WINTER POLAR WARMING IN THE MARS THERMOSPHERE.

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Introduction:

Mars winter polar warming is a phenomenon of the lower thermosphere temperatures and densities that is well documented by in-situ accelerometer data taken during three previous spacecraft aerobraking campaigns [1, 2, 3, 4]. The latitudinal variation in thermospheric densities and derived temperatures (at a constant altitude) is measured as the various spacecraft pass over the local winter pole. Temperatures are expected to be colder in the high latitude winter polar regions, as radiative equilibrium is maintained. However, significant departures from radiative equilibrium temperatures were observed during the perihelion season.

The Mars 2001 Odyssey (MO) accelerometer sampled high northern latitudes during aerobraking (Ls = 265 - 310) as periapsis passed over the northern winter pole. The MO aerobraking data in the northern winter night revealed a strong polar warming over 100-130 km [1]. Temperatures near periapsis (100-110 km) were discovered to increase with latitude (60-90N) from about 100 to 170-200 K, maximizing near the North pole on the nightside. Corresponding temperatures near 120-130 km were observed to increase from 110 K to 160-170 K as the North pole was approached. These MO accelerometer observations provide the first clear evidence of strong winter polar warming at Mars thermospheric heights during the perihelion season [1]. However, there was no concurrent lower atmosphere polar warming observed during this MO aerobraking period [5].

Conversely, Mars Global Surveyor (MGS) and Mars Reconnaissance Orbiter (MRO) accelerometer data were taken as the southern polar region was sampled during the aphelion season [1, 3, 4]. MGS Phase 2 aerobraking (Ls = 30-95) and MRO aerobraking (Ls = 35-109) periods span similar latitudes and seasons as periapsis passed over the South winter pole. Densities were retrieved and temperatures derived for two different Martian years, revealing no analogous warming of temperatures within the south polar thermosphere during these aphelion/winter seasons.

This dramatic seasonal variation in winter polar temperatures and the repeatable lack of winter polar warming during the aphelion season (over two Martian years), suggests a dynamical explanation that is independent of radiative equilibrium considerations. The winter polar warming in the Mars thermosphere may occur as a result of adiabatic heating from the subsiding branch of a strong inter-hemispheric circulation cell that operates during the solstices. This circulation pattern should be enhanced during the perihelion season due to stronger solar insolation (heating the entire atmosphere) and the remote effects of significant (and highly variable) aerosol heating in the lower atmosphere [1, 2]. Conversely, the aphelion season inter-hemispheric circulation should be weakened and possibly quite consistent (repeatable dust distributions) from one Martian year to the next, resulting in a weak (or non-existent) warming in the southern winter polar region.

Such a dynamical explanation for Mars is not without precedent. Lower atmosphere (25-80 km) north polar winter warming has previously been observed during several events [6, 7, 8, 9]. Winter polar warming in the lower atmosphere for specific events was realistically simulated using revised Mars lower atmosphere models that were extended to ~90 km or more [10, 11]. Such an extension enables these models to capture the diabatically driven inter-hemispheric (Hadley) circulation that is strong and deep on Mars, spanning the region from the ground to nearly 100 km. Strong meridional winds above 50 km lead to a horizontal convergence of mass and downward motion above the polar region, resulting in adiabatic warming down to ~25 km. This warming is shown to be most pronounced during perihelion conditions (Ls = 270), when maximum solar insolation and strong dust heating prevail.

Detailed global model simulations are likewise required to capture the energetics and dynamics of the combined lower and upper atmospheres in order to address this issue of Mars thermospheric winter polar warming. The processes driving these seasonal and interannual variations in the Martian thermosphere can be addressed through careful interpretation of available accelerometer datasets using several global thermospheric model simulations. Coupled yet separate Mars General Circulation Model (MGCM)-Mars Thermospheric General Circulation Model (MTGCM) simulations of the lower and upper atmospheres of Mars are now used to address these features and the underlying dynamical processes linking these Mars atmospheric regions.

Our strategy is to focus on changing lower atmosphere conditions from one Martian year to the next, while holding topside forcing (e.g. solar EUV fluxes) constant. For this presentation, we have selected Martian solstice simulations, which are driven by solar and aerosol heating corresponding to aphelion (Ls = 90) and perihelion (Ls = 270) conditions appropriate to existing MGS, MO and MRO observing periods (above). New MGCM-MTGCM simulations are conducted using three available mapping years of infrared (IR) optical depth.
Figure 1: Zonal average neutral temperatures, for both solstice seasons at each of the three TES Mapping Years as a function of both altitude (vertical axis) and latitude (horizontal axis). The solar flux is held constant at F10.7-cm = 130 for all simulations. The black horizontal line in all plots represents 120 km altitude level. Neutral temperatures (in K) for the northern summer solstice, $L_S = 090$ are depicted for the various lower atmospheric dust conditions: (a) TES Year 1, (b) TES Year 2, and (c) TES Year 3. Similarly, neutral temperatures (in K) for the opposite season of southern summer solstice, $L_S = 270$, are depicted for the various lower atmospheric dust TES Maps: (d) TES Year 1, (e) TES Year 2, and (f) TES Year 3.

Subsequently, specific calculations appropriate to the exact seasonal and solar cycle conditions of MGS, MO, and MRO aerobraking observing periods (near the solstices) are presented. Simulated polar warming features are compared with the observed temperature and density trends. Implications for the seasonal and interannual variability of the Mars winter polar warming phenomenon will be described; consequences for aerobraking planning exercises will be discussed.

MGCM-MTGCM Model Formulation:

The Mars Thermospheric General Circulation Model (MTGCM) itself is a finite difference primitive equation model that self-consistently solves for time-dependent neutral temperatures, neutral-ion densities, and three component neutral winds over the globe [2, 12]. MTGCM prognostic and diagnostic thermospheric fields are simulated on 33-pressure levels (at altitudes above 1.32 $\mu$bar corresponding to $\sim$60-300 km), with a 5x5 $^\circ$ latitude and longitude resolution. Recently, a fast non-Local Thermodynamic Equilibrium (NLTE) 15-micron cooling scheme was implemented in the MTGCM, along with corresponding near-IR heating rates. These improvements are based upon recent detailed one dimensional (1-D) NLTE model calculations for the Mars upper atmosphere [13].

The MTGCM is currently driven from below by the NASA Ames Mars General Circulation Model (MGCM) code [14] at the 1.32 $\mu$bar level (near 60-80 km), permitting a detailed coupling across this boundary. This coupling scheme captures both migrating and non-migrating
upward propagating tides plus the thermal expansion and contraction of the Mars lower atmosphere with the passage of the seasons and dust storm events [2, 12]. Key prognostic (temperatures, zonal & meridional winds) and diagnostic (geopotential height) fields are passed upward from the MGCM to the MTGCM at the 1.32-µbar pressure surface at every MTGCM gridpoint on 2-minute timestep intervals. No downward coupling from the MTGCM to the MGCM is presently activated. The inclusion of the Ames MGCM in providing a realistic lower atmosphere is critical for achieving a realistic simulation of the Mars upper atmosphere within the MGCM domain [2].

**Brief Model Results Illustrating Variability:**

Results from the MGCM-MTGCM simulations comparing TES years #1, 2, and 3 dust forcing for aphelion (Ls = 90) and perihelion (Ls = 270) conditions are presented in Figures 1 and 2 [15]. Simulated temperatures in Figure 1 reveal that the polar lower thermosphere exhibits a high degree of variability during perihelion, with reduced yet significant variability near aphelion. This behavior is consistent with that observed in the lower atmosphere, as documented by [16]. The underlying adiabatic cooling rates (summer hemisphere upwelling) and heating rates (winter hemisphere subsidence) that accompany the interhemispheric circulation shown in Figure 2 indicate that variations in winter polar temperatures are tightly coupled to significant variations in adiabatic heating.

Finally, specific simulations for MGS, MO, MRO aerobraking periods (near the solstices) are conducted. Latitudinal temperature variations near 130 km are illustrated in Figure 3. Notice that simulated MO northern winter polar temperatures (Ls = 270) approach 190-
200K, while southern winter polar temperatures drop to as low as 130K. These are not zonal average values, but rather specific to the local solar time (and averaged longitudes) of the accelerometer measurements. This seasonal trend is generally consistent with observations [1, 2, 3, 4]. However, simulated MO winter polar temperatures are slightly warmer than observed.

Conclusions:

It is demonstrated from this current research and previous studies that the entire Mars atmosphere is an integrated system that is highly coupled dynamically, thermally, and chemically. The proper characterization of the processes giving rise to observed winter polar warming in the Mars thermosphere is possible using such an integrated model treatment. Future aerobraking exercises will benefit from the ability to better predict the winter polar densities that accompany these winter polar temperatures.

References