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Mars Global Reference Atmospheric Model 2001 Version (Mars-GRAM 2001): Users Guide

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Errata

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Page 5 – Change equation (2.17) and description to:

$$\text{Height Offset (km)} = \Delta z_0 - 2.5\, Sin(\pi\ \mathrm{Ls}/180) \qquad (2.17)$$

where Δz_0 is an input value of constant height offset (parameter zoffset). With default value of Δz_0 = 5 km, height offset values from equation (2.17) vary seasonally from +2.5 km (at Ls = 90 degrees) to +7.5 km (at Ls = 270 degrees).

Page 15 – Replace description of parameter zoffset with:

zoffset = constant height offset (km) for MTGCM data or constant part of Ls-dependent (Bougher) height offset (0.0 means no constant offset). Positive offset increases density, negative offset decreases density.
ibougher = 0 for no Ls-dependent (Bougher) height offset term; 1 means add Ls-dependent (Bougher) term, -2.5*Sin(Ls) (km), to constant term (zoffset); 2 means use global mean height offset from data file hgtoffst.dat; 3 means use daily average height offset at local position; 4 means use height offset at current time and local position. Value of zoffset is ignored if ibougher = 2, 3, or 4.

Page 28 – Change description of label Height to:

Height = altitude (km) above MOLA areoid (Height=HgtMOLA) if MOLAhgts=1, or above ellipsoid (Height=HgtELPS) if MOLAhgts is not 1, or altitude above MOLA surface topography (Height=HgtSFCM) if NVARX=2 or NVARY=2

Page 32 – Change input value for parameter zoffset to:

zoffset = 5.
ibougher = 2

Page 33 – Change description of parameter zoffset to:

zoffset = constant height offset (km) for MTGCM data or constant part of Ls-dependent (Bougher) height offset (0.0 means no constant offset). Positive offset increases density, negative offset decreases density.
ibougher = 0 for no Ls-dependent (Bougher) height offset term; 1 means add Ls-dependent (Bougher) term, -2.5*Sin(Ls) (km), to constant term (zoffset); 2 means use global mean height offset from data file hgtoffst.dat; 3 means use daily average height offset at local position; 4 means use height offset at current time and local position. Value of zoffset is ignored if ibougher = 2, 3, or 4.

Pages 56 and 57 – Change input value for parameter zoffset to:

zoffset = 5.
ibougher = 1

Acknowledgments

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Preface

These improvements to the NASA/MSFC Mars Global Reference Atmospheric Model (Mars-GRAM 2001) were sponsored by the Environments Group, Engineering Systems Department, Engineering Directorate of the NASA Marshall Space Flight Center.

For those unfamiliar with earlier versions of Mars-GRAM, NASA Technical Memorandum 108509 "Mars Global Reference Atmospheric Model (Mars-GRAM 3.34) Programmer's Guide", and NASA TM 108513 "A Revised Thermosphere for the Mars Global Reference Atmospheric Model (Mars-GRAM Version 3.4)", NASA/TM-1999-209629 "Mars Global Reference Atmospheric Model (Mars-GRAM) Version 3.8: Users Guide", and NASA/TM-2000-210279 "Mars Global Reference Atmospheric Model 2000 Version (Mars-GRAM 2000): Users Guide", are recommended. These reports are available electronically from the NASA Marshall Space Flight Center Technical Report Server at

http://mtrs.msfc.nasa.gov/mtrs/

or from the Marshall Space Flight Center area of the NASA Technical Report Server at Internet address

http://techreports.larc.nasa.gov/cgi-bin/NTRS

For information on obtaining Mars-GRAM 2001 (or earlier) code and data, as well as additional copies of this report, contact

Environments Group
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Marshall Space Flight Center, AL 35812

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Examples of output from the University of Arizona Mars Thermospheric General Circulation Model (MTGCM) are available for browsing by interested readers at the following web site:

http://www.lpl.arizona.edu/~sengel/thermo.html

This web site has a constantly-changing archive of available MTGCM case runs for use by the scientific community at large.

Examples of output from the NASA Ames Mars General Circulation Model (MGCM) are available for browsing by interested readers at the following web site:

http://humbabe.arc.nasa.gov/mgcm/climate_data.html

This web site includes example MGCM output based on Mars Orbiter Laser Altimeter (MOLA) topography and pre-MOLA topography.

Table of Contents

Section	Title	Page
1. Introduction		1
2. New Features of Mars-GRAM 2001		2
2.1	Mars Orbiter Laser Altimeter (MOLA) Topography Data	2
2.1.1	*MOLA Areoid*	*2*
2.1.2	*MOLA Topography*	*2*
2.2	Mars General Circulation Model Input Data	3
2.2.1	*Introduction to MGCM and MTGCM Data*	*3*
2.2.2	*Evaluation of MGCM and MTGCM Tidal Components*	*4*
2.2.3	*Interpolation Methods*	*4*
2.2.4	*Interpolation in the Boundary Layer*	*5*
2.3	Longitude-Dependent (Terrain-Fixed) Wave Model	6
2.4	Mars-GRAM Climate Factors and Height Adjustment	7
2.5	Quantitative Dust Concentration Model	9
2.6	Solar and Thermal Radiation from Mars-GRAM Output	10
2.7	New Mars-GRAM Input and Output Options	11
3. How to Run Mars-GRAM		12
3.1	How to Obtain the Program	12
3.2	Running the Program	12
3.3	Program Input 13	
3.4	Program Output	17
4. Sample Results		19
4.1	New Mars-GRAM 2001 Output	19
4.2	Comparisons with Observations	21
5. References		25
Appendices		
A.	Headers for Mars-GRAM 2001 Output Files	28
B.	Example NAMELIST Format Input File	32
C.	Sample Output LIST File	35
D.	Summary of Files Provided with Mars-GRAM 2001	45
E.	Example Application of Mars-GRAM in a Trajectory Code	48
F.	Details of MGCM, MTGCM, and MOLA Data Files	50
G.	Auxiliary Programs for Use with Mars-GRAM	52
H.	Wave Model Data to Reproduce Mars Global Surveyor Density	55

List of Illustrations

Figure	Title	Page
2.1	Difference between MOLA areoid radius and old Mars-GRAM reference ellipsoid radius	3
2.2	Illustration of Mars-GRAM (MTGCM) height offsets required to match density observations on MGS orbit 40 and to match the MGCM profile at the same location and time.	9
4.1	Height-latitude cross section of atmospheric density through a portion of Valles Marineris	19
4.2	Latitude-longitude cross section of ground surface temperature at Ls = 270 degrees, dust optical depth 1.0.	20
4.3	Latitude-longitude cross section of air temperature five meters above ground level at Ls = 270 degrees, dust optical depth 1.0.	20
4.4	Latitude-longitude cross section of downwelling longwave irradiance at the surface, expressed as sky temperature, at Ls = 270 degrees, dust optical depth 1.0.	21
4.5	Seasonal variation of surface pressure measured by Viking Lander 2 and simulated by Mars-GRAM (MGCM) using nominal seasonal variation of dust optical depth (equation 2.18).	22
4.6	Mars-GRAM temperature profiles compared with average temperature profile derived from TES data for MER-B landing site selection studies.	23
4.7	Mars-GRAM density profiles compared with average density profile derived from TES data for MER-B landing site selection studies.	23
4.8	Atmospheric density at periapsis from Mars Global Surveyor accelerometer during phase-1 aerobraking and simulated by Mars-GRAM using seasonal height offset (equation 2.17) and longitude wave model (discussed in appendix H).	24
4.9	Atmospheric density at periapsis from Mars Global Surveyor accelerometer during phase-2 aerobraking and simulated by Mars-GRAM using seasonal height offset (equation 2.17) and longitude wave model (discussed in appendix H).	24

List of Tables

Table	Title	Page
2.1	Global average height offset (km) required for MTGCM-MGCM matchup as a function of solar longitude, Ls, and dust optical depth, tau	8

Mars Global Reference Atmospheric Model 2001 Version (Mars-GRAM 2001): Users Guide

1. Introduction

The Mars Global Reference Atmospheric Model (Mars-GRAM) is an engineering - oriented model of the atmosphere of Mars. Recent documented applications of Mars-GRAM include aerobraking operations of Mars Global Surveyor,[1] prediction and validation of Mars Pathfinder hypersonic aerodynamics,[2] and aerothermodynamic and entry dynamics studies for Mars Polar Lander.[3]

Earlier Mars-GRAM versions[4-8] were based on adhoc parameterizations to data observed by the Mariner and Viking missions. The previous Mars-GRAM version[9] and current version (Mars-GRAM 2001) are based on input data tables of output from the NASA Ames Mars General Circulation Model (MGCM)[10,11] and the University of Arizona Mars Thermospheric General Circulation Model (MTGCM).[12,13] Fully global in scope, and based on first-principles physics (e.g. atmospheric thermodynamics and equations of atmospheric motion), both MGCM and MTGCM have been somewhat "tuned" to insure that they represent Mariner and Viking results at the locations and times for which these data are available. Work on MGCM and MTGCM continues, to ensure that these models agree as well as possible with recent results from Mars Pathfinder and Mars Global Surveyor.

Section 2 of this report describes the MGCM and MTGCM data and how they are applied in Mars-GRAM 2001. Other new Mars-GRAM features are also described in section 2. Section 3 explains how to obtain the Mars-GRAM code and data files and how to set up and run the program. Sample results are presented in section 4. Appendices A through F provide additional details of Mars-GRAM 2001 input and output files and how to interpret program results. Appendix G describes several auxiliary programs provided with Mars-GRAM. Appendix H gives Mars-GRAM wave model information to reproduce atmospheric density observed during Mars Global Surveyor aerobraking.

2. New Features of Mars-GRAM 2001

2.1 Mars Orbiter Laser Altimeter (MOLA) Topography Data

2.1.1 MOLA Areoid

Flying on Mars Global Surveyor, Mars Orbiter Laser Altimeter (MOLA) produced topographic data[14-16] at a variety of high resolutions (one by one degree to 1/16 by 1/16 degree latitude-longitude grids). Details of MOLA topography data are available at the MOLA Data Product Archives web site

http://wufs.wustl.edu/missions/mgs/mola/

and the MOLA Science Investigation web site

http://ltpwww.gsfc.nasa.gov/tharsis/mola.html

MOLA topography is measured with respect to a zero elevation surface level known as the MOLA areoid, which is defined as the gravitational equipotential surface whose average value at the equator is equal to the mean radius determined by MOLA. Mars-GRAM 2001 uses half-degree latitude-longitude resolution data for both MOLA areoid and topography.

Previous Mars-GRAM versions use a simple ellipsoid of revolution as zero elevation level. Previous resolution for Mars-GRAM topography is 7.5 by 9 degrees, consistent with the evaluation grid of NASA Ames Mars General Circulation Model. Although Mars-GRAM 2001 works internally with MOLA areoid and topography, and uses these as defaults, program input options also allow users to input and output heights relative to the old Mars-GRAM ellipsoid. Figure 2.1 shows a latitude-longitude map of difference between MOLA areoid and old Mars-GRAM ellipsoid radius. MOLA areoid radius varies from less than one to more than two kilometers higher than the old Mars-GRAM ellipsoid radius.

For high-altitude applications based on orbit-propagation trajectories (e.g., aerobraking, planetary protection orbit evaluation, etc.) the old Mars-GRAM ellipsoid may still be more suitable for altitude reference. For near-surface applications (e.g., entry trajectory terminal descent, parachute deploy analysis, rover operations analysis, etc.) MOLA areoid and topography are more suitable for altitude reference.

2.1.2 MOLA Topography

MOLA topography and areoid radius in Mars-GRAM 2001 are specified in a text-format input file (molatoph.txt). For Mars-GRAM use, this file must be converted to a binary file (molatoph.bin) by running a conversion program (discussed in appendices D and F). Each line of the text file is for a given latitude-longitude grid, and contains grid-averaged values of longitude (degrees East), latitude (degrees North), planetary radius (meters), areoid radius (meters), topographic altitude (meters), and number of data points in the grid. Planetary radius (radius to the local topographic surface) and areoid radius (radius to the zero elevation surface) are measured (along a planeto-centric radius direction) from the center of mass of the planet. MOLA latitude data are planeto-centric, hence, differ slightly from planeto-graphic latitudes.

Topographic altitude is the difference between planetary radius and areoid radius. Because of non-linearities and interpolation methods used in processing MOLA data, grid-averaged topography (provided in the file, and used in Mars-GRAM 2001) is slightly different from the difference between the grid-averaged planetary radius and grid-averaged areoid radius.

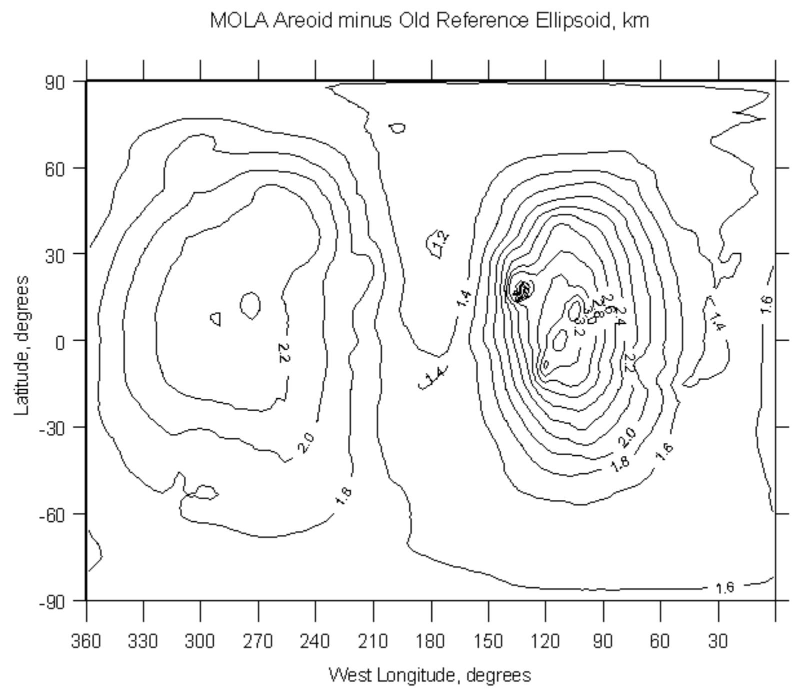

Figure 2.1. Difference between MOLA areoid radius and old Mars-GRAM reference ellipsoid radius

Relative to MOLA areoid, highest point on Mars (peak of Olympus Mons) is +21.2 km, and lowest (in the Hellas Basin) is -7.8 km. For half-degree resolution MOLA data used in Mars-GRAM 2001, highest and lowest elevations are +21.0 and -7.6 km, respectively.

2.2 Mars General Circulation Model Input Data

2.2.1 Introduction to MGCM and MTGCM Data

Earlier Mars-GRAM versions[4-8] used adhoc parameterizations derived from Mariner and Viking data, to represent temperature versus height, latitude, longitude, time of day, and Ls, and to prescribe surface pressure versus latitude, longitude, time of day, and Ls. Ls, celestial longitude of the Sun, viewed from Mars, gives time of year and Mars season. Ls = 0 is Northern spring equinox; Ls = 90° is Northern summer solstice, etc. In Mars-GRAM 2000[9] and Mars-GRAM 2001, all data-derived parameterization relations are replaced by input data tables, based on information from the NASA Ames Mars General Circulation Model (MGCM)[10,11] and the University of Arizona Mars Thermospheric General Circulation Model (MTGCM).[12,13] These tables give variation of temperature, density, pressure and wind components with height, latitude, time of day, and Ls. The tables also provide boundary layer data at topographic surface, 5 meters and 30 meters above the surface as a function of longitude, latitude, time of day, and Ls.

MGCM data tables cover altitudes from the surface to 80 kilometers. MTGCM data tables cover altitudes of 80 to 170 kilometers. A modified (latitude-longitude dependent) Stewart-type thermospheric model[6] is used for altitudes above 170 km, and for dependence on solar activity at higher levels. The Stewart-type thermosphere model starts at a lower boundary condition height of the 1.26 nbar pressure level (height ZF). Between 80 km and height ZF (typically at about 125 km), MTGCM data are used directly and also for dependence on solar activity. MTGCM values are interpolated/extrapolated to any desired solar activity value from MTGCM input data for F10.7 = 70 and 130. F10.7 is solar flux at 10.7 cm wavelength in units of 10^{-22} W/cm^2 at average Earth orbit position (1 AU). Above 170 km, modified Stewart-type thermosphere model data are used directly. Between height ZF and 170 km a fairing process is used that smoothly transitions from MTGCM values to Stewart-type model values.

Details and formats of Mars-GRAM, MGCM, and MTGCM data files are given in appendix F. To facilitate transfer, these files are provided in ASCII format. For run-time speed it is best to read the files in binary form. A program (discussed in appendix F) is provided to convert ASCII format MGCM and MTGCM data files to binary files on the user's machine.

2.2.2 Evaluation of MGCM and MTGCM Tidal Components

For each atmospheric parameter (temperature, pressure, density, wind components) MGCM and MTGCM data tables provide a diurnal (daily) mean value, and amplitudes and phases of diurnal and semi-diurnal tidal components. Tidal values for each parameter are computed from the relation

$$\text{Tide} = A_0 + A_1 \cdot Cos[\,\pi\,(t - \phi_1) / 12] + A_2 \cdot Cos[\pi\,(t - \phi_2) / 6\,] \qquad (2.1)$$

where t is local solar time in hours, A_0 is diurnal mean value of the given parameter, A_1 is amplitude of the diurnal tide component, ϕ_1 is phase (local time in hours) of the diurnal component, A_2 is amplitude of the semi-diurnal tide component, and ϕ_2 is phase (local time in hours) of the semi-diurnal component.

MGCM and MTGCM tidal coefficients are provided at 5-kilometer height increments [starting at 0 kilometer relative to datum level, and going to 80 kilometer (MGCM) or 170 kilometer (MTGCM)]. MGCM coefficient data are provided at 7.5 degree-latitude spacing, while MTGCM data have 5-degree latitude spacing. Both MGCM and MTGCM data are at every 30 degrees of Ls angle, and include three levels of dust optical depth (tau = 0.3, 1, and 3). MGCM tidal coefficients are also provided at the topographic surface and heights 5 meters and 30 meters above local topography. Surface layer MGCM data are at 9-degree longitude spacing (for the same latitudes, Ls values, and dust optical depths as MGCM data above the surface layer).

2.2.3 Interpolation Methods

Equation 2.1 is used to evaluate each atmospheric parameter, at the desired local solar time, t, at "corners" of a multi-dimensional "box" of grid points containing the desired interpolation location, Ls (time of year), and dust optical depth (tau). Multi-dimensional interpolation routines are used to evaluate all atmospheric parameters at locations between the MGCM or MTGCM grid-points. For data above the surface layer, interpolation is three-dimensional in latitude, Ls, and tau. For surface layer data (topographic surface, and 5 meters or

30 meters above the surface), interpolation is four-dimensional in longitude, latitude, Ls, and tau. Interpolation is logarithmic for tau, and linear for all other dimensions.

Interpolation to desired height (z) is done by first multi-dimensional interpolating at two height levels (z1 and z2) from grid-point altitudes just above and below z. Above the surface layer, z1 and z2 are at the 5 km vertical grid spacing of the MGCM or MTGCM data. Near the surface layer (topographic surface or 5 meters and 30 meters above surface height), altitudes z1 and z2 are adjusted as appropriate. Temperature T(z), and wind components u(z) and v(z) are found by linear interpolation on height. Pressure p(z) is found by first computing pressure scale height

$$H = (z2 - z1) / ln[\, p(z1) / p(z2) \,] \qquad (2.2)$$

and evaluating pressure p(z) from the hydrostatic relation

$$p(z) = p(z1)\, exp[\, (z1 - z) / H \,] \qquad (2.3)$$

Gas law "constant" R is evaluated from pressure, p, density, ρ, and temperature, T, heights, z1 and z2, by

$$R(z1) = p(z1) / [\rho(z1)\, T(z1)\,] \qquad (2.4)$$

$$R(z2) = p(z2) / [\rho(z2)\, T(z2)\,] \qquad (2.5)$$

Density ρ(z) at height z is then determined by the gas law relation and a linearly-interpolated R value, R(z)

$$\rho(z) = p(z) / [R(z)\, T(z)\,] \qquad (2.6)$$

2.2.4 Interpolation in the Boundary Layer

MGCM data tables used by Mars-GRAM now include ground surface temperature. Between surface and five-meter height, large temperature gradients can exist. There can also be a difference between ground surface temperature and air temperature "immediately" above ground. These features must be represented by a boundary layer model. Following the approach used in NASA Ames MGCM[17], Mars-GRAM assumes temperature varies from T_g at ground surface to T_5 at five-meter level according to the relation

$$T(z) = T_g + (T_5 - T_g)\, [\, 1 + F_h^{1/2} F(z)\,] / [\, 1 + F_h^{1/2}\,] \qquad (2.7)$$

where the factor F_h is given by

$$F_h = \begin{cases} (1 - 16 R_i)^{1/2} & R_i < 0 \\ [\, 1 + 15 R_i / (1 + 5 R_i)^{1/2}\,]^{-1} & R_i \geq 0 \end{cases} \qquad (2.8)$$

as a function of Richardson number, R_i, determined from wind and temperature gradients between ground and 5-meter level. Logarithmic height factor, F(z), is given by

$$F(z) = ln (z / z_0) / ln (5 / z_0) \tag{2.9}$$

where z_0 is surface roughness parameter, assumed to be 0.01 m, except over surface ice, where z_0 = 0.01 cm is used[18].

Wind components at heights less than 5 meters above the surface are evaluated from a logarithmic boundary layer profile relation

$$u(z) = u(5) F(z) \tag{2.10}$$

$$v(z) = v(5) F(z) \tag{2.11}$$

2.3 Longitude-Dependent (Terrain-Fixed) Wave Model

Tide components evaluated by equation (2.1) depend only on local solar time. Implicitly, this equation also depends on longitude. At any given instant, solar time varies at a rate of one hour for every 15 degrees of longitude. During aerobraking operations, accelerometer measurements by Mars Global Surveyor[19-22] revealed large-amplitude longitude-dependent wave patterns for atmospheric density. Being in a sun-synchronous orbit, Mars Global Surveyor passed through each periapsis at essentially the same local solar time. Nevertheless, it found large-amplitude variations that tended to repeat as a function of periapsis longitude. The density variations were of the form of longitude-dependent (i.e., terrain-fixed) wave patterns. Mars-GRAM 2001 includes a model for these longitude-dependent waves (LDW) of the form

$$LDW = B_0 + B_1 \, Cos[\pi (\lambda - \Phi_1) / 180] + B_2 \, Cos[\pi (2 \lambda - \Phi_2) / 180]$$

$$+ B_3 \, Cos[\pi (3 \lambda - \Phi_3) /180] \tag{2.12}$$

where λ is longitude (in degrees), B_0 is a mean wave perturbation offset, B_1, B_2, and B_3 are amplitudes and Φ_1, Φ_2, and Φ_3 are phases (longitudes) for wave-1, wave-2, and wave-3 components. The term wave-n means the wave component has n peaks and troughs through 360 degrees of longitude. Note differences in details of the form of LDW equation used in Mars-GRAM 2001 and in Mars-GRAM 2000. LDW perturbations computed by equation (2.12) are applied as a multiplier to the mean density and pressure computed from MGCM and MTGCM data, as interpolated by methods described in section 2.2.3. Wave model coefficients for equation (2.12) can be input from the NAMELIST format input file (see appendix B), or from an auxiliary file of time-dependent wave model coefficients (sections 3.2 and 3.3 and appendix H). Care should be taken to define values of phase angles according to the new form of equation (2.12). Values of LDW coefficients may be determined empirically by accelerometer observations,[19,21] or theoretically from wave characteristics of Mars GCMs.[20,22]

For altitudes above 100 km, LDW perturbations from equation (2.12) are assumed to be altitude independent. For altitudes below 100 km, LDW perturbations are assumed to diminish in magnitude at an exponential rate, namely,

$$LDW(z) = 1 + (LDW(100) – 1) \, exp[(z – 100) / S] \tag{2.13}$$

where S is the wave scale parameter Wscale, from the NAMELIST format input file.

Earlier Mars-GRAM versions allowed density adjustment up or down by “climate factors” no longer used in Mars-GRAM 2000 and 2001 versions. One way of adjusting Mars-GRAM 2001 density values up or down (at altitudes below 100 km) is the LDW mean term B_0. For example, if the user wants to adjust Mars-GRAM 2001 density values by a factor W1 = $B_0(z1)$ at height z1 and W2 = $B_0(z2)$ at height z2 (where z1 and z2 are both less than 100 kilometers), then use the scale parameter value

$$S = (z2 - z1) / \mathit{ln} [(W2 - 1) / (W1 - 1)] \qquad (2.14)$$

which yields a LDW multiplier value at 100 km $B_0(100)$ given by

$$B_0(100) = 1 + (W2 - 1) \mathit{exp}[(100 - z2) / S] \qquad (2.15)$$

Once values of S and $B_0(100)$ are input to the program, density at any height, z, (below 100 km) is adjusted by the factor

$$B_0(z) = 1 + (B_0(100) - 1) \mathit{exp}[(z - 100) / S] \qquad (2.16)$$

Note that multipliers may be larger or smaller than one (yielding density increase or decrease, respectively).

2.4 Mars-GRAM Climate Factors and Height Adjustment

Previous versions of Mars-GRAM allowed model output profiles to be adjusted (e.g., to better fit data profiles provided from MGCM output). These adjustments were accomplished with "climate factors" (CF0 through CF75 to adjust temperature from 0- to 75-km altitude, CFp to adjust surface pressure, deltaTF to adjust temperature at 1.26-nbar level, deltaZF to adjust height of the 1.26-nbar level (height ZF), and deltaTEX to adjust exospheric temperature. With Mars-GRAM 2001 based directly on MGCM and MTGCM output (below 170 km), none of these climate factors is needed (except deltaTEX, which allows adjustment of exospheric temperature). Adjustment of Mars-GRAM 2001 model output is affected by choice of dust optical depth (input parameter Dusttau), and by longitude-dependent wave (LDW) parameters (discussed in section 2.3).

Another additional way of adjusting Mars-GRAM 2001 density output is by direct height offset (input parameter zoffset) of the MTGCM data. Height offset adjustment affects density only above 80 km. The function of height offset is very similar to that of LDW wave parameter B_0, discussed in section 2.3. One thinks of B_0 as shifting a height-versus-density plot (figure 2.2) to the right (or left) as it increases (or decreases) density at a given height. Height offset shifts such a height-versus-density curve up (or down) as it increases (or decreases) height at which a given density applies. The net result of a positive (or negative) height offset is to increase (or decrease) density at a given height.

Height offsets to be used by Mars-GRAM 2001 may be specified in several ways (by the input parameter zoffset, described in section 3.3). A specific offset value (in kilometers) may be specified. Alternatively, the offset value required to match MTGCM data to MGCM data at 80 km can be computed and applied by the program. MTGCM-MGCM matchup can be specified as applicable locally or globally, from data shown in table 2.1. Local matchup can be on the basis of either density at a given location and time of day or daily average density at a given location.

Another option is to have the program compute and use a (global) height offset that depends on time of year (through solar longitude Ls). Based on comparisons of MTGCM with density observed during Mars Global Surveyor (MGS) aerobraking,[21] time-of-year dependence of height offset is given as

$$\text{Height Offset (km)} = 5 - 2.5\, Sin(\pi \text{ Ls} / 180) \qquad (2.17)$$

Height offset values from equation (2.17) vary seasonally from +2.5 km (at Ls = 90 degrees) to +7.5 km (at Ls = 270 degrees). Table 2.1 shows that required MTGCM-MGCM matchup offsets are all negative, ranging from –2.24 km (at Ls = 270 degrees, tau = 0.3) to –5.67 km (at Ls = 300 degrees, tau = 3).

Table 2.1. Global average height offset (km) required for MTGCM-MGCM matchup, as a function of solar longitude, Ls, and dust optical depth, tau

Solar Lon, Ls degrees	Dust Optical Depth, tau 0.3	1.0	3.0
0	-2.92	-3.46	-3.60
30	-2.92	-2.85	-3.55
60	-2.89	-2.86	-3.34
90	-2.99	-2.86	-3.96
120	-3.35	-2.68	-3.73
150	-3.16	-2.86	-3.64
180	-2.81	-2.65	-3.24
210	-2.61	-2.77	-3.04
240	-2.30	-2.74	-5.34
270	-2.24	-5.21	-5.28
300	-2.51	-4.55	-5.67
330	-2.61	-3.37	-3.92
360	-2.92	-3.46	-3.60

Mars-GRAM allows optional regional or global-scale dust storms to be “switched on” at any desired time (Ls). Dust storm simulations are discussed in section 2.5. Based on comparisons between Mars-GRAM and density observed by the accelerometer[19] on Mars Global Surveyor during the regional Noachis dust storm, additional height offset of MTGCM data is applied during simulated dust storms. Additional offset amount (in kilometers) is seven times dust storm orbital depth.

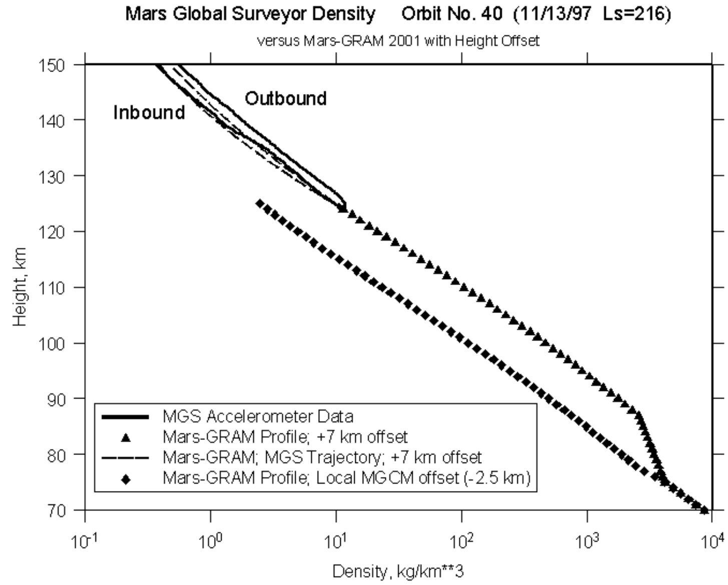

Figure 2.2. Illustration of Mars-GRAM (MTGCM) height offsets required to match density observations on MGS orbit 40 and to match the MGCM profile at the same location and time.

The dichotomy of large positive offsets required for MTGCM-MGS matchup and substantial negative offsets for MTGCM-MGCM matchup is illustrated in figure 2.2. This figure shows Mars-GRAM profiles with an MTGCM offset of +7 km, required to match observed MGS density on orbit 40, and MTGCM offset of –2.5 km, required to match the MGCM profile at the location and time of MGS orbit 40 periapsis.

In earlier Mars-GRAM versions, mismatch between density below about 75 km and above about 120 km could be addressed by program input option “ipopt”. Value ipopt = 1 produced hydrostatically-computed density profiles consistent with data below 75 km, somewhat analogous to the local offset curve in figure 2.2. Value ipopt = 0 produced a non-hydrostatic interpolation curve for density, somewhat like a line connecting the upper point on the MGCM curve at 75 km with the lower point on the MGS accelerometer data curve in figure 2.2.

In Mars-GRAM 2001, sharp discontinuities in vertical density gradient, such as the +7 km offset curve in figure 2.2, are avoided by a combination of height offset and longitude-dependent wave (LDW) coefficients B_0 and S (section 2.3). A value of height offset (which applies only to MTGCM data, above 80 km) is selected to match the upper conditions (MTGCM-MGS matchup in this case) and equations (2.14) through (2.16) are used, with some trial and error, to calculate coefficients B_0 and S to produce a smoother transition from MTGCM to MGCM values. Note that coefficients B_0 and S modify both MTGCM and MGCM values below 100 km.

Mars mesosphere-thermosphere coupling (e.g., matchup of MGCM and MTGCM model values) is an active area of research.[23] Improved methods are anticipated for producing MGCM and MTGCM results more consistent with each other and with observations both at low and high altitudes. As these GCM results become available, they will be incorporated into future Mars-GRAM versions.

2.5 Quantitative Dust Concentration Model

Background (nondust storm) dust optical depth (tau) is specified by input parameter Dusttau (section 3.3). Interpolation routines (section 2.2.3) interpolate logarithmically between tau values for both MGCM and MTGCM input data. If Dusttau = 0 is input, a prescribed Viking-like seasonal variation of dust optical depth is used, in which case variation of tau with Ls (in degrees) is specified by

$$\text{tau} = 0.65 - 0.35\, Sin(\pi\, \text{Ls} / 180) \qquad (2.18)$$

A model for global or local-scale dust storms[5] is retained. In Mars-GRAM 2001, input value for dust storm intensity (input parameter, INTENS) is equivalent to peak dust optical depth for the storm. The program does all necessary interpolations on dust optical depth as it varies with time, Ls, and space for local storms. A new input option (ALSDUR, section 3.3) allows users to control the duration of simulated dust storms.

Mars-GRAM 2001 computes several dust concentration parameters from dust optical depth. Methods used by Haberle, et al. in MGCM are employed.[24,17] Areal dust density, m_d, (total column mass of dust per unit ground surface area) is 0.005 times tau. Dust mixing ratio (mass of dust per unit mass of air) at the surface, q_0, is computed by

$$q_0 = m_d\, g / (\, 0.994\, exp^{-\nu}\, p_{sfc}\,) \qquad (2.19)$$

where g is gravity, ν is a parameter (input parameter Dustnu) controlling vertical dust distribution, and p_{sfc} is surface pressure. Dust mixing ratio at height z is determined by

$$q(z) = q_0\, exp\{\, \nu\, [\, 1 - p(z)/p_{sfc}\,]\, \} \qquad (2.20)$$

where p(z) is pressure at height z. Dust mass density (mass of dust per unit volume of air) is the product of dust mixing ratio and atmospheric density. From dust mixing ratio, assuming that dust particles are spheres of a given diameter and mass, Mars-GRAM 2001 also computes dust number density (number of dust particles per unit volume of air). Users can input values of dust particle diameter (input parameter Dustdiam) and dust particle density (input parameter Dustdens). Consistent with MGCM[24], Mars-GRAM 2001 assumes default particle diameter, 5 μm, and default particle density, 3000 kg/m^3.

Dust model input parameters are discussed in section 3.3. Dust model output values are written to file MarsRad.txt (appendix A).

2.6 Solar and Thermal Radiation from Mars-GRAM Output

Several auxiliary programs used with Mars-GRAM are described in appendix G. One, marsrad.f, computes upwelling and downwelling components of solar (shortwave) and thermal (longwave) radiation at the surface and top of atmosphere. This program uses Mars-GRAM output file MarsRad.txt, which includes dust concentration information discussed in the previous section. MarsRad.txt is discussed more fully in appendix A.

To compute upwelling shortwave radiation at the surface, Mars-GRAM uses surface albedo from a data file (albedo1.txt) containing surface albedo at 1-degree latitude-longitude resolution.[25,26]

Program marsrad.f produces two output files: radlist.txt and radout.txt. These files and the methods used to compute radiation components provided by them are discussed in appendix G. Mars-GRAM output used as input to marsrad.f consists of one or more vertical profiles of temperature versus pressure (altitude). To facilitate production of latitude-longitude, latitude-time, or longitude-time arrays of such profiles, program radtraj.f is also provided as an auxiliary program (appendix G).

2.7 New Mars-GRAM Input and Output Options

Sample Mars-GRAM input is provided in appendix B. New input parameter, zoffset, to specify MTGCM height offset, is discussed in section 2.4. New input parameters for dust concentration calculations (Dustnu, Dustdiam, Dustdens, and ALSDUR) are discussed in section 2.5. A new input parameter (MOLAhgts) controls whether input and output altitudes are with respect to MOLA areoid (default) or the old Mars-GRAM reference ellipsoid (section 2.1).

For users wishing to evaluate an array of atmospheric conditions at different locations, all within the boundary layer and all at a fixed height above the surface, new input parameter, hgtasfcm, is provided. This parameter gives the height (meters) where evaluations are to be performed. This parameter is used in conjunction with FHGT = -10 km (specifies that surface altitude is used for evaluations). Example: If values FHGT = -10 km and hgtasfcm = 1 m are input, evaluation is at one meter above the surface.

A new allowable value of 3 for parameter LOGSCALE specifies that output density is in units of kg/km^3, rather than normal units kg/m^3. Units kg/km^3 are especially appropriate at thermospheric altitudes.

Mars-GRAM outputs are described in appendices A and C. New output file, MarsRad.txt, is discussed in appendices A and G. In addition to daily average values, output data file DayData.txt now includes daily minimum and maximum values for density and temperature. Also, in a change from Mars-GRAM 2000, longitude-dependent wave parameters apply to daily data as well as data at local place and time.

Several parameters may be selected as independent variables for Mars-GRAM output files. These variables (Var_X and Var_Y on the output files) are described in appendix A. Two new choices for independent variable are sigma coordinate and pressure height parameter. These two variables are frequently used in display and analysis of general circulation model output. Sigma coordinate for a given altitude is pressure at the altitude divided by surface pressure. Pressure height parameter is equal to negative of natural logarithm of sigma coordinate. Pressure height parameter is proportional to hydrostatic altitude through the average value of pressure scale height.

3. How to Run Mars-GRAM

3.1 How to Obtain the Program

All source code and required data files are available from a file transfer protocol (ftp) server at NASA Marshall Space Flight Center. The ftp site also contains example input and output files and "readme" files. To obtain the program source code and data files by ftp, see contact information in the preface. See appendices D through H for summaries of the program and data files available on the ftp site.

3.2 Running the Program

There are two ways to run Mars-GRAM: (1) as a subroutine in a (user-provided) main driver program (such as a trajectory program) and (2) as a stand alone program, using a NAMELIST format input file, in which values for all input options are provided. To use Mars-GRAM as a subroutine, see discussion in appendix E and use example file dumytraj.f (available in the ftp file distribution) as a guide. File README2.txt (available in the ftp file distribution) also discusses use of dumytraj.f as an example for using Mars-GRAM as a subroutine.

The steps involved in setting up and running Mars-GRAM in stand-alone mode are the following:

- Compile and link the three FORTRAN source code files marsgram.f, marssubs.f, and setup.f, into an executable program (assumed to be called marsgram)

- Make sure that necessary data files albedo1.txt (surface albedo data), cospar2.dat (COSPAR model atmosphere data), molatoph.txt (MOLA topographic height information), and hgtoffst.dat (global average height offset values) are in an appropriate directory (whose pathname is specified by parameter DATADIR in the NAMELIST format input file)

- Compile and run programs readtopo.f (to convert MOLA data from ASCII to binary) and readalb.f (to convert albedo data from ASCII to binary)

- Compile and run program makebin.f (see appendix F) and convert the ASCII format MGCM and MTGCM data files provided to binary form (see appendix D); this conversion process needs to be done only once on each user's machine

- Make sure that the binary format MGCM and MTGCM data files (see appendices D and F) are in an appropriate directory (whose pathname is specified by parameter GCMDIR in the NAMELIST format input file)

- Prepare a NAMELIST format input file (whose name is specified at run time) with the desired values of all input options (example in appendix B)

- If trajectory input mode (rather than automatic profile mode) is desired, prepare a trajectory input file (whose name is set by parameter TRAJFL in the NAMELIST input file) containing time, height, latitude, and longitude (further discussion below)

- If time-dependent coefficients for longitude-dependent wave model are to be used, prepare a file (whose name is specified by parameter WaveFile in the NAMELIST format input file). This file contains one set of coefficients per line: time (seconds from start time) and wave model coefficients (B_0 through Φ_3, defined in section 2.3; further discussion below and in appendix H)

- Run the program by entering its executable name (e.g., marsgram); the program automatically opens and reads the NAMELIST input file (and the TRAJFL file, if trajectory mode is used); the data files albedo1.txt, cospar2.dat, molatoph.txt and hgtoffst.dat; all MGCM and MTGCM binary data files; and the WaveFile file (if time-dependent coefficients are used)

If the program is run in profile mode, the user provides (in the NAMELIST format input file) fixed values for increments of time, height, latitude, and longitude. In this mode, the program automatically increments position until the desired number of positions (NPOS) are evaluated. In trajectory mode (selected by using NPOS = 0), Mars-GRAM reads time and position information from the TRAJFL file.

If constant values of longitude-dependent wave model coefficients are used, values for these are read in as part of the NAMELIST input file (section 3.3). For time-dependent coefficients, values are read from the WaveFile file. Each set of coefficients applies from the time given with the coefficient data, until a new time and set of coefficients are given (on the next line of WaveFile). The last set of coefficients in WaveFile applies indefinitely, beginning with its given time.

3.3 Program Input

Appendix B gives a sample of NAMELIST format input file for Mars-GRAM 2001. Whether the subroutine or stand alone version is used, input variables whose values are supplied in the INPUT file are as follows:

LSTFL	Name of LIST file (example LIST file in appendix C); for a listing to the console in the stand alone version enter filename CON.
OUTFL	Name of OUTPUT file (discussion of this file in appendix A)
TRAJFL	(Optional) trajectory input file name; file contains time (seconds) relative to start time, height (km), latitude (degrees), longitude (degrees West if LonEW=0 or degrees East if LonEW=1; see below)
WaveFile	(Optional) file for time-dependent wave coefficient data (file description under parameter iuwave, below; examples in appendix H)
DATADIR	Pathname to directory for COSPAR data, topographic height data, surface albedo data, and global height offset data
GCMDIR	Pathname to directory for MGCM and MTGCM binary data files
MONTH	Integer month (1 through 12) for initial time

MDAY	Integer day of month for initial time
MYEAR	Integer year for starting time, a 4-digit number; alternately years 1970-2069 can be input as a 2-digit number
NPOS	Maximum number of positions to evaluate, if an automatically-generated profile is to be produced; use 0 if trajectory positions are to be read in from a TRAJFL file
IHR	Integer initial time, hour of day UTC (GMT)
IMIN	Integer initial time, minute of hour
SEC	Initial time, seconds of minute
LonEW	Longitude switch, 0 for input and output with West longitude positive (default) or 1 for East longitude positive
Dusttau	Optical depth of background dust level (no time-developing dust storm, just uniformly mixed dust), 0.3 to 3.0 (if 0.0 is input, a Viking-like annual variation of background dust is assumed)
Dustnu	Parameter for vertical distribution of dust density[17]
Dustdiam	Dust particle diameter (micrometers, assumed monodisperse)
Dustdens	Dust particle density (kg/m^3)
ALS0	Value of areocentric longitude of the Sun (Ls, in degrees) at which a dust storm is to start; use a value of 0 if no dust storm is to be simulated; dust storm can be simulated only during the season of the Mars year for which Ls is between 180 and 320 degrees
ALSDUR	Duration (in Ls degrees) for dust storm (default = 48)
INTENS	Dust storm intensity, measured as peak dust optical depth of the storm, with allowable values ranging from 0.0 (no dust storm) to 3.0 (maximum intensity dust storm). Dust storm intensity is added to background dust optical depth to give total dust optical depth
RADMAX	Maximum radius (km) a dust storm can attain, developing according to the parameterized space and time profile of build-up and decay in the program; if a value of 0 or more than 10 000 km is used, the storm is taken to be of global dimensions (uniformly covering the planet), but still assumed to build up and decay in intensity according to the same temporal profile
DUSTLAT	Latitude (degrees, North positive) for center of dust storm
DUSTLON	Longitude (degrees, West positive if LonEW=0, or East positive otherwise) for center of dust storm

F107 10.7 cm solar flux in its usual units of 10^{-22} W/cm^2 at average Earth orbit position (1 AU); solar flux is automatically converted by the program to its value at the position of Mars in its orbit

STDL Standard deviation parameter for short-term variations in Stewart model thermosphere; normal value is 0; allowable range is from -3.0 to +3.0

NR1 Seed value (integer) for random number generator; allowable range is 1 to 29 999; to do Monte-Carlo simulations with a variety of perturbations, use a different random number seed on each model run; to repeat a given random number sequence on a later model run, use the same random number seed value

NVARX x-code for the plotable output (x-y pairs for line graphs or x-y-z triplets for contour plots); appendix A lists the variables associated with the x-code (e.g., if NVARX = 1, x output for plotting is height above the MOLA areoid)

NVARY y-code for contour plot output (x-y-z triplets); use a y-code value of 0 for line graph (x-y pair) plots; appendix A lists y-code values and parameters represented

LOGSCALE Parameter to control units of output values of density and pressure on output plot files; a value of 0 means use regular density and pressure units (kg/m^3 and N/m^2); 1 means to output logarithm (base-10) of the regular units; 2 means to output percentage deviation from COSPAR values of density and pressure; 3 means use SI units, with density in kg/km^3 (suitable for high altitudes)

FLAT Latitude of initial point to simulate (degrees, North positive)

FLON Longitude of initial point to simulate (degrees, West positive if LonEW=0; East positive otherwise)

FHGT Height (km) of initial point to simulate above the reference ellipsoid; use FHGT ≤ -10. km to specify that surface altitude be used

MOLAhgts 1 for input heights relative to MOLA areoid, otherwise input heights are relative to old reference ellipsoid

hgtasfcm Height above surface (0-1000 m); use if FHGT ≤ -10. km

zoffset Height offset (km) for MTGCM data; zoffset < -19 means use daily value at local position to match MGCM data; > -19 and < -9 means use local position and current time to match MGCM data; > 17.5 and < 29 means use global MGCM-matchup values in file hgtoffst.dat; > 29 means use Ls-dependent height offset model. Use input value of zoffset if zoffset between -9 and 17.5 km. Offset > 0 increases pressure and density; offset < 0 decreases pressure and density.

DELHGT Height increment (km) between successive steps in an automatically generated profile (positive upward)

DELLAT Latitude increment (degrees, Northward positive) between successive steps in an automatically generated profile

DELLON Longitude increment (degrees, Westward positive if LonEW=0; Eastward positive otherwise) between successive steps in an automatically generated profile

DELTIME Time increment (seconds) between steps in an automatically generated profile

deltaTEX Additive adjustment to modify temperature (K) of the exosphere (asymptotic temperature approached at very high altitudes), nominal = 0

rpscale Multiplicative factor for density and wind perturbation magnitude (1 = nominal)

NMONTE Number of Monte Carlo runs during one execution of the program; new/different starting random numbers are automatically generated for each of the Monte Carlo profiles (or trajectories)

iup Option controlling output of LIST file and graphics output files (0 = none, other than 0 (default) indicates generate these files)

WaveA0 Mean term of longitude-dependent wave multiplier for density

WaveA1 Amplitude of wave-1 component of longitude-dependent wave multiplier for density

Wavephi1 Phase of wave-1 component of longitude-dependent wave multiplier (longitude, with West positive if LonEW = 0, East positive otherwise)

WaveA2 Amplitude of wave-2 component of longitude-dependent wave multiplier for density

Wavephi2 Phase of wave-2 component of longitude-dependent wave multiplier (longitude, with West positive if LonEW = 0, East positive otherwise)

WaveA3 Amplitude of wave-3 component of longitude-dependent wave multiplier for density

Wavephi3 Phase of wave-3 component of longitude-dependent wave multiplier (longitude, with West positive if LonEW = 0, East positive otherwise)

iuwave Unit number for (Optional) time-dependent wave coefficient data file "WaveFile" (or 0 for none); WaveFile contains time (sec) relative to start time, and wave model coefficients (WaveA0 through Wavephi3) from given time to next time in the data file

Wscale   Vertical scale (km) of longitude-dependent wave damping at altitudes below 100 km ($10 \leq$ Wscale $\leq 10\ 000$ km)

Four auxiliary input files are required (in addition to the MGCM and MTGCM input data files). Auxiliary file molatoph.txt contains ½-degree resolution topographic height data (height above MOLA areoid). File cospar2.dat contains COSPAR reference values of temperature, density, and pressure as a function of height. File hgtoffst.dat contains global values of MTGCM height offset versus Ls and dust optical depth. File albedo1.txt contains one-degree resolution surface albedo data. Before first use, ASCII format files molatoph.txt and albedo1.txt must be converted to binary with auxiliary programs readtopo.f and readalb.f, supplied with Mars-GRAM.

If the (pre-computed) trajectory mode is used (NPOS=0), trajectory data must be read from a file (whose name is specified by the input parameter TRAJFL). Each line of TRAJFL is a position and time for which to compute atmospheric parameters. TRAJFL input lines contain time (seconds, from initial time), height (km, relative to reference ellipsoid), latitude (degrees, North positive), and longitude (degrees, West positive if input switch LonEW=0, or East longitude if LonEW=1). For automatically-generated profiles, output is generated until the maximum number of positions (NPOS) is reached. For trajectory positions read in from TRAJFL file, output is generated until end of file is reached.

If time-dependent wave parameters (WaveA0 through Wavephi3) are desired, these are input from the file whose pathname is specified by parameter Wavefile on the NAMELIST format input file. Parameter iuwave determines whether time-dependent WaveFile values are read or not (iuwave = 0 mean no WaveFile data; otherwise iuwave is the WaveFile unit number). Each data line in the WaveFile file contains time (seconds) relative to start time, and wave model coefficients (WaveA0 through Wavephi3). Wave parameter values apply from the given time on each data line until the time given on the subsequent data line. Time-dependent wave parameters read in from WaveFile supercede any values given in the NAMELIST format input file. Appendix H gives wave files that reproduce observed density at periapsis of Mars Global Surveyor during both phase-1 and phase-2 aerobraking operations.

3.4 Program Output

There are three general types of program output: (1) a "LIST" file (name specified by LSTFL parameter) containing header and descriptor information, suitable for printing or viewing by an analyst (example LIST file in appendix C), (2) an "OUTPUT" file (name specified by OUTFL parameter) containing one header line and one line per output position, suitable for reading into another program for additional analysis (description in appendix A), and (3) a set of "plotable" output files, or graphics output files, i.e., text files suitable for input to a graphics program (descriptions in appendix A).

The graphics output files contain either x-y data pairs or x-y-z data triplets, determined by the selected values for the x-code (NVARX) and y-code (NVARY). If line-graph (x-y pair) data is the selected plot output option, then y-code = 0 is input. If contour plot (x-y-z triplet) data is the selected plot output option, then a non-zero value of y-code is input. Appendix A lists codes for x-code and y-code.

If the user desires to suppress the LIST, OUTPUT and graphics output files (so that output can be handled in a user-provided program), set LIST file unit number (iup) to 0 in the NAMELIST format input file. The unit number associated with the "screen" output (iu0 or iustdout), normally 6 in the stand alone version, can be set to any other value, by changing the assigned value of iustdout at program code line MGRM 21, and re-compiling the program.

4. Sample Results

4.1 New Mars-GRAM 2001 Output

Figure 4.1 illustrates a height-latitude cross section of density through a portion of the Valles Marineris region, a zone of rapidly varying topography. Dots in this figure show latitude dependence of MOLA half-degree-resolution surface altitude. Mars-GRAM density values below the topographic surface are evaluated assuming hydrostatic equilibrium and an isothermal temperature profile (with temperature equal to its surface value). MGCM atmospheric and surface data are available only every 7.5 degrees of latitude. However, because of the influence of higher resolution MOLA topography, horizontal interpolation, by methods discussed in section 2.2.3, introduces variations in density and other parameters at smaller scale than 7.5 degrees.

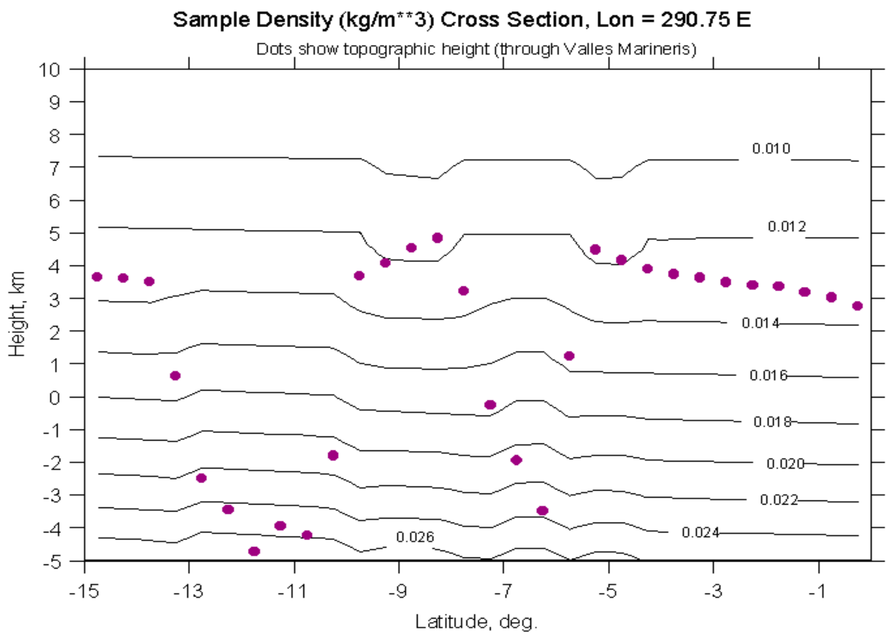

Figure 4.1. Height-latitude cross section of atmospheric density through a portion of Valles Marineris. Dots show height of MOLA ½-degree resolution topographic surface.

Ground surface temperature is a new input MGCM data field for Mars-GRAM 2001. Figures 4.2 and 4.3 illustrate the sharp differences that can exist between ground surface temperature and temperature at the first atmospheric level, five meters above the surface. In general, ground surface temperature is significantly higher than five-meter temperature near and just after solar noon, while the reverse holds true near and after solar midnight. At latitudes with polar ice on the surface, where carbon dioxide sublimation temperature has significant controlling influence, ground surface and five-meter temperatures are similar in value and have fairly small variation with time of day.

As discussed in section 2.6 and appendix G, Mars-GRAM 2001 profiles of temperature and pressure can be used in auxiliary program marsrad.f to compute various components of solar (shortwave) and thermal (longwave) radiation at the surface and top of atmosphere. Figure 4.4 shows an example

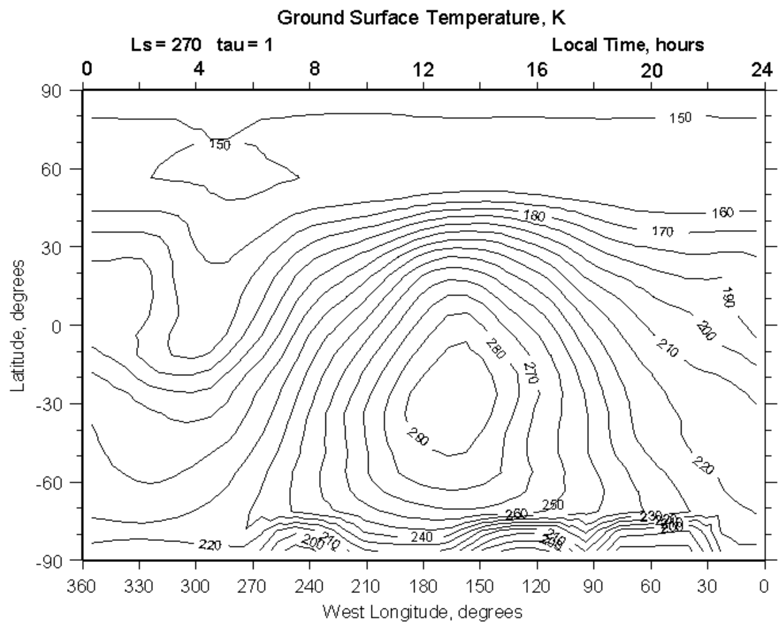

Figure 4.2. Latitude-longitude cross section of ground surface temperature at Ls = 270 degrees, dust optical depth 1.0. Local time is plotted across the top of the figure.

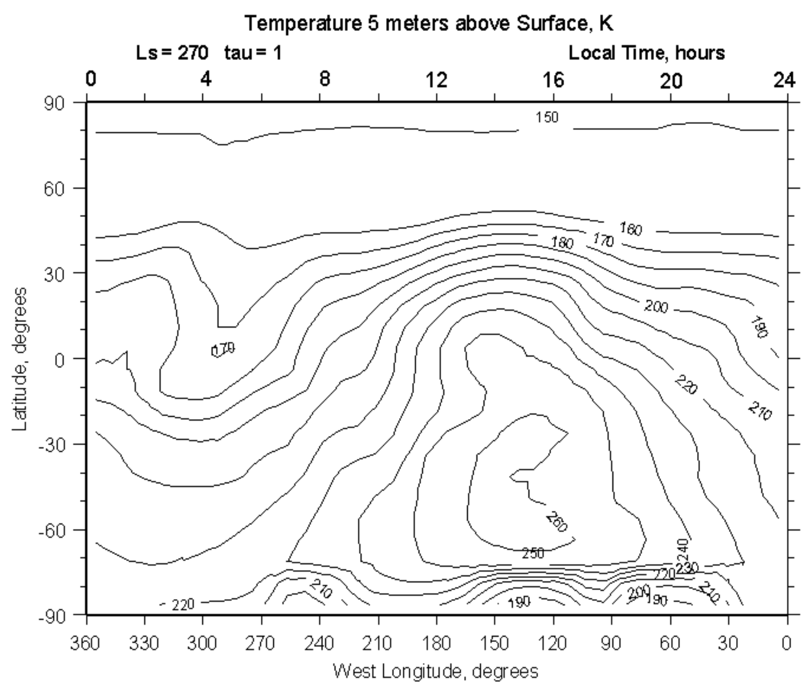

Figure 4.3. Latitude-longitude cross section of air temperature five meters above ground level at Ls = 270 degrees, dust optical depth 1.0. Local time is plotted across the top of the figure.

of downwelling longwave irradiance at the surface for the same conditions in figures 4.2 and 4.3. This figure plots downwelling longwave irradiance, L, expressed in terms of sky temperature, T_{sky}, defined by the relation

$$T_{sky} = (L / \sigma)^{1/4} \tag{4.1}$$

where σ is the Stefan-Boltzmann constant. Sky temperature is the effective radiative sink temperature that a surface system would experience for sky-facing surfaces. Although sky temperature depends on details of the temperature-pressure profile at each location, figure 4.4 shows a significant degree of correlation between T_{sky} and ground surface temperature and five-meter air temperature.

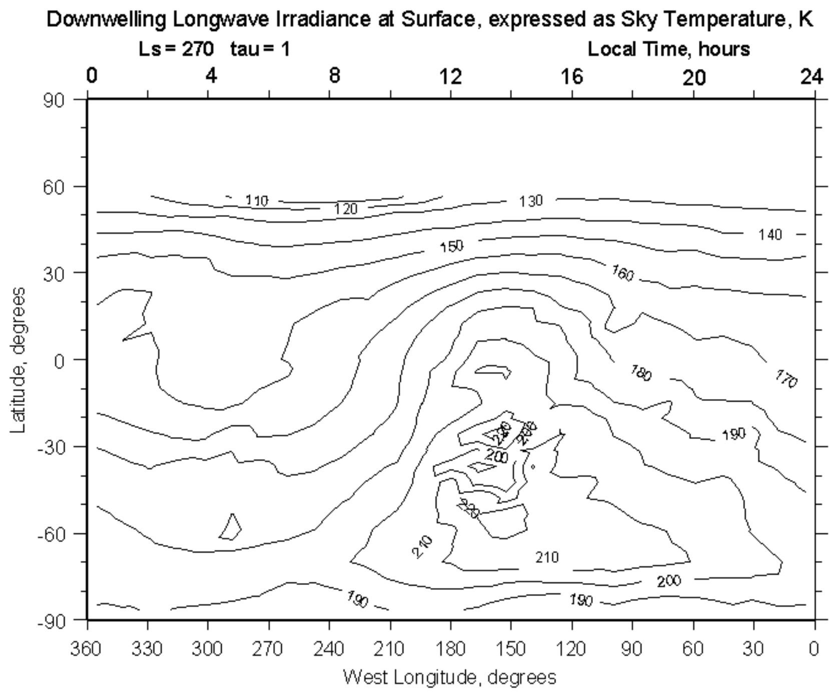

Figure 4.4. Latitude-longitude cross section of downwelling longwave irradiance at the surface, expressed as sky temperature, at Ls = 270 degrees, dust optical depth 1.0. Local time is plotted across the top of the figure.

4.2 Comparisons with Observations

The NASA Ames Mars General Circulation Model (MGCM) version that incorporated MOLA topography also underwent improvement in its surface parameterization, to better match seasonal variations in MTGCM surface pressure with Viking lander observations (R. M. Haberle, private communication). Figure 4.5 illustrates seasonal variation in surface pressure measured by Viking Lander 2 and compares this with Mars-GRAM (MGCM) daily average surface pressure under nominal conditions of dust optical depth (equation 2.18). Effects of two planetary-scale dust storms, one starting near Ls = 210 degrees and another starting near Ls = 280 degrees, are evident in the Viking observations (but not simulated in the Mars-GRAM results).

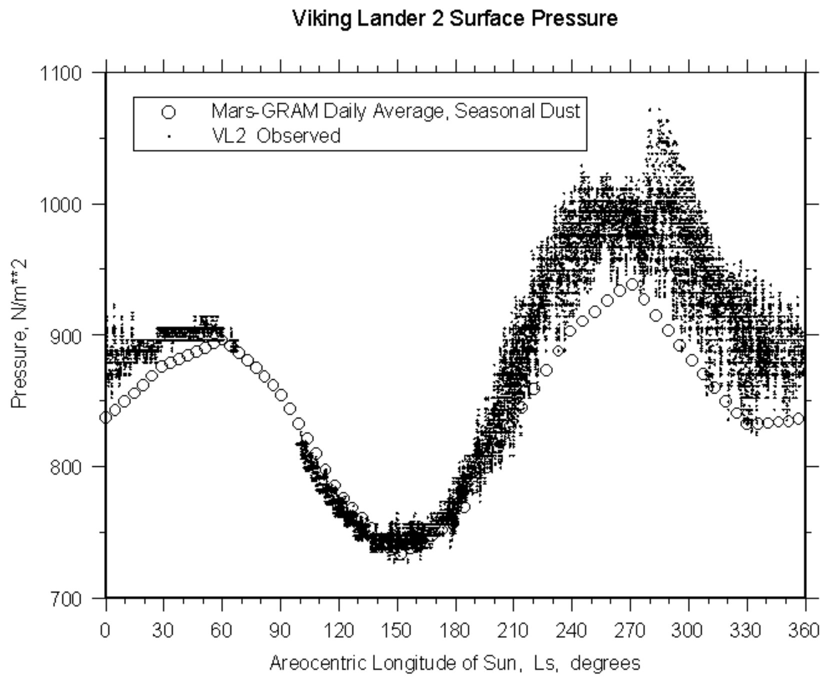

Figure 4.5. Seasonal variation of surface pressure measured by Viking Lander 2 and simulated by Mars-GRAM (MGCM) using nominal seasonal variation of dust optical depth (equation 2.18).

Figures 4.6 and 4.7 show comparisons of Mars-GRAM temperature and density with profiles derived from average Mars Global Surveyor Thermal Emission Spectrometer (TES) data,[30] compiled for Mars Exploration Rover (MER) landing site selection. Although Mars-GRAM/MGCM and MER/TES density agrees quite well near the surface, differences in Mars-GRAM/MGCM density and MER/TES density accumulate to about 30 percent near 30-km altitude. Note that an upward shift of Mars-GRAM/MGCM density at 30 km by about 2 km would bring it into line with MER/TES values and make it more consistent with pre-MOLA MTGCM values.

Atmospheric density at periapsis during Mars Global Surveyor (MGS) aerobraking, as measured by onboard accelerometer[19,21] is plotted in figures 4.8 and 4.9. Some variation of observed density is due to periapsis altitude changes, while additional variation is caused by strong longitude-dependent waves.[19,20,22] Figures 4.8 and 4.9 also show Mars-GRAM density at MGS periapsis, simulated using seasonal height offset (equation 2.17) and longitude-dependent wave coefficients described in appendix H.

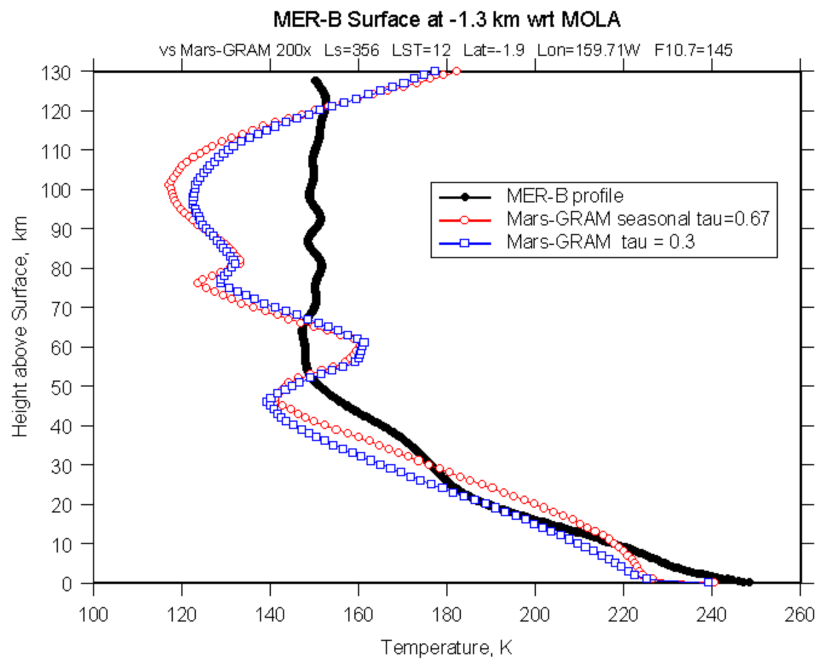

Figure 4.6. Mars-GRAM temperature profiles compared with average temperature profile derived from TES data for MER-B landing site selection studies.

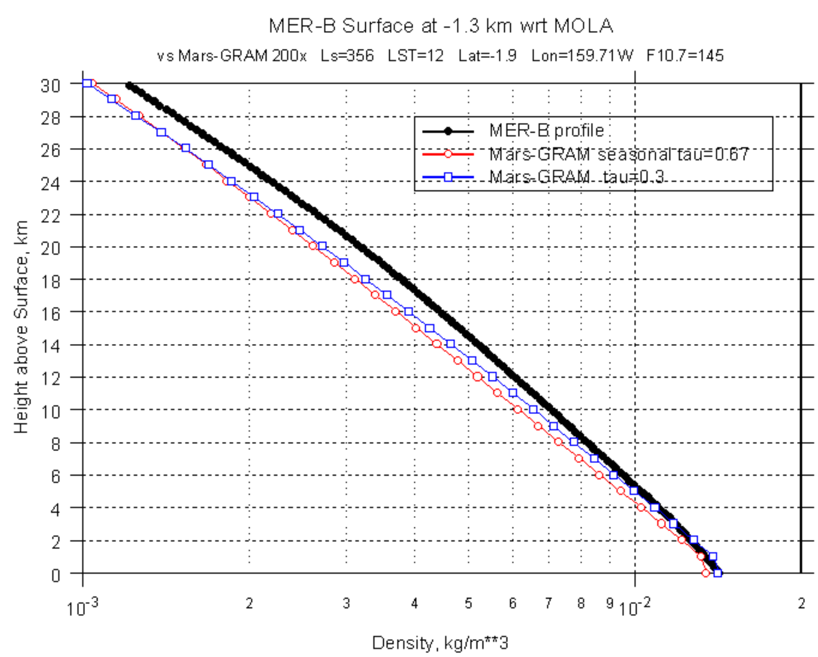

Figure 4.7. Mars-GRAM density profiles compared with average density profile derived from TES data for MER-B landing site selection studies.

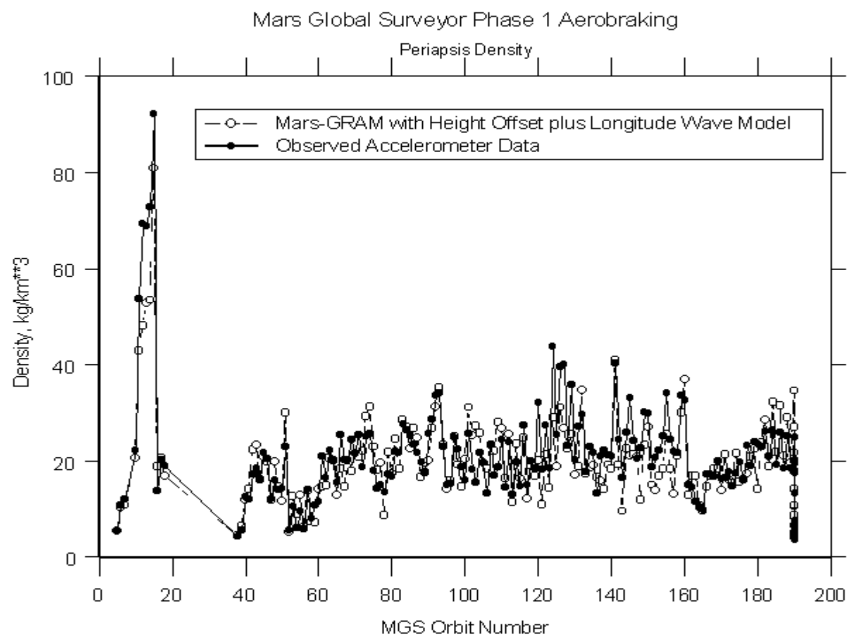

Figure 4.8. Atmospheric density at periapsis from Mars Global Surveyor accelerometer during phase-1 aerobraking and simulated by Mars-GRAM using seasonal height offset (equation 2.17) and longitude wave model (discussed in appendix H).

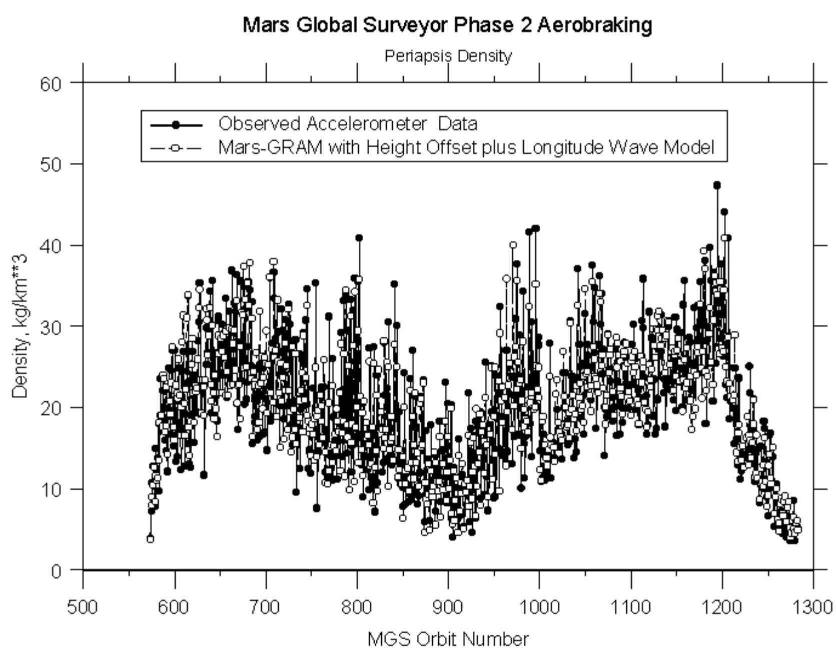

Figure 4.9. Atmospheric density at periapsis from Mars Global Surveyor accelerometer during phase-2 aerobraking and simulated by Mars-GRAM using seasonal height offset (equation 2.17) and longitude wave model (discussed in appendix H).

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Appendix A

Headers for Mars-GRAM 2001 Output Files

Mars-GRAM 2001 produces several output files suitable for passing to a graphics program for plotting and further analysis. Several of these files allow run-time selection from among several plotable parameters as the “X’ parameter in an X-Y graph, or the “X and Y” parameters in an X-Y-Z graph. See the list of parameter selection codes at the end of this appendix. The graphics output file names and their descriptive headers are:

File = Output.txt (or other name, as prescribed in the NAMELIST INPUT file)

Time = time after initial input time (sec)
Height = altitude above MOLA topography (km), or above ellipsoid
    if MOLAhgts is not 1, or altitude above MOLA surface
    if NVARX or NVARY = 2
Lat = latitude (degrees, North positive)
LonW/LonE = longitude (degrees, West positive or East Positive)
DensAV = average (mean plus wave-perturbed) density (kg/m^3 if
    LOGSCALE = 0, Log-10 if LOGSCALE = 1, % from COSPAR
    if LOGSCALE = 2, or kg/km^3 if LOGSCALE = 3)
Temp = average temperature (K)
EWind = eastward wind component (m/s, positive toward East)
NWind = northward wind component (m/s, positive toward North)
sigD = standard deviation for density perturbations (% of
    unperturbed mean)
Ls = areocentric longitude of Sun from Mars (degrees)
Dust = dust optical depth

File = DayData.txt (Daily averages for heights below 1.26 nbar level)

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
TempDay = Local daily average temperature (K)
PresDay = Local daily average pressure (N/m^2 or as prescribed by
    LOGSCALE)
DensDay = Local daily average density (kg/m^3 or as prescribed by
    LOGSCALE)
EWwnDay = Local daily average Eastward wind (m/s)
NSwnDay = Local daily average Northward wind (m/s)
Tempmin = Local daily minimum temperature (K)
Tempmax = Local daily maximum temperature (K)
Densmin = Local daily minimum density (kg/m^3 or as prescribed by
    LOGSCALE)
Densmax = Local daily maximum density (kg/m^3 or as prescribed by
    LOGSCALE)

File = Density.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
DENSLO = low (~ average - 1 standard deviation) density (kg/m^3 or Log-10 or % from COSPAR or kg/km^3, as controlled by LOGSCALE)
DENSAV = average (mean plus wave-perturbed) density (kg/m^3 or Log-10 or % from COSPAR, or kg/km^3, as controlled by LOGSCALE)
DENSHI = high (~ average + 1 standard deviation) density (kg/m^3 or Log-10 or % from COSPAR, or kg/km^3, as controlled by LOGSCALE)
DENSTOT = total (mean plus perturbed) density (kg/m^3 or Log-10 or % from COSPAR, or kg/km^3, as controlled by LOGSCALE)
DustOD = dust optical depth
Radius = Radial distance from planetary center of mass to spacecraft position (areoid radius plus altitude)
Grav = local acceleration of gravity (m/s^2)
RadAU = Mars orbital radius (Astronomical Units)

File = MarsRad.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
alb = surface albedo (ratio upward/downward SW radiation at surface)
mu0 = cosine of solar zenith angle
Dareaden = dust column areal density (kg/m^2)
Dmixrat = dust mixing ratio (kg dust / kg air)
Dmasden = dust mass density (micrograms dust / m^3)
Dnumden = dust number density (number dust particles / m^3)
Ice = surface polar ice indicator (0 = no, 1 = yes)

File = Perturb.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
SigD = standard deviation of density perturbations (% of unperturbed mean)
DensRand = density perturbation from random model (% of unperturbed mean)
DensWave = density perturbation from wave model (% of unperturbed mean)
DensP = total density perturbation value (% of unperturbed mean)
corlim = fraction of minimum step size for accuracy of perturbations (should be > 1 for insured accuracy of perturbations)
SigU = standard deviation of wind perturbations (m/s)

File = ThrmData.txt (Thermospheric parameters for heights above 80 km)

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
Tbase = temperature at 1.26 nbar level (K)
Zbase = altitude of 1.26 nbar level (km)
F1peak = altitude of F1 ionization peak (km)
MolWgt = mean molecular weight (kg/kg.mole)
Texos = exospheric temperature (K)
hgtoffset = height offset for thermospheric (MTGCM) data (km)

File = TPresHgt.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
Temp = mean temperature (K)
Pres = mean (plus wave-perturbed) pressure (N/m^2, or as controlled by LOGSCALE)
TdegC = mean temperature (degrees C)
Pres_mb = mean (plus wave-perturbed) pressure (mb)
Hrho = density scale height (km)
TerHgt = altitude of local surface above MOLA 1/2-degree areoid
Tgrnd = ground surface temperature (K)
Areoid = local radius (km) of MOLA 1/2-degree areoid
dAreoid = MOLA areoid minus radius of old reference ellipsoid (km); (equal to height from old ellipsoid minus height from MOLA areoid)

File = Winds.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
EWmean = mean eastward wind component (m/s, positive eastward)
EWpert = eastward wind perturbation (m/s)
EWtot = total (mean plus perturbed) eastward wind (m/s)
NSmean = mean northward wind component (m/s, positive northward)
NSpert = northward wind perturbation (m/s)
NStot = total (mean plus perturbed) northward wind (m/s)

Model input codes used to select the plotable x and y parameters (Var_X and Var_Y) are as follows:

Code	Parameter
1	Height (above local MOLA areoid, km)
2	Height (above local MOLA topographic surface, km)
3	Latitude (deg.)
4	Longitude (deg.) West+ if LonEW = 0, East+ if LonEW = 1
5	Time from start (Earth seconds)
6	Time from start (Martian Sols)
7	Areocentric Longitude of Sun, Ls (deg.)
8	Local Solar Time (Mars hours)
9	Pressure (mb)
10	Pressure Height [-log(Pres/PresSurf) = -log(sigma)]
11	Sigma coordinate [sigma = Pressure/(Pressure at Surface)]
12	Height (km) above old reference ellipsoid

Run-time selection of these plotable parameters is made by the input variables NVARX and NVARY on the NAMELIST format input file (see section 3.3 and appendix B).

Appendix B

Example NAMELIST Format Input File

Following is an example of the NAMELIST format input file required by Mars-GRAM 2001. Values given are the default values assigned by the program. Only values that differ from the defaults actually have to be included in the NAMELIST file.

```
 $INPUT
  LSTFL    = 'LIST.txt'
  OUTFL    = 'OUTPUT.txt'
  TRAJFL   = 'TRAJDATA.txt'
  WaveFile = 'null'
  DATADIR  = 'C:\Mars\Mars2001\MGbindat\'
  GCMDIR   = 'C:\Mars\Mars2001\MGbindat\'
  MONTH    = 7
  MDAY     = 20
  MYEAR    = 76
  NPOS     = 41
  IHR      = 12
  IMIN     = 30
  SEC      = 0.0
  LonEW    = 0
  Dusttau  = 0.3
  Dustnu   = 0.003
  Dustdiam = 5.0
  Dustdens = 3000.
  ALS0     = 0.0
  ALSDUR   = 48.
  INTENS   = 0.0
  RADMAX   = 0.0
  DUSTLAT  = 0.0
  DUSTLON  = 0.0
  F107     = 68.0
  STDL     = 0.0
  NR1      = 1234
  NVARX    = 1
  NVARY    = 0
  LOGSCALE = 0
  FLAT     = 22.48
  FLON     = 47.97
  FHGT     = -5.
  MOLAhgts = 1
  hgtasfcm = 0.
  zoffset  = 20.
  DELHGT   = 5.0
  DELLAT   = 0.5
  DELLON   = 0.5
  DELTIME  = 500.0
  deltaTEX = 0.0
  rpscale  = 1.0
  NMONTE   = 1
  iup      = 13
  WaveA0   = 1.0
  WaveA1   = 0.0
  Wavephi1 = 0.0
  WaveA2   = 0.0
  Wavephi2 = 0.0
  WaveA3   = 0.0
  Wavephi3 = 0.0
```

```
 iuwave   = 0
 Wscale   = 20.
$END

Explanation of variables:
LSTFL    =  List file name (CON for console listing)
OUTFL    =  Output file name
TRAJFL   =  (Optional) Trajectory input file. File contains time (sec)
             relative to start time, height (km), latitude (deg),
             longitude (deg W if LonEW=0, deg E if LonEW=1, see below)
WaveFile =  (Optional) file for time-dependent wave coefficient data.
             See file description under parameter iuwave, below.
DATADIR  =  Directory for COSPAR data and topographic height data
GCMDIR   =  Directory for GCM binary data files
MONTH    =  (Integer) month of year
MDAY     =  (Integer) day of month
MYEAR    =  (Integer) year (4-digit; 1970-2069 can be 2-digit)
NPOS     =  max # positions to evaluate (0 = read data from trajectory
             input file)
IHR      =  (Integer) UTC (GMT) hour of day
IMIN     =  (Integer) minute of hour
SEC      =  second of minute (for initial position)
LonEW    =  0 for input and output West longitudes positive; 1 for East
             longitudes positive
Dusttau  =  Optical depth of background dust level (no time-developing
             dust storm, just uniformly mixed dust), 0.1 to 3.0, or use
             0 for a Viking-like annual variation of background dust
Dustnu   =  Parameter for vertical distribution of dust density (Haberle
             et al., J. Geophys. Res., 104, 8957, 1999)
Dustdiam =  Dust particle diameter (micrometers, assumed monodisperse)
Dustdens =  Dust particle density (kg/m^3)
ALS0     =  starting Ls value (degrees) for dust storm (0 = none)
ALSDUR   =  duration (in Ls degrees) for dust storm (default = 48)
INTENS   =  dust storm intensity (0.0 - 3.0)
RADMAX   =  max. radius (km) of dust storm (0 or >10000 = global)
DUSTLAT  =  Latitude (degrees) for center of dust storm
DUSTLON  =  Longitude (degrees) (West positive if LonEW=0, or East
             positive if LonEW = 1) for center of dust storm
F107     =  10.7 cm solar flux (10^-22 W/cm^2 at 1 AU)
STDL     =  std. dev. for thermosphere variation (-3.0 to +3.0)
NR1      =  starting random number (0 < NR1 < 30000)
NVARX    =  x-code for plotable output (1=hgt above MOLA areoid).
             See file xycodes.txt
NVARY    =  y-code for 3-D plotable output (0 for 2-D plots)
LOGSCALE =  0=regular SI units, 1=log-base-10 scale, 2=percentage
             deviations from COSPAR model, 3=SI units, with density
             in kg/km^3 (suitable for high altitudes)
FLAT     =  initial latitude (N positive), degrees
FLON     =  initial longitude (West positive if LowEW = 0 or East
             positive if LonEW = 1), degrees
FHGT     =  initial height (km); ≤ -10 means evaluate at surface height
MOLAhgts =  1 for input heights relative to MOLA areoid, otherwise
            input heights are relative to old reference ellipsoid
hgtasfcm =  height above surface (0-1000 m); use if FHGT ≤ -10. km
zoffset  =  height offset (km) for MTGCM data; zoffset < -19 means
            use daily value at local position to match MGCM data; > -19
            and < -9 means use local position and current time to match
            MGCM data; > 17.5 and < 29 means use global MGCM-matchup
            values in file hgtoffst.dat; > 29 means use Ls-dependent
            height offset model. Use input value of zoffset if zoffset
            between -9 and 17.5 km.  Offset > 0 increases pressure and
            density; offset < 0 decreases pressure and density.
DELHGT   =  height increment (km) between steps
DELLAT   =  Latitude increment (deg) between steps (Northward positive)
DELLON   =  Longitude increment (deg) between steps (Westward positive
             if LonEW = 0, Eastward positive if LonEW = 1)
```

```
DELTIME  =  time increment (sec) between steps
deltaTEX =  adjustment for exospheric temperature (K)
rpscale  =  random perturbation scale factor (0-2)
NMONTE   =  number of Monte Carlo runs
iup      =  0 for no LIST and graphics output, or unit number for output
WaveA0   =  Mean term of longitude-dependent wave multiplier for density
WaveA1   =  Amplitude of wave-1 component of longitude-dependent wave
             multiplier for density
Wavephi1 =  Phase of wave-1 component of longitude-dependent wave
             multiplier (longitude, with West positive if LonEW = 0,
             East positive if LonEW = 1)
WaveA2   =  Amplitude of wave-2 component of longitude-dependent wave
             multiplier for density
Wavephi2 =  Phase of wave-2 component of longitude-dependent wave
             multiplier (longitude, with West positive if LonEW = 0,
             East positive if LonEW = 1)
WaveA3   =  Amplitude of wave-3 component of longitude-dependent wave
             multiplier for density
Wavephi3 =  Phase of wave-3 component of longitude-dependent wave
             multiplier (longitude, with West positive if LonEW = 0,
             East positive if LonEW = 1)
iuwave   =  Unit number for (Optional) time-dependent wave coefficient
             data file "WaveFile" (or 0 for none).
             WaveFile contains time (sec) relative to start time, and
             wave model coefficients (WaveA0 thru Wavephi3) from the
             given time to the next time in the data file.
Wscale   =  Vertical scale (km) of longitude-dependent wave damping
             at altitudes below 100 km (10≤Wscale≤10,000 km)
```

Appendix C

Sample Output LIST File

Following is LIST file output produced by standard input parameters given in appendix B. Standard input is also provided to users (along with the program code and other data files) as file "input.std". Output data given here are provided as file "list2001.txt". Availability of these files allows users to make a test run after compiling Mars-GRAM on their own machine, and to electronically check their output by a file-compare process (e.g. the "diff" command in UNIX or the "fc" command in DOS). Note that, due to machine-dependent or compiler-dependent rounding differences, some output values may differ slightly from those shown here. These differences are usually no more than one unit in the last significant digit displayed. As shown here, the listing gives numbers in the DOS convention of not displaying zero-valued leading digits before the decimal place. Leading zeroes are given in the UNIX version of list2001.txt provided. If necessary for performing the output test, changes from UNIX format to DOS format can be accomplished with an editing program (e.g. changing all character strings "_0." to "__." and changing all "-0." to "_ -.", where "_" indicates a blank space)

```
Mars-GRAM 2001 (Version 1) - May, 2001
LIST file= LIST.txt        OUTPUT file= OUTPUT.txt
Data directory= C:\Mars\Mars2001\MGbindat\
GCM  directory= C:\Mars\Mars2001\MGbindat\
Date =  7/20/1976  Julian Date = 2442980.0  UTC Time = 12:30:  .0
Input heights are relative to MOLA areoid
MTGCM Height offset from file hgtoffst.dat
F10.7 flux =  68.0 (1 AU)   25.0 (Mars),  standard deviation =   .0
Dustnu =  .0030   Dustdiam =  5.00 E-6 meters   Dustdens =  3000.0 kg/m**3
  Random seed =  1234   Scale factor = 1.0
A0,A1,phi1,A2,phi2,A3,phi3= 1.000  .000     .0  .000     .0  .000     .0
  Wave Scale =    20.0 km.    Wave phases are in degrees of West Longitude
Time (rel. to T0) =        .0 sec. (    .000 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  -5.000 km (  -1.365 km)
Topographic Height =   -3.635 km   Radius (Areoid) = 3387.949 (3392.949) km
Hgt Above Ellipsoid =  -3.466 km   Scale Hgt H(p) = 11.43 H(rho) = 13.08 km
Latitude =   22.48  degrees        Longitude =   47.97 W ( 312.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.       Local Time =  16.05 Mars hours
Temperature =   241.8 K            Pressure =    8.630E+02 N/m**2
Density (Low, Avg., High) =      1.852E-02   1.890E-02   1.928E-02 kg/m**3
Departure, COSPAR NH Mean =       -24.4 %     -22.9 %     -21.3 %
Tot.Dens. = 1.885E-02 kg/m**3   Dens.Pert. =   -.24% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =      .0    2.1    2.1 m/s
Northward Wind (Mean, Perturbed, Total) =      .0   -1.4   -1.4 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =     500.0 sec. (    .006 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =    .000 km (   3.605 km)
Topographic Height =   -3.605 km   Radius (Areoid) = 3392.848 (3392.848) km
Hgt Above Ellipsoid =   1.540 km   Scale Hgt H(p) = 11.36 H(rho) = 13.69 km
Latitude =   22.98  degrees        Longitude =   48.47 W ( 311.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  110.80 deg.       Local Time =  16.16 Mars hours
Temperature =   227.5 K            Pressure =    5.574E+02 N/m**2
Density (Low, Avg., High) =      1.271E-02   1.297E-02   1.323E-02 kg/m**3
Departure, COSPAR NH Mean =       -18.0 %     -16.3 %     -14.6 %
Tot.Dens. = 1.293E-02 kg/m**3   Dens.Pert. =   -.34% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     3.7    -.9    2.8 m/s
Northward Wind (Mean, Perturbed, Total) =    -7.7    1.1   -6.5 m/s
```

```
----------------------------------------------------------------------------
Time (rel. to T0) =    1000.0 sec. (    .011 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =   5.000 km (   8.573 km)
Topographic Height =   -3.573 km   Radius (Areoid) = 3397.744 (3392.744) km
Hgt Above Ellipsoid =   6.546 km   Scale Hgt H(p) = 10.31 H(rho) = 11.78 km
Latitude =   23.48  degrees        Longitude =   48.97 W ( 311.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  112.83 deg.       Local Time =  16.26 Mars hours
Temperature =   211.0 K            Pressure =    3.589E+02 N/m**2
Density (Low, Avg., High) =      8.820E-03   9.000E-03   9.180E-03 kg/m**3
Departure, COSPAR NH Mean =       -10.9 %      -9.1 %      -7.3 %
Tot.Dens. = 9.233E-03 kg/m**3   Dens.Pert. =   2.59% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     2.6   -2.2     .4 m/s
Northward Wind (Mean, Perturbed, Total) =     3.0   -1.6    1.4 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    1500.0 sec. (    .017 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  10.000 km (  13.557 km)
Topographic Height =   -3.557 km   Radius (Areoid) = 3402.638 (3392.638) km
Hgt Above Ellipsoid =  11.551 km   Scale Hgt H(p) =  9.78 H(rho) = 10.98 km
Latitude =   23.98  degrees        Longitude =   49.47 W ( 310.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  114.86 deg.       Local Time =  16.36 Mars hours
Temperature =   198.7 K            Pressure =    2.210E+02 N/m**2
Density (Low, Avg., High) =      5.751E-03   5.884E-03   6.017E-03 kg/m**3
Departure, COSPAR NH Mean =       -11.1 %      -9.1 %      -7.0 %
Tot.Dens. = 5.684E-03 kg/m**3   Dens.Pert. =  -3.39% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -16.4   -2.1  -18.5 m/s
Northward Wind (Mean, Perturbed, Total) =     9.5    1.2   10.7 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    2000.0 sec. (    .023 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  15.000 km (  18.575 km)
Topographic Height =   -3.575 km   Radius (Areoid) = 3407.529 (3392.529) km
Hgt Above Ellipsoid =  16.554 km   Scale Hgt H(p) =  9.28 H(rho) = 10.38 km
Latitude =   24.48  degrees        Longitude =   49.97 W ( 310.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  116.89 deg.       Local Time =  16.46 Mars hours
Temperature =   188.3 K            Pressure =    1.327E+02 N/m**2
Density (Low, Avg., High) =      3.633E-03   3.729E-03   3.824E-03 kg/m**3
Departure, COSPAR NH Mean =       -12.9 %     -10.6 %      -8.3 %
Tot.Dens. = 3.674E-03 kg/m**3   Dens.Pert. =  -1.46% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -19.7     .0  -19.7 m/s
Northward Wind (Mean, Perturbed, Total) =    10.8    -.5   10.2 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    2500.0 sec. (    .028 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  20.000 km (  23.623 km)
Topographic Height =   -3.623 km   Radius (Areoid) = 3412.417 (3392.417) km
Hgt Above Ellipsoid =  21.557 km   Scale Hgt H(p) =  8.78 H(rho) =  9.82 km
Latitude =   24.98  degrees        Longitude =   50.47 W ( 309.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  118.91 deg.       Local Time =  16.56 Mars hours
Temperature =   178.1 K            Pressure =    7.756E+01 N/m**2
Density (Low, Avg., High) =      2.237E-03   2.303E-03   2.370E-03 kg/m**3
Departure, COSPAR NH Mean =       -14.9 %     -12.4 %      -9.9 %
Tot.Dens. = 2.342E-03 kg/m**3   Dens.Pert. =   1.69% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -30.6   -3.6  -34.2 m/s
Northward Wind (Mean, Perturbed, Total) =     8.2     .3    8.5 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    3000.0 sec. (    .034 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  25.000 km (  28.481 km)
Topographic Height =   -3.481 km   Radius (Areoid) = 3417.302 (3392.302) km
Hgt Above Ellipsoid =  26.558 km   Scale Hgt H(p) =  8.31 H(rho) =  9.39 km
Latitude =   25.48  degrees        Longitude =   50.97 W ( 309.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  120.94 deg.       Local Time =  16.66 Mars hours
Temperature =   168.0 K            Pressure =    4.400E+01 N/m**2
Density (Low, Avg., High) =      1.340E-03   1.386E-03   1.431E-03 kg/m**3
Departure, COSPAR NH Mean =       -17.3 %     -14.5 %     -11.6 %
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Tot.Dens. = 1.310E-03 kg/m**3   Dens.Pert. =  -5.43% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -42.1    -.2  -42.3 m/s
Northward Wind (Mean, Perturbed, Total) =     9.5    6.9   16.4 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    3500.0 sec. (    .039 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  30.000 km (  33.372 km)
Topographic Height =   -3.372 km   Radius (Areoid) = 3422.185 (3392.185) km
Hgt Above Ellipsoid =  31.558 km   Scale Hgt H(p) =  7.85 H(rho) =  8.53 km
Latitude =   25.98  degrees        Longitude =   51.47 W ( 308.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  122.97 deg.       Local Time =  16.77 Mars hours
Temperature =   157.1 K            Pressure =    2.420E+01 N/m**2
Density (Low, Avg., High) =      7.840E-04   8.147E-04   8.453E-04 kg/m**3
Departure, COSPAR NH Mean =       -20.0 %     -16.9 %     -13.7 %
Tot.Dens. = 8.290E-04 kg/m**3   Dens.Pert. =   1.76% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -60.3    -.3  -60.5 m/s
Northward Wind (Mean, Perturbed, Total) =    -4.6   -5.2   -9.8 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    4000.0 sec. (    .045 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  35.000 km (  38.590 km)
Topographic Height =   -3.590 km   Radius (Areoid) = 3427.066 (3392.066) km
Hgt Above Ellipsoid =  36.559 km   Scale Hgt H(p) =  7.47 H(rho) =  8.35 km
Latitude =   26.48  degrees        Longitude =   51.97 W ( 308.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  125.00 deg.       Local Time =  16.87 Mars hours
Temperature =   149.4 K            Pressure =    1.286E+01 N/m**2
Density (Low, Avg., High) =      4.363E-04   4.555E-04   4.747E-04 kg/m**3
Departure, COSPAR NH Mean =       -25.0 %     -21.7 %     -18.4 %
Tot.Dens. = 4.474E-04 kg/m**3   Dens.Pert. =  -1.79% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -84.4   -1.0  -85.4 m/s
Northward Wind (Mean, Perturbed, Total) =   -14.5    3.1  -11.4 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    4500.0 sec. (    .051 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  40.000 km (  43.650 km)
Topographic Height =   -3.650 km   Radius (Areoid) = 3431.946 (3391.946) km
Hgt Above Ellipsoid =  41.560 km   Scale Hgt H(p) =  7.10 H(rho) =  7.59 km
Latitude =   26.98  degrees        Longitude =   52.47 W ( 307.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  127.02 deg.       Local Time =  16.97 Mars hours
Temperature =   139.3 K            Pressure =    6.626E+00 N/m**2
Density (Low, Avg., High) =      2.396E-04   2.516E-04   2.636E-04 kg/m**3
Departure, COSPAR NH Mean =       -29.5 %     -26.0 %     -22.5 %
Tot.Dens. = 2.668E-04 kg/m**3   Dens.Pert. =   6.05% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -99.5    7.0  -92.5 m/s
Northward Wind (Mean, Perturbed, Total) =    -9.0   -6.4  -15.4 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    5000.0 sec. (    .056 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  45.000 km (  48.636 km)
Topographic Height =   -3.636 km   Radius (Areoid) = 3436.826 (3391.826) km
Hgt Above Ellipsoid =  46.562 km   Scale Hgt H(p) =  6.69 H(rho) =  6.76 km
Latitude =   27.48  degrees        Longitude =   52.97 W ( 307.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  129.05 deg.       Local Time =  17.07 Mars hours
Temperature =   133.2 K            Pressure =    3.297E+00 N/m**2
Density (Low, Avg., High) =      1.239E-04   1.310E-04   1.381E-04 kg/m**3
Departure, COSPAR NH Mean =       -36.1 %     -32.5 %     -28.8 %
Tot.Dens. = 1.249E-04 kg/m**3   Dens.Pert. =  -4.64% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -130.0    6.1 -123.9 m/s
Northward Wind (Mean, Perturbed, Total) =   -12.8   -1.2  -13.9 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    5500.0 sec. (    .062 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  50.000 km (  53.500 km)
Topographic Height =   -3.500 km   Radius (Areoid) = 3441.706 (3391.706) km
Hgt Above Ellipsoid =  51.566 km   Scale Hgt H(p) =  6.83 H(rho) =  6.33 km
Latitude =   27.98  degrees        Longitude =   53.47 W ( 306.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  131.08 deg.       Local Time =  17.17 Mars hours
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Temperature =   132.4 K            Pressure =    1.572E+00 N/m**2
Density (Low, Avg., High) =      5.900E-05   6.287E-05   6.675E-05 kg/m**3
Departure, COSPAR NH Mean =       -45.4 %     -41.8 %     -38.2 %
Tot.Dens. = 5.984E-05 kg/m**3   Dens.Pert. =  -4.83% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -130.1    6.6 -123.5 m/s
Northward Wind (Mean, Perturbed, Total) =    12.2    5.5   17.7 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =    6000.0 sec. (    .068 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  55.000 km (  58.260 km)
Topographic Height =   -3.260 km   Radius (Areoid) = 3446.587 (3391.587) km
Hgt Above Ellipsoid =  56.572 km   Scale Hgt H(p) =  7.29 H(rho) =  6.86 km
Latitude =   28.48  degrees        Longitude =   53.97 W ( 306.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  133.11 deg.       Local Time =  17.28 Mars hours
Temperature =   140.4 K            Pressure =    7.612E-01 N/m**2
Density (Low, Avg., High) =      2.671E-05   2.874E-05   3.077E-05 kg/m**3
Departure, COSPAR NH Mean =       -54.9 %     -51.4 %     -48.0 %
Tot.Dens. = 2.766E-05 kg/m**3   Dens.Pert. =  -3.77% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -68.2  -12.2  -80.3 m/s
Northward Wind (Mean, Perturbed, Total) =    -1.9   -4.9   -6.8 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =    6500.0 sec. (    .073 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  60.000 km (  63.046 km)
Topographic Height =   -3.046 km   Radius (Areoid) = 3451.467 (3391.467) km
Hgt Above Ellipsoid =  61.579 km   Scale Hgt H(p) =  7.42 H(rho) =  7.38 km
Latitude =   28.98  degrees        Longitude =   54.47 W ( 305.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  135.13 deg.       Local Time =  17.38 Mars hours
Temperature =   146.6 K            Pressure =    3.859E-01 N/m**2
Density (Low, Avg., High) =      1.283E-05   1.396E-05   1.509E-05 kg/m**3
Departure, COSPAR NH Mean =       -59.6 %     -56.1 %     -52.6 %
Tot.Dens. = 1.295E-05 kg/m**3   Dens.Pert. =  -7.20% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -45.8   -3.0  -48.8 m/s
Northward Wind (Mean, Perturbed, Total) =   -12.6  -12.2  -24.9 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =    7000.0 sec. (    .079 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  65.000 km (  68.250 km)
Topographic Height =   -3.250 km   Radius (Areoid) = 3456.348 (3391.348) km
Hgt Above Ellipsoid =  66.588 km   Scale Hgt H(p) =  7.25 H(rho) =  7.39 km
Latitude =   29.48  degrees        Longitude =   54.97 W ( 305.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  137.16 deg.       Local Time =  17.48 Mars hours
Temperature =   147.0 K            Pressure =    1.981E-01 N/m**2
Density (Low, Avg., High) =      6.493E-06   7.140E-06   7.787E-06 kg/m**3
Departure, COSPAR NH Mean =       -61.4 %     -57.5 %     -53.6 %
Tot.Dens. = 7.190E-06 kg/m**3   Dens.Pert. =    .71% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -29.5     .0  -29.4 m/s
Northward Wind (Mean, Perturbed, Total) =   -23.1   -9.9  -33.0 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =    7500.0 sec. (    .084 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  70.000 km (  73.231 km)
Topographic Height =   -3.231 km   Radius (Areoid) = 3461.228 (3391.228) km
Hgt Above Ellipsoid =  71.598 km   Scale Hgt H(p) =  7.15 H(rho) =  7.37 km
Latitude =   29.98  degrees        Longitude =   55.47 W ( 304.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  139.19 deg.       Local Time =  17.58 Mars hours
Temperature =   144.6 K            Pressure =    9.993E-02 N/m**2
Density (Low, Avg., High) =      3.280E-06   3.656E-06   4.032E-06 kg/m**3
Departure, COSPAR NH Mean =       -62.4 %     -58.1 %     -53.8 %
Tot.Dens. = 3.701E-06 kg/m**3   Dens.Pert. =   1.25% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -48.9     .4  -48.5 m/s
Northward Wind (Mean, Perturbed, Total) =   -39.1    8.4  -30.7 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =    8000.0 sec. (    .090 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  75.000 km (  77.918 km)
Topographic Height =   -2.918 km   Radius (Areoid) = 3466.107 (3391.107) km
Hgt Above Ellipsoid =  76.608 km   Scale Hgt H(p) =  4.92 H(rho) =  5.43 km
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Latitude =   30.48  degrees        Longitude =   55.97 W ( 304.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  141.22 deg.       Local Time =  17.68 Mars hours
Temperature =   141.2 K            Pressure =    4.997E-02 N/m**2
Density (Low, Avg., High) =      1.647E-06   1.868E-06   2.088E-06 kg/m**3
Departure, COSPAR NH Mean =       -63.2 %     -58.2 %     -53.3 %
Tot.Dens. = 1.819E-06 kg/m**3   Dens.Pert. =  -2.62% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -48.0  -36.0  -84.0 m/s
Northward Wind (Mean, Perturbed, Total) =   -19.0   -7.4  -26.4 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    8500.0 sec. (    .096 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  80.000 km (  82.583 km)
Topographic Height =   -2.583 km   Radius (Areoid) = 3470.986 (3390.986) km
Hgt Above Ellipsoid =  81.618 km   Scale Hgt H(p) =  6.98 H(rho) =  7.16 km
Latitude =   30.98  degrees        Longitude =   56.47 W ( 303.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  143.25 deg.       Local Time =  17.79 Mars hours
Temperature =   128.1 K            Pressure =    2.185E-02 N/m**2
Density (Low, Avg., High) =      7.390E-07   8.553E-07   9.716E-07 kg/m**3
Departure, COSPAR NH Mean =       -67.7 %     -62.7 %     -57.6 %
Tot.Dens. = 8.519E-07 kg/m**3   Dens.Pert. =   -.39% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     8.3  -53.1  -44.9 m/s
Northward Wind (Mean, Perturbed, Total) =    -7.3    5.9   -1.5 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    9000.0 sec. (    .101 sols)  Ls =  97.0  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  85.000 km (  87.207 km)
Topographic Height =   -2.207 km   Radius (Areoid) = 3475.862 (3390.862) km
Hgt Above Ellipsoid =  86.627 km   Scale Hgt H(p) =  6.81 H(rho) =  6.99 km
Latitude =   31.48  degrees        Longitude =   56.97 W ( 303.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  145.27 deg.       Local Time =  17.89 Mars hours
Exospheric Temp. =  206.0 K        Tbase =  146.8 K    Zbase =  116.5 km
Solar Zenith Angle =  75.9 deg     F1 peak = 127.3 km    Mol.Wgt. = 41.67
Temperature =   125.9 K            Pressure =    1.062E-02 N/m**2
Density (Low, Avg., High) =      3.566E-07   4.228E-07   4.890E-07 kg/m**3
Departure, COSPAR NH Mean =       -69.5 %     -63.9 %     -58.2 %
Tot.Dens. = 4.504E-07 kg/m**3   Dens.Pert. =   6.54% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     8.9  -26.3  -17.4 m/s
Northward Wind (Mean, Perturbed, Total) =   -11.8   -6.2  -18.1 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    9500.0 sec. (    .107 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  90.000 km (  91.092 km)
Topographic Height =   -1.092 km   Radius (Areoid) = 3480.736 (3390.736) km
Hgt Above Ellipsoid =  91.636 km   Scale Hgt H(p) =  6.91 H(rho) =  6.88 km
Latitude =   31.98  degrees        Longitude =   57.47 W ( 302.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  147.30 deg.       Local Time =  17.99 Mars hours
Exospheric Temp. =  205.6 K        Tbase =  146.5 K    Zbase =  116.6 km
Solar Zenith Angle =  76.9 deg     F1 peak = 127.9 km    Mol.Wgt. = 41.62
Temperature =   125.3 K            Pressure =    5.170E-03 N/m**2
Density (Low, Avg., High) =      1.681E-07   2.065E-07   2.450E-07 kg/m**3
Departure, COSPAR NH Mean =       -72.0 %     -65.6 %     -59.2 %
Tot.Dens. = 1.919E-07 kg/m**3   Dens.Pert. =  -7.07% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     7.1    3.4   10.5 m/s
Northward Wind (Mean, Perturbed, Total) =   -18.2  -21.5  -39.7 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =   10000.0 sec. (    .113 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) =  95.000 km (  95.881 km)
Topographic Height =    -.881 km   Radius (Areoid) = 3485.608 (3390.608) km
Hgt Above Ellipsoid =  96.644 km   Scale Hgt H(p) =  6.73 H(rho) =  6.82 km
Latitude =   32.48  degrees        Longitude =   57.97 W ( 302.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  149.33 deg.       Local Time =  18.09 Mars hours
Exospheric Temp. =  205.2 K        Tbase =  146.3 K    Zbase =  116.7 km
Solar Zenith Angle =  77.9 deg     F1 peak = 128.6 km    Mol.Wgt. = 41.88
Temperature =   125.9 K            Pressure =    2.505E-03 N/m**2
Density (Low, Avg., High) =      7.890E-08   1.002E-07   1.216E-07 kg/m**3
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Departure, COSPAR NH Mean =       -74.5 %     -67.6 %     -60.7 %
Tot.Dens. = 7.784E-08 kg/m**3   Dens.Pert. = -22.34% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     2.3    4.6    6.9 m/s
Northward Wind (Mean, Perturbed, Total) =   -25.6  -35.8  -61.4 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   10500.0 sec. (    .118 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 100.000 km ( 101.011 km)
Topographic Height =   -1.011 km   Radius (Areoid) = 3490.479 (3390.479) km
Hgt Above Ellipsoid = 101.651 km   Scale Hgt H(p) =  7.06 H(rho) =  6.83 km
Latitude =   32.98  degrees        Longitude =   58.47 W ( 301.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  151.36 deg.       Local Time =  18.19 Mars hours
Exospheric Temp. =  204.8 K        Tbase =  146.0 K    Zbase =  116.8 km
Solar Zenith Angle =  78.9 deg     F1 peak = 129.3 km    Mol.Wgt. = 41.75
Temperature =   127.2 K            Pressure =    1.233E-03 N/m**2
Density (Low, Avg., High) =      3.701E-08   4.869E-08   6.037E-08 kg/m**3
Departure, COSPAR NH Mean =       -76.7 %     -69.4 %     -62.0 %
Tot.Dens. = 3.912E-08 kg/m**3   Dens.Pert. = -19.66% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    -5.1  -10.7  -15.7 m/s
Northward Wind (Mean, Perturbed, Total) =   -32.1  -12.6  -44.7 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   11000.0 sec. (    .124 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 105.000 km ( 106.165 km)
Topographic Height =   -1.165 km   Radius (Areoid) = 3495.347 (3390.347) km
Hgt Above Ellipsoid = 106.657 km   Scale Hgt H(p) =  6.88 H(rho) =  6.82 km
Latitude =   33.48  degrees        Longitude =   58.97 W ( 301.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  153.38 deg.       Local Time =  18.29 Mars hours
Exospheric Temp. =  204.4 K        Tbase =  145.8 K    Zbase =  116.9 km
Solar Zenith Angle =  79.9 deg     F1 peak = 130.1 km    Mol.Wgt. = 41.98
Temperature =   129.7 K            Pressure =    6.086E-04 N/m**2
Density (Low, Avg., High) =      1.730E-08   2.370E-08   3.010E-08 kg/m**3
Departure, COSPAR NH Mean =       -78.4 %     -70.4 %     -62.4 %
Tot.Dens. = 1.684E-08 kg/m**3   Dens.Pert. = -28.92% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -13.7  -35.2  -48.9 m/s
Northward Wind (Mean, Perturbed, Total) =   -35.4    2.8  -32.6 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   11500.0 sec. (    .130 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 110.000 km ( 111.262 km)
Topographic Height =   -1.262 km   Radius (Areoid) = 3500.214 (3390.214) km
Hgt Above Ellipsoid = 111.662 km   Scale Hgt H(p) =  7.41 H(rho) =  6.79 km
Latitude =   33.98  degrees        Longitude =   59.47 W ( 300.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  155.41 deg.       Local Time =  18.40 Mars hours
Exospheric Temp. =  203.9 K        Tbase =  145.5 K    Zbase =  117.0 km
Solar Zenith Angle =  80.9 deg     F1 peak = 131.8 km    Mol.Wgt. = 41.84
Temperature =   134.5 K            Pressure =    3.079E-04 N/m**2
Density (Low, Avg., High) =      8.059E-09   1.151E-08   1.497E-08 kg/m**3
Departure, COSPAR NH Mean =       -80.5 %     -72.2 %     -63.8 %
Tot.Dens. = 1.188E-08 kg/m**3   Dens.Pert. =   3.17% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -22.4    5.1  -17.3 m/s
Northward Wind (Mean, Perturbed, Total) =   -36.0  -26.2  -62.1 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   12000.0 sec. (    .135 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 115.000 km ( 116.305 km)
Topographic Height =   -1.305 km   Radius (Areoid) = 3505.078 (3390.078) km
Hgt Above Ellipsoid = 116.667 km   Scale Hgt H(p) =  7.69 H(rho) =  7.05 km
Latitude =   34.48  degrees        Longitude =   59.97 W ( 300.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  157.44 deg.       Local Time =  18.50 Mars hours
Exospheric Temp. =  203.5 K        Tbase =  145.3 K    Zbase =  117.1 km
Solar Zenith Angle =  81.8 deg     F1 peak = 132.7 km    Mol.Wgt. = 41.60
Temperature =   141.8 K            Pressure =    1.609E-04 N/m**2
Density (Low, Avg., High) =      3.974E-09   5.677E-09   7.380E-09 kg/m**3
Departure, COSPAR NH Mean =       -81.9 %     -74.2 %     -66.5 %
Tot.Dens. = 5.614E-09 kg/m**3   Dens.Pert. =  -1.11% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -28.6  -25.9  -54.5 m/s
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Northward Wind (Mean, Perturbed, Total) =   -34.7  -50.3  -84.9 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   12500.0 sec. (    .141 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 120.000 km ( 121.331 km)
Topographic Height =   -1.331 km   Radius (Areoid) = 3509.941 (3389.941) km
Hgt Above Ellipsoid = 121.670 km   Scale Hgt H(p) =  8.16 H(rho) =  7.44 km
Latitude =   34.98  degrees        Longitude =   60.47 W ( 299.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  159.47 deg.       Local Time =  18.60 Mars hours
Exospheric Temp. =  203.0 K        Tbase =  145.0 K    Zbase =  117.2 km
Solar Zenith Angle =  82.8 deg     F1 peak = 133.6 km    Mol.Wgt. = 41.57
Temperature =   150.1 K            Pressure =    8.678E-05 N/m**2
Density (Low, Avg., High) =      2.023E-09   2.890E-09   3.757E-09 kg/m**3
Departure, COSPAR NH Mean =       -83.0 %     -75.7 %     -68.4 %
Tot.Dens. = 2.003E-09 kg/m**3   Dens.Pert. = -30.68% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -31.1  -14.8  -45.8 m/s
Northward Wind (Mean, Perturbed, Total) =   -35.0  -22.6  -57.6 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   13000.0 sec. (    .146 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 125.000 km ( 126.315 km)
Topographic Height =   -1.315 km   Radius (Areoid) = 3514.803 (3389.803) km
Hgt Above Ellipsoid = 126.673 km   Scale Hgt H(p) =  8.80 H(rho) =  7.91 km
Latitude =   35.48  degrees        Longitude =   60.97 W ( 299.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  161.50 deg.       Local Time =  18.70 Mars hours
Exospheric Temp. =  202.5 K        Tbase =  144.7 K    Zbase =  117.2 km
Solar Zenith Angle =  83.7 deg     F1 peak = 134.6 km    Mol.Wgt. = 41.22
Temperature =   158.2 K            Pressure =    4.874E-05 N/m**2
Density (Low, Avg., High) =      1.069E-09   1.528E-09   1.986E-09 kg/m**3
Departure, COSPAR NH Mean =       -83.9 %     -77.0 %     -70.0 %
Tot.Dens. = 1.738E-09 kg/m**3   Dens.Pert. =  13.76% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -30.6  -22.4  -53.0 m/s
Northward Wind (Mean, Perturbed, Total) =   -37.2   -3.0  -40.2 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   13500.0 sec. (    .152 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 130.000 km ( 131.260 km)
Topographic Height =   -1.260 km   Radius (Areoid) = 3519.663 (3389.663) km
Hgt Above Ellipsoid = 131.675 km   Scale Hgt H(p) =  9.22 H(rho) =  8.45 km
Latitude =   35.98  degrees        Longitude =   61.47 W ( 298.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  163.52 deg.       Local Time =  18.80 Mars hours
Exospheric Temp. =  202.0 K        Tbase =  144.5 K    Zbase =  117.3 km
Solar Zenith Angle =  84.5 deg     F1 peak = 135.7 km    Mol.Wgt. = 40.74
Temperature =   164.9 K            Pressure =    2.822E-05 N/m**2
Density (Low, Avg., High) =      5.872E-10   8.388E-10   1.090E-09 kg/m**3
Departure, COSPAR NH Mean =       -84.4 %     -77.7 %     -71.0 %
Tot.Dens. = 9.001E-10 kg/m**3   Dens.Pert. =   7.30% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -27.8  -16.9  -44.7 m/s
Northward Wind (Mean, Perturbed, Total) =   -39.7    2.0  -37.7 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   14000.0 sec. (    .158 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 135.000 km ( 136.260 km)
Topographic Height =   -1.260 km   Radius (Areoid) = 3524.521 (3389.521) km
Hgt Above Ellipsoid = 136.677 km   Scale Hgt H(p) =  9.80 H(rho) =  8.95 km
Latitude =   36.48  degrees        Longitude =   61.97 W ( 298.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  165.55 deg.       Local Time =  18.91 Mars hours
Exospheric Temp. =  201.5 K        Tbase =  144.2 K    Zbase =  117.4 km
Solar Zenith Angle =  85.4 deg     F1 peak = 136.9 km    Mol.Wgt. = 40.02
Temperature =   169.8 K            Pressure =    1.680E-05 N/m**2
Density (Low, Avg., High) =      3.334E-10   4.763E-10   6.193E-10 kg/m**3
Departure, COSPAR NH Mean =       -82.6 %     -75.1 %     -67.7 %
Tot.Dens. = 4.832E-10 kg/m**3   Dens.Pert. =   1.45% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -24.1  -43.7  -67.8 m/s
Northward Wind (Mean, Perturbed, Total) =   -43.4    5.6  -37.8 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   14500.0 sec. (    .163 sols)  Ls =  97.1  Dust =  .30
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Height Above MOLA Areoid (Above Surface) = 140.000 km ( 141.257 km)
Topographic Height =   -1.257 km   Radius (Areoid) = 3529.378 (3389.378) km
Hgt Above Ellipsoid = 141.677 km   Scale Hgt H(p) = 10.17 H(rho) =  9.25 km
Latitude =   36.98  degrees        Longitude =   62.47 W ( 297.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  167.58 deg.       Local Time =  19.01 Mars hours
Exospheric Temp. =  201.0 K        Tbase =  144.0 K    Zbase =  117.5 km
Solar Zenith Angle =  86.2 deg     F1 peak = 138.2 km    Mol.Wgt. = 39.01
Temperature =   173.5 K            Pressure =    1.023E-05 N/m**2
Density (Low, Avg., High) =      1.937E-10   2.767E-10   3.597E-10 kg/m**3
Departure, COSPAR NH Mean =       -82.2 %     -74.6 %     -67.0 %
Tot.Dens. = 2.980E-10 kg/m**3   Dens.Pert. =   7.70% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -20.6   11.0   -9.6 m/s
Northward Wind (Mean, Perturbed, Total) =   -47.8  -42.8  -90.7 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   15000.0 sec. (    .169 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 145.000 km ( 146.336 km)
Topographic Height =   -1.336 km   Radius (Areoid) = 3534.234 (3389.234) km
Hgt Above Ellipsoid = 146.678 km   Scale Hgt H(p) = 10.35 H(rho) =  9.63 km
Latitude =   37.48  degrees        Longitude =   62.97 W ( 297.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  169.61 deg.       Local Time =  19.11 Mars hours
Exospheric Temp. =  200.5 K        Tbase =  143.8 K    Zbase =  117.5 km
Solar Zenith Angle =  87.1 deg     F1 peak = 139.7 km    Mol.Wgt. = 37.94
Temperature =   175.7 K            Pressure =    6.302E-06 N/m**2
Density (Low, Avg., High) =      1.145E-10   1.636E-10   2.127E-10 kg/m**3
Departure, COSPAR NH Mean =       -83.8 %     -76.8 %     -69.9 %
Tot.Dens. = 1.548E-10 kg/m**3   Dens.Pert. =  -5.42% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -17.0   40.4   23.4 m/s
Northward Wind (Mean, Perturbed, Total) =   -52.0  -13.7  -65.7 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   15500.0 sec. (    .175 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 150.000 km ( 151.282 km)
Topographic Height =   -1.282 km   Radius (Areoid) = 3539.090 (3389.090) km
Hgt Above Ellipsoid = 151.679 km   Scale Hgt H(p) = 10.80 H(rho) =  9.94 km
Latitude =   37.98  degrees        Longitude =   63.47 W ( 296.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  171.63 deg.       Local Time =  19.21 Mars hours
Exospheric Temp. =  200.0 K        Tbase =  143.5 K    Zbase =  117.6 km
Solar Zenith Angle =  87.9 deg     F1 peak = 141.3 km    Mol.Wgt. = 36.74
Temperature =   176.8 K            Pressure =    3.938E-06 N/m**2
Density (Low, Avg., High) =      6.892E-11   9.845E-11   1.280E-10 kg/m**3
Departure, COSPAR NH Mean =       -85.4 %     -79.2 %     -72.9 %
Tot.Dens. = 9.757E-11 kg/m**3   Dens.Pert. =   -.89% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -13.2    1.6  -11.6 m/s
Northward Wind (Mean, Perturbed, Total) =   -55.8   -3.1  -58.9 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   16000.0 sec. (    .180 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 155.000 km ( 156.174 km)
Topographic Height =   -1.174 km   Radius (Areoid) = 3543.945 (3388.945) km
Hgt Above Ellipsoid = 156.680 km   Scale Hgt H(p) = 11.24 H(rho) = 10.10 km
Latitude =   38.48  degrees        Longitude =   63.97 W ( 296.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  173.66 deg.       Local Time =  19.31 Mars hours
Exospheric Temp. =  199.4 K        Tbase =  143.3 K    Zbase =  117.6 km
Solar Zenith Angle =  88.6 deg     F1 peak = 143.1 km    Mol.Wgt. = 35.11
Temperature =   177.3 K            Pressure =    2.509E-06 N/m**2
Density (Low, Avg., High) =      4.184E-11   5.977E-11   7.770E-11 kg/m**3
Departure, COSPAR NH Mean =       -87.6 %     -82.2 %     -76.9 %
Tot.Dens. = 5.842E-11 kg/m**3   Dens.Pert. =  -2.26% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -10.1   -3.2  -13.3 m/s
Northward Wind (Mean, Perturbed, Total) =   -59.6   -3.4  -63.0 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   16500.0 sec. (    .186 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 160.000 km ( 161.000 km)
Topographic Height =   -1.000 km   Radius (Areoid) = 3548.801 (3388.801) km
Hgt Above Ellipsoid = 161.682 km   Scale Hgt H(p) = 11.96 H(rho) = 10.80 km
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Latitude =   38.98  degrees        Longitude =   64.47 W ( 295.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  175.69 deg.       Local Time =  19.41 Mars hours
Exospheric Temp. =  198.9 K        Tbase =  143.0 K    Zbase =  117.7 km
Solar Zenith Angle =  89.4 deg     F1 peak = 145.1 km    Mol.Wgt. = 34.55
Temperature =   182.6 K            Pressure =    1.857E-06 N/m**2
Density (Low, Avg., High) =      3.042E-11   4.236E-11   5.463E-11 kg/m**3
Departure, COSPAR NH Mean =       -87.5 %     -82.6 %     -77.5 %
Tot.Dens. = 3.366E-11 kg/m**3   Dens.Pert. = -20.53% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    -7.6     .8   -6.9 m/s
Northward Wind (Mean, Perturbed, Total) =   -63.3   71.3    8.0 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =   17000.0 sec. (    .191 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 165.000 km ( 165.855 km)
Topographic Height =    -.855 km   Radius (Areoid) = 3553.656 (3388.656) km
Hgt Above Ellipsoid = 166.684 km   Scale Hgt H(p) = 12.96 H(rho) = 11.77 km
Latitude =   39.48  degrees        Longitude =   64.97 W ( 295.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  177.72 deg.       Local Time =  19.52 Mars hours
Exospheric Temp. =  198.4 K        Tbase =  142.8 K    Zbase =  117.7 km
Solar Zenith Angle =  90.1 deg     F1 peak = 999.9 km    Mol.Wgt. = 35.64
Temperature =   192.6 K            Pressure =    1.562E-06 N/m**2
Density (Low, Avg., High) =      2.539E-11   3.488E-11   4.535E-11 kg/m**3
Departure, COSPAR NH Mean =       -85.9 %     -80.7 %     -74.9 %
Tot.Dens. = 3.477E-11 kg/m**3   Dens.Pert. =   -.33% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    -5.3  -29.8  -35.1 m/s
Northward Wind (Mean, Perturbed, Total) =   -66.8   15.7  -51.1 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =   17500.0 sec. (    .197 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 170.000 km ( 170.865 km)
Topographic Height =    -.865 km   Radius (Areoid) = 3558.511 (3388.511) km
Hgt Above Ellipsoid = 171.687 km   Scale Hgt H(p) = 13.70 H(rho) = 12.38 km
Latitude =   39.98  degrees        Longitude =   65.47 W ( 294.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  179.75 deg.       Local Time =  19.62 Mars hours
Exospheric Temp. =  197.8 K        Tbase =  142.6 K    Zbase =  117.8 km
Solar Zenith Angle =  90.8 deg     F1 peak = 999.9 km    Mol.Wgt. = 35.73
Temperature =   197.4 K            Pressure =    1.181E-06 N/m**2
Density (Low, Avg., High) =      1.814E-11   2.572E-11   3.344E-11 kg/m**3
Departure, COSPAR NH Mean =       -86.6 %     -80.9 %     -75.2 %
Tot.Dens. = 3.018E-11 kg/m**3   Dens.Pert. =  17.31% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    -2.9  -10.8  -13.7 m/s
Northward Wind (Mean, Perturbed, Total) =   -70.1  -20.2  -90.4 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =   18000.0 sec. (    .203 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 175.000 km ( 175.634 km)
Topographic Height =    -.634 km   Radius (Areoid) = 3563.367 (3388.367) km
Hgt Above Ellipsoid = 176.691 km   Scale Hgt H(p) = 14.28 H(rho) = 12.70 km
Latitude =   40.48  degrees        Longitude =   65.97 W ( 294.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  181.77 deg.       Local Time =  19.72 Mars hours
Exospheric Temp. =  197.3 K        Tbase =  142.4 K    Zbase =  117.8 km
Solar Zenith Angle =  91.5 deg     F1 peak = 999.9 km    Mol.Wgt. = 34.31
Temperature =   197.0 K            Pressure =    8.189E-07 N/m**2
Density (Low, Avg., High) =      1.201E-11   1.716E-11   2.231E-11 kg/m**3
Departure, COSPAR NH Mean =       -88.3 %     -83.4 %     -78.4 %
Tot.Dens. = 1.554E-11 kg/m**3   Dens.Pert. =  -9.47% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    -1.5   37.4   35.9 m/s
Northward Wind (Mean, Perturbed, Total) =   -72.6   49.6  -23.0 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =   18500.0 sec. (    .208 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 180.000 km ( 180.386 km)
Topographic Height =    -.386 km   Radius (Areoid) = 3568.223 (3388.223) km
Hgt Above Ellipsoid = 181.695 km   Scale Hgt H(p) = 14.96 H(rho) = 13.07 km
Latitude =   40.98  degrees        Longitude =   66.47 W ( 293.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  183.80 deg.       Local Time =  19.82 Mars hours
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Exospheric Temp. =  196.8 K        Tbase =  142.2 K    Zbase =  117.9 km
Solar Zenith Angle =  92.1 deg     F1 peak = 999.9 km    Mol.Wgt. = 32.77
Temperature =   196.6 K            Pressure =    5.760E-07 N/m**2
Density (Low, Avg., High) =      8.088E-12   1.155E-11   1.502E-11 kg/m**3
Departure, COSPAR NH Mean =       -89.8 %     -85.4 %     -81.0 %
Tot.Dens. = 8.919E-12 kg/m**3   Dens.Pert. = -22.81% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     -.3   12.2   11.8 m/s
Northward Wind (Mean, Perturbed, Total) =   -75.1   48.6  -26.5 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   19000.0 sec. (    .214 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 185.000 km ( 185.101 km)
Topographic Height =    -.101 km   Radius (Areoid) = 3573.078 (3388.078) km
Hgt Above Ellipsoid = 186.699 km   Scale Hgt H(p) = 15.75 H(rho) = 13.51 km
Latitude =   41.48  degrees        Longitude =   66.97 W ( 293.03 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  185.83 deg.       Local Time =  19.92 Mars hours
Exospheric Temp. =  196.2 K        Tbase =  142.0 K    Zbase =  117.9 km
Solar Zenith Angle =  92.7 deg     F1 peak = 999.9 km    Mol.Wgt. = 31.14
Temperature =   196.1 K            Pressure =    4.116E-07 N/m**2
Density (Low, Avg., High) =      5.505E-12   7.864E-12   1.022E-11 kg/m**3
Departure, COSPAR NH Mean =       -91.0 %     -87.1 %     -83.3 %
Tot.Dens. = 4.738E-12 kg/m**3   Dens.Pert. = -39.76% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =      .8  -26.9  -26.1 m/s
Northward Wind (Mean, Perturbed, Total) =   -77.6    9.5  -68.1 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   19500.0 sec. (    .220 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 190.000 km ( 189.845 km)
Topographic Height =     .155 km   Radius (Areoid) = 3577.933 (3387.933) km
Hgt Above Ellipsoid = 191.703 km   Scale Hgt H(p) = 16.65 H(rho) = 14.04 km
Latitude =   41.98  degrees        Longitude =   67.47 W ( 292.53 E) deg.
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  187.86 deg.       Local Time =  20.03 Mars hours
Exospheric Temp. =  195.7 K        Tbase =  141.8 K    Zbase =  117.9 km
Solar Zenith Angle =  93.3 deg     F1 peak = 999.9 km    Mol.Wgt. = 29.46
Temperature =   195.6 K            Pressure =    2.990E-07 N/m**2
Density (Low, Avg., High) =      3.793E-12   5.418E-12   7.044E-12 kg/m**3
Departure, COSPAR NH Mean =       -92.0 %     -88.6 %     -85.1 %
Tot.Dens. = 4.421E-12 kg/m**3   Dens.Pert. = -18.40% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     1.7  -22.2  -20.4 m/s
Northward Wind (Mean, Perturbed, Total) =   -80.2   -6.7  -86.9 m/s
---------------------------------------------------------------------------
Time (rel. to T0) =   20000.0 sec. (    .225 sols)  Ls =  97.1  Dust =  .30
Height Above MOLA Areoid (Above Surface) = 195.000 km ( 194.654 km)
Topographic Height =     .346 km   Radius (Areoid) = 3582.788 (3387.788) km
Hgt Above Ellipsoid = 196.707 km   Scale Hgt H(p) = 17.66 H(rho) = 14.65 km
Latitude =   42.48  degrees        Longitude =   67.97 W ( 292.03 E) deg.
Sun Latitude =    24.99 deg.       Mars Orbital Radius = 1.648 AU
Sun Longitude =  189.88 deg.       Local Time =  20.13 Mars hours
Exospheric Temp. =  195.2 K        Tbase =  141.6 K    Zbase =  118.0 km
Solar Zenith Angle =  93.9 deg     F1 peak = 999.9 km    Mol.Wgt. = 27.79
Temperature =   195.1 K            Pressure =    2.208E-07 N/m**2
Density (Low, Avg., High) =      2.649E-12   3.784E-12   4.919E-12 kg/m**3
Departure, COSPAR NH Mean =       -92.9 %     -89.8 %     -86.8 %
Tot.Dens. = 3.225E-12 kg/m**3   Dens.Pert. = -14.78% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     2.6    6.2    8.7 m/s
Northward Wind (Mean, Perturbed, Total) =   -82.8  -10.7  -93.4 m/s
---------------------------------------------------------------------------
```

Appendix D

Summary of Files Provided with Mars-GRAM 2001

Mars-GRAM 2001 file transfer protocol (ftp) directory contains the following files:

```
                SOURCE CODE FOR STAND-ALONE MARS-GRAM PROGRAM

marsgram.f   - source code for the "stand-alone" version main program
marssubs.f   - subroutines used by both marsgram and dumytraj versions
setup.f      - setup routines used by both marsgram and dumytraj versions


   SOURCE CODE FOR PROGRAMS TO CONVERT ASCII DATA PROVIDED TO BINARY DATA

makebin.f    - program to read ASCII version MGCM (ground surface, 5 and
                30 m above surface, and 0-80 km) and MTGCM (80-170 km)
                data files and write out binary version (for faster
                reading on user machine).  Binary conversion process
                required (once) before initial running of Mars-GRAM.
                See file README3.txt.
readalb.f    - program to read ASCII albedos and convert to binary
readtopo.f   - program to read ASCII MOLA topography and convert to binary


    SOURCE CODE FOR AUXILIARY PROGRAMS (SEE APPENDIX G)

bldtraj.f    - program to build pseudo-trajectory file for using in Mars-
                GRAM to compute output for maps or cross-sections
dumytraj.f   - source code for the dummy trajectory version main program.
                To be compiled with marssubs.f and setup.f, this program
                illustrates use of Mars-GRAM as a subroutine in trajectory
                programs or orbit propagator programs.
finddate.f   - utility to find Earth date/time for desired Ls or Mars time
marsrad.f    - uses Mars-GRAM output to compute various solar (shortwave)
               and thermal (longwave) fluxes at the surface and top of
               atmosphere
radtraj.f    - special "trajectory" building program to compute vertical
                profiles at lat-lon, lat-time, or lon-time cross sections,
                for input to Mars-GRAM runs to produce output for input
                to marsrad radiation calculations


             DATA FILES (ASCII FORMAT) FOR MGCM NEAR-SURFACE DATA

sfc00xxy.txt - MGCM boundary layer data at ground surface for dust optical
                depths 0.3, 1.0, and 3.0 (xx = 03, 10, 30), version
                number y
sfc05xxy.txt - MGCM boundary layer data at 5m height for dust optical
                depths 0.3, 1.0, and 3.0 (xx = 03, 10, 30), version
                number y
sfc30xxy.txt - MGCM boundary layer data at 30m height for 3 dust optical
                depths xx, version number y


               DATA FILES (ASCII FORMAT) FOR MGCM 0-80 KM DATA

tpdloxxy.txt - MGCM 0-80 km temperature, pressure, and density data for
                3 dust optical depths (xx = 03, 10, 30), version number y
uvloxxy.txt  - MGCM 0-80 km EW wind and NS wind data for 3 dust optical
```

```
                depths xx, version number y


             DATA FILES (ASCII FORMAT) FOR MTGCM 80-170 KM DATA

tpdlsxxy.txt - MTGCM 80-170 km temperature, pressure, and density data for
                3 dust optical depths (xx = 03, 10, 30), version number y,
                for solar activity F10.7 = 70
tpdmsxxy.txt - MTGCM 80-170 km temperature, pressure, and density data for
                3 dust optical depths xx, version number y, for solar
                activity F10.7 = 130
uvlsxxy.txt  - MTGCM 80-170 km EW wind and NS wind data for 3 dust optical
                depths xx, version number y, for solar activity F10.7 = 70
uvmsxxy.txt  - MTGCM 80-170 km EW wind and NS wind data for 3 dust optical
                depths xx, version number y, for solar activity F10.7 = 130
zfhtlsy.txt  - Height ZF of 1.26 nbar level for all dust optical depths,
                version number y, for solar activity F10.7 = 70
zfhtmsy.txt  - Height ZF of 1.26 nbar level for all dust optical depths,
                version number y, for solar activity F10.7 = 130


               OTHER DATA FILES REQUIRED TO RUN Mars-GRAM

albedo1.txt  - global surface albedo at 1 by 1 degree lat-lon resolution;
                must be converted to binary with program readalb.f
COSPAR2.DAT  - data file for the COSPAR reference model atmosphere
molatoph.txt - MOLA areoid and surface topography at 1/2 by 1/2 degree
                lat-lon resolution; must be converted to binary with
                program readtopo.f
hgtoffst.dat - global average MTGCM height offsets (km) by Ls and dust level


                     SAMPLE INPUT AND OUTPUT FILES

input.std    - commented test input file for reference case
inphxper.txt - input file to reproduce Mars Global Surveyor (MGS) Phase x
                (x = 1 or 2) periapsis conditions, when used with
                trajectory file trajphxp.txt and wave file wavephx.txt
list2001.txt - list output file for reference case
trajphxp.txt - "trajectory" file for MGS Phase x periapsis conditions
wavephx.txt  - longitude-dependent wave file for MGS Phase x conditions


              TEXT AND PDF FILES DOCUMENTING PROGRAM FEATURES

headers.txt  - list of output files and file header definitions
marsfix.txt  - history of code changes since first posting of Version 1
marsgram.hst - history file summarizing various versions and changes
Mars2001.pdf - a PDF version of the Mars-GRAM 2001 report
README1.txt  - a general program introduction file
README2.txt  - discussion of dumytraj.f dummy trajectory program
README3.txt  - discussion of MGCM and MTGCM input data files, including
                programs to convert ASCII files (provided) into binary
                files (for faster running of Mars-GRAM)
README4.txt  - discussion of auxiliary programs provided, including
                marsrad solar and thermal radiative transfer program
README5.txt  - discussion of Mars-GRAM sample input and output files,
                including reference test case, and files that reproduce
                periapsis conditions for Mars Global Surveyor Phase 1
                and Phase 2 aerobraking periods
xycodes.txt  - list of x-y plot codes (also given below)


Plotable output files can be generated with data given versus
several selected parameters.  Generation of LIST file output and
plotable output files is controlled by the value of iup on input.
For Mars-GRAM 2001, a number of plotable output files are generated,
```

each containing several parameters suitable for plotting. These plotable files have headers to help identify parameters in the files. File names and definitions of headers are given in the file headers.txt.

Plotable x and y parameters and their code values (set by input variables NVARX and NVARY) are as follows:

Code	Parameter
1	Height (above local MOLA areoid, km)
2	Height (above local MOLA topography, km)
3	Latitude (degrees)
4	Longitude (deg.) West positive if LonEW=0. East positive if LonEW=1
5	Time from start (Earth seconds)
6	Time from start (Martian Sols)
7	Areocentric Longitude of Sun, Ls (deg.)
8	Local Solar Time (Mars hours)
9	Pressure (mb)
10	Pressure Height [-log(Pres/PresSurf) = -log(sigma)]
11	Sigma coordinate [sigma = Pressure/(Pressure at Surface)]
12	Height (km) from old reference ellipsoid

To compile marsgram and dumytraj under UNIX, to produce executable files marsgram.x and dumytraj.x, you can use the commands:

```
f77 -o marsgram.x marsgram.f marssubs.f setup.f
```

and

```
f77 -o dumytraj.x dumytraj.f marssubs.f setup.f
```

To compile marsgram and dumytraj under PC-DOS (for example, with Microsoft FORTRAN Powerstation), to produce executable files marsgram.exe and dumytraj.exe, you can use the commands:

```
fl32 marsgram.f marssubs.f setup.f
```

and

```
fl32 dumytraj.f marssubs.f setup.f
```

To compile the auxiliary programs bldtraj.f, finddate.f, marsrad.f, or radtraj.f, or the binary conversion programs makebin.f, readalb.f, or readtopo.f, just use the FORTRAN compile statement for the specific auxiliary program source code file, i.e.

```
f77 -o auxiliary.x auxiliary.f
```

or

```
fl32 auxiliary.f
```

for each specific auxiliary program.

Appendix E

Example Application of Mars-GRAM in a Trajectory Code

With earlier versions of Mars-GRAM a dummy trajectory program, marstraj.f, was supplied. Beginning with Mars-GRAM version 3.8, an alternate version of a (double precision) dummy trajectory calculating program (dumytraj.f) was included. Although similar in general function to the original marstraj.f code, some details of dumytraj.f are different:

(1) In the original marstraj.f, interaction with Mars-GRAM was via calls to three subroutines -

```
                Call Setup(...)
                Call Randinit(...)
                Call Datastep(...)
```

These three subroutines are part of the Mars-GRAM 2001 code and are automatically available to be called whenever the Mars-GRAM 2001 code (marssubs.f and setup.f) is linked to the user's main trajectory driver program. IF YOU ALREADY HAVE A TRAJECTORY PROGRAM BUILT LIKE THIS, WITH CALLS TO SETUP, RANDINIT, AND DATASTEP IT MIGHT BE EASILY MODIFIED TO INCORPORATE Mars-GRAM 2001 SUBROUTINES WITHOUT USING THE APPROACH TAKEN IN DUMYTRAJ.F. Note, however, that the number of arguments in these subroutines has changed, so appropriate modifications in your trajectory programs must be made.

(2) In dumytraj.f, interaction with Mars-GRAM 2001 is via three calls to one "wrapper" subroutine (named Marstraj), but with different values of three control parameters (isetup, jmonte, and istep) -

```
                Call Marstraj(...)      with isetup=1
                Call Marstraj(...)      with isetup=0, jmonte>0, istep=0
                Call Marstraj(...)      with isetup=0, jmonte=0, istep>0
```

where isetup = 1 triggers the call to the Setup subroutine, jmonte>0 triggers the call to the reinitialization process (including the call to the Randinit subroutine), and istep = 1 to MAXNUM is a counter for steps along the trajectory (with a call to the Datastep subroutine at each step). Marstraj is a subroutine in the dumytraj.f code, and must be included (along with the basic Mars-GRAM code setup.f and marssubs.f) as a subroutine in the user's calling trajectory program.

(3) In the original marstraj.f dummy trajectory main code, transfer of double precision (trajectory) variables to and from single precision (Mars-GRAM) variables was assumed to be done within the user's main trajectory code. In the dumytraj.f code this transfer is handled within the Marstraj subroutine (which must be included as a subroutine in the user's trajectory program).

(4) In the original marstraj.f dummy trajectory main code, (single precision) values of position increments (DELHGT, DELLAT, and DELLON) were presumed to be calculated within the user's main trajectory program. In the dumytraj.f code, input variables to the Marstraj subroutine are current and next (double precision) position values (height, latitude, and longitude) and the position increments to be passed to the Datastep subroutine (increments of height, latitude, and longitude) are computed within the Marstraj subroutine.

Regardless of which dummy trajectory code you decide to use as your starting model from which to build the interface to Mars-GRAM 2001 for your own trajectory code, it is worthwhile to read the comments embedded in the dumytraj.f code. These comments give more explicit descriptions of the functions that are being performed. They also provide better hints about what to do if you are using predictor-corrector (or other) trajectory approaches that require mid-point corrections along trajectory steps and/or the use of density variations that occur within each trajectory step.

Another feature of dumytraj.f is that it allows high precision Mars ephemeris values for sun latitude, longitude, and Ls angle to be passed from the trajectory program for use by Mars-GRAM 2001 subroutines.

Appendix F

Details of MGCM, MTGCM, and MOLA Data Files

ASCII format data files are provided, each having values for amplitudes and phases of diurnal (period = 24 Mars hours) and semi-diurnal (period = 12 Mars hours) components. Generically, the amplitudes and phases are:

```
A0   = Diurnal mean value of the given parameter
A1   = Amplitude of the diurnal tide component
phi1 = Phase (local time in Mars hours) of the diurnal component
A2   = Amplitude of the semi-diurnal tide component
phi2 = phase (local time in Mars hours) of the semi-diurnal component
```

Tidal values for each parameter are computed from the relation

```
Tide=A0+A1*Cos((pi/12)*(time-phi1))+A2*Cos((pi/6)*(time-phi2))
```

where time is the local solar time in Mars hours.

For temperature and wind components, the data files give amplitudes in the same units as those of the parameter (K for temperature or m/s for wind). For pressure and density, the data files give amplitudes in units of percent of the mean value (A0). A0 values for pressure are N/m^2. A0 values for density are kg/m^3.

For each of three values of dust optical depth, three MGCM boundary layer data files are provided (in ASCII format):

```
sfc00xxy.txt - MGCM boundary layer ground surface data for dust optical
                depths 0.3, 1.0, and 3.0 (xx = 03, 10, 30), version number y
sfc05xxy.txt - MGCM boundary layer data at 5m height for dust optical
                depths 0.3, 1.0, and 3.0 (xx = 03, 10, 30), version number y
sfc30xxy.txt - MGCM boundary layer data at 30m height for 3 dust optical
                depths xx, version number y
```

Each record of these files contains Ls value, latitude, longitude, and tidal coefficients (A0, A1, phi1, A2, phi2) for temperature, and for EW wind and NS wind components (except for ground surface data files, which contain only temperature information).

For each of the same three dust optical depths, two ASCII format files of MGCM 0-80 km data are provided:

```
tpdloxxy.txt - MGCM 0-80 km temperature, pressure, and density data for
                3 dust optical depths xx, version number y
uvloxxy.txt  - MGCM 0-80 km EW wind and NS wind data for 3 dust optical
                depths xx, version number y
```

Each record of the tpdloxx.txt files contains Ls value, height, latitude, and tidal coefficients for temperature and pressure. Only the A0 coefficient is given for density. Tidal variations in density are computed from those for pressure and temperature by the perfect gas law relation. Each record of the uvloxx.txt files contains Ls value, height, latitude, and tidal coefficients for the Eastward and Northward wind components.

For each of the same three dust optical depths, two ASCII format files of MTGCM 80-170 km data are provided, for each of two levels of solar activity (10.7 cm flux, F10.7, at Earth position, 1AU):

```
tpdlsxxy.txt - MTGCM 80-170 km temperature, pressure, and density data for
```

```
                 3 dust optical depths xx, version number y, for solar
                 activity F10.7 = 70
tpdmsxxy.txt - MTGCM 80-170 km temperature, pressure, and density data for
                 3 dust optical depths xx, version number y, for solar
                 activity F10.7 = 130
uvlsxxy.txt  - MTGCM 80-170 km EW wind and NS wind data for 3 dust optical
                 depths xx, version number y, for solar activity F10.7
                 = 70
uvmsxxy.txt  - MTGCM 80-170 km EW wind and NS wind data for 3 dust optical
                 depths xx, version number y, for solar activity F10.7
                 = 130
```

Each record of the tpdlsxxy.txt or tphmsxxy.txt files contains Ls value, height, latitude, and tidal coefficients for temperature, pressure, and density. Because of height variations in molecular weight, tidal coefficients are retained for all three of these thermodynamic components. Each record of the uvlsxxy.txt and uvmsxxy.txt files contains Ls value, height, latitude, and tidal coefficients for the Eastward and Northward wind components.

A single file for each of the two solar activity levels, zfhtlsy.txt, and zfhtmsy, provides tidal coefficient information for altitude ZF, the height of the 1.26 nbar level, for all dust optical depths, version number y. Each record of the ZF files contains dust optical depth, Ls, latitude, and tidal coefficient values (mean value and tidal amplitudes are in km).

Source code (makebin.f) is also provided for a program to read the ASCII format MGCM and MTGCM data files and write them out in binary format. After this ASCII-to-binary conversion is once completed, subsequent reading of the binary format files significantly shortens the time required to initialize Mars-GRAM 2001 on each run.

MOLA areoid and topography data at 1/2 by 1/2 degree lat-lon resolution is provided in ASCII file molatoph.txt. Global surface albedo at 1 by 1 degree lat-lon resolution is given in file albedo1.txt. Source code for ASCII-to-binary conversion programs (readtopo.f and readalb.f) is provided.

Appendix G

Auxiliary Programs for Use with Mars-GRAM

Four auxiliary programs are provided for use with Mars-GRAM: bldtraj.f, finddate.f, marsrad.f, and radtraj.f. The stand-alone version Mars-GRAM program files (marsgram.f, marssubs.f, and setup.f) are discussed in appendix D. Appendix E discusses dummy trajectory program dumytraj.f, which provides an example of how to use Mars-GRAM as a subroutine in trajectory programs or orbit propagator programs. Programs makebin.f, readalb.f, and readtopo.f, to convert data provided in ASCII format into binary files, are discussed in appendix D and appendix F.

PROGRAM BLDTRAJ

bldtraj.f - program to build pseudo-trajectory file for using in Mars-GRAM to compute output for maps or cross-sections

It is frequently desirable to produce Mars-GRAM output for graphing as a map (i.e., lat-lon cross section at a given height) or other cross-section (e.g., height-lat cross section at a given longitude). Program bldtraj.f generates a "trajectory" file (with input lines containing time, height, latitude, and longitude) that can be used as Mars-GRAM input for generation of such maps or cross-sections. Program bldtraj is interactive and prompts the user to input starting values, ending values, and step sizes for height (z1,z2,dz), latitude (lat1,lat2,dlat), and longitude (lon1,lon2,dlon). The program also prompts for a value of time increment which is applied between each "trajectory" step (the time increment may be 0, if all trajectory points are at the same time). Time values in the trajectory file are time (seconds) from the start time specified by date and time information provided in the Mars-GRAM NAMELIST-format input file.

Example:
For a lat-lon map at height 10 km (above MOLA areoid), between latitudes -30 and 30 degrees (in steps of 5 degrees), and longitudes 0 to 180 degrees (in steps of 20 degrees), enter 10 10 0 for z1, z2, dz; enter -30 30 5 for lat1, lat2, dlat; and enter 0 180 20 for lon1, lon2, dlon. All of these input quantities are of type real, and can be entered to one or more significant digits beyond the decimal.

PROGRAM FINDDATE

finddate.f - utility to find Earth date/time for desired Ls or Mars time

Program finddate.f allows calculation of areocentric longitude of the Sun (Ls) and Mars local true solar time (LTST) for a given Earth date and time. It also computes the next occurrence (beyond the initial input date and time) of the Earth date and time for which Ls and LTST are any desired values. Low-resolution Mars-GRAM ephemeris is used. Accuracy information and other documentary comments are given within the source code. The program is interactive and prompts for all necessary inputs.

PROGRAM MARSRAD

marsrad.f - uses Mars-GRAM output to compute various solar (shortwave) and thermal (longwave) fluxes at the surface and top of atmosphere

Program marsrad.f uses Mars-GRAM output files containing height profile information. Profiles must start at the surface, should usually extend upward to a height of from 10 to 30 km, and may be at any desired height resolution (limit 1000 points per profile). Mars-GRAM output files used are TPresHgt.txt, Density.txt, and MarsRad.txt. See file headers.txt for a description of the parameters contained in these files. Program marsrad runs interactively, with the only user input required being the number (1 or 2) of plot variables (Var_X and, optionally, Var_Y) used in the Mars-GRAM output files. The marsrad program computes various solar (shortwave) and thermal (longwave) fluxes at the surface (sfc) and top of atmosphere (toa). Two marsrad output files are produced. Output file Radlist.txt contains an annotated set of radiation fluxes, equivalent (black-body) temperatures, and albedos. Output file Radout.txt, suitable for input to a plot program, contains fluxes and other information in one line for each set of output. With an input "trajectory" file (generated by program radtraj.f - see below), output file Radout.txt can be used to plot solar and thermal radiation data as a map (lat-lon cross section), or as lat-time or lon-time cross sections. Longwave radiative fluxes are computed by a broad-band (emissivity) method, patterned after Savijarvi.[27] Dust optical depth tau is for the shortwave (solar) spectrum. For longwave calculations, infrared emissivity versus shortwave solar optical depth curves are used, adapted from Haberle et al.[24]. Infrared emissivities for CO2 and water vapor are functions of pressure-scaled optical path lengths (with emissivities from Staley and Juricka[28]). Shortwave fluxes are computed from total dust optical depth (adjusted for small amount of clear-sky optical depth) by a delta-Eddington method.[29] Both longwave and shortwave effects of water vapor are included, with relative humidity assumed constant at 20 percent.[27] Dust optical properties assumed are 0.7 for asymmetry parameter, and 0.9 for single-scatter albedo. Other reasonable values may be found in Table 1 of Murphy et al.[30] Values of asymmetry parameter and single-scatter albedo (as well as assumed relative humidity) can be changed in data statements near the beginning of the marsrad program. Output parameters given in Radlist.txt output file (in addition to plot variables, Var_X and, optionally, Var_Y) are:

tau = total vertical dust optical depth
MarsAU = Mars orbital radius (AU)
mu0 = cosine of solar zenith angle
ice = 0 for no ice on the surface, 1 for ice on the surface (affects surface albedo)

Longwave (LW) fluxes F (W/m^2):
Fdown(sfc) = downwelling LW flux at surface
Fup(sfc) = upwelling LW flux at surface (related to Tsfc)
Fup(toa) = upwelling LW flux at top-of-atmosphere
Femit(atmos)= LW flux emitted by atmosphere [Fup(toa) + net LW at sfc]

Radiative (equivalent black-body) temperatures (K):
Tsky(sfc) = equivalent sky temperature [related to Fdown(sfc)]
Tsfc = ground surface temperature [related to Fup(sfc)]
Teff(toa) = effective black-body temperature at top-of-atmosphere

Shortwave (SW) fluxes E (W/m^2):
Edown(sfc) = downwelling SW flux at surface
Eup(sfc) = upwelling SW flux at surface [albedo times Edown(sfc)]
Eup(toa) = upwelling SW flux at top-of-atmosphere
Eabsorb(atmos)= net SW flux absorbed by atmosphere
Edown(toa) = solar flux at toa = mu0×(solar constant)/$MarsAU^2$

Surface albedo = surface albedo interpolated from file albedo1.txt, modified for ice surface and downwelling SW flux at the surface by a relation from page 1201 of Kieffer.[31]

Planetary albedo = ratio Eup(toa)/Edown(toa)

SW+LW Fluxes (W/m^2):
Absorbed(sfc) = SW+LW flux absorbed at the surface
Emitted(toa) = upwelling SW+LW flux at top-of-atmosphere

Controlled by parameter "heatrate" (set via a data statement within the program source code), marsrad also outputs optical path lengths for water vapor (H2O), CO2, and dust. H2O and CO2 optical path lengths are scaled by pressure to the 0.75 power. With heatrate set to 1, the program also outputs various fluxes (W/m^2) and heating rates (K/day) as a function of pressure level. These optional outputs are:

```
 Pres    = pressure (mb)
 uH2O    = pressure-scaled H2O optical path (precipitable micrometers)
 uCO2    = pressure-scaled CO2 optical path (atmosphere-centimeters)
 udust   = dust optical depth from surface to given pressure level
 LWFup   = upwelling LW flux at pressure level
 LWFdn   = downwelling LW flux at pressure level
 LWFnet  = net (up - down) LW flux at pressure level
 LWdTdt  = LW heating rate at pressure level
 SWdTdt  = SW heating rate at pressure level
 TotdTdt = Total (LW+SW) heating rate at pressure level
```

Parameters given in Radout.txt output file (in addition to plot variables, Var_X and, optionally, Var_Y) are:

 albsfc = surface albedo (interpolated from file albedo1.txt)
 tau = total vertical dust optical depth (for solar wavelengths)
 RadAU = Mars orbital radius (AU)
 mu0 = cosine of solar zenith angle
 ice = 0 for no ice on the surface, 1 for ice on the surface
 Tsfc = ground surface temperature (K)
 Fusfc = upwelling LW flux at surface (W/m^2)
 Tsky = equivalent sky temperature (K)
 Fdsfc = downwelling LW flux at surface (W/m^2)
 Teff = effective black-body temperature at top-of atmosphere (K)
 Futoa = upwelling LW flux at top-of-atmosphere (W/m^2)
 Edsfc = downwelling SW flux at surface (W/m^2)
 Eusfc = upwelling SW flux at surface (W/m^2)
 Edtoa = solar flux at toa = mu0$\times$(solar constant)/$RadAU^2$ (W/m^2)
 Eutoa = upwelling SW flux at top-of-atmosphere (W/m^2)
 planalb = planetary albedo = ratio Eutoa/Edtoa

PROGRAM RADTRAJ

radtraj.f - special "trajectory" building program to compute vertical profiles at lat-lon, lat-time, or lon-time cross sections, for input to Mars-GRAM runs to produce output for input to marsrad radiation calculations

The radtraj.f program is similar in function and use to the bldtraj.f "trajectory" building program, except that radtraj is especially designed for use in conjunction with Mars-GRAM runs for which radiation calculations are to be done by the marsrad.f program. Program radtraj produces a "trajectory" file consisting of sets of vertical profiles (constrained to start at the surface by automatically setting z1 = -10). Any heights that are below the surface are automatically ignored by the marsrad program. Any upper height z2 and height step dz may be used for the height profiles. However, it is not necessary to use z2 higher than about 30 km. The input time step (if other than zero) applies only as the "trajectory" goes from one vertical profile to the next.

Appendix H

Wave Model Data to Reproduce Mars Global Surveyor Density

The Mars-GRAM 2001 FTP site includes input files, trajectory files, and wave model parameter files to closely reproduce atmospheric conditions observed on each periapsis pass during Mars Global Surveyor (MGS) aerobraking operations. These files are:

```
inphxper.txt - input file to reproduce MGS Phase x x = 1 or 2) periapsis
                conditions, when used with trajectory file trajphxp.txt and
                wave file wavephx.txt
trajphxp.txt - "trajectory" file for MGS Phase x periapsis conditions
wavephx.txt  - longitude-dependent wave file for MGS Phase x conditions
```

Files inph1per.txt, inph2per.txt, waveph1.txt, and waveph2.txt are also listed later in this appendix.

Mars Global Surveyor (MGS) conducted Phase 1 aerobraking during the period from 9/19/97 (orbit 5) to 3/27/98 (orbit 201), and Phase 2 aerobraking from 9/24/98 (orbit 574) to 2/4/99 (orbit 1283). These input files, "trajectory" files, and wave files allow Mars-GRAM to reproduce periapsis conditions for these two observing periods. The trajectory files give time (seconds from 00:00 on 9/10/97 for Phase 1 or 00:00 on 9/1/98 for Phase 2). Other trajectory file inputs are height (km above MOLA areoid), latitude, and East longitude at MGS periapsis, followed by MGS orbit number. Note that the input files cause Mars-GRAM to use the Ls-dependent height offset model for MTGCM data (height offsets varying from +2.5 km at Ls = 90 to +7.5 km at Ls = 270). With these offsets, plus the wave model multipliers specified in the wave model files, average ratio between MGS accelerometer-observed density and Mars-GRAM model density at periapsis is 1.000 (with standard deviation 0.237) for Phase 1 and 1.003 (with standard deviation 0.203) for Phase 2. The wave files give time (seconds from start time noted above), mean value, and amplitudes and phases of wave-1 (period = 360 degrees longitude), wave-2 (period = 180 degrees longitude) and wave-3 (period = 120 degrees longitude) longitude-dependent wave components. With the following notation for amplitudes and phases:

```
W0    = Diurnal mean value of longitude-dependent wave (LDW)
W1    = Amplitude of the wave-1 LDW component
Wphi1 = Phase (degrees) of the wave-1 LDW component
W2    = Amplitude of the wave-2 LDW component
Wphi2 = Phase (degrees) of the wave-2 LDW component
W3    = Amplitude of the wave-3 LDW component
Wphi3 = Phase (degrees) of the wave-3 LDW component
```

Longitude-dependent wave multiplier values are computed in Mars-GRAM 2001 from the relation

```
  Wave=W0+W1*Cos((pi/180)*(Lon-Wphi1))+W2*Cos((pi/180)*(2*Lon-Wphi2))
        +W3*Cos((pi/180)*(3*Lon-Wphi3))
```

where Lon is longitude (East or West, as controlled by input parameter LonEW). Note that phases Wphi2 and Wphi3 are defined differently in Mars-GRAM 2001 than they were in Mars-GRAM 2000 (with wave-2 and wave-3 phases in Mars-GRAM 2001 being, respectively, twice and 3 times their Mars-GRAM 2000 values).

Input File inph1per.txt

```
 $INPUT
```

```
  LSTFL    = 'LISTph1p.txt'
  OUTFL    = 'OUTph1p.txt'
  TRAJFL   = 'TRAJph1p.txt'
  WaveFile = 'Waveph1.txt'
  DATADIR  = 'C:\Mars\Mars2001\MGbindat\'
  GCMDIR   = 'C:\Mars\Mars2001\MGbindat\'
  MONTH    = 9
  MDAY     = 10
  MYEAR    = 97
  NPOS     = 0
  IHR      = 0
  IMIN     = 0
  SEC      = 0.0
  LonEW    = 1
  Dusttau  = 0.4
  ALS0     = 224.0
  ALSDUR   = 20.
  INTENS   = 0.6
  RADMAX   = 0.0
  DUSTLAT  = 0.0
  DUSTLON  = 0.0
  F107     = 96.5
  STDL     = 0.0
  NR1      = 1234
  NVARX    = 1
  NVARY    = 7
  LOGSCALE = 3
  zoffset  = 30.
  iup      = 13
  WaveA0   = 1.0
  WaveA1   = 0.0
  Wavephi1 = 0.0
  WaveA2   = 0.0
  Wavephi2 = 0.0
  WaveA3   = 0.0
  Wavephi3 = 0.0
  iuwave   = 22
  Wscale   = 20.
 $END
```

Input File inph2per.txt

```
 $INPUT
  LSTFL    = 'LISTph2p.txt'
  OUTFL    = 'OUTph2p.txt'
  TRAJFL   = 'TRAJph2p.txt'
  WaveFile = 'Waveph2.txt'
  DATADIR  = 'C:\Mars\Mars2001\MGbindat\'
  GCMDIR   = 'C:\Mars\Mars2001\MGbindat\'
  MONTH    = 9
  MDAY     = 1
  MYEAR    = 98
  NPOS     = 0
  IHR      = 0
  IMIN     = 0
  SEC      = 0.0
  LonEW    = 1
  Dusttau  = 0.4
  ALS0     = 0.
  ALSDUR   = 0.
```

```
  INTENS   = 0.
  RADMAX   = 0.0
  DUSTLAT  = 0.0
  DUSTLON  = 0.0
  F107     = 138.4
  STDL     = 0.0
  NR1      = 1234
  NVARX    = 1
  NVARY    = 7
  LOGSCALE = 3
  zoffset  = 30.
  iup      = 13
  WaveA0   = 1.0
  WaveA1   = 0.0
  Wavephi1 = 0.0
  WaveA2   = 0.0
  Wavephi2 = 0.0
  WaveA3   = 0.0
  Wavephi3 = 0.0
  iuwave   = 22
  Wscale   = 20.
 $END
```

File waveph1.txt

```
        0 1.214 0.1178 122.022 0.1663 212.793 0.2328  15.507
  6738103 1.539 0.0389 114.865 0.2566 171.035 0.2066 233.772
  9486031 1.537 0.2065  55.415 0.1584 186.332 0.0657 239.430
 11522840 1.103 0.0822   8.872 0.2263 201.955 0.1632 211.958
```

File waveph2.txt

```
        0 1.0374 0.0195  32.540 0.0138 148.203 0.1542 302.757
  5382321 1.3434 0.0450  63.942 0.0769 192.792 0.2478 252.980
  7575895 1.4613 0.1540  54.082 0.2577 124.496 0.3618 258.897
  9233731 1.1976 0.0684 295.716 0.2207 131.052 0.3092 263.079
 10623970 1.0581 0.1756 225.946 0.0707  79.417 0.1033   8.194
 11775860 1.0789 0.1318 188.218 0.1046 357.495 0.1032  17.713
 12266030 1.5913 0.1030 200.097 0.1676 358.661 0.0798 217.354
 12703630 1.9017 0.1664 357.026 0.2204 282.310 0.0903 220.917
 13124610 1.5241 0.0840 294.068 0.0953 256.631 0.2306 353.044
```

APPROVAL

Mars Global Reference Atmospheric Model 2001 Version
(Mars-GRAM 2001): Users Guide

C. G. Justus and D. L. Johnson

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classifications Officer. This report, in its entirety, has been determined to be unclassified.

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13. ABSTRACT (*Maximum 200 words*)

This report presents Mars Global Reference Atmospheric Model 2001 Version (Mars-GRAM 2001) and its new features. As with the previous version (Mars-GRAM 2000), all parameterizations for temperature, pressure, density, and winds versus height, latitude, longitude, time of day, and season (Ls) use input data tables from NASA Ames Mars General Circulation Model (MGCM) for the surface through 80-km altitude and the University of Arizona Mars Thermospheric General Circulation Model (MTGCM) for 80 to 170 km. Mars-GRAM 2001 is based on topography from the Mars Orbiter Laser Altimeter (MOLA) and includes new MGCM data at the topographic surface. A new auxiliary program allows Mars-GRAM output to be used to compute shortwave (solar) and longwave (thermal) radiation at the surface and top of atmosphere. This memorandum includes instructions on obtaining Mars-GRAM source code and data files and for running the program. It also provides sample input and output and an example for incorporating Mars-GRAM as an atmospheric subroutine in a trajectory code.

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