THE MARTIAN WATER CYCLE BASED ON 3-D MODELING. H. Houben, *Space Physics Research Institute, Sunnyvale, CA 94087, USA (houben@humbabe.arc.nasa.gov)*, R. M. Haberle, *NASA-Ames Research Center, Moffett Field, CA 94035, USA*, M. M. Joshi, *SETI Institute, Mountain View, CA, USA*.

Understanding the distribution of Martian water is a major goal of the Mars Surveyor program. However, until the bulk of the data from the nominal missions of TES, PMIRR, GRS, MVACS, and the DS2 probes are available, we are bound to be in a state where much of our knowledge of the seasonal behavior of water is based on theoretical modeling. We therefore summarize the results of this modeling at the present time. The most complete calculations come from a somewhat simplified treatment of the Martian climate system [Houben et al., 1997a] which is capable of simulating many decades of weather. More elaborate meteorological models are now being applied to study of the problem. The results show a high degree of consistency with observations of aspects of the Martian water cycle made by Viking MAWD [Jakosky and Farmer, 1982], a large number of ground-based measurements of atmospheric column water vapor [Barker et al., 1970; Jakosky and Barker, 1984; Rizk et al., 1991; Clancy et al., 1992; Sprague et al., 1996], studies of Martian frosts [Svitek and Murray, 1990; Bass and Paige, 1996], and the widespread occurrence of water ice clouds [Clancy et al., 1996; Christensen et al., 1998].

The current Martian water cycle is characterized by a strong hemispheric asymmetry, with a permanent water ice cap in the north and no indication of a similar source in the south. Model simulations have shown that a substantial southern hemisphere exposed ice cap would rapidly lose water to a dry north pole under current climate conditions [Houben et al., 1997b]. But the same model is unable to restore all the vapor that evaporates off the north polar cap in summer without accumulating some water at other latitudes. This is one argument in favor of an adsorbing regolith (which could hold an order of magnitude more water than the $\sim$2 Gtons which are in the atmosphere [Fanale and Cannon, 1974]). The matter may not be fully resolved before GRS completes its survey of subsurface water. From a modeling point of view, very long times are required to charge and reach equilibrium with such a reservoir.

Martian atmospheric transport is dominated at almost all times (at least in GCM simulations) by a strong interhemispheric Hadley cell rising near the subsolar point with descending motion in the winter hemisphere. In northern summer, material is transported about 30 degrees in latitude in about 10 days by this flow. The southern summer circulation is even more vigorous [Haberle et al., 1999]. Of necessity, this circulation leads to substantial exchange of water vapor between the hemispheres. Simulations indicate that an amount on the order of the total atmospheric inventory of water (>1 Gton) is transported in this fashion. Since the descending branch of the Hadley cell is in the cold core of the polar night jet near 50 degrees latitude, it is probable that a large fraction of this water precipitates out and is incorporated in seasonal frost deposits. MAWD observations which show a continual increase in water vapor column in equatorial regions through northern summer appear to be consistent with this picture. (Even though this is a season of increasing equatorial temperatures, the low relative humidities that always prevail near the surface in Martian low latitudes argue against a substantial surface source of water vapor.) The southern summer case was obscured by the Viking dust storms. More observations at that season are very important (to test model predictions of about twice as much atmospheric water vapor as given by the MAWD lower limits and, indeed, to test the meteorological predictions concerning the Hadley cell at its strongest point). The upper branch of the Hadley cell is saturated over the equator above 10 km in northern (aphelion summer) and above 14 km in southern summer. (The model simulation does not yet include a seasonal dust cycle, so southern summer temperatures are too low and the saturation altitude should be higher.) Modeling of the microphysics of the resulting clouds and precipitation must take into account the strong horizontal transport at these levels.

The mid-latitude Martian circulation has been termed "sluggish" in comparison with the rapid cross-equatorial flow discussed above [Haberle and Jakosky, 1990]. Indeed, a substantial mid-latitude gradient is evident in northern summer with 4 times the vapor column at 60 degrees north as at 30. (The gradients across similar distances in the tropics are, of course, much smaller.) Nevertheless, water vapor amounts increase in spring near 30 degrees long before the permanent water ice cap is a source of vapor [Bass and Paige, 1996]. The seasonal frost cap is also an unlikely source for this water, again pointing to an adsorbing regolith as a substantial reservoir [Jakosky, 1983a; 1983b]. In simulations, most of the water vapor evaporated from the seasonal frost caps is transported polewards by baroclinic waves. Thus, the north polar residual cap accumulates water in northern spring [Houben et al., 1997a]. A similar situation should obtain in the southern hemisphere, but by the time of the arrival of the Mars Polar Lander it is expected that extremely dry conditions should prevail. It is possible that the repeated cycles of evaporation and precipitation, adsorption and desorption that we have described will leave their signatures in isotopic fractionations of the water reservoirs.

An adsorbing regolith represents the interface through which the atmospheric vapor column communicates with any possible subsurface ground ice. The adsorbed water loadings calculated by models are a better upper boundary condition for calculations of the stability of such ground ice than an assumed constant vapor column [Houben, 1999]. Based on the calculations summarized here, near surface ground ice (in the top few meters) should be unstable throughout the southern hemisphere. If the regolith is less adsorbing than we have assumed, ice would be even less stable. This is apparently consistent with the low thermal inertia of the south polar layered terrains [Herkenhoff et al., 1999]. On the other hand, ground ice should be stable in the north polar layered terrains, because of the high relative humidity that prevails year-round in the vicinity of the residual ice cap.

The Martian water cycle we have described includes many interesting physical phenomena (condensation, precipitation, adsorption, isotopic fractionation) which will be subjects of observational and theoretical studies for a long time to come. All of the missions mentioned above will contribute to the elucidation of this exciting story.

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