Space-based Observations of the Earth

In the wake of World War II, the US Naval Research Laboratory began experimenting with German-designed V-2 rockets as well as smaller, lighter launch vehicles called 'sounding rockets'. In order to monitor which way the rockets were pointing during their flights, scientists began putting aircraft gun cameras on them. During one of these flights, on 7 March 1947, the first space-based picture of Earth was taken at an altitude of 100 miles over New Mexico. In 1950, upon developing the film after another of these flights, scientist Otto Berg discovered a series of pictures of a huge tropical storm over Brownsville, Texas. He pieced the pictures together into a mosaic of the region enveloped by the storm, thus demonstrating the potential for space-based cameras to help us monitor our changing world (see also ROCKETS IN ASTRONOMY).

Interest quickly grew among the international community of Earth scientists in using sounding rockets to study the Earth's upper atmosphere. In 1952, the International Council of Scientific Unions proposed declaring 1957 the 'International Geophysical Year' (IGY) to satisfy a growing desire among scientists to expand the study of our home planet to include the whole Earth system and its surroundings. In 1954, the IGY committee challenged participating countries to launch a satellite as part of the IGY activities. On 29 July 1955, President Dwight Eisenhower announced that the United States would launch about six Earth satellites as a contribution to the IGY. On the following day, Premier Nikita Kruschev said the Soviet Union would also launch satellites during the IGY, and the race was on between the superpowers.

In October 1957, the Soviet Union successfully launched Sputnik I—a 22-inch spherical satellite weighing 175 pounds—into a low-Earth orbit. In January 1958, the United States successfully launched Explorer I, followed by the launch of Vanguard I two months after that. But the Russians' success and the United States' initial failures spread a sense of crisis in the latter country. The Americans declared space exploration a national priority, and in 1958 President Eisenhower asked his Science Advisory Committee to write a policy on space. Later that year Congress signed the act creating the National Aeronautics and Space Administration (NASA). Since then, NASA has played an international leadership role in developing and deploying satellite technologies for Earth observation.

A space-based perspective

The Soviet–American race to demonstrate technological superiority yielded a fortunate byproduct for Earth scientists—a newfound perspective from which to study our world. In 1959 the Russians, again followed closely by the Americans, launched the first humans into space. Looking back, the cosmonauts and astronauts saw the Earth as a tiny oasis of life—unique, as far as we know—adrift in a seemingly lifeless sea. Against the cold, black backdrop of space, these space pioneers observed how beautiful, how warm and inviting, and yet how small and fragile our world seemed. Looking closer, they saw changes occurring, some rapidly and some slowly, all over the planet. EARTH'S ATMOSPHERE seemed to almost boil with activity as clouds formed and dissipated daily. Vortices of violent storms raged across the surface. Changes on land were evident as volcanic eruptions and large wildfires sent plumes of smoke high into the atmosphere. At night, the extensive spread of humanity could clearly be seen as clusters of city lights outlining the Earth's habitable land masses. Outer space, scientists found, is an ideal perspective from which to observe and measure changes on our home planet as they happen.

In April 1960, NASA launched the Television and Infrared Observation Satellite (TIROS) into a mid-latitude orbit around the Earth. Followed later that same year by TIROS II, and by TIROS III a year later, these were the first satellites designed to study Earth's rapidly changing weather patterns. They collected and beamed back to Earth thousands of images of cloud cover as well as images of hurricanes, tropical storms and weather fronts that might have otherwise gone undetected for days using conventional methods.

Over the decades, the art and science of space-based observations of the Earth expanded and evolved. Scientists developed satellite 'remote sensors' that are sensitive to regions of the electromagnetic spectrum other than visible light, allowing us to observe things we would not ordinarily see. For instance, designing TIROS II and subsequent satellites to measure infrared light (basically heat) enabled scientists to produce 'false color' images of clouds at night. ('False color' images are made by assigning red, green and blue values to differing wavelengths of radiant energy.) In 1964, the TIROS design was succeeded by the more advanced Nimbus series of weather satellites, and NASA began to explore other orbit strategies for its spacecraft. The Nimbus satellites flew in near-polar, Sun-synchronous orbits, allowing scientists to piece their data together into mosaic images of the entire globe. Other satellites, such as the 1966 Applications Technology Satellite (ATS-1), flew in 'geosynchronous' orbits, where they had fixed views over roughly the same spots on Earth throughout their lifetimes. The ATS-1 provided images over the same areas progressively every 30 minutes, providing meteorologists with more updates of changes occurring in near-real time. In May 1974, NASA launched the first in the series of geostationary weather satellites, called SMS-1. In October 1975, NASA launched the National Oceanic and Atmospheric Association's (NOAA) first Geostationary Operational Environmental Satellites (GOES), each with a fixed and continuous view of the changing weather patterns beneath them. The GOES 8 and 10 satellites are still in operation, providing many of the daily weather images over North America that meteorologists display in their television evening news shows today.

Earth is a dynamic planet

Change is perhaps the only constant in our planet's history. Since the Earth's beginning about 4.5 billion years ago, natural climate and environmental conditions on our planet have been in constant flux. Solar variability, volcanic eruptions, meteor impacts, the emergence of life, the formation of an atmosphere rich in oxygen and greenhouse gases, changing ocean circulation patterns, wildfires—over the millennia these and other geological forces shaped an intricately intertwined global climate system that we are only just beginning to understand.

Fast forward to the late 1800s and witness the arrival of a new and profound force for change—humankind's Industrial Revolution. The Industrial Revolution not only ushered in a new era of prosperity for many, it also gave us the tools to dramatically reshape our environment. But the impact we are having on our environment appears to have set the wheels of climate change in motion at a rate not seen on Earth for millions of years. Over the last 100 years, the human population has tripled. In that time, we have consumed fossil fuels in increasing amounts to feed our rapidly industrializing economies, raising atmospheric carbon dioxide levels by 25 per cent. We have burned away forests to make room for our cities and roads, releasing carbon dioxide as well as eliminating trees that would otherwise be re-absorbing some of the gas from the air during photosynthesis. Over the last three decades, humans have burned more than 750 000 square kilometers of forestland every year. We introduced chlorofluorocarbons into the air, which destroy ozone in the stratosphere. Without its stratospheric ozone shield, the surface of our world would be exposed to the Sun's harmful ultraviolet rays, and life as we know it could not exist. Due, at least in part, to the rising levels of carbon dioxide, the average global temperature has risen by 0.5 °C over the last century, and some computer models predict it could rise another 1 °C over the next century. Already we see the polar ice caps melting at an alarming rate, while an average of two to three glaciers disappear worldwide every week. Geologists speculate that the US Glacier National Park will contain no glaciers by the year 2050. (See also GREENHOUSE EFFECT.)

What precisely are the causes of these changes? Which changes can be attributed to natural variability, and which are human-induced? How will these changes affect weather and climate patterns in the twenty-first century? How will climate and environmental change impact the quality of life for our grandchildren, and theirs? To help answer these questions and more, NASA developed a new series of satellite remote sensors, beginning with the Earth Resources Technology Satellite (ERTS) launched in 1972 (and later renamed Landsat 1).

From observing to measuring changes on Earth

Altogether, NASA launched a total of seven Landsats, the most recent, Landsat 7, was launched in April 1999. It and Landsat 5 are the only two of that series currently in operation. Since the first Landsat mission, the series' primary objective has been to measure changes on the land surface at high resolution. Whereas the first Landsat could collect images at about 65 m per pixel (at nadir), Landsat 7 can see the surface at resolutions as fine as 15 m per pixel. Such detailed imagery allowed scientists to find geologic features such as meteor impact craters previously undiscovered. Additionally, because healthy green plants reflect and absorb infrared light differently from dry brown plants, scientists found they could use Landsat data to monitor the health of croplands and forestlands over large areas. Landsat also provides an excellent data set for gauging the rates of deforestation, drying inland water bodies, expanding desert regions and sprawling urban centers. Researchers around the world routinely use Landsat data for these and myriad other applications.

In 1973, two researchers at the University of California, Irvine, published their theory that man-made chlorofluorocarbons (CFCs) could damage the Earth's stratospheric ozone shield. Two years later, Congress asked NASA to develop a 'comprehensive program of research, technology, and monitoring of phenomena of the upper atmosphere'. In particular, Congress' intent was to ascertain the 'health' of the ozone layer. In 1978, NASA launched the last of the Nimbus spacecraft series, Nimbus 7, carrying two new sensors called the Solar Backscatter Ultraviolet (SBUV) instrument and the Total Ozone Mapping Spectrometer (TOMS). Sensitive to radiant energy in the ultraviolet region of the electromagnetic spectrum, the Nimbus 7 sensors took advantage of the fact that molecules and aerosol particles reflect certain wavelengths of ultraviolet rays while ozone absorbs others at different levels in the atmosphere. By analyzing the amount of ultraviolet energy reflected back up to the spacecraft, researchers could produce profiles of how thick or thin the ozone was at different altitudes and locations.

But, ironically, the 'OZONE HOLE' over Antarctica was not discovered until May 1985, when a British researcher using a ground-based Dobson ozone spectrophotometer, found that stratospheric ozone over Halley Bay was about 40 per cent less than what had been measured during the previous winter. Surprised, NASA researchers hastily reviewed their TOMS data and found that it too had detected a dramatic loss of ozone over all of Antarctica. Why had they not they discovered the phenomenon earlier? Unfortunately, the TOMS data analysis software had been programmed to flag and set aside data points that deviated greatly from expected measurements, and so the initial measurements that should have set off alarms, perhaps years earlier, were simply overlooked. In short, the TOMS team failed to detect the ozone hole because it was much more severe than scientists expected.

In the years following the discovery of the ozone hole, NASA satellites recorded depleting ozone levels over Antarctica that grew worse with each passing year. In response, in 1987, 43 nations signed the 'Montreal Protocol' in which they agreed to reduce the use of CFCs by 50 per cent by 2000. In 1991, NASA's Upper Atmosphere

Research Satellite (UARS) mapped levels of chlorine monoxide in the stratosphere and quickly demonstrated that there is a direct link between the presence of chlorine, the formation of chlorine monoxide during winter in the Southern Hemisphere, and the destruction of ozone. Was a global disaster averted? Will levels of stratospheric ozone stabilize and return to normal in the coming years? We do not know yet, only time and more data will tell.

Towards predicting climate change

As we make the transition to the twenty-first century, the Earth's environment will be the focus of many agricultural, industrial, societal and political decisions. We recognize that we need more and better data to help us understand how current environmental change trends may impact climate years or even decades in the future. To collect these data, in 1991, NASA established the Earth Observing System (EOS) program in response to a US presidential initiative to provide in-depth scientific understanding about the functioning of the Earth as a system. The EOS charter is to collect, at a minimum, a new 15-year data set on which to base a long-term and comprehensive examination of our planet's climate system. EOS is a multinational endeavor comprising three parts: (1) a series of advanced satellite remote sensors; (2) a robust new computer network (called EOSDIS) for processing, storing and distributing EOS data; and (3) about 850 scientists working in many nations and in many Earth science disciplines who will use these new data in their research.

Already, NASA has launched four EOS spacecraft in the 1990s, including Landsat 7, QuikScat, ACRIMSAT and the EOS flagship, Terra, that was launched in December 1999. There are 15 more EOS satellites scheduled to launch through to 2003. Rather than focusing on individual disciplines, the data from these EOS satellites will be integrated into a more wholistic study of the Earth that includes seven overarching themes:

- radiation, clouds, water vapor, precipitation and atmospheric circulation;
- ocean circulation, productivity and exchange with the atmosphere;
- tropospheric chemistry and greenhouse gases;
- land ecosystems and hydrology;
- snow, ice and glacier extent;
- ozone and stratospheric chemistry;
- volcanoes and climate effects of aerosol.

With EOS, for the first time ever for a major Earth observation program, the goals include freely sharing the resulting data with both scientists and civilian organizations alike. This treatment of data contrasts sharply with previous satellite missions for which public access to data was quite costly. In fact, some EOS data are being directly broadcast to anyone anywhere who has a compatible receiving station and the capacity to process and store such a huge flow of information. As its name suggests, EOS is a large-scale, long-term collaborative mission involving scientists in government agencies, academia and industry from many nations.

Conclusion

Today, Earth scientists' goals are to not only observe weather patterns around our world, but to determine the causes and effects of climate and environmental change. With increasingly sophisticated satellite remote sensors, we can measure a wide range of geophysical parameters (such as surface temperature, distribution of clouds and aerosol particles, the abundance of trace gases in the atmosphere, or the distribution and types of life on land and in the ocean) with unprecedented accuracy and resolution. Moreover, we can now measure how changing certain aspects of the climate system (such as cloud cover) can have a 'ripple effect' through other aspects of the climate system (such as surface temperature, precipitation, the radiation budget). Scientists are feeding these new satellite data, collected throughout the Earth's climate system, into sophisticated new computer models that, ultimately, will enable them to predict climate changes months, years or even decades before they occur. If we are to become better stewards of our home planet—if we are to leave abundant natural resources to our grandchildren and to their grandchildren—then we must continue monitoring our planet with satellite sensors ever improving our understanding of how the Earth system works.

David D Herring and Michael D King