2	16	1991	0.5	30	1996	0	44	1967	–0.3
03	1999	1.7	17	1994	0.5	31	1948	0	45	1951	–0.4
04	1987	1.4	18	1980	0.4	32	1971	0	46	1978	–0.4
05	1953	1	19	1969	0.4	33	1990	0	47	1964	–0.5
06	1952	1	20	1963	0.3	34	1985	0	48	1956	–0.6
07	**2000**	**0.9**	21	1984	0.2	35	1957	0	49	1965	–0.6
08	1977	0.9	22	1954	0.2	36	1979	–0.1	50	1974	–0.8
09	1988	0.8	23	1968	0.2	37	1961	–0.1	51	1982	–0.9
10	1958	0.7	24	1983	0.2	38	1975	–0.1	52	1950	–1
11	1995	0.7	25	1962	0.1	39	1992	–0.1	53	1972	–1.8
12	1973	0.6	26	1986	0.1	40	1989	–0.2			
13	1997	0.6	27	1955	0	41	1966	–0.2			
14	1960	0.6	28	1976	0	42	1970	–0.2			

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* Chart reproduced from Environment Canada (2003). Used with permission. <http://www.msc-smc.ec.ca/ccrm/bulletin/annual00/ttabnafu_e.html>.

Table 3: Annual national temperature departures, warmest/coolest 10 years in the period 1948–2000*

	10 Warmest		10 Coolest	
Rank	**Year**	**Depart. °C**	**Year**	**Depart. °C**
1	1998	2.5	1972	–1.8
2	1981	2.0	1950	–1.0
3	1999	1.7	1982	–0.9
4	1987	1.4	1974	–0.8
5	1953	1.0	1965	–0.6
6	1952	1.0	1956	–0.6
7	2000	0.9	1964	–0.5
8	1977	0.9	1978	–0.4
9	1988	0.8	1951	–0.4
10	1958	0.7	1967	–0.3

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* Chart reproduced from Environment Canada (2003). Used with permission. <http://www.msc-smc.ec.ca/ccrm/bulletin/annual00/table_ttabna10_e.html>.

Table 4: Annual regional temperature departures, wettest 10 years in the period 1948–2000.*

	10 Wettest		10 Driest	
Rank	**Year**	**Depart. °C**	**Year**	**Depart. °C**
1	1996	10.2	1956	–7.3
2	1981	8.8	1957	–6.8
3	1982	7.5	1958	–6.0
4	1973	6.8	1948	–4.4
5	1980	6.6	1961	–4.2
6	1979	6.5	1967	–4.0
7	1988	6.3	1955	–3.4
8	1991	5.7	1952	–3.4
9	1999	5.6	1950	–2.4
10	1984	5.5	1969	–2.3

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* Chart reproduced from Environment Canada (2003). Used with permission. <http://www.msc-smc.ec.ca/ccrm/bulletin/annual00/table_ttabna10_e.html>.

Table 5: Annual regional temperature departures, warmest 10 years in the period 1948–1998*

Rank	Year	Depart. °C	Rank	Year	Depart. °C	Rank	Year	Depart. °C	Rank	Year	Depart. °C
Atlantic Canada			**Northwestern Forest**			**Pacific Coast**			**Arctic Tundra**		
1	1998	1.2	1	1987	3.0	1	1958	1.6	1	1998	3.3
2	1953	1.2	2	1981	2.5	2	1997	1.3	2	1981	2.2
3	1951	1.1	3	1998	2.3	3	1998	1.2	3	1996	1.4
4	1981	1.0	4	1993	1.5	4	1992	1.1	4	1977	1.3
5	1952	0.9	5	1977	1.3	5	1987	1.1	5	1995	1.2
6	1979	0.8	6	1991	1.2	6	1995	1.1	6	1973	1.1
7	1960	0.8	7	1953	1.2	7	1981	0.9	7	1952	1.0
8	1983	0.8	8	1988	1.2	8	1963	0.9	8	1969	1.0
9	1969	0.7	9	1976	1.2	9	1993	0.8	9	1988	1.0
10	1966	0.6	10	1986	1.2	10	1994	0.8	10	1953	0.8
Great Lakes/St. Lawrence			**Prairies**			**North BC/Yukon**			**Arctic Mountains/Fjords**		
1	1998	2.3	1	1987	3.1	1	1981	2.8	1	1981	2.2
2	1953	1.5	2	1981	2.5	2	1993	2.7	2	1998	1.9
3	1987	1.2	3	1988	1.9	3	1987	2.6	3	1988	1.3
4	1991	1.2	4	1998	1.8	4	1997	1.8	4	1996	1.3
5	1990	1.1	5	1986	1.5	5	1988	1.6	5	1995	1.2
6	1973	1.1	6	1991	1.3	6	1976	1.5	6	1960	1.0
7	1949	1.1	7	1963	1.3	7	1998	1.5	7	1980	0.9
8	1952	0.9	8	1953	1.3	8	1977	1.5	8	1955	0.9
9	1955	0.7	9	1976	1.2	9	1995	1.5	9	1969	0.9
10	1983	0.7	10	1961	1.1	10	1978	1.4	10	1958	0.9
Northeastern Forest			**South British Columbia**			**Mackenzie District**			**Canada**		
1	1998	2.1	1	1998	2.0	1	1998	3.9	1	1998	2.5
2	1987	1.7	2	1987	1.9	2	1981	2.8	2	1981	2.0
3	1981	1.5	3	1958	1.7	3	1987	2.4	3	1987	1.4
4	1952	1.2	4	1992	1.6	4	1993	2.3	4	1953	1.0
5	1953	1.1	5	1981	1.3	5	1997	1.8	5	1952	1.0
6	1973	0.9	6	1994	1.3	6	1953	1.4	6	1977	0.9
7	1955	0.8	7	1997	1.1	7	1995	1.3	7	1988	0.8
8	1977	0.8	8	1953	1.0	8	1980	1.2	8	1958	0.7
9	1983	0.5	9	1991	1.0	9	1973	1.2	9	1995	0.7
10	1960	0.5	10	1988	0.9	10	1976	1.2	10	1997	0.7

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Table 6: Annual regional temperature departures, coolest 10 years in the period 1948–1998*

Rank	Year	Depart. °C	Rank	Year	Depart. °C	Rank	Year	Depart. °C	Rank	Year	Depart. °C
Atlantic Canada			**Northwestern Forest**			**Pacific Coast**			**Arctic Tundra**		
1	1972	–1.4	1	1950	–2.1	1	1955	–1.2	1	1972	–2.4
2	1974	–0.9	2	1951	–1.7	2	1950	–1.1	2	1974	–1.4
3	1992	–0.9	3	1972	–1.6	3	1972	–0.8	3	1964	–1.1
4	1993	–0.8	4	1982	–1.4	4	1971	–0.7	4	1982	–0.9
5	1965	–0.8	5	1966	–1.2	5	1975	–0.7	5	1986	–0.8
6	1985	–0.7	6	1996	–1.1	6	1985	–0.6	6	1950	–0.8
7	1986	–0.7	7	1955	–1.1	7	1949	–0.6	7	1978	–0.8
8	1978	–0.6	8	1965	–0.9	8	1948	–0.6	8	1956	–0.7
9	1989	–0.6	9	1979	–0.4	9	1964	–0.5	9	1967	–0.7
10	1980	–0.6	10	1970	–0.4	10	1973	–0.5	10	1965	–0.6
Great Lakes/St. Lawrence			**Prairies**			**North BC/Yukon**			**Arctic Mountains/Fjords**		
1	1978	–1.0	1	1950	–2.1	1	1972	–2.1	1	1972	–1.9
2	1972	–0.9	2	1951	–2.1	2	1966	–1.7	2	1992	–1.3
3	1976	–0.7	3	1996	–1.7	3	1996	–1.5	3	1984	–1.1
4	1980	–0.7	4	1972	–1.3	4	1950	–1.3	4	1961	–0.9
5	1963	–0.6	5	1955	–1.3	5	1982	–1.3	5	1987	–0.9
6	1992	–0.6	6	1982	–1.2	6	1955	–1.3	6	1989	–0.8
7	1989	–0.6	7	1965	–1.1	7	1971	–1.2	7	1974	–0.8
8	1950	–0.4	8	1966	–0.9	8	1973	–1.1	8	1979	–0.8
9	1958	–0.4	9	1969	–0.8	9	1951	–1.0	9	1983	–0.7
10	1956	–0.4	10	1970	–0.7	10	1956	–0.9	10	1986	–0.7
Northeastern Forest			**South British Columbia**			**Mackenzie District**			**Canada**		
1	1972	–1.9	1	1955	–1.8	1	1982	–1.5	1	1972	–1.8
2	1950	–1.1	2	1950	–1.2	2	1966	–1.4	2	1950	–1.0
3	1974	–0.9	3	1951	–1.1	3	1972	–1.3	3	1982	–0.9
4	1965	–0.9	4	1972	–1.0	4	1961	–1.2	4	1974	–0.8
5	1992	–0.8	5	1975	–0.7	5	1974	–1.1	5	1965	–0.6
6	1978	–0.8	6	1996	–0.7	6	1951	–1.0	6	1956	–0.6
7	1982	–0.8	7	1985	–0.6	7	1950	–0.9	7	1964	–0.5
8	1989	–0.7	8	1949	–0.6	8	1959	–0.8	8	1978	–0.4
9	1976	–0.7	9	1982	–0.6	9	1955	–0.8	9	1951	–0.4
10	1956	–0.6	10	1964	–0.5	10	1964	–0.8	10	1967	–0.3

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Table 7: Annual regional temperature departures: trend, extremes, and current season ranking, 1948–1998 (51 years)*

		Extreme years				Annual 1998	
Region	**Trend °C**	**Coldest**	**Depart. °C**	**Warmest**	**Depart. °C**	**Rank***	**Depart. °C**
Atlantic Canada	–0.5	1972	–1.4	1998	1.2	1	1.2
Great Lakes/St. Lawrence Lowlands	0.0	1978	–1.0	1998	2.3	1	2.3
Northeastern Forest	0.1	1972	–1.9	1998	2.1	1	2.1
Northwestern Forest	1.4	1950	–2.1	1987	3.0	3	2.3
Prairies	1.2	1950	–2.1	1987	3.1	4	1.8
South British Columbia Mountains	1.4	1955	–1.8	1998	2.0	1	2.0
Pacific Coast	1.1	1955	–1.2	1958	1.6	3	1.2
North British Columbia Mountains/Yukon	1.7	1972	–2.1	1981	2.8	7	1.5
Mackenzie District	1.6	1982	–1.5	1998	3.9	1	3.9
Arctic Tundra	0.8	1972	–2.4	1998	3.3	1	3.3
Arctic Mountains and Fiords	0.3	1972	–1.9	1981	2.2	2	1.9
Canada	0.7	1972	–1.8	1998	2.5	1	2.5

The rank for the most recent value in the series (the 2000 annual value for each region in this case) is calculated on series data arranged in descending order, from warmest to coolest values. Note: the 2000 data are preliminary.

Table 8: Annual regional precipitation departures, extremes and current season ranking, 1948–1998 (51 years)*

	Extreme years				Annual 1998	
Region	**Driest**	**Depart. %**	**Wettest**	**Depart. %**	**Rank***	**Depart. %**
Atlantic Canada	1966	–15.5	1990	19.2	20	3.9
Great Lakes/St. Lawrence Lowlands	1963	–16.0	1990	19.1	47	–11.5
Northeastern Forest	1962	–10.3	1979	13.2	43	–7.0
Northwestern Forest	1998	–24.8	1973	16.5	51	–24.8
Prairies	1961	–29.1	1951	26.8	17	4.7
South British Columbia Mountains	1952	–21.3	1959	25.3	19	4.0
Pacific Coast	1985	–24.6	1980	17.4	40	–8.0
North British Columbia Mountains/Yukon	1998	–33.8	1997	23.0	51	–33.8
Mackenzie District	1995	–27.9	1974	27.6	23	1.0
Arctic Tundra	1954	–19.8	1996	24.9	6	15.7
Arctic Mountains and Fiords	1948	–46.4	1953	44.2	36	–7.8
Canada	1956	–7.3	1981	8.8	43	–2.7

The rank for the most recent value in the series (the 2000 annual value for each region in this case) is calculated on series data arranged in descending order, from wettest to driest values. Note: the 2000 data are preliminary.

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Table 9: Annual regional precipitation departures, wettest 10 years in the period 1948–1998*

Rank	Year	Depart. °C	Rank	Year	Depart. °C	Rank	Year	Depart. °C	Rank	Year	Depart. °C
Atlantic Canada			**Northwestern Forest**			**Pacific Coast**			**Arctic Tundra**		
1	1990	19.2	1	1973	16.5	1	1980	17.4	1	1996	24.9
2	1981	19.1	2	1955	11.2	2	1997	17.2	2	1981	22.8
3	1979	17.6	3	1988	11.2	3	1953	15.5	3	1987	21.7
4	1983	13.1	4	1962	10.7	4	1971	14.3	4	1980	18.8
5	1993	10.8	5	1949	9.0	5	1981	13.2	5	1993	17.7
6	1972	10.5	6	1984	8.9	6	1983	12.3	6	1998	15.7
7	1976	10.1	7	1976	7.7	7	1974	10.9	7	1960	15.2
8	1977	9.5	8	1954	7.5	8	1984	9.4	8	1994	14.9
9	1982	8.9	9	1977	7.5	9	1975	9.1	9	1982	14.8
10	1994	8.6	10	1974	7.1	10	1968	8.9	10	1985	14.2
Great Lakes/St. Lawrence			**Prairies**			**North BC/Yukon**			**Arctic Mountains/Fjords**		
1	1990	19.1	1	1951	26.8	1	1997	23.0	1	1953	44.2
2	1972	16.9	2	1954	26.1	2	1974	22.7	2	1951	43.1
3	1983	15.8	3	1993	23.9	3	1991	21.5	3	1979	35.7
4	1954	12.9	4	1975	22.4	4	1962	21.2	4	1978	31.0
5	1973	12.9	5	1953	21.6	5	1988	17.5	5	1981	30.4
6	1986	12.1	6	1991	20.5	6	1975	11.0	6	1989	29.4
7	1977	10.6	7	1978	15.8	7	1961	10.8	7	1968	27.7
8	1995	10.2	8	1965	15.3	8	1990	10.6	8	1982	25.4
9	1979	9.6	9	1955	14.9	9	1976	9.5	9	1984	23.8
10	1992	9.6	10	1956	11.1	10	1949	9.2	10	1952	21.1
Northeastern Forest			**South British Columbia**			**Mackenzie District**			**Canada**		
1	1979	13.2	1	1959	25.3	1	1974	27.6	1	1981	8.8
2	1983	9.2	2	1990	24.3	2	1988	27.0	2	1996	8.0
3	1982	7.9	3	1996	18.1	3	1962	25.1	3	1982	7.5
4	1965	7.3	4	1964	12.7	4	1960	21.6	4	1973	6.8
5	1966	6.2	5	1995	11.8	5	1991	19.8	5	1980	6.6
6	1968	5.5	6	1948	11.1	6	1997	15.8	6	1979	6.5
7	1971	5.3	7	1953	11.0	7	1981	15.8	7	1988	6.3
8	1996	4.9	8	1980	10.5	8	1963	15.6	8	1991	5.7
9	1964	4.9	9	1972	9.7	9	1961	15.3	9	1984	5.5
10	1973	4.5	10	1966	9.7	10	1948	15.2	10	1990	5.0

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Table 10: Annual regional precipitation departures, driest 10 years in the period 1948–1998*

Rank	Year	Depart. °C	Rank	Year	Depart. °C	Rank	Year	Depart. °C	Rank	Year	Depart. °C
Atlantic Canada			**Northwestern Forest**			**Pacific Coast**			**Arctic Tundra**		
1	1966	–15.5	1	1998	–24.8	1	1985	–24.6	1	1954	–19.8
2	1965	–14.6	2	1981	–21.8	2	1957	–20.5	2	1962	–14.3
3	1960	–13.7	3	1967	–18.9	3	1970	–17.3	3	1951	–12.9
4	1985	–11.7	4	1992	–15.3	4	1993	–16.5	4	1952	–11.0
5	1952	–10.7	5	1958	–14.2	5	1951	–13.8	5	1956	–10.7
6	1997	–10.2	6	1995	–12.0	6	1952	–12.2	6	1972	–9.8
7	1957	–8.7	7	1961	–10.3	7	1989	–10.6	7	1965	–8.8
8	1950	–8.0	8	1985	–10.2	8	1969	–10.1	8	1961	–8.6
9	1978	–7.7	9	1994	–8.4	9	1955	–10.1	9	1958	–7.8
10	1989	–7.4	10	1952	–8.2	10	1979	–9.5	10	1949	–7.5
Great Lakes/St. Lawrence			**Prairies**			**North BC/Yukon**			**Arctic Mountains/Fjords**		
1	1963	–16.0	1	1961	–29.1	1	1998	–33.8	1	1948	–46.4
2	1953	–15.6	2	1960	–21.8	2	1951	–24.7	2	1956	–37.9
3	1958	–13.5	3	1979	–18.6	3	1955	–22.8	3	1955	–23.1
4	1964	–12.9	4	1997	–15.9	4	1957	–22.5	4	1967	–20.0
5	1998	–11.5	5	1958	–15.8	5	1950	–20.7	5	1958	–18.3
6	1955	–10.4	6	1967	–15.7	6	1969	–14.0	6	1964	–17.1
7	1952	–8.3	7	1952	–15.6	7	1995	–12.8	7	1972	–14.2
8	1948	–8.0	8	1988	–15.3	8	1958	–8.7	8	1974	–13.4
9	1956	–7.9	9	1957	–14.4	9	1971	–8.4	9	1966	–12.2
10	1949	–7.3	10	1987	–13.1	10	1982	–8.3	10	1987	–11.8
Northeastern Forest			**South British Columbia**			**Mackenzie District**			**Canada**		
1	1962	–10.3	1	1952	–21.3	1	1995	–27.9	1	1956	–7.3
2	1987	–10.0	2	1970	–20.0	2	1955	–18.0	2	1957	–6.8
3	1948	–9.9	3	1987	–19.0	3	1951	–17.6	3	1958	–6.0
4	1997	–9.8	4	1979	–18.3	4	1979	–17.1	4	1948	–4.4
5	1957	–9.0	5	1985	–17.3	5	1953	–16.1	5	1961	–4.2
6	1989	–7.4	6	1973	–14.5	6	1994	–13.8	6	1967	–4.0
7	1956	–7.2	7	1978	–10.9	7	1983	–12.7	7	1955	–3.4
8	1961	–7.1	8	1960	–10.0	8	1978	–11.4	8	1952	–3.7
9	1998	–7.0	9	1967	–9.0	9	1949	–10.1	9	1998	–2.7
10	1963	–6.3	10	1991	–5.6	10	1971	–10.1	10	1950	–2.4

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* Chart reproduced from Environment Canada (2003). Used with permission. <http://www.msc-smc.ec.gc.ca/ccrm/bulletin/annual98/page2_e.html>.

BLM Blackline Master

Greenhouse Gases and Climate Change*

Figure 1: Percentage Abundance of Common "Greenhouse" Gases

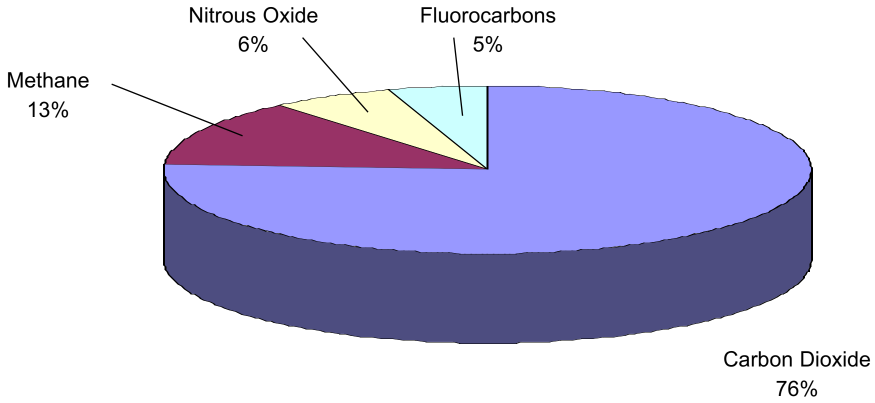
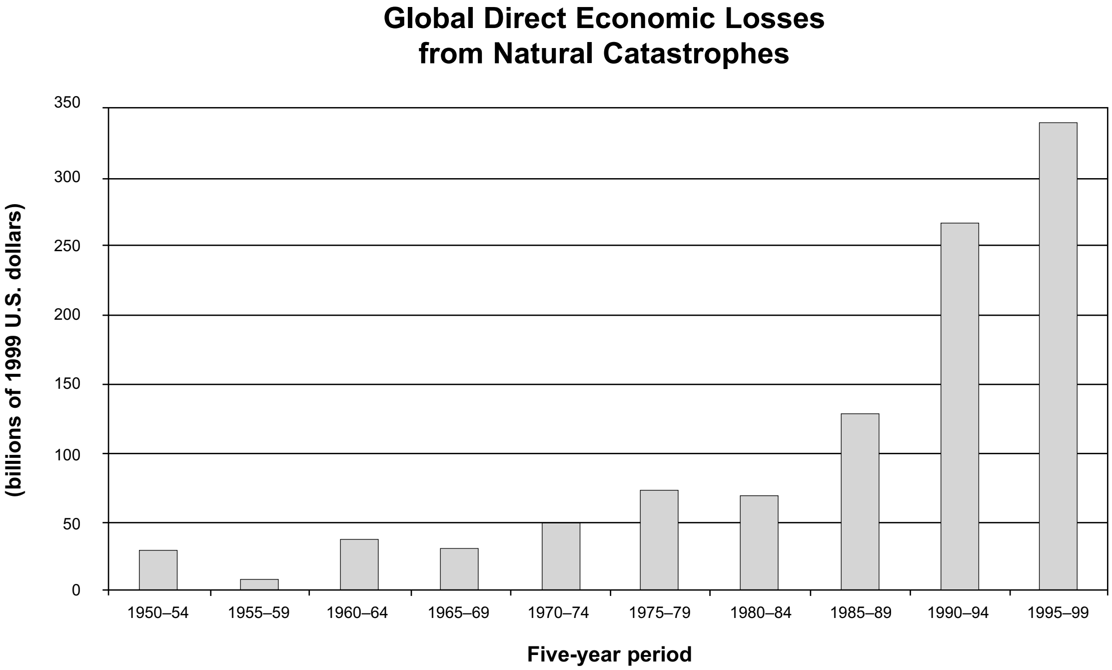


Figure 2: Economic Effects of Natural Catastrophes



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SLA
Student Learning Activity

Plotting CO_2 and Temperature*

Directions

- The table that follows shows temperature (actually the difference, or anomaly, from the current 30-year normal), and the concentration of CO_2 in the Earth's atmosphere back to 1840.
- We will assume that the pre-industrial global temperatures (before 1800) were about the same as they were in 1840.
- Use the rectangular graph paper provided for you at the end of this activity to plot the data.
- Label the vertical scale on **Graph 1** from 200 to 400 ppm (parts per million) of CO_2, and the horizontal scale from 1800 to 2100.
- Label the vertical scale on **Graph 2** from –1.00 to +1.00 (for the temperature anomaly data) and the horizontal scale from 250 to 450 ppm (parts per million) of CO_2.
- We will place the zero of the vertical scale in the middle, and label it –1 to +1 degree Celsius, using tick marks every 0.1 degree. The middle of this scale corresponds to the reference line of average temperature in the other figures in this activity showing temperature versus time.
- Now, using the table of temperature and CO_2 concentration, plot a graph of the **year (on the x-axis)** and the **carbon dioxide concentration (on the y-axis)** for each year.
- Plot a second graph of **temperature anomaly (on the x-axis)** and **carbon dioxide concentration (on the y-axis).**
- You should plot all the data from 1840 to 2000, and should see a scatter of points sloping upward to the right in both graphs. Draw a line of best fit through the centre of the points and extend it straight to the lower left and upper right of each graph.

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* All data and graphics courtesy of Environment Canada. <http://www.ec.gc.ca>. Used with permission.

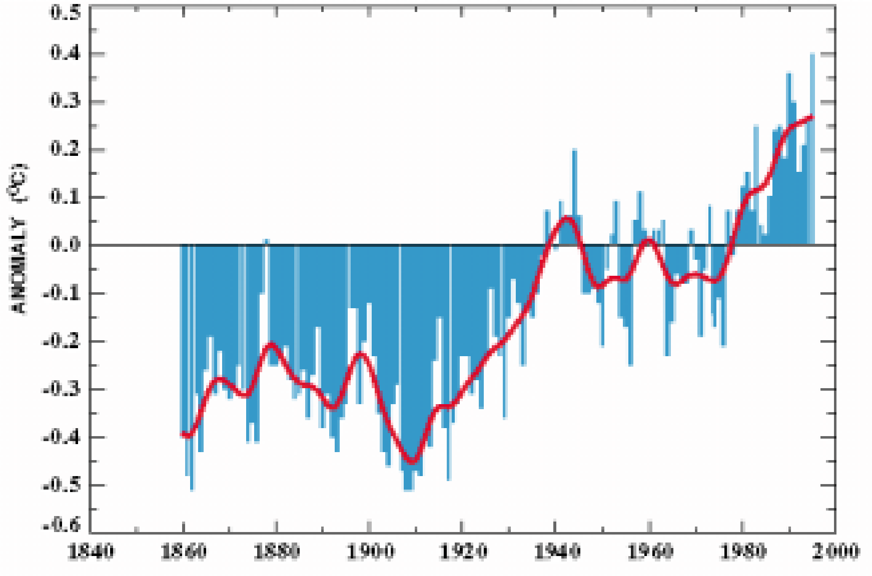
Table 1: Carbon Dioxide (CO_2) concentrations in the atmosphere and temperature changes (anomaly) in the period 1840–2000

Year	CO_2 Concentration (in parts per million by volume, ppmv**)	Temperature Anomaly (°C above/below normal)
1840	280	–0.40
1955	310	–0.05
1960	312	0.00
1965	316	–0.10
1970	320	–0.08
1975	327	–0.08
1980	335	–0.08
1985	345	+0.10
1990	352	+0.15
1995	355	+0.25
2000	360	+0.28

* 300 ppmv (300 parts per million by volume) would be equivalent to 300 CO_2 molecules / 1,000,000 molecules of dry air or, expressed as a percent, 0.03%

What follows are a number of graphs that highlight the relationships among global CO_2 concentration in the atmosphere, time, and temperature trends.

Figure 1: Graph of the temperature anomaly* over the years 1840–2000



Note: The temperature anomaly is the deviation of average global temperatures over the past 30 years (what we call “climate normals”). The horizontal “zero” line represents this 30-year normal for temperatures.

Figure 2: Plot of temperature changes over the last 1,000,000 years from ice core research

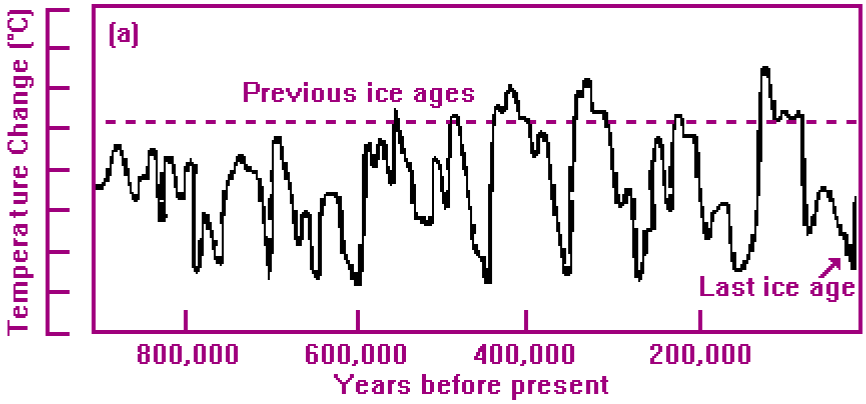


Figure 3: Plot of temperature changes over the last 10,000 years since the end of the most recent ice age

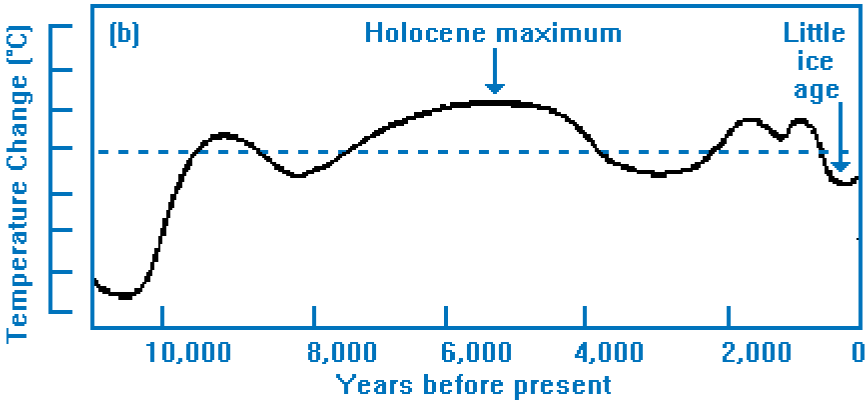
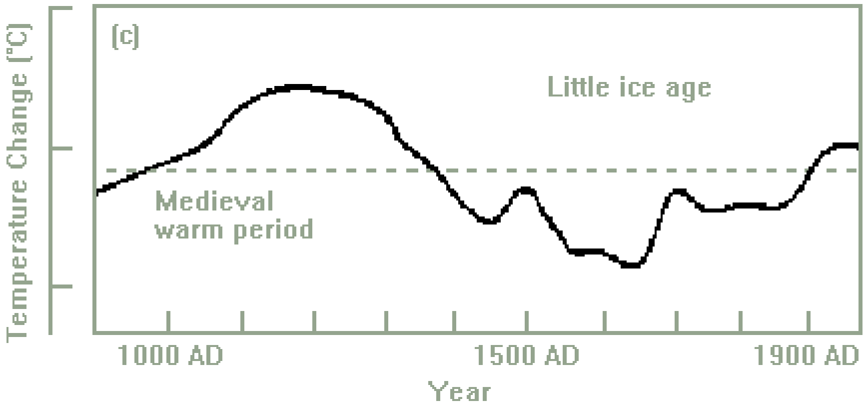
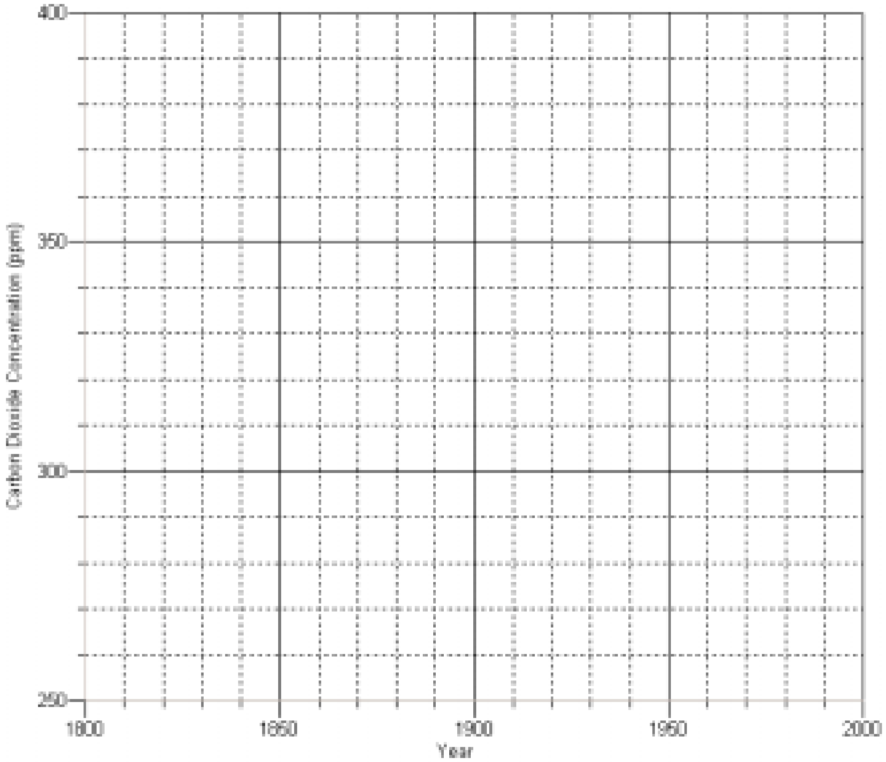


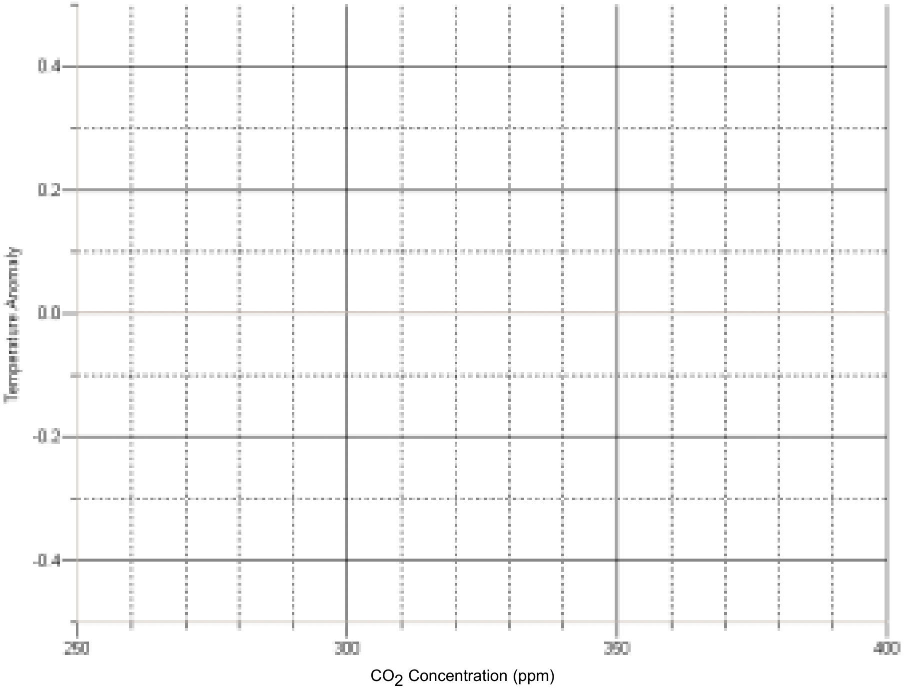
Figure 4: Plot of temperature changes over the last 1,000 years



Graph 1

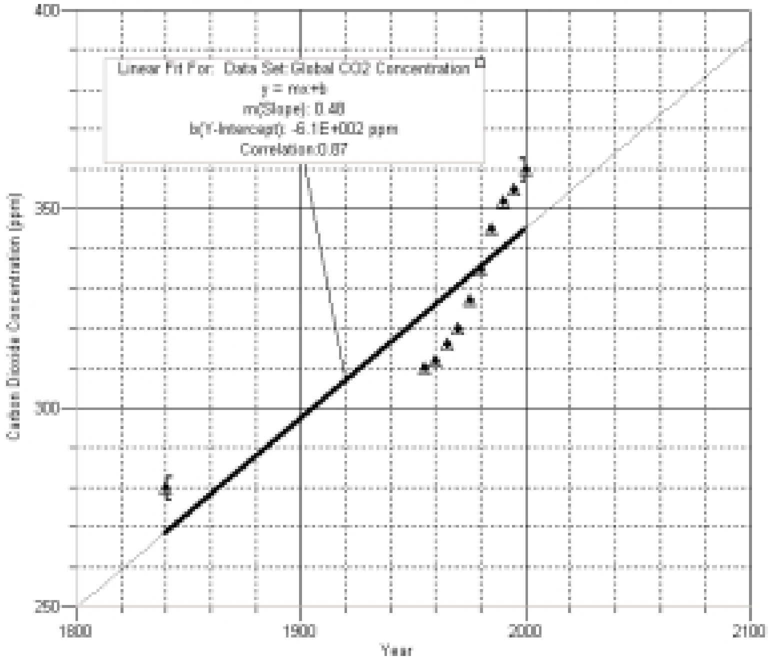


Graph 2



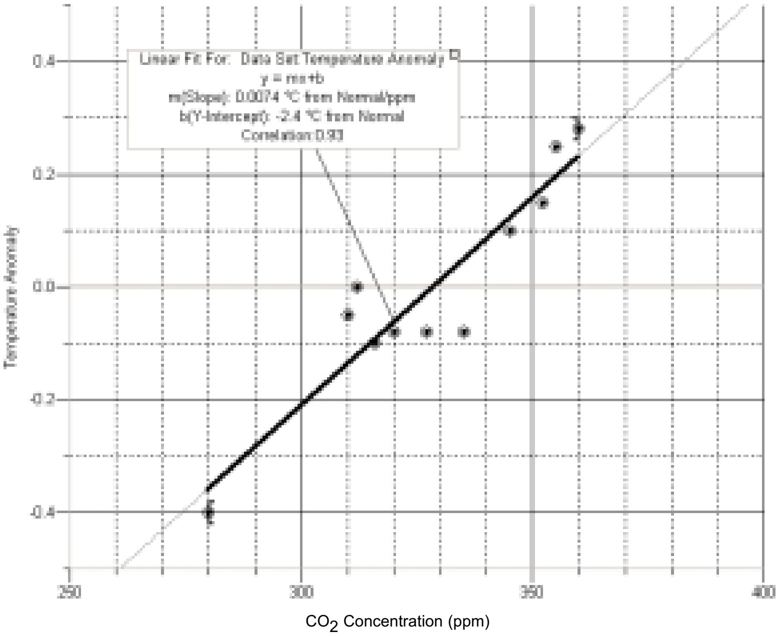
Possible Results (including line of best fit)—Graph 1

Global CO_2 Concentrations in the Period 1840–2000



Possible Results (including line of best fit)—Graph 2

Temperature Anomaly and CO_2 Concentration



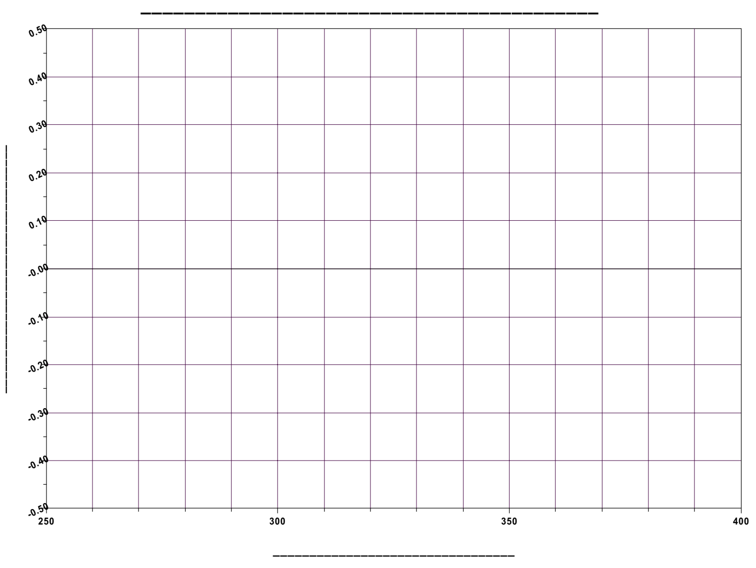
Follow-Up Questions

1. Look carefully at the graph in Figure 2 on page A211 (the last 1,000,000 years). What evidence exists for regular, dramatic shifts in temperature over this time span?

2. Note that the line acts like a wave (rising and falling in a pattern). How long does it take for one complete cycle—50,000 years, 100,000 years, 200,000 years, or 400,000 years? ______________________________

3. What relationship exists between the following two measured variables: **CO_2 Concentration** and **Temperature Changes?**

4. How could you demonstrate that the relationship identified in (3) above actually may be supported by the data in the table? If you were to say "why not draw a graph?" you would be on the right track. So let's get at it and plot a graph to see what the relationship might be. This time you will be responsible for setting up the x- and y-axes, deciding which variable goes on which axis, labeling the axes correctly as the **independent** and **dependent** variables, and giving your graph a title when it's complete. Use the axes on this page for your graph.



5. Based on your plot in part (4) above, what relationship exists (if any) between the CO_2 content of Earth's atmosphere and global temperatures?

TSM
Teacher
Support
Material

Ozone—What Is It, and Why Do We Care About It?

Ozone is a relatively unstable molecule found in the Earth's atmosphere. Most ozone is concentrated below a 48-km (30-mile) height. An ozone molecule is made up of three atoms of oxygen. Although it represents only a tiny fraction of the atmosphere, ozone is crucial for life on Earth.

Depending on where ozone resides, it can protect or harm life on Earth. High in the atmosphere at about 24 kilometres (15 miles) up, ozone acts as a shield to protect the Earth's surface from the Sun's harmful ultraviolet radiation. Without this shield, we would be more susceptible to skin cancer, cataracts, and impaired immune systems. Closer to Earth, in the air we breathe, ozone is a harmful pollutant that causes damage to lung tissue and plants.

The amounts of "good" and "bad" ozone in the atmosphere depend on a balance between processes that create ozone and those that destroy it. An upset in the ozone balance can have serious consequences for life on Earth. Scientists are finding evidence that changes are occurring in ozone levels—the "bad" ozone is increasing in the air we breathe, and the "good" ozone is decreasing in our protective ozone shield. This article describes processes that regulate "good" ozone levels.

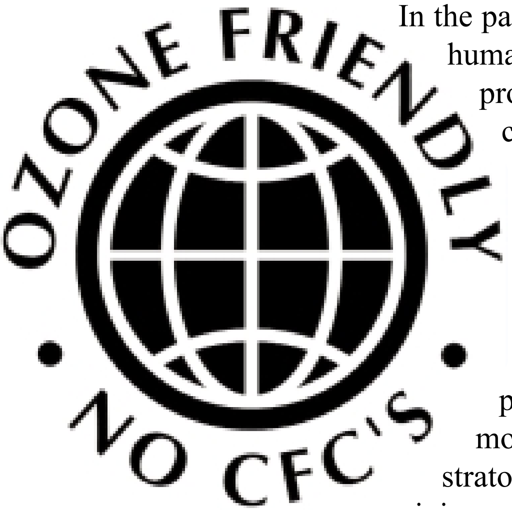
About 24 kilometres up in the atmosphere, in the region called the stratosphere, ozone is created and destroyed primarily by ultraviolet radiation. The air in the stratosphere is bombarded continuously with ultraviolet radiation from the Sun. When high-energy ultraviolet rays strike molecules of ordinary oxygen (O_2), they split the molecule into two single oxygen atoms, known as atomic oxygen. A freed oxygen atom then can bump into an oxygen molecule (O_2), and form a molecule of ozone (O_3).

The characteristic of ozone that makes it so valuable to us—its ability to absorb a range of ultraviolet rays—also causes its destruction. When an ozone molecule (O_3) absorbs even low-energy ultraviolet radiation, it splits into an ordinary oxygen molecule (O_2) and a free oxygen atom (O). The free oxygen atom then may join up with an oxygen molecule to make another ozone molecule, or it may steal an oxygen atom from an ozone molecule to make two ordinary oxygen molecules. These processes of ozone production and destruction that are initiated by ultraviolet radiation are often called the "Chapman Reactions."

Natural forces other than the Chapman Reactions also affect the concentration of ozone in the stratosphere. Because ozone is a highly unstable molecule, it reacts very easily, readily donating its "extra" oxygen molecule to the nitrogen, hydrogen, and chlorine found in natural compounds. These elements always have existed in the stratosphere, released from sources such as soil, water vapour, and the oceans.

In addition, scientists are finding that ozone levels change periodically as part of regular, natural cycles such as the changing seasons, Sun cycles, and winds. Moreover, volcanic eruptions may inject materials into the stratosphere that can destroy ozone.

Over the Earth's lifetime, natural processes have regulated the balance of ozone in the stratosphere. A simple way to understand the ozone balance is to think of a leaky bucket. As long as water is poured into the bucket at the same rate that water is leaking out, the amount of water in the bucket will remain the same. Likewise, as long as ozone is being created at the same rate that it is being destroyed, the total amount of ozone will remain the same.



In the past two decades, however, scientists have found evidence that human activities are disrupting the ozone balance. Human production of chlorine-containing chemicals, such as chlorofluorocarbons (CFCs), has added an additional force that destroys ozone. CFCs are compounds made up of chlorine, fluorine, and carbon bound together. Because they are such stable molecules, CFCs do not react easily with other chemicals in the lower atmosphere. One of the few forces that can break up CFC molecules is ultraviolet radiation. In the lower atmosphere, however, CFCs are protected from ultraviolet radiation by the ozone layer. CFC molecules are therefore able to migrate intact up into the stratosphere. Although the CFC molecules are heavier than air, the mixing processes of the atmosphere carry them into the stratosphere.

Once in the stratosphere, however, the CFC molecules no longer are shielded from ultraviolet radiation by the ozone layer. Bombarded by the Sun's ultraviolet energy, CFC molecules break up and release their chlorine atoms. The free chlorine atoms then can react with ozone molecules, taking one oxygen atom to form chlorine monoxide and leaving an ordinary oxygen molecule.

If each chlorine atom released from a CFC molecule destroyed only one ozone molecule, CFCs probably would pose very little threat to the ozone layer. However, when a chlorine monoxide molecule encounters a free atom of oxygen, the oxygen atom breaks up the chlorine monoxide, stealing the oxygen atom and releasing the chlorine atom back into the stratosphere to destroy more ozone. This reaction happens over and over again, allowing a single atom of chlorine to destroy many molecules of ozone.

Fortunately, chlorine atoms do not remain in the stratosphere forever. When a free chlorine atom reacts with gases such as methane (CH_4), it is bound up into a molecule of hydrogen chloride (HCl), which can be carried from the stratosphere into the troposphere, where it can be washed away by rain. Therefore, if humans stop putting CFCs and other ozone-destroying chemicals into the stratosphere, the ozone layer eventually may repair itself.

Ozone Depletion

The term “ozone depletion” means more than just the natural destruction of ozone; it means that ozone loss is exceeding ozone creation. Think again of the “leaky bucket.” Putting additional ozone-destroying compounds such as CFCs into the atmosphere is like causing the “bucket” of ozone to spring extra leaks. The extra leaks cause ozone to leak out at a faster rate—faster than ozone is being created. Consequently, the level of ozone protecting us from ultraviolet radiation decreases.

In the area over Antarctica, stratospheric clouds hold ice particles that are not present at warmer latitudes. Reactions occur on the surface of the ice particles that accelerate the ozone destruction caused by stratospheric chlorine. This phenomenon has caused documented decreases in ozone concentrations over Antarctica. In fact, ozone levels drop so low in spring in the southern hemisphere that scientists have observed what they call a “hole” in the ozone layer. In addition, scientists have observed declining concentrations of ozone over the whole globe. In the second half of 1992, for example, world-wide ozone levels were the lowest ever recorded.

Monitoring Ozone from Space

Since the 1920s, ozone has been measured from the ground. Scientists place instruments at locations around the globe to measure the amount of ultraviolet radiation getting through the atmosphere at each site. From these measurements, they calculate the concentration of ozone in the atmosphere above that location. These data, although useful in learning about ozone, are not able to provide an adequate picture of global ozone concentrations.

Contrary to the image created by the term “ozone layer,” the amount and distribution of ozone molecules in the stratosphere vary greatly over the globe. Ozone molecules drift and swirl around the stratosphere in changing concentrations—much as clouds do in the satellite weather pictures you see on television news. Therefore, scientists observing ozone fluctuations over just one spot could not be confident that a change in local ozone levels meant an alteration in global ozone levels, or simply a fluctuation in the concentration over that particular spot. Satellites have given scientists the ability to overcome this problem because they provide a picture of what is happening simultaneously over the entire Earth.

Scientists now are confident that ozone is being depleted worldwide—partly due to human activities. However, scientists still need to determine how much of the loss is the result of human activity, and how much is the result of fluctuations in natural cycles.

Predicting Ozone Levels

If scientists can separate the human and natural causes of ozone depletion, they can formulate improved models for predicting ozone levels. The predictions of early models already have been used by policy makers to determine what can be done to reduce the ozone depletion caused by humans. For example, faced with the strong possibility that CFCs could cause serious damage to the ozone layer, policy makers from around the world in 1987 signed a treaty known as the Montreal Protocol. This treaty set strict limits on the production and use of CFCs. By 1990, the growing amount of scientific evidence against CFCs prompted diplomats to strengthen the requirements of the Montreal Protocol. The revised treaty called for a complete phase-out of CFCs by the year 2000. Some countries have not met their targets for CFC elimination.

However, scientists agree that much remains to be learned about the interactions that affect ozone. To create accurate models, scientists must study simultaneously all of the factors affecting ozone creation and destruction. Moreover, they must study these factors from space continually, over many years, and over the entire globe. NASA’s Earth Observing System (EOS) will allow scientists to study ozone in just this way. The EOS series of satellites will carry a sophisticated group of instruments that will measure the interactions of the atmosphere that affect ozone. Building on more than 20 years of data gathered by previous NASA missions, these measurements will increase dramatically our knowledge of the chemistry and dynamics of the upper atmosphere and our understanding of how human activities are affecting the Earth’s protective ozone layer.

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Volcanoes and Global Cooling

Volcanic eruptions are thought to be responsible for the global cooling that has been observed to occur for a few years after a major eruption. The amount and global extent of the cooling depend on the force of the eruption and, possibly, its latitude. When large masses of gases from the eruption reach the stratosphere, they can produce a large, widespread cooling effect. As a prime example, the effects of Mount Pinatubo, Philippines, which erupted in June 1991, may have lasted a few years, serving to temporarily offset the predicted greenhouse effect.

As volcanoes erupt, they blast huge clouds into the atmosphere. These clouds are made up of particles and gases, including sulfur dioxide. Millions of tons of sulfur dioxide gas can reach the stratosphere from a major volcano. There, the sulfur dioxide converts to tiny persistent sulfuric acid (sulfate) particles, referred to as aerosols. These sulfate particles reflect energy coming from the Sun, thereby preventing the Sun's rays from heating the Earth.

Global cooling often has been linked with major volcanic eruptions. The year 1816 often has been referred to as "the year without a summer." It was a time of significant weather-related disruptions in New England and in Western Europe with killing summer frosts in the United States and Canada. These strange phenomena were attributed to a major eruption of the Tambora volcano in 1815 in Indonesia. The volcano threw sulfur dioxide gas into the stratosphere, and the aerosol layer that formed led to brilliant sunsets seen around the world for several years.

However, there is some confusion about the historical evidence that global cooling may be caused by volcanic emissions. Two recent volcanic eruptions have provided contradictory evidence on this point. Mount Agung, Malaysia in 1963 apparently caused a considerable decrease in temperatures around much of the world, whereas El Chichon, Mexico in 1982 seemed to have little effect, perhaps because of its different location or because of the El Niño that occurred the same year. El Niño is a Pacific Ocean phenomenon, but it causes worldwide weather variations that may have acted to cancel out the effect of the El Chichon eruption.

Volcanoes and Ozone Depletion

Another possible effect of a volcanic eruption is the destruction of stratospheric ozone. Researchers now are suggesting that ice particles containing sulfuric acid from volcanic emissions may contribute to ozone loss. When chlorine compounds resulting from the breakup of chlorofluorocarbons (CFCs) in the stratosphere are present, the sulfate particles may serve to convert them into more active forms that may cause more rapid ozone depletion.

Monitoring the Effects of Volcanoes

Even if one can get to a volcano, it’s practically impossible to measure its gas output because one can’t synoptically see the whole cloud. Even aircraft can’t do it because they’re too low and it’s too dangerous. Space observations from NASA’s Total Ozone Mapping Spectrometer (TOMS) instrument have contributed significantly to our knowledge of the total amount of sulfur dioxide emitted into the atmosphere in the course of major volcanic eruptions. Following the eruption of Mount Pinatubo, TOMS images show sulfur dioxide spreading across the Pacific. Several weeks later the sulfur dioxide had spread around the world, as observed by the Microwave Limb Sounder (MLS) instrument on NASA’s Upper Atmosphere Research Satellite (UARS).

In addition to detecting the sulfur dioxide from Mount Pinatubo, TOMS has made similar observations of more than 100 volcanic events including a major eruption from the Cerro Hudson volcano in Chile in 1991. A TOMS instrument was launched on the Russian Meteor–3 spacecraft in 1991; it flew on a special-purpose NASA satellite, an Earth Probe, in 1994, and on the Japanese Advanced Earth Observing System (ADEOS) mission in 1996. Current plans are for TOMS to monitor volcanic eruptions well into the next century.

Data from the Stratospheric Aerosol and Gas Experiment (SAGE II) instrument on NASA’s Earth Radiation Budget Satellite (ERBS) have shown that during the first five months after the Mount Pinatubo eruption, the optical depth of the stratospheric aerosol increased up to 100 times in certain locations. Optical depth is a general measure of the capacity of a region of the atmosphere to prevent the passage of visible light through it. Greater optical depth means greater blockage of the light. In this case, the increased optical depth meant that considerably less of the Sun’s energy could get through the cloud to warm the Earth’s surface.

Observations of the effects of Mt. Pinatubo aerosols on global climate have been used to validate scientists’ understanding of climate change and our ability to predict future climate. Researchers at NASA’s Goddard Institute for Space Studies in New York City have applied their general circulation model of the Earth’s climate to the problem. They have reported success in correctly predicting the effects of the sulfate aerosols from Mount Pinatubo’s eruption on lowering global temperatures.

Missions to Study Volcanoes

The first launch in the series of EOS satellites, the key element of NASA's Mission to Planet Earth took place in 1998.

The High Resolution Infrared Radiometer (HRIR), first flown on NASA's Nimbus–1 satellite in 1964, has been used to observe both active and dormant volcanoes. On Nimbus–2, HRIR recorded energy changes from the volcanic activity on Surstey, Iceland in 1966. The Multispectral Scanner (MSS) and Thematic Mapper (TM) instruments on the Landsat satellite have provided a long series of images of volcanic activity (e.g., venting, volcanic ash falls, and lava flows).

The EOS program will incorporate a series of satellites that will carry advanced instruments to provide a highly accurate, self-consistent, and long-term database of many aspects of the Earth's atmosphere, land, and ocean characteristics. The information gained from this major effort to study Earth phenomena will expand our knowledge of the interactions between volcanoes and the Earth's climate.

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Verkaik, Arjen. *Wind, Weather and Waves: A Guide to Marine Weather in the Great Lakes Region* (also included with: The Great Lakes marine weather kit for safer boating). Downsview, ON: Environment Canada, Ontario Region, 1998. ISBN 0-660-17436-7; Gov't Cat. No. En56-125/2-1998E.

Verkaik, Jerrine. *Under the Whirlwind: Everything You Need to Know About Tornadoes But Didn't Know Who to Ask.* Elmwood, ON: Whirlwind Books, 1997. ISBN 0-9681537-0-4.

Watts, Alan. *The Weather Handbook.* 2nd ed. Dobbs Ferry, NY: Sheridan House, 1999. ISBN 1-574-09081-X.

Weather Channel. *Hurricane Tracking Kit.* Livonia, MI: the Weather Channel, n.d. (This kit includes one map, one black felt-tipped marking pen.)

Running Pr. *Weather Tracker's Kit: Explore the Changing Forces of Nature* [CD-ROM]. Philadelphia, PA: Running Pr., 1995. ISBN 1-56138-641-3. (This kit includes one computer laser optical disc; one handbook; one observation weather station, one cloud chart).

Running Pr. *Weather Tracker's Kit: Exploring the Changing Forces of Nature* (Discovery kit series). Philadelphia, PA: Running Pr., 1991. ISBN 0-87471-998-X. (This kit includes one handbook, one observation station, and one cloud chart.)

Wheaton, Elaine. *But It's a Dry Cold: Weathering the Canadian Prairies.* Calgary, AB: Fifth House Publishers, 1998. ISBN 1-894004-01-9.

Williams, James Thaxter. *The History of Weather.* Cormack, NY: Nova Science Publishers, 1999. ISBN 1-56072-622-9.

Williams, Jack. *The Weather Book.* 2nd.ed. New York, NY: Vintage Books; Toronto, ON: Random House of Canada, 1997. ISBN 0-679776-65-6.

World Meteorological Organization. *Climate and Human Health.* Geneva, Switzerland: WMO, 1996. (WMO No. 843). ISBN 92-63-10843-9.

World Meteorological Organization. *A Decade Against Natural Disasters.* Geneva, Switzerland: WMO, 1994. [WMO No. 799]. ISBN No. 92-63-10799-8.

World Meteorological Organization. *Observing the World's Environment: Weather, Climate and Water.* Geneva, Switzerland: WMO, 1994. [WMO No. 796]. ISBN 92-63-10769-3.

World Meteorological Organization. *On the Front Line: Public Weather Services.* Geneva, Switzerland: WMO, 1994. (WMO No. 816). ISBN 92-63-10816-1.

World Meteorological Organization. *Weather and Sports.* Geneva, Switzerland: WMO, 1996. (WMO No. 835). ISBN 92-63-10835-8.

World Meteorological Organization. *Weather, Climate and Health.* Geneva, Switzerland: WMO, 1999. (WMO No. 892). ISBN 92-63-10892-7.

World Meteorological Organization. *WMO and Global Warming.* Geneva, Switzerland: WMO, 1990. (WMO No. 741). ISBN 92-63-10741-6.

World Meteorological Organization. *WMO and the Ozone Issue.*

Geneva, Switzerland: WMO, 1992. (WMO No. 778). ISBN 92-63-10778-5.

Web-Based Resources for Teachers

Specific Sites on Weather-Related Topics and Publications

<http://www.weatheroffice.pyr.ec.gc.ca/skywatchers/index_e.html>
The National Skywatchers website can be used in conjunction with the Skywatchers weather resource kit.

<http://www.weatheroffice.pyr.ec.gc.ca/skywatchers/index_f.html>
This is the French equivalent of Skywatchers website.

<www.weatheroffice.ec.gc.ca>
Bilingual Environment Canada Weather site, shows current conditions across the country, local five-day forecasts, and satellite imagery.

<http://www.cmc.ec.gc.ca>
Bilingual Canadian Meteorological Centre site shows weather bulletins, satellite and radar imagery, and climate normals.

<http://www.ec.gc.ca/acidrain/>
This is the Environment Canada acid rain website.

<http://www.ec.gc.ca/climate/>
This is a bilingual site within Environment Canada’s Green Lane, providing information on climate change.

<http://www.epa.gov/air/acidrain/index.html>
This is the U.S. Environmental Protection Agency Clean Air Markets website that deals with environmental issues, particularly acid rain.

<http://www.msc-smc.ec.gc.ca/cd/index_e.cfm#facts>
This site offers Canadian Meteorological Service Fact Sheets on weather-related topics.

<http://www.on.ec.gc.ca/pubs_e.html>
This site offers Environment Canada, Ontario Region Fact Sheets on weather and climate-related topics.

<http://www.qc.ec.gc.ca/envcan/indexe.html>
The Environment Canada, Quebec Region’s bilingual website has substantive information on weather and climate, including material on the St. Lawrence Valley and Project Biosphere.

<http://www.cmos.ca>
Canadian Meteorological and Oceanographic Society homepage contains a link under Education–Schools to a series of classroom activities about weather by Dave Phillips.

<http://www.atmos.uiuc.edu/>
This is a useful all-round Meteorology Education site from University of Illinois at Urbana-Champaign.

<http://www.ametsoc.org/dstreme>
The American Meteorological Society site has a program on Weather Education for Grades K–12.

<http://www.islandnet.com/~see/weather/doctor.htm>
The Weather Doctor's website by Keith Heidorn includes interesting information on weather events and phenomena, people in weather, effects of weather, and book reviews.

<http://iwin.nws.noaa.gov/iwin/graphicsversion/bigmain.html>
This site includes observations and forecasts for American and international locations.

<http://www.ucar.edu/40th/webweather>
This is a great website for kids from the University Corporation for Atmospheric Research. There is a lot of activities and information.

<http://cimss.ssec.wisc.edu/>
A website from Cooperative Institute for Meteorological Satellite Studies in Wisconsin is a comprehensive source of information on satellites, including GOES, and many photographs.

<http://www.msc-smc.ec.gc.ca/cd/brochures/elnino_e.cfm>
This MSC site includes description, animation, status of the El Niño phenomenon.

<http://www.msc-smc.ec.gc.ca/cd/brochures/lanina_e.cfm>
This MSC site includes description, animation, status of the La Niña phenomenon.

<http://www.pmel.noaa.gov/toga-tao/el-nino/>
This NOAA site gives excellent background information and current status of El Niño and La Niña.

<http://www.elnino.noaa.gov/edu.html>
This El Niño site also provides links to several other El Niño Educational Sites.

<http://www.epa.gov/students/global_warming_us.htm>
This is a website on global warming and climate change from the U.S. Environmental Protection Agency.

<http://weather.unisys.com/hurricane>
This site includes a hurricane database.

<http://www.tornadoproject.com>
This is a comprehensive resource for tornado information.

<http://www.caps.ou.edu/outreach.htm>
The Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma website offers a lot of information on tornadoes and summer severe weather events.

<http://www.msc-smc.ec.gc.ca/uvindex/index_e.html>
This MSC site includes information and activities on the UV Index.

<http://www.worldclimate.com>
This interesting site shows what the weather is normally like in thousands of places world-wide.

<http://www.usatoday.com/weather/wfront.htm>
This is one of the most useful general weather education sites with explanations in easily understandable terms. It also gives world weather conditions and forecasts.

<http://www.australiansevereweather.com/>
This Australian meteorology site demonstrates techniques on how to observe weather.

<http://www.great-lakes.net>
This site includes lots of information relating to the Great Lakes themselves and the surrounding region.

<http://cbc4kids.ca/teachers/>
The CBC’s website for teachers includes some useful information and resources.

<http://www.2learn.ca/mapset/mapset.html>
This website from Alberta includes ideas for teachers and provides links to other sites with lesson plans and other activities.

<http://www.ace.mmu.ac.uk/Resources/Teaching_Packs/Key_Stage_4/Acid_Rain/contents.html>
This website is an acid rain teaching pack from the United Kingdom.

<http://www.crh.noaa.gov/dtx/teach.htm>:
The U.S. National Weather Service, Central Region's Education website has weather information and lesson plans for teachers.

<http://www.education.noaa.gov>
NOAA's website for teachers includes information on weather, climate change, oceans, and satellites, and gives links to many other useful sites.

<http://www.ucar.edu/ucar/edout.html>
The Education and Outreach website from the University Corporation for Atmospheric Research has great tips for teachers and lesson plans for all grade levels from K–12.

<http://nsidc.org/links/index.html>
The U.S. National Snow and Ice Data Center has links to many wonderful educational sites dealing with snow, ice, glaciers, and polar regions. There is a lot of information to explore.

<http://www.weather.com:80/education>
The Weather Channel's website has many lesson plans for teachers.

<http://www.met.fsu.edu/explores/resources.html>
The "Explores" website provides links to sites providing curricula information and learning activities.

<http://www.bom.gov.au/lam/>
The Australian Bureau of Meteorology website contains a comprehensive educational section on weather. It is of special interest to students and teachers, and also the general public.

<http://www.homeworkcentral.com>
This is a huge teacher resource site with a number of useful lesson plans.

<http://www.explorescience.com>
This is an exciting site that lets you design your own snowflake or learn about the Doppler effect, among many other experiments.

<http://www.science.ca>
The Great Canadian Scientists page includes the "Ask a Scientist" feature.

Useful National and International Meteorology-Related Sites

<http://www.ec.gc.ca>
Environment Canada's "Green Lane" has links to Regional Offices and EC publications.

<http://www.msc-smc.ec.gc.ca>
The Meteorological Service of Canada homepage has links to its services and publications.

<http://www.noaa.gov>
The U.S. National Oceanic and Atmospheric Administration (NOAA) homepage has links to many different services and current issues.

<http://nsidc.org/links/index.html>
The U.S. National Snow and Ice Data Center has links to many national and international organizations, providing excellent information on snow, ice, glaciers, and polar regions.

<http://www.met-office.gov.uk>
The British Met Office homepage has information on weather in Britain, Europe, and around the world.

<http://www.meteo.fr>
The Météo France homepage has information on local weather and links to other European weather sites.

<http://www.bom.gov.au>
Australia's Bureau of Meteorology homepage has weather information from the Southern Hemisphere.

<http://www.wmo.ch>
The World Meteorological Organization (WMO) homepage has links to many different national weather services around the world.