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The Role of Thermal Tides in the Martian Dust Cycle

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Abstract

Modeling studies of Martian dust storms have generally focused on simulating storms in the solstice season due to the expectation that dust is most efficiently lifted and distributed by the Hadley circulation which is most intense in this time. However, the observational record indicates that most years are characterized by pre- and post-solstice regional dust lifting. Moreover, in some years (1977, 1982, and, most notably, 2001) major dust storms occurred well before the solstice, suggesting that the Hadley circulation may not necessarily play the dominant role in dust storm development. It is suggested here that the thermal tides may play a more prominent role in the dust cycle than is often assumed. Results from a simulation of a representative Mars year are used to illustrate and explore aspects of the thermal tides of relevance to the dust cycle.

1. Introduction

Thermal tides are the atmospheric response to diurnally varying thermal forcing due to aerosol heating within the atmosphere and radiative and convective heat transfer from the surface. Tides include westward propagating migrating (sun-synchronous) waves driven in response to solar heating and additional nonmigrating waves resulting from zonal variations in the thermotidal forcing. Nonmigrating tides appear as diurnally varying upslope/downslope circulations within the boundary layer. Numerical models have shown that winds associated with the Hadley circulation and the thermal tides respond strongly to the evolving spatial distribution of aerosol-induced heating. The Hadley response is most sensitive to the displacement of thermal forcing poleward from the equator and so is most intense in the period centered around SH summer solstice. Diurnal tides are generally strongest in the equinoctial seasons in the absence of seasonal variations in dust forcing.

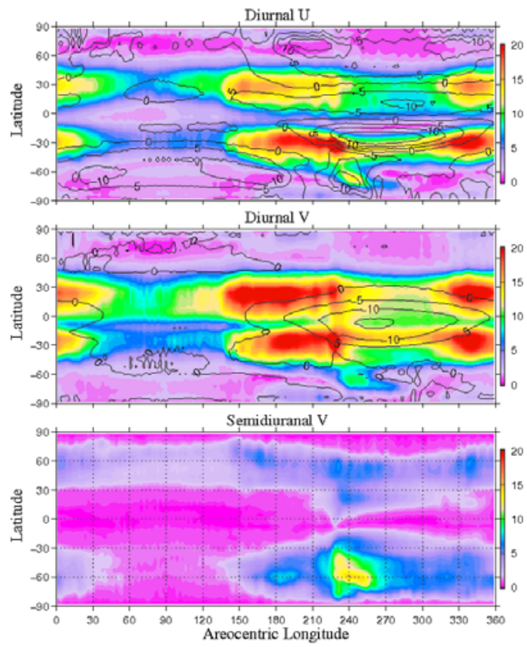

Figure 1. (a) Seasonal variation of the amplitude of the migrating diurnal component of zonal wind (ms^{-1} shading) at ~1 km above ground level from a simulation using opacities appropriate for MY24. The diurnally and zonally averaged zonal wind is contoured at intervals of 5 ms^{-1}. (b) As above, but for the meridional wind. (c) As above, but for the migrating semidiurnal meridional wind field.

2. Simulation results

The GFDL Mars GCM is employed and run with an evolving dust scenario based on the column opacity from MY24/25 [4]. This year was characterized by significant regional dust lifting that was initiated by flushing storm activity in the NH around L_s= 225° [1,2]. Subsequent lifting took place in the southern hemisphere, with the main lifting centers migrating southwest into Cimmeria and Promethei by L_s= 236°. The global opacity peaked at L_s= 238° and continued to decline through the solstice season. The seasonal variations of the migrating tide amplitudes of the low-level wind components are shown in Figure 1. There is a clear pattern of tide amplification that tends to peak in the equinoctial seasons. In this simulation, this pattern is modulated somewhat by the seasonal variation in dust opacity. The top panels also show the evolution of the low-level winds associated with the Hadley circulation. The development of a strong cross-equatorial circulation and intensification of the subtropical westerly jet in the SH is clearly seen in the solstice season, even as dust activity was observed to decline. The Hadley response is most sensitive to the displacement of thermal forcing poleward from the equator. The bottom panel shows the rapid amplification and decay of the semidiurnal tide, whose amplitude is strongly dependent on dust loading.

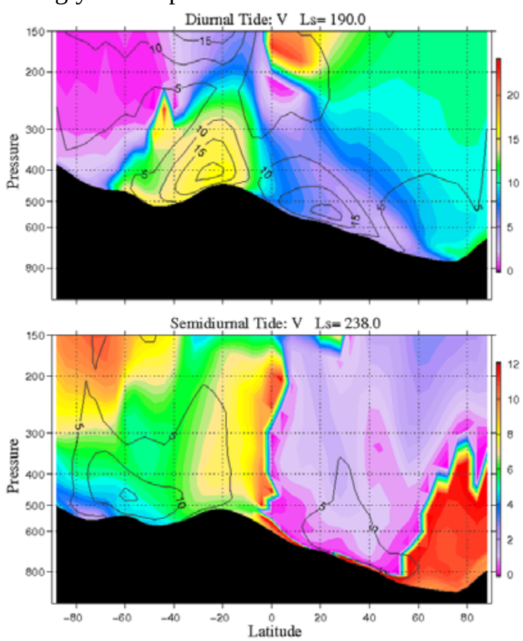

Figure 2. Latitude-height variation of amplitude and phase of the migrating diurnal (top) and semidiurnal (bottom) components of the meridional wind. The amplitude contour interval is 5 ms^{-1}. The phase (shading) is in local time hours. The pressure level is nominal, and represents height above the surface.

Figure 2 shows cross sections of the amplitude and phase of the migrating tide components of the meridional wind. Diurnal winds peak at ~30° latitude and are particularly prominent in the boundary layer. In general the low-level tide dominates the diurnal-mean winds. Tide amplitudes are a strong function of dust heating so that surface wind stresses amplify with dust lifting, yielding a significant positive feedback effect for regional storm intensification. The diurnal tide is phased so that maximum low-level convergence occurs in the afternoon. The maximal vertical motion associated with the diurnal tide significantly dominates that associated with the Hadley circulation [5]. It is notable that the 2001 dust storm [3] intensified at L_s~190° when tide winds most strongly dominate the Hadley circulation. Figure 2b shows the low-level semidiurnal wind peaking at mid-to-high latitudes in the summer hemisphere with a response is roughly proportional to column dust opacity. For dusty conditions the semidiurnal winds are the dominant component of the low-level wind field at mid to high latitudes. It is quite reasonable that the migration of dust lifting to high southern latitudes was a consequence of the intensification of the semidiurnal tide. Similar dust raising behavior was observed in MY26 and MY29.

3. Continuing work

There is also considerable longitude structure in the tides due to topography and variable dust. The regional responses associated with the nonmigrating tide components play a significant role in the development of dust storms. For example, the evolution of the spatially varying pattern of tide wind amplitude in a simulation of the 2001 dust storm was illustrated in [3]. Further developments will be discussed in this presentation.

References

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