GSI Tutorial 2010

Background and Observation Error Estimation and Tuning

Background Error

1. Background error covariance
2. Multivariate relation
3. Covariance with fat-tailed power spectrum
4. Estimate background error

Analysis system produces an analysis through the minimization of an objective function given by

$$J = x^T B^{-1} x + (H x - y)^T R^{-1} (H x - y)$$

J^b J^o

Where

x is a vector of analysis increments,

B is the background error covariance matrix,

y is a vector of the observational residuals, $y = y_{obs} - H x_{guess}$

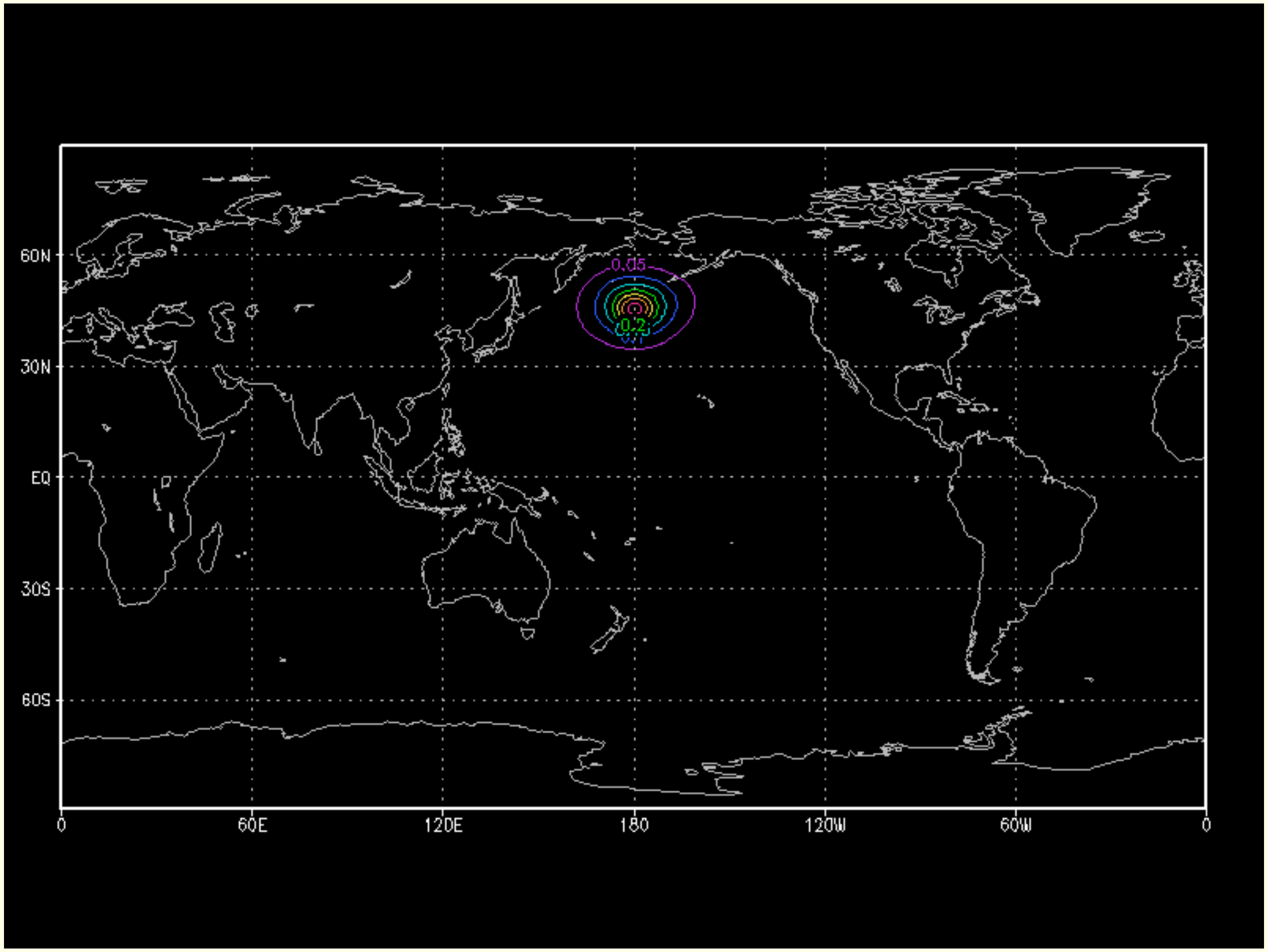
R is the observational and representativeness error covariance matrix

H is the transformation operator from the analysis variable to the form of the observations.

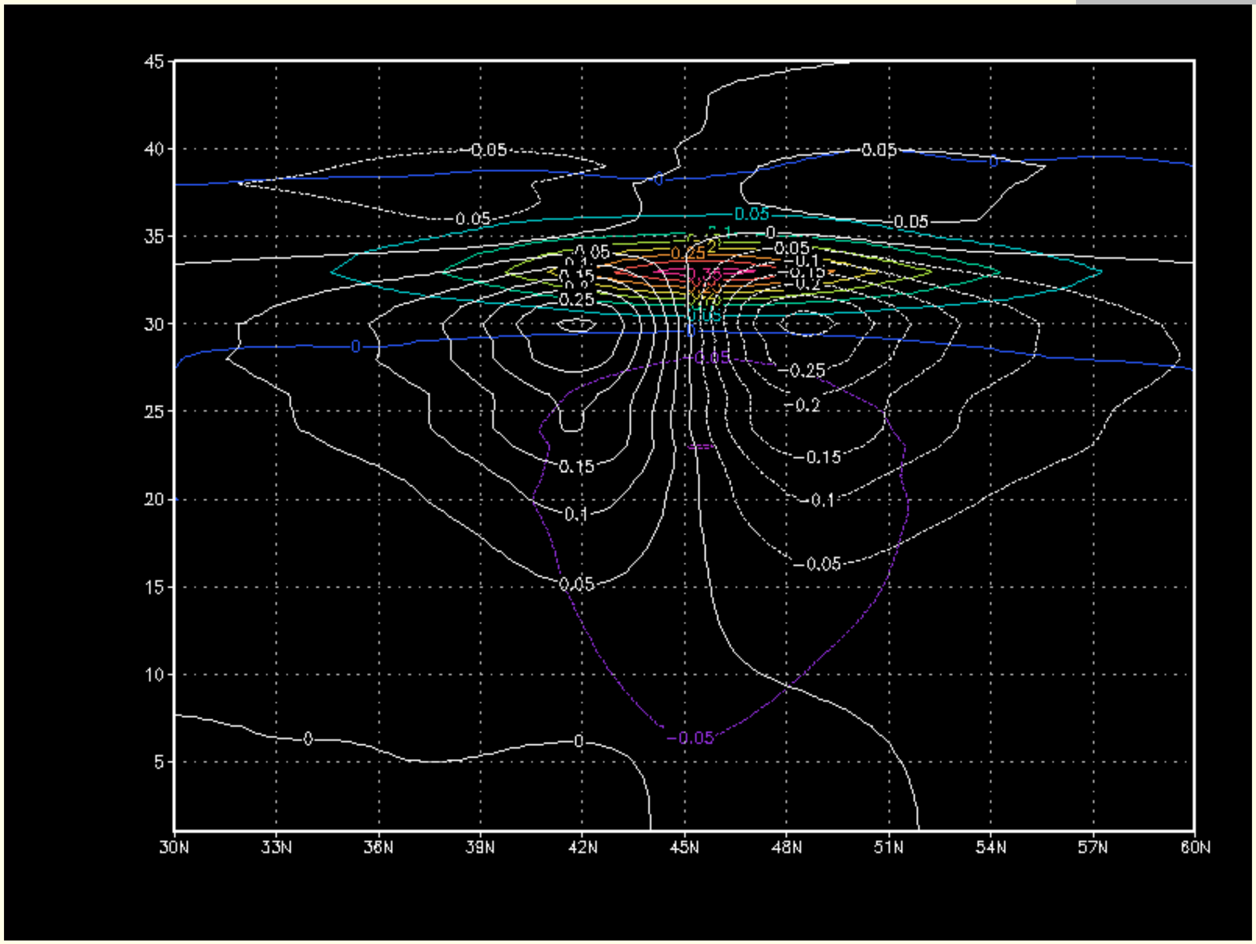
One ob test

```
&SETUP
   ….
   oneobtest=.true.
&SINGLEOB_TEST
   maginnov=1.,magoberr=1.,oneob_type=‘t’,
   oblat=45.,oblon=270.,obpres=850.,
   obdattime=2010062900,obhourset=0.,
```

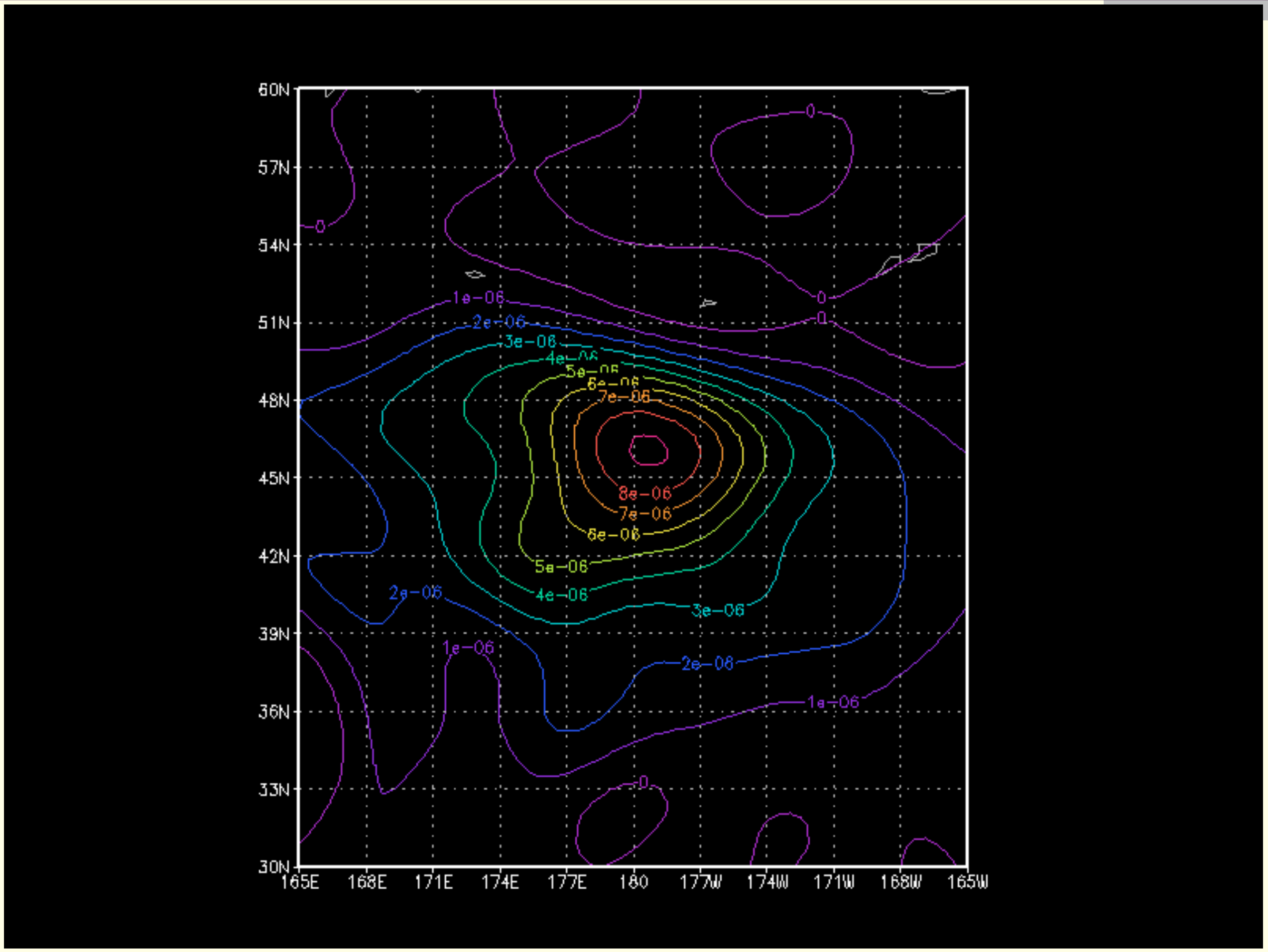
Temp Analysis Increment from Single Temp obs



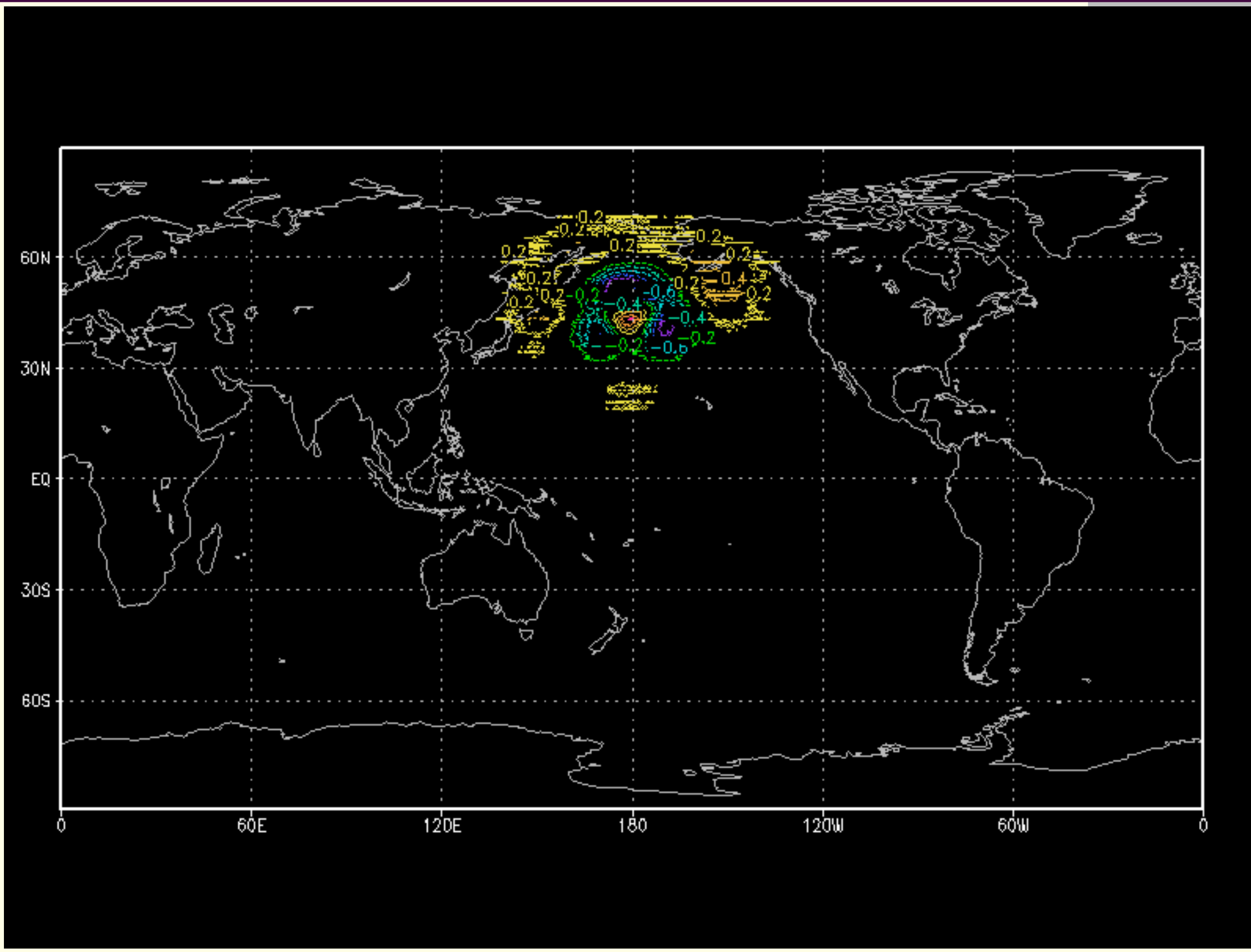
Temp and E-W Wind Analysis Increment from 1 Temp obs



Humidity Analysis Increment from Single Temp obs



Surface Pressure Analysis Increment from Single Temp obs



Multivariate relation

- Balanced part of the temperature is defined by

$$T_b = G\,\psi$$

where G is an empirical matrix that projects increments of stream function at one level to a vertical profile of balanced part of temperature increments. G is latitude dependent.

- Balanced part of the velocity potential is defined as

$$\chi_b = c\,\psi$$

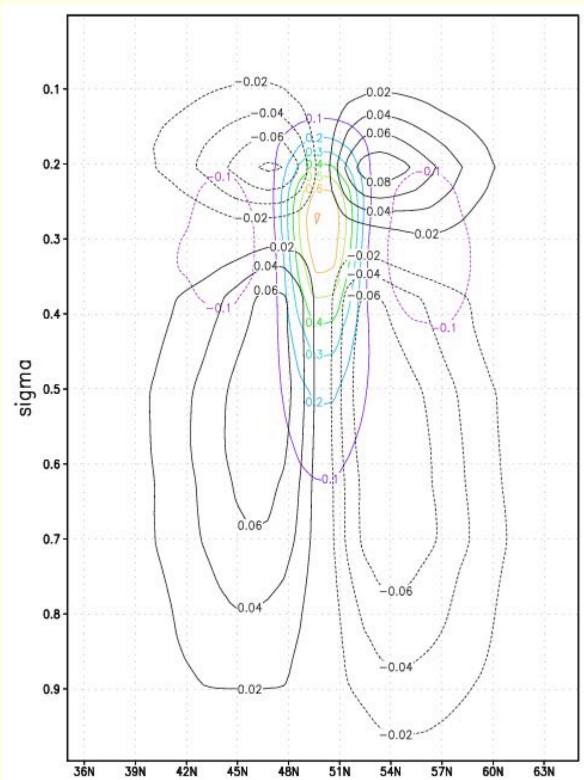
where coefficient c is function of latitude and height.

- Balanced part of the surface pressure increment is defined as

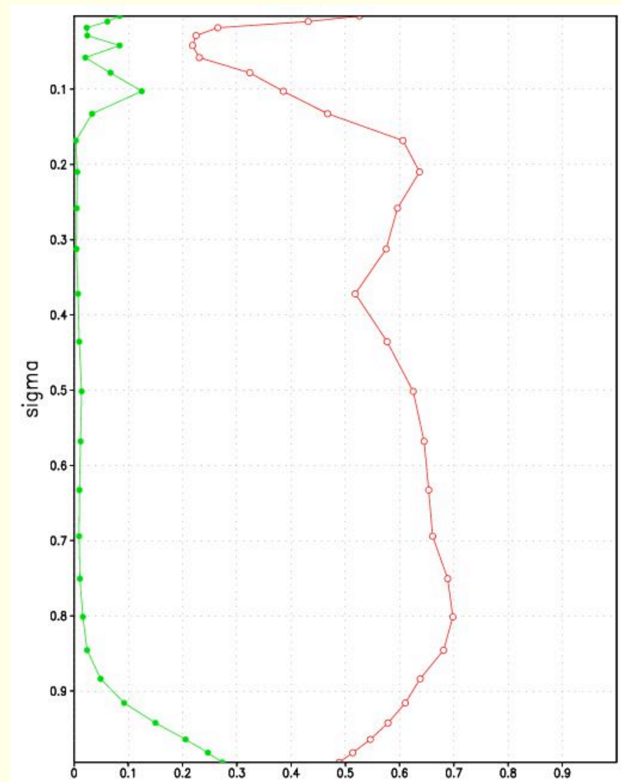
$$P_b = W\,\psi$$

where matrix W integrates the appropriate contribution of the stream function from each level.

Multivariate Relation



Vertical cross section of u and temp



global mean fraction of balanced temperature and velocity potential

Control Variable and Error Variances

Normalized relative humidity (qoption=2)

$$\delta RH / \sigma(RH^b) = RH^b (\delta P/P^b + \delta q /q^b - \delta T /\alpha^b)$$

where

$\sigma (RH^b)$: standard deviation of background error as function of RH^b

α^b : $- 1 / d(RH)/d(T)$

multivariate relation with Temp and P

*Holm et al.(2002) ECMWF Tech Memo

Background error variance of RH

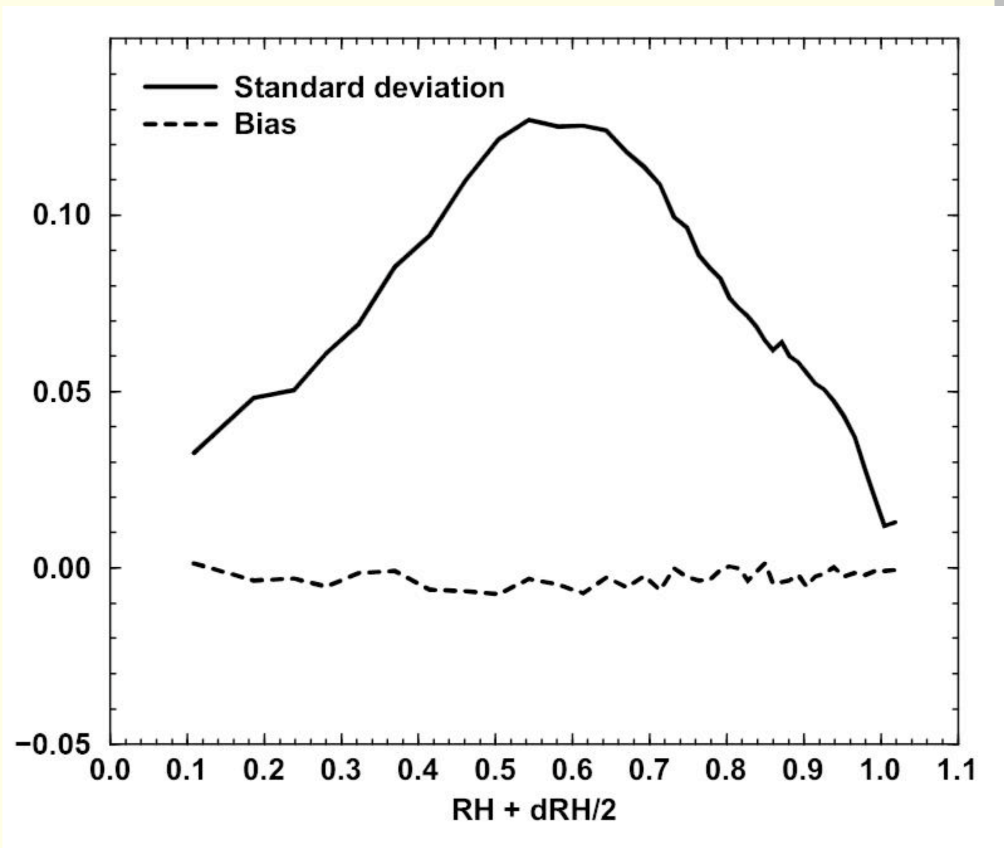
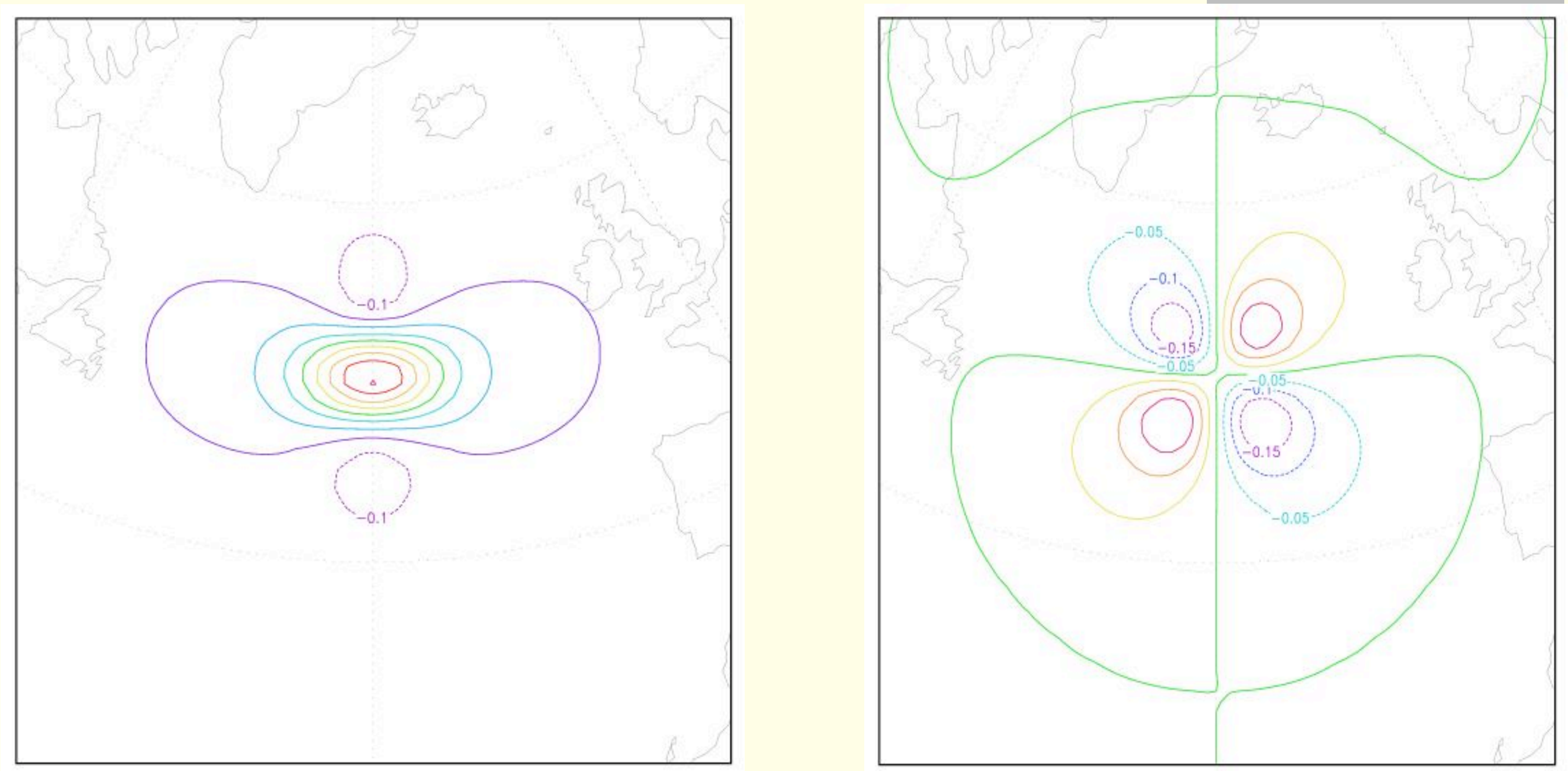


*Figure 23 in Holm et al.(2002) ECMWF Tech Memo

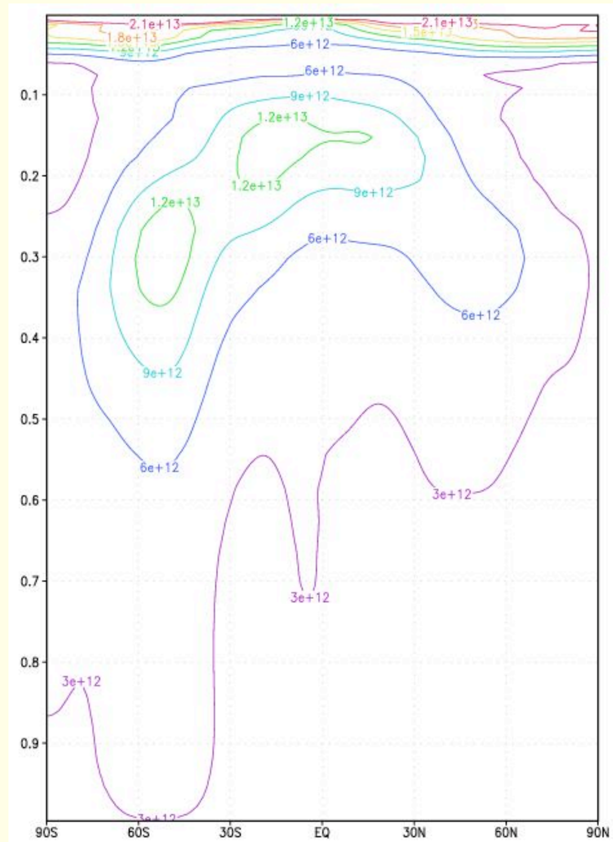
Control Variables and Model Vaiables



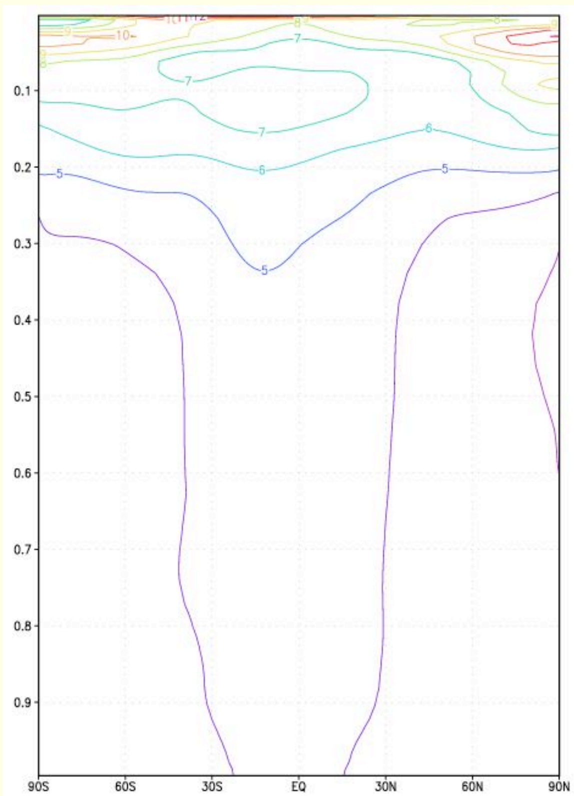
U (left) and v (right) increments at sigma level 0.267, of a 1 m/s westerly wind observational residual at 50N and 330 E at 250 mb.

Background error covariance

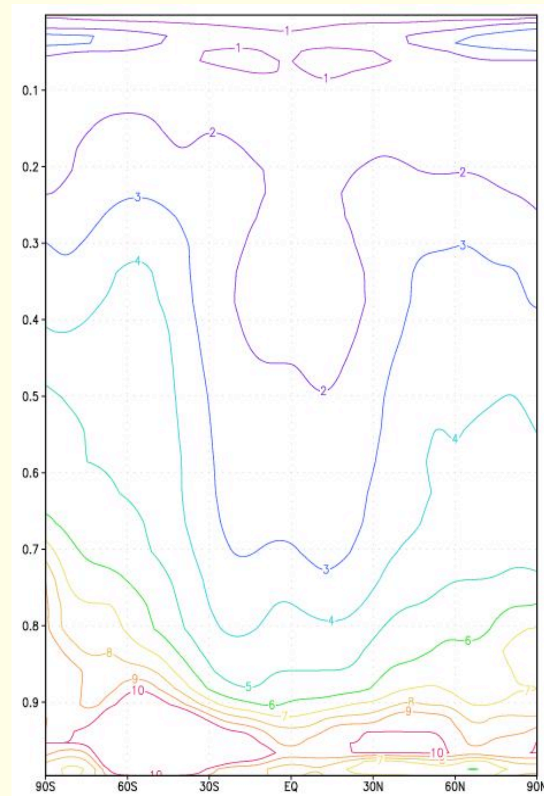
- The error statistics are estimated in grid space with the 'NMC' method. Stats of y are shown.
- Stats are function of latitude and sigma level.
- The error variance ($m^4\ s^{-2}$) is larger in mid-latitudes than in the tropics and larger in the southern hemisphere than in the northern.
- The horizontal scales are larger in the tropics, and increases with height.
- The vertical scales are larger in the mid-latitude, and decrease with height.



Background error covariance

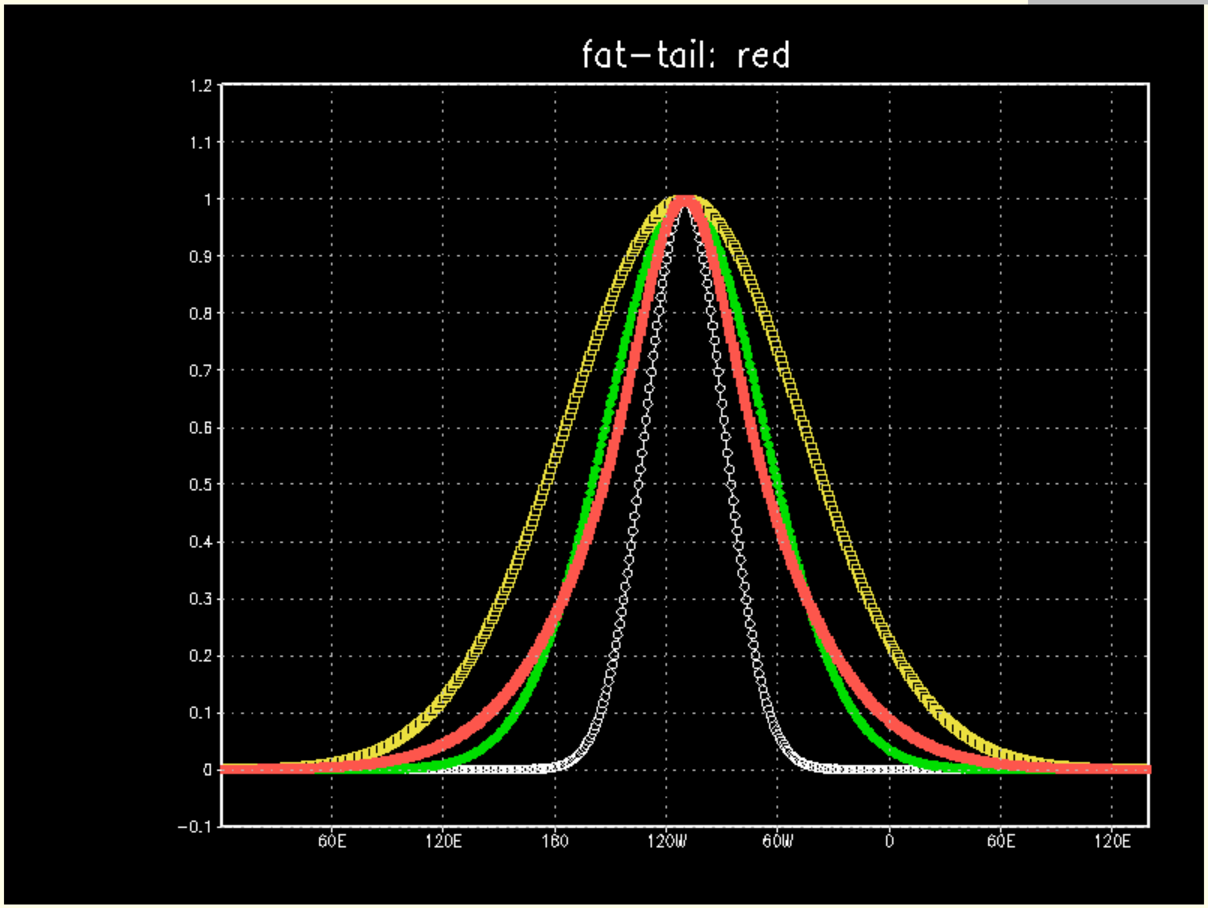


Horizontal scales in units of 100km

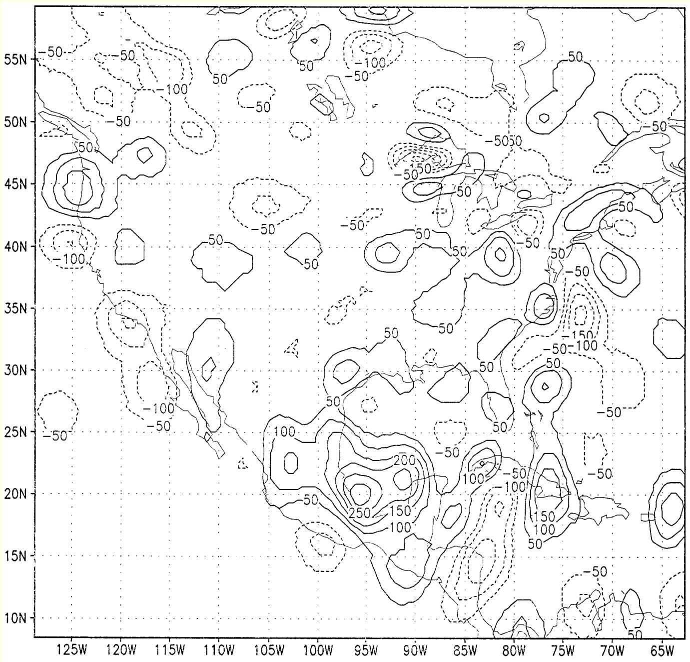


vertical scale in units of vertical grid

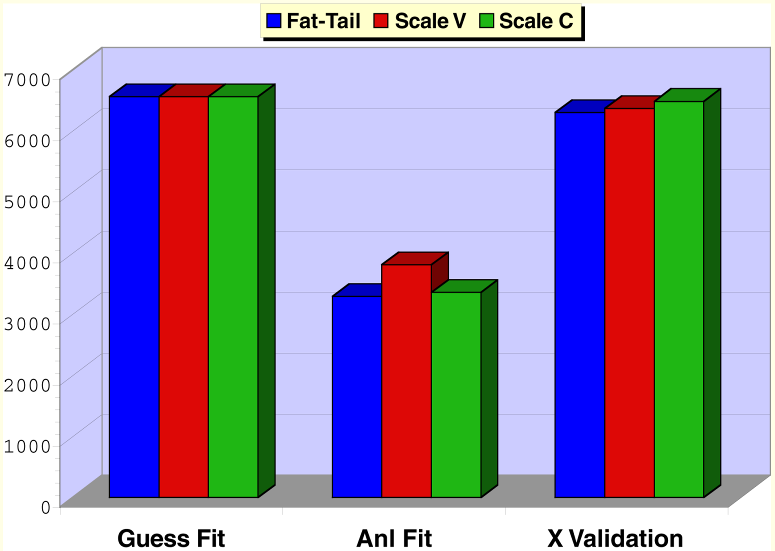
Fat-tailed Power Spectrum for B



Fat-tailed Power Spectrum

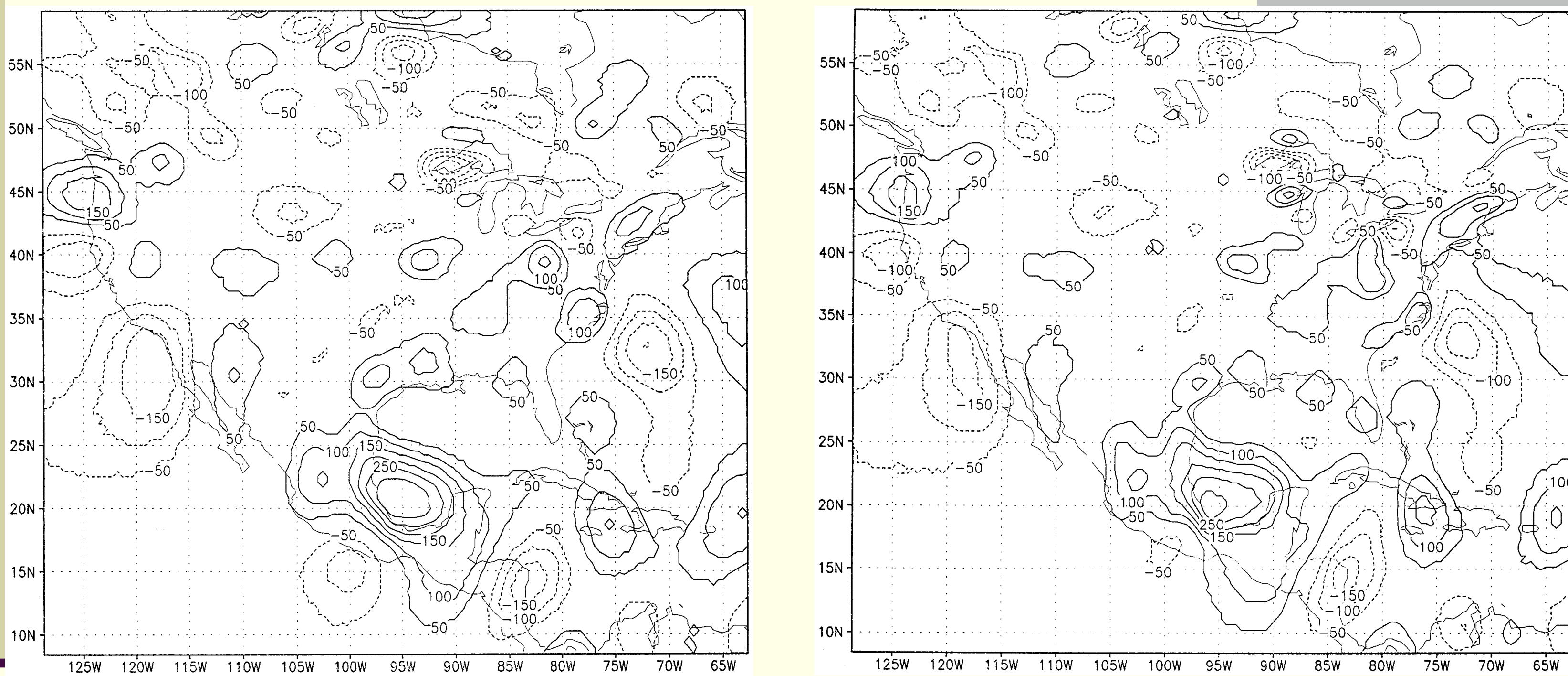


Psfc increments with single homogeneous recursive filter. (scale C)



Cross validation

Fat-tailed Power Spectrum



Psfc increments with inhomogeneous scales with single recursive filter: scale v (left) and multiple recursive filter: fat-tail (right)

Estimate Background Error

NMC method

- time differences of forecasts (48-24hr)
- Basic assumption: linear error growth with time

Ensemble method

- ensemble differences of forecasts
- Basic assumption: ensemble represents real spread

Conventional method

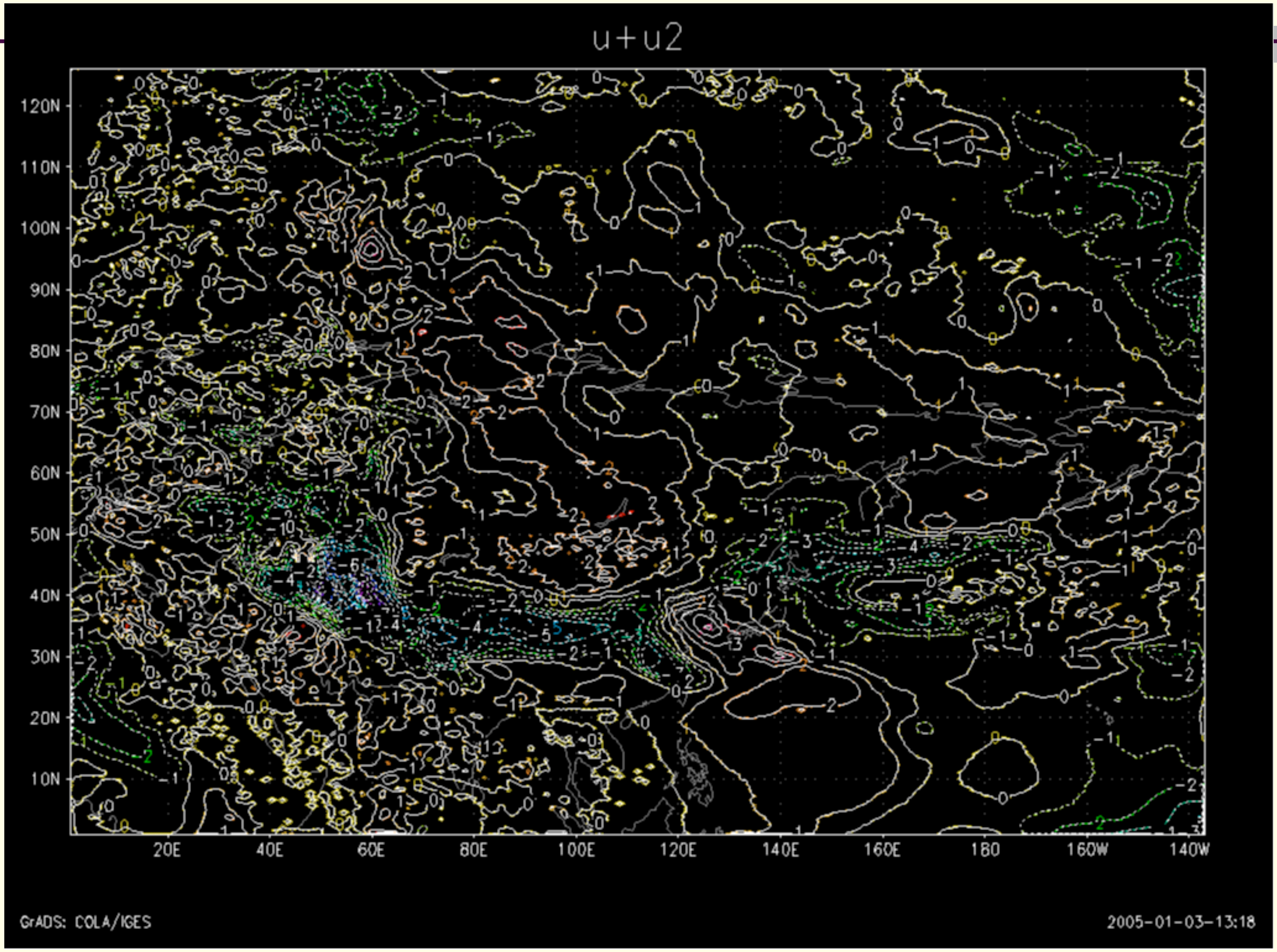
- differences of forecasts and obs
- difficulties: obs coverage, multivariate…

Estimate B from Regional Forecasts

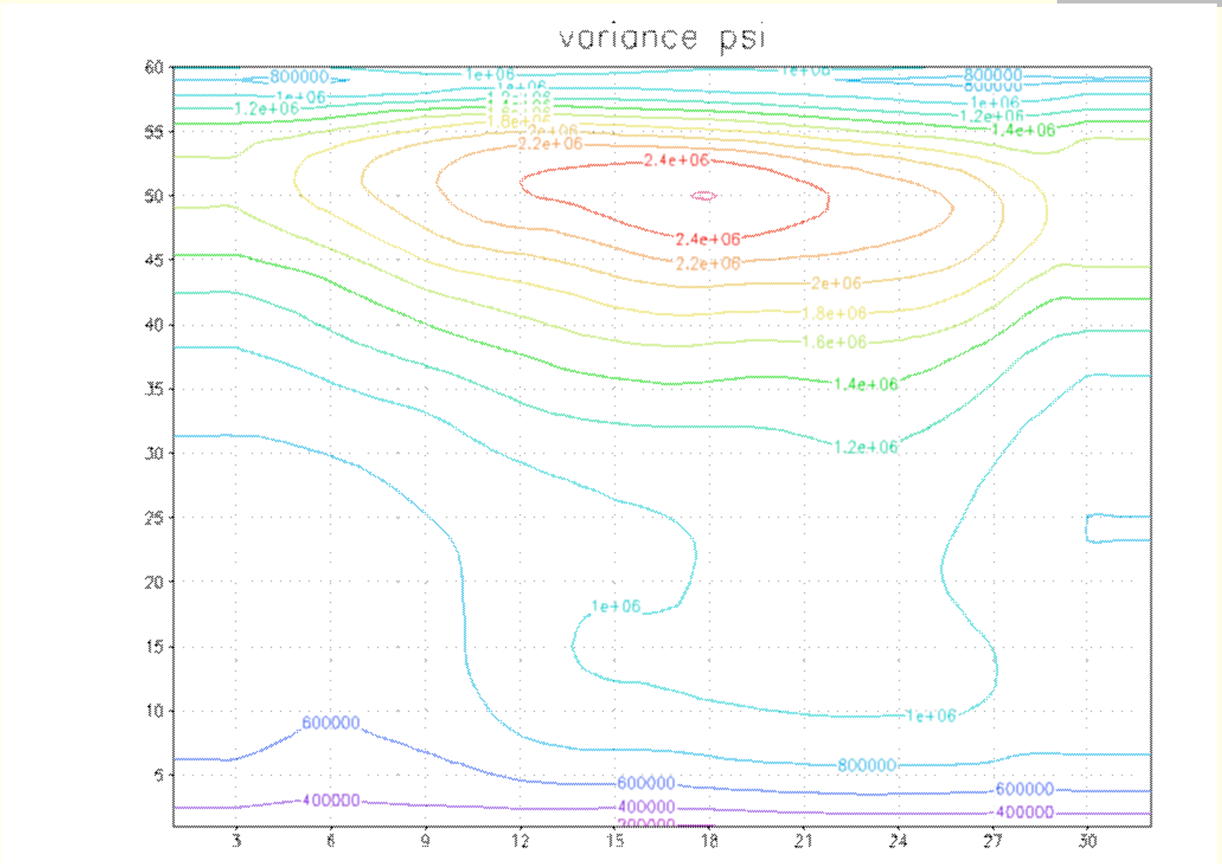
Spectral calculation of stream function and velocity potential from forecast differences of wind fields.

1. U & V : e 2 a grid
2. Fill to FFT grid number: taper & zero
3. FFT: both X & Y directions
4. Vor + Div
5. Del^{-2}
6. FFT back to for Psi & Chi
7. Derivatives of Psi & Chi to find U2 & V2

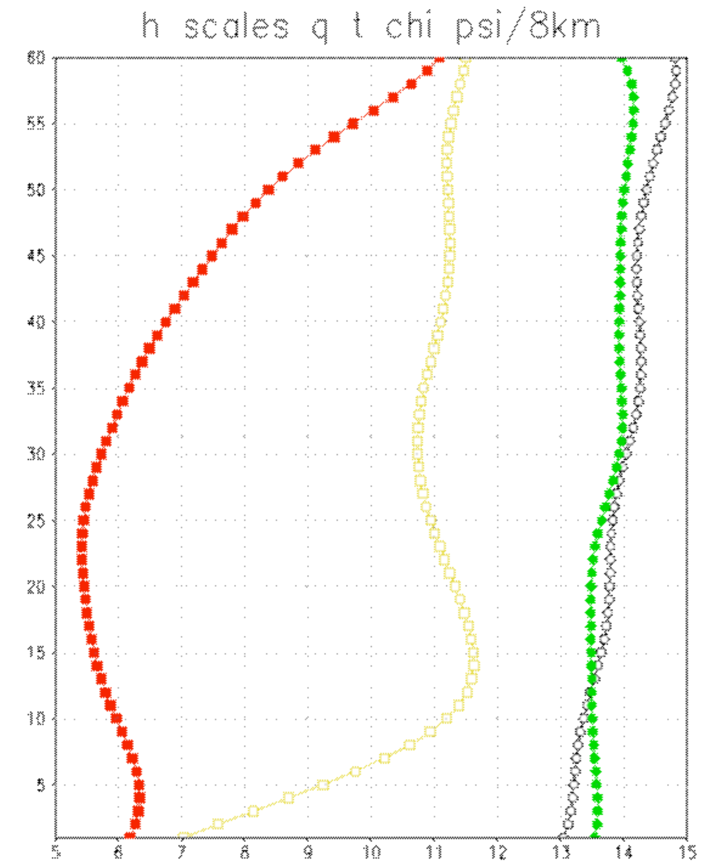
u & v from ψ & χ



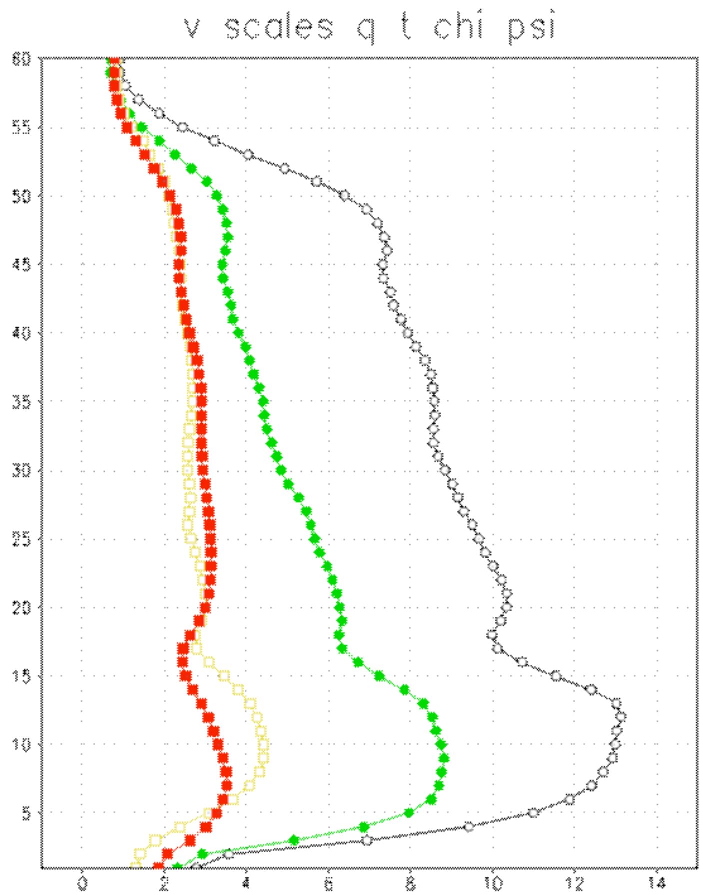
Estimate B from Regional Forecasts



Estimate B from Regional Forecasts



Estimate B from Regional Forecasts



Tuning Background Parameters

berror=$FIXnam/nam_glb_berror.f77

&BKGERR

as=0.28,0.28,0.3,0.7,0.1,0.1,1.0,1.0,

hzscl=0.373,0.746,1.50,

vs=0.6,

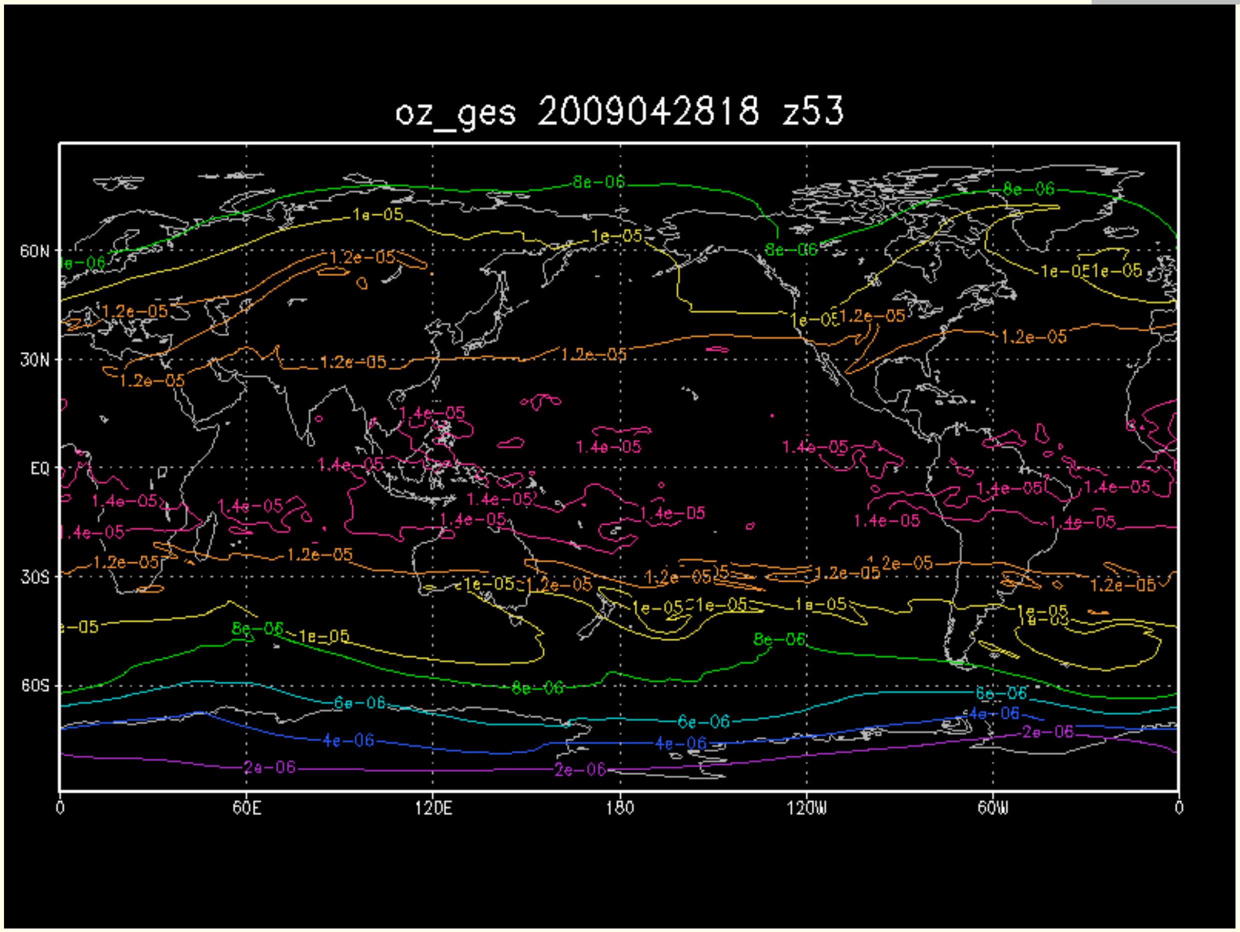
(Note that hzscl and vs apply to all variables)

Q: How to find out definitions of “as”?

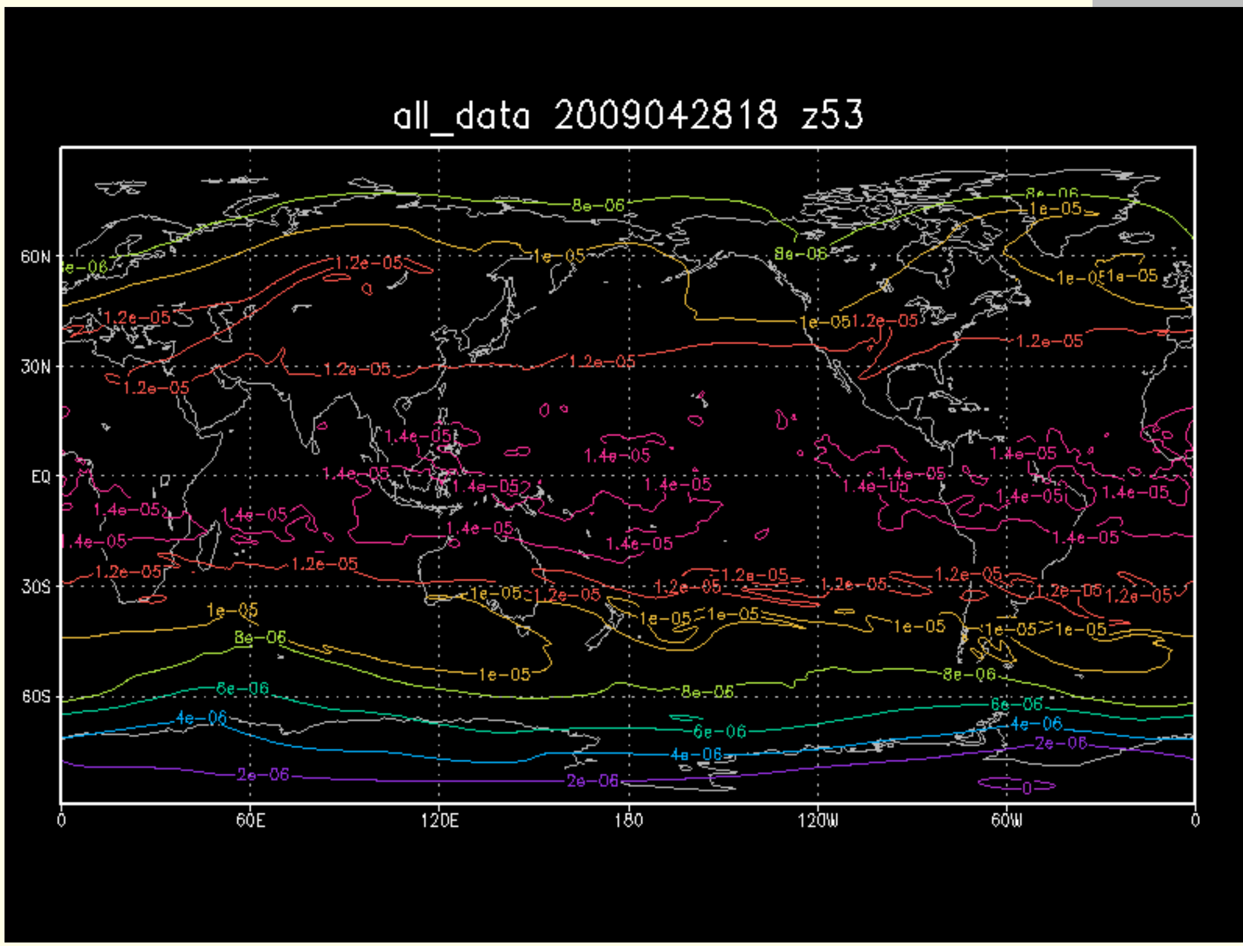
A: GSI code

(grep “as(4)” *90 to find in prewgt_reg.f90)

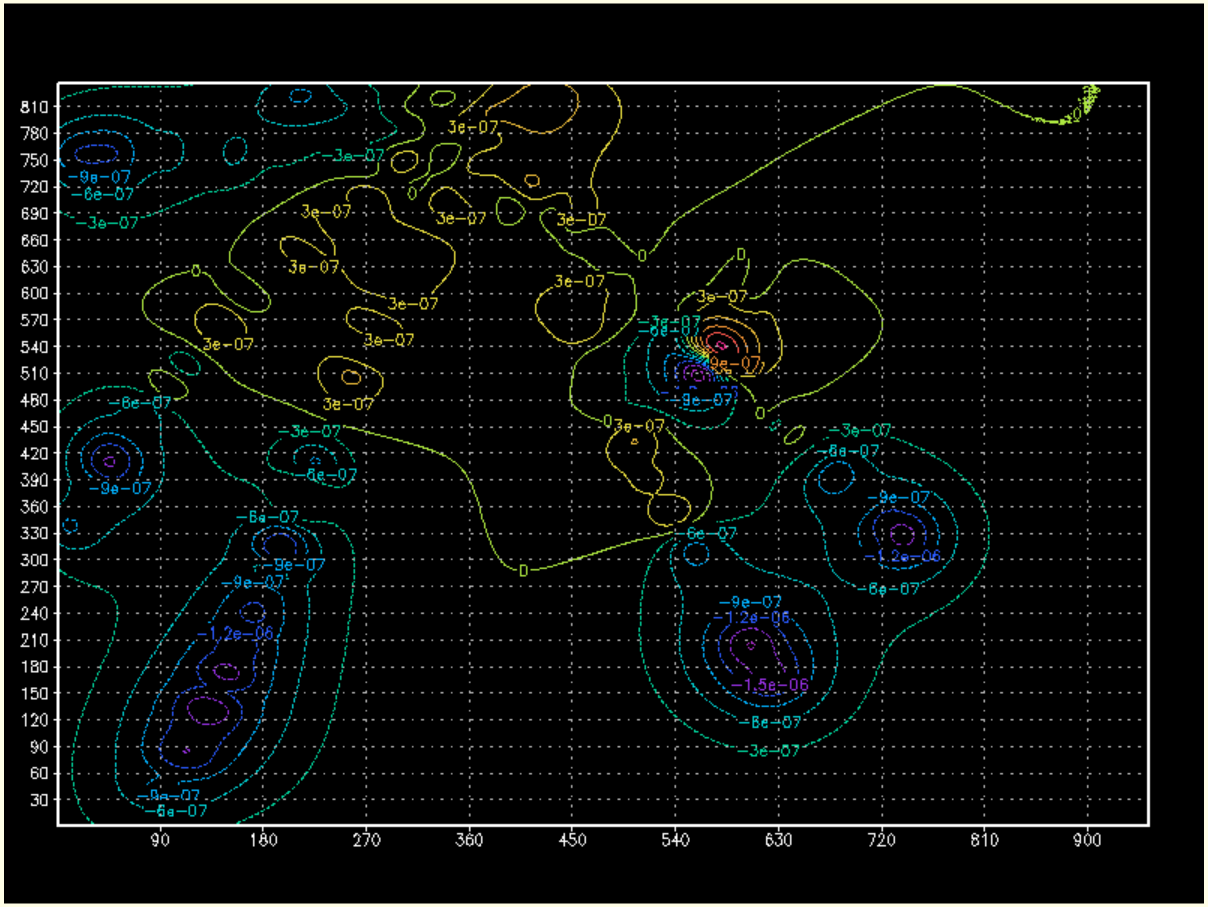
Impact of Background Error



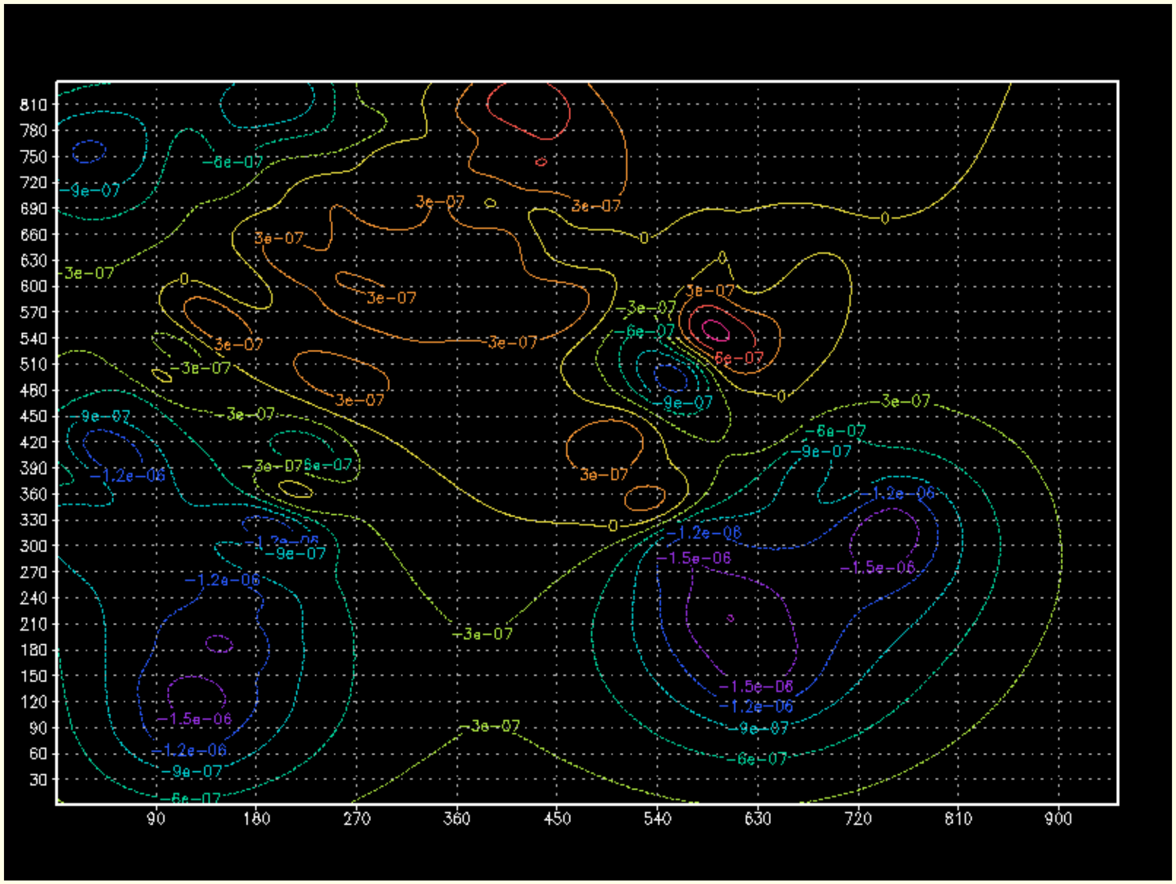
Impact of Background Error



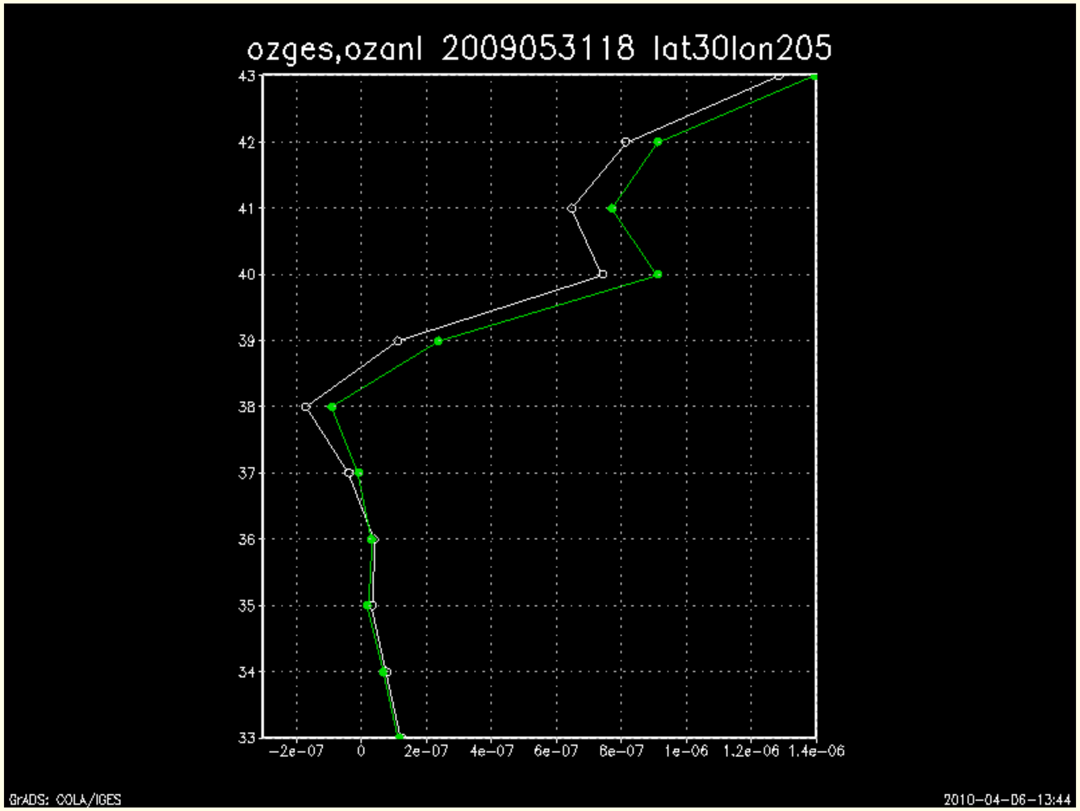
B adjustment ex2: Analysis increments of ozone



B adjustment ex1: Analysis increments of ozone

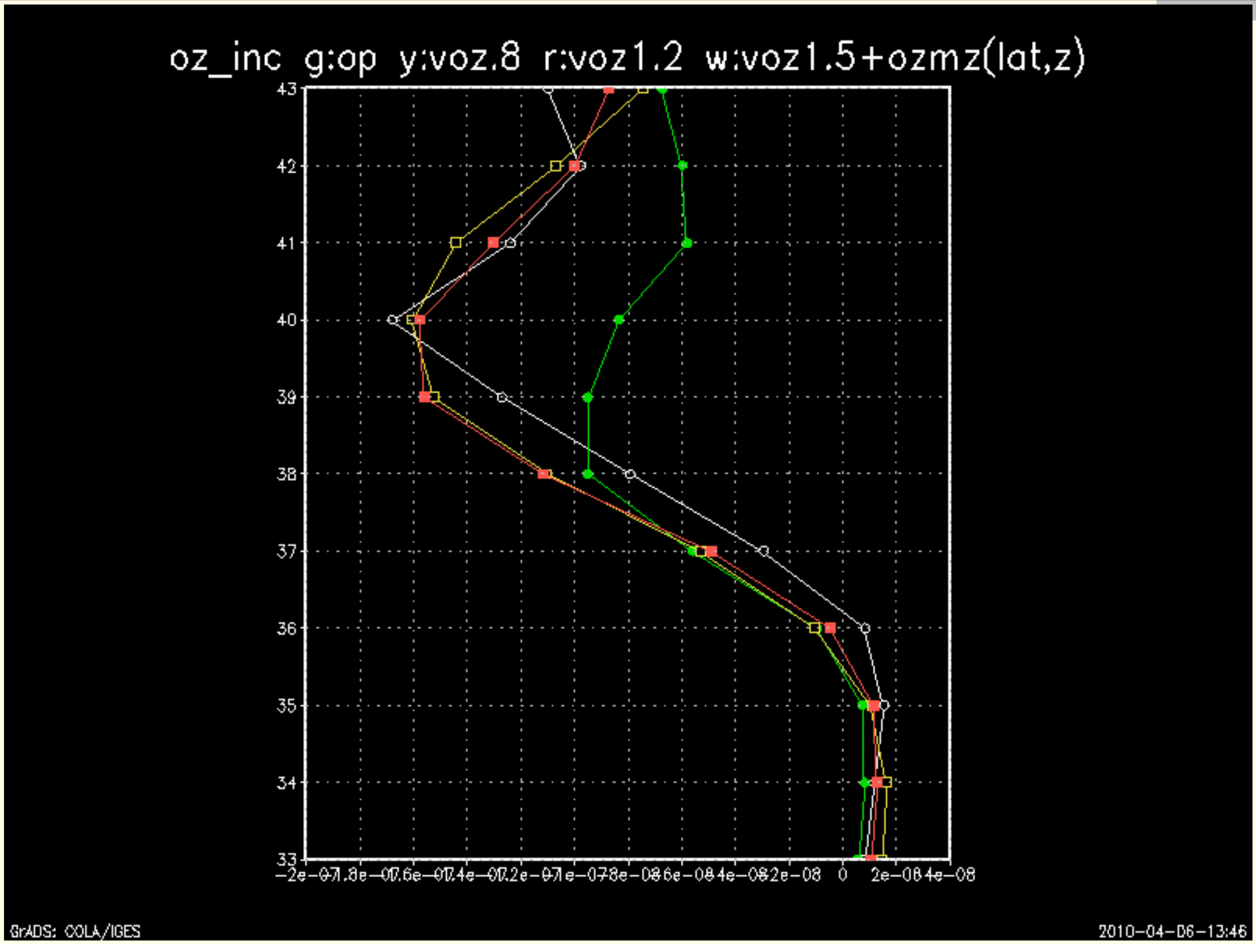


Impact of Vertical Scale



White: Analysis Green: First Guess

Impact of Vertical Scale



Setup B for a new control variable

Uni-variate

Sparse observations

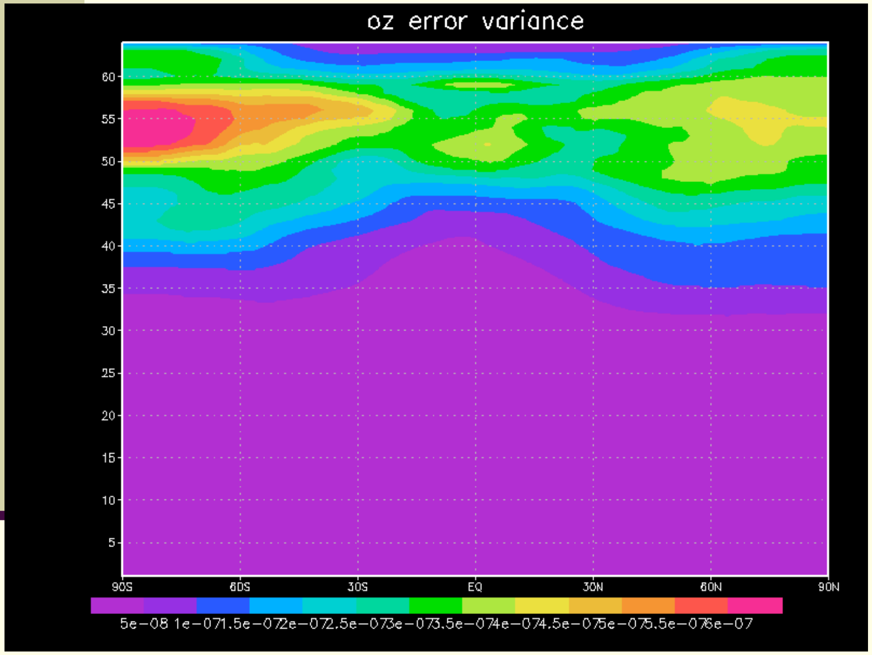
Poor first guess quality (large error variances)

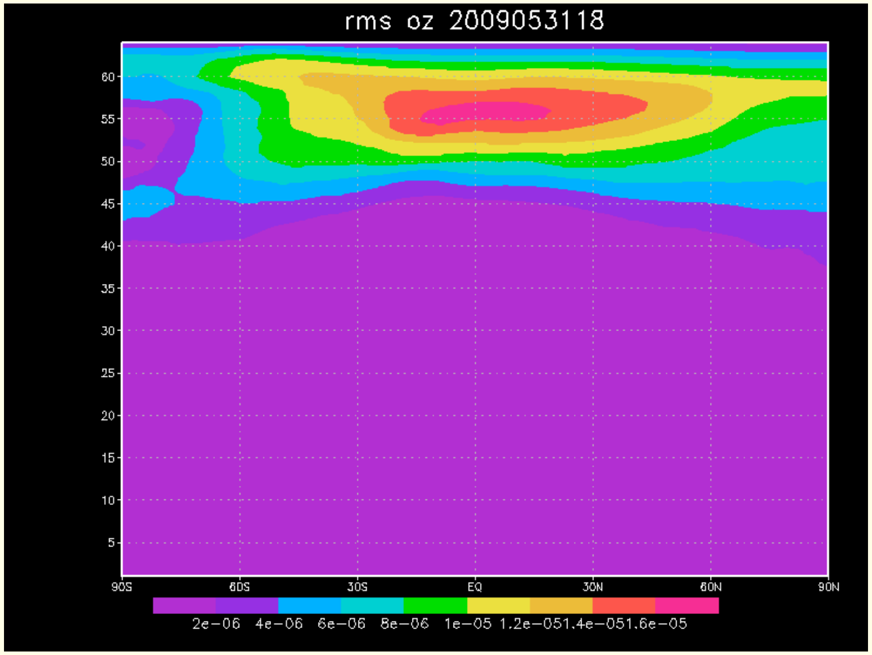
With physical limit of non-negative value

Passive scalars

Ex: chemicals, aerosols, co2, co,….

NMC method & Normalized Oz





Background error and their estimation

1. Multivariate relation
3. Background error covariance
4. Covariance with fat-tailed power spectrum
5. Estimate background error

Observational Error

Conventional adjustments
Adaptive Tuning

Analysis system produces an analysis through the minimization of an objective function given by

$$J = x^T B^{-1} x + (Hx - y)^T R^{-1} (Hx - y)$$

J^b J^o

Where

- x is a vector of analysis increments,
- B is the background error covariance matrix,
- y is a vector of the observational residuals, $y = y_{obs} - H x_{guess}$
- R is the observational and representativeness error covariance matrix
- H is the transformation operator from the analysis variable to the form of the observations.

Discussions

- No method is optimal; There'll be issues to solve and subjective tuning, smoothing, and averaging.

  Ex: 1) background error

  Ex: 2) ob error tune
- In a semi-operational system, tune B variances so that the analysis penalties are about half of original penalties; including the scale effects.
- Tune Oberror's so that they are about the same as guess fit to data

Adaptive Tuning of Oberror

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

  $E(J^o) = ½ Tr (I_p – HK)$

  $E(J^b) = ½ Tr (KH)$

  where I_p is identity matrix with order p

  K is Kalman gain matrix

  H is linearlized observation forward operator

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

Adaptive Tuning of Oberror

Tuning Procedure

$$J(\delta X) = 1/s_b^2 \, J^b(\delta X) + 1/s_o^2 \, J^o(\delta X)$$

Where s_b and s_o are the background and oberr weighting parameters

$$S_o = \mathrm{sqrt}(2J^o / \mathrm{Tr}(I_p - HK))$$

Analysis system produces an analysis through the minimization of an objective function given by

$$J = \underbrace{x^T B^{-1} x}_{J^b} + \underbrace{(H x - y)^T R^{-1} (H x - y)}_{J^o}$$

Where

- x is a vector of analysis increments,
- B is the background error covariance matrix,
- y is a vector of the observational residuals, $y = y_{obs} - H x_{guess}$
- R is the observational and representativeness error covariance matrix
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Randomized estimation of Tr (HK)

$$\mathrm{Tr}\,(I_p - HK) = N_{obs} - \left(\Sigma\, \xi\, R^{-1/2}\, H\, \delta X^a(y+R^{1/2}\xi) + \Sigma\, \xi\, R^{-1/2}\, H\, \delta X^a(y) \right)$$

where ξ is random number with standard Gaussian distribution (mean: 0;variance:1)

2 outer iterations each produces an analysis;

output new error table

Consecutive jobs show the method converged

$\mathrm{Sum} = \Sigma\, (1-s_o)^2$

S_o for each ob type

- S_o function of height (pressure)

  rawinsonde, aircft, aircar, profiler winds, dropsonde, satwind…
- S_o constant with height

  ship, synoptic, metar, bogus, ssm/I, ers speed, aircft wind, aircar wind…
- The setup can be changed in penal.f90

Turn on adaptive tuning of Oberr

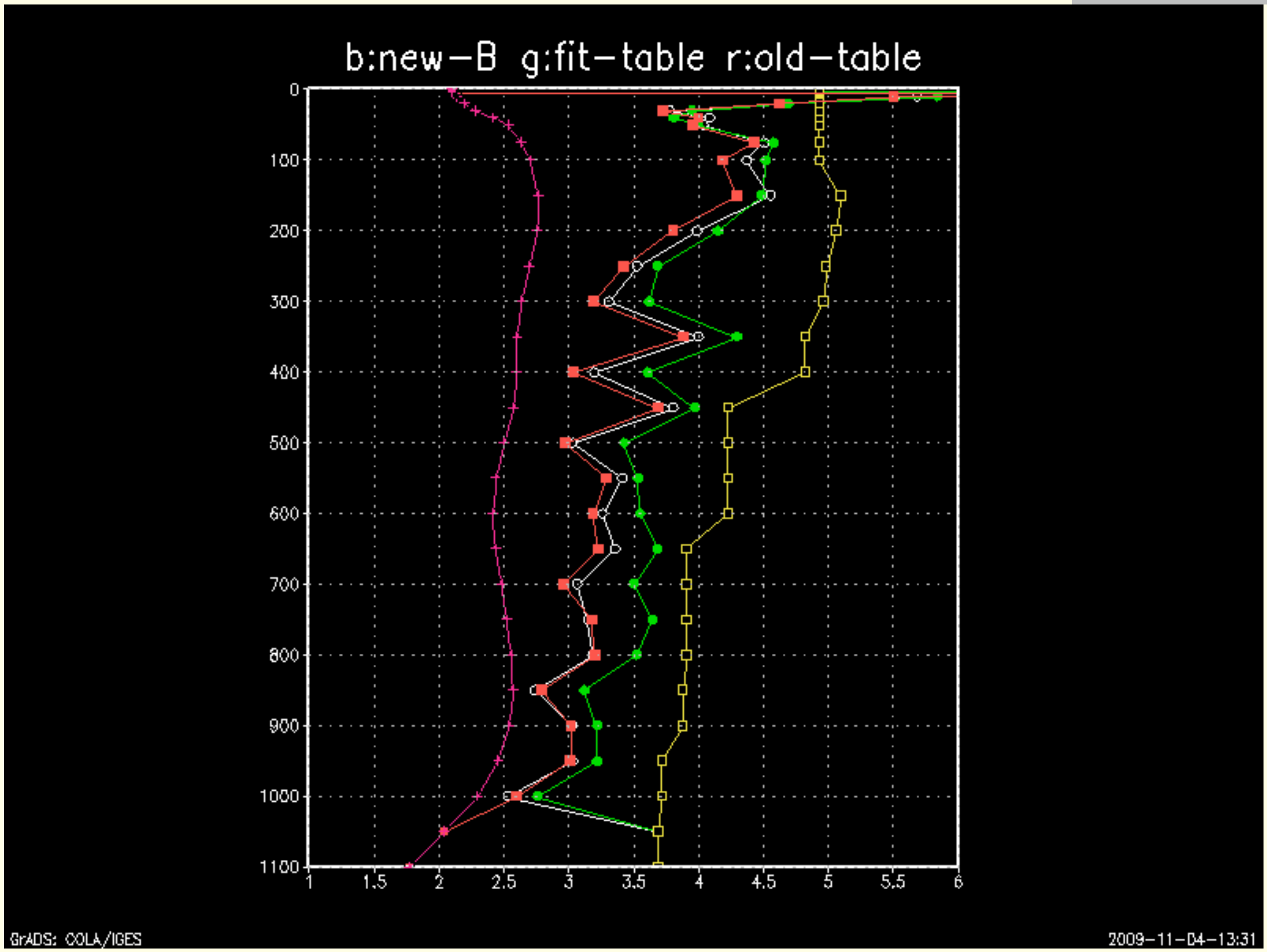
1) &SETUP
   oberror_tune=.true.
2) If Global mode:
   &OBSQC
   oberrflg=.true.

   (Regional mode: oberrflg=.true. is default)

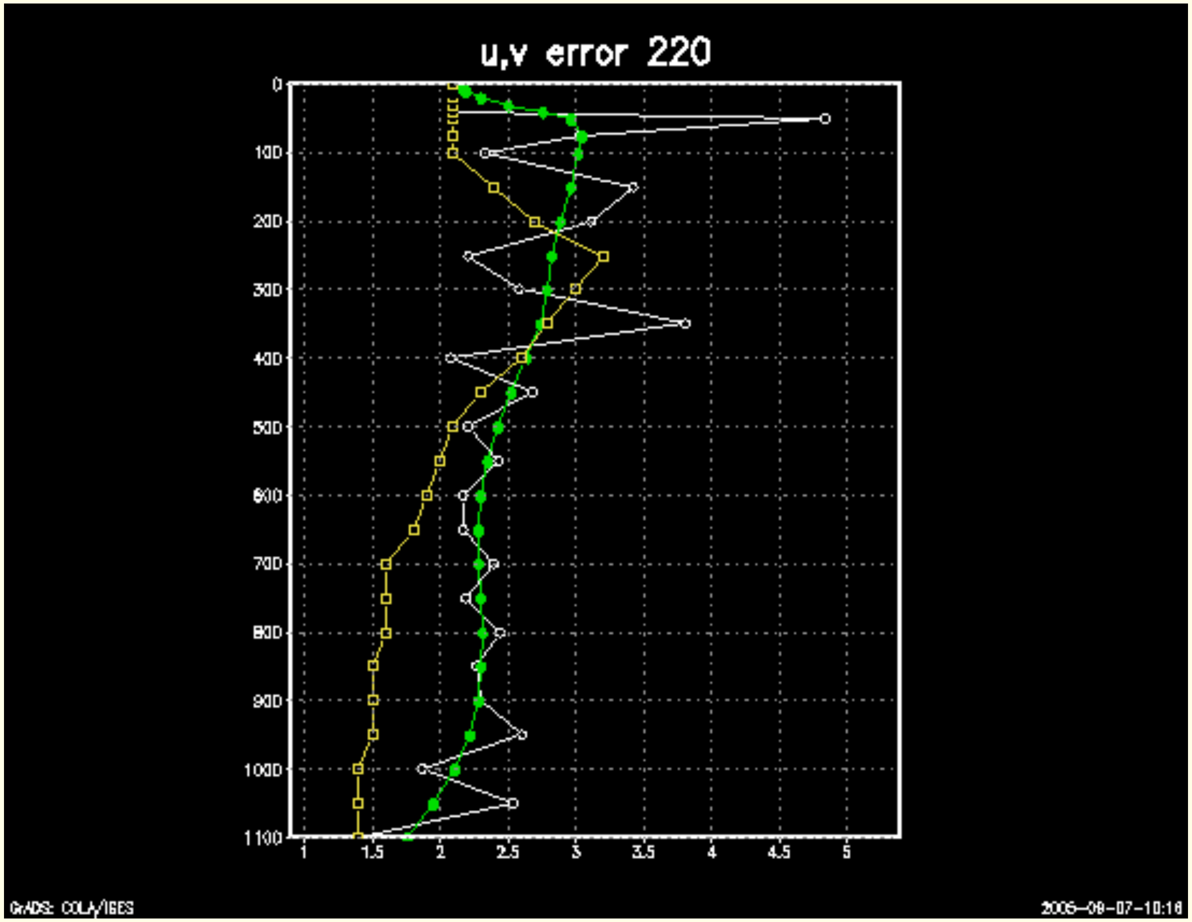
   (find in file stdout: GSIMOD: ***WARNING*** reset oberrflg= T)

Note: GSI does not produce a valid analysis under the setup

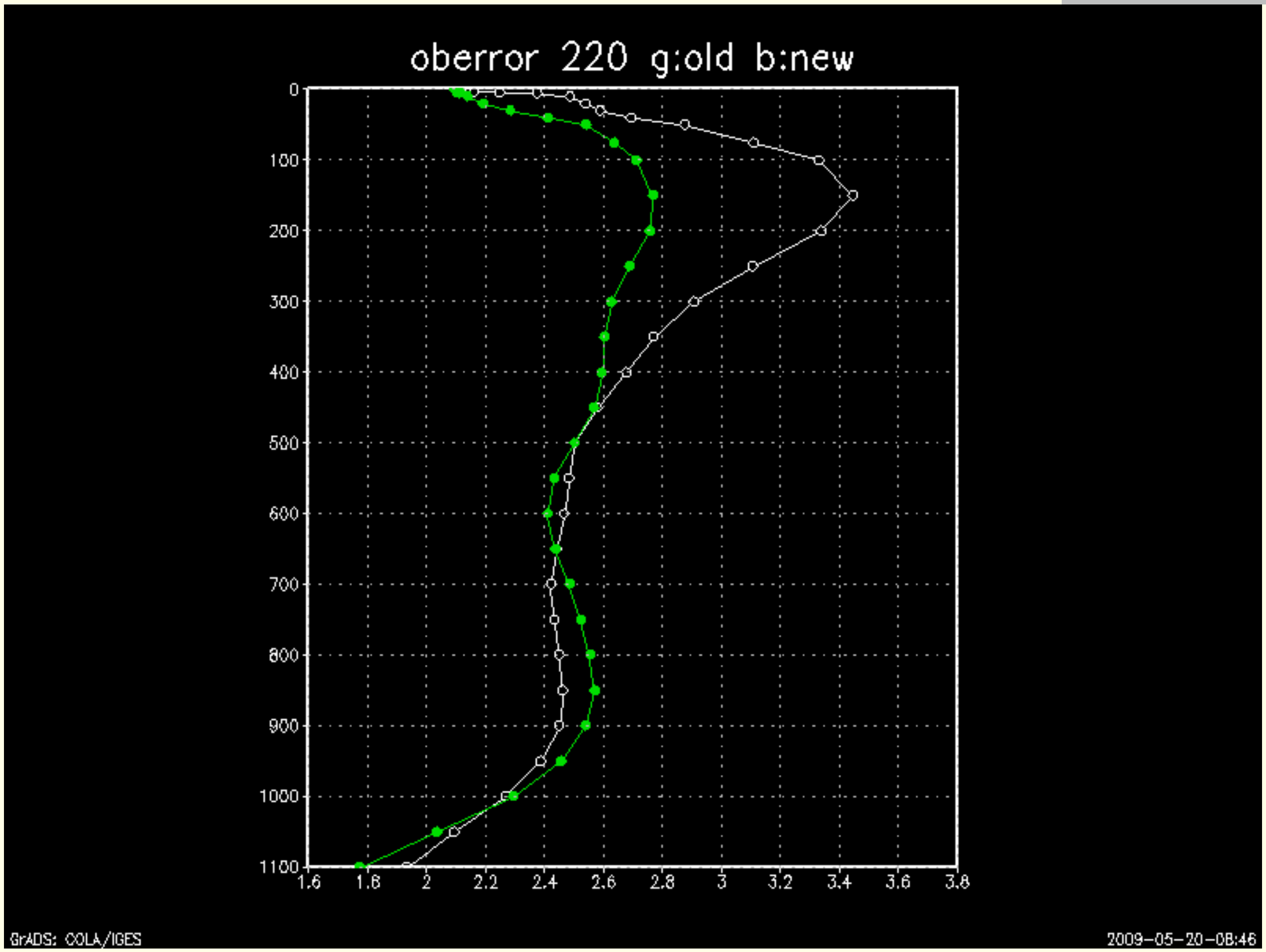
Sensitivity of adaptive tuning



Adjustment of tuned error table



Adaptive tuning of oberror of rawinsonde wind



Questions on B and outer loop

1) Can the tuning parameters of background error be changed with different outer loop?

A: No, they should not be changed. (solving for the same original problem)

2) Why more than one outer loop?

A: To account for the nonlinear effect of the observational forward operator.

Suggestions

- Working code = answers to most questions
  with print and plot
- Plot to check changes

Good Luck on Using GSI!