EVALUATING MARS SCIENCE LABORATORY LANDING SITES WITH THE MARS GLOBAL REFERENCE ATMOSPHERIC MODEL (Mars-GRAM 2005). H. 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.

Introduction: The Mars Global Reference Atmospheric Model (Mars-GRAM) is an 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]. From the surface to 80 km altitude, Mars-GRAM is based on the 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. Traditional Mars-GRAM options for representing the mean atmosphere along entry corridors include: (1) Thermal Emission Spectrometer (TES) mapping years 1 and 2, with Mars-GRAM data coming from NASA Ames Mars General Circulation Model (MGCM) results driven by observed TES dust optical depth or (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. Mars-GRAM 2005 has been validated [2] against Radio Science data, and both nadir and limb data from TES [3].

There are several new features included in Mars-GRAM 2005. The first is the 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. The TES Year 1 option includes values from April 1999 through January 2001. The TES Year 2 option includes values from February 2001 through December 2002. The second new feature is the option to read and use any auxiliary profile of temperature and density versus altitude. In exercising the auxiliary profile Mars-GRAM option, values from the auxiliary profile replace data from the original MGCM databases. Some examples of auxiliary profiles include data from TES nadir or limb observations and Mars mesoscale model output at a particular location and time. The final new feature is the addition of two Mars-GRAM parameters that allow standard deviations of Mars-GRAM perturbations to be adjusted. The parameter rpscale can be used to scale density perturbations up or down while rwscale can be used to scale wind perturbations.

Entry Probe Mission Site Selection: Mars-GRAM can provide data on density, temperature, pressure, winds, and selected atmospheric constituents for landing sites on Mars. Currently, Mars-GRAM is being used in the Mars Science Laboratory landing site selection process. 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 and N. Meridiani. For each of these proposed sites two mesoscale models have been run for the expected MSL landing season and time of day: the Mars Regional Atmospheric Modeling System (MRAMS) of Southwest Research Institute [4], and the Mars Mesoscale Model number 5 (MMM5) of Oregon State University [5]. To assess likely uncertainty in atmospheric representation at these candidate sites, two other sources of atmospheric data were also analyzed. The first was a global TES nadir 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 data. The second was 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.

MSL Landing Site Analysis: For each proposed MSL landing site, several comparisons were made to help determine the suitability of that site for EDL activities. These comparisons included looking at the density, zonal winds, density standard deviations, wind perturbations, surface pressures and dust bomb cases for the landing sites.

Density Comparison A comparison of vertical profiles of density ratio from TES nadir data, MRAMS, MMM5, and Mars-GRAM model output for the Mawrth MSL landing site is shown in Figure 1. The density values are represented as a ratio relative to TES Limb data. The TES Nadir and Limb data are for Map Year 1. TES Limb data is for Ls=130 +/- 15. TES nadir values are from Ls = 120 and Ls = 135. The Mars-GRAM results are for map year 0 with dust visible optical depth tau = 0.1 and LTST=1500. As shown in Figure 1, the TES nadir and TES limb data differ significantly. All of the models tend to agree with the limb data better than the nadir results at the MSL candidate sites. At MOLA altitudes above approximately 20 km, the differences increase between the MRAMS and MMM5 results.

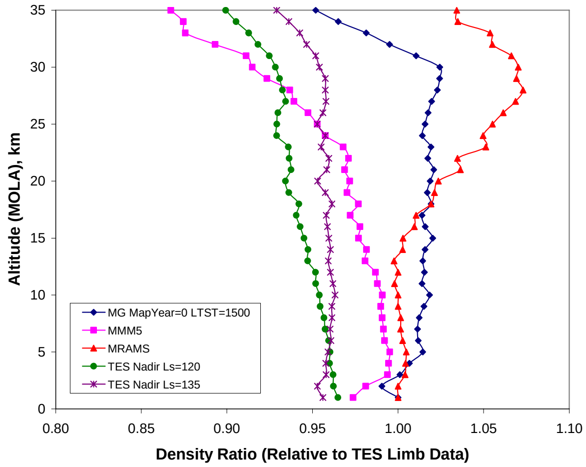

Figure 1 – Comparison of the vertical profiles of the density ratio relative to TES limb data for Mars-GRAM, MMM5, MRAMS, and TES nadir data.

Zonal Wind Comparison A comparison of vertical profiles of mean zonal (eastward) wind from MRAMS, MMM5, and Mars-GRAM for the Mawrth MSL landing site is given in Figure 2. The wind results from MRAMS and MMM5 are more consistent than the density results between these two models.

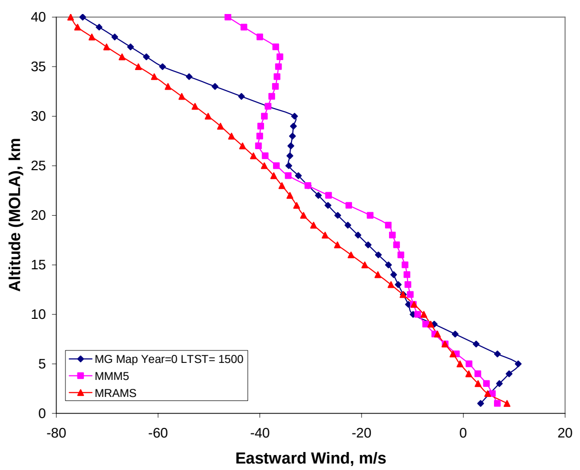

Figure 2 - Comparison of vertical profiles of mean zonal (eastward) wind from Mars-GRAM, MMM5, and MRAMS.

Density Standard Deviation Comparison A 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 are given in Figure 3. The 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 approximately 5 km altitude and TES limb data above 36 km. This figure demonstrates that with nominal value rpscale = 1, the Mars-GRAM perturbations would be conservative. To better represent TES and mesoscale model density perturbations, the rpscale value in the Mars-GRAM input file should be modified to a value as low as 0.4.

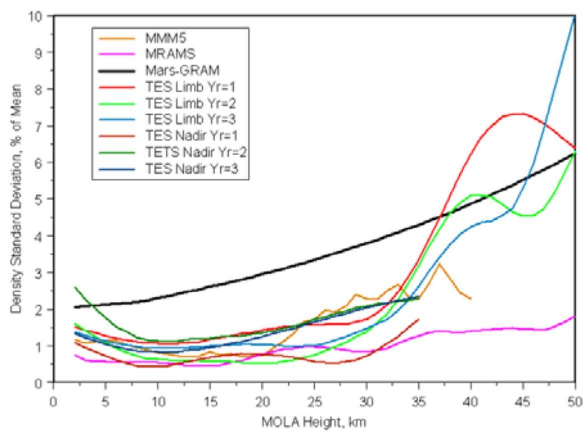

Figure 3 - Comparison of vertical profiles of density standard deviation from MMM5, MRAMS, Mars-GRAM, TES limb data, and TES nadir data.

Wind Perturbation Comparison Figure 4 shows the Mars-GRAM Wind Perturbation Ratio (rwscale) vs. Height for MRAMS, MMM5, and nominal Mars-GRAM perturbation model values at the Gale, Melas, and Terby MSL landing sites. The mesoscale-modeled wind standard deviations are slightly larger (by about a factor of 1.1 to 1.2) than Mars-GRAM wind standard deviations. If the value of rwscale in the Mars-GRAM input file is changed to 1.2, the Mars-GRAM results would better replicate the wind standard deviations from MRAMS or MMM5 simulations at the Gale, Terby, or Melas MSL landing sites.

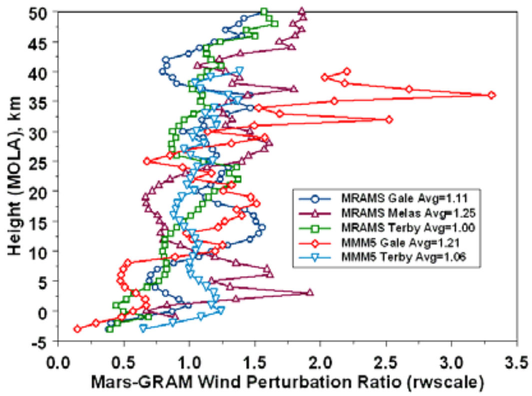

Figure 4 – Mars-GRAM Wind Perturbation Ratio (rwscale) vs. Height for MRAMS, MMM5, and Mars-GRAM model output at the Gale, Melas, and Terby MSL sites.

Surface Pressure The surface pressure values for seven of the MSL Landing sites were studied for the entire baseline and extended launch period. The results of the Mars-GRAM runs for this period of time are given in Figure 5. The landing sites have surface pressures that vary from approximately 525 Pa to 780 Pa. The lowest surface pressures are found at the Nili Fossae Trough site and the largest values at the Gale Crater site. The general trend is for the surface pressure to decrease as time progresses, with a slight pressure increase after Ls = 150 these results are fairly consistent with mesoscale model simulations (not shown).

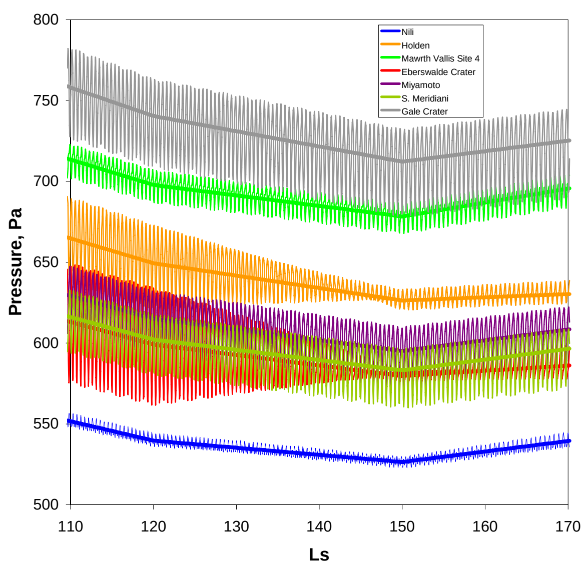

Figure 5 – Mars-GRAM surface pressure vs. Ls for selected MSL landing sites.

Dust Bomb The impacts of small and large "dust bombs" at the various MSL landing sites have also been studied. Figure 6 shows the results of a Mars-GRAM run for a "slim" dust bomb occurring at the Mawrth Vallis 2 MSL Landing site. The slim dust bomb starts at Ls=121 and lasts for 3 sols. The intensity of this dust storm is 1.5 with a maximum radius of 500 km with the center of the storm directly over the landing site. As shown in Figure 6, the dust bomb case results in densities that range from approximately -10 to +6 % of the nominal values for Mawrth Vallis 2.

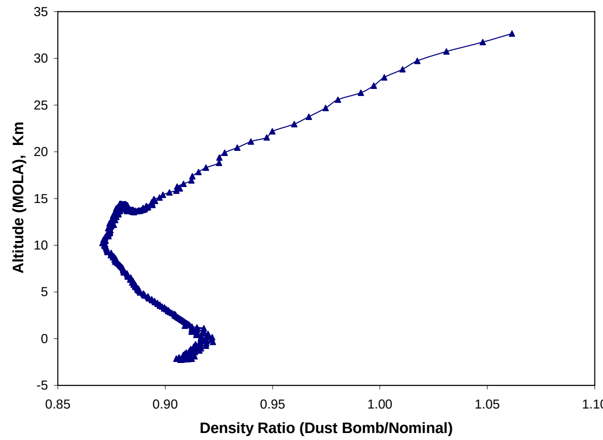

Figure 6 – Vertical profile of the density ratio of the slim dust bomb case for the Mawrth Vallis 2 MSL landing site

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. By adjusting the rpscale and rwscale values in Mars-GRAM based on figures such as those shown in Figures 3 and 4, we can provide more accurate end-to-end simulations for EDL at the candidate MSL landing sites. As shown by our work as a member of the MSL Council of Atmospheres, Mars-GRAM would be a valuable tool to use as part of the search for potential landing sites for future Mars entry probe missions.

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References: [1] Striepe S. A. at al. (2002), *AIAA Atmospheric Flight Mechanics Conference and Exhibit*, Abstract # 2002-4412. [2] Justus C. G. et al.

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