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Condensate Phenomena in the
Polar Regions of Mars
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INTRODUCTION

Observations suggest that climate changes have occurred on Mars with several different characteristic time scales (Carr, 1981 and 1982). Networks of channels in the southern highlands of the planet appear to be dendritic water drainage systems 3-4 billion years old; significant changes in Mars' atmosphere are therefore indicated on this time scale. Episodic formation of outflow channels and volcanism appear to have continued from 3 gy to less than 1 gy; the terminations of the production of volatiles by volcanism and of channel formation roughly coincide with the estimated age of layered, pitted plains in the south. More localized sedimentary layers in the polar regions which are too young to be dated by crater counts imply the existence of some sort of cyclic climate process which is still active and which has a time scale of hundreds of thousands or millions or years. Changes in the orbital elements of the planet due to astronomical perturbations probably drive these cycles of deposition and erosion; these intermediate scale changes therefore may be mechanically linked with terrestrial changes such as ice ages, for which similar mechanisms have been proposed. Finally, some terrestrial observations of the polar caps have been interpreted in terms of climate change with a period of decades. Comparisons of Mariner 9 and Viking views of Mars' south polar cap also reveal that some significant changes have occurred on that time scale.

Climate changes with these various time scales are related by the fact that they all depend upon the distribution of H_2O and CO_2 volatiles on the planet and, conversely, affect the evolution in time of these distributions. For example, large lithospheric reservoirs of CO_2 and H_2O which are in contact with the atmosphere may dominate climate changes on the intermediate scale; these reservoirs provide links to the ancient martian climate, to the availability of liquid H_2O necessary for carbonate formation, and to the amount of outgassing which has occurred. The effect of duststorms on the current CO_2 cycle is a good candidate for short term fluctuations (James and Lumme, 1982); and these same global duststorms are the most likely agents for the sedimentation on the polar regions on the intermediate time scale (Pollack etal., 1979). Achieving an understanding of the cycles of the major volatiles and of dust is therefore almost synonymous with solving the martian climate problem.

The available spacecraft data pertain to only the few martian seasons observed by Mariner and Viking spacecraft. Because any historical study must be anchored on the current martian climate, thorough analyses of these data and accurate modeling of the current climate are certainly prerequisite to a study of the broader questions outlined above. The principal data sets relevant to these questions are:

1. Viking Lander measurements of surface pressure, which were obtained piecewise continuously for three martian years (Leovy etal., 1985);

2. Viking orbiter and Mariner 9 photographs relevant to seasonal changes in the polar regions (James etal., 1979);

3. Viking MAWD observations of water vapor as a function of time and position on the planet (Jakosky and Farmer, 1982);

4. Mariner 9 IRIS and Viking IRTM observations of the thermal structures of the surface and atmosphere (Kieffer etal., 1979; Christensen and Zurek, 1984).

In addition, there is an extensive set of telescopic observations of Mars; since 1969 these data have been acquired and maintained by the

International Planetary Patrol. Photographic information on the behavior of the polar caps is relevant to short term climate fluctuations (James and Lumme, 1982). The interpretation of this record is assisted by the "ground truth" observations of Mariner 9 and Viking orbiters.

SCIENTIFIC OBJECTIVES

Models used to study the changes in martian climate must of necessity adequately describe the current volatile cycles. The focus of this project is on mathematical modeling of current volatile cycles and modest extrapolation to past regimes. Specifically, the objectives are:

1. To adequately model the current seasonal volatile cycles on Mars. A particular goal of this work is to understand the interdependence of these cycles and the implications of existing observations for the distribution of gas, solid, and adsorbed phases of the volatiles. The modeling should identify the physical processes which are currently most important in the martian climate, e.g. buffering by regolith, CO_2 emissivity, advection, effects of dust on radiative properties of the atmosphere, insolation dependent albedo, etc.

2. To apply the model to longer term variations, in particular to the intermediate range cycles caused by redistribution of insolation.

3. To analyze recently acquired telescopic images of Mars in order to define a regression curve for Mars' south polar cap in 1986 and to discover the 1986 dust cycle in southern spring.

Work Accomplished under NAGW - 742

1. Water cycle

Numerous pieces of evidence, most noticeably the asymmetry in water vapor abundances between the northern and southern hemispheres of Mars observed by MAWD, suggest that the southernn hemisphere is desiccated relative to the northern hemisphere of the planet. The fact that the annually averaged gradient of water vapor concentration is directed from south to north can be interpreted as implying a net north to south transfer of water over the annual cycle. This would certainly be the case unless there existed a pumping mechanism to maintain the gradient.

Such a pumping mechanism is provided by the dominant seasonal CO_2 cycle, which produces seasonally varying meridianal winds which can preferentially transport water vapor from south to north. A numerical simulation of this process, largely funded by this grant's predecessor NAGW-586, clearly indicated that the mechanism could indeed bring about the observed distribution of water on the planet.

The model has been used to study changes in the global water distribution which may occur as the orbital elements of Mars change under the influence of gravitational perturbations from other planets. The major conclusion of this work has been that the longitude of perihelion, which affects the phasing between solar heating and CO_2 sublimation winds, is the major controller of water distribution rather than inclination, which has major effects on the seasonal polar caps. A paper on this subject was presented at the MECA Symposium held in Washington, D.C. in July, 1986.

The direction of water transfer was also the object of an observational study based upon Viking images of the residual north polar cap of Mars taken two years apart. Changes occurred in the cap during the intervening period of time in the sense that regions which were ice covered in 1976 were ice free in 1978. This could suggest a transfer to the residual south, cap which can act as a cold trap on at least a short term basis, but it could also represent an exchange with other portions of the north polar cap.

The question of transfer to the south polar cap, which is composed at least partially of CO_2 ice, is of great interest because of the possible effects which water ice could have upon its stability. The CO_2 in the south cap is stable because of its high albedo which may be maintained, despite dust storms, by some sort of self cleaning mechanism (Kieffer and Page, 1986 MECA Symposium). Water ice would be less susceptible to such a mechanism, and transfer of water to the residual south polar cap could limit its stability. These issues were discussed at the 1985 meeting of the Division of Planetary Sciences of the AAS in Baltimore.

2. Dust Storms

A series of storms which were at least partially dust storms occurred in 1978 near the westernmost portions of the Valles Marineris canyon system between Noctis Labyrinthus and Echus Chasma. These storms were observed several times by Viking cameras, and the region (without storms) was photographed several additional times. Therefore, limited statistics on seasonal and interannual variability in their occurrence can be deduced. In addition, there are various topographical and geological clues to the mechanisms which could produce these dust clouds. The most likely candidate is the slope induced wind which results from the large SW → NE slope in the region; they are thus related to the "bore wave" clouds seen to the west during the same general season. A manuscript is being prepared for submission to Icarus on this new type of meteorological phenomenon.

3. Polar variability

The seasonal variations in the martian polar caps are the best markers for the seasonal climate cycle on Mars in the absence of in situ meteorology stations. This is because of the sensitivity of the CO_2 cycle to insolation and to other processes which contribute to the local energy balance. The historical record of terrestrial observations provides the best evidence available at this time for the amount of variability in the martian climate system. Because data on the south polar cap sublimation are acquired when Mars is relatively close to Earth and the southern hemisphere is tilted towards us, this season (southern spring) is most completely documented and the data have maximum resolution. Therefore, these are the prime data sets for use in searching for interannual variations.

The high quality 1971 and 1973 telescopic data had been previously analyzed and compared to Viking observations from 1977. One of the projects undertaken under NAGW-742 was a reanalysis of Lowell Observatory data from 1956 in order to reduce them to a form amenable for comparison with the later years. The results of this study provide the most conclusive evidence for interannual variability in the polar cap recession; they have been accepted for publication in Icarus.

4. North polar clouds

Telescopic pictures of Mars during the spring season in the martian northern hemisphere have been used to study the behavior of clouds and surface cap during the recession phase of the north polar deposits. Images acquired using red and violet filters were compared in order to separate atmospheric and surface condensate deposits. The red filter pictures, which show the surface cap, provide a regression curve which is essentially identical to curves observed previously from Earth and by spacecraft; there is a standstill or "plateau" in the north cap's regression during early-mid spring. The violet pictures display a late winter/early spring hood --as expected. But they also show that in mid-spring, when the cap recession recommences, clouds appear along the periphery of the north cap. These data suggest that the clouds are formed from water which is released from the surface cap rather than from water released from the bare soil which is exposed. The results are currently in press at Icarus.

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