MEETING AMERICAN GEOPHYSICAL UNION

Geophysicists Probe the Solar System's Cold Spots

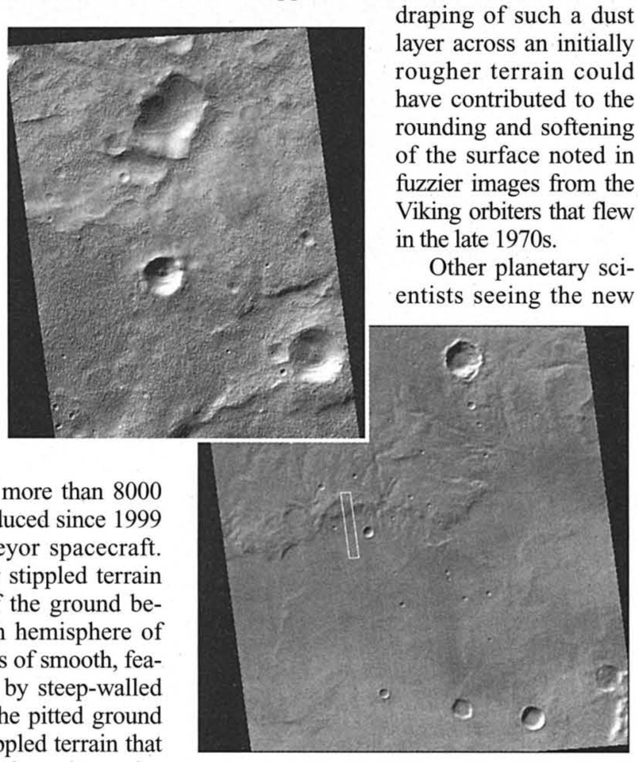
SAN FRANCISCO, CALIFORNIA—Last month, the American Geophysical Union held its annual fall meeting here as a nip in the air strained the state's power grid. Temperatures, especially low ones, were prominent in several of the offerings: ice in martian mid-latitudes, coordinated climate change on Earth, and ozone problems in the chilly stratosphere.

Girding Mars With Icy Dust

The mid-latitudes of Mars have long looked odd to earthly observers. In the late 1970s, the Viking spacecraft imaged ground there that seemed to have "softened" like ice cream on a warm day into a rounded, much subdued terrain. Now, closer inspection has revealed a wealth of textural detail in mid-latitudes that planetary scientists are comparing to the surface of a basketball. The martian mid-latitudes, it seems, harbor ice whose gradual removal leaves much of the planet wildly textured. If so, the two mid-latitude zones may harbor the lingering remnants of Mars's last ice age a million years or so ago, rather than the possibly life-sustaining liquid water suggested by last summer's discovery of spring-like seeps on Mars.

As described at the meeting, the "stippled terrains" came to light as planetary geologists John Mustard, Christopher Cooper, and Moses Rifkin of Brown University in Providence, Rhode Island, laboriously inspected more than 8000 high-resolution images produced since 1999 by the Mars Global Surveyor spacecraft. They found that a peculiar stippled terrain covers a sizable portion of the ground between 30° and 60° in each hemisphere of Mars. It consists of expanses of smooth, featureless terrain interrupted by steep-walled pits a few meters across. The pitted ground grades into a knobby or stippled terrain that grades in turn into a roughened terrain. "We've noticed this [texture] as well," says planetary geologist Michael Carr of the U.S. Geological Survey (USGS) in Menlo Park, California. "It's very real."

Mustard and his colleagues have also put together a plausible scenario for how the stippled terrain might have been generated. They suggest that about a million years ago, when the changing tilt of Mars's rotation axis last favored an even colder climate than today's, windblown dust accumulating in the mid-latitudes could have become welded into smooth-surfaced icy rock as water condensed and froze between dust grains. "This is the last glacial event on Mars," said Mustard. Then, once the axial tilt swung back to favor a somewhat less chilly climate, the finely divided ice holding the soil particles together began sublimating away to the poles. As a result, the smooth ice layer, originally 1 to 3 meters thick, began to disintegrate slowly, producing an increasingly textured surface. Carr supports this idea and adds that the draping of such a dust layer across an initially rougher terrain could have contributed to the rounding and softening of the surface noted in fuzzier images from the Viking orbiters that flew in the late 1970s.



On closer inspection. Stippling seen at higher resolution hints at an ice-rich martian surface.

Other planetary scientists seeing the new images also think the Brown group is onto something. "I know what they're talking about," says James Zimbelman of the National Air and Space Museum in Washington, D.C. Their interpretation "is certainly believable. I think ice is involved." Still, he adds, "I don't believe ice explains everything." Wind erosion may play a role too, he says.

Whereas the extensive ice age remnants proposed by the Brown group could explain the odd look of a fair portion of the surface of Mars, they could pose a problem for astrobiologists hoping to find life on the planet. Mustard and his colleagues noted that the distribution of the stippled terrain closely coincides with that of the "weeping layers" of rock reported last summer. At the time, some researchers proposed that the water that flowed at the surface had always been liquid, having flowed up from deeper, warmer rock. Such continuously liquid water is requisite for life.

But the Brown workers estimate that if those weeping layers contain as much water in the form of ice as stippled terrain seems to, simply melting the ice of the first few meters of rock would have been sufficient to produce the observed flows and debris fans. "It's all consistent with a lot of water ice in the near-surface," says planetary geologist Ken E. Herkenhoff of the USGS in Flagstaff, Arizona. And because it's unlikely that perennially frozen surface layers could support living organisms, those seeking signs of life may have to look elsewhere.

Getting Climate In Sync

It's natural enough in this age of telecommunications to view the world as tightly interconnected. Until now, however, researchers have always regarded major regional climate fluctuations as independent of one another. The warm-cool cycle of El Niños and La Niñas in the tropical Pacific seemed not to affect the great monsoon that so many in southeast Asia depend on; the shifting weather patterns of the North Atlantic that alternately warm and chill Europe seemed unconnected to the fluctuations in and over the North Pacific that drive everything from salmon populations to big surf in southern California. But now that view may be changing. At the meeting, a group of climate researchers reported finding decades-long intervals when two or more of these "climate modes" seem to dance in step. How they interconnect and why they sometimes fall out of sync remain mysteries, but the finding bodes well for long-term climate prediction.

Teasing out interconnections among these climate modes required a nontraditional approach to climate analysis. Climate researcher Tim P. Barnett of the Scripps Institution of Oceanography in La Jolla, California, and his colleagues borrowed a statistical analysis technique from signal processing in electrical engineering. Unlike conventional climatological methods, the technique can identify when two modes are in step with each other, even if they fall out of step from time to time. Barnett and his colleagues compared 118-year-long records of indices

CREDITS: NASA/JPL/MALIN SPACE SCIENCE SYSTEMS gauging the states of two modes at a time. (The synchronization technique can't yet handle three or more.) To test how much synchronization chance alone might produce, they ran 1000 tests analyzing records that they themselves had constructed to have no real synchronization. Only if the actual observations were more synchronized than these simulated records could mode synchronization be considered real.

Somewhat to their surprise, Barnett and his colleagues found that climate modes are not as independent-minded as had been assumed. "I think there's definitely something there," says Barnett. The tests of synchronization "turn out to be highly significant statistically. About half the time one pair of modes or another is in synchrony with each other. The other half of the time they're off doing their own thing." Barnett is calling the synchronization of any two or more modes the "hypermode," a term coined by coauthor Niklas Schneider.

For 2 or 3 decades at a time, the Southeast Asian monsoon, for example, waxed and waned in strength in step with El Niño, only to go its own way later, as it has during the past decade. "There seem to be some tantalizing hints that there are at least times when these modes are acting in concert," says climate modeler Benjamin Santer of Lawrence Livermore National Laboratory in California. Adds modeler Jeffrey Kiehl of the National Center for Atmospheric Research in Boulder, Colorado: "Tim showed that communities of scientists that focus on their favorite mode of climate variability may have to talk to one another. That's unique."

How individual climate modes communicate to create the hypermode or are forced into it remains unclear. The 20- to 30-year pacing of shifts in and out of the hypermode suggests to Barnett that some part of the ocean is calling the tune, because only the ponderous changes of ocean circulation could pace such slow changes in the climate system. The atmosphere, however, under the direction of the ocean, could provide connections between modes in much the way El Niño can reach out through the atmosphere to affect weather as far away as North America. Identifying such mechanisms of pacing and interconnection will take a lot of climate modeling, says Barnett; even a 118-year record is too short for that.

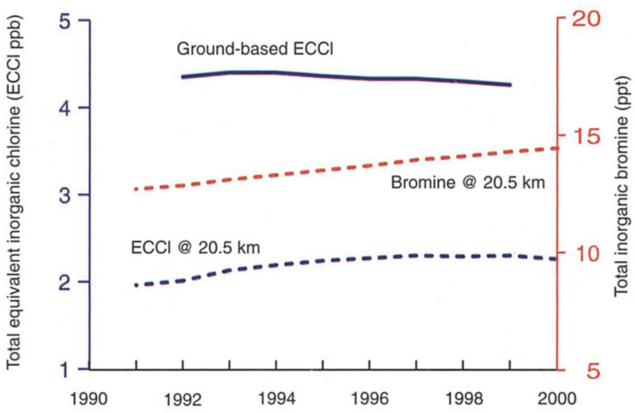
An Ozone Milestone

The battle to save the ozone layer has reached a major goal: halting the decades-long rise in the burden of ozone-destroying chemicals in the stratosphere. International controls on the production of chlorine-containing compounds such as chlorofluorocarbon (CFC) refrigerants have slowed and finally stopped the increase, atmospheric chemists reported at the meeting. If all goes according to plan, the antarctic ozone hole could heal by the middle of this century. But researchers are quick to caution that uncertainties remain, particularly in the future course of ozone-destroying bromine in the atmosphere. And as stratospheric temperature and water content change, they threaten to enhance the destructive power of existing chlorine and bromine.

Atmospheric chemists have been monitoring the stratosphere's buildup of the full suite of ozone-destroying substances for a decade. At the meeting, Dale Hurst of the National Oceanic and Atmospheric Administration (NOAA) in Boulder, Colorado, speaking for his colleague James Elkins (who was stuck in Antarctica by bad weather), reported that the combined ozone-destroying capacity of chlorine and bromine in the lower stratosphere—where most ozone loss occurs—leveled off around 1999.

The prime driver behind the stratospheric plateauing was the precipitous decline—as mandated by the 1987 Montreal Protocol—in the production of methyl chloroform. Production of the industrial cleaning agent ceased in 1994, supplies were rapidly depleted, and its stores in the atmosphere are quickly being eroded by natural destruction. Methyl chloroform's decline was so sharp that it compensated for the continued increase in stratospheric bromine from fire-extinguishing chemicals called halons, whose abundance in the atmosphere is still increasing at rates of 2% to 5% per year.

So far, NOAA data—gathered from gas chromatographs on NASA's high-flying planes and balloons, and ground measurements—suggest all is proceeding according to the protocol plan. But "the future is somewhat uncertain," warns Elkins. Soon the decline in chlorine from methyl chloroform will cease to be a factor, but mandated reductions in CFCs and in halons manufactured in developing countries will begin to kick in, assuming the protocol is followed. But, in fact, emissions of halons have been running 50% above the amounts expected, according to calculations by Stephen Montzka of NOAA, Boulder, suggesting that the production figures from such countries as China are off, that more halons stored in fire-extinguishing systems around the world are being released than assumed, or both.



A stratospheric balancing act. Although the powerful ozone-destroyer bromine is still increasing (yellow), decreases in chlorine have caused the overall ozone-destroying potential (ECCl, dashed blue) to plateau.

CREDIT: J. W. ELKINS/NOAA

Another sort of threat to the recovery of stratospheric ozone arises from a matter of accounting. Researchers have long recognized that, molecule for molecule, bromine is far more destructive of ozone than chlorine is. The usual assumption in calculating ozone-destroying potential is that bromine is 45 times more potent than chlorine in destroying ozone molecules. That's the assumption underlying the NOAA calculation that the stratosphere's burden of ozone-destroying chemicals has plateaued. But "it's pretty clear that 45 is the low end of the range," says atmospheric chemist James Anderson of Harvard University. An analysis by Anderson and his Harvard colleagues suggests a better factor "is closer to 60 to 80 times," he says. If so, the ongoing rise in stratospheric bromine would still be driving up ozone destruction. Anderson hopes that researchers can settle on a single bromine factor this year.

Beyond accounting uncertainties loom nonhalogen atmospheric changes. Increasing greenhouse gases in the stratosphere are radiating more heat to space and cooling the stratosphere. At the same time, stratospheric water vapor is increasing, for unknown reasons. Each of these changes tends to encourage the formation of the icy cloud particles that accelerate springtime ozone destruction over polar regions (*Science*, 10 April 1998, p. 202). "Over the next few decades," says Anderson, "changes in stratospheric temperature and water vapor could overwhelm reductions" in chlorine and bromine.

To follow how stratospheric ozone is coping with all its stresses, keep your eye on the Arctic, says Anderson. Each spring the mix of chemicals, water vapor, and temperature has been depleting ozone until a full-fledged ozone hole, approaching the one that forms each year over the Antarctic, now threatens to emerge. The Arctic is "sitting right on this cusp," Anderson says. The next decade or so should tell.

–RICHARD A. KERR