REMOTE SENSING

Earth Scientists Look NASA's Gift Horse in the Mouth

In 1989, the National Aeronautics and Space Administration (NASA) made what looked like a historic about-face, turning its sights from outer space to the troubled home planet and embarking on a vast program designed to monitor the effects of climate change on Earth's atmosphere, land surface, and oceans. The initiative was known as the Mission to Planet Earth, and Shelby Tilford, director of NASA's Earth Science and Applications division, called it "without doubt the largest science program the agency has ever undertaken." Its centerpiece was to be the Earth Observing System, or EOS, a group of 30,000-pound space platforms that could cost as much as $30 billion to build, launch, and operate. Once aloft, the platforms would beam home 1 trillion bits of data each day on everything from the flux of solar radiation into the atmosphere to the growth of plankton beneath the ocean surface.

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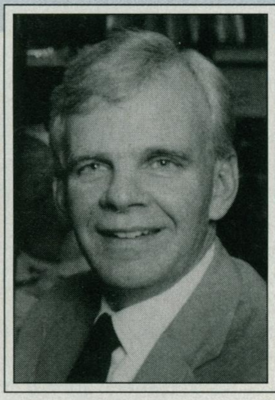

Having been awarded a chunk of NASA second only to the space station in cost, earth scientists were less grateful than one might have expected. Indeed, the EOS program was launched into a storm of controversy, which, rather than dying away, has grown more raucous over time. Critics suggested that in planning EOS, NASA was committing itself to a grandiose space program that would gather huge amounts of undigestible data. Furthermore, they argued, the huge cost of EOS would inevitably squeeze out funding for other—perhaps more worthy—efforts at climate monitoring.

What's needed to make informed policy decisions on global climate change, they say, is long-term, continuous monitoring of crucial climate variables—something that has been deferred until EOS gets aloft. "If we start now," says Ram Ramanathan, an ocean and atmospheric scientist at the Scripps Institution of Oceanography, "it will still take 10 years [to understand what's happening]. The longer we delay, the longer it will take." Targeted studies of atmospheric change from aircraft and from the ground, says Jim Anderson, an atmospheric chemist at Harvard University, have also been slighted in favor of "a drawn-out program detached from the reality of how rapidly the earth is changing."

Now, just 3 years after the announcement of the program, EOS's budget through the end of the century has been trimmed from $17 billion to $11 billion to $8 billion, and NASA has modified the program in response to critical reviews. Says remote sensing specialist Jeff Dozier of the University of California, Santa Barbara, the former chief scientist for EOS, "What we've got at $8 billion is a pretty good program that addresses a whole suite of issues of global change." The downsizing hasn't mollified the critics, though. They say NASA hasn't really rethought the mission—and the amount of money involved is still big enough to forestall other climate monitoring efforts. In fact, NASA seems to be caught in the Catch-22 of big science in a fiscally frugal world: As the EOS budget shrinks, diverting money to beef up the in situ monitoring program or fund other satellites would in turn delay progress on EOS—and boost its cost. All in all, says Ralph Cicerone, president of the American Geophysical Union, "the scientific community and NASA have a real problem with EOS."

Cicerone and other critics trace the size and priorities of EOS to its origin in a political alliance forged in the early 1980s between NASA's manned space program and its science program. By 1982, the NASA administration had concluded that the manned space station was "problematic for science," in the words of NASA scientist Dixon Butler, who was responsible for EOS planning. To gain scientific support for the space station project, says University of Michigan planetary scientist Thomas Donahue, who chaired the National Research Council (NRC) space science board in the 1980s, NASA made a tempting offer. The agency convened a group of earth scientists to ponder how they might use large, unmanned satellites in low Earth orbit and offered to fund the design of the platforms—then known as System Z—out of the space station budget.

The System Z researchers then developed a plan to exploit the platforms scientifically. "That gift," says Donahue, "was merged with the developing ideas about putting a lot of Earth observing remote sensing instruments on a single platform." As Butler explains it, the guiding idea was that understanding the complex relationships of the global environment required a satellite-monitoring program that would measure, in essence, everything it could. "The space station gave us the optimism for the first time to think of a mission that addresses the comprehensive earth science need."

In particular, the System Z researchers saw the opportunity for a style of measurement that came to be called simultaneity. The complex relationships among climate variables like air and surface temperature, humidity, cloud reflectivity, and vegetation would emerge most clearly, they reasoned, if all the variables could be measured at the same time and place. Mounting a large set of instruments on the same orbiting platform offered an opportunity to do just that.

The Mission to Planet Earth was born when that plan was in effect endorsed by the Earth Systems Sciences Committee (ESSC), a panel of scientists appointed by a NASA advisory council and chaired by Francis Bretherton of the University of Wisconsin. The ESSC, which included several System Z researchers, seconded the need for "a highly integrated suite of new measurements with new instruments" and agreed that the best way to do it was "a sustained program of large platforms." The ESSC report became EOS's operative scientific document in 1989, when NASA sent out an announcement of opportunity for the Mission to Planet Earth.

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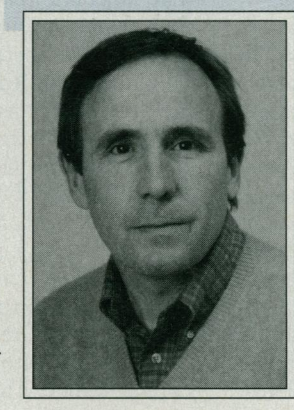


After its birth in 1989, the project consisted of two 15-ton platforms, each carrying 12 to 15 instruments to monitor Earth's atmosphere and surface. Each platform would ride a huge Titan 4 rocket into a polar orbit, from which it could scan the entire world as the globe rotated below it. The launch of EOS-A was scheduled for 1996, and EOS-B would go up 2 years later. The platforms had 5-year design lifetimes, after which new versions would be launched.

Outsized ambitions? In retrospect, Bretherton admits to reservations about the scale of the program that his committee blessed. His committee, he says, "was probably as guilty as everyone else of putting forward a scientific program that was overambitious."

And from the beginning, EOS's critics expressed the same reservations, but more strongly. As Jim Anderson puts it, "The idea that gathering data is equivalent to solving problems is a fallacy. You can collect huge amounts of data, but if those are not carefully matched to problems, then the data just gather in databanks and you make no progress." The critics also warned that EOS was in danger of collapsing under its own complexity. It would have a better chance of surviving budget vagaries if it were less ambitious. In particular, they advocated a multitude of small, cheap satellites aimed at specific climate change questions (*Science*, 16 June 1989, p. 1248).

Some NASA researchers, though, see pitfalls in such a focused approach. Nobody knows what surprises might emerge in the course of global change, they say, and a targeted research program would be in danger of missing them. As Dozier puts it, "What we haven't done [in planning EOS] is ask a question and design an instrument to answer that question. What we have instead tried to do is design instruments with a range of measurement capabilities so they can answer a lot of questions, some of which we haven't been smart enough to ask yet." In 1990, an NRC review lent its support to that strategy, although it recommended that EOS be limited to a single large platform.

But the EOS vision collided with fiscal realities in 1991, when the Senate trimmed the EOS budget from $17 billion through the year 2000 to $11 billion. In response to the budgetary squeeze, the White House convened a panel of outside experts, unaffiliated with NASA or EOS, to do an engineering review of the program. The panel, led by Ed Frieman, director of the Scripps Institution of Oceanography, concluded that EOS in its original grand form could hardly be maintained under the lowered budget ceiling. Indeed, EOS had been straining against even its original budget. The mass of the instruments alone, for example, had grown by 16% just between 1990 and 1991, with concomitant increases in cost. According to physicist Greg Canavan of Los Alamos, a Frieman panel member, the governing philosophy of the EOS investigators seemed to be to design instruments "worth their weight in gold" rather than compromise on specifications that were technologically optimistic. Or, as Dixon Butler put it: "We tried to stick to our guns toward quality of measurement."

The panel recommended a sharp change of course. Its first target was the plan to mount all the instruments aboard the same platform. The rationale for doing so had been simultaneity, but the panel demonstrated, with the help of NASA's Robert Watson, who heads the research and analysis program, that by flying two of the key instruments on both EOS-A and EOS-B, while dropping or deferring less essential instruments, simultaneity could be maintained, fewer instruments could be stacked on each platform, and the platforms themselves could be considerably smaller.

Smaller platforms, the panel went on to argue, could be developed and flown more quickly, and there would be less to lose in a single accident or malfunction. What's more, dividing up the instruments into smaller sets, which could be sped up or delayed with less effect on the rest of the program, would make the program as a whole much more resilient in the face of unexpected budget changes (*Science*, 27 September 1991, p. 1481). EOS as originally planned, says Frieman panel member Peter Banks, dean of the school of

The Sad Saga of Small Satellites

While the massive EOS program lumbers toward its first scheduled launch in 1998, many global change variables are going unmonitored (see main text). So why not fill the gap with a separate program of simpler, cheaper satellites to monitor such things as atmospheric aerosols, water vapor, clouds and the radiation budget? Good idea, many NASA advisers have said. But a combination of NASA's reluctance and agency tug-of-wars seems likely to keep the small satellites grounded.

Although researchers had been pushing for such satellites for years, they didn't emerge as a formal proposal until Jim Hansen of the Goddard Institute for Space Studies articulated the need in a "roundtable" discussion in January 1990, called by then-Senator Al Gore of Tennessee and Maryland Senator Barbara Mikulski. Hansen's suggestion grew into a formal proposal, requested by Gore, for what he calls Climsat. Hansen envisioned a pair of relatively inexpensive satellites that between them could monitor all the necessary variables and could be built, launched, and operated for 5 years for a total of $350 million. Replacement satellites could then be sent up for as little as $40 million each.

The relevant scientific community is firmly behind the Hansen proposal or something like it. Atmospheric chemist Jim Anderson of Harvard, for instance, says Hansen is "dead on the mark." Francis Bretherton of the University of Wisconsin, who headed a committee that laid out the scientific mission for EOS, regrets in hindsight that his committee didn't place a high priority on a small satellite program similar to Hansen's. And Ed Frieman of the Scripps Institution of Oceanography, who headed a later EOS review, says his panel liked the general idea of small satellites.

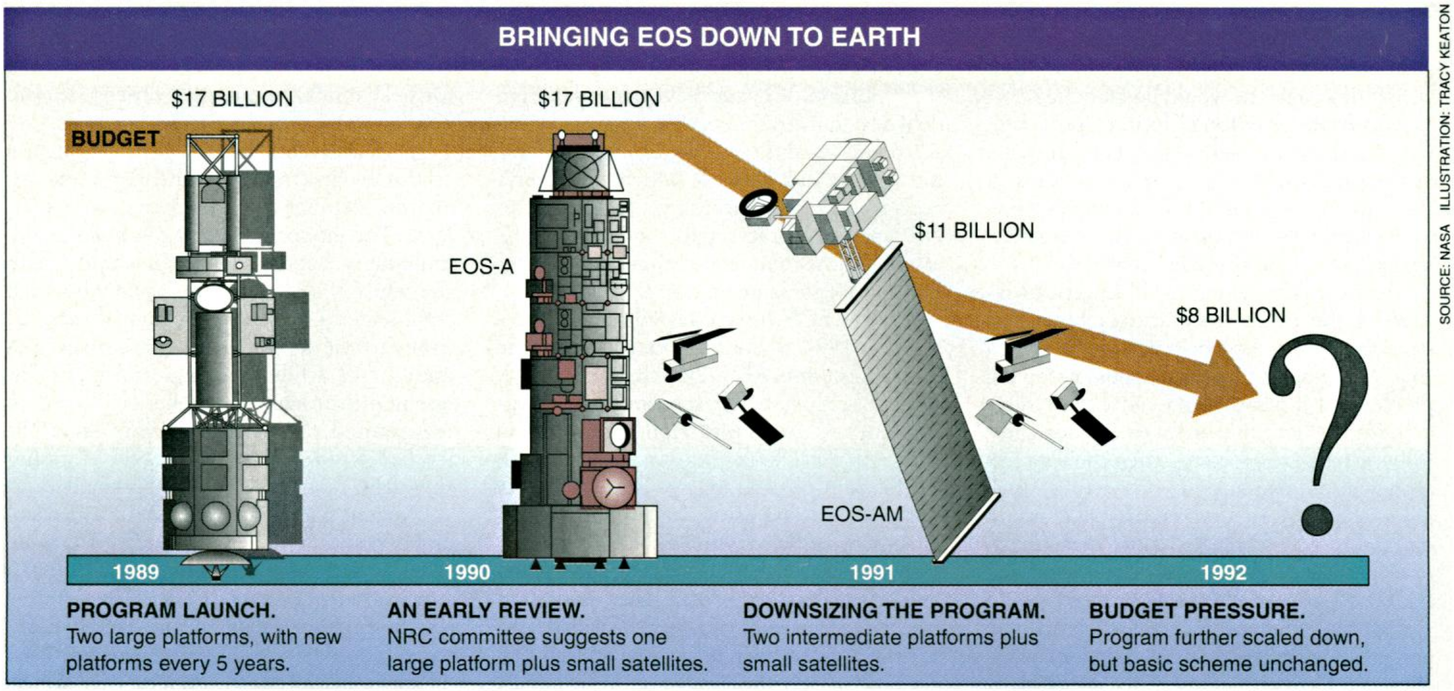
Even so, NASA rejected Hansen's proposal in the summer of 1991. Berrien Moore, an EOS scientist, argues that, with EOS, NASA is doing most of what Hansen recommended anyway—albeit on a later schedule. He points out that NASA has scheduled CERES, an instrument that would study clouds and the radiation budget, to fly on both of the large EOS platforms. And he adds that if NASA can manage to advance the flights of an instrument called SAGE III—the Stratospheric Aerosol and Gas Experiment—into the same time frame as the first two EOS satellites, then "we would in effect implement most of Climsat, the heart and soul of it, just on the regular EOS program."

The Office of Management and Budget (OMB) still saw a gap that could be filled by a small-satellite program like Hansen's, and last February it tried to take the situation into its own hands. According to Jack Fellows, OMB's branch chief of space science programs, OMB had a commitment from the Bush Administration for $100 million to fund a small climate satellite, provided it could be launched by 1995. But NASA, the Defense Advanced Research Projects Agency (DARPA), and the Department of Energy (DOE) asked that OMB postpone an open competition, claiming that, working jointly, they could deliver a satellite for less money and in less time then the OMB requirements specified.

As Fellows tells it, "We reluctantly waited, which in hindsight was a real mistake. Suddenly it became a little bit of a contest. First NASA brought in its own proposal. This was followed by bickering back and forth over who would do the mission." When it came time in September to submit the 1994 budget, he recalls, NASA submitted no proposal and the DOE, NASA, and DARPA triad fell apart. They had made "absolutely no progress."

Now, says Fellows, it's almost too late. It would be hard to get any satellite up before 1996, and EOS is scheduled for 1998. "It may not be worth $100 million for a gap-filling instrument," he says. In space-based climate monitoring, EOS is still the only game in town.

–G.T.



engineering at the University of Michigan, "was tying up the whole infrastructure of atmospheric monitoring into a direction that didn't give much flexibility."

The panel didn't just focus on logistics, however. It also criticized the EOS philosophy, saying the perception of EOS as solving all questions of global change had "led to distorted priorities." Frieman and his colleagues recommended that even as the platforms were downsized, EOS's scope should be broadened. They called for expanding the program to include "science-driven process studies using small and intermediate-sized space systems, remotely piloted aircraft, in situ and ground-based programs." The panel also endorsed the notion, popular among global change researchers, of a series of small satellites that could go up quickly to "fill critical gaps" until the EOS platforms were ready to fly (see box).

NASA responded to the budget cuts and the Frieman review—which Dixon Butler calls a "sufficiently painful" experience—with a March 1992 proposal for flying the EOS instruments on two downsized platforms, now called EOS-AM and EOS-PM, followed by four small satellites, which would carry key instruments that didn't fit on AM and PM. An EOS payload panel report described the new configuration as "a minimum set of instruments to pursue the focused objective of global climate change."

NASA scientists say they've responded to the "Frieman solution" as requested. But members of the Frieman committee disagree. As one panel member put it, "They just took the old EOS and tried squeezing it down." NASA rejected the recommendation for generic, small, cheap satellites to be launched by 1995, saying that the costs of building such satellites would only delay the launch of EOS. Panelists also think that NASA hasn't followed their recommendation to focus EOS on the most urgent scientific questions.

A case in point, they say, is the order in which the platforms are to be launched. Frieman's experts urged that EOS-PM, which is aimed at studying global warming, be launched before EOS-AM, which is geared toward terrestrial ecosystems. The panel's logic, says Frieman, was that the most pressing issue of global change is global warming. Yet under NASA's latest schedule, which calls for EOS-AM to go up in 1998 and EOS-PM in 2000, studies of global warming could easily fall by the wayside if the budget were cut further. As Frieman puts it, "You'd get EOS-AM up there, and it was not clear when the hell you were ever going to get PM up there."

But the program's complex logistics made it unwise to change course, NASA administrators argued. AM was less technologically ambitious and therefore less like to be delayed by technical problems. Equally important, as they explained to the panel and to Congress, Japan was providing the single most expensive instrument. Thus AM was cheaper than PM and more likely to meet the 1998 launch target, a date Congress was now insisting on. What's more, explains Peter Backlund, NASA's assistant director of earth science, General Electric was in the process of designing the original large platforms, and when EOS was downsized the agency decided "to stay with GE for the first platform, EOS-AM, or else we would miss the launch date." EOS-PM doesn't yet have a builder.

History repeats. This year, Frieman and his fellow panelists watched with a sense of déjà vû as EOS again escaped a thorough revamping, in spite of new budgetary pressure. Last summer, when new NASA administrator Daniel Goldin set about slimming his programs by 30%, the EOS 8-year budget was cut again. Now it is down to $8 billion, a number confirmed by Congress. As a result some EOS instuments have been scaled down and others have been deferred or dropped. But the same basic satellite package remains.

Meanwhile, to keep EOS on schedule—and on budget—NASA has had to squeeze other parts of its earth science program. NASA requested—and received—all of the $440 million requested for EOS and its accompanying data information system, a $120 million increase over the 1992 budget. Anything less, say Backlund and other NASA officials, would delay the program and ultimately result in higher costs. Meanwhile, NASA's research and analysis program, which Watson describes as paying for "all the stuff that you can't do from space—the life blood of the university scientist," was less fortunate: NASA requested $174 million for the program, down from $200 million in 1992. It received only $159 million when $15 million was extracted to pay for the operation of satellites in orbit.

But none of those maneuverings will head off the need for a thorough rethinking of Mission to Planet Earth if the budget gets much tighter. Even Berrien Moore of the University of New Hampshire, who is head of the EOS payload panel, agrees that it would then be time "seriously to consider radically rescoping the mission." As a result, says Frieman panel member Warren Washington of the National Center for Atmospheric Research, "NASA is going to be facing major decisions in the first year of the new administration, and how much money it puts into Mission to Planet Earth to carry out monitoring and research is a real big question."

–**Gary Taubes**