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Mars Global Reference Atmospheric Model 2000 Version (Mars–GRAM 2000): Users Guide

C.G. Justus
Computer Sciences Corporation, Huntsville, Alabama

B.F. James
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

May 2000

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National Aeronautics and
Space Administration

Marshall Space Flight Center • MSFC, Alabama 35812

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PREFACE

These improvements to the NASA/MSFC Mars Global Reference Atmospheric Model (Mars-GRAM 2000) 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)" and NASA/TM-1999-209629 "Mars Global Reference Atmospheric Model (Mars-GRAM) Version 3.8: 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 2000 (or earlier) code and data, as well as additional copies of this report, contact

Environments Group
Mail Code ED44
Marshall Space Flight Center, AL 35812

Attn: Ms. Bonnie James
Phone: (256) 544-6985
E-mail: *bonnie.james@msfc.nasa.gov*

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.

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Mars Global Reference Atmospheric Model 2000 Version (Mars-GRAM 2000): 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] among others.

Earlier Mars-GRAM versions[4-8] were based on ad-hoc parameterizations to data observed by the Mariner and Viking missions. The current Mars-GRAM version (Mars-GRAM 2000) is based on input data tables of output from the NASA Ames Mars General Circulation Model (MGCM)[9,10] and the University of Arizona Mars Thermospheric General Circulation Model (MTGCM).[11,12] 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 2000. 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 2000 input and output files and how to interpret program results.

2. New Features of Mars-GRAM 2000

2.1 Mars General Circulation Model Input Data

2.1.1 Introduction to MGCM and MTGCM Data

Earlier Mars-GRAM versions used ad-hoc 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 is celestial longitude of the Sun, as viewed from Mars. It gives time of year and Mars season. Ls = 0 is Northern spring equinox; Ls = 90° is Northern summer solstice, etc. In Mars-GRAM 2000, all data-derived parameterization relations are replaced by input data tables, based on information from the NASA Ames Mars General Circulation Model (MGCM)[9,10] and the University of Arizona Mars Thermospheric General Circulation Model (MTGCM).[11,12] 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 5 m and 30 m above the surface as a function of longitude, latitude, time of day, and Ls. MGCM data tables cover altitudes ranging from the surface to 80 km. MTGCM data tables cover 80 to 170 km-altitude. A modified (latitude-longitude dependent) Stewart-type thermospheric model[6] is still used for altitudes above 170 km, and for dependence on solar activity. The Stewart-type thermosphere model starts at a lower boundary condition at the height of the 1.26 nbar pressure level (height ZF). Between 80 km and height ZF (which is typically at about 125 km), MTGCM data are used directly. 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's MGCM and MTGCM data files are given in Appendix F. To make file transfer easy, 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.

2.1.2 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 km-height increments [starting at 0 km relative to datum level, and going to 80 km (MGCM) or 170 km (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 heights of 5 m and 30 m above local topographic height level at 9 degree-longitude spacing (for the same latitudes, Ls values, and dust optical depths).

2.1.3 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 that contain 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 (5 m or 30 m), 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 doing multi-dimensional interpolation 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 (5 m and 30 m 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

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

and evaluating pressure p(z) from the hydrostatic relation

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

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

$$R(z1) = p(z1) / [\rho(z1)\, T(z1)\,] \tag{2.4}$$

$$R(z2) = p(z2) / [\rho(z2)\, T(z2)\,] \tag{2.5}$$

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

$$\rho(z) = p(z) / [R(z)\, T(z)\,] \tag{2.6}$$

Winds at heights less than 5 m above the surface are evaluated from a logarithmic boundary layer profile relation

$$u(z) = u(5)\, \ln(z/z_0) / \ln(5/z_0) \tag{2.7}$$

$$v(z) = v(5)\, \ln(z/z_0) / \ln(5/z_0) \tag{2.8}$$

where the surface roughness parameter z_0 is taken to be 0.03 m.

2.2 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° of longitude. During aerobraking operations, accelerometer measurements by Mars Global Surveyor[13] 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 2000 includes a model for these longitude-dependent waves (LDW) of the form

$$\begin{aligned} \mathrm{LDW} &= B_0 + B_1\, Cos[\,\pi\,(\lambda - \Phi_1) / 180] + B_2\, Cos[\,\pi\,(\lambda - \Phi_2) / 90\,] \\ &\quad + B_3\, Cos[\,\pi\,(\lambda - \Phi_3) / 60\,] \end{aligned} \tag{2.9}$$

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. LDW perturbations computed by equation (2.9) are applied as a multiplier to the mean density and pressure computed from MGCM and MTGCM data, as interpolated by methods described in section 2.1.3. Wave model coefficients for equation (2.9) can be input from the NAMELIST format input file (see Appendix B), or from an auxiliary file of time-dependent wave model coefficients (see sections 3.2 and 3.3). Values of LDW coefficients may be determined empirically, such as by accelerometer observations,[13] or theoretically from wave characteristics of Mars General Circulation Models.[14]

For altitudes below 100 km, LDW perturbations are assumed to diminish in magnitude at an exponential rate, namely,

$$\mathrm{LDW}(z) = \mathrm{LDW}(100)\, exp[\,(z - 100) / S\,] \tag{2.10}$$

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

2.3 Earlier Mars-GRAM Versions and Climate Factors

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 2000 based directly on MGCM and MTGCM output (below 170 km), none of these climate factors are needed any longer (except deltaTEX, which still allows adjustment of exospheric temperature).

Adjustment of Mars-GRAM 2000 model output can still be affected by choice of dust optical depth (input parameter Dusttau), and by longitude-dependent wave parameters (discussed in section 2.2).

2.4 Simplified Perturbation Model

In previous Mars-GRAM versions, a perturbation model, based on terrain-influenced gravity waves[5] was used. In the previous model, perturbation magnitudes are proportional to terrain relief (height above surrounding topographic heights), and depend on temperature gradients (through the Brunt-Vaisala frequency), and on the ratio of surface air density to local air density. In addition to being complicated to evaluate, the previous model was found to produce perturbation magnitudes that appear to change too rapidly from place to place in response to changes in topography and temperature gradients. For Mars-GRAM 2000 a simplified perturbation model is introduced that does not require evaluation of surface density or temperature gradients. Perturbation magnitude (standard deviation, σ_D) in the new model (as a fraction of mean density) is given as a function of height, z, (km) and topographic surface height, z_S, (km) by the relation

$$\sigma_D = 0.01\,(\,25 + z_S\,)\,exp[\,(\,z - 100\,)\,/\,40\,] \tag{2.11}$$

A maximum value of 0.3 is imposed on σ_D.

2.5 Background Dust Level and Dust Storm Conditions

Background (nondust storm) dust optical depth (tau) can be specified by the input parameter, Dusttau (see section 3.2). Interpolation routines (discussed in section 2.1.3) 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

$$\text{tau} = 0.65 - 0.35\,Sin(\,\pi\,\text{Ls}\,/\,180) \tag{2.12}$$

A model for global or local-scale dust storms[5] is retained. In Mars-GRAM 2000, 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 as it varies with space, for local storms).

2.6 Choice of West or East Longitude

The astronomical community (and "official" US Geological Survey maps of Mars) use West longitude positive (0 to 360°). Engineers and spacecraft navigation teams tend to use East longitude positive (0 to 360°). A program switch (input parameter, LonEW) allows Mars-GRAM 2000 users to select either East Longitude positive, or West Longitude positive. Default (LonEW=0) is West Longitude positive. The LonEW switch also determines if the longitude-dependent wave model phase values (Φ_1 through Φ_3 in equation 2.9) are in West or East Longitude.

2.7 New File Name Input Options

Options are now provided whereby the user can specify a name for the NAMELIST format input file, for the (optional) trajectory input file, and for the (optional) file of longitude-dependent wave parameters. Users can also specify path names to the directories where the MGCM, MTGCM, and other input data reside. Upon executing the program, the user is prompted to enter a name for the NAMELIST input file. Trajectory file name is specified by input parameter, TRAJFL. Name for the longitude-dependent wave parameter file is given by input parameter, WaveFile. Path names for COSPAR and topographic data and for MGCM and MTGCM data are parameters, DATADIR and GCMDIR, respectively. See details in Appendix B.

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 and F 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 ARCHGTS.DAT (topographic height information) and COSPAR.DAT (COSPAR model atmosphere data) are in an appropriate directory (whose pathname is specified by parameter DATADIR in the NAMELIST format input file)
- Compile and run the makebin.f program (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 the 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 2.2; further discussion below)

- 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, ARCHGTS.DAT and COSPAR.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, 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 2000. Whether the subroutine or stand alone version is used, input variables whose values must be 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)
DATADIR	Pathname to directory for the COSPAR data and topographic height data
GCMDIR	Pathname to directory for MGCM and MTGCM binary data files
MONTH	Month (1 through 12) for initial time
MDAY	Day of month for initial time

MYEAR	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	Initial time, hour of day UTC (GMT)
IMIN	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)
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
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); intensity value (if > 0) must be greater than Dusttau
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 perturbation 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 reference ellipsoid)
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
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
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<=Wscale<=10 000 km)

Two auxiliary input files are required (in addition to the MGCM and MTGCM input data files). Auxiliary file ARCHGTS.DAT contains topographic height data (height, km, above the reference ellipsoid datum level). File COSPAR.DAT contains COSPAR reference values of temperature, density, and pressure as a function of height.

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.

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. See the list of codes for x-code and y-code in Appendix A.

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 15, and re-compiling the program.

4. Sample Results

4.1 Model Variations with Latitude, Season, Height, and Time of Day

Because of its small mass, the atmosphere of Mars has low heat capacity and little physical inertia. Therefore, it responds dramatically to changes in heat input (such as diurnal and seasonal changes in solar radiation) and mechanical forcing (such as winds flowing over strong topographic relief). This fact is illustrated by Figure 4.1, which shows seasonal and latitudinal variations of daily average atmospheric density at 100-km altitude. This figure shows seasonal variation by almost a factor of 30 between southern winter solstice (Ls = 90°) and southern summer solstice (Ls = 270°) in the south polar region at this altitude.

Figures 4.2 and 4.3 illustrate temperature versus height and latitude at Ls = 270°, with tau = 0.3 and moderate solar activity, at 3 AM and 3 PM local solar time, respectively. Near-surface temperatures at 3 AM show strong inversion. Near-surface temperature inversions between about 30° and 60° N latitude are also evident at 3 PM. Sharp north-south temperature gradients are seen from the surface to about 40-km altitude near the north polar cap edge (about 60° N). Strong diurnal changes in temperature (differences between 3 PM and 3 AM values) are seen in northern latitudes above about 150 km and in southern latitudes near the surface.

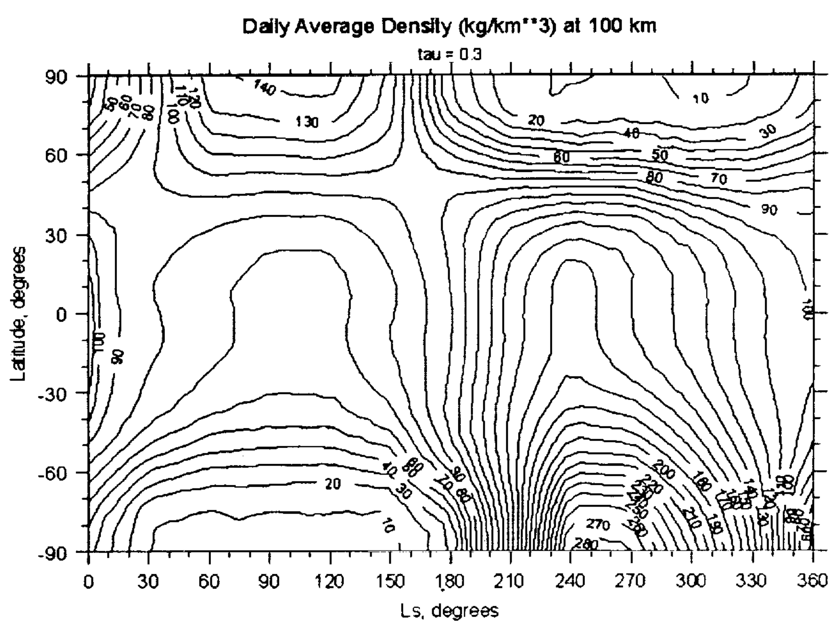

Figure 4.1. Variation of daily average atmospheric density with latitude and season (Ls angle) at 100 km altitude. Density units are kg/km^3. Dust optical depth (tau) is 0.3.

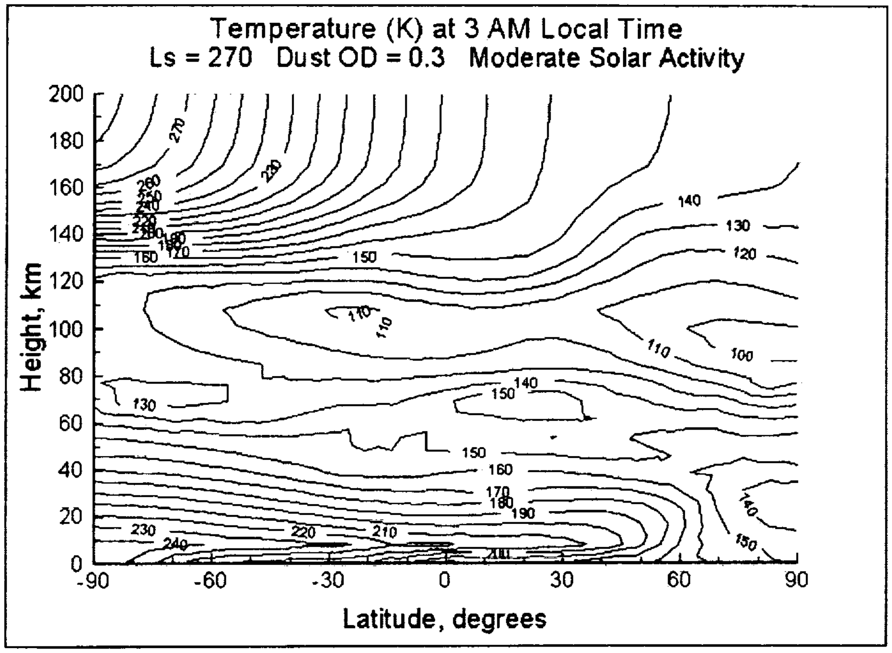

Figure 4.2. Temperature at 3 AM local solar time at Ls 270° versus height and latitude. Dust optical depth (tau) is 0.3 and solar activity is moderate.

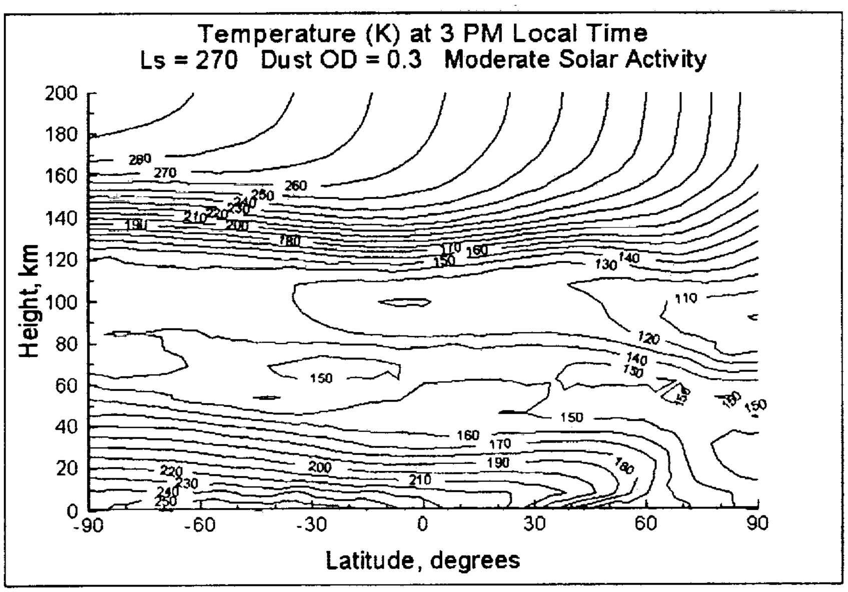

Figure 4.3. Temperature at 3 PM local solar time at Ls 270° versus height and latitude. Dust optical depth (tau) is 0.3 and solar activity is moderate.

Figures 4.4 and 4.5 show zonal (Eastward) winds versus height and latitude at Ls = 270° with tau = 0.3 and moderate solar activity at 3 AM and 3 PM local solar time, respectively. A strong polar jet is evident at both times of day, centered at about 40 km altitude, near 60° N.

Zones of strong, oppositely-directed winds above about 150-km altitude exhibit large diurnal variation.

4.2 Comparisons with Observations

As illustrated in Figure 4.6, Mars-GRAM 2000 compares favorably with observed atmospheric density measured during entry and descent of Mars Pathfinder.[15] Model evaluation was at the same location, date, and time of day as the entry observations.

Figure 4.7 compares temperature measured at a height of 1 m above the surface by Mars Pathfinder lander, with comparable temperature estimates from Mars-GRAM 2000. Pathfinder data represent averages of the entire period of its surface operation, with bars on the data points showing ± 1 standard deviation. Model values are indicated for dates near the beginning and end of Pathfinder lander operations for dust optical depths (tau) of 0.5 and 0.6, the approximate values observed at these times.

Observed average daily maximum, minimum, and average surface air temperatures (1.6 m level) from Viking 2 lander are compared with Mars-GRAM 2000 modeled surface air temperature in Figure 4.8. Model values assume an annual variation of dust optical depth (tau) between 0.3 and 1.0, given by equation (2.12). Large symbols show observed average daily

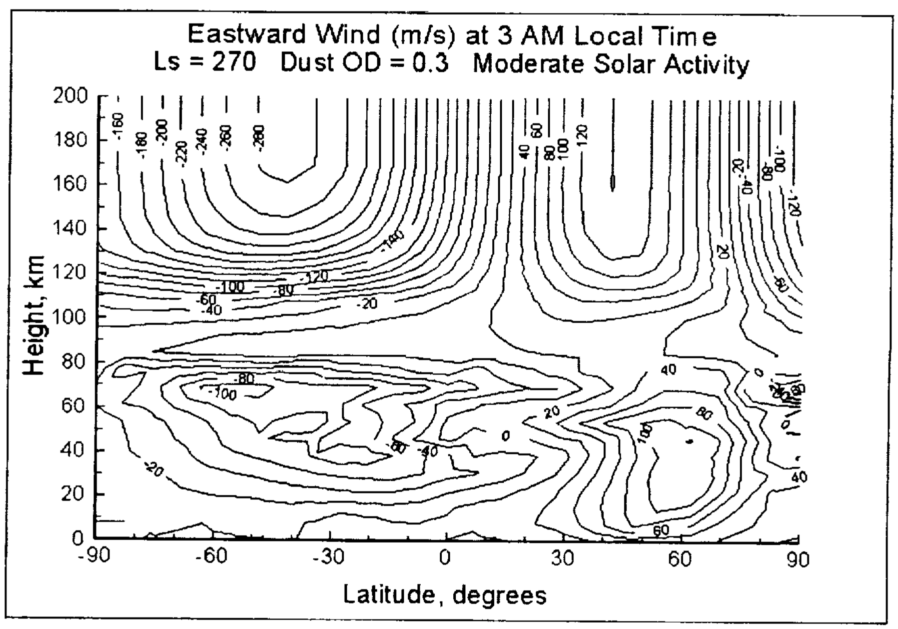

Figure 4.4. Eastward wind at 3 AM local solar time at Ls 270° versus height and latitude. Dust optical depth (tau) is 0.3, and solar activity is moderate.

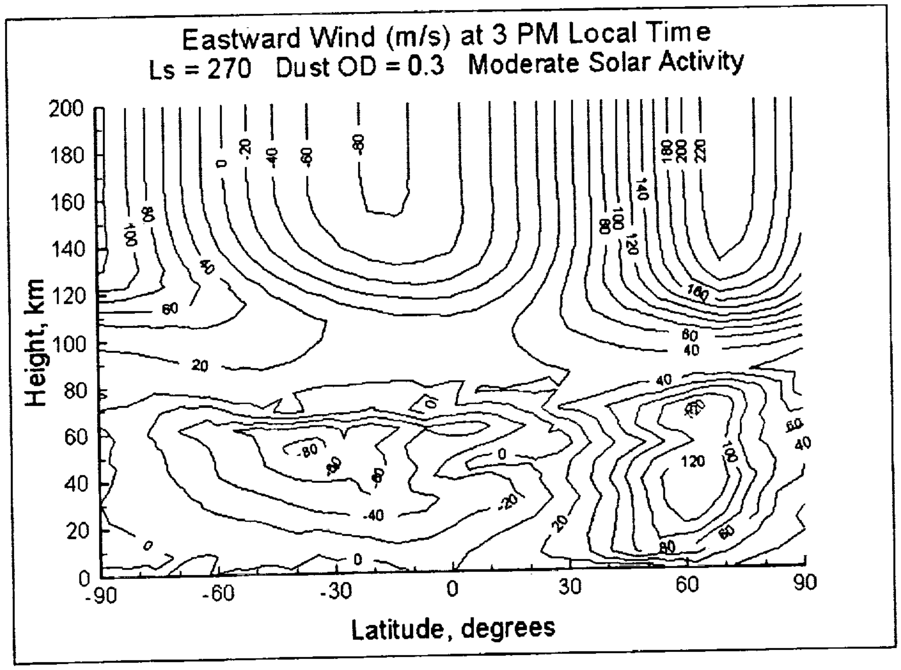

Figure 4.5. Eastward wind at 3 PM local solar time at Ls 270° versus height and latitude. Dust optical depth (tau) is 0.3, and solar activity is moderate.

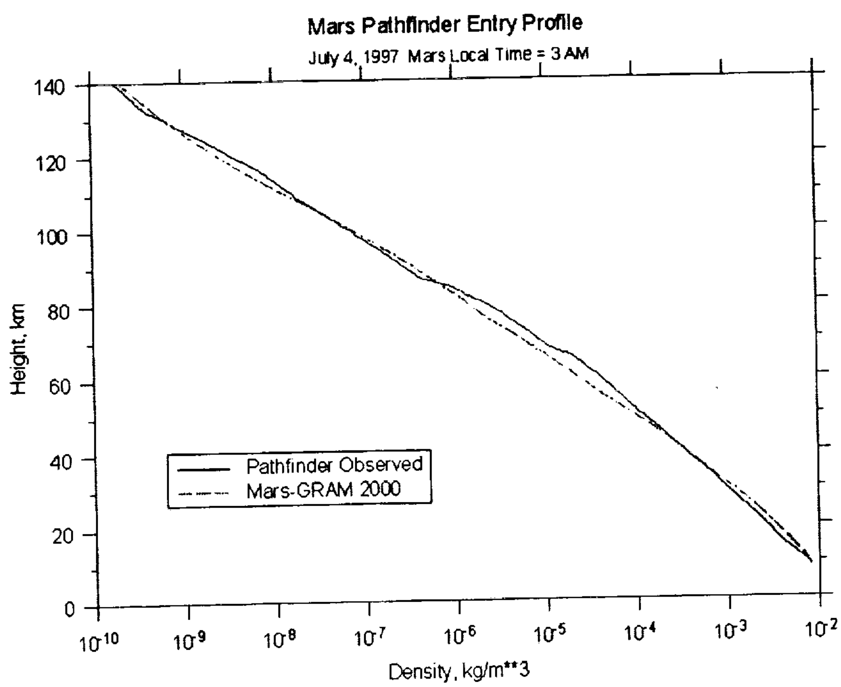

Figure 4.6. Atmospheric density measured during entry and descent by Mars Pathfinder,[15] and modeled by Mars-GRAM 2000 for the same date and time.

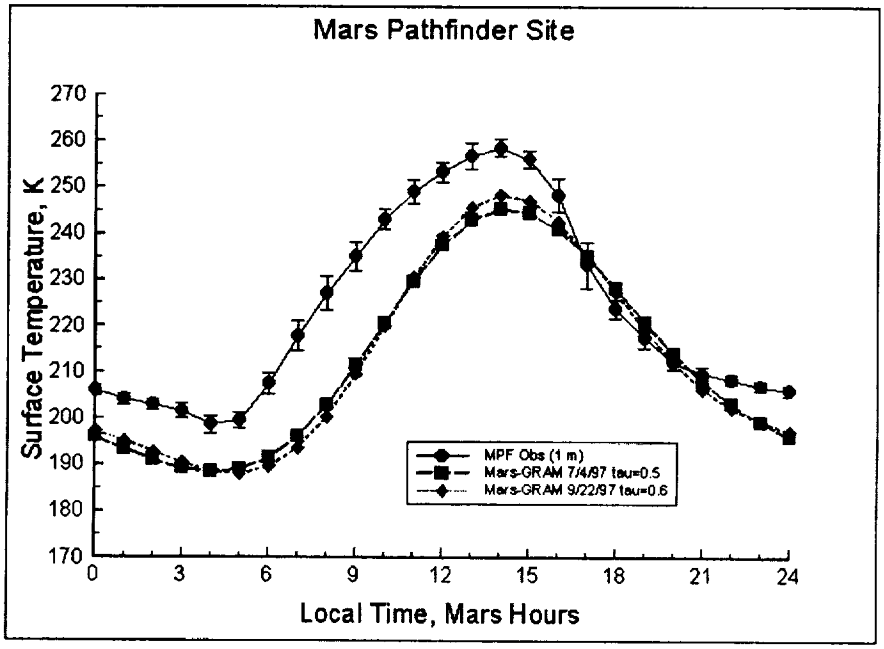

Figure 4.7. Average temperature observed at 1-m height by Mars Pathfinder lander compared with Mars-GRAM 2000 values near beginning and end of Pathfinder operations. Bars on Pathfinder data points indicate ± 1 standard deviation.

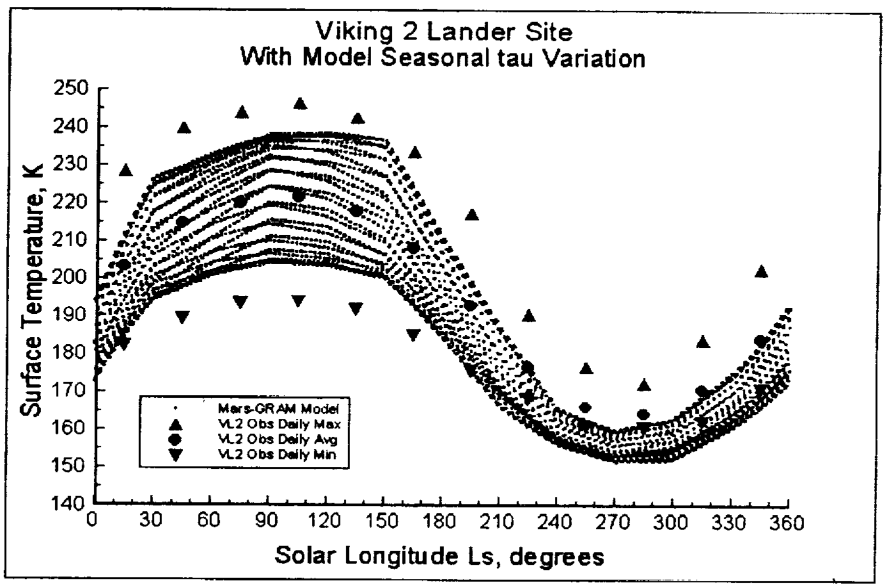

Figure 4.8. Observed average daily maximum, minimum, and average surface air temperature (1.6-m level) from Viking 2 lander and Mars-GRAM 2000 modeled surface air temperature for a full Mars year. Model values assume an annual variation of dust optical depth (tau) between 0.3 and 1.0, given by equation (2.12).

maximum, daily mean, and daily minimum by 30 degree Ls intervals. Small dots show Mars-GRAM 2000 temperature every few hours for the entire Mars year, from which the envelope of daily maximum and daily minimum can be inferred. Between about Ls = 200 and Ls = 330, observed data are influenced by two global-scale dust storms that occurred during the Viking observation period. No dust storm effects are included in the Mars-GRAM 2000 simulations in Figure 4.8.

Figure 4.9 shows gradient of atmospheric density with latitude (% per degree) as measured by Mars Global Surveyor (MGS) accelerometer[13] at 130-km altitude on inbound and outbound legs of each periapsis pass during phase 1 aerobraking, compared with modeled density gradient from Mars-GRAM 3.8 and Mars-GRAM 2000. This figure shows that usage of MTGCM data input in Mars-GRAM 2000 results in considerable improvement in density gradient estimates over that of Mars-GRAM 3.8.

Atmospheric density at periapsis measured by MGS accelerometer[13] during phase 2 aerobraking is compared in Figure 4.10 with modeled density from Mars-GRAM 3.8 and Mars-GRAM 2000. As evidenced by the "sawtooth" pattern in modeled values, particularly noticeable between orbits 700 and 900, much of the density variation with orbit is due to altitude changes from orbit-to-orbit. Additional large variations in observed density from orbit-to-orbit are due to observed longitude-dependent waves,[13] not represented in the model results, except by application of the mean coefficient (B_0 in equation (2.9)). Values of B_0 used in Figure 4.10 are 1.5 for Mars-GRAM 3.8 and 1.7 for Mars-GRAM 2000 results. At about the time of orbit 1200, MGS made its closet pass to the south (winter) pole. Figure 4.10 shows considerable improvement in representation of density near this zone for Mars-GRAM 2000 versus that for Mars-GRAM 3.8.

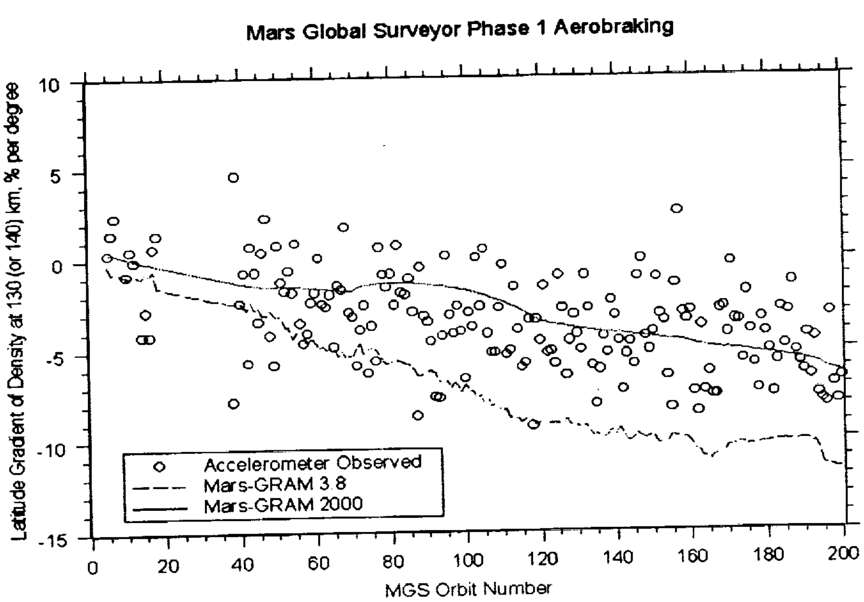

Figure 4.9. Gradient of atmospheric density with latitude (% per degree) as measured by Mars Global Surveyor accelerometer[13] at 130-km altitude on inbound and outbound legs of each periapsis pass during phase 1 aerobraking, compared with modeled density gradient from Mars-GRAM 3.8 and Mars-GRAM 2000.

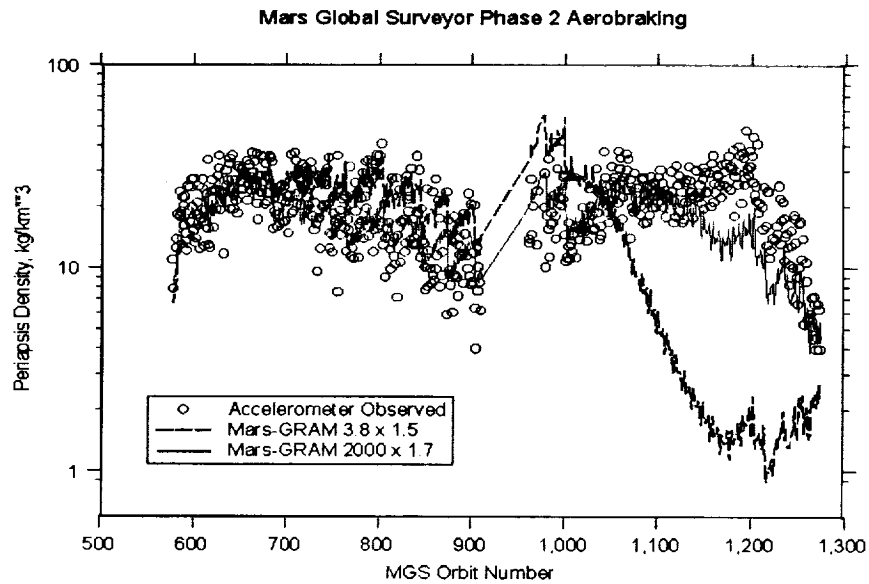

Figure 4.10. Atmospheric density at periapsis measured by Mars Global Surveyor accelerometer[13] during phase 2 aerobraking, compared with modeled density from Mars-GRAM 3.8 and Mars-GRAM 2000.

5. References

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Appendix A

Headers for Mars-GRAM 2000 Output Files

Mars-GRAM 2000 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 reference ellipsoid (km)
Lat = latitude (degrees, North positive)
LonW/LonE = longitude (degrees, West positive or East Positive)
DensAV = average (mean plus wave-perturbed) density (kg/m^3 or
    Log-10 if LOGSCALE = 1 or % from COSPAR if LOGSCALE = 2)
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)
DensDay = Local daily average density (kg/m^3)
EWwnDay = Local daily average Eastward wind (m/s)
NSwnDay = Local daily average Northward wind (m/s)

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, controlled by LOGSCALE)
DENSAV = average (mean plus wave-perturbed) density (kg/m^3 or
    Log-10 or % from COSPAR, controlled by LOGSCALE)

DENSHI = high (~ average + 1 standard deviation) density (kg/m^3 or
Log-10 or % from COSPAR, controlled by LOGSCALE)
DENSTOT = total (mean plus perturbed) density (kg/m^3 or
Log-10 or % from COSPAR, controlled by LOGSCALE)
DustOD = dust optical depth

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)

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)
TdegC = mean temperature (degrees C)
Pres_mb = mean (plus wave-perturbed) pressure (mb)
Hrho = density scale height (km)

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 reference ellipsoid, km)
2	Height (above local terrain, 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)

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 2000. 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\Mars2000\MGbindat\'
 GCMDIR   = 'C:\Mars\Mars2000\MGbindat\'
 MONTH    = 7
 MDAY     = 20
 MYEAR    = 76
 NPOS     = 41
 IHR      = 12
 IMIN     = 30
 SEC      = 0.0
 LonEW    = 0
 Dusttau  = 0.3
 ALS0     = 0.0
 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.
 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     =  month of year
MDAY      =  day of month
MYEAR     =  year (4-digit; 1970-2069 can be 2-digit)
NPOS      =  max # positions to evaluate (0 = read data from trajectory
              input file)
IHR       =  UTC (GMT) hour of day
IMIN      =  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), 0.3 to 3.0, or use
              0 for a Viking-like annual variation of background dust
ALS0      =  starting Ls value (degrees) for dust storm (0 = none)
INTENS    =  dust storm intensity (0.0 - 3.0). Storm intensity (>0) must
              be larger than Dusttau.
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 ref. ellipse).
              See file xycodes.txt
NVARY     =  y-code for 3-D plotable output (0 for 2-D plots)
LOGSCALE =   0=regular linear scale, 1=log-base-10 scale, 2=percentage
              deviations from COSPAR model
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), above ref. ellipsoid
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 "listmg2k.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 listmg2k.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)

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Mars-GRAM 2000 (Version 1) - March, 2000
LIST file= LIST.txt        OUTPUT file= OUTPUT.txt
Data directory= C:\Mars\Mars2000\MGbindat\
GCM  directory= C:\Mars\Mars2000\MGbindat\
Date =  7/20/1976  Julian Date = 2442980.0  UTC Time = 12:30:  .0
deltaTEX=      .0
F10.7 flux =  68.0 (1 AU)   25.0 (Mars),  standard deviation =   .0
  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 =  -1.54 km (    .00 km)   Scale Hgt H(p) = 11.75 H(rho) = 13.27 km
Latitude =   22.48  degrees        Longitude =   47.97 W ( 312.03 E) degrees
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.       Local Time =  16.05 Mars hours
Temperature =   234.9 K            Pressure =    8.484E+02 N/m**2
Density (Low, Avg., High) =      1.873E-02   1.911E-02   1.950E-02 kg/m**3
Departure, COSPAR NH Mean =         4.7 %        6.8 %        8.9 %
Tot.Dens. = 1.907E-02 kg/m**3  Dens.Pert. =   -.25% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     7.6     2.1     9.8 m/s
Northward Wind (Mean, Perturbed, Total) =    -3.0    -1.4    -4.4 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =      500.0 sec. (     .006 sols)  Ls =  97.0  Dust =  .30
Height =     .00 km (   1.33 km)  Scale Hgt H(p) = 11.31 H(rho) = 13.25 km
Latitude =   22.98  degrees        Longitude =   48.47 W ( 311.53 E) degrees
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  110.80 deg.       Local Time =  16.16 Mars hours
Temperature =   230.7 K            Pressure =    7.437E+02 N/m**2
Density (Low, Avg., High) =      1.672E-02   1.706E-02   1.740E-02 kg/m**3
Departure, COSPAR NH Mean =         7.9 %       10.1 %       12.3 %
Tot.Dens. = 1.700E-02 kg/m**3  Dens.Pert. =   -.34% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    14.1     -.9    13.2 m/s
Northward Wind (Mean, Perturbed, Total) =    -4.4     1.2    -3.3 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =     1000.0 sec. (     .011 sols)  Ls =  97.0  Dust =  .30
Height =    5.00 km (   5.65 km)  Scale Hgt H(p) = 10.54 H(rho) = 11.90 km
Latitude =   23.48  degrees        Longitude =   48.97 W ( 311.03 E) degrees
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Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  112.83 deg.      Local Time =  16.26 Mars hours
Temperature =   216.3 K           Pressure =    4.777E+02 N/m**2
Density (Low, Avg., High) =      1.142E-02   1.169E-02   1.195E-02 kg/m**3
Departure, COSPAR NH Mean =        15.4 %      18.1 %      20.7 %
Tot.Dens. = 1.203E-02 kg/m**3  Dens.Pert. =   2.93% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     6.6   -2.5    4.1 m/s
Northward Wind (Mean, Perturbed, Total) =    -3.2   -1.9   -5.1 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =    1500.0 sec. (    .017 sols)  Ls =  97.0  Dust =  .30
Height =  10.00 km (   9.70 km)   Scale Hgt H(p) = 10.06 H(rho) = 11.32 km
Latitude =   23.98  degrees       Longitude =   49.47 W ( 310.53 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  114.86 deg.      Local Time =  16.36 Mars hours
Temperature =   205.1 K           Pressure =    2.973E+02 N/m**2
Density (Low, Avg., High) =      7.469E-03   7.673E-03   7.878E-03 kg/m**3
Departure, COSPAR NH Mean =        15.4 %      18.6 %      21.8 %
Tot.Dens. = 7.371E-03 kg/m**3  Dens.Pert. =  -3.94% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    -2.9   -2.6   -5.4 m/s
Northward Wind (Mean, Perturbed, Total) =     1.6    1.4    3.0 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =    2000.0 sec. (    .023 sols)  Ls =  97.0  Dust =  .30
Height =  15.00 km (  14.63 km)   Scale Hgt H(p) =  9.55 H(rho) = 10.69 km
Latitude =   24.48  degrees       Longitude =   49.97 W ( 310.03 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  116.89 deg.      Local Time =  16.46 Mars hours
Temperature =   194.2 K           Pressure =    1.810E+02 N/m**2
Density (Low, Avg., High) =      4.783E-03   4.932E-03   5.082E-03 kg/m**3
Departure, COSPAR NH Mean =        14.7 %      18.3 %      21.9 %
Tot.Dens. = 4.848E-03 kg/m**3  Dens.Pert. =  -1.70% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -27.0     .0  -27.0 m/s
Northward Wind (Mean, Perturbed, Total) =     9.0    -.6    8.3 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =    2500.0 sec. (    .028 sols)  Ls =  97.0  Dust =  .30
Height =  20.00 km (  19.57 km)   Scale Hgt H(p) =  9.02 H(rho) = 10.17 km
Latitude =   24.98  degrees       Longitude =   50.47 W ( 309.53 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  118.91 deg.      Local Time =  16.56 Mars hours
Temperature =   183.8 K           Pressure =    1.074E+02 N/m**2
Density (Low, Avg., High) =      2.984E-03   3.090E-03   3.197E-03 kg/m**3
Departure, COSPAR NH Mean =        13.5 %      17.5 %      21.6 %
Tot.Dens. = 3.153E-03 kg/m**3  Dens.Pert. =   2.01% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -30.5   -4.3  -34.8 m/s
Northward Wind (Mean, Perturbed, Total) =    11.0     .3   11.4 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =    3000.0 sec. (    .034 sols)  Ls =  97.0  Dust =  .30
Height =  25.00 km (  24.51 km)   Scale Hgt H(p) =  8.50 H(rho) =  9.56 km
Latitude =   25.48  degrees       Longitude =   50.97 W ( 309.03 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  120.94 deg.      Local Time =  16.66 Mars hours
Temperature =   172.9 K           Pressure =    6.184E+01 N/m**2
Density (Low, Avg., High) =      1.818E-03   1.892E-03   1.966E-03 kg/m**3
Departure, COSPAR NH Mean =        12.2 %      16.8 %      21.4 %
Tot.Dens. = 1.770E-03 kg/m**3  Dens.Pert. =  -6.43% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -40.7    -.3  -41.0 m/s
Northward Wind (Mean, Perturbed, Total) =     6.1    8.1   14.2 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =    3500.0 sec. (    .039 sols)  Ls =  97.0  Dust =  .30
Height =  30.00 km (  29.46 km)   Scale Hgt H(p) =  8.02 H(rho) =  8.82 km
Latitude =   25.98  degrees       Longitude =   51.47 W ( 308.53 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  122.97 deg.      Local Time =  16.77 Mars hours
Temperature =   162.3 K           Pressure =    3.445E+01 N/m**2
Density (Low, Avg., High) =      1.073E-03   1.123E-03   1.173E-03 kg/m**3
Departure, COSPAR NH Mean =         9.5 %      14.6 %      19.7 %
Tot.Dens. = 1.146E-03 kg/m**3  Dens.Pert. =   2.05% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   -55.4    -.3  -55.7 m/s
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Northward Wind (Mean, Perturbed, Total) =     3.6   -6.2   -2.6 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =     4000.0 sec. (     .045 sols)  Ls =  97.0  Dust =  .30
Height =  35.00 km (  34.40 km)   Scale Hgt H(p) =  7.64 H(rho) =  8.42 km
Latitude =   26.48  degrees       Longitude =   51.97 W ( 308.03 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  125.00 deg.      Local Time =  16.87 Mars hours
Temperature =   153.5 K           Pressure =    1.854E+01 N/m**2
Density (Low, Avg., High) =     6.067E-04   6.389E-04   6.711E-04 kg/m**3
Departure, COSPAR NH Mean =        4.2 %        9.8 %        15.3 %
Tot.Dens. = 6.254E-04 kg/m**3  Dens.Pert. =  -2.11% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -65.8   -1.2  -67.0 m/s
Northward Wind (Mean, Perturbed, Total) =   -6.8    3.6   -3.2 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =     4500.0 sec. (     .051 sols)  Ls =  97.0  Dust =  .30
Height =  40.00 km (  39.35 km)   Scale Hgt H(p) =  7.30 H(rho) =  7.86 km
Latitude =   26.98  degrees       Longitude =   52.47 W ( 307.53 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  127.02 deg.      Local Time =  16.97 Mars hours
Temperature =   144.5 K           Pressure =    9.678E+00 N/m**2
Density (Low, Avg., High) =     3.342E-04   3.545E-04   3.747E-04 kg/m**3
Departure, COSPAR NH Mean =       -1.7 %        4.3 %        10.2 %
Tot.Dens. = 3.800E-04 kg/m**3  Dens.Pert. =   7.21% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -75.6    8.3  -67.3 m/s
Northward Wind (Mean, Perturbed, Total) =   -6.6   -7.6  -14.1 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =     5000.0 sec. (     .056 sols)  Ls =  97.0  Dust =  .30
Height =  45.00 km (  44.30 km)   Scale Hgt H(p) =  7.03 H(rho) =  7.37 km
Latitude =   27.48  degrees       Longitude =   52.97 W ( 307.03 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  129.05 deg.      Local Time =  17.07 Mars hours
Temperature =   137.7 K           Pressure =    4.903E+00 N/m**2
Density (Low, Avg., High) =     1.763E-04   1.885E-04   2.008E-04 kg/m**3
Departure, COSPAR NH Mean =       -9.1 %       -2.8 %         3.5 %
Tot.Dens. = 1.786E-04 kg/m**3  Dens.Pert. =  -5.28% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -80.2   -5.0  -85.2 m/s
Northward Wind (Mean, Perturbed, Total) =  -17.3   -1.7  -19.0 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =     5500.0 sec. (     .062 sols)  Ls =  97.0  Dust =  .30
Height =  50.00 km (  49.26 km)   Scale Hgt H(p) =  6.92 H(rho) =  6.85 km
Latitude =   27.98  degrees       Longitude =   53.47 W ( 306.53 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  131.08 deg.      Local Time =  17.17 Mars hours
Temperature =   133.1 K           Pressure =    2.420E+00 N/m**2
Density (Low, Avg., High) =     8.915E-05   9.625E-05   1.034E-04 kg/m**3
Departure, COSPAR NH Mean =      -17.4 %      -10.9 %        -4.3 %
Tot.Dens. = 9.062E-05 kg/m**3  Dens.Pert. =  -5.85% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) = -106.7    5.5 -101.2 m/s
Northward Wind (Mean, Perturbed, Total) =   -8.1    6.5   -1.5 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =     6000.0 sec. (     .068 sols)  Ls =  97.0  Dust =  .30
Height =  55.00 km (  54.22 km)   Scale Hgt H(p) =  6.76 H(rho) =  6.36 km
Latitude =   28.48  degrees       Longitude =   53.97 W ( 306.03 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  133.11 deg.      Local Time =  17.28 Mars hours
Temperature =   134.1 K           Pressure =    1.180E+00 N/m**2
Density (Low, Avg., High) =     4.272E-05   4.662E-05   5.052E-05 kg/m**3
Departure, COSPAR NH Mean =      -27.8 %      -21.2 %       -14.7 %
Tot.Dens. = 4.460E-05 kg/m**3  Dens.Pert. =  -4.33% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -93.0  -14.7 -107.7 m/s
Northward Wind (Mean, Perturbed, Total) =   14.7   -6.0    8.6 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =     6500.0 sec. (     .073 sols)  Ls =  97.0  Dust =  .30
Height =  60.00 km (  59.20 km)   Scale Hgt H(p) =  7.01 H(rho) =  6.75 km
Latitude =   28.98  degrees       Longitude =   54.47 W ( 305.53 E) degrees
Sun Latitude =    25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  135.13 deg.      Local Time =  17.38 Mars hours
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Temperature =    140.5 K           Pressure =    5.658E-01 N/m**2
Density (Low, Avg., High) =      1.932E-05   2.134E-05   2.337E-05 kg/m**3
Departure, COSPAR NH Mean =        -39.3 %     -32.9 %     -26.5 %
Tot.Dens. = 1.953E-05 kg/m**3  Dens.Pert. =  -8.48% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -27.2   -3.9  -31.1 m/s
Northward Wind (Mean, Perturbed, Total) =   21.1  -14.5    6.5 m/s
---------------------------------------------------------------------
Time (rel. to T0) =    7000.0 sec. (    .079 sols)  Ls =  97.0  Dust =  .30
Height =  65.00 km (  64.18 km)   Scale Hgt H(p) =  7.10 H(rho) =  7.24 km
Latitude =   29.48  degrees        Longitude =   54.97 W ( 305.03 E) degrees
Sun Latitude =     25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  137.16 deg.       Local Time =  17.48 Mars hours
Temperature =    144.3 K           Pressure =    2.781E-01 N/m**2
Density (Low, Avg., High) =      9.122E-06   1.022E-05   1.132E-05 kg/m**3
Departure, COSPAR NH Mean =        -45.7 %     -39.2 %     -32.6 %
Tot.Dens. = 1.029E-05 kg/m**3  Dens.Pert. =    .67% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   24.3    -.1   24.1 m/s
Northward Wind (Mean, Perturbed, Total) =    9.2  -12.0   -2.8 m/s
---------------------------------------------------------------------
Time (rel. to T0) =    7500.0 sec. (    .084 sols)  Ls =  97.0  Dust =  .30
Height =  70.00 km (  69.16 km)   Scale Hgt H(p) =  6.99 H(rho) =  7.35 km
Latitude =   29.98  degrees        Longitude =   55.47 W ( 304.53 E) degrees
Sun Latitude =     25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  139.19 deg.       Local Time =  17.58 Mars hours
Temperature =    142.1 K           Pressure =    1.377E-01 N/m**2
Density (Low, Avg., High) =      4.510E-06   5.137E-06   5.764E-06 kg/m**3
Departure, COSPAR NH Mean =        -48.3 %     -41.2 %     -34.0 %
Tot.Dens. = 5.212E-06 kg/m**3  Dens.Pert. =   1.45% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =   28.3     .5   28.8 m/s
Northward Wind (Mean, Perturbed, Total) =    7.0    9.3   16.3 m/s
---------------------------------------------------------------------
Time (rel. to T0) =    8000.0 sec. (    .090 sols)  Ls =  97.0  Dust =  .30
Height =  75.00 km (  74.11 km)   Scale Hgt H(p) =  7.24 H(rho) =  7.26 km
Latitude =   30.48  degrees        Longitude =   55.97 W ( 304.03 E) degrees
Sun Latitude =     25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  141.22 deg.       Local Time =  17.68 Mars hours
Temperature =    136.8 K           Pressure =    6.742E-02 N/m**2
Density (Low, Avg., High) =      2.246E-06   2.607E-06   2.969E-06 kg/m**3
Departure, COSPAR NH Mean =        -49.8 %     -41.7 %     -33.6 %
Tot.Dens. = 2.530E-06 kg/m**3  Dens.Pert. =  -2.96% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    8.6  -41.7  -33.1 m/s
Northward Wind (Mean, Perturbed, Total) =  -14.8   -8.3  -23.1 m/s
---------------------------------------------------------------------
Time (rel. to T0) =    8500.0 sec. (    .096 sols)  Ls =  97.0  Dust =  .30
Height =  80.00 km (  79.06 km)   Scale Hgt H(p) =  7.00 H(rho) =  7.16 km
Latitude =   30.98  degrees        Longitude =   56.47 W ( 303.53 E) degrees
Sun Latitude =     25.00 deg.      Mars Orbital Radius = 1.649 AU
Sun Longitude =  143.25 deg.       Local Time =  17.79 Mars hours
Temperature =    130.5 K           Pressure =    3.396E-02 N/m**2
Density (Low, Avg., High) =      1.108E-06   1.314E-06   1.521E-06 kg/m**3
Departure, COSPAR NH Mean =        -51.6 %     -42.6 %     -33.6 %
Tot.Dens. = 1.309E-06 kg/m**3  Dens.Pert. =   -.42% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    7.1  -61.4  -54.3 m/s
Northward Wind (Mean, Perturbed, Total) =   -6.1    6.9     .8 m/s
---------------------------------------------------------------------
Time (rel. to T0) =    9000.0 sec. (    .101 sols)  Ls =  97.0  Dust =  .30
Height =  85.00 km (  84.00 km)   Scale Hgt H(p) =  6.83 H(rho) =  7.01 km
Latitude =   31.48  degrees        Longitude =   56.97 W ( 303.03 E) degrees
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 =  160.4 K    Zbase =  120.2 km
Solar Zenith Angle =  75.9 deg     F1 peak = 133.1 km    Mol.Wgt. = 41.50
Temperature =    127.2 K           Pressure =    1.672E-02 N/m**2
Density (Low, Avg., High) =      5.390E-07   6.562E-07   7.735E-07 kg/m**3
Departure, COSPAR NH Mean =        -53.9 %     -43.9 %     -33.9 %
Tot.Dens. = 7.052E-07 kg/m**3  Dens.Pert. =   7.46% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    9.5  -30.1  -20.6 m/s
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Northward Wind (Mean, Perturbed, Total) =    -9.4   -7.0  -16.5 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =     9500.0 sec. (    .107 sols)  Ls =  97.1  Dust =  .30
Height =  90.00 km (  88.95 km)   Scale Hgt H(p) =   6.93 H(rho) =   6.90 km
Latitude =   31.98  degrees        Longitude =   57.47 W ( 302.53 E) degrees
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 =  160.1 K     Zbase =  120.3 km
Solar Zenith Angle =  76.9 deg     F1 peak = 133.8 km     Mol.Wgt. = 41.83
Temperature =    126.0 K           Pressure =    8.106E-03 N/m**2
Density (Low, Avg., High) =       2.579E-07   3.236E-07   3.892E-07 kg/m**3
Departure, COSPAR NH Mean =         -57.1 %      -46.2 %      -35.2 %
Tot.Dens. = 2.988E-07 kg/m**3  Dens.Pert. =  -7.66% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     9.1     3.6   12.7 m/s
Northward Wind (Mean, Perturbed, Total) =   -14.8  -23.4  -38.2 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =    10000.0 sec. (    .113 sols)  Ls =  97.1  Dust =  .30
Height =  95.00 km (  93.90 km)   Scale Hgt H(p) =   6.76 H(rho) =   6.83 km
Latitude =   32.48  degrees        Longitude =   57.97 W ( 302.03 E) degrees
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 =  159.9 K     Zbase =  120.4 km
Solar Zenith Angle =  77.9 deg     F1 peak = 134.5 km     Mol.Wgt. = 41.58
Temperature =    126.0 K           Pressure =    3.982E-03 N/m**2
Density (Low, Avg., High) =       1.216E-07   1.581E-07   1.945E-07 kg/m**3
Departure, COSPAR NH Mean =         -60.6 %      -48.8 %      -37.1 %
Tot.Dens. = 1.199E-07 kg/m**3  Dens.Pert. = -24.16% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     6.2     4.9   11.1 m/s
Northward Wind (Mean, Perturbed, Total) =   -22.3  -38.7  -61.1 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =    10500.0 sec. (    .118 sols)  Ls =  97.1  Dust =  .30
Height = 100.00 km (  98.84 km)   Scale Hgt H(p) =   7.09 H(rho) =   6.87 km
Latitude =   32.98  degrees        Longitude =   58.47 W ( 301.53 E) degrees
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 =  159.6 K     Zbase =  120.5 km
Solar Zenith Angle =  78.9 deg     F1 peak = 135.3 km     Mol.Wgt. = 42.08
Temperature =    126.7 K           Pressure =    1.925E-03 N/m**2
Density (Low, Avg., High) =       5.678E-08   7.689E-08   9.700E-08 kg/m**3
Departure, COSPAR NH Mean =         -64.3 %      -51.6 %      -39.0 %
Tot.Dens. = 6.038E-08 kg/m**3  Dens.Pert. = -21.48% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =      .9  -11.6  -10.7 m/s
Northward Wind (Mean, Perturbed, Total) =   -30.2  -13.9  -44.1 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =    11000.0 sec. (    .124 sols)  Ls =  97.1  Dust =  .30
Height = 105.00 km ( 103.79 km)   Scale Hgt H(p) =   6.99 H(rho) =   6.75 km
Latitude =   33.48  degrees        Longitude =   58.97 W ( 301.03 E) degrees
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 =  159.3 K     Zbase =  120.6 km
Solar Zenith Angle =  79.9 deg     F1 peak = 136.2 km     Mol.Wgt. = 41.60
Temperature =    128.3 K           Pressure =    9.645E-04 N/m**2
Density (Low, Avg., High) =       2.644E-08   3.761E-08   4.877E-08 kg/m**3
Departure, COSPAR NH Mean =         -67.0 %      -53.1 %      -39.1 %
Tot.Dens. = 2.563E-08 kg/m**3  Dens.Pert. = -31.84% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    -6.8  -38.7  -45.6 m/s
Northward Wind (Mean, Perturbed, Total) =   -36.0    3.0  -33.0 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =    11500.0 sec. (    .130 sols)  Ls =  97.1  Dust =  .30
Height = 110.00 km ( 108.74 km)   Scale Hgt H(p) =   7.49 H(rho) =   6.72 km
Latitude =   33.98  degrees        Longitude =   59.47 W ( 300.53 E) degrees
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 =  158.9 K     Zbase =  120.7 km
Solar Zenith Angle =  80.9 deg     F1 peak = 137.0 km     Mol.Wgt. = 41.99
Temperature =    132.7 K           Pressure =    4.779E-04 N/m**2
Density (Low, Avg., High) =       1.273E-08   1.818E-08   2.364E-08 kg/m**3
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Departure, COSPAR NH Mean =         -69.3 %      -56.1 %      -42.9 %
Tot.Dens. = 1.875E-08 kg/m**3  Dens.Pert. =   3.11% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -14.5    5.1   -9.4 m/s
Northward Wind (Mean, Perturbed, Total) =  -38.2  -26.2  -64.4 m/s
------------------------------------------------------------------------------
Time (rel. to T0) =   12000.0 sec. (    .135 sols)  Ls =  97.1  Dust =  .30
Height = 115.00 km ( 113.69 km)   Scale Hgt H(p) =  8.18 H(rho) =  7.07 km
Latitude =   34.48  degrees       Longitude =   59.97 W ( 300.03 E) degrees
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 =  158.7 K    Zbase =  120.7 km
Solar Zenith Angle =  81.8 deg    F1 peak = 138.0 km    Mol.Wgt. = 41.76
Temperature =   142.1 K           Pressure =    2.477E-04 N/m**2
Density (Low, Avg., High) =      6.128E-09   8.754E-09   1.138E-08 kg/m**3
Departure, COSPAR NH Mean =         -72.1 %      -60.2 %      -48.3 %
Tot.Dens. = 8.655E-09 kg/m**3  Dens.Pert. =  -1.13% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -19.8  -25.9  -45.7 m/s
Northward Wind (Mean, Perturbed, Total) =  -38.7  -50.3  -89.0 m/s
------------------------------------------------------------------------------
Time (rel. to T0) =   12500.0 sec. (    .141 sols)  Ls =  97.1  Dust =  .30
Height = 120.00 km ( 118.64 km)   Scale Hgt H(p) =  9.02 H(rho) =  7.64 km
Latitude =   34.98  degrees       Longitude =   60.47 W ( 299.53 E) degrees
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 =  158.4 K    Zbase =  120.8 km
Solar Zenith Angle =  82.8 deg    F1 peak = 139.0 km    Mol.Wgt. = 41.70
Temperature =   155.8 K           Pressure =    1.357E-04 N/m**2
Density (Low, Avg., High) =      3.058E-09   4.369E-09   5.680E-09 kg/m**3
Departure, COSPAR NH Mean =         -74.3 %      -63.3 %      -52.3 %
Tot.Dens. = 3.028E-09 kg/m**3  Dens.Pert. = -30.68% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -21.3  -14.8  -36.0 m/s
Northward Wind (Mean, Perturbed, Total) =  -40.7  -22.6  -63.4 m/s
------------------------------------------------------------------------------
Time (rel. to T0) =   13000.0 sec. (    .146 sols)  Ls =  97.1  Dust =  .30
Height = 125.00 km ( 123.59 km)   Scale Hgt H(p) =  9.88 H(rho) =  8.44 km
Latitude =   35.48  degrees       Longitude =   60.97 W ( 299.03 E) degrees
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 =  158.1 K    Zbase =  120.9 km
Solar Zenith Angle =  83.7 deg    F1 peak = 140.1 km    Mol.Wgt. = 41.54
Temperature =   171.0 K           Pressure =    7.856E-05 N/m**2
Density (Low, Avg., High) =      1.618E-09   2.296E-09   2.974E-09 kg/m**3
Departure, COSPAR NH Mean =         -75.6 %      -65.4 %      -55.1 %
Tot.Dens. = 2.607E-09 kg/m**3  Dens.Pert. =  13.53% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -19.0  -22.1  -41.0 m/s
Northward Wind (Mean, Perturbed, Total) =  -43.7   -3.0  -46.7 m/s
------------------------------------------------------------------------------
Time (rel. to T0) =   13500.0 sec. (    .152 sols)  Ls =  97.1  Dust =  .30
Height = 130.00 km ( 128.54 km)   Scale Hgt H(p) = 10.73 H(rho) =  9.31 km
Latitude =   35.98  degrees       Longitude =   61.47 W ( 298.53 E) degrees
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 =  157.8 K    Zbase =  121.0 km
Solar Zenith Angle =  84.5 deg    F1 peak = 141.3 km    Mol.Wgt. = 41.51
Temperature =   185.3 K           Pressure =    4.776E-05 N/m**2
Density (Low, Avg., High) =      9.290E-10   1.287E-09   1.645E-09 kg/m**3
Departure, COSPAR NH Mean =         -75.3 %      -65.8 %      -56.2 %
Tot.Dens. = 1.374E-09 kg/m**3  Dens.Pert. =   6.75% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =  -14.5  -15.7  -30.2 m/s
Northward Wind (Mean, Perturbed, Total) =  -48.2    1.8  -46.4 m/s
------------------------------------------------------------------------------
Time (rel. to T0) =   14000.0 sec. (    .158 sols)  Ls =  97.1  Dust =  .30
Height = 135.00 km ( 133.50 km)   Scale Hgt H(p) = 11.41 H(rho) = 10.01 km
Latitude =   36.48  degrees       Longitude =   61.97 W ( 298.03 E) degrees
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 =  157.5 K    Zbase =  121.0 km
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Solar Zenith Angle =  85.4 deg     F1 peak = 142.5 km     Mol.Wgt. = 41.29
Temperature =    195.9 K           Pressure =     3.024E-05 N/m**2
Density (Low, Avg., High) =       5.784E-10   7.672E-10   9.554E-10 kg/m**3
Departure, COSPAR NH Mean =        -69.8 %     -59.9 %     -50.1 %
Tot.Dens. = 7.760E-10 kg/m**3  Dens.Pert. =   1.15% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    -9.0  -35.8  -44.8 m/s
Northward Wind (Mean, Perturbed, Total) =   -55.6    4.6  -51.0 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =   14500.0 sec. (    .163 sols)  Ls =  97.1  Dust =  .30
Height = 140.00 km ( 138.45 km)   Scale Hgt H(p) = 11.78 H(rho) = 10.69 km
Latitude =   36.98  degrees        Longitude =   62.47 W ( 297.53 E) degrees
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 =  157.3 K     Zbase =  121.1 km
Solar Zenith Angle =  86.2 deg     F1 peak = 144.0 km     Mol.Wgt. = 40.76
Temperature =    202.4 K           Pressure =     1.964E-05 N/m**2
Density (Low, Avg., High) =       3.760E-10   4.767E-10   5.765E-10 kg/m**3
Departure, COSPAR NH Mean =        -65.5 %     -56.3 %     -47.1 %
Tot.Dens. = 5.023E-10 kg/m**3  Dens.Pert. =   5.37% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    -3.4    7.9    4.5 m/s
Northward Wind (Mean, Perturbed, Total) =   -61.9  -30.1  -92.0 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =   15000.0 sec. (    .169 sols)  Ls =  97.1  Dust =  .30
Height = 145.00 km ( 143.40 km)   Scale Hgt H(p) = 12.10 H(rho) = 11.14 km
Latitude =   37.48  degrees        Longitude =   62.97 W ( 297.03 E) degrees
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 =  157.0 K     Zbase =  121.2 km
Solar Zenith Angle =  87.1 deg     F1 peak = 145.6 km     Mol.Wgt. = 40.47
Temperature =    205.2 K           Pressure =     1.287E-05 N/m**2
Density (Low, Avg., High) =       2.485E-10   3.062E-10   3.630E-10 kg/m**3
Departure, COSPAR NH Mean =        -64.8 %     -56.6 %     -48.6 %
Tot.Dens. = 2.956E-10 kg/m**3  Dens.Pert. =  -3.47% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     1.8   25.3   27.0 m/s
Northward Wind (Mean, Perturbed, Total) =   -70.2   -8.4  -78.5 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =   15500.0 sec. (    .175 sols)  Ls =  97.1  Dust =  .30
Height = 150.00 km ( 148.43 km)   Scale Hgt H(p) = 12.34 H(rho) = 11.45 km
Latitude =   37.98  degrees        Longitude =   63.47 W ( 296.53 E) degrees
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 =  156.8 K     Zbase =  121.3 km
Solar Zenith Angle =  87.9 deg     F1 peak = 147.3 km     Mol.Wgt. = 39.99
Temperature =    204.7 K           Pressure =     8.488E-06 N/m**2
Density (Low, Avg., High) =       1.642E-10   1.999E-10   2.353E-10 kg/m**3
Departure, COSPAR NH Mean =        -65.3 %     -57.7 %     -50.3 %
Tot.Dens. = 1.989E-10 kg/m**3  Dens.Pert. =   -.52% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =     7.6     .7    8.3 m/s
Northward Wind (Mean, Perturbed, Total) =   -75.7   -1.6  -77.4 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =   16000.0 sec. (    .180 sols)  Ls =  97.1  Dust =  .30
Height = 155.00 km ( 153.45 km)   Scale Hgt H(p) = 12.43 H(rho) = 11.59 km
Latitude =   38.48  degrees        Longitude =   63.97 W ( 296.03 E) degrees
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 =  156.5 K     Zbase =  121.3 km
Solar Zenith Angle =  88.6 deg     F1 peak = 149.3 km     Mol.Wgt. = 39.44
Temperature =    202.8 K           Pressure =     5.607E-06 N/m**2
Density (Low, Avg., High) =       1.071E-10   1.313E-10   1.560E-10 kg/m**3
Departure, COSPAR NH Mean =        -68.2 %     -61.0 %     -53.7 %
Tot.Dens. = 1.295E-10 kg/m**3  Dens.Pert. =  -1.39% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    12.0   -2.1    9.9 m/s
Northward Wind (Mean, Perturbed, Total) =   -82.6   -2.0  -84.7 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =   16500.0 sec. (    .186 sols)  Ls =  97.1  Dust =  .30
Height = 160.00 km ( 158.48 km)   Scale Hgt H(p) = 12.56 H(rho) = 11.73 km
Latitude =   38.98  degrees        Longitude =   64.47 W ( 295.53 E) degrees
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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 =  156.3 K    Zbase =  121.4 km
Solar Zenith Angle =  89.4 deg     F1 peak = 151.4 km    Mol.Wgt. = 38.78
Temperature =   200.3 K            Pressure =     3.702E-06 N/m**2
Density (Low, Avg., High) =       6.868E-11   8.622E-11   1.051E-10 kg/m**3
Departure, COSPAR NH Mean =        -71.7 %      -64.5 %      -56.8 %
Tot.Dens. = 7.338E-11 kg/m**3  Dens.Pert. = -14.89% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    16.4     .5   17.0 m/s
Northward Wind (Mean, Perturbed, Total) =   -89.4   53.1  -36.3 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =   17000.0 sec. (    .191 sols)  Ls =  97.1  Dust =  .30
Height = 165.00 km ( 163.51 km)   Scale Hgt H(p) = 12.83 H(rho) = 11.90 km
Latitude =   39.48  degrees        Longitude =   64.97 W ( 295.03 E) degrees
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 =  156.1 K    Zbase =  121.4 km
Solar Zenith Angle =  90.1 deg     F1 peak = 999.9 km    Mol.Wgt. = 37.96
Temperature =   198.3 K            Pressure =     2.458E-06 N/m**2
Density (Low, Avg., High) =       4.345E-11   5.661E-11   7.160E-11 kg/m**3
Departure, COSPAR NH Mean =        -75.9 %      -68.6 %      -60.3 %
Tot.Dens. = 5.659E-11 kg/m**3  Dens.Pert. =   -.04% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    19.2  -26.1   -7.0 m/s
Northward Wind (Mean, Perturbed, Total) =   -95.5   12.9  -82.5 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =   17500.0 sec. (    .197 sols)  Ls =  97.1  Dust =  .30
Height = 170.00 km ( 168.53 km)   Scale Hgt H(p) = 13.20 H(rho) = 12.10 km
Latitude =   39.98  degrees        Longitude =   65.47 W ( 294.53 E) degrees
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 =  155.8 K    Zbase =  121.5 km
Solar Zenith Angle =  90.8 deg     F1 peak = 999.9 km    Mol.Wgt. = 36.89
Temperature =   197.3 K            Pressure =     1.656E-06 N/m**2
Density (Low, Avg., High) =       2.734E-11   3.724E-11   4.842E-11 kg/m**3
Departure, COSPAR NH Mean =        -79.7 %      -72.4 %      -64.1 %
Tot.Dens. = 4.379E-11 kg/m**3  Dens.Pert. =  17.58% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    21.7  -10.0   11.7 m/s
Northward Wind (Mean, Perturbed, Total) =  -100.8  -20.0 -120.8 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =   18000.0 sec. (    .203 sols)  Ls =  97.1  Dust =  .30
Height = 175.00 km ( 173.56 km)   Scale Hgt H(p) = 13.70 H(rho) = 12.37 km
Latitude =   40.48  degrees        Longitude =   65.97 W ( 294.03 E) degrees
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 =  155.6 K    Zbase =  121.5 km
Solar Zenith Angle =  91.5 deg     F1 peak = 999.9 km    Mol.Wgt. = 35.59
Temperature =   197.0 K            Pressure =     1.134E-06 N/m**2
Density (Low, Avg., High) =       1.731E-11   2.464E-11   3.204E-11 kg/m**3
Departure, COSPAR NH Mean =        -83.2 %      -76.1 %      -68.9 %
Tot.Dens. = 2.227E-11 kg/m**3  Dens.Pert. =  -9.63% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    22.4   37.9   60.3 m/s
Northward Wind (Mean, Perturbed, Total) =  -104.2   49.7  -54.5 m/s
-----------------------------------------------------------------------------
Time (rel. to T0) =   18500.0 sec. (    .208 sols)  Ls =  97.1  Dust =  .30
Height = 180.00 km ( 178.59 km)   Scale Hgt H(p) = 14.28 H(rho) = 12.68 km
Latitude =   40.98  degrees        Longitude =   66.47 W ( 293.53 E) degrees
Sun Latitude =     25.00 deg.      Mars Orbital Radius = 1.648 AU
Sun Longitude =  183.80 deg.       Local Time =  19.82 Mars hours
Exospheric Temp. =  196.8 K        Tbase =  155.4 K    Zbase =  121.6 km
Solar Zenith Angle =  92.1 deg     F1 peak = 999.9 km    Mol.Wgt. = 34.15
Temperature =   196.6 K            Pressure =     7.863E-07 N/m**2
Density (Low, Avg., High) =       1.151E-11   1.644E-11   2.137E-11 kg/m**3
Departure, COSPAR NH Mean =        -85.4 %      -79.2 %      -72.9 %
Tot.Dens. = 1.267E-11 kg/m**3  Dens.Pert. = -22.94% Wave =    .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    22.9   11.9   34.8 m/s
Northward Wind (Mean, Perturbed, Total) =  -107.7   48.3  -59.3 m/s
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Time (rel. to T0) =    19000.0 sec. (    .214 sols)  Ls =  97.1  Dust =  .30
Height = 185.00 km ( 183.62 km)    Scale Hgt H(p) = 14.97 H(rho) = 13.06 km
Latitude =   41.48  degrees        Longitude =   66.97 W ( 293.03 E) degrees
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 =  155.2 K     Zbase =  121.6 km
Solar Zenith Angle =  92.7 deg     F1 peak = 999.9 km     Mol.Wgt. = 32.60
Temperature =    196.1 K           Pressure =     5.535E-07 N/m**2
Density (Low, Avg., High) =       7.748E-12   1.107E-11   1.439E-11 kg/m**3
Departure, COSPAR NH Mean =         -87.3 %      -81.9 %      -76.5 %
Tot.Dens. = 6.672E-12 kg/m**3  Dens.Pert. = -39.73% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    23.3  -27.4    -4.1 m/s
Northward Wind (Mean, Perturbed, Total) =  -111.1    8.6 -102.5 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    19500.0 sec. (    .220 sols)  Ls =  97.1  Dust =  .30
Height = 190.00 km ( 188.65 km)    Scale Hgt H(p) = 15.77 H(rho) = 13.51 km
Latitude =   41.98  degrees        Longitude =   67.47 W ( 292.53 E) degrees
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 =  155.1 K     Zbase =  121.7 km
Solar Zenith Angle =  93.3 deg     F1 peak = 999.9 km     Mol.Wgt. = 30.95
Temperature =    195.6 K           Pressure =     3.958E-07 N/m**2
Density (Low, Avg., High) =       5.275E-12   7.535E-12   9.796E-12 kg/m**3
Departure, COSPAR NH Mean =         -88.9 %      -84.1 %      -79.3 %
Tot.Dens. = 6.191E-12 kg/m**3  Dens.Pert. = -17.85% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    23.5  -22.1     1.4 m/s
Northward Wind (Mean, Perturbed, Total) =  -114.6   -7.3 -122.0 m/s
----------------------------------------------------------------------------
Time (rel. to T0) =    20000.0 sec. (    .225 sols)  Ls =  97.1  Dust =  .30
Height = 195.00 km ( 193.68 km)    Scale Hgt H(p) = 16.68 H(rho) = 14.04 km
Latitude =   42.48  degrees        Longitude =   67.97 W ( 292.03 E) degrees
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 =  154.9 K     Zbase =  121.7 km
Solar Zenith Angle =  93.9 deg     F1 peak = 999.9 km     Mol.Wgt. = 29.27
Temperature =    195.1 K           Pressure =     2.877E-07 N/m**2
Density (Low, Avg., High) =       3.635E-12   5.193E-12   6.751E-12 kg/m**3
Departure, COSPAR NH Mean =         -90.2 %      -86.0 %      -81.8 %
Tot.Dens. = 4.450E-12 kg/m**3  Dens.Pert. = -14.32% Wave =     .00% of mean
Eastward Wind  (Mean, Perturbed, Total) =    23.5    6.6    30.1 m/s
Northward Wind (Mean, Perturbed, Total) =  -118.2  -10.9 -129.1 m/s
----------------------------------------------------------------------------
```

Appendix D

Summary of Files Provided with Mars-GRAM 2000

```
      Mars-GRAM 2000 Version 1 directory on the FTP server contains the
following files:

marsgram.hst - history file summarizing various versions and changes
marsfix.txt  - history of minor code changes since first posting of Version 1
marsgram.f   - source code for the "stand alone" version main program
dumytraj.f   - source code for the dummy trajectory version main program
marssubs.f   - subroutines used by both marsgram and dumytraj versions
setup.f      - setup subroutines used by both marsgram and dumytraj versions
ARCHGTS.DAT  - data file for low resolution Ames GCM topographic heights
COSPAR.DAT   - data file for the COSPAR reference model atmosphere
input.std    - commented test input file for reference case
listmg2k.txt - list output file for reference case
headers.txt  - list of plotable output files and file header definitions
README1.txt  - this general program introduction file
README2.txt  - discussion of the dumytraj.f dummy trajectory program
README3.txt  - discussion of the MGCM and MTGCM input data files
xycodes.txt  - list of x-y plot codes (also given below)
makebin.f    - program to read ASCII version MGCM and MTGCM data files
                and write out binary version (for faster reading on user
                machine)
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
tpdloxxy.txt - MGCM 0-80 km temperature, pressure, and density data for
                3 dust optical depths xx
uvloxxy.txt  - MGCM 0-80 km EW wind and NS wind data for 3 dust optical
                depths xx, version number y
tpdhixxy.txt - MTGCM 80-170 km temperature, pressure, and density data for
                3 dust optical depths xx, version number y
uvhixxy.txt  - MTGCM 80-170 km EW wind and NS wind data for 3 dust optical
                depths xx, version number y
zfhgtsy.txt  - Height ZF of 1.26 nbar level for all dust optical depths,
                version number y


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 2000, 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 are as follows:

Values of x-code and y-code for Mars-GRAM plotable output files

 Code              Parameter
 ----  -----------------------------------------------------------------
   1   Height (above reference ellipsoid, km)
   2   Height (above local terrain, 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 (degrees)
8   Local Solar Time (Mars hours = 1/24 Sols)
9   Pressure (mb)

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
```

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 2000 code and are automatically available to be called whenever the Mars-GRAM 2000 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 2000 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 2000 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 2000 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 2000 subroutines.

Appendix F

Details of MGCM and MTGCM Data Files

ASCII format MGCM and MTGCM data files are provided, each having values for amplitudes and phases of diurnal (24-hour period) and semi-diurnal (12-hour period) 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 hours) of the diurnal component
A2   = Amplitude of the semi-diurnal tide component
phi2 = phase (local time in 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 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, two MGCM boundary layer data files are provided (in ASCII format):

```
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.

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

```
tpdloxxy.txt - MGCM 0 to 80 km temperature, pressure, and density data for
                 3 dust optical depths xx, version number y
uvloxxy.txt  - MGCM 0 to 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 to 170 km data are provided:

```
tpdhixxy.txt - MTGCM 80 to 170 km temperature, pressure, and density data for
                 3 dust optical depths xx, version number y
uvhixxy.txt  - MTGCM 80 to 170 km EW wind and NS wind data for 3 dust optical
                 depths xx, version number y
```

Each record of the tpdhixx.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 uvhixx.txt files contains Ls value, height, latitude, and tidal coefficients for the Eastward and Northward wind components.

A single file, zfhgtsy.txt, 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 this file contains dust optical depth, Ls, latitude, and tidal coefficient values.

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 2000 on each run.

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C.G. Justus* and B.F. James

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13. ABSTRACT *(Maximum 200 words)*

This report presents Mars Global Reference Atmospheric Model 2000 Version (Mars-GRAM 2000) and its new features. All parameterizations for temperature, pressure, density, and winds versus height, latitude, longitude, time of day, and Ls have been replaced by 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. A modified Stewart thermospheric model is still used for higher altitudes and for dependence on solar activity. "Climate factors" to tune for agreement with GCM data are no longer needed. Adjustment of exospheric temperature is still an option. Consistent with observations from Mars Global Surveyor, a new longitude-dependent wave model is included with user input to specify waves having 1 to 3 wavelengths around the planet. A simplified perturbation model has been substituted for the earlier one. An input switch allows users to select either East or West longitude positive. 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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