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An interpretation of Martian Thermospheric Waves Based on Analysis of a General Circulation Model

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An interpretation of Martian thermospheric waves based on analysis of a general circulation model

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Abstract.
Planetary-scale longitudinal variations in density observed by the Mars Global Surveyor accelerometer in the 125 km region can be qualitatively reproduced by the NASA Ames Mars general circulation model in the 80 km altitude region, but only when locations having specific local times are used in the analysis. If the model results are averaged over all local times, the high-altitude longitudinal variations nearly disappear, leaving only a small stationary wave 1 pattern, consistent with theory and previous modeling studies. This analysis suggests that the observed wavelike structures are a result of sampling tidal modes at a limited range of local times, rather than by topographically forced Rossby waves as previously suggested.

1. Introduction

The orbiting Mars Global Surveyor (MGS) spacecraft carries an accelerometer instrument, which was designed to retrieve densities in the Martian thermosphere during the aerobraking phase of the mission [*Albee et al.,* 1998]. Preliminary results of this investigation are described in *Keating et al.* [1998a] (henceforth *K98*), with model interpretation in Bougher et al. [1999]. *K98* reported significant zonal variations in density in the Martian thermosphere between 30°N and 60°N, above the 125 km level. Similar density variations persisted over nearly all of northern autumn and winter [*Keating et al.* 1998b]. It has been suggested that the density variations are associated with topographically forced stationary Rossby waves that propagate into the thermosphere, since the MGS observations have wavelengths comparable to these modes [*Hollingsworth and Barnes* 1996].

The NASA Ames Mars general circulation model (MGCM) is used to present an alternative explanation for the observations. It should be noted that the MGCM is not designed to simulate physical processes that become increasingly important above 80 km, such as non-LTE effects or molecular species separation. However, thermospheric models of Mars have hitherto only exercised latitude and local time as the horizontal co-ordinates [Bougher et al. 1993], and as such, are not suited to investigations of longitudinal variability.

Details of the MGCM are given in *Haberle et al.* [1999]. However, some changes to this model have been made for the present work. A new topography dataset obtained using the Mars orbiting laser altimeter [*Smith et al.* 1999] has been incorporated into the model. In addition, the visible optical depth of atmospheric dust varies with latitude. For the present case (southern summer solstice), the optical depth is a function of the form $\tau = A\cos(\phi - \phi_0)$, where ϕ_0 is the subsolar latitude (25.2°S), and A is 0.6. Where this function is negative, τ is set to zero. The dust extends up to approximately the 0.01 mb level. This distribution results in a good fit between MGCM temperatures and measurements made by the thermal emission spectrometer (TES) at this time [*Hollingsworth et al.* 1999]. The present MGCM has 31 layers in the vertical, with a vertical resolution of approximately half a scale height. The pressure at the model top is 3.0×10^{-7} mbar ($\approx$ 130 km).

2. MGCM and Data Comparison

Figure 1(a) shows 30-sol [1] time-averaged normalized density on the 80 km geopotential surface of the MGCM. This level is chosen as it is just below the lowest height of the so-called sponge layers, in which a linear momentum drag is applied to eliminate spurious

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[1]A sol is a Martian day and is approximately 24 hours and 40 minutes

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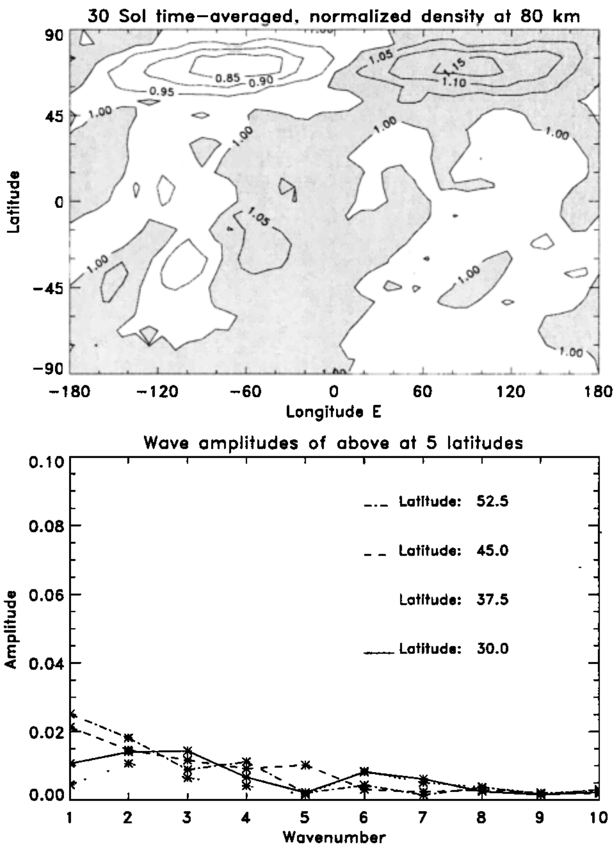

Figure 1. (a) The top panel shows 30 sol time-averaged normalized density at the 80 km level. the normalization is achieved by dividing the time-averaged density at each point by the time-and-zonal average at its latitude. Locations having values > 1 are shaded light grey. (b) The bottom panel shows a Fourier transform of the longitudinal variability in the normalized density over the latitude range observed by Mars Global Surveyor during phase one aerobraking.

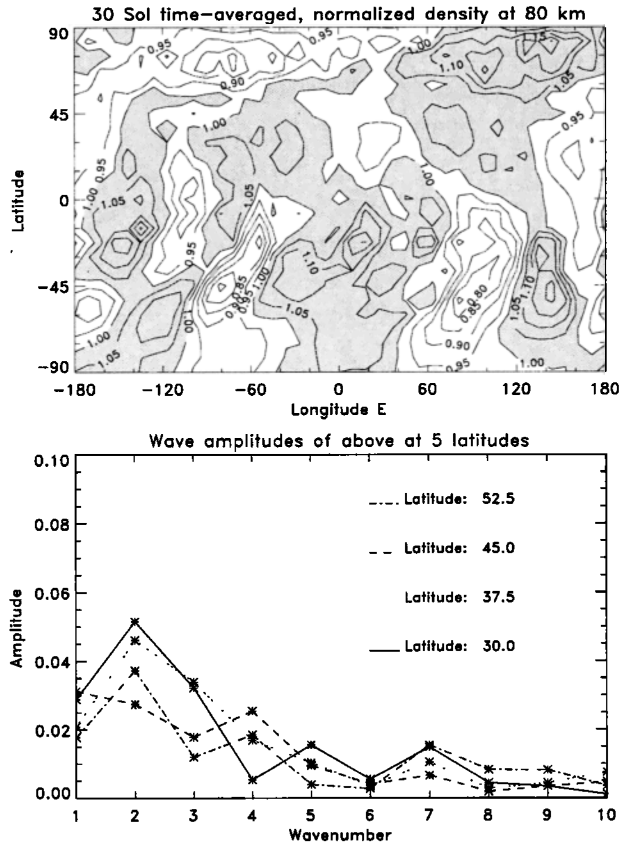

Figure 2. As for figure 1, except the time averaging only includes those MGCM locations where the local time lies between 12 pm and 2 pm.

wave reflection from the model top. Since such friction changes the wind and thermal structure of the model, our analysis is carried out below the sponge layers. The only activity present is a weak wave 1 in the northern (winter) midlatitudes, which is consistent with previous studies [*Hollingsworth and Barnes*, 1996]. Figure 1(b) shows normalized wave amplitudes obtained from a Fourier decomposition of Figure 1(a), at latitudes that coincide with those observed by MGS. The amplitude of wave 1 is O(2%) of the mean zonal value. Some wave 2 activity is evident, although its amplitude is even smaller.

The above analysis is repeated, but this time only those locations where the local time is between 12 pm and 2 pm are considered. This is done in order to duplicate as closely as possible the sampling in local time of MGS during the 20-orbit solstice period closely studied in *K98*. The results are shown in Figure 2(a), and indicate much stronger wave activity at the latitudes sampled by MGS, as well as considerable wave activity in the summer hemisphere. Normalized wave amplitudes are shown in Figure 2(b). When compared to Figure 1(b), it can be seen that the second sampling method causes a significant increase in the apparent amplitude of waves 2-4.

Note that the amplitude of a true stationary wave should be independent of the local time at which sampling occurs at. This does indeed appear mostly to be the case for wave 1 in the winter midlatitudes. The fact that waves 2-4 increase by a large amount in amplitude, particularly in the subtropics, using the second sampling method, is an indication that waves 2-4 vary diurnally, and are smoothed out by averaging the model results over all local times.

A further illustration of the effects of sampling at one local time is shown in Figure 3. The solid line is the time-averaged density at the 80 km level at 45 °N, and, as in Figure 1(a) a low-amplitude stationary wave 1 can be seen. When the analysis is repeated, but now including local times between 12 pm and 2 pm, the variability is as indicated by the dashed curve. Waves 2-4 appear far more substantial.

Figure 3 should be compared with Figure 6 of *K98*, which shows density interpolated to the 125 km level. A broad maximum lies at 90°W, and another at 90°E, with peaks at 15% and 30% respectively above the

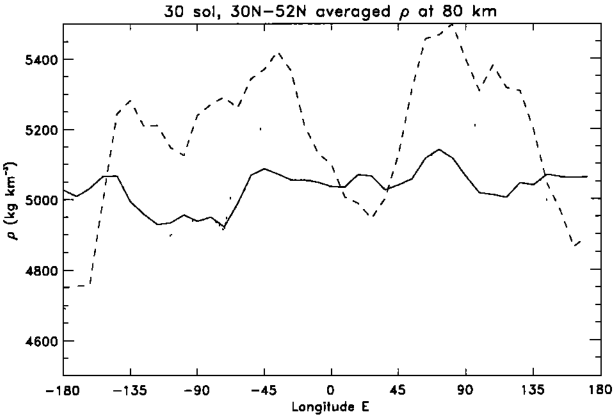

Figure 3. Solid line: 30 sol time-averaged density at the 80 km level (kg km^{-3}) averaged between 30°N and 52°N inclusively. Dashed line: as above but the averaging process only includes those MGCM grid points where the local time lies between 12 pm and 2 pm. Dotted line: as above but the averaging process includes those MGCM grid points where the local time lies between 11 pm and 6 pm.

mean. The longitudinal pattern is similar to that indicated in *K98*, although although the wave amplitudes in the MGCM are smaller than observed.

Keating et al [1998b] suggest that a wave 2 feature similar to the observations described above persists in measurements taken from 11 am to 6 pm. Figure 3 (dotted curve) shows that when the MGCM analysis is repeated using an 11 am to 6 pm window, a pattern emerges having approximately the same phase and amplitude. A full comparison between model and data over this extended period is a source for future work once the data are available from the Planetary Data System (PDS).

3. Conclusions and Further Work

A comprehensive study of tidal activity in the MGCM such as in *Wilson and Hamilton* [1996] is not performed here, since the only aim of this paper is to show that the MGS observations may be caused by diurnally varying modes sampled at a small local time interval. In the future we intend to determine which modes in the MGCM are responsible for the pattern shown in Figure 2(a). Such work will examine effects such as wave interference and length of the sampling window on modes having periods less than 12 hours.

The interpretation of the thermospheric observations as stationary Rossby waves requires a waveguide to duct these modes into the thermosphere. This contradicts previous modeling studies (e.g., *Hollingsworth and Barnes*, [1996]) which show that topographically forced Rossby waves having wavenumbers >1 should not be able to propagate above 50 km in altitude. Invoking interfering large-amplitude tidal modes as a mechanism to explain the observations eliminates the need for such a waveguide.

Increased atmospheric dust loading should lead to an amplification of the wave 2-4 pattern because of an enhanced atmospheric tidal response [*Bridger and Murphy*, 1998]. This is exactly what was reported by *K98* following a hemispheric dust storm in December 1997 [*Christensen et al.* 1998], and further supports our interpretation of the observations.

The discrepancy between the wave amplitudes shown in Figure 2(b) and those described in *K98* is most probably because the measurements are obtained at the 125 km level, where diurnal variability and tides are much larger than at 80 km [*Bougher et al.*, 1993]. Further work should therefore include simulations using thermospheric models that incorporate longitude and local time as separate independent coordinates. Such models would also shed light on possible phase changes in the wave pattern in the 80-125 km region.

We finally note that the MGS accelerometer obtained measurements of density over a range of different seasons, local times and locations. Analysis of the whole data set should provide an important insight into the behaviour of diurnally varying modes in the Martian atmosphere.

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