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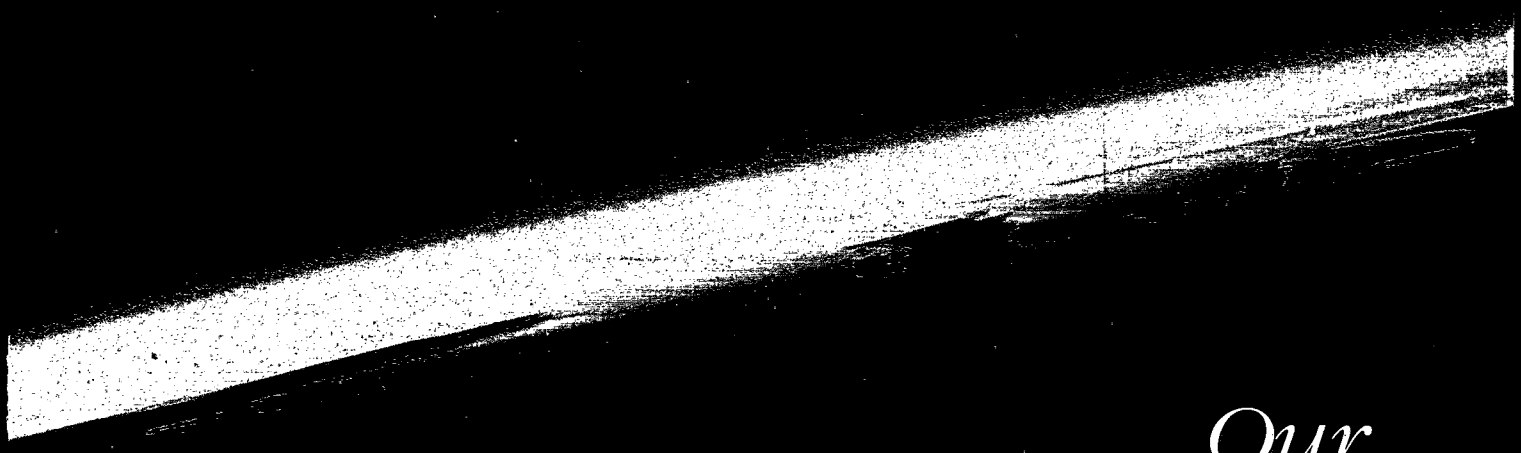
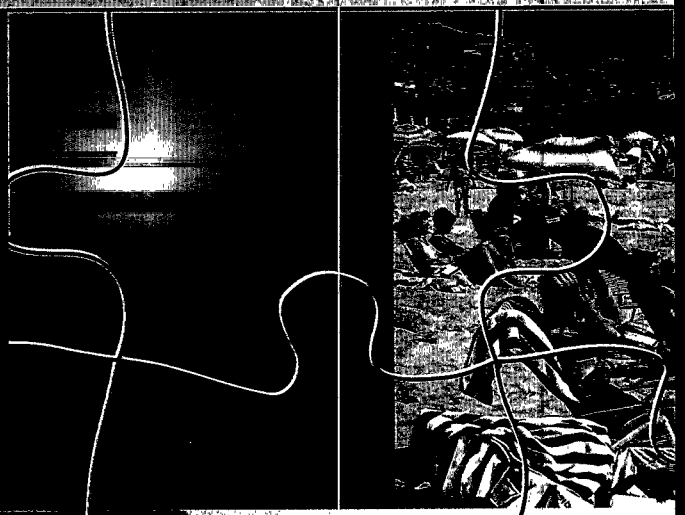
REPORTS TO THE NATION™

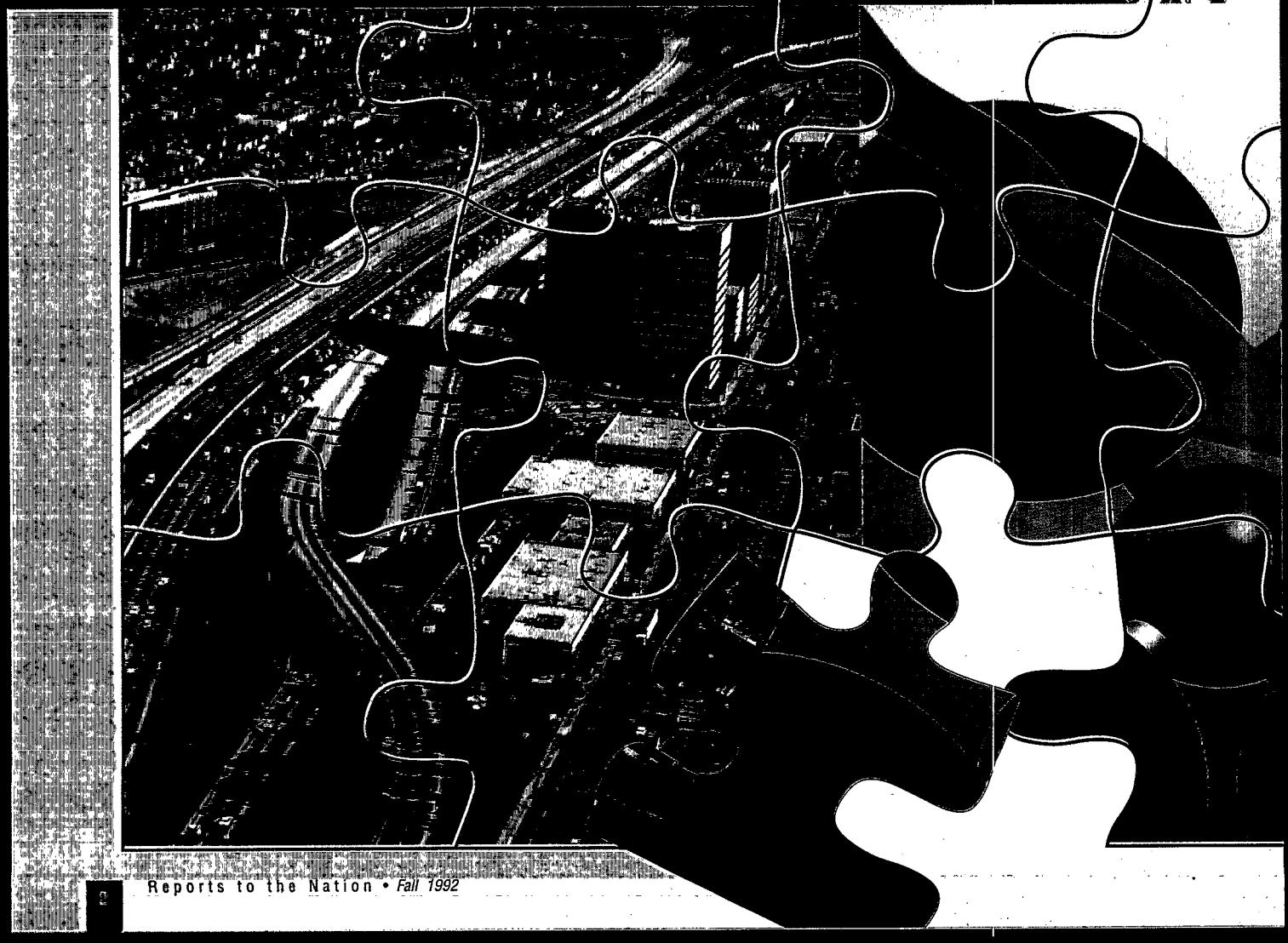
On Our Changing Planet

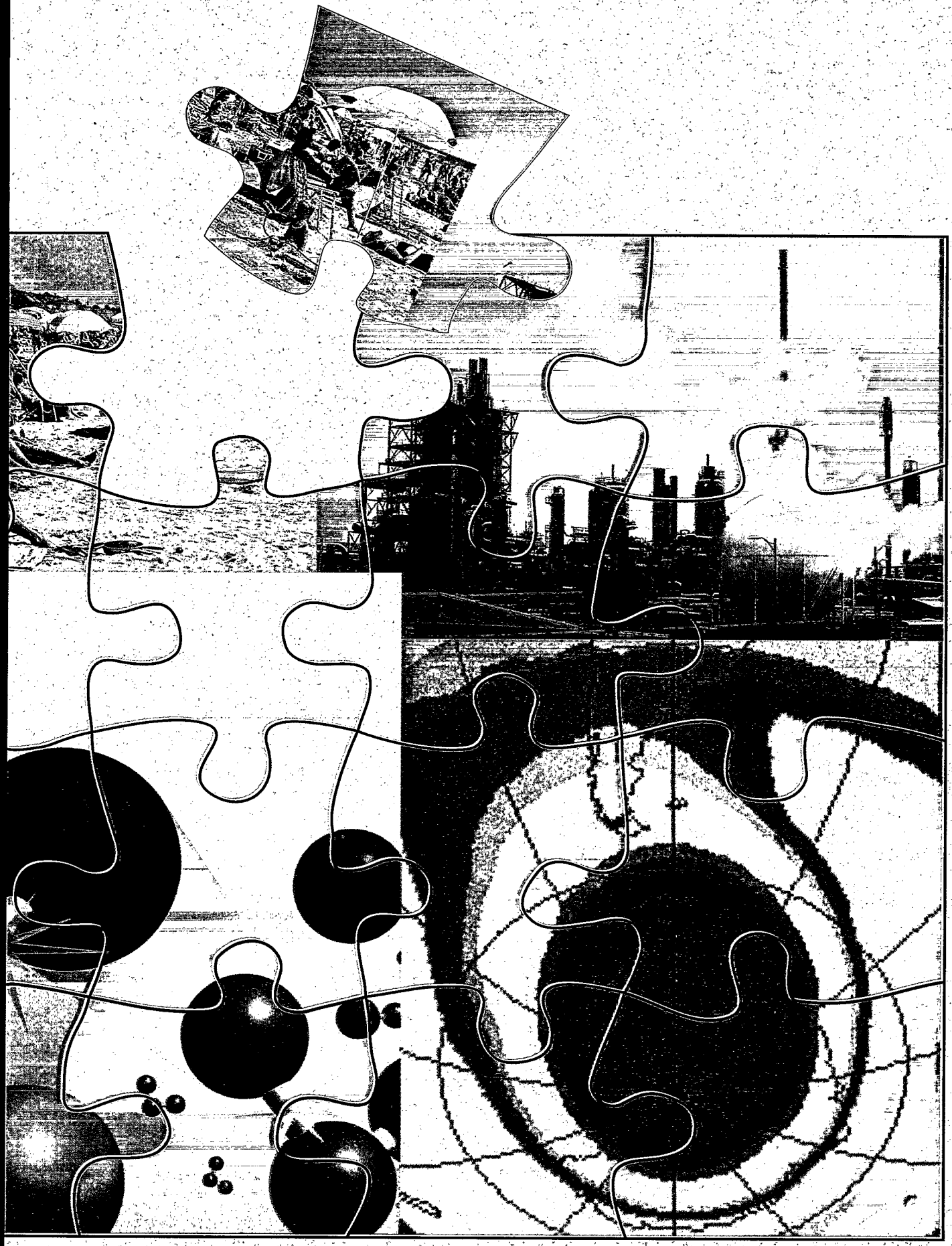


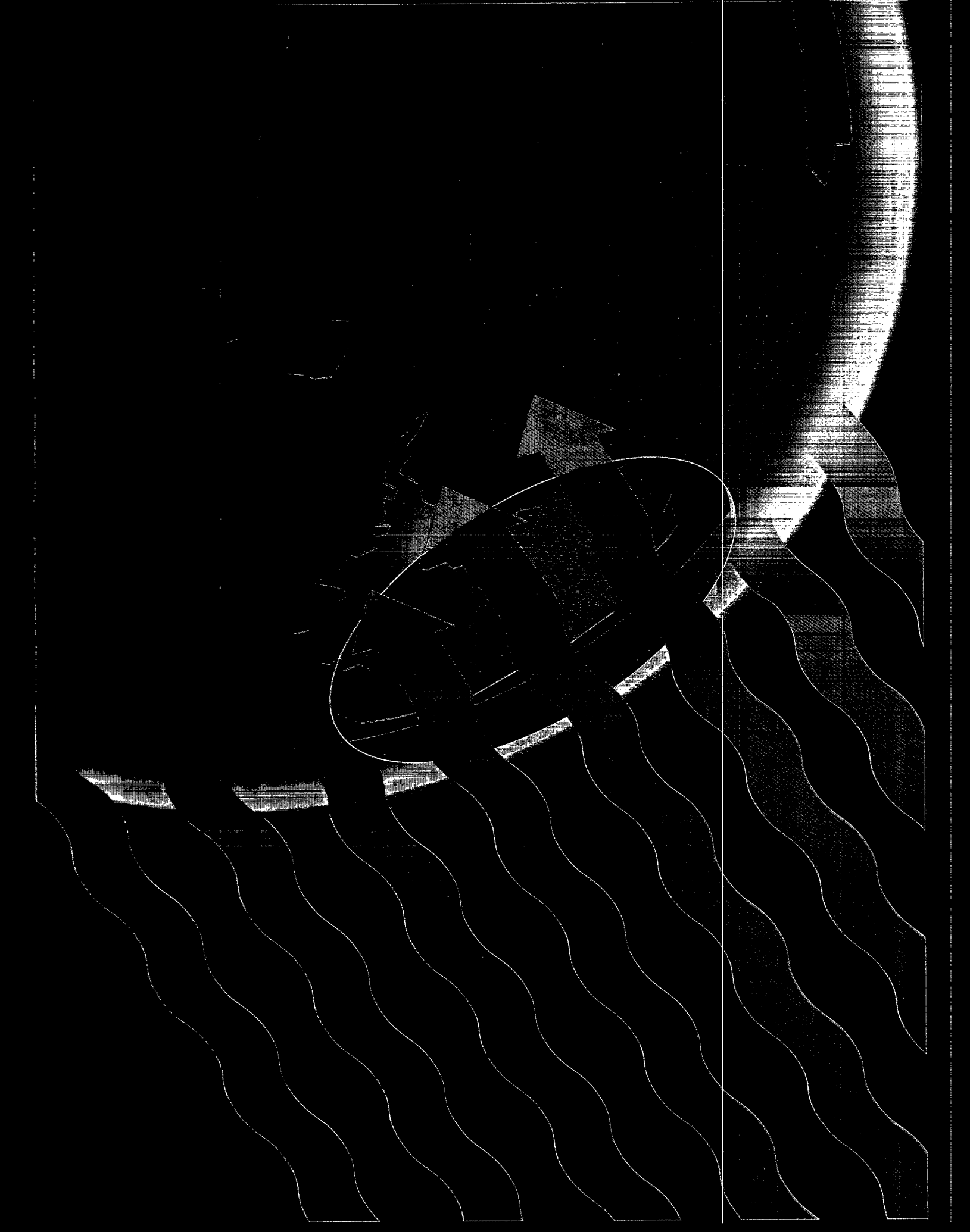
Our Ozone Shield

Life as we know it is possible in part because of the protection afforded by the ozone layer. Gradually, it has become clear to scientists and to governments alike that human activities are threatening our ozone shield. Behind this environmental problem lies a tale of twin challenges: the scientific quest to understand our ozone shield and the debate among governments over how to best protect it. Here is the story.









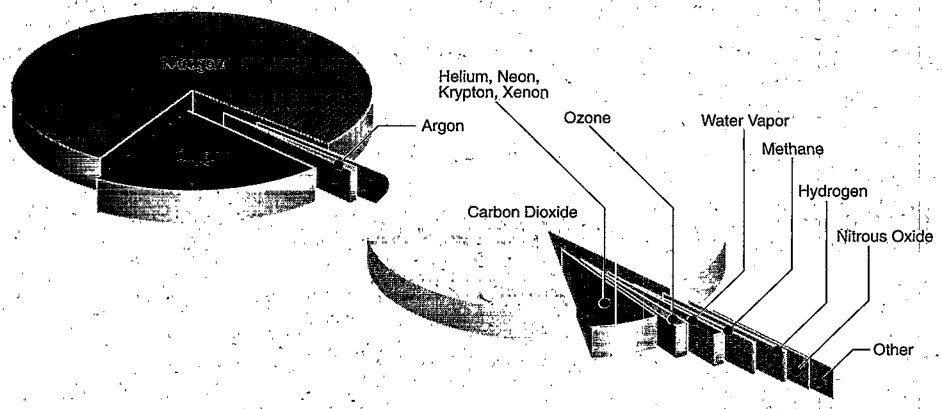
Our Ozone Shield

OZONE AND HUMANKIND. For nearly a billion years, ozone molecules in the atmosphere have safeguarded life on this planet. But over the past half century, humans have placed the ozone layer in jeopardy. We have unwittingly polluted the air with chemicals that threaten to eat away the life-protecting shield surrounding our world.

Although ozone molecules play such a vital role in the atmosphere, they are exceedingly rare; in every million molecules of air, fewer than ten are ozone. Nitrogen and oxygen make up the vast proportion of the molecules in the air we breathe. In this way, ozone resembles a critical spice in a pot of soup. Using just a few grains of a particular herb, a chef can season the whole pot with a distinctive flavor.

Ozone molecules show different character traits depending on where they exist in the atmosphere. About 90 percent of the ozone resides in a layer between 10 and 40 kilometers (6 and 25 miles) above the Earth's surface in a region of the atmosphere called the stratosphere. Ozone there plays a beneficial role by absorbing dangerous ultraviolet radiation from the sun. This is the ozone threatened by some of the chemical pollutants that we have released into the atmosphere.

Close to the planet's surface, however, ozone displays a destructive side. Because it reacts strongly with other molecules, it can severely damage the living tissue of plants and animals. Low-lying ozone is a key component of the smog that hangs over many major cities across the world, and governments are attempting to decrease its levels. Ozone in the region below the stratosphere—called the troposphere—can also contribute to greenhouse warming.



Although smog ozone and stratospheric ozone are the same molecule, they represent separate environmental issues, controlled by different forces in the atmosphere. This monograph will focus on the stratospheric ozone layer and the world's attempts to protect it.

What is ozone and where does it originate? The term itself comes from the Greek word meaning "smell," a reference to ozone's distinctively pungent odor. Each molecule contains three oxygen atoms bonded together in the shape of a wide triangle. In the stratosphere, new ozone molecules are constantly created in chemical reactions fueled by power from the sun.

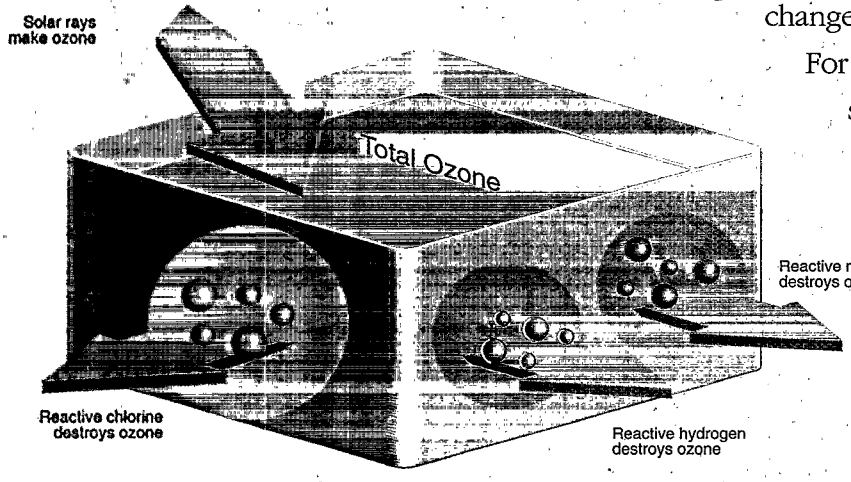
The recipe for making ozone starts off with oxygen molecules (O_2). When struck by the sun's rays, the molecules split apart into single oxygen atoms (O), which are exceedingly reactive. Within a fraction of a second, the atoms bond with nearby oxygen molecules to form triatomic molecules of ozone (O_3).

Even as the sun's energy produces new ozone, these gas molecules are continuously destroyed by natural compounds containing nitrogen, hydrogen, and chlorine. Such chemicals were all present in the stratosphere—in small amounts—long before humans began polluting the air. Nitrogen comes from soils and the oceans, hydrogen comes mainly from atmospheric water vapor, and chlorine comes from the oceans.

The stratospheric concentration of ozone therefore represents a balance, established over the aeons, between creative and destructive forces. The total level of ozone in the stratosphere remains fairly constant, an arrangement resembling a tank with open drains. As long as the amount of water pouring in equals the amount flowing out the drain holes, the water level in the tank stays the same.

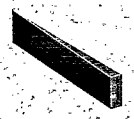
In the stratosphere, the concentration of ozone does vary slightly, reflecting small shifts in the balance between creation and destruction. These fluctuations result from many natural processes such as the seasonal cycle, volcanic eruptions, and changes in the sun's intensity.

For about a billion years, the natural ozone system worked smoothly, but now human beings have upset the delicate balance. By polluting the atmosphere with additional chlorine-containing chemi-



The amount of ozone in the Earth's stratosphere is a balance between continuous production and loss. Ozone is produced by the sun's rays. It is removed by chemical reactions. But humans have added to the amount of reactive chlorine compounds in the stratosphere. Since the loss of ozone is now greater than the production of ozone, we are thinning our protective shield.

How does such a small piece play such a huge role?



cals, we have enhanced the forces that destroy ozone—a situation that leads to lower ozone concentrations in the stratosphere. The addition of these chemicals is the same as drilling a larger "chlorine" drain in the tank, causing the level to drop.

A Problem Arises: The Early 1970s

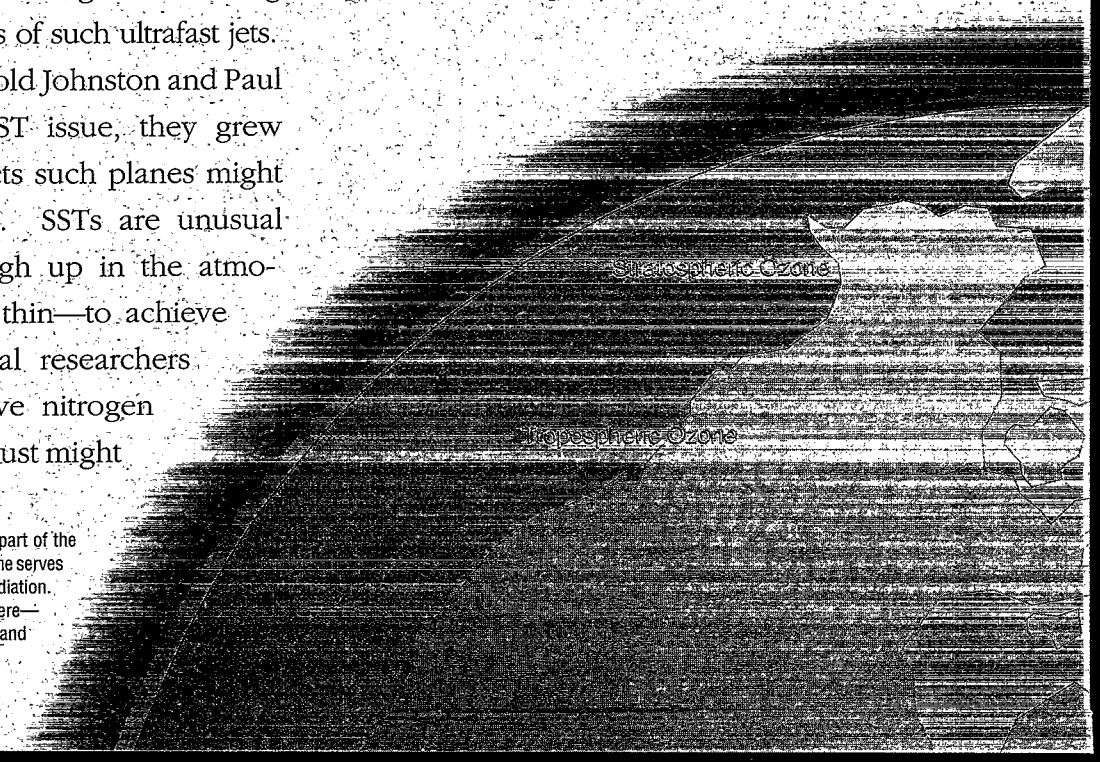
No one dreamed human activity would threaten the ozone layer until the early to mid-1970s, when scientists discovered two potential problems: ultrafast passenger planes and spray cans.

The plane threat surfaced first, after the invention of a new breed of commercial aircraft called supersonic transport (SST). These planes could fly faster than the speed of sound and promised to trim hours off long journeys. In the 1970s, the United States and other nations began considering whether to build large fleets of such ultrafast jets.

As scientists such as Harold Johnston and Paul Crutzen looked at the SST issue, they grew concerned about the effects such planes might have on the stratosphere. SSTs are unusual because they must fly high up in the atmosphere—where the air is thin—to achieve their fast speeds. Several researchers suspected that the reactive nitrogen compounds from SST exhaust might accelerate the natural chemical destruction of ozone, causing ozone levels to drop.

In 1974, news of another possible threat to the ozone layer made national headlines. This time scientists implicated a widely used class of chemicals known as chlorofluorocarbons (CFCs), which were most commonly known as the aerosol propellant in spray cans. Invented in the late 1920s, CFCs contain chlorine, fluorine, and carbon atoms arranged in an extremely stable structure.

Through decades of use, CFCs proved themselves to be ideal compounds for many purposes. They are nontoxic, noncorrosive, nonflammable, and unreactive with most other substances. Because of their special properties, they make excellent coolants for refrigerators and air conditioners. CFCs also trap heat well, so manufacturers put them into foam



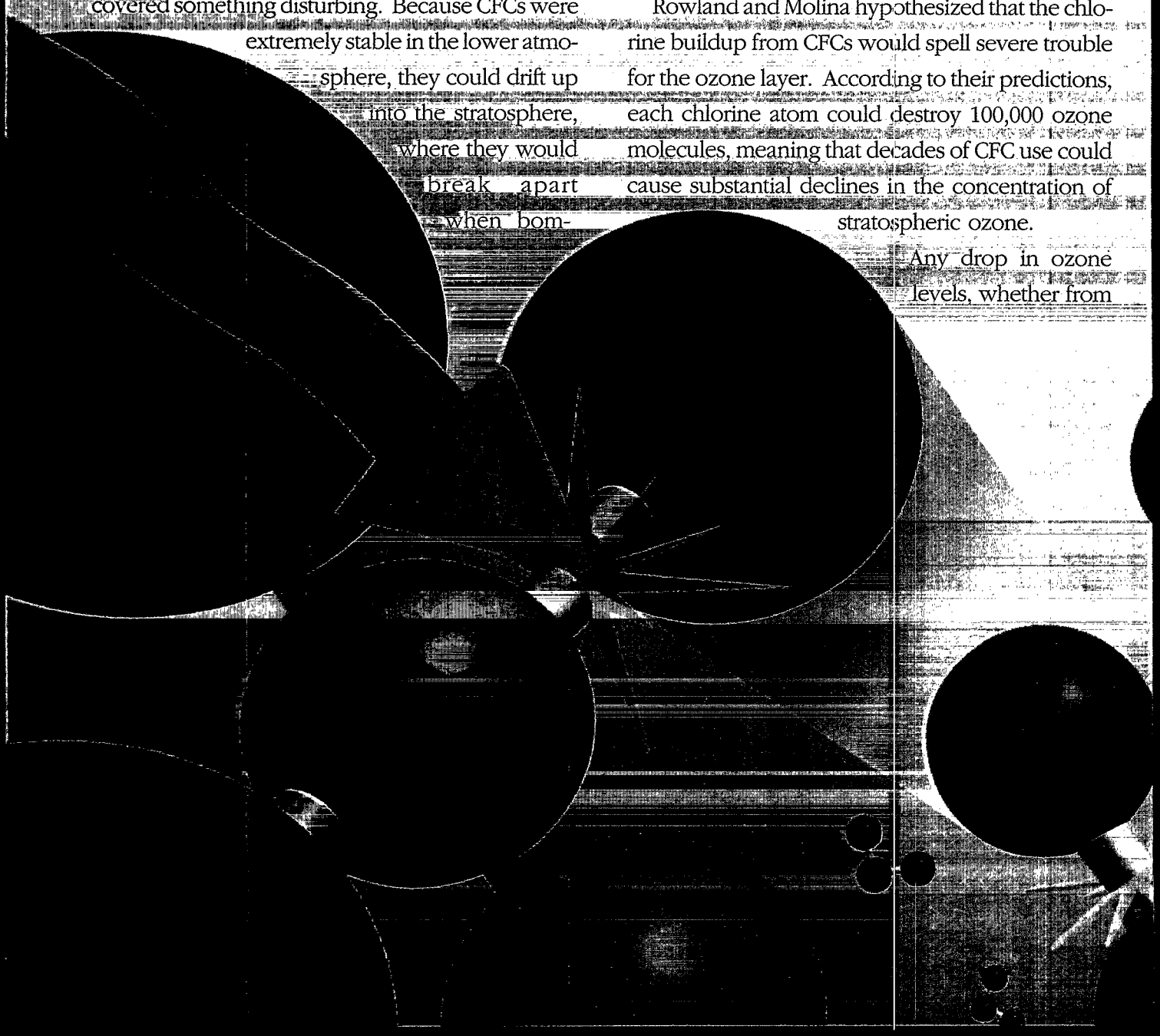
Most of the Earth's ozone is high in the upper part of the atmosphere—the stratosphere. This "good" ozone serves as our shield against incoming solar ultraviolet radiation. The "bad" ozone in the lower part of the atmosphere—the troposphere—adds to greenhouse warming and is a major part of smog in cities.

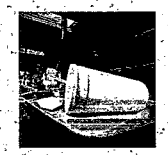
products such as cups and insulation for houses.

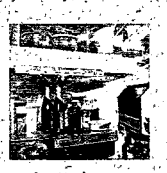
Most scientists had not worried about how CFCs would affect the atmosphere. But two chemists, F. Sherwood Rowland and Mario Molina, began considering these wonder compounds, and they uncovered something disturbing. Because CFCs were extremely stable in the lower atmosphere, they could drift up into the stratosphere, where they would break apart when bombarded by the sun's high-energy radiation. CFCs therefore carried millions of tons of extra chlorine atoms into the stratosphere, adding much more than the amount of chlorine supplied naturally by the oceans in the form of methyl chloride.

Rowland and Molina hypothesized that the chlorine buildup from CFCs would spell severe trouble for the ozone layer. According to their predictions, each chlorine atom could destroy 100,000 ozone molecules, meaning that decades of CFC use could cause substantial declines in the concentration of stratospheric ozone.

Any drop in ozone levels, whether from





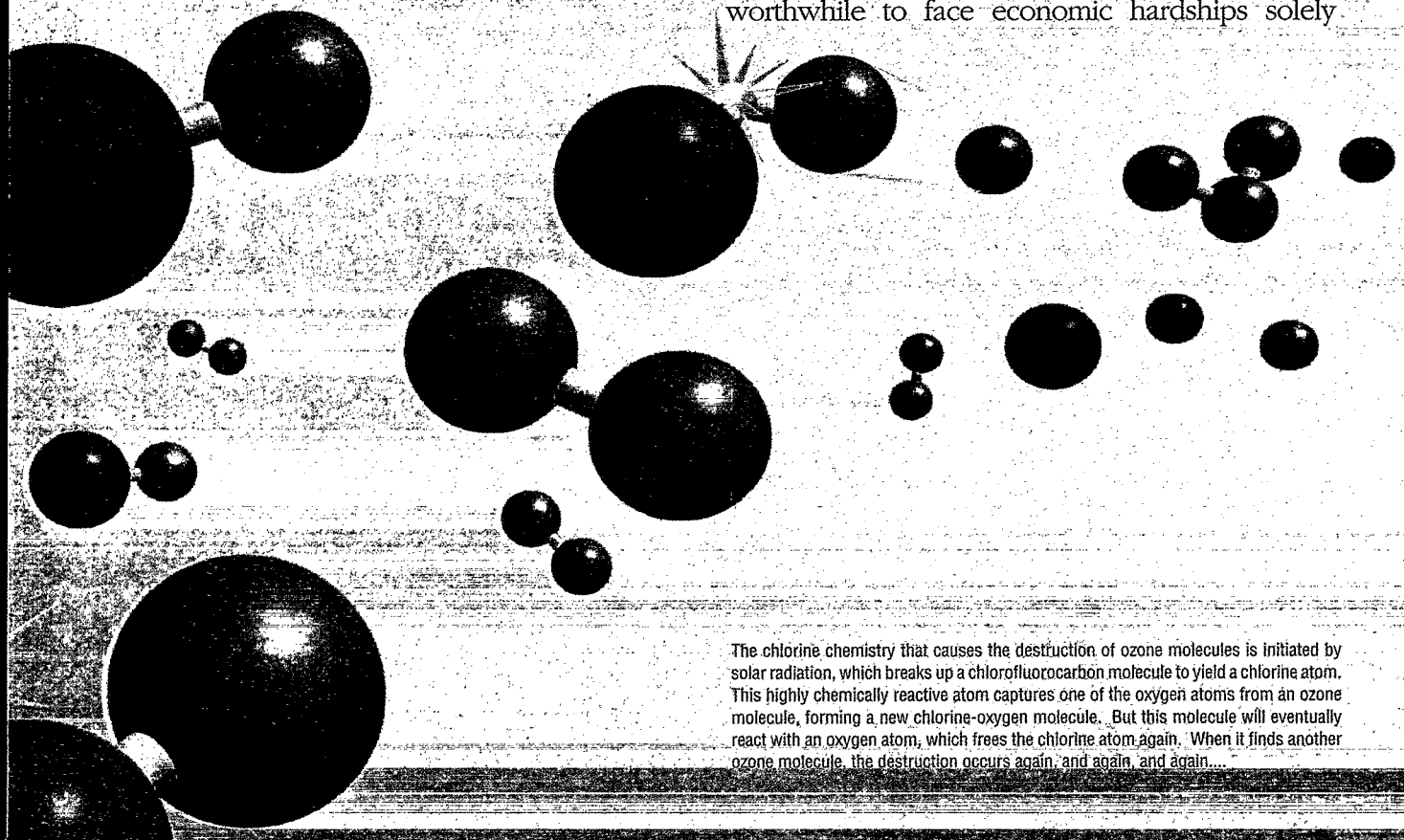


SSTs or CFCs, would allow more ultraviolet light to reach the Earth's surface—an effect that holds severe consequences for life on the planet. Exposure to ultraviolet light enhances an individual's risk for skin cancer and cataracts, so an increase in this radiation could lead to more cases of such diseases. Ultraviolet light also harms food crops and other plants, as well as many species of animals.

Thus the world faced two ozone-related environmental issues in the first half of the 1970s. In terms of SSTs, policy makers had to decide whether to build such planes. With CFCs, the question was whether to limit the production and use of these chemicals.

Of all the countries considering SSTs, the United States had planned the largest fleet, and it addressed this issue rather quickly. When preliminary scientific studies suggested the planes would significantly thin the ozone layer, the U.S. government decided against the proposed fleet.

Political leaders faced a much tougher decision on the subject of CFCs. For example, in the United States, these extremely reliable chemicals formed the center of a multi-billion-dollar industry. Though the Rowland/Molina hypothesis warned that CFCs might endanger the health of the planet's inhabitants, officials feared that a ban on such chemicals would disrupt many segments of society. Was it worthwhile to face economic hardships solely



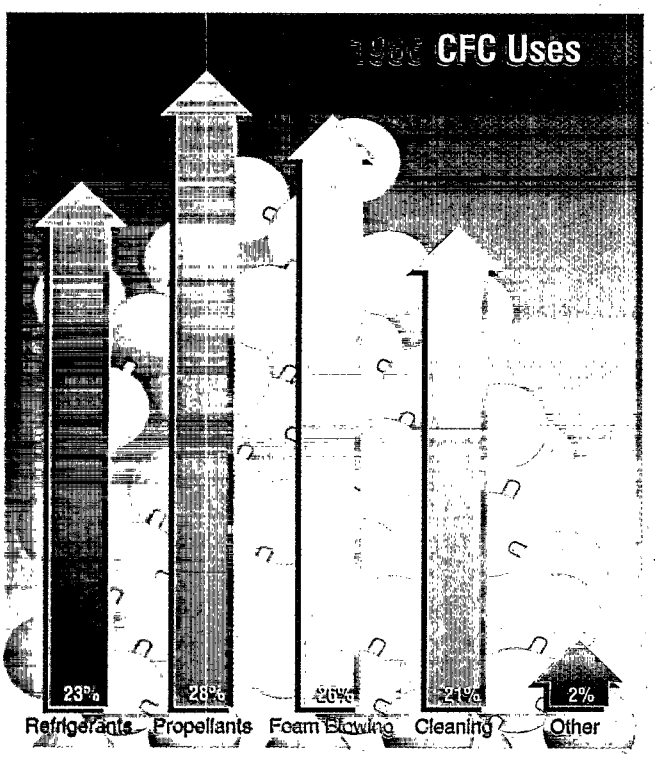
The chlorine chemistry that causes the destruction of ozone molecules is initiated by solar radiation, which breaks up a chlorofluorocarbon molecule to yield a chlorine atom. This highly chemically reactive atom captures one of the oxygen atoms from an ozone molecule, forming a new chlorine-oxygen molecule. But this molecule will eventually react with an oxygen atom, which frees the chlorine atom again. When it finds another ozone molecule, the destruction occurs again, and again, and again....

because of a scientific hypothesis and its predicted effects?

Decision makers also knew that the ozone layer belonged to the entire world, meaning that all countries would have to address the problem.

Stratospheric Ozone: The First Decade (1974–1984)

Would CFCs really bring significant harm to the ozone layer? That was the question politicians were asking in 1974, and the scientific community set out to provide an answer.



The human-made chlorofluorocarbons (CFCs) were "miracle" compounds. Their uses proved to be manyfold. They cooled refrigerators, propelled spray from cans, filled the insulating bubbles in foam, and cleaned delicate electronic parts. The rapid worldwide growth in the use of these ozone-depleting compounds in the mid-1980s rekindled international debate over whether their production should be curtailed.

Atmospheric researchers had to judge the seriousness of the problem. If ozone levels were to decline by only 1 percent in the next 50 years, nations would have little cause for concern. On the other hand, a substantial drop in ozone levels could jeopardize the world.

The first attempts to assess the problem produced dire forecasts, suggesting that CFCs could destroy perhaps half the ozone shield by the middle of the next century. Yet experts did not know how much to believe these early estimates, because they were based on a very simplistic understanding of chemical reactions in the stratosphere.

It was like trying to decipher a partially completed jigsaw puzzle, spread out on a table. Scientists wondered what the missing pieces looked like and whether they would change the emerging picture.

Over the next few years, researchers took many different routes toward filling in the gaps in the ozone puzzle. Experiments in the laboratory allowed chemists to gauge how quickly chlorine destroyed ozone molecules. Other scientists launched balloons that carried instruments up into the stratosphere, where they measured the concentrations of key chemicals that controlled ozone levels. All this information fed into new computer models that predicted how chemicals would affect the ozone layer.

By 1976, many experts had grown convinced that CFCs did indeed present a serious threat. In the United States—the world's largest producer and

but recently a downward trend has started.

user of CFCs—the public called for the government to place limitations on these chemicals. Civic leaders launched boycotts against items that used CFCs, and some companies even eliminated the compounds from their products.

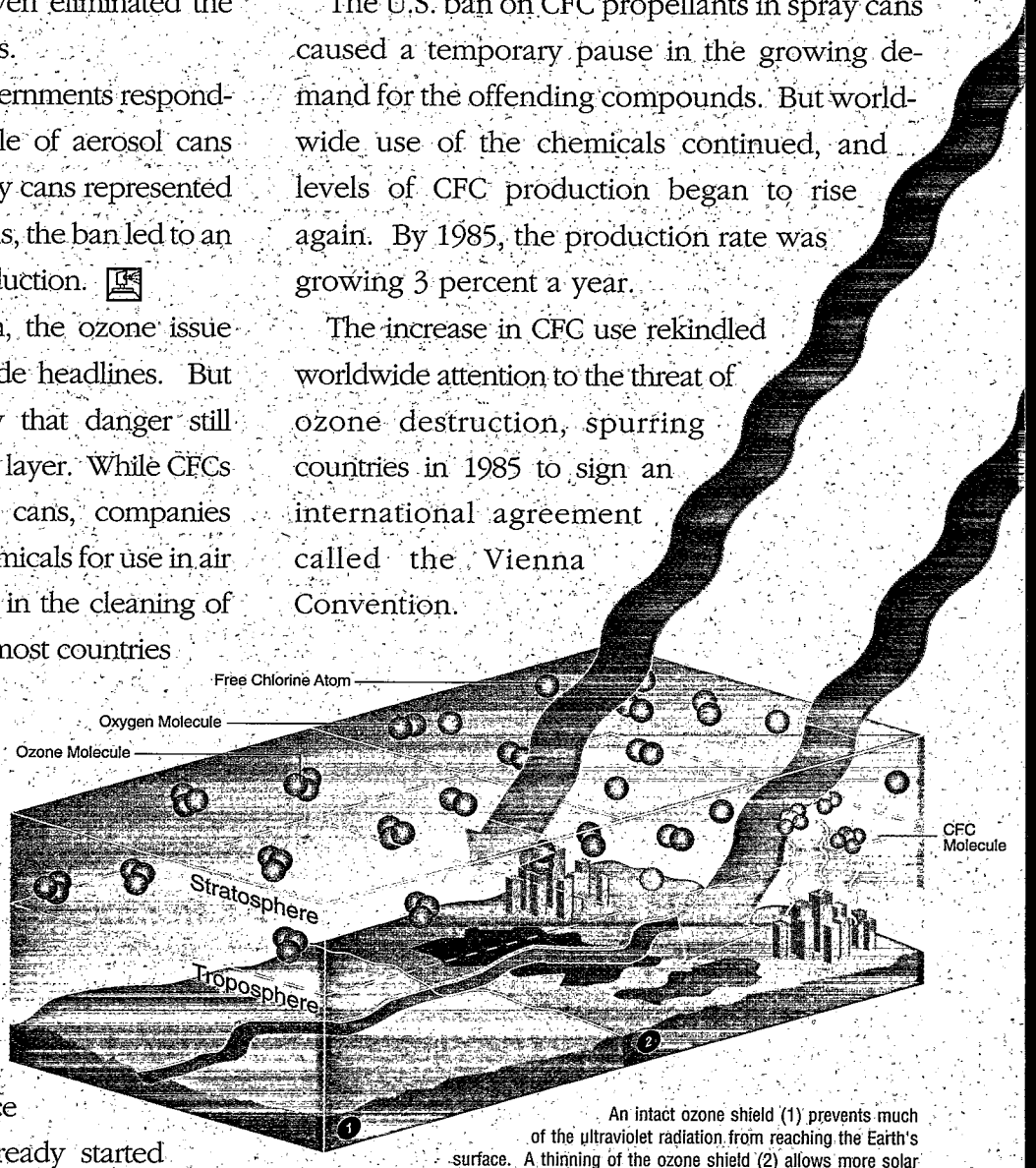
The U.S. and some other governments responded in 1979 by banning the sale of aerosol cans containing CFCs. Because spray cans represented the largest use of these chemicals, the ban led to an abrupt leveling off of CFC production.

After the spray can decision, the ozone issue quickly receded from worldwide headlines. But atmospheric researchers knew that danger still threatened the protective ozone layer. While CFCs no longer filled U.S. aerosol cans, companies continued to produce these chemicals for use in air conditioners, in insulation, and in the cleaning of electronic parts. What's more, most countries aside from the United States continued to use CFCs in spray cans. So even as the threat to the ozone layer slipped from the public spotlight, scientists extended their investigations into the problem.

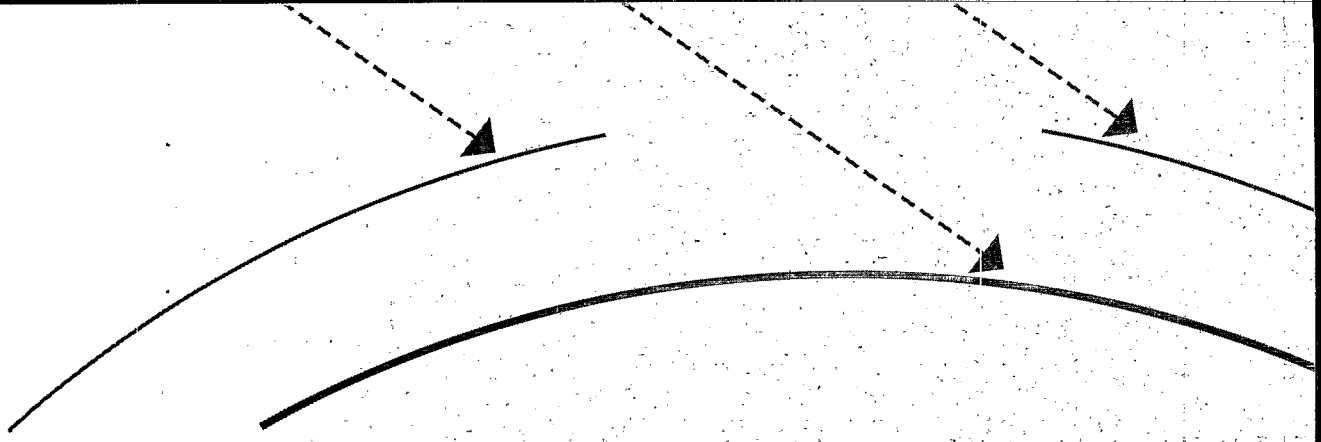
Researchers also began watching the ozone layer more closely, searching for evidence that chlorine pollution had already started weakening the protective shield. They knew it might be difficult to spot such destruction at first. Ozone levels fluctuate naturally by several percent, so identifying the subtle signs of unnatural ozone loss would be like to trying to hear someone whisper a message across a crowded room.

The U.S. ban on CFC propellants in spray cans caused a temporary pause in the growing demand for the offending compounds. But worldwide use of the chemicals continued, and levels of CFC production began to rise again. By 1985, the production rate was growing 3 percent a year.

The increase in CFC use rekindled worldwide attention to the threat of ozone destruction, spurring countries in 1985 to sign an international agreement called the Vienna Convention.



An intact ozone shield (1) prevents much of the ultraviolet radiation from reaching the Earth's surface. A thinning of the ozone shield (2) allows more solar ultraviolet rays to reach the surface of the Earth. Such radiation is known to increase the number of skin cancers and cataracts in humans. It is also harmful to both terrestrial and aquatic ecosystems. Scientists in the 1970s were predicting that the impacts of such harmful ultraviolet radiation could become very significant indeed if humans continued to produce more and more CFCs.



The convention called on negotiators to draw up a plan for worldwide action on this issue. It also required scientists to summarize the latest information on the atmospheric consequences of CFCs and related bromine-containing chemicals called Halons, which had grown popular over the previous decade because of their ability to extinguish fires. Collectively, CFCs and Halons fit under the name halocarbons.

Using the most complete models, experts predicted that if levels of halocarbon production continued to increase as they had in the past, ozone concentrations in the stratosphere would drop by about 5 percent by the year 2050. Although much less severe than the predictions of earlier years, even a 5 percent decrease would still allow a very serious surge in the amount of ultraviolet radiation reaching the Earth's surface, causing millions of new cases of skin cancer in the United States alone.

By the time of the Vienna Convention, scientists remained uncertain whether ozone levels had actually started to drop. The research community, nonetheless, warned that countries could not afford to take a wait-and-see approach. Halocarbons present an insidious danger for the future because they can survive in the atmosphere for decades; some can last several centuries. That means even if the entire world stopped producing such compounds instantly, the halocarbons already in the atmosphere would continue to damage the ozone layer for more than 100 years. Many governments thought it critically important to limit the chemicals as soon as possible.

Then in May of 1985, shocking news spread throughout the scientific community. British researchers reported finding dramatic declines in ozone values over Antarctica each spring—actual "holes" in the ozone layer. Atmospheric scientists didn't know how to explain these large and unanticipated changes. Some proposed that natural processes were at work, while others thought it was the first sign that halocarbons were wearing away the protective ozone shield.

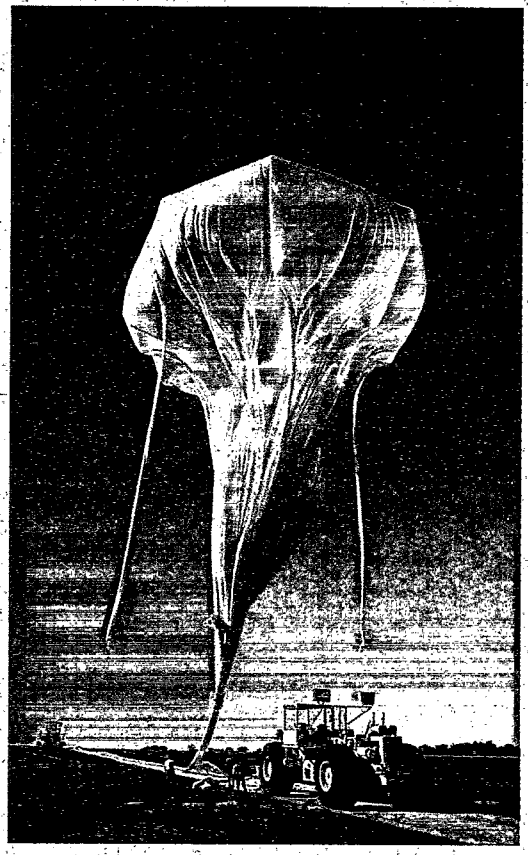
Despite uncertainty about the Antarctic phenomenon's cause, scientists firmly believed halocarbons would eventually deplete the global ozone shield. Their certainty and the jarring unexpectedness of the ozone hole's appearance motivated countries to act. In September 1987, diplomats from around the world met in Montreal and forged a treaty unprecedented in the history of international negotiations. Environmental ministers from 24 nations, representing most of the industrialized world, agreed to set sharp limits on the use of CFCs and Halons. According to the treaty, by mid-1989 countries would freeze their production and use of halocarbons at 1986 levels. Then over the next ten years, they would cut CFC production and use in half.

For scientists and policy makers, the Montreal Protocol marked a truly profound moment. When negotiators drew up the treaty, they were motivated by concerns about *future* ozone loss,

rather than by direct observations of current ozone destruction by CFCs. (Certainly the ozone hole in Antarctica had unnerved world leaders, but it was by no means clear whether chemical pollutants had caused this decline.) Thus, the agreement was based primarily on confidence in a theory.

The Montreal Protocol established a new way of viewing environmental problems. In the past, the world had addressed such issues only after damage grew noticeable. For example, nations agreed to limit above-ground nuclear tests once it became evident these explosions poisoned the air and water with radioactivity. The Montreal agreement, however, tackled the ozone issue early, demonstrating a heightened sense of environmental responsibility.

The framers of the protocol also broke new ground in another way: they realized their agreement might not suffice if future scientific work revealed that the ozone layer faced even greater danger. Uppermost in their minds was concern over the Antarctic ozone hole and its possible implications for global ozone. The diplomats therefore included a provision calling for negotiators to reconvene in 1990 to examine any new scientific or technical information that might necessitate adopting deeper cuts.



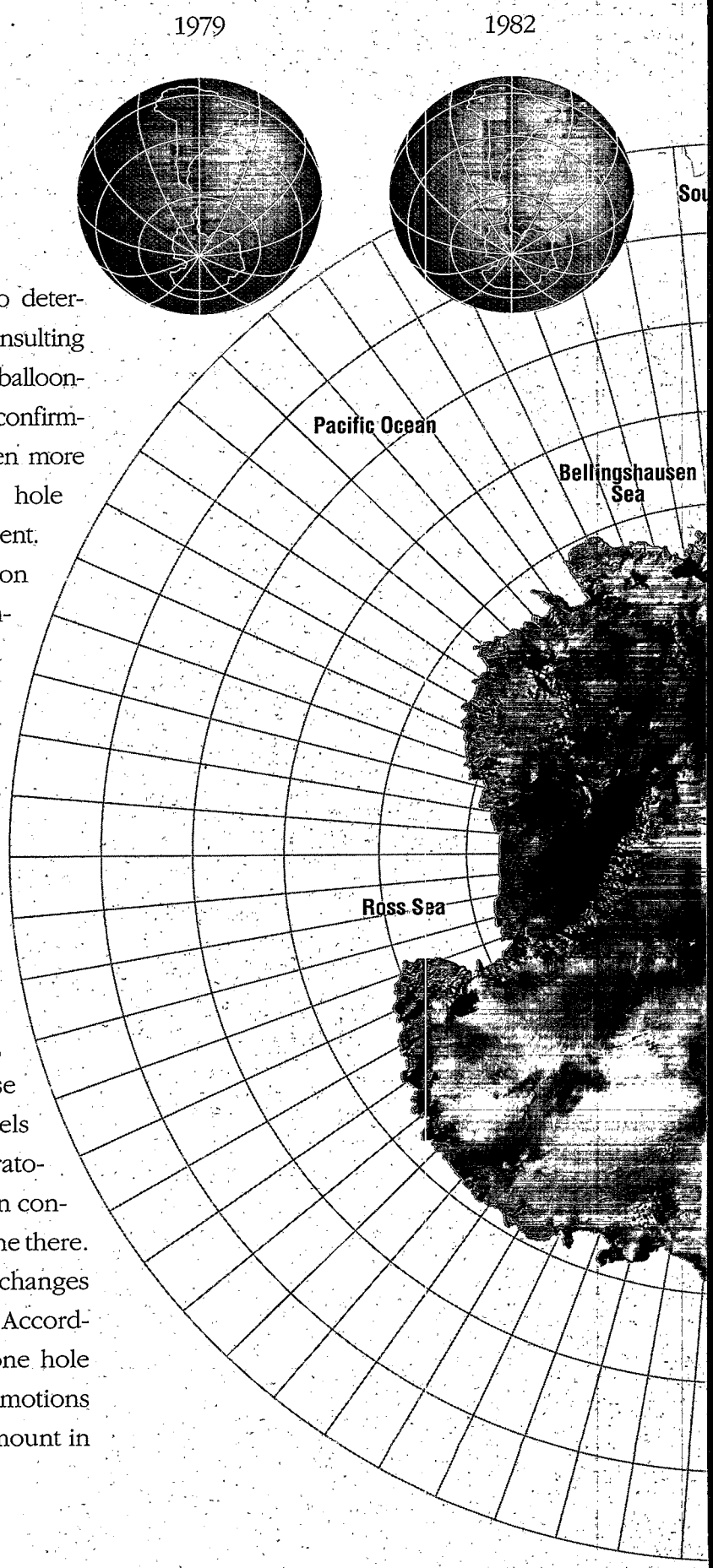
After it was hypothesized that CFCs could destroy ozone, researchers focused on quantifying this theory. Some hoisted instruments into the stratosphere with huge balloons. Others probed the inner workings of the ozone-destroying chemical reactions in the laboratory. Still others crafted all of this information into computer models, which foretold mounting ozone losses if CFC usage continued to grow.

The Ozone Years: 1985–1989

The ozone hole was born in the late 1970s, long before the Montreal Protocol was signed. Like a leak in the roof over the distant part of a house, the hole at first grew unnoticed by any human being living below.

Each spring, ozone abundances over the ice-covered continent dropped below normal and then rose gradually toward normal amounts in summer. And each year, the springtime losses grew worse.

A British team, which had measured ozone levels over the Antarctic coast since 1956, first began noticing the phenomenon in the early 1980s. But it was hard to swallow the evidence at first. Was the ozone hole real, or were the instruments malfunctioning? wondered the scientists. After checking and rechecking the instruments, the British researchers grew confident of their discovery. In 1985, they announced their startling news to the rest of the world.

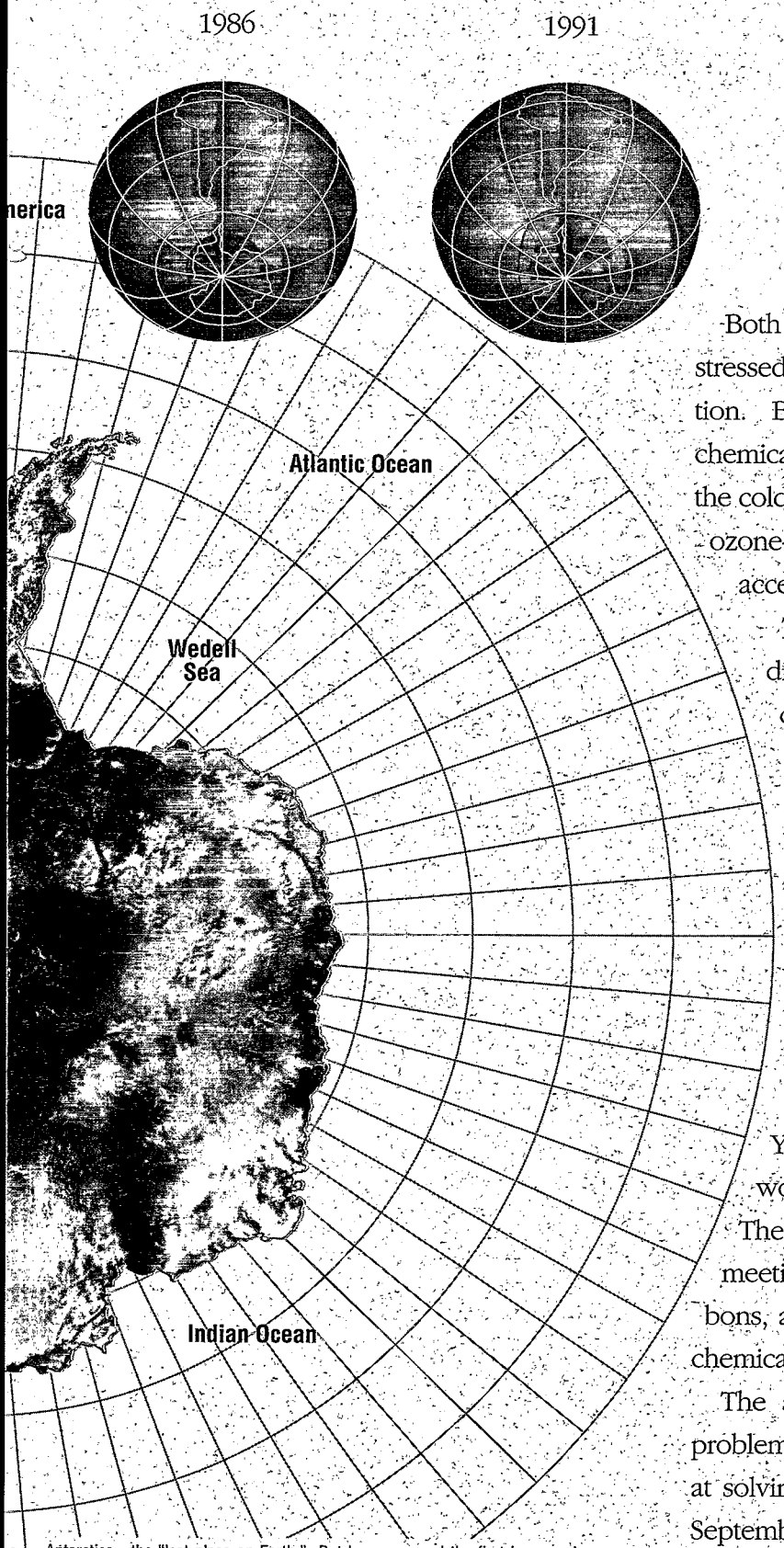


Atmospheric experts moved quickly to determine whether the ozone hole was real. Consulting measurements made by satellite-borne and balloon-borne instruments, they found evidence confirming the springtime ozone depletion. Even more staggering, measurements showed the hole extending over the entire Antarctic continent.

The discovery of the ozone depletion blindsided the scientific community, catching it totally off guard and without a suitable explanation. But within a few months, theoretical scientists came up with three competing ideas that could explain why the ozone hole had developed over Antarctica.

One group of scientists focused on the solar cycle—the periodic waxing and waning of the sun's energy output. Noting that solar radiation had grown particularly strong in the early 1980s, some researchers proposed the intense radiation had created above-normal levels of reactive nitrogen chemicals in the stratosphere. These compounds could then concentrate over Antarctica and destroy ozone there.

A second group suggested that natural changes in stratospheric winds were responsible. According to this "dynamical" theory, the ozone hole resulted from changes in the system of air motions that transport ozone and establish its amount in the polar regions.



Antarctica—the "last place on Earth." But here occurred the first large-scale ozone losses. British scientists discovered that, in the mid-1970s, the ozone layer over Antarctica began to thin during each springtime. By the mid-1980s, the magnitude of these seasonal losses had grown to 50 percent, which was much greater than any known natural variation. The Antarctic ozone "hole" had been discovered, presenting both scientists and policy makers with a complex puzzle.

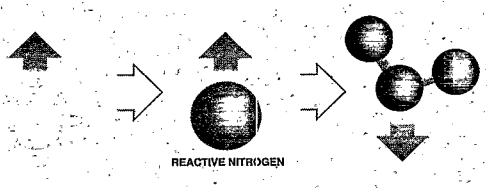
Both the solar cycle and dynamical theories stressed natural processes as a cause for the depletion. But a third theory held that human-made chemicals deserved blame. According to this idea, the cold conditions above Antarctica amplified the ozone-destroying power of CFCs and Halons, accelerating the loss in this region.

The three separate theories held profoundly different implications for the world. If halocarbon pollution created the hole, then scientists had gravely underestimated the chemicals' destructive power, and the ozone layer faced even more danger than previously thought. But if the hole formed because of natural processes, then humans could breathe a sigh of relief.

With very little known about the Antarctic ozone losses, atmospheric researchers could not tell which theory was correct. Yet they recognized that political leaders would need an answer as soon as possible. The signers of the Montreal Protocol would be meeting to review the limitations on halocarbons, and it was critical to know whether these chemicals lurked behind the ozone hole.

The scientific community threw itself at the problem, launching several field expeditions aimed at solving the riddle of the ozone depletion. In September of 1986, a hastily assembled team hurried off to McMurdo Station in the Antarctic. Using ground-based instruments and balloons to probe the stratosphere, this team found high levels

What's causing the ozone hole?



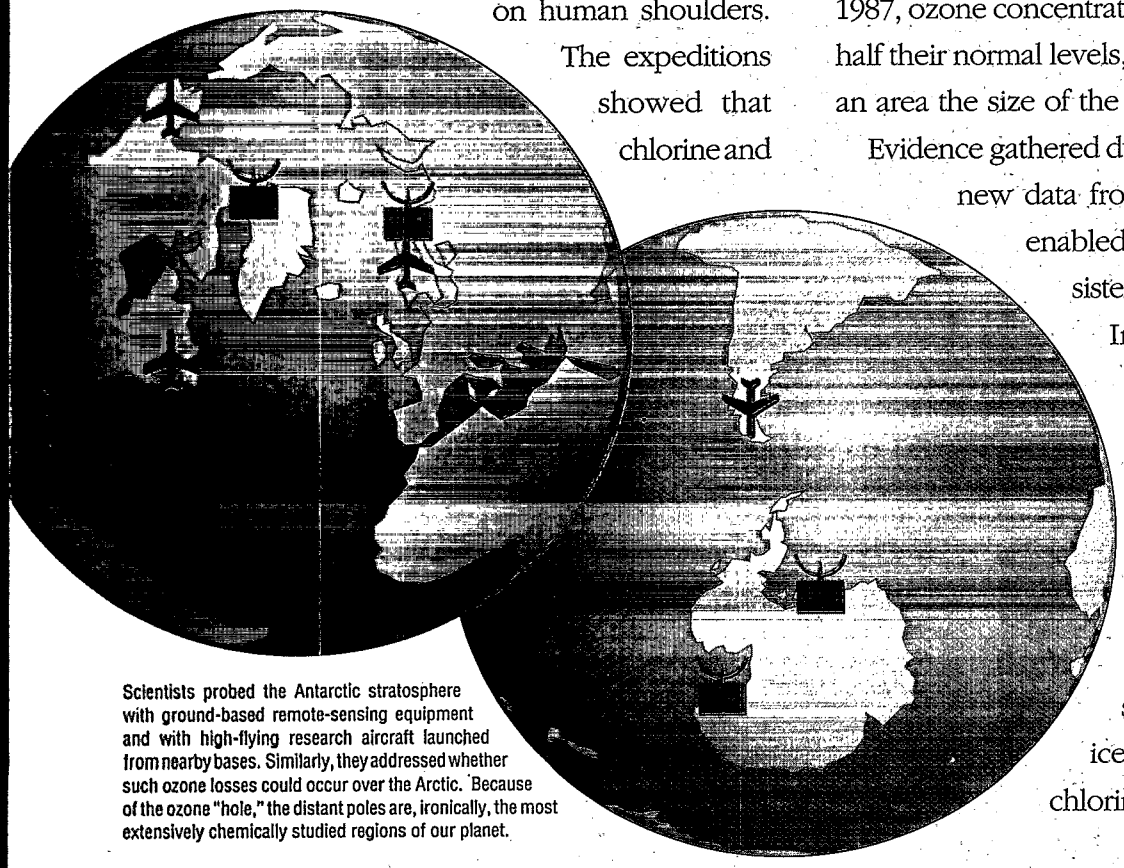
Sunspots?

of ozone-destroying compounds. A year later, the United States, in conjunction with other countries, sent a massive group of more than 100 scientists, engineers, and technicians to Punta Arenas, Chile, at the southern tip of South America. From this distant base, two research airplanes flew into the dangerously cold Antarctic sky to gather conclusive data about the mysterious affairs in the stratosphere over that icy land. Other scientists returned to McMurdo for further measurements.

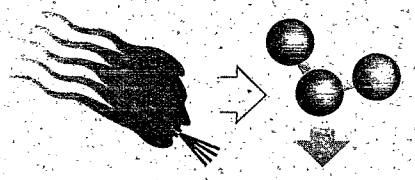
By October 1987, the researchers came back from the Southern Hemisphere with a dark message for the world: blame for the ozone hole falls on human shoulders. The expeditions showed that chlorine and bromine pollution had shifted the fragile chemical balance in the Antarctic, thereby draining those skies of ozone during the spring.

Ozone loss is accelerated over the frozen continent because the Antarctic stratosphere contains cloud particles not normally present in warmer climes. These icy particles have a critical effect on the chlorine and bromine pollution floating in the stratosphere. Normally, the chlorine and bromine are largely locked into "safe" compounds that cannot harm ozone, but the ice particles transform them into destructive chemicals that can break apart ozone molecules with amazing efficiency. In 1987, ozone concentrations above Antarctica fell to half their normal levels, and the hole spread across an area the size of the United States.

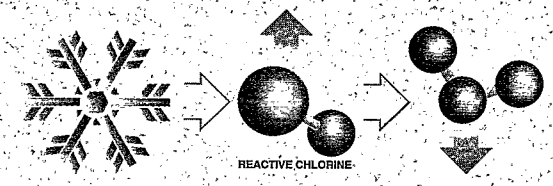
Evidence gathered during these expeditions and new data from laboratories back home enabled scientists to fashion a consistent theory to explain the hole. In the prelude to ozone depletion, ice particles form during the polar night, when several months of darkness descend on Antarctica and temperatures plummet below -80°C (-112°F) in the stratosphere. On those floating ice particles, reactions convert chlorine from the "safe" to the



Scientists probed the Antarctic stratosphere with ground-based remote-sensing equipment and with high-flying research aircraft launched from nearby bases. Similarly, they addressed whether such ozone losses could occur over the Arctic. Because of the ozone "hole," the distant poles are, ironically, the most extensively chemically studied regions of our planet.



Meteorology?



Chemistry?

"destructive" form. The real action begins when the sun returns to this part of the world during springtime, energizing the chemical cycle that destroys ozone. Wind patterns during winter and spring contribute by isolating the Antarctic stratosphere from warmer air to the north.

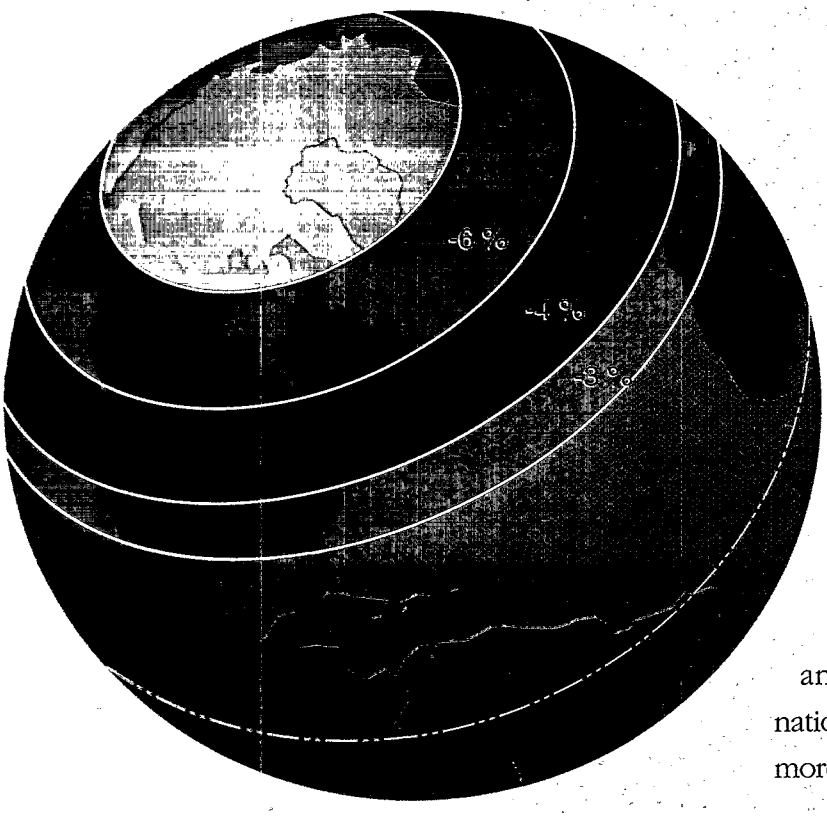
The ozone hole forms only in Antarctica because this region has a unique combination of weather conditions: it is the coldest and most isolated spot on Earth. But somewhat similar conditions exist in the Arctic, and scientists wondered whether the North also suffered from ozone loss. Even small depletions in this region would represent cause for concern, because many people live in northern latitudes potentially affected by Arctic ozone loss. So in 1988, two small teams traveled to Greenland and Canada to gather data. A year later, an extensive group headed to Norway to take measurements with the two airplanes that helped to solve the Antarctic puzzle.

The northern expeditions revealed that during wintertime, the Arctic stratosphere has the same types of destructive chlorine and bromine compounds that cause the problems in the Antarctic. Indeed, when scientists returned to the Arctic for an extended study in 1991 and 1992, they discovered strong hints that such compounds had destroyed significant amounts of ozone in the polar region. But because the Arctic atmosphere is not as isolated, the ozone losses there appear to be much smaller than those in Antarctica—at least for the present.

Between trips to the ends of the Earth, atmospheric scientists during this period also stepped up their search for signs of a global erosion in the ozone layer. An international panel of experts came together to scrutinize measurements made by satellites and by ground-based instruments around the world. In 1988, they reached a verdict: global ozone levels *had* declined over the past 17 years, mainly in the winter. Normal processes such as the solar cycle had caused part of the drop, but natural effects could not explain the entire ozone loss.

The news grew even worse. An international panel announced that ozone levels had dropped by measurable amounts not only in winter and spring but also in summer. Because people spend far more time outdoors during summer, ozone loss at this time of the year poses the greatest threat to the health of humans.

Scientists suspect that CFCs and Halons are to blame for much of the ozone decline, which has reached several percent over the midlatitudes of the Northern Hemisphere—the segment of the globe that encompasses the United States and Europe. But atmospheric researchers are not yet fully confident that they know what mechanism lies behind the drop. The largest changes have occurred over the poles and neighboring midlatitudes, leading some researchers to suggest that loss near the poles has enhanced the decline in global ozone levels. Others suspect that the



Spurred by the CFC – ozone hypothesis, scientists began closely watching the variations in global ozone, searching for the first sign of the predicted ozone losses. In the late 1980s, they began to see ozone losses, even outside of the polar regions, that could not be explained by natural variation. These losses, which increase poleward from the equator, appear to be related to the CFCs, but the details are not yet fully explained.

natural, thin layer of sulfur-containing particles in the stratosphere could be involved in midlatitude ozone loss, in a role somewhat similar to that played by ice particles over Antarctica.

The fast-paced research of the late 1980s revealed that the original Montreal Protocol would not go far enough toward protecting the fragile ozone layer. Even with the 50 percent cuts mandated by the treaty, levels of chlorine and bromine would still rise in the stratosphere, meaning that ozone loss would only worsen with time.

In June 1990, diplomats met in London and voted to significantly strengthen the Montreal Protocol. The treaty calls for a complete phaseout of CFCs by the year 2000, a phaseout of Halons (except for essential uses) by 2000, and a rapid phaseout of other ozone-destroying chlorine compounds (carbon tetrachloride by 2000 and methyl chloroform by 2005).

The treaty also attempts to make the phaseouts fair for developing countries, which cannot easily afford the higher-priced substitutes that will replace banned compounds. The revised agreement establishes an environmental fund—paid for by developed nations—to help developing nations switch over to more "ozone-friendly" chemicals.

Our Ozone Layer: Present and Future

But many pieces of the ozone puzzle remain missing, and scientists wonder whether new ozone problems will develop in the near future. Experts are exploring several unanswered questions, including:

- What surprises lurk in the next decade or so? Even with the amended protocol, chlorine abundances will continue to rise until around the turn of the century.
- Will ozone losses grow worse in the Arctic as chlorine abundances increase?
- How safe are the CFC substitutes? Will some of them significantly contribute to ozone loss, global warming, or other environmental problems?
- How appropriate is it to allow countries to continue "essential" uses of the powerful ozone

For the first time in my life I saw the horizon as a curved line. It was accentuated by a thin seam of dark blue light—our atmosphere. Obviously this was not the ocean of air I had been told it was so many times in my life. I was terrified by its fragile appearance.

Ulf Merbold, German Astronaut

depleting Halons? The current treaties permit these uses.

- Are there other compounds that significantly deplete the ozone layer and hence could deserve attention under the Montreal Protocol—such as methyl bromide, which is used widely as a fumigant?

- How will polar ozone destruction affect populated countries? Will the Antarctic hole cause ozone declines over Chile, Argentina, and New Zealand? Will Arctic losses spur drops in ozone concentration over Canada, Scandinavia, the United States, and the former Soviet Union?

- How much do the natural particles in the stratosphere, other than the icy polar clouds, accelerate the chemical destruction of ozone at midlatitudes?

- How will large volcanic eruptions—which can inject immense amounts of dust into the stratosphere—affect the ozone layer when the chlorine from CFCs reaches unprecedented abundances?

- How will the ozone hole and global ozone losses affect worldwide weather and climate?

- Does a proposed new class of high-altitude aircraft threaten the ozone layer?

Decision makers will need answers to such questions as they continue to revisit their international agreements in the future and ask if these are adequate in light of new research findings.

The Montreal Protocol provides a dramatic example of science in the service of humankind. By quickly piecing together the ozone puzzle, atmospheric researchers revealed the true danger of halocarbons, allowing world leaders to take decisive action to protect the ozone layer.

This international agreement represents a critical step toward saving the world's ozone layer. But perhaps more importantly, it has taught scientists and policy makers an invaluable lesson about addressing environmental problems. Negotiations on this issue mark the first time the nations of the world have joined forces to protect the Earth for future generations.

The treaty can serve as a crucial apprenticeship for world leaders and scientists, who now face an even more daunting environmental matter—the threat of global greenhouse warming that looms over the future of this planet. The successful ozone agreement offers hope that scientific understanding can once again provide the foundation for responsible action by the international community.

Understanding our global environme

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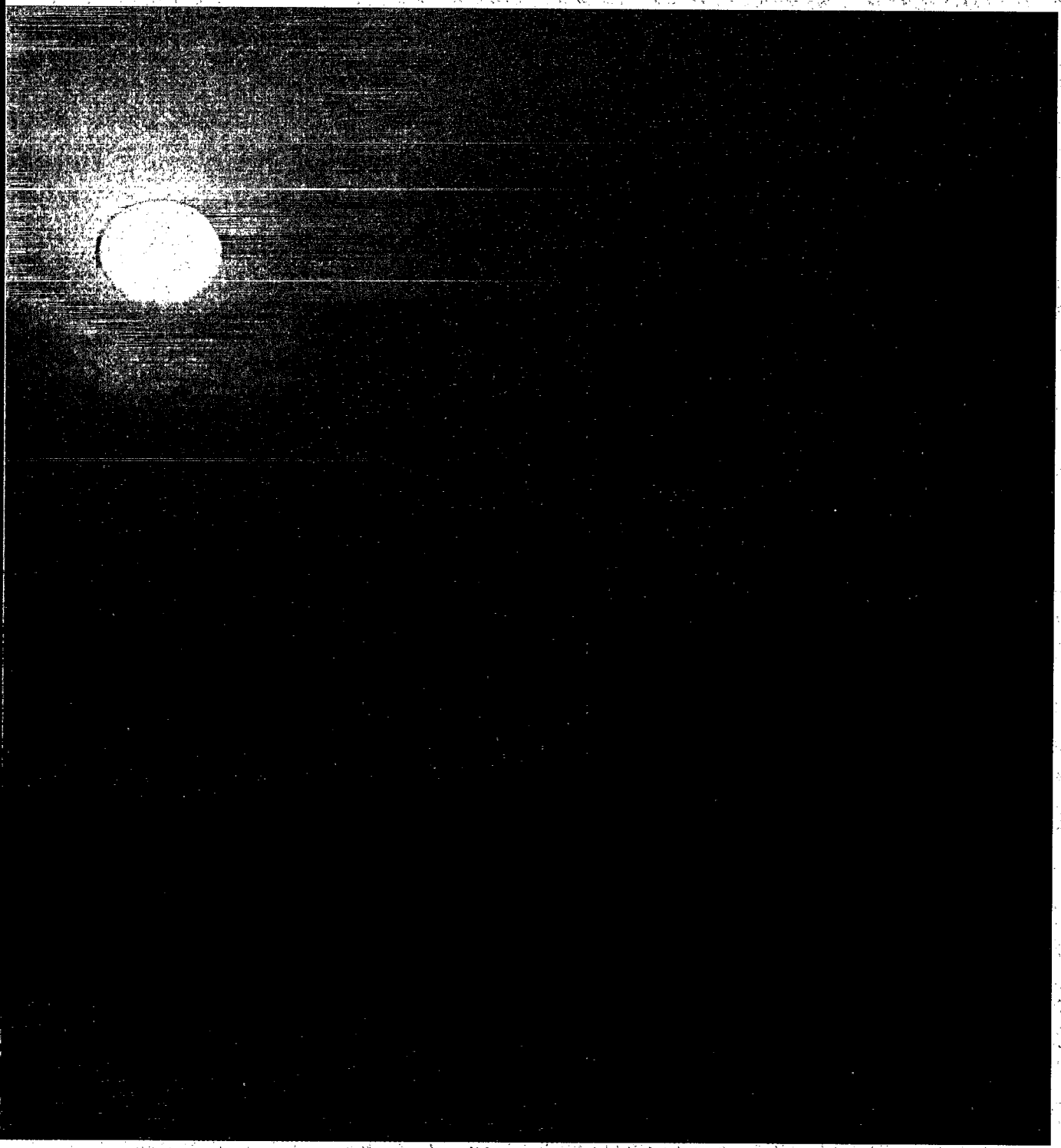
ıd our role in it is the first step toward living in better harmony with nature.



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