Final Report

ADDITIONS TO MARS GLOBAL REFERENCE ATMOSPHERIC MODEL (MARS-GRAM)

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Abstract

Three major additions or modifications have been made to the Mars Global Reference Atmospheric Model (Mars-GRAM). (1) In addition to the interactive version, a new batch version is available, which uses NAMELIST input, and is completely modular, so that the main driver program can easily be replaced by any calling program, such as a trajectory simulation program. (2) Both the interactive and batch versions now have an option for treating local-scale dust storm effects, rather than just the global-scale dust storms in the original Mars-GRAM. (3) The Zurek wave perturbation model has been added, to simulate the effects of tidal perturbations, in addition to the random (mountain wave) perturbation model of the original Mars-GRAM. A minor modification has also been made which allows heights to go "below" local terrain height and return "realistic" pressure, density and temperature, not the surface values, as returned by the original Mars-GRAM. This feature will allow simulations of Mars rover paths which might go into local "valley" areas which lie below the average height of the present, rather coarse-resolution, terrain height data used by Mars-GRAM. Sample input and output of both the interactive and batch versions of Mars-GRAM are presented.

INTRODUCTION

The Mars Global Reference Atmospheric Model (Mars-GRAM; Justus and Chimonas, 1988; Justus, 1990, 1991), includes simulation capabilities for mean values of density, temperature, pressure and wind components. Density perturbations, simulated by a mountain-wave simulation model are also included, for simulation of density perturbation profiles along specified trajectories through the atmosphere of Mars.

Up to a height of 75 km, Mars-GRAM is based upon parameterizations of height, latitudinal, longitudinal and seasonal variations of temperature, determined from a survey of published measurements from the Mariner and Viking programs (a complete set of references in provided by Justus and Chimonas, 1989). Pressure and density are inferred in Mars-GRAM from the temperature by making use of the hydrostatic and perfect gas law relationships. Above about 120 km, Mars-GRAM uses the thermospheric model of Stewart (1987). A hydrostatic interpolation routine is used to insure a smooth transition from the lower portion of the model to the Stewart thermosphere model.

Mars-GRAM includes parameterizations to simulate the effects of seasonal variation, diurnal variation, dust storm effects, effects due to the orbital position of Mars, effects of the large seasonal variation in surface atmospheric pressure because of differential condensation/sublimation of the CO_2 atmosphere in the polar caps, and effects of Martian atmospheric mountain wave perturbations on the magnitude of the expected density perturbations. The thermospheric model includes a parameterization for the effects of solar activity, measured by the 10.7 cm solar radio flux. Winds are computed by the thermal wind approximation, with the inclusion of the effects of molecular viscosity, which, because of the low atmospheric densities, can be very important at high altitudes. The mountain wave perturbation model also includes a damping approximation due to the effects of molecular viscosity.

During much of 1990 and early 1991, the Mars Atmosphere Knowledge Requirements Working Group (Bourke, 1991) met by video-conference, with the objectives of

- Understanding the sensitivity and consequences of various levels of uncertainties in the Martian atmosphere

- Understanding the realistic limits on modeling the Mars atmosphere, both deterministically and statistically

- Recommending a set of atmospheric information requirements to be satisfied by the robotic portion of the Mars Exploration Program

Specific recommendations were made by the working group for improvements and additions to the Mars-GRAM program:

(1) The addition of a capability to treat local-scale dust storms. The current Mars-GRAM treats all storms as growing and decaying with time, but with a size of full global dimensions.

(2) The addition of the Zurek wave model (Pitts et al., 1988) to represent the large-scale temperature and density perturbations caused by atmospheric tides. The current Mars-GRAM perturbations are rather small-scale, gravity-wave-like variations.

(3) A modular version of Mars-GRAM, specifically designed for use as a subroutine in a calling program, such as a trajectory guidance and control analysis program. This version would allow easy application of user-defined perturbation models, such as sine-wave perturbations or hyperbolic tangent or step-like perturbations.

The purpose of this report is to describe the Mars-GRAM modifications recently made to satisfy these recommendations.

ADDITIONS TO MARS-GRAM

The Zurek Wave Perturbation Model

Parameters necessary to evaluate wave-structure perturbations in temperature are provided by Zurek's tables on pages 11-12 of Pitts et al.

(1988). The Zurek wave model was designed to allow estimation of temperature perturbations which would be produced by atmospheric tides (expected to be an important process in the Martian atmosphere). In order to compute wave-structure perturbations in density from the original temperature perturbation estimates of Zurek, a simple model is assumed, based on approximate hydrostatic equilibrium for these large-scale perturbations. The perfect gas law, $p = \rho RT$, requires that perturbations in pressure, density and temperature be related (to first order) by

$$p'/\langle p\rangle = \rho'/\langle \rho\rangle + T'/\langle T\rangle \quad , \tag{1}$$

where the angle brackets denote average values. The perturbation version of the hydrostatic equation, $\partial p'/\partial z = -\rho' g$, requires that

$$\partial(p'/\langle p\rangle)/\partial z = -(\rho'/\langle \rho\rangle - p'/\langle p\rangle)(g/RT) = -(T'/\langle T\rangle)(g/RT) \quad . \tag{2}$$

If one assumes a simple cosine function for the vertical variation of $T'/\langle T\rangle$, i.e.

$$T'/\langle T\rangle = A\cos(kz) \quad , \tag{3}$$

then equations (1) and (2) require that

$$\rho'/\langle \rho\rangle = A\,[\sin(kz)/(kH) - \cos(kz)] \quad , \tag{4}$$

where H is the scale height (RT/g). The temperature perturbation data provided in Zurek's table provide information to determine the values of k and the wave amplitude A for both clear-sky and dust-storm cases. If it is assumed that kH ≃ 1, then the density perturbation may be evaluated from this k value, with the approximate form of equation (4), namely

$$\rho'/\langle\rho\rangle \simeq A\,[\sin(kz) - \cos(kz)] \quad . \tag{5}$$

Figure 1 shows a sample evaluation of the Zurek density wave perturbation model at the location and time of the Viking 1 lander entry (7/20/76 12:30 GMT, at Mars latitude 22°N, longitude 48°W). Since the random (mountain-wave) perturbations no longer constitute the only perturbations in Mars-GRAM, their minimum acceptable perturbation magnitudes have been decreased somewhat. A sample of the random density perturbations at the Viking 1 lander location and time is shown in Figure 2. The total density perturbations, found by adding the wave-component and random-component perturbations from Figures 1 and 2, are consistent with the density perturbations observed by the Viking 1 and 2 landers (shown as figures in the Pitts et al. 1988 report), which have peak values of 10-20%.

Figure 3 shows the density wave perturbation values from the Zurek model, evaluated on a height-latitude cross section, through the Viking 1 longitude (48°N) at the time of the lander entry. Peak contour values in Figure 3 are +14% and -14% (not labeled, because of the small area within these contours).

Local-Scale Dust Storm Simulations

At run time, the Mars-GRAM user selects the time of start (within seasonal bounds) for a dust storm (if any) to be simulated. A time profile of build-up and decay for the dust storm intensity (up to a selectable maximum value) is part of the program. The new additions also allow selection of a location (latitude and longitude) at which the dust storm is to start and a maximum radius (up to 10,000 km) that the dust storm is allowed to grow. These parameters of dust-storm location and maximum radius (r_{max}) are used to compute a size factor which multiplies the intensity of the dust storm effects. The size factor, as a function of position and height, is given by

$$\text{size factor} = 0.25\ [1 + \cos(90°r/r_d)][1 + \cos(90°z/z_d)] \quad , \qquad (6)$$

where r is the local radius from the dust storm center location, r_d is the temporally varying dust-storm radius (up to a maximum of r_{max}), z is the local height and z_d is the height of the dust storm. z_d also grows temporally up to a maximum value of 60 km or $r_d/3$ (whichever is smaller).

The dust storm radius r_d and height z_d are values for 1/2 the full effect. Thus the size factor given by equation (6) is 1 when $r/r_d = 0$ and $z/z_d = 0$; it is 1/2 when $r/r_d = 1$ and $z/z_d = 1$; and it is 0 when $r/r_d = 2$ or $z/z_d = 2$. As illustrated by Figure 4 the function $0.5[1 + \cos(x)]$ used in equation (6) is very similar to the Gaussian distribution function $\exp(-x^2/\pi)$ frequently used as a size factor function is diffusion models.

Figure 5 illustrates the effects of a local dust storm on the mean density simulated along a hypothetical trajectory, starting at latitude 0°N, longitude 0°W at 40 km altitude, and moving at constant height and latitude along longitude from 0 to 100° W, with a local dust storm centered at latitude 0°N, longitude 50°W, with radius = 1000 km. The values plotted in Figure 5 are the differences between mean density with dust storm perturbation and that with no dust storm effects. Deviations in mean density of 25% or more are seen near the center position of the local storm, with 0 deviations seen at distances from the storm center of more than twice the storm radius.

The Mars-GRAM Batch Version

A new batch version of Mars-GRAM has been developed, which uses NAMELIST input, and is completely modular, so that the main driver program can easily be replaced by any calling program, such as a trajectory simulation program. As with the interactive version, fixed values of trajectory displacements in height, latitude, longitude and time may be read in as input, or position along an arbitrary trajectory may be read in from an input file. In the batch version of Mars-GRAM, values of the trajectory displacement values can easily be changed with time by simple modifications to the short driver program, or from within the trajectory program which replaces the Mars-GRAM batch version driver program.

OTHER PROGRAM MODIFICATIONS

The wave perturbations are modeled in a new subroutine WAVEPERT and associated functions AMPINT and PHASINT to interpolate wave amplitudes and phases. The Zurek wave model parameters are input to the program via a new BLOCK DATA routine. The local dust storm modifications are incorporated into the previous subroutine DUSTFACT.

Other program modifications are that:

(1) A minor modification has also been made which allows heights to go "below" local terrain height and return "realistic" pressure, density and temperature, not the surface values, as returned by the original Mars-GRAM. This feature will allow simulations of Mars rover paths which might go into local "valley" areas which lie below the average height of the present, rather coarse-resolution, terrain height data used by Mars-GRAM.

(2) For simulations which are to follow the Mars GRAM terrain heights exactly, an input height below -5 km will specify this option.

(3) For 1-D plots versus either of the height variables (height above reference ellipsoid or above local terrain), the plotable output files have the height variable in the second (y) position (ordinate). This simplifies input to plot routines which do not allow run-time selection of which input variable is the abcissa and which is the ordinate.

Samples of input and output from both the interactive version and the batch version of Mars-GRAM are given in the following section.

SAMPLE INPUT AND OUTPUT WITH THE REVISED MARS-GRAM

Documentation of the original Mars-GRAM program, including examples of input and output were described by Justus and Chimonas (1989). This section describes some of the new input-output features added for the wave perturbation model, the local-scale dust storm model, and for the batch version of Mars-GRAM.

In the interactive version of Mars-GRAM (see listing of the main routine in Appendix A), the program prompts the user for values of all required input options. Table 1 shows an example of such an interactive session: the model run done to produce the vertical profile of wave perturbation values shown in Figure 1.

Differences in the input required by the new program options are:

(1) If the season permits (L_s between 180° and 320°), and if the user selects a dust storm condition, then the user must select (a) an intensity of storm (maximum 3.0), (b) a maximum radius for the dust storm ($r_{max} = 0$ or $r_{max} > 10{,}000$ km means a global-scale storm), and (c) a latitude and longitude for the storm center if the storm is local-scale.

(2) The user can select the perturbation model to be either the original random (mountain-wave) model (model 1), the new Zurek wave perturbation model (model 2), or the combined perturbations from both the random and wave models (model 3).

(3) If either model 1 or model 3 is selected, then the user must supply a starting random number (1 - 30,000) for the random number generator used for the random perturbations.

The LIST output file produced from the model run of Table 1 is shown in Table 2. The OUTPUT file from this run is given in Table 3. The plotable file DENSAV produced in this run is shown in Table 4.

The new batch version of Mars-GRAM (see listing of the short main driven routine in Appendix B) uses NAMELIST input. An example NAMELIST input file is given in Table 5: the model run used to produce the data along the trajectory shown in Figure 5 (i.e at constant height = 40 km, from latitude 0°, longitude 0° to latitude 0°, longitude 100° W, in 100 steps of 1° longitude each). The NAMELIST input shown in Table 5 selects a local scale dust storm of intensity 3.0, starting at L_s = 280°, centered at latitude 0°, longitude 50° W (the trajectory midpoint), with maximum storm radius 1000 km. Notice that the time of simulation in Table 5 is one Earth year after the Viking 1 landing (7/20/77); no dust storms are possible at the season of the Viking 1 landing (when L_s = 90°).

A computer diskette is available, containing nine files:

(1) MARSGRAM.FOR - the main routine for the interactive version of Mars-GRAM, version 3.0

(2) MARSGRMB.FOR - the main routine for the batch version of Mars-GRAM, version 3.0

(3) MARSSUBS.FOR - all of the subroutines used by both interactive and batch versions of Mars-GRAM

(4) SETUP.FOR - a setup subroutine, called once at the start of the run of the batch version of Mars-GRAM

(5) MARSGRAM.EXE - a PC-DOS executable file for the interactive version of Mars-GRAM

(6) HEIGHTS.DAT - terrain height data file (same as used by earlier versions of Mars-GRAM)

(7) MARSGRAM.HST - an ASCII readable "history" file describing the current (3.0) and all previous versions of Mars-GRAM

(8) INPUT.DOC - a sample NAMELIST file, with inline comments appended (after exclamation points)

(9) INPUT - a sample NAMELIST file, without inline comments (for those Fortran compilers which do not allow inline comments in NAMELIST input)

To obtain a copy of the diskette, contact Ms. Bonnie James, Code ES-44, NASA Marshall Space Flight Center, Huntsville, AL 35812.

DIGITAL TERRAIN DATA

A new set of digital terrain height data for Mars, produced by the U. S. Geological Survey, has been received on large format magnetic tape. The feasibility of extracting a more detailed set of terrain heights from this set, for improvement over those currently used by Mars-GRAM, has been be examined. Some potential problems with this are that the data are on DEC VAX format tapes (we have no easy access to a DEC VAX with 9-track tape drives), and the data on the tapes are in "pixel" form for ease in producing images, not necessarily for extracting tabular data at an array (e.g. 1° × 1°) of fixed locations.

This digital terrain model data base is now available on CD-ROM (Batson, 1992), and has been ordered in this format. However, the data were not received in time to process during this contract period.

REFERENCES

Batson, R.M., et al. (1992): CD-ROM Publication of the Mars Digital Cartographic Data Base, NTIS HC/MF A25.

Bourke, R. D., editor (1991): Report of the Mars Atmosphere Knowledge Requirements Working Group, JPL Technical Report.

Justus, C. G. (1990): A Mars Global Reference Atmospheric Model (Mars-GRAM) for Mission Planning and Analysis, AIAA 90-004, presented at the 28th Aerospace Sciences Meeting, Reno, NV, January.

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Pitts, D. E., J. E. Tillman, J. Pollack and R. Zurek (1988): Model Profiles of the Mars Atmosphere for the Mars Rover and Sample Return Mission, draft technical report, March 11.

Stewart, A. I. F. (1987): Revised Time Dependent Model of the Martian Atmosphere for use in Orbit Lifetime and Sustenance Studies. Final Report JPL PO# NQ-802429, March 26.

Table 1. Sample operation of Mars-GRAM Program. This shows a sample run of the program to produce vertical height profiles at the location and time of the Viking-1 Lander entry.

```
marsgram
 Mars-GRAM Interactive version 3.0 - October 14, 1991
 Enter name for LIST file (CON for console listing):
viking1.lst
 Enter name for OUTPUT file:
viking1.out
 Enter Month, Day of Month, 4-digit Year, and Max Number Positions
7 20 76 21
 Enter initial GMT Time (Hours, Minutes, Seconds)
12 30 0
 Ls =   97.0 degrees for this date.
 Dust storms can occur between Ls = 180 and Ls = 320.
 Enter starting Ls value for dust storm (or 0 for none).
0
 Enter mean F10.7 flux at 1AU (nominal value = 150)
 and +/- number of std. deviations for thermosphere variation
68 0
 Enter perturbation model: 1=random, 2=wave, 3=both
3

Enter Starting Random Number  (any positive integer < 30,000)
1001

 Select x-code and y-code for plotable output versus desired parameter(s):

 Code             Parameter
 ----   ---------------------------------------------
   1    Height (above reference ellipsoid, km)
   2    Height (above local terrain, km)
   3    Latitude (deg.)
   4    Longitude (deg.)
   5    Time from start (Earth seconds)
   6    Time from start (Martian Sols)
   7    Areocentric Longitude of Sun, Ls (deg.)
   8    Hour Angle for Local Time (Mars hours * 15)

 Use y-code = 0 for plotable output vs x-code variable only
2 0
  Enter 1 for log-base-10 density and pressure on plot files, 0 for normal
0
 Enter Initial Latitude (deg.), West Longitude (deg.)
22 48
 Surface elevation =   -.50 km at this location
 Enter Initial Height (km)
-.5
 Enter Increments in Height (km), Latitude (deg.), West Longitude (deg.),
  and Time (sec.)
5 0 0 0
```

```
 Computing data.
 Enter Month, Day of Month, 4-digit Year, and Max Number Positions
0 0 0 0
STOP  Normal Termination
```

Table 2. Printout of the LIST file produced by the sample run in Table 1. Heights are above reference ellipsoid, with height above local terrain shown in parentheses.

```
Mars-GRAM Interactive version 3.0 - October 14, 1991
Date = 7/20/1976  Julian Date = 2442980.0  GMT Time = 12:30:  .0
F10.7 flux = 68.0,  standard deviation =   .0
Perturbation model = 3  Starting random number = 1001
Time (relative to initial time) =         .0 sec.  Ls =   97.0 deg.
Height =   -.50 km (   .00 km)  Scale Height = 12.33 km
Latitude =  22.000 degrees      West Longitude =  48.000 degrees
Sun Longitude = 111.188 deg.    Local Time = 16.21 Mars hours
Temperature =  240.5 K          Pressure =    748.3     N/m**2
Density (Low, Avg., High) =    .1612E-01   .1627E-01   .1643E-01 kg/m**3
Density plus perturbation =    .1770E-01 kg/m**3
Eastward Wind =     4.2 m/s     Northward Wind =      -.3 m/s
------------------------------------------------------------------------
Time (relative to initial time) =         .0 sec.  Ls =   97.0 deg.
Height =   4.50 km (  5.00 km)  Scale Height = 10.79 km
Latitude =  22.000 degrees      West Longitude =  48.000 degrees
Sun Longitude = 111.188 deg.    Local Time = 16.21 Mars hours
Temperature =  210.4 K          Pressure =    485.5     N/m**2
Density (Low, Avg., High) =    .1189E-01   .1207E-01   .1224E-01 kg/m**3
Density plus perturbation =    .1238E-01 kg/m**3
Eastward Wind =     1.5 m/s     Northward Wind =     -3.8 m/s
------------------------------------------------------------------------
Time (relative to initial time) =         .0 sec.  Ls =   97.0 deg.
Height =   9.50 km ( 10.00 km)  Scale Height = 10.30 km
Latitude =  22.000 degrees      West Longitude =  48.000 degrees
Sun Longitude = 111.188 deg.    Local Time = 16.21 Mars hours
Temperature =  200.9 K          Pressure =    302.7     N/m**2
Density (Low, Avg., High) =    .7732E-02   .7882E-02   .8036E-02 kg/m**3
Density plus perturbation =    .7908E-02 kg/m**3
Eastward Wind =    -2.2 m/s     Northward Wind =     -5.5 m/s
------------------------------------------------------------------------
Time (relative to initial time) =         .0 sec.  Ls =   97.0 deg.
Height =  14.50 km ( 15.00 km)  Scale Height =  9.81 km
Latitude =  22.000 degrees      West Longitude =  48.000 degrees
Sun Longitude = 111.188 deg.    Local Time = 16.21 Mars hours
Temperature =  191.4 K          Pressure =    184.7     N/m**2
Density (Low, Avg., High) =    .4929E-02   .5049E-02   .5173E-02 kg/m**3
Density plus perturbation =    .4930E-02 kg/m**3
Eastward Wind =    -4.4 m/s     Northward Wind =     -7.2 m/s
------------------------------------------------------------------------
Time (relative to initial time) =         .0 sec.  Ls =   97.0 deg.
Height =  19.50 km ( 20.00 km)  Scale Height =  9.45 km
Latitude =  22.000 degrees      West Longitude =  48.000 degrees
Sun Longitude = 111.188 deg.    Local Time = 16.21 Mars hours
Temperature =  184.4 K          Pressure =    110.5     N/m**2
Density (Low, Avg., High) =    .3044E-02   .3133E-02   .3226E-02 kg/m**3
Density plus perturbation =    .3090E-02 kg/m**3
Eastward Wind =    -5.7 m/s     Northward Wind =     -9.1 m/s
```

```
------------------------------------------------------------------------
Time (relative to initial time) -          .0 sec.   Ls -   97.0 deg.
Height -  24.50 km (  25.00 km)   Scale Height -   9.10 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   177.6 K           Pressure -     64.91      N/m**2
Density (Low, Avg., High) -      .1848E-02   .1912E-02   .1978E-02 kg/m**3
Density plus perturbation -      .1900E-02 kg/m**3
Eastward Wind -     -7.1 m/s      Northward Wind -   -11.4 m/s
------------------------------------------------------------------------
Time (relative to initial time) -          .0 sec.   Ls -   97.0 deg.
Height -  29.50 km (  30.00 km)   Scale Height -   8.75 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   170.8 K           Pressure -     37.41      N/m**2
Density (Low, Avg., High) -      .1102E-02   .1146E-02   .1191E-02 kg/m**3
Density plus perturbation -      .1160E-02 kg/m**3
Eastward Wind -     -8.4 m/s      Northward Wind -   -14.0 m/s
------------------------------------------------------------------------
Time (relative to initial time) -          .0 sec.   Ls -   97.0 deg.
Height -  34.50 km (  35.00 km)   Scale Height -   8.48 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   165.5 K           Pressure -     21.17      N/m**2
Density (Low, Avg., High) -      .6405E-03   .6690E-03   .6987E-03 kg/m**3
Density plus perturbation -      .6519E-03 kg/m**3
Eastward Wind -     -9.8 m/s      Northward Wind -   -17.1 m/s
------------------------------------------------------------------------
Time (relative to initial time) -          .0 sec.   Ls -   97.0 deg.
Height -  39.50 km (  40.00 km)   Scale Height -   8.22 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   160.4 K           Pressure -     11.79      N/m**2
Density (Low, Avg., High) -      .3662E-03   .3844E-03   .4034E-03 kg/m**3
Density plus perturbation -      .3681E-03 kg/m**3
Eastward Wind -    -11.2 m/s      Northward Wind -   -20.2 m/s
------------------------------------------------------------------------
Time (relative to initial time) -          .0 sec.   Ls -   97.0 deg.
Height -  44.50 km (  45.00 km)   Scale Height -   7.96 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   155.3 K           Pressure -     6.449      N/m**2
Density (Low, Avg., High) -      .2069E-03   .2173E-03   .2281E-03 kg/m**3
Density plus perturbation -      .2071E-03 kg/m**3
Eastward Wind -    -12.8 m/s      Northward Wind -   -23.5 m/s
------------------------------------------------------------------------
Time (relative to initial time) -          .0 sec.   Ls -   97.0 deg.
Height -  49.50 km (  50.00 km)   Scale Height -   7.70 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   150.2 K           Pressure -     3.465      N/m**2
Density (Low, Avg., High) -      .1149E-03   .1207E-03   .1267E-03 kg/m**3
Density plus perturbation -      .1239E-03 kg/m**3
Eastward Wind -    -14.4 m/s      Northward Wind -   -26.9 m/s
```

```
------------------------------------------------------------------------
Time (relative to initial time) -         .0 sec.   Ls -    97.0 deg.
Height -  54.50 km (  55.00 km)   Scale Height -   7.55 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   147.2 K           Pressure -     1.833      N/m**2
Density (Low, Avg., High) -      .6201E-04   .6511E-04   .6836E-04 kg/m**3
Density plus perturbation -      .7493E-04 kg/m**3
Eastward Wind -   -16.2 m/s       Northward Wind -    -30.6 m/s
------------------------------------------------------------------------
Time (relative to initial time) -         .0 sec.   Ls -    97.0 deg.
Height -  59.50 km (  60.00 km)   Scale Height -   7.42 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   144.7 K           Pressure -     .9603      N/m**2
Density (Low, Avg., High) -      .3306E-04   .3472E-04   .3645E-04 kg/m**3
Density plus perturbation -      .3176E-04 kg/m**3
Eastward Wind -   -18.2 m/s       Northward Wind -    -34.1 m/s
------------------------------------------------------------------------
Time (relative to initial time) -         .0 sec.   Ls -    97.0 deg.
Height -  64.50 km (  65.00 km)   Scale Height -   7.29 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   142.2 K           Pressure -     .4984      N/m**2
Density (Low, Avg., High) -      .1747E-04   .1834E-04   .1926E-04 kg/m**3
Density plus perturbation -      .1598E-04 kg/m**3
Eastward Wind -   -20.2 m/s       Northward Wind -    -37.2 m/s
------------------------------------------------------------------------
Time (relative to initial time) -         .0 sec.   Ls -    97.0 deg.
Height -  69.50 km (  70.00 km)   Scale Height -   7.16 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   139.6 K           Pressure -     .2562      N/m**2
Density (Low, Avg., High) -      .9140E-05   .9597E-05   .1008E-04 kg/m**3
Density plus perturbation -      .9741E-05 kg/m**3
Eastward Wind -   -22.2 m/s       Northward Wind -    -40.0 m/s
------------------------------------------------------------------------
Time (relative to initial time) -         .0 sec.   Ls -    97.0 deg.
Height -  74.50 km (  75.00 km)   Scale Height -   7.03 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   137.1 K           Pressure -     .1303      N/m**2
Density (Low, Avg., High) -      .4735E-05   .4972E-05   .5221E-05 kg/m**3
Density plus perturbation -      .5777E-05 kg/m**3
Eastward Wind -   -24.3 m/s       Northward Wind -    -42.4 m/s
------------------------------------------------------------------------
Time (relative to initial time) -         .0 sec.   Ls -    97.0 deg.
Height -  79.50 km (  80.00 km)   Scale Height -   7.42 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   138.1 K           Pressure -     .5741E-01 N/m**2
Density (Low, Avg., High) -      .2009E-05   .2173E-05   .2349E-05 kg/m**3
Density plus perturbation -      .2242E-05 kg/m**3
Eastward Wind -   -24.0 m/s       Northward Wind -    -39.9 m/s
```

```
--------------------------------------------------------------------------
Time (relative to initial time) -          .0 sec.   Ls -    97.0 deg.
Height -  84.50 km (  85.00 km)   Scale Height -   7.60 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   140.8 K           Pressure -     .2377E-01 N/m**2
Density (Low, Avg., High) -      .7887E-06   .8805E-06   .9829E-06 kg/m**3
Density plus perturbation -      .7743E-06 kg/m**3
Eastward Wind -   -22.3 m/s       Northward Wind -    -34.8 m/s
--------------------------------------------------------------------------
Time (relative to initial time) -          .0 sec.   Ls -    97.0 deg.
Height -  89.50 km (  90.00 km)   Scale Height -   7.79 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   143.6 K           Pressure -    .9865E-02 N/m**2
Density (Low, Avg., High) -      .3109E-06   .3579E-06   .4120E-06 kg/m**3
Density plus perturbation -      .3074E-06 kg/m**3
Eastward Wind -   -20.5 m/s       Northward Wind -    -29.6 m/s
--------------------------------------------------------------------------
Time (relative to initial time) -          .0 sec.   Ls -    97.0 deg.
Height -  94.50 km (  95.00 km)   Scale Height -   7.97 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   146.3 K           Pressure -    .4105E-02 N/m**2
Density (Low, Avg., High) -      .1220E-06   .1459E-06   .1745E-06 kg/m**3
Density plus perturbation -      .1474E-06 kg/m**3
Eastward Wind -   -18.5 m/s       Northward Wind -    -24.2 m/s
--------------------------------------------------------------------------
Time (relative to initial time) -          .0 sec.   Ls -    97.0 deg.
Height -  99.50 km ( 100.00 km)   Scale Height -   8.15 km
Latitude -   22.000 degrees       West Longitude -   48.000 degrees
Sun Longitude -  111.188 deg.     Local Time -  16.21 Mars hours
Temperature -   149.0 K           Pressure -    .1712E-02 N/m**2
Density (Low, Avg., High) -      .4808E-07   .5966E-07   .7403E-07 kg/m**3
Density plus perturbation -      .6246E-07 kg/m**3
Eastward Wind -   -16.3 m/s       Northward Wind -    -18.8 m/s
--------------------------------------------------------------------------
```

Table 3. Printout of the OUTPUT file produced by the sample run shown in Table 1. The headings shown here are not part of the file, but have been added for readability of this table.

Hgt (km)	Lat (deg)	Lon (deg)	log-10 Density	Temp (K)	EW Wind (m/s)	NS Wind (m/s)	Std. Dev. (%)
-.50	22.00	48.00	-1.79	240.49	4.24	-.27	.95
4.50	22.00	48.00	-1.92	210.42	1.54	-3.85	1.44
9.50	22.00	48.00	-2.10	200.86	-2.23	-5.50	1.93
14.50	22.00	48.00	-2.30	191.35	-4.38	-7.17	2.42
19.50	22.00	48.00	-2.50	184.45	-5.73	-9.11	2.91
24.50	22.00	48.00	-2.72	177.59	-7.06	-11.39	3.39
29.50	22.00	48.00	-2.94	170.76	-8.37	-14.04	3.87
34.50	22.00	48.00	-3.17	165.52	-9.77	-17.07	4.36
39.50	22.00	48.00	-3.42	160.38	-11.24	-20.23	4.83
44.50	22.00	48.00	-3.66	155.26	-12.77	-23.49	4.88
49.50	22.00	48.00	-3.92	150.16	-14.36	-26.88	4.88
54.50	22.00	48.00	-4.19	147.23	-16.23	-30.61	4.88
59.50	22.00	48.00	-4.46	144.69	-18.18	-34.08	4.88
64.50	22.00	48.00	-4.74	142.15	-20.17	-37.19	4.88
69.50	22.00	48.00	-5.02	139.63	-22.22	-39.96	4.88
74.50	22.00	48.00	-5.30	137.11	-24.31	-42.37	4.88
79.50	22.00	48.00	-5.66	138.08	-24.00	-39.86	7.83
84.50	22.00	48.00	-6.06	140.83	-22.30	-34.82	11.02
89.50	22.00	48.00	-6.45	143.56	-20.48	-29.60	14.13
94.50	22.00	48.00	-6.84	146.29	-18.49	-24.24	18.01
99.50	22.00	48.00	-7.22	149.01	-16.31	-18.83	21.75

Table 4. Printout of the plotable file, DENSAV, produced by the sample run shown in Table 1. A change from the earlier Mars-GRAM is that, for plots versus height, the height variable is given as the second (y) variable (ordinate). This simplifies input to plot routines which do not allow run-time selection of which variable is the abcissa and which is the ordinate.

.1627E-01	.0000
.1207E-01	5.000
.7882E-02	10.00
.5049E-02	15.00
.3133E-02	20.00
.1912E-02	25.00
.1146E-02	30.00
.6690E-03	35.00
.3844E-03	40.00
.2173E-03	45.00
.1207E-03	50.00
.6511E-04	55.00
.3472E-04	60.00
.1834E-04	65.00
.9597E-05	70.00
.4972E-05	75.00
.2173E-05	80.00
.8805E-06	85.00
.3579E-06	90.00
.1459E-06	95.00
.5966E-07	100.0

Table 5. Sample of the NAMELIST input file (filename INPUT), used by the batch version of Mars-GRAM. Comments are appended, following the exclamation points. Inline comments are not allowed in NAMELIST input on some Fortran compilers. In such case, the comments cannot actually be included in the NAMELIST file.

```
 $INPUT
   LSTFL    = 'LIST',   ! List file name (CON for console listing)
   OUTFL    = 'OUTPUT',! Output file name
   MONTH    = 7,        ! month of year
   MDAY     = 20,       ! day of month
   MYEAR    = 77,       ! year (4-digit; 1970-2069 can be 2-digit)
   NPOS     = 101,      ! max # positions to evaluate (0 = read data from file)
   IHR      = 12,       ! GMT hour of day
   IMIN     = 30,       ! minute of hour
   SEC      = 0.0,      ! second of minute (for initial position)
   ALS0     = 280.0,    ! starting Ls value (degrees) for dust storm (0 = none)
   INTENS   = 3.0,      ! dust storm intensity (0.0 - 3.0)
   RADMAX   = 1000.0,   ! max. radius (km) of dust storm (0 or >10000 = global)
   DUSTLAT  = 0.0,      ! latitude (deg) for center of dust storm
   DUSTLON  = 50.0,     ! West longitude (deg) for center of dust storm
   F107     = 68.0,     ! 10.7 cm solar flux (10**-22 W/cm**2, at 1 AU)
   STDL     = 0.0,      ! std. dev. for thermosphere variation (-3.0 to +3.0)
   MODPERT  = 3,        ! perturbation model; 1=random, 2=wave, 3=both
   NR1      = 1001,     ! starting random number (0 < NR1 < 30000)
   NVARX    = 4,        ! x-code for plotable output (1=hgt above ref. ellipse)
   NVARY    = 0,        ! y-code for 2-D plotable output (0 for 1-D plots)
   LOGSCALE = 0,        ! 1 for log-base-10 scale plots, 0 for linear scale
   FLAT     = 0.0,      ! initial latitude (N positive), degrees
   FLON     = 0.0,      ! initial longitude (West positive), degrees
   FHGT     = 40.0,     ! initial height (km), above ref. ellipsoid
   DELHGT   = 0.0,      ! height increment (km) between steps
   DELLAT   = 0.0,      ! latitude increment (deg) between steps
   DELLON   = 1.0,      ! West longitude increment (deg) between steps
   DELTIME  = 0.0,      ! time increment (sec) between steps
 $END
```

APPENDIX A

Listing of the Mars-GRAM Interactive Version
(Main Routine Only - No Subroutine Listings Shown)

```
C...    Program Mars-GRAM  Interactive version 3.0 - October 14, 1991
C
C       Mars Global Reference Atmospheric Model (Interactive Version)
C
C       A program to evaluate density, temperature, pressure and wind
C       components at any given time and position in the atmosphere
C       of Mars
C
C...............................................................
C
  1     Format(' Mars-GRAM Interactive version 3.0 - October 14, 1991')
C
        DOUBLE PRECISION XYEAR,DATE,DATE0
        Integer EOF
        REAL MARSAU,NSWIND,intens
        DIMENSION IDAY(12),IERR(14)
        character*12 lstfl,FILES(14),outfl
        COMMON /RAND/IX,IY,IZ
        COMMON /TERHGT/th(19,19)
        COMMON /THERM/F107,stdl
        COMMON /DATA/DTR,BETA,SVAL,DAY,CORFAC,MAXNUM,NPOS,als0,intens,
     &  NVARX,NVARY,DELHGT,DELLAT,DELLON,DELTIME,logscale,dustlat,
     &  dustlon,dusthgt,radmax,Rref,modpert
        COMMON /FILENAME/lstfl,outfl
        Common /WAVEDAT/ampc100(12),phc100(12),ampd100(12),phd100(12),
     &       ampd200(12),phd200(12),ampc120(12),phc120(12),ampd120(12),
     &       phd120(12),ampd220(12),phd220(12),ampc145(12),phc145(12),
     &       ampd145(12),phd145(12),ampd245(12),phd245(12)
        EQUIVALENCE (IERR1,IERR(1)),(IERR2,IERR(2)),(IERR3,IERR(3)),
     &  (IERR4,IERR(4)),(IERR5,IERR(5)),(IERR6,IERR(6)),(IERR7,IERR(7))
     &  ,(IERR8,IERR(8)),(IERR9,IERR(9)),(IERR10,IERR(10)),
     &  (IERR11,IERR(11)),(IERR12,IERR(12)),(IERR13,IERR(13)),
     &  (IERR14,IERR(14))
C...    number of latitudes and longitudes in terrain height array
        DATA nlat,nlon/19,19/
        DATA FILES/'LIST','DENSLO','DENSAV','DENSHI','DENSRP','TEMP',
     &  'PRES','EWWIND','NSWIND','OUTPUT','HEIGHTS.DAT','TMAX','TMIN',
     &  'TAVG'/
C...    Days for months of the year
        DATA IDAY/0,31,59,90,120,151,181,212,243,273,304,334/
C...    Write version number to screen
        Write(0,1)
C...    LIST file contains outputs with descriptive format
        Write(0,10)
 10     format(' Enter name for LIST file (CON for console listing): ')
        read(*,20)lstfl
```

```
  20    format(A)
        files(1)=lstfl
C...    OUTPUT file contains ASCII output, without descriptive
C...    formatting, suitable for reading by another program
        Write(0,30)
  30    FORMAT(' Enter name for OUTPUT file: ')
        read(*,20)outfl
        files(10)=outfl
C...    Write version number to LIST file
        If (lstfl .ne. 'CON' .and. lstfl .ne. 'con')Then
           OPEN(6,file=lstfl,iostat=ierr1)
           Write(6,1)
        Endif
C...    Files on units 21-29 and 30-32 contain parameters suitable for
C...    plotting.  Data is in either of two forms: (1)  X  Y, where X
C...    is the variable to be plotted against (e.g. height), and Y is
C...    the variable to be plotted, or (2) X Y Z, where X and Y are
C...    two variables (e.g. latitude and height) to provide position
C...    for plotting contour plots of variable Z
C...    Unit 21 file = low density value (approx. average - 1 sigma,
C...    kg/m**3)
        OPEN(21,file='DENSLO',iostat=ierr2)
C...    Unit 22 file = average density value (kg/m**3)
        OPEN(22,file='DENSAV',iostat=ierr3)
C...    Unit 23 file = high density value (approx. average + 1 sigma,
C...    kg/m**3)
        OPEN(23,file='DENSHI',iostat=ierr4)
C...    Unit 24 file = time-varying density (kg/m**3), including the
C...    random perturbations
        OPEN(24,file='DENSRP',iostat=ierr5)
C...    Unit 25 file = temperature (K)
        OPEN(25,file='TEMP',iostat=ierr6)
C...    Unit 26 file = pressure (N/m**2)
        OPEN(26,file='PRES',iostat=ierr7)
C...    Unit 27 file = eastward vector wind component (m/s)
        OPEN(27,file='EWWIND',iostat=ierr8)
C...    Unit 28 file = northward vector wind component (m/s)
        OPEN(28,file='NSWIND',iostat=ierr9)
C...    Unit 29 file = OUTPUT file, suitable for reading by other
C       programs
        OPEN(29,file=outfl,iostat=ierr10)
C...    Unit 30 file = Daily maximum surface temperature (K)
        OPEN(30,file='TMAX',iostat=ierr12)
C...    Unit 31 file = Daily minimum surface temperature (K)
        OPEN(31,file='TMIN',iostat=ierr13)
C...    Unit 32 file = Daily average surface temperature (K)
        OPEN(32,file='TAVG',iostat=ierr14)
C...    Unit 9 HEIGHTS.DAT file contains local terrain heights above
C...    the reference ellipsoid, versus latitude and longitude
        OPEN(9,file='HEIGHTS.DAT',status='old',iostat=ierr11)
C...    Test for file open error condition
        Do 40 j=1,14
        If(ierr(j).ne.0)then
```

```
 50           Write(0,60)files(j),ierr(j)
 60           Format(1x,a12,' File open error! Error =',i5)
              Goto 9998
         Endif
 40      Continue
C...     Read terrain height data file
         Do 80 i = 1,nlat
         Read(9,90)lat,(th(i,j),j=1,nlon)
 80      If (lat .ne. -100+10*i)Stop ' Error reading HEIGHTS.DAT!'
 90      Format(I4,19F5.1)
         DTR = Atan(1.)/45.
C...     CORFAC = CORIOLIS FACTOR (EXCEPT FOR LATITUDE EFFECT)
         CORFAC = 0.2*DTR/DAY
 200     Write(0,210)
 210     FORMAT(' Enter Month, Day of Month, 4-digit Year,',
     &   ' and Max Number Positions ')
         READ(*,*)MONTH,MDAY,MYEAR,NPOS
C...     Go to next input set if month <1 or > 12
         If (MONTH .le. 0 .and. MDAY .le. 0 .and. MYEAR .le. 0)Goto 9999
         IF(MONTH.LT.1.OR.MONTH.GT.12)Goto 200
         If(MDAY .lt. 1 .or. MDAY .gt. 31)Goto 200
 240     Write(0,250)
 250     FORMAT(' Enter initial GMT Time (Hours, Minutes, Seconds)')
         READ(*,*)IHR,IMIN,SEC
         If (IHR .lt. 0 .or. IHR .gt. 23)Goto 240
         If (IMIN .lt. 0 .or. IMIN .gt. 59)Goto 240
         If (SEC .lt. 0 .or. SEC .gt. 59)Goto 240
C...     20th century years > 1970 can be entered in 2-digit form.
C...     21st century years < 2070 can be entered in 2-digit form.
         If(MYEAR.LT.70)MYEAR = MYEAR + 2000
         IF(MYEAR.LT.1900)MYEAR = MYEAR + 1900
         IF(NPOS.GT.0) GOTO 280
C...     If NPOS = 0 is entered, program reads position data from
C...     unit 7, trajectory data file
         OPEN(7,file='TRAJDATA',status='old',iostat=ierr7)
         if(ierr7.ne.0)then
 260          Write(0,270)
 270          format(' Unable to open Trajectory Data file!')
              goto 9998
         Endif
 280     MAXNUM = NPOS - 1
         IF(NPOS.LE.0)MAXNUM = 32000
         NDAY = IDAY(MONTH) + MDAY
C...     Correct for leap year
         IF(MOD(MYEAR,4).EQ.0.AND.MONTH.GT.2)NDAY = NDAY + 1
         XYEAR = (MYEAR - 1.9665d3)/4.0d0
C...     Compute Julian date
         DATE = 2.439856d6 + 3.65d2*(MYEAR - 1.968d3) + NDAY +
     &   DINT(XYEAR + DSIGN(0.5d0,XYEAR)) - 0.5d0
C...     Continuously running, fractional Julian date
         DATE = DATE + IHR/2.4d1 + IMIN/1.440d3 + SEC/8.6400d4
         DATE0 = DATE
         Write(6,290)MONTH,MDAY,MYEAR,DATE,IHR,IMIN,SEC
```

```
 290    FORMAT(' Date = ',I2,'/',I2,'/',I4,'  Julian Date = ',F9.1,
     &  '  GMT Time = ',I2,':',I2,':',F4.1)
C...    Sun position in Mars latitude (areocentric latitude) and
C...    longitude. ALS = Ls = areocentric longitude of sun in orbital
C...    position (Ls = 0 at spring equinox). MARSAU = Mars orbital
C...    radius in Astronomical Units
        CALL ORBIT(DATE0,SUNLAT,SUNLON,ALS,MARSAU)
        Write(0,300)ALS
 300    Format(' Ls = ',F6.1,' degrees for this date.')
C...    Select Ls value at start of dust storm, and intensity of dust
C...    storm (if any)
        Write(0,310)
 310    Format(' Dust storms can occur between Ls = 180 and Ls = 320.'/
     &  ' Enter starting Ls value for dust storm (or 0 for none).')
        Read(*,*)als0
        If (als0 .lt. 180.0 .or. als0 .gt. 320.0)then
                If (als0 .gt. 0.)Write(0,*)' Ls outside range. ',
     &          ' No dust storm assumed.'
                als0 = -999.
                intens = 0.0
        Else
 320            Write(0,330)
 330            Format(' Enter dust storm intensity: 1.0 = light,',
     &          ' 2.0 = moderate, 3.0 = heavy')
                Read(*,*)intens
                If (intens .lt. 0.0 .or. intens .gt. 3.0)then
                        Write(0,*)' Intensity must be between 0 and 3'
                        Goto 320
                Endif
                Write(0,332)
 332            Format(' Enter maximum radius of dust storm (km): '/
     &               ' (global if radmax = 0 or radmax > 10000)')
                Read(*,*)radmax
                If (radmax .le. 0.0 .or. radmax .gt. 10000.)radmax=0.
C...            Set max 'half' height of local dust storms to 60. km
                dusthgt = 60.
                If (radmax .ne. 0.0)Then
                   Write(0,333)
 333               Format(' Enter latitude and West longitude of dust',
     &                  ' storm center (deg.)')
                   Read(*,*)dustlat,dustlon
C...               Limit size of dusthgt for small storms
                   If (radmax .le. 180.)dusthgt = radmax/3.
                Endif
        Endif
C...    Enter 10.7 cm solar radio flux (units 10**-22 W/cm**2), as
C...    measured at Earth position (1 AU)
 335    Write(0,340)
 340    Format(' Enter mean F10.7 flux at 1AU (nominal value = 150)'/
     &  ' and +/- number of std. deviations for thermosphere variation')
        Read(*,*)F107,stdl
        If (F107 .lt. 50.0 .or. F107 .gt. 450.0)then
                Write(0,*)' F10.7 must be between 50 and 450'
                Goto 335
```

```
      Endif
      If (stdl .lt. -3.0 .or. stdl .gt. 3.0)then
              Write(0,*)' Std. deviations must be between -3 and +3'
              Goto 335
      Endif
      NR1 = 101
 341  Write(0,342)
 342  Format(' Enter perturbation model: 1=random, 2=wave, 3=both')
      Read(*,*)modpert
      If (modpert .lt. 1 .or. modpert .gt. 3)goto 341
      If (modpert .eq. 2)goto 361
C...  Seed random number for random perturbation model
 350  Write(0,360)
 360  FORMAT(/' Enter Starting Random Number (any positive integer',
     & ' < 30,000)')
      READ(*,*)NR1
      IF (NR1 .LE. 0 .OR. NR1 .GE. 30000)GOTO 350
 361  IX = NR1
      IY = 172 * Mod(IX, 176) - 35 * (IX / 176)
      IZ = 170 * Mod(IX, 178) - 63 * (IX / 178)
      If (IY .lt. 0) IY = IY + 30307
      If (IZ .lt. 0) IZ = IZ + 30323
      RHO = RANDOM(L)
      IF (L .EQ. 1)GOTO 350
      If(lstfl .ne. 'CON' .and. lstfl .ne. 'con')Then
         If (als0 .gt. 0.)Then
            If (radmax .ne. 0.0)Then
               Write(6,363)als0,intens,radmax,dustlat,dustlon
 363           Format(' Local scale dust storm, starting at Ls = ',
     &              F5.1,' deg.,  Intensity = ',F3.1/
     &              ' Maximum radius = ',F7.1, ' km,  Starting at',
     &              ' lat-lon = ',F6.2,' N,  ',F6.2,' W')
            Else
               Write(6,366)als0,intens
 366           Format(' Global scale dust storm, starting at Ls = ',
     &              F5.1,' deg.,  Intensity = ',F3.1)
            Endif
         Endif
         Write(6,368)F107,stdl
 368     Format(' F10.7 flux = ',F5.1,',  standard deviation = ',F4.1)
         Write(6,370)modpert,NR1
      Endif
 370  FORMAT(' Perturbation model = ',I1,'   Starting random',
     &     ' number = ',I5)
C...  Select variable for plotting against (X in files on units 21-29
C...  and 30-32)
      Write(0,380)
 380  FORMAT(/' Select x-code and y-code for plotable output versus',
     & ' desired parameter(s):'//
     & ' Code              Parameter'/
     & ' ----   ------------------------------------------------'/
     & '   1    Height (above reference ellipsoid, km)'/
     & '   2    Height (above local terrain, km)'/
```

```
     &  '    3     Latitude (deg.)'/
     &  '    4     Longitude (deg.)'/
     &  '    5     Time from start (Earth seconds)'/
     &  '    6     Time from start (Martian Sols)'/
     &  '    7     Areocentric Longitude of Sun, Ls (deg.)'/
     &  '    8     Hour Angle for Local Time (Mars hours * 15)'//
     &  ' Use y-code = 0 for plotable output vs x-code variable only')
        READ(*,*)NVARX,NVARY
C...    Default plotting variable = height above reference ellipsoid
        IF(NVARX.LT.1.OR.NVARX.GT.8)NVARX = 1
        IF(NVARY.lt.0.or.NVARY.gt.8)NVARY = 0
        Write(0,*)' Enter 1 for log-base-10 density and pressure',
     &  ' on plot files, 0 for normal'
        READ(*,*)logscale
        If (logscale .ne. 1)logscale = 0
C...    Skip input of positions if trajectory data file is being read
        FLAT = 0.0
        FLON = 0.0
        IF(NPOS.LE.0)GO TO 430
 385    Write(0,390)
 390    FORMAT(' Enter Initial Latitude (deg.),',
     &  ' West Longitude (deg.)')
        READ(*,*)FLAT,FLON
        If (FLAT .lt. -90.0 .or. FLAT .gt. 90.0)Goto 385
        If (FLON .lt. 0.0)FLON = FLON + 360.0
        If (FLON .lt. 0.0 .or. FLAT .gt. 360.0)Goto 385
        thgt = Terrain(FLAT,FLON)
        Write(0,400)thgt
 400    Format(' Surface elevation = ',F6.2,' km at this location')
        Write(0,410)
 410    Format(' Enter Initial Height (km)')
        Read(*,*)FHGT
C...    Constant increments in height, latitude, longitude, and/or
C...    time allowed between successive evaluations of parameters
        Write(0,420)
 420    FORMAT(' Enter Increments in Height (km), Latitude (deg.),',
     &  ' West Longitude (deg.),'/'  and Time (sec.)')
        READ(*,*)DELHGT,DELLAT,DELLON,DELTIME
C...    Initialize position data
        CHGT = FHGT
        CLAT = FLAT
        CLON = FLON
        CSEC = 0.
C...    Write message to screen indicating computations are in progress
 430    Write(0,440)
 440    FORMAT(' Computing data.')
        Call RELLIPS(FLAT,Rref,0.0,gzero)
C...    Step through all positions and evaluate data
        DO 900 I = 0,MAXNUM
        Call Datastep(I,CHGT,CLAT,CLON,CSEC,DATE0,RHO,EOF)
        If (EOF .eq. 1)Goto 200
 900    CONTINUE
        GOTO 200
```

```
9998    Stop ' Error termination on opening or reading input file'
9999    STOP ' Normal Termination'
        END
```

APPENDIX B

Listing of the Mars-GRAM Batch Version
(Main Routine Only - No Subroutine Listings Shown)

```
C...    Program Mars-GRAM  Batch version 3.0 - October 14, 1991
C
C       Mars Global Reference Atmospheric Model (Batch Version)
C
C       A program to evaluate density, temperature, pressure and wind
C       components at any given time and position in the atmosphere
C       of Mars
C
C..............................................................
        DOUBLE PRECISION DATE0
        Integer EOF
        REAL intens
C--------------------------------------------------------------
C       If output to list file and output file are not desired, the
C       following statement may be removed
        character*12 lstfl,outfl
C--------------------------------------------------------------
        Common /INDATA/MONTH,MDAY,MYEAR,IHR,IMIN,SEC,NR1,FLAT,FLON,FHGT
        COMMON /RAND/IX,IY,IZ
        COMMON /TERHGT/th(19,19)
        COMMON /THERM/F107,stdl
        COMMON /DATA/DTR,BETA,SVAL,DAY,CORFAC,MAXNUM,NPOS,als0,intens,
     &  NVARX,NVARY,DELHGT,DELLAT,DELLON,DELTIME,logscale,dustlat,
     &  dustlon,dusthgt,radmax,Rref,modpert
C--------------------------------------------------------------
C       If output to list file and output file are not desired, the
C       following statement may be removed, and the variables LSTFL
C       and OUTFL may be removed from the NAMELIST definition
        COMMON /FILENAME/lstfl,outfl
C       Definition of the Namelist input data
        Namelist /INPUT/LSTFL,OUTFL,MONTH,MDAY,MYEAR,NPOS,IHR,IMIN,
     &  SEC,ALS0,INTENS,RADMAX,DUSTLAT,DUSTLON,F107,STDL,MODPERT,NR1,
     &  NVARX,NVARY,LOGSCALE,FLAT,FLON,FHGT,DELHGT,DELLAT,DELLON,
     &  DELTIME
C--------------------------------------------------------------
C...    Open Namelist data file
        OPEN(8,file='INPUT',status='old')
C...    Read Namelist data
        Read(8,INPUT)
C--------------------------------------------------------------
C       For compilers not supporting the NAMELIST input mode, the
C       previous Read statement may be replaced by:
C
C       Read(8,10)LSTFL
C       Read(8,10)OUTFL
C  10   Format(A)
```

```
C       Read(8,*)MONTH,MDAY,MYEAR,NPOS,IHR,IMIN,SEC,ALSO,INTENS,RADMAX,
C     & DUSTLAT,DUSTLON,F107,STDL,MODPERT,NR1,NVARX,NVARY,LOGSCALE,
C     & FLAT,FLON,FHGT,DELHGT,DELLAT,DELLON,DELTIME
C
C       and the NAMELIST file INPUT may be modified to contain free-
C       field input data as in the above list.
C-----------------------------------------------------------------------
C...    Setup information for start of run
        Call Setup(CHGT,CLAT,CLON,CSEC,DATEO,RHO)
C...    Sample of special parameters to change trajectory steps in the
C       main program
C        zi = CHGT
C        z0 = 20.
C        t0 = 500.
C...    Step through all positions and evaluate data
        DO 900 I = 0,MAXNUM
C-----------------------------------------------------------------------
C       If control of movement along the trajectory is desired from
C       within this main program, then values of the trajectory
C       displacement values (DELHGT, DELLAT, DELLON, and DELTIME)
C       may be re-set here, as illustrated by the following simple
C       example.  Optional reading of trajectory data from
C       the trajectory input data file is handled from within the
C       Datastep subroutine.
C-----------------------------------------------------------------------
C        DELHGT = ((zi-z0)/t0**2)*(2.*(CSEC - t0) + DELTIME)*DELTIME
        Call Datastep(I,CHGT,CLAT,CLON,CSEC,DATEO,RHO,EOF)
        If (EOF .eq. 1)Goto 999
  900   CONTINUE
  999   STOP ' Normal Termination'
        END
```

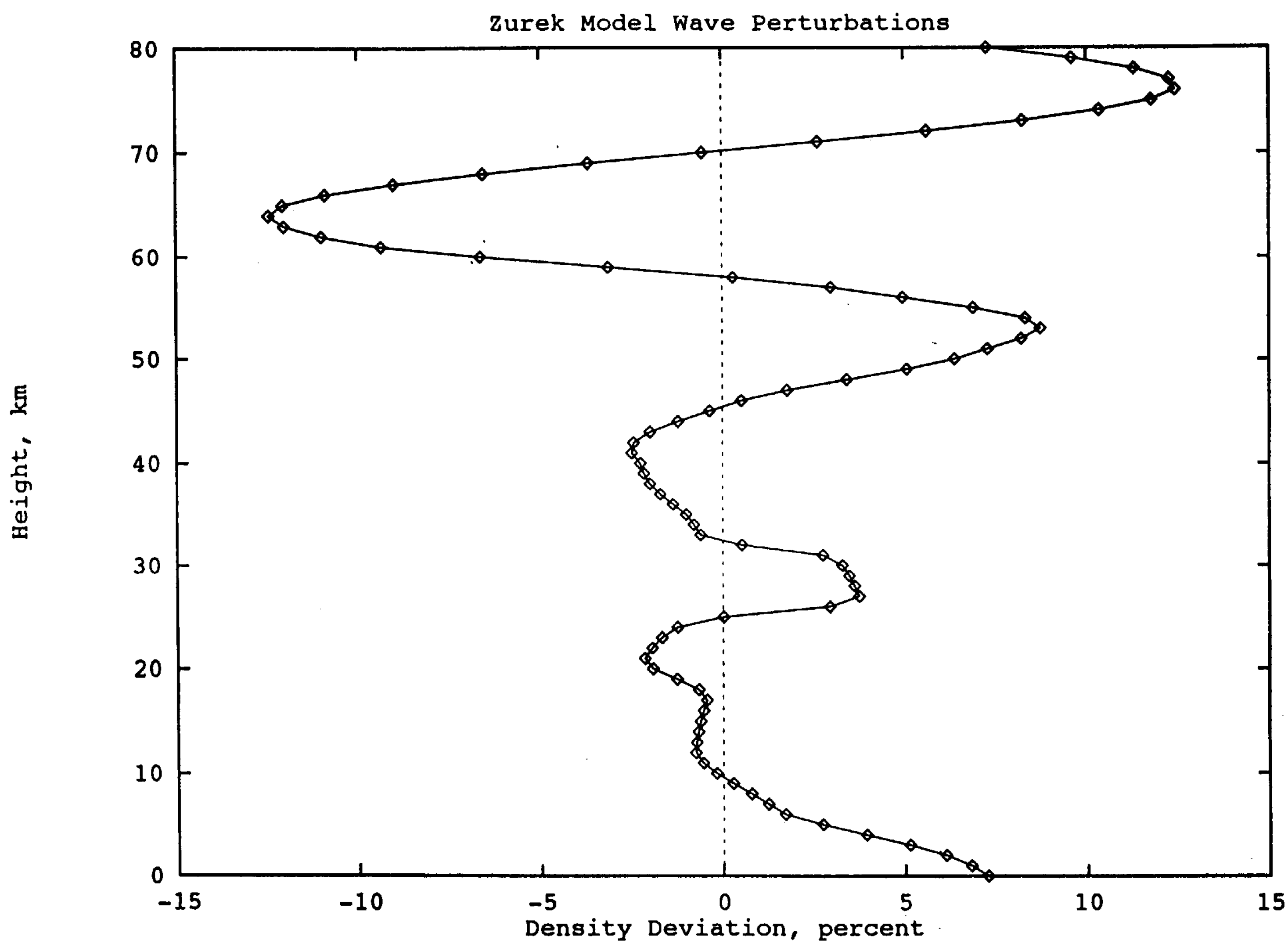

Figure 1 - Sample evaluation of the Zurek density wave perturbation model (based on temperature perturbation parameters in Pitts et al., 1988). Location and time corresponds to that of the Viking 1 Lander entry (22°N 48°W, 12:30 GMT on 7/20/76).

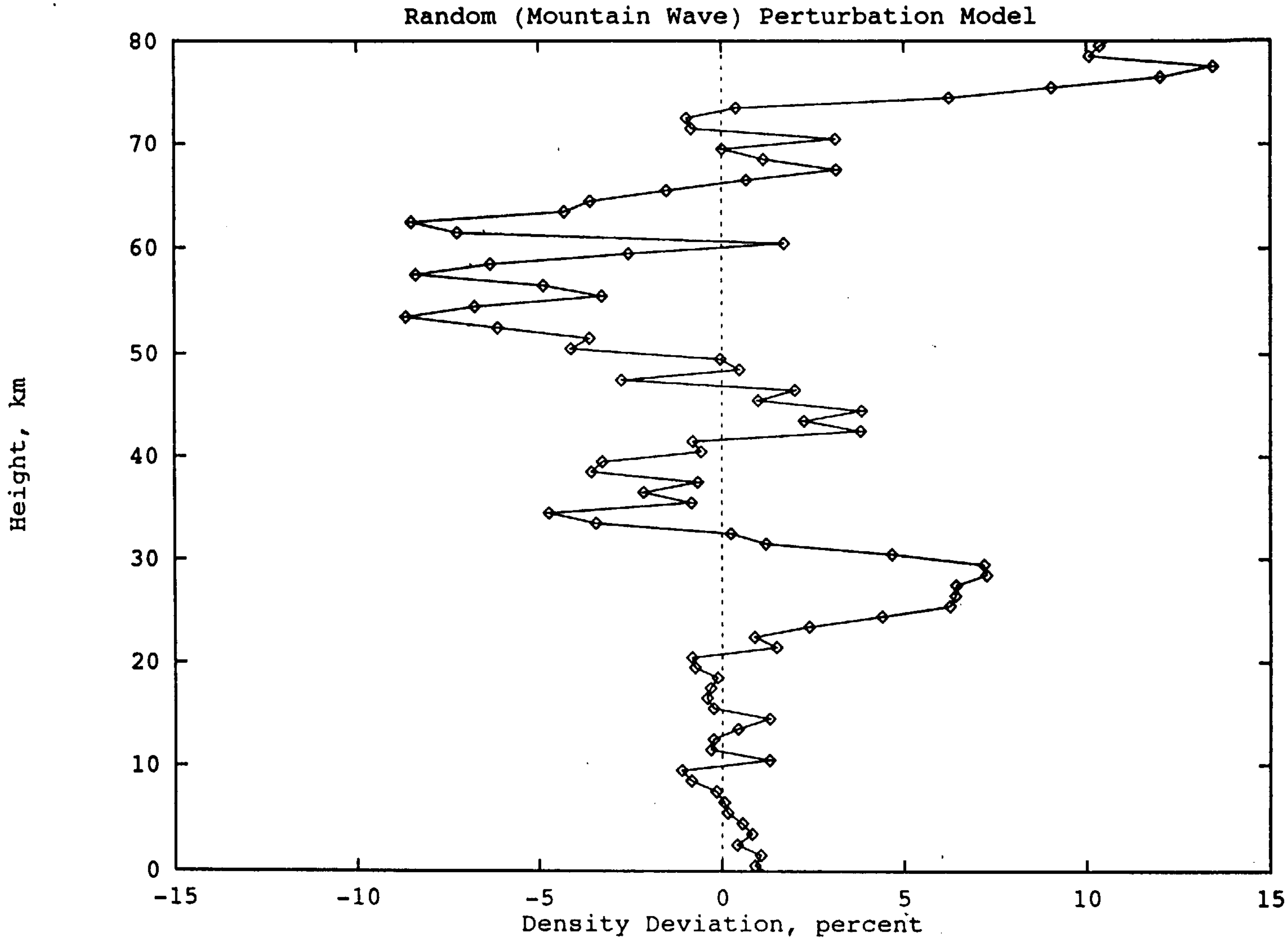

Figure 2 - Random (mountain-wave) perturbations in density, evaluated for the same location and time as in Figure 1.

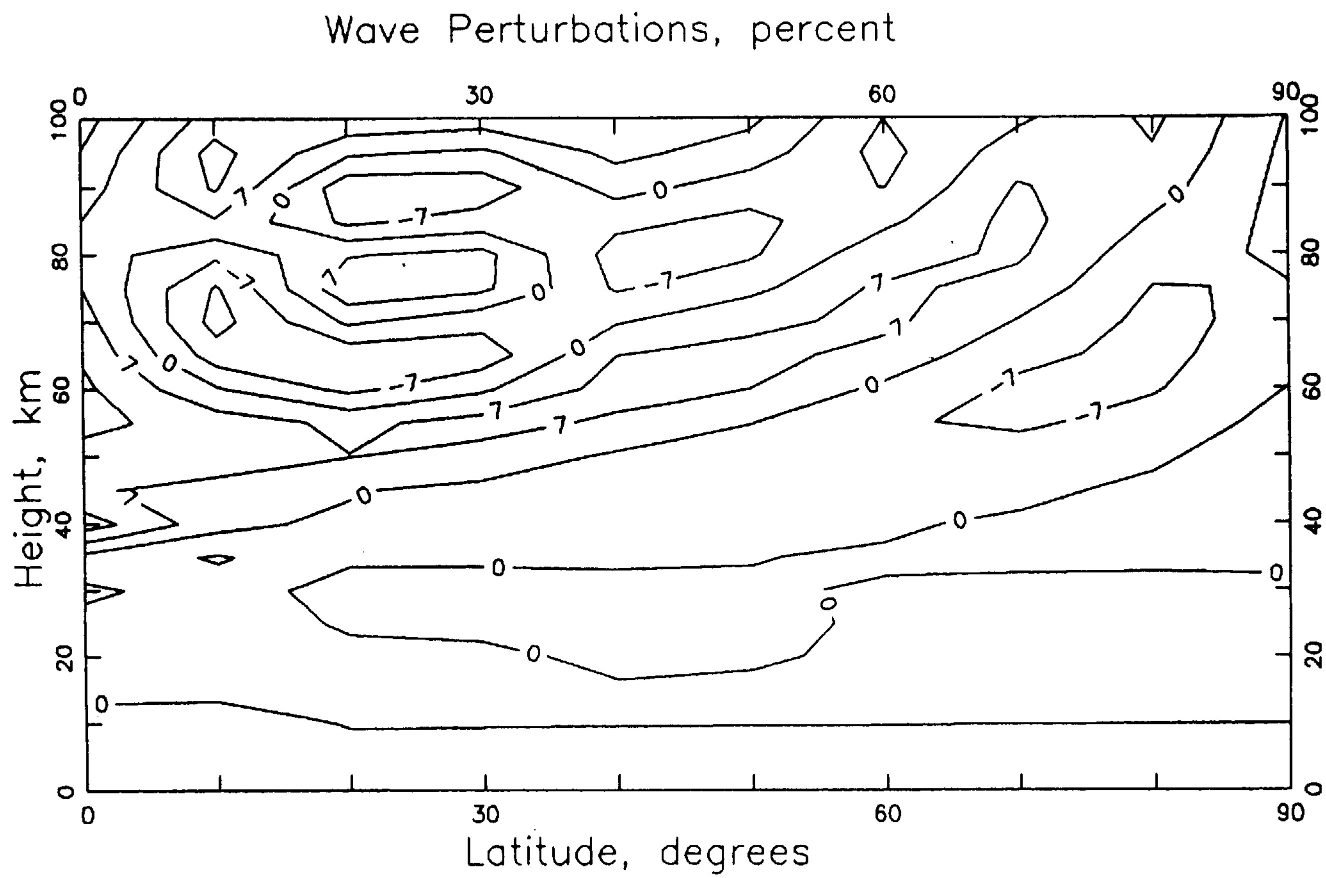

Figure 3 - Zurek density wave perturbations evaluated along a height-latitude cross section through the longitude 48°W at the time of the Viking 1 Lander entry.

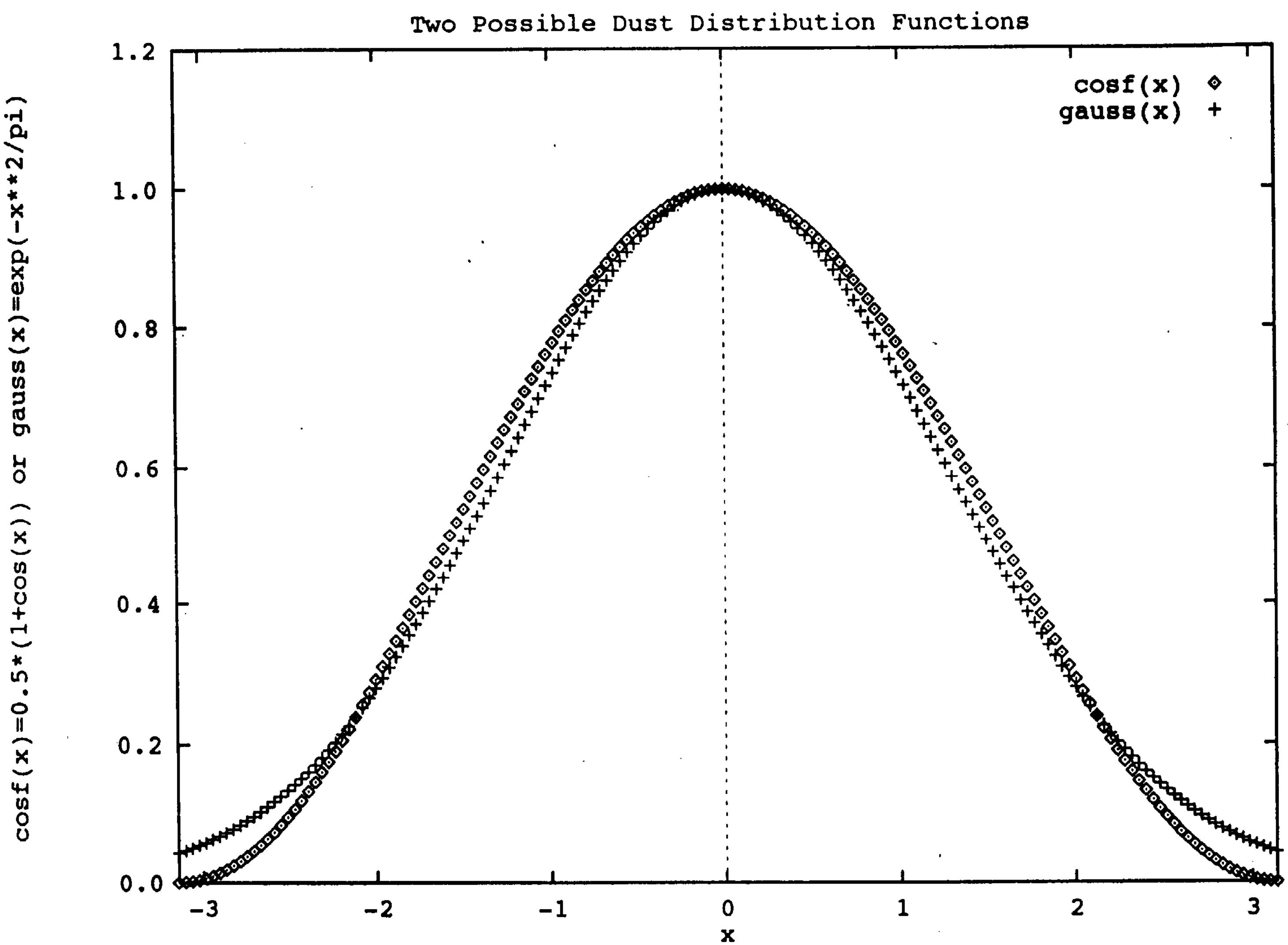

Figure 4 - Comparison of two possible spatial distribution model functions for local-scale dust storms. $cosf(x) = 0.5[1 + \cos(x)]$, for $-\pi \le x \le \pi$, with x in radians, and $gauss(x) = \exp(-x^2/\pi)$. The functions are normalized to 1 at x=0, with the area under cosf(x) from $-\pi \le x \le \pi$ the same as the area under gauss(x) from $-\infty \le x \le +\infty$.

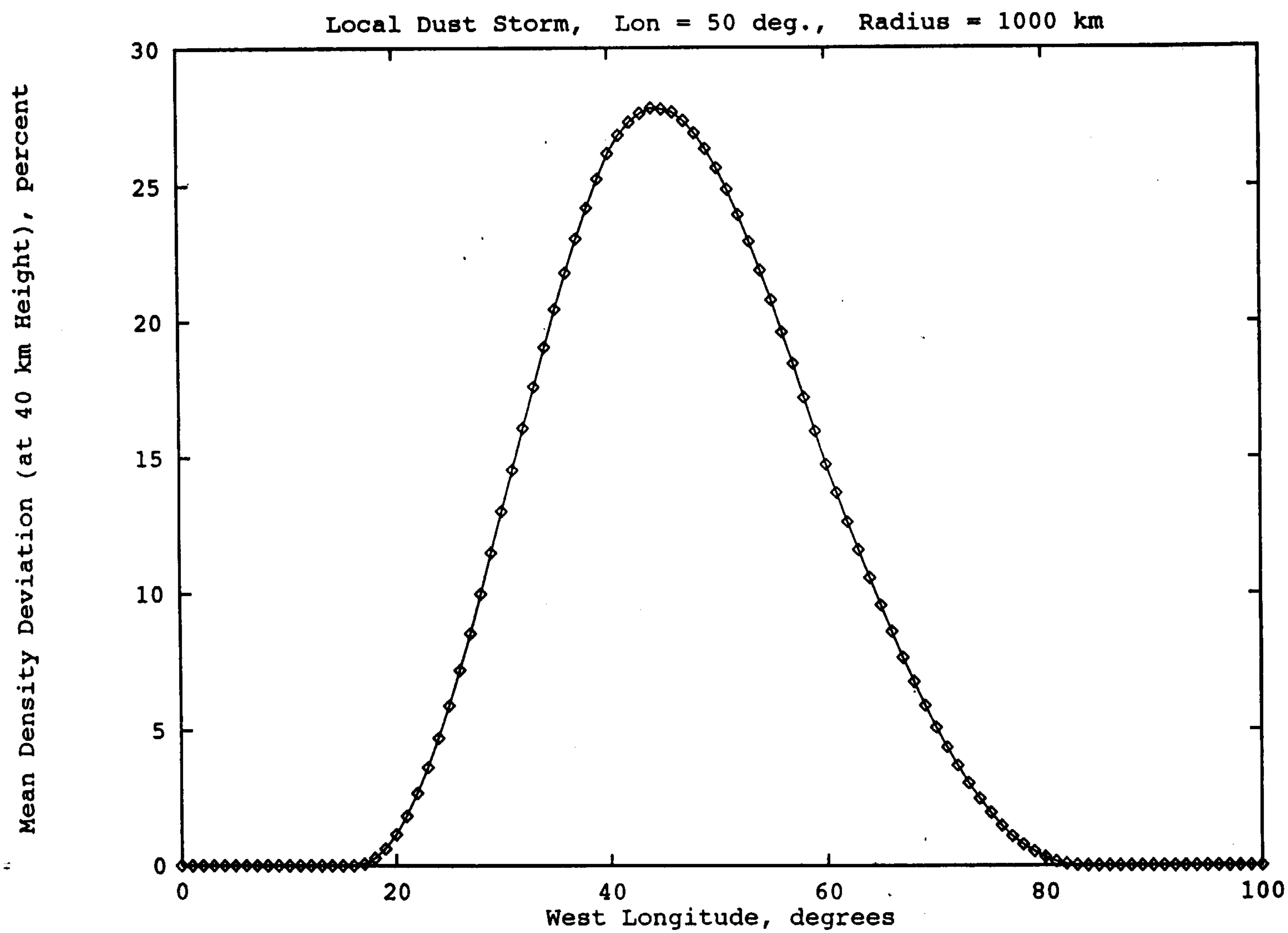

Figure 5 - The effect on mean atmospheric density due to a local dust storm of radius 1000 km, centered at 0°N, 50°W. Density was evaluated along a trajectory at a constant height of 40 km from 0°N, 0°W to 0°N, 100°W. Mean density deviations are in percent, relative to density in the non-dust storm case.