



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

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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 validated² 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

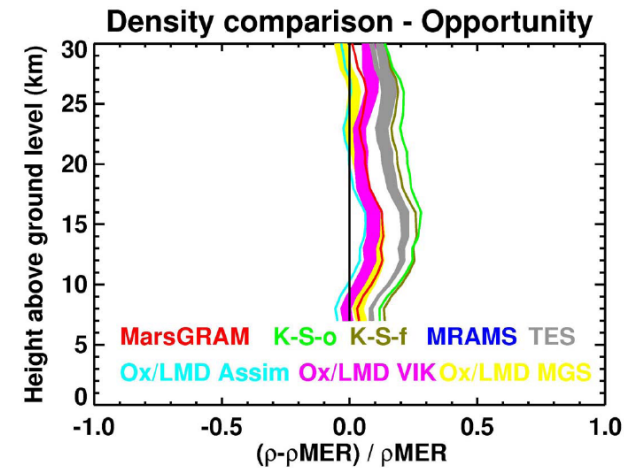
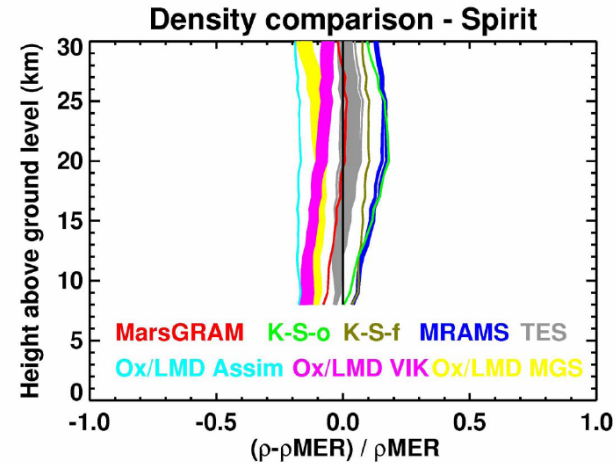
- Mars-GRAM auxiliary profiles (either vertical or along the actual entry corridor) were generated by interpolation from the mesoscale model output data.
- Table shows an example Mars-GRAM auxiliary profile from MRAMS model output at the Terby landing site.
- These Mars-GRAM auxiliary profiles can be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

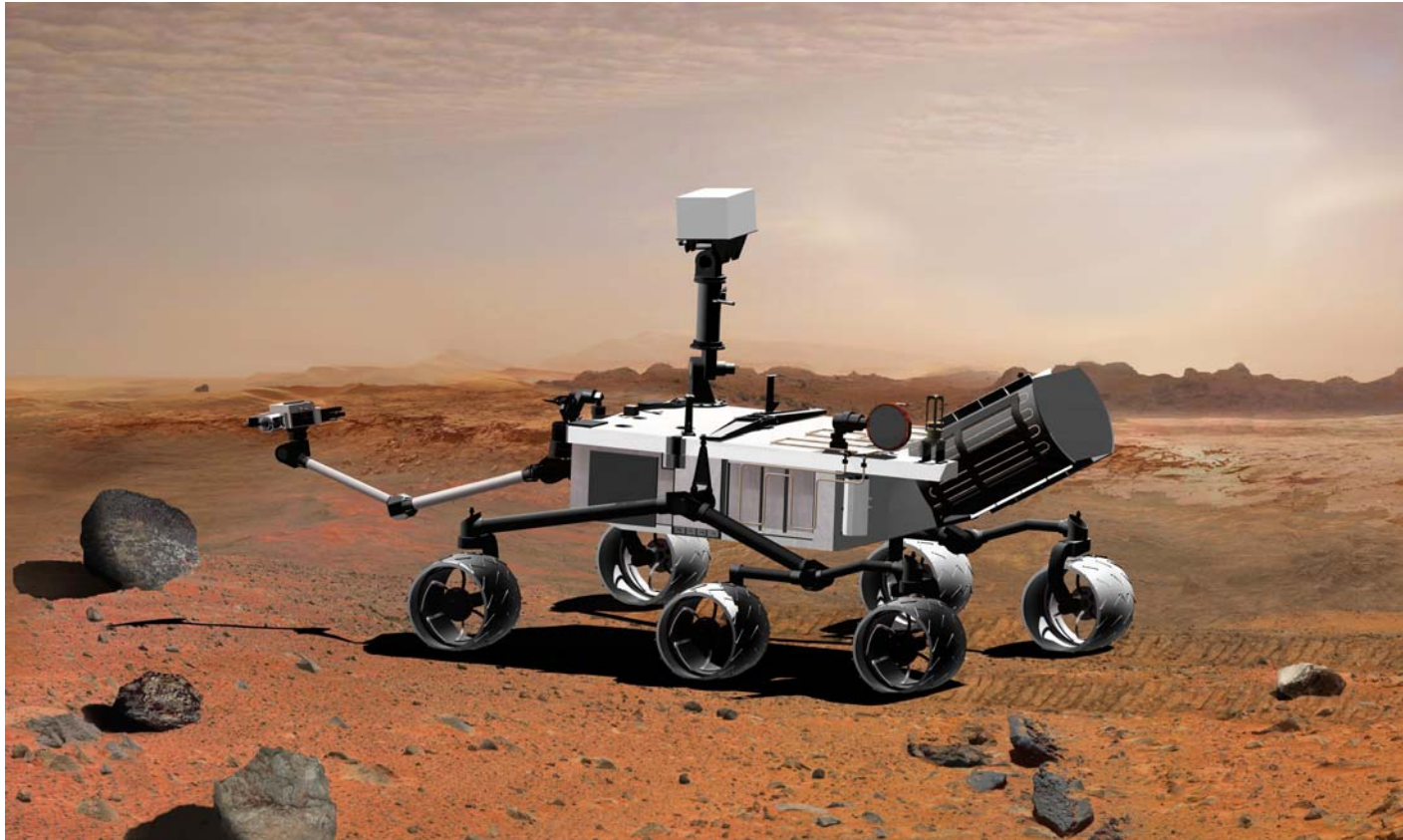




Entry Probe Mission Site Selection

- 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 Institute⁴
 - Mars Mesoscale Model number 5 (MMM5) of Oregon State University⁵.



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

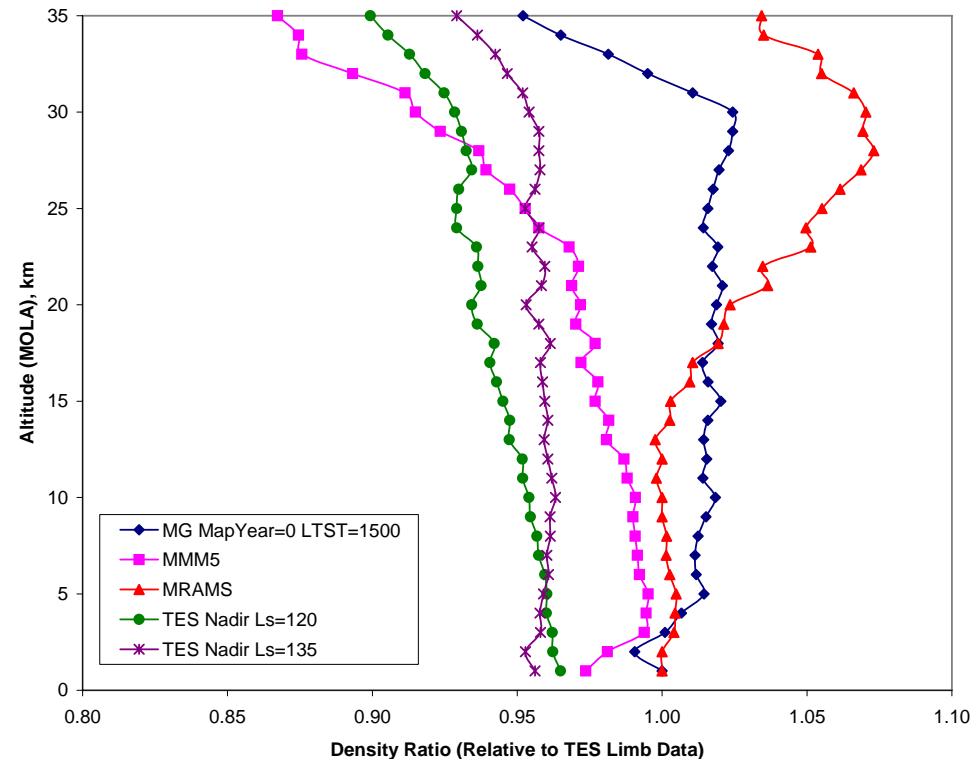


Characteristics of TES Limb Database

- 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

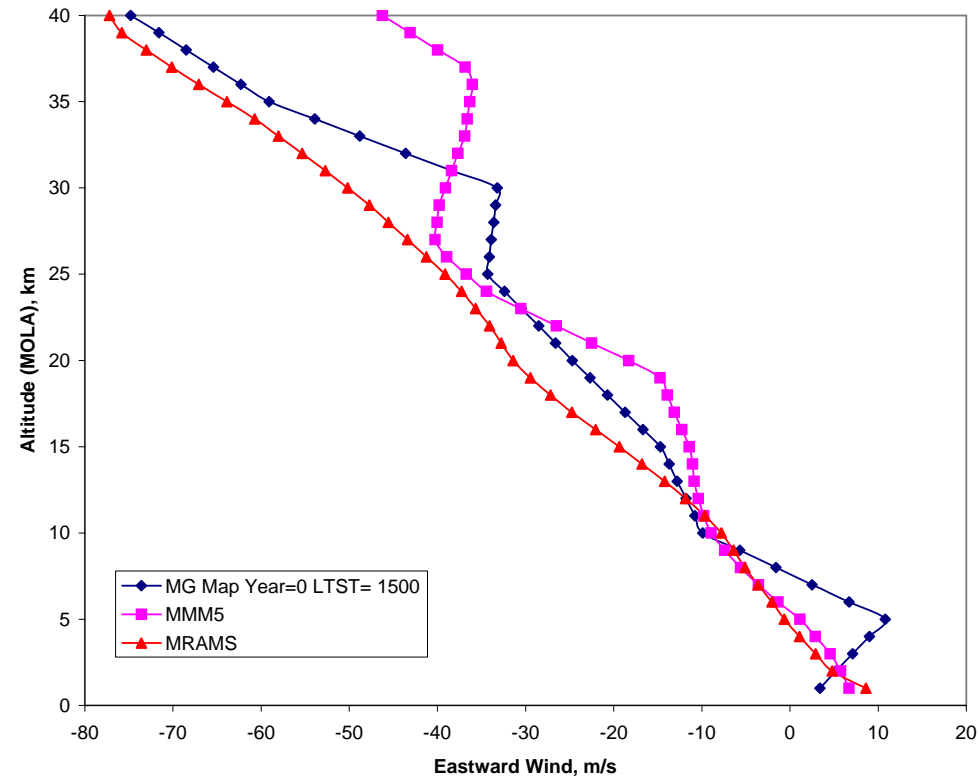
Density Comparison

- 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



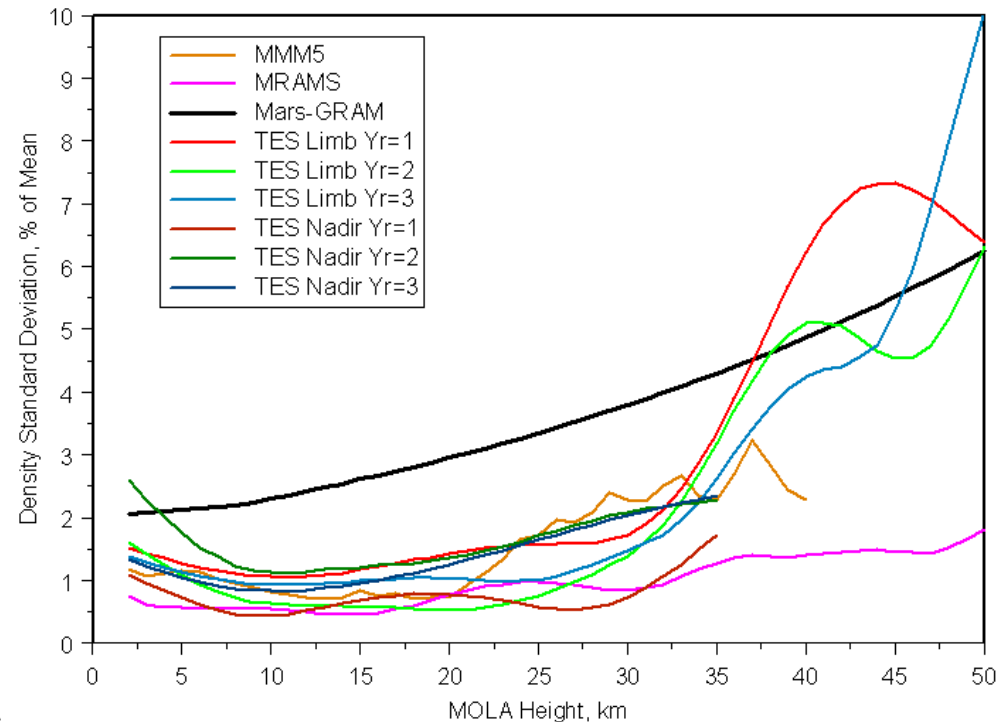
Zonal Wind Comparison

- 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



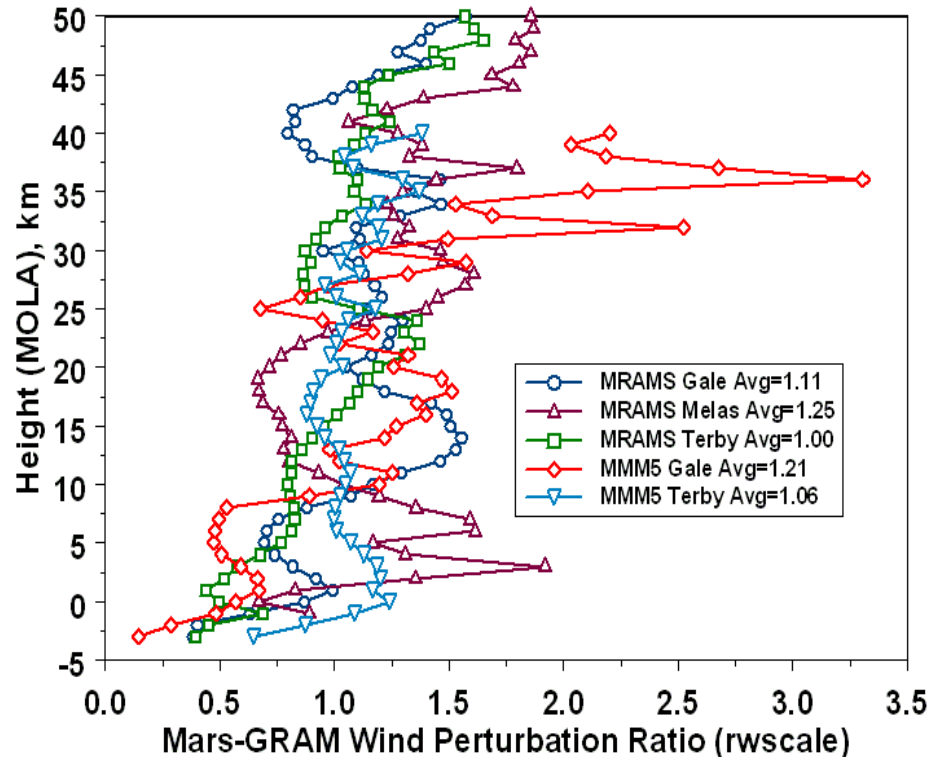
Density Standard Deviation Comparison

- 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.



Acknowledgments

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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

- ¹Striepe S. A. et al. (2002), *AIAA Atmospheric Flight Mechanics Conference and Exhibit*, Abstract # 2002-4412.
- ²Justus C. G. et al. (2005) “Mars Aerocapture and Validation of Mars-GRAM with TES Data”, *53rd JANNAF Propulsion Meeting*.
- ³Smith M. D. (2004) *Icarus*, 167, 148-165.
- ⁴Rafkin S. C. R. et al. (2001) *Icarus* 151, 228–256.
- ⁵Tyler D., and Barnes J. R. (2003) *Workshop on Mars Atmosphere Modeling and Observations*, paper # 6-2.