



The NASA Marshall Space Flight Center Earth Global Reference Atmospheric Model—2010 Version

F.W. Leslie

Marshall Space Flight Center, Marshall Space Flight Center, Alabama

C.G. Justus

Dynetics Technical Services, Huntsville, Alabama

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National Aeronautics and
Space Administration

Marshall Space Flight Center • MSFC, Alabama 35812

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LIST OF ACRONYMS AND SYMBOLS

AFB	Air Force Base
AFGL	Air Force Geophysics Laboratory
AFMS	Air Force Midlatitude Summer
AFMW	Air Force Midlatitude Winter
AFSS	Air Force Subarctic Summer
AFSW	Air Force Subarctic Winter
AFTR	Air Force Tropical
AMU	Applied Meteorological Unit
Ar	argon
ARL	Air Resources Lab
ASCII	American Standard Code for Information Interchange
BL	boundary layer
CDAS	Climate Data Assimilation System
CH ₄	methane
CIRA	Committee on Space Research International Reference Atmosphere
CO	carbon monoxide
CO ₂	carbon dioxide
COSPAR	Committee on Space Research
DVD	digital videodisc
EAFB	Edwards Air Force Base
F10	solar radio noise flux at 10.7 nm (surrogate for extreme ultraviolet flux)
FTP	File Transfer Protocol
GPS	Global Positioning System
GRAM	Global Reference Atmospheric Model
GRS	Geodetic Reference System
GUACA	Global Upper Air Climatic Atlas
H	hydrogen
H ₂ O	water vapor
He	helium
HWM	harmonic wind model
IAU	International Astronomical Unit
JB	Jacchia-Bowman

LIST OF ACRONYMS AND SYMBOLS (Continued)

kmr	Kwajalein Missile Range
KSC	Kennedy Space Center
LaRC	Langley Research Center
lat-lon	latitude-longitude
Lya	Lyman alpha extreme ultraviolet radiation
MAP	Middle Atmosphere Program
MET	Marshall Engineering Thermosphere
MG2	double-ionized magnesium
MSFC	Marshall Space Flight Center
MSIS	Mass Spectrometer, Incoherent Scatter
MSL	mean sea level
N ₂	nitrogen
N ₂ O	nitrous oxide
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
NRLMSISE	Naval Research Laboratory Mass Spectrometer, Incoherent Scatter Radar Extended model
O	atomic oxygen
O ₂	molecular oxygen
O ₃	ozone
PC	personal computer
POR	period-of-record
RH	relative humidity
RRA	Range Reference Atmosphere
Ruv	cross-correlation of the horizontal and wind components
SI	International Standard
SLF	Shuttle Landing Facility
SODAR	sound detection and ranging
TM	Technical Memorandum
U.S.	United States
UDF	universal diurnal factor

LIST OF ACRONYMS AND SYMBOLS (Continued)

url	uniform resource locator
UT	universal time
UTC	universal time coordinated
WGS	World Geodetic System
WMO	World Meteorological Organization
WSMR	White Sands Missile Range

NOMENCLATURE

A	local wave amplitude
A_Q	large-scale amplification factor
$A(z)$	data set, amplitude
$B(z)$	data set
C	faired variable
$c(t)$	specific concentrations
c_s	the speed of sound
\bar{c}_s	the monthly mean speed of sound
d	boundary layer depth
d_N	neutral boundary layer depth
Dst	index of worldwide geomagnetic storm level
E_l	solar elevation
E_{md}	solar elevation at midday
E_R	site elevation in km
F	adjustment factor
$F(h)$	surface wind adjustment factor as a function of height
$F_S(H)$	universal diurnal factor for wind speed as a function of hour
$F_T(H)$	universal diurnal factor for temperature as a function of hour
f	coriolis parameter
$f(z)$	fairing parameter
f_L	large-scale fractional variance
f_{non}	factor for variance of nonsevere perturbation
f_{sev}	factor for variance of severe perturbation
g	acceleration of gravity
$G(E_l)$	time-factor multiplier
H	hour
h	topographic altitude in km
L	local vertical correlation scale (small-scale perturbation) or Monin-Obukhov scaling length (stability dependent) in meters
L_{avg}	average scale size
L_h	horizontal scale parameter
L_{max}	maximum scale size

NOMENCLATURE (Continued)

L_{min}	minimum scale size
L_z	vertical scale parameter
m	wave number in the latitudinal direction
mn	input value of month
n	wave number in the longitudinal direction
n_r	net radiation index
P_{sev}	probability of severe perturbations
P_{tail}	tail probability of a Gaussian distribution
p	pressure
\bar{p}	monthly mean pressure
Q	a uniformly distributed random number between 0 and 1
q	Gaussian-distributed random number
R	gas constant
R_i	Richardson number
r	autocorrelation value
r_c	cross-correlation
r_q	a correlation coefficient
r_t	concentration rate of change
r_v	a correlation coefficient
r_μ	a correlation coefficient
S	wind speed
S_{day}	wind speed daily average for a given month
S_N	National Centers for Environmental Prediction wind speed in m/s
S_R	Range Reference Atmosphere surface wind speed in m/s
s_u	stationary eastward wind
s_v	stationary northward wind
s_y	stationary perturbation
T	temperature or wave period
\bar{T}	monthly mean temperature
$T(H)$	temperature as a function of local hour
T_{Tot}	monthly mean temperature plus perturbations
t	year
t_0	initial time in concentration formula
U_{10}	surface wind speed measured at the standard 10-m height above surface

NOMENCLATURE (Continued)

U_{18}	surface wind speed measured at the standard 18-m height above surface
u	west-to-east component of wind
u_*	friction velocity
u_m	monthly mean eastward wind
V	variable available on two-dimensional grid
v	south-to-north component of wind
v_m	meridional (northward) mean wind
$W(U_{10})$	wind speed factor as a function of surface wind speed
x	longitude, height, or log pressure
\mathbf{x}	vector position
\mathbf{x}'	trajectory position
y	latitude, pressure, density, or temperature parameter
y_m	monthly mean value
z	geopotential altitude
z_o	surface roughness
z_u	zonal-mean value of the eastward wind
z_y	zonal-mean value
α	a constant used in the computation of surface roughness over water, 0.015 or interpolation constant
β	interpolation constant
γ	temperature gradient
γ_c	the ratio of specific heats of a gas at a constant pressure to a gas at a constant volume
δh	horizontal step
δt	time step
δz	vertical step
θ	longitude
λ	local vertical wavelength
λ_z	vertical wavelength number
μ	normalized variant
ξ	stability category
ρ	density
$\bar{\rho}$	monthly mean density
ρ_l	large scale density
σ	local standard deviation (small-scale perturbation)

NOMENCLATURE (Continued)

σ^2	total variance of small-scale perturbation
σ_{cos}	standard deviation of the cosine function
σ_L	standard deviation of large scale
σ_P	standard deviation of pressure
σ_S	standard deviation of wind speed or small-scale standard deviation
σ_T	total standard deviation or standard deviation of temperature
σ_u	standard deviation of west-to-east component of wind
σ_v	standard deviation of south-to-north component of wind
σ_w	standard deviation of the vertical wind component
σ_ρ	standard deviation of density
$\sigma_{\rho l}$	standard deviation of large-scale density
τ	time scale
ϕ	latitude
ϕ_q	random wave phase
ψ	boundary layer wind function
ω	Brunt-Vaisala frequency

TECHNICAL MEMORANDUM

THE NASA MARSHALL SPACE FLIGHT CENTER EARTH GLOBAL REFERENCE ATMOSPHERIC MODEL—2010 VERSION

1. INTRODUCTION

1.1 Background and Overview

Reference or standard atmospheric models have long been used for design and mission planning of various aerospace systems. The NASA Marshall Space Flight Center (MSFC) Global Reference Atmospheric Model (GRAM) was developed in response to the need for a design reference atmosphere that provides complete global geographical variability, complete altitude coverage (surface to orbital altitudes), and complete seasonal and monthly variability of the thermodynamic variables and wind components. A unique feature of GRAM is that, in addition to providing the geographical, height, and monthly variation of the mean atmospheric state, it includes the ability to simulate spatial and temporal perturbations in these atmospheric parameters (e.g., fluctuations due to turbulence and other atmospheric perturbation phenomena). A summary comparing GRAM features to characteristics and features of other reference or standard atmospheric models can be found in reference 1.

The original GRAM (found in ref. 2) has undergone a series of improvements over the years with recent additions and changes.^{3–9} The software program is called Earth-GRAM2010 to distinguish it from similar programs for other bodies (e.g., Mars, Venus, Neptune, and Titan). However, in order to make this Technical Memorandum (TM) more readable, the software will be referred to simply as GRAM2010 or GRAM unless additional clarity is needed. Section 1 gives an overview of the basic features of GRAM2010 including the newly added features. Section 2 provides a more detailed description of GRAM2010 and how the model output is generated. Section 3 presents sample results and section 4 gives specific user information. Appendix A describes the National Centers For Environmental Prediction (NCEP) Reanalysis Project Climatology Data. Appendix B provides instructions for compiling and running GRAM2010. Appendix C gives a description of the required NAMELIST input file. Appendix D gives sample output. Appendix E shows a list of available parameters to enable the user to generate special output. Appendix F gives an example and guidance on incorporating GRAM2010 as a subroutine in other programs such as trajectory codes.

1.2 Basic Description of the Global Reference Atmospheric Model 2010

GRAM2010 is a mixture of empirically based models that represents different altitude ranges and the geographical and temporal variations within these altitude ranges. Figure 1 shows

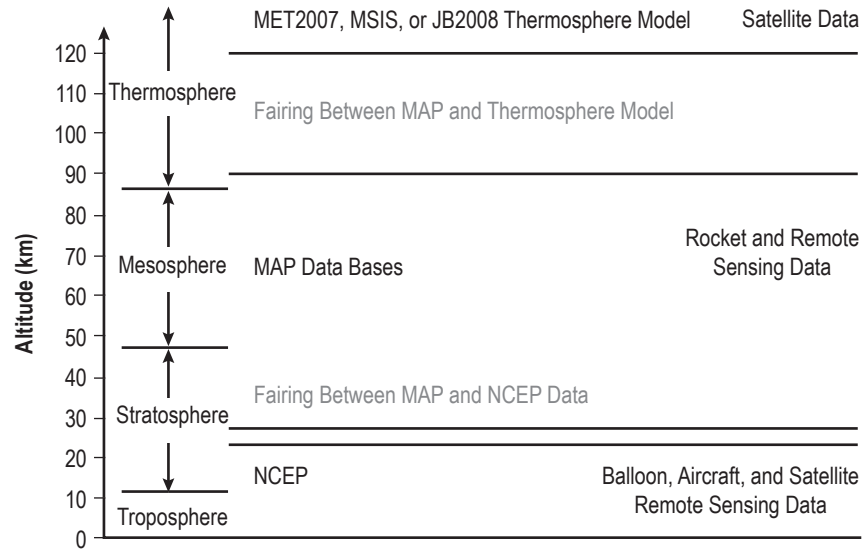


Figure 1. Summary of the atmospheric regions in the GRAM2010 program, sources for the model, and data on which the mean monthly GRAM2010 values are based.

how GRAM divides the atmosphere into three regions from which mean values of atmospheric parameters are provided. A perturbation model (see sec. 2.7) then computes variations about these means if dispersions are desired. Monthly mean values and standard deviations in the lower atmosphere come from the NCEP database. These are newly added for GRAM2010 and described more fully in the next section.

Unlike the Global Upper Air Climatic Atlas (GUACA) data used by previous versions of GRAM that had to be ordered from the National Climatic Data Center (NCDC), the NCEP database is provided with the GRAM2010 software. The database read by GRAM is in binary form, but an American Standard Code for Information Interchange (ASCII) version is also provided. A program is available on the GRAM digital videodisc (DVD) that the user may run on their machine to convert the ASCII version to their machine-specific binary.

The middle atmospheric region (20–120 km) data set is compiled from Middle Atmosphere Program (MAP) data¹⁰ and other sources referenced in the GRAM-90 and GRAM-95 reports.^{5,6} For the highest altitude region (above 90 km), the user has the choice of three thermosphere models (see sec. 2.1). Fairing techniques provide smooth transition between the altitude regions. Unlike interpolation (used to ‘fill in’ values across a gap in data), fairing is a process that provides a smooth transition from one set of data to another in overlapping regions (e.g., 20 km–10 mb level for NCEP and MAP data and 90–120 km for MAP data and the thermosphere models). Figure 1 provides a graphical summary of the data sources and height regions. In addition to these databases, the user has the option of instructing GRAM to use the 2006 Range Reference Atmosphere (RRA) data set of specific sites or the user can provide an auxiliary profile of mean values and standard deviations.

Beginning with GRAM-95, the model provides estimates of atmospheric species concentrations for water vapor (H_2O), ozone (O_3), nitrous oxide (N_2O), carbon monoxide (CO), methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2), molecular oxygen (O_2), atomic oxygen (O), argon (Ar), helium (He), and hydrogen (H). The thermosphere models provide the species concentrations for N_2 , O_2 , O , Ar , He , and H above 90 km. Air Force Geophysics Laboratory (AFGL) atmospheric constituent profiles are also used extensively for the constituents to a 120-km altitude.¹¹ The NASA Langley Research Center (LaRC) H_2O climatology includes H_2O values from a 6.5- to a 40.5-km altitude.¹² The MAP data include H_2O data from the 100- to 0.01-mb pressure level.¹³ Other details of the species concentration model are given in sections 1.4 and 2.4 of reference 6.

1.3 Summary of Significant Changes and Features for Global Reference Atmospheric Model 2010

1.3.1 Programming Changes

For the 2010 version, GRAM has been converted to Fortran90. This allows the use of modules that can group related procedures and data together and make them available to other program units. In addition, interface blocks provide a vastly improved argument-passing mechanism, allowing them to be checked at compile time. The program was also converted to double precision.

1.3.2 New Database for the Lower Atmosphere With Diurnal Variation

The GUACA database previously used in GRAM has been replaced by the NCEP database for GRAM2010. Not only does this new database have a more contemporary period-of-record (POR), it also provides monthly means for four different times of day: 00Z, 06Z, 12Z, and 18Z. In addition, the new database is now provided with the GRAM software (all on a DVD) so there is no longer a requirement for the user to order it from a second party. The following description was adapted from reference 14.

The NCEP/NCAR Reanalysis Project is a joint project between the NCEP and the NCAR. The goal of this joint effort is to produce new atmospheric analyses using historical data (1948 onwards) and to produce analyses of the current atmospheric state (Climate Data Assimilation System (CDAS)). Until recently, the meteorological community has had to use analyses that supported the real-time weather forecasting. These analyses are very inhomogeneous in time as there have been big improvements in the data assimilation systems. The quality and utility of the reanalyses should be superior to NCEP's original analyses because of the following:

- A state-of-the-art data assimilation is used.
- More observations are used.
- Quality control has been improved.
- The model/data assimilation procedure remains unchanged during the project.
- Many more fields are being saved.

- Global coverage (some older analyses were hemispheric).
- Better vertical resolution (stratosphere).

More information about the reanalysis project and data are available from several sources, including reference 15 and at <<http://www.cdc.noaa.gov/cdc/data.nmc.reanalysis.html>>.

Data used in Earth-GRAM 2010 were downloaded from the National Oceanic and Atmospheric Administration (NOAA) Air Resources Lab (ARL) archives at <<http://www.arl.noaa.gov/archives.php>>.

The NCEP data are provided with the GRAM software in both ASCII and personal computer (PC) binary formats. GRAM inputs the NCEP data as binary files. Files for each month are named Nby1y2mm.bin, where the POR is for years y1 through y2 (e.g., 9008 is for POR 1990 through 2008), and month is mm. For a non-PC platform, the user may need to convert the ASCII data to binary on their specific machine. A utility program named NCEPbin is provided for the conversion. More details of the NCEP database can be found in appendix A.

1.3.3 Revised Model for the Vertical Wind

A new model computes standard deviation for boundary layer (BL) vertical wind as a function of surface type (water or various land types) and surface-horizontal wind (at 10-m height). Surface height (above mean sea level (MSL)) is interpolated from a $1^\circ \times 1^\circ$ topographic database in the new 'atmosdat' file (see sec. 4.3) or from RRA surface altitude (if within the zone-of-influence of any RRA site). Boundary layer depth (d) (height of the top of the BL above the surface) is computed from a new time-of-day and stability-dependent model. Land cover type is taken from a $1^\circ \times 1^\circ$ resolution data set also in the new 'atmosdat' file. Further details can be found in section 2.4.

1.3.4 New Input Parameters

Earth-GRAM 2010 has 10 new input parameters that are provided through the NAMELIST input file:

rralist:	File name for list of RRA sites (optional).
y10:	Solar X-Ray and Lya index scaled to F10 (for JB2008).
y10b:	Solar X-Ray and Lya 81-day avg. centered index (for JB2008).
dstdtc:	Temperature change computed from Dst index (for JB2008).
NCEPyr:	Period-of-record (POR = y1y2) for NCEP climatology. POR includes years y1 through y2 (e.g., NCEPyr = 9008 for POR = 1990 through 2008). NCEP monthly climatology is determined by input value of month (mn) in initial time input.
NCEPhr:	Code for universal time (UT) hour of day for NCEP climatology: 1 = 00UT, 2 = 06UT, 3 = 12UT, 4 = 18UT, 5 = all times of day combined, or 0 to use NCEP time-of-day based on input UT coordinated (UTC) hour (ihro).

ruscale:	Random perturbation scale for horizontal winds; nominal = 1, maximum = 2, minimum = 0.1.
rwscale:	Random perturbation scale for vertical winds; nominal = 1, maximum = 2, minimum = 0.1 .
z0in:	Surface roughness (z0) for sigma-w model (<0 to use 1°×1° lat-lon surface data, from new file atmosdat_E10.txt; = 0 for speed-dependent z0 over water; or enter a value between 1×10^{-5} and 3 for user-specified z0 value).
ibltest:	Unit number for boundary layer model output file (bltest.txt), or 0 for no BL model output (see description in sec. 4.6.4).

Two previous input parameters (iguayr and iyrrra) are no longer used and should not be included in the NAMELIST input file.

1.3.5 New Range Reference Atmosphere Input Parameter

An option exists to use data (in the form of vertical profiles) from a set of RRAs at RRA site locations as an alternate to the usual GRAM climatology. RRA data includes information on both monthly means and standard deviations of the various parameters at the RRA site. Under the RRA option, when a given trajectory point is sufficiently close to an RRA site, the mean RRA data replace the mean values of the conventional GRAM climatology, and the RRA standard deviations replace the conventional GRAM standard deviations in the perturbation model computations. A new feature for GRAM2010 is that the user has the option to provide a file name for a list of available sites. Different RRA sites or combinations of sites can be made available by building various RRA lists, and the RRA set to use can be controlled at run time.

1.3.6 Updated Thermosphere Models

The JB2006 thermosphere model has been replaced with the new JB2008. Global climatology of chemical release winds was also used to revise wind perturbation standard deviations in the 90–120-km altitude range.

1.3.7 New Scaling Parameter for Standard Deviations

The user now has the option of independently changing the standard deviations of the horizontal wind, the vertical wind, and the thermodynamic variables (density, temperature, and pressure).

1.3.8 New Option for Auxiliary Profiles

An option was added to input standard deviations (sigmas) in auxiliary profiles. If all zero values are entered, sigmas are taken from conventional climatology. An exception to this is for isolated zero values of sigma; in which case, the previous value along the profile or trajectory is used.

1.3.9 Additional Output Parameters

The mean sound speed and perturbed sound speed were added to the ‘print format’ and ‘special format’ output files. Wind speed means and standard deviations, and cross-correlation (Ruv) between eastward and northward wind components were also added to the output. Ruv is used to compute the wave-like large-scale northward wind perturbation in such a way as to produce the appropriate degree of cross-correlation. See section 2.8 for further discussion of Ruv.

1.3.10 Moisture Corrections

The Elliott-Gaffen moisture corrections were revised to take advantage of all moisture variables available in the NCEP data. Revisions were also made in the calculation of standard deviation of relative humidity (RH), to account for correlation between vapor pressure and saturation vapor pressure (correlation evaluated empirically from study of NCEP RH data).

1.4 Summary of Global Reference Atmospheric Model 2010 Characteristics

1.4.1 Output is Based on Atmospheric Measurements

The lowest region of the model utilizes measurements from the NCEP or the RRA database that have been quality checked. Although other databases may exist, the NCEP dataset has global coverage; contains pressure, temperature, and winds; and also contains both means and standard deviations. The middle atmosphere of the model is based on the available (though limited) data from rocket and remote sensing programs. Finally, the upper atmosphere uses one of three thermospheric models that have been guided by data from satellite observations and space research.

1.4.2 Can be Driven by External Data

If the user has atmospheric data that is believed more appropriate for their application than that contained within GRAM2010, it can be easily ingested into the model using the Auxiliary Profile option. The auxiliary profile need not be a vertical profile, but could also be data dependent on latitude, longitude, and height. Alternatively, the user could also provide model data by adding an RRA site to the database as described in section 2.10.

1.4.3 Monte Carlo Runs of Global Reference Atmospheric Model 2010 Reproduce the Observed Means and Standard Deviations

When a large number of dispersions are generated at any location, the mean and standard deviation of these data will match those of the observations. This is important in order for the model to be statistically equivalent to available measurements.

1.4.4 The Total (Large-Scale + Small-Scale) Dispersions of Global Reference Atmospheric Model 2010 are Approximately Gaussian Distributed

The exception is pressure where most of the variance is due to the large scale since small-scale pressure variations equilibrate quickly. Because the large scale is modeled with a cosine wave, the probability distribution is influenced by that function to a larger degree. Newly introduced randomly varying amplitudes for large-scale wave perturbations make the total dispersions more Gaussian. Therefore, dispersions can be expected to have a more normal frequency than earlier.

1.4.5 The Small-Scale Dispersions Have a Dryden Power Spectrum

Since the small-scale dispersions are modeled with a one step Markov technique having a correlation coefficient that decreases exponentially with distance (and time), the energy spectrum is inversely proportional to the square of the length (and time) scale. Thus, most of the observed variance occurs over large length (and time) scales.

1.4.6 The Computed Wind Shears are Consistent With Those Observed at the Kennedy Space Center

Structure function analysis of wind shears observed at Kennedy Space Center (KSC) from balloon and tower data resulted in improvements in the perturbation model. See reference 16 for a comparison of the model to measured data. In addition, data for the cross-correlation of the horizontal wind component data in NCEP have been utilized.

2. TECHNICAL DESCRIPTION OF THE MODEL

2. 1 The Upper Atmosphere Section (Above 90 km)

GRAM2010 has the option of three different thermosphere models for use above 90 km. The Marshall Engineering Thermosphere (MET) 07 (MET-07) constitutes the default upper atmosphere model.¹⁷⁻²³ The Jacchia model in MET-07 for the thermosphere and exosphere was originally implemented to compute atmospheric density and temperature at satellite altitudes.²⁴ It represents total atmospheric density by summing the densities of six, separately modeled, atmospheric constituents (N_2 , O_2 , O, Ar, He, and H). The Jacchia model accounts for temperature and density variations due to solar and geomagnetic activity and diurnal, seasonal, and latitude-longitude (lat-lon) variations throughout the height range above 90 km. The Jacchia model assumes a uniformly mixed composition below 105 km, with diffusive equilibrium among the constituents above 105 km. Fixed (time-independent) boundary values for temperature and density are assumed at 90 km. Alterations described in reference 2 were made to allow atmospheric pressure to be computed from the density and temperature. Geostrophic wind components, modified by the effects of molecular viscosity,⁵ are evaluated in the Jacchia section by using the Jacchia model to estimate horizontal pressure gradients. This wind model has been used in GRAM since the 1990 version.⁵ Between 90 and 120 km, a fairing process described in section 2.6.4 ensures smooth transition between the MET model values and the middle atmosphere data.

As an alternative to MET, an option is provided to use the 2000 version Naval Research Laboratory (NRL) Mass Spectrometer, Incoherent Scatter Radar Extended (NRLMSISE) model, NRLMSISE-00, for thermospheric conditions. If this option is selected, thermospheric winds are evaluated using the NRL 1993 Harmonic Wind Model (HWM), HWM-93. Information on the Mass Spectrometer, Incoherent Scatter (MSIS) and HWM models is available at the following uniform resource locators (urls):

- <<http://www.nrl.navy.mil/content.php?P=03REVIEW105>>.
- <<http://modelweb.gsfc.nasa.gov/atmos/nrlmsise00.html>>.
- <<http://www.answers.com/topic/nrlmsise-00>>.
- <<http://fact-archive.com/encyclopedia/NRLMSISE-00>>.
- <<http://www.eiscat.rl.ac.uk/svn/guisdap.svn/trunk/dist/g85/models/nrlmsise00/readme.txt>>.
- <<http://modelweb.gsfc.nasa.gov/atmos/hwm.html>>.
- <<http://adsabs.harvard.edu/abs/2006AGUFMSA11A..07D>>.
- <<http://nssdcftp.gsfc.nasa.gov/models/atmospheric/hwm07/readme.txt>>.

Minor corrections in MSIS and HWM have been made. Therefore, MSIS/HWM output from GRAM will not agree totally with output from the original NRLMSISE-00 version.

Another thermosphere option is the JB2008 model that replaces JB2006 used in the previous version of GRAM.²⁵ The model was developed using the Committee on Space Research (COSPAR) International Reference Atmosphere (CIRA) 72 (CIRA-72) Jacchia 71 model as the basis for the diffusion equations. If JB2008 is selected for calculation of thermospheric density and temperature, winds are computed with the HWM-93, used in conjunction with the MSIS model. Other information and references to developmental papers for JB2008 are given at the JB2008 Web sites at the following urls:

- <http://sol.spacenvironment.net/~JB2008/>.
- <http://sol.spacenvironment.net/~JB2008/code.html>.
- <http://adsabs.harvard.edu/abs/2008cosp...37..367B>.

These sites have links to solar indices required by JB2008 (s10 and xm10), JB2008 source code, publications, contacts, figures, and the Space Environment Technologies Space Weather site.

2.2 The Middle Atmosphere Section (20–120 km)

The MAP data in GRAM characterizes the monthly mean middle atmosphere (20–120 km) by two gridded data sets, one representing the zonal mean atmospheric values (gridded by height and latitude) and the other the monthly mean stationary wave patterns (i.e., stationary perturbations about the monthly mean gridded by height, latitude, and longitude). The zonal mean data set was merged from six separate data sets covering the 20–120-km altitude range. The zonal monthly mean data set (pressure, density, temperature, and mean eastward wind component) is gridded in 10° latitude and 5-km height increments (–80° to +80° and 20–120 km). Zonal mean values at ±90° are computed by an across-the-pole interpolation scheme discussed in section 2.6. Zonal mean values between the gridded data set values are interpolated vertically by hydrostatic and perfect gas law assumptions and horizontally by two-dimensional (lat-lon) interpolation methods.

The stationary perturbation data set (standing wave perturbations in pressure, density, temperature, and eastward and northward wind components) was merged from three sources of data on planetary scale standing wave patterns.⁵ This data set is gridded in 10° latitude increments (–80° to +80°), 20° longitude increments (180° W., 160° W., 140° W.,..., 140° E., 160° E.), and 5-km height intervals (20–90 km). Stationary perturbations are identically zero at the poles. Stationary perturbation values are linearly interpolated in the vertical dimension and horizontally by two-dimensional (lat-lon) interpolation methods.

2.3 The Lower Atmosphere Section (Surface to 10 mb)

2.3.1 The National Centers for Environmental Prediction Database

For the lower atmosphere, GRAM2010 uses climatological data derived from an NCEP global reanalysis database. The NCEP data consist of means and standard deviations (at a global lat-lon resolution of $2.5^\circ \times 2.5^\circ$) at 4 specific times of day (00, 06, 12, and 18 UTC) and for all 4 times-of-day combined at the surface and at each of 17 pressure levels. Averages and standard deviations are by month over a POR from 1990 through 2008. More information about the reanalysis project and data are available from several sources, including reference 15. As part of validation studies conducted for GRAM2010, NCEP hourly and daily averages of surface winds and temperatures were compared with statistics from more directly observed surface winds and temperatures. During these studies, it was found that NCEP average surface winds and temperatures did not have nearly as much variation with hour-of-day as did observed surface winds and temperatures. Consequently, a more detailed study of surface and near-surface NCEP data and observed winds and temperatures were undertaken.

2.3.2 National Centers for Environmental Prediction Versus 2006 Range Reference Atmospheres (Daily Data)

For 21 selected locations (mostly NASA or Air Force test ranges), GRAM2010 provides an alternative to NCEP climatology in the form of RRA profiles. These data contain only monthly average ‘daily’ averages and standard deviations (i.e., no information from individual hours of the day, as with NCEP). Temperature and wind speed data from NCEP daily averages for various months were compared with monthly average profiles from 17 of the RRA sites. Excluded from this analysis were four ‘island’ RRA sites (Ascension, Barking Sands, Kwajalein, and Taguac islands), because of possible cross-contamination between water-surface and land-surface characteristics. Analysis indicated that over the available altitude range, there is no significant bias error between NCEP and RRA values for either temperature or wind speed (except near the surface).

Surface altitude at a given RRA site is the altitude (above MSL) of the actual local topographic surface. This may differ significantly from the surface altitude in GRAM which uses a $1^\circ \times 1^\circ$ topographic database, as given by Gates and Nelson.²⁶ For this reason, a more detailed comparison was made between monthly-average, near-surface RRA values of wind speed and temperature, and monthly-average GRAM values interpolated to RRA surface altitude from the NCEP data. Ratios of RRA to NCEP monthly surface wind speed values were averaged over several months, and the results for average wind speed ratio are plotted in figure 2. The stations included China Lake, El Paso, White Sands Missile Range (WSMR), Edwards Air Force Base (AFB) (EAFB), and other sites. This figure indicates a significant tendency of the NCEP surface winds to overestimate the true (RRA) surface winds.

The solid trend line in figure 2 is given by,

$$S_R = [0.634 + 0.205E_R] S_N , \quad (1)$$

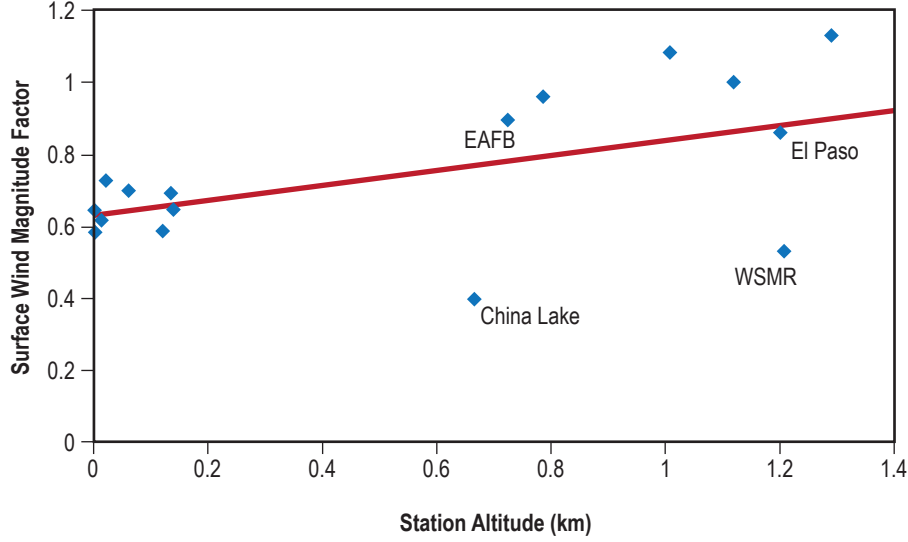


Figure 2. Average ratio of RRA surface wind speed to NCEP wind speed evaluated at the RRA surface altitude.

where S_R is the RRA surface wind speed in m/s, E_R is the site elevation in km, and S_N is the NCEP wind speed in m/s. This suggests that a multiplication factor could be applied to the NCEP winds in order to make it agree more closely with the RRA winds.

For consistency between means and standard deviations of the wind components and the mean and standard deviation for wind speed, the factor given by the term in brackets in equation (1) must be applied to all of these statistics. That a common factor on all the wind statistics preserves consistency is easily seen from the fact that a given wind speed value (S) is related to wind components u and v by,

$$S^2 = u^2 + v^2, \quad (2)$$

and taking an average of equation (2) yields a relationship between the average wind speed, its components, and their standard deviations.

$$\langle S \rangle^2 + \sigma_S^2 = \langle u \rangle^2 + \sigma_u^2 + \langle v \rangle^2 + \sigma_v^2, \quad (3)$$

where the brackets indicate an average value. Any common factor applied to all the means and standard deviations in equation (3) leaves this equation unchanged.

In figure 2, the wind speed factor for China Lake is seen to be significantly lower than the factor for nearby EAFB. This might be due to the fact that China Lake could be significantly more affected by local topography than EAFB. It is also likely that the NCEP POR (1990–2008) yields significantly different results than the China Lake RRA POR (1948–2000). Some instrumental problems are known to exist in pre-1990 data, which may adversely influence the China Lake

RRA data. An analogous situation exists for the different results between nearby sites El Paso and WSMR in figure 2. WSMR RRA has a POR 1949–1993, but WSMR may be more affected by local topography than nearby El Paso. A similar analysis was performed for temperature but, unlike wind speed, there was no significant bias between surface RRA temperature and NCEP surface temperature.

2.3.3 Land-Surface Diurnal Data

Since the land-surface RRA data examined earlier did not include diurnal variations of hourly mean wind speed or temperature, these factors for near-surface data had to be examined by using specially collected data. To this end, multiyear, POR hourly wind and temperature data were assembled from Cape Canaveral, EAFB, and WSMR. Two data sets were used from Cape Canaveral—one from a small tower at the Shuttle Landing Facility (SLF) site and one from the 16.5-m (54-ft) height on KSC tower 313.

From each of these four data sets and for each month, ratios of POR average monthly average hourly mean values and daily mean values were evaluated. Ratios of hourly average to daily average, by local hour of the day, were averaged across the data sets to produce a ‘universal diurnal factor’ (UDF) curve. Standard deviations about the UDF averages give a sense of the variability of UDF values among the four data sets and 12 months examined. UDF data values for wind speed are shown in figure 3 and for temperature are given in figure 4.

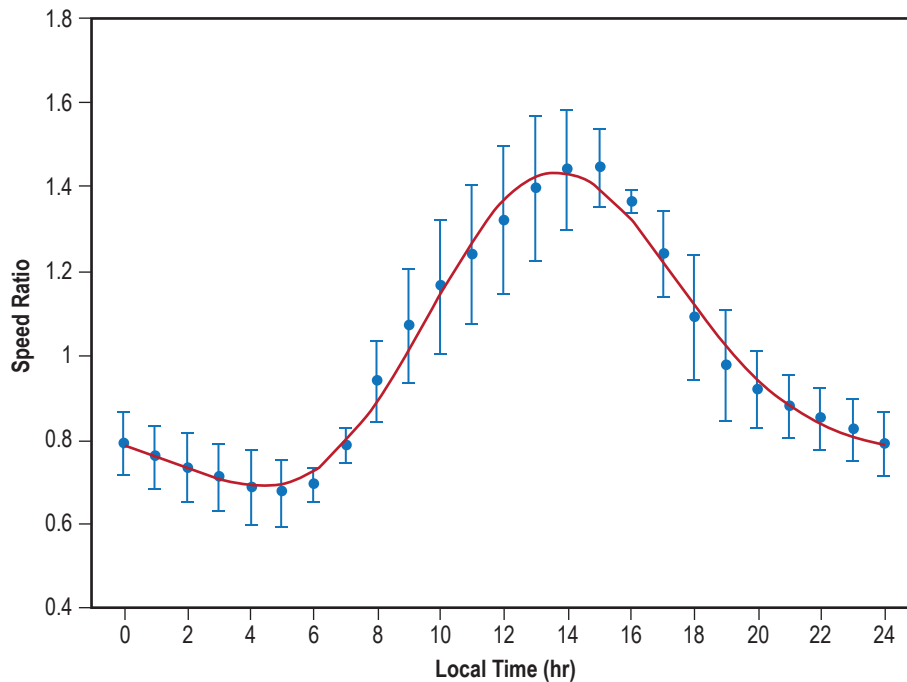


Figure 3. Multisite average of surface wind speed ratio of hourly average wind speed to daily average wind speed.

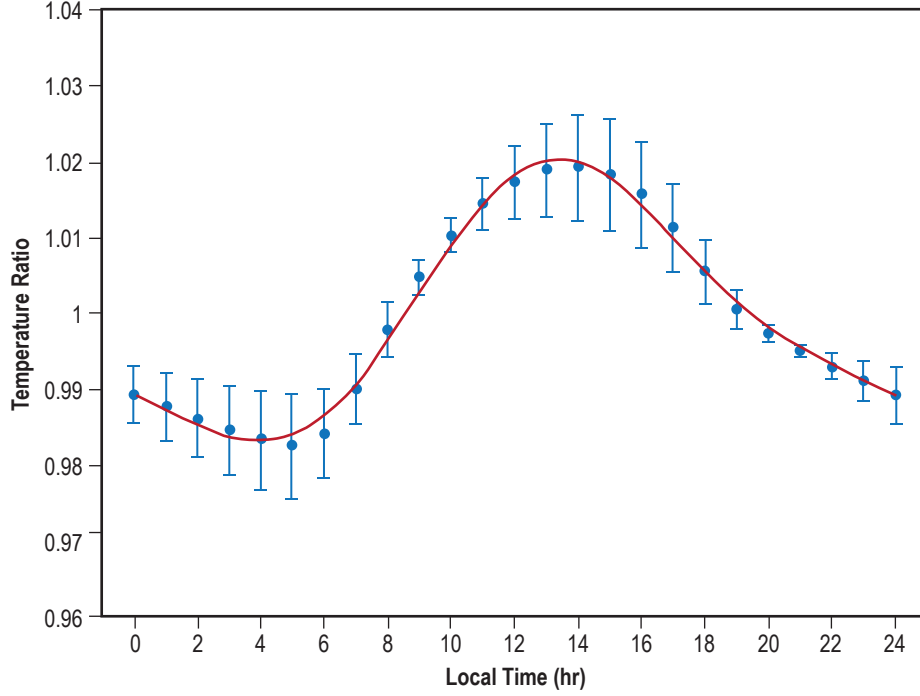


Figure 4. Multisite average of surface temperature ratio of hourly average temperature to daily average temperature.

The solid curves in figures 3 and 4 show least squares fits to these UDF data points, with both diurnal and semidiurnal harmonics represented in the UDF analytical curves. The UDF curve for wind speed as a function of local time (hour, (H)) is given by,

$$F_S(H) = 1.0 + 0.3525 \cdot \cos((H/12) - 3.727) + 0.09447 \cdot \cos((H/6) - 0.5930) , \quad (4)$$

while the UDF for temperature is given by,

$$F_T(H) = 1.0 + 0.01745 \cdot \cos((H/12) - 3.715) + 0.004083 \cdot \cos((H/6) - 0.2043) . \quad (5)$$

By definition, the leading term in both UDF equations is 1.0, since averaging over all hours should leave the daily average unchanged. A similar analysis was performed comparing the NCEP surface data over water to data sets for 23 buoys. Based on these results, no need for NCEP adjustment is perceived to be required for either daily averages or hourly averages for either wind speed or air temperature at water-surface NCEP grid locations.

2.3.4 Methodology for ‘Fixing’ Near-Surface National Center for Environmental Prediction Data

Based on study results described in the previous section, the following methodology is used to ‘fix’ near-surface values of hourly average and daily average NCEP wind and temperature data. The methodology is applied (as necessary) at each $2.5^\circ \times 2.5^\circ$ NCEP grid point, for each of the 12 monthly data sets. The $1^\circ \times 1^\circ$ global surface-type data set of DeFries and Townshend is used

to determine if the NCEP grid point has a water surface or land surface.²⁷ For water-surface grid points, no adjustment is applied to the NCEP data for either wind or temperature. For land-surface locations, topographic altitude (h) at the NCEP grid point is determined from the $1^\circ \times 1^\circ$ global topography,²⁶ and a surface wind adjustment factor, $F(h) = 0.634 + 0.205h$, is computed. For large h , $F(h)$ is limited to be ≤ 1 . If the geopotential altitude (z) above the surface is ≤ 0 (i.e., below sea level) for a given NCEP pressure level, then $F(h)$ is used as a multiplier on the hourly averages and standard deviations and daily averages and standard deviations for wind speed and for both horizontal wind components. If $z > 0$ and $z \leq 500$ m, then F is linearly interpolated between $F = F(h)$ at $z = 0$ and $F = 1$ (no adjustment) at $z = 500$ m. The factor F is then used as an adjustment multiplier on all wind statistics. If $z > 500$ m, no adjustment is applied to wind statistics.

Local time (H) is computed based on longitude of the NCEP grid point and on UTC time for the NCEP hourly average. Values of UDFs, ($F_S(H)$ for speed and $F_T(H)$ for temperature) are computed from equations (4) and (5). As for wind adjustment factor F , values of F are interpolated on height above the surface, z , until UDF = 1 (no diurnal adjustment) at $z \geq 500$ m. Then the factor $F_T(H)$ is used to adjust hourly average and standard deviation of temperature if the data does not show sufficient variability. Atmospheric density and moisture variables are also adjusted to preserve the perfect gas law relation, based on the given hourly average RH. Factor $F_S(H)$ is also used to adjust hourly averages and standard deviations of wind speed and both horizontal wind components if there is insufficient variability in the NCEP data.

2.3.4.1 Summary. No adjustments are made to any NCEP data over the oceans or to any data above 500 m over land. Furthermore, no corrections are made to the monthly mean temperature data anywhere. If hourly average NCEP temperature $\langle T(H) \rangle$ deviates from the daily average by less than the amount expected from $F_T(H)$, then $\langle T(H) \rangle$ is adjusted until the deviation from the daily average is as expected. If $\langle T(H) \rangle$ deviates from the daily average by more than the amount expected from $F_T(H)$, the value of $\langle T(H) \rangle$ is assumed to be valid and is left unchanged. To ensure consistency with adjusted hourly NCEP values, the daily NCEP average value $\langle T_{day} \rangle$ is recomputed from the adjusted hourly values after the hourly adjustment has been completed. Since the NCEP data is provided on pressure levels, the pressure data is also unchanged and the density is calculated from the gas law and corrected NCEP temperature.

The UDF for wind speed ($F_S(H)$) is used in a similar fashion to adjust surface wind statistics. For wind adjustment, $R(H)$ is the ratio $\langle S(H) \rangle / \langle S_{day} \rangle$, where $\langle S(H) \rangle$ is hourly average surface wind speed and $\langle S_{day} \rangle$ is daily average surface wind speed. Once an adjustment factor $F_S(H)/R(H)$ (other than 1) is determined, this factor is used to multiply both hourly average speed and standard deviation of speed, and to multiply hourly averages and standard deviations for both horizontal wind components. The factor F makes no adjustment to daily average wind statistics. These adjustments are made once to create a fixed NCEP database that is supplied with the GRAM software.

2.3.5 Example Results and Validation

Figure 5 compares the observed POR average, monthly average, hourly mean surface wind speed at the KSC. The POR for the observed data is similar to the POR for NCEP data

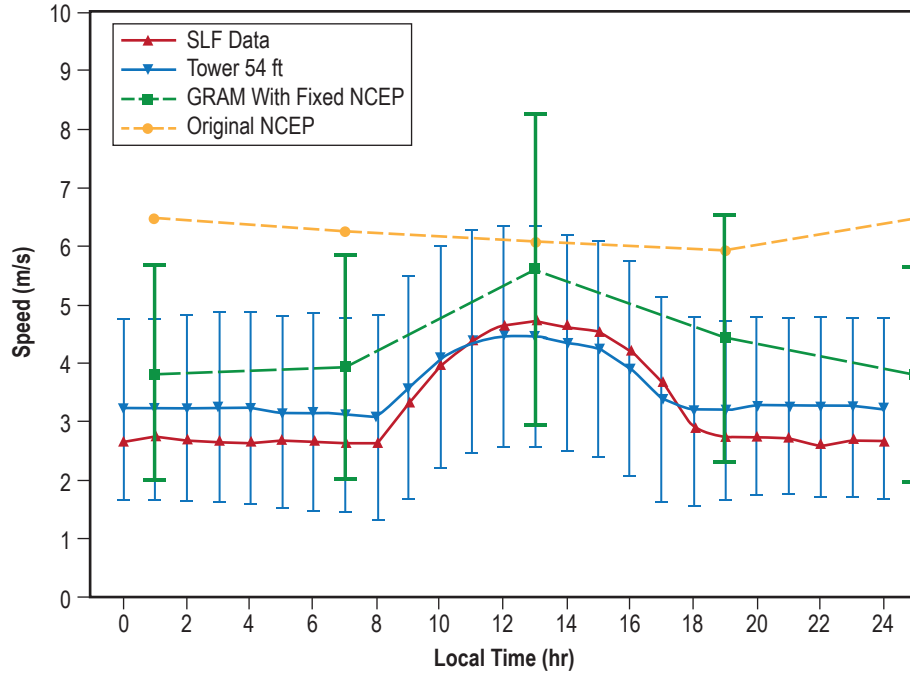


Figure 5. Observed diurnal variation of January hourly average surface wind speed at KSC.

(1990–2008). GRAM2010 output values for hourly average surface-wind speed and standard deviation at the four NCEP UTC times (expressed as local time at each site) are shown by the data points and ‘error bars’ connected by a dashed line. For the GRAM output, near-surface NCEP data were employed after having been ‘fixed’ by the procedure discussed in the previous section. For comparison, original NCEP data values are also shown.

Figure 5 shows that the ‘fixed’ NCEP surface winds have about the right amplitude of diurnal variation, but the NCEP daily average wind speed is somewhat larger than observed. This results from the fact that one of the four NCEP grid point locations surrounding KSC is a water-surface site (in the Atlantic Ocean). NCEP winds at this grid location are not adjusted downward, as are the winds at the other three (land-surface) NCEP grid locations surrounding KSC. Even after GRAM does horizontal interpolation to the lat-lon of KSC, GRAM output winds at KSC are still ‘contaminated’ somewhat by this nearby water-surface grid point. Users should realize that adjustment of the NCEP data (particularly the diurnal data) near the land surface is somewhat crude and may not be the best choice for their particular application. Alternative choices include site-specific data such as RRA data or site measurements that can be ingested into GRAM using an auxiliary profile (see app. B.9).

2.4 The Boundary Layer Model for Vertical Velocity

2.4.1 Background

A small-scale vertical wind perturbation model has been part of the GRAM since its 1995 release.⁶ Height-dependent standard deviations of vertical winds were taken from reference 28.

This vertical wind model continued in GRAM through the 1999 release⁸ and version 1.1 of the 2007 release.⁹ Recent strong interest in capsule parachute landing simulations led to including a vertical wind distribution as a function of horizontal wind and underlying surface characteristics (surface roughness). An earlier version vertical wind model, designed to address these issues, was released (in October 2008) as GRAM 2007 Version 1.2. That model incorporated many features of BL effects on vertical wind standard deviations. However, time-of-day effects were not addressed, atmospheric stability influence was represented in only an approximate fashion, and BL depth was assumed to be a constant value of 1,500 m. The revised vertical wind model discussed here, and being released in GRAM2010, incorporates effects of these additional factors. This new model computes standard deviation for BL vertical wind as a function of surface type (water or various land types), and surface horizontal wind (at 10-m height). Surface height (above MSL) is interpolated from the $1^\circ \times 1^\circ$ topographic database of reference 26 or from RRA surface altitude, if the GRAM RRA option is selected. Boundary layer depth is computed from a new time-of-day and stability-dependent model. Land cover type is given at 1° resolution from the database of reference 27.

Surface type codes are shown in table 1. Surface roughness (z_o) values assumed for each surface type were computed as the geometric mean value from a variety of sources and are also given in table 1. To account, in an approximate way, for the influence of mountainous topography on z_o , values from table 1 are increased linearly for surface altitudes above 1.5-km MSL up to either a maximum surface height of 4.5 km or to a maximum z_o of 3 m, whichever is appropriate. Surface wind dependence is based on hourly average wind speed computed from wind components given by monthly mean wind at 10 m plus GRAM large-scale perturbed wind components at the surface. Since GRAM large-scale wind perturbations change from profile-to-profile in a Monte-Carlo run, surface wind speed changes from profile-to-profile.

Table 1. Surface codes and associated z_o values.

Code	Land Cover Class	z_o (m)
0	Water	u-dependent
1	Broadleaf evergreen forest	0.6
2	Coniferous evergreen forest and woodland	0.48
3	High-latitude deciduous forest and woodland	0.42
4	Tundra	0.0056
5	Mixed coniferous forest and woodland	0.45
6	Wooded grassland	0.12
7	Grassland	0.046
8	Bare ground	0.015
9	Shrubs and bare ground	0.042
10	Cultivated crops	0.065
11	Broadleaf deciduous forest and woodland	0.45
12	Data unavailable (reassigned to codes 4, 6, or 13, as appropriate)	-. -
13	Ice	3.2×10^{-4}

While the surface roughness over land is determined from table 1, z_o over water is based on the formulation of Donelan et al. as,²⁹

$$z_o = \frac{\alpha u_*^2}{g}, \quad (6)$$

where g is the gravitational acceleration and u_* is the friction velocity. The codependence of z_o and u_* is solved by a four-step iteration process. There is also an option whereby the user may supply any desired z_o value (between 10^{-3} m and 3 m), to be used in place of these prescribed values.

Friction velocity is computed from the standard logarithmic law-of-the-wall for neutral atmospheric stability, modified by a stability-dependent term (ψ),

$$u_* = \frac{0.4U_{10}}{\ln\left(\frac{10}{z_o}\right) - \psi\left(\frac{10}{L}\right)}, \quad (7)$$

where U_{10} is the wind speed at 10-m height and L is the Monin-Obukhov length. The BL wind profile function is given by,

$$\begin{aligned} \psi(10/L) &= -50/L && \text{if } 1/L > 0 \quad (\text{stable}) \\ \psi(10/L) &= 0.0 && \text{if } 1/L = 0 \quad (\text{neutral}) \\ &= 1.0496(-10/L)^{0.4591} && \text{if } 1/L < 0 \quad (\text{unstable}). \end{aligned} \quad (8)$$

The unstable formulation for ψ is from reference 30 and is a simplification of an often used but more complicated expression derived by Paulson.³¹

The inverse of the Monin-Obukhov length ($1/L$) is calculated by a four-step process, based on information derived from table 4-7, table 4-8, and figure 4-9 of reference 32. First, a net radiation index (n_r) is computed that depends on solar elevation angle and time-of day (or night), where n_r ranges from -3.5 (strong outgoing net radiation) to $+4.5$ (strong incoming net radiation). See table 4-7 in reference 32. Then a wind-speed factor $W(U_{10})$ is computed from empirically derived functions,

$$\begin{aligned} W(U_{10}) &= (1 - U_{10}/7.5) && \text{if } U_{10} < 6 \text{ m/s} \\ W(U_{10}) &= 0.2 && \text{if } U_{10} = 6 \text{ m/s} \\ &= 0.2 \text{Exp}(12 - 2U_{10}) && \text{if } U_{10} > 6 \text{ m/s}. \end{aligned} \quad (9)$$

A stability category ξ is computed as a function of $W(U_{10})$ and n_r by,

$$\xi = 4.229 - n_r W, \quad (10)$$

which is an empirical fit to table 4-7 in reference 32. Values of ξ are limited to 0.5 on the low side (most unstable) and 7.5 on the high side (most stable). Finally, the inverse Monin-Obukhov length versus stability category ξ and surface roughness length is determined using,

$$1/L = (1/4)(-0.2161 + 0.0511\xi) \text{Log}_{10}(10/z_o), \quad (11)$$

which is an empirical fit to figure 4-9 of reference 32. These steps are similar to the methodology of Blackadar et al. for the estimation of L .³³

The standard deviation of vertical wind is now computed as a function of height above the surface and stability dependent Monin-Obukhov length by,

$$\begin{aligned} \sigma_w &= 1.25u_* \left(1 + 0.2 z/L\right) && \text{(stable: } 1/L > 0) \\ \sigma_w &= 1.25u_* && \text{(neutral: } 1/L = 0) \\ \sigma_w &= 1.25u_* \left(1 - 3z/L\right)^{1/3} && \text{(unstable: } 1/L < 0), \end{aligned} \quad (12)$$

where the stable relation is from equation 1.33 of reference 34 and also found in reference 35, and the unstable relation is from equation (2) on page 161 of reference 36, a relation which has been widely used to represent this factor for the unstable atmospheric surface layer.^{34, 37-39} A variety of different formulations for σ_w in stable situations has been suggested, including a formula equivalent to the unstable relation in equation (12) (e.g., eq. (8) and table 1 of ref. 40). However, a simple linear relationship for the stable case, such as given in equation (12), has been more widely used.

As shown by references 41 and 42 and in the discussion of figure 7.2 of reference 36, equation (12) is not expected to apply above about $z = 0.1d$, where d is the BL depth. Therefore, for stable and neutral cases, σ_w is limited to a value of $3.75u_*$, while for unstable cases, σ_w is limited by the magnitude of the convective velocity w_* to a value of $\sigma_w < 0.62w_*$, where w_* is given by,

$$w_* = u_* \left[-d / (0.4L)\right]^{1/3}, \quad (13)$$

(eq. (4) of ref. 41). These limiting values account for transition from the surface layer to the convective layer ($z/L < 0$) or to the stable BL ($z/L > 0$).

The BL depth d is calculated from simplifications of methodologies given by references 43, 44, and 45. For stable-to-neutral cases, the methodology of section 2.1 of reference 43 is used.

$$d = 2d_N / \left[1 + \left(1 + 4d_N / L\right)^{1/2}\right], \quad (14)$$

except that their form for the neutral BL depth (d_N) is changed from,

$$d_N = 0.2u_* / f, \quad (15)$$

to,

$$d_N = u_* \left[80 / (\omega^2 f) \right]^{1/3}, \quad (16)$$

where f is the coriolis parameter and ω is the Brunt-Vaisala frequency.

For the unstable BL, the time-dependent differential equation solution in reference 44, as expressed in reference 45, is converted to an algebraic equation by assuming that the time rate of change of d can be replaced by $df/2$. This operation yields an analytical equation for d ,

$$d = d_N \left(1 - 0.1125d / L \right)^{1/3}, \quad (17)$$

whose solution can be found by iteration.

For time variation between sunrise (if applicable) and midday, a time-factor multiplier $G(E_l)$, given by,

$$G(E_l) = 0.3 + 0.7 E_l / E_{md}, \quad (18)$$

is applied, where E_l is solar elevation at the current time and E_{md} is midday solar elevation. This allows for time variation of d to be accounted for in an analytical fashion rather than the solution of a differential equation versus time.

Subject to the limiting values mentioned above, the height-dependent equations (12) are used to compute σ_w from the surface to the top of the BL. As part of its original vertical wind model, GRAM contains values of σ_w at 5-km intervals (above MSL). Between the top of the BL and the next height for which σ_w is available, linear interpolation is used to estimate σ_w .

Calculation of the vertical wind perturbations in GRAM is not changed, only the methodology for computing standard deviation of vertical wind. Values of σ_w are constrained to be 0.1 m/s or greater, since the perturbation calculation methodology does not work properly if σ_w is 0. Calculation of mean vertical winds (typically a few cm/s or less) is still done by a Montgomery stream function approach, first implemented in GRAM-90 (sec. 2.7 of ref. 5), and the perturbations are determined from a 1-step Markov algorithm.

2.4.2 Example Model Output

The above equations are used to compute standard deviation of vertical wind as a function of height above the surface, the surface roughness, and the surface wind speed. These have been implemented as the revised vertical wind model in GRAM2010. In this model, values of U_{10} are computed from wind components given by GRAM lat-lon-dependent monthly mean wind at 10-m height, plus GRAM large-scale perturbed wind components at the surface. For each randomly selected wind profile in a Monte-Carlo simulation sequence, different large-scale wind perturbations are produced, so U_{10} values used in the σ_w model vary from profile to profile.

Table 2 provides statistics for σ_w , computed from 600+ profile Monte Carlo runs of GRAM2010 at three different BL altitudes above the surface and at a variety of sites for specific months. Sites examined include EAFB (low surface roughness, $z_o = 0.04$ m), KSC land surface (moderate surface roughness, $z_o = 0.45$ m), KSC water surface, and ocean sites near San Clemente and in the North Atlantic (latitude 50° N. longitude 30° W.).

Table 2. Sample output statistics for vertical wind standard deviation (m/s) from GRAM2010.

	KSC Feb Land			KSC June Land		
Height (m)	10	100	1,000	10	100	1,000
Average	0.60	0.87	1.05	0.45	0.71	0.85
Std.Dev.	0.25	0.38	0.49	0.21	0.42	0.54
Minimum	0.10	0.10	0.19	0.10	0.10	0.19
Maximum	1.29	1.75	2.38	1.10	1.92	2.69
	KSC Feb Water			EAFB Feb		
Height (m)	10	100	1,000	10	100	1,000
Average	0.16	0.26	0.33	0.37	0.50	0.57
Std.Dev.	0.06	0.11	0.10	0.20	0.25	0.24
Minimum	0.10	0.10	0.19	0.10	0.10	0.20
Maximum	0.36	0.57	0.57	0.85	1.11	1.23
	San Clemente Feb Water			North Atlantic Ocean Feb		
Height (m)	10	100	1,000	10	100	1,000
Average	0.26	0.31	0.37	0.59	0.61	0.63
Std.Dev.	0.12	0.12	0.10	0.32	0.30	0.28
Minimum	0.10	0.10	0.19	0.10	0.10	0.19
Maximum	0.58	0.58	0.58	1.79	1.79	1.79

As expected from equation (12), the average σ_w in table 2 increases with height at all sites. The increase in z_o from EAFB to KSC land surface produces a significant increase in σ_w . A change from KSC land surface to KSC water surface, with resultant decrease in z_o (by eq. (6)), causes a significant decrease in σ_w . With similar statistics for surface wind speed, KSC water results and San Clemente values are fairly similar. However, because of substantially higher surface wind speeds at the North Atlantic site, there is a substantial increase in σ_w over values for KSC (water) or San Clemente. Effects of stability are illustrated by comparison of σ_w values from KSC February with KSC June. Lighter winds (hence smaller u_* values) in June make both the average σ_w and the range of variability of σ_w at 10-m height smaller for June than for February. While the average σ_w for June at KSC remains lower at all altitudes, effects of convection under more prevalent unstable conditions in June make the range of σ_w larger in June than in February, at both 100-m and 1,000-m altitudes.

2.4.3 Boundary Layer Model Validation

Vertical winds are roughly an order of magnitude smaller than horizontal winds and are correspondingly roughly an order of magnitude more difficult (and more expensive) to measure than horizontal winds. Consequently, availability of vertical wind measurements for model validation is fairly limited. For example, despite extensive meteorological instrumentation at KSC, vertical winds are not routinely measured. However, a limited amount of KSC vertical wind data, discussed below, provides some degree of model validation. The surface roughness value ($z_o = 0.45$ m) used for KSC land surface results in table 2, comes directly from the GRAM $1^\circ \times 1^\circ$ global database (discussed above). Nevertheless, this value is in good agreement with average z_o values at KSC determined from wind profile analysis using the NASA 150-m meteorological tower.^{33,46}

In 1992 and 1993, the KSC Applied Meteorology Unit (AMU) used a doppler and sound detection and ranging (SODAR) instrument (called a MiniSODAR™) to study horizontal and vertical winds near Space Launch Complex (SLC) 37 (SLC-37) at KSC.⁴⁷ They report (in ref. 47 fig. 14) that vertical wind standard deviation during June 17–30 reached a diurnal peak of 0.57 m/s at about 1800 hrs local time, at an altitude of 60 m. This MiniSODAR value is noticeably less than the maximum KSC σ_w between 10-m and 100-m altitude from table 2 for both February and June. Part of this discrepancy may be due to the limited sampling period (June 17–30) used by the AMU. It is also possible that the vertical winds are underestimated by the SODAR instrument, since the AMU report notes “...an underspecification of vertical velocity variations by the phased array scanning sequence and the mathematical form of retrieval algorithms required for estimating peak wind speeds.” This is referred to elsewhere in the report as a problem with “...undersampling of the vertical wind velocity over the profiler beams.”⁴⁷

High-resolution tracking of balloon trajectories has also been used to estimate vertical winds near KSC. Rider and Armendariz measured σ_w at KSC from high-resolution tracking of 37 wintertime and 10 summertime Jimsphere flights.⁴⁸ At altitudes between 100 and 1,200 m, this study found that “vertical wind components ranged from 10–25 cm/s in a stable atmosphere to 55–100 cm/s under unstable conditions, depending on wind speed.” A maximum vertical wind of 100 cm/s agrees fairly well with values at KSC (land surface) from table 2. Record et al., measured σ_w at KSC from high-resolution tracking of 10 overland and 5 overwater tetron flights.⁴⁹ This study found (in their table 2-3) that in four of the overland cases (40% of observations) 10-min average σ_w values exceeded 1 m/s, and that one of the five overwater cases had a 10-min average σ_w of 0.97 m/s, also in fairly good agreement with values from table 2 of this TM.

Blackadar, et al., examined wind profiles observed from the KSC 150-m tower and used observed mean speed at $z = 18$ m (U_{18}) and BL theory to estimate surface roughness and surface friction velocity.³³ Although estimates of the standard deviations of the horizontal wind components are given, there are no direct measurements or estimates for σ_w . However, Blackadar’s table 3 gives u_* values from which approximate values for σ_w can be calculated by $\sigma_w = \text{Factor}(z/L)u_*$ (e.g., as in equation (12)). Blackadar et al., give values of Richardson number (R_i) from which values of z/L can be calculated, namely (from their eq. (18) and (19)),³³

$$\begin{aligned}
z/L &= R_i && \text{(unstable conditions)} \\
&= 5R_i / (1 - 5R_i) && \text{(stable conditions)}.
\end{aligned} \tag{19}$$

Table 3 gives a statistical summary computed from data given by Blackadar et al., for cases having estimated u_* values.³³ Both estimated average σ_w and maximum σ_w from this table are somewhat larger than the GRAM-estimated values from table 2 for heights up to 100 m. The fact that estimates of σ_w at KSC range from less than to greater than values given from GRAM estimates in table 2 is taken as an indication that the new GRAM vertical wind model is at least approximately correct, within the constraints and limitations of the present model.

Table 3. Summary of KSC vertical wind estimates from data in table 3 of reference 33.

	U_{10} , m/s	z_0 , m	u_* , m/s	Factor(z/L)	σ_w (m/s) = Factor(z/L) $\times u_*$
Avg	4.88	0.46	0.67	1.58	1.04
Std. Dev	2.47	0.17	0.28	0.32	0.41
Min	1.40	0.27	0.20	1.25	0.27
Max	11.70	0.79	1.47	2.79	2.36

2.5 Water Vapor and Other Atmospheric Species Concentrations

Water vapor and other atmospheric species concentrations were introduced in GRAM-95, with values above 90 km from the MET model and via a new species concentration database discussed in section 4.3 of reference 6. Water vapor output from GRAM includes both monthly means and standard deviations. The H_2O values vary with month, height, latitude, and longitude.

Means and standard deviations in H_2O are represented in the form of vapor pressure (N/m^2), vapor density (kg/m^3), dewpoint temperature (K), and RH (%). Mean H_2O values in the form of volume concentration (ppmv) and number density ($molecules/m^3$) are also output. Only monthly mean concentration values are output for the species, other than H_2O , and in the form of volume concentration and number density.

Interpolation of the dewpoint temperature for altitudes between the input pressure levels and for latitude and longitude between the input grid points is handled the same as the other variables. Height and latitude interpolation between input height-latitude grid points for H_2O above the 10-mb level, and for the other species, is done by an adaptation of the two-dimensional interpolation discussed in the next section (to do height-latitude interpolation rather than lat-lon interpolation).

Species concentrations $c(t)$ are assumed to change with year t according to the relation,

$$c(t) = c(t_0) (1 + r_t)^{t-t_0}, \tag{20}$$

where t_0 is 1976 (the initial time) for the AFGL data and 1981 for the MAP concentration data and the concentration rate of change (r_i) is 0.005 for CO₂, 0.009 for CH₄, 0.007 for CO, and 0.003 for N₂O. For O₃, r_i varies linearly from 0.003 at the surface to 0 at 15 km, linearly from 0 at 30 km to -0.005 at 40 km, and again linearly from -0.005 to 0 at 120 km. The rate of change, r_i , for H₂O and the other constituents is assumed to be 0.

2.6 Interpolation and Fairing Techniques

2.6.1 Vertical Interpolation

Pressure ($p(z)$), temperature ($T(z)$), and density ($\rho(z)$) obey the perfect gas law,

$$p = \rho RT, \quad (21)$$

where R is the gas constant. They also agree very closely with the hydrostatic assumption,

$$dp/dz = -\rho g, \quad (22)$$

where g is the acceleration of gravity. If there exists grid-point pressure values p_1 and p_2 and temperature values T_1 and T_2 at heights z_1 and z_2 , then vertical interpolation to any height z (between z_1 and z_2) is done by assuming a linear temperature variation,

$$T(z) = T_1 + \gamma (z - z_1), \quad (23)$$

where γ is the temperature gradient,

$$\gamma = (T_2 - T_1) / (z_2 - z_1). \quad (24)$$

The hydrostatic relation with a constant γ implies a power-law variation with pressure. Therefore, $p(z)$ may be computed by,

$$p(z) = p_1 \left[T(z) / T_1 \right]^{-a}, \quad (25)$$

where the exponent a is given by,

$$a = g / (R\gamma). \quad (26)$$

In the NCEP height range, this vertical interpolation is complicated by the fact that the moisture varies with height and the gas constant for moist air depends on the moisture concentration. For the NCEP data, a variant of equation (25) uses an interpolated gas constant R .

The exponent a can be evaluated using two levels where temperature and pressure are known,

$$a = \log(p_2/p_1)/\log(T_1/T_2). \quad (27)$$

For an isothermal layer where $T_1 = T_2$, equation (25) becomes

$$p(z) = p_1 \exp\left[\frac{-g(z - z_1)}{RT_1}\right]. \quad (28)$$

The density, $\rho(z)$, is found by solving the perfect gas law relation (eq. (21)).

The form of vertical interpolation given by equation (25) is used to fill in mean values of pressure, density, and temperature between the input pressure levels of the NCEP data (with z the geopotential height) and the zonal mean values between the input height grids of the MAP database. Other variables that do not obey perfect gas law relationships (e.g., wind components, dewpoint temperature, and all standard deviations) are interpolated linearly in the vertical.

2.6.2 Two-Dimensional Interpolation

Let V be a variable that is available on a two-dimensional grid array (x and y) and consider the grid point values $V_{11} = V(x_1, y_1)$, $V_{12} = V(x_1, y_2)$, $V_{21} = V(x_2, y_1)$ and $V_{22} = V(x_2, y_2)$. Then any value $V(x, y)$ (for x between x_1 and x_2 and y between y_1 and y_2) may be found by the interpolation scheme,

$$V(x, y) = \alpha' \beta' V_{11} + \alpha' \beta V_{12} + \alpha \beta' V_{21} + \alpha \beta V_{22}, \quad (29)$$

where $\alpha = (x - x_1)/(x_2 - x_1)$, $\alpha' = 1 - \alpha$, $\beta = (y - y_1)/(y_2 - y_1)$, and $\beta' = 1 - \beta$. This interpolation relation is mathematically equivalent to that used (for lat-lon interpolation) in earlier GRAM versions but is expressed here in a more symmetric notation.

Equation (29) is used to interpolate between lat-lon grid points (x = longitude and y = latitude) for the NCEP grids and the stationary perturbation grids of the MAP data. For variables dependent on a height-latitude (or a pressure-latitude) grid (such as the species concentration data), then equation (29) is used with y = latitude and x = height (or x = log pressure). The variables actually interpolated for concentration data are the logarithms of the concentration values.

2.6.3 Interpolation Across the Poles

Several GRAM height-latitude dependent databases lack values at or near the poles. These are filled in by an interpolation procedure that assumes a parabolic variation (across both sides of the pole) that fits the last and next-to-last available latitudes. The results are a weighted average of these last and next-to-last latitude values. For example, if values of a parameter are available at $\pm 70^\circ$ and $\pm 80^\circ$, but not at $\pm 90^\circ$, then the missing polar values are supplied by,

$$y_{\pm 90} = (4y_{\pm 80} - y_{\pm 70})/3. \quad (30)$$

If values are available at $\pm 60^\circ$ and $\pm 70^\circ$ but not at $\pm 80^\circ$ or $\pm 90^\circ$, then the missing values are supplied by,

$$y_{\pm 90} = (9y_{\pm 70} - 4y_{\pm 60})/5, \quad (31)$$

and

$$y_{\pm 80} = (8y_{\pm 70} - 3y_{\pm 60})/5. \quad (32)$$

For the species concentration data, this interpolation is done on the logarithm of the concentration values.

2.6.4 Fairing Between Two Data Sets

If we have two data sets, $A(z)$ and $B(z)$, that overlap throughout the height range from z_1 to z_2 (with A valid below z_2 , B valid above z_1 , and $z_2 > z_1$), then a fairing process,

$$C(z) = f(z)A(z) + [1 - f(z)]B(z), \quad (33)$$

ensures a smooth transition for the faired variable C across the height interval from z_1 to z_2 if $f(z_1) = 1$ and $f(z_2) = 0$. Thus, $A(z)$ is used below z_1 , $B(z)$ above z_2 , and the faired variable, $C(z)$ varies smoothly between $A(z)$ and $B(z)$ as z varies from z_1 to z_2 . A linear form is used for f ,

$$f(z) = (z_2 - z)/(z_2 - z_1), \quad (34)$$

or, with variables for which continuity of vertical derivatives is important, f is taken as,

$$f(z) = \cos^2[(\pi/2)(z - z_1)/(z_2 - z_1)]. \quad (35)$$

Equation (35) is used in fairing between the NCEP and MAP data between 20 and 27 km, between the thermosphere model and MAP data between 90 and 120 km, and the helium number density in the MET model between 440 and 500 km. For fairing the species concentration data, equation (34) is used with the logarithm of the species concentration as the variable to fair.

2.6.5 Seasonal and Monthly Interpolation

Some of the species concentration databases do not contain monthly data. For example, the AFGL concentrations are seasonal averages (summer and winter), the LaRC H_2O data have four seasonal averages, and the MAP H_2O data have only certain months of the year (November through May). The initialization routines in GRAM use an annual harmonic temporal variation model to estimate the concentration data for the specific month to be simulated. For the AFGL data, this is accomplished by applying precomputed weights to obtain a weighted average of the summer and winter values used to estimate the value for the specific month. For the LaRC H_2O data, a weighted average of the two adjacent seasonal values is used to estimate the monthly value

(i.e., Mar–April–May and Jun–July–August values are used to estimate the monthly values for May and June with different weights applied for month). For the MAP H₂O data, a combination of annual harmonic Fourier fit and 6-month displacement from northern to southern hemisphere (and vice-versa) is used at initialization to establish the global values for each month from the monthly values of November through May in the database.

2.7 The Perturbation Model

2.7.1 Small Scale Perturbation Model

GRAM2010 uses a simple, first-order, autoregressive model to compute a perturbation at each new position from the correlated perturbation value at the previous position. In addition to maintaining the correlation necessary between these successive perturbation values, the model accounts for the effects of variation in the mean values and the standard deviation from one position to another. Consider a normalized variate $\mu(\mathbf{x})$ (i.e., μ is the deviation of the value from the mean value divided by the standard deviation, all at the vector position \mathbf{x}). The perturbation model computes $\mu(\mathbf{x}')$ at the next trajectory position \mathbf{x}' ,

$$\mu(\mathbf{x}') = r\mu(\mathbf{x}) + (1 - r^2)^{1/2} q(\mathbf{x}), \quad (36)$$

where q is a Gaussian-distributed random number with a mean of 0 and standard deviation of 1, and r is the autocorrelation between the successive values of the normalized variate,

$$r = \langle \mu(\mathbf{x}') \mu(\mathbf{x}) \rangle, \quad (37)$$

where the angle brackets denote an average. The autocorrelation value (r) is obviously a function of the vector displacement, $\delta\mathbf{x} = \mathbf{x}' - \mathbf{x}$.

Consider two normalized variates, $\mu(\mathbf{x})$ and $v(\mathbf{x})$ (each relative to its own mean value and each normalized by its own standard deviation) that have a cross-correlation (r_c) between them (i.e., $r_c = \langle \mu(\mathbf{x}) v(\mathbf{x}) \rangle$). Variate $v(\mathbf{x}')$ at the new position is computed from $v(\mathbf{x})$ and $\mu(\mathbf{x}')$ by,

$$v(\mathbf{x}') = r_v v(\mathbf{x}) + r_\mu \mu(\mathbf{x}') + r_q q(\mathbf{x}), \quad (38)$$

where the coefficients are given by,

$$r_v = r(1 - r_c^2) / [1 - (rr_c)^2], \quad (39)$$

$$r_\mu = r_c(1 - r^2) / [1 - (rr_c)^2], \quad (40)$$

and

$$r_q = \left(1 - r_v^2 - r_\mu^2 - 2r_v r_\mu r_c r\right)^{1/2}. \quad (41)$$

Values of r are computed by assuming an exponential correlation function,

$$r(\delta\mathbf{x}) = \exp(-\delta h/L_h) \exp(-\delta z/L_z) \exp(-\delta t/\tau), \quad (42)$$

where δh and δz are the magnitudes of the horizontal and vertical components of $\delta\mathbf{x} = \mathbf{x}' - \mathbf{x}$ and L_h and L_z are horizontal and vertical scale parameters that are functions of height and latitude only. Time correlation (even in the special case when the user selects $\delta h = 0$ and $\delta z = 0$) is accounted for by the third exponential term in equation (42), where τ is a time scale that varies with height and δt is the magnitude of the time step between data points.

GRAM2010 computes the density and vertical velocity perturbations using only autocorrelation (using a form of equation (36) with the correlation coefficient from equation (42)). Pressure perturbations are computed with cross-correlation to density (using a form of equation (38), correlation coefficients from equations (39)–(42), and a Buell^{50,51} formulation for the pressure-density correlation). The temperature perturbation is computed from a first order version of the ideal gas law and Buell relations. The horizontal wind perturbations are also cross-correlated with density with the wind-density correlation given in the ‘atmosdat’ data file (see sec. 4.3). For additional discussion of the perturbation model, see sections 2.6 and 2.7 of reference 6.

Generation of GRAM perturbations starts with the observed (climatological) values of total standard deviation of observations about the monthly mean. Total variance (square of the standard deviation) is partitioned into variance contributed by two perturbation components: (1) A large-scale, wave-like perturbation and (2) a small-scale, stochastic (random) perturbation.

Vertical shears from the large-scale, wave-like perturbations in GRAM are proportional to A/λ , where A is the local wave amplitude and λ is the local vertical wavelength. Vertical shears from the small-scale, stochastic perturbations in GRAM are proportional to σ/L , where σ is the local standard deviation of the small-scale perturbations, and L is the local vertical correlation scale for the small-scale perturbations. An increase in vertical wavelength λ therefore yields smaller vertical shears from the large-scale, wave-like perturbations. A height-dependent factor on vertical and horizontal correlation scales increases L below ≈ 15 km, while decreasing L above ≈ 15 km. This effect decreases (increases) small-scale shears at heights below (above) 15 km, while leaving small-scale shears above 30 km unchanged. The addition of time dependence for the large-scale perturbations allows GRAM to simulate synoptic-scale variations in time and space.

2.7.2 Patchy Severe Turbulence

In order to approximate intermittency (‘patchiness’) in the perturbations, a variable scale model was introduced in GRAM-95 (sec. 2.6 of ref. 6) and also used in GRAM2010. The GRAM database (‘atmosdat’ data file described in sec. 4.3) includes (for both horizontal and vertical scales) values for average scale size (L_{avg}), minimum scale size (L_{min}), and standard deviation of the variable scale size (σ_L). Periods of ‘severe’ perturbations are characterized as having a scale size of L_{min} .

In the perturbation model, ‘nonsevere’ (i.e., light-to-moderate) perturbations are characterized as having a scale size of L_{max} , such that,

$$L_{avg} = P_{sev}L_{min} + (1 - P_{sev})L_{max} , \quad (43)$$

where P_{sev} is the probability of encountering severe perturbations given by,

$$P_{sev} = P_{tail} \left(\left(L_{avg} - L_{min} \right) / \sigma_L \right) . \quad (44)$$

where P_{tail} is the tail probability of a Gaussian distribution. From equation (43) the scale for nonsevere perturbations is given by,

$$L_{max} = \left(L_{avg} - P_{sev}L_{min} \right) / (1 - P_{sev}) . \quad (45)$$

When in severe turbulence, the length scales used in equation (42) are the minimum length scale read in (and height interpolated) from the ‘atmosdat’ file. When in nonsevere turbulence, the length scales in equation (42) are the maximum value computed from equation (45). The triggering of severe turbulence occurs by tracking an artificial horizontal scale that is autocorrelated (using a form of eq. (36)) and an artificial vertical scale that is cross-correlated with the horizontal scale (using a form of eq. (38)). If either of these scales goes below a minimum value, severe turbulence is initiated.

Furthermore, the variance of the severe perturbations is assumed to be $f_{sev} \sigma^2$, and the variance of the nonsevere perturbations is assumed to be $f_{non} \sigma^2$, where σ^2 is the total variance of the small-scale perturbations (σ , the standard deviation of the small-scale perturbations is also given in the ‘atmosdat’ file data). Considering the probability of occurrence, σ^2 is given by,

$$\sigma^2 = P_{sev}f_{sev}\sigma^2 + (1 - P_{sev})f_{non}\sigma^2 . \quad (46)$$

From standard deviation data in reference 27, the factor f_{sev} is approximated as varying with height z , having values ranging from 6 at $z = 0$ km to 12 at $z = 10$ km and back to 6 at $z = 16$ km (and higher). With f_{sev} thus specified, f_{non} is calculated from equation (46) by,

$$f_{non} = (1 - f_{sev}P_{sev}) / (1 - P_{sev}) . \quad (47)$$

As GRAM simulates perturbations along a given trajectory, it uses a random number generator to decide when (with probability P_{sev}) the perturbations are in the severe category. During this time, the variance is adjusted from its nonsevere magnitude ($f_{non}\sigma^2$) to its severe magnitude ($f_{sev}\sigma^2$). Patchy severe turbulence is applied only to the small-scale perturbations and not the large-scale perturbations and is enabled only when the parameter *patchy* (in the input file) has a nonzero value.

2.7.3 The Large-Scale Perturbation Model

While the small-scale perturbations are modeled using a stochastic process that is approximately Gaussian distributed, the large-scale perturbations are modeled with a sinusoidal formulation to represent the atmospheric wave phenomena observed at this scale. The large-scale density (again normalized by its mean value) is given by,

$$\frac{\rho_l}{\sigma_{\rho_l}} = A_Q \frac{\cos\left(n\theta + m\phi + 2\pi \frac{z}{\lambda_z} + 2\pi \frac{t}{T} + \phi_q\right)}{\sigma_{\cos}}, \quad (48)$$

where ρ_l is the large-scale density, σ_{ρ_l} is the large-scale standard deviation, A_Q is an amplification factor, m is the number of waves in the north-south direction, n is the number of waves in the east-west direction, z is height, λ_z is the vertical wavelength, t is the elapsed time, T is a randomized wave period, ϕ_q is a random wave phase, and σ_{\cos} is the standard deviation of the cosine function and equal to $1/\sqrt{2}$. A_Q was added to this model in GRAM in order to provide exceedances beyond $\sqrt{2}$ sigma that would otherwise not occur. A_Q was determined empirically (but constrained so that the standard deviation of density is unchanged) as,

$$A_Q = 0.4808 + 0.96 \cdot Q, \quad (49)$$

where Q is a uniformly distributed random number between 0 and 1. Therefore A_Q varies from 0.4808 to 1.4408 and thus allows for 2 sigma exceedances. The same value is used for both horizontal wave numbers n and m . They are determined randomly for a given Monte-Carlo run from

$$m = n = \text{IntegerOf}\left[4.0 + 0.833 \cdot Q_{nm}\right], \quad (50)$$

where Q_{nm} is a Gaussian-distributed random number with a mean of 0 and sigma of 1. This formulation is derived so that the horizontal wave numbers are between two and six waves. The vertical wavelength λ_z is computed as a function of height with parameters a_v (which is randomized) and b_v which is equal to 0.045,

$$\lambda_z = a_v + b_v \sqrt{|z^3|}. \quad (51)$$

The large-scale pressure is similarly calculated except that an additional phase term is added to the cosine argument so that pressure and density are properly correlated. The large-scale temperature is then calculated from the Buell relation and rescaled so that it reproduces the observed variance. The large-scale horizontal wind components are also modeled with a cosine function and a phase shift is used for proper correlation. This correlation is taken from the RRA data or the NCEP data as appropriate. There is no model for large-scale vertical velocity, only small-scale values and mean (Montgomery stream function) values. Once the small- and large-scale perturbations are determined, they are added to the mean for the total atmospheric value.

2.8 Perturbation Model Initialization

Initial values for the perturbation model may be selected by user input, as described in the next section, or they may be random values, automatically selected by the program, as described here. Because large-scale perturbations (sec. 2.7.3) are wave-like and small-scale perturbations (sec. 2.7.1) are Gaussian-distributed random values, two different processes are used for their initialization.

2.8.1 Small-Scale Perturbations

Initial values for small-scale perturbations in all three components of wind and in density and pressure are selected randomly from Gaussian distributions having the appropriate standard deviation for each of these quantities (at the initial position to be simulated). The first-order perfect gas law from the initial small-scale pressure and density perturbations is then used to compute the initial small-scale temperature perturbation. This initial small-scale temperature perturbation is then rescaled so that it reproduces the appropriate small-scale temperature variance.

2.8.2 Large-Scale Perturbations

Initial values for large-scale perturbations are computed from a randomly selected-wave amplitude (A_Q in eq. (48)) and a randomly selected phase for density perturbation (ϕ_q in eq. (48)). Phases for other large-scale perturbations are selected to produce appropriate phase differences among all the large-scale perturbations. Once these initial wave phase values have been selected for a particular program run, variations of wave phases progress in time and space according to prescribed wave numbers and period (n , m , and T in eq. (48)).

Initial density wave phase ϕ_q is randomly selected from a uniform distribution with values ranging between 0 and 2π . Wave phase for pressure is shifted by an amount required to yield appropriate pressure-density cross-correlation, and wave phase for large-scale perturbation in an eastward wind is shifted by an amount required to yield appropriate density-velocity correlation. Wave phase difference between northward and eastward wind components is selected to produce observed amount of cross-correlation (R_{uv}) between these components. Note that R_{uv} is observed cross-correlation between total (large- plus small-scale) perturbations. Required phase shift for the large-scale northward component is computed from $R_{uv}/(0.02 + 0.98f_L)$, where f_L is the large-scale fractional variance (0–1) discussed in section 4.3.4.

The first-order perfect gas law is used to compute the initial large-scale temperature perturbation from the initial large-scale pressure and density perturbations. This initial large-scale temperature perturbation is then rescaled so that it reproduces the appropriate large-scale temperature variance. Finally, large-scale pressure perturbation is recomputed from the second-order perfect gas law.

2.9 Optional User-Selected Initial Perturbations

Like the previous version of GRAM, GRAM2010 allows, as a user-controlled option, the input of user-selected initial perturbation values. This option is controlled by the input parameter, *initpert*. When *initpert* = 0 (the default value), then GRAM selects the random initial values. When *initpert* = 1, the user selects values for the initial perturbations.

The following is an example application for user-selected initial perturbations.

Suppose a measured profile (e.g., a day-of-launch atmospheric sounding) is to be used as an actual (perturbed) profile to the highest measured altitude and a GRAM perturbed profile (or profiles) is desired for higher altitudes. Actual atmospheric values from a measured profile are used to compute perturbed values to initialize GRAM (by methods discussed more fully in the next paragraph). With these initial perturbation values, GRAM perturbed profile(s) for the higher altitude region have complete continuity with the measured profile from the lower altitude region.

In this example, suppose the measured profile extends to an altitude of 25 km. Also suppose the measured values at 25 km are density = 0.044 kg/m³ and eastward wind = 14 m/s (along with other measured values). To use the user-selected initial perturbation option, first perform a GRAM run starting at 25 km in this example with the same latitude, longitude, and month as the measured profile. Suppose this GRAM run gives a mean density of 0.04 kg/m³ and mean eastward wind of 20 m/s. The values of user-selected initial density and eastward wind perturbations to use in subsequent GRAM runs are as follows:

- Initial density perturbation (%) = $100 \times (\text{measured density} - \text{GRAM mean}) / \text{GRAM mean}$
= $100 \times (0.044 - 0.04) / 0.04 = 10(\%)$.
- Initial east-west wind perturbation (m/s) = measured eastward wind – GRAM mean eastward wind = 14 m/s – 20 m/s = –6 m/s.

Similar calculations apply to the density, temperature, and other wind components. The pressure perturbation is calculated internally from the density and temperature perturbations.

For subsequent GRAM runs (in this example), start at 25 km using *initpert* = 1, *rdinit* = 10, and *ruinit* = –6 (and whatever values apply to the other initial perturbation components). These values ensure that the highest altitude (25 km) data point in the measured profile is consistent with the starting value (at 25 km) of the perturbed profile from GRAM. If multiple perturbed profiles are desired for a Monte Carlo application, each is initialized with the same values (*rdinit* = 10, *ruinit* = –6, etc.).

2.10 Optional Range Reference Atmosphere Data

An option exists to use data (in the form of vertical profiles) from a set of RRA as an alternate to the usual GRAM climatology at a set of RRA site locations. With this feature for example, it is possible to simulate a flight profile that takes off from the location of one RRA site

(e.g., EAFB, using the EAFB RRA atmospheric data) to smoothly transition into an atmosphere characterized by the GRAM climatology, then smoothly transition into an atmosphere characterized by a different RRA site (e.g., White Sands, NM) to be used as the landing site in the simulation.

RRA data include information on both monthly means and standard deviations of the various parameters at the RRA site (see description below). Under the RRA option, when a given trajectory point is sufficiently close to an RRA site (lat-lon radius from site less than *sitenear*, see below), the mean RRA data replace the mean values of the conventional GRAM climatology, and the RRA standard deviations replace the conventional GRAM standard deviations in the perturbation model computations. In Earth-GRAM 2007, a feature was introduced to replace GRAM surface data with surface data from the appropriate RRA site when the RRA option is used.

A total of 21 sites are available for 2006 RRA data (1983 RRA data available in Earth-GRAM 2007 are no longer provided for Earth-GRAM 2010). After discovery of an error in standard deviations of pressure and density in RRA data from the Roosevelt Roads Puerto Rico site (code *rrd*), data from this RRA site are no longer included. The 2006 RRA data POR varies from site to site, but is generally 1990–2002. Exceptions are El Paso (1990–1995), Great Falls (1990–1994), Taguac (1990–1999), China Lake (1948–2000), and White Sands (1949–1993). El Paso RRA data (0–30 km) are augmented with White Sands rocket-sonde data from 30–70 km. White Sands RRA file includes only 0–30 km data. The user can also prepare (in the appropriate format as described below) data for any other site desired for use in the RRA mode. Another mode to use alternatives for the conventional GRAM climatology is the ‘Auxiliary Profile’ option. Auxiliary profiles also allow substitution of alternate data for both means and standard deviations. The format for preparing auxiliary profiles is much simpler than the required formatting for additional RRA data files (see app. B.9).

In addition to the RRA data files, a file called *rras2006.txt* is provided. This file gives file-code identifier, year, geodetic and geocentric latitude, longitude, surface altitude, maximum altitude, World Meteorological Organization (WMO) site number, and site name for each of the available 2006 RRA sites. The user may prepare alternate lists of RRA files if new sites or a different set of sites are desired. The RRA site list file to be used by Earth-GRAM 2010 for a specific program run is specified by input parameter *rralist*. Table 4 is a list of RRA site data.

Use of the RRA data option in Earth-GRAM 2010 is controlled by several input parameters: (1) *rrapath* gives the name of the directory containing the RRA data, (2) *rralist* gives the name of the file containing the list of RRA sites to be used, (3) *iurra* is the unit number to be used by the program for reading the RRA data, and (4) *sitelim* and *sitenear* control the size of the lat-lon region in the vicinity of any RRA site for which data from that RRA site is to be used (the RRA zone of influence). For any location having a radial distance (in lat-lon terms) of less than the value given by *sitenear*, the RRA data (with a full weight of 1) is used. For any location outside a lat-lon radius given by *sitelim*, the GRAM climatology data is used (i.e., a weight of 0 for the RRA data). Between radial distances of *sitenear* and *sitelim*, a weighted average of RRA and GRAM climatology data is used, ensuring a smooth transition from RRA data to GRAM data.

Table 4. List of RRA site data provided, file 'rras2006.txt.'

Code	Year	GdLat	GcLat	Lon (E+)	Hgt (m)	Zmax	WMO #	Site Name
anf	2006	47.62	47.43	-52.73	140.	30.	718010	Argentia, Newfoundland (St. Johns Airport)
asc	2006	-7.93	-7.88	-14.42	79.	70.	619020	Ascension Island, Atlantic
bar	2006	21.98	21.85	-159.34	31.	30.	911650	Barking Sands, Hawaii (Lihue)
cap	2006	28.47	28.31	-80.55	3.	70.	747940	Cape Canaveral, Florida
chl	2006	35.68	35.50	-117.68	665.	30.	746120	China Lake Naval Air Weapons Center, CA
dug	2006	40.77	40.58	-111.97	1,288.	30.	725720	Dugway Proving Ground (Salt Lake City), UT
eaf	2006	34.92	34.74	-117.90	724.	30.	723810	Edwards Air Force Base, California
egl	2006	30.48	30.31	-86.52	20.	30.	722210	Eglin AFB, Florida
elp	2006	31.81	31.64	-106.38	1,199.	70.	722700	El Paso, Texas
fad	2006	64.80	64.65	-147.88	135.	30.	702610	Fairbanks, Alaska
fha	2006	32.12	31.95	-110.93	787.	30.	722740	Ft. Huachuca Elec Prvng Grnd (Tucson), AZ
gtf	2006	47.47	47.28	-111.38	1,118.	30.	727750	Great Falls, MT
kmr	2006	8.73	8.67	167.75	2.	70.	913660	Kwajalein Missile Range, Pacific
ncf	2006	43.87	43.68	4.40	62.	30.	076450	Nimes-Courbessac, France (STS TAL Site)
nel	2006	36.62	36.44	-116.02	1,007.	30.	723870	Nellis AFB, Nevada (Mercury)
ptu	2006	34.12	33.94	-119.12	2.	70.	723910	Point Mugu Naval Air Weapons Center, CA
tag	2006	13.55	13.46	144.85	78.	30.	912170	Taguac, Guam (Anderson AFB)
vaf	2006	34.75	34.57	-120.57	121.	30.	723930	Vandenberg AFB, California
wal	2006	37.85	37.66	-75.48	13.	30.	724020	Wallops Island, Virginia (NASA)
wsm	2006	32.38	32.21	-106.48	1,207.	30.	722690	White Sands Missile Range, New Mexico
ysd	2006	32.87	32.69	-117.14	134.	30.	722930	Yuma Proving Ground, AZ (San Diego, CA)

Notes:

- Latitudes in the RRA data files are geodetic. In the rras2006.txt file, latitudes GdLat are geodetic and latitudes GcLat are geocentric. Earth-GRAM input latitudes are geocentric. Internally, Earth-GRAM works with geocentric RRA site latitudes if the RRA data option is used. The Earth-GRAM output file lists both geodetic and geocentric RRA site latitudes.
- For the Kwajalein Missile Range (kmr), data are available above 30 km for the annual mean case only. None of the individual months have sufficient data (number must be greater than 10) to be used, so all months have missing data codes (e.g., 99.99) between 30 and 70 km.

Nominal (default) values are $sitenear = 0.5^\circ$ and $sitelim = 2.5^\circ$. For these values then, any lat-lon within a radius of 0.5° from any of the RRA sites will use data from that RRA site. Any location beyond a radius of 2.5° would use the GRAM data. Between 0.5° and 2.5° radius, a weighted average of RRA data and GRAM data would be used, with the RRA data weight smoothly changing from 1 at a radius of 0.5° to a weight of 0 at a radius of 2.5° .

Depending on the value of *sitelim* and the proximity of the various RRA sites used, it may be possible that a given trajectory location is in the vicinity of more than one RRA site (e.g., for locations near Point Mugu, EAFB, and Vandenberg AFB). If a given trajectory location could be influenced by more than one RRA site, only data from the nearest (highest weight) site is used. Note, that if in such a situation, the user desires to always use a specific RRA site (e.g., EAFB) and never use a nearby RRA site (e.g., Point Mugu), then the name and information for the undesired nearby RRA site should be removed from the file list, and the modified site list used as specified by input parameter *rralist*.

RRA data apply from 0 km to a maximum of 70 km (above MSL). There is also a smooth interpolation process used to transition from the RRA data to GRAM data as the top of the RRA data is approached. This transition takes place between the next-to-highest RRA altitude (where the RRA weight = 1) and the highest RRA altitude (where the RRA weight becomes 0).

RRA data files for a given site consist of three data files: T1sssyy.txt, T2sssyy.txt, and T3sssyy.txt, where sss is the three-character site code from the list of sites given in table 4, and yy = 06 for the 2006 RRA data. The RRA data files are in the format given in the series of RRA reports (e.g., see ref. 52). Files Txsssyy.txt correspond to table x ($x = 1-3$) in the RRA reports.

Each Txsssyy.txt file contains an annual average data set and 12 monthly data sets. GRAM uses only the RRA data for the desired month, and the annual average data are always ignored on read-in. For 2006 RRA data, the annual average data must follow the 12 monthly data sets. Annual data preceded the 12 monthly data sets in the 1983 RRA data files (no longer used in Earth-GRAM2010).

RRA table-1 data contain wind statistical parameters: Height, mean eastward wind, standard deviation of eastward wind, correlation between eastward and northward wind, mean northward wind, standard deviation of northward wind, mean wind speed, standard deviation of wind speed, skewness of wind speed(*), and number of observations(*). Asterisks denote parameters that are not used or output by GRAM, although any RRA data having fewer than 10 observations are ignored by the RRA read routines.

RRA table-2 data contain thermodynamic statistical parameters: Height, mean pressure, standard deviation of pressure, skewness of pressure(*), mean temperature, standard deviation of temperature, skewness of temperature(*), mean density, standard deviation of density, skewness of density(*), number of pressure observations(*), number of temperature observations(*), and number of density observations(*). Asterisks denote parameters that are not used or output by GRAM, although any RRA data having fewer than 10 observations are ignored by the RRA read routines.

RRA table-3 data contain moisture related statistical parameters: Height, mean vapor pressure, standard deviation of vapor pressure, skewness of vapor pressure(*), mean virtual temperature(*), standard deviation of virtual temperature(*), skewness of virtual temperature(*), mean dewpoint temperature, standard deviation of dewpoint temperature, skewness of dewpoint temperature(*), number of observations of vapor pressure and dewpoint temperature(*), and number of observations of virtual temperature(*). Asterisks denote parameters that are not used or output by GRAM. RRA table-4 data are not used in GRAM.

User-provided RRA data can also be used if the following conditions are adhered to. Each new RRA site must be entered into the 'rralist' file (maximum total number of sites allowed is 99). The site code can be any three-character code not already being used. Heights for any new RRA data must be in the range from 0 to altitude Z_{max} (km), as given in the 'rralist' file. Heights should be given in ascending order in the Txsssyy.txt files with 300 or fewer heights entered (height increments can be any value and fixed height increments do not have to be used). The first data line of each Txsssyy.txt may have descriptive information (such as site name). However, the first data line

of each file MUST contain the site geodetic latitude and longitude. Latitude is given as xx.xxN. or xx.xxS.; longitude is given as xxx.xxE. or xxx.xxW., in format (17X,F5.2,A1,2X,F6.2,A1). Latitude and longitude values from the first data line are compared with the latitude and longitude in the 'rralist' file to ensure that the appropriate site data are being used. In the 'rralist' file, north latitudes are positive and south latitudes are negative, while east longitudes are positive and west longitudes are negative. Each file T1ssyy.txt or T2ssyy.txt must have five 'header' lines preceding each monthly set of data values. Each file T3ssyy.txt must have six 'header' lines preceding each monthly set of data values. Monthly data values for all 12 months must be provided. The data lines may be in free-field (list-directed) format but must contain a numerical value for each of the parameters expected, depending on the table type. Parameters not used by GRAM (those indicated by asterisks) may be input as zero values (except for number of observations, which can be any number greater than 10). Missing values (i.e., those that will be ignored) may be indicated by using 99.99 or 999.99.

2.11 Speed of Sound Calculation

Many users have a need to determine the local speed of sound (c_s) for determining the Mach number. To facilitate this, GRAM2010 performs the calculation and makes it available for output. The c_s is computed from the total temperature (monthly mean temperature plus perturbations) T_{Tot} as,

$$c_s = \sqrt{\gamma_c R T_{Tot}} , \quad (52)$$

where γ_c is the ratio of specific heats of air at a constant pressure to air at a constant volume and is equal to 1.4 . Because the gas constant R can vary with molecular weight, it is calculated from the ideal gas equation of state based on monthly mean values (which vary with height),

$$R = \frac{\bar{p}}{\bar{\rho} \bar{T}} . \quad (53)$$

Thus, in the GRAM code, c_s (coded as csp) is computed as

$$c_s = \sqrt{1.4 \frac{\bar{p}}{\bar{\rho}} \frac{T_{Tot}}{\bar{T}}} . \quad (54)$$

If the user desires the monthly mean speed of sound \bar{c}_s (coded as $csp0$), then equation (54) becomes,

$$\bar{c}_s = \sqrt{1.4 \frac{\bar{p}}{\bar{\rho}}} . \quad (55)$$

3. SAMPLE RESULTS

3.1 Large-Scale Perturbations

Figure 6 illustrates an example of the large-scale wave perturbation model. Amplitudes of the wave perturbations are randomly selected within reasonable bounds. Wavelengths are also established from a stochastic process in the GRAM code. Phase of the wave perturbation is initialized randomly from the starting random number seed. Thus, in a Monte Carlo run using various seed values, different phases of the wave perturbations are sampled.

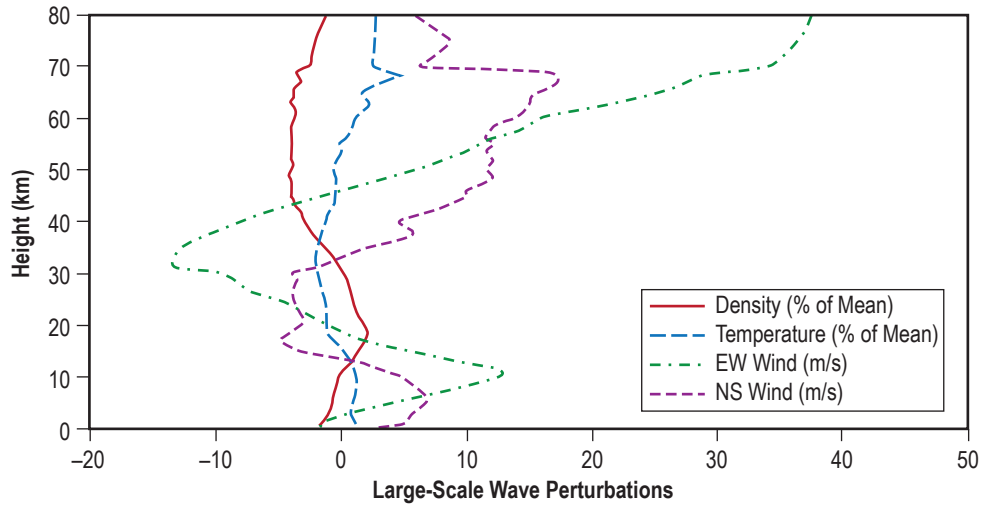


Figure 6. Sample vertical profile of large-scale wave perturbations using a large-scale wave perturbation model output.

Because the amplitudes and wavelengths of the wave perturbations depend on altitude, the waves are not purely sinusoidal in shape. Generally, the amplitude and wavelength increase as the altitude increases. The model systematically controls relative phases of the various wave perturbations. Temperature and density wave perturbations tend to be roughly 180° out of phase.

3.2 Density Perturbations

The perturbation model provides a realistic dispersion set. Figure 7 shows the results of a 1,000 profile Monte Carlo run of density perturbation versus height at the KSC. Also shown are the 2- and 3-sigma envelopes. Evident from this plot is that the dispersions (driven by the standard deviations) reach a local maximum at jet stream altitudes (≈ 15 km) and then diminish before trending upward at higher altitudes. The significant number of 2-sigma exceedances and a few exceedances beyond 3 sigma are also apparent.

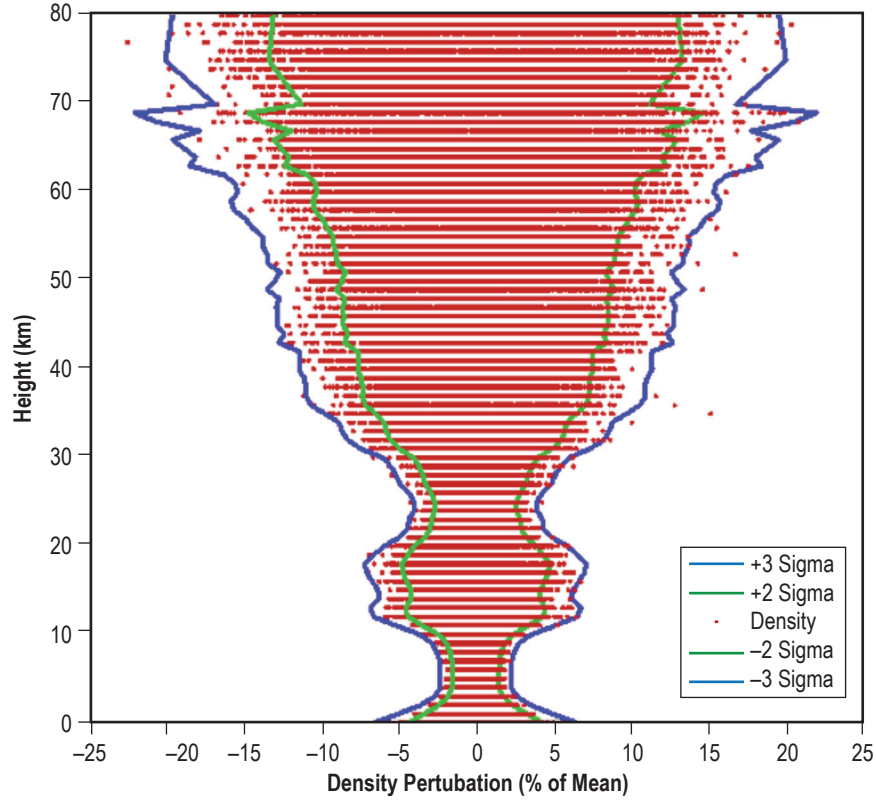


Figure 7. A plot of a 1,000 profile Monte Carlo run of density perturbation (in percent of the mean value) as a function of height. The 2- and 3-sigma envelopes are also shown.

3.3 Revised Boundary Layer Model for Vertical Velocity

As described in section 2.4, the calculation of standard deviation of the vertical velocity (σ_w) has been modified from the previous GRAM. The σ_w increases with the horizontal wind, site elevation, surface roughness, and solar elevation. Once determined, σ_w is used to drive the perturbation model of the vertical velocity. Figure 8 shows a global plot for a particular case in September at 00Z. Panel (a) of figure 8 shows a number of structures in the σ_w field (e.g., relatively higher values in the Rockies of the United States (U.S.), Canada, Iceland, Asia, parts of west central South America, Antarctica, and structures in the southern hemisphere ocean). A detailed explanation will not be presented here, but panel (b) shows a correlation of many of these features with the surface roughness. Furthermore, panel (c) suggests that the local elevation in these regions contributes to this roughness by grossly modeling the influence of mountainous regions. The wave structure of the southern hemisphere ocean, while of uniform elevation, correlates well with the wave structure of the horizontal wind shown in panel (d).

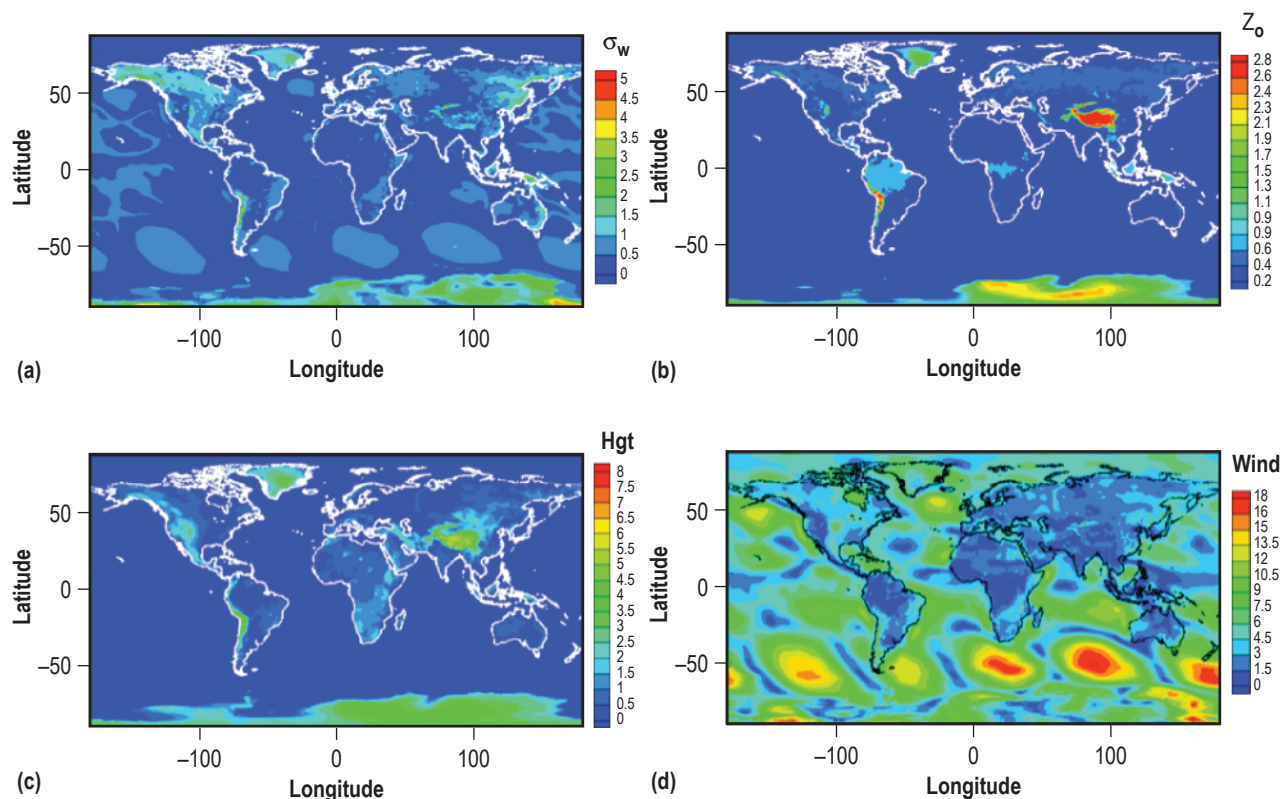


Figure 8. An example realization of the global distribution of: (a) The standard deviation of the vertical velocity in m/s, (b) the surface roughness in m, (c) the surface elevation in km, and (d) the mean horizontal surface wind in m/s.

3.4 Range Reference Atmosphere Data Option

Section 2.10 describes the RRA data option for GRAM2010. A simplified example is illustrated in figures 9 and 10. For this example, a parabolic trajectory is assumed, with take-off from EAFB, flying to an apogee at 100-km altitude, followed by a landing at WSMR. Default values are used in this example. Hence, RRA values are used when the trajectory is within a lat-lon radius of 0.5 km from either of the RRA sites, GRAM climatology is used when the trajectory is beyond a lat-lon radius of 2.5° from either RRA site, and a smooth transition is assumed between RRA data and GRAM data between 0.5° and 2.5° lat-lon radius.

Figure 9 illustrates the temperature profile between takeoff and landing for a pure GRAM climatology trajectory (solid line) and the RRA/GRAM option (dotted line). Percentage differences between pure GRAM values and RRA/GRAM values of less than $\pm 4\%$ are shown in figure 10.

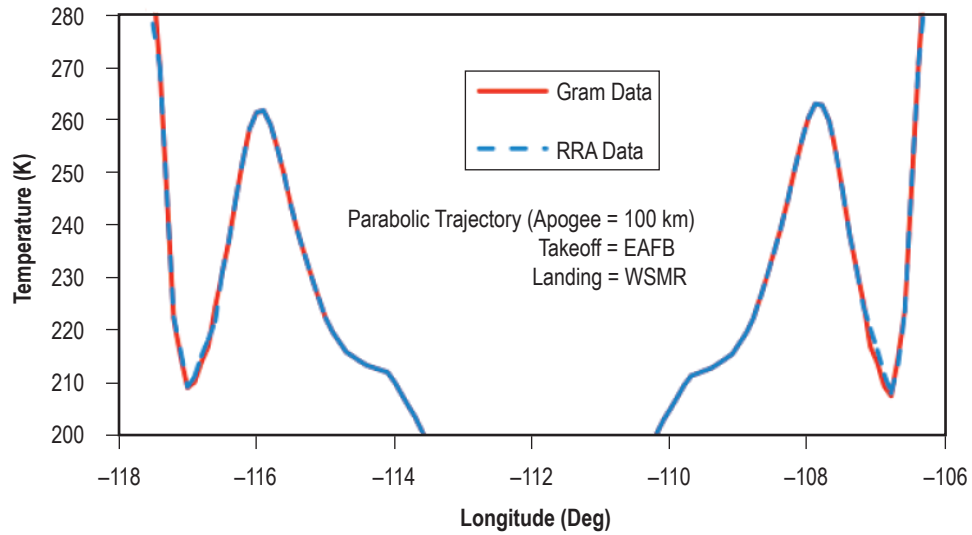


Figure 9. GRAM2010 (solid line) or RRA/GRAM2010 (dotted line) profiles of temperature along hypothetical parabolic trajectory between EAFB and WSMR with 100-km apogee.

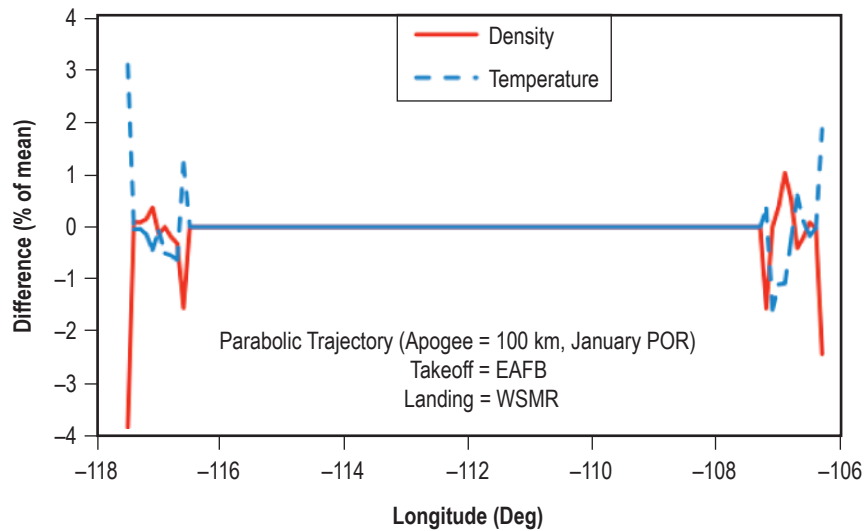


Figure 10. Differences in density (solid line) and temperature (dotted line) between GRAM2010 and RRA/GRAM2010 values for the hypothetical trajectory used in figure 9.

4. GLOBAL REFERENCE ATMOSPHERIC MODEL 2010 USERS GUIDE

4.1 General Program Review

Like its predecessors, GRAM2010, is designed to produce atmospheric parameter values either along a linear path (a profile) or along any set of related time-position data (a trajectory). Based on user-selected input values, the program can step automatically in height, latitude, longitude, and time along any desired linear profile. For the trajectory evaluation option, times and positions are provided to the program as a separate input (trajectory) file. Optionally GRAM2010 can also be incorporated as a subroutine in the users trajectory (or orbit propagation) code for evaluation along trajectory or orbital positions.

GRAM2010 uses two required input files and up to five other input files, depending on user-selected options. Required files are the NAMELIST-formatted input file (app. C) and ‘atmos-dat’ file (sec. 4.3). An optional input file for the lower atmosphere (0 km to the 10 mb level) is the NCEP database (app. A). Optional RRA data input are described in section 2.10. Optional trajectory input file format is described in section 4.4. An optional auxiliary profile input is described in appendix B.9. Note that RRA data cannot be used if an auxiliary profile is being employed. For use in Monte-Carlo analysis, with a number of identical profiles or trajectories using different random number seeds, a file of such seed numbers is described in section 4.5.

Output of GRAM2010 consists of four files. For cases in which GRAM was incorporated as a subroutine in a user-provided trajectory code, an option exists to suppress all output from GRAM. The primary output file is the standard formatted output described in section 4.6.1 and appendix D.1. An optional species concentration output file (sec. 4.6.2 and app. D.2) can be produced. An optional special formatted output file (sec. 4.6.3 and app. D.3) is designed to make it easy for the user to select from a wide range of output variables and to output them in an easily modified format. Lastly, there is an optional BL file that provides information about specific parameters in this region (sec. 4.6.4 and app. D.4).

Path names for the input and output files (except the NAMELIST input file) are provided via input from the NAMELIST input file. Options selected in the NAMELIST input file determine which of the optional input and output files are actually used for a given program run.

4.2 Units, Coordinates, and Conventions

The coordinate system used by GRAM is that of geocentric latitude, longitude, and geocentric height above sea level for a reference ellipsoid. Note that the latitudes in the RRA files are geodetic and GRAM converts these internally to geocentric. The equatorial and polar Earth radii for the sea-level reference ellipsoid have been updated to World Geodetic System (WGS) 84 (WGS 84) values. The equatorial radius used is 6,378.137 km and the polar radius is 6,356.752314 km. WGS 84 values are used by the Global Positioning System (GPS) navigation system. These are

also equivalent (to 10 significant figures) to the Geodetic Reference System (GRS) 80 (GRS 80) values. In Earth-GRAM 2010, input values of altitude greater than 6,000 km are treated as geocentric radius values, rather than heights. Both radius and height are now given in the output file. Although all input latitudes are geocentric, GRAM now gives both geocentric and geodetic values in the output file.

GRAM input and output uses the International Standard (SI) for units (i.e., metric). Users who desire nonstandard units must perform the conversions for their application. Time is measured in seconds except where noted in the input file that specifically requests year, hour, and minutes. Lengths are in km except as noted in the optional BL output file. Latitude and longitude are in degrees. Pressure is in N/m^2 (pascals), density in kg/m^3 , and temperature in K. The u-component of wind is in m/s and is positive when blowing from west to east. The v-component is also in m/s and is positive when blowing from south to north. The w-component is in m/s and positive when blowing vertically upward. Relative humidity is in percent. Species concentrations that output as mole fraction (volume mixing ratio) are given in ppm while output as number density is given as number/ m^3 . Additional details can be found in comments in the subroutine `atmod_e10` within `models_E10.f90`.

4.3 The ‘atmosdat’ Input File

The ‘atmosdat’ file consists of several types of data in several formats easily readable as ASCII characters. The file requires a little more than 4 Mb of disk storage.

4.3.1 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 $+90^\circ$ and 5-km height increments from 20 km to 120 km. Prefix codes, ZP, ZD, ZT, and ZU indicate pressure, density, temperature, and zonal wind, respectively. Each record contains the code, month, height in km, and -90° , -80° , ..., 80° , 90° latitude values of the parameter expressed as a four-digit integer with an exponent common to all 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 $2,761 \times 10^{-6}$ or 2.761×10^{-3} . Pressure data are in units of N/m^2 , density values kg/m^3 , temperatures in K, and zonal winds in m/s. The zonal-mean data set contains 1,008 Fortran readable records, the code, and 22 integer values in each record (format A2, I4, I5, 19I6, I4).

4.3.2 Stationary Perturbations

The stationary perturbations are lat-lon dependent (relative perturbations) to be applied to the zonal-mean values. Data for each of 12 months are given for the 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, month, height in km, latitude (-80° to $+80^\circ$) and 18 values of stationary perturbations in per mil ($\%/10$) for thermodynamic variables, and 0.1 m/s for winds at longitudes of 180° W., 160° W., 140° W., ..., 140° E., and 160° E. The monthly mean value (y_m) for parameter y (pressure, density, or temperature) at any latitude and longitude is computed

from the zonal-mean value (z_y) at the latitude and stationary perturbation (s_y) (in per mil) at the latitude and longitude by the relation,

$$y_m = z_y(1 + s_y/1,000). \quad (56)$$

For zonal (eastward) wind components, the monthly mean is $u_m = z_u + s_u/10$, while meridional (northward) mean winds are equal to the stationary northward wind perturbation value (i.e., $v_m = s_v/10$), where s_u and s_v are zonal and meridional stationary wind perturbations (in 0.1 m/s). Note that the 90° latitude stationary perturbation values are always 0. The stationary perturbation data consists of 15 300 Fortran readable records with a code and 21 integer values in each record (format A2, 21I5).

4.3.3 Random Perturbations

Random perturbation magnitudes (standard deviations) are dependent only on latitude. Prefix codes RP, RD, RT, RU, and RV indicate random perturbation magnitudes in pressure, density, temperature, zonal (northward) wind, and meridional (eastward) wind components, respectively. Each random perturbation record has the code, month, and height in km, followed by 19 values of random perturbation magnitude at 10° latitude increments from -90° to +90° followed by a common exponent value. These data give the relative standard deviations σ_p/p , σ_ρ/ρ , and σ_T/T (in %) for use in the random perturbation model. The code RU and RV data are similar, except 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 20–200 km. Random perturbation magnitudes for 0 km to the 10 mb level altitudes are provided by the NCEP database for both the thermodynamic and wind variables. The random perturbation data consist of 1,596 Fortran readable records with code and 22 integer values in each record (format A2, I4, I5, 19I6, I4).

4.3.4 Large-Scale Fraction Data

From daily difference analysis described in section 2 of reference 3, the fraction of the total variance (σ^2 from the random perturbation data) contained in the large-scale perturbations was determined as a function of height and latitude. The ‘atmosdat’ file contains the annual average fraction (expressed as per mil) of total variance contained in the large scale. Large- and small-scale magnitudes (σ_L and σ_S) are computed from the fractional data (f_L) in per mil (code PT for pressure, density, and temperature or code PW for winds), by the relations,

$$\sigma_L = (f_L / 1,000)^{1/2} \sigma_T, \quad (57)$$

and

$$\sigma_S = \left(1 - (f_L / 1,000)\right)^{1/2} \sigma_T, \quad (58)$$

where σ_T is the total perturbation magnitude. The code PT and PW data sets contain 25 Fortran readable records with code word PT or PW, followed by 17 integer values in each record (format A2, 17I7) for code PT and 12 integer values (format A2, 12I7) for PW code records.

4.3.5 Density-Velocity Correlations

Daily difference analysis was also used to evaluate the cross-correlations for use in the velocity perturbation model described in section 2 of reference 6 and in references 3 and 4. Both large-scale and small-scale values of the density-velocity correlations were evaluated and are given in the ‘atmosdat’ database (codes CL and CS) in per mil (i.e., divide by 1,000 to get correlations in the range -1 to $+1$). The code CL and CS data consist of 50 Fortran readable records with code word CL or CS followed by 12 integer values in each record (format A2, 12I7).

All foregoing data values in the ‘atmosdat’ database are ingested into the GRAM program through the subroutine setup in the initial_E10.f90 file.

4.3.6 Variable-Scale Random Perturbation Model Data

Variable-scale random perturbation model data appear next in the ‘atmosdat’ database. They consist of 29 Fortran readable records containing a code RS and 10 real (floating-point) values each (1 height and 9 associated parameters (sec. 2.6)), which are ingested into the GRAM program through the subroutine scalinit found in the initial_E10.f90 file. See page 12 of reference 6 for a description of these parameters. The format is A2, F5.0, 2F7.1, F7.2, F7.1, 5F7.2.

4.3.7 Langley Research Center Data

The next segment of data in the ‘atmosdat’ database is the NASA LaRC concentration data for the atmospheric constituent H_2O .¹² The data consist of 4 groups of 35 Fortran readable records of a code and 9 data values each (1 height and 8 associated array values at latitudes -70° through $+70^\circ$) and are ingested into the GRAM program through the subroutine concinit in the speconc_E10.f90 file. The four record groups present seasonal data at latitudes -70° through $+70^\circ$ for heights 6.5 through 40.5 km. Codes are LDJF for December-January-February, LMAM for March-April-May, LJJA for June-July-August, and LSON for September-October-November.

4.3.8 Air Force Geophysics Lab Data

The next segment of data in the ‘atmosdat’ database is the AFGL concentration data for the atmospheric constituents H_2O , O_3 , N_2O , CO , and CH_4 .¹¹ The data consist of 5 groups of 50 Fortran readable records of 6 values each (1 height and 5 associated array values for each of the 5 constituents) and are ingested into the GRAM program through the subroutine concinit. The five record groups present tropical (Air Force Tropical (AFTR)), midlatitude summer (Air Force Midlatitude Summer (AFMS)), midlatitude winter (Air Force Midlatitude Winter (AFMW)), subarctic summer (Air Force Subarctic Summer (AFSS)), and subarctic winter (Air Force Subarctic Winter (AFSW)) data. Tropical data are for latitudes of $\pm 15^\circ$, midlatitude data are for $\pm 45^\circ$, and subarctic data are for $\pm 60^\circ$. As necessary, a 6-month displacement is used to estimate southern hemisphere values from northern hemisphere values.

4.3.9 Middle Atmosphere Program Data

The next-to-last segment of data in the ‘atmosdat’ database is the MAP concentration data for the years 1979–1983.¹³ The code O3 data are for O₃ at 24 pressure levels (0.003–20 mb) for 12 months. Each of the 288 records consists of the code, month, pressure level (mb), and data values for 17 latitudes (–80° to +80°) and a common exponent value. The code H2O data are for H₂O at 11 pressure levels (1.5 to 100 mb) for 12 months, followed by 8 annual values (denoted by month 13) for the pressure levels 0.01–1 mb. There are a total of 140 H2O records. Each record contains the code, month, pressure level (mb), and five mean values at latitudes –60°, –45°, ±15°, +45° and +60° (with –60° estimated by 6-month displacement of +60° data), followed by five standard deviation values at these latitudes. The code N2O data are for MAP N₂O (code CH4 data for CH₄). The N2O and CH4 data consist of 204 records each. Each record contains the code, month (1–12), pressure level (17 levels, 0.1–20 mb), data at 15 latitudes (–70° to +70°) and a common exponent. The code OX data is for atomic oxygen (O) at 19 altitudes (130–40 km) for each month. There are 228 total records, each containing the code, month, height (km), data values at 17 latitudes (–80° to +80°), and a common exponent. Units of the MAP code OX data are atoms/cm³. The MAP code O3, H2O, and CH4 species data values are volume concentrations in units of ppmv while the code N2O data are in ppbv.

4.3.10 Topographic and Land Code Data

The last group of data in the ‘atmosdat’ data file contains global information used for the BL model. The first column and second column contain longitude and latitude, respectively, in degrees. The third column is the land code as shown in table 1 of section 2.4. The fourth column is the elevation of the surface in meters above sea level.

4.4 The Trajectory Input File

The trajectory file is required only when a trajectory rather than an automatically determined profile is desired. The file may contain an unlimited number of individual list-directed (free-field) records (i.e., lines) consisting of four real values: Time (real seconds), height (km), latitude (±90°, with southern latitudes being negative), and longitude (±360°, with west longitudes being negative). Using the values in the first record of the trajectory file, the program evaluates the atmospheric parameters and continues looping back to read a new trajectory position until a position below the surface (height <0) or the end of the file is reached.

4.5 Random Number Seed Input File

If a number of Monte-Carlo simulations are to be computed in one program run, subsequent starting random number seed values are input via a special optional input file. The file contains one random seed number per line. Each random number seed value is an integer, ranging from 1 to 900,000,000. Random seed values do not have to be randomly generated numbers, but values should not repeat in the list. Thus, any convenient sequence of consecutive integers may serve as valid random seed values.

4.6 Output Data Files

4.6.1 The Standard Formatted Output File

The standard output file (example in app. D.1) has header information consisting of the principal input data values and the Julian date required by the thermosphere section of the program, and it is calculated internally by the program. Positions and times, generated by the automatic linear profile feature or as input by the trajectory input data, are listed on the output with the associated calculated values of the atmospheric variables. If a latitude greater than 90° in absolute magnitude is generated (or input), the following transformation is made,

$$lat = (180^\circ - |lat|)(lat/|lat|), \quad (59)$$

and

$$lon = lon - 180^\circ. \quad (60)$$

All longitudes are converted to the range -180° to $+180^\circ$ before being output. The ‘mean’ line shows the current height above the reference ellipsoid (i.e., sea level), geocentric latitude, and the longitude.

The ‘mean’ line also provides values of pressure, density, temperature, and wind components consisting of one of the following:

- (1) Values calculated from the NCEP database input if the height is 20 km or below.
- (2) The sum of middle atmosphere zonal-mean plus stationary perturbation values if the height is between the 10-mb pressure level and 90 km.
- (3) A value faired between the NCEP data and zonal-mean plus stationary perturbations if the height is between 20-km and the 10-mb level.
- (4) Thermosphere model values if the height is above 120 km.
- (5) Faired values between middle atmosphere and the thermosphere model values if the height is between 90 and 120 km.

Standard atmosphere values computed by the subroutine stdatm in the gramsubs_E10.f90 file are used to evaluate the percent deviations from the 1976 U.S. Standard Atmosphere on the ‘M-76’ line. 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 U.S. Standard Atmosphere values. This subroutine accurately reproduces the tabulated 1976 U.S. Standard Atmosphere values within an accuracy of better than 0.2% above 90 km and even more accurately in the height region below 90 km, where the molecular weight is constant. Since the 1976 U.S. Standard Atmosphere is not defined above 1,000 km, the percent deviations output for heights above 1,000 km are 0. Because the

thermosphere models are 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 ‘M-76’ line also gives the current radius from the Earth’s center and the geodetic latitude.

The values on the ‘ranS,’ ‘ranL,’ and ‘ranT’ lines are the small-scale, large-scale, and total random perturbations evaluated at the output time and place. The values on the ‘sigS,’ ‘sigL,’ and ‘sigT’ lines are standard deviations of the small-scale, large-scale, and total random components at the output time and place. According to the Gaussian distribution on which the random perturbations are based, the perturbation values should be within the range $\pm\sigma$ 68 % of the time and outside the range $\pm\sigma$ 32 % of the time. Similarly, the perturbation values should be within the range $\pm2\sigma$ 95 % of the time and outside the range $\pm2\sigma$ 5 %. The values of the foregoing parameters are derived from the variable-scale perturbation model discussed in section 2.7. Also on the ‘ranS’ line is the elapsed time and an identifier denoting what data source was used. If GRAM climatology was used, ‘GRM’ will appear in that slot. If an RRA site was used, the site identifier will be shown, such as ‘cap06’ to indicate KSC 2006 RRA. On the other hand, ‘profl’ will appear if an auxiliary profile was used. The weight also appears on this line indicating how much of the RRA or auxiliary profile is used.

The parameter values output on the ‘Tot.’ line are the mean values defined above plus the random and wave model perturbations. These mean-plus-perturbation values represent typical ‘instantaneous’ evaluations of the pressure, density, temperature, and winds. The percent deviations from the U.S. Standard Atmosphere on the ‘T-76’ line are computed in the same way as the percent deviations of the monthly mean values from the U.S. Standard Atmosphere.

Values on the ‘H2O’ line are the mean H₂O values expressed as vapor pressure (N/m²), vapor density (kg/m³), dewpoint temperature (K), and RH (%). Mean H₂O values are computed from the NCEP, LaRC, MAP, or AFGL data according to altitude. Fairing is used for a smooth transition between these data sources. Values on the ‘sigH’ line are standard deviations in H₂O in the same units as the mean H₂O values.

New for GRAM2010 is a table showing the correlation between the horizontal wind components (Ruv), the average wind speed (SpdAv), the standard deviation of the wind speed (SpdSd), the monthly average speed of sound (SoSav), and the speed of sound for the perturbed environment (SoSpt).

4.6.2 The Species Concentration Output File

The species concentration output file (example in app. D.2) is also optional and controlled similarly to the special format output file by the value of an input parameter *iuc* and the pathname parameter *conpath*.

4.6.3 The ‘Special’ Format Output File

The ‘special’ output file is optional and is controlled by the input value of the *iopp* parameter switch and special output file pathname *nprpath* (app. D.3). As incorporated in the standard

distributed code, this output file is configured at two separate locations. The file's header definition is found in the init subroutine of the initial_E10.f90 file in the section near line number INIT603, while the file's parameter output definition is found in the atmod subroutine of the models_E10.f90 file in the section near line ATMD880. The code at both locations may be modified to fit the requirements of the user.

As a further aid to the user in constructing special output files, appendix E gives tables listing the standard variables available for output. The tables are also given in the code in the atmod subroutine of the models_E10.f90 file near line ATMD779.

4.6.4 The 'BLTest.txt' Output File

The 'BLTest.txt' output file is optional and controlled by the input parameter *iblttest*. It lists the parameters used to compute σ_w in the BL model. A description of the output parameters is provided in table 5.

Table 5. Boundary layer output parameters.

Header	Description
Day:	Day of month (including fractional part)
LST:	Local solar time (hours)
Hgt:	Height above MSL (MSL, km)
Lat:	Geocentric latitude (degrees)
Lon:	East longitude (degrees)
hsrf:	Surface height (MSL, km)
spdsrf:	Surface (10 m) wind speed (from mean-plus-large-scale-perturbation, m/s)
LC:	Land surface type code (see table 1, section 2.4.1)
z0:	Surface roughness length (m)
Elmn:	Solar elevation at midnight (degrees)
El:	Current solar elevation angle (degrees)
Elmd:	Solar elevation at midday (degrees)
sha:	Current solar hour angle (degrees)
blfct:	Height factor for unstable BL during early daytime (unitless)
nri:	Net radiation index (unitless), for stability calculation
S:	Atmospheric stability category (unitless)
ool:	Inverse of Monin-Obukhov scale length (1/m)
ustar:	Surface friction velocity (u^* , m/s)
BVfsq:	Square of Brunt-Vaisala frequency (s^{-2})
hN:	Depth of neutral boundary layer (m)
hbl:	Current depth of boundary layer (m)
chb:	Current height above surface (m) or height to top of boundary layer (for evaluating height variation of standard deviation of vertical wind)
sigrat:	Ratio of sigma-w to ustar at current height
swb:	Vertical wind standard deviation at top of boundary layer (m/s)

Table 5. Boundary layer output parameters (continued).

Header	Description
swh:	Current standard deviation of vertical winds (m/s)
spdvrsrf:	Monthly average wind speed at surface (10 m) (m/s)
spdsdsrf:	Standard deviation of surface wind speed (m/s)
tsrf:	Monthly average surface temperature (K)
stsr:	Standard deviation of surface temperature (K)

4.7 Description of Program Files and Subroutines

There are 14 source code files for the basic GRAM2010 program (Cfiles_E10_C.f90, gram_E10.f90, gramsubs_E10.f90, HWMsubs_E10.f90, Ifile_E10_I.f90, initial_E10.f90, JB2008_E10.f90, MET07prg_E10.f90, models_E10.f90, MSISsubs_E10.f90, NCEPsubs_E10.f90, random_E10.f90, rramods_E10.f90, and speconc_E10.f90). In addition to these programs required to run GRAM2010, there are a number of utility codes that accompany the software. Brief descriptions of these GRAM2010 program source code files and auxiliary source code files are:

Cfiles_E10_C.f90	Module file for all common block variables.
gram_E10.f90	Main Earth-GRAM 2010 program.
gramsubs_E10.f90	General Earth-GRAM 2010 subroutines.
HWMsubs_E10.f90	Harmonic Wind Model (used with MSIS thermosphere model).
Ifile_E10_I.f90	Interface module file for all subroutines.
initial_E10.f90	Reads atmosdat file and initializes data.
JB2008_E10.f90	Jacchia-Bowman 2008 model.
MET07prg_E10.f90	The Marshall Engineering Thermosphere (MET-07) model.
models_E10.f90	Other Earth-GRAM 2010 subroutines, not in gramsubs.
MSISsubs_E10.f90	Naval Research Labs MSIS (00) thermosphere model.
NCEPsubs_E10.f90	Reads and prepares NCEP climatology data.
random_E10.f90	Random number generators.
rramods_E10.f90	Reads the Range Reference Atmosphere (RRA) data.
speconc_E10.f90	Species concentration subroutines.
trajcalc_E10.f90	Subroutines used in trajectory demonstration programs.
gramtraj_E10.f90	Subroutine for use in user-provided trajectory program.
trajdemo_E10.f90	Main driver (replaces gram_E10.f90) in simple trajectory demonstration program.
trajopts_E10.f90	Main driver (replaces gram_E10.f90) in example trajectory program that demonstrates several special options.
multtraj_E10.f90	Main driver (replaces gram_E10.f90) program illustrating how to call Earth-GRAM 2010 to evaluate several different (multiple) trajectories in one program run.
corrtraj_E10.f90	Main driver (replaces gram_E10.f90) program illustrating how to call Earth-GRAM 2010 to evaluate multiple profiles in one program run, with small-scale and large-scale correlations preserved between the profiles.

multbody_E10.f90	Main driver illustrating how to call GRAM to evaluate perturbations along trajectories of multiple bodies which start out together and at various times separate from each other. The perturbations for each body start out the same, and then remain correlated over both position and time along the body trajectories, and across the spatial separation between the bodies.
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4.8 Setup of Global Reference Atmospheric Model 2010

Before running GRAM10, all files must be available in the proper configuration and location. Following is a discussion of how to set up the files. The first example is for a PC and the second is for a UNIX system.

4.8.1 Manual Setup on a Personal Computer

The following example of manual setup on a PC assumes that the user wants to set up Earth-GRAM 2010 in a directory called EarthGRAM2010 on the C: drive. The distribution DVD is assumed to be on the E: drive. This example is as follows:

- (1) Copy the E:\AuxProfiles folder to C:\EarthGRAM2010\AuxProfiles.
- (2) Copy the E:\DOCUMENTATION folder to C:\EarthGRAM2010\DOCUMENTATION.
- (3) Copy the E:\GRAM_code folder to C:\EarthGRAM2010\GRAM_code.
- (4) Copy the E:\NCEPdata folder to C:\EarthGRAM2010\NCEPdata.
- (5) Copy the E:\PC_Executables folder to C:\EarthGRAM2010\PC_Executables.
- (6) Copy the E:\IOfiles folder to C:\EarthGRAM2010\PC_IOfiles.
- (7) Copy the E:\RRAdat folder to C:\EarthGRAM2010\RRAdat.
- (8) Copy the E:\Utilities_Code folder to C:\EarthGRAM2010\Utilities_Code.

In Windows Explorer, all of these operations can be done at one time by creating a folder C:\EarthGRAM2010 then highlighting all folders on the E: drive (AuxProfiles, DOCUMENTATION, GRAM_code, NCEPdata, PC_Executables, IOfiles, RRAdat, and Utilities_Code), then dragging and dropping these folders to folder C:\EarthGRAM2010.

Note: Personal computer executable files are provided. Unless the user wishes to make code changes (e.g., to modify the ‘special-formatted’ output), it is not necessary to compile the GRAM code. The user can run the executable program gram_E10.exe located in the subdirectory PC_Executables. The program will then prompt the user for the Namelist input file. This input file

gives GRAM the instructions for the type of run and the location of files that it needs. Details of the input file can be found in appendix C. If the user wants to edit the source code, then GRAM must be compiled and linked. A description of the source code can be found in section 4.7. Details about compiling GRAM can be found in appendix B. See appendix F for integrating GRAM into another program.

If the user makes changes to GRAM, it is recommended that the output be compared to output from the provided program `gram_E10.exe`. For example, the user should run the example input file `NameRef.txt` located in the subdirectory `IOfiles` and ensure that files generated are the same as output files `OutputRef.txt`, `SpecialRef.txt`, and `SpeciesRef.txt` located in the same folder. Alternatively, the user could take an input file and run it in `gram_E10.exe` to compare with its output. Lastly, if the user has imbedded GRAM into a trajectory program, the user could create a trajectory file (see app. B.7) and run that in `gram_E10.exe` to compare outputs. More details about testing can be found in appendix B.6.

Note: NCEP binary data files are provided. These should work as-is with the PC executable programs provided. If the user changes any of the source code provided and recompile, then it is possible that the user may need to rebuild the NCEP binary files from the NCEP ASCII files provided. In that case, proceed as follows:

- (1) Copy the `E:\EarthGRAM2010\NCEPdata\ASCIIdata` folder-to-folder `C:\Earth-GRAM2010\NCEPdata\ASCIIdata`.
- (2) Compile and run utility program `NCEPbinF.f90` to generate binary format NCEP data file.

4.8.2 Manual Setup on a UNIX Platform

If the user has access to a UNIX machine with a DVD drive called `/DVDROM` for example, then a setup procedure similar to that for PC installation, given above, can be used. Note that source code and other text files may still have PC end-of-line markers rather than UNIX end-of-line markers when copied directly from the DVD. The following assumes that the user wants to set up Earth-GRAM 2010 in a directory `/usr/EarthGRAM2010` on the UNIX machine:

- (1) Copy the `/DVDROM/AuxProfiles` folder to `/usr/EarthGRAM2010/AuxProfiles`.
- (2) Copy the `/DVDROM/DOCUMENTATION` folder to `/usr/EarthGRAM2010/DOCUMENTATION`.
- (3) Copy the `/DVDROM/GRAM_code` folder to `/usr/EarthGRAM2010/GRAM_code`.
- (4) Copy the `/DVDROM/NCEPdata/ASCIIdata` folder to folder `/usr/EarthGRAM2010/NCEPdata/ASCIIdata`; Compile and run utility program `NCEPbinF.f90` to generate binary format NCEP data file. See further details in `README4.txt` and `README8.txt`.

- (5) Copy the /DVDROM/RRAdat folder to /usr/EarthGRAM2010/RRAdat.
- (6) Copy the /DVDROM/IOfiles folder to /usr/EarthGRAM2010/UNIX_IOfiles.
- (7) Copy the /DVDROM/Utilities_Code folder to /usr/EarthGRAM2010/Utilities_Code.

Note: UNIX executable files are not provided. Executable files must be compiled on UNIX platforms. Details for this procedure can be found in appendix B. For setup on UNIX machines for which a DVD drive is not easily accessible, the distribution DVD may be loaded on a PC, and File Transfer Protocol (FTP) software may be used to transfer files, rather than using the copy commands as outlined above. If files are transferred to a UNIX platform from a PC platform by using ASCII-mode FTP, conversion of end-of-line markers is handled automatically.

4.8.3 Setup on Other Platforms

MSFC Natural Environments Group does not have adequate resources to provide program versions and installation setups for all possible user platforms. Hopefully, the guidance provided above will be adequate to allow users to set up Earth-GRAM 2010 on whatever platform they desire to use. For example, the setup process on a Linux machine would be similar to that on a UNIX platform.

APPENDIX A—NATIONAL CENTERS FOR ENVIRONMENTAL PREDICTION REANALYSIS PROJECT CLIMATOLOGY DATA

(Adapted from NCEP/NCAR Reanalysis Data Archive Description Version Revised: 26
September 2003)

A.1 General Description

A subset of the full NCEP data is available from ARL in a format suitable for many applications, by selecting "Reanalysis" in the meteorological data set selection pull-down menu.

Data Period Availability: 1948 ==> 2008

The directory contains data files with the following syntax:

R{S|P}{YEAR}{MONTH}.{gbl|tbd}

where R indicates "Reanalysis," S or P indicates that the data are on Sigma or Pressure surfaces, YEAR is a four digit year, and MONTH is a two digit month. The "RP" (pressure level data) is used in Earth-GRAM 2010. The file suffix identifies the projection as either the 2.5 degree global latitude -longitude projection (gbl, as used in Earth-GRAM 2010), or a regional conformal map projection.

The sigma level data were obtained from NCEP's internal spectral coefficient archive, and are not used by Earth-GRAM 2010. The pressure level data were obtained from the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA.

A.2 Additional Data Set Details

A.2.1 Pressure Level Data

2.5 degree latitude-longitude global grid

144 X 73 points from 90N-90S, 0E-357.5E

1/1/1948 - present with output every 6 hours

Levels (hPa): 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10

Surface or near the surface (.995 sigma level) winds and temperature

Precipitation

Model Type: LAT-LON

Vert Coord: 2

Numb X pt: 144

Numb Y pt: 73

Numb Levels: 18

Sfc Variables: 5 PRSS T02M U10M V10M TPP6
Upper Levels: 6 HGTS TEMP UWND VWND WWND RELH

A.2.2 Example Header

```
92 1 1 0 0 099INDX 0 .00000000E+00 .00000000E+00CDC1 0 0 90.00 357.50 2.50 2.50
.00 .00 .00 1.00 1.00 -90.00 .00 .00144 73 18 2 996.00000 5PRSS199 T02M232
U10M 77 V10M176 TPP6195 1000.0 6HGTS 60 TEMP183 UWND212 VWND 49 WWND 42 RELH149 925.00 6HGTS
16 TEMP110 UWND215 VWND 88 WWND131 RELH 3 850.00 6HGTS247 TEMP185 UWND234 VWND100 WWND182
RELH 52 700.00 6HGTS161 TEMP 20 UWND123 VWND 72 WWND187 RELH 96 600.00 6HGTS152 TEMP 60
UWND211 VWND148 WWND137 RELH 38 500.00 6HGTS136 TEMP193 UWND144 VWND 99 WWND130 RELH161
400.00 6HGTS107 TEMP212 UWND159 VWND117 WWND136 RELH139 300.00 6HGTS 80 TEMP127 UWND131
VWND 6 WWND198 RELH255 250.00 5HGTS 25 TEMP 66 UWND101 VWND247 WWND 57 200.00 5HGTS188
TEMP153 UWND169 VWND 92 WWND 23 150.00 5HGTS 86 TEMP 3 UWND133 VWND 98 WWND149 100.00
5HGTS201 TEMP 71 UWND135 VWND136 WWND 12 70.000 4HGTS 46 TEMP 82 UWND153 VWND208 50.000
4HGTS122 TEMP 4 UWND230 VWND162 30.000 4HGTS 20 TEMP132 UWND117 VWND211 20.000 4HGTS 37
TEMP119 UWND212 VWND165 10.000 4HGTS108 TEMP157 UWND101 VWND159
```

A.2.3 Data Packing Format

NCEP typically saves their model output in GRIB format. However, at ARL the data are reprocessed and stored in a 1-byte packing algorithm. This 1-byte packing is a bit more compact than GRIB and can be directly used on a variety of computing platforms with direct access I/O. The data array is packed and stored into one byte characters. To preserve as much data precision as possible the difference between the values at grid points is saved and packed rather than the actual values. The grid is then reconstructed by adding the differences between grid values starting with the first value, which is stored in unpacked ASCII form in the header record. To illustrate the process, assume that a grid of real data, R , of dimensions i,j is given by the below example.

$1, j$	$2, j$	....	$i-1, j$	i, j
$1, j-1$	$2, j-1$	....	$i-1, j-1$	$i, j-1$
....
$1, 2$	$2, 2$	....	$i-1, 2$	$i, 2$
$1, 1$	$2, 1$	....	$i-1, 1$	$i, 1$

The packed value, P , is then given by

$$P_{i,j} = (R_{i,j} - R_{i-1,j}) * (2^{** (7-N)}),$$

where the scaling exponent

$$N = \ln dR_{\max} / \ln 2 .$$

The value of dR_{\max} is the maximum difference between any two adjacent grid points for the entire array. It is computed from the differences along each i index holding j constant. The

difference at index (1,j) is computed from index (1,j-1), and at 1,1 the difference is always zero. The packed values are one byte unsigned integers, where values from 0 to 126 represent -127 to -1, 127 represents zero, and values of 128 to 254 represent 1 to 127. Each record length is then equal in bytes to the number of array elements plus 50 bytes for the header label information. The 50 byte label field precedes each packed data field and contains the following ASCII data:

Field	Format	Description
Year	I2	Greenwich date for which data valid
Month	I2	"
Day	I2	"
Hour	I2	"
Forecast*	I2	Hours forecast, zero for analysis
Level	I2	Level from the surface up
Grid	I2	Grid identification
Variable	A4	Variable label
Exponent	I4	Scaling exponent needed for unpacking
Precision	E14.7	Precision of unpacked data
Value 1,1	E14.7	Unpacked data value at grid point 1,1

*Forecast hour is -1 for missing data.

Example: 2 1 1 0 0 099PRSS 8 .1007874E+01 .6867000E+03

ARL provides a Fortran-90 program that can be used to unpack and read the first few elements of the data array for each record of an ARL packed meteorological file. This file, called CHK_DATA.F, was adapted for reading and processing the ARL data files for use in Earth-GRAM 2010. Additional information can be found in Kalnay *et al.*¹⁵

A.2.4 NCEP Data in Earth-GRAM 2010

NCEP climatology is provided in ASCII format in folder NCEPdata\FixedASCII. Files for each month are named Nfy1y2mm.txt, where the period of record (POR) covers years y1 through y2 (e.g. 9008 is for POR 1990 through 2008), and month is mm. Surface and near-surface NCEP data in these files have been adjusted according to procedures described in file NCEPmods.pdf, in the DOCUMENTATION folder, and in Section 2.3.4, above. ASCII data in these files have been prepared in a compact format, with decimals removed, and some spaces removed. An example file header and first few data lines is given by:

```
h L J I N Hav Hsd Uav Us Vav Vs Tav Ts Dav Dsn RHaRHs TdaTds eTa eTsn Sav Ss Ruv
1 1 1 1 589 6828 56 12 27 -20 302467 3696401321 4572742355107357627202 42 21 12
1 2 1 1 589 16 597 8 23 -30 262656 381310 190 7451692615 51270910241 42 20 -89
1 3 1 1 589 6111 573 7 23 -29 262617 371231 180 7451692576 501989 7611 41 19 -91
1 4 1 1 589 12621 562 7 22 -29 262576 371149 160 7451692538 491439 5571 41 19 -80
1 5 1 1 589 27172 591 14 25 -32 282483 3398181311 7451692448 46645624912 46 22-137
1 6 1 1 589 38380 651 22 42 -29 442455 278512 951 4562732344 96295619212 62 33-230
1 7 1 1 589 51290 745 10 48 -19 512381 287314 861 4392272282 761417 8292 65 35-240
1 8 1 1 589 66535 869 6 58 3 632286 256097 661 3352162164 84418830893 75 42-265
1 9 1 1 589 85419 967 1 65 25 692220 214708 441 941321996 67533373864 84 50-314
```

110	1	1	589	97290	952	-3	61	33	642232	303903	531	861182003	62535966994	81	50-350	
111	1	1	589111984	932	-7	53	38	572264	333078	451	791042025	62721790274	73	45-326		
112	1	1	589131199	962	-8	44	37	482291	262281	261	72	902042	59	87310453	65	37-244
113	1	1	589158571	1021	-8	34	32	432320	171502	111	64	762061	54105511593	55	32-182	
114	1	1	589182933	1012	-11	31	29	392343	151041	71	57	622074	49119711983	51	30-180	
115	1	1	589206107	978	-11	28	28	332359	177383	542	50	472082	44126411293	45	27-128	
116	1	1	589241563	948	-11	25	20	292384	214383	392	43	332096	38142310613	38	23 -38	
117	1	1	589270016	990	-13	24	13	262409	222892	262	37	202107	301557	8273	35	20 -6
118	1	1	589319695	1189	-9	24	21	242500	211392	122	31	202166	183065	7283	36	19 -12

where

- h = UT hour of day: 1=00 UT, 2=06UT, 3=12UT, 4=18UT. Statistics for all hours of day combined (h=5) are added in the conversion from ASCII format to binary format, by utility program NCEPbinF.f90.
- L = Pressure levels 1-18. In mb, these are surface,1000,925,850,700,600,500,400,300,250,200,150,100,70,50,30,20, and 10. Data for sea-level are computed in the conversion from ASCII format to binary format, by utility program NCEPbinF.f90.
- J = Latitude index (1-73)
- I = East longitude index (1-144).
- N = Number of data in the period of record (e.g. if there are no missing data, POR 1990-2008 has 589 values for a 31-day month)
- Hav = Monthly average geopotential altitude for given UT hour (m times 10). For level 1, Hav is average surface pressure (mb times 10)
- Hsd = Standard deviation for geopotential altitude (m times 10). For level 1, Hsd is standard deviation of surface pressure (mb times 10)
- Uav = Monthly average Eastward wind for given UT hour (m/s times 10)
- Us = Standard deviation for Eastward wind (m/s times 10)
- Vav = Monthly average Northward wind for given UT hour (m/s times 10)
- Vs = Standard deviation for Northward wind (m/s times 10)
- Tav = Monthly average temperature for given UT hour (K times 10)
- Ts = Standard deviation for temperature (K times 10)
- Dav = Monthly average density for given UT hour
- Ds = Standard deviation for density
- n = Density exponent. Densities in kg/m**3 are given by Dav*10**(-(3+n)) and Ds*10**(-(3+n))
- RHa = Monthly average relative humidity for given UT hour (percent times 10)
- RHs = Standard deviation for relative humidity (percent times 10)
- Tda = Monthly average dewpoint temperature for given UT hour (K times 10)
- Tds = Standard deviation for dewpoint temperature (K times 10)
- eTa = Monthly average vapor pressure for given UT hour
- eTs = Standard deviation for vapor pressure
- n = Vapor pressure exponent. Vapor pressures in N/m**2 are given by eTa*10**(-n) and eTs*10**(-n)
- Sav = Monthly average wind speed (m/s times 10)
- Ss = Monthly standard deviation of wind speed (m/s times 10)
- Ruv = Cross-correlation between Eastward and Northward wind components (times 1000)

NCEP ASCII data format is (I1,2I2,I3,I4,I6,I5,4(I4,I3),I1,2(I4,I3),2I4,I1,I4,I3,I4).

Binary format NCEP data are provided in PC form. Files for each month are named Nby1y2mm.bin, where the period of record is for years y1 through y2 (e.g. 9008 is for POR 1990 through 2008), and month is mm. Utility program NCEPbinF is used to generate similar binary format files on any non-PC platform. In addition to building binary format versions of the NCEP data, utility program NCEPbinF can also be used at any time to output easily-readable vertical profile data and horizontal grids ("maps") of NCEP data values. The NCEPbinF utility program MUST be used to generate binary version NCEP data for use by Earth-GRAM 2010 on non-PC computer platforms.

APPENDIX B—COMPILING AND RUNNING GLOBAL REFERENCE ATMOSPHERIC MODEL 2010

B.1 General Introduction

Earth-GRAM 2010 can be run in stand-alone mode (i.e. as an independent program), or as a set of subroutines in a user-provided program, such as a trajectory code. The following material gives several examples of how to compile and run Earth-GRAM 2010 in each of these modes. Examples are given for both PC and UNIX machines. If you wish to run stand-alone GRAM on a PC, and do not need to make any code changes, you can use PC executable files provided on the distribution DVD. It is necessary to compile the Earth-GRAM 2010 source code if you:

- 1) wish to run on a UNIX or other non-PC platform,
- 2) make changes in the code (e.g. by selecting other/additional parameters for output, as described in Appendix E), or
- 3) want to incorporate Earth-GRAM 2010 as subroutines in your own code, such as a trajectory program.

Unless otherwise noted below, it is assumed in the following material that all files from the distribution DVD have been copied to folders as named in the instructions for how to setup Earth-GRAM 2010, given in Section 4.8.

B.2 Command-Line Compiling on a PC

One example of how to compile Earth-GRAM 2010 on a PC is to use command line mode. Command line mode is initiated by clicking on "Start," then "Run," then entering "CMD.EXE" (without the quotes) in the run window. For the GNU PC Fortran compiler (gfortran), stand-alone Earth-GRAM can be compiled (to an executable file named *gram_E10.exe*) by entering the following commands:

```
gfortran -c Cfiles_E10_C.F90
gfortran -c Ifiles_E10_I.F90
gfortran -c GRAMSUBS_E10.F90
gfortran -c INITIAL_E10.F90
gfortran -c MET07PRG_E10.F90
gfortran -c MODELS_E10.F90
gfortran -c RANDOM_E10.F90
gfortran -c SPECONC_E10.F90
gfortran -c RRAmods_E10.F90
gfortran -c MSISsubs_E10.F90
gfortran -c HWMsubs_E10.F90
gfortran -c JB2008_E10.F90
gfortran -c NCEPsubs_E10.F90
gfortran GRAM_E10.F90 Cfiles_E10_C.o Ifiles_E10_I.o GRAMSUBS_E10.o INITIAL_E10.o
MET07PRG_E10.o MODELS_E10.o RANDOM_E10.o SPECONC_E10.o RRAmods_E10.o
```

```
MSISsubs_E10.o HWMsubs_E10.o JB2008_E10.o NCEPsubs_E10.o -o gram_E10.exe
```

Note - For some compilers Cfiles_E10.F90 and Ifiles_E10.F90 must appear first in the list as in the above example.

Alternatively, these commands may be put into an executable batch (.bat) file, in which case it is advisable to include a pause statement at the end of the batch file, so the temporary command window remains open after compilation has completed, allowing the user to view any compilation error messages that may have been produced. Optionally, the last gfortran call may include any of several switches to get various run-time error messages, such as

```
gfortran -fbacktrace -std=f95 -Wextra -Wall -pedantic -fbounds-check ...
```

Other compilers will have different commands and compile switches for doing command-line compile operations. Compilers also generally provide a "Programmer's Workbench" or similar graphical-user-interface mode for doing program compile-and-link operations.

Subroutines trajcalc_E10.f90 and gramtraj_E10.f90 and a dummy main driver (trajdemo_E10.f90) are provided, to give an example of how to incorporate and use Earth-GRAM 2010 as subroutines in your own code. To compile this example "trajectory" code (using gfortran), enter each of the following command lines (or incorporate them into an executable batch file) -

To compile trajdemo, enter the following commands:

```
gfortran -c Cfiles_E10_C.F90
gfortran -c Ifiles_E10_I.F90
gfortran -c gramtraj_E10.F90
gfortran -c trajcalc_E10.F90
gfortran -c GRAMSUBS_E10.F90
gfortran -c INITIAL_E10.F90
gfortran -c MET07PRG_E10.F90
gfortran -c MODELS_E10.F90
gfortran -c RANDOM_E10.F90
gfortran -c SPECONC_E10.F90
gfortran -c RRAmods_E10.F90
gfortran -c MSISsubs_E10.F90
gfortran -c HWMsubs_E10.F90
gfortran -c JB2008_E10.F90
gfortran -c NCEPsubs_E10.F90
gfortran trajdemo_E10.F90 gramtraj_E10.o trajcalc_E10.o Cfiles_E10_C.o
Ifiles_E10_I.o GRAMSUBS_E10.o INITIAL_E10.o MET07PRG_E10.o MODELS_E10.o
RANDOM_E10.o SPECONC_E10.o RRAmods_E10.o MSISsubs_E10.o HWMsubs_E10.o
JB2008_E10.o NCEPsubs_E10.o -o trajdemo_E10.exe
```

NOTE - After successful compilation to executable programs, all object files and module files can be deleted, such as by the commands:

```
erase *.o
erase *.mod
```

These commands may also be incorporated into the executable compile batch files.

Program trajdemo illustrates a basic trajectory program implementation. Other example trajectory driver programs, offering special options and features, are available upon approved request. These include: (1) Program trajopts, which shows how to implement various trajectory options, (2) Program multtraj, which illustrates implementation for calculating multiple trajectories in one program run (without cross-correlation between perturbations on the separate trajectories), (3) Program corrtraj, which evaluates multiple profiles in one program run, with time cross-correlations preserved between the profiles, and (4) Program multbody (including associated subroutines), which provides as an example of how to use GRAM in a trajectory code to compute space and time-correlated perturbations influencing multiple spacecraft bodies. Extensive comments in these example trajectory program driver routines provide more details.

B.3 Compiling on a UNIX Machine

The UNIX f90 command can be used to compile Earth-GRAM 2010, to an executable named gram_E10.x, by entering the following-

```
f90 Cfiles_E10_C.f90 Ifiles_E10_I.f90 gram_E10.f90 gramsubs_E10.f90 /
  NCEPsubs_E10.f90 initial_E10.f90 MET07prg_E10.f90 models_E10.f90 /
  random_E10.f90 speconc_E10.f90 rramods_E10.f90 MSISsubs_E10.f90 /
  HWMsubs_E10.f90 JB2008_E10.f90
mv a.out gram_E10.x
```

Similarly, the f90 command may also be used to compile the trajdemo program that provides an example of how to incorporate Earth-GRAM 2010 in user code-

```
f90 Cfiles_E10_C.f90 Ifiles_E10_I.f90 trajdemo_E10.f90 trajcalc_E10.f90 /
  gramtraj_E10.f90 gramsubs_E10.f90 NCEPsubs_E10.f90 initial_E10.f90 /
  MET07prg_E10.f90 models_E10.f90 random_E10.f90 speconc_E10.f90 /
  rramods_E10.f90 MSISsubs_E10.f90 HWMsubs_E10.f90 JB2008_E10.f90
mv a.out trajdemo_E10.x
```

It should be noted that the forward slash character indicates a continuation line. After successful compilation to executable programs, all object files and module files can be deleted, such as by the commands:

```
rm -f *.o
rm -f *.mod
```

The above compilation commands and rm commands may also be incorporated into an executable batch file.

Note: If the fullwarn compile option is used on the UNIX f90 compiler, several CAUTION or NOTE messages may result. Specifically, there may be several CAUTIONS about the VAST_KIND_PARAM module having "already been directly or indirectly use associated into" the current scope. These CAUTION and NOTE messages can safely be ignored. However, no Error or Warning messages should be produced by the compilation process.

B.4 Running in Command-Line Mode on a PC

With PC executable files placed in folder C:\EarthGRAM10\PC_Executables, and example input/output files placed in folder C:\EarthGRAM10\PC_IOfiles, GRAM 2010 can easily be run from any directory. For example, to run from a directory named C:\MyTest, do the following:

- 1) Copy (and edit and/or rename, if desired) the file C:\EarthGRAM10\PC_IOfiles\NameRef.txt to the C:\MyTest folder. Note that NAMELIST input file names are limited to 99 characters.
- 2) Open a PC command-line window by Clicking Start and Run and entering the command CMD.EXE
- 3) Change directory by entering the commands C: and CD \MyTest
- 4) Execute Earth-GRAM 2010 by entering the command C:\EarthGRAM10\PC_Executables\gram_E10.exe
- 5) Enter the name of the input file (from step 1) when prompted
- 6) Output files will appear in the C:\MyTest folder

If file open errors are encountered, make sure that file pathnames are properly set in the NAMELIST input file. For files residing in folders as described in Section 4.8.2, set the following path names in the NAMELIST input file:

- atmpath = 'C:\EarthGRAM10\PC_IOfiles\atmosdat_E10.txt'
- NCEPpath
 - = 'C:\EarthGRAM10\NCEPdata\' if the NCEP data are to be read from the C: drive, or
 - = 'E:\NCEPdata\' if the NCEP data are to be read from the DVD on the E: drive.

For test or demonstration purposes, it is also possible to run Earth-GRAM 2010 directly from the distribution DVD. To do this, from the C:\MyTest directory, as above, simply replace "C:\EarthGRAM10\" with "E:\" (assuming that E: is the DVD drive) in the command and input pathnames for the executable file, the atmosdat_E10.txt file, and the NCEP path name. See later discussion on how to set file path names if using the input trajectory option, the Range Reference Atmosphere input option, the auxiliary profile input option, and/or the multiple-profile Monte Carlo option. Output file path names can be any name specified by the user. All path names are limited to 99 characters in length.

B.5 Running in Command-Line Mode on a UNIX Machine

UNIX executable files must be compiled and created, as discussed above. For example, suppose the Earth-GRAM 2010 UNIX executable is created and named `gram_E10.x` in directory `/usr/EarthGRAM10/UNIX_Executables`. If the setup procedure discussed in Section 4.8.3 is used, example input/output files are placed in folder `/usr/EarthGRAM10/UNIX_IOfiles`. Earth-GRAM 2010 can easily be run from any directory. For example, to run from a directory named `/usr/MyTest`, do the following-

- 1) Copy (and edit and/or rename, if desired) the file `/usr/EarthGRAM10/UNIX_IOfiles/NameRef.txt` to the `/usr/MyTest` folder. Note that NAMELIST input file names are limited to 99 characters.
- 2) Change directory by entering the command `cd /usr/MyTest`
- 3) Execute Earth-GRAM 2010 by entering the command `/usrEarthGRAM10/UNIX_Executables/gram_E10.x`
- 4) Enter the name of the input file (from step 1) when prompted
- 5) Output files will appear in the `/usr/MyTest` folder

If file open errors are encountered, make sure that file pathnames are properly set in the NAMELIST input file. For files residing in folders as described in Section 4.8.3, set the following path names in the NAMELIST input file:

- `atmpath = '/usr/EarthGRAM10/UNIX_IOfiles/atmosdat_E10.txt'`
- `NCEPpath`
 - `= '/usr/EarthGRAM10/NCEPdata/'` if the NCEP data are to be read from the `/usr/EarthGRAM10` area, or
 - `= '/DVDROM/NCEPdata/'` if NCEP data are to be read from the DVD on the `/DVDROM/` drive

See later discussion on how to set file path names if using the input trajectory option, the Range Reference Atmosphere input option, the auxiliary profile input option, and/or the multiple-profile Monte Carlo option. Output file path names can be any name specified by the user. All path names are limited to 99 characters in length.

B.6 Reference Input/Output Files for Testing

To facilitate runtime testing, a NAMELIST-formatted reference input file, called `NameRef.txt`, is provided on the distribution DVD (in folder `EarthGRAM10\IOfiles` on the distribution DVD). Reference output files are also provided (`OutputRef.txt` and `SpeciesRef.txt` on the distribution DVD). If a test run (as described in the above sections) is done using input file `NameRef.txt`, to produce output files named `output.txt` and `species.txt`, these output files can be tested against the reference output files provided. On a PC (from the directory where the test output files reside), to compare against reference files on the DVD (E: drive), enter PC commands

```
fc output.txt E:\PC_IOfiles\OutputRef.txt
```

```
fc special.txt E:\PC_IOfiles\SpecialRef.txt
```

```
fc species.txt E:\PC_IOfiles\SpeciesRef.txt
and
fc BLTest.txt E:\PC_IOfiles\BLTestRef.txt
```

Any file differences will be noted in the output from the `fc` (file compare) command. To do the same tests on a UNIX machine, the commands are

```
diff output.txt /DVDROM/UNIX_IOfiles/OutputRef.txt
diff special.txt /DVDROM/UNIX_IOfiles/SpecialRef.txt
diff species.txt /DVDROM/UNIX_IOfiles/SpeciesRef.txt
and
diff BLTest.txt /DVDROM/UNIX_IOfiles/BLTestRef.txt
```

Be sure to compare against files from the appropriate directory on the distribution DVD, since there are small differences in the PC and UNIX version reference output files. In UNIX format, numbers that are less than 1 (in magnitude) are written (0.xxx -0.xxx etc.). For some compilers in the PC environment, such numbers are written without the leading zeroes (i.e., as .xxx -.xxx etc.). Because of variations in handling of round-off by different operating systems and/or compilers, a few numbers in the reference output files may differ from those in the user-generated test output files. Such differences should be no larger than about 1 in the last significant digit of the output.

B.7 Running with an Input Trajectory File

To run the stand-alone Earth-GRAM 2010 program with a pre-computed input trajectory file of positions and times, set the trajectory file pathname (*trapath*) in the NAMELIST input file to whatever file name is desired, set the number of computed positions (*nmax*) to zero, and set the trajectory file unit number (*iopt*) to any non-conflicting value. The trajectory file contains one time and position per line, having values for elapsed time (seconds), height (km), geocentric latitude (degrees, North positive), and longitude (degrees, East positive). Trajectory input heights greater than 6000 km are treated as geocentric radius values, rather than as altitudes above reference ellipsoid. Example programs illustrating how to drop Earth-GRAM into trajectory code cannot be run with trajectory file input, since trajectory positions are generated "on the fly" in these programs. For additional discussion of input options, see Appendix C.

Multiple profiles or trajectories can be computed in one run of the program, in a Monte-Carlo simulation of various perturbation profiles, by providing input for any number of random seed values. Input random seeds are provided, with one seed value per line, in a file whose path name is specified by input parameter *rndpath*, the file unit number for which is specified by input parameter *iun*. Integer random seed values must be in the range $0 \leq \text{seed} \leq 900,000,000$. Other aspects of the perturbation model can be controlled by input parameters such as *rpscale*, *initpert*, *patchy*, *rdinit*, *rtinit*, *ruinit*, *rvinit*, *rwinit*, etc. For additional discussion of input options, see Appendix C.

B.8 Running with Range Reference Atmosphere (RRA) Input

A major feature is the (optional) ability to use data (in the form of vertical profiles) from a set of Range Reference Atmospheres (RRA), as an alternate to the usual GRAM climatology, at a set of RRA site locations. With this feature it is possible, for example, to simulate a flight profile that takes off from the location of one RRA site (e.g., Edwards AFB, using the Edwards RRA data), to smoothly transition into an atmosphere characterized by the GRAM climatology, then smoothly transition into an atmosphere characterized by a different RRA site (e.g., White Sands, NM), to be used as the landing site in the simulation. Use of the RRA option is controlled by setting input parameters `rpath`, `rralist`, `iurra`, `sitelim`, and `sitenear`. For further discussion of input options, see Appendix C. For further discussion of RRA data, see Section 3.4.

B.9 Running with Auxiliary Profile Input

As an option, data read from an auxiliary profile may be used to replace data from the conventional (NCEP/MAP/etc.) climatology. This option is controlled by setting parameters `profile`, `sitenear`, and `sitelim` in the NAMELIST input file. Each line of the auxiliary profile input file consists of: (1) height, in km [height values greater than 6,000 km are interpreted as radius values, in km], (2) geocentric latitude, in degrees, (3) longitude, in degrees (East positive), (4) mean temperature, in K, (5) mean pressure, in N/m^2 , (6) mean density, in kg/m^3 , (7) mean Eastward wind, in m/s, (8) mean Northward wind, in m/s, (9) standard deviation (sigma) temperature, in K, (10) sigma pressure, in N/m^2 , (11) sigma density, in kg/m^3 , (12) sigma Eastward wind, in m/s, (13) sigma Northward wind, in m/s. Heights are relative to the reference ellipsoid, except that values greater than 6,000 km are interpreted as radius values, rather than altitudes. Latitudes are geocentric. Regular climatological values (NCEP/MAP data etc.) are used if any of the three values for temperature, pressure, or density data are input as zero in the auxiliary profile. Regular climatological values of wind components are used if BOTH wind components are zero in the auxiliary profile file. Note that RRA input option and auxiliary profile input option cannot be used simultaneously. Example auxiliary profiles are provided with the software.

B.10 Compiling and Running on Other Platforms

MSFC Natural Environments Group does not have adequate resources to provide program versions and installation setups for all possible user platforms. Hopefully, the guidance provided above will be adequate to allow users to set up, compile and run Earth-GRAM 2010 on whatever platform they desire to use. For questions on compiling or running Earth-GRAM 2010, see contact information below.

If you have any questions or problems, please contact:

Fred Leslie
e-mail: Fred.W.Leslie@nasa.gov
phone: (256)-544-1633

fax: (256)-544-5754

Mail Code EV44
NASA Marshall Space Flight Center
Huntsville, AL 35812

OR

C. G. (Jere) Justus
e-mail: Carl.G.Justus@nasa.gov
phone: (256)-544-3260
fax: (256)-544-5754

Mail Code EV44/Dynbetics Technical Services
NASA Marshall Space Flight Center
Huntsville, AL 35812

PDF versions of the background GRAM-95 and GRAM-99 reports [NASA Technical Memorandum 4715, "The NASA/MSFC Global Reference Atmospheric Model - 1995 Version (GRAM-95)," August, 1995 and NASA/TM-1999-209630 "The NASA/MSFC Global Reference Atmospheric Model - 1999 Version (GRAM-99)," May 1999] are on the Earth-GRAM 2010 distribution DVD.

APPENDIX C—DESCRIPTION OF NAMELIST FORMAT INPUT FILE

Following is a sample NAMELIST format input file (NameRef.txt) for use by Earth-GRAM 2010. Note that some compilers use different formats for the beginning and ending lines of the file. This sample file contains values required to produce the reference output data (file OutputRef.txt). These input values are also the default values, set if none are provided. Only values that differ from these default values actually need to be input in the NAMELIST file. Definitions and discussion of Earth-GRAM 2010 input parameters that are the same as GRAM-99 input parameters are given in Appendix D of NASA/TM-1999-209630.

```
$namein_e10
atmpath = 'D:\GRAMs\EarthGRAM2010Ver1.0\PC_IOfiles\atmosdat_E10.txt'
NCEPpath = 'D:\GRAMs\EarthGRAM2010Ver1.0\NCEPdata\BinData\'
trapath = 'null'
prtpath = 'output.txt'
nprpath = 'special.txt'
conpath = 'species.txt'
rndpath = 'null'
rrapath = 'D:\GRAMs\EarthGRAM2010Ver1.0\RRAdat\'
rralist = 'rras2006.txt'
profile = 'null'
hl = 140.
phil = 0.45
thet1 = -164.53
f10 = 230.
f10b = 230.
ap = 20.3
s10      = 0.
s10b     = 0.
xm10     = 0.
xm10b    = 0.
y10      = 0.
y10b     = 0.
dstdtc   = 0.
mn = 1
ida = 1
iyr = 2010
ihro = 0
mino = 0
seco = 0.0
dphi = 0.4
dthet = 1.2
dhgt = -2.0
nmax = 71
delt = 60.0
iopt = 0
iopp = 17
iu0 = 0
iup = 6
ius = 3
```

```

iuc = 4
iug = 22
NCEPyr = 9008
NCEPhr = 5
ioppr = 1
nr1 = 1234
iun = 0
rpscale = 1.0
ruscale = 1.0
rwscale = 1.0
iurra = 35
sitelim = 2.5
sitenear = 0.5
initpert = 0
rdinit = 0.
rtinit = 0.
ruinit = 0.
rvinit = 0.
rwinit = 0.
patchy = 0.
itherm = 1
z0in = -1.
ibltest = 99
$End
Parameter Descriptions:
atmpath = path name for "atmosdat" atmospheric data file
NCEPpath = path name for NCEP data files
trapath = path name for trajectory input file ('null' if none)
prtpath = path name for standard formatted output file ('null' if none)
nprpath = path name for the "special" format output file ('null' if none)
conpath = path name for species concentration output file ('null' if none)
rndpath = path name for file containing more random number seeds (optional)
rrapath = DIRECTORY for Range Reference Atmosphere (RRA) data (optional)
rralist = File name for list of RRA sites (optional)
profile = path name for auxiliary profile data ('null' if none)
hl = initial height (km). Heights > 6000 km are interpreted as radius.
phil = initial geocentric latitude (degrees, N positive)
thet1 = initial longitude (degrees, East positive)
f10 = daily 10.7-cm flux
f10b = mean 10.7-cm flux
ap = geomagnetic index (Note: Valid ap must be used if JB2008 selected,
    for use in HWM wind model)
s10 = EUV index (26-34 nm) scaled to F10 units (0.0 -> s10=f10)
s10b = EUV 81-day center-averaged index (0.0 -> s10b = f10b)
xm10 = MG2 index scaled to F10 units (0.0 -> xm10 = f10)
xm10b = MG2 81-day center-averaged index (0.0 -> xm10b = f10b)
y10 = Solar X-Ray & Lya index scaled to F10 (0.0 -> y10=f10)
y10b = Solar X-Ray & Lya 81-day avg. centered index (0.0 -> y10b=f10b)
dstdtc = Temperature change computed from Dst index (for JB2008)
mn = month (1-12)
ida = day of month
iyr = 4-digit year, or 2-digit year: >56=19xx <57=20XX
ihro = initial UTC (Greenwich) time hour (0-23)
mino = initial UTC (Greenwich) time minutes (0-59)
seco = initial UTC (Greenwich) time seconds (0.0-60.0)
dphi = geocentric latitude increment (degrees, Northward positive)
dthet = longitude increment (degrees, Eastward positive)

```

dhgt = height increment (km, upward positive). If radius input is used, dhgt is interpreted as a radius increment.
 nmax = maximum number of positions (including initial one; 0 means read trajectory input file)
 delt = time increment between positions (real seconds)
 iopt = trajectory option (0 = no trajectory data; otherwise unit number for trajectory input file)
 iopp = "special" output option (0 = no "special" output; otherwise unit number of "special" output file)
 iu0 = unit number for screen output (normally 6 or 0)
 iup = unit number for standard formatted output file (0 for none)
 ius = unit number for atmosdat data
 iuc = unit number for concentrations output (0 for none)
 iug = unit for NCEP data files
 NCEPyr = yly2 to use NCEP climatology for period-of-record (POR) from year y1 through year y2 (e.g. NCEPyr=9008 for POR = 1990 through 2008). NCEP monthly climatology is determined by input value of month (mn) in initial time input
 NCEPhr = Code for UT hour of day if NCEP climatology is used: 1=00 UT, 2=06UT, 3=12UT, 4=18UT, 5=all times of day combined, or 0 to use NCEP time-of-day based on input UTC hour (ihro)
 iopr = random output option (1 = random output, 2 = none)
 nrl = first starting random number (1 to 9 * 10**8)
 iun = unit number for more starting random numbers (0 for none)
 rpscale = random perturbation scale for density, temperature and pressure; nominal=1.0, max=2.0, min=0.1
 ruscale = random perturbation scale for horizontal winds; nominal=1.0, maximum=2.0, minimum=0.1
 rwscale = random perturbation scale for vertical winds; nominal=1.0, maximum=2.0, minimum=0.1
 iurra = unit number for Range Reference Atmosphere (RRA) data (0 if none)
 sitelim = lat-lon radius (deg) from RRA site, outside which RRA data are NOT used. Also used, with a similar meaning, for auxiliary profile input. Note that RRA and auxiliary profile input cannot be used simultaneously.
 sitenear = lat-lon radius (deg) from RRA site, inside which RRA data is used with full weight of 1 (smooth transition of weight factor from 1 to 0 between sitenear and sitelim). Also used, with a similar meaning, for auxiliary profile input.
 initpert = Use 1 for user-selected initial perturbations or 0 (default) for GRAM-derived, random initial perturbation values
 rdinit = initial density perturbation value (% of mean)
 rtinit = initial temperature perturbation value (% of mean). Note - initial pressure perturbation is computed from rdinit and rtinit.
 ruinit = initial eastward velocity perturbation (m/s)
 rvinit = initial northward velocity perturbation (m/s)
 rwinit = initial upward velocity perturbation (m/s)
 patchy = not equal 0 for patchiness; 0 to suppress patchiness in perturbation model
 itherm = 1 for MET (Jacchia), 2 for MSIS, or 3 for JB2008 thermosphere
 z0in = surface roughness (z0) for sigma-w model [< 0 to use 1-by-1 deg lat-lon surface data, from file atmosdat_E10.txt; = 0 for speed-dependent z0 over water; or enter a value between 1.0e-5 and 3 for user-specified z0 value]. For more information, see file README7.txt.
 ibltest = unit number for BL model output file (bltest.txt), or 0 for no BL model output

APPENDIX D—SAMPLE OUTPUT PF GLOBAL REFERENCE ATMOSPHERIC MODEL 2010

D.1 Sample Standard Formatted Output Produced by Input File of Appendix C

**** Earth Global Reference Atmospheric Model - 2010 (Earth-GRAM-2010) ****

Version 1.0, Released Jul, 2010

MM/DD/YYYY = 1/ 1/2010 HH:MM:SS(UTC) = 0: 0: 0.0 Julian Day = 2455197.500

F10.7 = 230.00 Mean F10.7 = 230.00 ap Index = 20.30

Max of 71 positions, generated automatically.

Range Reference Atmosphere (RRA) sites available

No	Code	Yr	GdLat	GcLat	Lon(E+)	Hgt(m)	Zmax	WMO #	Site Name
1	anf	06	47.62	47.43	-52.73	140.	30.	718010	Argentia, Newfoundland (St. Johns Airport)
2	asc	06	-7.93	-7.88	-14.42	79.	70.	619020	Ascension Island, Atlantic
3	bar	06	21.98	21.85	-159.34	31.	30.	911650	Barking Sands, Hawaii (Lihue)
4	cap	06	28.47	28.31	-80.55	3.	70.	747940	Cape Canaveral, Florida
5	chl	06	35.68	35.50	-117.68	665.	30.	746120	China Lake Naval Air Weapons Center, CA
6	dug	06	40.77	40.58	-111.97	1288.	30.	725720	Dugway Proving Ground (Salt Lake City), UT
7	eaf	06	34.92	34.74	-117.90	724.	30.	723810	Edwards Air Force Base, California
8	egl	06	30.48	30.31	-86.52	20.	30.	722210	Eglin AFB, Florida
9	elp	06	31.81	31.64	-106.38	1199.	70.	722700	El Paso, Texas
10	fad	06	64.80	64.65	-147.88	135.	30.	702610	Fairbanks, Alaska
11	fha	06	32.12	31.95	-110.93	787.	30.	722740	Ft. Huachuca Elec Prvng Grnd (Tucson), AZ
12	gtf	06	47.47	47.28	-111.38	1118.	30.	727750	Great Falls, MT
13	kmr	06	8.73	8.67	167.75	2.	70.	913660	Kwajalein Missile Range, Pacific
14	ncf	06	43.87	43.68	4.40	62.	30.	076450	Nimes-Courbessac, France (STS TAL Site)
15	nel	06	36.62	36.44	-116.02	1007.	30.	723870	Nellis AFB, Nevada (Mercury)
16	ptu	06	34.12	33.94	-119.12	2.	70.	723910	Point Mugu Naval Air Weapons Center, CA
17	tag	06	13.55	13.46	144.85	78.	30.	912170	Taguac, Guam (Anderson AFB)
18	vaf	06	34.75	34.57	-120.57	121.	30.	723930	Vandenberg AFB, California
19	wal	06	37.85	37.66	-75.48	13.	30.	724020	Wallops Island, Virginia (NASA)
20	wsm	06	32.38	32.21	-106.48	1207.	30.	722690	White Sands Missile Range, New Mexico
21	ysd	06	32.87	32.69	-117.14	134.	30.	722930	Yuma Proving Ground, AZ (San Diego, CA)

NCEP Global Climatology Data: POR = 9008 NCEPhr = 5
Path = D:\GRAMs\EarthGRAM2010Ver1.0\NCEPdata\FixedBin\
Thermospheric conditions from MET model
Random Option = 1 1st Random No. = 1234 Random Scale Factors = 1.00 1.00 1.00
Patchy Turbulence Option = Off

Mean-76 and Total-76 are percent deviations from 1976 US Standard Atmosphere.

Other deviations in percent are with respect to mean values. RH is relative humidity in percent. Zeroes for H2O indicate no estimate available.

E-W wind positive toward East; N-S wind positive toward North.

Height/ Radius (km) Time_sec	GcLat (deg) /RRA	Long. [E+W-] (deg) /Weight	Pressure /Vap.Pr. (Nt/m**2)	Density/ Vap.Dens. (kg/m**3)	Tempera- ture/ Dewpt. (K)	E-W Wind (m/s)	N-S Wind (m/s)	Vert. Wind (m/s) RH(%)	
140.000	0.450	-164.530	9.966E-04	4.406E-09	690.2	20.4	0.3	-0.000	Mean
6518.136	0.453		38.36%	15.00%	23.34%				M-76
0.0	GRM	0.0000	-0.88%	3.90%	-8.64%	83.9	-8.9		ranS
			2.90%	6.19%	12.54%	45.0	45.0		sigS
Wind and SoS			-4.55%	4.32%	-3.97%	-12.9	-60.8		ranL
-----			12.16%	3.69%	7.47%	52.3	52.3		sigL
Ruv = 0.014			-5.43%	8.21%	-12.61%	71.0	-69.7	-3.45	ranT
SpdAv= 78.6			12.50%	7.20%	14.60%	69.0	69.0	8.33	sigT
SpdSd= 61.3			9.424E-04	4.768E-09	603.2	91.5	-69.4	-3.45	Tot.
SoSav= 562.7			30.84%	24.45%	7.78%				T-76
SoSpt= 526.0			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH

138.000	0.850	-163.330	1.085E-03	5.022E-09	662.0	17.5	0.5	-0.000	Mean

6516.132	0.856		36.08%	14.26%	21.94%				M-76
60.0	GRM	0.0000	-2.70%	0.70%	-6.27%	64.4	14.5		ranS
			3.05%	6.22%	13.15%	43.1	43.0		sigS
Wind and SoS			-4.79%	4.27%	-5.59%	-21.1	-56.2		ranL
-----			12.84%	3.77%	7.97%	50.5	50.4		sigL
Ruv = 0.014			-7.48%	4.97%	-11.87%	43.4	-41.7	-4.10	ranT
SpdAv= 75.0			13.20%	7.27%	15.37%	66.4	66.2	8.16	sigT
SpdSd= 58.9			1.004E-03	5.272E-09	583.5	60.8	-41.2	-4.10	Tot.
SoSav= 550.0			25.90%	19.94%	7.47%				T-76
SoSpt= 516.3			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH
-----			-----	-----	-----	-----	-----	-----	-----
136.000	1.250	-162.130	1.186E-03	5.764E-09	633.2	14.0	0.6	-0.000	Mean
6514.127	1.258		33.85%	13.60%	20.49%				M-76
120.0	GRM	0.0000	-3.55%	-4.43%	1.67%	50.8	13.0		ranS
			3.18%	6.25%	13.72%	41.1	40.9		sigS
Wind and SoS			-2.25%	4.13%	-7.18%	-28.1	-50.4		ranL
-----			13.49%	3.85%	8.45%	48.6	48.3		sigL
Ruv = 0.013			-5.80%	-0.31%	-5.51%	22.7	-37.5	8.50	ranT
SpdAv= 71.2			13.86%	7.35%	16.11%	63.6	63.3	7.99	sigT
SpdSd= 56.4			1.117E-03	5.746E-09	598.3	36.8	-36.9	8.50	Tot.
SoSav= 536.8			26.09%	13.25%	13.85%				T-76
SoSpt= 521.8			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH
-----			-----	-----	-----	-----	-----	-----	-----
134.000	1.650	-160.930	1.303E-03	6.667E-09	603.8	10.1	0.6	0.000	Mean
6512.119	1.661		31.73%	13.08%	18.98%				M-76
180.0	GRM	0.0000	-3.59%	-4.86%	2.43%	54.9	0.5		ranS
			3.30%	6.29%	14.25%	39.1	38.8		sigS
Wind and SoS			-3.58%	3.87%	-8.68%	-33.8	-43.8		ranL
-----			14.11%	3.94%	8.93%	46.6	46.2		sigL
Ruv = 0.013			-7.17%	-0.98%	-6.25%	21.1	-43.3	9.04	ranT
SpdAv= 67.4			14.49%	7.42%	16.82%	60.8	60.3	7.82	sigT
SpdSd= 53.8			1.209E-03	6.602E-09	566.1	31.1	-42.7	9.04	Tot.
SoSav= 523.0			22.28%	11.97%	11.54%				T-76
SoSpt= 506.4			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH
-----			-----	-----	-----	-----	-----	-----	-----
132.000	2.050	-159.730	1.438E-03	7.778E-09	573.9	5.7	0.5	0.000	Mean
6510.109	2.064		29.67%	12.65%	17.43%				M-76
240.0	GRM	0.0000	-2.74%	-5.07%	4.53%	49.9	49.5		ranS
			3.41%	6.32%	14.76%	37.0	36.6		sigS
Wind and SoS			-4.23%	3.52%	-10.04%	-38.1	-36.6		ranL
-----			14.70%	4.02%	9.39%	44.5	44.0		sigL
Ruv = 0.013			-6.97%	-1.55%	-5.51%	11.8	12.9	9.05	ranT
SpdAv= 63.6			15.09%	7.49%	17.49%	57.9	57.2	7.65	sigT
SpdSd= 51.1			1.338E-03	7.658E-09	542.3	17.5	13.4	9.05	Tot.
SoSav= 508.8			20.63%	10.91%	10.96%				T-76
SoSpt= 494.6			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH
-----			-----	-----	-----	-----	-----	-----	-----
130.000	2.450	-158.530	1.597E-03	9.159E-09	543.6	1.0	0.4	0.000	Mean
6508.098	2.466		27.71%	12.34%	15.85%				M-76
300.0	GRM	0.0000	-1.38%	-1.66%	0.56%	22.0	48.8		ranS
			3.52%	6.35%	15.23%	34.9	34.3		sigS
Wind and SoS			-7.99%	3.08%	-11.19%	-40.9	-29.1		ranL
-----			15.27%	4.11%	9.85%	42.3	41.6		sigL
Ruv = 0.013			-9.37%	1.42%	-10.63%	-18.9	19.8	7.72	ranT
SpdAv= 59.8			15.67%	7.56%	18.14%	54.9	53.9	7.48	sigT
SpdSd= 48.3			1.448E-03	9.288E-09	485.8	-17.9	20.2	7.72	Tot.
SoSav= 494.1			15.75%	13.93%	3.53%				T-76
SoSpt= 467.1			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH

128.000	2.850	-157.330	1.785E-03	1.090E-08	513.1	-4.0	0.3	0.000	Mean
6506.084	2.869		25.90%	12.17%	14.26%				M-76
360.0	GRM	0.0000	2.28%	-3.75%	12.05%	37.8	43.7		ranS
			3.63%	6.37%	15.69%	32.7	32.0		sigS
Wind and SoS			-3.54%	2.54%	-12.09%	-42.2	-21.5		ranL
-----			15.82%	4.19%	10.31%	40.0	39.1		sigL
Ruv = 0.012			-1.25%	-1.21%	-0.04%	-4.4	22.1	7.13	ranT
SpdAv= 56.3			16.23%	7.63%	18.77%	51.7	50.5	7.31	sigT
SpdSd= 45.4			1.763E-03	1.077E-08	512.9	-8.4	22.4	7.13	Tot.
SoSav= 478.9			24.32%	10.81%	14.21%				T-76
SoSpt= 478.8			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH
126.000	3.250	-156.130	2.011E-03	1.312E-08	482.3	-9.1	0.1	0.000	Mean
6504.068	3.271		24.15%	12.04%	12.68%				M-76
420.0	GRM	0.0000	1.71%	-8.30%	20.15%	22.6	5.9		ranS
			3.75%	6.40%	16.12%	30.4	29.5		sigS
Wind and SoS			-1.10%	1.93%	-12.71%	-42.1	-14.2		ranL
-----			16.35%	4.27%	10.76%	37.5	36.4		sigL
Ruv = 0.012			0.60%	-6.36%	7.44%	-19.5	-8.3	6.55	ranT
SpdAv= 53.1			16.77%	7.70%	19.38%	48.3	46.8	7.14	sigT
SpdSd= 42.3			2.023E-03	1.228E-08	518.2	-28.7	-8.2	6.55	Tot.
SoSav= 463.2			24.90%	4.91%	21.07%				T-76
SoSpt= 480.2			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH
124.000	3.650	-154.930	2.284E-03	1.599E-08	451.5	-14.2	-0.0	0.000	Mean
6502.050	3.674		22.59%	12.05%	11.15%				M-76
480.0	GRM	0.0000	1.81%	-12.96%	30.01%	52.9	18.7		ranS
			3.87%	6.43%	16.53%	28.0	26.9		sigS
Wind and SoS			1.50%	1.26%	-13.00%	-40.5	-7.5		ranL
-----			16.86%	4.36%	11.20%	34.8	33.5		sigL
Ruv = 0.012			3.32%	-11.70%	17.00%	12.4	11.2	3.45	ranT
SpdAv= 50.3			17.30%	7.77%	19.97%	44.7	42.9	6.97	sigT
SpdSd= 39.0			2.359E-03	1.412E-08	528.3	-1.8	11.1	3.45	Tot.
SoSav= 447.1			26.66%	-1.06%	30.05%				T-76
SoSpt= 483.6			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH
122.000	4.050	-153.730	2.619E-03	1.978E-08	421.0	-19.0	-0.2	0.000	Mean
6500.030	4.077		21.09%	11.96%	9.75%				M-76
540.0	GRM	0.0000	-1.04%	0.45%	-3.05%	19.5	-2.2		ranS
			3.98%	6.45%	16.92%	25.5	24.1		sigS
Wind and SoS			-14.13%	0.54%	-12.96%	-37.7	-1.7		ranL
-----			17.35%	4.44%	11.65%	31.9	30.3		sigL
Ruv = 0.011			-15.17%	0.99%	-16.00%	-18.2	-3.9	3.04	ranT
SpdAv= 47.7			17.81%	7.83%	20.54%	40.8	38.7	6.80	sigT
SpdSd= 35.4			2.222E-03	1.997E-08	353.6	-37.1	-4.0	3.04	Tot.
SoSav= 430.6			2.72%	13.07%	-7.81%				T-76
SoSpt= 394.7			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH
120.000	4.450	-152.530	3.038E-03	2.481E-08	391.1	-23.3	-0.3	-0.000	Mean
6498.008	4.479		19.69%	11.66%	8.65%				M-76
600.0	GRM	0.0000	-0.68%	-3.30%	5.39%	28.5	-15.2		ranS
			4.09%	6.48%	17.30%	22.7	21.1		sigS
Wind and SoS			-9.76%	-0.22%	-12.56%	-33.7	3.1		ranL
-----			17.84%	4.52%	12.08%	28.7	26.7		sigL
Ruv = 0.011			-10.44%	-3.51%	-7.17%	-5.2	-12.1	-0.92	ranT
SpdAv= 45.3			18.30%	7.90%	21.10%	36.6	34.0	6.63	sigT
SpdSd= 31.4			2.721E-03	2.394E-08	363.1	-28.4	-12.4	-0.92	Tot.
SoSav= 414.0			7.20%	7.74%	0.86%				T-76

SoSpt= 398.9			0.000E+00	0.000E+00	0.0			0.0%	H2O
			0.000E+00	0.000E+00	0.0			0.0%	sigH
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
118.000	4.850	-151.330	3.559E-03	3.154E-08	362.3	-26.5	-0.3	-0.000	Mean
6495.983	4.882		18.07%	10.82%	7.82%				M-76
660.0	GRM	0.0000	2.68%	-10.05%	25.25%	6.0	13.2		ranS
			3.98%	7.11%	16.16%	22.3	23.2		sigS
Wind and SoS			-2.12%	-1.09%	-12.10%	-32.5	8.3		ranL
-----			17.34%	5.04%	11.46%	28.5	29.5		sigL
Ruv = 0.011			0.56%	-11.13%	13.16%	-26.5	21.5	5.68	ranT
SpdAv= 48.4			17.79%	8.71%	19.81%	36.2	37.5	6.49	sigT
SpdSd= 32.8			3.578E-03	2.803E-08	409.9	-53.0	21.1	5.68	Tot.
SoSav= 397.4			18.73%	-1.52%	22.01%				T-76
SoSpt= 422.8			1.135E-09	7.362E-15	186.1			0.0%	H2O
			4.085E-10	2.650E-15	0.0			0.0%	sigH
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
116.000	5.250	-150.130	4.207E-03	4.063E-08	334.3	-28.1	-0.5	-0.000	Mean
6493.957	5.285		15.83%	9.17%	7.14%				M-76
720.0	GRM	0.0000	2.94%	-13.17%	30.55%	23.4	42.0		ranS
			3.86%	7.67%	14.96%	21.9	24.9		sigS
Wind and SoS			-1.95%	-2.08%	-11.40%	-30.7	14.1		ranL
-----			16.83%	5.52%	10.76%	28.2	32.0		sigL
Ruv = 0.011			0.98%	-15.25%	19.15%	-7.3	56.2	-1.85	ranT
SpdAv= 50.6			17.27%	9.45%	18.43%	35.7	40.6	6.36	sigT
SpdSd= 34.0			4.249E-03	3.443E-08	398.3	-35.5	55.7	-1.85	Tot.
SoSav= 380.8			16.97%	-7.48%	27.66%				T-76
SoSpt= 415.6			1.450E-09	1.015E-14	180.0			0.0%	H2O
			5.222E-10	3.653E-15	0.0			0.0%	sigH
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
114.000	5.650	-148.930	5.037E-03	5.320E-08	307.3	-27.9	-0.6	-0.000	Mean
6491.929	5.687		13.27%	6.92%	6.70%				M-76
780.0	GRM	0.0000	3.03%	-7.38%	18.60%	26.0	5.1		ranS
			3.75%	8.25%	13.79%	22.7	25.7		sigS
Wind and SoS			-6.45%	-3.19%	-10.60%	-29.8	19.7		ranL
-----			16.34%	6.02%	10.07%	29.4	33.3		sigL
Ruv = 0.010			-3.42%	-10.57%	8.00%	-3.8	24.8	2.10	ranT
SpdAv= 51.8			16.77%	10.21%	17.07%	37.1	42.0	6.22	sigT
SpdSd= 35.2			4.865E-03	4.758E-08	331.9	-31.7	24.2	2.10	Tot.
SoSav= 364.1			9.39%	-4.38%	15.23%				T-76
SoSpt= 378.4			1.868E-09	1.413E-14	173.2			0.0%	H2O
			6.723E-10	5.088E-15	0.0			0.0%	sigH
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112.000	6.050	-147.730	6.134E-03	7.115E-08	281.5	-26.0	-0.9	-0.000	Mean
6489.898	6.090		10.43%	4.05%	6.62%				M-76
840.0	GRM	0.0000	-0.82%	-11.95%	18.42%	20.4	8.2		ranS
			3.64%	8.82%	12.66%	24.3	25.7		sigS
Wind and SoS			-8.26%	-4.38%	-9.76%	-29.2	24.4		ranL
-----			15.88%	6.53%	9.37%	31.7	33.6		sigL
Ruv = 0.010			-9.08%	-16.33%	8.66%	-8.8	32.7	-2.25	ranT
SpdAv= 52.2			16.29%	10.98%	15.75%	39.9	42.3	6.09	sigT
SpdSd= 36.6			5.577E-03	5.953E-08	305.9	-34.8	31.8	-2.25	Tot.
SoSav= 347.4			0.40%	-12.94%	15.85%				T-76
SoSpt= 362.2			2.433E-09	1.999E-14	166.0			0.0%	H2O
			8.759E-10	7.195E-15	0.0			0.0%	sigH
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110.000	6.450	-146.530	7.637E-03	9.791E-08	256.3	-22.7	-1.3	-0.000	Mean
6487.866	6.492		7.50%	0.85%	6.80%				M-76
900.0	GRM	0.0000	-4.08%	-15.90%	17.83%	4.0	68.1		ranS
			3.53%	9.36%	11.44%	25.6	25.8		sigS
Wind and SoS			-10.41%	-5.60%	-8.91%	-27.3	28.8		ranL
-----			15.40%	7.02%	8.59%	33.7	34.0		sigL
Ruv = 0.010			-14.49%	-21.50%	8.92%	-23.3	97.0	0.22	ranT
SpdAv= 52.0			15.80%	11.70%	14.30%	42.3	42.7	5.95	sigT

SpdSd= 37.8			6.530E-03	7.686E-08	279.2	-46.0	95.7	0.22	Tot.
SoSav= 330.5			-8.08%	-20.83%	16.33%				T-76
SoSpt= 344.9			3.243E-09	2.906E-14	158.2			0.0%	H2O
			1.167E-09	1.046E-14	0.0			0.0%	sigH
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108.000	6.850	-145.330	9.758E-03	1.367E-07	236.1	-18.0	-1.8	-0.000	Mean
6485.831	6.895		4.71%	-1.04%	5.73%				M-76
960.0	GRM	0.0000	-2.57%	-1.57%	-1.35%	7.5	40.5		ranS
			3.42%	9.91%	10.38%	23.5	25.2		sigS
Wind and SoS			-14.47%	-6.85%	-8.07%	-21.4	31.8		ranL
-----			14.91%	7.54%	7.90%	31.2	33.4		sigL
Ruv = 0.010			-17.05%	-8.42%	-9.42%	-14.0	72.3	1.48	ranT
SpdAv= 48.1			15.29%	12.45%	13.05%	39.0	41.9	5.81	sigT
SpdSd= 36.0			8.094E-03	1.252E-07	213.8	-32.0	70.5	1.48	Tot.
SoSav= 316.1			-13.14%	-9.38%	-4.23%				T-76
SoSpt= 300.9			4.507E-09	4.357E-14	151.3			0.0%	H2O
			1.623E-09	1.569E-14	0.0			0.0%	sigH
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106.000	7.250	-144.130	1.281E-02	1.955E-07	218.1	-12.7	-2.4	-0.000	Mean
6483.795	7.298		2.84%	0.09%	2.46%				M-76
1020.0	GRM	0.0000	-2.94%	-10.35%	8.77%	16.4	17.7		ranS
			3.30%	10.42%	9.23%	21.4	24.6		sigS
Wind and SoS			-14.33%	-8.05%	-7.37%	-15.8	34.1		ranL
-----			14.40%	8.04%	7.13%	28.7	32.9		sigL
Ruv = 0.010			-17.26%	-18.40%	1.40%	0.6	51.8	0.95	ranT
SpdAv= 44.3			14.77%	13.16%	11.66%	35.8	41.1	5.68	sigT
SpdSd= 34.2			1.060E-02	1.595E-07	221.2	-12.1	49.4	0.95	Tot.
SoSav= 302.8			-14.91%	-18.33%	3.89%				T-76
SoSpt= 304.9			6.438E-09	6.690E-14	144.7			0.0%	H2O
			2.318E-09	2.408E-14	0.0			0.0%	sigH
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104.000	7.650	-142.930	1.728E-02	2.839E-07	204.1	-8.1	-3.2	-0.000	Mean
6481.756	7.700		2.37%	2.56%	-0.59%				M-76
1080.0	GRM	0.0000	-2.30%	-5.18%	2.91%	21.0	-21.6		ranS
			3.19%	10.95%	8.12%	22.1	24.1		sigS
Wind and SoS			-15.58%	-9.21%	-7.00%	-12.2	35.9		ranL
-----			13.89%	8.57%	6.36%	29.8	32.6		sigL
Ruv = 0.009			-17.89%	-14.39%	-4.09%	8.8	14.3	0.69	ranT
SpdAv= 43.6			14.25%	13.90%	10.31%	37.1	40.5	5.54	sigT
SpdSd= 34.5			1.419E-02	2.431E-07	195.8	0.7	11.1	0.69	Tot.
SoSav= 291.9			-15.94%	-12.20%	-4.65%				T-76
SoSpt= 285.9			9.394E-09	1.036E-13	139.2			0.0%	H2O
			3.382E-09	3.730E-14	0.0			0.0%	sigH
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102.000	8.050	-141.730	2.385E-02	4.139E-07	194.5	-4.8	-4.1	-0.000	Mean
6479.716	8.103		3.12%	5.26%	-2.51%				M-76
1140.0	GRM	0.0000	-3.42%	-12.71%	7.80%	21.0	-13.7		ranS
			3.07%	11.49%	7.06%	25.1	23.8		sigS
Wind and SoS			-18.49%	-10.30%	-6.36%	-9.0	37.2		ranL
-----			13.39%	9.12%	5.60%	34.2	32.4		sigL
Ruv = 0.009			-21.91%	-23.02%	1.44%	12.0	23.6	1.36	ranT
SpdAv= 45.9			13.73%	14.67%	9.02%	42.4	40.2	5.40	sigT
SpdSd= 36.7			1.862E-02	3.186E-07	197.3	7.2	19.4	1.35	Tot.
SoSav= 284.0			-19.47%	-18.97%	-1.10%				T-76
SoSpt= 286.1			1.393E-08	1.601E-13	135.4			0.0%	H2O
			5.014E-09	5.762E-14	0.1			0.0%	sigH
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100.000	8.450	-140.530	3.351E-02	6.094E-07	186.9	-2.7	-5.2	-0.000	Mean
6477.673	8.505		4.69%	8.75%	-4.19%				M-76
1200.0	GRM	0.0000	-4.93%	-19.68%	9.53%	9.6	35.5		ranS
			2.95%	12.00%	5.84%	27.7	23.5		sigS
Wind and SoS			-23.21%	-11.25%	-5.49%	-4.3	38.0		ranL
-----			12.87%	9.65%	4.70%	38.0	32.3		sigL

Ruv =	0.009			-28.14%	-30.93%	4.04%	5.3	73.5	-4.01	ranT
SpdAv=	48.4			13.20%	15.40%	7.50%	47.0	40.0	5.26	sigT
SpdSd=	38.8			2.408E-02	4.209E-07	194.5	2.6	68.3	-4.01	Tot.
SoSav=	277.5			-24.77%	-24.89%	-0.32%				T-76
SoSpt=	283.0			2.103E-08	2.498E-13	132.2			0.0%	H2O
				7.571E-09	8.994E-14	0.3			0.0%	sigH
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	98.000	8.850	-139.330	4.775E-02	8.875E-07	183.9	-2.1	-6.0	-0.001	Mean
	6475.628	8.908		6.08%	10.07%	-4.09%				M-76
	1260.0	GRM	0.0000	-1.83%	0.47%	-1.64%	2.6	16.8		ranS
				3.05%	11.33%	5.91%	26.9	21.4		sigS
Wind and SoS				-15.54%	-11.17%	-5.83%	1.0	35.7		ranL
-----				13.32%	9.46%	4.94%	37.8	30.2		sigL
Ruv =	0.009			-17.37%	-10.70%	-7.48%	3.7	52.4	-9.67	ranT
SpdAv=	46.6			13.66%	14.76%	7.70%	46.4	37.0	5.16	sigT
SpdSd=	37.3			3.946E-02	7.926E-07	170.1	1.6	46.4	-9.67	Tot.
SoSav=	274.5			-12.35%	-1.70%	-11.26%				T-76
SoSpt=	264.0			3.397E-08	4.080E-13	131.1			0.0%	H2O
				1.223E-08	1.469E-13	0.6			0.0%	sigH
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	96.000	9.250	-138.130	6.841E-02	1.291E-06	182.1	-2.3	-6.5	-0.001	Mean
	6473.582	9.310		7.28%	11.07%	-3.81%				M-76
	1320.0	GRM	0.0000	-1.19%	-2.06%	0.69%	19.5	-1.2		ranS
				3.17%	10.66%	5.97%	26.0	19.1		sigS
Wind and SoS				-16.44%	-10.87%	-6.09%	6.2	32.2		ranL
-----				13.80%	9.23%	5.17%	37.5	27.5		sigL
Ruv =	0.008			-17.63%	-12.93%	-5.40%	25.7	31.0	-5.43	ranT
SpdAv=	44.6			14.16%	14.10%	7.90%	45.7	33.5	5.06	sigT
SpdSd=	35.6			5.635E-02	1.124E-06	172.3	23.3	24.5	-5.43	Tot.
SoSav=	272.4			-11.63%	-3.29%	-9.00%				T-76
SoSpt=	265.0			5.516E-08	6.655E-13	131.9			0.0%	H2O
				1.986E-08	2.396E-13	0.8			0.0%	sigH
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	94.000	9.650	-136.930	9.907E-02	1.872E-06	182.6	-3.6	-6.8	-0.001	Mean
	6471.533	9.713		9.39%	12.10%	-2.74%				M-76
	1380.0	GRM	0.0000	-0.50%	-0.13%	-0.33%	7.8	7.5		ranS
				3.29%	10.01%	6.04%	26.4	18.0		sigS
Wind and SoS				-15.94%	-10.40%	-6.27%	11.6	30.5		ranL
-----				14.33%	8.99%	5.43%	38.9	26.6		sigL
Ruv =	0.008			-16.44%	-10.54%	-6.60%	19.4	38.0	-1.64	ranT
SpdAv=	45.0			14.71%	13.45%	8.12%	47.0	32.1	4.96	sigT
SpdSd=	35.8			8.278E-02	1.675E-06	170.5	15.8	31.1	-1.64	Tot.
SoSav=	272.2			-8.59%	0.28%	-9.16%				T-76
SoSpt=	263.1			9.327E-08	1.118E-12	133.2			0.0%	H2O
				3.358E-08	4.024E-13	0.8			0.0%	sigH
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	92.000	10.050	-135.730	1.441E-01	2.695E-06	185.1	-5.5	-7.0	0.003	Mean
	6469.483	10.115		11.85%	12.64%	-0.99%				M-76
	1440.0	GRM	0.0000	0.21%	1.46%	-1.28%	-23.4	-1.7		ranS
				3.42%	9.38%	6.12%	27.5	18.5		sigS
Wind and SoS				-15.54%	-9.78%	-6.36%	17.6	30.9		ranL
-----				14.90%	8.73%	5.70%	41.6	28.0		sigL
Ruv =	0.008			-15.33%	-8.32%	-7.64%	-5.7	29.3	-1.38	ranT
SpdAv=	47.6			15.29%	12.81%	8.36%	49.9	33.5	4.85	sigT
SpdSd=	37.8			1.220E-01	2.471E-06	171.0	-11.3	22.2	-1.38	Tot.
SoSav=	273.6			-5.30%	3.27%	-8.56%				T-76
SoSpt=	263.0			1.632E-07	1.923E-12	134.8			0.0%	H2O
				5.876E-08	6.924E-13	0.9			0.0%	sigH
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	90.000	10.450	-134.530	2.082E-01	3.845E-06	188.0	-6.6	-6.7	0.004	Mean
	6467.430	10.518		13.38%	12.54%	0.61%				M-76
	1500.0	GRM	0.0000	-0.33%	-1.31%	1.16%	-24.2	12.8		ranS
				3.52%	8.74%	6.18%	28.3	18.8		sigS

Wind and SoS				-14.64%	-9.01%	-6.34%	23.9	30.9		ranL
-----				15.36%	8.43%	5.96%	44.0	29.3		sigL
Ruv = 0.008				-14.96%	-10.32%	-5.18%	-0.3	43.6	-3.17	ranT
SpdAv= 49.8				15.76%	12.14%	8.58%	52.3	34.8	4.75	sigT
SpdSd= 39.5				1.770E-01	3.448E-06	178.3	-6.9	36.9	-3.17	Tot.
SoSav= 275.3				-3.59%	0.92%	-4.60%				T-76
SoSpt= 268.1				2.845E-07	3.278E-12	136.4			0.0%	H2O
				1.024E-07	1.180E-12	0.9			0.0%	sigH
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88.000	10.850	-133.330		2.957E-01	5.367E-06	191.5	-3.8	-5.1	0.003	Mean
6465.376	10.920			12.97%	10.09%	2.48%				M-76
1560.0	GRM	0.0000		-2.85%	-8.88%	7.16%	-40.0	-2.4		ranS
				2.93%	7.20%	5.16%	27.1	19.4		sigS
Wind and SoS				-10.18%	-7.23%	-3.48%	28.2	30.6		ranL
-----				12.78%	7.19%	5.16%	43.2	30.9		sigL
Ruv = 0.009				-13.03%	-16.12%	3.68%	-11.8	28.2	-0.30	ranT
SpdAv= 49.1				13.11%	10.18%	7.29%	50.9	36.4	4.49	sigT
SpdSd= 39.4				2.571E-01	4.502E-06	198.5	-15.6	23.1	-0.30	Tot.
SoSav= 277.7				-1.75%	-7.65%	6.25%				T-76
SoSpt= 282.8				4.789E-07	5.419E-12	138.0			0.0%	H2O
				1.724E-07	1.951E-12	0.9			0.0%	sigH
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86.000	11.250	-132.130		4.174E-01	7.449E-06	195.0	-0.9	-3.6	0.002	Mean
6463.319	11.323			11.80%	7.07%	4.36%				M-76
1620.0	GRM	0.0000		-2.42%	-5.01%	3.09%	4.9	2.9		ranS
				2.20%	5.36%	3.99%	26.0	19.7		sigS
Wind and SoS				-5.84%	-5.16%	-0.97%	32.1	29.7		ranL
-----				9.59%	5.55%	4.13%	42.6	32.3		sigL
Ruv = 0.011				-8.26%	-10.17%	2.12%	37.0	32.5	5.63	ranT
SpdAv= 48.8				9.84%	7.71%	5.74%	49.9	37.8	4.22	sigT
SpdSd= 39.3				3.829E-01	6.692E-06	199.2	36.1	28.9	5.64	Tot.
SoSav= 280.1				2.56%	-3.82%	6.57%				T-76
SoSpt= 283.0				8.014E-07	8.904E-12	139.7			0.0%	H2O
				2.885E-07	3.206E-12	1.0			0.0%	sigH
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84.000	11.650	-130.930		5.844E-01	1.027E-05	198.2	1.6	-2.9	0.001	Mean
6461.261	11.725			10.04%	5.90%	3.86%				M-76
1680.0	GRM	0.0000		-0.50%	0.85%	-1.62%	22.4	-45.9		ranS
				1.64%	4.00%	3.14%	24.3	18.5		sigS
Wind and SoS				-3.18%	-3.63%	0.69%	34.5	26.2		ranL
-----				7.14%	4.29%	3.37%	40.9	31.2		sigL
Ruv = 0.012				-3.69%	-2.78%	-0.94%	56.9	-19.6	-2.79	ranT
SpdAv= 46.7				7.33%	5.86%	4.61%	47.6	36.3	3.93	sigT
SpdSd= 37.6				5.628E-01	9.981E-06	196.4	58.5	-22.5	-2.79	Tot.
SoSav= 282.3				5.98%	2.96%	2.89%				T-76
SoSpt= 281.0				1.344E-06	1.470E-11	141.4			0.0%	H2O
				4.840E-07	5.292E-12	1.0			0.0%	sigH
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82.000	12.050	-129.730		8.121E-01	1.407E-05	201.0	4.1	-3.0	0.001	Mean
6459.200	12.128			8.26%	4.84%	3.23%				M-76
1740.0	GRM	0.0000		-0.37%	-1.00%	0.74%	19.8	-27.0		ranS
				1.45%	3.57%	2.83%	21.8	16.0		sigS
Wind and SoS				-1.49%	-3.00%	1.49%	34.7	20.8		ranL
-----				6.34%	3.97%	3.15%	37.7	27.6		sigL
Ruv = 0.013				-1.86%	-4.00%	2.23%	54.5	-6.1	-3.99	ranT
SpdAv= 42.3				6.51%	5.34%	4.23%	43.5	31.9	3.62	sigT
SpdSd= 33.9				7.970E-01	1.350E-05	205.5	58.7	-9.1	-3.99	Tot.
SoSav= 284.3				6.25%	0.65%	5.54%				T-76
SoSpt= 287.4				2.263E-06	2.439E-11	143.1			0.0%	H2O
				8.148E-07	8.783E-12	1.0			0.0%	sigH
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80.000	12.450	-128.530		1.123E+00	1.920E-05	203.8	7.1	-3.2	0.001	Mean
6457.138	12.530			6.74%	4.04%	2.58%				M-76

1800.0	GRM	0.0000	0.01%	0.24%	-0.26%	13.0	-27.8		ranS
			1.25%	3.12%	2.51%	19.2	13.2		sigS
Wind and SoS			-0.32%	-2.37%	2.13%	33.7	15.6		ranL
-----			5.44%	3.60%	2.89%	34.1	23.5		sigL
Ruv = 0.014			-0.31%	-2.14%	1.87%	46.7	-12.2	-4.87	ranT
SpdAv= 37.7			5.58%	4.76%	3.82%	39.1	26.9	3.30	sigT
SpdSd= 29.8			1.120E+00	1.879E-05	207.6	53.8	-15.4	-4.87	Tot.
SoSav= 286.2			6.41%	1.81%	4.50%				T-76
SoSpt= 288.9			3.458E-06	3.677E-11	144.6			0.0%	H2O
			1.084E-06	1.153E-11	0.9			0.0%	sigH

78.000	12.850	-127.330	1.549E+00	2.618E-05	206.0	13.6	-1.1	0.000	Mean
6455.074	12.933		5.54%	3.73%	1.72%				M-76
1860.0	GRM	0.0000	0.72%	1.87%	-1.34%	-23.8	-23.0		ranS
			1.24%	3.00%	2.44%	18.2	12.3		sigS
Wind and SoS			0.26%	-2.01%	2.47%	34.9	12.9		ranL
-----			5.40%	3.59%	2.92%	33.4	22.6		sigL
Ruv = 0.016			0.98%	-0.14%	1.13%	11.1	-10.1	-4.08	ranT
SpdAv= 38.2			5.54%	4.68%	3.80%	38.0	25.8	2.98	sigT
SpdSd= 28.9			1.564E+00	2.614E-05	208.3	24.7	-11.1	-4.08	Tot.
SoSav= 287.8			6.58%	3.58%	2.87%				T-76
SoSpt= 289.4			4.018E-06	4.225E-11	145.0			0.0%	H2O
			1.494E-06	1.571E-11	1.1			0.0%	sigH

76.000	13.250	-126.130	2.128E+00	3.559E-05	208.3	20.1	0.8	-0.000	Mean
6453.008	13.335		4.68%	3.72%	0.89%				M-76
1920.0	GRM	0.0000	1.18%	4.01%	-3.35%	-33.8	-12.0		ranS
			1.23%	2.88%	2.37%	17.2	11.5		sigS
Wind and SoS			0.57%	-1.65%	2.75%	35.5	10.4		ranL
-----			5.37%	3.57%	2.94%	32.6	21.7		sigL
Ruv = 0.017			1.75%	2.36%	-0.60%	1.7	-1.7	0.86	ranT
SpdAv= 39.9			5.51%	4.59%	3.78%	36.9	24.6	2.67	sigT
SpdSd= 27.8			2.166E+00	3.643E-05	207.0	21.7	-0.8	0.86	Tot.
SoSav= 289.4			6.51%	6.17%	0.28%				T-76
SoSpt= 288.5			6.122E-06	6.369E-11	146.4			0.0%	H2O
			2.053E-06	2.136E-11	1.1			0.0%	sigH

74.000	13.650	-124.930	2.919E+00	4.805E-05	211.6	25.4	1.5	-0.000	Mean
6450.940	13.737		4.20%	3.58%	0.58%				M-76
1980.0	GRM	0.0000	2.86%	5.83%	-3.48%	-31.3	-4.5		ranS
			1.18%	2.72%	2.22%	17.0	10.8		sigS
Wind and SoS			1.10%	-1.27%	2.90%	35.1	7.2		ranL
-----			5.13%	3.49%	2.85%	31.2	19.7		sigL
Ruv = 0.004			3.95%	4.56%	-0.58%	3.8	2.6	-0.18	ranT
SpdAv= 41.4			5.26%	4.43%	3.61%	35.5	22.4	2.39	sigT
SpdSd= 26.4			3.034E+00	5.024E-05	210.3	29.2	4.1	-0.18	Tot.
SoSav= 291.6			8.32%	8.31%	-0.01%				T-76
SoSpt= 290.8			9.302E-06	9.526E-11	148.2			0.0%	H2O
			2.816E-06	2.884E-11	0.9			0.0%	sigH

72.000	14.050	-123.730	3.983E+00	6.428E-05	215.9	29.7	1.1	-0.000	Mean
6448.871	14.140		3.83%	3.07%	0.75%				M-76
2040.0	GRM	0.0000	1.79%	1.34%	0.51%	-32.3	4.1		ranS
			1.06%	2.51%	1.97%	17.5	9.7		sigS
Wind and SoS			2.04%	-0.89%	2.86%	33.8	3.7		ranL
-----			4.61%	3.33%	2.61%	29.4	16.3		sigL
Ruv = -0.024			3.83%	0.45%	3.37%	1.5	7.8	1.47	ranT
SpdAv= 42.5			4.73%	4.17%	3.26%	34.2	19.0	2.15	sigT
SpdSd= 24.6			4.136E+00	6.457E-05	223.1	31.2	9.0	1.47	Tot.
SoSav= 294.5			7.81%	3.53%	4.14%				T-76
SoSpt= 299.5			1.691E-05	1.698E-10	151.2			0.0%	H2O
			4.812E-06	4.831E-11	0.7			0.0%	sigH

70.000	14.450	-122.530	5.404E+00	8.555E-05	220.1	34.1	0.8	-0.000	Mean
6446.799	14.542		3.50%	3.28%	0.24%				M-76
2100.0	GRM	0.0000	1.68%	2.70%	-1.07%	-20.7	2.5		ranS
			0.92%	2.29%	1.70%	17.8	8.0		sigS
Wind and SoS			2.15%	-0.54%	2.70%	32.2	1.1		ranL
-----			4.02%	3.13%	2.33%	27.6	12.4		sigL
Ruv = -0.052			3.83%	2.16%	1.63%	11.5	3.6	1.70	ranT
SpdAv= 44.1			4.13%	3.88%	2.88%	32.8	14.7	1.91	sigT
SpdSd= 22.6			5.611E+00	8.740E-05	223.7	45.6	4.4	1.70	Tot.
SoSav= 297.4			7.46%	5.51%	1.87%				T-76
SoSpt= 299.8			3.004E-05	2.957E-10	154.1			0.0%	H2O
			7.602E-06	7.484E-11	0.6			0.0%	sigH
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68.000	14.850	-121.330	7.281E+00	1.121E-04	226.4	35.1	0.6	-0.000	Mean
6444.726	14.945		3.22%	2.67%	0.58%				M-76
2160.0	GRM	0.0000	0.84%	-1.36%	2.15%	-5.8	-7.5		ranS
			0.90%	2.31%	1.61%	17.3	8.5		sigS
Wind and SoS			2.27%	-0.28%	2.68%	29.4	0.9		ranL
-----			3.94%	3.26%	2.28%	25.0	12.3		sigL
Ruv = -0.008			3.11%	-1.64%	4.83%	23.6	-6.6	-0.26	ranT
SpdAv= 43.9			4.04%	4.00%	2.79%	30.4	15.0	1.76	sigT
SpdSd= 21.3			7.508E+00	1.102E-04	237.3	58.7	-6.0	-0.26	Tot.
SoSav= 301.6			6.43%	0.98%	5.44%				T-76
SoSpt= 308.8			4.839E-05	4.632E-10	157.6			0.0%	H2O
			9.194E-06	8.800E-11	0.3			0.0%	sigH
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66.000	15.250	-120.130	9.730E+00	1.458E-04	232.5	36.3	0.4	-0.000	Mean
6442.651	15.347		2.84%	2.00%	0.86%				M-76
2220.0	GRM	0.0000	0.51%	0.14%	0.35%	6.5	-11.3		ranS
			0.88%	2.30%	1.52%	16.5	9.1		sigS
Wind and SoS			2.58%	-0.01%	2.62%	26.4	0.9		ranL
-----			3.83%	3.36%	2.22%	22.3	12.3		sigL
Ruv = 0.037			3.09%	0.12%	2.96%	32.9	-10.4	0.56	ranT
SpdAv= 43.9			3.93%	4.07%	2.69%	27.8	15.3	1.61	sigT
SpdSd= 19.9			1.003E+01	1.460E-04	239.4	69.2	-10.0	0.56	Tot.
SoSav= 305.6			6.02%	2.13%	3.85%				T-76
SoSpt= 310.1			7.695E-05	7.170E-10	161.0			0.0%	H2O
			1.106E-05	1.031E-10	0.2			0.0%	sigH
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64.000	15.650	-118.930	1.292E+01	1.890E-04	238.2	36.3	0.4	0.001	Mean
6440.574	15.749		2.49%	1.60%	0.90%				M-76
2280.0	GRM	0.0000	-0.07%	0.32%	-0.34%	-0.3	-12.5		ranS
			0.92%	2.40%	1.47%	16.4	9.5		sigS
Wind and SoS			2.80%	0.25%	2.50%	23.9	0.6		ranL
-----			3.99%	3.44%	2.12%	20.2	11.7		sigL
Ruv = 0.059			2.73%	0.56%	2.16%	23.6	-11.9	-1.11	ranT
SpdAv= 43.2			4.10%	4.20%	2.58%	26.0	15.0	1.55	sigT
SpdSd= 18.9			1.327E+01	1.901E-04	243.3	59.9	-11.5	-1.11	Tot.
SoSav= 309.3			5.28%	2.17%	3.07%				T-76
SoSpt= 312.7			1.111E-04	1.011E-09	163.8			0.0%	H2O
			1.659E-05	1.509E-10	0.1			0.0%	sigH
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62.000	16.050	-117.730	1.707E+01	2.444E-04	243.3	35.1	0.5	0.001	Mean
6438.495	16.152		2.28%	1.53%	0.74%				M-76
2340.0	GRM	0.0000	-1.04%	-3.57%	2.12%	-21.9	-3.2		ranS
			1.01%	2.63%	1.45%	17.0	9.5		sigS
Wind and SoS			2.20%	0.49%	2.24%	22.0	0.0		ranL
-----			4.42%	3.54%	1.95%	18.7	10.5		sigL
Ruv = 0.061			1.16%	-3.08%	4.37%	0.1	-3.2	0.91	ranT
SpdAv= 41.7			4.54%	4.41%	2.43%	25.3	14.2	1.58	sigT
SpdSd= 18.2			1.727E+01	2.369E-04	253.9	35.2	-2.7	0.91	Tot.
SoSav= 312.7			3.46%	-1.60%	5.14%				T-76
SoSpt= 319.5			1.580E-04	1.407E-09	166.3			0.0%	H2O

				2.530E-05	2.253E-10	0.1			0.0%	sigH
60.000	16.450	-116.530		2.243E+01	3.144E-04	248.4	34.0	0.6	0.001	Mean
6436.414	16.554			2.12%	1.53%	0.57%				M-76
2400.0	GRM	0.0000		-2.06%	-5.15%	2.44%	-3.3	2.6		ranS
				1.10%	2.86%	1.41%	17.4	9.4		sigS
Wind and SoS				1.41%	0.72%	1.51%	20.1	-0.3		ranL
-----				4.81%	3.61%	1.78%	17.2	9.3		sigL
Ruv = 0.063				-0.65%	-4.43%	3.95%	16.8	2.3	-0.69	ranT
SpdAv= 40.3				4.94%	4.61%	2.27%	24.4	13.2	1.61	sigT
SpdSd= 17.5				2.228E+01	3.005E-04	258.2	50.8	2.9	-0.69	Tot.
SoSav= 316.0				1.46%	-2.96%	4.55%				T-76
SoSpt= 322.2				2.140E-04	1.866E-09	168.7			0.0%	H2O
				3.383E-05	2.950E-10	0.1			0.0%	sigH

58.000	16.850	-115.330		2.929E+01	4.026E-04	253.5	29.5	0.2	0.000	Mean
6434.332	16.956			1.96%	1.59%	0.38%				M-76
2460.0	GRM	0.0000		-0.73%	0.19%	-0.72%	12.4	0.1		ranS
				1.06%	2.84%	1.40%	17.9	9.4		sigS
Wind and SoS				1.49%	0.85%	0.45%	19.1	-0.4		ranL
-----				4.62%	3.37%	1.66%	16.4	8.6		sigL
Ruv = 0.073				0.76%	1.03%	-0.27%	31.4	-0.3	1.49	ranT
SpdAv= 36.4				4.74%	4.40%	2.18%	24.3	12.7	1.53	sigT
SpdSd= 17.3				2.951E+01	4.068E-04	252.8	60.9	-0.1	1.49	Tot.
SoSav= 319.1				2.73%	2.64%	0.11%				T-76
SoSpt= 318.7				2.725E-04	2.329E-09	170.6			0.0%	H2O
				3.807E-05	3.254E-10	0.1			0.0%	sigH

56.000	17.250	-114.130		3.805E+01	5.129E-04	258.6	25.0	-0.3	-0.000	Mean
6432.248	17.358			1.84%	1.67%	0.22%				M-76
2520.0	GRM	0.0000		0.93%	4.02%	-2.41%	18.3	-8.0		ranS
				1.02%	2.80%	1.39%	18.5	9.3		sigS
Wind and SoS				1.99%	0.92%	0.49%	18.0	-0.4		ranL
-----				4.43%	3.13%	1.55%	15.7	7.9		sigL
Ruv = 0.081				2.92%	4.94%	-1.93%	36.3	-8.3	2.80	ranT
SpdAv= 32.8				4.55%	4.20%	2.09%	24.3	12.2	1.46	sigT
SpdSd= 17.1				3.916E+01	5.383E-04	253.6	61.3	-8.6	2.80	Tot.
SoSav= 322.3				4.81%	6.70%	-1.71%				T-76
SoSpt= 319.2				3.453E-04	2.893E-09	172.6			0.0%	H2O
				4.274E-05	3.581E-10	0.1			0.0%	sigH

54.000	17.650	-112.930		4.920E+01	6.535E-04	262.4	21.0	-0.5	-0.000	Mean
6430.162	17.761			1.78%	2.26%	-0.42%				M-76
2580.0	GRM	0.0000		2.01%	5.55%	-2.79%	-6.1	-14.0		ranS
				0.98%	2.71%	1.36%	18.9	9.3		sigS
Wind and SoS				2.09%	0.97%	0.51%	17.5	-0.6		ranL
-----				4.26%	2.96%	1.49%	15.4	7.5		sigL
Ruv = 0.080				4.10%	6.52%	-2.27%	11.5	-14.6	-0.52	ranT
SpdAv= 29.8				4.37%	4.01%	2.02%	24.4	11.9	1.37	sigT
SpdSd= 17.0				5.122E+01	6.961E-04	256.5	32.5	-15.1	-0.52	Tot.
SoSav= 324.7				5.95%	8.94%	-2.68%				T-76
SoSpt= 320.9				4.357E-04	3.598E-09	174.0			0.0%	H2O
				4.789E-05	3.954E-10	0.1			0.0%	sigH

52.000	18.050	-111.730		6.343E+01	8.341E-04	265.0	17.3	-0.6	-0.000	Mean
6428.075	18.163			1.95%	3.53%	-1.50%				M-76
2640.0	GRM	0.0000		1.00%	0.76%	0.19%	-1.4	4.2		ranS
				0.94%	2.56%	1.31%	19.1	9.2		sigS
Wind and SoS				1.51%	1.00%	0.54%	17.6	-1.1		ranL
-----				4.08%	2.83%	1.45%	15.6	7.5		sigL
Ruv = 0.071				2.51%	1.77%	0.73%	16.3	3.1	-2.14	ranT
SpdAv= 27.4				4.19%	3.82%	1.95%	24.7	11.9	1.26	sigT
SpdSd= 17.2				6.502E+01	8.488E-04	266.9	33.6	2.5	-2.14	Tot.

SoSav= 326.3			4.50%	5.36%	-0.78%				T-76
SoSpt= 327.5			5.609E-04	4.586E-09	175.1			0.0%	H2O
			5.379E-05	4.398E-10	0.1			0.0%	sigH

50.000	18.450	-110.530	8.158E+01	1.062E-03	267.7	13.5	-0.6	-0.000	Mean
6425.985	18.565		2.26%	3.41%	-1.10%				M-76
2700.0	GRM	0.0000	1.08%	2.24%	-0.96%	-15.1	4.6		ranS
			0.89%	2.40%	1.24%	19.3	9.1		sigS
Wind and SoS			1.73%	1.00%	0.54%	17.8	-1.4		ranL
-----			3.90%	2.70%	1.40%	15.8	7.5		sigL
Ruv = 0.063			2.81%	3.24%	-0.42%	2.7	3.2	-0.61	ranT
SpdAv= 25.4			4.00%	3.62%	1.87%	25.0	11.8	1.15	sigT
SpdSd= 17.4			8.387E+01	1.096E-03	266.5	16.2	2.6	-0.61	Tot.
SoSav= 328.0			5.13%	6.76%	-1.52%				T-76
SoSpt= 327.3			6.984E-04	5.653E-09	175.9			0.0%	H2O
			5.267E-05	4.264E-10	0.0			0.0%	sigH

48.000	18.850	-109.330	1.048E+02	1.368E-03	266.8	13.6	-0.7	-0.000	Mean
6423.895	18.967		2.41%	3.91%	-1.44%				M-76
2760.0	GRM	0.0000	1.53%	3.65%	-1.79%	6.2	-8.1		ranS
			0.85%	2.30%	1.24%	18.7	8.5		sigS
Wind and SoS			2.72%	1.00%	1.40%	17.7	-1.5		ranL
-----			3.71%	2.67%	1.44%	15.7	7.1		sigL
Ruv = 0.061			4.25%	4.65%	-0.39%	23.8	-9.6	-0.64	ranT
SpdAv= 24.9			3.81%	3.53%	1.91%	24.4	11.1	1.05	sigT
SpdSd= 16.8			1.092E+02	1.432E-03	265.7	37.5	-10.3	-0.64	Tot.
SoSav= 327.4			6.76%	8.75%	-1.82%				T-76
SoSpt= 326.8			8.568E-04	6.959E-09	175.3			0.0%	H2O
			5.117E-05	4.156E-10	0.0			0.0%	sigH

46.000	19.250	-108.130	1.346E+02	1.764E-03	265.9	13.6	-0.7	0.000	Mean
6421.802	19.369		2.50%	2.89%	-0.38%				M-76
2820.0	GRM	0.0000	1.06%	1.46%	-0.35%	-24.9	-5.8		ranS
			0.81%	2.20%	1.25%	18.0	7.8		sigS
Wind and SoS			2.79%	0.98%	1.72%	17.6	-1.4		ranL
-----			3.51%	2.65%	1.50%	15.6	6.8		sigL
Ruv = 0.059			3.84%	2.44%	1.37%	-7.3	-7.3	0.25	ranT
SpdAv= 24.4			3.61%	3.44%	1.95%	23.8	10.3	0.94	sigT
SpdSd= 16.3			1.398E+02	1.807E-03	269.5	6.3	-8.0	0.25	Tot.
SoSav= 326.9			6.44%	5.40%	0.98%				T-76
SoSpt= 329.1			1.086E-03	8.847E-09	174.9			0.0%	H2O
			7.047E-05	5.743E-10	0.1			0.0%	sigH

44.000	19.650	-106.930	1.733E+02	2.291E-03	263.5	13.9	-0.8	0.000	Mean
6419.708	19.771		2.23%	1.43%	0.79%				M-76
2880.0	GRM	0.0000	0.90%	1.60%	-0.61%	5.5	-5.9		ranS
			0.76%	2.07%	1.23%	17.3	7.1		sigS
Wind and SoS			2.82%	0.90%	1.80%	17.2	-1.3		ranL
-----			3.32%	2.56%	1.53%	15.3	6.2		sigL
Ruv = 0.063			3.72%	2.50%	1.19%	22.7	-7.1	0.20	ranT
SpdAv= 23.9			3.41%	3.29%	1.97%	23.1	9.4	0.86	sigT
SpdSd= 15.7			1.797E+02	2.348E-03	266.6	36.7	-7.9	0.20	Tot.
SoSav= 325.4			6.04%	3.96%	1.99%				T-76
SoSpt= 327.3			1.360E-03	1.119E-08	173.8			0.0%	H2O
			8.185E-05	6.731E-10	0.1			0.0%	sigH

42.000	20.050	-105.730	2.239E+02	3.007E-03	259.4	14.7	-0.8	-0.000	Mean
6417.612	20.173		1.77%	0.39%	1.37%				M-76
2940.0	GRM	0.0000	1.09%	2.45%	-1.26%	3.9	-7.4		ranS
			0.72%	1.89%	1.20%	16.5	6.3		sigS
Wind and SoS			2.70%	0.78%	1.81%	16.5	-1.0		ranL
-----			3.13%	2.41%	1.53%	14.7	5.6		sigL
Ruv = 0.072			3.79%	3.23%	0.54%	20.4	-8.4	-0.37	ranT

SpdAv= 23.6			3.21%	3.06%	1.94%	22.1	8.4	0.81	sigT
SpdSd= 14.9			2.324E+02	3.104E-03	260.8	35.1	-9.2	-0.37	Tot.
SoSav= 322.9			5.64%	3.64%	1.92%				T-76
SoSpt= 323.8			1.696E-03	1.417E-08	172.0			0.0%	H2O
			8.753E-05	7.313E-10	0.2			0.0%	sigH
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40.000	20.450	-104.530	2.902E+02	3.961E-03	255.2	14.9	-0.9	-0.000	Mean
6415.515	20.576		1.06%	-0.86%	1.94%				M-76
3000.0	GRM	0.0000	1.24%	2.02%	-0.77%	-13.7	-0.5		ranS
			0.68%	1.71%	1.17%	15.6	5.5		sigS
Wind and SoS			2.49%	0.64%	1.81%	15.8	-0.7		ranL
-----			2.95%	2.25%	1.54%	14.0	4.9		sigL
Ruv = 0.080			3.73%	2.66%	1.05%	2.1	-1.2	0.91	ranT
SpdAv= 22.9			3.03%	2.83%	1.93%	21.0	7.4	0.75	sigT
SpdSd= 14.0			3.010E+02	4.067E-03	257.9	17.0	-2.1	0.91	Tot.
SoSav= 320.3			4.84%	1.78%	3.00%				T-76
SoSpt= 321.9			2.381E-03	2.021E-08	170.7			0.0%	H2O
			9.956E-05	8.457E-10	0.2			0.0%	sigH
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38.000	20.850	-103.330	3.787E+02	5.287E-03	249.5	13.9	-1.0	-0.000	Mean
6413.416	20.978		0.42%	-1.47%	1.92%				M-76
3060.0	GRM	0.0000	0.86%	0.41%	0.47%	15.3	7.4		ranS
			0.63%	1.64%	1.22%	14.8	5.3		sigS
Wind and SoS			2.36%	0.48%	1.84%	15.1	-0.5		ranL
-----			2.76%	2.10%	1.57%	13.2	4.7		sigL
Ruv = 0.083			3.22%	0.89%	2.31%	30.4	6.9	0.38	ranT
SpdAv= 21.5			2.83%	2.67%	1.99%	19.9	7.1	0.70	sigT
SpdSd= 13.3			3.909E+02	5.335E-03	255.3	44.4	5.9	0.38	Tot.
SoSav= 316.7			3.65%	-0.60%	4.27%				T-76
SoSpt= 320.3			3.389E-03	2.943E-08	171.7			0.0%	H2O
			1.163E-04	1.011E-09	0.2			0.0%	sigH
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36.000	21.250	-102.130	4.973E+02	7.106E-03	243.8	12.8	-1.0	-0.000	Mean
6411.316	21.380		-0.24%	-2.10%	1.89%				M-76
3120.0	GRM	0.0000	0.67%	0.60%	0.08%	-9.0	1.5		ranS
			0.58%	1.55%	1.26%	13.9	5.1		sigS
Wind and SoS			2.19%	0.31%	1.85%	14.3	-0.2		ranL
-----			2.54%	1.95%	1.59%	12.4	4.5		sigL
Ruv = 0.086			2.87%	0.91%	1.93%	5.3	1.3	0.54	ranT
SpdAv= 20.1			2.60%	2.49%	2.03%	18.6	6.8	0.65	sigT
SpdSd= 12.5			5.116E+02	7.171E-03	248.5	18.1	0.3	0.53	Tot.
SoSav= 313.0			2.62%	-1.20%	3.86%				T-76
SoSpt= 316.0			4.381E-03	3.894E-08	172.6			0.0%	H2O
			1.370E-04	1.219E-09	0.2			0.0%	sigH
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34.000	21.650	-100.930	6.575E+02	9.614E-03	238.3	12.1	-0.9	-0.000	Mean
6409.214	21.782		-0.89%	-2.77%	1.95%				M-76
3180.0	GRM	0.0000	0.43%	1.02%	-0.66%	-13.6	-4.3		ranS
			0.53%	1.45%	1.25%	12.7	4.7		sigS
Wind and SoS			1.90%	0.14%	1.81%	13.4	0.1		ranL
-----			2.32%	1.79%	1.55%	11.5	4.2		sigL
Ruv = 0.076			2.33%	1.16%	1.16%	-0.2	-4.1	-0.30	ranT
SpdAv= 18.7			2.38%	2.30%	2.00%	17.1	6.3	0.61	sigT
SpdSd= 11.5			6.728E+02	9.725E-03	241.1	11.8	-5.0	-0.30	Tot.
SoSav= 309.4			1.42%	-1.64%	3.13%				T-76
SoSpt= 311.2			5.653E-03	5.140E-08	173.7			0.0%	H2O
			1.742E-04	1.586E-09	0.2			0.0%	sigH
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32.000	22.050	-99.730	8.751E+02	1.309E-02	233.0	11.8	-0.5	-0.000	Mean
6407.110	22.184		-1.57%	-3.43%	1.99%				M-76
3240.0	GRM	0.0000	0.29%	-0.86%	1.30%	11.0	1.0		ranS
			0.48%	1.31%	1.19%	11.3	4.1		sigS
Wind and SoS			1.81%	-0.04%	1.72%	12.2	0.4		ranL

-----				2.10%	1.62%	1.47%	10.3	3.8		sigL
Ruv = 0.052				2.10%	-0.90%	3.02%	23.2	1.4	-0.09	ranT
SpdAv= 17.3				2.16%	2.08%	1.89%	15.3	5.6	0.57	sigT
SpdSd= 10.2				8.935E+02	1.297E-02	240.1	35.0	0.9	-0.09	Tot.
SoSav= 305.9				0.49%	-4.29%	5.07%				T-76
SoSpt= 310.5				7.334E-03	6.819E-08	174.9			0.0%	H2O
				2.126E-04	1.979E-09	0.2			0.0%	sigH
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30.000	22.450	-98.530		1.172E+03	1.794E-02	227.8	11.3	-0.2	-0.000	Mean
6405.005	22.586			-2.11%	-2.57%	0.58%				M-76
3300.0	GRM	0.0000		0.11%	-0.68%	0.92%	1.3	-0.1		ranS
				0.41%	1.13%	1.09%	9.5	3.5		sigS
Wind and SoS				1.50%	-0.19%	1.58%	10.4	1.1		ranL
-----				1.81%	1.39%	1.34%	8.9	3.3		sigL
Ruv = 0.088				1.60%	-0.87%	2.49%	11.7	1.0	0.48	ranT
SpdAv= 15.7				1.86%	1.79%	1.73%	13.0	4.8	0.53	sigT
SpdSd= 8.5				1.191E+03	1.778E-02	233.5	23.0	0.8	0.48	Tot.
SoSav= 302.4				-0.54%	-3.42%	3.08%				T-76
SoSpt= 306.2				9.662E-03	9.190E-08	176.3			0.1%	H2O
				2.613E-04	2.487E-09	0.2			0.0%	sigH
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28.000	22.850	-97.330		1.581E+03	2.476E-02	222.5	8.8	0.7	-0.000	Mean
6402.899	22.987			-2.17%	-1.25%	-0.90%				M-76
3360.0	GRM	0.0000		0.20%	-0.66%	0.95%	0.0	-0.7		ranS
				0.31%	0.90%	0.85%	7.4	3.2		sigS
Wind and SoS				1.06%	-0.32%	1.31%	8.2	2.3		ranL
-----				1.34%	1.19%	1.12%	7.1	3.1		sigL
Ruv = 0.214				1.25%	-0.98%	2.26%	8.3	1.5	0.22	ranT
SpdAv= 12.4				1.37%	1.49%	1.40%	10.3	4.4	0.50	sigT
SpdSd= 6.5				1.601E+03	2.452E-02	227.5	17.0	2.2	0.22	Tot.
SoSav= 299.0				-0.95%	-2.23%	1.34%				T-76
SoSpt= 302.3				1.294E-02	1.260E-07	177.8			0.1%	H2O
				3.280E-04	3.197E-09	0.2			0.0%	sigH
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26.000	23.250	-96.130		2.143E+03	3.430E-02	217.7	5.9	2.1	-0.000	Mean
6400.791	23.389			-2.05%	0.14%	-2.17%				M-76
3420.0	GRM	0.0000		0.15%	-0.26%	0.45%	0.1	4.0		ranS
				0.23%	0.76%	0.76%	5.9	2.7		sigS
Wind and SoS				0.81%	-0.45%	1.23%	6.4	2.6		ranL
-----				1.00%	1.08%	1.08%	5.8	2.7		sigL
Ruv = 0.300				0.96%	-0.71%	1.68%	6.5	6.7	0.71	ranT
SpdAv= 9.6				1.02%	1.32%	1.32%	8.3	3.8	0.47	sigT
SpdSd= 5.5				2.164E+03	3.406E-02	221.4	12.4	8.8	0.71	Tot.
SoSav= 295.8				-1.11%	-0.57%	-0.53%				T-76
SoSpt= 298.2				1.723E-02	1.715E-07	179.3			0.3%	H2O
				4.658E-04	4.640E-09	0.2			0.0%	sigH
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24.000	23.650	-94.930		2.930E+03	4.763E-02	214.3	5.0	2.4	0.000	Mean
6398.681	23.791			-1.42%	1.48%	-2.86%				M-76
3480.0	GRM	0.0000		0.39%	0.71%	-0.35%	-6.6	4.9		ranS
				0.19%	0.65%	0.65%	4.6	2.8		sigS
Wind and SoS				0.54%	-0.54%	1.11%	4.8	2.7		ranL
-----				0.83%	0.95%	0.96%	4.6	2.8		sigL
Ruv = 0.227				0.93%	0.17%	0.76%	-1.8	7.5	0.54	ranT
SpdAv= 8.1				0.85%	1.16%	1.16%	6.5	3.9	0.44	sigT
SpdSd= 4.8				2.957E+03	4.771E-02	215.9	3.2	9.9	0.54	Tot.
SoSav= 293.4				-0.50%	1.65%	-2.11%				T-76
SoSpt= 294.6				2.241E-02	2.266E-07	180.7			0.6%	H2O
				6.709E-04	6.792E-09	0.2			0.0%	sigH
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22.000	24.050	-93.730		4.035E+03	6.716E-02	209.3	6.1	2.7	-0.000	Mean
6396.570	24.193			-0.30%	4.12%	-4.24%				M-76
3540.0	GRM	0.0000		0.27%	0.90%	-0.66%	-1.1	-0.8		ranS

				0.17%	0.69%	0.67%	3.9	2.6		sigS
Wind and SoS				0.37%	-0.70%	1.10%	3.8	2.6		ranL
-----				0.72%	0.97%	0.94%	3.9	2.6		sigL
Ruv = 0.189				0.64%	0.20%	0.44%	2.7	1.7	0.74	ranT
SpdAv= 8.4				0.74%	1.19%	1.15%	5.5	3.7	0.43	sigT
SpdSd= 4.5				4.061E+03	6.730E-02	210.2	8.8	4.5	0.74	Tot.
SoSav= 290.0				0.33%	4.33%	-3.82%				T-76
SoSpt= 290.6				2.822E-02	2.921E-07	182.0			1.5%	H2O
				1.010E-03	1.047E-08	0.3			0.1%	sigH
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20.000	24.450	-92.530		5.586E+03	9.537E-02	204.1	9.0	3.0	-0.000	Mean
6394.458	24.595			1.02%	7.26%	-5.81%				M-76
3600.0	GRM	0.0000		0.24%	0.50%	-0.27%	-3.5	-0.3		ranS
				0.16%	0.73%	0.71%	3.7	2.7		sigS
Wind and SoS				0.26%	-0.86%	1.13%	3.2	2.9		ranL
-----				0.68%	0.99%	0.96%	3.8	2.8		sigL
Ruv = 0.167				0.49%	-0.36%	0.86%	-0.2	2.6	0.75	ranT
SpdAv= 10.5				0.69%	1.23%	1.19%	5.3	3.9	0.42	sigT
SpdSd= 4.9				5.614E+03	9.502E-02	205.8	8.8	5.6	0.75	Tot.
SoSav= 286.4				1.52%	6.88%	-5.00%				T-76
SoSpt= 287.6				3.446E-02	3.659E-07	183.1			3.6%	H2O
				1.762E-03	1.873E-08	0.4			0.2%	sigH
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18.000	24.850	-91.330		7.819E+03	1.360E-01	200.3	16.2	4.0	-0.020	Mean
6392.345	24.997			3.35%	11.79%	-7.53%				M-76
3660.0	GRM	0.0000		-0.05%	1.57%	-1.71%	5.1	-4.7		ranS
				0.18%	0.76%	0.76%	4.9	3.7		sigS
Wind and SoS				0.03%	-1.00%	1.13%	3.5	4.1		ranL
-----				0.78%	0.99%	0.99%	5.0	3.7		sigL
Ruv = 0.129				-0.01%	0.58%	-0.58%	8.5	-0.5	-0.57	ranT
SpdAv= 17.6				0.80%	1.25%	1.24%	7.0	5.2	0.46	sigT
SpdSd= 6.8				7.818E+03	1.368E-01	199.2	24.7	3.5	-0.59	Tot.
SoSav= 283.7				3.34%	12.43%	-8.07%				T-76
SoSpt= 282.9				3.908E-02	4.227E-07	183.8			7.0%	H2O
				4.167E-03	4.512E-08	0.9			0.7%	sigH
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16.000	25.250	-90.130		1.096E+04	1.884E-01	202.6	25.5	5.5	-0.125	Mean
6390.230	25.398			5.85%	13.20%	-6.46%				M-76
3720.0	GRM	0.0000		0.32%	1.17%	-0.94%	12.8	6.5		ranS
				0.22%	0.71%	0.70%	6.4	5.1		sigS
Wind and SoS				-0.34%	-1.00%	0.74%	3.3	6.3		ranL
-----				0.96%	0.90%	0.88%	6.7	5.3		sigL
Ruv = 0.167				-0.02%	0.17%	-0.19%	16.0	12.8	0.28	ranT
SpdAv= 27.1				0.99%	1.15%	1.12%	9.3	7.4	0.49	sigT
SpdSd= 9.3				1.096E+04	1.888E-01	202.3	41.5	18.3	0.15	Tot.
SoSav= 285.3				5.83%	13.39%	-6.64%				T-76
SoSpt= 285.1				4.913E-02	5.253E-07	185.1			6.3%	H2O
				2.845E-02	3.046E-07	5.2			3.7%	sigH
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14.000	25.650	-88.930		1.524E+04	2.523E-01	210.5	33.1	7.1	-0.153	Mean
6388.114	25.800			7.56%	10.74%	-2.86%				M-76
3780.0	GRM	0.0000		0.35%	1.06%	-0.81%	14.7	8.1		ranS
				0.25%	0.74%	0.74%	7.8	6.8		sigS
Wind and SoS				-0.61%	-1.15%	0.63%	2.1	8.2		ranL
-----				1.07%	0.98%	0.98%	8.2	7.2		sigL
Ruv = 0.244				-0.26%	-0.08%	-0.18%	16.8	16.3	-1.32	ranT
SpdAv= 35.2				1.10%	1.23%	1.23%	11.3	9.9	0.53	sigT
SpdSd= 11.6				1.520E+04	2.521E-01	210.1	49.9	23.4	-1.48	Tot.
SoSav= 290.8				7.27%	10.65%	-3.03%				T-76
SoSpt= 290.5				1.138E-01	1.171E-06	190.1			5.1%	H2O
				6.670E-02	6.876E-07	5.6			3.0%	sigH
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12.000	26.050	-87.730		2.086E+04	3.305E-01	219.9	34.4	6.2	0.036	Mean

6385.996	26.202			7.54%	5.97%	1.50%				M-76
3840.0	GRM	0.0000		0.23%	-0.15%	0.43%	1.3	-5.3		ranS
				0.25%	0.73%	0.74%	8.9	8.4		sigS
Wind and SoS				-0.68%	-1.31%	0.59%	-0.2	9.7		ranL
-----				1.10%	1.11%	1.13%	9.6	9.0		sigL
Ruv = 0.212				-0.45%	-1.46%	1.03%	1.1	4.5	-0.47	ranT
SpdAv= 37.0				1.12%	1.33%	1.35%	13.1	12.3	0.58	sigT
SpdSd= 13.3				2.077E+04	3.257E-01	222.2	35.5	10.7	-0.43	Tot.
SoSav= 297.3				7.06%	4.42%	2.55%				T-76
SoSpt= 298.8				5.286E-01	5.208E-06	200.1			7.4%	H2O
				2.997E-01	2.957E-06	6.2			4.2%	sigH
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10.000	26.450	-86.530		2.816E+04	4.221E-01	232.4	29.7	4.9	0.136	Mean
6383.877	26.604			6.27%	2.07%	4.12%				M-76
3900.0	GRM	0.0000		0.09%	-0.59%	0.82%	13.2	1.9		ranS
				0.24%	0.47%	0.47%	8.5	7.9		sigS
Wind and SoS				-0.87%	-0.94%	-0.07%	-2.8	8.4		ranL
-----				1.03%	0.85%	0.85%	9.3	8.7		sigL
Ruv = 0.187				-0.78%	-1.53%	0.75%	10.4	10.3	-0.48	ranT
SpdAv= 32.3				1.06%	0.97%	0.97%	12.6	11.7	0.63	sigT
SpdSd= 12.6				2.794E+04	4.156E-01	234.2	40.1	15.3	-0.35	Tot.
SoSav= 305.6				5.44%	0.51%	4.90%				T-76
SoSpt= 306.8				9.835E+00	9.168E-05	222.7			34.5%	H2O
				4.883E+00	4.561E-05	6.9			17.1%	sigH
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8.000	26.850	-85.330		3.735E+04	5.271E-01	246.8	23.5	4.0	0.151	Mean
6381.757	27.005			4.75%	0.25%	4.48%				M-76
3960.0	GRM	0.0000		-0.01%	-0.62%	0.69%	21.4	5.1		ranS
				0.20%	0.44%	0.44%	7.1	6.7		sigS
Wind and SoS				-0.86%	-0.79%	-0.15%	-4.6	6.4		ranL
-----				0.86%	0.83%	0.82%	7.9	7.5		sigL
Ruv = 0.139				-0.87%	-1.40%	0.55%	16.8	11.5	0.21	ranT
SpdAv= 25.9				0.89%	0.94%	0.93%	10.7	10.1	0.63	sigT
SpdSd= 10.6				3.702E+04	5.197E-01	248.1	40.3	15.5	0.36	Tot.
SoSav= 315.0				3.84%	-1.16%	5.05%				T-76
SoSpt= 315.8				2.627E+01	2.307E-04	233.3			37.0%	H2O
				2.121E+01	1.864E-04	8.9			25.3%	sigH
-----				-----	-----	-----	-----	-----	-----	-----
6.000	27.250	-84.130		4.883E+04	6.526E-01	260.6	17.4	3.0	0.072	Mean
6379.636	27.407			3.42%	-1.14%	4.56%				M-76
4020.0	GRM	0.0000		-0.02%	-0.11%	0.10%	12.0	-9.2		ranS
				0.16%	0.44%	0.43%	6.0	5.7		sigS
Wind and SoS				-0.80%	-0.60%	-0.21%	-5.7	4.6		ranL
-----				0.70%	0.83%	0.82%	6.8	6.4		sigL
Ruv = 0.082				-0.82%	-0.71%	-0.11%	6.3	-4.6	0.88	ranT
SpdAv= 19.8				0.72%	0.94%	0.92%	9.1	8.6	0.63	sigT
SpdSd= 8.9				4.844E+04	6.480E-01	260.3	23.8	-1.7	0.95	Tot.
SoSav= 323.7				2.58%	-1.84%	4.45%				T-76
SoSpt= 323.5				6.657E+01	5.536E-04	242.8			28.5%	H2O
				5.088E+01	4.236E-04	9.3			21.3%	sigH
-----				-----	-----	-----	-----	-----	-----	-----
4.000	27.650	-82.930		6.299E+04	8.038E-01	272.7	11.7	1.9	0.075	Mean
6377.513	27.808			2.15%	-1.90%	4.02%				M-76
4080.0	cap06	0.0536		0.17%	0.24%	-0.08%	-1.7	-3.1		ranS
				0.13%	0.40%	0.40%	5.1	4.6		sigS
Wind and SoS				-0.67%	-0.33%	-0.33%	-6.1	2.8		ranL
-----				0.56%	0.81%	0.80%	5.9	5.3		sigL
Ruv = 0.019				-0.50%	-0.09%	-0.41%	-7.8	-0.3	-0.27	ranT
SpdAv= 14.1				0.58%	0.90%	0.90%	7.8	7.1	0.62	sigT
SpdSd= 7.4				6.267E+04	8.031E-01	271.6	3.9	1.6	-0.20	Tot.
SoSav= 331.2				1.64%	-1.98%	3.59%				T-76
SoSpt= 330.5				1.710E+02	1.358E-03	253.5			29.2%	H2O
				1.309E+02	1.041E-03	9.9			21.3%	sigH

2.000	28.050	-81.730	8.045E+04	9.927E-01	281.6	6.3	1.7	0.081	Mean
6375.390	28.210		1.19%	-1.37%	2.35%				M-76
4140.0	cap06	0.8115	0.03%	-0.10%	0.13%	-0.6	-0.8		ranS
			0.11%	0.47%	0.47%	4.6	3.9		sigS
Wind and SoS			-0.57%	-0.06%	-0.51%	-6.2	1.2		ranL
-----			0.49%	1.10%	1.09%	5.3	4.6		sigL
Ruv = -0.011			-0.54%	-0.16%	-0.38%	-6.8	0.5	0.18	ranT
SpdAv= 9.7			0.51%	1.20%	1.19%	7.0	6.0	0.50	sigT
SpdSd= 5.8			8.002E+04	9.912E-01	280.5	-0.5	2.1	0.26	Tot.
SoSav= 336.8			0.65%	-1.53%	1.96%				T-76
SoSpt= 336.2			5.594E+02	4.304E-03	268.6			50.2%	H2O
			3.611E+02	2.783E-03	10.8			21.7%	sigH
0.000	28.450	-80.530	1.020E+05	1.220E+00	289.6	0.1	-0.2	0.000	Mean
6373.265	28.611		0.66%	-0.39%	0.49%				M-76
4200.0	cap06	1.0000	0.07%	0.24%	-0.16%	-0.5	-1.4		ranS
			0.11%	0.85%	0.70%	1.9	2.2		sigS
Wind and SoS			-0.17%	0.63%	-0.81%	-2.6	1.1		ranL
-----			0.46%	2.01%	1.67%	2.2	2.6		sigL
Ruv = -0.258			-0.10%	0.87%	-0.96%	-3.1	-0.3	-0.53	ranT
SpdAv= 3.3			0.47%	2.18%	1.81%	2.9	3.4	0.34	sigT
SpdSd= 3.0			1.019E+05	1.231E+00	286.8	-2.9	-0.5	-0.53	Tot.
SoSav= 342.1			0.55%	0.47%	-0.48%				T-76
SoSpt= 340.4			1.607E+03	1.202E-02	286.1			85.8%	H2O
			5.767E+02	4.324E-03	6.6			21.9%	sigH

D.2 Sample Species Concentration Output File Produced by Input File of Appendix C

**** Earth Global Reference Atmospheric Model - 2010 (Earth-GRAM-2010) ****
 Version 1.0, Released Jul, 2010
 Species Concentration Data

MM/DD/YYYY = 1/ 1/2010 HH:MM:SS(UTC) = 0: 0: 0.0 Julian Day = 2455197.500
 F10.7 = 230.00 Mean F10.7 = 230.00 ap Index = 20.30

Standard deviations of concentration variation may be a substantial fraction
 (50% or more) of the mean value. Zero concentration values indicate no
 estimate available.

Thermospheric constituents from MET model

Height/ Radius (km) Time_sec	GcLat GdLat (deg)	Long. [E+W-] (deg)	Concen- tration (ppmv)	Number Density (#/m**3)	Concen- tration (ppmv)	Number Density (#/m**3)	Species
+-----+-----							
140.000	0.450	-164.530	0.000E+00	0.000E+00	0.000E+00	0.000E+00	H2O | O3
6518.136	0.453		0.000E+00	0.000E+00	0.000E+00	0.000E+00	N2O | CO
0.0			0.000E+00	0.000E+00	0.000E+00	0.000E+00	CH4 | CO2
			6.532E+05	6.830E+16	9.206E+04	9.627E+15	N2 | O2
			2.523E+05	2.638E+16	2.324E+03	2.430E+14	O | Ar
			1.894E+02	1.980E+13	9.563E-06	1.000E+06	He | H
			0.000E+00	0.000E+00	MW=25.373	1.046E+17	N | Tot
+-----+-----							
138.000	0.850	-163.330	0.000E+00	0.000E+00	0.000E+00	0.000E+00	H2O | O3
6516.132	0.856		0.000E+00	0.000E+00	0.000E+00	0.000E+00	N2O | CO
60.0			0.000E+00	0.000E+00	0.000E+00	0.000E+00	CH4 | CO2
			6.588E+05	7.821E+16	9.411E+04	1.117E+16	N2 | O2
			2.444E+05	2.902E+16	2.440E+03	2.896E+14	O | Ar
			1.735E+02	2.060E+13	8.424E-06	1.000E+06	He | H
			0.000E+00	0.000E+00	MW=25.477	1.187E+17	N | Tot
+-----+-----							
136.000	1.250	-162.130	0.000E+00	0.000E+00	0.000E+00	0.000E+00	H2O | O3
6514.127	1.258		0.000E+00	0.000E+00	0.000E+00	0.000E+00	N2O | CO
120.0			0.000E+00	0.000E+00	0.000E+00	0.000E+00	CH4 | CO2
			6.646E+05	9.017E+16	9.626E+04	1.306E+16	N2 | O2
			2.364E+05	3.208E+16	2.566E+03	3.481E+14	O | Ar
			1.582E+02	2.147E+13	7.370E-06	1.000E+06	He | H
			0.000E+00	0.000E+00	MW=25.583	1.357E+17	N | Tot
+-----+-----							
134.000	1.650	-160.930	0.000E+00	0.000E+00	0.000E+00	0.000E+00	H2O | O3
6512.119	1.661		0.000E+00	0.000E+00	0.000E+00	0.000E+00	N2O | CO
180.0			0.000E+00	0.000E+00	0.000E+00	0.000E+00	CH4 | CO2
			6.704E+05	1.048E+17	9.852E+04	1.540E+16	N2 | O2
			2.283E+05	3.567E+16	2.703E+03	4.225E+14	O | Ar
			1.436E+02	2.244E+13	6.399E-06	1.000E+06	He | H
			0.000E+00	0.000E+00	MW=25.693	1.563E+17	N | Tot
+-----+-----							
132.000	2.050	-159.730	0.000E+00	0.000E+00	0.000E+00	0.000E+00	H2O | O3
6510.109	2.064		0.000E+00	0.000E+00	0.000E+00	0.000E+00	N2O | CO
240.0			0.000E+00	0.000E+00	0.000E+00	0.000E+00	CH4 | CO2
			6.762E+05	1.227E+17	1.009E+05	1.832E+16	N2 | O2
			2.199E+05	3.991E+16	2.855E+03	5.182E+14	O | Ar
			1.296E+02	2.352E+13	5.510E-06	1.000E+06	He | H
			0.000E+00	0.000E+00	MW=25.805	1.815E+17	N | Tot
+-----+-----							

130.000	2.450	-158.530	0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	H2O	|	O3
6508.098	2.466		0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	N2O	|	CO
300.0			0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	CH4	|	CO2
			6.821E+05	1.451E+17	|	1.034E+05	2.201E+16	N2	|	O2
			2.113E+05	4.495E+16	|	3.022E+03	6.431E+14	O	|	Ar
			1.162E+02	2.472E+13	|	4.701E-06	1.000E+06	He	|	H
			0.000E+00	0.000E+00	|	MW=25.921	2.128E+17	N	|	Tot
-----	-----	-----	-----	-----	+	-----	-----	-----	+	-----
128.000	2.850	-157.330	0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	H2O	|	O3
6506.084	2.869		0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	N2O	|	CO
360.0			0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	CH4	|	CO2
			6.881E+05	1.734E+17	|	1.061E+05	2.675E+16	N2	|	O2
			2.024E+05	5.102E+16	|	3.208E+03	8.086E+14	O	|	Ar
			1.035E+02	2.607E+13	|	3.970E-06	1.000E+06	He	|	H
			0.000E+00	0.000E+00	|	MW=26.040	2.520E+17	N	|	Tot
-----	-----	-----	-----	-----	+	-----	-----	-----	+	-----
126.000	3.250	-156.130	0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	H2O	|	O3
6504.068	3.271		0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	N2O	|	CO
420.0			0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	CH4	|	CO2
			6.941E+05	2.096E+17	|	1.090E+05	3.292E+16	N2	|	O2
			1.934E+05	5.838E+16	|	3.417E+03	1.032E+15	O	|	Ar
			9.140E+01	2.759E+13	|	3.314E-06	1.001E+06	He	|	H
			0.000E+00	0.000E+00	|	MW=26.164	3.019E+17	N	|	Tot
-----	-----	-----	-----	-----	+	-----	-----	-----	+	-----
124.000	3.650	-154.930	0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	H2O	|	O3
6502.050	3.674		0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	N2O	|	CO
480.0			0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	CH4	|	CO2
			7.001E+05	2.565E+17	|	1.121E+05	4.108E+16	N2	|	O2
			1.840E+05	6.741E+16	|	3.652E+03	1.338E+15	O	|	Ar
			8.003E+01	2.932E+13	|	2.732E-06	1.001E+06	He	|	H
			0.000E+00	0.000E+00	|	MW=26.291	3.663E+17	N	|	Tot
-----	-----	-----	-----	-----	+	-----	-----	-----	+	-----
122.000	4.050	-153.730	0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	H2O	|	O3
6500.030	4.077		0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	N2O	|	CO
540.0			0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	CH4	|	CO2
			7.062E+05	3.183E+17	|	1.155E+05	5.204E+16	N2	|	O2
			1.744E+05	7.859E+16	|	3.919E+03	1.766E+15	O	|	Ar
			6.939E+01	3.127E+13	|	2.222E-06	1.001E+06	He	|	H
			0.000E+00	0.000E+00	|	MW=26.424	4.507E+17	N	|	Tot
-----	-----	-----	-----	-----	+	-----	-----	-----	+	-----
120.000	4.450	-152.530	0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	H2O	|	O3
6498.008	4.479		0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	N2O	|	CO
600.0			0.000E+00	0.000E+00	|	0.000E+00	0.000E+00	CH4	|	CO2
			7.122E+05	4.007E+17	|	1.191E+05	6.698E+16	N2	|	O2
			1.645E+05	9.252E+16	|	4.224E+03	2.376E+15	O	|	Ar
			5.952E+01	3.348E+13	|	1.781E-06	1.002E+06	He	|	H
			0.000E+00	0.000E+00	|	MW=26.561	5.626E+17	N	|	Tot
-----	-----	-----	-----	-----	+	-----	-----	-----	+	-----
118.000	4.850	-151.330	2.151E-01	1.531E+11	|	1.248E-03	8.879E+08	H2O	|	O3
6495.983	4.882		2.158E-04	1.536E+08	|	5.871E+01	4.177E+13	N2O	|	CO
660.0			5.357E-02	3.811E+10	|	4.365E+01	3.106E+13	CH4	|	CO2
			7.209E+05	5.129E+17	|	1.201E+05	8.546E+16	N2	|	O2
			1.542E+05	1.097E+17	|	4.576E+03	3.256E+15	O	|	Ar
			5.046E+01	3.590E+13	|	1.406E-06	1.000E+06	He	|	H
			0.000E+00	0.000E+00	|	MW=26.693	7.115E+17	N	|	Tot
-----	-----	-----	-----	-----	+	-----	-----	-----	+	-----
116.000	5.250	-150.130	2.314E-01	2.109E+11	|	3.108E-03	2.834E+09	H2O	|	O3
6493.957	5.285		2.270E-04	2.069E+08	|	5.426E+01	4.946E+13	N2O	|	CO
720.0			7.039E-02	6.417E+10	|	4.585E+01	4.180E+13	CH4	|	CO2
			7.289E+05	6.644E+17	|	1.221E+05	1.113E+17	N2	|	O2
			1.439E+05	1.311E+17	|	4.988E+03	4.547E+15	O	|	Ar
			4.226E+01	3.853E+13	|	1.093E-06	9.966E+05	He	|	H
			0.000E+00	0.000E+00	|	MW=26.831	9.116E+17	N	|	Tot

114.000	5.650	-148.930	2.475E-01	2.939E+11	7.748E-03	9.199E+09	H2O	O3
6491.929	5.687		2.391E-04	2.838E+08	4.994E+01	5.929E+13	N2O	CO
780.0			8.833E-02	1.049E+11	5.089E+01	6.043E+13	CH4	CO2
			7.359E+05	8.738E+17	1.251E+05	1.486E+17	N2	O2
			1.333E+05	1.583E+17	5.470E+03	6.495E+15	O	Ar
			3.494E+01	4.148E+13	8.370E-07	9.937E+05	He	H
			0.000E+00	0.000E+00	MW=26.976	1.187E+18	N	Tot
112.000	6.050	-147.730	2.633E-01	4.156E+11	1.938E-02	3.059E+10	H2O	O3
6489.898	6.090		2.529E-04	3.992E+08	4.590E+01	7.245E+13	N2O	CO
840.0			1.062E-01	1.676E+11	5.986E+01	9.449E+13	CH4	CO2
			7.421E+05	1.171E+18	1.292E+05	2.040E+17	N2	O2
			1.225E+05	1.934E+17	6.033E+03	9.523E+15	O	Ar
			2.845E+01	4.491E+13	6.300E-07	9.945E+05	He	H
			0.000E+00	0.000E+00	MW=27.129	1.579E+18	N	Tot
110.000	6.450	-146.530	2.800E-01	6.043E+11	4.887E-02	1.055E+11	H2O	O3
6487.866	6.492		2.697E-04	5.820E+08	4.252E+01	9.176E+13	N2O	CO
900.0			1.286E-01	2.776E+11	7.097E+01	1.532E+14	CH4	CO2
			7.475E+05	1.613E+18	1.345E+05	2.903E+17	N2	O2
			1.112E+05	2.400E+17	6.669E+03	1.439E+16	O	Ar
			2.273E+01	4.906E+13	4.648E-07	1.003E+06	He	H
			0.000E+00	0.000E+00	MW=27.294	2.158E+18	N	Tot
108.000	6.850	-145.330	3.026E-01	9.059E+11	8.533E-02	2.554E+11	H2O	O3
6485.831	6.895		2.886E-04	8.641E+08	3.787E+01	1.134E+14	N2O	CO
960.0			1.374E-01	4.112E+11	9.109E+01	2.727E+14	CH4	CO2
			7.528E+05	2.254E+18	1.396E+05	4.178E+17	N2	O2
			1.000E+05	2.995E+17	7.419E+03	2.221E+16	O	Ar
			1.789E+01	5.357E+13	3.377E-07	1.011E+06	He	H
			0.000E+00	0.000E+00	MW=27.457	2.994E+18	N	Tot
106.000	7.250	-144.130	3.271E-01	1.391E+12	1.496E-01	6.360E+11	H2O	O3
6483.795	7.298		3.101E-04	1.319E+09	3.385E+01	1.439E+14	N2O	CO
1020.0			1.473E-01	6.262E+11	1.174E+02	4.991E+14	CH4	CO2
			7.576E+05	3.222E+18	1.453E+05	6.181E+17	N2	O2
			8.867E+04	3.771E+17	8.257E+03	3.512E+16	O	Ar
			1.379E+01	5.866E+13	2.404E-07	1.022E+06	He	H
			0.000E+00	0.000E+00	MW=27.627	4.253E+18	N	Tot
104.000	7.650	-142.930	3.512E-01	2.154E+12	2.280E-01	1.398E+12	H2O	O3
6481.756	7.700		3.331E-04	2.043E+09	2.987E+01	1.832E+14	N2O	CO
1080.0			1.558E-01	9.558E+11	1.500E+02	9.202E+14	CH4	CO2
			7.627E+05	4.678E+18	1.516E+05	9.300E+17	N2	O2
			7.678E+04	4.709E+17	8.678E+03	5.322E+16	O	Ar
			1.197E+01	7.342E+13	1.684E-07	1.033E+06	He	H
			0.000E+00	0.000E+00	MW=27.801	6.133E+18	N	Tot
102.000	8.050	-141.730	3.748E-01	3.328E+12	3.011E-01	2.673E+12	H2O	O3
6479.716	8.103		3.564E-04	3.164E+09	2.591E+01	2.301E+14	N2O	CO
1140.0			1.622E-01	1.440E+12	1.896E+02	1.684E+15	CH4	CO2
			7.684E+05	6.822E+18	1.583E+05	1.405E+18	N2	O2
			6.450E+04	5.726E+17	8.613E+03	7.647E+16	O	Ar
			1.188E+01	1.055E+14	1.170E-07	1.038E+06	He	H
			0.000E+00	0.000E+00	MW=27.975	8.879E+18	N	Tot
100.000	8.450	-140.530	4.000E-01	5.195E+12	3.970E-01	5.155E+12	H2O	O3
6477.673	8.505		3.807E-04	4.944E+09	2.245E+01	2.915E+14	N2O	CO
1200.0			1.685E-01	2.189E+12	2.393E+02	3.107E+15	CH4	CO2
			7.736E+05	1.005E+19	1.654E+05	2.148E+18	N2	O2
			5.228E+04	6.789E+17	8.510E+03	1.105E+17	O	Ar
			1.174E+01	1.525E+14	8.023E-08	1.042E+06	He	H

			0.000E+00	0.000E+00		MW=28.149	1.299E+19	N		Tot
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98.000	8.850	-139.330	4.510E-01	8.484E+12		4.330E-01	8.145E+12	H2O		O3
6475.628	8.908		4.080E-04	7.674E+09		1.843E+01	3.467E+14	N2O		CO
1260.0			1.743E-01	3.279E+12	|	2.730E+02	5.135E+15	CH4	|	CO2
			7.815E+05	1.470E+19	|	1.731E+05	3.255E+18	N2	|	O2
			3.659E+04	6.883E+17	|	8.513E+03	1.601E+17	O	|	Ar
			1.174E+01	2.209E+14		5.546E-08	1.043E+06	He		H
			0.000E+00	0.000E+00		MW=28.369	1.881E+19	N		Tot
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96.000	9.250	-138.130	5.085E-01	1.384E+13		4.705E-01	1.280E+13	H2O		O3
6473.582	9.310		4.356E-04	1.185E+10		1.508E+01	4.103E+14	N2O		CO
1320.0			1.797E-01	4.888E+12	|	3.104E+02	8.445E+15	CH4	|	CO2
			7.873E+05	2.142E+19	|	1.808E+05	4.920E+18	N2	|	O2
			2.301E+04	6.262E+17	|	8.511E+03	2.316E+17	O	|	Ar
			1.174E+01	3.195E+14		3.824E-08	1.040E+06	He		H
			0.000E+00	0.000E+00		MW=28.564	2.721E+19	N		Tot
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94.000	9.650	-136.930	5.913E-01	2.324E+13		4.922E-01	1.934E+13	H2O		O3
6471.533	9.713		4.657E-04	1.830E+10		1.242E+01	4.881E+14	N2O		CO
1380.0			1.847E-01	7.258E+12	|	3.394E+02	1.334E+16	CH4	|	CO2
			7.918E+05	3.112E+19	|	1.869E+05	7.344E+18	N2	|	O2
			1.243E+04	4.886E+17	|	8.503E+03	3.342E+17	O	|	Ar
			1.173E+01	4.610E+14		2.636E-08	1.036E+06	He		H
			0.000E+00	0.000E+00		MW=28.715	3.930E+19	N		Tot
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92.000	10.050	-135.730	7.089E-01	3.998E+13		4.955E-01	2.794E+13	H2O		O3
6469.483	10.115		4.983E-04	2.810E+10		1.030E+01	5.809E+14	N2O		CO
1440.0			1.893E-01	1.068E+13	|	3.570E+02	2.013E+16	CH4	|	CO2
			7.949E+05	4.483E+19	|	1.906E+05	1.075E+19	N2	|	O2
			5.558E+03	3.134E+17	|	8.514E+03	4.802E+17	O	|	Ar
			1.175E+01	6.625E+14		1.825E-08	1.029E+06	He		H
			0.000E+00	0.000E+00		MW=28.813	5.640E+19	N		Tot
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90.000	10.450	-134.530	8.500E-01	6.816E+13		4.968E-01	3.984E+13	H2O		O3
6467.430	10.518		5.311E-04	4.259E+10		8.507E+00	6.822E+14	N2O		CO
1500.0			1.933E-01	1.550E+13	|	3.740E+02	2.999E+16	CH4	|	CO2
			7.943E+05	6.370E+19	|	1.935E+05	1.552E+19	N2	|	O2
			2.299E+03	1.843E+17	|	9.511E+03	7.627E+17	O	|	Ar
			5.295E+00	4.247E+14		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.876	8.019E+19	N		Tot
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88.000	10.850	-133.330	1.007E+00	1.127E+14		4.856E-01	5.430E+13	H2O		O3
6465.376	10.920		5.723E-04	6.400E+10		6.841E+00	7.650E+14	N2O		CO
1560.0			1.982E-01	2.216E+13	|	3.777E+02	4.224E+16	CH4	|	CO2
			7.923E+05	8.860E+19	|	1.969E+05	2.202E+19	N2	|	O2
			8.944E+02	1.000E+17	|	9.483E+03	1.060E+18	O	|	Ar
			5.280E+00	5.904E+14		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.907	1.118E+20	N		Tot
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86.000	11.250	-132.130	1.194E+00	1.851E+14		4.010E-01	6.217E+13	H2O		O3
6463.319	11.323		6.162E-04	9.553E+10		5.496E+00	8.521E+14	N2O		CO
1620.0			2.029E-01	3.146E+13	|	3.810E+02	5.908E+16	CH4	|	CO2
			7.896E+05	1.224E+20	|	2.002E+05	3.104E+19	N2	|	O2
			3.505E+02	5.434E+16	|	9.447E+03	1.465E+18	O	|	Ar
			5.259E+00	8.154E+14		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.926	1.550E+20	N		Tot
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84.000	11.650	-130.930	1.431E+00	3.055E+14		3.478E-01	7.426E+13	H2O		O3
6461.261	11.725		6.655E-04	1.421E+11		4.099E+00	8.753E+14	N2O		CO
1680.0			2.049E-01	4.376E+13	|	3.839E+02	8.197E+16	CH4	|	CO2
			7.867E+05	1.680E+20	|	2.034E+05	4.343E+19	N2	|	O2
			1.685E+02	3.599E+16	|	9.410E+03	2.009E+18	O	|	Ar

			5.239E+00	1.119E+15		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.940	2.135E+20	N		Tot
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82.000	12.050	-129.730	1.733E+00	5.072E+14		3.272E-01	9.572E+13	H2O		O3
6459.200	12.128		7.213E-04	2.110E+11		2.838E+00	8.303E+14	N2O		CO
1740.0			2.042E-01	5.974E+13	|	3.862E+02	1.130E+17	CH4	|	CO2
			7.837E+05	2.293E+20	|	2.064E+05	6.039E+19	N2	|	O2
			9.898E+01	2.896E+16	|	9.375E+03	2.743E+18	O	|	Ar
			5.219E+00	1.527E+15		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.953	2.926E+20	N		Tot
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80.000	12.450	-128.530	1.915E+00	7.645E+14		2.828E-01	1.129E+14	H2O		O3
6457.138	12.530		7.816E-04	3.121E+11		1.965E+00	7.846E+14	N2O		CO
1800.0			2.034E-01	8.123E+13	|	3.886E+02	1.552E+17	CH4	|	CO2
			7.808E+05	3.118E+20	|	2.094E+05	8.364E+19	N2	|	O2
			5.821E+01	2.324E+16	|	9.339E+03	3.730E+18	O	|	Ar
			5.199E+00	2.076E+15		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.965	3.993E+20	N		Tot
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78.000	12.850	-127.330	1.614E+00	8.785E+14		2.161E-01	1.176E+14	H2O		O3
6455.074	12.933		8.571E-04	4.667E+11		1.316E+00	7.164E+14	N2O		CO
1860.0			2.034E-01	1.107E+14	|	3.895E+02	2.121E+17	CH4	|	CO2
			7.808E+05	4.251E+20	|	2.095E+05	1.140E+20	N2	|	O2
			2.498E+01	1.360E+16	|	9.339E+03	5.085E+18	O	|	Ar
			5.200E+00	2.831E+15		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.965	5.444E+20	N		Tot
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76.000	13.250	-126.130	1.789E+00	1.324E+15		1.653E-01	1.223E+14	H2O		O3
6453.008	13.335		9.399E-04	6.957E+11		8.813E-01	6.523E+14	N2O		CO
1920.0			2.034E-01	1.506E+14	|	3.905E+02	2.890E+17	CH4	|	CO2
			7.808E+05	5.779E+20	|	2.095E+05	1.550E+20	N2	|	O2
			1.081E+01	8.001E+15	|	9.340E+03	6.913E+18	O	|	Ar
			5.200E+00	3.849E+15		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	7.402E+20	N		Tot
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74.000	13.650	-124.930	1.982E+00	1.981E+15		1.517E-01	1.515E+14	H2O		O3
6450.940	13.737		1.036E-03	1.035E+12		5.816E-01	5.811E+14	N2O		CO
1980.0			2.034E-01	2.032E+14	|	3.910E+02	3.907E+17	CH4	|	CO2
			7.808E+05	7.802E+20	|	2.095E+05	2.093E+20	N2	|	O2
			5.821E+00	5.817E+15	|	9.340E+03	9.332E+18	O	|	Ar
			5.200E+00	5.196E+15		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	9.992E+20	N		Tot
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72.000	14.050	-123.730	2.641E+00	3.530E+15		1.831E-01	2.447E+14	H2O		O3
6448.871	14.140		1.149E-03	1.535E+12		3.782E-01	5.055E+14	N2O		CO
2040.0			2.034E-01	2.719E+14	|	3.910E+02	5.225E+17	CH4	|	CO2
			7.808E+05	1.044E+21	|	2.095E+05	2.800E+20	N2	|	O2
			3.875E+00	5.180E+15	|	9.340E+03	1.248E+19	O	|	Ar
			5.200E+00	6.950E+15		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	1.337E+21	N		Tot
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70.000	14.450	-122.530	3.457E+00	6.148E+15		2.314E-01	4.116E+14	H2O		O3
6446.799	14.542		1.273E-03	2.264E+12		2.459E-01	4.373E+14	N2O		CO
2100.0			2.034E-01	3.617E+14	|	3.910E+02	6.952E+17	CH4	|	CO2
			7.808E+05	1.388E+21	|	2.095E+05	3.725E+20	N2	|	O2
			2.579E+00	4.586E+15	|	9.340E+03	1.661E+19	O	|	Ar
			5.200E+00	9.246E+15		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	1.778E+21	N		Tot
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68.000	14.850	-121.330	4.134E+00	9.631E+15		3.121E-01	7.272E+14	H2O		O3
6444.726	14.945		1.420E-03	3.308E+12		1.824E-01	4.249E+14	N2O		CO
2160.0			2.034E-01	4.739E+14	|	3.910E+02	9.108E+17	CH4	|	CO2
			7.808E+05	1.819E+21	|	2.095E+05	4.880E+20	N2	|	O2

			2.164E+00	5.042E+15	|	9.340E+03	2.176E+19	O	|	Ar
			5.200E+00	1.211E+16		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	2.330E+21	N		Tot
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66.000	15.250	-120.130	4.919E+00	1.491E+16		4.192E-01	1.271E+15	H2O		O3
6442.651	15.347		1.582E-03	4.794E+12		1.374E-01	4.163E+14	N2O		CO
2220.0			2.034E-01	6.165E+14	|	3.910E+02	1.185E+18	CH4	|	CO2
			7.808E+05	2.366E+21	|	2.095E+05	6.348E+20	N2	|	O2
			1.827E+00	5.536E+15	|	9.340E+03	2.831E+19	O	|	Ar
			5.200E+00	1.576E+16		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	3.031E+21	N		Tot
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64.000	15.650	-118.930	5.349E+00	2.102E+16		5.418E-01	2.129E+15	H2O		O3
6440.574	15.749		1.092E-03	4.290E+12		1.145E-01	4.500E+14	N2O		CO
2280.0			1.681E-01	6.604E+14	|	3.910E+02	1.536E+18	CH4	|	CO2
			7.808E+05	3.068E+21	|	2.095E+05	8.231E+20	N2	|	O2
			1.520E+00	5.973E+15	|	9.340E+03	3.670E+19	O	|	Ar
			5.200E+00	2.043E+16		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	3.929E+21	N		Tot
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62.000	16.050	-117.730	5.755E+00	2.924E+16		7.003E-01	3.559E+15	H2O		O3
6438.495	16.152		1.208E-03	6.141E+12		1.044E-01	5.305E+14	N2O		CO
2340.0			1.820E-01	9.249E+14	|	3.910E+02	1.987E+18	CH4	|	CO2
			7.808E+05	3.968E+21	|	2.095E+05	1.064E+21	N2	|	O2
			1.246E+00	6.334E+15	|	9.340E+03	4.746E+19	O	|	Ar
			5.200E+00	2.642E+16		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	5.081E+21	N		Tot
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60.000	16.450	-116.530	5.935E+00	3.881E+16		9.036E-01	5.908E+15	H2O		O3
6436.414	16.554		1.386E-03	9.063E+12		9.478E-02	6.197E+14	N2O		CO
2400.0			1.980E-01	1.295E+15	|	3.910E+02	2.556E+18	CH4	|	CO2
			7.808E+05	5.105E+21	|	2.095E+05	1.370E+21	N2	|	O2
			1.026E+00	6.706E+15	|	9.340E+03	6.107E+19	O	|	Ar
			5.200E+00	3.400E+16		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	6.538E+21	N		Tot
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58.000	16.850	-115.330	5.787E+00	4.842E+16		1.146E+00	9.591E+15	H2O		O3
6434.332	16.956		1.627E-03	1.361E+13		8.984E-02	7.518E+14	N2O		CO
2460.0			2.185E-01	1.829E+15	|	3.910E+02	3.272E+18	CH4	|	CO2
			7.808E+05	6.534E+21	|	2.095E+05	1.753E+21	N2	|	O2
			7.801E-01	6.528E+15	|	9.340E+03	7.816E+19	O	|	Ar
			5.200E+00	4.351E+16		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	8.368E+21	N		Tot
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56.000	17.250	-114.130	5.644E+00	6.016E+16		1.378E+00	1.468E+16	H2O		O3
6432.248	17.358		2.019E-03	2.152E+13		8.467E-02	9.024E+14	N2O		CO
2520.0			2.625E-01	2.798E+15	|	3.910E+02	4.167E+18	CH4	|	CO2
			7.808E+05	8.322E+21	|	2.095E+05	2.232E+21	N2	|	O2
			5.963E-01	6.355E+15	|	9.340E+03	9.954E+19	O	|	Ar
			5.200E+00	5.542E+16		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	1.066E+22	N		Tot
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54.000	17.650	-112.930	5.508E+00	7.480E+16		1.641E+00	2.228E+16	H2O		O3
6430.162	17.761		2.639E-03	3.584E+13		7.889E-02	1.071E+15	N2O		CO
2580.0			3.228E-01	4.384E+15	|	3.910E+02	5.309E+18	CH4	|	CO2
			7.808E+05	1.060E+22	|	2.095E+05	2.844E+21	N2	|	O2
			4.312E-01	5.855E+15	|	9.340E+03	1.268E+20	O	|	Ar
			5.200E+00	7.061E+16		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	1.358E+22	N		Tot
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52.000	18.050	-111.730	5.500E+00	9.535E+16		1.917E+00	3.324E+16	H2O		O3
6428.075	18.163		3.428E-03	5.943E+13		7.256E-02	1.258E+15	N2O		CO
2640.0			3.745E-01	6.492E+15	|	3.910E+02	6.778E+18	CH4	|	CO2

			7.808E+05	1.354E+22	|	2.095E+05	3.631E+21	N2	|	O2
			2.943E-01	5.103E+15	|	9.340E+03	1.619E+20	O	|	Ar
			5.200E+00	9.014E+16		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	1.734E+22	N		Tot
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50.000	18.450	-110.530	5.325E+00	1.175E+17		2.304E+00	5.085E+16	H2O		O3
6425.985	18.565		4.240E-03	9.360E+13		6.624E-02	1.462E+15	N2O		CO
2700.0			4.170E-01	9.205E+15	|	3.910E+02	8.630E+18	CH4	|	CO2
			7.808E+05	1.724E+22	|	2.095E+05	4.624E+21	N2	|	O2
			2.013E-01	4.444E+15	|	9.340E+03	2.062E+20	O	|	Ar
			5.200E+00	1.148E+17		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	2.207E+22	N		Tot
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48.000	18.850	-109.330	5.087E+00	1.447E+17		2.827E+00	8.041E+16	H2O		O3
6423.895	18.967		5.164E-03	1.469E+14		5.764E-02	1.640E+15	N2O		CO
2760.0			4.551E-01	1.295E+16	|	3.910E+02	1.112E+19	CH4	|	CO2
			7.808E+05	2.221E+22	|	2.095E+05	5.958E+21	N2	|	O2
			1.136E-01	3.231E+15	|	9.340E+03	2.657E+20	O	|	Ar
			5.200E+00	1.479E+17		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	2.844E+22	N		Tot
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46.000	19.250	-108.130	5.016E+00	1.839E+17		3.508E+00	1.286E+17	H2O		O3
6421.802	19.369		6.730E-03	2.468E+14		5.131E-02	1.882E+15	N2O		CO
2820.0			5.016E-01	1.840E+16	|	3.910E+02	1.434E+19	CH4	|	CO2
			7.808E+05	2.863E+22	|	2.095E+05	7.682E+21	N2	|	O2
			6.410E-02	2.351E+15	|	9.340E+03	3.425E+20	O	|	Ar
			5.200E+00	1.907E+17		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	3.667E+22	N		Tot
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44.000	19.650	-106.930	4.883E+00	2.326E+17		4.331E+00	2.063E+17	H2O		O3
6419.708	19.771		9.316E-03	4.438E+14		4.598E-02	2.191E+15	N2O		CO
2880.0			5.653E-01	2.693E+16	|	3.910E+02	1.863E+19	CH4	|	CO2
			7.808E+05	3.720E+22	|	2.095E+05	9.978E+21	N2	|	O2
			3.176E-02	1.513E+15	|	9.340E+03	4.449E+20	O	|	Ar
			5.200E+00	2.477E+17		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	4.764E+22	N		Tot
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42.000	20.050	-105.730	4.712E+00	2.946E+17		5.227E+00	3.267E+17	H2O		O3
6417.612	20.173		1.298E-02	8.117E+14		4.124E-02	2.578E+15	N2O		CO
2940.0			6.329E-01	3.957E+16	|	3.910E+02	2.444E+19	CH4	|	CO2
			7.808E+05	4.881E+22	|	2.095E+05	1.309E+22	N2	|	O2
			1.375E-02	8.593E+14	|	9.340E+03	5.839E+20	O	|	Ar
			5.200E+00	3.251E+17		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	6.252E+22	N		Tot
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40.000	20.450	-104.530	5.102E+00	4.203E+17		6.152E+00	5.067E+17	H2O		O3
6415.515	20.576		1.728E-02	1.423E+15		3.721E-02	3.065E+15	N2O		CO
3000.0			6.879E-01	5.666E+16	|	3.910E+02	3.220E+19	CH4	|	CO2
			7.808E+05	6.431E+22	|	2.095E+05	1.725E+22	N2	|	O2
			5.895E-03	4.856E+14	|	9.340E+03	7.693E+20	O	|	Ar
			5.200E+00	4.283E+17		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	8.237E+22	N		Tot
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38.000	20.850	-103.330	5.566E+00	6.120E+17		6.866E+00	7.548E+17	H2O		O3
6413.416	20.978		2.553E-02	2.807E+15		3.380E-02	3.716E+15	N2O		CO
3060.0			7.647E-01	8.407E+16	|	3.910E+02	4.298E+19	CH4	|	CO2
			7.808E+05	8.584E+22	|	2.095E+05	2.303E+22	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	1.027E+21	O	|	Ar
			5.200E+00	5.716E+17		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	1.099E+23	N		Tot
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36.000	21.250	-102.130	5.479E+00	8.095E+17		7.561E+00	1.117E+18	H2O		O3
6411.316	21.380		4.250E-02	6.279E+15		3.118E-02	4.606E+15	N2O		CO

3120.0			8.928E-01	1.319E+17	|	3.910E+02	5.776E+19	CH4	|	CO2
			7.808E+05	1.154E+23	|	2.095E+05	3.095E+22	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	1.380E+21	O	|	Ar
			5.200E+00	7.682E+17		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	1.477E+23	N		Tot
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34.000	21.650	-100.930	5.347E+00	1.069E+18		7.760E+00	1.551E+18	H2O		O3
6409.214	21.782		8.116E-02	1.622E+16		2.893E-02	5.781E+15	N2O		CO
3180.0			1.088E+00	2.174E+17	|	3.910E+02	7.813E+19	CH4	|	CO2
			7.808E+05	1.560E+23	|	2.095E+05	4.186E+22	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	1.867E+21	O	|	Ar
			5.200E+00	1.039E+18		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	1.999E+23	N		Tot
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32.000	22.050	-99.730	5.213E+00	1.418E+18		7.703E+00	2.095E+18	H2O		O3
6407.110	22.184		1.087E-01	2.957E+16		2.672E-02	7.268E+15	N2O		CO
3240.0			1.214E+00	3.303E+17	|	3.910E+02	1.063E+20	CH4	|	CO2
			7.808E+05	2.124E+23	|	2.095E+05	5.697E+22	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	2.540E+21	O	|	Ar
			5.200E+00	1.414E+18		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	2.720E+23	N		Tot
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30.000	22.450	-98.530	5.129E+00	1.911E+18		7.356E+00	2.740E+18	H2O		O3
6405.005	22.586		1.390E-01	5.177E+16		2.433E-02	9.063E+15	N2O		CO
3300.0			1.353E+00	5.041E+17	|	3.910E+02	1.457E+20	CH4	|	CO2
			7.808E+05	2.909E+23	|	2.095E+05	7.804E+22	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	3.479E+21	O	|	Ar
			5.200E+00	1.937E+18		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	3.726E+23	N		Tot
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28.000	22.850	-97.330	5.092E+00	2.621E+18		6.740E+00	3.469E+18	H2O		O3
6402.899	22.987		1.832E-01	9.430E+16		2.192E-02	1.128E+16	N2O		CO
3360.0			1.495E+00	7.696E+17	|	3.910E+02	2.012E+20	CH4	|	CO2
			7.808E+05	4.018E+23	|	2.095E+05	1.078E+23	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	4.807E+21	O	|	Ar
			5.200E+00	2.676E+18		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	5.147E+23	N		Tot
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26.000	23.250	-96.130	5.000E+00	3.566E+18		5.975E+00	4.261E+18	H2O		O3
6400.791	23.389		1.588E-01	1.132E+17		2.003E-02	1.428E+16	N2O		CO
3420.0			1.285E+00	9.163E+17	|	3.910E+02	2.788E+20	CH4	|	CO2
			7.808E+05	5.568E+23	|	2.095E+05	1.494E+23	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	6.660E+21	O	|	Ar
			5.200E+00	3.708E+18		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	7.131E+23	N		Tot
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24.000	23.650	-94.930	4.757E+00	4.711E+18		4.422E+00	4.379E+18	H2O		O3
6398.681	23.791		1.762E-01	1.745E+17		1.775E-02	1.757E+16	N2O		CO
3480.0			1.417E+00	1.403E+18	|	3.910E+02	3.872E+20	CH4	|	CO2
			7.808E+05	7.732E+23	|	2.095E+05	2.074E+23	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	9.249E+21	O	|	Ar
			5.200E+00	5.149E+18		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	9.903E+23	N		Tot
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22.000	24.050	-93.730	4.350E+00	6.073E+18		2.790E+00	3.896E+18	H2O		O3
6396.570	24.193		1.948E-01	2.719E+17		1.559E-02	2.177E+16	N2O		CO
3540.0			1.635E+00	2.283E+18	|	3.910E+02	5.459E+20	CH4	|	CO2
			7.808E+05	1.090E+24	|	2.095E+05	2.925E+23	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	1.304E+22	O	|	Ar
			5.200E+00	7.260E+18		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	1.396E+24	N		Tot
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20.000	24.450	-92.530	3.837E+00	7.608E+18		1.770E+00	3.510E+18	H2O		O3

6394.458	24.595		2.328E-01	4.615E+17		1.686E-02	3.342E+16	N2O		CO
3600.0			1.836E+00	3.639E+18	|	3.910E+02	7.751E+20	CH4	|	CO2
			7.808E+05	1.548E+24	|	2.095E+05	4.153E+23	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	1.852E+22	O	|	Ar
			5.200E+00	1.031E+19		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	1.983E+24	N		Tot
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18.000	24.850	-91.330	3.109E+00	8.788E+18		7.675E-01	2.170E+18	H2O		O3
6392.345	24.997		2.762E-01	7.807E+17		2.497E-02	7.059E+16	N2O		CO
3660.0			1.968E+00	5.563E+18	|	3.910E+02	1.105E+21	CH4	|	CO2
			7.808E+05	2.207E+24	|	2.095E+05	5.921E+23	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	2.640E+22	O	|	Ar
			5.200E+00	1.470E+19		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	2.827E+24	N		Tot
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16.000	25.250	-90.130	2.788E+00	1.092E+19		2.909E-01	1.139E+18	H2O		O3
6390.230	25.398		3.083E-01	1.208E+18		3.892E-02	1.524E+17	N2O		CO
3720.0			2.051E+00	8.033E+18	|	3.910E+02	1.531E+21	CH4	|	CO2
			7.808E+05	3.058E+24	|	2.095E+05	8.204E+23	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	3.658E+22	O	|	Ar
			5.200E+00	2.037E+19		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	3.917E+24	N		Tot
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14.000	25.650	-88.930	4.643E+00	2.435E+19		2.189E-01	1.148E+18	H2O		O3
6388.114	25.800		3.241E-01	1.700E+18		6.376E-02	3.344E+17	N2O		CO
3780.0			2.120E+00	1.112E+19	|	3.910E+02	2.051E+21	CH4	|	CO2
			7.808E+05	4.095E+24	|	2.095E+05	1.099E+24	N2	|	O2
			0.000E+00	0.000E+00	|	9.340E+03	4.899E+22	O	|	Ar
			5.200E+00	2.727E+19		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	5.245E+24	N		Tot
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12.000	26.050	-87.730	1.576E+01	1.083E+20		1.618E-01	1.112E+18	H2O		O3
6385.996	26.202		3.366E-01	2.313E+18		9.900E-02	6.803E+17	N2O		CO
3840.0			2.174E+00	1.494E+19	|	3.910E+02	2.686E+21	CH4	|	CO2
			7.808E+05	5.365E+24	|	2.095E+05	1.439E+24	N2	|	O2
			0.000E+00	0.000E+00	|	9.339E+03	6.417E+22	O	|	Ar
			5.200E+00	3.573E+19		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.966	6.871E+24	N		Tot
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10.000	26.450	-86.530	2.173E+02	1.907E+21		1.006E-01	8.829E+17	H2O		O3
6383.877	26.604		3.486E-01	3.059E+18		1.262E-01	1.108E+18	N2O		CO
3900.0			2.233E+00	1.960E+19	|	3.909E+02	3.430E+21	CH4	|	CO2
			7.806E+05	6.850E+24	|	2.094E+05	1.838E+24	N2	|	O2
			0.000E+00	0.000E+00	|	9.338E+03	8.194E+22	O	|	Ar
			5.199E+00	4.562E+19		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.963	8.775E+24	N		Tot
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8.000	26.850	-85.330	7.040E+02	7.716E+21		6.484E-02	7.107E+17	H2O		O3
6381.757	27.005		3.540E-01	3.881E+18		1.507E-01	1.652E+18	N2O		CO
3960.0			2.266E+00	2.483E+19	|	3.907E+02	4.282E+21	CH4	|	CO2
			7.802E+05	8.552E+24	|	2.093E+05	2.294E+24	N2	|	O2
			0.000E+00	0.000E+00	|	9.333E+03	1.023E+23	O	|	Ar
			5.196E+00	5.695E+19		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.958	1.096E+25	N		Tot
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6.000	27.250	-84.130	1.365E+03	1.853E+22		4.868E-02	6.608E+17	H2O		O3
6379.636	27.407		3.538E-01	4.803E+18		1.633E-01	2.217E+18	N2O		CO
4020.0			2.285E+00	3.103E+19	|	3.904E+02	5.300E+21	CH4	|	CO2
			7.797E+05	1.058E+25	|	2.092E+05	2.840E+24	N2	|	O2
			0.000E+00	0.000E+00	|	9.327E+03	1.266E+23	O	|	Ar
			5.193E+00	7.049E+19		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.951	1.357E+25	N		Tot
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4.000	27.650	-82.930	2.722E+03	4.553E+22		3.733E-02	6.245E+17	H2O		O3
6377.513	27.808		3.533E-01	5.911E+18		1.656E-01	2.771E+18	N2O		CO
4080.0			2.299E+00	3.846E+19	|	3.899E+02	6.523E+21	CH4	|	CO2
			7.787E+05	1.303E+25	|	2.089E+05	3.495E+24	N2	|	O2
			0.000E+00	0.000E+00	|	9.314E+03	1.558E+23	O	|	Ar
			5.186E+00	8.675E+19		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.936	1.673E+25	N		Tot
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2.000	28.050	-81.730	7.002E+03	1.449E+23		3.288E-02	6.804E+17	H2O		O3
6375.390	28.210		3.518E-01	7.279E+18		1.762E-01	3.646E+18	N2O		CO
4140.0			2.289E+00	4.737E+19	|	3.882E+02	8.033E+21	CH4	|	CO2
			7.753E+05	1.604E+25	|	2.080E+05	4.304E+24	N2	|	O2
			0.000E+00	0.000E+00	|	9.274E+03	1.919E+23	O	|	Ar
			5.163E+00	1.068E+20		0.000E+00	0.000E+00	He		H
			0.000E+00	0.000E+00		MW=28.889	2.069E+25	N		Tot
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0.000	28.450	-80.530	1.601E+04	4.084E+23		3.004E-02	7.663E+17	H2O		O3
6373.265	28.611		3.486E-01	8.894E+18		1.871E-01	4.773E+18	N2O		CO
4200.0			2.268E+00	5.787E+19	|	3.847E+02	9.815E+21	CH4	|	CO2
			7.683E+05	1.960E+25	|	2.061E+05	5.258E+24	N2	|	O2
			0.000E+00	0.000E+00	|	9.190E+03	2.345E+23	O	|	Ar
			5.117E+00	1.305E+20	|	0.000E+00	0.000E+00	He	|	H
			0.000E+00	0.000E+00	|	MW=28.790	2.551E+25	N	|	Tot

D.3 Sample Special Output File Produced by Input File of Appendix C

Time Hg1km	GeocentLat	Lon(East)	DensMean	PresMean	Tmean	EWmean	NSmean	DensPert	PresPert	Tpert	EWpert	NSpert	Dpert%	Ppert%	SDden%	SDprs%	SDlenK	SDuwnd	SDwvnd	SDwvnd	Wpert	SpdAvg	SpdStd	SoSmean	SoSpert	Sav	LC	20(m)	
0	130	0.45	-164.53	4.41E-09	9.97E-04	690.23	20.45	0.51	4.77E-09	9.42E-04	603.18	91.47	-69.41	8.21	-5.43	7.2	12.5	100.77	69	69	8.33	-3.45	78.61	562.72	526.04	0	99	9.99999	
60	138	0.85	-163.33	5.02E-09	1.09E-03	682.03	17.48	0.51	5.27E-09	1.00E-03	583.48	60.84	-41.21	8.21	-7.48	7.27	13.2	101.78	66.36	66.2	8.16	-4.1	74.98	58.91	549.98	516.32	0	99	9.99999
120	136	1.25	-162.13	5.76E-09	1.19E-03	633.2	14.02	0.59	5.75E-09	1.12E-03	598.32	36.76	-36.88	-0.31	-5.8	7.35	13.86	102.02	63.64	63.3	7.99	8.5	71.22	56.42	536.75	521.76	0	99	9.99999
180	134	1.65	-160.93	6.67E-09	1.30E-03	603.8	10.08	0.59	6.60E-09	1.21E-03	566.05	31.14	-42.72	-0.98	-7.17	7.42	14.49	101.53	60.83	60.31	7.82	9.04	67.38	53.83	523.03	506.41	0	99	9.99999
240	132	2.05	-159.73	7.76E-09	1.44E-03	573.92	5.7	0.52	7.66E-09	1.34E-03	542.28	17.52	13.41	-1.55	-6.97	7.49	15.09	100.39	57.9	57.9	7.65	9.05	63.96	51.15	508.81	494.59	0	99	9.99999
300	130	2.45	-158.53	9.16E-09	1.60E-03	543.84	0.96	0.4	9.29E-09	1.45E-03	485.84	-17.91	20.16	-1.42	-9.37	7.56	15.67	98.64	54.85	53.92	7.48	7.72	59.84	48.34	494.1	467.1	0	99	9.99999
360	128	2.85	-157.33	1.09E-08	1.79E-03	513.08	-4.04	0.26	1.08E-08	1.78E-03	512.85	-8.45	22.39	-1.21	-11.25	7.63	16.23	96.32	51.66	50.49	7.31	7.13	56.33	45.4	478.91	478.8	0	99	9.99999
420	126	3.25	-156.13	1.31E-08	2.01E-03	482.33	-9.15	0.11	1.23E-08	2.02E-03	518.22	-28.67	-8.22	-6.36	0.6	7.7	16.77	93.48	48.28	46.85	7.14	6.55	53.12	42.28	463.24	480.16	0	99	9.99999
480	124	3.65	-154.93	1.60E-08	2.28E-03	451.51	-14.19	-0.03	1.41E-08	2.38E-03	528.29	-1.8	11.13	-11.17	3.32	7.77	17.3	90.17	44.69	42.94	6.97	3.45	50.25	38.95	447.11	483.63	0	99	9.99999
540	122	4.05	-153.73	1.98E-08	2.62E-03	420.96	-18.96	-0.15	2.00E-08	2.22E-03	363.6	-37.12	-4.03	0.99	-15.17	7.83	17.81	86.48	40.83	38.7	6.8	3.04	47.69	35.36	430.63	394.67	0	99	9.99999
600	120	4.45	-152.53	2.48E-08	3.04E-03	391.14	-23.26	-0.25	2.39E-08	2.72E-03	363.08	-28.42	-12.38	-0.31	-10.44	7.9	18.3	82.53	36.6	33.99	6.63	-0.92	45.28	31.39	414.02	398.9	0	99	9.99999
660	118	4.85	-151.33	3.15E-08	3.56E-03	362.27	-26.54	-0.34	2.80E-08	3.58E-03	409.94	-53.03	21.14	-11.13	0.56	8.71	17.79	71.77	36.17	37.51	6.49	5.68	48.45	32.75	397.41	422.75	0	99	9.99999
720	116	5.25	-150.13	4.06E-08	4.21E-03	334.29	-28.14	-0.46	3.44E-08	4.25E-03	398.31	-35.46	55.69	-15.25	0.98	9.45	17.27	61.61	35.71	40.57	6.36	-1.85	50.59	33.97	380.77	415.63	0	99	9.99999
780	114	5.65	-148.93	5.32E-08	5.04E-03	307.3	-27.95	-0.64	4.76E-08	4.87E-03	331.87	-31.72	24.16	-10.57	-3.42	10.21	16.77	52.47	37.08	42.05	6.22	2.1	51.8	35.23	364.09	378.37	0	99	9.99999
840	112	6.05	-147.73	7.11E-08	6.13E-03	281.47	-26.01	-0.89	5.95E-08	5.58E-03	305.85	-34.79	31.77	-16.33	-9.08	10.98	16.29	44.33	39.91	42.33	6.09	-2.25	52.2	36.57	347.43	362.17	0	99	9.99999
900	110	6.45	-146.53	9.79E-08	7.64E-03	256.31	-22.71	-1.27	7.69E-08	6.53E-03	279.18	-46.05	95.69	-21.5	-14.49	11.7	15.8	36.65	42.33	42.72	5.95	0.22	52.02	37.8	330.46	344.88	0	99	9.99999
960	108	6.85	-145.33	1.37E-07	9.76E-03	236.08	-17.99	-1.78	1.25E-07	8.09E-03	213.84	-31.99	70.5	-8.42	-17.05	12.45	15.29	30.8	39.05	41.86	5.81	1.48	48.06	35.98	316.12	300.87	0	99	9.99999
1020	106	7.25	-144.13	1.96E-07	1.28E-02	218.13	-12.73	-2.43	1.60E-07	1.06E-02	221.18	-12.13	49.41	-18.4	-17.26	13.16	14.77	25.43	35.77	41.08	5.68	0.95	44.3	34.23	302.83	304.94	0	99	9.99999
1080	104	7.65	-142.93	2.84E-07	1.73E-02	204.1	-8.09	-3.23	2.43E-07	1.42E-02	195.76	0.72	11.11	-14.39	-17.89	13.9	14.25	21.04	37.13	40.52	5.54	0.69	43.62	34.54	291.91	285.88	0	99	9.99999
1140	102	8.05	-141.73	4.14E-07	2.38E-02	194.53	-4.8	-4.15	3.19E-07	1.86E-02	197.33	7.19	19.42	-23.02	-21.91	14.67	13.73	17.54	42.42	40.2	5.4	1.35	45.89	36.73	284.02	286.06	0	99	9.99999
1200	100	8.45	-140.53	6.98E-07	3.35E-02	186.92	-2.74	-5.16	4.21E-07	2.41E-02	194.46	2.57	88.33	-30.93	-28.14	15.4	13.2	14.02	47.02	40	5.26	-4.01	48.37	38.79	277.47	283.02	0	99	9.99999
1260	98	8.85	-139.33	8.89E-07	4.79E-02	183.88	-2.12	-5.96	7.93E-07	3.95E-02	170.13	1.56	46.45	-10.7	-17.37	14.76	13.66	14.17	46.38	37.01	5.16	-9.67	46.58	37.29	274.46	264	0	99	9.99999
1320	96	9.25	-138.13	1.29E-06	6.84E-02	182.1	-2.32	-6.47	1.12E-06	5.63E-02	172.27	23.34	24.54	-12.93	-17.63	14.1	14.16	14.39	45.69	33.46	5.06	-5.43	44.58	35.59	272.41	264.96	0	99	9.99999
1380	94	9.65	-136.93	1.87E-06	9.91E-02	182.59	-3.63	-6.84	1.67E-06	8.28E-02	170.54	15.79	31.13	-10.54	-16.44	13.45	14.71	14.83	47.01	32.13	4.96	-1.64	44.96	35.79	272.2	263.07	0	99	9.99999
1440	92	10.05	-135.73	2.70E-06	1.44E-01	185.12	-5.52	-7.01	2.47E-06	1.22E-01	170.96	-11.26	22.25	-8.32	-15.33	12.81	15.29	15.48	49.9	33.5	4.85	-1.38	47.59	37.77	273.64	262.97	0	99	9.99999
1500	90	10.45	-134.53	3.84E-06	2.08E-01	188	-6.55	-6.73	3.45E-06	1.77E-01	178.27	-6.86	36.91	-10.32	-14.96	12.14	15.76	16.14	52.32	34.8	4.75	-3.17	49.73	39.49	275.31	268.09	0	99	9.99999
1560	88	10.85	-133.33	5.37E-06	2.96E-01	191.5	-3.75	-5.1	4.50E-06	2.57E-01	198.54	-15.59	23.15	-16.12	-13.03	10.18	13.31	13.97	50.95	36.45	4.49	-0.37	49.11	39.37	277.71	282.77	0	99	9.99999
1620	86	11.25	-132.13	7.45E-06	4.17E-01	195.01	-0.93	-3.61	6.69E-06	3.83E-01	199.15	36.07	28.93	-10.17	-8.26	7.71	9.84	11.2	49.9	37.79	4.22	5.64	48.83	39.34	280.09	283.05	0	99	9.99999
1680	84	11.65	-130.93	1.03E-05	5.84E-01	198.22	1.6	-2.9	9.98E-06	5.63E-01	196.35	58.46	-22.51	-4	-1.86	5.34	6.51	8.5	43.92	31.92	3.82	-3.99	46.68	37.62	282.3	280.97	0	99	9.99999
1740	82	12.05	-129.73	1.41E-05	8.12E-01	201.03	4.13	-2.98	1.35E-05	7.97E-01	205.53	58.65	-9.1	-4	-1.86	5.34	6.51	8.5	43.92	31.92	3.82	-3.99	46.68	37.62	282.3	280.97	0	99	9.99999
1800	80	12.45	-128.53	1.92E-05	1.12E+00	203.76	7.07	-3.19	1.88E-05	1.12E+00	207.57	53.78	-15.42	-2.14	-0.31	4.76	5.68	7.79	39.1	26.93	3.3	-4.87	37.73	29.84	286.19	288.85	0	99	9.99999
1860	78	12.85	-127.33	2.62E-05	1.55E+00	206.03	13.56	-1.05	2.61E-05	1.56E+00	208.35	24.69	-11.15	-0.14	0.98	4.68	5.54	7.83	38.03	25.76	2.98	-4.08	38.23	28.87	287.79	289.4	0	99	9.99999
1920	76	13.25	-126.13	3.56E-05	2.13E+00	208.28	20.06	0.84	3.64E-05	2.17E+00	207.03	21.75	-0.81	2.36	1.75	4.59	5.51	7.87	36.86	24.57	2.67	0.86	39.88	27.84	289.36	288.49	0	99	9.99999
1980	74	13.65	-124.93	4.80E-05	2.92E+00	211.57	25.43	1.51	5.02E-05	3.03E+00	210.33	29.2	4.13	4.56	3.95	4.43	5.26	7.63	35.54	22.44	2.39	-0.18	41.45	26.42	291.62	290.77	0	99	9.99999
2040	72	14.05	-123.73	6.43E-05	3.98E+00	215.86	29.72	1.14	6.46E-05	4.14E+00	223.14	31.22	8.97	0.45	3.83	4.17	4.73	7.05	34.17	18.99	2.15	1.47	42.53	24.57	294.53	299.45	0	99	9.99999
2100	70	14.45	-122.53	8.56E-05	5.40E+00	220.11	34.07	0.81	8.74E-05	5.61E+00	223.7	45.55	4.4	2.16	3.83	3.88	4.13	6.35	32.8	14.74	1.91	1.7	44.09	22.6	297.38	299.79	0	99	9.99999
2160	68	14.85	-121.33	1.12E-04	7.28E+00	226.37	35.1	0.59	1.10E-04	7.51E+00	237.3	58.74	-5.98	-1.64	3.11	4	4.04	6.31	30.37	15.01	1.76	-0.26	43.9	21.29	301.57	308.77	0	99	9.99999
2220	66	15.25	-120.13	1.46E-04	9.79E+00	232.53	36.27	0.39	1.46E-04	1.00E+01	239.42	69.16	-10.03	0.12	3.09	4.07	3.93	6.26	27.77	15.31	1.61	0.56	43.86	19.93	305.63	310.13	0	99	9.99999
2280	64	15.65	-118.93	1.89E-04	1.29E+01	238.16	36.26	0.43	1.90E-04	1.33E+01	243.29	59.89	-11.48	0.56	2.73	4.2	4.1	6.14	26.03	15.04	1.55	-1.11	43.15	18.9	309.34	312.66	0	99	9.99999
2340	62	16.05	-117.73	2.44E-04	1.71E+01	243.32	35.09	0.53	2.37E-04	1.73E+01	253.95	35.19	-2.68	-3.08	1.16	4.41	4.54	5.92	25.28	14.16	1.58	0.91	41.7	18.21	312.71	319.47	0	99	9.99999

3240 32	22.05	-99.73	1.31E-02	8.79E+02	233.04	11.81	-0.53	1.30E-02	8.83E+02	240.08	35	0.86	-0.9	2.1	2.08	2.16	4.41	15.31	5.55	0.57	-0.09	17.32	10.23	305.93	310.51	0	99	9.99999
3300 30	22.45	-98.53	1.79E-02	1.17E+03	227.81	11.34	-0.24	1.78E-02	1.19E+03	233.5	23.05	0.8	-0.87	1.6	1.79	1.86	3.94	12.99	4.79	0.53	0.48	15.65	8.53	302.43	306.17	0	99	9.99999
3360 28	22.85	-97.33	2.48E-02	1.58E+03	222.51	8.77	0.72	2.48E-02	1.60E+03	227.54	17.02	2.25	-0.98	1.25	1.49	1.37	3.12	10.32	4.44	0.5	0.22	12.43	6.53	288.99	302.35	0	99	9.99999
3420 26	23.25	-96.13	3.43E-02	2.14E+03	217.72	5.86	2.14	3.41E-02	2.16E+03	221.37	12.36	8.8	-0.71	0.96	1.32	1.02	2.87	8.27	3.81	0.47	0.71	9.62	5.48	295.77	298.24	0	99	9.99999
3480 24	23.65	-94.93	4.76E-02	2.93E+03	214.26	5.05	2.41	4.77E-02	2.96E+03	218.9	3.2	9.93	0.17	0.93	1.16	0.85	2.48	6.46	3.93	0.44	0.54	8.13	4.79	283.44	294.56	0	99	9.99999
3540 22	24.05	-93.73	6.72E-02	4.04E+03	209.32	6.11	2.74	6.73E-02	4.06E+03	210.23	8.83	4.47	0.2	0.64	1.19	0.74	2.41	5.53	3.68	0.43	0.74	8.41	4.53	290.02	290.65	0	99	9.99999
3600 20	24.45	-92.53	9.54E-02	5.59E+03	204.07	9.04	3	9.50E-02	5.61E+03	205.82	8.8	5.62	-0.36	0.49	1.23	0.69	2.43	5.31	3.87	0.42	0.75	10.54	4.93	286.36	287.58	0	99	9.99999
3660 18	24.85	-91.33	1.36E-01	7.82E+03	200.34	16.18	4.01	1.37E-01	7.82E+03	198.17	24.71	3.47	0.58	-0.01	1.25	0.8	2.49	6.98	5.23	0.46	-0.59	17.57	6.81	283.72	282.89	0	99	9.99999
3720 16	25.25	-90.13	1.88E-01	1.10E+04	202.65	25.47	5.54	1.89E-01	1.10E+04	202.26	41.51	18.3	0.17	-0.02	1.15	0.99	2.27	9.26	7.4	0.49	0.15	27.08	9.3	285.34	285.07	0	99	9.99999
3780 14	25.65	-88.93	2.52E-01	1.52E+04	210.46	33.12	7.1	2.52E-01	1.52E+04	210.08	49.88	23.38	-0.08	-0.26	1.23	1.1	2.59	11.31	9.88	0.53	-1.48	35.2	11.59	290.8	290.54	0	99	9.99999
3840 12	26.05	-87.73	3.31E-01	2.09E+04	219.91	34.37	6.18	3.28E-01	2.08E+04	222.16	35.51	10.67	-1.46	-0.45	1.33	1.12	2.98	13.11	12.27	0.58	-0.43	36.97	13.32	297.25	298.78	0	99	9.99999
3900 10	26.45	-86.53	4.22E-01	2.82E+04	232.44	29.68	4.95	4.16E-01	2.79E+04	234.2	40.08	15.26	-1.53	-0.78	0.97	1.06	2.25	12.63	11.74	0.63	-0.35	32.33	12.57	305.64	306.79	0	0	0.00008
3960 8	26.85	-85.33	5.27E-01	3.73E+04	246.79	23.53	3.98	5.20E-01	3.70E+04	248.14	40.32	15.5	-1.4	-0.87	0.94	0.89	2.29	10.67	10.07	0.63	0.36	25.94	10.59	314.96	315.82	0	0	0.00007
4020 6	27.25	-84.13	6.53E-01	4.88E+04	260.56	17.43	2.97	6.48E-01	4.84E+04	260.27	23.75	-1.67	-0.71	-0.82	0.94	0.72	2.4	9.11	8.62	0.63	0.95	19.77	8.95	323.67	323.49	0	0	0.00005
4080 4	27.65	-82.93	8.04E-01	6.30E+04	272.69	11.72	1.93	8.03E-01	6.27E+04	271.57	3.92	1.64	-0.09	-0.5	0.9	0.58	2.44	7.83	7.06	0.62	-0.2	14.07	7.41	331.22	330.54	0	6	0.12
4140 2	28.05	-81.73	9.93E-01	8.04E+04	281.61	6.27	1.68	9.91E-01	8.00E+04	280.54	-0.52	2.14	-0.16	-0.54	1.2	0.51	3.34	7.03	6.03	0.5	0.26	9.73	5.8	336.83	336.19	0	6	0.12
4200 0	28.45	-80.53	1.22E+00	1.02E+05	289.55	0.14	-0.16	1.23E+00	1.02E+05	286.77	-2.94	-0.47	0.87	-0.1	2.18	0.47	5.25	2.9	3.35	0.34	-0.53	3.27	3	342.08	340.43	0	5	0.45

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D.4 Sample Boundary Layer Output File Produced by Input File of Appendix C

Day	LST	Hgt	Lat	Lon	hsrf	spdsrf	LC	z0	Elmn	El	Elmd	sha	blfct	nri	S	ool	ustar	BV/fsq	hN	hbl	chb	sigrat	swb	swh	spdavsrf	spdsdsrf	tsrf	stsrfr
1.815	19.55	4.000	27.650	-82.930	0.000	3.84	6	0.12000	-85.4	-30.2	39.3	113.24	1.000	-1.27	4.85	0.01527	0.296	0.00011	651.	200.	200.	2.013	0.60	0.62	4.41	2.42	291.01	5.09
1.819	19.65	2.000	28.050	-81.730	0.012	2.47	6	0.12000	-85.0	-31.5	38.9	114.69	1.000	-1.35	5.13	0.02216	0.179	0.00011	390.	200.	200.	2.358	0.42	0.50	3.39	2.83	289.72	5.26
1.823	19.74	0.000	28.450	-80.530	0.003	2.63	5	0.45000	-84.6	-32.9	38.5	116.14	1.000	-1.42	5.15	0.01584	0.270	0.00011	587.	200.	0.	1.250	0.34	0.34	3.27	3.00	289.52	5.25

APPENDIX E—PARAMETERS AVAILABLE FOR SPECIAL OUTPUT

Following is a listing of the section of GRAM where the "Special Output" can be prepared and generated. This identifies logical places to do computations of special variables or to do units conversions (e.g., multiplying by conversion factors). Comments in this code section also provide lists of the names of the variables that are available for writing to the Special Output. An example of a write statement and user-provided format for writing to the Special Output is given on lines ATMD880 through ATMD884. Another feature is the capability to write surface data values to the special output file. Surface data parameter identifiers are discussed on lines ATMD845 - ATMD861.

```

!-----"Special" output option section                                !ATMD748
      if (iopp /= 0) then                                             !ATMD749
!      EXAMPLES OF SPECIALLY COMPUTED OUTPUT:                        !ATMD750
!----- Wind speed (m/s) and direction (meteorological convention) from !ATMD751
!      mean winds                                                    !ATMD752
!      wndspd = dsqrt(ugh**2 + vgh**2)                                !ATMD753
!      wnmdir = 180.0D0                                              !ATMD754
!      if (dabs(ugh)>0.0D0 .and. dabs(vgh)>0.0D0) wnmdir = 180.0D0*(1.0D0 + & !ATMD755
!      datan2(ugh,vgh)/pi)                                           !ATMD756
!----- Pressure scale height (m), density scale height (m)         !ATMD757
!      hgtp = pgh/(dgh*g)                                           !ATMD758
!      if (ch <= hj1) then                                           !ATMD759
!      hgtd = hgtp/(1.0D0 + hgtp*dtz/tgh)                             !ATMD760
!      else                                                           !ATMD761
!      hgtd = hgtp/(1.0D0 + hgtp*dtz/tgh - hgtp*dmdz/wtmol)         !ATMD762
!      endif                                                         !ATMD763
!----- Mean free path (m) (assume mean values of pressure and temp.) !ATMD764
!      mfpdth = 7.071D17/(0.424D0*totnd)                             !ATMD765
!----- Other variables that are functions of pressure, density,     !ATMD766
!      temperature, wind and/or moisture, can be calculated here.    !ATMD767
!      Some such variables are: coefficient of viscosity, kinematic   !ATMD768
!      viscosity, thermal conduction coefficient, potential          !ATMD769
!      temperature, equivalent potential temperature, etc.           !ATMD770
!      !ATMD771
!----- **** To print out header information, refer to the section   !ATMD772
!      **** near format label 200 in init subroutine of initial_E10.f. !ATMD773
!      !ATMD774
!      !ATMD775
!      As an aid to the user, the following tables give the names of !ATMD776
!      the variables that are available for output:                  !ATMD777
!      !ATMD778
!----- Position and time parameters                                  !ATMD779
!      !ATMD780
!      ch - Geocentric Height (km) above WGS84 Reference Ellipsoid   !ATMD781
!      Rlocal - Radius from Earth center (km) (Earth radius plus ch) !ATMD782
!      phi - Geocentric Latitude (deg)                                !ATMD783
!      GdLat - Geodetic Latitude (deg)                                !ATMD784
!      thet - Longitude (deg), East(+) West(-)                        !ATMD785
!      elt - Elapsed Time (sec)                                       !ATMD786
!      !ATMD787
!----- Thermodynamic, wind and moisture parameters (on standard output) !ATMD788
!      !ATMD789
!      !ATMD790
!      !ATMD791
!      !ATMD792
!      !ATMD793
!      !ATMD794
!      !ATMD795
!      !ATMD796
!      !ATMD797
!      !ATMD798
!      !ATMD799
!      !ATMD800

```

	Pressure /Vap.Pr. (Nt/m**2)	Density/ Vap.Dens. (kg/m**3)	Temperature /Dewpt. (K)	E-W Wind (m/s)	N-S Wind (m/s)	Vert. Wind (m/s) RH(%)
*Mean	pgh	dgh	tgh	ugh	vgh	wgh
*Mean-76	pghp (%)	dghp (%)	tghp (%)	n/a	n/a	n/a
*Small-Scale						

```

! Perturbation prhs (%)      drhs (%)      trhs (%)      urhs      vrhs      n/a      !ATMD801
!                               !                               !                               !                               !                               !
!*Small-Scale                !                               !                               !                               !                               !
! Stand. Dev.  sphs (%)      sdhs (%)      sths (%)      suhs      svhs      n/a      !ATMD803
!                               !                               !                               !                               !                               !
!*Large-Scale                !                               !                               !                               !                               !
! Perturbation prhl (%)      drhl (%)      trhl (%)      urhl      vrhl      n/a      !ATMD807
!                               !                               !                               !                               !                               !
!*Large-Scale                !                               !                               !                               !                               !
! Stand. Dev.  sphl (%)      sdhl (%)      sthl (%)      suhl      svhl      n/a      !ATMD810
!                               !                               !                               !                               !                               !
!*Total                      !                               !                               !                               !                               !
! Perturbation prh  (%)      drh  (%)      trh  (%)      urh      vrh      wrh      !ATMD813
!                               !                               !                               !                               !                               !
!*Total Stand.              !                               !                               !                               !                               !
! Deviation    sph  (%)      sdh  (%)      sth  (%)      suh      svh      swh      !ATMD816
!                               !                               !                               !                               !                               !
!*Total=Mean+              !                               !                               !                               !                               !
! Perturbation ph           dh           th           uh      vh      wh      !ATMD819
!                               !                               !                               !                               !                               !
!*Total-US76  php (%)      dhp (%)      thp (%)      n/a      n/a      n/a      !ATMD821
!                               !                               !                               !                               !                               !
!*Mean H2O     eofT          rhov          tdgh          n/a      n/a      rhp      !ATMD823
!                               !                               !                               !                               !                               !
!*Stand. Dev.   H2O          seofT          srhov          stdgh          n/a      n/a      srhp      !ATMD826
!                               !                               !                               !                               !                               !
!----- Wind and Speed-of-Sound Statistics (on standard output)      !ATMD826a
!-----                               !ATMD826b
!-----                               !ATMD826c
!-----                               !ATMD826d
!*Ruv              =  uvt2 (U-V cross correlation coefficient)      !ATMD826e
!                               !ATMD826f
!*SpdAv, SpdSd  =  spdgh, sdsph (wind speed average and standard deviation, m/s)      !ATMD826g
!                               !ATMD826h
!*SoSav, SoSpt  =  csp0, csp (average and perturbed speed-of-sound , m/s)      !ATMD826i
!                               !ATMD826j
!                               !ATMD827k
!----- Species concentration parameters (on species output)      !ATMD828
!-----                               !ATMD829
!-----                               !ATMD830
!                               !ATMD831
!                               !ATMD832
!          H2O  O3   N2O  CO   CH4  CO2   N2  O2   O  Ar  He  H   N
!          ---  --   ---  --   ---  ---   --  --   -  --  --  -   -
! Concen-  ppmh2o  ppmn2o  ppmch4  ppmn2  ppmo  ppmhe  ppmn
! tration   ppmo3   ppmco   ppmco2  ppmo2  ppmar  ppmh
!-----                               !ATMD835
! Number   h2ond   n2ond   ch4nd   n2nd   ond   hend   nnd
! Density   o3nd   cond   co2nd   o2nd   arnd   hnd
!                               !ATMD837
!                               !ATMD838
!                               !ATMD839
!                               !ATMD840
!                               !ATMD841
!----- Surface data (passed from Subroutine NCEPmod, via Common      !ATMD842
! Block srfdat)      !ATMD843
!-----                               !ATMD844
! psrf      = average surface pressure (N/m**2)      !ATMD845
! dsrf      = average surface density (kg/m**3)      !ATMD846
! tsrf      = average surface temperature (K)      !ATMD847
! usrf      = average surface Eastward wind component (m/s)      !ATMD848
! vsrf      = average surface Northward wind component (m/s)      !ATMD849
! hsrf      = height of surface (km, above sea level)      !ATMD850
! tdsrf     = average surface dewpoint temperature (K)      !ATMD851
! spsrf     = standard deviation of surface pressure (N/m**2)      !ATMD852
! sdsrf     = standard deviation of surface density (kg/m**3)      !ATMD853
! stsrfe    = standard deviation of surface temperature (K)      !ATMD854
! susrf     = standard deviation of surface Eastward wind (m/s)      !ATMD855
! svsrfe    = standard deviation of surface Northward wind (m/s)      !ATMD856
! shsrfe    = std. dev. (uncertainty) of surf. hgt (m, from spsrf)      !ATMD857
! stdsrfe   = standard deviation of surface dewpoint temp. (K)      !ATMD858
! spdavsrfe = average wind speed at surface (m/s)      !ATMD859
! spdsdsrfe = standard deviation of surface wind speed (m/s)      !ATMD860
! uvtsrfe   = U-V cross correlation at surface (unitless)      !ATMD861

```

```

!
!...   Surface roughness information (passed from Subroutine pertrb,
!      via Common Block vert) for sigma-w model
!      -----
!      lc      = land surface code (0-13 if from 1-by-1 deg data base
!                  or 99 if z0 is from user input)
!      z0      = surface roughness (m), determined from 1-by-1 deg
!                  land surface type, or as specified by user via z0in)
!
!-----At this point, the user is invited to insert whatever output
!      parameters (in whatever format) are desired for the "special"
!      output instead of the Write and Format statements below. Any new
!      variables introduced must be declared at the beginning of the
!      atmod subroutine.
!
!      isev = 0
!      if (densfact > 1.0D0) isev = 1
!---- Release code version of write to special output file
!      write (iopp, 9000) elt, ch, phi, thet, dgh, pgh, tgh, ugh, vgh, dh, &
!          ph, th, uh, vrh, drh, prh, sdh, sph, 0.01D0*sth*tgh, suh, svh, &
!          swl, wh, spdgh, sdsph, csp0, csp, isev, lc, z0
!9000   format(f10.2,f9.3,f10.5,f11.5,1p,2e11.4,0p,f8.2,2f8.2,1p,2e11.4,0p, &
!          f8.2,2f8.2,9f7.2,4f8.2,i3,i4,f8.5)
!
!----- Any change of units for writing to "special" output file can
!      be done here [e.g. International Standard (SI) to English
!      units, etc.]
!
!---- Samples of how to change units:
!
!      Change pressure and standard deviation to millibars
!      pgh = pgh/100.0d0
!      sph = pgh*sph/100.0d0
!      ph = ph/100.0d0
!---- Change density and standard deviation to gm/m**3
!      dgh = dgh*1000.0d0
!      sdh = dgh*sdh/100.
!      dh = dh*1000.0d0
!---- Change temperature and standard deviation to deg C
!      sth = tgh*sth/100.0d0
!      tgh = tgh - 273.15d0
!      th = th - 273.15d0
!
!---- Samples of some other write statements and formats for special
!      output file, including some changes of units (e.g. dividing
!      height by 0.3048 to convert to k-feet), dividing mission
!      elapsed time by 3600. to convert to hours)
!
!      Write(iopp,9000)ch,mfpath,dgh,tgh
!9000   Format(F6.1,1p,2E11.3,0p,F7.1)
!      Write(iopp,9000)ch,suh,svh,sdh,urh,vrh,drh
!9000   Format(F6.2,6F8.2)
!---- Write(iopp,9000)elt/3600.,ch/0.3048,prhs,prhl,prh,drhs,drhl,drh, &
!      trhs,trhl,trh,prhs/sphs,drhs/sdhs,trhs/sths
!9000   Format(2F8.1,12F8.3)
!---- Write(iopp,9000)elt/3600.,ch/0.3048,pgh,sph,ph,dgh,sdh,dh,tgh, &
!      sth,th,prhs/sphs,drhs/sdhs,trhs/sths
!9000   Format(2F8.1,1p,6E10.3,0p,3F10.2,3F8.3)
!---- Write(iopp,9000)ch,sphs/sph,sdhs/sdh,sth/sth,suhs/suh,svhs/svh &
!      sphl/sph,sdhl/sdh,sth/sth,suhl/suh,svhl/svh,sph,sdh,sth,suh, &
!      svh,suhs
!9000   Format(F7.2,10F6.4,3F7.3,F6.2,2F7.2)
!---- Write(iopp,9000)elt/3600.,ch,uh,vh
!9000   Format(F8.1,F8.3,2F8.2)
!---- Write(iopp,9000)elt, ch, phi, thet, dgh, dgph, sdh, drh, tgh, sth, trh, ugh, &
!      suh, urh, vgh, svh, vrh
!9000   Format(F9.1,F9.3,F8.3,F9.3,1p,E10.3,0p,3F6.1,F7.1,2F6.1,6F7.1)
!
!----- The "special" output option Write and Format section ends here.
!      endif
!.....
!ATMD862
!ATMD863
!ATMD864
!ATMD865
!ATMD866
!ATMD867
!ATMD868
!ATMD869
!ATMD870
!ATMD871
!ATMD872
!ATMD873
!ATMD874
!ATMD875
!ATMD876
!ATMD877
!ATMD878
!ATMD879
!ATMD880
!ATMD881
!ATMD882
!ATMD883
!ATMD884
!ATMD885
!ATMD886
!ATMD887
!ATMD888
!ATMD889
!ATMD890
!ATMD891
!ATMD892
!ATMD893
!ATMD894
!ATMD895
!ATMD896
!ATMD897
!ATMD898
!ATMD899
!ATMD900
!ATMD901
!ATMD902
!ATMD903
!ATMD904
!ATMD905
!ATMD906
!ATMD907
!ATMD908
!ATMD909
!ATMD910
!ATMD911
!ATMD912
!ATMD913
!ATMD914
!ATMD915
!ATMD916
!ATMD917
!ATMD918
!ATMD919
!ATMD920
!ATMD921
!ATMD922
!ATMD923
!ATMD924
!ATMD925
!ATMD926
!ATMD927
!ATMD928
!ATMD929
!ATMD930
!ATMD931
!ATMD932

```

```

!
!      return
!      end subroutine atmod_e10
!-----
!ATMD933
!ATMD934
!ATMD935
!ATMD936
!ATMD937

```

Note that the header for the special output is written in the subroutine initial_E10.f90. The following code section shows the header that is written for the sample special output list above.

```

2
!----- This is the header for the "special" output file. The user
!      should insure that the 200 format is compatible with the output
!      format in subroutine atmod near label number 9000 in the
!      models_E10.f90 file.
!      write (iopp, 200)
!
!--- Header format for write statement in normal release code
!
!      200 format('      Time      Hgtkm GeocenLat Lon(East)  DensMean',      &
!      '      PresMean Tmean EWmean NSmean DensPert PresPert ',      &
!      '      Tpert EWpert NSpert Dpert% Ppert% SDden% SDprs%',      &
!      '      SDtemK SDuwnd SDvwnd SDwwnd Wpert SpdAvg SpdStd SoSmean ',      &
!      '      SoSpert Sev LC      z0(m)')
!
!--- Header formats corresponding to other example write statements
!      given in file models_E10.f90
!
!      200 Format(' Hgtkm SigmaU SigmaV SigmaD Upert Vpert Dpert')
!      200 Format(' Timehrs Hgtkft PAvgmb PStdmb Ppertmb',      &
!      '      DAvggm3 DStdgm3 Dpertgm3 TAvgdegC TstddegC TpertdegC'      &
!      '      dPsmn% dDsmn% dTsmn%')
!      200 Format(' Timehrs Hgtkft dPsm1% dPlrg% dPtot% dDsm1%',      &
!      '      dDlrg% dDtot% dTsm1% dTlrg% dTtot% dPsmn% dDsmn%',      &
!      '      dTsmn%')
!      200 Format(' Hgtkm spS sdS stS suS svS spL sdL',      &
!      '      stL suL svL spT sdT stT suT svT ')
!      200 Format(' Timehrs Hgtkm Uwndmps Vwndmps')
!      200 Format(' Time_sec Hgt_km Lat LonE Dens_kgm3 D-76%',      &
!      '      sigD% dDen% Temp_K sigT% dTem% Uwnm/s sigUms dU_m/s',      &
!      '      Vwnm/s sigVms dV_m/s')
!      endif
!----- The "special" output header Write and Format section ends here.
!.....
!INIT595
!INIT596
!INIT597
!INIT598
!INIT599
!INIT600
!INIT601
!INIT602
!INIT603
!INIT604
!INIT605
!INIT606
!INIT607
!INIT608
!INIT609
!INIT610
!INIT611
!INIT612
!INIT613
!INIT614
!INIT615
!INIT616
!INIT617
!INIT618
!INIT619
!INIT620
!INIT621
!INIT622
!INIT623
!INIT624
!INIT625
!INIT626

```

APPENDIX F—EXAMPLE APPLICATION OF GLOBAL REFERENCE ATMOSPHERIC MODEL 2010 AS SUBROUTINES IN ANOTHER MAIN DRIVER

F.1 General Description

For many applications, it is desirable to use GRAM2010 in the form of subroutines in another program. For example, the main driver program may be a trajectory calculating program, for which GRAM2010 provides the atmospheric density and winds used to update the trajectory positions (or to provide the densities and temperatures to compute heat loads, etc.). Several code files are provided that illustrate how to use GRAM as a subroutine in a user-provided trajectory program, and how to implement these new features of the perturbation model. These files include:

- gramtraj_E10.f90 A subroutine for use in user-provided trajectory programs
- trajdemo_E10.f90 A main driver (replaces gram_E10.f) for use in a simple trajectory demonstration program
- trajopts_E10.f90 A main driver (replaces gram_E10.f) for use in an example trajectory program that demonstrates several special options of the perturbation model.
- multtraj_E10.f90 A main driver (replaces gram_E10.f) program that illustrates how to call Earth-GRAM 2010 to evaluate multiple trajectories in one program run, with independent (un-correlated) small-scale correlations between trajectories.
- trajcalc_E10.f90 Subroutines used in these trajectory demonstration programs, illustrating how the user's trajectory program should calculate and provide position and velocity information to GRAM.
- corrtraj_E10.f90 A main driver (replaces gram_E10.f) program illustrating how to call Earth-GRAM 2010 to evaluate multiple profiles in one program run, with small-scale correlations preserved between the profiles.
- multbody_E10.f90 Main driver illustrating how to call GRAM to evaluate perturbations along trajectories of multiple bodies which start out together and at various times separate from each other. The perturbations for each body start out the same, and then remain correlated over both position and time along the body trajectories, and across the spatial separation between the bodies.

As an example of how one might use GRAM2010 in a user-provided trajectory code, trajdemo_E10.f90 will be discussed and this program is shown below. As provided, trajdemo is a simple driver, not exercising any of several available GRAM calling options. Programs trajopts_E10.f90 and multtraj_E10.f90 illustrate how to call GRAM using these options and could be substituted for trajdemo_E10.f90 if the additional features are desired. To utilize trajdemo_E10.f90 in the user's code, it must be compiled and linked with the GRAM routines:

CFiles_E10.f90, IFiles_E10.f90, gramtraj_E10.f90, gramsubs_E10.f90, NCEPsubs_E10.f90, initial_E10.f90, MET07prg_E10.f90, models_E10.f90, random_E10.f90, speconc_E10.f90, RRAMods_E10.f90, MSISsubs_E10.f90, HWMsubs_E10.f90, and JB2008_E10.f90. Certain output parameters are currently passed through the argument list of gramtraj (e.g., mean and perturbed values of density, pressure, temperature and winds; U.S. standard atmosphere values of density, pressure, and temperature). The user can add other atmospheric variables to the argument list. See Appendix E for a description of the output variable names available.

Following is a simplified description of the functions required to be performed in the main driver program, as given in the “uncommented” lines of code in trajdemo_E10. Note that comment lines preceded with “!” are not executable and the syntax is case insensitive.

1. TRJD66: Call to a dummy routine (setipos_E90 found in trajcalc_E10.f90) that should be replaced with the user’s code to provide the initial (starting) time (seconds), initial height (kilometers) above mean sea level or radius if above 6,000 kilometers, initial geocentric latitude (degrees), and initial longitude (degrees).
2. TRJD68 – 71: Sets “previous” values (used later in the code) to the above initial values.
3. TRJD82: The parameter *ifirst* is set equal to 1 which will subsequently trigger gramtraj_E10 to initialize the GRAM model.
4. TRJD84 – 89: Initial perturbations are set to zero unless over-ridden by values supplied by the user in the input file parameters *initpert*, *rdinit*, *rtinit*, *ruinit*, *rvinit*, and *rwinit*.
5. TRJD92 – 96: The first call to gramtraj_E10 which will initialize the code. The inputs used by the code are *ifirst* (= 1 at this point), initial time *ctime*, initial height *chgt*, initial latitude *clat*, initial longitude *clon*, and the initial user perturbations if any (see Section 2.9 above) *ppert*, *dpert*, *tpert*, *upert*, *vpert*, and *wpert*.
6. TRJD101 – 102: Call to a routine (exemplified by dummy routine newpos_E10 in trajcalc_E10.f90) that allows trajdemo_E10 to compute changes in time and position that it will use later. The call to newpos_E10 here, simply initializes the time and position values.
7. TRJD107: In preparation for the next call to gramtraj_E10, the parameter *ifirst* is set to zero. This will prohibit a reinitialization of GRAM since that was accomplished in step 5 above. This line (label 20) also begins the loop over calculated positions and corresponding calculated atmospheric values.
8. TRJD112 – 113: This is where newpos_E10 (or its functional equivalent in the user’s trajectory code) is called to compute the next time and position along the trajectory.
9. TRJD118 – 122: This is the second call to gramtraj_E10. Since *ifirst* is now zero, GRAM will take the previous and current time and position and evaluate new mean and perturbed

atmospheric values for the new position. This process continues (by looping back to label 20) until *ifirst* is set to a nonzero value by gramtraj_E10.

10. TRJD123: As long as *ifirst* is equal to zero, the code will continue along the trajectory. In this example, the new positions are provided by the call to newpos_E10 at TRJD129, but should be replaced by the user's new positions. The corresponding atmospheric values at these points are determined by the call to gramtraj_E10 at TRJD135. This looping continues until the end of the trajectory is reached. At the point, the user should change the value of *ifirst* to trigger a different action. If the user no longer requires additional GRAM values, then setting *ifirst* less than one (or any integer other than 0 or -1) will send the program to TRJD172 where the user can end the program or perform additional tasks at his discretion. If the user is performing a Monte Carlo run, then *ifirst* should be set to -1.

11. TRJD 145: If *ifirst* has been set to -1 by gramtraj_E10, for another iteration of a Monte Carlo run, then the user perturbations and time are set to zero again (TRJD149 – 155).

12. TRJD158 – 162: This is a call to gramtraj_E10 which will utilize the next random number seed and reinitialize GRAM.

13. TRJD164: A call to dummy routine newpos_E10 to reset the initial position, and should be replaced by the user's initial position data.

14. TRJD166: The program is directed back to label 20 to start at the beginning of the trajectory for the next Monte Carlo cycle.

F.2 Listing of Example Main Driver Program (trajdemo_E10.f90) Using gramtraj_E10.f90 as Subroutines

```

PROGRAM TRAJDEMO_E10                                !TRJD 1
!-----!TRJD 2
!  M O D U L E S                                !TRJD 3
!-----!TRJD 4
      USE VAST_KIND_PARAM, ONLY: DOUBLE             !TRJD 5
!  EXAMPLE GRAM DRIVER DEMONSTRATING HOW TO USE GRAMTRAJ SUBROUTINE !TRJD 6
!-----!TRJD 7
!  THIS EXAMPLE DRIVER SHOULD BE COMPILED AND LINKED WITH;          !TRJD 8
!  GRAMTRAJ_E10.F90 - A SUBROUTINE THAT CAN BE USED TO CALL GRAM    !TRJD 9
!  FROM WITHIN IN THE USERS TRAJECTORY CODE                        !TRJD 10
!  TRAJCALC_E10.F90 - A FILE CONTAINING SIMPLE EXAMPLES OF ROUTINES !TRJD 11
!  TO INITIALIZE TRAJECTORY POSITION (SETIPOS) AND                   !TRJD 12
!  UPDATE THE TRAJECTORY VELOCITY AND POSITION                       !TRJD 13
!  (NEWPOS)                                                         !TRJD 14
!  ALL THE OTHER GRAM ROUTINES (CFILES_E10.F90, IFILES_E10.F90,    !TRJD 15
!  GRAMSUBS_E10.F90, NCEPSUBS_E10.F90, INITIAL_E10.F90, MET07PRG_E10.F90, !TRJD 16
!  MODELS_E10.F90, RANDOM_E10.F90, SPECONC_E10.F90, RRAMODS_E10.F90, !TRJD 17
!  MSISSUBS_E10.F90, HWMSUBS_E10.F90, AND JB2008_E10.F90)          !TRJD 18
!-----!TRJD 19
!  AS PROVIDED, TRAJDEMO IS A "PLAIN VANILLA" DRIVER, NOT EXERCISING !TRJD 20
!  ANY OF SEVERAL AVAILABLE GRAM CALLING OPTIONS. PROGRAMS         !TRJD 21
!  TRAJOPTS_E10.F90 AND MULTTRAJ_E10.F90 ILLUSTRATE HOW TO CALL GRAM !TRJD 22
!  USING THESE OPTIONS.                                             !TRJD 23
!-----!TRJD 24
!  CERTAIN OUTPUT PARAMETERS ARE CURRENTLY PASSED THROUGH THE      !TRJD 25
!  ARGUMENT LIST OF GRAMTRAJ (E.G. MEAN AND PERTURBED VALUES OF   !TRJD 26

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! DENSITY, PRESSURE, TEMPERATURE AND WINDS; US STANDARD !TRJD 27
! ATMOSPHERE VALUES OF DENSITY, PRESSURE, AND TEMPERATURE). !TRJD 28
! OTHER ATMOSPHERIC VARIABLES CAN BE ADDED TO THE ARGUMENT LIST !TRJD 29
! BY THE USER. SEE README FILES FOR A DESCRIPTION OF THE OUTPUT !TRJD 30
! VARIABLE NAMES AVAILABLE . !TRJD 31
! !TRJD 32
! AS AN EXAMPLE OF HOW A DOUBLE PRECISION TRAJECTORY CODE WOULD !TRJD 33
! BE CONFIGURED, THE CURRENT ARGUMENT LIST VARIABLES IN GRAMTRAJ !TRJD 34
! HAVE BEEN MADE DOUBLE PRECISION (REAL*8). IF ONLY SINGLE !TRJD 35
! PRECISION IS DESIRED, THESE DECLARATIONS (AND THE DBLE !TRJD 36
! ASSIGNMENT STATEMENTS OF THE ARGUMENT LIST VARIABLES IN !TRJD 37
! GRAMTRAJ) MAY BE MODIFIED ACCORDINGLY. !TRJD 38
! !TRJD 39
!----- !TRJD 40
! I N T E R F A C E   B L O C K S !TRJD 41
!----- !TRJD 42
!   USE SETIPOS_E10_I !TRJD 43
!   USE GRAMTRAJ_E10_I !TRJD 44
!   USE NEWPOS_E10_I !TRJD 45
!   IMPLICIT NONE !TRJD 46
!----- !TRJD 47
! L O C A L   V A R I A B L E S !TRJD 48
!----- !TRJD 49
!   INTEGER :: IFIRST !TRJD 50
!   REAL(DOUBLE) :: DSMALL, PSMALL, WAVERAND, PHIDENS, AMPFACT, WSMALL, & !TRJD 51
!     VSMALL, USMALL, TSMALL, CTIME, CHGT, CLAT, CLON, DCTIME, DCHGT, DCLAT & !TRJD 52
!     , DCLON, DMEAN, PMEAN, TMEAN, UMEAN, VMEAN, WMEAN, DPERT, PPERT, TPERT & !TRJD 53
!     , UPERT, VPERT, WPERT, DSTAND, PSTAND, TSTAND, SOSMEAN, SOSPERT, PTIME & !TRJD 54
!     , PHGT, PLAT, PLON !TRJD 55
!   !TRJD 56
!   SAVE IFIRST, DSMALL, PSMALL, WAVERAND, PHIDENS, AMPFACT, WSMALL, & !TRJD 57
!     VSMALL, USMALL, TSMALL, CTIME, CHGT, CLAT, CLON, DCTIME, DCHGT, & !TRJD 58
!     DCLAT, DCLON, DMEAN, PMEAN, TMEAN, UMEAN, VMEAN, WMEAN, DPERT, & !TRJD 59
!     PPERT, TPERT, UPERT, VPERT, WPERT, DSTAND, PSTAND, TSTAND, & !TRJD 60
!     SOSMEAN, SOSPERT, PTIME, PHGT, PLAT, PLON !TRJD 61
!----- !TRJD 62
! !TRJD 63
!---- INITIALIZE THE TIME (SEC) AND POSITION (HEIGHT OR RADIUS, KM; !TRJD 64
! LATITUDE, DEG N; LONGITUDE, DEG E) !TRJD 65
! CALL SETIPOS_E10 (CTIME, CHGT, CLAT, CLON) !TRJD 66
!---- SAVE CURRENT TIME, POSITION AS PREVIOUS TIME, POSITION !TRJD 67
! PTIME = CTIME !TRJD 68
! PHGT = CHGT !TRJD 69
! PLAT = CLAT !TRJD 70
! PLON = CLON !TRJD 71
! !TRJD 72
! IFIRST IS USED AS A PARAMETER TO TRIGGER GRAM INITIALIZATION !TRJD 73
! (IFIRST = 1), AND TO BE USED AS A RETURN CODE TO TRIGGER ANY !TRJD 74
! DESIRED ACTIONS BY THE MAIN PROGRAM. IN THIS EXAMPLE, IFIRST !TRJD 75
! = 0 CAUSES RECYCLE TO NEXT POSITION; IFIRST = -1 CAUSES !TRJD 76
! RE-INITIALIZATION OF POSITION (AND VELOCITY) VALUES; !TRJD 77
! IFIRST < -1 CAUSES THE PROGRAM TO TERMINATE !TRJD 78
! !TRJD 79
! INITIALIZE THE ATMOSPHERIC VARIABLES WITH THE GRAMTRAJ ROUTINE !TRJD 80
! !TRJD 81
! IFIRST = 1 !TRJD 82
! !TRJD 83
! PPERT = 0.0D0 !TRJD 84
! DPERT = 0.0D0 !TRJD 85
! TPERT = 0.0D0 !TRJD 86
! UPERT = 0.0D0 !TRJD 87
! VPERT = 0.0D0 !TRJD 88
! WPERT = 0.0D0 !TRJD 89
!---- CALL TO GRAMTRAJ FOR SETTING INITIAL VALUES, INCLUDING READING OF !TRJD 90
! NAMELIST INPUT FILE, NCEP DATA AND ATMOSDAT FILES !TRJD 91
! CALL GRAMTRAJ_E10 (IFIRST, CTIME, CHGT, CLAT, CLON, DMEAN, PMEAN, TMEAN, & !TRJD 92
!   UMEAN, VMEAN, WMEAN, DPERT, PPERT, TPERT, UPERT, VPERT, WPERT, DSTAND & !TRJD 93
!   , PSTAND, TSTAND, 0, CTIME, CHGT, CLAT, CLON, 1, 1, 1, PHIDENS, & !TRJD 94
!   WAVERAND, PSMALL, DSMALL, TSMALL, USMALL, VSMALL, WSMALL, AMPFACT, & !TRJD 95
!   SOSMEAN, SOSPERT) !TRJD 96
! !TRJD 97

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!      INITIALIZE THE TRAJECTORY VELOCITY (OR POSITION DISPLACEMENT)      !TRJD 98
!      VALUES (IF INITIALIZATION IS NECESSARY)                          !TRJD 99
!                                                                           !TRJD100
!      CALL NEWPOS_E10 (IFIRST, PTIME, PHGT, PLAT, PLON, CTIME, CHGT, CLAT, CLON & !TRJD101
!      , DCTIME, DCHGT, DCLAT, DCLON, 0)                                !TRJD102
!                                                                           !TRJD103
!      BEGIN CYCLE OF POSITIONS AND ATMOSPHERIC VALUES                    !TRJD104
!                                                                           !TRJD105
20  CONTINUE                                                                !TRJD106
    IFIRST = 0                                                            !TRJD107
!                                                                           !TRJD108
!      UPDATE THE VELOCITY (OR POSITION DISPLACEMENT) VALUES AND THE      !TRJD109
!      TIME AND POSITION VALUES                                           !TRJD110
!                                                                           !TRJD111
!      CALL NEWPOS_E10 (IFIRST, PTIME, PHGT, PLAT, PLON, CTIME, CHGT, CLAT, CLON & !TRJD112
!      , DCTIME, DCHGT, DCLAT, DCLON, 0)                                !TRJD113
!                                                                           !TRJD114
!      EVALUATE THE ATMOSPHERIC PARAMETERS AT THE NEW POSITION              !TRJD115
!                                                                           !TRJD116
!---- CALL TO GRAMTRAJ FOR NEXT TRAJECTORY POSITION                       !TRJD117
!      CALL GRAMTRAJ_E10 (IFIRST, CTIME, CHGT, CLAT, CLON, DMEAN, PMEAN, TMEAN, & !TRJD118
!      UMEAN, VMEAN, WMEAN, DPERT, PPERT, TPERT, UPERT, VPERT, WPERT, DSTAND & !TRJD119
!      , PSTAND, TSTAND, 0, PTIME, PHGT, PLAT, PLON, 1, 1, 1, PHIDENS, & !TRJD120
!      WAVERAND, PSMALL, DSMALL, TSMALL, USMALL, VSMALL, WSMALL, AMPFACT, & !TRJD121
!      SOSMEAN, SOSPERT)                                                !TRJD122
!      DO WHILE(IFIRST == 0)                                              !TRJD123
!      IFIRST = 0                                                        !TRJD124
!                                                                           !TRJD125
!      UPDATE THE VELOCITY (OR POSITION DISPLACEMENT) VALUES AND THE      !TRJD126
!      TIME AND POSITION VALUES                                           !TRJD127
!                                                                           !TRJD128
!      CALL NEWPOS_E10 (IFIRST, PTIME, PHGT, PLAT, PLON, CTIME, CHGT, CLAT, & !TRJD129
!      CLON, DCTIME, DCHGT, DCLAT, DCLON, 0)                            !TRJD130
!                                                                           !TRJD131
!      EVALUATE THE ATMOSPHERIC PARAMETERS AT THE NEW POSITION              !TRJD132
!                                                                           !TRJD133
!---- CALL TO GRAMTRAJ FOR NEXT TRAJECTORY POSITION                       !TRJD134
!      CALL GRAMTRAJ_E10 (IFIRST, CTIME, CHGT, CLAT, CLON, DMEAN, PMEAN, & !TRJD135
!      TMEAN, UMEAN, VMEAN, WMEAN, DPERT, PPERT, TPERT, UPERT, VPERT, & !TRJD136
!      WPERT, DSTAND, PSTAND, TSTAND, 0, PTIME, PHGT, PLAT, PLON, 1, 1, 1 & !TRJD137
!      , PHIDENS, WAVERAND, PSMALL, DSMALL, TSMALL, USMALL, VSMALL, WSMALL & !TRJD138
!      , AMPFACT, SOSMEAN, SOSPERT)                                    !TRJD139
!                                                                           !TRJD140
!      REPEAT THE CYCLE OR TERMINATE, DEPENDING ON THE RETURN VALUE      !TRJD141
!      OF THE PARAMETER IFIRST                                           !TRJD142
!                                                                           !TRJD143
!      END DO                                                            !TRJD144
!      IF (IFIRST == (-1)) THEN                                          !TRJD145
!                                                                           !TRJD146
!---- RE-INITIALIZE THE VELOCITY OR POSITION DISPLACEMENT VALUES        !TRJD147
!      (IF NECESSARY)                                                    !TRJD148
!      PPERT = 0.0D0                                                    !TRJD149
!      DPERT = 0.0D0                                                    !TRJD150
!      TPERT = 0.0D0                                                    !TRJD151
!      UPERT = 0.0D0                                                    !TRJD152
!      VPERT = 0.0D0                                                    !TRJD153
!      WPERT = 0.0D0                                                    !TRJD154
!      CTIME = 0.0D0                                                    !TRJD155
!---- CALL TO GRAMTRAJ FOR RE-INITIALIZING AT BEGINNING OF NEXT          !TRJD156
!      MONTE-CARLO PROFILE                                              !TRJD157
!      CALL GRAMTRAJ_E10 (IFIRST, CTIME, CHGT, CLAT, CLON, DMEAN, PMEAN, & !TRJD158
!      TMEAN, UMEAN, VMEAN, WMEAN, DPERT, PPERT, TPERT, UPERT, VPERT, & !TRJD159
!      WPERT, DSTAND, PSTAND, TSTAND, 0, PTIME, PHGT, PLAT, PLON, 1, 1, 1 & !TRJD160
!      , PHIDENS, WAVERAND, PSMALL, DSMALL, TSMALL, USMALL, VSMALL, WSMALL & !TRJD161
!      , AMPFACT, SOSMEAN, SOSPERT)                                    !TRJD162
!---- RE-SET INITIAL TRAJECTORY POSITION FOR NEXT MONTE-CARLO PROFILE      !TRJD163
!      CALL NEWPOS_E10 (IFIRST, PTIME, PHGT, PLAT, PLON, CTIME, CHGT, CLAT, & !TRJD164
!      CLON, DCTIME, DCHGT, DCLAT, DCLON, 0)                            !TRJD165
!      GO TO 20                                                         !TRJD166
!      ENDIF                                                            !TRJD167
!      STOP                                                            !TRJD168

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!		!TRJD169
!	TERMINATE FOR ANY OTHER VALUES OF IFIRST	!TRJD170
!		!TRJD171
	END PROGRAM TRAJDEMO_E10	!TRJD172
!-----		!TRJD173

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