SEASONAL CYCLE OF THE MARTIAN CLIMATE: COMPARISON OF GCM SIMULATIONS WITH SPACECRAFTDATA

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Introduction:

Recent data collected by Mars Express spacecraft complement the full-scale, complex picture of the current Martian water cycle earlier made evident by the MGS mission. In addition to the prominent seasonal migration of atmospheric water, the aphelion cloud belt, thermal structure of the atmosphere and evidences of the wave activity in the atmosphere, several new climate elements in the Martian atmosphere have been discovered. These are: thermal profiles obtained with better than earlier vertical resolution; high-altitude aerosol layers extending up to 80 km in some latitudes, presumably composed of very small particles of mineral dust or both CO_2 and H_2O ice; vertical structure of dust and cloud layers revealed by limb imaging. Also important features related to the current and past climate have been observed at the Martian surface: large inventory of water ice in the area of the South permanent polar cap; glaciers on Tharsis volcanoes; seasonal migration of bound and absorbed water in the regolith. Global mapping of the subsurface water provided by GRS and HEND instruments onboard Mars Odyssey spacecraft also reveal features potentially related to the interactions with the climate system, such as the antipodal areas of the enhanced content of bound water in the equatorial region.

Although some disagreements still exist in the results of water cycle observations by different instruments, GCMs will need to be adapted to the increasing complexity of the observed climate cycle. We present simulations of the current Martian climate with the GFDL Mars GCM and explore the key climate elements recorded by the recent spacecraft missions.

The model:

Below we present results obtained with the GFDL Mars GCM [Wilson and Hamilton, 1996], taking into account the microphysical processes in water ice clouds and making use of radiation code fully coupled with microphysics of dust and clouds. In its basic features the model is identical to what has been reported in previous workshop [*Rodin et al.*, 2003] with several minor improvements:

- two sources of the atmospheric dust are assumed: one due to dust devil activity and the second resulting from the sublimation of the retreating polar caps in spring season. The sources are controlled by threshold relationships, their intensities for different sizes of dust particles are tuning parameters.
- The model has been run at higher spatial resolution (2°×2.4°)
- bimodal dust size distribution was assumed, with a fraction of submicron (0.01 – 0.1 μm) particles.

Water cycle:

Most contemporary Mars GCMs agree in the general picture of the atmospheric water cycle, which was first revealed by the Viking mission. Strong annual maximum of the water column in the aphelion season, gradual meridional migration of water along with subsolar latitude, weaker summer maximum at the South pole accompanied by the local maximum in the winter Northern tropics – all these features are robustly reproduced by the models, implying that the water cycle is in a large degree controlled by winds and thermal structure of the atmosphere. In order to achieve the quantitative agreement between the model and observations, we present sensitivity tests of the

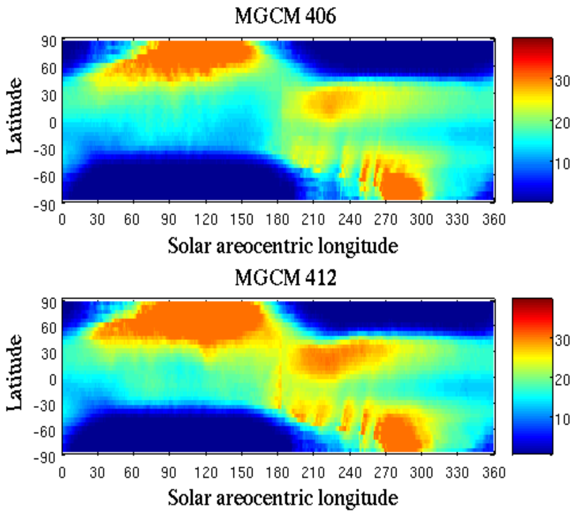

Figure 1. Zonal average seasonal map of the atmospheric water column according to GCM with different dust scenarios (pr. μm).

simulated water cycle to different dust scenarios. Fig. 1 shows two typical zonal averaged maps of water vapor, corresponding to different intensities of dust sources. In the lower panel, polar dust source is twice as strong as in the upper panel. Increasing warming of polar latitudes due to enhanced dust opacity results in weakening of the Hadley cell circulation. As a result, water content in the Northern tropics remains stable during the aphelion season, as

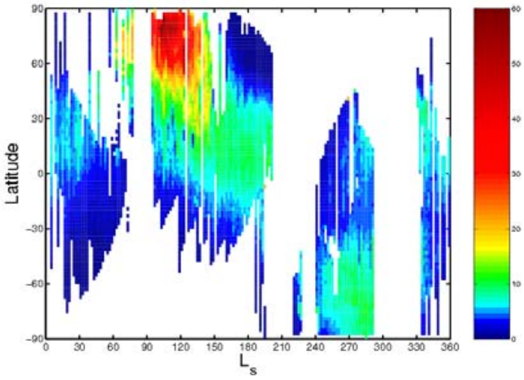

Figure 2. Atmospheric water cycle as observed by SPICAM experiment [Fedorova *et al*., 2005]

observed (see Fig. 2). In the case of stronger circulation (Fig. 1, upper panel) sublimation of the North polar cap is combined with overall northward migration of water in midlatitudes. In spite of the effective control that the dust source specification provides to the water cycle simulation, we were not able to reproduce the low water content currently observed by SPICAM instrument on Mars Express [*Fedorova et al*., 2005]. It can be concluded that quantitative agreement with observations will likely require a more complicated description of surface processes, e.g. adsorption on the regolith or reversible hydration of minerals on the course of the meridional migration of water [*Langevin et al*., 2005].

Submicron aerosol fraction:

Based on the assumption that the submicron aerosol is composed of nonvolatile mineral particles, we imposed a weak source of small dust particles, whose sizes vary from 0.01 to 0.1 microns. Since for the condensation of water vapor on small mineral particles the nucleation time decreases as squared radius, fine dust fraction penetrate through the cloud deck without nucleation. The ability of the fine-sized aerosol fraction to survive in a supersaturated medium without nucleation allows them to avoid gravitational scavenging by condensation, and hence provides the presence of nucleation cores throughout the atmosphere. The availability of nucleation cores at all altitudes has an important consequence in the global atmospheric water cycle, since otherwise water vapor would be able to reach high degree of supersaturation and be advected by the Hadley cell circulation to the poles. GCM experiments employing only large dust particles result in a significant amount of cold-trapping by the polar caps so that water is removed from the atmospheric cycle. Although this mechanism results in the decrease of tropical water during the aphelion season, it would produce a very strong meridional gradient of water and, hence cannot alone explain the observed low abundance of water. The presence of high altitude dust and cloud aerosols provides significant heating due to absorption of solar radiation, as it can be seen from Fig. 3. The nearly isothermal atmosphere above 0.5 mbar is due to additional solar heating. In turn, the decrease of temperature over the North pole is due to faint clouds formed above the 1 mbar level. This thermal structure, as well as the diurnal tide (right panel) is in better agreement with current PFS observations [*Formisano et al*., 2005] than previous simulations without a fine aerosol fraction.

Surface-atmosphere interactions and wave

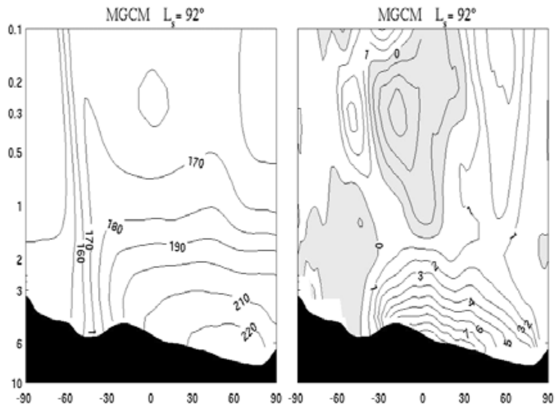

Figure 3. Zonal mean temperature (left) and diurnal tide (right) simulated by the MGCM assuming dust mode with radius 0.1 μm

Wave activity in the water cycle:

Not only does the atmospheric water column imply additional sinks of water at the surface, but the distribution of subsurface water inventory may indicate the significant role of the atmosphere in its formation. Recent observations by Mars Odyssey spacecraft indicate two “wet” anomalies near Terra Arabia and the antipodal province, roughly coinciding with the areas of low thermal inertia [*Jakosky et al.*, 2005]. These areas correspond to a minimal, rather than maximal, annual mean water column [*Smith*

2002]. However, GCM simulations indicate that it is these locations that correspond to the maximal lifetime of surface frost and thermal contrast (Fig. 4) which provide conditions for more intense sink of the atmospheric water into hydrated minerals.

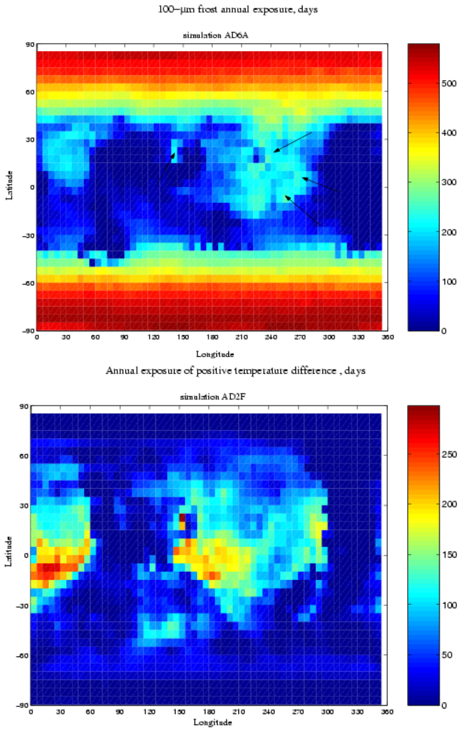

Figure 4. Annual average maps of lifetime of frost exceeding 100 μm (upper panel) and thermal contrast exceeding 30K (lower panel). Locations of maxima in the tropics correspond to neutron flux anomalies observed by Mars Odyssey. Arrows on the upper plot indicate major volcanoes where the physics of frost deposition differs from the rest of Martian surface.

The antipodal structure of the anomalies seen in simulations is a result of a stationary wave forced by a combination of thermal inertia and topography [*Feldman et al.*, 2005]. Stationary and quasi-stationary planetary waves with seasonally evolving zonal wavenumbers ranging from 1 to 3 have been observed in both the thermal field [*Banfield et al.*, 2002] and the water vapor column [*Smith*, 2002, *Fedorova et al.*, 2004]. GCM simulations indicate that the transitions between these waves produce short-lived, coherent waves with zonal wavenumbers 2 and 3 extending from polar latitudes to the equator. These waves, which are likely a result of interference of waves in the polar vortex and low-level western boundary currents in the tropics, appear to provide strong meridional transport of dust and water, in the form of western boundary currents. This mechanism seems to be common for the transport of water out of the subliming North polar cap in the aphelion season, and for the meridional expansion of dust storms at their initial stages.

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