MSFC-436

Earth Global Reference Atmospheric Model (GRAM99)

Short Course

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Agenda

- Place-holder for agenda with times, etc

Earth-GRAM Summary

- Earth-GRAM is a FORTRAN software package that can run on a variety of platforms including PC's
- For any time and location in the Earth's atmosphere, Earth-GRAM provides values of atmospheric quantities such as temperature, pressure, density, winds, constituents, etc
- Dispersions (perturbations) of these parameters are also provided and have realistic correlations, means, and variances – useful for Monte Carlo analysis
- Earth-GRAM is driven by observations including a tropospheric database available from the National Climatic Data Center
- Although Earth-GRAM can be run in a "stand-alone" mode, many users incorporate it into their trajectory codes
- The source code is distributed free-of-charge to eligible recipients

Background

- Original GRAM was developed (1974) to study Space Shuttle entry guidance and thermal protection issues
- GRAM is usually referred to as Earth-GRAM, to distinguish it from models of other planetary bodies (Venus, Mars, Titan, Neptune)
- Several Earth-GRAM updates have been made; The current version is Earth-GRAM-99, version 3 (a new version is currently undergoing testing)
- Earth-GRAM99 is based on global climatologies from balloon, aircraft, rocket, ground-based remote sensing, satellite remote sensing, and in-situ satellite observations
- Earth-GRAM99 covers all global locations, all heights (surface to ~ 1000 km), and all months
- Earth-GRAM 99 is diagnostic, not prognostic(i.e. it describes the atmosphere, but it does not forecasts)

Applications

- Shuttle re-entry studies
  - Guidance algorithm design
  - Thermal Protection System design
  - RCS thruster fuel use analysis
- Other NASA Projects (X33, X37, X38, X43, etc.)
- Columbia investigation
- Military applications
- Stardust & Genesis missions
- Constellation

Available Documentation

- *The NASA/MSFC Global Reference Atmospheric Model – 1999 Version (GRAM99)* NASA/TM-1999-209630 [On the GRAM CD]
- *The NASA/MSFC Global Reference Atmospheric Model – 1995 Version (GRAM-95)* NASA/TM4715 [On the GRAM CD]
- Bibliography [In Backup Slides]
- WebPages:
  - http://see.msfc.nasa.gov/tte/model_gram.htm
  - http://see.msfc.nasa.gov/ModelDB/ModelDB.htm

Earth-GRAM99 Output

For any position and time, Earth-GRAM provides mean and (optional) perturbed values of:

- Temperature, K
- Pressure, N/m^2
- Density, kg/m^3
- E-W wind, m/s
- N-S wind, m/s
- Vertical wind, m/s

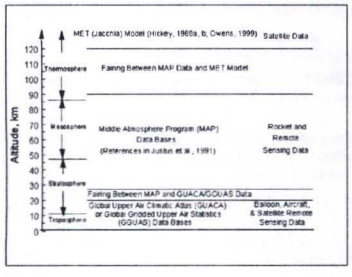
Earth-GRAM99 Output (cont'd)

GRAM also provides mean values (no perturbations) of:

- Water vapor pressure
- Water vapor density
- Relative humidity
- O_3, N_2O, CO, CH_4, CO_2, N_2, O_2, O, Ar, He, H, N

GRAM does not provide global distributions of cloud cover, precipitation, visibility, or lightning

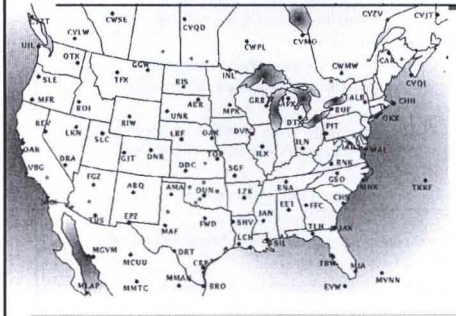
Earth-GRAM99 Data Sources



In addition to global data sets shown at left, Earth-GRAM99 has an option to use Range Reference Atmospheres (1983 RRAs) at and near several launch range site locations

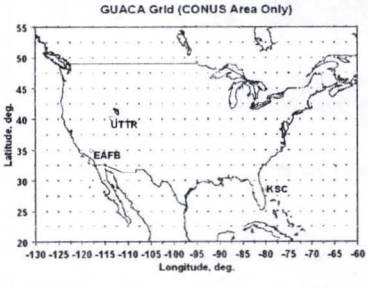
Depending on site, RRAs cover either 0-30 km or 0-70 km altitudes

Source of GUACA Data – Daily Synoptic Observations



- Darker Blue: standard rawinsonde sites with balloons every day, 00Z and 12Z
- Lighter Blue: supplemental sites with balloons at irregular days and times
- Satellite data used mostly over oceans

GUACA - Daily Data Gridded and Averaged



- **Gridded to 2.5-by-2.5 Deg Lat-Lon Grid (Used to initialize ECMWF weather forecast model)**
- **Data for GUACA assembled into monthly averages and standard deviations**
- **Data at Surface and 14 pressure levels (1000 mb to 10 mb; ~ 0-27 km)**

Other GUACA Data Characteristics

- Binary data files containing gridded monthly means and standard deviations (sigmas)
- Monthly means and sigmas for Period-of-Record (POR) 1980 – 1991
- Monthly means and sigmas for individual years 1985 – 1991
- Optional GGUAS (ASCII) data available for POR 1980 – 1995 (no individual years)
- Further description in files guaca.txt and gguas.txt (on the GRAM CD)

Middle Atmosphere Program (MAP)

- Height range: 20 km to 120 km
- Monthly mean values of atmospheric parameters
  - 10° latitude interval from -90° to +90°
  - 20° longitude interval from 180° W to 160° E
  - 5 km height increments
- Standard deviations depend on month, height, and latitude
- Data from rockets and remote sensing
- The dataset resides in the atmosdat.txt file

Marshall Engineering Thermosphere (MET)

- Used for heights above 90 km
- Uses the Jacchia model to calculate atmospheric temperature and pressure based on solar angle/activity
- Computes density from ideal gas equation
- Computes winds using a geostrophic assumption with a viscous modification

Range Reference Atmosphere Data (1983)

- Site specific monthly (and annual average) data
- Period of Record: 1957 - 1979
- Included in GRAM software package
- Sites:
  - Ascension Island
  - Barking Sands, Hawaii
  - Cape Canaveral, Florida
  - Dugway Proving Ground, UT
  - Edwards Air Force Base, CA
  - Eglin AFB, FL
  - Kwajalein Missile Range
  - Point Mugu, CA
  - Taquac, Guam
  - Vandenberg AFB, CA
  - Wallops Island, VA
  - White Sands, NM

Range Reference Atmosphere Data (e.g. table1.wsm)

JANUARY
STATION = 722696 WHITE SANDS, NM

Z	MEAN U	SD U	R(U,V)	MEAN V	SD V	MEAN WS	SD WS	SKEW WS	NOBS
KM	M/S	M/S		M/S	M/S	M/S	M/S		
0.000	0.00	0.00	0.0000	0.00	0.00	0.00	0.00	0.00	0.
1.246	0.02	2.29	-.0457	0.06	2.77	2.73	2.33	1.28	346.
2.000	2.30	3.41	0.3109	-0.60	4.94	5.61	3.17	0.97	345.
3.000	6.61	5.60	0.1951	-1.61	5.75	9.66	4.15	0.45	344.
4.000	10.13	7.54	0.2764	-2.22	7.01	13.43	5.75	0.35	342.
5.000	13.01	9.96	0.2958	-2.33	8.56	16.94	7.73	0.59	337.
6.000	15.16	11.80	0.3858	-1.73	9.88	19.48	9.48	0.65	326.
7.000	16.62	13.52	0.4683	-1.24	11.44	21.70	10.95	0.77	319.
8.000	18.09	14.79	0.5126	-1.15	13.05	23.89	12.09	0.74	313.
9.000	19.64	15.73	0.5153	-0.92	14.47	25.89	13.13	0.60	305.
10.000	21.61	15.80	0.4808	-0.87	15.88	27.83	13.91	0.50	294.
11.000	23.37	15.51	0.4369	-1.02	15.50	29.07	13.49	0.39	279.
12.000	25.25	15.28	0.3802	-0.61	14.47	30.20	12.95	0.41	274.
13.000	25.54	13.44	0.3053	-0.74	13.06	29.42	11.75	0.45	264.
14.000	24.67	11.27	0.4086	-0.92	11.77	27.81	10.07	0.12	248.
15.000	22.62	10.52	0.4217	-0.97	10.46	25.35	9.47	0.09	230.

Range Reference Atmosphere Data (e.g. table2.wsm)

JANUARY
STATION = 722696 WHITE SANDS, NM

Z	MEAN P	SD P	SKEWP	MEAN T	SD T	SKEWT	MEAN D	SD D ..
KM	MB	MB		DEG K	DEG K		G/MJ	G/MJ
0.000	1021.6001	9.0775	-0.24	280.46	10.64	0.27	1268.0000	58.9000
1.000	903.8899	5.3868	-0.11	277.81	7.47	0.15	1132.0000	35.4300
1.246	876.9900	4.8866	-0.04	276.95	6.77	0.10	1102.0000	30.8800
2.000	800.3301	4.1375	-0.04	277.70	5.21	-0.98	1003.0000	20.1900
3.000	707.1201	4.1898	-0.26	272.66	5.00	-0.85	902.6001	14.4900
4.000	623.2300	4.6670	-0.45	267.32	4.71	-0.41	811.7000	10.4100
5.000	547.8601	5.1809	-0.51	261.09	4.54	-0.31	730.7000	8.0810
6.000	479.9700	5.4018	-0.51	254.16	4.38	-0.30	657.7000	6.4520
7.000	418.9099	5.5981	-0.51	246.71	4.33	-0.29	591.3999	5.3440
8.000	364.2800	5.6206	-0.45	239.23	4.21	-0.15	530.3999	4.8300
9.000	315.2500	5.4136	-0.35	231.76	3.79	0.01	473.8999	4.9990
10.000	271.5200	5.1199	-0.27	224.80	3.24	0.01	420.8000	6.3920
11.000	232.9700	4.6069	-0.14	219.39	3.16	0.32	370.0000	8.5270
12.000	199.3400	3.8999	-0.04	215.43	4.76	0.47	322.5000	10.4400
13.000	170.1300	3.1878	0.05	213.97	4.99	-0.05	277.2000	9.6650
14.000	145.0000	2.5366	0.02	212.47	4.03	-0.35	237.9000	7.3000
15.000	123.5600	1.9738	-0.05	210.13	3.58	-0.33	204.9000	5.8340

Range Reference Atmosphere Data (e.g. table3.wsm)

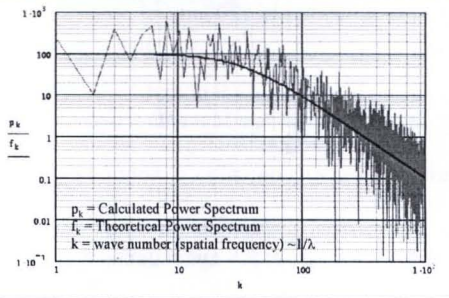
JANUARY
STATION = 722696 WHITE SANDS, NM

Z	VAPOR P	SD VP	SKEW VP	TV	TV	SKEW TV	DEWPT T	SD DPT ..
	MEAN			MEAN	SD		MEAN	
KM	MB	MB		DEG K	DEG K		DEG K	DEG K
0.000	5.935	3.818	1.82	281.09	10.98	0.30	270.42	8.66
1.000	4.616	2.119	0.92	278.36	7.64	0.14	268.06	6.49
1.246	4.337	1.830	0.70	277.47	6.91	0.09	267.40	6.05
2.000	3.462	1.411	0.47	278.16	5.31	-0.98	264.56	5.67
3.000	2.332	1.162	0.73	273.00	5.06	-0.87	259.16	6.62
4.000	1.351	0.807	1.34	267.55	4.76	-0.42	252.32	6.91
5.000	0.775	0.511	1.81	261.25	4.58	-0.32	245.97	6.71
6.000	0.461	0.319	1.67	254.27	4.42	-0.31	240.36	6.61
7.000	0.256	0.175	1.31	246.79	4.36	-0.29	234.44	6.40
8.000	0.130	0.084	0.98	239.28	4.23	-0.17	228.00	6.42
9.000	0.056	0.039	0.78	231.77	3.80	0.01	219.99	7.32
10.000	0.026	0.015	0.36	224.80	3.24	0.01	214.73	5.61
11.000	99.999	99.999	999.99	219.39	3.16	0.32	999.99	99.99
12.000	99.999	99.999	999.99	215.43	4.76	0.47	999.99	99.99
13.000	99.999	99.999	999.99	213.97	4.99	-0.05	999.99	99.99
14.000	99.999	99.999	999.99	212.47	4.03	-0.35	999.99	99.99
15.000	99.999	99.999	999.99	210.13	3.58	-0.33	999.99	99.99

Perturbation Model

- GRAM data is based on monthly averages at a selected spatial scale. Variability at smaller scales is accomplished by the perturbation model
- The observed variability is partitioned into a large-scale (e.g. large weather systems with time scales of several days) and a small-scale (e.g. storms and turbulence)
- The large-scale is simulated with a cosine model to represent the wave nature of this phenomenon using a randomized phase
- The small-scale is simulated as a stochastic (random) process using a one step Markov technique
  - NewValue = OldValue • Correlation + RandomFunction
  - Correlation decays exponentially with time and distance
- Monte Carlo runs of GRAM reproduce the observed monthly means and standard deviations

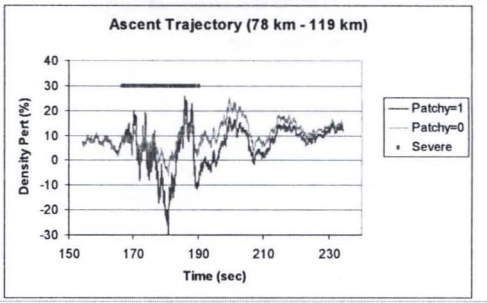
GRAM Produces Dryden Power Spectrum



"Patchy" Parameter

- Enables severe turbulence for patchy = 1 and only light-to-moderate turbulence otherwise (e.g. patchy = 0)
- For severe turbulence, the variances are increased by a factor of 6 to 12 (sigmas are increased by factor or 2.5 to 3.5) depending on height
- The probability of encountering severe turbulence in GRAM is consistent with the likelihood observed in nature (~ 0.2 to 2.5%, depending on height)

Patchy Turbulence



Getting Started

- Requests for GRAM99
  - Sopo Yung at 256-544-0900
  - sopo.yung@msfc.nasa.gov
- Written agreements
  - NASA employees: Software Request Form
  - Domestic non-NASA employees: Software Usage Agreement (SUA)
  - Foreign requests: SUA Form F (Export Controlled)
  - Forms available from GRAM Web Site (see Chart 6)

Contents of the GRAM99 CD

- OrderGUACA.txt
  - How to order full GUACA data CD
- GRAMfixVer3.doc
  - Description of updates from earlier GRAM-99
- README.txt
  - Overview of CD contents
- PCFiles directory
  - Source code, PC executables, data files, README and other documentation, reference input/output test files
- UnxFiles directory
  - UNIX-specific source code and reference input/output test files

PCFiles Directory

- **NameVer3.txt** – Example input file
- **OutVer3.txt** – Resulting standard output file
- **SpclVer3.txt** – Resulting special output file
- **SpcsVer3.txt** – Resulting species output file
- guaca.txt – Description of the Global Upper Air Climatic Atlas data
- gguas.txt – Description of Global Gridded Upper Air Statistics files
- gramfix.txt – Description of any fixes made since original code release
- gramhist.txt – Development history
- README.txt files

PCFiles Directory (cont'd)

- README0.txt – General information as well as a description of the following readme files
- README1.txt – Instructions for compiling and running the program
- README2.txt – Description of the NAMELIST data input file
- README3.txt – Parameters available for the "Special Output" file
- README4.txt – New Global Gridded Upper Air Statistics (0-27km) data option
- README5.txt – New Range Reference Atmosphere Data option and data files
- README6.txt – New MET-99 model and wave perturbation model features
- README7.txt – New option for user-selected initial perturbations

PCFiles Directory (cont'd)

- GRAM95.pdf – GRAM-95 Tech Memo
- GRAM99.pdf – GRAM-99 Tech Memo
- GRAM99.exe – GRAM-99 PC executable
- GRAMTRAJ.exe – Example PC executable for GRAM-99 incorporated into trajectory program
- bldtraj.exe – Program to build array of GRAM input times/locations, as "trajectory" file input
- atmosdat.txt – Atmospheric input file for GRAM
- randin.txt – Sample random seed input file
- Range Reference Atmosphere Data (1983)
- FORTRAN source code (.f extension)

PCFiles Directory - GRAM99 Source Code Files

1) gram99.f - GRAM-99 main program
2) gramsubs.f - Various subroutines used by GRAM
3) guaca.f - Subroutines related to GUACA data
4) **initial.f** - **Subroutine to initialize data**
5) met99prg.f - Source code for MET model
6) **models.f** - **Various sub-models use in GRAM**
7) random.f - Subroutines for random number generator
8) rramods.f - RRA data handling routines for GRAM
9) speconc.f - Subroutines for species concentrations
10) *bldtraj.f* - *Auxiliary program to build "trajectory" input file*
11) *gguasrd.f* - *Auxiliary program to read and convert GGUAS data*
12) *gramtraj.f* - *Routine to facilitate calling GRAM from within user's driver program*

PCFiles Directory – RRA Data Files

- rrasites.txt - List of RRA sites, and 3-character site codes
- table1.xxx - Wind data files for RRA site xxx
- table2.xxx - Pressure, density, temperature data files for RRA site xxx
- table3.xxx - Moisture data files for RRA site xxx

PCFiles Directory – GUACA Binary Data Files

- GUACA monthly mean data files mxxx01.dat
- GUACA monthly standard deviation files sxxx01.dat
- Separate GUACA Files for Parameters xxx =
  - den = Density
  - dwp = Dewpoint temperature
  - hgt = Geopotential heights for pressure levels
  - slp = Sea-level pressure
  - tmp = Temperature
  - uwd = Eastward wind component
  - vwd = Northward wind component
- Data provided for January (Month 01) Period-of-Record only; See file OrderGUACA.txt for how to order full GUACA data CD
- See file guaca.txt for how to set up GUACA data files in appropriate directory structure

GRAM Output Files

Species Output File:

Height (km) Time (sec)	Lati-tude (deg)	Long. [E+W-] (deg)	Concen-tration (ppmv)	Number Density (#/m**3)	Concen-tration (ppmv)	Number Density (#/m**3)	Species	
140.00	.470	-164.550	0.000E+00	0.000E+00	0.000E+00	0.000E+00	H2O	O3
			0.000E+00	0.000E+00	0.000E+00	0.000E+00	N2O	CO
.0			0.000E+00	0.000E+00	0.000E+00	0.000E+00	CH4	CO2
			6.527E+05	6.727E+16	9.188E+04	9.470E+15	N2	O2
			2.533E+05	2.908E+16	2.314E+03	2.385E+14	O	Ar
			1.920E+02	1.964E+13	9.702E-06	1.000E+06	He	H
139.80	.510	-164.430	0.000E+00	0.000E+00	0.000E+00	0.000E+00	H2O	O3
			0.000E+00	0.000E+00	0.000E+00	0.000E+00	N2O	CO
6.0			0.000E+00	0.000E+00	0.000E+00	0.000E+00	CH4	CO2
			6.538E+05	6.817E+16	9.208E+04	9.609E+15	N2	O2
			2.522E+05	2.632E+16	2.325E+03	2.426E+14	O	Ar
			1.890E+02	1.972E+13	9.583E-06	1.000E+06	He	H

Output Files (cont'd)

Standard Output File:

Height (km) Time (sec)	Lati-tude (deg) /RPA	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(%)	
140.00	.470	-164.550	9.820E-04	4.341E-09	690.1	7.7	.3	.000	Mean
			36.3%	13.3%	23.3%				M-76
.0	GRM	.0000	.1%	3.9%	-6.9%	83.7	-9.4		ranS
			2.9%	6.2%	12.6%	45.0	45.0		sigS
			6.1%	4.9%	.7%	-31.2	-24.2		ranL
			12.2%	3.7%	7.4%	52.3	52.3		sigL
			6.2%	8.8%	-6.2%	52.5	-33.7	7.27	ranT
			12.5%	7.2%	14.6%	69.0	69.0	8.33	sigT
			1.043E-03	4.722E-09	647.2	60.2	-33.4	7.27	Tot.
			44.8%	23.2%	15.6%				T-76
			0.000E+00	0.000E+00	.0			.0%	H2O
			0.000E+00	0.000E+00	.0			.0%	sigH

Output Files (cont'd)

Special Output File:

Time	Hgtkm	Latitude	Longitude	DensMean	PresMean	Tmean	EWmean ...
.00	140.000	.47000	-164.55000	4.3410E-09	9.8198E-04	690.07	7.71
6.00	139.800	.51000	-164.43000	4.3969E-09	9.9021E-04	687.28	7.50
12.00	139.600	.55000	-164.31000	4.4539E-09	9.9855E-04	684.48	7.28
18.00	139.400	.59000	-164.19000	4.5119E-09	1.0070E-03	681.68	7.05
24.00	139.200	.63000	-164.07000	4.5710E-09	1.0156E-03	678.87	6.84
30.00	139.000	.67000	-163.95000	4.6311E-09	1.0242E-03	676.05	6.62
36.00	138.800	.71000	-163.83000	4.6923E-09	1.0330E-03	673.22	6.39
42.00	138.600	.75000	-163.71000	4.7547E-09	1.0419E-03	670.39	6.15
48.00	138.400	.79000	-163.59000	4.8182E-09	1.0509E-03	667.55	5.90
54.00	138.200	.83000	-163.47000	4.8829E-09	1.0601E-03	664.71	5.65
60.00	138.000	.87000	-163.35010	4.9491E-09	1.0694E-03	661.89	5.42
66.00	137.800	.91000	-163.23010	5.0162E-09	1.0788E-03	659.03	5.17
72.00	137.600	.95000	-163.11010	5.0847E-09	1.0883E-03	656.16	4.90
78.00	137.400	.99000	-162.99010	5.1544E-09	1.0979E-03	653.29	4.63
84.00	137.200	1.03000	-162.87010	5.2255E-09	1.1077E-03	650.42	4.36
90.00	137.000	1.07000	-162.75010	5.2979E-09	1.1176E-03	647.54	4.09

Controlling Special Output

- Specify variables for output in *models.f*

```
      Write(iopp,9000)elt,h,phi,thet,dgh,pgh,tgh,ugh,vgh,dh,ph,th,uh,      ATMD555c
     &   vh,drh,prh,sdh,sph,0.01*sth*tgh,suh,svh,wh,isev                   ATMD556
9000  Format(F10.2,F9.3,F10.5,F11.5,1p,2E11.4,0p,F7.2,2F8.2,1p,            ATMD557
     &   2E11.4,0p,F7.2,2F8.2,8F7.2,I3)                                    ATMD558
```

- Header can be changed in *initial.f*

```
      Write(iopp,954)                                                      INIT208
954   Format('      Time    Hgtkm  Latitude  Longitude   DensMean',        INIT209
     &   '   PresMean  Tmean  EWmean  NSmean   DensPert   PresPert ',     INIT210
     &   ' Tpert  EWpert  NSpert Dpert% Ppert% SDden% SDpra%',            INIT210a
     &   ' SDtemK SDuwnd SDvwnd  Wpert Sev')                              INIT211
```


Sample Variables For Special Output

- elt – time, sec
- h – height, km
- ph – total pressure, N/m**2
- dh – total density, kg/m**3
- th – total temperature, K
- uh – total east wind, m/s
- vh – total north wind, m/s
- wh – total vertical wind, m/s
- Complete list in file README3.txt

Input Files

- NAMELIST input file (mandatory)
- GUACA database (full set must be ordered)
- Atmosdat.txt file (provided)
- Range Reference Atmosphere input file (Data supplied, use optional)
- Trajectory input file (optional)
- Random seed input file (Monte Carlo option)

Earth-GRAM99 Input File

```
$namein.dat
 atmpath = 'D:\GRAM99\atmosdat.txt'! path name for atmospheric data file
 guapath = 'D:\CDguaca'            ! path name for GUACA or GGUAS files
 trapath = 'null'                  ! path name for trajectory input file
                                     ('null' if none)
 prtpath = 'OutVer3.txt'           ! path name for standard formatted
                                     output file ('null' if none)
 nprpath = 'SpclVer3.txt'          ! path name for the "special" format
                                     output file ('null' if none)
 conpath = 'SpcsVer3.txt'          ! path name for species concentration
                                     output file ('null' if none)
 rndpath = 'null'                  ! path name for file containing more
                                     random number seeds (if needed)
 rrapath = 'D:\GRAM99\RRAdata'     ! DIRECTORY for RRA data
 h1 = 140.                         ! initial height (km)
 phi1 = 0.47                       ! initial latitude (deg, North + )
 thet1 = -164.55                   ! initial longitude (deg,East + )
 f10 = 230.                        ! 10.7-cm flux
 f10b = 230.                       ! mean 10.7-cm flux
```


Earth-GRAM99 Inputs (cont'd)

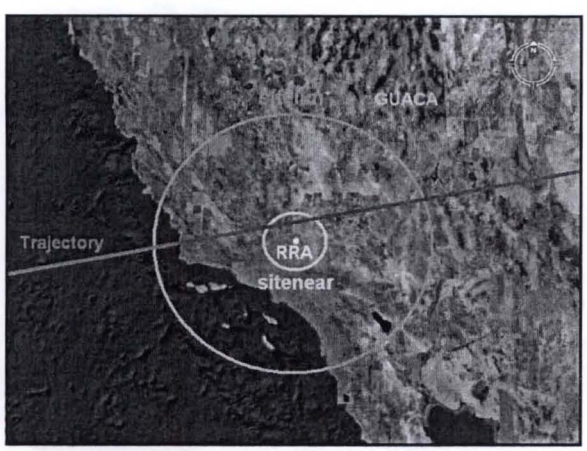
```
ap = 20.3        ! geomagnetic index
mn = 1           ! month (1-12)
ida = 1          ! day of month
iyr = 2006       ! 4-digit year, or 2-digit year yy, with >56=19yy
                   <57=20yy
ihro = 0         ! initial UTC (Greenwich)time hour (0-23)
mino = 0         ! initial UTC (Greenwich)time minutes (0-59)
seco = 0.0       ! initial UTC (Greenwich)time seconds (0.0-60.0)
dphi = 0.04      ! latitude increment (deg, Northward positive)
dthet = 0.12     ! longitude increment (deg, Eastward positive)
dhgt = -0.2      ! height increment (km, upward positive)
nmax = 701       ! maximum number of positions (including initial
                   position;ignored for trajectory input (iopt > 0))
delt = 6.0       ! time increment between positions (real seconds)
iopt = 0         ! trajectory option (0=no trajectory data; otherwise
                   unit number for trajectory input file)
iopp = 17        ! "special" output option (0=no "special" output;
                   otherwise unit number of "special" output file)
iu0 = 0          ! unit number for screen output (normally 6 or 0)
```


Earth-GRAM99 Inputs (cont'd)

```
iup = 6          ! unit number for standard formatted output file
                   (0 for none)
ius = 3          ! unit number for atmosdat data
iuc = 4          ! unit number for concentrations output (0 for none)
iug = 22         ! unit for GUACA or GGUAS input data, 0-27km (0 for no
                   GUACA or GGUAS data)
iguayr = 1       ! Use: 1 for GUACA period of record, 2 for actual GUACA
                   year (1985-1991), based on input value of year (iyr)
                   3 for binary data converted from ASCII Global
                   Gridded Upper Air Statistics (GGUAS) POR data
                   (conversion done with GGUASRD program, provided)
iopr = 1         ! random output option (1 = random output, 2 = none)
nr1 = 1234       ! first starting random number (1 to 9 * 10**8)
iun = 0          ! unit number for more starting random numbers (0 for none)
rpscale = 1.0 ! random perturbation scale, nominal=1.0, max=2.0, min=0.1
iurra = 0        ! unit number for Range Reference Atmosphere (RRA) data
                   (0 if none used)
```


Earth-GRAM99 Inputs (cont'd)

```
sitelim = 2.5    ! lat-lon radius (deg) from RRA site, outside which RRA
                   data are NOT used
sitenear = 0.5   ! 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)
initpert = 1     ! Use 1 for user-selected initial perturbations or 0
                   (default) for GRAM-derived, random initial
                   perturbation values
rpinit = 10.0    ! initial pressure perturbation value (% of mean)
rdinit = 15.0    ! initial density perturbation value (% of mean)
rtinit = -5.0    ! initial temperature perturbation value (% of mean)
ruinit = 3.      ! initial eastward velocity perturbation (m/s)
rvinit = 5.      ! initial northward velocity perturbation (m/s)
rwinit = 1.      ! initial upward velocity perturbation (m/s)
patchy = 1.      ! not equal 0 for patchiness; 0 to suppress
                   patchiness in perturbation model
$End
```

Laptop Demo 1 – Simple Vertical Profile

Placeholder

Laptop Demo 2 – Horizontal Flyover

Placeholder

Trajectory Input File

- Used for a known trajectory or an array of input positions
- Overrides times and positions in the NAMELIST input file.
- Set *nmax* equal to 0 in the NAMELIST input file.
- Set *iopt* to a unit number in the NAMELIST input file.
- Set *trapath* to the path name for the trajectory input file.
- The trajectory input file consists of a text file (with no header record) containing columns of
  - time (sec)
  - height (km)
  - lat (+/- 90°)
  - lon (+/-360°), e.g.

Trajectory Input File Example

```
0.00000E+00    2.78541E-02    2.86084E+01   -8.06041E+01
2.02000E+00    3.34559E-02    2.86084E+01   -8.06041E+01
3.46000E+00    5.23947E-02    2.86084E+01   -8.06041E+01
4.54000E+00    7.51876E-02    2.86084E+01   -8.06041E+01
5.44000E+00    9.99682E-02    2.86084E+01   -8.06041E+01
6.22000E+00    1.25826E-01    2.86084E+01   -8.06041E+01
6.90000E+00    1.51748E-01    2.86084E+01   -8.06041E+01
7.52000E+00    1.78148E-01    2.86084E+01   -8.06041E+01
8.10000E+00    2.05251E-01    2.86084E+01   -8.06041E+01
8.64000E+00    2.32591E-01    2.86084E+01   -8.06041E+01
9.16000E+00    2.60852E-01    2.86084E+01   -8.06041E+01
9.64000E+00    2.88638E-01    2.86084E+01   -8.06041E+01
1.01000E+01    3.16808E-01    2.86084E+01   -8.06040E+01
1.05400E+01    3.45175E-01    2.86085E+01   -8.06040E+01
```


Laptop Demo 3 – trajectory input

- Placeholder

Random Seed Input File

- Used for Monte Carlo runs
- A text file with a single column of integers that need not be random but should not repeat numbers
- Set *iun* to a unit number in the NAMELIST input file.
- Set *iopr* = 1 on the NAMELIST input file
- Set *rndpath* to the path of the random seed file in the NAMELIST input file.

Random Seed Input File Example

- The first number to be used is the value of *nr1* on the NAMELIST input file
- The following file would produce 10 Monte Carlo runs:

```
2
3
4
5
6
7
8
9
10
```

Laptop Demo 4 – Monte Carlo run

- Placeholder

Compiling GRAM99 as a 'Stand-Alone' Program

- On a PC, if you don't change anything in the source code, you don't have to re-compile, you can use the PC executable (gram99.exe) provided on the GRAM CD
- Example of command-line compiling on a PC with compile-and-link command "fl32"
  - fl32 gram99.f gramsubs.f guaca.f initial.f met99prg.f models.f random.f rramods.f speconc.f
  - Creates PC-executable gram99.exe
- Example of command-line compiling under UNIX with FORTRAN 77 command "f77"
  - f77 gram99.f gramsubs.f guaca.f initial.f met99prg.f models.f random.f rramods.f speconc.f
  - mv a.out gram99.x
  - Creates UNIX-executable gram99.x

Running Stand-Alone GRAM

- On a PC (using executable gram99.exe)
  - Open a command-line window (***Start/Run cmd.exe***)
  - Type in ***cd GRAMdirectory*** to move to directory where executable resides and then type in ***gram99.exe***, OR
  - Type in ***pathname\gram99.exe***, where pathname is directory where executable resides
  - Type in the name of the desired NAMELIST input file (must be in same directory)
- Under UNIX (using executable gram99.x
  - Type in ***cd GRAMdirectory*** to move to directory where executable resides and then type in ***gram99.x***, OR
  - Type in ***pathname\gram99.x***, where pathname is directory where executable resides
  - Type in the name of the desired NAMELIST input file (must be in same directory)

Incorporating GRAM99 Into A Trajectory Code

- Subroutine gramtraj provides a GRAM interface, accessible from within a user's program by a "Call" statement
- Subroutine gramtraj, along with other GRAM subroutines (gramsubs.f, guaca.f, initial.f, met99prg.f, models.f, random.f, rramods.f, speconc.f) should be compiled and linked with the user's program
- File gramtraj.f contains the gramtraj subroutine code, as well as some "dummy" code illustrating how a user program can be set up to call GRAM
- File gramtraj.f has many comment statements, designed to aid the user in setting up the gramtraj subroutine in his or her program

Operating Tips – Verify Operation with Sample Input/Output Provided

- After GRAM is properly configured, run it (as in chart 51) with example NAMELIST input file NameVer3.txt
- If you get errors, see additional tips in following charts
- If GRAM runs error free, verify output by comparing with sample output file NameVer3.txt, provided on GRAM CD

Operating Tips – Error Messages

- GRAM writes out error messages when it encounters certain kinds of error conditions
  - Use a text editor to try to find where in the code this error message is coming from; this may help in figuring out and correcting what caused the error condition
  - Extensive COMMENT statements are embedded throughout the code; these also may help in figuring out what the program is doing where the error occurred, and how to correct the error condition
  - If you wish to ask MSFC for assistance in resolving an error, it is VERY helpful to provide the input file you used, and the output you got (or the specific error message that you got)

Operating Tips – GRAM Perturbations

- GRAM uses a one-step process to compute perturbations
  - If you change the random seed value, you will get a different sequence of perturbations
  - If you repeat a given random seed value AND use the same set of calling step sizes, you will get the same sequence of perturbations
  - If you repeat a given random seed value, BUT you change the set of calling step sizes, you will get a different sequence of perturbations (because the steps are different)
- Theoretically, GRAM perturbations can be evaluated at any calling frequency (step size)
  - If large steps are used, successive perturbations will be essentially uncorrelated
  - The small-scale Dryden spectrum means that perturbation energy will be present at all frequencies, with diminishing energy as the steps get smaller (calling frequency increases)
  - It is counterproductive (and may cause spurious results, depending on how your program treats high-frequency dynamics) to call GRAM perturbations too frequently (it is recommended that successive step sizes be used that are no smaller than the size of the vehicle)

Operating Tips – GUACA Data Problems

- Read file guaca.txt (on the GRAM CD)
- Verify that you have put GUACA files in the right pathname structure; examples:
  - GUACA data files in directory D:\GUACA\por\01 for January POR data on a PC and input guapath = 'D:\GUACA'
  - GUACA data files in directory /username/GUACA/por/01 for January POR data on a UNIX platform and input guapath = '/username/GUACA'
- Possible "big-endian vs. little-endian" or other problems with binary data
  - Several GUACA read parameters can be changed in the code, and MAY solve the problem (or some compilers may have switches that correct a "big-endian vs. little-endian" problem)
  - Parameters provided in code in directory PCFiles should work on a PC running Windows (with Linux, there may be a problem)
  - Parameters provided in code in directory UnxFiles should work on most UNIX platforms
  - See comments in README0.txt and in the code on following charts if you need to change GUACA read parameters

Code to Change GUACA Read Parameters (PC Version Shown)

```
C...  Set the following parameter values according to your system      GRAM 67
C     characteristics                                                 GRAM 68
      iswap = 0                                                       GRAM 69
      iblwd = 0                                                       GRAM 70
      irlbw = 0                                                       GRAM 71
      nhdr = 45                                                       GRAM 72
      iur = 5                                                         GRAM 73
      dirsep = '\'                                                    GRAM 74
      endsep = '\'                                                    GRAM 75
      termchar = ' '                                                  GRAM 76
      scrstat = 'scratch'                                             GRAM 77
      sysform = 'binary'                                              GRAM 78
C...  Open the NAMELIST input file                                    GRAM 78a
      Write(*,*)' Enter NAMELIST input file name'                     GRAM 78b
      Read(*,5)namefile                                               GRAM 78c
    5 Format(A)                                                       GRAM 78d
      Open(unit=iur,file=namefile,status='old',iostat=ioerr)          GRAM 78e
      If (ioerr.ne.0)Then                                             GRAM 78f
        Write(*,*)' Error opening NAMELIST file'                      GRAM 78g
        Stop                                                          GRAM 78h
      Endif                                                           GRAM 78i
C                                                                     GRAM 79
```


GUACA Read Parameters (cont'd)

```
C.... Common variable iur is the unit number of the NAMELIST input file GRAM 80
C.... Common variable iswap is a switch to control byte-swapping in the GRAM 82
C     GUACA data, which may be required for certain platforms, e.g.     GRAM 83
C     swapping is required for SGI machines. System level commands may  GRAM 84
C     also be used to do the byte swapping on some machines. To prevent GRAM 85
C     swapping, (e.g. on a VAX) set iswap=0.                           GRAM 86
C.... Common variable iblwd is the block length, in 4-byte words, if   GRAM 87
C     the GUACA files have to be pre-read into a scratch file (iblwd =  GRAM 88
C     0 means no pre-reading necessary; on a VAX use iblwd = 128)      GRAM 89
C.... Common variable irlbw is 4 if unformatted file record lengths are GRAM 90
C     specified in bytes (e.g Sun, RS/6000); irlbw is 1 if unformatted GRAM 91
C     file record lengths are specified in 4-byte words (e.g. SGI,VAX); GRAM 92
C     Compiler options (e.g. old_rl on the SGI) can also change this.  GRAM 93
C...  If GUACA files are to be read as direct access, fixed record     GRAM 94
C     length, use iblwd record length in 4-byte words and irlbw = 1 or GRAM 95
C     4.  If files are to be read as sequential access, use irlbw = 0  GRAM 96
C     and iblwd = 0.                                                   GRAM 97
C.... Common variables dirsep, endsep and termchar are interior and    GRAM 98
C     ending directory separator characters and terminating character  GRAM 99
C     in file pathname structures (e.g, use the following values for   GRAM100
C     the various systems and file pathname structures)                GRAM101
```


Earth-GRAM07

- Currently undergoing Beta-testing
- Expected release date November 2007
- Operationally similar to GRAM99

Earth-GRAM07 New Features

1. **Revised Range Reference Atmosphere (RRA) data**
   - In 2006, the Air Force Combat Climatology Center (AFCCC) developed a set of revised Range Reference Atmosphere (RRA) data including several new sites.
   - Earth GRAM-07 has the option of using either the 2006 revised RRA data, or the earlier (1983) RRA data, as a replacement for conventional Earth GRAM climatology.

GRAM07 RRA Sites (1983)

- Ascension Island, Atlantic
- Barking Sands, Hawaii
- Cape Canaveral, Florida
- Dugway Proving Ground (Salt Lake City), UT
- Edwards Air Force Base, California
- Eglin AFB, Florida
- Kwajalein Missile Range, Pacific
- Point Mugu Naval Air Weapons Center, CA
- Taguac, Guam
- Vandenberg AFB, California
- Wallops Island, Virginia
- White Sands, New Mexico
- Fairbanks, Alaska
- Nellis AFB, Nevada
- Shemya, Alaska
- Thule, Greenland
- Wake Island, Pacific
- Kodiak, AK (unofficial: Developed by MSFC)

GRAM07 RRA Sites (2006)

- Argentia, Newfoundland (St. Johns Airport)
- Ascension Island, Atlantic
- Barking Sands, Hawaii (Lihue)
- Cape Canaveral, Florida
- China Lake Naval Air Weapons Center, CA
- Dugway Proving Ground (Salt Lake City), UT
- Edwards Air Force Base, California
- Eglin AFB, Florida
- El Paso, Texas
- Fairbanks, Alaska
- Huachuca Elec Prvng Grnd (Tucson), AZ
- Great Falls, MT
- Kwajalein Missile Range, Pacific
- Nimes-Courbessac, France (STS TAL Site)
- Nellis AFB, Nevada (Mercury)
- Point Mugu Naval Air Weapons Center, CA
- Roosevelt Roads (San Juan), Puerto Rico
- Taguac, Guam (Anderson AFB)
- Vandenberg AFB, California
- Wallops Island, Virginia (NASA)
- White Sands Missile Range, New Mexico
- Yuma Proving Ground, AZ (San Diego, CA)

New Features (cont'd)

2. Optional auxiliary profile input

- In addition to RRA options, an "auxiliary profile" feature has been implemented.
- This allows the user to input a data profile of pressure, density, temperature, and/or winds versus altitude, in place of conventional climatology values.
- Mean conditions are given by the profile if the desired point is within a prescribed radius of influence and are otherwise given by Earth GRAM climatology.

New Features (cont'd)

3. Updated thermosphere models

- Users now have the choice of 3 thermosphere models:
- The revised Marshall Engineering Thermosphere (MET-2007) model.
- The Naval Research Labs Mass Spectrometer, Incoherent Scatter Radar Extended Model for the thermosphere (NRL MSIS E-00) and the associated Harmonic Wind Model (HWM-93).
- The Jacchia-Bowman 2006 thermosphere model (JB2006).

New Features (cont'd)

4. Perturbation model revisions

- A new feature to update atmospheric mean values without updating perturbation values.
- The ability to simulate large-scale, partially-correlated perturbations as they progress over time for a few hours to a few days.
- A multiple-trajectory driver routine that allows multiple trajectories and perturbations to be simulated in one run.
- A multiple-profile driver routine that allows multiple profiles and perturbations to be simulated in one run, with small-scale correlations maintained between the profiles.
- Modifications which now produce wind shears from the model more similar to those observed at KSC.

New Features (cont'd)

5. Coordinate system changes and revised earth reference ellipsoid

- Equatorial and polar Earth radii for the "sea-level" reference ellipsoid have been updated to World Geodetic System (WGS 84) values used by the GPS navigation system.
- These are also equivalent (to 10 significant figures) to the Geodetic Reference System (GRS 80) values.
- Input values of altitude greater than 6000 km are treated as geocentric radius values, rather than heights.
- Although all input latitudes are geocentric, Earth GRAM-07 now gives both geocentric and geodetic values on the output file.
- A new subroutine has also been added which computes horizontal distance from great-circle distance between two input latitude-longitude positions.

BACKUP CHARTS

Abbreviations

- AFB – Air Force Base
- DSNE – Design Specification for Natural Environments
- ECMWF – European Center for Medium-range Weather Forecasting
- EAFB – Edwards Air Force Base
- GPS – Global Positioning System
- GRAM – Global Reference Atmospheric Model
- GGUAS – Global Gridded Upper Air Statistics
- GUACA – Global Upper Air Climatic Atlas
- MAP – Middle Atmosphere Program
- MET – Marshall Engineering Thermosphere
- POR – Period-of-Record
- RRA – Range Reference Atmosphere
- UTTR – Utah Test and Training Range

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Data Set Period of Record

- GUACA data: 1980-1991
- GGUAS data (option): 1980-1995
- 1983 RRAs: ~ 1957-1979
- 2006 RRAs: 1990-2002

Small-scale model

Auto-correlated variable (density):

$$\rho_2 = r\rho_1 + q\sqrt{(1-r^2)}$$

$$r = \exp\left(-\delta h / L_h\right)\exp\left(-\delta z / L_z\right)\exp\left(-U\delta t / L_h\right)$$

Cross-correlated variables (pres-dens, temp-dens)

$$p_2 = r_v p_1 + r_\mu \rho_2 + r_q Q$$

Dryden Spectrum

According to Lumley and Panofsky "The Structure of Atmospheric Turbulence", the energy spectrum is given by

$$E(k) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-ikl} r(l)\,\bar{u}^2\,dl$$

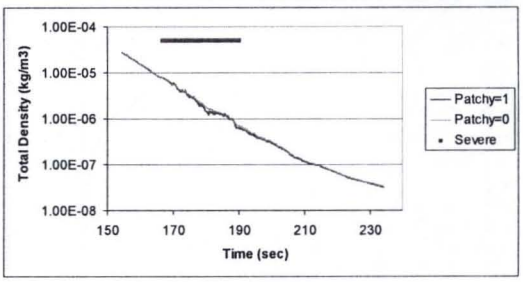
Where r is the correlation coefficient given by

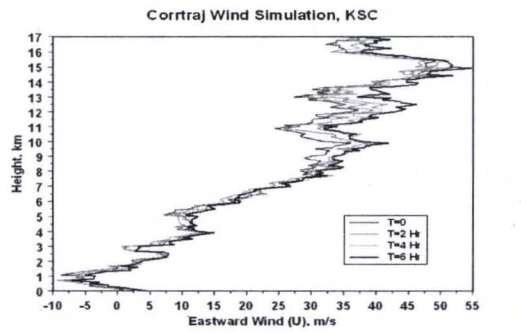
$$r(l) = e^{-l/L} \quad \text{for} \quad l \geq 0$$

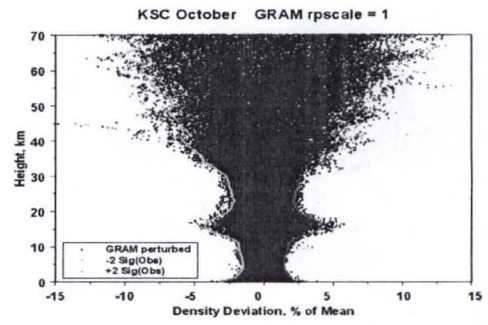
$$r(l) = e^{l/L} \quad \text{for} \quad l \leq 0$$

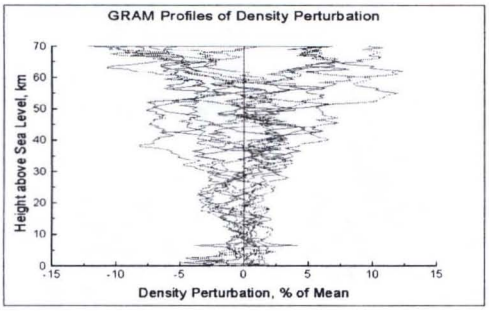
$$\therefore E(k) = \frac{\sigma^2}{\pi}\left[\frac{L}{1+k^2L^2}\right]$$

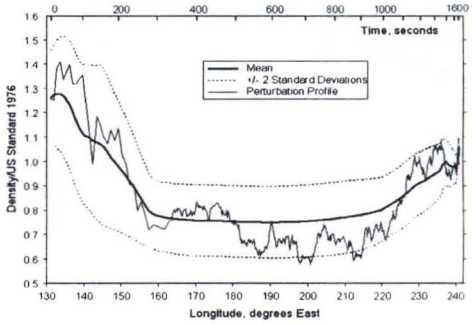
Patchy Turbulence

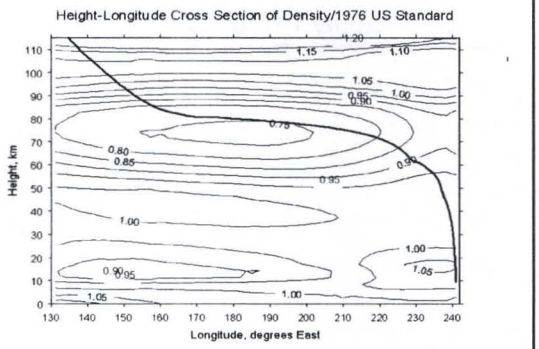


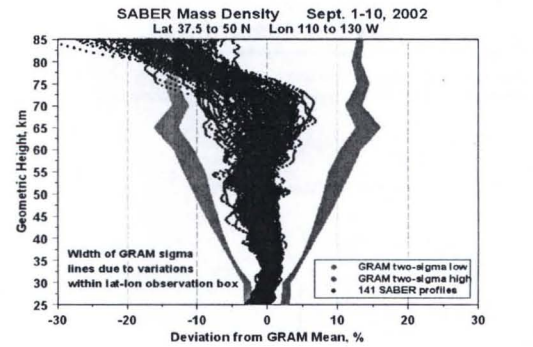


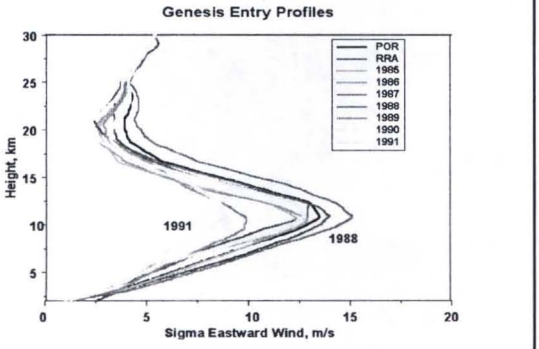


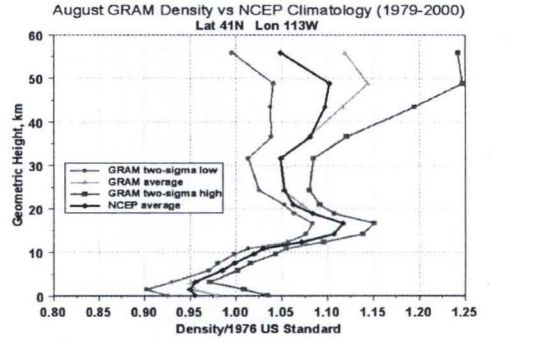


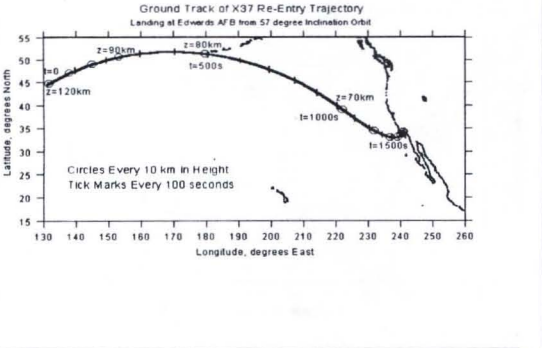


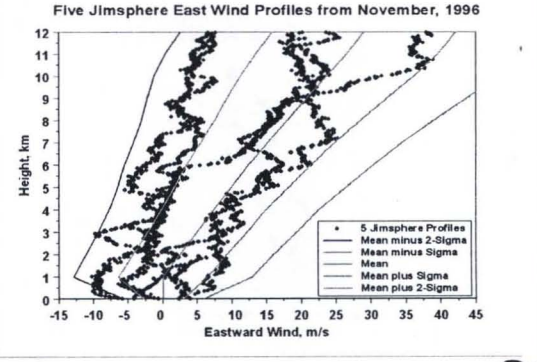

Height-Longitude Cross Section of Density/1976 US Standard
Height, km
Longitude, degrees East

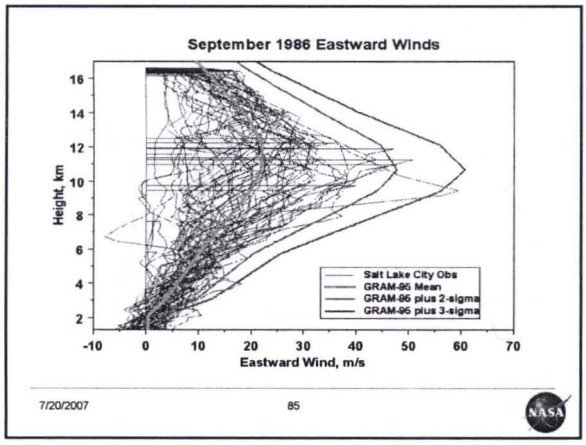

SABER Mass Density Sept. 1-10, 2002
Lat 37.5 to 50 N Lon 110 to 130 W
Geometric Height, km
Width of GRAM sigma lines due to variations within lat-lon observation box
GRAM two-sigma low
GRAM two-sigma high
141 SABER profiles
Deviation from GRAM Mean, %

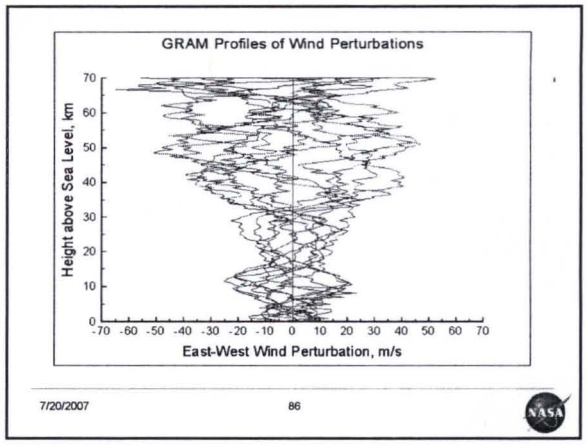

Genesis Entry Profiles
POR
RRA
1985
1986
1987
1988
1989
1990
1991
Height, km
Sigma Eastward Wind, m/s

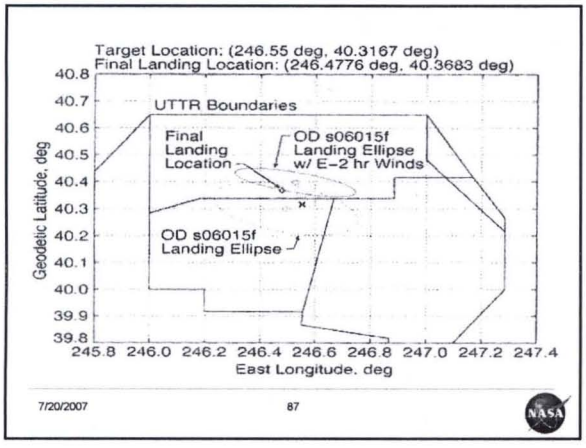

August GRAM Density vs NCEP Climatology (1979-2000)
Lat 41N Lon 113W
GRAM two-sigma low
GRAM average
GRAM two-sigma high
NCEP average
Geometric Height, km
Density/1976 US Standard


Ground Track of X37 Re-Entry Trajectory
Landing at Edwards AFB from 57 degree Inclination Orbit
t=0
z=120km
z=90km
t=500s
z=80km
z=70km
t=1000s
t=1500s
Circles Every 10 km in Height
Tick Marks Every 100 seconds
Latitude, degrees North
Longitude, degrees East


Five Jimsphere East Wind Profiles from November, 1996
5 Jimsphere Profiles
Mean minus 2-Sigma
Mean minus Sigma
Mean
Mean plus Sigma
Mean plus 2-Sigma
Height, km
Eastward Wind, m/s


September 1986 Eastward Winds
Height, km
Eastward Wind, m/s
Salt Lake City Obs
GRAM-96 Mean
GRAM-96 plus 2-sigma
GRAM-96 plus 3-sigma
7/20/2007
85


GRAM Profiles of Wind Perturbations
Height above Sea Level, km
East-West Wind Perturbation, m/s
7/20/2007
86


Target Location: (246.55 deg, 40.3167 deg)
Final Landing Location: (246.4776 deg, 40.3683 deg)
UTTR Boundaries
Final Landing Location
OD s06015f Landing Ellipse w/ E-2 hr Winds
OD s06015f Landing Ellipse
Geodetic Latitude, deg
East Longitude, deg
7/20/2007
87