ASSESSMENT OF SEASONAL AND INTERANNUAL VARIABILITY IN TES AND MCS OBSERVATIONS.

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Introduction: The characterization of the spatial and seasonal variation of the atmospheric thermal structure and circulation, and their coupled dependence on dust and water ice clouds, is a fundamental aspect of the description of the Martian climate. Temperature retrievals from the Thermal Emission Spectrometer (TES) [1] and Mars Climate Sounder (MCS) [2] instruments are the basis of our understanding of weather and climate variability, including their recent use in data assimilation systems for constructing reanalyses of the evolving atmospheric state over the course of the two spacecraft missions [3,4]. The data are also being used for benchmarks for tuning Mars Global Climate Models (MGCMs). Therefore consideration of the strengths and weaknesses of these datasets, and their impact on studies of interannual variability, is relevant.

Figure 1a summarizes the seasonal variation of equatorial T_{15} observed by TES and MCS for MY 24-26 and MY 29-32, respectively. T_{15} is a depth-weighted brightness temperature (at 15 μm) that is broadly centered at 30-50 Pa. Apart from episodic global dust storms and the more regular occurrence of regional dust storms in the pre-solstice (L_s =210-240°) and post-solstice (L_s =310-340°) seasons, there is a well-defined annual variation that reflects the season cycle of insolation and the background variation in dust and ice clouds.

This regular variation suggests the possibility of characterizing the evolving distribution of aerosols as a first step in investigating the source, sinks and transport mechanisms that control the climatology. Is there a slowly evolving "background" envelope of temperature and aerosol distribution that characterizes the seasonally evolving climate? An affirmative answer might allow the study of episodic storms to focus on perturbations of this more slowly evolving climate state.

The Aphelion Season: Temperature structure in the aphelion season (L_s=0-135°) is dominated by thermal tides in the tropics and stationary waves at southern mid- and high latitudes, and these also have a well-defined seasonal cycle. Traveling waves are present only at high latitudes in the southern (winter) hemisphere. The MCS data reveal a very high degree of reproducibility in tropical temperature and aerosol structure from year to year during this aphelion season [1], which suggests robust maintenance mechanisms are at play. Figure 1a indicates that there are deviations from this pattern in the TES data that are due to differences between the two types of observations. This is evident in Fig. 1b and 1c, where MCS indicates a layer of enhanced stability between 200 and 30 Pa that is not seen in the TES data. This layer of enhanced stability has been attributed to the radiative influence of water ice clouds [5]. These significant differences (~10 K) between TES and MCS in 50 Pa temperature that suggest that care is needed in using spacecraft observations for tuning atmospheric models.

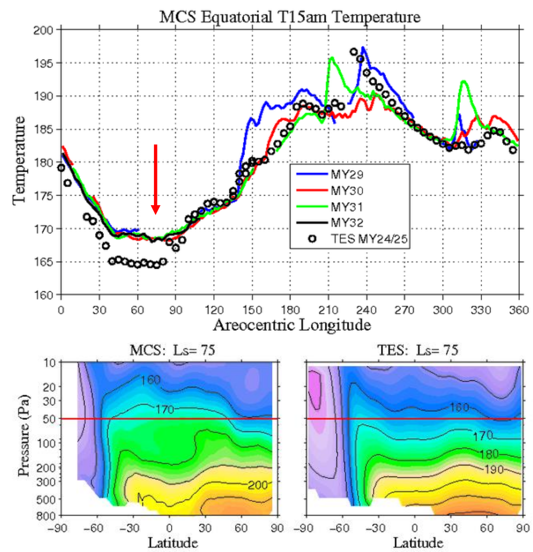

Figure 1. (top) Seasonal variation of zonally-averaged morning equatorial T_{15} for MCS and TES (bottom) Latitude-height sections of zonally-averaged morning (3am and 2am) temperatures for MCS (left) and TES (right) at L_s= 75°.

A fundamental issue for atmospheric modeling is how the aerosol and temperature fields relate to each other. There is currently significant uncertainty about the 4-D distribution of aerosol in the aphelion season. One significant discovery from MCS and TES limb profiles is the presence of elevated dust maxima at around 25 km altitude [6,7]. However the TES limb observations are relatively sparse and the MCS tropical coverage below ~25 km is largely restricted to nighttime as the daytime observations are frequently compromised by water ice clouds at ~50 Pa in the aphelion season [8]. These daytime distributions would be very useful for understanding dust injection and aerosol maintenance.

TES Retrieval Issues: Figure 2 shows the seasonal evolution of retrieved afternoon (2 pm) zonally averaged equatorial temperatures by TES at 470 Pa. There are striking differences in temperature from one year to the next that undermine the notion of little variability from year-to-year in between episodes of regional dust lifting. The relatively cool temperatures are all associated with the use of high resolution (6 cm^{-1}) spectra rather than the nominal 12 cm^{-1} spectra. The cross section in Figure 2b indicates that this issue is significant for assessing the impact of aerosols on the vertical structure of temperature.

TES will remain an important data set for a number of reasons. The column integrated dust and cloud opacity observations have a distinct advantage over MCS profiling, which appears to miss low-lying opacity or is affected by high-opacity conditions (tropical cloud belt and dust storms) and provides limited information on the boundary layer. We believe that TES may provide better resolution of shallow baroclinic waves, though this remains to be assessed.

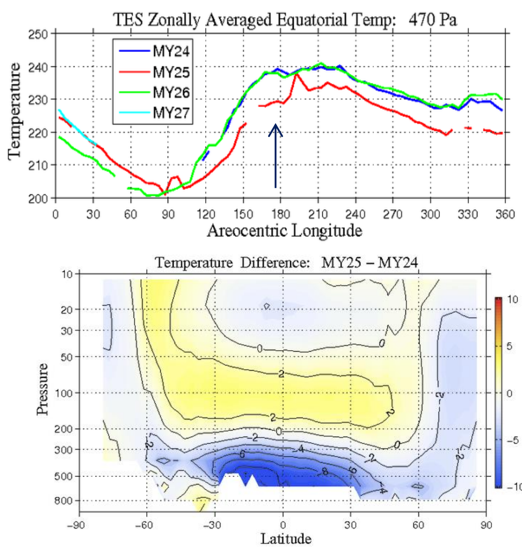

Figure 2. (a) Zonally averaged daytime near-surface (470 Pa) equatorial temperatures derived from TES single and double scanned spectra (12 cm^{-1} and 6 cm^{-1} resolution, respectively). Relatively cold temperatures occur when double scanning is employed from L_s~100° in MY25 to L_s=110° in MY26. (b) The difference in afternoon temperature at L_s = 175-180°.

Multi-instrument combination advantages: We propose that in seasons and regions with little interannual variability, there is potentially much to be gained by using multiple data sets, from different Mars years, to improve our knowledge/understanding of how aerosol (clouds especially) shape the thermal structure. A hybrid compositing of observations could then be used in a data assimilation (DA) system to better constrain the full state of the atmosphere.

Data assimilation has proven to be an effective means of synthesizing spacecraft observations with the dynamics provided by a GCM to produce a four-dimensional representation of the atmospheric state. A successful atmospheric and aerosol reanalysis should successfully involve observations from all available spacecraft datasets, including TES nadir, TES limb, and MCS limb, as each has its own advantages as well as challenges for assimilation. This opens the possibility for using TES and MCS data sets simultaneously to better constrain the climatological aerosol during the aphelion season (L_s= 0-130°) when daily atmospheric variability in the tropics is minimal. The aerosol profiles provide the needed vertical structure in the analyses, whereas column opacities can help estimate the missing aerosol in the boundary layer which is not well sampled by limb instruments. Therefore, we able to extract the best characteristics of both data sets. The resulting reanalysis will be essential for studying the relationship between temperature and aerosol structure, as the determination of aerosol distributions is the first step in the development of physical parameterizations for explaining the maintenance and evolution of aerosols.

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