COMPARISON OF MARS GCM DUST STORM SIMULATIONS WITH VIKING MISSION OBSERVATIONS. R.J. Wilson, GFDL/NOAA, P.O. Box 308, Princeton, NJ 08542. e-mail rjw@gfdl.gov, M.I. Richardson GPS/Caltech, 1200 E. California Blvd. Pasadena, CA 91125, e-mail mir@gps.caltech.edu.

To date, comparisons of Mars General Circulation Model (MGCM) simulations with spacecraft infrared observations have generally focussed on the zonal mean temperature structure and derived wind fields [1, 2, 3]. The recent identification of, and accounting for a surface radiance bias in the Viking IRTM 15 µm radiances has enabled atmospheric 0.5 mb (~25 km) temperatures (T_{15}) to be recovered [4] providing a fresh look at the data. In this presentation, we consider the evolution of the diurnal variation of T_{15} during the rise and subsequent decay of two major dust storms observed by the Viking spacecraft in 1977. The profound influence of aerosol heating on the temperature structure of the atmosphere is evident in the increase in diurnally averaged temperature and in the prominence of the thermal tides following storm initiation. The dust storm events are also reflected in the record of surface pressure, opacity, and near-surface temperature at the two Viking Lander sites, VL1 and VL2. The semidiurnal tide provides an effective measure of aerosol heating as a consequence of the broad meridional scale and large vertical wavelength of the dominant mode of response to sun-synchronous semidiurnal thermal forcing. The focus on thermal tides provides a basis for relating the observed atmospheric response to estimates of thermotidal forcing due to aerosol heating. We refer to the semidiurnal surface pressure variation as $S_2(p)$ and the semidiurnal T_{15} variation as $S_2(T_{15})$.

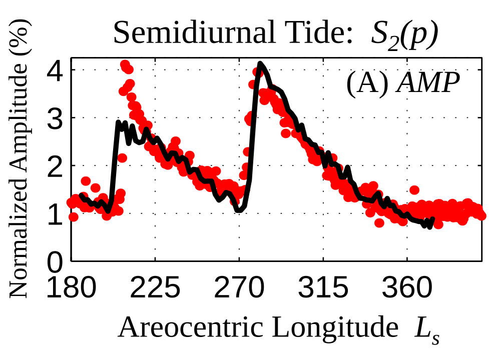

Figure 1: Semidiurnal Tide Amplitude at VL1 during the first Mars year.

We present MGCM simulations of the evolution of the IRTM temperatures and the surface pressure observations as a means of gaining insight into the state of the atmospheric thermal, dynamic and aerosol fields. The simulations have been carried out with a comprehensive MGCM developed at the Geophysical Fluid Dynamics Laboratory. We have examined a range of assumptions about the injection of dust into the lowest atmospheric layer and compared the resulting simulated atmospheric temperature response with the observations. The simulations employ a resolved particle size distribution representing particles ranging from 0.1 to 4.0 µm. The calculation of solar and IR heating rates due to aerosol takes into account the evolving aerosol size distribution.

Figure 1 shows a comparison of the observed and simulated amplitude of $S_2(p)$ corresponding to the VL1 site during the 1977 dust storm season. We imposed a rapid, episodic injection of dust into the lowest model atmosphere layer in a manner similar to that in previous dust storm studies [5, 6]. The correspondence between the simulated and observed semidiurnal tide amplitude and phase following the 1977b global dust is very good. There are distinct differences in the semidiurnal tide following the 1977a global dust storm. The simulation was conducted with a zonally-uniform aerosol source, allowing the model circulation to determine the preferred regions for efficient dust lofting. The Solis Planum and Hellespontus regions are favored during the 1977b global dust storm simulation, in general agreement with observations. We speculate that the simulated aerosol distribution during the onset phase of the 1977a dust storm differs from the actual distribution so that the tide amplitudes (and phases) only achieve a good match after the aerosol becomes more uniformly mixed in space. We will report on simulations that explore the influence of more localized dust raising.

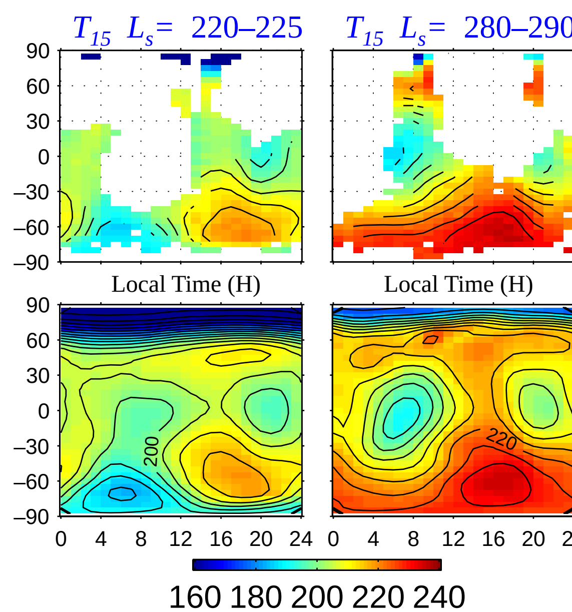

Figure 2. IRTM (top) and MGCM (bottom) T_{15} plotted as a function of latitude and local time for the 1977a (left) and 1977b (right) dust storm periods.

Figure 2 shows the diurnal variation of T_{15} for a period following the 1977a dust storm and for a period at the height of the 1977b dust storm. The correspondence between the simulated and observed temperatures is quite good for both dust storm periods. In particular, the character of the tidal response is faithfully captured by the MGCM simulation. In each case, there is a prominent semidiurnal temperature variation at tropical latitudes that is evidently consistent with the agreement between the observed and simulated semidiurnal surface pressure variation. There is also a strong diurnal tide in the IRTM data at extratropical latitudes. This signal is much stronger for the 1977a storm (and peaks further poleward) than for the 1977b storm, although the (observed and simulated) thermotidal forcing is stronger in the latter case. This difference in response is a consequence of different zonal flows as has been confirmed with linear tide model calculations. The 1977a storm simulation indicates a residual westerly flow in the Southern Hemisphere while the 1977b storm simulation is characterized by easterly flow in the summer hemisphere. Hence, the diurnal tide response is a consequence of both the strength of the thermotidal forcing and the transmission characteristics of the atmosphere. The simulated $S_2(p)$ is in excellent agreement with the observations for both periods shown in Fig. 2.

The close agreement between model and observation for both the T_{15} and $S_2(p)$ makes a strong case that the thermotidal forcing due to aerosol has been reasonably well simulated. We propose that the simultaneous satisfaction of the T_{15} and surface tide data place a strong constraint on the aerosol evolution. We have found that the presence of large particles are necessary to obtain the initially large but rapidly decaying $S_2(P)$ amplitudes observed at VL1 immediately after the onset of each simulated storm. These particles rapidly fall out, leaving intermediate particles (~1 μm) to supply the bulk of the radiative heating. This result is broadly consistent with the conclusion that 1 μm particles can account for the observed decline in Mariner 9 0.3 and 2.0 mb temperatures during the dissipating phase of the 1971 global dust storm [7]. Smaller particles are required to provide sufficient heating to maintain realistic temperatures at high latitudes during the decay phase of the two storms.

In the GCM simulation, aerosol extends to 60 km during dust storm conditions, in general agreement with observations of aerosol at these heights following the peak of 1971 dust storm observed by Mariner 9 [8]. The dust distribution at the peak of the 1977b global dust storm is interesting in that the presence of dust particles at high altitudes (>25 km) over the South Pole is indicated. The advection of dust over the pole was noted in Wilson [3] and attributed to zonal-mean meridional motion induced by the thermal tides. The model circulation indicates a pole-to-pole circulation that leads to a realistic simulation of the polar warming that was coincident with the 1977b global dust storm [3, 9, 10].

The dissipating stage of the two dust storm simulations is characterized by a dust distribution that is evolving toward smaller particles. It is interesting to note that the amplitude of the simulated semidiurnal tide in Fig. 1 continues to decrease, falling below the level of the observed tide after L_s ~ 360. Depending on the presence of sufficient small particles, the simulated T_{15} temperatures can remain too warm relative to the decaying IRTM temperature. A weak, but steady injection of mainly large particles into the atmosphere well after the 1977b storm has relatively little impact on the T_{15} temperature but provides for a more realistic forcing of the semidiurnal surface pressure oscillation. This also maintains a low altitude size distribution that is more realistic, with the dominant contribution from opacity due to 1.6 μm particles. This is an important consideration for simulating the climate of the aphelion season, a period that is evidently characterized by a relatively unchanging aerosol distribution.

In summary, we have found that close quantitative agreement can be demonstrated between MGCM temperature simulations and spacecraft data. We have additionally found further support for the correction for a surface radiance bias in the IRTM T_{15} temperatures [4]. We propose that this comparison represents the best quantitative agreement between observations and models to date. This provides confidence in the use of models for interpolating/extrapolating observed temperature fields and in synthesizing varied observations. The MGCM provides self-consistent dynamics and aerosol fields, which enable detailed studies of the model circulation.

References: [1] Haberle R.M. et al. (1993), JGR 98, 3093-3123. [2] Hourdin F. et al. (1993), JAS 50, 3625-3640. [3] R.J. Wilson (1997), GRL, 24, 123-126. [4] Wilson R.J. and Richardson M.I. (1999), Icarus, submitted. [5] Murphy J.R. et al. (1995) JGR, 100 26357-26376. [6] Wilson R.J. and Hamilton K. (1996), JAS, 53, 1290-1326. [7] Conrath B.J. (1971), Icarus, 24, 36-46. [8] Anderson E. and Leovy C.B. (1978), JAS, 35, 723-734. [9] Martin T.Z. and Kieffer H.H. (1979), JGR, 84, 2843-2852. [10] Jakosky B. and Martin T.Z. (1987), Icarus, 72, 528-534.