MARS GLOBAL REFERENCE ATOMSPHERIC MODEL (Mars-GRAM 2005) APPLICATIONS FOR MARS SCIENCE LABORATORY MISSION SITE SELECTION PROCESSES. H. L. Justh[1] and C. G. Justus[2], [1]NASA, Marshall Space Flight Center, Mail Code EV13, Marshall Space Flight Center, AL 35812, Hilary.L.Justh@nasa.gov, [2]Morgan Research Corporation, Marshall Space Flight Center, Mail Code EV13, Marshall Space Flight Center, AL 35812, Carl.G.Justus@nasa.gov.

Introduction: Mars Global Reference Atmospheric Model (Mars-GRAM 2005) is an engineering-level atmospheric model widely used for diverse mission applications. 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. The latest version (Mars-GRAM 2005), has been validated [1] against Radio Science data, and both nadir and limb data from the Thermal Emission Spectrometer (TES) [2].

Two new features of Mars-GRAM 2005 that are of particular importance are: (1) an 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), and (2) an option to read and use any "auxiliary profile" of temperature and density versus altitude. In exercising the auxiliary profile Mars-GRAM option, the alternate data (i.e., values from the auxiliary profile) totally replace data from the original MGCM databases. Examples of auxiliary profiles would be data from TES (nadir or limb) observations or Mars mesoscale model output at a particular location and time.

Applications for Mars Science Laboratory Mission Site Selection: In order to assess Mars Science Laboratory (MSL) landing capabilities under a wide range of candidate site conditions, three of the candidate sites (Terby Crater, Melas Chasma, and Gale Crater) were selected to represent a wide range of atmospheric conditions. Two mesoscale models were run for the expected MSL landing season and time of day. These models are the Mars Regional Atmospheric Modeling System (MRAMS) of Southwest Research Institute [3] and the Mars Mesoscale Model number 5 (MMM5) of Oregon State University [4]. For use in detailed MSL entry dynamics simulations, Mars-GRAM auxiliary profiles (either vertical or along the actual entry corridor) can be generated by interpolation from the mesoscale model output data. Table 1 shows an example Mars-GRAM auxiliary profile from MRAMS model output at the Terby site.

Table 1 – 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	-27.5	74.11	190.46	8.12E+02	2.23E-02	1.04	11.63
-2	-27.5	74.11	177.78	6.84E+02	2.01E-02	-0.2	10.3
0	-27.5	74.11	190.04	5.53E+02	1.52E-02	-3.24	2.91
2	-27.5	74.11	196.26	4.53E+02	1.21E-02	-2.25	8.49
4	-27.5	74.11	199.76	3.73E+02	9.76E-03	2.87	10.49
6	-27.5	74.11	199.88	3.08E+02	8.05E-03	9.61	12.16
8	-27.5	74.11	198.28	2.53E+02	6.68E-03	14.95	12.17
10	-27.5	74.11	195.73	2.09E+02	5.57E-03	18.24	12.43
12	-27.5	74.11	193.29	1.71E+02	4.63E-03	20.72	13.52
14	-27.5	74.11	191.06	1.40E+02	3.83E-03	21.44	13.9
16	-27.5	74.11	188.9	1.14E+02	3.17E-03	20.25	12.35
18	-27.5	74.11	186.7	9.32E+01	2.61E-03	17.41	8.97
20	-27.5	74.11	184.2	7.55E+01	2.15E-03	13.57	4.22
22	-27.5	74.11	181.02	6.09E+01	1.76E-03	9.81	-1.48
24	-27.5	74.11	176.57	4.89E+01	1.45E-03	8.32	-7.31
26	-27.5	74.11	171.65	3.93E+01	1.20E-03	8.94	-9.99
28	-27.5	74.11	167.03	3.13E+01	9.81E-04	8.64	-10.73
30	-27.5	74.11	162.61	2.48E+01	7.97E-04	8.01	-10.62
32	-27.5	74.11	158.4	1.94E+01	6.41E-04	6.83	-10.19
34	-27.5	74.11	154.53	1.51E+01	5.11E-04	4.02	-9.51
36	-27.5	74.11	151.51	1.17E+01	4.05E-04	-1.06	-9.08
38	-27.5	74.11	149.89	9.11E+00	3.18E-04	-5.7	-7.41
40	-27.5	74.11	149.63	7.04E+00	2.46E-04	-8.09	-4.23
42	-27.5	74.11	150.64	5.43E+00	1.89E-04	-8.17	0.42
44	-27.5	74.11	152.18	4.19E+00	1.44E-04	-6.77	7.08
46	-27.5	74.11	152.67	3.22E+00	1.10E-04	-5.43	17.36
48	-27.5	74.11	149.78	2.51E+00	8.76E-05	-6.7	19.86
50	-27.5	74.11	145.65	1.93E+00	6.95E-05	-10.2	17.98

To assess likely uncertainty in atmospheric representation at these candidate sites, three other sources of atmospheric data were also analyzed: (1) 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 bins and 15 degree Ls bins, for each of three Mars years of TES nadir data, (2) 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, and (3) output of means and standard deviations of temperature, density, and winds from Version 4 of the European Mars Climate Data-base (MCD) [5].

Figures 1 and 2 compare vertical profiles of mean density and zonal wind from MRAMS, MMM5, MCD, and Mars-GRAM model output, and from TES nadir data, and TES limb data (density only). Strictly for reference purposes, density values in Figure 1 are represented as percentage difference from MMM5 values. A significant bias difference of about 15% is noted between TES nadir and TES limb data, with all of the models tending to agree closer with the limb data than the nadir results. Above about 20 km, differences greater than 10% are noted between MRAMS and MMM5 results. Nadir and Limb data in Figure 1 were averaged over three years of Mars observations. Mars-GRAM results are averages from TES mapping years 1 and 2 and "Map year 0" with dust visible optical depth tau = 0.1, all three of which were quite comparable. Wind results from MRAMS and MMM5, shown in Figure 2, are more consistent than density results between these two models (Figure 1), while Mars-GRAM wind results for TES mapping years 1and 2 and for dust tau = 0.1 are significantly different from each other, and are plotted separately in Figure 2.

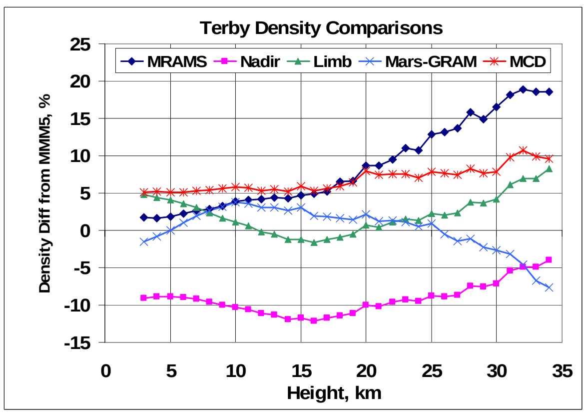

Figure 1 – Comparison of vertical profiles of mean density from TES nadir data, TES limb data, and MRAMS, MMM5, MCD, and Mars-GRAM model output.

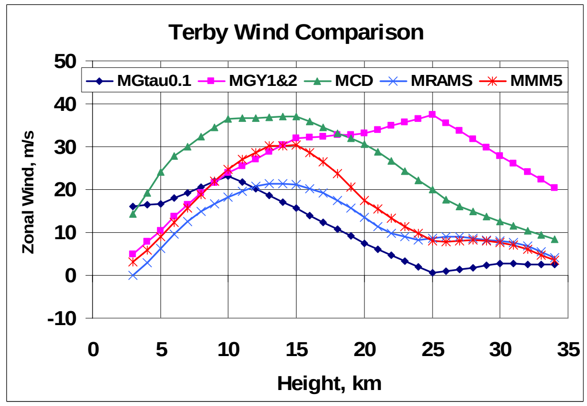

Figure 2 - Comparison of vertical profiles of mean zonal (eastward) wind from MRAMS, MMM5, MCD, and Mars-GRAM model output.

Figures 3 and 4 compare vertical profiles of standard deviations of density and zonal wind from MRAMS, MMM5, and Mars-GRAM model output, and from TES nadir data, and TES limb data (density only). Observed and mesoscale-modeled density standard deviations are generally less than Mars-GRAM density standard deviations, an exception being TES nadir values below about 6 km altitude. Mesoscale-modeled wind standard deviations are slightly larger (by about a factor of 1.1 to 1.2) than Mars-GRAM wind standard deviations.

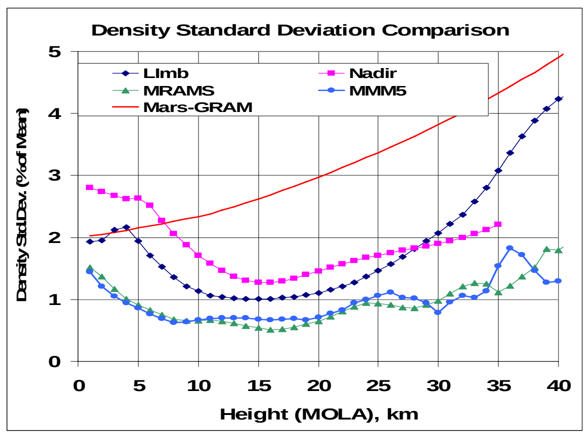

Figure 3 - Comparison of vertical profiles of density standard deviation from TES nadir data, TES limb data, and MRAMS, MMM5, and Mars-GRAM model output.

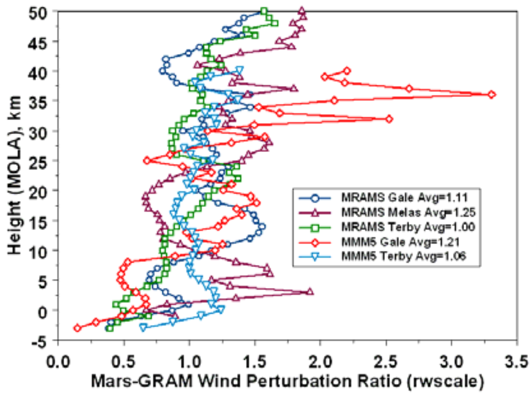

Figure 4 - Comparison of vertical profiles of zonal wind standard deviation from MRAMS, MMM5, and Mars-GRAM model output.

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 [6]. Traditional Mars-GRAM options for representing the mean atmosphere along entry corridors include: (1) "TES Mapping Years 1 and 2", with Mars-GRAM data coming from MGCM model results driven by observed TES dust optical depth, and (2) "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. 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. In addition to atmospheric mean values, set by the auxiliary profile input, two Mars-GRAM parameters allow standard deviations of Mars-GRAM perturbations to be adjusted. Parameter "rpscale" can be used to scale density perturbations up or down, while parameter "rwscale" performs a similar function for Mars-GFRAM wind perturbations. Figure 3 indicates that, with nominal value rpscale=1, Mars-GRAM perturbations would be conservative (i.e. would tend to overestimate observed or mesoscale-modeled variability). To better represent TES and mesoscale model density perturbations, rpscale values as low as about 0.4 could be used. Some trajectory model implementations of Mars-GRAM allow the user to dynamically change rpscale value with altitude. Figure 4 shows that an rwscale value of about 1.2 would better replicate wind stand deviations from MRAMS or MMM5 simulations at the Gale, Terby, or Melas sites.

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References: [1] Justus C. G. et al. (2005) "Mars Aerocapture and Validation of Mars-GRAM with TES Data", *53rd JANNAF Propulsion Meeting*. [2] Smith M. D. (2004) *Icarus*, 167, 148-165. [3] Rafkin S. C. R. et al. (2001) *Icarus* 151, 228–256. [4] Tyler D., and Barnes J. R. (2003) *Workshop on Mars Atmosphere Modeling and Observations*, paper # 6-2. [5] Angelats i Coll M. et al. (2005) *Geophysical Research Letters*, Vol. 32, Issue 4. [6] Striepe S. A. at al. (2002), *AIAA Atmospheric Flight Mechanics Conference and Exhibit*, Abstract # 2002-4412.