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

Investigation Overview

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

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

Materials

A copy of the Briefing and Log for each student

World atlases

A current list of countries of the world and their populations. The *World Population Data Sheet*, published annually by the Population Reference Bureau, Inc., of Washington, D.C., is highly recommended: <http://www.prb.org>. Another source is the United Nations Population Division at <http://www.undp.org/popin/wdtrends/p98/fp98.htm>.

Computer with CD-ROM. The Mission Geography CD-ROM contains color graphics that are required to explain the materials.

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

Content Preview

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

Geography Standards

Standard 7: Physical Systems

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

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

Standard 10: Human Systems

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

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

Standard 14: Environment and Society

How human actions modify the physical environment

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

Standard 15: Environment and Society

How physical systems affect human systems

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

Geography Skills

Skill Set 4: Analyzing Geographic Information

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

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

Classroom Procedures

Beginning the Investigation

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

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

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

Developing the Investigation

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

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

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

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

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

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

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

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

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

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

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

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

- Point out to students that there are natural processes that can destroy stratospheric ozone, including volcanoes and burning of plants. A common assumption among scientists is that the natural processes of ozone destruction were balanced by the natural processes of ozone creation for the many years that humans did not have refrigerators and air conditioning.

- Unfortunately, we do not have any record of ozone levels before the 1950s. The best records are from the 1980s to today, as measured by NASA satellites. These records show a great decline in stratospheric ozone each polar spring. And the decline gets worse each year.

- So we are left with a problem: we know that our chemicals destroy ozone. We do not know if there were past natural changes that could also cause this type of destruction.

- Some in industry argue that this uncertainty means that we should not act prematurely to ban low-cost refrigeration systems and move to high-cost substitutes.

- Others argue that we can't afford to wait. We know that it takes decades for the chlorine we release today to destroy the ozone and fall out of the atmosphere.

6. **Part 3** provides a partial list of effects of ozone destruction.

   - Direct class discussion of these effects and to students' answers to Log Question 14: What do you think are the two most serious effects of stratospheric ozone depletion and why?

   - Following the discussion, students should write their own answers to Question 14 in the **Log**.

7. **Part 4: Where are the largest populations at risk?** asks students to estimate populations at risk from stratospheric ozone depletion. The purpose is to have students discover that the potential risk to humans is much more serious in the Northern than in the Southern Hemisphere.

   - To complete Table 3 (Log Question 15), students will need world atlases, and you will need to provide a recent list of countries and their populations (see Materials/Resources). Alternatively, direct students to the library or Internet to find this information.

   - Estimation methods and assumptions are listed in the **Briefing**. These methods and assumptions are arbitrary—they were designed only to facilitate this student activity. Note that, following Table 3, students are asked to critique these methods and assumptions.

   - The Log key to Table 3 lists only countries in the Northern Hemisphere because no Southern Hemisphere countries qualify under the assumption that more than half of a country's area must lie at 50 degrees or more of latitude. Students will discover that, excluding uninhabited Antarctica, the only land area south of 50 degrees S is the southern tip of South America—small parts of Argentina and Chile that are virtually uninhabited.

Concluding the Investigation

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

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

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

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

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

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

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

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

The following points could be made by the MDC groups:

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

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

Evaluation

Log

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Module 3, Investigation 2: Briefing

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

Background

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

Objectives

In this investigation, you will

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

Part 1: What is NASA's SOLVE project?

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

PROJECT SEEKS KEYS TO OZONE HOLE, REGROWTH

By Katy Human

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

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

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

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

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

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

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

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

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

Module 3, Investigation 2: Briefing

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

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

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

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

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

Table 1: Ozone time-line

1928
- Thomas Midgely produced a chemical compound called CFC-12 (dichlorodifluoromethane) to serve as a replacement for the highly toxic and flammable refrigerants such as ammonia.

1930s
- Dupont and General Motors began to market CFCs under the trade name Freon. Since then, other CFCs have been synthesized and produced in large quantities. CFCs have been extensively used in refrigerators and as propellants in aerosol cans.

1960s
- Recognition that O_3 was naturally low over Antarctic.

1970s
- Discovery of curious "hole" in ozone layer over Antarctica, a seasonal thinning of the layer occurring in early spring, reaching a minimum in October.
- United States issues ban on CFCs.

1980s
- Studies of SOL (stratospheric ozone layer) indicated substantial decline in total global ozone—8 percent decline from 1979-1987.
- Landmark paper in *Nature* by Farman, Gardiner, and Shanklin of the British Antarctic Survey showed that O_3 was disappearing over Antarctic during the southern hemisphere spring.
- Vienna Conference convened by United Nations Environment Programme (UNEP)—43 countries brought forth the Vienna Convention for the Protection of the Ozone Layer.
- Corresponding to the Antarctic hole, a hole was identified over the Arctic Ocean in February (maximum thinning at both poles matches the time of lowest surface temperatures).
- Scientists agreed that a serious and persistent global decrease was in progress at a rate far faster than what had been previously predicted.
- Twenty-three countries endorsed the UNEP plan for cutting global CFC consumption by 50 percent by 1999.
- In an agreement known as the Montreal Protocol, the United States joined 31 other countries in approving a similar goal.
- Airborne Arctic Stratospheric Expedition (AASE-I) found high concentrations of chlorine monoxide inside the Arctic vortex, suggesting that significant ozone depletion could occur during the Arctic spring. Several studies calculated and deduced ozone losses based on these observations.

1990s
- Slight increase in UVR—about 1 percent/year over preceding 8 years—had been documented at an observing station in the Swiss Alps at an altitude of 3600 meters (12,000 feet).
- Montreal Protocol was expanded and strengthened to a goal of 50 percent reduction of CFCs by 1995 and 85 percent by 1997.
- With the Upper Atmosphere Research Satellite (UARS), the AASE-II, and the European Arctic Stratospheric Ozone Experiment (EASOE), the Arctic winter of 1991-1992 was studied extensively. A number of researchers deduced various ozone loss rates inside the Arctic vortex.
- 1995-1996 was the first winter to show very large ozone losses and a polar ozone low in the Arctic that was very similar to the one observed over Antarctica each year.
- March 1997 Arctic ozone amounts were the lowest on record for the previous 20 years of observations.
- United States signed the Montreal Protocol on Substances that Deplete the Ozone.

2000s
- NASA's SOLVE project finds a significant decline in stratospheric ozone over the Arctic caused by an increase in the area and duration of polar stratospheric clouds (PSCs).
- Next global ozone report scheduled for 2002: UNEP publishes ozone report every four years.
- 2050 is the year it is estimated that the severely depleted Antarctic ozone layer will return to its 1980 thickness.

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

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

ARCTIC OZONE DEPLETION LINKED TO LONGEVITY OF POLAR STRATOSPHERIC CLOUDS

NASA Press Release 00-43, May 30, 2000

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

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

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

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

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

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

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

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

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

Module 3, Investigation 2: Briefing

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

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

Part 2. What is the natural geography of ozone?

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

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

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

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

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

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

Table 2: Ozone-destroying chemicals

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

Module 3, Investigation 2: Briefing

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

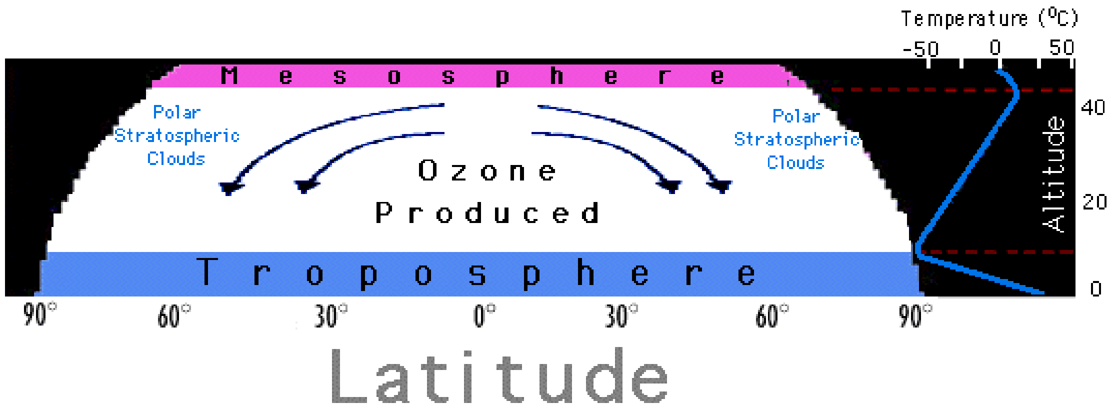

Figure 1: Ozone is produced over the tropics in the stratosphere. Winds then distribute the ozone to higher latitudes.

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

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

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

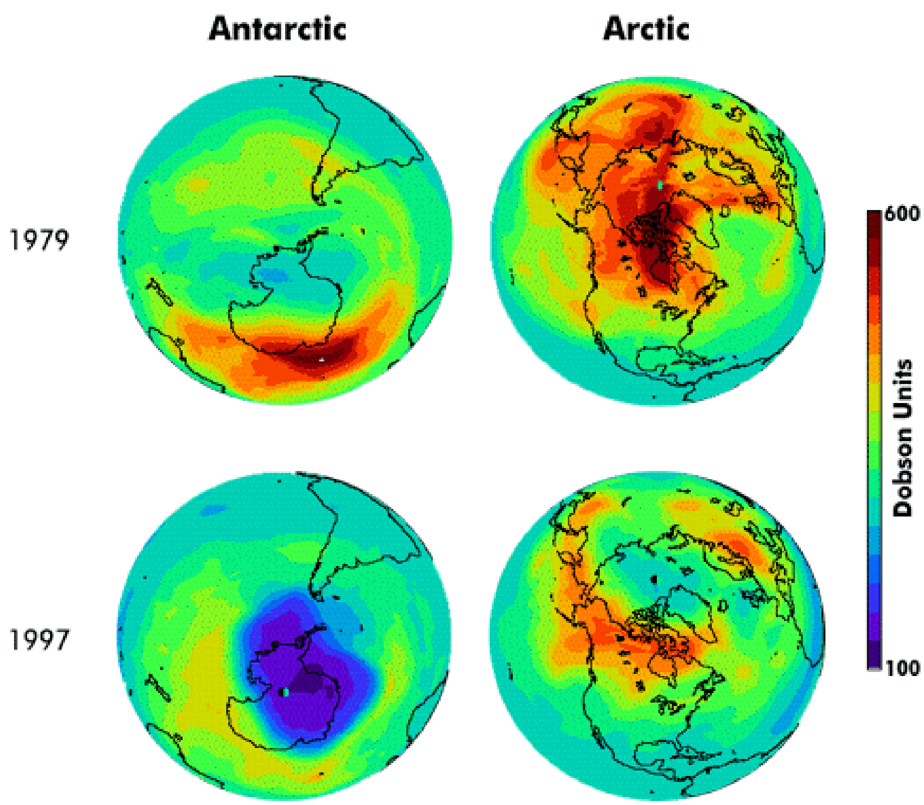

Figure 2: Polar ozone depletion over an 18-year period as measured by NASA's Total Ozone Mapping Spectrometer (TOMS). Red indicates high-ozone amounts; blue indicates low ozone.

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

Module 3, Investigation 2: Briefing

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

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

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

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

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

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

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

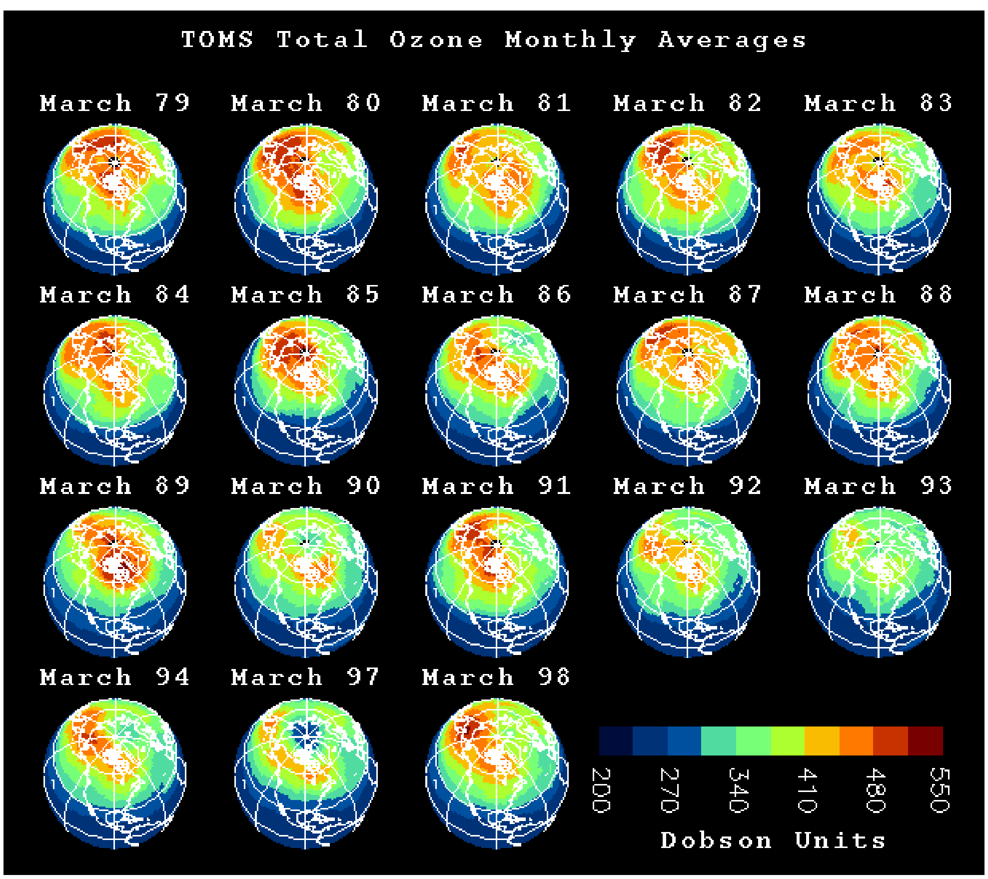

Figure 4: The springtime decline in ozone concentrations over the Arctic and adjacent high-latitude countries

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

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

Part 3: What are the effects of ozone destruction?

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

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

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

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

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

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

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

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

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

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

Answer Question 14 on the Log.

Module 3, Investigation 2: Briefing

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

Part 4: Where are the largest populations at risk?

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

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

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

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

Answer Question 15 on the Log.

Part 5: What are the geopolitics of ozone?

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

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

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

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

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

So the world is faced with a geographical irony:

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

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

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

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

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

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

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

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

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

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

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

Part 6: A geopolitical confrontation?

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

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

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

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

GLOSSARY

aerosols: tiny dust-sized particles in the atmosphere.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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Module 3, Investigation 2: Log

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

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

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

   ____

   ____

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

   ____

   ____

   ____

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

   ____

   ____

   ____

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

   ____

   ____

   ____

6. What are polar stratospheric clouds (PSCs)?

   ____

   ____

   ____

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

   ____

   ____

   ____

   ____

   ____

   ____

Module 3, Investigation 2: Log

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

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

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

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

11. Explain your answer to Question 10.

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

13. Explain your answer to Question 12.

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

    1)

    2)

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

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

Countryb	Population (millions)
Russia	145.2
Total	

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

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