Utilizing Mars Global Reference Atmospheric Model (Mars-GRAM 2005) to Evaluate Entry Probe Mission Sites

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Mars Global Reference Atmospheric Model (Mars-GRAM)

- 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].
- Traditional Mars-GRAM options for representing the mean atmosphere along entry corridors include:
  - TES Mapping Years 1 and 2, with Mars-GRAM data coming from MGCM model results driven by observed TES dust optical depth
  - 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.
- 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.
- Mars-GRAM 2005 has been validated[2] against Radio Science data, and both nadir and limb data from the Thermal Emission Spectrometer (TES)[3].

New Features of Mars-GRAM 2005

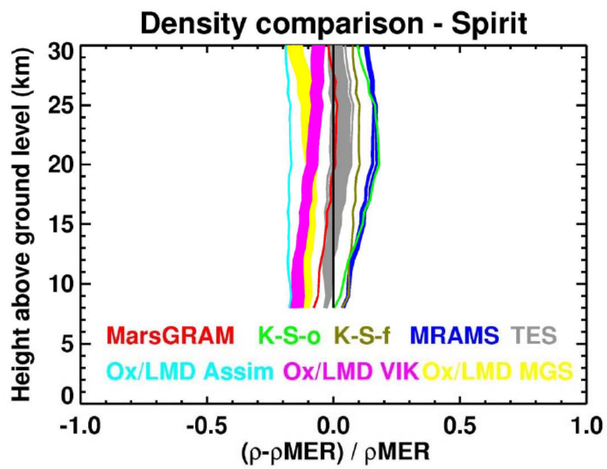
- Option to use input data sets from MGCM model runs that were designed to closely simulate conditions observed during the first two years of TES observations at Mars
  - TES Year 1 = April 1999 through January 2001
  - TES Year 2 = February 2001 through December 2002
- Option to read and use any auxiliary profile of temperature and density versus altitude. In exercising the auxiliary profile Mars-GRAM option, the values from the auxiliary profile replace data from the original MGCM databases
  - Examples of auxiliary profiles:
    - Data from TES (nadir or limb) observations
    - Mars mesoscale model output at a particular location and time
- Two Mars-GRAM parameters allow standard deviations of Mars-GRAM perturbations to be adjusted
  - rpscale can be used to scale density perturbations up or down
  - rwscale can be used to scale wind perturbations

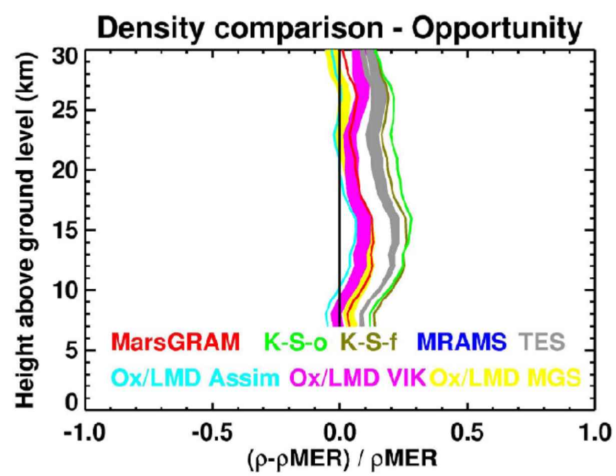
Entry Probe Mission Site Selection

- Mars-GRAM could be a valuable tool for planning of future Mars entry probe missions
- Mars-GRAM can provide data on density, temperature, pressure, winds, and selected atmospheric constituents for mission sites on Mars
- Currently, Mars-GRAM is being used in the Mars Science Laboratory landing site selection process

Comparison with MER EDL models

- Paul Withers at Boston University compared the MER EDL data with various models including Mars-GRAM
- Mars-GRAM averages within 5% of the MER values
- For surface-pressure corrected results, Mars-GRAM is one of two models that averages a ratio of 1.0 to the MER data, the other is MGCM (TES dust)





Applications for Mars Science Laboratory Mission Site Selection:

- In order to assess Mars Science Laboratory (MSL) landing capabilities, the following candidate sites have been studied as part of our work as a member of the MSL Council of Atmospheres:

Terby Crater	Holden Crater	Nili
Melas Chasma	Mawrth	E. Meridiani
Gale Crater		

- Two mesoscale models were run for the expected MSL landing season and time of day.
  – Mars Regional Atmospheric Modeling System (MRAMS) of Southwest Research Institute[4]
  – Mars Mesoscale Model number 5 (MMM5) of Oregon State University[5].

Other Sources of Mars Atmospheric Data

- To assess likely uncertainty in atmospheric representation at these candidate sites, two other sources of atmospheric data were also analyzed:
  – A global Thermal Emission Spectrometer (TES) database containing averages and standard deviations of temperature, density, and thermal wind components, averaged over 5-by-5 degree latitude - longitude bins and 15 degree Ls bins, for each of three Mars years of TES nadir data
  – A global set of TES limb sounding data, which can be queried over any desired range of latitude-longitude and Ls, to estimate averages and standard deviations of temperature and density

Characteristics of TES Nadir Database

- Three TES Mapping Years
  - Yr 1 = 4/99 – 2/01
  - Yr 2 = 2/01 – 1/03
  - Yr 3 = 1/03 – 11/04

- Global TES Nadir Data Set - Means and Standard Deviations for temperature, density, and thermal wind components **:**
  - 5-by-5 degree Lat-Lon bins
  - 15 degree Ls bins
  - Local Solar Time = 2 or 14 hours
  - Up to 21 Pressure Levels, automatically converted to Geometric Height by Database Query Program
  - Query program gives output at TES pressure levels or interpolated to 1-km altitude intervals
  - Output automatically formatted for Mars-GRAM input as Auxiliary Profile

Characteristics of TES Limb Database

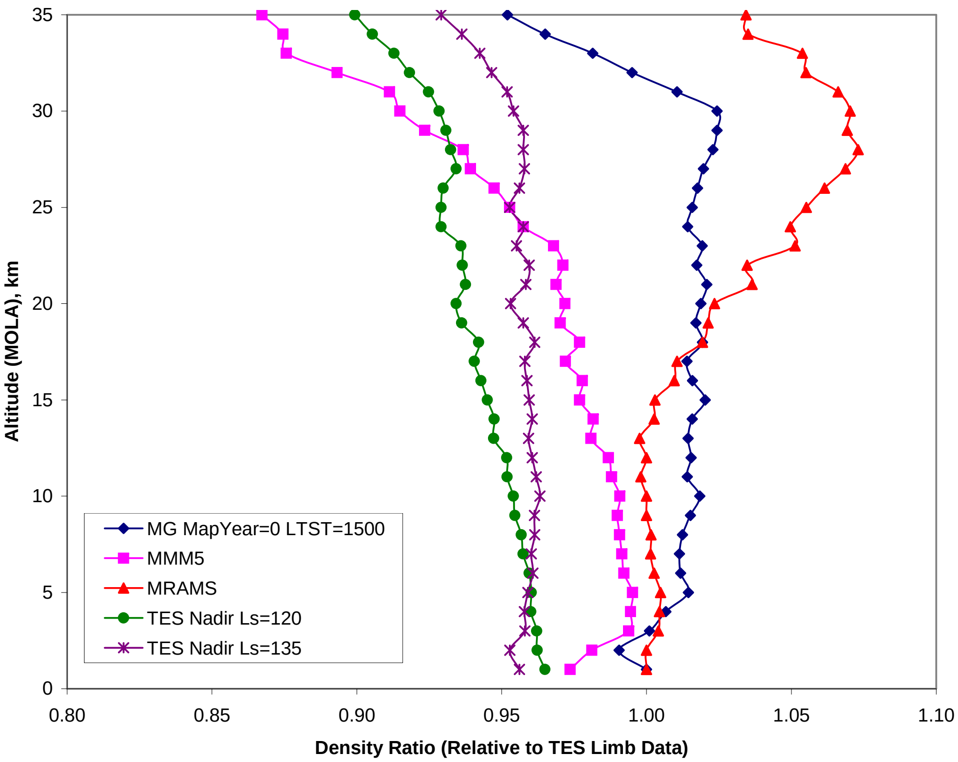
- Data for TES Mapping Years 1 and 2 and ~1/2 of TES Mapping Year 3

- Query Program Allows User to Select Lat-Lon, and Ls Bins and Local True Solar Time
  - Input desired Lat-Lon and select Lat-Lon Bin widths
  - Input desired Ls and select Ls Bin width
  - Choose LTST = 2 or 14 hours (or both)

- Query Program outputs all individual profiles that match criteria, plus average and standard deviation of temperature and density of all output profiles
  - Up to 38 Pressure levels, automatically converted to geometric altitude
  - Output at pressure levels, or interpolated to 1-km altitude intervals
  - Output automatically formatted for Mars-GRAM input as Auxiliary Profile

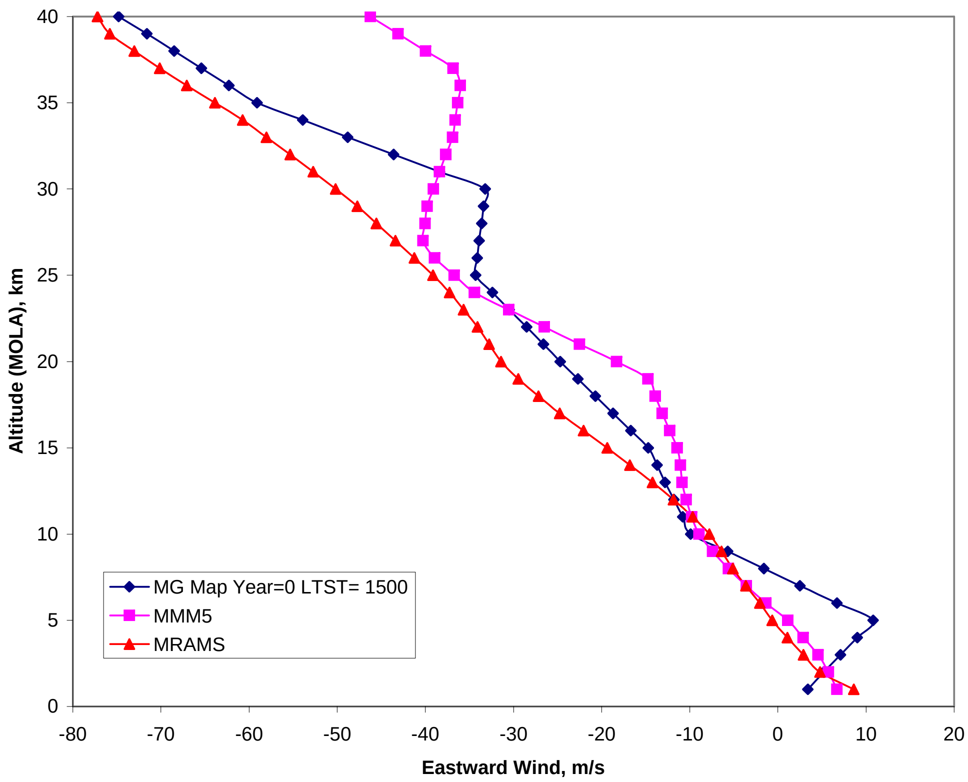
Density Comparison

- Comparison of vertical profiles of density ratio from TES nadir data, MRAMS, MMM5, and Mars-GRAM model output for the Mawrth MSL landing site.
- Density values are represented as a ratio relative to TES Limb data
- TES Nadir and Limb data are for Map Year 1. TES Limb data is for Ls=130 +/- 15. TES nadir values from Ls=120 and Ls-135
- Mars-GRAM results are Map Year 0 with dust visible optical depth tau = 0.1, LTST = 1500
- TES nadir and TES limb data differ significantly - all of the models tend to agree with the limb data more than the nadir results at the MSL candidate sites
- Above ~ 20 km, differences increase between MRAMS and MMM5 results



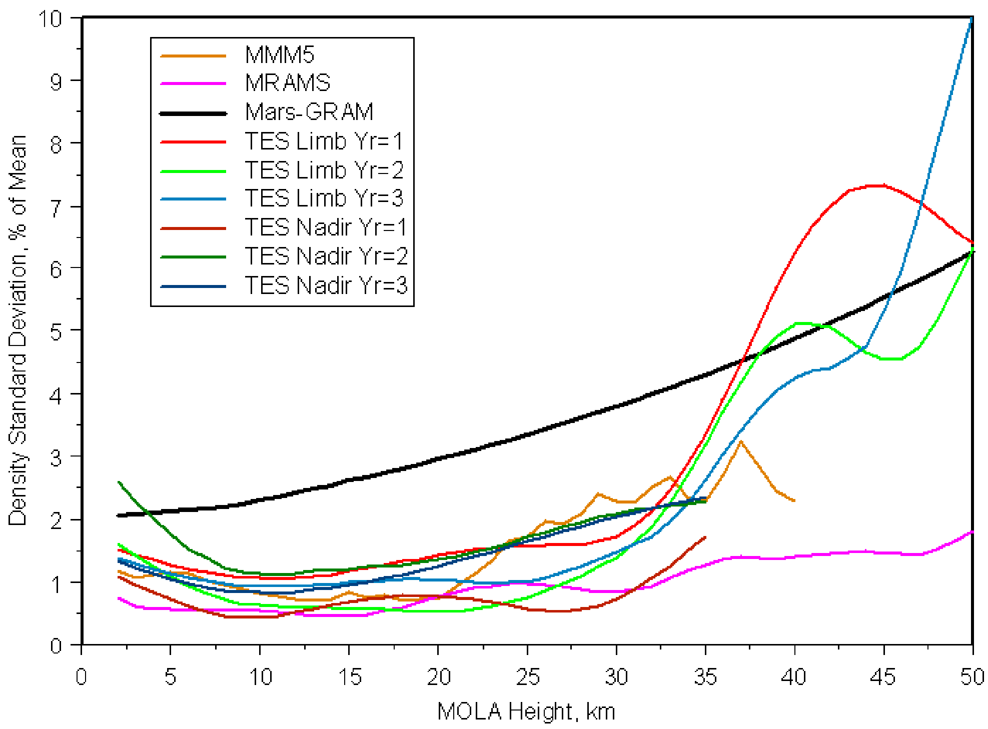
Zonal Wind Comparison

- Comparison of vertical profiles of mean zonal (eastward) wind from MRAMS, MMM5, and Mars-GRAM for the Mawrth MSL landing site
- Wind results from MRAMS and MMM5 are more consistent than the density results between these two models



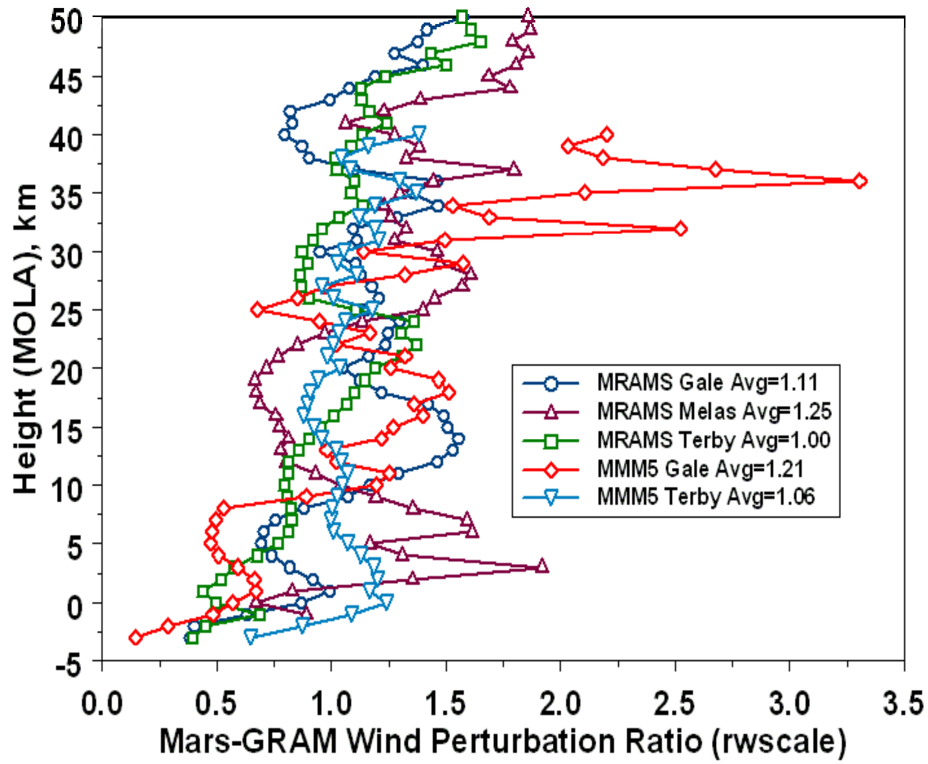
Density Standard Deviation Comparison

- Comparison of vertical profiles of density standard deviation from TES nadir data, TES limb data, and MRAMS, MMM5, and Mars-GRAM model output for the Mawrth MSL landing site
- Observed and mesoscale-modeled density standard deviations are generally less than Mars-GRAM density standard deviations, an exception being TES nadir year 2 values below ~ 5 km altitude and TES limb data above ~ 36 km.
- With nominal value rpscale=1, Mars-GRAM perturbations would be conservative
- To better represent TES and mesoscale model density perturbations, rpscale values as low as ~ 0.4 could be used.



Wind Perturbation Comparisons

- Mars-GRAM Wind Perturbation Ratio (rwscale) vs Height for MRAMS, MMM5, and nominal Mars-GRAM perturbation model values at the Gale, Melas, Terby MSL sites
- Mesoscale-modeled wind standard deviations are slightly larger (by about a factor of 1.1 to 1.2) than Mars-GRAM wind standard deviations.
- An rwscale value of about 1.2 would better replicate wind standard deviations from MRAMS or MMM5 simulations at the Gale, Terby, or Melas sites.



Conclusions

- The new Mars-GRAM auxiliary profile capability, using data from TES observations, mesoscale model output, or other sources, allows a potentially higher fidelity representation of the atmosphere, and a more accurate way of estimating inherent uncertainty in atmospheric density and winds.
- When comparing the MER EDL data with Mars-GRAM results, Mars-GRAM does well and averages a ratio of 1.0 to the MER data.
- By adjusting the rpscale and rwscale values in Mars-GRAM based on figures such as Figure 3 and 4, we can provide more accurate end-to-end simulations for EDL at the candidate MSL landing sites
- Mars-GRAM would be an valuable tool to use as part of the search for potential landing sites for future Mars entry probe missions.

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- Jeff Barnes and Dan Tyler (Oregon State University) for providing MMM5 output data
- Paul Withers (Boston University) for providing MER EDL comparison data

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.

[4]Rafkin S. C. R. et al. (2001) *Icarus* 151, 228–256.

[5]Tyler D., and Barnes J. R. (2003) *Workshop on Mars Atmosphere Modeling and Observations*, paper # 6-2.