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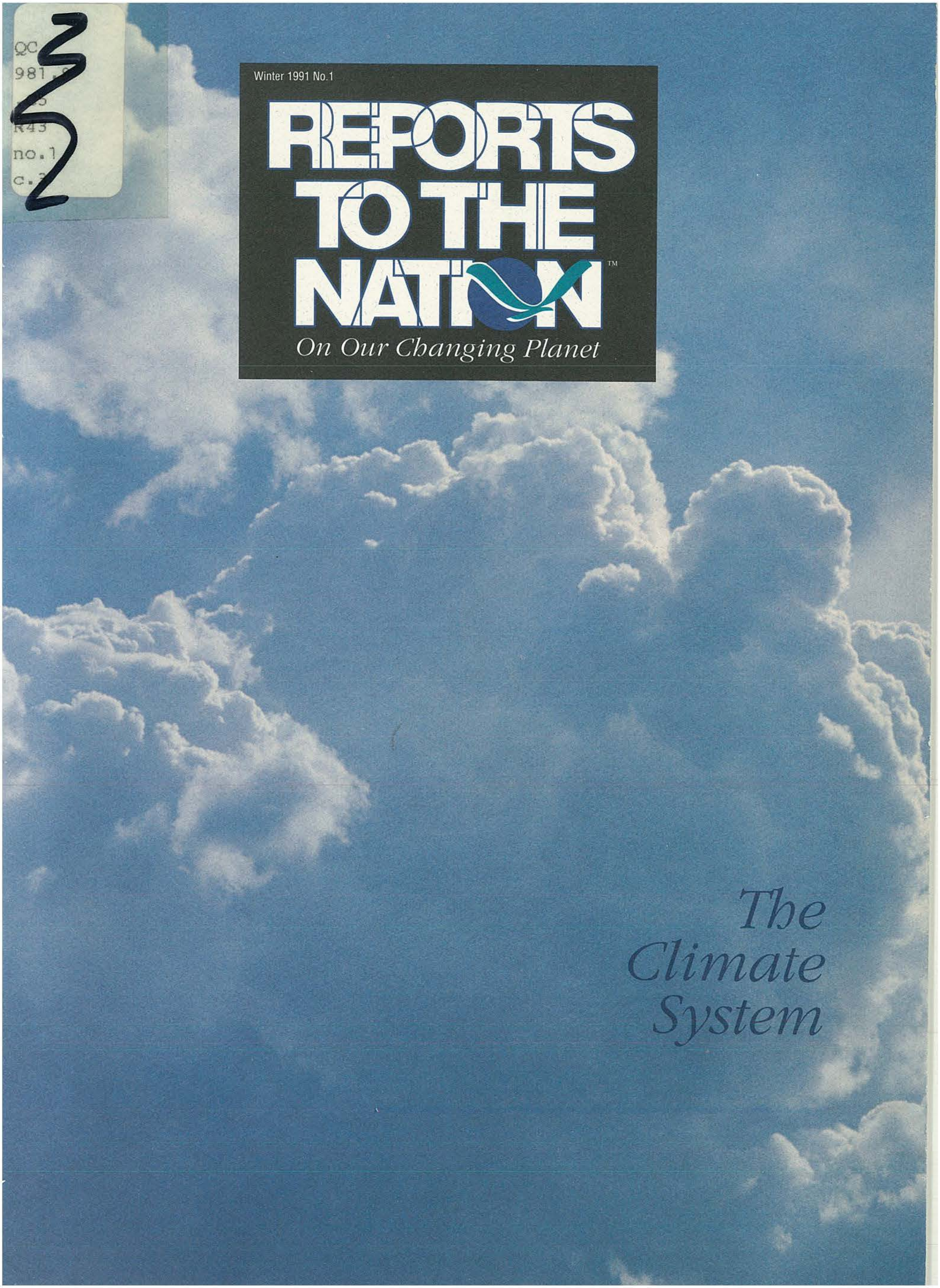
REPORTS TO THE NATION™

On Our Changing Planet



The Climate System

REPORTS TO THE NATION
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The Climate System

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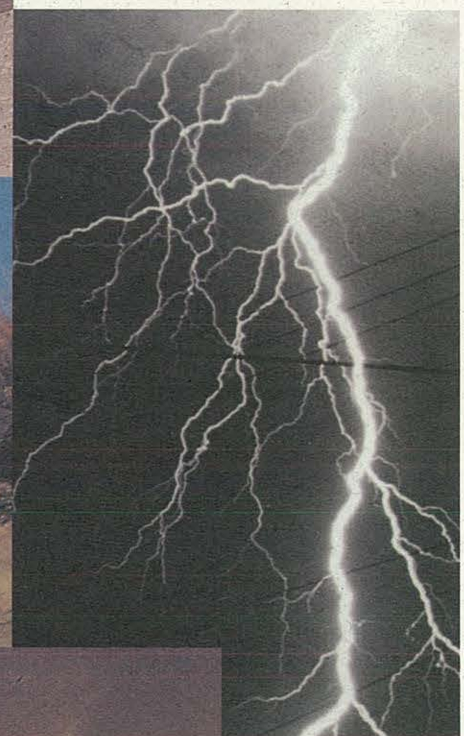
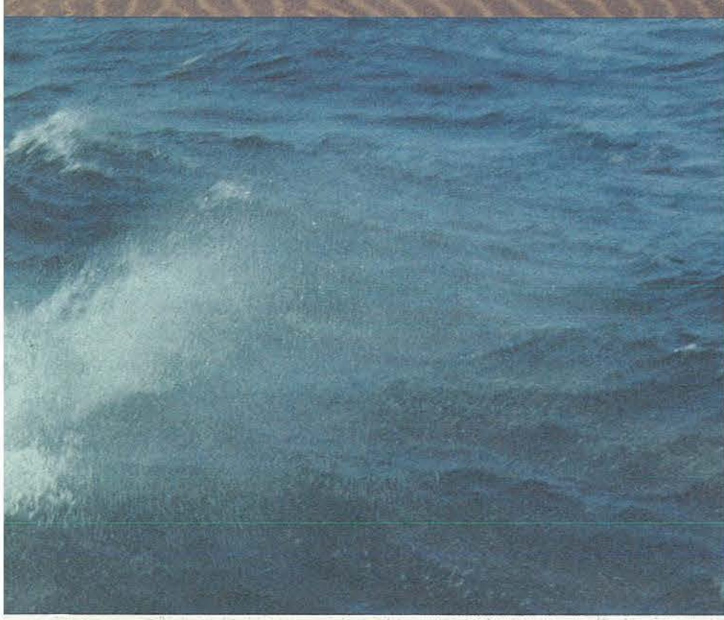
The Earth, for all we know, is a unique planet where a thin blanket of air, a thinner film of water and the thinnest veneer of soil combine to support a web of life of wondrous diversity and continual change. The daily needs of more than five billion people now stress the limits of this naturally regulated system.

The impacts of a changing climate on such a world can be profound. They can be illuminated, in advance, by scientific research and anticipated through broadened public understanding.





Only by comparing measurements taken over many years and decades, can we sense the shifting patterns of climate.

The Climate System

WHAT IS CLIMATE? The summer of 1988 burned a new fear into the minds of many Americans. We watched amber waves of grain in the nation's heartland turn brown and shriveled under the rainless sky, while water levels dropped along the Mississippi River and temporarily stranded thousands of barges. Wildfires in the western states blazed through millions of forested acres and shrouded majestic mountains in a veil of smoke. Across the nation, record heat and drought forced us to wonder: Is Earth's climate changing before our very eyes?

One extreme summer in the United States can't answer that question. Our picture of the climate develops slowly as we watch scores of seasons pass. Some winters bring unusual warmth, some springs are dryer than normal. Only by comparing measurements taken over many years and decades, can we sense the shifting patterns of climate.

Indeed, if we look at temperature records taken over the last century, we find the Earth's surface has warmed a significant amount over that period. But the meaning of the warming remains unclear. Long before humans inhabited the planet, Earth experienced major environmental changes. The dinosaurs roamed a world much warmer than that of today. Our Cro-Magnon ancestors huddled through an ice age that sent massive glaciers spreading over North America and Europe. Such natural shifts in climate have punctuated the different eras in Earth's history, forcing animals and plants either to go extinct or to adapt to new conditions.

Climate fluctuations are nothing new to this world. Even in our own lives we experience a large degree of natural change in the march of the seasons, which pass from warm to cold and back again.

Yet we now face the prospect of a different kind of climate change—one substantially brought on by human actions. Our industry, agriculture and daily living cause important gases such as carbon dioxide to accumulate in the thin blanket of air surrounding the planet. If we do not alter our course, scientists predict, severe consequences may await us in the not-too distant future.

To face such critical issues, we look at the science behind the immensely complex system called climate—an entity that ties together the atmosphere, oceans, land surface and the living kingdoms of plants and animals. If we want to measure climate, to predict its course, we must examine the relationships among these various components, just as a doctor studies the interactions of skeleton and muscles, heart and lungs.

The Light from Above

As we look at our Earth from space, we see a multicolored marble. Clouds and snow-coated lands create patches of cottony white that interweave with the royal blue background of the oceans. Breaks in the cloud cover reveal the continents, brown hues with lighter splotches of color that indicate desert regions.

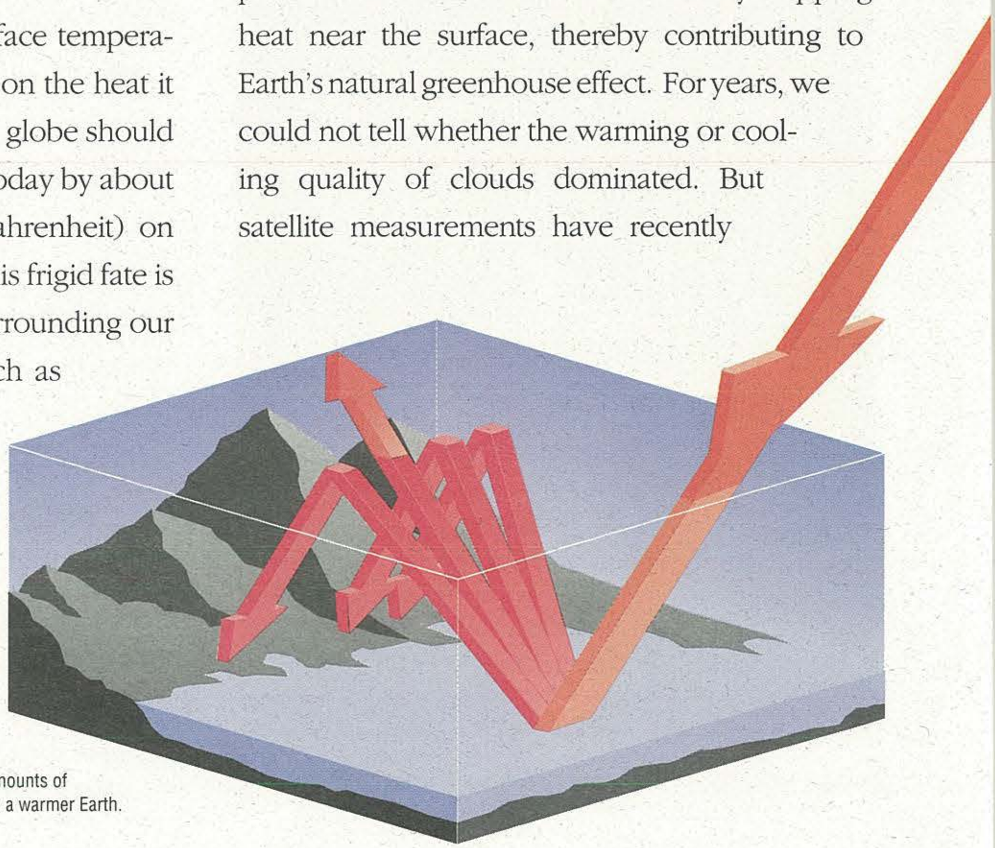
The white areas make Earth a bright planet. About 30 percent of the sun's radiation reaching our world gets reflected immediately back into space. We notice the reflected light when we travel by airplane over a painfully bright field of cloud tops or when we walk over a snowy landscape on a sunny day.

The solar energy that doesn't reflect off clouds and snow is absorbed by the atmosphere and Earth's surface. As the surface warms, it sends infrared radiation, or heat, back toward space. This type of radiation resembles the warmth we feel when sitting at a distance from a hot stove or campfire.

When we calculate what the surface temperature of the planet should be, based on the heat it radiates to space, we find the whole globe should be a frozen wasteland, colder than today by about 33 degrees Celsius (60 degrees Fahrenheit) on average. The force saving us from this frigid fate is the atmosphere. The layer of air surrounding our globe contains important gases such as water vapor and carbon dioxide, which absorb the heat radiated by Earth's surface and reemit their own heat at much lower temperatures. We say they "trap" Earth's radiation and call this planetary warming mechanism the "greenhouse effect."

Looking at other planets, we can see both stronger and weaker greenhouse effects. Our nearest neighbor, Venus, has a thick cloak of carbon dioxide that heats the planet's surface to an average of 470 degrees C. Mars, with a mean surface temperature hovering around -60 degrees C, has a very thin atmosphere that provides little greenhouse warming.

Aside from gases in the atmosphere, clouds also play a major climatic role. By reflecting solar radiation away from Earth, some clouds cool the planet. But others warm the world by trapping heat near the surface, thereby contributing to Earth's natural greenhouse effect. For years, we could not tell whether the warming or cooling quality of clouds dominated. But satellite measurements have recently



The "Greenhouse Effect": Incoming energy from the sun (at right) penetrates the atmosphere and heats the surface of the Earth. The warmed surface releases heat in wavelengths that are absorbed by CO_2 and other gases in the air. Only a small amount escapes back to space when large amounts of these contaminants are present: the rest is trapped, leading to a warmer Earth.

A Global Heat Engine: solar energy incident on the Earth is continually redistributed by currents in the ocean and the atmosphere.

proved that, all told, clouds exert a powerful cooling effect on the Earth. In some areas, though, such as the tropics, heavy clouds may markedly warm the regional climate.

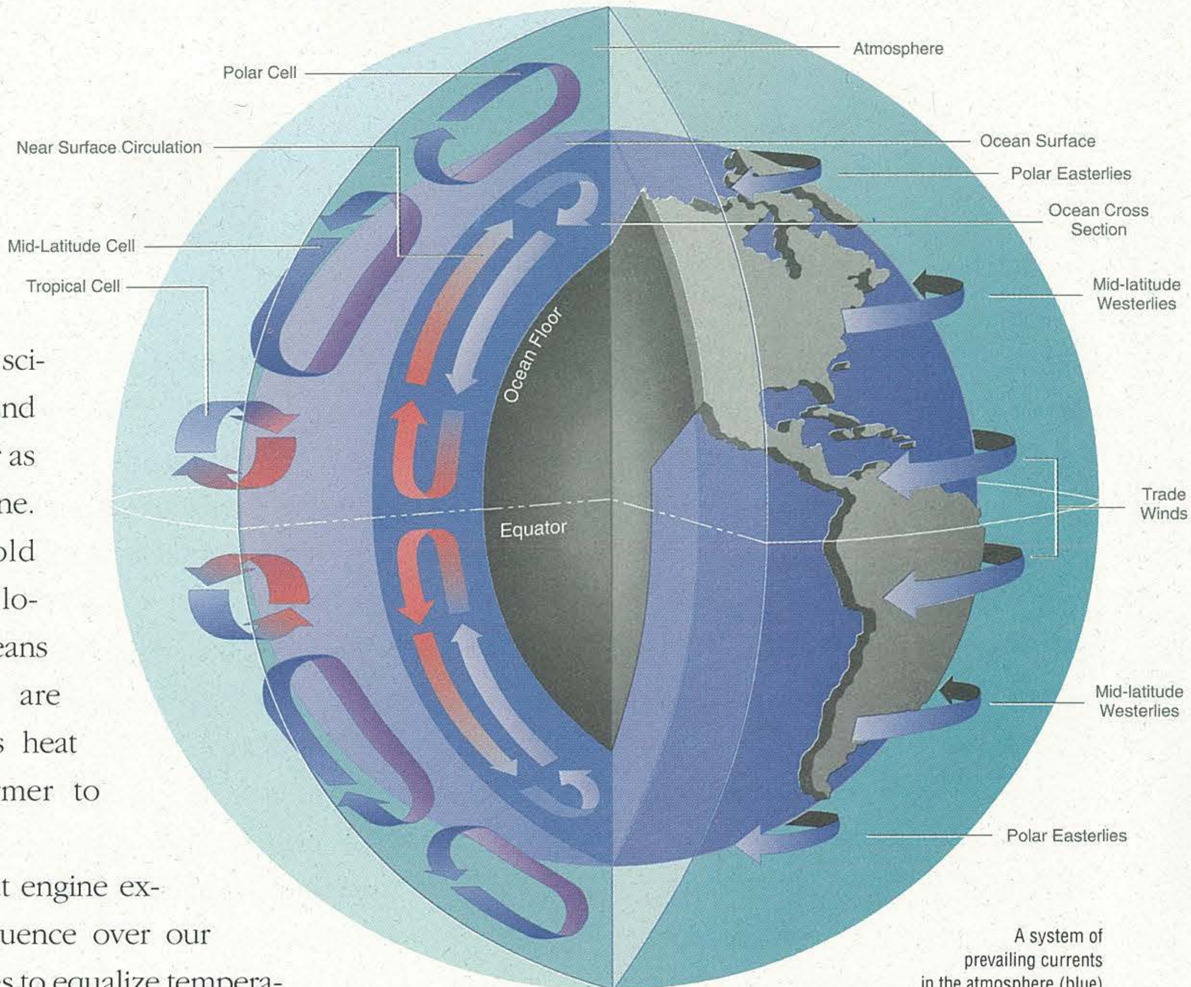
Clouds and greenhouse gases fit into something called the global radiation budget. Just like a well-constructed economic budget, the radiation budget must balance itself. Solar energy reaching Earth must equal the energy leaving the planet, otherwise the oceans would eventually boil away or freeze solid.

Scientists warn that we are currently upsetting the Earth's radiation balance through activities such as burning fossil fuels and cutting forests. These actions cause carbon dioxide and other gases to accumulate in the air and therefore strengthen Earth's greenhouse effect. We expect the planet's surface will warm up until a new radiation balance emerges.

The Global Heat Engine

While the radiation budget must balance for the entire Earth, it does not balance at each particular spot on the globe. For instance, very little solar energy reaches the white, ice-covered polar regions, especially during the winter months. Our spinning planet absorbs most solar radiation around its waistline, in the tropics and the lower latitudes.

Over time, though, energy absorbed near the equator spreads to the colder regions of the globe, carried by winds in the atmosphere and by currents



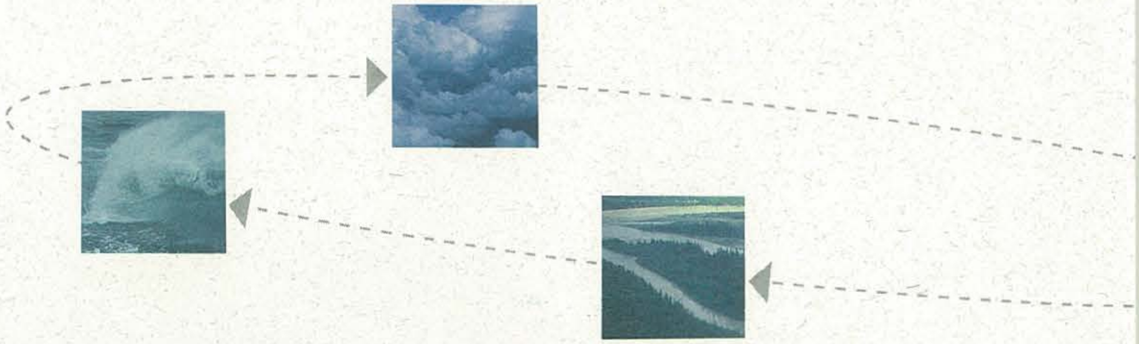
A system of prevailing currents in the atmosphere (blue) and oceans (red) carry heat from one part of the planet to another. The forces that drive them are provided by incoming solar energy and the spinning motion of the Earth.

in the oceans. To scientists, both air and water act together as a giant heat engine. Just like the old steam-powered locomotives, the oceans and atmosphere are set in motion as heat flows from warmer to cooler regions.

The global heat engine exerts a strong influence over our daily lives as it tries to equalize temperatures. It pumps energy into the storm fronts that sweep across the plains and it powers the hurricanes that pound the East Coast and Gulf of Mexico. In the colder seasons, low-pressure and high-pressure cells jockey for position every few days, allowing blasts of Arctic air to pass over the United States while warm winds move toward the pole.

The restless atmosphere also transports energy around the globe by shuffling masses of wet and dry air. Through evaporation, the air over the warm oceans absorbs water vapor and then travels to colder regions and to the continental interiors. Here, the water vapor condenses and falls out of the sky as rain or snow—a process that releases heat into the atmosphere.

In the oceans, salt helps drive the heat engine. Over some areas, like the arid Mediterranean, water evaporates from the sea faster than rain or river discharge can replace it. As the sea water becomes increasingly salty, it grows denser. In the North Atlantic, cool air temperatures and excess salt cause the surface water to sink, creating a current of heavy water that spreads throughout the world's oceans. By redistributing heat in this fashion, the oceans act to smooth out differences in temperature and saltiness.



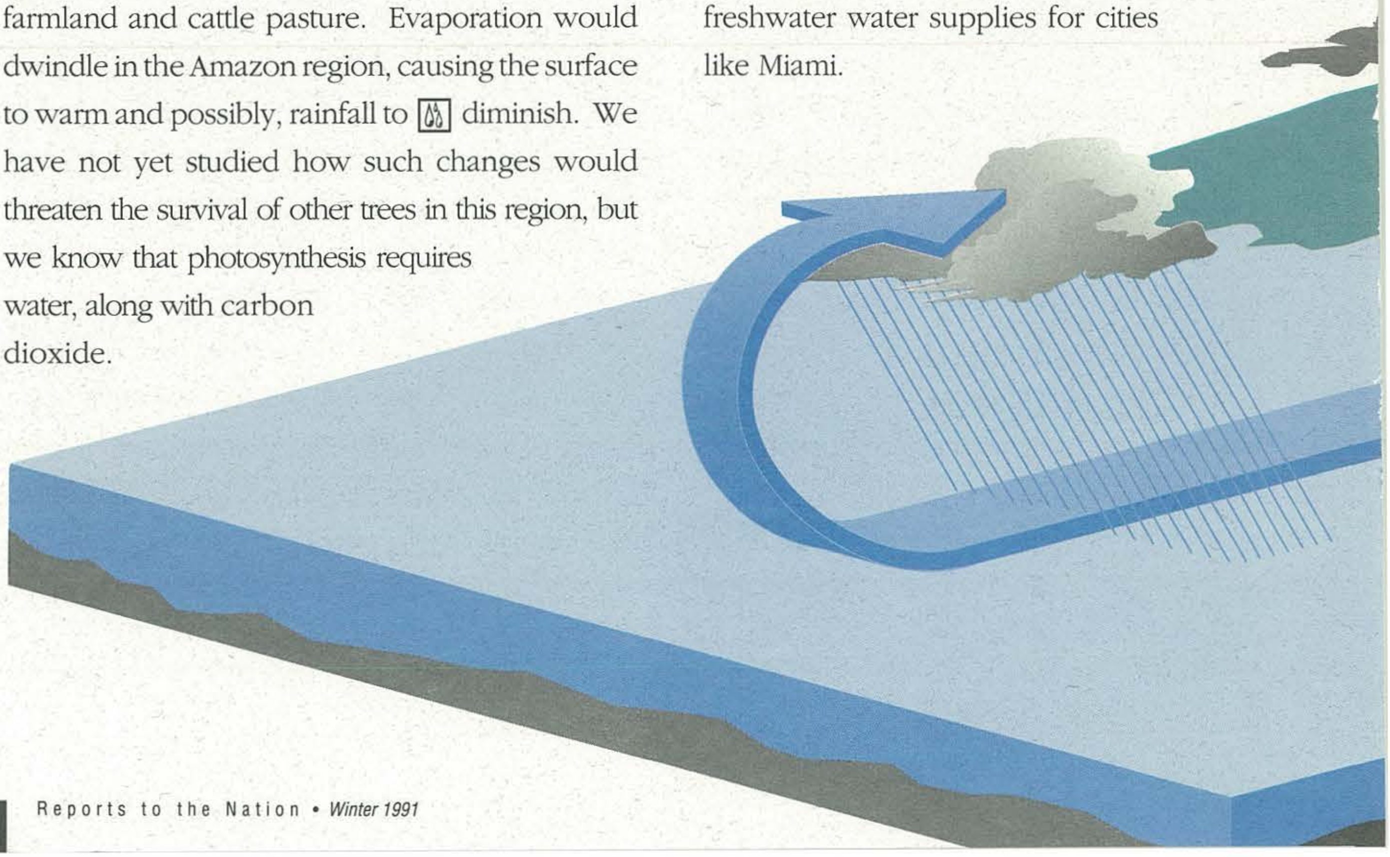
Water, Water Everywhere

Through rain, hurricanes, and snowstorms, we recognize a few roles water plays in the daily weather and in the climate system. But water also exerts critical but less obvious influences on our environment. Evaporation from moist soils and plants helps to cool the land surface in the same way that perspiring cools our bodies in warm weather. When we have a summer drought and the soil dries, temperatures rise because the land can no longer use evaporation to cool itself.

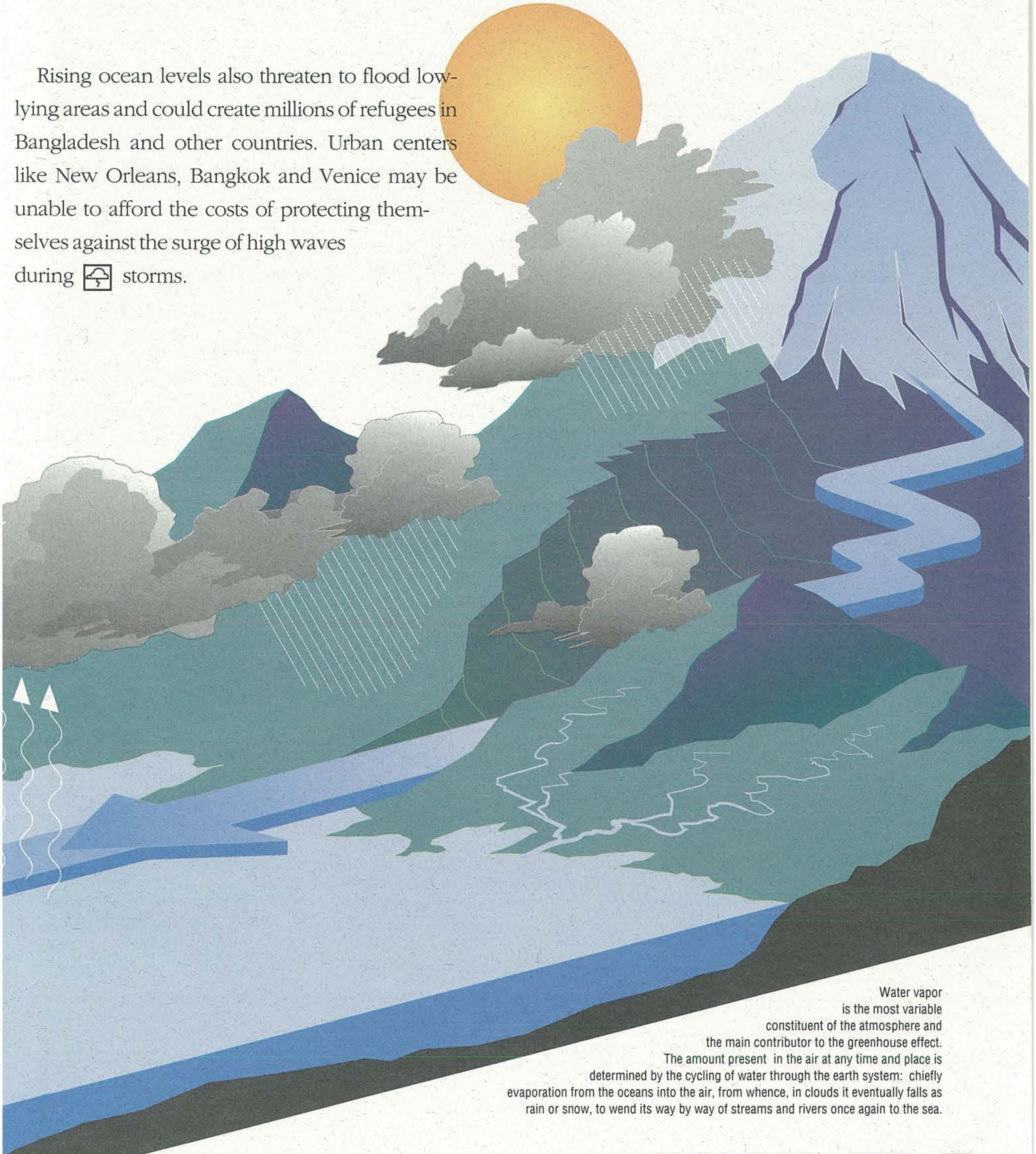
Through computer models, we see how water and vegetation are woven together by the climate. For example, the models tell us what might happen if we cut and burn much of the Amazon rain forest and then convert the cleared areas into farmland and cattle pasture. Evaporation would dwindle in the Amazon region, causing the surface to warm and possibly, rainfall to diminish. We have not yet studied how such changes would threaten the survival of other trees in this region, but we know that photosynthesis requires water, along with carbon dioxide.

Our economy depends heavily on the lakes, reservoirs, and underground aquifers that store water for drinking and for irrigating the crops we eat. Climate changes will almost certainly affect these water resources. Some studies indicate that a lengthening of the warm season will disrupt agriculture in regions like the northern Great Plains, where substantial soil moisture comes from springtime snow melt. These areas may become more arid which would place stress on growing crops.

Supplies of drinking water in some places also face danger from rising sea levels. If the climate warms in the future, scientists predict ocean levels may swell a foot or more by the middle of the next century. Salt water could potentially invade coastal aquifers and poison the freshwater water supplies for cities like Miami.



Rising ocean levels also threaten to flood low-lying areas and could create millions of refugees in Bangladesh and other countries. Urban centers like New Orleans, Bangkok and Venice may be unable to afford the costs of protecting themselves against the surge of high waves during storms.



Water vapor is the most variable constituent of the atmosphere and the main contributor to the greenhouse effect. The amount present in the air at any time and place is determined by the cycling of water through the earth system: chiefly evaporation from the oceans into the air, from whence, in clouds it eventually falls as rain or snow, to wend its way by way of streams and rivers once again to the sea.

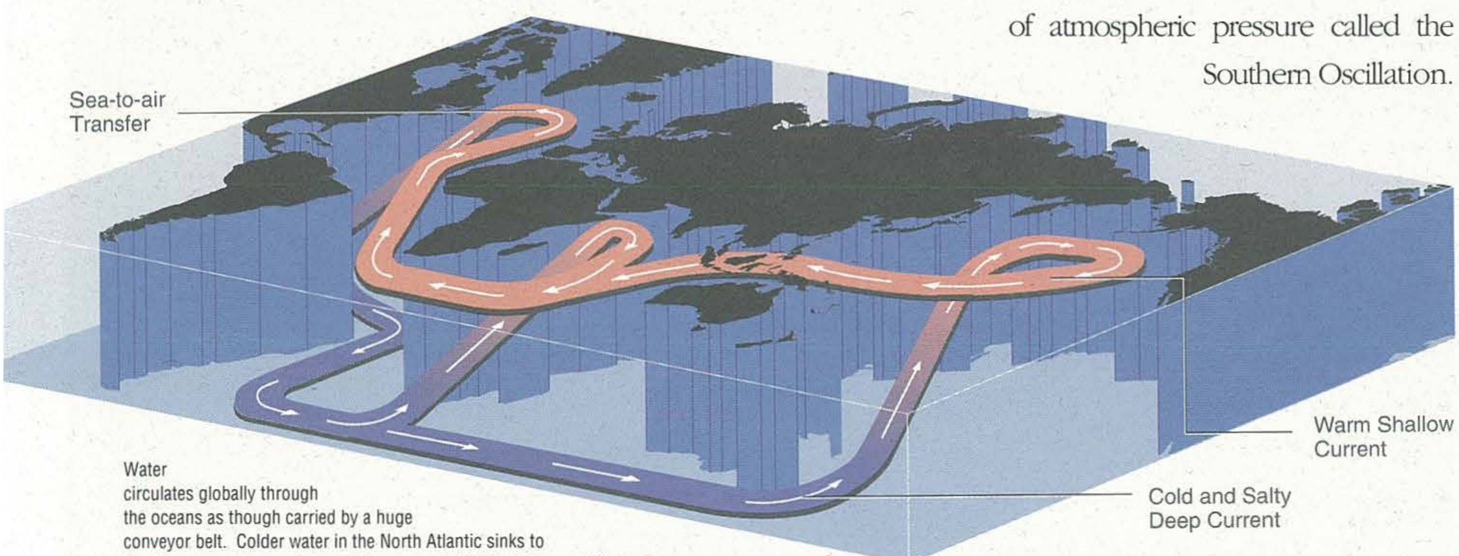
The temperature patterns of the s

The Oceans

Climate experts know much less about the oceans than about the atmosphere. But one fact stands out: When compared with the air above, the oceans react like a sluggish beast. While the atmosphere can adjust in a few days to a warming or cooling in the ocean, it takes the sea surface months or longer to respond to changes in heat coming from the atmosphere. People living near the coast appreciate the ocean's sluggishness because they enjoy relatively warm winters and cool summers, especially on the western side of a continent where ocean winds blow onto the land. We need only compare the winter climates of Seattle, Washington, with Duluth, Minnesota to see how the slow transfer of heat from the ocean exerts a profound climatic effect.

The temperature patterns of the sea surface also determine where storms develop and the directions they travel. The Gulf Stream guides the path of winter gales in the western North Atlantic and hurricanes over the subtropical oceans. Because the ocean can only absorb heat slowly, individual storms have very little effect on sea surface temperature.

In recent years, we have learned much about an important phenomenon called El Niño—a climate pattern that results when the Pacific Ocean teams up with the global atmosphere to wreak widespread changes in weather. During a particularly strong El Niño in 1983, torrential rains flooded the west coast of South America, while India, Indonesia and Australia suffered severe droughts. El Niños are highly irregular, but on the average occur three to five years apart and are linked to a pattern of atmospheric pressure called the Southern Oscillation.



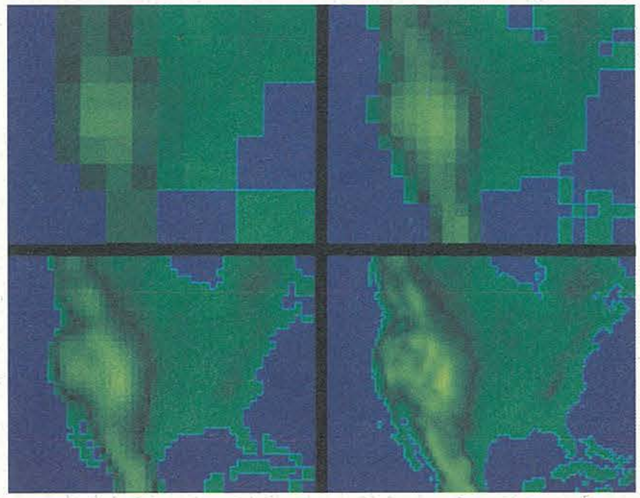
Water circulates globally through the oceans as though carried by a huge conveyor belt. Colder water in the North Atlantic sinks to the deep ocean to resurface and be rewarmed in the Indian and North Pacific oceans. Surface currents carry the warmer stream back again through the Pacific and South Atlantic. The circuit takes almost 1000 years.

rface also determine where storms develop and where they travel.

During El Niños, the air and sea perform an intricate dance. The strong trade winds over the equator grow weak and allow warm currents to flow into the central and eastern Pacific. Along with the warm water, storms in the atmosphere shift eastward. While we do not yet completely understand El Niños, we believe these events can alter conditions around much of the globe. Some scientists think part of the El Niño-Southern Oscillation cycle helped create the searing drought across North America in 1988. Through ongoing research projects, we are learning how to predict the arrival of El Niños a year or more before they fully develop, which may greatly aid our ability to forecast general weather patterns several months in advance.

Climate By Computer

In some ways, Earth's climate system resembles the intricate web of a spider. The clouds, ocean currents, solar radiation and myriad other elements all weave together in a chaotic and complex way to create our climate. In the real world, we cannot isolate one piece from the rest. So we create mathematical climate models in order to study individual parts and to assess how the different elements interact. The models also help us predict future changes in the behavior of the climate. For example, we can test how a global greenhouse warming might alter rainfall patterns for a time in the middle of the next century.



Terrain over North America at four increasingly higher spatial (grid) resolutions. Current climate models use the terrain depicted in upper left. Increased resolutions from upper left to bottom right, are expected to yield increasingly useful climate predictions in the years ahead.

In theory, the models are simple. They treat both the atmosphere and the oceans as fluids that obey basic physical laws.

But the models become complex because they must include many different and interrelated parts of the climate including the soil, water vapor in the air, salt in the oceans, and biological systems. They slice up the atmosphere and oceans into thousands of grid boxes and calculate how the weather changes in each box. The mathematic equations require so many calculations that only the most powerful computers can solve them. Even on such machines, it can take weeks of expensive computer time to simulate how rising carbon dioxide levels might effect climate.


The models show that temperature could rise considerably over many areas of the globe if our activities continue to intensify the earth's greenhouse effect. Yet, we wonder how much to trust the computer simulations. Despite all their complexity, the models are not completely accurate and we know they do not do a good job of simulating clouds or the oceans. While we continually work to improve the models, we can still learn much from the imperfect versions in use today.

The Fire and Ice Before

Computer models are not the only tool for studying climate change. We also draw lessons from records of Earth's history that reach back through the eons.

For the last few hundred years, weather instruments in scattered locations around the globe have collected information on temperature, rainfall and other factors. Going back further, tree rings can trace climate changes over many millennia. In the western United States, experts have found a living Bristlecone pine tree that began growing over 4,800 years ago. The oldest known organism alive on Earth today, this tree set its roots centuries before the ancient Egyptians began building the Great Pyramid. But even Bristlecone pines cannot compete with the geologic record. Rocks and fossils provide a window to times billions of years before today.

From thermometer measurements to the rock record, these various chronicles of the past not

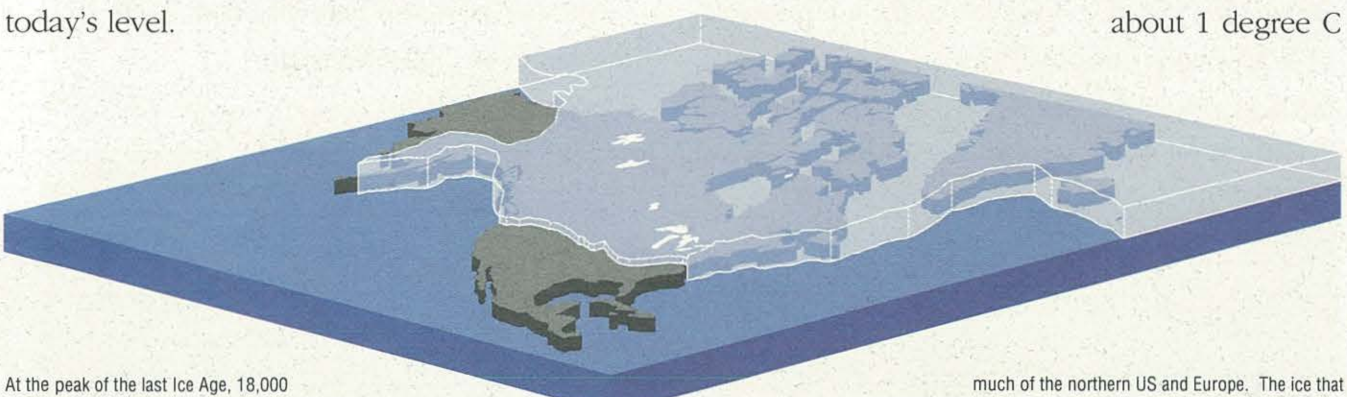
only tell us what previous conditions on Earth were like, they also provide clues about the causes of climate change.

Looking back through the ages, we see evidence that the planet has passed many times through warm and cold spells. One of the warmest known intervals was the Cretaceous period about 100 million years ago, near the end of the reign of dinosaurs. With temperatures about 10 degrees C warmer than today, sea levels swelled because water was not locked up in major ice sheets near the poles. The oceans spilled onto the continents and split North America effectively into two landmasses. We believe such warm conditions resulted in part from extra carbon dioxide that accumulated in the atmosphere because of widespread volcanic activity.

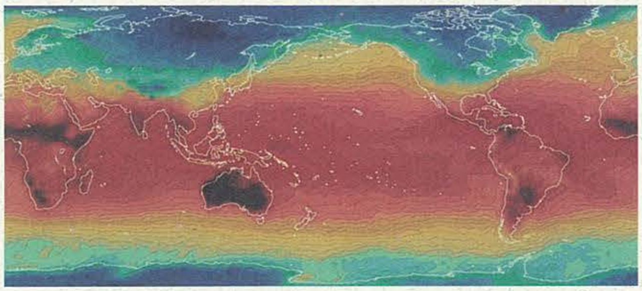
About 100 million years ago, Earth's climate began a slow slide toward cooler conditions, culminating during the past two million years in a series of repeated ice ages, when the average surface temperature dropped about 5 degrees C below today's level.

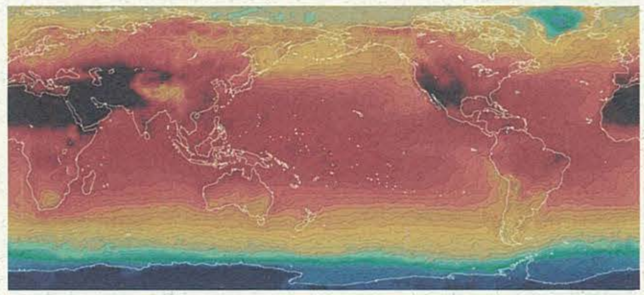
What caused such drastic climate shifts during the ice ages? While we believe periodic changes in Earth's orbit triggered the advance and retreat of the glacial sheets, the planet's greenhouse effect must also have played an important role. Bubbles of ice age air preserved in the glacial sheets of Antarctica and Greenland reveal that the atmospheric concentration of carbon dioxide and methane dropped significantly during the glacial times. Such low levels weakened the greenhouse effect and helped cool the Earth. To explain the dramatic fluctuations in carbon dioxide levels, we must turn to the oceans for answers. A reorientation in major currents during the ice ages may have increased the ocean's ability to absorb carbon dioxide from the atmosphere.

The last ice age began to wane about 18,000 years ago, long before modern human civilizations blossomed. However, our recent ancestors experienced a so-called Little Ice Age, which lasted from 1400 A.D. to 1850. During this cold phase, the global climate probably registered about 1 degree C



At the peak of the last Ice Age, 18,000 years ago, a permanent glacier had reached down from the North Pole to cover all of Canada, Greenland, Iceland and much of the northern US and Europe. The ice that overlay present day New York and Chicago was more than half a mile deep; two miles of ice weighed down on Hudson's Bay.





The temperature of the land and water surface of the Earth, derived from spaceborne sensors on NOAA weather satellites. Average temperatures for January, measured in 1979, are shown at left, representing midwinter in the Northern Hemisphere, midsummer in the Southern. Above are temperatures for July of the same year, showing opposite conditions. Temperatures below freezing are green and blue; warmer temperatures are in red and dark brown.

colder than now, with more severe changes in some places. Norse settlers disappeared from Greenland at that time, presumably because they could not survive the cold conditions. Though we don't know why the Little Ice Age developed, we suspect a decrease in solar radiation or an increase in volcanic dust may have triggered the cooling.

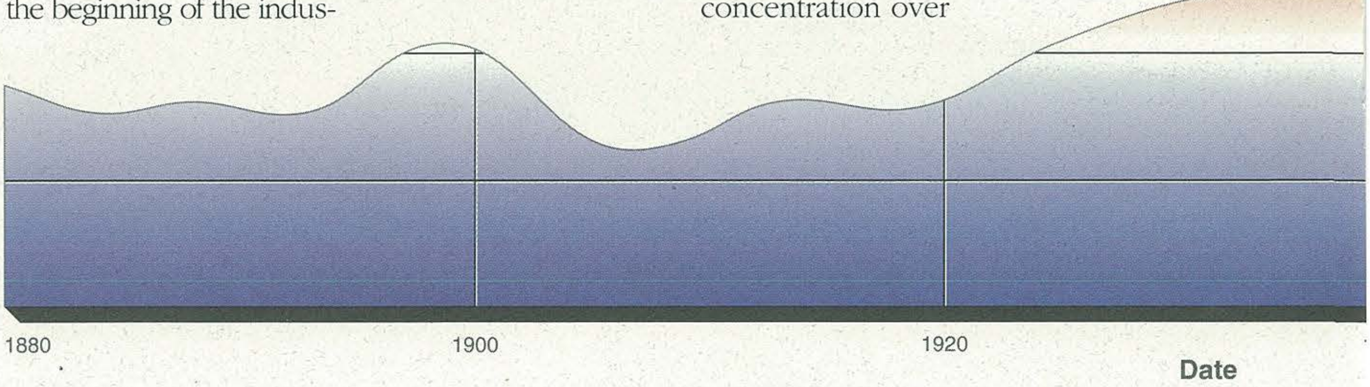
Warmer Than We've Ever Known

If the climate cycle were to follow its natural course, in a few thousand years the Earth would start sliding into another ice age. But our activities threaten to send the climate speeding in another direction, toward a greenhouse warming.

The burning of coal, oil and natural gas and the destruction of forests have raised the total amount of atmospheric carbon dioxide by 25 percent since the beginning of the industrial revolution. The accumulation of this gas over the last century alone now adds as much heat to the climate system as would a one-half percent increase in the sun's energy output.

Carbon dioxide is not the only climatically-important gas accumulating in the atmosphere. Manufactured chemicals called chlorofluorocarbons now supply about one quarter of current additions to Earth's greenhouse effect. Used in refrigerators, air conditioners, foam and insulation, these potent greenhouse gases spell double trouble. Besides warming the Earth, they have also weakened the stratospheric ozone layer—a protective shield that blocks out damaging ultraviolet radiation from the sun.

Another powerful heat absorber, methane, has more than doubled in concentration over



Our activities threaten to send the climate speeding in another direction, toward a greenhouse warming.

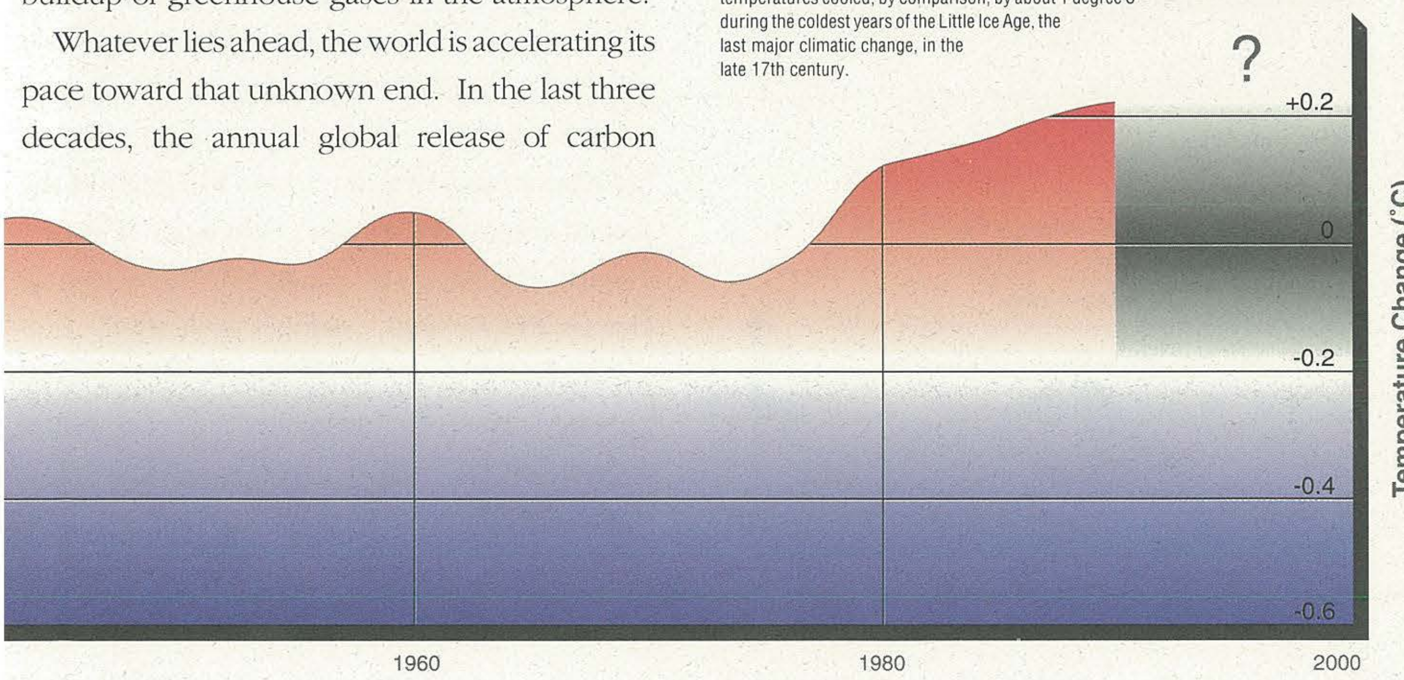
the last three centuries, in part from increased rice cultivation and livestock rearing. Methane levels are currently climbing at the extraordinarily fast rate of almost one percent per year.

The buildup of these and other gases has already strengthened Earth's greenhouse effect. But it may take several decades to feel the warming because atmospheric temperatures will rise significantly only after the oceans of the world have slowly warmed.

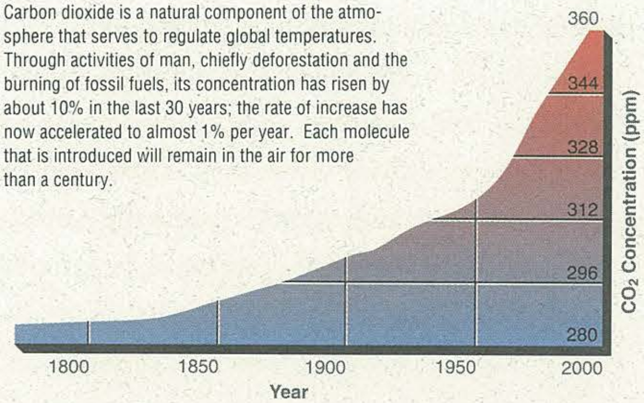
The postponement may seem like an advantage, in that it gives us more time to prepare. However, the time lag could lead us to underemphasize the importance of the problem while we still have a chance to avert drastic climate change. In truth, we have already committed ourselves to some degree of warming, even if we could instantly halt the buildup of greenhouse gases in the atmosphere.

Whatever lies ahead, the world is accelerating its pace toward that unknown end. In the last three decades, the annual global release of carbon dioxide has doubled, reflecting a climb in the rate of fossil fuel burning and deforestation. As human population and economic activities continue to grow, carbon dioxide emissions could double again in the next three decades unless the nations of the world limit their consumption of fossil fuels.

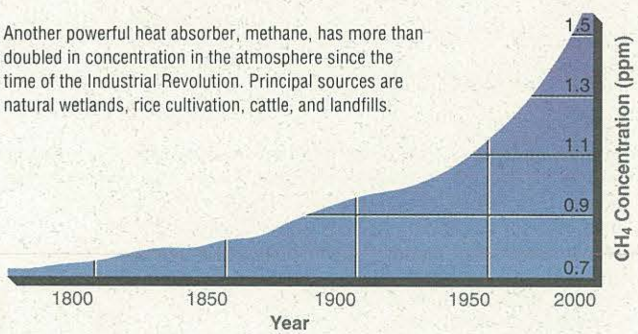
Such action would benefit society in many ways. For instance, through energy conservation, we can personally save substantial amounts of money and help reduce our nation's dependence on foreign fuels. Therefore, despite our uncertainty concerning future climate change, we are already beginning to take certain steps that will slow the buildup of greenhouse gases.



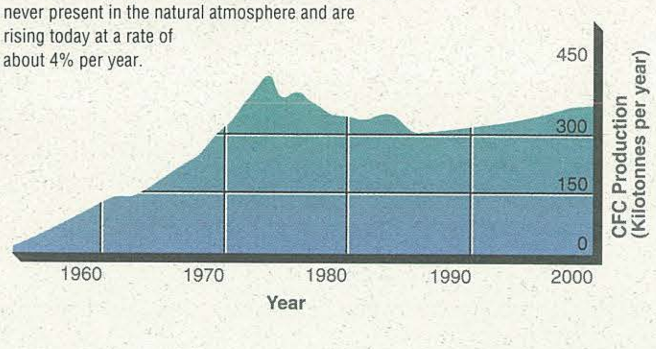
Annual and 5-year averaged values of combined land and ocean temperature of the Earth for the period 1880–1989, expressed as a deviation from the average temperature for 1951–1980. It is now thought that global mean temperature will rise an additional 1 degree C by the year 2025 due to enhanced greenhouse warming, and about 3 degrees C by the end of the next century. Surface temperatures cooled, by comparison, by about 1 degree C during the coldest years of the Little Ice Age, the last major climatic change, in the late 17th century.



Carbon dioxide is a natural component of the atmosphere that serves to regulate global temperatures. Through activities of man, chiefly deforestation and the burning of fossil fuels, its concentration has risen by about 10% in the last 30 years; the rate of increase has now accelerated to almost 1% per year. Each molecule that is introduced will remain in the air for more than a century.



Another powerful heat absorber, methane, has more than doubled in concentration in the atmosphere since the time of the Industrial Revolution. Principal sources are natural wetlands, rice cultivation, cattle, and landfills.



Man made gases that combine chlorine, fluorine, and carbon (chlorofluorocarbons) have shown the greatest increase of any of the greenhouse gases. They were never present in the natural atmosphere and are rising today at a rate of about 4% per year.

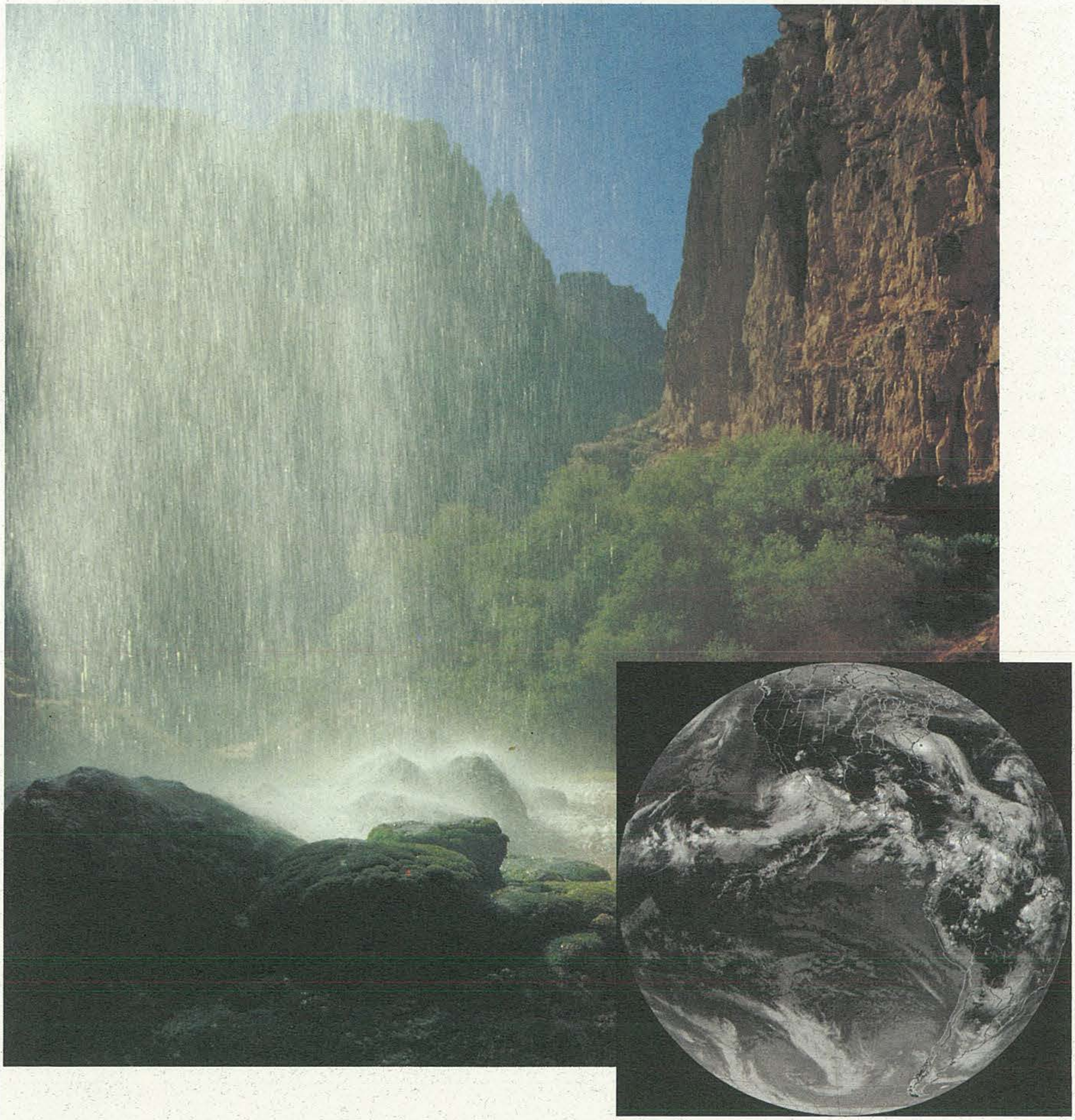
The Challenge Ahead

Are we barrelling down a runaway route toward climatic catastrophe, or will the future bring relatively benign changes that will not threaten society?

The accumulation of greenhouse gases in the atmosphere will almost certainly cause Earth's surface temperature to rise. But we do not know how quickly the planet will warm or how that warming will affect different regions of the globe.

Answers to such questions will only come through intensive research into the mysteries of Earth's climate system. To this end, scientists from around the world are joining together, as they never have before, in an effort to address critical issues. For example, several international projects are now seeking to improve our understanding of clouds and the oceans—two factors that will greatly influence the pace of global warming.

Compared to other forms of life, humankind has inhabited the Earth for a short span of time. Nonetheless, the needs of a rapidly growing population have begun to stress the limits of the natural system. The nations of the world now face a great challenge—to anticipate future climate change and develop a rational program for protecting the environment. No need could be more pressing, no mission of greater import to future generations.



The great challenge is to anticipate fut

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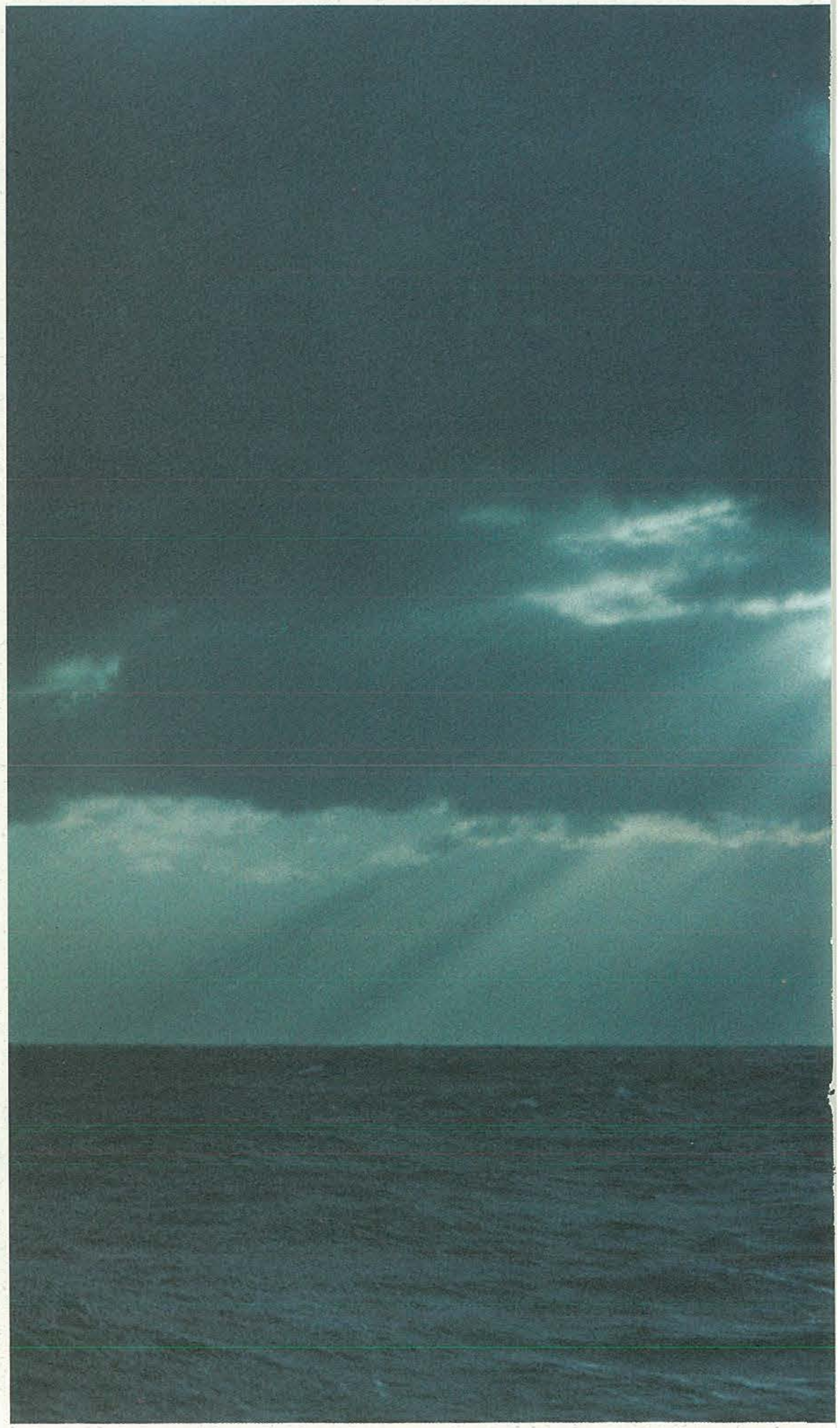

mate change and develop a rational program for protecting the environment.