The
# PLANETARY REPORT
Volume XXVIII Number 4 July/August 2008

**Riders on the Earth Together**

# From The Editor

We've all done it at some time, just for fun—written our address to include our name, street, city, state, and country, then extended it to planet, solar system, galaxy, and universe. You might think such a perspective is the result of the Space Age and the realization that we could walk on other worlds, with our planet just one stopping place on the journey. The impulse goes back, however, at least to a famous 19th-century naturalist who inscribed his address in a journal as "John Muir, Earth-planet, Universe."

As Muir discovered, people can be mindless about how they use Earth and its resources, not thinking or understanding that a single species, such as Homo sapiens, can be powerful enough to alter a world. From the new perspective of space, we now watch the polar caps retreat, see spring arrive earlier each year, and record a steady warming of Earth's climate.

In this special issue, we address directly how humanity is changing this planet—and how we must monitor these changes. Ironically, just as scientists reach a long-sought consensus on climate change, some governments have scaled back their plans to observe Earth from space. This is now an issue for The Planetary Society, with our unique way of seeing Earth as one planet among many.

In The Planetary Society, we identify with the impulse to see ourselves as inhabitants of a planet, not just of a building on a street. The protection of our home planet is the responsibility of all those who live here, and we must take the utmost care of our home world.

*—Charlene M. Anderson*

**This special issue of *The Planetary Report* was sponsored in part by Northrup Grumman Corporation.**

## On the Cover:

When seen from space, Earth—with its ultramarine oceans, green and tan land masses, and swirling white clouds—looks like no other planet in our solar system. This spectacular image of our "blue marble" is the most detailed true-color image of Earth to date. Using a collection of satellite-based observations, scientists stitched together months of data on the land, oceans, sea ice, clouds, and even city lights into a seamless true-color mosaic of every square kilometer of our planet. This portrait of Earth's Western Hemisphere shows North America, Central America, and the top of South America.

Image: NASA Goddard Space Flight Center, United States Geological Survey, Defense Meteorological Satellite Program (city lights).

## Background:

Liquid water below, water vapor above—Earth truly is a water world. The interaction of water in its various forms on Earth—from liquid to ice to vapor—is essential in the cycle of life on our planet. In this image, sky and water seem to meet, enveloping the viewer with Earth's characteristic blue hue. Image: © Uguntia/Shutterstock Images

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# Planet Earth Special Issue
## with Guest Editor Charles F. Kennel

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A PUBLICATION OF THE PLANETARY SOCIETY

# Earth Is, After All, *a Planet*

By Charles F. Kennel and Louis D. Friedman

Our planet is changing. Although public debates over why things happen and what to do about them may never be settled, the scientific community has reached that magical state called *consensus* with the latest report from the Intergovernmental Panel on Climate Change (IPCC). Amazingly, a group of contentious, jargon-talking researchers managed to write a cohesive document, one that earned them, along with Al Gore, the Nobel Peace Prize for 2007.

The IPCC never could have reached that point without the data collected by generations of orbiting spacecraft dedicated to studying Earth. Global rainfall patterns, sea surface height, atmospheric structure—these are the sorts of measurements we need to understand the large-scale processes that control Earth's climate.

Orbiting instrument platforms are not the sole sources of these important data. Space exploration changed forever the way we humans see our home world. *Apollo 8* astronauts brought us the iconic image that showed us Earth as it truly is—blue and inviting in the black immensity of space. This image jump-started the environmental movement.

It is ironic, then, that just as NASA's satellites are making new discoveries about the state of our planet, in February 2006, the United States' space agency chose to drop the phrase "to understand and protect the Earth" from its mission statement. We won't speculate on the reasons. It's enough for us to say that The Planetary Society was prepared to pick up the phrase and the mission.

## The View From Space

Last year, the Society added Earth to its mission statement, which now reads, "To inspire the people of Earth to explore new worlds, understand our own, and search for life elsewhere." We are now developing programs to initiate that new mission. This special issue of *The Planetary Report* is a step toward fulfilling our updated commitment.

With a change in wording that may seem small, The Planetary Society was not merely making a political statement; it was codifying a large and important goal. Understanding the planet we live on has always been an implicit part of the enterprise of planetary exploration that we so ardently advocate. We have just made it explicit. We have broadened our mission statement to encompass one of the most important benefits of space exploration: providing a context among other worlds and a vantage point in space from which we can look back on our home world.

What NASA once called a *Mission to Planet Earth* is critical now, as human actions change our planet in ways that are not beneficial to our species—or to others. Knowing this intellectually is one thing; moving from knowledge to action is another.

Coping with change is hard, and mitigating the effects of change is even harder. Stopping global climate change probably is impossible, but an informed humanity probably can slow it down and cope better with its effects. It is critical that we understand the processes.

No nation can tackle this on its own. The spacefaring nations in particular must work together to address global change.

The sheer complexity of Earth's weather and climate makes it difficult to tease out the trends of change. Standing on the surface, it's hard to get the kind of data needed to fill in details of the big picture. When you're talking about global change, you need to step back until you reach a global perspective. That perspective can be found only in space.

*This view of Earth rising over the lunar horizon is one of the most famous images of the twentieth century, captured in December 1968 by the* Apollo 8 *crew during the first manned trip behind the far side of the Moon. It showed us Earth, as it appears floating in space, for the first time.* Image: NASA

## Getting to Know Our Neighbors

Space exploration has triggered another change in perspective. Earth's sister planets were once only wandering lights in the night sky. As our robotic pathfinders reached them, however, they became idiosyncratic worlds of amazing diversity and beauty. From information gathered at such diverse worlds as banded Jupiter, large enough to swallow 1,000 Earths, to the seemingly insignificant rocky asteroids measured in meters, we've come to know that our world is just one among many unique individuals in this solar system—but it is the one with life on it.

In our planet's history, our solar system neighbors have had a profound effect. Consider one of the greatest mysteries of science: what happened to the dinosaurs? The leading suspect is now an invader from space, an asteroid. Although scientists still debate if an asteroid impact alone was enough to wipe out the dinosaurs, there is consensus that an object from space struck near the Yucatan Peninsula 65 million years ago and changed Earth's climate in ways that made it impossible for dinosaurs, and many other life-forms, to survive.

Critics of space programs around the world are badly off target when they claim it is a waste of good money to study other worlds when there's so much trouble on this one. Even bigger trouble can come from space—as the dinosaurs learned the hard way. Trouble on this planet sometimes is visible only from space. We need to maintain that perspective.

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*Charlie is working with The Planetary Society because of his respect for its effectiveness, its success in rallying public support for space exploration, and the way it brings science and scientists to the public. He is a leader in Earth observations from space and a respected scientist who served as associate administrator for Mission to Planet Earth at NASA headquarters.*

*Lou is executive director of The Planetary Society and is honored to have Charlie working with us.*

## Venus and Mars, Earth's Sister Worlds

Our Earth is not the only child of its parent star, and as any parent or teacher knows, to understand the behavior of one child, you must consider the siblings.

Venus and Mars, worlds without oceans and that pesky phenomenon called life, provide simpler test beds for scientists to work out interactions among atmospheres and hard surfaces and, in the process, refine hypotheses about how our more complex climate behaves. By working backward from observations of the present-day states of planets, scientists can try to determine how they evolved into such inhospitable places.

Venus has become notorious for the runaway greenhouse effect created by its massive carbon dioxide atmosphere, which produces surface temperatures of nearly 900 degrees Fahrenheit (500 degrees Celsius). We've learned much more than that about Earth's nearest neighbor: spacecraft have uncovered evidence of how aerosols—tiny airborne particles—helped turn the atmosphere into an opaque blanket and how sulfuric acid forms massive cloud decks that rain poison through the deadly atmosphere.

Earth is not in danger of becoming a Venus-like hellhole, but a carbon dioxide greenhouse effect is warming our climate, aerosols degrade the air we breathe, and acid rain kills forests and wears away our monuments to ourselves. What we learn from Venus can help us deal with such destructive processes on our home planet.

Although smaller than Venus and farther away from Earth, Mars also has lessons to teach us. The Red Planet lost its once-thick atmosphere, and any liquid water it possessed froze into the poles and permafrost or was lost to space. Without a protective ozone layer like Earth's, Mars receives ultraviolet radiation from the Sun that passes unimpeded through thin air and destroys any organic compounds on the planet's surface.

Again, Earth will never see such extreme effects, but scientists did discover an ozone hole over the Antarctic caused by atmospheric pollutants. Mars, along with Venus, has given us lessons on how fragile, precious, and unique our own world is.

*—Charlene M. Anderson, Associate Director of The Planetary Society*

## Carl Sagan—on Venus and Mars

In any comprehensive history of the idea of climate change, references to Mars and Venus will keep popping up—and with them, the name Carl Sagan.

Carl made his first major contribution to planetary science in 1960, when he published work that identified the greenhouse effect as the culprit in heating Venus' surface to more than 900 degrees Fahrenheit (500 degrees Celsius). By 1973, he had devoted considerable attention to Mars and published a paper titled "Climate Change on Mars" in *Science* magazine.

Perhaps more important than his scientific papers were Carl's contributions to helping people everywhere appreciate how different our Earth is from its close siblings—and how distinctive are the physical systems that make it an abode for life. Planet-girding oceans, ever-churning plate tectonics, the water cycle, and the carbon cycle will keep our world from ever reaching the barren states of Mars and Venus.

Carl cofounded The Planetary Society in 1980 with Bruce Murray and Lou Friedman, and we keep his example in mind as we expand our organization's mission to include the planet Earth. *—CMA*


# The Earth's Changing
## As Seen From

**by Michael D. King**

Earth's land, oceans, and atmosphere are being watched from space. Earth-orbiting satellites, representing a technology only 50 years old, have transformed our understanding of the planet's natural variability and enabled us to see how our planet is being modified by human activity. This is a perspective on Earth that previous generations could only dream about.

The era of remote sensing began in the late 1960s and early 1970s, when instruments on Earth-oriented spacecraft first observed our planet from above. Without regard to political boundaries and human-created structures, these observations opened the public's eyes to our precious planet, as well as to its vulnerability and susceptibility to natural and anthropogenic development.

Consider, for example, that land and ocean surfaces, like the semipermanent ice caps and seasonally varying polar sea ice, often change dynamically, with sometimes strikingly large short-term changes on top of seasonal and interannual variations. Glaciers and other forms of land ice generally change slowly, creeping up or down their tracks, but sometimes they collapse unexpectedly.

Can we notice such phenomena while standing on the ice? Of course we can. From the vantage point of space, however, using the extraordinary technological developments of the last decade, we can observe changes in Earth's environment that are simply not visible, or at least not practically observable, from ground-based, shipborne, or airborne instruments. The Earth-observing satellites of today have evolved in capability from the earliest Earth-orbiting satellites, and they are monitoring and helping us understand the many changes that are rippling through our planet's climate system.

In this article, I will explain some of the ways we watch from space as our planet changes below our "eyes in the sky."

### Precipitation—Rain and Snow

To sustain life on Earth, rain must fall and snow must melt to provide the liquid to drive the water cycle. Spaceborne microwave radiometers have been measuring this precipitation for nearly 30 years. Based on these observations, we now know that the average depth of global precipitation—averaged over an entire year and assuming that it didn't sink into the soil or run off to the sea—would create a liquid layer of about one meter, or about waist deep. The amount of rain varies tremendously across Earth's surface, however, as shown in **Figure 1**; most falls in the tropical western

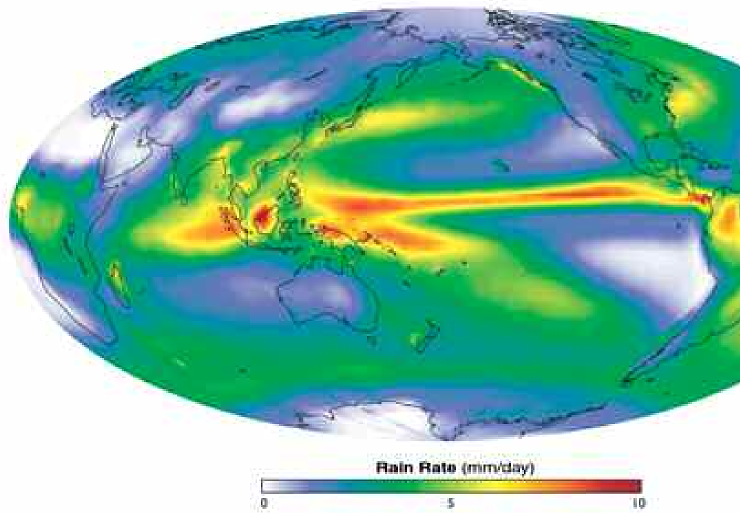



**Figure 1** ***Humans have always been concerned about rainfall. The distribution of forest, desert, and arable land is determined to a large extent by the relative abundance or absence of precipitation. This image shows the average precipitation across Earth's surface between 1979 and 2006. The highest global precipitation (shown in red) is in the tropics.*** *Image: Data from the Global Precipitation Climatology Project*

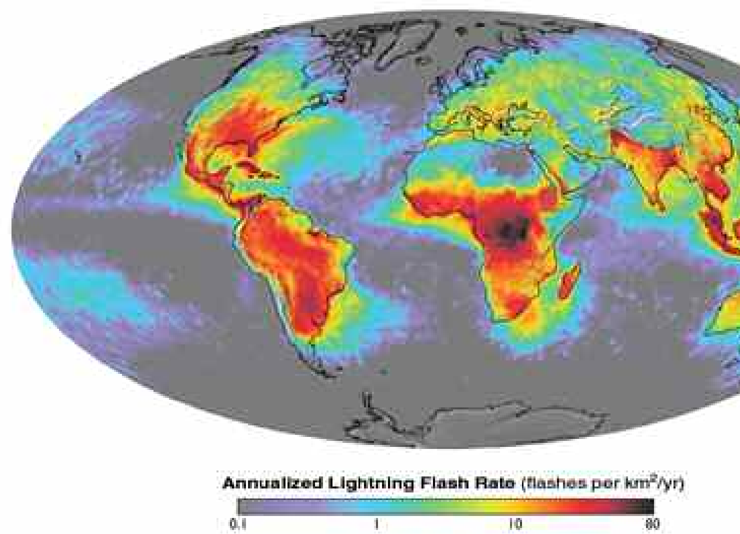
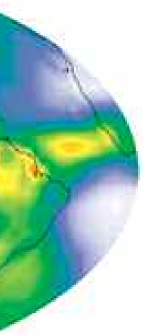



**Figure 2** ***Because lightning storms often are seen prior to severe storms, monitoring the lightning flash rate of thunderstorms aids forecasters in predicting and detecting severe weather. This image shows the mean annual global lightning flash rate, derived from a combined eight years, from April 1995 to February 2003.*** *Image: Data from the OTD instrument on the* OrbView-1 *satellite and the LIS instrument on the* TRMM satellite



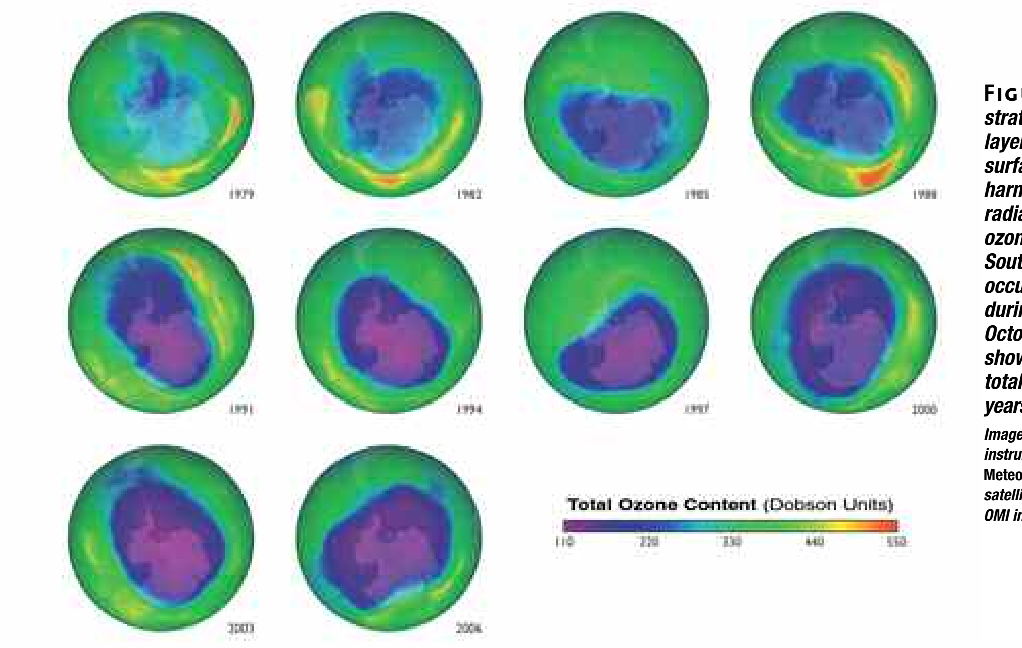
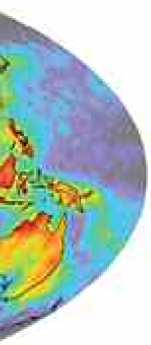




**Figure 3** ***The stratospheric ozone layer protects Earth's surface from the Sun's harmful ultraviolet radiation. The minimum ozone content in the Southern Hemisphere occurs over Antarctica during September and October. This sequence shows the minimum total ozone for selected years from 1979 to 2006.***

*Image: Data from the TOMS instrument on the* Nimbus 7, Meteor 3, *and* Earth Probe *satellites, as well as the OMI instrument on* Aura.



Pacific and the tropical jungles of the Amazon basin of South America and the Congo basin of Africa. Meanwhile, across vast desert regions, there is scant precipitation.

Precipitation varies spatially, and there is also considerable variability over the years, which is associated with irregular tropical patterns such as El Niño, La Niña, and the monsoon circulation on the Indian subcontinent. Space-based technologies allow us to track these phenomena worldwide without relying on local rain gauges, and all nations of the world use satellite data to monitor drought, extreme rainfall, floods, and climate variations.

## Lightning Strikes

Another natural phenomenon that injures and kills people worldwide is lightning, which was first monitored from space in 1995. Space-based observations have confirmed that about 90 percent of all lightning occurs over land. Oceanic lightning appears primarily along warm ocean currents with deep convective activity, such as the Gulf Stream of the North Atlantic and the Agulhas Current of South Africa.

**Figure 2** shows the annual average lightning flash rate, based on satellite observations between 1995 and 2003. These data reveal that the Congo basin of central Africa is the lightning "hot spot" of the world, with a rate of 158 flashes per square kilometer per year, and that lightning is more prevalent in the summer months, owing to deep convective cloud activity. Overall, there is very little lightning north of the east-west band of mountains that extends from Europe across Asia. These mountains serve to limit the poleward flow of tropical moisture.

## The Ozone Hole

Ground-based observations first alerted us to the increase in carbon dioxide concentration since the Industrial Revolution and the decrease in stratospheric ozone over Antarctica in the austral spring, producing the so-called ozone hole. Satellite and aircraft data have increased our understanding and subsequently played a key role in establishing the size and transformation of the ozone hole over the Antarctic.

Since 1978, satellites have monitored the ozone hole's areal extent, depth, and dynamic evolution (see **Figure 3**). They are crucial in monitoring ozone recovery and the yearly variability expected following the Montreal Protocol, which restricted the emission of ozone-depleting substances. Upper-atmospheric ozone is expected to recover to its 1980 level by about 2070. During the annual peak in ozone hole size, in late September and early October, the ozone hole has attained a size of more than 25 million square kilometers

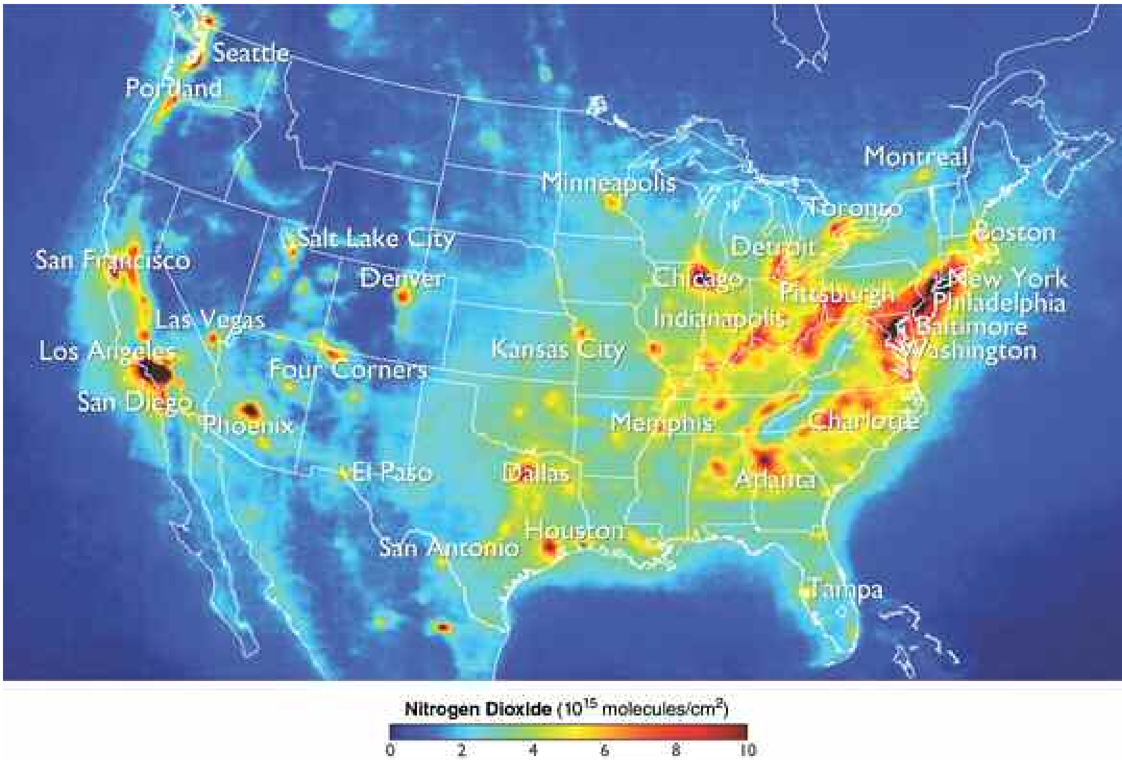




**Figure 4** ***The principal sources for nitrogen dioxide ($NO_2$) in Earth's troposphere occur over large populated regions, heavily industrialized areas, and individual power plants. This image shows the annually averaged $NO_2$ for the continental United States for 2006, clearly revealing the high concentration of $NO_2$ above numerous cities throughout the country.***

***Image: Data from the OMI instrument on the Aura satellite***

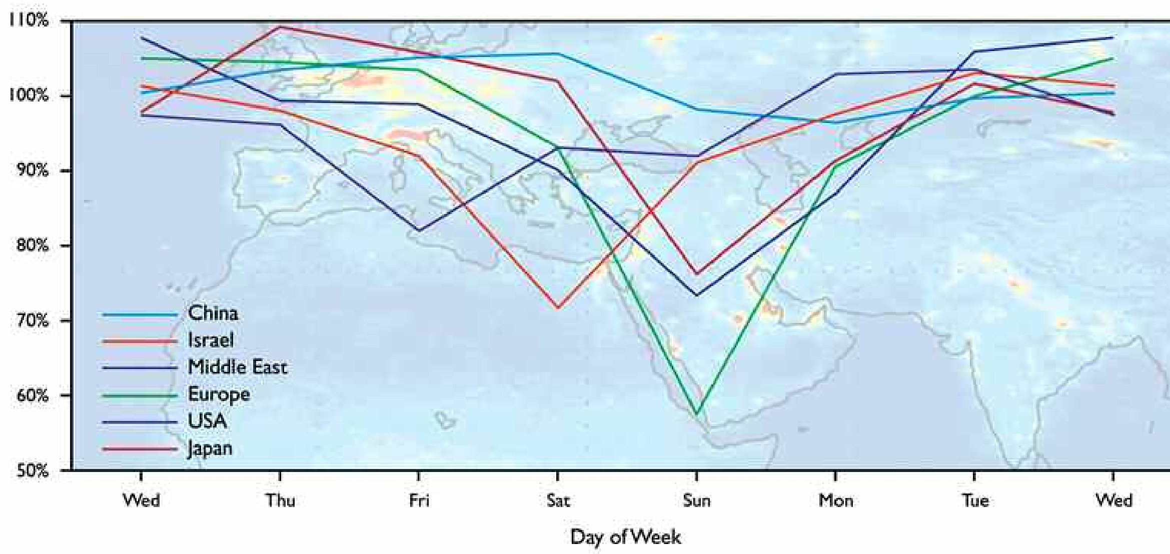



**Figure 5** ***Human transportation practices in Western countries follow the seven-day cycle, and consequently many emissions are reduced over weekends. This figure illustrates the "weekend effect" for selected regions as observed from space. All plots are normalized with respect to the median value for Monday–Thursday.***

***Image: Data from the GOME instrument on the ERS-2 satellite***

in some recent years, exceeding the area of the entire North American continent.

## Constituents of Earth's Atmosphere

Satellites can monitor our atmosphere's constituents, including water vapor, sulfur dioxide ($SO_2$), and nitrogen dioxide ($NO_2$). $NO_2$ is a short-lived, human-made chemical of the lower atmosphere that leaves a daily signal reflecting human activity. All major cities of the world, as well as industrial coal-fired power plants, are evident from space-based observations of $NO_2$.

**Figure 4** shows the annually averaged tropospheric $NO_2$ for the continental United States for 2006, clearly revealing the high concentration of $NO_2$ along the Interstate 95 corridor of the northeastern United States, as well as above numerous cities throughout the country. There is also a high concentration of $NO_2$ along the Ohio River Valley and the Four Corners region of the Southwest, associated with coal-fired power plants.

When plotted globally, the daily satellite data reveal that the eastern United States and Europe (especially the Po Valley of Italy) see a large reduction in $NO_2$ concentration on Sunday, reflecting the day of rest in predominantly Christian nations. In contrast, the Islamic countries of the Middle East exhibit their lowest $NO_2$ concentration on Friday, while in Israel, the lowest $NO_2$ concentration occurs on Saturday, the Jewish Sabbath. This day-of-the-week signal, clearly evident in **Figure 5**, follows as a consequence of the short lifetime of $NO_2$ in the atmosphere and the religious preferences of people in different regions, which are reflected in the use of transportation conveyances.

## Rising Sea Level

The rise in sea level is an unfortunate and unintended consequence of burning fossil fuels and clearing forests, activities that warm the lower atmosphere system by increasing atmospheric carbon dioxide. The sea level responds because ocean waters expand as they warm and because of the melting of land ice caps, including the Greenland and Antarctic ice sheets.

Sea level, which rose in the late 20th century by approximately 3.1 millimeters (0.1 inch) per year, is not uniform around the globe. Space-based radar altimeters, orbiting Earth continuously since 1992, have allowed us to monitor the spatial and temporal patterns. This would not be possible using only tide gauges located along continental shorelines and a few islands in the open ocean.

**Figure 6** shows the spatial distribution of sea level change from 1993 to 2006. It reveals that the rise is greatest in the sensitive tropical western Pacific, with its high concentration of low-lying island nations. The change in sea level arises primarily from thermal expansion as the ocean's surface warms and cools.

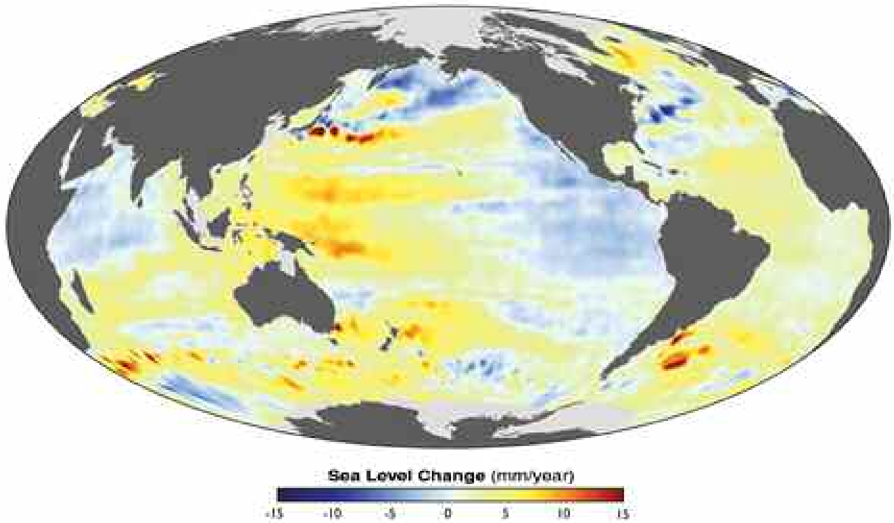



**Figure 6** *Current estimates indicate that more than one third of the world's population lives within 100 kilometers (about 60 miles) of coastline. This map shows the spatial distribution of sea level change (measured in millimeters per year) from 1993 to 2006. It reveals that the rise is greatest in the tropical western Pacific.* *Image: Data from the* TOPEX/Poseidon *and* Jason-1 *altimeter missions*

## Earth's Surface Temperature

Satellites today enable us to measure temperatures on the sea surface as well as on land. The land measurements complement the air temperature measurements that are routinely taken two meters above ground at meteorological stations throughout the world. By comparing the satellite-derived land surface data for a given period or time of day with the average over many years, we can infer large-scale heat waves or abnormally cold episodes.

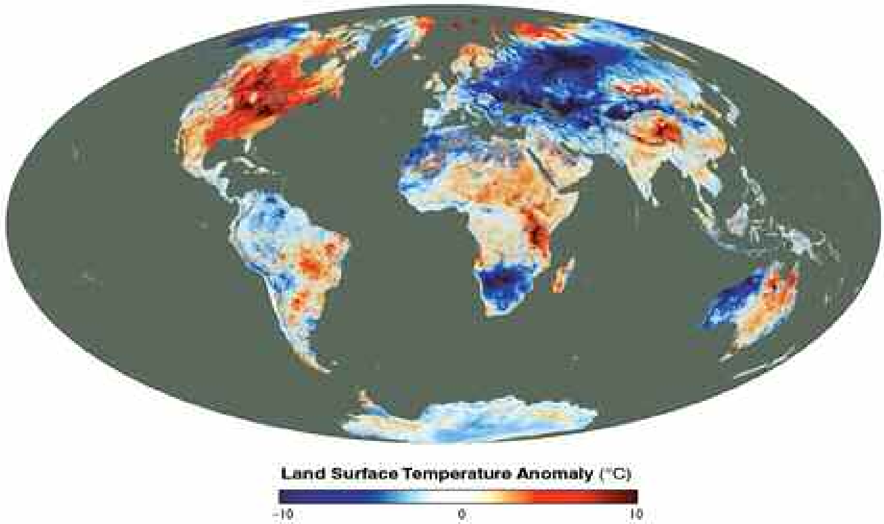



**Figure 7** *In January 2006, the eastern half of the United States experienced unusually mild temperatures while vast areas of Europe, Asia, southern Africa, and western Australia experienced temperatures that were 10 degrees Celsius (18 degrees Fahrenheit) colder than normal. This map illustrates the temperature anomaly for January 1–24, 2006, in contrast with the average for that period from 2001 to 2005.* *Image: Data from the MODIS instrument on the* Terra *satellite*

**Figure 7** illustrates the temperature "anomaly" for January 1–24, 2006 in contrast with the average for that period from 2001 to 2005. In January 2006, the U.S. news media focused on the unusually warm winter in the eastern United States and the abnormally cold winter in Moscow. **Figure 7** greatly broadens the discussion, showing the global picture and indicating that the land was more than 10 degrees Celsius (18 degrees Fahrenheit) colder than normal throughout eastern Europe and much of the Russian Federation, as well as in southern Africa, western Australia, and Alaska. The abnormal warmth experienced in the eastern United States extended well into Canada and also was exhibited in east Africa, Tibet, and northern Australia. Observations such as these rely on thermal emissions from the land surface and can be obtained for multiple times of day. They are widely used to forecast crop productivity and to assess drought.

## Fire

Taking advantage of the intense thermal emission from hot fires, satellites also are used to monitor fires worldwide. **Figure 8** illustrates the annual distribution of fires for 2005, based on satellite analysis from the Moderate Resolution Imaging Spectroradiometer on the *Terra* and *Aqua* Earth Observing System missions.

On a global basis, most fires occur in Africa, primarily as the result of clearing land for agriculture, a practice dating from at least 100,000 years ago. Archaeological evidence suggests that fire might have been exploited in eastern Africa as early as 1.6 million years ago. Although widespread, especially in the tropics, fires are largely set during the "dry season." The widespread fires seen in **Figure 8** in sub-Sahelian Africa occur primarily in December, January, and February, whereas the fires in southern Africa (Angola, Zambia, Mozambique, and Malawi) occur primarily in August, September, and October.

Globally, fires in North America are few but intense, and they often are suppressed when they approach residential areas or population centers. Although some of these fires are set by humans, most are started by lightning. Again, satellites provide a uniform and border-independent way of assessing the transformation of the landscape.

## Changing Land Use

Satellites often have been used to assess the transformation of open land to urban use as cities develop and rural areas are transformed by roads,

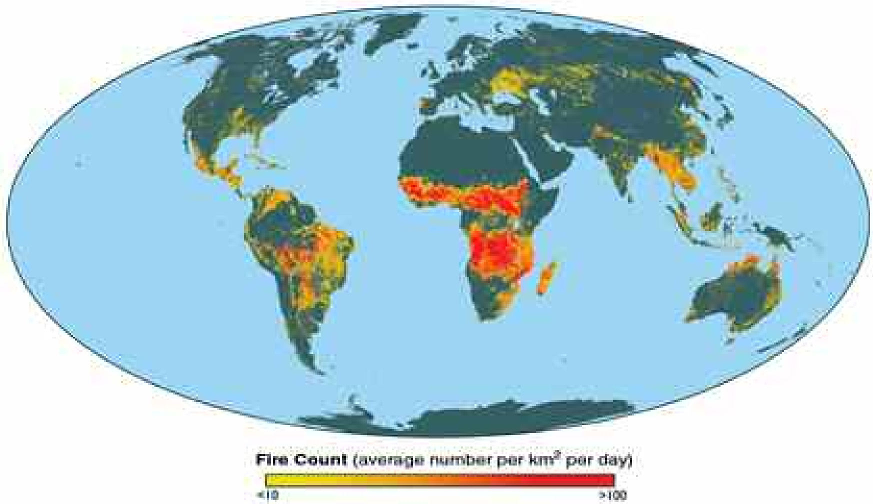



**Figure 8** *The frequency, intensity, seasonal timing, and type of fire that prevail in a region are referred to as the* fire regime. *Scientists are eager to understand whether the world's fire regimes are changing. Pictured here is the annual global distribution of fires in 2005. The widespread fires seen in sub-Sahelian Africa occur primarily in December, January, and February, whereas the fires in southern Africa (Angola, Zambia, Mozambique, and Malawi) occur primarily in August, September, and October.* *Image: MODIS Rapid Response Team; data from the MODIS instruments on the* Terra *and* Aqua *satellites*

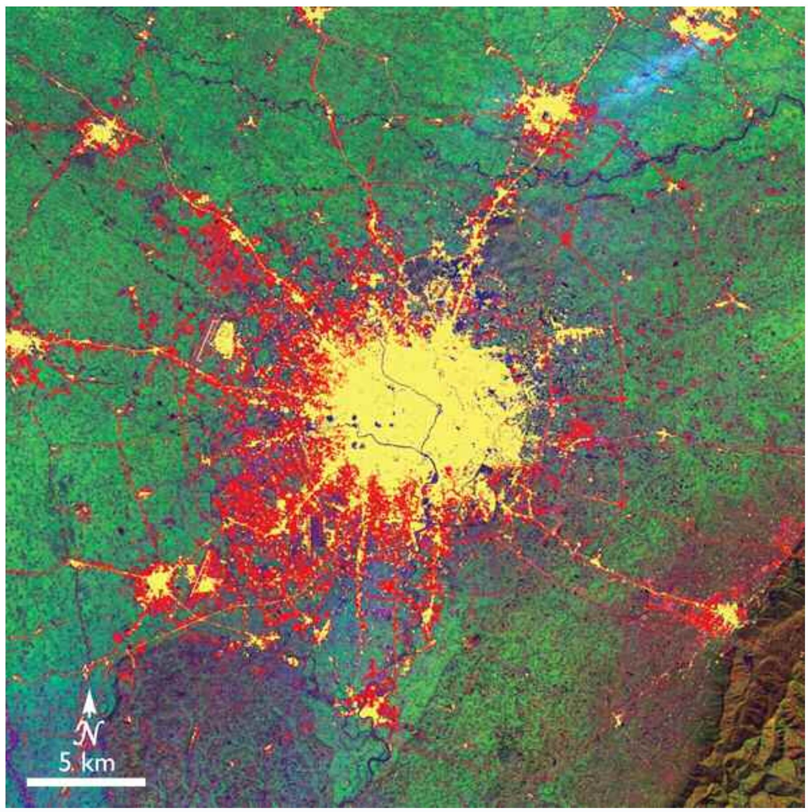



**Figure 9** *This image shows how Chengdu, a city in China, changed over a decade. The base satellite image was taken in November 2000, with vegetation represented in green, water in dark blue/black, and bare ground in purple. Maps of urban extent have been added to the image, with yellow depicting the amount of urban land cover circa 1990 and orange showing the amount of land developed between 1990 and 2000.* *Image: Data from the ETM+ instrument, bands 7, 4, and 2, on the* Landsat 7 *satellite*

## Here, There, and Not Quite Everywhere

Some of the earthly phenomena that satellites monitor from space also occur on other worlds. Here's a brief look at those mentioned in this article.

**Precipitation**—It's just a light drizzle, but it falls all the time on Titan, Saturn's largest moon. The temperature there is about –150 degrees Celsius (about –240 degrees Fahrenheit), so the rain that falls is liquid methane. At depths within the gas giant planets, deeper than we can see, other strange species of rain also may be falling.

**Lightning**—Thunderstorms big enough to swallow Earth rage around Jupiter, generating lightning 10 times as powerful as any strike on our planet. From radio signals detected by passing spacecraft, we know that lightning occurs on Venus, Saturn, Uranus, and Neptune as well.

**Ozone ($O_3$)**—Nasty-smelling ozone occurs on other worlds, but not in quantities large enough to form an atmospheric layer that can block ultraviolet (UV) light from the Sun—and protect organic things from that damaging radiation. Mars has traces of ozone in its atmosphere, but not enough to shield its surface from UV rays. The top layers of soil are effectively sterilized.

**Nitrogen dioxide ($NO_2$)**—This noxious creation of human industry is not found on other worlds. Earth alone must cope with it.

**Sea level**—On Earth, mean sea level is the reference point for measuring height and depth on the surface. On Jupiter's moon Europa, the entire world beneath the ice is covered by an ocean. Determining sea level there is a problem future explorers would like to solve.

**Surface temperature**—Our benign climate is perfect for life as we know it, but Earth is a neighborhood anomaly. Temperatures on other worlds range from about 480 degrees Celsius (almost 900 degrees Fahrenheit) on the surface of Venus to around –230 degrees Celsius (–380 degrees Fahrenheit) on Pluto. Even a minor change in average temperature can tip the balance, positively or negatively, for terrestrial life-forms.

**Planetary surface**—Some worlds in our solar system may have no solid surface at all. On these gas giants, the gases just get denser and denser with depth until, for example at Jupiter, the lightest element in the universe—hydrogen—is compressed into liquid metal.

**Fire**—Should we ever detect fire on another world, we will have found a signature of life. To start the chemical reaction we call fire, an oxidizer is necessary. On Earth, we would run out of the oxygen we breathe unless plants continually replenished it. Without plant life, oxygen would react with minerals and metals to get locked away in rocks.

**Land use**—As far as we know, Earth is the only planet with life-forms that modify its atmosphere and surface. For most of humanity's history, these changes were invisible from space. Now our "eyes in the sky" look down on cultivated fields, diverted rivers, and city lights at night, all dramatic demonstrations of our species' power over the planet.

*—Charlene M. Anderson, Associate Director of The Planetary Society*

buildings, and housing. **Figure 9** shows how Chengdu, a city in China, changed between 1990 (yellow) and 2002 (orange). Population growth forces changes in land use, which are easiest to monitor and map worldwide using high-resolution satellites from the *Landsat* series that date from 1972.

Earth-orbiting satellites enable us to observe our changing environment in ways that are impossible to accomplish from the ground. The land, atmosphere, ocean, and cryosphere are readily observable from space, often at less expense and effort than using land-based methods. This short article cannot address all the phenomena we monitor from space. Other phenomena not illustrated in this article include

- stratospheric sulfur dioxide ($SO_2$) arising from volcanic eruptions
- tropospheric $SO_2$ arising from coal-fired power plants and copper smelters
- the spatial distribution of human-made and natural aerosol particles
- the vertical distribution of many atmospheric constituents
- sources and sinks of carbon in the oceans and on land
- wind speed and direction over the global oceans
- sea ice extent and change
- glacier extent and ice sheet topography
- surface reflectance and the length of the growing season
- cloud cover and microphysical properties of liquid water and ice clouds.

Satellite imagery and data analysis can show more readily than any other means the large-scale state of the Earth-atmosphere-ocean system, its many dynamic processes, and the evolution of conditions worldwide. Our planet is changing, and only from space can we monitor it effectively.

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*Michael D. King is senior project scientist for the Earth Observing System at NASA Goddard Space Flight Center.*

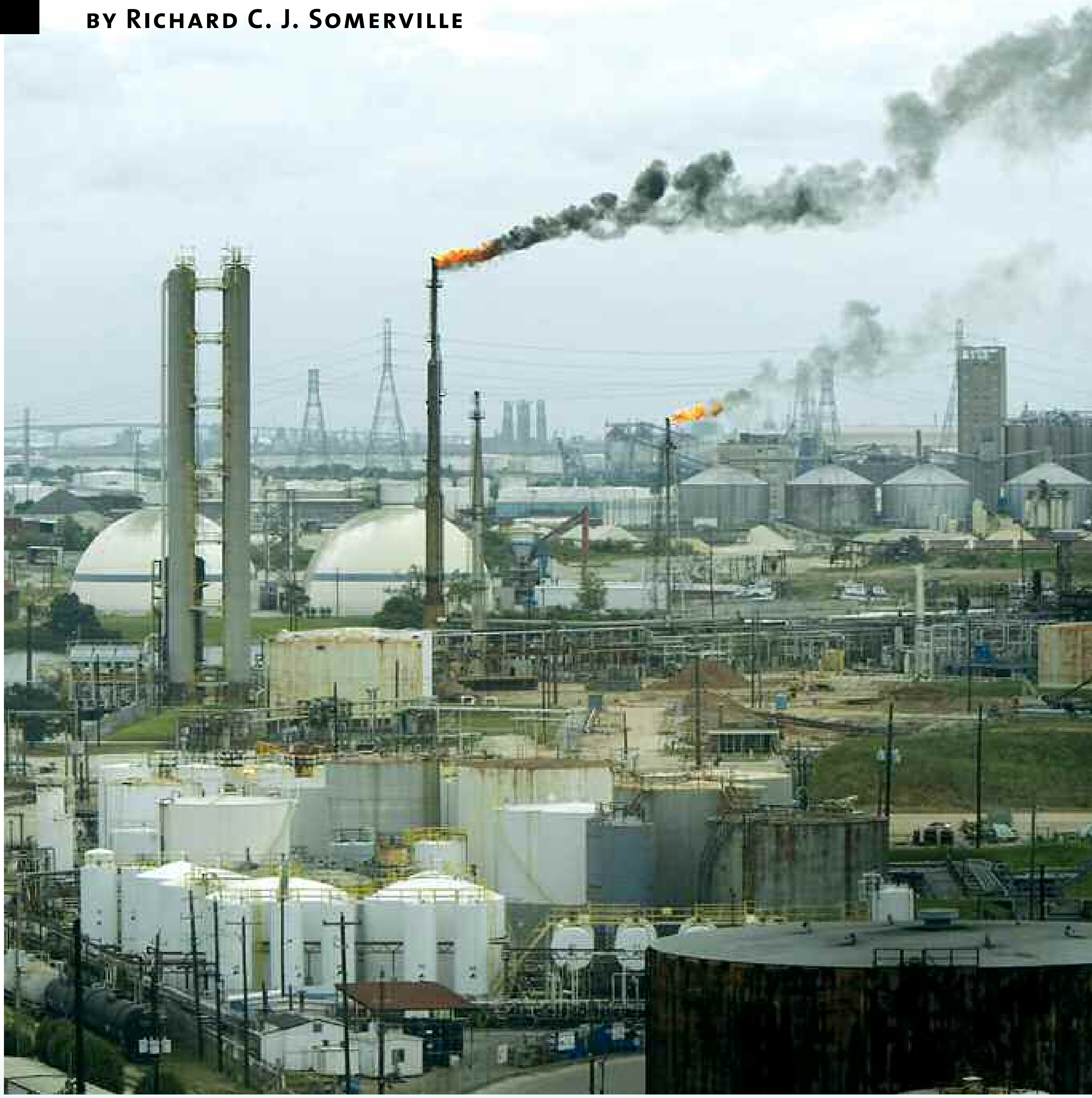
*Images adapted from the book* Our Changing Planet: The View From Space *by Michael D. King, Claire C. Parkinson, Kim C. Partington, and Robin G. Williams, Cambridge University Press, 2007.*

# Connecting Policy an

## The Intergovernmen

EARTH

by Richard C. J. Somerville



*Human activity—especially the production of greenhouse gases—is very likely the main cause of the unequivocal rise in global temperatures during the last century. Unabated, these gases will cause a more dramatic rise by 2099. Higher temperatures will lead to major climate change, which will have a significant impact on Earth's ecosystems.*

*As the Texas Gulf Coast braces for the arrival of Hurricane Rita on September 23, 2005, an oil refinery continues work.*

*Credit: Scott Olson, Getty Images News*

We climate scientists are planetary physicians. As is true for the findings of medical science, we have learned many things about Earth's health, but we still have a lot to learn. Our understanding of climate, though incomplete, is already highly useful.

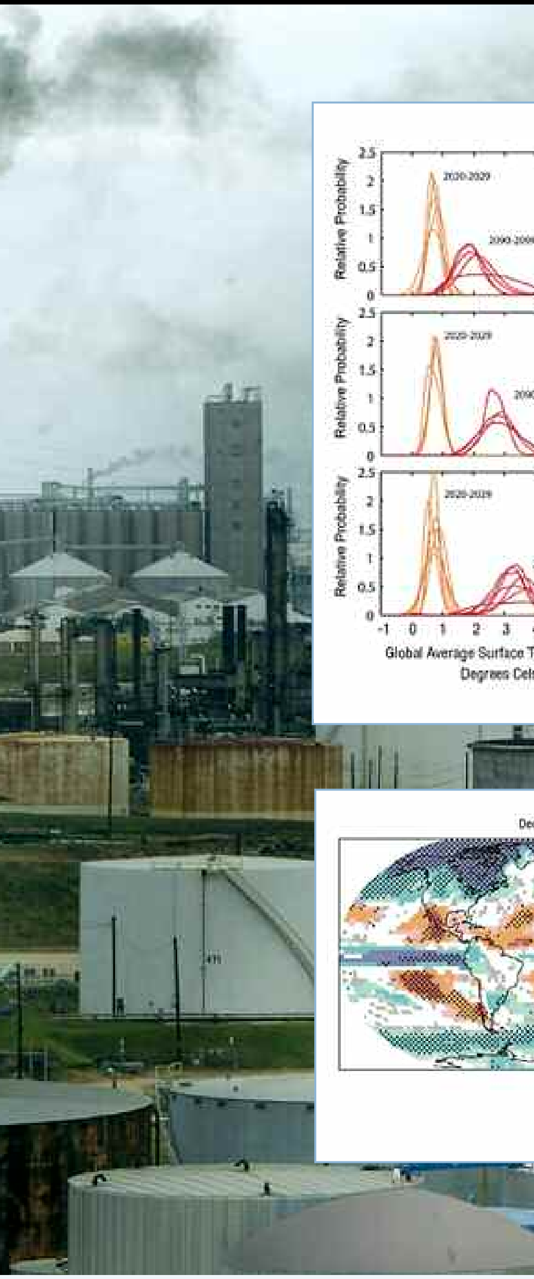
For example, we have answered the fundamental question of whether all of us—more than 6 billion humans—by adding to the greenhouse effect, have caused Earth's atmosphere to warm up in recent decades. The answer is yes.

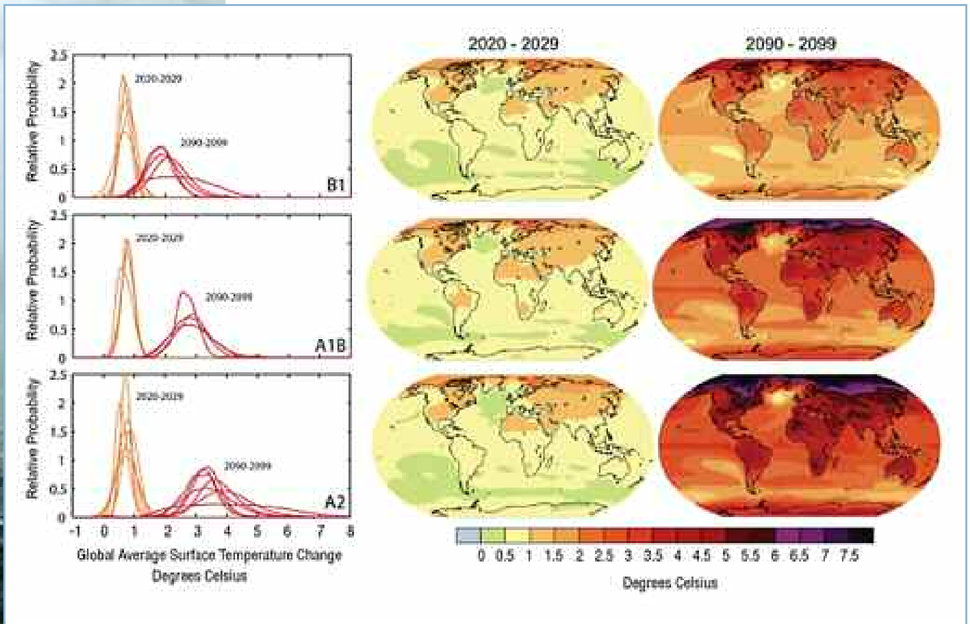
That's an affirmative answer with 90 percent certainty. Nothing in science can be said to be known with 100 percent certainty—the self-correcting human endeavor of science just doesn't work that way. To reach 90 percent certainty in any scientific work is remarkable, but the Intergovernmental Panel on Climate Change (IPCC) has reached this unusual state.

This international organization of scientists and governments, founded in 1988 under United Nations auspices, is charged with providing objective and transparent assessments of climate change science that will be rele-

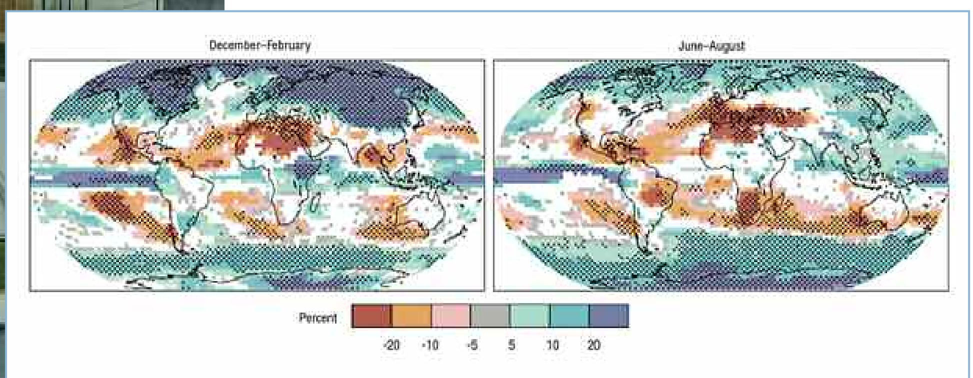
# d Science:

## tal Panel on Climate Change






***Shown here are three hypothetical future scenarios for projected temperature changes in the early and late 21st century, relative to those of 1980 to 1999. The pairs of globes illustrate the corresponding climate models—labeled B1, A1B, and A2—which are based on differing growth rates of greenhouse gases. The column at right shows dramatic differences in projected Earth surface temperatures for the last decade of this century based on which scenario occurs.*** *Graphic: Intergovernmental Panel on Climate Change (IPCC)*




***These are the expected precipitation changes, relative to records for 1980 to 1999, for winter and summer months in the years 2020 to 2099. The values, multimodel averages based on the A1B scenario, show increasing precipitation in high latitudes and decreases in most subtropical land regions, continuing the pattern of recent observed trends.*** *Graphic: IPCC*

vant and useful to policymakers. Over its 20-year history, the IPCC has acquired an enviable reputation for scientific accuracy and integrity. It is widely regarded as the authoritative voice of the climate science research community, and its main findings have been endorsed by national academies of science and scientific professional societies globally.

The IPCC is unique. No parallel organization exists in any other domain where science and public policy are so closely intertwined. In recognition of its effectiveness, in 2007 the IPCC shared, with Al Gore, the Nobel Peace Prize. It is the only scientific organization ever to be awarded this high honor.

### Recognizing Climate Change

For more than a century, we've known that atmospheric carbon dioxide ($CO_2$), a greenhouse gas, can raise the temperature of Earth's atmosphere. Thanks to the research of Charles David Keeling, we have known with increasing clarity since 1960 that the amount of carbon dioxide in the atmosphere is continually increasing and that the burning of fossil fuels and other human activities

***The first cyclone of 2008 in the northern Indian Ocean was a devastating one for Myanmar (formerly Burma). These before-and-after images taken by the Moderate Resolution Imaging Spectrometer (MODIS) on NASA's*** **Terra** ***satellite show Myanmar's coastline on April 15, before tropical cyclone Nargis, and on May 5, after the storm flooded the region. In the first image, rivers and lakes are sharply defined. Water is blue to nearly black, vegetation is green, bare earth is tan, and clouds are white or blue. In the May 5 image, the entire coastal plain is flooded. Muddy runoff colors the Gulf of Martaban turquoise.***

*Images: NASA/MODIS/Rapid Response Team*

are the reasons for the increase. The 2007 IPCC assessment describes, in stark and sobering terms, the current status and future projections of human-caused climate. Despite the strong scientific consensus on the reality and seriousness of global warming and its likely consequences, however, global emissions of $CO_2$ and other greenhouse gases continue to increase each year.

The IPCC is mandated to be policy-neutral and to refrain from prescribing or advocating policy, which is the prerogative of sovereign governments. It will not be easy to reduce the global dependence on fossil fuels, which provide 80 percent of the world's energy but are primarily responsible for the increasing levels of greenhouse gases in the atmosphere. As the U.N. climate negotiations in Bali in late 2007 clearly showed, the nations of Earth are still far from agreeing on how to implement and enforce effective policies to stabilize our atmosphere's chemical composition to avoid dangerous climate change.

The report I'll discuss here is officially known as the Working Group One portion of the Fourth Assessment Report of IPCC. Although it is only part of the full Fourth Assessment Report, I'll simply call it "the IPCC report." Working Group One is concerned with the physical science basis of climate change; two other IPCC working groups deal with mitigation of and adaptation to climate change.

Two major statements characterize this report:

• "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."

• "Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." (Here, "very likely" is calibrated language denoting 90 percent or greater certainty.)

These statements are stronger than those in previous IPCC reports. The first of the four assessment reports appeared in 1990 and contained no such summary statement. The second report, issued in 1995, concluded, "The balance of evidence suggests a discernible human influence on global climate." The third report, issued in 2001, stated, "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." In this language, we can track the progression of certainty.

The IPCC report also discusses projections of climate change, but in general, the IPCC does not specifically forecast what the climate will do. Instead, it explores a range of hypothetical scenarios in which different rates of population growth, greenhouse gas emissions, and other factors are assumed. Climate models can be run under the different assumptions, so these thought experiments can best be regarded as "what-if" exercises rather than predictions.

Furthermore, the IPCC does not itself carry out research. Thus, the projections are a sampling of important results from research carried out by leading climate model groups worldwide and published in the peer-reviewed research literature, then assessed by the IPCC author teams.

## Tracking Climate Change From Space

Modern climate science would be impossible without satellite remote sensing, and our ability to observe the climate system from space provides bedrock empirical data. We now know that Earth is globally about 0.76 degrees Celsius (about 1.4 degrees Fahrenheit) warmer than it was in the late 19th century. Consider, also, these results:

• The overall trend in warming per year in the last 50 years is nearly twice that for the last century.

• North Atlantic hurricanes have intensified since 1970.

• Arctic temperatures have increased at about twice the global rate.

• Arctic sea ice has shrunk by about 2.7 percent per decade.

• Eleven of the twelve most recent years' reports are among the twelve warmest on record since 1850.

• The global ocean is warming to depths of at least 3,000 meters.

• The ocean has absorbed more than 80 percent of the heat added to the climate system.

• Sea level rise averaged globally over the 20th century was about 17 centimeters.

• The largest $CO_2$ growth rate in the instrumental record is found in the most recent decade.

As for the future, sea level will rise by perhaps 18 to 59 centimeters (7 to 23 inches) during the 21st century, according to projections summarized by the IPCC. This outlook is subject to important uncertainties, however, because scientists cannot yet quantitatively assess the potential for further sea level rise. This is because of ice sheet dynamics that might affect Greenland and Antarctica in particular, dynamics that we don't understand


APRIL 15, 2008


MAY 5, 2008

sufficiently because of the physical processes involved. As a result, we can't rule out even greater sea level rise. In fact, about 125,000 years ago, the sea level was some 4 to 6 meters higher than today, but relatively high temperatures at that time were sustained for centuries.

Over the next two decades, the IPCC projects further climate warming of about 0.2 degrees Celsius (about 0.4 degrees Fahrenheit) per decade. This anticipated warming is relatively independent of which scenario is assumed and continues observed recent trends, which themselves are consistent with earlier IPCC projections.

Here are some other anticipated changes.

- Snow cover and sea ice will continue to contract.
- Heat waves and heavy precipitation will become more frequent.
- Tropical cyclones will become more intense.

*Icebergs continue to break away from Antarctica's Ross Ice Shelf. This true-color MODIS image, taken on September 21, 2000, shows the level of breakage along the shelf near Ross Island. The labeled iceberg fragments are pieces of the huge iceberg, nearly 11,007 square kilometers (4,250 square miles), that broke away from the Antarctic shelf in March 2000. Scientists are using close satellite observations of the Antarctic shelf to study the potential effects of global warming.* Image: Brian Montgomery, NASA/GSFC, MODIS Science Team

- Warming and sea level rise will continue for centuries.
- The part of the Atlantic Ocean circulation that includes the Gulf Stream will slow.
- Precipitation will tend to increase in high latitudes and decrease in subtropical latitudes.

## Absolutely Certain Truth?

Does the IPCC report provide absolutely certain truth? No—and one never gets absolute certainty in science. The results are simply today's best summary assessment of what science says, and they include estimates of uncertainty. The IPCC addresses the questions most often asked by policymakers and the public, such as how to distinguish natural climate variability from change caused by humans, what we can learn from past climate changes, what we can predict for the future (and how and why), and what we still do not know.

The IPCC report is simply an honest and competent assessment of published peer-reviewed science. It is disconnected from advocacy, spin, and ulterior motives of all kinds. It was prepared in the conviction that sound science can inform wise policy-making. Like medical science, climate science never will be complete, but it is highly useful.

The strong reputation of the IPCC derives mainly from the processes involved in drafting its reports, processes that were exceptionally open and transparent. Anyone who wished to review the report in draft form had ample opportunity to do so. According to established IPCC procedure, the 2007 report, which took three years to write, underwent several formal and fully documented expert and government review processes, in which tens of thousands of comments were addressed. All the author responses to each comment are publicly available.

The Summary for Policymakers for Working Group One received unanimous line-by-line approval by more than 100 governments at a week-long plenary session in Paris early in 2007. Governments had the right to refine the wording, and they did this in a harmonious and constructive way, but we scientists who drafted the report determined its substance and ensured consistency with the full report. In the end, the scientists never lost control of the document, and the final version was close to the initial draft.

The wide participation of the scientific community, the exceptional level of scientific accuracy, and the absence of policy prescriptions are the characteristics that render the report so powerful. This is precisely why it serves a unique role in informing policymakers as well as others in industry, the media, and the broad public.

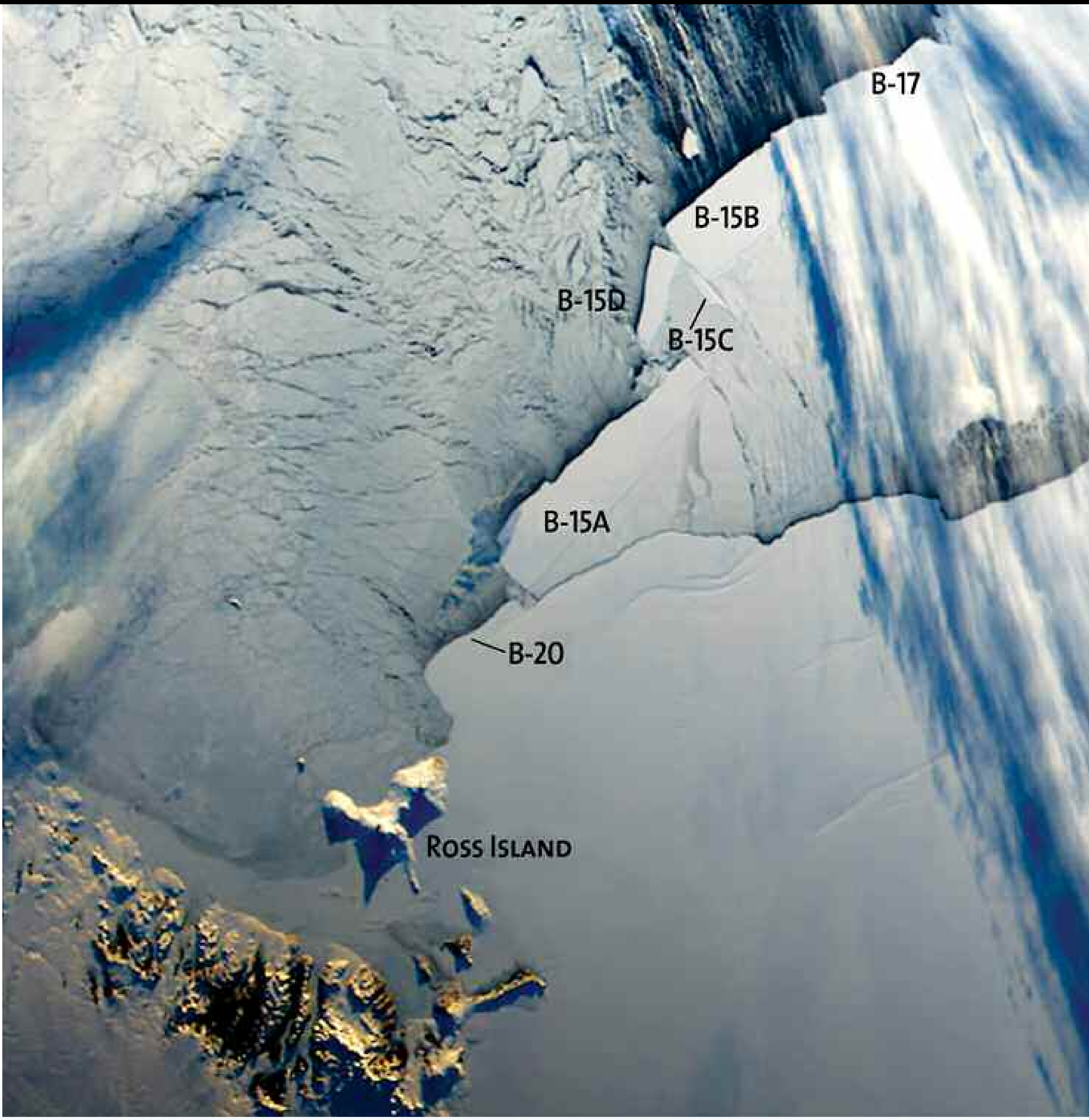
The writing of this Fourth Assessment Report was done not by any self-selected group with its own agenda but by 152 lead authors chosen from more than 700 nominations from governments. They were diverse in gender and scientific discipline. Fully 25 percent of them had earned their highest degree within 10 years of the time at which they were appointed. They represent new talent, in that 75 percent had not worked on previous IPCC reports. They thus had no selfish motive to defend previous IPCC reports. They provide a global range of viewpoints and experience, and 35 percent were from developing countries and countries with economies in transition.

## Science Meets Policy

The nations of Earth agree that the amount of greenhouse gases released by humans into the atmosphere should be kept below a level that would dangerously change our climate. In fact, a formal agreement called the United Nations Framework Convention on Climate Change (UNFCCC), negotiated at the Earth Summit in Rio de Janeiro in 1992, has exactly that as its primary objective. Virtually all countries, including the United States, have signed this agreement. The UNFCCC does not, however, specify what level would be dangerous, and thus there is no precise target or limit to greenhouse gas concentrations that all countries have adopted.

Science can contribute to this debate but cannot settle it. The IPCC, as I mentioned earlier, is required by its mandate to be policy-neutral. Neither science nor the IPCC can say that a given atmospheric level of greenhouse gases is safe and another, slightly higher, one is dangerous. It is possible, however, for science, speaking through the IPCC, to provide guidance by suggesting and predicting the severity of climate change, depending on the specific level of greenhouse gases. As a result, various groups, including governments and nongovernmental organizations, have issued statements advocating particular limits on allowable climate change and corresponding greenhouse gas levels.

Perhaps the most important public function of climate science with regard to an issue such as global warming is to provide useful input into the policy process. Governments, media, corporations, and individuals should listen to and learn from the science, just as intelligent people listen to their physicians when their health is in question. Sound science can




thus inform wise policy-making.

Climate is more than just temperature; it is a rich tapestry of interlinked phenomena, multifaceted and inherently complex. The most important effects of climate change will be local, not global, and will not be confined to warming. Global warming is only a symptom of planetary ill health, like a fever. Climate scientists are working to diagnose the causes and help prescribe a cure.

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*Richard C. J. Somerville is a theoretical meteorologist and distinguished professor emeritus at the Scripps Institution of Oceanography at the University of California, San Diego.*

The Working Group One IPCC report is available for free download at *http://www.ipcc.ch*. It is more than 1,000 pages in length and has been published in hard copy by Cambridge University Press. As a coordinating lead author for the IPCC, I helped write it, but in this article I am speaking only for myself and not on behalf of the IPCC. —*R. C. J. S.*

EARTH

# As Riders on the Ear

## MONITORING OUR

by Berrien Moore III

"Everywhere the sun, moon and stars, the climates and weathers, have meanings for people. Though meanings vary, we are alike in all countries and tribes in trying to read what the sky, land and sea say to us."

These remarkable words, written by poet Carl Sandburg in 1955, speak clearly to us more than half a century later. Even now, they quietly strike raw nerves and sensitive areas: Are we humans changing the Earth? What are the sky, land, and sea saying to us now? Are we listening?

Paradoxically, the most profound way we can listen to Earth is to watch it from space, a vantage point from which we can see it as a planet—not as separate jigsaw-puzzle pieces of land, oceans, atmosphere, and biosphere set on a rocky sphere, but as a whole functioning system. Only from space can we truly see how the pieces fit together, how they are changing, and how we are affecting our home world, for good or ill. "Earth observations" is the inelegant term for what satellites equipped with sensitive and powerful instruments do in orbit. These observations are essential for safeguarding our life on the planet.

I was privileged to serve as the cochair of the committee charged with producing the first-ever decadal survey in the Earth sciences, which called for a renewal of the U.S. commitment to Earth observations. In our report, securing practical benefits for humankind plays an equal role with the quest for new knowledge about the Earth system. Satellite observations are critical to understanding our planet as a system of connected parts, and they serve society by saving lives, protecting property, strengthening the security of nations, and helping the growth of the economy through timely acquisition of environmental information. The decadal survey set forth a number of key Earth-observing missions to fulfill humanity's need for information.

Unfortunately, the United States had become "lost in space" when it came to future Earth observations. The number of missions began to decrease dramatically in 2006, and the slide was expected to continue to the end of the decade. The number of operating sensors and instruments on NASA spacecraft, most well past their nominal lifetimes, will decrease by some 40 percent. Furthermore, some of the replacement sensors to be flown on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) are less capable than their counterparts now flying in the Earth Observing System (EOS). Several of the climate sensors on NPOESS were eliminated because of significant cost increases, and the system is no longer robust, so if the launch fails or the system dies in orbit, there is no backup.

### A System at Risk of Collapse

As a consequence, our committee announced in the interim report that the U.S. "system of environmental satellites is at risk of collapse." During the 20 months between the announcement in our interim report in April 2005 and the release of the Decadal Survey in January 2007, events at NASA and the National Oceanic and Atmospheric Administration (NOAA) painted an even bleaker picture of the U.S. Earth-observing capability. Earth satellite programs, once the envy of the world, are in disarray, even as the needs have never been greater.

Our world faces significant environmental challenges: shortages of clean and accessible fresh water, degradation of terrestrial and aquatic ecosystems, increases in soil erosion, changes in atmospheric chemistry, declines in fisheries, and the likelihood of substantial climate changes. These changes interact with one another and with natural variability in complex ways on local, regional, and global scales.

To address societal challenges, we must confront key scientific questions about the sources and sinks of greenhouse gases, ice sheets and sea level change, large-scale and persistent shifts in precipitation and water availability, transcontinental air pollution, modified ecosystems, impacts on human health, and natural disasters such as severe storms, heat waves, earthquakes, and volcanic eruptions.

To act wisely, we require information and understanding. We know that societies are capable of making smart decisions when they have information. We also know that without information, we often make poor decisions. Information about the past, the present, and the future is invaluable—and critical to survival.

Beyond recommending key Earth-observing missions, in the Decadal Survey, we sought to initiate a dialogue and strategy in the Earth sciences that balance economic competitiveness, protection of life and property, and stewardship of the planet for this and future generations. The need for this strategy is illustrated by hazards such as earthquakes, volcanoes, and landslides. Whether these natural hazards have consequences that are serious or truly catastrophic depends on whether or not people have prepared to mitigate the effects of those hazards. Mitigation is expensive, however, and resources are limited, so expenditures must be prioritized.

# th Together:

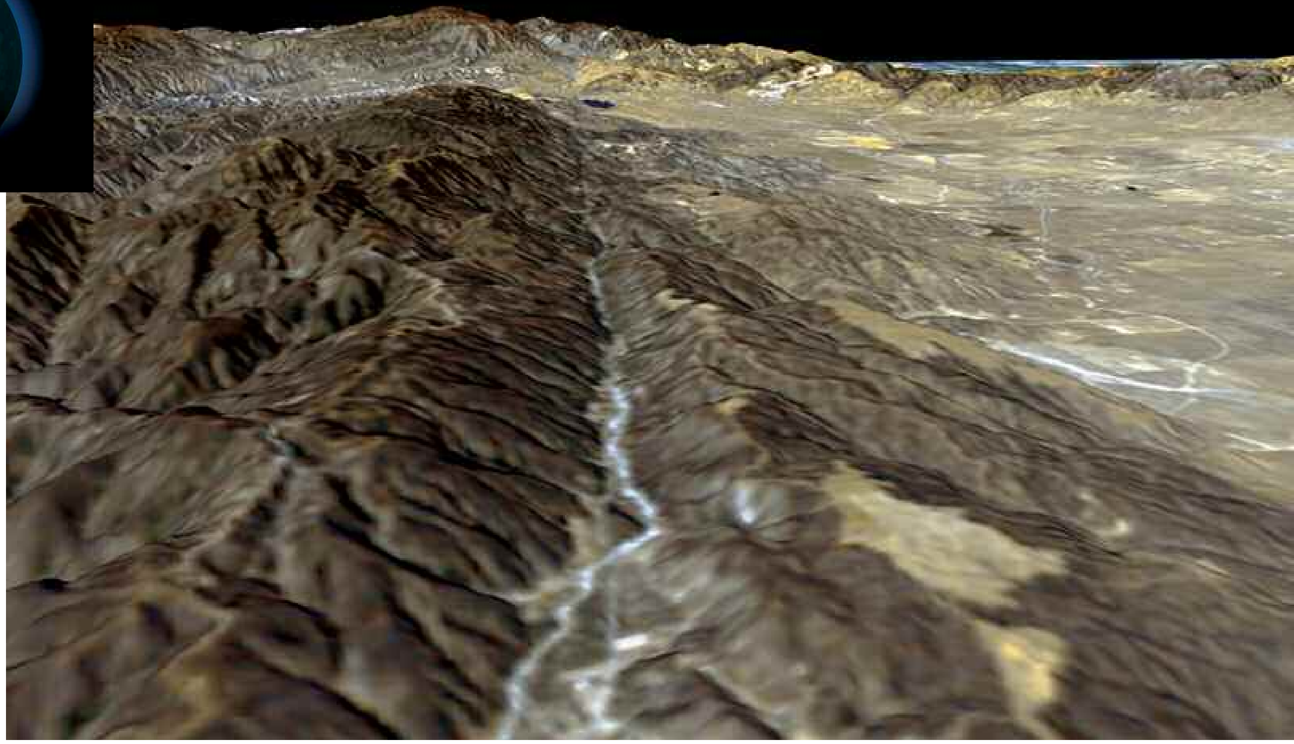
# Changing Planet

*Viewing our planet from space is essential to understanding Earth as a system of connected parts. Such observation reveals humans' impact on our world, as well as the impact of natural processes, such as earthquakes and volcanoes.*

*On May 18, 1980, a series of earthquakes preceded the explosive eruption of Washington's Mount Saint Helens—the worst volcanic eruption in U.S. history. Twenty-two years later, on October 25, 2002, an astronaut on board the International Space Station took this photo. The volcano remains the most active in the continental United States.*
*Photo: NASA*

*We are seeing evidence of the environmental challenges facing Earth on global, regional, and local scales, such as shortages of clean and accessible fresh water and worldwide declines in fish populations. Normally, hundreds of thousands of fall Chinook salmon (shown here) return from the ocean to spawn in California's Sacramento River. This year, fewer than 60,000 salmon will return, a shortage that is prompting the closure of recreational and commercial fishing in the area. Scientists suggest that unfavorable shifts in ocean temperatures and food sources may be affecting the juvenile salmon.*
*Photo: U.S. Fish and Wildlife Service*

*Satellite data are critical in answering key scientific questions about natural disasters such as heat waves and severe storms. Here, a statue sits among the ruins of a cyclone-damaged temple in Pyapon, Myanmar.* *Photo: AP Photo*

***We lack the information necessary to determine which earthquake faults are most likely to rupture, let alone when ruptures will occur. The prominent linear feature down the center of this Shuttle Radar Topography Mission perspective view is California's famous San Andreas fault.*** *Image: NASA*

***Rescue workers carry a victim of the Sichuan earthquake that rocked China on May 12, 2008. As of June 1, 2008, the death toll from this earthquake was 69,000. Governments still do not have the Earth science necessary to anticipate such natural disasters.*** *Photo: AP Photo/Oded Balilty*

***This lake was created when landslides generated by China's recent Sichuan earthquake dammed the Tangjashan River. At the time of this writing, engineers were working around the clock to dig emergency sluiceways to drain the water before the dam breaks and floods the town below. Although about 200,000 people who live close by have been evacuated, more than a million people risk being affected if the dam fails. Thirty-three other lakes were created by the quake, and twenty-eight dams are at risk of bursting.*** *Photo: AP Photo/Xinhua, Shu Wei*

## A Need for Decisions

Right now, the solid-Earth science that we need for decision making is hampered by a lack of data—a situation analogous to forecasting weather before global observations were available. We know the total rates of deformation across earthquake-prone fault systems, but we lack the information to determine which faults are most likely to rupture, let alone when these ruptures will occur. For example, it is tremendously important whether the earthquake deficit in Southern California is more likely to be balanced by ruptures beneath heavily populated Los Angeles or the nearly empty Mojave Desert. The answer to that question has tremendous bearing on where to allocate resources to reinforce buildings and retrofit bridges and freeways.

Dangerous volcanic eruptions and landslides often have precursors, but our ability to detect and interpret these events is limited severely by lack of observations.

***Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important challenges for society as it seeks to achieve prosperity, health, and sustainability.***

Last year, the Committee on Earth Science and Applications from Space of the Space Studies Board of the U.S. National Research Council (NRC) released a Decadal Survey that laid out recommendations for the next 10 years of observing Earth from space. That report strongly affirmed this vision as an essential long-term guidepost to support the health, prosperity, safety, and sustainability of our planet.

The NRC Decadal Surveys set priorities for U.S. federal funding for specific research fields, such as astronomy and planetary science. As statements from the scientific communities actually doing the research, these decadal studies effectively influence the course of research and discovery. Author Berrien Moore co-chaired the survey committee; his cochair was Rick Anthes, president of the University Corporation for Atmospheric Research. The committee worked from the summer of 2004 to January 2007.

This lack does more than just hamper our preparations for catastrophes; the economic sphere is affected as well. Such data could aid in searching for and producing hydrocarbon and mineral resources, as well as in managing our precious groundwater. Human endeavors to improve our situation under all these circumstances will benefit from observations from space.

The challenges, however, extend well beyond the so-called natural hazards. Consider the following questions:

- What is the distribution of natural sources and sinks of greenhouse gases, and how will this distribution change as the climate changes?
- Will the major ice sheets, including those of Greenland and the West Antarctic, collapse catastrophically and, if so, how rapidly will this occur? What will happen to the sea level as a result?
- Will droughts become more widespread in the western United States, Australia, and sub-Saharan Africa? How will this affect wildfires and agriculture? How will reduced snowfall change the needs for water storage?
- How will economic development affect the production of air pollutants, and how will these pollutants be transported across oceans and continents? How do these pollutants transform during transport?
- How will coastal and ocean ecosystems respond to changes in physical forcing, particularly those harvested intensely by humans? How will the boreal forest shift as temperature and precipitation change at high latitudes? How will animal migration patterns and invasive species change?
- Will previously rare diseases become common? How will mosquito-borne viruses spread with changes in rainfall and drought? Can we better predict the outbreak of avian flu? What are the health impacts of an expanded ozone hole that could result from the cooling stratosphere?
- Will tropical cyclones and heat waves become more frequent and/or more intense?

These questions demand vigorous efforts to gather data about Earth and to apply the improved understanding to growing societal needs. The challenges are immediate and call for a shared responsibility and partnership among the government, the private sector, and academia.

Unfortunately, the institutional structure of the U.S. government is not aligned well to meet these challenges. Consequently, the committee also recommended in the Decadal Survey that the government take a fresh look at how to implement and sustain programs to address issues that *require* long-term and highly accurate data with global coverage.

In particular, the committee recommended that the Office of Science and Technology Policy, in collaboration with relevant agencies and departments and the scientific community, implement a strategy for sustaining global Earth observations. This strategy should recognize the complexity of differing agency roles, responsibilities, and capabilities. This is an important recommendation and one on which the new administration might act. One thing is certain: the United States does not have the appropriate federal structure to confront long-term global environmental challenges such as climate change.

## A Reasonable Request?

Returning to the Earth observing program, the scientists undertaking the Decadal Survey asked themselves a very simple question: what does it take to provide society with the information required for people to be proper stewards of our planet? They then asked this question: is it a reasonable request in view of the fiscal constraints on the federal budget? With regard to NASA, they were comforted to know that if Earth science in NASA was simply restored to the funding level it had in fiscal year 2000, it would be possible to fund an observation, research, and

EARTH

## Earth Observations: An International Venture

Preserving scientists' ability to observe and monitor Earth from space is a high priority not only for the United States but also for the international community as a whole. Alongside NASA and NOAA, the European Space Agency (ESA) has an active Earth-observing program, as do the national space agencies of India, Japan, France, Brazil, China, Argentina, and other countries. Numerous organizations are engaged in both research and advocacy for a robust international Earth observation program, including the United Nations Environment Programme, which has been promoting Earth observations since the 1970s.

One of the leaders in the field of international Earth observations is a relative newcomer to the field, GEO—the Group on Earth Observations. Formed in 2005 at the third Earth Observations Summit in Brussels, GEO is a voluntary association of governments, nongovernmental organizations, and international organizations. GEO's purpose is to coordinate the many current Earth observation programs from both space and the ground, facilitate the distribution of data to researchers and officials around the world who can make best use of them, and add new observation programs in areas not adequately covered by existing ones. The organization's ultimate goal is to create a Global Earth Observation System of Systems, which would coordinate and manage all the interlocking observational systems that monitor Earth's complex environment.

Unlike U.N. organizations, which require the assent of nearly 200 governments for their decisions, GEO provides a forum in which any two participants can join forces and launch a new project. This unorthodox structure allows GEO to react quickly to emerging needs and launch new initiatives with relatively little delay.

In its three years of existence, GEO has helped launch several projects aimed at coordinating Earth observations from space, drastically improving the availability of data for Earth regions not accessible with current observation programs and closely monitoring the world's water supplies from both the Earth and space.

*—Amir Alexander, Writer-Editor for* planetary.org

applications program that could provide the required information.

The committee's recommended observational strategy consists of

- 14 missions for NASA,
- 2 missions for NOAA, and
- 1 mission that has separate components for both NASA and NOAA.

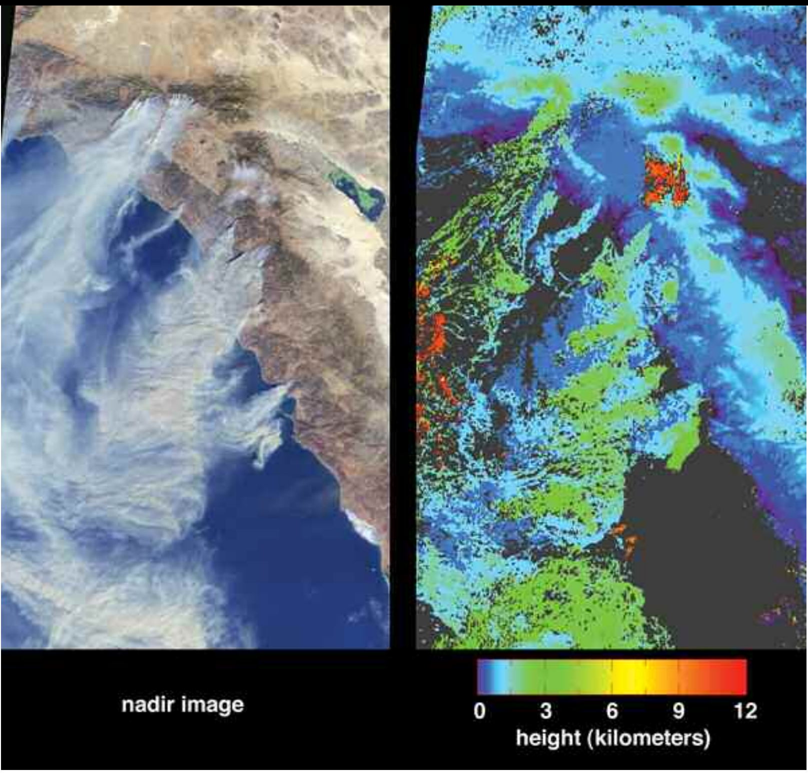
With this observing strategy, we can make progress across the range of societal issues.

The number of recommended missions and observations is only a fraction of the number of those currently operating. Although the number may seem large, the committee chose to distribute the sensors among several satellites rather than gathering the systems into grouped payloads on a few large platforms. This distributed architecture creates a robust and integrated program—one that does not crumble if one or several missions are delayed, or if the list evolves to meet changing needs. Robustness is measured by the strength of the overall program, not by the particular missions. We must protect the range of observations rather than the individual missions themselves.

***The hazards faced by our home world extend far beyond those of earthquakes, volcanoes, and landslides; they funnel down to all the life-forms on this planet. For example, how will ocean and coastal ecosystems respond to human-generated changes such as rising ocean temperatures and pollution?***
*Photo: Donna Stevens*

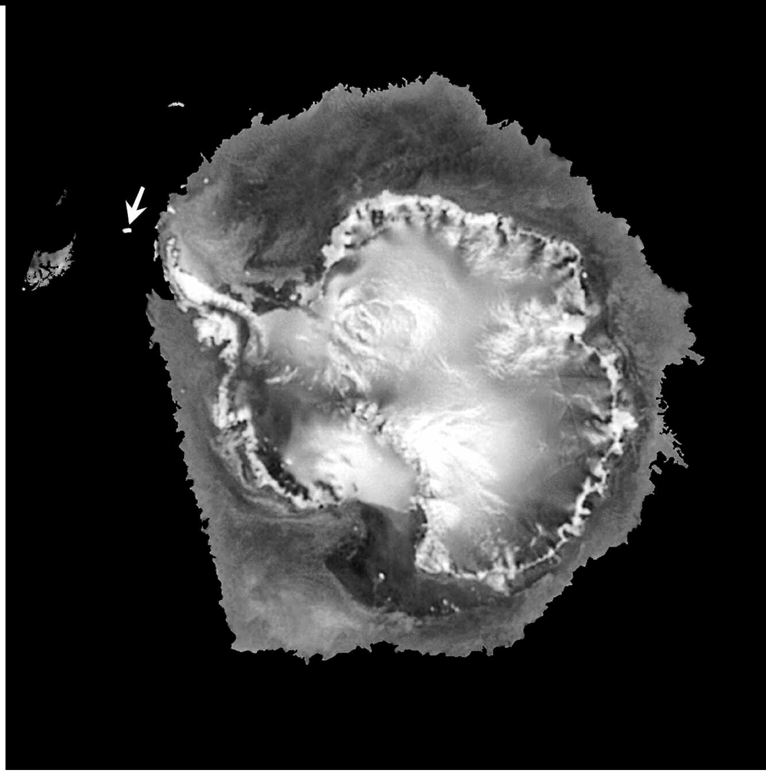
### A Glass Half Full

Where are we today? The glass is half full: the 2008 and 2009 U.S. federal budgets make a




*Will reduced snowfall and increased drought affect agriculture in already dry regions such as Australia, sub-Saharan Africa, and the western United States? Will wildfires become more frequent? Multiple massive wildfires burned in Southern California during the last week of October 2003.*

*Two views of the fires were imaged by the Multiangle Imaging Spectroradiometer (MISR) on NASA's* Terra *satellite. The nadir camera (left) took this true-color view, and the height of the plumes was measured by an automated stereo height retriever (right).* Images: NASA/GSFC/LaRC/JPL, MISR Team



*Earth science satellites, our "stethoscopes in space," provide the most effective means of listening to our planet and diagnosing its overall condition. The information they return also can help keep us safe and economically viable. The SeaWinds radar instrument on board NASA's* QuikScat *satellite took this image in 1999. Iceberg B10A (shown with arrow), which broke off Antarctica in 1992, had drifted into a shipping lane. This was the first time that space technology was used to track a potential threat to international shipping.* Image: NASA/JPL

solid down payment. The glass also is half empty, however: the out-year funding is at best "subprime," if not in default. I hope the next administration will have the foresight and courage to fill the glass, to create the needed Earth observation and information system. The challenges are real and growing.

Change is afoot, and change is rapid, more rapid than at any time in human history and perhaps at any time in Earth's history. We are seeing change across all the Earth's systems, including the human system. The accumulation and interaction of these changes, many caused by human activity, may well threaten both our species' and the planet's well-being. They are stresses from the natural variability of our dynamic planet, and they intersect with patterns of conflict, poverty, disease, and malnutrition.

We have profoundly changed the human-nature relationship, and these changes cascade through Earth's environment in ways that are difficult to understand and often impossible to predict. Surprises abound. At the least, these human-driven changes in the global environment will require that societies develop a multitude of creative responses and adaptive strategies. Some societies are adapting already; most are not. At worst, these changes may drive Earth itself into a different state that may be much less hospitable to humans and other forms of life.

The linked challenges of confronting and coping with global environmental changes and securing a sustainable future are daunting and immediate, but they are not insurmountable. The challenges can be met, but only with a new and even more vigorous approach to observing and understanding our changing planet.

In my view, there must be a concomitant commitment by all to alter our actions. Those who consume the most must take the greatest actions. We simply must take some of the pressure off Earth.

In 1969, Archibald MacLeish, on seeing the image of our planet rise above its moon, said, "To see the Earth as we now see it, small and beautiful in that eternal silence where it floats, is to see ourselves as riders on the Earth together, brothers on that bright loveliness in the unending night."

This image must inspire us even more now.

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