ATMOSPHERIC TIDES ON MARS IN THE PHOENIX LANDING SEASON.

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Introduction

Our research focuses on characterizing the atmospheric tides on Mars around the time of the Mars Phoenix landing. For this we compared three different datasets: insitu measurements during the entry, descent and landing (EDL) phase of the Mars Phoenix lander [1, 2], orbiter data from the Mars Climate Sounder (MCS) on board the Mars Reconaissance Orbiter (MRO) [3] and the Mars Global Circulation Model from the Laboratoire de Météorologie Dynamique (LMD) [4].

As a first step we reconstructed the temperature profile along the EDL trajectory of the Mars Phoenix lander and analyzed the fluctuations of the temperature about its background value. In the next phase we studied the nonmigrating tides in the same season by analyzing data from the MCS for all available zones. Finally we compared and complemented our results with simulated data from the LMD, taken from the Mars Climate Database (MCD). For this we took two different approaches: we studied the contributions of the migrating tides by calculating the zonal mean profiles, and the contributions of the nonmigrating tides by calculating the daytime mean profiles.

We conclude our analysis with a few remarks on the vertical wavelengths observed throughout this study.

Mathematical background

It is possible to write the atmospheric temperature field as a Fourier series in function of the local time t_L, latitude θ, longitude λ and altitude z:

$$\sum_{n,s} T_{n,s}(z,\theta)\cos\left(n\Omega t_L + (s-n)\lambda - \phi_{n,s}(z,\theta)\right)$$

where Ω is the planetary rotation rate, s is the wavenumber and n represents the frequency (eg. $n = 1$ for a diurnal mode, $n = 2$ for a semidiurnal mode, and so on). Throughout our study we've applied Fourier analysis on the atmospheric profiles, both in space (λ) and time (t_L).

When we keep the local time t_L constant, we see that the terms representing the migrating tides ($s = n$) will only contribute to the background temperature in the Fourier analysis. Only the nonmigrating tides ($s \neq n$) will show up in the spectrum.

When we liberate the time t_L again and instead calculate the zonal mean by averaging over all longitudes λ, it can be shown that we will only see the migrating modes in the Fourier spectrum.

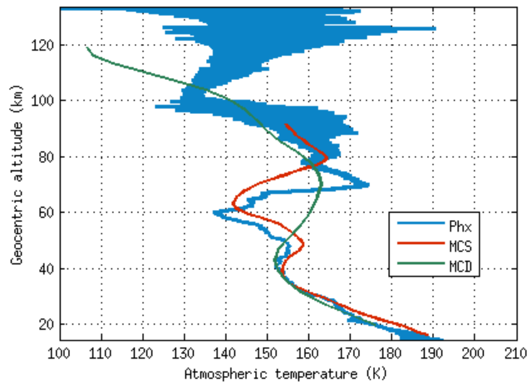

Figure 1: Mars Phoenix reconstructed profile *(blue)*, Mars Climate Sounder *(red)* and Mars Climate Database *(green)* profiles near the time ($t_L = 16.33h$, $L_S = 76.6°$) and location ($68.22° N$ $234.25° E$) of the Mars Phoenix landing.

Phoenix entry, descent and landing reconstruction

The Mars Phoenix lander recorded accelerations and rotation rates during its atmospheric entry. By reconstructing the flown trajectory and combining it with the axial acceleration measurement, the atmospheric density profile was reconstructed [1]. Next, hydrostatic equilibrium and the ideal gas law were used to derive pressure and temperature profiles respectively. The latter corresponds well to an MCS limb profile obtained at a similar time and location as the Phoenix landing site ($68.22° N$ $234.25° E$), this is shown in Figure 1.

We studied the fluctuations of the temperature by subtracting the background temperature from the profile and Fourier analysing the result. We found vertical wavelengths that, according to classical tidal theory [5], correspond to diurnal and semidiurnal modes, but the strongest contribution comes from modes with intermediate vertical wavelengths. This leads us to the conclusion that classical tidal theory may not suffice to describe the atmospheric tides in this case. We'll come back to this in the last section.

Mars Climate Sounder

In order to characterize the atmospheric tides at the season of the Mars Phoenix landing, we studied data from the Mars Climate Sounder taken at Mars Year 29, month 3 ($L_S = 60 - 90°$). We averaged all daytime ($t_L \approx 15h$)

and nighttime ($t_L \approx 3h$) profiles separately over a $5^\circ \times 5^\circ$ grid covering the planet surface. We then Fourier analyzed these day- and nightside profiles in the longitudinal direction, for each altitude and latitude. The resulting Fourier amplitudes for the daytime profiles can be seen in Figure 2 for all zones and in Figure 3 for the Mars Phoenix landing zone ($68.22^\circ N$) specifically.

As we are working in a frame where the local time is kept constant, we will only see a sum of nonmigrating tides with wavenumber s and frequency n (1/sol) such that $|s-n| = m$ in each wave-m contourplot, where $m = 1, 2, 3$. A more detailed treatment on this can be found in literature [6, 7, 8]. At the Phoenix landing latitude the wave-3 mode is clearly dominant at higher altitudes. This can be a combination of different tidal modes, such as the diurnal $n = 1$ mode with wavenumber $s = -2$ or the semidiurnal $n = 2$ mode with wavenumber $s = -1$. This was also observed in [7]. One way to get a clearer picture of each contribution is by looking at the day-night average and difference profiles, which will only show the semidiurnal and diurnal modes respectively [6]. For the wave-3 mode at the Phoenix landing zone we find equal contributions of the diurnal and semidiurnal tidal modes.

Mars Climate Database

We compared the results from our Mars Climate Sounder study with a similar analysis of profiles obtained from the Mars Climate Database, again limiting ourselves to solar longitudes of $L_s = 60 - 90^\circ$. For all local times we divided the profiles into a $3.75^\circ \times 5^\circ$ grid and then studied the migrating and nonmigrating tides separately.

First we averaged the profiles over all longitudes, resulting in zonal mean profiles in function of local time t_L. As discussed earlier, these will only show the migrating tides in the Fourier analysis and the result is given in Figure 4. We can see that the diurnal migrating tide is in many places dominant compared to the semidiurnal migrating tide, especially in equatorial regions where it has amplitudes up to $16K$. In the midlatitudes the semidiurnal tide becomes comparable to the diurnal tide at altitudes around $0.1 - 1Pa$. For the Phoenix landing zone we find a dominant migrating diurnal tide with an amplitude up to $4.61K$ in the upper part of the profile, accompanied by a migrating semidiurnal tide with an amplitude up to $1.35K$ closer to the ground.

As a second case we kept the local time constant at $t_L = 15h$ and did the Fourier analysis in the longitudinal direction, giving us amplitudes that should be comparable to those measured by MCS. The result for the Mars Climate Database profiles is given in Figure 5. When comparing this with Figure 2 (note the difference in the temperature and pressure scales) we see that the general contours compare relatively well, but the amplitudes seem to be more smudged out for the MCD case. One of the bigger differences lies in the southern part of

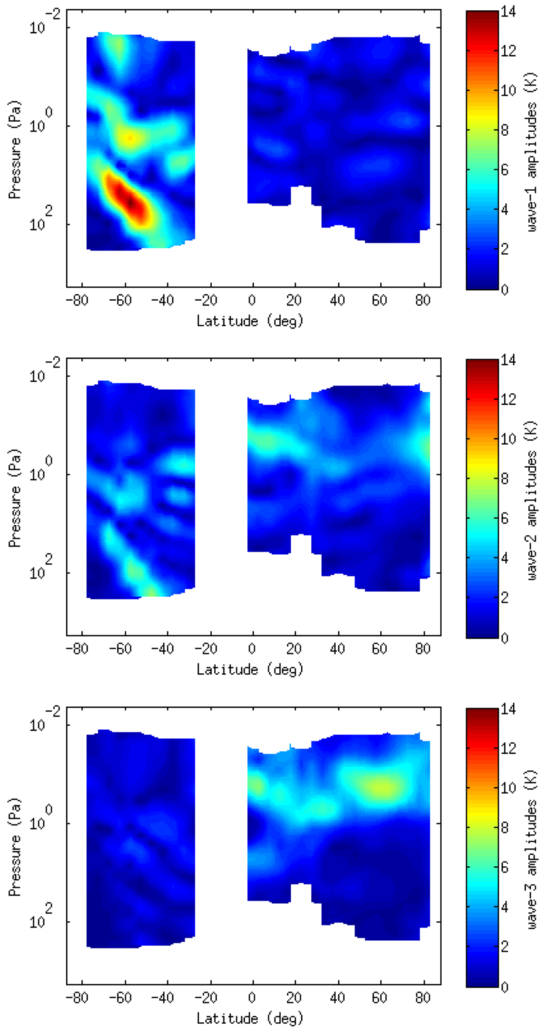

Figure 2: Amplitudes of the different tidal modes for the daytime averaged ($t_L \approx 15h$) profiles in the MCS data. Each of these amplitudes is a combination of different nonmigrating tidal modes (s, n) such that $m = |s-n|$ for each $m = 1, 2, 3$.

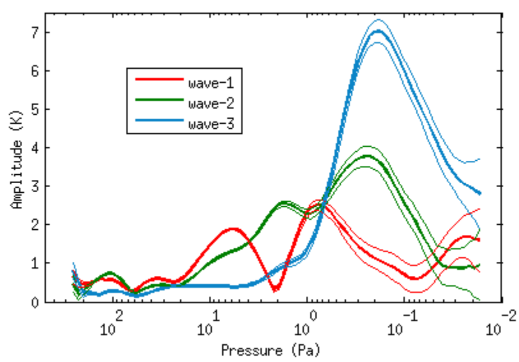

Figure 3: Amplitudes of the nonmigrating modes at the Mars Phoenix EDL latitude, from the MCS data.

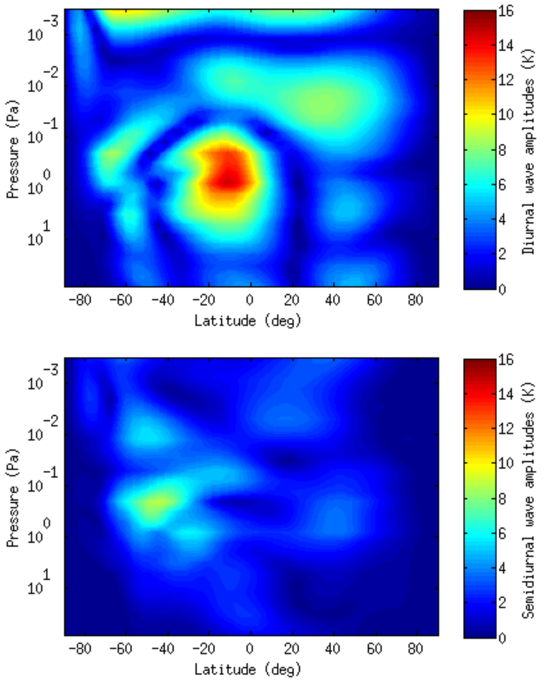

Figure 4: Amplitudes of the migrating tides in the zonal mean Mars Climate Database profiles.

the wave-1 amplitudes, where the strong $14K$ peak of the MCS data appears much weaker in the MCD data. Some amplitudes at the Phoenix latitude differ as well from the MCS data, especially the wave-3 component, as can be seen in Figure 6.

Again, looking at the averages and differences of the day- and nightside profiles suggests that both the diurnal and semidiurnal modes contribute equally at the latitude of the Phoenix landing zone.

Vertical wavelengths

In the atmospheric temperature profile derived from the Phoenix EDL data we observed temperature fluctuations with various vertical wavelengths. Many of these could be explained by classical tidal theory: we found vertical wavelengths around 20km, pointing to diurnal modes, and wavelengths around 120km, pointing to semidiurnal modes [5, 7]. However, we also found strong contributions from intermediate wavelengths around 40km and 60km which are not explained by classical tidal theory. By analyzing the phases of the migrating tides in the MCD data we found them to have intermediate wavelengths (around 45km) as well, for both the diurnal and semidiurnal modes.

From this it becomes clear that classical tidal theory fails to explain the atmospheric tides correctly. One possible nonclassical process that may affect the vertical

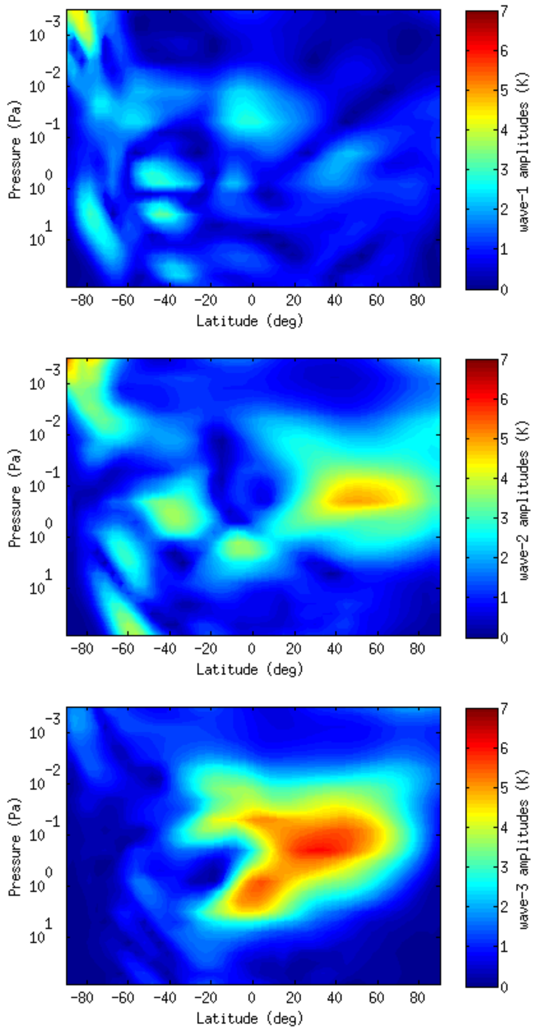

Figure 5: Amplitudes of the different tidal modes for constant daytime ($t_L = 15h$) in the MCD data.

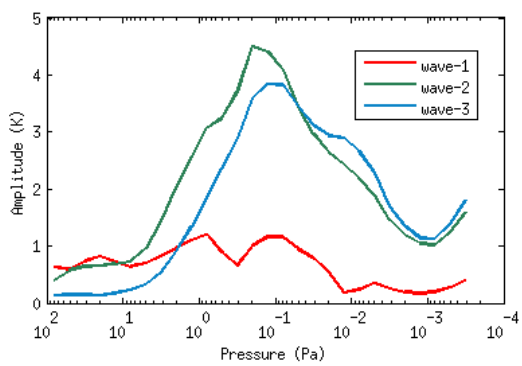

Figure 6: Amplitudes of the nonmigrating modes at the Mars Phoenix landing zone, from the MCD data.

structure of the tides is the presence of a nonzero zonal mean vorticity, as shown in [10]. We are currently studying this effect in the MCD data at the Phoenix landing season to see whether this may shed some light on the observed vertical wavelengths.

References

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