THE ORBITAL (L_s) VARIATION OF THERMAL STRUCTURE OVER THE 60-80 km MARS ATMOSPHERIC REGION

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Introduction:

JCMT sub-millimeter line observations of the optically thick J=2-3 absorption spectrum (at 345 GHz,) of Mars atmospheric CO have been analyzed to determine the disk-average variation of Mars upper atmospheric temperatures over more than one full Mars year (Sep1996-Aug1999). Similar millimeter (230 GHz) disk-averaged atmospheric temperature retrievals for the lower Mars atmosphere (0-30 km) compare accurately with low-to-mid latitudinal averaged atmospheric temperature profiles obtained from the thermal infrared spectrometer (TES) onboard the Mars Global Surveyor (MGS) orbiter (Clancy et al., 2000). Figure 1 (modified from Clancy and Sandor, 1998) compares the orbital variation in Mars upper atmospheric temperatures at four key seasons (solar longitudes, Ls, of 8°, 89°, 187°, and 281°). The depth of the full absorption line, relative to the Mars continuum and as a function of frequency offset from line center, provides an accurate measure of Mars atmospheric temperatures over the 0-80 km altitude range (60-80 temperatures shown in figure 1).

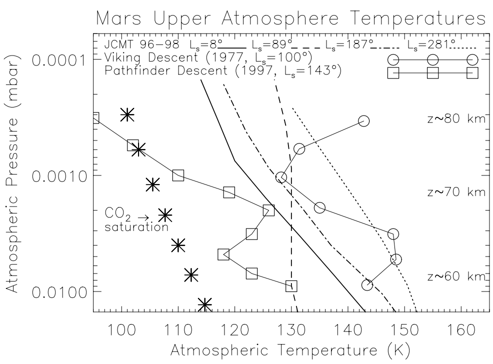

FIGURE 1. Mars mesospheric temperature measurements (JCMT vs lander entry)

JCMT Mars observations provide unique measurements of the high opacity 346 GHz CO absorption line, to retrieve atmospheric temperatures in the essentially unexplored mesosphere of Mars, over the 60-80 km altitude range (highest weighting function peaks at~75-85 km for 346 GHz). Existing spacecraft measurements of the Mars mesosphere consist of three lander entry profiles, two from Viking in 1976 and one from Pathfinder in 1997.

Temperature Profiles:

Figure 1 includes the average of the two Viking entry profiles (circle symbols connected by a solid line) and the single Pathfinder entry profile (square symbols connected by a solid line). The Pathfinder atmospheric team interpreted the 20-30K difference between the cold night-side Pathfinder versus warm dayside Viking temperatures as a consequence of large radiative diurnal variations in Mars mesospheric temperatures (Schofield et al., 1998). In contrast, we have employed JCMT measurements (Sept96-Jul98) of Mars CO to argue that very cold (≤ 120K) conditions are typical around L_s=0-10° and 180-190° periods for this altitude region during daylight as well as nighttime hours. An important aspect of such cold mesospheric temperatures, which approach CO_2 saturation temperatures as indicated by asterisk symbols in figure 1, is their potential to account for previously unexplained Mariner 6/7 near IR spectral measurements of atmospheric CO_2 ice clouds (Herr and Pimental, 1970; Calvin, 1996- at L_s~200°, noon local times, and equatorial latitudes) and 1997 Pathfinder imaging of high altitude, very fine (blue color) ice clouds (Smith et al., 1997- at L_s=162°, pre-dawn local time, at 19N latitude). On these observational bases, we argued that CO_2 ice clouds in the Mars mesosphere form as a consequence of relatively common saturation conditions for the CO_2 atmosphere at these altitudes, and that the large differences among the spacecraft and JCMT temperature retrievals for the Mars mesosphere indicate significant seasonal variation (15-20K) in low-to-mid latitude average temperatures over this altitude region (Clancy and Sandor, 1998).

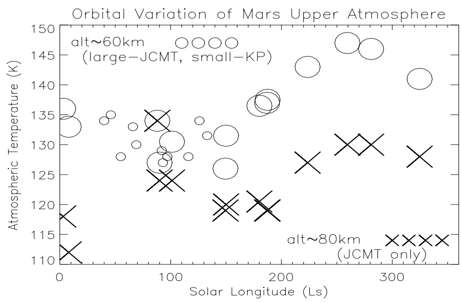

FIGURE 2. Orbital/seasonal variation in Mars disk average atmospheric temperatures at ~60 (circles) and 80 (X symbols) km altitudes from JCMT sub-millimeter (large symbols) and Kitt Peak millimeter (small circles, at 60 km only) ^{12}CO absorption line measurements

Orbital (L_s) Variations:

Since this publication, we have extended the Ls coverage of JCMT sub-millimeter CO spectra to provide a relatively complete representation of orbital variation in the average mesospheric temperature profile at low-to-mid latitudes (appropriate to disk average measurements of Mars). Figure 2 presents the seasonal/orbital variation of dayside Mars temperatures at altitudes of ~60 km (.01 mbar-circles) and 80km (.0003 mbar-X's), as derived from the accumulation of 1996-99 JCMT measurements and 1997 Kitt Peak millimeter observations (small circles, at 60 km only). Altitudes below 65 km (e.g., circles in figure

2) display ≥20K L_s variations which are annual rather than seasonal in character. This behavior is typical of the global atmospheric variations at lower altitudes, which are forced by 40% variations in incident solar flux over the highly eccentric Mars orbit (Clancy et al., 1996, 2000). The L_s variation for atmospheric temperatures above this level (X's in figure 2) remains less well determined due to the insensitivity of more numerous millimeter CO observations from Kitt Peak to altitudes above 60 km. The JCMT temperature measurements in this region (X symbols in figure 2) suggest more semi-annual variation at altitudes above 70 km. In particular, the seasonal variations of 60 and 80 km temperatures appear opposite in phase over L_s=0-200°. The aphelion period around L_s=100° is characterized by distinctly isothermal mesospheric temperature profiles, as indicated in figures 1 and 2. The separate character of the aphelion mesospheric temperature structure is directly evident in the very different 345 GHz ^{12}CO absorption lines observed for this period, as indicated in figure 3. In all seasons observed outside of L_s= 80-100°, a deep and narrow absorption core (e.g., dotted line spectrum of figure 3) is present, indicating significant atmospheric lapse rates in mesospheric temperatures over the 50-80 altitude region (i.e., solid, dotted, and dash-dotted line temperature profiles in figure 1). By comparison, all three aphelion period measurements obtained to date (another is to be obtained in Oct/Nov 2002) lack a narrow, deep absorption core, and so indicate very small lapse rates for the aphelion atmosphere over 50-80 km altitudes (e.g.., the dashed–line temperature profile in figure 1) .

JCMT mesospheric temperature profiles place important constraints on the radiative and dynamical balances that determine thermal structure in this region. The three lander descent profiles have been interpreted to describe both the average and diurnal character of atmospheric temperatures in this region, but are clearly affected by local variations. Large vertical waves in these *in situ* profile measurements suggest significant gravity and/or tidal variations which impair interpretations of the background average temperature and lapse rate at these mesospheric altitude levels. In contrast, the JCMT whole disk measurements effectively average out local wave effects, including semi-diurnal tidal variations. The proven accuracy of such ground-based CO line measurements of Mars atmospheric temperatures in the 0-50 km altitude region (see Clancy et al., 2000) provides a self-consistent and accurate calibration to sub-millimeter mesospheric temperature retrievals. Consequently, JCMT definition of the Mars mesospheric thermal structure versus L_s constitutes our most complete data set for the essentially unexplored mesosphere of Mars.

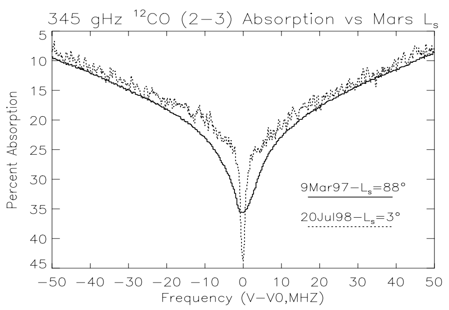

FIGURE 3. Comparison of line center 345 GHz CO absorption for an aphelion (solid line) versus a non-aphelion (dotted line) measurement.

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