THE POLAR REGIONS AND MARTIAN CLIMATE: STUDIES WITH A GLOBAL CLIMATE MODEL. R. J. Wilson, M. I. Richardson, and A. V. Rodin, Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08542, rjw@gfdl.gov, Division of Geological and Planetary Sciences, MC 150-21, California Institute of Technology, Pasadena, CA 91125, mir@gps.caltech.edu, IKI, Profsoyuznaya 84/32, 117810 Moscow, Russia; rodin@irtn.iki.rssi.ru

Introduction: Much of the interest in the polar regions centers on the fact that they likely contain the best record of Martian climate change on time scales from years to eons. This expectation is based upon the observed occurrence of weathering product deposits and volatile reservoirs that are coupled to the climate. The interpretation of these records requires an understanding of the exchange of dust, water, and CO₂ between the surface and atmosphere, and the atmospheric redistribution of these species. Here we discuss a global climate model that incorporates these elements at some level and will allow examination of the coupling between polar deposits and global climate systems to begin in earnest.

Model: The GFDL Mars GCM simulates the circulation of the Martian atmosphere from the surface to roughly 90 km [1]. The GCM provides for the transport of an arbitrary number of aerosol tracers and includes parameterizations for the interactive calculation of heating rates at infrared and visible wavelengths due to aerosols. We have examined a range of assumptions about the injection of dust into the lowest atmospheric layer. The water cycle is addressed by including surface ice and regolith water reservoirs, atmospheric transport and ice cloud formation [2]. Recently, a cloud microphysical scheme has been implemented to explicitly track the growth of water ice on dust aerosol [3]. The optical properties of ice-coated dust aerosol are accounted for, allowing investigation of the potential radiative-dynamical-microphysical effects of water ice cloud formation to be examined in a Mars GCM for the first time.

Dust Cycle: Variations in the amount of suspended dust provides a primary control on atmospheric heating and the vigor of the resulting circulation. It is likely that the signature of the dust cycle and its varying intensity at different times is recorded in some fashion in the polar layered terrains. The fundamental issue is the determination of dust raising mechanisms.

To date we have focussed on simulating the evolution of the dust distribution following the onset of global dust storms. A substantial amount of data exist which provide constraints on the character and behavior of dust, including measurements of the surface pressure tide, atmospheric optical depths, measurements of atmospheric temperatures as a function of height, and extended seasonal and local time coverage of air temperatures in a deep layer centered at roughly 25 km. The model does exceptionally well in simultaneously fitting these diverse observations, suggesting that processes after dust injection into the lowest model level are now captured and understood [4].

The injection feedback is the most important individual piece missing. While stresses resulting from large-scale winds can be tuned to raise dust by arbitrarily scaling the lifting stress threshold, simulations have been unsatisfying due to a strong dependence on model resolution suggesting that the true processes are of smaller than resolved scales [5]. Determination of dust lifting processes will require study with higher resolution models, such as the Mars Mesoscale Model described by [6].

The modeled cycles of dust and air temperature do not currently show any significant interannual variability. As only the dust injection rate is specified, this suggests that the atmospheric side of the dust cycle (above the surface layer) possesses little internal variability and subseasonal memory. A possible mechanism for interannual variability is the spatial distribution of dust on the surface, supported by spacecraft and telescopic observations of interannual albedo variations. A future line of research will couple injection and sedimentation to surface budgets of dust to investigate their role in interannual variability.

Water Cycle: The water cycle has been incorporated in the GCM through the prescription of a northern residual ice cap, treatment of water vapor and ice atmospheric transport, regolith diffusion and adsorption, surface water condensation, and surface-atmosphere exchange. Studies of the water cycle to date have concentrated on an effort to determine those physical processes controlling the total atmospheric abundance of water and the annual cycle of water between reservoirs. An understanding of these mechanisms is a fundamental prerequisite for study of the paleo-water cycle. We have undertaken a number of multi-annual simulations of the water cycle with varying degrees of regolith activity and dust loading (differing air temperatures).

As discussed in [2], we find that the primary
"spigot" controlling the amount of water in the atmosphere is the northern residual water ice cap temperature. We describe a feedback control mechanism involving transport to and from the cap over an annual cycle. While the regolith plays a role in altering the distribution of vapor as a function of time, it is of secondary importance for controlling atmospheric water amounts. We also find that substantial amounts of water move between the hemispheres during the cycle, effectively "sloshing" between the seasonal caps with a small net loss of water annually to the southern residual CO₂ ice cap.

An important theoretical consequence of the control mechanism is the prediction of relative water ice cap stability. Simulations initiated with water ice caps at both poles result in a net transfer of water from south to north, and the elimination of the southern cap (the net transport of water in the current climate would be south-to-north were it not for the south polar cap cold trap). This occurs even when the cap surface temperatures are arbitrarily equalized. Transport asymmetries therefore destabilize water at the southern pole even in the absence of a cap temperature difference.

A major unresolved issue in our modeling of the water cycle involves the hemispheric asymmetry of water vapor mass observed by the Viking Mars Atmospheric Water Detector (MAWD). While MAWD suggests a rough doubling of vapor between southern and northern summers, the model shows a much smaller gradient (although the vast majority of water is always in the northern hemisphere). Regolith activity does not allow the model to be in any better agreement with the data. Nor do changes in cloud precipitation rate (although a more detailed treatment of clouds offers some modest hope of better agreement). However, southern spring and summer MAWD data are badly degraded by dust scattering due to two dust storms. Further, the model is in somewhat better agreement with telescopic observations.

**Coupling of Cycles:** The aphelion season (Lₐ~40-130°) is characterized by relatively cold temperatures, low dust loading, and a prominent tropical water ice cloud belt [7]. We have carried out simulations that reproduce the major observable features this period and have found that dust/water ice cloud interactions may be significant in suppressing the depth and amount of the dust aerosol. The predicted water condensation level is ~10 km in the tropics. The simulations show a realistic development and decay of both the tropical cloud belt in the aphelion season and the water ice cloud component of the North Polar hood that forms in autumn and decays in early spring. We suggest that the characteristics of the tropical cloud belt, and hence, the global dust loading and temperature, may be strongly linked to the physical conditions of the residual North polar water ice cap.

**Response to Orbital Variations:** We have begun using the model to examine surface wind patterns and their variation with orbital parameters and have found that surface winds are remarkably resilient to changes in orbital parameters and dust injection [8]. The wind speeds can vary by a factor of 2 between 15° and 35° obliquity. The phasing of the perihelion season modifies the relative intensity of northern and southern summer flows, however the strong zonally-averaged cross-equatorial topographical slope significantly favors the southern hemisphere summer circulation. At high obliquity there is the expectation of increased dustiness due to the intensified Hadley circulation and increased water column at the summer pole due to increased insolation. We are examining the possible influence of increased tropical water ice clouds in these circumstances.