IMPROVING MARS-GRAM: INCREASING THE ACCURACY OF SENSITIVITY STUDIES AT LARGE OPTICAL DEPTHS

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ABSTRACT

Extensively utilized for numerous mission applications, the Mars Global Reference Atmospheric Model (Mars-GRAM) is an engineering-level atmospheric model. In a Monte-Carlo mode, Mars-GRAM's perturbation modeling capability is used to perform high fidelity engineering end-to-end simulations for entry, descent, and landing (EDL). Mars-GRAM has been found to be inexact when used during the Mars Science Laboratory (MSL) site selection process for sensitivity studies for MapYear=0 and large optical depth values such as tau=3. Mars-GRAM is based on the NASA Ames Mars General Circulation Model (MGCM) from the surface to 80 km altitude. Mars-GRAM with the MapYear parameter set to 0 utilizes results from a MGCM run with a fixed value of tau=3 at all locations for the entire year. Imprecise atmospheric density and pressure at all altitudes is a consequence of this use of MGCM with tau=3. Density factor values have been determined for tau=0.3, 1 and 3 as a preliminary fix to this pressure-density problem. These factors adjust the input values of MGCM MapYear 0 pressure and density to achieve a better match of Mars-GRAM MapYear 0 with Thermal Emission Spectrometer (TES) observations for MapYears 1 and 2 at comparable dust loading. These density factors are fixed values for all latitudes and Ls and are included in Mars-GRAM Release 1.3. Work currently being done, to derive better multipliers by including variations with latitude and/or Ls by comparison of MapYear 0 output directly against TES limb data, will be highlighted in the presentation. The TES limb data utilized in this process has been validated by a comparison study between Mars atmospheric density estimates from Mars-GRAM and measurements by Mars Global Surveyor (MGS).   This comparison study was undertaken for locations on Mars of varying latitudes, Ls, and LTST. The more precise density factors will be included in Mars-GRAM 2005 Release 1.4 and thus improve the results of future sensitivity studies done for large optical depths.

Improving Mars-GRAM: Increasing the Accuracy of Sensitivity Studies at Large Optical Depths

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Background

It has been discovered during the Mars Science Laboratory (MSL) site selection process that the Mars Global Reference Atmospheric Model (Mars-GRAM) when used for sensitivity studies for TES MapYear = 0 and large optical depth values such as tau = 3 is less than realistic.

Mars-GRAM is an engineering-level atmospheric model widely used for diverse mission applications

- Mars-GRAM's perturbation modeling capability is commonly used, in a Monte-Carlo mode, to perform high fidelity engineering end-to-end simulations for entry, descent, and landing (EDL)[1]
- Mars-GRAM 2005 has been validated[2] against Radio Science data, and both nadir and limb data from the Thermal Emission Spectrometer (TES)[3]
- Traditional Mars-GRAM options for representing the mean atmosphere along entry corridors include:
  - TES Mapping Year 0, with user-controlled dust optical depth and Mars-GRAM data interpolated from MGCM model results driven by selected values of globally-uniform dust optical depth.
  - TES Mapping Years 1 and 2, with Mars-GRAM data coming from MGCM model results driven by observed TES dust optical depth
- From the surface to 80 km altitude, Mars-GRAM is based on NASA Ames Mars General Circulation Model (MGCM). Mars-GRAM and MGCM use surface topography from Mars Global Surveyor Mars Orbiter Laser Altimeter (MOLA), with altitudes referenced to the MOLA areoid, or constant potential surface.

Why are the Sensitivity Studies Inaccurate at Large Optical Depths?

MGCM results for Mars-GRAM with MapYear = 0 were from MGCM runs with fixed values of tau (0.3, 1.0, and 3.0) for the entire year at all locations.

For the tau = 3 case, it has been determined that:

- Unrealistic energy absorption by uniform atmospheric dust leads to an unrealistic thermal energy balance on the polar caps
- Outcome is an inaccurate cycle of condensation/sublimation of the polar caps and, as a consequence, an inaccurate cycle of total atmospheric mass and global-average surface pressure.
- Under an assumption of unchanged temperature profile and hydrostatic equilibrium, a given percentage change in surface pressure would produce a corresponding percentage change in density at all altitudes
- Consequently, for tau = 3, the final result is an imprecise atmospheric density at all altitudes

References

[1]Striepe S. A. at al. (2002), AIAA Atmospheric Flight Mechanics Conference and Exhibit, Abstract # 2002-4412.
[2]Justus C. G. et al. (2005) "Mars Aerocapture and Validation of Mars-GRAM with TES Data", 53rd JANNAF Propulsion Meeting.
[3]Smith M. D. (2004) Icarus, 167, 148-165.

Background Image of Mars Sunset Courtesy NASA/JPL/Texas A&M/Cornell

Comparison Study Between Mars-GRAM and MGS Data

A comparison study between Mars atmospheric density estimates from Mars-GRAM and measurements by Mars Global Surveyor (MGS) has been undertaken for locations of varying latitudes, Ls, and LTST on Mars for both TES MapYear 1 and 2.

- TES MapYear 1: April 1999 - January 2001 - normal conditions
- TES MapYear 2: February - December 2002 - global dust storm

The ratios of TES Limb/Radio Science shown in Figure 1 and TES Nadir/Radio Science shown in Figure 2 illustrate how the observed atmospheric density profiles compare to each other.
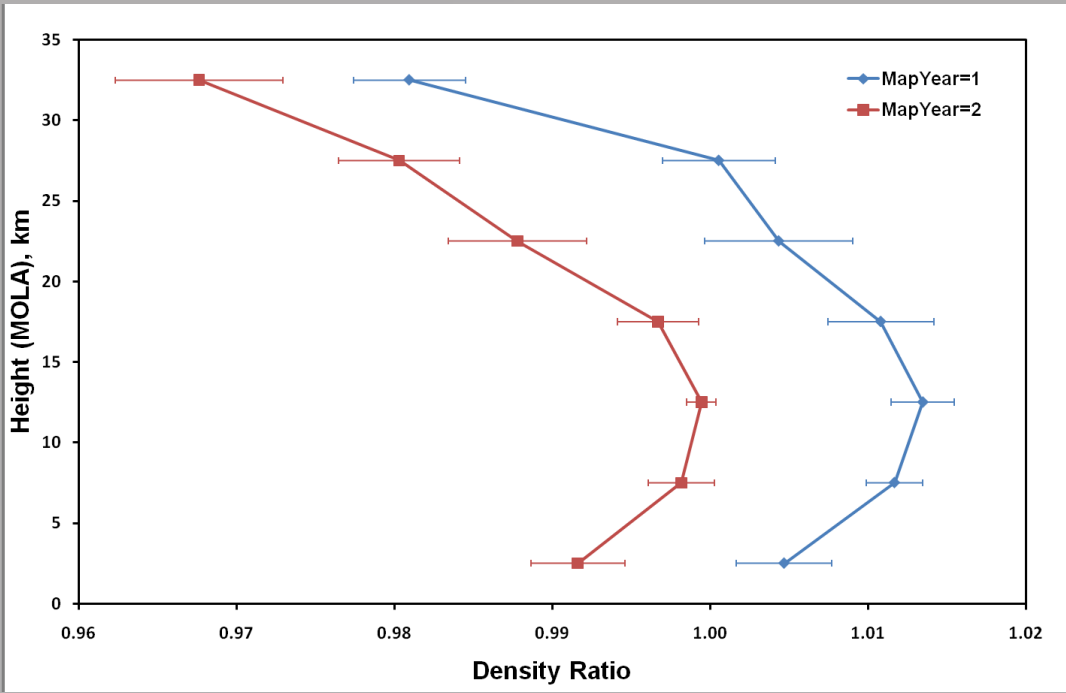

Figure 1. Atmospheric density comparison of ratios and standard deviations for TES Limb/Radio Science
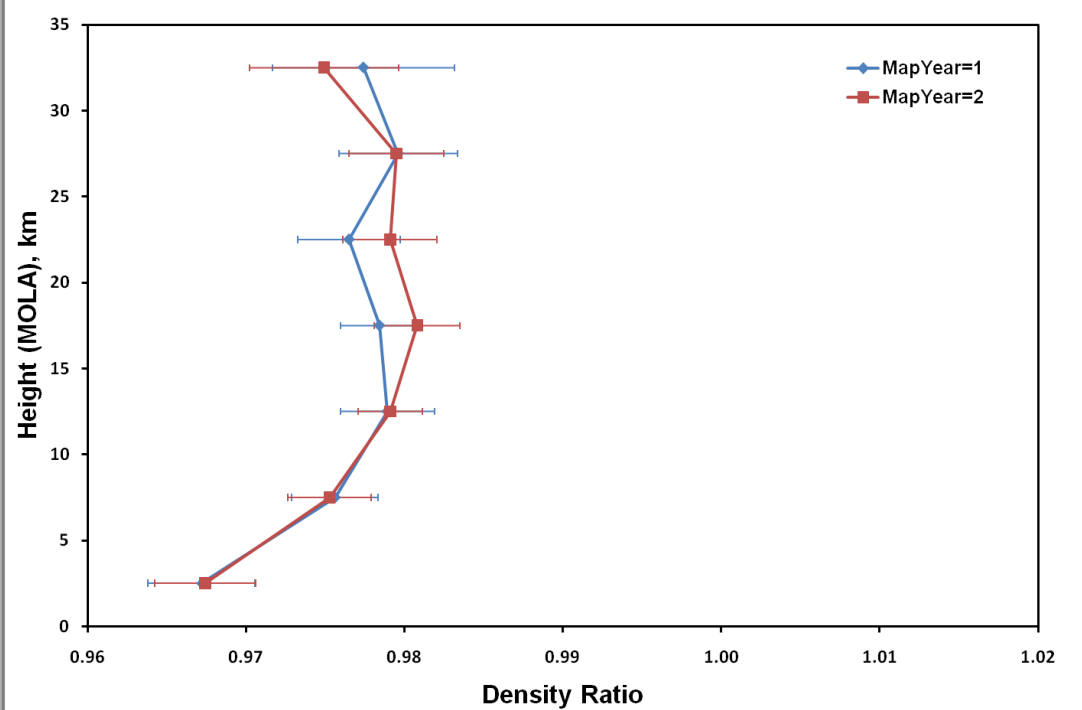

Figure 2. Atmospheric density comparison of ratios and standard deviations for TES Nadir/Radio Science

As Figures 1 and 2 show, the density ratios never varied by more than 0.04 from 1 and were always within 0.02 of each other. These results demonstrate that the observational profiles are consistent with each other and thus, validate the TES limb data.

Solving the Sensitivity Study Discrepancy for Large Optical Depths

In determining a solution to the discrepancy shown in the sensitivity study results for TES MapYear = 0 and large optical depths, the TES Limb profiles were chosen for comparison because they extend to approximately 50 km.

- TES Radio Science and TES Nadir data extend only to approximately 35 km.
- This allows the Mars-GRAM and TES Limb profiles to be compared in the upper atmosphere.

This approach was derived by doing comparisons between Mars-GRAM MapYear = 0 and MapYear = 2 output.

- MapYear = 2 contains a large global dust storm, and so has a large number of tau = 3 values.
- Separately, it was verified that Mars-GRAM MapYear = 2 output agreed fairly well with TES limb observations.

Preliminary Fix

A preliminary fix has been made to Mars-GRAM by adding a density factor value that was determined for tau = 0.3, 1 and 3.

- This factor adjusts the input values of MGCM MapYear 0 pressure and density to achieve a better match of Mars-GRAM MapYear 0 with MapYears 1 and 2 MGCM output at comparable dust loading.
- This factor multiplies the tau = 3 densities and pressures by about 1.2, but leaves the tau = 0.3 and 1.0 densities and pressures almost unchanged (multipliers near 1.0).
- These factors will automatically take care of intermediate tau values between 1.0 and 3.0, since the tau-interpolated values will have effective multipliers between 1.0 and 1.2.

These updates can be found in Mars-GRAM 2005 Release 1.3.

Current Work

Currently, these density factors are fixed values for all latitudes and Ls. Presently, work is being done to derive better multipliers by including possible variation with latitude and/or Ls by comparison of MapYear = 0 output with TES limb data.

- Preliminary results for tau = 3 have shown some latitude dependence.
- The tau = 3 values occurred in the limb data only near Ls = 210, no Ls dependence could be determined for the high density cases.
- Significantly more cases for tau = 1 and tau = 0.3 have provided more information into the latitude and Ls variations.

The latest results utilizing these improved density factors are given in Figures 3 and 4
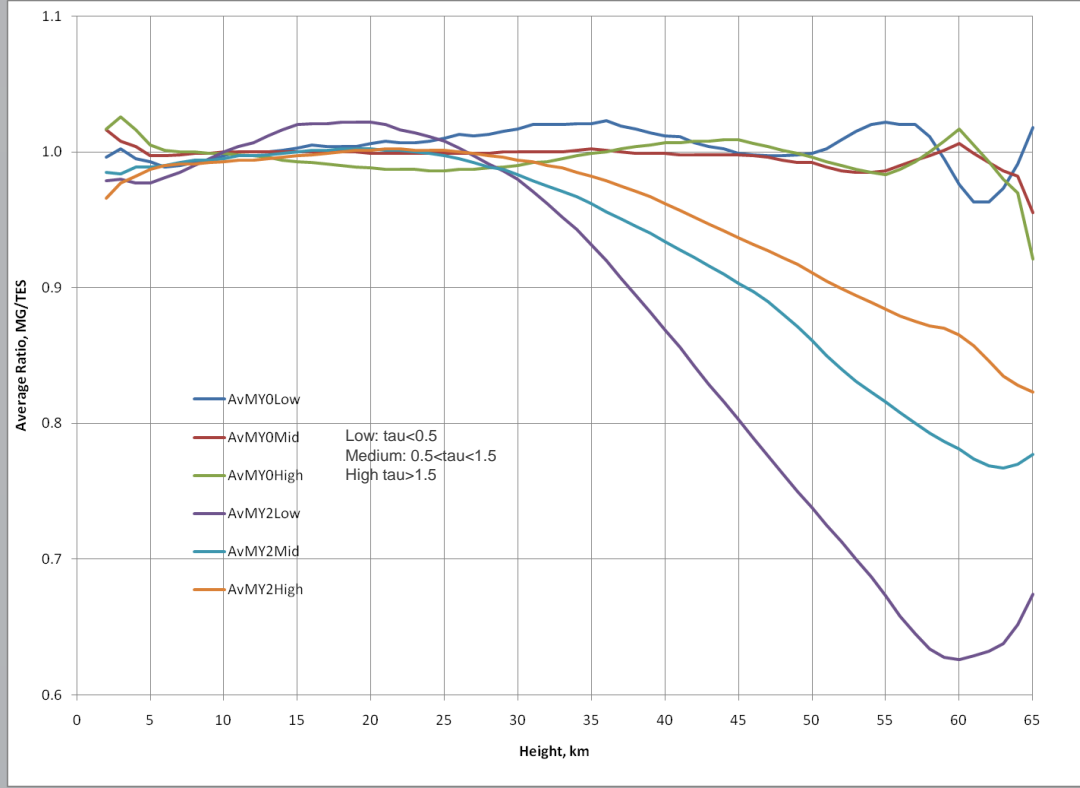

Figure 3. Profiles from Mars-GRAM using Mapping Year 2, compared with modified Mars-GRAM output using revised MGCM data for Mapping Year 0. Density ratios are Mars-GRAM (MG) relative to observed TES Limb value . These values are averages over all Ls values which have high dust (Ls = 180 - 270).
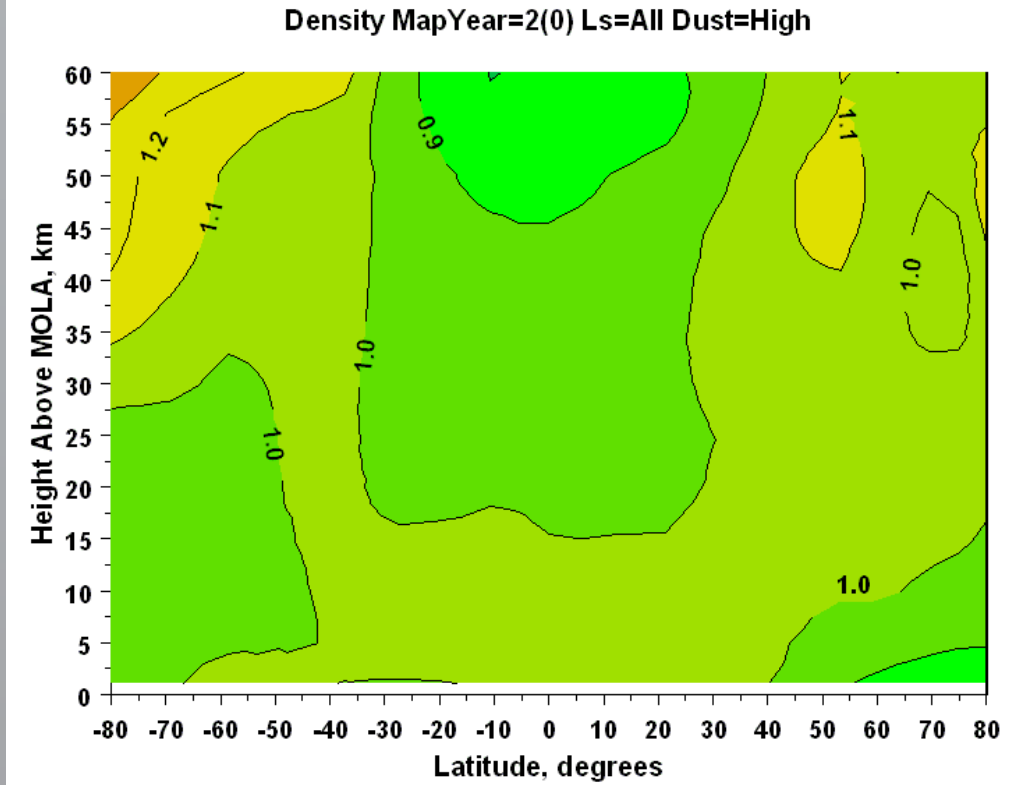

Figure 4. Lat-Height contours of ratio of MG/TES(limb) for high dust case (tau>1.5). These values are averages over all Ls values which have high dust (Ls = 180 - 270).

New Version of Mars-GRAM: Mars-GRAM 2010

Mars-GRAM 2010 developed and ready for beta testing

- Uses Fortran 90/95
- Density factors are used to adjust the input data from MGCM and MTGCM
  - Greatest adjustment at large optical depths (tau>1)
  - Better correspondence to TES Limb data (0-60 km)
  - Better agreement with Odyssey and MRO (~ 90-120 km)
- Expected to be released later this year