BE, gen_be, Single ob experiments and Introduction to "Practice Session3"

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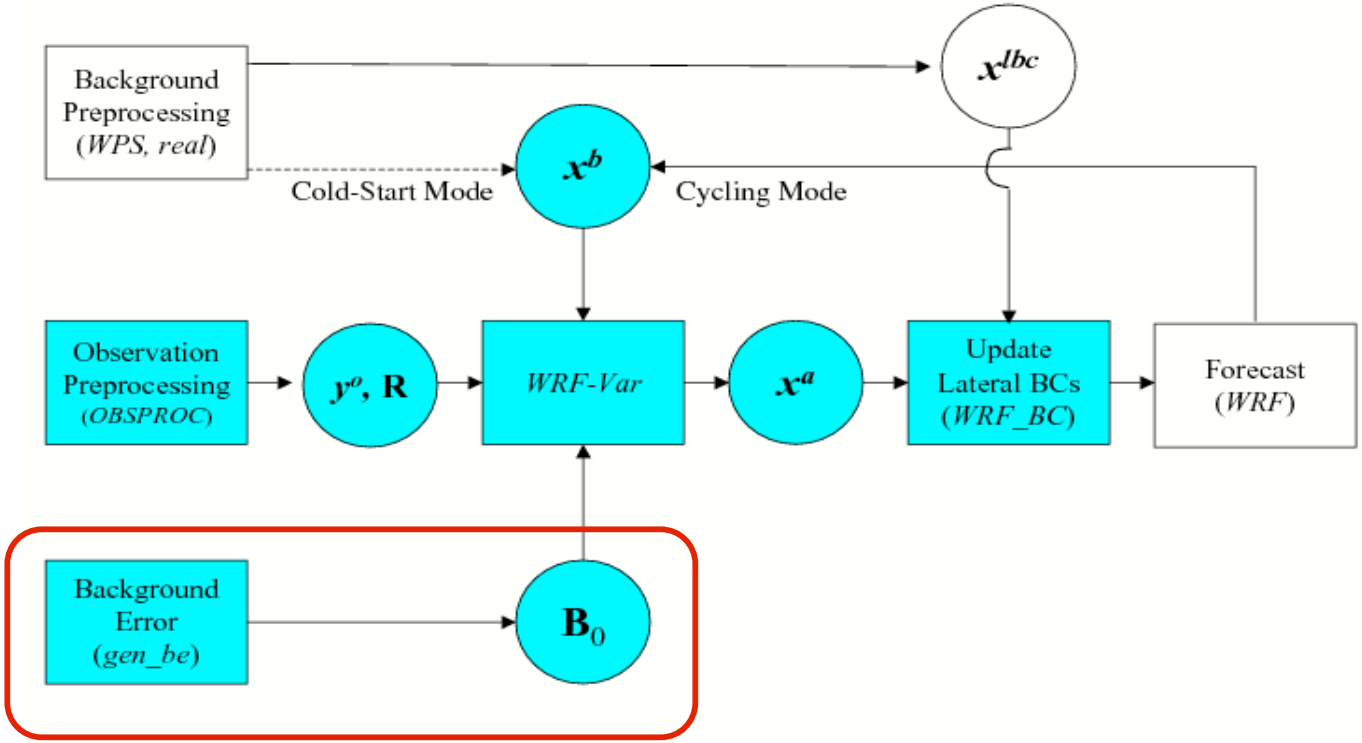
Talk overview:

- What is Background Error (BE) ?
- Role of BE in WRF-Var
- Importance of BE
- How is it computed ("gen_be" utility)?
- Impact of Background Error on minimization
- Single Observation Tests
- Tuning of background error
- Introduction to "Practice on Session 3"

Where BE fits in WRF-modelling System



What is BE?

- It is the covariance of (forecast-truth) for analysis control variables

$$BE = \langle (x-x^t), (x-x^t)^T \rangle$$

- Since "truth" is not known, it needs to be estimated

- Common methods to estimate BE

  a) Innovation Based approach

  b) NMC Method: $(x-x^t) \approx (x^{t1} - x^{t2})$

  (Forecast differences valid for same time)

  c) Ensemble Method: $(x-x^t) \approx (x^{ens} - \langle x^{ens} \rangle)$

  (Ensemble - Ensemble mean)

  d) Flow dependent (adaptive approach)

Role of BE in WRF-Var cost Function:

- Basic WRF-Var cost function (J):

$$J = 1/2[\ (x-x^b)^T B^{-1}(x-x^b) + (y^o - H(x))^T R^{-1}(y^o - H(x)))\ ]$$

x - Analysis control variable

x^b - Background (FG)

B - Background Error covariance

H - Full (Non-linear) Forward Observation Operator

y^o - Observations

R - Observation error covariance

Role of BE:

- BE is used for preconditioning the analysis equation

$$x^a = x^b + BH^T(HBH^T + R)^{-1}[y^o - H(x^b)]$$

by representing it with a suitable choice U as follows

$$B = U\,U^T \qquad \text{with} \quad U = U_p U_v U_h$$

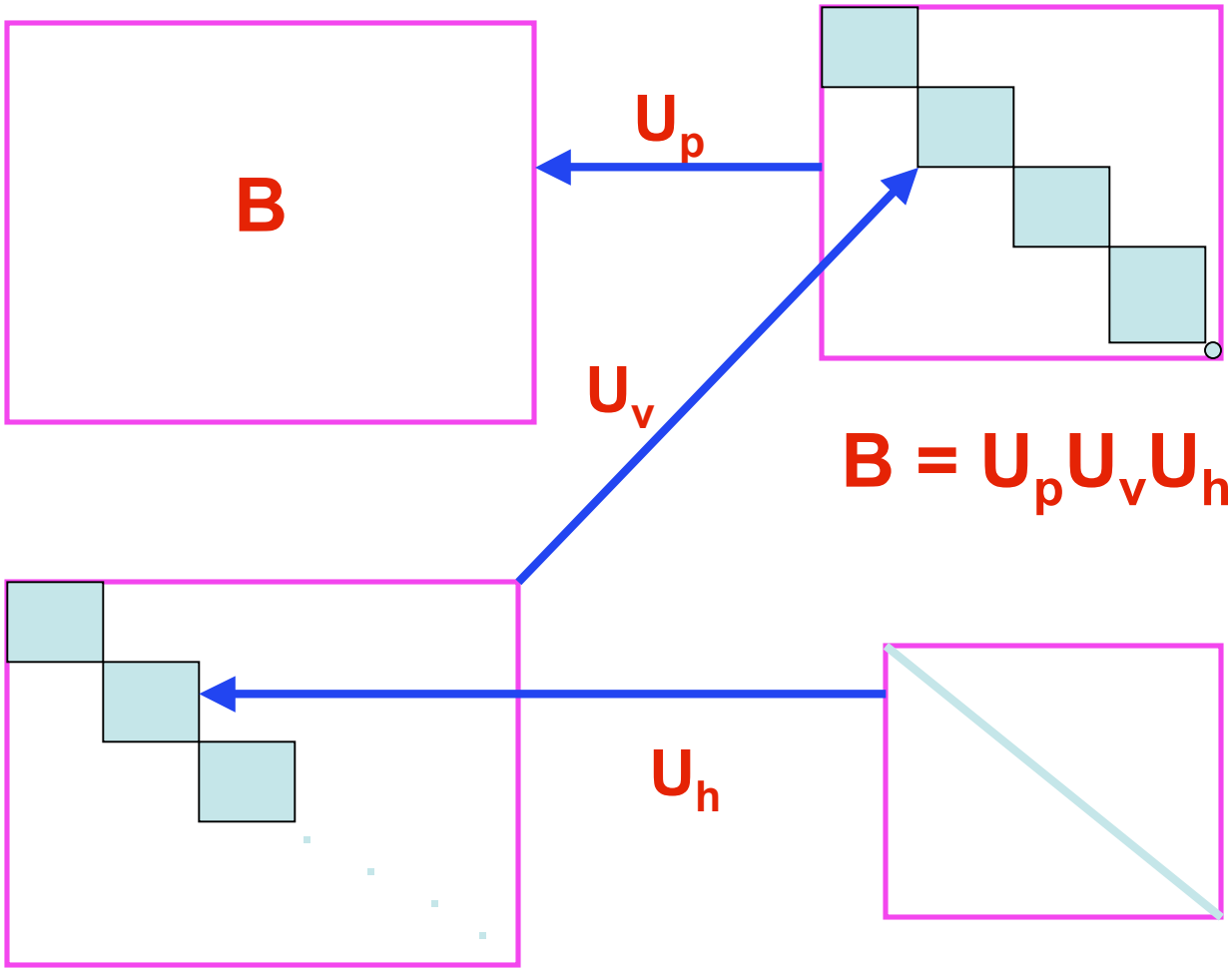
U_h Horizontal Transform
U_v Vertical Transform
U_p Physical Transform

- Horizontal transformation (U_h) is via
  - Regional ----- Recursive filters
  - Global ----- Power spectrum
- Vertical transformation (U_v) is via EOF's
- Physical transformation (U_p) depends upon the choice of the analysis control variable

How BE is represented?

- In true sense the size of B is typically of the order of $10^7 x 10^7$
- Thus it is not possible to handle such huge matrix
- Size of B is reduced by designing the analysis control variables in such a way that cross covariance between these variables are minimum
- Currently the analysis control variables for WRF-Var are the amplitudes of EOF's of
  - stream function (ψ)
  - Unbalanced part of velocity potential (χ_u)
  - Unbalanced part of temperature (T_u)
  - Relative Humidity (q)
  - Unbalanced part of surface pressure (p_{s_u})
- With this choice of analysis control variables off-diagonal elements of BE is very small and thus its size typically reduces to the order of 10^7

How BE is represented *Contd.*



$$B = U_p U_v U_h \, U_h^T U_v^T U_p^T$$

Basic statistical parameters of BE

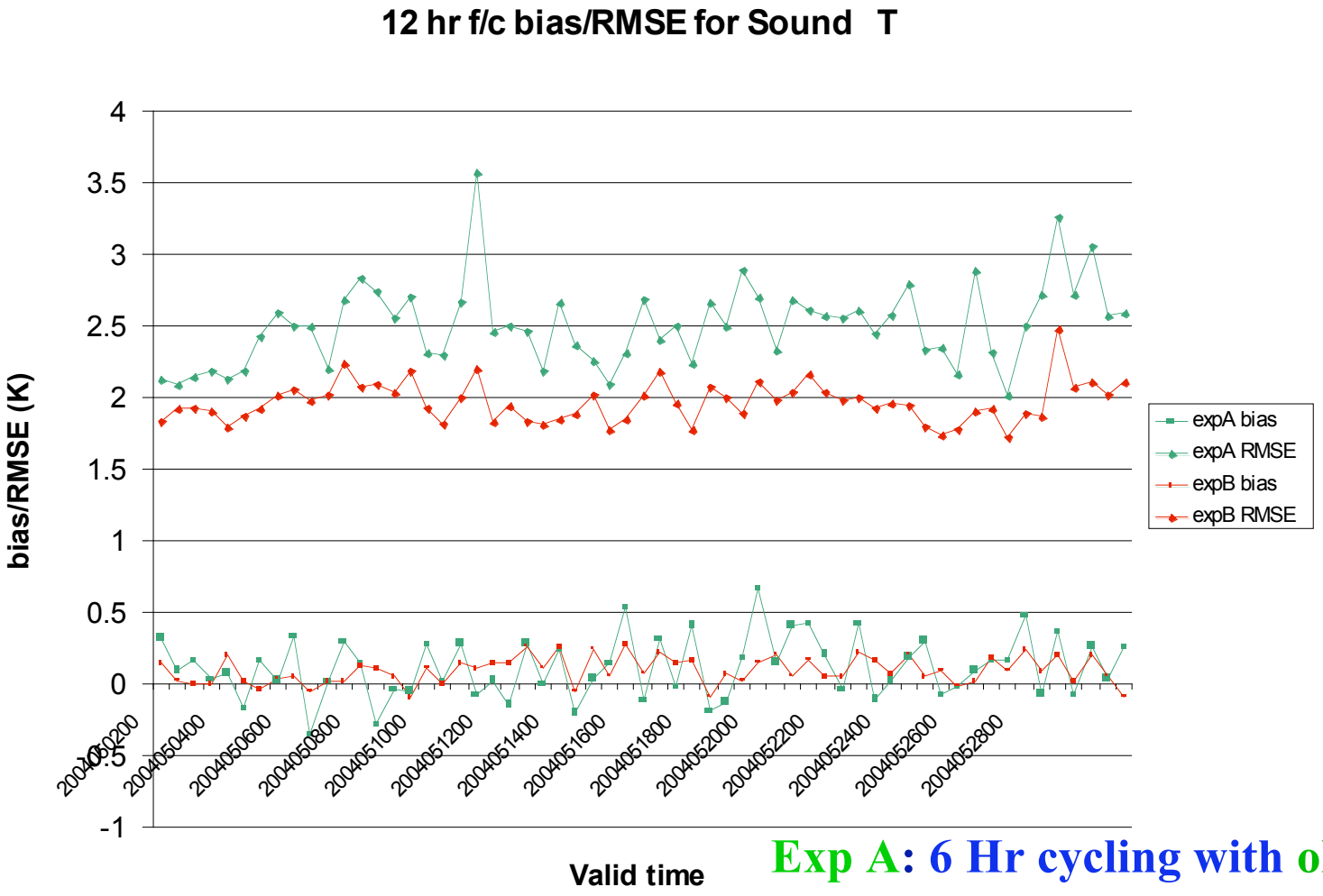
Corresponding to each control variables, following parameters constitutes the basic statistics of BE

a) Regression Coefficient for estimating balanced (statistical) part of Velocity potential, Temperature and Surface pressure

b) Eigen vectors and Eigen values

c) Scalelength for regional and power spectrum for global option

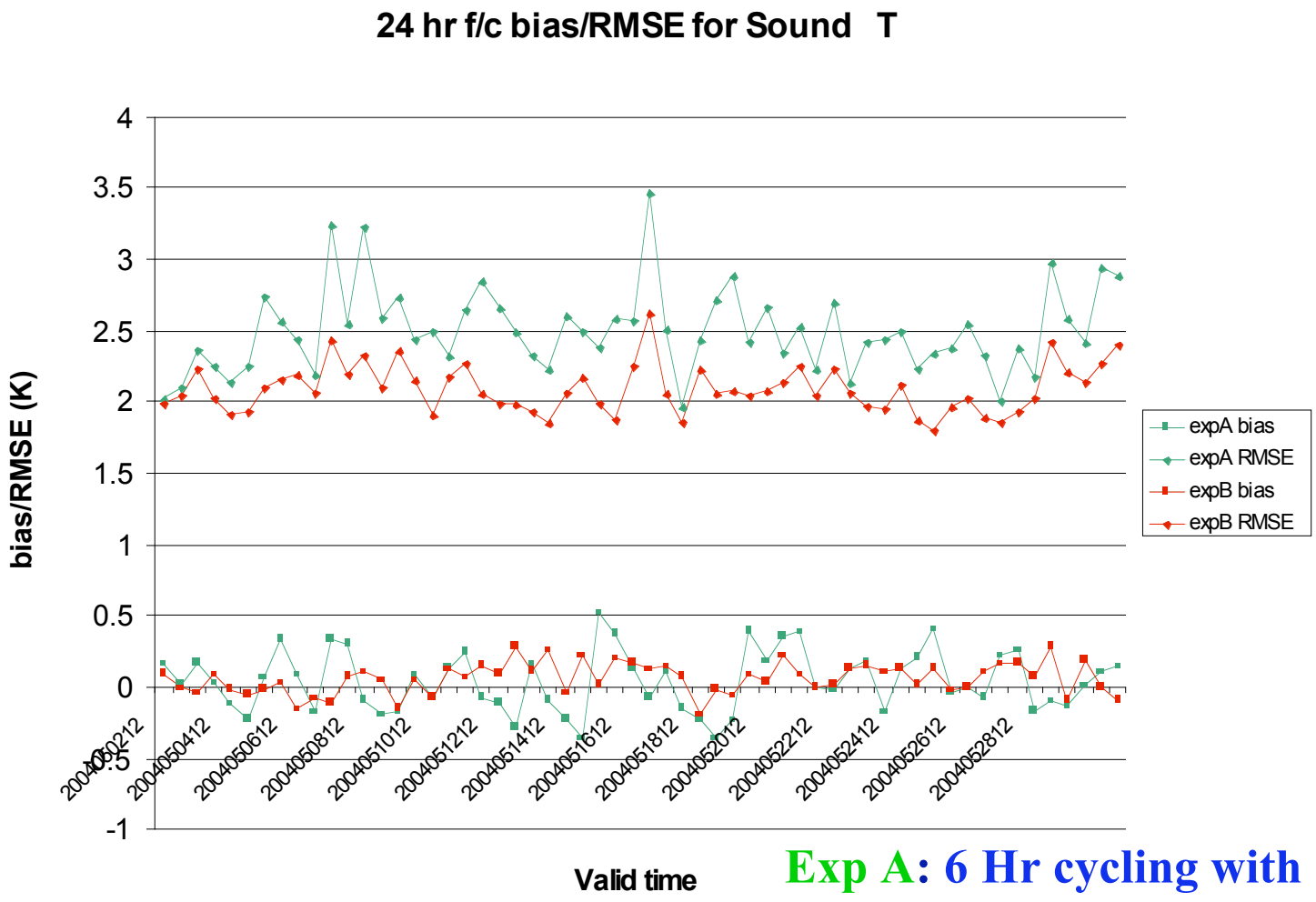
Importance of BE



Exp A: 6 Hr cycling with old BE

Exp B: 6 Hr cycling with new BE

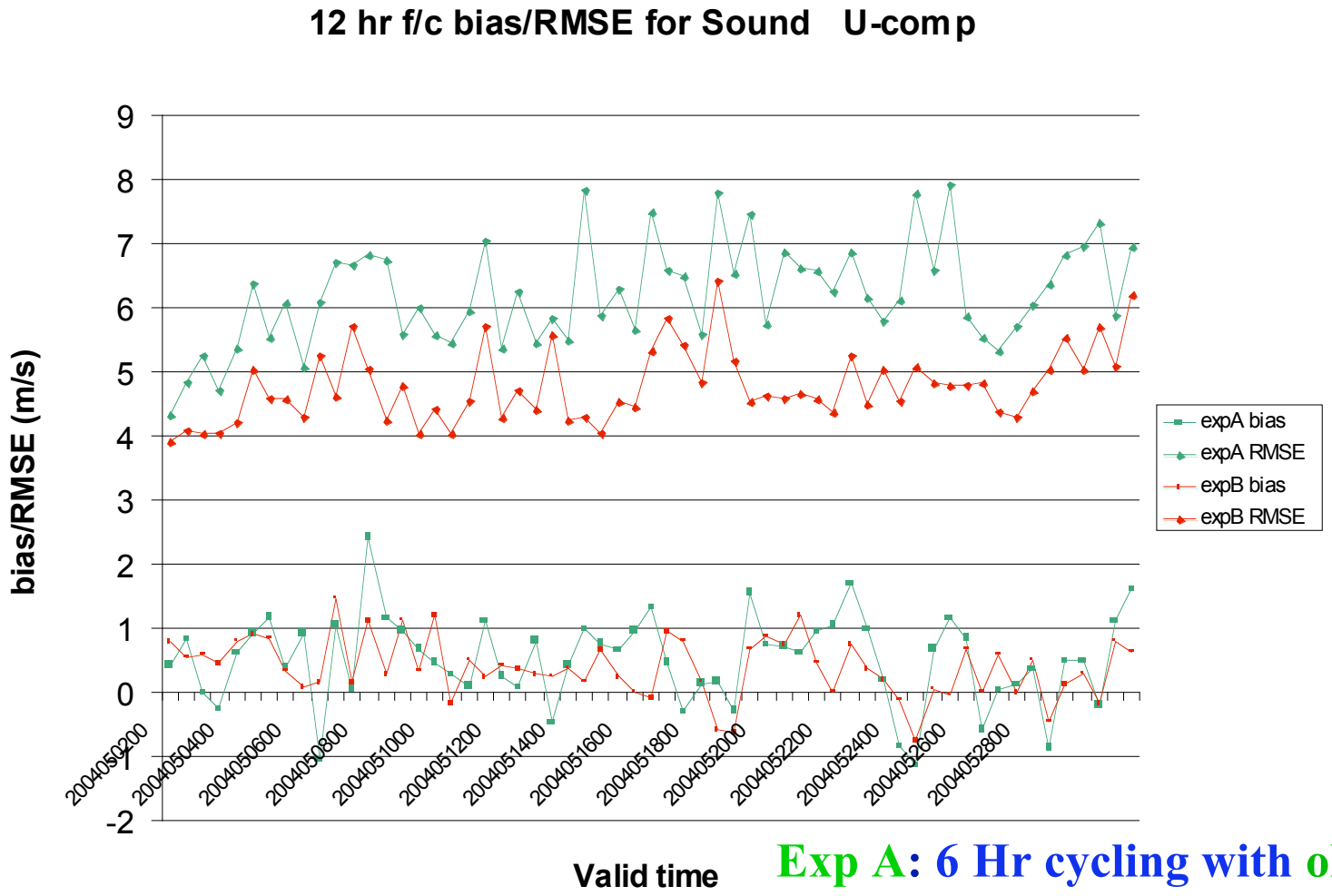
Importance of BE *Contd.*



Exp A: 6 Hr cycling with old BE

Exp B: 6 Hr cycling with new BE

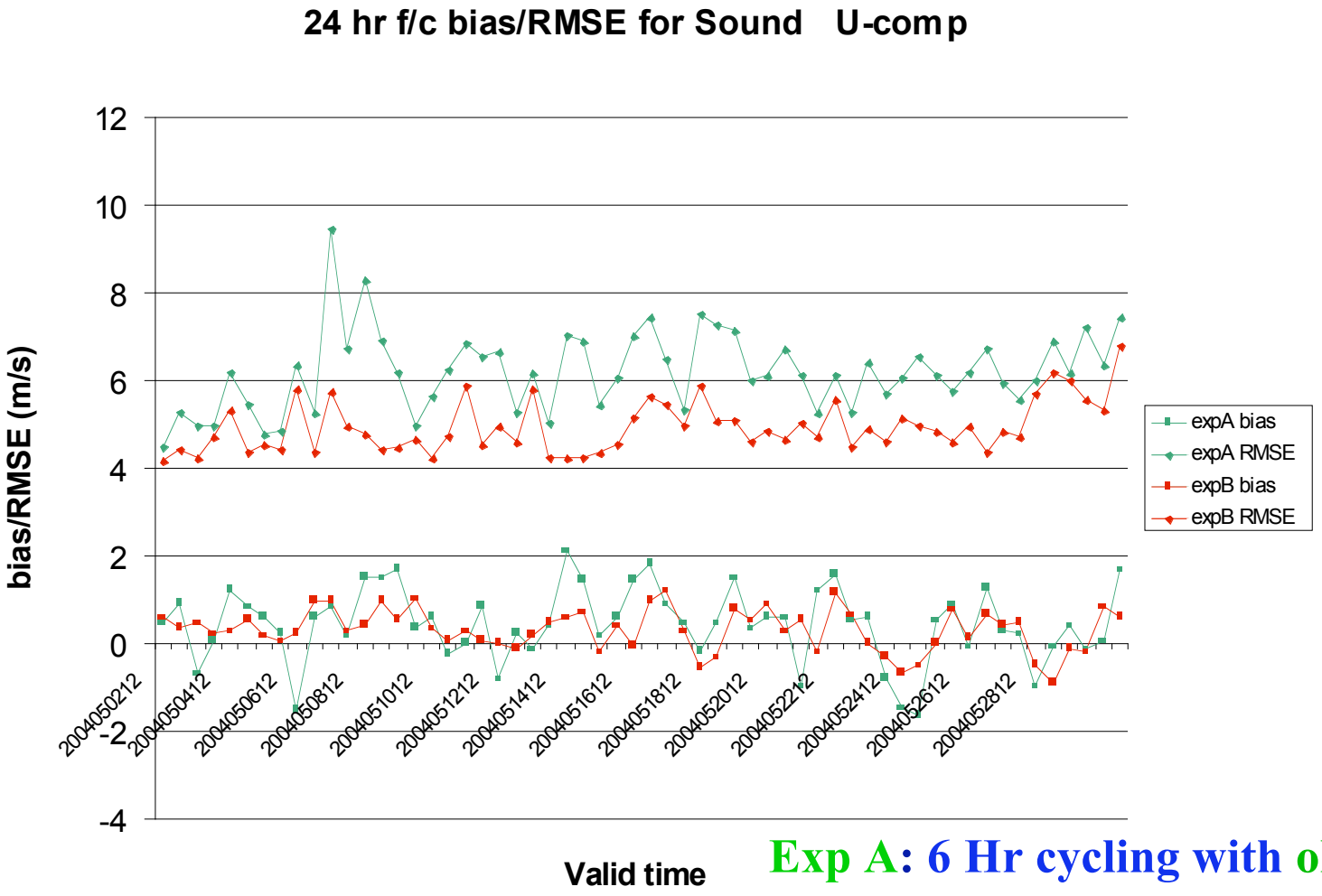
Importance of BE *Contd.*



Exp A: 6 Hr cycling with old BE

Exp B: 6 Hr cycling with new BE

Importance of BE *Contd.*



Exp A: 6 Hr cycling with old BE

Exp B: 6 Hr cycling with new BE

WRF-Var "gen_be" utility:

- Computes various components of BE statistics needed for the WRF-Var
- Resides in WRF-Var top directory
- Designed both for NMC and Ensemble methods
- Consists of five stages
- Basic goal is to compute the error in Analysis Control Variable Space (Coefficients of the EOF's for ψ, χ_u, T_u, q and p_{s_u}) from the Background Variable Space (U, V, T, q & P_s)

"gen_be" - Stage0:

- Computes (ψ , χ) from (u,v)
- Forms desired differences for the following fields

ψ - Stream Function
χ - Velocity potential
T - Temperature
q - Relative Humidity
p_s - Surface Pressure

"gen_be" - Stage1:

- Reads "gen_be_stage1" namelist
- Fixes "bins" for computing BE statistics
- Computes "mean" of the differences formed in stage0
- Removes respective "mean" and forms perturbations for

Stream Function	(ψ')
Velocity potential	(χ')
Temperature	(T')
Relative Humidity	(q')
Surface Pressure	(p_s')

"gen_be" bins structure

- Currently "gen_be" utility has provisions of following seven (0-6) "bin_types"

  0: No binning (each grid point is a bin)
  1: mean in X-direction (Each latitude is a bin)
  2: bins with binwidth_lat/binwidth_hgt
  3: bins with binwidth_lat/nk
  4: bins with binwidth_lat/nk (binwidth_lat (integer) is defined in terms of latitudinal grid points)
  5: bins with all horizontal points (nk bins)
  6: Average over all points (only 1 bin)

  nk - Number of vertical levels

  Default option is "bin_type=5"

"gen_be" - Stage2 & 2a:

- Reads "gen_be_stage2" namelist
- Reads field written in stage1 and computes covariance of the respective fields
- Computes regression coefficient & balanced part of χ, T & p_s

$$\chi_b = C\,\psi'$$
$$T_b(k) = \Sigma_l G(k,l)\,\psi'(l)$$
$$p_{s\_b} = \Sigma_l W(k)\,\psi'(k)$$

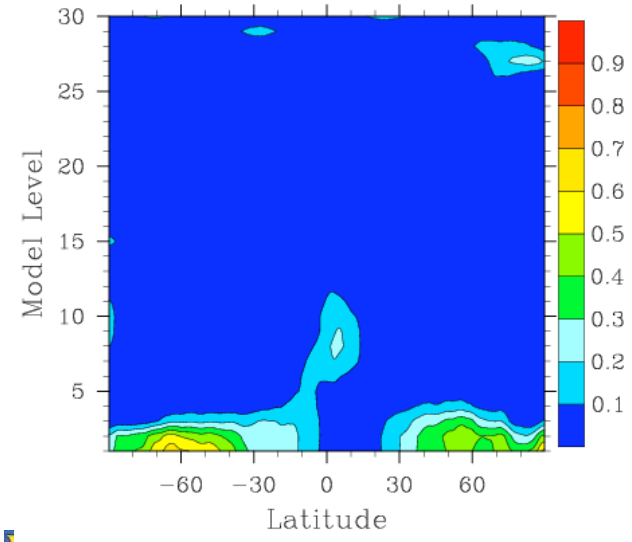
- Computes unbalanced part

$$\chi_u' = \chi' - \chi_b$$
$$T_u' = T' - T_b$$
$$p_{s\_u}' = p_s' - p_{s\_b}$$

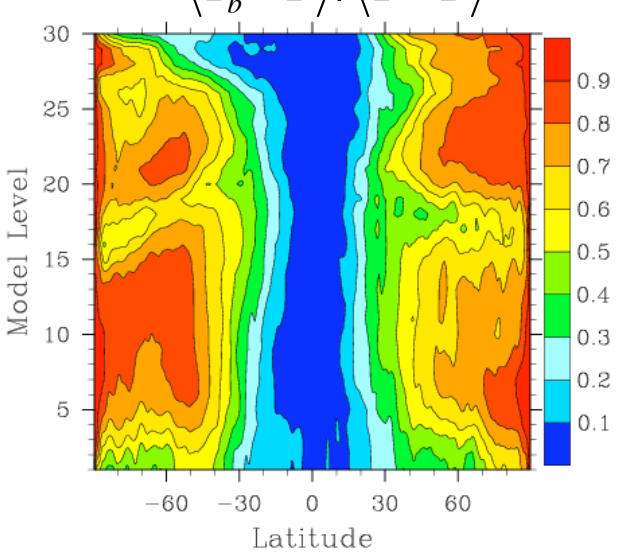
WRF-Var Balance constraints

- WRF-Var imposes statistical balanced constraints between
  - Stream Function & Velocity potential
  - Stream Function & Temperature
  - Stream Function & Surface Pressure
- How good are these balanced constraints? Based on KMA global model

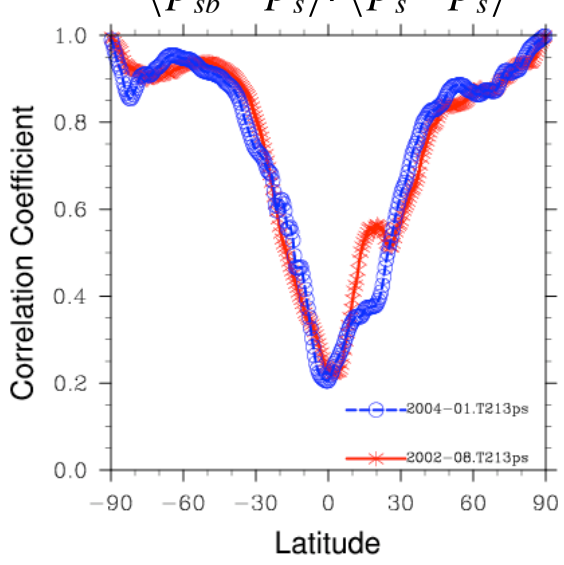
$\langle \chi_b \bullet \chi \rangle / \langle \chi \bullet \chi \rangle$



$\langle T_b \bullet T \rangle / \langle T \bullet T \rangle$



$\langle p_{sb} \bullet p_s \rangle / \langle p_s \bullet p_s \rangle$



"gen_be" - Stage3:

- Reads "gen_be_stage3" namelist
- Removes mean for χ_u', T_u' & p_{s_u}'
- Computes eigenvector and eigen values for vertical error covariance matrix of ψ', χ_u', T_u' & q
- Computes variance of p_{s_u}'
- Computes eigen decomposition of ψ', χ_u', T_u' & q

"gen_be" - Stage4:

- Reads "gen_be_stage4" namelist
- For each variable & each eigen mode, for regional option computes "lengthscale (s)"

$$B(r) = B(0)\exp\{-r^2/8s^2\}$$

$$y(r) = 2\sqrt{2}[\ln(B(0)/B(r)]^{1/2} = r/s$$

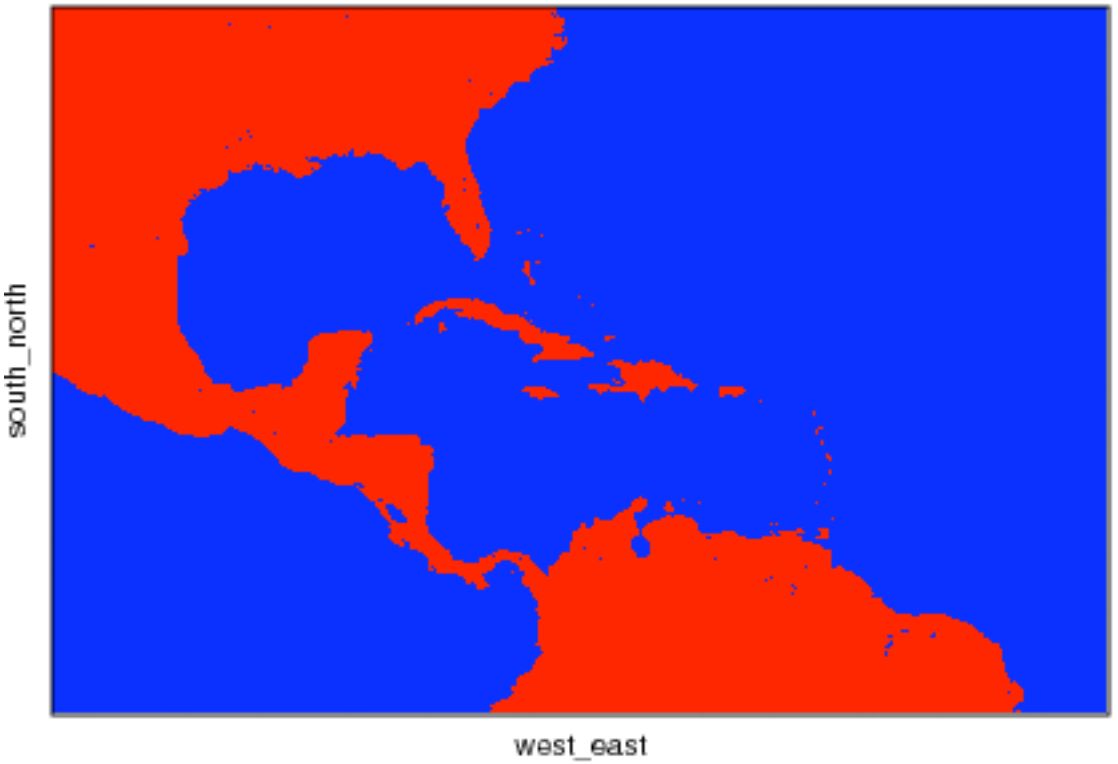
- For global option, computes "power spectrum (D_n)"

$$D_n = \sum_{m=-n}^{n}\left(F_n^m\right)^2 = \left(F_n^0\right)^2 + 2\sum_{m=1}^{n}\left[\left(\mathrm{Re}(F_n^m)\right)^2 + \left(\mathrm{Im}(F_n^m)\right)^2\right]$$

Standard BE diagnostics

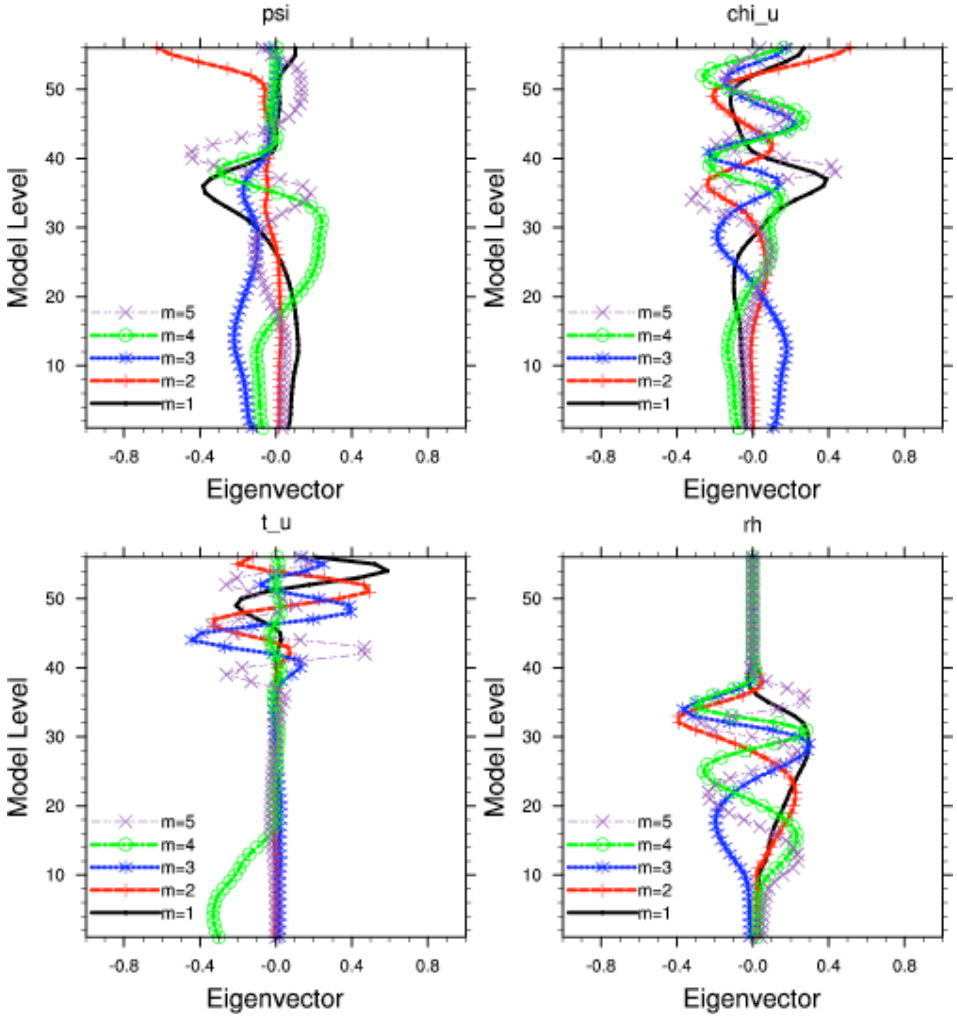
Various NCL scripts are available in "graphics/ncl" directory to display the contents of BE statistics

T8-domain

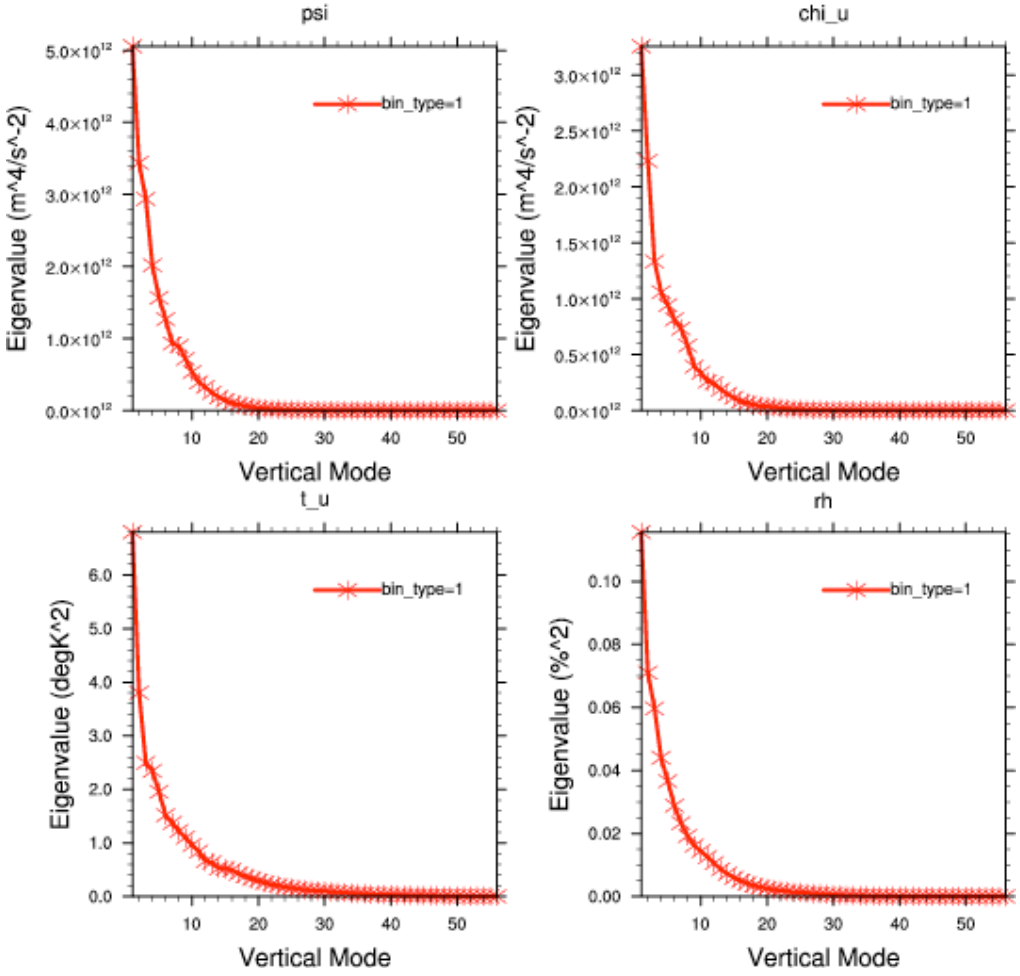


418 x 280 x 57 15 Km resolution

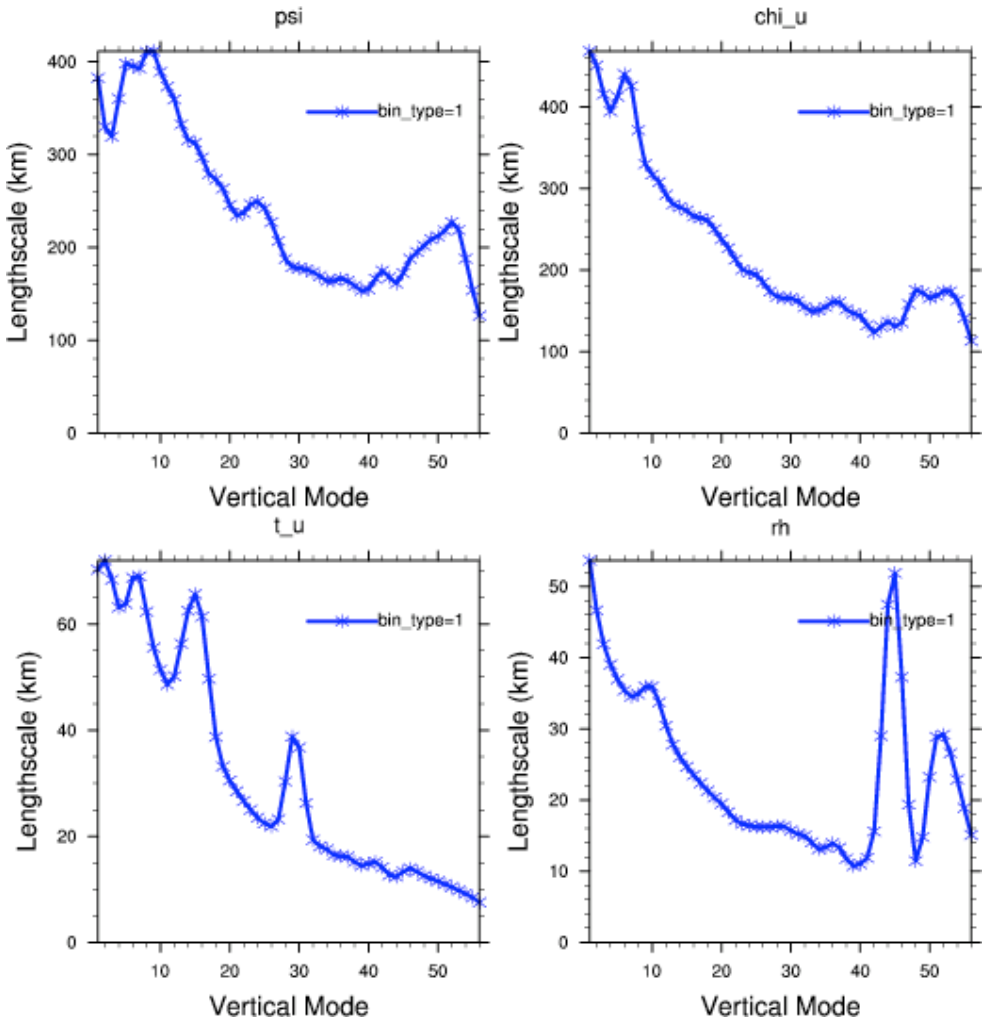
First five Eigen vectors -- T8-domain



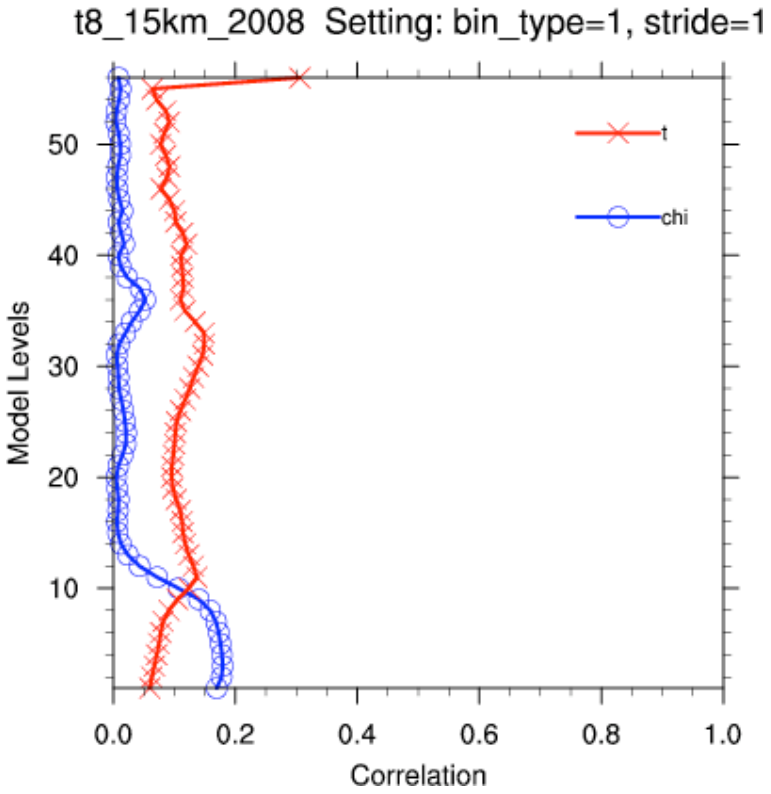
Eigen values -- T8-domain



Lengthscale -- T8-domain



Contribution of balance part -- T8-domain



$$\langle \chi_b \bullet \chi \rangle / \langle \chi \bullet \chi \rangle$$

$$\langle T_b \bullet T \rangle / \langle T \bullet T \rangle$$

Single observation test

- Through single observation, one can understand
  a) structure of BE
  b) It identifies the "shortfalls" of BE
  c) It gives a broad guidelines for tuning BE

Basic concept:

Analysis equation: $x^a = x^b + BH^T(HBH^T + R)^{-1}[y^o - H(x^b)]$

Set single observation (U,V,T etc.) as follows:

$$[y^o - H(x^b)] = 1.0 \; ; \; R = I$$

Thus,

$$x^a - x^b = B * \text{constant delta vector}$$

How to activate PSOT

"single obs utility" or "psot" may be activated by setting the following namelist parameters

num_pseudo = 1

pseudo_var =" Variable name" like "U", "T", "P", etc.

pseudo_x = "X-coordinate of the observation"

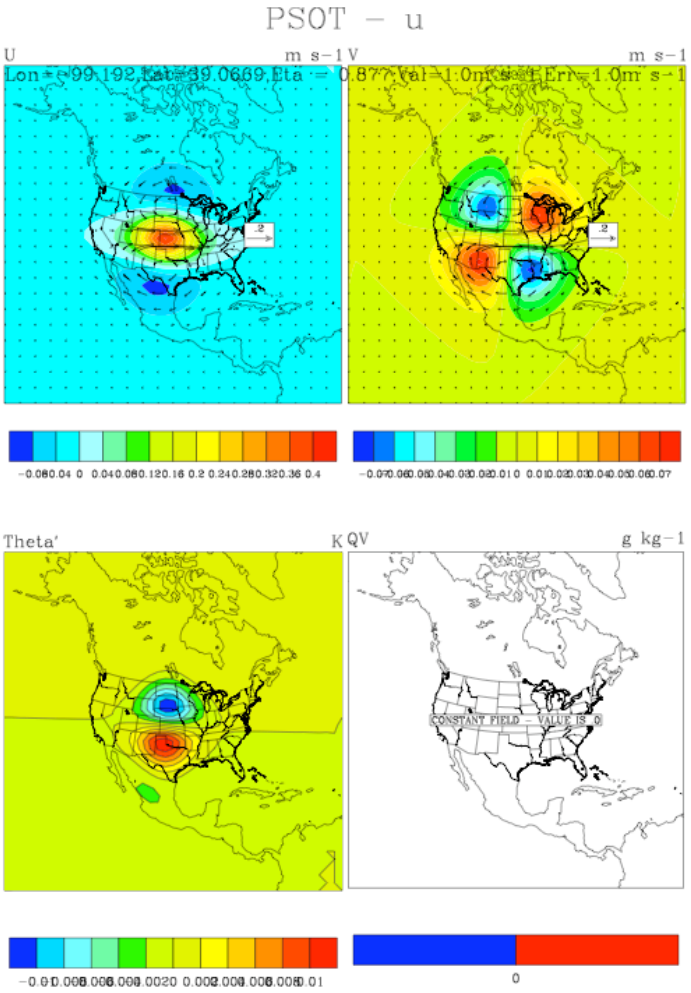
pseudo_y = "Y-coordinate of the observation"

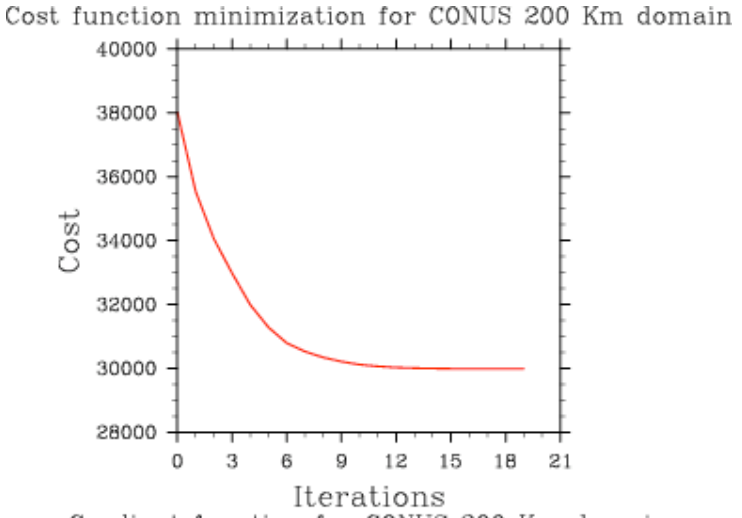
pseudo_z = "Z-coordinate of the observation"

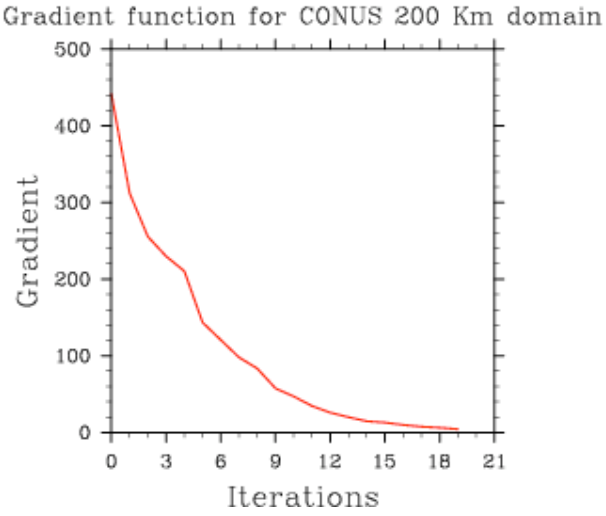
pseudo_val = "Observation value", departure from FG"

pseudo_err = "Observation error"

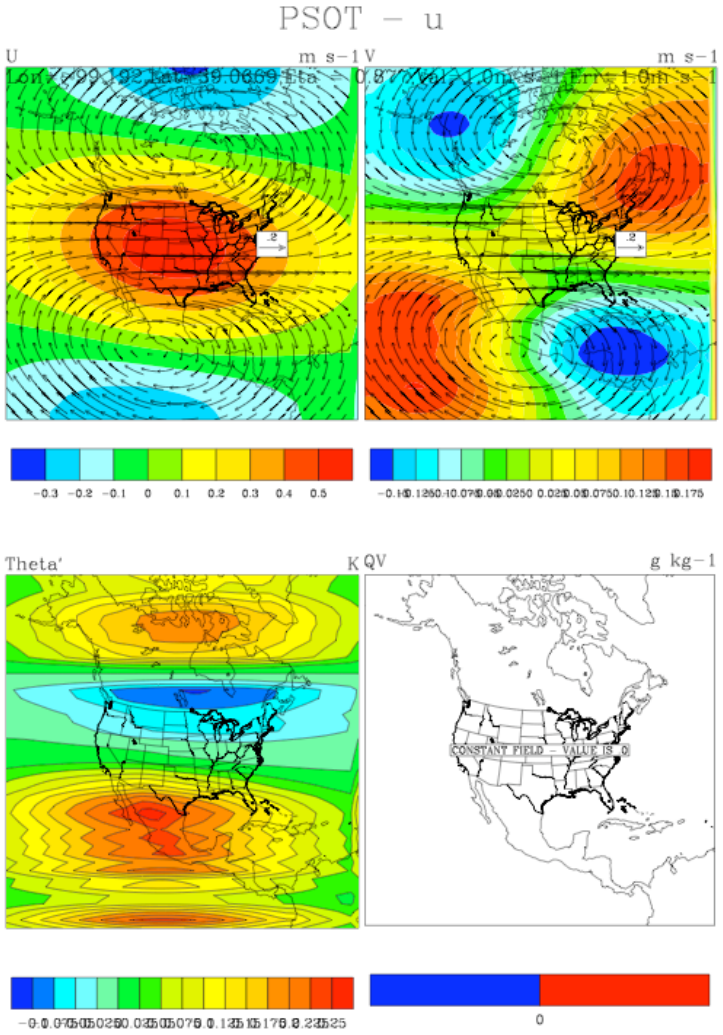
Single Observation (U) test

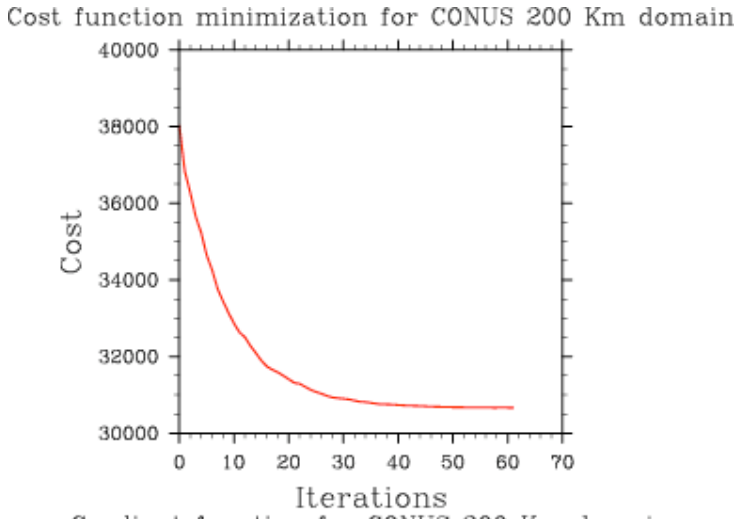


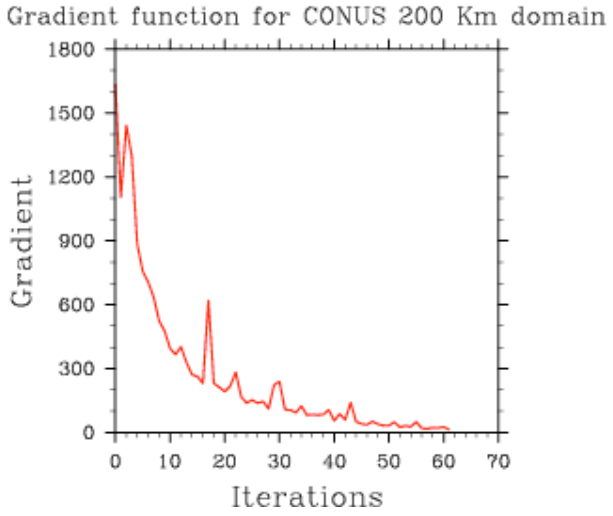




Single Observation (U) test - different BE







BE tuning

- Horizontal component of BE can be tuned with following namelist parameters

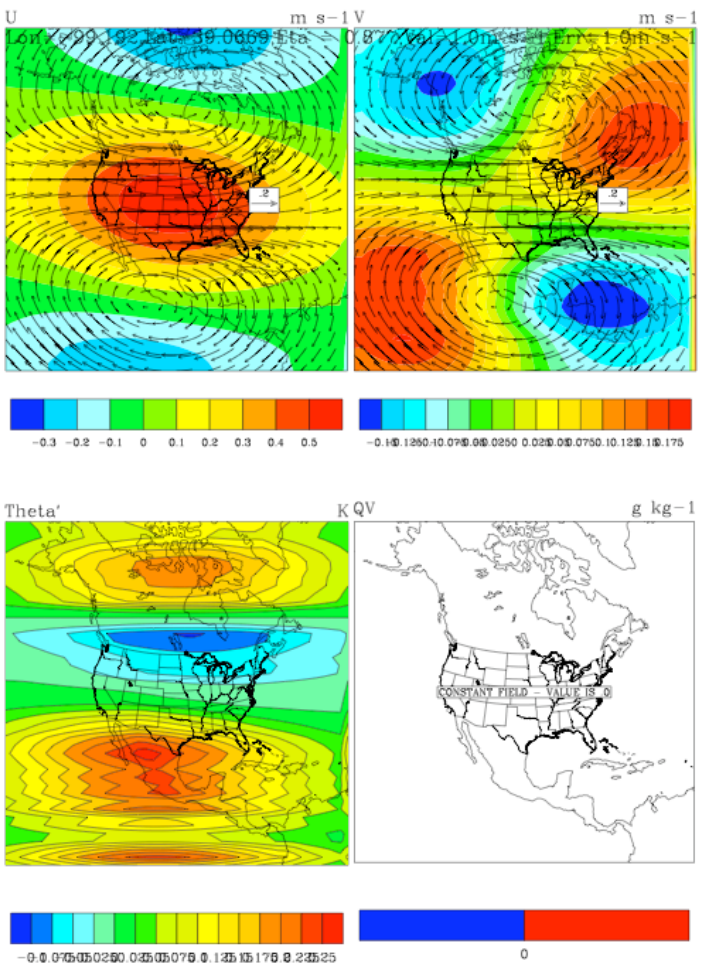
  LEN_SCALING1 - 5 (Length scaling parameters)
  VAR_SCALING1 - 5 (Variance scaling parameters)

- Vertical component of BE can be tuned with following namelist parameter

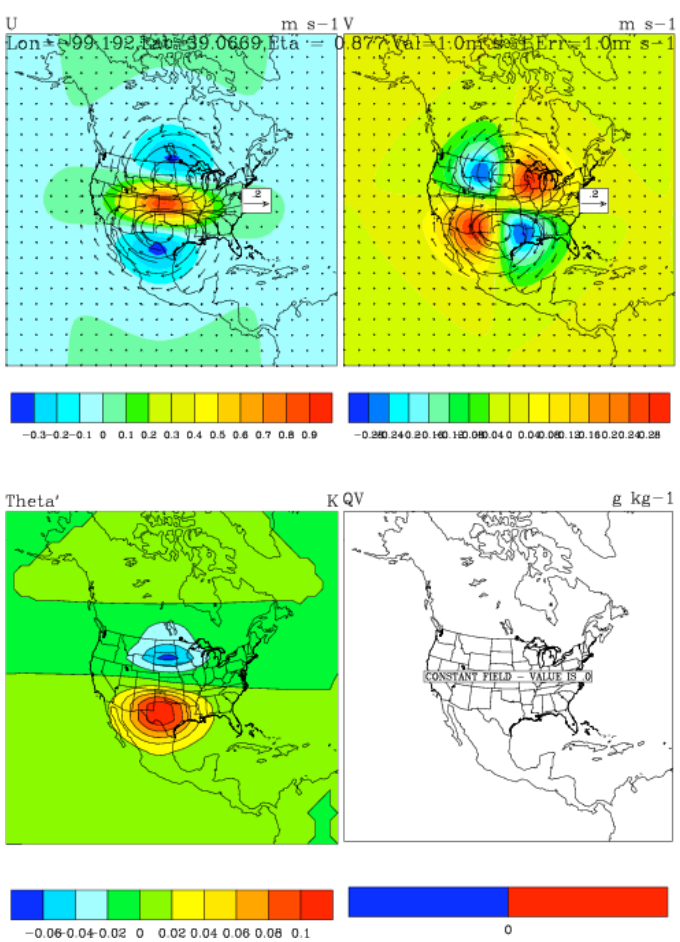
  MAX_VERT_VAR1 - 5 (Vertical variance parameters)

Tuning BE

No tuning

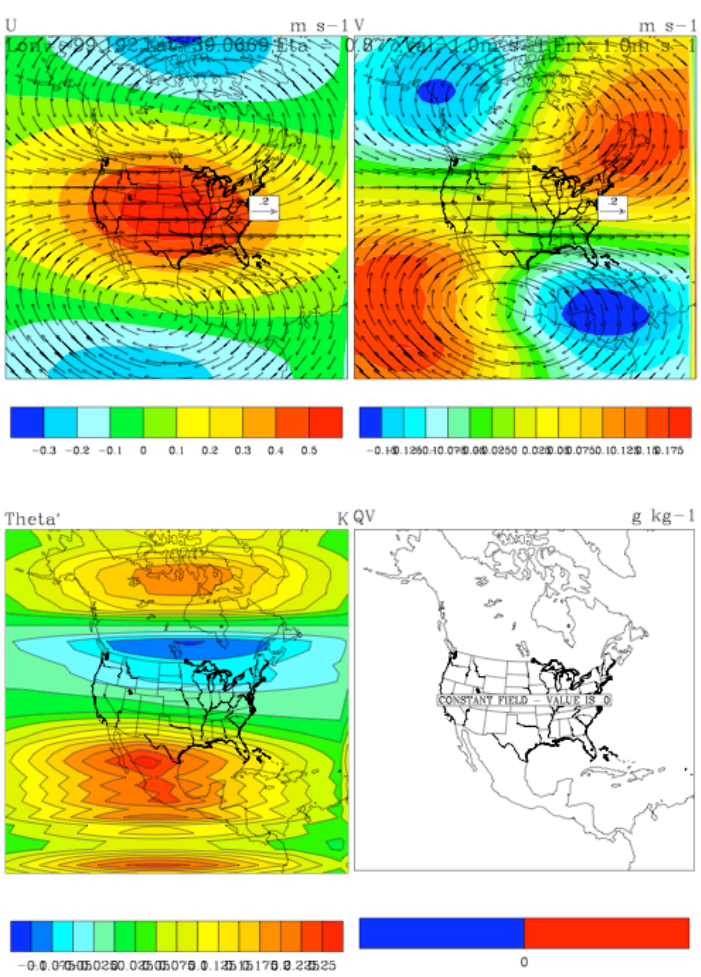


Len_scaling1=0.25

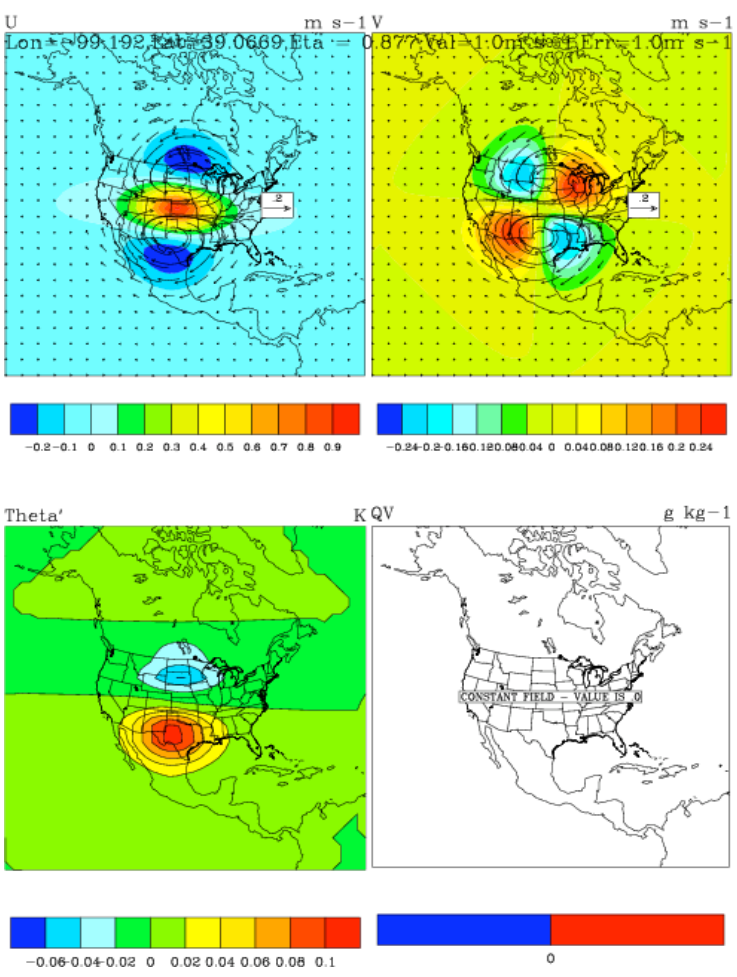


Tuning BE

No tuning



Len_scaling1 & 2 =0.25



Introduction to Practice Session 3

- Compilation of “gen_be” utility
- Generation of BE statistics
- Familiarization with various graphical utilities to display “gen_be” diagnostics
- Running single observation tests to understand the structure of BE
- BE error tuning

Generation of BE

- "gen_be_wrapper.ksh" script for generating BE for "CONUS" at 200 Km domain with:

  Grid Size : 45 x 45 x 28
  BE Method : NMC Method
  Data Input : January, 2007 forecasts, both from 00 & 12 UTC IC

Basic environment variables that needs to be set are:

- Gen_be executables location (WRFVAR_DIR)
- Forecast input data (FC_DIR)
- Run directory (BE_DIR)
- Data Range (START_DATE, END_DATE)

"gen_be" wrapper script basically executes "var/scripts/gen_be/gen_be.ksh" script

Gen_be diagnostics

- "gen_be" creates various diagnostic files which may be used to display various components of BE statistics.
- Important files are:

  Eigen vectors: fort.174, fort.178, fort.182, fort.186

  Eigen values: fort.175, fort.179, fort.183, fort.187

  scalelength: fort.194, fort.179, fort.183, fort.187

  Correlation between χ_u & χ_b (chi_u.chi.dat)

  Correlation between T_u & T_b (T_u.T.dat)

  Correlation between p_{s_u} & (ps_u.ps.dat)

Important Strings that needs to be defined in the wrapper script

"var/script/gen_be/gen_be_plot_wrapper.ksh"

BE_DIR --- gen_be Run directory

Single Observation Test

- Familiarization with single observation “wrapper” script (“da_run_suite_wrapper_con200.ksh”) to run Single Observation test
- Key parameters are

  Type of observation (pseudo_var)

  Obs co-ordinates (pseudo_x, pseudo_y & pseudo_z)

  Observation value (pseudo_val)

  Observation error (pseudo_err)

- Running Single Observation tests and display analysis increments to understand BE structure

BE tuning

- The key parameters for tuning BE are the following namelist options

  LEN_SCALING1-5 (May be set > 0.0)

  VAR_SCALING1-5 (May be set > 0.0)

  MAX_VERT_VAR1-4 (May be set between > 0.0 to 100.0)

Note: If BE is available for the same domain configuration, its tuning is not required