MIGRATING THERMAL TIDES IN THE MARTIAN ATMOSPHERE DURING APHELION SEASON OBSERVED BY EMM/EMIRS

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Overview:

Temperature profiles retrieved using the first set of data obtained during the science phase of the Emirates Mars Mission (EMM, Almatroushi et al. 2021) by the Emirates Mars InfraRed Spectrometer (EMIRS, Edwards et al. 2021) are used for the analysis of thermal tides in the Martian atmosphere. The selected data cover a solar longitude (L_S) range of 60°-90° of Martian Year (MY) 36. The novel orbit design of the Hope Probe leads to a good local time coverage that significantly improves thermal tides analysis. Wave mode decomposition suggests dominant diurnal tide and important semi-diurnal tide with maximal amplitudes of 6K and 2K, respectively, as well as the existence of ~0.5K ter-diurnal tide. The results agree well with predictions by the LMD Mars General Circulation Model (GCM, Forget et al. 1999), but the observed diurnal tide has earlier phase (3h), and the semi-diurnal tide has much larger wavelength (~200km).

Introduction:

Thermal tides are planetary-scale harmonic responses driven by diurnal solar forcing and influenced by planetary topography. Excited by solar heating absorbed by the atmosphere and energy exchange with the surface, thermal tides grow in Martian atmosphere. These tides usually have large amplitudes due to the low atmospheric heat capacity, and dominate its diurnal variations. To investigate such global and diurnal/sub-diurnal mechanisms, data with planetary-scale spatial coverage that sample all local times within a short range of season is necessary. Observations obtained by EMM/EMIRS can meet such a requirement due to the novel design of spacecraft orbit, which is the subject of this work.

Observations:

Analysis in this work is based on the first set of data obtained by EMIRS (Edwards et al. 2021), a Fourier transform infrared spectrometer onboard the Hope Probe. The selected data are during L_S= 60°-90° of MY 36, which contains ~7.0×10^4 temperature profiles, and have a full coverage in geography and local time (Figure 1). This is a dust-clear season in the late northern spring when Mars is near aphelion.

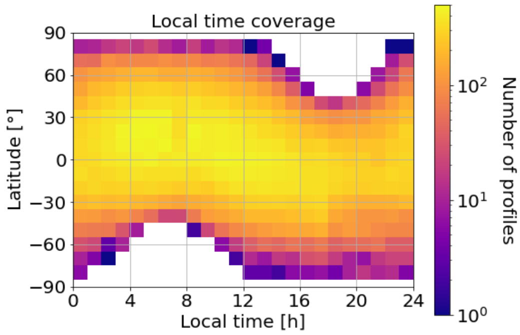

Figure 1. Data coverage of EMIRS observations during L_S= 60°-90° of MY 36.

Results:

Individual temperature profiles are first binned in longitude, latitude, and local time with grid sizes of 5°, 10°, and 1h, respectively (Figure 1). Daily temperature anomalies are then obtained across most of the latitudes by subtracting the zonal and diurnal means (Figure 2). This is the first time that such variations are observed on a global scale without any significant gaps in local time or sampling bias in

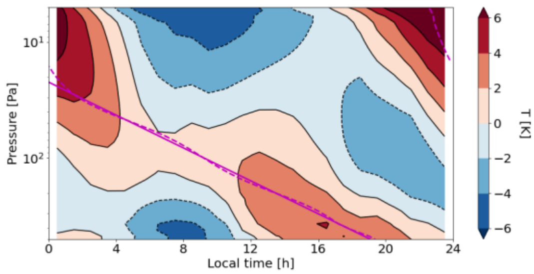

Figure 2. Zonal mean daily temperature anomaly between ±5° in latitude. The magenta dashed and solid lines denote the local time of daily temperature maximum, and the linear fit result of its downward phase progression, respectively.

season. Near the equator, the daily temperature anomaly shows signatures of dominant downward phase propagating of diurnal tide with an amplitude of ~6K at <10Pa to ~2K at >100Pa. The daily temperature maximum propagates approximately from 23h at 5Pa to 19h at 500Pa.

Through wave mode decomposition, contributions of the first three migrating thermal tides are derived. In the equatorial region, the diurnal tide dominates the diurnal temperature variation with an amplitude of ~2-6K, with a similar vertical wavelength compared to model predictions, but an earlier phase of ~3h in local time. The semi-diurnal tide shows an amplitude of ~1.5-2K across all pressure levels with a wavelength of ~200km, far larger than that in the model prediction. As a new finding, the observations show the existence of the ter-diurnal tide with an amplitude of ~0.3-0.5K.

Latitudinal and vertical distributions of amplitudes and phases of the migrating tides are obtained by repeatedly applying the wave mode decomposition to each latitude bin at each pressure level (Figure 3). The diurnal tide has a maximal amplitude of ~6K near the equator at ~5Pa, and also large values north of 30°N (Figure 3a). Its downward phase progression is well constrained in the equatorial region between ±30°, but the phase is close to ~±π at mid-latitudes (Figure 3b). Similar to the example shown above for the equatorial bin, the semi-diurnal tide between ±20° in latitude have similar amplitudes (Figure 3c), but slightly different downward propagating phases (Figure 3d). The phase in the northern hemisphere is earlier than that in the south. The ter-diurnal tide has a maximal amplitude of ~0.5K at ~20Pa (Figure 3e), and also downward phase progression at most of the latitudes (Figure 3f). Its phase distribution seems to have a symmetric patter by 20°N.

Discussion:

The sampling advantage of EMM/EMIRS observations that cover all geographic locations and local times within 10 days (~5° in L_S) largely address the sampling problem in analyzing observations obtained by previous missions, and enables detailed tide investigations with good constraints on their amplitudes and phases. The EMM/EMIRS data obtained during Martian aphelion season shows dominant diurnal tide and important semi-diurnal tide, as well as the existence of ter-diurnal tide. Compared to the LMD Mars GCM, the observed diurnal tide shows similar wavelength but an earlier phase, while the wavelength of the semi-diurnal tide is much larger than predicted.

Discrepancies of the migrating tide phases suggest improvements of GCMs. Preliminary attempts show that the phases of tides in the GCMs are not sensitive to any currently included parameters. Upgrades of the GCMs with more mechanisms are anticipated. Moreover, the large wavelength of the semi-diurnal tide suggests improvements on the physical properties of the modeled Martian atmosphere, and the asymmetric and symmetric distributions of semi-diurnal and ter-diurnal tides provide further indication, which is possibly important for

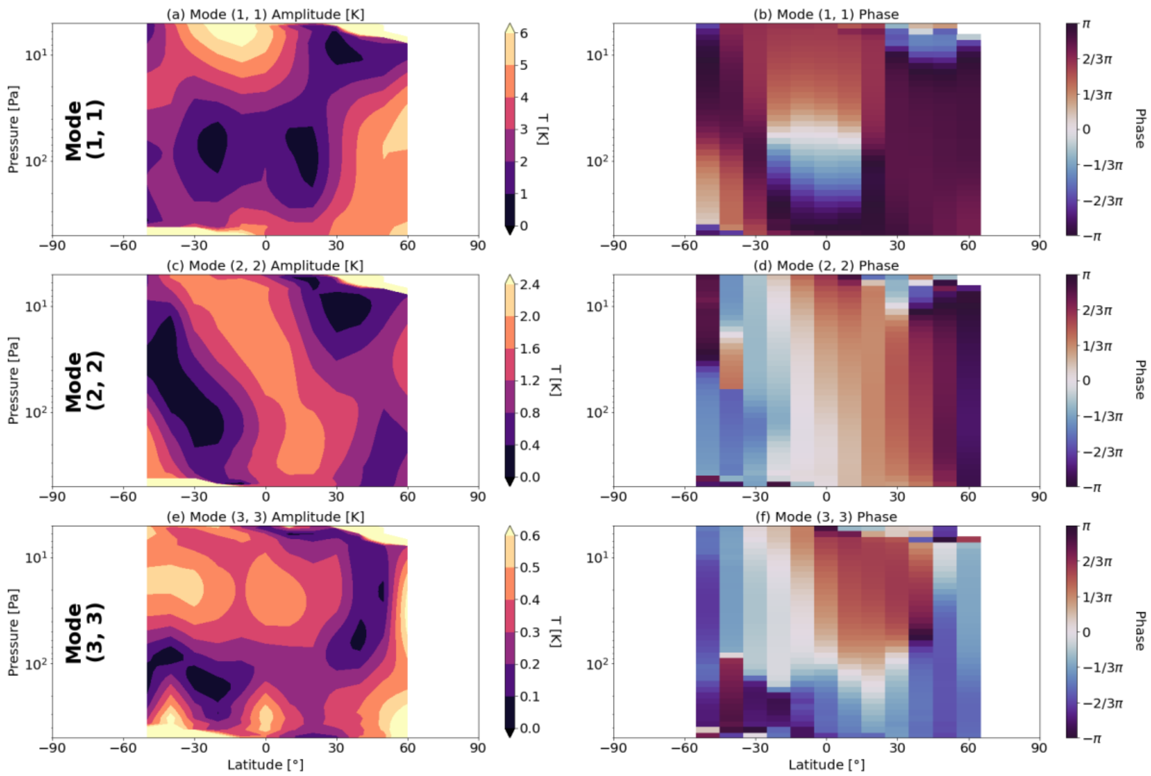

Figure 3. Amplitudes and phases of migrating thermal tides.

further understanding of the Martian atmosphere on a daily basis.

References:

Almatroushi, H., et al. (2021), *Space Sci. Rev.*, **217,** 89.

Edwards, C. S., et al. (2021), *Space Sci. Rev.*, **217,** 77.

Forget, F., et al. (1999), *JGR,* **104,** 24155.