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

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C.J. Justus
Computer Sciences Corporation • Huntsville, Alabama

D. L. Johnson and B.F. James
Marshall Space Flight Center • MSFC, Alabama
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Preface

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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 \( (1.26 \times 10^{-4} \text{ N/m}^2) \), (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 \( \Delta Z = Z - ZF \) above the base of the thermosphere, located where the radius of the Mars reference ellipsoid is \( R_0 \) (and \( RF = R_0 + ZF \)), the vertical temperature variation is computed by

\[
YSC = \frac{ZZF \times RF}{RF + ZZF} \quad \text{THRM108}
\]

\[
TZ = TINF - (TINF - TF) \times \exp\left(-\frac{YSC}{SCALE}\right) \quad \text{THRM109}
\]

(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

\[
HH(I) = \frac{BK \times TINF}{\left(GF \times DM(I)\right) / 1.0E5} \quad \text{THRM111}
\]

\[
PRZ(I) = PRESSF \times FF(I) \times \exp\left(-\frac{YSC}{HH(I)} - \left(\frac{SCALE}{HH(I)}\right) \times \text{ALOG}(TZ/TF)\right) \quad \text{THRM113}
\]

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.

<table>
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<tr>
<th>Data Source</th>
<th>R(AU)</th>
<th>1 AU Mars</th>
<th>TINF (K)</th>
<th>TF (K)</th>
<th>ZF (km)</th>
<th>SCALE (km)</th>
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<tr>
<td>Mariner 4</td>
<td>1.55</td>
<td>77</td>
<td>32</td>
<td></td>
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<tr>
<td>Mariner 6-7</td>
<td>1.45</td>
<td>206</td>
<td>98</td>
<td>240</td>
<td>170</td>
<td>117</td>
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<tr>
<td>Mariner 9 (primary)</td>
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<td>110</td>
<td>50</td>
<td>220</td>
<td>160</td>
<td>123</td>
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<tr>
<td>Mariner 9 (extended)</td>
<td>1.62</td>
<td>115</td>
<td>44</td>
<td></td>
<td></td>
<td>115</td>
</tr>
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<td>Viking Lander 1</td>
<td>1.62</td>
<td>68</td>
<td>26</td>
<td>180</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>Viking Lander 2</td>
<td>1.63</td>
<td>74</td>
<td>28</td>
<td>180</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>Phobos (DMED)</td>
<td>1.53</td>
<td>150</td>
<td>64</td>
<td>215</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phobos (DMAX)</td>
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<td>150</td>
<td>54</td>
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<tr>
<td>Phobos (DMIN)</td>
<td>1.38</td>
<td>150</td>
<td>79</td>
<td>230</td>
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<td>MTGCM, MGS97L</td>
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<td>130</td>
<td>68</td>
<td>228</td>
<td>147</td>
<td>128 15.0</td>
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<td>130</td>
<td>47</td>
<td>196</td>
<td>141</td>
<td>115 12.9</td>
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<tr>
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<td>64</td>
<td>229</td>
<td>147</td>
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<td>185</td>
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<td>127 12.4</td>
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Regression relations versus both 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:

\[
<TINF> = 156.3 + 0.9427 \ F10.7 \\
<TZ> = 197.94 - 49.058 \ R \\
<TF> = 113.7 + 0.5791 \ F10.7 \\
<SCALE> = 8.38 + 0.09725 \ F10.7
\]

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 $<T_{INF}>$ and $<T_F>$ regressions, but the VL-1 point is a significant "outlier" in the $<Z_F>$ 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 $<Z_F>$ 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 Bouger et al. (1990), which also applies to global mean exospheric temperature. [The middle and upper curves within the shaded area of Bouger'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 $<T_F> = 267.13 - 80.905 \times R$) 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 ($T_{INF}0$, K) is computed from the global average value ($<T_{INF}> = T_{bar}$) by the program steps:

```
C... Zonal average exospheric temperature (K) versus latitude
Tavg = Tbar*(1 + 1.369E-4*sunlat*lat) TPAR 47

C... Phase angles (hours) for local solar time variation
tl = 13.2 - 0.00119*sunlat*lat TPAR 48
t2 = 9.4 - 0.00231*sunlat*lat TPAR 49

C... Amplitude factor for local solar time variation
Cphi = cos(pilS0*(lat + sunlat)/(1 + LATMAX/90.)) TPAR 50

C... Exospheric temperature (K) versus local solar time
TINF0 = Tavg*(1 + 0.22*cphi*cos(pil80*15.0*(LST-tl)) +
& 0.04*cphi*cos(pil80*30.0*(LST-t2))) TPAR 51
```
where "lat" is the local latitude (in degrees), "sunlat" is the latitude (in degrees) of the subsolar 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 + 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  
TINF = TINF0 * EXP(ES(2) + ES(3)) + deltaTEX  
TF = TF0 * EXP(ES(8) + ES(9)) + deltaTF

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 T/NF 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:

\[
\begin{align*}
\text{VISCFAC} & = 0.04 \cdot \frac{\text{VISC}}{(1.0E6 \cdot \text{DENS} \cdot \text{VLL}^2)} \\
\text{DENOM} & = \text{CORIOL}^2 + \text{VISCFAC}^2 \\
\text{EWWIND} & = \frac{\text{CORIOL} \cdot \text{FUG} - \text{VISCFAC} \cdot \text{FVG}}{\text{DENOM}} \\
\text{NSWIND} & = \frac{\text{CORIOL} \cdot \text{FVG} + \text{VISCFAC} \cdot \text{FUG}}{\text{DENOM}}
\end{align*}
\]

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-isotherm 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. Bouger et al., 1990, figure 7a; Bouger 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-isotherm 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)
ALSO   = 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   = 48.0, ! initial latitude (N positive), degrees
FLON   = 48.0, ! initial longitude (West positive), degrees
FHGT   = -0.5, ! initial height (km), above ref. ellipse
DELIHGT = 10.0, ! height increment (km) between steps
DELLAT = 0.0, ! latitude increment (deg) between steps
DELLON = 0.0, ! West longitude increment (deg) between steps
DELTME = 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,
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


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 (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/m³) 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-GRAM 3.4\MARSGRAM.FOR
C... Program Mars-GRAM Interactive version 3.4 - April 1, 1996 MARS 1
C
*****

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

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

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

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)
format(' Enter name for LIST file (CON for console listing): ') MARS 44
***** Mars-GRAM 3.34\MARSGRAM.FOR
Write(iu0,10)
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
  CF(i) = 1.0 MARS 44b
  Continue 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
*****

A-1
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
***** Mars-GRAM 3.4\MARSGRMB.FOR
C... Program Mars-GRAM Batch version 3.4 - April 1, 1996 MARB 1
C
*****

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

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

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/FI07,stdl
  ATM2 5
Dimension ES(0:II)
  ATM2 6
C
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

A-3
The climate adjustment factors (CF) are added to the argument list of the subroutine TEMPS.
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
ZF = 124.4 * (SMA / MARSAU) * EXP(ES(8)) + DR + DUST
C... Shgt = height for call to thermosphere model
Shgt = ZF if current height < ZF
Shgt = CHGT
If (CHGT < ZF) Shgt = ZF
C... Evaluate atmospheric parameters at base of thermosphere
Call Stewart2(MARSAU, ALS, CLAT, TIME, PRES, TEMP, DENST, & Shgt, Rstar, H, AMF, 0.0, als0, INTENS, iu0)
C... Evaluate density perturbation factor at base of thermosphere
Call Stewart2(MARSAU, ALS, CLAT, TIME, PRESHI, TEMPHI, & DENSHI, Shgt, Rstar, HHI, AMHI, 1.0, als01, INTENS, iu0)
tfactor = DENSHI/DENST - 1.0
C... Use stratosphere model if current height < ZF
If (CHGT < ZF) then
PF = PRES
***** Mars-GRAM 3.4\MARSSUBS.FOR
C... Height of base of thermosphere
Call Thermpar(MARSAU, 70., CLAT, TIME, SUNLAT, TINF0, TF0, ZF0, SCALE)
ZF = ZF0 * EXP(ES(8)) + DR + DUST + deltaZF
C... Use stratosphere model if current height < ZF
If (CHGT < ZF) then
Shgt = ZF
C... Evaluate thermospheric parameters at current height
Call Stewart2(MARSAU, ALS, CLAT, TIME, PRES, TEMP, DENST, & Shgt, Rstar, H, AMF, 0.0, als0, INTENS, iu0, sunlat, deltaZF, deltaTF, & deltaTEX, TINF, TF)
Tbase = TF
Texos = TINF
C... Evaluate density perturbation factor at base of thermosphere
Call Stewart2(MARSAU, ALS, CLAT, TIME, PRESHI, TEMPHI, & DENSHI, Shgt, Rstar, HHI, AMHI, 1.0, als0, INTENS, iu0, sunlat, & deltaZF, deltaTF, deltaTEX, TINF, TF)
tfactor = DENSHI/DENST - 1.0
PF = PRES
*****

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
Call Stewart2(MARSAU, ALS, CLAT, TIME, PRESHI, & TEMPHI, DENSHI, Shgt, Rstar, HHI, AMHI, 1.0, als0, INTENS, iu0)
Call Stewart2(MARSAU, ALS, CLAT, TIME, PRESLO, & TEMPLEO, DENSLO, Shgt, Rstar, HLO, AMLO, -1.0, als0, INTENS, iu0)
UPFCTR = DENSHI/DENST
***** Mars-GRAM 3.4\MARSSUBS.FOR
Else
Shgt = CHGT
C... Evaluate thermospheric parameters at current height
Call Stewart2(MARSAU, ALS, CLAT, TIME, PRES, TEMP, DENST,
Adjustment parameters CF, deltaZF, deltaTF, and deltaTEX are added to the common DATACOM.

***** Mars-GRAM 3.34\MARSSUBS.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Ref,modpert,als0,
& intens,iu0,iup,maxfiles
C... Unit numbers for messages (normally to screen) and to list output

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

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/
C... Zurek wave perturbation parameter data values

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

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

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

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

***** Mars-GRAM 3.34\MARSSUBS.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Ref,modpert,als0,
& intens,iu0,iup,maxfiles
***** Mars-GRAM 3.4\MARSSUBS.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Ref,modpert,als0,
& intens,iu0,iup,maxfiles

A-6
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.

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.

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.

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.
The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texes, 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,
& TMAM,TMIM,TAVM,bvf,den0,tfac,zt,als0,INTENS,iu0) DSTDPI14

C... Area average height
**** Mars-GRAM 3.4\MARSSUBS.FOR
& dustM,dustA,HLATM,TLATM,DLATM,FHI,FLO,PLATM,RLATM,thgt,
& TMAM,TMIM,TAVM,bvf,den0,tfac,zt,als0,INTENS,iu0,CF,deltaZF,
& deltaTF,deltaTEX,TINF,TF) DSTDPI15

C... Area average height

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) DSTDPI13
VISCFAC = VISC/(1.0E6*DENS*VLL**2) DSTDPI14

C... FUG, FVG = Coriolis parameter times components of areostrophic

**** Mars-GRAM 3.4\MARSSUBS.FOR
VISC = BETA*TEMP**1.5/(TEMP + SVAL) DSTDPI13
VISCFAC = 0.04*VISC/(1.0E6*DENS*VLL**2) DSTDPI14a

C... FUG, FVG = Coriolis parameter times components of areostrophic

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 DSTDPI237
If (DENSP .lt. 0.0)DENSP = 0.05*DENS DSTDPI238

C... Standard deviation in random density perturbation (% of mean),

**** Mars-GRAM 3.4\MARSSUBS.FOR
IF(RHO.GE.0.0)DENSP = DENS*(1. + wave) + RHO*DPLUS DSTDPI237
If (DENSP .lt. 0.05*DENS)DENSP = 0.05*DENS DSTDPI238a
If (DENSP .gt. (1.+pertmax)*DENS)DENSP = (1.+pertmax)*DENS DSTDPI238b

C... Standard deviation in random density perturbation (% of mean),

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 DSTDPI241

C... Add Zurek wave amplitudes to DENSHI, subtract from DENSLO

**** Mars-GRAM 3.4\MARSSUBS.FOR
SIGD = 50.*(DENSHI-DENSLO)/DENS DSTDPI241

C... Re-check SIGD, DENSHI and DENSLO
If (SIGD.gt.100.*pertmax)Then DSTDPI241a
SIGD = 100.*pertmax DSTDPI241b
DENSHI = DENS*(1. + pertmax) DSTDPI241c
DENSLO = DENS/(1. + pertmax) DSTDPI241d
Endif

C... Add Zurek wave amplitudes to DENSHI, subtract from DENSLO

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, DSTDPI248
The output variable for NVARX=8 is changed to local solar time in hours (from hour angle in degrees).

The output variable for NVARY=8 is changed to local solar time in hours (from hour angle in degrees).
The new coefficients are loaded for the 687 day plus 777 day sun longitude calculations (previously a single, 696 day, periodicity was assumed).

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

The new, dual period, solar longitude model equations are evaluated.
The new variables (sunlat, deltaZF, deltaTF, deltaTEX, TINF, and TF) are added to the argument list for the call to subroutine Stewart2.

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

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

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.

The modifications, for the Stewart adjustments (ES) and the new adjustment parameter deltaTEX, are added to the value (TTF0) computed by Thermpar.
***** Mars-GRAM 3.34\MARSSUBS.FOR
RF = RREF + ZF
TINF = 4.11 * (11.0 + FBBAR) * EXP(ES(2) + ES(3))
TF = (170.0 * SMA / RAU) * EXP(ES(8) + ES(9))
If (FLAG .GT. 0) then
***** Mars-GRAM 3.4\MARSSUBS.FOR
RF = RREF + ZF

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

C... Exospheric temperature
TINF = TINF0 * EXP(ES(2) + ES(3)) + deltaTEX
C... Temperature at base of thermosphere
TF = TF0 * EXP(ES(8) + ES(9)) + deltaTF
If (FLAG .GT. 0) then

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

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

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

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

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)
C
***** Mars-GRAM 3.4\MARSSUBS.FOR
C-----------------------------------------------THRM143
Subroutine Temps(T0bar,Tsurf,gam,alat,dlon,dustM,dustA,als,T,CF)
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), A25(0:6), B25(0:6), C25(0:6)
C... Coefficients for T(25 km) correction to gammas
***** Mars-GRAM 3.4\MARSSUBS.FOR
Dimension gam(5), T(0:5), dz(5), z(5), factor(5), dfactor(5), afact(5), A25(0:6), B25(0:6), C25(0:6), CF(0:5)
C... Coefficients for T(25 km) correction to gammas
*****

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
C... Re-evaluate lapse rates (deg./km), based on actual temperatures
*****

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 Tsurf(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, SCALE)

REAL lat, LST, LATMAX
Data LATMAX/25.4/

The new parameterizations are based on four data sets from the University of Arizona Mars Thermospheric Global Circulation Model (MTGCM), cases MGS97L, MGS98L, MANC00, and MGS97E. For a description of the MTGCM model and its output, see Bougher, et al., Journal of Geophysical Research, vol. 95 (B9), pp. 14,811 - 14,827, August 30, 1990.

C..................................................................................................TPAR 1
C... Thermospheric parameters, revised from the orginal Stewart parameterizations:
C
C SMA = 1.523691
C ZF0 = 124.4 * (SMA/RAU)
C TINF0 = 4.11 * (11.0 + FBARR)
C TF0 = 170.0 * (SMA/RAU)
C SCALE = TF0 / 9.20

C The new parameterizations are based on four data sets from the University of Arizona Mars Thermospheric Global Circulation Model (MTGCM), cases MGS97L, MGS98L, MANC00, and MGS97E. For a description of the MTGCM model and its output, see Bougher, et al., Journal of Geophysical Research, vol. 95 (B9), pp. 14,811 - 14,827, August 30, 1990.
C
Inputs:

RAU = orbital position radius (AU)

FBARR = 10.7 cm solar flux at Mars position

lat = latitude for evaluation of parameters (degrees)

LST = local solar time (Mars hours) at evaluation point

sunlat = latitude of sun (degrees)

Outputs:

TINF0 = Exospheric temperature (K)

TF0 = Temperature at base of thermosphere (K)

ZF0 = Height of base of thermosphere (km)

SCALE = Scale height for temperature variations (km)

Output values are un-corrected for Stewart (ES array) variations, pressure and dust effects. These factors are accounted for in the Stewart2 subroutine. Adjustment factors deltaTEX, deltaTF and deltaZF are also added after computation of these values.

Degrees to radians conversion factor

pi180 = \pi(1.)/45.

Global mean exospheric temperature (K) versus 10.7 cm flux

Tbar = 156.3 + 0.9427*FBARR

Zonal average exospheric temperature (K) versus latitude

Tavg = Tbar*(1. + 1.369E-4*sunlat*lat)

Phase angles (hours) for local solar time variation

t1 = 13.2 - 0.00119*sunlat*lat
t2 = 9.4 - 0.00231*sunlat*lat

Amplitude factor for local solar time variation

cphi = \cos(pi180*(lat + sunlat)/(1. + LATMAX/90.))

Exospheric temperature (K) versus local solar time

TINF0 = Tavg*(1. + 0.22*cphi*\cos(pi180*15.0*(LST-tl)) + 0.04*cphi*\cos(pi180*30.0*(LST-t2)))

Global mean height of thermosphere base (km)

Zbar = 197.94 - 49.058*RAU

Latitude variation factor

factlat = (sunlat/LATMAX)*(lat/77.5)**3

Zonal average base height (km) versus latitude

Zavg = Zbar + 4.3*factlat

Amplitudes for local solar time variation

A1 = 1.5*\cos(pi180*4.0*lat)

A2 = 2.3*(\cos(pi180*(lat + 0.5*sunlat)))**3

Phase angles (hours) for local solar time variation

t1 = 16.2 - (sunlat/LATMAX)*\atan(pi180*10.0*lat)
t2 = 11.5

Base height of thermosphere (km) versus local solar time

ZF0 = Zavg + A1*\cos(pi180*15.0*(LST-tl)) + A2*\cos(pi180*30.0*(LST-t2))

Global mean temperature (K) at thermosphere base, versus FBARR

Tbar = 113.7 + 0.5791*FBARR

Zonal average temperature at thermosphere base (K) vs. latitude

Tavg = Tbar*(1. + 0.186*factlat)

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

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

Thermosphere base temperature (K) versus local solar time

TF0 = Tavg*(1.0 + A1*\cos(pi180*15.0*(LST-tl)) + A2*\cos(pi180*30.0*(LST-t2)))

Global mean scale height (km) of thermospheric temperature

SCALE = 8.38 + 0.09725*FBARR

Zonal average temperature scale height (km) vs. latitude

SCALE = SCALE*(1.14 - 0.18*\cos(pi180*lat))

Return

End
Subroutine Tsurface(sitla,sitlo,sunla,sunlo,als,au,Tsurf, TSRF

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

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
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
C... Establish default values for input parameters
DATA IDAY/0,31,59,90,120,151,181,212,243,273,304,334/
C... Default time = Viking 1 Lander Site, height = 0
DATA Month,Mday,Myear,Ihr,Imin,Sec/7,20,76,12,30,0.0/
C... Default Solar Flux parameters
DATA F107,Stdl/68.,0.0/
C... Default position = Viking 1 Lander Site, height = 0
DATA Flat,Flon,Fhgt,Delhgt,Dellat,Dellon,Deltime/22.,48.,-0.5, & i0.,3°0./
C... CF climate factors default to 1.0
DATA CF0,CF5,CF15,CF30,CF50,CF75/6*I.O/
C... Terms deltaZF, deltaTF and deltaTEX default to 0.0
DATA deltaZF,deltaTF,deltaTEX/3*0.0/
C... Default random number seed
DATA NRI/1001/
C...................................................................... SETU 43

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

```fortran
**** Mars-GRAM 3.34\SETUP.FOR
       Read(8, INPUT)
C .................................................................
**** Mars-GRAM 3.4\SETUP.FOR
       Read(8, INPUT)
C .................................................................
```

```fortran
**** Mars-GRAM 3.4\SETUP.FOR
       Read(8, INPUT)
        CF(0) = CF0
       SETU 47
        CF(1) = CF5
       SETU 47
        CF(2) = CF15
       SETU 48
        CF(3) = CF30
       SETU 48
        CF(4) = CF50
       SETU 49
        CF(5) = CF75
       SETU 49
      Do 5 i = 0, 5
        If (CF(i).le.0.0) Stop 'Bad CF value'
       SETU 47
      5 Continue
        dzF = deltaZF
       SETU 48
        dTF = deltaTF
       SETU 48
        dTEX = deltaTEX
       SETU 49
C .................................................................
****
```
## Appendix B - Reference LIST Output for Mars-GRAM 3.4

**Mars-GRAM Batch version 3.4 - April 1, 1996**

<table>
<thead>
<tr>
<th>Date</th>
<th>Julian Date</th>
<th>GMT Time</th>
<th>PFI 0.7 flux</th>
<th>(1 AU)</th>
<th>25.0 (Mars)</th>
<th>standard deviation</th>
<th>Perturbation model</th>
<th>Starting random number</th>
<th>Time (rel. to TO)</th>
<th>Height</th>
<th>Latitude</th>
<th>Sun Latitude</th>
<th>Sun Longitude</th>
<th>Temperature</th>
<th>Density (Low, Avg., High)</th>
<th>Departure, COSPAR NH Mean</th>
<th>Density perturbation</th>
<th>Eastward Wind</th>
<th>Northward Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/20/1976</td>
<td>2442980.0</td>
<td>12:30:0</td>
<td>68.0</td>
<td>68.0</td>
<td>25.0</td>
<td>0.0</td>
<td>3</td>
<td>1001</td>
<td>0.0 sec. (00.000 sols)</td>
<td>0.00</td>
<td>22.000</td>
<td>25.000</td>
<td>108.77</td>
<td>243.8 K</td>
<td>1.500E-02 1.604E-02 1.709E-02</td>
<td>-7.6 % -1.2 % 5.3 %</td>
<td>-1.39 %</td>
<td>4.3 m/s</td>
<td>-0.4 m/s</td>
</tr>
<tr>
<td>7/20/1976</td>
<td>2442980.0</td>
<td>12:30:0</td>
<td>68.0</td>
<td>68.0</td>
<td>25.0</td>
<td>0.0</td>
<td>3</td>
<td>1001</td>
<td>0.0 sec. (00.000 sols)</td>
<td>9.50</td>
<td>22.000</td>
<td>25.000</td>
<td>108.77</td>
<td>202.9 K</td>
<td>7.621E-03 7.868E-03 8.154E-03</td>
<td>12.9 % 15.1 % 20.1 %</td>
<td>-1.42 %</td>
<td>1.4 m/s</td>
<td>-8.7 m/s</td>
</tr>
<tr>
<td>7/20/1976</td>
<td>2442980.0</td>
<td>12:30:0</td>
<td>68.0</td>
<td>68.0</td>
<td>25.0</td>
<td>0.0</td>
<td>3</td>
<td>1001</td>
<td>0.0 sec. (00.000 sols)</td>
<td>19.50</td>
<td>22.000</td>
<td>25.000</td>
<td>108.77</td>
<td>185.2 K</td>
<td>3.041E-03 3.175E-03 3.312E-03</td>
<td>10.3 % 15.1 % 20.1 %</td>
<td>-0.33 %</td>
<td>-1.7 m/s</td>
<td>-13.5 m/s</td>
</tr>
<tr>
<td>7/20/1976</td>
<td>2442980.0</td>
<td>12:30:0</td>
<td>68.0</td>
<td>68.0</td>
<td>25.0</td>
<td>0.0</td>
<td>3</td>
<td>1001</td>
<td>0.0 sec. (00.000 sols)</td>
<td>29.50</td>
<td>22.000</td>
<td>25.000</td>
<td>108.77</td>
<td>170.4 K</td>
<td>1.038E-03 1.170E-03 1.244E-03</td>
<td>6.2 % 11.2 % 20.3 %</td>
<td>-0.34 %</td>
<td>-4.6 m/s</td>
<td>-19.7 m/s</td>
</tr>
<tr>
<td>7/20/1976</td>
<td>2442980.0</td>
<td>12:30:0</td>
<td>68.0</td>
<td>68.0</td>
<td>25.0</td>
<td>0.0</td>
<td>3</td>
<td>1001</td>
<td>0.0 sec. (00.000 sols)</td>
<td>39.50</td>
<td>22.000</td>
<td>25.000</td>
<td>108.77</td>
<td>160.0 K</td>
<td>3.667E-04 3.915E-04 4.173E-04</td>
<td>2.1 % 9.1 % 16.2 %</td>
<td>-0.34 %</td>
<td>-8.0 m/s</td>
<td>-19.7 m/s</td>
</tr>
<tr>
<td>7/20/1976</td>
<td>2442980.0</td>
<td>12:30:0</td>
<td>68.0</td>
<td>68.0</td>
<td>25.0</td>
<td>0.0</td>
<td>3</td>
<td>1001</td>
<td>0.0 sec. (00.000 sols)</td>
<td>49.50</td>
<td>22.000</td>
<td>25.000</td>
<td>108.77</td>
<td>160.0 K</td>
<td>2.1E-04 2.1E-04 2.1E-04</td>
<td>9.1 % 16.2 % 20.3 %</td>
<td>-0.34 %</td>
<td>-8.0 m/s</td>
<td>-19.7 m/s</td>
</tr>
</tbody>
</table>

**Note:**
- Time (rel. to TO) is measured as seconds since the start of the observation, divided by 1000 to convert to sols.
- Ls is the solar elongation, measured in degrees.
- Density perturbation and wind measurements are expressed as percentages of the mean value.
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 TO) = .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 = 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 = -15.9 m/s  Northward Wind = -33.7 m/s

Time (rel. to TO) = .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 = 6.05E-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 TO) = .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 % -9.5 %
Density perturbation = -34.81% of mean value
Eastward Wind = -38.3 m/s  Northward Wind = -45.7 m/s

Time (rel. to TO) = .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) = 6.54E-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 TO) = .0 sec. ( .000 sols)  Ls = 97.0 deg.
Height = 109.50 km ( 110.00 km)  Scale Height = 7.11 km

B-2
<table>
<thead>
<tr>
<th>Latitude = 22.000 degrees</th>
<th>West Longitude = 48.000 degrees</th>
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<tbody>
<tr>
<td>Sun Latitude = 25.00 deg.</td>
<td>Mars Orbital Radius = 1.649 AU</td>
</tr>
<tr>
<td>Sun Longitude = 108.77 deg.</td>
<td>Local Time = 16.05 Mars hours</td>
</tr>
<tr>
<td>Exospheric Temp. = 210.9 K</td>
<td>Tbase = 128.2 K Zbase = 117.1 km</td>
</tr>
<tr>
<td>Temperature = 128.9 K</td>
<td>Pressure = 4.402E-04 N/m**2</td>
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<tr>
<td>Density (Low, Avg., High) =</td>
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<tr>
<td>Departure, COSPAR NH Mean =</td>
<td>-71.3 % -60.0 % -46.8 %</td>
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<tr>
<td>Density perturbation =</td>
<td>24.11 % of mean value</td>
</tr>
<tr>
<td>Eastward Wind =</td>
<td>-103.2 m/s</td>
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<tr>
<td>Northward Wind =</td>
<td>-50.0 m/s</td>
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<table>
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<th>Time (rel. to TO)</th>
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<tbody>
<tr>
<td>Ls = 97.0 deg.</td>
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<tr>
<td>Height = 119.50 km</td>
<td>(120.00 km)</td>
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<td>Scale Height = 8.09 km</td>
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<tr>
<td>West Longitude = 48.000 degrees</td>
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</tr>
<tr>
<td>Mars Orbital Radius = 1.649 AU</td>
<td></td>
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<tr>
<td>Local Time = 16.05 Mars hours</td>
<td></td>
</tr>
<tr>
<td>Tbase = 128.2 K Zbase = 117.1 km</td>
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</tr>
<tr>
<td>Pressure = 9.240E-05 N/m**2</td>
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</tr>
<tr>
<td>Density (Low, Avg., High) =</td>
<td>6.286E-10 8.759E-10 1.164E-09 kg/m**3</td>
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<tr>
<td>Departure, COSPAR NH Mean =</td>
<td>-84.2 % -78.0 % -70.7 %</td>
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<tr>
<td>Density perturbation =</td>
<td>46 % of mean value</td>
</tr>
<tr>
<td>Eastward Wind =</td>
<td>-177.2 m/s</td>
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<tr>
<td>Northward Wind =</td>
<td>-72.5 m/s</td>
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</tbody>
</table>

<table>
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<th>Time (rel. to TO)</th>
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<tbody>
<tr>
<td>Ls = 97.0 deg.</td>
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<td>Height = 129.50 km</td>
<td>(130.00 km)</td>
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<td>Scale Height = 10.57 km</td>
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<td>West Longitude = 48.000 degrees</td>
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<tr>
<td>Mars Orbital Radius = 1.649 AU</td>
<td></td>
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<tr>
<td>Local Time = 16.05 Mars hours</td>
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<tr>
<td>Tbase = 128.2 K Zbase = 117.1 km</td>
<td></td>
</tr>
<tr>
<td>Pressure = 3.201E-05 N/m**2</td>
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<tr>
<td>Density (Low, Avg., High) =</td>
<td>2.325E-10 3.240E-10 4.306E-10 kg/m**3</td>
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<tr>
<td>Departure, COSPAR NH Mean =</td>
<td>-79.8 % -71.8 % -62.5 %</td>
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<tr>
<td>Density perturbation =</td>
<td>7.64 % of mean value</td>
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<tr>
<td>Eastward Wind =</td>
<td>-193.9 m/s</td>
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<tr>
<td>Northward Wind =</td>
<td>-108.6 m/s</td>
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</table>

<table>
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<th>Time (rel. to TO)</th>
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<tbody>
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<td>Scale Height = 12.59 km</td>
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<td>West Longitude = 48.000 degrees</td>
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<tr>
<td>Mars Orbital Radius = 1.649 AU</td>
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<tr>
<td>Local Time = 16.05 Mars hours</td>
<td></td>
</tr>
<tr>
<td>Tbase = 128.2 K Zbase = 117.1 km</td>
<td></td>
</tr>
<tr>
<td>Pressure = 5.780E-06 N/m**2</td>
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</tr>
<tr>
<td>Density (Low, Avg., High) =</td>
<td>9.633E-11 1.342E-10 1.784E-10 kg/m**3</td>
</tr>
<tr>
<td>Departure, COSPAR NH Mean =</td>
<td>-80.4 % -72.7 % -63.7 %</td>
</tr>
<tr>
<td>Density perturbation =</td>
<td>24.11 % of mean value</td>
</tr>
<tr>
<td>Eastward Wind =</td>
<td>-178.4 m/s</td>
</tr>
<tr>
<td>Northward Wind =</td>
<td>-157.3 m/s</td>
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</table>

<table>
<thead>
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<th>Time (rel. to TO)</th>
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<tbody>
<tr>
<td>Ls = 97.0 deg.</td>
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<tr>
<td>Height = 159.50 km</td>
<td>(160.00 km)</td>
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<tr>
<td>Scale Height = 13.39 km</td>
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<tr>
<td>West Longitude = 48.000 degrees</td>
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<tr>
<td>Mars Orbital Radius = 1.649 AU</td>
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<tr>
<td>Local Time = 16.05 Mars hours</td>
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<tr>
<td>Tbase = 128.2 K Zbase = 117.1 km</td>
<td></td>
</tr>
<tr>
<td>Pressure = 2.674E-06 N/m**2</td>
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</tr>
<tr>
<td>Density (Low, Avg., High) =</td>
<td>4.217E-11 5.875E-11 7.808E-11 kg/m**3</td>
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<tr>
<td>Departure, COSPAR NH Mean =</td>
<td>-83.2 % -76.6 % -68.9 %</td>
</tr>
</tbody>
</table>

B-3
Density perturbation = -46.41 \% of mean value
Eastward Wind = -112.9 m/s  Northward Wind = -191.6 m/s

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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

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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 = 6.552E-07 N/m**2
Density (Low, Avg., High) = 9.081E-12  1.265E-12  1.682E-12 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

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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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B-4
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.

James N. Strickland
Director, Systems Analysis and Integration Laboratory

Robert E. Smith
Chief, Systems Engineering Division

Steven D. Pearson
Chief, Electromagnetics and Aerospace Environments Branch
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

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Prepared by Systems Analysis and Integration Laboratory, Science and Engineering Directorate
*Computer Sciences Corporation

Unclassified-Unlimited

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.