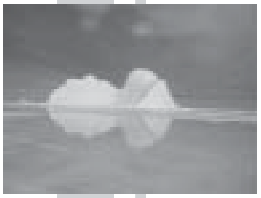
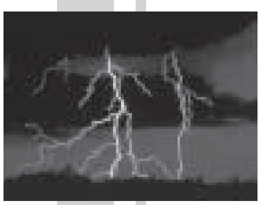


Welcome to

NASA's Earth Science Enterprise



Educational CD-ROM Activity Supplement

Introduction

Since its inception in 1958, NASA has been studying the Earth and its changing environment by observing the atmosphere, oceans, land, ice, and snow, and their influence on weather and climate. We now understand that the key to gaining a better understanding of the global environment is exploring how the Earth's systems of air, land, water, and life interact with each other. This approach—called Earth Systems Science—blends together fields like meteorology, oceanography, geology, and biology.

In 1991, NASA launched a more comprehensive program to study the Earth as an integrated environmental system. They call it NASA's Earth Science Enterprise. A major component of the Earth Science Enterprise is the Earth Observing System (EOS). EOS is series of satellites to be launched over the next two decades that will be used to intensively study the Earth, with the hopes of expanding our understanding of how natural processes affect us, and how we might be affecting them. Such studies will yield improved weather forecasts, tools for managing agriculture and forests, information for fishermen and local planners, and, eventually, the ability to predict how the climate will change in the future. Today's program is laying the foundation for long-term environmental and climate monitoring and prediction. Potentially, this will provide the understanding needed in the future to support difficult decisions regarding the Earth's environment.

Earth Science Enterprise CD-ROM

The goals of NASA's Earth Science Enterprise are to expand scientific knowledge of the Earth system using NASA's unique vantage points of space, aircraft, and ground-based platforms, creating an international capability to forecast and asses the health of the Earth system. A comprehensive education component is essential to accomplishing these goals. The Earth Science Enterprise CD-ROM has been developed to provide educators, students, and the general public with an overview of the latest research related to our global environment, while providing the necessary background material to comprehend these efforts. The viewer will encounter myriad images, animations, and movies illustrating the natural and human-induced processes affecting Earth's atmosphere, land, and oceans.

Four major sections comprise the Earth Science Enterprise CD-ROM: Land, Sea, Ice, and Air. Each section is divided into subsections highlighting the major topics related to current research. In addition, overviews of the Earth Observing System and Educational Resources are presented.

This activity supplement covers seven key areas in depth. After a topic is introduced, a student activity is described. Each activity consists of an objective, study materials and a procedure to achieve the objective. By completing these activities, the student will acquire both knowledge about Earth system science and the methodology for conducting research.

National Science Education Standards

Content Standards: 9-12

Science as Inquiry

Content Standard A – as a result of activities in grades 9-12, all students should develop:

- abilities necessary to do scientific inquiry; and
- understandings about scientific inquiry.

Physical Science

Content Standard B – as a result of activities in grades 9-12, all students should develop an understanding of:

- chemical reactions;
- motions and forces; and
- interaction of energy and matter.

Earth and Space Science

Content Standard D – as a result of activities in grades 9-12, all students should develop understanding of:

- energy in the Earth system; and
- geochemical cycles.

Science and Technology

Content Standard E – as a result of activities in grades 9-12, all students should develop:

- understandings about science and technology.

Activities

Seven activities accompany this Educator's Guide and complement the major topics highlighted on the Earth Science Enterprise CD-ROM. These activities include:

1. *Ozone* - The Sky Isn't Falling but There's a Hole Up There
   Students calculate the rate of change of ozone depletion over Antarctica

2. *Clouds* - Clouds and the Energy Cycle
   Students determine the radiative characteristics of clouds

3. *Volcanoes* - When the Sulfur Flows You Get Temperature Lows
   Students calculate the dispersal rate of the sulfur dioxide cloud associated with the eruption of Mt. Pinatubo.

4. *El Niño* - El Niño and the state of the Pacific Ocean
   Students determine an El Niño year with the use of sea surface temperature maps

5. *Sea Level* - The Highs and Lows Create the Flows
   Students determine the direction and speed of surface ocean currents

6. *Sea Ice* - Just the Cold Facts
   Students calculate seasonal changes in sea ice for the North and South pole

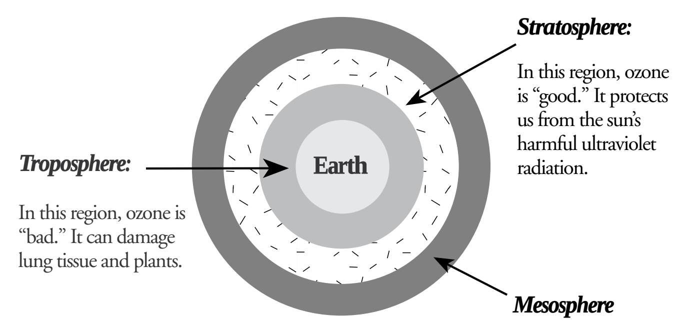
7. *Deforestation* - Loss of Habitat on the Cutting Edge
   Students evaluate the rate and consequences of tropical deforestation

Ozone

What is it, and why do we care about it?

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

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



Ozone in Earth's Atmosphere

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

Ground-level Ozone - The "Bad" Ozone

Ground-level (tropospheric) ozone forms when sunlight reacts with hydrocarbons from automobile exhaust, factory emissions and evaporated gasoline. This ozone readily forms in hot weather. On warm days, ozone concentrations can reach high levels and can be transported to other locations by the wind. Ground-level ozone is irritating to the nose and throat, and when inhaled can damage lung tissue. Relatively low amounts of ozone can cause chest pain, coughing, nausea, throat irritation and congestion. It may also enhance the effects of bronchitis, heart disease, emphysema, and asthma. It damages rubber, plastics, and all plant and animal life. Ozone alone, or in combination with sulfur dioxide (SO_2) accounts for 90% of annual crop losses in the United States that are caused by air pollution.

The Environmental Protection Agency (EPA) uses the Pollutant Standards Index (PSI) to measure five major pollutants including ground-level ozone. The PSI converts the measured pollutant concentration in a communities air to a number on a scale from 0 to 500. A 0.12 ppm (parts per million) reading for ozone would translate to a PSI level of 100. The most important number on the PSI scale is 100, since the number corresponds to the standard established under the Clean Air Act. In other words, anything above 100 is unhealthy.

The following intervals describe the PSI air quality levels.

Index Value	PSI Descriptor
0-50	good
50-100	moderate
100-200	unhealthy
200-300	very unhealthy
over 300	hazardous

Index Value	General Health Effects
0-50	None for the general public
50-100	Few or none to the general public
100-200	Mild aggravation of symptoms among susceptible people, with irritation symptoms in the healthy population
200-300	Significant aggravation of symptoms and decreased tolerance in persons with heart or lung disease; widespread symptoms in the healthy population
over 300	Early onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons. At PSI levels above 400, premature dealth of ill and elderly persons may result. Healthy people experience adverse symptoms that affect normal activity

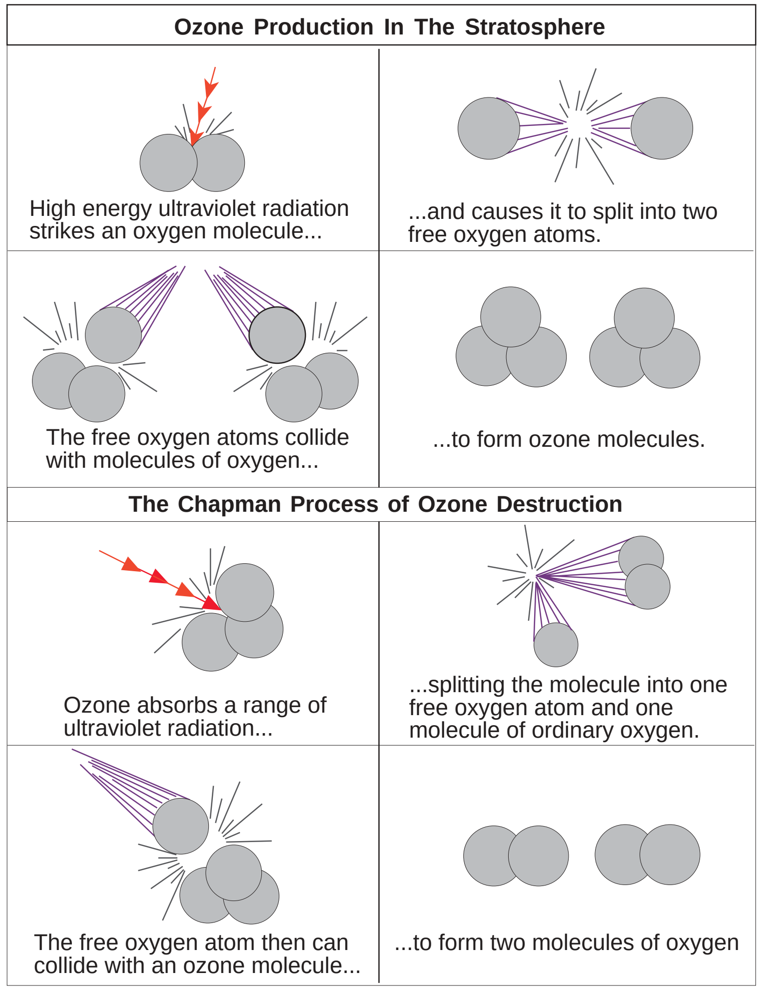
Ozone Balance in the Stratosphere - The “Good” Ozone

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

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

Natural forces other than the Chapman Reactions also affect the concentration of ozone in the stratosphere. Because ozone is a highly unstable molecule, it reacts very easily, readily donating its “extra” oxygen atom to nitrogen, hydrogen, and chlorine found in natural compounds. These elements always have existed in the stratosphere, released from both land and ocean sources.

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

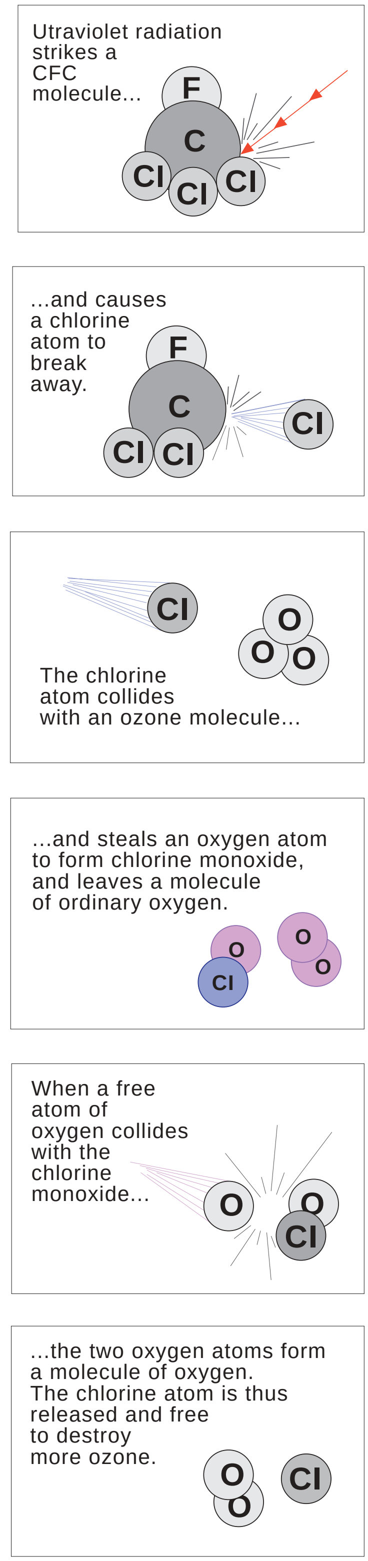


Over the Earth's lifetime, natural processes have regulated the balance of ozone in the stratosphere. A simple way to understand the ozone balance is to think of a leaky bucket. As long as water is poured into the bucket at the same rate that water is leaking out, the amount of water in the bucket will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

Starting in the early 1970's, however, scientists have found evidence that human activities are disrupting the ozone balance. Human production of chlorine-containing chemicals such as chlorofluorocarbons (CFCs) has added an additional factor that destroys ozone. CFCs are compounds made up of chlorine, fluorine and carbon bound together. Because they are extremely stable molecules, CFCs do not react easily with other chemicals in the lower atmosphere. One of the few forces that can break up CFC molecules is ultraviolet radiation. In the lower atmosphere, however, CFCs are protected from ultraviolet radiation by the ozone layer itself. CFC molecules thus are able to migrate intact up into the stratosphere. Although the CFC molecules are heavier than air, the mixing processes of the atmosphere carry them into the stratosphere.

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

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



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

Ozone Depletion

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

In the area over Antarctica, there are stratospheric cloud and ice particles that are not present at warmer latitudes. Reactions occur on the surface of the ice particles that accelerate the ozone destruction caused by stratospheric chlorine. This phenomenon has caused documented decreases in ozone concentrations over Antarctica. In fact, ozone levels drop so low in spring in the southern hemisphere that scientists have observed what they call a “hole” in the ozone layer.

In addition, scientists have observed declining concentrations of ozone over the whole globe. In the second half of 1993, for example, worldwide ozone levels were the lowest ever recorded.

Monitoring Ozone from Space

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

The Total Ozone Mapping Spectrometer (TOMS) instrument, first flown on the Nimbus-7 satellite in October 1978, makes daily, worldwide observations of the total amount of ozone in the atmosphere, measured on a Dobson scale (see next paragraph). TOMS measures sunlight that has been scattered back toward space from the atmosphere in multiple wavelengths. Since ozone absorbs ultraviolet light, the more ozone present, the less reflected ultraviolet radiation. To illustrate this principle, imagine pouring some water into a beaker and measuring the amount. Repeat the procedure, but now put a sponge between the glass and the beaker. Since the ozone acts like a sponge, absorbing the UV radiation, less gets through to the Earth's surface and also less is reflected back out to space.

One Dobson unit refers to a layer of ozone that would be 0.001 cm thick under conditions of standard temperature (0°C) and standard pressure (1013.25 millibars, the average pressure at the surface of the Earth). Thus, for example, 300 Dobson units of ozone brought down to the surface of the Earth at 0°C would occupy a layer only 0.3 cm thick! When Dobson units fall below 225, a hole is said to exist (since there is actually still some ozone in the stratosphere, it is not a hole in the traditional sense, but the amount is not sufficient to prevent considerable harmful ultraviolet radiation from reaching the surface of the Earth). With less ozone to absorb harmful ultraviolet rays, more ultraviolet radiation is received at the surface of our planet. Amounts of ozone can be compared from region to region over vast areas by color coding the measurement units from the Dobson scale.

Contrary to the image created by the term "ozone layer," the amount and distribution of ozone molecules in the stratosphere vary greatly over the globe. Ozone molecules are transported around the stratosphere much as water clouds are transported in the troposphere. Therefore, scientists observing ozone fluctuations over just one spot could not know whether a change in local ozone levels meant an alteration in global ozone levels, or simply a fluctuation in the concentration over that particular spot. Satellites have given scientists the ability to overcome this problem because they provide a picture of what is happening simultaneously over the entire Earth.

A continuing ozone monitoring program is underway using TOMS. TOMS instruments were flown on a Russian Meteor-3 polar-orbiting satellite in 1991 and on the Japanese Advanced Earth Observing Satellite-1 (ADEOS-1) in 1996. Additional TOMS instruments are scheduled to fly on several Earth Observing System (EOS) satellites in the future.

Scientists now are confident that stratospheric ozone is being depleted worldwide—partly due to human activities. However, scientists still do not know how much of the loss is the result of human activity, and how much is the result of fluctuations in natural cycles.

Predicting Ozone Levels

If scientists can separate the human and natural causes of ozone depletion, they can formulate improved models for predicting ozone levels. The predictions of early models already have been used by policy makers to determine what can be done to reduce the ozone depletion caused by humans. For example, faced with the strong possibility that CFCs could cause serious damage to the ozone layer, policy makers from around the world in 1987 signed a treaty known as the Montreal Protocol. This treaty set strict limits on the production and use of CFCs. By 1990, the growing amount of scientific evidence against CFCs prompted diplomats to strengthen the requirements of the Montreal Protocol. The revised treaty called for a complete phaseout of CFC production in the developed countries by the year 1996.

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

Seasonal Ozone Changes

Exposure Category	Index Value	Precautions
Minimal	0-2	hat
Low	3-4	sunscreen (15+)
Moderate	5-6	shady areas
High	7-9	indoors 10 AM-4 PM
Very High	10+	indoors all day

Stratospheric ozone levels vary be season and latitude. Since 1979, mid-latitude (30° - 60°) ozone levels have fallen about 5%. The creation of the ozone hole involves high concentrations of chlorine, polar stratospheric clouds, and a strong wind vortex (called the polar vortex). Ozone loss is accelerated over Antarctica because the stratosphere contains icy particles which make it difficult for chlorine and bromine to be included in "safe molecular forms" and increase their role as destructive chemicals that can break apart ozone molecules with amazing efficiency. During the polar night, when several months of darkness descend on Antarctica, temperatures plummet below -80°C. The real action begins when the Sun returns to this part of the world during springtime, energizing the chemical cycle that destroys ozone.

Health Effects of Ultraviolet Radiation

We also measure the amount of ultraviolet radiation reaching the surface. Ultraviolet light, especially UV-B, can be dangerous. It can cause immediate effects such as blistering sunburns, as well as longer-term problems like skin cancer and cataracts. Higher levels can suppress the immune system, and lower phytoplankton populations (phytoplankton comprise the bottom of the marine food web). For each 1% decrease in stratospheric ozone there is calculated to be a 2% increase in the amount of solar ultraviolet radiation reaching the ground. This could raise the number of skin cancer cases by 3% to 6% per year. In 1994, the National Weather Service and the Environmental Protection Agency developed the Ultraviolet (UV) Index as a way of quantifying the amount of exposure to ultraviolet radiation for a specific day. The index numbers range from 0 to 10+. In conjunction with the UV Index, the EPA has initiated a toll-free Stratospheric Ozone Information Hotline (1-800-296-1996). Callers can request information on how the United States is implementing stratospheric ozone policy.

The Sky Isn't Falling but There's a Hole Up There

Objective

- *Explain the formation and destruction of stratospheric ozone and its effects on people.*
- *Differentiate between tropospheric and stratospheric ozone*
- *Describe how scientists measure and categorize the amounts of stratospheric ozone*
- *Calculate the rate of change for stratospheric ozone over Antarctica*

Materials

- Ozone: What is it, and why do we care about it?
- ESE CD-ROM
- Worksheets (2) - South Polar Plot of Monthly Mean Total Ozone - October 1980 and October 1989
- Graph paper and tracing paper or a transparency of graph paper

Note: Included is a worksheet illustrating the location of Antarctica and degrees latitude. You many want to make a transparency of this. sheet to overlay the Ozone Monthly Mean plots.

Procedure

Read the chapter "Ozone: What is it, and why do we care about it?" and answer the following questions.

1. Describe the formation of stratospheric ozone.
2. Draw a picture that illustrates the destruction of stratospheric ozone by CFC's.
3. How do ice crystals impact the destruction of ozone?
4. How many DU's (Dobson Units) constitute a hole?
5. Describe the precautions you would need to take if the UV Index = 5.0.

Next, examine the two South Polar Total Ozone Monthly Mean plots showing the levels of ozone for October during two different years. Trace around the areas where the ozone level is at or below 225 DU's in October 1980. Use the graph paper to determine the number of squares occupied by the "hole." Repeat this procedure for October 1989.

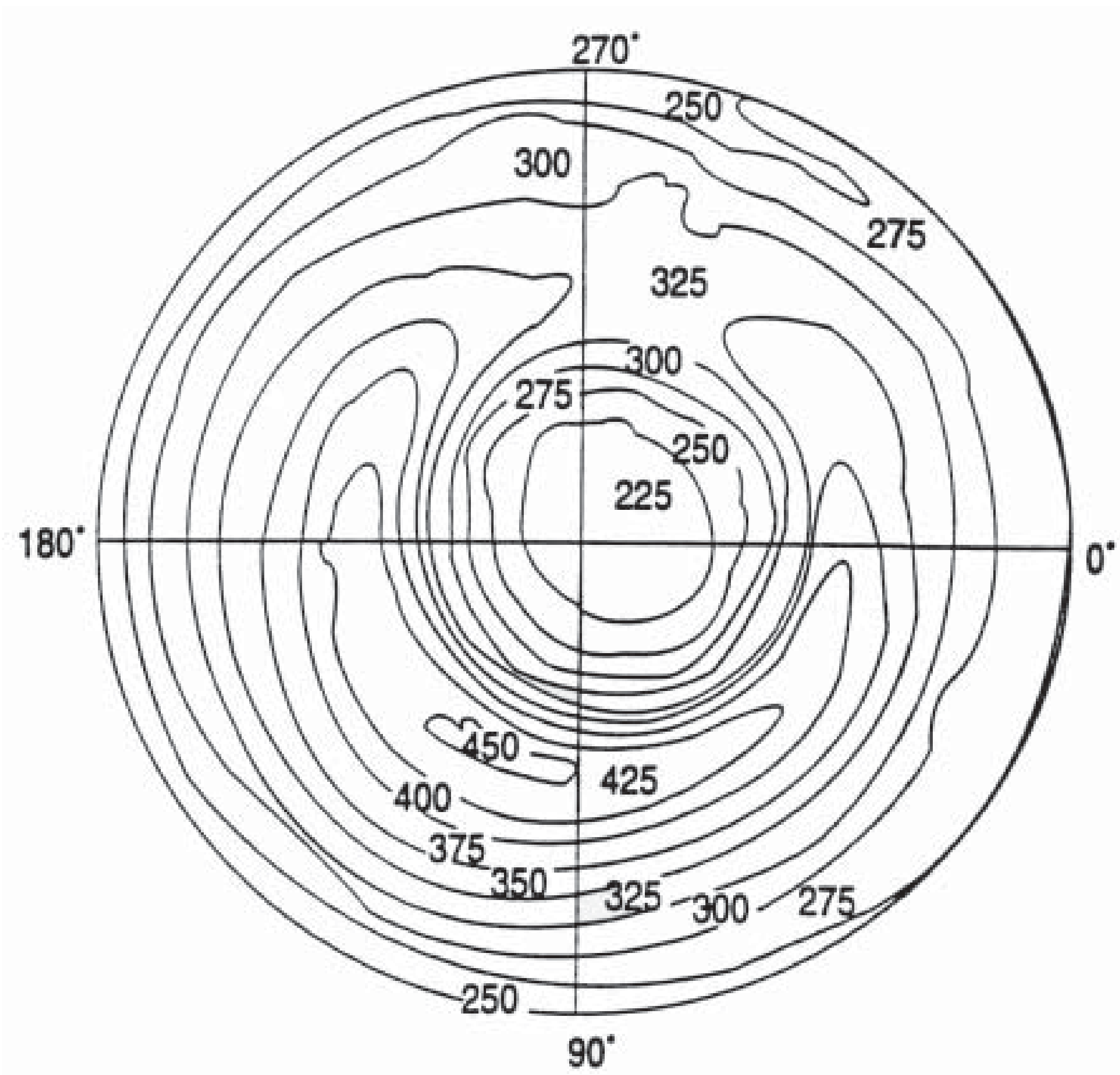
Data

1980

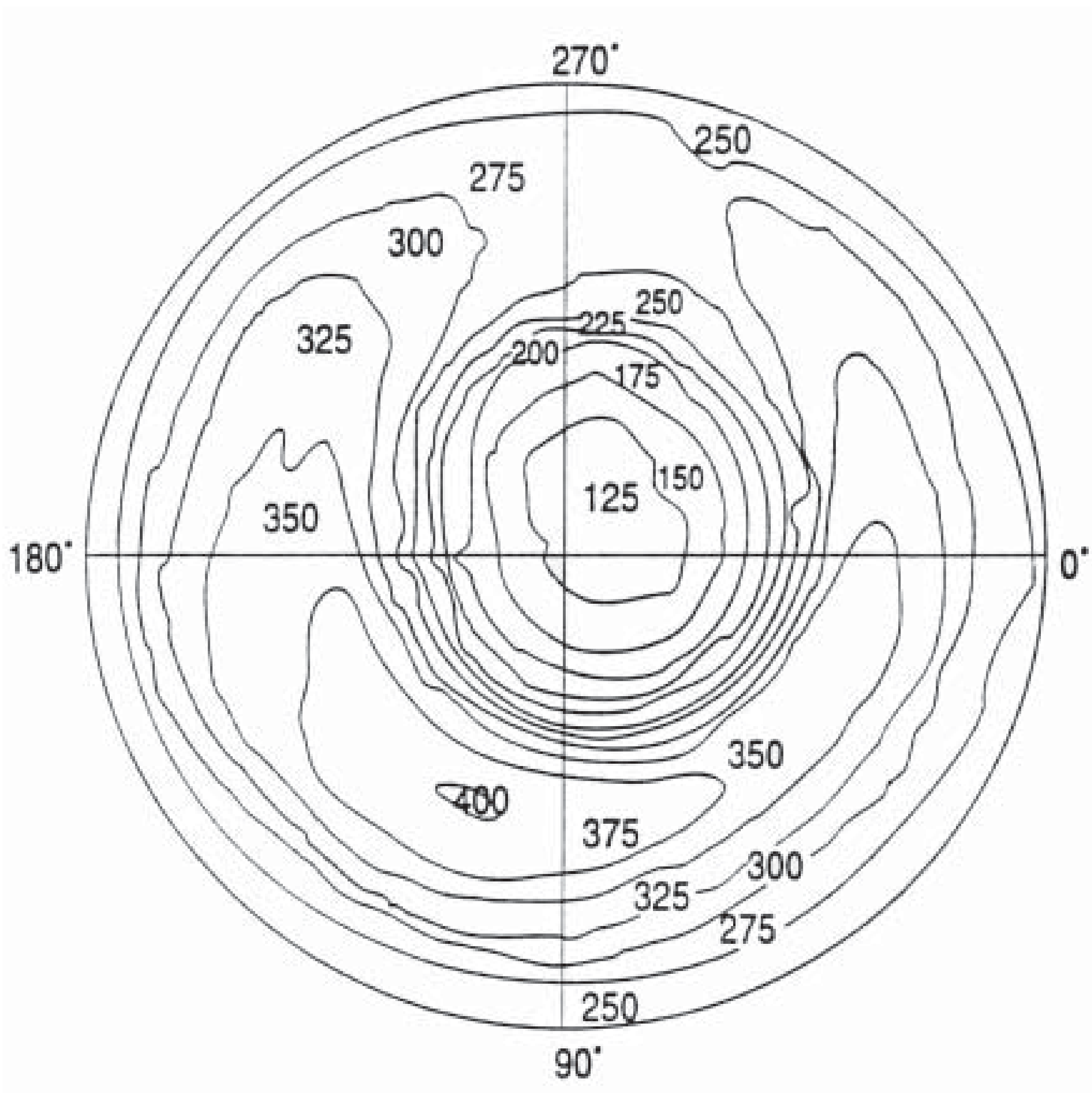
- The total number of squares in the plot = _______
- The number of squares of ozone at or below 225 DU = _____
- The number of squares of the "hole" divided by the total number of squares in the plot times 100 = % space occupied by the "hole." Hole = _____% 1980

1989

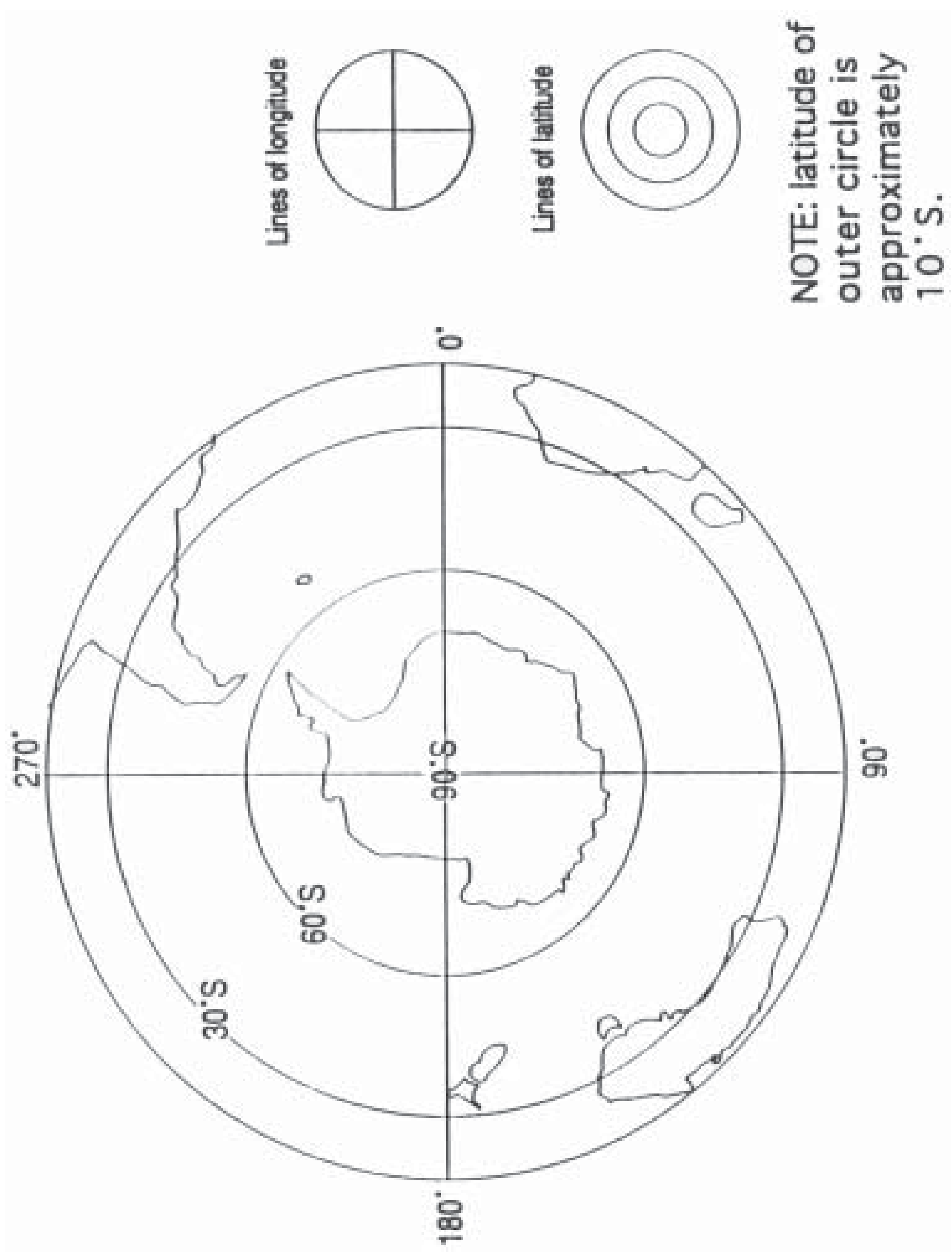
- The total number of squares in the plot = _______
- The number of squares of ozone at or below 225 DU = _____
- Hole = _____% 1989
- Calculate the % of change by dividing the 1980 % difference into the difference between the 1989 and the 1980 % differences. % change between 1980 and 1989 = _____



South Polar Plot - October 1980



South Polar Plot - October 1989



South Polar Plot - Antarctica

Ozone

After completing the Data section, answer the following questions.

1. During which year was the ozone "hole" larger?
2. If the rate of change of ozone stayed the same, predict how large the hole would be this October.
3. Explain the current theory behind this change in ozone levels.
4. List three consequences of depleted ozone levels in the stratosphere.
5. Design a poster describing the ozone hole.

View the ESE CD-ROM section on AIR: Atmospheric Chemistry and answer the following questions.

1. How has the concentration and area of the ozone hole changed between 1979 and 1991?
2. During which of the following time periods was the ozone hole largest?
   Sept 27, 1991; Oct 13, 1991; Oct 29, 1991; or Nov 14, 1991
3. In the "Eight Marches" in the Northern Hemisphere, what is thought to be the cause of a lowered ozone level?
4. What caused the increase in chlorine and bromine in the upper and lower atmosphere?
5. Why have the levels of chlorine and bromine in the lower atmosphere decreased since 1994?

Ozone

The following questions are intended to be answered through research using the ESE CD-ROM section on AIR: Atmospheric Chemistry, and reading the chapter, "Ozone: What is it, and why do we care about it?"

1. During which season are tropospheric ozone levels highest in the United States?
2. Which hemisphere has a greater concentration of tropospheric ozone?
3. Describe the formation of tropospheric ozone.
4. Explain why there is a need to decrease the levels of tropospheric ozone.
5. What are the first four layers of the atmosphere (from the ground up)?
6. In which layer are thunderstorms located?
7. How do gases such a carbon dioxide (CO_2), methane (CH_4), and chlorofluorocarbons (CFCs) contribute to global warming?
8. What accounts for the seasonal fluctuations observed in CO_2 levels?
9. List two causes of increasing levels of CH_4 between 1984 and 1994.
10. Contrast the levels of carbon monoxide (CO) during April 9-19, 1994 and September 30-October 11, 1994 in the Northern Hemisphere.
11. Where is the greatest concentration of atmospheric ozone found?
12. Describe the process by which ozone is created in the stratosphere.
13. Draw a series of pictures to explain the destruction of ozone by CFCs.
14. In which two ways has the ozone hole changed since 1979?
15. How does the cold climate at higher latitudes impact stratospheric ozone levels?
16. What is thought to be a reason that ozone in the stratosphere is being depleted globally?
17. What happened in the 1990s that could be responsible for a dip in ozone levels in 1993?
18. What occurred in 1987 to decrease the levels of tropospheric ozone?

Ozone

Procedure Questions: Suggested Answers

1. Stratospheric ozone is created when high energy UV light splits oxygen molecules apart. The freed oxygen atoms react with other oxygen molecules and form ozone.

2. Student pictures should illustrate:
   - A chlorine atom (which has been broken away from a CFC molecule) reacting with a molecule of oxygen forming a molecule of chlorine monoxide and a free oxygen a atom
   - The chlorine monoxide reacting with an oxygen molecule freeing the chlorine molecule and forming another oxygen molecule

3. Ice crystals accelerate the ozone loss. Icy particles make it difficult for chlorine and bromine to be included in "safe molecular forms" and increase their role as destructive chemicals that can break apart ozone molecules.

4. 225 Dobson Units and below is considered a hole.

5. At UV level 5 you should wear a hat, use sunscreen with a sun protection factor (SPF) of 15 and stay in shady areas.

Lab Results

Shade in the number of squares that you count using 0.5 cm x 0.5 cm graph paper. Instead of making transparencies of the graph paper, you can cut out the ozone area and trace it onto the graph paper. Decide ahead of time how to count the squares. How will you count parts of squares? Choose a method for your students and be consistent.

Ozone

Data (possible answers)

1980

- The total number of squares in the plot = 373
- The number of squares of ozone at or below 225 DU = 18
- The number of squares of the "hole" divided by the total number of squares in the plot X 100 = 4.8%

1989

- The total number of squares in the plot = 373
- The number of squares of ozone at or below 225 DU = 64
- Hole = 17.2%
- Calculate the % change by dividing the 1980 % difference into the (1989-1980) % difference. % change between 1980 and 1989 = 17.2% - 4.8%/4.8% = 258%

Evaluation Questions: Answers

1. The hole was larger in 1989.

2. This answer depends on the current year. In 9 years the ozone hole grew by 258%. Use a ratio to calculate the answer.

3. The change has been a result of man made chemicals such as CFCs that destroy ozone.

4. Three consequences of stratospheric ozone depletion are increased amount of skin cancers and cataracts and decreased phytoplankton in the oceans.

5. Students design a poster describing the ozone hole.

Ozone

ESE CD-ROM Questions: Answers

1. Since 1979 the ozone layer has declined in concentration and the ozone hole has increased in area. It fluctuated a great deal between 1979 and 1991, but in 1991 it was much larger than the entire Antarctic continent and was approximately the size of North America

2. September 1991

3. The reduction in ozone is thought to be the result of the Mt. Pinatubo eruption.

4. Chlorine and bromine increased due to the use of refrigerants, foam-blowing agents, chlorinated solvents, and fire retardants.

5. International environmental legislation has led to a decrease of ozone-depleting chemicals.

Supplemental Questions: Answers

1. June

2. Northern Hemisphere

3. Tropospheric ozone if formed when hydrocarbons from automobile exhaust, factory emissions, and evaporated gasoline react in the presence of sunlight (UV radiation).

4. Tropospheric ozone is harmful to the health of all plants and animals. Examples should be cited.

5. Troposphere, Stratosphere, Mesosphere, Thermosphere

6. Troposphere

7. Greenhouse gases warm the Earth by blocking radiation emitted from the Earth's surface into the atmosphere, preventing it from escaping into space.

Ozone

8. Photosynthesis in the spring and summer absorbs great quantities of CO_2 from the atmosphere, thus the amount of atmospheric CO_2 drops.
9. Increase in the population (human) and agricultural practices.

10. Levels of CO are highest in the spring in the Northern Hemisphere, so that the April 9-19 levels are higher than the September 30-October 11 levels.

11. Most atmospheric ozone is found in the stratosphere.

12. Ozone is created in the stratosphere when UV radiation frees an oxygen atom (O) which then reacts with an oxygen molecule (O_2) to form ozone (O_3).

13. Students' diagrams should illustrate the following: A CFC molecule is hit by UV radiation which frees an atom of chlorine (Cl). The freed atom of chlorine collides with an ozone molecule (O_3) forming chlorine monoxide (ClO) and an ordinary oxygen molecule (O_2). When chlorine monoxide collides with a free atom of oxygen (O), the two oxygen atoms form a molecule of oxygen (O_2) and the chlorine atoms is free to destroy more ozone.

14. Since 1979 the ozone hole over Antarctica has declined in concentration and increased in area. However the concentrations and areas have fluctuated from one year to another, not always proceeding in the same direction.

15. Ice particles present in the cold, dry Antarctic air act as surfaces to speed the reactions of destroy ozone.

16. Global destruction of ozone is partly due to the manufactured chemicals called CFCs.

17. In 1991 Mt. Pinatubo erupted and by 1993 sulfuric acid aerosols from the eruption had spread globally. This could have been responsible for a reduction in stratospheric ozone levels.

18. International environmental legislation, the Montreal Protocol, was passed.

Clouds

and the Energy Cycle

The study of clouds, where they occur, and their characteristics, may well be a central key to understanding climate change. Low, thick clouds primarily reflect solar radiation and cool the surface of the Earth. High, thin clouds primarily transmit incoming solar radiation; at the same time, they trap some of the outgoing infrared radiation emitted by the Earth and radiate it back downward, thereby warming the surface of the Earth.

Whether a given cloud will heat or cool the surface depends on several factors, including the cloud's altitude, its size, and the make-up of the particles that form the cloud. The balance between the cooling and warming actions of clouds is very close although, overall, averaging the effects of all the clouds around the globe, cooling predominates.

The Earth's climate system constantly adjusts in a way that tends toward maintaining a balance between the energy that reaches the Earth from the sun and the energy that goes from Earth back out to space. Scientists refer to this as Earth's "radiation budget." The components of the Earth system that are important to the radiation budget are the planet's surface, atmosphere, and clouds. The energy coming from the sun to the Earth's surface is called solar energy. Most of it is in the form of radiation from the "visible" wavelengths, i.e., those responsible for the light detected by our eyes. Visible radiation and radiation with shorter wavelengths, such as ultraviolet radiation are labeled "shortwave." Both the amount of energy and the wavelengths at which energy is emitted by any system are controlled by the average temperature of the system's radiating surfaces, plus the emission properties. The temperature of the sun's radiating surface, or photosphere, is more than 5500°C (9900°F). However, not all of the sun's energy comes to Earth. The sun's energy is emitted in all directions, with only a small fraction being in the direction of the Earth.

Energy goes back to space from the Earth system in two ways: reflection and emission. Part of the solar energy that comes to Earth is reflected back out to space in the same, short wavelengths in which it came to Earth. The fraction of solar energy that is reflected back to space is called the albedo. Different parts of the Earth have different albedos. For example, ocean surfaces and rain forests have low albedos, which means that they reflect only a small portion of the sun's energy. Deserts, ice, and clouds, however, have high albedos; they reflect a large portion of the sun's energy. Over the whole surface of the Earth, about 30 percent of incoming solar energy is reflected back to space. Because a cloud usually has a higher albedo than the surface beneath it, the cloud reflects more shortwave radiation back to space than the surface would in the absence of the cloud, thus leaving less solar energy available to heat the surface and atmosphere. Hence, this "cloud albedo forcing," taken by itself, tends to cause a cooling or "negative forcing" of the Earth's climate. The shortwave reflection by clouds is illustrated in Figure 1.

Another part of the energy going to space from the Earth is the electromagnetic radiation emitted by the Earth. The solar radiation absorbed by the Earth causes the planet to heat up until it is emitting as much energy back into space as it absorbs from the sun. Because the Earth is absorbing only a tiny fraction of the sun's energy, it remains cooler than the sun, and therefore emits much less radiation. Most of this radiation is at longer wavelengths than solar radiation. Unlike solar radiation, which is mostly at wavelengths visible to the human eye, the Earth's longwave radiation is mostly at infrared wavelengths, which are invisible to the human eye. When a cloud absorbs longwave radiation emitted by the Earth's surface, the cloud reemits a portion of the energy to outer space and a portion back toward the surface. The intensity of the emission from a cloud varies directly as its temperature and also depends upon several other factors, such as the cloud's thickness and the makeup of the particles that form the cloud. The top of the cloud is usually colder than the Earth's surface. Hence, if a cloud is introduced into a previously clear sky, the cold cloud top will reduce the longwave emission to space, and (disregarding the cloud albedo forcing for the moment) energy will be trapped beneath the cloud top. This trapped energy will increase the temperature of the Earth's surface and atmosphere until the longwave emission to space once again balances the incoming absorbed shortwave radiation. This process is called "cloud greenhouse forcing" and, taken by itself, tends to cause a heating or "positive forcing" of the Earth's climate. Usually, the higher a cloud is in the atmosphere, the colder is its upper surface and the greater is its cloud greenhouse forcing. The absorption and reemission of longwave radiation by clouds is illustrated in Figure 2.

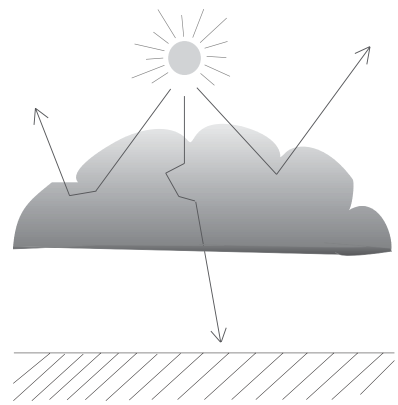


***Figure 1.** The shortwave rays from the sun are scattered in a cloud. Many of the rays return to space. The resulting "cloud albedo forcing," taken by itself, tends to cause a cooling of the Earth.*

If the Earth had no atmosphere, a surface temperature ar below freezing would produce enough emitted radiation to balance the absorbed solar energy. But the atmosphere warms the planet and makes Earth more livable. Clear air is largely transparent to incoming shortwave solar radiation and, hence, transmits it to the Earth's surface. However, a significant fraction of the longwave radiation emitted by the surface is absorbed by trace gases in the air. This heats the air and causes it to radiate energy both out to space and back toward the Earth's surface. The energy emitted back to the surface causes it to heat up more, which then results in greater emission from the surface. This heating effect of air on the surface, called the atmospheric greenhouse effect, is due mainly to water vapor in the air, but also is enhanced by carbon dioxide, methane, and other infrared-absorbing trace gases.

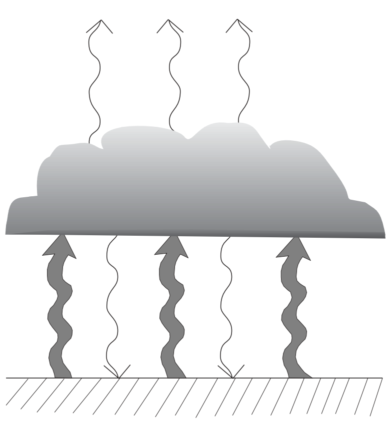


***Figure 2.** Longwave rays emitted by the Earth are absorbed and reemitted by a cloud, with some rays going to space and some going to the surface. Wavy arrows indicate longwave rays (distinguished from straight arrows, which indicate shortwave rays, as in the previous figure), and thicker arrows indicate more energy. The resulting "cloud greenhouse forcing," taken by itself, tends to cause a warming of the Earth.*

In addition to the warming effect of clear air, clouds in the atmosphere help to moderate the Earth's temperature. The balance of the opposing cloud albedo and cloud greenhouse forcings determines whether a certain cloud type will add to the air's natural warming of the Earth's surface or produce a cooling effect. As explained below, the high thin cirrus clouds tend to enhance the heating effect, and low thick stratocumulus clouds have the opposite effect, while deep convective clouds are neutral. The overall effect of all clouds together is that the Earth's surface is cooler than it would be if the atmosphere had no clouds.

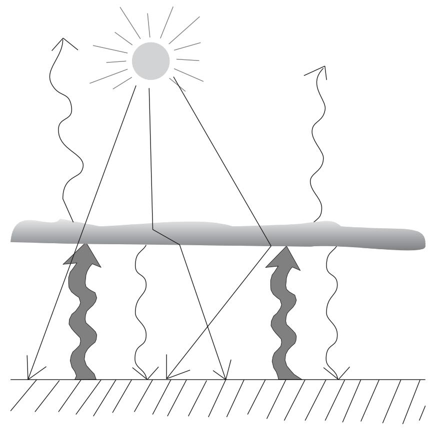


Figure 3. *Cirrus clouds transmit most of the incoming shortwave radiation, but they trap some of the outgoing longwave radiation. Their cloud greenhouse forcing is greater than their albedo forcing, resulting in a net warming of the Earth.*

High Clouds

The high, thin cirrus clouds in the Earth's atmosphere act in a way similar to clear air because they are highly transparent to shortwave radiation (their cloud albedo forcing is small), but they readily absorb the outgoing longwave radiation. Like clear air, cirrus clouds absorb the Earth's radiation and then emit longwave, infrared radiation both out to space and back to the Earth's surface. Because cirrus clouds are high, and therefore cold, the energy radiated to outer space is lower than it would be without the cloud (the cloud greenhouse forcing is large). The portion of the radiation thus trapped and sent back to the Earth's surface adds to the shortwave energy from the sun and the longwave energy from the air already reaching the surface. The additional energy causes a warming of the surface and atmosphere. The overall effect of the high thin cirrus clouds then is to enhance atmospheric greenhouse warming. The effect of cirrus clouds is illustrated in Figure 3.

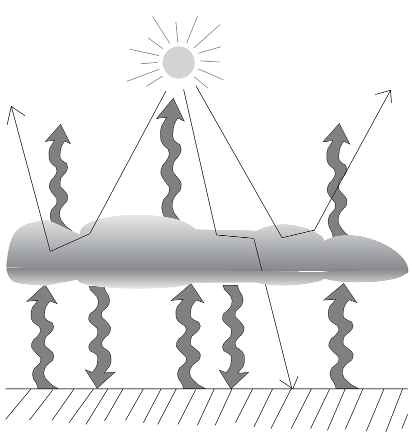


Figure 4. *Stratocumulus clouds reflect much of the incoming shortwave radiation but also reemit large amounts of longwave radiation. Their cloud albedo forcing is larger than their cloud greenhouse forcing, resulting in a net cooling of the Earth.*

Low Clouds

In contrast to the warming effect of the higher clouds, low stratocumulus clouds act to cool the Earth system. Because lower clouds are much thicker than high cirrus clouds, they are not as transparent: they do not let as much solar energy reach the Earth's surface. Instead, they reflect much of the solar energy back to space (their cloud albedo forcing is large). Although stratocumulus clouds also emit longwave radiation out to space and toward the Earth's surface, they are near the surface and at almost the same temperature as the surface. Thus, they radiate at nearly the same intensity as the surface and do not greatly affect the infrared radiation emitted to space (their cloud greenhouse forcing on a planetary scale is small). On the other hand, the longwave radiation emitted downward from the base of a stratocumulus cloud does tend to warm the surface and the thin layer of air in between, but the preponderant cloud albedo forcing shields the surface from enough solar radiation that the net effect of these clouds is to cool the surface. The effect of stratocumulus clouds is illustrated in Figure 4.

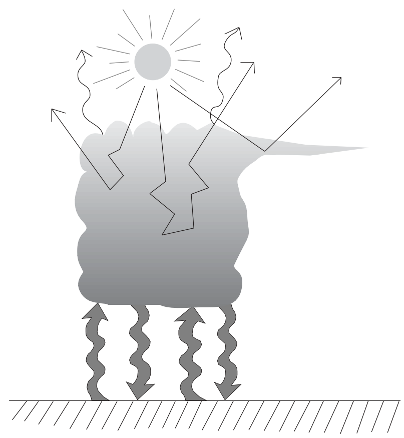


Figure 5. *Deep convective clouds emit little longwave radiation at the top but much at the bottom. They also reflect much of the incoming shortwave radiation. Their cloud greenhouse and albedo forcings are both large, but nearly in balance, resulting in neither warming nor cooling.*

Deep Convective Clouds

In contrast to both of the cloud categories previously discussed are deep convective clouds, typified by cumulonimbus clouds. A cumulonimbus cloud can be many kilometers thick, with a base near the Earth's surface and a top frequently reaching an altitude of 10 km (33,000 feet), and sometimes much higher. Because cumulonimbus cloud tops are high and cold, the energy radiated to outer space is lower than it would be without the cloud (the cloud greenhouse forcing is large). But because they also are very thick, they reflect much of the solar energy back to space (their cloud albedo forcing is also large); hence, with the reduced shortwave radiation to be absorbed, there is essentially no excess radiation to be trapped. As a consequence, overall, the cloud greenhouse and albedo forcings almost balance, and the overall effect of cumulonimbus clouds is neutral—neither warming nor cooling. The effect of deep convective clouds is illustrated in Figure 5.

Clouds—A Key Variable in Global Change

- The effect of clouds on climate depends on the competition between the reflection of incoming solar radiation and the absorption of Earth's outgoing infrared radiation.
- Low clouds have a cooling effect because they are optically thick and reflect much of the incoming solar radiation out to space.
- High thin cirrus clouds have a warming effect because they transmit most of the incoming solar radiation while, at the same time, they trap some of the Earth's infrared radiation and radiate it back to the surface.
- Deep convective clouds, on average have neither a warming nor a cooling effect because their cloud greenhouse and albedo forcings, although both large, nearly cancel one another.

NASA Missions to Study Clouds and the Energy Cycle

Studies of clouds and the energy cycle have been performed for many years as part of a number of NASA missions. In the near future, small missions addressing specific investigations are planned, leading up to the main initiative of NASA's Earth Science Program, the Earth Observing System (EOS) series of satellites beginning in 1999.

Historically, the Television Infrared Observation Satellite (TIROS) series provided a technology test to obtain daily temperature and global cloud-cover data. The Nimbus series provided the first global radiation budget analysis from space, indicating that the planetary albedo was lower and the outgoing infrared radiation higher than previously believed. The Earth Radiation Budget Experiment (ERBE) provided an improved and more-comprehensive analysis of the global radiation budget and, especially, the first global observations of cloud greenhouse and albedo forcings. The Upper Atmosphere Research Satellite (UARS) monitors the solar energy reaching the Earth and provides data on upper atmospheric chemistry and dynamics. The early Spacelab/Space Transportation System (STS) and the Atmospheric Laboratory for Applications and Science (ATLAS) payloads launched on the Space Shuttle provided data on solar energy, sun-atmosphere interactions, and upper atmospheric chemistry and dynamics.

The Next Steps

An important mission for the study of clouds is the joint U.S./Japan Tropical Rainfall Measuring Mission (TRMM). TRMM, launched in November 1997 carries the EOS Clouds and the Earth's Radiant Energy System (CERES) instrument, an improved version of the ERBE instrumentation. Also, TRMM carries instrumentation to study evaporation of water vapor into the atmosphere and its condensation to produce rainfall, processes of primary importance to the global energy budget. Several of the EOS series of satellites will carry the CERES instrument and other advanced instrumentation to provide a highly-accurate, self-consistent, and long-term (15 years) cloud and radiation data base. Analyses of these data, building on the foundation laid by previous missions, will lead to a better understanding of the role of clouds and the energy cycle in global climate change.

Clouds and the Energy Cycle

Objective

- *Determine the radiative characteristics of high, low, and vertical clouds and their affect on the Earth's radiation budget*
- *Contrast shortwave and longwave radiation*

Materials

- Clouds and the Energy Cycle
- ESE CD-ROM

Procedure

1. Read "Clouds and the Energy Cycle."
2. View the ESE CD-ROM section on AIR and review the sections on Radiative Energy Fluxes and Atmospheric Properties.
3. Based on what you have just read, fill in the chart below to classify the major cloud types and their radiative effects.

- Shortwave radiation: Determine if the cloud reflects more shortwave radiation out to space than most clouds and therefore has a high albedo or if the cloud has a relatively low albedo. Record high albedo or low albedo in the shortwave category.
- Longwave radiation: Determine if the cloud absorbs and then re-emits longwave energy. Record yes or no in this category.
- Net Effect: Record cooling, warming, or neutral.
- Composition: Record ice crystals, water droplets, or both.

Type	Shortwave	Longwave	Net Effect	Composition
Cirrus (high)				
Stratocumulus (low)				
Cumulonimbus (vertical)				

Clouds and the Energy Cycle

The following questions are intended to be answered through research using the ESE CD-ROM section on AIR: Radiative Energy Fluxes, and reading the chapter, "Clouds and the Energy Cycle."

1. Define solar irradiance.
2. What is the correlation between the sunspot cycle and solar irradiance?
3. Why is it necessary to monitor solar irradiance?

Examine the diagram of the Earth Radiation Balance to answer the following questions.

4. How many units of shortwave radiation are reflected back into space?
5. What percent of incoming solar radiation is absorbed by land and oceans?
6. The processes of evaporation and precipitation release what precent of longwave radiation?
7. Define "radiation balance".
8. Contrast the "net radiation" at low and high latitudes.
9. What is the relationship between clouds and the longwave radiation being emitted from the Earth's surface?

Examine the Outgoing Radiation figures from Shortwave Radiation in July and Longwave Radiation in July to answer the following questions.

10. Which colors show the highest amounts of outgoing radiation?
11. Why is there a large difference between the Northern and Southern Hemisphere?
12. Is there a greater amount of shortwave radiation or longwave radiation shown for the northern polar region?
13. What is the overall effect of all clouds together on the Earth's surface temperature?

Clouds and the Energy Cycle

14. List three factors that determine how a cloud re-emits radiation.

15. Define "cloud greenhouse forcing" or "positive forcing".

16. Why do cirrus clouds tend to be responsible for "positive forcing"?

17. Contrast what occurs as shortwave radiation strikes stratocumulus clouds versus cirrus clouds.

18. Contrast the net effect of stratocumulus clouds and cirrus clouds on the temperature of the Earth's surface.

19. What is the net effect of cumulonimbus clouds?

20. Explain how atmospheric aerosols affect the heat balance of the Earth.

21. Name two natural sources of aerosols and an anthropogenic source.

Examine the Direct Effect Plates 15.6 - 15.9 to answer the following questions.

22. Which colors are used to indicate cooling in plate 15.6?

23. Over which location in the Northern Hemisphere is the net cooling greatest?

24. Over which location in the Northern Hemisphere is the net warming the greatest?

25. Contrast the net effect on climate of polluted clouds and normal clouds.

26. How do natural greenhouse gases affect the Earth's surface temperature?

27. The Earth's air temperature at the surface has increased by ____ during the past century.

Clouds and the Energy Cycle

Type	Shortwave	Longwave	Net Effect	Composition
Cirrus (high)	low albedo	yes	warming	ice crystals
Stratocumulus (low)	high albedo	yes	cooling	water droplets
Cumulonimbus (vertical)	high albedo	yes	neutral	ice crystals and water droplets

Supplemental Questions: Answers

1. Solar irradiance is the energy reaching the Earth from the Sun.
2. As the number of sunspots increases, so does the amount of solar irradiation.
3. Variations of only a few tenths of a percent could cause a global surface air temperature change of 0.1 degrees.
4. 36
5. 51%
6. 23%
7. Radiation balance - The Earth's balance between the energy received from the Sun and the energy that is emitted back out to space.
8. Net radiation is positive (more radiation input than output) at low latitudes and negative at high latitudes.

Clouds and the Energy Cycle

9. Cloud layers trap some of the outgoing longwave infrared radiation from the Earth's surface. Then the clouds emit longwave radiation both outward and back to the surface.

10. Pinks and reds

11. It is summer in the Northern Hemisphere, so there is a greater amount of solar radiation reaching this area.

12. There is a greater amount of outgoing radiation.

13. Net cooling effect.

14. The cloud's temperature, thickness, and the makeup of the particles that form the cloud.

15. Positive forcing causes a heating of the Earth's climate. It is the re-emission of longwave radiation by clouds both out to space and back towards Earth.

16. Cirrus clouds are highly transparent to shortwave radiation, yet they absorb the outgoing longwave radiation. Then they emit longwave radiation both out to space and back to the Earth's surface.

17. Shortwave radiation passes readily through cirrus clouds but much of the shortwave radiation is reflected by stratocumulus clouds.

18. The net effect is that cirrus clouds warm the surface while stratocumulus clouds cool the surface.

19. The net effect is neither cooling or warming but an approximate abalance between incoming and outgoing radiation.

20. Atmospheric aerosols affect the heat balance directly by reflecting and absorbing incoming solar radiation and indirectly by influencing the clouds and by changing the atmospheric chemistry, especially greenhouse gases.

21. Natural sources include volcanoes, forest fires, and dust storms. Human sources come from burning of fossil fuels.

22. Blue and black

23. Europe

Clouds and the Energy Cycle

24. Northern Africa

25. Polluted clouds reflect more of the Sun's radiation and have more of a cooling effect than unpolluted clouds.

26. Natural greenhouse gases cause the mean temperature of the Earth's surface to be 33°C warmer than without them.

27. One half degree Celsius.

Volcanoes

Volcanoes and Global Cooling

Volcanic gases are thought to be responsible for the global cooling that has sometimes been observed for a few years after a major eruption. Recent studies have shown that when sulfate aerosols released by volcanic eruptions reach the stratosphere, they can produce a large, widespread cooling effect. The aerosols reflect a great deal of incoming solar radiation back out to space and therefore create a net cooling effect on the surface of the Earth. In fact 1992, following the eruption of Mt. Pinatubo in June 1991, was one of the coolest years on record.

The dispersal of aerosols depends on the amount ejected, the angle and strength of ejection, and the latitude of occurrence. If the volcano ejects the material out of its side, then most of the sulfur dioxide will stay in the troposphere and will not be widely dispersed. However, if the material is ejected vertically and enters the stratosphere, there are increased chances that the aerosols will be widely distributed by the prevailing wind belts of our planet. Less mixing occurs between the high latitiude wind belts and the rest of the planet, especially during the polar winters, and therefore, volcanoes that erupt in high latitudes (60°+) are less likely to have global effects. The opposite is true of mid and low latitude eruptions because there is a great amount of mixing between them.

Mt. Pinatubo, erupted on June 15, 1991. Located in the Philippines at 15.0 °N and 120.0°E, the aerosol cloud travelled westward with the prevailing winds. More than 5 billion cubic meters of ash and pyroclastic debris were ejected from the volcano. The eruption caused 847 deaths, 184 injuries, and displaced approximately 1 million people.

Figure 1 illustrates that as volcanoes erupt, they blast huge clouds into the atmosphere. These clouds are made up of particles and gases, including sulfur dioxide. Millions of tons of sulfur dioxide gas can reach the stratosphere from a major eruption. There, the sulfur dioxide converts to tiny persistent sulfuric acid (sulfate) particles, referred to as

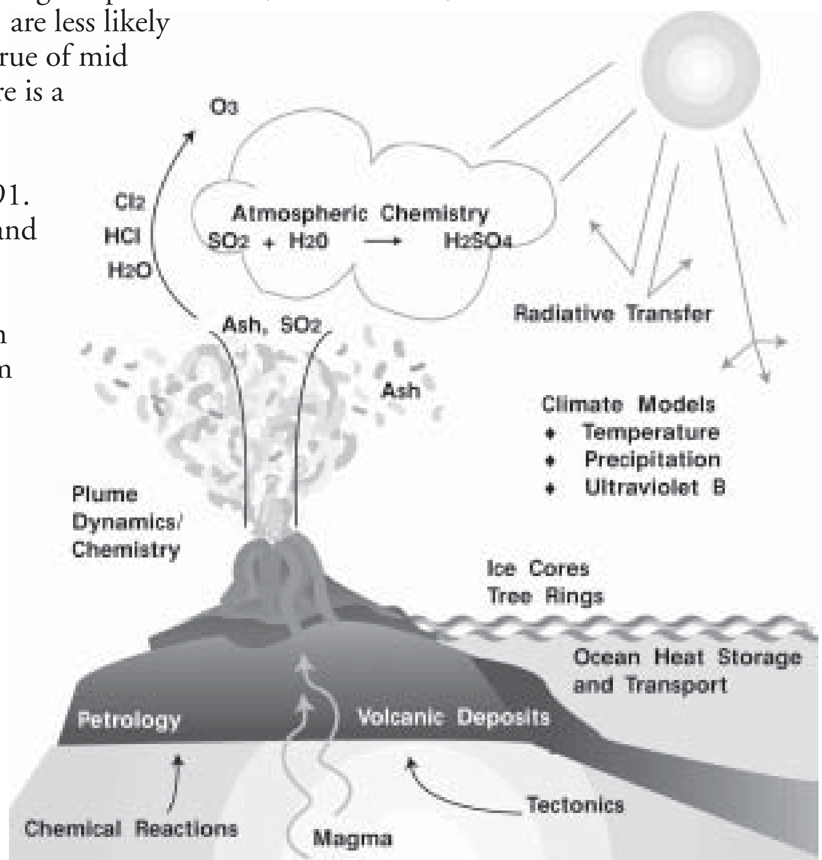


Figure 1. *Volcanism studies are an important aspect of climate research.*

aerosols. These sulfate particles reflect energy coming from sun, thereby decreasing the amount of sunlight reaching and heating the Earth's surface.

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

But, not all volcanic eruptions, not even all large volcanic eruptions, produce global-scale cooling. Mount Agung in 1963 apparently caused a considerable decrease in temperatures around much of the world, whereas El Chichón in 1982 seemed to have little effect, perhaps because of its different location or because of the El Niño that occurred the same year. (See El Niño chapter.) El Niño is a Pacific Ocean phenomenon, but it causes worldwide weather variations that may have acted to cancel out the effect of the El Chichón eruption.

Volcanoes and Ozone Depletion

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

Monitoring the Effects of Volcanoes

Space-based instruments are the only practical way to observe large and transitory volcanic eruption clouds. NASA's Total Ozone Mapping Spectrometer (TOMS) instruments have contributed significantly to our knowledge of the total amount of sulfur dioxide emitted into the atmosphere in the course of major volcanic eruptions. Figure 2 shows TOMS images of sulfur dioxide spreading across the Indian Ocean region following the eruption of Mount Pinatubo. Several weeks later the sulfur dioxide had spread around the world as observed by the Microwave Limb Sounder (MLS) instrument on NASA's Upper Atmosphere Research Satellite (UARS) (Figure 3).

In addition to detecting the sulfur dioxide from Mount Pinatubo, TOMS has made similar observations of more than 100 volcanic events, including a major eruption from the Cerro Hudson volcano in Chile in 1991. TOMS instruments were launched on a Nimbus-7 spacecraft in 1978; a Russian Meteor-3 spacecraft in 1991; and on the Earth Probe and the Japanese Advanced Earth Observing System (ADEOS) platforms in 1996. A TOMS instrument is also scheduled to fly on a Russian-3M satellite in 2000.

Data from the Stratospheric Aerosol and Gas Experiment (SAGE II) instrument on NASA's Earth Radiation Budget Satellite (ERBS) have shown that during the first five months after the Mount

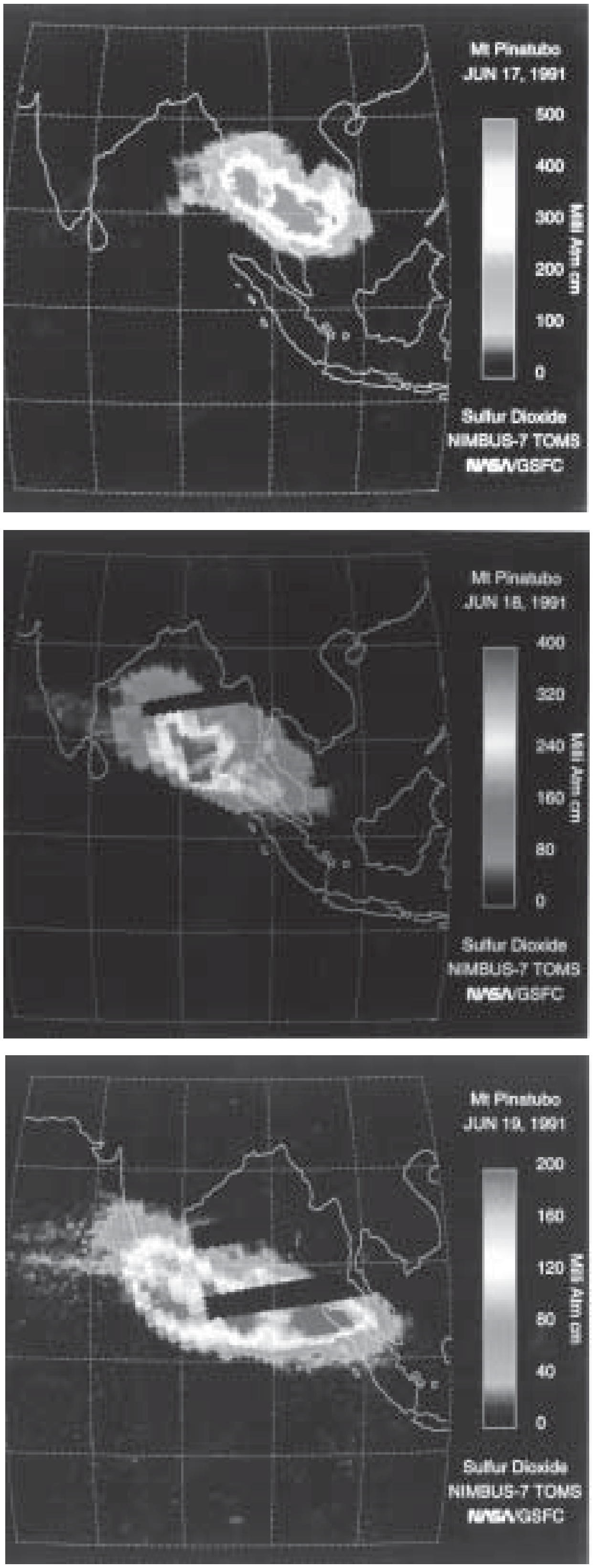


Figure 2: *Images from Nimbus -7 TOMS showing the spread of sulfur dioxide from the Mt. Pinatubo eruption. The "gray scale" indicates the thickness of the sulfur dioxide layer would have if observed at standard surface conditions of temperature and pressure.*

Pinatubo eruption, the optical depth of the stratospheric aerosol increased up to 100 times in certain locations. Optical depth is a general measure of the capacity of a region of the atmosphere to prevent the passage of visible light through it. Greater optical depths mean greater blockage of the light. In this case, the increased optical depth means that considerably less of the sun's energy can get through the cloud to warm the Earth's surface. An advanced SAGE III instrument, which will make similar observations, is scheduled to be launched on a Russian Meteor-3M spacecraft in the second half of 1998.

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

NASA Missions to Study Volcanoes

Some of NASA's past and present missions that contribute to the study of volcanoes are listed in the accompanying table. Included in the table is the Earth Observing System (EOS), the key element of NASA's Earth Science Enterprise. The first launch in the series of EOS satellites is scheduled to take place in 1998.

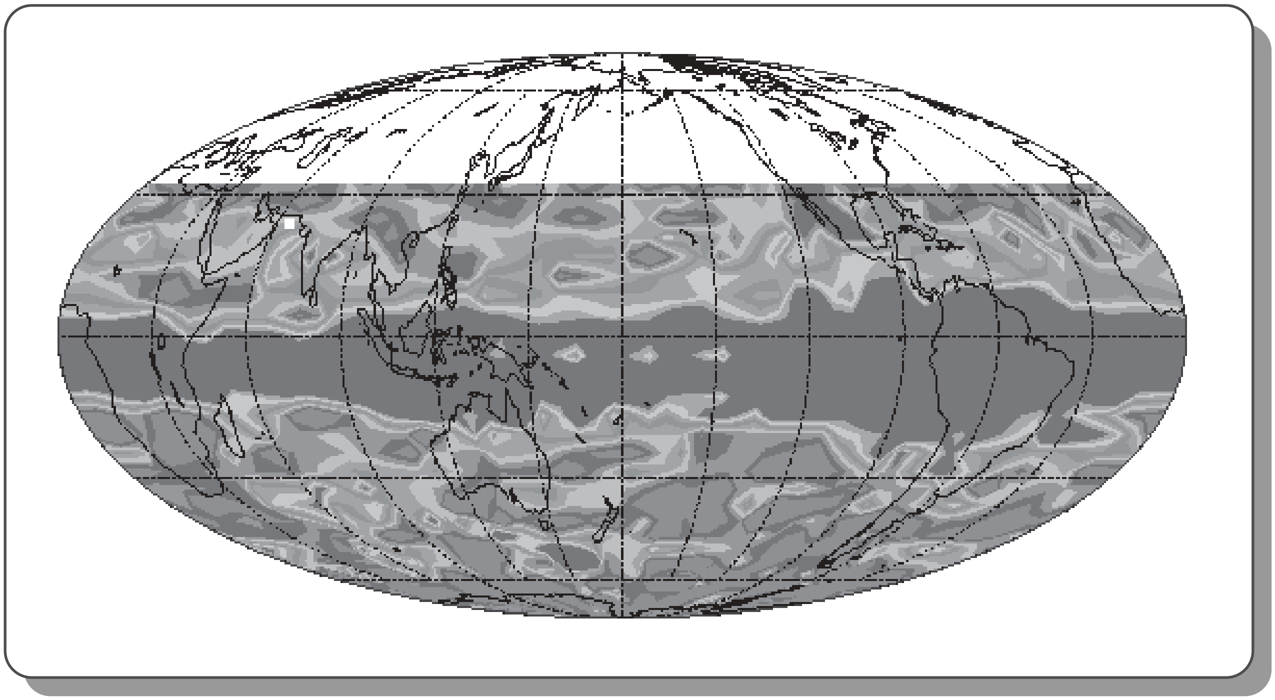


Figure 3. *Images from the UARS satellite—sulfur dioxide cloud from Mt. Pinatubo on September 23, 1991, after dispersal around the world.*

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

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

Glossary of Chemistry

Cl_2	chlorine molecule
HCl	hydrogen chloride
H_2O	water
O_3	ozone
H_2SO_4	sulfuric acid
SO_2	sulfur dioxide

When the Sulfur Flows-You Get Temperature Lows

Objective

- *Calculate the rate of sulfur dioxide dispersal after the 1991 eruption of Mt. Pinatubo*

Materials

- Volcanoes and Global Climate Change
- ESE CD-ROM
- Satellite images of Mt. Pinatubo's sulfur dioxide cloud for June 17; June 18; June 19, 1991
- Ruler
- Atlas

Procedure

Use the images in Figure 2 to answer the following questions.

1. Use an atlas to label the latitude and longitude lines on the Figure 2 images.
2. On June 15, 1991 Mt. Pinatubo erupted. Its location is 15°N and 120°E. Find the western-most edge of the cloud of sulfur dioxide and record the longitude in degrees for June 17, 1991.
3. Calculate the velocity of the cloud between June 15 and June 17, 1991.
4. Record the western-most edge of the cloud for June 18, 1991.
5. Calculate the velocity of the cloud between June 15 and June 18.
6. Repeat #3 with the image labeled June 19th.
7. Calculate the velocity of the cloud between June 15 and June 19.

$$\text{Distance (along latitude)} = 111\text{ km}\,(\cos\phi)(\Delta\theta)$$

ϕ = latitude in degrees
θ = longitude in degrees

Velocity = distance/time

When the Sulfur Flows- You Get Temperature Lows

1. Compare the initial rate of dispersal from June 15 to June 17 to the rate of dispersal between June 15 and June 19.

2. The circumference of the Earth is 39,840 km (24, 900 miles). Approximately how long would it take the cloud to circle the globe assuming it maintains the velocity obtained in #6?

3. How did the velocity of sulfur dispersal change over time?

4. What factors determine the rate of dispersal?

5. Explain why a volcano erupting near the polar regions would generally not present a global threat

When the Sulfur Flows-
You Get Temperature Lows

1. Besides changing the topography of our planet, in what way do volcanoes affect our climate?

2. Mt. pinatubo erupted in June 1991. Why was 1992 (versus 1991) the coolest year since 1986?

3. How do the sulfate particles from a volcanic eruption influence the ozone layer?

4. Examine the September 23, 1991 image of "Mt. Pinatubo Sulfur Dioxide." Where was the concentration of sulfur dioxide greatest?

5. The sulfate particles traveled 5500 km in 36 hours. Calculate the rate of dispersion and explain the color legend in the image of "Mt. Pinatubo Sulfur Dioxide Clouds (TOMS)."

1. Twenty million tons of sulfur dioxide were released during the eruption of Mt. Pinatubo. This eruption contributed to lowering average global temperatures by 0.5°C by the following summer. Another possible consequence of the eruption is the destruction of stratospheric ozone (the protective blanket that shields life from the harmful effects of UV light). Write a brief story for a newspaper explaining the differences between the eruption of a volcano like Mt. Tambora, which is located near the equator, and Mt. Redoubt, which is located at 60°N.

2. Volcanic eruptions have both positive and negative consequences. Research this topic on the Internet or in your library. Discuss two positive consequences of volcanic eruptions.

When the Sulfur Flows-
You Get Temperature Lows

Procedure: Answers

2. 90°E

3. 1608.27 km/day
   - 111 km (cos 15° = .966)(change in longitude = 30°) = 3216.53 km
   - 3216.53 km/2 days = 1608.27 km/day

4. 80°E

5. 1429.57 km/day
   - 111 km (cos 15° = .966)(change in longitude = 40°) = 4288.71 km
   - 4288.71 km/3 days = 1429.57 km/day

6. 60°E

7. 1608.26 km/day
   - 111 km (cos 15° = .966))(change in longitude = 60°) = 6433.07 km
   - 6433.07 km/4 days = 1608.26 km/day

Evaluation: Answers

1. The cloud slowed down between June 17 and June 18 and then increased in velocity.

2. 39, 840 km/1608 km/day = 24.78 days

3. It stayed about the same.

4. The latitude of the volcano, whether it erupts vertically or horizontally, the wind speed, and the contents of the eruption.

5. The polar air circulation is isolated and the contents of the eruption would stay in higher latitudes.

When the Sulfur Flows-
You Get Temperature Lows

1. Particles from volcanic eruptions reflect the incoming solar radiation and cool the planet.

2. The particles took time to encircle the globe and then disperse to other latitudes.

3. Sulfate particles help to transform CFC's into a more active from that can cause more rapid ozone depletion.

4. Sulfur dioxide concentration was greatest in the tropics after the Mt. Pinatubo eruption.

5. 152 km/hour. The colors are used to show the thickness of a vertical column of sulfur dioxide. Reds indicate a greater thickness and blues a lesser thickness.

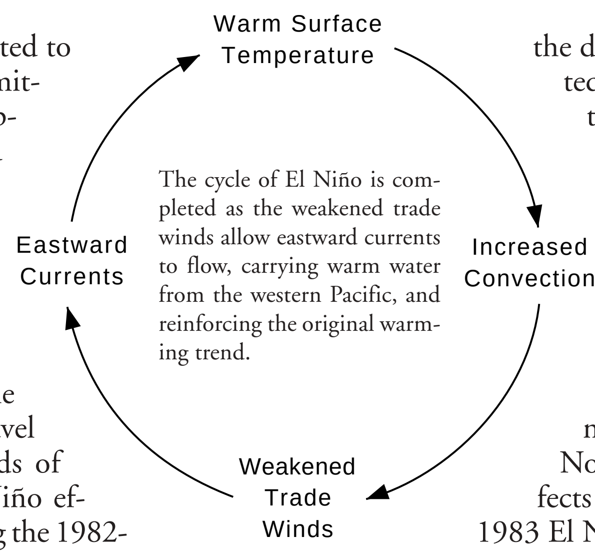
El Niño

The Child

Fishermen who ply the waters of the Pacific off the coast of Peru and Ecuador have known for centuries about the El Niño. Every three to five years during the months of December and January, fish in the coastal waters off of these countries virtually vanish, causing the fishing business to come to a standstill. South American fishermen have given this phenomenon the name El Niño, which is Spanish for "The Child," because it comes about the time of the celebration of the birth of the Christ Child.

An understanding of the complex processes at work to produce the El Niño requires information about phenomena occurring all across the tropical Pacific, not just its eastern boundary, the west coast of South America. Remote sensing, particularly from the weather satellites, has been the source of data that finally has made it possible to understand the interactions between atmospheric winds and oceanic temperatures and currents that lead to the El Niño.

Worldwide Effects



The cycle of El Niño is completed as the weakened trade winds allow eastward currents to flow, carrying warm water from the western Pacific, and reinforcing the original warming trend.

El Niño effects are not limited to the disturbed areas off of Peru and Ecuador. They can be transmitted great distances. In many parts of the world, the disruption of normal climate can have tragic and/or profound economic consequences. El Niño has been shown to be related to the unusual flooding in Texas in the winter of 1991-1992 and to the anomalous warmth experienced in the southeast United States in the same period.

Nightly cloud images on television news from weather satellites show us the paths followed by the storms that cross the Pacific and travel northward from equatorial regions to the central lands of North America. Important indirect or secondary El Niño effects have been noted in other locations worldwide. During the 1982-1983 El Niño, there were huge drought-related fires in Borneo and Australia; drought-related eradication of sea bird populations on islands in the Pacific; flooding and landslides in Peru, Ecuador and in the Colorado River basin of the United States; 6 tropical cyclones in Tahiti; devastation of coral reefs throughout the Pacific; and drought, disease, and malnutrition in South Africa.

Closer to home El Niño years have been associated with changing North Pacific atmospheric and oceanic currents bringing warmer waters to the west coast of Washington, Oregon, and Callifornia. These changes have been responsible for increased shark attacks off the Oregon coast, increased spinal injuries in California (due to weather-altered coastal sea floors that fooled surfers), and changes in salmon populations. In addition, the east coast of the United States has experienced warmer and wetter springtime conditions, increasing the mosquito population and encephalitis cases. Changing weather patterns have driven mice, and therefore snakes into Montana, increasing snake bite incidents. Cooler and wetter springtime conditions in New Mexico have led to a rise in bubonic plague as the rodent population increased.

Air/Sea Interaction

A key element of the El Niño phenomenon is the interaction between the winds in the atmosphere and the sea surface. Without this air/sea interaction, there would be no El Niño. Taking advantage of observations from the National Oceanic and Atmospheric Administration (NOAA) weather satellites, scientists have been able to track shifting patterns of sea surface temperatures. The pool of warm waters that normally resides in the western waters of the Pacific has been seen to drift eastward toward the western coast of South America. This foretells the advent of an El Niño.

NASA satellite images also help us see the shifting patterns of storms over the equator that are a consequence of the shifting locations of

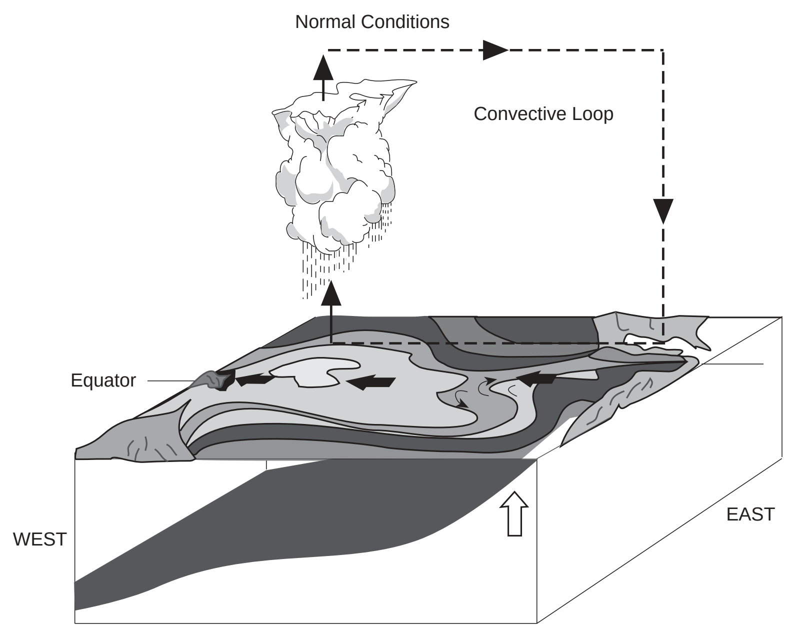


Figure 1. *Normal conditions over the Pacific basin.*

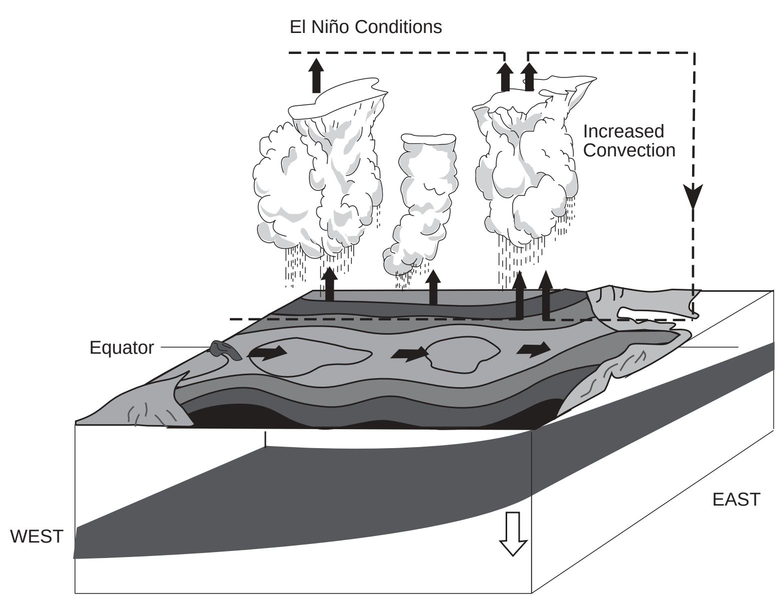


Figure 2. *Disturbed conditions over the Pacific basin during an El Niño.*

the warm water pool. Towering cumulus clouds, reaching high into the atmosphere with multiple regions of strong up- and- down vertical (convective) motions, form and move eastward across the Pacific as they are generated by the warm surface waters. This movement of the powerfully active convective regions alters the surface winds, and weakens the normally prevailing east-to-west trade winds. (See Figures 1 and 2.)

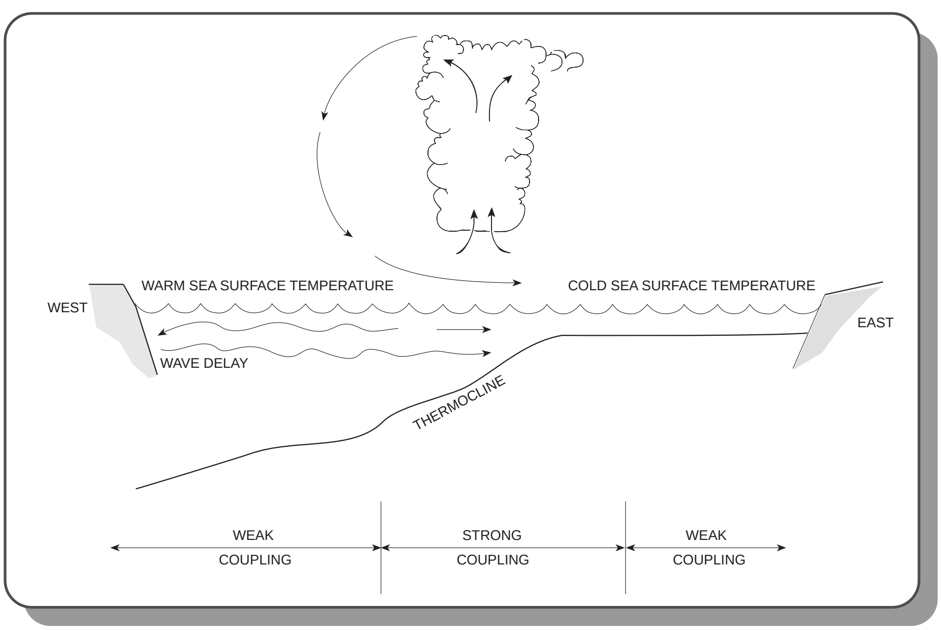
Space Observations Pin Down the El Niño Phenomenon

Scientists at the Goddard Space Flight Center and elsewhere have used numerical models and theoretical studies to understand the processes that lead to El Niño. Comparison with data has shown the sequence of events leading up to El Niño.

In normal years, when there is no El Niño, the trade winds tend to blow from east to west across the waters of the eastern Pacific. They tend to drag the surface waters westward across the ocean. In turn, this causes deeper, colder waters to rise to the surface along the coast. The "upwelling" of deep ocean waters brings with it nutrients that otherwise would lie near the bottom of the ocean. The fish population living in the upper waters is dependent on these nutrients from below for survival.

During an El Niño, the westward trade winds weaken, causing the upwelling of deep water to cease. The consequent warming of the ocean surface further weakens the trade winds, and strengthens El Niño. Without upwelling, the nutrients from the deep water are no longer available. This signals a severe reduction in the fishing industry until the time that normal conditions return.

Prediction of El Niño events is now the focus of a major scientific initiative. The prediction of El Niño requires sophisticated numerical models to simulate: 1) the changes within the ocean that cause surface



Schematic of the main processes thought to produce El Niño. Above-normal sea surface temperatures produce increased precipitation and changes in atmospheric circulation. These tend to maintain the warm temperatures by driving oceanic currents. Some of these effects are immediate; others act after the forced signal reflects from the western boundary and returns to the region of strong coupling.

temperatures to warm; 2) the changes in atmospheric convection and clouds due to surface warming; and 3) the changes in surface winds that are caused by the convective disturbances. The societal impacts of accurately forecasting El Niño up to a year in advance are huge, allowing economic and agricultural policy makers to adapt to short-term climate fluctuations in a beneficial way. Satellite observations will continue to play a crucial role in ensuring the success of these forecasts, by providing accurate measurements of the present conditions in the region, an essential first task for prediction.

NASA Missions to Study El Niño

Over the years, several NASA missions have studied the effects associated with El Niño, such as changes in sea-surface temperature (SST) and cloud cover changes. These studies are augmented by data from operational satellites of the National Oceanic and Atmospheric Administration (NOAA).

Initial efforts at mapping SST and cloud cover were conducted using data from NASA's Nimbus series of satellites. The four-channel Advanced Very High Resolution Radiometer (AVHRR), flown on NOAA's TIROS-N weather satellite in 1978 and on the NOAA-6 satellite in 1979, greatly increased the accurate measurements of El Niño effects. ("Four channel" means that the instrument views in four different parts of the electromagnetic visible and infrared spectrum.) Still further increases in accuracy resulted when a fifth channel was added to the AVHRR instrument flown on NOAA-7 in 1981, and on subsequent NOAA satellites. The fifth channel improved the measurement of SST by providing corrections for atmospheric water vapor that otherwise would have interfered with the temperature measurements.

The joint U.S.-French TOPEX/Poseidon mission was launched in 1992 and is providing global determinations of changes in ocean surface currents that are related to the El Niño phenomenon. The currents are determined from changes in ocean surface elevations measured by altimeters on TOPEX/Poseidon with accuracies of a few centimeters.

NASA has initiated a "Pathfinder Program" to make higher-quality data available from past and current missions. These efforts will lead up to the Earth Observing System (EOS), the main initiative of NASA's Earth Science Enterprise. The first in the series of EOS satellites will be launched in 1998.

The joint U.S.-Japanese Tropical Rainfall Measuring Mission (TRMM), launched November 27, 1997 uses for the first time, both active (radar) and passive microwave detectors from space to provide measurements of precipitation, clouds, and radiation processes in lower latitudes, including the portions of the Pacific Ocean where El Niño occurs.

A NASA scatterometer called NSCAT flew on the Japanese Advanced Earth Observing System (ADEOS) spacecraft, which was launched in August 1996. NSCAT provided very high quality data on the speed and direction of ocean-surface winds worldwide. Unfortunately, after nine months in orbit, a spacecraft failure brought to an end the stream of extremely valuable NSCAT data. Recognizing the important contributions to Earth science made by NSCAT, NASA now plans to launch a copy of the new SeaWinds scatterometer as early as November 1998 as part of a dedicated mission named QuikSCAT to bridge the gap remaining before launch (planned for August 1999) of the Japanese spacecraft designated ADEOS II, which will also carry a SeaWinds instrument.

In addition to the scatterometer measurements, which use active microwave radar systems to determine surface wind speeds and directions over the ocean, surface wind speeds are also being obtained from a passive microwave sensor on a Department of Defense spacecraft. The instrument is called the Special Sensor Microwave/Imager (SSM/I).

Key sources of Pathfinder data related to El Niño are data from the five-channel AVHRRs flown on NOAA-7, 9, and 11. These historic data sets cover the period 1981 through 1992 and beyond and will permit more-accurate SST determinations than were previously available. These data are important to the development and testing of a new generation of computer models in which the interacting processes of the land, the atmosphere, and the oceans are coupled. These coupled models will lead the way to an increased understanding of phenomena such as El Niño and the teleconnections that link El Niño with changes in weather patterns throughout the world.

NASA's SeaWiFS (Sea-viewing Wide Field of View Sensor) was launched on the OrbView-2 satellite in August 1997. The SeaWiFS sensor is designed to detect ocean color, which is an indicator of microscopic plant life in the ocean. The growth of such plants (called phytoplankton) is affected by the changes in sea surface temperature that are related to El Niño.

With the launch of the EOS satellites, starting in 1999, we will have the means to collect and analyze the most-comprehensive data set ever acquired for the development of coupled models. This data set will increase markedly our understanding of the causes and effects of such large-scale ocean-atmosphere phenomena as El Niño.

EL Niño and the state of the Pacific Ocean

Objective

- *Contrast Pacific Ocean temperature patterns during an El Niño and non El Niño year*
- *Predict the effects of an El Niño on weather patterns over the Pacific Ocean*
- *Correlate El Niño with global weather changes, econimic impacts, and health consequences*

Materials

- El Niño
- ESE CD-ROM
- Worksheets (2) - Pacific Ocean Temperature Maps
- Colored Pencils

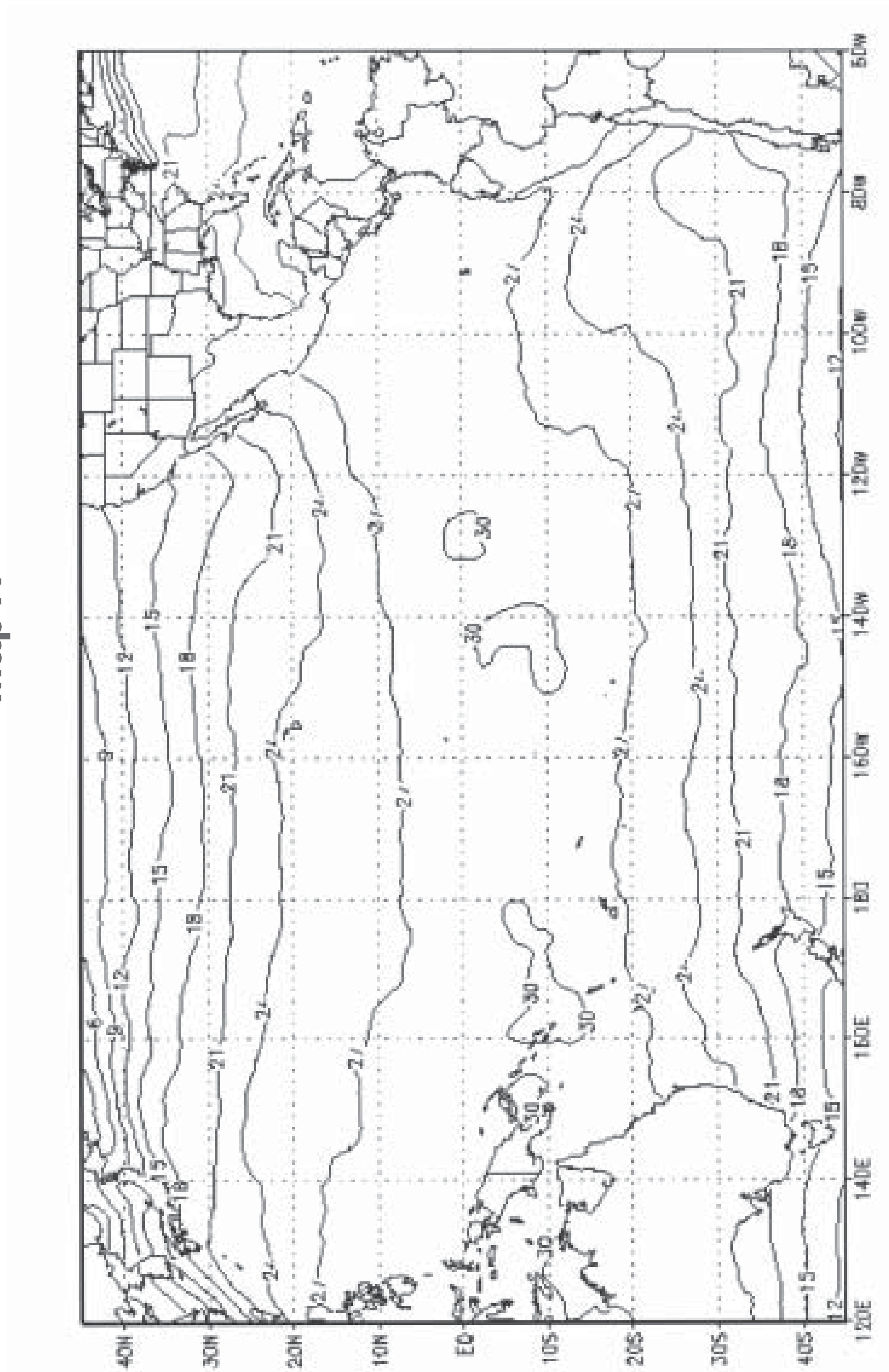
Procedure

1. Read the chapter “El Niño”
2. Maps A and B show contours of sea surface temperatures for the Pacific Ocean at different times. Using the color key, color in the sea surface temperatures on both maps.
3. View the ESE CD-ROM section on “SEA: Ocean Topography and Air-Sea Exchange”
4. Answer the Evaluation Questions

Color Key (in °C)

<6	Dark Purple
6-9	Purple
9-12	Dark Blue
12-15	Light Blue
15-18	Yellow
18-21	Light Green
21-24	Dark Green
24-27	Orange
27-30	Light Red
30>	Dark Red

Map A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80W
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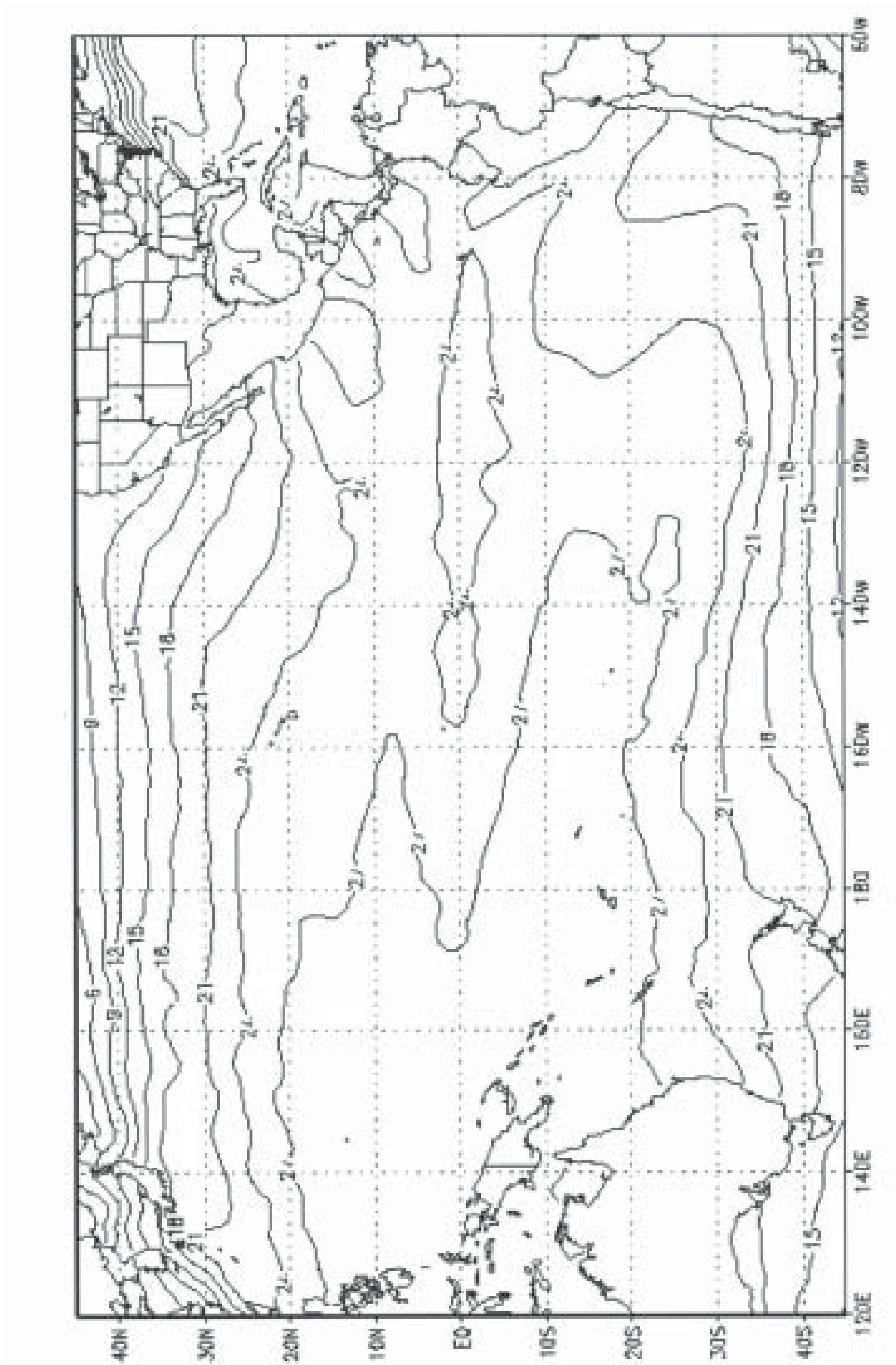
Map B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100W
80W
60W

EL Niño and the state of the Pacific Ocean

1. When was El Niño first recognized, by whom, and how often do they occur?

2. Based on the sea surface temperature maps you have colored, which Pacific Ocean map is not an El Niño year and which map is an El Niño year. Why?

3. What happens to the fish population off the Pacific coast of South America during an El Niño year? Speculate on the economic impacts.

4. Give three examples of global changes in weather patterns associated with an El Niño.

5. How does El Niño influence thunderstorm development in the eastern tropical Pacific?

6. What climatic effects are felt in Indonesia during El Niño events?

7. What is SST? How is it measured? What are typical units?

Extension

Write a brief newspaper article describing suggestions you would make to people living in Australia with an El Niño predicted for the coming year.

EL Niño and the state of the Pacific Ocean

The following questions are intended to be answered through research of the ESE CD-ROM section on "SEA."

1. Explain the important role played by our ocean's currents.

2. How does the "Coriolis Force" influence the direction of sea currents?

3. Why is it important to study changes in tropical ocean currents?

Examine "Gulf Stream Currents" to answer questions 4, 5, and 6:

4. Which color represents the warmest water temperature?

5. Using an atlas, determine the latitude at which the Gulf Stream begins to cool. (Keep in mind that this represents a transfer of energy from the warmer ocean to cooler ocean water and/or to the air).

6. Why is it important to understand the role and specifically the amount of carbon dioxide that the ocean can absorb?

7. Contrast the flow of ocean water before and during an El Niño.

8. Describe the shift in rain patterns associated with the El Niño.

9. The difference in atmospheric temperature over the central Pacific causes shifts in atmospheric patterns too. List some areas affected by these shifting patterns.

10. Compare the abundance of phytoplankton in Baja during the summer and fall.

11. What is the connection between sea surface temperature and ocean circulation?

12. Use the tabs on the CD to contrast the sea surface temperatures in January and July 1994. (Pacific and Atlantic Oceans)

13. Contrast the sea surface temperatures in the southern Pacific during an El Niño in 1983 and one year later when the temperature is back to normal.

EL Niño and the state of the Pacific Ocean

14. List three global results of anomalies such as El Niño.

15. Explain how wind speed is determined from satellite observations.

16. Since there is a high degree of correlation between wind speed and wave height, where would you expect to find the largest waves?

17. How much carbon (in billions of metric tons) is released to the atmosphere from the sea surface each year? (Hint: Use the illustration on "Ocean-Atmosphere carbon exchange" to answer the question.)

18. List three ways that coastal areas would be impacted by global warming.

EL Niño and the state of the Pacific Ocean

Background Questions: Answers

1. El Niño was first recognized in the late 1800's by fisherman off the coast of Peru and Ecuador. They occur every 2-7 years.

2. Map A is the El Niño year, Map B is the non El Niño year. Map A represents the abnormally warm waters off of the coast of South America.

3. The fish population off the Pacific coast of South America virtually vanishes, having negative economic impacts on the fishing industry.

4. These suggestions come from the factoids in the activity. Global weather changes include: increased precipitation along the northwestern coast of South America, decreased precipitation in Indonesia and Australia, increased precipitation along the east coast of the U.S., hot, dry weather in Montana, and cool, wet weather in New Mexico. There are many other changes associated with this event. If students have time to surf the net they will find a bonanza of information.

5. El Niño enhances thunderstorm development in the eastern tropical Pacific.

6. The normally heavy rains found in Indonesia move into the central Pacific, causing abnormally dry conditions in Indonesia.

7. Sea surface temperature; measured with the AVHRR on board NASA satellites; typical units are either °C or °F.

EL Niño and the state of the Pacific Ocean

Supplemental Questions: Answers

1. Ocean circulation moves 1/3 to 1/2 of the heat from the tropics toward the poles, moderating the climate at higher latitudes. Ocean currents also transport and store dissolved gases, nutrients and other biochemical constituents.

2. Currents in the Northern Hemisphere flow in a clockwise direction and in the Southern Hemisphere they flow counterclockwise.

3. Variations in ocean currents in the tropics can lead to variations in global weather and rainfall patterns.

4. Red represents the warmer water in the Gulf Stream.

5. At approximately 35 degrees latitude the water begins to cool off.

6. Carbon dioxide is a greenhouse gas that may contribute to global warming.

7. In non-El Niño times, strong trade winds blow from the east toward the west in the equatorial Pacific, pushing warm water toward Indonesia. During an El Niño, the trade winds weaken and a wave of warm water moves eastward along the equator toward South America.
8. Rain usually found over Indonesia moves eastward over the central Pacific.

9. Canada and Central Chile have been affected by the shifting weather patterns caused by El Niño, as have many other regions.

10. Phytoplankton is more abundant in the fall due to seasonal northwest winds.

11. Sea surface temperature affects atmospheric circulation which in turn drives the ocean currents. The temperature can also change ocean density which contributes a buoyancy component to ocean circulation.

12. Warmer water is located in the southern Pacific and Atlantic during January 1994. In July this is reversed with warmer waters in the Northern Hemisphere.

EL Niño and the state of the Pacific Ocean

13. During normal conditions between June 20 and July 4, 1984, the warmest water is located in the western Pacific. From June 8-22, 1983, during an El Niño, the warmer water is further east.

14. Precipitation changes can lead to flooding, drought, and higher sea levels.

15. Wind speed is determined by the strength of the microwave radar pulses reflected by the ocean's surface. Calm seas return strond radar pulses in one direction and rough seas scatter signals and return weak pulses.

16. The highest waves should be found in the southern part of the ocean, where wind speed is the greatest.

17. Ninety billion metric tons of carbon are released from the ocean surface to the atmosphere.

18. Global warming would cause submergence if low-lying areas, loss of wetlands, and erosion of beaches.

Sea Level

Ocean topography is a measure of sea level relative to the Earth's geoid, the surface on which the Earth's gravitational field in uniform. Oceanographers use ocean topography maps to calculate the speed and direction of ocean currents in much the same way that meteorologists use maps of atmospheric pressure to calculate the speed and direction of winds.

Motion in the Ocean

Together, the oceans and the atmosphere redistribute the Sun's energy from the tropics (where the Sun's energy input is highest) to the poles (where the Sun's energy input is lowest). The Sun drives ocean circulation by changing the temperature and salinity of seawater. Near the poles, ocean water sinks because it is cold and salty (the ice formed at the poles does not take up salt very well and leaves it behind in the seawater, making it more dense). Another way the Sun drives ocean circulation is by wind forcing. The Sun sets up temperature and (therefore) pressure differences, creating winds that drive the surface ocean circulation.

Ocean Heat Transport

The Global Conveyor Belt is an energy transport system in the oceans that moves energy from the tropics to the poles and back again, maintaining a balance in global climate. The ocean is generally divided into two major layers, a warm upper layer that is much thinner than the cold bottom layer. As ocean surface water is warmed in the tropics, it moves toward the poles where it loses heat, becomes saltier, denser and sinks. The cold bottom layer circulates through the oceans, taking up to 1000 years for water to completely circulate throughout the oceans. How well this "conveyor belt" transports heat about the world oceans helps control the global climate.

Sea Height and the Earth's Geoid

Many oceanographers are interested in how much the height of the sea surface changes over time. To determine this, they measure the sea surface height relative to an imaginary surface called the "geoid." The "geoid" is the shape the sea surface would have if the ocean were not in motion and were only influenced by gravity. Other factors that contribute to sea surface height differences are waves, tides, ocean currents and circulation, ocean eddies, and the temperature of the surface water layer. Except for gravity, each of these phenomena changes over days, months, or a few years and all are dependent on their location in the ocean. Of these remaining factors, basin-wide ocean circulation is the most stable - it does not change significantly over periods of days or months. Each of these factors contributes differently to sea level height. Their respective impacts can be:

- Ocean eddies–up to about 25 centimeters (10 inches)
- Temperature of the upper ocean water–up to about 35 centimeters (13 inches), similar to the contribution from ocean eddies
- Tides in the deep ocean up to 1 meter (3 feet)
- Ocean currents or ocean circulation–about 2 meters (6 feet)
- Gravity - up to 150 meters! (almost 500 feet!)

Believe it or not, the height of the Earth's oceans changes by approximately 150 meters (almost 500 feet) between the north Indian Ocean (off of the south coast of India) and the western Pacific Ocean (off New Guinea)! Earth's geoid is a calculated surface of equal gravitational potential energy and represents the shape the sea surface would have if the ocean were not in motion. How the "real" ocean surface differs from the geoid gives ocean currents. To study how various factors like ocean circulation and eddies affect the height of our oceans, oceanographers eliminate the height of sea surface caused by gravity.

How the Earth's rotation affects winds and currents

Our planet's rotation produces an apparent force on all bodies moving relative to the Earth. This force is greatest at the poles and least at the Equator because of Earth's approximately spherical shape; i.e., the apparent force, called the Coriolis effect increases with increasing latitude. The Coriolis effect, causes the direction of winds and ocean currents to be deflected. The "rule of thumb" is that in the Northern Hemisphere, wind and currents are deflected to the right; in the Southern Hemisphere they are deflected to the left. You can better imagine how the Coriolis effect works with the use of a turntable, a round piece of cardboard, a ruler, and a marker. Place the cardboard on the turntable and spin it counterclockwise (emulating the Northern Hemisphere). Hold the ruler still and draw a straight line on the cardboard from the center (the North Pole) to the edge (the equator). Even though you draw a straight line, the line on the moving cardboard is curved to the right. Also, try spinning the turntable in a clockwise direction (emulating the Southern Hemisphere) and at different speeds. You will notice that your line is curved to the left and that the faster you spin the turntable, the more curved the line is.

Hills and Valleys in the Ocean

The direction of ocean currents at the sea surface is related to wind forcing. However, the Coriolis effect also affects the motion of the ocean. The "Coriolis effect" causes the movement of water in the uppermost wind-driven part of ocean (known as the "Ekman layer") to create hills and valleys in the ocean topography, or shape. In the Northern Hemisphere, counterclockwise winds cause surface ocean water to move to the right and away from a central point, causing a sea surface valley. The slope of the sea surface creates currents that flow around these hills and valleys, known as "geostrophic currents." In the Northern Hemisphere, clockwise-flowing winds cause surface ocean water to move to the right and toward a the central point, causing a sea surface hill. "Geostrophic currents" flow around these high and low centers of water pressure, similar to how winds blow from high to low pressure. They are located below the wind-driven layer and their velocity is proportional to the slope of the sea surface. These "hills" and "valleys"—or ocean topography—are measured by TOPEX/Poseidon and used to calculate "geostrophic" ocean currents, similarly to how meteorologists use atmospheric pressure maps to track winds and weather.

Dynamic Ocean Topography - Sea Level Height Changes for the Long Run

Ocean currents are mapped by studying the "hills" and "valleys" in maps of the height of the sea surface relative to the geoid. This height is called "Dynamic Ocean Topography." Currents move around ocean dynamic topography "hills" and "valleys" in a predictable way. Note that a clockwise sense of rotation is found around "hills" in the Northern Hemisphere and "valleys" in the Southern Hemisphere. This is because of the Coriolis effect. Conversely, a counterclockwise sense of rotation is found around "valleys" in the Northern Hemisphere and "hills" in the Southern Hemisphere. In general, major ocean currents are stable and so maps of dynamic ocean topography change very little over time.

Changes in Sea Height Over Short Time Scales

Just like the atmosphere, the oceans have seasons. In a similar fashion to the way air temperatures change with the seasons, ocean temperatures change on a "seasonal" basis too. During the summer months, surface ocean temperatures increase, causing a rise in sea heights. Conversely, during the winter months when ocean temperatures decrease, there is a decrease in sea heights. In the Northern Hemisphere, the overall change in sea surface height between these seasons is very dramatic, while in the Southern Hemisphere, season-to-season changes are much more moderate. The "ocean seasons" look different in the

Northern and Southern Hemispheres because the oceans have a slower reaction to seasonal temperature differences than land surfaces have and there is a higher percentage of ocean in the Southern Hemisphere than in the Northern Hemisphere. Comparatively, sea surface variability due to the ocean seasons is about 1/16 of the overall variation in sea surface height caused by ocean circulation (dynamic ocean topography). Sea surface variability maps are used to study the changes in sea height over months or seasons. They show how currents vary over short times and distances as well as showing seasonal changes in the temperature of the upper ocean layer.

NASA’s Mission to Study Ocean Topography

In August 1992, TOPEX/Poseidon (named after the Greek God of the oceans) was launched into low Earth orbit by an Ariane 42P rocket from the European Space Agency’s Space Center located in Kourou, French Guiana—the first launch of a NASA payload from this site. From its orbit 1,336 kilometers (830 miles) above the Earth’s surface, TOPEX/Poseidon measures sea level along the same path every 10 days using a dual frequency altimeter developed by NASA and a CNES single frequency solid-state altimeter. This information is used to relate changes in ocean currents with atmospheric and climate patterns. Measurements from NASA’s Microwave Radiometer provide estimates of the total water-vapor content in the atmosphere, which is used to correct errors in the altimeter measurements. These combined measurements allow scientists to chart the height of the seas across ocean basins with an accuracy of less than 13 centimeters (5 inches)!

TOPEX/Poseidon is a vital part of a strategic research effort to explore ocean circulation and its interaction with the atmosphere. It complements a number of international oceanographic and meteorological programs, including the World Circulation Experiment (WOCE) and the Tropical Ocean and Global Atmosphere (TOGA) Program, both of which are sponsored by the World Climate Research Program (WCRP). TOPEX/Poseidon’s three-year prime mission ended in fall 1995 and is now in its extended observational phase. Its first follow-on mission, Jason-1, will continue this program of long-term observations of ocean circulation from space into the next century.

Information courtesy of the Jet Propulsion Laboratory (JPL), Pasadena, CA. Additional information can be found at http://topex-www.jpl.nasa.gov/education/tutorial1.html

Sea Level: The Highs & Lows Create the Flows

Objective

- *Create a contour profile of the North Pacific Ocean*
- *Determine the direction of current flow using the contour map*
- *Calculate the velocity of an ocean current*

Materials

- August 1993 Pacific Ocean sea level contour map
- Graph paper

Procedure

Part I

A contour profile creates a cross-section of a contour map. Using your graph paper, construct your graph with the latitude on the x-axis and height on the y-axis. On the Pacific Ocean sea level contour map, sea surface heights are given in centimenters, and the contour interval is 10 cm.

For the contour map:

1. Draw a vertical line along longitude line 156° W
2. Place the horizontal axis of the contour profile graph along the 156 °W longitude line
3. Graph each point in which the 156°W longitude line intersects a contour line
4. The points on your graph should be lined up vertically to match the points in the Pacific Ocean

Part II (Advanced)

As mentioned in the reading, scientists use sea level heights from the TOPEX/Poseidon measurements to determine the speed of surface ocean currents. Using the formula below, determine the speed of the Pacific Ocean current in August 1993. Your calculcations should be done along longitude line 156°W and between latitudes 35°N and 37°N. For f we will use latitude 37°N.

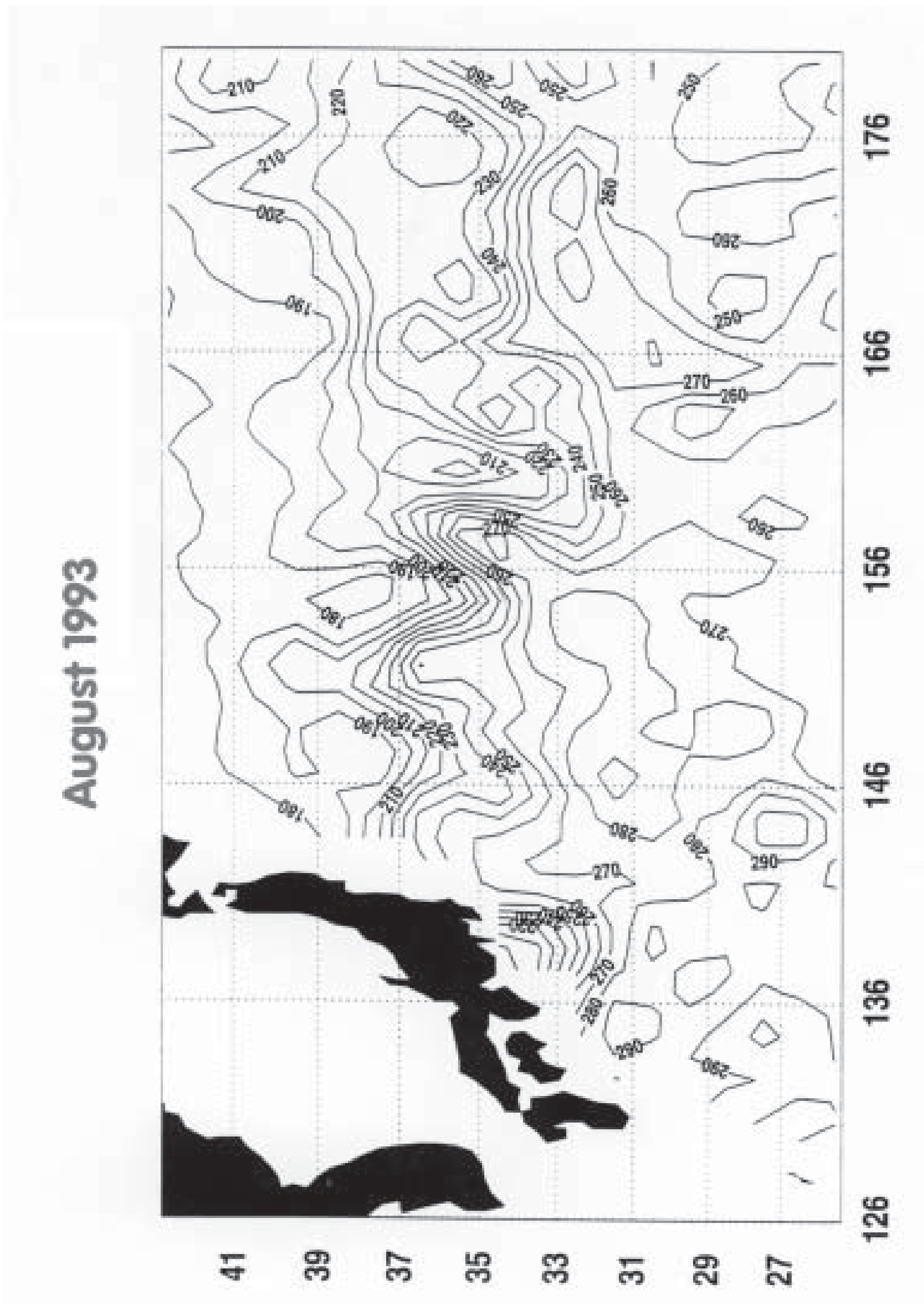
$$\text{Speed} = g\Delta h/f\,s$$

$g=981$ cm s^{-2} (Gravity)

$f=2\Omega\sin\phi$ (Coriolis parameter)
$\Omega=7.29\times10^{-5}$ s^{-1} [Angular velocity of the Earth = 2π/sidereal day (86160 s)]
ϕ=latitude (37°)

Δh=change in height

Δs=change in distance (1 ° of latitude = 111.1×10^{5} cm)


August 1993
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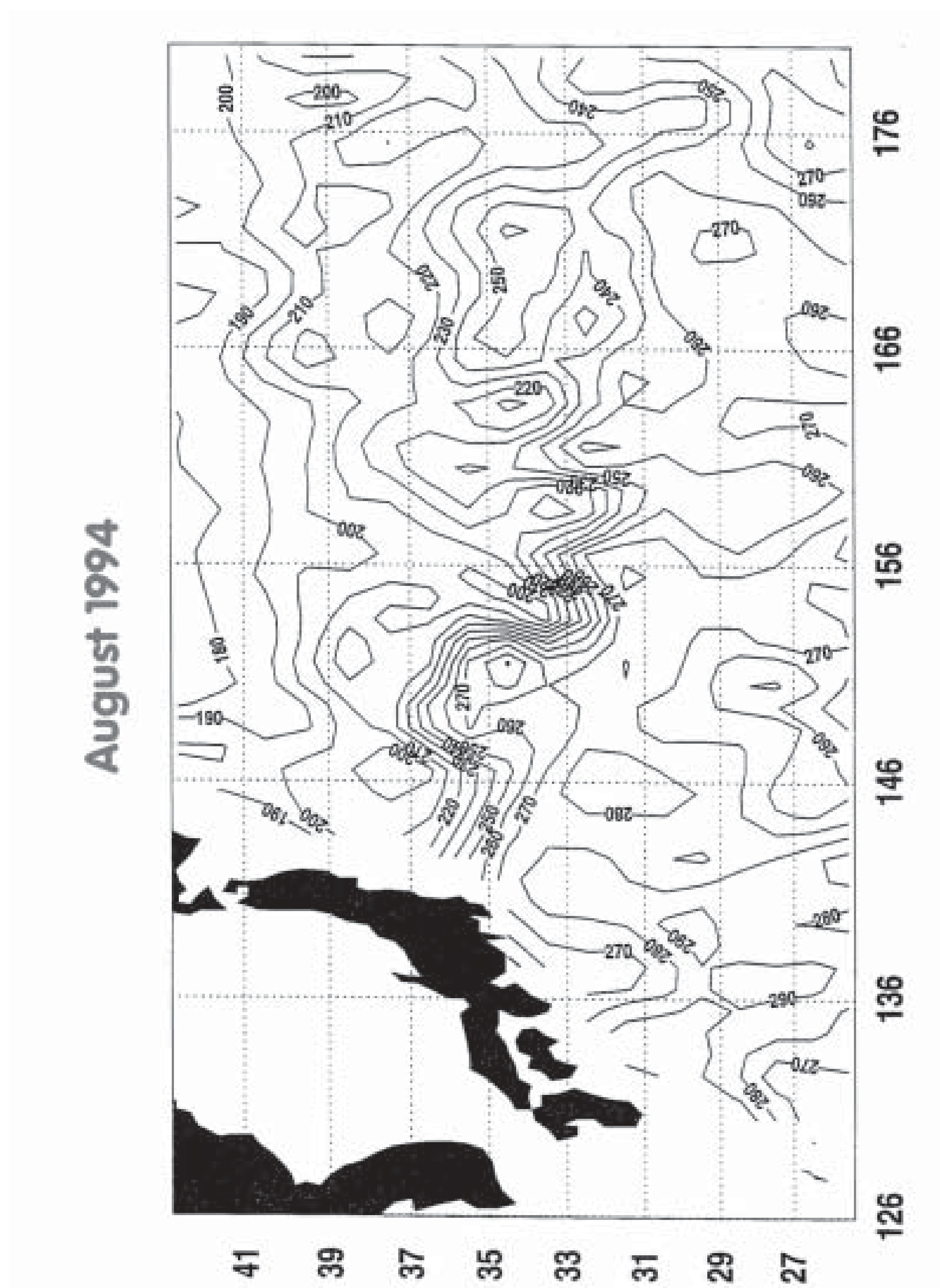
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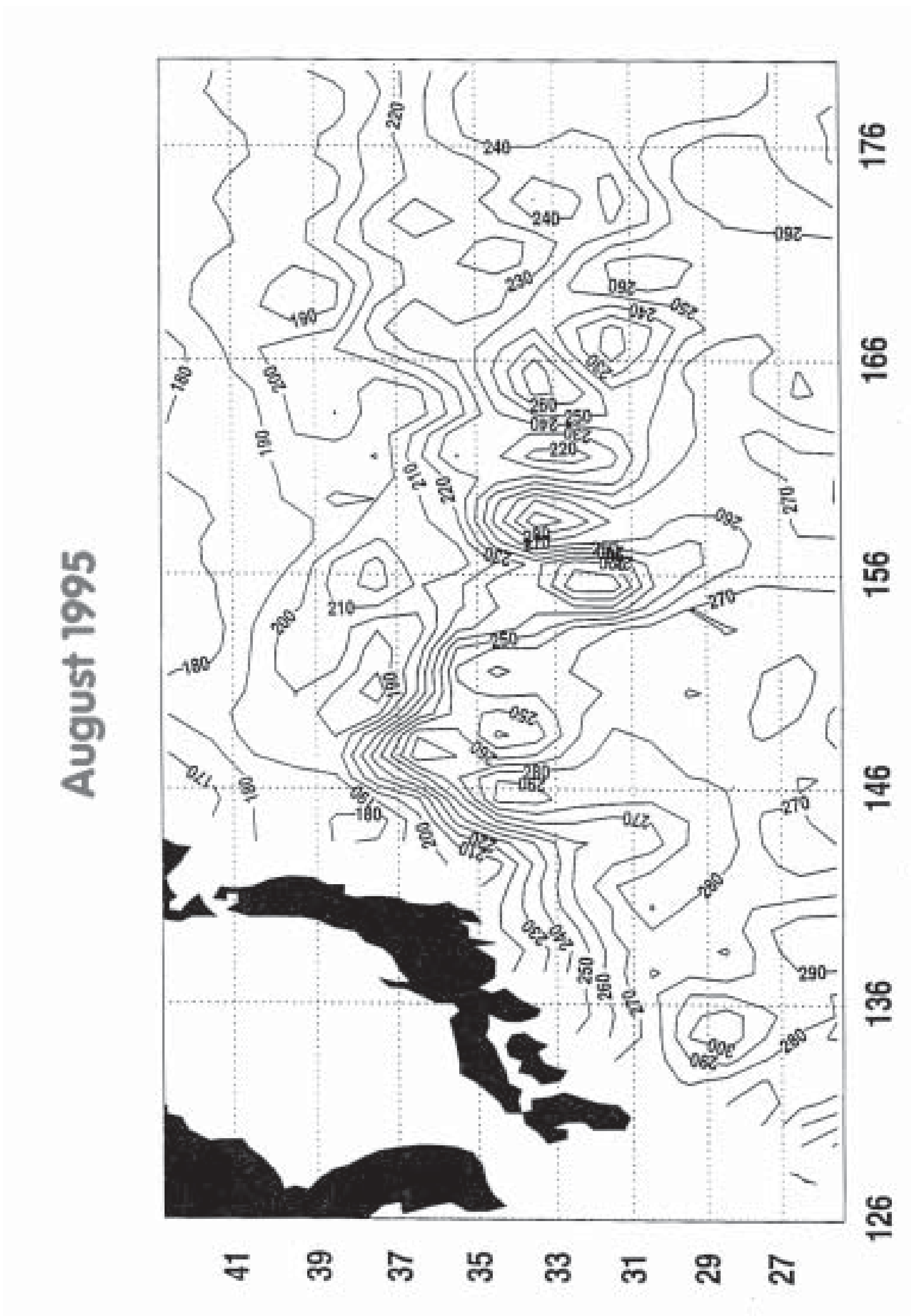
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Sea Level: The Highs & Lows Create the Flows

Part I

1. For the August 1993 graph, what is the relation between latitude and sea level along the longitude line 156°W?

2. What factor(s) could account for this difference?

3. Describe the direction of current movement in relation to the countour highs and lows.

Part II

1. What is the calculated speed of the current?

2. Examine the contour map along 166°W between 35°N and 37°N latitude. How do you think the speed of the current would compare to your calculated current speed?

3. In what ways did the current change along longitude line 156°W from August 1993 to August 1994?

4. Examine the countour maps dated August 1993, 1994 and 1995. What conclusions can you draw regarding sea level height in the Pacific Ocean?

Sea Level: The Highs & Lows Create the Flows

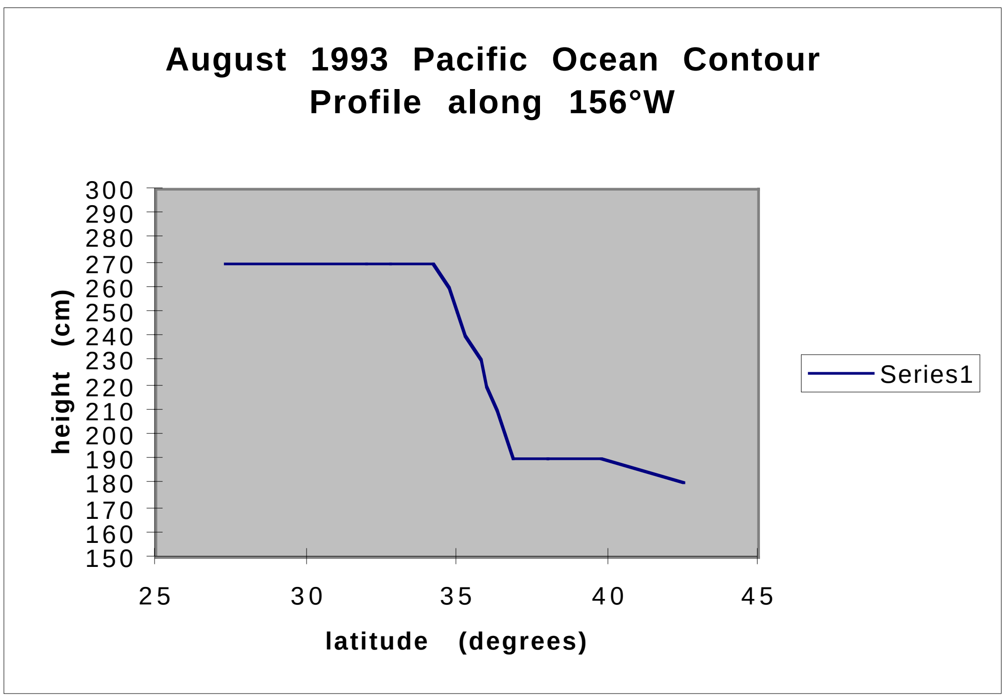
Procedure

Students contour profiles should resemble the following graph.

Part I:

1. Along longtude line 156°W, sea level decreases from the south to the north.

2. The change in sea level is due to differences in temperature. Warm water expansion near the equator translates into higher sea levels.



3. Around contour highs, the flow is clockwise, around countour lows, the flow is counterclockwise.

Sea Level: The Highs & Lows Create the Flows

Part II:

To fully understand this section, it is recommended that students have completed their first semester of physics.

1. Speed = 981 cm s^{-2} • 60 cm/2(7.29×10^{-5} s^{-1}) sin 37° • 2.222×10^{7} cm = 30.19 cm s^{-1}

2. Along longitude lines 166°W the gradient is less, therefore the current would be slower.

3. From 1993 to 1994 there is a slight southerly dip along longitude line 156°W.

4. Although the northern Pacific current flows in the same direction from year to year, the sea level highs move both north and south and east and west.

Polar Ice

Polar ice consists of sea ice formed from the freezing of sea water, and ice sheets and glaciers formed from the accumulation and compaction of falling snow. Both types of ice extend over vast areas of the polar regions. Global sea-ice coverage averages approximately 25 million km^2, the area of the North American continent, whereas ice sheets and glaciers cover approximately 15 million km^2, roughly 10% of the Earth's land surface area.

Effects on Energy Exchange

Ice, both on land and in the sea, affects the exchange of energy continuously taking place at the Earth's surface. Ice and snow are among the most reflective of naturally occurring Earth surfaces. In particular, sea ice is much more reflective than the surrounding ocean, so that if it were to increase in extent, for instance because of large-scale cooling, then more solar energy would be reflected back to space and less would be absorbed at the surface. This would tend to cool the local region further, with the likelihood that more ice would be formed and still more cooling would occur.

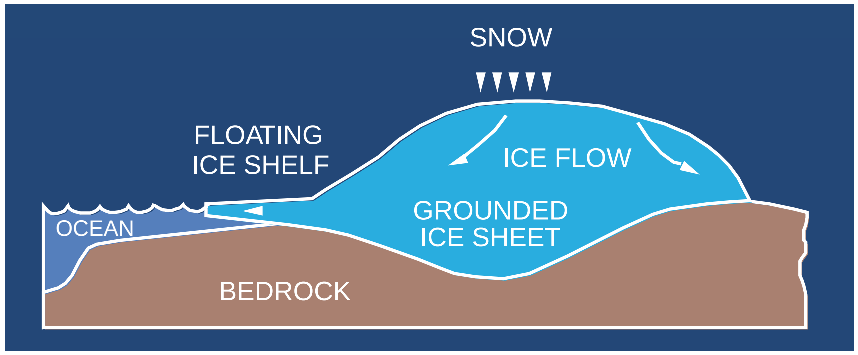
On the other hand, if global warming occurs, then more ice would be expected to melt, reducing the energy reflected back to space and increasing the energy absorbed at the surface. The affected portions of the Earth would become still warmer. Scientists refer to this kind of reinforcing process as a "positive feedback."

Global observations are needed in order to make our theoretical and computer models of the Earth System as correct as feasible and to ensure that they include the major relevant phenomena for understanding the ice and other components of the Earth's climate. Generally, these observations can be obtained systematically only from space-based satellites. In the U.S., missions conducted by NASA, NOAA, and the Department of Defense are all contributing to our knowledge of polar ice on a global basis.

Global Warming and Land Ice

Over the past century, sea level has slowly been rising. This is in part due to the addition of water to the oceans through either the melting of or the "calving" off of icebergs from the world's land ice. Many individual mountain glaciers and ice caps are known to have been retreating, contributing to the rising sea levels. It is uncertain, however, whether the world's two major ice sheets—Greenland and Antarctica—have been growing or diminishing. This is of particular importance because of the huge size of these ice sheets, with their great potential for changing sea level. Together, Greenland and Antarctica contain about 75% of the world's fresh water, enough to raise sea level by over 75 meters, if all the ice were returned to the oceans. Measurements of ice elevations are now being made by satellite radar altimeters for a portion of the polar ice sheets, and in the future they will be made by a laser altimeter as part of NASA's Earth Observing System (EOS). The laser altimeter will provide more accurate measurements over a wider area.

The Greenland ice sheet is warmer than the Antarctic ice sheet and as a result, global warming could produce serious melting on Greenland while having less effect in the Antarctic. In the Antarctic, temperatures are far enough below freezing that even with some global warming, temperatures could remain sufficiently cold to prevent extensive surface melting.



Where ice sheets extend outward to the ocean, the ice tends to move out over the surrounding water, forming "ice shelves." There is concern that, with global warming, the water under the ice shelves would be warmer and cause them to break up more readily, forming very large icebergs. If the ice shelves of West Antarctica were to break up, this would release more inland ice in an irreversible process, possibly leading to sea level rises of several meters.

In addition to increasing the amount of melting, global warming would also be expected to increase the amount of precipitation in the polar regions. There are three reasons for this: 1) warmer air can carry more moisture than colder air; 2) warmer wates would encourage increased evaporation from the ocean; and 3) lessened sea ice would also lead to more evaporation from the ocean, as more ocean area would be exposed directly to the atmosphere. Global warming could therefore be expected initially to increase both melting and snowfall. Depending on which increase dominates, the early result could be either an overall decay or an overall growth of the ice sheets.

Global Warming Detection and Sea Ice

The melting and growth of sea ice, in contrast to land ice, does not affect sea level, because the sea ice is floating on the ocean already and is in equilibrium with it. Sea ice is nonetheless still important in the context of climate change. Sea ice, with its high reflectance and the insulation it provides between the polar atmospheres and oceans, is a key part of the climate system. Furthermore, sea ice responds to changes in the atmosphere and oceans, and hence changes in it could be a clue to broader climate change, such as global warming. However, the record to date is not clear enough to make any definitive conclusions about long-term climate trends based on the sea-ice observations alone. Sea ice varies significantly from season to season and from year to year, and the extent of its natural variability is not yet fully known.

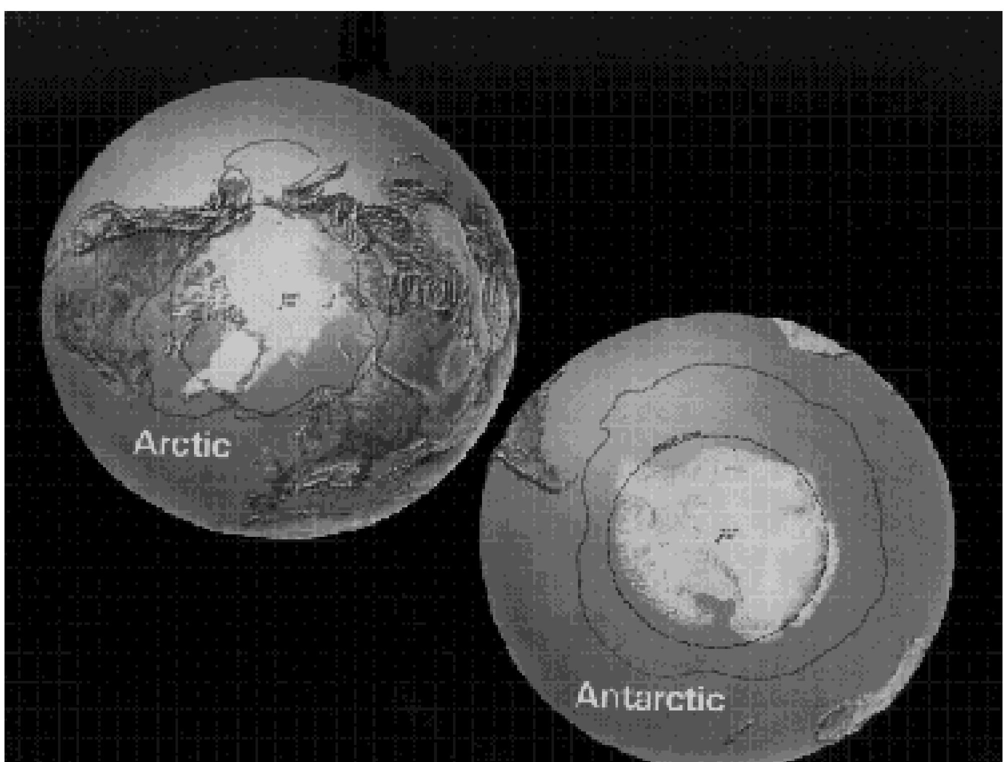
We need to continue to monitor the location and extent of sea ice and its changes seasonally and interannually. We also need additional studies to determine ice thicknesses and reflectivities. This kind of information can be fed into climate models to attempt to simulate future climate conditions. The same information will also serve as a check on models to see if they are properly simulating existing sea-ice amounts and distributions.

NASA Missions to Study Ice

NASA has had missions that collected ice data for many years (see the accompanying table), and ice is among the many variables included in NASA's Pathfinder Program, which is providing research-quality data sets on global change from past and current satellite missions. The Pathfinder Program will lead up to the main initiative of NASA's Earth Science Program, the Earth Observing System (EOS). EOS involves a series of satellites to be launched in 1998 and thereafter, providing coverage of the Earth over a period of fifteen to twenty years.

Several sensors on the early satellites in the 1960's and 1970's obtained valuable ice data, especially under cloud-free conditions. However, cloudiness and polar darkness often obscured the observations that were obtained with visible and infrared sensors. A major breakthrough occurred in December 1972 with the launch of the Electrically Scanning Microwave Radiometer (ESMR) on the Nimbus-5 satellite. Taking advantage of the microwave radiation that is emitted from the Earth's surface, ESMR could see through the clouds, providing for the first time detailed data sets of sea-ice distributions for cloudy as well as cloud-free conditions, and could do this at night as well as during daylight.

Microwave radiation is emitted in varying amounts by everything on the surface of the Earth. The amount of radiation emitted depends on the temperature of the substance and its "emissivity," which is a measure of the substance's ability to emit radiation. Because the microwave emissivity of sea ice is markedly greater than that of water, it generally radiates more microwave energy than the water, even though the temperature of the water is higher. The greater intensity of the microwave radiation coming from ice allows the ice/water distinction to be made in the satellite data.



The data from the Nimbus-5 ESMR and its successor, NASA's Scanning Multichannel Microwave Radiometer (SMMR), which was launched on Nimbus-7 in 1978, have resulted in three major atlases, giving the history of the Arctic and Antarctic sea-ice covers for the years 1973-76 and

1978-87. NASA's Seasat satellite also carried a SMMR instrument in 1978, but, unfortunately, a power failure caused data acquisition to cease after 106 days. The Defense Meteorological Satellite Program (DMSP) has flown a Special Sensor Microwave/Imager (SSM/I) since 1987. This instrument is similar to SMMR, and its data are being analyzed and converted to sea-ice concentrations by NASA and other scientists.

Seasat also carried a Synthetic Aperture Radar (SAR) able to acquire 25-meter resolution images of the Earth surface in all weather conditions. These data gave NASA scientists the opportunity to demonstrate the powerful capability of SAR for detailed investigations of polar sea ice, and since then, additional SARs have been launched on other satellites.

Data from these recent missions have also enabled scientists to develop new ways to study the vast ice sheets in Greenland and Antarctica. For instance, the first high-resolution map (approximately 25 meters) of Antarctica will be compiled from September-October 1997 SAR data obtained by the Canadian RADARSAT mission, which was launched in November 1995 by NASA.

Other satellite data also used in the study of ice include data from the Landsat series of satellites and from radar altimetry. For instance, high-resolution Landsat images have been converted into photo maps for parts of the Antarctic and Greenland ice sheets. Landsat images have also been used to measure ice flow rates and the advance and retreat of glacier margins. Radar altimetry data from NASA's Seasat and the Department of Defense Geosat satellites have been used to determine and map the elevation contours of the southern half of the Greenland ice sheet and a small fraction of northern Antarctica. (The Seasat and Geosat orbits did not allow data collection in the central polar regions.)

The EOS series of satellites will carry several important instruments for ice studies starting in 1999. Of particular interest are the Geoscience Laser Altimeter System (GLAS), scheduled to fly in 2001, and the Advanced Microwave Scanning Radiometer (AMSR and AMSR-E), which will fly, respectively, on the ADEOS II mission in 2000 and the EOS PM-1 mission in 2000. AMSR and AMSR-E will obtain sea-ice information with greater spatial detail than earlier microwave radiometers, while GLAS will measure growth or shrinkage of the ice sheets. GLAS will be 100 times more accurate than radar altimeters, which have been designed for ocean measurements, and will be flown in an orbit that reaches very close to flying over the South pole. GLAS measurements of ice melting, changes in snowfall in the polar regions, and changes in ice volume will provide critical data for understanding and predicting sea-level change during the next century. GLAS will also be very useful in the study of individual ice streams and ice shelves in the West Antarctic. Observing these ice streams and shelves is particularly important because of the possibility that they might become unstable under certain conditions of global change.

Sea Ice: Just the Cold Facts

Objective

- *Explore the current views about the relationship between sea ice and global climate change*
- *Calculate the seasonal change of sea ice in the polar regions*
- *Compare and contrast the extent of sea ice in the Arctic and Antarctic*

Materials

- Polar Ice
- ESE CD-ROM
- Maps: March 1986 and September 1986 Arctic Sea Ice; March 1986 and September 1986 Antarctic Sea Ice
- Graph Paper
- Atlas

Predictions

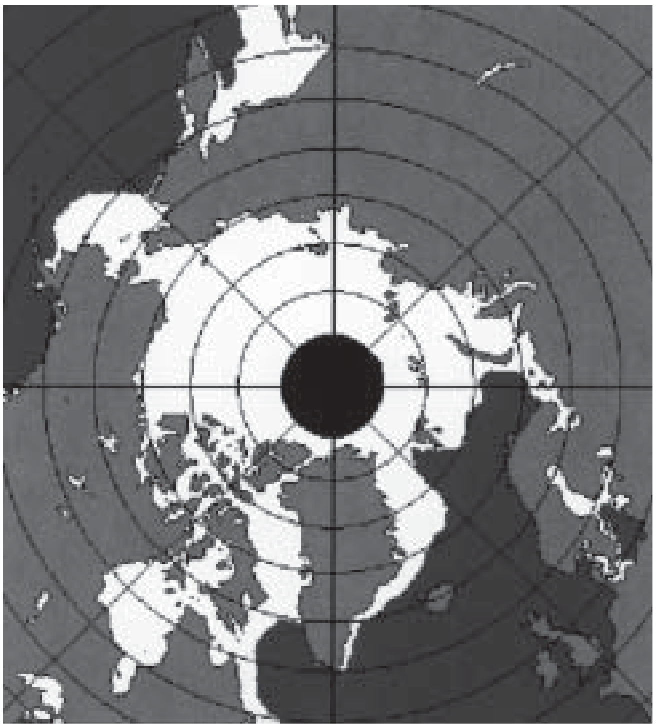
1. During which month would you expect sea ice in the Arctic to be at its maximum? Antarctic?
2. In which polar area would you expect the greatest amount of sea ice?
3. Look at location maps for the north and south polar regions (atlas). How could geographical differences in the north and south polar regions influence sea ice production?

Procedure

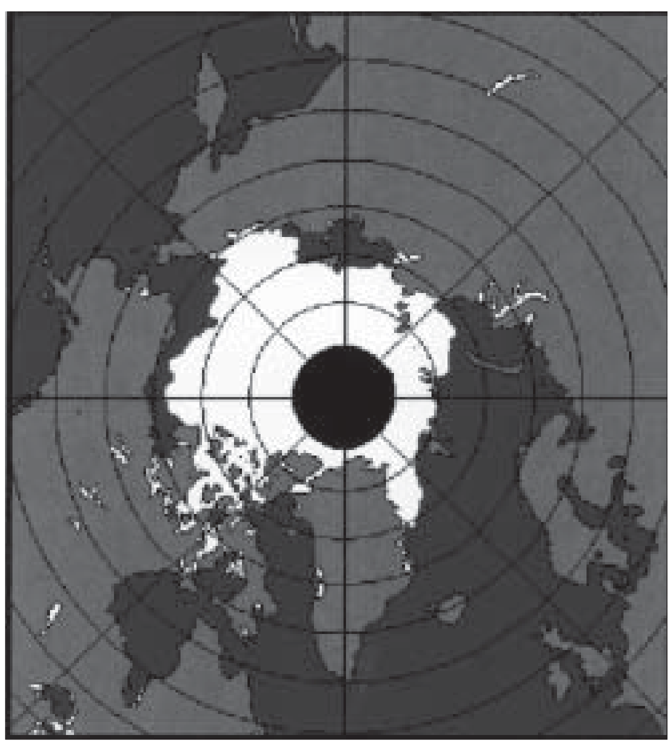
1. Read the chapter on "Polar Ice"
2. View the ESE CD-ROM section on Ice
3. Using an atlas, indentify the Arctic and Antarctic maps and label them.
4. Use the graph paper to count and record the number of squares occupied by sea ice in each of the satellite maps
5. Fill in your data in the area below and answer the Evaluation Questions. Ice is represented by the white areas in each of the maps.

Data

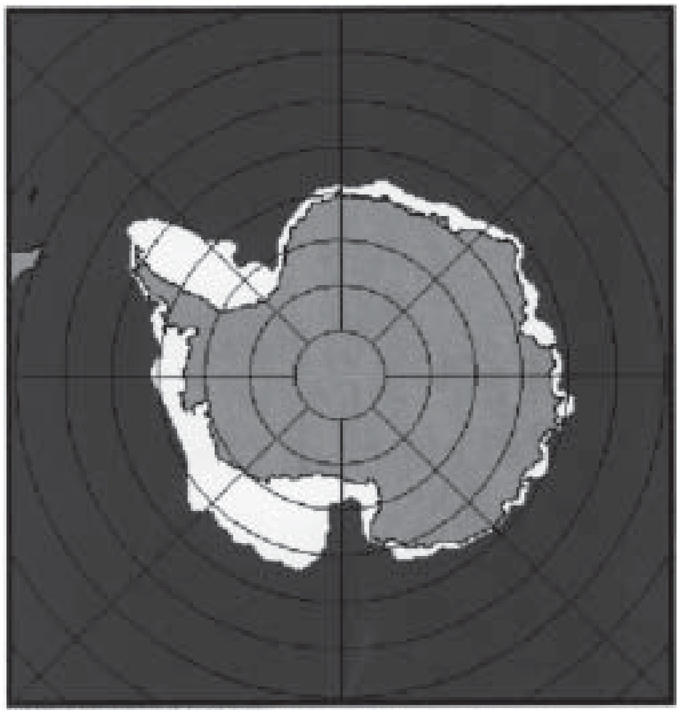
1. Arctic sea ice in March 1986 =
2. Arctic sea ice in September 1986 =
3. % change of sea ice in the Arctic =
4. Antarctic sea ice in March 1986 =
5. Antarctic sea ice in September 1986 =
6. % change of sea ice in the Antarctic =
7. % difference between the Arctic and Antarctic winter (March and September, respectively) ice coverages =



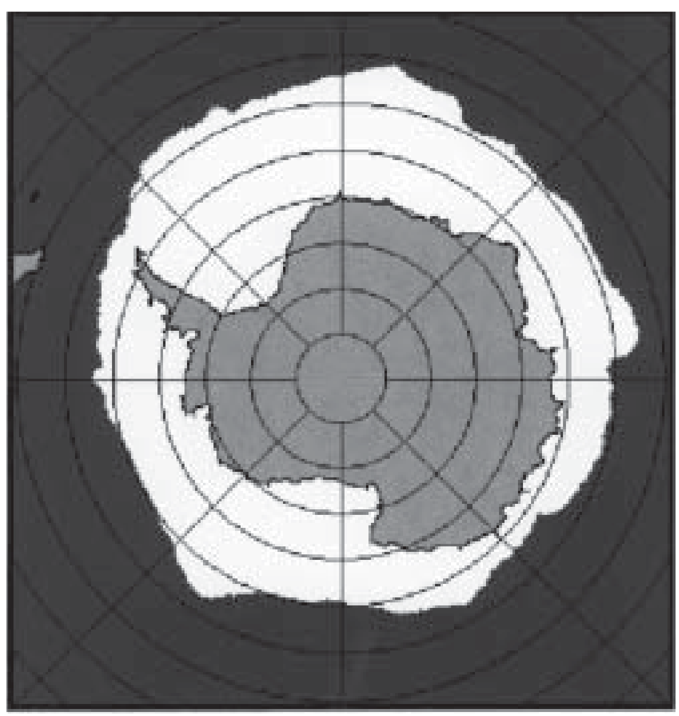
March 1986



September 1986



March 1986



September 1986

Sea Ice: Just the Cold Facts

1. Of the maps provided, during which month is sea ice coverage at its maximum in the Arctic? Antarctic? Compare to your prediction.

2. Which polar region had the greatest total sea ice coverage? Compare to your prediction.

3. What factors could account for the difference in sea ice coverage between the polar regions? Coompare to your prediction.

4. Which instruments are used to measure sea ice extents?

5. Some climate scientists think that rising sea level would be a consequence of greenhouse warming. Although sea ice, which forms from ocean water, does not affect sea level, what mechanisms connect sea ice and temperatures?

Sea Ice: Just the Cold Facts

The following questions are intended to be answered through research using the ESE CD-ROM section on Ice and reading the chapter "Polar Ice."

Distribution of Earth's Water

1. What percent of the Earth's water is saline?

2. The fresh water on our planet is divided among the following three categories:
   - Polar Ice Sheets and Glaciers
   - Ground Water
   - Lakes, Rivers, Snow, Soil Moisture, and Water Vapor

   List the percentage of the Earth's fresh water contained in each category.

3. The majority of fresh water is located in Polar Ice and Glaciers. What percent of this fresh water is located in teh Antarctic Ice Sheet?

Ice Sheets

4. In what direction has the temperature trend in the West Antarctic ice sheet been over the past few decades?

5. Why are temperature trends important?

6. How are ice shelves created?

Polar Sea Ice

7. Describe three imapcts sea ice has on climate.

8. During which month is sea ice most prevalent over the Northern Hemisphere?

9. Which instrument is being used to measure the amount of sea ice coverage?

Global Snow Cover

10. Explain how snow pack affects climate.

11. Compare the effects of snow versus ice on the global climate.

Sea Ice: Just the Cold Facts

Evaluation: Answers

1. The number of squares will vary depending on the size of the squares on the graph paper. Arctic sea ice is at its maximum in March (end of the Northern Hemisphere winter). Antarctic sea ice is at its maximum in September (end of Southern Hemisphere winter).

2. The Antarctic region has the greatest maximum sea ice coverage (~19 million km^2 in September), but the Arctic region has the greatest minimum sea ice coverage at approximately 9 million km^2 in September. Arctic maximum sea ice coverage is approximately 15 million km^2 in March. Antarctic minimum sea ice coverage is approximately 4 million km^2 in February. At its maximum, the Arctic is only 79% of the maximum coverage of the Antarctic.

3. The difference between the Arctic and Antarctic sea ice coverage is due to the geography. The area in the central polar region of the Arctic is ocean, bounded largely by the continents of the Northern Hemisphere. The continental boundaries limit the extent to which Arctic sea ice can grow during the cold months. In contrast, sea ice in the Southern Hemisphere has no land boundaries to the north to limit the winter's sea ice growth. In the summer, geography again plays a role in sea ice coverage. In the Arctic, the highest-latitude region is covered by water. Arctic sea ice shrinks less in the summer because it lies in an area that stays very cold. The Earth's south polar region on the other hand, is covered by the continent of Antarctica. Sea ice extends from the coast of the continent, which is further away from the extreme cold in central Antarctica. The sea ice therefore lies in a relatively warm climate, causing greater melting during the warm summer months.

4. Data are now collected from the Special Sensor Microwave/Imager (SSM/I). Earlier instruments include the Electrically scanning microwave radiometer (ESMR) and the scanning multichannel Mircowave Radiometer (SMMR). An instrument now being built is the Advanced Microwave Scanning Radiometer (AMSR) which is scheduled for flight on the EOS satellites. FYI: Each of these instruments is a passive microwave radiometer, all of which measure microwave radiation given off by objects. Active instruments, like radars, actually send out a signal which they later receive back. Additional information can be found on the ESE CD-ROM in the "How Will We Study the Earth" section.

5. Scientists have measured a global climate change of 0.3 to 0.6 °C over the last 100 years (from the Intergovernmental Panel on Climate Change) and predict further warming in the future. Possible contributions to warming include any reduction in the amount of sea ice coverage and/or any decrease in the amount of time sea ice covers certain areas. Both of these scenarios would lead to a

Sea Ice: Just the Cold Facts

positive feedback. Less sea ice translates into less solar radiation reflected, which would warm the climate and therefore lead to even less sea ice. A greater direct ocean-atmosphere interface uninterrupted by sea ice would cause an increased heat transfer, especially in the polar winter when the water temperature is often considerably warmer that the air temperature. Conversely, increased sea ice converage would encourage cooling.

Sea Ice: Just the Cold Facts

Supplemental Questions: Answers

1. 97% of Earth's water is saline.

2. 77% in polar ice and glaciers, 22% in ground water, and 1% divided among lakes, rivers, snow, soil moisture, and water vapor.

3. 91% of fresh water in polar ice and glaciers is in the Antarctic Ice Sheet.

4. The temperature in the West Antarctic Ice Sheet has shown a warming trend for the past few decades.

5. Increases could lead to melting and to discharges of ice into the ocean.

6. As a result of the outward flow of an ice sheet, an ice sheet sometimes extends outward from land over the suroundng water, creating an "ice shelf."

7. Any three of the following: Sea ice restricts the transfer of heat bewteen the ocean and the atmosphere; it has a high reflectance, thereby reducing the amount of solar radiation absorbed at the surface; it restricts evaporation into the atmosphere; and it affects the circulation of the ocean.

8. March

9. The Special Sensor Microwave/Imager (SSM/I)

10. Snow reflects incoming solar energy, which affects the Earth's radiation balance and in turn the climate. Snow also provides insolation between teh atmosphere and the underlying surface.

11. Snow and ice both have a cooling effect on the climate. Both have high reflectivities and provide insolation between the atmosphere and the underlying surface.

Substantial information in this activity came from Claire Parkinson's book, "Earth From Above." The book uses satellite images to examine the global environment. Claire explains the science of remote sensing in easy to understand terms. She includes a set of questions for students and a set of answers for teachers at the conclusion of each chapter. This book is highly recommended! Thank you, Claire.

Deforestation

The clearing of tropical forests across the Earth has been occuring on a large scale basis for many centuries. This process, known as deforestation, involves the cutting down, burning, and damaging of forests.

The loss of tropical rainforest is more profound than merely destruction of beautiful areas. If the current rate of deforestation continues, the world's rain forests will vanish within 100 years—causing unknown effects on global climate and eliminating the majority of plant and animal species on the planet.

Why Deforestation Happens

Deforestation occurs in many ways. Most of the clearing is done for agricultural purposes—grazing cattle, planting crops. Poor farmers chop down a small area (typically a few acres) and burn the tree trunks—a process called Slash and Burn agriculture. Intensive, or modern, agriculture occurs on a much larger scale, sometimes deforesting several square miles at a time. Large cattle pastures often replace rain forest to grow beef for the world market.

Commercial logging is another common form of deforestation, cutting trees for sale as timber or pulp. Logging can occur selectively–where only the economically valuable species are cut–or by clearcutting, where all the trees are cut. Commercial logging uses heavy machinery, such as bulldozers, road graders, and log skidders, to remove cut trees and build roads, which is just as damaging to a forest overall as the chainsaws are to the individual trees.

The causes of deforestation are very complex. A competitive global economy drives the need for money in economically challenged tropical countries. At the national level, governments sell logging concessions to raise money for projects, to pay international debt, or to develop industry. For example, Brazil had an international debt of $159 billion in 1995, on which it must make payments each year. The logging companies seek to harvest the forest and make profit from the sales of pulp and valuable hardwoods such as mahogany.

Deforestation by a peasant farmer is often done to raise crops for self-subsistence, and is driven by the basic human need for food. Most tropical countries are very poor by U.S. standards, and farming is a basic way of life for a large part of the population. In Brazil, for example, the average annual earnings per person is U.S. $5400, compared to $26,980 per person in the United States (World Bank, 1998). In Bolivia, which holds part of the Amazon rain forest, the average earnings per person is $800. Farmers in these countries do not have the money to buy necessities and must raise crops for food and to sell.

There are other reasons for deforestation, such as to construct towns or dams which flood large areas. Yet, these latter cases constitute only a very small part of the total deforestation.

The Rate of Deforestation

The actual rate of deforestation is difficult to determine. Scientists study the deforestation of tropical forests by analyzing satellite imagery of forested areas that have been cleared. Figure 1 is a satellite image illustrating how scientists classify the landscape. Contained within the image are patches of deforestation in a distinctive “fishbone” of deforestation along roads. Forest fragments are isolated areas left by deforestation, where the plants and animals are cut off from the larger forest area. Regrowth–also called secondary forest–is abandoned farmland or timber cuts that are growing back to become forest. The majority of the picture is undisturbed, or “primary,” forest, with a network of rivers draining it.

The Food and Agriculture Organization (FAO) estimates that 53,000 square miles of tropical forests (rain forest and other) were destroyed each year during the 1980s. Of this, they estimate that 21,000 square miles were deforested annually in South America, most of this in the Amazon Basin. Based on these estimates, an area of tropical forest large enough to cover North Carolina is deforested each year!

The rate of deforestation varies from region to region. Recent research results showed that in the Brazilian Amazon, the rate of deforestation was around 6200 square miles per year from 1978-1986, but fell to 4800 square miles per year from 1986-1993. By 1988, 6% of the Brazilian Amazon had been cut down (90,000 square miles, an area the size of New England). However, due to the isolation of fragments and the increase in forest/clearing boundaries, a total of 16.5% of the forest (230,000 square miles, an area nearly the size of Texas) was affected by deforestation. Scientists are currently analyzing rates of deforestation for the current decade, as well as studying how deforestation changes from year to year.

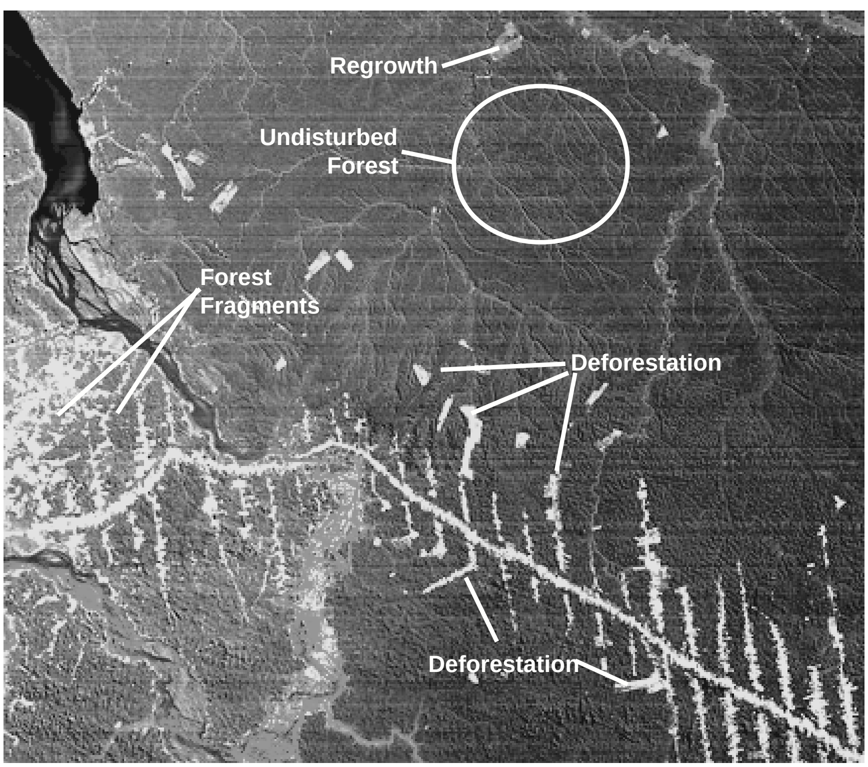


Figure 1. *Satellite image of deforestation in the Amazon region, taken from the Brazilian state of Para on July 15, 1986. The dark areas are forest, the white is deforested areas, and the gray is re-growth. The pattern of deforestation spreading along roads is obvious in the lower half of the image. Scattered larger clearings can be seen near the center of the image.*

The much smaller region of Southeast Asia (Cambodia, Indonesia, Laos, Malaysia, Myanmar, Thailand, and Vietnam) lost nearly as much forest per year as the Brazilian Amazon from the mid-1970s to the mid-1980s, with 4800 square miles per year converted to agriculture or cut for timber.

Deforestation and the Global Carbon Cycle

Deforestation increases the amount of carbon dioxide (CO_2) and other trace gases in the atmosphere. The plants and soil of tropical forests hold 460-575 billion metric tons of carbon worldwide with each acre of tropical forest storing about 180 metric tons of carbon. When a forest is cut and burned to establish cropland and pastures, the carbon that was stored in the tree trunks (wood is about 50% carbon) joins with oxygen and is released into the atmosphere as CO_2.

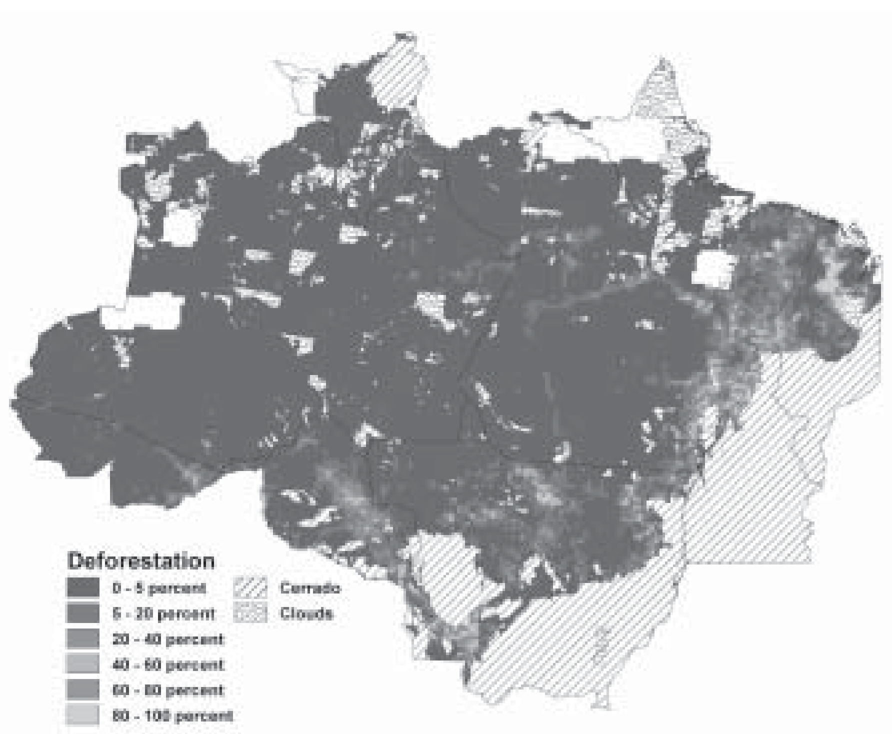


Figure 2. *Deforestation in the Brazilian Amazon in 1986. The darker the area, the more forest that is remaining.*

The loss of forests has a profound effect on the global carbon cycle. From 1850 to 1990, deforestation worldwide (including the United States) released 122 billion metric tons of carbon into the atmosphere, with the current rate being approximately 1.6 billion metric tons per year. In comparison, fossil fuel burning (coal, oil, and gas) releases about 6 billion metric tons per year, so it is clear that deforestation makes a significant contribution to the increasing CO_2 in the atmosphere. Releasing CO_2 into the atmosphere enhances the greenhouse effect, and could contribute to an increase in global temperatures (see Global Warming Fact Sheet, NF-222).

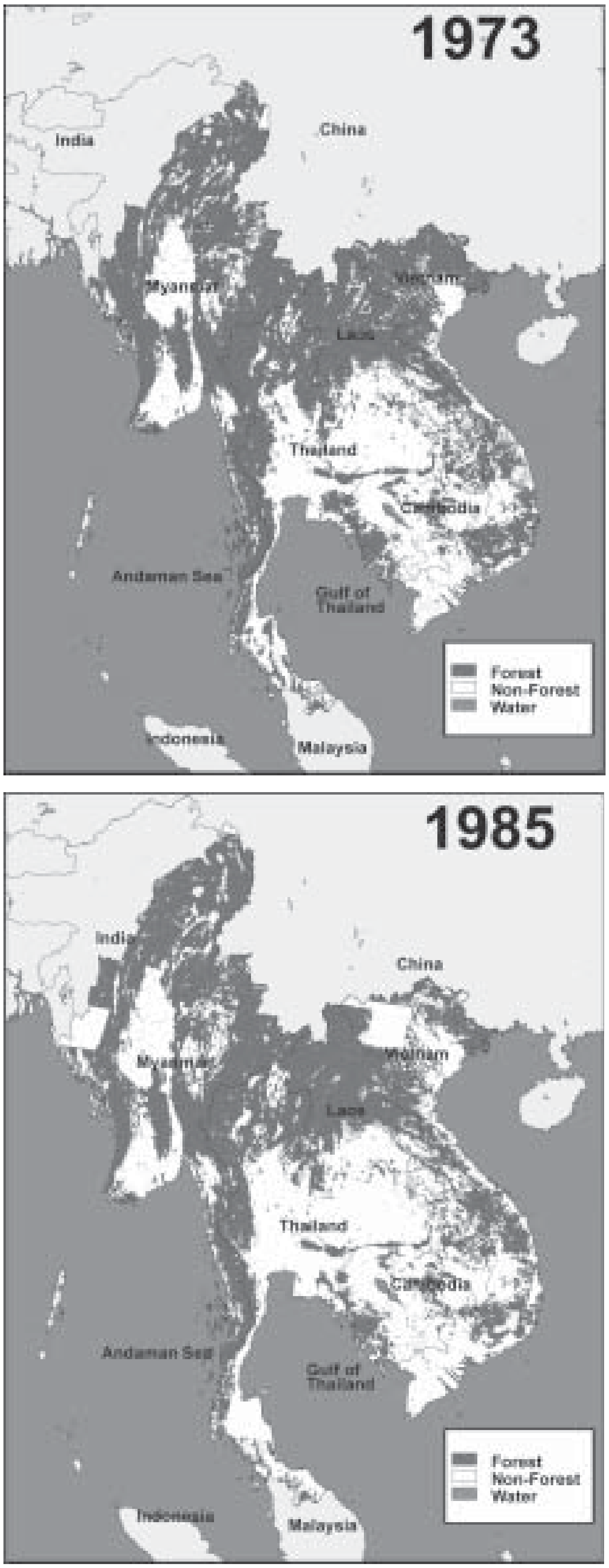


Figure 3. *Deforestation in continental Southeast Asia (excludes Malaysia and Indonesia) from 1973 to 1985. The dark gray represents forest, the lighter areas deforestation. The white box-like areas on the 1985 map are places for which no satellite information was avaliable. During this time period, about 50,000 square miles was deforested. China and India are included on the map but no assessment of their forest cover was made.*

Deforestation and the Hydrologic Cycle

Tropical deforestation also affects the local climate of an area by reducing the evaporative cooling that takes place from both soil and plant life. As trees and plants are cleared away, the moist canopy of the tropical rainforest quickly diminishes. Recent research suggests that about half of the precipitation that falls in a tropical rainforest is a result of its moist, green canopy. Evaporation and evapotranspiration processes from the trees and plants return large quantities of water to the local atmosphere, promoting the formation of clouds and precipitation. Less evaporation means that more of the Sun's energy is able to warm the surface and, consequently, the air above, leading to a rise in temperatures.

Deforestation and Biodiversity

Worldwide, 5 to 80 million species of plants and animals comprise the "biodiversity" of planet Earth. Tropical rain forests–covering only 7% of the total dry surface of the Earth–hold **over half** of all these species. Of the tens of millions of species believed to be on Earth, scientists have only given names to about 1.5 million of them, and even fewer of the species have been studied in depth.

Many of the rain forest plants and animals can only be found in small areas, because they require a special habitat in which to live. This makes them

Activity	Factors	Time to Regrow
Slash-and-Burn Agriculture	Abandoned rapidly	Less than 50 years
Perennial Shade Agriculture	Some trees left	20 years
Intensive Agriculture	Many pesticides, alteration of hydrology	More than 50 years
Cattle Pasture	Degradation of soils	More than 50 years
Selective Logging	Few trees cut	Less than 50 years
Clearcut Logging	No trees or nutrients left	More than 50 years

very vulnerable to deforestation. If their habitat is destroyed, they may become extinct. Every day, species are disappearing from the tropical rain forests as they are cleared. We do not know the exact rate of extinction, but estimates indicate that up to 137 species disappear worldwide each day.

The loss of species will have a great impact on the planet. We are losing species that might show us how to prevent cancer or help us find a cure for AIDS. Other organisms are losing species they depend upon, and thus face extinction themselves.

After Deforestation

What happens after a forest is cut is very important in the regeneration of that forest. Different cutting techniques and uses of the land have diverse effects on the ground and surviving organisms that make up a rain forest.

In a tropical rain forest, nearly all of the life-sustaining nutrients are found in the plants and trees, not in the ground as in a northern, or temperate forest. When the plants and trees are cut down to sow the land, farmers usually burn the tree trunks to release the nutrients necessary for a fertile soil. When the rains come, they wash away most of the nutrients, leaving the soil much less fertile. In as little as 3 years, the ground is no longer capable of supporting crops.

When the fertility of the ground decreases, farmers seek other areas to clear and plant, abandoning the nutrient-deficient soil. The area previously farmed is left to grow back to a rain forest. However, just as the crops did not grow well because of low nutrients, the forest will grow back just as slow because of poor nutrients. After the land is abandoned, the forest may take up to 50 years to grow back.

Another type of farming practiced in rain forests is called shade agriculture. In this type of farming, many of the original rain forest trees are left to provide shade for shade-loving crops like coffee or chocolate. When the farm is abandoned, the forest grows back very quickly, because much of it was left unharmed in the first place. After this type of farming, forests can grow back as quickly as 20 years.

Other types of farming can be more devastating for forest regrowth. Intensive agricultural systems use large quantities of chemicals like pesticides and fertilizers. These chemicals kill a lot of the living organisms in the area, seeping into the soil and washing into the surrounding areas. On banana plantations, pesticides are used on the plants and in the soil to kill pest animals. However, these pesticides also kill other animals as well, and weaken ecosystem health. Banana plantations also use irrigation ditches and underground pipes for water transport, changing the water balance of the land. After the abandonment of a banana plantation, or other intensive agricultural system, it can take many centuries for a forest to regrow.

A study in Indonesia found that when only 3% of the trees were cut, a logging operation damaged 49% of the trees in the forest. Yet, even with that much damage, the rain forest will grow back relatively quickly if left alone after selective logging, because there are still many trees to provide seeds and protect young trees from too much sun.

Clearcutting is much more damaging to a tropical rain forest. When the land is commercially clearcut and all of the trees removed, the bare ground is left behind with very little regrowth. Unlike when the farmer cleared the land, there are almost no nutrients left behind because all the tree trunks were removed. A clearcut forest can require many years to regenerate–in fact, scientists do not know how long it takes for a clearcut forest to grow back.

The Future

The deforestation of tropical rain forests is a threat to life worldwide. Deforestation may have profound effects on global climate and cause the extinction of thousands of species annually. Stopping deforestation in the tropics has become an international movement, seeking ways to stop the loss of rain forests.

Because the loss of rain forests is driven by a complex group of factors, the solutions are equally complex. Simple solutions that do not address the nature of world economics and rain forest ecology have little chance of succeeding. The future requires solutions based on solving the economic crises of countries holding rain forests, as well as improvement of the living conditions of the poor people often responsible for deforestation.

NASA Missions to Study Deforestation

NASA's Earth Science Enterprise future plans to study the effects of deforestation include continuing analyses using data from such instruments as the Enhanced Thematic Mapper Plus (ETM+), scheduled for flight on Landsat-7, and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the Moderate Resolution Imaging Spectroradiometer (MODIS), scheduled for flight on the EOS AM-1 satellite. The observational capabilities and scientific studies planned as part of the Earth Science Enterprise, including the Earth Observing System, will help to assess the impacts of deforestation on the global climate system. An overarching objective of the Earth Science Enterprise is to improve our understanding of the causes and effects of climatic and environmental change so that we may become more effective and efficient managers of our natural resources, as well as mitigate potential impacts from natural disasters.

Loss of Habitat on the Cutting Edge

Objective

- *To evaluate the rate and consequences of tropical deforestation*

Materials

- Deforestation
- ESE CD-ROM

Procedure

Read the chapter "Deforestation". Then examine the LAND section of the ESE CD-ROM: Land Cover, Use and Change. The chart on the CD (reproduced on page 4) depicts the results of deforestation in the Brazilian Amazon rain forest in 1978 and comopares it to conditions in 1988. Use the table to answer the questions.

1. In 1988, the amount of deforestation in the Brazilian Amazon totaled 230,324 km^2. The area of the forest was 4,092,831 km^2 before deforestation. Calculate the percentage of forest loss by the end of 1988.

2. Between 1978 and 1988, the area deforested increased from 78,268 km^2 to 230,324 km^2. What is the percent increase in loss?

3. If this rate were to continue, what would you expect the total amount of forest loss to be by 1998?

4. Explain how an increase in isolated areas and an increase in edge effect might impact the diversity of the rainforest.

5. Using what your knowledge of the effects of deforestation, write a persuasive speech on why the rainforest should not be deforested. Your audience is a development company headed for the Amazon Rainforest.

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The following questions are intended to be answered through research using the ESE CD-ROM section on LAND.

1. NASA's Earth Observing System will collect data on precipitation, soil moisture, and radiation budgets. What major objectives do they hope to accomplish?

2. How does deforestation affect the soil and local climate?

3. What effects can result from deforestation?

4. Tropical rainforests occupy less than 7 percent of the terrestrial surface. Why does their elimination have such a profound effect on animal diversity?

Examine the chart depicting the results of deforestation in 1978 compared to 1988. Use this chart to answer the next two questions.

5. Tropical deforestation leads to areas of the forest that are cut off from other forested areas. Some animals will not cross deforested areas to find food, water, shelter or mates. They are essentially isolated from these areas. Calculate the percent increase of isolated forest patches from 1978 to 1988.

6. Edges are areas where two different habitats meet. An example would be a forest next to a meadow. The edge area provides a good habitat for some species but for other species that are area sensitive and need greater amounts of space to find food mates and shelter, this edge effect amounts to a loss of habitat. Give an example of edge creation in your community.

7. How do smoke particles released during burning affect climate?

8. What has been the outcome of vanishing old growth forests in the Pacific Northwest?

9. Define: Desertification.

10. How does the surface of a desert impact climate?

11. Use an atlas to determine the latitude of the largest desert areas.

Loss of Habitat on the Cutting Edge

12. Describe the overall trend of the Sahara Desert over the time period

13. What has been the trend on the Eastern Shore of Maryland regarding marshes?

14. What anthropogenic changes caused the shrinking of the Aral Sea region?

15. Explain three ways that reduced water flow and evaporation had an effect on the Aral area.

16. If the process of desertification continues at its present rate, how long will it take until the Aral Sea ceases to exist.

17. List three impacts that topography has on our planet.

18. Which colors are used to represent areas of high relief (increased elevation)on the topography slide?

19. Describe the role of global vegetation on our planet.

20. In September 1994, the MODIS Fire Science Team conducted a test to develop remote sensing techniques for monitoring and characterizing fires from biomass. What relationship were they able to establish?

Loss of Habitat on the Cutting Edge

Procedure: Answers

1. 5.6% loss of forested area.

2. In 1978, 1.9% of the forested area had been lost. By 1988 the loss was 5.6%. This is an increase of 3.7%

3. If the rate increased by 3.7% every 10 years, then in 1998 we would expect a loss of 9.3% which would translate into 380,633 total square kilometers of forest lost.

4. Area sensitive species have less habitat and decrease in numbers. This could lead to decreased diversity.

Supplemental Questions: Answers

1. One of NASA's objectives is to understand key hydrological & vegetative processes in a global context.

2. Deforestation reduces the evaporative cooling that takes place from plant life.

3. The results of deforestation include temperature rises, increases in soil erosion and rainfall runoff and decreases in biological diversity

4. Even though tropical rain forests occupy less than 7 percent of the terrestrial surface, they are home to half or more of all plant and animal species.

5. Isolation increased by 217% between 1978 and 1988 (16228-5115)/5115.

6. Students can give various examples including highway construction, shopping centers, housing areas or even a new school.

Loss of Habitat on the Cutting Edge

7. Smoke particles can change the amount of solar radiation reaching the Earth's surface and also reradiate outgoing radiation. They can also increase the number of droplets in clouds. The net effect of smoke particles is a slight cooling at the Earth's surface.
8. Habitat fragmentation has destroyed the habitats required of many species of animals.
9. Desertification is a complex land degradation process involving man, land and climate. Desertification reduces both resilience and productive potential of the land to an extent that can neither be readily reversed by removing the cause, nor easily reclaimed.
10. The bright surface of the desert strongly reflects solar radiation. An increase in desert area would result in more solar energy reflected back to space and less absorbed at the surface.
11. Deserts are found along approximately 30° latitude and also at latitudes greater than 65°.
12. Although the Sahara has both expanded and contracted in size, the overall trend has been expansion.
13. Maryland marshes have been lost as interior ponds coalesce.
14. The rerouting of two large rivers for the irrigation of cotton fields.
15. Reduced water flow and evaporation had three primary effects on the Aral sea region. (1) The remaining water became extremely salty. (2) The moderating effect of the Aral Sea was diminished resulting in hotter summers and colder winters and a shorter growing season. (3)Over 20,000 square kilometers that were once submerged are now exposed. These areas are a source of windblown salts that are deposited on surrounding land and reduce crop production.
16. The Aral Sea will cease to exist by the year 2020 if present practices prevail.

Loss of Habitat on the Cutting Edge

17. Globally topography affects the circulation of the atmosphere and ocean water. It also affects the gravity field. Local topography is used to predict areas of flooding, distribution of vegetation and degree of expected soil erosion. (They needed to list 3 of the above).

18. Bright red areas indicate areas of high relief.

19. Vegetation absorbs carbon dioxide from the atmosphere and gives off oxygen. It releases moisture through evapotranspiration. When vegetation dies and decays the biomass is oxidized and carbon dioxide is released.

20. The remote sensing established a relationship between the rate of emission of thermal radiation from the fire and the rate of emission of smoke.

Acronyms

ADEOS Advanced Earth Observing Satellite *(Japan)*
AIDS Acquired Immune Deficiency Syndrome
AMSR Advanced Microwave Scanning Radiometer
AM-1 former name of the EOS Terra satellite
ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATLAS Atmospheric Laboratory for Applications and Science
AVHRR Advanced Very High-Resolution Radiometer
CERES Clouds and the Earth's Radiant Energy System instrument
CFCs Chlorofluorocarbons
CH_4 Methane
Cl Chlorine atom
Cl_2 Chlorine molecule
ClO Chlorine monoxide
CNES Centre National d'Etudes Spatiale, the French National Space Agency
CO Carbon monoxide
CO_2 Carbon dioxide
DMSP Defense Meteorological Satellite Program
DU Dobson unit
EPA Environmental Protection Agency
EOS Earth Observing System
ERBE Earth Radiation Budget Experiment
ERBS Earth Radiation Budget Satellite
ESE Earth Science Enterprise
ESMR Electrically Scanning Microwave Radiometer
ETM+ Enhanced Thematic Mapper Plus
FAO Food and Agricultural Organization
Geosat Geodetic-geophysical satellite
GLAS Geoscience Laser Altimeter System
HCl Hydrogen chloride
H_2O Water
H_2SO_4 Sulfuric acid
HRIR High Resolution Infrared Radiometer
JPL Jet Propulsion Laboratory
MLS Microwave Limb Sounder
MODIS Moderate-Resolution Imaging Spectroradiometer
MSS Multispectral Scanner
NASA National Aeronautics and Space Administration
NOAA National Oceanic and Atmospheric Administration
NSCAT NASA Scatterometer
O Oxygen atom
O_2 Oxygen molecule
O_3 Ozone
PM-1 former name of the EOS Aqua satellite
PSI Pollutants Standards Index
QuikSCAT Satellite carrying the SeaWinds instrument
Radarsat Canadian satellite carrying a SAR instrument
SAGE Stratospheric Aerosol and Gas Experiment instrument
SAR Synthetic Aperture Radar
Seasat Mission operated by NASA that carried the first imaging radar, launched in 1978
SeaWiFS Sea-viewing Wide Field-of-view Sensor
SeaWinds Conically scanned microwave radiometer, flown on QuikSCAT
SMMR Scanning Multichannel Microwave Radiometer
SO_2 Sulfur dioxide
SST Sea surface temperature
SSM/I Special Sensor Microwave/Imager
STS Spacelab/Space Transportation System
TIROS Television Infrared Observation Satellite
TIROS-N Television Infrared Observation Satellite-N
TM Thematic Mapper
TOGA Tropical Ocean and Global Atmosphere program
TOMS Total Ozone Mapping Spectrometer
TOPEX/Poseidon Joint U.S./French satellite carrying radar altimeters
TRMM Tropical Rainfall Measuring Mission
UARS Upper Atmosphere Research Satellite
UV Ultraviolet
WCRP World Climate Research Program
WOCE World Ocean Circulation Experiment

Internet Resources

NASA
http://www.nasa.gov/

NASA's Earth Science Enterprise
http://earth.nasa.gov/

NASA's Earth Observing System
http://eospso.gsfc.nasa.gov/eospso_homepage.html

NASA Fact Sheets
http://eospso.gsfc.nasa.gov/eos_homepage/misc_html/nasa_facts.html

NASA's Earth Observatory
http://earthobservatory.nasa.gov

Ozone
http://earthobservatory.nasa.gov/Library/Ozone/

Clouds
http://earthobservatory.nasa.gov/Library/Clouds/clouds.html

Energy Cycle
http://earthobservatory.nasa.gov/Library/ACRIMSAT/acrimsat.html

Volcanoes
http://volcano.und.nodak.edu/

El Nino
http://earthobservatory.nasa.gov/Library/ElNino/
http://topex-www.jpl.nasa.gov/

Polar Ice
http://earthobservatory.nasa.gov/Library/PolarIce/
http://nsidc.org/NASA/SOTC/index.html

Deforestation
http://earthobservatory.nasa.gov/Library/Deforestation/

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