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Borehole Temperatures Record Changing Climate

PAGE 55

Henry Pollack

Recent changes in the Earth's surface temperature can now be probed by measuring the temperature of rocks beneath the surface. Rock temperatures at shallow depths are an archive of temperature changes that have occurred at the surface of the Earth in the recent past. Thus, subsurface temperatures comprise a valuable complement to surface meteorological data in understanding the Earth's surface temperature history, particularly for times before the establishment of a worldwide network of meteorological stations. The subsurface observations are relevant to an assessment of the role of atmospheric greenhouse gases in the global warming of the 20th century.

As anyone whose buried water pipes have frozen during a harsh winter knows, temperature changes at the surface of the Earth are propagated into the subsurface. Short-term variations of temperature such as the diurnal and seasonal oscillations penetrate only a few centimeters and meters, respectively, but longer term variations propagate to greater depths. The temperature excursion associated with the Little Ice Age of the 16th and 17th centuries can be detected in boreholes at depths of a few hundred meters, and those associated with the last of the Pleistocene glaciations can be detected at kilometer depths. However, there is insufficient data to resolve events much older than a few centuries because of the progressive attenuation of surface temperature disturbances as they propagate downward.

Subsurface temperatures are important because they offer a filtered record of surface temperature variations over the past few centuries, an interval of time comprising both the pre-industrial and industrial eras. By contrast, surface temperature records from meteorological stations offer a global perspective only for the past century. In the context of the current discussion over global warming and its likely causes, the time interval represented in the borehole record is of particular significance. The strong correlation of increasing carbon dioxide and methane concentrations in the atmosphere over the past century with the apparent warming of the atmosphere by 0.5–0.6°C has given strength to the notion that the greenhouse gases, produced largely by the burning of fossil fuels, have caused the warming.

However, if the warming over the past century is a continuation of a longer trend beginning before the industrial era, perhaps a continuing recovery from the Little Ice Age, then the proposed causal link between greenhouse gas concentrations and global warming would be open to question. Each scenario has different implications for remediation policy. Subsurface temperatures stored worldwide in the rocks of the Earth's continental crust have the potential to address this important topic. Great care must be taken, however, to separate local anthropogenic effects such as urbanization, deforestation, and wetland destruction, and microclimatic effects associated with topography and vegetation patterns, from true regional climatological changes.

A few studies [*Cermak*, 1971; *Lachenbruch and Marshall*, 1986; *Nielsen and Beck*, 1989; *Beltrami and Mareschal*, 1991] have shown the efficacy of this methodology in the analysis of recent climate change. These investigations, principally in North America, have shown warming of variable magnitude over the past century in the Alaskan arctic and southeastern Canada, and over the past 2 centuries in south central Canada. Just as surface temperature patterns deduced from the past century of meteorological data show considerable regional variation, the earlier temperature history stored in the subsurface will likewise reveal regional differences. Thus, it is imperative that borehole investigations be carried out on all the continents. Plans are now being made by international scientific associations for the implementation of this global paleotemperature survey.

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Io and Jupiter: The Volcano-Magnetosphere Connection

PAGES 55, 57

Nick Schneider and John Spencer

In the interlude between spacecraft encounters with Jupiter, Earth-bound observers using clever and powerful techniques have made substantial headway in monitoring two major phenomena: volcanos on Jupiter's moon Io (most active in the solar system) and Jupiter's magnetosphere (largest and densest of all the planets). While these two may seem unrelated, planetary scientists believe they are quite closely tied. Astronomers are working together to probe the fundamental and enigmatic connection between volcanos and magnetospheres.

Volcanic activity on Io is powered not by radioactive heating, as it is on Earth, but by the continual flexing of Io by Jupiter's intense gravitational field, which generates heat as in a rapidly flexed tennis ball. Most of this heat is eventually radiated into space from a series of hot volcanic centers, or "hot spots," where the surface is up to several hundred degrees hotter than its surroundings. The heat radiation is so intense that Io literally "glows in the dark" at infrared wavelengths, allowing astronomers with infrared telescopes to follow the frequent changes in the level of volcanic activity.

Recently, infrared cameras have obtained images of Io's tiny disk that show several glowing hot spots, whose positions and relative brightnesses can be measured and followed as they change from month to month (Figure 1). An even more detailed look at the volcanic activity was possible in early 1991, when the moon Europa passed repeatedly in front of Io, blocking the radiation from its hot spots. By timing the disappearances and reappearances of the hot spots, astronomers could precisely locate them on Io and even learn something about their sizes and internal structures.

The volcanos on Io eject huge quantities of gases such as sulfur dioxide and other materials rich in sulfur from Io's interior. The prodigious volcanic output replenishes Io's rapidly escaping atmosphere: about a ton of material is lost from Io each second. At first the escaping atoms and molecules slowly orbit Jupiter in Io's vicinity, but eventually they are ionized and swept up by Jupiter's magnetic field. This creates a charged-particle ring locked to Jupiter as it rotates. Both the "cloud" of neutrals (orbiting at 17 km/sec) and the rotating "torus" of plasma (traveling at 75 km/sec) can be easily imaged by ground-based telescopes. Figure 2 shows the emissions caused by collisions with electrons and scattering of sunlight. The plasma overtakes Io, smashing into the atmosphere and/or surface at 60 km/sec and causing the remarkable escape of material.

The volcanos are thought to be linked to the magnetosphere through Io's atmosphere. The level of volcanic activity may determine the density and extent of the atmosphere, which in turn will affect the supply to the plasma torus. While this theory is plausible, it can only be tested by coordinated observations of both volcanic activity and the magnetosphere. The International Jupiter Watch was created about five years ago to address this question and numerous others related to the many variable phenomena observed on Io and Jupiter. The last few years have seen increasingly successful observing campaigns, and very large variations have been observed both in volcanic activity and in magnetospheric emissions. By the time the Galileo spacecraft arrives at Jupiter in 1996, astronomers observing the volcanos and magnetosphere hope to understand the relationship between these two major phenomena.

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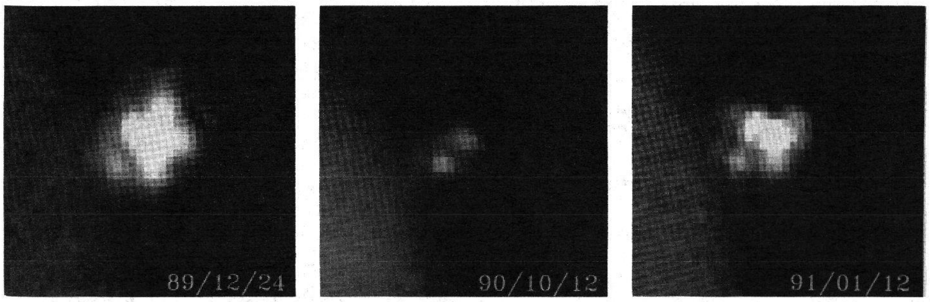

Fig 1. Infrared images of Io, in Jupiter's shadow, showing the varying heat radiation from its volcanic hot spots on three occasions. The disk of Jupiter itself is faintly visible on the left of each frame. In late 1989 and again in early 1991 there was intense volcanic activity at Loki, the rightmost hot spot in the images, and it was very bright (its apparent irregular shape is an artifact), but through much of 1990 it was very faint. A second hot spot on the opposite side of Io's invisible disk glows more steadily to the lower left of Loki. Images taken at the NASA Infrared Telescope Facility on Mauna Kea.

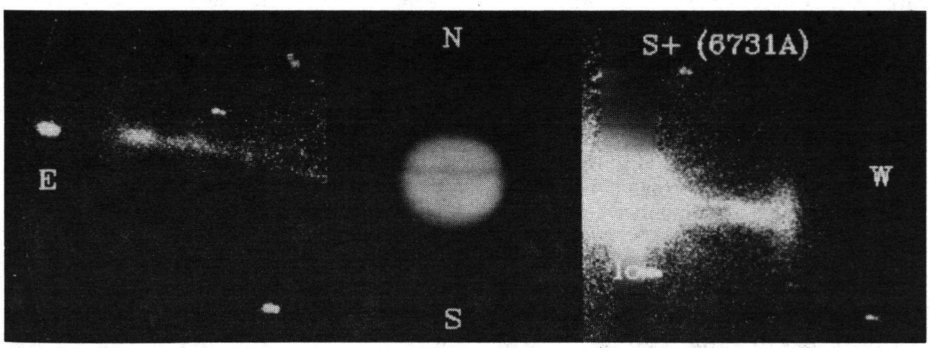

Fig 2. The Io plasma torus. The orbital plane of the satellites is horizontal; the emissions from sulfur ions (and from some of the sodium) are tilted due to the tip of Jupiter's magnetic pole. Images were recorded using a CCD camera and filters that select the proper wavelength for the emission. Jupiter's bright image is recorded in the same exposure as the faint emission by using a filter that lets through 0.01% of Jupiter's light. Images taken with the Catalina Observatory 1.5m telescope, in collaboration with John Trauger, Jet Propulsion Laboratory.

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