STRUCTURE OF THE MARS UPPER ATMOSPHERE: MGS AEROBRAKING DATA AND MODEL INTERPRETATION. S. W. Bougher[1] and G. M. Keating[2], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721-0092, USA (sbougher@lpl.arizona.edu), [2]George Washington University, Hampton VA 23681, USA.

Mars Global Surveyor (MGS) recently obtained coordinated lower-atmosphere (thermal and dust) measurements and simultaneous upper atmosphere accelerometer data (densities, scale heights and temperatures) yielding the first quantitative glimpse of the physical processes connecting the Mars lower and upper atmospheres during mildly dusty conditions and during a regional dust storm event [1]. In particular, measurements from the MGS z-axis accelerometer (ACC) aboard MGS have provided to date more than ~1200 vertical structures of the Mars thermospheric density and derived temperature and pressure, as compared to only 3 previous in-situ profiles [1]. These data have been obtained over two distinct Mars seasons (Fig. 1): (Phase 1) 7-months approaching perihelion from southern Spring to early Summer (Ls = 180 to 300), and (Phase 2) 4.5-months near aphelion from northern Spring to early Summer (L_s = 30 to 95).

During MGS Phase 1 aerobraking, the spacecraft periapsis moved from 32°N to 61°N and from a solar local time (SLT) of 18 to 11 hours, with data acquired from 170 to as low as 110 km. During Phase 2, the spacecraft covered similar dayside local times (SLT = 17 to 15) and briefly sampled the nightside (SLT ~ 2), while traversing a wider latitude (60°N to 90°S) range. This local time-latitude coverage for solar minimum (SMIN) to moderate (SMED) conditions ($F_{10.7}$-cm = 80–150 units) far surpasses the limited spatial and temporal coverage afforded by the previous Viking Landers and Mars Pathfinder. Additional Phase 1 CO_2 15-μm band measurements from the Thermal Emission Spectrometer (TES) have yielded temperature maps from the ground to 0.1-mb (about 30 km); corresponding IR dust opacities have also been gleaned from the 9.0-μm silicate band. Independent ground-based microwave measurements (disk-averaged) have routinely obtained temperatures over 0–60 km, generally confirming the TES values when available. The major features of this MGS upper atmosphere data are reviewed, and its trends elucidated in order to: (1) illustrate the aerobraking environment experienced by the MGS spacecraft, and (2) decompose the likely processes responsible for the atmospheric structure and its observed variations.

Phase 1 of MGS aerobreaking witnessed the onset, rise, and decay of a regional dust storm event (centered at 20°–40°S), and the resulting responses of the lower atmosphere temperatures (TES, microwave), dust opacties (TES), and upper atmosphere densities (ACC) at a given height. Throughout this “Noachis storm”, the ACC density increases (decreases) coincided with the warming (cooling) and hydrostatic expansion (contraction) of the lower atmosphere. ACC densities at 130 km increased by a factor of two to three over 2–3 days (storm onset), in concert with an expansion of the atmosphere by 8 km. Dust opacities also doubled at mid-latitudes, consistent with an increase of TES temperatures in both hemispheres and microwave temperatures (both near 30 km) of at least 10–15 K. The gradual decay of this storm occurred over 1–2 months. This observed global response of a regional dust storm, significantly impacting thermospheric densities over the course of 2–4 days, was extraordinary and unexpected (Fig. 2).

MGS also confirmed that the Mars lower thermosphere (100–130 km) is a highly variable region on time scales of a day or less. Orbit-to-orbit 2-σ variability of ACC densities at a constant height was observed to be ~70% [1], in accord with previous Mariner and Viking values [2]. During the onset of the Noachis dust storm, this variability increased to 200%. Longitude fixed thermospheric variations were also observed throughout Phase 1 that seemed to be correlated with the gross wave #2 features of the topography at Northern mid-latitudes [1]. Phase 2 aerobraking witnessed the dominance of wave #1 features throughout Southern mid-latitudes (wave #2 near the equator). This aerobraking experience monitoring the Mars atmosphere near perihelion (Phase 1) and near aphelion (Phase 2) suggests that the coupling of the Mars lower and upper atmospheres is composed of: (1) inflation/contraction of the atmosphere, and (2) dynamical forcing (tides, planetary waves, and gravity waves) connected to the unexplored middle atmosphere (50–100 km) [1,3,4].

Initial model studies have been conducted to simulate the Mars lower to upper atmosphere coupling observed by these MGS measurements [e.g., 4]. The Mars Thermospheric General Circulation Model (MTGCM) (70–300 km) and the NASA Mars General Circulation Model (MGCM) (0–90 km) have been crudely coupled for this purpose. Early simulations suggest that the limited solar cycle, seasonal, latitude, and diurnal variations of the Mars lower thermosphere (aerobraking altitudes) are generally reproduced. Phase 2 provides a large latitude sampling over limited afternoon local times (SLT = 17–15). Figure 3 compares ACC density data and MTGCM predictions, showing that the latitudinal variations of 130 km densities are well reproduced, except in the Southern polar night region at the very end of Phase 2. In addition, diurnal variations of 130 km densities (60°–70°S) are displayed and compared to MTGCM imulations (Fig. 4). The polar day-to-night contrast observed is slightly larger than predicted by the MTGCM. Finally, a rather small solar cycle response of Mars temperatures ($F_{10.7}$ = 80–150) is observed over both aerobraking phases; exospheric temperatures near 45°N latitude appear to hover around 220 K.

Not surprisingly, observed day-to-day variations over 100 to 130 km (70–200%) (especially during the Noachis dust storm period) are not well modeled, owing to missing dynamical processes. It is clear that longitudinally-fixed planetary waves must be properly addressed in 3-D model simulations in order to explain the short-term wave #1, 2 or 3 thermospheric variations monitored throughout Phase 1 and 2. Furthermore, coupled 3-D model simulations have thusfar not been able to reproduce the rapid thermal expansion or the global response of the Mars atmosphere to the Noachis dust event (Fig. 2). Model shortcomings point to our present lack of understanding regarding dynamical processes connecting the Mars lower and upper atmospheres. A sophisticated coupling of the MGCM and MTGCM codes (fluxes and model fields at every grid point) is under development.

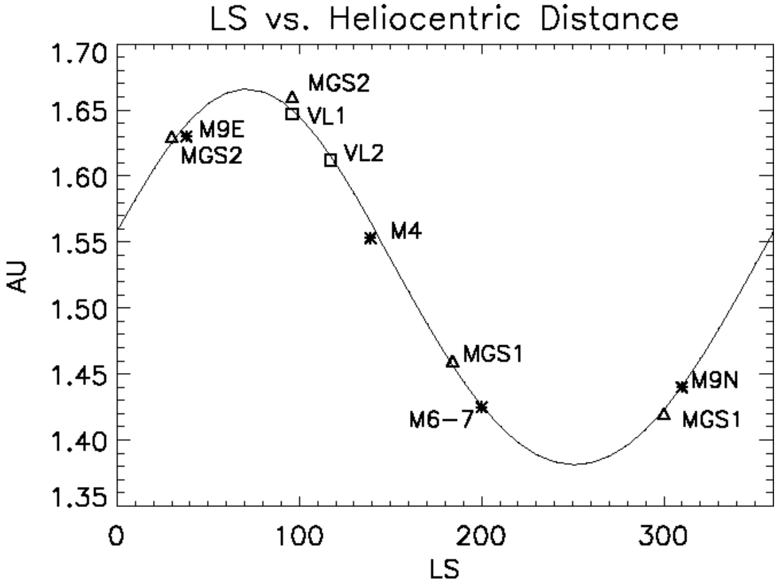

Fig. 1. Ls vs. heliocentric distance including superimposed spacecraft missions (seasonal sampling) [4].

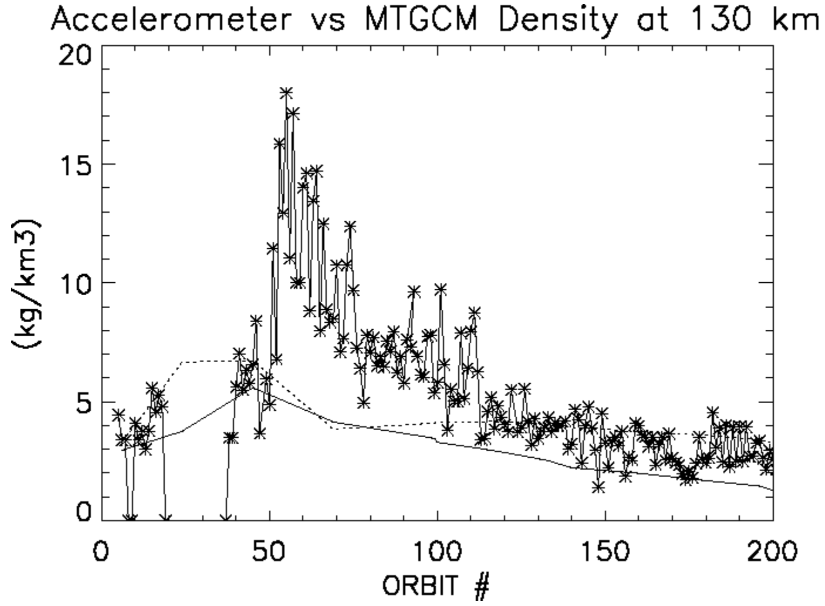

Fig. 2. MGS ACC data vs. MTGCM simulations of densities at 130 km over Phase 1 orbits P005-200. MTGCM curves are as follows: dotted ($\tau = 1.0$) and solid ($\tau = 0.3$) [4].

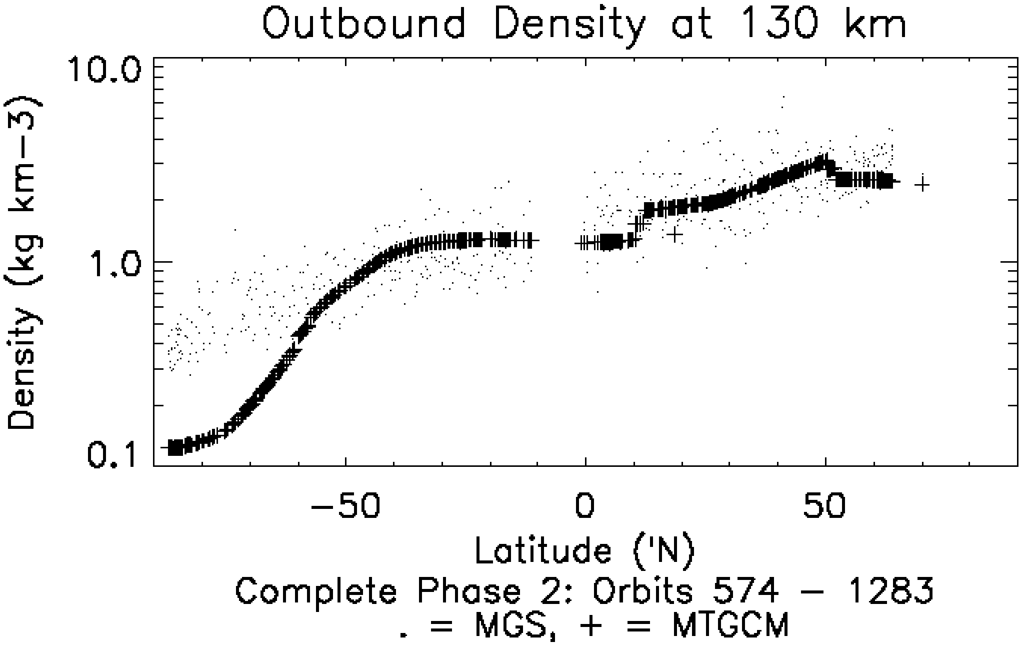

Fig. 3. MGS Phase 2 latitudinal variations of outbound 130 km ACC densities over SLT = 17–15 (all afternoon local times combined). Orbits P574-1283.

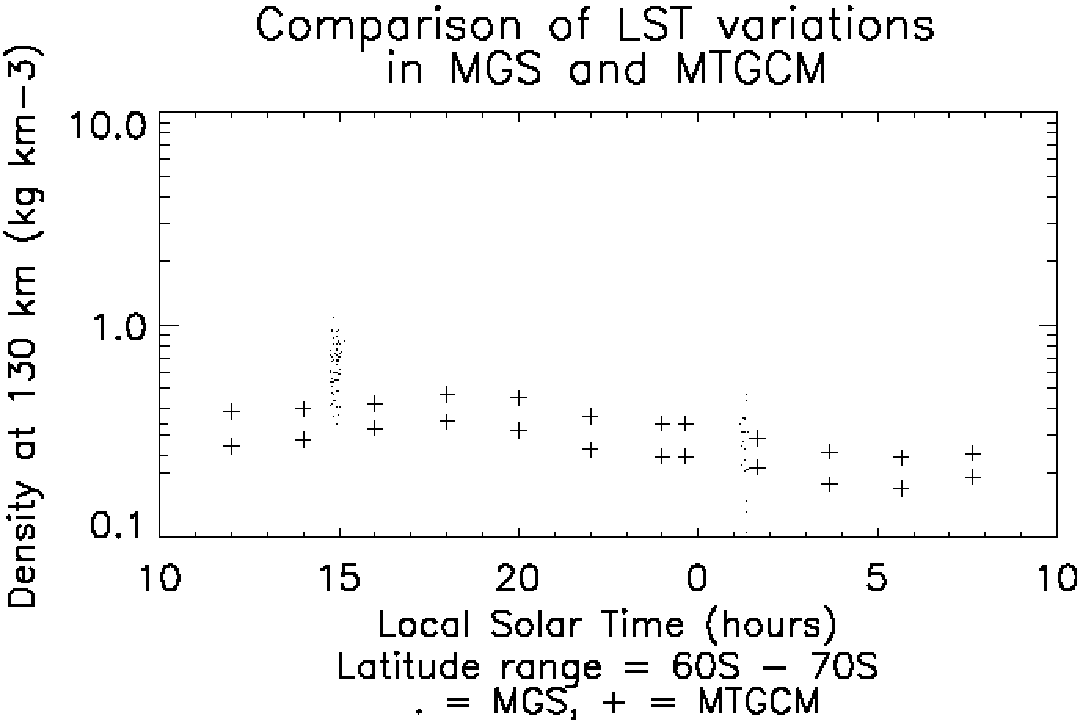

Fig. 4. MGS Phase 2 diurnal variations of 130 km ACC densities over 60°–70°S. Data at SLT = 15 and 2 are compared to MTGCM simulations.

References: [1] Keating G. M. et al. (1998) *Science, 279,* 1672–1676. [2] Stewart. A. I. F. (1987) *LASP-JPL Internal Rep. PO # NQ-802429,* JPL, Pasadena, CA. [3] Stewart A. I. F. et al. (1992) *JGR, 97,* 91–102. [4] Bougher S. W. et al. (1999) *Adv. Space Res.,* in press.