SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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SCOPE, SEQUENCE, and COORDINATION

Student Materials

Learning Sequence Item:

938

Heat, Temperature, and Transfer

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Contents

This micro-unit was adapted by Linda W. Crow (University of Houston-Downtown)

Student Sheet

Science as Inquiry

Hot Sources

Where does heat come from?

Demonstration

Overview:

How is heat produced? Watch and feel the heat in these demonstrations.

Procedure:

Your teacher will conduct a series of demonstrations. Carefully observe what happens in each of these events.

Questions:

1. How can heat be produced?

2. Which demonstration event surprised you the most? Why?

Student Sheet

Science as Inquiry

Solar Heating

How does solar heat reach the earth?

Demonstration

Overview:

The sun is a source of heat, how does heat move from the sun to the earth?

Procedure:

Watch the demonstration carefully and answer the following.

Questions:

1. Why is this transfer of heating different from the ones demonstrated in the previous activity?

2. How did you know that the heat from the heater affected the water in the bottle?

Student Sheet

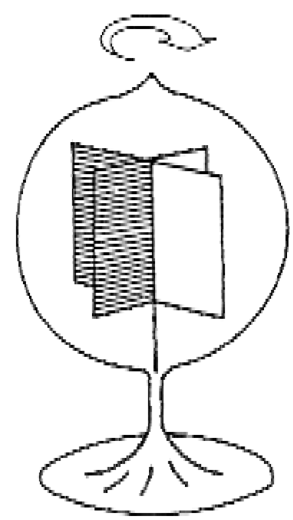
Science as Inquiry

Radiometer Experiment

How does solar heat reach the earth?

Overview:
This simple toy provides a demonstration of heat transfer. What makes the vanes move?

Procedure:
Place the radiometer in a bright light and observe what happens. Try different light sources of different intensities. Cover the radiometer with a black cloth and look under the cover. What are the vanes doing?



Questions:
1. Describe the motion of the radiometer vanes under the various conditions.

2. In terms of a particulate model of gases, explain what you have observed.

3. Light actually does exert a pressure. It is called radiation pressure. As a result, which way should the vanes turn from the pressure of light? How do you know that this pressure is much lower than the pressure produced by heated gas particles?

4. Using a particulate model for gases, explain why the radiometer would not work if the vanes were removed from the enclosure and the experiment repeated using air in the room.

5. Set up an arrangement where sunlight is passed through a prism. Place a radiometer in that region just outside of the red end of the spectrum where no visible light strikes the radiometer vanes. What do you observe? Explain this observation.

Science as Inquiry

Measuring the Temperature of Three Liquids

How does heat compare to temperature?

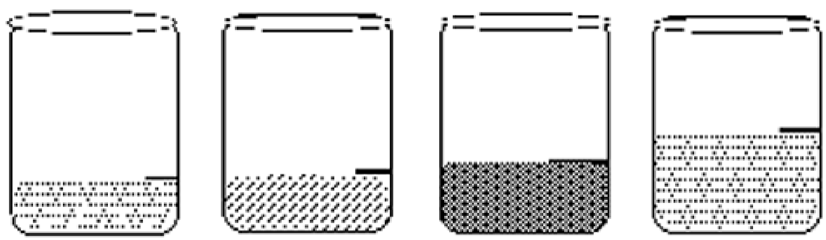
Overview:

What heats quicker? Water or oil?

Procedure:

In this experiment you will use water, Karo syrup, and cooking oil. Place 100 mL of each liquid into three separate beakers. Then place 150 mL of water in a fourth beaker.

Heat all four beakers for 5 minutes. Take the temperature of the beakers with 100 mL of liquids every 30 seconds during this 5-minute period. At the end of the 5-minute heating period, take the temperature of the fourth beaker (150 mL of water). Then construct a graph of time versus temperature for each 100-mL sample. A ring stand and clamp may be useful for holding the thermometer in place.



Questions:

1. How did the graphs of the different liquids compare?

2. What would be the temperature of the 100 mL of Karo syrup after 6 minutes?

3. How did the temperature of the 150-mL sample of water taken after 5 minutes of heating compare to the temperature of the 100-mL sample of water taken after 5 minutes of heating?

4. Which contains more heat, a 300-mL sample of water heated for 5 minutes or a 400-mL sample of water heated for 5 minutes?

Science as Inquiry

The Divided Cup

How does a hot object affect a cold object?

Overview:

Will hot water ever have the same temperature as cold water if allowed to cool? Find out in this activity.

Procedure:

Using the divided cup, place hot water in one side and an equal amount of cold water in the other side. Determine the temperature of each side very minute for 15 minutes. Repeat the experiment, varying the amounts of water. In each case, construct a graph of time versus temperature.

Questions:

1. How does the temperature of a cup of cold water change over time?

2. How does the temperature of a cup of hot water change over time?

3. How does the temperature of a cold soft drink change when it is left sitting on a table in a room? How does the temperature of the room change? How do these changes occur?

4. If you discover that your bath water is not the right temperature to be comfortable, describe how you could adjust the temperature to suite your needs.

5. How do the interacting temperatures know when to stop changing?

6. One afternoon you make a glass of iced tea. Before you drink it, some friends come to see you and you go out to a movie. How will the temperature of your glass of iced tea have changed when you return that evening?

7. If 50 L of cold water at a temperature of 10 °C is added to 100 L of boiling water in a completely closed tank, how will the temperature of the water change?

Student Sheet

Science as Inquiry

Great Bolts of Fire!

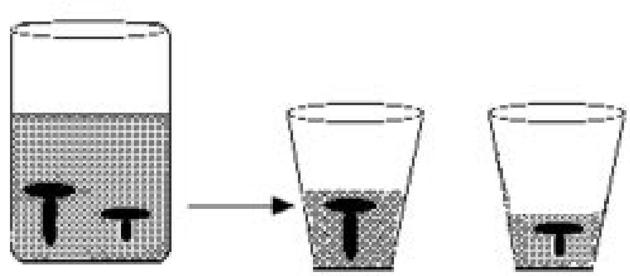
How is temperature different from heat?

Overview:

Sometimes when you stir a hot liquid with a metal spoon, the spoon will become warm. What if the spoon was hot and the liquid cold? Would the spoon become cold?

Procedure:

Place two bolts of different sizes into a beaker of water and boil for several minutes. Then remove the bolts and place each of them into a separate Styrofoam cup containing some tap water. Measure the temperature of the tap water before you add these hot bolts. Then measure the temperature of the tap water every minute for 3 minutes after you have added the bolts.



Questions:

1. After the bolts boiled for several minutes, how did their temperatures compare?

2. After each bolt was place in a cup of water, how did the temperature change over the three minutes, if at all?

3. If water heats up in the cups, then a transfer must occur. What other evidence indicates that a transfer has occurred?

4. How did the bolts compare in their heat content?

Student Sheet

Science as Inquiry

Putting on the Heat

What is the relationship between mass of water and temperature change when heat is applied?

Demonstration

Overview:

How does increasing water mass affect temperature change when heat is applied? What if you change the initial temperature of the water? Does it take equal amounts of heat to raise the temperature of 1 gram of water 1 °Celsius from 40° to 41° and from 60° to 61°?

Procedure:

Watch the demonstration carefully and answer the following questions.

Questions:

1. What happened to the temperature of the water as mass was increased?

2. If the initial temperatures of the masses of water were different and the experiment was repeated, what would be the results?

Student Sheet

Science as Inquiry

Radiating Cans

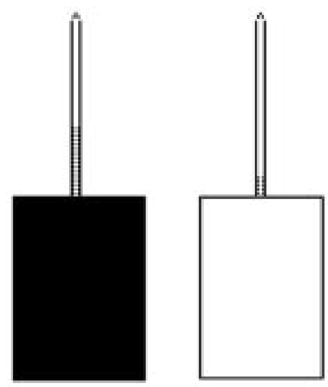
How fast do cans radiate heat?

Overview:

What color of car do you want? Sounds like a good color, but is it the best choice?

Procedure:

Insert a thermometer and stopper into a blackened can and a shiny can. Be sure any other holes are plugged with clay. Place these cans in front of a heater and measure the temperature every minute for 10 minutes.



Space heater

Questions:

1. How did the temperature change over time?

2. Two cars are sitting in the sun, one is black and one is silver. How will the heat affect these cars?

3. Apply what you observed in this experiment to staying cool. How could you stay as cool as possible?

Science in Personal and Social Perspectives

Clues to Past Found Down a Hole

Can past changes in climate be deciphered from the temperature of bedrock deep underground? Some scientists think so and they have begun to look for the climate record down several existing boreholes in Canada.

Only recently have the possible economic ramifications of global warming been considered; the scientific uncertainties have been researched and discussed for a longer time, but progress has been slow. Although climate modeling has been given a high priority, more research on corroborating evidence and past climates is needed to calibrate the models and verify the associated assumptions. Proxy methods such as tree-ring studies and isotope studies on glacier ice generally give very good indications of past changes in temperature, especially over periods of a few years. Annual temperatures estimated from tree-ring data for the eastern United States and high-latitude North America are at a minimum in the mid- to late-l9th century and increase into the 20th century. Reconstructed annual temperatures over 35-year intervals for central Canada generally are low in the mid 1800s and increase dramatically in the 20th century. Variations in temperature derived from tree-ring data for Russia and Tasmania also show that a cold period preceded the recent warming. Air temperature is the parameter most directly related to climate and climatic change discussions; ground-surface temperature is one of several parameters controlled by air temperature. In addition to variations in the average annual ground surface temperature reflecting changes in average air temperature, ground temperature itself is a controlling factor for growing crops and an important parameter for maintaining permafrost or glaciers. The analysis of temperature perturbations still propagating downward in bedrock is a method to obtain information about past changes in ground-surface temperature. A warming effect has been observed in all boreholes in certain regions such as eastern and central Canada, and the increase in ground temperature suggested for the last century 10 is very similar to the change in regional air temperatures during the same period.

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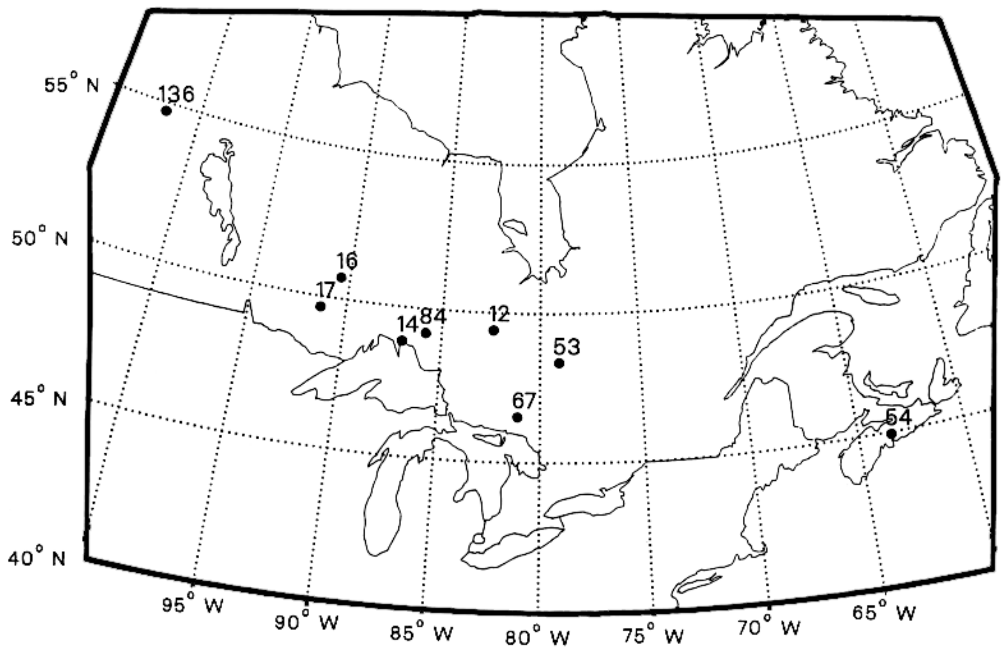

Locations of sites in eastern and central Canada where ground-surface temperature histories were estimated.

For central and eastern Canada, our results indicate a warming over the past century, delineate a preceding cold period, and yield reliable estimates of the mean ground-surface temperature over the last few centuries. Part of the recent warming is a recovery from a cold period: the picture of climatic warming in central and eastern Canada based on instrumental observations of air temperatures starts at a time when ground-surface temperatures were below average. These results confirm the conclusions of research on tree rings referenced above.

Technique

Heat generated within the Earth flows through continental crust toward Earth's surface mostly by conduction. The climate controls the ground-surface temperature, the boundary condition for conduction of heat through solid Earth.

This temperature is related to air temperature by many complex interactions, and its average value is generally a few degrees warmer than the average air temperature in Canada. When the ground temperature changes in response to a climatic change, the temperature perturbation at this boundary propagates downward into the solid Earth, dispersing as it goes. The present, maximum effect of a one-degree excursion lasting from 200 to 100 years ago at the surface is approximately 0.2 K at 100 m depth. Such a perturbation is superimposed on the nearly steady-state temperature field controlled by the thermal conductivity and radiogenic heat generation of the rock, and by the heat flow from the interior of the Earth.

Geothermal data bases containing borehole temperatures and thermal properties of the associated rocks were acquired in order to determine heat flow variations on most continents. These represent a resource in terms of determining Earth's surface temperature over the last few centuries and its spatial variation.

Recently, rigorous methods of inverting thermal data to obtain estimates of past surface temperatures have been developed. Factors such as slope and its azimuth, topography and elevation, type of vegetation, lakes, and water or snow on the surface cause the ground-surface temperature to differ from air temperature. A change in air temperature due to climatic variation or a terrain change such as deforestation due to logging or forest fires causes a temporal change in ground temperatures. Temperature anomalies in the ground may also be due to spatial differences in terrain. For example, a deforested area or a shallow shield lake in a Boreal zone may have a temperature 4 K warmer than that of the surrounding forested areas. In a borehole near such a feature, underground temperatures will be abnormally warm, the effect dependent on the relative geometry of the feature to the borehole. To obtain past surface temperatures from underground temperatures, it is necessary to determine if the temperatures are disturbed by any such effects and where they are disturbed, either to discard the data or to correct them.

Higher-frequency perturbations diminish quickly as they propagate downward. Low-frequency surface temperature variations that occurred in the past 300 years can be detected in a borehole over 600 m deep. However, the resolution of surface temperatures deteriorates rapidly as we look back further in time.

For central and eastern Canada we selected the deepest holes tat least 600 m deep) from a Canadian geothermal data base. We chose holes that were apparently undisturbed by water flow, and that had carefully measured temperatures and associated thermal conductivities at small intervals of depth.

The agreement between the surface temperature histories derived from different boreholes at one site (Lac Dufault, site 53) demonstrates the value of this method. Data from many boreholes at this site were discarded on the basis of the demonstrated effects of very small water flows. Data from three boreholes located within 2 km of each other that had vertical temperature gradients unaffected by terrain effects were analyzed. Boreholes 22 and 24 are located on a relatively flat, weathered surface of a granodiorite body, but borehole 389 is located on a southward-facing slope of a series of ridges formed by Archean greenstones. The agreement of the inferred past surface temperatures from the three boreholes over the last 400 years is remarkable. The slightly higher surface temperature and the different surface temperature prior to 1600 A.D. for borehole 389 are attributed to the southward-facing, well-drained slope and the smaller depth penetrated, respectively.

Results from Lac Dufault and most other sites studied show a warming trend in the past 100-200 years until about 1950, similar to the recorded increase in surface air temperature over the last century in this region. Estimated ground-surface temperatures from eight additional sites also yield reliable results. This warming trend is associated 11 with the large, ubiquitous temperature anomalies in the upper 100 m of nearly all boreholes in eastern and central Canada, similar to anomalies at other locations (for example, Alaska).

The majority of the results for eastern and central Canada also show a relatively cold period before the onset of warming: the recent warming is partially a recovery from a cold period. The warming trend obtained from observations of air temperatures over the last century in this region started when ground temperatures were colder than average, and some portion of the warming since then represents a return to the average ground temperature over the last thousand years. The presence of a cold period at this time has been suggested by tree-ring studies in the Ural Mountains, Tasmania, at high elevation in the state of Washington, and in the eastern United States.

Future Research

Research at present is concentrating on analyzing data acquired in the past. The International Heat Flow Commission of the International Association of Seismologists and Physicists of the Earth's Interior has formed a working group to assemble a global data base of subsurface temperature observations in the quadrennium 1991–1995 relevant to the understanding of recent climate change. One of the aims of the working group is to define regional 12 variations of recent surface temperature changes. The need to analyze all data, including those that do not show any obvious effect due to a recent warming, has been identified.

Drilling is expensive, and most geothermal data are obtained today from boreholes drilled for other purposes, such as mineral or hydrocarbon exploration. If these data are really needed for particular areas or for study of particular effects, then it may be necessary to drill special boreholes. Boreholes at higher elevations in western North America sited to avoid effects of terrain and water flows would define past ground temperature variations related to average air temperatures at higher elevations. A very deep borehole in an area of the northern Yukon or eastern Alaska that was not glaciated during the Pleistocene would be very helpful.

Realistic atmospheric modeling must take into account the complete climatic record, including the relation of the cold period to greenhouse gases in the 19th century, solar variability, etc. Thermal techniques have the advantage of producing an estimate of the mean surface temperature, whereas many proxy methods better define short-term, relative changes. For determining the cause of global warming, we need to know both how the present surface temperature compares to the temperature average over long times, and how the rates of change in temperature with respect to time in recent shorter periods compare to such rates in the past. ❑

Science in Personal and Social Perspectives

The Sun's Effect on Global Warming

Global warming has the potential to drastically alter the planet. Man's impact on global warming has been studied, but the sun's role in global warming is only beginning to be explored.

The smallest increase in Earth's average temperature has the potential to change precipitation patterns, increase evaporation, and raise sea level around the world. Sea level rise could lead to higher storm surges and increased coastal erosion, and shifts in precipitation could lead to more floods and droughts and water supply disruptions.

Scientists use global climate models to predict climate change, but because global warming research is relatively young, global climate models vary widely in their predictions. Part of the reason for this lies in the fact that many factors, such as the amount of solar heat that reaches Earth, must be taken into account to accurately predict global warming.

The U.S. Global Warming Research Program was conceived to study natural and human-induced changes in the global Earth system. Initially, the program focused on anthropogenic changes in climate by increasing "greenhouse" gases carbon dioxide (CO_2), methane (CH_4), nitrogen (NO_2), and chlorofluorocarbons (CFCs); tropospheric aerosols, primarily sulfur (SO_4); and albedo changes, such as those associated with deforestation. Later, solar influences were added to the list.

For research funding purposes, solar influences have been relegated to a status of lower importance. Yet if the goal of the program is to be achieved, uncertainties surrounding solar forcing must be reduced.

Do Solar Variations Modify Global Surface Temperature?

Yes. Until the past few years, the total energy radiated from the Sun was generally considered, for the purposes of climate change research, to be constant. Variations were therefore generally omitted from studies that sought to reproduce and predict variations in global surface temperature. Indeed, the solar "constant" is not, in fact, constant. Rather, the energy radiated from the Sun varies continuously at all wavelengths and, apparently on all time scales with the amplitude of the variability strongly dependent on the wavelength of the radiation.

The figure on the cover shows calculations of the Earth's temperature response to a reduction of 0.25% in the Sun's radiative output. Satellite observations

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made during the past decade have measured long-term changes of about 0.1% in total solar irradiance. Maximum irradiance occurs near the peak of the Sun's 11-year activity cycle. The response of the Earth's temperature to a decrease in the Sun's radiative output of 0.1% that occurred as solar activity levels declined from 1980 to 1986 is about 0.2°C. For comparison, the equilibrium increase in global temperature caused by greenhouse gases over this same period is also about 0.2°C. Thus, on time scales of a decade and less, solar variability vies with greenhouse gas variations in influencing the global climate, assuming that a substantial portion of the solar variability is at wavelengths that reach the troposphere. The current estimate is that 20% of the solar variability reaches the troposphere.

Have Solar Variations Been Responsible for Climate Changes Over the Past Several Centuries? Probably. The answer to this question depends on the magnitude of past solar variability. Significant natural changes in the Earth's climate indeed occurred prior to the industrial era. The mechanism for these changes may potentially be found in combinations of changing volcanic aerosols, North Atlantic Deep Water production, solar radiation and insolation, and greenhouse gases. Over time scales of decades to centuries, changes in total solar irradiance have not been reliably determined experimentally and must be inferred from interpretation of the contemporary variations.

A basic assumption is that irradiance variations arise from processes other than just the changes in sunspots associated with the Sun's 11-year activity cycle. Numerous studies have related past temperature changes on Earth to measures of solar variability, including the sunspot cycle, solar diameter variations, the length of the solar cycle, and the ratio of sunspot umbra and penumbra.

Will Solar Variability Be Significant for Future Climate Changes? Possibly. According to current models, a doubling of $C0_2$ is equivalent to a change in the Sun's radiative output of 2%. If the magnitude of total irradiance changes is limited to 0.1%, then current studies indicate that they would ultimately cause small perturbations in the anticipated influence of greenhouse gases. Recently scientists asked what impact a Little Ice Age cooling of about 0.5°C would have on the coming climate if it began in the year 2000 and lasted for 200 years. With climate sensitivity at the extremes of 1.5°–4.5°C for doubled CO_2, the impact could halve the warming for the next century, or simply slow its growth.

Recent studies indicate that about half of the greenhouse forcing over the past 150 years has been tempered by anthropogenic cooling due to ozone depletion and aerosol and cloud effects. In the figure is a scenario in which a reduction of solar forcing of 0.25% occurring from 2000 to 2200 vies with 12 the net anthropogenic forcing. Is this magnitude of solar change likely to occur? Our understanding of solar variability is not sufficient to estimate the probability. Those who extrapolate future solar effects by superimposing apparent past cycles in cosmogenic isotopes (^{14}C and ^{10}Be) predict a warming effect of solar irradiance change for the next half century. In the scenario presented in Figure, the effect is obviously significant. Reliable knowledge of future solar radiative output changes is also essential to verify that ozone density increases are accruing as a result of CFC restrictions and not of solar forcing.

What Can We Do to Reduce the Uncertainties? Monitor, understand, and predict. Given our newfound understanding that the Sun is a variable star on decadal time scales, and our continuing uncertainty of the potential size of solar variability on longer time scales, it is mandatory that observational programs be in place to monitor ongoing solar irradiance variations. The observations should be long-term to identify true solar radiative output variations.

To determine whether greenhouse gas forcing is occurring, we need to differentiate any observed climate changes from "natural variability," which implies that we must be able to disentangle forced and unforced past climate variations. To improve our estimates of solar variability over the past 1000 years and clarify future projections, we need to quantify ancient changes in the Sun's radiance. Therefore, we must continue the ground-based observations that have associated time histories and compare them with the observed irradiances as well as with the Sun's past activity. Empirical and solar physics models can then be employed to solidify cause and effect relationships. ❐

GLOSSARY

anthropogenic—involving the impact of man on nature, in this case due to greenhouse gases, ozone, aerosols, and cloud cover; aerosols—suspended ultramicroscopic liquid or as particles in air or gas; albedo—the amount of solar radiation reflected from an object to the total amount reflect on it; irradiance—emission of rays; umbra—the inner, darker region of a sunspot; penumbra—the outer, lighter region of a sunspot;
Little Ice Age—a cool, brief interval in an otherwise warm interglacial stage.

Science in Personal and Social Perspectives

Do Solar Variations Change Climate?

Most specialists now agree that the average temperature at the Earth's surface has increased by about half a degree Celsius since the beginning of the 20th century. The cause of this global warming, however, is a matter for intense debate and controversy, ranging from one extreme attributing it all to the increasing greenhouse effect brought about by human activities, to the opposite position attributing the warming to natural climate variability. Some model calculations have shown that the greenhouse effect can account for the size of the observed temperature increase, but the models are still relatively crude and cannot account for the shape of the increase. As a result, most researchers now think that some combination of natural and anthropogenic causes is at work.

The natural causes that are most often invoked include major volcanic eruptions, which can partially block the Sun's incoming radiation, and variations in the Sun's radiation itself, caused by some unknown process or processes occurring in the surface layers or the deep interior of the Sun. Until quite recently, the constancy of the Sun's output of radiation went unquestioned, but several factors have combined to change this view. Measurements from spacecraft of the Sun's total energy output have shown that it varies slightly in association with sunspot activity, both on a day-to-day basis, which is too short to affect our climate, and also on the time scale of the 11-year sunspot cycle. While these variations are probably too small to have much of a climatic effect, attention is now focusing on a longer 80-100 year cycle that influences the amplitude of the 11-year cycle. Scientists in the United States and Denmark have presented evidence that the Earth's surface temperature has shown a striking correlation with this so-called Gleissberg cycle of solar activity since about 1850, when reliable temperature records began to be kept. The temperature record of the more distant past, determined from ice cores taken from the Greenland ice cap, has also shown a periodicity close to that of the Gleissberg cycle.

This evidence, while circumstantial, bolsters earlier studies of a mysterious period in the late 17th and early 18th centuries when sunspots apparently disappeared from view. The existence of this period—known as the "Maunder Minimum"

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after its discoverer—was long questioned, but even in those early days the Sun was being observed regularly by telescope, and there is a great deal of supporting evidence for the absence of sunspots. The intriguing fact from the climatic point of view is that the Maunder Minimum coincided in Europe with the coldest part of the so-called Little Ice Age that affected the entire Earth in the late 16th century, and from which we may still be recovering. The Maunder Minimum may reflect a still longer periodicity in the Sun's activity, and evidence from radiocarbon studies has tended to support this view.

Climate models have been used to estimate the magnitude of the variation in the Sun's output that would be needed to cause the terrestrial temperature changes observed. The climate system is quite sensitive to small changes in solar radiation, and current estimates are that a few tenths of a percent, or about 1% at most, is all that would be needed. Solar astronomers have not been able to identify a mechanism that could produce such variations, but studies of other stars in our galaxy of the same general size and type as our Sun have indeed shown evidence that brightness does vary at this level.

The mounting evidence for the Sun's control of our past climate should not be taken, however, as an indication that human activities are not important. The increasing atmospheric burden of greenhouse gases such as carbon dioxide must inevitably lead to further warming. The only question is one of timing, and it is of the utmost importance to try to determine when this anthropogenic warming will overcome the natural variability. Much current research activity focuses on attempts to answer this question. ■