

2017 GSI Community Tutorial  
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# GSI fundamentals (4): Background Error Covariance and Observation Error

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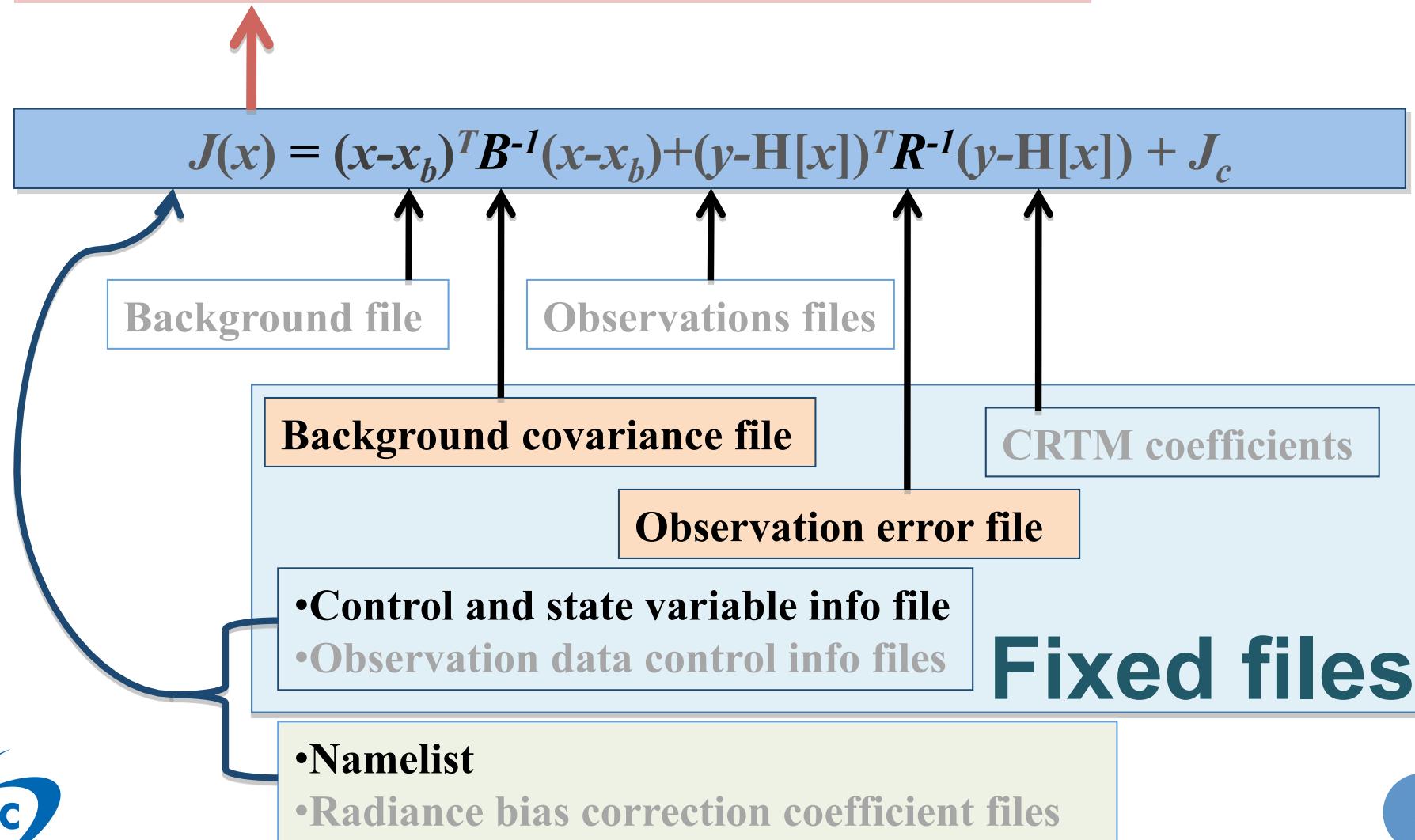
# Outline

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- GSI fundamentals (1): Setup and Compilation
- GSI fundamentals (2): Run and Namelist
- GSI fundamentals (3): Diagnostics
- GSI fundamentals (4): Background Error and Observation Error
  - Background error covariance
  - Observation error
- GSI fundamentals (5): PrepBUFR and BUFR format
- GSI fundamentals (6): Review and Applications

# GSI input and output files

Analysis results; stdout and diagnostic files, ...



# Background Error (BE) Covariance

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What BE does and structure of a GSI BE ?

Options to tune a GSI BE?

Generate your own BE: GenBE

Setup EnVar hybrid analysis

# Background Error Covariance (BE)

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- In 3D-Var analysis, background error covariance (BE) is the most important and complex part, which includes three pieces of information:
  - **Variance**: represents the quality of the background.  
Ratio of background error variance and observation error variance decides the fit of analysis to the observation.
  - **Horizontal and vertical impact scale**: decide the area and depth of the observation information should spread.
  - **Balance**: relation between different analysis variables, such as temperature and wind.

# GSI BE structure

- BE is huge matrix that cannot be calculate explicitly. In GSI, the **B** matrix is decomposed into the following form:

$$B = B_{balance} V B_z (B_x B_y B_y B_x) B_z V B^T_{balance}$$

**Balance** among different variables represented with pre-computed “regression coefficients”

Pre-calculated square root of **variance**

**Vertical impact** is modeled as a Gaussian distribution with pre-computed “lengthscale” parameters in recursive filter

**Horizontal impact** is modeled as a Gaussian distribution with pre-computed “lengthscale” parameters in recursive filter

# GSI BE structure

	Category	Array name	Dimension	Content
$\mathbf{B}_{balance}$ $\mathbf{B}^T_{balance}$	Balance (Horizontal regression coefficients)	<i>agvi</i>	0:mlat+1,1:nsig,1:nsig	Regression coefficients for stream function and temperature
		<i>wgvi</i>	0:mlat+1,1:nsig	Regression coefficients for stream function and surface pressure
		<i>bvi</i>	0:mlat+1,1:nsig	Regression coefficients for stream function and velocity potential
$\mathbf{B}_z$ $(\mathbf{B}_x \mathbf{B}_y \mathbf{B}_y \mathbf{B}_x)$ $\mathbf{B}_z$	Horizontal and vertical influence scale	<i>hwll</i>	0:mlat+1,1:nsig,1:nc3d	horizontal lengthscales for stream function, unbalanced velocity potential, unbalanced temperature, and relative humidity
		<i>hwllp</i>	0:mlat+1, nc2d	horizontal lengthscale for unbalanced surface pressure
		<i>vz</i>	1:nsig, 0:mlat+1, 1:nc3d	Vertical lengthscale for stream function, unbalanced velocity potential, unbalanced temperature, and relative humidity
$\mathbf{V}$	variance	<i>corz</i>	1:mlat,1:nsig,1:nc3d	Square root of variance for stream function, unbalanced velocity potential, unbalanced temperature, and relative humidity
		<i>corp</i>	1:mlat,nc2d	Square root of variance for unbalanced surface pressure

Note: mlat = number of latitude in original background error coefficient domain,

nsig = number of vertical levels in analysis grid

nc3d = number of 3 dimensional analysis variables

nc2d = number of 2 dimensional analysis variables

# BE Tuning Options

- In GSI namelist:

$B_z$	vs	scale factor for vertical correlation lengths for background error
$(B_x, B_y, B_z)$	nhscrf	number of horizontal scales for recursive filter
$(B_x, B_y, B_z)$	hzscl (3)	scale factor for horizontal smoothing. Specifies factor by which to reduce horizontal scales (i.e. 2 would then apply 1/2 of the horizontal scale)
$(B_x, B_y, B_z)$	hswgt (3)	empirical weights to apply to each horizontal scale

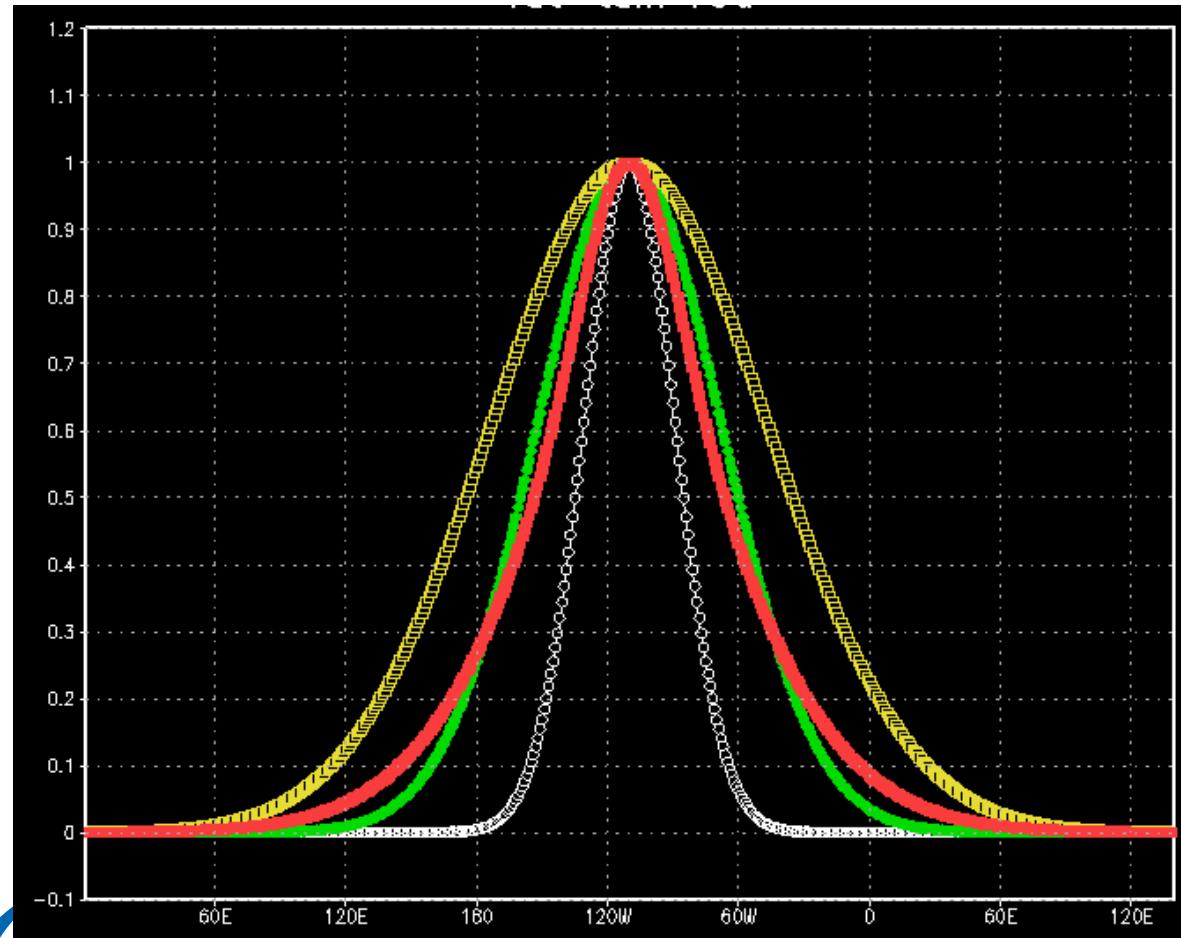
- In anavinfo

- Column “as” under section “control\_vector::”

control_vector::						
!var	level	itracer	as/tsfc_sdv	an_amp0	source	funcf
sf	40	0	1.00	-1.0	state	u,v
vp	40	0	1.00	-1.0	state	u,v
ps	1	0	0.50	-1.0	state	prse
t	40	0	0.70	-1.0	state	tv
q	40	1	0.70	-1.0	state	q

# Fat-tailed Power Spectrum for horizontal impact

Horizontal impact is modeled by the combination of three recursive filters that have different impact scales



Yellow: filter 1 (wide)  
Green: filter 2 (middle)  
White: filter 3 (narrow)  
Red: combined to make fat-tail impact pattern

# GSI BE in release Package

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- *nam\_nmmstat\_na.gcv* : contains the regional background error statistics
  - Computed using forecasts from the NCEP's NAM model covering North America.
  - Covers the northern hemisphere with 93 latitude lines from -2.5 degree to 89.5 degree
  - With 60 vertical sigma levels from 0.9975289 to 0.01364.
- *nam\_glb\_berror.f77.gcv* : contains the global background errors
  - Based on the NCEP's GFS model, a global forecast model.
  - Covers global with 192 latitude lines from -90 degree to 90 degree and
  - With 42 vertical sigma levels from 0.99597 to 0.013831.
- Global BE:
  - Many GFS BE files match different versions of operational GFS.

# Reference values for BE Tuning options

	Global	Regional
fixed B matrix	nam_glb_berror.f77.gcv	nam_nmmstat_na.gcv
vs	0.7	1.0
hzscl	1.7, 0.8, 0.5	0.373, 0.746, 1.50
hswgt	0.45, 0.3, 0.25	0.45, 0.3, 0.25
ss/tsfc_sdv	control_vector:: !var as/tsfc_sdv sf 0.60 vp 0.60 ps 0.75 t 0.75 q 0.75 oz 0.75 sst 1.00 cw 1.00 stl 3.00 sti 3.00	control_vector:: !var as/tsfc_sdv sf 1.00 vp 1.00 ps 0.50 t 0.70 q 0.70 oz 0.50 sst 1.00 cw 1.00 stl 1.00 sti 1.00

GSI run scripts in community release can pick right values based the set of choice to bkcv\_option=(GLOBAL or NAM)

# BE tuning examples

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- Through **single observation test**, we can see how those BE tuning option works
  - Check fundamental talks on setting up single observation test
- Regional BE “*nam\_nmmstat\_na.gcv*” is used
- In GSI namelist:
  - Horizontal impact scale of BE before tuning:  
`hzscl_op='0.373,0.746,1.50,'`
  - Vertical impact scale of BE before tuning:  
`vs_op='1.0,'`

# Single Obs(U) Test with BE tuning

**Single observation test parameters**

Parameter	Value
$\Delta U$	1m/s
Observation Error	2m/s
Horizontal Location	Domain Center
Vertical Location	700hPa

## Horizontal impact scale tuning

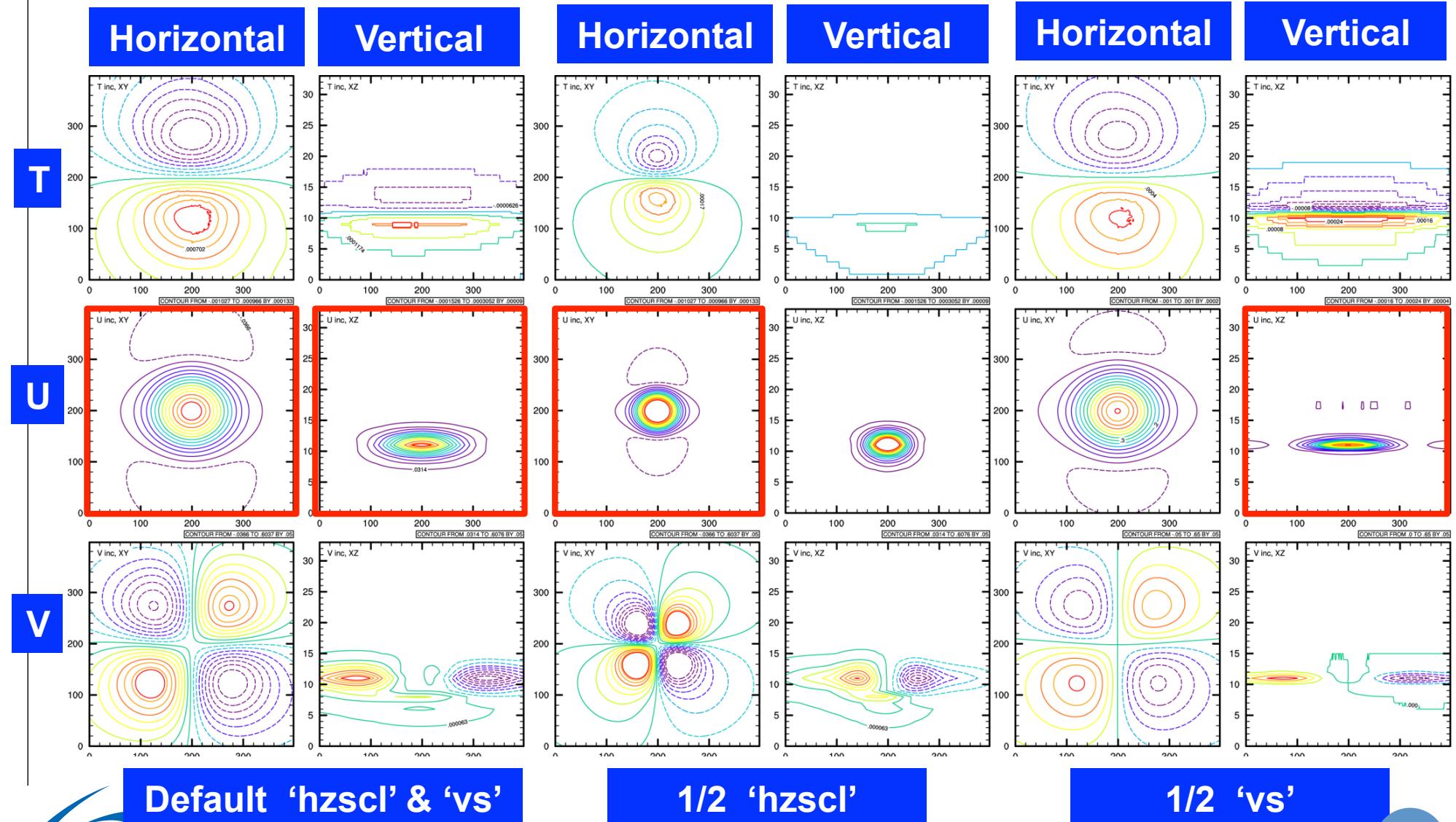
Horizontal Test	'hzscl' Value
Original	0.373, 0.746, 1.50
1/2	0.1865, 0.373, 0.75
1/4	0.09325, 0.1865, 0.375
1/8	0.046625, 0.09325, 0.1875
1/16	0.0233125, 0.046625, 0.09375
1/32	0.01165625, 0.0233125, 0.046875

## Vertical impact scale tuning

Vertical Test	'vs'Value
original	1.0
1/2	0.5
1/4	0.25



# Analysis Increment from Single Obs(U) Test



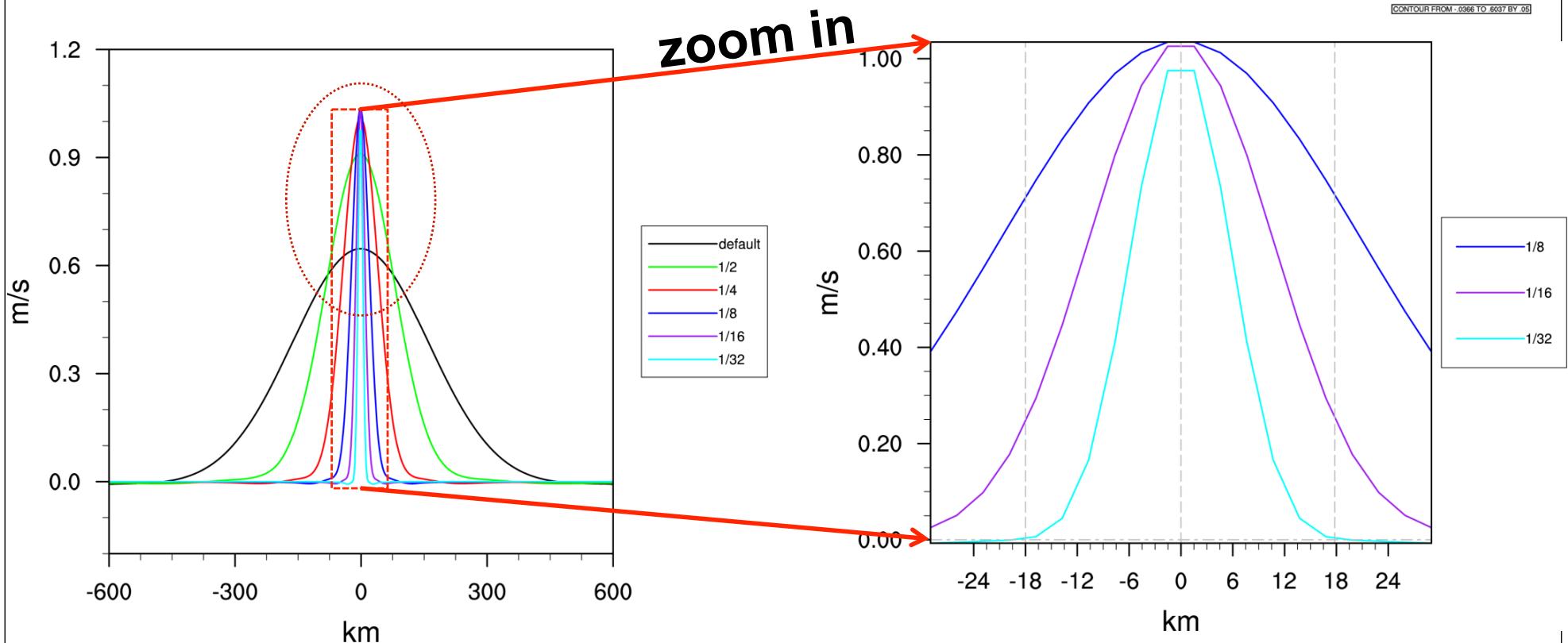
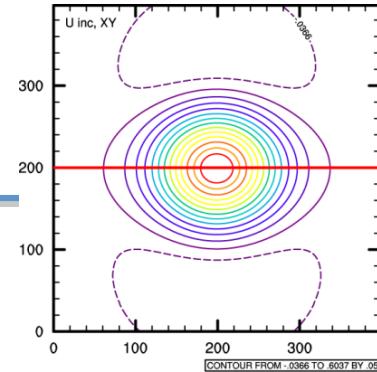
Default 'hzscl' & 'vs'

1/2 'hzscl'

1/2 'vs'

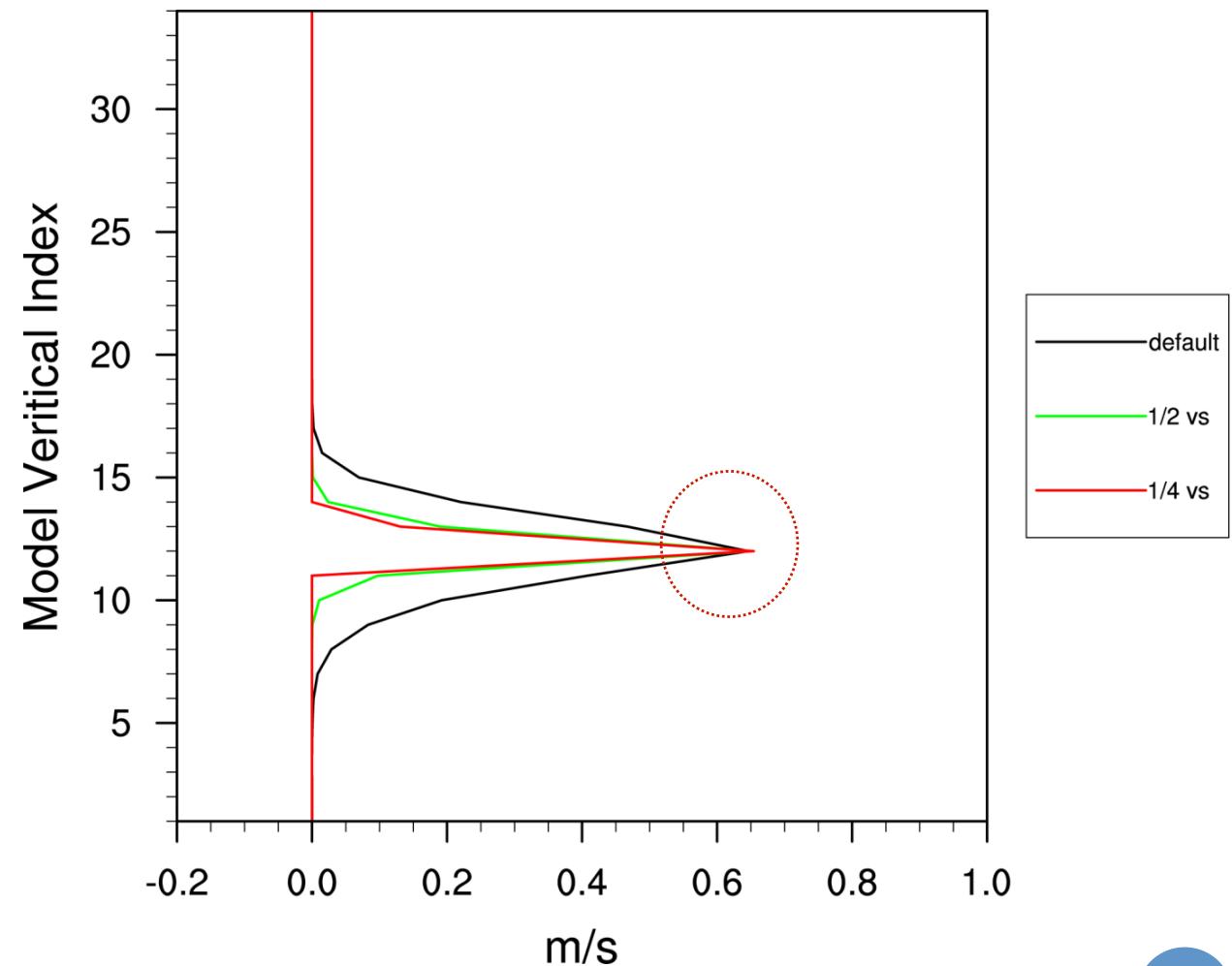
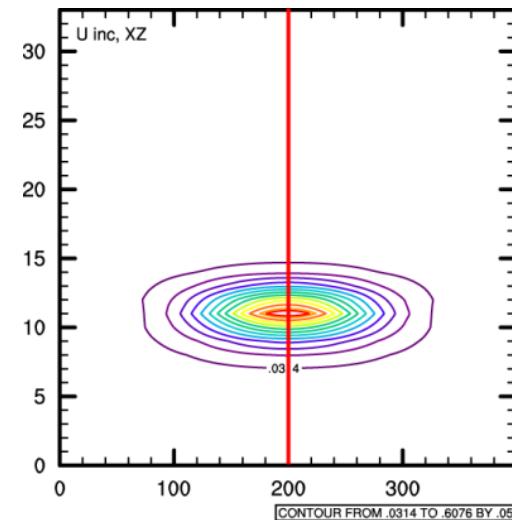
Courtesy of Min Sun

# Horizontal Cross Section of U Increment



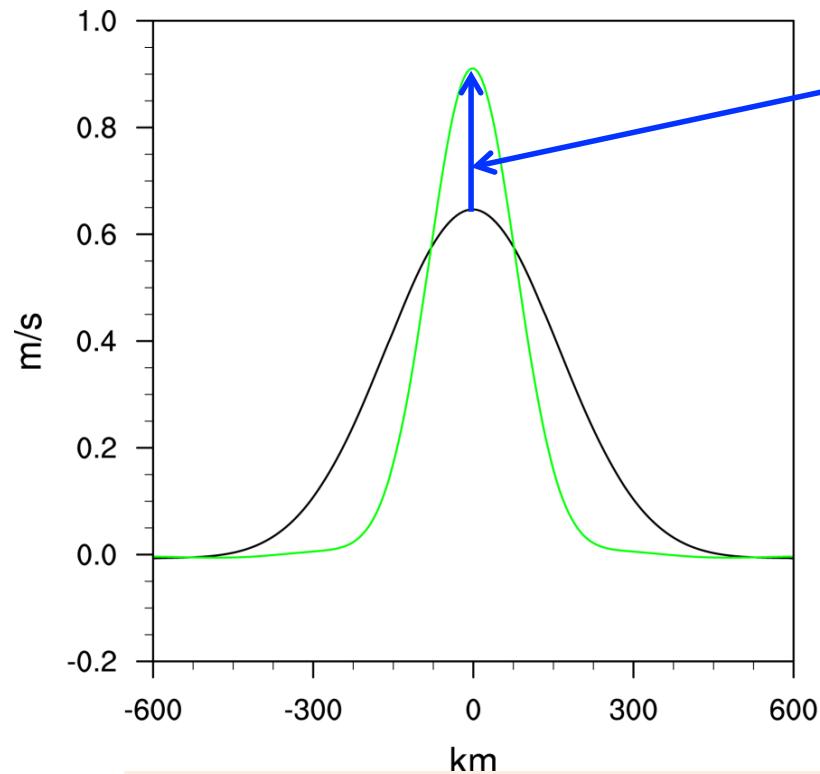
Change '`hzscl_op`' not only change the horizontal influence scale, but also the weight (how much analysis results fit to the observations)!

# Vertical Cross Section of U Analysis Increment

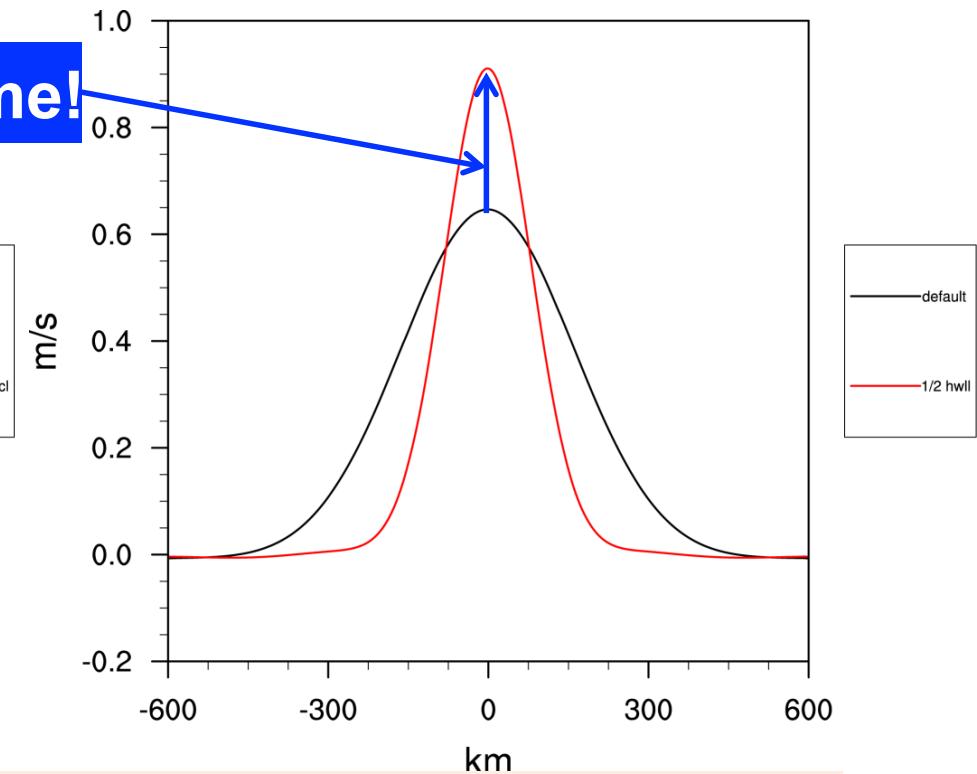


# Two Ways to Change Horizontal Influence Scale

- By changing parameter '**hzscl**' in namelist



- By reading BE matrix directly and changing '**hwll**' array which stores horizontal influence scales



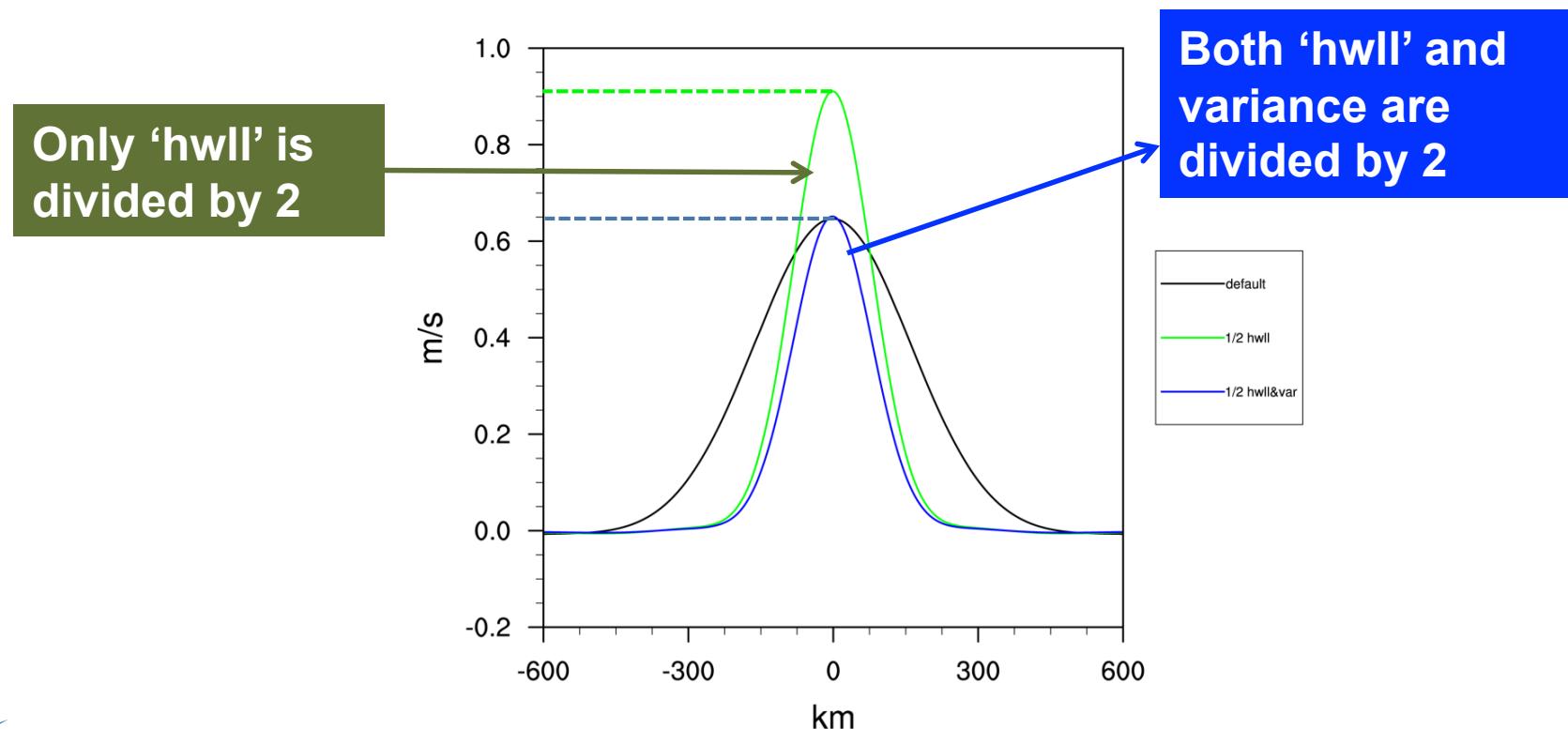
How to change the horizontal influence scale, meanwhile do not affect the weight ?

Courtesy of Min Sun

# Change Variance in BE

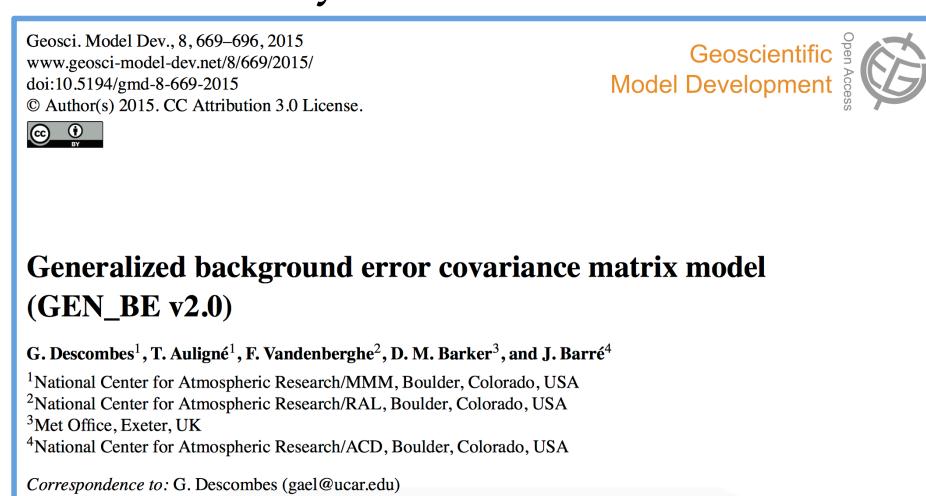
How to change the horizontal influence scale, meanwhile do not influence the weight ?

Change the arrays which store horizontal influence scales '**hwll**' and **variance** of BE simultaneously!



# GEN-BE

- Reference 2012 GSI tutorial:
  - GenBE version 1 with WRF-DA
- GEN\_BE v2.0:
  - Gael Descombes (2015)
  - Included in GSI package under directory *util/GEN\_BE\_V2.0*
  - No support from DTC.



# GSI Variational-Ensemble (EnVar) hybrid

- Important way to construct background error covariance in GSI
- Details will be covered in Daryl's talk tomorrow morning
- Only introduce the setup of GSI EnVar hybrid here

The slide features the NOAA/NCEP logos in the top corners. The main title "GSI Hybrid/4DEnVar Data Assimilation" is centered in a large box. Below it, the author's name "Daryl Kleist" and affiliation "NOAA/NWS/NCEP/EMC" are listed. The date "2017 Joint DTC-EMC-JCSDA GSI-EnKF Tutorial" and location "College Park, MD, July 11-14, 2017" are also included. A note at the bottom credits Dave Parrish and Jeff Whitaker for their contributions.

GSI Hybrid/4DEnVar Data Assimilation

Daryl Kleist  
NOAA/NWS/NCEP/EMC

2017 Joint DTC-EMC-JCSDA GSI-EnKF Tutorial

NCEP  
College Park, MD, July 11-14, 2017

Many people have contributed to the GSI Hybrid/EnVar developments over the past several years. In particular, I would like to acknowledge Dave Parrish (GSI EnVar) and Jeff Whitaker (EnKF) for their significant contributions.

# Setup GSI hybrid

- Step 1: Link the ensemble members to the GSI run directory

regional_ensemble option	explanation	GSI recognized ensemble file names
1	GFS ensemble internally interpolated to hybrid grid	<i>filelist : a text file include path and name of ensemble files</i>
2	ensembles are in WRF NMM (HWRF) format	<i>d01_en001,</i> <i>d01_en002,</i> ...
3	ensembles are in ARW netcdf format	<i>wrf_en001,</i> <i>wrf_en002,</i> ...
4	ensembles are in NEMS NMMB format	<i>nmmb_ens_mem001,</i> <i>nmmb_ens_mem002,</i>

- Step 2: Setup namelist (Daryl's talk)

## 3D EnVar Hybrid:

- Basic Practical case 4
- Advanced Practical case A4

## 4D EnVar hybrid:

- Advanced Practical case C

# Observation Error

**Introduction to observations errors**

**External observation error table for conventional obs**

**Satellite radiance observation error**

**Radar radial wind observations error**

**Adaptive Tuning of Observation Error**

# Introduction to observation errors

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- Observation error has to be available for variational analysis
- Observation error decides the impact of this observation in variational analysis.

The ratio of observation error and background error decide how much analysis results fit to the observation value.

- For most of observations, observation errors are unrelated
- Each type of observations has their own way to set error:
  - Error for conventional observation:
    - Read in from the PrepBUFR file for Global analysis when “*oberrflg*” set to false.
    - Calculated based on an external observation error table for regional analysis or for global analysis when “*oberrflg*” set to true.
  - Satellite radiance
  - Radar radial wind
  - ...

# External observation error table

Column #

1

2

3

4

5

6

120 OBSERVATION TYPE

0.11000E+04	0.12671E+01	0.56103E+00	0.10000E+10	0.68115E+00	0.10000E+10
0.10500E+04	0.13302E+01	0.63026E+00	0.10000E+10	0.68115E+00	0.10000E+10
0.10000E+04	0.14017E+01	0.73388E+00	0.10000E+10	0.68115E+00	0.10000E+10
0.95000E+03	0.14543E+01	0.86305E+00	0.10000E+10	0.71307E+00	0.10000E+10
0.90000E+03	0.14553E+01	0.99672E+00	0.10000E+10	0.74576E+00	0.10000E+10
0.85000E+03	0.13865E+01	0.11210E+01	0.10000E+10	0.77845E+00	0.10000E+10

220 OBSERVATION TYPE

0.11000E+04	0.10000E+10	0.10000E+10	0.17721E+01	0.10000E+10	0.10000E+10
0.10500E+04	0.10000E+10	0.10000E+10	0.20338E+01	0.10000E+10	0.10000E+10
0.10000E+04	0.10000E+10	0.10000E+10	0.22927E+01	0.10000E+10	0.10000E+10
0.95000E+03	0.10000E+10	0.10000E+10	0.24559E+01	0.10000E+10	0.10000E+10
0.90000E+03	0.10000E+10	0.10000E+10	0.25377E+01	0.10000E+10	0.10000E+10
0.85000E+03	0.10000E+10	0.10000E+10	0.25705E+01	0.10000E+10	0.10000E+10

Column #	1	2	3	4	5	6
Content	Pressure	T	q	UV	Ps	Pw
Unit	hPa	degree C	percent/10	m/s	mb	kg/m <sup>2</sup> (or mm)

D For each observation, error is from a vertical interpolation based on error table

# Satellite radiance observation error

- In *satinfo* file, observation error is set based on sensor, satellite, and channel:

<code>!sensor/instr/sat</code>	<code>chan</code>	<code>iuse</code>	<code>error</code>	<code>error_cld</code>	<code>ermax</code>	<code>var_b</code>	<code>var_pg</code>	<code>cld_det</code>
amsua_n15	1	1	3.000	9.100	4.500	10.000	0.000	-2
amsua_n15	2	1	2.000	13.500	4.500	10.000	0.000	-2
amsua_n15	3	1	2.000	7.100	4.500	10.000	0.000	-2
amsua_n15	4	1	0.600	1.300	2.500	10.000	0.000	-2
...								
amsua_n15	15	1	3.000	10.000	4.500	10.000	0.000	-2
hirs3_n17	1	-1	2.000	0.000	4.500	10.000	0.000	-1
hirs3_n17	2	-1	0.600	0.000	2.500	10.000	0.000	1
...								
hirs3_n17	9	-1	1.100	0.000	3.500	10.000	0.000	-1

Observation error for  
clear radiance

Observation error for  
cloudy radiance

# Radar radial wind observation error

- Level II radial wind observations are superobed as new radial wind observations and the observation error for new radial velocity is:

$$error = \sqrt{\overline{V_r^2} - \overline{V_r}^2}$$

where,  $V_r$  is a vector includes all level-II radial wind observations in a superob box.

- The observation error can be inflated through a namelist variable “erradar\_inflate” in section `/obsqc/`. The default value is 1.

# Gross check

- Gross check is a QC check to exclude questionable obs that degrade the analysis
- Users can adjust thresholds for data types in *convinfo*:

Gross check controlled by these columns													
!otype	type	sub	iuse	twindow	numgrp	ngroup	nmriter	gross	ermax	ermin	var_b	var_pg	ithin
ps	120	0	1	3.0	0	0	0	4.0	3.0	1.0	4.0	0.000300	0
ps	180	0	1	3.0	0	0	0	4.0	3.0	1.0	4.0	0.000300	0
t	120	0	1	3.0	0	0	0	8.0	5.6	1.3	8.0	0.000001	0
t	126	0	-1	3.0	0	0	0	8.0	5.6	1.3	8.0	0.001000	0

If ratio > gross: observation rejected

ratio = (Observation-Background)/max(ermin,min(ermax,obserror))

Rejected observations will show up in fit files under “rej”

# Adaptive Tuning of Observation Error

- Talagrand (1997) on  $E(J(X^a))$
- Desroziers & Ivanov (2001)

$$E(J^o) = \frac{1}{2} \text{Tr}(I_p - HK)$$

$$E(J^b) = \frac{1}{2} \text{Tr}(KH)$$

where  $I_p$  is identity matrix with order p

K is Kalman gain matrix

H is linearized observation forward operator

- Chapnik et al.(2004): robust even when B is incorrectly specified

More details please see Wan-Shu Wu's talk in 2013 GSI summer tutorial:  
*"Background and Observation Error Estimation and Tuning"*

**Questions? ...**

**[gsi-help@ucar.edu](mailto:gsi-help@ucar.edu)**



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