Independent Verification of Mars-GRAM 2010 with Mars Climate Sounder Data

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Background

The Mars Global Reference Atmospheric Model (Mars-GRAM) is an engineering-level atmospheric model of the Martian atmosphere widely used for diverse mission and engineering applications. Examples of Mars-GRAM utilization in the Mars exploration program include systems design, performance analysis, and operations planning for aerobraking, entry, descent and landing, and aerocapture. Atmospheric influences on landing site selection and long-term mission conceptualization and development can also be addressed using Mars-GRAM. The latest version of Mars-GRAM includes adjustment factors, the ratio of observed Thermal Emission Spectrometer (TES) density to Mars-GRAM density. These factors were generated by evaluating Mars-GRAM at locations and times of TES limb observations. Verification of Mars-GRAM 2010 using Mars Climate Sounder (MCS) instrument data independent of that utilized in the generation of the adjustment factors will provide an independent verification of Mars-GRAM 2010.

Mars-GRAM Features

Input Climatology

From the surface to 80 km altitude, Mars-GRAM is based on the NASA Ames Mars General Circulation Model (MGCM).[1] Above 80 km, Mars-GRAM is based on the University of Michigan Mars Thermospheric General Circulation Model (MTGCM).[2]

Dust Options

- TES Mapping Year 0, with user-controlled dust optical depth and Mars-GRAM data interpolated from NASA Ames 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.

Sample Run Time Options

- Perturbation capability allows high-fidelity Monte-Carlo simulations through dispersed atmospheres.[3]
- Boundary layer and slope wind outputs for improved realism near the surface. Slope winds can be scaled with input factor, blwinfac.
- Mars-GRAM input parameters allow standard deviations of Mars-GRAM perturbations to be adjusted: rpscale (density perturbations), rwscale (wind perturbations), and wlscale (adjusts wavelengths (spectral range) of the perturbations).
- Auxiliary profile option allows user to use any auxiliary profile of temperature and density versus altitude in the TES mapping year 0 option. Auxiliary profile values replace original MGCM data.
- Mars-GRAM 2010 has been updated to Fortran 90/95 for increased performance over previous Fortran 77 versions.

Mars-GRAM 2010 Users Guide

A Mars-GRAM 2010 Users Guide has been published as a NASA Technical Memo (NASA/TM—2014–217499) and is available to Mars-GRAM 2010 users.

Methodology

- Develop a process for selecting MCS data subsets based on user-selected ranges of latitude, longitude, local true solar time (LTST), and L_s.
- Define analysis cases by selecting representative sets of subset ranges.
- For each case, determine appropriate Mars-GRAM input namelist values and run the model to obtain mean density profiles over the altitude range the surface to 100 km.
- For each case, identify all MCS profiles within the given data subset. Observed temperatures and pressures are used to compute MCS densities for all profiles in the subset.
- Interpolate MCS subset profiles to 0.1 km grid spacing in order to compute subset mean profiles.
- Plot all individual MCS subset profile densities, the MCS subset mean density, the associated Mars-GRAM output mean densities, and the Mars-GRAM mean +/- 3 standard deviation profiles.
- Compute density ratios (Mars-GRAM outputs/MCS data) for all individual subset profiles and for the subset mean profile.

Mars Climate Sounder Data

MCS Derived Data Record Level 2 geophysical profile data were downloaded from the Planetary Data System (PDS) website and archived locally for processing. Approximately 3 million data records were extracted spanning the MCS science operation period of record from September 24, 2006 to January 31, 2012. Individual profiles exist at all latitudes and longitudes except very near the poles. The data span all values of L_s. As the satellite is in a sun-synchronous orbit, observations are primarily made at two times of the day, approximately 0.1-0.2 LTST and 0.6 to 0.7 LTST, depending on the ascending/descending node of the orbit.

References

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Background Image of Mars Courtesy NASA

Mars-GRAM 2010 Adjustment Factors

The latest version of Mars-GRAM includes adjustment factors derived from densities observed by TES limb soundings.[4] The addition of adjustment factors to Mars-GRAM 2010 resolved discrepancies noted in sensitivity studies for mapping year 0 and large optical depth values, such as tau equal to 3.

- Adjustment factors were expressed as a function of height (z), latitude and areocentric solar longitude (L_s).
- For altitudes above 80 km, Mars-GRAM MTGCM densities were compared to aerobraking densities from Mars Global Surveyor (MGS), Mars Odyssey (ODY), and Mars Reconnaissance Orbiter (MRO).
- The adjustment factors were constrained by the ideal gas law: $p = \rho RT$ as well as the hydrostatic relation: $dp/dz = -\rho g$.
- Greatest adjustment occurs at large optical depths (tau>1).

Improvement of Mars-GRAM as a Result of Applying Adjustment Factors

Application of adjustment factors to the MGCM data yields improved comparisons between Mars-GRAM and TES limb data, as shown by density ratios (Mars-GRAM/TES Limb) given in figure 1 (a). Prior to adjustment, density ratios ranged from 0.6 to 3.0 over the altitude domain from 0-60 km. Figure 1 (a) shows the values after adjustment with density ratios ranging from 0.9 to 1.3.

Application of adjustment factors to the MTGCM data yields improved comparisons between Mars-GRAM and MGS, ODY, and MRO aerobraking densities, from approximately 90 to 130 km, as shown in Figure 1 (b). Prior to adjustment, density ratios were as high as 3.2 near the poles. After adjustment, the density ratios are near 1.0 over much of the planet, especially at mid-latitudes.

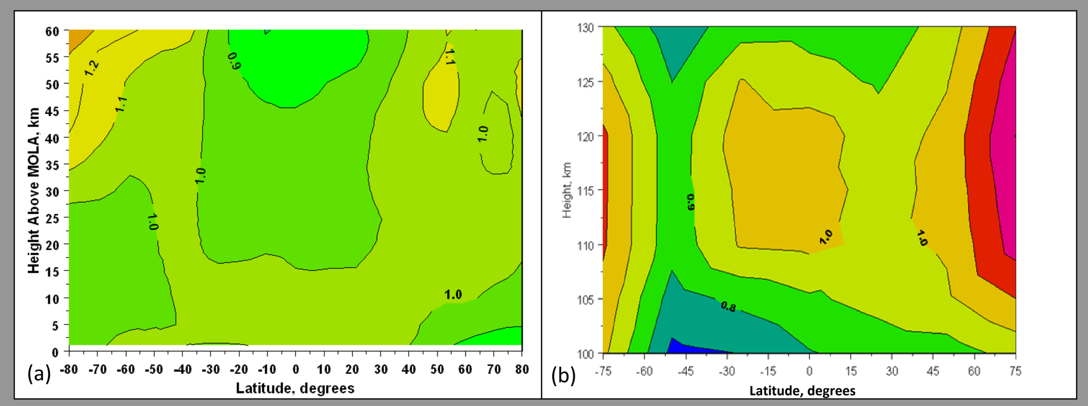

Figure 1. Density ratios (R) shown as latitude-height contours for (a) MGCM adjustments at lower altitudes (0-60 km) where R is defined as the ratio of Mars-GRAM outputs to observed TES limb density values, and for (b) MTGCM adjustments at aerobraking altitudes (100-160 km) where R is defined as the ratio of Mars-GRAM outputs to densities from MGS, MRO, and ODY aerobraking operations.

Results of Current Independent Verification Study at Lower Altitudes: Mars-GRAM 2010 Versus MCS Comparison

Four cases were selected for analysis. The first three cases represent L_s values spanning the expected landing dates for the 2020 Rover mission, for latitudes of 0°, -25° and 60°. The fourth case is a dust season case at 20° latitude. Both aggregate and mean density profiles were compared to Mars-GRAM outputs using appropriate case-specific input values. Profiles of density and density ratios (Mars-GRAM/MCS) were computed with results shown in Figure 2. All cases show good comparison, with mean density ratios close to identity. Departures are noted but no systematic trend is apparent across cases.

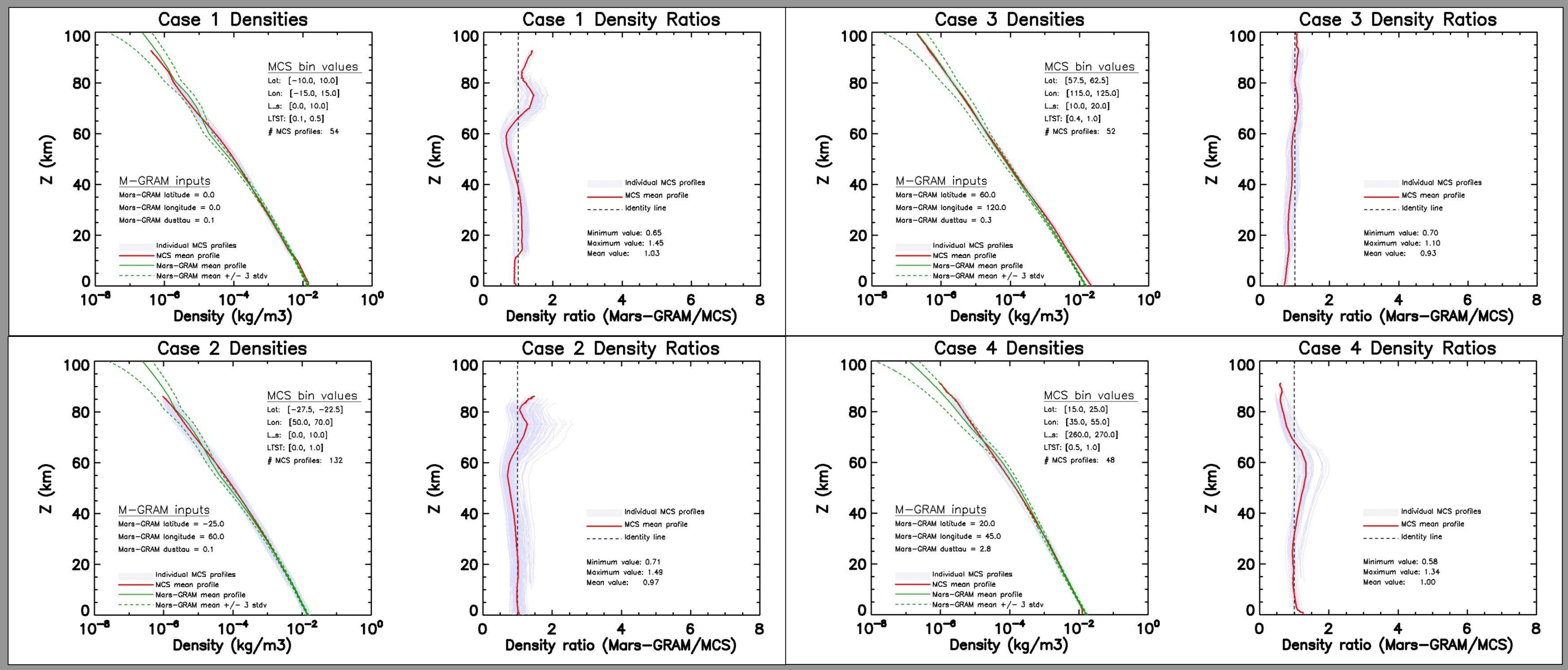

Figure 2. Profiles of density and density ratios for four cases comparing Mars-GRAM outputs to densities computed from MCS data. Specific case input values are shown on each graph.

Conclusions

- Adjustment factors have led to better correspondence to TES Limb data (0-60 km) as well as MGS, Odyssey and MRO data at approximately 90-130 km.[4]
- Mars-GRAM outputs agree well with MCS data over a range of values for latitude, longitude, L_s, and LTST, throughout the full MCS vertical domain, but especially over the altitude range from 20 to 60 km.
- The results of this study are important because they represent the first fully independent verification of the Mars-GRAM 2010 model using an extensive dataset of observed values from MCS.

Forward Work

- Analyze additional cases in order to characterize the scenario conditions under which density ratio departures occur. Any trends that are identified can potentially be used to further refine the adjustment factors.
- Update the Mars-GRAM climatologies by incorporating new model runs using the current state-of-the-art versions of MGCM and MTGCM.
- Provide the option to use MCS data as the background climatology at lower altitudes in place of the default MGCM climatology.