VALIDATION OF MARS-GRAM AND PLANNED NEW FEATURES

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ABSTRACT

For altitudes below 80 km, Mars Global Reference Atmospheric Model (Mars-GRAM 2001) is based on output climatology from NASA Ames Mars General Circulation Model (MGCM). At COSPAR 2002, results were presented of validation tests of Mars-GRAM versus data from Mars Global Surveyor Thermal Emission Spectrometer (TES) and Radio Science (RS) experiment. Further validation tests are presented comparing Mars-GRAM densities with those from the European Mars Climate Database (MCD), and comparing densities from both Mars-GRAM and MCD against TES observations. Throughout most of the height and latitude range of TES data (0-40 km and 70S to 70N), good agreement is found between atmospheric densities from Mars-GRAM and MCD. However, at the season and latitude zone for Mars Phoenix arrival and landing (Ls = 65 to 80 degrees and latitude 65 to 75N), Mars-GRAM densities are about 30 to 45 percent higher than MCD densities near 40 km altitude. Further evaluation is warranted concerning potential impact of these model differences on planning for Phoenix entry and descent. Three planned features for Mars-GRAM update are also discussed: (1) new MGCM and Thermospheric General Circulation Model data sets to be used as a revised basis for Mars-GRAM mean atmosphere, (2) a new feature to represent planetary-scale traveling waves for upper altitude density variations (such as found during Mars Odyssey aerobraking), and (3) a new model for effects of high resolution topographic slope on winds near the surface (0 to 4.5 km above MOLA topography level). Mars-GRAM slope winds will be computed from a diagnostic (algebraic) relationship based on Ye, Segal, and Pielke (1990). This approach differs from mesoscale models (such as MRAMS and Mars MM5), which use prognostic, full-physics solutions of the time- and space-dependent differential equations of motion. As such, slope winds in Mars-GRAM will be consistent with its "engineering-level" approach, and will be extremely fast and easy to evaluate, compared with mesoscale model solutions. Mars-GRAM slope winds are not being suggested as a replacement for sophisticated, full-physics Mars mesoscale models, but may have value, particularly for preliminary screening of large numbers of candidate landing sites for future Mars missions, such as Phoenix and Mars Science Laboratory. Test output is presented from Mars-GRAM slope winds in the area of Gusev Crater and Valles Marineris.

INTRODUCTION

Similar to the Global Reference Atmospheric Model (GRAM) for Earth (Justus et al., 2000), Mars Global Reference Atmospheric Model (Mars-GRAM 2001) is an engineering-level atmospheric model, widely used for many mission applications (Justus and Johnson, 2001, Justus et al., 2002). From 0-80 km, Mars-GRAM is based on NASA Ames Mars General Circulation Model (MGCM) (Haberle et al., 1993), while above 80 km it is based on Mars Thermospheric General Circulation Model (MTGCM) (Bougher et al., 1990). Mars-GRAM 2001 and MGCM use surface topography from Mars Global Surveyor (MGS) Mars Orbiting Laser Altimeter (MOLA) (Smith and Zuber, 1998). At COSPAR 2002, validation studies were described comparing Mars-GRAM with MGS Radio Science (RS) density profiles (Hinson et al., 1999) and a global summary data set of MGS Thermal Emission Spectrometer (TES) data (Smith et al., 2001).

RS data from 2480 profiles were used, covering latitudes 75° S to 72° N, surface to ~ 40 km, for seasons ranging over areocentric longitude of Sun (Ls) = 70-160° and 265-310°. RS data spanned a range of local times, mostly 0-9 hours and 18-24 hours. For interests in aerocapture and precision landing, comparisons concentrated on atmospheric density. TES data were used covering surface to ~ 40 km, over more than a full Mars year (February, 1999 – June, 2001, just before start of a Mars global dust storm). Depending on season, TES data covered latitudes 85° S to 85° N. Most TES data were concentrated near local times 2 hours and 14 hours. Figure 1 shows results of Mars-GRAM/RS comparisons versus height and latitude. Except for heights above ~ 30 km and latitudes above ~ 45° N, Mars-GRAM/RS density differences are generally within about ±6%.

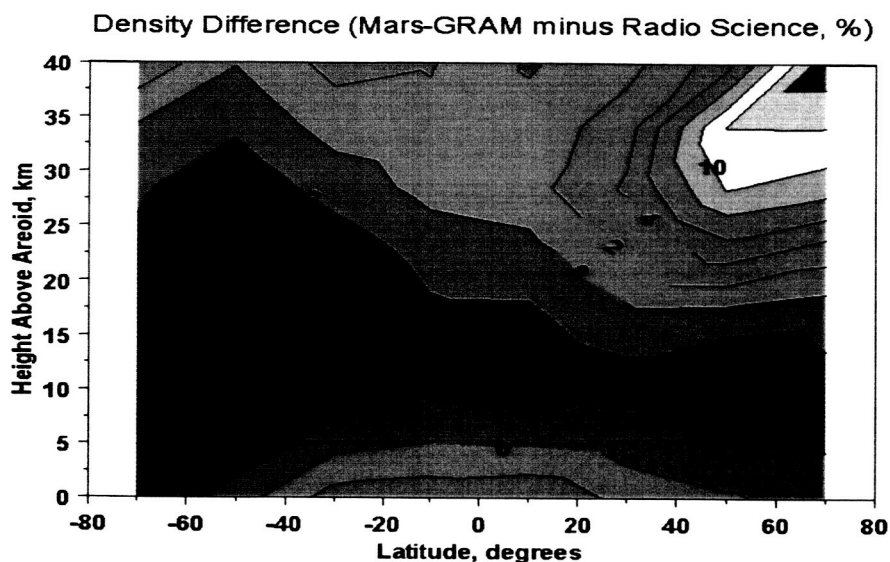**Density Difference (Mars-GRAM minus Radio Science, %)**

Figure 1. Percentage density difference, Mars-GRAM minus Radio Science observations.

MARS-GRAM VAILDATION WITH EUROPEAN MARS CLIMATE DATABASE AND TES DATA

Results of Mars-GRAM validation versus the European Mars Climate Database (MCD) (Lewis et al., 1999; Forget et al., 2003; Bingham et al, 2003) are shown in Figures 2 through 5. The dotted box in these figures denotes the approximate height-latitude area of comparison with RS data in Figure 1. Dust optical depth in MCD was simulated with their latitudinally- and seasonally-varying "MGS Scenario" (Forget et al., 2003). In Mars-GRAM, spatially uniform, seasonally-varying dust optical depth was used, ranging between 0.1 (at Ls = 90°) and 0.5 (at Ls = 270°). Although Mars-GRAM-versus-MCD density comparisons are generally good, large differences exist for Ls = 0, 90 and 270°, above ~ 35 km and poleward of ~ 70°N. These modeling uncertainties at high northern latitudes could have significant impact on planning Mars Phoenix mission EDL scenarios and systems. Candidate Phoenix landing sites are between 65 and 75° N. RS and TES data do little to resolve these MCD/Mars-GRAM discrepancies, since most of the model differences are at higher altitudes and latitudes than the observations. However, comparison of Figure 1 with Figures 2 and 3 indicates that at these high latitudes and altitudes, Mars-GRAM tends to over-estimate the observations, while MCD tends to underestimate them by a like or larger amount.
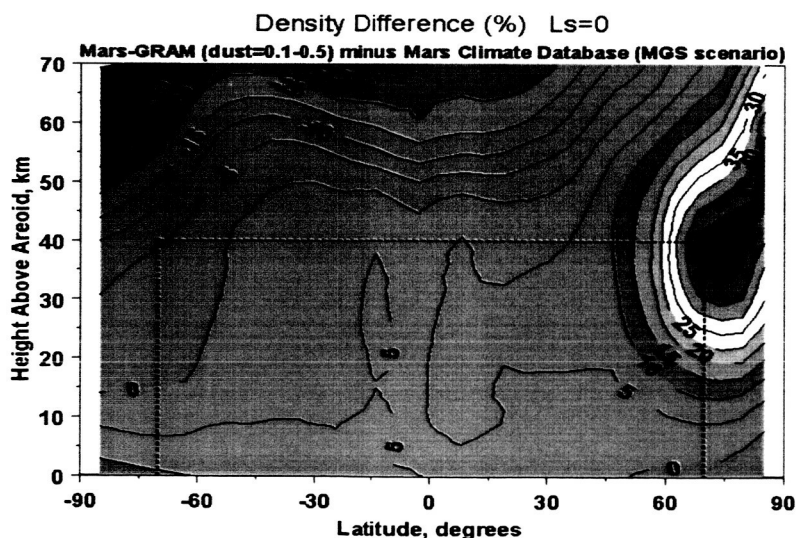
Density Difference (%) Ls=0
Mars-GRAM (dust=0.1-0.5) minus Mars Climate Database (MGS scenario)

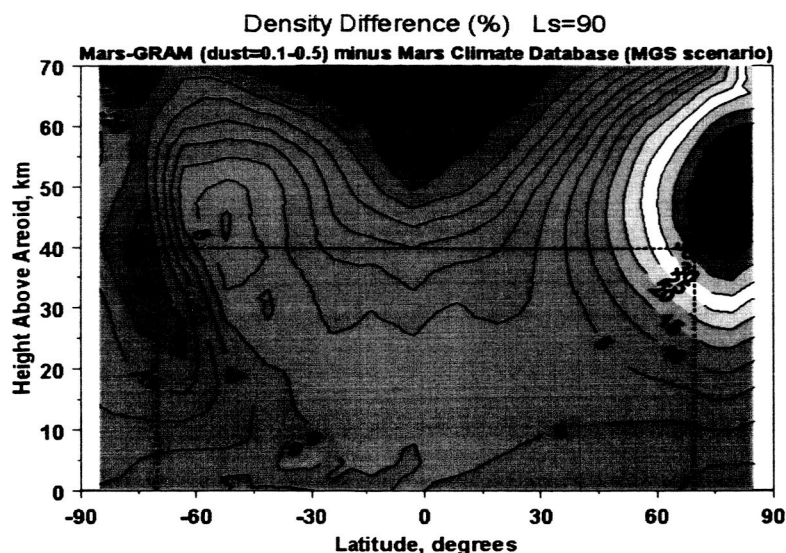Figure 2. Percentage density difference, Mars-GRAM minus Mars Climate Database, Ls=0

Figure 3. Percentage density difference, Mars-GRAM minus Mars
Climate Database, Ls=90

Table 1 gives quantitative statistics for comparisons of both Mars-GRAM and Mars Climate Database with TES (over essentially the same height/latitude area as for the RS comparison shown in Figure 1). Average and standard deviation of model-minus-observed density difference (in percent) are given for local times 2 hr and 14 hr. Larger magnitude values (between the two models) are shown in bold. For the sixteen statistics given, Mars-GRAM had the larger density difference from observed in five cases, while Mars Climate Database had larger density deviations from observed in 11 cases. However, all values of average and standard deviation were generally less than 10% in magnitude, indicating good agreement of both models with TES observations (in the latitude and height range for which TES data are available).

NEW MARS-GRAM FEATURES

During MGS aerobraking operations, large density variations were observed between successive periapsis passes (Keating et al., 1998). These appeared to be longitude-fixed or terrain-fixed waves, usually dominated by wave-2 or wave-3 components (wave-n meaning that n wavelengths fit around a 360° longitude circle). During Mars Odyssey aerobraking, similar large-amplitude density variations were observed. However, during some periods, Odyssey-observed density variations appeared to be traveling waves whose phase speed relative to a fixed longitude seemed to remain constant for a matter of a few days. Mars-GRAM 2001 has an option to represent terrain-fixed waves of the type observed by MGS. Work is underway to develop a new version of Mars-GRAM that will (among other features) include the option to allow user input values for phase speed of traveling wave components, of the type observed by Mars Odyssey.

Also during MGS and Odyssey aerobraking, it was observed that Mars-GRAM produced better correspondence with observed atmospheric density if the altitude scale of its input MTGCM data base was shifted (described as a "height offset"). New sets of MGCM and MTGCM data are being produced for use as input in the next Mars-GRAM update. These GCM model runs include better treatment of the matchup conditions (both mean conditions and upward wave fluxes) between the upper boundary of MGCM and lower boundary of MTGCM (at the 1.32 μbar level, near 80 km). A new non-local thermodynamic equilibrium (non-LTE) method for treating near-infrared heating and CO_2 15-micron cooling will also be employed in the MTGCM model runs. This methodology is based on a non-LTE model of López-Valverde and López-Puertas (1994). More realistic dynamics in both MGCM and MTGCM data sets is also anticipated from the use of latitude and seasonal variations of dust optical depth observed by MGS TES in its mapping years 1 and 2. It is hoped that these new MGCM/MTGCM input data sets for Mars-GRAM will significantly lessen the need for height offset, and significantly improve the correspondence with observed densities during Mars-GRAM use in support of aerobraking operations for Mars Reconnaissance Orbiter.
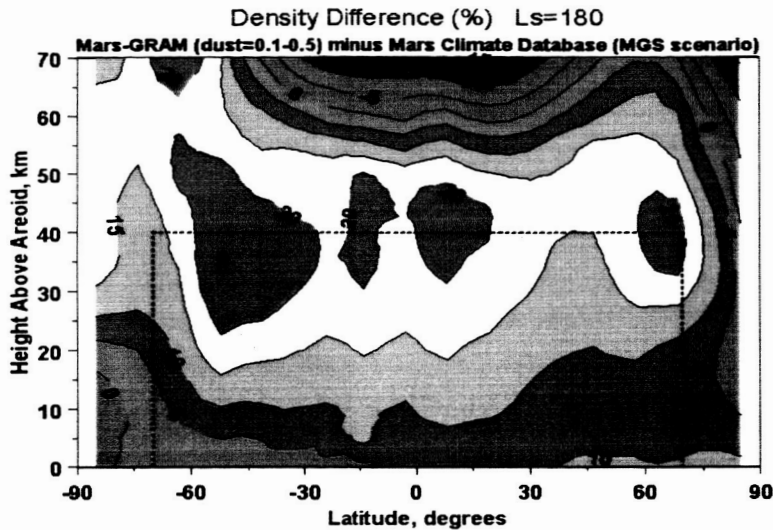
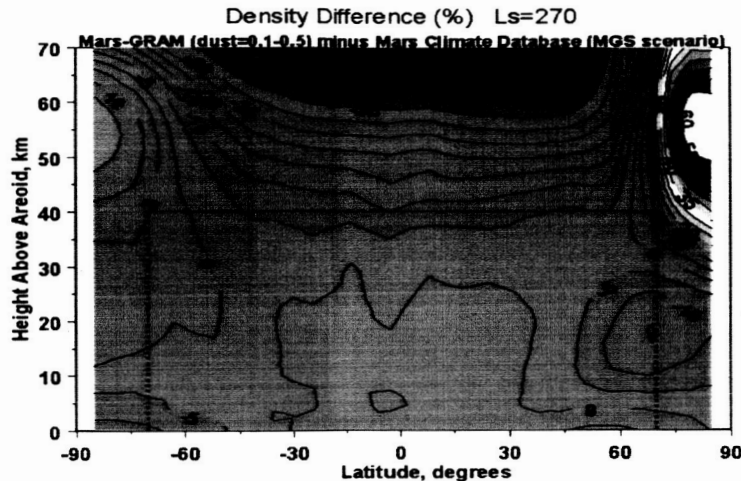Figure 4. Percentage density difference, Mars-GRAM minus Mars Climate Database, Ls=180

Figure 5. Percentage density difference, Mars-GRAM minus Mars Climate Database, Ls=270

NEW SLOPE-WIND FEATURE

For potential applications in preliminary site screening for Mars landers, a new slope wind feature is being developed for Mars-GRAM. Slope winds are computed in Mars-GRAM from a diagnostic (algebraic) relationship based on Ye et al. (1990). This approach differs from mesoscale models, such as MRAMS (Rafkin et al., 2001), and Mars MM5 (Toigo and Richardson, 2002), which use prognostic, full-physics solutions to the time- and space-dependent differential equations of motion. As such, slope winds in Mars-GRAM will be consistent with its "engineering-level" approach, and will be extremely easy and fast to evaluate, compared with mesoscale model solutions. Mars-GRAM slope winds are not being suggested as a replacement for more sophisticated, full-physics mesoscale models, but may have value, particularly for preliminary screening of large numbers of candidate landing sites for future Mars missions.

Terrain slopes used in the slope wind model are computed from 0.5 × 0.5 degree MOLA topography. Mars-GRAM slope winds will be added to winds from MGCM, which have a resolution of 7.5 × 9 degrees in latitude and longitude. The Mars-GRAM slope wind model will thus add significantly higher resolution information about possible near-surface winds than is provided by MGCM.

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Table 1. Comparison of Mars-GRAM (MG) versus Thermal Emission Spectrometer (TES) observed density and Mars Climate Database (MCD) vs. TES. Avg.% and Sigma% are average and standard deviation of model-minus-observed density difference (in percent) at local time 2 or 14 hours local solar time. Larger magnitude values (between the two models) are shown in bold.

Model	Ls	Avg.% (hour 2)	Sigma% (hour 2)	Avg.% (hour 14)	Sigma% (hour 14)
MG	0	**-2.8**	7.8	1.0	5.7
MG	90	-5.5	6.8	**-4.2**	5.6
MG	180	**-6.5**	7.0	-1.8	5.8
MG	270	2.7	**9.9**	6.0	**8.9**
MCD	0	1.8	**8.3**	**4.6**	7.6
MCD	90	**-7.4**	7.2	-1.7	**7.6**
MCD	180	2.2	**8.5**	3.4	**8.7**
MCD	270	**3.4**	9.1	**10.4**	7.3

Figure 6 shows Mars-GRAM slope winds, evaluated at a level 2 km above local terrain height for the Gusev Crater area, at the date and time of Rover Spirit landing. If this wind field is valid, then Spirit would have experienced up to ~ 25 m/s winds "opposing" its entry into Gusev Crater near an altitude of 1-2 km above surface level. Spirit experienced significant turbulence or winds during its descent (Prasun Desai, private communication), causing it to fire its Transverse Impulse Rocket System to correct for off-vertical firing of its main retrorockets, and to reduce its lateral impact speed.
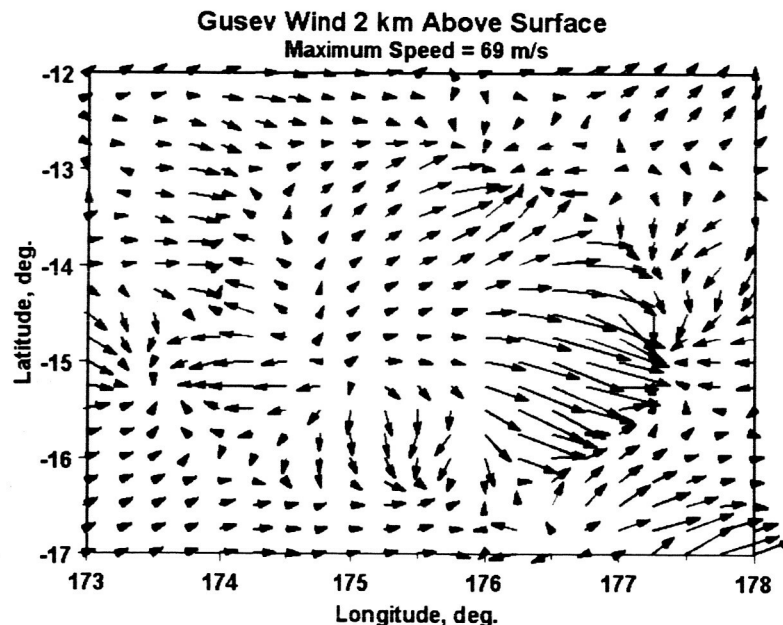

Figure 6. Slope wind vectors at Gusev Crater, 2 km above surface, for date and time of Spirit landing.

Figure 7 shows MOLA terrain heights in a portion of the eastern end of Valles Marineris, used in these preliminary tests of the slope wind model.
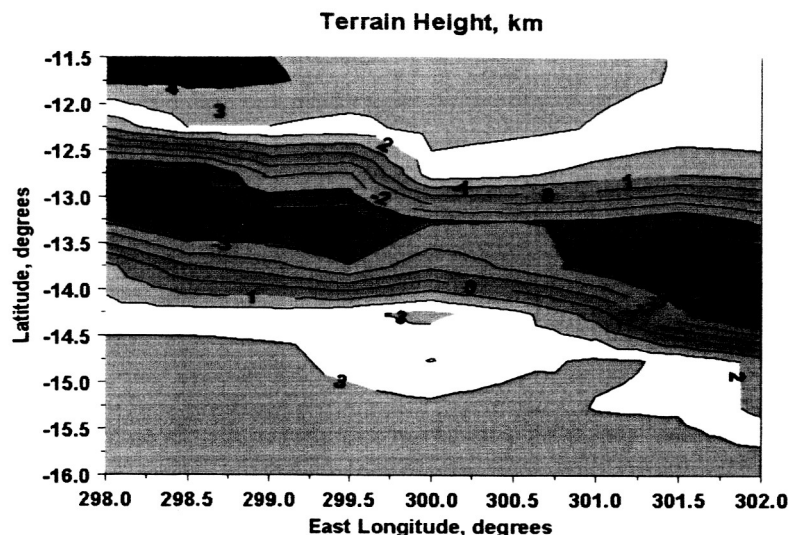
Terrain Height, km

Figure 7. Terrain Heights in portion of Valles Marineris region

Figures 8 and 9 show northward and vertical components of Mars-GRAM slope winds, evaluated at a level 1 km above local terrain height for the study area shown in Figure 7. The season assumed is Ls = 0 (northern spring equinox) at local time 14 hours. Comparison of Figures 8 and 9 with Figure 7 shows that the major pattern for slope winds at this time is northward and upward along the north wall of the valley and southward and upward along the south wall (i.e. upslope flow on both valley walls), a reasonable situation for early afternoon local time.

These examples of test output from the new Mars-GRAM slope wind model may be compared with wind simulations from Mars mesoscale models, presented by Rafkin and Michaels (2003) and Kass, et al. (2003).
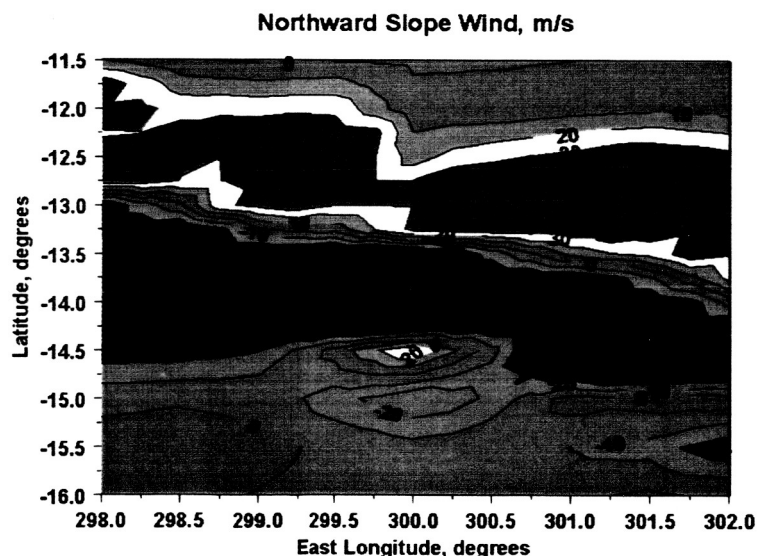
Northward Slope Wind, m/s

Figure 8. Northward slope winds at Ls = 0 and LST = 14 hours, 1km above terrain surface.

CONCLUSIONS

Mars-GRAM is an engineering-level atmospheric model, suitable for a wide range of mission design, systems analysis, and operations tasks, for both Mars orbiter and lander missions. For orbiter missions, Mars-GRAM applications include analysis for aerocapture or aerobraking operations, analysis of station-keeping issues for science orbits, analysis of orbital lifetimes for end-of-mission planetary protection orbits, and atmospheric entry

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issues for accidental break-up and burn-up scenarios. For lander missions, Mars-GRAM applications include analysis for entry, descent and landing (EDL), and guidance, navigation and control analysis for precision landing. New MGCM and MTGCM data bases for use in Mars-GRAM, plus other new features being developed, are expected to greatly enhance the utility of Mars-GRAM for these applications
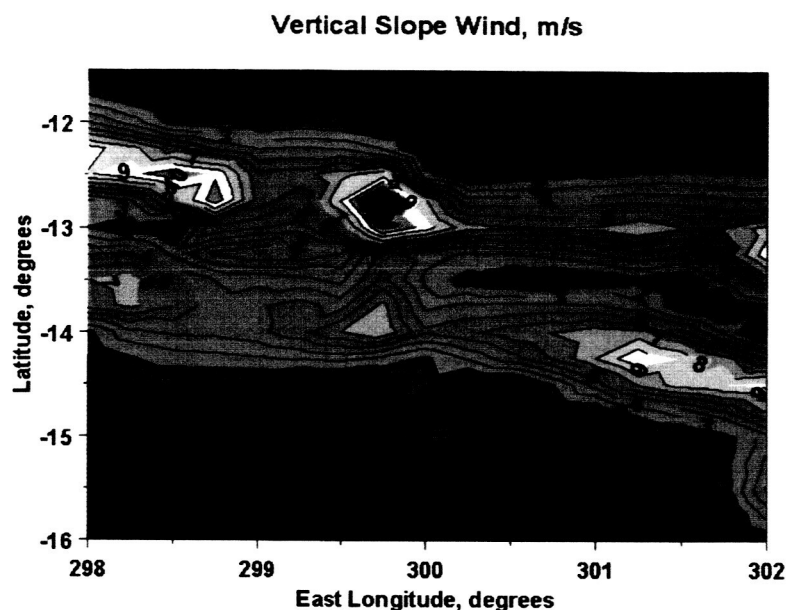
Vertical Slope Wind, m/s

Figure 9. Vertical slope winds at Ls = 0 and LST = 14 hours, 1km above terrain surface.

ACKNOWLEDGMENTS

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