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Thermal Tides During the 2001 Martian Global Dust Storm

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Abstract

Limb-scans by the Thermal Emission Spectrometer (TES) during the 2001 Martian global dust storm and a MarsWRF general circulation model simulation of the storm have provided a unique perspective on the atmospheric wave response to this historic event. The extratropical diurnal migrating tide exhibited amplitudes of more than 20 K, while the tropical tide was nearly undetectable. The diurnal Kelvin waves were weakened during the storm's expansion. In contrast, a westward-propagating diurnal wavenumber 2 nonmigrating tide was strengthened to 4-8 K. Lastly, the northern hemisphere wavenumber 1 stationary wave was strongly forced (amplitudes of 11-13 K) and appears to be a response to a tropical Rossby wave previously identified in TES dust mixing ratio observations.

1. 2001 Global Dust Storm

The 2001 global dust storm began unusually early in Mars Year 25 just after southern spring equinox (L_s = 184°). It grew for several weeks and was truly global by L_s = 197° [1]. Dust reached altitudes of 60-80 km and took months to completely settle out of the atmosphere [2]. Atmospheric temperatures and circulation were radically altered by the storm. Surface temperatures cooled by 20-30 K while temperatures in the lower atmosphere rose by 20-40 K [6].

2. TES Limb-scan Observations

TES observed infrared radiances in nadir- and limb-scanning geometries, and from these vertical profiles of temperature were retrieved [5]. This study uses the limb-scanning data primarily, but nadir-sounding data has been incorporated into the temperatures in the lowest altitudes. Waves were analyzed using the "average and difference" method of [3] (and others).

3. MarsWRF Atmospheric Model

MarsWRF simulations were conducted utilizing two atmospheric dust loading scenarios: (1) the 3 Mars Year period of TES limb-scanning observations which include the 2001 global dust storm (simulation S5 of [4]) and (2) the commonly-used "MGS scenario" from the Mars Climate Database as a base reference case (simulation S1 of [4]).

4. Tidal and Wave Analysis

4.1 Migrating Diurnal Tide

As the storm grew from L_s = 184° to L_s = 197°, the equatorially-trapped gravest Hough mode of the diurnal migrating tide became suppressed and was not detected in the observations. The vertically-trapped extratropical Hough modes of the tide are strongly forced by dust heating and grew to reach amplitudes of 20-22 K at L_s = 210° in the southern hemisphere. At similar times and locations, the MarsWRF dust storm simulation indicates amplitudes of 16-18 K. The northern hemisphere tide was also enhanced, achieving amplitudes of 10-12 K. The extratropical tide began to slowly weaken after dust lifting ceased following L_s = 210° (Figure 1). The gravest mode of the tide did not become clearly present again until after L_s = 270°.

4.2 Nonmigrating Tides

The wavenumber 1 and 2 diurnal Kelvin waves both weakened by 50% or more during the period of maximum dust loading in the observations and MarsWRF dust storm simulation. This runs contrary to GCM simulations, which suggest that the wavenumber 1 diurnal Kelvin wave remains relatively immune to changes in dust loading if the dust is zonally well-mixed. This suggests a wavenumber 2 component to the aerosol forcing.

The westward-propagating nonmigrating tides were strengthened, particularly the wavenumber 2 westward diurnal tide. We identify this change through the change in the behavior of the phase of the appropriate difference temperature field. The observations suggest an amplitude of 4-8 K for this tide component during the L_s = 200°-220° period and the MarsWRF dust storm simulation indicates a peak amplitude of 6 K.

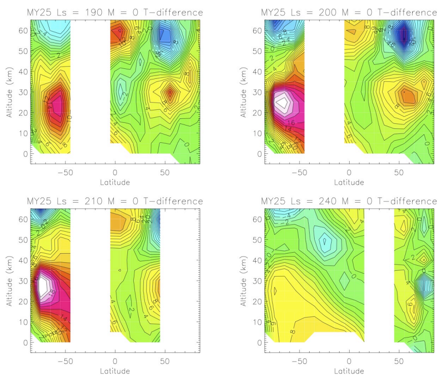

Figure 1: Wavenumber 0 difference temperature (K) (representing the migrating diurnal tide) for L_s = 190° (upper left), L_s = 200° (upper right), L_s = 210° (lower left) and L_s = 240° (lower right).

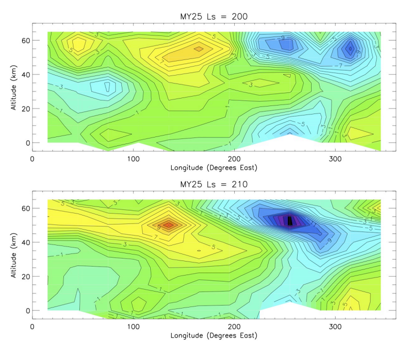

Figure 2: Temperature perturbations with the zonal mean temperature removed for L_s = 200° (top) and L_s = 210° (bottom). The wavenumber 1 pattern above 30 km with a westward-tilt with height indicates the westward-propagating wavenumber 2 diurnal tide.

4.3 Stationary Waves

The global dust storm enhanced the northern hemisphere wavenumber 1 stationary wave which reached peak amplitudes of 11-13 K during L_s = 210°-220°. A westward-propagating Rossby wave signature in high altitude dust mixing ratios was also observed during this period [2,5]. Interestingly, the phase of the stationary wave corresponds to the western (leading) edge of this Rossby wave-like maximum in dust mixing ratio for the L_s = 190°-220° period, before the dust mixing ratio pattern (and presumably the Rossby wave) dissipates.

4. Summary and Conclusions

TES limb-scanning observations of temperatures during the 2001 Martian global dust storm verify some predictions about thermal tide response to such an event (e.g., the strengthening of the extratropical migrating diurnal tide) while providing some unexpected results (e.g., the strengthening of the westward diurnal nonmigrating tides). This suggests that our knowledge of wave forcing in the Martian atmosphere is still incomplete despite a robust theoretical framework.

References

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