Constrained Bias Correction (CBC) For Satellite Radiance Assimilation

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NWPC/CMA

ITSC19, March 27, 2014

Outline

- Background
  - The bias correction is an ill-posed problem
  - Two Remain Issues of bias correction
  - Efforts has been done

$$\delta J = \left\langle \frac{\partial J}{\partial \mathbf{y}}, \mathbf{y} - \mathbf{H}\mathbf{x}_b - \mathbf{b} \right\rangle$$

FSO: Forecast sensitivity to observation
Over or under bias correction could lead to negative impact

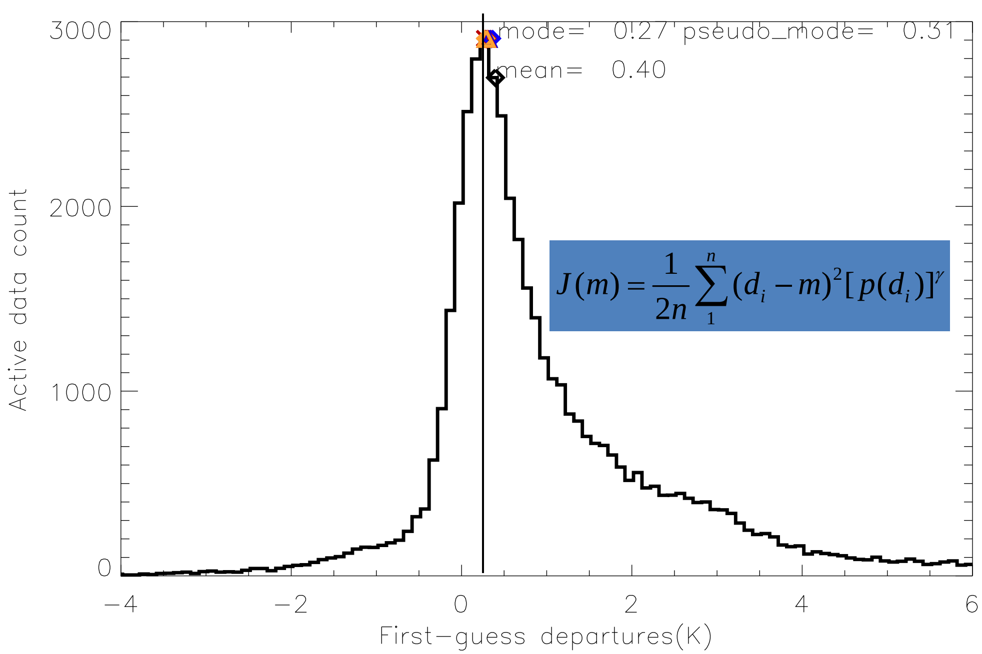
- Methodology
  - Use of priori information as constraint: **Constrained BC (CBC)**
  - Implementation in VarBC
  - Implementation in offline BC
- Experiments of CBC in GRAPES
  - Consideration of imperfect QC: AMSUA Ch4
  - Consideration of imperfect model: AMSUA Ch9
  - Impact on forecasts
- Discussions and Further Plan

Background

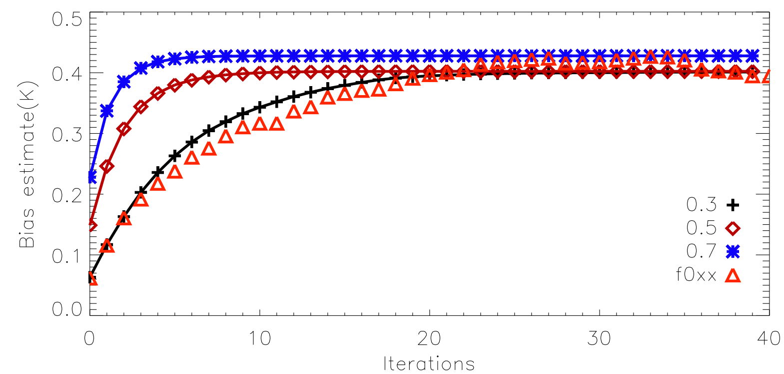
- The bias correction is an ill-posed problem: O-B?
  - There is no absolute calibration of satellite instruments on orbit
  - There is no truth of the atmosphere
  - How to separate observation bias from model bias using O-B?
- Two main issues
  - **Imperfect QC affacted BC: QC and BC interaction**
    - Window channel: cloud contamination
  - **Model bias**
    - Temperature sounding channel in stratosphere
    - Trace gas sounding channel, e.g. IASI Ozone channels
    - Developing models : GRAPES

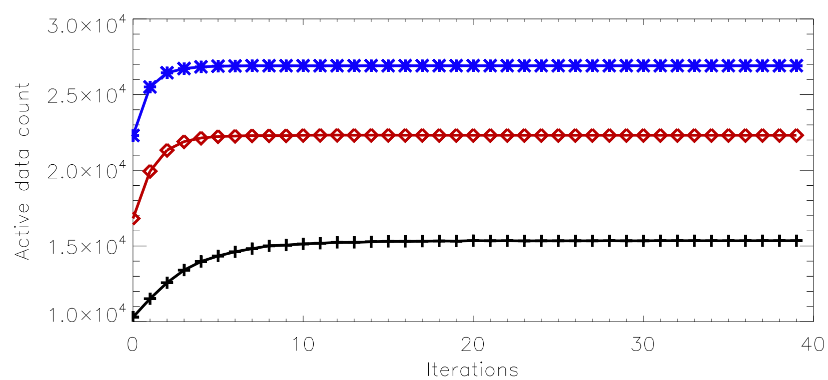
Background--Efforts been done for **QC feedback**

- Imperfect QC
  - Warm tail for microwave window channel departures O-B
  - Cold tail for IR window channel departures O-B
  - Over correction on observations by Least Square based estimation
- Using mode
  - Han and McNally 2008
  - Li ,McNally and Geer,2010



$$J(m)=\frac{1}{2n}\sum_{1}^{n}(d_i-m)^2[p(d_i)]^{\gamma}$$



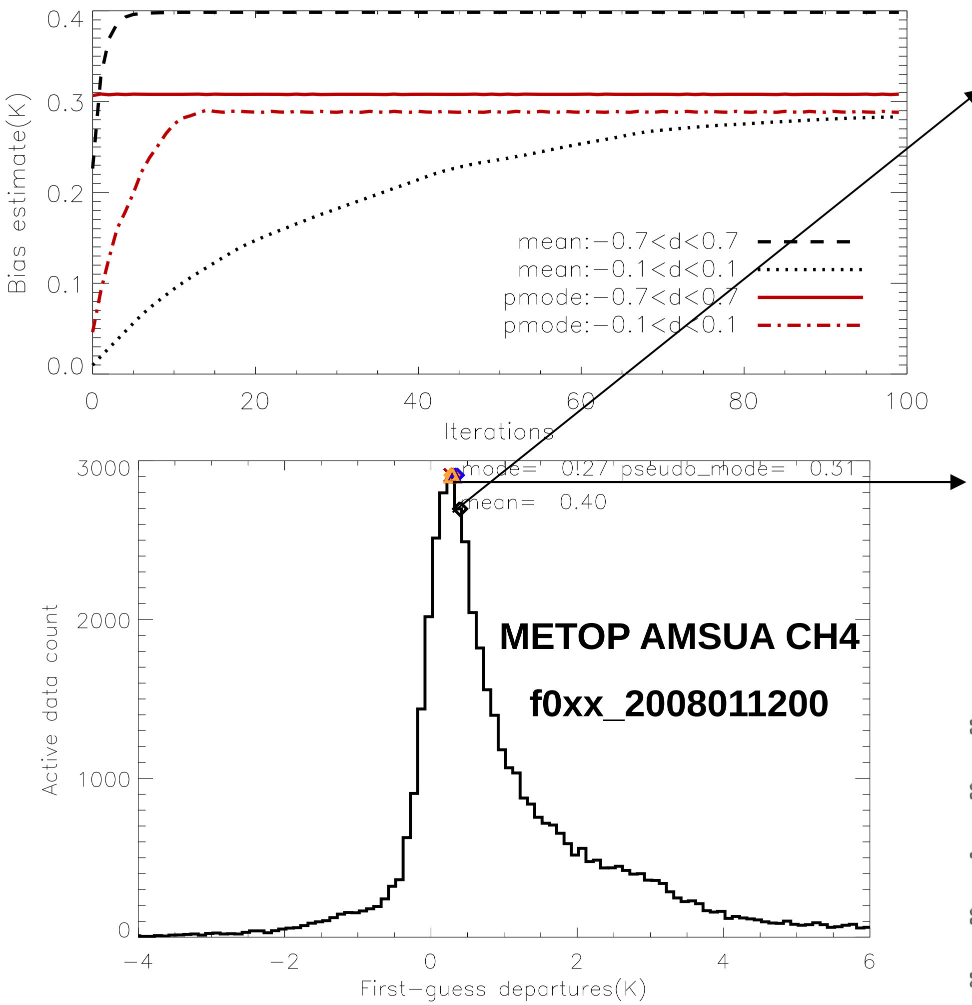


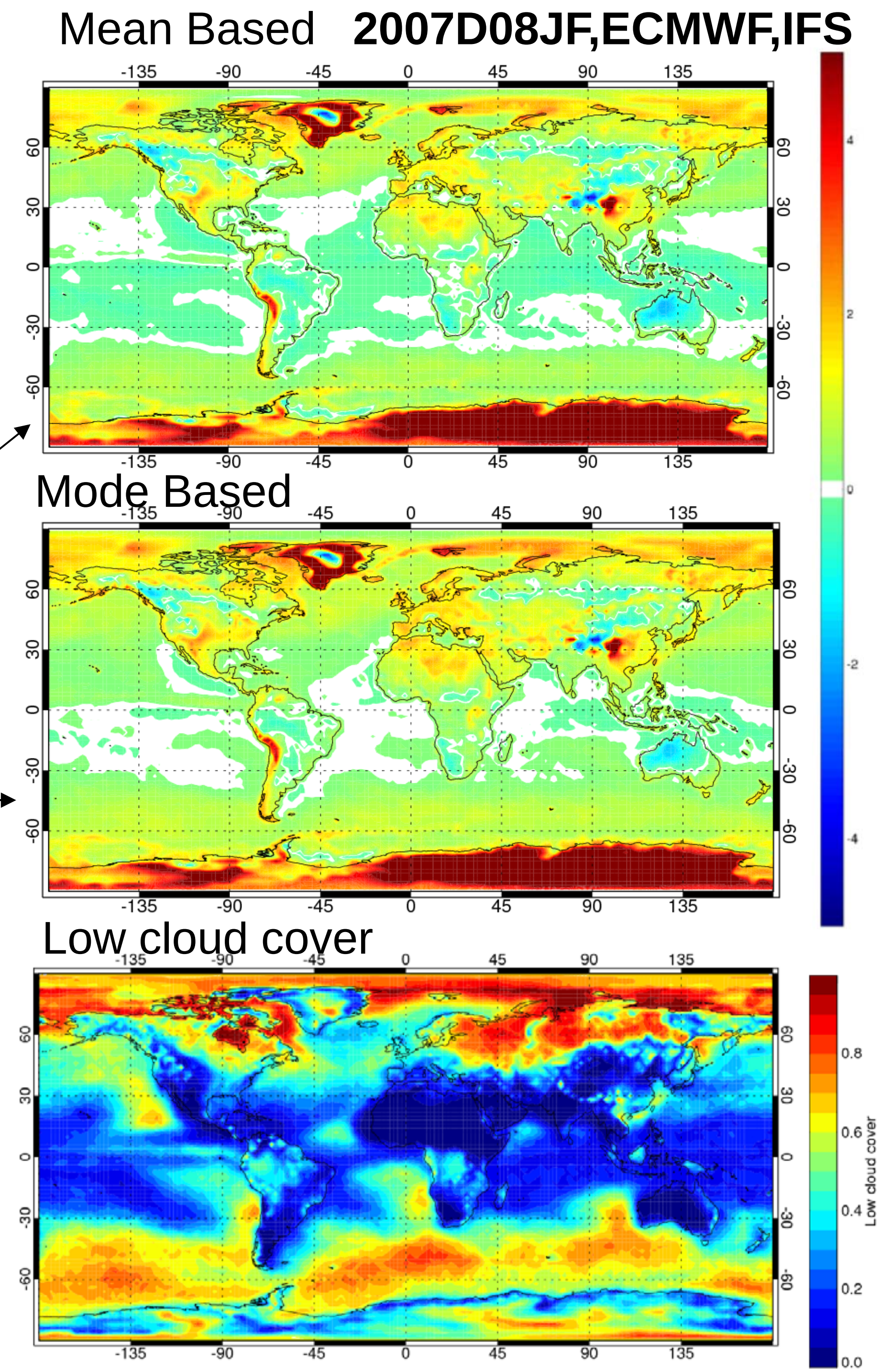
Han and McNally,2008

Impact of over bias correction

Mean: If bias is estimated by <O-B>, It will strongly depend on the QC,

0.7 → b=0.4; 0.1 → b=0.28





Background--Efforts been done for **model error**

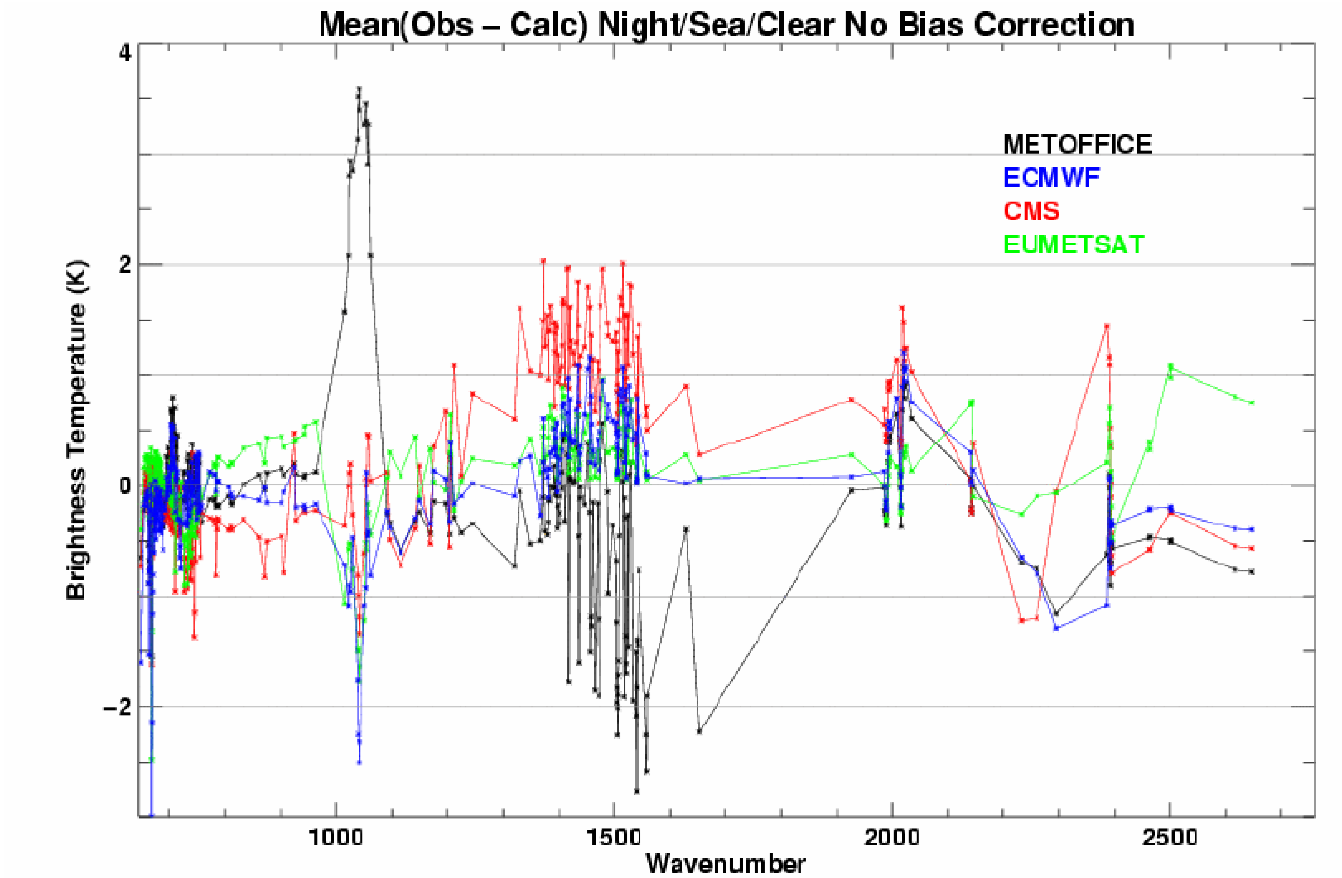
- Using “UNBIASED” observations
  - *Radiosonde mask (Eyre 1992)*
  - *Radiosonde profile (Joiner and Rokke 2000;Kozo et al.,2005)*
  - *GPS RO temperature sounding (Zou et al.,2014)*
- VarBC using all other un-corrected observations
  - *Derber and Wu 1998; Dee 2004; Auligne et al.2007*
- Anchor channel
  - *AMSUA Ch14 (McNally,2007)*
  - *IASI ozone channel (Han and McNally,2010)*
- Bias model selection: Constrain the freedom of bias predictor
  - *Freedom of the predictor*
  - *Absorption correction (Watts and McNally 2004)*
  - *Frequency correction (Lu et al.,2011)*

Comparison of IASI radiances with NWP models from four operational centres

Fiona Hilton[1], Andrew Collard[2], Lars Fiedler[3],Lydie Lavanant[4]

[1]Met Office [2]ECMWF [3]EUMETSAT [4]Météo-France/CMS

How to separate observation bias from O-B?



Courtesy of Fiona Hilton,ITSC16

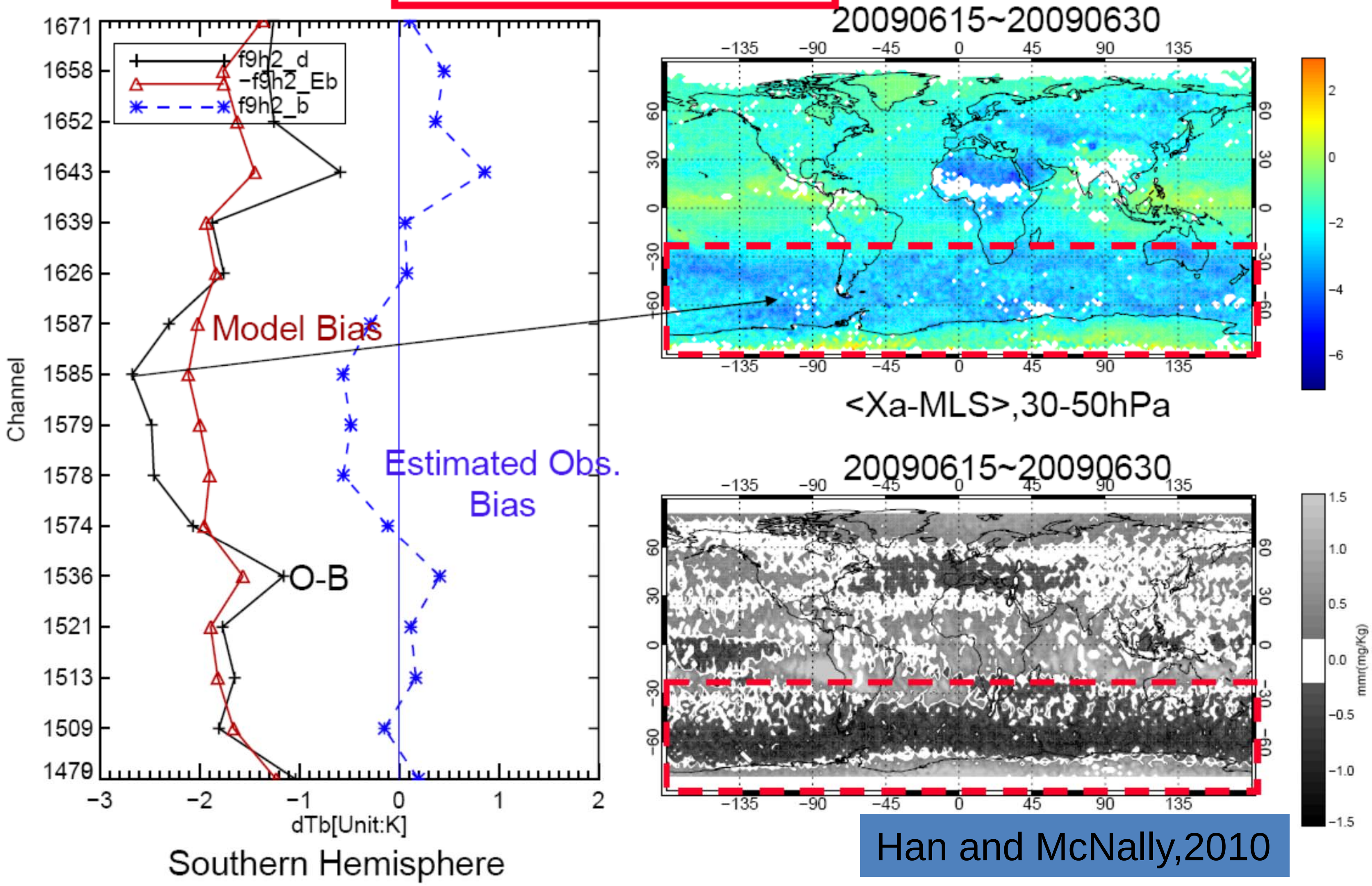
Radiance priori information: bias and uncertainty

MLS→ Model Bias and Obs. Bias

$d = Y_o - Hx = (Y_t + b) - H(X_t + E_b)$

$\langle d \rangle = \langle b \rangle - H(E_b)$

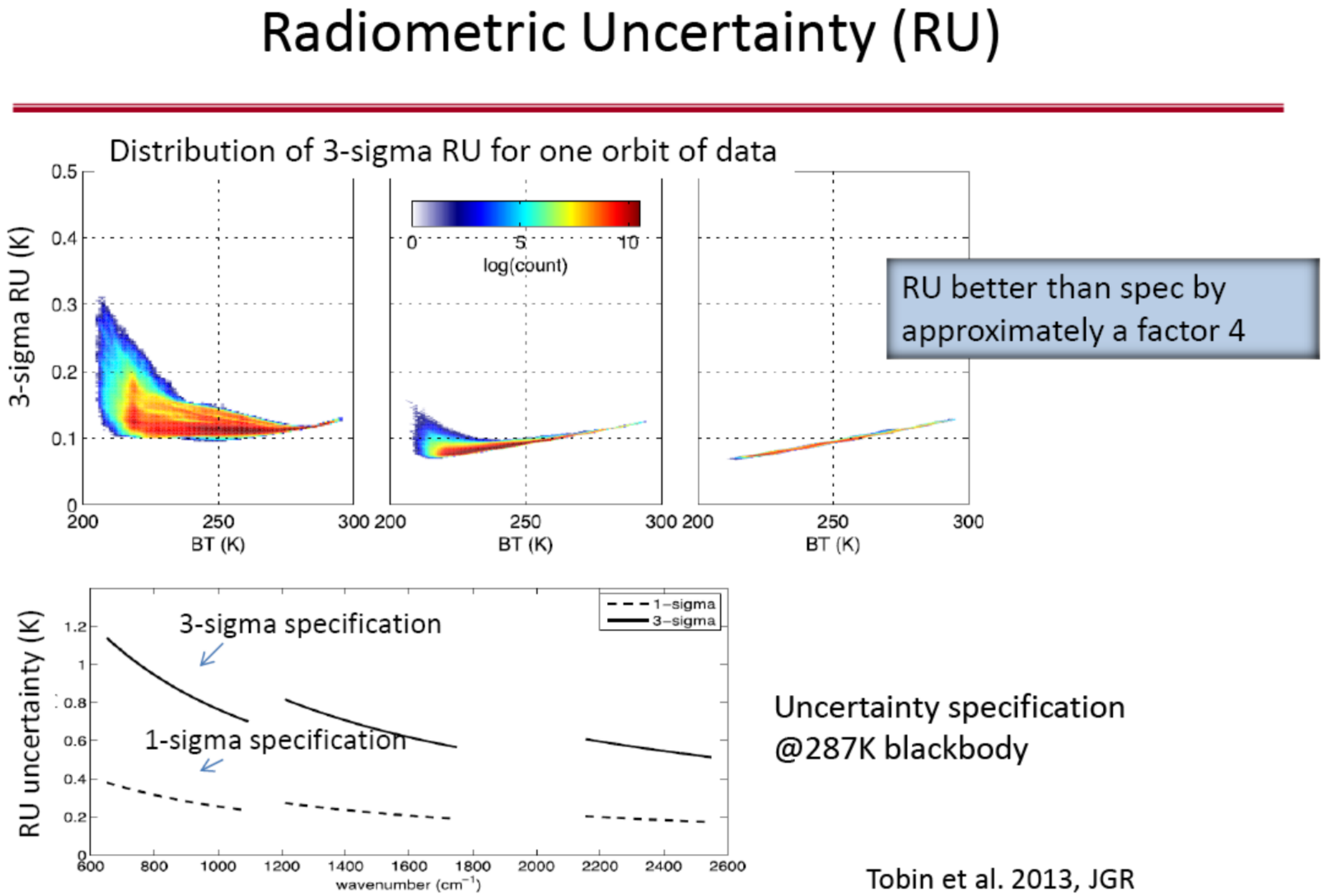
$\langle b \rangle = \langle d \rangle + H(E_b)$



Han and McNally,2010

Connection between BC and Calibration

- Account for the calibration uncertainty in BC



Courtesy of Yong Han,2014,ITSC19

Methodology

$$2J(\mathbf{x},\boldsymbol{\beta}) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x})$$
$$+ \gamma_b (\boldsymbol{\beta} - \boldsymbol{\beta}_b)^T \mathbf{B}_\beta^{-1} (\boldsymbol{\beta} - \boldsymbol{\beta}_b)$$
$$+ [\mathbf{y} - H(\mathbf{x}) - h(\mathbf{x},\boldsymbol{\beta})]^T \mathbf{R}^{-1} [\mathbf{y} - H(\mathbf{x}) - h(\mathbf{x},\boldsymbol{\beta})]$$
$$+ \gamma [h(\mathbf{x},\boldsymbol{\beta}) - b_0]^T \mathbf{R}_b^{-1} [h(\mathbf{x},\boldsymbol{\beta}) - \mathbf{b}_0]$$

Use of PRIORI information
Radiometric Uncertainty
RT model Uncertainty

γ : Regularization parameter $\gamma \geq 0$

$\mathbf{b}_0$: Priori estimate of observation bias

$\mathbf{R}_b$: Priori estimate uncertainty

$\boldsymbol{\beta}_b$: Background predictor coefficients

$\mathbf{B}_\beta$: Background predictor coefficients uncertainty

Adaptive

Constrained Bias Correction (CBC) scheme

$$
\begin{aligned}
2J(\mathbf{x},\boldsymbol{\beta}) \;=\; & (\mathbf{x}_b-\mathbf{x})^T\mathbf{B}_x^{-1}(\mathbf{x}_b-\mathbf{x}) \\
& +\; \gamma_b(\boldsymbol{\beta}-\boldsymbol{\beta}_b)^T\mathbf{B}_\beta^{-1}(\boldsymbol{\beta}-\boldsymbol{\beta}_b) \\
& +\; [\mathbf{y}-H(\mathbf{x})-h(\mathbf{x},\boldsymbol{\beta})]^T\mathbf{R}^{-1}[\mathbf{y}-H(\mathbf{x})-h(\mathbf{x},\boldsymbol{\beta})] \\
& +\gamma[h(\mathbf{x},\boldsymbol{\beta})-b_0]^T\mathbf{R}_b^{-1}[h(\mathbf{x},\boldsymbol{\beta})-\mathbf{b}_0]
\end{aligned}
$$

$$\mathbf{d}=\mathbf{y}-H(\mathbf{x})$$

$$\mathbf{P}\boldsymbol{\beta}=h(\mathbf{x},\boldsymbol{\beta})$$

$$
\begin{aligned}
&\nabla_{\boldsymbol{\beta}}J(\mathbf{x},\boldsymbol{\beta}) \\
&\quad=\gamma_b\mathbf{B}_\beta^{-1}(\boldsymbol{\beta}-\boldsymbol{\beta}_b)-\mathbf{P}^T\mathbf{R}^{-1}[\mathbf{d}-\mathbf{P}\boldsymbol{\beta}]+\gamma\mathbf{P}^T\mathbf{R}_b^{-1}[\mathbf{P}\boldsymbol{\beta}-\mathbf{b}_0] \\
&\quad=(\gamma_b\mathbf{B}_\beta^{-1}+\mathbf{P}^T\mathbf{R}^{-1}\mathbf{P}+\gamma\mathbf{P}^T\mathbf{R}_b^{-1}\mathbf{P})\boldsymbol{\beta}-(\gamma_b\mathbf{B}_\beta^{-1}\boldsymbol{\beta}_b+\mathbf{P}^T\mathbf{R}^{-1}\mathbf{d}+\gamma\mathbf{P}^T\mathbf{R}_b^{-1}\mathbf{b}_0)
\end{aligned}
$$

$$\nabla_{\boldsymbol{\beta}}J(\mathbf{x},\boldsymbol{\beta})=0 \quad\Rightarrow\quad \mathbf{A}\boldsymbol{\beta}=\mathbf{z}$$

$$\mathbf{A}=\gamma_b\mathbf{B}_\beta^{-1}+\mathbf{P}^T\mathbf{R}^{-1}\mathbf{P}+\gamma\mathbf{P}^T\mathbf{R}_b^{-1}\mathbf{P}$$

$$\mathbf{z}=\gamma_b\mathbf{B}_\beta^{-1}\boldsymbol{\beta}_b+\mathbf{P}^T\mathbf{R}^{-1}\mathbf{d}+\gamma\mathbf{P}^T\mathbf{R}_b^{-1}\mathbf{b}_0$$

VarBC, Regression BC and Constrained BC(CBC)

$$\mathbf{A}\boldsymbol{\beta} = \mathbf{z}$$

$$\mathbf{A} = \gamma_b \mathbf{B}_\beta^{-1} + \mathbf{P}^T\mathbf{R}^{-1}\mathbf{P} + \gamma \mathbf{P}^T R_b^{-1}\mathbf{P}$$

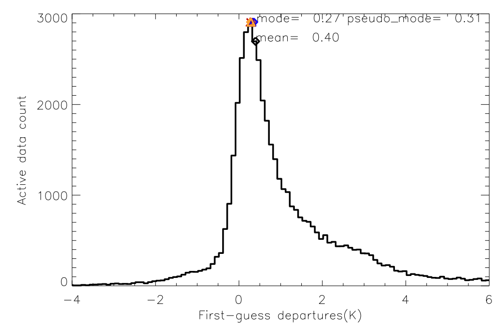
$$\mathbf{z} = \gamma_b \mathbf{B}_\beta^{-1}\boldsymbol{\beta}_b + \mathbf{P}^T\mathbf{R}^{-1}\mathbf{d} + \gamma \mathbf{P}^T R_b^{-1}\mathbf{b}_0$$

$\gamma_b = 0, \gamma = 0, \mathbf{R} = \mathbf{I} \quad \Longrightarrow \quad \mathbf{P}\boldsymbol{\beta} = \mathbf{d}$ **Linear Regression BC**

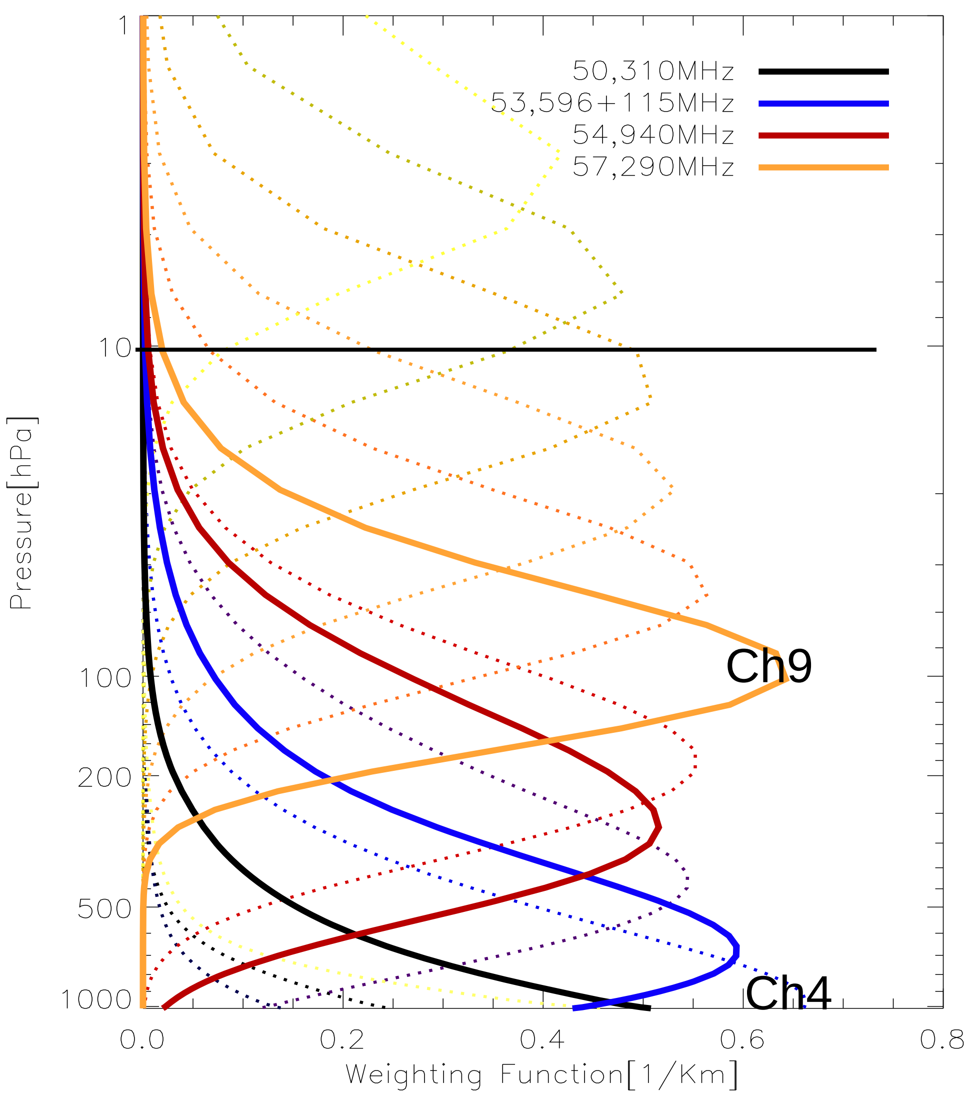
$\gamma_b = 1, \gamma = 0 \quad \Longrightarrow \quad \nabla_{\boldsymbol{\beta}} J(\mathbf{x}, \boldsymbol{\beta}) = \gamma_b \mathbf{B}_\beta^{-1}(\boldsymbol{\beta} - \boldsymbol{\beta}_b) - \mathbf{P}^T\mathbf{R}^{-1}[\mathbf{d} - \mathbf{P}\boldsymbol{\beta}]$ **VarBC**

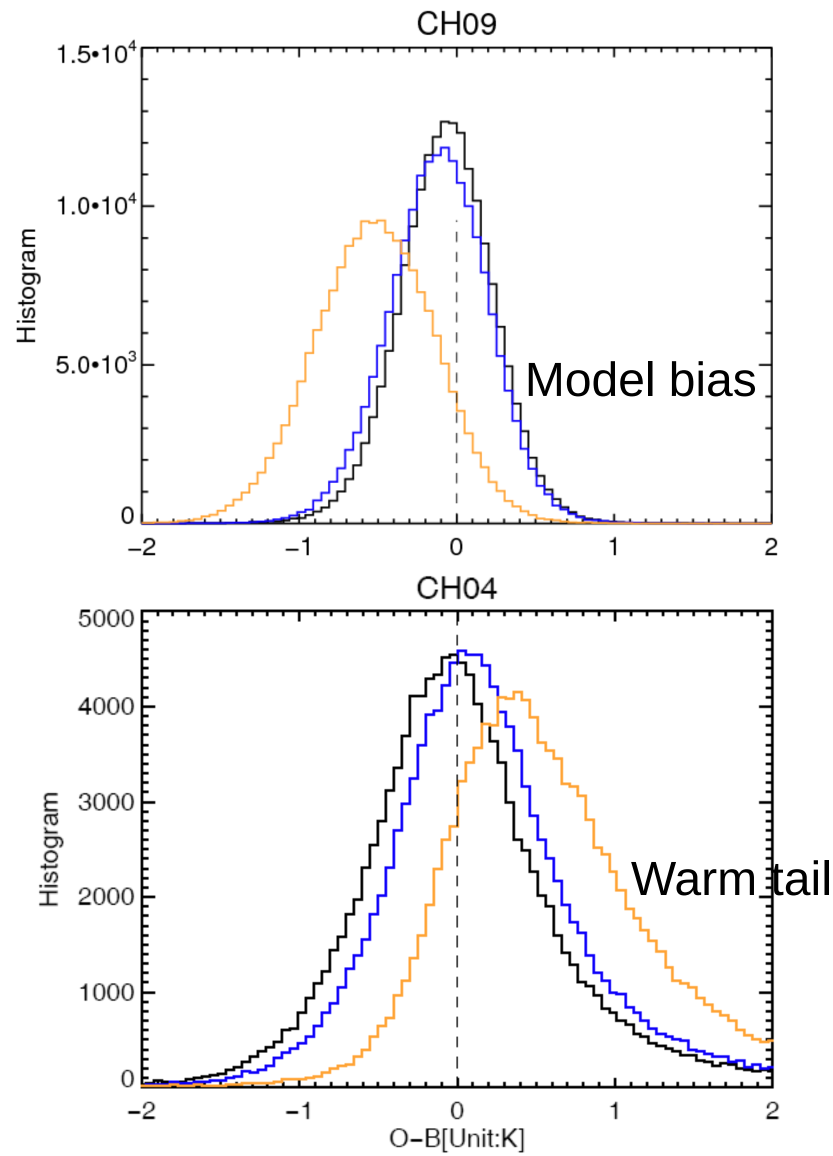
For the simplest example, with a global constant as predictor:

$$\mathbf{P} = 1, \boldsymbol{\beta} = \beta_0, \mathbf{R} = \mathbf{R}_b = 1 \quad \Longrightarrow \quad \beta_0 = \frac{1}{1+\gamma}\sum_{i=1}^{N}(d + \gamma b_0)_i$$

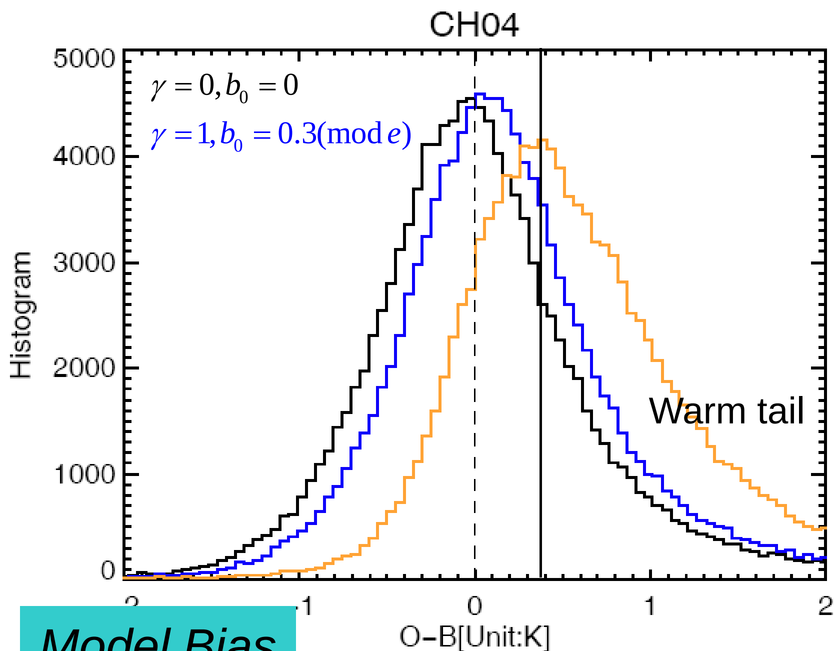


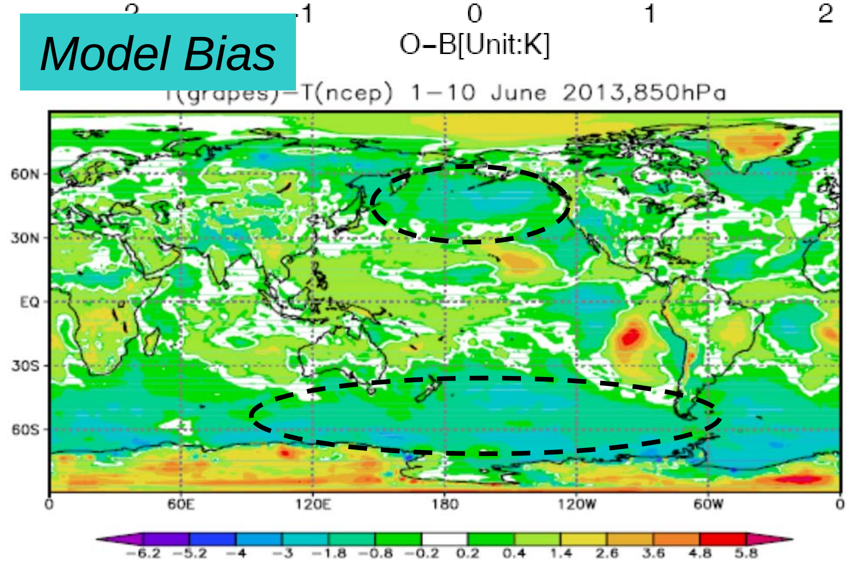
Experiments of CBC in GRAPES

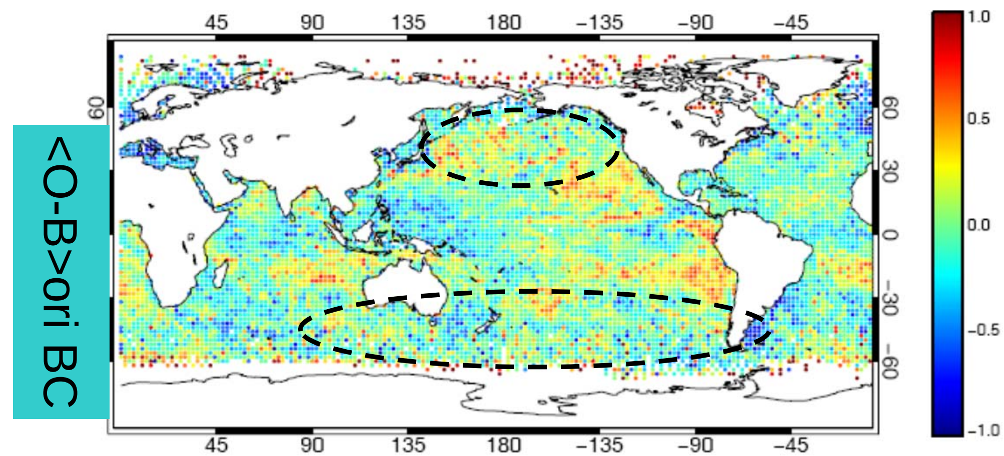


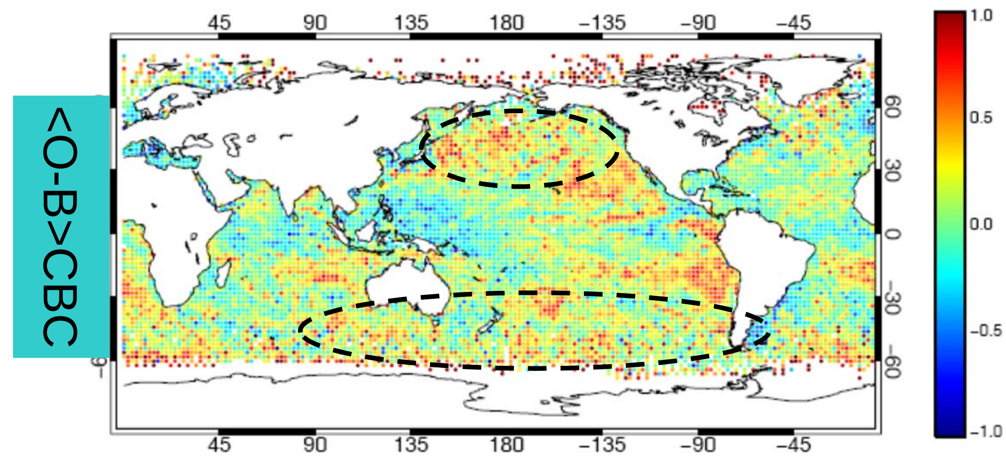


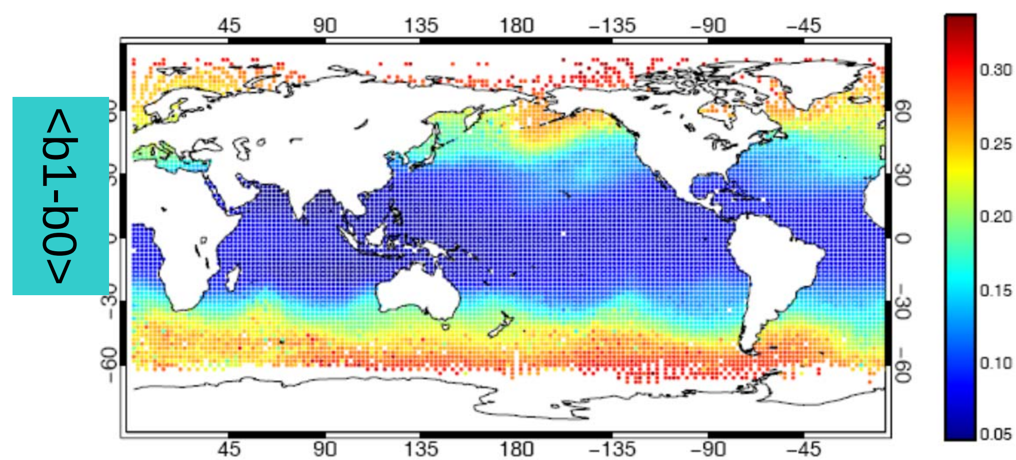
AMSUA CH4(Metop_A)





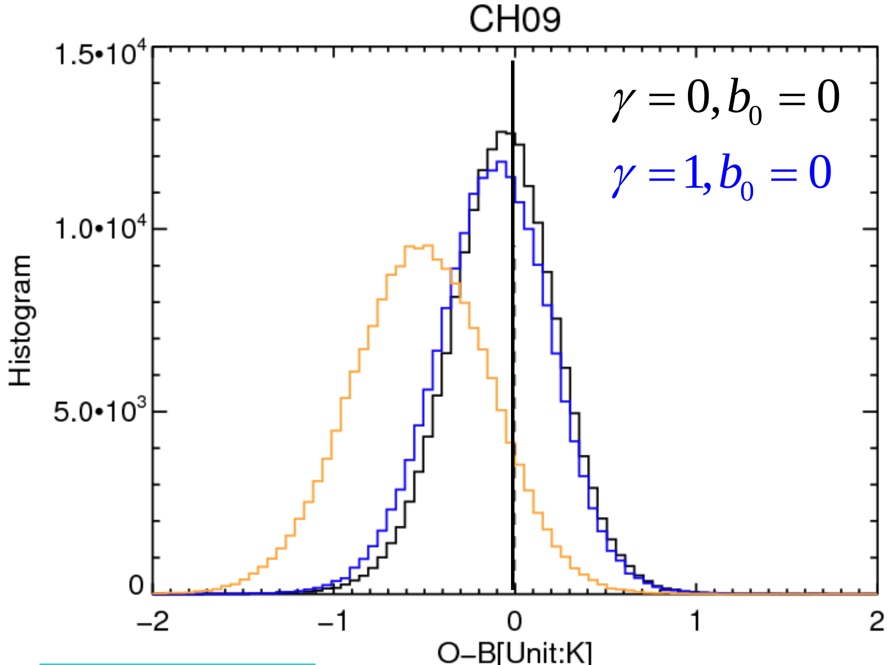




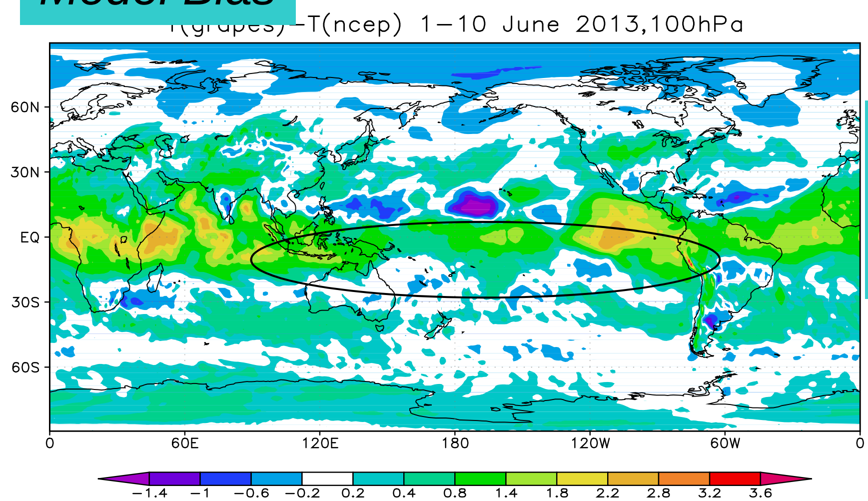


AMSUA CH9(Metop_A)

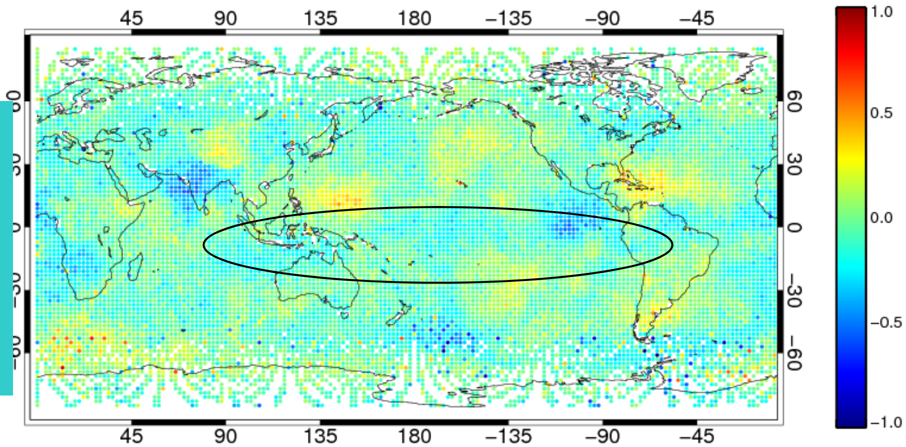
1-10 June 2013



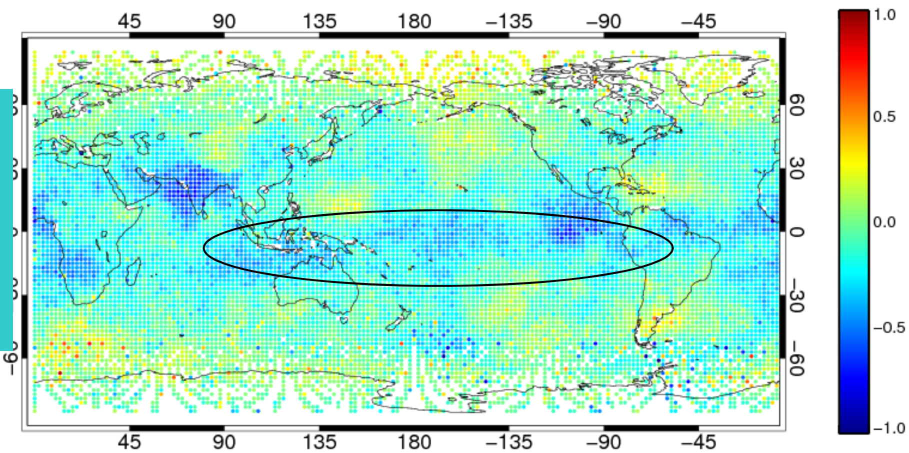
Model Bias



<O-B>ori BC



<O-B>CBC



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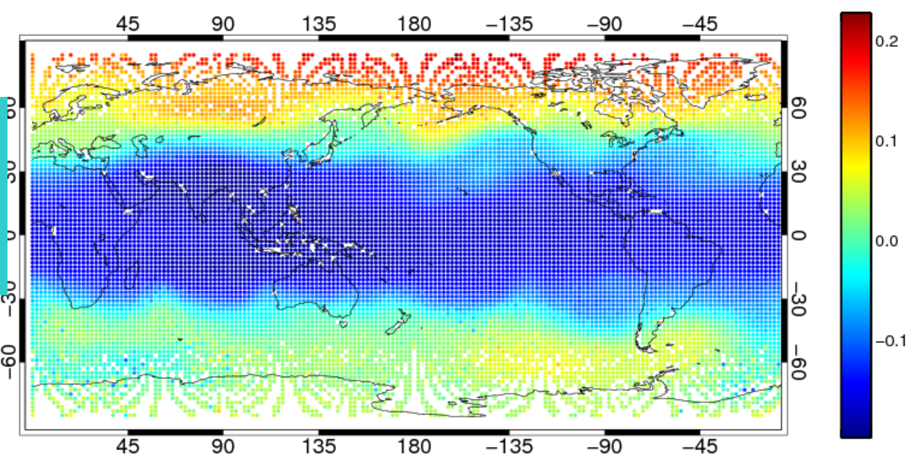
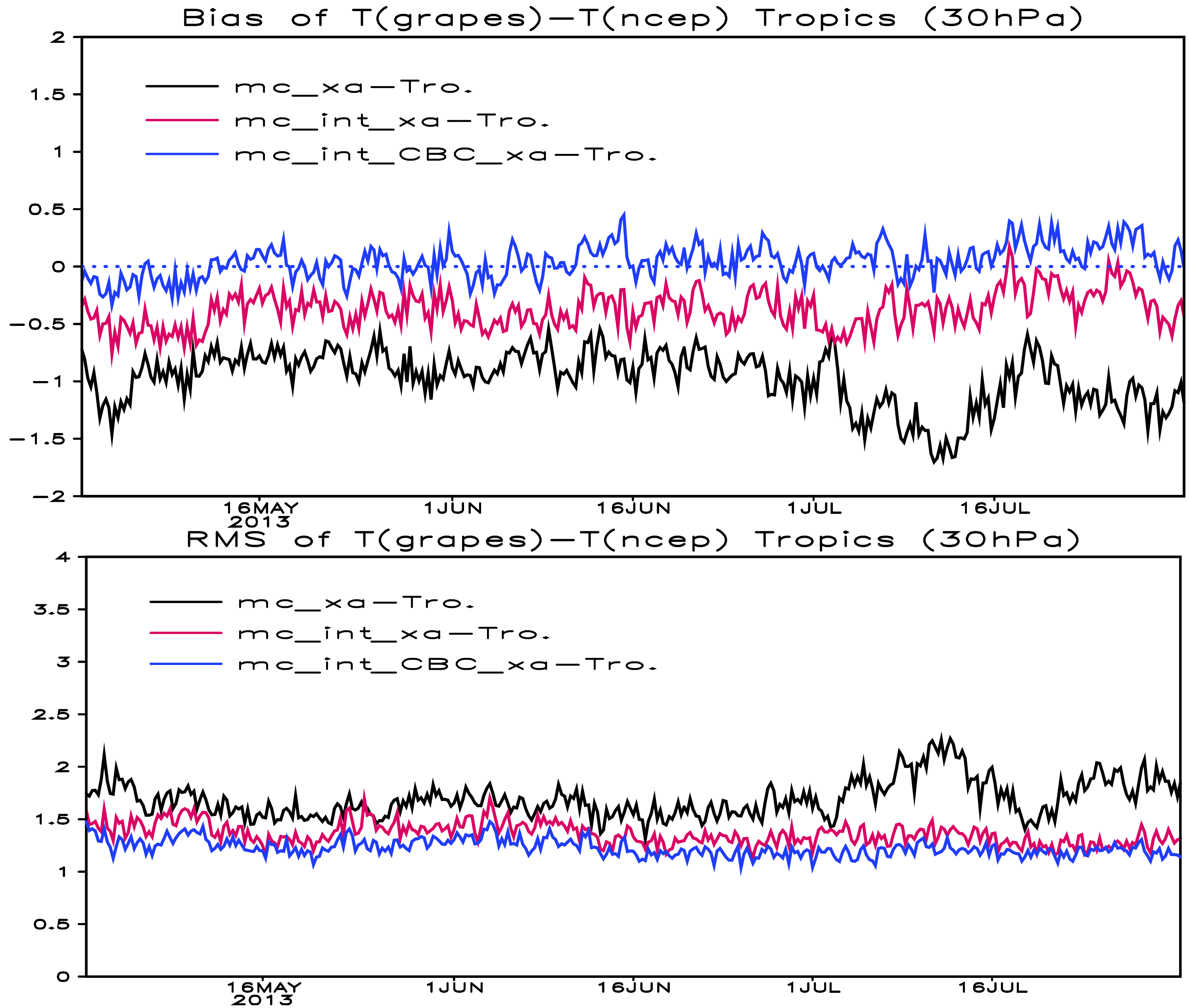
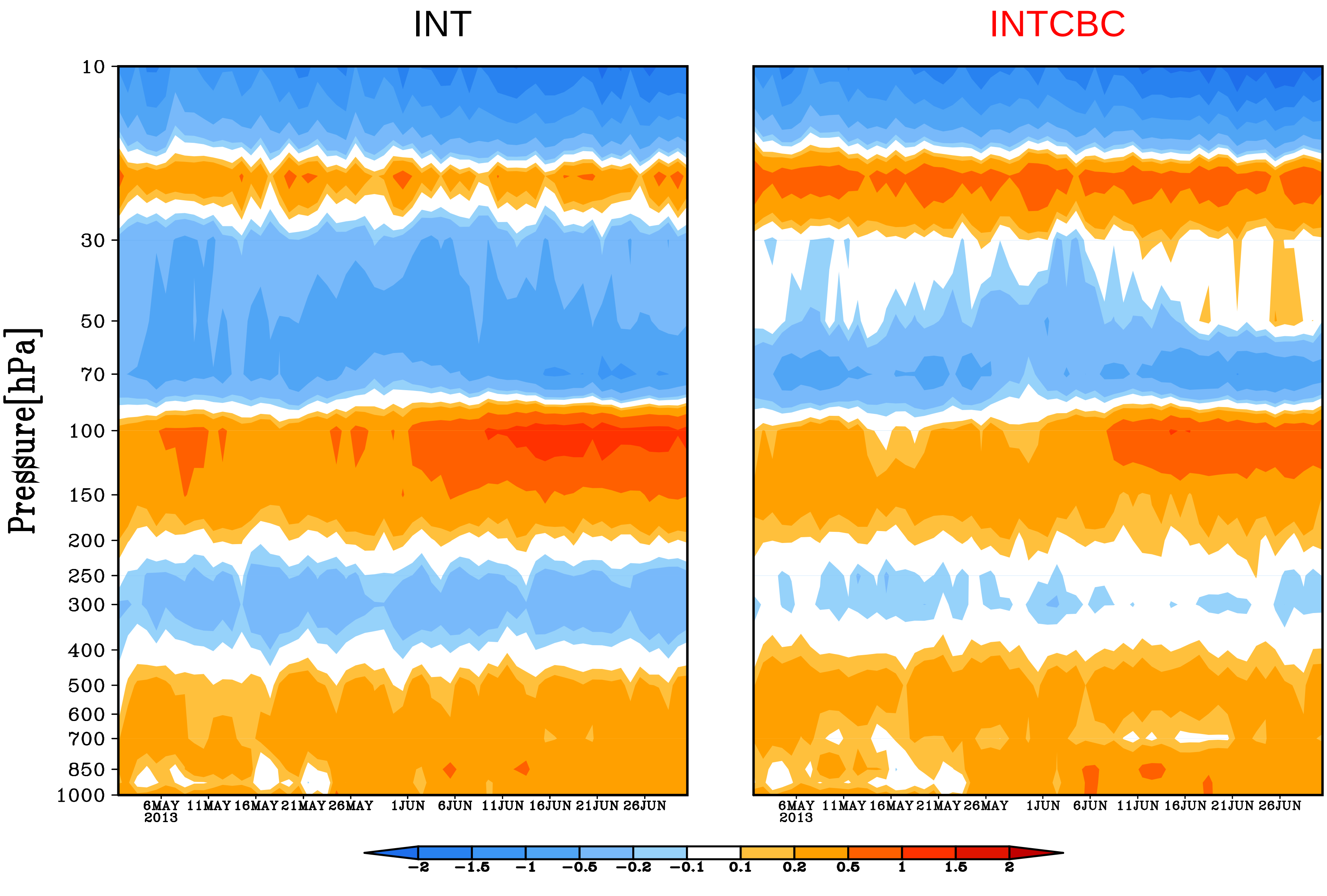
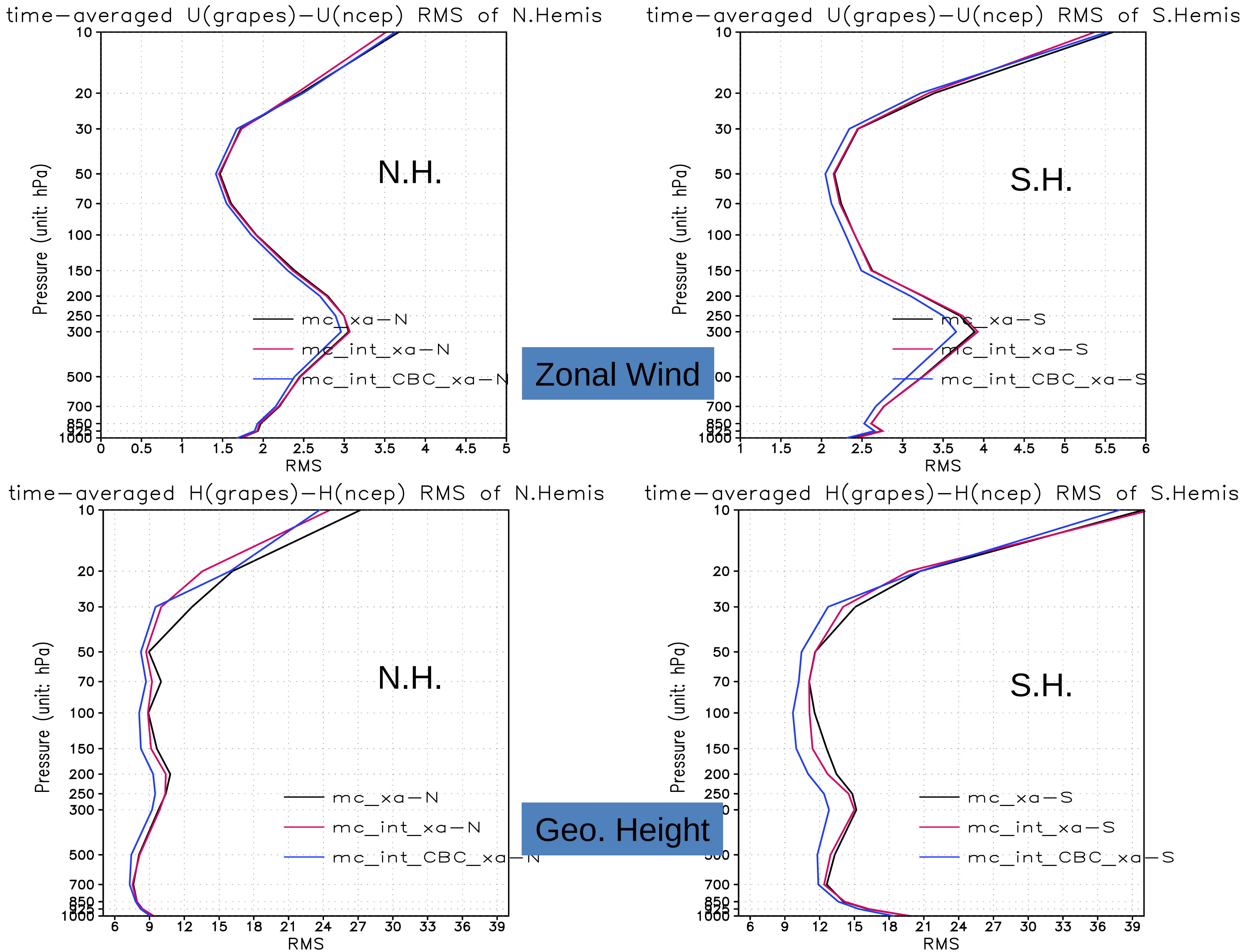


Two months cycle experiments in GRAPES global
May-June 2013



Impact on Analysis: <T_grapes-T_ncep> ,20S-20N

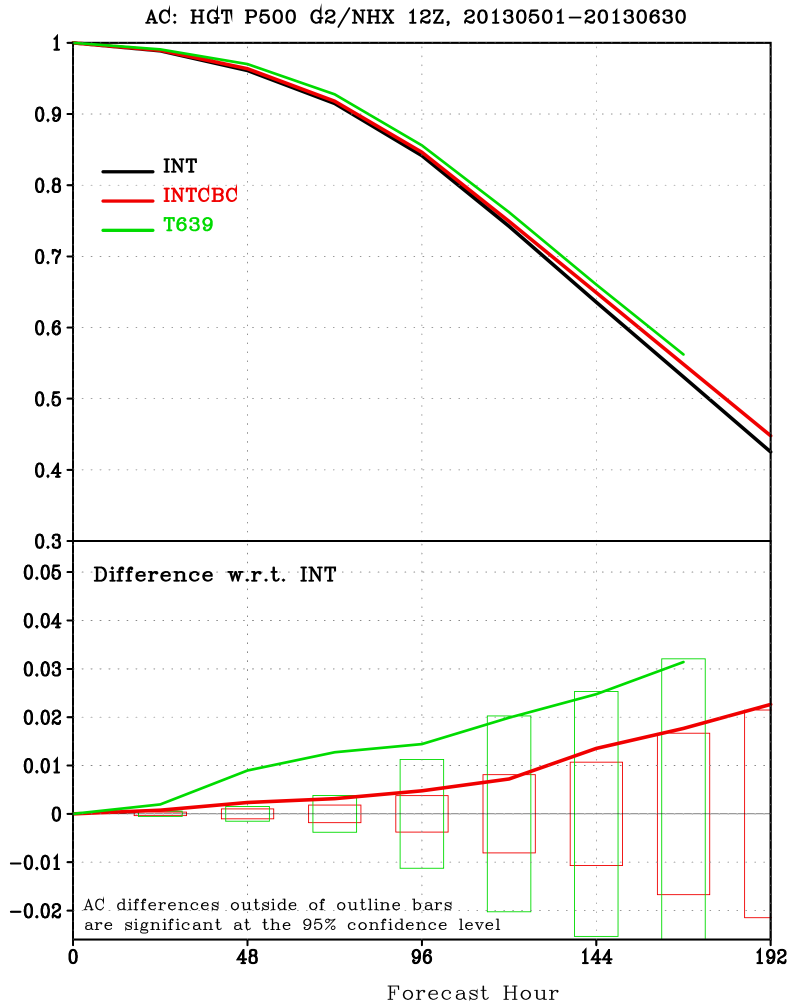


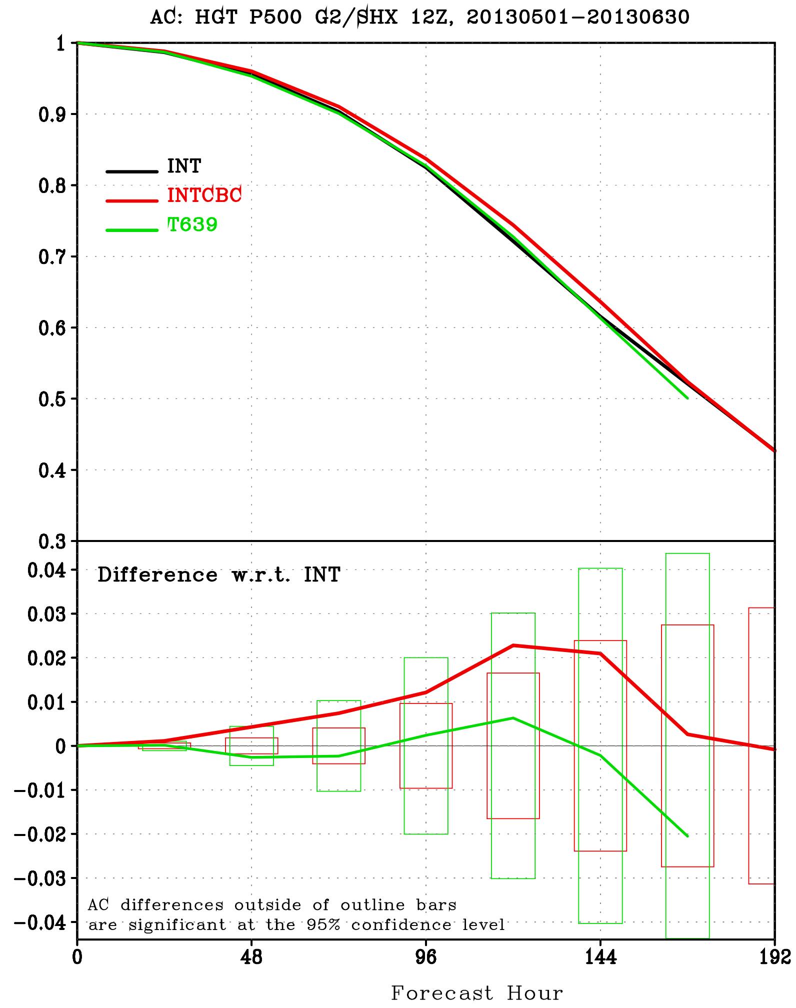


time−averaged U(grapes)−U(ncep) RMS of N.Hemis
time−averaged U(grapes)−U(ncep) RMS of S.Hemis
time−averaged H(grapes)−H(ncep) RMS of N.Hemis
time−averaged H(grapes)−H(ncep) RMS of S.Hemis
N.H.
S.H.
Zonal Wind
Geo. Height
Pressure (unit: hPa)
RMS
mc_xa−N
mc_int_xa−N
mc_int_CBC_xa−N
mc_xa−S
mc_int_xa−S
mc_int_CBC_xa−S

Impact of CBC on forecasts

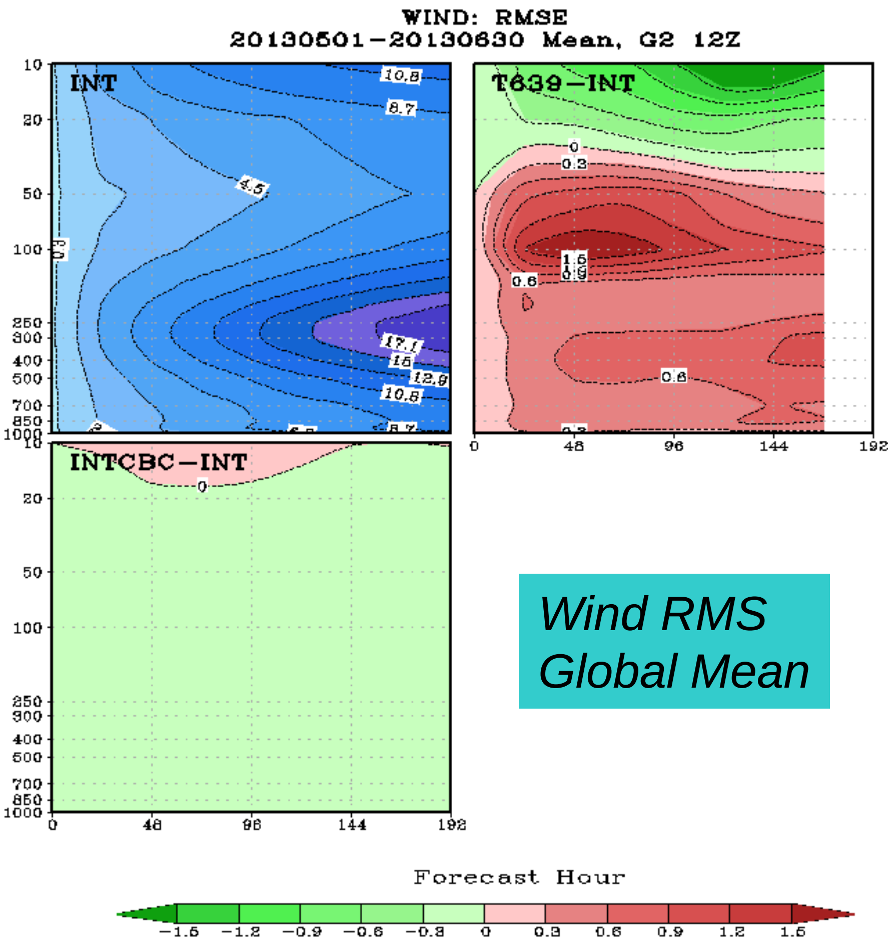
60 cases, May 1 – June 30 ,2013



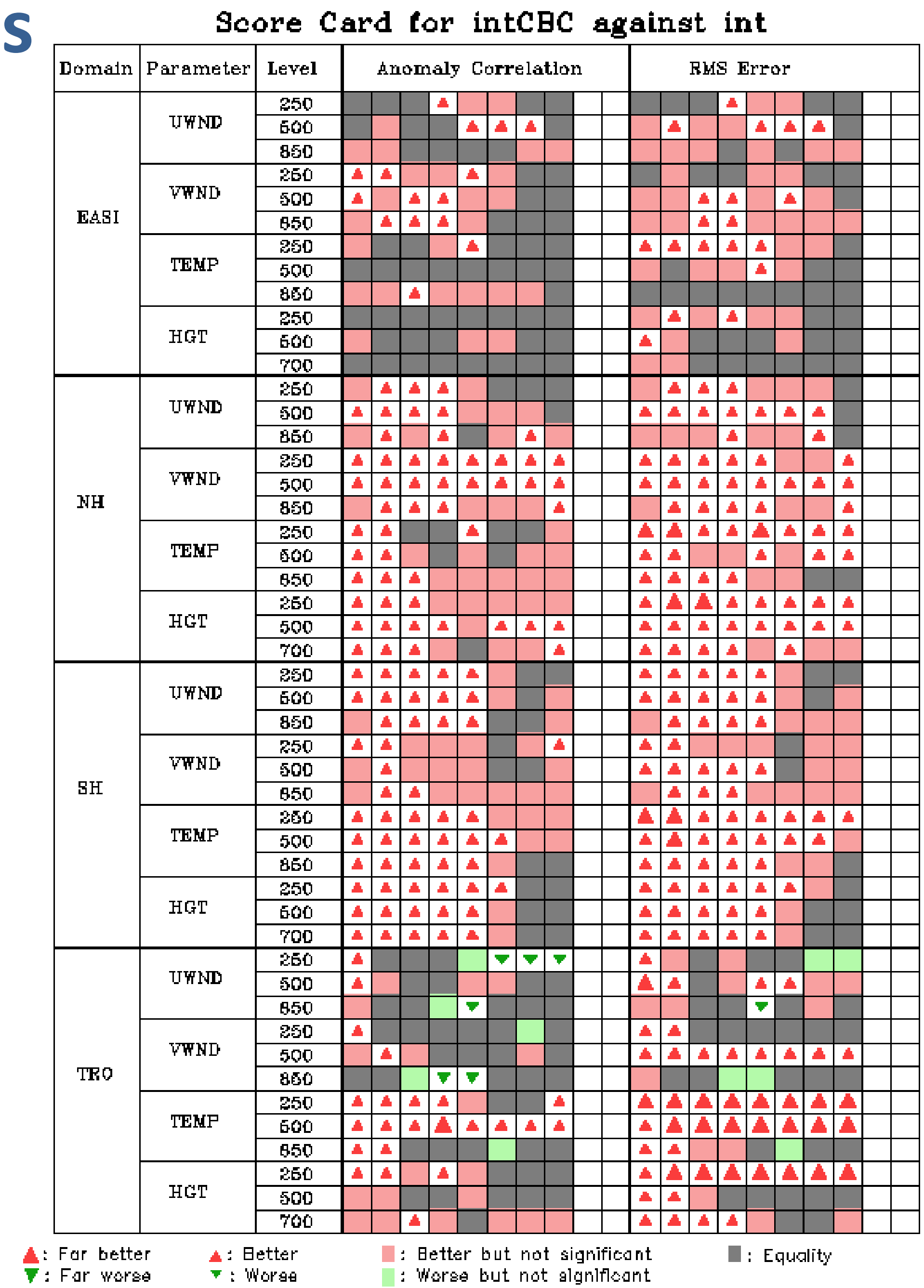


Impact of CBC on forecasts

- Positive Impact



Wind RMS Global Mean



Discussions and Further Plan

- Implementation of Constrained Bias Correction (CBC) scheme
  - VarBC
  - offline regression BC
- Capabilities of CBC
  - Considering imperfect QC
  - Considering model bias
    - important for developing models
    - Important for trace gases
- Estimation and Tuning of the Priori Parameters
  - Using mode as priori bias estimate
  - Using other unbiased obs. to get
  - Radiometric calibration uncertainty
  - RT model uncertainty