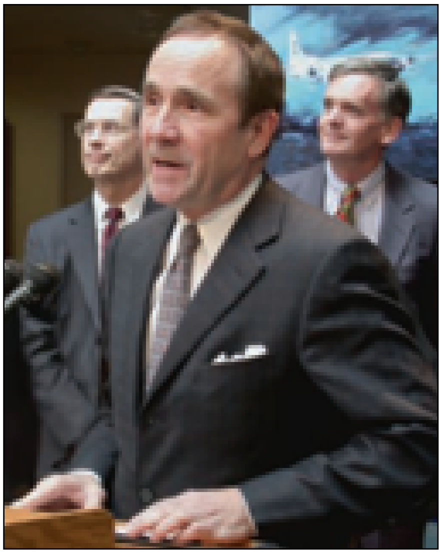
With NASA's Earth Observing System complete, climate researchers are facing a confused and perilous future

Stormy Forecast for Climate Science

On 15 July, a spacecraft bristling with instruments to measure Earth's atmospheric chemistry soared into orbit. The successful launch of Aura rounds out NASA's Earth Observing System (EOS), an ambitious multibillion-dollar effort to understand global climate. The three large EOS platforms launched since 1999 join nearly a dozen smaller U.S. satellites monitoring everything from the world's ice sheets to solar radiation. The flotilla of instruments has left researchers awash in data. But they are learning that data alone won't buy happiness.

Next week, as a group of senior scientists gathers on the coast of Massachusetts to debate the future of space-based earth science, the mood will be grim. Despite receiving nearly $2 billion in annual funding from the U.S. government, climate researchers say their discipline is in trouble. A fractious community has failed to come up with a clear scientific agenda, they say, and political support for climate change research is waning. The combination has created a deep crisis. "Earth scientists say they are fighting for their lives," says Berrien Moore, a biogeochemical modeler at the University of New Hampshire in Durham, who will co-chair the National Research Council (NRC) meeting in Woods Hole, Massachusetts.

The NRC meeting is an attempt to do for climate change what has been done for astronomy, planetary science, and solar physics: create consensus on a realistic, long-term blueprint for the field, including the most important questions to be answered and the tools needed to explore them. It won't be an easy task. Although NASA and the National Oceanic and Atmospheric Administration (NOAA) have requested the study, authority for climate research is spread among many federal agencies with different agendas. The topic draws researchers from innumerable subdisciplines—from geophysics to oceanography—and with vastly different needs. A white paper prepared by NRC staff and outside researchers for next week's gathering concludes that diffuse objectives and a lack of priorities have already left the program "marginalized and politically expendable."



"EOS has revolutionized earth sciences—but we can't fully appreciate it because we are inside the revolution."

—Berrien Moore, co-chair, NRC panel on space-based climate research

Point of the spear

That blunt assessment would probably have shocked the earth scientists who, a generation ago, conceived of EOS as a way to gather massive amounts of data for use in unlocking the mysteries of the complex global climate system. That vision became the centerpiece of a global change research program created by the U.S. government in 1990. The initial plan called for NASA to build and launch six massive platforms that, over 15 years, would gather simultaneous data on a host of ground, ocean, and atmosphere parameters.

Then reality intervened. Staring at an estimated $30 billion price tag for building and operating the system, NASA delayed and scaled back its plans. The result is three smaller platforms—Terra, Aqua, and Aura—plus other more modest spacecraft. Even so, EOS accounted for half of the government's $1.6 billion climate change program by the time the first satellite, Terra, was launched in 1999 (see graphic, p. 1097).

The size of a school bus, Terra's package of five instruments is examining land-surface changes, atmospheric aerosols, global cloud cover, and ocean temperatures. Aqua followed in 2002, with a half-dozen instruments measuring stratosphere temperatures and Earth's thermal radiation budget, among other parameters. Aura completed the trio of satellites in July with its focus on atmospheric chemistry. Each satellite is designed to run for 6 years, although each could last longer.

The trio's scientific output has been staggering. From delivering 17 terabytes of data in 1999, EOS is expected to approach a delivery of 1000 terabytes this year. Despite those impressive data rates, the earth sciences community is bitterly divided over whether EOS has been worth the investment. Answering this question will be a difficult but important part of the NRC panel's job.

Advocates argue that it is too early to judge the system's impact, given the years needed to first calibrate instruments and then sift through mountains of complex data. Moore contends that EOS "has revolutionized earth sciences—but we can't fully appreciate it because we are inside the revolution." He expects that in a few years the data will help scientists produce much better climate models based on a better understanding of how the land surfaces, oceans, and atmosphere interact.

And even if the science may be lagging, the EOS data system alone is a huge leap forward, says Lawrence Smarr, a computer scientist at the University of California, San Diego, and chair of the panel that advises NASA on earth sciences. It's the largest data system in use in the world, he says, and could pave the way for applications in many fields. "The EOS program has been at the point of the spear," he adds. "They've been the pioneers."

Critics, however, say that the NASA satellite and data system has failed to deliver on its promise to be a coordinated system providing long-term coverage. "EOS is an

CREDITS: (TOP TO BOTTOM) NASA/GSFC; K.DONAHUE/UNH-EOS

unmitigated disaster," says William Rossow, an atmospheric scientist at NASA's Goddard Institute for Space Studies in New York City. "I don't believe it has done much of anything." He and others insist that EOS is actually an expensive and haphazard bevy of instruments with relatively short lives. They fear that the vast majority of EOS data, produced at such a high cost, is not being used—and will never prove useful.

Few dispute, however, that satellites have given researchers a view of global systems that is far more sweeping than that obtained from in situ measurements taken on ocean buoys or balloons. But they have their foibles. Orbits decay and satellites drift. If an instrument measures temperatures in a region later in the day because of a change in orbit, for example, an apparent cooling trend may simply be a result of diurnal variation. As instruments become more sensitive, they also become more vulnerable to the harsh conditions of space. And calibrating instruments is still a painstaking process, which one scientist describes as "a black art." Satellites also have their limits; they cannot provide detailed views of the ocean depths or what's happening under Antarctic ice sheets.

Many of NASA's smaller, cheaper, and more focused earth science satellites of the past decade have won plaudits from researchers. They include the 7-year-old Tropical Rainfall Measuring Mission, whose fate is up in the air (*Science*, 13 August, p. 927); a joint U.S.-French ocean observing satellite called TOPEX/Poseidon; and a mission to examine the elevation of Earth's ice sheets. NASA's earth science chief Ghassem Asrar notes that his agency has plans for 10 new missions—although none is on the scale of EOS.

Just Say NOAA

At the heart of the debate is how to satisfy researchers' needs for long-term, accurate, and continuous data streams. A related question is which federal agency should take the lead role for that next generation of climate research. Asrar argues that NASA is in the business of providing research satellites, not long-term operational spacecraft. He suggests that NOAA, which operates U.S. weather satellites, is in a better position to take charge of a post-EOS observation program. "The problem is that NASA wants to move on, but we say we need 20 to 30 more years of records," says Mark Abbott, an oceanographer at Oregon State University in Corvallis.

Scientists also fear that earth sciences at NASA are no longer seen as an up-and-coming enterprise. Asrar was just named deputy for a new science office that subsumes the old independent earth science office created in 1992. "A lot of earth scientists are afraid astronomy will eat their lunch when their lunch is already a quarter-sandwich short," quips Charles Kennel, director of Scripps Institution of Oceanography in La Jolla, California, and chair of NASA's advisory council.

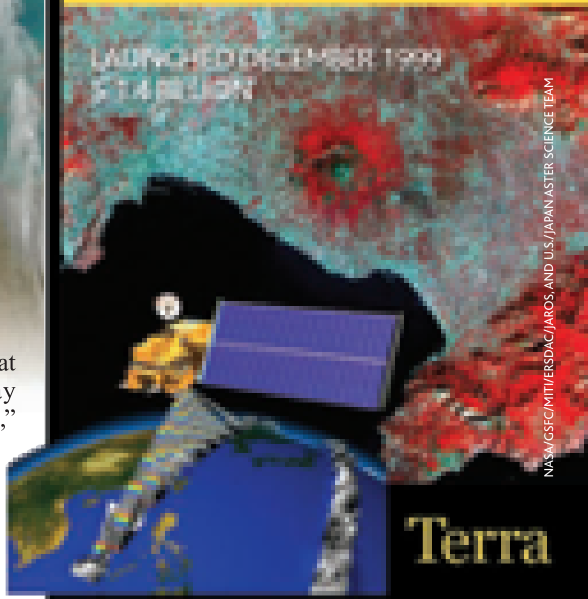
Meanwhile, the agency's budget for earth science is projected to decline from today's $1.6 billion to $1.3 billion in 2008. And earth science's star seemed to pale further in January, when President George W. Bush told NASA to focus on astronaut missions to the moon and Mars. "If the Bush initiative goes somewhere, earth science will take it on the chin," predicts John Townsend, former director of NASA's Goddard Space Flight Center in Greenbelt, Maryland.

NOAA Administrator Conrad C. Lautenbacher Jr. says his agency is ready and willing to take on the job of continuous climate monitoring. He sees that task as a natural extension of NOAA's long history of monitoring the weather, although he acknowledges that "I don't believe the process we have today is optimal." But weather and climate science are not the same, say researchers, many of whom are skeptical of NOAA's ability to come up with the money and expertise to take over climate monitoring from NASA.

NOAA's first big step into the field will be the National Polar-Orbiting Environmental Satellite System (NPOESS). A decade ago, NOAA and the Defense Department agreed to merge their two weather-monitoring systems, and the first of the $7 billion series is slated for launch by 2010, around the time EOS is winding down. Originally slated to be solely a weather satellite, NPOESS has added climate elements as well.

In part to smooth the transition from EOS's research instruments to an operational system, NASA and NOAA plan to

CREDIT: (TOP) NASA/GSFC



NASA/GSFC/MIT/ERSDAC/JAROS, AND U.S./JAPAN ASTER SCIENCE TEAM

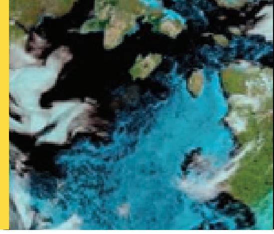
Mount Vesuvius reigns over Italy's west coast in this view from a Terra instrument, one of five examining a wide range of earth, ocean, and air parameters.

JACQUES DESCLOITRES, MODIS RAPID RESPONSE TEAM, NASA/GSFC

This glimpse of last fall's forest fires in southern California comes from one of six instruments monitoring clouds, atmosphere, humidity, and sea-surface temperatures.

NASA/GSFC

Scientists are still calibrating the five instruments that will probe Earth's atmosphere, including the Antarctic ozone hole.


Fields of sea ice melt in northeastern Canada's Hudson Bay


U.S. coastal areas along the Gulf of Mexico

launch NPP—the NPOESS Preparatory Project—in 2006. The spacecraft will include four instruments derived from EOS. Greg Withey, who manages NOAA's satellites, says that "climate will get a nice ride" with NPP and NPOESS. And NASA's Asrar says the satellites will provide climate researchers with a continuity of data beyond EOS—as well as sufficient overlap to calibrate delicate climate instruments.

But many researchers hotly dispute Asrar's assertion. "He is changing facts to fit his view," complains Richard Goody, a Harvard University emeritus climate researcher. "Weather and climate systems are different." Weather work typically requires high-resolution images without the absolute accuracy and stability that climate researchers say they need to do their jobs. Whereas a weather forecaster has little need to store data, climate researchers depend heavily on an organized and accurate long-term database. And weather and climate needs can conflict. For example, some EOS spacecraft are rolled in orbit so they can spot the moon and use it to calibrate delicate climate instruments. Although NASA is willing to take such risks, Withey admits that such a maneuver might be too dangerous for an operational satellite critical for national weather forecasting.

Researchers are convinced that the needs of the weather program inevitably must trump those of climate. "There's a lot of angst about NPOESS," says Bruce Wielicki of NASA's Langley Research Center in Hampton, Virginia. "It is not actually tasked to do climate." And scientists' skepticism extends beyond NPOESS itself. They fear that NOAA—part of the U.S. Commerce Department—is ill equipped to handle the expensive and long-term task of climate observation. NOAA's $3.3 billion budget is less than one-fourth the size of NASA's, and it lacks a lab like the one at Goddard, which manages EOS, with the necessary talent and resources to handle a complex environmental research data and satellite system. "NOAA is the problem," says Goody. "It has the mandate" on climate, he adds. "But it is not really a good research agency."

Wielicki also wonders who will pay for the extensive ground-based research, information systems, and infrastructure that NASA currently funds. "NOAA spends very little on these now," he says. "I hope we can find a way to work with NASA and maybe the National Science Foundation." Others suggest that NASA and NOAA should share Goddard's facilities to smooth the transition from NASA's research satellites to an operational system run by NOAA. Getting agencies to cooperate more closely, however, will be difficult, and researchers fear that their needs will fall through the government cracks.

Cats and dogs

But eliminating the confusion about agency roles won't resolve all the problems plaguing climate researchers. "I don't think the community has produced plans and programs which can be funded and supported," says Lautenbacher. Adds Asrar: "There has been an absence of unified support in the [scientific] community." Both men say they want earth scientists to come up with a clear list of future missions that federal agencies and Congress can support.

Part of the problem is that climate research remains a fragmented business. Rossow maintains that the vast majority of research is actually old-fashioned earth sci-

Stitching Together a Global System of Systems

Keeping an eye on the planet is no simple task. NASA alone is currently flying 15 satellites designed to understand various aspects of the Earth system. Europe and Japan also have large spacecraft carrying out climate research, and there is a fleet of weather satellites operated by countries including India and China. And that's only what is in space: Many nations also deploy ocean buoys, balloons, and aircraft to gather additional climate and weather data on everything from atmospheric temperature to deep-ocean currents.

Scientists have long dreamed of flowing together these many rivulets of data to create a common stream from which all climate researchers may drink. And last summer in Evian, France, leaders of the eight richest nations pledged to create a comprehensive, continuous, and coordinated system of global observation systems. Since then, 50 nations—from Argentina to Uzbekistan—have signed up to take part in what Charles Kennel, director of Scripps Institution of Oceanography in La Jolla, California, calls "a remarkable and profound event."


Slow going. NOAA's Conrad Lautenbacher is working on a coordinated plan for Earth observation.

In February, ministers from around the world will gather in Belgium, the third such meeting since the one in Evian, to draw up a 10-year plan to coordinate observation plans, involve developing countries in data gathering, and exchange all data quickly and openly. But many researchers, frustrated by what they see as a lack of progress, fear that the entire exercise is part of an attempt by U.S. President George W. Bush to talk about climate change rather than take action. They also worry that further delays will produce a proliferation of redundant instruments and a chaotic sea of data. "How can this work when U.S. agencies aren't even able to coordinate?" asks Kevin Trenberth of the National Center for Atmospheric Research in Boulder, Colorado. Adds another climate researcher: "They've just created a new acronym and a new committee."

Such cynicism is unwarranted, says Conrad C. Lautenbacher Jr., chief of the National Oceanic and Atmospheric Administration (NOAA), which is the U.S. representative to the talks. The mere presence of so many high-level officials shows that governments are taking the issue seriously, argues NOAA's Greg Withey, who is in charge of satellite systems. "You don't get 40 to 50 ministers coming to a conference just because they like to travel," he says. But Withey predicts "it is going to take another year" to come up with an approach that will iron out the technical difficulties of creating common data sets and calibrating instruments.

Withey says that by the end of this year, NOAA will have a plan for U.S. observation strategy for the next decade to present at the February meeting. Japan is working on its own document, and Europe has just wrapped up work on a global system that combines environmental and security monitoring. –A.L.

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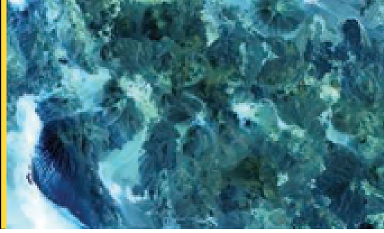
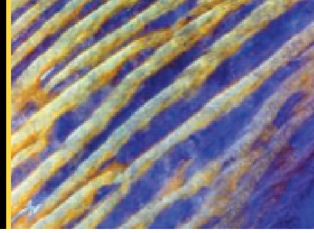
A stretch of the Yangtze River in China, including the Wu Gorge



Volcanoes along the Chilean-Argentinean border



A great sea of linear dunes in Saudi Arabia

ence in disguise. He says that scientists, instead of working on a problem such as how clouds interact with radiation, aerosols, and general planet circulation, too often simply extend previous work on cloud physics. "Our community blinds itself if it thinks it is doing climate," he says. Goody agrees that the community jumped on climate research because that is where the money is and that it has failed to transform itself into an interdisciplinary powerhouse. Unlike an area such as systems biology, climate research remains too focused on small-scale issues, he and others say.

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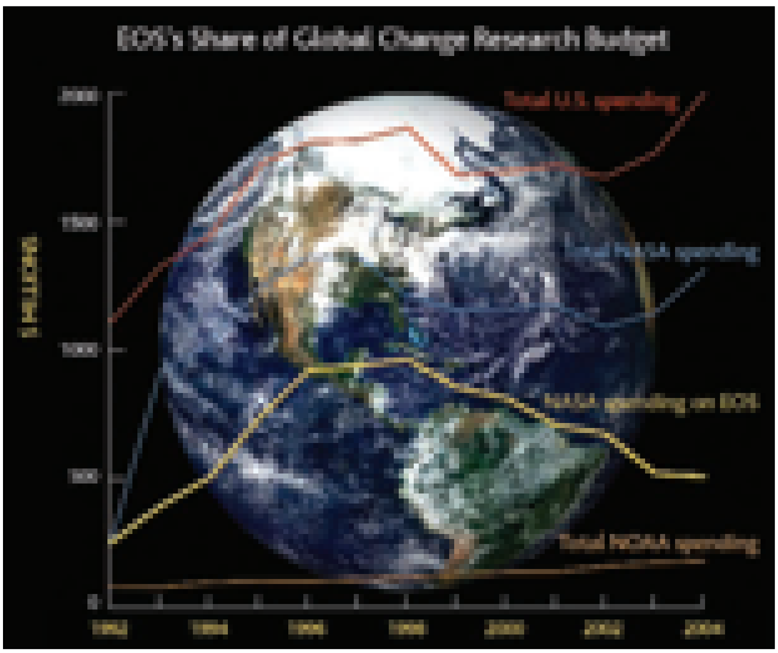
> —William Rossow, NASA Goddard Institute for Space Studies

Kevin Trenberth of the National Center for Atmospheric Research in Boulder, Colorado, recalls being "astonished and appalled" to learn that members of different Aqua instrument teams were not communicating with one another, although one of the reasons for launching several instruments on one platform was to compare simultaneous data. "We have a pile of numbers," says Rossow. "But we need a structure to take these measurements and analyze them."

Wielicki says that taking the necessary interdisciplinary approach is tough work. To understand the global radiation budget, for example, his team is using 11 instruments on seven spacecraft. "It's a huge job," he adds, despite the fact that they have data from an instrument that flew before EOS. "Other fields in most cases are doing this for the first time." The diverse interests of earth scientists complicate the picture. "We're not like the astronomy community; our disciplines range from solid Earth to upper atmosphere to weather, climate, ecosystems, and oceanography," says Richard Anthes, president of the University Corporation for Atmospheric Research in Boulder, Colorado, who is co-chairing the NRC panel with Moore. In the past few years, astronomers, solar system researchers, and solar physicists reached consensus on long-term plans and priorities for their respective fields. But reconciling the many and competing desires of climate researchers is a formidable task. Says Anthes: "The challenge is to hold this community of cats and dogs together."

Climate awakening

Both NASA and NOAA want the NRC panel to review recent advances in Earth-system science, pose the principal scientific questions that need answers, and suggest which measurements and systems are needed. "We've got the foundation. We've got to figure out what kind of house we are going to build," says Moore.



Lion's share. NASA's EOS budget has consumed the largest single chunk of U.S. Global Change Research Program funds since the early 1990s.

A central question is how to create and deploy a climate-observing system that can provide consistent and accurate data. Moore, Trenberth, Thomas R. Karl, director of the National Climatic Data Center in Asheville, North Carolina, and Carlos Nobre, director of Brazil's Center for Weather Forecasting and Climate Studies, recently proposed a climate observation and data system that would tie together all the world's environmental satellites, along with in situ data, a global telecommunications network, comprehensive models of the land, ocean, and atmosphere, and a center to monitor data quality.

Karl says the space portion of such a system could instead use existing capabilities from many nations (see sidebar). Wielicki, however, estimates that a complete climate satellite system could cost $5 billion to $10 billion annually—more than triple what NASA now spends on Earth observation.

Given the U.S. political climate, such an investment, even with contributions from other countries, seems highly unlikely. "What a waste of money! What would you do with the knowledge?" says one congressional aide. Whereas fiscal conservatives would attack any massive new research program as unaffordable, liberals are likely to see it as a ruse to delay action on the underlying problems that are causing global warming. Congressional "enthusiasm has waned," adds the congressional aide. "It doesn't seem at all sexy or interesting."

A clear and comprehensive vision statement might help persuade skeptical politicians, says Withey. But Goody and others aren't convinced of the need for a bigger budget, especially with the trend toward microsatellites and miniature instruments. "The money in global change research is ample for what we need to do," says Goody.

Given these longstanding problems, climate researchers aren't sure how to regain the enthusiasm and high hopes of the early 1990s. Wielicki fears that it will take a disaster—"a really bizarre weather event such as a Category 6 storm or a falling ice sheet"—to alert the public and the politicians to the perils facing the planet. Without such a catastrophe, earth scientists will have to find another way to make their case that understanding climate change is every bit as important as finding life on Mars or warning citizens of an approaching hurricane.

–Andrew Lawler

CREDITS: (TOP TO BOTTOM) USGS; NASA GSFC, MITI, ERSDAC, JAROS, AND U.S./JAPAN ASTER SCIENCE TEAM; SOURCE: NASA/NOAA