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Preface

The effort required for the preparation of this report was sponsored by the Mars Global Surveyor Project, through NASA Jet Propulsion Laboratory (Sam Dallas JPL Mission Manager), under project 215-000-042. Technical questions on the Mars-GRAM may be addressed to Dr. C. G. Justus, EL23/CSC, NASA Marshall Space Flight Center, Huntsville, Alabama 35812 (205-544-3260; e-mail jere@profiles.msfc.nasa.gov).

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1. Background

The Mars Global Reference Atmospheric Model (Mars-GRAM) was developed (Johnson et al., 1989; Justus 1990, 1991) as an engineering-oriented, empirical model of the Mars atmosphere. A complete history and description of the model, through version 3.34, was recently given in the Mars-GRAM programmer's guide (Justus et al., 1996). Mars-GRAM is based on surface and atmospheric temperature data observed during the Mariner (orbiter) and Viking (orbiter and lander) missions and on surface pressure data observed by the Viking landers. At the higher altitudes (above about 120 km), Mars-GRAM (through version 3.34) was based on the Stewart (1987) model for the global-mean thermosphere.

Mars-GRAM provides both mean and mountain-wave perturbed atmospheric density for any location (height, latitude, and longitude) and time (seasonal and diurnal). Other atmospheric variables provided include atmospheric temperature, pressure, and wind components. Dust storm effects are included for all atmospheric parameters controlled by user-selected options. The model also includes the option to simulate either local-scale or global-scale dust storms and density perturbations from tidal waves, computed by the Zurek wave model, Pitts et al. (1990?). Other recent features include (1) a limitation, based on atmospheric stability considerations, for the magnitude of the mountain-wave density perturbations, (2) comparisons of density, temperature, and pressure with the COSPAR reference atmosphere (Pitts et al., 1990?), and (3) a new method for estimating the diurnal range of the surface temperature based on the diurnal variability of the surface-absorbed solar energy. Technical descriptions of all these features are given in the programmer's guide (Justus et al., 1996).

The original Stewart (1987) thermospheric model, designed to estimate global mean conditions only, has two major shortcomings for use as the thermospheric portion of Mars-GRAM: (1) does not produce realistic variations of temperature and density with latitude and time of day (or longitude), (2) is not capable of providing realistic horizontal gradients of pressure, from which thermospheric winds are estimated. The additions to Mars-GRAM discussed here are designed to overcome these deficiencies.

Mars-GRAM was developed from parameterizations to atmospheric data observed by the Mariner (orbiter) and Viking (orbiter and lander) missions and thus, is representative of the Mars atmosphere during the 1970's. Recent observations by Clancy et al. (1990) indicate that, in response to atmospheric cooling as the dusty atmosphere has cleared in the last two decades, current Mars temperature profiles are distinctly cooler than those observed in the Viking era. Comparisons of Mars-GRAM 3.34 mid-latitude average temperature profiles with recent data from Clancy (provided by Rich Zurek, private communication), indicate about 20 K cooling in the 40-50 km height range, about 15 K at 20-30 km, but little change in the 5-10 km region. This temperature change could have significant effects on atmospheric density at high altitudes and, as pointed out by Clancy et al. (1990), is quite important in planning for Mars missions that involve aerobraking.

To accommodate these possible effects of climate shifts, Mars-GRAM version 3.4 allows the user to select climate modification factors for the temperature profile between the surface and 75 km. Additionally, the user may adjust at run time relevant values of the global mean thermosphere (exospheric temperature, and temperature and height of the base of the thermosphere).

Proper computations of variation with time of day depend on accurate estimates of longitude of the sub-solar point on the surface of Mars. In the original (1989) development of Mars-GRAM an empirical fit for sub-solar longitude versus time was derived from Mars ephemeris data for 1984 through 1988. This empirical fit was incorporated into the "ORBIT" subroutine. The original ORBIT subroutine used a time variation for sub-solar longitude based on a Fourier harmonic series with a basic period of 696 days. For Mars-GRAM version 3.4, we obtained (Myles Standish, Jet Propulsion Laboratory, private communication) a set of Mars ephemeris data from 1984 through 2003. A Fourier fit with this longer time series revealed that the sub-solar longitude was reproduced significantly better with two harmonic series, one with the basic period of the Mars orbit (687 days) and another with 777 days. This new, dual-period parameterization was incorporated into the ORBIT subroutine of Mars-GRAM 3.4.

2. Methods for Thermospheric Calculations

2.1 Overview of Thermospheric Model Methods

Five basic parameters are used to prescribe the height variation of pressure, density, and temperature in the Stewart (1987) thermospheric model: (1) pressure (PRESSF) at base of the thermosphere, assumed to be the fixed value 1.26 nanobars (1.26×10^{-4} N/m^2), (2) height (ZF) of base of the thermosphere, (3) temperature (TF) of base of the thermosphere, (4) exospheric temperature (TINF), and (5) a parameter (SCALE) that describes the height variation of temperature between base of the thermosphere and the exosphere. In the original Stewart thermospheric model, ZF, TF, TINF and SCALE are considered global average values dependent on either the 10.7-cm solar flux (F10.7) or the heliocentric distance of Mars from the Sun, in Astronomical Units (RAU). In the new thermospheric model, these parameters are also functions of latitude and time of day (longitude). Details of computation of the height variation of temperature, pressure, and density are identical to the original Stewart thermospheric model.

For an altitude (Z) above the base of the thermosphere of ZZF = Z - ZF, located where the radius of the Mars reference ellipsoid is R0 (and RF = R0 + ZF), the vertical temperature variation is computed by

```
YSC = ZZF * RF / (RF + ZZF)                                THRM108
TZ = TINF - (TINF - TF) * EXP(-YSC / SCALE)                THRM109
```

(Letters and number at the right are line numbers of the FORTRAN source code of the Mars-GRAM program.) Scale height (HH) and partial pressure (PRZ) for each thermospheric constituent are computed by

```
HH(I) = BK * TINF / (GF * DM(I)) / 1.0E5                        THRM111

PRZ(I) = PRESSF*FF(I)*EXP(-YSC/HH(I)-(SCALE/HH(I))*ALOG(TZ/TF)) THRM113
```

where FF is a fractional composition for each constituent. This fairly simple analytical expression for pressure variation can be used because the particular functional form assumed for temperature variation (code line THRM109) yields a closed-form solution for the vertical integral of the hydrostatic equation. Note that the decrease of gravity with height (inversely proportional to the square of radial distance) is explicitly accounted for in this hydrostatic integral solution (code line THRM113).

Density is computed from the total pressure (sum of the partial pressures) and temperature, using the perfect gas law relation. The problem of specifying temperature, pressure, and density at any height, latitude, time of day, time of year, and solar activity condition, becomes specifying dependence of ZF, TF, TINF, and SCALE on these factors.

2.2 Dependence on Heliocentric Distance and Solar Activity

A collection of thermospheric parameter estimates, observations and model results, is assembled in table 2.1. The data were collected and given in model results or measurement-model comparisons by Bougher et al. (1988, 1990, 1993) and Bougher (1995). All parameter values in table 2.1 are global mean conditions.

Table 2.1. Global mean values of thermospheric parameters from various measurements or model results [Bougher et al. (1988, 1990, 1993) and Bougher (1995)]. R is the heliocentric distance of Mars, TINF is exospheric temperature, TF and ZF are (respectively) the temperature and height of the base of the thermosphere, and SCALE is the height variation parameter for thermospheric temperature.

		10.7-cm Solar Flux					
Data Source	R(AU)	1 AU	Mars	TINF (K)	TF (K)	ZF (km)	SCALE (km)
Mariner 4	1.55	77	32			117	
Mariner 6-7	1.45	206	98	240	170	129	
Mariner 9 (primary)	1.48	110	50	220	160	123	
Mariner 9 (extended)	1.62	115	44			115	
Viking Lander 1	1.62	68	26	180	125	125	
Viking Lander 2	1.63	74	28	180	125	121	
Phobos (DMED)	1.53	150	64	215		125	
Phobos (DMAX)	1.67	150	54	200		115	
Phobos (DMIN)	1.38	150	79	230		135	
MTGCM, MGS97L	1.38	130	68	228	147	128	15.0
MTGCM, MGS98L	1.66	130	47	196	141	115	12.9
MTGCM, MANC00	1.53	150	64	229	147	122	14.6
MTGCM, MGS97T	1.40	80	41	185	139	127	12.4

Regression relations versus <u>both</u> heliocentric distance (R) and 10.7 cm solar flux at Mars (F10.7) were tested. The resulting best fit relationships to describe the variation of the global mean thermospheric parameters are the following:

$$\langle TINF \rangle = 156.3 + 0.9427\ F10.7 \qquad (2.1)$$

$$\langle ZF \rangle = 197.94 - 49.058\ R \qquad (2.2)$$

$$\langle TF \rangle = 113.7 + 0.5791\ F10.7 \qquad (2.3)$$

$$\langle SCALE \rangle = 8.38 + 0.09725\ F10.7 \qquad (2.4)$$

where the angle brackets denote global average values.

Figures 2.1 through 2.4 illustrate the regression relations (2.1) through (2.4) versus data from table 2.1. The example point (labeled VL-1) in each figure is the data point for the Viking 1 Lander (VL-1) case. The figures show the VL-1 point is reproduced fairly well for <TINF> and <TF> regressions, but the VL-1 point is a significant "outlier" in the <ZF> regression. Thus, in order for the model to reproduce specific cases, it may be necessary for the user to adjust the regression values by appropriate amounts (e.g., an increase of about 8 km in <ZF> to replicate the VL-1 case). Note that the VL-1 case was also a significant outlier in the regression plot Stewart (1987) derived for ZF versus heliocentric distance (from which he derived a 1/R regression relation for ZF). The user-input adjustment parameters (deltaTEX for exospheric temperature, and deltaTF and deltaZF for temperature and height of the base of the thermosphere) are discussed more fully below and in Appendix A.

The regression relation for global mean exospheric temperature [equation (2.1) and figure 2.1] gives exospheric temperatures significantly lower than the original Stewart regression. However, the new exospheric temperature regression is quite similar to the curve described by the lower boundary of the shaded portion of figure 9 of Bougher et al. (1990), which also applies to global mean exospheric temperature. [The middle and upper curves within the shaded area of Bougher's figure 9 are for mid-afternoon and dayside-mean exospheric temperatures, not global mean values.] Note that equation (2.3) implies a dependence of T_F on solar activity ($F_{10.7}$), rather than an orbital radius (R), as assumed by Stewart. Residual error from regression via equation (2.3) is 8.1 K (essentially the same as residual error from multiple regression against both $F_{10.7}$ and R). Residual error from regression against R alone (yielding $\langle T_F \rangle = 267.13 - 80.905\ R$) is 13.9 K. The physical reality of the dependence of T_F on $F_{10.7}$, implied by equation (2.3), is still being evaluated.

2.3 Dependence on Latitude, Sub-Solar Latitude, and Time of Day

Four sets of output from the Mars Thermospheric Global Circulation Model (MTGCM, Bouger et al., 1990) were used to derive the dependence of the thermospheric parameters on latitude, sub-solar latitude, and time of day. Parameterization relations for the various thermospheric parameters were derived and incorporated into a new subroutine (Thermpar, line numbers denoted TPAR, see Appendix A). The four MTGCM cases used were "MGS97L", "MGS98L", "MANC00" and "MGS97T"; characteristics are given in table 2.1.

In the subroutine Thermpar, the local (latitude and time of day dependent) value of exospheric temperature (TINF0, K) is computed from the global average value (<TINF> = Tbar) by the program steps:

```
C...  Zonal average exospheric temperature (K) versus latitude       TPAR 47
      Tavg = Tbar*(1. + 1.369E-4*sunlat*lat)                         TPAR 48
C...  Phase angles (hours) for local solar time variation            TPAR 49
      t1 = 13.2 - 0.00119*sunlat*lat                                 TPAR 50
      t2 = 9.4 - 0.00231*sunlat*lat                                  TPAR 51
C...  Amplitude factor for local solar time variation                TPAR 52
      cphi = Cos(pi180*(lat + sunlat)/(1. + LATMAX/90.))             TPAR 53
C...  Exospheric temperature (K) versus local solar time              TPAR 54
      TINF0 = Tavg*(1. + 0.22*cphi*Cos(pi180*15.0*(LST-t1)) +        TPAR 55
     &  0.04*cphi*Cos(pi180*30.0*(LST-t2)))                          TPAR 56
```

where "lat" is the local latitude (in degrees), "sunlat" is the latitude (in degrees) of the sub-solar point on the Mars surface, and "LST" is the local Mars solar time (in Mars hours = 1/24th sol).

Local height of the base of the thermosphere (ZF0 in km) is computed from the global average value (<ZF> = Zbar) by program steps:

```
C...   Latitude variation factor
       factlat = (sunlat/LATMAX)*(lat/77.5)**3
C...   Zonal average base height (km) versus latitude
       Zavg = Zbar + 4.3*factlat
C...   Amplitudes for local solar time variation
       A1 = 1.5 - Cos(pi180*4.0*lat)
       A2 = 2.3*(Cos(pi180*(lat + 0.5*sunlat)))**3
C...   Phase angles (hours) for local solar time variation
       t1 = 16.2 - (sunlat/LATMAX)*Atan(pi180*10.0*lat)
       t2 = 11.5
C...   Base height of thermosphere (km) versus local solar time
       ZF0 = Zavg + A1*Cos(pi180*15.0*(LST-t1)) +
     & A2*Cos(pi180*30.0*(LST-t2))
```

Local temperature (TF0, K) at the base height of the thermosphere is computed from its global average value (<TF> = Tbar), by subroutine steps:

```
C...   Zonal average temperature at thermosphere base (K) vs. latitude
       Tavg = Tbar*(1. + 0.186*factlat)
C...   Amplitudes for local solar time variation
       A1 = 0.06 - 0.05*Cos(pi180*4.0*lat)
       A2 = 0.1*(Cos(pi180*(lat + 0.5*sunlat)))**3
C...   Phase angles (hours) for local solar time variation
       t1 = 17.5 - 2.5*(sunlat/LATMAX)*Atan(pi180*10.0*lat)
       t2 = 10.0 + 2.0*(lat/77.5)**2
C...   Thermosphere base temperature (K) versus local solar time
       TF0 = Tavg*(1.0 + A1*Cos(pi180*15.0*(LST-t1)) +
     & A2*Cos(pi180*30.0*(LST-t2)))
```

The SCALE parameter does not depend significantly on time of day, so the global average value is simply adjusted for latitude dependence by program step:

```
C...   Zonal average temperature scale height (km) vs. latitude
       SCALE = SCALE*(1.14 - 0.18*Cos(pi180*lat))
```

Following computation of the local (latitude and time-of-day-dependent) thermospheric parameters by subroutine Thermpar, the values are adjusted for long-term and short-term variability via the "ES" array of the Stewart model for the effects of seasonal variations in surface pressure ("DR"), the effects of dust storms ("DUST"), and the user-selected adjustment parameters ("deltaZF" for the height of the base of the thermosphere, "deltaTEX" for exospheric temperature, and "deltaTF" for temperature at the base of the thermosphere). The adjustments are accomplished in the "STEWART2" subroutine as follows:

```
ZF = ZF0 * EXP(ES(8) + ES(9)) + DR + DUST + deltaZF            STW2 38

TINF = TINF0 * EXP(ES(2) + ES(3)) + deltaTEX                   STW2 46

TF = TF0 * EXP(ES(8) + ES(9)) + deltaTF                        STW2 47
```

The two ways to adjust thermospheric values are: (1) through input of "STDL", which controls the long-term variability by the Stewart ES parameters [ES(2) for TINF and ES(8) for ZF and TF], see section 6, and (2) through input of adjustment parameters deltaZF, deltaTEX, and deltaTF, see section 6. Short-term variability by the Stewart ES parameters [ES(3) for TINF and ES(9) for ZF and TF] are set automatically in the program, during computation of the high and low density perturbation magnitudes.

2.4 Revised Thermospheric Wind Calculations

Wind components in the Mars-GRAM thermospheric height region are computed as follows:

```
      VISCFAC = 0.04*VISC/(1.0E6*DENS*VLL**2)                  DSTP134a

      DENOM = CORIOL**2 + VISCFAC**2                           DSTP158
C...  Viscous-corrected areostrophic wind components           DSTP159
      EWWIND = (CORIOL*FUG - VISCFAC*FVG)/DENOM                DSTP160
      NSWIND =  (CORIOL*FVG + VISCFAC*FUG)/DENOM               DSTP161
```

where "VISC" is the coefficient of molecular viscosity, "DENS" is the atmospheric density, "VLL" is a vertical scale parameter, and "CORIOL" is the coriolis factor. At lower altitudes, where the viscosity effect is small, the eastward (northward) wind component ("EWWIND" or "NSWIND") becomes equal to the eastward (northward) areostrophic wind (on Earth called the geostrophic wind) component ("FUG" or "FVG"). The areostrophic wind blows parallel to isobars (lines of constant pressure). At higher altitudes, where the viscosity effect becomes dominant, the winds take on a significant cross-isobar component, with the viscous-corrected wind blowing perpendicular to the isobars (toward the low pressure side). In the thermosphere, isotherms (lines of constant temperature) tend to align somewhat with the isobars. Therefore, the viscous wind model above has significant components along the isotherms at lower thermospheric altitudes and significant cross-iostherm components at higher altitudes.

The only change in the viscous wind model for Mars-GRAM version 3.4 was to reduce the coefficient (line DSTP134a) from 1 to 0.04. In the original Stewart model, the pressure had extremely weak horizontal gradients (yielding weak areostrophic wind component estimates). With the realistic latitude-longitude variability for pressure that is now incorporated into the Mars-GRAM 3.4 thermospheric model, pressure gradients (and areostrophic winds) are much larger in the thermosphere and require the smaller coefficient on the viscosity term. The value of 0.04 was derived to reproduce as closely as possible the wind data in the four MTGCM cases used to derive the parameterizations for the other thermospheric variables.

3. Results from the New Thermospheric Model

Figures 3.1 and 3.2 compare plots of exospheric temperature versus latitude and time of day from the Mars Thermospheric Circulation Global Model (MTGCM) case MGS98L (see table 2.1 for characteristics of the model cases) with similar estimates from the new Mars-GRAM thermospheric model. Figures 3.3 and 3.4 show analogous comparisons between MTGCM case MGS97L and Mars-GRAM thermospheric temperatures.

Figure 3.4 also illustrates the wind vectors from the new thermospheric model and shows the expected strong cross-isotherm components, discussed in Section 2.4. Strong cross-isotherm components are also a feature of the upper levels of the MTGCM output (e.g. Bougher et al., 1990, figure 7a; Bougher et al., 1993, figure 4a).

Figures 3.5 and 3.6 illustrate the latitude versus time of day dependence of atmospheric density at a height intermediate between the base of the thermosphere and the exosphere (180 km), for the MTGCM case MGS98L. Figures 3.7 and 3.8 are comparable plots for MTGCM case MGS97L and Mars-GRAM new thermospheric model.

Figure 3.9 shows the MTGCM case MGS98L values of temperature (TF) at the base of the thermosphere versus latitude and time of day. Figure 3.10 is a plot from Mars-GRAM for temperature at a height of 130 km (near the base of the thermosphere) and for the time corresponding to the MGS97L case. Figure 3.10 also shows the wind components derived from Mars-GRAM, and illustrates the expected significant along-iostherm components. Figure 3.11 illustrates the latitude and time of day dependence for the height of the base of the thermosphere (ZF) for MTGCM case MGS97L.

Characteristics of the new thermospheric model in Mars-GRAM are to have a predominant wave-one (one wavelength per 360 degrees of longitude) component for exospheric temperature, but a predominant wave-two component, especially at low latitudes, for the temperature and height of the base of the thermosphere. These features can be seen as general characteristics of the MTGCM data (in figures 3.1, 3.3, 3.5, 3.9 and 3.11). Although Mars-GRAM cannot reproduce the effects of components with wave numbers higher than two, the effects are evident in the MTGCM results. General features of latitude versus time of day variation of the MTGCM results are considered to be adequately represented by the new Mars-GRAM thermospheric model.

Figures 3.12 and 3.13 compare the height versus time of day behavior for MTGCM case MGS97L and Mars-GRAM. The general structure of the MTGCM results is reproduced in the Mars-GRAM plot.

4. The New Sub-Solar Longitude Model

Regular publication of latitude and longitude of the sub-solar point on the Mars surface began in 1984. Consequently, when Mars-GRAM was originally developed in 1989, the time series of longitude for the sub-solar point on Mars was limited to the time period 1984-1988. Mars ephemeris data are now available in computer-readable form from the Jet Propulsion Laboratory (JPL). The available data include not only prior time periods, but also projections for a number of years into the future. A set on Mars longitudes for the sub-solar point for 1984 through 2003 was constructed by making use of this JPL data (sent to us via electronic file transfer by Myles Standish of JPL).

From the limited (1984 to 1988) time series, it was apparent that the sub-solar longitude has a significant contribution from periods longer than the Mars orbit period (687 days). An empirical Fourier harmonic fit (with three harmonic terms) and a basic period of 696 days was used in the original Mars-GRAM version. This procedure is retained through Mars-GRAM version 3.34. However, it was recently noticed (Penny Niles, Lockheed Martin) that for the years near the end of this century, the sub-solar longitude values from Mars-GRAM could be in error by several degrees.

With the longer time series (1984 to 2003) a new harmonic fit showed that the sub-solar longitude variations are much better reproduced by a (three harmonic) Fourier series with two basic periods. The two periods in the new parameterization are 687 days (the fundamental period of the Mars orbit) and 777 days. The new relations reproduce sub-solar longitude values within a few tenths of a degree over the data series. This accuracy is comparable to frequently-used methods to compute the solar position from Earth using the day of the year as input. For leap year versus non-leap year variations, methods using day of the year input are accurate to a few tenths of a degree.

Details of the new calculations for sub-solar longitude are seen in program changes for the ORBIT subroutine in Appendix A.

5. New Climate Adjustment Parameters

Mars-GRAM was developed from parameterizations to atmospheric data observed by the Mariner (orbiter) and Viking (orbiter and lander) missions and represented the Mars atmosphere during the 1970's. Recent observations by Clancy et al. (1990) indicate, in response to atmospheric cooling as the dusty atmosphere has cleared in the last two decades, that current Mars temperature profiles are distinctly cooler than those observed in the Viking era. Comparisons between Mars-GRAM 3.34 mid-latitude average temperature profiles with recent data from Clancy (provided by Rich Zurek, private communication), indicate about 20 K cooling in the 40-50 km height range, about 15 K at 20-30 km, but little change in the 5-10 km altitude region. This temperature change could have significant effects on atmospheric density at high altitudes, and, as pointed out by Clancy et al. (1990), is quite important in planning for Mars missions that involve aerobraking.

The temperature profiles in Mars-GRAM are built from parameterizations that estimate temperatures at significant levels (0, 5, 15, 30, 50 and 75-km altitudes). To allow user-controlled input incorporating the effects of temperature changes since the Viking era, a set of climate factor values may be input to Mars-GRAM version 3.4. These factors, specified by values of the climate adjustment factors (CF array), are multiplicative factors that alter temperatures derived from the original parameterizations in Mars-GRAM. For example, if all temperature values (from surface to 75 km) are to be increased by 10%, use values of 1.1 for all CF array elements. For a decrease of all temperatures by 10% use CF values of 0.9. Separate CF values may be selected at each significant level altitude (see section 6).

After the effects of the climate factor array are included in the temperature estimates, effects on the pressure and density variations with altitude are then computed by applying the hydrostatic balance equation and perfect gas law to the temperature profile values.

Together with adjustment parameters for the thermospheric variables (deltaTEX, deltaTF, and deltaZF), the climate adjustment factors now allow maximum flexibility in adjusting Mars-GRAM results to reproduce the temperature, pressure, and density expected under any specific simulation case. Appendix A lists all changes in the program code required to incorporate the new climate change factors.

6. Revised Program Execution Procedures

Operation of the interactive form of Mars-GRAM is unchanged. Note however, that input values for the climate adjustment factors (CF array) and thermospheric adjustment parameters are not accepted by the interactive form (only default values of CF = 1 and deltaTEX = deltaTF = deltaZF = 0 are allowed in interactive mode).

In the batch form of Mars-GRAM, input is provided via the NAMELIST file INPUT. The complete set of values for the reference INPUT file is as follows:

```
$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    = 76,        ! year (4-digit; 1970-2069 can be 2-digit)
 NPOS     = 11,        ! max # positions to evaluate (0 = read from TRAJDATA)
 IHR      = 12,        ! GMT hour of day
 IMIN     = 30,        ! minute of hour
 SEC      = 0.0,       ! second of minute (for initial position)
 ALS0     = 0.0,       ! starting Ls value (degrees) for dust storm (0 = none)
 INTENS   = 0.0,       ! dust storm intensity (0.0 - 3.0)
 RADMAX   = 0.0,       ! max. radius (km) of dust storm (0 or >10000 = global)
 DUSTLAT  = 0.0,       ! latitude (deg) for center of dust storm
 DUSTLON  = 0.0,       ! West longitude (deg) of 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    = 1,         ! 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,         ! 0=linear scale, 1=log scale, 2=COSPAR % deviations
 FLAT     = 22.0,      ! initial latitude (N positive), degrees
 FLON     = 48.0,      ! initial longitude (West positive), degrees
 FHGT     = -0.5,      ! initial height (km), above ref. ellipse
 DELHGT   = 10.0,      ! height increment (km) between steps
 DELLAT   = 0.0,       ! latitude increment (deg) between steps
 DELLON   = 0.0,       ! West longitude increment (deg) between steps
 DELTIME  = 0.0,       ! time increment (sec) between steps
 CF0      = 1.0        ! climate adjustment factor at surface
 CF5      = 1.0        ! climate adjustment factor at 5 km
 CF15     = 1.0        ! climate adjustment factor at 15 km
 CF30     = 1.0        ! climate adjustment factor at 30 km
 CF50     = 1.0        ! climate adjustment factor at 50 km
 CF75     = 1.0        ! climate adjustment factor at 75 km
 deltaZF  = 0.0        ! adjustment for base of thermosphere (km)
 deltaTF  = 0.0        ! adjustment for temperature at height ZF (K)
 deltaTEX = 0.0        ! adjustment for exospheric temperature (K)
$END
```

The newly required inputs are CF0 through CF75 (climate adjustment factors at significant levels 0, 5, 15, 30, 50 and 75 km) and the thermospheric adjustment parameters (deltaZF for base height of the thermosphere, deltaTF for temperature of the base of the thermosphere, and deltaTEX for the exospheric temperature).

A new feature of Mars-GRAM is that values of the input parameters are needed as input into the NAMELIST INPUT files only if they differ from the default values listed above. Thus, the output for the above reference case is generated by using an empty INPUT file, namely,

```
$INPUT
$END
```

The reference LIST output file for the reference input case above is given in Appendix B and contains values for latitude and longitude of the sub-solar point, the heliocentric distance (Mars orbital radius), and if the altitude is above 75 km, the local exospheric temperature and the local height and temperature of the base of the thermosphere.

7. References

1. Bougher, S.W., et al. (1988): "Mars Thermospheric General Circulation Model: Calculations for the Arrival of Phobos at Mars", _Geophys. Res. Let.,_ _15_(13), 1511-1514.

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3. Bougher, S.W. et al. (1990): "The Mars Thermosphere: 2. General Circulation with Coupled Dynamics and Composition", _Jour. Geophys. Res.,_ _95_(B9), 14,811-14,827.

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5. Clancy, R.T., D.O Muhleman and G.L. Berge (1990): "Global Changes in the 0-70 km Thermal Structure of the Mars Atmosphere Derived from 1975 to 1989 Microwave CO Spectra", _J. Geophys. Res._, _95_(B9), 14,543-14,554.

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8. Justus, C.G. (1991): "Mars Global Reference Atmospheric Model for Mission Planning and Analysis", _J. Spacecraft and Rockets_, _28_(2), 216-221.

9. Justus, C.G., Bonnie F. James and Dale L. Johnson (1996): "Mars Global Reference Atmospheric Model (Mars-GRAM version 3.34): Programmer's Guide", NASA TMX XXXX, April, 1996.

10. Pitts, David E. et al. (1990?): "The Mars Atmosphere: Observations and Model Profiles for Mars Missions, NASA JSC-24455.

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, 52 pp.

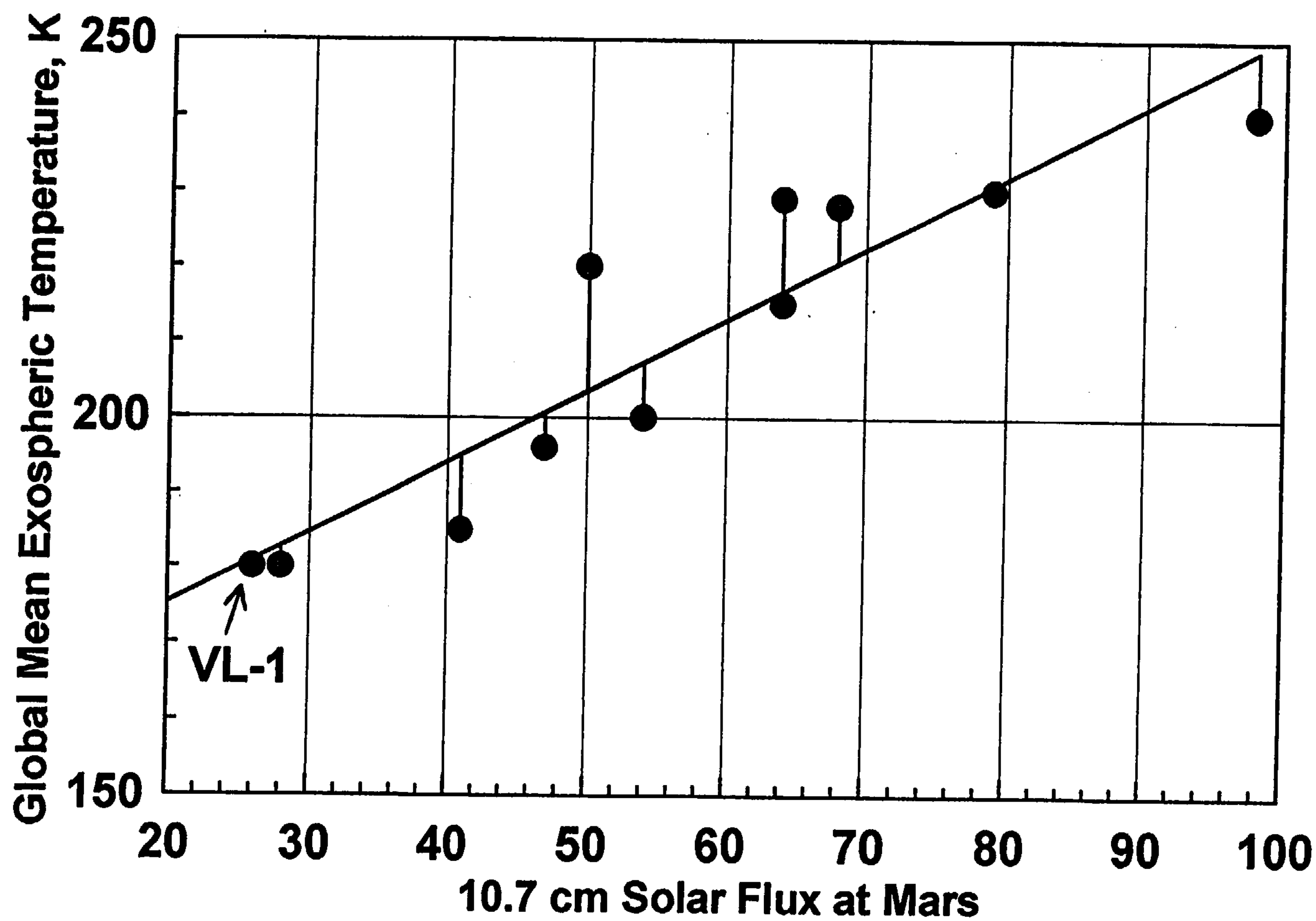

Figure 2.1. Global mean exospheric temperature (K), versus 10.7 cm solar flux. Data are from Table 2.1. The regression line is equation (2.1).

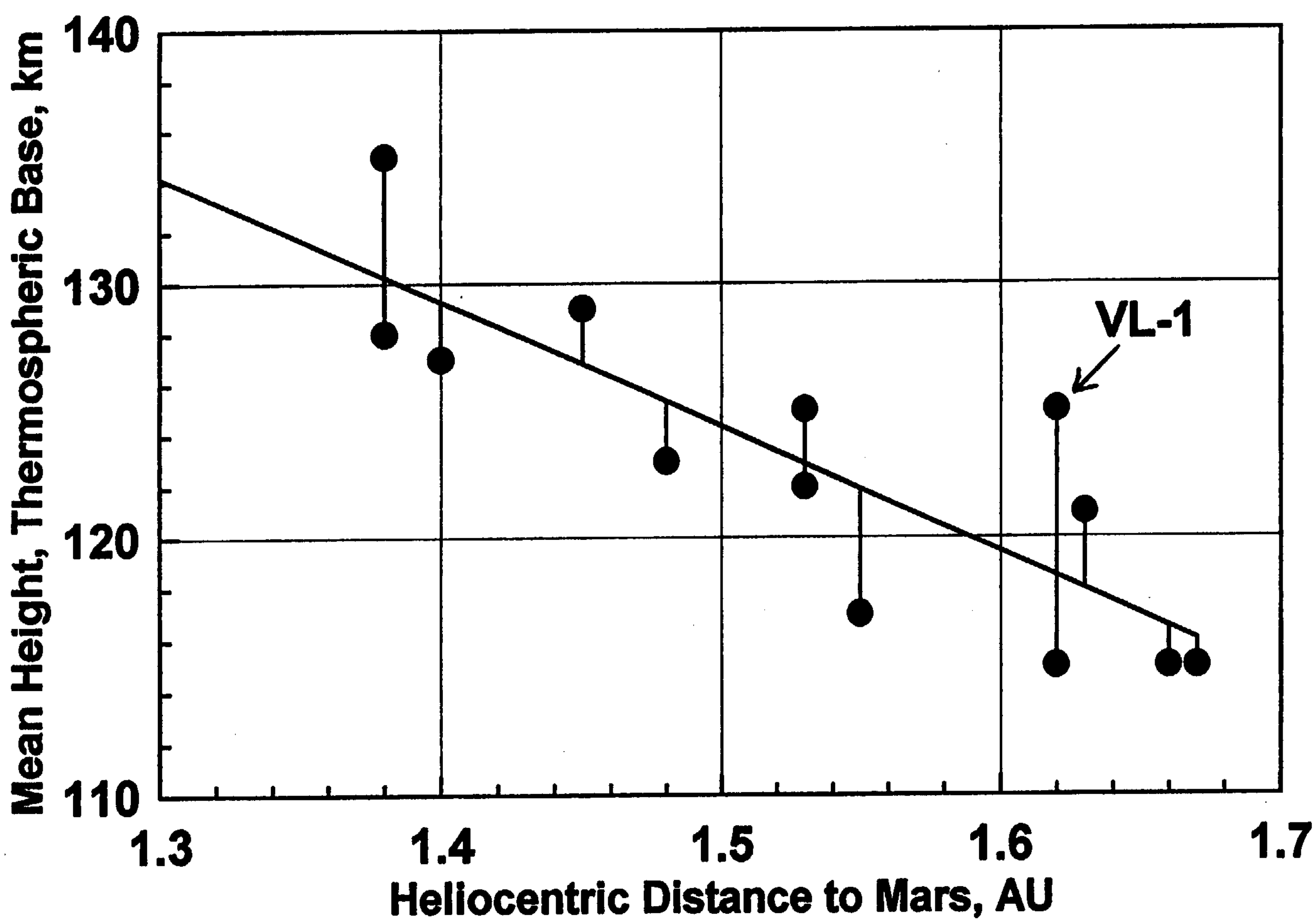

Figure 2.2. Global mean height (km) of the base of the thermosphere, versus heliocentric distance. Data are from Table 2.1. The regression line is equation (2.2).

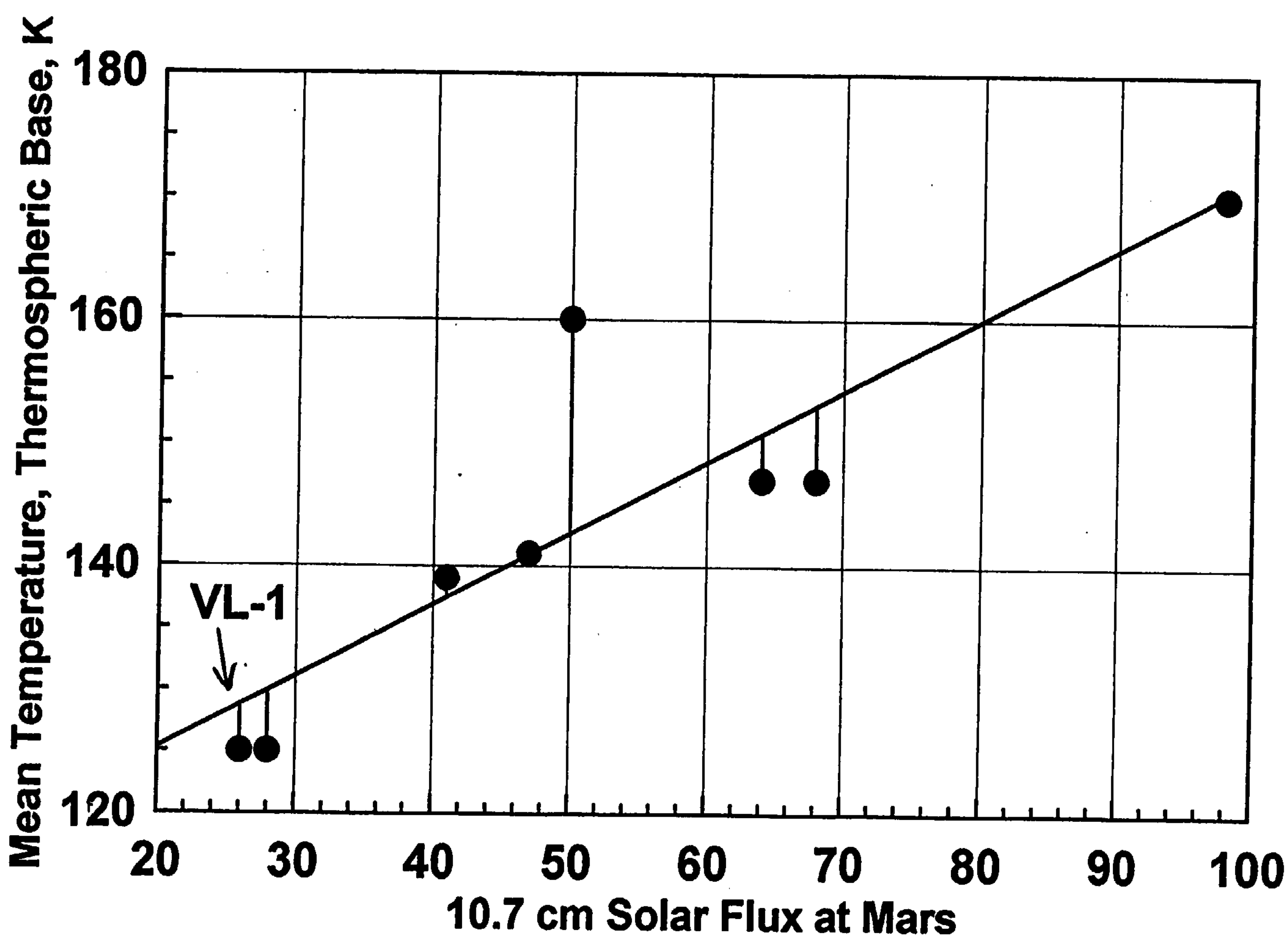

Figure 2.3. Global mean temperature (K) at the base of the thermosphere, versus 10.7 cm solar flux. Data are from Table 2.1. The regression line is equation (2.3).

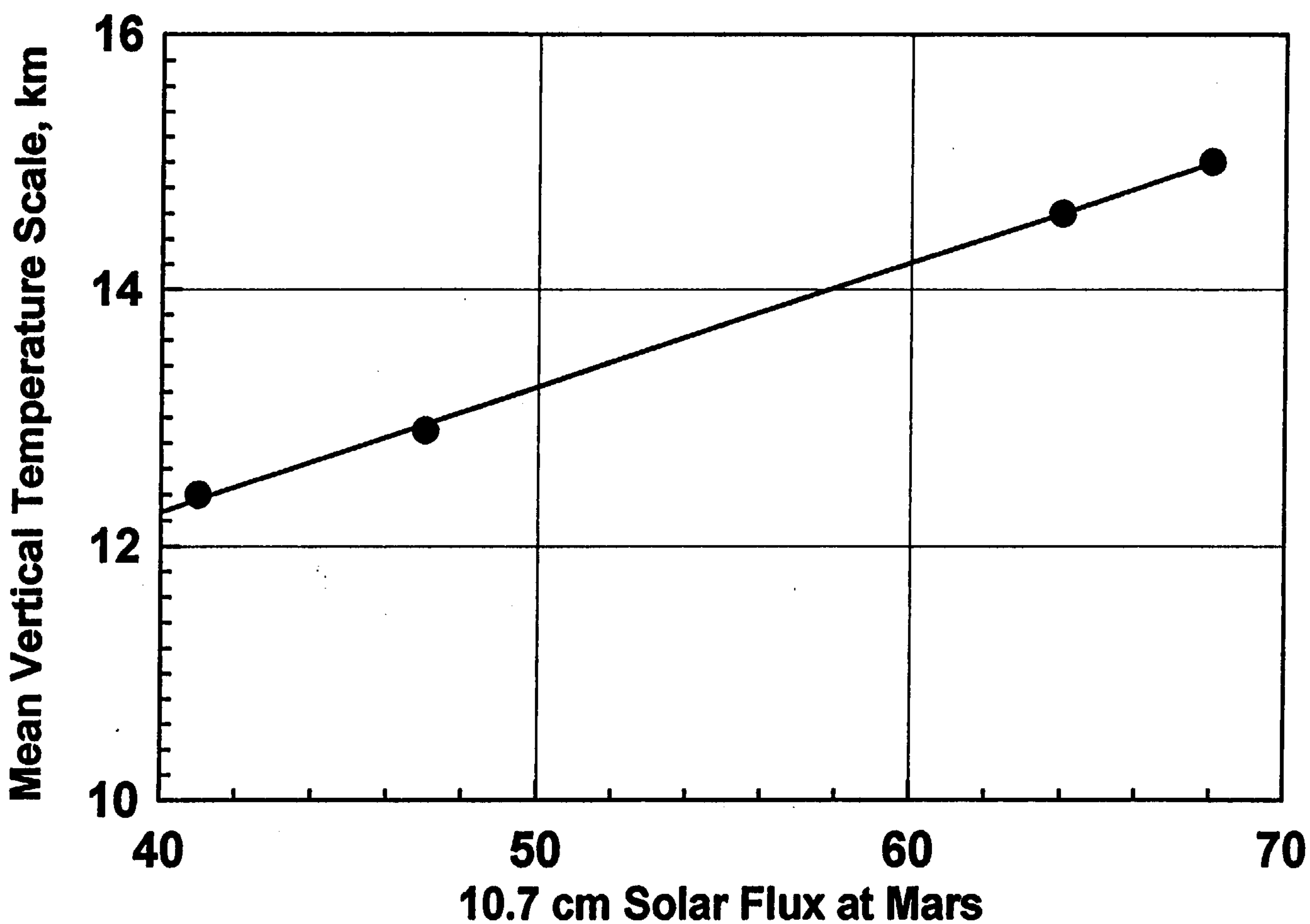

Figure 2.4. Global mean vertical thermospheric temperature scale (km), versus 10.7 cm solar flux. Data are from Table 2.1. The regression line is equation (2.4).

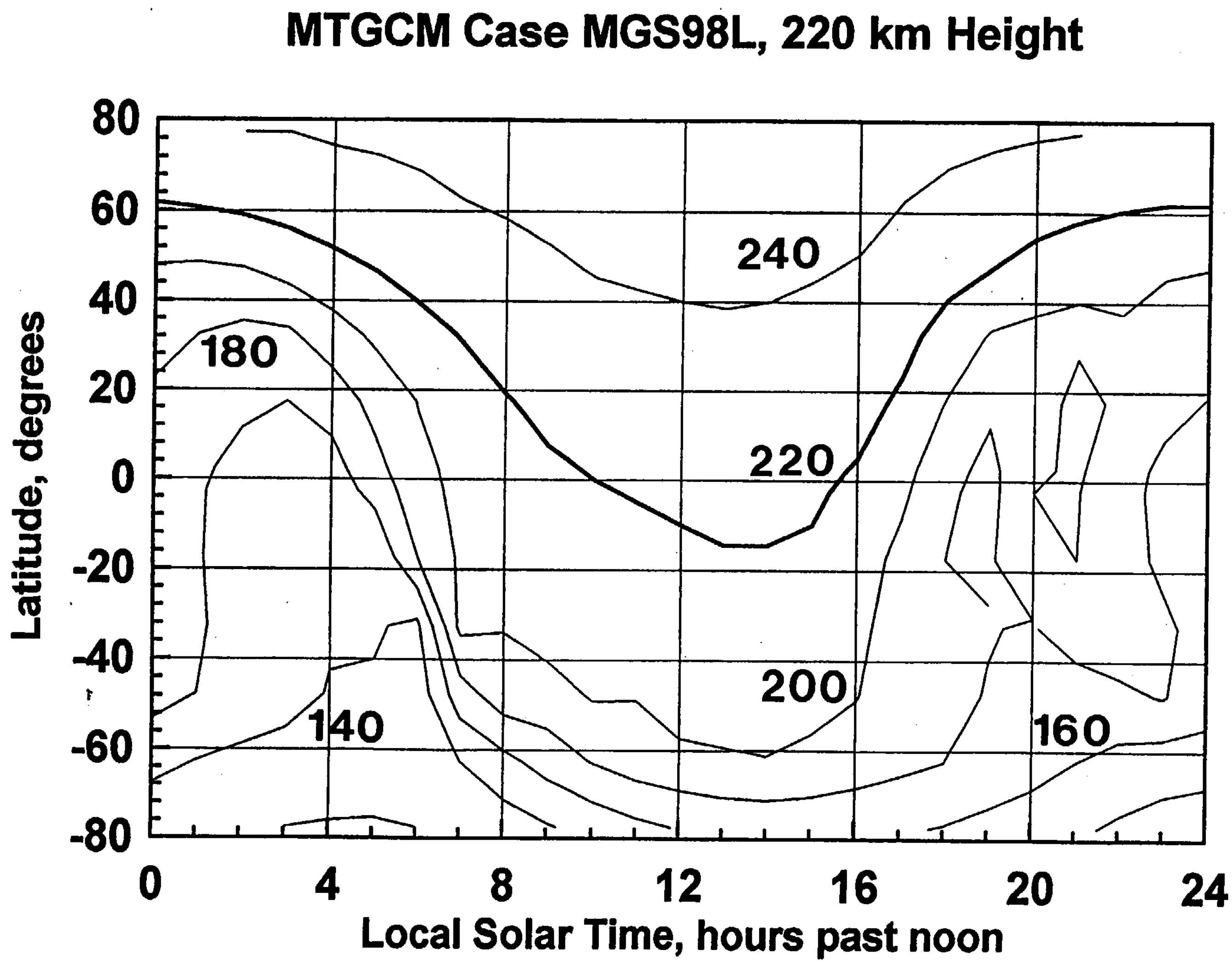

Figure 3.1. MTGCM model exospheric temperature (K) versus latitude and time of day for model case MGS98L. See Table 2.1 for values of model case parameters.

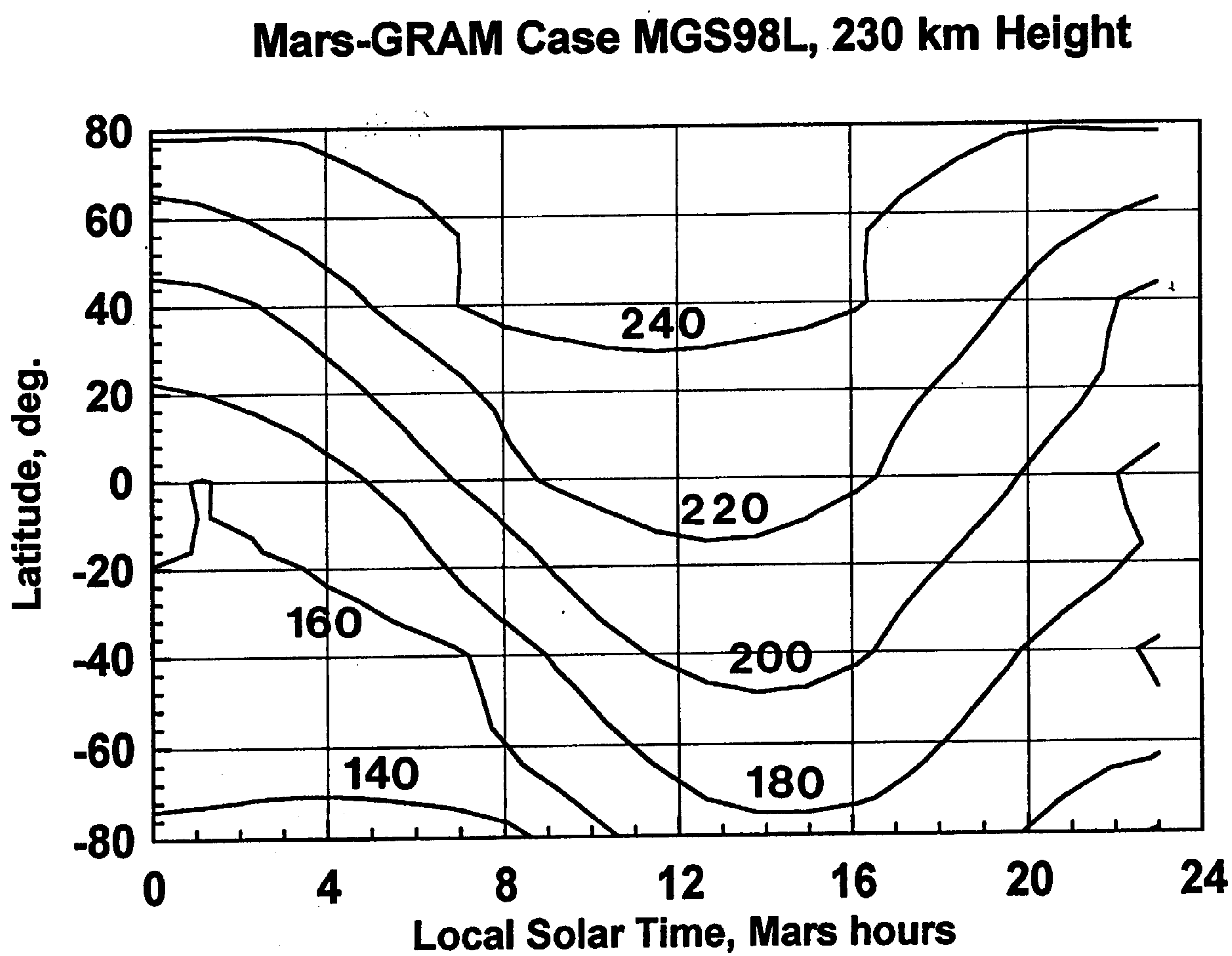

Figure 3.2. Mars-GRAM model exospheric temperature (K) versus latitude and time of day for model case MGS98L. See Table 2.1 for values of model case parameters.

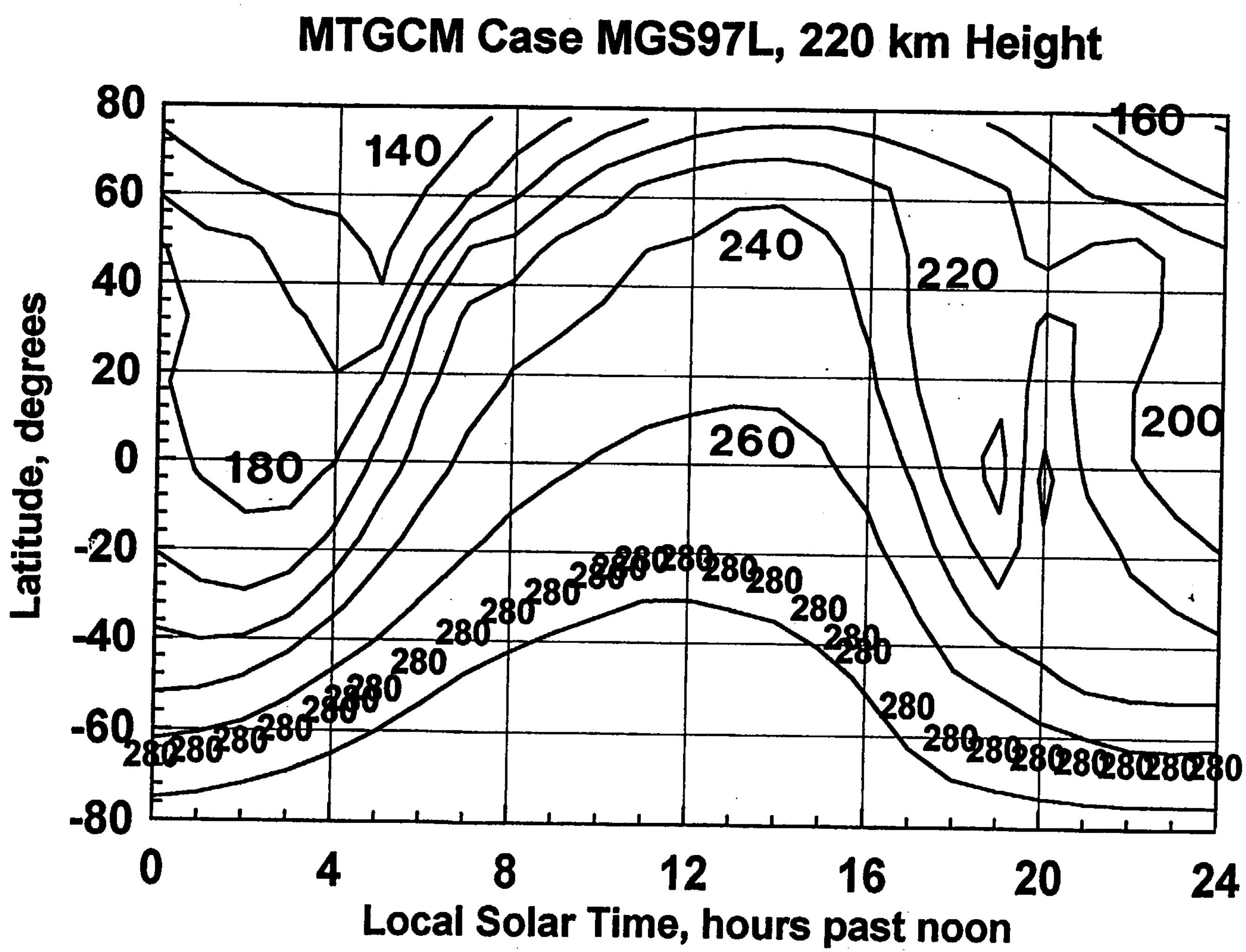

Figure 3.3. MTGCM model exospheric temperature (K) versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters.

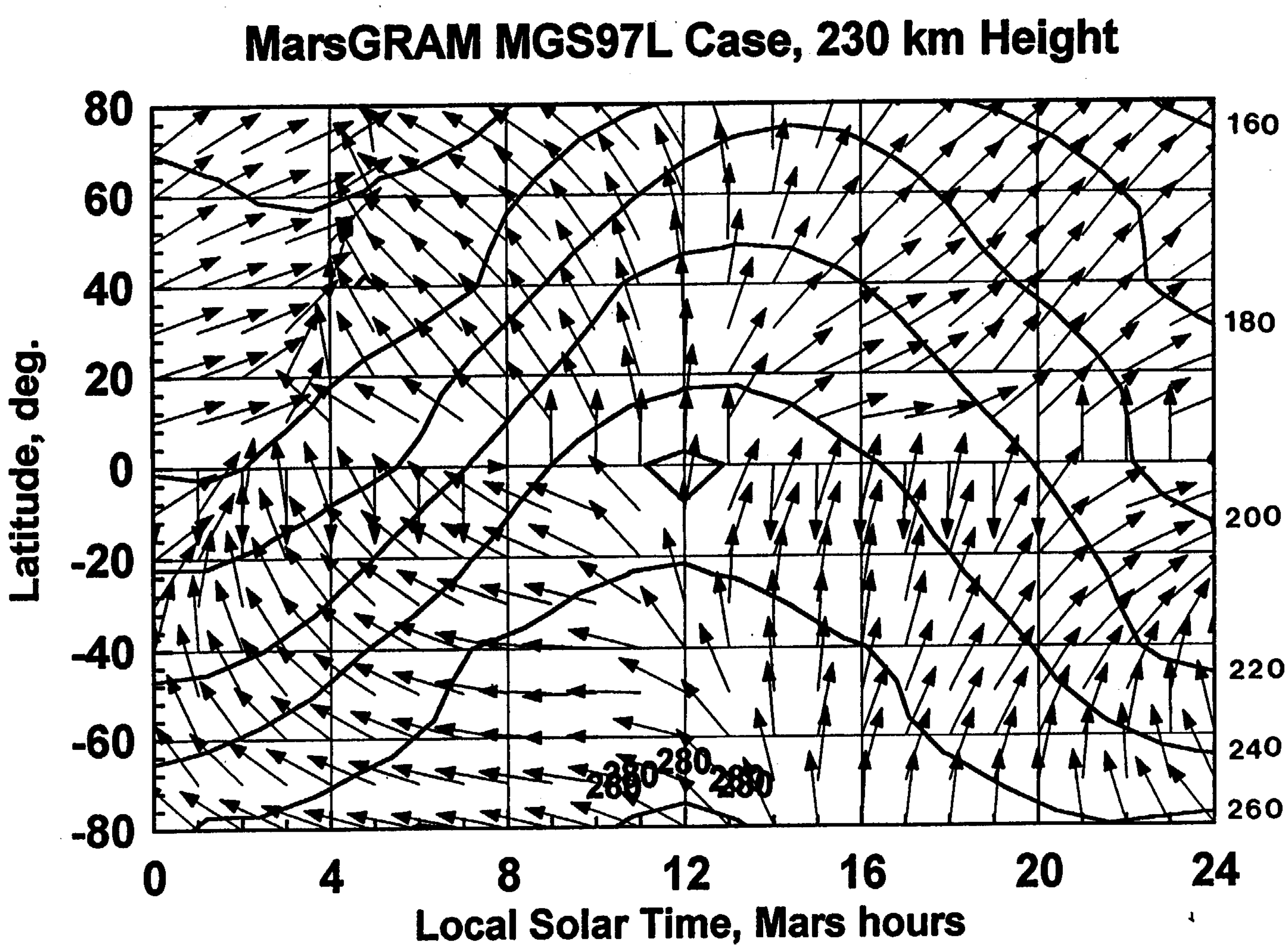

Figure 3.4. Mars-GRAM model exospheric temperature (K) versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters. Wind speed vectors range from 0 to 129 m/s.

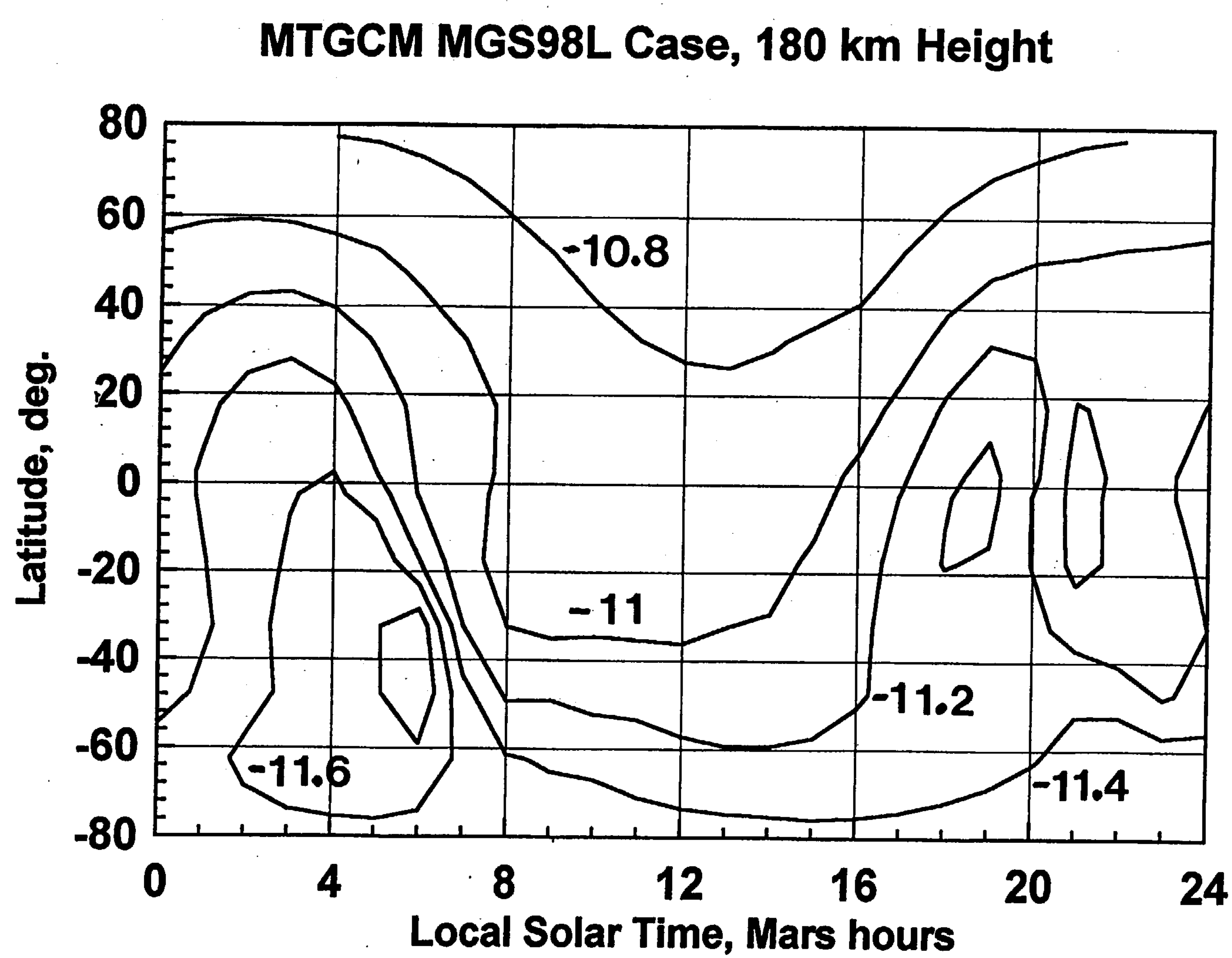

Figure 3.5. MTGCM model density (log-base-10, kg/m^3) at 180 km height, versus latitude and time of day for model case MGS98L. See Table 2.1 for values of model case parameters.

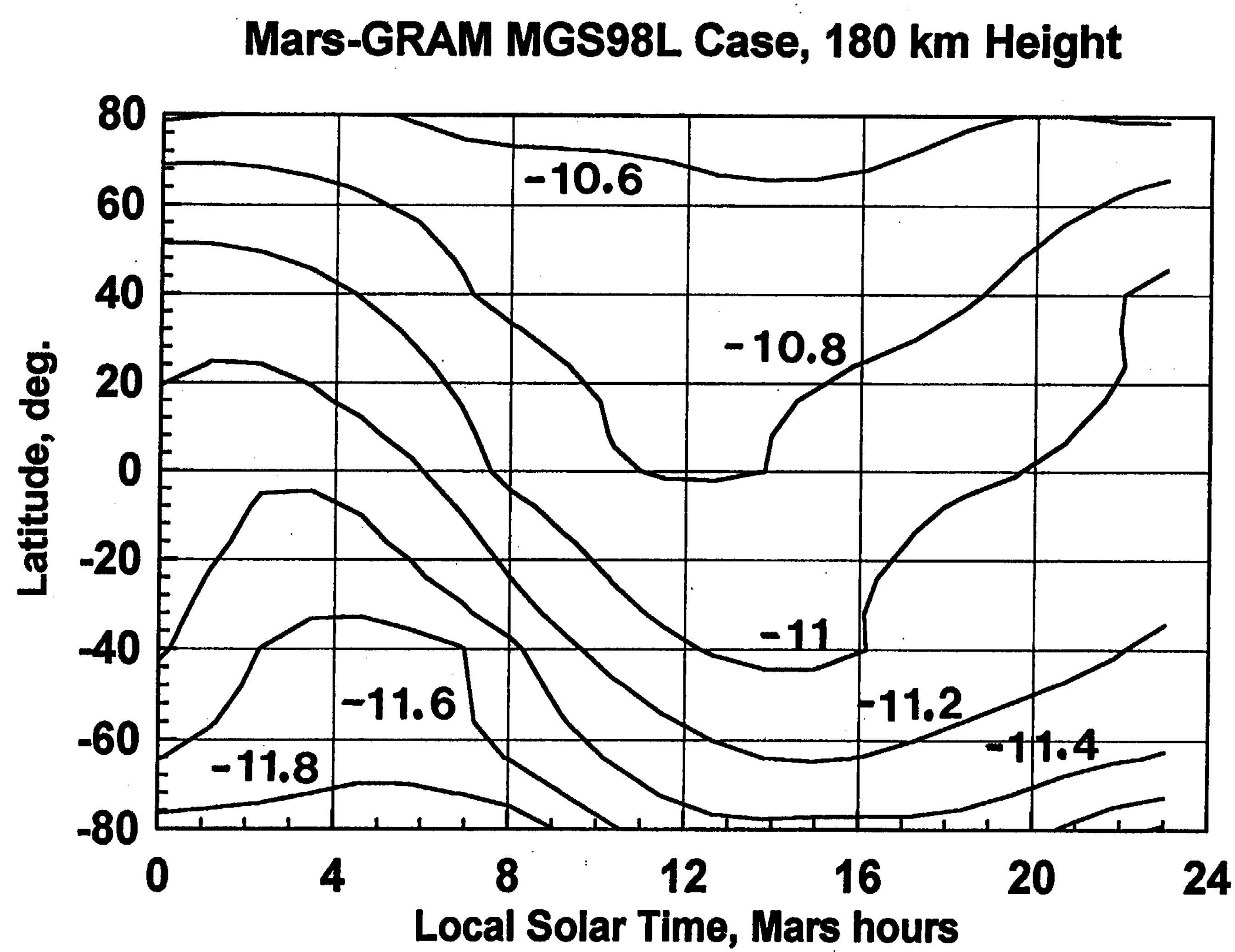

Figure 3.6. Mars-GRAM model density (log-base-10, kg/m^3) at 180 km height, versus latitude and time of day for model case MGS98L. See Table 2.1 for values of model case parameters.

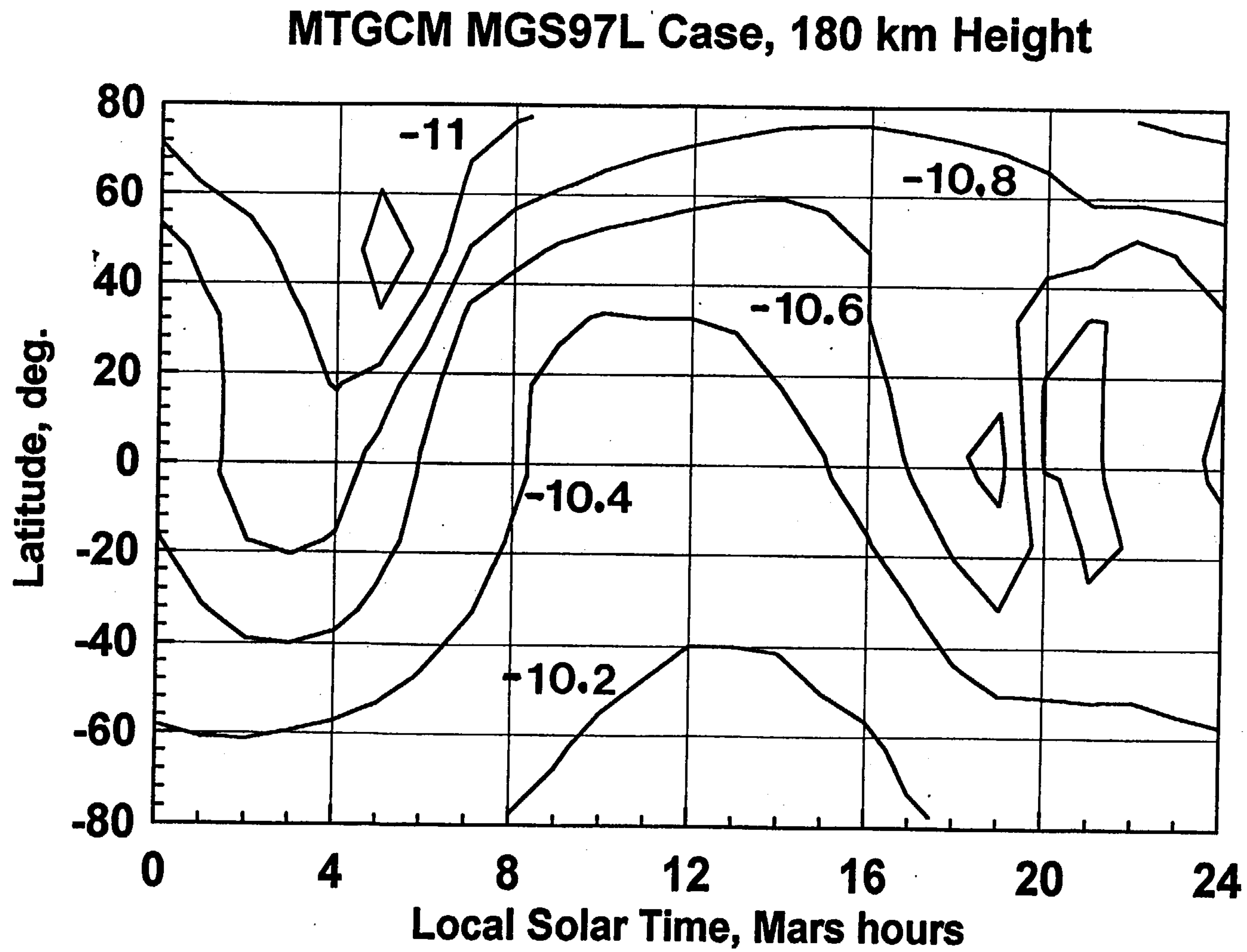

Figure 3.7. MTGCM model density (log-base-10, kg/m^3) at 180 km height, versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters.

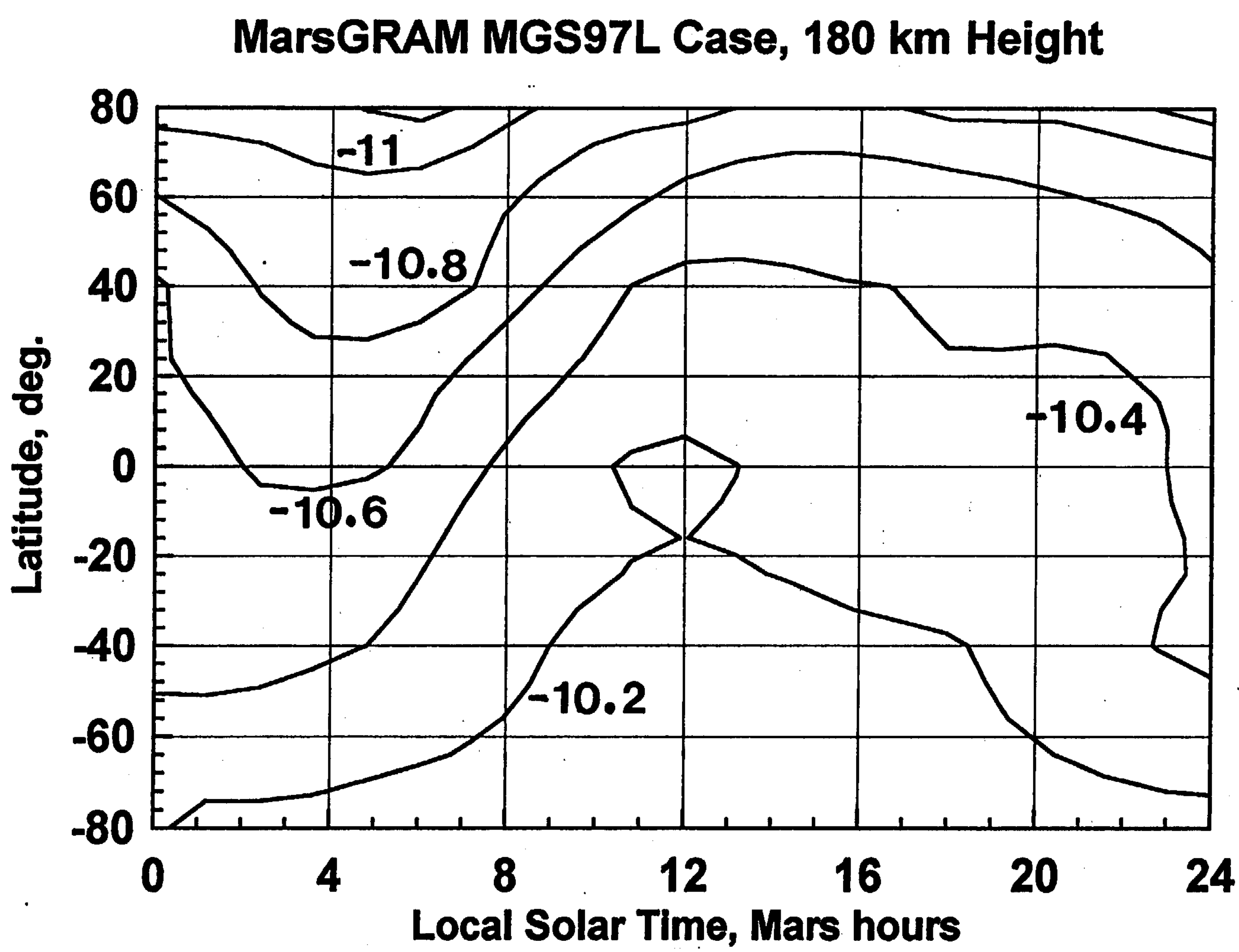

Figure 3.8. Mars-GRAM model density (log-base-10, kg/m^3) at 180 km height, versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters.

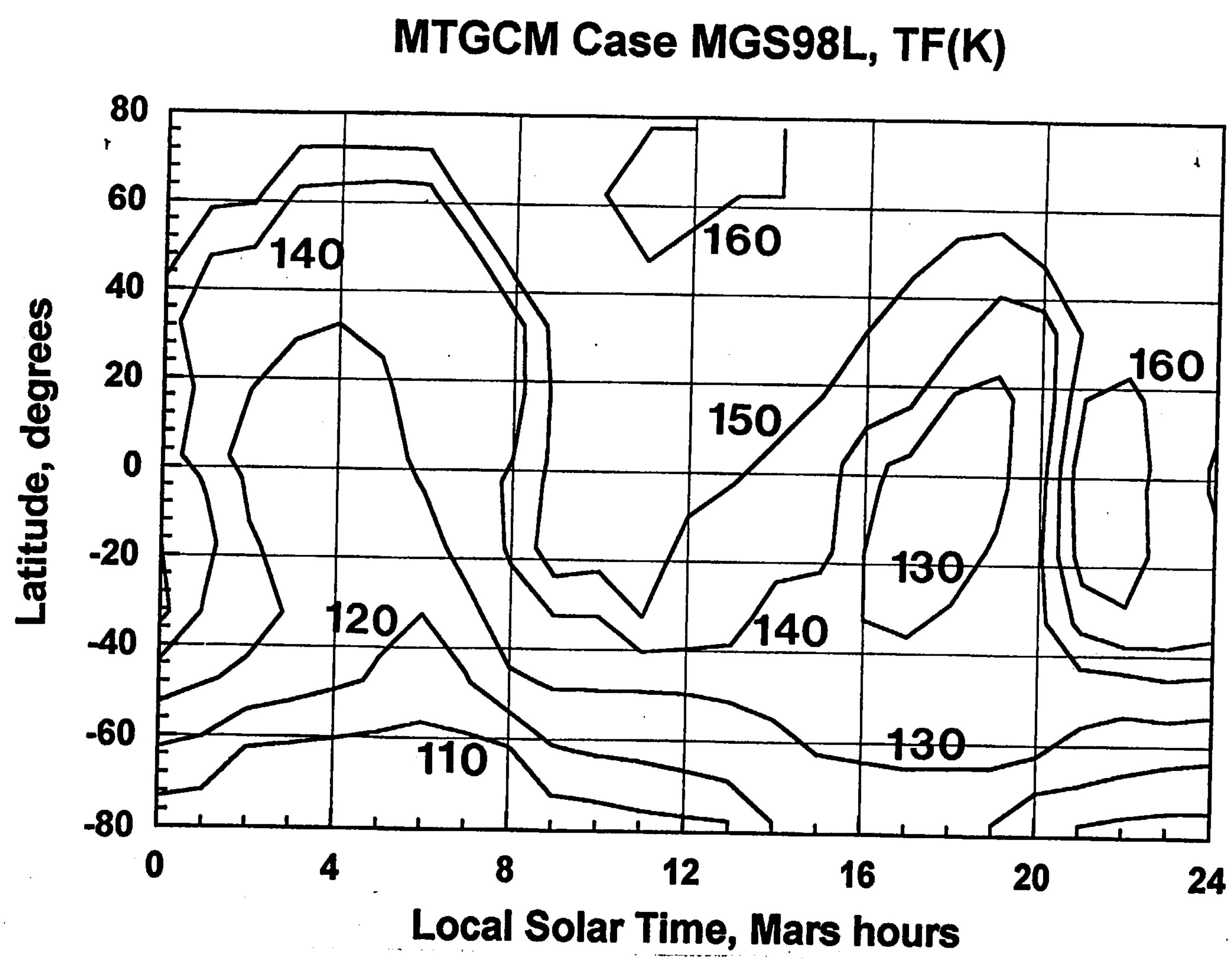

Figure 3.9. MTGCM model temperature (K) at base of the thermosphere, versus latitude and time of day for model case MGS98L. See Table 2.1 for values of model case parameters.

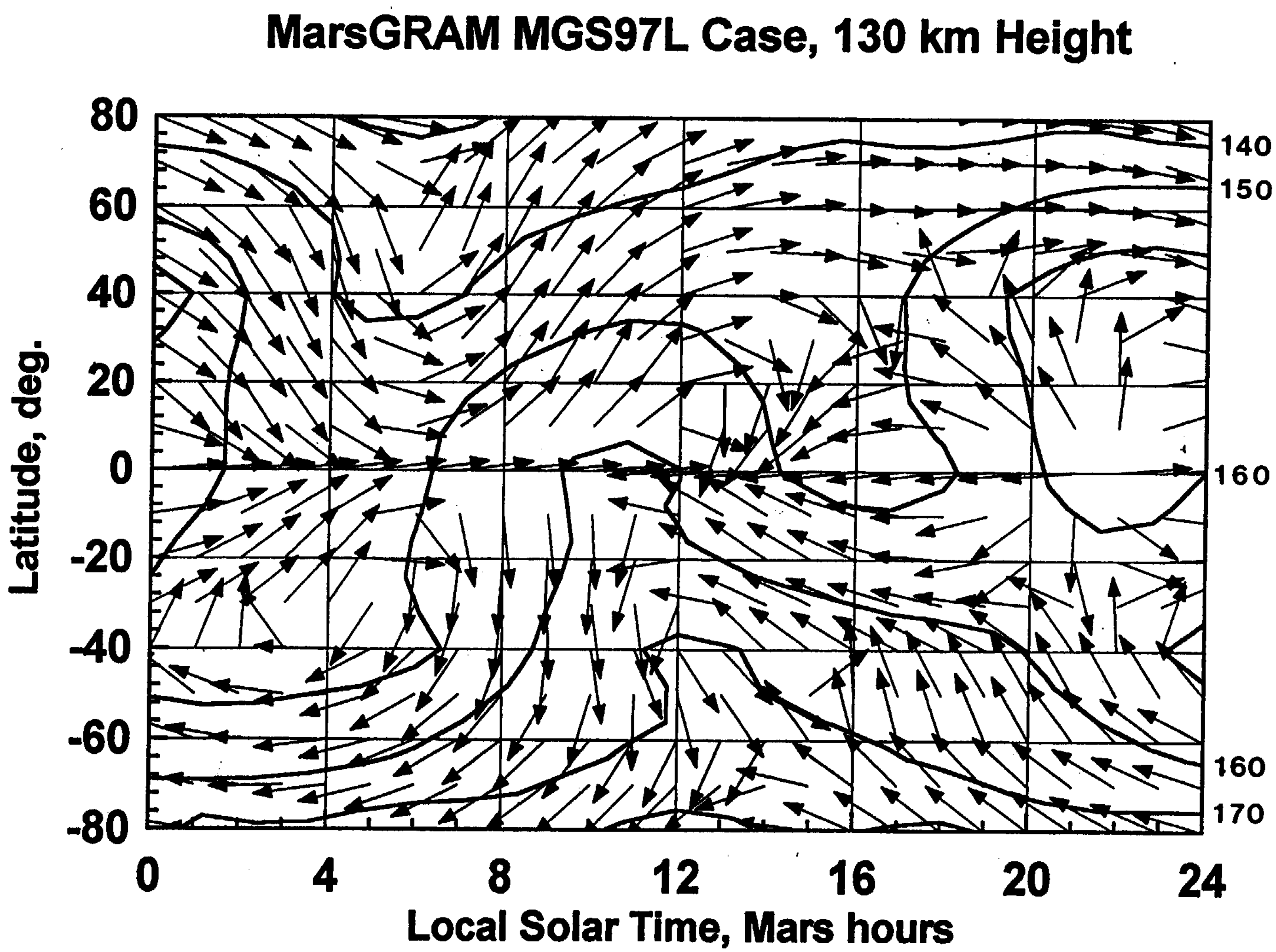

Figure 3.10. Mars-GRAM model temperature (K) at 130 km height, versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters. Wind speed vectors range from 0 to 188 m/s.

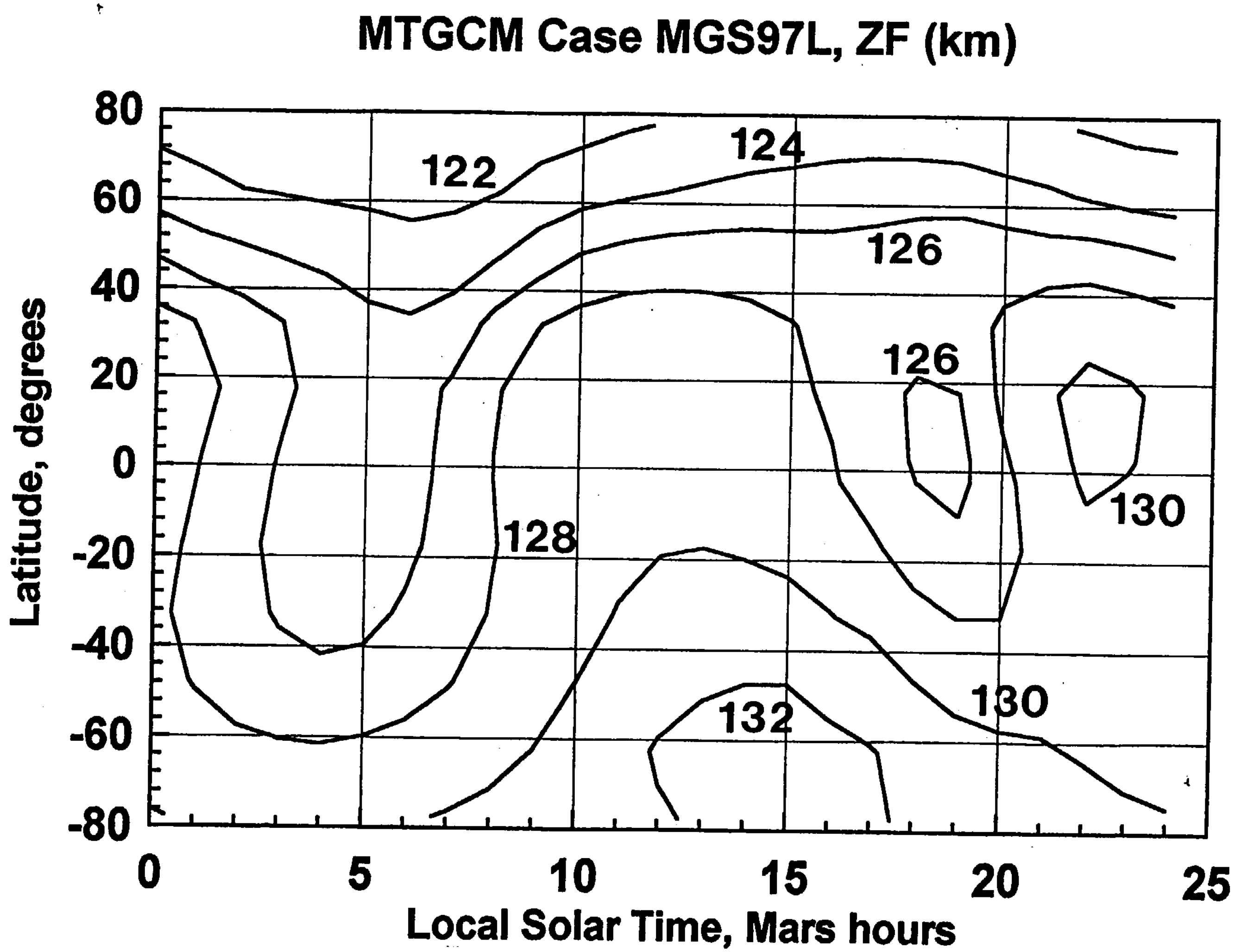

Figure 3.11. MTGCM model height (km) of the base of the thermosphere, versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters.

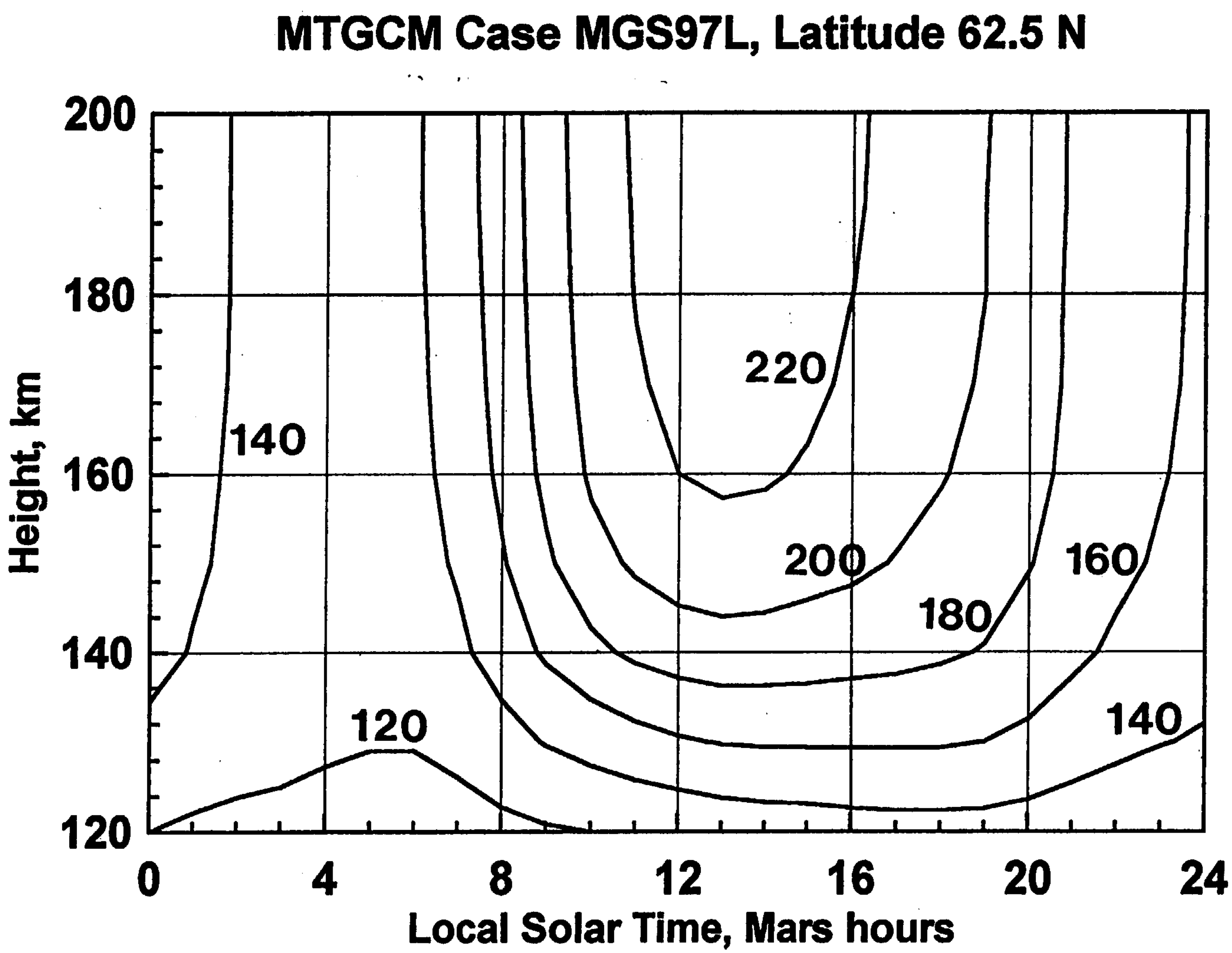

Figure 3.12. MTGCM model temperature (K), versus height and time of day at latitude 62.5 degrees North, for model case MGS97L. See Table 2.1 for values of model case parameters.

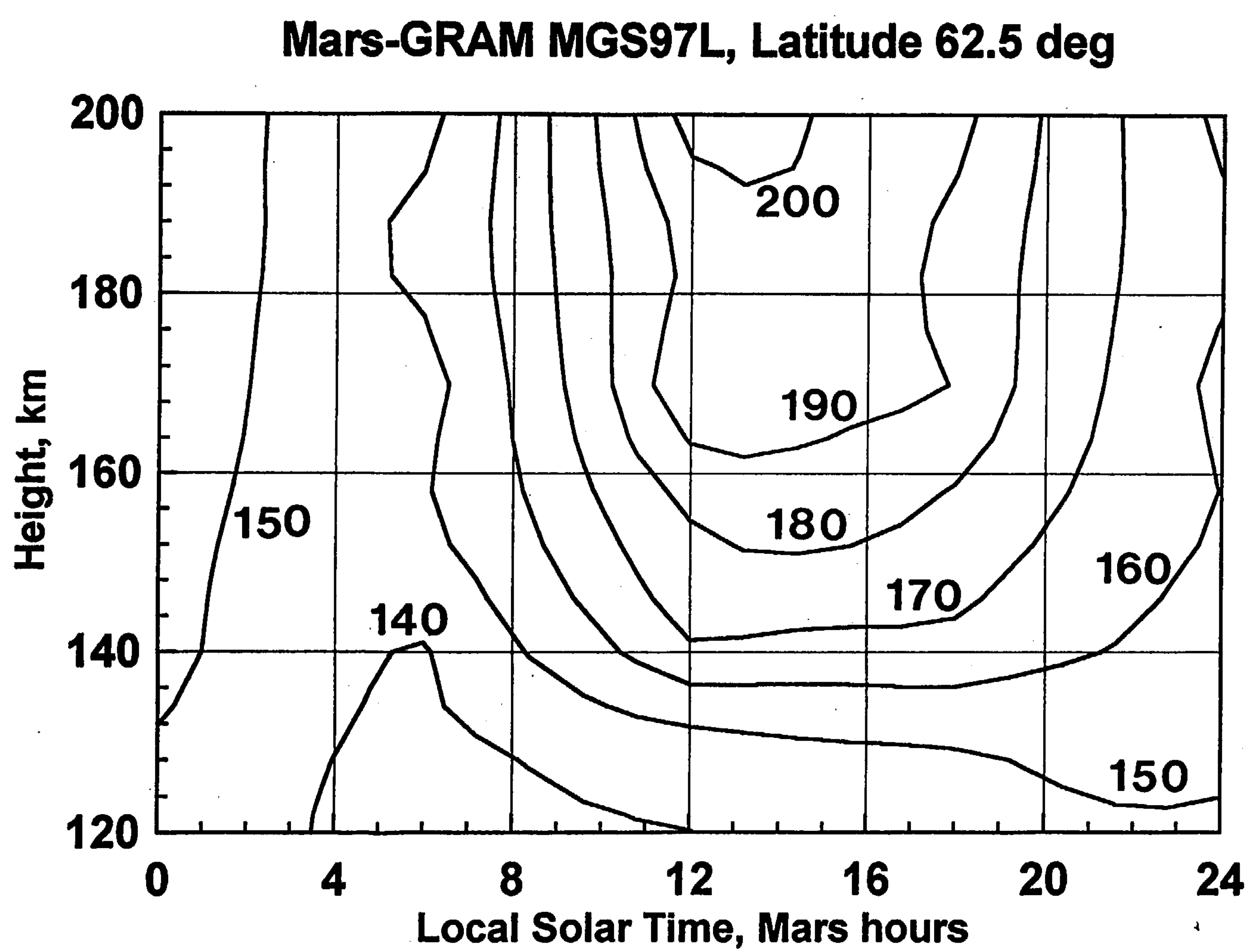

Figure 3.13. Mars-GRAM model temperature (K) , versus height and time of day at latitude 62.5 degrees North, for model case MGS97L. See Table 2.1 for values of model case parameters.

Appendix A - Updates in the Mars-GRAM Program Code

1. Comparing MARSGRAM.FOR for Mars-GRAM 3.34 and Mars-GRAM 3.4

The official version number is changed.

```
***** Mars-GRAM 3.34\MARSGRAM.FOR
C...  Program Mars-GRAM  Interactive version 3.34 - November 1, 1995    MARS  1
C                                                                       MARS  2
***** Mars-GRAM 3.4\MARSGRAM.FOR
C...  Program Mars-GRAM  Interactive version 3.4 - April 1, 1996        MARS  1
C                                                                       MARS  2
*****
```

Output of the official version number to the LIST file is changed.

```
***** Mars-GRAM 3.34\MARSGRAM.FOR
C                                                                       MARS 10
    1 Format(' Mars-GRAM Interactive version 3.34 - November 1, 1995')  MARS 11
C                                                                       MARS 12
***** Mars-GRAM 3.4\MARSGRAM.FOR
C                                                                       MARS 10
    1 Format(' Mars-GRAM Interactive version 3.4 - April 1, 1996')      MARS 11
C                                                                       MARS 12
*****
```

Climate factors (CF) and thermospheric adjustment parameters (deltaZF, deltaTF, and deltaTEX) are added to the common DATACOM.

```
***** Mars-GRAM 3.34\MARSGRAM.FOR
     & logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,       MARS 22
     & intens,iu0,iup,maxfiles                                          MARS 23
      COMMON /FILENAME/lstfl,outfl                                      MARS 24
***** Mars-GRAM 3.4\MARSGRAM.FOR
     & logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,       MARS 22
     & intens,iu0,iup,maxfiles,CF(0:5),deltaZF,deltaTF,deltaTEX         MARS 23
      COMMON /FILENAME/lstfl,outfl                                      MARS 24
*****
```

The climate factors (CF) are initialized to their default values of 1.0. The thermospheric adjustment parameters (deltaZF, deltaTF, and deltaTEX) are initialized to their default values of 0.0. User selected values of these parameters can be used in the batch form of Mars-GRAM. In the interactive form of Mars-GRAM, these parameters cannot be changed from their default values.

```
***** Mars-GRAM 3.34\MARSGRAM.FOR
      Write(iu0,10)                                                     MARS 44
   10 format(' Enter name for LIST file (CON for console listing): ')   MARS 45
***** Mars-GRAM 3.4\MARSGRAM.FOR
      Write(iu0,10)                                                     MARS 44
C...  Set CF climate factors to 1.0 (.ne. 1 available in Batch version) MARS 44a
      Do 5 i = 0,5                                                      MARS 44b
        CF(i) = 1.0                                                     MARS 44c
  5   Continue                                                          MARS 44d
C...  Set deltaZF, deltaTF & deltaTEX to 0.0 (available in Batch only)   MARS 44e
      deltaZF = 0.0                                                     MARS 44f
      deltaTF = 0.0                                                     MARS 44g
      deltaTEX = 0.0                                                    MARS 44h
   10 format(' Enter name for LIST file (CON for console listing): ')   MARS 45
*****
```

2. Comparing MARSGRMB.FOR for Mars-GRAM 3.34 and Mars-GRAM 3.4

The official version number is changed.

```
***** Mars-GRAM 3.34\MARSGRMB.FOR
C...  Program Mars-GRAM  Batch version 3.34 - November 1, 1995          MARB  1
C                                                                       MARB  2
***** Mars-GRAM 3.4\MARSGRMB.FOR
C...  Program Mars-GRAM  Batch version 3.4 - April 1, 1996              MARB  1
C                                                                       MARB  2
*****
```

The default value of solar flux at 1AU (F107) is changed to 68, from 185. The 1AU value of F107 on the day of the Viking 1 landing (July 20, 1976) was 68.

```
***** Mars-GRAM 3.34\MARSGRMB.FOR
C  DUSTLON  = 0.0,      ! West longitude (deg) of center of dust storm  MARB 35
C  F107     = 185.0,    ! 10.7 cm solar flux (10**-22 W/cm**2 at 1 AU)  MARB 36
C  STDL     = 0.0,      ! std. dev. for thermosphere variation (-3.0    MARB 37
***** Mars-GRAM 3.4\MARSGRMB.FOR
C  DUSTLON  = 0.0,      ! West longitude (deg) of center of dust storm  MARB 35
C  F107     = 68.0,     ! 10.7 cm solar flux (10**-22 W/cm**2 at 1 AU)  MARB 36
C  STDL     = 0.0,      ! std. dev. for thermosphere variation (-3.0    MARB 37
*****
```

The comment about the COSPAR model comparison (LOGSCALE = 2) is added.

```
***** Mars-GRAM 3.34\MARSGRMB.FOR
C                       !                                       plots)  MARB 44
C  LOGSCALE = 0,        ! 1 for log-base-10 scale plots, 0 for linear   MARB 45
C                       !                                        scale  MARB 46
C  FLAT     = 22.0,     ! initial latitude (N positive), degrees        MARB 47
***** Mars-GRAM 3.4\MARSGRMB.FOR
C                       !                                       plots)  MARB 44
C  LOGSCALE = 0,        ! 0=regular linear scale, 1=log-base-10 scale,  MARB 45
C                       !    2=percentage deviations from COSPAR model  MARB 46
C  FLAT     = 22.0,     ! initial latitude (N positive), degrees        MARB 47
*****
```

Descriptions are added to the NAMELIST input for the new climate adjustment factors (CF) and thermospheric adjustment parameters (deltaZF, deltaTF, and deltaTEX).

```
***** Mars-GRAM 3.34\MARSGRMB.FOR
C  DELTIME  = 0.0,      ! time increment (sec) between steps            MARB 53
C $END                                                                  MARB 54
***** Mars-GRAM 3.4\MARSGRMB.FOR
C  DELTIME  = 0.0,      ! time increment (sec) between steps            MARB 53
C  CF0      = 1.0       ! climate adjustment factor at surface          MARB 53a
C  CF5      = 1.0       ! climate adjustment factor at 5 km             MARB 53b
C  CF15     = 1.0       ! climate adjustment factor at 15 km            MARB 53c
C  CF30     = 1.0       ! climate adjustment factor at 30 km            MARB 53d
C  CF50     = 1.0       ! climate adjustment factor at 50 km            MARB 53e
C  CF75     = 1.0       ! climate adjustment factor at 75 km            MARB 53f
C  deltaZF  = 0.0       ! adjustment for base of thermosphere (km)      MARB 53g
C  deltaTF  = 0.0       ! adjustment for temperature at height ZF (K)   MARB 53h
C  deltaTEX = 0.0       ! adjustment for exospheric temperature (K)     MARB 53i
C                                                                       MARB 53j
C $END                                                                  MARB 54
*****
```

3. Comparing MARSSUBS.FOR for Mars-GRAM 3.34 and Mars-GRAM 3.4

The official version number is changed.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
C     Subroutines and Functions for Interactive and Batch versions of   ALBL  1
C     Mars-GRAM  version 3.34 - November 1, 1995                        ALBL  2
C.......................................................................ALBL  3
***** Mars-GRAM 3.4\MARSSUBS.FOR
C     Subroutines and Functions for Interactive and Batch versions of   ALBL  1
C     Mars-GRAM  version 3.4 - April 1, 1996                            ALBL  2
C.......................................................................ALBL  3
*****
```

The climate adjustment factors (CF) and the thermospheric adjustment parameters (deltaZF, deltaTF, and deltaTEX) are added to the argument list for subroutine ATMOS2. The local exospheric temperature (Texos) and local temperature of the base of the thermosphere (Tbase) are added as output arguments, to pass these values for output to the LIST file.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
     & dustM,dustA,H,TEMP,DENST,UPFCTR,LWFCTR,PRES,RSC,Z0,TMAX,TMIN,    ATM2  2
     & TAVG,Bruntf,densurf,tfactor,ZF,als0,intens,iu0)                  ATM2  3
      REAL LWFCTR,MARSAU,INTENS                                         ATM2  4
***** Mars-GRAM 3.4\MARSSUBS.FOR
     & dustM,dustA,H,TEMP,DENST,UPFCTR,LWFCTR,PRES,RSC,Z0,TMAX,TMIN,    ATM2  2
     & TAVG,Bruntf,densurf,tfactor,ZF,als0,intens,iu0,CF,deltaZF,       ATM2  3
     &  deltaTF,deltaTEX,Texos,Tbase)                                   ATM2  3a
      REAL LWFCTR,MARSAU,INTENS                                         ATM2  4
*****
```

Comments about the input/output argument list for ATMOS2 are updated, to reflect the new argument variables.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      COMMON /THERM/F107,stdl                                           ATM2  5
      Dimension ES(0:11)                                                ATM2  6
C                                                                       ATM2  7
C     CHGT    SPACECRAFT HEIGHT ABOVE REFERENCE SURFACE (KM)(INPUT)     ATM2  8
C     CLAT    APACECRAFT LATITUDE (DEGREES) (INPUT)                     ATM2  9
C     CLON    WEST LONGITUDE OF SPACECRAFT (DEGREES) (INPUT)            ATM2 10
C     MARSAU  MARS ORBITAL RADIUS (AU) (INPUT)                          ATM2 11
C     SUNLAT  AREOCENTRIC LATITUDE OF SUN (DEGREES) (INPUT)             ATM2 12
C     SUNLON  MARS WEST LONGITUDE OF SUN (DEGREES) (INPUT)              ATM2 13
C     ALS     AREOCENTRIC LONGITUDE OF SUN ORBIT (INPUT)                ATM2 14
C     DATE    JULIAN DATE (INPUT)                                       ATM2 15
C     dustM   dust storm magnitude for average T and p effect           ATM2 16
C     (1 = full magnitude, 0 = no dust storm) (INPUT)                   ATM2 17
C     dustA   dust storm magnitude for daily amplitude T and p effect   ATM2 18
C     (1 = full magnitude, 0 = no dust storm) (INPUT)                   ATM2 19
C     H       SCALE HEIGHT AT SPACECRAFT POSITION (KM) (OUTPUT)         ATM2 20
C     TEMP    TEMPERATURE AT SPACECRAFT POSITION (K) (OUTPUT)           ATM2 21
C     DENST   MASS DENSITY AT SPACECRAFT POSITION (KG/M**3) (OUTPUT)    ATM2 22
C     UPFCTR  UPPER DEVIATION FACTOR ON MASS DENSITY  (OUTPUT)          ATM2 23
C     LWFCTR  LOWER DEVIATION FACTOR ON MASS DENSITY  (OUTPUT)          ATM2 24
C     PRES    PRESSURE AT SPACECRAFT POSITION (N/M**2) (OUTPUT)         ATM2 25
C     RSC     AREOCENTRIC RADIUS TO SPACECRAFT (KM) (OUTPUT)            ATM2 26
C     Z0      LOCAL TERRAIN HEIGHT RELATIVE TO REFERENCE ELLIPSOID      ATM2 27
C     (KM) (INPUT)                                                      ATM2 28
C     TMAX    Daily maximum surface temperature (K) (OUTPUT)            ATM2 29
C     TMIN    Daily minimum surface temperature (K) (OUTPUT)            ATM2 30
C     TAVG    Daily average surface temperature (K) (OUTPUT)            ATM2 31
C     Bruntf  Brunt-Vaisala frequency = Sqrt((g/T)*(dT/dZ + g/Cp))      ATM2 32
C     (OUTPUT)                                                          ATM2 33
```

```
C      densurf Density at surface (kg/m**3) (OUTPUT)                      ATM2 34
C      tfactor Density perturbation factor at base of thermosphere        ATM2 35
C      (OUTPUT)                                                           ATM2 36
C      ZF      Height of base of thermosphere (OUTPUT)                    ATM2 37
C      als0    Initial Ls for dust storm                                  ATM2 38
C      INTENS  Dust storm intensity (0.0-3.0)                             ATM2 39
C      iu0     unit number for messages                                   ATM2 40
C                                                                         ATM2 41
***** Mars-GRAM 3.4\MARSSUBS.FOR
       COMMON /THERM/F107,stdl                                            ATM2  5
       Dimension ES(0:11),CF(0:5)                                         ATM2  6
C                                                                         ATM2  7
C      CHGT     SPACECRAFT HEIGHT ABOVE REFERENCE SURFACE (KM)(INPUT)     ATM2  8
C      CLAT     SPACECRAFT LATITUDE (DEGREES) (INPUT)                     ATM2  9
C      CLON     WEST LONGITUDE OF SPACECRAFT (DEGREES) (INPUT)            ATM2 10
C      MARSAU   MARS ORBITAL RADIUS (AU) (INPUT)                          ATM2 11
C      SUNLAT   AREOCENTRIC LATITUDE OF SUN (DEGREES) (INPUT)             ATM2 12
C      SUNLON   MARS WEST LONGITUDE OF SUN (DEGREES) (INPUT)              ATM2 13
C      ALS      AREOCENTRIC LONGITUDE OF SUN ORBIT (INPUT)                ATM2 14
C      DATE     JULIAN DATE (INPUT)                                       ATM2 15
C      dustM    dust storm magnitude for average T and p effect           ATM2 16
C               (1 = full magnitude, 0 = no dust storm) (INPUT)           ATM2 17
C      dustA    dust storm magnitude for daily amplitude T and p effect   ATM2 18
C               (1 = full magnitude, 0 = no dust storm) (INPUT)           ATM2 19
C      H        SCALE HEIGHT AT SPACECRAFT POSITION (KM) (OUTPUT)         ATM2 20
C      TEMP     TEMPERATURE AT SPACECRAFT POSITION (K) (OUTPUT)           ATM2 21
C      DENST    MASS DENSITY AT SPACECRAFT POSITION (KG/M**3) (OUTPUT)    ATM2 22
C      UPFCTR   UPPER DEVIATION FACTOR ON MASS DENSITY  (OUTPUT)          ATM2 23
C      LWFCTR   LOWER DEVIATION FACTOR ON MASS DENSITY  (OUTPUT)          ATM2 24
C      PRES     PRESSURE AT SPACECRAFT POSITION (N/M**2) (OUTPUT)         ATM2 25
C      RSC      AREOCENTRIC RADIUS TO SPACECRAFT (KM) (OUTPUT)            ATM2 26
C      Z0       LOCAL TERRAIN HEIGHT RELATIVE TO REFERENCE ELLIPSOID      ATM2 27
C               (KM) (INPUT)                                              ATM2 28
C      TMAX     Daily maximum surface temperature (K) (OUTPUT)            ATM2 29
C      TMIN     Daily minimum surface temperature (K) (OUTPUT)            ATM2 30
C      TAVG     Daily average surface temperature (K) (OUTPUT)            ATM2 31
C      Bruntf   Brunt-Vaisala frequency = Sqrt((g/T)*(dT/dZ + g/Cp))      ATM2 32
C               (OUTPUT)                                                  ATM2 33
C      densurf  Density at surface (kg/m**3) (OUTPUT)                     ATM2 34
C      tfactor  Density perturbation factor at base of thermosphere       ATM2 35
C               (OUTPUT)                                                  ATM2 36
C      ZF       Local height of base of thermosphere (OUTPUT)             ATM2 37
C      als0     Initial Ls for dust storm                                 ATM2 38
C      INTENS   Dust storm intensity (0.0-3.0)                            ATM2 39
C      iu0      unit number for messages                                  ATM2 40
C      CF       climate adjustment factor array for temperature levels    ATM2 40a
C      deltaZF  adjustment in height (km) of base of thermosphere         ATM2 40b
C      deltaTF  adjustment in temperature (K) at height ZF                ATM2 40c
C      deltaTEX adjustment in exospheric temperature (K)                  ATM2 40d
C      Texos    local exospheric temperature (K) (OUTPUT)                 ATM2 40e
C      Tbase    local temperature for base of exosphere (K) (OUTPUT)      ATM2 40f
C                                                                         ATM2 41
*****
```

The climate adjustment factors (CF) are added to the argument list of the subroutine TEMPS.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
C...   Evaluate temperatures at significant levels                        ATM2 68
       Call Temps(T0bar,Tsurf,gam,CLAT,dlon,dustM,dustA,ALS,T)            ATM2 69
C...   Evaluate surface pressure, N/m**2                                  ATM2 70
***** Mars-GRAM 3.4\MARSSUBS.FOR
C...   Evaluate temperatures at significant levels                        ATM2 68
       Call Temps(T0bar,Tsurf,gam,CLAT,dlon,dustM,dustA,ALS,T,CF)         ATM2 69
C...   Evaluate surface pressure, N/m**2                                  ATM2 70
*****
```

The local height of the base of the thermosphere (ZF) is computed, by calling the new subroutine Thermpar, and applying the Stewart (ES), pressure (DR), and dust corrections. The calling order for the Stewart2 subroutine is modified, to improve the program logic and run-time efficiency. This is the section that calls Stewart2 for use in the interpolation between 75 km altitude and the base of the thermosphere. The temperatures at the base of the thermosphere (Tbase) and in the exosphere (Texos) are passed for output to the LIST file.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
C...    Height of base of thermosphere                                 ATM2136
        ZF = 124.4 * (SMA / MARSAU)*EXP(ES(8)) + DR + DUST             ATM2137
C...    Shgt = height for call to thermosphere model                   ATM2138
C...    Shgt = ZF if current height < ZF                               ATM2139
        Shgt = CHGT                                                    ATM2140
        If (CHGT .lt. ZF) Shgt = ZF                                    ATM2141
C...    Evaluate atmospheric parameters at base of thermosphere        ATM2142
        Call Stewart2(MARSAU,ALS,CLAT,TIME,PRES,TEMP,DENST,            ATM2143
     &   Shgt,Rstar,H,AMF,0.0,als0,INTENS,iu0)                         ATM2144
C...    Evaluate density perturbation factor at base of thermosphere   ATM2145
        Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESHI,TEMPHI,              ATM2146
     &   DENSHI,Shgt,Rstar,HHI,AMHI,1.0,als0,INTENS,iu0)               ATM2147
        tfactor = DENSHI/DENST - 1.0                                   ATM2148
C...    Use stratosphere model if current height < ZF                  ATM2149
        If (CHGT .lt. ZF)then                                          ATM2150
          PF = PRES                                                    ATM2151
***** Mars-GRAM 3.4\MARSSUBS.FOR
C...    Height of base of thermosphere                                 ATM2136
        Call Thermpar(MARSAU,70.,CLAT,TIME,SUNLAT,TINF0,TF0,ZF0,SCALE) ATM2136a
        ZF = ZF0*EXP(ES(8)) + DR + DUST + deltaZF                      ATM2137
C...    Use stratosphere model if current height < ZF                  ATM2149
        If (CHGT .lt. ZF)then                                          ATM2149a
          Shgt = ZF                                                    ATM2149b
C...      Evaluate thermospheric parameters at base of thermosphere    ATM2149c
          Call Stewart2(MARSAU,ALS,CLAT,TIME,PRES,TEMP,DENST,Shgt,     ATM2149d
     &     Rstar,H,AMF,0.0,als0,INTENS,iu0,sunlat,deltaZF,deltaTF,     ATM2149e
     &     deltaTEX,TINF,TF)                                           ATM2149f
          Tbase = TF                                                   ATM2149g
          Texos = TINF                                                 ATM2149h
C...      Evaluate density perturbation factor at base of thermosphere ATM2149i
          Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESHI,TEMPHI,            ATM2149j
     &     DENSHI,Shgt,Rstar,HHI,AMHI,1.0,als0,INTENS,iu0,sunlat,      ATM2149k
     &     deltaZF,deltaTF,deltaTEX,TINF,TF)                           ATM2149l
          tfactor = DENSHI/DENST - 1.0                                 ATM2149m
          PF = PRES                                                    ATM2151
*****
```

The calling order for the Stewart2 subroutine is modified, to improve the program logic and run-time efficiency. This is the section that calls Stewart2 within the thermosphere. The temperatures at the base of the thermosphere (Tbase) and in the exosphere (Texos) are passed for output to the LIST file.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
        Else                                                           ATM2163
          Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESHI,                   ATM2164
     &     TEMPHI,DENSHI,Shgt,Rstar,HHI,AMHI,1.0,als0,INTENS,iu0)      ATM2165
          Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESLO,                   ATM2166
     &     TEMPLO,DENSLO,Shgt,Rstar,HLO,AMLO,-1.0,als0,INTENS,iu0)     ATM2167
          UPFCTR = DENSHI/DENST                                        ATM2168
***** Mars-GRAM 3.4\MARSSUBS.FOR
        Else                                                           ATM2163
          Shgt = CHGT                                                  ATM2163a
C...      Evaluate thermospheric parameters at current height          ATM2163b
          Call Stewart2(MARSAU,ALS,CLAT,TIME,PRES,TEMP,DENST,          ATM2163c
```

```
     &      Shgt,Rstar,H,AMF,0.0,als0,INTENS,iu0,sunlat,deltaZF,deltaTF,  ATM2163d
     &      deltaTEX,TINF,TF)                                              ATM2163e
           Texos = TINF                                                    ATM2163f
           Tbase = TF                                                      ATM2163g
           tfactor = DENSHI/DENST - 1.0                                    ATM2163h
           Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESHI,TEMPHI,               ATM2164
     &      DENSHI,Shgt,Rstar,HHI,AMHI,1.0,als0,INTENS,iu0,sunlat,         ATM2165
     &      deltaZF,deltaTF,deltaTEX,TINF,TF)                              ATM2165a
           Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESLO,TEMPLO,               ATM2166
     &      DENSLO,Shgt,Rstar,HLO,AMLO,-1.0,als0,INTENS,iu0,sunlat,        ATM2167
     &      deltaZF,deltaTF,deltaTEX,TINF,TF)                              ATM2167a
           UPFCTR = DENSHI/DENST                                           ATM2168
*****
```

Adjustment parameters CF, deltaZF, deltaTF, and deltaTEX are added to the common DATACOM.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
     & logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,      BLKD  8
     & intens,iu0,iup,maxfiles                                         BLKD  9
C...  Unit numbers for messages (normally to screen) and to list output BLKD 10
***** Mars-GRAM 3.4\MARSSUBS.FOR
     & logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,      BLKD  8
     & intens,iu0,iup,maxfiles,CF(0:5),deltaZF,deltaTF,deltaTEX        BLKD  9
C...  Unit numbers for messages (normally to screen) and to list output BLKD 10
*****
```

Data statements are added, to establish default parameters. Note, the parameter maxfiles may need to be 16, for PC-based, 16-bit compilers. This will limit the number of output files that will be produced; maxfiles may be set to a larger value on UNIX systems and 32-bit PC compilers.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      Data maxfiles/16/                                                BLKD 18
C...  Zurek wave perturbation parameter data values                    BLKD 19
***** Mars-GRAM 3.4\MARSSUBS.FOR
      Data maxfiles/16/                                                BLKD 18
C...  Default = no dust storm                                          BLKD 18a
      Data Als0,Intens,Radmax,Dustlat,Dustlon/5*0.0/                   BLKD 18b
C...  Default model parameters                                         BLKD 18c
      Data Modpert,NVARX,NVARY,LOGSCALE,NPOS/3,1,0,0,21/               BLKD 18d
C...  Zurek wave perturbation parameter data values                    BLKD 19
*****
```

Adjustment parameters CF, deltaZF, deltaTF, and deltaTEX are added to the common DATACOM.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
     & logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,      DSTF 11
     & intens,iu0,iup,maxfiles                                         DSTF 12
      Real intens                                                      DSTF 13
***** Mars-GRAM 3.4\MARSSUBS.FOR
     & logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,      DSTF 11
     & intens,iu0,iup,maxfiles,CF(0:5),deltaZF,deltaTF,deltaTEX        DSTF 12
      Real intens                                                      DSTF 13
*****
```

Adjustment parameters CF, deltaZF, deltaTF, and deltaTEX are added to the common DATACOM.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
     & logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,      DSTP  9
     & intens,iu0,iup,maxfiles                                         DSTP 10
```

```
      COMMON /FILENAME/lstfl,outfl                                      DSTP 11
***** Mars-GRAM 3.4\MARSSUBS.FOR
     & logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,       DSTP  9
     & intens,iu0,iup,maxfiles,CF(0:5),deltaZF,deltaTF,deltaTEX         DSTP 10
      COMMON /FILENAME/lstfl,outfl                                      DSTP 11
*****
```

The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texos, and Tbase) are added to the argument list in the call statement for subroutine ATMOS2.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
     & dustM,dustA,HSCALE,TEMP,DENS,FACTHI,FACTLO,PRES,RSC,thgt,        DSTP 41
     & TMAX,TMIN,TAVG,Bruntf,densurf,tfactor,ZF,als0,INTENS,iu0)        DSTP 42
C...  CHGT = height above reference ellipsoid                           DSTP 43
***** Mars-GRAM 3.4\MARSSUBS.FOR
     & dustM,dustA,HSCALE,TEMP,DENS,FACTHI,FACTLO,PRES,RSC,thgt,        DSTP 41
     & TMAX,TMIN,TAVG,Bruntf,densurf,tfactor,ZF,als0,INTENS,iu0,CF,     DSTP 42
     & deltaZF,deltaTF,deltaTEX,Texos,Tbase)                            DSTP 42a
      Zbase = ZF                                                        DSTP 42b
C...  CHGT = height above reference ellipsoid                           DSTP 43
*****
```

The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texos, and Tbase) are added to the argument list in the call statement for subroutine ATMOS2.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
     & dustM,dustA,HLONP,TLONP,DLONP,FHI,FLO,PLONP,RLONP,thgt,          DSTP 87
     & TMAP,TMIP,TAVP,bvf,den0,tfac,zt,als0,INTENS,iu0)                 DSTP 88
      CLONM = CLON - 2.5                                                DSTP 89
***** Mars-GRAM 3.4\MARSSUBS.FOR
     & dustM,dustA,HLONP,TLONP,DLONP,FHI,FLO,PLONP,RLONP,thgt,          DSTP 87
     & TMAP,TMIP,TAVP,bvf,den0,tfac,zt,als0,INTENS,iu0,CF,deltaZF,      DSTP 88
     &  deltaTF,deltaTEX,TINF,TF)                                       DSTP 88a
      CLONM = CLON - 2.5                                                DSTP 89
*****
```

The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texos, and Tbase) are added to the argument list in the call statement for subroutine ATMOS2.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
     & dustM,dustA,HLONM,TLONM,DLONM,FHI,FLO,PLONM,RLONM,thgt,          DSTP 92
     & TMAM,TMIM,TAVM,bvf,den0,tfac,zt,als0,INTENS,iu0)                 DSTP 93
C...  First two heights for area average height                        DSTP 94
***** Mars-GRAM 3.4\MARSSUBS.FOR
     & dustM,dustA,HLONM,TLONM,DLONM,FHI,FLO,PLONM,RLONM,thgt,          DSTP 92
     & TMAM,TMIM,TAVM,bvf,den0,tfac,zt,als0,INTENS,iu0,CF,deltaZF,      DSTP 93
     & deltaTF,deltaTEX,TINF,TF)                                        DSTP 93a
C...  First two heights for area average height                        DSTP 94
*****
```

The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texos, and Tbase) are added to the argument list in the call statement for subroutine ATMOS2.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
     & dustM,dustA,HLATP,TLATP,DLATP,FHI,FLO,PLATP,RLATP,thgt,          DSTP105
     & TMAP,TMIP,TAVP,bvf,den0,tfac,zt,als0,INTENS,iu0)                 DSTP106
      CLATM = CLAT - 2.5                                                DSTP107
***** Mars-GRAM 3.4\MARSSUBS.FOR
     & dustM,dustA,HLATP,TLATP,DLATP,FHI,FLO,PLATP,RLATP,thgt,          DSTP105
     & TMAP,TMIP,TAVP,bvf,den0,tfac,zt,als0,INTENS,iu0,CF,deltaZF,      DSTP106
     & deltaTF,deltaTEX,TINF,TF)                                        DSTP106a
      CLATM = CLAT - 2.5                                                DSTP107
*****
```

The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texos, and Tbase) are added to the argument list in the call statement for subroutine ATMOS2.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
     & dustM,dustA,HLATM,TLATM,DLATM,FHI,FLO,PLATM,RLATM,thgt,           DSTP114
     & TMAM,TMIM,TAVM,bvf,den0,tfac,zt,als0,INTENS,iu0)                  DSTP115
C...  Area average height                                                DSTP116
***** Mars-GRAM 3.4\MARSSUBS.FOR
     & dustM,dustA,HLATM,TLATM,DLATM,FHI,FLO,PLATM,RLATM,thgt,           DSTP114
     & TMAM,TMIM,TAVM,bvf,den0,tfac,zt,als0,INTENS,iu0,CF,deltaZF,       DSTP115
     & deltaTF,deltaTEX,TINF,TF)                                         DSTP115a
C...  Area average height                                                DSTP116
*****
```

The coefficient on the viscosity term for the wind calculations is changed to 0.04 (from 1.0).

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      VISC = BETA*TEMP**1.5/(TEMP + SVAL)                                DSTP133
      VISCFAC = VISC/(1.0E6*DENS*VLL**2)                                 DSTP134
C...  FUG, FVG = Coriolis parameter times components of areostrophic     DSTP135
***** Mars-GRAM 3.4\MARSSUBS.FOR
      VISC = BETA*TEMP**1.5/(TEMP + SVAL)                                DSTP133
C...  Use multiplier to scale wind magnitude                             DSTP134
      VISCFAC = 0.04*VISC/(1.0E6*DENS*VLL**2)                            DSTP134a
C...  FUG, FVG = Coriolis parameter times components of areostrophic     DSTP135
*****
```

The allowable upper and lower limits on the density perturbations are adjusted to better account for the stability limits that would be encountered.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      IF(RHO.GE.0.0)DENSP = DENS*(1. + wave) + RHO*DPLUS                 DSTP237
      If (DENSP .lt. 0.0)DENSP = 0.05*DENS                               DSTP238
C...  Standard deviation in random density perturbation (% of mean),     DSTP239
***** Mars-GRAM 3.4\MARSSUBS.FOR
      IF(RHO.GE.0.0)DENSP = DENS*(1. + wave) + RHO*DPLUS                 DSTP237
C...  Re-check upper and lower bounds on density perturbations           DSTP237a
      If (DENSP .lt. 0.05*DENS)DENSP = 0.05*DENS                         DSTP238
      If (DENSP .gt. (1.+pertmax)*DENS)DENSP = (1.+pertmax)*DENS         DSTP238a
C...  Standard deviation in random density perturbation (% of mean),     DSTP239
*****
```

A re-check of the density perturbation values is done, by comparing with the stability limits.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      SIGD = 50.*(DENSHI-DENSLO)/DENS                                    DSTP241
C...  Add Zurek wave amplitudes to DENSHI, subtract from DENSLO           DSTP242
***** Mars-GRAM 3.4\MARSSUBS.FOR
      SIGD = 50.*(DENSHI-DENSLO)/DENS                                    DSTP241
C...  Re-check SIGD, DENSHI and DENSLO                                    DSTP241a
      If (SIGD.gt.100.*pertmax)Then                                      DSTP241b
        SIGD = 100.*pertmax                                              DSTP241c
        DENSHI = DENS*(1. + pertmax)                                     DSTP241d
        DENSLO = DENS/(1. + pertmax)                                     DSTP241e
      Endif                                                              DSTP241f
C...  Add Zurek wave amplitudes to DENSHI, subtract from DENSLO           DSTP242
*****
```

The Mars orbital radius (MARSAU) and the solar longitude (SUNLON) are added to the output for the LIST file.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      If(iup.gt.0)Write(iup,590)CSEC,CSEC/onesol,ALS,OHGT,OHGTS,          DSTP248
```

```
     & HSCALE,CLAT,CLON,SUNLON,TLOCAL                               DSTP249
  590 FORMAT(' Time (rel. to T0) =',F10.1,' sec. (',F8.3,' sols)   ',  DSTP250
***** Mars-GRAM 3.4\MARSSUBS.FOR
      If(iup.gt.0)Write(iup,590)CSEC,CSEC/onesol,ALS,OHGT,OHGTS,     DSTP248
     & HSCALE,CLAT,CLON,SUNLAT,MARSAU,SUNLON,TLOCAL                  DSTP249
  590 FORMAT(' Time (rel. to T0) =',F10.1,' sec. (',F8.3,' sols)   ',  DSTP250
*****
```

The formats are revised to accommodate the new output values. The line numbers are changed on several lines to allow for these changes.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
     & 'Scale Height = ',F6.2,' km'/' Latitude = ',F8.3,' degrees    ',  DSTP252
     & '    West Longitude = ',F8.3,' degrees'/' Sun Longitude = ',     DSTP253
     & F8.3,' deg.      Local Time = ',F6.2,' Mars hours')              DSTP254
      Call cospar(OHGT,tcos,pcos,dcos)                                  DSTP254b
      If (dcos.le.0.0)Then                                              DSTP254c
        devlo = -99.9                                                   DSTP254d
        devav = -99.9                                                   DSTP254e
        devhi = -99.9                                                   DSTP254f
      Else                                                              DSTP254g
        devlo = 100.*(DENSLO-dcos)/dcos                                 DSTP254h
        devav = 100.*(DENS-dcos)/dcos                                   DSTP254i
        devhi = 100.*(DENSHI-dcos)/dcos                                 DSTP254j
      Endif                                                             DSTP254k
      If(iup.gt.0)Write(iup,600)TEMP,PRES,DENSLO,DENS,DENSHI,           DSTP255
***** Mars-GRAM 3.4\MARSSUBS.FOR
     & 'Scale Height = ',F6.2,' km'/' Latitude = ',F8.3,' degrees    ',  DSTP252
     & '    West Longitude = ',F8.3,' degrees'/' Sun Latitude =',F9.2,  DSTP252a
     & ' deg.       Mars Orbital Radius =',F6.3,' AU'/' Sun Longitude =' DSTP253
     & ,F8.2,' deg.       Local Time = ',F6.2,' Mars hours')            DSTP254
      If (iup.gt.0.and.OHGT.gt.75.0) Write(iup,595)Texos,Tbase,Zbase    DSTP254a
  595 Format(' Exospheric Temp. = ',F6.1,' K',7X,'Tbase = ',F6.1,       DSTP254b
     & ' K',3X,' Zbase = ',F6.1,' km')                                  DSTP254c
      Call cospar(OHGT,tcos,pcos,dcos)                                  DSTP254d
      If (dcos.le.0.0)Then                                              DSTP254e
        devlo = -99.9                                                   DSTP254f
        devav = -99.9                                                   DSTP254g
        devhi = -99.9                                                   DSTP254h
      Else                                                              DSTP254i
        devlo = 100.*(DENSLO-dcos)/dcos                                 DSTP254j
        devav = 100.*(DENS-dcos)/dcos                                   DSTP254k
        devhi = 100.*(DENSHI-dcos)/dcos                                 DSTP254l
      Endif                                                             DSTP254m
      If(iup.gt.0)Write(iup,600)TEMP,PRES,DENSLO,DENS,DENSHI,           DSTP255
*****
```

The output variable for NVARX=8 is changed to local solar time in hours (from hour angle in degrees).

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      If(NVARX.EQ.7)VARX = ALS                                          DSTP272
      If(NVARX.EQ.8)VARX = TLOCAL*15.                                   DSTP273
      Alogdens = 0.0                                                    DSTP273a
***** Mars-GRAM 3.4\MARSSUBS.FOR
      If(NVARX.EQ.7)VARX = ALS                                          DSTP272
      If(NVARX.EQ.8)VARX = TLOCAL                                       DSTP273
      Alogdens = 0.0                                                    DSTP273a
*****
```

The output variable for NVARY=8 is changed to local solar time in hours (from hour angle in degrees).

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
        If(NVARY.EQ.7)VARY = ALS                                        DSTP324
        If(NVARY.EQ.8)VARY = TLOCAL*15.                                 DSTP325
        WRITE(21,795)VARX,VARY,SIGD                                     DSTP326
***** Mars-GRAM 3.4\MARSSUBS.FOR
        If(NVARY.EQ.7)VARY = ALS                                        DSTP324
        If(NVARY.EQ.8)VARY = TLOCAL                                     DSTP325
        WRITE(21,795)VARX,VARY,SIGD                                     DSTP326
*****
```

The new coefficients are loaded for the 687 day plus 777 day sun longitude calculations (previously a single, 696 day, periodicity was assumed).

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
C...  d0-d6 = Fourier coefficients for lonsun calculation              ORBT 12a
      data d0,d1,d2,d3,d4,d5,d6/-3.5158255d0,6.5240771d0,-9.3284323d0,  ORBT 13
     & 1.9052424d0,2.4887938d0,-0.49182825d0,0.10130513d-1/             ORBT 14
C...  per1 = 687 day period; per2 = 696 day period                     ORBT 14a
      per1=6.87d2/TWOPI                                                 ORBT 15
      per2=6.96d2/TWOPI                                                 ORBT 16
      PI180 = TWOPI/3.60d2                                              ORBT 17
***** Mars-GRAM 3.4\MARSSUBS.FOR
C...  d0-d6 = Fourier coefficients for lonsun calculation              ORBT 12a
      Data e0,e1,e2,e3,e4,e5,e6/-.61024174D-01,1.8014752D0,.35080142D0, ORBT 12b
     & .11820528D0,-.23869660D0,-.56879633D-01,-.42787450D-01/          ORBT 12c
      Data d0,d1,d2,d3,d4,d5,d6/-3.4766116D0,10.199478D0,2.7450878D0,   ORBT 13
     & -3.2726522D0,-.67435053D-01,.52016400D0,.11903292D0/             ORBT 13a
C...  per1 = 687 day period; per2 = 777 day period                     ORBT 14
      per1=6.87d2/TWOPI                                                 ORBT 15
      per2=7.77d2/TWOPI                                                 ORBT 16
      PI180 = TWOPI/3.60d2                                              ORBT 17
*****
```

The comment line is modified and the computation of the time variable TIME2 is moved.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      xlon = lon0 + 3.60d2*(date - 2.922d3)/perlon                      ORBT 20
C...  TIME1, TIME2 = time variables for periods PER1 and PER2          ORBT 20a
      TIME1=DATE/PER1                                                   ORBT 21
      TIME2=DATE/PER2                                                   ORBT 22
C...  Lsubs calculation (REAL*8)                                        ORBT 22a
***** Mars-GRAM 3.4\MARSSUBS.FOR
      xlon = lon0 + 3.60d2*(date - 2.922d3)/perlon                      ORBT 20
C...  TIME1 = time variable for period PER1                             ORBT 20a
      TIME1=DATE/PER1                                                   ORBT 21
C...  Lsubs calculation (REAL*8)                                        ORBT 22a
*****
```

The new, dual period, solar longitude model equations are evaluated.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
C...  lonsun calculation (REAL*8)                                       ORBT 27a
      LON=D0+D1*DSIN(TIME2)+D2*DCOS(TIME2)+D3*DSIN(2.0d0*TIME2)         ORBT 28
     & +d4*DCOS(2.0d0*time2)+d5*DSIN(3.0d0*time2)+d6*DCOS(3.0d0*time2)  ORBT 29
     & +xlon                                                            ORBT 30
C...  Put Lsubs and lonsun into 0-360 degree range                      ORBT 30a
      LS = DMOD(LS,3.6D2)                                               ORBT 31
***** Mars-GRAM 3.4\MARSSUBS.FOR
C...  lonsun calculation (REAL*8)                                       ORBT 27a
      time = (date-2.921d3)/per1                                        ORBT 27b
      time2 = (date-2.921d3)/per2                                       ORBT 27c
      xlon=D0+D1*DSIN(TIME)+D2*DCOS(TIME)+D3*DSIN(2.0d0*TIME)           ORBT 28
     & +d4*DCOS(2.0d0*time)+d5*DSIN(3.0d0*time)+d6*DCOS(3.0d0*time)     ORBT 29
     & + xlon                                                           ORBT 30
      LON=E0+E1*DSIN(time2)+E2*DCOS(time2)+E3*DSIN(2.0d0*time2)         ORBT 30a
```

```
     & +E4*DCOS(2.0d0*time2)+E5*DSIN(3.0d0*time2)+E6*DCOS(3.0d0*time2)   ORBT 30b
     & + xlon                                                            ORBT 30c
C...  Put Lsubs and lonsun into 0-360 degree range                       ORBT 30d
      LS = DMOD(LS,3.6D2)                                                ORBT 31
*****
```

The new variables (sunlat, deltaZF, deltaTF, deltaTEX, TINF, and TF) are added to the argument list for the call to subroutine Stewart2.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      SUBROUTINE STEWART2 ( RAUI, LSUN, LAT, LST, TOTALPRZ, TZ,          STW2  1
     & TOTALMDZ, CHGT, RSTAR, H, MOLWTG, SIGMA, als0, INTENS, iu0)       STW2  2
C                                                                        STW2  3
***** Mars-GRAM 3.4\MARSSUBS.FOR
      SUBROUTINE STEWART2 ( RAUI, LSUN, LAT, LST, TOTALPRZ, TZ,          STW2  1
     & TOTALMDZ, CHGT, RSTAR, H, MOLWTG, SIGMA, als0, INTENS, iu0,       STW2  2
     & sunlat,deltaZF,deltaTF,deltaTEX,TINF,TF)                          STW2  2a
C                                                                        STW2  3
*****
```

A comment line is added to clarify that FBARR is for the Mars orbital position.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      RAU = RAUI                                                         STW2 28
      FBARR = FBAR / (RAU**2)                                            STW2 29
***** Mars-GRAM 3.4\MARSSUBS.FOR
      RAU = RAUI                                                         STW2 28
C...  Convert solar 10.7 cm flux to Mars position                        STW2 28a
      FBARR = FBAR / (RAU**2)                                            STW2 29
*****
```

The local values of the thermospheric parameters are evaluated by calling the new subroutine Thermpar.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      CALL PRSEAS(LSUN, LAT, PFAC)                                       STW2 31
      if(FLAG.gt.0)Write(iu0,*)' RREF, RAU, GZ = ',RREF,RAU,GZ           STW2 32
***** Mars-GRAM 3.4\MARSSUBS.FOR
      CALL PRSEAS(LSUN, LAT, PFAC)                                       STW2 31
C...  Evaluate the basic parameters for the thermosphere model           STW2 31a
      Call Thermpar(RAU,FBARR,LAT,LST,SUNLAT,TINF0,TF0,ZF0,SCALE)        STW2 31b
      if(FLAG.gt.0)Write(iu0,*)' RREF, RAU, GZ = ',RREF,RAU,GZ           STW2 32
*****
```

The modifications, for the Stewart adjustments (ES), pressure (DR), dust, and the new adjustment parameter deltaZF, are added to the value (ZF0) computed by Thermpar.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      DUST = DUST * EXP(ES(10))                                          STW2 37
      ZF = (124.4 * SMA / RAU) * EXP(ES(8) + ES(9)) + DR + DUST          STW2 38
      ZZF = CHGT - ZF                                                    STW2 39
***** Mars-GRAM 3.4\MARSSUBS.FOR
      DUST = DUST * EXP(ES(10))                                          STW2 37
C...  Height of base of thermosphere                                     STW2 37a
      ZF = ZF0 * EXP(ES(8) + ES(9)) + DR + DUST + deltaZF                STW2 38
C...  Height above base of thermosphere                                  STW2 38a
      ZZF = CHGT - ZF                                                    STW2 39
*****
```

The modifications, for the Stewart adjustments (ES) and the new adjustment parameter deltaTEX, are added to the value (TINF0) computed by Thermpar.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      RF = RREF + ZF                                                    STW2 45
      TINF = 4.11 * (11.0 + FBARR) * EXP(ES(2) + ES(3))                 STW2 46
      TF = (170.0 * SMA / RAU) * EXP(ES(8) + ES(9))                     STW2 47
      If (FLAG .GT. 0) then                                             STW2 48
***** Mars-GRAM 3.4\MARSSUBS.FOR
      RF = RREF + ZF                                                    STW2 45
C...  Exospheric temperature                                            STW2 45a
      TINF = TINF0 * EXP(ES(2) + ES(3)) + deltaTEX                      STW2 46
C...  Temperature at base of thermosphere                               STW2 46h
      TF = TF0 * EXP(ES(8) + ES(9)) + deltaTF                           STW2 47
      If (FLAG .GT. 0) then                                             STW2 48
*****
```

The SCALE parameter is added as an argument for the THERMOS subroutine.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      CALL THERMOS(FLAG, ES, TINF, TF, LAT, LST, ZF,RF, ZZF, TOTALPRZ,  STW2 58
     & TOTALNDZ, TZ, MOLWTG, PRZ, NDZ, MDZ, TOTALMDZ ,iu0)              STW2 59
C...  SCALE HEIGHT, km                                                  STW2 60
***** Mars-GRAM 3.4\MARSSUBS.FOR
      CALL THERMOS(FLAG, ES, TINF, TF, LAT, LST, ZF,RF, ZZF, TOTALPRZ,  STW2 58
     & TOTALNDZ, TZ, MOLWTG, PRZ, NDZ, MDZ, TOTALMDZ ,iu0, SCALE)       STW2 59
C...  SCALE HEIGHT, km                                                  STW2 60
*****
```

The SCALE parameter is added as an argument is the call statemnt for the THERMOS subroutine.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      SUBROUTINE THERMOS (FLAG, ES, TINF, TF, LAT, LST, ZF, RF, ZZF,    THRM  1
     & TOTALPRZ, TOTALNDZ, TZ, MOLWTG, PRZ, NDZ, MDZ, TOTALMDZ, iu0)    THRM  2
      INTEGER FLAG ,iu0                                                 THRM  3
      DIMENSION ES(0:11),PRZ(0:11),NDZ(0:11),MDZ(0:11)                  THRM  4
***** Mars-GRAM 3.4\MARSSUBS.FOR
      SUBROUTINE THERMOS (FLAG, ES, TINF, TF, LAT, LST, ZF, RF, ZZF,    THRM  1
     & TOTALPRZ, TOTALNDZ, TZ, MOLWTG, PRZ, NDZ, MDZ, TOTALMDZ, iu0,    THRM  2
     & SCALE)                                                           THRM  2a
      INTEGER FLAG ,iu0                                                 THRM  3
      DIMENSION ES(0:11),PRZ(0:11),NDZ(0:11),MDZ(0:11)                  THRM  4
*****
```

Computation of the SCALE parameter within the THERMOS subroutine is deleted, since its value now is input via the argument list.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
C.... FO = PARAMETER IN EQUATION FOR ATOMIC OXYGEN CONTENT I             THRM 39
      SCALE = TF / 9.20                                                 THRM 40
      M(0) = 44.011                                                     THRM 41
***** Mars-GRAM 3.4\MARSSUBS.FOR
C.... FO = PARAMETER IN EQUATION FOR ATOMIC OXYGEN CONTENT I             THRM 39
      M(0) = 44.011                                                     THRM 41
*****
```

The climate adjustment factors (CF) are added to the argument list for the subroutine TEMPS.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
C-----------------------------------------------------------------------THRM143
      Subroutine Temps(T0bar,Tsurf,gam,alat,dlon,dustM,dustA,als,T)     TMPS  1
C                                                                       TMPS  2
***** Mars-GRAM 3.4\MARSSUBS.FOR
C-----------------------------------------------------------------------THRM143
      Subroutine Temps(T0bar,Tsurf,gam,alat,dlon,dustM,dustA,als,T,CF)  TMPS  1
```

```
C                                                                      TMPS   2
*****
```

The climate adjustment factors (CF) are added to the dimension statement for the subroutine TEMPS.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      Dimension gam(5),T(0:5),dz(5),z(5),factor(5),dfactor(5),afact(5)  TMPS  17
     & ,A25(0:6),B25(0:6),C25(0:6)                                      TMPS  18
C...  Coefficients for T(25 km) correction to gammas                    TMPS  19
***** Mars-GRAM 3.4\MARSSUBS.FOR
      Dimension gam(5),T(0:5),dz(5),z(5),factor(5),dfactor(5),afact(5)  TMPS  17
     & ,A25(0:6),B25(0:6),C25(0:6),CF(0:5)                              TMPS  18
C...  Coefficients for T(25 km) correction to gammas                    TMPS  19
*****
```

The temperature at the significant levels are evaluated, with the inclusion of a multiplicative climate adjustment factor (CF).

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      T(0) = Tsurf                                                      TMPS138
C...  Re-evaluate lapse rates (deg./km), based on actual temperatures   TMPS139
***** Mars-GRAM 3.4\MARSSUBS.FOR
      T(0) = Tsurf                                                      TMPS138
C...  Apply climate adjustment factors                                  TMPS138a
      Do 45 i = 0,5                                                     TMPS138b
       T(i) = T(i)*CF(i)                                                TMPS138c
   45 Continue                                                          TMPS138d
C...  Re-evaluate lapse rates (deg./km), based on actual temperatures   TMPS139
*****
```

The new subroutine Thermpar is added. Thermpar evaluates the local values of TINF0, the exospheric temperature (K), TF0, the temperature (K) at the base of the thermosphere, ZF0, the height (km) of the base of the thermosphere, and SCALE, the scale height (km) for the thermospheric temperature variations.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
C-----------------------------------------------------------------------TMPS144
      Subroutine Tsurface(sitla,sitlo,sunla,sunlo,als,au,Tsurf,         TSRF   1
***** Mars-GRAM 3.4\MARSSUBS.FOR
C-----------------------------------------------------------------------TMPS144
      Subroutine Thermpar(RAU,FBARR,lat,LST,sunlat,TINF0,TF0,ZF0,       TPAR   1
     & SCALE)                                                           TPAR   2
      REAL lat,LST,LATMAX                                               TPAR   3
      Data LATMAX/25.4/                                                 TPAR   4
C                                                                       TPAR   5
C.....................................................................  TPAR   6
C                                                                       TPAR   7
C...  Thermospheric parameters, revised from the orginal Stewart        TPAR   8
C     parameterizations:                                                TPAR   9
C     SMA = 1.523691                                                    TPAR  10
C     ZF0 = 124.4 * (SMA/RAU)                                           TPAR  11
C     TINF0 = 4.11 * (11.0 + FBARR)                                     TPAR  12
C     TF0 = 170.0 * (SMA/RAU)                                           TPAR  13
C     SCALE = TF0 / 9.20                                                TPAR  14
C                                                                       TPAR  15
C     The new parameterizations are based on four data sets from the   TPAR  16
C     University of Arizona Mars Thermospheric Global Circulation       TPAR  17
C     Model (MTGCM), cases MGS97L, MGS98L, MANC00, and MGS97E. For      TPAR  18
C     a description of the MTGCM model and its output, see Bougher,     TPAR  19
C     et al., Journal of Geophysical Research, vol. 95 (B9), pp.        TPAR  20
C     14,811 - 14,827, August 30, 1990.                                 TPAR  21
C                                                                       TPAR  22
C.....................................................................  TPAR  23
C                                                                       TPAR  24
```

```
C     Inputs:
C       RAU    = orbital position radius (AU)
C       FBARR  = 10.7 cm solar flux at Mars position
C       lat    = latitude for evaluation of parameters (degrees)
C       LST    = local solar time (Mars hours) at evaluation point
C       sunlat = latitude of sun (degrees)
C     Outputs:
C       TINF0  = Exospheric temperature (K)
C       TF0    = Temperature at base of thermosphere (K)
C       ZF0    = Height of base of thermosphere (km)
C       SCALE  = Scale height for temperature variations (km)
C
C     Output values are un-corrected for Stewart (ES array) variations,
C     pressure and dust effects.  These factors are accounted for in
C     the Stewart2 subroutine.  Adjustment factors deltaTEX, deltaTF
C     and deltaZF are also added after computation of these values.
C.............................................................
C
C...  Degrees to radians conversion factor
      pi180 = Atan(1.)/45.
C...  Global mean exospheric temperature (K) versus 10.7 cm flux
      Tbar = 156.3 + 0.9427*FBARR
C...  Zonal average exospheric temperature (K) versus latitude
      Tavg = Tbar*(1. + 1.369E-4*sunlat*lat)
C...  Phase angles (hours) for local solar time variation
      t1 = 13.2 - 0.00119*sunlat*lat
      t2 = 9.4 - 0.00231*sunlat*lat
C...  Amplitude factor for local solar time variation
      cphi = Cos(pi180*(lat + sunlat)/(1. + LATMAX/90.))
C...  Exospheric temperature (K) versus local solar time
      TINF0 = Tavg*(1. + 0.22*cphi*Cos(pi180*15.0*(LST-t1)) +
     &  0.04*cphi*Cos(pi180*30.0*(LST-t2)))
C...  Global mean height of thermosphere base (km)
      Zbar = 197.94 - 49.058*RAU
C...  Latitude variation factor
      factlat = (sunlat/LATMAX)*(lat/77.5)**3
C...  Zonal average base height (km) versus latitude
      Zavg = Zbar + 4.3*factlat
C...  Amplitudes for local solar time variation
      A1 = 1.5 - Cos(pi180*4.0*lat)
      A2 = 2.3*(Cos(pi180*(lat + 0.5*sunlat)))**3
C...  Phase angles (hours) for local solar time variation
      t1 = 16.2 - (sunlat/LATMAX)*Atan(pi180*10.0*lat)
      t2 = 11.5
C...  Base height of thermosphere (km) versus local solar time
      ZF0 = Zavg + A1*Cos(pi180*15.0*(LST-t1)) +
     & A2*Cos(pi180*30.0*(LST-t2))
C...  Global mean temperature (K) at thermosphere base, versus FBARR
      Tbar = 113.7 + 0.5791*FBARR
C...  Zonal average temperature at thermosphere base (K) vs. latitude
      Tavg = Tbar*(1. + 0.186*factlat)
C...  Amplitudes for local solar time variation
      A1 = 0.06 - 0.05*Cos(pi180*4.0*lat)
      A2 = 0.1*(Cos(pi180*(lat + 0.5*sunlat)))**3
C...  Phase angles (hours) for local solar time variation
      t1 = 17.5 - 2.5*(sunlat/LATMAX)*Atan(pi180*10.0*lat)
      t2 = 10.0 + 2.0*(lat/77.5)**2
C...  Thermosphere base temperature (K) versus local solar time
      TF0 = Tavg*(1.0 + A1*Cos(pi180*15.0*(LST-t1)) +
     & A2*Cos(pi180*30.0*(LST-t2)))
C...  Global mean scale height (km) of thermospheric temperature
      SCALE = 8.38 + 0.09725*FBARR
C...  Zonal average temperature scale height (km) vs. latitude
      SCALE = SCALE*(1.14 - 0.18*Cos(pi180*lat))
      Return
      End
C-----------------------------------------------------------------
```

```
      Subroutine Tsurface(sitla,sitlo,sunla,sunlo,als,au,Tsurf,          TSRF   1
*****
```

4. Comparing SETUP.FOR for Mars-GRAM 3.34 and Mars-GRAM 3.4

The official version number is changed.

```
***** Mars-GRAM 3.34\SETUP.FOR
C                                                                         SETU   3
    1 Format(' Mars-GRAM Batch version 3.34 - November 1, 1995')         SETU   4
C                                                                         SETU   5
***** Mars-GRAM 3.4\SETUP.FOR
C                                                                         SETU   3
    1 Format(' Mars-GRAM Batch version 3.4 - April 1, 1996')             SETU   4
C                                                                         SETU   5
*****
```

The climate adjustment factors (CF) and the thermospheric adjustment parameters (DZF = deltaZF, dTF = deltaTF, and dTEX = deltaTEX) are added to the common DATACOM.

```
***** Mars-GRAM 3.34\SETUP.FOR
     & logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,        SETU  19
     & intens,iu0,iup,maxfiles                                           SETU  20
C.......................................................................  SETU  21
***** Mars-GRAM 3.4\SETUP.FOR
     & logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,        SETU  19
     & intens,iu0,iup,maxfiles,CF(0:5),dZF,dTF,dTEX                      SETU  20
C.......................................................................  SETU  21
*****
```

Default values are established for all of the input parameters. The default values are those that are applicable to the Viking 1 lander site date and time, at the Viking 1 lander surface position. With the default values set, only those parameters that differ from their default values need to be input in the NAMELIST file.

```
***** Mars-GRAM 3.34\SETUP.FOR
      DATA IDAY/0,31,59,90,120,151,181,212,243,273,304,334/              SETU  42
C.......................................................................  SETU  43
***** Mars-GRAM 3.4\SETUP.FOR
      DATA IDAY/0,31,59,90,120,151,181,212,243,273,304,334/              SETU  42
C...  Establish default values for input parameters                      SETU  42a
      Data LSTFL,OUTFL/'LIST','OUTPUT'/                                  SETU  42b
C...  Default time = Viking 1 Lander                                     SETU  42c
      Data Month,Mday,Myear,Ihr,Imin,Sec/7,20,76,12,30,0.0/              SETU  42d
C...  Default Solar Flux parameters                                      SETU  42e
      Data F107,Stdl/68.,0.0/                                            SETU  42f
C...  Default position = Viking 1 Lander Site, height = 0                SETU  42g
      Data Flat,Flon,Fhgt,Delhgt,Dellat,Dellon,Deltime/22.,48.,-0.5,     SETU  42h
     &  10.,3*0./                                                        SETU  42i
C...  CF climate factors default to 1.0                                  SETU  42j
      Data CF0,CF5,CF15,CF30,CF50,CF75/6*1.0/                            SETU  42k
C...  Terms deltaZF, deltaTF and deltaTEX default to 0.0                 SETU  42l
      Data deltaZF,deltaTF,deltaTEX/3*0.0/                               SETU  42m
C...  Default random number seed                                         SETU  42n
      Data NR1/1001/                                                     SETU  42o
C.......................................................................  SETU  43
*****
```

The climate adjustment factors (CF) and the thermospheric adjustment parameters (deltaZF, deltaTF, and deltaTEX) are added to the NAMELIST definition.

```
***** Mars-GRAM 3.34\SETUP.FOR
     & NVARX,NVARY,LOGSCALE,FLAT,FLON,FHGT,DELHGT,DELLAT,DELLON,             SETU 47
     & DELTIME                                                               SETU 48
C......................................................................     SETU 49
***** Mars-GRAM 3.4\SETUP.FOR
     & NVARX,NVARY,LOGSCALE,FLAT,FLON,FHGT,DELHGT,DELLAT,DELLON,             SETU 47
     & DELTIME,CF0,CF5,CF15,CF30,CF50,CF75,deltaZF,deltaTF,deltaTEX          SETU 48
C......................................................................     SETU 49
*****
```

The climate adjustment factors and thermospheric adjustment parameters are loaded into the common DATACOM.

```
***** Mars-GRAM 3.34\SETUP.FOR
      Read(8,INPUT)                                                          SETU 53
C......................................................................     SETU 54
***** Mars-GRAM 3.4\SETUP.FOR
      Read(8,INPUT)                                                          SETU 53
      CF(0) = CF0                                                            SETU 53a
      CF(1) = CF5                                                            SETU 53b
      CF(2) = CF15                                                           SETU 53c
      CF(3) = CF30                                                           SETU 53d
      CF(4) = CF50                                                           SETU 53e
      CF(5) = CF75                                                           SETU 53f
      Do 5 i = 0,5                                                           SETU 53g
        If (CF(i).le.0.0)Stop ' Bad CF value'                                SETU 53h
  5   Continue                                                               SETU 53i
      dzF = deltaZF                                                          SETU 53j
      dTF = deltaTF                                                          SETU 53k
      dTEX = deltaTEX                                                        SETU 53l
C......................................................................     SETU 54
*****
```

Appendix B - Reference LIST Output for Mars-GRAM 3.4

```
Mars-GRAM Batch version 3.4 - April 1, 1996
 Date =  7/20/1976  Julian Date = 2442980.0  GMT Time = 12:30:  .0
 F10.7 flux =  68.0 (1 AU)   25.0 (Mars),  standard deviation =   .0
 Perturbation model = 3   Starting random number =  1001
 Time (rel. to T0) =          .0 sec. (    .000 sols)    Ls =   97.0 deg.
 Height =   -.50 km (    .00 km)   Scale Height =  12.50 km
 Latitude =   22.000 degrees       West Longitude =   48.000 degrees
 Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
 Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
 Temperature =    243.8 K          Pressure =    7.479E+02 N/m**2
 Density (Low, Avg., High) =     1.500E-02   1.604E-02   1.709E-02 kg/m**3
 Departure, COSPAR NH Mean =       -7.6 %       -1.2 %        5.3 %
 Density perturbation =          5.72 % of mean value
 Eastward Wind =      4.3 m/s      Northward Wind =     -.4 m/s
 -------------------------------------------------------------------------
 Time (rel. to T0) =          .0 sec. (    .000 sols)    Ls =   97.0 deg.
 Height =   9.50 km (  10.00 km)   Scale Height =  10.40 km
 Latitude =   22.000 degrees       West Longitude =   48.000 degrees
 Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
 Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
 Temperature =    202.9 K          Pressure =    3.058E+02 N/m**2
 Density (Low, Avg., High) =     7.621E-03   7.886E-03   8.154E-03 kg/m**3
 Departure, COSPAR NH Mean =       12.9 %       16.8 %       20.8 %
 Density perturbation =         -1.39 % of mean value
 Eastward Wind =      1.4 m/s      Northward Wind =    -5.3 m/s
 -------------------------------------------------------------------------
 Time (rel. to T0) =          .0 sec. (    .000 sols)    Ls =   97.0 deg.
 Height =  19.50 km (  20.00 km)   Scale Height =   9.50 km
 Latitude =   22.000 degrees       West Longitude =   48.000 degrees
 Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
 Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
 Temperature =    185.2 K          Pressure =    1.124E+02 N/m**2
 Density (Low, Avg., High) =     3.041E-03   3.175E-03   3.312E-03 kg/m**3
 Departure, COSPAR NH Mean =       10.3 %       15.1 %       20.1 %
 Density perturbation =         -1.42 % of mean value
 Eastward Wind =     -1.7 m/s      Northward Wind =    -8.7 m/s
 -------------------------------------------------------------------------
 Time (rel. to T0) =          .0 sec. (    .000 sols)    Ls =   97.0 deg.
 Height =  29.50 km (  30.00 km)   Scale Height =   8.73 km
 Latitude =   22.000 degrees       West Longitude =   48.000 degrees
 Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
 Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
 Temperature =    170.4 K          Pressure =    3.812E+01 N/m**2
 Density (Low, Avg., High) =     1.098E-03   1.170E-03   1.244E-03 kg/m**3
 Departure, COSPAR NH Mean =        6.2 %       13.2 %       20.3 %
 Density perturbation =          -.33 % of mean value
 Eastward Wind =     -4.6 m/s      Northward Wind =   -13.5 m/s
 -------------------------------------------------------------------------
 Time (rel. to T0) =          .0 sec. (    .000 sols)    Ls =   97.0 deg.
 Height =  39.50 km (  40.00 km)   Scale Height =   8.20 km
 Latitude =   22.000 degrees       West Longitude =   48.000 degrees
 Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
 Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
 Temperature =    160.0 K          Pressure =    1.198E+01 N/m**2
 Density (Low, Avg., High) =     3.667E-04   3.915E-04   4.173E-04 kg/m**3
 Departure, COSPAR NH Mean =        2.1 %        9.1 %       16.2 %
 Density perturbation =          -.34 % of mean value
 Eastward Wind =     -8.0 m/s      Northward Wind =   -19.7 m/s
 -------------------------------------------------------------------------
 Time (rel. to T0) =          .0 sec. (    .000 sols)    Ls =   97.0 deg.
 Height =  49.50 km (  50.00 km)   Scale Height =   7.68 km
 Latitude =   22.000 degrees       West Longitude =   48.000 degrees
 Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
```

```
Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
Temperature =    149.8 K          Pressure =     3.511E+00 N/m**2
Density (Low, Avg., High) =      1.108E-04   1.226E-04   1.347E-04 kg/m**3
Departure, COSPAR NH Mean =        -3.5 %       6.8 %       17.3 %
Density perturbation =           5.25 % of mean value
Eastward Wind =   -11.7 m/s       Northward Wind =   -26.4 m/s
------------------------------------------------------------------------
Time (rel. to T0) =        .0 sec. (     .000 sols)    Ls =   97.0 deg.
Height =  59.50 km (  60.00 km)   Scale Height =   7.40 km
Latitude =   22.000 degrees       West Longitude =   48.000 degrees
Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
Temperature =   144.3 K           Pressure =     9.703E-01 N/m**2
Density (Low, Avg., High) =      3.040E-05   3.517E-05   4.002E-05 kg/m**3
Departure, COSPAR NH Mean =       -10.3 %       3.8 %       18.1 %
Density perturbation =          -8.82 % of mean value
Eastward Wind =   -15.9 m/s       Northward Wind =   -33.7 m/s
------------------------------------------------------------------------
Time (rel. to T0) =        .0 sec. (     .000 sols)    Ls =   97.0 deg.
Height =  69.50 km (  70.00 km)   Scale Height =   7.14 km
Latitude =   22.000 degrees       West Longitude =   48.000 degrees
Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
Temperature =    139.2 K          Pressure =     2.579E-01 N/m**2
Density (Low, Avg., High) =      8.376E-06   9.690E-06   1.103E-05 kg/m**3
Departure, COSPAR NH Mean =       -10.2 %       3.9 %       18.2 %
Density perturbation =          -2.23 % of mean value
Eastward Wind =   -20.4 m/s       Northward Wind =   -39.8 m/s
------------------------------------------------------------------------
Time (rel. to T0) =        .0 sec. (     .000 sols)    Ls =   97.0 deg.
Height =  79.50 km (  80.00 km)   Scale Height =   7.25 km
Latitude =   22.000 degrees       West Longitude =   48.000 degrees
Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K       Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   134.9 K           Pressure =     6.050E-02 N/m**2
Density (Low, Avg., High) =      1.838E-06   2.343E-06   2.892E-06 kg/m**3
Departure, COSPAR NH Mean =       -24.9 %      -4.3 %       18.1 %
Density perturbation =           3.56 % of mean value
Eastward Wind =   -25.4 m/s       Northward Wind =   -43.8 m/s
------------------------------------------------------------------------
Time (rel. to T0) =        .0 sec. (     .000 sols)    Ls =   97.0 deg.
Height =  89.50 km (  90.00 km)   Scale Height =   7.16 km
Latitude =   22.000 degrees       West Longitude =   48.000 degrees
Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K       Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   132.1 K           Pressure =     1.182E-02 N/m**2
Density (Low, Avg., High) =      3.388E-07   4.663E-07   6.134E-07 kg/m**3
Departure, COSPAR NH Mean =       -47.3 %     -27.4 %       -4.5 %
Density perturbation =         -34.81 % of mean value
Eastward Wind =   -38.3 m/s       Northward Wind =   -45.7 m/s
------------------------------------------------------------------------
Time (rel. to T0) =        .0 sec. (     .000 sols)    Ls =   97.0 deg.
Height =  99.50 km ( 100.00 km)   Scale Height =   7.11 km
Latitude =   22.000 degrees       West Longitude =   48.000 degrees
Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K       Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   129.9 K           Pressure =     2.279E-03 N/m**2
Density (Low, Avg., High) =      6.544E-08   9.113E-08   1.211E-07 kg/m**3
Departure, COSPAR NH Mean =       -61.5 %     -46.4 %      -28.8 %
Density perturbation =          -9.68 % of mean value
Eastward Wind =   -62.1 m/s       Northward Wind =   -47.3 m/s
------------------------------------------------------------------------
Time (rel. to T0) =        .0 sec. (     .000 sols)    Ls =   97.0 deg.
Height = 109.50 km ( 110.00 km)   Scale Height =   7.11 km
```

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Latitude =   22.000 degrees        West Longitude =   48.000 degrees
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.       Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K        Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   128.9 K            Pressure =    4.402E-04 N/m**2
Density (Low, Avg., High) =      1.269E-08   1.768E-08   2.350E-08 kg/m**3
Departure, COSPAR NH Mean =        -71.3 %      -60.0 %      -46.8 %
Density perturbation =           24.11 % of mean value
Eastward Wind =  -103.2 m/s        Northward Wind =   -50.0 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =         .0 sec. (    .000 sols)    Ls =   97.0 deg.
Height = 119.50 km ( 120.00 km)   Scale Height =   8.09 km
Latitude =   22.000 degrees        West Longitude =   48.000 degrees
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.       Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K        Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   144.9 K            Pressure =    9.240E-05 N/m**2
Density (Low, Avg., High) =      2.358E-09   3.285E-09   4.366E-09 kg/m**3
Departure, COSPAR NH Mean =        -81.4 %      -74.1 %      -65.5 %
Density perturbation =          -23.70 % of mean value
Eastward Wind =  -139.0 m/s        Northward Wind =   -49.7 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =         .0 sec. (    .000 sols)    Ls =   97.0 deg.
Height = 129.50 km ( 130.00 km)   Scale Height =  10.57 km
Latitude =   22.000 degrees        West Longitude =   48.000 degrees
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.       Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K        Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   185.2 K            Pressure =    3.201E-05 N/m**2
Density (Low, Avg., High) =      6.286E-10   8.759E-10   1.164E-09 kg/m**3
Departure, COSPAR NH Mean =        -84.2 %      -78.0 %      -70.7 %
Density perturbation =             .46 % of mean value
Eastward Wind =  -177.2 m/s        Northward Wind =   -72.5 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =         .0 sec. (    .000 sols)    Ls =   97.0 deg.
Height = 139.50 km ( 140.00 km)   Scale Height =  11.78 km
Latitude =   22.000 degrees        West Longitude =   48.000 degrees
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.       Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K        Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   200.9 K            Pressure =    1.313E-05 N/m**2
Density (Low, Avg., High) =      2.325E-10   3.240E-10   4.306E-10 kg/m**3
Departure, COSPAR NH Mean =        -79.8 %      -71.8 %      -62.5 %
Density perturbation =            7.64 % of mean value
Eastward Wind =  -193.9 m/s        Northward Wind =  -108.6 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =         .0 sec. (    .000 sols)    Ls =   97.0 deg.
Height = 149.50 km ( 150.00 km)   Scale Height =  12.59 km
Latitude =   22.000 degrees        West Longitude =   48.000 degrees
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.       Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K        Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   206.9 K            Pressure =    5.780E-06 N/m**2
Density (Low, Avg., High) =      9.633E-11   1.342E-10   1.784E-10 kg/m**3
Departure, COSPAR NH Mean =        -80.4 %      -72.7 %      -63.7 %
Density perturbation =           24.11 % of mean value
Eastward Wind =  -178.4 m/s        Northward Wind =  -157.3 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =         .0 sec. (    .000 sols)    Ls =   97.0 deg.
Height = 159.50 km ( 160.00 km)   Scale Height =  13.39 km
Latitude =   22.000 degrees        West Longitude =   48.000 degrees
Sun Latitude =    25.00 deg.       Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.       Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K        Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   209.3 K            Pressure =    2.674E-06 N/m**2
Density (Low, Avg., High) =      4.217E-11   5.875E-11   7.808E-11 kg/m**3
Departure, COSPAR NH Mean =        -83.2 %      -76.6 %      -68.9 %
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Density perturbation =          -46.41 % of mean value
Eastward Wind =  -112.9 m/s       Northward Wind =  -191.6 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =        .0 sec. (    .000 sols)    Ls =   97.0 deg.
Height = 169.50 km ( 170.00 km)   Scale Height =  14.36 km
Latitude =   22.000 degrees       West Longitude =   48.000 degrees
Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K       Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   210.2 K           Pressure =     1.298E-06 N/m**2
Density (Low, Avg., High) =      1.919E-11   2.674E-11   3.554E-11 kg/m**3
Departure, COSPAR NH Mean =        -86.2 %      -80.8 %      -74.4 %
Density perturbation =          -14.25 % of mean value
Eastward Wind =   -33.4 m/s       Northward Wind =  -168.4 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =        .0 sec. (    .000 sols)    Ls =   97.0 deg.
Height = 179.50 km ( 180.00 km)   Scale Height =  15.64 km
Latitude =   22.000 degrees       West Longitude =   48.000 degrees
Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K       Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   210.6 K           Pressure =     6.652E-07 N/m**2
Density (Low, Avg., High) =      9.081E-12   1.265E-11   1.682E-11 kg/m**3
Departure, COSPAR NH Mean =        -88.8 %      -84.4 %      -79.3 %
Density perturbation =             -.62 % of mean value
Eastward Wind =     6.0 m/s       Northward Wind =  -116.9 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =        .0 sec. (    .000 sols)    Ls =   97.0 deg.
Height = 189.50 km ( 190.00 km)   Scale Height =  17.30 km
Latitude =   22.000 degrees       West Longitude =   48.000 degrees
Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K       Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   210.8 K           Pressure =     3.617E-07 N/m**2
Density (Low, Avg., High) =      4.489E-12   6.254E-12   8.312E-12 kg/m**3
Departure, COSPAR NH Mean =        -90.8 %      -87.1 %      -82.9 %
Density perturbation =              .27 % of mean value
Eastward Wind =    15.7 m/s       Northward Wind =   -77.2 m/s
--------------------------------------------------------------------------
Time (rel. to T0) =        .0 sec. (    .000 sols)    Ls =   97.0 deg.
Height = 199.50 km ( 200.00 km)   Scale Height =  19.35 km
Latitude =   22.000 degrees       West Longitude =   48.000 degrees
Sun Latitude =     25.00 deg.     Mars Orbital Radius = 1.649 AU
Sun Longitude =  108.77 deg.      Local Time =  16.05 Mars hours
Exospheric Temp. =  210.9 K       Tbase =  128.2 K    Zbase =  117.1 km
Temperature =   210.8 K           Pressure =     2.092E-07 N/m**2
Density (Low, Avg., High) =      2.334E-12   3.252E-12   4.322E-12 kg/m**3
Departure, COSPAR NH Mean =        -92.2 %      -89.1 %      -85.6 %
Density perturbation =           -8.87 % of mean value
Eastward Wind =    15.5 m/s       Northward Wind =   -52.9 m/s
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APPROVAL

A REVISED THERMOSPHERE FOR THE MARS GLOBAL REFERENCE ATMOSPHERIC MODEL (Mars-GRAM VERSION 3.4)

C. G. Justus, D. L. Johnson and B. F. James

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

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13. ABSTRACT *(Maximum 200 words)*
This report describes the newly-revised model thermosphere for the Mars Global Reference Atmospheric Model (Mars-GRAM, Version 3.4). It also provides descriptions of other changes made to the program since publication of the programmer's guide (Justus et al., 1996) for Mars-GRAM Version 3.34. The original Mars-GRAM model thermosphere was based on the global-mean model of Stewart (1987). The revised thermosphere is based largely on parameterizations derived from output data from the three-dimensional Mars Thermospheric Global Circulation Model (MTGCM) of Bougher et al. (1990). The new thermospheric model includes revised dependence on the 10.7 cm solar flux for the global means of exospheric temperature, temperature of the base of the thermosphere, and scale height for the thermospheric temperature variations, as well as revised dependence on orbital position for global mean height of the base of the thermosphere. Other features of the new thermospheric model are (1) realistic variations of temperature and density with latitude and time of day, (2) more realistic wind magnitudes, based on improved estimates of horizontal pressure gradients, and (3) allowance for user-input adjustments to the model values for mean exospheric temperature and for height and temperature at the base of the thermosphere. Other new features of Mars-GRAM 3.4 include (1) allowance for user-input values of climatic adjustment factors for temperature profiles from the surface to 75 km, and (2) a revised method for computing the sub-solar longitude position in the "ORBIT" subroutine.

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