THERMAL TIDES AND STATIONARY WAVES REVEALED BY MGS TES.

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Introduction: Atmospheric temperature retrievals from TES observed radiances make possible the most complete separation of the constituent wave modes evident in Mars atmosphere to date. We use all of the data from the pre-mapping mission phase, which affords good sampling of the diurnal tides and stationary waves. TES retrievals of atmospheric temperature on a grid of pressure levels are the fundamental data set in this study. We then fit this data to selected fourier modes in longitude and time for latitude and L_s bins. From this we have identified the amplitudes and phases of the diurnal and semi-diurnal tides, the first few (gravest) stationary waves and standing waves, as well as an estimate of the zonal and time mean temperature meridional cross sections. These results will be compared with existing models and theory. A possible critical layer for the sun-synchronous diurnal tide may indicate 40 m/s surface zonal wind near 50S for L_s=255-285.

Data Set: *Orbits and Coverage.* Before the MGS's mapping mission phase, its orbit slowly varied with time, affording the instruments views of the planet that changed with time. The current mapping orbit views each latitude at exactly 2 times of day. For questions regarding the thermal tides on Mars, it is crucial to use the data from the pre-mapping phase of the mission. Atmospheric temperature variations that occur on timescales of less than or equal to a sol are not properly resolved from the mapping orbit. The scattered nature of the pre-mapping data allows us to at least partially resolve the short period variations that constitute thermal tides. When the spacecraft was near apoapse in the pre-mapping mission phase, TES observations scanned the instrument field of view across the planet, sensing many combinations of latitude, longitude, and local time in a short period. These sequences, which primarily covered the southern hemisphere are what we make extensive use of in this work.

TES Retrievals. The TES instrument measures atmospheric thermal emission using the 15 micron CO_2 absorption band complex. The TES team has prepared a data set reporting the atmospheric temperature of each retrieval on a standard pressure grid with a half scale height interval, starting at 6.1 mbar. The retrievals of atmospheric temperature fom TES spectra are subject to several noise sources, with magnitudes of between 2-6K.

Modes Considered: This work is focused on the wave modes in Mars' atmosphere that are either constant with time and of integral wave number in longitude, or varying with a frequency that is an exact multiple of 1 sol^{-1}, or some combination of both of these. That means we are interested in the zonal mean temperatures, stationary oscillations which are fixed in longitude, and the diurnal tide and its higher harmonics (e.g., the semidiurnal tide). Finally, we are also interested in standing wave modes, i.e., those that are fixed in longitude and have time variations that are multiples of exactly 1 sol^{-1}. The other wave modes not within these groups represent wave modes that are neither fixed to surface features, nor directly forced by the sun. They are the traveling waves that are usually called "weather" by most, and will be the subject of our next work with this data set. In fact, to better reveal the "weather," we must first remove the well defined variations under scrutiny here.

Estimation: *Amplitudes and Phase.* To estimate the amplitudes of the different wave modes outlined above, we used a combination of binning and least squares fitting. The data set we used from the TES team was already sampled on 9 distinct pressure levels, each separated by half a scale height. We kept that vertical sampling, and broke the data into L_s blocks of 15 degrees to resolve seasonal and dustiness changes well. We chose to bin the data further by latitude, and then within each of those bins, fit fourier series in longitude and time to the data. This proved to be simple, and allowed us to keep relatively high resolution in the meridional.

Because our data set neither uniformly nor even completely samples the longitude-time domain, the process of ascribing amplitudes to the modes of interest is challenging. Aliasing is a significant problem. We used least squares fitting of the modes rather than periodogram techniques. A least squares fit will return formal error bars to accompany the retrieved parameters. However, the formal error bars only represent how well the model fits the existing data. It includes no estimate of aliasing possibilities. To include this, we modeled the error bars using a monte carlo technique instead. We took the observing pattern for each set of $L_{s,}$ altitude and latitude bins that we were fitting, and manufactured many sets of fake data with 2K observational errors. Then by examining the standard deviations of the retrieved mode amplitudes, we estimated the combined effects of the noise in the data, as well as the gaps in the coverage contributing to aliasing.

Results: In our results which are plots of amplitude and phase as a function of latitude and height, regions were left blank for one of several reasons. The strongest reason was due to the least squares fit being ill-determined. This typically resulted from there being fewer filled bins (in longitude and time) than the number of modes being fit. The regions affected by this were at all latitudes in the north and near the ground. Another reason was if the retrieved amplitude of the mode was less than the estimate of the error bars on that mode. That is, that mode is consistent with a value of zero. The amplitude for the mode that we retrieved in those locations may be correct, but we chose to cut those values from the plot to ensure that the values displayed are significant. Finally, we did not display the few scattered values which had error bars associated with them greater than 5K.

$s=0, \sigma=0$. For many values of L_s we were only able to constrain this mode well as far north as about 30S. We were also unable to constrain this mode well in the lowest half scale height at any latitudes. Results like these have been presented by Conrath et al. (1999) showing significantly more complete coverage. However, their results have not been filtered to remove the possible effects of incomplete, non-uniform sampling in the presence of waves. We are in the process of carefully comparing these results with those of Conrath et al. (1999) in an effort to understand those effects. The effects of the dust opacity changes as the seasons progress can be seen in these results similar to that documented in Conrath et al. (1999).

$s=1, \sigma=-1$. Throughout much of the southern hemisphere, the diurnal tide is well resolved by the TES data, with amplitudes of order 4K. Simple tidal theory predicts a constant phase of about 90° poleward of ~30°, because in that latitude range, this mode is expected to lag the sun and not propagate vertically. In fact, this is what we generally see for the southern hemisphere for most of the L_s values we cover. The most evident departure from this is from L_s =255-285, poleward of about 50S and above 2 scale heights. In this region, we see the amplitude significantly decrease (down to about 2K), and the phase change to leading the sun by about 90°. One possible explanation for this phenomena is a critical layer, where the phase speed of the wave matches the wind speed. This should result in a phase reversal from above this critical layer to below it, as is observed. Since the forcing is predominately below the altitude of this critical layer, the amplitude should precipitously decrease above the layer, also as observed.If this mechanism is responsible for the observations, using the thermal winds from the zonal mean temperature cross section, one can infer the surface zonal wind at these locations to be roughly 40 m/s. If real, this high value would certainly have some dust lifting consequences.

There are two aspects of this mode in the region in which it vertically propagates which are interesting. The first is that this region extends to nearly 50S for some L_s values. Simple tidal theory predicts that vertical propagation stops at 30S, although modelling work (Wilson and Hamilton, 1996) shows it extending poleward of 30 degrees. The second aspect of interest is that the amplitude does not seem to grow with height inversely with the density to maintain a constant energy flux through the domain. Instead, the amplitude is roughly constant with height near the equator, perhaps decreasing with height at more values of L_s than increasing. Both of these aspects of this dominant tidal mode are puzzling and need further explanation.

Outside of the latitude band where the mode appears to vertically propagate, it is interesting to note the distribution of amplitude as a function of location and season. The amplitude is very high at the same locations and the same season as the large Noachis dust storm near L_s =225-240. This is expected, as a large dust opacity should indicate a strong coupling between the solar forcing and the atmosphere's thermal response. This range of L_s in fact exhibits amplitudes in excess of 8K as high as 4 scale heights above the surface, perhaps suggesting that the dust is well mixed very high into the atmosphere. The amplitude decreases again as the seasons advance, in concert with the dust opacity, until at L_s =310-320 it shows amplitude greater than 8K over a broad region of the southern extra-tropics, two or more scale heights up. This period once again coincides with one of the other significant dust storms already identified by TES retrievals (Smith et al. 1999). This dust storm appears to excite high amplitude diurnal tide even higher than that during the Noachis dust storm, perhaps suggesting that the dust was more concentrated at altitude than below.

Other Modes. Other modes that have been found to exhibit significant power are the $(s,\sigma)=(1,0)$ stationary wave mode, the (0,1), (0,2), (0,3) zonally symmetric tidal modes, and the (1,1) standing wave mode. If time permits, analysis and discussion of these modes will be included.

References: Conrath, B.J., J.C. Pearl, M.D. Smith, W.C Maguire, S. Dason, M.S. Kaelberer, P.R. Christensen, 1999. Mars Global Surveyor Thermal Emission Spectrometer (TES) observations: Atmospheric temperatures during aerobraking and science phasing. *J. Geophys. Res*., submitted. Smith, M.D., et al., 1999. *JGR* submitted. Wilson, R.J., K. Hamilton, 1996. Comprehensive model simulation of thermal tides in the Martian atmosphere. *J. Atmos. Sci.*, **53**, 1290-1326.