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Part I

The NASA/MSFC Global Reference
Atmospheric Model—1990
Version (GRAM-90)

Part I: Technical / Users Manual

C. C. Justus, F. N. Alyea, D. M. Cunnold,
W. R. Jeffries III, and D. L. Johnson

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Part I

The NASA/MSFC Global Reference
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Version (GRAM-90)

Part I: Technical / Users Manual

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PREFACE

The effort required to improve the NASA/MSFC Global Reference Atmospheric Model (GRAM) was sponsored by the Environmental Analysis Branch, Earth Science and Applications Division, Space Science Laboratory, NASA Marshall Space Flight Center. The modeling work was accomplished by the Georgia Institute of Technology, School of Earth and Atmospheric Sciences, under NASA GRANT NAG8-078. The effort was funded largely by NASA Headquarters Code M. New Technology Inc. (NTI) coordinated the transfer of the program and program checkout for use on the MSFC IBM computer. This report presents the latest developmental work on the GRAM model and was accomplished under the technical monitorship of Mr. Dale L. Johnson, the NASA Contracting Officer's Representative. Other key individuals who have either contributed toward the completion and testing of the GRAM-90 model (and/or report) are Steve Smith (MSFC) and Rhonda Blocker (Boeing Computer Support Services). The technical work and user help information has been documented in part I of this report; whereas part II of this report presents a complete listing of both the program and the key data bases utilized in GRAM-90. Qualified requestors may obtain (purchase) copies of the computer program for GRAM-90 by contacting: COSMIC, The University of Georgia, 382 East Broad Street, Athens, GA 30602; telephone (404) 542-3265.



TABLE OF CONTENTS

	Page
1. INTRODUCTION	1
1.1 Background	1
1.2 Description of the Basic Model	1
1.3 New Zonal Mean Data	3
1.4 New Stationary Perturbation Data	3
1.5 New Middle Atmosphere Wind Model	4
1.6 The Quasi-Biennial Perturbations	4
1.7 The Random Perturbations	4
1.8 Overview of This Report	5
2. TECHNICAL DESCRIPTION OF THE MODEL	5
2.1 The Jacchia Section (Above 90 km)	5
2.2 The 4-D Section (Below 25 km)	5
2.3 The Middle Atmosphere Section	6
2.4 Interpolation and Fairing	7
2.5 Geostrophic Winds	8
2.6 Thermal Wind Shear	9
2.7 Mean Vertical Winds	10
2.8 The Quasi-Biennial Perturbations	11
2.9 The Random Perturbation Model	11
3. SAMPLE RESULTS	12
3.1 Example GRAM-90 Results and Comparison With GRAM-88	12
3.2 Comparison of GRAM-90 Results With 3-D SCM Output	13
4. USER'S MANUAL	38
4.1 General Program Overview	38
4.2 The 4-D Data Files (0 to 25 km)	38
4.3 The SCIDAT9 Data File	39
NMC Grid Data	39
Zonal-Mean Data	39
Stationary Perturbations	40
The Random Perturbation Data	40
Large Scale Fraction Data	40
Density-Velocity Correlations	41
The Quasi-Biennial Oscillation (QBO) Data	41
4.4 The Initial Input Data	41
Input Line Number 1	42

TABLE OF CONTENTS (continued)

	Page
Input Line Number 2	44
Input Line Number 3	45
Trajectory Input.....	46
4.5 Output of the Program.....	46
Heading Information	46
Position and Time Output	47
Monthly Mean Data	47
The Total (Mean Plus Perturbation) Data	48
Perturbation Values	48
Nonprint Output	48
4.6 Program Diagnostics	49
5. PROGRAMMER'S MANUAL	50
5.1 Description of Subroutines	50
5.2 The Primary Section	53
Main Section GRAM	53
Subroutine SCIMOD.....	54
5.3 The Setup Section	54
5.4 The Jacchia Section.....	54
5.5 The 4-D Section	54
5.6 GRAM-90 Input and Output.....	54
REFERENCES.....	55
APPENDIX A – Description of the Revised Middle Atmosphere Data File “SCIDAT9” for the GRAM-90 Program	57
APPENDIX B – Sample Input and Output for the GRAM-90 Program	60
ERRATA.....	78

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.1.	Schematic summary of the atmospheric regions in the GRAM-90 program, and the simulation methods used for mean monthly values in each region	2
3.1.	GRAM-90 height-latitude cross section for January temperature (K)	16
3.2.	GRAM-90 height-latitude cross section for July temperature (K)	17
3.3.	GRAM-90 height-latitude cross section for January density (percent from U.S. 1976 standard).....	18
3.4.	GRAM-90 height-latitude cross section for July density (percent from U.S. 1976 standard).....	19
3.5.	GRAM-90 height-latitude cross section for January zonal wind (m/s).....	20
3.6.	GRAM-90 height-latitude cross section for July zonal wind (m/s)	21
3.7.	GRAM-90 height-latitude cross section for January standard deviation in temperature (percent of mean)	22
3.8.	GRAM-90 height-latitude cross section for January standard deviation in density (percent of mean).....	23
3.9.	GRAM-90 height-latitude cross section for January standard deviation in zonal wind (m/s).....	24
3.10.	GRAM-90 height-latitude cross section for January standard deviation in meridional wind (m/s)	25
3.11.	GRAM-90 latitude-longitude cross section for January temperature deviations from zonal-mean value (percent) at 30-km altitude	26
3.12.	GRAM-90 latitude-longitude cross section of January temperature deviations from zonal-mean (percent) at 80-km altitude.....	27
3.13.	GRAM-90 latitude-longitude cross section of January density deviations from zonal-mean (percent) at 30-km altitude	28
3.14.	GRAM-90 latitude-longitude cross-section of January density deviations from zonal-mean (percent) at 80-km altitude	29
3.15.	GRAM-90 latitude-longitude cross section of January zonal wind deviations from zonal-mean (m/s) at 30-km altitude	30

LIST OF ILLUSTRATIONS (cont.)

Figure	Title	Page
3.16	GRAM-90 latitude-longitude cross section of January zonal-wind deviations from zonal-mean (m/s) at 80-km altitude.....	31
3.17.	GRAM-90 latitude-longitude cross section of January meridional wind deviations from zonal-mean (m/s) at 30-km altitude.....	32
3.18.	GRAM-90 latitude-longitude cross section of January meridional wind deviations from zonal-mean (m/s) at 80-km altitude.....	33
3.19.	SCM height-latitude cross section for July temperature (K).....	34
3.20.	SCM height-latitude cross section for July zonal wind (m/s).....	35
3.21.	SCM height-latitude cross section for January temperature (K).....	36
3.22.	SCM height-latitude cross section for January zonal wind (m/s).....	37

TECHNICAL MEMORANDUM

THE NASA/MSFC GLOBAL REFERENCE ATMOSPHERIC MODEL – 1990 VERSION (GRAM-90)

Part I: Technical/Users Manual

1. INTRODUCTION

1.1 Background

In response to needs for engineering reference model atmospheres of wide scope and application, Georgia Tech developed, under NASA sponsorship, a Global Reference Atmospheric Model (GRAM) with latitude, longitude, and monthly variations over a height range of 0 to 700 km (Justus et al., 1974a,b, 1975, 1976). The original GRAM version has undergone a series of improvements over the years (Justus et al., 1980, 1986, 1988). This report describes additions and improvements to this model whereby extensive new data sets from the middle atmosphere (20 to 120 km) have been incorporated. This new version is called GRAM-90. This section describes the basic GRAM-90 version and section 2 provides a more detailed description of the GRAM-90 program. Section 3 presents some sample results for the middle atmosphere height region. Sections 4 and 5 are user's and programmer's manuals for the GRAM-90 program. A complete listing of the GRAM-90 code and middle atmosphere input data set is available in part II of this report (contact Dale Johnson, ES44, NASA Marshall Space Flight Center, Huntsville, AL 35812).

1.2 Description of the Basic Model

The 1990 version of GRAM-90 is an amalgamation of two previously existing empirical atmospheric models for the low (<25 km) and high (>90 km) atmosphere, with the new empirical latitude-longitude dependent model for the middle atmosphere (20 to 120 km). Smooth transition between these height regions is insured by fairing techniques in the overlap height regions. In the original GRAM version, the high atmospheric region above 115 km was simulated by the Jacchia (1970, 1971) model. In GRAM-90, a version of the Jacchia model called the Marshall Engineering Thermosphere (MET) model is used (Hickey, 1988a,b). The atmospheric region between 25 km and 120 km is simulated by a new latitude-longitude dependent empirical model, based on extensive new data sets which have come primarily from the Middle Atmosphere Program (MAP). These data sources and the resultant new data set used in GRAM-90 are described more fully later in this report. Between 90 and 120 km, a smooth transition between the middle atmosphere data and the MET values is accomplished by a fairing technique. Below 25 km the atmospheric parameters are computed by a four-dimensional (4-D) world-wide atmospheric model developed for NASA by Allied Research Associates (Fowler and Willard, 1972; Spiegler and Fowler, 1972). Between 25 and 30 km, an interpolation scheme is used between the 4-D results and the middle atmosphere values. Figure 1.1 presents a schematic summary of the atmospheric regions of the GRAM-90 program and how they are modeled.

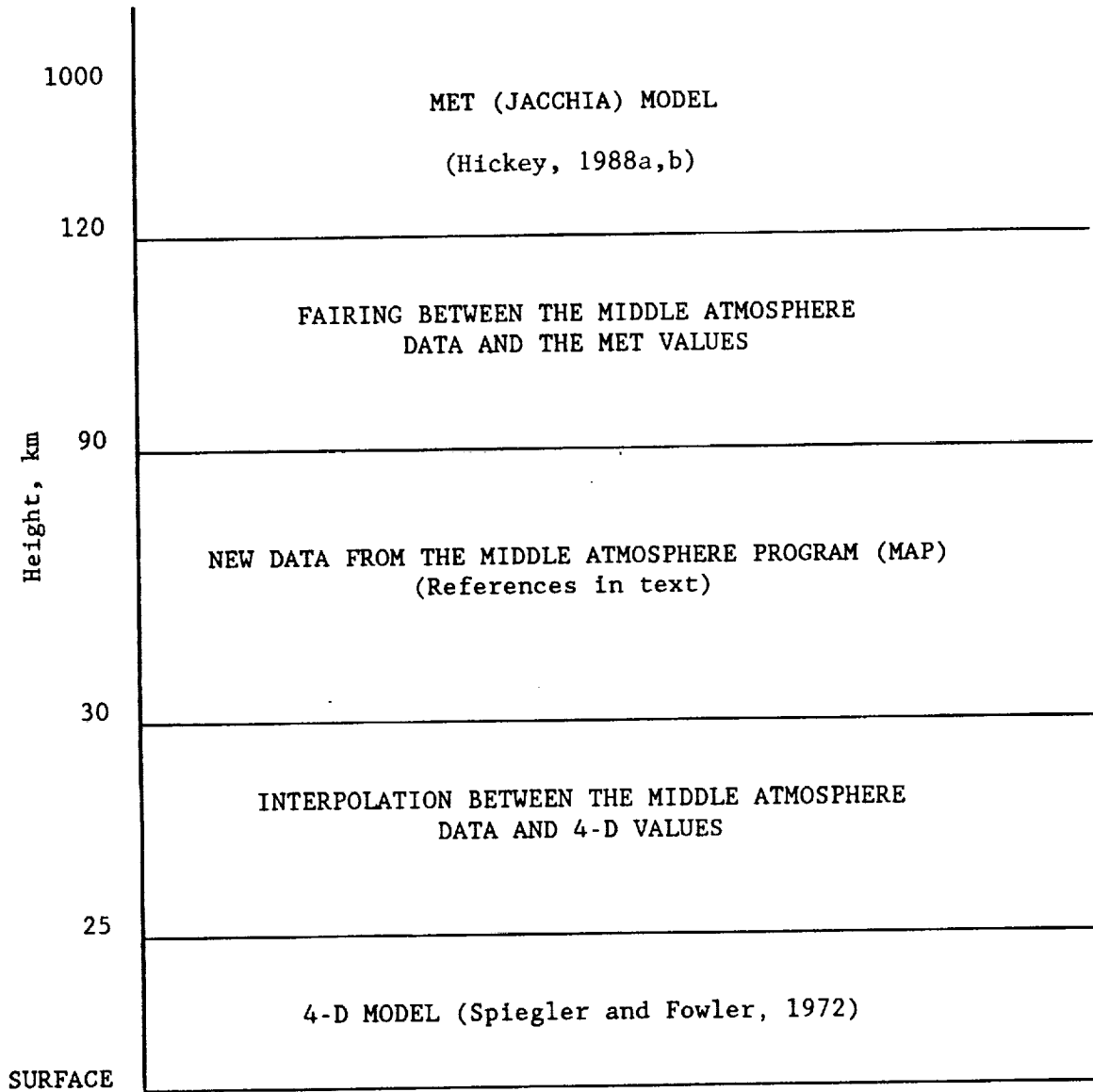


Figure 1.1. Schematic summary of the atmospheric regions in the GRAM-90 program, and the simulation methods used for mean monthly values in each region.

1.3 New Zonal Mean Data

For the middle atmosphere section, described more fully in section 2, monthly zonal mean data from six different sources have been merged:

- (1) Groves (1985) zonal mean thermodynamic and zonal wind data for 18 to 80 km.
- (2) Barnett and Corney (1985a) zonal mean thermodynamic and zonal wind data for 20 to 80 km.
- (3) Fleming et al. (1988) zonal mean thermodynamic and zonal wind data for 20 to 120 km.
- (4) Zonal mean thermodynamic zonal wind and meridional wind data from Dartt et al. (1988) for 20 to 85 km.
- (5) Koshelev (1985) zonal mean thermodynamic and zonal wind data for Southern Hemisphere meteorological rocket data (20 to 65 km).
- (6) Zonal mean thermodynamic, zonal wind, and meridional wind data processed from the latest (1969–1986) “SUMS” data for the Meteorological Rocket Network (MRN) for the Northern Hemisphere (20 to 65 km).

These data have been processed at 10° -latitude intervals from 80° S. to 80° N. and at 5-km height intervals from 20 km upward (to the top of the respective data sets). Values for the poles (90° S. and 90° N.) are added by an extrapolation procedure.

1.4 New Stationary Perturbation Data

Monthly latitude-longitude cross section data (for revision of the stationary perturbation data) have been prepared from three different sources:

- (1) Groves (1985) planetary wave 1 and 2 amplitudes and phases for thermodynamic data over 18- to 80-km height.
- (2) Barnett and Corney (1985b) planetary wave 1 and 2 amplitudes and phases for thermodynamic data over 20- to 80-km height.
- (3) Latitude-longitude cross sections of thermodynamic, zonal wind, and meridional winds from Dartt et al. (1988) data for 20 to 85 km.

These data have been reduced to relative perturbations about the zonal-mean value (stationary perturbations) for the 10° latitude increments from 80° S. to 80° N., 20° longitude intervals (180° , 160° W., 140° W., ..., 160° E.), and 5-km height intervals from 20 km upward (to 80 or 85 km). Stationary perturbations above 85 km were estimated by a vertical extrapolation technique.

1.5 New Middle Atmosphere Wind Model

Observational data for zonal-mean zonal wind (at 10° latitude increments) and latitude-longitude variations of zonal and meridional wind (at 10° -latitude by 20° -longitude increment) have been added to the data base for the middle atmosphere. These replace the spherical harmonic wind model of the previous versions of GRAM.

Below 25 km and above 90 km, the winds are computed from horizontal pressure gradients, estimated by finite differences, from the geostrophic wind relations. Near the equator, an interpolation scheme is used instead of the geostrophic relation (which approaches infinite values as the latitude approaches zero). In the height range 25 to 90 km, the newly developed data base of middle atmosphere winds is used, at all latitudes. Mean vertical winds, of the order of 1 cm/s or less, are evaluated from the slopes of isentropic surfaces and the horizontal advective winds. Wind shear in the monthly mean horizontal wind is estimated from horizontal temperature gradients in the regions below 25 km and above 90 km. In the 25- to 90-km height range, mean wind shear is computed from finite differences of the winds in the new middle atmosphere data base.

1.6 The Quasi-Biennial Perturbations

In addition to the monthly mean values of pressure, density, and temperature, two types of perturbations are evaluated: quasi-biennial oscillations (QBO) and random perturbations. The QBO variations in pressure, density, temperature, and winds, empirically determined to be represented by an 870-day-period sinusoidal variation, have amplitudes and phases which vary with height and latitude. The QBO amplitudes are primarily significant at low altitudes (~ 20 to 40 km) for equatorial latitudes, and at higher altitudes (50 to 60 km) for higher latitudes.

1.7 The Random Perturbations

For realistic simulation of actual atmospheric parameter values, as they would likely be at any given time, random perturbations are also computed and applied as perturbations to the monthly mean values. The random perturbations are evaluated by a simulation technique which uses empirical values of magnitudes and scales for the perturbations, in order to generate random perturbations which have realistic space and time correlations. Complete descriptions of the random perturbation model have been presented by Justus et al. (1986, 1988) and Justus (1988).

For the GRAM-90 random perturbation model, standard deviations about the monthly means have been obtained and processed for three data sets:

- (1) Zonal-mean values of standard deviations of thermodynamics, zonal wind, and meridional winds from the Dartt et al. (1988) data for 20 to 85 km.
- (2) Zonal-mean values of standard deviations for thermodynamics, zonal wind, and meridional wind from the MRN "SUMS" tape (20 to 65 km).
- (3) Monthly standard deviations at 44° N., 6° E. from Chanin et al. (1985) lidar data.

These data have been processed as zonal-means of the standard deviations at 10°-latitude intervals for 80° S. to 80° N. and height intervals of 5 km for 20 km upward.

For GRAM-90 a new vertical component for the random perturbation winds has also been added, based on the turbulence model of Justus et al. (1990).

1.8 Overview of This Report

The following sections give a technical description of the GRAM-90, with emphasis on the new additions, and new user's manual descriptions of the program operation aspects of the revised model. Section 2 provides a more detailed technical description of the GRAM-90 program. Section 3 presents some sample results for the new middle atmosphere section and provides comparisons with results from a 3-D global circulation model. Section 4 is a user's manual which provides details on how to run GRAM-90. Section 5 is a programmer's manual which provides more details for those wishing to make their own GRAM program adaptations.

2. TECHNICAL DESCRIPTION OF THE MODEL

2.1 The Jacchia Section (Above 90 km)

The Jacchia (1970, 1971) model for the thermosphere and exosphere was originally implemented to compute atmospheric density at satellite altitudes. The Jacchia model accounts for temperature and density variations due to solar and geomagnetic activity, diurnal and semiannual variations, and seasonal and latitudinal variations. The Jacchia model assumes a uniformly mixed composition from sea level to 105 km, with diffusive equilibrium among the constituents (nitrogen, oxygen, argon, helium, and hydrogen) above 105 km. Fixed boundary values for temperature and density are assumed at 90 km. Alterations, described in Justus et al. (1974a), were made to allow atmospheric pressure to be computed from the density and temperature. Geostrophic winds are evaluated in the Jacchia section by computing horizontal pressure gradients with successive evaluations of the Jacchia model at different latitudes and longitudes. For GRAM-90, the NASA MET model (Hickey, 1988a,b) has been implemented as the version of the Jacchia model, for altitudes above 120 km. Between 90 and 120 km, a fairing routine, described below, is used to insure a smooth transition between the middle atmosphere and the MET model.

2.2 The 4-D Section (Below 25 km)

The 4-D atmospheric model, developed by Allied Research Associates (Spiegler and Fowler, 1972) was designed to extract from data bases and interpolate on latitude and longitude, mean monthly and daily variance profiles of pressure, density, and temperature, at 1-km intervals from the surface to a height of 25 km for any location on the globe. The data bases contain empirically determined, atmospheric-parameter profiles at a large array of locations. The Northern Hemisphere grid array is equivalent to the NMC grid network. Grids spaced at 5° intervals of latitude and longitude are used in the equatorial and Southern Hemisphere regions.

Technical changes previously made in the 4-D program were: a modified latitude-longitude interpolation method, previously described in Justus et al. (1974a); an adjustment routine to modify the variance to comply with the constraints imposed by the perfect gas law (Buell, 1970, 1972); and a check routine to determine vertical and horizontal consistency of the 4-D data.

For the GRAM-90 program, a routine has been incorporated to read the 4-D data by random access from disk files, rather than by serially reading through the 4-D data tape files. The random access feature computes the record number in the 4-D file, based on the latitude and longitude required. The specific record is then read directly by accessing that record number from the data base. This feature should provide a substantial increase in speed of execution for simulations along trajectories which traverse long distances at altitudes below 30 km (e.g., for the National Aero-Space Plane (NASP) and the High Speed Civil Transport (HSCT) programs).

The method of application of the 4-D model in the GRAM-90 program is as follows: the first time that atmospheric parameters at a location below 30 km are required, a set of atmospheric profiles of monthly mean and daily variances of pressure, density, and temperature are generated at a 16-point grid of locations spaced at 5° latitude and longitude intervals (a slightly different grid is used near the poles and equator). This grid of profiles, covering 15° × 15° of latitude-longitude, is then stored in the computer, and all further atmospheric parameter values in the 0- to 25-km range are found by interpolation between locations within this grid. If the trajectory goes outside this grid while the height remains below 25 km, the program executes an additional call on the routine which sets up the 4-D data grid.

The location of the grid points to be evaluated is determined dynamically, based on the position and direction of travel along the trajectory, when the 4-D grid is first required, by a procedure described in Justus et al. (1974a). The 4-D data bases normally contain data for the surface to 25 km in 1-km steps. At locations where the surface is at more than 1 km above sea level, the surface value will be followed by one or more zero records, and the first nonzero record above the surface value will be at the lowest integer km higher than the surface. For example, if the surface is at 700 m, then there will be data at surface, 1 km, 2 km, etc.; but if the surface is at 1.3 km, the data will contain the surface, one zero record, 2 km, 3 km, etc. An interpolation routine (based on the hydrostatic relation and constant lapse rate altitude segments) is used to fill in data between sea level and the first nonzero data above the surface. Interpolation is also used to fill in any missing data immediately below the 25-km height. The basic interpolation equations were described in Justus et al. (1974a).

2.3 The Middle Atmosphere Section

For incorporation into the revised GRAM, the six sets of zonal-mean data have been merged into one set covering the 20- to 120-km altitude range. The latitude-longitude cross-section (stationary-perturbation) data were also merged into one set covering the 20- to 85-km height range. Both of these sets include explicit Southern Hemisphere data for the first time (as opposed to using only 6-month displaced and north-south reflected Northern Hemisphere data, as was done in the original GRAM version. These data also include, for the first time, zonal-mean and latitude-longitude cross-section data for zonal and meridional wind components. These replace the previous spherical harmonic wind model.

The starting point for the middle atmosphere (20- to 120-km) section of GRAM-90 is the zonal-mean data set, derived for the data sources discussed in section 1.3. Tabulations of the middle atmosphere data base are at intervals of 5 km in height, 10° in latitude (−90° to +90°), and 1 month in time. Since the original data bases included only the latitude range −80° to +80°, polar values were added by the extrapolation relation

$$y_{\pm 90} = (4 y_{\pm 80} - y_{\pm 70})/3 . \quad (2.1)$$

This assumes a parabolic variation between the $\pm 70^\circ$ and $\pm 80^\circ$ values across the polar latitude $\pm 90^\circ$.

Longitudinal variation about the zonal-mean data is provided by revised stationary perturbations, based on new data sets described in section 1.4. The stationary perturbation, s_y , in parameter y is given by

$$s_y = (y - \langle y \rangle) / \langle y \rangle , \quad (2.2)$$

where $\langle y \rangle$ represents the zonal-mean value of y (i.e., averaged around a circle of fixed latitude). Note that the definition of s_y makes it be identically zero at the pole. The stationary perturbation s_y for parameter y is added to the zonal-mean value $\langle y \rangle = z_y$ to produce the longitudinally variable value, $y(\text{lat.}, \text{long.})$, according to the relation

$$y(\text{lat.}, \text{long.}) = z_y(1 + s_y) . \quad (2.3)$$

The latitude-longitude dependent values computed by equation (2.3) are used as the monthly mean values for the altitude range 30 to 90 km and as the basis for interpolation or fairing over 25 to 30 km and 90 to 120 km.

2.4 Interpolation and Fairing

The 4-D data are available in the data bases at 1-km height intervals and at $5^\circ \times 5^\circ$ latitude-longitude grids in the southern and equatorial areas and at the NMC grid locations in the Northern Hemisphere. NMC grid profiles are always converted (by interpolation) to $5^\circ \times 5^\circ$ grids before interpolation to the trajectory locations. The general interpolation requirements for the 4-D section are height interpolation over 1 km and latitude-longitude interpolation over a $5^\circ \times 5^\circ$ square grid.

The middle atmosphere zonal-mean data are tabulated at 5-km height intervals and 10°-latitude intervals. Interpolation is required between these tabulated locations. The stationary perturbations are evaluated at 10°-latitude and 20°-longitude intervals and at 5-km height intervals

between 30- and 90-km altitudes. Interpolation between these tabulated locations is also required. For values between 25 and 30 km, interpolation between the 4-D data and middle atmosphere data is required. The interpolations are always carried out in the program by doing the latitude (zonal-mean) or latitude-longitude (4-D or stationary perturbations) interpolation first, and then doing the height interpolation.

The MET model can be evaluated at any height above 90 km and at any latitude and longitude, so no interpolation is required. However, between 90 and 120 km, there is overlap between the middle atmosphere data and the MET model, so a fairing procedure is used to effect a smooth transition between the middle atmosphere data at 90 km and the MET values at 120 km.

The method used to interpolate pressure, density, and temperature over a height interval between heights z_1 and z_2 is to assume a linear variation of the temperature and of the logarithm of the density. The latitude interpolation for the middle atmosphere zonal-mean data is done by assuming linear variation between the latitudes ϕ_1 and ϕ_2 (which are at $\Delta\phi = 10^\circ$ apart). Two-dimensional latitude-longitude interpolation between a square or rectangular array of positions at latitudes ϕ_1 and ϕ_2 and west longitudes λ_1 and λ_2 is done by the relation

$$F(\phi, \lambda) = F_0 + (F_1 - F_0)\delta\phi + (F_2 - F_0)\delta\lambda + (F_3 - F_1F_2 + F_0)\delta\phi \delta\lambda, \quad (2.4)$$

where $\delta\phi$ is $(\phi - \phi_1)/(\phi_2 - \phi_1)$ and $\delta\lambda$ is $(\lambda - \lambda_1)/(\lambda_2 - \lambda_1)$.

To accomplish smooth transition between the middle atmosphere values at 90 km and the MET values at 120 km, a fairing technique is used. This fairing technique was described in Justus et al. (1974a). The fairing is done only at the altitudes 95, 100, 105, 110, and 115 km, i.e., heights for which there are middle atmosphere values in the data base. Linear interpolation is then used to fill in intervening heights, as discussed in the height interpolation section above.

Interpolation of the random perturbation magnitudes is done linearly on the variance (σ^2) rather than linearly on the magnitude (σ). This is because the perfect gas law adjustment equations (Buell, 1970, 1972) are nearly linear in the variances. Thus, once variances have been adjusted for the perfect gas law constraint, their adjustment would tend to be preserved by linear interpolation on variances, not magnitudes.

2.5 Geostrophic Winds

The eastward (i.e., blowing toward the east) wind component u and northward component v can be evaluated from the geostrophic wind equations

$$u_g = -(1/\rho f) \partial p / \partial y \quad (2.5)$$

$$v_g = (1/\rho f) \partial p / \partial x, \quad (2.6)$$

where ρ is the density, f is the Coriolis parameter ($2 \Omega \sin \phi$) and $\partial p/\partial x$ and $\partial p/\partial y$ are the eastward and northward components of the horizontal pressure gradient. For evaluation in the model, the pressure gradient terms must be approximated by finite differences. Geostrophic wind values are computed in the 4-D height range, by finite differencing of the 4-D pressure data.

Since density appears in the denominator of equations (2.5) and (2.6), the geostrophic wind components u_g and v_g can become unreasonably large at high altitudes (low densities). Physically this condition is prevented from occurring because of the effects of molecular viscosity, which become important at high altitudes. Therefore, winds in the upper (MET) height range are computed by viscous-modified geostrophic relations

$$u = \frac{f(f u_g - k v_g)}{f^2 + k^2} \quad (2.7)$$

$$v = \frac{f(f v_g + k u_g)}{f^2 + k^2} , \quad (2.8)$$

where $k = \mu/(\rho L^2)$, μ is the coefficient of viscosity, and L is a viscous damping scale ($\partial^2 u/\partial z^2 \approx u/L^2$). When viscosity is small ($k \ll f$), equations (2.7) and (2.8) become equivalent to the geostrophic relations ($u = u_g$; $v = v_g$). At high altitudes, where viscosity effects are large ($k \gg f$), equations (2.7) and (2.8) become

$$u \approx -(L^2/\mu)\partial p/\partial x \quad (2.9)$$

$$v \approx -(L^2/\mu)\partial p/\partial y . \quad (2.10)$$

Thus, as the effects of viscosity go from small to large, the winds computed by equations (2.7) and (2.8) go from being parallel to the isobars to becoming parallel to the pressure gradient.

2.6 Thermal Wind Shear

The wind shear components $\partial u_g/\partial z$ and $\partial v_g/\partial z$ in the 0- to 25-km height range are evaluated by the thermal wind equations

$$\partial u_g/\partial z = -(g/fT) \partial T/\partial y \quad (2.11)$$

$$\partial v_g/\partial z = (g/fT) \partial T/\partial x , \quad (2.12)$$

which is the usual form, leaving off a correction term in $\partial T/\partial z$, which is normally small. The horizontal temperature gradient terms are estimated by finite differences in a similar manner to the pressure gradient components in equations (2.5) and (2.6).

Thermal wind shears are also computed in the MET height range by relations derived from differentiation of equations (2.7) and (2.8)

$$\partial u/\partial z = \frac{f(f \partial u_g/\partial z - k \partial v_g/\partial z)}{f^2 + k^2} \quad (2.13)$$

$$\partial v/\partial z = \frac{f(f \partial v_g/\partial z + k \partial u_g/\partial z)}{f^2 + k^2} , \quad (2.14)$$

with the geostrophic wind shears coming from the thermal wind relations (equations (2.11) and (2.12)).

Since the ordinary geostrophic winds are inversely proportional to the coriolis parameter f (which goes to zero at the equator), these relations give unrealistically large winds at low latitudes. To overcome this problem, interpolation between about $+15^\circ$ and -15° latitude is used in GRAM-90. This interpolation limit, the "minimum geostrophic latitude," is specified in the program input and can be selected as any value between 5° and 18° .

2.7 Mean Vertical Winds

GRAM-90 also evaluates mean vertical winds from the slope of isentropic surfaces. On such surfaces, the entropy function ψ is

$$\psi = C_p T + gz + (u^2 + v^2)/2 = \text{const.} \quad (2.15)$$

Therefore, on isentropic surfaces

$$\partial\psi/\partial t + u\partial\psi/\partial x + v\partial\psi/\partial y + w\partial\psi/\partial z = 0 , \quad (2.16)$$

and, if $\partial\psi/\partial t$ is assumed zero, the vertical wind w can be solved for as

$$w = -[u\partial\psi/\partial x + v\partial\psi/\partial y]/(\partial\psi/\partial z) . \quad (2.17)$$

By differentiation of equation (2.15), with the assumption that u and v are the geostrophic winds u_g and v_g , and that $\partial u/\partial z$ and $\partial v/\partial z$ are given by the thermal wind relations, equation (2.17) becomes

$$w = -C_p [u_g(\partial T/\partial x) + v_g(\partial T/\partial y)] / \{g + C_p(\partial T/\partial z) + (g/fT) [v_g(\partial T/\partial x) - u_g(\partial T/\partial y)]\} \quad (2.18)$$

Mean vertical winds evaluated by equation (2.18) are generally less than 1 cm/s, and hence are realistic values for the large scale mean vertical winds affecting mean meridional circulation.

2.8 The Quasi-Biennial Perturbations

In the original GRAM, MRN data from 1964 to 1969 were used to evaluate quasi-biennial amplitudes and phases in the height range 25 to 65 km. The quasi-biennial period which produced minimum variance, when simultaneously evaluating the annual, semiannual, and quasi-biennial variation, was found to be 870 days. For a later GRAM version, the harmonic analysis was done the same way with MRN data for 1970 to 1972 added to the original data base. Again, the 870-day period was found to produce minimum variance for the QBO winds, while a 900-day period did slightly better for the thermodynamic variables. In order to retain a single period, the original 870-day period was chosen as still the preferable value overall. This model for the QBO perturbations is retained in the GRAM-90 version as well.

2.9 The Random Perturbation Model

GRAM-90 uses a simple, first-order, autoregressive model to compute a perturbation value at each new trajectory position from the perturbation value at the previous position. The effects of variation of the mean values and standard deviations about the mean are accounted for in the calculation of the perturbations. The process of computing the perturbations is exemplified by the computation of a new density perturbation ρ'_2 at the new position (coordinates x_2 , y_2 , and z_2), where the mean value is $\bar{\rho}_2$ and the standard deviation about the mean is σ_2 . The density perturbation ρ'_1 at the previous position (coordinates x_1 , y_1 , and z_1) has already been computed (or given as a starting seed value if position 1 is the first position in the trajectory). The mean density value at position 1 is $\bar{\rho}_1$, and the standard deviation is σ_1 . The new perturbation value ρ_2 is then computed from

$$\rho'_2 = A\bar{\rho}_2\rho'_1/\bar{\rho}_1 + B q_1 \quad (2.19)$$

where A and B are coefficients which force the proper correlation R between the successive perturbations ρ'_1 and ρ'_2 , and q_1 is a random number (mean = 0, standard deviation = 1) selected from a Gaussian (normal) distribution.

If the magnitude of the separation between the positions is r , where

$$r = [(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2]^{1/2} , \quad (2.20)$$

then the correlation R is assumed to be

$$R = \langle \rho_2 \rho_1 \rangle / (\sigma_2 \sigma_1) = e^{-r/L} , \quad (2.21)$$

where the angle brackets denote averaging, and L is the correlation integral scale length. The coefficients A and B in equation (2.19) are given by

$$\begin{aligned} A &= R \sigma_2 / \sigma_1 \\ B &= \sigma_2 [1 - R^2]^{1/2} . \end{aligned} \quad (2.22)$$

In the actual perturbation computations, two forms of equations (2.19) and (2.21) are used, one for small scale (turbulence, gravity wave, etc.) perturbations and one for large scale (tides, planetary waves, etc.) perturbations.

Calculations for temperature, pressure, and wind perturbations are done by more complicated expressions, which include additional terms required to preserve density-temperature cross correlations and density-wind cross correlations. More complete descriptions of the random perturbation model, including recent modifications, are given by Justus et al. (1980, 1986, 1988) and Justus (1988).

3. SAMPLE RESULTS

3.1 Example GRAM-90 Results and Comparison With GRAM-88

Figures 3.1 and 3.2 show height-latitude cross sections of zonally averaged temperature for the GRAM-90 version for the months of January and July. The new zonal-mean temperature contours are similar to the 1988 GRAM version (GRAM-88) results, except near 70° N. to 90° N. (or 70° S. to 90° S.) and 70- to 75-km altitude. This difference is largely due to unrealistic values of temperature extrapolations to the poles in the earlier GRAM version (see figures 10 and 11 of Justus and Roper, 1987).

Figures 3.3 and 3.4 similarly compare zonal-mean density in GRAM-90 for January and July (expressed as percent deviation from the U.S. 1976 Standard Atmosphere density). The largest differences between GRAM-88 and GRAM-90 density values are near 80 km in the polar regions, with January values having larger negative deviations near the North Pole for GRAM-88 and larger positive deviations near the South Pole for GRAM-90.

Figures 3.5 and 3.6 show the zonal-mean zonal wind for GRAM-90 data for January and July.

Magnitudes of the total standard deviations for the month of January are shown for GRAM-90 temperature in figure 3.7, for density in figure 3.8, for zonal wind in figure 3.9, and for meridional wind in figure 3.10. The standard deviations for temperature and density are quite similar for GRAM-88 and GRAM-90. The standard deviations for zonal wind are somewhat larger for GRAM-88 near 50° N. and 50-km altitude than for GRAM-90.

The longitudinal variability for temperature in GRAM-90 is illustrated by figures 3.11 and 3.12, which show latitude-longitude cross sections of temperature at 30 km (fig. 3.11) and 80 km (fig. 3.12) altitudes, with temperature expressed as percentage deviation from the zonal-mean temperature at the respective heights and latitudes.

Comparable GRAM-90 data on longitudinal variability of density are shown in figures 3.13 and 3.14 for the month of January, also expressed as percent deviations from the zonal-mean value.

Longitudinal variations of zonal and meridional wind in GRAM-90 are shown in figures 3.15 to 3.18. Values are in meters per second.

3.2 Comparison of GRAM-90 Results With 3-D SCM Output

As noted in section 1, the data for GRAM-90 was compiled from a variety of sources, including both rocket and satellite data in the 20- to 120-km height range. These data sources represent averages, for each month, over a period of several years, the longest period being the MRN data (1969 to 1986). Four of the data sets (Groves, 1985; Barnett and Corney, 1985a,b; Fleming et al., 1988; and Dartt et al., 1988) are all derived from the same basic set of upper atmospheric satellite observations. The excellent consistency among these data sets, and with the combined averages for the GRAM-90, are illustrated by comparison of figures 3.1 to 3.18 with the extensive plots provided by Groves (1985) and Fleming et al. (1988).

In this section, a comparison between the empirically-based GRAM-90 and a physically-based, 3-D stratospheric circulation model (SCM) is presented. For purposes of comparison with the GRAM-90 results, a 3-D stratospheric dynamical/chemical circulation model was run for an annual simulation of the global atmosphere to a height of ~85 km above the surface. The model used was an enlarged version of the quasi-geostrophic, spectral model of Cunnold et al. (1975) which includes the relevant ozone chemistry in interaction with the dynamical and thermodynamical components. A detailed description of the enhanced dynamical/chemical model is contained in Alyea et al. (1985). Briefly, however, the model was formulated with 32 vertical levels spaced in constant increments of the logarithm of pressure (the top being along the 0.00348-mb pressure level or at a height of ~85.4 km) and was truncated in its horizontal spectral resolution after planetary wave number 18 (using a triangular truncation scheme). The principal forecast equations represent the quasi-geostrophic vorticity and the ozone mixing ratio. Temperature is obtained from a form of the "thermal wind" relationship, and vertical motion is computed at each time step from the diagnostic 3-D " ω -equation."

At the Earth's surface, topographic data in spectral form is used to determine the vertical motion from the horizontal wind field. Tropospheric heat forcing is specified using a simple symmetric (about the Equator) model based on climatological observations (see Cunnold et al., 1975). At the stratospheric and mesospheric levels, solar heating is determined by the ozone distribution, and the position of the Sun while ultraviolet (UV) heating/cooling is approximated using a linearization involving an "equilibrium" temperature field toward which the UV heating/cooling term attempts to adjust (see Cunnold et al., 1975).

For the comparison runs, the model was initialized with output from a previous seven-wave version of the model (Cunnold et al., 1975) and integrated forward in time for 1 and one-half years. These initial conditions resulted from a more than 3-year run of the earlier model. For comparison with the GRAM-90 results, monthly mean temperature and zonal wind fields from the last July and January runs of the SCM will be used.

Figures 3.19 and 3.20 show the SCM results for the July zonal-mean temperature (K) and zonal-mean zonal wind (m/s) fields, respectively. These are to be compared with figure 3.2 for the GRAM-90 July zonal-mean zonal temperature cross section and figure 3.6 for the GRAM-90 July zonal-mean zonal winds. As seen from these figures, there is a great similarity between the SCM and GRAM-90 representations (but note that the SCM figures top off at 80-km altitude). In the wind fields, the polar night jets in the two models are represented by westerly wind maximums with speeds in excess of 90 m/s (greater than 110 m/s for the SCM) centered on ~50- to 60-km altitude and ~40° S. to 50° S. latitude. The summer-hemisphere, easterly, upper-level maximums are somewhat higher in altitude than the westerly jets, located at a height of approximately 70 km in the ~40° N. to 50° N. latitude belt but, as expected, contain maximum wind speeds that are lower than those of the polar night westerlies. This is particularly true for the SCM results in which the easterly winds attain maximum speeds that are less than 40 m/s. In both cases, the wind fields undergo an approximately 150-m/s change in passing from the polar night westerly jet to the summer hemisphere easterly maximum, but the SCM maintains an approximately 20-m/s stronger westerly component throughout. This feature is linked, through thermal wind considerations, to the somewhat stronger horizontal temperature gradients of the winter (southern) hemisphere found in the SCM below about 50 to 60 km than for the observationally based GRAM-90.

During January the two models exhibit greater differences. Figure 3.21 (temperature) and figure 3.22 (zonal wind) represent the SCM zonal-mean cross sections for January and are to be compared respectively to figures 3.1 and 3.5, representing the GRAM-90 results. In these cases not only are the westerly and easterly maximum wind speeds different, but their locations also differ significantly. For example, the GRAM-90 wind maximums are both located at about 65 km above the surface and within the 30° to 40° latitude belts of their respective hemispheres. The two maximum speeds are similar, in the 50- to 60-m/s range. The SCM cross sections are not nearly so antisymmetrical about the Equator. Again, these differences can be seen in the temperature cross sections as well as in the wind data. In particular, the horizontal temperature gradient in the lower stratosphere (~20- to 35-km altitude) of the Northern Hemisphere SCM cross section (fig. 3.21) shows a fairly large warm patch between ~35° N. to 50° N. latitude. This feature is nearly undetectable in the GRAM-90 results and no doubt accounts, through thermal wind considerations, for the more northerly (60° N.) and lower (50-km) altitude of the SCM January polar night jet than in the GRAM-90. Other aspects of the January SCM and GRAM-90 comparisons show less deviation.

Part of the reason for the observed differences in the SCM results and the GRAM-90 data is due to the effects of interannual variability. For example, winters at higher latitudes are affected by varying intensities of stratospheric warming conditions. Near-equatorial latitudes are affected by quasi-biennial oscillations. For the GRAM-90 data base, the effects of interannual variability are averaged out because of the use of the multiyear data bases. The SCM results shown here are for a single year of model run.

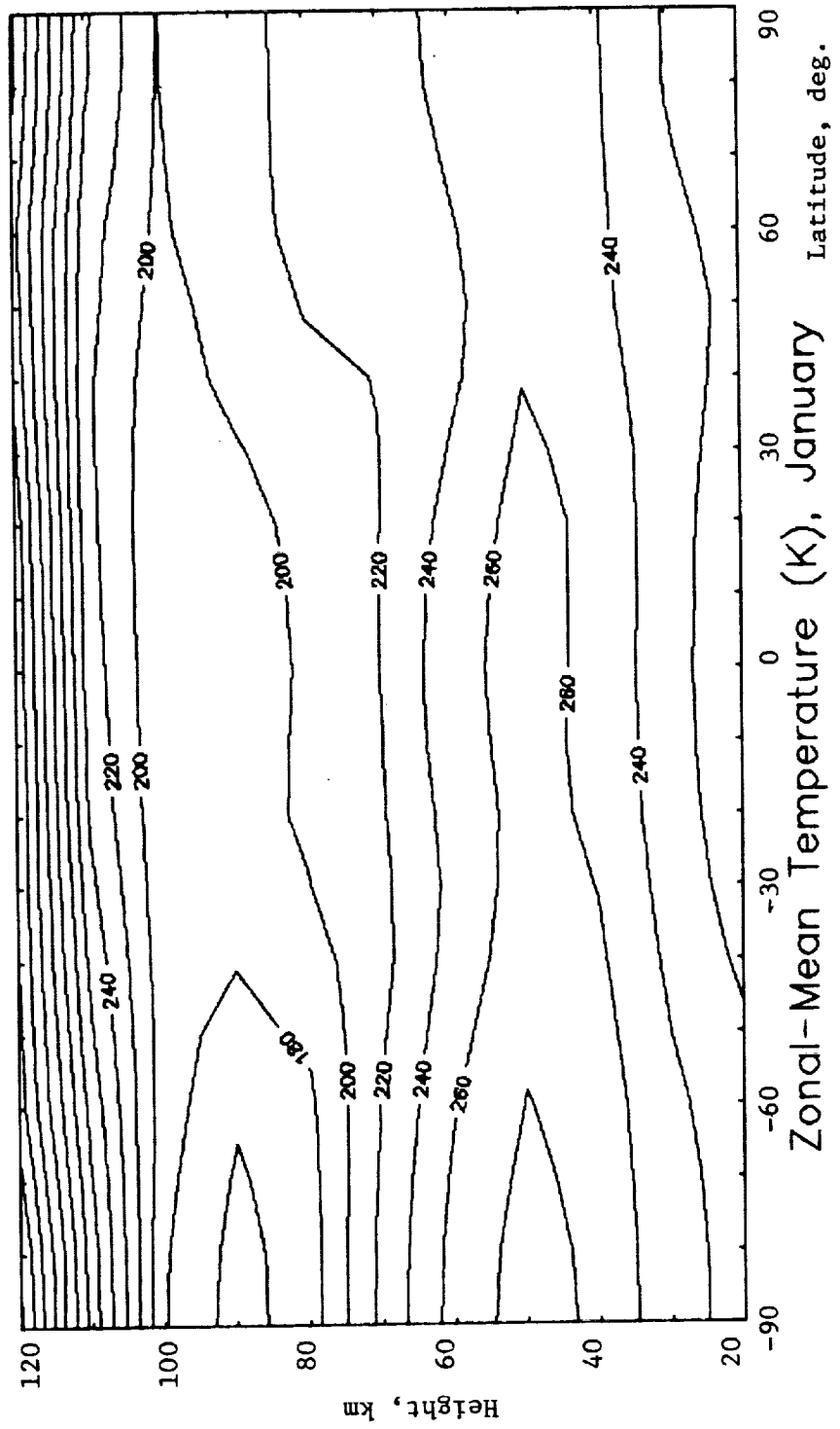


Figure 3.1. GRAM-90 height-latitude cross section for January temperature (K).

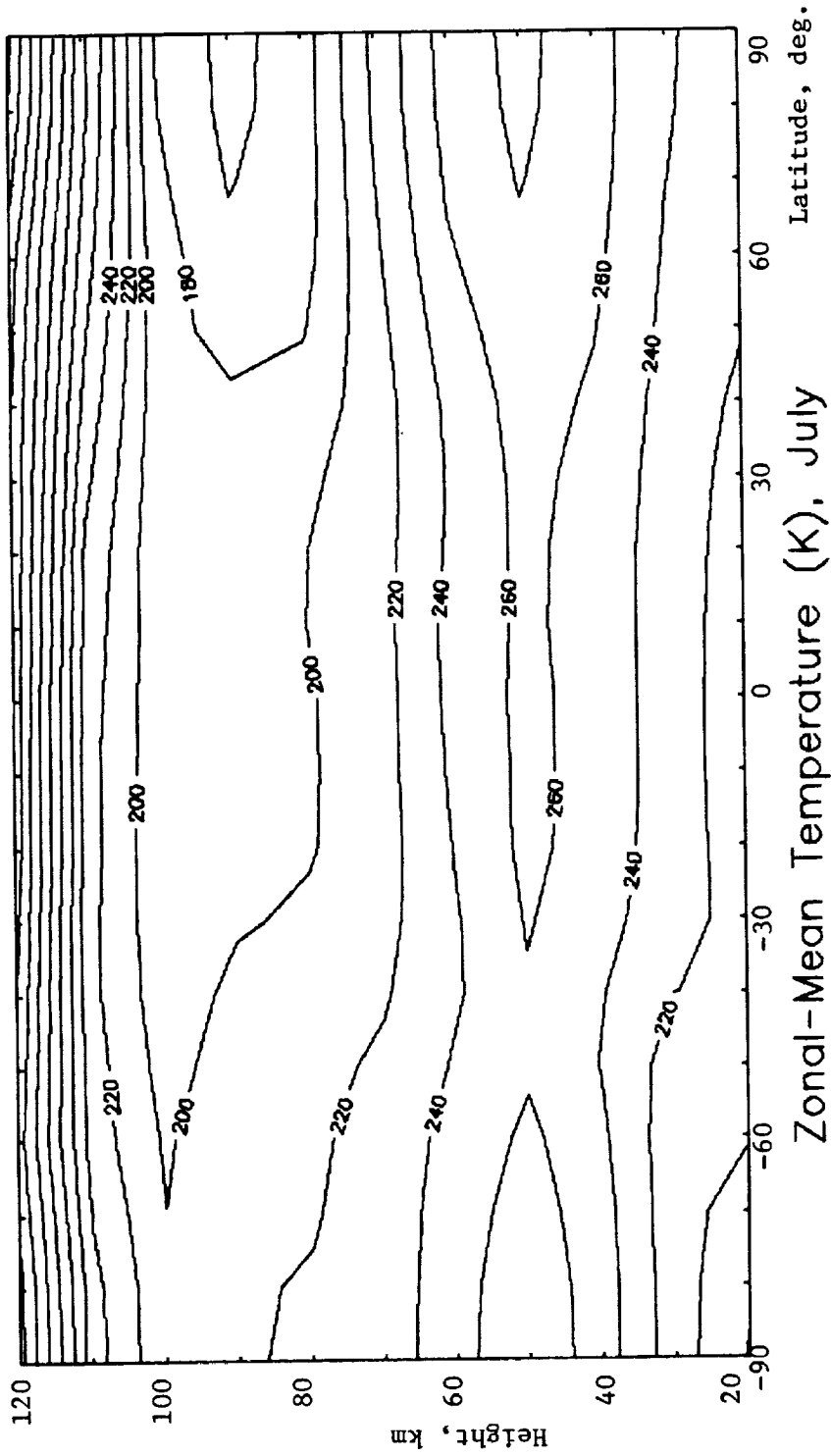


Figure 3.2. GRAM-90 height-latitude cross section for July temperature (K).

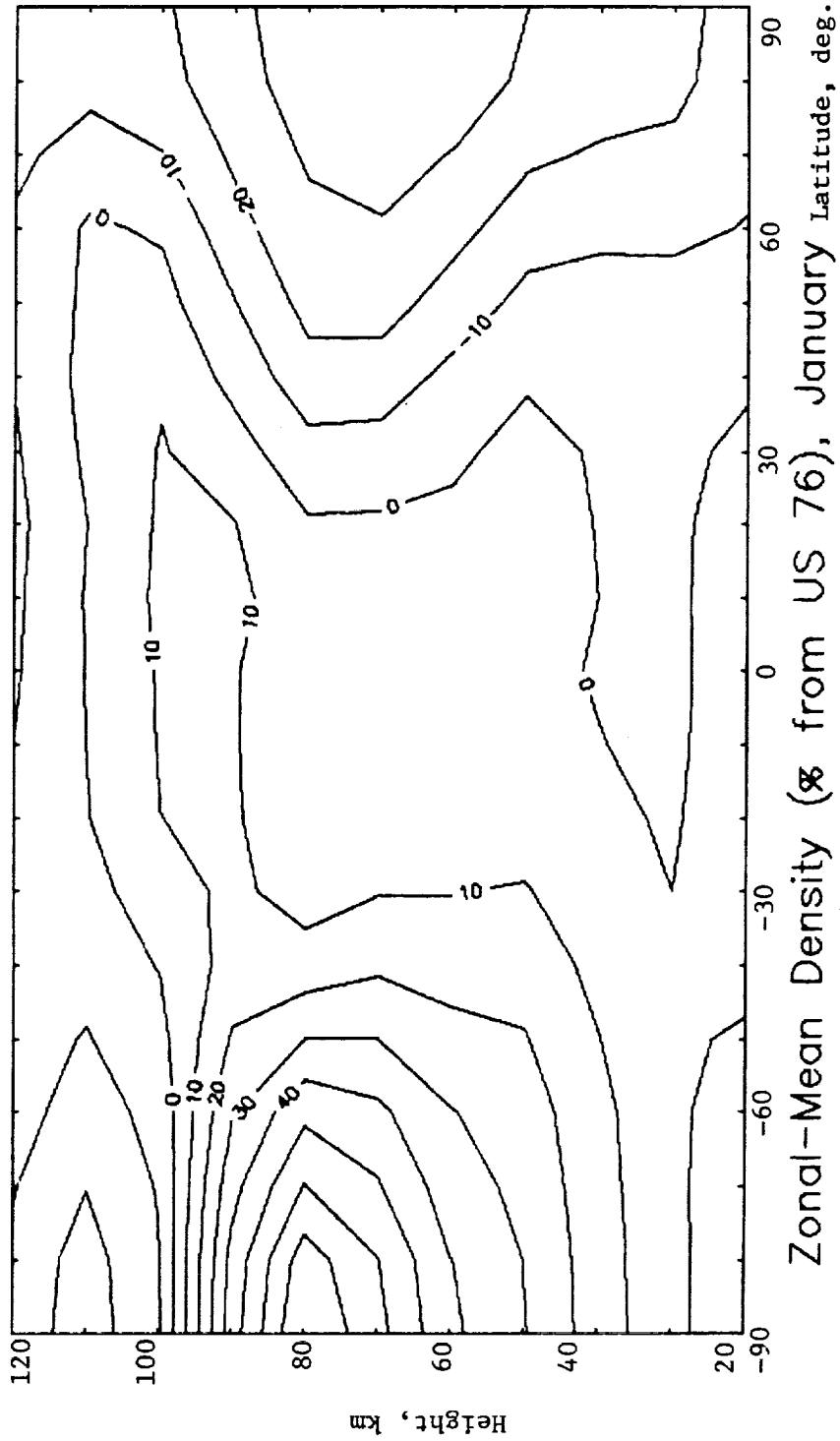


Figure 3.3. GRAM-90 height-latitude cross section for January density (percent from U.S. 1976 standard).

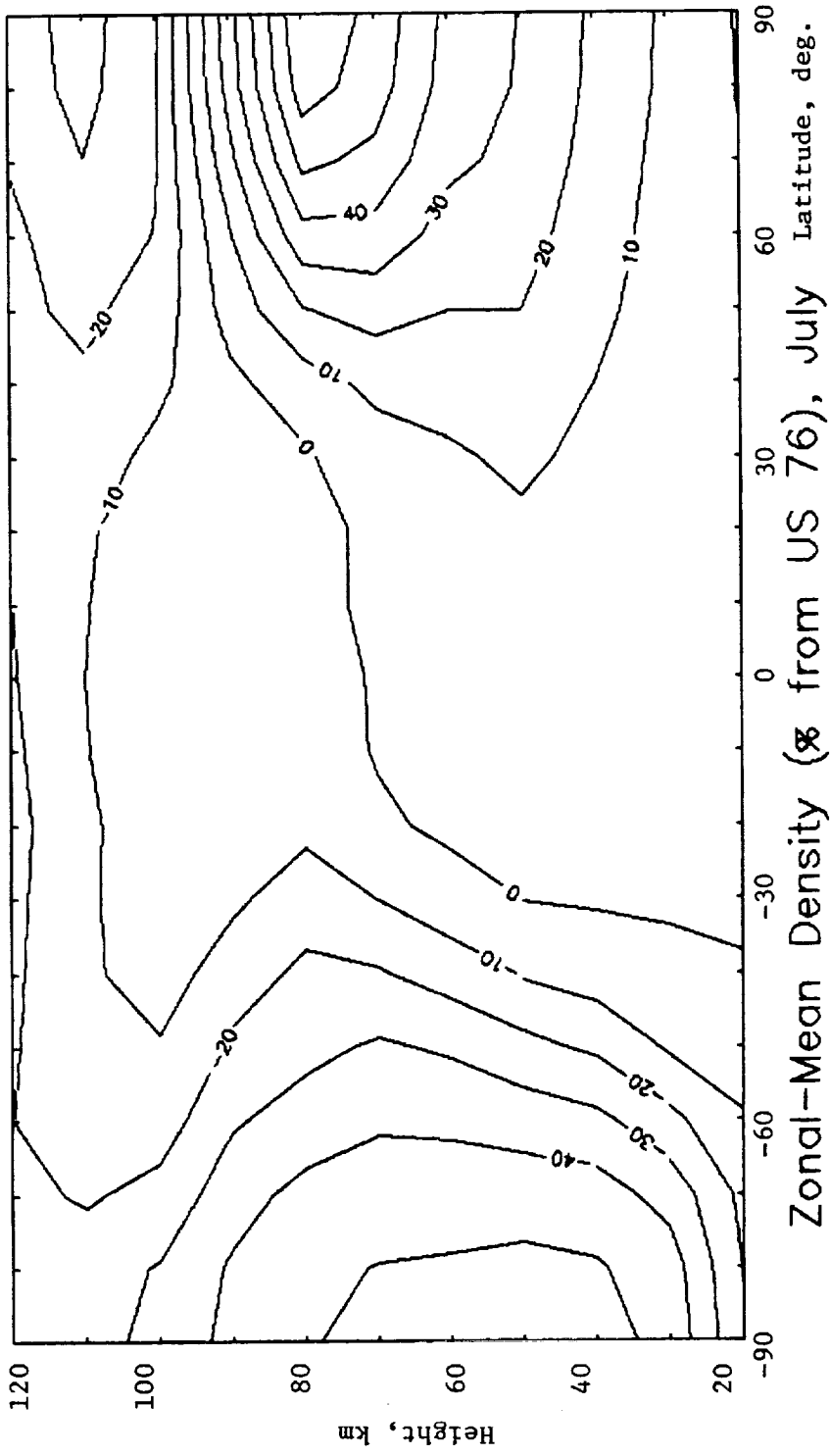


Figure 3.4. GRAM-90 height-latitude cross section for July density (percent from U.S. 1976 standard).

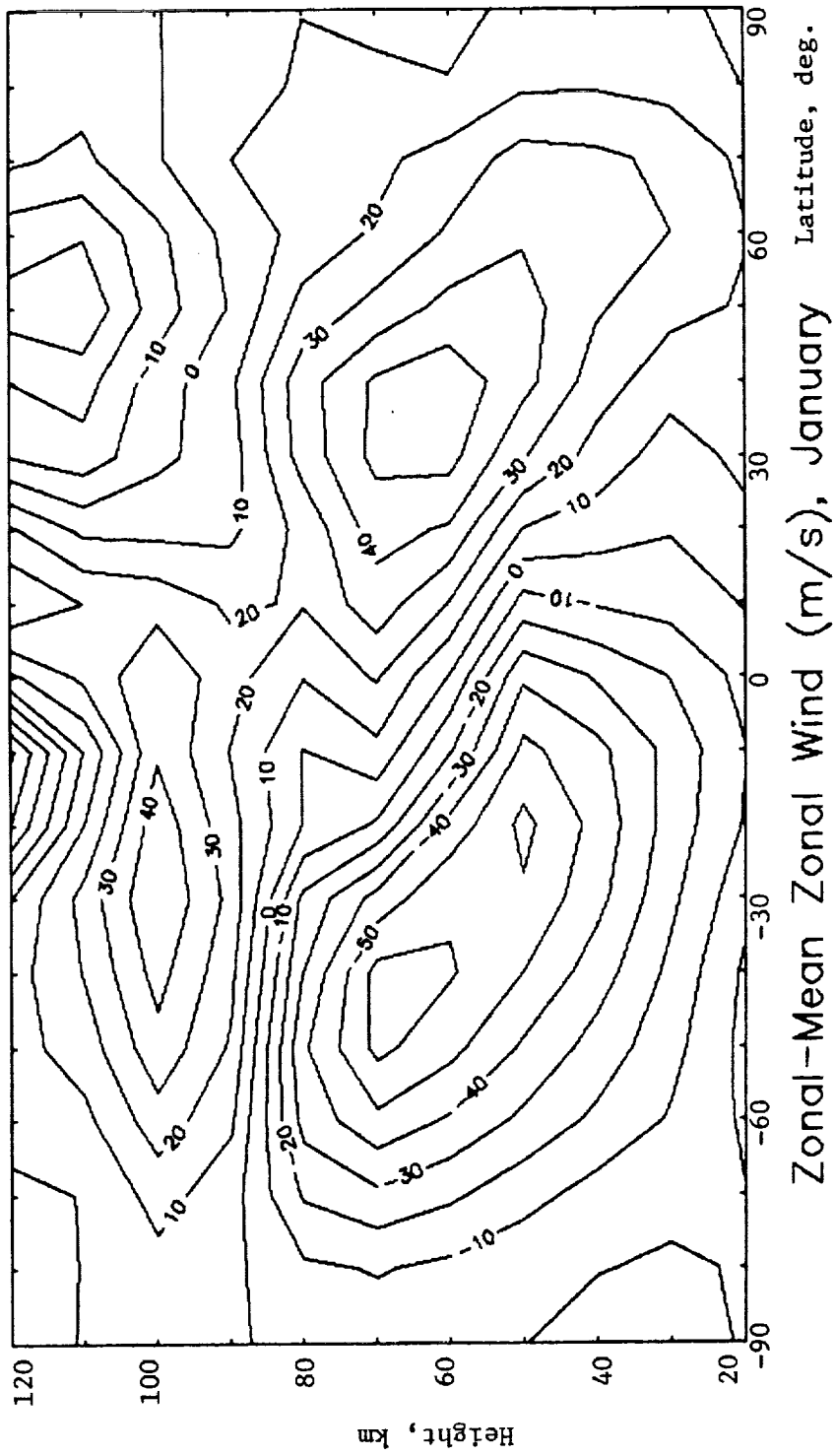


Figure 3.5. GRAM-90 height-latitude cross section for January zonal wind (m/s).

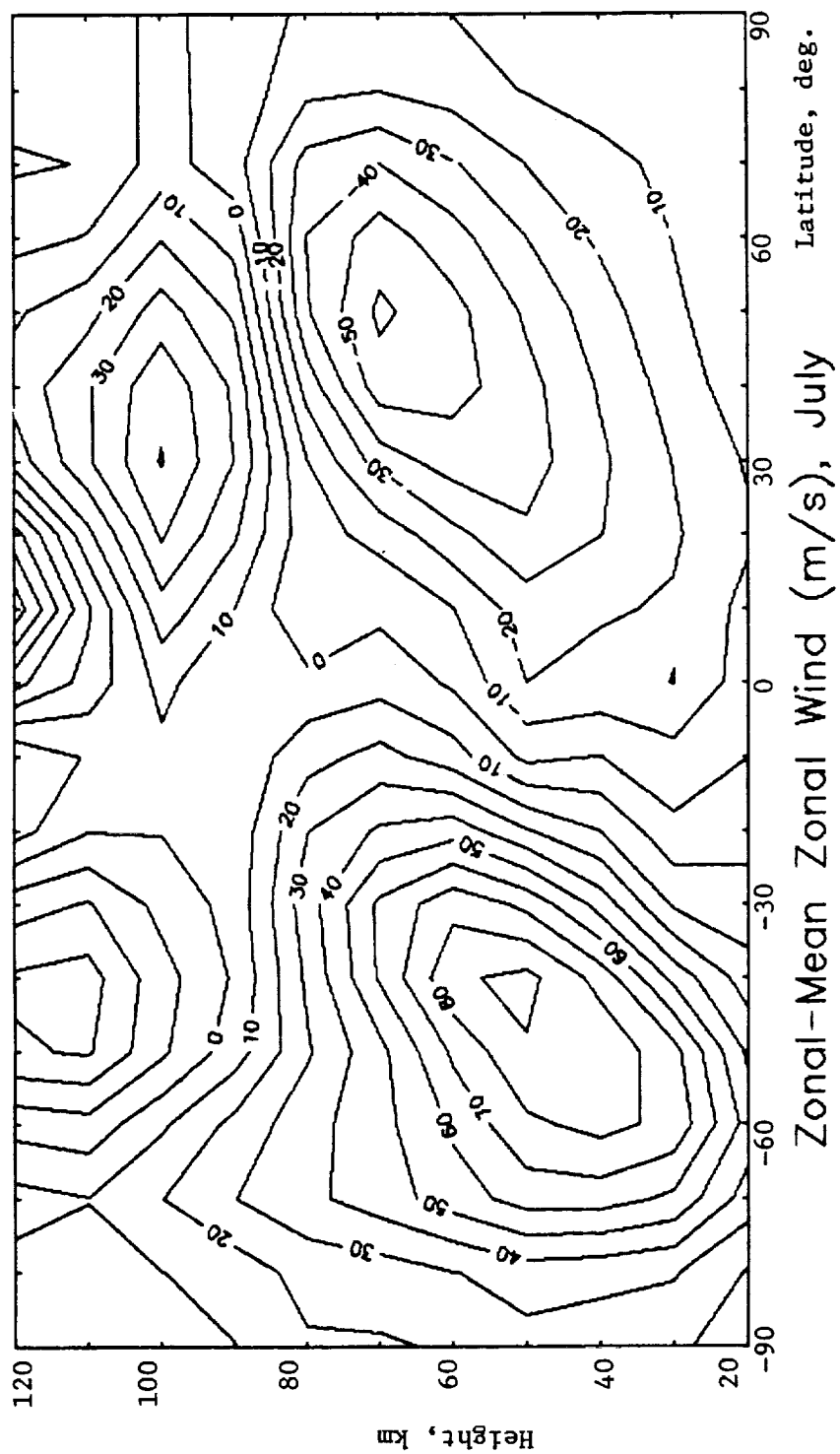


Figure 3.6. GRAM-90 height-latitude cross section for July zonal wind (m/s).

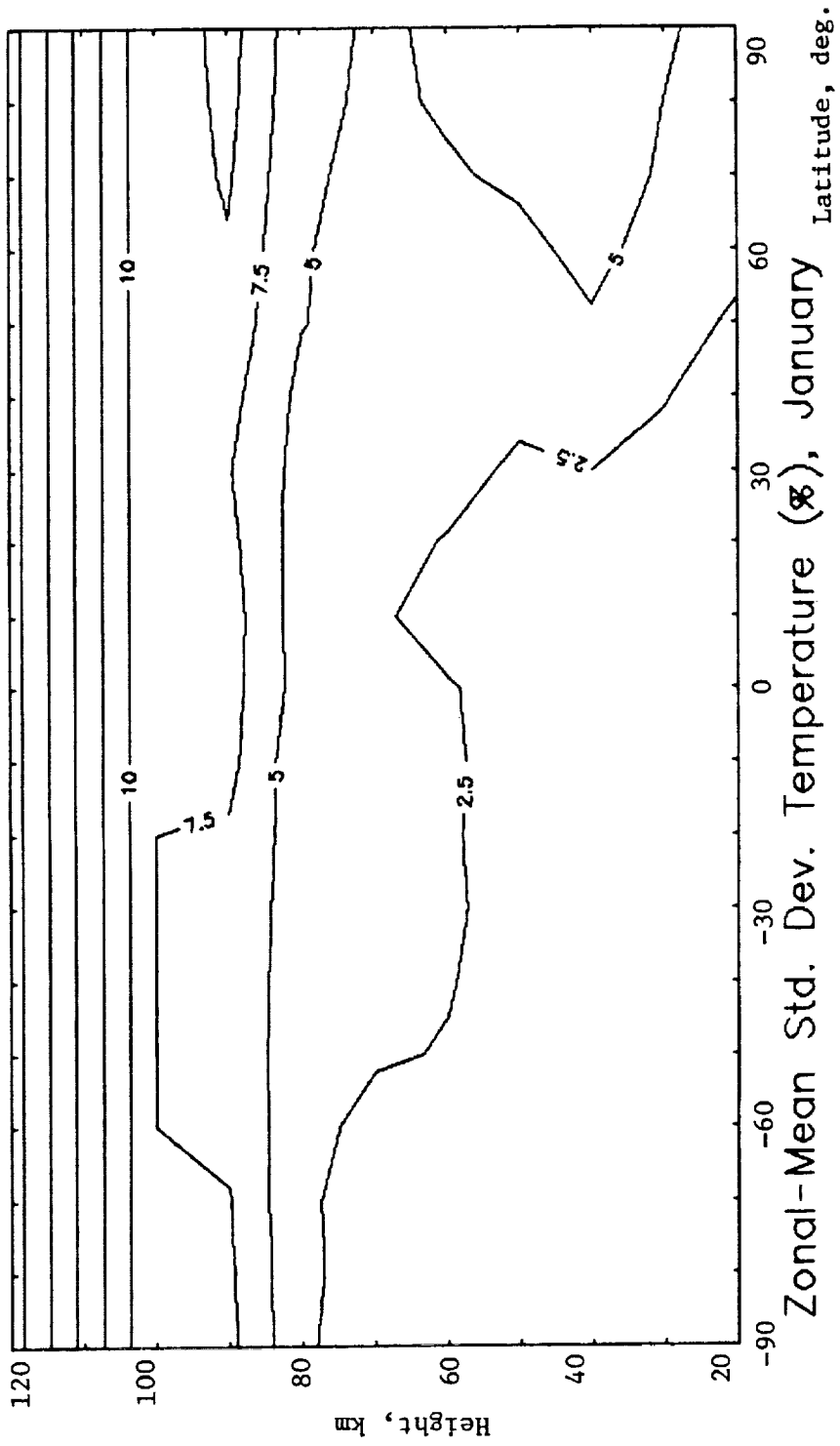


Figure 3.7. GRAM-90 height-latitude cross section for January standard deviation in temperature (percent of mean).

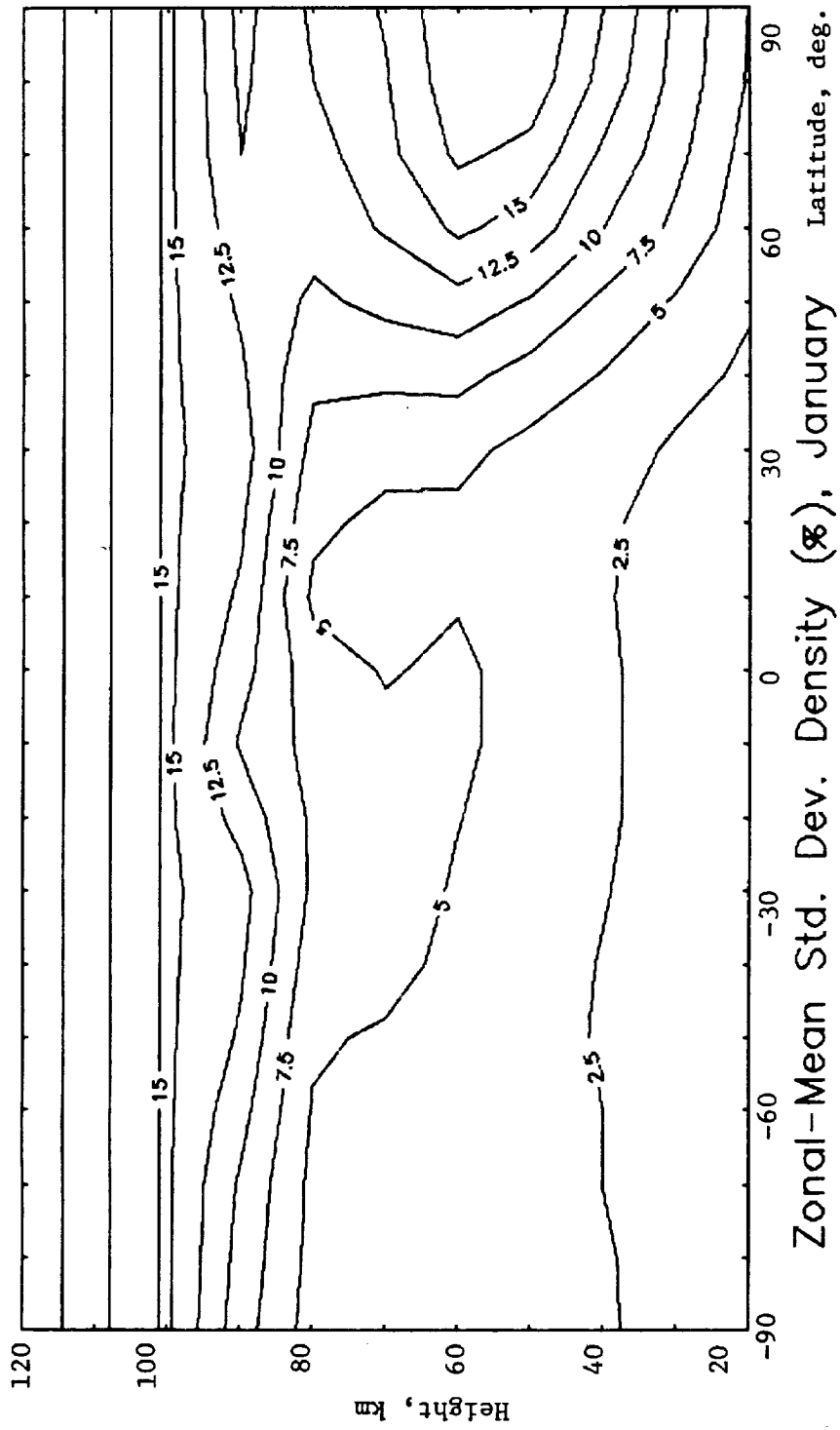


Figure 3.8. GRAM-90 height-latitude cross section for January standard deviation in density (percent of mean).

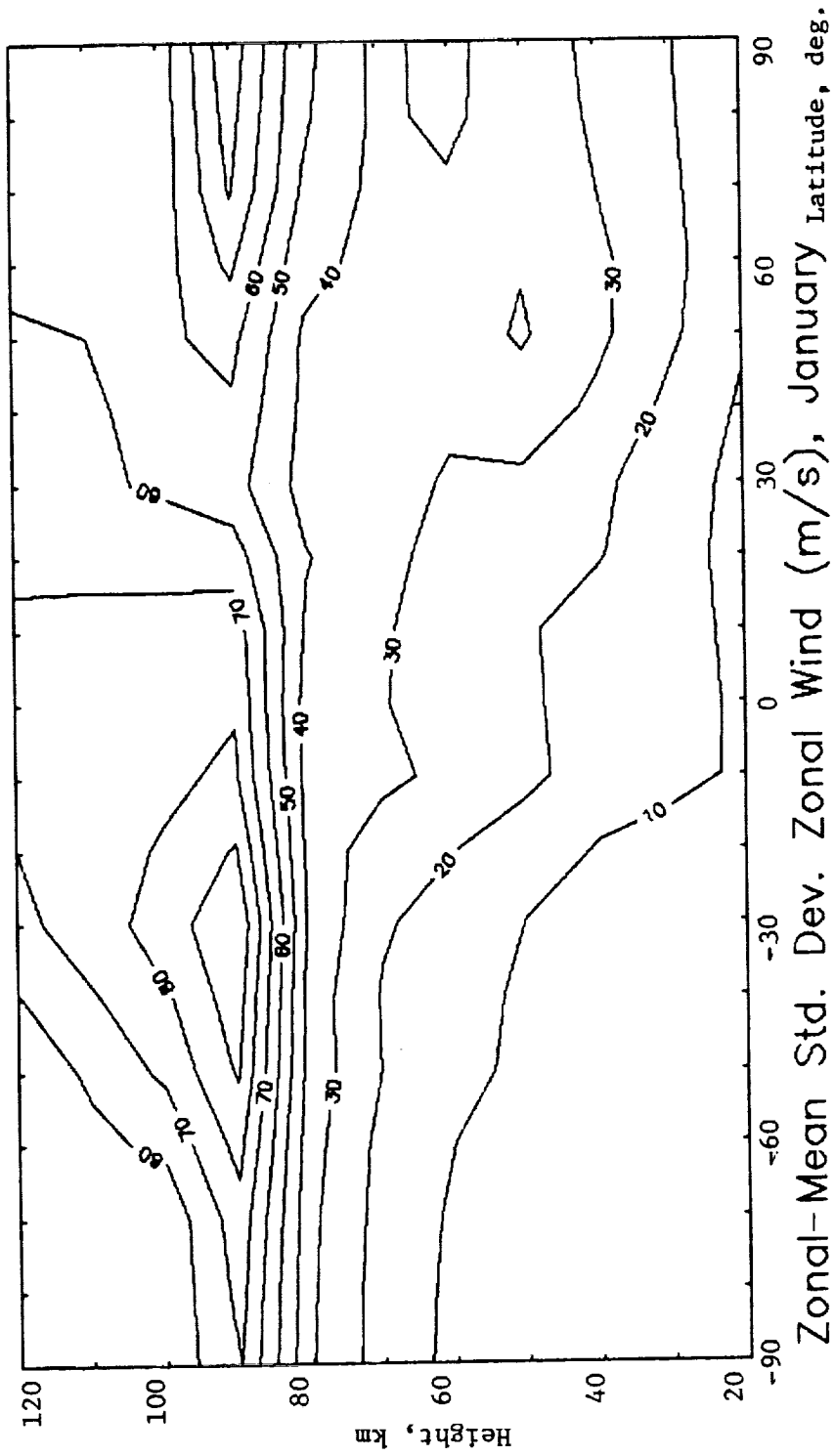


Figure 3.9. GRAM-90 height-latitude cross section for January standard deviation in zonal wind (m/s).

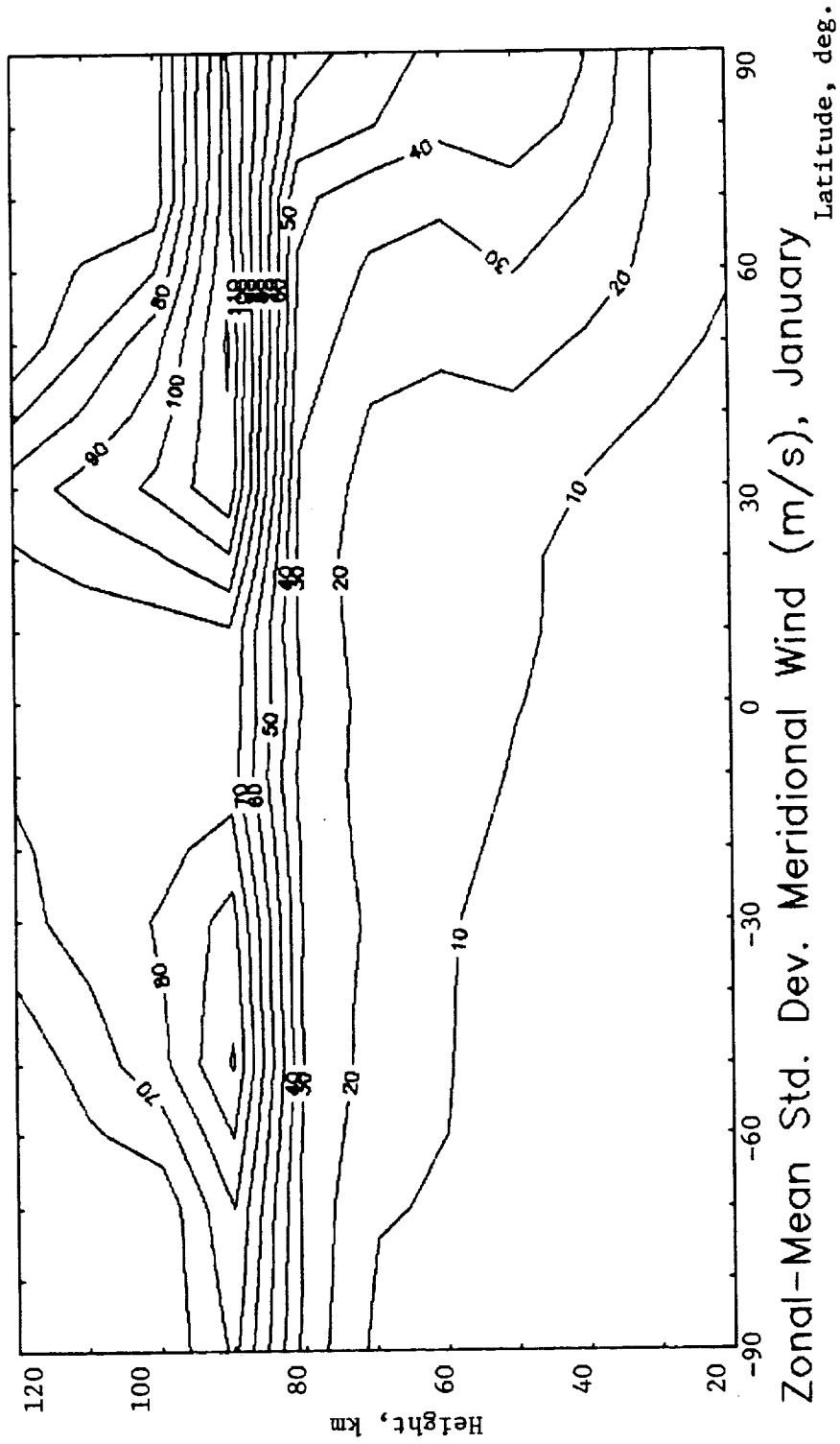


Figure 3.10. GRAM-90 height-latitude cross section for January standard deviation in meridional wind (m/s).

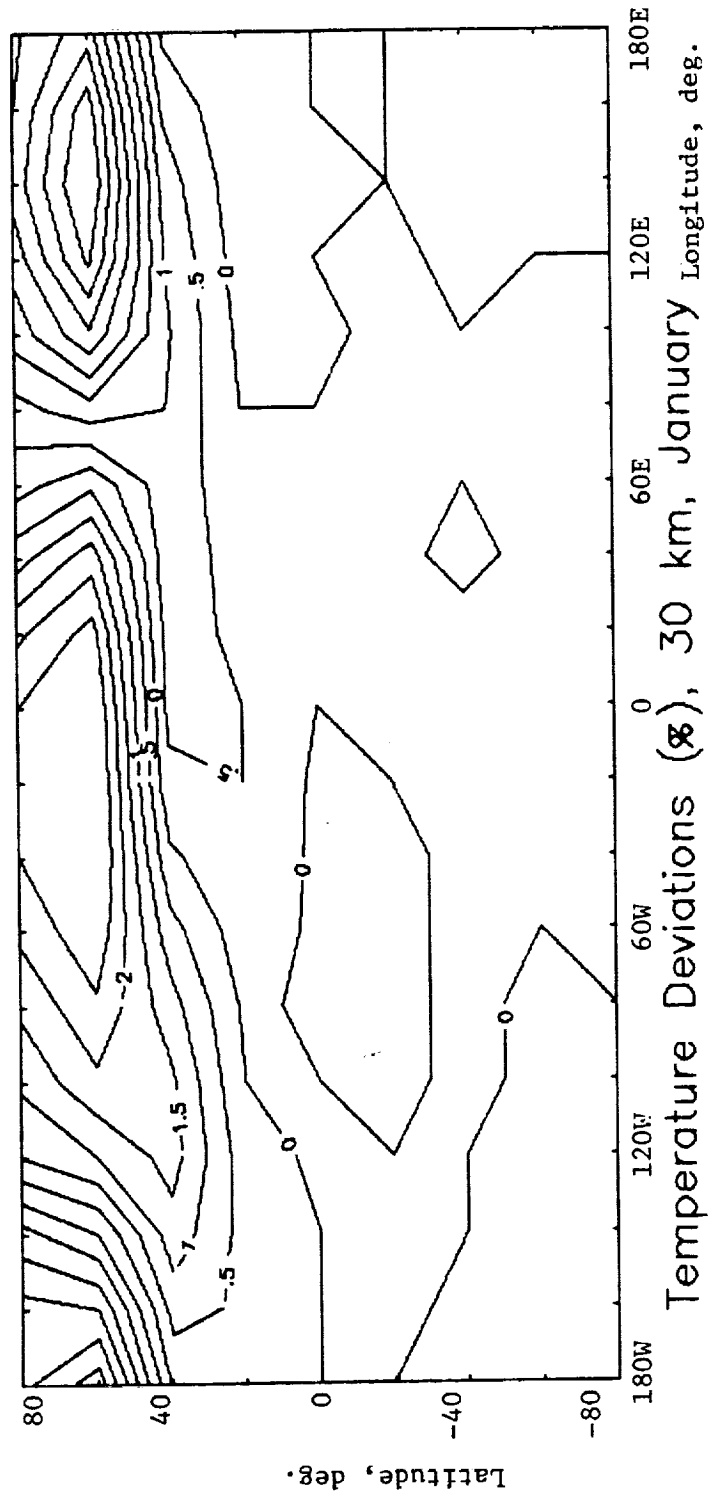


Figure 3.11. GRAM-90 latitude-longitude cross section for January temperature deviations from zonal-mean value (percent) at 30-km altitude.

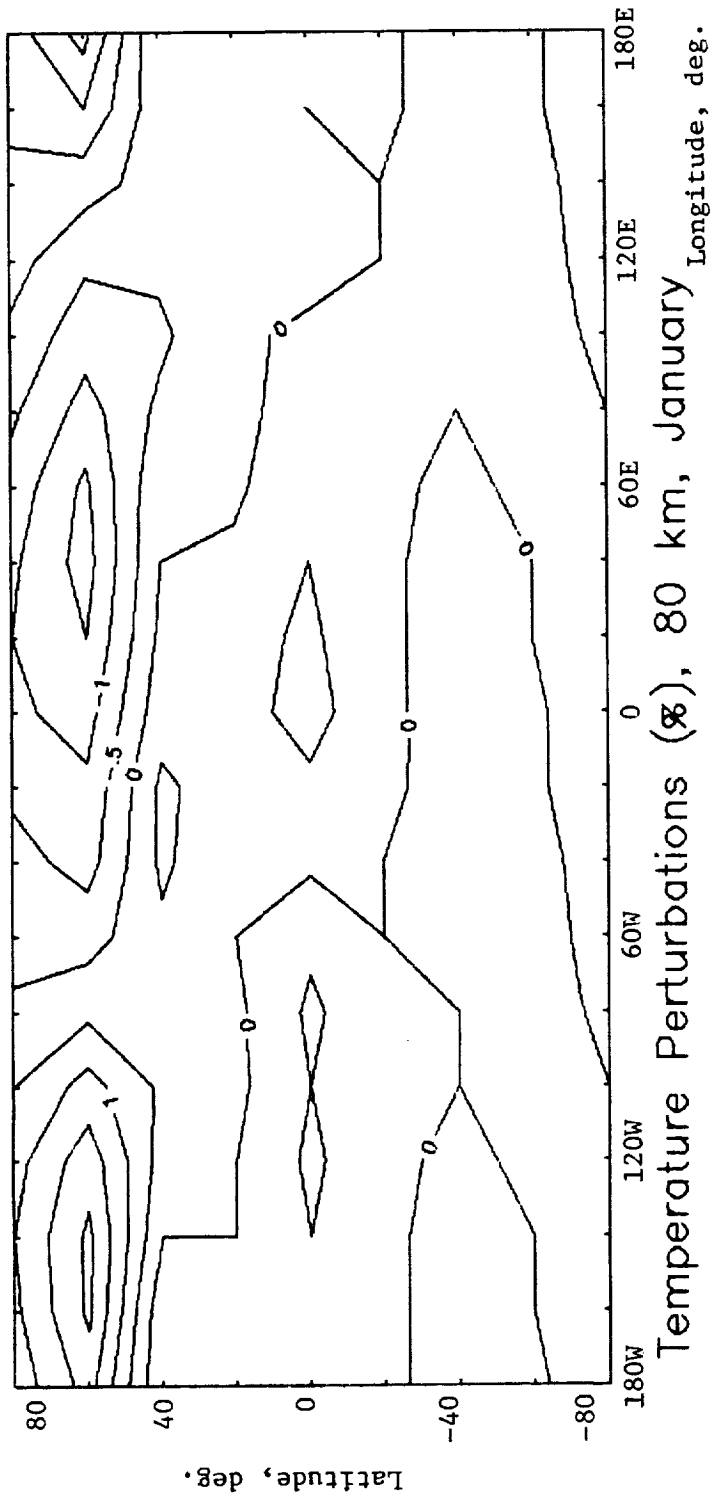


Figure 3.12. GRAM-90 latitude-longitude cross section of January temperature deviations from zonal-mean (percent) at 80-km latitude.

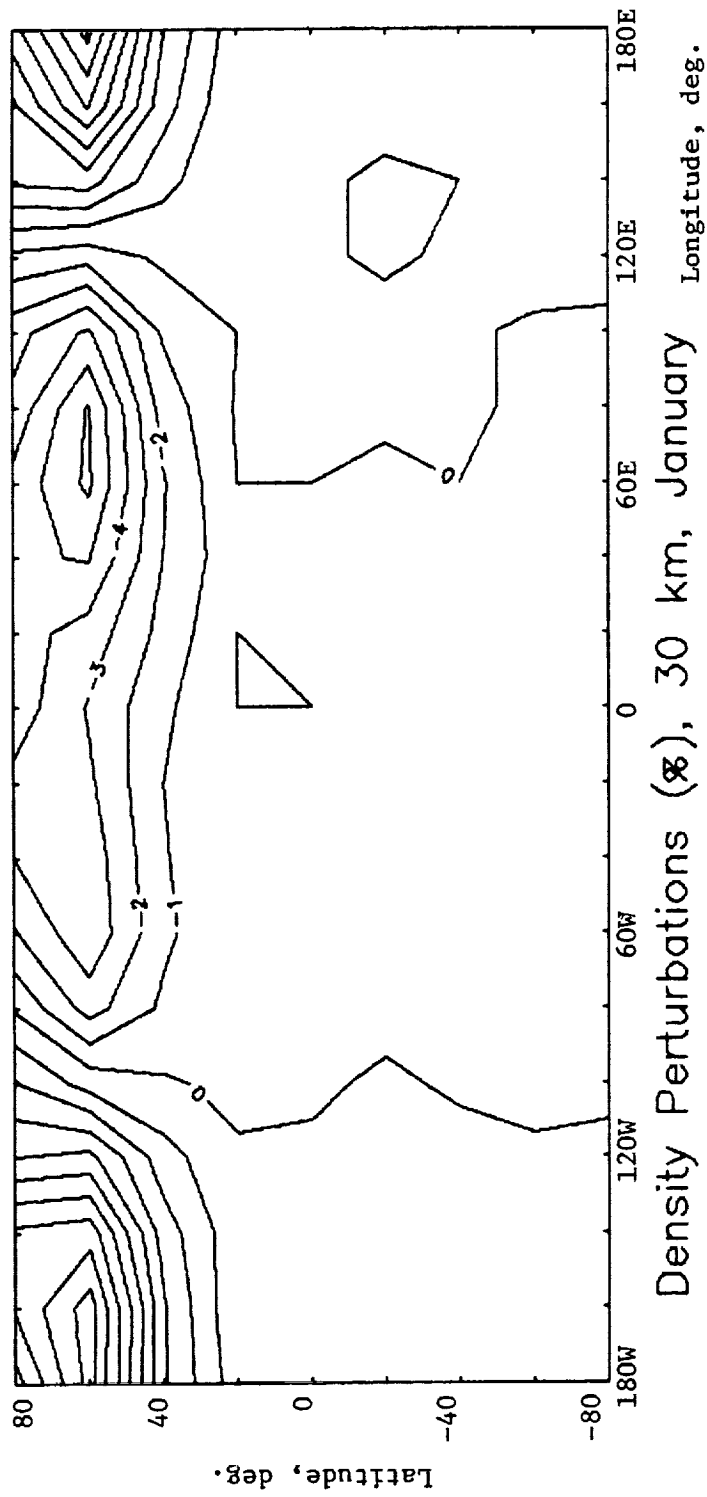


Figure 3.13. GRAM-90 latitude-longitude cross section of January density deviations from zonal-mean (percent) at 30-km altitude.

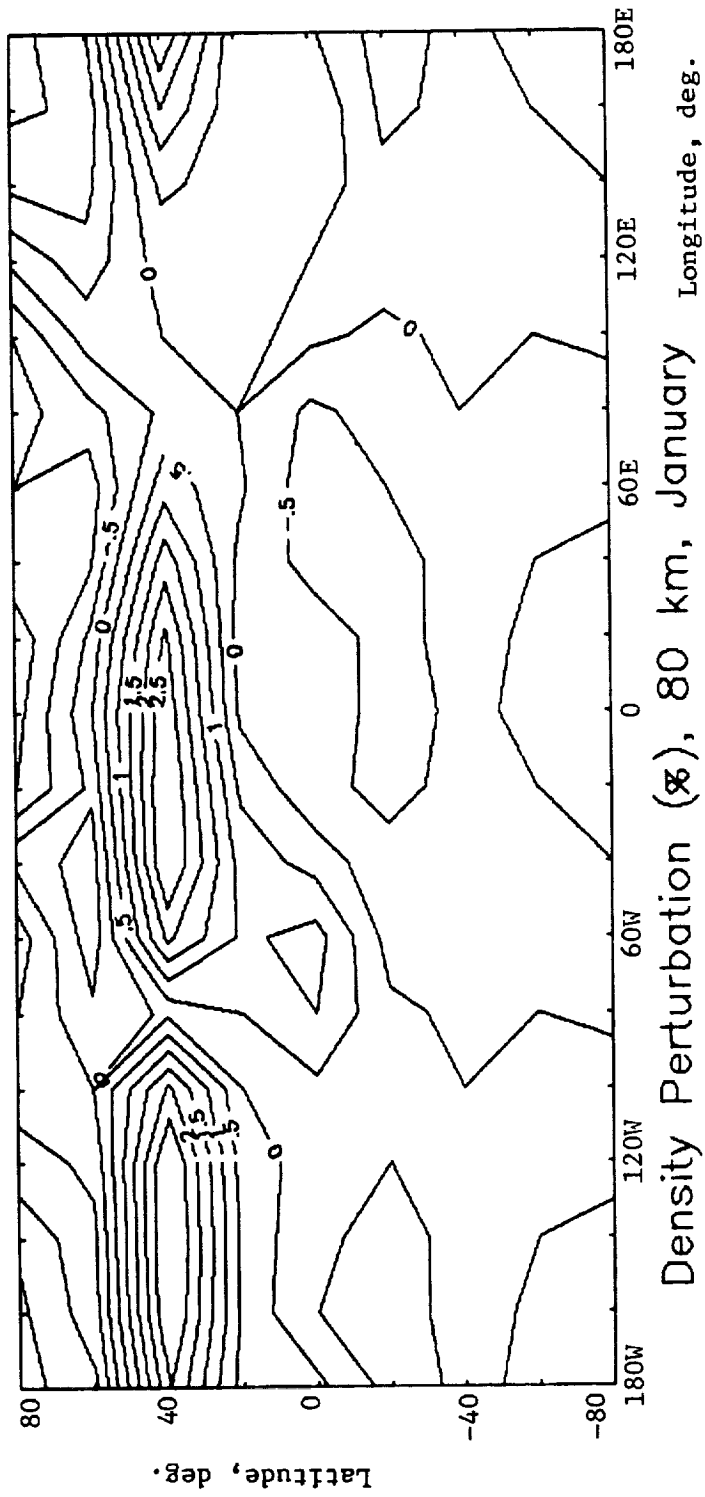


Figure 3.14: GRAM-90 latitude-longitude cross-section of January density deviations from zonal-mean (percent) at 80-km altitude.

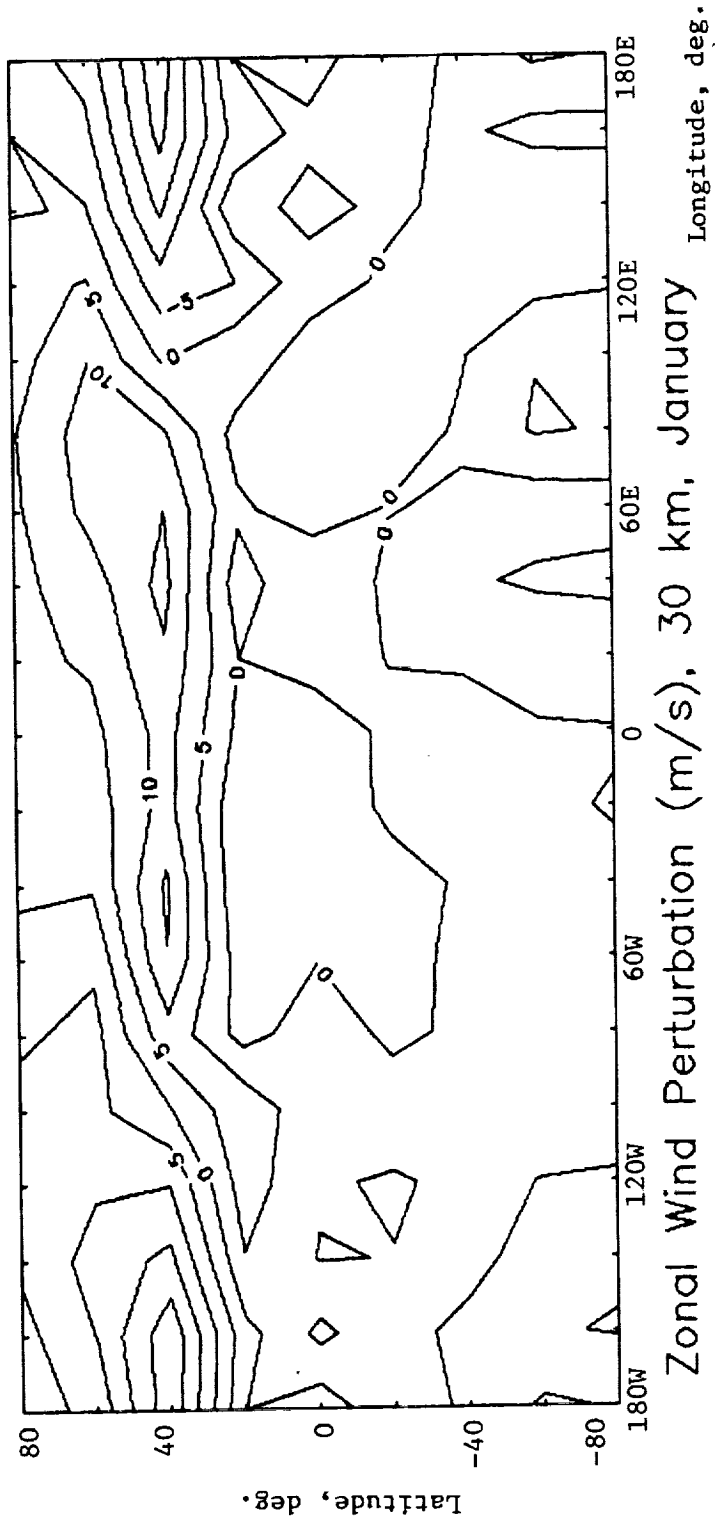


Figure 3.15. GRAM-90 latitude-longitude cross section of January zonal wind deviations from zonal-mean (m/s) at 30-km altitude.

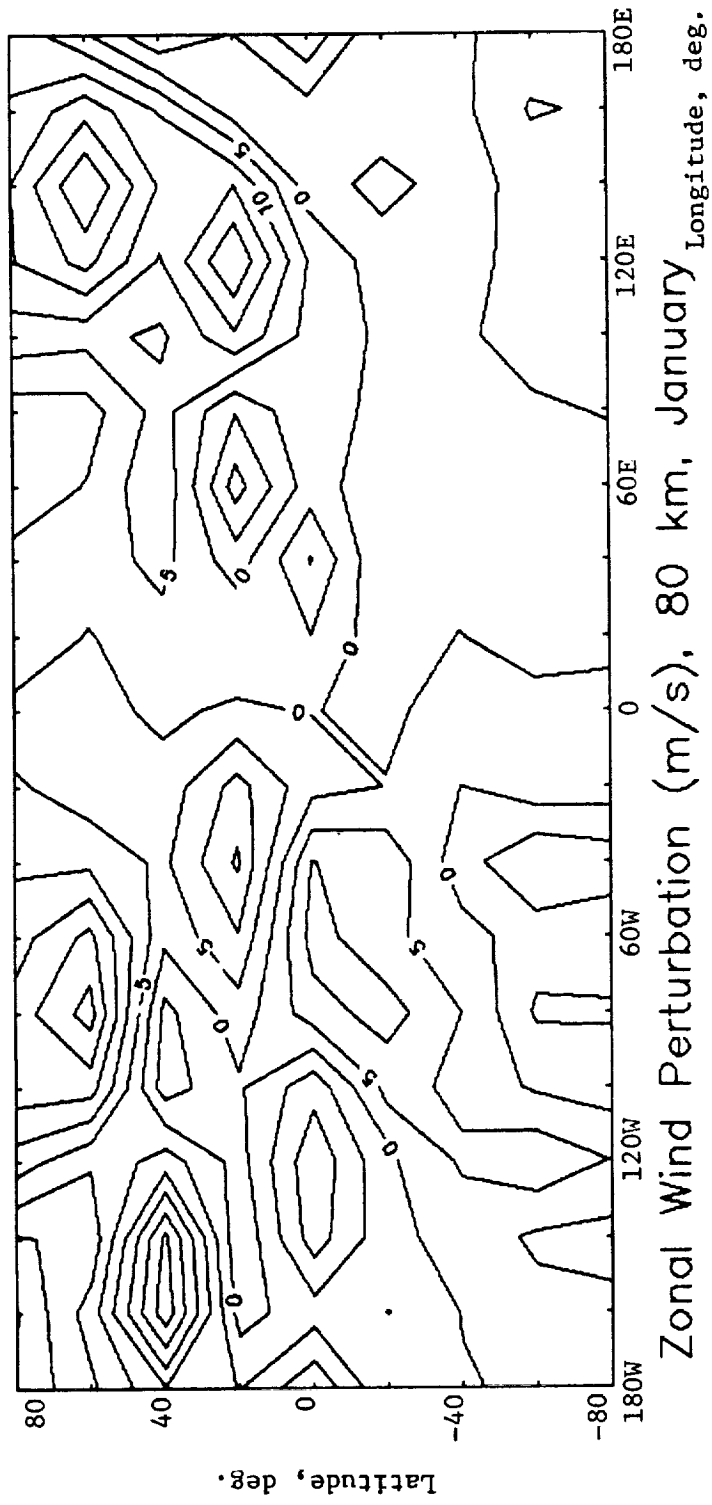


Figure 3.16 GRAM-90 latitude-longitude cross section of January zonal-wind deviations from zonal-mean (m/s) at 80-km altitude.

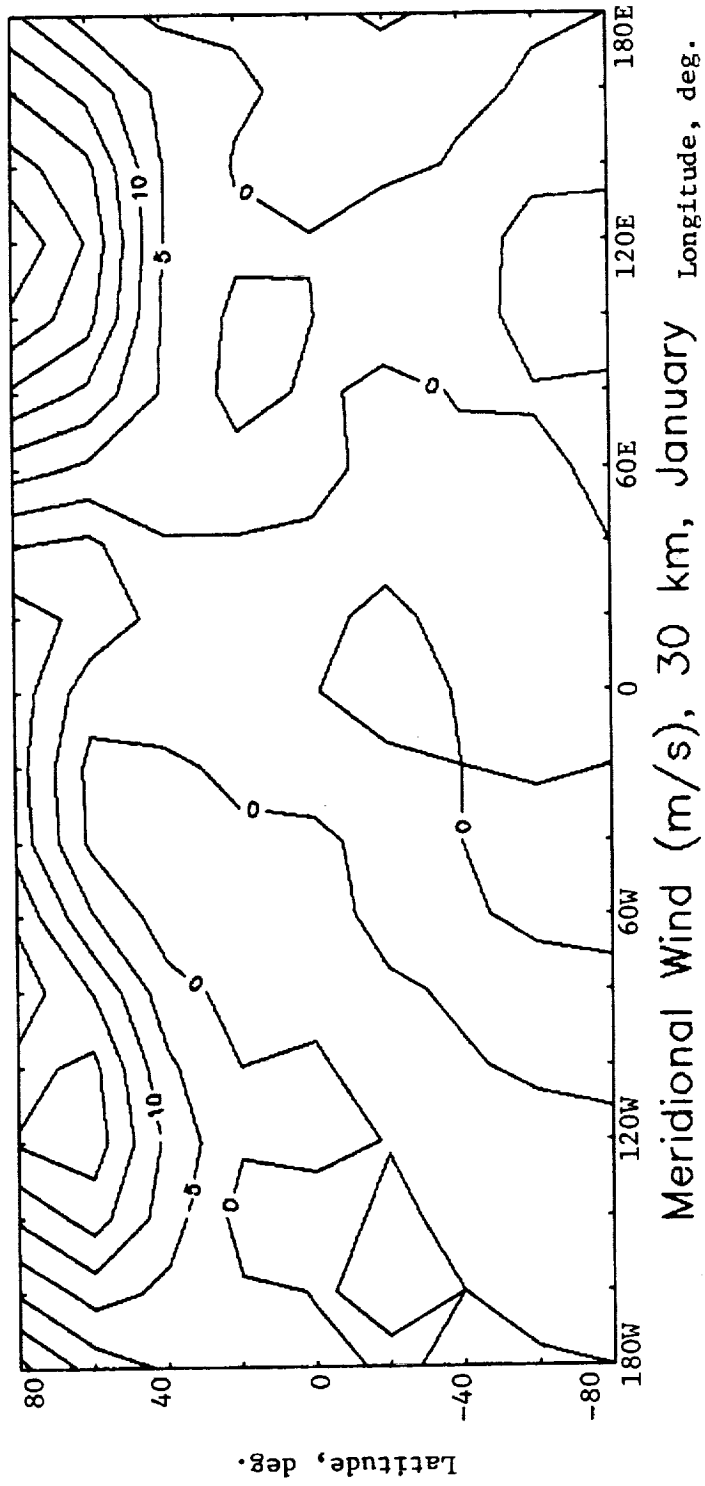


Figure 3.17. GRAM-90 latitude-longitude cross section of January meridional wind deviations from zonal-mean (m/s) at 30-km altitude.

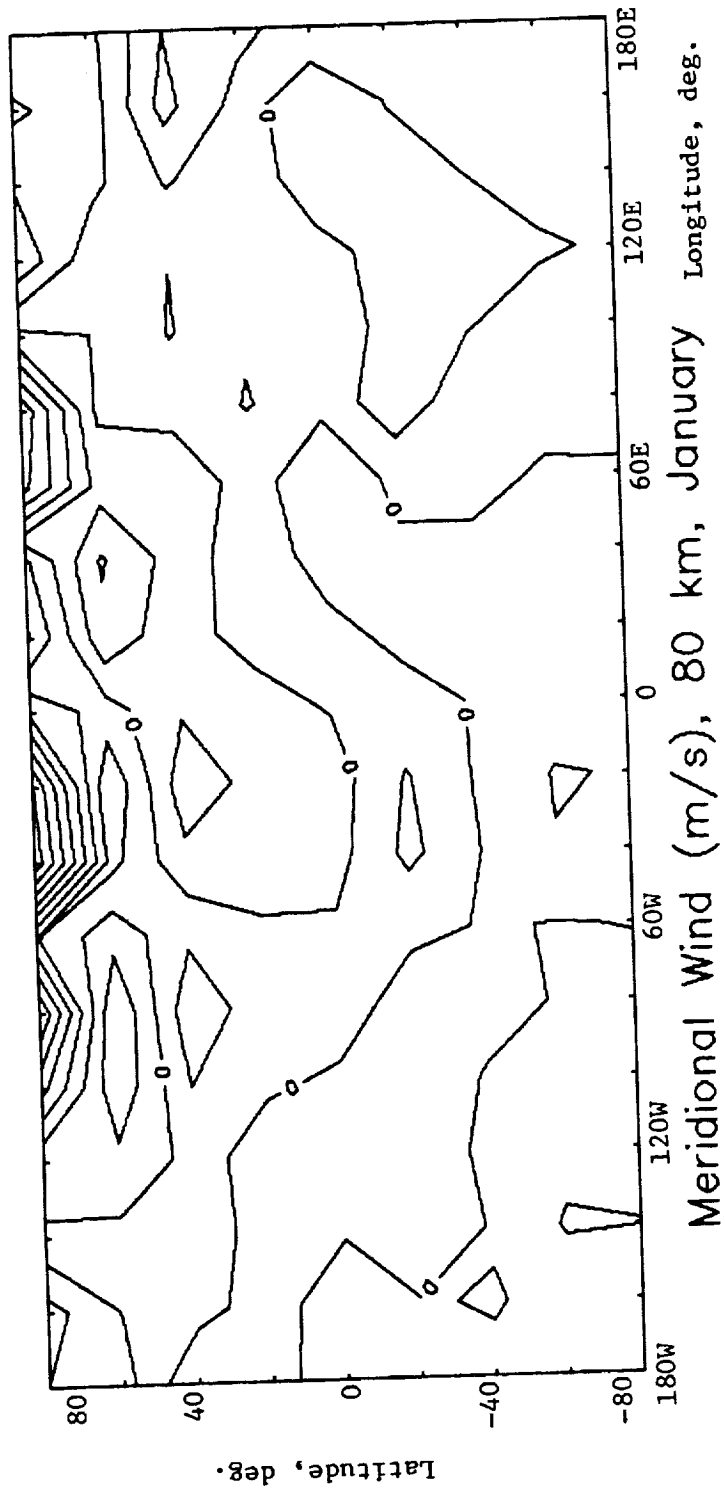


Figure 3.18. GRAM-90 latitude-longitude cross section of January meridional wind deviations from zonal-mean (m/s) at 80-km altitude.

ZONAL-MEAN TEMPERATURE (K), JUL

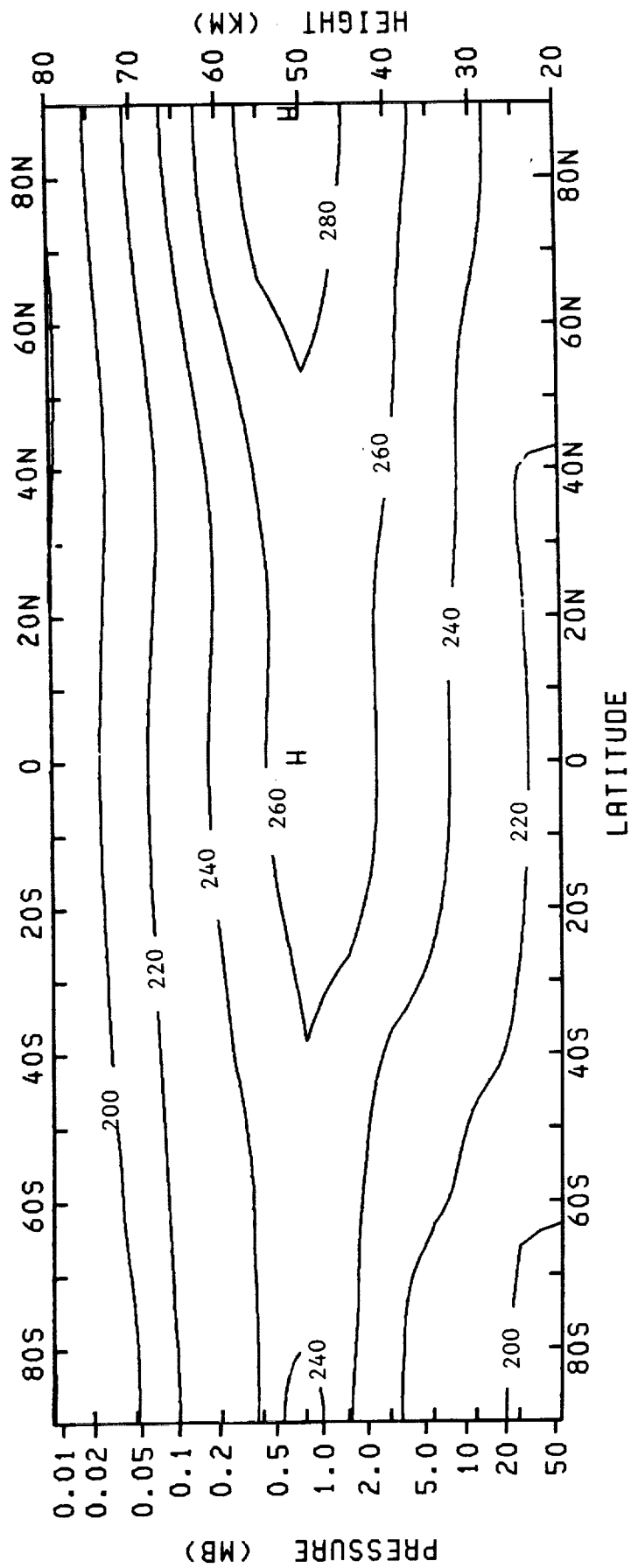


Figure 3.19. SCM height-latitude cross section for July temperature (K).

ZONAL-MEAN ZONAL WIND (M/S), JUL

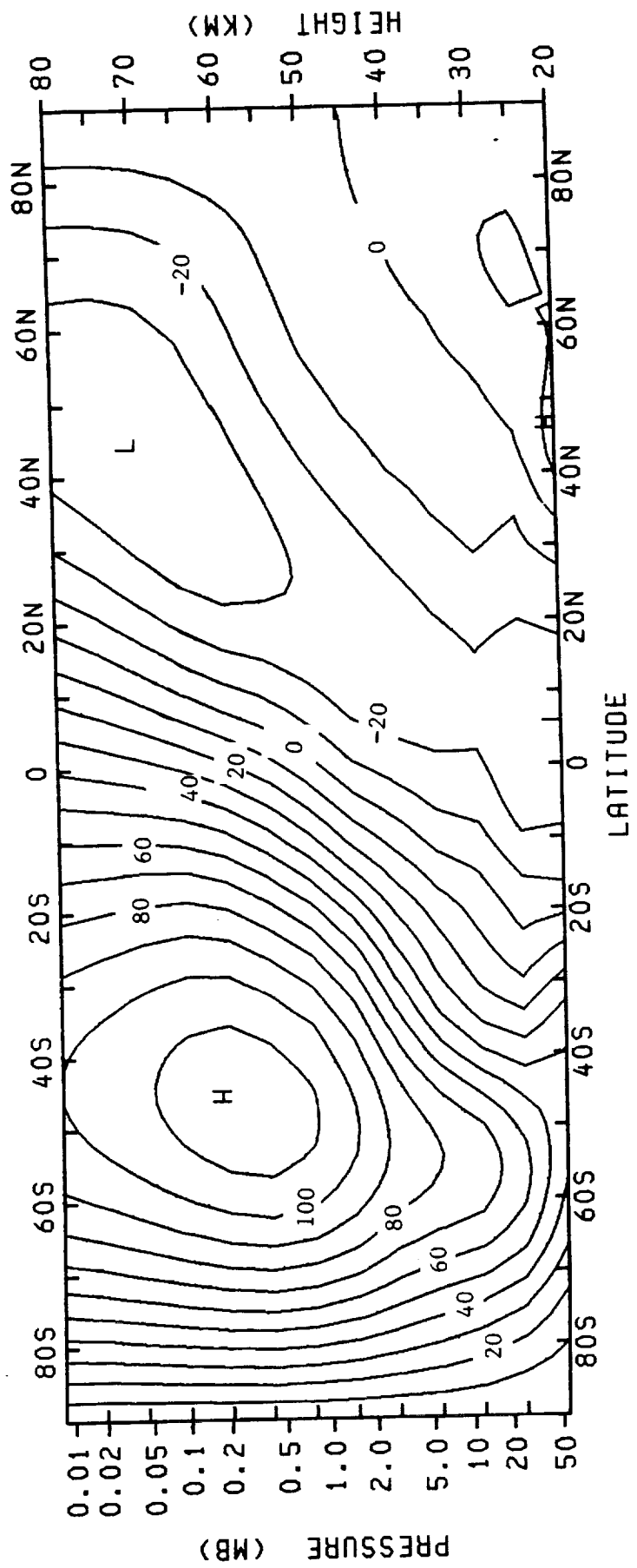


Figure 3.20. SCM height-latitude cross section for July zonal wind (m/s).

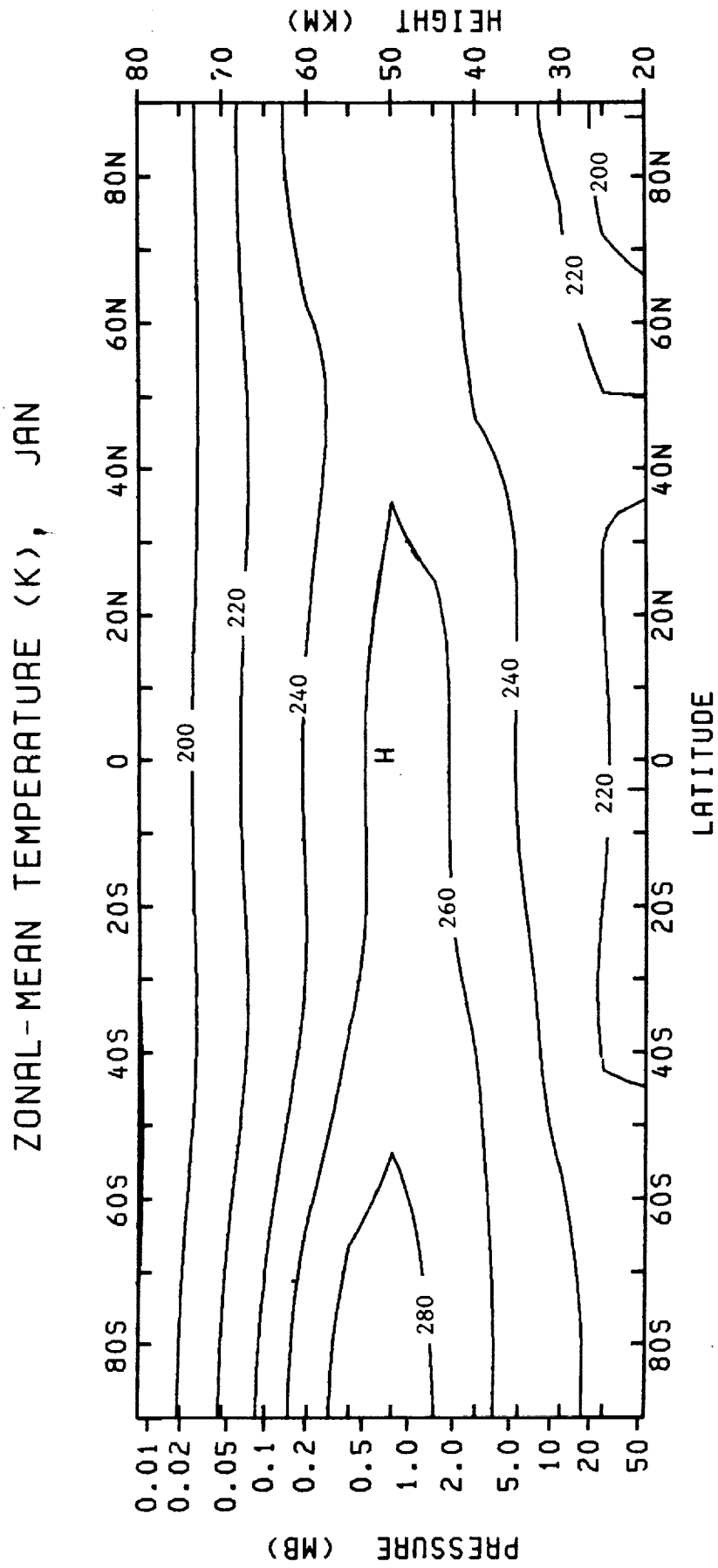


Figure 3.21. SCM height-latitude cross section for January temperature (K).

ZONAL-MEAN ZONAL WIND (M/S), JAN

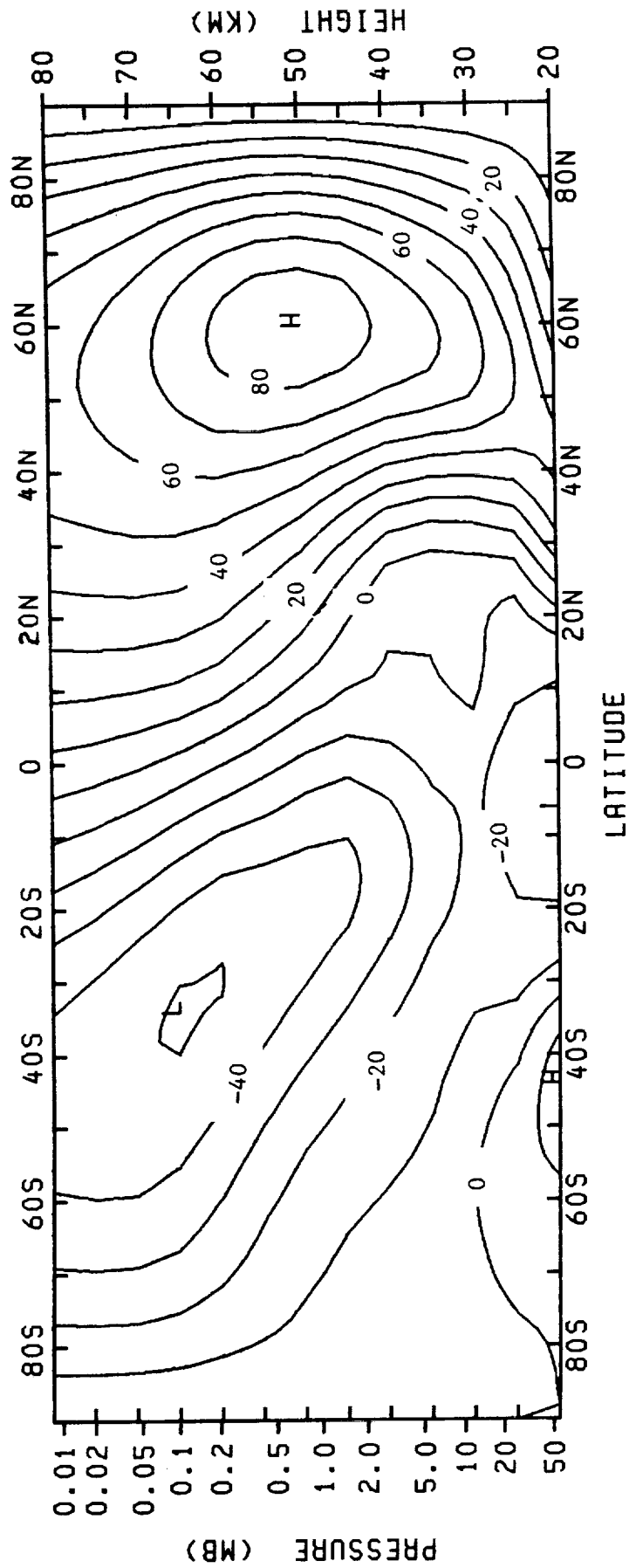


Figure 3.22. SCM height-latitude cross section for January zonal wind (m/s).

4. USER'S MANUAL

4.1 General Program Overview

The GRAM-90 version of the program is designed to produce atmospheric parameter values either along a linear path (to be called a profile), with automatically stepped constant height, latitude, and longitude increments, or along any set of connected positions (to be called a trajectory) which must be input individually into the program.

There are three general types of input to the GRAM program: (1) a set of three lines, called the initial data, which contain the values of the program options, the initial position, the profile increments, and other information required before the calculations are begun; (2) a data file (SCIDAT9) containing parameter values for the middle atmosphere zonal-mean data, the stationary perturbations (deviations from the zonal-means, to produce longitude varying monthly means), and random and quasi-biennial perturbation parameter values; and (3) the 4-D data files with one data file for each month, containing profiles of monthly mean pressure, density, temperature, and their variances from the surface to 25 km, for the entire globe. If it is desired to compute atmospheric parameters along a trajectory instead of a linear profile, then a fourth type of data—the trajectory times and positions—must be input.

In terms of program function, the major elements of the GRAM program are the main segment (GRAM), the subroutine SCIMOD, which is a driver for all of the atmospheric evaluation subroutines, and SETUP, a subroutine used to read the SCIDAT9 data file, and load the necessary starting conditions for execution.

Output of the GRAM-90 program consists of monthly mean pressure, density, temperature, wind and wind shear, total (mean plus perturbation) values of pressure, density, temperature, and winds, as well as perturbation values and magnitudes.

A complete discussion of the input, output, and program operation characteristics for the GRAM-90 program is given in the following sections of the user's manual. Section 5 is a programmer's manual giving additional program details which might be useful to users wishing to modify the program for specific applications.

4.2 The 4-D Data Files (0 to 25 km)

The world-wide meteorological data set developed for the 4-D model by Allied Research Associates (Spiegler and Fowler, 1972) was originally binary tapes labelled WW1A to WW3A. These binary tape files, one per month, have now been converted to ASCII files which can be read by random access (or "direct access") I/O operations.

Within each file are 3,490 records representing the values at individual grid points of latitude and longitude. These points are grouped into three grid areas: 288 points on the Northern Hemisphere Equatorial (EQN) grid; 1,977 points on the Northern Hemisphere (National Meteorological Center (NMC)) grid; and 1,225 points on the Southern Hemisphere (SH) grid. On the NMC grid, the data were computed at NMC points and are stored in the order given by the NMC grid

table given in the SCIDAT9 data file. For the other two grid areas, the data are given at 5° latitude-longitude intersections westward from the Greenwich Meridian to 5° E. The EQN grid covers the latitudes from 0° to 15° N. with points occurring in the following order: 1–4 = long. 0, lat. 0, 5, 10, 15; 5–8 = long. 5° W., lat. 0, 5, 10, 15; ...285–288 = long. 5° E., lat. 0, 5, 10, 15. The SH grid contains all data from 5° S. to the South Pole as follows: 1 = South Pole, 2–18 = long. 0, lat. –5 to –85; 19–35 = long. 5° W., lat. –5 to –85; ...1,209–1,225 = long. 5° E., lat. –5 to –85. It should be noted that the South Pole is given only once, as the first point of the SH data set.

Each record consists of 1,268 ASCII characters (formatted 20F6.2, 2F4.2, and 3F4.0). The first 208 parameter values contain the thermodynamic data for a latitude-longitude grid point. The last five variable values are identifiers. The data are arranged by altitude level for each parameter; thus, the first 26 values contain the pressure means from the surface to 25 km, and the next 26 values contain the pressure variances for the same levels. This pattern continues for the 26 levels of temperature means and variances, moisture means and variances, and density means and variances. Temperatures are in K, pressures are in mb (multiplied by 100 for use in GRAM-90 to give N/m²), and densities are in g/m³ (divided by 1,000 for use in GRAM-90 to give kg/m³). GRAM-90 does not use the moisture means and variances.

Variables 209 and 210 contain the latitude and longitude of the data grid point (in tenths of a degree). The latitude is always positive (since the Southern Hemisphere is identified by grid), and the longitude is always west.

The last three values (variables 211 to 213) contain three identifier parameters. The first of these is the homogeneous moisture region in which the point lies, the second is the point number, and the third is the month. It should be noted that the 4-D points are numbered within the grid that contains them, and not by their location in the file. Thus, the point numbers run from 1 to 288 (EQN) grid, 1 to 1,977 (NMC grid), and 1 to 1,225 (SH grid), not from 1 to 3,490.

4.3 The SCIDAT9 Data File

This section describes in detail the data contained in the SCIDAT9 data file.

NMC Grid Data. This data set gives the 4-D Northern Hemisphere point number and the dual index for the corresponding NMC location. The NMC grid locations form an octagonal array, centered on the North Pole. The points are at square grid locations on the polar projection used for the NMC grid. A conversion between the latitude and longitude (treated as polar coordinates on the flat NMC grid plane) and the NMC grid indices (treated as Cartesian coordinates on the projection plane) is accomplished by a polar-to-Cartesian coordinate transformation, via equations programmed into the 4-D model. The NMC grid data in the SCIDAT9 file merely establishes the equivalence between the sequential 4-D NMC point number and the 2-D *x-y* NMC grid point location. The NMC grid data constitute the first group of data in the SCIDAT9 file. The NMC grid data file contains 396 FORTRAN readable records with code "N" and 15 integers (A2, 15I7 format) in each record.

Zonal-Mean Data. The zonal-mean data consists of 12 monthly sets of zonal-mean values for pressure, density, temperature, and zonal wind, tabulated at 10° latitude intervals (from –90° to +90°) and 5-km height increments (from 20 to 120 km) for each month. Prefix codes, ZP, ZD,

ZT, and ZU indicate pressure, density, temperature, and zonal wind, respectively. Each record contains the code, the month, the height in km, and the $-90^\circ, -80^\circ, \dots, 80^\circ, 90^\circ$ latitude values of the parameter expressed as a four-digit integer, with an exponent common to all of the values in the field appearing at the end of the record. Thus, a value of 2,761 with an exponent at the end of the record of -6 would be the same as $2,761 \times 10^{-6} = 2.761 \times 10^{-3}$. Pressure data are in units of N/m², density values are in kg/m³, temperatures are in K, and zonal winds are in m/s. The zonal-mean data set contains 1,008 FORTRAN readable records, with the code and 22 integer values in each record (format A2, I4, I5, 19I6, I4).

Stationary Perturbations. The stationary perturbations are latitude-longitude dependent relative perturbations to be applied to the zonal-mean values. Data for each of 12 months are given for both Northern and Southern Hemisphere latitudes. Prefix codes SP, SD, ST, SU, and SV indicate stationary perturbation values for pressure, density, temperature, zonal (eastward), or meridional (northward) wind components, respectively.

Each record contains the code, the month, the height in km, the latitude (-80 to $+80$) in degrees, and then 18 values of stationary perturbations, in per mil (%/10) for the thermodynamic variables, and 0.1 m/s for the winds at longitude $180^\circ, 160^\circ$ W., 140° W., ..., 140° E., 160° E. The monthly mean value y_m for parameter y at any latitude and longitude can be computed from the zonal-mean value z_y , at the latitude, and the stationary perturbation s_y (in per mil) at the latitude and longitude, by the relation

$$y_m = z_y(1 + s_y / 1,000) \quad (4.1)$$

Note that the stationary perturbation values at 90° latitude are always zero. The stationary perturbation data consists of 15,300 FORTRAN readable records, with a code and 21 integer values (format A2, 21I5).

The Random Perturbation Data. Random perturbation magnitudes (standard deviations) are latitude dependent only. Prefix codes RP, RD, RT, RU, and RV indicate random perturbation magnitudes in pressure, density, temperature, zonal wind, and meridional wind components, respectively. Each random perturbation record has the code, the month, and the height in km, followed by 19 values of random perturbation magnitude, at 10° latitude increments -90° to $+90^\circ$, followed by a common exponent value. These data give the relative standard deviations σ_p / \bar{p} , $\sigma_\rho / \bar{\rho}$, and σ_T / \bar{T} (in percent) for use in the random perturbation model. The code RU and RV data are similar, except that the wind perturbations are absolute deviations in m/s, and cover the height range 0 to 200 km, whereas the RP, RD, and RT data cover 20 to 200 km. Random perturbation magnitudes for 0 to 25 altitudes are provided by the 4-D data base for the thermodynamic variables. The random perturbation data consist of 1,596 FORTRAN readable records with a code and 22 integer values (A2, I4, I5, 19I6, I4) in each record.

Large-Scale Fraction Data. From daily difference analysis described in section 2 of Justus et al. (1980), the fraction of the total variance (σ^2 from the random perturbation data) contained in the large scale perturbations has been determined as a fraction of height and latitude. The SCIDAT9 file contains the annual average fraction (expressed as per mil) of total variance contained in the large scale. Large-scale and small-scale magnitudes σ_L and σ_s are computed from the

fractional data f_L in per mil (code P for pressure, density, and temperature or code PW for winds) by the relations

$$\sigma_L = (\sqrt{f_L} / 1,000)\sigma_T \quad (4.2)$$

$$\sigma_s = (\sqrt{1-f_L} / 1,000)\sigma_T , \quad (4.3)$$

where σ_T is the total perturbation magnitude. The code P and code PW data sets each contain 25 FORTRAN readable records, with code word P or PW, followed by 17 integer values (A2, 17I7) on each record.

Density-Velocity Correlations. Daily difference analysis (Justus et al., 1980) was also used to evaluate the cross correlations R_{up} and R_{vp} for use in the velocity perturbation model, described in section 2. Both large-scale and small-scale values of the density-velocity correlations were evaluated and are given in the SCIDAT9 data file (codes CL and CS) in per mil (i.e., divide by 1,000 to get correlations in the range -1 to $+1$).

The code CS and CL data consist of 50 FORTRAN readable records, with code word CS or CL, followed by 12 integer values (A2, 12I7) in each record.

The Quasi-Biennial Oscillation (QBO) Data. The QBO data consist of height- and latitude-dependent amplitudes and phases for quasi-biennial variations in pressure (QP), density (QD), temperature (QT), and eastward and northward wind components (QU and QV, respectively). The amplitudes of the QBO wind components are in decimeters per second (0.1 m/s). The phases of all of the QBO parameters are measured in days after January 0, 1966, for the occurrence of the first maximum value. Since the period of the QBO variations is taken to be 870 days, the phases can vary from 0 to 870.

Each QBO data record contains the code, the height in km, the amplitude and phase for 10° latitude, the amplitude and phase for 30° latitude, etc., out to the amplitude and phase for 90° latitude. There are 80 FORTRAN readable records in the QBO data set. Each record contains 11 integer values, following a code word (QP, QD, QT, QU, or QV) in format A2, 15I7.

4.4 The Initial Input Data

The initial input data consists of two free-field (no set format with commas after each number) lines containing initial position data, program options, and other information required to begin computation, plus an optional third free-field line to give initial random perturbation data if random perturbations are to be computed, plus an optional set of trajectory position data (followed by a backup card), if trajectory positions are to be read in rather than a linear profile generated automatically in the program. Appendix B gives a brief summary of the input characteristics, a summary of the data file setup, and some sample input and output for the program. The following gives a more detailed description of each program input line.

Input Line Number 1. The first input line, read in by the main program segment GRAM, in free-field format, contains the following information. Designation R indicates real quantities, I denotes integer quantities.

1. **Initial Height (R), H1:** The initial height in km for the beginning point of the profile or trajectory. This can be any nonnegative real number. Atmospheric parameters are never evaluated at the first position, which is used only to establish the initial conditions.

2. **Initial Latitude (R), PHI1:** The latitude of the initial position, in degrees, with southern latitudes negative. If the initial latitude, or any subsequent latitude is greater than 90° in absolute magnitude, then a transformation is made:

$$\text{lat.} = (180^\circ - |\text{lat.}|)(\text{lat.}/|\text{lat.}|) \quad (4.4)$$

$$\text{long.} = \text{long.} + 180^\circ \quad (4.5)$$

3. **Initial West Longitude (R), THET1:** The west longitude of the initial position in degrees. East longitude can be put in as negative or converted to 0° to 360° west longitude. If negative (east) longitudes are input, they are converted to the 0° to 360° scale before being used by the program. At any time during the run, if a longitude gets outside the 0° to 360° it is put back into that range by adding or subtracting 360°, as necessary.

4. **10.7-cm Flux (R), F10:** The solar 10.7-cm radio noise flux in units of 10^{-22} W /m² (the normal units for this parameter) at the time for which the atmospheric values are to be computed. This factor is used only in the Jacchia (MET) section, so a value of zero can be used on input if the height never goes above 90 km. A value of 230 for both design steady state conditions and for maximum conditions may be used, or consult MSFC for monthly predictions.

5. **Mean 10.7-cm Flux (R), F10B:** The 81-day mean solar 10.7-cm radio flux. This parameter is used in the Jacchia (MET) section to compute the nighttime minimum global exospheric temperature (equation 14 in Jacchia, 1970). Use zero if the height does not above 90 km. A value of 230 may be used for both design steady-state or maximum conditions, or consult MSFC for monthly predictions.

6. **Geomagnetic Index (R), AP:** The geomagnetic index a_p , used to compute a geomagnetic correlation to the exospheric temperature, in equation (22) of Jacchia (1970). Use zero if the height does not go above 90 km. A design steady-state value of 20.3 and a maximum-condition value of 400 may be used for a_p , or consult MSFC for monthly predictions.

7-9. **Date (I), MN, IDA, IYR:** The date, for the starting time of the trajectory or profile evaluation in month/day/two-digit year form, as three integer input values. The day of the month and the year have no direct effect on the program calculations, except for the Jacchia section altitudes or the quasi-biennial oscillation terms. The month is used to establish which middle

atmosphere data, stationary perturbation data, and random perturbation data (including large scale fractions and velocity-density correlations) to load from the SCIDAT9 data file into the working arrays. The program will work more efficiently if multiple trajectories or profiles are evaluated during one run operation and the months are the same. (This avoids repeated look-up of the middle atmosphere, stationary perturbation, and random data from the SCIDAT9 file).

10–12. **Greenwich Time (I), IHRO, MINO, ISECO:** The Greenwich mean time for the starting position in hours, minutes, and seconds as three integer values. Only the Jacchia (MET) section is directly affected by the time of day, so unless the height goes above 90 km, the starting time would serve merely as a reference parameter for the particular run being done. Greenwich time corresponding to a local time of 0900 hours should be used for design steady-state Jacchia (MET) section conditions. and for maximum conditions the local time should be taken as 1400 hours.

13. **Latitude Increment (R), DPHI:** If a linear profile is to be generated automatically, this is the latitude increment (in degrees) between successive profile positions. The new latitude would be the old latitude plus the latitude increment. For a profile with decreasing latitude (going southward) the increment must be negative. Use zero if separate trajectory position input is to be read in. If a vertical profile (i.e., changing only height) is to be evaluated, then use zero latitude increment.

14. **West Longitude Increment (R), DTHET:** If a linear profile is to be generated automatically, this is the west longitude increment (in degrees) between successive profile positions. The new longitude will be the old longitude plus the longitude increment. For a profile progressing eastward, use a negative increment. Use zero if separate trajectory position input is to be read in. If a vertical profile is to be evaluated, then use zero increment.

15. **Height Increment (R), DH:** The height decrease in km between successive positions, for an automatically generated linear profile. The profiles are normally generated downward (descending height). (New height = old height – the height increment). If an upward generated profile is desired, the height increment should be negative. Downward generated profiles will be evaluated until the height is incremented to a negative value or until the maximum number of positions (item 16, first line) is exceeded.

16. **Maximum Number of Positions (I), NMAX:** The maximum number of profile positions to be generated automatically. This does not include the initial position, for which no atmospheric parameters are evaluated. Use zero if trajectory positions are to be read in.

17. **Time Increment (I), INCT:** The time displacement (seconds) between successive automatically generated profile positions. This would normally be set to zero, but could be used as a counter to be printed out in the time position with the output. For trajectories, the time for each position is read in with the position data (see trajectory input section). The hours, minutes, and seconds parameters (read in as items 10–12, first line) are updated according to the new time generated by the time increment. However, only the elapsed time in seconds is printed out on the output.

18. Trajectory Option (I), IOPT: This option tells the program whether a trajectory or a linear profile is to be evaluated. A value of zero means that a linear profile is to be generated automatically from the parameters read on the first line. A value greater than zero means that trajectory position data must be read in to determine the positions at which atmospheric parameters are to be evaluated. The unit from which the trajectory data are to be read is specified by the (nonzero) trajectory option. Thus, if trajectory data are to be read in from unit 5, use a trajectory option of 5.

19. Output Option (I), IOPP: This option tells the program whether or not to produce nonprint output of the atmospheric parameters (see the output description section). Nonprint (i.e., disk) output is convenient to use as input to plotter programs. A value of zero means no nonprint output. A value greater than zero means to output the data on the unit number equal to the output option value.

20. Minimum Geostrophic Latitude (R), GLAT: Below this latitude (in absolute magnitude) winds are computed by latitude-interpolation between the geostrophic values at latitudes $+GLAT$ and $-GLAT$. Above this latitude, the usual geostrophic relations are used. Values of $GLAT$ between 5° and 18° may be input. Values below 5° are set to 5° ; values above 18° are set to 18° .

With normal numbers of decimal places and no unnecessary blank spaces, the above 20 items should fit into one line. However, if they occupy more than the number of columns allowed on one line (usually 80) they may be spread out onto two lines if the appropriate rules of free-field input are observed. Consult the operations or FORTRAN manual for your particular system for characteristics of free-field input.

Input Line Number 2. The second input line is read in by the subroutine SETUP and contains various unit numbers to be used and various options controlling the random and quasi-biennial calculations and other functions of the program. The unit numbers are the parameters used in read statements in the FORTRAN program to control which file is being read from. The unit numbers are required in the input in order to give maximum flexibility in choice of I/O devices for the program. All input items on line number 2 are integers.

1. SCIDAT9 Input Unit, IUS: This is the unit number of the SCIDAT9 file. If the SCIDAT9 file has been assigned by control statements, which establish unit 3 for the SCIDAT9 file, then the SCIDAT9 input unit number should be three on this input line.

2. 4-D Input Unit, IU4: This is the unit number for the 4-D data file. Any available unit number can be used. If the 4-D file containing the January data, DAT4D01, has been assigned by control statements establishing this as unit 4, then the 4-D input unit number is four on line 2. 4-D data files must be named DAT4D01 for January, DAT4D02 for February, ..., DAT4D12 for December.

3. Random Option, IOPR: This option tells the program whether or not to compute random perturbations. If the value is one, random perturbations are computed. If the value is two, then random perturbations are not computed. If any values other than one or two are input, the run is terminated with a message "ERROR IN SETUP INPUT" and a dump of the parameters most recently read in.

4. **QBO Option, IOPQ:** This option tells the program whether or not to compute QBO perturbations. If the value is one, QBO perturbations are computed. For two no QBO perturbations are computed, and for any other values the "ERROR IN SETUP INPUT" and dump of most recent parameters read in is given.

5. **First Random Number, NR1:** This number is required as a starting parameter for the random number generating subroutine RANDOM. Any positive integer 1 to 30,000 can be used. Use a value of one for a standard design application run. Provided all other input is the same, a given value for the starting random number will always produce the same random perturbation output. Therefore, to get a set of different perturbations along a given single trajectory, a set of different starting random numbers should be used. Note, however, that if any other parameters are changed (different spacing along the trajectory, different starting position, etc.) then the same starting random number will produce a different set of random perturbations.

6. **4-D Scratch Unit, IOTEM1:** In order to save array space, the 4-D profiles required to interpolate to the $5^\circ \times 5^\circ$ grid locations are read from the 4-D files to this scratch file rather than being put into arrays. The unit number for this scratch file can be any available unit. Normally, the file is a temporary (scratch) file, and, if so, does not have to be assigned before execution of the program.

7. **NMC Grid Point Scratch Unit, IOTEM2:** Also in order to save computer storage, the NMC grid point array read in from the SCIDAT file is stored in a temporary scratch file and does not have to be assigned before execution of the program.

8. **4-D Diagnostic Print Output Option, IPRT:** Use a value of zero to get diagnostic information printed out at the initial generation of a 4-D grid. Use $IPRT = 1$ to suppress this diagnostic output.

9. **Maximum Allowable Test Violations, NLIMIT:** In the generation of 4-D data grids, GRAM-90 tests for perfect gas law and hydrostatic law violations in the original 4-D data base. NLIMIT sets the upper limit on the allowed number of test violations which can occur without automatic termination of the program. Normally, $NLIMIT = 12$ is used, but a value up to $NLIMIT = 25$ is allowed. Any input value of NLIMIT less than 12 is reset to 12; any value greater than 25 is reset to 25.

Input Line Number 3. This card is read by the SETUP subroutine and contains starting values for the random perturbation parameters at the initial position and the scale parameter for the random perturbation magnitudes. If random perturbations are not to be computed (Random Option = 2), this line should not be put in. All values of this free-field format line are real. For a normal design application, the values of the initial perturbations on this line should all be zero, unless the run is to be a continuation of a previously run trajectory or profile segment, in which case the output random parameters of the last output position are input, and the last output position becomes the initial position of the new run.

1-6. **Initial Pressure, Density, and Temperature Perturbations:** Parameters RP1L, RP1S, RD1L, RD1S, RT1L, and RT1S are, respectively, the initial values of random relative pressure (p'/\bar{p}), density ($\rho'/\bar{\rho}$), and temperature (T'/\bar{T}), in percent, for the large-scale (L) and

small-scale (S) components. These are starting values for the initial position. Use zeros for standard design applications.

7-10. **Initial Wind Component Perturbations:** Parameters RUIL, RUIS, RVIL, and RVIS are initial values of the random eastward (U) and northward (V) random wind components in m/s for the large-scale (L) and small-scale (S) components. Use zeros for standard design applications.

11. **Random Perturbation Scale (RPSCALE):** This is a parameter to allow random perturbations which are more disturbed ($RPSCALE > 1$) or more quiescent ($RPSCALE < 1$) than normal ($RPSCALE = 1$). Values can range from zero (no perturbations) to two (twice normal perturbation magnitudes).

Trajectory Input. The free-field trajectory position input and backup record are put in only if a trajectory is to be evaluated, rather than a linear profile, generated automatically in the program from information on the first input line. There is no limit to the number of trajectory position records which can be put in. The program continues evaluating the atmospheric parameters and looping back to read a new trajectory position until a position below the surface is reached, or until the trajectory backup record is reached. Each free-field trajectory record has the time (integer seconds), the height (kilometers), the latitude (degrees, southern latitude negative), and the west longitude (degrees, 0° to 360° or east longitudes negative). Any east longitudes read in as negative values are converted to the 0° to 360° system before being used by the program. The trajectory backup record has the same free-field form as a regular trajectory record, except that any negative value for height is used. The negative height terminates the loop which evaluates atmospheric parameters. The trajectory data can be input from any unit (with trajectory option = unit number). The trajectory option is item 18 on line number 1.

4.5 Output of the Program

The first few lines of print output are primarily a listing of the input parameters. Following a heading which describes each output value for the trajectory or profile evaluations, the position, time monthly mean, and total pressure, density, temperature, and winds are listed for each position. The thermal wind shear for the monthly mean winds, the percent deviation from the standard atmosphere, the mean vertical wind, and the perturbation data are also given for each position. The perturbation data consists of the stationary perturbations, the quasi-biennial values at the position and time, the quasi-biennial magnitudes, the random perturbation values, and the random perturbation standard deviations. Optional nonprint (e.g., disk) output for values at each position is also available to be used for input to plotter programs, or for other purposes.

Heading Information. Primarily, the heading information contains a listing of the input data values. However, there are some changes from the values input. If an east longitude is put in as a negative value, $-180^\circ < \text{lat.} < 0^\circ$, then it is converted to a west longitude in the 0° to 360° range before the heading is listed. The program evaluates the initial random pressure, density, temperature and wind standard deviations and the initial density-velocity correlation from data in the SCIDAT9 data file, and lists the computed values on the heading. The Julian date is computed by the program from the input date and is also listed with the heading information. The Julian date is required by the Jacchia and QBO sections of the program.

Position and Time Output. Positions and times as generated by the automatic linear profile features, or as input by the trajectory input data, are listed on the output. The time is given in seconds. Within the program, the input time in hours, minutes, and seconds are updated in that form also. However, only a continuously increasing time in seconds is printed out. If time in hours, minutes, and seconds were desired, these variables could easily be printed out by adding them to the output list. All output west longitudes are converted to the 0° to 360° range before being printed out. If a latitude greater than 90° in absolute magnitude is generated (or input) then a transformation is made.

$$\text{lat.} = (180^\circ - |\text{lat.}|)(\text{lat.}/|\text{lat.}|) \quad (4.6)$$

$$\text{long.} = \text{long.} + 180^\circ \quad (4.7)$$

Monthly Mean Data. The monthly mean values of pressure, density, and temperatures consist of either: (1) values from the 4-D data file if the height is below 25 km, (2) the sum of middle atmosphere zonal-mean plus stationary perturbation values if the height is between 30 and 90 km, (3) an interpolation between 4-D at 25 km and zonal-mean plus stationary perturbations at 30 km if the height is between 25 and 30 km, (4) Jacchia (MET) model values if the height is above 120 km, or (5) faired values between middle atmosphere and MET model values if the height is between 90 and 120 km.

The percent deviations from the U.S. 1976 Standard Atmosphere are evaluated by using standard atmosphere values computed by the subroutine STDATM. The percent deviations are evaluated by the relations $100(T - T_s)/T_s$, $100(\rho - \rho_s)/\rho_s$, and $100(p - p_s)/p_s$, where the subscript s refers to the standard atmosphere values. This subroutine accurately reproduces the tabulated U.S. 1976 Standard Atmosphere values to within an accuracy of better than 0.2 percent above 90 km. The subroutine reproduces the tabular values even more accurately in the height region below 90 km, where the molecular weight is constant. Since the U.S. 1976 Standard Atmosphere is not defined above 1,000 km, the percent deviations printed out for heights above 1,000 km are zero. Since the Jacchia (MET) model is sensitive to solar activity conditions, large deviations from U.S. Standard Atmosphere values can be produced in this height range for certain ranges of F10.7 and a_p values.

The thermal wind shear values are values of $\partial u/\partial z$ and $\partial v/\partial z$ for the monthly mean wind (see section 2). The wind values are computed from the geostrophic wind equation or from the new wind data base. The wind shear components are computed by either the thermal wind equations, which are determined by the horizontal gradients of the monthly mean temperature, or computed as vertical gradients from the new wind data base. The mean vertical wind is evaluated, as described in section 2, by combinations of horizontal and vertical temperature gradients and the monthly mean winds.

The Total (Mean Plus Perturbation) Data. The parameter values listed under the heading of "Mean Plus Perturbations" are the monthly mean values, as defined above, plus the random perturbations, plus (if the height is between 10 and 90 km) the quasi-biennial perturbations. These mean-plus-perturbation values represent values which would be typical "instantaneous" values of the pressure, density, temperature, and winds. The percent deviations from the U.S. Standard Atmosphere are computed in the same way as for the percent deviations of the monthly mean values from the standard atmosphere.

Perturbation Values. The data under the "Perturbation Values" heading are the various perturbation values, magnitudes, and amplitudes. The stationary perturbations (denoted SP on the printout) are defined only if the height is between 25 and 90 km. The monthly mean, y_m , of parameter y should be the zonal-mean value Z_y , evaluated from the SCIDAT9 data file, modified by the given stational perturbation value s_y , in percent, by the relation

$$y_m = Z_y(1 + s_y/100) . \quad (4.8)$$

The data labeled "QBO" are the values of the QBO oscillation at the output time and position. The data labeled "MAG" give the magnitude of the QBO oscillations at the output position and time. The QBO perturbation values should always be less than or equal to the magnitude values in absolute value. The data labeled "RANL," "RANS," and "RANT" are the large-scale, small-scale, and total-random perturbations evaluated at the output time and place. The data labeled "SIGL," "SIGS," and "SIGT" are the standard deviations of the large-scale, small-scale, and total-random components at the output time and positions. According to the Gaussian distribution, on which the random perturbations are based, the perturbation values should be within the range $\pm\sigma$ 68 percent of the time and outside the range $\pm\sigma$ 32 percent of the time. Similarly, the perturbation values should be within the range $\pm 2\sigma$ 95 percent of the time and outside the range $\pm 2\sigma$ 5 percent of the time. The evaluation of the QBO and random perturbation output can be suppressed by the QBO and random options, if desired. SIGW gives the magnitude of the random vertical wind perturbations (m/s). These data are from the turbulence model of Justus et al. (1990).

Nonprint Output. The nonprint output is available, as an option, controlled by the input value of the output option parameter. If nonprint output is desired, it comes out in the form of records with format F5.1, 7F7.2, 4F6.2, containing the following information: (1) the height in kilometers; (2) the latitude in degrees; (3) the west longitude in 0° to 360° ; (4) the percentage deviation of the mean monthly value of density from the 1976 U.S. Standard Atmosphere; (5) the monthly mean temperature; (6–8) the eastward, northward, and vertical components of the monthly mean (geostrophic) wind; and (9–12) the magnitudes of the large-scale random perturbations in pressure, density, temperature (percent), and eastward and northward wind (m/s). If different output parameters or formats are desired, the statement WRITE (IOPP, 951)..., immediately after label 920, and/or the format 951, in subroutine SCIMOD, can easily be modified to accommodate these requirements.

4.6 Program Diagnostics

There are several possible reasons which can cause the printing of diagnostic messages and termination of the run during the setup phase. If during the setup procedure, the NMC grid point number data table does not contain the required 1,977 values, a message "N RECORDS WRITTEN BY SETNMC IN SCRATCH FILE M" is printed, and execution is terminated. A premature end-of-file encountered while attempting to read the NMC data from the SCIDAT9 file results in a diagnostic message "PREMATURE END-OF-FILE FOUND ON UNIT IUS CALLED FROM SUBROUTINE GETNMC" where IUS is the SCIDAT9 unit number. A similar message is produced by subroutine RTRAN if a premature end-of-file occurs elsewhere in the SCIDAT9 file.

If, during the reading of the SCIDAT9 data file, any record is read which does not have the expected code character or characters, then the message results: "ERROR IN SETUP INPUT" followed by a listing of the latest data values read in. This message is also produced if the random option and the quasi-biennial option do not have a value of either one or two. Any condition which results in this error message terminates the execution.

If an initial random number outside the range 1 to 30,000 is input, the message "FIRST RANDOM NUMBER OUT OF RANGE" is printed and execution is terminated.

There are also several conditions which could result in diagnostic messages in the 4-D section: If, during the reading of the 4-D data file, the incorrect month or record number is encountered, then a message "***** UNIT NO. IU4 IN ERROR. IRN = XXXX DTEMP(213) = XXXX MONTH = XX DTEMP(212) = XXXX IPT(I, J) = XXXX" is printed, where:

IU4 = Unit on which 4-D file is being read

IRN = 4-D file record number

DTEMP(213) = Month value in last record read from 4-D file

MONTH = Month requested to be read

DTEMP(212) = Point number in last record read from 4-D file

IPT(I, J) = Point number required for profile J to be interpolated to Ith requested profile.

If this error condition occurs, execution is terminated.

If, during steps along a profile or trajectory, the next position is outside the current 4-D grid area, a new 4-D grid is generated, suitable for the new location. If the new grid cannot be successfully generated, a message "UNABLE TO GENERATE 4-D GRID. TOO MANY RETRIES IN INTER4" is generated and program execution terminates.

If a large number of perfect gas law violations are encountered or a hydrostatic violation occurs at too low an altitude, the program may terminate execution with a message "UNABLE TO GENERATE 4-D GRID. TOO MANY TEST VIOLATIONS," or "UNABLE TO GENERATE 4-D GRID. IHV = XX," where IHV is the height where the lowest hydrostatic violation occurred.

In some cases, this condition may be removed by increasing the value input for NLIMIT (item 9, input line 2).

As optional diagnostic output, various information can be requested (by parameter IPRT: item 8, input line 2). These output are generated in the 4-D section of the program, during the generation of the 4-D grid, by subroutines GEN4D, GRID4D, and SCIMOD. This information includes data on which 4-D data produced gas law violations or hydrostatic law violations, which 4-D values had to be replaced by new values as a result of the gas law and hydrostatic tests, along with the new values generated. The complete array of 4-D pressure, density, and temperature data (means and standard deviations) is also printed out, both those read in directly from the 4-D file, and those produced after the gas law and hydrostatic tests.

5. PROGRAMMER'S MANUAL

5.1 Description of Subroutines

The following is a brief description of each of the GRAM-90 program subroutines, in alphabetical order:

- ADJUST:** Adjusts the 4-D profiles of pressure, density, and temperature variance (read from the 4-D file) to satisfy the Buell constraints imposed by the perfect gas law.
- CHECK:** A consistency check routine for the 4-D grid data produced by GEN4D. CHECK is called for each height to be evaluated, and tests for reasonable values of scale height immediately above and below that height. It also tests for reasonable horizontal pressure gradients. Failure of either test produces the diagnostic asterisk between the output values of wind components.
- CORLAT:** Evaluates the horizontal and vertical scales for large- and small-scale density, temperature, and wind components; computes the autocorrelations and cross correlations for the two scale perturbation model; and evaluates new perturbation values having appropriate correlations with the perturbations at the previous position.
- CORREL:** Correlation function used in the random perturbation model.
- DIAGEQ:** A matrix diagonalizing procedure used by the ADJUST subroutine.
- FAIR:** Fairs between the middle atmosphere and Jacchia (MET) values in the 90- to 120-km height range.
- FAIR5:** Fairs between the region below and above 500 km in the MET subroutine.
- GAUSS:** Gaussian quadrature routine, used in the MET model.
- GEN4D:** Generates the 4-D polar ($|\text{latitude}| > 75^\circ$) or nonpolar ($16, 5^\circ \times 5^\circ$ points) grid of pressure, density, temperature, and variance profiles.

- GETNMC: Reads the NMC grid point values from the SCIDAT9 data file and loads them onto a scratch file. This subroutine is essentially unchanged from the subroutine of the same name in the original 4-D program.
- GRAM: The main segment of GRAM-90. The main segment serves as a driver for the SETUP and SCIMOD subroutines.
- GRID4D: After the array of 4-D grid latitudes-longitudes has been evaluated, this subroutine looks up the data from the 4-D data file and interpolates to determine profiles of pressure, density, temperature, and variance at the 4-D grid locations. Profiles to be interpolated to 4-D grid locations are loaded onto a scratch file from the 4-D file before the interpolation is done.
- GROUP: A subroutine, called by CHECK, which groups the 16 4-D pressure data at the given height into one or more groups which have consistent and reasonable horizontal pressure gradients within each group. If the subsequent geostrophic wind calculations in WIND use horizontal pressure gradients evaluated from differences across inconsistent groups of 4-D data, the diagnostic asterisk is printed between the output values of wind components.
- GTERP: Uses linear latitude interpolation, linear temperature, and linear logarithm of density interpolation on height to evaluate middle-atmosphere zonal-mean data to a given latitude and height.
- INTERW: Two-variable, linear interpolation between known value U1 and V1 at height Z1 and U2 and V2 at height Z2 to determine U and V at height Z, where Z is between Z1 and Z2.
- INTERZ: Three-variable interpolation, linear on temperature, and gas constant ($R = p/\rho T$), and linear on the logarithm of density, with pressure computed from perfect gas law and interpolated temperature, density, and gas constant.
- INTER2: Three-variable interpolation, linear on all three variables.
- INTER4: Interpolates between the pressure, density, and temperature profiles at the 4-D grid locations. This subroutine calls subroutine INTLL to do the latitude-longitude interpolation.
- INTLL: One-variable interpolation between values in an array of latitude and longitude locations by equation (2.4).
- INTRP4: The subroutine for the latitude-longitude interpolation of values from the 4-D data file into the 4-D grid array. This is a modification of the INTERP subroutine of the original 4-D program.
- INTRUV: Evaluates the standard deviations of the random wind components at given height and latitude by calling INTERW subroutine.

- INTRW: Finds standard deviation for random vertical wind components.
- INTR25: Subroutine to find large-scale fractional variances (f_L in equations (4.2) and (4.3)) at a given height and latitude.
- JAC: Calculates the molecular weight, density, and temperature for the Jacchia (MET) model.
- JACCH: Main subroutine driver for the Jacchia (MET) section, serves as a driver for J70 and other Jacchia section subroutines.
- J70: Subroutine called by JACCH driver subroutine for the Jacchia (MET) model.
- MOLWT: Calculates molecular weight for the Jacchia (MET) model.
- PDTUV: Interpolates the stationary perturbations on latitude and longitude at a given height. This subroutine is similar to INTLL.
- PERTRB: Evaluates the pressure, density, temperature, and wind component random perturbations by the correlated random perturbation model discussed in section 2.
- PHASE: A linear height-latitude interpolation routine for the quasi-biennial phase. The interpolation properly accounts for the phase discontinuity between 0 and 870 days (the quasi-biennial period).
- PPND: Function to produce normal (Gaussian) distributed random variable, for use in the random perturbation model (q_1 , in equation (2.19)).
- QBOGEN: Computes the QBO perturbation values and their amplitudes and phases. The amplitudes and phases of the QBO pressure, density, temperature, and wind perturbations are interpolated from the amplitude and phase data from the SCIDAT9 data file, by calling the INTERZ and INTERW subroutines.
- RANDOM: Produces a random number selected from a uniform distribution between zero and one. This is required as input to the subroutine PPND.
- RIG: Computes the acceleration of gravity and the radius from the center of the Earth for a position at a given latitude and height.
- RTERP: Computes the standard deviations of the random pressure, density, and temperature perturbations by calling subroutine INTERZ.
- RTRAN: This subroutine contains several read sections with multiple entry points coming from subroutine SETUP. The read statements are for reading the SCIDAT9 data file.

- SCIMOD: The heart of the GRAM-90 program. This subroutine branches on height to evaluate the atmospheric parameters by the Jacchia (MET), the middle atmosphere, or the 4-D methods. The QBO and random perturbations are also evaluated and the output is printed (and optionally also written to a file) by the SCIMOD subroutine.
- SELEC4: Selects the 4-D data needed for interpolation. This subroutine is a modification of the INPUT subroutine of the original 4-D program.
- SETUP: This subroutine reads in the NMC grid points with the GETNMC subroutine and reads and loads the data from the required month in the SCIDAT9 data file into arrays.
- SLV: Computes the seasonal-latitudinal variation of density in the lower thermosphere portion of the Jacchia (MET) model.
- SORT4: Sorts the 4-D locations for sequential reading from the 4-D data file. This subroutine is a modification of the SORT subroutine from the original 4-D program.
- STDATM: Evaluates the 1976 U.S. Standard Atmosphere values of pressure, density, and temperature at any given height up to 1,000 km.
- TINF: This subroutine computes the exospheric temperature for the Jacchia (MET) model.
- TME: This subroutine calculates the variables necessary for input into the subroutine TINF in the Jacchia (MET) model.
- WIND: This subroutine evaluates the geostrophic winds from input values of horizontal pressure gradient if the height is less than 25 km or more than 90 km. If the latitude is below the minimum geostrophic latitude, it evaluates geostrophic wind at minimum geostrophic north latitude and at minimum geostrophic south latitude and then interpolates in between. If the height is between 25 and 90 km, the new middle atmosphere wind data base is used. Between 20 and 25 km and between 90 and 95 km, a smooth fairing between geostrophic and middle atmosphere wind is used.

5.2 The Primary Section

This section consists of the main program segment GRAM, the SCIMOD subroutine, the subroutines for evaluating the middle atmosphere values, the stationary perturbations, the QBO and random perturbations, and general interpolation subroutines. With the exception of GRAM and SCIMOD, the parts of this section were adequately described in the previous section.

Many of the subroutines transfer their input and output via COMMON statements. This procedure saves much in core storage space.

Main Segment GRAM. This program serves as a driver for the SETUP and SCIMOD subroutines. It reads one line of input, the first input line, as described in section 4. The trajectory

input records (if used) are also read by GRAM, after control has returned from SETUP, which reads the second and third initial data input lines. Section 4.4 and appendix B give a further description of the input required.

Subroutine SCIMOD. This is the primary subroutine of the GRAM program. It serves as a driver for all of the various sections of the atmospheric evaluation. The SCIMOD subroutine prints and (optionally) generates output on a nonprint output file, the output described in section 4 and appendix B. It also transfers data values to other subroutines via the above-mentioned COMMON lists. The SCIMOD subroutine updates the profile or trajectory positions by setting the current position equal to the previous position before exit. The previous position information then stays in the COMMON lists until the next call to SCIMOD. The previous random perturbations are handled in similar fashion.

5.3 The Setup Section

The function of the setup section of the program is to load the initial data and the data from the SCIDAT9 file.

The SETUP subroutine reads the second and third lines of input, as described in section 4. COMMON lists transfer the arrays, loaded with the appropriate data from the SCIDAT9 data file, to the other subroutines. COMMON lists are also used to transfer data to SETUP from the read subroutine RTRAN, which has multiple entry points, for various different types of data from the SCIDAT9 data file.

5.4 The Jacchia Section

The subroutine JACCH calculates the pressure, density, and temperature at a point in space for heights above 90 km for a particular time. It is essentially unchanged from the MET model (Hickey, 1988a,b).

5.5 The 4-D Section

GRID4D and subroutines SORT4, INTRP4, and SELEC4 are basically the MAIN PROGRAM, SORT, INTERP, and INPUT as documented in the 4-D user's reference manual and subsequent updates (Fowler and Willard, 1972; Spiegler and Fowler, 1972). Some changes have been made, as documented in earlier versions of the GRAM program (e.g., Justus et al., 1980). In GRAM-90 a new option has been added which allows output of extensive diagnostic data from the 4-D section during the generation process for producing the 4-D grid values.

5.6 GRAM-90 Input and Output

Input required by GRAM-90 for setting up the desired profile or trajectory, and for selecting the various program options, was described in section 4. Appendix A gives more complete details on the middle atmosphere data file, SCIDAT9 GRAM-90 output was also discussed in section 4. Additional details on program input and output are given in appendix B.

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APPENDIX A

DESCRIPTION OF THE REVISED MIDDLE ATMOSPHERE DATA FILE "SCIDAT9" FOR THE GRAM-90 PROGRAM

The SCIDAT9 file contains the following data, identified by code characters at the beginning of each record. For additional discussion of the SCIDAT9 input data, see section 4.3.

Code	Data	Description
N	NMC grid data	Same as NMC grid required by original 4-D program. Data consists of sequential point number followed by the two corresponding NMC grid indices. There are five points per record in format (A2, 15I7).
ZP	Zonal mean pressure (N/m ²)	Month, height, values at latitudes -90, -80, ..., 10, 20, ... 90, exponent. Format is A2, I4, I5, 19I6, I4.
ZD	Zonal mean density (kg/m ³)	
ZT	Zonal mean temperature (K)	
ZU	Zonal mean zonal wind (m/s)	
SP	Stationary perturbations in monthly mean pressure (per mil)	Month, height, latitude, $\Delta p/\bar{p}$ at longitude 180, 160W, 140W, ..., 140E, 160E, in format A2, 2I15.
SD	Stationary perturbations in monthly mean density (per mil)	Same as for code SP data, for $\Delta \rho/\bar{\rho}$.
ST	Stationary perturbations in monthly mean temperature (per mil)	Same as code SP data, for $\Delta T/\bar{T}$.
SU	Stationary perturbations in monthly mean zonal (eastward) wind component (0.1 m/s)	Same as for code SP data, for Δu .
SV	Stationary perturbations in monthly mean meridional (northward) wind component (0.1 m/s)	Same as for code SP data, for Δv .
RP	Random perturbation magnitude for pressure (percent)	Month, height, values of σ_p/\bar{p} at latitudes -90°, -80°, ..., 80°, 90°, exponent, in format A2, I4, I5, 19I6, I4.
RD	Random perturbation magnitude for density (percent)	Same as for code RP data, for $\sigma_\rho/\bar{\rho}$.

Code	Data	Description
RT	Random perturbation magnitudes for temperature (percent)	Same as for code RP data, for $\sigma_{T/\bar{T}}$.
RU	Random perturbation magnitudes for zonal wind (m/s)	Same as for code RP data, for σ_u .
RV	Random perturbation magnitudes for meridional wind (m/s)	Same as for code RP data, for σ_v .
P	Fractional variance in large scale thermodynamic variables	13 (denotes annual average) height, fractional variance in large scale per mil for pressure, density, and temperature, each at latitude 10°, 30°, 50°, 79°, 90°, in format A2, 1717.
PW	Fractional variance in large scale wind	13 (denotes annual average) height, fractional variance in u at 10°, 30°, 50°, 70°, 90°, in format A2, 1217.
CS	Small-scale density-velocity correlations	13 (denoting annual average), height, $\langle \rho u \rangle_s$ at 10°, 30°, 50°, 70°, 90° latitude, same for $\langle \rho v \rangle_s$, in format A2, 1217.
CL	Large-scale density-velocity correlations	13 (denoting annual average), height, $\langle \rho u \rangle_L$ at 10°, 30°, 50°, 70°, 90° latitude, same for $\langle \rho v \rangle_L$, in format A2, 1217.
QP	QBO pressure parameters-amplitude (per mil) and phase (days after January 0, 1966 when first maximum occurs)	Height, amplitude, and phase at 10° latitude, amplitude, and phase at 30° ..., amplitude and phase at 90°, in format A2, 1117.
QD	QBO density parameters (as in QP)	Same as for code QP data.
QT	QBO temperature parameters	Same as for code QP data.
QU	QBO eastward wind parameters-amplitude (0.1 m/s) and phase (days after January 0, 1966)	Same as for code QP data.
QV	QBO northward wind parameters (as in QU)	Same as for code QP data.

The SCIDAT9 file contains the NMC grid data, the middle atmosphere zonal mean data and stationary perturbation data, the random perturbation data, the fractional large-scale variances and the density-velocity correlations, and the QBO data. Each record of the NMC grid data file contains the code (N) and x - y coordinates for five points. The total number of NMC grid points is 1,977. The NMC grid data file contains a total of 396 records, with the last record containing points 1,976 and 1,977 and zeros for the remaining values. The zonal mean data contains 1,008 records, the stationary perturbation data contains 15,300 records, the code random perturbation data contains 1,596 records, the code P large-scale fractional variances contain 25 records, the code PW large-scale fractional wind variances contain 25 records, code CS and CL density-velocity correlation data contain 25 records each, and the QBO data contain 80 records.

APPENDIX B

SAMPLE INPUT AND OUTPUT FOR THE GRAM-90 PROGRAM

Input to GRAM-90 is as follows:

(All input data lines are in free-field format. R designates real; I denotes integer).

↑	INITIAL HEIGHT (R)	Height of starting position, km.
	INITIAL LATITUDE (R)	Latitude of starting position (degrees, southern latitudes negative).
	INITIAL WEST LONGITUDE (R)	West longitude of starting position (degrees, 0° to 360°, or east longitudes negative).
	10.7 cm FLUX (R)	Solar 10.7 cm radio noise flux (10^{-22} watts/m ²) at time of calculations. Use zero if height does not go over 90 km. Use 230 for design applications or consult MSFC for monthly predictions.
	MEAN 10.7 cm FLUX (R)	81 day mean solar cm flux. Use zero if height does not go over 90 km. Use 230 for design applications or consult MSFC for monthly predictions.
Line 1	GEOMAGNETIC INDEX (R)	Geomagnetic index a_p . Use zero if height does not go over 90 km. Use 20.3 for design steady-state conditions, or 400 for maximum conditions, or consult MSFC.
	DATE: MONTH, DAY, YEAR (I)	Date for starting time of calculations (month, date, two digit year)
	GREENWICH TIME: HOUR, MINUTE, SECOND (I)	Time for starting position (hours, minutes, seconds). Use time corresponding to local time = 0900 for design steady-state, or local time = 1400 for maximum conditions.
	LAT INCREMENT (R)	Latitude displacement (degrees) between successive positions (new lat. = old lat. + lat. increment). Use zero if trajectory positions are to be read in.
	WEST LON INCREMENT (R)	West longitude displacement (degrees) between successive positions (new long. = old long. + long. increment). Use zero if trajectory positions are to be read in.
↓	HEIGHT INCREMENT (R)	Height decrease (km) between successive positions (new height = old height - height increment). Normal profiles are generated downward. If an upward generated profile is desired, set height increment negative.

Line 1 (cont.)	MAXIMUM NUMBER OF POSITIONS (I)	Number of positions to be computed, not including initial position. Use zero if trajectory positions are to be read in.
	TIME INCREMENT (I)	Time displacement (seconds) between successive positions for automatically generated profiles (new time = old time + time increment).
	TRAJECTORY OPTION (I)	0 for linear profile generated automatically, internal to the program, or value equal to unit number for a trajectory with each position to read in.
	OUTPUT OPTION (I)	0 for no nonprint output of atmospheric parameter values, or value equal to unit number to get nonprint output.
	MIN. GEOSTROPH. LAT (R)	Lowest latitude (magnitude) for which geostrophic winds are to be used in 4-D (0–25 km) and Jacchia (above 90-km height segments). Otherwise, interpolation is used to fill in winds. In middle heights (25–90 km), the new middle atmosphere data base is used at all latitudes.
Line 2	SCIDAT9 INPUT UNIT (I)	Unit number for file containing SCIDAT9 data. Use any available unit number.
	4-D INPUT UNIT (I)	Unit number for 4-D input data file. Use any available unit number.
	RANDOM OPTION (I)	Use 1 to compute random perturbation output, 2 means do not compute random perturbation output.
	QBO OPTION (I)	Use 1 to compute QBO output, 2 means do not compute QBO output.
	FIRST RANDOM NUMBER (I)	Initial number for random generator used to compute random perturbations (can be any positive integer 1–30,000). Use 1 for standard design applications.
	4-D SCRATCH UNIT (I)	Unit number for scratch file for 4-D grid profiles required in computations. Use any available unit number. This normally is a temporary scratch file.
	NMC GRID POINTS SCRATCH UNIT (I)	Unit number for scratch file to store NMC grid point data. Use any available unit number. This normally is a temporary scratch file.
	4-D DIAGNOSTIC OUTPUT OPTION (I)	Use 0 for optional 4-D diagnostic output, and 1 for no diagnostic output.
	MAX ALLOWABLE TEST VIOLATIONS (I)	Maximum number of test violations allowed for 4-D data, normally 12, can be up to 25.

↑ Line 3 ↓	INITIAL PL, PS, DL, DS, TL, TS (R)	Initial values of large-scale and small-scale random relative pressure, density, and temperature perturbations, percent. Use zeros for standard design applications.
	INITIAL UL, US, VL, VS (R)	Initial values of large-scale and small-scale random wind components, m/s. Use zeros for standard design applications.
	RPSCALE	Random perturbation scale: 1 = normal, minimum 0, maximum 2.

*Include line 3 only if random option = 1.

TRAJECTORY INPUT (11, 3R)	Use only if linear profile is not to be generated automatically. Each record has time (seconds as integer), height (km), latitude (degrees), and west longitude (degrees).
TRAJECTORY BACKUP RECORD (11, 3R)	Only if trajectory input is used. Same form as a trajectory position but with any negative height value.

The trajectory input records are optional, in free-field format. If included, use as many records as necessary.

Input for the following sample output listing is as follows:

LINE1: 142.0, 28.45, 80.53, 230.0, 230.0, 20.3, 1, 1, 90, 0, 0, 0, .0, .0, 2., 72, 0, 0, 99, 18

LINE2: 3, 4, 1, 1, 1, 12, 13, 1, 12

LINE3: 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 1.

A SUMMARY OF THE ORGANIZATION OF AN INPUT DATA FILE IS AS FOLLOWS:

Initial Data

Line 1, as described at the beginning of this appendix.

Line 2, as described at the beginning of this appendix.

Line 3, optional, included only if random option = 1.

Trajectory Position Data and Backup Card

Optional. Include if trajectory, rather than linear profile generated by the program is to be evaluated.

More Data of the Same Kind (Starting With Initial Data, Line 1)

If additional trajectories or profiles are to be evaluated, the data may be input one set immediately after the other. The program is actually more efficient for such multiple runs if the month remains the same. This is because as long as the month remains the same, the SCIDAT9 data file read can be avoided for each subsequent data set.

OUTPUT TO GRAM:

INITIAL POSITION	Listing of input values of initial position.
PROGRAM OPTIONS	Listing of input values of program options.
HEIGHT, LAT., LONG., TIME	Position and time where atmospheric parameters are evaluated.
UNPERTURBED PRESSURE DENSITY, TEMPERATURE, AND WIND (monthly mean values)	Computed from Jacchia (MET), 4-D, or middle atmosphere (zonal mean plus stationary perturbations), depending on height.
TOTAL PRESSURE, DENSITY, TEMPERATURE, AND WIND	Monthly means plus random perturbations and QBO perturbations.
THERMAL WIND SHEAR	From thermal wind equations using finite differences of Jacchia (MET), 4-D, or middle atmosphere data, depending on height.
MEAN VERTICAL WIND	From mean isentropic surface slopes.
PERTURBATION VALUES	Stationary perturbations, QBO perturbations, and amplitudes, and random perturbations and magnitudes for the small-scale (S), large-scale (L), and total (T) perturbations. Perturbations are those which are added to monthly means to produce total results output.

Following is a listing of sample output from the GRAM-90 program. Initial lines of output are merely listings of the input data for each reference. For a listing of the input data for this sample output, see above.

0	20.1%	14.9%	5.3%	-.34E-02	53.8%	23.0%	27.4%	-22.31	.7	-.2	.6	-.8	5. SP
									.0	.0	.0	.0	0. OBO
									.0	.0	.0	.0	0. MAG
									19.9	4.0	15.9	37.	39. RANS
									10.1	8.2	13.8	39.	54. SIGS
									8.1	3.0	5.1	-12.	32. RANL
									13.4	6.0	10.0	50.	70. SIGL
									28.1	7.1	21.0	24.	71. RANT
									16.8	10.2	17.1	63.	89. SIGT
													11.05
112.00	28.45	80.53	.656E-02	.769E-07	279.	-.46	-.2.	.803E-02	.860E-07	308.	-.43.	.87.	5. SP
0			18.2%	12.5%	5.5%	-.17E-02	44.6%	25.8%	16.7%		-18.50		0. OBO
													0. MAG
									16.0	5.6	10.5	11.	22. RANS
									9.7	8.8	12.7	38.	55. SIGS
									6.4	6.2	.1	-8.	67. RANL
									13.1	6.5	9.3	50.	72. SIGL
									22.4	11.8	10.6	3.	89. RANT
									16.3	11.0	15.7	63.	90. SIGT
													11.13
110.00	28.45	80.53	.800E-02	.104E-06	254.	-.40.	0.	.942E-02	.118E-06	263.	-.40.	.119.	5. SP
0			12.6%	6.6%	5.8%	-.43E-03	32.6%	21.9%	9.4%		-18.16		0. OBO
													0. MAG
									12.4	8.7	3.7	-3.	62. RANS
									9.2	9.4	11.5	38.	56. SIGS
									5.3	5.6	-.3	2.	56. RANL
									12.8	7.0	8.6	50.	73. SIGL
									17.7	14.3	3.4	-1.	119. RANT
									15.8	11.7	14.3	62.	92. SIGT
													11.21
108.00	28.45	80.53	.104E-01	.146E-06	236.	-.32.	0.	.117E-01	.166E-06	234.	-.26.	.146.	5. SP
0			11.8%	5.6%	5.9%	-.57E-03	25.9%	19.9%	4.9%		-16.00		0. OBO
													0. MAG
									6.6	7.8	-1.2	12.	76. RANS
									8.8	9.9	10.4	37.	56. SIGS
									5.9	5.7	-.3	-7.	70. RANL
									12.5	7.5	7.9	50.	75. SIGL
									12.6	13.5	-.9	6.	146. RANT
									15.3	12.5	13.0	62.	94. SIGT
													11.28
106.00	28.45	80.53	.135E-01	.206E-06	219.	-.26.	1.	.156E-01	.240E-06	216.	-.4.	.147.	5. SP
0			8.4%	5.3%	2.8%	-.34E-04	24.9%	22.8%	1.3%		-16.50		0. OBO
													0. MAG
									7.9	9.0	-1.1	27.	59. RANS
									8.3	10.4	9.3	37.	57. SIGS
									7.4	7.7	-.3	-5.	87. RANL
									12.2	8.0	7.1	49.	76. SIGL
									15.2	16.7	-1.4	21.	146. RANT
									14.8	13.2	11.7	62.	95. SIGT
													11.36
104.00	28.45	80.53	.180E-01	.293E-06	206.	-.20.	1.	.204E-01	.352E-06	192.	3.	.90.	5. SP
0			6.6%	6.0%	.3%	.41E-04	20.7%	27.1%	-6.4%		-25.87		0. OBO
													0. MAG
									7.4	11.8	-4.4	16.	29. RANS
									7.9	10.9	8.1	36.	58. SIGS

92.00	28.45	80.53	.142E+00	.255E-05	193.	-3.	4.	.147E+00	.285E-05	178.	-24.	199.	-.9	.0	.7	.2	.6	-8.	5.	9.97
0			10.1%	6.6%	3.3%	-.26E-02		14.4%	19.0%	-4.8%	5.64				.0	.0	.0	0.	0.	0.080
															0	0	0	0	0	0.080
															1.8	11.9	-10.1	-12.	167.	RANS
															7.7	10.2	5.9	31.	62.	SIGS
															2.0	-2	2.3	-9.	28.	RANL
															11.4	9.5	5.0	47.	94.	SIGL
															3.9	11.7	-7.8	-21.	195.	RANT
															13.8	14.0	7.7	57.	112.	SIGT
																				9.58
90.00	28.45	80.53	.205E+00	.360E-05	198.	-2.	5.	.203E+00	.398E-05	175.	-15.	150.	-1.5	.1	.7	.2	.6	-8.	5.	5.72
0			11.6%	5.4%	5.9%	-.37E-02		10.4%	16.5%	-6.3%	2.75				.0	.0	.0	0.	0.	0.080
															0	0	0	0	0	0.080
															5.4	11.9	-6.5	-6.	101.	RANS
															7.9	9.8	5.9	30.	62.	SIGS
															-6.4	-1.4	-5.0	-6.	44.	RANL
															11.5	9.4	5.1	47.	97.	SIGL
															-1.0	10.5	-11.5	-12.	145.	RANT
															14.0	13.6	7.8	56.	115.	SIGT
																				8.27
88.00	28.45	80.53	.286E+00	.495E-05	201.	4.	5.	.283E+00	.522E-05	188.	1.	47.	-3.2	-.1	.7	.2	.6	-6.	5.	5.72
0			9.4%	1.5%	7.8%	-.38E-02		8.1%	7.0%	.8%	-2.70			-.1	.0	.0	.0	0.	0.	0.080
															0	0	0	0	0	0.080
															4.0	6.2	-2.1	-3.	41.	RANS
															6.9	8.2	5.1	27.	49.	SIGS
															-5.1	-8	-4.3	1.	2.	RANL
															9.8	8.2	4.4	43.	78.	SIGL
															-1.0	5.4	-6.4	-3.	42.	RANT
															12.0	11.6	6.7	50.	92.	SIGT
																				6.96
86.00	28.45	80.53	.400E+00	.680E-05	205.	10.	4.	.399E+00	.721E-05	193.	6.	30.	-3.2	.1	.7	.1	.6	-5.	4.	5.72
0			7.2%	-2.3%	9.7%	-.42E-02		6.8%	3.6%	3.0%	-5.58			-.3	.1	-.1	.0	0.	0.	0.080
															0	0	0	0	0	0.080
															.4	.2	-1.1	1.	0.	MAG
															.1	5.5	-5.4	-19.	30.	RANS
															5.6	6.3	4.1	23.	32.	SIGS
															-1	.5	-6	14.	-5.	RANL
															7.8	6.5	3.6	38.	52.	SIGL
															0	6.0	-6.0	-5.	25.	RANT
															9.6	9.1	5.5	44.	61.	SIGT
																				5.72
84.00	28.45	80.53	.556E+00	.933E-05	207.	17.	5.	.548E+00	.943E-05	203.	2.	23.	-3.2	-.4	.8	.2	.6	-4.	5.	5.72
0			4.6%	-3.8%	8.7%	-.40E-02		3.2%	-2.7%	6.5%	-1.10			-.5	.0	-.1	.0	0.	0.	0.080
															0	0	0	0	0	0.080
															.6	.4	-1.1	1.	0.	MAG
															.9	1.7	-8	-25.	8.	RANS
															4.7	5.0	3.4	21.	18.	SIGS
															-1.7	-6	-1.1	11.	10.	RANL
															6.5	5.4	3.1	35.	30.	SIGL
															-8	1.0	-1.9	-14.	18.	RANT
															8.0	7.4	4.6	40.	34.	SIGT
																				4.56
82.00	28.45	80.53	.766E+00	.128E-04	209.	29.	5.	.786E+00	.133E-04	207.	22.	41.	-3.2	-.4	.8	.4	.4	-3.	5.	5.72
0			2.2%	-4.7%	7.2%	-.39E-02		4.9%	-.7%	6.2%	-4.27			-.7	.0	-.1	.0	0.	0.	0.080
															0	0	0	0	0	0.080
															.8	.5	.2	1.	0.	MAG
															3.3	2.2	1.1	-18.	6.	RANS

80.00	28.45	80.53	.106E+01	.175E-04	210.	29.	6.	.107E+01	.180E-04	208.	10.	31.	-3.2	-.4	4.5	4.7	3.3	19.	16.	SIGS
0			.5%	-5.0%	5.9%	-.33E-02		1.5%	-2.3%	4.6%	-1.10				-.9	-.6	-.3	-3.	6.	SP
															1.0	-.1	-.2	-1.	0.	QBO
															5.7	3.2	2.5	-30.	0.	MAG
															4.2	4.3	3.1	18.	-1.	RANS
															-3.7	-.2	-3.5	12.	14.	SIGS
															5.6	4.9	2.8	32.	26.	RANL
															2.0	3.0	-1.0	-18.	24.	SIGL
															7.0	6.5	4.2	37.	28.	RANT
																				SIGT
78.00	28.45	80.53	.145E+01	.239E-04	212.	36.	5.	.147E+01	.250E-04	206.	23.	31.	-3.5	.3	-.9	.7	.2	0.	5.	SP
0			-1.4%	-5.5%	4.5%	-.26E-02		.0%	-1.1%	1.7%	.33				-1.2	-.3	-.2	-2.	0.	QBO
															1.2	.7	.2	2.	0.	MAG
															6.7	4.4	2.2	-27.	16.	RANS
															4.3	4.2	3.0	18.	13.	SIGS
															-4.1	.6	-4.7	15.	9.	RANL
															5.6	5.1	2.8	32.	24.	SIGL
															2.6	5.0	-2.4	-12.	26.	RANT
															7.1	6.6	4.2	37.	27.	SIGT
76.00	28.45	80.53	.198E+01	.324E-04	213.	43.	5.	.192E+01	.333E-04	201.	41.	23.	-3.5	.3	1.0	.8	.2	2.	5.	SP
0			-2.6%	-5.5%	3.1%	-.22E-02		-5.7%	-2.8%	-2.4%	1.14				-1.4	-.5	-.3	-2.	0.	QBO
															1.4	.9	.3	2.	0.	MAG
															2.8	2.1	.7	-8.	16.	RANS
															4.5	4.2	3.0	17.	12.	SIGS
															-4.6	1.2	-5.8	8.	2.	RANL
															5.7	5.2	2.8	32.	24.	SIGL
															-1.8	3.3	-5.1	0.	18.	RANT
															7.2	6.6	4.2	37.	27.	SIGT
74.00	28.45	80.53	.270E+01	.438E-04	215.	49.	4.	.261E+01	.441E-04	208.	81.	20.	-1.9	-.1	1.0	.8	.2	4.	4.	SP
0			-3.5%	-5.5%	2.1%	-.18E-02		-6.7%	-4.9%	-1.2%	.35				-1.6	-.7	-.3	-3.	0.	QBO
															1.6	1.0	.3	3.	0.	MAG
															1.0	-.5	1.4	10.	19.	RANS
															4.4	4.0	2.9	17.	12.	SIGS
															-2.7	1.8	-4.4	25.	-3.	RANL
															5.6	5.1	2.8	32.	22.	SIGL
															-1.7	1.3	-3.0	35.	16.	RANT
															7.1	6.5	4.0	36.	25.	SIGT
72.00	28.45	80.53	.368E+01	.589E-04	218.	52.	5.	.353E+01	.589E-04	210.	119.	19.	-1.9	-.1	.9	.7	.2	4.	5.	SP
0			-4.1%	-5.6%	1.5%	-.94E-03		-8.0%	-5.6%	-2.1%	-.16				-1.8	-.9	-.4	-3.	0.	QBO
															1.8	1.2	.4	3.	1.	MAG
															1.0	1.9	-.9	18.	9.	RANS
															4.0	3.6	2.6	18.	10.	SIGS
															-3.3	-1.0	-2.3	51.	6.	RANL
															5.2	4.9	2.8	32.	18.	SIGL
															-2.3	.9	-3.2	69.	15.	RANT
															6.6	6.1	3.8	36.	21.	SIGT

70.00	28.45	80.53	.500E+01	.791E-04	220.	56.	5.	.485E+01	.785E-04	216.	101.	-1.	-1.9	-1.	.9	.6	.3	5.	5.	5.	1.30	
0			-4.2%	-4.5%	.3%	-.19E-05		-7.1%	-5.2%	-1.5%					-2.0	-1.1	-4	-3.	0.	0.	QB0	
															2.0	1.3	.4	3.	1.	1.	MAG	
															-2.0	-3	-1.8	14.	0.	0.	RANS	
															3.7	3.3	2.3	18.	8.	8.	SIGS	
															1.0	.7	.3	34.	-5.	5.	RANL	
															4.7	4.6	2.7	32.	14.	14.	SIGL	
															-1.1	.4	-1.4	48.	-5.	5.	RANT	
															6.0	5.6	3.5	36.	16.	16.	SIGT	
																						1.07
68.00	28.45	80.53	.673E+01	.104E-03	225.	58.	5.	.647E+01	.104E-03	217.	113.	12.	-9	-1.	.7	.5	.3	5.	5.	5.	5.	
0			-4.5%	-4.3%	-.2%	.53E-03		-8.3%	-4.6%	-3.4%					-2.2	-1.3	-4	-3.	0.	0.	QB0	
															2.2	1.4	.4	3.	1.	1.	MAG	
															-8	.5	-1.3	13.	11.	11.	RANS	
															3.5	3.1	2.2	18.	9.	9.	SIGS	
															-1.0	.5	-1.5	45.	-4.	4.	RANL	
															4.5	4.5	2.8	30.	14.	14.	SIGL	
															-1.8	1.0	-2.8	58.	7.	7.	RANT	
															5.7	5.4	3.6	35.	16.	16.	SIGT	
																						.84
66.00	28.45	80.53	.906E+01	.138E-03	229.	60.	5.	.852E+01	.192E-03	225.	113.	12.	-9	-1.	.6	.3	.3	6.	5.	5.	5.	
0			-4.2%	-3.6%	-.7%	.11E-02		-9.9%	-7.5%	-2.3%					-2.3	-1.5	-5	-2.	-1.	-1.	QB0	
															2.4	1.5	.5	4.	1.	1.	MAG	
															-2.7	-1.8	-.9	10.	8.	8.	RANS	
															3.3	2.9	2.0	17.	9.	9.	SIGS	
															-1.0	-.8	-2	46.	-1.	1.	RANL	
															4.3	4.4	2.9	28.	14.	14.	SIGL	
															-3.7	-2.6	-1.1	56.	7.	7.	RANT	
															5.4	5.3	3.6	33.	17.	17.	SIGT	
																						.68
64.00	28.45	80.53	.121E+02	.181E-03	233.	60.	5.	.115E+02	.177E-03	228.	96.	9.	.1	.0	.5	.2	.3	7.	5.	5.	5.	
0			-3.9%	-2.8%	-1.1%	.15E-02		-8.6%	-5.1%	-3.5%					-2.4	-1.6	-5	-1.	-1.	-1.	QB0	
															2.6	1.6	.5	4.	1.	1.	MAG	
															-3.8	-2.3	-1.5	6.	7.	7.	RANS	
															3.2	2.9	2.0	17.	10.	10.	SIGS	
															1.2	1.6	-.4	31.	-2.	2.	RANL	
															4.2	4.4	2.9	26.	14.	14.	SIGL	
															-2.6	-.7	-1.9	37.	4.	4.	RANT	
															5.3	5.2	3.5	31.	17.	17.	SIGT	
																						.57
62.00	28.45	80.53	.161E+02	.236E-03	238.	60.	5.	.150E+02	.227E-03	232.	80.	-1.	.1	.0	.4	.1	.3	7.	5.	5.	5.	
0			-3.6%	-2.1%	-1.5%	.19E-02		-9.9%	-5.7%	-4.1%					-2.4	-1.6	-.6	0.	-1.	-1.	QB0	
															2.8	1.8	.6	4.	1.	1.	MAG	
															-3.6	-2.2	-1.4	1.	4.	4.	RANS	
															3.3	3.0	2.0	16.	10.	10.	SIGS	
															-6	.1	-.8	19.	-10.	10.	RANL	
															4.3	4.4	2.6	25.	12.	12.	SIGL	
															-4.3	-2.1	-2.2	21.	-5.	5.	RANT	
															5.4	5.3	3.2	29.	16.	16.	SIGT	
																						.46
60.00	28.45	80.53	.214E+02	.307E-03	243.	60.	5.	.207E+02	.305E-03	238.	63.	-4.	.1	.0	.3	.0	.3	8.	5.	5.	5.	
0			-2.7%	-.9%	-1.8%	.22E-02		-5.5%	-1.6%	-3.7%					-2.3	-1.4	-.6	1.	-1.	-1.	QB0	
															3.0	1.9	.6	5.	1.	1.	MAG	

58.00	28.45	80.53	.280E+02	.394E-03	248.	55.	6.	.267E+02	.385E-03	242.	69.	-14.	2.2	-2	-1.1	-1.6	-5	-11.	4.	RANS
0			-2.5%	-.7%	-1.8%	.34E-02		-7.2%	-2.9%	-4.2%		-.40			3.3	3.1	2.0	15.	10.	SIGS
															4	1.3	-9	13.	-13.	RANL
															4.5	4.4	2.3	23.	11.	SIGL
															-7	.7	-1.4	2.	-9.	RANT
															5.6	5.4	3.0	28.	14.	SIGT
58.00	28.45	80.53	.280E+02	.394E-03	248.	55.	6.	.267E+02	.385E-03	242.	69.	-14.	2.2	-2	.1	-1.1	.3	9.	6.	SP
0						.34E-02									-2.1	-1.5	-5	2.	-1.	OBO
															2.8	2.1	.5	5.	1.	MAG
															-4.1	-2.6	-1.5	-9.	-1.	RANS
															3.3	3.1	2.0	15.	10.	SIGS
															1.4	1.9	-5	21.	-18.	RANL
															4.4	4.2	2.1	24.	10.	SIGL
															-2.7	-7	-2.0	12.	-19.	RANT
															5.5	5.2	2.9	28.	14.	SIGT
56.00	28.45	80.53	.367E+02	.505E-03	253.	51.	6.	.354E+02	.486E-03	254.	72.	2.	2.2	-2	-1.1	-3	.3	9.	6.	SP
0			-1.8%	.0%	-1.8%	.44E-02		-5.1%	-3.6%	-1.6%					-2.0	-1.7	-4	3.	-1.	OBO
															2.6	2.3	.4	5.	1.	MAG
															-2.6	-1.3	-1.2	-7.	6.	RANS
															3.2	3.0	1.9	14.	10.	SIGS
															1.2	.6	1.8	25.	-9.	RANL
															4.3	3.9	1.9	24.	9.	SIGL
															-1.4	-1.9	.6	18.	-3.	RANT
															5.3	4.9	2.7	28.	14.	SIGT
54.00	28.45	80.53	.478E+02	.645E-03	258.	47.	6.	.462E+02	.625E-03	257.	81.	8.	2.0	.1	-1.1	-4	.4	10.	6.	SP
0			-1.2%	1.0%	-2.1%	.40E-02		-4.5%	-2.2%	-2.4%					-1.9	-1.7	-3	3.	-1.	OBO
															2.5	2.5	.3	5.	1.	MAG
															-1.1	.3	-1.4	2	17.	RANS
															3.1	2.9	1.8	13.	10.	SIGS
															-3	-1.8	1.5	29.	-14.	RANL
															4.1	3.7	1.7	25.	9.	SIGL
															-1.4	-1.5	.1	31.	3.	RANT
															5.2	4.7	2.5	28.	13.	SIGT
52.00	28.45	80.53	.618E+02	.824E-03	262.	43.	6.	.610E+02	.813E-03	261.	62.	14.	2.0	.1	-1.1	-4	.4	10.	6.	SP
0			-.6%	2.2%	-2.8%	.34E-02		-2.0%	.9%	-2.8%					-1.9	-1.6	-3	3.	-1.	OBO
															2.5	2.6	.3	5.	1.	MAG
															-2.4	-4	-2.0	-9.	16.	RANS
															2.9	2.7	1.7	13.	10.	SIGS
															2.9	.7	2.2	25.	-6.	RANL
															4.0	3.5	1.6	25.	9.	SIGL
															.5	.3	.2	16.	10.	RANT
															4.9	4.4	2.4	28.	13.	SIGT
50.00	28.45	80.53	.800E+02	.105E-02	265.	39.	6.	.777E+02	.104E-02	261.	46.	9.	2.0	.1	-1.1	-4	.4	11.	6.	SP
0			.3%	2.4%	-2.0%	.28E-02		-2.6%	1.2%	-3.6%					-1.8	-1.4	-2	3.	-2.	OBO
															2.6	2.6	.2	4.	2.	MAG
															-1.0	.4	-1.4	-7.	4.	RANS
															2.8	2.5	1.5	12.	10.	SIGS
															-2	-2	.0	10.	1.	RANL
															3.8	3.4	1.5	25.	9.	SIGL
															-1.2	.2	-1.4	4.	5.	RANT

48.00	28.45	80.53	.103E+03	.135E-02	265.	36.	.20E-02	.100E+03	.135E-02	258.	33.	.15	1.2	.1	4.7	4.2	2.2	28.	13.	SIGT
0			.7%	2.8%	-2.0%	.20E-02	-2.0%	.100E+03	2.8%	-4.7%					-1	-5	.4	11.	6.	SP
															-1.5	-1.0	-4	3.	-1.	OBO
															2.5	2.5	.4	4.	1.	MAG
															-5	2.4	-2.8	-4.	6.	RANS
															2.6	2.5	1.6	11.	9.	SIGS
															-8	-1.3	.6	-2.	0.	RANL
															3.6	3.3	1.6	25.	9.	SIGL
															-1.3	1.0	-2.3	-6.	6.	RANT
															4.4	4.1	2.3	27.	13.	SIGT
46.00	28.45	80.53	.133E+03	.174E-02	265.	34.	.18E-02	.126E+03	.172E-02	255.	35.	.11	1.2	.1	-2	-7	.4	12.	5.	SP
0			.9%	1.7%	-.7%	.18E-02	-3.7%	.126E+03	.6%	-4.3%					-1.1	-7	-5	3.	-1.	OBO
															2.5	2.4	.7	3.	1.	MAG
															-1.3	1.7	-3.0	4.	-1.	RANS
															2.4	2.4	1.6	10.	8.	SIGS
															-2.2	-2.1	-1	-6.	0.	RANL
															3.4	3.3	1.7	24.	9.	SIGL
															-3.5	-4	-3.1	-1.	-1.	RANT
															4.2	4.0	2.4	26.	12.	SIGT
44.00	28.45	80.53	.171E+03	.227E-02	263.	31.	.15E-02	.162E+03	.228E-02	248.	37.	.07	1.2	.2	-3	-8	.4	12.	5.	SP
0			1.0%	.4%	.6%	.15E-02	-4.2%	.162E+03	.9%	-5.2%					-9	-4	-6	3.	0.	OBO
															2.4	2.1	.8	3.	1.	MAG
															-8	2.6	-3.4	4.	2.	RANS
															2.2	2.3	1.6	10.	8.	SIGS
															-3.5	-1.7	-1.8	-1.	3.	RANL
															3.2	3.1	1.8	23.	8.	SIGL
															-4.3	.9	-5.2	3.	5.	RANT
															3.9	3.9	2.4	25.	11.	SIGT
42.00	28.45	80.53	.222E+03	.298E-02	259.	29.	.16E-02	.210E+03	.294E-02	248.	39.	.31	1.2	.2	-4	-9	.4	12.	5.	SP
0			.7%	-.4%	1.2%	.16E-02	-4.7%	.210E+03	-1.7%	-3.1%					-7	-2	-6	3.	0.	OBO
															2.2	1.8	.8	4.	1.	MAG
															-1.5	-1	-1.4	-1.	-5.	RANS
															2.1	2.1	1.6	9.	7.	SIGS
															-3.2	-1.0	-2.2	8.	-2.	RANL
															3.1	2.9	1.8	22.	7.	SIGL
															-4.7	-1.1	-3.6	7.	-7.	RANT
															3.7	3.6	2.4	24.	10.	SIGT
40.00	28.45	80.53	.287E+03	.392E-02	255.	27.	.16E-02	.275E+03	.386E-02	248.	39.	.28	1.2	.2	-5	-1.0	.4	12.	4.	SP
0			-.1%	-1.8%	1.7%	.16E-02	-4.1%	.275E+03	-3.3%	-.8%					-5	-1	-6	3.	1.	OBO
															2.1	1.4	.8	5.	2.	MAG
															-9	-1	-8	-5.	-5.	RANS
															2.0	2.0	1.6	9.	6.	SIGS
															-2.5	-1.4	-1.1	15.	-6.	RANL
															2.9	2.7	1.8	20.	7.	SIGL
															-3.4	-1.5	-1.9	9.	-11.	RANT
															3.5	3.3	2.4	22.	9.	SIGT
38.00	28.45	80.53	.377E+03	.528E-02	249.	24.	.15E-02	.366E+03	.530E-02	240.	48.	.23	1.5	.3	-6	-9	.3	11.	4.	SP
0			-.1%	-1.7%	1.6%	.15E-02	-3.0%	.366E+03	-1.2%	-1.8%					-4	.0	-5	3.	0.	OBO

36.00	28.45	80.53	.495E+03	.710E-02	243.	21.	3.	.480E+03	.708E-02	237.	28.	-2.	1.5	.3	1.8	1.2	-.8	7.	1.	MAG
0			-.8%	-2.2%	1.5%	.14E-02		-3.7%	-2.7%	-1.1%	.19				-.7	-.9	-.2	10.	3.	SP
															-.4	.0	-.4	2.	0.	OBO
															1.6	1.0	.9	9.	1.	MAG
															-.6	.0	-.6	-3.	-1.	RANS
															1.7	1.8	1.6	7.	6.	SIGS
															-2.0	-.5	-1.5	9.	-5.	RANL
															2.5	2.3	1.7	18.	6.	SIGL
															-2.6	-.5	-2.1	6.	-6.	RANT
															3.0	2.9	2.3	19.	8.	SIGT
															-.8	-.8	-.1	11.	3.	SP
															-.3	-.1	-.4	0.	0.	OBO
															1.3	.8	.9	10.	1.	MAG
															1.2	1.3	.0	1.	-3.	RANS
															1.5	1.7	1.6	7.	5.	SIGS
															-3.8	-2.4	-1.4	1.	-4.	RANL
															2.2	2.1	1.5	16.	5.	SIGL
															-2.6	-1.1	-1.5	2.	-7.	RANT
															2.7	2.7	2.2	18.	7.	SIGT
															-.8	-.7	-.1	14.	2.	SP
															-.2	-.3	-.4	-2.	0.	OBO
															1.0	.7	.9	10.	1.	MAG
															2.2	3.9	-1.7	-6.	0.	RANS
															1.4	1.6	1.5	6.	4.	SIGS
															-.4	-1.0	1.4	16.	-2.	RANL
															2.0	1.9	1.4	15.	5.	SIGL
															2.7	2.9	-.2	10.	-2.	RANT
															2.4	2.4	2.1	16.	7.	SIGT
															-.8	-.6	-.2	16.	2.	SP
															-.1	.4	-.4	-4.	0.	OBO
															.8	.5	1.0	10.	1.	MAG
															1.2	2.2	-1.5	-6.	0.	RANS
															1.2	1.4	1.5	5.	4.	SIGS
															-.6	-.6	1.2	12.	-2.	RANL
															1.8	1.6	1.3	13.	4.	SIGL
															1.3	1.6	-.3	6.	-1.	RANT
															2.1	2.1	2.0	14.	6.	SIGT
															.0	.0	.0	13.	2.	SP
															-.1	.6	-.5	-5.	0.	OBO
															.6	.6	1.0	9.	1.	MAG
															1.8	1.5	.2	-7.	2.	RANS
															1.1	1.2	1.3	5.	3.	SIGS
															-1.0	-1.2	.2	20.	1.	RANL
															1.6	1.5	1.2	12.	4.	SIGL
34.00	28.45	80.53	.655E+03	.961E-02	237.	19.	3.	.636E+03	.952E-02	233.	22.	-4.	-.4	.2	-.8	-.8	-.1	11.	3.	SP
0			-1.3%	-2.8%	1.6%	.12E-02		-4.1%	-3.8%	-.4%	.06				-.3	-.1	-.4	0.	0.	OBO
															1.3	.8	.9	10.	1.	MAG
															1.2	1.3	.0	1.	-3.	RANS
															1.5	1.7	1.6	7.	5.	SIGS
															-3.8	-2.4	-1.4	1.	-4.	RANL
															2.2	2.1	1.5	16.	5.	SIGL
															-2.6	-1.1	-1.5	2.	-7.	RANT
															2.7	2.7	2.2	18.	7.	SIGT
32.00	28.45	80.53	.874E+03	.131E-01	233.	20.	2.	.895E+03	.135E-01	231.	28.	0.	-.4	.2	-.8	-.7	-.1	14.	2.	SP
0			-1.7%	-3.4%	1.8%	.98E-03		.7%	-.3%	1.1%	-.02				-.2	-.3	-.4	-2.	0.	OBO
															1.0	.7	.9	10.	1.	MAG
															2.2	3.9	-1.7	-6.	0.	RANS
															1.4	1.6	1.5	6.	4.	SIGS
															-.4	-1.0	1.4	16.	-2.	RANL
															2.0	1.9	1.4	15.	5.	SIGL
															2.7	2.9	-.2	10.	-2.	RANT
															2.4	2.4	2.1	16.	7.	SIGT
30.00	28.45	80.53	.117E+04	.178E-01	228.	21.	2.	.118E+04	.182E-01	226.	22.	1.	-.4	.2	-.8	-.6	-.2	16.	2.	SP
0			-2.6%	-3.1%	.6%	.78E-03		-1.4%	-1.2%	-.2%	-.02				-.1	.4	-.4	-4.	0.	OBO
															.8	.5	1.0	10.	1.	MAG
															1.2	2.2	-1.5	-6.	0.	RANS
															1.2	1.4	1.5	5.	4.	SIGS
															-.6	-.6	1.2	12.	-2.	RANL
															1.8	1.6	1.3	13.	4.	SIGL
															1.3	1.6	-.3	6.	-1.	RANT
															2.1	2.1	2.0	14.	6.	SIGT
28.00	28.45	80.53	.156E+04	.243E-01	224.	15.	1.	.158E+04	.245E-01	224.	24.	3.	1.3	.0	.0	.0	.0	13.	2.	SP
0			-3.3%	-3.0%	-.2%	.19E-03		-2.4%	-2.1%	-.2%	-.01				-.1	.6	-.5	-5.	0.	OBO
															.6	.6	1.0	9.	1.	MAG
															1.8	1.5	.2	-7.	2.	RANS
															1.1	1.2	1.3	5.	3.	SIGS
															-1.0	-1.2	.2	20.	1.	RANL
															1.6	1.5	1.2	12.	4.	SIGL

14.00	28.45	80.53	.149E+05	.246E+00	210.	37.	4.	.147E+05	.241E+00	213.	34.	11.	-1.1	-1	.2	0.	OBO
0			5.0%	8.1%	-2.9%	-.35E-03		4.0%	5.7%	-1.5%	.03			.1	.3	0.	MAG
														-7	-1.0	3.	RANS
														6	1.1	7	SIGS
														3	-9	-6	RANL
														7	1.2	6	SIGL
														-4	-1	-3	RANT
														9	1.6	9	SIGT
														0	0	0	SP
														1	1	0	OBO
														1	2	2	MAG
														-3	-1.0	7	RANS
														7	1.1	7	SIGS
														-8	-1.4	6	RANL
														9	1.3	7	SIGL
														-1.0	-2.4	1.4	RANT
														1.1	1.7	1.0	SIGT
														0	0	0	SP
														0	0	0	OBO
														0	1	1	MAG
														-5	-7	2	RANS
														7	1.0	8	SIGS
														-1.4	-1.2	-2	RANL
														9	1.1	7	SIGL
														-1.9	-1.9	0	RANT
														1.1	1.5	1.1	SIGT
														0	0	0	SP
														0	0	0	OBO
														0	0	0	MAG
														-2	-8	7	RANS
														7	9	8	SIGS
														5	-7	1.2	RANL
														9	1.0	8	SIGL
														4	-1.5	1.8	RANT
														1.1	1.3	1.1	SIGT
														0	0	0	SP
														0	0	0	OBO
														0	0	0	MAG
														-2	-1.0	1.2	RANS
														6	8	8	SIGS
														4	-6	1.0	RANL
														8	8	8	SIGL
														6	-1.6	2.2	RANT
														1.0	1.1	1.1	SIGT
														0	0	0	SP
														0	0	0	OBO
														0	0	0	MAG
														-2	-1.0	1.2	RANS
														6	8	8	SIGS
														4	-6	1.0	RANL
														8	8	8	SIGL
														6	-1.6	2.2	RANT
														1.0	1.1	1.1	SIGT
														0	0	0	SP
														0	0	0	OBO
														0	0	0	MAG
														-1.0	-1.7	7	RANS
														5	7	7	SIGS
														-9	-2	-7	RANL

ERRATA

THE NASA/MSFC GLOBAL REFERENCE ATMOSPHERIC MODEL—1990 VERSION (GRAM-90)

PART II FICHE ERRATA

Users of the GRAM-90 part II program and data listings, from the enclosed Fiche, will need to apply the following errata corrections in order to interpret a correct listing.

Fiche 01 - Row 3 - Column 6 - Page 29

In SUBROUTINE INTRUV -
Insert line INUV 7A to read:

I=1+INT(H)/5	INUV 6
IF (H.GE.125) I=25+(INT(H)-120)/20	INUV 7
IF (I.GT.29) I=29	INUV 7A
C UPPER HEIGHT INDEX	INUV 8
IP=I+1	INUV 9

Fiche 01 - Row 4 - Column 8 - Page 45

In SUBROUTINE RTERP -
Insert line RTER 9A and modify lines RTER 11 and RTER 25 to read:

IF (H.GE.120) I=25+INT((H-120)/20)	RTER 8
IF (I.LT.1) I = 1	RTER 9
IF (I.GT.29) I = 29	RTER 9A
IP = I+1	RTER 10
IF (IP.GT.29) IP=29	RTER 11
C LOWER LATITUDE INDEX	RTER 12
J=INT((PHI+100)/10)	RTER 13
Z2=5.*IP-5.	RTER 23
GO TO 40	RTER 24
30 Z2=120.+20.*(IP-25)	RTER 25
40 PHI1=-100.+10.*J	RTER 26
PHI2=-100.+10.*JP	RTER 27

In SUBROUTINE SCIMOD -

Modify lines SCIM 141, SCIM 158 and SCIM 159 to read:

THETE=THET-5.	SCIM 140
C.....JACCHIA VALUES AT LOWER HEIGHT, CURRENT LON-LAT+5 DEGREES	SCIM 141
C LAT, FOR DP/DY AND DT/DY	SCIM 142

PHIN=PHIR+5/FAC	SCIM 157
THETE=THET-5.	SCIM 158
C.....JACCHIA VALUES AT UPPER HEIGHT, CURRENT LON-LAT+5 DEGREES	SCIM 159
C LAT, FOR DP/DY AND DT/DY	SCIM 160



Report Documentation Page

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				6. Performing Organization Code	
7. Author(s) C.G. Justus, ¹ F.N. Alyea, ¹ D.M. Cunnold, ¹ W.R. Jeffries III, ² and D.L. Johnson ³				8. Performing Organization Report No.	
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				15. Supplementary Notes Prepared by Space Science Laboratory, Science and Engineering Directorate. ¹ Georgia Institute of Technology, Atlanta, GA ² New Technology, Inc., Huntsville, AL ³ Marshall Space Flight Center, AL	
16. Abstract A new (1990) version of the NASA/MSFC Global Reference Atmospheric Model (GRAM-90) is presented and discussed. GRAM-90 incorporates extensive new data, mostly collected under the Middle Atmosphere Program (MAP), to produce a completely revised middle atmosphere model (20 to 120 km). Because of earlier data sparseness in this altitude region, previous versions of GRAM relied on a 6-month displacement of Northern Hemisphere data to represent the Southern Hemisphere. GRAM-90 alleviates this shortcoming by utilizing actual data from the Southern Hemisphere for each month. The NASA Marshall Engineering Thermosphere (MET) model has also been incorporated into the GRAM-90 program, at all orbital altitudes greater than 120 km. Part I of this report serves as a technical description of the GRAM-90 program, with extensive documentation on the program operation and usage. Sample results are presented, in the form of height-latitude and latitude-longitude plots. Comparisons are made between the empirically based GRAM-90 model and results from a "first principles" stratospheric circulation model (SCM) in the 20- to 80-km height region. Specific areas of improvement of GRAM-90 over the earlier GRAM model results are also noted. A test case example is also included. Part II of this report presents the entire GRAM-90 program listing along with the major data base listings.					
17. Key Words (Suggested by Author(s)) Global Reference Atmosphere Model, Orbital Altitude Atmosphere Model, pressure, temperature, density, winds, atmospheric perturbations, upper atmosphere, technical description/users manual			18. Distribution Statement Unclassified – Unlimited Subject Category: 47		
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