MIDWINTER SUPPRESSION OF BAROCLINIC STORM ACTIVITY ON MARS: OBSERVATIONS AND MODELS.

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Introduction:

Baroclinic instability and intense traveling wave activity on Mars is well known to occur in "storm zones" (Hollingsworth et al. 1996) close to the edge of the advancing or retreating polar ice cap. Such activity usually sets in during Martian fall and continues until the onset of the summer season when large-scale instability mostly ceases as the atmosphere is no longer baroclinically unstable. The stormy season is typically characterized by large-scale, zonally-propagating waves with zonal wavenumbers $m = 1\text{-}3$, the lower wavenumber modes typically penetrating to considerable altitude though may also be surface-intensified.

As we show below, however, some observations suggest that this eddy activity does not persist uniformly throughout the autumn, winter and spring seasons, but appears to die down quite consistently within 10 sols or so either side of the winter solstice. This midwinter 'solsticial pause' appears to be a sufficiently consistent feature of each winter season in both hemispheres to be regarded as a significant feature of Martian climatology, and could affect a variety of aspects of Martian meteorology including global heat and momentum transport, occurrence of dust storms etc.

A somewhat similar phenomenon has also been documented for the Earth (e.g. Nakamura 1992; Penny et al. 2010), especially in relation to seasonal variations in the north Pacific storm tracks. The cause of this phenomenon is still not well established, though suggested mechanisms include the effects of enhanced barotropic shear (the so-called 'barotropic governor' (James & Gray 1986) and interactions with topography over central Asia.

In this presentation we examine evidence for this phenomenon in the assimilated record of Martian climate from the Thermal Emission Spectrometer on board the Mars Global Surveyor mission (MGS-TES), in conjunction with the UK version of the LMD-Oxford-OU-IAA Mars GCM (Forget et al. 1999; Montabone et al. 2006; Lewis et al. 2007). This is further corroborated in other evidence from seasonal variations in the incidence of local and regional dust storms that owe their origin to circumpolar baroclinic storms. We also discuss the extent to which this 'solsticial pause' phenomenon is reproduced in stand-alone atmospheric models and present results of some simulations to test a number of hypotheses for its dynamical origin on Mars.

Observational evidence for 'Solstitical pause':

The UK Mars reanalysis dataset comprises a synoptic record of Martian global meteorology obtained from MGS-TES retrievals of atmospheric temperature and dust optical depth, assimilated into the UK version of the LMD-Oxford-OU-IAA Mars GCM (Forget et al. 1999). The reanalysis was conducted using a version of the Analysis Correction sequential estimation scheme (Lorenc et al. 1991), and results in a complete synoptic record of Martian weather and atmospheric circulation at the model resolution of T31 (equivalent to a horizontal resolution of approximately 5^o x 5^o in latitude and longitude) and 25 vertical σ levels from the surface to around 120 km altitude, sampled every 2 hours during the three Mars Years (MY) 24-26.

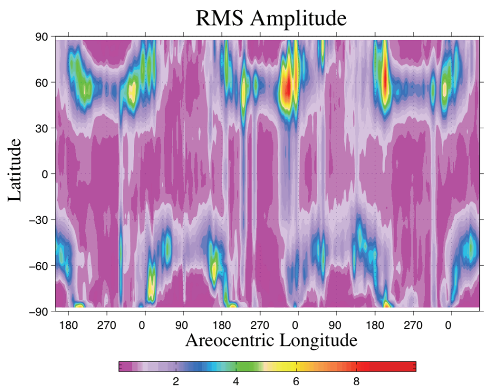

Figure 1: Standard deviation of transient eddy temperature at the 4 hPa level as a function of latitude and areocentric longitude (L_s), as represented in the UK Mars reanalysis dataset for MY24-26.

Figure 1 presents a summary of baroclinic eddy activity during all three Mars years in this record, and shows contours of the standard deviation of transient eddy temperature as a function of latitude and time (areocentric longitude) at the 4 hPa level, where eddy activity is relatively strong. This clearly illustrates the onset and migration of baroclinic storms during autumn towards the equator and then polewards in spring. In both the northern and southern hemisphere, however, there is a clear lull in eddy activity around, or shortly after, the winter solstices.

This is reproduced remarkably clearly every year, despite interannual variations in dust loading and other factors.

This tendency for reduced storminess during an interval of 20°-40° in L_s around solstice is also apparent in the incidence of dust storms. Figure 2 shows statistics for the seasonal frequency of dust storms obtained by Cantor et al. (2010), which shows a clear absence of high latitude storms around winter solstice in the north.

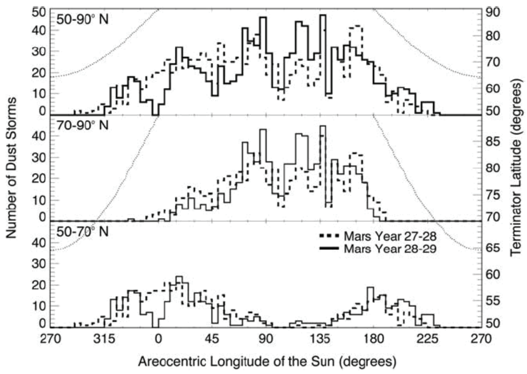

Figure 2: Temporal distribution of dust storms for 50–90° N for MYs 27–29 starting at northern winter solstice (L_s = 270°), using a bin size of 5° of L_s, as obtained by Cantor et al. (2010) using data from Mars Reconnaissance Orbiter. No distinction for the areal extent of storms has been made.

A similar absence of activity is also evident in the occurrence of condensate cloud features associated with frontal storms (Cantor et al. 2010). There seems, therefore, to be clear evidence in obervations for a lull in baroclinic storm activity close to winter solstice.

Model studies:

The clear occurrence of such a solsticial pause in baroclinic activity is a strong feature of Martian climatology that should be reproduced in general circulation model simulations of Martian weather and climate. In practice, however, models seem to vary in the extent to which they exhibit this phenomenon.

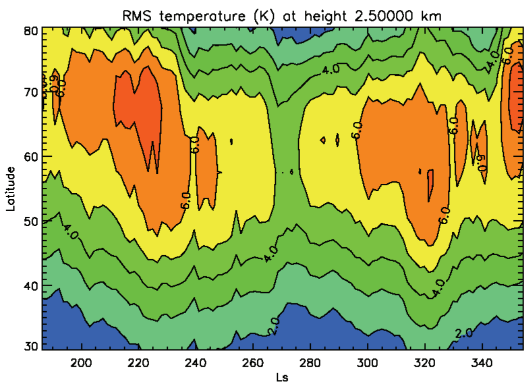

Figure 3: Contours of RMS temperature standard deviation at approximately 2.5 km altitude as a function of latitude and L_s in the UK MGCM at T31 horizontal resolution. Model uses a prescribed dust loading that reflects the observed non-dust storm conditions during the MGS period.

Figure 3 shows an example from the free-standing UK MGCM, which indicates a weak tendency to produce a lull in baroclinic activity around the time of the winter solstice, but rather less pronounced than in the assimilated observations (Fig. 1). Figure 4, on the other hand, shows results from the GFDL MGCM (Basu et al. 2006), which indicates a rather stronger solsticial pause. Both models were run at quite similar spatial resolution and with similar physical parametrizations, so it is unclear why these two models capture the phenomenon so differently.

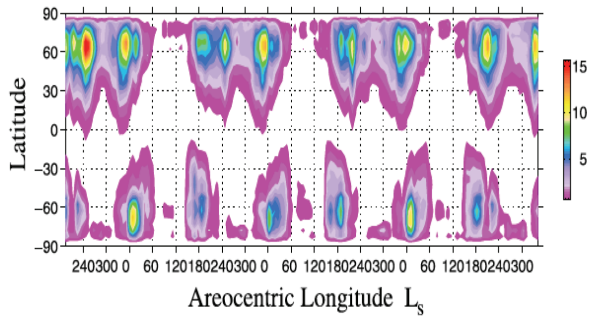

Figure 4: Standard deviation of transient eddy meridional velocity amplitude (m s^{-1}) at 2.5 km altitude as a function of latitude and areocentric longitude (L_s), as obtained in dust transporting simulations using the GFDL Mars GCM (Basu et al. 2006).

Mechanisms:

Although the occurrence of this phenomenon seems consistent and reproducible from one year to the next, the mechanism behind it is not clear. As for the Earth, effects related to the barotropic governor (James & Gray 1986) and topographic interactions affecting baroclinic growth rates may play a role. In this presentation we will explore a number of possible hypotheses for the underlying mechanism for the solsticial pause, using both observations and model simulations. The results will be compared with similar investigations of the midwinter suppression of baroclinic activity in the Earth's atmosphere.

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