MARS GLOBAL REFERENCE ATMOSPHERIC MODEL (MARS-GRAM) AND DATABASE FOR MISSION DESIGN

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Introduction:

Mars Global Reference Atmospheric Model (Mars-GRAM 2001) is an engineering-level Mars atmosphere model widely used for many Mars mission applications (Justus and Johnson, 2001; Justus et al., 2002a). From 0-80 km, it is based on NASA Ames Mars General Circulation Model (MGCM; Haberle et al., 1993), while above 80 km it is based on Mars Thermospheric General Circulation Model (Bougher et al., 1990). Mars-GRAM 2001 and MGCM use surface topography from Mars Global Surveyor Mars Orbiting Laser Altimeter (MOLA; Smith and Zuber, 1998).

Validation with TES and Radio Science Data:

Validation studies (Justus et al., 2002b,c) are described comparing Mars-GRAM with Mars Global Surveyor Radio Science (RS; Hinson et al., 1999) and Thermal Emission Spectrometer (TES; Smith et al., 2001) data. RS data from 2480 profiles were used, covering latitudes 75° S to 72° N, surface to ~ 40 km, for seasons ranging from areocentric longitude of Sun (Ls) = 70-160° and 265-310°. RS data spanned a range of local times, mostly 0-9 hours and 18-24 hours. For interests in aerocapture and precision landing, comparisons concentrated on atmospheric density. Figure 1 shows that, at a fixed height of 20 km, RS density varied by about a factor of 2.5 over ranges of latitudes and Ls values observed. Evaluated at matching positions and times, average RS/Mars-GRAM density ratios, shown in Figure 2, were generally 1±0.05, except at heights above ~ 25 km and latitudes above ~ 50° N. Average standard deviation of RS/Mars-GRAM density ratio was 6%.

TES data were used covering surface to ~ 40 km, over more than a full Mars year (February, 1999 – June, 2001, just before start of a Mars global dust storm). Depending on season, TES data covered latitudes 85° S to 85° N. Most TES data were concentrated near local times 2 hours and 14 hours. Observed average TES/Mars-GRAM density ratios were generally 1±0.05, except at high altitudes (15-30 km, depending on season) and high latitudes (> 45° N), or at most altitudes in the southern hemisphere at Ls ~ 90 and 180°. Compared to TES averages for a given latitude and season, Figures 3-5 show that TES data had average density standard deviation about the mean of ~ 2.5% for all data, or ~ 1-4%, depending on time of day and dust optical depth. Average standard deviation of TES/Mars-GRAM density ratio was 8.9% for local time 2 hours and 7.1% for local time 14 hours. Thus standard deviation of observed TES/Mars-GRAM density ratio, evaluated at matching positions and times, is about three times the standard deviation of TES data about the TES mean value at a given position and season.

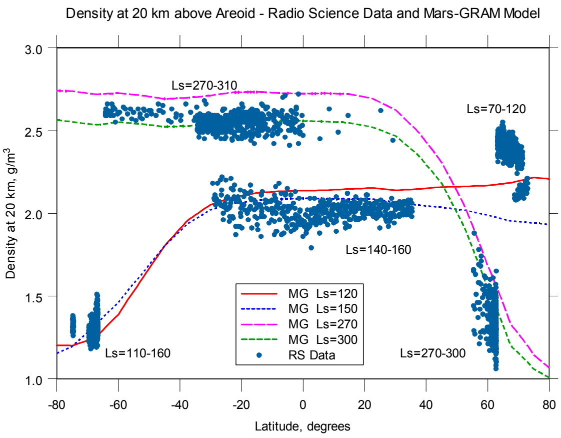

Figure 1 – Comparison of density at 20 km altitude from Mars Global Surveyor Radio Science observations and Mars-GRAM 2001 model.

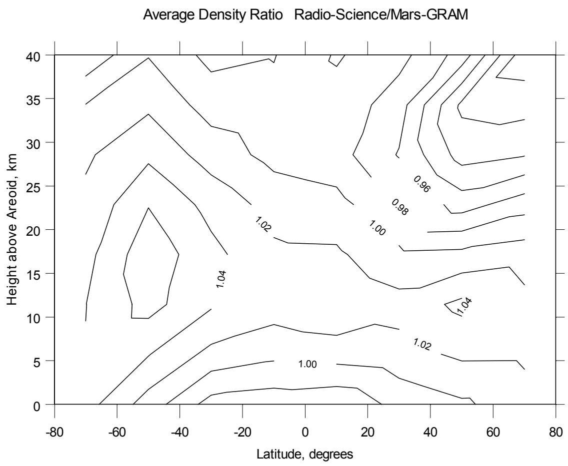

Figure 2 - Height-latitude cross section of average observed density ratio (Radio-Science/Mars- GRAM 2001) for all Ls and times of day.

Validation with Accelerometer Data:

Mars-GRAM has been used for operational support of aerobraking for both Mars Global Surveyor (Keating et al., 1998) and Mars Odyssey (Tolson et al., 2002). Figures 6-8 show some results of comparisons between Mars-GRAM and periapsis density and scale height from these two aerobraking opera-

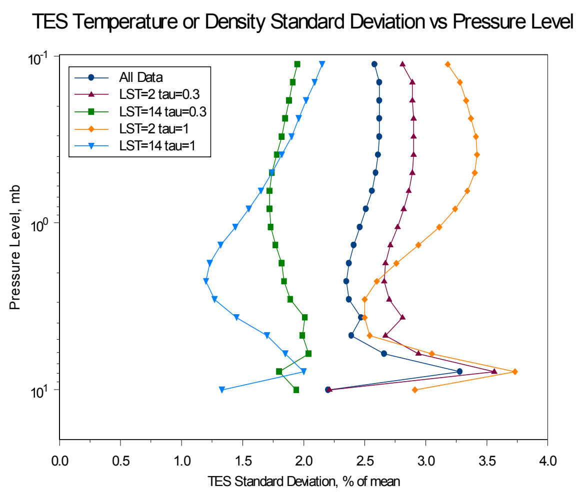

Figure 3. Standard deviation of TES temperature or density versus pressure level.

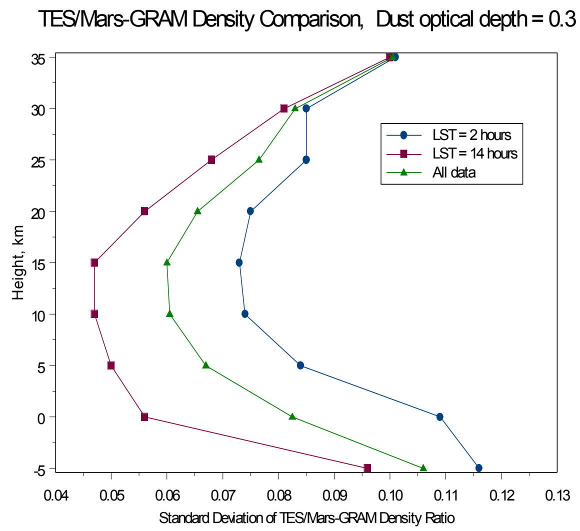

Figure 4. Standard deviation of TES/Mars-GRAM density ratio.

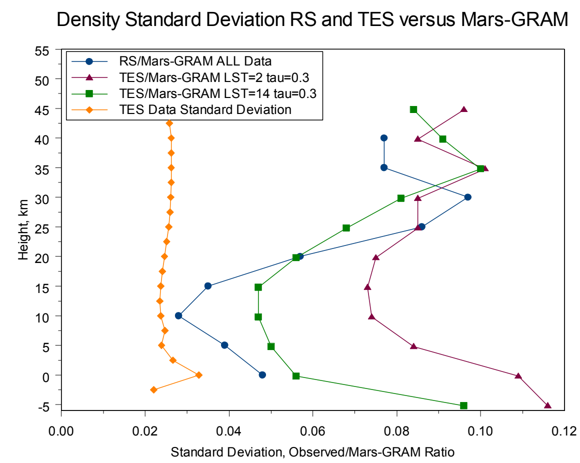

Figure 5 - Standard deviation of density ratio (RS/Mars-GRAM; circles) versus height. Standard deviations of TES/Mars-GRAM ratio (triangles and squares) and of TES data (RMS over all TES data bins; diamonds) are also shown for comparison.

tions. Figures 7 and 8 shows much better comparison between Mars-GRAM and Odyssey observed density and scale height if a large dust optical depth (about 1.5) is used. The good results obtained for large optical depth values are not indicative that the atmosphere really was this opaque during Odyssey aerobraking, simply that (used as a model "tuning parameter") Mars-GRAM model characteristics at large optical depth values correspond better with observations.

Table 1 gives height offsets (km) and statistics of averages and standard deviations for the Odyssey/Mars-GRAM density comparisons.

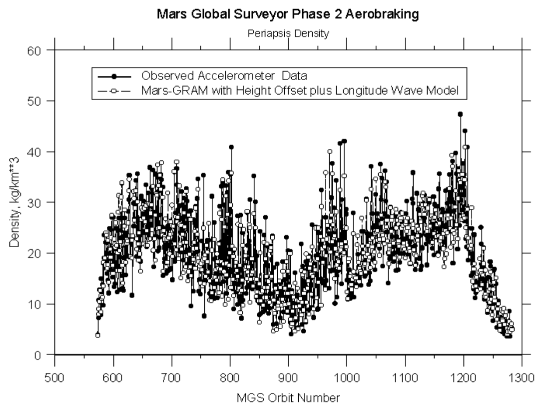

Figure 6 - Atmospheric density at periapsis from Mars Global Surveyor accelerometer during phase-2 aerobraking and simulated by Mars-GRAM using seasonal height offset and longitude wave model.

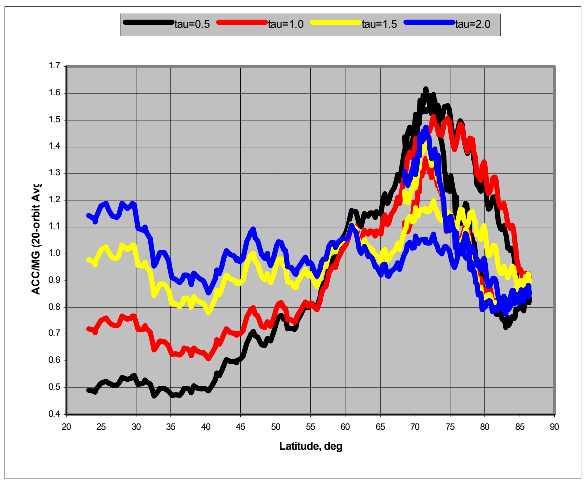

Figure 7 - Atmospheric density at periapsis from Mars Odyssey accelerometer during aerobraking and simulated by Mars-GRAM using various seasonal height offsets and dust optical depths.

New Near-Surface Mars-GRAM Features:

A new feature in Mars-GRAM 2001 allows quantitative evaluation of dust physical and optical properties, and details of near-ground-surface conditions (including surface albedo) so that estimates can be made for upwelling and downwelling components

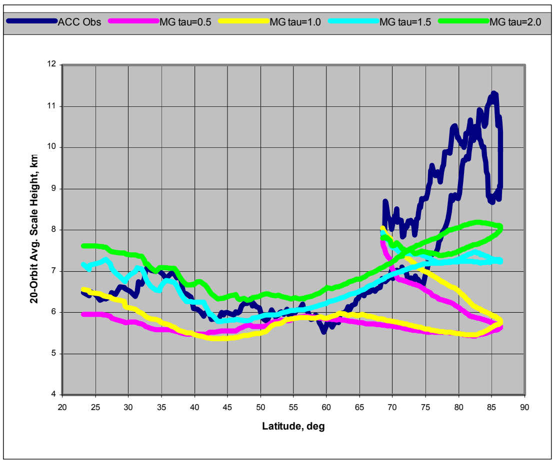

Figure 8 - Density scale height at periapsis from Mars Odyssey accelerometer during aerobraking and simulated by Mars-GRAM using various seasonal height offsets and dust optical depths.

Table 1 – Height offset used, and statistical results from Odyssey Accelerometer/Mars-GRAM density comparison, shown in Figure 7.

Optical Depth	Height Offset (km)	Average Acc/Mars-GRAM	Std. Dev. (%); 1-Orbit Value	Std. Dev. (%); 20-Orbit Mean
0.5	3.5	1.007	45.5	34.0
1.0	1.1	1.007	38.0	24.5
1.5	-1.4	1.004	32.6	14.8
2.0	-2.8	0.999	33.5	15.8

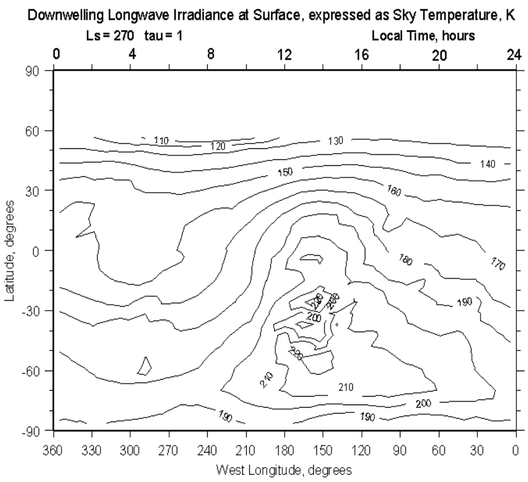

Figure 9. Latitude-longitude cross section of downwelling longwave irradiance at the surface, expressed as sky temperature, at Ls = 270 degrees, dust optical depth 1.0. Local time is plotted across the top of the figure.

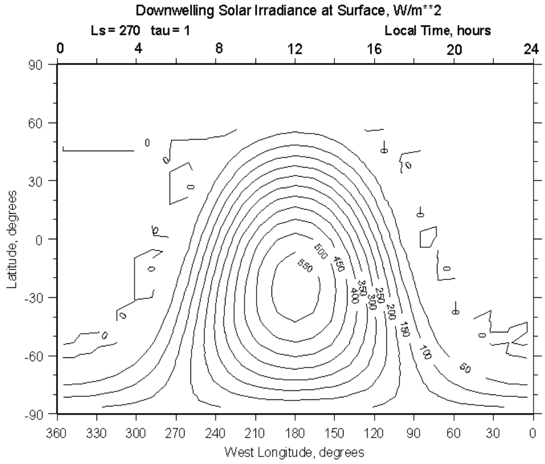

Figure 10. Latitude-longitude cross section of downwelling shortwave (solar) irradiance at the surface, at Ls = 270 degrees, dust optical depth 1.0. Local time is plotted across the top of the figure.

of solar (shortwave) and thermal (longwave) radiation at the surface. Figures 9 and 10 show latitude-longitude plots of downwelling longwave radiation at the surface (expressed as equivalent black-body sky temperature) and downwelling shortwave solar irradiance at the surface. Both of these figures were evaluated at Ls = 270 degrees, with dust optical depth = 1.0.

Other new Mars-GRAM 2001 features (Justus and Johnson, 2001) related to near-surface environments include realistic boundary layer representation of temperature gradients and winds and wind shears.

Conclusions:

As demonstrated by the validation studies here, Mars-GRAM 2001 is an engineering-level Mars atmospheric model suitable for a wide range of mission design, systems analysis, and operations tasks.

For orbiter missions, Mars-GRAM applications include analysis for aerocapture or aerobraking operations, analysis of station-keeping issues for science orbits, analysis of orbital lifetimes for end-of-mission planetary protection orbits, and atmospheric entry issues for accidental break-up and burn-up scenarios.

For lander missions, applications include analysis for entry, descent and landing (EDL), guidance and control analysis for precision landing, and (with the new near-surface environment features) systems design, thermal loads analysis, and solar power system performance analysis for lander operations.

With its realistic wind fields (not discussed here), Mars-GRAM is also well suited for studies of systems to operate within the atmosphere of Mars, such as airplanes or balloons used as mobile remote sensing platforms.

Using Mars-GRAM's perturbation model (not discussed here) in Monte-Carlo mode makes Mars-

GRAM especially suited for design and testing of guidance and control algorithms and for heat loads analysis of thermal protection systems.

Acknowledgments:
The authors gratefully acknowledge support from the Mars Data Analysis Program (MDAP), Dr. Joseph Boyce, NASA Headquarters, MDAP Discipline Scientist. We also thank Dr. John Pearl and other members of the Mars Global Surveyor Thermal Emission Spectrometer team for providing their CD ROM data in a timely and useful form.

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