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Mars Global Reference Atmospheric Model 2010 Version: Users Guide

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PREFACE

The 2010 version of the Mars Global Reference Atmospheric Model (Mars-GRAM 2010) was developed by the Natural Environments Branch, Spacecraft and Vehicle Systems Department, Engineering Directorate, of the NASA Marshall Space Flight Center.

For those unfamiliar with earlier versions of Mars-GRAM, NASA TM-108509, "Mars Global Reference Atmospheric Model (Mars-GRAM 3.34) Programmer's Guide," NASA TM-108513, "A Revised Thermosphere for the Mars Global Reference Atmospheric Model (Mars-GRAM Version 3.4)," NASA/TM—1999–209629, "Mars Global Reference Atmospheric Model (Mars-GRAM) Version 3.8: Users Guide," NASA/TM—2000–210279, "Mars Global Reference Atmospheric Model 2000 Version (Mars-GRAM 2000): Users Guide," and NASA/TM—2001–210961, "Mars Global Reference Atmospheric Model 2001 Version (Mars-GRAM 2001): Users Guide" are recommended. These Technical Memorandums are available electronically from the NASA Technical Report Server at <http://ntrs.nasa.gov/> or in hardcopy from

National Technical Information Service
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For information on obtaining Mars-GRAM 2010 (or earlier) code and data, as well as additional copies of this Technical Memorandum, contact

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Examples of output from the University of Michigan Mars Thermospheric General Circulation Model (MTGCM) are available for browsing by interested readers at the following Web site: <http://data.engin.umich.edu/tgcm_planets_archive/thermo.html>. This Web site has a constantly changing archive of available MTGCM case runs for use by the scientific community at large.

Examples of output from the NASA Ames Mars General Circulation Model (MGCM) are available for browsing by interested readers at the following Web site: <http://humbabe.arc.nasa.gov/>. This Web site includes example MGCM output based on Mars Orbiter Laser Altimeter (MOLA) topography and pre-MOLA topography.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
AU	astronomical unit
COSPAR	Committee on Space Research
ERT	Earth-receive time
FTP	file transfer protocol
GCM	General Circulation Model
IAU	International Astronomical Union
Lat	latitude
LDW	longitude-dependent waves
Lon	longitude
LTST	local true solar time
Mars-GRAM	Mars Global Reference Atmospheric Model
MET	Mars-event time
MGCM	Mars General Circulation Model
MGS	Mars Global Surveyor
MOLA	Mars Orbiting Laser Altimeter
MRO	Mars Reconnaissance Orbiter
MTGCM	Mars Thermospheric General Circulation Model

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

NPOS	desired number of positions
ODY	Mars Odyssey
PC-DOS	personal computer Disc Operating System
PDS	Planetary Data System
TES	thermal emission spectrometer
TT	terrestrial (dynamical) time
UTC	coordinated universal time

NOMENCLATURE

A	coefficient
A_0	diurnal mean value of the given parameter (temperature, pressure, density and wind components)
A_1	amplitude of the diurnal tide component
A_2	amplitude of the semi-diurnal tide component
B	coefficient
B_0	diurnal mean value of longitude-dependent wave
B_1,B_2,B_3	amplitude of the LDW peak for wave-1, wave-2, and wave-3 components
d	Julian day at which LDW is evaluated
d_0	Julian day for the primary peak(s) of the LDW traveling component
F	adjustment factor
F10	solar activity parameter
F10.7	solar flux at 10.7 cm wavelength (10^{-22} W/cm^2 at 1 AU)
F_h	height factor
$F(z)$	logarithmic height factor
g	gravity (3.712 m/s^2 at the surface of Mars)
H	local pressure scale height (km)
Lat	latitude (degrees)
L_s	areocentric longitude of the Sun from Mars (degrees)
m_d	areal dust density (kg/m^2)
n	number of peaks and troughs the wave component has through 360 degrees of longitude

NOMENCLATURE (Continued)

p	pressure (N/m^2)
p_{sfc}	surface pressure (N/m^2)
q_0	dust mixing ratio, mass of dust per unit mass of air, at the surface
R	gas law 'constant'
R_i	Richardson number
S	wave scale parameter
T	temperature (K)
T_5	temperature at 5 m (K)
T_g	temperature at ground surface (K)
t	local solar time (hours)
u	wind component (m/s)
v	wind component (m/s)
ZF	height of the 1.26 nbar pressure level (km)
z	height (km)
z_0	surface roughness parameter
λ	longitude (degrees)
Δz_0	input value of constant height offset (km)
ς	height parameter
ρ	density (kg/m^3)
τ	optical depth
Φ_1, Φ_2, Φ_3	phases (longitude) of the LDW peak for wave-1, wave-2, and wave-3 components
$\dot{\Phi}_1, \dot{\Phi}_2, \dot{\Phi}_3$	rate of movement of the LDW peak for wave-1, wave-2, and wave-3 components

NOMENCLATURE (Continued)

ϕ_1	phase (local time in hours) of diurnal tide component
ϕ_2	phase (local time in hours) of semi-diurnal tide component

TECHNICAL MEMORANDUM

MARS GLOBAL REFERENCE ATMOSPHERIC MODEL 2010 VERSION: USERS GUIDE

1. INTRODUCTION

1.1 Background and Overview

The Mars Global Reference Atmospheric Model (Mars-GRAM) is an engineering-level atmospheric model widely used for diverse mission applications. Applications include systems design, performance analysis, and operations planning for aerobraking, entry, descent and landing, and aerocapture. Mars-GRAM has been utilized during the aerobraking operations of Mars Global Surveyor (MGS),[1] Mars Odyssey (ODY), and Mars Reconnaissance Orbiter (MRO). Mars-GRAM has also been used in the prediction and validation of Mars Pathfinder hypersonic aerodynamics,[2] the aerothermodynamic and entry dynamics studies for Mars Polar Lander,[3] the Mars Aerocapture System Study, as well as the Aerocapture Technology Assessment Group.

Mars-GRAM versions[4–8] prior to Mars-GRAM 2000 were based on ad hoc parameterizations to data observed by the Mariner and Viking missions. Mars-GRAM 2000,[9] Mars-GRAM 2001, Mars-GRAM 2005, and the current version, Mars-GRAM 2010, are based on input data tables derived from output results from the NASA Ames Mars General Circulation Model (MGCM)[10,11] and the University of Michigan Mars Thermospheric General Circulation Model (MTGCM).[12,13]

Section 1 provides an overview of Mars-GRAM 2010. Section 2 of this Technical Memorandum describes the MGCM and MTGCM data and how they are applied in Mars-GRAM. The new features of Mars-GRAM 2010 are described in section 3. Section 4 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 5. Appendices A–F provide additional details of Mars-GRAM 2010 input and output files and how to interpret program results. Appendix G describes several auxiliary programs that are provided with Mars-GRAM 2010.

1.2 Basic Description of Mars-GRAM 2010

Mars-GRAM's perturbation modeling capability is commonly used, in a Monte Carlo mode, to perform high-fidelity engineering end-to-end simulations for entry, descent, and landing.[14] Mars-GRAM has been validated[15] against Radio Science data, and both nadir and limb data from thermal emission spectrometer (TES).[16]

From the surface to 80 km altitude, Mars-GRAM is based on the NASA Ames MGCM. Above 80 km, Mars-GRAM is based on the MTGCM. Mars-GRAM and MGCM use surface topography from the MGS Mars Orbiter Laser Altimeter (MOLA), with altitudes referenced to the MOLA constant potential surface (areoid).

There are several traditional Mars-GRAM options for representing the mean atmosphere along entry corridors. The first option is mapping year 0, with user-controlled dust optical depth and Mars-GRAM data interpolated from MGCM results driven by selected values of globally-uniform dust optical depth. The second is the auxiliary profile option in which the user can read and use any auxiliary profile of temperature and density versus altitude in the mapping year 0 option. In exercising the auxiliary profile Mars-GRAM option, the values from the auxiliary profile replace data from the original MGCM databases. Examples of auxiliary profiles include data from TES nadir or limb observations or Mars mesoscale model output at a particular location and time. The final option is mapping years 1 and 2, with Mars-GRAM data coming from MGCM results driven by the observed TES dust optical depth during TES year 1 and 2.

Mars-GRAM standard inputs are geographic position and time. The user can also adjust the optical depth of the uniformly mixed background dust level, add a seasonal dust optical depth, set the dust particle diameter and density, and provide the starting areocentric longitude of the Sun from Mars (L_s), position, duration, intensity, and radius of a dust storm. Mars-GRAM outputs include density, temperature, pressure, winds, and selected atmospheric constituents. Three Mars-GRAM parameters allow standard deviations of Mars-GRAM perturbations to be adjusted: *rpscale* can be used to scale density perturbations up or down, *rwscale* can be used to scale wind perturbations, and *wlscale* can be used to adjust wavelengths (spectral range) of the perturbations.

1.3 Significant Changes in Mars-GRAM 2010

Mars-GRAM 2010 has been updated to FORTRAN 90/95. Mars-GRAM 2010 now includes adjustment factors that are used to alter the input data from MGCM and MTGCM for the mapping year 0 user-controlled dust case.[17] The greatest adjustments are made at large optical depths such as $\tau > 1$. The addition of the adjustment factors has led to better correspondence to TES limb data from zero to 60 km altitude as well as better agreement with MGS, ODY, and MRO data at approximately 90 to 130 km altitude.

2. PREEXISTING FEATURES OF MARS-GRAM 2010

2.1 Mars Orbiter Laser Altimeter Topography Data

2.1.1 MOLA Areoid

Flying on MGS, the MOLA produced topographic data[18–20] at a variety of high resolutions from 1 by 1 degree to 1/16 by 1/16 degree latitude-longitude grids. MOLA topography is measured with respect to a zero elevation surface level known as the MOLA areoid, which is defined as the gravitational equipotential whose average value at the equator is equal to the mean radius determined by MOLA. Mars-GRAM 2010 uses half-degree latitude-longitude resolution data for both MOLA areoid and topography.

Prior to Mars-GRAM 2001, a simple ellipsoid of revolution as zero elevation level was used. Previous resolution for Mars-GRAM topography was 7.5 by 9 degrees, a resolution that is consistent with the evaluation grid of the Ames MGCM. Although Mars-GRAM 2010 works internally with MOLA areoid and topography, and uses these as defaults, program input options also allow users to input and output heights relative to the old Mars-GRAM ellipsoid.

2.1.2 MOLA Topography

MOLA topography and areoid radius in Mars-GRAM 2010 are specified in a text-format input file, MOLATOPH.TXT. For Mars-GRAM use, this file must be converted to a binary file, molatoph.bin, by running a conversion program, makebin.f90, discussed in appendices D and F. Each line of the text file is for a given latitude-longitude grid, and contains grid-averaged values of longitude (° E.), latitude (° N.), planetary radius (m), areoid radius (m), topographic altitude (m), and number of data points in the grid. Planetary radius (radius to the local topographic surface) and areoid radius (radius to the zero elevation surface) are measured along a planetocentric radius direction from the center of mass of the planet. MOLA latitude data are planetocentric, hence, differ slightly from planetographic latitudes. Topographic altitude is the difference between planetary radius and areoid radius. Because of nonlinearities and interpolation methods used in processing MOLA data, grid-averaged topography that is provided in the MOLATOPH.TXT file and used in Mars-GRAM 2010 is slightly different from the difference between the grid-averaged planetary radius and grid-averaged areoid radius.

Relative to MOLA areoid, the highest point on Mars, the peak of Olympus Mons, is 21.2 km, and lowest, a point in the Hellas Basin, is –7.8 km. For the half-degree resolution MOLA data that is used in Mars-GRAM 2010, the highest and lowest elevations are 21 and –7.6 km, respectively.

2.2 Mars General Circulation Model Input Data

2.2.1 Introduction to MGCM and MTGCM Data

Mars-GRAM 2010 utilizes input data tables from the NASA Ames MGCM[10,11] and the University of Michigan MTGCM.[12,13] These tables give the variation of temperature, density, pressure, and wind components with height, latitude, time of day, and L_s. The tables also provide boundary layer data at the topographic surface, as well as 5 and 30 m above the surface as a function of longitude, latitude, time of day, and L_s. MGCM data tables cover altitudes from the surface to 80 km. MTGCM data tables cover altitudes of 80 to 170 km. A modified latitude-longitude dependent Stewart-type thermospheric model[6] is used for altitudes above 170 km, and for dependence on solar activity at higher levels. The Stewart-type thermosphere model starts at a lower boundary condition height of the 1.26 nbar pressure level referred to as height *ZF*. Between 80 km and height *ZF* (typically at about 125 km), MTGCM data are used directly and also for dependence on solar activity. MTGCM values are interpolated/extrapolated to any desired solar activity value from MTGCM input data for F10.7 = 70 and 130. F10.7 is the solar flux at 10.7 cm wavelength in units of 10^{-22} W/cm^2 at 1 astronomical unit (AU). Above 170 km, modified Stewart-type thermosphere model data are used directly. Between height *ZF* and 170 km, a fairing process is used that smoothly transitions from MTGCM values to Stewart-type model values.

Details and formats of MOLA, MGCM, and MTGCM data files are given in appendices D and F. To facilitate transfer, these files are provided to the user in American Standard Code for Information Interchange (ASCII format). For a shorter Mars-GRAM run time it is best to read the files in binary form. A program, makebin.f, which is discussed in appendix F is provided to convert the ASCII format MGCM and MTGCM data files to binary files on the user's machine.

2.2.2 Evaluation of MGCM and MTGCM Tidal Components

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

$$\text{Tide} = A_0 + A_1 \cdot \cos\left[\frac{\pi\left(t-\phi_1\right)}{12}\right] + A_2 \cdot \cos\left[\frac{\pi\left(t-\phi_2\right)}{6}\right] , \quad (1)$$

where A_0 is diurnal mean value of the given parameter, A_1 is amplitude of the diurnal tide component, t is local solar time in hours, 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 tide component.

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

2.2.3 Interpolation Methods

Equation (1) is used to evaluate each atmospheric parameter at the desired local solar time (t), at 'corners' of a multidimensional 'box' of grid points. This box contains the desired interpolation location, L_s, and dust optical depth (τ). Multidimensional 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, L_s, and τ. For surface layer data (topographic surface, and 5 or 30 m above the surface), interpolation is four-dimensional in longitude, latitude, L_s, and τ. Interpolation is logarithmic for τ and linear for all other dimensions.

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

$$H = \frac{(z2 - z1)}{\ln\left[\dfrac{p(z1)}{p(z2)}\right]} \tag{2}$$

and evaluating pressure in N/m^2, $p(z)$, from the hydrostatic relation:

$$p(z) = p(z1)\exp\left[\frac{z1 - z}{H}\right] . \tag{3}$$

Gas law 'constant' R is evaluated from pressure (p), density (ρ), and temperature (T) at heights $z1$ and $z2$ by:

$$R(z1) = \frac{p(z1)}{\left[\rho(z1)T(z1)\right]} \tag{4}$$

and

$$R(z2) = \frac{p(z2)}{\left[\rho(z2)T(z2)\right]} . \tag{5}$$

Density in kg/m^3, $\rho(z)$, at height (z) is then determined by the gas law relation and a linearly interpolated R value, $R(z)$:

$$\rho(z) = \frac{p(z)}{\left[R(z)T(z)\right]} . \tag{6}$$

2.2.4 Interpolation in the Boundary Layer

MGCM data tables used by Mars-GRAM include ground surface temperature. Between the surface and 5 m height, large temperature gradients can exist. There can also be a difference between ground surface temperature and air temperature 'immediately' above ground. These features must be represented by a boundary layer model. Following the approach used in the Ames MGCM,[21] Mars-GRAM assumes temperature varies from T_g at ground surface to T_5 at the 5 m level according to the relation:

$$T(z) = T_g + \frac{\left(T_5 - T_g\right)\left[1 + F_h^{\ 1/2} F(z)\right]}{\left[1 + F_h^{\ 1/2}\right]} , \tag{7}$$

where the factor F_h is given by:

$$F_h = \left(1 - 16 R_i\right)^{1/2} \text{ if } R_i < 0; \; F_h = \left[1 + \frac{15 R_i}{\left(1 + 5 R_i\right)^{1/2}}\right]^{-1} \text{ if } R_i \geq 0 \tag{8}$$

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

$$F(z) = \frac{\ln\left(\frac{z}{z_0}\right)}{\ln\left(\frac{5}{z_0}\right)} , \tag{9}$$

where z_0 is the surface roughness parameter assumed to be 0.01 m, except over surface ice, where z_0 = 0.0001 m is used.[22]

Wind components at heights <5 m above the surface are evaluated from a logarithmic boundary layer profile relation:

$$u(z)=u(5)F(z) \tag{10}$$

and

$$v(z)=v(5)F(z) \; . \tag{11}$$

2.3 Longitude-Dependent (Terrain-Fixed) Wave Model

Tide components evaluated by equation (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 1 hour for every 15 degrees of longitude. During aerobraking operations, measurements by MGS,[23–26] ODY and MRO revealed substantial longitude-dependent wave patterns for atmospheric density. Being in Sun synchronous orbits, MGS, ODY and MRO passed through each periapsis at essentially the same latitude and local solar time. Nevertheless, they found substantial variations that tended to repeat as a function of the periapsis longitude. The density variations were of the form of longitude-dependent (i.e., terrain fixed) wave patterns. Mars-GRAM 2010 includes an optional model for these longitude-dependent waves (LDW) of the form:

$$\mathrm{LDW} = B_0 + B_1 \cos\left[\pi\left(\lambda - \Phi_1 - \Phi_1^{\bullet}\left(d - d_0\right)\right)/180\right] + B_2 \cos\left[\pi\left(2\lambda - \Phi_2 - \Phi_2^{\bullet}\left(d - d_0\right)\right)/180\right]$$

$$+B_3 \cos\left[\pi\left(3\lambda - \Phi_3 - \Phi_3^{\bullet}\left(d - d_0\right)\right)/180\right] , \qquad (12)$$

where λ is longitude (in degrees), B_0 is the diurnal mean value of longitude-dependent wave, B_1, B_2, and B_3 are amplitude, Φ_1, Φ_2, and Φ_3 are phases (longitudes), $\Phi_1^{\bullet}$, $\Phi_2^{\bullet}$, and $\Phi_3^{\bullet}$ are the rate of movement of the LDW peak for wave-1, wave-2, and wave-3 components, d_0 is the Julian day for the primary peak(s) of the LDW traveling component, and d is the Julian day at which LDW is evaluated. The term wave-n means the wave component has n peaks and troughs through 360 degrees of longitude. LDW perturbations computed by equation (12) are applied as a multiplier to the mean density and pressure computed from MGCM and MTGCM data, as interpolated by methods described in section 2.2.3. Wave model coefficients for equation (12) can be input from the NAMELIST format input file (see app. B), or from an auxiliary file of time-dependent wave model coefficients named by the input parameter WaveFile (secs. 4.2 and 4.3). Values of LDW coefficients may be determined empirically by accelerometer observations,[23,25] or theoretically, from wave characteristics of Mars GCMs.[24,26]

For altitudes above 100 km, LDW perturbations from equation (12) are assumed to be altitude independent. For altitudes below 100 km, LDW perturbations are assumed to diminish in magnitude at an exponential rate, namely,

$$\mathrm{LDW}(z) = 1 + \left(\mathrm{LDW}(100) - 1\right)\exp\left[(z - 100)/S\right] , \qquad (13)$$

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

One way of adjusting Mars-GRAM 2010 density values up or down (at altitudes below 100 km) is by changing the LDW mean term, B_0. For example, if the user wants to adjust Mars-GRAM 2010 density values by a factor $W1 = B_0(z1)$ at height $z1$ and $W2 = B_0(z2)$ at height $z2$ (where $z1$ and $z2$ are both <100 km), then use the scale parameter value:

$$S = (z2 - z1)/\ln[(W2 - 1)/(W1 - 1)] , \qquad (14)$$

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

$$B_0(100) = 1 + (W2 - 1)\exp[(100 - z2)/S] . \qquad (15)$$

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

$$B_0(z) = 1 + \left(B_0(100) - 1\right)\exp\left[(z - 100)/S\right] \ . \tag{16}$$

Note that multipliers may be larger or smaller than 1 (yielding density increase or decrease, respectively).

2.4 Mars-GRAM Climate Factors and Height Adjustment

Below 170 km, Mars-GRAM 2010 is based directly on MGCM and MTGCM output and does not need any of the climate factors that were included prior to Mars-GRAM 2001. The only climate adjustment factor that is still included in Mars-GRAM 2010 is *deltaTEX*, which adjusts the exospheric temperature. Mars-GRAM 2010 model output can be affected as a result of the choice of dust optical depth through the input parameter *Dusttau* and by the LDW parameters that were discussed in section 2.3.

Mars-GRAM 2010 density output can also be adjusted through the use of the input parameter *zoffset*, the direct height offset of the MTGCM data. The height offset adjustment only affects density above 80 km. The function of the height offset is very similar to that of the LDW wave parameter B_0 that was discussed in section 2.3. B_0 shifts a height versus density plot to the right or left as it increases or decreases density at a given height. Height offset shifts such a height-versus-density curve up or down as it increases or decreases the height at which a given density applies. The net result of a positive or negative height offset is to increase or decrease the density at a given height.

Zoffset can be specified in several ways. A specific offset value in kilometers may be specified in the NAMELIST format input file. Alternatively, the offset value required to match MTGCM data to MGCM data at 80 km can be computed and applied by Mars-GRAM. The MTGCM-MGCM matchup can be specified as applicable locally or globally, based on data shown in table 1. A local matchup can be based on either density at a given location and time of day or the daily average density at a given location.

Another option is to have the program compute and use a global height offset that depends on time of year given by the solar longitude (L_s). Based on comparisons of MTGCM with density observed during MGS aerobraking,[25] time-of-year dependence of height offset is given as:

$$\text{Height Offset (km)} = \Delta z_0 - 2.5\sin\left(\pi L_s / 180\right) \ , \tag{17}$$

where Δz_0 is an input value of constant height offset given by input parameter *zoffset*. With a default value of $\Delta z_0 = 5$ km, height offset values from equation (17) vary seasonally from 2.5 km at $L_s = 90$ degrees to 7.5 km at $L_s = 270$ degrees.

Table 1. Global average height offset (km) required for MTGCM-MGCM matchup, as a function of solar longitude and dust optical depth.

Solar Longitude (deg)	Dust Optical Depth		
	0.3	1	3
0	–0.002	–0.001	–0.002
30	–0.001	0.000	0.003
60	0.001	–0.003	–0.002
90	–0.002	–0.002	–0.000
120	0.001	–0.002	–0.001
150	0.004	–0.002	0.011
180	–0.003	–0.004	–0.002
210	–0.002	0.001	–0.001
240	–0.002	–0.001	0.018
270	–0.002	0.004	–0.003
300	–0.001	0.008	–0.002
330	0.033	–0.001	–0.003
360	–0.002	–0.001	–0.003

Mars-GRAM allows optional regional or global scale dust storms to be activated at any desired L_s. Dust storm simulations are discussed in section 2.5. Based on comparisons between Mars-GRAM and density observed by the MGS accelerometer[23] during the regional Noachis dust storm, an additional height offset of MTGCM data is applied during simulated dust storms. This additional offset amount in kilometers is seven times the dust storm optical depth.

2.5 Quantitative Dust Concentration Model

Background dust optical depth (τ) in a non dust storm case is specified by the input parameter *Dusttau*. Interpolation routines given in section 2.2.3 interpolate logarithmically between τ 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 τ with L_s (in degrees) is specified by:

$$\tau = 0.65 - 0.35\sin\left(\pi L_s / 180\right). \tag{18}$$

A model for global or local scale dust storms[5] is retained for mapping year 0. In Mars-GRAM 2010, the input value for dust storm intensity given by input parameter, *INTENS*, is equivalent to the peak dust optical depth for the storm. Allowable values for *INTENS* range from zero for no dust storm to three for the maximum intensity dust storm. Dust storm intensity is added to background dust optical depth to give total dust optical depth. Mars-GRAM does all necessary interpolations on dust optical depth as it varies with time, L_s, and space for local storms. *DUSTLAT* and *DUSTLON* input parameters give the location of the dust storm. The input option, *ALSDUR*, allows users to control the duration of simulated dust storms. Input parameter *RADMAX* is the maximum radius (kilometers) a dust storm can attain. The radius develops according to the parameterized space and time profile of buildup and decay in the program. If a value of zero or more than 10,000 km is used for *RADMA*X, the storm is taken to be of global dimensions and uniformly covers Mars, but is still assumed to build up and decay in intensity according to the same temporal profile.

Mars-GRAM 2010 computes several dust concentration parameters from dust optical depth. Methods used by Haberle et al. in the MGCM are employed.[21,27] Areal dust density (m_d), total column mass of dust per unit ground surface area, is 0.005 times τ. Dust mixing ratio, the mass of dust per unit mass of air, at the surface (q_0) is computed by:

$$q_0 = m_d g / \left(0.994 \exp^{-v} p_{sfc}\right) , \tag{19}$$

where g is gravity, 3.712 m/s^2 at the surface of Mars; v is input parameter *Dustnu*, which controls the vertical dust distribution; and p_{sfc} is surface pressure. Dust mixing ratio at height z is determined by:

$$q(z) = q_0 \exp\left\{v\left[1 - p(z) / p_{sfc}\right]\right\} , \tag{20}$$

where $p(z)$ is pressure at height z. Dust mass density, the mass of dust per unit volume of air, is the product of dust mixing ratio and atmospheric density. From the dust mixing ratio, assuming that dust particles are spheres of a given diameter and mass, Mars-GRAM 2010 also computes dust number density, number of dust particles per unit volume of air. Users can also input values of dust particle diameter through the use of the input parameter *Dustdiam* and dust particle density using the input parameter *Dustdens*. Consistent with the MGCM,[27] Mars-GRAM 2010 assumes a default particle diameter, 5 µm, and a default particle density, 3,000 kg/m^3.

Dust model output values are written to the file MarsRad.txt details of which are discussed in appendix A.

2.6 Solar and Thermal Radiation From Mars-GRAM Output

Several auxiliary programs used with Mars-GRAM are described in appendix G. One, marsrad.f90, computes the upwelling and downwelling components of the solar (shortwave) and thermal (longwave) radiation at the surface and the top of the atmosphere. This auxiliary program uses the Mars-GRAM output file MarsRad.txt, which includes the dust concentration information discussed in section 2.5. A full discussion of MarsRad.txt is contained in appendix A.

To compute upwelling shortwave radiation at the surface, Mars-GRAM uses surface albedo values from the data file albedo1.txt that contains the surface albedo at 1 degree latitude-longitude resolution.[28,29]

The auxiliary program marsrad.f90 produces two output files: radlist.txt and radout.txt. The computation methods that are used within marsrad.f90 to determine the radiation components contained in the output files are discussed in appendix G. Mars-GRAM output that is used as input to marsrad.f90 consists of one or more vertical profiles of temperature versus pressure (altitude). To facilitate the production of latitude-longitude, latitude-time, or longitude-time arrays of such profiles, program radtraj.f90 is also provided as an auxiliary program and is discussed in appendix G.

2.7 Slope Wind Model

The slope wind model contained in the Mars-GRAM 2010 subroutine slopewind is based on Ye et al.[30] In this model, the slope winds depend on terrain slopes that are determined from MOLA 0.5 degree resolution topography for the MOLA grid containing the latitude-longitude of interest. The method of Ye et al.[30] provides an analytical relationship to compute winds as a function of altitude and terrain slope for daytime, thermally-driven, upslope winds. The slopewind subroutine assumes a diurnal pattern of slope wind variation with time of day. The slope winds apply up to 4.5 km above the surface during the day and up to 2.5 km above the surface at night and are added to background MGCM winds at 7.5×9 degree resolution. Peak daytime winds are assumed to occur at 15 hours local solar time. Peak nighttime winds, due to downslope drainage flows, are assumed to occur at 3 hours local solar time. Lighter, cross-slope flows occur between these two times. Vertical component slope winds are also computed. These are proportional to the terrain slope, to the horizontal slope winds, and have an assumed variation with altitude, which gives maximum vertical winds near the middle of the slope wind altitude region, and zero vertical winds near the surface and near the top of the slope wind altitude region. The slope winds can also be scaled with the input factor, *blwinfac*, with a value of zero suppressing the slope wind output.

2.8 Traditional Mars-GRAM Options for Representing the Mean Atmosphere Along Entry Corridors

Mars-GRAM has several options for representing the mean atmosphere along entry corridors and these can be set using the input parameter *MapYear*. The *MapYear* = 0 option allows the user to control the dust optical depth and utilizes data interpolated from MGCM model results driven by selected values of globally-uniform dust optical depth. If *MapYear* = 1 is chosen, data are from MGCM model results driven by observed TES dust optical depth during TES mapping year 1 which was from April 1999 through January 2001. If *MapYear* = 2 is chosen, data are from MGCM model results driven by observed TES dust optical depth during TES mapping year 2 which was from February 2001 through December 2002. TES mapping year 1 had no global dust storm while TES mapping year 2 had a major, global-scale dust storm, peaking at $L_s = 210$. The Map Year 1 and 2 data sets have a 1 km vertical resolution up to 10 km.

2.9 Auxiliary Profile Option

The auxiliary profile option provides the user with the choice to read and use any auxiliary profile of temperature and density versus altitude. In exercising the auxiliary profile Mars-GRAM option, the values from the auxiliary profile replaces data from the original MGCM and MTGCM databases. This option is controlled by setting parameters *profile*, *profnear*, and *proffar* in the NAMELIST input file. Each line of the auxiliary profile input file consists of: (1) height, in km, (2) latitude, in degrees, (3) longitude, in degrees, (4) temperature, in K, (5) pressure, in N/m^2, (6) density, in kg/m^3, (7) eastward wind, in m/s, and (8) northward wind, in m/s. Heights are relative to the MOLA areoid or reference ellipsoid, as set by input parameter *MOLAhgts*. Latitudes are planetocentric or planetographic, as set by input parameter *ipclat*. Longitudes are east or west, as set by input parameter *LonEW*. MGCM/MTGCM temperature, pressure, and density data are used if any of the profile inputs for temperature, pressure, or density are zero. MGCM/MTGCM winds are used if both wind components are zero on the profile file. A sample auxiliary profile file named profiledata.txt is provided with the Mars-GRAM 2010 distribution. Additional examples of auxiliary profiles include data from TES nadir or limb observations or Mars mesoscale model output at a particular location and time.

3. NEW FEATURES OF MARS-GRAM 2010

3.1 Mars-GRAM 2010 Adjustment Factors

3.1.1 Adjustment Factor Requirements

The adjustment factors generated by this process had to satisfy the gas law: $p = \rho RT$, as well as the hydrostatic relation: $dp/dz = -\rho g$. If T is assumed to be unchanged and both p and ρ are adjusted by a common factor, F, both relations are preserved. The adjustment factors [$F(z,Lat,L_s)$] were expressed as a function of height (z), latitude (Lat), and areocentric solar longitude (L_s). This adjustment factor (F) is applied to the daily mean density and pressure values from MGCM (0–80 km) and MTGCM (above 80 km). The pressure scale height (RT/g) is unchanged by this process. However, since the pressure has been changed by the adjustment factor, the height of the 1.26 nbar pressure level, referred to as ZF in Mars-GRAM, has also been changed.

The daily mean MGCM or MTGCM density, DTA0, and the daily mean MGCM or MTGCM pressure, PTA0, depend on height (z), latitude (Lat), solar longitude (L_s), dust amount (τ), and solar activity parameter (F10). The adjusted values of DTA0′ and PTA0′ are computed from the adjustment factors (F) using the following equations:

$$\mathrm{DTA0}' = \mathrm{DTA0} * F\left(z, Lat, L_s\right) \tag{21}$$

and

$$\mathrm{PTA0}' = \mathrm{PTA0} * F\left(z, Lat, L_s\right) \ , \tag{22}$$

where the adjustment factor (F) has been determined as described above. Adjustment factors (F) are also used to adjust ZF by the relation:

$$ZF' = ZF + H \ln(F) \ , \tag{23}$$

where H is local pressure scale height.

3.1.2 Development of MTGCM Factors

Mars-GRAM density and pressure need to be consistent at 80 km, where the transition from MGCM to MTGCM data occurs. Thus, the assumption was made that $F(80,Lat,L_s)$ for the MTGCM data had to be the same as the adjustment factor at 80 km for the MGCM data. After adjustment factors $F(80,Lat,L_s)$ were determined from the MGCM analysis, they were used to determine MTGCM adjustment factors by use of the following equation:

$$F\left(z, Lat, L_s\right) = F\left(80, Lat, L_s\right) * \left(1 + A\varsigma + B\varsigma^2\right) \ , \tag{24}$$

where the height parameter $\varsigma = (z - 80)$ and the coefficients A and B depend on Lat and L_s.

Final adjustment factors $F(z, Lat, L_s)$ for MTGCM data were implemented into Mars-GRAM and a validation run comparing Mars-GRAM 2010 versus MGS, ODY, and MRO aerobraking data from the Planetary Data System (PDS) was completed. Any residual variation of aerobraking density about mean values that became apparent during this process was used to update the height dependence of Mars-GRAM perturbation standard deviations.

4. HOW TO RUN MARS-GRAM 2010

4.1 How to Obtain the Program

All source code and required data files are available as a downloadable zip file issued by the Marshall Space Flight Center Natural Environments Branch (EV44). The software is offered free of charge. To obtain the program source code and data files, refer to the contact information in the preface. See appendices D through G for summaries of the program and data files available in the downloaded file.

4.2 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 zip file distribution) as a guide. File README2.txt (available in the zip file distribution) also discusses use of dumytraj_M10.f90 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:

- To compile marsgram_M10.f90, dumytraj_M10.f90, and multtraj_M10.f90 under UNIX, to produce executable files marsgram_M10.x, dumytraj_M10.x, and multtraj_M10.exe, you can use the commands:

```
f90 Cfiles_M10_C.f90 Ifiles_M10_I.f90 marsgram_M10.x marsgram_M10.f90 marssubs_M10.
    f90/
setup_M10.f90 TESsubs_M10.f90
mv a.out marsgram_M10.x
erase *.o
erase *.mod

f90 Cfiles_M10_C.f90 Ifiles_M10_I.f90 dumytraj_M10.f90 marssubs_M10.f90 setup_M10.f90 /
TESsubs_M10.f90 wrapper_M10.f90
mv a.out dumytraj_M10.x
erase *.o
erase *.mod
```

```
f90 Cfiles_M10_C.f90 Ifiles_M10_I.f90 multtraj_M10.f90 marssubs_M10.f90 setup_M10.f90 /
TESsubs_M10.f90 wrapper_M10.f90
mv a.out multtraj_M10.x
erase *.o
erase *.mod
```

- To compile marsgram_M10.f90, dumytraj_M10.f90, and multtraj_M10.f90 under personal computer Disk Operating System (PC-DOS) (for example, with gfortran), to produce executable files marsgram_M10.exe, dumytraj_M10.exe, and multtraj_M10.exe, you can use the example compile-and-link macros in the Code directory.

- To compile the auxiliary programs bldtraj.f90, finddate.f90, marsrad.f90, julday.f90, or radtraj.f90, or the binary conversion programs makebin.f90, readalb.f90, or READTOPO.f90 under UNIX, just use the FORTRAN compile statement for the specific auxiliary program source code file, i.e.

  ```
  f90 -o auxiliary.x auxiliary.f90
  ```

  or for PC-DOS, use the compile-and-link macros in the Utilities directory.

- Make sure that necessary data files albedo1.txt (surface albedo data), COSPAR2.DAT (Committee on Space Research (COSPAR) model atmosphere data), MOLATOPH.TXT (MOLA topographic height information), and hgtoffst.dat (global average height offset values) are in an appropriate directory whose pathname is specified by parameter *DATADIR* in the NAMELIST format input file.

- Compile and run programs READTOPO.f90 to convert the MOLA data from ASCII to binary and readalb.f90 to convert the albedo data from ASCII to binary.

- Compile and run program makebin.f90 (see app. F) and convert the ASCII format MGCM and MTGCM data files provided to binary form (see app. 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 apps. 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 app. 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 of this is included below.

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

- Run the program by entering its executable name (e.g., marsgram); the program automatically opens and reads the NAMELIST input file, the *TRAJFL* file (if the trajectory mode is used), the data files albedo1.txt, COSPAR2.DAT, MOLATOPH.TXT and hgtoffst.dat, all MGCM and MTGCM binary data files, and the *WaveFile* file (if time-dependent coefficients are used).

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

If constant values of longitude-dependent wave model coefficients are used, values for these are read in as part of the NAMELIST input file (sec. 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.

4.3 Program Input

Appendix B gives a sample of a NAMELIST format input file for Mars-GRAM 2010. Whether the subroutine or stand-alone version is used, input variables whose values are supplied in the INPUT file are as follows:

LSTFL	Name of LIST file; example of a LIST file is given in appendix C; for a listing to the console in the stand-alone version enter filename CON
OUTFL	Name of OUTPUT file; a complete description of this file is contained 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)
profile	(Optional) auxiliary profile input file name
WaveFile	(Optional) input file for time-dependent wave coefficient data; see file description under parameter *iuwave*, below
DATADIR	Pathname to directory for COSPAR data, topographic height data, surface albedo data, and global height offset data files

GCMDIR	Pathname to directory for MGCM and MTGCM binary data files
IERT	1 for time input as Earth-receive time (ERT) or 0 Mars-event time (MET)
IUTC	1 for time input as Coordinated Universal Time (UTC), or 0 for Terrestrial (Dynamical) Time (TT)
MONTH	Integer month (1 through 12) for initial time
MDAY	Integer day of month for initial time
MYEAR	Integer year for starting time, a four-digit number; alternatively years 1970–2069 can be input as a two-digit number
NPOS	Maximum number of positions to evaluate, if an automatically-generated profile is to be produced; use 0 if trajectory positions are to be read in from a *TRAJFL* file
IHR	Integer initial time, hour of day (ERT or MET, controlled by *IERT* value and UTC or TT, controlled by *IUTC* value)
IMIN	Integer initial time, minute of hour (meaning controlled by *IERT* and *IUTC* values)
SEC	Initial time, seconds of minute (meaning controlled by *IERT* and *IUTC* values)
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), 0.1 to 3 (if 0 is input, a Viking-like annual variation of background dust is assumed)
Dustmin	Minimum seasonal dust τ if input *Dusttau* = 0 (> = 0.1)
Dustmax	Maximum seasonal dust τ if input *Dusttau* = 0 (< = 3)
Dustnu	Parameter for vertical distribution of dust density (Haberle et al.[21])
Dustdiam	Dust particle diameter (micrometers, assumed monodisperse)
Dustdens	Dust particle density (kg/m^3)
ALS0	Value of areocentric longitude of the Sun (L_s, 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 L_s is between 180° and 320°

ALSDUR Duration in L_s degrees for dust storm (default = 48)

INTENS Dust storm intensity, measured as peak dust optical depth of the storm, with allowable values ranging from 0 (no dust storm) to 3 (maximum intensity dust storm). Dust storm intensity is added to background dust optical depth to give total dust optical depth

RADMAX Maximum radius (km) a dust storm can attain, developing according to the parameterized space and time profile of buildup 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 and therefore 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

MapYear 1 or 2 for TES mapping year 1 or 2 GCM input data, or 0 for Mars-GRAM 2001 GCM input data sets

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

NR1 Seed value (integer) for random number generator; allowable range is 1 to 29999; to do Monte Carlo simulations with a variety of perturbations, use a different random number seed on each model run; to repeat a given random number sequence on a later model run, use the same random number seed value

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

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

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

FLAT	Latitude of initial point to simulate (degrees, North positive)
FLON	Longitude of initial point to simulate (degrees, West positive if *LonEW* = 0; East positive otherwise)
FHGT	Height (km) of initial point to simulate above the reference ellipsoid; use *FHGT* ≤ –10. km to specify that surface altitude should be used
MOLAhgts	1 for input heights relative to the MOLA areoid, otherwise input heights are relative to the old reference ellipsoid
hgtasfcm	Height above surface (0–1,000 m); use if *FHGT* ≤ –10 km
zoffset	Constant height offset (km) for MTGCM data or constant part of L_s-dependent (Bougher) height offset (0.0 means no constant offset). Positive offset increases density, negative offset decreases density
ibougher	0 for no L_s-dependent (Bougher) height offset term; 1 means add L_s-dependent (Bougher) term, $-A*\sin(L_s)$ (km), to constant term (*zoffset*), offset amplitude *A* = 2.5 for *MapYear* = 0 or 0.5 for *MapYear* > 0; 2 means use global mean height offset from data file hgtoffst.dat; 3 means use daily average height offset at local position; 4 means use height offset at current time and local position. Value of *zoffset* is ignored if *ibougher* = 2, 3, or 4
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 if *LonEW* = 1) between successive steps in an automatically generated profile
DELTIME	Time increment (s) 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
profnear	Latitude-longitude radius (degrees) within which weight for auxiliary profile is 1 (use *profnear* = 0.0 for no profile input)
proffar	Latitude-longitude radius (degrees) beyond which weight for auxiliary profile is 0.0
rpscale	Random density perturbation scale factor (0–2, 1 = nominal)

rwscale Random wind perturbation scale factor (> = 0)

wlscale Scale factor for perturbation wavelengths (0.1–10)

wmscale Scale factor for mean winds

blwinfac Scale factor for boundary layer slope winds (0 = none)

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

WaveDate Julian date for (primary) peak(s) of wave (0 for no traveling component)

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)

phi1dot Rate of longitude movement (degrees per day) for wave-1 component (Westward positive if *LonEW* = 0, Eastward 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 otherwise)

phi2dot Rate of longitude movement (degrees per day) for wave-2 component (Westward positive if *LonEW* = 0, Eastward 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 otherwise)

phi3dot Rate of longitude movement (degrees per day) for wave-3 component (Westward positive if *LonEW* = 0, Eastward positive if *LonEW* = 1)

iuwave	Unit number for (Optional) time-dependent wave coefficient data file named by input parameter *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)
corlmin	Minimum relative step size for perturbation updates (0.0-1.0); 0.0 means always update perturbations, x.x means only update perturbations when corlim > x.x
ipclat	1 for planetocentric latitude and height input, 0 for planetographic latitude and height input
requa	Equatorial radius (km) for reference ellipsoid
rpole	Polar radius (km) for reference ellipsoid
idaydata	1 for daily max/min data output; 0 for none

Four auxiliary input files are required in addition to the MGCM and MTGCM input data files. The file MOLATOPH.TXT contains the MOLA areoid and topography data at 1/2 by 1/2 degree latitude-longitude resolution. Each line of MOLATOPH.TXT contains East longitude and latitude at the center of the 1/2 by 1/2 degree grid box, grid-box-average radius (m) to topographic surface, areoid radius (m) which is the radius to reference constant potential surface, evaluated at the center of the grid box, topography which is the grid-box-average difference (m) between local planetary radius and areoid, analogous to local terrain height above sea level for Earth, and Num, the number of MOLA laser measurements averaged over the grid box. MOLA latitudes are planetocentric. Longitudes in the MOLA input file are with respect to the IAU 1991 prime meridian. A shift (of about 0.24°) is made automatically within Mars-GRAM 2010, in order to convert to longitudes relative to the International Astronomical Union (IAU) 2000 prime meridian.

File COSPAR2.DAT contains COSPAR reference values of temperature, density, and pressure as a function of height. File hgtoffst.dat contains global values of MTGCM height offset versus L_s and dust optical depth. File albedo1.txt contains 1-degree resolution surface albedo data. Each line of albedo1.txt contains latitude, and West longitude at the center of the 1 by 1 degree grid box, and grid-box-average surface albedo, the ratio of surface-reflected solar flux to that incident on the surface. Before Mars-GRAM is first used, the ASCII format files MOLATOPH.TXT and albedo1.txt must be converted to binary with the auxiliary programs READTOPO.f90 and readalb.f90, that are supplied with Mars-GRAM 2010.

If the number of positions to be calculated, *NPOS* is set to 0, an optional trajectory input file is read from a file whose name is given by the input parameter *TRAJFILE*. Each line of the trajectory file consists of: time, in seconds past the start time specified in the NAMELIST input, height in km, latitude in degrees, and longitude in degrees. Heights are relative to the MOLA areoid or reference ellipsoid, as set by the input parameter *MOLAhgts*. Latitudes are planetocentric or planetographic, as set by the input parameter *ipclat*. Longitudes are East or West, as set by the input parameter *LonEW*. Any additional information included on each line (e.g. orbit number, measured density, etc.) is ignored. Trajectory positions in these files do not have to be at small time or space steps. For example, a trajectory file may consist of successive periapsis times and positions for a simulated or observed aerobraking operation. Trajectory files may also contain arrays of locations used for computing height-latitude cross sections or latitude-longitude cross sections. Such trajectory input files can be as built by the program BLDTRAJ.f90.

If time-dependent wave parameters *WaveA0* through *Wavephi3* are desired, these are input from the file whose pathname is specified by the parameter *Wavefile* in the NAMELIST format input file. Parameter *iuwave* determines whether time-dependent *WaveFile* values are read or not. *Iuwave* = 0 means no *WaveFile* data; otherwise *iuwave* is the *WaveFile* unit number. Each data line in the *WaveFile* file contains the time in 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.

4.4 Program Output

There are three general types of program output provided in Mars-GRAM. The first is a LIST file whose name is specified by the input parameter *LSTFL* and contains header and descriptor information that is suitable for printing or viewing by an analyst. An example LIST file is given in appendix C. Second is an OUTPUT file whose name is specified by the input parameter *OUTFL* which contains one header line and one line per output position and is suitable for reading into another program for additional analysis. A description of this file can be found in appendix A. Finally, there is a set of plotable output files, or graphics output files, that are text files suitable for input to a graphics program. Descriptions of these files can be found 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 input parameters *NVARX* and *NVARY*. If line-graph (*x*-*y* pair) data is the selected plot output option, then *NVARY* = 0 is input. If contour plot (*x*-*y*-*z* triplet) data are the selected plot output option, then a non-zero value of *NVARY* is input. Appendix A lists codes for *NVARX* and *NVARY*.

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

5. SAMPLE RESULTS

5.1 Improvement of Mars-GRAM 2010 at Lower Altitudes

Application of adjustment factors to the Ames MGCM data yields improved comparisons between Mars-GRAM and TES limb data, as shown by the density ratios (Mars-GRAM/TES Limb) given in figure 1. Prior to adjustment these density ratios were as low as 0.65 near 60 km.

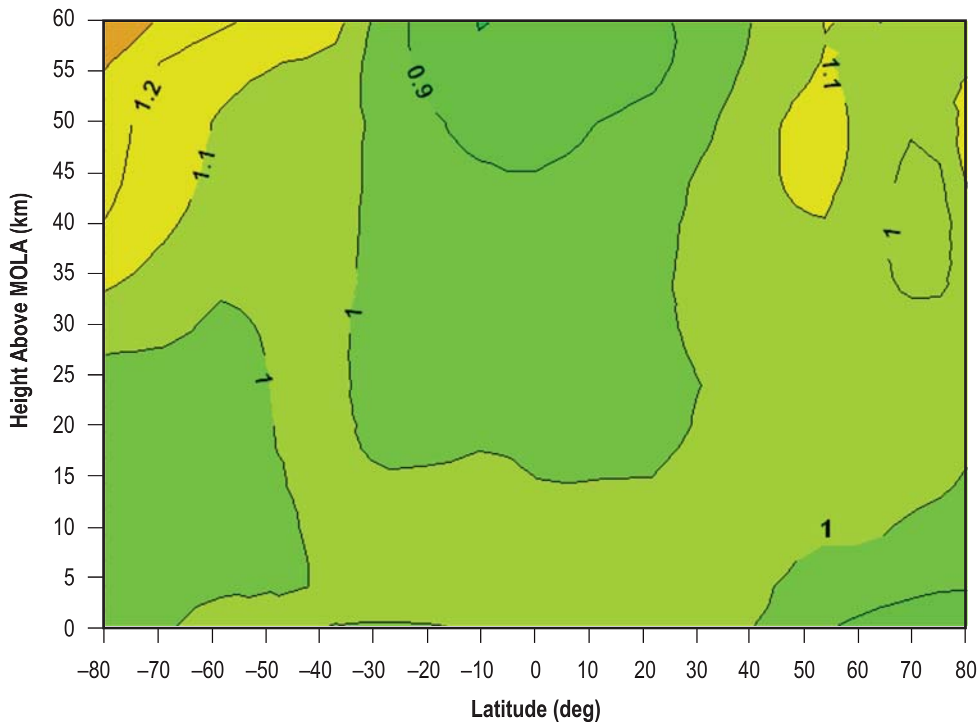

Figure 1. Latitude-height contours of density ratio (Mars-GRAM/TES limb) after application of MGCM adjustment factors.

Mars-GRAM 2005 and Mars-GRAM 2010 *MapYear* = 0 results have also been compared for three locations at local true solar time (LTST) 2 and 14:

- Location 1 (L1) = 22.5º S., 180º E., $L_s = 90 \pm 5$, $\tau = 0.11$
- Location 2 (L2) = 22.5º S., 180º E., $L_s = 75 \pm 5$, $\tau = 0.12$
- Location 3 (L3) = 2.5º N., 180º E., $L_s = 210 \pm 5$, $\tau = 2.65$ *dust storm case*

Figure 2 provides the density ratios of Mars-GRAM to TES for Mars-GRAM 2005. As figure 3 shows, the application of the adjustment factor in Mars-GRAM 2010 results in ratios of ≈1 at lower altitudes.

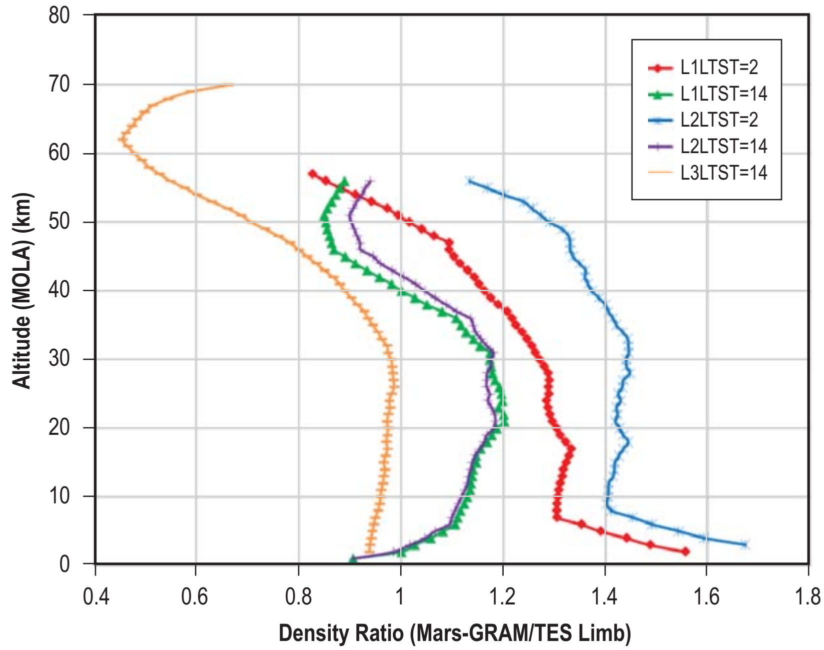

Figure 2. Density ratio (Mars-GRAM/TES) for Mars-GRAM 2005.

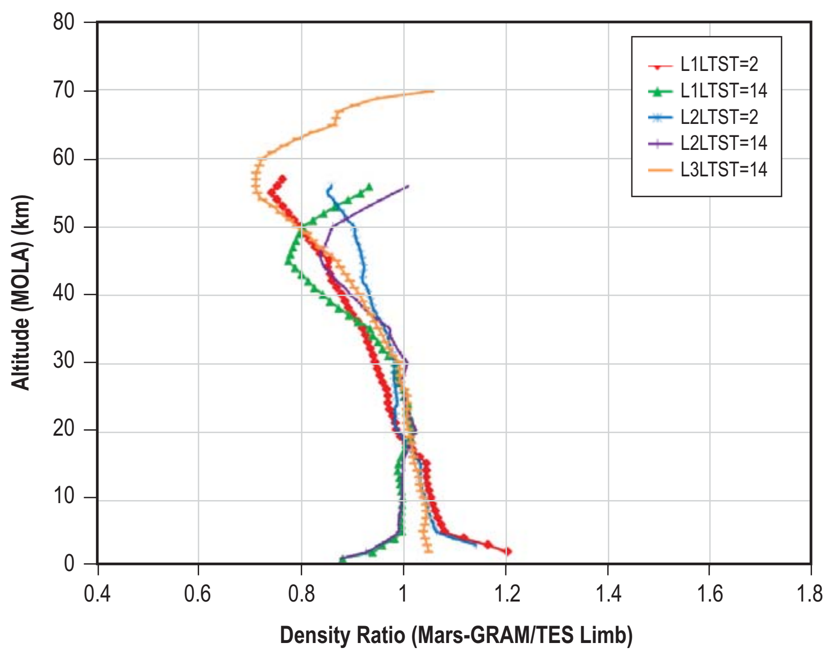

Figure 3. Density ratio (Mars-GRAM/TES) for Mars-GRAM 2010.

At the higher altitudes, Mars-GRAM 2010 results have corrected the effect of the underestimated dust aloft in the MGCM. At location 3, the Mars-GRAM 2010 density ratio has shifted closer to 1. This demonstrates that the addition of adjustment factors to Mars-GRAM 2010 has improved the results for the $MapYear = 0$ cases for large τ values.

5.2 Improvement of Mars-GRAM 2010 at Aerobraking Altitudes

Mars-GRAM modeled data output has improved at aerobraking altitudes by adding MTGCM adjustment factors which included height parameters and thermosphere coefficients. Improvement has been quantified by examining profile data density ratios for MGS, MRO, and ODY.

Taking the 99th percentile of all the density profiles illustrates the significant change the updated Mars-GRAM 2010 has on the profile density ratios. As shown in figure 4, the least amount of change was observed in the MGS data over the 99th percentile profile data, with an overall change of 2 units across the altitude range. The MRO data showed a significant improvement from the previous version of Mars-GRAM, reducing the higher altitude ratios from 6 to close to the optimal value of 1 on the updated data. However, the greatest change in ratio values occurred with the ODY data where the older data reached values close to 20 but the newer data brought the ratios down to a range between <1 to over 4 at the higher altitudes. All of the ratio values of the datasets improved from the old Mars-GRAM data output to the updated Mars-GRAM 2010 version.

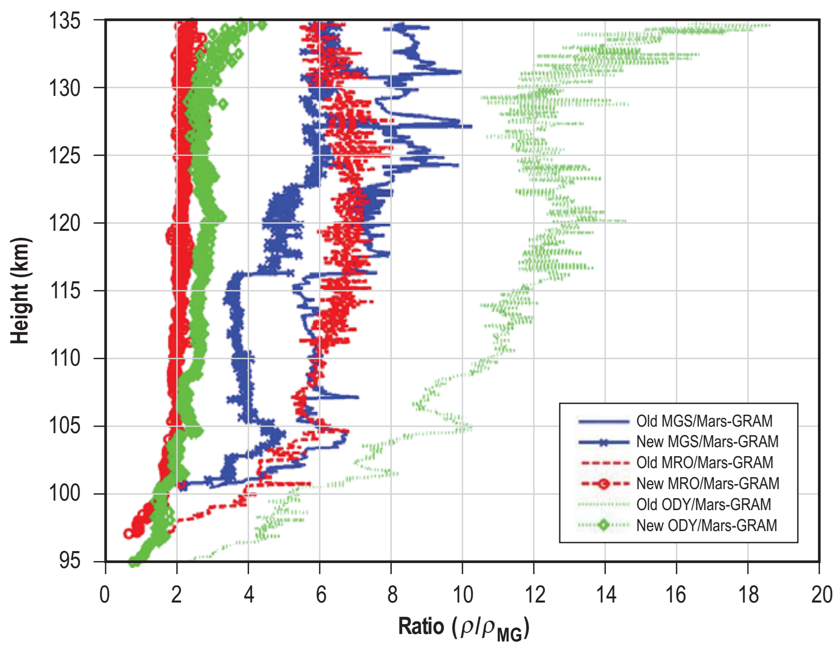

Figure 4. The 99th percentile density ratios of the profile data from MGS, MRO, and ODY to Mars-GRAM 2010 output versus height.

Figures 5 and 6 show the ratio of the observed density values to the Mars-GRAM output values for the old version and the updated Mars-GRAM 2010 version versus height and Mars latitude. Before the MTGCM adjustment factors, including thermosphere coefficients, were added to the Mars-GRAM code (fig. 5), the ratio values were higher than the optimal value of 1, especially at locations towards the poles. The contour lines are very tight near the poles, meaning lots of variability exists with the comparisons. In the updated plot shown in figure 6, a large area of the map is covered with the 1 ratio value, especially between –30° S. and 15° N. Although a large discrepancy of ratio values still exists towards the poles, the variability has decreased with the inclusion of the adjustment factors.

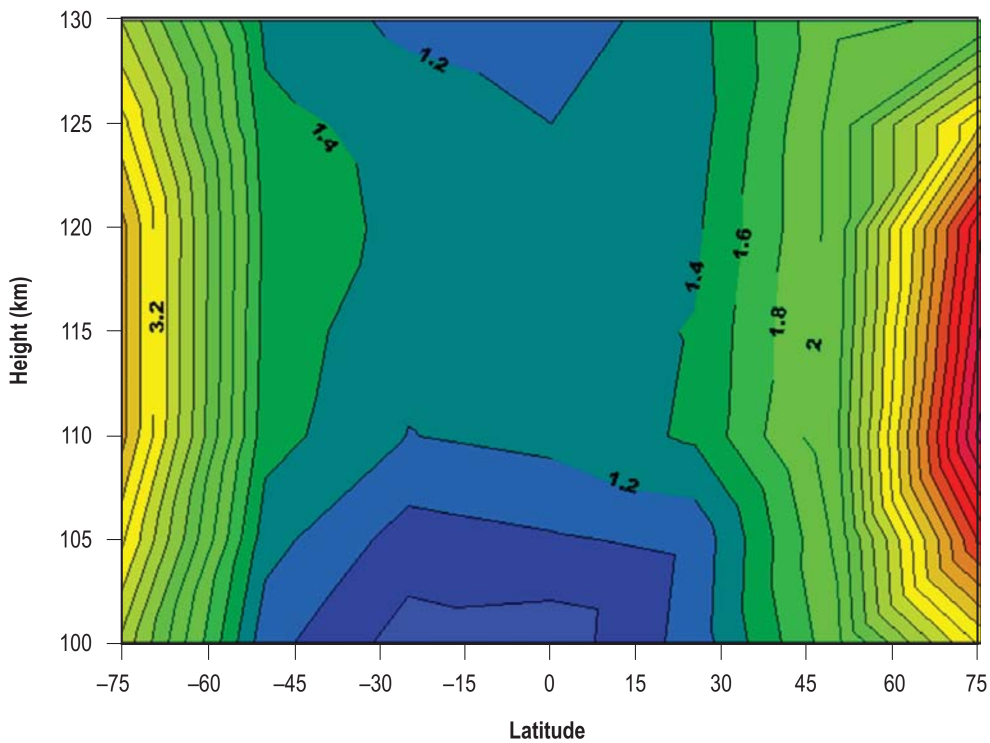

Figure 5. Contour plots of the ratio of observed PDS density values to Mars-GRAM output values (before adjustment) versus height and latitude.

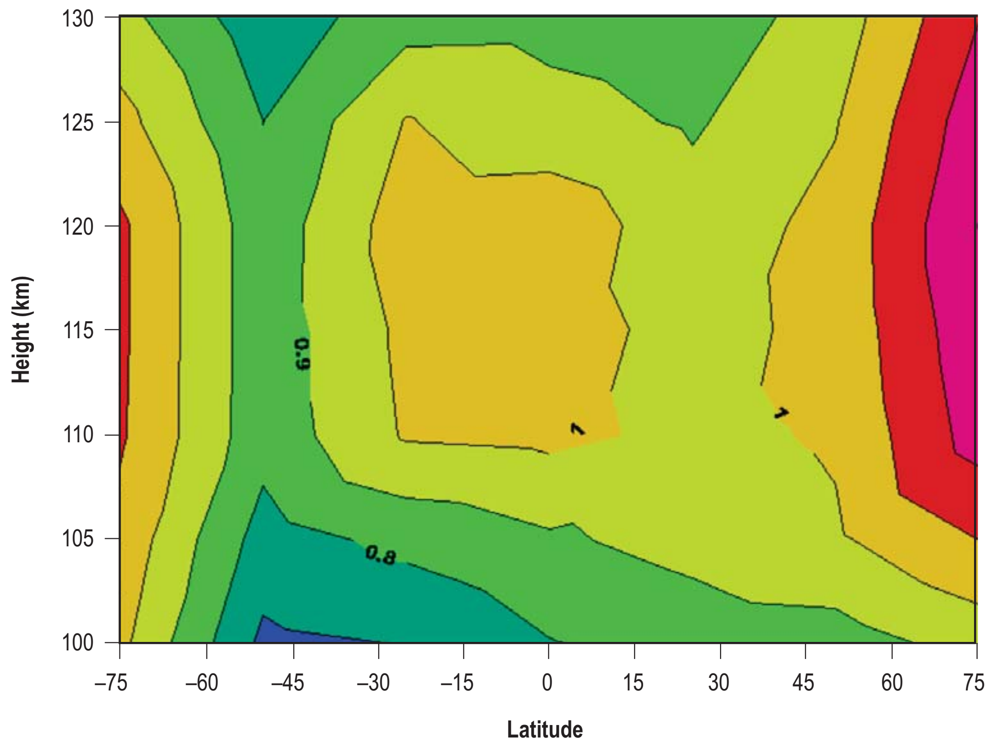

Figure 6. Contour plots of the ratio of observed PDS density values to Mars-GRAM 2010 output values (after adjustment) versus height and latitude.

APPENDIX A—HEADERS FOR MARS-GRAM 2010 OUTPUT FILES

Mars-GRAM 2010 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 as follows:

OUTPUT.txt (or other name, as prescribed in the NAMELIST INPUT file)

Time	Time after initial input time (seconds)
Height	Planetocentric height (km) above MOLA areoid (Height = HgtMOLA) OR planetocentric height (km) above ellipsoid (Height = HgtELPS) OR planetocentric height (km) above local MOLA topographic surface (Height = HgtSFCM) OR planetographic height (km) above ellipsoid (Height = HgtGRPH), as determined by input parameters *MOLAhgts*, *NVARX*, *NVARY*, and *ipclat*
Lat	Planetocentric latitude (Lat = LatPC) or planetographic latitude (Lat = LatPG) in degrees (North positive)
LonW/LonE	Longitude (degrees, West positive or East positive)
Denkgm3	Average (mean plus wave perturbed) density (kg/m^3) or “Logkgm3” for Log10(kg/m^3) or “Den%Avg” for percent deviation from COSPAR average, or “Denkgkm3” for kg/km^3, depending on input value of *LOGSCALE*
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
LTST	Local true solar time (Mars hours)
CO2%m	Carbon Dioxide mass concentration (% by mass)
N2%m	Nitrogen mass concentration (% by mass)

Ar%m	Argon mass concentration (% by mass)
O2%m	Molecular Oxygen mass concentration (% by mass)
CO%m	Carbon Monoxide mass concentration (% by mass)
O%m	Atomic Oxygen mass concentration (% by mass)
He%m	Helium mass concentration (% by mass)
H2%m	Molecular Hydrogen mass concentration (% by mass)
H%m	Atomic Hydrogen mass concentration (% by mass)
H2O%m	Water vapor mass concentration (% by mass)
DensP	Ratio of perturbed density to mean density

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

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

Density.txt

Var_X	User-selected plot variable determined by *NVARX* value

Var_Y	(Optional) user-selected plot variable from *NVARY* value
DENSLO	Low (~ average - 1 standard deviation) density (kg/m^3 or Log-10 or % from COSPAR or kg/km^3, as controlled by *LOGSCALE*)
DENSAV	Average (mean plus wave-perturbed) density (kg/m^3 or Log-10 or % from COSPAR, or kg/km^3, as controlled by *LOGSCALE*)
DENSHI	High (~ average + 1 standard deviation) density (kg/m^3 or Log-10 or % from COSPAR, or kg/km^3, as controlled by *LOGSCALE*)
DENSTOT	Total (mean plus perturbed) density (kg/m^3 or Log-10 or % from COSPAR, or kg/km^3, as controlled by *LOGSCALE*)
DustOD	Dust optical depth
Radius	Radial distance from planetary center of mass to spacecraft position (areoid radius plus altitude)
Grav	Local acceleration of gravity (m/s^2)
RadAU	Mars orbital radius (Astronomical Units)
LOGSCALE	Option controlling units of density output
Hgtoffset	Local height offset (km) for MTGCM and MGCM data
Ibougher	Input parameter controlling height offset option
MapYear	TES mapping year (0 for Mars-GRAM 2001 data)
Profwgt	Weight factor for auxiliary input profile data

MarsRad.txt

Var_X	User-selected plot variable (determined by *NVARX* value)
Var_Y	(Optional) user-selected plot variable (from *NVARY* value)
alb	Surface albedo (ratio upward/downward SW radiation at surface)
mu0	Cosine of solar zenith angle
Dareaden	Dust column areal density (kg / m^2)
Dmixrat	Dust mixing ratio (kg dust / kg air)
Dmasden	Dust mass density (micrograms dust / m^3)
Dnumden	Dust number density (number dust particles / m^3)

Ice	Surface polar ice indicator (0 = no, 1 = yes)

File = Perturb.txt

Ice	Surface polar ice indicator (0 = no, 1 = yes)
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 horizontal wind perturbations (m/s)
SigW	Standard deviation of vertical wind perturbations (m/s)
iupdate	1 if perturbations updated, 0 if perturbations not updated but perturbation step updated, -1 if neither perturbations nor step updated

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

Var_X	User-selected plot variable (determined by *NVARX* value)
Var_Y	(Optional) user-selected plot variable (from *NVARY* value)
Tbase	Temperature at 1.26 nbar level (K)
Zbase	Altitude of 1.26 nbar level (km)
F1peak	Altitude of F1 ionization peak (km)
MolWgt	Mean molecular weight (kg / kg.mole)
Texos	Exospheric temperature (K)
hgtoffset	Height offset for thermospheric (MTGCM) data (km)
ibougher	Input parameter controlling height offset option

TPresHgt.txt

ibougher	Input parameter controlling height offset option
Var_X	User-selected plot variable (determined by *NVARX* value)
Var_Y	(Optional) user-selected plot variable (from *NVARY* value)
Temp	Mean temperature (K)
Pres	Mean (plus wave-perturbed) pressure (N/m^2, or as controlled by *LOGSCALE*)
TdegC	Mean temperature (°C)
Pres_mb	Mean (plus wave-perturbed) pressure (mb)
Hrho	Density scale height (km)
Hpres	Pressure scale height (km)
MolWt	Molecular weight (kg/kg-mole)
TerHgt	Altitude of local surface above MOLA 1/2-degree areoid (km)
Tgrnd	Ground surface temperature (K)
Areoid	Local radius (km) of MOLA 1/2-degree areoid
dAreoid	MOLA areoid minus radius of old reference ellipsoid (km); equal to height from old ellipsoid minus height from MOLA areoid
CO2%v	Mole fraction (%) Carbon Dioxide concentration (% by volume)
N2%v	Mole fraction (%) Nitrogen concentration (% by volume)
Ar%v	Mole fraction (%) Argon concentration (% by volume)
O2%v	Mole fraction (%) Molecular Oxygen concentration (% by volume)
CO%v	Mole fraction (%) Carbon Monoxide concentration (% by volume)
O%v	Mole fraction (%) Atomic Oxygen concentration (% by volume)
He%v	Mole fraction (%) Helium concentration (% by volume)
H2%v	Mole fraction (%) Molecular Hydrogen concentration (% by volume)
H%v	Mole fraction (%) Atomic Hydrogen concentration (% by volume)
H2O%v	Mole fraction (%) Water vapor concentration (% by volume)
LOGSCALE	Option controlling units of pressure output

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)
VWpert	Vertical wind perturbation (m/s)
iupdate	1 if perturbations updated, 0 if perturbations not updated but perturbation step updated, -1 if neither perturbations nor step updated

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

Code	Parameter
1	Planetocentric height above local MOLA areoid (km)
2	Planetocentric height above local MOLA topographic surface (km)
3	Planetocentric latitude (degree (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, L_s (deg.)
8	Local Solar Time (Mars hours)
9	Pressure (mb)
10	Pressure Height (km) [-H*log(Pres/PresSurf) = -H*log(sigma)]
11	Sigma coordinate [sigma = Pressure/(Pressure at Surface)]
12	Planetocentric Height (km) above reference ellipsoid (km)
13	Planetographic Height (km) above reference ellipsoid (km)
14	Planetographic Latitude (deg.)
15	Longitude in range -180 to +180 (East or West, controlled by *LonEW*)

Run-time selection of these plotable parameters is made by the input variables *NVARX* and *NVARY* contained in the NAMELIST format input file as described in section 4.3 and appendix B.

APPENDIX B—EXAMPLE NAMELIST FORMAT INPUT FILE

The following is an example of the NAMELIST format input file required by Mars-GRAM 2010. Input data given here are provided as file inputstd0.txt. 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_M10
LSTFL  = 'LIST.txt'
OUTFL  = 'OUTPUT.txt'
TRAJFL  = 'TRAJDATA.txt'
profile = 'null'
WaveFile = 'null'
DATADIR = 'D:\Mars\Mars2010\Release1.0_Nov10\binFiles\'
GCMDIR  = 'D:\Mars\Mars2010\Release1.0_Nov10\binFiles\'
IERT   = 1
IUTC   = 1
MONTH  = 7
MDAY   = 20
MYEAR  = 76
NPOS   = 41
IHR   = 12
IMIN   = 30
SEC   = 0.0
LonEW  = 0
Dusttau = 0.3
Dustmin = 0.3
Dustmax = 1.0
Dustnu  = 0.003
Dustdiam = 5.0
Dustdens = 3000.
ALS0   = 0.0
ALSDUR  = 48.
INTENS  = 0.0
RADMAX  = 0.0
DUSTLAT = 0.0
DUSTLON = 0.0
MapYear = 0
F107   = 68.0
NR1   = 1234
NVARX  = 1
NVARY  = 0
LOGSCALE = 0
FLAT   = 22.48
FLON   = 47.97
FHGT   = -5.
MOLAhgts = 1
hgtasfcm = 0.
zoffset = 3.25
ibougher = 1
DELHGT  = 5.0
DELLAT  = 0.5
```

DELLON = 0.5
DELTIME = 500.0
deltaTEX = 0.0
profnear = 0.0
proffar = 0.0
rpscale = 1.0
rwscale = 1.0
wlscale = 1.0
wmscale = 1.0
blwinfac = 1.0
NMONTE = 1
iup   = 13
WaveA0 = 1.0
WaveDate = 0.0
WaveA1 = 0.0
Wavephi1 = 0.0
phi1dot = 0.0
WaveA2 = 0.0
Wavephi2 = 0.0
phi2dot = 0.0
WaveA3 = 0.0
Wavephi3 = 0.0
phi3dot = 0.0
iuwave = 0
Wscale = 20.
corlmin = 0.0
ipclat = 1
requa = 3396.19
rpole = 3376.20
idaydata = 1
$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)
profile = (Optional) auxiliary profile input file name
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
IERT   = 1 for time input as Earth-Receive time (ERT) or 0 Mars-event
time (MET)
IUTC   = 1 for time input as Coordinated Universal Time (UTC), or 0
for Terrestrial (Dynamical) Time (TT)
MONTH = (Integer) month of year
MDAY   = (Integer) day of month
MYEAR = (Integer) year (4-digit; 1970-2069 can be 2-digit)
NPOS   = max # positions to evaluate (0 = read data from trajectory
input file)
IHR   = Hour of day (ERT or MET, controlled by IERT and UTC or TT,
controlled by IUTC)
IMIN   = minute of hour (meaning controlled by IERT and IUTC)
SEC   = seconds of minute (meaning controlled by IERT and IUTC).
IHR:IMIN:SEC is time for initial position to be evaluated
LonEW = 0 for input and output West longitudes positive; 1 for East
longitudes positive

Dusttau = Optical depth of background dust level (no time-developing dust storm, just uniformly mixed dust), 0.1 to 3.0, or use 0 for assumed seasonal variation of background dust

Dustmin = Minimum seasonal dust tau if input Dusttau=0 (>=0.1)

Dustmax = Maximum seasonal dust tau if input Dusttau=0 (<=1.0)

Dustnu = Parameter for vertical distribution of dust density (Haberle et al., J. Geophys. Res., 104, 8957, 1999)

Dustdiam = Dust particle diameter (micrometers, assumed monodisperse)

Dustdens = Dust particle density (kg/m**3)

ALS0 = starting Ls value (degrees) for dust storm (0 = none)

ALSDUR = duration (in Ls degrees) for dust storm (default = 48)

INTENS = dust storm intensity (0.0 - 3.0)

RADMAX = max. radius (km) of dust storm (0 or >10000 = global)

DUSTLAT = Latitude (degrees) for center of dust storm

DUSTLON = Longitude (degrees) (West positive if LonEW=0, or East positive if LonEW = 1) for center of dust storm

MapYear = 1 or 2 for TES mapping year 1 or 2 GCM input data, or 0 for Mars-GRAM 2001 GCM input data sets

F107 = 10.7 cm solar flux (10**-22 W/cm**2 at 1 AU)

NR1 = starting random number (0 < NR1 < 30000)

NVARX = x-code for plotable output (1=hgt above MOLA areoid). See file xycodes.txt

NVARY = y-code for 3-D plotable output (0 for 2-D plots)

LOGSCALE = 0=regular SI units, 1=log-base-10 scale, 2=percentage deviations from COSPAR model, 3=SI units, with density in kg/km**3 (suitable for high altitudes)

FLAT = initial latitude (N positive), degrees

FLON = initial longitude (West positive if LowEW = 0 or East positive if LonEW = 1), degrees

FHGT = initial height (km); <=-10 means evaluate at surface height; > 3000 km means planeto-centric radius

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

hgtasfcm = height above surface (0-4500 m); use if FHGT <= -10. km

zoffset = constant height offset (km) for MTGCM data or constant part of Ls-dependent (Bougher) height offset (0.0 means no constant offset). Positive offset increases density, negative offset decreases density.

ibougher = 0 for no Ls-dependent (Bougher) height offset term; 1 means add Ls-dependent (Bougher) term, -A*Sin(Ls) (km), to constant term (zoffset) [offset amplitude A = 2.5 for MapYear=0 or 0.5 for MapYear > 0]; 2 means use global mean height offset from data file hgtoffst.dat; 3 means use daily average height offset at local position; 4 means use height offset at current time and local position. Value of zoffset is ignored if ibougher = 2, 3, or 4.

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)

profnear = Lat-lon radius (degrees) within which weight for auxiliary profile is 1.0 (Use profnear = 0.0 for no profile input)

proffar = Lat-lon radius (degrees) beyond which weight for auxiliary profile is 0.0

rpscale = random density perturbation scale factor (0-2)

rwscale = random wind perturbation scale factor (>=0)

wlscale = scale factor for perturbation wavelengths (0.1-10)

wmscale = scale factor for mean winds

blwinfac = scale factor for boundary layer slope winds (0 = none)

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

WaveDate = Julian date for (primary) peak(s) of wave (0 for no traveling component)

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)

phi1dot = Rate of longitude movement (degrees per day) for wave-1 component (Westward positive if LonEW = 0, Eastward 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)

phi2dot = Rate of longitude movement (degrees per day) for wave-2 component (Westward positive if LonEW = 0, Eastward 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)

phi3dot = Rate of longitude movement (degrees per day) for wave-3 component (Westward positive if LonEW = 0, Eastward 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)

corlmin = minimum relative step size for perturbation updates (0.0-1.0); 0.0 means always update perturbations, x.x means only update perturbations when corlim > x.x

ipclat = 1 for Planeto-centric latitude and height input, 0 for Planeto-graphic latitude and height input

requa = Equatorial radius (km) for reference ellipsoid

rpole = Polar radius (km) for reference ellipsoid

idaydata = 1 for daily max/min data output; 0 for none

APPENDIX C—SAMPLE OUTPUT LIST FILE

Following is the LIST file output produced by the standard input parameters given in appendix B. Standard input files for *MapYear* = 0, 1, and 2 are provided to users as the files inputstd0.txt, inputstd1.txt, and inputstd2.txt. The output data given below are provided in the file ListMapYr0.txt. Output files that result from the use of inputstd1.txt and inputstd2.txt are provided to users in the files ListMapYr1.txt and ListMapYr2.txt. Availability of these files allows users to complete a test run after compiling Mars-GRAM 2010 on their own computer and to electronically check their output by a file-compare process (e.g. the 'diff' command in UNIX or the 'fc' command in DOS). Please 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:

```
Mars-GRAM 2010 (Version 1.0) - Nov 2010
LIST file= LIST.txt
OUTPUT file= OUTPUT.txt
Data directory= D:\Mars\Mars2010\Release1.0_Nov10\binFiles\
GCM directory= D:\Mars\Mars2010\Release1.0_Nov10\binFiles\
Input time is Earth-Receive Time (ERT)
Input time is Coordinated Universal Time (UTC)
Date = 7/20/1976 Julian Day = 2442980.02083 Time = 12:30: 0.0
Input heights are planeto-centric, relative to MOLA areoid
Reference ellipsoid radii (km): Equator = 3396.19 Pole = 3376.20
Output heights are planeto-centric, except as noted.
Longitude & ephemeris use IAU 2000 rotational system.
F10.7 flux = 68.0 (1 AU)  25.0 (Mars)
Dust optical depth from NAMELIST input
Dustnu = 0.0030  Dustdiam = 5.00 E-6 meters  Dustdens = 3000.0 kg/m**3
 Random seed = 1234 Dens.Pert.Scale Factor = 1.00  corlmin = 0.000
 Wind.Pert.Scale Factor = 1.00  Wavelength Scale Factor = 1.00
 Mean Wind Scale Factor = 1.00  Slope Wind Scale Factor = 1.00
A0,A1,phi1,A2,phi2,A3,phi3= 1.000 0.000  0.0 0.000  0.0 0.000  0.0
 Wave Scale =  20.0 km.  Wave phases are in degrees of West Longitude
Time (rel. to T0) =    0.0 sec. (  0.000 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = -5.000 km ( -1.372 km) OWLT = 19.01 Min
Topographic Height =  -3.628 km  Radius (Areoid) = 3387.954 (3392.954) km
Hgt Above Ellipsoid = -5.292 km  Scale Hgt H(p)= 10.94 H(rho)= 10.94 km
Height Offset Parameters:  ibougher = 1  Local Height Offset = 0.000 km
Planeto-Centric Lat =  22.48 deg Longitude =  47.97 W ( 312.03 E) deg.
Planeto-Graphic Lat =  22.72 deg Planeto-Graphic Hgt (Ellps)=  -5.292 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.69 deg.W   Local True Solar Time = 16.05 Mars hrs
Temperature =  241.8 K    Pressure = 8.953E+02 N/m**2  profwgt = 0.000
Density (Low, Avg., High) =  1.922E-02  1.960E-02  1.999E-02 kg/m**3
Departure, COSPAR NH Mean =  -21.6 %   -20.0 %   -18.4 % iupdate = 1
Tot.Dens. = 2.006E-02 kg/m**3  Dens.Pert. =  2.34% Wave =  0.00% of mean
Eastward Wind (Mean,Perturbed,Total) =  0.0  -1.1  -1.1 m/s  VertWind
Northward Wind(Mean,Perturbed,Total) =  0.0  -0.4  -0.4 m/s  -0.2 m/s
CO2=2.577E+23 N2=7.809E+21 Ar=4.685E+21 O2=3.692E+20 CO=2.840E+20 #/m**3
   96.084    1.854    1.586    0.100    0.067 % by mass
   94.445    2.862    1.717    0.135    0.104 % by volume
```

H2O=2.025E+21 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=2.729E+23 #/m**3
    0.308   0.000   0.000   0.000 % by mass MolWgt=43.259
    0.742   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) =   500.0 sec. (0.006 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 0.000 km (3.585 km) OWLT = 19.01 Min
Topographic Height = -3.585 km Radius (Areoid) = 3392.852 (3392.852) km
Hgt Above Ellipsoid = -0.268 km Scale Hgt H(p)= 10.85 H(rho)= 12.96 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 0.000 km
Planeto-Centric Lat = 22.98 deg Longitude = 48.47 W (311.53 E) deg.
Planeto-Graphic Lat = 23.22 deg Planeto-Graphic Hgt (Ellps)= -0.268 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 110.72 deg.W   Local True Solar Time = 16.15 Mars hrs
Temperature = 227.5 K   Pressure = 5.670E+02 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.294E-02 1.320E-02 1.346E-02 kg/m**3
Departure, COSPAR NH Mean = -16.5 %   -14.9 %   -13.2 % iupdate = 1
Tot.Dens. = 1.338E-02 kg/m**3 Dens.Pert. = 1.41% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = 2.8 2.9 5.7 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -7.9 -2.5 -10.4 m/s -0.7 m/s
CO2=1.739E+23 N2=5.267E+21 Ar=3.160E+21 O2=2.490E+20 CO=1.915E+20 #/m**3
   96.290   1.857   1.589   0.100   0.068 % by mass
   94.928   2.875   1.725   0.136   0.105 % by volume
H2O=4.244E+20 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=1.832E+23 #/m**3
    0.096   0.000   0.000   0.000 % by mass MolWgt=43.386
    0.232   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 1000.0 sec. (0.011 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 5.000 km (8.545 km) OWLT = 19.01 Min
Topographic Height = -3.545 km Radius (Areoid) = 3397.749 (3392.749) km
Hgt Above Ellipsoid = 4.756 km Scale Hgt H(p)= 9.92 H(rho)= 11.27 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 0.000 km
Planeto-Centric Lat = 23.48 deg Longitude = 48.97 W (311.03 E) deg.
Planeto-Graphic Lat = 23.73 deg Planeto-Graphic Hgt (Ellps)= 4.756 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 112.74 deg.W   Local True Solar Time = 16.25 Mars hrs
Temperature = 211.0 K   Pressure = 3.577E+02 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 8.793E-03 8.969E-03 9.148E-03 kg/m**3
Departure, COSPAR NH Mean = -11.2 %   -9.4 %   -7.6 % iupdate = 1
Tot.Dens. = 8.701E-03 kg/m**3 Dens.Pert. = -2.99% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = 2.5 -1.9 0.6 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = 3.0 1.3 4.3 m/s -0.3 m/s
CO2=1.183E+23 N2=3.581E+21 Ar=2.149E+21 O2=1.693E+20 CO=1.302E+20 #/m**3
   96.366   1.858   1.590   0.100   0.068 % by mass
   95.107   2.880   1.728   0.136   0.105 % by volume
H2O=5.525E+19 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=1.244E+23 #/m**3
    0.018   0.000   0.000   0.000 % by mass MolWgt=43.434
    0.044   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 1500.0 sec. (0.017 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 10.000 km (13.513 km) OWLT = 19.01 Min
Topographic Height = -3.513 km Radius (Areoid) = 3402.642 (3392.642) km
Hgt Above Ellipsoid = 9.778 km Scale Hgt H(p)= 9.48 H(rho)= 10.60 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 0.000 km
Planeto-Centric Lat = 23.98 deg Longitude = 49.47 W (310.53 E) deg.
Planeto-Graphic Lat = 24.23 deg Planeto-Graphic Hgt (Ellps)= 9.778 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 114.77 deg.W   Local True Solar Time = 16.35 Mars hrs
Temperature = 198.7 K   Pressure = 2.161E+02 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 5.624E-03 5.753E-03 5.885E-03 kg/m**3
Departure, COSPAR NH Mean = -13.1 %   -11.1 %   -9.0 % iupdate = 1

```
Tot.Dens. = 5.749E-03 kg/m**3  Dens.Pert. = -0.07% Wave =  0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -16.4  -0.9 -17.3 m/s  VertWind
Northward Wind(Mean,Perturbed,Total) =  9.5  2.0  11.4 m/s  -0.8 m/s
CO2=7.588E+22 N2=2.297E+21 Ar=1.378E+21 O2=1.086E+20 CO=8.352E+19 #/m**3
   96.380    1.857    1.589    0.100    0.068 % by mass
   95.139    2.880    1.728    0.136    0.105 % by volume
H2O=9.639E+18 O=0.000E+00 He=0.000E+00 H2=0.000E+00  Total=7.975E+22 #/m**3
    0.005    0.000    0.000    0.000 % by mass MolWgt=43.442
    0.012    0.000    0.000    0.000 % volume (mole) fraction
----------------------------------------------------------------------------------------------------------------------
Time (rel. to T0) =  2000.0 sec. (  0.023 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 15.000 km ( 18.545 km) OWLT = 19.01 Min
Topographic Height =  -3.545 km  Radius (Areoid) = 3407.533 (3392.533) km
Hgt Above Ellipsoid = 14.800 km  Scale Hgt H(p)=  9.08 H(rho)= 10.13 km
Height Offset Parameters:  ibougher = 1  Local Height Offset = 0.000 km
Planeto-Centric Lat =  24.48 deg Longitude =  49.97 W ( 310.03 E) deg.
Planeto-Graphic Lat =  24.73 deg Planeto-Graphic Hgt (Ellps)=  14.800 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 116.80 deg.W   Local True Solar Time = 16.46 Mars hrs
Temperature =  188.3 K    Pressure = 1.276E+02 N/m**2  profwgt = 0.000
Density (Low, Avg., High) =  3.494E-03  3.587E-03  3.682E-03 kg/m**3
Departure, COSPAR NH Mean =  -16.2 %   -14.0 %   -11.7 % iupdate = 1
Tot.Dens. = 3.597E-03 kg/m**3  Dens.Pert. =  0.28% Wave =  0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -19.7  -6.0 -25.7 m/s  VertWind
Northward Wind(Mean,Perturbed,Total) =  10.8  0.2  11.0 m/s   1.4 m/s
CO2=4.731E+22 N2=1.431E+21 Ar=8.589E+20 O2=6.767E+19 CO=5.205E+19 #/m**3
   96.385    1.857    1.589    0.100    0.067 % by mass
   95.149    2.879    1.727    0.136    0.105 % by volume
H2O=1.827E+18 O=0.000E+00 He=0.000E+00 H2=0.000E+00  Total=4.972E+22 #/m**3
    0.002    0.000    0.000    0.000 % by mass MolWgt=43.445
    0.004    0.000    0.000    0.000 % volume (mole) fraction
----------------------------------------------------------------------------------------------------------------------
Time (rel. to T0) =  2500.0 sec. (  0.028 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 20.000 km ( 23.571 km) OWLT = 19.01 Min
Topographic Height =  -3.571 km  Radius (Areoid) = 3412.420 (3392.420) km
Hgt Above Ellipsoid = 19.821 km  Scale Hgt H(p)=  8.69 H(rho)=  9.71 km
Height Offset Parameters:  ibougher = 1  Local Height Offset = 0.000 km
Planeto-Centric Lat =  24.98 deg Longitude =  50.47 W ( 309.53 E) deg.
Planeto-Graphic Lat =  25.24 deg Planeto-Graphic Hgt (Ellps)=  19.821 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 118.83 deg.W   Local True Solar Time = 16.56 Mars hrs
Temperature =  178.1 K    Pressure = 7.374E+01 N/m**2  profwgt = 0.000
Density (Low, Avg., High) =  2.125E-03  2.190E-03  2.257E-03 kg/m**3
Departure, COSPAR NH Mean =  -19.2 %   -16.7 %   -14.2 % iupdate = 1
Tot.Dens. = 2.229E-03 kg/m**3  Dens.Pert. =  1.78% Wave =  0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -30.6  -0.7 -31.3 m/s  VertWind
Northward Wind(Mean,Perturbed,Total) =  8.2  -6.1  2.1 m/s  -0.3 m/s
CO2=2.888E+22 N2=8.737E+20 Ar=5.242E+20 O2=4.130E+19 CO=3.177E+19 #/m**3
   96.388    1.856    1.588    0.100    0.067 % by mass
   95.153    2.878    1.727    0.136    0.105 % by volume
H2O=3.014E+17 O=0.000E+00 He=0.000E+00 H2=0.000E+00  Total=3.036E+22 #/m**3
    0.000    0.000    0.000    0.000 % by mass MolWgt=43.446
    0.001    0.000    0.000    0.000 % volume (mole) fraction
----------------------------------------------------------------------------------------------------------------------
Time (rel. to T0) =  3000.0 sec. (  0.034 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 25.000 km ( 28.359 km) OWLT = 19.01 Min
Topographic Height =  -3.359 km  Radius (Areoid) = 3417.305 (3392.305) km
Hgt Above Ellipsoid = 24.841 km  Scale Hgt H(p)=  8.34 H(rho)=  9.43 km
Height Offset Parameters:  ibougher = 1  Local Height Offset = 0.000 km
Planeto-Centric Lat =  25.48 deg Longitude =  50.97 W ( 309.03 E) deg.
```

Planeto-Graphic Lat = 25.74 deg Planeto-Graphic Hgt (Ellps)= 24.841 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 120.85 deg.W   Local True Solar Time = 16.66 Mars hrs
Temperature = 168.0 K   Pressure = 4.160E+01 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.265E-03 1.310E-03 1.356E-03 kg/m**3
Departure, COSPAR NH Mean = -21.9 %   -19.1 %   -16.3 % iupdate = 1
Tot.Dens. = 1.302E-03 kg/m**3 Dens.Pert. = -0.63% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -42.1 3.7 -38.5 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = 9.5 5.4 14.9 m/s   1.3 m/s
CO2=1.728E+22 N2=5.224E+20 Ar=3.134E+20 O2=2.469E+19 CO=1.900E+19 #/m**3
96.389   1.855   1.588   0.100   0.067 % by mass
95.156   2.877   1.726   0.136   0.105 % by volume
H2O=4.024E+16 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=1.816E+22 #/m**3
0.000   0.000   0.000   0.000 % by mass MolWgt=43.446
0.000   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 3500.0 sec. (0.039 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 30.000 km (33.384 km) OWLT = 19.01 Min
Topographic Height = -3.384 km Radius (Areoid) = 3422.188 (3392.188) km
Hgt Above Ellipsoid = 29.861 km Scale Hgt H(p)= 8.01 H(rho)= 8.72 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 0.000 km
Planeto-Centric Lat = 25.98 deg Longitude = 51.47 W (308.53 E) deg.
Planeto-Graphic Lat = 26.25 deg Planeto-Graphic Hgt (Ellps)= 29.861 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 122.88 deg.W   Local True Solar Time = 16.76 Mars hrs
Temperature = 157.1 K   Pressure = 2.293E+01 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 7.418E-04 7.719E-04 8.032E-04 kg/m**3
Departure, COSPAR NH Mean = -24.3 %   -21.2 %   -18.0 % iupdate = 1
Tot.Dens. = 7.296E-04 kg/m**3 Dens.Pert. = -5.47% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -60.3 -4.5 -64.8 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -4.5 -4.2 -8.8 m/s -0.0 m/s
CO2=1.018E+22 N2=3.077E+20 Ar=1.846E+20 O2=1.455E+19 CO=1.119E+19 #/m**3
96.391   1.855   1.587   0.100   0.067 % by mass
95.158   2.876   1.726   0.136   0.105 % by volume
H2O=3.427E+15 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=1.070E+22 #/m**3
0.000   0.000   0.000   0.000 % by mass MolWgt=43.446
0.000   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 4000.0 sec. (0.045 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 35.000 km (38.545 km) OWLT = 19.01 Min
Topographic Height = -3.545 km Radius (Areoid) = 3427.069 (3392.069) km
Hgt Above Ellipsoid = 34.882 km Scale Hgt H(p)= 7.76 H(rho)= 8.72 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 0.000 km
Planeto-Centric Lat = 26.48 deg Longitude = 51.97 W (308.03 E) deg.
Planeto-Graphic Lat = 26.75 deg Planeto-Graphic Hgt (Ellps)= 34.881 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 124.91 deg.W   Local True Solar Time = 16.86 Mars hrs
Temperature = 149.4 K   Pressure = 1.234E+01 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 4.175E-04 4.371E-04 4.576E-04 kg/m**3
Departure, COSPAR NH Mean = -28.3 %   -24.9 %   -21.4 % iupdate = 1
Tot.Dens. = 4.215E-04 kg/m**3 Dens.Pert. = -3.58% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -84.4 4.2 -80.2 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -14.5 4.7 -9.7 m/s -0.5 m/s
CO2=5.765E+21 N2=1.742E+20 Ar=1.045E+20 O2=8.234E+18 CO=6.334E+18 #/m**3
96.392   1.854   1.587   0.100   0.067 % by mass
95.160   2.875   1.725   0.136   0.105 % by volume
H2O=4.724E+14 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=6.059E+21 #/m**3
0.000   0.000   0.000   0.000 % by mass MolWgt=43.446
0.000   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 4500.0 sec. (0.051 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 40.000 km (43.648 km) OWLT = 19.01 Min
Topographic Height = -3.648 km Radius (Areoid) = 3431.950 (3391.950) km
Hgt Above Ellipsoid = 39.903 km Scale Hgt H(p)= 7.56 H(rho)= 8.12 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 0.000 km
Planeto-Centric Lat = 26.98 deg Longitude = 52.47 W (307.53 E) deg.
Planeto-Graphic Lat = 27.25 deg Planeto-Graphic Hgt (Ellps)= 39.903 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 126.94 deg.W   Local True Solar Time = 16.96 Mars hrs
Temperature = 139.3 K   Pressure = 6.522E+00 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 2.350E-04 2.477E-04 2.610E-04 kg/m**3
Departure, COSPAR NH Mean = -30.9 %   -27.2 %   -23.2 % iupdate = 1
Tot.Dens. = 2.232E-04 kg/m**3 Dens.Pert. = -9.88% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -89.0 -4.8 -93.7 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -9.0 -4.4 -13.4 m/s -0.0 m/s
CO2=3.267E+21 N2=9.865E+19 Ar=5.919E+19 O2=4.663E+18 CO=3.587E+18 #/m**3
96.393   1.853   1.586   0.100   0.067 % by mass
95.162   2.874   1.724   0.136   0.105 % by volume
H2O=2.599E+13 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=3.433E+21 #/m**3
0.000   0.000   0.000   0.000 % by mass MolWgt=43.447
0.000   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 5000.0 sec. (0.056 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 45.000 km (48.628 km) OWLT = 19.01 Min
Topographic Height = -3.628 km Radius (Areoid) = 3436.830 (3391.830) km
Hgt Above Ellipsoid = 44.926 km Scale Hgt H(p)= 7.33 H(rho)= 7.41 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 0.000 km
Planeto-Centric Lat = 27.48 deg Longitude = 52.97 W (307.03 E) deg.
Planeto-Graphic Lat = 27.75 deg Planeto-Graphic Hgt (Ellps)= 44.926 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 128.97 deg.W   Local True Solar Time = 17.07 Mars hrs
Temperature = 133.2 K   Pressure = 3.389E+00 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.267E-04 1.346E-04 1.430E-04 kg/m**3
Departure, COSPAR NH Mean = -34.7 %   -30.6 %   -26.3 % iupdate = 1
Tot.Dens. = 1.225E-04 kg/m**3 Dens.Pert. = -8.99% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -86.7 1.6 -85.1 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -12.8 0.3 -12.4 m/s -1.0 m/s
CO2=1.776E+21 N2=5.361E+19 Ar=3.216E+19 O2=2.534E+18 CO=1.949E+18 #/m**3
96.395   1.853   1.585   0.100   0.067 % by mass
95.163   2.873   1.724   0.136   0.104 % by volume
H2O=3.620E+12 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=1.866E+21 #/m**3
0.000   0.000   0.000   0.000 % by mass MolWgt=43.447
0.000   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 5500.0 sec. (0.062 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 50.000 km (53.523 km) OWLT = 19.01 Min
Topographic Height = -3.523 km Radius (Areoid) = 3441.711 (3391.711) km
Hgt Above Ellipsoid = 49.951 km Scale Hgt H(p)= 7.86 H(rho)= 7.21 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 0.000 km
Planeto-Centric Lat = 27.98 deg Longitude = 53.47 W (306.53 E) deg.
Planeto-Graphic Lat = 28.26 deg Planeto-Graphic Hgt (Ellps)= 49.951 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 130.99 deg.W   Local True Solar Time = 17.17 Mars hrs
Temperature = 132.4 K   Pressure = 1.726E+00 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 6.440E-05 6.903E-05 7.399E-05 kg/m**3
Departure, COSPAR NH Mean = -40.4 %   -36.1 %   -31.5 % iupdate = 1
Tot.Dens. = 6.888E-05 kg/m**3 Dens.Pert. = -0.21% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -86.4 0.5 -86.0 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = 12.2 7.8 20.0 m/s -0.5 m/s
CO2=9.105E+20 N2=2.747E+19 Ar=1.648E+19 O2=1.299E+18 CO=9.990E+17 #/m**3

```
  96.396    1.852    1.585    0.100    0.067 % by mass
  95.165    2.872    1.723    0.136    0.104 % by volume
H2O=2.765E+12 O=0.000E+00 He=0.000E+00 H2=0.000E+00  Total=9.568E+20 #/m**3
   0.000    0.000    0.000    0.000 % by mass MolWgt=43.447
   0.000    0.000    0.000    0.000 % volume (mole) fraction
--------------------------------------------------------------------------------------------------------------------------
Time (rel. to T0) =  6000.0 sec. (  0.068 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 55.000 km ( 58.286 km) OWLT = 19.01 Min
Topographic Height =  -3.286 km  Radius (Areoid) = 3446.592 (3391.592) km
Hgt Above Ellipsoid = 54.978 km  Scale Hgt H(p)=  9.17 H(rho)=  8.50 km
Height Offset Parameters:  ibougher = 1  Local Height Offset = 0.000 km
Planeto-Centric Lat =  28.48 deg Longitude =  53.97 W ( 306.03 E) deg.
Planeto-Graphic Lat =  28.76 deg Planeto-Graphic Hgt (Ellps)=  54.978 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 133.02 deg.W   Local True Solar Time = 17.27 Mars hrs
Temperature =  140.4 K    Pressure = 9.204E-01 N/m**2  profwgt = 0.000
Density (Low, Avg., High) =  3.209E-05  3.475E-05  3.764E-05 kg/m**3
Departure, COSPAR NH Mean =  -45.8 %   -41.3 %   -36.4 % iupdate = 1
Tot.Dens. = 2.639E-05 kg/m**3  Dens.Pert. = -24.06% Wave =  0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -68.2  -6.4 -74.6 m/s  VertWind
Northward Wind(Mean,Perturbed,Total) =  -1.9  1.7  -0.1 m/s  -4.6 m/s
CO2=4.584E+20 N2=1.383E+19 Ar=8.296E+18 O2=6.536E+17 CO=5.028E+17 #/m**3
  96.398    1.851    1.584    0.100    0.067 % by mass
  95.167    2.870    1.722    0.136    0.104 % by volume
H2O=3.607E+13 O=0.000E+00 He=0.000E+00 H2=0.000E+00  Total=4.817E+20 #/m**3
   0.000    0.000    0.000    0.000 % by mass MolWgt=43.447
   0.000    0.000    0.000    0.000 % volume (mole) fraction
--------------------------------------------------------------------------------------------------------------------------
Time (rel. to T0) =  6500.0 sec. (  0.073 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 60.000 km ( 63.123 km) OWLT = 19.01 Min
Topographic Height =  -3.123 km  Radius (Areoid) = 3451.473 (3391.473) km
Hgt Above Ellipsoid = 60.007 km  Scale Hgt H(p)= 12.00 H(rho)= 11.87 km
Height Offset Parameters:  ibougher = 1  Local Height Offset = 0.000 km
Planeto-Centric Lat =  28.98 deg Longitude =  54.47 W ( 305.53 E) deg.
Planeto-Graphic Lat =  29.26 deg Planeto-Graphic Hgt (Ellps)=  60.006 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 135.05 deg.W   Local True Solar Time = 17.37 Mars hrs
Temperature =  146.6 K    Pressure = 5.372E-01 N/m**2  profwgt = 0.000
Density (Low, Avg., High) =  1.774E-05  1.943E-05  2.129E-05 kg/m**3
Departure, COSPAR NH Mean =  -44.2 %   -38.9 %   -33.0 % iupdate = 1
Tot.Dens. = 1.943E-05 kg/m**3  Dens.Pert. =  0.01% Wave =  0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -45.7  2.1 -43.6 m/s  VertWind
Northward Wind(Mean,Perturbed,Total) = -12.5  -2.2 -14.7 m/s  -2.0 m/s
CO2=2.563E+20 N2=7.728E+18 Ar=4.637E+18 O2=3.653E+17 CO=2.810E+17 #/m**3
  96.399    1.850    1.583    0.100    0.067 % by mass
  95.169    2.869    1.721    0.136    0.104 % by volume
H2O=2.233E+14 O=0.000E+00 He=0.000E+00 H2=0.000E+00  Total=2.693E+20 #/m**3
   0.000    0.000    0.000    0.000 % by mass MolWgt=43.448
   0.000    0.000    0.000    0.000 % volume (mole) fraction
--------------------------------------------------------------------------------------------------------------------------
Time (rel. to T0) =  7000.0 sec. (  0.079 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 65.000 km ( 68.349 km) OWLT = 19.02 Min
Topographic Height =  -3.349 km  Radius (Areoid) = 3456.354 (3391.354) km
Hgt Above Ellipsoid = 65.038 km  Scale Hgt H(p)=  9.35 H(rho)=  9.59 km
Height Offset Parameters:  ibougher = 1  Local Height Offset = 0.498 km
Planeto-Centric Lat =  29.48 deg Longitude =  54.97 W ( 305.03 E) deg.
Planeto-Graphic Lat =  29.77 deg Planeto-Graphic Hgt (Ellps)=  65.037 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 137.08 deg.W   Local True Solar Time = 17.47 Mars hrs
```

Temperature = 147.0 K   Pressure = 3.605E-01 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.170E-05 1.299E-05 1.443E-05 kg/m**3
Departure, COSPAR NH Mean = -30.3 %   -22.7 %   -14.1 % iupdate = 1
Tot.Dens. = 1.228E-05 kg/m**3 Dens.Pert. = -5.46% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -29.4 7.5 -21.9 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -23.0 -9.5 -32.6 m/s -2.1 m/s
CO2=1.714E+20 N2=5.165E+18 Ar=3.099E+18 O2=2.442E+17 CO=1.878E+17 #/m**3
  96.401   1.849   1.583   0.100   0.067 % by mass
  95.171   2.868   1.721   0.136   0.104 % by volume
H2O=2.476E+14 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=1.801E+20 #/m**3
   0.000   0.000   0.000   0.000 % by mass MolWgt=43.448
   0.000   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 7500.0 sec. (0.084 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 70.000 km (73.223 km) OWLT = 19.02 Min
Topographic Height = -3.223 km Radius (Areoid) = 3461.234 (3391.234) km
Hgt Above Ellipsoid = 70.069 km Scale Hgt H(p)= 7.91 H(rho)= 8.18 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 0.993 km
Planeto-Centric Lat = 29.98 deg Longitude = 55.47 W (304.53 E) deg.
Planeto-Graphic Lat = 30.27 deg Planeto-Graphic Hgt (Ellps)= 70.068 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 139.10 deg.W   Local True Solar Time = 17.58 Mars hrs
Temperature = 144.6 K   Pressure = 2.166E-01 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 7.027E-06 7.922E-06 8.931E-06 kg/m**3
Departure, COSPAR NH Mean = -19.5 %   -9.3 %   2.3 % iupdate = 1
Tot.Dens. = 7.945E-06 kg/m**3 Dens.Pert. = 0.29% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -48.9 -9.9 -58.8 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -39.0 -6.5 -45.5 m/s -1.5 m/s
CO2=1.045E+20 N2=3.148E+18 Ar=1.889E+18 O2=1.488E+17 CO=1.145E+17 #/m**3
  96.402   1.849   1.582   0.100   0.067 % by mass
  95.173   2.867   1.720   0.136   0.104 % by volume
H2O=1.255E+14 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=1.098E+20 #/m**3
   0.000   0.000   0.000   0.000 % by mass MolWgt=43.448
   0.000   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 8000.0 sec. (0.090 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 75.000 km (77.908 km) OWLT = 19.02 Min
Topographic Height = -2.908 km Radius (Areoid) = 3466.114 (3391.114) km
Hgt Above Ellipsoid = 75.101 km Scale Hgt H(p)= 6.87 H(rho)= 7.12 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 1.481 km
Planeto-Centric Lat = 30.48 deg Longitude = 55.97 W (304.03 E) deg.
Planeto-Graphic Lat = 30.77 deg Planeto-Graphic Hgt (Ellps)= 75.100 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 141.13 deg.W   Local True Solar Time = 17.68 Mars hrs
Temperature = 141.2 K   Pressure = 1.160E-01 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 3.779E-06 4.334E-06 4.971E-06 kg/m**3
Departure, COSPAR NH Mean = -15.5 %   -3.0 %   11.2 % iupdate = 1
Tot.Dens. = 4.403E-06 kg/m**3 Dens.Pert. = 1.59% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -47.9 -10.4 -58.2 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -19.0 -13.1 -32.1 m/s   0.2 m/s
CO2=5.718E+19 N2=1.721E+18 Ar=1.033E+18 O2=8.138E+16 CO=6.260E+16 #/m**3
  96.404   1.848   1.581   0.100   0.067 % by mass
  95.176   2.865   1.719   0.135   0.104 % by volume
H2O=4.693E+13 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=6.008E+19 #/m**3
   0.000   0.000   0.000   0.000 % by mass MolWgt=43.448
   0.000   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 8500.0 sec. (0.096 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 80.000 km (82.699 km) OWLT = 19.02 Min
Topographic Height = -2.699 km Radius (Areoid) = 3470.992 (3390.992) km

Hgt Above Ellipsoid = 80.133 km Scale Hgt H(p)= 6.87 H(rho)= 7.11 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 1.961 km
Planeto-Centric Lat = 30.98 deg Longitude = 56.47 W (303.53 E) deg.
Planeto-Graphic Lat = 31.27 deg Planeto-Graphic Hgt (Ellps)= 80.132 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 143.16 deg.W   Local True Solar Time = 17.78 Mars hrs
Temperature = 133.8 K   Pressure = 5.632E-02 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.843E-06 2.155E-06 2.521E-06 kg/m**3
Departure, COSPAR NH Mean = -19.5 %   -5.9 %   10.1 % iupdate = 1
Tot.Dens. = 2.363E-06 kg/m**3 Dens.Pert. = 9.61% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -10.7 3.3 -7.5 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -10.3 -13.9 -24.2 m/s -0.1 m/s
CO2=2.843E+19 N2=8.557E+17 Ar=5.134E+17 O2=4.045E+16 CO=3.111E+16 #/m**3
96.406   1.847   1.581   0.100   0.067 % by mass
95.178   2.864   1.718   0.135   0.104 % by volume
H2O=4.214E+12 O=0.000E+00 He=0.000E+00 H2=0.000E+00 Total=2.987E+19 #/m**3
0.000   0.000   0.000   0.000 % by mass MolWgt=43.449
0.000   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 9000.0 sec. (0.101 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 85.000 km (87.133 km) OWLT = 19.02 Min
Topographic Height = -2.133 km Radius (Areoid) = 3475.868 (3390.868) km
Hgt Above Ellipsoid = 85.164 km Scale Hgt H(p)= 6.18 H(rho)= 6.31 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 31.48 deg Longitude = 56.97 W (303.03 E) deg.
Planeto-Graphic Lat = 31.77 deg Planeto-Graphic Hgt (Ellps)= 85.163 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 145.19 deg.W   Local True Solar Time = 17.88 Mars hrs
Exospheric Temp. = 186.9 K   Tbase = 149.1 K Zbase = 123.1 km
Solar Zenith Angle = 75.8 deg   F1 peak = 134.1 km
Temperature = 128.6 K   Pressure = 2.617E-02 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 8.547E-07 1.022E-06 1.221E-06 kg/m**3
Departure, COSPAR NH Mean = -27.0 %   -12.7 %   4.4 % iupdate = 1
Tot.Dens. = 8.968E-07 kg/m**3 Dens.Pert. = -12.23% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = 7.9 -13.0 -5.1 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -7.9 -16.0 -23.9 m/s -0.3 m/s
CO2=1.313E+19 N2=4.190E+17 Ar=2.510E+17 O2=2.104E+16 CO=3.575E+16 #/m**3
93.902   1.908   1.630   0.109   0.163 % by mass
89.097   2.843   1.704   0.143   0.243 % by volume
O=8.797E+17 He=0.000E+00 H2=0.000E+00 H=0.000E+00 Total=1.474E+19 #/m**3
2.287   0.000   0.000   0.000 % by mass MolWgt=41.757
5.970   0.000   0.000   0.000 % volume (mole) fraction

Time (rel. to T0) = 9500.0 sec. (0.107 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 90.000 km (90.974 km) OWLT = 19.02 Min
Topographic Height = -0.974 km Radius (Areoid) = 3480.742 (3390.742) km
Hgt Above Ellipsoid = 90.195 km Scale Hgt H(p)= 6.04 H(rho)= 6.19 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 31.98 deg Longitude = 57.47 W (302.53 E) deg.
Planeto-Graphic Lat = 32.28 deg Planeto-Graphic Hgt (Ellps)= 90.194 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 147.22 deg.W   Local True Solar Time = 17.98 Mars hrs
Exospheric Temp. = 186.4 K   Tbase = 148.8 K Zbase = 123.2 km
Solar Zenith Angle = 76.9 deg   F1 peak = 134.7 km
Temperature = 126.3 K   Pressure = 1.163E-02 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 3.765E-07 4.613E-07 5.654E-07 kg/m**3
Departure, COSPAR NH Mean = -37.4 %   -23.2 %   -5.9 % iupdate = 1
Tot.Dens. = 4.314E-07 kg/m**3 Dens.Pert. = -6.48% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = 8.6 4.9 13.5 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -12.5 -12.2 -24.7 m/s   0.3 m/s

CO2=5.917E+18 N2=1.882E+17 Ar=1.126E+17 O2=1.001E+16 CO=2.537E+16 #/m**3
93.730 1.898 1.620 0.115 0.256 % by mass
88.755 2.823 1.689 0.150 0.381 % by volume
O=4.135E+17 He=0.000E+00 H2=0.000E+00 H=0.000E+00 Total=6.667E+18 #/m**3
2.381 0.000 0.000 0.000 % by mass MolWgt=41.673
6.202 0.000 0.000 0.000 % volume (mole) fraction

Time (rel. to T0) = 10000.0 sec. (0.113 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 95.000 km (95.839 km) OWLT = 19.02 Min
Topographic Height = -0.839 km Radius (Areoid) = 3485.614 (3390.614) km
Hgt Above Ellipsoid = 95.225 km Scale Hgt H(p)= 6.14 H(rho)= 6.11 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 32.48 deg Longitude = 57.97 W (302.03 E) deg.
Planeto-Graphic Lat = 32.78 deg Planeto-Graphic Hgt (Ellps)= 95.224 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 149.24 deg.W Local True Solar Time = 18.08 Mars hrs
Exospheric Temp. = 185.9 K Tbase = 148.6 K Zbase = 123.3 km
Solar Zenith Angle = 77.9 deg F1 peak = 135.3 km
Temperature = 125.7 K Pressure = 5.170E-03 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.636E-07 2.061E-07 2.597E-07 kg/m**3
Departure, COSPAR NH Mean = -47.1 % -33.3 % -16.0 % iupdate = 1
Tot.Dens. = 2.028E-07 kg/m**3 Dens.Pert. = -1.62% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = 6.7 -1.0 5.7 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -19.0 -3.5 -22.5 m/s 0.0 m/s
CO2=2.641E+18 N2=8.355E+16 Ar=4.992E+16 O2=4.696E+15 CO=1.543E+16 #/m**3
93.638 1.886 1.607 0.121 0.348 % by mass
88.602 2.803 1.675 0.158 0.518 % by volume
O=1.861E+17 He=0.000E+00 H2=0.000E+00 H=0.000E+00 Total=2.980E+18 #/m**3
2.399 0.000 0.000 0.000 % by mass MolWgt=41.642
6.245 0.000 0.000 0.000 % volume (mole) fraction

Time (rel. to T0) = 10500.0 sec. (0.118 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 100.000 km (100.979 km) OWLT = 19.02 Min
Topographic Height = -0.979 km Radius (Areoid) = 3490.485 (3390.485) km
Hgt Above Ellipsoid = 100.255 km Scale Hgt H(p)= 6.10 H(rho)= 6.17 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 32.98 deg Longitude = 58.47 W (301.53 E) deg.
Planeto-Graphic Lat = 33.28 deg Planeto-Graphic Hgt (Ellps)= 100.253 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 151.27 deg.W Local True Solar Time = 18.19 Mars hrs
Exospheric Temp. = 185.3 K Tbase = 148.3 K Zbase = 123.4 km
Solar Zenith Angle = 78.9 deg F1 peak = 136.0 km
Temperature = 126.1 K Pressure = 2.316E-03 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 7.110E-08 9.243E-08 1.202E-07 kg/m**3
Departure, COSPAR NH Mean = -55.3 % -41.9 % -24.4 % iupdate = 1
Tot.Dens. = 6.524E-08 kg/m**3 Dens.Pert. = -29.42% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = 1.9 1.5 3.4 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -26.4 1.5 -24.9 m/s 2.4 m/s
CO2=1.188E+18 N2=3.703E+16 Ar=2.210E+16 O2=2.194E+15 CO=8.707E+15 #/m**3
93.892 1.864 1.586 0.126 0.438 % by mass
89.262 2.784 1.661 0.165 0.654 % by volume
O=7.283E+16 He=0.000E+00 H2=0.000E+00 H=0.000E+00 Total=1.330E+18 #/m**3
2.093 0.000 0.000 0.000 % by mass MolWgt=41.839
5.474 0.000 0.000 0.000 % volume (mole) fraction

Time (rel. to T0) = 11000.0 sec. (0.124 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 105.000 km (106.163 km) OWLT = 19.02 Min
Topographic Height = -1.163 km Radius (Areoid) = 3495.353 (3390.353) km
Hgt Above Ellipsoid = 105.284 km Scale Hgt H(p)= 6.61 H(rho)= 6.41 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km

Planeto-Centric Lat = 33.48 deg Longitude = 58.97 W (301.03 E) deg.
Planeto-Graphic Lat = 33.78 deg Planeto-Graphic Hgt (Ellps)= 105.282 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 153.30 deg.W Local True Solar Time = 18.29 Mars hrs
Exospheric Temp. = 184.8 K Tbase = 148.0 K Zbase = 123.5 km
Solar Zenith Angle = 79.8 deg F1 peak = 136.7 km
Temperature = 127.2 K Pressure = 1.072E-03 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 3.196E-08 4.235E-08 5.612E-08 kg/m**3
Departure, COSPAR NH Mean = -60.1 % -47.1 % -29.9 % iupdate = 1
Tot.Dens. = 2.125E-08 kg/m**3 Dens.Pert. = -49.83% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -5.4 -3.1 -8.5 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -32.9 15.8 -17.0 m/s 1.4 m/s
CO2=5.435E+17 N2=1.687E+16 Ar=1.005E+16 O2=1.051E+15 CO=4.824E+15 #/m**3
93.787 1.853 1.575 0.132 0.530 % by mass
89.077 2.765 1.647 0.172 0.791 % by volume
O=3.386E+16 He=0.000E+00 H2=0.000E+00 H=0.000E+00 Total=6.102E+17 #/m**3
2.124 0.000 0.000 0.000 % by mass MolWgt=41.799
5.548 0.000 0.000 0.000 % volume (mole) fraction

Time (rel. to T0) = 11500.0 sec. (0.130 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 110.000 km (111.266 km) OWLT = 19.02 Min
Topographic Height = -1.266 km Radius (Areoid) = 3500.219 (3390.219) km
Hgt Above Ellipsoid = 110.312 km Scale Hgt H(p)= 6.48 H(rho)= 6.43 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 33.98 deg Longitude = 59.47 W (300.53 E) deg.
Planeto-Graphic Lat = 34.28 deg Planeto-Graphic Hgt (Ellps)= 110.310 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 155.33 deg.W Local True Solar Time = 18.39 Mars hrs
Exospheric Temp. = 184.3 K Tbase = 147.8 K Zbase = 123.6 km
Solar Zenith Angle = 80.8 deg F1 peak = 137.5 km
Temperature = 129.4 K Pressure = 5.056E-04 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.459E-08 1.970E-08 2.660E-08 kg/m**3
Departure, COSPAR NH Mean = -64.8 % -52.4 % -35.8 % iupdate = 1
Tot.Dens. = 1.592E-08 kg/m**3 Dens.Pert. = -19.19% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -13.7 -8.5 -22.2 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -36.3 7.7 -28.6 m/s 0.4 m/s
CO2=2.532E+17 N2=7.770E+15 Ar=4.623E+15 O2=5.081E+14 CO=2.621E+15 #/m**3
93.931 1.835 1.557 0.137 0.619 % by mass
89.481 2.746 1.634 0.180 0.926 % by volume
O=1.424E+16 He=0.000E+00 H2=0.000E+00 H=0.000E+00 Total=2.830E+17 #/m**3
1.921 0.000 0.000 0.000 % by mass MolWgt=41.924
5.034 0.000 0.000 0.000 % volume (mole) fraction

Time (rel. to T0) = 12000.0 sec. (0.135 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 115.000 km (116.271 km) OWLT = 19.02 Min
Topographic Height = -1.271 km Radius (Areoid) = 3505.084 (3390.084) km
Hgt Above Ellipsoid = 115.339 km Scale Hgt H(p)= 6.94 H(rho)= 6.41 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 34.48 deg Longitude = 59.97 W (300.03 E) deg.
Planeto-Graphic Lat = 34.79 deg Planeto-Graphic Hgt (Ellps)= 115.338 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 157.35 deg.W Local True Solar Time = 18.49 Mars hrs
Exospheric Temp. = 183.7 K Tbase = 147.5 K Zbase = 123.7 km
Solar Zenith Angle = 81.8 deg F1 peak = 138.2 km
Temperature = 133.9 K Pressure = 2.434E-04 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 6.659E-09 9.156E-09 1.259E-08 kg/m**3
Departure, COSPAR NH Mean = -69.7 % -58.4 % -42.8 % iupdate = 1
Tot.Dens. = 8.091E-09 kg/m**3 Dens.Pert. = -11.64% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -22.0 -4.4 -26.5 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -36.9 -6.4 -43.3 m/s 0.4 m/s

CO2=1.176E+17 N2=3.591E+15 Ar=2.133E+15 O2=2.460E+14 CO=1.397E+15 #/m**3
93.823 1.825 1.546 0.143 0.710 % by mass
89.289 2.727 1.620 0.187 1.061 % by volume
O=6.734E+15 He=0.000E+00 H2=0.000E+00 H=0.000E+00 Total=1.317E+17 #/m**3
1.954 0.000 0.000 0.000 % by mass MolWgt=41.882
5.115 0.000 0.000 0.000 % volume (mole) fraction

Time (rel. to T0) = 12500.0 sec. (0.141 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 120.000 km (121.331 km) OWLT = 19.02 Min
Topographic Height = -1.331 km Radius (Areoid) = 3509.947 (3389.947) km
Hgt Above Ellipsoid = 120.366 km Scale Hgt H(p)= 7.21 H(rho)= 6.65 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 34.98 deg Longitude = 60.47 W (299.53 E) deg.
Planeto-Graphic Lat = 35.29 deg Planeto-Graphic Hgt (Ellps)= 120.364 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 159.38 deg.W Local True Solar Time = 18.59 Mars hrs
Exospheric Temp. = 183.2 K Tbase = 147.2 K Zbase = 123.7 km
Solar Zenith Angle = 82.7 deg F1 peak = 139.1 km
Temperature = 140.8 K Pressure = 1.213E-04 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 3.078E-09 4.309E-09 6.033E-09 kg/m**3
Departure, COSPAR NH Mean = -74.1 % -63.8 % -49.3 % iupdate = 1
Tot.Dens. = 8.499E-09 kg/m**3 Dens.Pert. = 97.23% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -27.9 2.7 -25.2 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -35.7 -17.8 -53.5 m/s -1.5 m/s
CO2=5.504E+16 N2=1.690E+15 Ar=1.003E+15 O2=1.211E+14 CO=7.461E+14 #/m**3
93.343 1.825 1.544 0.149 0.805 % by mass
88.228 2.709 1.607 0.194 1.196 % by volume
O=3.784E+15 He=0.000E+00 H2=0.000E+00 H=0.000E+00 Total=6.239E+16 #/m**3
2.333 0.000 0.000 0.000 % by mass MolWgt=41.597
6.066 0.000 0.000 0.000 % volume (mole) fraction

Time (rel. to T0) = 13000.0 sec. (0.146 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 125.000 km (126.297 km) OWLT = 19.02 Min
Topographic Height = -1.297 km Radius (Areoid) = 3514.808 (3389.808) km
Hgt Above Ellipsoid = 125.392 km Scale Hgt H(p)= 7.62 H(rho)= 7.00 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 35.48 deg Longitude = 60.97 W (299.03 E) deg.
Planeto-Graphic Lat = 35.79 deg Planeto-Graphic Hgt (Ellps)= 125.390 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 161.41 deg.W Local True Solar Time = 18.70 Mars hrs
Exospheric Temp. = 182.7 K Tbase = 146.9 K Zbase = 123.8 km
Solar Zenith Angle = 83.6 deg F1 peak = 140.0 km
Temperature = 149.0 K Pressure = 6.236E-05 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.468E-09 2.091E-09 2.980E-09 kg/m**3
Departure, COSPAR NH Mean = -77.9 % -68.5 % -55.1 % iupdate = 1
Tot.Dens. = 3.509E-09 kg/m**3 Dens.Pert. = 67.79% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -30.2 2.7 -27.4 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -35.8 -21.3 -57.1 m/s -2.4 m/s
CO2=2.665E+16 N2=8.580E+14 Ar=4.889E+14 O2=6.273E+13 CO=4.131E+14 #/m**3
93.136 1.909 1.551 0.159 0.919 % by mass
87.940 2.831 1.613 0.207 1.363 % by volume
O=1.830E+15 He=1.645E+12 H2=6.592E+10 H=1.925E+11 Total=3.031E+16 #/m**3
2.325 0.001 0.000 0.000 % by mass MolWgt=41.554
6.039 0.005 0.000 0.001 % volume (mole) fraction

Time (rel. to T0) = 13500.0 sec. (0.152 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 130.000 km (131.276 km) OWLT = 19.02 Min
Topographic Height = -1.276 km Radius (Areoid) = 3519.668 (3389.668) km
Hgt Above Ellipsoid = 130.418 km Scale Hgt H(p)= 8.18 H(rho)= 7.42 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km

Planeto-Centric Lat = 35.98 deg Longitude = 61.47 W (298.53 E) deg.
Planeto-Graphic Lat = 36.29 deg Planeto-Graphic Hgt (Ellps)= 130.416 km
Planeto-Cent Sun Lat = 25.02 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 163.44 deg.W Local True Solar Time = 18.80 Mars hrs
Exospheric Temp. = 182.2 K Tbase = 146.7 K Zbase = 123.9 km
Solar Zenith Angle = 84.5 deg F1 peak = 141.0 km
Temperature = 157.1 K Pressure = 3.331E-05 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 7.256E-10 1.052E-09 1.526E-09 kg/m**3
Departure, COSPAR NH Mean = -80.7 % -72.0 % -59.4 % iupdate = 1
Tot.Dens. = 2.051E-09 kg/m**3 Dens.Pert. = 94.97% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -29.5 31.2 1.7 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -38.0 -18.7 -56.7 m/s -1.5 m/s
CO2=1.327E+16 N2=5.269E+14 Ar=2.569E+14 O2=3.657E+13 CO=2.537E+14 #/m**3
92.205 2.330 1.620 0.185 1.122 % by mass
86.451 3.431 1.673 0.238 1.652 % by volume
O=1.005E+15 He=1.378E+12 H2=5.683E+10 H=1.689E+11 Total=1.535E+16 #/m**3
2.537 0.001 0.000 0.000 % by mass MolWgt=41.263
6.543 0.009 0.000 0.001 % volume (mole) fraction

Time (rel. to T0) = 14000.0 sec. (0.158 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 135.000 km (136.272 km) OWLT = 19.02 Min
Topographic Height = -1.272 km Radius (Areoid) = 3524.526 (3389.526) km
Hgt Above Ellipsoid = 135.443 km Scale Hgt H(p)= 8.69 H(rho)= 8.00 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 36.48 deg Longitude = 61.97 W (298.03 E) deg.
Planeto-Graphic Lat = 36.79 deg Planeto-Graphic Hgt (Ellps)= 135.440 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 165.46 deg.W Local True Solar Time = 18.90 Mars hrs
Exospheric Temp. = 181.7 K Tbase = 146.4 K Zbase = 124.0 km
Solar Zenith Angle = 85.3 deg F1 peak = 142.1 km
Temperature = 163.9 K Pressure = 1.843E-05 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 3.803E-10 5.515E-10 7.996E-10 kg/m**3
Departure, COSPAR NH Mean = -80.1 % -71.2 % -58.2 % iupdate = 1
Tot.Dens. = 9.922E-10 kg/m**3 Dens.Pert. = 79.92% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -26.7 -1.7 -28.4 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -40.7 -25.3 -66.0 m/s -2.0 m/s
CO2=6.861E+15 N2=3.338E+14 Ar=1.405E+14 O2=2.206E+13 CO=1.608E+14 #/m**3
90.923 2.816 1.690 0.213 1.356 % by mass
84.264 4.099 1.725 0.271 1.974 % by volume
O=6.229E+14 He=1.171E+12 H2=4.963E+10 H=1.501E+11 Total=8.143E+15 #/m**3
3.001 0.001 0.000 0.000 % by mass MolWgt=40.786
7.650 0.014 0.001 0.002 % volume (mole) fraction

Time (rel. to T0) = 14500.0 sec. (0.163 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 140.000 km (141.237 km) OWLT = 19.02 Min
Topographic Height = -1.237 km Radius (Areoid) = 3529.383 (3389.383) km
Hgt Above Ellipsoid = 140.467 km Scale Hgt H(p)= 9.75 H(rho)= 8.91 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 36.98 deg Longitude = 62.47 W (297.53 E) deg.
Planeto-Graphic Lat = 37.29 deg Planeto-Graphic Hgt (Ellps)= 140.465 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 167.49 deg.W Local True Solar Time = 19.00 Mars hrs
Exospheric Temp. = 181.2 K Tbase = 146.2 K Zbase = 124.1 km
Solar Zenith Angle = 86.2 deg F1 peak = 143.2 km
Temperature = 169.0 K Pressure = 1.069E-05 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 2.104E-10 3.051E-10 4.423E-10 kg/m**3
Departure, COSPAR NH Mean = -80.7 % -72.0 % -59.4 % iupdate = 1
Tot.Dens. = 4.091E-10 kg/m**3 Dens.Pert. = 34.10% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -22.8 -6.1 -28.9 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -44.5 -17.2 -61.7 m/s -1.6 m/s

```
CO2=3.722E+15 N2=2.222E+14 Ar=8.106E+13 O2=1.400E+13 CO=1.070E+14 #/m**3
   89.174    3.389    1.763    0.244    1.632 % by mass
   81.209    4.847    1.768    0.305    2.335 % by volume
 O=4.358E+14 He=1.036E+12 H2=4.507E+10 H=1.386E+11  Total=4.584E+15 #/m**3
    3.796    0.002    0.000    0.000 % by mass MolWgt=40.078
    9.508    0.023    0.001    0.003 % volume (mole) fraction
-------------------------------------------------------------------------------------------------------------------------------
Time (rel. to T0) =  15000.0 sec. (  0.169 sols) Ls = 97.0 Dust = 0.30
Height Above MOLA (or Surface) = 145.000 km ( 146.335 km) OWLT = 19.02 Min
Topographic Height =  -1.335 km  Radius (Areoid) = 3534.239 (3389.239) km
Hgt Above Ellipsoid = 145.492 km  Scale Hgt H(p)= 10.14 H(rho)=  9.20 km
Height Offset Parameters:  ibougher = 1  Local Height Offset = 2.280 km
Planeto-Centric Lat =  37.48 deg Longitude =  62.97 W ( 297.03 E) deg.
Planeto-Graphic Lat =  37.79 deg Planeto-Graphic Hgt (Ellps)= 145.490 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 169.52 deg.W   Local True Solar Time = 19.10 Mars hrs
Exospheric Temp. = 180.7 K    Tbase = 145.9 K  Zbase = 124.1 km
Solar Zenith Angle = 87.0 deg   F1 peak = 144.5 km
Temperature =  172.7 K    Pressure = 6.444E-06 N/m**2  profwgt = 0.000
Density (Low, Avg., High) =  1.208E-10  1.752E-10  2.540E-10 kg/m**3
Departure, COSPAR NH Mean =  -82.9 %   -75.2 %   -64.0 % iupdate = 1
Tot.Dens. = 2.445E-10 kg/m**3  Dens.Pert. = 39.54% Wave =  0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -19.2  -7.0 -26.2 m/s  VertWind
Northward Wind(Mean,Perturbed,Total) = -49.3  -5.6 -54.9 m/s  -0.6 m/s
CO2=2.079E+15 N2=1.535E+14 Ar=4.868E+13 O2=9.234E+12 CO=7.396E+13 #/m**3
   86.732    4.077    1.844    0.280    1.963 % by mass
   76.952    5.682    1.802    0.342    2.737 % by volume
 O=3.362E+14 He=9.462E+11 H2=4.226E+10 H=1.320E+11  Total=2.702E+15 #/m**3
    5.099    0.004    0.000    0.000 % by mass MolWgt=39.046
   12.444    0.035    0.002    0.005 % volume (mole) fraction
-------------------------------------------------------------------------------------------------------------------------------
Time (rel. to T0) =  15500.0 sec. (  0.175 sols) Ls = 97.1 Dust = 0.30
Height Above MOLA (or Surface) = 150.000 km ( 151.272 km) OWLT = 19.02 Min
Topographic Height =  -1.272 km  Radius (Areoid) = 3539.095 (3389.095) km
Hgt Above Ellipsoid = 150.517 km  Scale Hgt H(p)= 10.31 H(rho)=  9.58 km
Height Offset Parameters:  ibougher = 1  Local Height Offset = 2.280 km
Planeto-Centric Lat =  37.98 deg Longitude =  63.47 W ( 296.53 E) deg.
Planeto-Graphic Lat =  38.29 deg Planeto-Graphic Hgt (Ellps)= 150.514 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 171.55 deg.W   Local True Solar Time = 19.21 Mars hrs
Exospheric Temp. = 180.1 K    Tbase = 145.7 K  Zbase = 124.2 km
Solar Zenith Angle = 87.8 deg   F1 peak = 146.0 km
Temperature =  175.0 K    Pressure = 3.962E-06 N/m**2  profwgt = 0.000
Density (Low, Avg., High) =  7.125E-11  1.033E-10  1.498E-10 kg/m**3
Departure, COSPAR NH Mean =  -84.9 %   -78.2 %   -68.3 % iupdate = 1
Tot.Dens. = 1.792E-10 kg/m**3  Dens.Pert. = 73.48% Wave =  0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -15.5  -8.1 -23.6 m/s  VertWind
Northward Wind(Mean,Perturbed,Total) = -53.6 -14.6 -68.2 m/s   2.9 m/s
CO2=1.187E+15 N2=1.083E+14 Ar=2.989E+13 O2=6.219E+12 CO=5.218E+13 #/m**3
   83.980    4.878    1.920    0.320    2.349 % by mass
   72.413    6.607    1.823    0.379    3.183 % by volume
 O=2.546E+14 He=8.800E+11 H2=4.035E+10 H=1.282E+11  Total=1.640E+15 #/m**3
    6.548    0.006    0.000    0.000 % by mass MolWgt=37.948
   15.531    0.054    0.002    0.008 % volume (mole) fraction
-------------------------------------------------------------------------------------------------------------------------------
Time (rel. to T0) =  16000.0 sec. (  0.180 sols) Ls = 97.1 Dust = 0.30
Height Above MOLA (or Surface) = 155.000 km ( 156.136 km) OWLT = 19.02 Min
Topographic Height =  -1.136 km  Radius (Areoid) = 3543.950 (3388.950) km
Hgt Above Ellipsoid = 155.542 km  Scale Hgt H(p)= 10.81 H(rho)=  9.89 km
Height Offset Parameters:  ibougher = 1  Local Height Offset = 2.280 km
```

Planeto-Centric Lat = 38.48 deg Longitude = 63.97 W (296.03 E) deg.
Planeto-Graphic Lat = 38.80 deg Planeto-Graphic Hgt (Ellps)= 155.540 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 173.58 deg.W Local True Solar Time = 19.31 Mars hrs
Exospheric Temp. = 179.5 K Tbase = 145.4 K Zbase = 124.3 km
Solar Zenith Angle = 88.6 deg F1 peak = 147.6 km
Temperature = 176.2 K Pressure = 2.474E-06 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 4.275E-11 6.198E-11 8.987E-11 kg/m**3
Departure, COSPAR NH Mean = -87.3 % -81.6 % -73.3 % iupdate = 1
Tot.Dens. = 1.247E-10 kg/m**3 Dens.Pert. = 101.12% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -11.7 -9.2 -20.9 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -57.6 -18.4 -75.9 m/s 3.1 m/s
CO2=6.844E+14 N2=7.744E+13 Ar=1.861E+13 O2=4.246E+12 CO=3.731E+13 #/m**3
80.695 5.813 1.992 0.364 2.799 % by mass
67.278 7.612 1.829 0.417 3.667 % by volume
O=1.943E+14 He=8.284E+11 H2=3.899E+10 H=1.259E+11 Total=1.017E+15 #/m**3
8.328 0.009 0.000 0.000 % by mass MolWgt=36.692
19.099 0.081 0.004 0.012 % volume (mole) fraction

Time (rel. to T0) = 16500.0 sec. (0.186 sols) Ls = 97.1 Dust = 0.30
Height Above MOLA (or Surface) = 160.000 km (160.950 km) OWLT = 19.02 Min
Topographic Height = -0.950 km Radius (Areoid) = 3548.806 (3388.806) km
Hgt Above Ellipsoid = 160.568 km Scale Hgt H(p)= 11.25 H(rho)= 10.06 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 38.98 deg Longitude = 64.47 W (295.53 E) deg.
Planeto-Graphic Lat = 39.30 deg Planeto-Graphic Hgt (Ellps)= 160.566 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 175.60 deg.W Local True Solar Time = 19.41 Mars hrs
Exospheric Temp. = 179.0 K Tbase = 145.2 K Zbase = 124.3 km
Solar Zenith Angle = 89.3 deg F1 peak = 149.3 km
Temperature = 176.7 K Pressure = 1.577E-06 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 2.591E-11 3.757E-11 5.447E-11 kg/m**3
Departure, COSPAR NH Mean = -89.3 % -84.5 % -77.6 % iupdate = 1
Tot.Dens. = 6.128E-11 kg/m**3 Dens.Pert. = 63.11% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -8.5 6.0 -2.5 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -61.5 -36.3 -97.8 m/s -6.1 m/s
CO2=3.917E+14 N2=5.610E+13 Ar=1.174E+13 O2=2.937E+12 CO=2.703E+13 #/m**3
76.187 6.947 2.073 0.415 3.346 % by mass
60.610 8.681 1.817 0.455 4.182 % by volume
O=1.558E+14 He=7.899E+11 H2=3.815E+10 H=1.253E+11 Total=6.462E+14 #/m**3
11.017 0.014 0.000 0.001 % by mass MolWgt=35.011
24.108 0.122 0.006 0.019 % volume (mole) fraction

Time (rel. to T0) = 17000.0 sec. (0.191 sols) Ls = 97.1 Dust = 0.30
Height Above MOLA (or Surface) = 165.000 km (165.854 km) OWLT = 19.02 Min
Topographic Height = -0.854 km Radius (Areoid) = 3553.661 (3388.661) km
Hgt Above Ellipsoid = 165.595 km Scale Hgt H(p)= 11.63 H(rho)= 10.40 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 39.48 deg Longitude = 64.97 W (295.03 E) deg.
Planeto-Graphic Lat = 39.80 deg Planeto-Graphic Hgt (Ellps)= 165.592 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.649 AU
Sun Longitude = 177.63 deg.W Local True Solar Time = 19.51 Mars hrs
Exospheric Temp. = 178.5 K Tbase = 144.9 K Zbase = 124.4 km
Solar Zenith Angle = 90.0 deg F1 peak = 999.9 km
Temperature = 177.0 K Pressure = 1.020E-06 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.590E-11 2.305E-11 3.342E-11 kg/m**3
Departure, COSPAR NH Mean = -91.2 % -87.2 % -81.5 % iupdate = 1
Tot.Dens. = 3.656E-11 kg/m**3 Dens.Pert. = 58.62% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -6.1 0.7 -5.4 m/s VertWind

Northward Wind(Mean,Perturbed,Total) = -65.4 -14.4 -79.8 m/s -4.3 m/s
CO2=2.240E+14 N2=4.084E+13 Ar=7.443E+12 O2=2.042E+12 CO=1.968E+13 #/m**3
   71.020   8.243   2.143   0.471   3.971 % by mass
   53.651   9.781   1.783   0.489   4.713 % by volume
 O=1.226E+14 He=7.571E+11 H2=3.753E+10 H=1.252E+11 Total=4.175E+14 #/m**3
   14.130   0.022   0.001   0.001 % by mass MolWgt=33.246
   29.363   0.181   0.009   0.030 % volume (mole) fraction

Time (rel. to T0) = 17500.0 sec. (0.197 sols) Ls = 97.1 Dust = 0.30
Height Above MOLA (or Surface) = 170.000 km (170.917 km) OWLT = 19.02 Min
Topographic Height = -0.917 km Radius (Areoid) = 3558.517 (3388.517) km
Hgt Above Ellipsoid = 170.623 km Scale Hgt H(p)= 12.23 H(rho)= 10.72 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 39.98 deg Longitude = 65.47 W (294.53 E) deg.
Planeto-Graphic Lat = 40.30 deg Planeto-Graphic Hgt (Ellps)= 170.620 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.648 AU
Sun Longitude = 179.66 deg.W   Local True Solar Time = 19.61 Mars hrs
Exospheric Temp. = 177.9 K   Tbase = 144.7 K Zbase = 124.4 km
Solar Zenith Angle = 90.7 deg   F1 peak = 999.9 km
Temperature = 177.1 K   Pressure = 6.716E-07 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 9.886E-12 1.434E-11 2.079E-11 kg/m**3
Departure, COSPAR NH Mean = -92.7 %   -89.4 %   -84.6 % iupdate = 1
Tot.Dens. = 1.551E-11 kg/m**3 Dens.Pert. = 8.21% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -3.9 9.6 5.7 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -69.0 -41.7 -110.7 m/s   0.9 m/s
CO2=1.279E+14 N2=2.985E+13 Ar=4.737E+12 O2=1.425E+12 CO=1.438E+13 #/m**3
   65.184   9.688   2.193   0.528   4.667 % by mass
   46.551   10.867   1.724   0.519   5.237 % by volume
 O=9.553E+13 He=7.288E+11 H2=3.708E+10 H=1.258E+11 Total=2.747E+14 #/m**3
   17.704   0.034   0.001   0.001 % by mass MolWgt=31.429
   34.778   0.265   0.013   0.046 % volume (mole) fraction

Time (rel. to T0) = 18000.0 sec. (0.203 sols) Ls = 97.1 Dust = 0.30
Height Above MOLA (or Surface) = 175.000 km (175.556 km) OWLT = 19.02 Min
Topographic Height = -0.556 km Radius (Areoid) = 3563.373 (3388.373) km
Hgt Above Ellipsoid = 175.651 km Scale Hgt H(p)= 12.56 H(rho)= 11.25 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 40.48 deg Longitude = 65.97 W (294.03 E) deg.
Planeto-Graphic Lat = 40.80 deg Planeto-Graphic Hgt (Ellps)= 175.648 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.648 AU
Sun Longitude = 181.69 deg.W   Local True Solar Time = 19.71 Mars hrs
Exospheric Temp. = 177.4 K   Tbase = 144.5 K Zbase = 124.5 km
Solar Zenith Angle = 91.4 deg   F1 peak = 999.9 km
Temperature = 177.1 K   Pressure = 4.470E-07 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 6.284E-12 9.113E-12 1.321E-11 kg/m**3
Departure, COSPAR NH Mean = -93.9 %   -91.2 %   -87.2 % iupdate = 1
Tot.Dens. = 9.602E-12 kg/m**3 Dens.Pert. = 5.37% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -2.6 2.6 0.0 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -71.4 -23.2 -94.6 m/s   2.8 m/s
CO2=7.495E+13 N2=2.172E+13 Ar=3.000E+12 O2=9.901E+11 CO=1.047E+13 #/m**3
   60.104   11.087   2.184   0.577   5.342 % by mass
   40.997   11.879   1.641   0.542   5.725 % by volume
 O=7.083E+13 He=6.988E+11 H2=3.649E+10 H=1.258E+11 Total=1.828E+14 #/m**3
   20.651   0.051   0.001   0.002 % by mass MolWgt=30.018
   38.746   0.382   0.020   0.069 % volume (mole) fraction

Time (rel. to T0) = 18500.0 sec. (0.208 sols) Ls = 97.1 Dust = 0.30
Height Above MOLA (or Surface) = 180.000 km (180.274 km) OWLT = 19.02 Min
Topographic Height = -0.274 km Radius (Areoid) = 3568.229 (3388.229) km
Hgt Above Ellipsoid = 180.679 km Scale Hgt H(p)= 13.20 H(rho)= 11.60 km

Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 40.98 deg Longitude = 66.47 W (293.53 E) deg.
Planeto-Graphic Lat = 41.30 deg Planeto-Graphic Hgt (Ellps)= 180.676 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.648 AU
Sun Longitude = 183.71 deg.W Local True Solar Time = 19.82 Mars hrs
Exospheric Temp. = 176.9 K Tbase = 144.3 K Zbase = 124.5 km
Solar Zenith Angle = 92.1 deg F1 peak = 999.9 km
Temperature = 176.7 K Pressure = 3.027E-07 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 4.040E-12 5.858E-12 8.495E-12 kg/m**3
Departure, COSPAR NH Mean = -94.9 % -92.6 % -89.2 % iupdate = 1
Tot.Dens. = 9.702E-12 kg/m**3 Dens.Pert. = 65.60% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -1.4 12.9 11.5 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -73.9 0.8 -73.1 m/s -2.8 m/s
CO2=4.338E+13 N2=1.582E+13 Ar=1.902E+12 O2=6.887E+11 CO=7.626E+12 #/m**3
54.107 12.564 2.154 0.625 6.054 % by mass
34.957 12.750 1.533 0.555 6.146 % by volume
O=5.384E+13 He=6.714E+11 H2=3.598E+10 H=1.261E+11 Total=1.241E+14 #/m**3
24.414 0.076 0.002 0.004 % by mass MolWgt=28.433
43.388 0.541 0.029 0.102 % volume (mole) fraction

Time (rel. to T0) = 19000.0 sec. (0.214 sols) Ls = 97.1 Dust = 0.30
Height Above MOLA (or Surface) = 185.000 km (185.015 km) OWLT = 19.02 Min
Topographic Height = -0.015 km Radius (Areoid) = 3573.084 (3388.084) km
Hgt Above Ellipsoid = 185.708 km Scale Hgt H(p)= 13.96 H(rho)= 12.02 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 41.48 deg Longitude = 66.97 W (293.03 E) deg.
Planeto-Graphic Lat = 41.80 deg Planeto-Graphic Hgt (Ellps)= 185.705 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.648 AU
Sun Longitude = 185.74 deg.W Local True Solar Time = 19.92 Mars hrs
Exospheric Temp. = 176.4 K Tbase = 144.1 K Zbase = 124.6 km
Solar Zenith Angle = 92.7 deg F1 peak = 999.9 km
Temperature = 176.3 K Pressure = 2.090E-07 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 2.632E-12 3.816E-12 5.534E-12 kg/m**3
Departure, COSPAR NH Mean = -95.7 % -93.8 % -90.9 % iupdate = 1
Tot.Dens. = 5.493E-12 kg/m**3 Dens.Pert. = 43.92% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = -0.2 -13.4 -13.7 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -76.4 24.1 -52.3 m/s 0.4 m/s
CO2=2.474E+13 N2=1.152E+13 Ar=1.205E+12 O2=4.787E+11 CO=5.553E+12 #/m**3
47.366 14.044 2.094 0.666 6.768 % by mass
28.805 13.415 1.403 0.557 6.466 % by volume
O=4.158E+13 He=6.452E+11 H2=3.549E+10 H=1.263E+11 Total=8.588E+13 #/m**3
28.941 0.112 0.003 0.006 % by mass MolWgt=26.764
48.414 0.751 0.041 0.147 % volume (mole) fraction

Time (rel. to T0) = 19500.0 sec. (0.220 sols) Ls = 97.1 Dust = 0.30
Height Above MOLA (or Surface) = 190.000 km (189.754 km) OWLT = 19.02 Min
Topographic Height = 0.246 km Radius (Areoid) = 3577.940 (3387.940) km
Hgt Above Ellipsoid = 190.737 km Scale Hgt H(p)= 14.85 H(rho)= 12.53 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 41.98 deg Longitude = 67.47 W (292.53 E) deg.
Planeto-Graphic Lat = 42.30 deg Planeto-Graphic Hgt (Ellps)= 190.733 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.648 AU
Sun Longitude = 187.77 deg.W Local True Solar Time = 20.02 Mars hrs
Exospheric Temp. = 175.9 K Tbase = 143.9 K Zbase = 124.6 km
Solar Zenith Angle = 93.3 deg F1 peak = 999.9 km
Temperature = 175.8 K Pressure = 1.473E-07 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.741E-12 2.524E-12 3.660E-12 kg/m**3
Departure, COSPAR NH Mean = -96.3 % -94.7 % -92.3 % iupdate = 1
Tot.Dens. = 3.176E-12 kg/m**3 Dens.Pert. = 25.83% Wave = 0.00% of mean

Eastward Wind (Mean,Perturbed,Total) = 0.7 -9.5 -8.8 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -79.0 13.9 -65.1 m/s -0.5 m/s
CO2=1.380E+13 N2=8.383E+12 Ar=7.622E+11 O2=3.325E+11 CO=4.041E+12 #/m**3
 39.955   15.450   2.004   0.700   7.446 % by mass
 22.751   13.819   1.256   0.548   6.662 % by volume
 O=3.256E+13 He=6.201E+11 H2=3.500E+10 H=1.266E+11 Total=6.066E+13 #/m**3
 34.269   0.163   0.005   0.008 % by mass MolWgt=25.059
 53.676   1.022   0.058   0.209 % volume (mole) fraction

Time (rel. to T0) = 20000.0 sec. (0.225 sols) Ls = 97.1 Dust = 0.30
Height Above MOLA (or Surface) = 195.000 km (194.639 km) OWLT = 19.02 Min
Topographic Height = 0.361 km Radius (Areoid) = 3582.794 (3387.794) km
Hgt Above Ellipsoid = 195.765 km Scale Hgt H(p)= 15.85 H(rho)= 13.15 km
Height Offset Parameters: ibougher = 1 Local Height Offset = 2.280 km
Planeto-Centric Lat = 42.48 deg Longitude = 67.97 W (292.03 E) deg.
Planeto-Graphic Lat = 42.80 deg Planeto-Graphic Hgt (Ellps)= 195.762 km
Planeto-Cent Sun Lat = 25.01 deg Mars Orbital Radius = 1.648 AU
Sun Longitude = 189.80 deg.W   Local True Solar Time = 20.12 Mars hrs
Exospheric Temp. = 175.5 K   Tbase = 143.7 K Zbase = 124.6 km
Solar Zenith Angle = 93.8 deg   F1 peak = 999.9 km
Temperature = 175.4 K   Pressure = 1.060E-07 N/m**2 profwgt = 0.000
Density (Low, Avg., High) = 1.171E-12 1.699E-12 2.463E-12 kg/m**3
Departure, COSPAR NH Mean = -96.8 %   -95.4 %   -93.4 % iupdate = 1
Tot.Dens. = 1.686E-12 kg/m**3 Dens.Pert. = -0.73% Wave = 0.00% of mean
Eastward Wind (Mean,Perturbed,Total) = 1.6 4.2 5.8 m/s VertWind
Northward Wind(Mean,Perturbed,Total) = -81.6 1.2 -80.4 m/s   0.0 m/s
CO2=7.443E+12 N2=6.096E+12 Ar=4.819E+11 O2=2.308E+11 CO=2.939E+12 #/m**3
 32.021   16.697   1.882   0.722   8.048 % by mass
 17.007   13.930   1.101   0.527   6.716 % by volume
 O=2.581E+13 He=5.960E+11 H2=3.453E+10 H=1.269E+11 Total=4.376E+13 #/m**3
 40.377   0.233   0.007   0.013 % by mass MolWgt=23.374
 58.989   1.362   0.079   0.290 % volume (mole) fraction

APPENDIX D—SUMMARY OF FILES PROVIDED WITH MARS-GRAM 2010

The Mars-GRAM 2010 zip file contains the following directories:

binFiles	PC binary version of data files required
Code	Source code for Mars-GRAM stand-alone and example trajectory programs
Documentation	README and other .txt and .pdf documentation files
Executables	PC executables for Mars-GRAM and the various Utilities programs executables for other platforms must be compiled from the source code
IOfiles	Reference input and output files [sample output files ListMapYrx.txt (x = 0, 1, 2)]
txtFiles	Text version of data files required. Source code makebin.f90 in Utilities directory is a program to read these text files and create the binary files on non-PC systems (see Conversion of ASCII Data to Binary in appendix F).
Utilities	Source code for utilities programs to perform various tasks related to Mars-GRAM.

NOTE: Text files provided have end-of-line marks in PC format. These may need to be converted to end-of-line marks on your non-PC platform. File transfer protocol (FTP) file transfer to your target platform from the zip files, read on a PC, can make the transform, if the FTP file transfer is done in ASCII mode. On-line or GNU utilities are also available that can perform this end-of-line transform for you.

The directories contain the following files:

Directory Code:

Cfiles_M10_C.f90	Mars-GRAM common block modules
Ifiles_M10_I.f90	Mars-GRAM interface modules
marsgram_M10.f90	Source code for the “stand-alone” version main program
marssubs_M10.f90	Subroutines used by marsgram_M10, dumytraj_M10, and multtraj_M10
setup_M10.f90	Setup routines used by marsgram_M10, dumytraj_M10, and multtraj_M10
TESsubs_M10.f90	Subroutines to read and interpolate TES mapping year 1 and 2 data; used by marsgram_M10, dumytraj_M10, and multtraj_M10

dumytraj_M10.f90 Source code for main driver of dumytraj example trajectory program. To be compiled with marssubs_M10.f90, TESsubs_M10.f90, setup_M10.f90, and wrapper_M10.f90; this program illustrates the use of Mars-GRAM as a subroutine in trajectory programs or orbit propagator programs.

multtraj_M10.f90 Source code for main driver of multtraj example trajectory program that computes multiple trajectories during one run. This is to be compiled with marssubs_M10.f90, TESsubs_M10.f90, setup_M10.f90, and wrapper_M10.f90. This program illustrates the use of Mars-GRAM as a subroutine in trajectory programs or orbit propagator programs that compute positions of multiple spacecraft during one run.

wrapper_M10.f90 Wrapper routine (subroutine marstraj), called by dumytraj_M10 and multtraj_M10, for including in user's trajectory code (along with marssubs, TESsubs, and setup routines, called by wrapper)

ldMarsGRAM.bat Example macro to compile and link the Mars-GRAM stand-alone program

lddumytraj.bat Example macro to compile and link the dummy trajectory program dumytraj_M10

ldmulttraj.bat Example macro to compile and link the dummy trajectory program multtraj_M10

Directory Utilities:

makebin.f90 Program to read ASCII version MGCM and MTGCM data files and write out binary version for faster reading on the user's machine. This program reads the near-surface MGCM data at the ground surface, 5 m, and 30 m above surface for both Mars-GRAM 2001 data with dust optical depths of 0.3, 1, and 3 and the TES mapping year 1 and 2 data. Reads 0.0 to 80.0 km Mars-GRAM 2001 MGCM data and -5 to 80 km TES mapping year 1 and 2 MGCM data. This program also reads 80.0 to 170.0 km Mars-GRAM 2001 MTGCM data and 80 to 240 km TES mapping year 1 and 2 MTGCM data. Finally, it reads optical depth file, tau versus latitude-longitude-L_s, for TES mapping years 1 and 2. Binary conversion process is required only once, before the initial running of Mars-GRAM. See appendix F for file descriptions.

readalb.f90 Program to read ASCII albedos and convert to binary

READTOPO.f90 Program to read ASCII MOLA topography and convert to binary

BLDTRAJ.f90 Program to build pseudo-trajectory file for use in Mars-GRAM to compute output for maps or cross-sections

finddate.f90 Utility to find Earth date/time for desired L_s or Mars time

julday.f90 Utility to find Julian day from year, month, day input

marsrad.f90 Uses Mars-GRAM output to compute various solar (shortwave) and thermal (longwave) fluxes at the surface and the top of the atmosphere

radtraj.f90	Special "trajectory" building program to compute vertical profiles at latitude-longitude, latitude-time, or longitude-time cross sections, for input to Mars-GRAM runs to produce output for input to marsrad radiation calculations
LdBldTraj.bat	Example macro to compile and link program BLDTRAJ
LdFindDate.bat	Example macro to compile and link program finddate
LdJulDay.bat	Example macro to compile and link program julday
LdMakebin.bat	Example macro to compile and link program makebin
LdMarsRad.bat	Example macro to compile and link program marsrad
LdRadTraj.bat	Example macro to compile and link program radtraj
LdReadalb.bat	Example macro to compile and link program readalb
LdReadtopo.bat	Example macro to compile and link program READTOPO

Directory txtFiles:

Data files (ASCII format) for MGCM near-surface data

sfc00xxy.txt	MGCM boundary layer data at ground surface for Mars-GRAM 2001 data at dust optical depths 0.3, 1.0, and 3.0 (xx = 03, 10, 30) and for TES mapping years 1 and 2 (xx = y1, y2), and version number y
sfc05xxy.txt	MGCM boundary layer data at 5.0 m height for Mars-GRAM 2001 data at dust optical depths 0.3, 1.0, and 3.0 (xx = 03, 10, 30) and for TES mapping years 1 and 2 (xx = y1, y2), and version number y
sfc30xxy.txt	MGCM boundary layer data at 30.0 m height for Mars-GRAM 2001 data at dust optical depths 0.3, 1.0, and 3.0 (xx = 03, 10, 30) and for TES mapping years 1 and 2 (xx = y1, y2), and version number y

MGCM data files (ASCII format) for 0 to 80 km or -5 to 80 km

tpdloxxy.txt	Mars-GRAM 2001 MGCM 0 to 80 km temperature, pressure, and density data for 3 dust optical depths (xx = 03, 10, 30), version number y, or TES mapping year 1 and 2 data (xx = y1, y2) for -5 to 80 km, version number y
uvloxxy.txt	Mars-GRAM 2001 MGCM 0 to 80 km EW wind NS wind data for 3 dust optical depths (xx = 03, 10, 30), version number y, or TES mapping year 1 and 2 data (xx = y1, y2) for -5 to 80 km, version number y

Data files (ASCII format) for MTGCM 80 to 170 (or 240) km data

tpdlsxxy.txt	Mars-GRAM 2001 MTGCM 80 to 170 km temperature, pressure, and density data for 3 dust optical depths (xx = 03, 10, 30), version number y, for solar activity F10.7 = 70; or MTGCM data for 80 to 240 km for TES mapping years 1 and 2 (xx = y1, y2)
tpdmsxxy.txt	Mars-GRAM 2001 MTGCM 80 to 170 km temperature, pressure, and density data for 3 dust optical depths (xx = 03, 10, 30), version number y, for solar activity F10.7 = 130; or MTGCM data for 80 to 240 km for TES mapping years 1 and 2 (xx = y1, y2)
tpdhsxxy.txt	MTGCM 80 to 240 km temperature, pressure, and density data for TES mapping years 1 and 2 (xx = y1, y2), version number y, for solar activity F10.7 = 200
uvlsxxy.txt	MTGCM 80 to 170 km EW wind and NS wind data for 3 dust optical depths xx, version number y, for solar activity F10.7 = 70; or 80 to 240 km for TES mapping years 1 and 2 (xx = y1, y2)
uvmsxxy.txt	MTGCM 80 to 170 km EW wind and NS wind data for 3 dust optical depths xx, version number y, for solar activity F10.7 = 130; or 80 to 240 km for TES mapping years 1 and 2 (xx = y1, y2)
uvhsxxy.txt	MTGCM 80 to 240 km EW wind and NS wind data for TES mapping years 1 and 2 (xx = y1, y2) version number y, for solar activity F10.7 = 200

Other text files, which must be converted to binary format

albedo1.txt	Global surface albedo at 1 by 1 degree latitude-longitude resolution; must be converted to binary with program readalb.f90
MOLATOPH.TXT	MOLA areoid and surface topography at 1/2 by 1/2 degree latitude-longitude resolution; must be converted to binary with program READTOPO.f90
TESdust1.txt	TES dust optical depth data versus L_s, latitude, longitude for TES mapping years 1 and 2; must be converted to binary with program makebin.f90

Directory binFiles:

sfc*.bin	Binary format MGCM surface data files
tpdlo*.bin	Binary format MGCM thermodynamic files
uvlo*.bin	Binary format MGCM wind files
tpdxs*.bin	Binary format MTGCM thermodynamic files (x=l, m, or h for low, medium, or high solar activity)

uvxs*.bin	Binary format MTGCM wind files (x = l, m, or h for low, medium, or high solar activity)
albedo1.bin	Binary format albedo file
molatoph.bin	Binary format topography file
TESdust1.bin	Binary format dust file
COSPAR2.DAT	Text format data file for COSPAR reference model atmosphere
hgtoffst.dat	Text format height offset file
zfhtlsy.txt	Height ZF of 1.26 nbar level for all dust optical depths, version number y, for solar activity F10.7 = 70 for Mars-GRAM 2001 MTGCM data
zfhtmsy.txt	Height ZF of 1.26 nbar level for all dust optical depths, version number y, for solar activity F10.7 = 130 for Mars-GRAM 2001 MTGCM data
zfTESlsy.txt	Height ZF of 1.26 nbar level for TES mapping years 1 and 2, MTGCM data version y, for solar activity F10.7 = 70
zfTESmsy.txt	Height ZF of 1.26 nbar level for TES mapping years 1 and 2, MTGCM data version y, for solar activity F10.7 = 130
zfTEShsy.txt	Height ZF of 1.26 nbar level for TES mapping years 1 and 2, MTGCM data version y, for solar activity F10.7 = 200

Note: For PC users, binary version MGCM files, MTGCM files, and albedo1.bin, molatoph.bin, and TESdust1.bin are supplied and the readalb, readtopo, and makebin programs do not have to be run. For more details, see appendix F.

Directory IOfiles:

inputstd0.txt	Commented test input file for reference case using mapping year 0 MGCM and MTGCM input data
inputstd1.txt	Commented test input file for reference case using TES mapping year 1 MGCM and MTGCM input data
inputstd2.txt	Commented test input file for reference case using TES mapping year 2 MGCM and MTGCM input data
ListMapYr0.txt	List output file for inputstd0.txt reference case
ListMapYr1.txt	List output file for inputstd1.txt reference case
ListMapYr2.txt	List output file for inputstd2.txt reference case

profiledata.txt	Sample auxiliary profile
dumytraj.bat	Example execute macro for dummy trajectory program dumytraj_M10
marsgram0.bat	Example execute macro for mapping year 0 reference input
marsgram1.bat	Example execute macro for mapping year 1 reference input
marsgram2.bat	Example execute macro for mapping year 2 reference input
multtraj.bat	Example execute macro for dummy trajectory program multtraj_M10

Directory Documentation:

headers.txt	List of output files and file header definitions
marsfix.txt	List of code changes since Mars-GRAM 2010 Version 1.0 (Nov 2010)
marshist.txt	History file summarizing various Mars-GRAM versions and changes
Mars2000.pdf	A portable document format (PDF) version of the Mars-GRAM 2000 user guide
Mars2001.pdf	A PDF version of the Mars-GRAM 2001 user guide.
Mars2010.pdf	A PDF version of the Mars-GRAM 2010 user guide
MarsEnvironment.pdf	A PDF version of the Mars Transportation Environment Definition Document (NASA/TM—2001–210935)
README1.txt	General program introduction file
README2.txt	Discussion of dumytraj_M10.f90 dummy trajectory program
README3.txt	Discussion of MGCM and MTGCM input data files, including provided programs to convert ASCII files into binary files for faster running of Mars-GRAM
README4.txt	Discussion of auxiliary programs provided, including marsrad (solar and thermal radiative transfer program)
README5.txt	Discussion of Mars-GRAM sample input and output files, including reference test case
README6.txt	Description of some special program features not fully covered in other README files
xycodes.txt	List of x-y plot codes (also given below)

Plotable output files can be generated with data given versus several selected parameters. Generation of LIST file output and plotable output files is controlled by the value of *iup* on input.

For Mars-GRAM 2010, a number of plotable output files are generated, each containing several parameters suitable for plotting. These plotable files have headers to help identify parameters in the files.

File names and definitions of headers are given in the file headers.txt.

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

Code	Parameter
1	Planetocentric Height (above local MOLA areoid, km)
2	Planetocentric Height (above local MOLA topographic surface, km)
3	Planetocentric 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, L_s (deg.)
8	Local True Solar Time (Mars hours)
9	Pressure (mb)
10	Pressure Height (km) [-H*log(Pres/PresSurf) = -H*log(sigma)]
11	Sigma coordinate [sigma = Pressure/(Pressure at Surface)]
12	Planetocentric Height (km) above reference ellipsoid
13	Planetographic Height (km) above reference ellipsoid
14	Planetographic Latitude (deg.)
15	Longitude in range -180 to +180 (East or West, controlled by *LonEW*)

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 2010 code and are automatically available to be called whenever the Mars-GRAM 2010 code (marssubs_M10.f90 and setup_M10.f90) 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 2010 subroutines without using the approach taken in dumytraj_M10.f90. 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_M10.f90, interaction with Mars-GRAM 2010 is via three calls to one wrapper subroutine named Marstraj_M10 and provided as file wrapper_ M10.f90, but with different values of three control parameters called isetup, jmonte, and istep:

Call Marstraj_M10(...) with isetup = 1

Call Marstraj_M10(...) with isetup = 0, jmonte > 0, istep = 0

Call Marstraj_M10(...) 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_M10 is a subroutine in the dumytraj_M10.f90 code, and must be included along with the basic Mars-GRAM code setup_M10.f90 and marssubs_M10.f90 as a subroutine in the user's calling trajectory program.

(3) In the original marstraj.f dummy trajectory main code, the 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_M10.f90 code this transfer is handled within the Marstraj_ M10 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_M10.f90 code, input variables to the Marstraj_M10 subroutine are current and next double precision position values of height, latitude, and longitude and the position increments to be passed to the Datastep subroutine including increments of height, latitude, and longitude are computed within the Marstraj_M10 subroutine.

Regardless of which dummy trajectory code you decide to use as your starting model from which to build the interface to Mars-GRAM 2010 for your own trajectory code, it is worthwhile to read the comments embedded in the dumytraj_M10.f90 code. These comments give more explicit descriptions of the functions that are being performed. They also provide valuable 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_M10.f90 is that it allows high precision Mars ephemeris values for sun latitude, longitude, and L_s angle to be passed from the trajectory program for use by Mars-GRAM 2010 subroutines.

The multiple perturbation version, multtraj_M10.f90 , allows different realizations of perturbation profiles to be generated on a single trajectory run. This can be used, for example, to test sensitivity of a guidance algorithm to different gain levels.

APPENDIX F—DETAILS OF MGCM, MTGCM, AND MOLA DATA FILES

Time-of-Day Variation of MGCM and MTGCM Data

ASCII format MGCM and MTGCM data files are provided, each having values for amplitudes and phases of diurnal and semi-diurnal components. The diurnal period is 24 Mars hours and the semi-diurnal period is 12 Mars hours. Generically, the amplitudes and phases are as follows:

A0 = Diurnal mean value of the given parameter

A1 = Amplitude of the diurnal tide component

phi1 = Phase (local time in Mars hours) of the diurnal component

A2 = Amplitude of the semi-diurnal tide component

phi2 = Phase (local time in Mars hours) of the semi-diurnal component

For temperature, wind components, and height of 1.26 nbar level (ZF), data files give amplitudes in the same units as those of the parameter, K for temperature, m/s for wind, or km for ZF. For pressure and density, data files give amplitudes in units of percent of the mean value A0. A0 units for pressure are N/m^2, while density A0 units are kg/m^3.

Three slightly different functions for tidal variation versus time of day are used. For MGCM and MTGCM temperatures and winds and MTGCM ZF heights, function TideX is used, where

TideX = A0 + A1 * cos((π/12) * (time – phi1)) + A2 * cos((π/6) * (time – phi2))

and time is the local solar time in Mars hours. Note that units for A1 and A2 are same as those for A0 in this function form. For Mars-GRAM 2001, MGCM and MTGCM pressure and density data which have A1 and A2 in units of percent of A0, function TideY is used, where

TideY = A0 * (1 + 0.01 * A1 * cos((π/12) * (t – phi1)) + 0.01 * A2 * cos((π/6) * (t – phi2)))

TES MTGCM data extend to higher altitude, 240 km versus 170 km for Mars-GRAM 2001 MTGCM data. Consequently, tidal amplitudes for density and pressure for the new data grow to larger values than for the Mars-GRAM 2001 data. To accommodate this situation, an alternate model is adopted for pressure and density variation with time of day, whereby it is the log of pressure and density that are assumed to vary as cosine of time of day. Namely TES mapping year 1 and 2 MTGCM pressure and density tides are computed by

tTideY = A0 * ((1.0d0 + 0.01d0 * A1) ** c1) * ((1.0d0 + 0.01d0 * A2) ** c2) where exponents c1 and c2 are given by

$$c1 = \cos((\pi/12) * (time - phi1))$$

$$c2 = \cos((\pi/6) * (t - phi2))$$

Near-Surface MGCM Data

Near-surface MGCM data files are provided as follows in ASCII format:

sfc00xxy.txt MGCM temperature data at topographic surface

sfc05xxy.txt MGCM temperature and wind data at 5 m height above the surface

sfc30xxy.txt MGCM temperature and wind data at 30 m height above the surface

Naming convention for these files is:

xx = 03, 10, 30 for Mars-GRAM 2001 data at globally-uniform dust optical depths of 0.3, 1.0, and 3.0

xx = y1, y2 for data at time-and space-variable dust optical depth as observed during TES mapping years 1 and 2

y = version number

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

MGCM Data Up to 80.0 km Altitude

Files of zonally-averaged MGCM data up to 80.0 km altitude above the MOLA areoid are provided as follows in ASCII format:

tpdloxxy.txt MGCM temperature, pressure, and density data

uvloxxy.txt MGCM Eastward and Northward wind data

Naming convention for these files is:

xx = 03, 10, 30 for Mars-GRAM 2001 data at globally-uniform dust optical depths of 0.3, 1.0, and 3.0. These data are at 5.0 km intervals from 0.0 km to 80.0 km above MOLA

xx = y1, y2 for data at time-and space-variable dust optical depths as observed during TES mapping years 1 and 2. These data are at 1.0 km interval from -5.0 km to +10.0 km above MOLA, and 5.0 km interval from 10.0 km to 80.0 km above MOLA

y = version number

For the MGCM data sets, each record of the tpdloxx.txt files contains L_s 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. For the TES mapping year 1 and 2 data, each record of the tpdloxx.txt files contains L_s value, height, latitude, and tidal coefficients for temperature and density. Only the A0 coefficient is given for pressure. Tidal variations in pressure are computed from those for density and temperature by the perfect gas law relation.

For both MGCM and TES mapping year 1 and 2 data, each record of the uvloxx.txt files contains L_s value, height, latitude, and tidal coefficients for the Eastward and Northward wind components.

MTGCM Data Up to 170.0 or 240.0 km Altitude

Zonally-averaged MTGCM data are provided in ASCII format at 5.0 km height resolution for the altitude range of 80.0 to 170.0 km for Mars-GRAM 2001 data and 80.0 to 240.0 km for TES mapping year 1 and 2 data. Data sets are provided for different levels of solar activity as characterized by 10.7 cm solar flux, F10.7, as measured at 1.0 AU.

tpdlsxxy.txt MTGCM temperature, pressure, and density data for low solar activity (F10.7 = 70)

tpdmsxxy.txt MTGCM temperature, pressure, and density data for moderate solar activity (F10.7 = 130)

tpdhsxxy.txt MTGCM temperature, pressure, and density data for high solar activity (F10.7 = 200; available for TES mapping years 1 and 2 only)

uvlsxxy.txt MTGCM Eastward and Northward wind data for F10.7 = 70

uvmsxxy.txt MTGCM Eastward and Northward wind data for F10.7 = 130

uvhsxxy.txt MTGCM Eastward and Northward wind data for F10.7 = 200 (available for TES mapping years 1 and 2 only)

Naming convention for these files is:

xx = 03, 10, 30 for Mars-GRAM 2001 data at globally-uniform dust optical depths of 0.3, 1.0, and 3.0.

xx = y1, y2 for data at time-and space-variable dust optical depths as observed during TES mapping years 1 and 2.

y = version number

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

Files zfhtlsy.txt, and zfhtmsy for Mars-GRAM 2001 data, F10.7 = 70 or 130 and zfTESlsy.txt, zfTESmsy.txt, and zfTEShsy.txt for TES mapping years 1 and 2, F10.7 = 70, 130, or 200 provide tidal coefficient information for altitude ZF, the height of the 1.26 nbar level. Each record of the ZF files contains dust optical depth or TES mapping year, L_s, latitude, and tidal coefficient values. The mean ZF value and tidal amplitudes are given in km.

MOLA Areoid and Topography Data

MOLA areoid and topography data at 1/2 by 1/2 degree latitude-longitude resolution is provided in ASCII file MOLATOPH.TXT. Each line of this file contains East longitude and latitude at the center of the 1/2 by 1/2 degree grid box, grid-box-average radius in meters to the topographic surface, areoid radius in meters which is the radius to reference constant potential surface, evaluated at the center of the grid box, topography which is the grid-box-average difference in meters between the local planetary radius and areoid; this is analogous to the local terrain height above sea level for Earth, and Num which equals the number of laser shots averaged over the grid box. MOLA latitudes are planetocentric. Longitudes in the MOLA input file are with respect to the IAU 1991 prime meridian. A shift of about 0.24 degrees is made automatically within Mars-GRAM 2010, in order to convert to longitudes relative to the IAU 2000 prime meridian.

Surface Albedo Data

Global surface albedo at 1 by 1 degree latitude-longitude resolution is given in file albedo1.txt. Each line of this file contains latitude, and West longitude at the center of the 1 by 1 degree grid box, and grid-box-average surface albedo which is the ratio of the surface-reflected solar flux to that incident on the surface.

Global Mean MGCM-MTGCM Height Offset Data

Height offsets can be used to control the smoothness of the transition at 80 km altitude between MGCM data and MTGCM data. Height offset options are controlled by input parameters *zoffset* and *ibougher*. The file README6.txt contains more details about height offsets and these input parameters. Option *ibougher* = 2 causes the height offsets to be evaluated from global average height offset data given in the file hgtoffst.dat. In the first part of this file, global-average offsets in km are given for Mars-GRAM 2001 data as a function of L_s and dust optical depth of 0.3, 1.0, and 3.0. In the second part of this file, global-average offsets are given versus L_s for TES mapping years 1 and 2, y1 or y2.

TES Dust Optical Depth Data

Observed average dust optical depth from TES mapping years 1 and 2 are provided in the file TESdust1.txt. TES mapping year 1 was from April 1999 through January 2001. TES mapping year 2 was from February 2001 through December 2002. In terms of L_s, TES mapping years 1 and 2 cover from L_s = 115, through L_s = 360/0, and back to L_s = 115 the following Mars year. A conventional Mars year runs from L_s = 0 to L_s = 360. There were no global-scale dust storms during TES mapping year 1. However, a very intense, global-scale dust storm began near the end of June 2001, during TES mapping year 2. Each line of file TESdust1.txt contains TES mapping year (1 or 2), L_s, latitude, West longitude, and the average TES optical depth expressed as visible-wavelength optical depth, approximately twice the optical depth values measured by TES at its 9 micron observing wavelength. Data in this file are at a resolution of 5.0 degrees in Ls, 7.5 degrees in latitude, and 9.0 degrees in longitude.

COSPAR Reference Data

COSPAR Northern hemisphere mean reference data, as given in Pitts et al[31], are provided in file COSPAR2.DAT. Each line of this file contains height (km), temperature (K), pressure (mbar), and density (g/cm^3).

Conversion of ASCII Data to Binary

Source code is provided for a program called makebin.f90 that reads the ASCII format MGCM and MTGCM data files and the TES dust optical depth data file and writes them out in binary format. After this ASCII-to-binary conversion is completed once, subsequent reading of the binary format files significantly shortens the time required to initialize Mars-GRAM on each run. Source code is also provided for the ASCII-to-binary conversion programs called READTOPO.f90 and readalb.f90 that covert the MOLA topography data and the albedo data files. ZF data files, height offset file, and COSPAR reference data file are sufficiently small that they can be read in ASCII format, so no conversion to binary is required for these files.

Note: For PC users, all necessary binary version files are supplied and the ASCII-to-binary conversion programs (readalb, readtopo, and makebin) do not have to be run.

To run Mars-GRAM, the binary-version MGCM and MTGCM files, together with the ASCII-format ZF data files, must be in the directory whose pathname is given by the input parameter *GCMDIR* in the NAMELIST input file. The binary version albedo, MOLA topography, and TES dust optical depth data files, together with ASCII-format files COSPAR2.DAT and hgtoffst.dat must be in the directory whose pathname is given by the input parameter *DATADIR* in the NAMELIST input file. In this distribution of Mars-GRAM, the default pathname for *DATADIR* and *GCMDIR* are the same, with all necessary files together in the binFiles directory.

Optional Trajectory Input Files

If the number of positions to be calculated given by the input parameter *NPOS* is set to 0, an optional trajectory input file is read from a file with the name given by the input parameter *TRAJFL*. Each line of the trajectory file consists of: time, in seconds past the start time specified in the NAMELIST input, height, in km, latitude in degrees, and longitude in degrees. Heights are relative to the MOLA areoid or reference ellipsoid, as set by the input parameter *MOLAhgts*. Latitudes are planetocentric or planetographic, as set by the input parameter *ipclat*. Longitudes are East or West, as set by the input parameter *LonEW*. Any additional reference information included on each line (e.g. orbit number, measured density, etc.) is ignored. Trajectory positions in these files do not have to be at small time or space steps. For example, a trajectory file may consist of successive periapsis times and positions for a simulated or observed aerobraking operation. Trajectory files may also contain arrays of locations used for computing height-latitude cross sections or latitude-longitude cross sections. Such trajectory input files can be built by the program BLDTRAJ.f90 (see appendix G).

Optional Auxiliary Profile Input File

As an option, data read from an auxiliary profile may be used to replace data from the MGCM and MTGCM data files. This option is controlled by setting the input parameters *profile*, *profnear*, and *proffar* in the NAMELIST input file. Input parameter *profile* gives the file name of the file containing the profile data values. Input parameter *profnear* is the latitude-longitude radius in degrees within which the weight for the auxiliary profile is 1.0. Input parameter *proffar* is the latitude-longitude radius in degrees beyond which the weight for the auxiliary profile is 0.0. A weighting factor for the profile data, profwgt, having values between 0 and 1, is applied between the *proffar* and *profnear* radii. Mean conditions are as given in the profile file if the desired point is within a latitude-longitude radius of *profnear* from the profile latitude-longitude at the given altitude; mean conditions are as given by the original MGCM or MTGCM data if the desired point is beyond a latitude-longitude radius of *proffar* from the latitude-longitude of the profile at the given altitude. If *profnear* = 0, then profile data are NOT used. The profile weight factor, profwgt, for the auxiliary profile also varies between 0 at the first profile altitude level and 1 at the second profile altitude level and between 1 at the next-to-last profile altitude level and 0 at the last profile altitude level. First and second profile points and the next-to-last and last profile points should therefore be selected widely enough apart in altitude that a smooth transition can occur as profwgt changes from 0 to 1 near these profile end points.

Each line of the auxiliary profile input file consists of: height, in km, latitude, in degrees, longitude, in degrees, temperature, in K, pressure, in N/m^2, density, in kg/m^3, Eastward wind, in m/s, and Northward wind, in m/s. Heights are relative to the MOLA areoid or reference ellipsoid, as set by the input parameter *MOLAhgts*. Latitudes are planetocentric or planetographic, as set by the input parameter *ipclat*. Longitudes are East or West, as set by the input parameter *LonEW*. MGCM/MTGCM temperature, pressure, and density data are used if any of the profile inputs for temperature, pressure, or density are 0. MGCM/MTGCM winds are used if BOTH wind components are 0 in the profile file. A sample auxiliary profile file named profiledata.txt is provided in the IOfiles directory.

APPENDIX G—AUXILIARY PROGRAMS FOR USE WITH MARS-GRAM

Four auxiliary programs are provided for use with Mars-GRAM: BLDTRAJ.f90, finddate.f90, marsrad.f90, and radtraj.f90. The stand-alone version Mars-GRAM program files (marsgram_M10.f90, marssubs_M10.f90, and setup_M10.f90) are discussed in appendix D. Appendixes D and E discuss dummy trajectory programs dumytraj_M10.f90 and multtraj_M10.f90, which provide examples of how to use Mars-GRAM as a subroutine in trajectory programs or orbit propagator programs. Programs makebin.f90, readalb.f90, and READTOPO.f90, which convert data provided in ASCII format into binary files, are discussed in appendixes D and F.

Program BLDTRAJ

It is frequently desirable to produce Mars-GRAM output for graphing as a map (i.e. latitude-longitude cross section at a given height) or other cross-section (e.g. height- latitude cross section at a given longitude). Program BLDTRAJ.f90 generates a trajectory file with input lines containing time, height, latitude, and longitude that can be used as Mars-GRAM input for generation of such maps or cross-sections. Program BLDTRAJ is interactive and prompts the user to input starting values, ending values, and step sizes for height (z1, z2, dz), latitude (lat1, lat2, dlat), and longitude (lon1, lon2, dlon). The program also prompts for a value of time increment which is applied between each trajectory step. This time increment may be 0, if all trajectory points are at the same time. Time values in the trajectory file are time in seconds from the start time that is specified by the date and time information provided in the Mars-GRAM NAMELIST-format input file.

NOTE: If heights > 3,000.0 km are used, they are interpreted as planetocentric radius values (km).

Example:

For a latitude-longitude map at height 10.0 km above the MOLA areoid, between latitudes -30 and 30 degrees in steps of 5 degrees, and longitudes 0 to 180 degrees in steps of 20 degrees, enter 10 10 0 for z1, z2, dz; enter -30 30 5 for lat1, lat2, dlat; and enter 0 180 20 for lon1, lon2, dlon. All of these input quantities are of type real, and can be entered to one or more significant digits beyond the decimal.

Program finddate

Program finddate.f90 allows calculation of the areocentric longitude of the Sun, L_s, and Mars local true solar time, LTST, for a given Earth date and time. It also computes the next occurrence beyond the initial input date and time of the Earth date and time for which L_s and LTST are any desired values. Accuracy information and other documentary comments are given within the source code. The program is interactive and prompts for all necessary inputs.

Program julday

Program julday.f90 calculates the Julian day from year, month, and day input. Traveling wave components require the Julian day for initialization of wave phases. The program is interactive and prompts for all necessary inputs.

Program marsrad

Program marsrad.f90 uses Mars-GRAM output files containing height profile information to compute various solar (shortwave) and thermal (longwave) fluxes at the surface and the top of the atmosphere. These profiles must start at the surface, should usually extend upward to a height of from 10.0 to 30.0 km, and may be at any desired height resolution with a limit of 1,000 points per profile. Mars-GRAM output files used by marsad.f90 are TPresHgt.txt, Density.txt, and MarsRad.txt. See the file headers.txt that is provided in the Documentation Directory of the Mars-GRAM 2010 zip file for a description of the parameters contained in these files.

Program marsrad.f90 runs interactively, with the only user input required being the number 1 or 2 of plot variables Var_X and, optionally, Var_Y used in the Mars-GRAM output files. The marsrad program computes various solar (shortwave) and thermal (longwave) fluxes at the surface and the top of the atmosphere. Two marsrad output files are produced. Output file Radlist.txt contains an annotated set of radiation fluxes, equivalent black-body temperatures, and albedos. Output file Radout.txt, suitable for input to a plot program, contains fluxes and other information in one line for each set of output. With an input trajectory file that is generated by program radtraj.f90 - see below, output file Radout.txt can be used to plot solar and thermal radiation data as a map lat-lon cross section, or as latitude-time or longitude-time cross sections.

Longwave radiative fluxes are computed by a broad-band (emissivity) method, patterned after Savijarvi[32]. Dust optical depth tau is for the shortwave (solar) spectrum. For longwave calculations, infrared emissivity versus shortwave solar optical depth curves are used, adapted from Haberle et al.[27]. Infrared emissivities for CO_2 and water vapor are functions of pressure-scaled optical path lengths with emissivities from Staley and Jurica[33]. Shortwave fluxes are computed from total dust optical depth adjusted for small amount of clear-sky optical depth by a delta-Eddington method[34]. Both longwave and shortwave effects of water vapor are included, with relative humidity assumed constant at 20%[32]. Dust optical properties assumed are 0.7 for asymmetry parameter, and 0.9 for single-scatter albedo. Other reasonable values may be found in Table 1 of Murphy et al.[35]. Values of asymmetry parameter and single-scatter albedo as well as assumed relative humidity can be changed in data statements near the beginning of the marsrad program.

Output parameters given in Radlist.txt output file in addition to plot variables, Var_X and, optionally, Var_Y are:

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

Longwave (LW) fluxes F (W/m^2):

Fdown(sfc)	Downwelling LW flux at surface
Fup(sfc)	Upwelling LW flux at surface (related to Tsfc)
Fup(toa)	Upwelling LW flux at top-of-atmosphere

Femit(atmos)	LW flux emitted by atmosphere [Fup(toa) - net LW at sfc]

Radiative (equivalent black-body) temperatures (K):

Tsky(sfc)	Equivalent sky temperature [related to Fdown(sfc)]
Tsfc	Ground surface temperature [related to Fup(sfc)]
Teff(toa)	Effective black-body temperature at top-of-atmosphere

Shortwave (SW) fluxes E (W/m^2):

Edown(sfc)	Downwelling SW flux at surface
Eup(sfc)	Upwelling SW flux at surface [albedo times Edown(sfc)]
Eup(toa)	Upwelling SW flux at top-of-atmosphere
Eabsorb(atmos)	Net SW flux absorbed by atmosphere
Edown(toa)	Solar flux at toa = mu0*(solar constant)/$MarsAU^2$
Surface albedo	Surface albedo interpolated from file albedo1.txt
Planetary albedo	Ratio Eup(toa)/Edown(toa)

SW+LW Fluxes (W/m^2):

Absorbed(sfc)	SW+LW flux absorbed at the surface
Emitted(toa)	Upwelling SW+LW flux at top-of-atmosphere

Controlled by parameter “heatrate” set via user input, marsrad.f90 also outputs optical path lengths for water vapor (H_2O), CO_2, and dust. H_2O and CO_2 optical path lengths are scaled by pressure to the 0.75 power. With heatrate set to 1, the program also outputs various fluxes (W/m^2) and heating rates (K/day) as a function of pressure level. These optional outputs are:

Pres	Pressure (mb)
uH2O	Pressure-scaled H_2O optical path (precipitable micrometers)
uCO2	Pressure-scaled CO_2 optical path (atmosphere-centimeters)
udust	Dust optical depth from surface to given pressure level
LWFup	Upwelling LW flux at pressure level
LWFdn	Downwelling LW flux at pressure level

LWFnet	Net (up - down) LW flux at pressure level
LWdTdt	LW heating rate at pressure level
SWdTdt	SW heating rate at pressure level
TotdTdt	Total (LW+SW) heating rate at pressure level

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

albsfc	Surface albedo (interpolated from file albedo1.txt)
tau	Total vertical dust optical depth (for solar wavelengths)
RadAU	Mars orbital radius (AU)
mu0	Cosine of solar zenith angle
ice	0 for no ice on the surface, 1 for ice on the surface
Tsfc	Ground surface temperature (K)
Fusfc	Upwelling LW flux at surface (W/m^2)
Tsky	Equivalent sky temperature (K)
Fdsfc	Downwelling LW flux at surface (W/m^2)
Teff	Effective black-body temperature at top-of atmosphere (K)
Futoa	Upwelling LW flux at top-of-atmosphere (W/m^2)
Edsfc	Downwelling SW flux at surface (W/m^2)
Eusfc	Upwelling SW flux at surface (W/m^2)
Edtoa	Solar flux at toa = mu0*(solar constant)/$RadAU^2$ (W/m^2)
Eutoa	Upwelling SW flux at top-of-atmosphere (W/m^2)
Planalb	Planetary albedo = ratio Eutoa/Edtoa
thet	Solar zenith angle (degrees)
Tdif	Diffuse transmittance for diffuse irradiance
Tdir	Diffuse transmittance for beam irradiance
Tbeam	Beam transmittance

Program radtraj

Radtraj.f90 is a special trajectory building program to compute vertical profiles at latitude-longitude, latitude-time, or longitude-time cross sections, for input to Mars-GRAM runs to produce output for input to marsrad radiation calculations. The radtraj.f90 program is similar in function and use to the BLDTRAJ.f90 trajectory building program, except that radtraj.f90 is especially designed for use in conjunction with Mars-GRAM runs for which radiation calculations are to be done by the marsrad.f90 program.

Program radtraj.f90 produces a trajectory file consisting of sets of vertical profiles that are constrained to start at the surface by automatically setting z1 = -10. Any heights that are below the surface are automatically ignored by the marsrad.f90 program. Any upper height z2 and height step dz may be used for the height profiles. However, it is not necessary to use z2 higher than about 30.km. The input time step if other than zero applies only as the trajectory goes from one vertical profile to the next.

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14. ABSTRACT
This Technical Memorandum (TM) presents the Mars Global Reference Atmospheric Model 2010 (Mars-GRAM 2010) and its new features. Mars-GRAM is an engineering-level atmospheric model widely used for diverse mission applications. Applications include systems design, performance analysis, and operations planning for aerobraking, entry, descent and landing, and aerocapture. Additionally, this TM includes instructions on obtaining the Mars-GRAM source code and data files as well as running Mars-GRAM. It also contains sample Mars-GRAM input and output files and an example of how to incorporate Mars-GRAM as an atmospheric subroutine in a trajectory code.

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