Earth Global Reference Atmospheric Model 2007 (Earth-GRAM07)

Fred W. Leslie and C. G. Justus

Earth-GRAM Overview

- GRAM is a Fortran software package that can run on a variety of platforms including PC's.
- GRAM provides values of atmospheric quantities such as temperature, pressure, density, winds, constituents, etc.
- GRAM99 covers all global locations, all months, and heights from the surface to ~ 1000 km).
- Dispersions (perturbations) of these parameters are also provided and are spatially and temporally correlated.
- GRAM can be run in a stand-alone mode or called as a subroutine from a trajectory program.
- GRAM07 is diagnostic, not prognostic (i.e., it describes the atmosphere, but it does not forecast).
- The source code is distributed free-of-charge to eligible recipients.

GRAM07 Characteristics

- GRAM output comes from a database of atmospheric measurements.
- New measurements can be introduced using the Auxiliary Profile feature.
- Monte Carlo runs reproduced the observed mean and standard deviations.
- The dispersions are pseudo-Gaussian distributed (except for pressure which is dominated by large-scale disturbances).
- The small-scale dispersions have a Dryden power spectrum.
- The computed wind shears are consistent with those observed at KSC.

Earth-GRAM07 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-GRAM07 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

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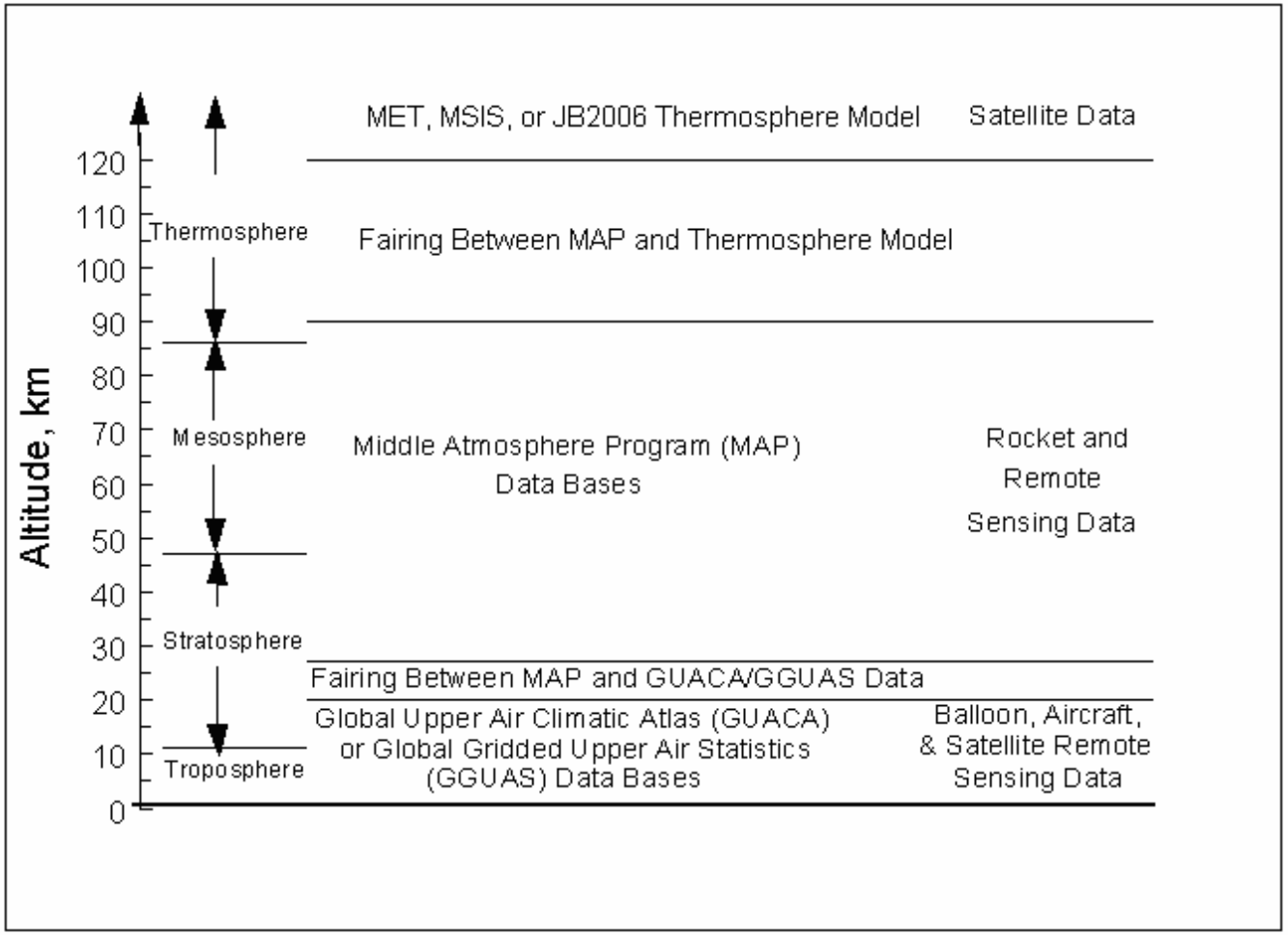
Applications

- 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

Earth-GRAM07 Data Sources



Alternative Data Sources:

- Range Reference Atmospheres
- Auxiliary Profiles

Data Set Period of Record

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

Earth-GRAM 2007 Changes

Perturbation model revisions

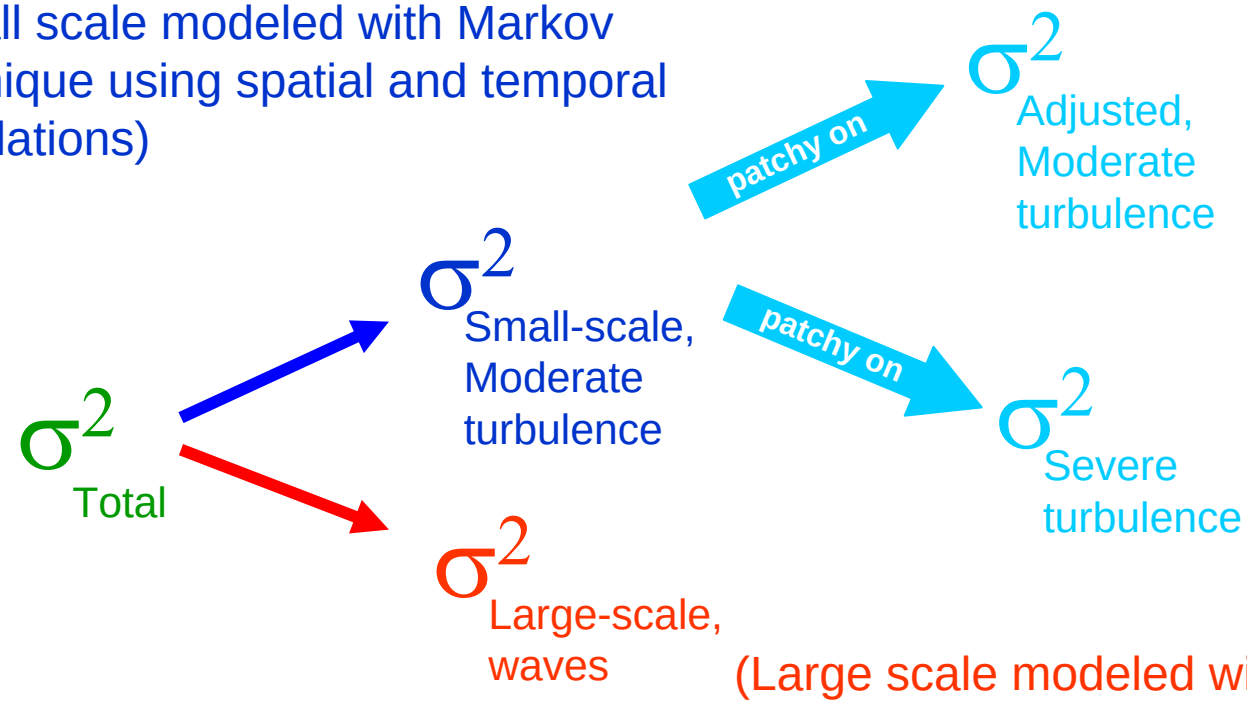
- A new option to update atmospheric mean values without updating perturbation values.
- Large scale perturbations now have randomized amplitude, wavelengths, phase, and period.
- Modifications which produce more realistic wind shears.
- A driver routine that generates multiple profiles that are both time and space correlated for simulating wind persistence.

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
  - Value = cosine [*f* (horizontal, vertical wave numbers, height, random 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

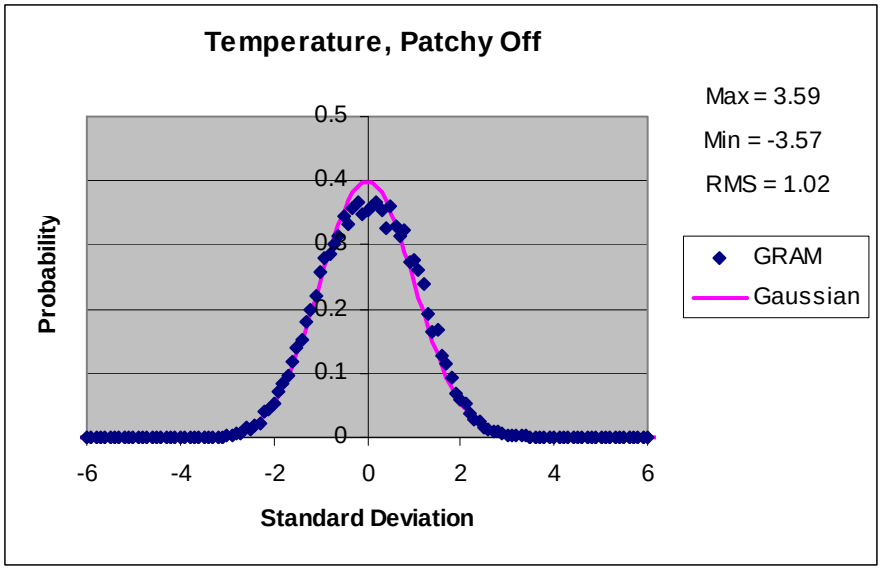
Partitioning of Observed Variance

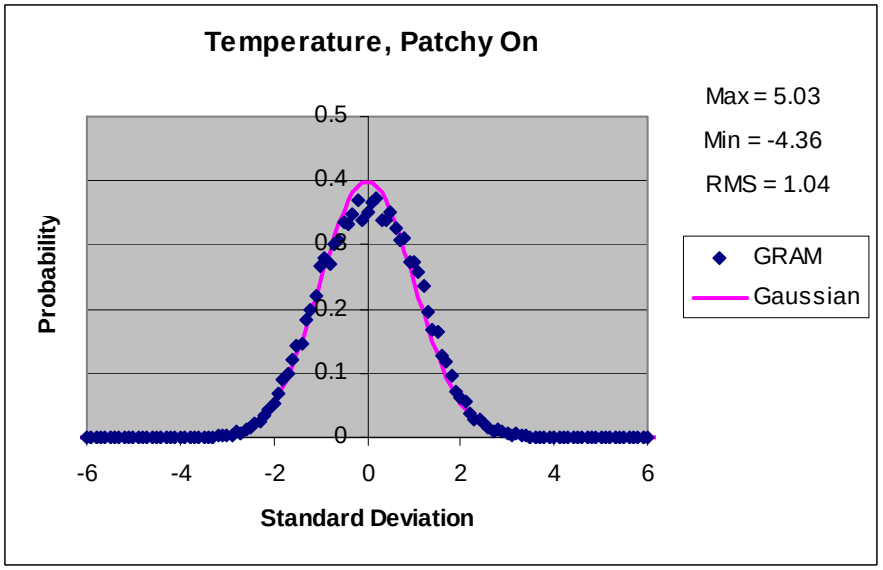
(Small scale modeled with Markov technique using spatial and temporal correlations)

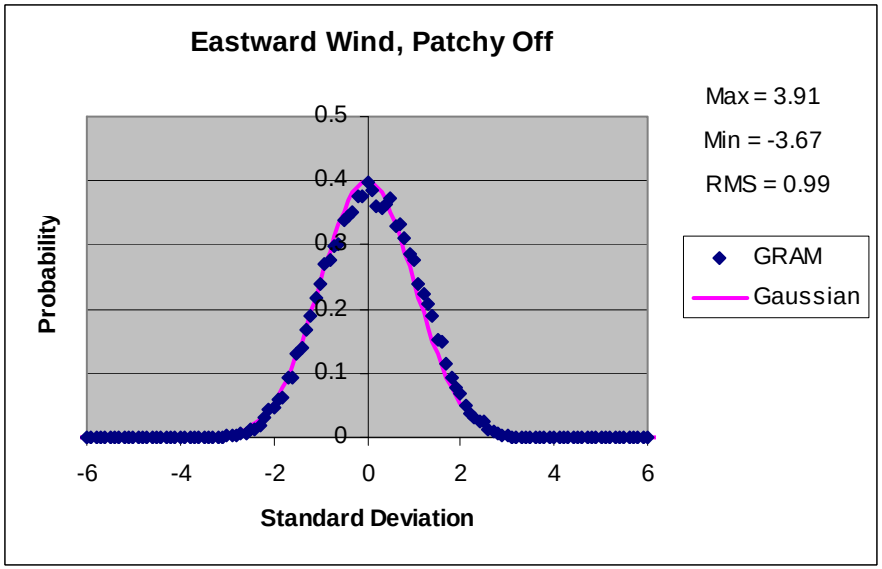


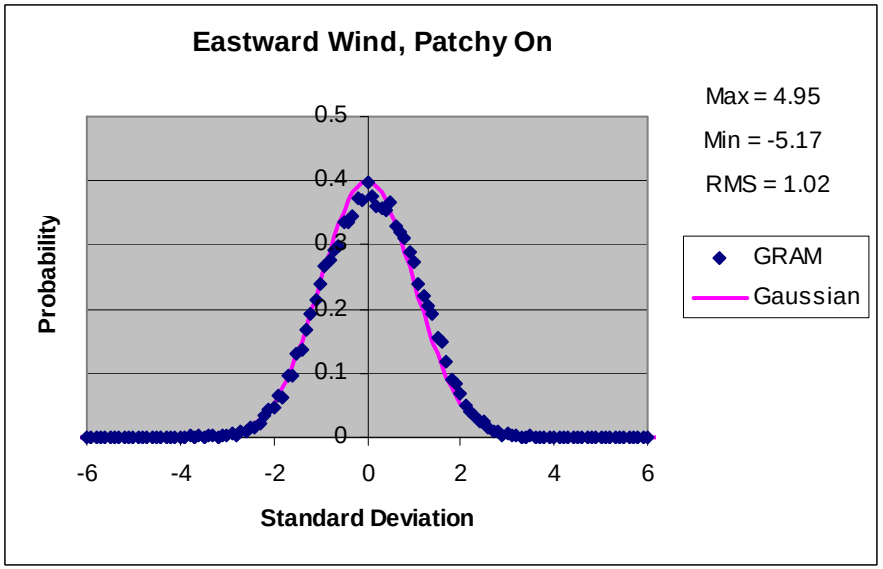
(Large scale modeled with cosine function using randomized amplitude, wavelength, period, and phase)

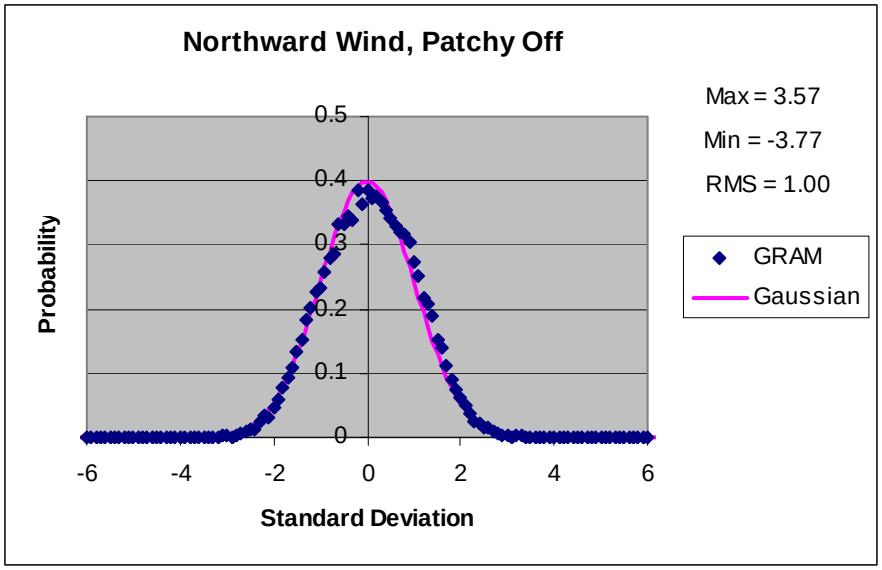
50 point profile X 500 Monte Carlo runs (KSC)

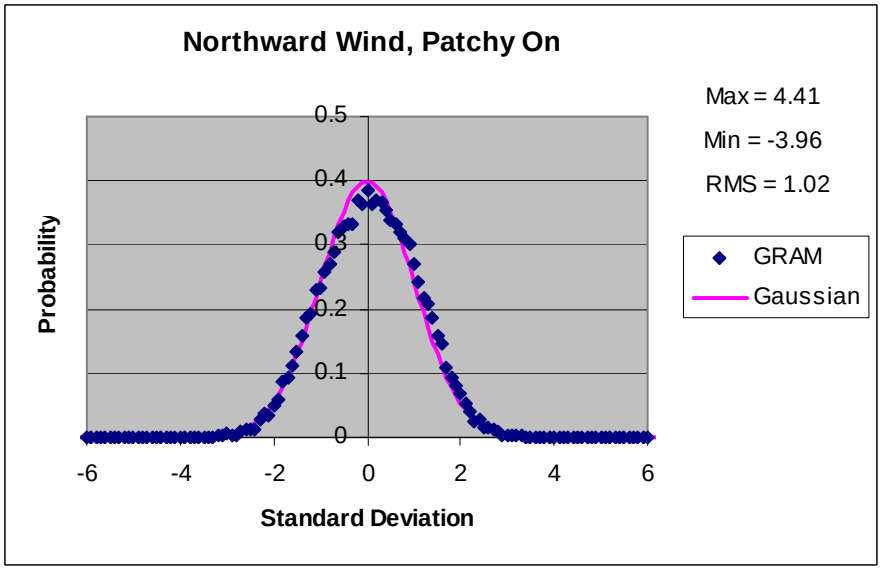









Northward Wind, Patchy Off
Max = 3.57
Min = -3.77
RMS = 1.00
GRAM
Gaussian
Probability
0.5
0.4
0.3
0.2
0.1
0
-6
-4
-2
0
2
4
6
Standard Deviation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Min = -3.96
RMS = 1.02
GRAM
Gaussian
Probability
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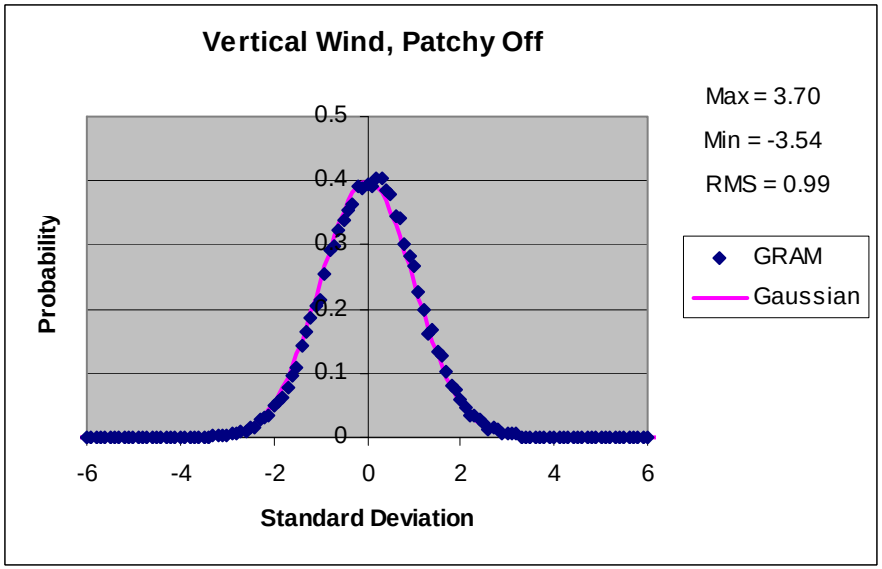
0.3
0.2
0.1
0
-6
-4
-2
0
2
4
6
Standard Deviation


Vertical Wind, Patchy Off
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Min = -3.54
RMS = 0.99
GRAM
Gaussian
Probability
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0.3
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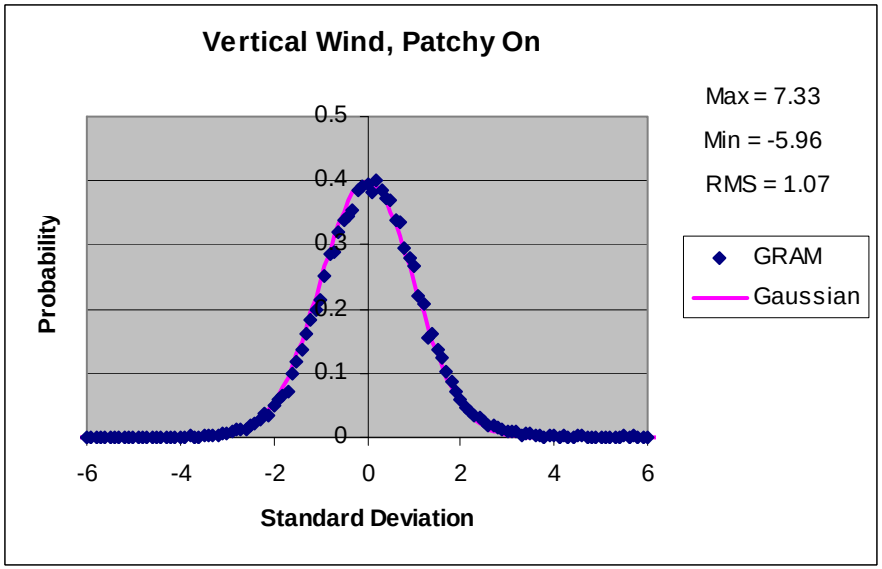
0.1
0
-6
-4
-2
0
2
4
6
Standard Deviation


Vertical Wind, Patchy On
Max = 7.33
Min = -5.96
RMS = 1.07
GRAM
Gaussian
Probability
0.5
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0.3
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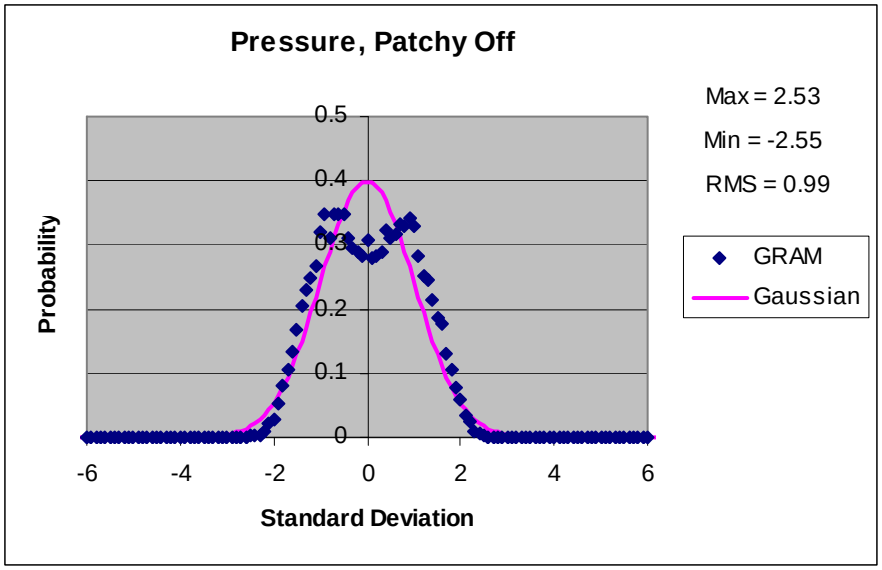
-6
-4
-2
0
2
4
6
Standard Deviation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Min = -2.55
RMS = 0.99
GRAM
Gaussian
Probability
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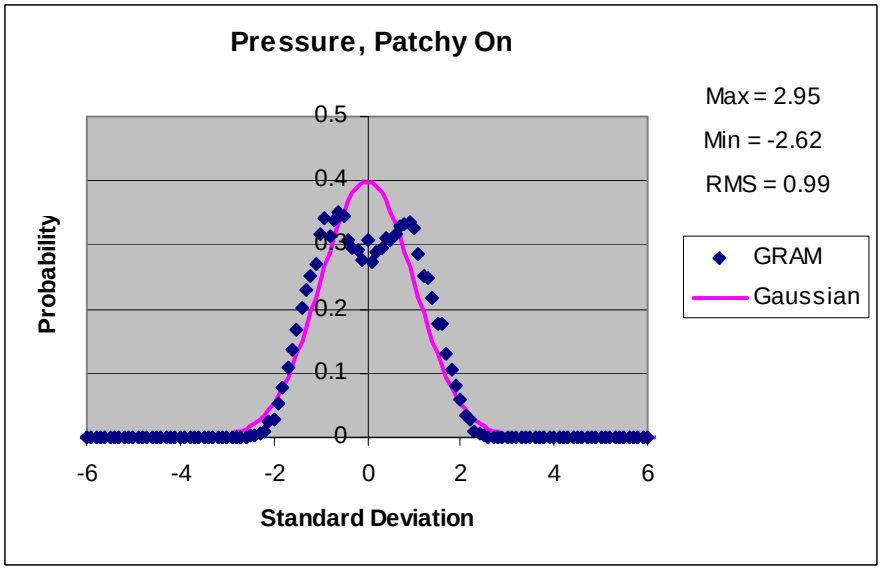
0.3
0.2
0.1
0
-6
-4
-2
0
2
4
6
Standard Deviation


Pressure, Patchy On
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Min = -2.62
RMS = 0.99
GRAM
Gaussian
Probability
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0.3
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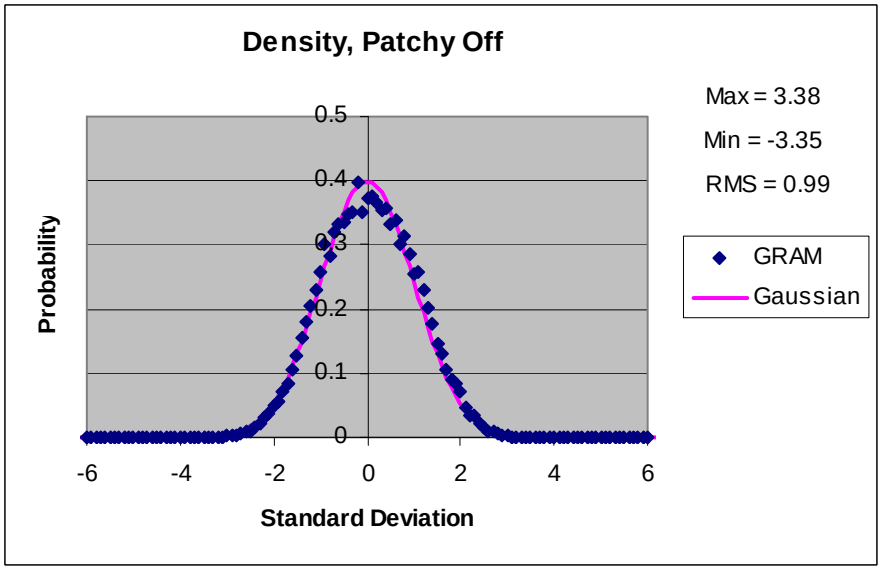
0.1
0
-6
-4
-2
0
2
4
6
Standard Deviation


Density, Patchy Off
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Min = -3.35
RMS = 0.99
GRAM
Gaussian
Probability
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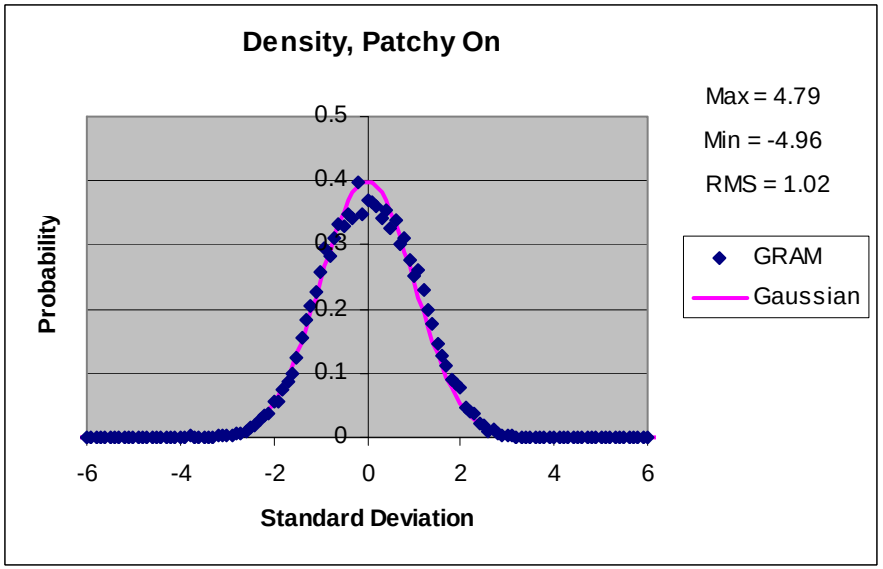
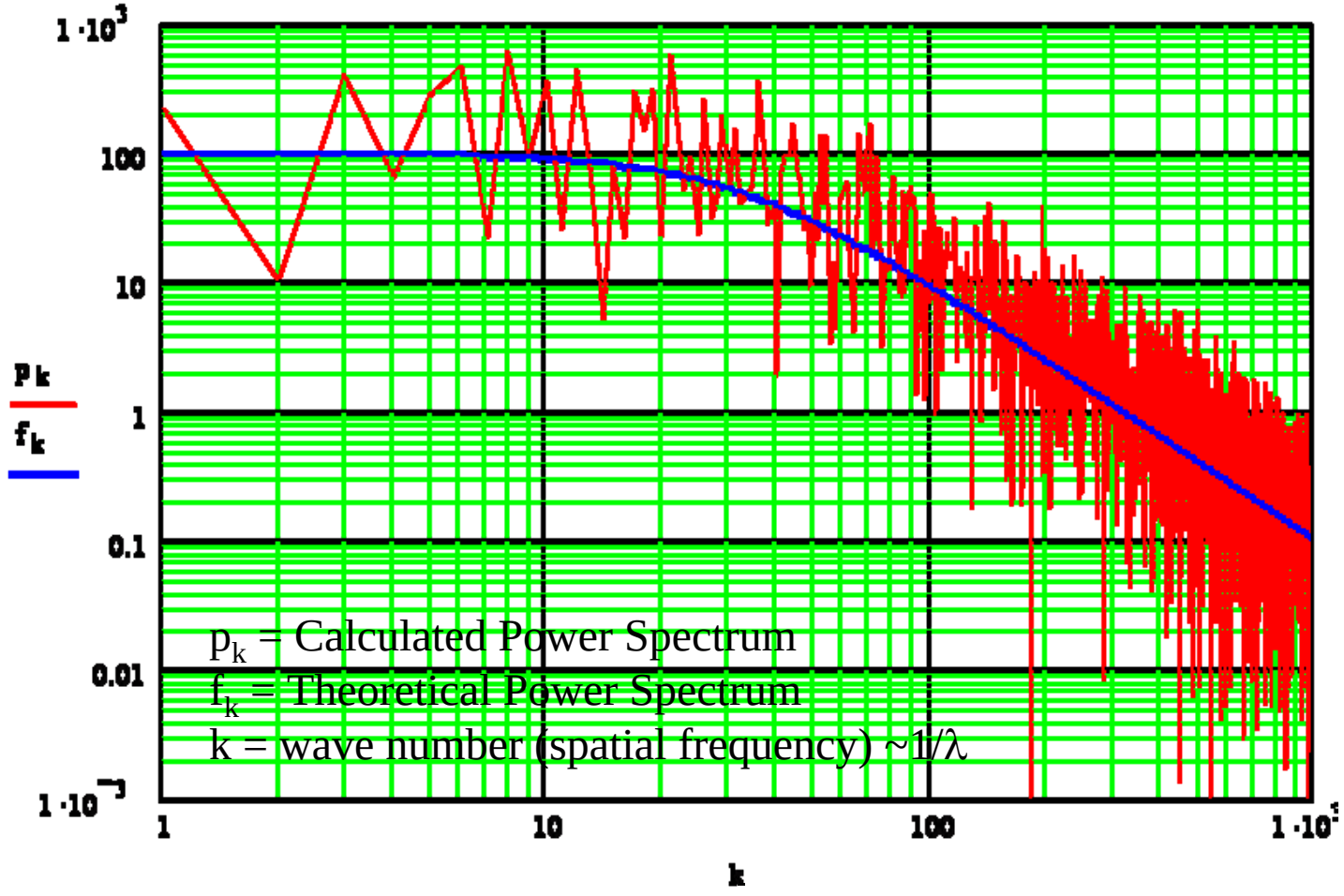
0.3
0.2
0.1
0
-6
-4
-2
0
2
4
6
Standard Deviation


Density, Patchy On
Max = 4.79
Min = -4.96
RMS = 1.02
GRAM
Gaussian
Probability
0.5
0.4
0.3
0.2
0.1
0
-6
-4
-2
0
2
4
6
Standard Deviation

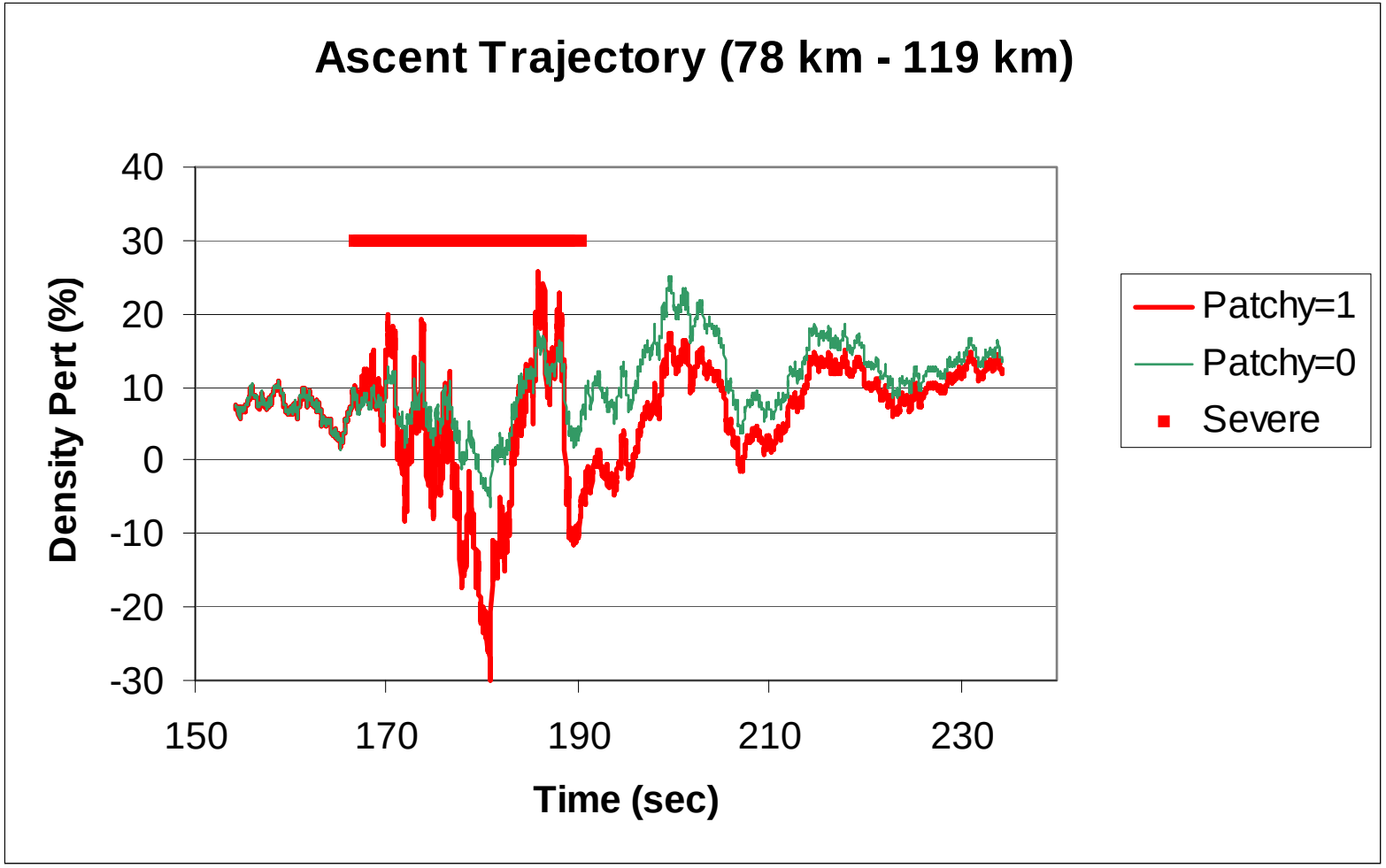
GRAM Produces Dryden Power Spectrum



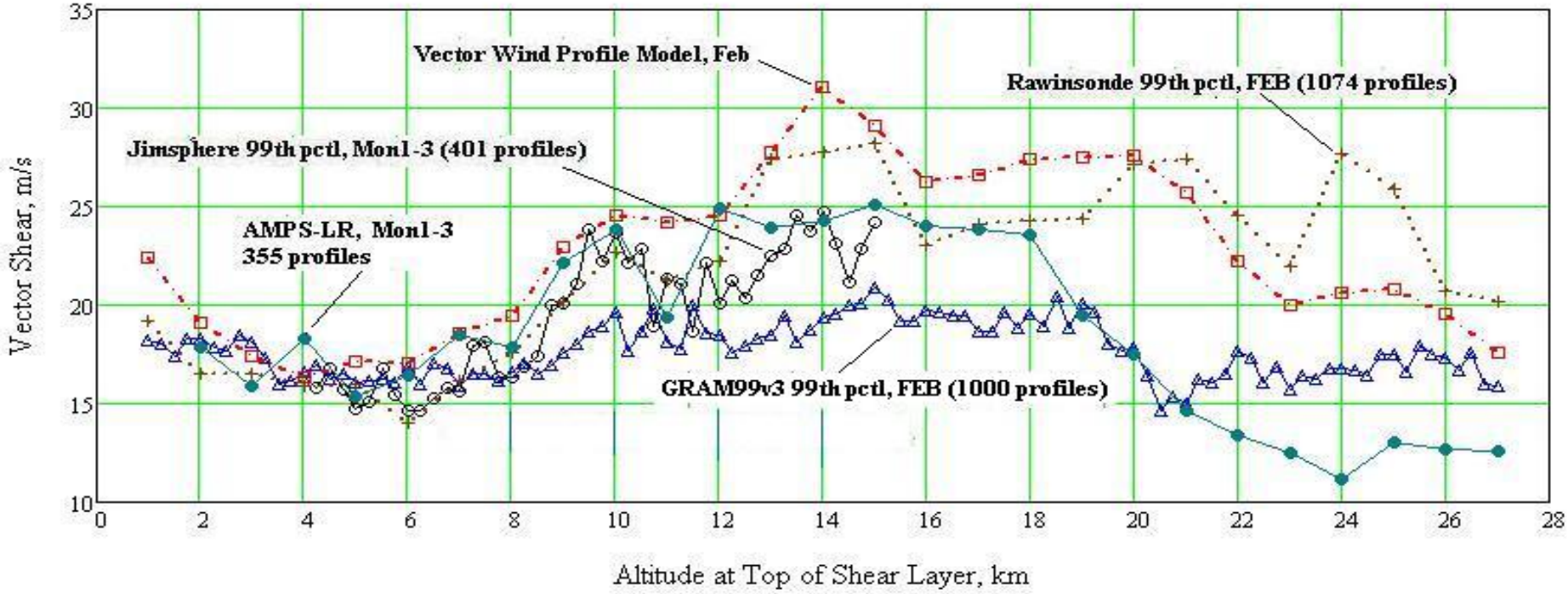
“Patchy” Parameter

- Enables severe turbulence for patchy = 1, and only light-to-moderate turbulence otherwise (e.g. patchy = 0)
- For severe turbulence, the standard deviations are increased by a factor of 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)

Sample Results - Patchy Turbulence (Density)



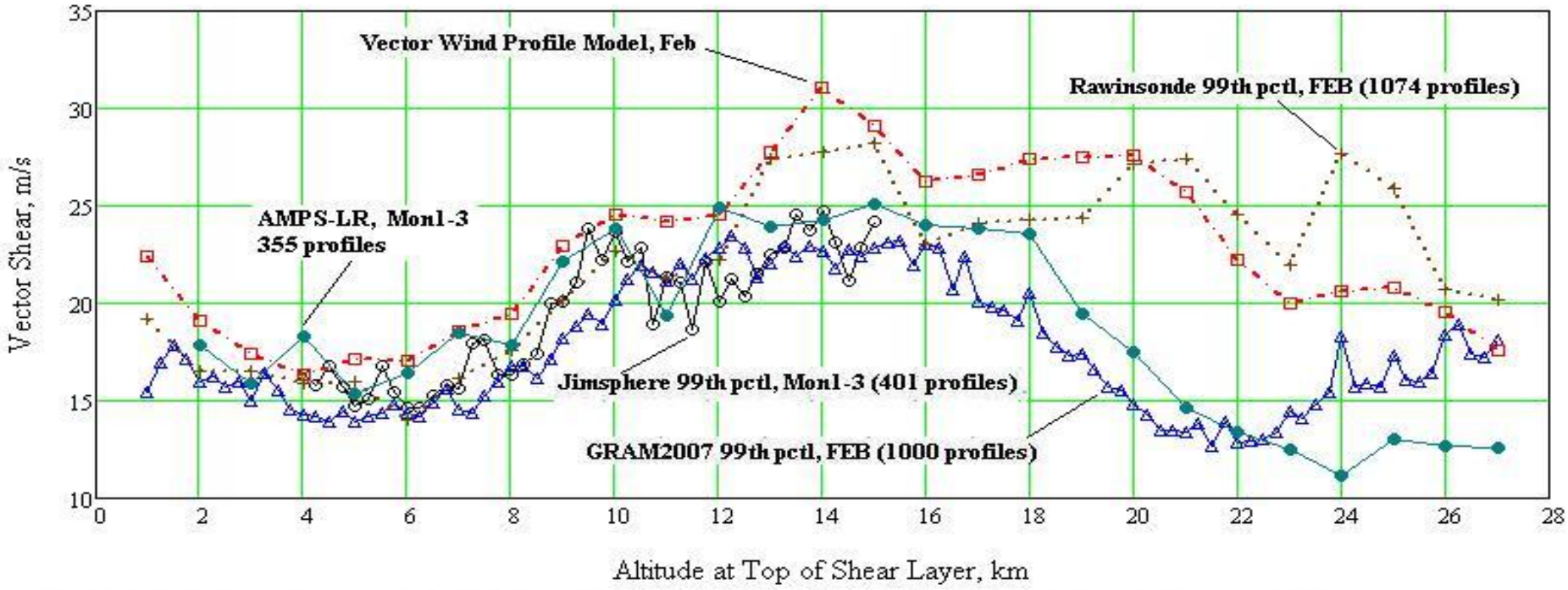
RMS Vector Wind Change across 1-km (GRAM-99 Ver 3 versus Observations)



Empirical 99th percentile 1000-m vector wind shesr in samples of Jimsphere, Rawinsonde, AMPS-LR and GRAM* profiles and the largest vector shear of 12 values generated by the Vector Wind Model at each altitude

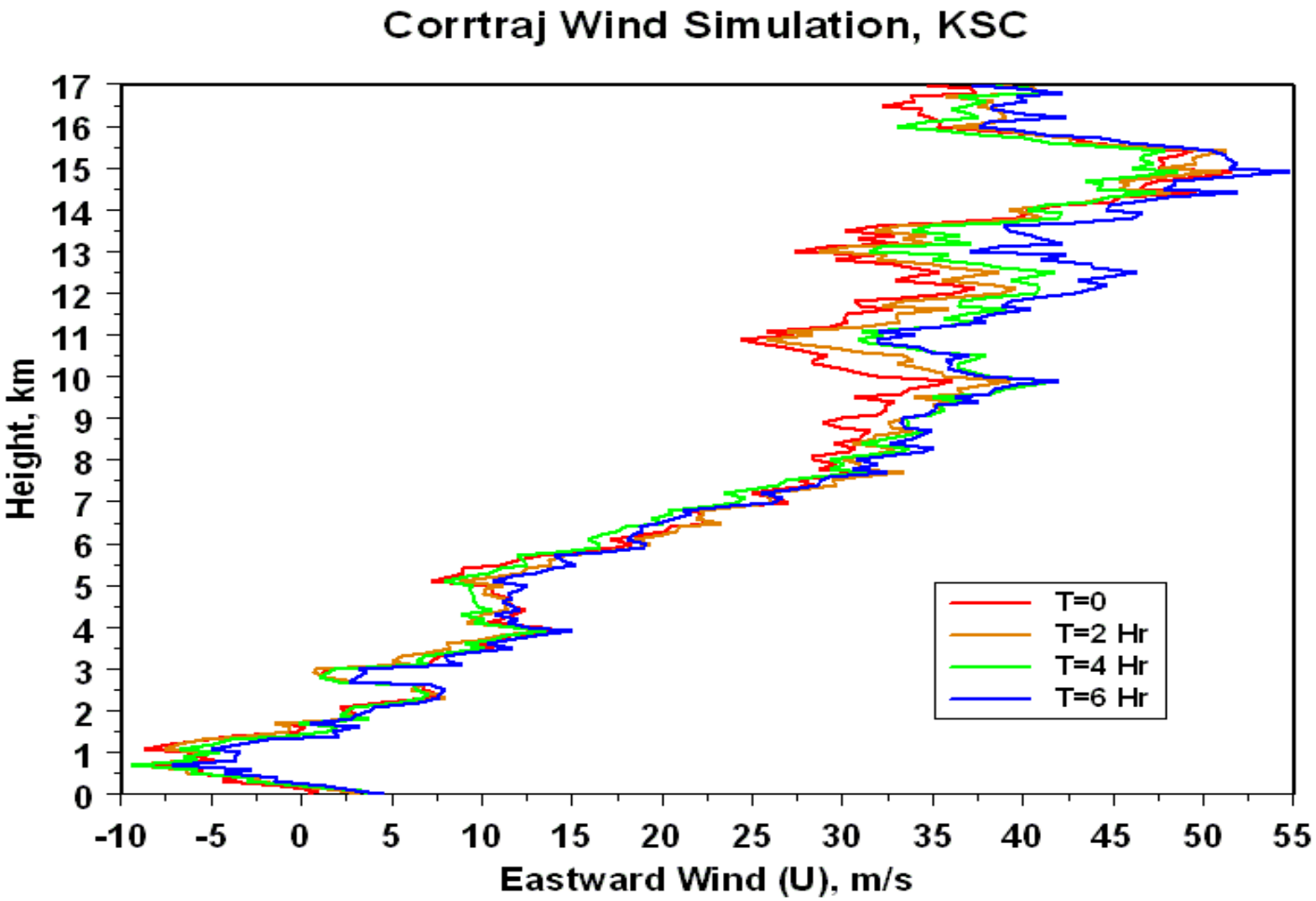
(*)GRAM99v3 with 1983 Range Reference Atmosphere Statistics

RMS Vector Wind Change across 1-km (GRAM-2007 versus Observations)



Empirical 99th percentile 1000-meter vector wind shear in samples of Jimsphere, AMPS-LR, Rawinsonde and GRAM*profiles and the largest vector shear of 12 values generated by the Vector Wind Profile Model at each altitude, KSC

(*) GRAM 2007 with 2006 Range Reference Atmosphere


Corrtraj Wind Simulation, KSC
Height, km
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
Eastward Wind (U), m/s
T=0
T=2 Hr
T=4 Hr
T=6 Hr

Earth-GRAM 2007 Changes (cont'd)

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.
- New stations were added to the list of available 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)**

Earth-GRAM 2007 Changes (cont'd)

Optional auxiliary profile input

- An alternative to the RRA option or the GRAM climatology.
- Allows the user to input mean values of pressure, density, temperature, and/or winds versus altitude, in place of conventional climatology values.
- GRAM can then generate dispersion around these mean values.
- Mean conditions are given by the auxiliary profile if the desired point is within a prescribed radius of influence and are otherwise given by GRAM climatology.

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).

Updates to the MET

- Correction of number density and molecular weight, according to discussion in Justus et al. "Earth GRAM-99 and Trace Constituents", COSPAR, 2004.
- Change from spherical-Earth approximation to latitude-dependent surface gravity and effective Earth radius.
- Change from time resolution only to the nearest integer minute to (real) seconds time resolution.
- Correction of small discontinuities in the semi-annual variation term by converting day-of-year to real instead of integer, and treating each year as having either 365 or 366 days (as appropriate), rather than all years being treated as of length 365.2422 days.
- Additional output from MET07_TME subroutine of modified Julian Day, right ascension of Sun, and right ascension at local lat-lon (used for input to new JB2006 thermosphere model)

New Thermosphere Models

- NRL MSIS E-00 / HWM-93:

http://uap-www.nrl.navy.mil/models_web/msis/msis_home.htm

- JB2006:

http://sol.spacenvironment.net/~JB2006/

Earth-GRAM 2007 Changes (cont'd)

- Earth radii for reference ellipsoid have been updated to World Geodetic System (WGS 84) values, used by the GPS navigation system.
- Input values of altitude greater than 6000 km are treated as geocentric radius values, rather than heights.
- Both radius and height are now given on the output file.
- Although all input latitudes are geocentric, GRAM now outputs both geocentric and geodetic values.
- To create unique program element names, "_E07" has been appended to names of all program files, subroutines, functions, and common blocks.
- All code lines have been re-numbered (from GRAM-99 code).
- Added subroutine radll to compute horizontal distance from great-circle distance between two input lat-lon positions.
- Added new subroutine CaltoJul for conversion from calendar date to Julian day.

BACKUP SLIDES

Small-scale model

Auto-correlated variable (density):

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

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

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

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

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

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

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

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

Available Documentation

- *The NASA/MSFC Global Reference Atmospheric Model – 2007 Version (GRAM07)* In work
- *The NASA/MSFC Global Reference Atmospheric Model – 1999 Version (GRAM99)* NASA/TM-1999-209630 [On the GRAM07 CD]
- *The NASA/MSFC Global Reference Atmospheric Model – 1995 Version (GRAM-95)* NASA/TM4715 [On the GRAM07 CD]
- ReadMe Files [On the GRAM07 CD]
- WebPages:
  - http://see.msfc.nasa.gov/tte/model_gram.htm
  - http://see.msfc.nasa.gov/ModelDB/ModelDB.htm

Ordering Information

Requests for GRAM07:

Sopo Yung at 256-544-9511

sopo.yung@nasa.gov

http://see.msfc.nasa.gov/tte/model_gram.htm