WRF-Var
Background Error Estimation

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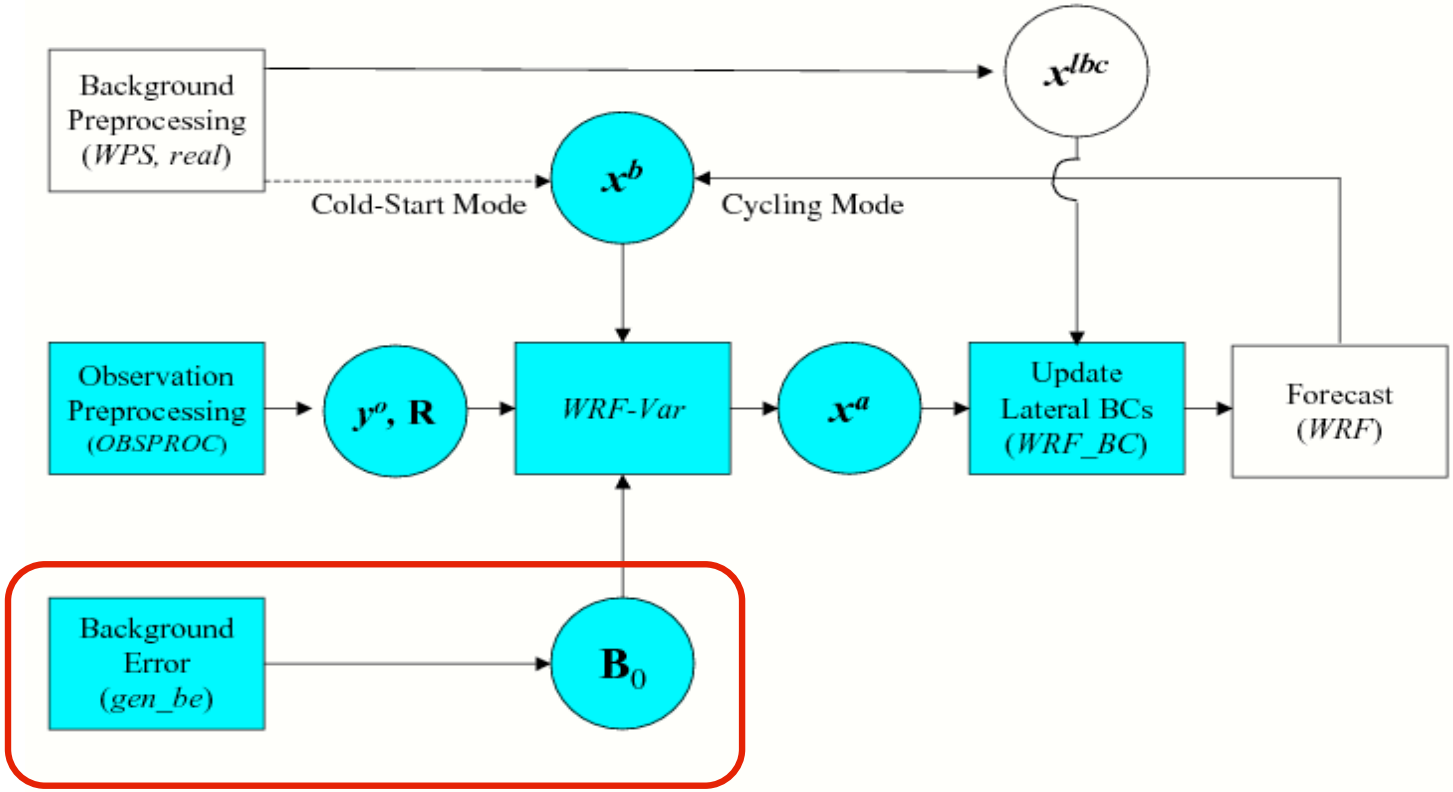
Talk overview:

- What is Background Error (BE) ?
- Role of BE in WRF-Var
- Various components of BE
- Impact of BE on minimization and forecasts
- How to compute ("gen_be" utility)?
- Single Observation Test
- Introduction to Practice Session-3

Where BE fits in WRF-modelling System



What is BE?

- It is the covariance of forecast-truth in analysis control variable space

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

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

- Common methods to estimate BE
  - Innovation Based approach (Hollingsworh & Lonnberg,1986)
  - NMC Method: $(x-x^t) \approx (x^{t1} - x^{t2})$
    (Forecast differences valid for same time
  - Ensemble Method: $(x-x^t) \approx (x^{ens} - \langle x^{ens} \rangle)$
    (Ensemble - Ensemble mean)
  - 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 - Forward Observation Operator (Possibly non-linear)

y^o - Observations

R - Observation error covariance

Role of BE:

- BE is used for preconditioning the analysis equation

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

- It is represented with a suitable choice of U as follows

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

  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

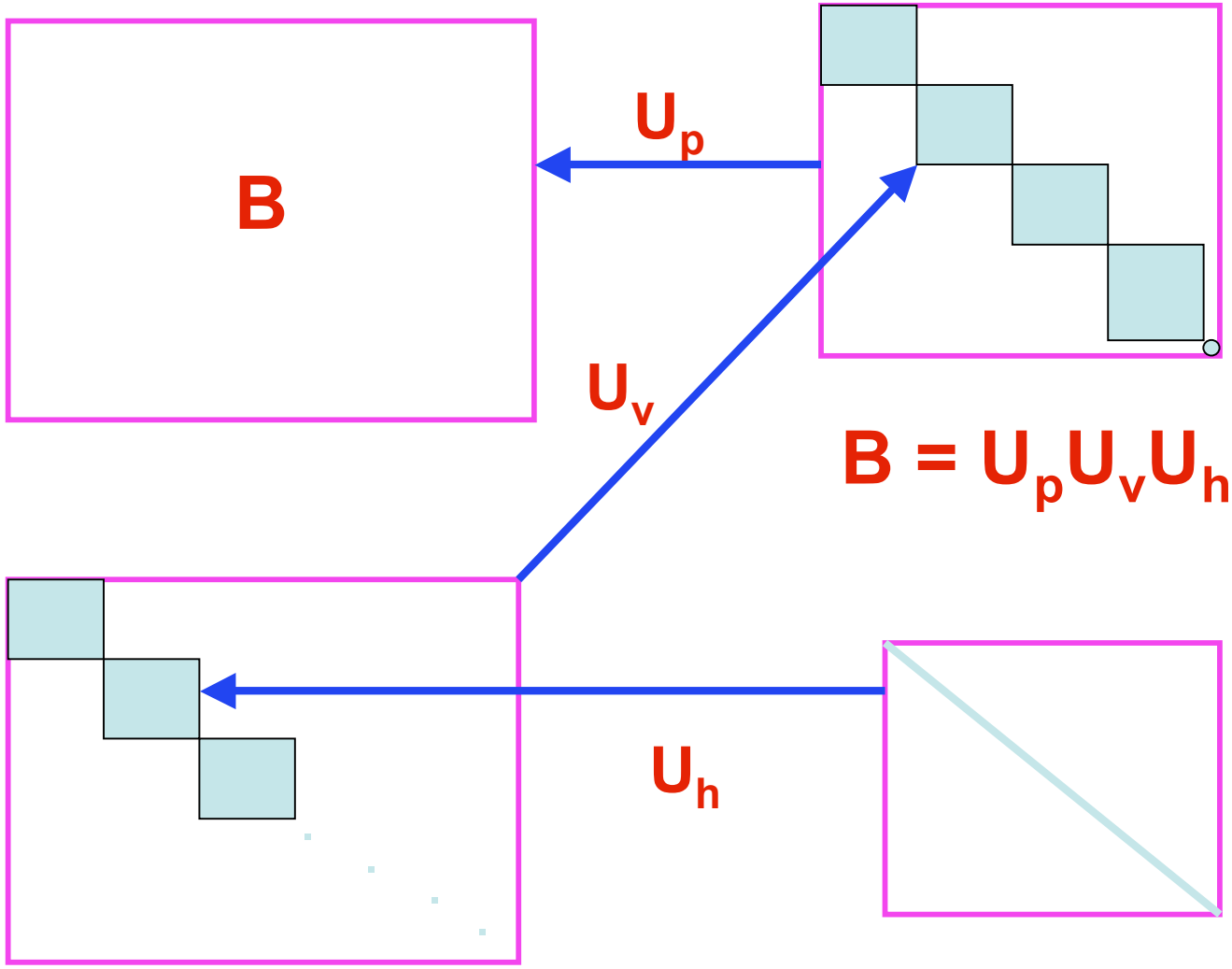
How BE is represented?

- In true sense, size of B is typically of the order of $10^7 x 10^7$
- 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.*



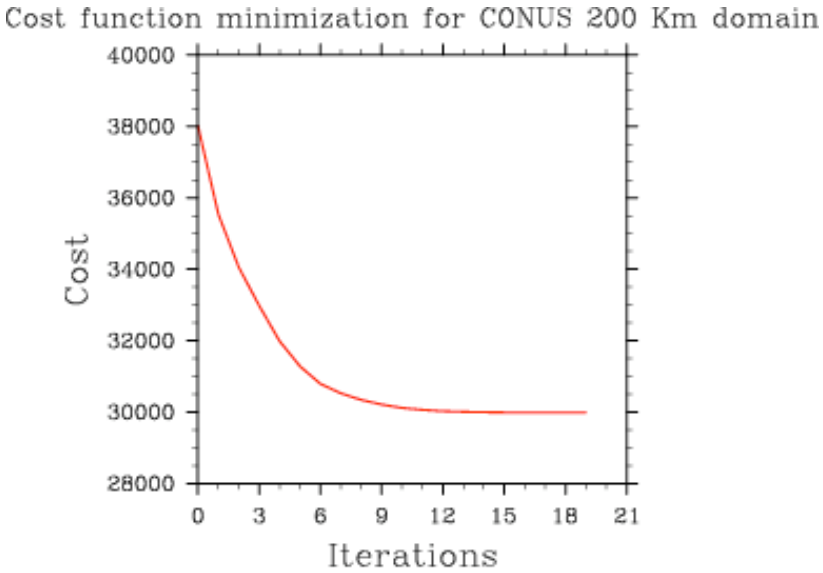
$$B = U_p U_v U_h U_h^T U_v^T U_p^T$$

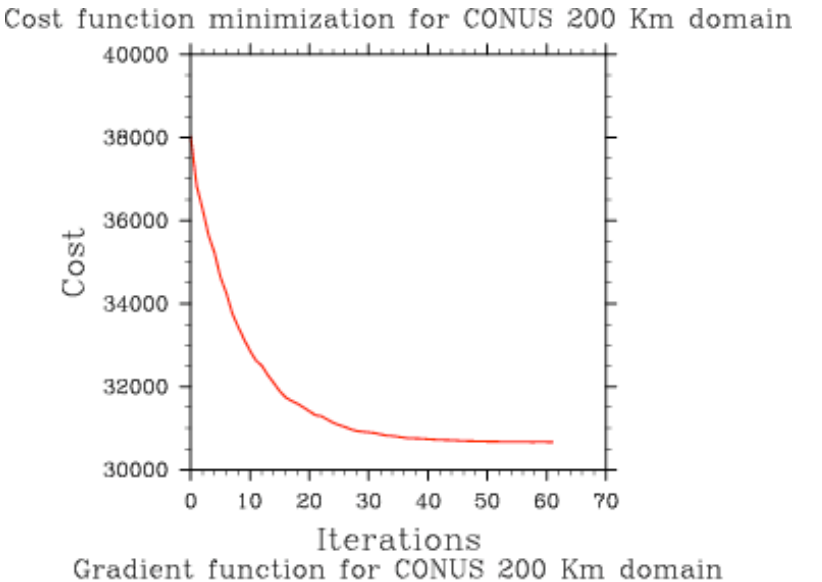
Components of BE

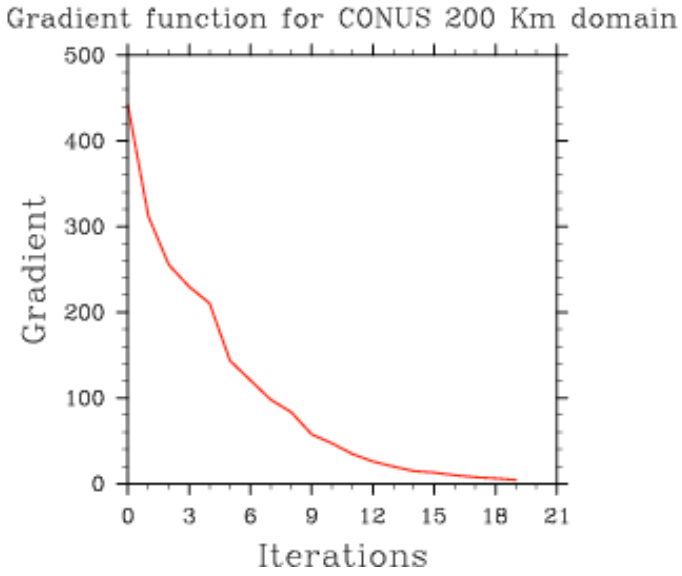
Corresponding to each control variable, following are the main components of BE

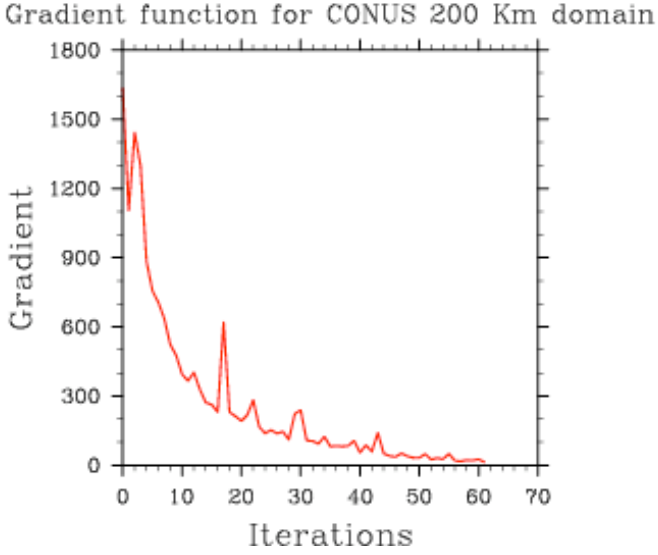
- Regression Coefficient for balanced part of Velocity potential, Temperature and Surface pressure
- Eigen vectors and Eigen values
- Scalelength for regional and power spectrum for global option

Impact of BE on Minimization

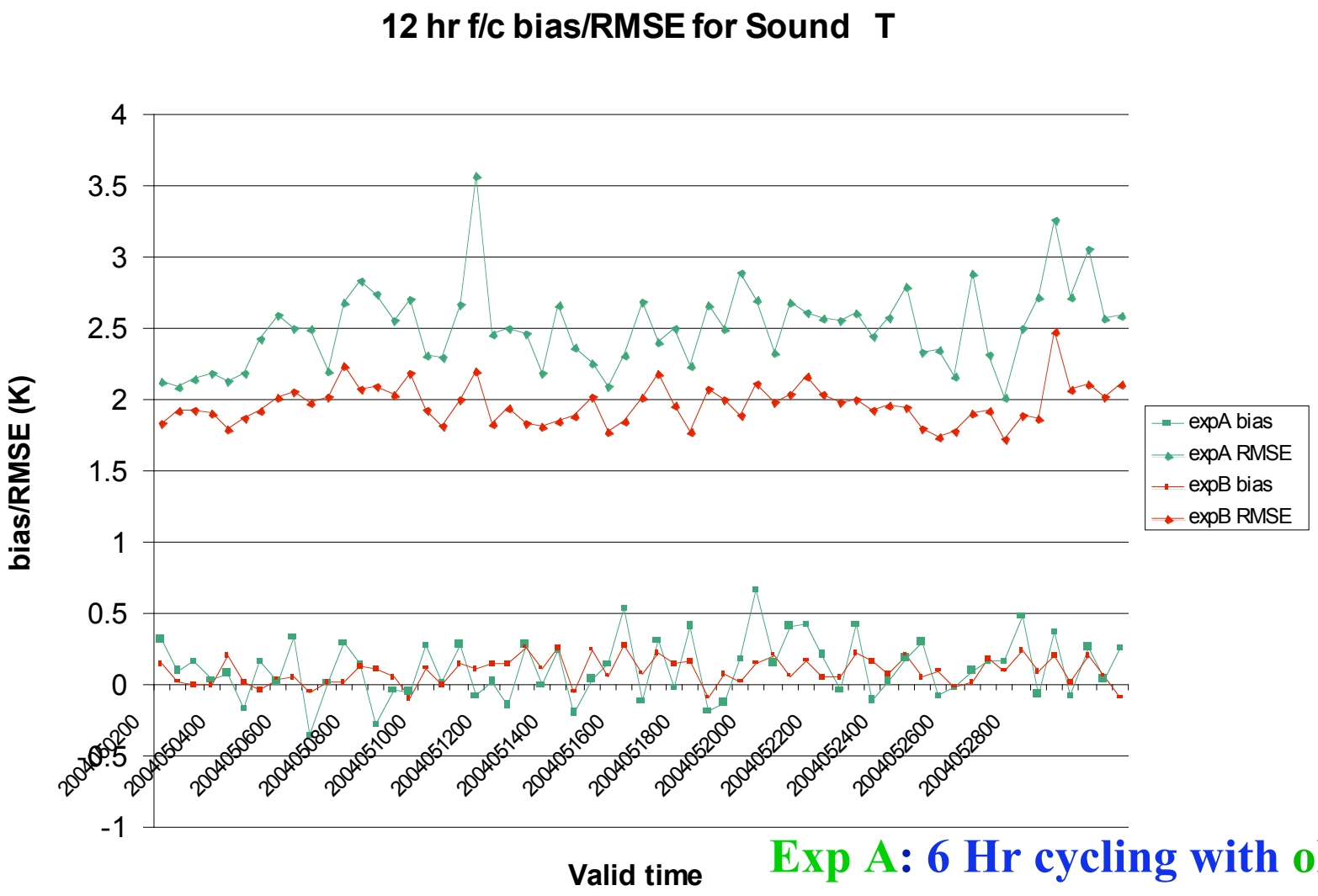








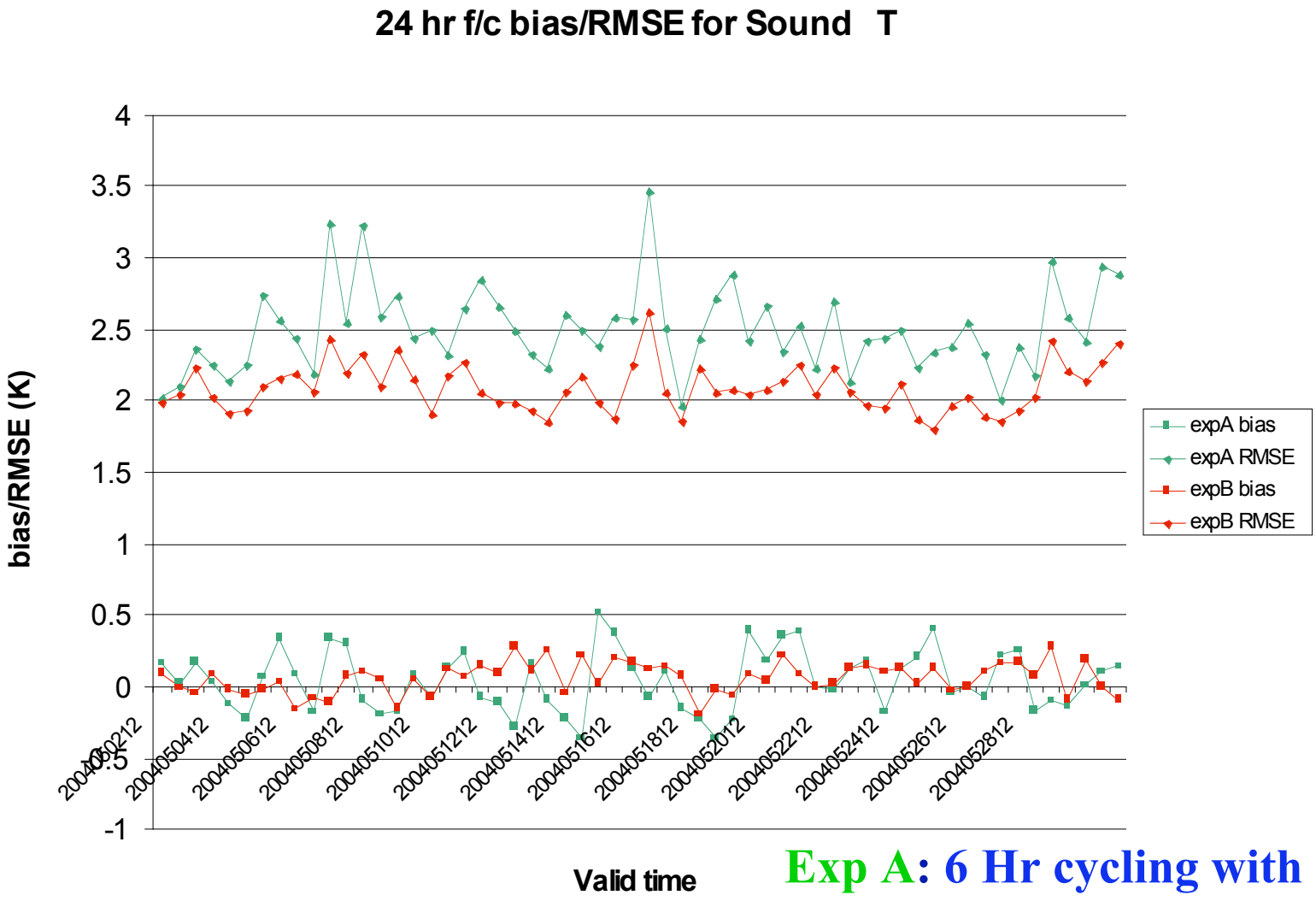
Impact of BE on Temperature forecast



Exp A: 6 Hr cycling with old BE

Exp B: 6 Hr cycling with new BE

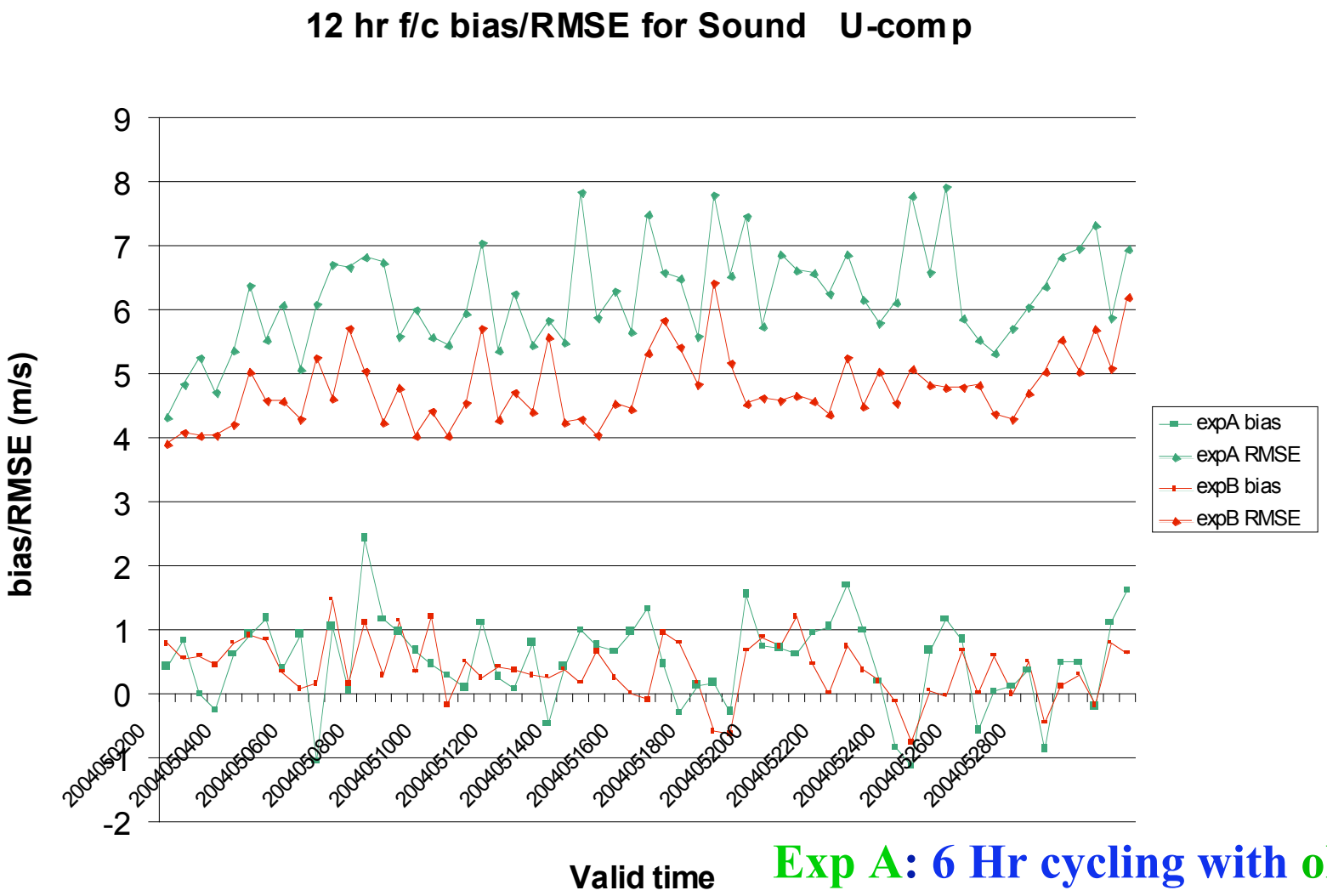
Impact of BE on Temperature forecast



Exp A: 6 Hr cycling with old BE

Exp B: 6 Hr cycling with new BE

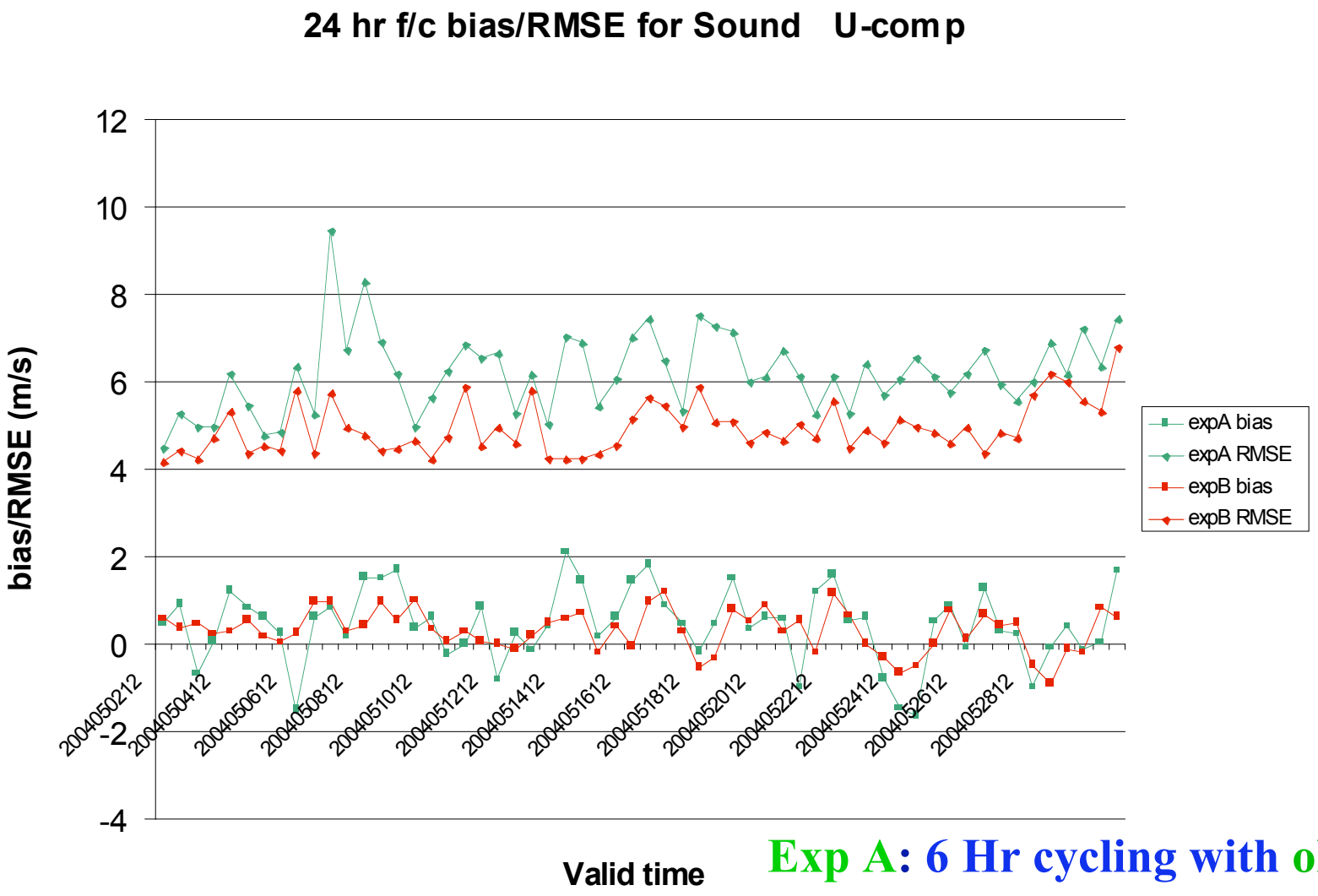
Impact of BE on Wind (U Comp.) forecast



Exp A: 6 Hr cycling with old BE

Exp B: 6 Hr cycling with new BE

Impact of BE on Wind (U Comp.) forecast



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
- Resides in WRFDA under "var" directory
- Designed both for NMC and Ensemble methods
- Consists of five stages
- Basic goal is to estimate the error covariance 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

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

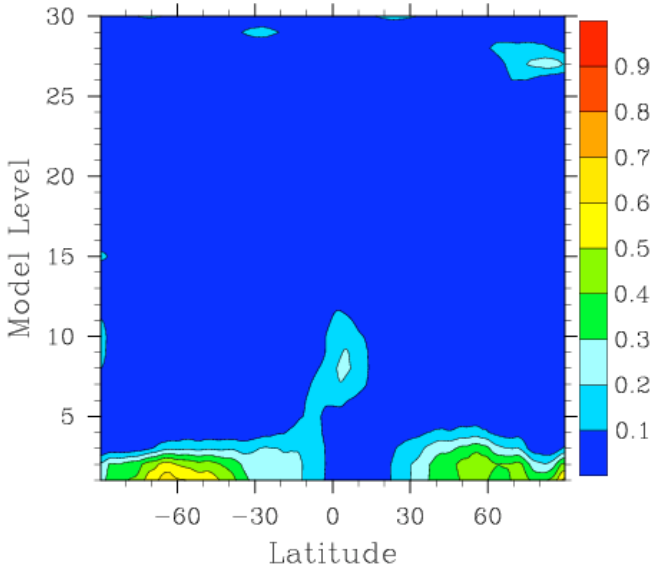
- Computes unbalanced part

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

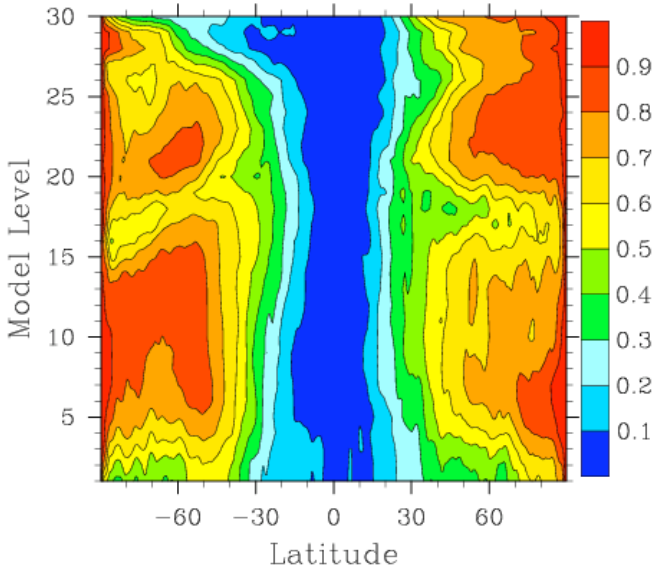
WRF-Var Balance constraints

- 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

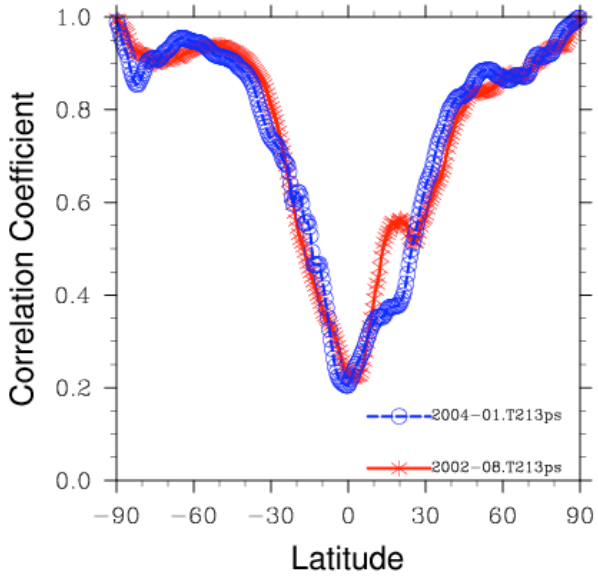
$\langle \chi_b \bullet \chi \rangle / \langle \chi \bullet \chi \rangle$



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



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



"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)"

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

Single observation test

- Through single observation, one can understand
  - structure of BE
  - It identifies the "shortfalls" of BE
  - 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:

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

Thus,

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

How to activate Single obs test (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"

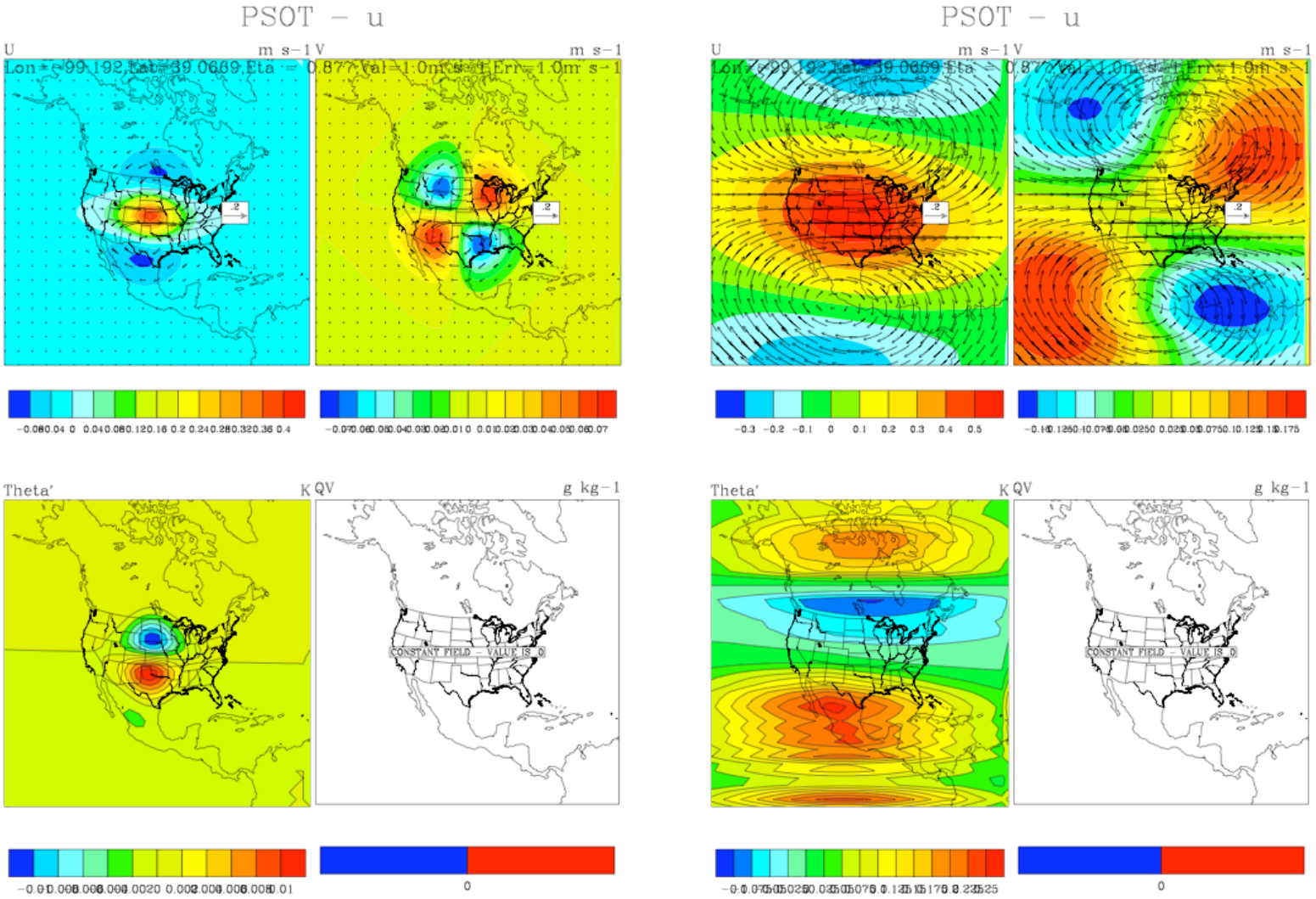
pseudo_y = "Y-coordinate of the observation"

pseudo_z = "Z-coordinate of the observation"

pseudo_val = "Observation value", departure from FG"

pseudo_err = "Observation error"

Single Obs (U) test with different BE



How to perform tuning of BE?

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

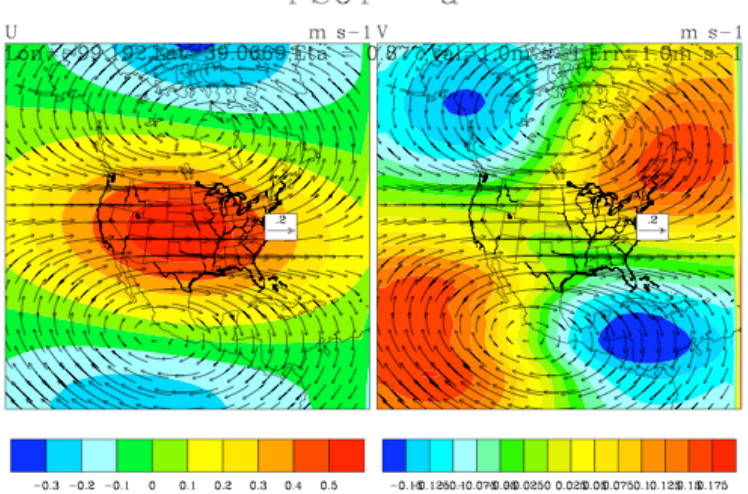
  LEN_SCALING1 - 5 (Length scaling parameters)
  VAR_SCALING1 - 5 (Variance scaling parameters)

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

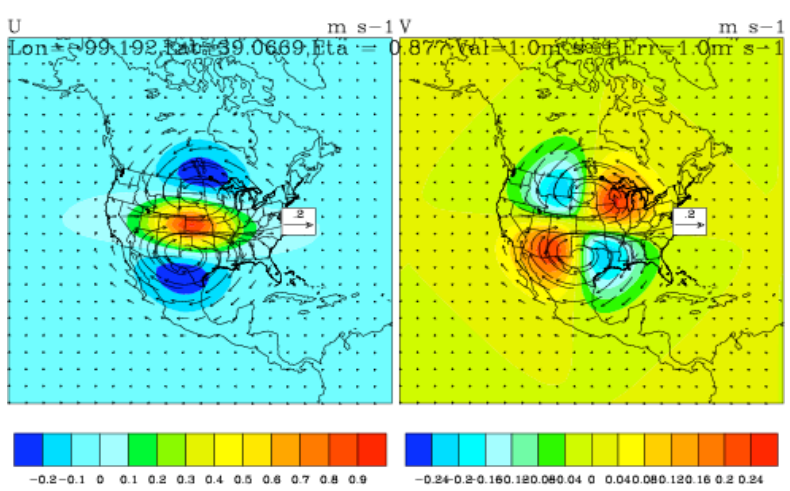
  MAX_VERT_VAR1 - 5 (Vertical variance parameters)

Results with BE Tuning

No tuning



Len_scaling1 & 2 =0.25



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

How to run 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)

- Display analysis increments to understand BE structure

BE tuning

- Understand the role of BE-tuning parameters through namelist options

  LEN_SCALING1 - 5 (Length scaling parameters)
  VAR_SCALING1 - 5 (Variance scaling parameters)
  MAX_VERT_VAR1 - 5 (Vertical variance parameters)

Note: If BE is available for the same domain configuration, it's tuning is not required