MARS ORBITER CAMERA CLIMATE OBSERVATIONS

M. Malin, *Malin Space Science Systems, San Diego, CA, USA (malin@msss.com),* **B. A. Cantor** *Malin Space Science Systems, San Diego, CA, USA.*

Introduction:

In our companion abstract (Cantor and Malin), we address Mars Orbiter Camera (MOC) observations and interpretations of meteorological phenomena. In this abstract we address MOC observations that have longer term implications for the atmosphere, which we consider climate. Three specific topics will be explored: the global dust event of 2001, recent changes in the configuration of the south polar residual CO_2 ice cap, and relict landscapes.

Global Dust Event of 2001:

Synoptic monitoring of Mars using 7.5 km/pixel daily global map swaths acquired by the MOC wide angle cameras fully documented the events leading up to the initiation of the global dust event of 2001, and subsequently observations at 7.5 and 3.75 km/pixel documented the evolution of that event. From the MOC perspective, the location of dust storms are indicated by very characteristic cauliflower clouds of high optical opacity and well-defined morphologic structure. A dust veil is a significantly more diffuse region of atmospheric dust that has very little local structure and may or may not be completely opaque (i.e., such that the ground is not visible). We infer that the dust clouds of a storm are being raised by high surface winds at or somewhat up-stream (as indicated by the orientation of the dust clouds) of the location at which the clouds are seen; we infer that veils are created by clouds that penetrate the tropopause and inject dust into the stratosphere, and that the winds at such altitudes responsible for the spread of dust veils are not necessarily correlated with the surface winds generating the dust.

Throughout the month of June 2001, a moderately large number of local dust storms were noted, especially along the retreating margin of the seasonal south polar CO2 frost cap and around the Hellas impact basin. On June 21, an otherwise undistinguished small dust storm surged into the basin from the southwest. When viewed 24 hours later, the storm had circulated clockwise about 1/3 of the circumference of Hellas, indicating 24-hr averaged winds in excess of 25 m/sec. For the next three days, this storm moved north and northeast out of Hellas into Hesperia, but did not cross the equator. Then, sometime between 2 PM local Mars time on June 25 and 2 PM local Mars time on June 26, the storm exploded north across the equator, and in less than 24 hours thereafter, dust was being raised from separate locations in Arabia, Nilosyrtis, and Hesperia, thousands of kilometers away from Hellas. This was the start of the global dust event (Figure 1).

Over the following week, dust injected high (we presume into the stratosphere) from the initial Hellas and Hesperia storms drifted eastward, carried by the prevailing south circumpolar jet stream. Beneath this veil of dust but apparently mostly independent of it (as shown by differences in the rates at which they moved around the planet), an intense wind front moved across Mars, setting up conditions for many other local and regional dust storms. By July 4, a large regional storm was raging between Daedalia Planitia south of the Tharsis volcanoes and Syria Planum (just south of Labyrinthus Noctis). Another storm was raising plumes of dust in north-central Noachis/southwestern Meridiani. Plumes were rising in Hesperia but not Hellas.

Throughout July and August, MOC observations revealed a general pattern of regional storm centers beneath an expanding veil of stratospheric dust. While many of the storm centers went though the typical regional storm lifecycle (we have come to categorize storms more by their durations than by their areal extent), lasting of the order of week before dissipating, the Claritas/Syria storm center created dust plumes on over 90 consecutive days.

Previous views and perceptions of global dust events had noted regional brightenings within the overall pall of what were called a "global dust storm." From our observations, we know that at least this global event was really a set of storms, triggered initially by conditions near and around Hellas, but which then propagated quickly around the planet. We also know that dust was not raised from everywhere on the surface during this global event, but rather from discrete centers of activity, some but not all of which were longer-lived than typical regional storms. We saw rapid, cross-equatorial flow of dust-raising winds.

One interesting observation by the camera did not involve taking a picture. The temperature of the front end of the tube that holds and protects the telescope mirror of the high resolution camera is very sensitive to the heat emitted by Mars. That temperature oscillates every orbit, showing not only variations associated with local time of day and season, but also with thermal inertia; the average closely follows the annual temperature change as Mars orbits the sun. So the MOC structure is a pretty good integrating bolometer. As soon as the global dust event began, the MOC temperature began to drop. The globally-averaged average instrument temperature cooled about 1°C, the daytime average dropped almost 3°, and the nighttime average actually increased by 2/3°. These changes are consistent with models and theories of the influence of dust mixed throughout the atmosphere: high altitude dust reflects sunlight so that less solar energy gets down to the ground to heat it. This cools the planet during the day. Dust throughout the atmosphere also absorbs heat radiated from the surface during the day. These variations closely correlation with the beginning of the storm and, although the dust veil obscured the surface, the temperatures suggest that the storm's primary climatological impact was over by mid-August, although it took more than two additional months for the stratospheric dust to clear. Later observations of Mars showed that most of its meteorological phenomena occurred more-or-less on the same schedule as had been seen a year earlier. Both these observations, and the temperature of the instrument, suggest that the effect on the climate of Mars of the global dust event of 2001 was roughly comparable to but demonstrably less than (somewhat greater in temperature, substantially shorter in duration) the effect on Earth's climate of the dust and aerosols erupted by Mt. Pinatubo in 1991.

Polar CO_2:

As the global dust event of 2001 developed, high resolution images of the planet became increasingly degraded. As was also observed by Mariner 9 during the global dust event of 1971, visibility in the south polar region remained more-or-less unaffected by the increase in atmospheric dust. As it was essentially the only place we could photograph, we developed a procedure to re-image locations in and around the residual south polar cap to look for changes. Within a week of initiating this campaign, we had discovered that in fact measureable changes had in fact occured.

Pits in the perennial south polar cap were first seen in MOC images during its first year of mapping. At that time, they were recognized as being very unusual and interesting. We suspected that they were formed in solid CO_2, but had no way to demonstrate that. The walls of some of the pits, and of some of the mesas surmounting the adjacent smooth surfaces, showed layering, suggesting cyclic deposition. The pits and remnant mesas argued that erosion has been occurring most recently. Thus, these layers and pits together indicated that Mars had experienced environmental change. The questions were, "What was the magnitude of the changes, how rapidly did (do?) they occur, and when was the last change?"

We observed that the bounding escarpments of the polar ice pits had retreated by between 0 and 8 meters, with 3 m being about average (Figure 2). We initially wanted to know if such rapid changes (these changes are larger than anything we've previously seen on Mars using the MOC) were consistent with water ice or carbon dioxide ice. We eliminated water ice as a candidate by modeling the energy balance--only CO_2 is sufficiently volatile to have changed so much in so short a time. The energy we calculated would be needed to sublime CO_2 was very close to (but importantly less than) the energy available from sunlight. Thus, the magnitude of the change, and its occurrence only in pits and mesas in the remnant south polar ice cap, indicates that the ice cap consists of layers of CO_2 (probably mixed with small amounts of water ice and dust from occasional global dust storms). The amount of CO_2 visible through surface exposure is probably equivalent to 5-10% of the present atmospheric mass. There may be more CO_2 buried, but we can't tell that from the present observations.

More important than the admittedly limited information we have about the amount of CO_2 buried beneath the surface is how fast the surface CO_2 is being eroded. At the present rate, a layer 3 m thick can be completely eroded away in a few tens of martian years. Since each layer is equivalent to about 1% of the mass of the present atmosphere, if sufficient CO_2 is buried in the south polar cap, the mass of the atmosphere could double in a few hundred to a thousand Mars years (although how the mass increase is partitioned between the atmosphere and seasonal frost cap is not clear). Equally interesting, the evidence for previous layers, now mostly removed but remaining in the form of mesas superadjacent to the layer in which pits are presently forming, indicates that the process has been going on for at least several hundred Mars years. This means that the martian atmosphere may have increased perhaps by as much as 5% since Schiaparelli and Antoniadi observed the planet just over a century ago, and 1% since Viking. We have seen no evidence that the CO_2 coming off the cap now is being redeposited in the south polar region.

We liken the observation of these changes and the rate at which they are occurring to observations of the "ozone hole" over Antarctica, or the steady increase in atmospheric CO_2 in the Earth's atmosphere. Although the implications of these observations is often hotly debated (as we believe the implications we have drawn will be debated), everyone agrees that the terrestrial phenomena are evidence of contemporary climate change. We think that same perspective will eventually be attained for our observations, i.e., that Mars, too, is experiencing climate change "today."

Relict Landscapes:

Among the more perplexing results of the MOC investigation now some 5 years into the mission is the absence of changes in landforms that we would have expected to exhibit changes over relatively short timescales on the bases of their nature, location, and form.

Sand dunes are representative of these types of landforms. With nearly three years of high resolution observations of relatively small dunes, no evidence whatsoever has been found to support the contention that any dunes on Mars are presently mobile. Yet their dune crests appear to be quite sharp (inactive dunes still shed sand from their crests and become rounded with age), and subtle markings on their slip faces suggest that a small amount of avalanche sand may move under the added weight of winter snow. Occasionally, dunes exhibit striations that suggest that their surfaces may be cemented or crusted, but for the most part their inactivity in the presence of winds likely to be able to move sand (we see dust-devil tracks on some dunes) suggests that their inactivity may be related to some environmental factor, such as the absence of locally sustained winds.

The gullies found on the bounding slopes of a relatively small number of mid- to sub-polar latitude depressions (craters, graben, etc.) also appear to be exotic to the present environment. They typically are young (they superpose patterned ground and some eolian bedforms), but how young cannot be determined. Whether formed by nivation related to surficial deposition of water or carbon dioxide frost or release of subterranean water or some other fluid, nothing about these gullies seems related to the present environment.

Exposures of layered materials in western Candor Chasma illustrates yet another incongruent relationship: these layered outcrops display very few impact craters on their surface. Indeed, they show crater densities two to three orders of magnitude lower than those seen within the summit caldera of Arsia Mons (Figure 3). Since the evidence is very good that these materials are ancient and being exhumed, the absence of craters means that the layers have been recently exhumed, or that their surfaces have been recently eroded (if the Arsia Mons caldera is of the order of hundreds of milllions of years old, then the surfaces in Candor are only hundreds of thousands to millions of years old, and in cases where there are no craters at all, even younger). We see no evidence of the process that has exposed these materials, and no evidence for where the materials have gone. There is certainly nothing acting today that could create what we see. This landscape, too, is not representative of the present-day suite of processes.

When taken together, these and several other relationships suggest that the Mars we see today (in terms of environmental conditions and processes) is not the Mars that is responsible for much of what we see on the surface. We find ourselves facing a dilemma not unlike that experienced by geologists in the middle of the 19th century: evidence for the action of glaciers of almost unprecedented scale in areas (such as most of North America and Europe) where such glaciers do not exist. Overshadowed by the nearly contemporaneous Darwinian revolution, the recognition that glaciers once covered much of the Earth, and the subsequent realization that these glaciers had existed in the geologically recent past, represented a true paradigm shift for terrestrial sciences. We suspect that a similar change our view and understanding of Mars is likely to be needed.

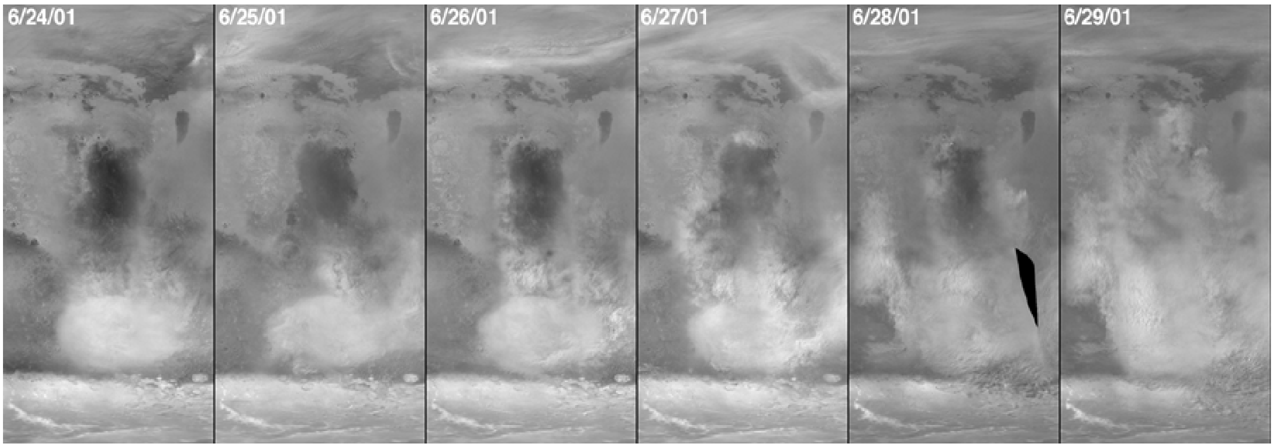

Figure 1: Time-series sequence of initial stages of the global dust event of 2001

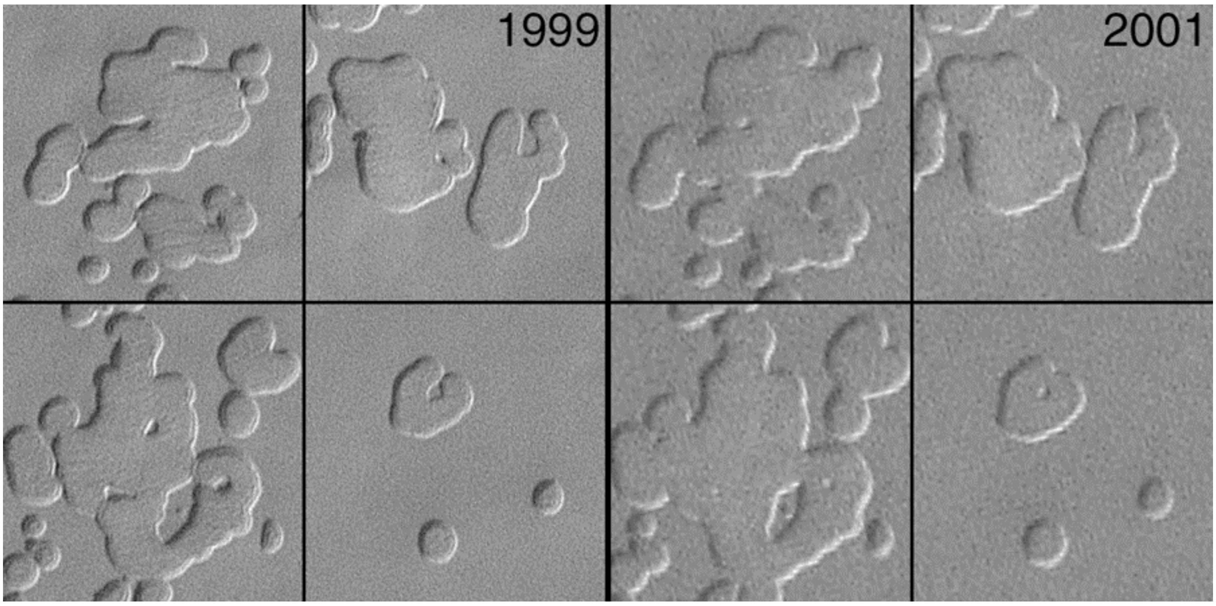

Figure 2: Changes in Pits in Residual South Polar Cap in 1 year

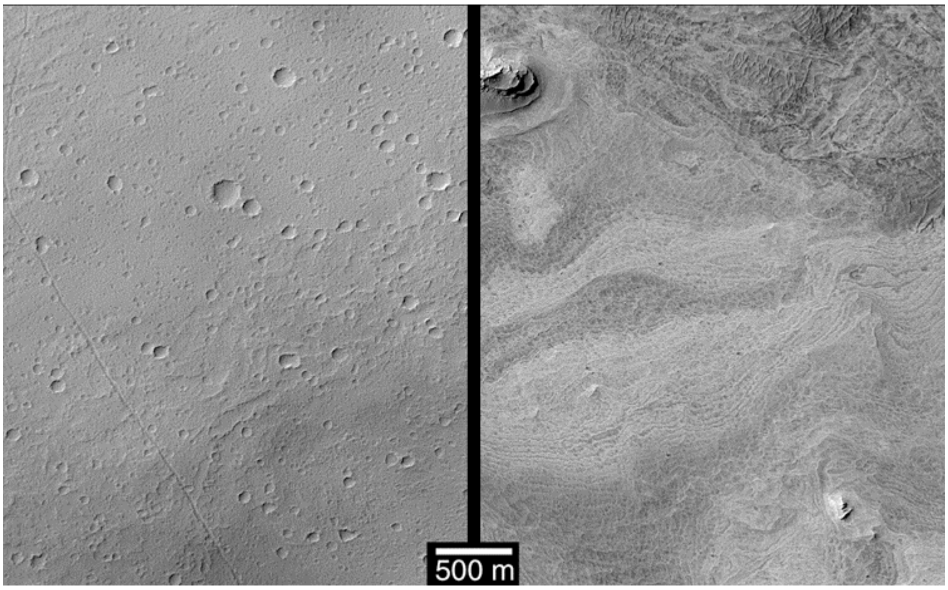

Figure 3: Differences in crater population on "young" volcanic surface (Arsia Mons caldera floor), left, and exhumed surface in Candor Chasma, right