# Applications of Mars Global Reference Atmospheric Model (Mars-GRAM 2005) Supporting Mission Site Selection for Mars Science Laboratory


Hilary L. Justh[1] and C. G. Justus[2]

[1]NASA, Marshall Space Flight Center, Mail Code EV44, Marshall Space Flight Center, AL 35812, Hilary.L.Justh@nasa.gov

[2]Stanley Associates, Marshall Space Flight Center, Mail Code EV44, Marshall Space Flight Center, AL 35812, Carl.G.Justus@nasa.gov



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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

# Mars-GRAM Auxiliary Profiles

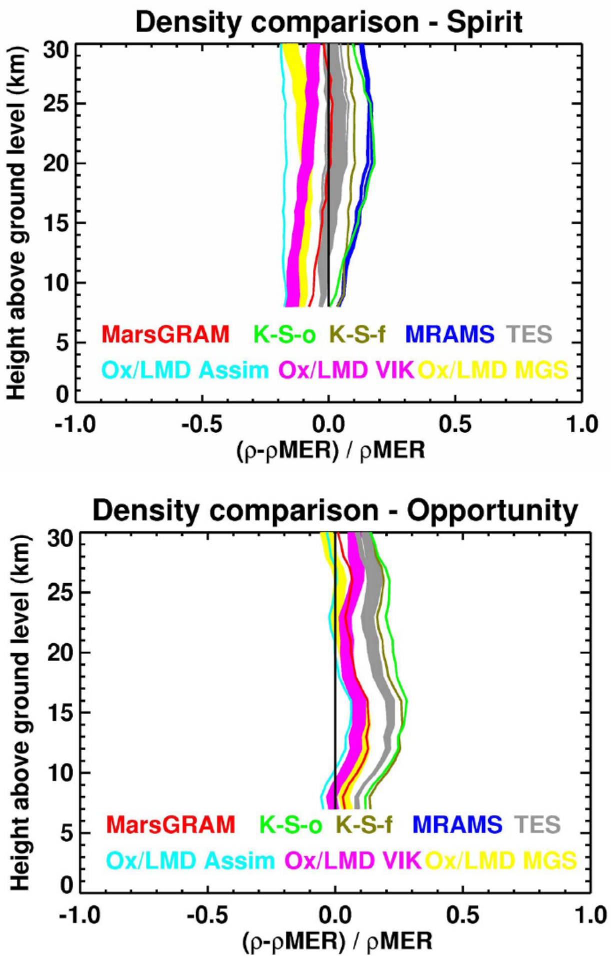
- Mars-GRAM auxiliary profiles (either vertical or along the actual entry corridor) were generated by interpolation from the mesoscale model output data.
- Table shows an example Mars-GRAM auxiliary profile from MRAMS model output at the Terby landing site.
- These Mars-GRAM auxiliary profiles can be used in Mars-GRAM to provide detailed MSL entry dynamics simulations

**Example Mars-GRAM Auxiliary Profile – Mean Values from Terby MRAMS Simulation**

| Hgt_km | Lat | LonE | Temp_K | Pres_Nm2 | Dens_kgm3 | U_m/s | V_m/s |
|---|---|---|---|---|---|---|---|
| -3.66 | -27.466 | 74.11 | 190.46 | 8.12E+02 | 2.23E-02 | 1.04 | 11.63 |
| -2 | -27.466 | 74.11 | 177.78 | 6.84E+02 | 2.01E-02 | -0.2 | 10.3 |
| 0 | -27.466 | 74.11 | 190.04 | 5.53E+02 | 1.52E-02 | -3.24 | 2.91 |
| 2 | -27.466 | 74.11 | 196.26 | 4.53E+02 | 1.21E-02 | -2.25 | 8.49 |
| 4 | -27.466 | 74.11 | 199.76 | 3.73E+02 | 9.76E-03 | 2.87 | 10.49 |
| 6 | -27.466 | 74.11 | 199.88 | 3.08E+02 | 8.05E-03 | 9.61 | 12.16 |
| 8 | -27.466 | 74.11 | 198.28 | 2.53E+02 | 6.68E-03 | 14.95 | 12.17 |
| 10 | -27.466 | 74.11 | 195.73 | 2.09E+02 | 5.57E-03 | 18.24 | 12.43 |
| 12 | -27.466 | 74.11 | 193.29 | 1.71E+02 | 4.63E-03 | 20.72 | 13.52 |
| 14 | -27.466 | 74.11 | 191.06 | 1.40E+02 | 3.83E-03 | 21.44 | 13.9 |
| 16 | -27.466 | 74.11 | 188.9 | 1.14E+02 | 3.17E-03 | 20.25 | 12.35 |
| 18 | -27.466 | 74.11 | 186.7 | 9.32E+01 | 2.61E-03 | 17.41 | 8.97 |
| 20 | -27.466 | 74.11 | 184.2 | 7.55E+01 | 2.15E-03 | 13.57 | 4.22 |
| 22 | -27.466 | 74.11 | 181.02 | 6.09E+01 | 1.76E-03 | 9.81 | -1.48 |
| 24 | -27.466 | 74.11 | 176.57 | 4.89E+01 | 1.45E-03 | 8.32 | -7.31 |
| 26 | -27.466 | 74.11 | 171.65 | 3.93E+01 | 1.20E-03 | 8.94 | -9.99 |
| 28 | -27.466 | 74.11 | 167.03 | 3.13E+01 | 9.81E-04 | 8.64 | -10.73 |
| 30 | -27.466 | 74.11 | 162.61 | 2.48E+01 | 7.97E-04 | 8.01 | -10.62 |
| 32 | -27.466 | 74.11 | 158.4 | 1.94E+01 | 6.41E-04 | 6.83 | -10.19 |
| 34 | -27.466 | 74.11 | 154.53 | 1.51E+01 | 5.11E-04 | 4.02 | -9.51 |
| 36 | -27.466 | 74.11 | 151.51 | 1.17E+01 | 4.05E-04 | -1.06 | -9.08 |
| 38 | -27.466 | 74.11 | 149.89 | 9.11E+00 | 3.18E-04 | -5.7 | -7.41 |
| 40 | -27.466 | 74.11 | 149.63 | 7.04E+00 | 2.46E-04 | -8.09 | -4.23 |
| 42 | -27.466 | 74.11 | 150.64 | 5.43E+00 | 1.89E-04 | -8.17 | 0.42 |
| 44 | -27.466 | 74.11 | 152.18 | 4.19E+00 | 1.44E-04 | -6.77 | 7.08 |
| 46 | -27.466 | 74.11 | 152.67 | 3.22E+00 | 1.10E-04 | -5.43 | 17.36 |
| 48 | -27.466 | 74.11 | 149.78 | 2.51E+00 | 8.76E-05 | -6.7 | 19.86 |
| 50 | -27.466 | 74.11 | 145.65 | 1.93E+00 | 6.95E-05 | -10.15 | 17.98 |

# Comparison with MER EDL models

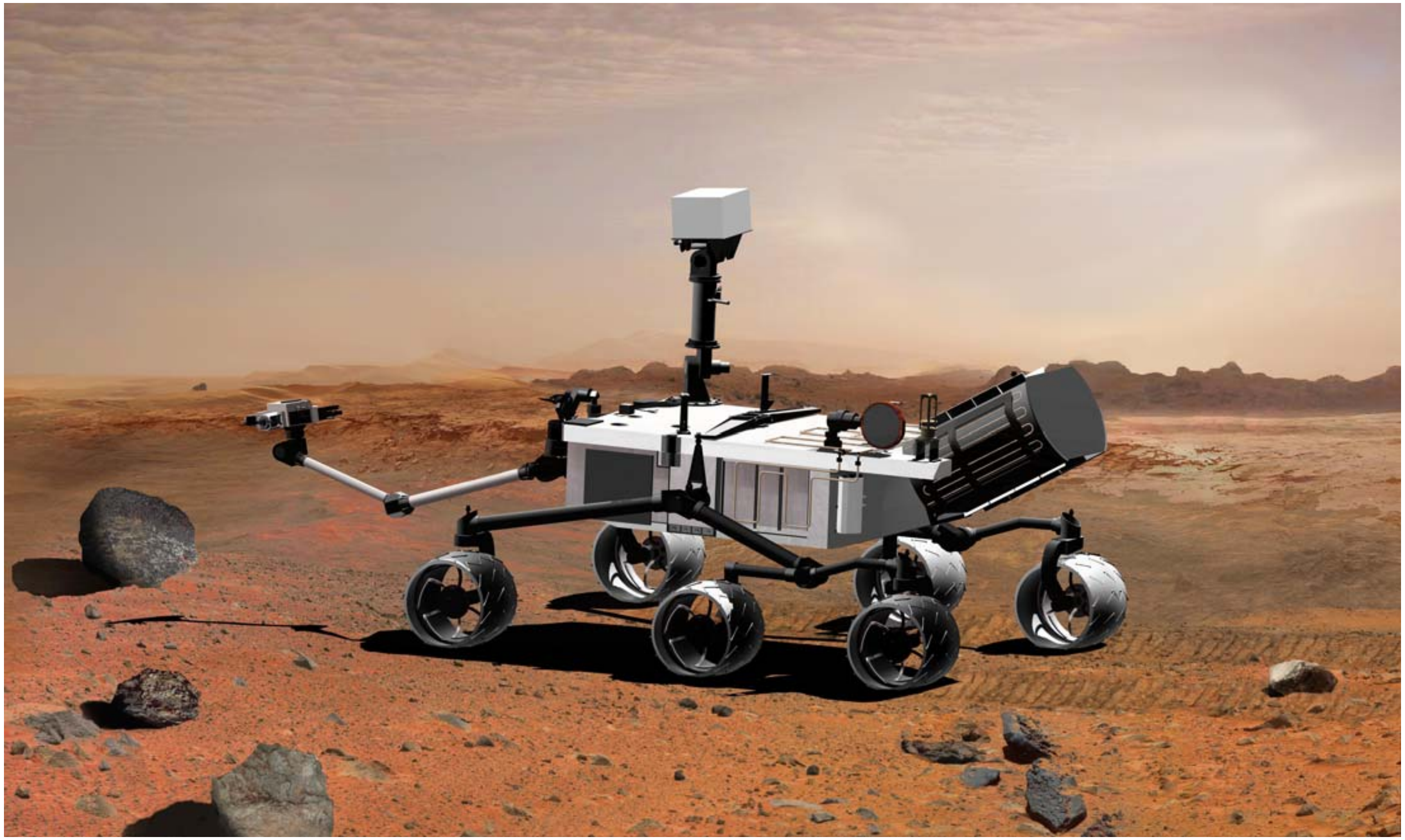
- Paul Withers at Boston University compared the MER EDL data with various models including Mars-GRAM
- Mars-GRAM averages within 5% of the MER values
- For surface-pressure corrected results, Mars-GRAM is one of two models that averages a ratio of 1.0 to the MER data, the other is MGCM (TES dust)



# 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

# Mars Science Laboratory



Mars Science Laboratory with Power Source and Extended Arm, Artist's Concept (Courtesy NASA/JPL-Caltech)

# 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 | Miyamoto | N. Meridiani |

- 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

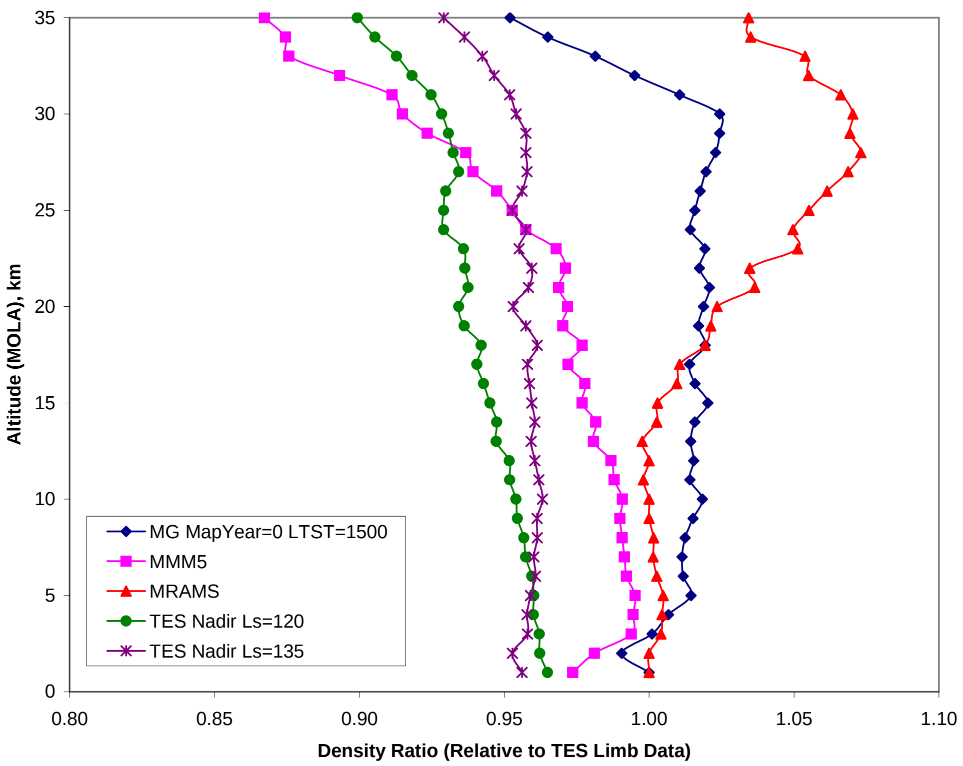
- Data for TES Mapping Years 1 and 2 and ~1/2 of TES Mapping Year 3

- 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

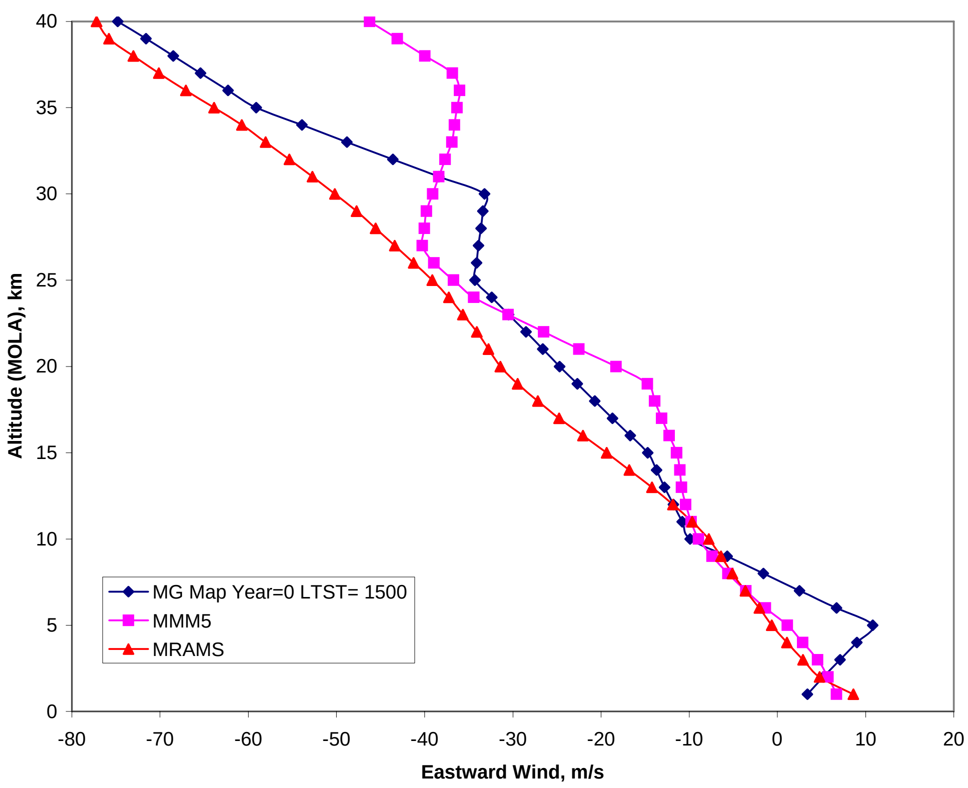
# Density Comparison

- 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



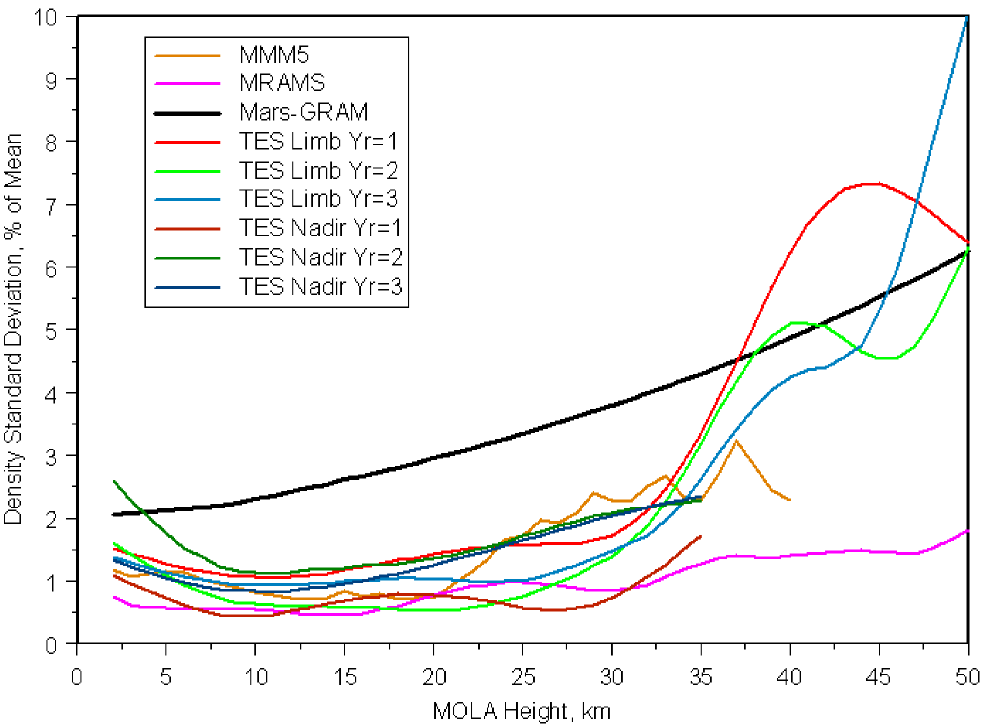
# Zonal Wind Comparison

- 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



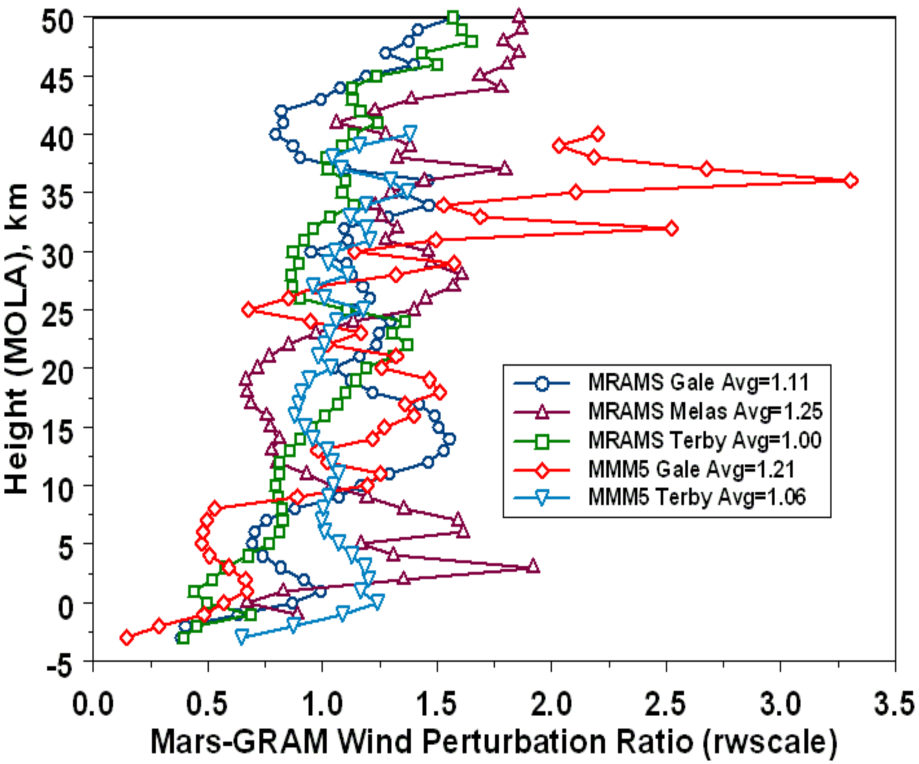
# Density Standard Deviation Comparison

- 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 those shown in slides 14 and 15, 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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- Scot Rafkin (Southwest Research Institute) for providing MRAMS output data
- Jeff Barnes and Dan Tyler (Oregon State University) for providing MMM5 output data
- Paul Withers (Boston University) for providing MER EDL comparison data

# References

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