THE EFFECTS OF ATMOSPHERIC OPACITY ON THE SEASONAL VARIATION OF MARTIAN SURFACE TEMPERATURE.

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Introduction: The daily and seasonal variation of surface temperature is a central element in the description of martian climate. Surface thermal inertia and albedo are critical boundary inputs for simulating surface temperature in Mars general circulation models (MGCMs). Thermal inertia (TI) is also of intrinsic interest as it may be related to regolith properties such as particle size and surface character and so high spatial resolution is desirable. The recent mapping of TI at very high (0.25°) spatial resolution was achieved by fitting a thermal model to surface temperature observations obtained over a broad range of several martian years [2]. However, varying atmospheric opacity (dust and water ice clouds) can significantly influence the estimated TI field and this effect was not fully compensated for. Opacity leads to an increase in morning temperature and a decrease in afternoon temperature, thus increasing the apparent thermal inertia. For atmospheric modeling purposes we are particularly interested in assessing the influence of dust aerosol and water ice clouds on simulated surface temperature and using differences between simulated and observed temperatures to constrain our representation of atmospheric opacity. We have used MGS TES surface temperatures, albedo and thermal inertia estimates [1,3,4] to derive improved thermal inertia fields suitable for use in versions of the GFDL MGCM with resolutions from 5x6° to 2x2.4°. In deriving TI at the coarser resolutions appropriate for GCMs, we are able to bin the observed temperatures with sufficient temporal resolution to more clearly resolve the influence of the seasonal evolution of atmospheric opacity. This aids our focus on relating the evolution of observed morning and afternoon temperatures (and thermal inertia estimates) to variations in atmospheric opacity. By construction, the newly fitted *TI* field allows the MGCM to reproduce the observed morning and afternoon temperatures in seasons and locations where our assumptions of atmospheric opacity are well founded. Differences between observed and simulated temperatures typically reflect the influence of dust and/or water ice clouds not accounted for in the simulation. We illustrate the utility of accurate modeling of surface temperatures by presenting a derivation of the spatial distribution of tropical nighttime water ice clouds, which are shown to lead to enhanced nighttime surface temperatures. In a companion presentation, we demonstrate the influence of a global dust storm on surface temperatures.

General Circulation Model: The GFDL MGCM simulates the circulation of the Martian atmosphere with a comprehensive set of physical parameterizations [5,6,7]. These include parameterizations for radiative transfer associated with CO_2 gas and aerosols. The aerosol fields may be specified or can be allowed to evolve with the circulation following prescribed or interactive lifting at the surface. The water cycle is represented by surface ice and regolith water reservoirs, atmospheric transport and ice cloud formation [6]. The predicted ice clouds are optionally radiatively active [7]. The MGCM has a 12-layer soil model. Typically the soil thermal conductivity is assumed to be vertically uniform. However we obtain better fits to observed polar regions temperatures by including the thermal influence of shallow subsurface water ice, which influences the effective thermal inertia on timescales of tens of sols.

Zonal mean surface temperatures: Figure 1 shows the seasonal evolution of simulated zonally-averaged 2pm surface temperature from a reference simulation representing relatively clear sky conditions (fixed dust with τ=0.2). There is a large seasonal variation in temperature that reflects the seasonal migration of the subsolar latitude and the annual variation in insolation due to the eccentric orbit. The advance and retreat of the polar CO_2 ice caps approximately follows the 150 K isotherm. Figure 1 also shows the difference between zonally-averaged TES surface temperatures and those from the reference simulation. These differences highlight the seasonal changes of observed temperatures that may be largely attributed to variations in atmospheric opacity. Temperature differences are minimal during the relatively clear NH spring/summer season when the opacity assumed in the simulation most closely approximates that of the actual atmosphere. The effects of regional scale dust storms at L_s=225 and 320° in the first mapping year (MY24) and a major, planet-encircling dust storm at L_s=187° in the second year (MY25) are evident. There are temperature differences in the immediate vicinity of the polar caps that point up deficiencies in the model simulation of the CO_2 cap evolution. In particular, the model does not predict a residual CO_2 cap in the SH. Temperature differences over the polar caps are due to the influence of dust and ice clouds on retrieved brightness temperatures. This effect is also significant for dust storm events and can be accounted for by comparing observed and simulated brightness temperature.

Cloud Radiative Effects: Figure 2 shows the seasonal variation of 2am and 2pm TES surface temperatures at a location in the Tharsis region. Also shown are the corresponding temperatures from the reference simulation. There are large perturbations in both the daytime and nighttime temperatures due to the dust storm activity noted above. However, it is striking that the observed 2am temperatures are anomalously warm during the NH summer solstice season when the atmosphere is most clear of dust aerosol. Figure 3a shows the spatial pattern of this anomaly in the Tharsis region. There is a prominent tropical water ice cloud belt present in this solstice season [*4*] and MGCM simulations [*7*] suggest that the cloud belt undergoes a significant diurnal cycle, with maximum opacity in the early morning. Figure 3b shows that a simulation with radiatively active water ice clouds is able to reasonably match the observed spatial pattern and amplitude of the surface temperature anomaly. Significantly, the same nighttime water ice clouds that yield atmospheric radiative cooling sufficient to explain the observed tropical temperature inversions in Radio Science data [7] also provide the enhanced IR radiation at the surface needed to account for the observed temperature anomalies. Although previous observations have hinted at diurnal cloud variations, they have been necessarily restricted to daylight hours. Hence our indirect cloud retrievals are the first to spatially map the nighttime clouds and provide an estimate of their thermal influence.

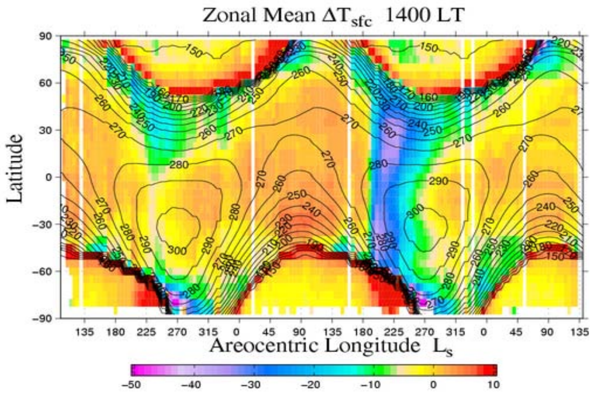

Figure 1. The seasonal evolution of zonally-averaged predicted afternoon surface temperature from a reference MGCM simulation employing a low (τ=0.1) atmospheric dust column is shown with 10 K contour intervals. The shading indicated the temperature anomaly resulting when the reference field is subtracted from the observed TES temperatures. The cooling effect of the regional and major dust storms is clearly evident.

References: [1] Mellon et al. (2000), *Icarus, 148*, 437-455. [2] Putzig et al. (2004) *Icarus, in press.* [3] Christensen et al. (2001) *JGR 106*(E10), 23823-23872. [4] Smith M.D. (2004) *Icarus 108*, 148-165. [5] Wilson R.J. and Hamilton K. (1996) *J. Atmos. Sci., 53*, 1290-1326. [6] Richardson M.I. and Wilson R.J. (2002) *JGR 107(E5)*. 2001JE001536. [7] Hinson D.P. and Wilson R.J. (2004) *JGR 109*, E0100265.

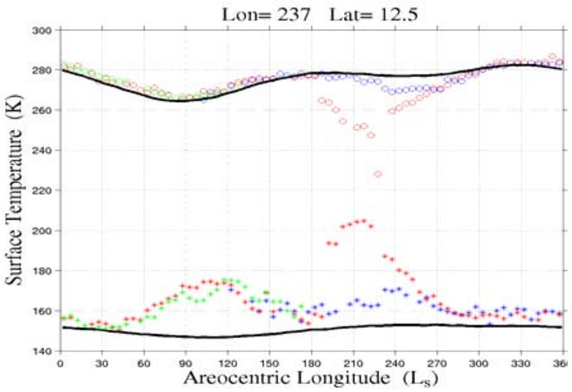

Figure 2. The seasonal variation of 2am (stars) and 2pm (circles) TES surface temperatures for a location in the Tharsis region. Three Mars years are shown: MY24 (blue), MY25 (red), and MY26 (green). The solid curves represent the corresponding temperatures from the reference simulation. The large nighttime temperature anomaly present around NH summer solstice is attributed to enhanced IR radiation from nighttime water ice clouds

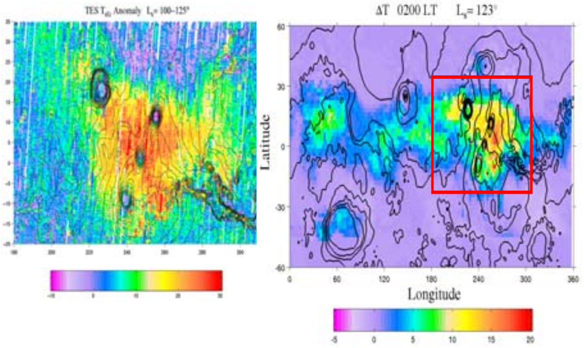

Figure 3. (a) Surface temperature anomaly field constructed by subtracting the simulated reference temperature field from observed TES nighttime surface temperatures. The MGCM simulation (2x2.4° resolution) is in very close agreement with TES observations at L_s= 45° when the assumed low atmospheric opacity is most realistic. (b) The simulated surface temperature anomaly, obtained by subtracting the reference temperature field from the corresponding surface temperatures from a simulation with radiatively active water ice clouds. The red box encloses the region shown in panel (a).