## Could Plants Help Tame the Greenhouse?

It's easy to see how climate change might affect the globe's vegetation, driving hardwood forests into regions now covered with evergreens and causing deserts to shift (see main text). It's less easy to picture the other side of the coin: biology's impact on the atmosphere. So mathematician Berrien Moore III of the University of New Hampshire, who heads the International Geosphere-Biosphere Program task force on global analysis, interpretation, and modeling, staged a simple demonstration. He modeled the effects of a biosphere "fertilized" by increased $CO_2$—and found that it could first help, then hinder, human efforts to slow the buildup of greenhouse gases.

There are signs that increased plant growth may already be affecting the course of global change. Only about half of the 7 billion or so tons of $CO_2$ emitted each year by human activity remains in the atmosphere. About 2 billion tons seem to be soaked up by the oceans, leaving at least a billion tons unaccounted for (*Science*, 3 April 1992, p. 35). Support for the idea that the missing carbon dioxide is fertilizing greater plant growth—which then stores up the carbon—comes from studies of the seasonal rise and fall of $CO_2$, as growing plants "inhale" carbon in spring and summer and decaying leaves "exhale" it in autumn and winter. Since the mid-1960s the amplitude of those cycles has been increasing, suggesting a larger total biosphere.

To simulate such a biotic carbon "sink," Moore combined a simple model of $CO_2$ uptake by the ocean with an equally simple model of its uptake by photosynthesis on land and its release by deforestation and plant decay. He then "forced" this simple ocean-atmosphere-vegetation model with fossil fuel $CO_2$ emissions from 1860 to the present. As expected, his model ended up with too much carbon in the atmosphere. So he turned up photosynthesis, fertilizing plant growth in his model, until the rate of $CO_2$ buildup just matched the observed increase.

Moore then explored how this terrestrial carbon sink would respond if the $CO_2$ buildup slowed. The result: "If you were to cap the rate of $CO_2$ emissions from fossil fuel burning, [this terrestrial] sink would reduce the atmospheric lifetime of $CO_2$ by a factor of four or five." This cleansing effect would operate on timescales of years or decades, compared with centuries for the ocean, says Moore—fast enough to aid human efforts to slow the $CO_2$ buildup. "However, it doesn't do it forever." If at some point emissions cuts and the terrestrial sink succeeded in reducing atmospheric $CO_2$, plant growth would drop and $CO_2$ levels would bounce back up as all the extra biomass rotted away. That makes $CO_2$ fertilization a mixed blessing for those who would slow climate change, Moore observes.

–Y.B.

simplifying assumptions must be calibrated with real data. And that accounts for another major topic at the meeting: a series of large-scale field experiments by IGBP scientists on the interplay between vegetation and climatic factors such as carbon dioxide, temperature, and moisture.

One example discussed in Ensenada: the ongoing Long-Term Free-Air $CO_2$ Enrichment (FACE) experiments, in which a system of pipes and pumps is used to bathe a small patch of a natural ecosystem with an atmosphere containing double today's $CO_2$ concentrations. Existing efforts to describe the response of vegetation to a rise in $CO_2$ have to rely mostly on the results of short-term experiments done with individual plant species in greenhouses. But how much of a boost in plant growth would be seen in a real ecosystem depends on the mixture of species, which of the two photosynthetic pathways most of the plants use, and the availability of light, water, and nutrients, notes ecologist Harold A. Mooney of Stanford. Such complexities can be studied only in a real ecosystem.

The global change specialists gathered in Ensenada were well aware, however, that the biosphere isn't all green. There's another factor in global change: people, who are transforming the landscape as dramatically as climate ever will. So the biological and physical scientists welcomed emissaries from a third group: social scientists taking part in a new international program on Human Dimensions of Global Environmental Change. In collaboration with IGBP, the human dimensions group is planning a new project on land use and land cover change. The goal: To find a way to quantify human "forcing functions"—the human dynamics driving deforestation in Haiti, desertification in Mongolia, or the retreat of the Aral Sea—so that the models can reckon with human effects on the land and how they might influence global climate.

As one speaker noted, no model can track the future of rain forests by putting in $CO_2$ and temperature but leaving out chainsaws.

–Yvonne Baskin

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PLANETARY SCIENCE

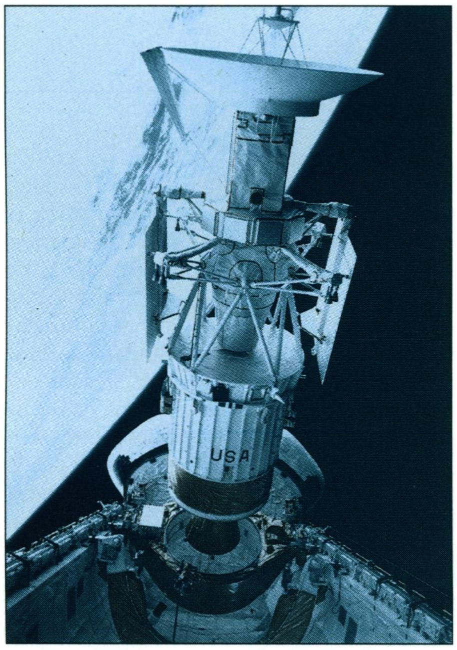
# More Venus Science, or The Off Switch For Magellan?

Later this year an engineer at the Jet Propulsion Laboratory (JPL) may do something that's never been done before: shut down a still productive planetary probe because the National Aeronautics and Space Administration (NASA) couldn't come up with the pittance in additional funding required to extend the mission. The Magellan spacecraft has been a spectacular success since it began radar mapping of the surface of Venus in September 1990. But it completed its prime mission just 200 days later. NASA extended the $800 million Magellan mission until last fall, when the Bush Administration cut off funding and it began living off money that managers had scrimped from the previous fiscal year.

Mission scientists and some agency officials now want a mere $8.2 million for a bare-bones, seat-of-the-pants effort in which Magellan would probe the deep interior of Venus.The study of the internal workings of Venus is crucial, scientists say, to understanding what created the sometimes exotic geology of Earth's nearest relative. But the budget-strapped agency has yet to produce the funding, and if it doesn't the spacecraft will have to be shut down when the current money runs out in 3 months' time.

Planetary scientists are now worried that the threatened termination of the Magellan mission may be a harbinger of similar problems for the other three NASA spacecraft recently launched across the solar system that have yet to complete their prime missions. These include Galileo, whose goal is to explore the Jovian system, the Ulysses mission to study the sun's polar regions, and Mars Observer.

The problem is rooted in NASA's long-standing tradition of not planning for the likely costs of operating a spacecraft after it has completed its prime mission, defined as what the spacecraft's designers can more or less promise will be achieved. In Magellan's case, that was mapping 70% of the Venusian surface. But the science from a prime mission can fall far short of what spacecraft can achieve. They're usually capable of years of additional operations. Indeed, says Thomas Donahue of the University of Michigan, a veteran of the 14-year Pioneer Venus Orbiter mission: "Technologically, these [spacecraft] are built to last." In the absence of any


NASA

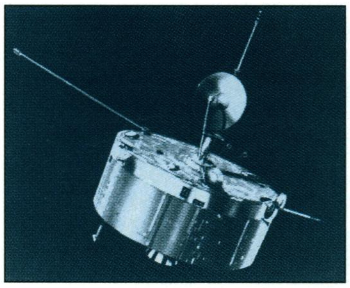
**Feeling the pinch.** The Magellan spacecraft may be turned off for lack of funds.

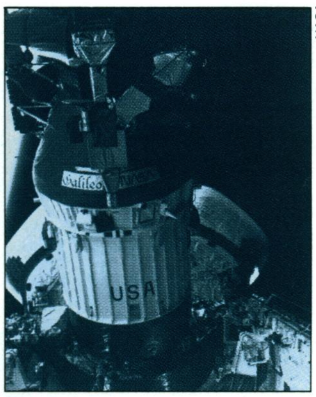
long-range plans, though, that durability has given rise to the "politics of survival," he notes. In the past, whenever NASA threatened to cut off funds for an operating probe, researchers raised the specter of the "scientific crime" of turning off a productive spacecraft, and NASA always relented. But now "someone may be calling their bluff on Magellan," notes one observer.

The reason NASA appears reluctant to rescue the Magellan mission is that its budget for planetary mission operations, which currently stands at $163 million, is caught in a squeeze between the increasing operating costs for existing missions and plans to launch new missions, such as the long-planned Cassini probe to Saturn. Mounting operation costs are in part a byproduct of NASA's recent planetary successes. After the launch hiatus imposed by the 1986 explosion of the Space Shuttle Challenger, NASA played catchup by launching Magellan, Galileo, Ulysses, and Mars Observer within 3 ½ years of each other, even as planning for new missions geared up and pressure on the federal budget intensified. The resulting crunch drove the Bush Administration to scrap the Comet Rendezvous/Asteroid Flyby mission and eliminate funding for Magellan operations from the fiscal year 1993 budget, though 1992 money was stretched into this year to cover some—but not all—of the observations scientists wanted.

Among the observations that got squeezed out are highly precise measurements of gravity. As planetary geologist James Head of Brown University explains it, the radar mapping revealed the "what" of Venusian geology—the lava plains, volcanoes, impact craters, and mountains. But researchers are still anxious to learn the "why"—how the underlying churnings of the planet's mantle give rise to the surface geology seen by Magellan. Key to that is measuring the varying gravitational pull across the planet. It reflects the density variations of the mantle and thus its motions as it convects heat from the planet's interior like a pot of boiling water. The planet's geology is just the crustal scum formed and shaped by these deeper motions.

Both Magellan and its predecessor, the Pioneer Venus Orbiter, have obtained some gravity data, but researchers want a sharper picture of gravity variations. Magellan, for example, detected for the first time the increased gravity associated with the planet's highest mountain, Maxwell Montes, located in the northern mid-latitudes. But the spacecraft's elliptical orbit makes the absolute numbers suspect at such high latitudes because the resolution of the resulting gravity map decreases as the spacecraft moves away from the low point of its orbit near the equator of Venus. "Our concern," says gravity specialist William Sjogren of JPL, "is that even though we're seeing these features, the quantitative values are dubious. They can't be used with much confidence" more than 30° away from the equator. But if Magellan's orbit were made nearly circular at its lowest altitude, high-latitude features would be almost as sharply defined as those near the equator are now. The gravity variations of Maxwell Montes would be reliable and even more modest-sized mountain ranges would show up.

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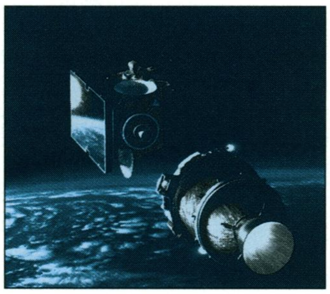

**How long?** Pioneer Venus *(above)* lasted 14 years, but Galileo and Mars Observer have uncertain futures.

Although the scientific value of such high-resolution gravity measurements may rank right up there with that of the radar map produced by the prime mission, orbital dynamics prevented Magellan mission scientists from performing both types of observations early in the mission. Every planetary orbiter must enter a highly elliptical orbit on arrival, and Magellan lacked the powerful thrusters necessary to circularize its orbit. The only way that engineers can do that is to dip the spacecraft into the Venusian atmosphere at the low point of its orbit and let atmospheric drag take off a bit of its speed so that it climbs back to a lower high point. Such aerobraking of a planetary spacecraft has never before been attempted because it's so hazardous. One slip, such as bringing down the craft too fast, and friction could overheat and disable Magellan, eventually sending it on a meteoric plunge into the deep atmosphere. Such risks kept high-resolution gravity measurements out of the prime mission.

The risks of circularizing Magellan's orbit are even greater now. The Magellan operations team has been slashed from 200 to 30 to shrink costs from the projected $40 million per year to the $8.2 million requested for a year and a half of high-resolution gravity mapping. Operating with a short-handed crew only heightens the risks, team members admit. "I don't know how far into this we can get" before running out of money, says project scientist Stephen Saunders of JPL, "but at least far enough to demonstrate it's possible to" circularize an orbit.

As the Magellan team takes its spacecraft to the edge, planetary scientists are wondering why they've come to such brinkmanship. "We should stop playing games," says Torrence Johnson of JPL. "If you've got known objectives, you ought to put them in the planning process [at the start], then make some priority judgments." As it is, Johnson, who is Galileo project scientist, and his counterparts on the Mars Observer and Ulysses teams are only now starting to consider seriously what they might do with hundreds of millions of dollars worth of spacecraft should they be operating when their prime missions end—if money is still available.

Wesley Huntress, director of NASA's Solar System Exploration Division, thinks there is an alternative to playing these games of scrounging up funding for extended missions. They could be redefined as new missions, he says, to compete for funding with all other missions on an equal footing. But such a change would come too late for Magellan, even if the aerobraking succeeds. And if it doesn't and the spacecraft comes to a catastrophic end? Then, says a philosophical Huntress: "That's the way it is. It's better than turning it off."

**–Richard A. Kerr**