What are the causes and consequences of climate change?

Module Overview

This module investigates climatic variability. It focuses on the evidence for global climate change. It includes investigations of the El Niño Southern Oscillation (ENSO), the geography and politics of stratospheric ozone, and the theory of global warming.

Investigation 1:* *What are the causes and effects of ENSO?

The changing temperatures of the tropical Pacific Ocean greatly affect climate variability. These variations often cause heat waves, droughts, floods, and other disruptive phenomena. One result of changing ocean temperatures is called the *El Niño Southern Oscillation* (or ENSO). Students role-play policy makers deciding how to allocate Peru's resources to manage for possible ENSO-related problems. They learn how ENSO works, how it affects the environment, and how it creates problems for humans.

Investigation 2:* *The loss of stratospheric ozone: Where are people at risk?

Students learn about the recent declines of ozone concentrations above Antarctica and the Arctic. These declines increase the risk that unusually high amounts of harmful ultraviolet radiation will reach Earth's surface and threaten life, especially in the high latitudes. Students learn how human actions have affected the natural geography of stratospheric ozone, they estimate populations at risk from ozone destruction, and they learn how international complications obstruct solutions to the problem.

Investigation 3:* *Are we warming Earth?

Students assess the theory of global warming—that human activities are enhancing the greenhouse effect and thus causing Earth's temperature to rise. Role-playing science writers for a major newspaper, students write a story about global warming focusing on (1) what facts point to global warming? (2) what are the possible causes of global warming? and (3) how might global warming affect physical and human systems?

Connection to the Curriculum

"What are the causes and consequences of climate change?" is an instructional unit—about three to four weeks in length—that can be integrated, either in whole or in part, into high school courses in world geography, physical geography, environmental geography, regional geography, earth science, and global studies. The material supports instruction about many physical processes, such as those affecting large-

Geography Standards

The World in Spatial Terms
- **Standard 1:** How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective

Physical Systems
- **Standard 7:** The physical processes that shape the patterns of Earth's surface

Human Systems
- **Standard 10:** The characteristics, distribution, and complexity of Earth's cultural mosaics

Environment and Society
- **Standard 14:** How human actions modify the physical environment
- **Standard 15:** How physical systems affect human systems

The Uses of Geography
- **Standard 18:** How to use geography to interpret the present and plan for the future

Science Standards

Unifying Concepts and Processes
- Systems, order, and organization
- Evidence, models, and explanation
- Constancy, change, and measurement

Life Science
- Structure and function in living systems
- Populations and ecosystems

Earth and Space Science
- Structure of the earth system

Science and Technology
- Understandings about science and technology

Science in Personal and Social Perspectives
- Risks and benefits
- Science and technology in society

scale oceanic and atmospheric systems as well as the dynamic environmental interactions between physical and human systems at both regional and global scales of analysis. Connections to mathematics skills are easily made because the material requires students to work with quantitative data in both graphic and tabular form. The stratospheric ozone activity has links to chemistry.

Time

Investigation 1: Five to six 45-minute sessions
Investigation 2: Five to nine 45-minute sessions
Investigation 3: Four to seven 45-minute sessions

Mathematics Standards

Number and Operation

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Compute fluently and make reasonable estimates

Algebra

- Understand patterns, relations, and functions
- Analyze change in various contexts

Data Analysis and Probability

- Develop and evaluate inferences and predictions that are based on data

Communication

- Communicate mathematical thinking coherently and clearly to peers, teachers, and others

Connections

- Recognize and apply mathematics in contexts outside of mathematics

Representation

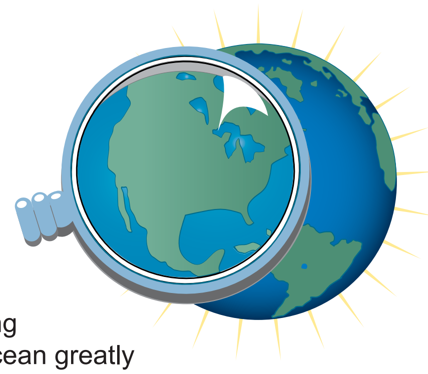
- Use representations to model and interpret physical, social, and mathematical phenomena

Technological Literacy Standards

Technology and Society

- **Standard 4:** The cultural, social, economic, and political effects of technology

What are the causes and effects of ENSO?



Investigation Overview

Investigation 1 shows that the changing temperatures of the tropical Pacific Ocean greatly affect climate variability. These variations often cause heat waves, droughts, floods, and other disruptive phenomena. Students learn how ENSO works, how it affects the environment, and how it creates problems for humans. The investigation concludes with students role-playing policy makers and deciding how to allocate Peru's resources to manage for possible ENSO-related problems.

Time required: Five to six 45-minute sessions (as follows):
- Introduction and Part 1: One session
- Parts 2 and 3: One or two sessions
- Part 4: One session
- Part 5: Two sessions

Materials

Briefings and Logs (one copy of each per student)
- Briefing 1: What are the effects of ENSO?
- Briefing 2: The ENSO game: Predicting and managing for El Niño and La Niña
- Log 1: What are the effects of ENSO?
- Log 2: The ENSO game: Predicting and managing for El Niño and La Niña

Computer with CD-ROM. The Mission Geography CD-ROM contains color graphics needed for this activity.

Optional: Access to the Internet, which offers opportunities for extending this investigation

Content Preview

Climate change is a major topic of scientific and popular interest and debate. Issues about global warming caused by a human-enhanced greenhouse effect dominate this debate, but it is important to know that natural variability is a fundamental feature of weather and climate. The El Niño Southern Oscillation (ENSO) is a major example of natural climatic variability, which also has significant effects on humans.

Classroom Procedures

Beginning the Investigation

1. Have students bring to class newspaper and magazine clippings and photos of severe *weather-related* events, such as storms, floods, mud slides, cold spells, heat waves, fires, and droughts. Alternatively, have students conduct Internet searches for this information.
   - Have students organize clippings on a bulletin board or Internet data in a database according to types and locations of events.

Geography Standards

Standard 1: The World in Spatial Terms

How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information
- Produce and interpret maps and other graphic representations to solve geographic problems.

Standard 7: Physical Systems

The physical processes that shape the patterns of Earth's surface
- Explain Earth's physical processes, patterns, and cycles using concepts of physical geography.

Standard 15: Environment and Society

How physical systems affect human systems
- Analyze examples of changes in the physical environment that have reduced the capacity of the environment to support human activity.

Standard 18: The Uses of Geography

How to apply geography to interpret the present and plan for the future
- Develop plans to solve local and regional problems that have spatial dimensions.

Geography Skills

Skill Set 4: Analyzing Geographic Information
- Make inferences and draw conclusions from maps and other geographic representations.
- Use the processes of analysis, synthesis, evaluation, and explanation to interpret geographic information from a variety of sources.

- Focus class discussion on (a) the locations and spatial patterns of these events, (b) the accompanying human costs in lost lives, injury, and property destruction (emphasizing that these costs are especially difficult to bear when they occur in poor, developing countries), and (c) suggestions for reducing these costs.
- Tell students that this investigation focuses on many of these issues.

Developing the Investigation

2. Hand out copies of **Briefing 1** and **Log 1: What are the effects of ENSO?** to each student or to small groups of students. Students can work on this activity individually, but it is recommended that they work in small groups—pairs or triads are especially recommended.

3. Leaf through the **Briefing** and **Log** with the students and point out the underlined questions, which are to be answered on the Log at the end of the materials. Give students a schedule for completing the questions in the Log.

4. Have students read the **Background** and **Objectives** and then assist them with any questions they may have.

5. Set students working through the materials, beginning with **Part 1. What is ENSO?** Emphasize the importance of carefully studying and discussing the images and working together on group answers to the Log questions. Figures 1 and 2 are especially important.

6. To monitor progress and to keep students moving through the materials at about the same pace, ask students to read aloud passages, give their interpretations of the images, and/or use the Log questions (or other questions) to generate class discussion.

7. **Part 4. How are human activities affected by ENSO?** contains some URLs that students may use to find specific examples of ENSO effects. You may wish to have students skip over these Internet resources or use them to extend their knowledge.

8. You may wish to have students complete the Log before moving on to the ENSO Game. Move on to the ENSO Game after debriefing the Log.

9. **Part 5. The ENSO game** may be played as individuals or in small groups. Direct students to proceed with the game as it is presented in **Briefing 2: The ENSO game**. After deciding whether the data point to an El Niño or La Niña, students can use the table in the ENSO Game Log to record their investment decisions. Tell them to leave blank the two columns marked "Multiplier" and "Outcome" because you will supply them with the multiplier information at the end of the game.

10. ENSO game scoring, examples, and explanations are in **Background** below. In debriefing the game, you may wish to hand out this information to the class or put it on a transparency. Also, you may wish to have students share their game decisions by showing their investment tables.

11. The evidence strongly points to an El Niño event: sea surface temperatures—current of warm water pushed against South American coast (Figure 11), increased precipitation forecasts for Peru—in many cases above 300 percent (Figure 12), and a severely curtailed upwelling (Figure 13). Students who miss this suffer greatly in the game scoring. The Peruvian background is critical for understanding how ENSO affects each of the categories.

12. The two keys to this game are to have students (1) recognize that the upcoming episode is an El Niño and (2) understand the effects of an El Niño on agriculture, fishing, and disaster preparedness. Students who invest all of the money on one item will lose money, as will students who think that it is a La Niña year. The highest scoring students will invest money in rice production, move the fishing fleets north and south for the season, and invest a substantial percentage of the funds in infrastructure and disaster preparedness. For illustration, three possible outcome scenarios follow:

    Student (or group) A, thinking that the upcoming event is a La Niña, invests in the following:
    $100 million—cotton
    $100 million—more fishing boats and fishing production

    Outcome: loses $50 million of the cotton investment (-50%) and $75 million on the fishing investment (-75%). The total before the disaster preparedness score would be $75 million. However, because the student (or group) did not account for the floods and other natural disasters, she/they suffer an additional $600 million loss, thus ending with a final loss of $525 million.

    Student (or group) B, thinking that the upcoming event is an El Niño, invests in the following:

$100 million—rice
$100 million—move the fleet north and south for the season

Outcome: earns $200 million for the rice investment ($100 million x 2) and $300 million on the fishing industry ($100 million x 3). The total score before disaster preparedness scoring is $500 million. But she/they lose $600 million because of no investment in disaster preparedness, so the final loss is $100 million.

Note: Students who do not invest in the fishing industry lose money because the fishing industry in Peru is based on large annual yields. If the fishing industry simply does nothing in the face of an El Niño, it is likely that it will still suffer economic losses.

<u>Student (or group) C</u>, thinking that the upcoming event is an El Niño, allocates investments as follows:
$100 million—rice
$50 million—move the fleet north and south for the season
$50 million—disaster preparedness

Outcome: students who invest across all three categories will always do best in this game. Student (or group) C earns $200 million for the rice investment ($100 million x 2) and $150 million ($50 million x 3) for moving the fleet north and south. Then, the $50 million invested in disaster preparedness earns $100 million ($50 million x 2), for final earnings of $450 million.

Concluding the Investigation

13. Use the ENSO Game Log key to debrief the game. Have students discuss the evidence they used to decide whether this was an El Niño or a La Niña event.

14. Generate further discussion around various students' investment strategies. If you wish to use more math, have students find out the range and average of total scores in the class.

15. Refer students to the **Objectives** to have them summarize what they learned with the activity:
    - interpretation of satellite images;
    - how, when, and where ENSO events occur;
    - how ENSO events affect humans in different places; and
    - how to use geographic information to plan and make decisions.

Background

The ENSO Game Scoring

Agricultural Investments:

<u>Rice production</u>

Multiplier: 2 x original investment
For example, for a $50 million investment in rice, the payoff is $100 million.

The upcoming El Niño episode brings torrential rains to the highlands and coasts of Peru. Rice, because it thrives in wet conditions, prospers this year. The rice industry in Peru experiences a bumper crop. Your investment helps to feed thousands of people and generates foreign exchange for Peru's economy when rice is exported to neighboring countries that do not invest in rice production.

<u>Cotton production</u>

Multiplier: 50% loss of original investment
For example, for a $50 million investment in cotton, the payoff is $25 million.

The torrential rains of the El Niño do not let up at the end of the growing season. Although your cotton crops grow fairly well this year, heavy rains at the end of the season seriously damage the cotton. Poor climate prediction leads to a serious economic hardship for cotton growers and a setback to economic development in the country.

Fishing Industry Investments:

<u>More fishing boats and fishing production</u>

Multiplier: 75% loss of original investment
For example, for a $100 million investment in boats and fishing, the payoff is $25 million.

The El Niño event reduces cold upwelling along the coast. Fewer nutrients are brought to the surface. Consequently, fewer phytoplankton grow, fewer fish arrive to feed on the phytoplankton, and fewer fish are caught by fishermen. The fishing industry along the coast suffers economic hardship. Investment in more fishing boats and production triggers overfishing along the coast of the few species in the waters. This, in turn, leads to unemployment in the fishmeal and manufacturing industries and a substantial loss of your investment.

<u>Move the fleet north and south for the season</u>

Multiplier: 3 x original investment
For example, for a $50 million investment to move the fleet, the payoff is $150 million.

During the El Niño, the fishing fleet moves to the north and south to take advantage of the shift in upwelling.

Because of good climate predictions, the fleet captures a great quantity of fish, which are processed in Peru, leading to substantial economic growth for the country.

No investments in fishing this year

Multiplier: $50 million penalty

Subtract $50 million from your total.

During the El Niño period, the fishing industry has no funds with which to fish. Fishermen and others working in the industry are unemployed and suffer economic hardship. Economic experts estimate that the fishing industry loses $50 million during the El Niño episode.

Disaster Preparedness Investments:

Invest in disaster preparedness

Multiplier: 2 x original investment

For example, for a $75 million investment in infrastructure for disaster preparedness, the payoff is $150 million.

During the El Niño episode, torrential rains fall on the coasts and mountains of Peru. This creates a potential for serious flooding problems. But your planning and investment in infrastructure saves much of the agricultural production from flooding, soil erosion, and destruction. In addition, roads, highways, bridges, and hospitals are saved from flooding, which provides for future economic growth in the upcoming years. Your wise planning and predictions save many lives and homes.

No investment in disaster preparedness

Multiplier: $600 million penalty

Subtract $600 million from your total.

During the El Niño episode, torrential rains lead to serious problems. Soil erosion and flooding destroy most of the cotton production in the country. In addition, flooding destroys highways, roads, bridges, and hospitals throughout the country. Furthermore, many homes are destroyed, and many people lose their lives. Poor climate predictions and failure to fully understand the potential threats of El Niño to Peru's infrastructure have led to consequences that have set the country back many years in economic development.

Evaluation

Log 1

1. Why are the easterly trade winds important in ENSO?
   Easterly trade winds push water toward the western Pacific, which gives that area the warmest ocean temperatures on Earth. This leads to a heating of the atmosphere above the pool of water and convection and precipitation. In fact, oceanic heat surrounding Indonesia and other western Pacific islands leads to frequent thunderstorms and some of the heaviest rainfall on Earth.

2. What is the thermocline?
   The thermocline is the layer dividing the warm surface water and deep cold water in the ocean. The thermocline is also a key ingredient in upwelling, nutrient cycling in the ocean, and fish and other animal well-being.

3. What are the indicators of a La Niña?
   First, unusually cold ocean temperatures occur in the equatorial Pacific. This also leads to an increase in the intensity of easterly trade winds and more oceanic upwelling.

4. Why do you think ocean-based measurements are important?
   A number of reasons might be mentioned for the importance of ocean-based measurements. First, ocean measurements can help us more accurately predict when an ENSO event is taking place. In addition, ocean-based measurements also allow scientists to predict ENSO events more rapidly. For example, as ocean temperatures change along the equator, buoys and ships can quickly detect these changes. Another possible reason for the importance of ocean-based measurements is that they will increase our understanding of how ENSO events occur and how they may be changing. Yet another response may be that ocean-based measurements will increase our understanding of how the oceans function and how tides, climate, and currents change and interact with the atmosphere.

5. Describe the different effects of El Niño and La Niña on each of the following regions:
   North America
   El Niño—Warmer temperatures in Alaska and western and eastern Canada. Wet and cool conditions in the southern United States.
   La Niña—Cool temperatures in Alaska and western Canada. Dry and warm conditions in the southern United States.

South America
El Niño—Wet and warm conditions in the northwestern region (Ecuador and Peru). Dry conditions along the northeastern portion of the region (French Guyana, northern Brazil). Warm conditions in eastern Brazil. Wet conditions in southern Brazil and Uruguay.
La Niña—Dry and cool conditions in the northeastern region. Wet conditions along the northwestern portion of the region. Cool conditions in eastern Brazil.

Africa
El Niño—Wet in central Africa and dry and warm in southern Africa and Madagascar.
La Niña—Cool conditions in western Africa. Dry conditions in central Africa. Wet and cool conditions in southern Africa.

Asia
El Niño—Dry and warm conditions throughout most of Asia.
La Niña—Wet conditions in the southern portion of Asia. Cool temperatures in Japan and the Korean peninsula.

Southeast Asia
El Niño—Dry and warm conditions throughout southeast Asia.
La Niña—Wet conditions throughout most of southeast Asia.

6. What are the El Niño temperature and precipitation predictions for your hometown?
Answers to this question based on Figures 8 and 9 will vary depending on where students live.

Log 2

1. Is an El Niño or a La Niña forming? Support your answer by referring to Figures 11, 12, and 13.
The evidence supplied to students strongly points to an El Niño event: sea surface temperatures—warm water pushed against South American coast (Figure 11), increased precipitation forecasts for Peru—in many cases above 300 percent (Figure 12), and a severely curtailed upwelling (Figure 13).

2. Use this table to allocate a total of $200 million on any combination of investments. Make investments in increments of $10 million.

Investment Category	Amount $ millions	Multiplier	Outcome $ millions
Agriculture			
Rice		2 x investment	
Cotton		50% loss of investment	
Fishing			
More boats/production		75% loss of investment	
Move fleet north and south		3 x investment	
No investment		$50 million penalty	
Disaster Preparedness			
Invest		2 x investment	
No investment		$600 million penalty	
Totals	200	n/a	

3. Give your reasons for your investment decisions in the spaces provided below.
Student reasons will vary but should be logical and based primarily on their knowledge of the effects of El Niño as well as of the Peruvian economy.

Module 3, Investigation 1: Briefing 1
What are the effects of ENSO?

Background
The changing temperatures of the tropical Pacific Ocean affect climate variability all over Earth. Ocean warming and cooling dramatically affect human activities by changing weather patterns and ocean currents. Often, these climate variations cause heat waves, droughts, floods, mud slides, tornadoes, wildfires, and many other disasters that affect human activity. One result of dramatically changing ocean temperatures (both warm and cold) is called the *El Niño Southern Oscillation* (or ENSO). The warming period, often called "El Niño" or "the Christ Child," is so named because of its frequent late-December appearance. The cooling period is referred to as "La Niña." These ENSO events cause severe problems, but prediction and management of these periods can reduce human suffering and damage. In this investigation, you play the role of a Peruvian government policy maker deciding how to allocate Peru's resources to manage for possible ENSO-related problems. In order to play your role successfully, you will first need to learn how ENSO works, how it affects the environment, and how it creates problems for humans.

Objectives
In this investigation, you will
- interpret satellite images and maps to draw conclusions about the physical processes producing ENSO;
- explain how, when, and where ENSO events occur;
- give examples of how ENSO events affect humans in different places; and
- use geographic information to develop national plans and investments to prepare for ENSO events in Peru and other places.

Part 1. What is ENSO?
Atmospheric and oceanic variability affect the weather. Weather and climate change through complex links between the oceans and the atmosphere. Sources of variability in weather and climate around the world are changes in water currents, atmospheric pressure, and temperature in the oceans, especially the Pacific Ocean. These changes in the Pacific are often referred to as the El Niño Southern Oscillation, or ENSO. Two types of changes are referred to as El Niño and La Niña.

El Niño is the name given to the occasional warming of surface waters in the central and eastern equatorial Pacific Ocean. Under normal conditions, easterly trade winds blow from east to west along the equator and push warm surface water to the western tropical Pacific, where it piles up near Indonesia and the Australian continent (Figure 1). The persistent easterly trade winds are key ingredients of ENSO because they push warm water toward the western Pacific. This gives that area the warmest ocean temperatures on Earth. Usually above 28 degrees C (82 degrees F), parts of this pool are sometimes as warm as 31.5 degrees C (89 degrees F). Because this large pool of warm water is pushed towards the western Pacific, the

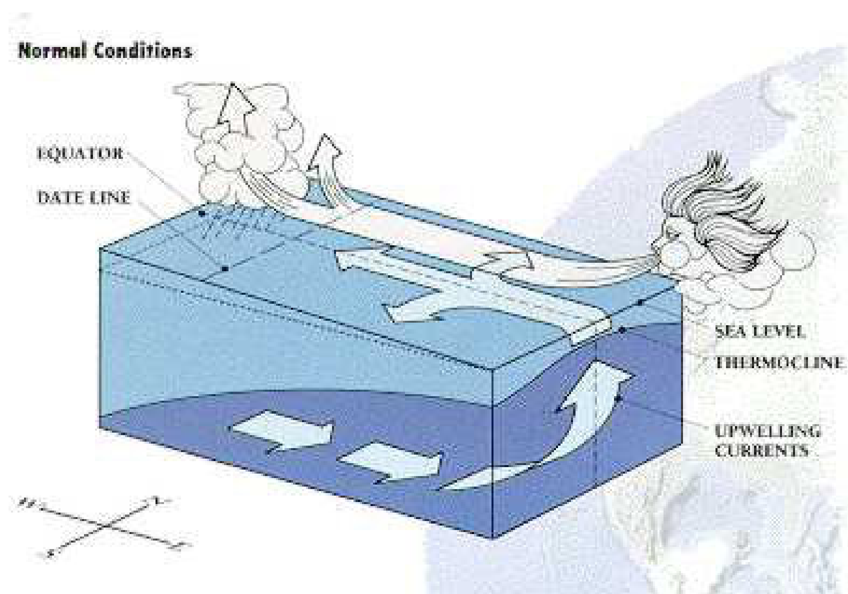


Figure 1: Normal atmospheric-oceanic circulation

Source: http://airsea-www.jpl.nasa.gov/ENSO/ElNino.html atmosphere above the ocean is heated, causing favorable conditions for convection and precipitation. In fact, the persistent oceanic heat surrounding Indonesia and other western Pacific islands leads to frequent thunderstorms and some of the heaviest rainfall on Earth.

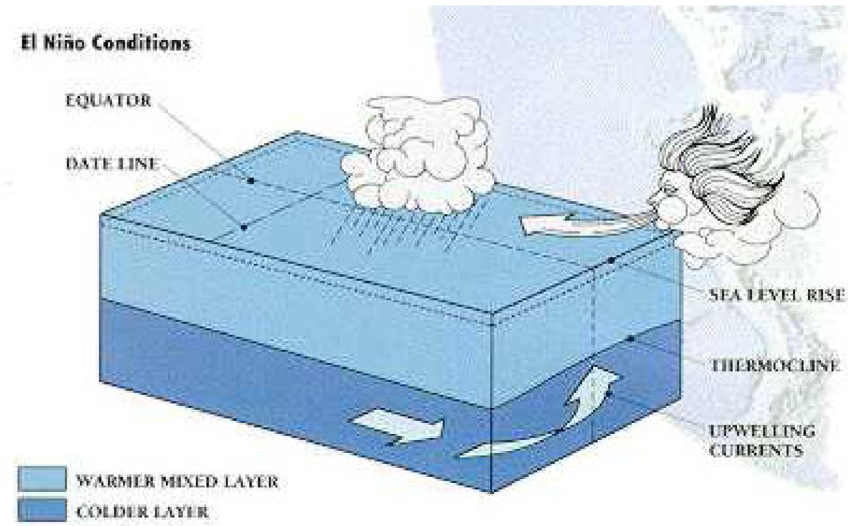


Figure 2: El Niño circulation

Source: http://airsea-www.jpl.nasa.gov/ENSO/ElNino.html

As the easterly trade winds push warm surface water against the western boundary of the Pacific Ocean, colder, nutrient-rich water comes up from below along the coast of South America to replace it. This is called **upwelling**. Upwelling helps fish and other animals thrive. In addition, as the warm surface water moves westward, the layer dividing the warm surface water and deep cold water, known as the **thermocline**, is raised. Because warm water contains more volume than colder water, and because trade winds push the water westward, the sea level is higher on the western side of the Pacific. In fact, the sea level in the Philippines is normally about 60 centimeters (23 inches) higher than the sea level on the southern coast of Panama.

In the upper levels of the atmosphere, the winds blow from west to east, completing a large-scale atmospheric circulation known as the Walker Circulation, named after Sir Gilbert Walker who studied variations in the tropical Pacific atmosphere during the 1920s.

In an El Niño year (Figure 2), which typically occurs every three to seven years, the normal trade winds diminish and the warm pool of water in the western Pacific is free to move back along the equator toward the east and the South American continent. The sea level drops in the west and rises in the east as warm surface water surges along the equator in the form of a pulse, or a Kelvin Wave. In addition, the upwelling of cold water along the South American coast decreases, reducing the supply of nutrients to fish and other animals.

This displacement of the warm water affects the atmosphere. The convection and precipitation that previously occurred in the western Pacific shifts with the warm pool to the central and eastern Pacific and usually results in heavier than normal rains over areas such as northern Peru, Ecuador, and other areas in tropical South America. In the western Pacific, the mechanism for precipitation is shut off, and Indonesia and Australia will often experience drought conditions while an El Niño persists.

In a La Niña year, unusually cold ocean temperatures occur in the equatorial Pacific, which is the opposite of an El Niño. Generally, during a La Niña, the easterly trade winds increase in intensity, more upwelling occurs, and the water temperatures along the equator are reduced. This usually results in less cloudiness and rainfall for South America and more rainfall over Indonesia, Malaysia, and northern Australia.

Throughout this investigation, you should answer the questions on the Log at the end of this briefing. Here are the first three questions:

1. <u>Why are easterly trade winds key ingredients in ENSO?</u>
2. <u>What is the thermocline?</u>
3. <u>What are the indicators of a La Niña?</u>

Module 3, Investigation 1: Briefing 1
What are the effects of ENSO?

Part 2. How is ENSO measured?

In order to both understand how ENSO works more fully and predict its effects, better measurements of ocean conditions and climate change are needed. Scientists have begun a number of different measurement projects to identify El Niño and La Niña. For example, space-borne sensors are helping to monitor variations of surface wind, sea level, and sea surface temperature along the equator and the west coasts of the American continents.

Sea level measurements. NASA satellites can measure sea level for the entire Pacific Ocean within 5 centimeters (2 inches) (Figure 3). Images from these satellites can tell us where the warm water is located in the Pacific Ocean because it takes up more volume, thus raising the level of the ocean.

Upwelling measurements. Another way of measuring ENSO using satellites is by examining upwelling. Upwelling currents carry nutrients with them, which leads to phytoplankton growth and chlorophyll blooms. Satellites can detect the pigments of the phytoplankton from space. Figure 4 illustrates what satellite images of phytoplankton look like.

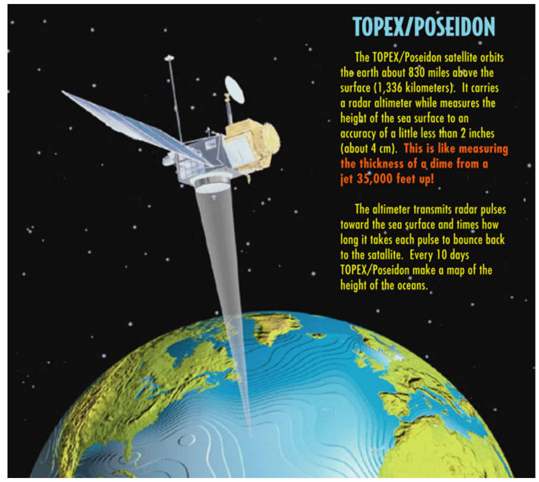
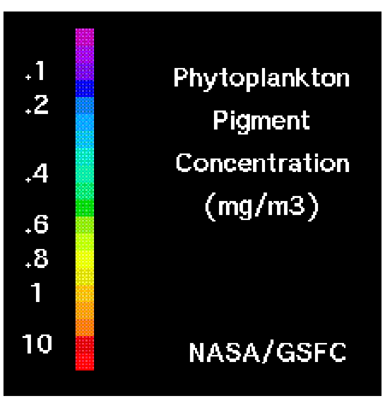


Figure 3: Topex-Poseiden satellite

Source: http://topex-www.jpl.nasa.gov/discover/image-gallery/gifs/tp-jpl-oh99-disp1.jpg



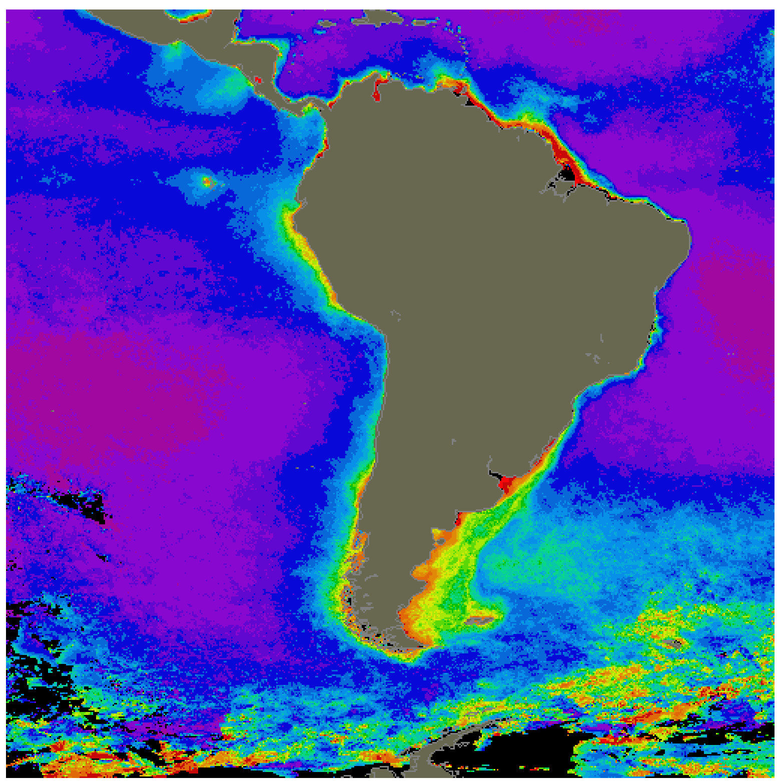


Figure 4: Upwelling along South American coast

Sources: http://seawifs.gsfc.nasa.gov/SEAWIFS.html
http://seawifs.gsfc.nasa.gov/SEAWIFS/CZCS_DATA/south_america.html

Module 3, Investigation 1: Briefing 1
What are the effects of ENSO?

Ocean-based measurements. Another method of identifying when an ENSO event is starting is through measurements taken in the water of the Pacific Ocean. Scientists have created an extensive system of floating and moored buoys, tide gage stations, and ship-based observation systems throughout the Pacific Ocean (Figure 5).

<u>Answer Question 4 on the Log.</u>

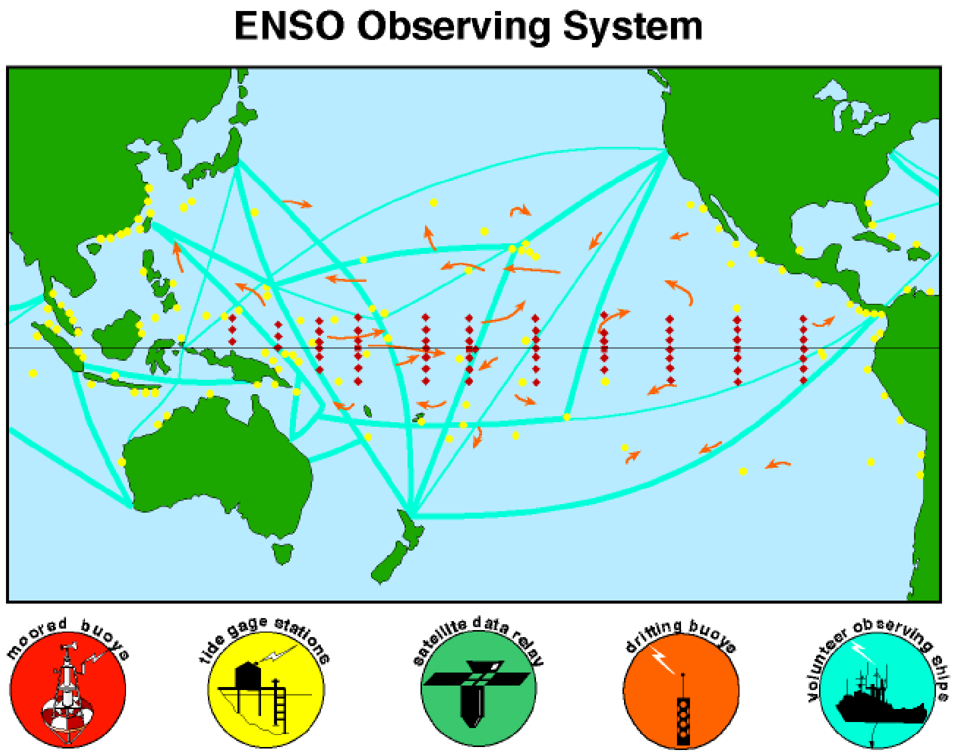


Figure 5: Ocean monitoring system

Source: http://www.pmel.noaa.gov/toga-tao/pmel-graphics/gif/enso-obs-sys.gif

Part 3. How do El Niño and La Niña affect the weather?

The large oceanic and atmospheric changes caused by El Niño and La Niña have a profound effect on Earth's weather. This is because ENSO occurrences have strong **teleconnections** to other weather patterns. Teleconnections are atmospheric interactions between widely separated regions. One way of thinking of teleconnections is that changes in the ocean and atmosphere in the Pacific can have a ripple effect on climatic conditions in other parts of Earth. This worldwide message is conveyed by shifts in tropical rainfall and wind patterns over much of the globe. Imagine a rushing stream flowing over and around a series of large boulders. The boulders create a train of waves that extend downstream, with crests and troughs that show up in fixed positions. If one of the boulders were to shift, the shape of the wave train would also change and the crests and troughs would occur in different places.

Scientists are studying the relationships between ENSO events and weather around the globe to determine whether links exist. Understanding these teleconnections can help in forecasting droughts, floods, tropical storms, and hurricanes. Based on ENSO patterns and on measurements of the general circulation of the atmosphere and oceans, scientists are predicting abnormally wet, dry, warm, or cold conditions for different regions at different times. Figures 6 and 7 illustrate the global weather patterns during an El Niño and a La Niña.

<u>Answer Question 5 on the Log.</u>

Module 3, Investigation 1: Briefing 1
What are the effects of ENSO?

EL NIÑO RELATIONSHIPS DECEMBER - FEBRUARY

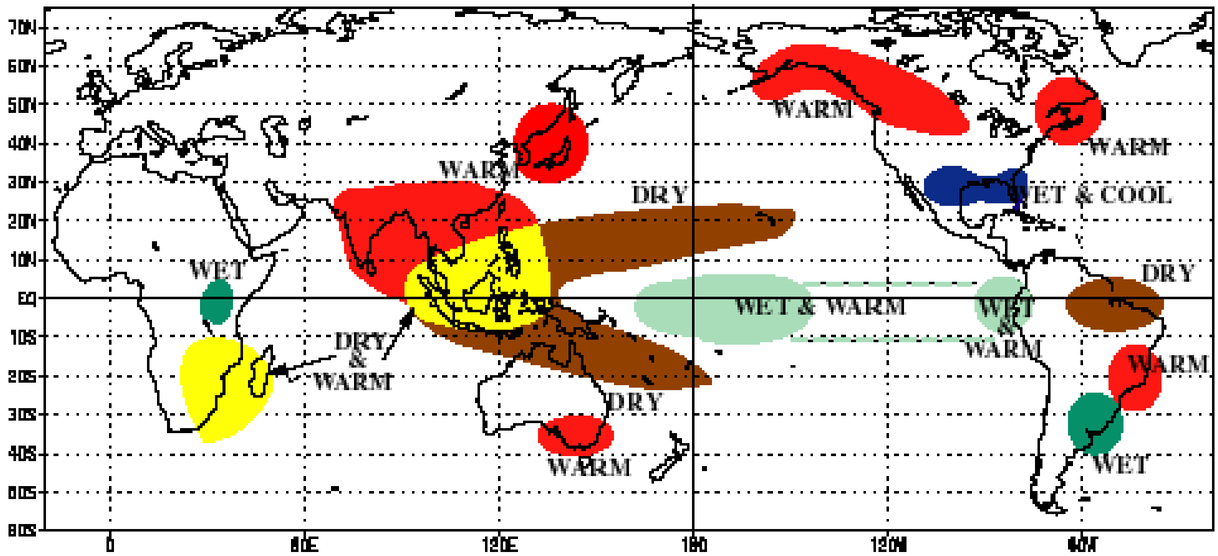


Figure 6: El Niño global weather effects

Source: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/impacts/warm.gif

LA NIÑA RELATIONSHIPS DECEMBER - FEBRUARY

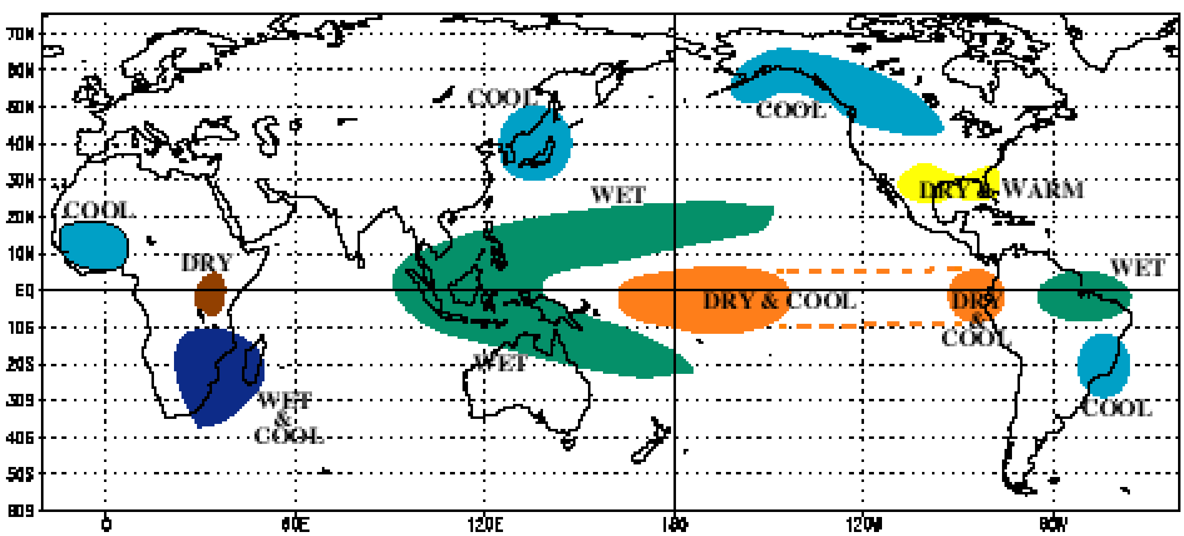


Figure 7: La Niña global weather effects

Source: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/impacts/cold.gif

Module 3, Investigation 1: Briefing 1
What are the effects of ENSO?

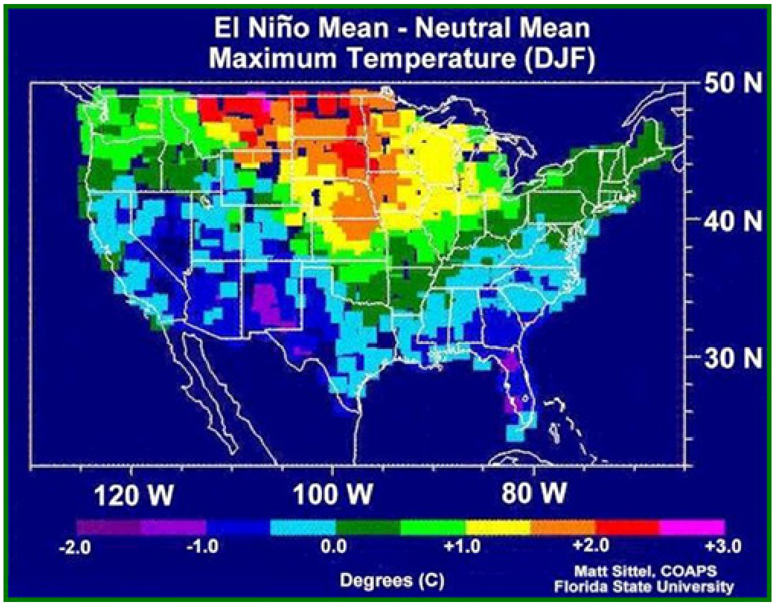


Figure 8: Temperature change during El Niño in the United States

Source: http://nsipp.gsfc.nasa.gov/enso/primer/englishprimer5.html

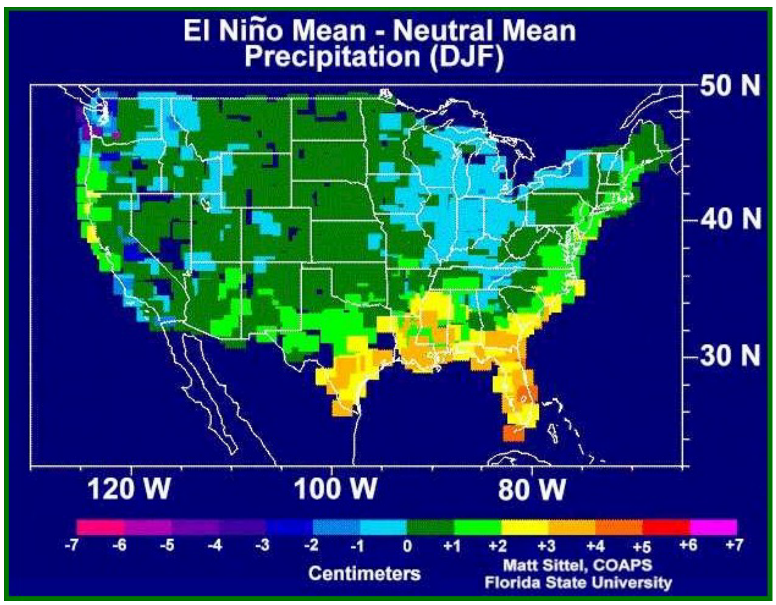


Figure 9: El Niño precipitation in the United States

Source: http://nsipp.gsfc.nasa.gov/enso/primer/englishprimer6.html

How does ENSO affect weather patterns in North America? During an El Niño, there is a tendency for higher than normal temperatures in western Canada and the upper plains of the United States. This is because the low-pressure system in the Pacific draws up warm air into Canada, some of which filters into the northern United States (Figure 8). Another low-pressure system draws cold moist air into the southern United States, bringing lower than normal temperatures.

The same low-pressure system in the southern United States is also responsible for increases in precipitation during an El Niño, especially in those areas close to the Gulf of Mexico (Figure 9).

<u>Answer Question 6 on the Log.</u>

Module 3, Investigation 1: Briefing 1
What are the effects of ENSO?

Part 4. How are human activities affected by ENSO?

ENSO has many effects on human activities. The economic impacts of the 1982-1983 El Niño, perhaps the strongest event in recorded history, are conservatively estimated to have exceeded $8 billion worldwide from droughts, fires, flooding, and hurricanes (Table 1). Virtually every continent was affected by this strong event. An estimated 1,000 to 2,000 deaths were blamed on El Niño and the disasters that accompanied it. In addition, the extreme drought in the Midwest Corn Belt of the United States during 1988 has been tentatively linked to the "cold event," or La Niña, of 1988 that followed the ENSO event of 1986-1987.

The effects of El Niño and La Niña vary according to the strength of the episodes and the geographic distribution of weather changes. Some areas experience heat waves and droughts, while others have torrential rains and flooding. These specific weather events occur within wet, dry, warm, and cool zones associated with the episodes (Figure 10).

Table 1: The costs of the 1982-83 El Niño

Event/Region	Cost
Flooding	
Bolivia	$ 300,000,000
Equador, Northern Peru	650,000,000
Cuba	170,000,000
U.S. Gulf States	1,270,000,000
Hurricanes	
Tahiti	$ 50,000.000
Hawaii	230,000,000
Drought/Fires	
Southern Africa	$1,000,000,000
Southern India, Sri Lanka	150,000,000
Philippines	450,000.000
Indonesia	500,000,000
Australia	2,500,000,000
Southern Peru, Western Bolivia	240,000,000
Mexico, Central America	600,000,000
Total	**$8,110,000,000**

Source: http://nsipp.gsfc.nasa.gov/enso/primer

Generalized Effects of El Niño

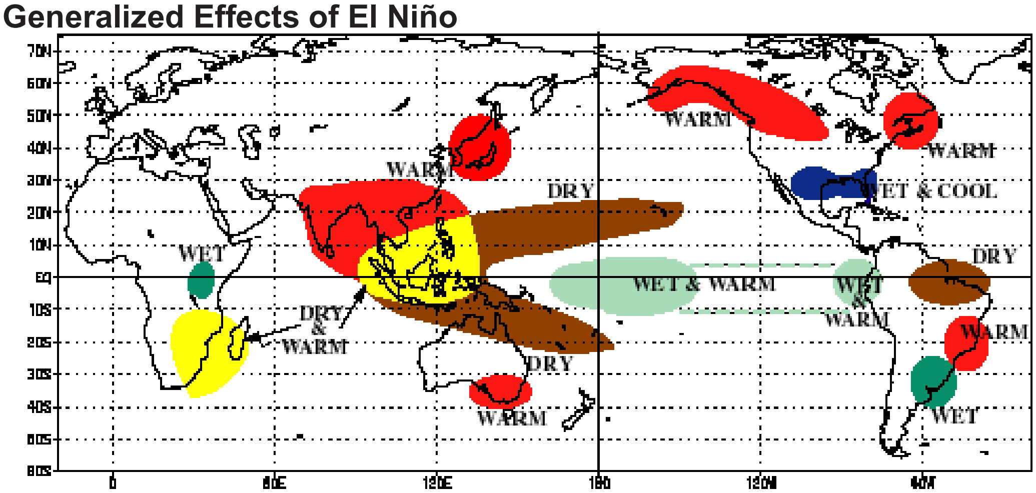


Figure 10: Generalized effects of El Niño

Source: http://globe.gsfc.nasa.gov/cgi-bin/show.cgi?l=en&b=g&rg=n&page=gallery-elnino-background.ht

Module 3, Investigation 1: Log 1
What are the effects of ENSO?

1. Why are the easterly trade winds key ingredients in ENSO?

2. What is the thermocline?

3. What are the indicators of a La Niña?

4. Why do you think ocean-based measurements are important?

5. Describe the different effects of El Niño and La Niña on each of the following regions:

   North America

   South America

   Africa

   Asia

   Southeast Asia

6. What are the El Niño temperature and precipitation predictions for your hometown?

Module 3, Investigation 1: Briefing 2

The ENSO game: Predicting and managing for El Niño and La Niña

Part 5. The ENSO game

How can prediction help avoid ENSO's tragic human consequences? Scientists from around the world are involved in forecasting, with computer models and sophisticated measurements, how ENSO affects various countries. These scientists are increasingly being asked by policy makers and political leaders to help them plan and manage for the effects of ENSO. In the ENSO game, you play the role of a policy maker in Peru. You must determine, based on information given to you by climate specialists, what sort of ENSO variation is occurring. Then you must decide how to allocate Peru's resources to manage for possible weather-related problems.

Background for the ENSO game

Long ago, Peruvians observed that the usually cool water along the Pacific coast of their country became warmer in some years. Because this happened around Christmas time, they called it El Niño, which means "Christ Child." Frequently, these warming spells were associated with increased rainfall and flooding within the country. Many times the flooding was disastrous. In fact, El Niño-related weather disasters in 1997-1998 led to massive flooding in the region, causing large negative economic effects and the loss of human life.

Peru provides a prime example of how even short-term El Niño forecasts can be valuable. There, as in most developing countries in the tropics, the economy (and food production in particular) is highly sensitive to climate fluctuations. Warm (El Niño) years tend to be unfavorable for fishing, and some of them have been marked by damaging floods along the coastal plain and in the western Andean foothills in the northern part of the country. Cold years are welcomed by fishermen, but not by farmers, because these years have frequently been marked by drought and crop failures. Peruvians have reason to be concerned, not only about El Niño events, but about both extremes of the El Niño cycle.

Peruvian planners have three primary concerns: agriculture, fishing, and disaster preparedness.

Agriculture—Since 1983, forecasts of the upcoming rainy season have been issued each November based on observations of water temperatures and upwelling in the tropical Pacific region. Once the forecast is issued, policy makers meet to decide on the best combination of crops to plant in order to get the best overall yield. Rice and cotton, two of the primary crops grown in northern Peru, are highly sensitive to the quantities and timing of rainfall. Rice thrives on wet conditions during the growing season. Cotton, with its deeper root system, can tolerate drier weather but cannot tolerate wet weather during the harvest season. Hence, a forecast of El Niño weather might induce farmers to plant more rice and less cotton than in a year without El Niño.

Fishing—Policy makers and fishermen also meet to decide how to manage for El Niño's effects on the fishing industry. El Niño is usually detrimental to Peru's coastal fisheries. Declines in coastal upwelling reduce the fish population. In addition, coastal flooding increases the amount of sediment in the water so that the fish either leave or die from unendurable water conditions. During El Niño years, the Peruvian fishing industry either reduces fishing or moves its fleets to the north or south to catch migrating fish as upwelling patterns shift away from the Peruvian coast.

Disaster preparedness—Policy makers meet with disaster preparedness teams to determine what weather-related problems associated with El Niño may occur. Usually, El Niño periods lead to intense rainfall and disastrous flooding and destruction of critical property such as roads, bridges, dams, and power lines—things referred to as **infrastructure**. Disaster teams need to prepare the country for this eventuality or the effects of flooding will create serious economic and social problems.

Data for the ENSO game

Climate specialists have submitted three key pieces of data to you in your role as a Peruvian planner and policy maker (Figures 11, 12, and 13). By interpreting these data correctly, you can determine whether an El Niño or a La Niña event is developing off the coast of Peru.

<u>Is an El Niño or a La Niña forming? Support your answer by referring to Figures 11, 12, and 13.</u> Write your answer to this question on the ENSO Game Log.

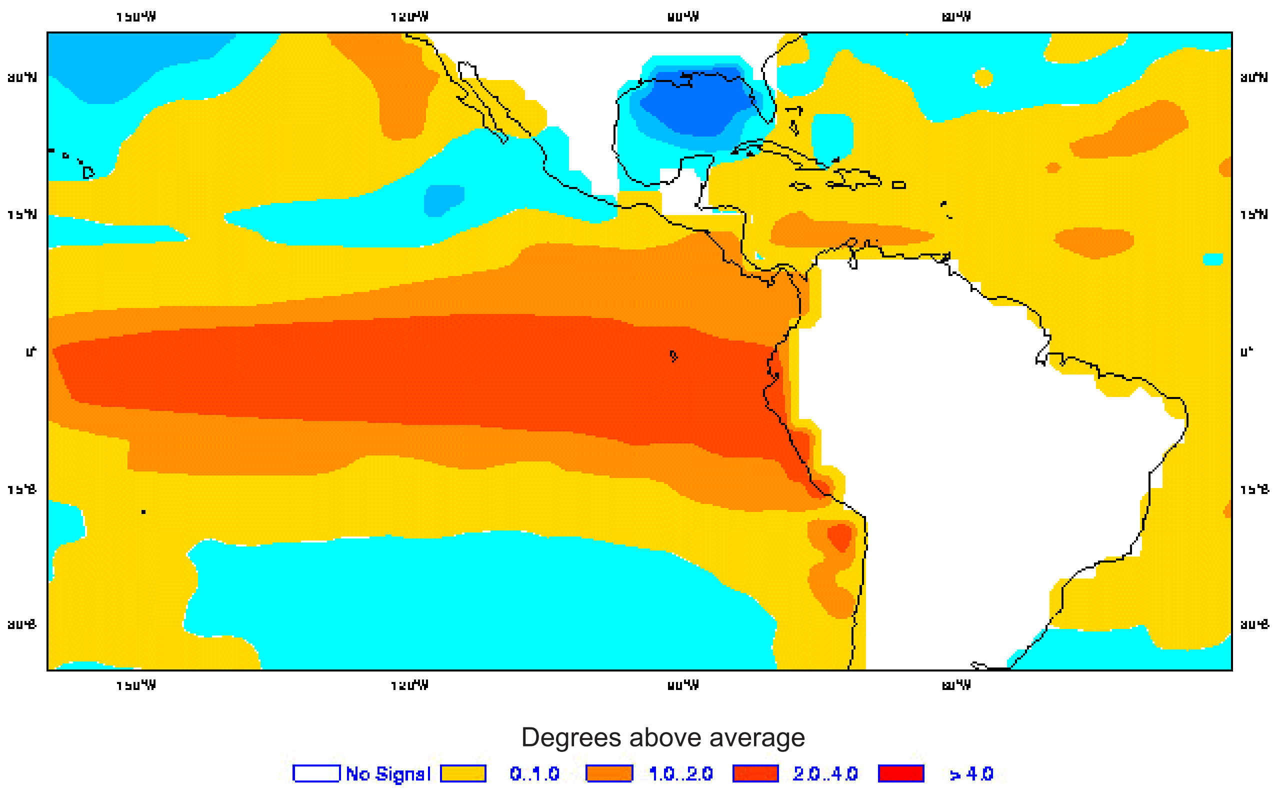


Figure 11: Average sea surface temperature anomalies (degrees above or below normal), measured in Celsius

Source: European Centre for Medium-Range Weather Forecasts (ECMWF) http://www.ecmwf.int/services/seasonal/forecast/index.jsp

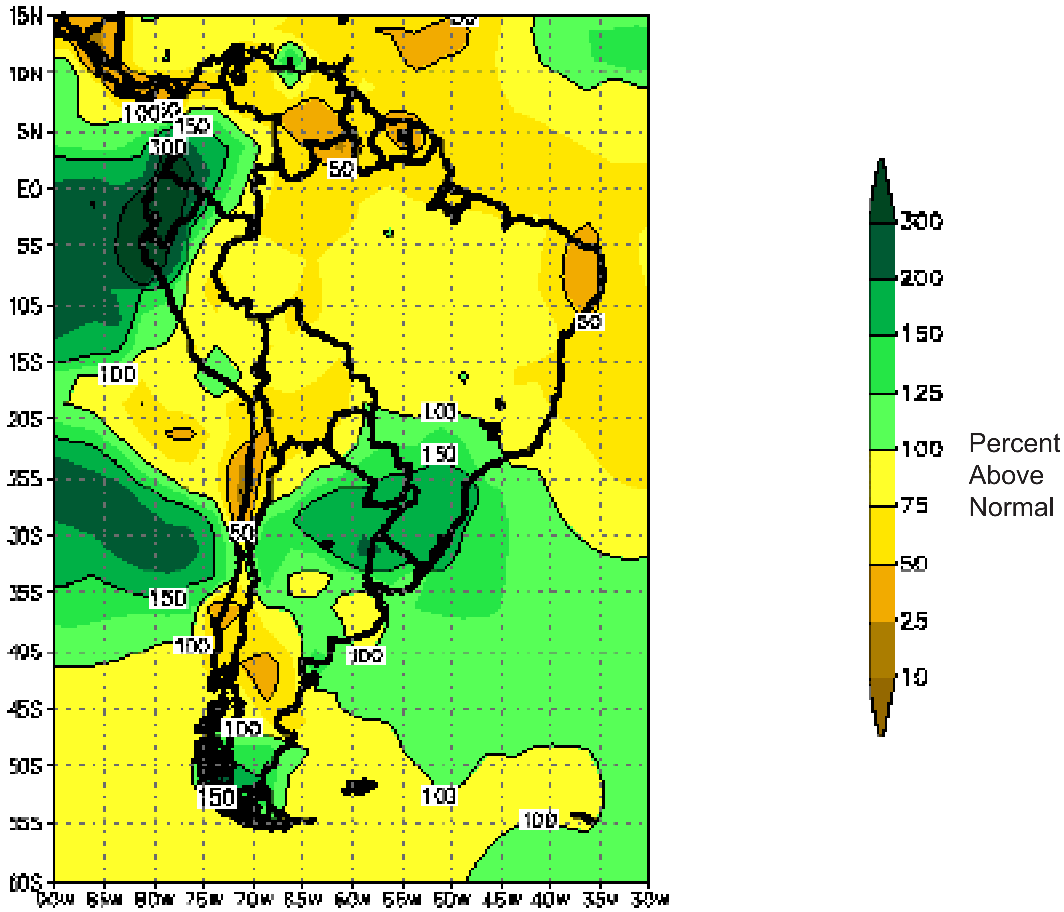
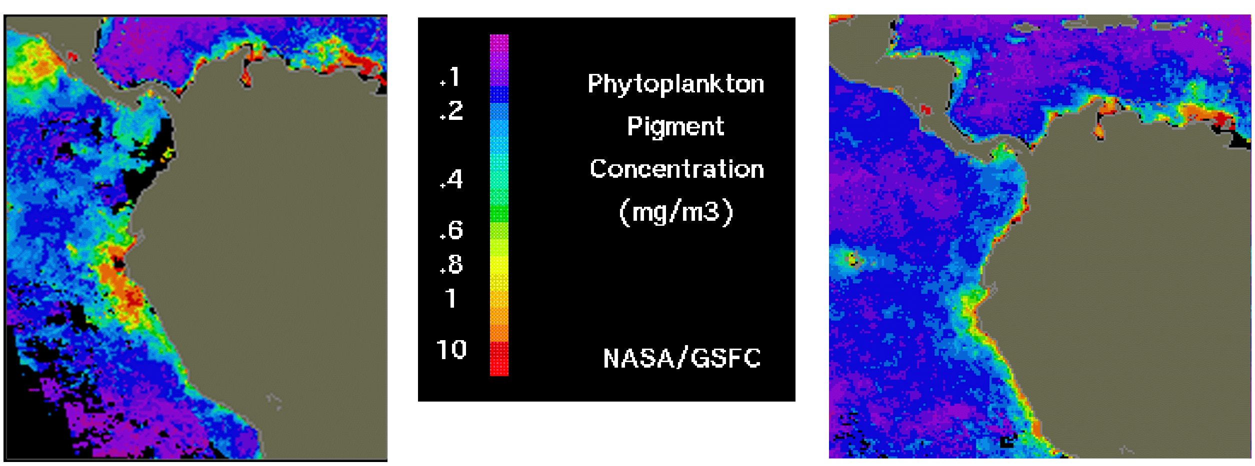


Figure 12: Precipitation forecast (percent above normal)

Source: International Research Institute for Climate Prediction (NOAA), http://iri.ldeo.columbia.edu/climate/forecasts/net_asmt/



Previous Year **This Year**

Figure 13: Upwelling

http://seawifs.gsfc.nasa.gov/SEAWIFS.html

Module 3, Investigation 1: Briefing 2
The ENSO game: Predicting and managing for El Niño and La Niña

Investments for the ENSO Game
Now that you have determined whether an El Niño or a La Niña is occurring, you need to decide how to allocate the resources you have, based on what is likely to happen. You will consider the effects of this event on agricultural productivity, the fishing industry, and weather-related damage to infrastructure.

The World Bank is lending Peru $200 million to invest in development efforts this year. The loan will fund efforts to improve agricultural productivity, the fishing industry, and infrastructure (flood management, highways, bridge supports, first aid, etc.). Based on the likelihood of an El Niño or a La Niña event, your investments will either contribute to the future prosperity of the country or result in disaster and economic decline. You have three categories to invest in, which are:

Agricultural Investments
A. Rice production
B. Cotton production

Fishing Industry Investments
A. More fishing boats and fishing production
B. Move the fleet north and south for the season
C. No investments in fishing this year

Disaster Preparedness Investments
A. Invest in disaster preparedness
B. No investments

You should allocate a total of $200 million on any combination of investments, based on your determination of whether the upcoming year will have an El Niño or a La Niña. Investments should be rounded up or down to the nearest $10 million.

Use the table on The ENSO Game Log to make your investments and then give your reasons for them.

To check on specific effects of El Niño, you can use the following Internet resources:

Indonesia
Resources at this site include forest fires, drought, and warm temperatures
http://www.ogp.noaa.gov/enso/asia.html#Fires

Southern Africa
Resources at these sites include famine and drought links
http://www.ogp.noaa.gov/enso/africa.html
http://enso.unl.edu/ndmc/enigma/elnino.htm
http://www.info.usaid.gov/fews/imagery/sat_nino.html#El Nino

Southeastern United States
Resources at these sites include flooding, cooler temperatures, and possible links to tornadoes
http://www.ogp.noaa.gov/enso/regional.html#Southeast
http://www.srh.noaa.gov/ftproot/sjt/HTML/science/elninosjt.html

California
http://twister.sfsu.edu/elnino/elnino.html

Module 3, Investigation 1: Log 2

The ENSO game: Predicting and managing for El Niño and La Niña

1. Is an El Niño or a La Niña forming? Support your answer by referring to Figures 11, 12, and 13.

2. Use this table to allocate a total of $200 million on any combination of investments. Make investments in increments of $10 million.

Investment Category	Amount $ millions	Multiplier	Outcome $ millions
Agriculture			
Rice			
Cotton			
Fishing			
More boats/production			
Move fleet north and south			
No investment			
Disaster Preparedness			
Invest			
No investment			
Totals	200		

3. Give your reasons for your investment decisions in the spaces provided below.

- Agricultural production
- Fishing industry
- Disaster preparedness infrastructure

The loss of stratospheric ozone: Where are people at risk?

Investigation Overview

In this investigation, students learn about the recent declines of ozone concentrations above Antarctica and the Arctic. These facts pose the risk that unusually high amounts of harmful ultraviolet radiation will reach Earth's surface and threaten life, especially in the high latitudes. Students learn how human actions have affected the natural geography of stratospheric ozone, they estimate populations at risk from ozone destruction, and they learn how international complications obstruct solutions to the problem.

Time required:

Beginning and Part 1: One to two 45-minute sessions
Part 2: One to two 45-minute sessions
Parts 3 and 4: Two to three 45-minute sessions
Parts 5 and 6: One to two 45-minute sessions (if time is short, these parts can be deleted)

Materials

A copy of the Briefing and Log for each student
World atlases
A current list of countries of the world and their populations. The *World Population Data Sheet*, published annually by the Population Reference Bureau, Inc., of Washington, D.C., is highly recommended: <http://www.prb.org>. Another source is the United Nations Population Division at <http://www.undp.org/popin/wdtrends/p98/fp98.htm>.
Computer with CD-ROM. The Mission Geography CD-ROM contains color graphics that are required to explain the materials.
Optional: Access to the Internet, which offers opportunities for extending this investigation

Content Preview

A rapid decline in stratospheric ozone over the Antarctic (the Ozone Hole) was discovered in the 1970s. This discovery alarmed the scientific community because the stratospheric ozone layer protects Earth from the Sun's deadly ultraviolet radiation. The destruction of ozone was attributed to the use of certain industrial chemical compounds, especially chlorofluorocarbons (CFCs), which for decades have been used for refrigeration and as the propellant in aerosol cans. This realization led to the signing of international agreements to cut back on CFC use and to seek substitutes for CFCs, but these agreements have not been universally honored. In the 1990s, scientists began to observe significant losses of stratospheric ozone over the Arctic. Since this region lies so close to very large concentrations of population, Arctic ozone loss poses a much more serious threat to humans than does Antarctic ozone loss.

Geography Standards

Standard 7: Physical Systems

The physical processes that shape the patterns of Earth's surface

- Describe how physical processes affect different regions of the United States and the world.

Standard 10: Human Systems

The characteristics, distribution, and complexity of Earth's cultural mosaics

- Compare the role that culture plays in incidents of cooperation and conflict in the present-day world.

Standard 14: Environment and Society

How human actions modify the physical environment

- Explain the global impacts of human changes in the physical environment.

Standard 15: Environment and Society

How physical systems affect human systems

- Analyze examples of changes in the physical environment that have reduced the capacity of the environment to support human activity.

Geography Skills

Skill Set 4: Analyzing Geographic Information

- Use the processes of analysis, synthesis, evaluation, and explanation to interpret geographic information from a variety of sources.

International solutions are complicated by the fact that the rich, industrialized, high-latitude countries in the Northern Hemisphere are more threatened than the poor, less developed, low-latitude countries. Because the poor low-latitude countries have fewer incentives to be concerned about the problem, they are more likely to continue the manufacture and use of CFCs because they are cheaper than more advanced substitutes. Perhaps only the transfer of hundreds of millions of dollars of technology from the rich high-latitude countries to the poor low-latitude countries will be able to stop the manufacture and use of these chemical compounds. In any event, it will take many years for the destructive compounds that are already in the atmosphere to disappear.

Classroom Procedures

Beginning the Investigation

1. Distribute copies of the **Briefing** and the **Log** to each student or, if you wish, to pairs (students can work through this investigation individually, but it is recommended that they work in pairs or small groups).
   - Leaf through these materials with students, and call attention to the questions they should answer in the Log.
   - Point out the **Glossary** at the end of the Briefing.

2. Explain that all ozone is the same (O_3, a gas molecule with three oxygen atoms), but ozone is "good" in one place (the upper atmosphere or stratosphere), but "bad" in another place (lower atmosphere, called the troposphere, especially in the air around cities).
   - Tell students that high ozone levels, which contribute to air pollution in cities like Los Angeles, Denver, and Phoenix, is an interesting geographic topic but one that is not the focus of this investigation.
   - Instead, this investigation looks at the problem of the loss of ozone in the stratosphere.

3. Have students read (silently or aloud) the **Background** and **Objectives** in the **Briefing**. Assist them with any questions they may have, and initiate a discussion about the problem. For example, ask students:
   - Have you heard of the hole in the ozone layer?
   - What do you know about it?
   - How does the loss of ozone affect life on Earth?
   - What parts of the Earth are likely to be most affected?

Developing the Investigation

4. Direct students to **Part 1: What is NASA's SOLVE project?** Students should work together to answer Log Questions 1-7, which are based on the two readings in the **Briefing**.
   - **Table 1: Ozone time-line** should help students develop a historical perspective on this problem.
   - Have students use atlases to find the latitude and longitude of Kiruna, Sweden (Log Question 1).

5. **Part 2: What is the natural geography of ozone?** requires careful study to answer Log Questions 8-13. (Although the material is not highly technical, you may wish to work with a science/chemistry educator.)

   - You should clarify that, although this "natural geography" deals with natural processes, the heart of this problem is that *human influences have modified the natural geography.*

   - Use the eight steps below to help students understand how people have influenced the natural geography of stratospheric ozone:

     Step 1. Ozone-destroying chemicals, such as chlorine and bromine, are manufactured for industrial purposes and are released by the actions of people. The release can come from actions as innocent as replacing refrigerants on a car air conditioner or hauling an old refrigerator to a dump.

     Step 2. These ozone destroyers float up through the lower atmosphere (troposphere) and into the stratosphere.

     Step 3. The ozone-destroying chemicals float around the stratosphere and reach the areas above the North Pole and South Pole.

     Step 4. Winter comes. There is no sunlight in a polar winter, which causes very low temperatures. A special type of cloud, a polar stratospheric cloud, forms in the very cold air.

Step 5. Polar stratospheric clouds change the ozone-destroying chemicals into another chemical during the long polar night during winter. This chemical is bad because when the sunlight strikes it, chlorine is released. The polar stratospheric clouds also lock away a natural agent (nitric acid) that protects ozone.

Step 6. When the spring comes (March over the North Pole, September over the South Pole), these dangerous forms of ozone-destroying chemicals are touched by sunlight, which releases chlorine (Cl).

Step 7. Each atom of chlorine destroys approximately 1,000 molecules of ozone! Eventually, the chlorine is neutralized by other chemical reactions. But a lot of destruction occurs in a short period of time each polar spring.

Step 8. The ozone-depleted air over the poles spreads towards the equator. For example, the Antarctic "ozone hole" in the stratosphere moves toward Argentina and Chile, New Zealand, and Australia. The Arctic "ozone reduction" moves toward Alaska, Canada, northern Europe, and northern Asia.

- Point out to students that there are natural processes that can destroy stratospheric ozone, including volcanoes and burning of plants. A common assumption among scientists is that the natural processes of ozone destruction were balanced by the natural processes of ozone creation for the many years that humans did not have refrigerators and air conditioning.
- Unfortunately, we do not have any record of ozone levels before the 1950s. The best records are from the 1980s to today, as measured by NASA satellites. These records show a great decline in stratospheric ozone each polar spring. And the decline gets worse each year.
- So we are left with a problem: we know that our chemicals destroy ozone. We do not know if there were past natural changes that could also cause this type of destruction.
- Some in industry argue that this uncertainty means that we should not act prematurely to ban low-cost refrigeration systems and move to high-cost substitutes.
- Others argue that we can't afford to wait. We know that it takes decades for the chlorine we release today to destroy the ozone and fall out of the atmosphere.

6. **Part 3** provides a partial list of effects of ozone destruction.
   - Direct class discussion of these effects and to students' answers to Log Question 14: What do you think are the two most serious effects of stratospheric ozone depletion and why?
   - Following the discussion, students should write their own answers to Question 14 in the **Log**.
7. **Part 4: Where are the largest populations at risk?** asks students to estimate populations at risk from stratospheric ozone depletion. The purpose is to have students discover that the potential risk to humans is much more serious in the Northern than in the Southern Hemisphere.
   - To complete Table 3 (Log Question 15), students will need world atlases, and you will need to provide a recent list of countries and their populations (see Materials/Resources). Alternatively, direct students to the library or Internet to find this information.
   - Estimation methods and assumptions are listed in the **Briefing**. These methods and assumptions are arbitrary—they were designed only to facilitate this student activity. Note that, following Table 3, students are asked to critique these methods and assumptions.
   - The Log key to Table 3 lists only countries in the Northern Hemisphere because no Southern Hemisphere countries qualify under the assumption that more than half of a country's area must lie at 50 degrees or more of latitude. Students will discover that, excluding uninhabited Antarctica, the only land area south of 50 degrees S is the southern tip of South America—small parts of Argentina and Chile that are virtually uninhabited.

Concluding the Investigation

8. If time is short, the investigation can be concluded at the end of Part 4. Students will have learned about the physical and human processes contributing to the depletion of stratospheric ozone, the potential risks to life, and the basic geographic dimensions of the problem. If you decide to conclude here, use the Log key to debrief student responses.

9. Alternatively, it is recommended that you extend the investigation by adding the important political geographic perspective contained in **Parts 5 and 6**.

10. Have students read silently or aloud **Parts 5 and 6**.
    - You may want to download and print in advance a copy of the Montreal Protocol, since students may want to see the details of political arrangement. The Montreal Protocol can be found at <http://www.unep.org/mont_t.shtml>.
    - To provide more information, you may wish to have students access a web site giving up-to-date information on the status of the ozone layer at <http://jwocky.gsfc.nasa.gov/ozone/today.html>.

11. Put students into an even number of small groups, with three to five students in each.
    - These groups should prepare to make presentations at a meeting of the Executive Committee of the Multilateral Fund for the Montreal Protocol.
    - The ECMF is the international body that was established to help LDCs reduce their use of ozone-destroying chemicals.
    - See 12 and 13, below.

12. Assign *half* of the small groups to role-play high-latitude, rich industrialized countries (MDCs), such as Germany, United Kingdom, Sweden, Canada, or the United States.
    - Encourage these groups to develop the positions and arguments they should make, based upon their understanding of the geopolitics of stratospheric ozone. If necessary, lead them to the following:
    - Groups playing the MDCs should prepare to support the position that lower latitude countries *should work* to avoid ozone destruction.
    - Their goal should be to convince the low-latitude LDCs that they should implement new restrictions on the manufacturing and use of compounds that destroy stratospheric ozone.

13. Assign the *other half* of the small groups to role-play low-latitude poor developing countries (LDCs), such as India, China, Brazil, Indonesia, or Nigeria.
    - Encourage these groups to develop the positions and arguments they should make, based upon their understanding of the geopolitics of stratospheric ozone. If necessary, lead them to the following:
    - Groups playing the LDCs should prepare to support the position that lower latitude countries *should not work* to avoid ozone destruction.
    - Their goal is to convince their fellow developing countries to not rush too fast into new and expensive restrictions on the manufacturing and use of compounds that destroy stratospheric ozone.

14. Establish a time schedule for presentations by each of the groups. You may wish to structure presentations using a conventional debate format (e.g., with rebuttals, etc.) or simply allow each of the groups to have equal time to make their arguments and offer their resolutions.

    The following are points to look for from the LDC groups:
    - The ozone layer is made in the stratosphere over our low-latitude countries, and it is not being depleted over our countries.
    - Developed nations want us to stop using the inexpensive chemicals that now go into our refrigerators and pesticides, but
    - Who is going to pay for new refrigerators?
    - Who is going to give us a substitute for the methyl bromide pesticide that has been so good at increasing the yield of our crops?
    - It is the rich industrialized countries that have put most of the ozone-destroying chemicals into the atmosphere.
    - Unlike the poor low-latitude countries, the high-latitude countries have the wealth to cope with the ozone problem.
    - If the rich countries want the poor countries to stop using ozone-destroying chemicals, the rich countries should pay the poor countries for the new chemicals and new equipment that would substitute for the old ozone-destroying compounds.
    - In any event, the breakdown of the ozone layer may be occurring naturally. Science is not absolutely certain on this point.
    - So why make our people change from cheap refrigerants and air conditioning until we learn more about natural variability in the ozone layer?
    - Low-latitude countries might put up a resolution such as: Resolved: that we agree to ban the manufacturing and use of all ozone-destroying chemicals when the high-latitude countries agree to replace all facilities and machines that produce and use ozone-destroying chemicals.

The following points could be made by the MDC groups:

- The ozone layer shields us from harmful ultraviolet radiation.
- The world's use of ozone-destroying chemicals is the main cause of stratospheric ozone depletion.
- Ozone depletion is taking place over the high-latitude countries; thus, it is life in these countries that faces the greatest threat from increased UV radiation.
- Earth's ozone layer has existed for billions of years in a balance between natural breakdown and natural creation.
- We can't afford to take the chance that recently observed ozone changes are nothing more than natural variability. If we wait to take action to stop the use of ozone-destroying compounds, it will take decades for the chlorine we make today to fall out of the stratosphere.
- An example of a resolution that might be offered by a rich, high-latitude country is: Resolved: that we agree to crack down on the illegal use of ozone-destroying chemicals.

15. Debrief the presentations by having students critique the arguments and resolutions made by the small groups.

Evaluation

Log

1. The latitude and longitude of Kiruna, Sweden, is
67.49°N and 20.08°E.

2. Complete this sentence: The purpose of the SOLVE project is to:
*Understand exactly why so much **ozone** disappears above the North Pole in winter and when that ozone layer might recover.*

3. What is the significance of the stratospheric ozone layer to life on Earth?
*The ozone layer of the atmosphere protects Earth below from **ultraviolet radiation** from the Sun. Too much UV radiation reaching the planet's surface can burn skin, cause cataracts, kill living cells, and harm crops.*

4. Complete this sentence: The major observation of the SOLVE project during the winter of 1999-2000 was that:
In some parts of the Arctic stratosphere—located from about 16 kilometers to 48 kilometers above Earth—ozone concentrations declined as much as 60 percent from November 1999 through March 2000.

5. Complete this sentence: According to SOLVE project scientists, the significant decline in ozone over the Arctic in the winter of 1999-2000 was caused by:
An increase in the area and longevity of polar stratospheric clouds (PSCs).

6. What are polar stratospheric clouds (PSCs)?
PSCs, which are made up of ice and nitric acid, form about 21 kilometers (13 miles) above the poles where winter temperatures can drop to -93°C (-110°F) and below.

7. What is the role of PSCs in the destruction of stratospheric ozone?
PSCs are hosts to the chemical reactions that destroy ozone. Chlorine and bromine atoms in the stratosphere attach to the ice crystals of the PSCs. Sunlight on the PSCs in late winter and early spring causes reactions that change these atoms into a form that destroys ozone. One chlorine or bromine atom can destroy thousands of ozone molecules.

8. According to Figure 2, where has the most stratospheric ozone been depleted, over the Arctic or Antarctic?
Antarctic

9. Where are the lowest temperatures, over the Arctic or Antarctic?
Antarctic

10. Where would you expect to find the most and longest lasting PSCs, over the Arctic or Antarctic?
Antarctic

11. Explain your answer to Question 10.
The coldest temperatures are over the Antarctic, and so the most and longest lasting PSCs will form where the temperatures are the coldest.

12. In which hemisphere, the Northern or Southern, would stratospheric ozone depletion affect the most people?
The Northern Hemisphere

13. Explain your answer to Question 12.
The Northern Hemisphere has much larger populations at high latitudes than does the Southern Hemisphere, so one would expect Arctic ozone depletion to affect more people than Antarctic depletion.

14. What do you think are the two most serious effects of stratospheric ozone depletion and why?
Since this question asks for an opinion, there is no one correct answer. However, a useful discussion can be based on student opinions. Possible answers include:
- *increases in skin cancers, cataracts and blindness, and infections; and*
- *decreases in life in northern lakes, food production, tree growth, and ocean phytoplankton that make oxygen.*

15. Complete Table 3 and write your critique in the space provided below.

Table 3: Estimated populations at risk from stratospheric ozone depletion in the Northern Hemisphere a

Country[b]	Population (millions)
Russia	145.2
Germany	82.1
United Kingdom	59.8
Poland	38.6
Canada	30.8
Netherlands	15.9
Belgium	10.2
Belarus	10.0
Sweden	8.9
Denmark	5.3
Finland	5.2
Norway	4.5
Ireland	3.8
Lithuania	3.7
Latvia	2.4
Estonia	1.4
Iceland	0.3
TOTAL	428.1

[a.] Populations at risk are assumed to lie at 50 degrees or more of latitude.
[b.] These estimates come from the following rule: Countries listed have more than half of their areas lying at more than 50 degrees. For example, less than half of France but more than half of Germany lie north of 50 degrees. Thus, France should not be listed, but Germany should be. Population numbers come from Population Reference Bureau. *2000 World Population Data Sheet.* Washington, D.C.: Population Reference Bureau, http://www.prb.org.
NOTE: No Southern Hemisphere countries qualify for inclusion under the above criteria.

In the space below, critique the above method of estimating and describe what you think might be a more accurate method.
In their critiques, students might make the following points:
- *The 50 degrees or higher assumption is arbitrary: Ozone depletion may affect countries and areas lower in latitude than 50 degrees, depending upon variations in atmospheric circulation.*
- *The assumption that populations are distributed evenly over a country's area is hard to defend, given that populations are typically clustered into urban areas; also population density varies regionally within a country. Population estimation would be more accurate if it were based on the actual distribution of populations.*

Module 3, Investigation 2: Briefing

The loss of stratospheric ozone: Where are lives at risk?

Background

Have you heard of the ozone hole? In the 1970s, scientists began noticing a hole developing in the stratospheric ozone layer high above Antarctica. Scientists attributed the ozone destruction to human action. This alarmed them because the ozone layer protects Earth against harmful amounts of ultraviolet radiation. Life on Earth could be threatened if too much ozone is destroyed. The Antarctic ozone hole puts the health of populations in the Southern Hemisphere at risk. In 1986, a similar hole was identified over the Arctic Ocean, which meant that the much larger populations in the Northern Hemisphere might be at risk. Observations by the NASA SOLVE project showed a decline in Arctic ozone in the winter of 1999-2000. How were these discoveries made? What human actions are to blame? What are the risks to human populations? How many lives are at risk? Will countries cooperate to halt ozone destruction? These are some of the questions raised in this investigation.

Objectives

In this investigation, you will

- learn how, where, and why stratospheric ozone is made and destroyed;
- learn about the effects of the loss of stratospheric ozone;
- estimate the size of the populations at risk from ozone depletion; and
- learn why there is an international debate about the problem of stratospheric ozone.

Part 1: What is NASA's SOLVE project?

To answer this question, study the following two readings, a newspaper article and a NASA news release, and <u>answer Questions 1-7 on the Log</u>.

PROJECT SEEKS KEYS TO OZONE HOLE, REGROWTH

By Katy Human

More than 300 scientists from around the world spent most of December 1999 in Kiruna, Sweden, collecting data for a scientific mission called SOLVE.

goal: to understand exactly why so much **ozone** [words in bold print are defined in the glossary at the end of this investigation] disappears above the North Pole in winter, and when that ozone layer might recover.

They're flying airplanes high into the atmosphere to collect data, sending up balloons bearing instruments, and collecting data from ground-based devices.

The chemical, ozone, is vital for life. The ozone layer of the atmosphere protects the Earth below from **ultraviolet radiation**. UV radiation, when it reaches the planet's surface, burns skin, causes cataracts, and can kill a living cell and harm crops.

"UV radiation is the bad boy in the whole story here," said Paul Newman, an atmospheric physicist at NASA's Goddard Space Flight Center in Greenbelt, Maryland, and a SOLVE scientist. Newman said, "And because ozone screens UV radiation, we have to understand how ozone might change in the future and what affects it today."

A better understanding of ozone layer dynamics could also help industry design products more intelligently.

"If we create a new chemical, what's the impact on ozone?" Newman asked. "If we fly airplanes higher into the **stratosphere**, what's the effect of that?"

In Kiruna, David Fahey, an atmospheric researcher with NOAA, said "winter is taken very seriously up here." He and his colleagues have long taken winter seriously, because that's when the chilly air above the poles sets the scene for ozone destruction.

Winter winds keep a **vortex** of cold air trapped above the North Pole, creating a virtual cauldron in which all the ingredients essential to ozone destruction can mix. **Chlorine** and **bromine**, with numerous industrial uses, are among the most important.

Module 3, Investigation 2: Briefing

The loss of stratospheric ozone: Where are lives at risk?

"One chlorine atom in the stratosphere can destroy thousands of ozone molecules. Bromine is even more effective," said Rick Shetter, an atmospheric scientist from the National Center for Atmospheric Research in Boulder, Colorado.

Industries once used chlorine- and bromine-containing chemicals almost indiscriminately, because no one knew what they might do to the atmosphere. But in the 1980s, researchers realized that the pollutants not only destroy ozone, they have a long life span in the stratosphere, once they drifted there. They might wreak havoc on ozone for decades, even if industry were to shift immediately to alternative chemicals. [See Table 1 for a timeline of ozone developments.]

In 1997, the United States signed the Montreal Protocol on Substances that Deplete the Ozone. Many nations have phased out and even eliminated the use of chemicals that destroy the ozone layer. [See Table 2 for a list of ozone-destroying chemicals.]

But Fahey says ozone is still in danger. "The active agent, the perpetrator, has been contained, but that doesn't mean ozone has recovered," he said. "It's like a fire: First you keep it from spreading, but then you have to wait for it to burn itself out." It'll be at least 2050 before the severely depleted Antarctic's ozone layer returns to its 1980 thickness, Fahey estimated.

Table 1: Ozone time-line

1928

- Thomas Midgely produced a chemical compound called CFC-12 (dichlorodifluoromethane) to serve as a replacement for the highly toxic and flammable refrigerants such as ammonia.

1930s

- Dupont and General Motors began to market CFCs under the trade name Freon. Since then, other CFCs have been synthesized and produced in large quantities. CFCs have been extensively used in refrigerators and as propellants in aerosol cans.

1960s

- Recognition that O_3 was naturally low over Antarctic.

1970s

- Discovery of curious "hole" in ozone layer over Antarctica, a seasonal thinning of the layer occurring in early spring, reaching a minimum in October.
- United States issues ban on CFCs.

1980s

- Studies of SOL (stratospheric ozone layer) indicated substantial decline in total global ozone—8 percent decline from 1979-1987.
- Landmark paper in *Nature* by Farman, Gardiner, and Shanklin of the British Antarctic Survey showed that O_3 was disappearing over Antarctic during the southern hemisphere spring.
- Vienna Conference convened by United Nations Environment Programme (UNEP)—43 countries brought forth the Vienna Convention for the Protection of the Ozone Layer.
- Corresponding to the Antarctic hole, a hole was identified over the Arctic Ocean in February (maximum thinning at both poles matches the time of lowest surface temperatures).
- Scientists agreed that a serious and persistent global decrease was in progress at a rate far faster than what had been previously predicted.
- Twenty-three countries endorsed the UNEP plan for cutting global CFC consumption by 50 percent by 1999.
- In an agreement known as the Montreal Protocol, the United States joined 31 other countries in approving a similar goal.
- Airborne Arctic Stratospheric Expedition (AASE-I) found high concentrations of chlorine monoxide inside the Arctic vortex, suggesting that significant ozone depletion could occur during the Arctic spring. Several studies calculated and deduced ozone losses based on these observations.

1990s

- Slight increase in UVR—about 1 percent/year over preceding 8 years—had been documented at an observing station in the Swiss Alps at an altitude of 3600 meters (12,000 feet).
- Montreal Protocol was expanded and strengthened to a goal of 50 percent reduction of CFCs by 1995 and 85 percent by 1997.
- With the Upper Atmosphere Research Satellite (UARS), the AASE-II, and the European Arctic Stratospheric Ozone Experiment (EASOE), the Arctic winter of 1991-1992 was studied extensively. A number of researchers deduced various ozone loss rates inside the Arctic vortex.
- 1995-1996 was the first winter to show very large ozone losses and a polar ozone low in the Arctic that was very similar to the one observed over Antarctica each year.
- March 1997 Arctic ozone amounts were the lowest on record for the previous 20 years of observations.
- United States signed the Montreal Protocol on Substances that Deplete the Ozone.

2000s

- NASA's SOLVE project finds a significant decline in stratospheric ozone over the Arctic caused by an increase in the area and duration of polar stratospheric clouds (PSCs).
- Next global ozone report scheduled for 2002: UNEP publishes ozone report every four years.
- 2050 is the year it is estimated that the severely depleted Antarctic ozone layer will return to its 1980 thickness.

SOLVE researchers are not only trying to put numbers on all the chemical reactions that lead to ozone depletion; they're also trying to understand a dangerous new player in the ozone depletion game up north.

In recent years, though the Earth's surface appears to have warmed slightly, the stratosphere has cooled. Those cold temperatures let a particular type of cloud form—polar stratospheric clouds. These clouds are host to the chemical reactions that deplete ozone. [Human, Katy. 2000. [Boulder, CO] *Daily Camera*, Jan. 29, pp. 1A, 4A.]

ARCTIC OZONE DEPLETION LINKED TO LONGEVITY OF POLAR STRATOSPHERIC CLOUDS

NASA Press Release 00-43, May 30, 2000

A significant decline in ozone over the Arctic last winter was due to an increase in the area and longevity of **polar stratospheric clouds** (PSCs), according to a group of researchers who participated in a large, international atmospheric science campaign.

The ozone-destroying clouds are made of ice and **nitric acid**, said University of Colorado at Boulder Professor Owen B. Toon, one of five project scientists heading up NASA's SAGE III Ozone Loss and Validation Experiment, or SOLVE. The massive SOLVE project involved satellites, aircraft, balloons and ground-based instruments operated from December 1999 through March 2000 by more than 200 scientists and support staff from the United States, Canada, Europe, Russia, and Japan.

"Even very small numbers of particles in PSCs can efficiently remove **nitrogen** from the stratosphere," said Eric Jensen, a scientist at NASA Ames Research Center, located in California's Silicon Valley. "We found that the clouds lasted longer during the 1999-2000 winter than during past winters, allowing greater ozone depletion over the Arctic."

"Polar stratospheric clouds generally form about 13 miles above the poles where temperatures can drop to minus 110 degrees Fahrenheit and below," said Toon. The SOLVE campaign was staged out of Kiruna, Sweden.

In some parts of the Arctic stratosphere—which is located from about 10 miles to 30 miles above Earth—ozone concentrations declined as much as 60 percent from November 1999 through March 2000. The fragile stratospheric ozone layer shields life on Earth from the harmful effects of ultraviolet radiation.

Although seasonal ozone loss is more severe in the Antarctic, the ozone loss in the Arctic presents potentially more serious health problems to human beings, said Toon. Ozone-depleted air from the Arctic drifts south toward North America, Europe, and Russia each spring, increasing the amounts of ultraviolet light reaching Earth's surface in the highly populated mid-latitudes and potentially causing increases in several types of cancer.

Most chlorine compounds pumped into Earth's atmosphere in recent decades by human activity initially were tied up as chlorine nitrate or hydrochloric acid, both of which are nonreactive. But if there is a surface area to attach to, like the polar stratospheric cloud ice crystals, the chlorine compounds change into ozone-gobbling chlorine radicals in late winter and early spring after reacting with sunlight.

The greenhouse effect, which warms Earth near its surface, may ironically be cooling the stratosphere enough to cause these clouds to form earlier and persist longer. Greenhouse gases are radiating energy and heat away from the upper stratosphere, creating prime conditions for polar stratospheric cloud formation.

"With the clouds persisting longer, we are seeing greater ozone losses even though the amount of chlorine in the atmosphere has declined slightly," said Toon. Manufacture of **chlorofluorocarbons** [CFCs] ceased in 1996 in signatory countries under the terms of the Montreal Protocol and its amendments (NASA 2000).

Module 3, Investigation 2: Briefing

The loss of stratospheric ozone: Where are lives at risk?

Ozone-destroying chemicals that contain chlorine and bromine are released by the action of people. The release can come from actions as innocent as replacing refrigerants in a car air conditioner or hauling an old refrigerator to a dump (Table 2).

Part 2. What is the natural geography of ozone?

Is ozone good or bad? The answer to that question is fundamentally geographic: It depends on *where* it is. Ozone is the same molecule (O_3 or 3 oxygens) no matter where it is found, but we don't like the "bad ozone" in the lower atmosphere (**troposphere**), and we are worried about the loss of "good ozone" in the upper atmosphere (**stratosphere**).

- The ozone close to the surface (in the troposphere) causes air pollution in our cities. Ozone air pollution is harmful to our health.
- But the stratospheric ozone is good. Stratospheric ozone absorbs a lot of the harmful ultraviolet solar radiation. Without stratospheric ozone, life as we know it would not be possible on Earth.

There are three keys to understanding the natural geography of stratospheric ozone (Figure 1):

1. The oxygen that we breath (O_2) is hit by the intense sunlight in the tropics, including the intense ultraviolet radiation.

2. The ultraviolet sunlight in the stratosphere (10-50 kilometers above the surface) hitting the O_2 makes O_3 over the tropics.

3. The O_3 surplus over the tropics is moved all over the planet by winds to provide a global ozone layer.

Table 2: Ozone-destroying chemicals

Chemicals	Uses and Sources
Chlorofluorocarbons (CFCs)	Refrigerators, air conditioners, aerosol sprays, fire extinguishers
Halons	Fire suppression
Methyl bromide	Pesticide and natural ocean release
Sulfate aerosols	From natural volcanoes
Methyl chloride	From natural and human-made savanna fires

Module 3, Investigation 2: Briefing

The loss of stratospheric ozone: Where are lives at risk?

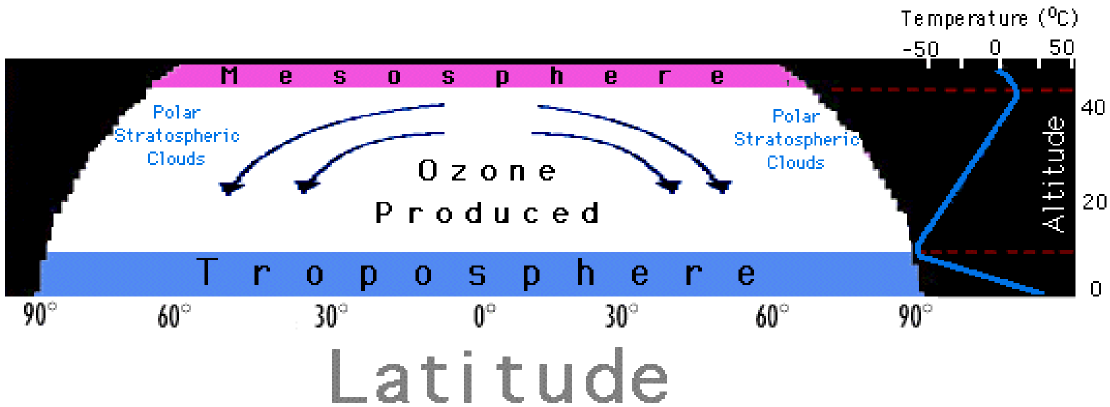


Figure 1: Ozone is produced over the tropics in the stratosphere. Winds then distribute the ozone to higher latitudes.

Use Figure 2 to find out how the geography of the ozone layer over the Antarctic and Arctic has changed in the last two decades.

<u>Answer Questions 8-13 on the Log.</u>

You can see how important ozone is by examining the temperature curve on the right of Figure 1. In the troposphere, the source of heat comes only indirectly from the Sun. The Sun first heats up Earth, and then Earth heats up the troposphere. So the farther you go from Earth, the colder it gets. Temperatures rise in the stratosphere because the ozone layer absorbs harmful ultraviolet radiation. The process of absorbing the ultraviolet radiation heats up the stratosphere.

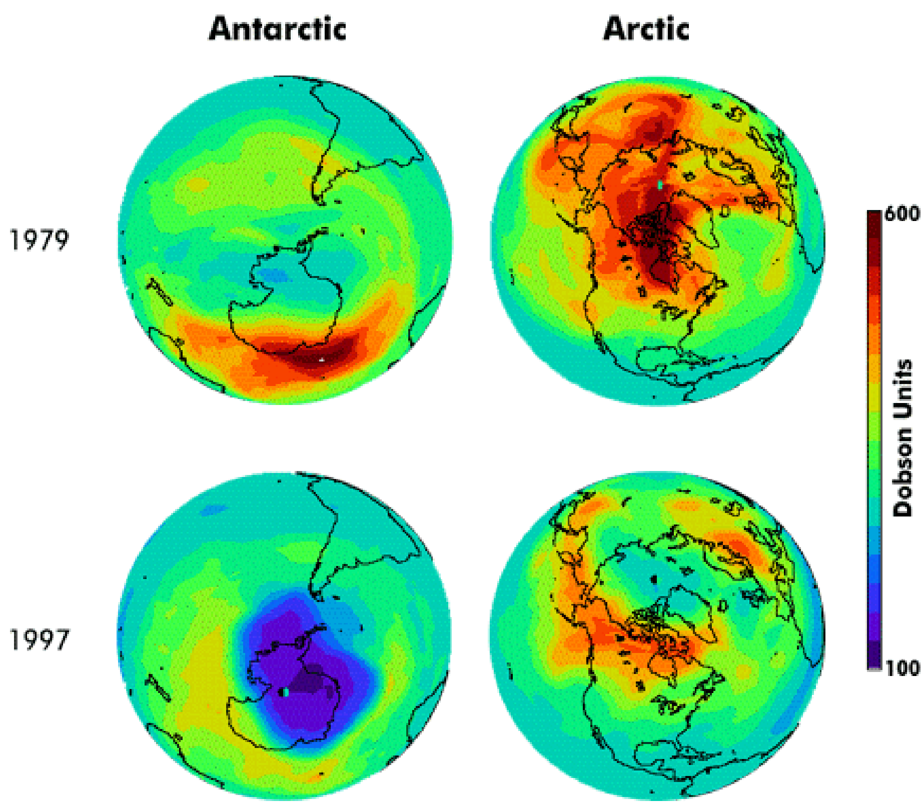


Figure 2: Polar ozone depletion over an 18-year period as measured by NASA's Total Ozone Mapping Spectrometer (TOMS). Red indicates high-ozone amounts; blue indicates low ozone.

Source: http://eos-chem.gsfc.nasa.gov/science.html

Module 3, Investigation 2: Briefing

The loss of stratospheric ozone: Where are lives at risk?

If you're thinking that ozone destruction in the high latitudes relates to the fact that it's cold near the poles, you're absolutely right! During the Southern Hemisphere's winter, air can reach temperatures colder than -90°C near the South Pole. In the Northern Hemisphere winter, the lowest temperatures reach about -65°C. As a result of the intense cold, a circular current of strong winds (called a **vortex**) surrounds each pole in the winter. The vortex around Antarctica is much stronger than the vortex around the Arctic. The vortex helps create a "witches brew" of ozone-destroying compounds.

Keep in mind that there is no sunlight reaching the polar latitudes in the winter. So, of course, it's going to be cold. The very cold temperatures help form **polar stratospheric clouds (PSCs)** (Figure 3).

The Northern Hemisphere has not seen as much seasonal ozone destruction as has been experienced over Antarctica. This is because the Arctic does not have the extremely cold temperatures

Figure 3: Polar stratospheric clouds (PSCs) are seen above Stavanger, Norway

This photograph was taken from the NASA DC-8 flying laboratory at nearly 39,000 feet on February 28, 1989. The lower polar stratospheric clouds (seen edge-on as a thin, dark orange or brown layer) are made up of nitrogen compounds, including nitric acid. Multiple layering can be seen. The whiter clouds consist mostly of frozen water molecules.

Source: http://ails.arc.nasa.gov/Images/EarthSci/AC89-0114-605.html

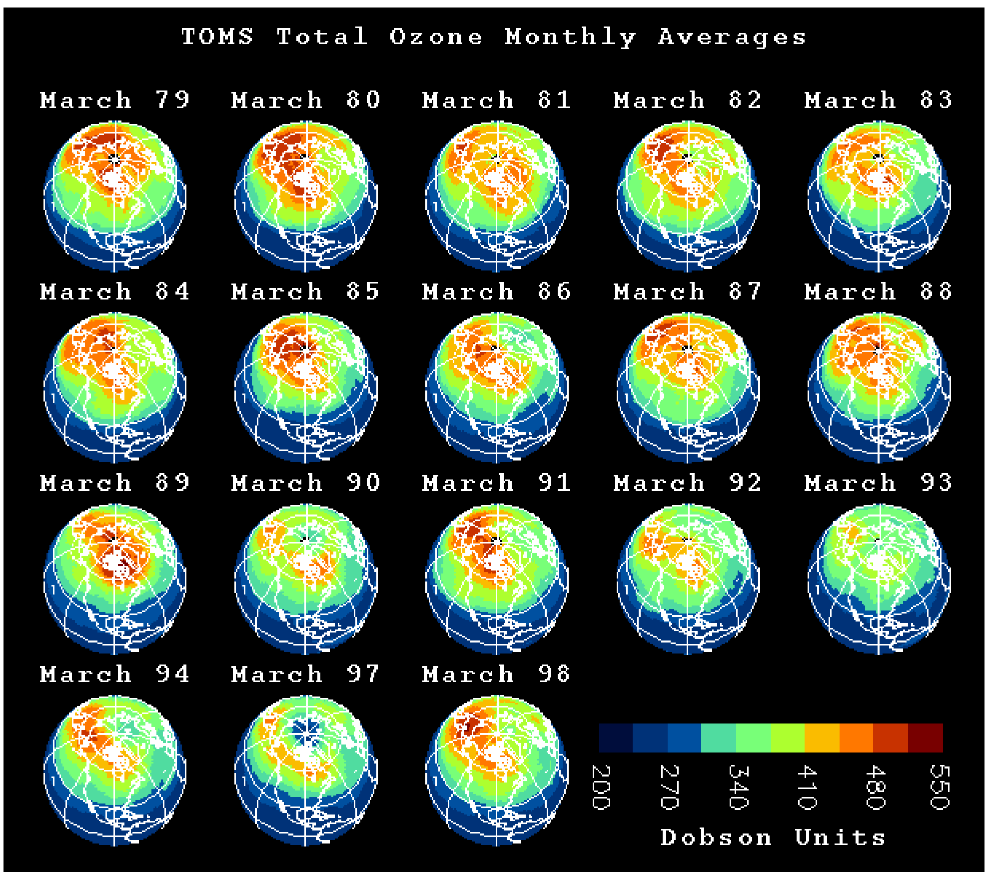


Figure 4: The springtime decline in ozone concentrations over the Arctic and adjacent high-latitude countries

The red and orange indicate high ozone values, which have been slowly getting less since at least 1979—when NASA started gathering data. There isn't a consistent decline in ozone levels over the Arctic because some winters are not cold enough to form polar stratospheric clouds (PSCs).

Source: http://jwocky.gsfc.nasa.gov/multi/TOMSmarch79_98.gif needed to form polar stratospheric clouds each year. Intense PSC formation occurs only in some years over the Arctic, leading to destruction of ozone but much less than over Antarctica. NASA's TOMS satellite has kept track of ozone concentrations over North America since 1979 (Figure 4). What trends do you see in Figure 4?

Part 3: What are the effects of ozone destruction?

The problem of stratospheric ozone destruction in the tropics is minimal. Although some ozone-destroying chemicals are manufactured in the tropics, ozone depletion is least there. Even though there is a lot of solar radiation hitting the tropics, tropical plants and animals are adapted to it.

Almost all of the effects of ozone depletion are at high latitudes. Since plants and animals at these high latitudes have adapted to only low levels of ultraviolet radiation, a large increase could be potentially dangerous. Here are some worrisome points.

- Information from NASA's Total Ozone Mapping Satellite (TOMS) indicates spring and summer ultraviolet radiation has increased 5 percent per decade at 45°N, 7 percent at 55°N, and 10 percent per decade at 55°S. The ability of ultraviolet radiation to damage DNA increases 2.5 percent for each 1 percent reduction in ozone. Increases in skin cancers, nonmelanoma for example, are estimated to have increased from 3 percent at low latitudes to 39 percent at 55°S.

- People of fair skin are generally more prone to skin cancer. Today, in the United States, more than 50 percent of new cancers are skin cancers. Skin cancer is now the fastest growing type of cancer among men and the third fastest among women.

- Medical researchers think that increases in ultraviolet radiation reduce effectiveness of the human immune system, which increases susceptibility to infections.

- Higher ultraviolet concentrations can lead to cataracts and eventually blindness. The United Nations Environment Program (UNEP) estimates that a 1 percent decrease in ozone can lead to cataracts in an additional 100,000 people.

- Northern lakes in areas formerly glaciated (such as Canada and Scandinavia) are affected by small increases in ultraviolet radiation, with the downward migration of zooplankton and reduction in chlorophyll, causing complications in the food chain in these lakes.

- Some agricultural plants appear to be sensitive to increases in ultraviolet radiation, particularly barley, broccoli, carrots, cauliflower, cucumbers, oats, peas, soybeans, sweet corn, and tomatoes. For every 1 percent increase in ultraviolet radiation, food production decreases 1 percent.

- About 45 percent of tree species appear to be sensitive to ultraviolet increases.

- Today, ultraviolet radiation is penetrating to depths in the ocean never previously seen. **Phytoplankton** grow just below the ocean surface and do not benefit much from the natural blocking effect of ultraviolet radiation by water. Phytoplankton in the ocean absorb carbon dioxide, produce oxygen, produce compounds that help clouds form, and are the foundation of the ocean food chain. In the area around the Antarctic ozone hole, there has been a 6-12 percent decrease in phytoplankton productivity in the spring, when the ozone hole appears. When averaged out over the entire year, the decrease is 2 percent. The long-term effects of such a decline in phytoplankton productivity are uncertain.

<u>Answer Question 14 on the Log.</u>

Module 3, Investigation 2: Briefing

The loss of stratospheric ozone: Where are lives at risk?

Part 4: Where are the largest populations at risk?

The ozone-depleted air over the poles spreads toward the equator. For example, the Antarctic “ozone hole” in the stratosphere moves toward Argentina, New Zealand, and Australia. The Arctic “ozone reduction” moves toward Canada, the northern United States, northern Europe, and northern Asia. Where are the largest populations at risk?

You have read that PSCs have been photographed above Kiruna, Sweden (68°N), and Stavanger, Norway (58°N). These are obviously high-latitude places. Since PSCs form in the coldest air, which is found near the poles, we can assume that populations at the highest latitudes face the greatest risk from ozone depletion.

It is your job to estimate which populations are most at risk:

- Let us assume that human populations at risk from stratospheric ozone depletion lie at latitudes of 50 degrees or more.
- Use an atlas and a recent listing of populations of countries to estimate the size of the populations at risk in the northern and the southern hemispheres.
- Use the following rule to make your estimate: List only those countries with more than half of their areas lying at more than 50 degrees of latitude.
- On the Log, complete the table listing the countries and their populations that are at risk according to the estimation method described above.

Answer Question 15 on the Log.

Part 5: What are the geopolitics of ozone?

Because scientists convinced politicians about the dangers of the Antarctic ozone hole, an international agreement called the Montreal Protocol was reached. Countries that signed agreed to stop using ozone-destroying chemicals.

A copy of the Montreal Protocol can be found on the Internet at: <http://www.unep.org/unep/secretar/ozone/mont_t.shtml>.

Following the Montreal Protocol, the United States, Canada, Germany, and other more developed countries (**MDCs**) have begun to use substitutes for CFCs that are less harmful to the ozone layer. On the positive side, there are signs that human-made ozone-destroying chemicals may be starting to decrease in the atmosphere.

On the other hand, the problem of ozone destruction has not gone away because

1) Ozone-destroying chemicals stay up in the stratosphere for decades,
2) Some countries that signed the agreement still produce and use ozone-destroying chemicals, and
3) Some countries still have not signed the agreement.

So the world is faced with a geographical irony:

- Most of the countries still using ozone-destroying chemicals are found in the lower latitudes. These are less-developed countries (**LDCs**), such as India and China. This is because CFCs and other ozone-destroying chemicals are cheaper to produce and can be used in their equipment.

- Most of the countries affected by the loss of ozone are found in the higher latitudes— MDCs, such as Canada, the United Kingdom, and Germany. All of these countries signed the Montreal Protocol and have made progress in stopping the use of ozone-destroying chemicals.

In 1986, LDCs accounted for only 15 percent of the total usage of ozone-depleting substances. But by 1991, this figure jumped to 21 percent. China alone increased use 20 percent per year in the 1980s, as refrigeration increased dramatically. By 1996, China produced 60,000 tons of CFCs, India 20,000 tons, Russia 18,000 tons, and the rest of the world 52,000 tons.

In 1987, the Montreal Protocol called for the worldwide elimination or reduction of ozone-destroying substances. The protocol has been updated several times as understanding of the ozone problem increased. The Montreal Protocol has been signed by more than 160 nations.

MDCs at first did not want to freely transfer new technology using ozone-friendly chemicals because companies in the MDCs did not want to lose profits. LDCs argued that they weren't responsible for the problem and they shouldn't have to pay.

A Multilateral Fund, created mainly by MDCs, was established by the Montreal Protocol to help LDCs meet the protocol.

The future is not at all certain because it is far cheaper to use ozone-depleting chemicals than substitutes. The rest of this section explains some problems the Executive Committee of the Multilateral Fund faces.

- The Montreal Protocol allows MDCs such as the United States to export ozone-depleting compounds to LDCs. But LDCs cannot export these compounds to MDCs. The justification is that replacing old refrigeration technology using ozone-destroying compounds would have been enormously expensive. Thus, LDCs who signed the protocol were given a 10-year grace period to phase out ozone-destroying chemicals.

- But China and India will continue to produce and use CFCs legally for the first decade of the 21st century. Also, there is speculation that illegal production will continue in these countries for some time to come.

- There are also problems with new substitutes because several substitutes themselves destroy the ozone layer. Because the chemical industry is constantly creating new products, many countries are worried that new ozone-depleting chemicals could be made and sold.

- A major concern among MDCs is that LDCs simply have no ability or will to enforce the provisions of the Montreal Protocol.

Part 6: A geopolitical confrontation?

You now know the basics. Science can explain where and how ozone destruction occurs, but science alone cannot solve the problem. This is because ozone destruction occurs in the high latitudes, not in the low latitudes where future ozone-destroying chemicals will be manufactured and released by LDCs. And the high-latitude MDCs suffering from problems have already moved towards substitutes for ozone-destroying chemicals.

The Montreal Protocol was intended to help reduce the manufacture of ozone-destroying chemicals, but not all countries have signed the agreement. Also, the Montreal Protocol specifies that higher latitude MDCs give aid through the Multilateral Fund to help poorer nations make the transition to substitutes. But because CFCs are far cheaper than substitutes, ozone-depleting chemicals are still made and used in vast quantities.

Thus, the stage is set for an unusual geopolitical confrontation. The LDCs are in control of the health of the world's ozone layer. These countries are trying to industrialize, using ozone-destroying refrigeration for food preservation and comfort. China and other LDCs are still using ozone-destroying refrigerants. Thus, the poorer countries in the lower latitudes have the power over rich, industrialized countries (MDCs) in the higher latitudes where the effects of ozone destruction will be most pronounced.

Can the LDCs be convinced to make changes to save the ozone layer above the MDCs? Or should the LDCs put their priorities on their own development and let the MDCs use their wealth to try to cope with ozone depletion in the higher latitudes? Resolving these questions will require worldwide commitment and agreement.

GLOSSARY

aerosols: tiny dust-sized particles in the atmosphere.

bromine: an element that destroys stratospheric ozone. Bromine is included in the compound methyl bromide. Methyl bromide is used as a pesticide, and it is also made naturally by oceans.

chlorine: an element that destroys stratospheric ozone. Chlorine is included in chlorofluorocarbons.

chlorofluorocarbons (CFCs): compounds containing chlorine, fluorine, and carbon. CFCs are used in refrigerators and air conditioners. The term is sometimes used to include chlorocarbons, fluorocarbons, and hydrochlorofluorocarbons.

halons: chemicals similar to CFCs but containing bromine. Used for fire suppression.

LDCs: less-developed countries, sometimes called developing countries. These are the poorer, least industrialized countries.

MDCs: more-developed countries, sometimes called developed countries. These are the more wealthy, industrialized countries.

nitric acid: a natural compound (HNO_3) in the stratosphere that protects the ozone layer.

nitrogen: an element and a gas that makes up 77 percent of Earth's atmosphere. Nitrogen is important in protecting the ozone layer when it exists in the form of nitric acids—that is, until polar stratospheric clouds (PSCs) get involved. The PSCs remove nitric acids and allow ozone destruction.

ozone: a form of oxygen molecule containing three (O_3) atoms of oxygen, rather than two oxygen atoms.

phytoplankton: small, floating plants, such as algae, living in water; they form the bottom of the oceanic food chain.

polar stratospheric clouds (PSCs): clouds in the stratosphere that only form when the stratosphere is very, very cold—in the dead of the polar winter. Polar stratospheric clouds remove ozone's natural guardian (nitric acid).

stratosphere: the layer of the atmosphere immediately above the troposphere. Temperatures increase with altitude within the stratosphere.

sulfates: compounds that include sulfur and oxygen. Sulfates occur in the atmosphere as tiny dust-sized particles called aerosols. Sulfate aerosols are released by some types of volcanic eruptions. When these volcanic eruptions are very violent, the sulfate aerosols can be thrown into the stratosphere and help destroy ozone.

troposphere: the lowest layer of the atmosphere. Almost all weather occurs in this layer. Its average thickness is 11 kilometers (7 miles).

ultraviolet radiation: solar radiation with wavelengths less than that of visible light. Ultraviolet sunlight has a lot of energy and damages cells in animals and plants.

vortex: intense circular wind flow; a vortex forms in the winter over the poles—and is sometimes called a "circumpolar vortex."

References

Human, Katy. 2000. [Boulder, CO] *Daily Camera*. Jan. 29, pp. 1A, 4A.

NASA. 2000. *Arctic ozone depletion linked to longevity of polar stratospheric clouds.* NASA Press release 00-43, NASA Ames Research Center, Moffett Field, California, May 30, 2000.

Population Reference Bureau. 2000. *2000 World population data sheet.* Washington, D.C.: Population Reference Bureau. http://www.prb.org

http://george.arc.nasa.gov/dx/basket/pix/pscpix/PSCcloudcaps/PSCpix.html

http://eos-chem.gsfc.nasa.gov/science.html

http://ails.arc.nasa.gov/Images/EarthSci/AC89-0114-605.html

http://jwocky.gsfc.nasa.gov/multi/TOMSmarch79_98.gif

http://www.unep.org/mont_t.shtml

Module 3, Investigation 2: Log

The loss of stratospheric ozone: Where are lives at risk?

1. The latitude and longitude of Kiruna, Sweden, is __________ degrees ______ minutes and __________ degrees ______ minutes.

2. Complete this sentence: The purpose of the SOLVE project is to ______________________________

3. What is the significance of the stratospheric ozone layer to life on Earth?

4. Complete this sentence: The major observation of the SOLVE project during the winter of 1999-2000 was that

5. Complete this sentence: According to SOLVE project scientists, the significant decline in ozone over the Arctic in the winter of 1999-2000 was caused by

6. What are polar stratospheric clouds (PSCs)?

7. What is the role of PSCs in the destruction of stratospheric ozone?

Module 3, Investigation 2: Log

The loss of stratospheric ozone: Where are lives at risk?

8. According to Figure 2, where has the most stratospheric ozone been depleted, over the Arctic or Antarctic?

___

9. Where are the lowest temperatures, over the Arctic or Antarctic? ___

10. Where would you expect to find the most and longest lasting PSCs, over the Arctic or Antarctic?

___

11. Explain your answer to Question 10.

___

___

___

12. In which hemisphere, the Northern or Southern, would stratospheric ozone depletion affect the most people?

___

13. Explain your answer to Question 12.

___

___

___

14. What do you think are the two most serious effects of stratospheric ozone depletion and why?

1) ___

___

___

___

2) ___

___

___

___

Module 3, Investigation 2: Log

The loss of stratospheric ozone: Where are lives at risk?

15. Complete Table 3 and write your critique in the space provided below.

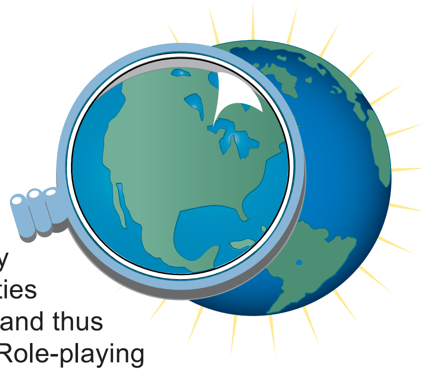
Table 3: Estimated populations at risk from stratospheric ozone depletion [a]

Country[b]	Population (millions)
Russia	145.2
Total	

[a] Populations at risk are assumed to lie at 50 degrees or more of latitude.
[b] These estimates come from the following rule: countries listed have more than half of their areas lying at more than 50 degrees. For example, less than half of France but more than half of Germany lie north of 50 degrees. Thus, France should not be listed but Germany should be. Population numbers come from Population Reference Bureau 2000, http://www.prb.org

In the space below, critique the above method of estimating and describe what you think might be a more accurate method.

Are we warming Earth?



Investigation Overview

This investigation assesses the theory of global warming—that human activities are enhancing the greenhouse effect and thus causing Earth's temperature to rise. Role-playing science writers for a major newspaper, students write a persuasive editorial, titled "Are We Warming Earth?" that focuses on (1) what facts point to global warming?; (2) what are the possible causes of global warming?; and (3) how might global warming affect physical and human systems?

Time required: Four to seven 45-minute sessions (as follows):

- Introduction and Part 1: One or two 45-minute sessions
- Part 2: One or two 45-minute sessions
- Part 3: One 45-minute session
- Part 4 and Conclusion: One or two 45-minute sessions

Materials

Copies of the Briefing and Log (one copy of each per student)
Computer with CD-ROM drive. The Mission Geography CD contains color graphics that help explain the materials.
Optional: Access to the Internet, which offers opportunities for extending this activity

Content Preview

There is a large body of evidence that has convinced nearly all scientists that Earth's average temperatures are on the rise. In other words, the vast majority of scientists accept this as a fact. Opinions differ, however, about the cause or causes. All reputable scientists know that climate variation occurs naturally both in the short run (a few years) and in the long run (hundreds and thousands of years). They also know that the greenhouse effect is real and that it plays a large role in determining global temperatures. But scientists debate the role of human activities in this issue.

The majority of scientists have decided that current global warming is at least partly caused by an *enhanced,* or *human-induced*, *greenhouse effect*—that human activities have increased the amount of greenhouse gases in the atmosphere and thus enhanced the greenhouse effect. A few scientists remain unconvinced of this theory. They argue that the global warming we are now experiencing may well be the result of natural variation. Neither side's explanation can be proven conclusively at this time. Scientists can only weigh the evidence and express their opinions as to what the evidence means.

Geography Standards

Standard 1: The World in Spatial Terms

How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information

- Produce and interpret maps and other graphic representations to solve geographic problems.

Standard 7: Physical Systems

The physical processes that shape the patterns of Earth's surface

- Explain Earth's physical processes, patterns, and cycles using concepts of physical geography.
- Explain the various interactions resulting from Earth-Sun relationships

Standard 14: Environment and Society

How human actions modify the physical environment

- Explain the global impacts of human changes in the environment.

Standard 15: Environment and Society

How physical systems affect human systems

- Analyze examples of changes in the physical environment that have reduced the capacity of the environment to support human activity.

Geography Skills

Skill Set 4: Analyze Geographic Information

- Make inferences and draw conclusions from maps and other geographic representations.

Skill Set 5: Answer Geographic Questions

- Evaluate the answers to geographic questions.

Classroom Procedures

Beginning the Investigation

1. Generate discussion by asking students what they know about global warming, e.g.:
   - Do they think that Earth is getting warmer?
   - How would we know?
   - Are human activities contributing to the warming of Earth? How?
   - How might global warming affect human activities?
   - How might global warming affect physical systems?

Developing the Investigation

2. Hand out copies of the **Briefing** and **Log** to each student or to small groups of students. Students can work on this activity individually, but it is recommended that they work in small groups—pairs or triads are especially recommended so students can help each other.

3. Leaf through the materials with students and point out the underlined questions, which are to be answered on the **Log**. Give students a schedule for completing the questions.

4. Have students read the **Background** and **Objectives**. Take questions and ask questions to be sure students understand the reading. Try to draw out examples in support of ideas in the Background, e.g.:
   - What is the global warming debate?
   - Why is global warming contested?
   - What do proponents of a human-enhanced greenhouse effect believe?
   - What do critics of this view believe?
   - Do students think global warming should be stopped? Can be stopped? How?

5. Draw attention to the **Scenario**, which sets up the culminating assignment:
   - Tell students that their main task in this investigation is to write a persuasive, newspaper-style editorial about global warming as described in the **Briefing** under **Scenario**.
   - Tell them that their editorials need not take sides on the cause of global warming, i.e., students do not have to argue that it is caused by human activity, but they do need to persuade their readers that global warming is a fact and that it should be taken seriously.
   - Challenge students to write their own newspaper editorial.
   - Give them a suggested length for the editorial and any other guidelines you wish to make. For example, you might make a scoring rubric using the four questions listed in the **Scenario**.

6. Set students working through the **Briefing**, beginning with **Part 1: What facts point to global warming?**
   - Emphasize the importance of studying and discussing the data in figures and tables found throughout the investigation.
   - Discuss any questions arising from the newspaper articles "Global warming in '99" and "North Pole visitors find no ice."

7. Work with students to ensure they understand the idea of *climate variability*. Ask questions to draw out discussion:
   - What is climate variability? Give examples of it.
   - Why is the issue of variability so important for this topic?
   - Students need to understand that recorded temperatures began only in the 1880s, and it is difficult to completely verify how climate is changing over the long term.
   - The best that science can do is to determine *trends* of global temperatures.

8. To monitor progress and to keep students moving through the materials at about the same pace, ask students to give their interpretations of the tables and figures and/or use the **Log** questions (or other questions) to generate class discussion. Remind students that their answers to the Log questions can be incorporated into their newspaper editorials.

9. **Part 2: What are the possible causes of global warming?** is the section that explains the greenhouse effect and greenhouse gases, which are major concepts in the theory of human-induced global warming.
   - You may wish to have students put the number for the 2030 CO_2 concentration from Table 1 on the top graph of Figure 6 to see how high the modern figures are. They can then use the link between the graphs in Figure 6 to speculate about probable temperature associated with the most recent CO_2 figures.
   - Have students rank the four sources of greenhouse gas emissions shown on Figure 7.

10. **Part 3: How will global warming affect physical systems?** starts by challenging students to brainstorm a list of possible human and physical effects of global warming. Monitor this brainstorming carefully because their responses here should help you determine their understanding of the relationships among the physical systems. For example, global warming would
    - melt glaciers and polar ice caps, which would bring
    - rising sea levels, which would bring
    - coastal flooding, which would
    - etc.

    Or, increasing temperatures, for example, would
    - bring higher evaporation,
    - adding more moisture to the atmosphere,
    - which could make for more cloudiness, and, therefore,
    - more precipitation in some regions.

11. Figure 8 is a frequency distribution of annual U.S. precipitation. Global warming is resulting in increased precipitation in the United States, and students can observe that there are less extreme events below the average after 1960. This section stresses the impact of increased precipitation upon river flooding and rising sea levels upon coastal environments.

12. In **Part 4: How will global warming affect human systems?**, global warming is predicted to increase the spread of rare diseases as rising temperatures enable tropical insects to migrate poleward. The effects upon agriculture are major concerns about human systems. To provide an example, the last part of this section examines NASA research into agricultural production in the Mediterranean. Students can use this as an example for their editorials, which they should begin after they have answered Question 8 on the **Log**.

Concluding the Investigation

13. Debrief the investigation by discussing the **Log** and newspaper editorials. Have some students read their editorials to the class and ask for discussion. Use the **Objectives** listed at the beginning of the **Briefing** to organize a debriefing.

Evaluation

Log

1. Using Figure 1, describe the trend in average global surface temperatures since 1880.
   The trend in average global surface temperatures is increasing as measured from 1880 to 1998.

2. Explain why average temperatures are used in Figure 1, as opposed to "highest" or "lowest" temperatures for that year.
   Average temperatures are a better reflection of the temperatures for the entire year. Extreme fluctuations either above or below the average in a given year are not indicative of the year as a whole.

3. Describe any trends that you see in the 100-year temperature record for the United States (Figure 2). Also, note the three highest and three lowest recorded years for temperature in the United States since 1895.
   It is difficult to detect clear trends in Figure 2. There are clear fluctuations both above and below the average; however, less extreme fluctuations below the average occur over time. Additionally, more fluctuations above the average occur from 1895 to 1998. An easier way to detect trends is to draw a line along the gradient to get a sense of what has occurred.
   Highest: 1921, 1935, and 1998.
   Lowest: 1903, 1911, and 1916.

4. Describe the past and projected trends in the production of greenhouse gases.
   All data presented show that both past and projected trends are increasing.

5. Which of the greenhouse gases documented in Table 1 and Figure 4 increased the most in the atmosphere?
   Carbon dioxide (CO2) and methane (CH4).

6. Brainstorm a list of possible effects on physical and human systems from increasing global temperatures. (The items listed below are only suggestive rather than exhaustive of the possible answers.)
   <u>Effects on physical systems</u>
   - *Glaciers and polar ice caps would melt, resulting in rising sea levels and flooded coastal areas.*
   - *Precipitation and temperature patterns would make latitudinal shifts, thus changing regional climates.*
   - *Ecosystems and biodiversity would be changed.*
   - *Some species of flora and fauna would be forced to migrate to new areas or die.*

   <u>Effects on human systems</u>
   - *Coastal communities and economies would be threatened and would have to move inland to avoid flooding because of rising sea levels.*

- *Some existing crops would be subjected to extreme drought or moisture, so agricultural systems would have to change, e.g., cropping patterns in the United States would shift north; warmer climates would allow more tropical crops to grow.*
- *Extreme dryness would bring devastating wildfires and loss of life and property; it could also threaten regional water supplies.*
- *Extremely moist conditions would bring regional flooding, insect infestations, and diseases.*

7. What is the trend in U.S. precipitation patterns? *There has been an increase in precipitation, especially since 1970. Extreme anomalies below the average were more common in the 1930s and 1950s.*

8. In the climate change models (Figure 10), what happens to temperature and precipitation in the Mediterranean region? How would this information help you if you were a producer of olive oil or grapes? *The climate change models for 2050 show an increase in temperature and a decrease in precipitation throughout the Mediterranean. In the western Mediterranean region, there will be an increase of 5-6°C in temperatures, accompanied by a decrease in precipitation of 30-40 percent. In the eastern Mediterranean region, there will be an increase of 3-5°C with a decrease in precipitation of 40 percent. As a farmer, this information would assist in making needed preparations to deal with the changes in precipitation and temperatures. Farmers may need to invest in more irrigation, or choose different crops that would be more receptive to the changing climatic conditions.*

Additional Resources

The GSFC DAAC is the Goddard Space Flight Center's examination of upper atmosphere, global biosphere, and atmospheric dynamics. The Greenhouse Effect Detection Experiment (GEDEX) has data collection on more than 60 data sets that may be global, regional, or local. Contact them at http://daac.gsfc.nasa.gov/ or gsfc@eos.nasa.gov.

SEDAC is the Human Interactions in Global Change Center. ENTRI has information on environmental treaties and resource indicators and has data on global change treaties. Contact them at http://sedac.ciesin.org.

The Center for Earth and Space Science Education (CESSE) has a web site at CESSE.terc.edu.

McCarthy, J. J., and M. C. McKenna. 2000. How Earth's ice is changing. *Environment* 42(10): 8-18.

NASA's Earth Observing System (EOS AM-1) is designed to provide global data on the state of the atmosphere, land, and oceans. They have a web page at http://modarch.gsfc.nasa.gov/EOS-AM.

Global Hydrology and Climate Center http://www.ghcc.msfc.nasa.gov/temperature/

Sherbinin, Alex de. Climate change impacts on agriculture. *Environment* 42(2):3. [includes a listing of numerous Internet sites concerned with this topic.]

The 1997 Kyoto Conference on Climate Change, an agreement signed by the United States and other countries to limit CO_2 emissions, may be examined at these sites:

- Spotlight: Climate Change; archive site for the State Department as of January 20, 2001 www.state.gov/www/global_issues/climate/index.html
- EPA Global Warming Site www.epa.gov/globalwarming/kids
- CNN Text www.cnn.com/SPECIALS/1997/globalwarming/stories/treaty

James E. Hart and Mark O. Lombardi (editors). *Taking sides: Clashing views on controversial global issues.* (McGraw-Hill/Dushkin, 2001) provides background in a section called "Is the threat of global warming real?"

An excerpt from Ross Gelbspan, "The heat is on: The high-stakes battle over Earth's threatened climate" (Addison-Wesley, 1997) answers "Yes, climate change is here. Now." But Brian Tucker answers "No" in an excerpt from "Science friction: The politics of global warming." *The National Interest*, no. 49. (Fall 1997).

In addition to the periodic reports of the United Nations-sponsored Intergovernmental Panel on Climate Change, which are always covered in newspapers, three valuable studies are:

S. Fred Singer. *Hot talk, cold science: Global warming's unfinished debate*. (Independent Institute, 1998). Singer is one of the leading opponents of global warming's adverse consequences.

John Houghton, in *Global Warming: The complete briefing*, 2d ed. (Cambridge University Press, 1997) accepts global warming as a significant concern and describes how it can be reversed.

S. George Philander, in *Is the temperature rising? The uncertain science of global warming* (Princeton University Press, 1998), concludes that the global temperatures will rise 2°C over several decades, creating the prospect of some regional climate changes.

Module 3, Investigation 3: Briefing
Are we warming Earth?

Background
Mark Twain once remarked that everybody talks about the weather but nobody does anything about it. If that was true in Twain's time, it may not be true today. Many scientists today think that rising temperatures on Earth are caused by specific human activities—that we *are* "doing something about the weather" but that we shouldn't be doing it. They have identified increasing global temperatures as a significant issue that requires the attention of the global community. They believe that major changes in our behavior are needed to stop human-caused **global warming**, also known as the theory of an **enhanced greenhouse effect**.

But some scientists disagree with this: they remind us that many climate changes have occurred in the past, and that attributing global warming to a human-enhanced greenhouse effect might be wrong. They argue that the assumptions and predictions of climate change are flawed and that we should not make significant changes in our behavior until more is understood. This investigation introduces you to the global warming debate and provides data to assist you in writing a persuasive editorial about it.

Objectives
In this investigation you will
- analyze variability of weather and climate,
- interpret global climate data,
- identify areas experiencing temperature and precipitation extremes,
- critically examine possible causes of global warming,
- describe human and physical consequences of global warming,
- consider possible changes humans need to make to reduce global warming, and
- synthesize information into a persuasive newspaper editorial.

Scenario
Imagine that you are a science writer for a major newspaper in the United States. You are writing an editorial, to be titled "Are We Warming Earth?," to try to persuade your readers that global warming should be taken seriously. You have decided to develop your editorial around the following four questions:

1. What facts point to global warming?
2. What are the possible causes of global warming?
3. How might global warming affect physical systems?
4. How might global warming affect human systems?

Work through this investigation so that you can write the best editorial you can about global warming.

Part 1: What facts point to global warming?
You can find many newspaper stories on this subject. The following are only two such examples.

Global Warming in '99
By Seth Borenstein
Knight Ridder Newspapers

WASHINGTON—Last year was the second hottest year ever recorded in the United States, despite a La Niña weather phenomenon that was supposed to cool off the Earth a tad. And that strengthens the scientific case for an ever-warming world, meteorologists say. . . .

Globally, the 1990s are the hottest decade ever recorded. The five hottest years were 1998, 1997, 1995, 1990, and 1999, in that order. Each year of the 1990s ranks among the 15 hottest years since 1880, when record keeping began.

Even though 1998 was the hottest year both globally and nationally, it is 1999 that really makes global warming hard to deny, meteorologists said. Even some of the few skeptics who have challenged the theory of global warming now say they are convinced.

"When you have a very warm year that occurs during a La Niña, that makes it more difficult to argue against the reality of global warming," said NASA senior climate scientist Roy W. Spencer, one of the more prominent skeptics. "We're now more willing to admit that global warming is occurring. The debate now is how much warming is going to be in the future."

Last year, the heat rose when it shouldn't have. When the water in the central Pacific Ocean warms, that's a weather event called El Niño that raises global temperatures. Scientists say El Niño was partly to blame for 1998's record heat. Some said 1998 was a freak year caused by a super-sized El Niño.

But El Niño's warm water turned cold in 1999, because of a strong La Niña, a separate weather phenomenon that is the cooling mirror image of El Niño. The arrival of La Niña is supposed to cool things down.

It didn't.

"This also tells you that there's a real warming here that's beyond what's going on in an El Niño," said Kevin Trenberth, head of climate analysis for the National Center for Atmospheric Research in Boulder [Colorado].

In 1999, water temperatures dropped to their lowest levels in five years, but global temperatures were still three-quarters of a degree above normal. The worldwide land temperatures alone were the second hottest ever, 1.36 degrees warmer than normal.

"It's becoming clearer each year that there is something unusual going on," said James Hansen, the godfather of global-warming alarms and head of NASA's Goddard Institute of Space Studies in New York.

The 1999 temperature statistics come on the heels of a National Research Council report that strengthened the scientific case for global warming. The report reconciled an apparent anomaly—why surface temperatures had been rising even though recent satellite data showed no warming in the lower atmosphere.

The report said there were reasons for the mismatched data, including volcanic eruptions in 1982 and 1991. It also said the rate of 20th-century warming has accelerated by 30 percent since 1995, when a majority of global climate scientists first agreed the phenomenon is indeed a problem. . . .

The average temperature in the United States last year was 55.98 degrees—second only to 1998's 56.36 degrees. Normal is about 54 degrees, based on 105 years of record keeping.

"America's 1999 heat was not from summer sizzle; it resulted more from a mild winter," said Michael Changery, head of the climate-monitoring branch at NOAA's National Climatic Data Center in Asheville, N.C., where the temperature figures were compiled. "January, February, March, December, and especially November were far warmer than normal," he said.

Nearly every Northern state recorded one of its 10 hottest years ever in 1999. Every state, save Alaska and California, was hotter than normal.

NASA's Hansen calculates numbers differently from NOAA's Changery. He factors in the heat-island effect for cities. [Temperatures taken in cities will usually be higher than temperatures taken in surrounding rural areas.] "Allowing for that measurement difference," he said, "1999 was only the 10th hottest year on record in the United States and the sixth hottest year globally."

"The difference between the two measures isn't much," said University of Washington meteorologist John M. Wallace. "What's important—and weird—is that it was hot when it shouldn't have been," he said (Borenstein 2000).

North Pole Visitors Find No Ice

By John Noble Wilford
The New York Times

The North Pole is melting.

The thick ice that has for ages covered the Arctic Ocean at the pole has turned to water, recent visitors there reported. . . . At least for the time being, an ice-free patch of ocean about a mile wide has opened at the very top of the world, something that has presumably never before been seen by human beings and is more evidence that global warming may be real and already affecting climate. . .

"It was totally unexpected," said James J. McCarthy, an oceanographer [and] . . . the co-leader of a group working for the U.N.-sponsored Intergovernmental Panel on Climate Change. . . .

McCarthy was a lecturer on a tourist cruise in the Arctic on a Russian icebreaker earlier this month. On a similar cruise six years ago, he recalled, the icebreaker plowed through an icecap 6 to 9 feet thick at the North Pole.

This time, ice was generally so thin that sunlight could penetrate and support concentrations of plankton growing under the ice. . . .

Recalling the reaction of passengers when they saw an iceless North Pole, McCarthy said: "There was a sense of alarm. Global warming was real, and we were seeing its effects for the first time that far north" (Wilford 2000).

Variability is a major characteristic of weather and climate. Weather varies (or changes) from hour to hour, day to day, month to month, and year to year. Climate, which is measured as long-term average weather, varies as well. Average values (such as the ones in Figure 1) can have extreme variations. As you look at temperature and precipitation data, remember that because of short-term variability, you will need to examine *trends* over periods of time to assess what is occurring to climate systems. This will become very important as you consider possible *causes* of increasing global temperatures. At the heart of the global warming debate is whether rising temperatures are the result of a human-enhanced greenhouse effect or just another natural trend.

Figure 1 gives annual global surface temperatures from 1880-1998 by showing the differences between annual global mean temperatures compared to the five-year mean.

Throughout this investigation, you should answer the questions on the Log at the end of this Briefing. Here are the first two questions:

1. <u>Using Figure 1, describe the trend in average (mean) global surface temperatures since 1880.</u>

2. <u>Explain why average (mean) temperatures are used in Figure 1, as opposed to “highest” or “lowest” temperatures for that year.</u>

You may be curious to know why global temperatures are not measured earlier than the 1800s. The first year that temperatures were recorded was 1886, so there is no measured data from prior years (Worldwatch Institute 1997). Critics of the theory of global warming will argue that the meteorological record is too short to assert that human activities are the cause of rising global temperatures.

Global temperatures in 1998 were the warmest in the past 119 years, since reliable instrument records began. The previous record was set in 1997. The global mean temperature in 1998 was 0.66°C above the long-term average value of 13.8°C. This was the 20th consecutive year with an annual global mean surface temperature that exceeded the long-term average.

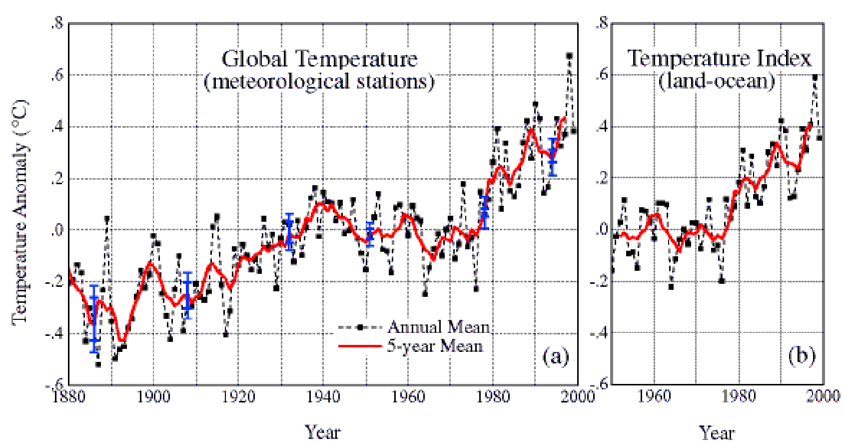
Scientists at the NASA Goddard Institute for Space Studies (2000) reported that global surface temperatures in 1999 fell from the record-setting high level of 1998. These scientists note, however, that 1999 was still a very warm year—the sixth warmest year on record.

Global warming patterns have been detected in the United States as well as the rest of the world. Figure 2 details average annual temperatures for the United States from 1895-1998. In these data, each mean annual temperature is subtracted from 13.8°C (56.9°F) to determine whether that year had increasing or decreasing temperatures (differences from the average are called **anomalies**). As you did with Figure 1, try to determine the trend in annual temperatures over time.

<u>Answer Question 3 on the Log.</u>

Figure 1: Annual global surface mean temperatures

Source: NASA Goddard Institute for Space Studies 2000, http://www.giss.nasa.gov/research/observe/surftemp/



Module 3, Investigation 3: Briefing
Are we warming Earth?

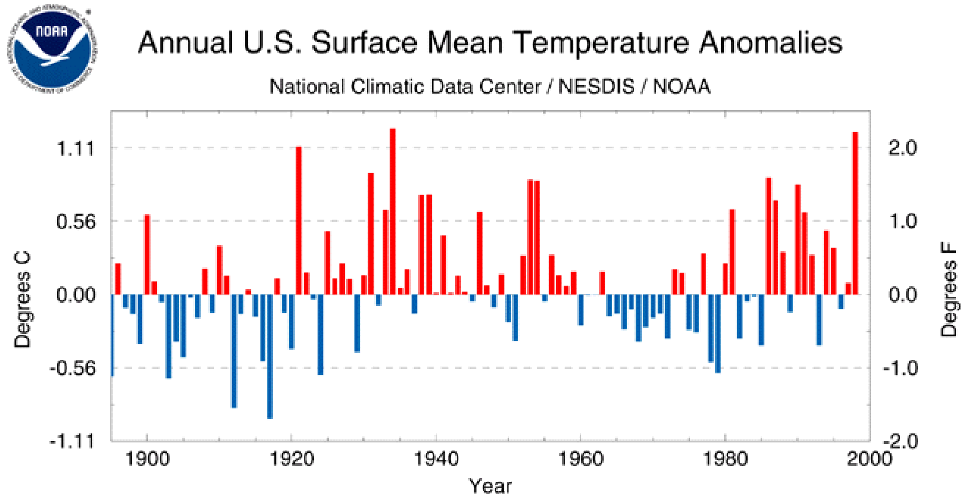


Figure 2: Average temperatures from 1895-1998 in the United States

Source: National Climatic Data Center 2000, http://www.ncdc.noaa.gov/ol/climate/research/1998/ann/us_annual.html

Part 2: What are the possible causes of global warming?

Temperature trends may very well indicate that we are experiencing a warming, but they do not tell us the cause of the warming. Without an agreed-upon scientific explanation for these trends, the cause of global warming is likely to continue to be debated.

Consider the argument that recent increases in global temperatures are part of a long-term recurring natural cycle. At many periods of Earth's history, global temperatures have been both warmer and cooler than they are today (recall our earlier discussion about variability). For example, the world has warmed by 3 to 5°C since the depths of the last ice age, 18,000 to 20,000 years ago (Stevens 1999). Some scientists—the skeptics about a human-enhanced global warming—say that current temperature change may be a return trend towards warmer temperatures. They argue that changing global temperatures are part of a natural, long-term trend.

On the other hand, it appears that most scientists support the idea of an enhanced greenhouse effect as a major contributor to increasing global temperatures. This view was reported as follows in 1995.

Panel finds humans cause warming
by Associated Press

NEW YORK—A U.N. scientific panel on climate change says it is now convinced that global temperatures have warmed over the last century because of human activity, *The New York Times* reported Sunday.

The statement, contained in a draft summary of a report by the Intergovernmental Panel on Climate Change, marks a shift in the views of top climatologists, who previously said that they could not tell whether global warming has been caused by the burning of fossil fuels or natural climatic variations.

The experts now say that a new generation of computer studies has given them confidence in data that suggests why the globe's surface temperature has risen 1 degree Fahrenheit since 1900, the *Times* reported.

The panel's summary says global warming "is unlikely to be entirely due to natural causes and that a pattern of climatic response to human activities is identifiable in the climatological record."

Scientific data now proves that the burning of wood, oil, and coal, which releases carbon dioxide into the air, is at least partly responsible for the so-called [enhanced] greenhouse effect, or warming of the Earth's atmosphere, said Dr. Tom M. L. Wigley, a climatologist at the National Center for Atmospheric Research in Boulder

[Colorado], one of the report's authors. . . .

The panel of international scientists advises world governments now negotiating reductions in the emissions of carbon dioxide and other greenhouse gases under a 1992 treaty on climate change.

At a U.N. Climate Conference in Berlin in April [1995], the panel said emissions of heat-trapping gases must be cut 60 percent if humanity is going to reverse the eventually catastrophic effects of global warming (Associated Press 1995).

Let's look at the so-called "greenhouse effect" (Figure 3). Like a greenhouse for growing flowers, Earth's temperature is determined by three factors: 1) sunlight received, 2) sunlight reflected, and 3) heat energy trapped and reradiated back to Earth by the atmosphere. If there were no atmosphere, incoming shortwave radiation (sunlight) and outgoing longwave radiation (heat energy) would be balanced. Earth would have an average surface temperature of -18°C. Since Earth has an atmosphere that includes gases such as carbon

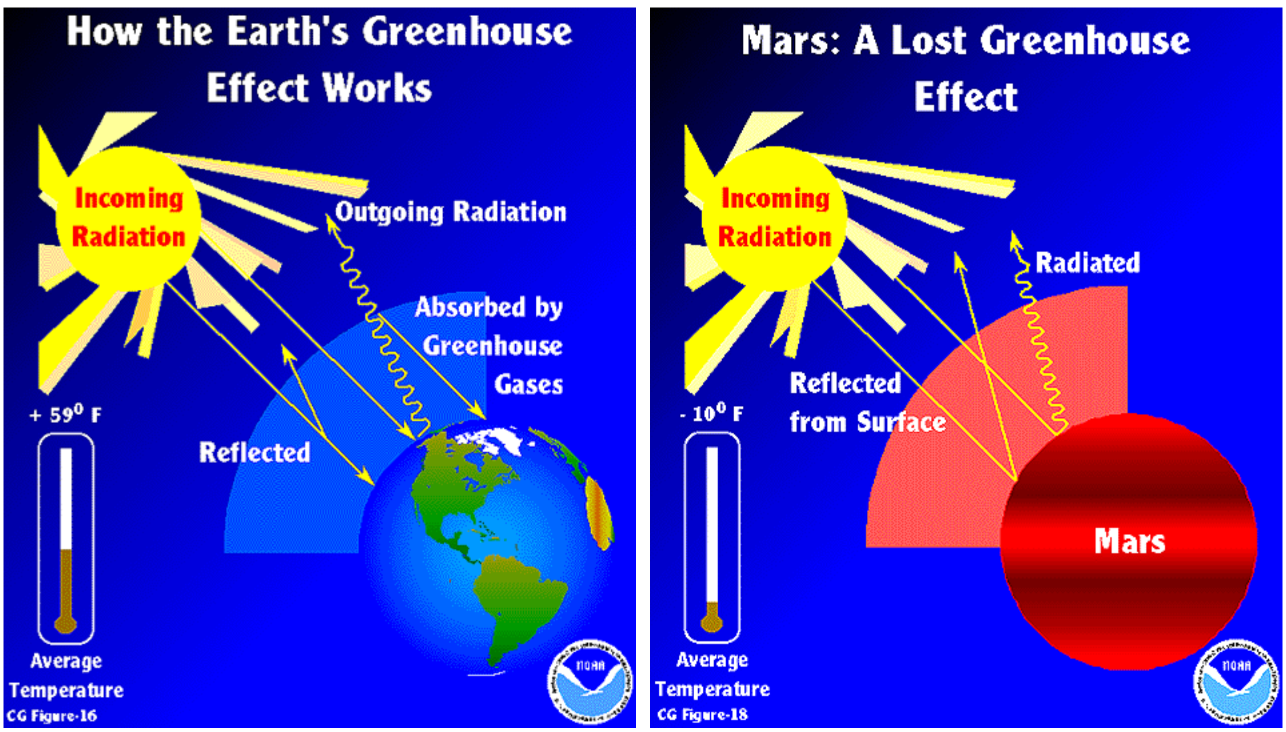


Figure 3: The greenhouse effect of the atmosphere on Earth's average temperature

Source: http://www.fsl.noaa.gov/~osborn/CG_Figure_16.gif.html> and <http://www.fsl.noaa.gov/~osborn/CG_Figure_18.gif.html

Module 3, Investigation 3: Briefing

Are we warming Earth?

Table 1: Increases of greenhouse gas amounts in Earth's atmosphere, 1850-2030 (parts per billion of atmosphere volume)

	1850 Estimated Average Concentration	1980 Measured Average Concentration	1990 Measured Average Concentration	2030 Probable Average Concentration
CO_2	260,000	338,500	353,000	450,000
CH_4	750	1,554	1,720	2,340
N_2O	280	296	310	375
CFCs	0	0.49	0.76	3.1

Sources: Smith and Tirpak 1988; World Resources Institute 1990; Brown and Postel 1987; Office for Interdisciplinary Studies 1991

dioxide (CO_2) and water vapor, outgoing heat energy is trapped, which results in a warmer climate. Because of this effect, Earth's average surface temperature is 15°C.

Carbon dioxide (CO_2) and water vapor are just two of the gases that contribute to the greenhouse effect. Two other important greenhouse gases are methane (CH_4) and chlorofluorocarbons (CFCs). Carbon dioxide and methane come from both natural sources and human activities. CFCs are synthetic gases that began being manufactured in the 1940s. They are used in refrigeration, foam packaging, and many other products. Water vapor mainly comes from the evaporation of the oceans.

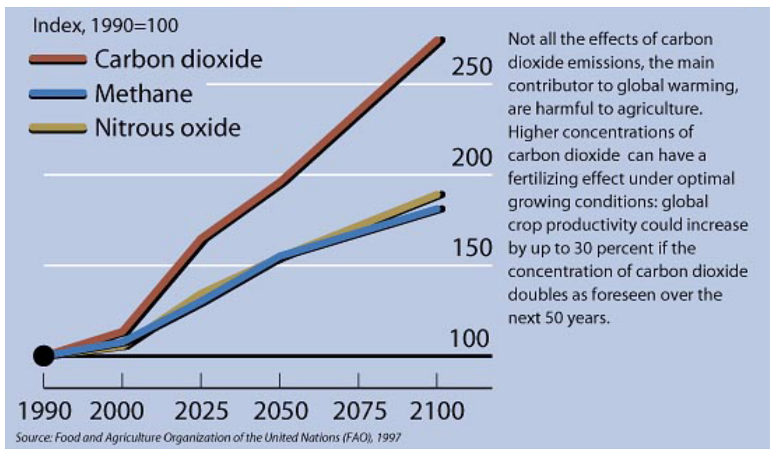


Figure 4: Projected emissions of greenhouse gases

Source: Food and Agricultural Organization of the United Nations 2000, http://www.fao.org/NEWS/FACTFILE/FF9714-E.HTM

Three gases—CO_2, CH_4, and CFCs—account for 86 percent of all human-produced greenhouse-gas emissions. Other greenhouse gases, including nitrous oxide (N_2O), represent the remaining total of about 14 percent of all human greenhouse-gas emissions (World Resources Institute 1990; Shea 1988). The amounts of all these gases have increased since the Industrial Revolution began in about 1850 (Table 1), and projections of the emissions of greenhouse gases have been made to 2100 (Figure 4).

<u>Answer Questions 4 and 5 on the Log.</u>

Module 3, Investigation 3: Briefing
Are we warming Earth?

Carbon dioxide, the major greenhouse gas, enters the atmosphere in a variety of ways (Figure 5), many of which result from *anthropogenic* (human) activities.

With the increasing concentration of greenhouse gases in the atmosphere, there is a tendency to link these increases with the changes in global temperature (Figure 6).

If the amount of carbon dioxide in the atmosphere continues to grow at its present rate, it will be twice as great as its pre-industrial concentration within the next century. Most scientists agree that this will increase the average surface temperature from 1.5° to 4.5°C (Schneider 1991). Earth's average surface temperature could go from its present 15°C to nearly 20°C by the year 2030.

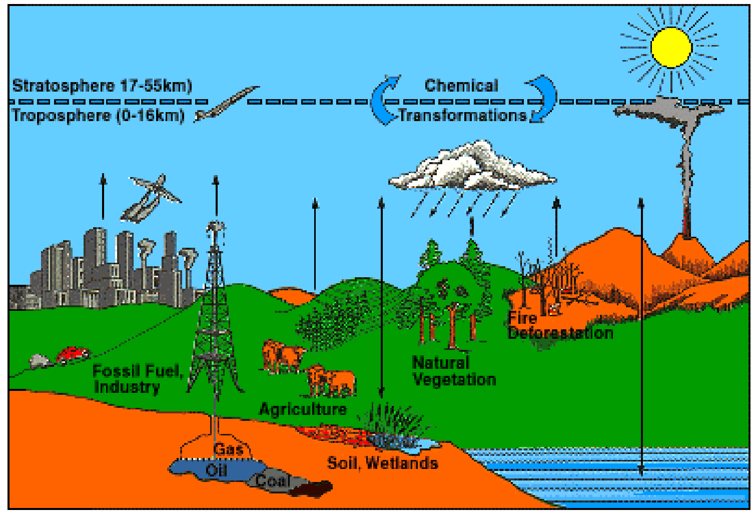


Figure 5: Illustration of biogeochemical cycles

Arrows denote major pathways of the biogeochemical cycling of trace gases.

Source: Fung 2000, http://www.giss.nasa.gov/research/intro/fung.01/

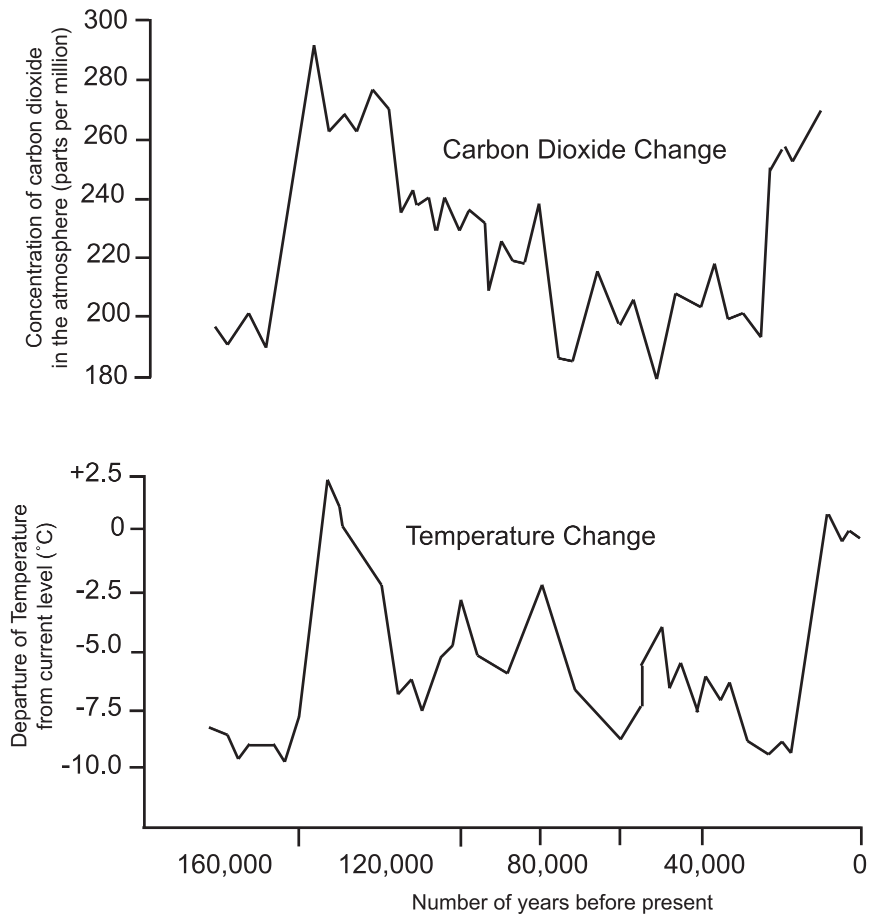


Figure 6: Long-term trends of global temperature and atmospheric carbon dioxide

Vertical scale on the bottom graph shows the temperature difference from the present average temperature (that is, the graph defines the present average temperature as zero).

Source: Barnola et al. 1987

Module 3, Investigation 3: Briefing
Are we warming Earth?

Energy (e.g., the burning of fossil fuels for heating and transportation), industrial processes (e.g., power used for manufacturing), deforestation (e.g., CO_2 released by burning forests), and agriculture (including methane released by livestock) are major sources of greenhouse gases as shown on Figure 7.

When you write your editorial at the end of this investigation, you will need to consider both sides of the global warming debate. Scientists on both sides of the issue agree that global temperatures are rising; however, they disagree on the cause. Remember, the greenhouse effect is a *fact*; if it did not exist, there would be no warmth on Earth for animal and plant production. On the other hand, the explanation that the human production of greenhouse gases is causing global warming is currently a scientific *theory*.

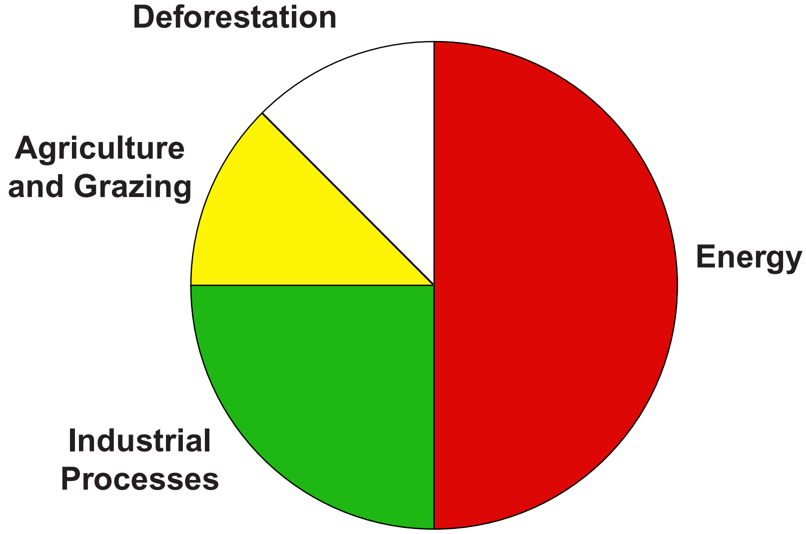


Figure 7: Sources of greenhouse-gas emissions by type of human activity

Source: World Resources Institute 1990

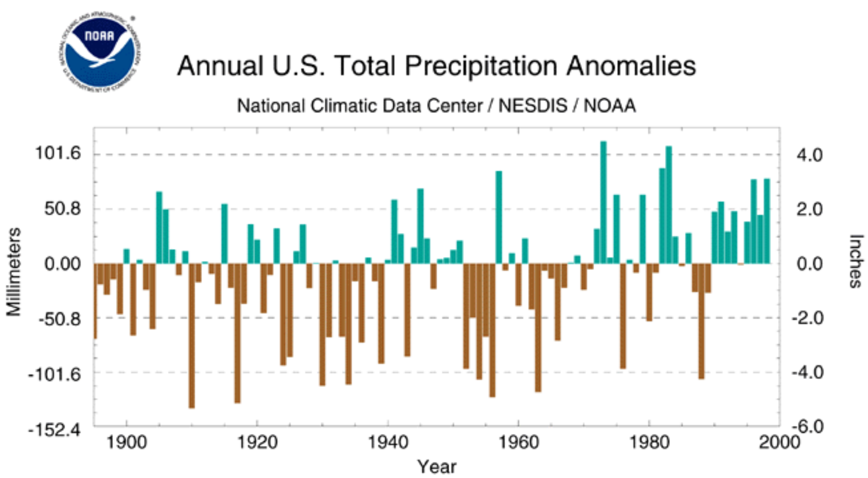


Figure 8: Annual total precipitation anomalies in the United States, 1895-1998

Source: National Climatic Data Center 2000, http://www.ncdc.noaa.gov/ol/climate/research/1998/ann/us_annual.html

Part 3: How will global warming affect physical systems?

In writing your editorial, you should include the assumed positive and negative consequences of global warming on physical and human systems. Note that a number of effects are predictions, largely because we can't be certain what will occur.

Answer Question 6 on the Log.

Along with increasing global temperatures, sea levels are expected to rise (as glaciers melt). Changes in precipitation and other local climate conditions are also expected. Some of the effects of warming temperatures are observable today as we look at annual precipitation patterns in the United States since 1895 (Figure 8). The national precipitation index expresses precipitation departure from the 60-year mean.

Module 3, Investigation 3: Briefing
Are we warming Earth?

Answer Question 7 on the Log. (This isn't easy to determine. For a rough estimate, try counting the number of years above and below the long-term average in recent decades.)

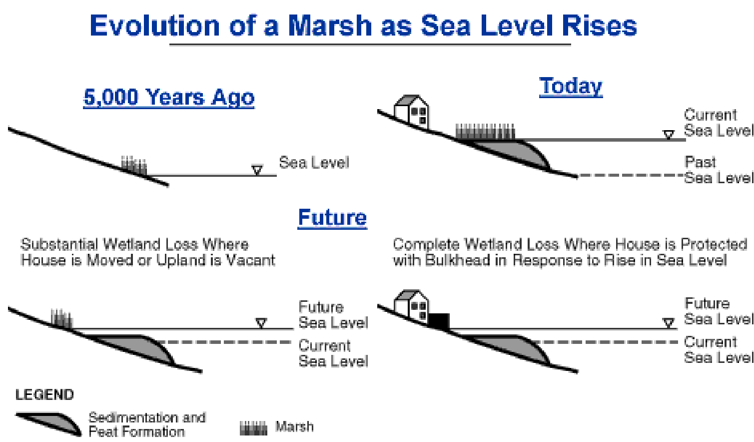


Figure 9: Predicted effect of rising sea levels upon coastal marshes

Source: U.S. Environmental Protection Agency 2000a, http://www.epa.gov/globalwarming/impacts/coastal/index.html

The United States had the fifth wettest year on record in 1998, with a national average of 828 millimeters of precipitation. The wettest year was 1973 at 863 millimeters. Considerable regional and seasonal variation in precipitation occurred throughout the year. For example, the Southeast and Great Lakes regions had their wettest January-March in 1998, and the West had its wettest January-June.

A record dry April-June 1998 resulted in drought conditions from the Southern Plains to the Gulf Coast states. The spring and summer heat and drought led to massive wildfire outbreaks in Florida. Late summer and autumn rains from tropical systems helped abate the dry conditions in the south, while drought intensified in the eastern United States. The region from the central Atlantic Coast to New York experienced the second driest July-November on record, with local water restrictions implemented in many areas.

Increases in precipitation will not be felt equally throughout the world, and it is generally agreed that while flooding may occur in some areas, continental regions are likely to get drier. This will increase the likelihood of drought in various regions. For example, the International Panel on Climate Change (IPCC) for the United Nations reported that climate change could eliminate 85 percent of the wetlands remaining in Spain and Greece (Worldwatch Institute 1997).

Rising sea levels could affect coastal marshes that are important habitats for a variety of birds, fish, and other species. A 0.6 meter rise in sea level could eliminate 17-43 percent of U.S. wetlands (U.S. Environmental Protection Agency 2000a). This effect is depicted in Figure 9.

Global warming could also change ecosystems. Forest ecosystems may be threatened, as rising temperatures reduce the diversity of tree species in forests. Forest fires are likely to become more frequent and severe if soils become drier. Changes in pest populations could further increase the stress on forest ecosystems (U.S. Environmental Protection Agency 2000a). A variety of bird and fish species may have their breeding and migratory patterns changed with changes in regional climate. Some research indicates that the waters off western Canada may warm by 2°C by 2070, which would reduce the summer range of the Pacific salmon species by 50 percent and eliminate the winter range entirely (Worldwatch Institute 1997).

Part 4: How will global warming affect human systems?

There are a number of predicted effects upon human systems from global warming. Global warming may increase the risk of some infectious diseases, particularly from diseases that only appear in warm areas. Diseases that are spread by mosquitoes and other insects could become more prevalent if warmer temperatures enabled those insects to become established farther north. Such "vector-borne" diseases include malaria, dengue fever, yellow fever, and encephalitis (U.S. Environmental Protection Agency 2000a).

Module 3, Investigation 3: Briefing
Are we warming Earth?

Perhaps the most serious effect of global warming upon human systems is the threat to regional agricultural systems. Rising temperatures and changes in precipitation patterns may radically change current agricultural production around the world. But, as was stated in Figure 4, some areas may benefit from increased CO_2 emissions.

NASA scientists are attempting to predict the impact of global warming upon agricultural production in the Mediterranean (Figure 10). The Mediterranean basin provides a good case study for analyzing regional differences in vulnerability to climate change. Mediterranean agriculture accounts for virtually all olive oil produced worldwide, 60 percent of wine production, 45 percent of grape production, 25 percent of dried nuts (mostly almonds, chestnuts, and walnuts), 20 percent of citrus production, and about 12 percent of total cereal production.

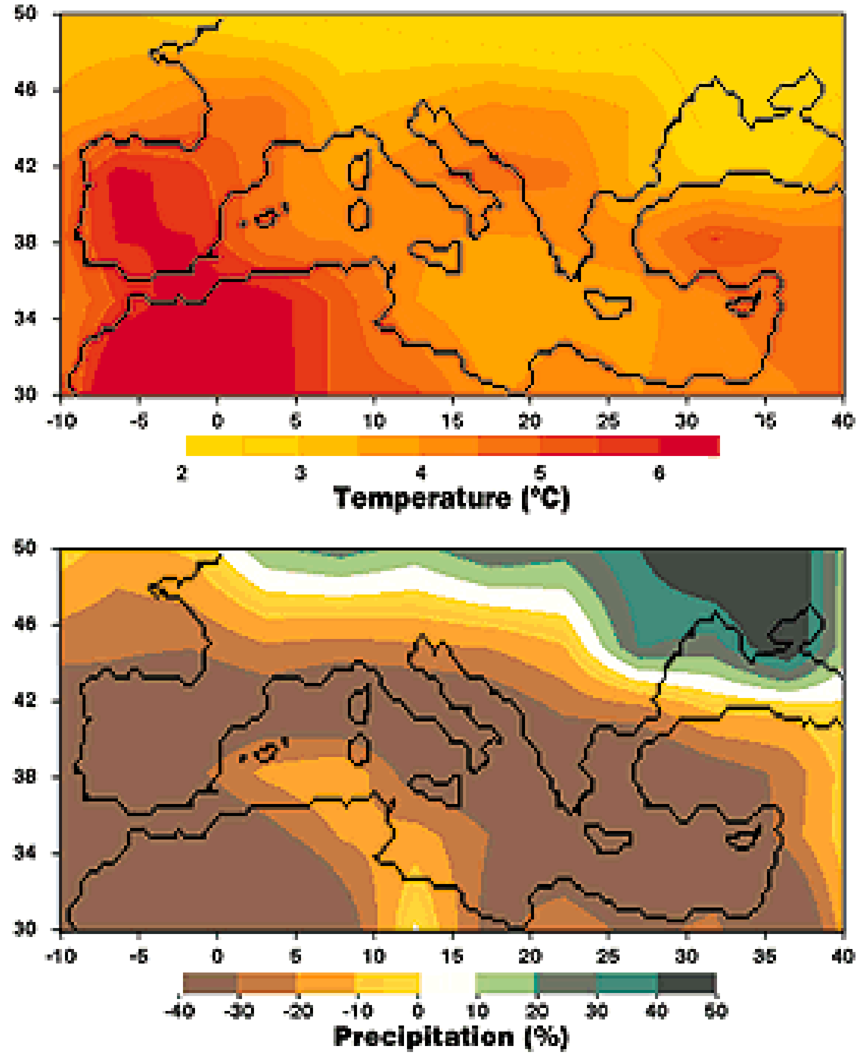


Figure 10: Summer seasonal mean temperature and precipitation changes for the Mediterranean region corresponding to a doubling of carbon dioxide

This climate might occur in the 2050s, if greenhouse gases increase very rapidly.

Source: Rosenzweig et al. 2000, http://www.giss.nasa.gov/research/intro/rosenzweig.01/

Figure 10 is a simulation by the NASA team to predict the effect of rising temperatures and precipitation upon the Mediterranean region. The increased temperatures and lower precipitation simulated for this region by the NASA GISS global climate model is driven by a scenario with rapidly increasing greenhouse gases that would adversely affect crops and water availability, critically influencing the patterns of future agricultural production.

These models predict the climate of the Mediterranean region in 2050 with a rapid increase in greenhouse gases. Although computer models can simulate the possible effects of global warming upon human systems, they are still making predictions. Unless global temperature patterns change, we will have to wait and see how agricultural systems are affected by climate change.

Answer Question 8 on the Log.

Module 3, Investigation 3: Briefing
Are we warming Earth?

After you have answered Log Question 8, review your answers to all the questions and use that information to help you organize your thoughts before you begin writing your editorial on global warming. Remember to develop your editorial around the following four questions:

1. What facts point to global warming?
2. What are the possible causes of global warming?
3. How might global warming affect physical systems?
4. How might global warming affect human systems?

References

Associated Press. 1995. Panel finds humans cause warming. [Boulder] *Daily Camera* September 10:1.

Barnola, J. M., et al. 1987. Vostok ice core provides 160,000-year record of atmospheric CO_2. *Nature*, 329(6138): 410.

Borenstein, Seth. 2000. Global warning in '99. [Boulder] *Daily Camera*. January 14: 1A and 9A.

Brown, L. R., and S. Postel. 1987. Thresholds of change. In *State of the world—1987*, edited by L. R. Brown, 3-19. New York: W. W. Norton.

Food and Agricultural Organization of the United Nations. 2000. *Factfile* http://www.fao.org/NEWS/FACTFILE

Fung, I. 2000. *Oh where oh where does the CO2 go?* NASA Goddard Institute for Space Studies. http://www.giss.nasa.gov/research/intro/fung.01/

Henderson-Sellers, A., and R. Blong. 1989. *The greenhouse effect: Living in a warmer Australia.* Kensington, NSW: New South Wales University Press.

NASA Goddard Institute for Space Studies. 2000. *Global temperature trends: Continued global warmth in 1999.* http://www.giss.nasa.gov/research/observe/surftemp/

National Climatic Data Center. 2000. *Climate 1998 annual review: Annual U.S. national overview.* National Oceanic and Atmospheric Administration (NOAA) website. http://www.ncdc.noaa.gov/ol/climate/research/1998/ann/us_annual.html

Office for Interdisciplinary Earth Studies. 1991. Science capsule. *Earthquest*, 5(1), Spring.

Rosenzweig, C., F. Tubiello, and S. Cavalieri. 2000. *Olive oil, sun-dried tomatoes, and global warming*. NASA Goddard Institute for Space Studies. http://www.giss.nasa.gov/research/intro/rosenzweig.01/

Schneider, S. H. 1991. Three reports of the Intergovernmental Panel on Climate Change. *Environment*, 33(1): 25-30.

Shea, C. P. 1988. *Protecting life on Earth: Steps to save the ozone layer*. Worldwatch Paper 87. Washington, D.C.: Worldwatch Institute.

Smith, J. B., and D. A. Tirpak. eds. 1988. *The potential effects of global climate change on the United States*. Washington, D.C.: U.S. Environmental Protection Agency.

Stevens, W. K. 1999. Weather pushes 1990s into record books. *Denver Post*, December 19:9A.

United States Environmental Protection Agency. 2000a. *Coastal zones.* http://www.epa.gov/globalwarming/impacts/coastal/index.html

United States Environmental Protection Agency. 2000b. *Flood control.* http://www.epa.gov/globalwarming/impacts/water/flood.html

Wilford, J. N. 2000. North Pole visitors find no ice. *New York Times*, August 19: 4A.

World Resources Institute. 1990. *World resources 1990-91*. New York: Oxford University Press.

Worldwatch Institute. 1997. *State of the world*. New York: W. W. Norton.

Module 3, Investigation 3: Log
Are we warming Earth?

1. Using Figure 1, describe the trend in average (mean) global surface temperatures since 1880.

2. Explain why average (mean) temperatures are used in Figure 1, as opposed to "highest" or "lowest" temperatures for that year.

3. Describe any trends that you see in the 100-year temperature record for the United States (Figure 2). Also, note the three highest *and* three lowest recorded years for temperature in the United States since 1895.

4. Describe the past and projected trends in the production of greenhouse gases.

5. Which of the greenhouse gases, documented in Table 1 and Figure 4, increased the most in the atmosphere?

Module 3, Investigation 3: Log
Are we warming Earth?

6. Brainstorm a list of possible effects on physical and human systems from increasing global temperatures.

   Effects on physical systems

   Effects on human systems

7. What is the trend in U.S. precipitation patterns?

8. In the climate change models (Figure 10), what happens to temperature and precipitation in the Mediterranean region? How would this information help you if you were a producer of olive oil or grapes?