Enhancements of Radiance Bias Correction in NCEP's Data Assimilation Systems

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- **Part I**: The enhanced radiance bias correction scheme
    - ➢ Methodology for enhanced scheme
    - ➢ New emissivity sensitivity predictor to handle large land-sea differences with CRTM 2.1.3
- **Part II**: all-sky microwave radiance assimilation : radiance bias correction

Part I: Enhanced radiance bias correction scheme

- The original radiance bias correction scheme
- The enhancements to the original scheme
- Methodology for the enhanced scheme
- Performance of the enhanced scheme with CRTM v2.0.6
- Bias correction with CRTM v2.1.3 – the new emissivity sensitivity predictor, and its performance

Why radiance bias correction –
to generate unbiased analysis

- the error associated with the calibration of the instrument
- the error of the radiative transfer model
- Inconsistencies between the data usage and the model or algorithms

Derber et al. (1991), Harris and Kelly (2001), Dee (2004), etc

Original radiance bias correction scheme

A two-step procedure $\begin{cases} \textbf{Air-mass dependent in GSI} \\ \textbf{Separate scan-angle dependent} \end{cases}$

$$\boxed{\tilde{h} = h(x) + b^{air}(x, \beta) + b^{angle},}$$

x

where

$$b^{air}(x, \beta) = \sum_{i=1}^{N} \beta_i \left[\alpha_i p_i(x) \right]$$

$h(x)$ is radiative transfer model

p_i is predictor term with predictor coeff. β_i

α_i is pre-specified parameter

Predictors used in the original scheme

- **P0**: global offset
- **P1**: zenith angle predictor
- **P3**: cloud liquid water predictor, only applied to microwave radiances over ocean, and only when clear microwave radiances are assimilated
- **P4**: temperature lapse rate predictor
- **P5**: square of temperature lapse rate predictor

The control variables x and β are estimated by minimizing (Derber et al., 1991, Derber and Wu, 1998)

$$J(x,\beta) = \frac{1}{2}(x - x_b)^T B_x^{-1}(x - x_b) + \frac{1}{2}(\beta - \beta_b)^T B_\beta^{-1}(\beta - \beta_b) + \frac{1}{2}\left[y - \widetilde{h}(x,\beta)\right]^T R^{-1}\left[y - \widetilde{h}(x,\beta)\right]$$

Enhancements to the radiance bias correction scheme

- **Combine the scan angle and air-mass bias components inside the GSI variational framework.**
  - Eliminate the duplications and potential risk of opposite drifting between the two components
- **Remove the pre-specified parameter for each predictor**, so avoid the trial-and-error procedure for any new bias predictors
- Apply a new pre-conditioning to the predictor coefficients taking into account of observation contribution, **speeding up the convergence**

Enhancements to the radiance bias correction scheme (cont.)

Radiance bias correction is based on the data passing the quality control

Quality control is performed on the bias corrected data

Reasonable radiance bias correction estimate need to be manually derived prior to the use of any new radiance data or during the re-analysis process with the original scheme

Enhancements to the radiance bias correction scheme (cont.)

- **Automatically detect any new/missing/recovery of radiance data and initialize new radiance data;**

Any new radiance data can be used now with initial radiance bias correction set to be zero

- **Quickly capture any changes in the data and the system.**
- **Capability to perform bias correction for passive channels**
- **New option variables: newpc4prd, adp_anglebc, passive_bc, use_edges**

Methodology for the enhancements

- A modified pre-conditioning is applied to the bias correction coefficients and the analysis variables. A new procedure to applying the modified pre-conditioning in the GSI is utilized.
- A new scheme is proposed and employed to automatically adjust the background error variances for the bias coefficients.
- An new initialization procedure for any new radiance data is implemented.
- A new method of bias correction for passive channels in the GSI is developed.
- The one-step radiance bias correction in the GSI, incorporating the scan angle bias correction component into the GSI.

Zhu et al., 2013: Enhanced radiance bias correction in the National Centers for Environmental Prediction's Gridpoint Statistical Interpolation Data Assimilation System . Accepted by QJRMS

Performance of the enhanced scheme with CRTM v2.0.6

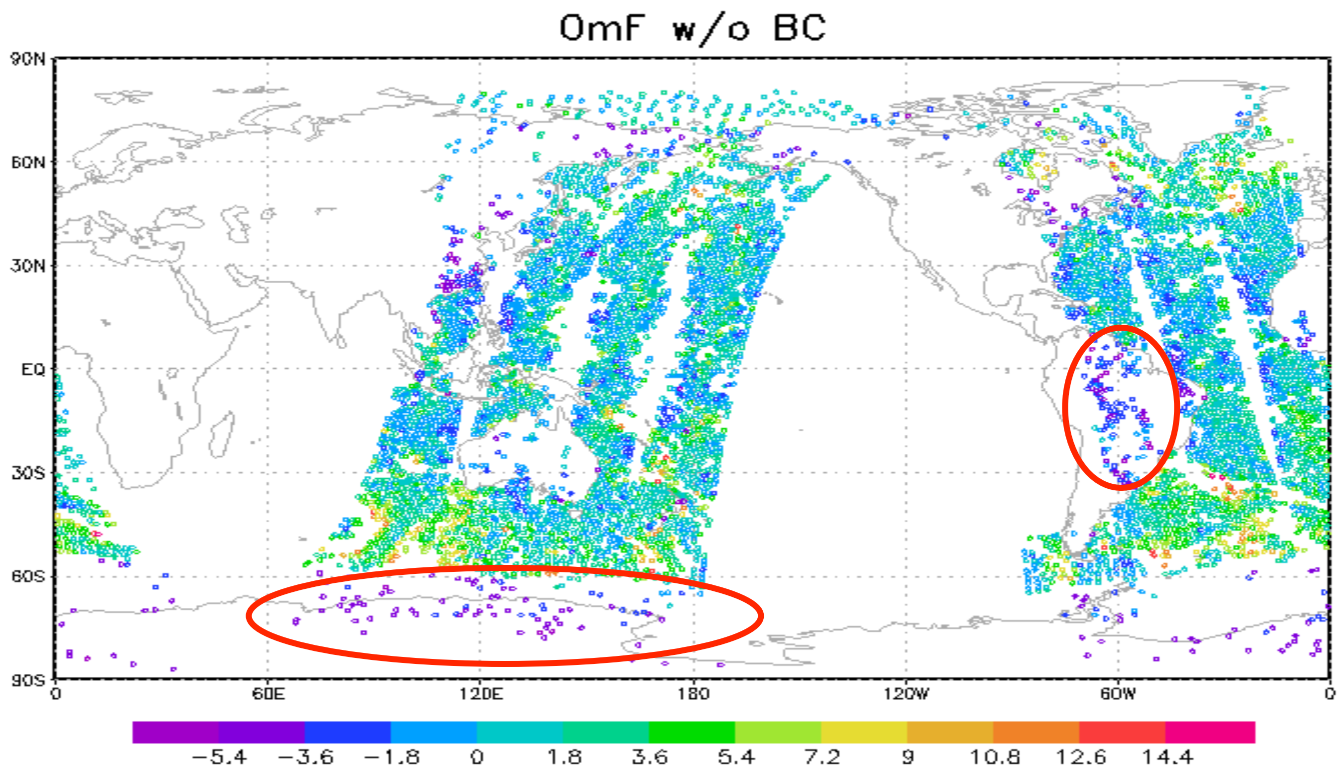
- GFS experiments with T574L64 3D Hybrid and T254L64 EnKF with 80 ensemble members
    - Improved convergence rate
    - Neutral forecast skills in NH and Tropics
    - Better forecast skills in SH

- The scheme was also tested on NDAS/NAM
- Currently is used in the wind energy project (Jacob's talk at 6th WMO Symposium on Data Assimilation)

Bias correction with the use of CRTM v2.1.3

Improved microwave sea surface emmisivity

→ OmF with larger land-sea differences



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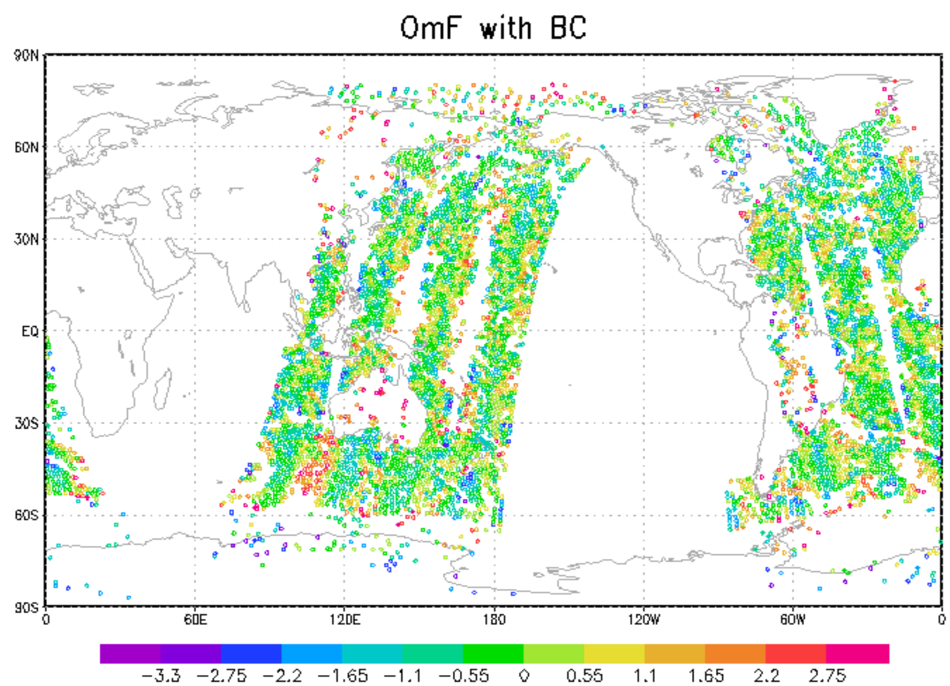
New emissivity sensitivity predictor

$$P6 = \begin{cases} 0 & \text{(over open water)} \\ \partial T_b / \partial \varepsilon & \text{(elsewhere)} \end{cases}$$

Option emiss_bc:

- **Handles large land-sea differences**
- **Non-zero for surface sensitive channels over non-open water areas**



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Performance of the enhanced scheme with CRTM v2.1.3

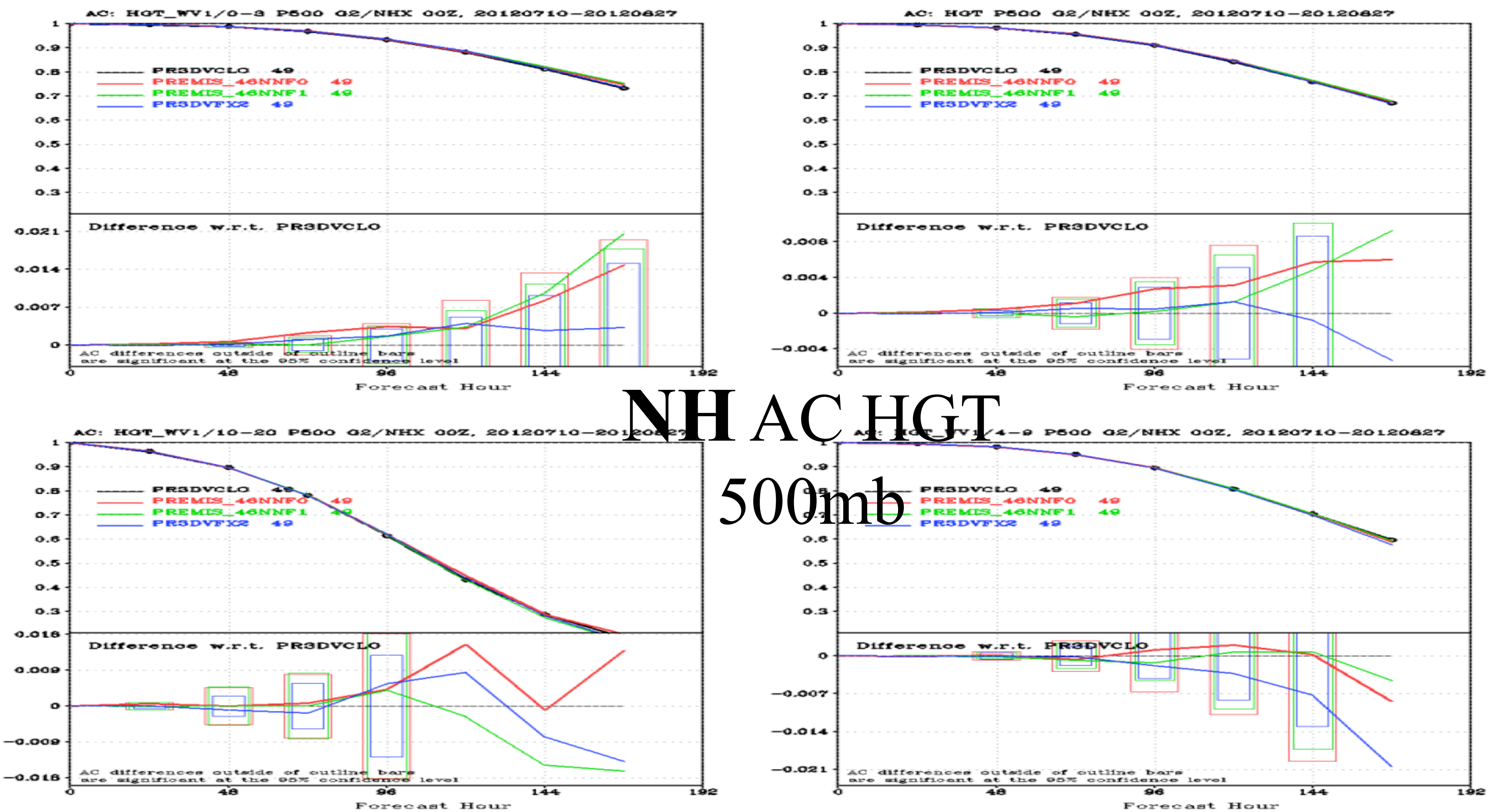
Experiment	CRTM	BC	Use_edge
pr3dvclo	v2.06	original	Yes
pr3dvfx2	v2.1.3	original	Yes
premis_46nnf0	v2.1.3	enhanced	No
premis_46nnf1	v2.1.3	enhanced	Yes

Performance of the enhanced scheme with CRTM v2.1.3 (cont.)

Experiment	Radiance Nobs	Jo	Jo/Nobs
pr3dvclo	2621805	8.69E+05	0.332
pr3dvfx2	2593584	8.69E+05	0.335
premis_46nnf0	2110564	6.66E+05	0.316
premis_46nnf1	2642664	8.87E+05	0.336

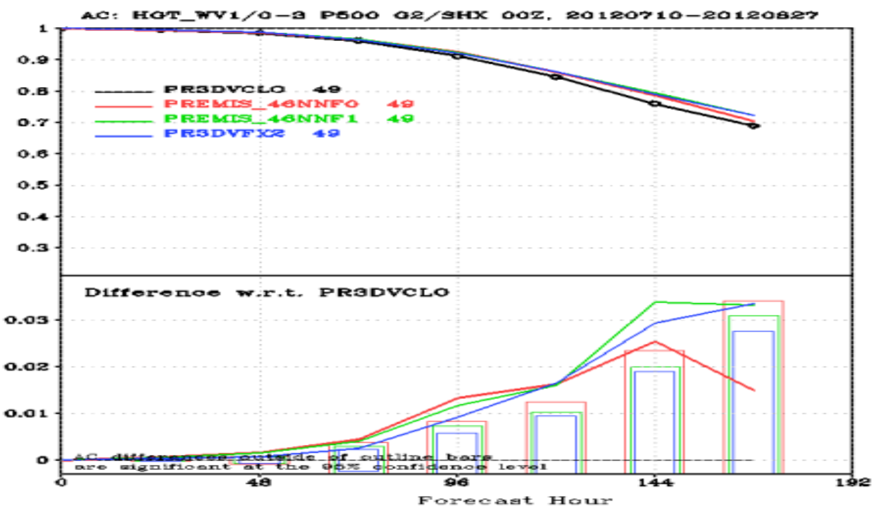
Radiance data usage at one analysis cycle

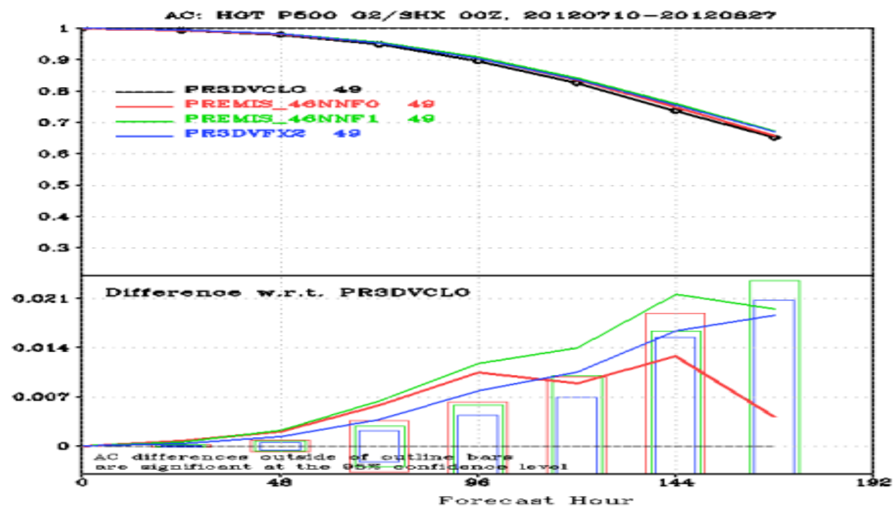
Performance of the enhanced scheme with CRTM v2.1.3 (cont.)



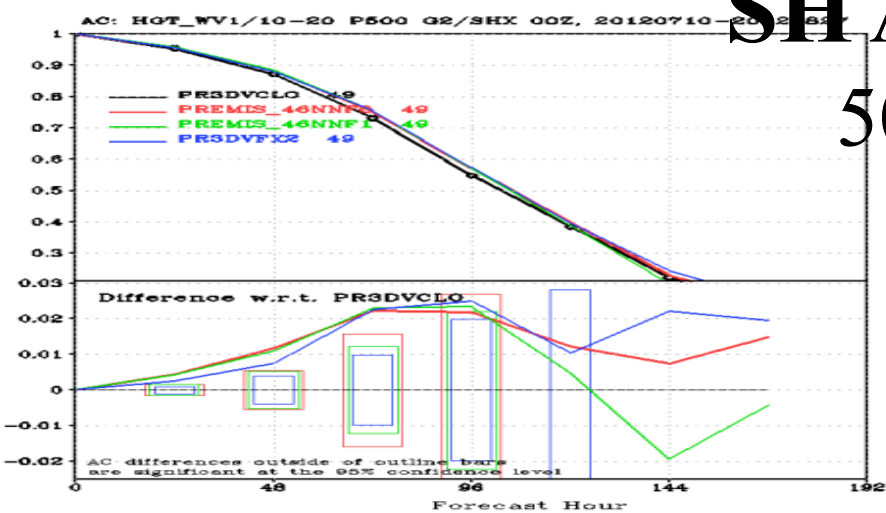
NH AC HGT
500mb

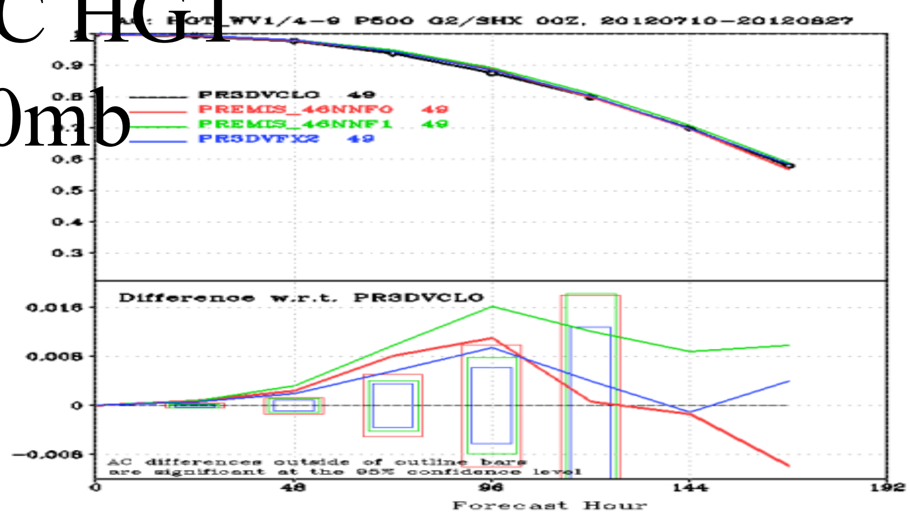
Performance of the enhanced scheme with CRTM v2.1.3 (cont.)



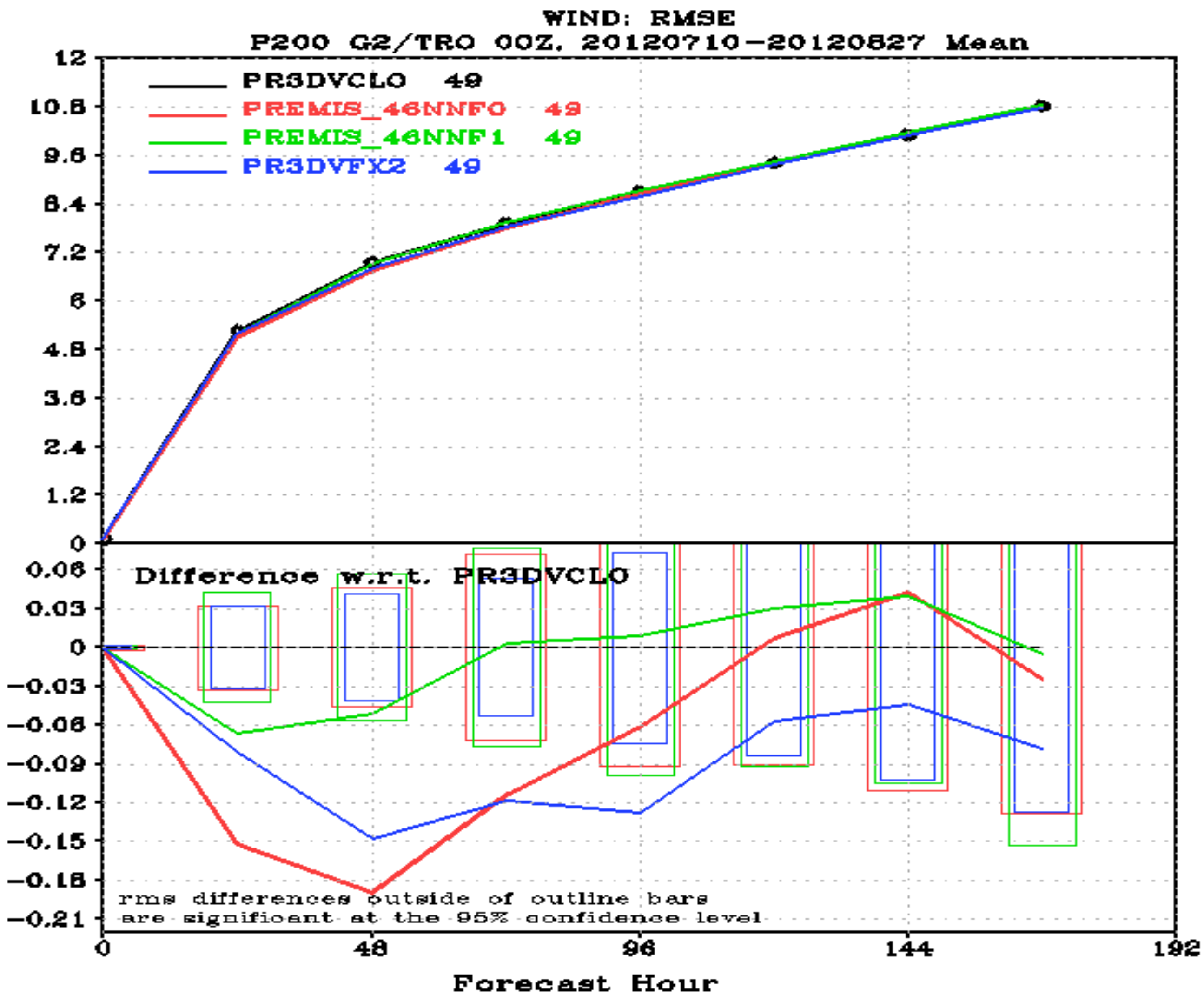


SH AC HGT 500mb





Performance of the enhanced scheme with CRTM v2.1.3 (cont.)



TROPICS

RMSE
200mb

Part II: all-sky microwave radiance assimilation issue – bias correction

All-sky microwave radiance assimilation

- *Control variable: total cw/normalized cw/normalized RH*
- *State variables: Hydrometeors ql, qi, (qr, qs, qg, qh)*
- *The cloud liquid water predictor is removed*
- Background error covariance from static and ensemble
- Observation error based on averaged CLW
- Quality control: cloud filtering is removed
- Linearized moist physics
- Bias correction strategy

Bias correction for Operational clear radiance

- Angle bias correction
- Air-mass bias correction with five predictor terms: global offset, a zenith angle term, cloud liquid water, lapse rate, and the square of the lapse rate.

Cloud liquid water

Clear radiance assimilation	All-sky radiance assimilation
▪ CLW predictor ▪ Cloud filtering in quality control	▪ No CLW predictor ▪ No cloud filtering in QC ▪ Observation error assignment based on average CLW ▪ Radiance bias correction strategy

CLW over ocean (Grody et al. 2001; Weng et al. 2003):

$$CLW = \cos\theta * \{c_0 + c_1 \ln[285 - T_B(23.8)] + c_2 \ln[285 - T_B(31.4)]\}$$

Issues of radiance bias correction with all-sky microwave radiance assimilation

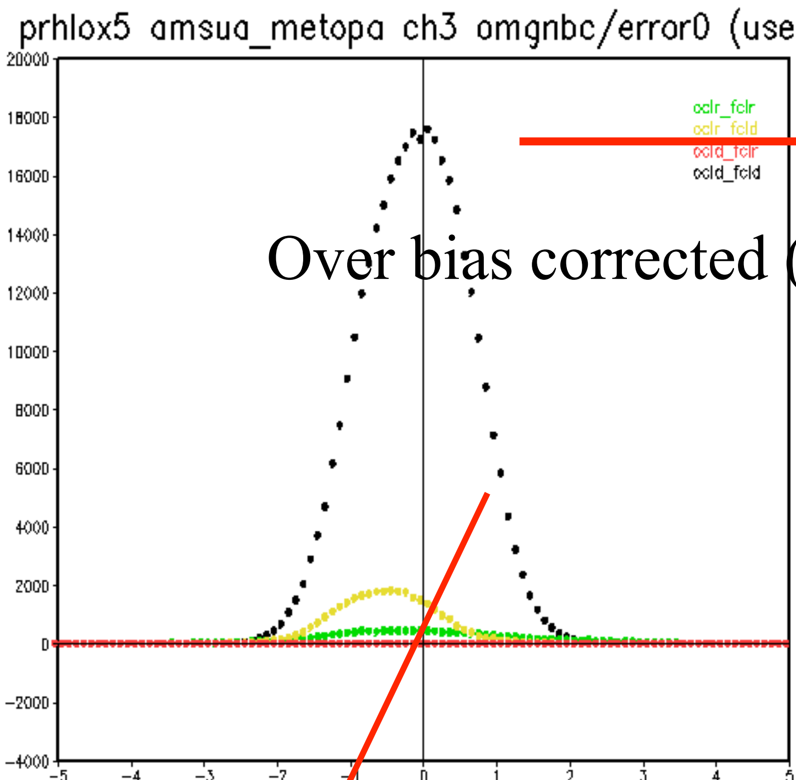
- Different error characteristics between clear-sky and cloudy radiances
- Different cloud information between radiance observation and first guess

1. O:clear vs. F:clear
2. O:clear vs. F:cloudy → eliminate cloud
3. O:cloudy vs. F:clear → add cloud
4. O:cloudy vs. F:cloudy

Ideally, Gaussian distributed (O:clr,F:clr) & (O:cld,F:cld), with one hump ((O:clr,F:cld), (O:cld,F:clr)) on each side

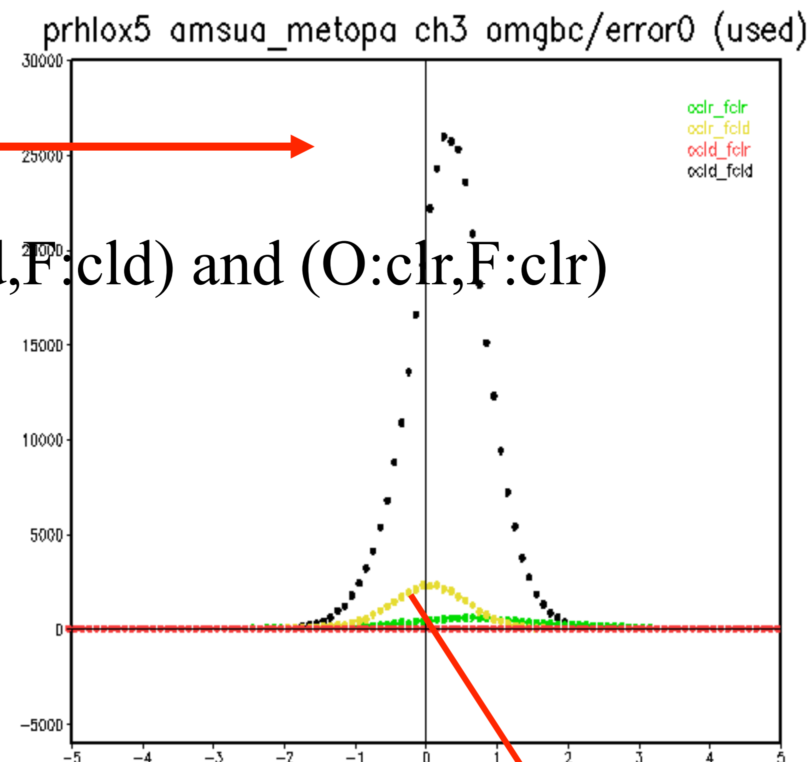
Issues of radiance bias correction with all-sky radiance assimilation (cont.)

OmF before BC



Normalized OmF

OmF after BC



Normalized OmF

Over bias corrected (O:cld,F:cld) and (O:clr,F:clr)

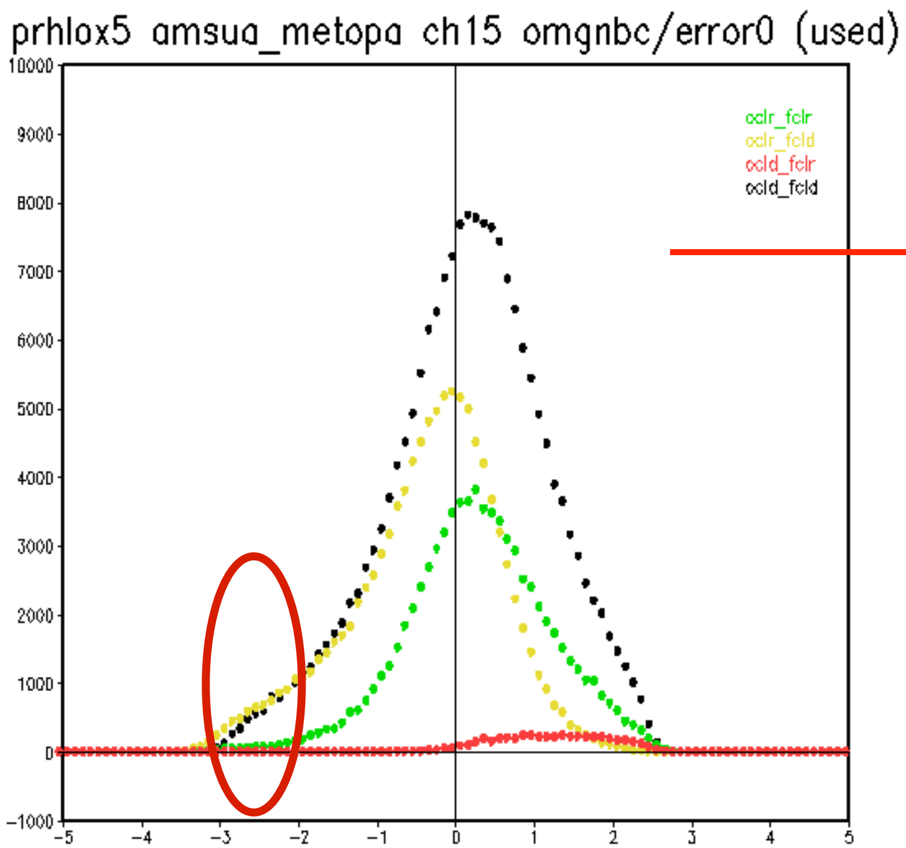
Lots of (O:cld, F:cld)

too fewer other categories

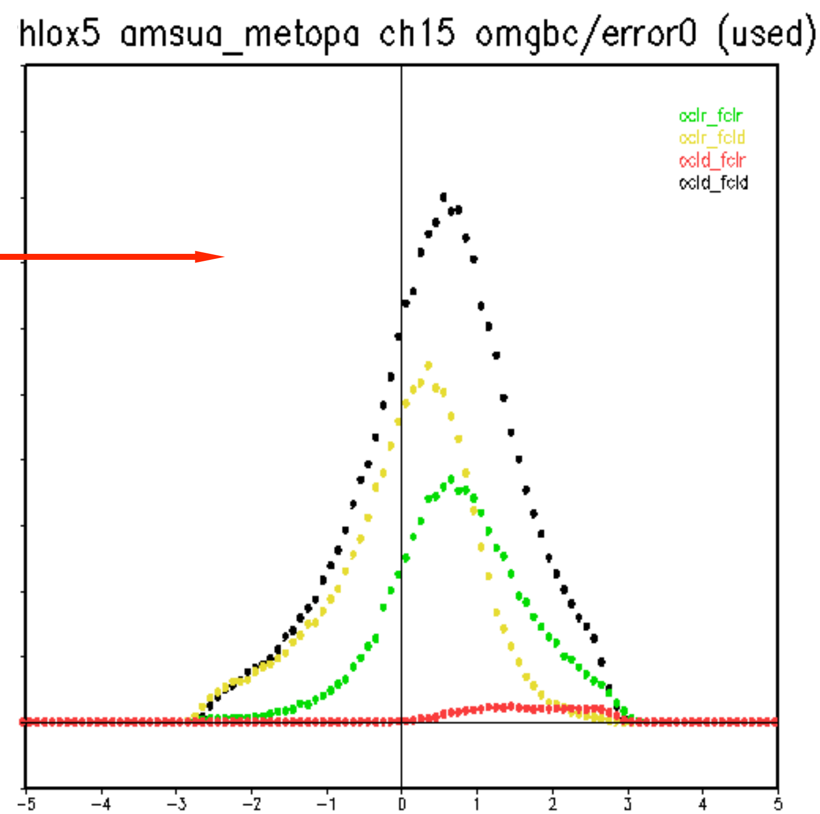
Will increase clear criteria slightly

Issues of radiance bias correction with all-sky radiance assimilation (cont.)

OmF before BC



OmF after BC



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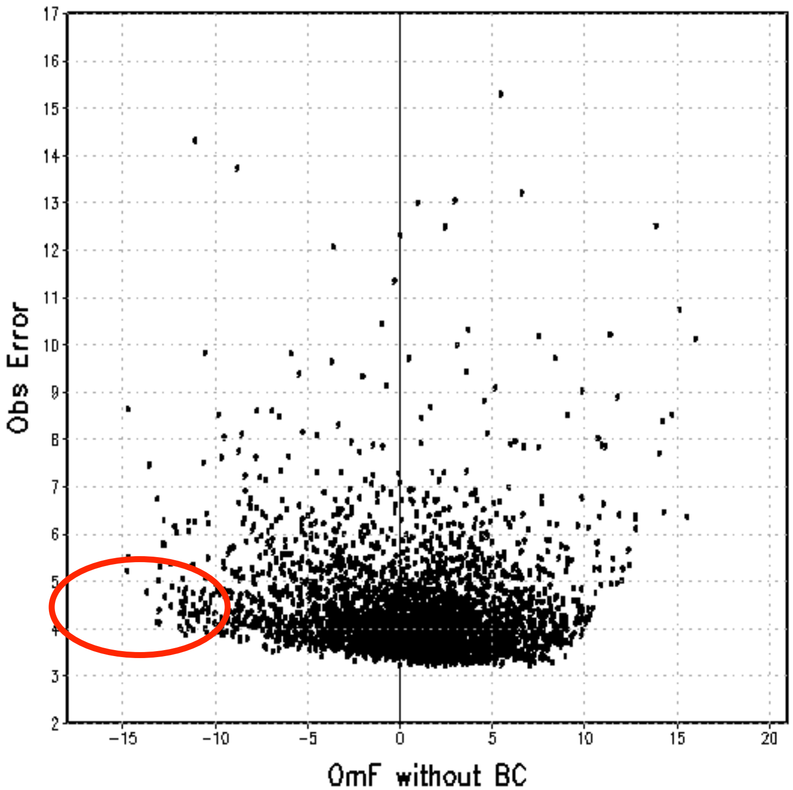
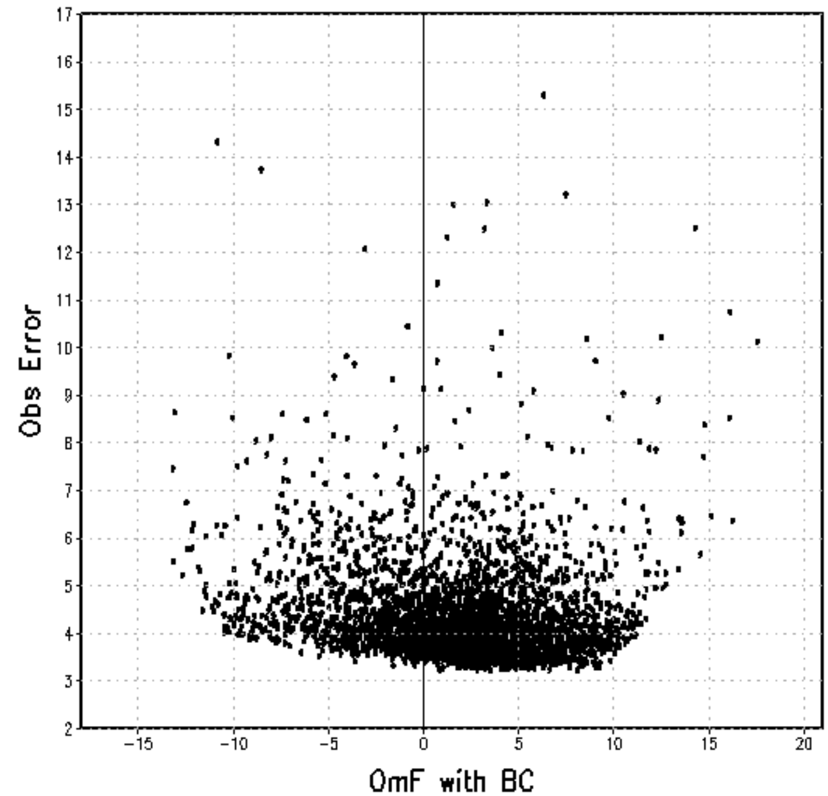
Issues of radiance bias correction with all-sky radiance assimilation (cont.)

(O:cld, F:cld)



OmF before BC



OmF after BC

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What may have hurt the radiance bias correction

1. Inclusion of the (O:clr,F:cld) and (O:cld,F:clr) in bias correction
2. Radiance data with large OmF but small obs error

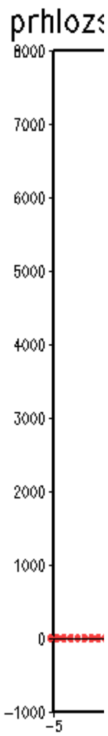
Radiance bias correction strategies:

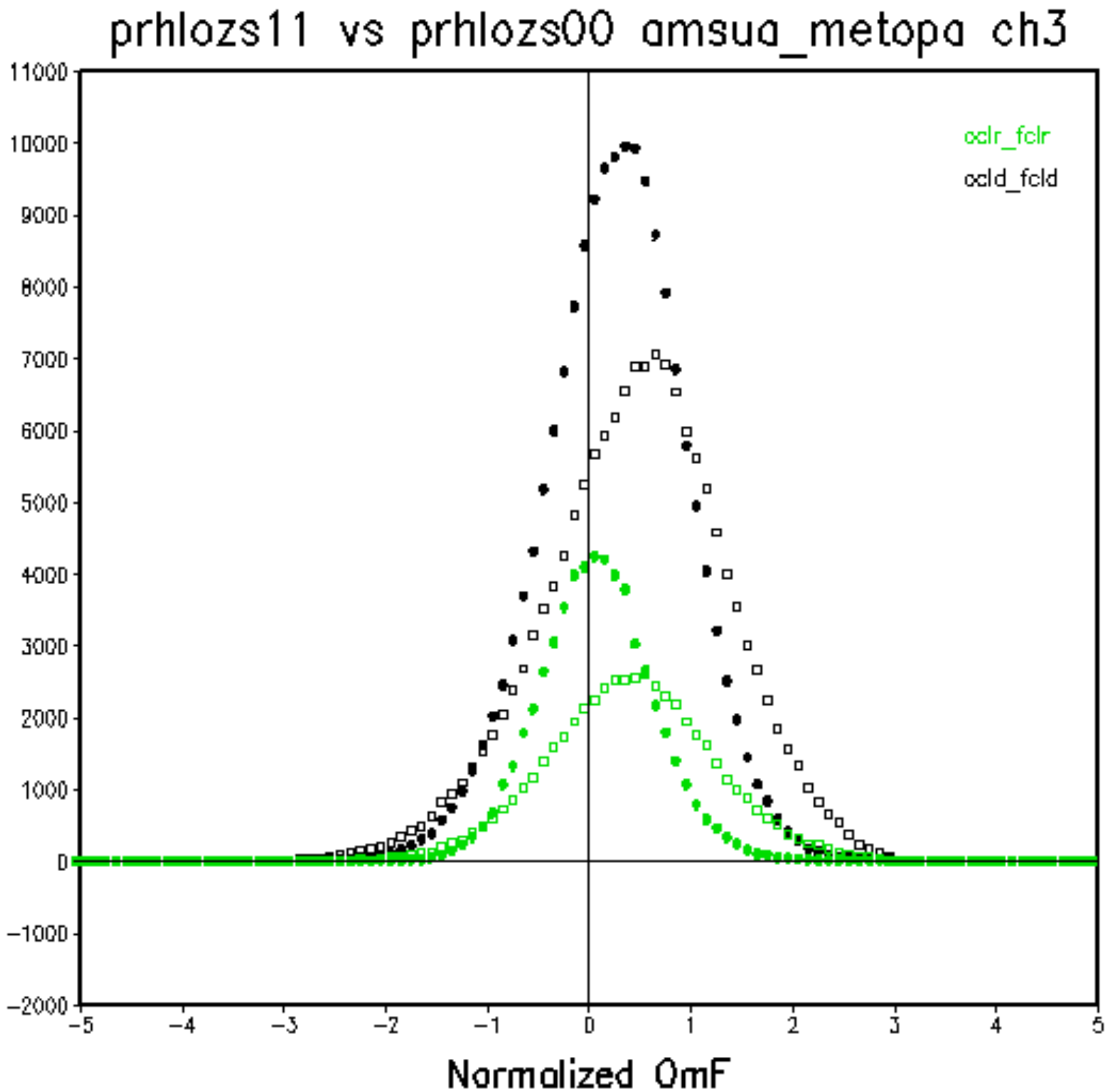
1. Diff. treatment of radiance data for bias correction

- ✓ Bias correction coef. are retrieved using only (O:clr,F:clr) and (O:cld,F:cld);
- ✓ Bias correction for (O:clr,F:cld) & (O:cld,F:clr) uses latest bias coef. available;

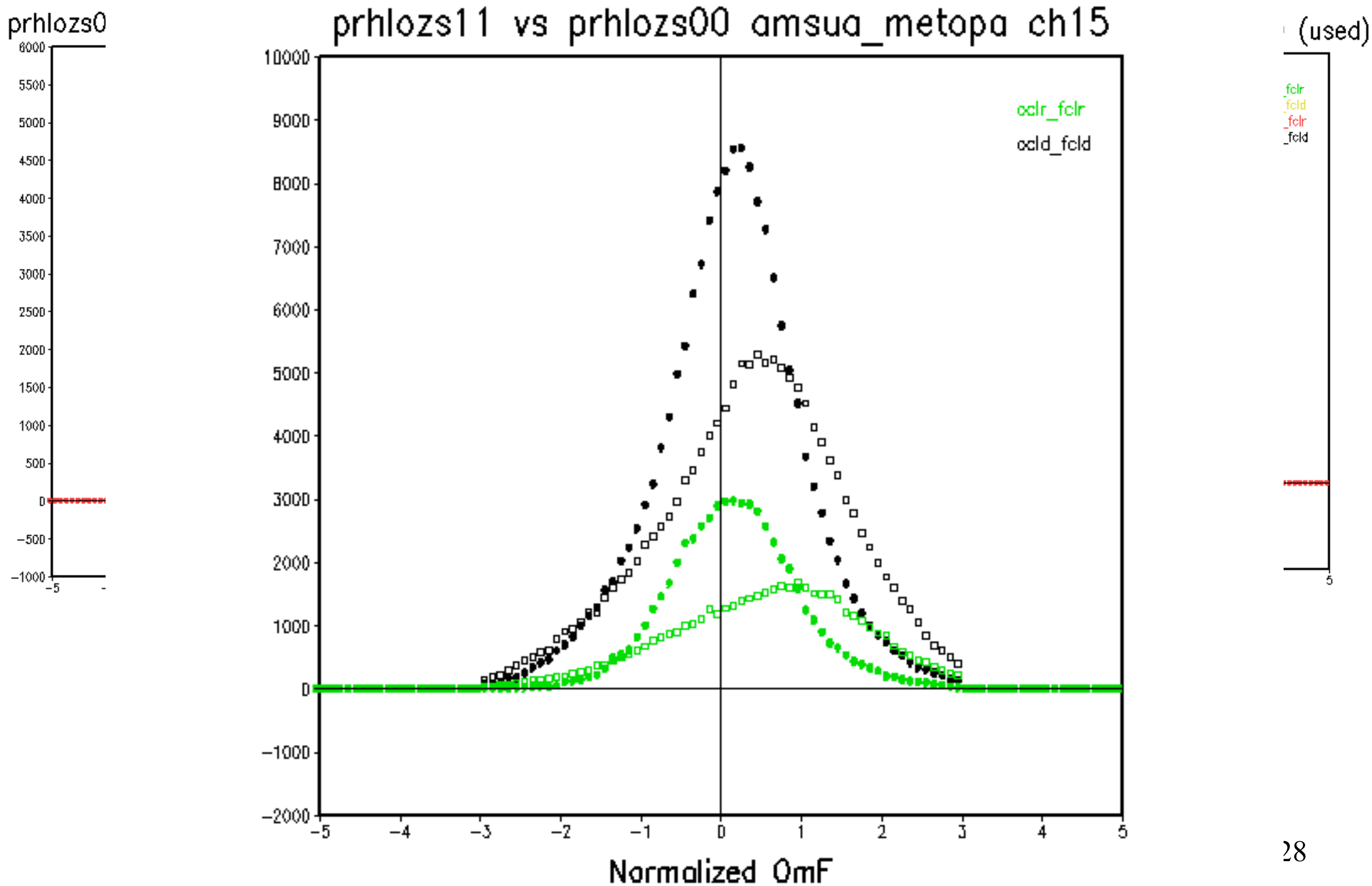
2. Variational quality control (Ingleby and Lorenc, 1993; Andersson and Jarvinen, 1999; Su coded in GSI and tested for conventional data)

OmF with bias correction

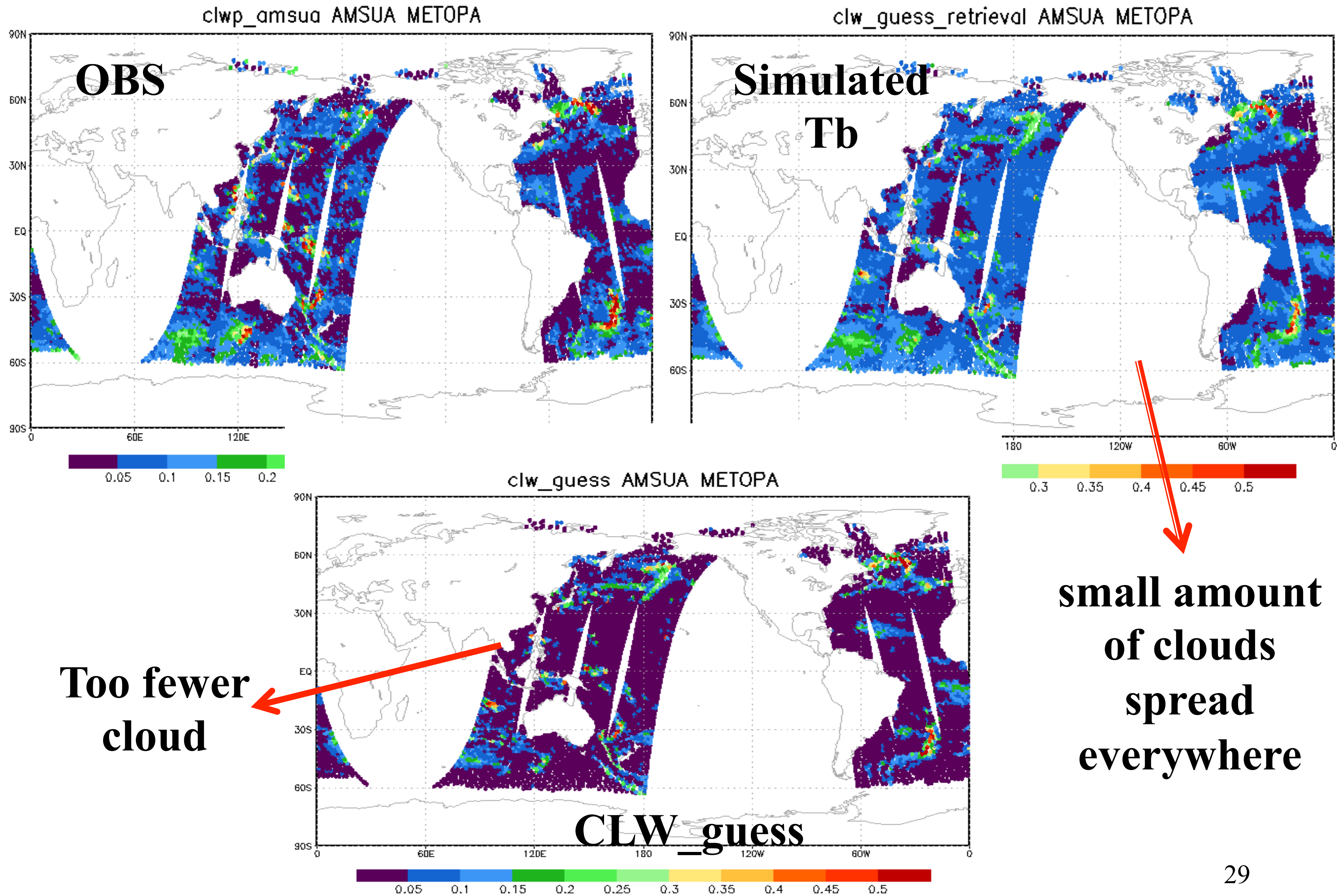




OmF with bias correction



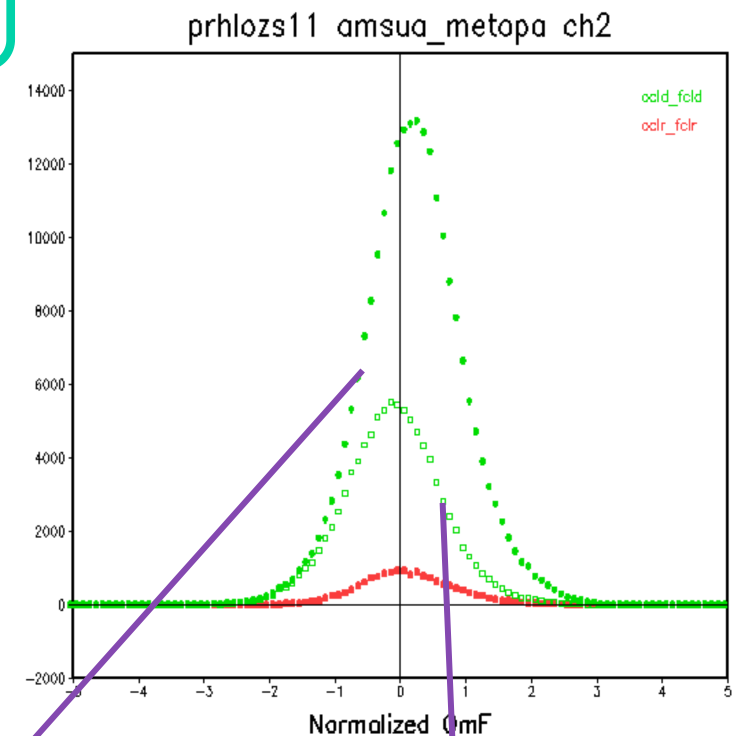
CLW (Grody et al 2001, Weng et al 2003) vs CLW_guess



CLW using simulated Tb

small amount of clouds spread everywhere

Larger obs error



CLW using simulated Tb

CLW_guess

Future work

- Further examine CLW and CLW from first guess, and refine bias correction
- Continue to evaluate the performance using normalized cw as the control variable
- Examine the background error covariance
- Incorporate moist physics

EXTRA SLIDES for enhanced scheme

Original scheme: a two-step procedure

- b^{angle} is computed outside GSI, a running average of OMF
- The predictors of air-mass are computed inside the GSI

Enhanced scheme: a one-step procedure

$$b^{angle} = \sum_{k=1}^{K} \beta_{N+k} \phi^{k}$$

- Variational angle bias correction, b^{angle} is computed inside the GSI along with other predictor terms
- satang file no longer needed
- Special attention to the initialization of bias coefficients: using quality-controlled data from previous run; or mode of all data

Change of the Preconditioning

Current preconditioner **Modified preconditioner**

$$\mathbf{B} = \begin{bmatrix} \mathbf{B}_\mathbf{x} & 0 \\ 0 & \mathbf{B}_\boldsymbol{\beta} \end{bmatrix} \longrightarrow \mathbf{B} = \begin{bmatrix} \gamma\mathbf{B}_\mathbf{x} & 0 \\ 0 & \mathbf{M}_\boldsymbol{\beta} \end{bmatrix}$$

- Hessian w.r.t. predictor coeff. of the cost function

$$\left.\frac{\partial^2 J}{\partial \boldsymbol{\beta}^2}\right|_{\boldsymbol{\beta}=\boldsymbol{\beta}_\mathbf{a}} = \mathbf{B}_\boldsymbol{\beta}^{-1} + \mathbf{H}_\boldsymbol{\beta}^\mathbf{T}\mathbf{R}^{-1}\mathbf{H}_\boldsymbol{\beta}, \quad \mathbf{H}_\boldsymbol{\beta} = \left.\frac{\partial \tilde{h}}{\partial \boldsymbol{\beta}}\right|_{\boldsymbol{\beta}=\boldsymbol{\beta}_\mathbf{a}}$$

Modified block-diagonal preconditioning $\mathbf{M}_\boldsymbol{\beta}$ is set to be the inverse of $\frac{\partial^2 J}{\partial \boldsymbol{\beta}^2}$ (Dee 2004)

For simplicity, only diagonal elements of $\mathbf{M}_\boldsymbol{\beta}$ are considered at each analysis cycle

Background variance for predictor coeff.

Currently scheme

$$B_\beta = diag(\sigma^2_{\beta_1}, \ldots, \sigma^2_{\beta_N})$$

$$\sigma^2_{\beta_i} = 10.0,$$
$$i = 1, \ldots, N$$

Automatically adjust variances of coeff.

Enhanced scheme

More & high quality data

Smaller variance

- Set $\sigma^2_{\beta_i}$ to be the estimate of analysis error variance of the coeff. from previous analysis cycle
- New data: $\sigma^2_{\beta_i}$ is initialized to be 10000.0
- Missing data: $\sigma^2_{\beta_i}$ is twice as much as that of the previous analysis cycle

Bias correction for passive channels (passive_bc=.true.)

- Make preparation for assimilating passive channels data
- Aid quality control of other channels

At the end of analysis, minimizing the functional

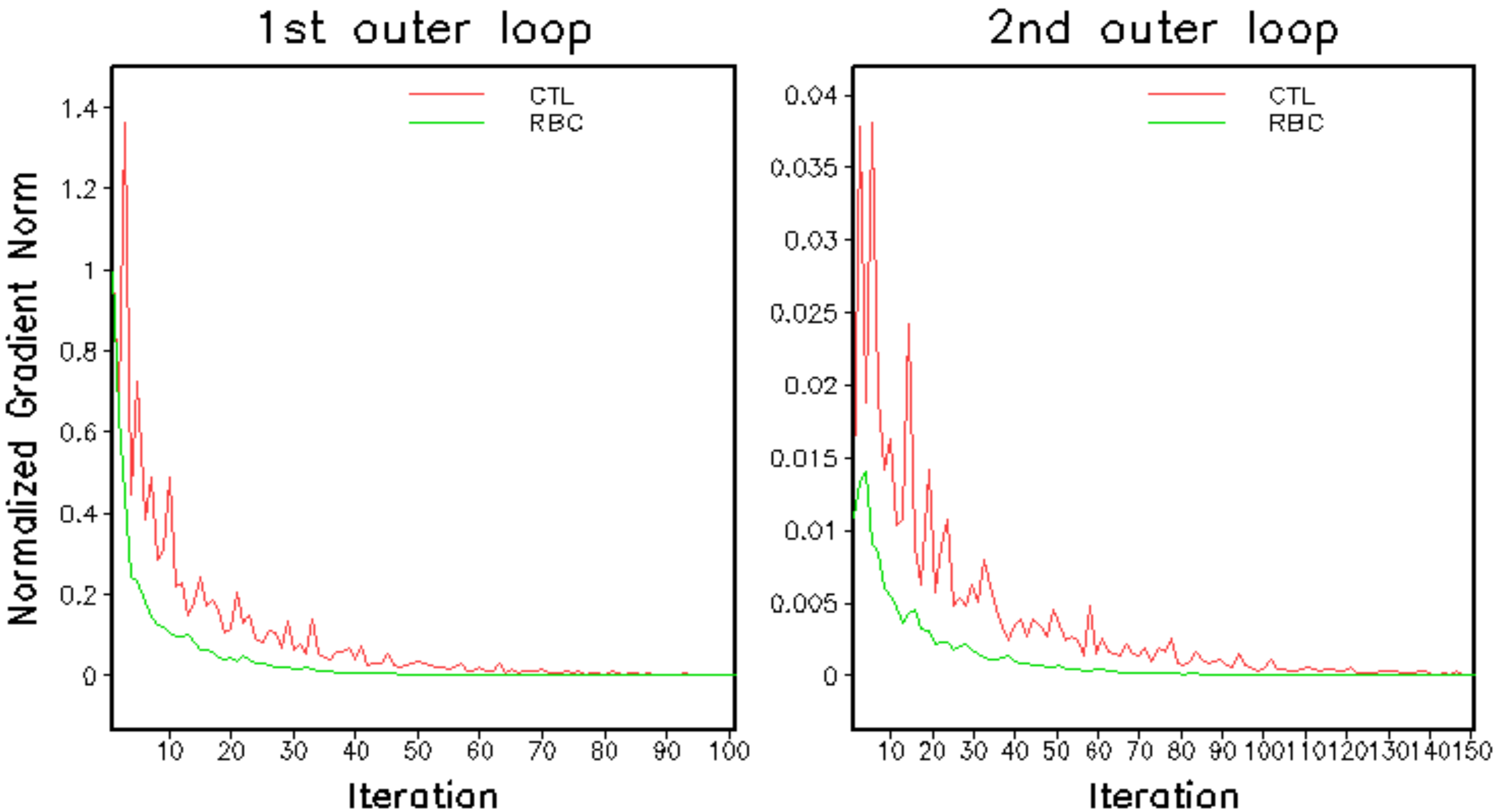
$$F(\beta)=\frac{1}{2}(\beta-\beta_b)^T B_\beta^{-1}(\beta-\beta_b)+\frac{1}{2}\left[y-\tilde{h}(x_a,\beta)\right]^T R^{-1}\left[y-\tilde{h}(x_a,\beta)\right]$$

where

$$\tilde{h}(x_a,\beta)=h(x_a)+\sum_{i=1}^{N}\beta_i p_i(x_a)+b^{angle}$$

or $\tilde{h}(x_a,\beta)=h(x_a)+\sum_{i=1}^{N+K}\beta_i p_i(x_a)$ *If adp_anglebc=.t.*

Convergence comparison



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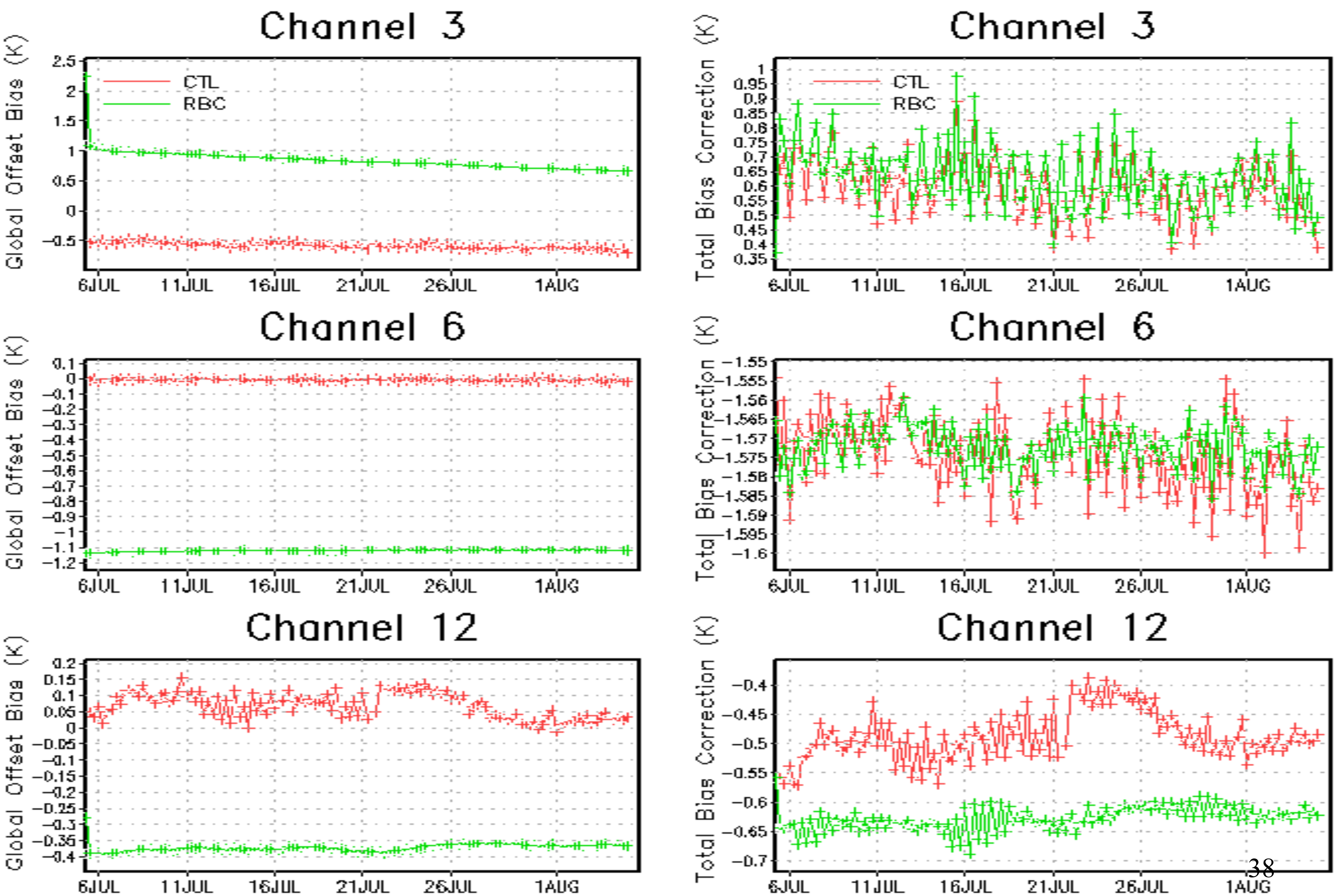
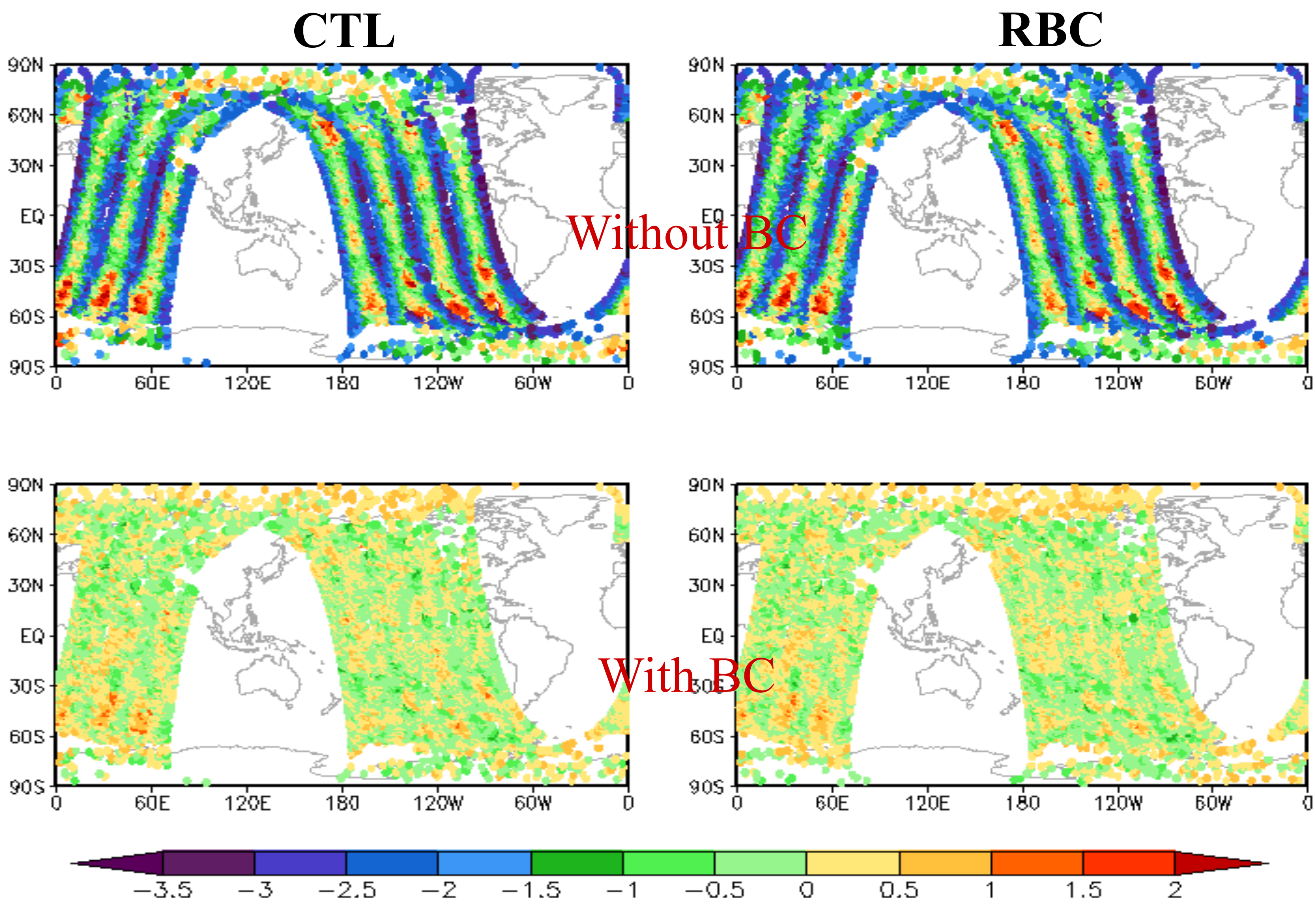
Global offset and total bias terms: AMSUA-NOAA18



OMF with and without bias correction



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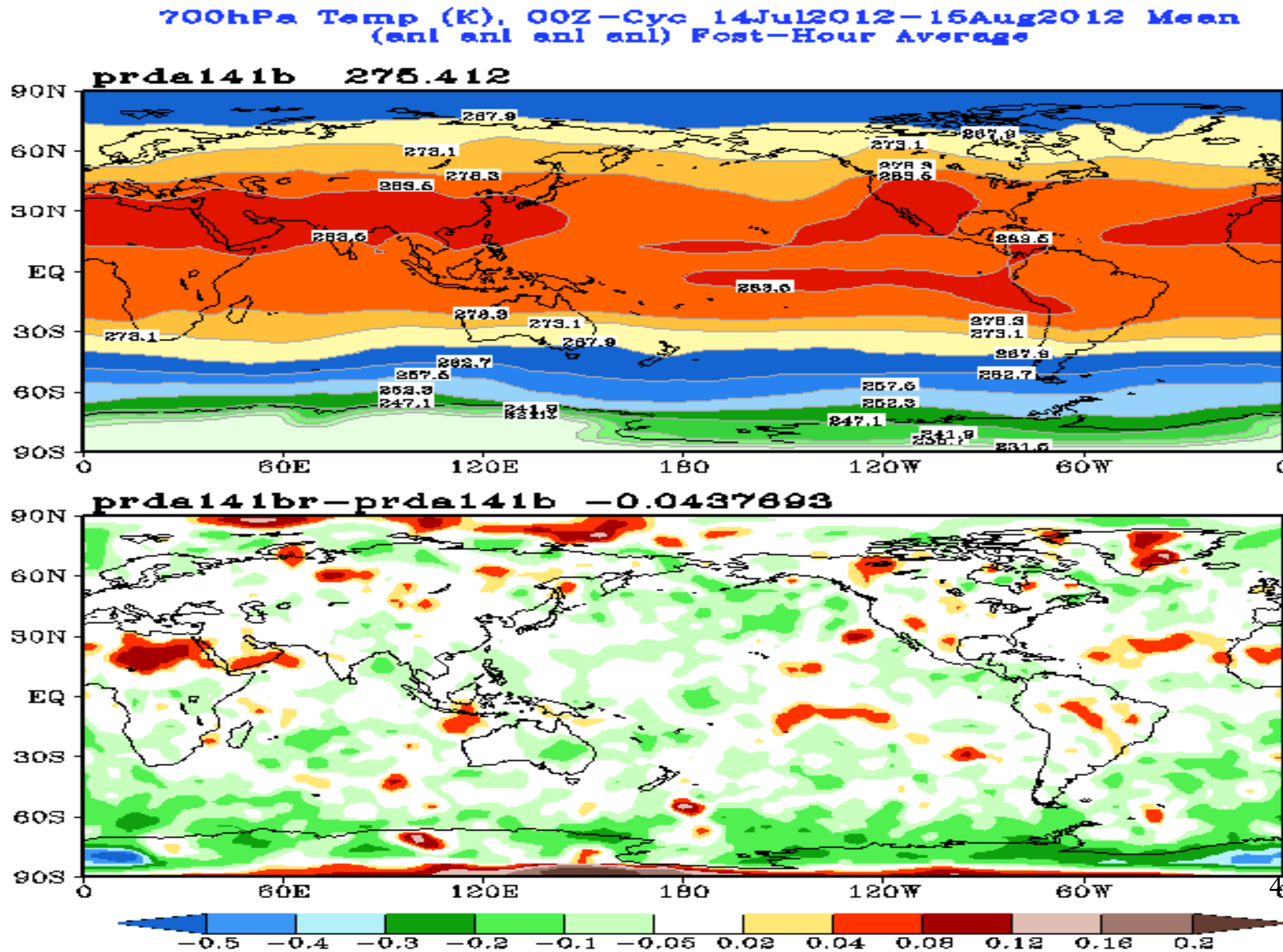
Mean Temperature Analysis & Difference 700hpa



24h & 48h Forecasts Fits to Obs