CVarBC
for satellite radiances assimilation

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ITSC-XXI, Darmstadt, Germany, 2017

Outline

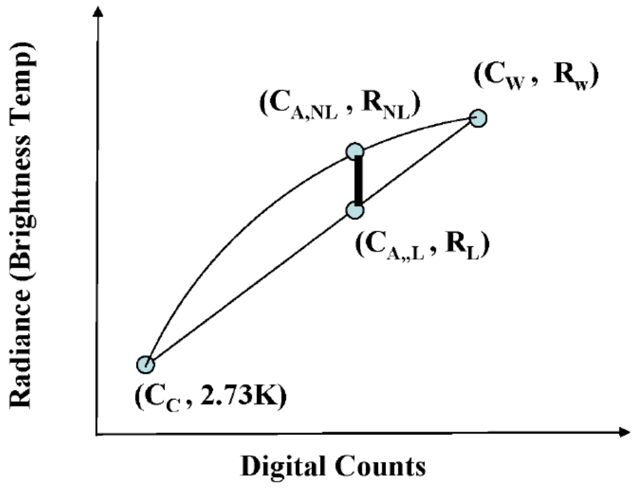
- **Motivation**
  - The bias correction is an ill-posed problem
  - Two Remain Issues of bias correction and Efforts has been done
- **Methodology**
  - **Use of priori information as constraint: Constrained Variational BC (CVarBC)**
  - Implementation in VarBC and offline BC
- **CBC in GRAPES (2014) and CVarBC in ECMWF IFS (2016)**
  - Window channel and Upper sounding channels
  - Stratosphere Temp. sounding and integration with weak constraint 4D-Var
- **Summary and Discussions**
  - Using Radiance Uncertainty and RT model uncertainty
  - Optimal Estimate of parameters in CVarBC

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

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

Motivation

- **Interaction between Bias Correction and Quality Control**
  - **Window channel**: cloud contamination
  - Bias estimation for **Non-Gaussian** observations(IR: cold tail; MW: warm tail)
- **How to separate observation bias and model bias from O-B?**
  - Temperature sounding channels in **stratosphere**
  - **Trace gas** sounding channels, e.g. IASI Ozone channels
  - **Humidity** sounding channels
  - Developing NWP systems
- **What did we know about Observation Bias?**
  - **Radiometric Uncertainty** Estimation
  - Systematic differences from **GSICS**
  - **RT** model uncertainty
- **Using the PRIORI information to constrain BC**

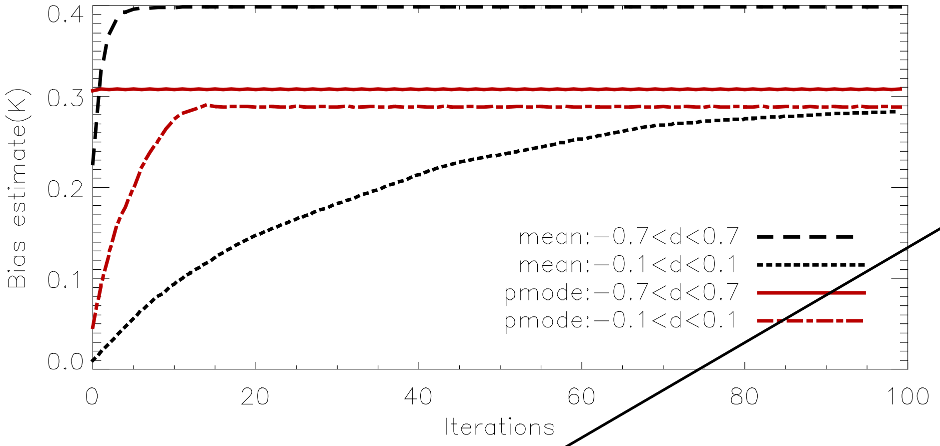


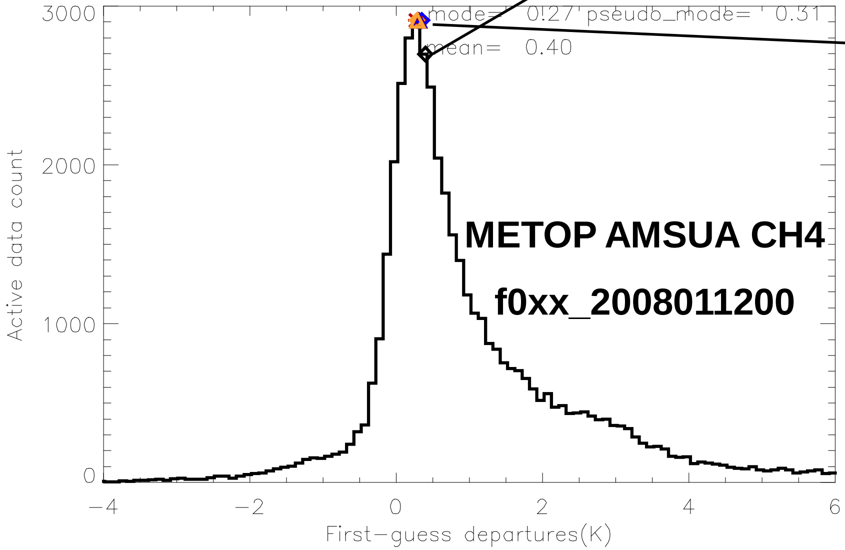
$$R_A = R_C + S(C_A - C_C) + \mu S^2 (C_A - C_C)(C_A - C_W)$$

BC and QC interaction

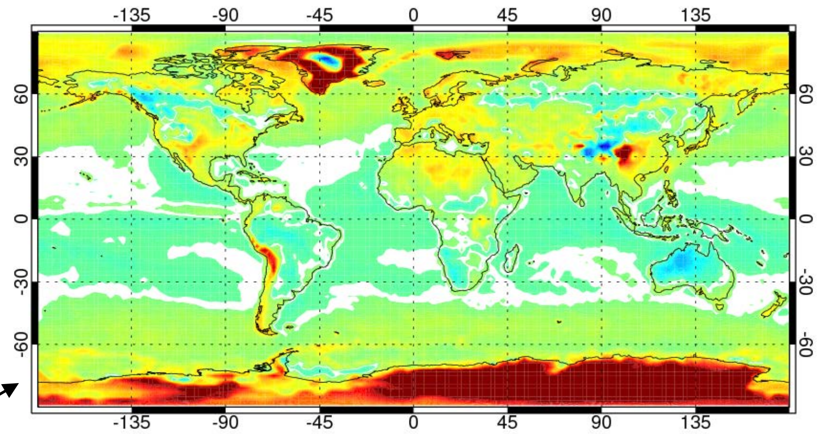
Mean: If bias is estimated by <O-B>, It will strongly depend on the QC,

0.7 → b=0.4; 0.1 → b=0.28

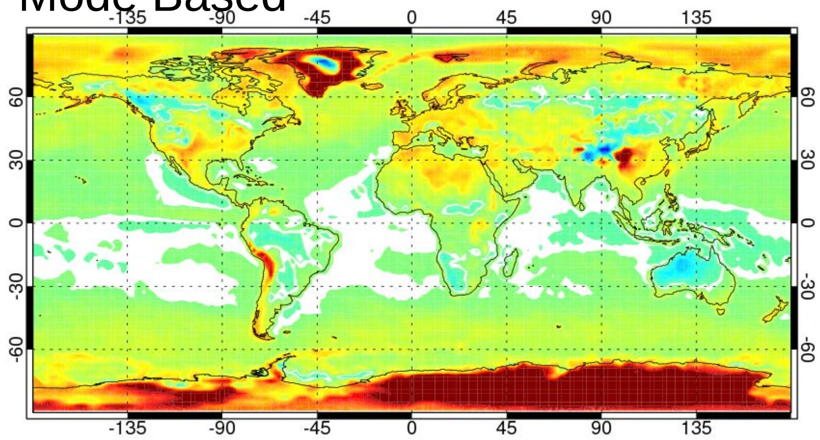




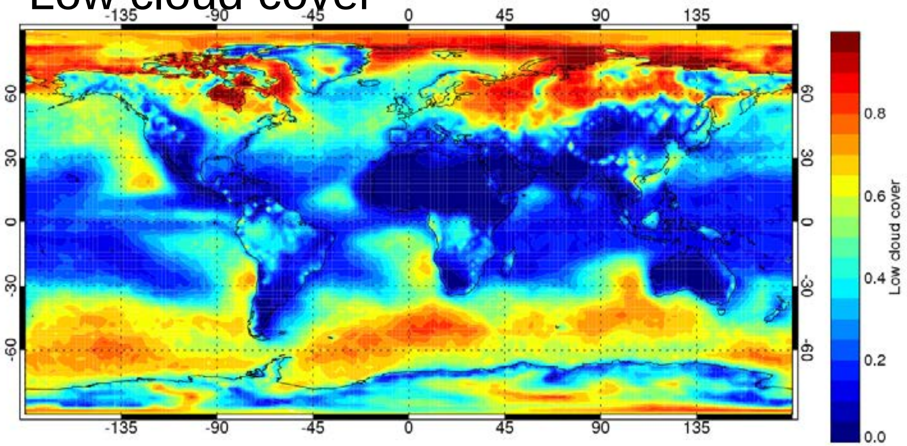
Mean Based **2007D08JF,ECMWF,IFS**



Mode Based



Low cloud cover

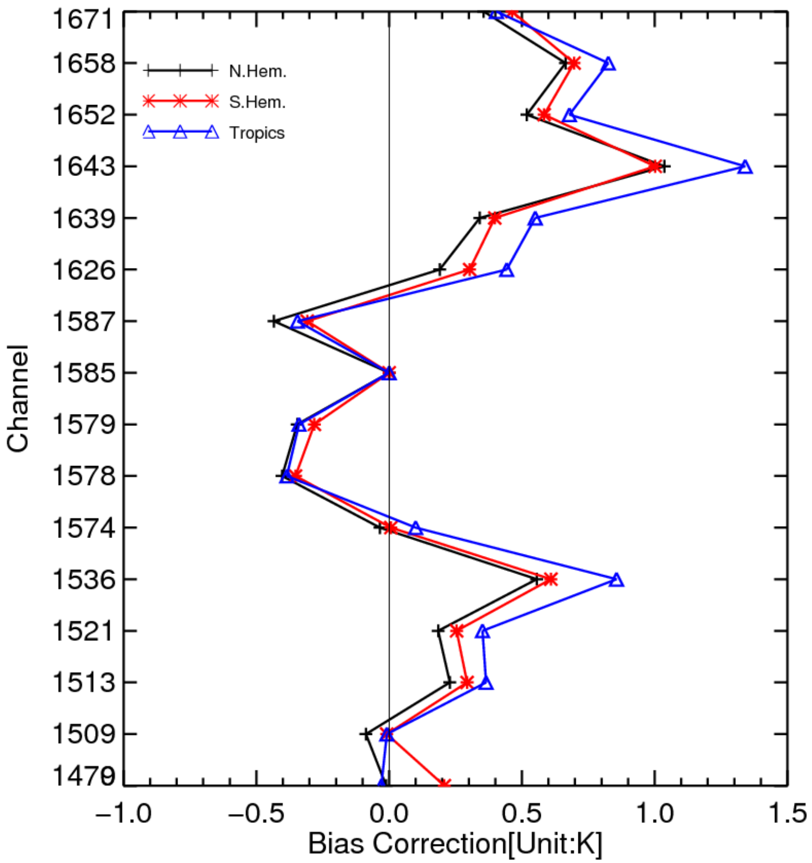


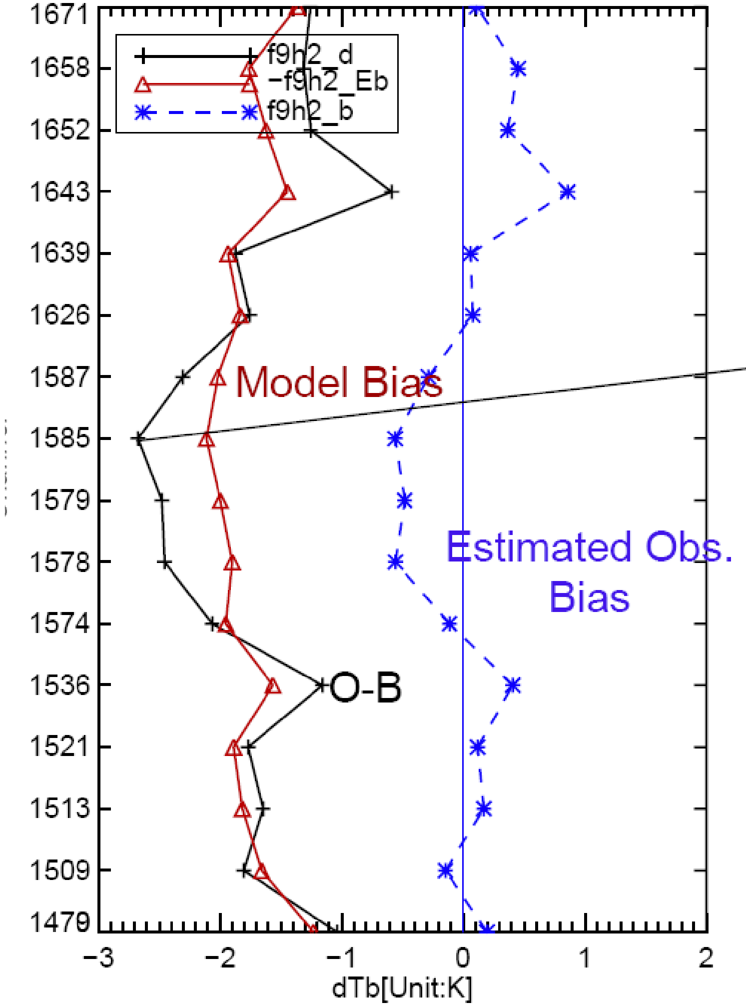
Han and McNally 2008; Li ,McNally and Geer,2010

“Anchor channel” method for IASI ozone channels

MLS→ Model Bias and Obs. Bias

d=Yo-Hx=(Yt+b)-H(Xt+Eb)
<d>=<b>-H(Eb)
<b>=<d>+ H(Eb)

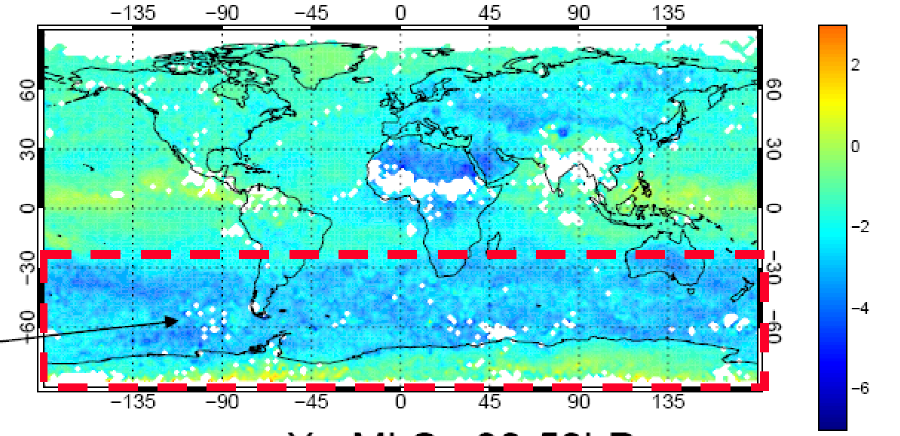




Southern Hemisphere

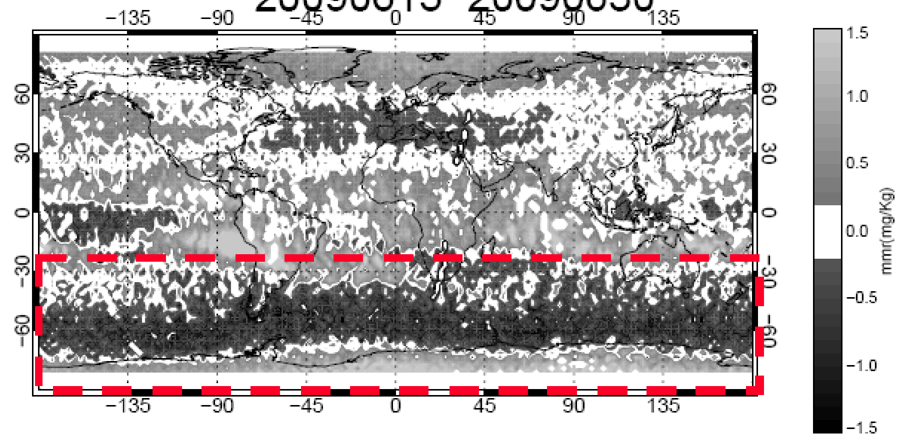
<O-B>,CH1585

20090615~20090630



<Xa-MLS>,30-50hPa

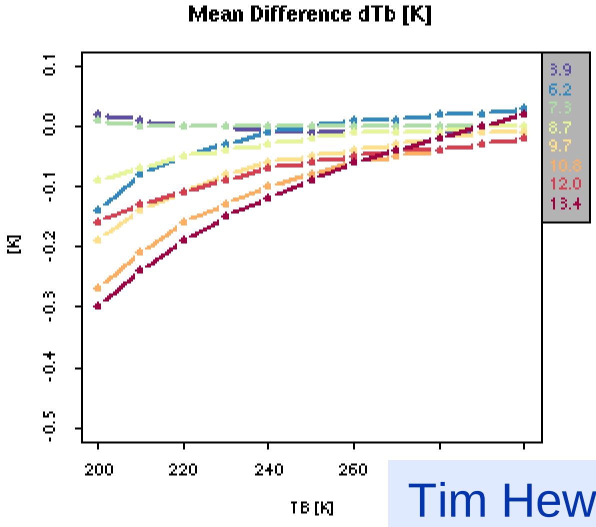
20090615~20090630

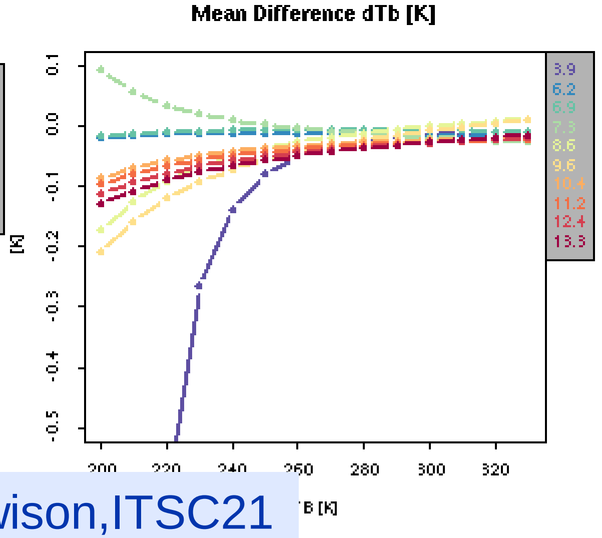


Han W. and McNally AP. 2010: The 4D-Var assimilation of ozone-sensitive infrared radiances measured by IASI. *Q. J. R. Meteorol. Soc.* 136: 2025–2037. DOI:10.1002/qj.708

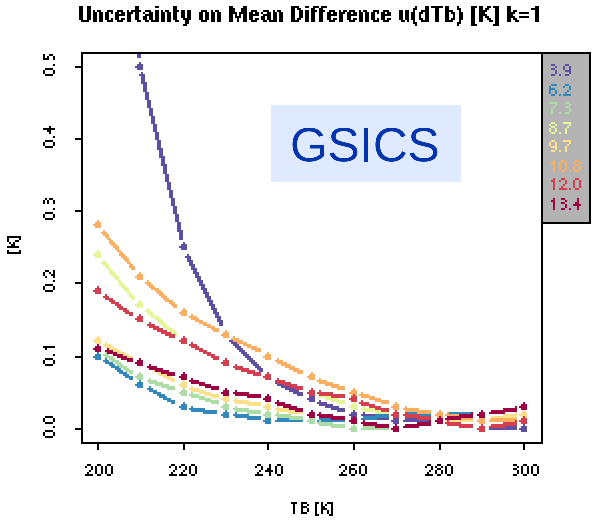
Radiometric Uncertainty

Meteosat-10/SEVIRI IR 2013-03-01/2017-03-01	Himawari-8/AHI IR 2015-07-01/2017-06-30

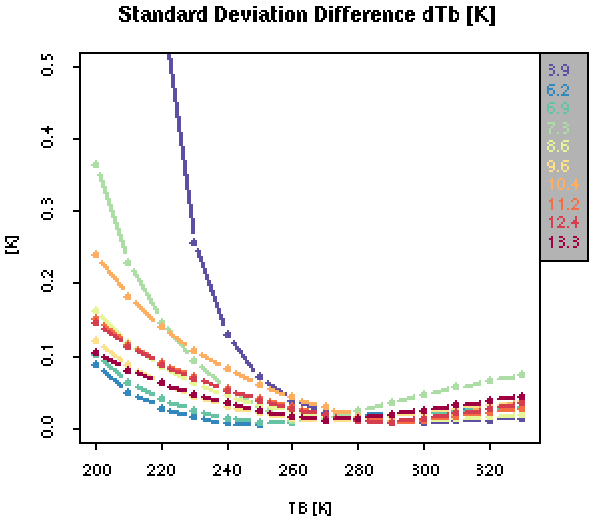




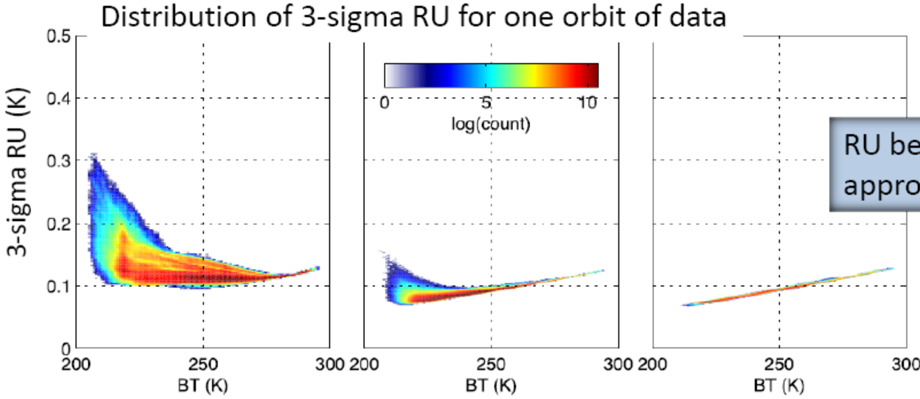
Tim Hewison,ITSC21



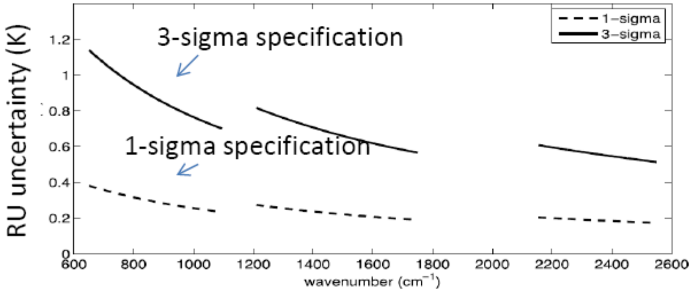
GSICS



Radiometric Uncertainty (RU)



RU better than spec by approximately a factor 4

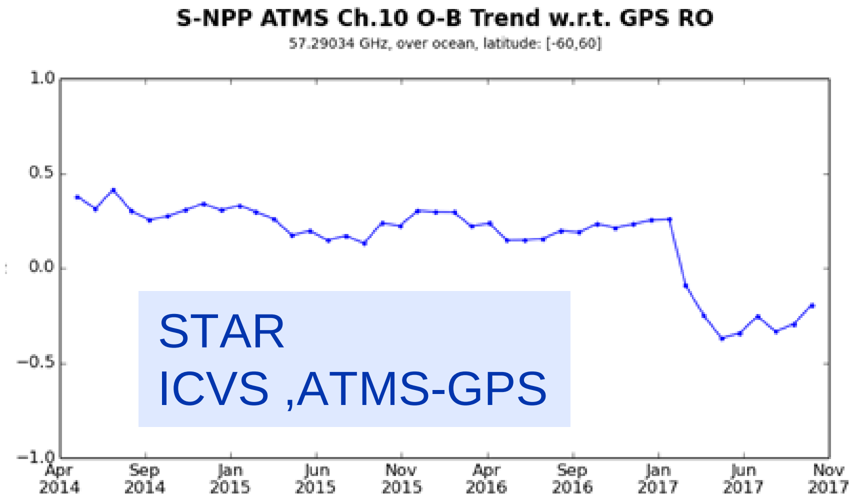


Tobin et al ,2013

Uncertainty specification @287K blackbody

Tobin et al. 2013, JGR

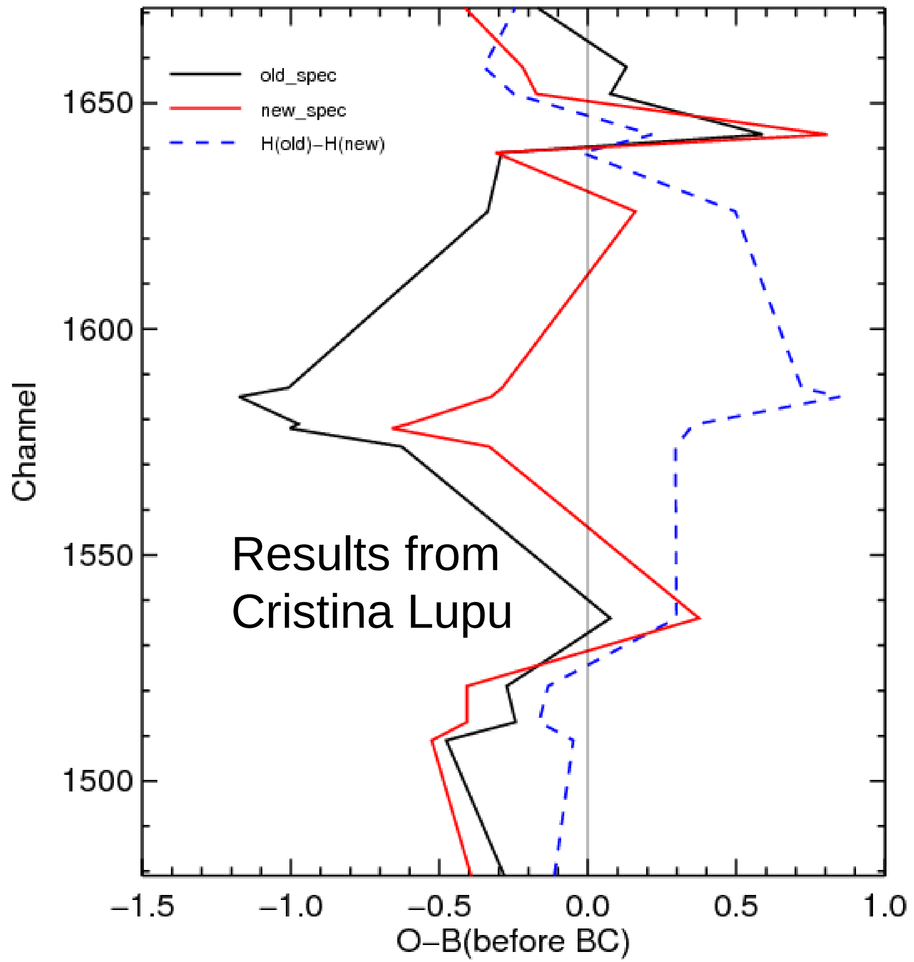
15



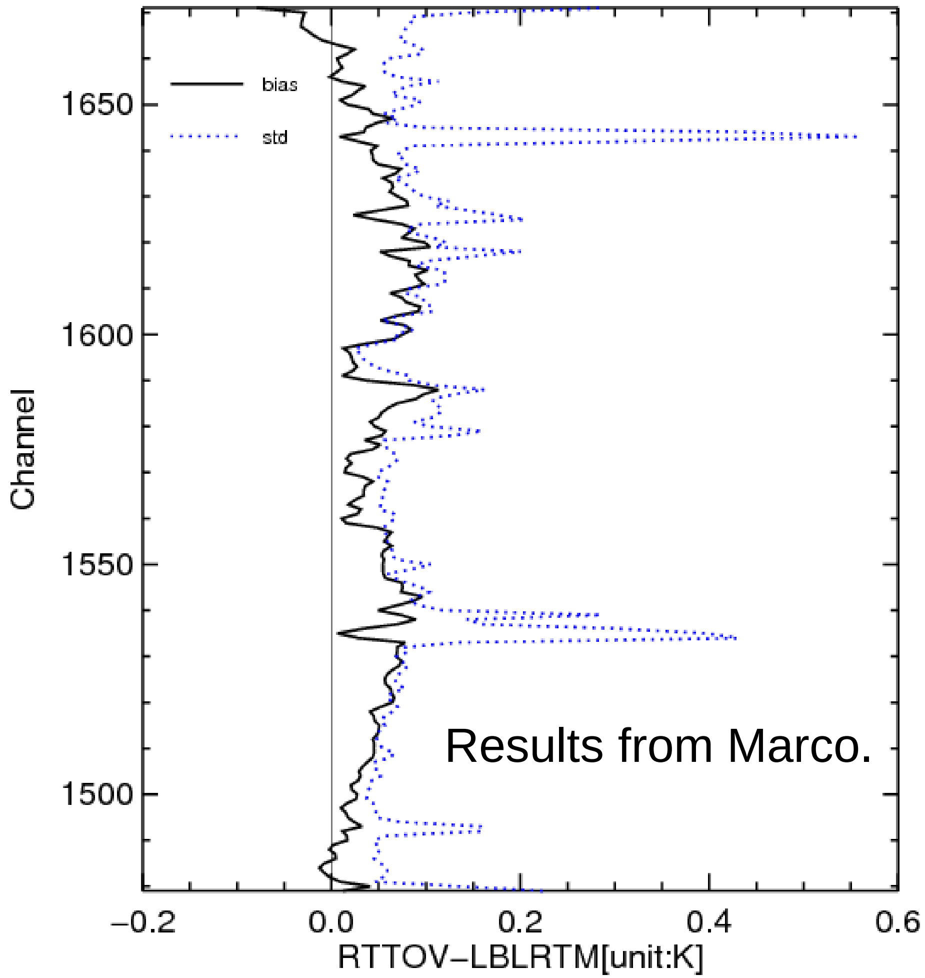
STAR
ICVS ,ATMS-GPS

RT uncertainty

RT uncertainty: old and new Spectroscopy



RT uncertainty: RTTOV-LBLRTM



IASI ozone channels

Constrained Bias Correction

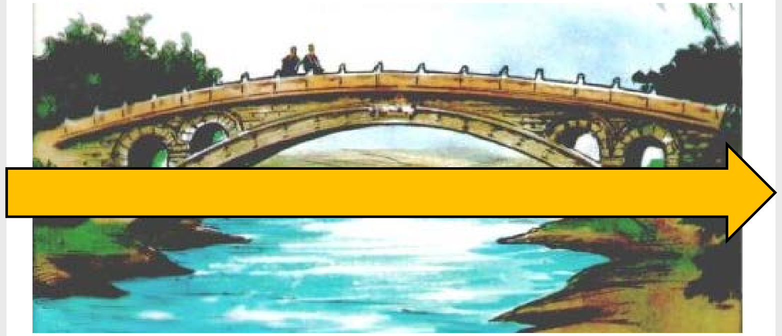
Comparison of IASI radiances with NWP models from four operational centres

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

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

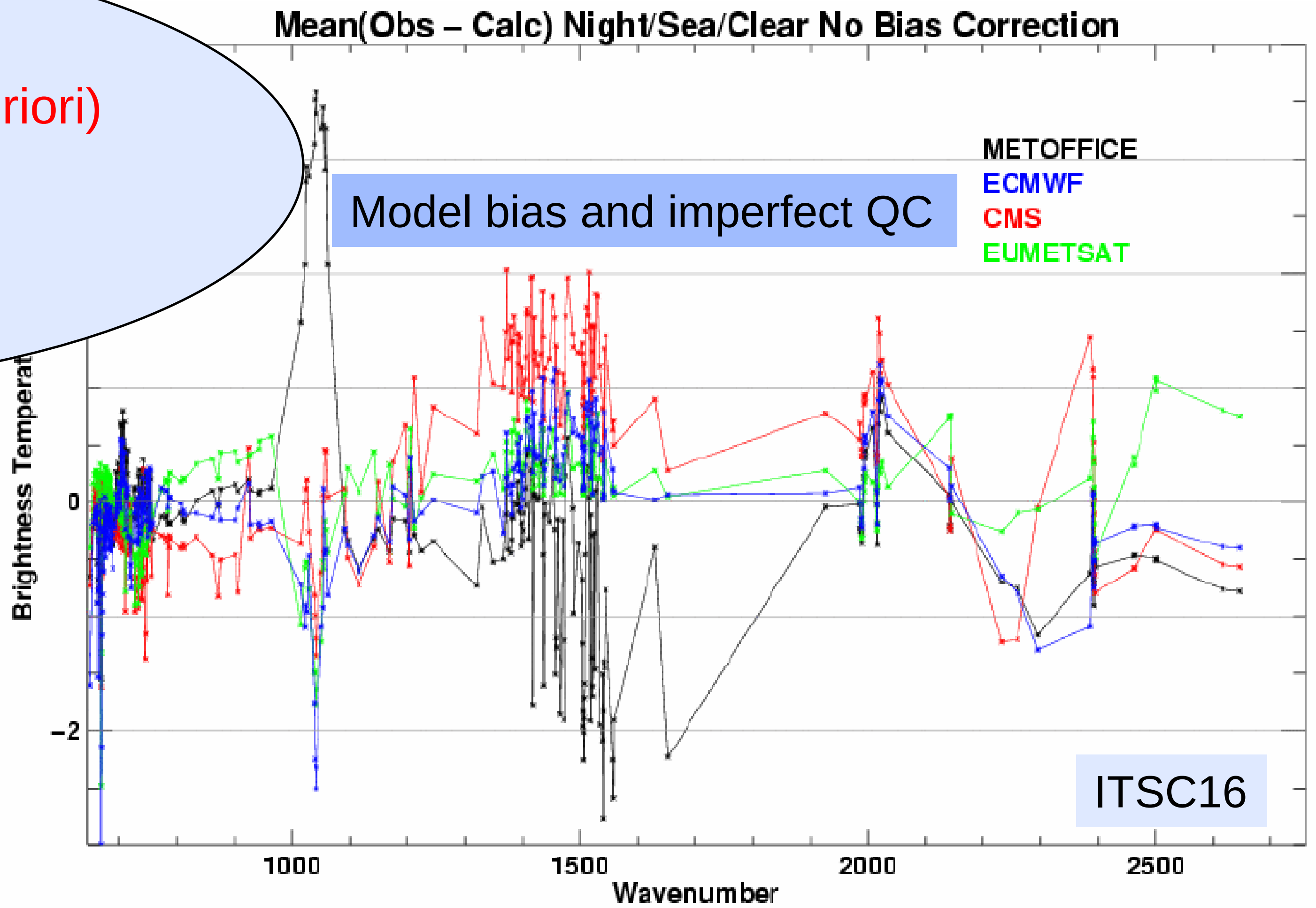
How to use the
UNCERTAINTY INFORMATION(Priori)
From GSICS、calibration and RT model in
BIAS CORRECTION?

UNCERTAINTY



BIAS CORRECTION

Connect the two GROUP



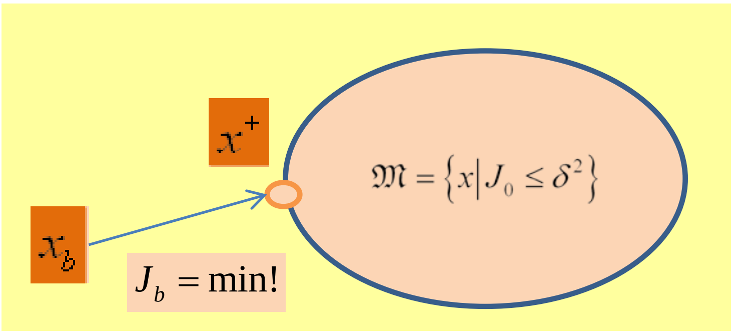
Model bias and imperfect QC

ITSC16

Methodology: Constrained Variational Bias Correction (CvarBC)

$$\|\mathbf{b}\| \le \|\mathbf{e}\|_{calibration} + \|\mathbf{e}\|_{RT\,model} + \|\mathbf{e}\|_{other}$$

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



$$J_b = \min_{x \in m} \qquad m = \{x \mid J_0 \le \delta\}$$

$$||\mathrm{h}(\mathrm{x},\beta) - b_0|| \le \delta^2$$

Constrain the total size of bias correction to each channel (Weak Constraint)

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

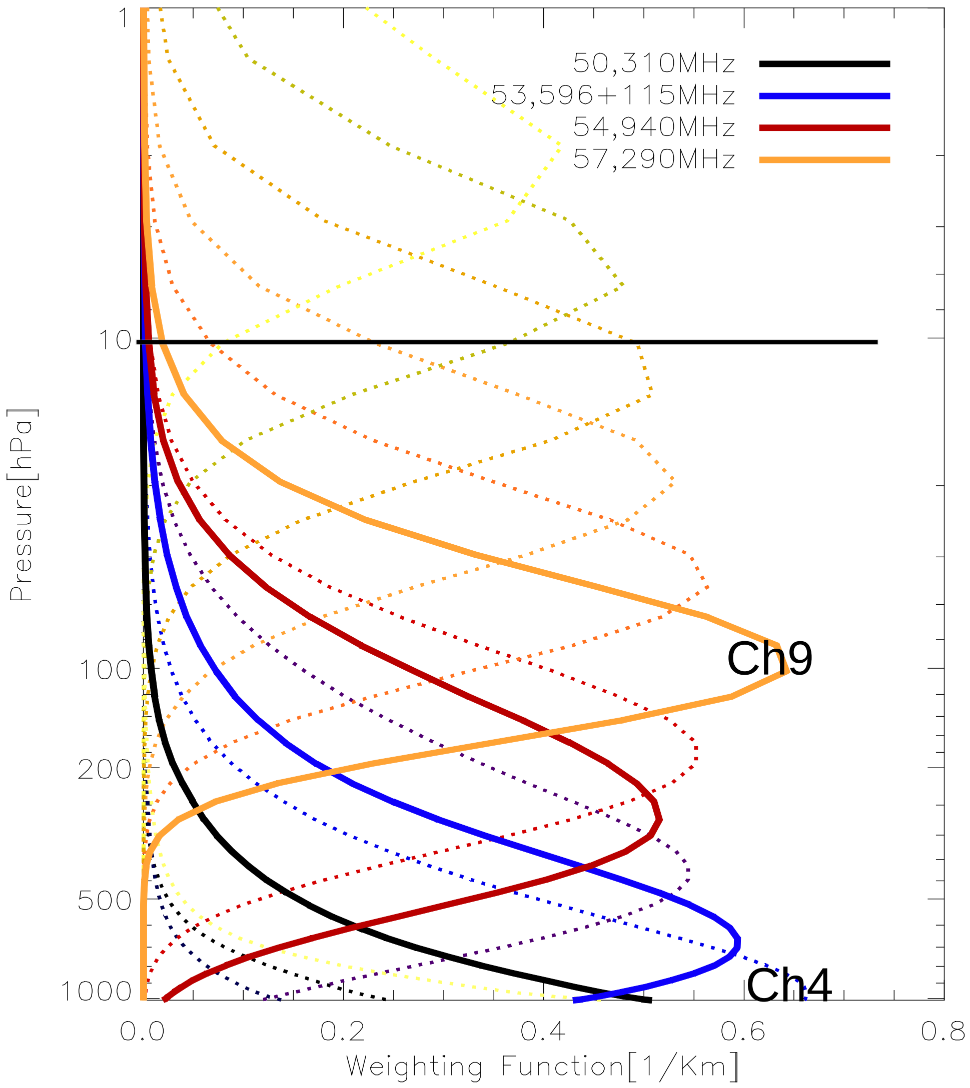
$$\mathbf{d} = \mathbf{y} - H(\mathbf{x})$$

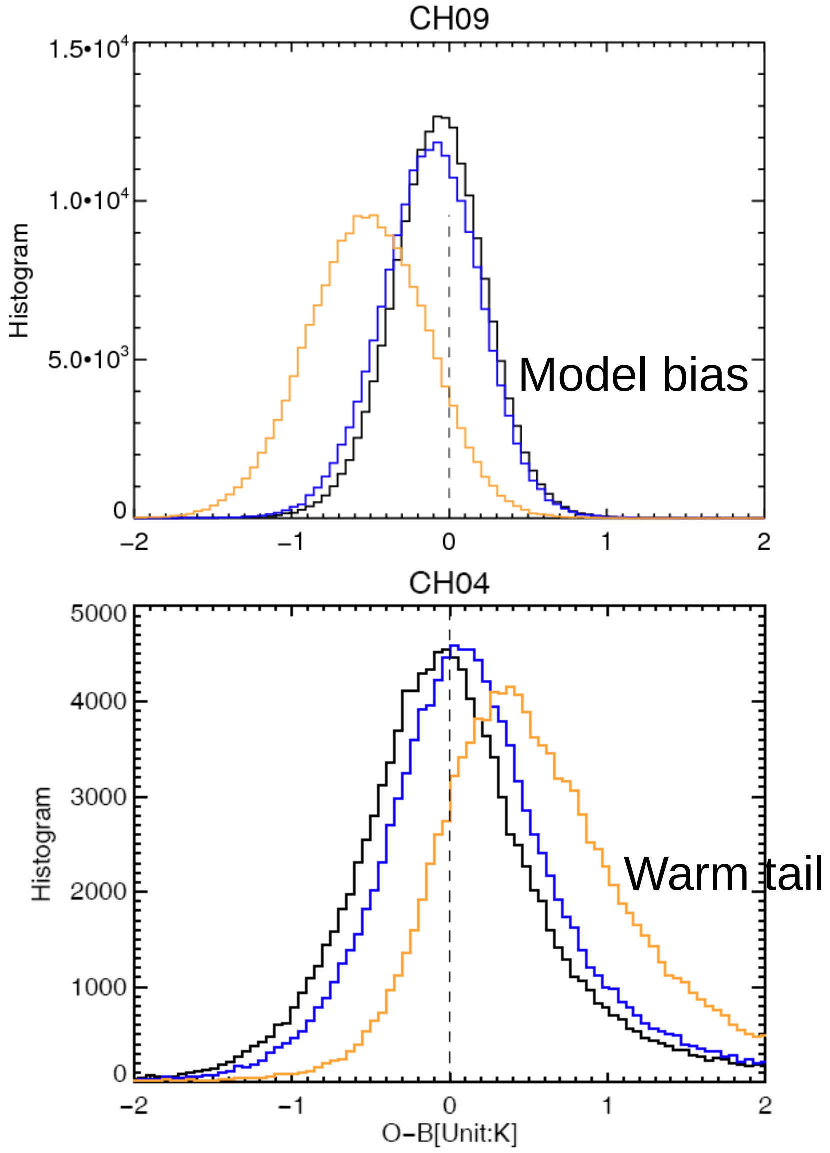
$$\mathbf{P}\boldsymbol{\beta} = h(\mathbf{x},\boldsymbol{\beta})$$

Han,2014,ITSC19

$$\begin{aligned}\nabla_{\boldsymbol{\beta}} J(\mathbf{x},\boldsymbol{\beta}) &= \mathbf{B}_\beta^{-1}(\boldsymbol{\beta}-\boldsymbol{\beta}_b) - \mathbf{P}^T\mathbf{R}^{-1}[\mathbf{d}-\mathbf{P}\boldsymbol{\beta}] + \alpha^2\mathbf{P}^T\mathbf{R}_b^{-1}[\mathbf{P}\boldsymbol{\beta}-\mathbf{b}_0] \\ &= (\mathbf{B}_\beta^{-1} + \mathbf{P}^T\mathbf{R}^{-1}\mathbf{P} + \alpha^2\mathbf{P}^T\mathbf{R}_b^{-1}\mathbf{P})\boldsymbol{\beta} - (\mathbf{B}_\beta^{-1}\boldsymbol{\beta}_b + \mathbf{P}^T\mathbf{R}^{-1}\mathbf{d} + \alpha^2\mathbf{P}^T\mathbf{R}_b^{-1}\mathbf{b}_0)\end{aligned}$$

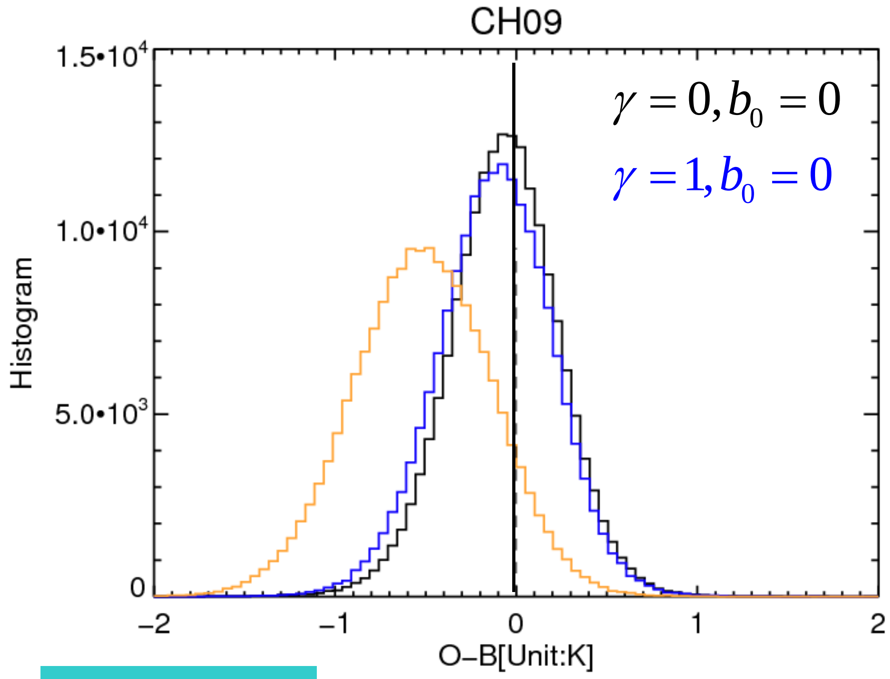
Experiments in GRAPES



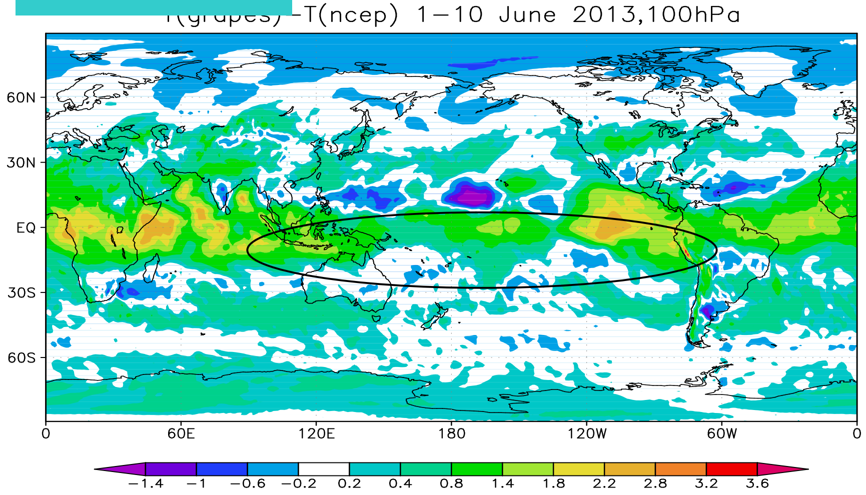


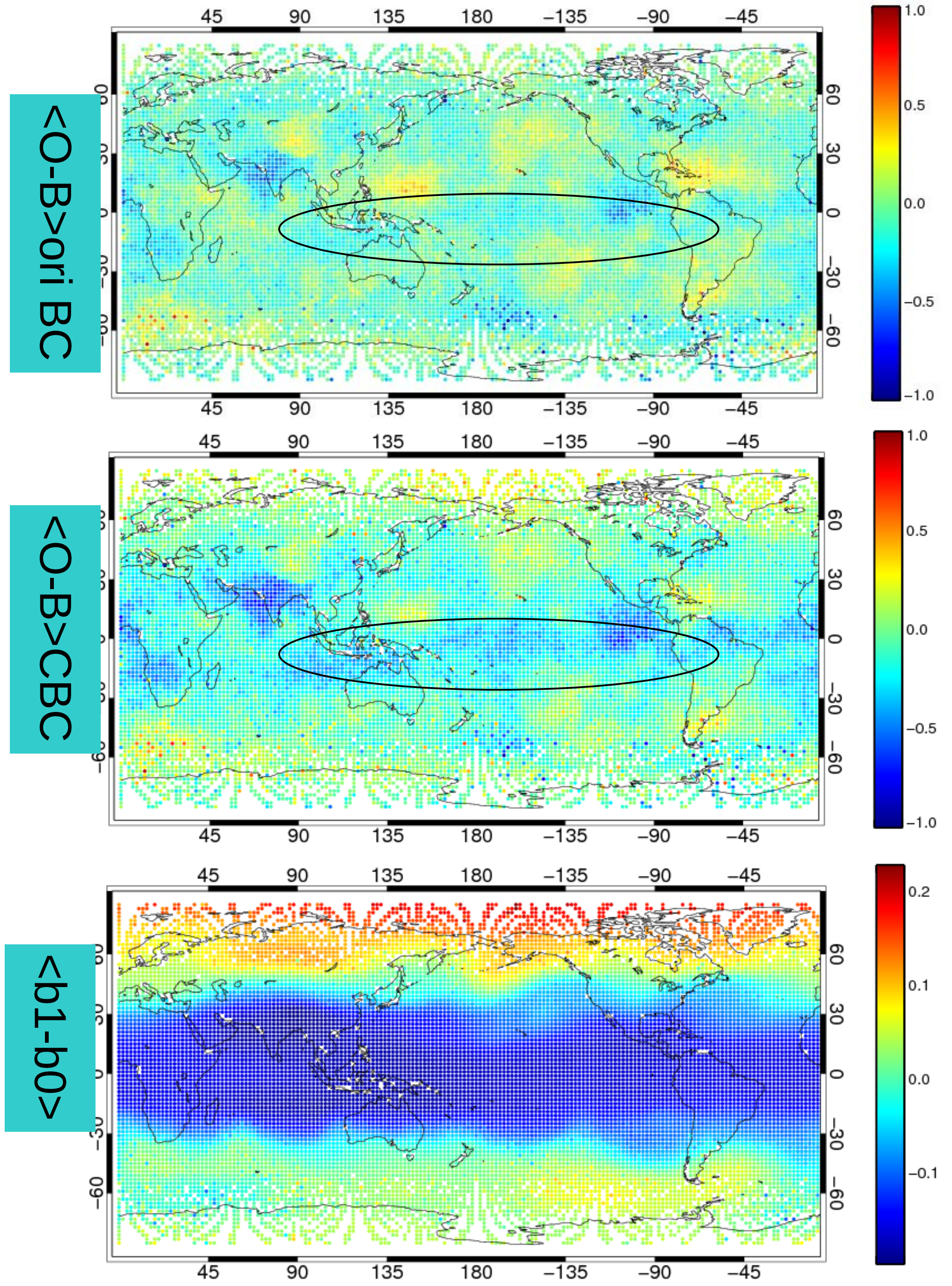
AMSUA CH9(Metop_A)

1-10 June 2013

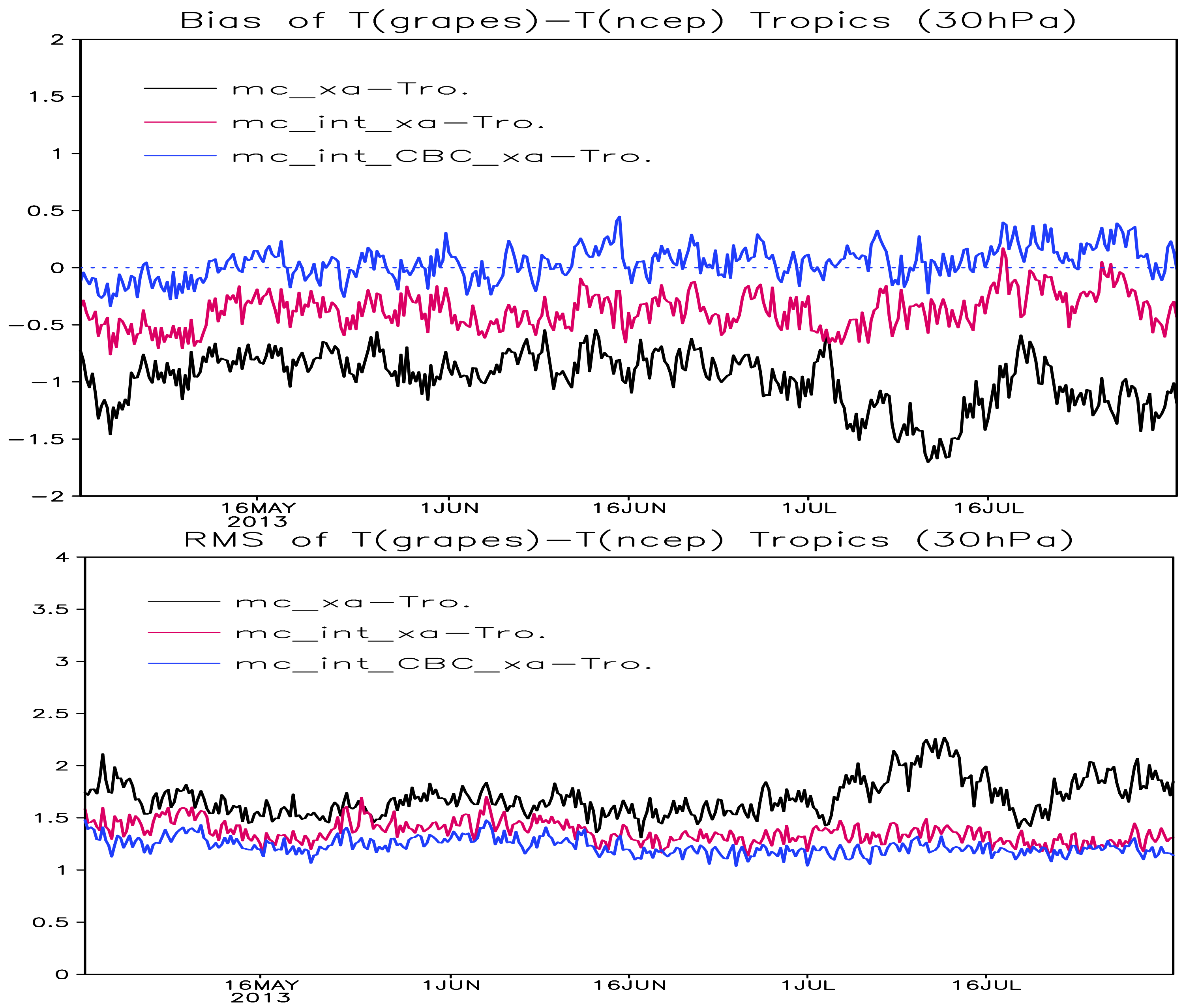


Model Bias





Two months cycle experiments in GRAPES global May-June 2013

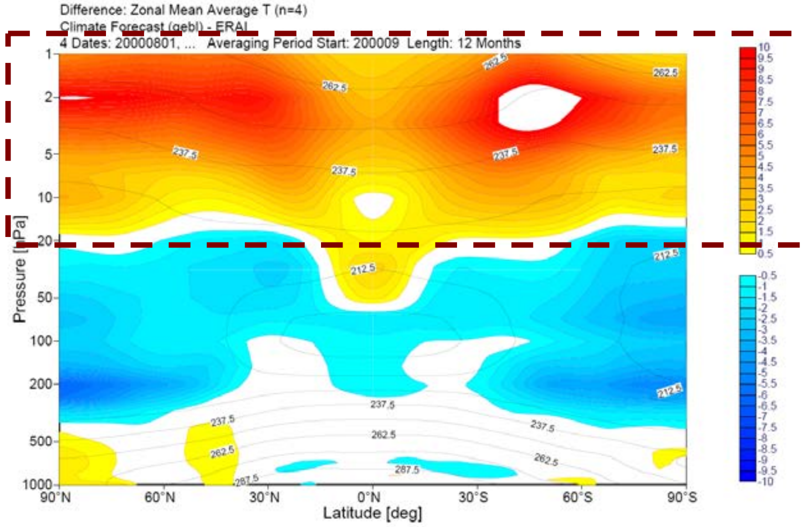


CVarBC for AMSU-A Ch14 in ECMWF IFS: Background

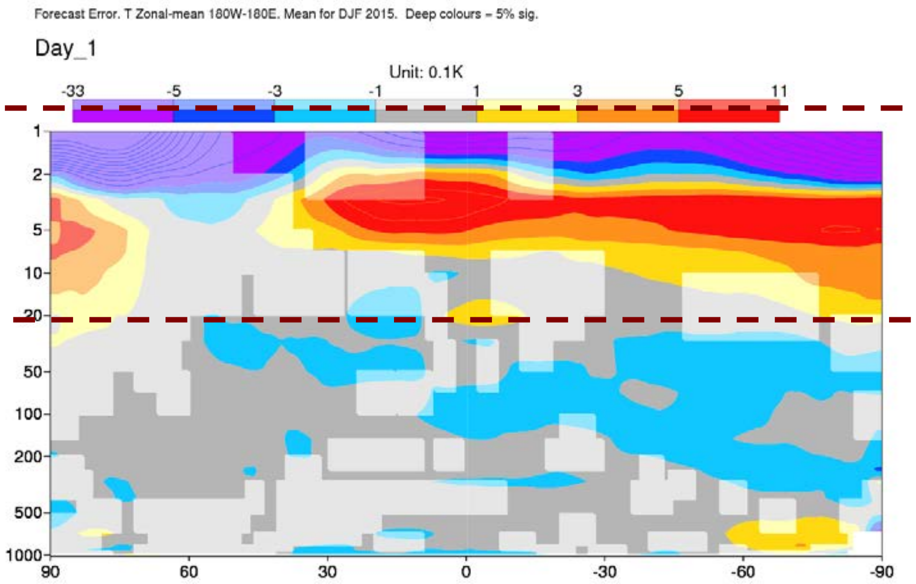
There are systematic errors in model background,

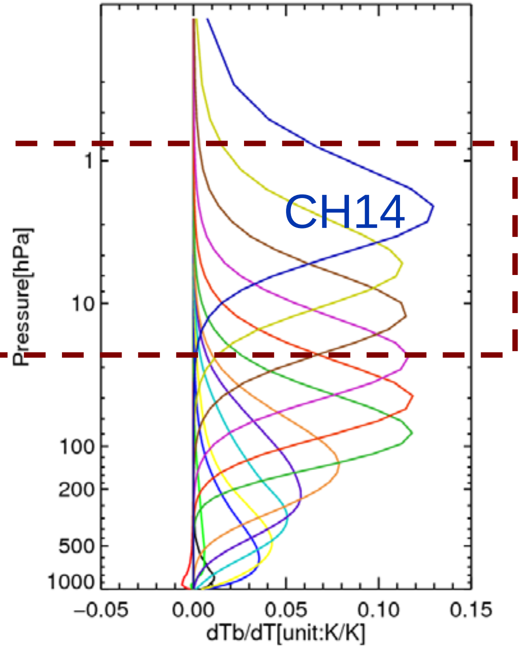
IF there are not enough unbiased observations to constrain the analysis.

CY42R1:Climate 2000-2001



2014D15JF: 24h Forecast T bias

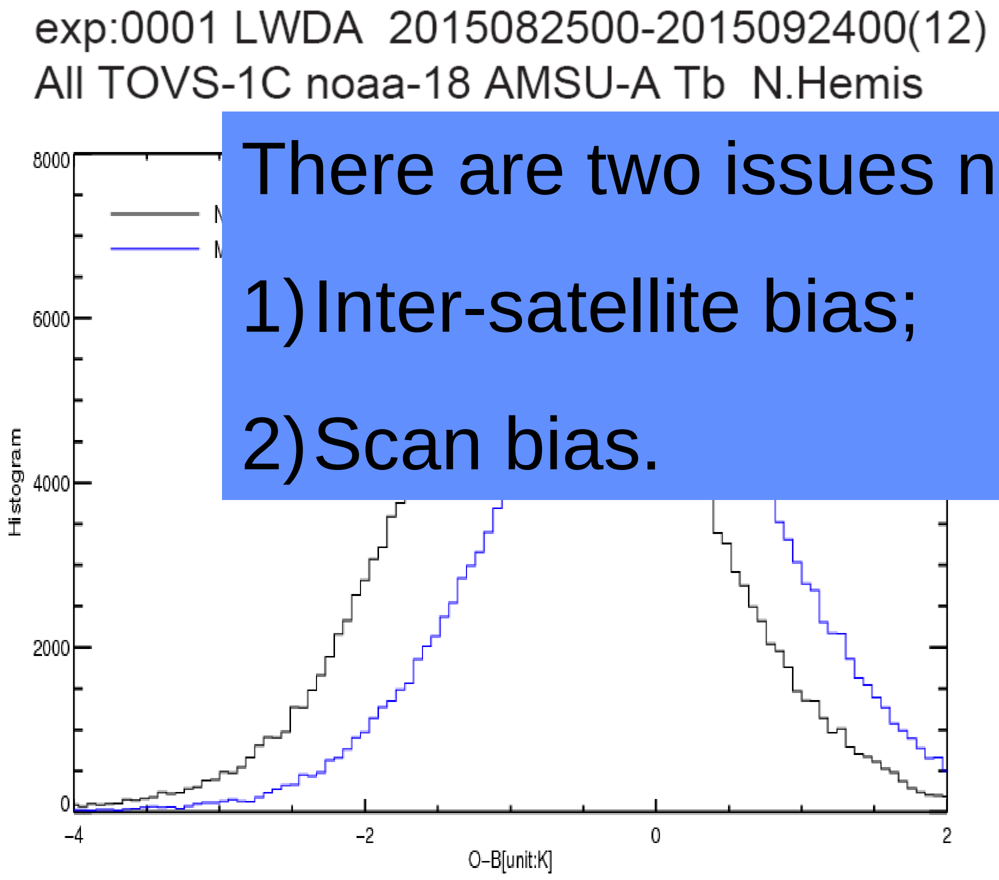


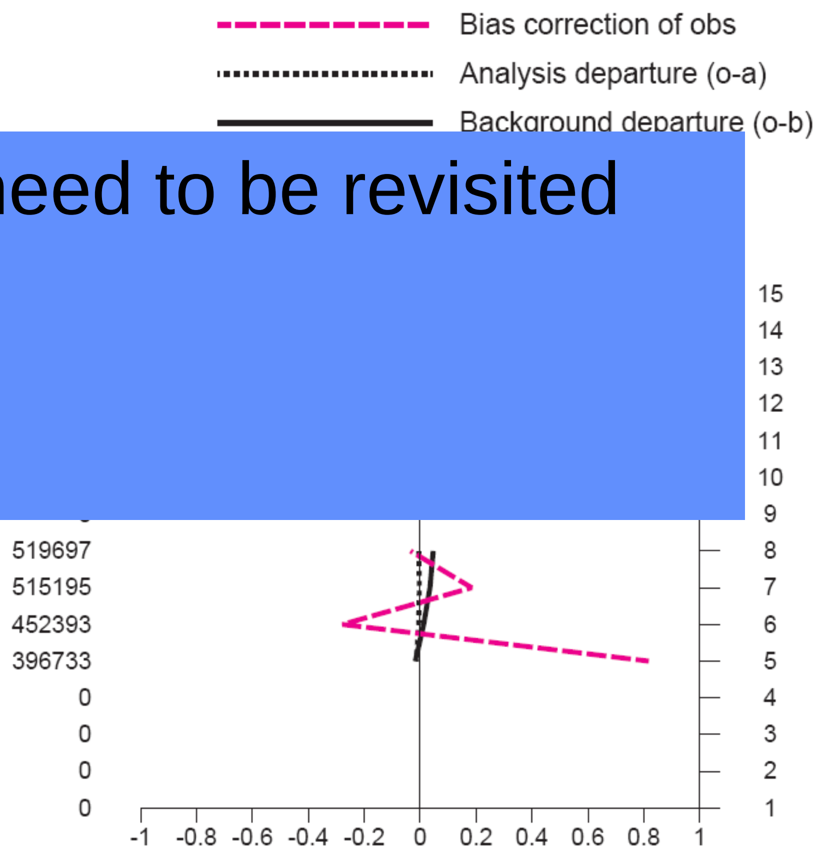


Constrained VarBC in IFS

CVarBC for AMSU-A Ch14 in ECMWF IFS : Background

A.McNally,2007: The assimilation of uncorrected AMSU-A ch14 to anchor the VarBC





There are two issues need to be revisited

1) Inter-satellite bias;

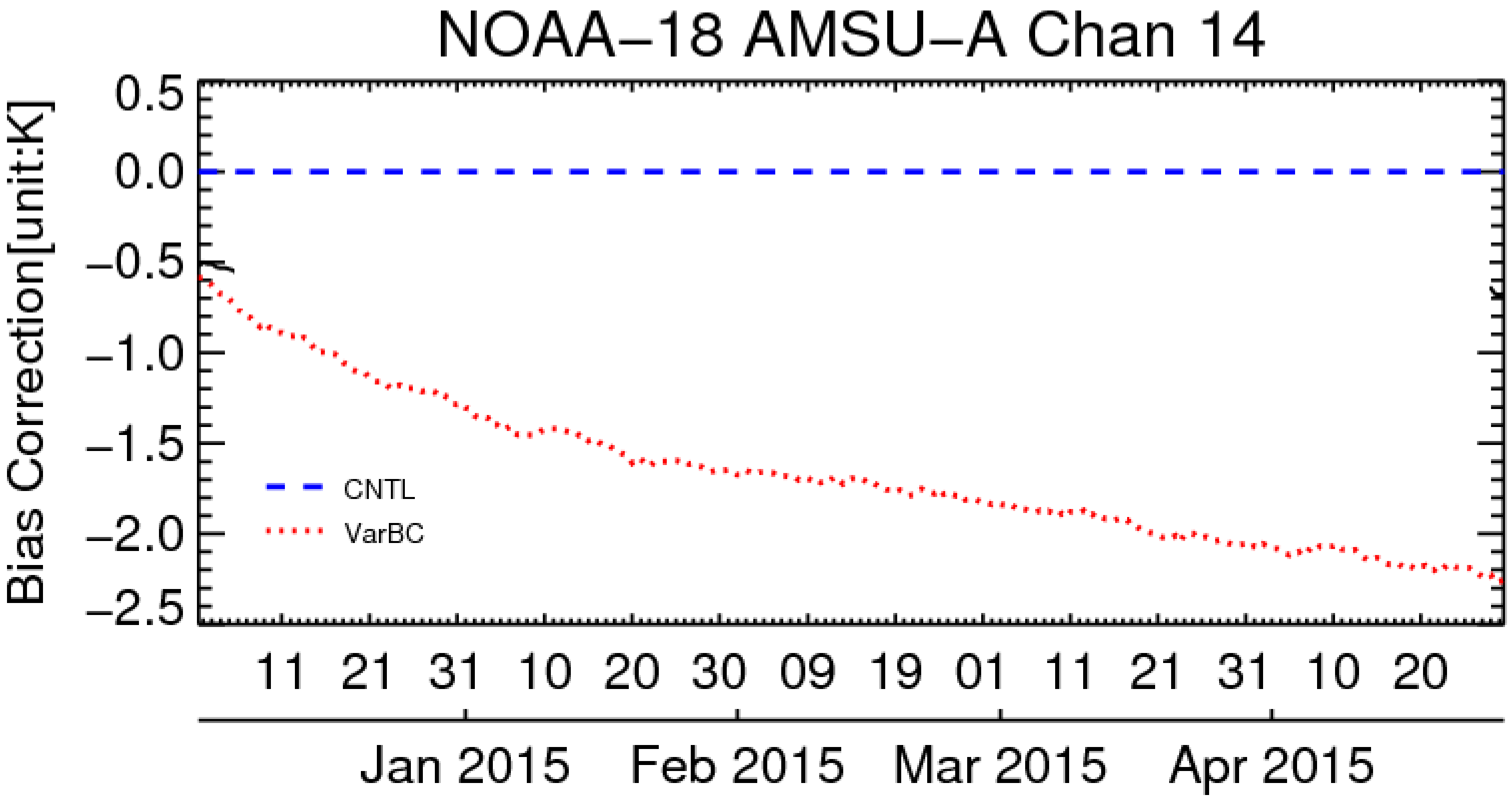
2) Scan bias.

Constrained VarBC in IFS

Drift to model bias without anchor

Bias correction of AMSU-A Ch14 in IFS CY41R2(nbgstdv=10):

1) Free VarBC will drift gradually;
2) It will affect the bias correction of Ch13 and Ch12;



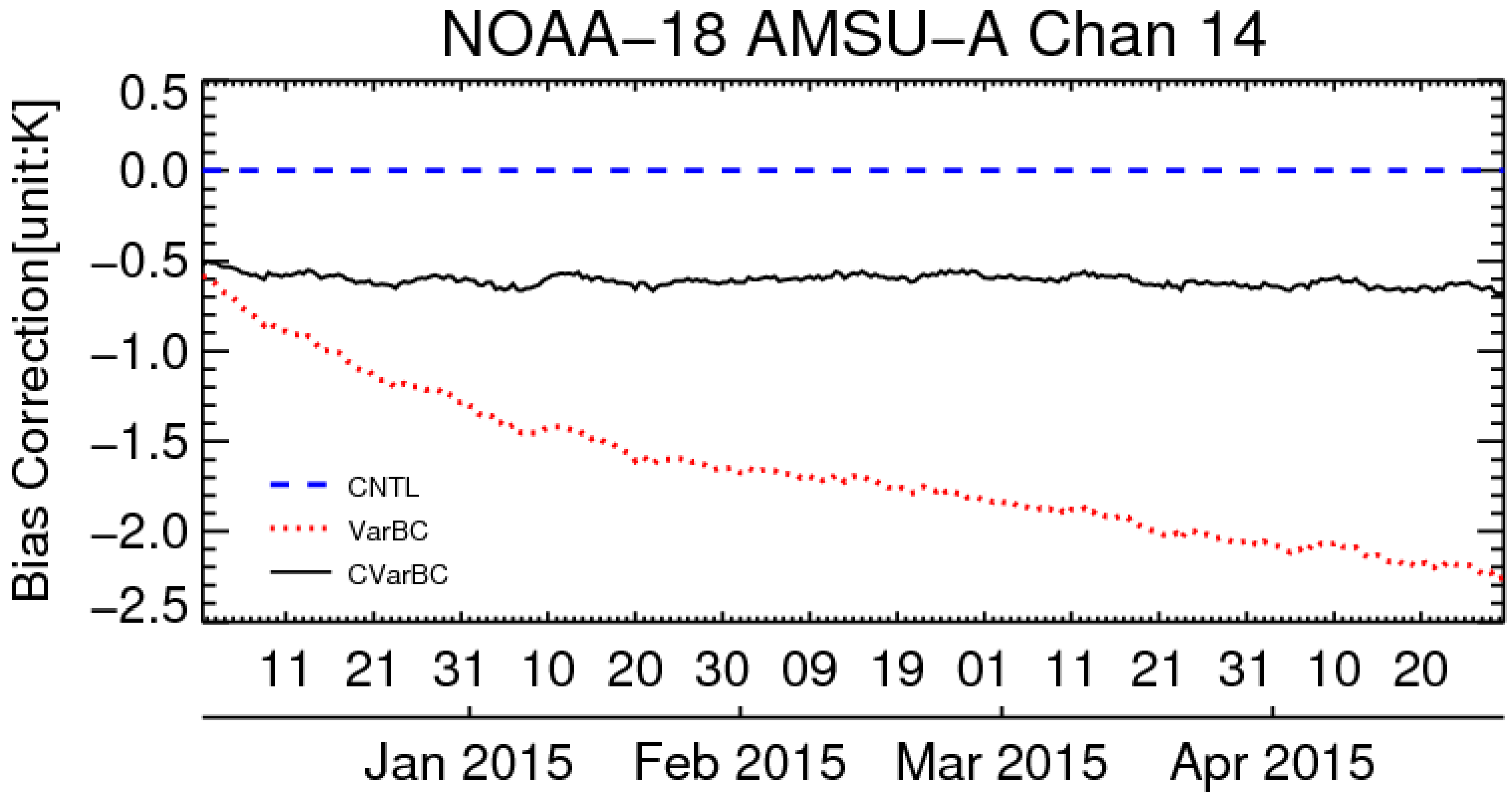
Implementation of Constrained VarBC in IFS and CY41R2 experiments

$$\alpha^2[h(\mathbf{x},\boldsymbol{\beta})-\mathbf{b}_0]^T\mathbf{R}_b^{-1}[h(\mathbf{x},\boldsymbol{\beta})-\mathbf{b}_0]$$

CVarBC

AMSU-A	alpha	Bias0	B(bias0)*
Channel 14	0.3	0	1.4
Channel 13	0.0	0	0.85
Channel 12	0.0	0	0.5

*Same as observation error

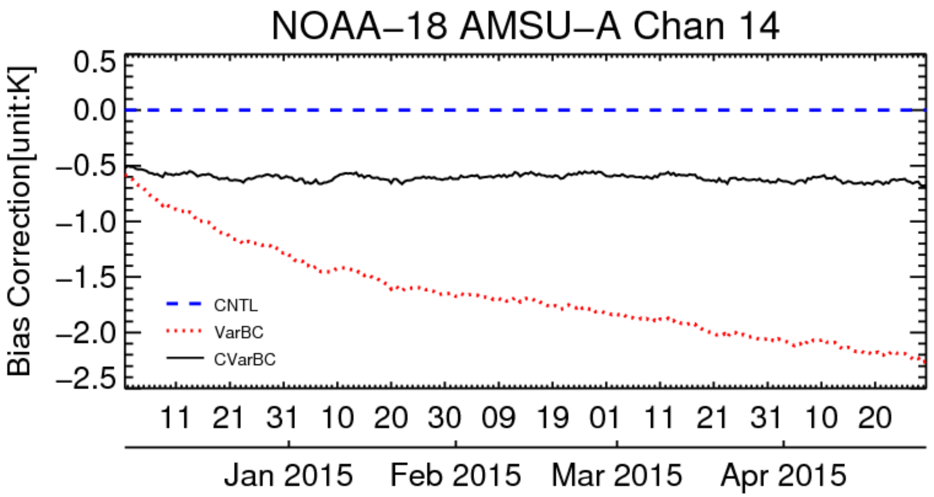


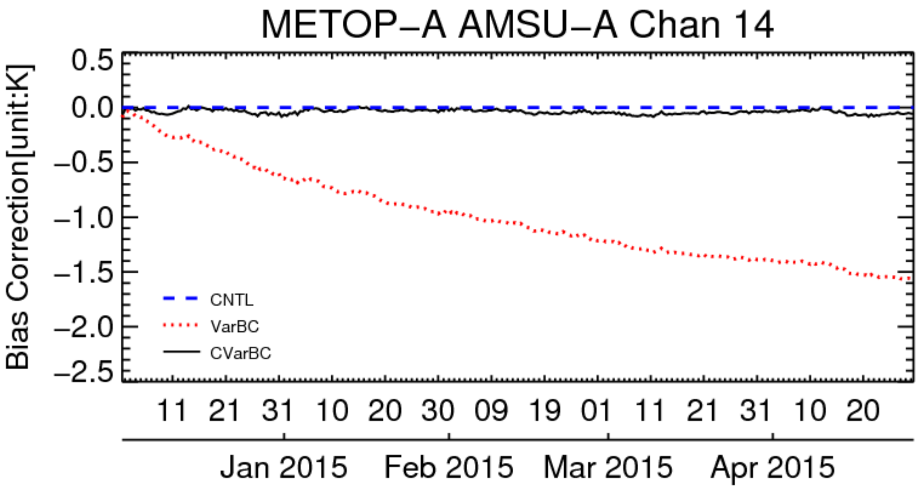
Constrained VarBC in IFS

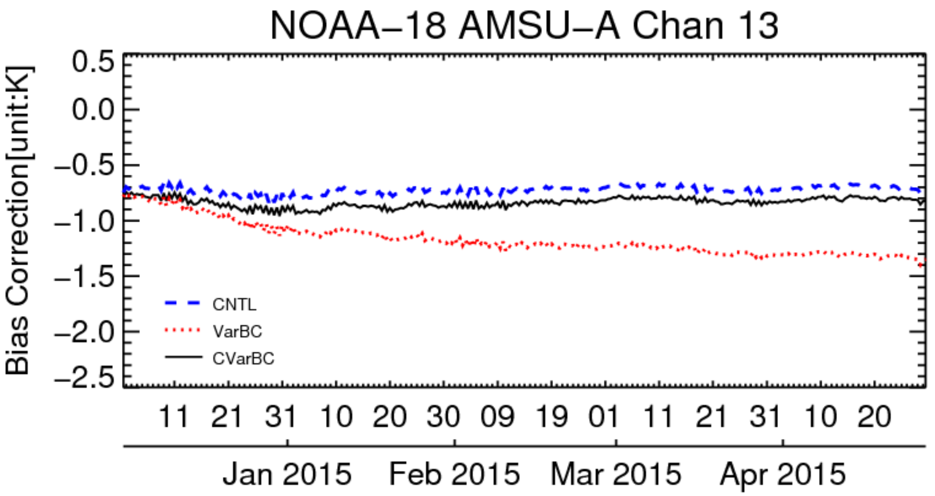
Temporal Evolution of bias correction

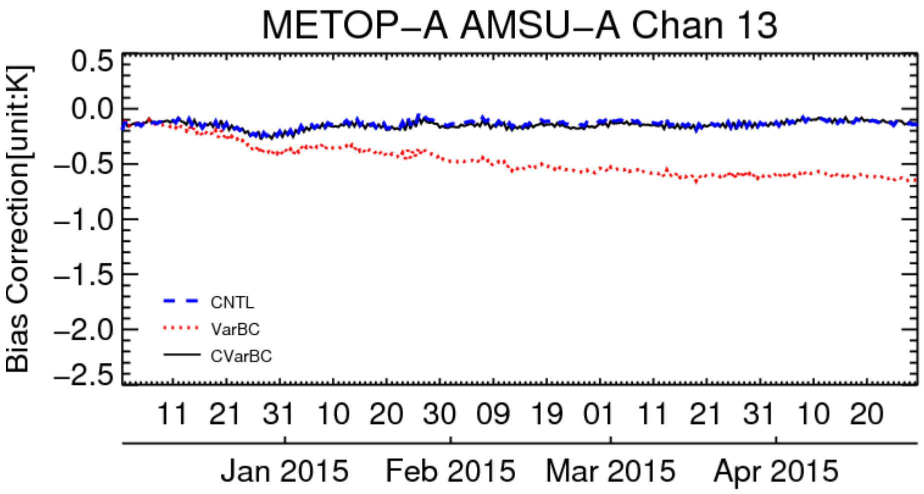
NOAA-18

METOP-A



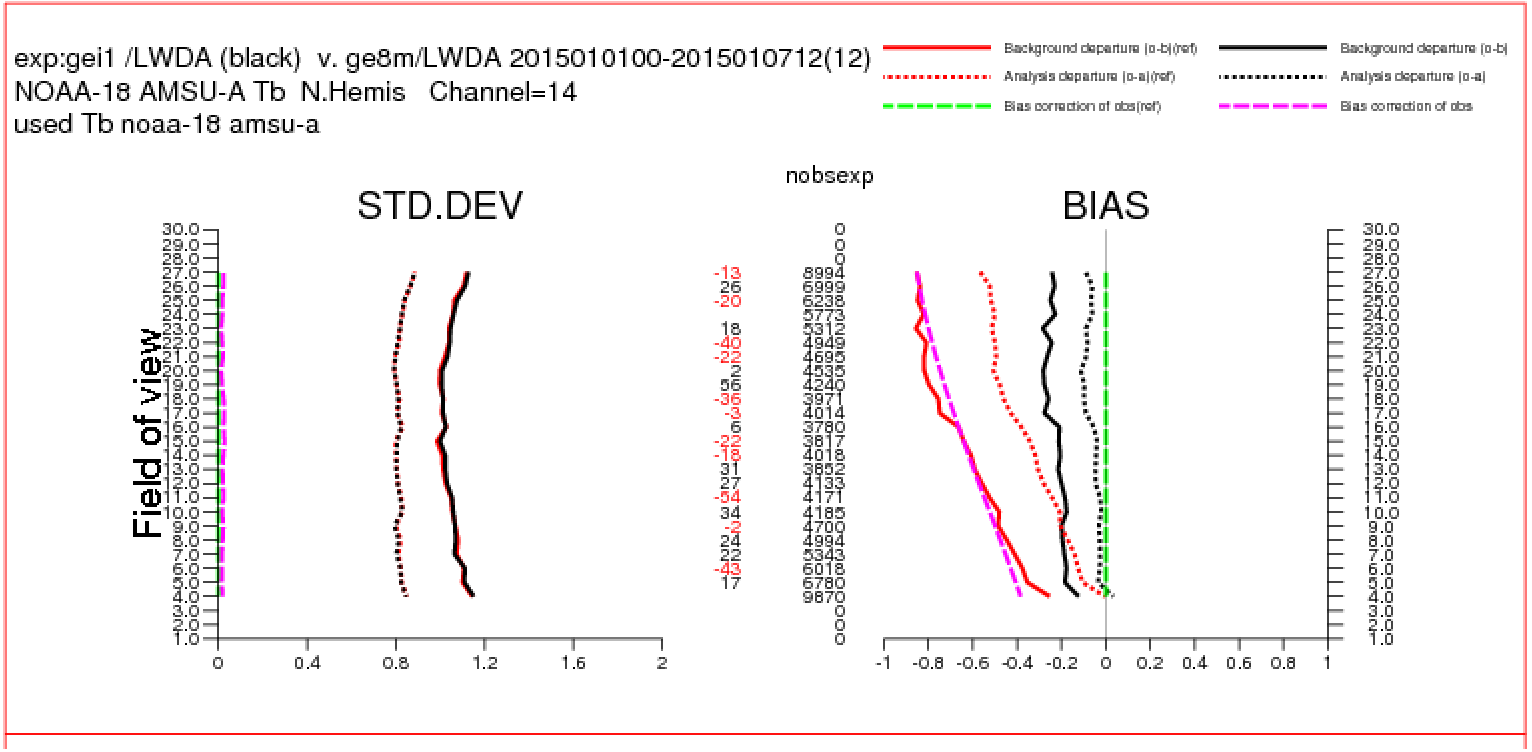






Constrained VarBC in IFS

Scan bias correction



Constrained VarBC in IFS

AMSU-A Ch14 <O-B>(2014-12-15~ 2014-12-31)

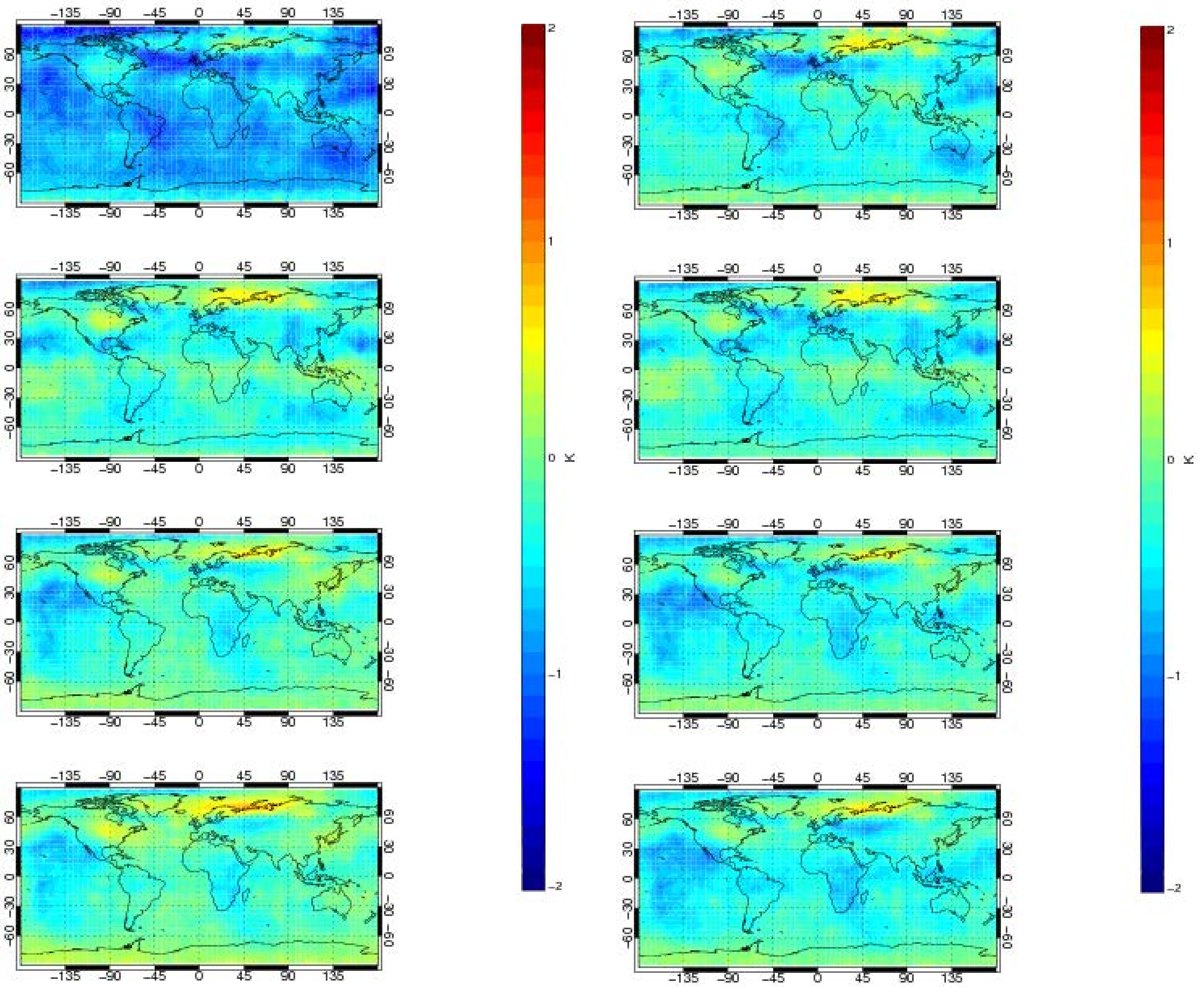
CNTL | CVarBC

NOAA-18

NOAA-19

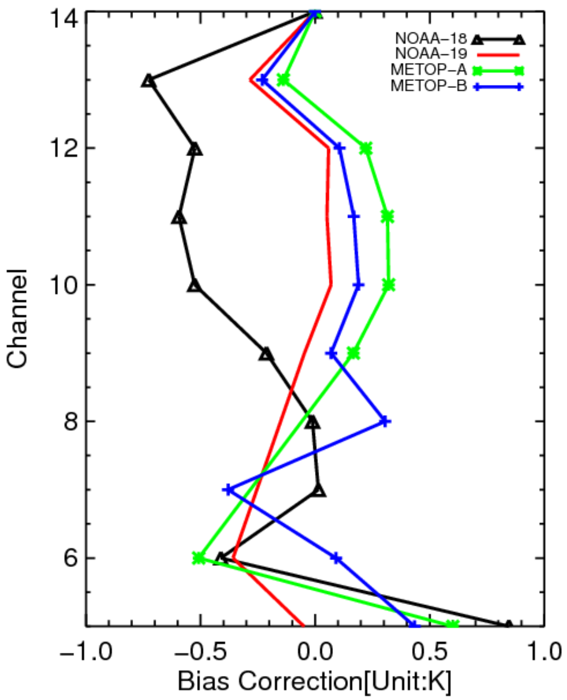
METOP-A

METOP-B

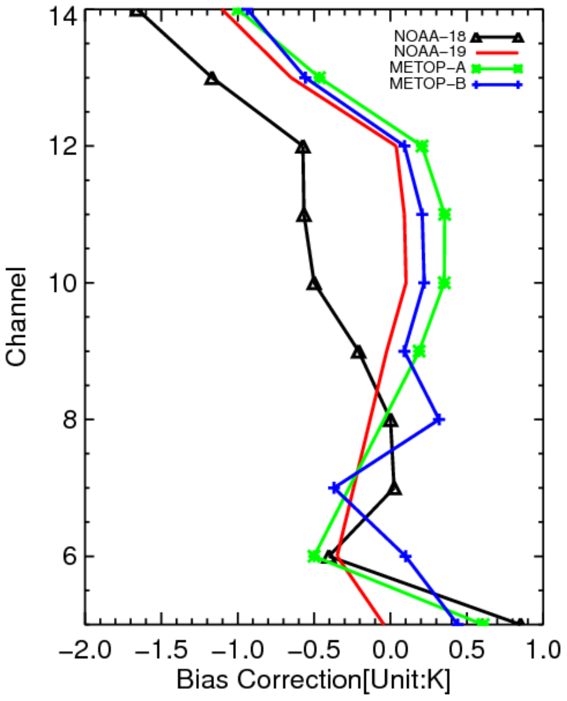


Mean Bias Correction in 2014D15JF

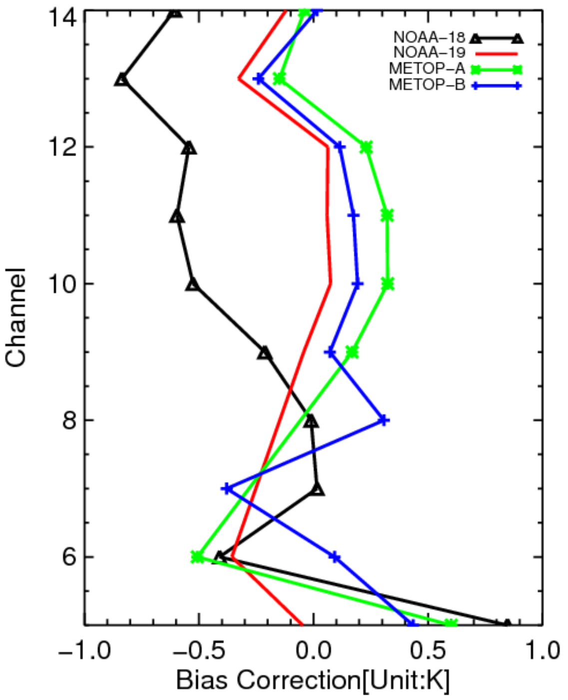
CNTL



VarBC



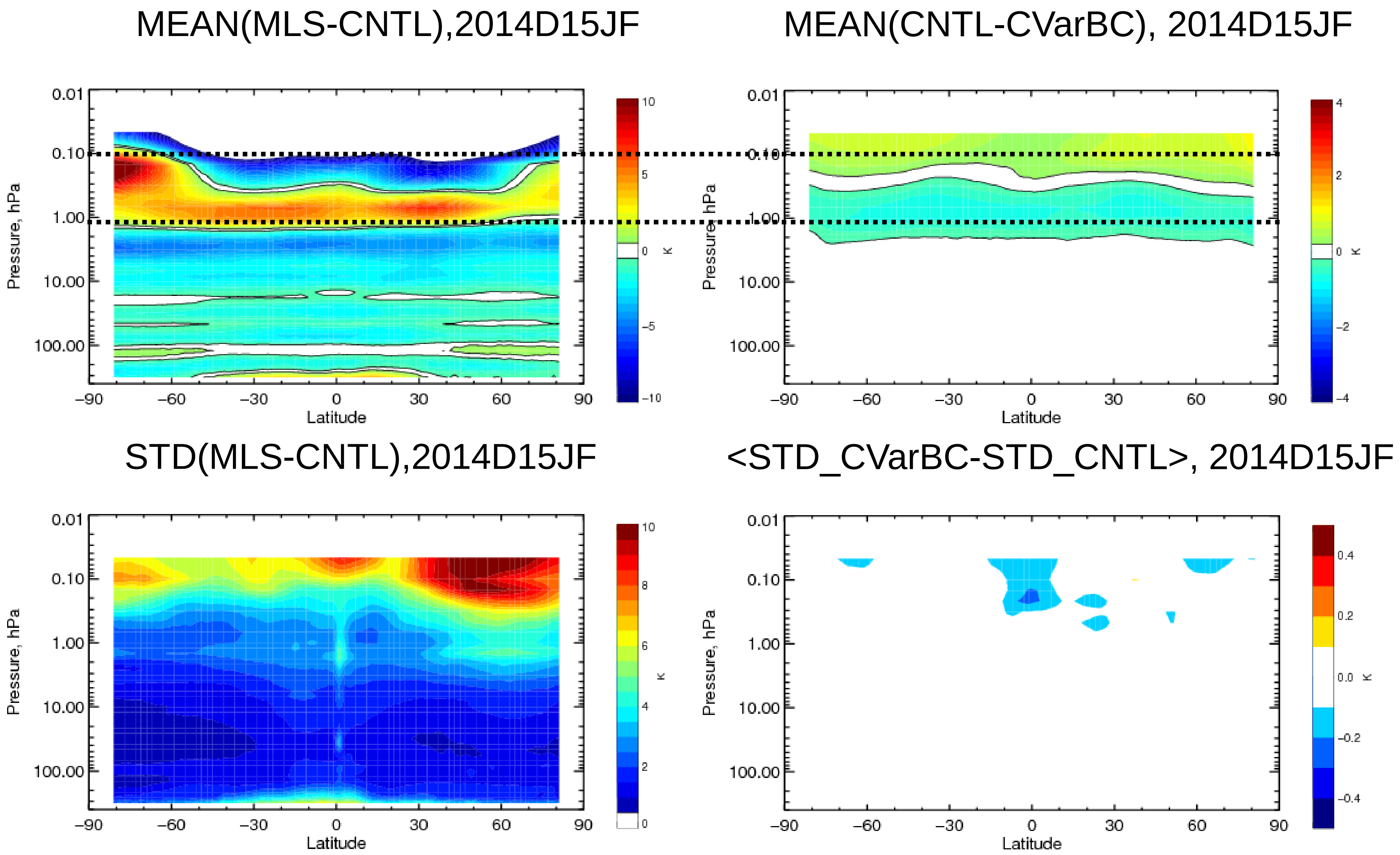
CVarBC



Constrained VarBC in IFS

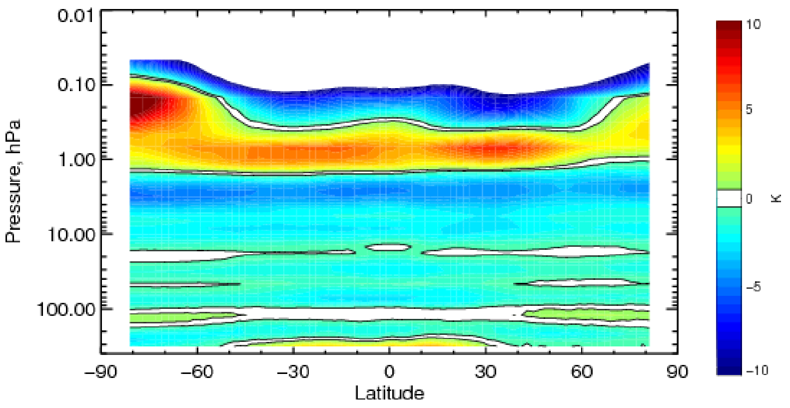
Thanks Rossana!

Verification using MLS Temperature retrieval

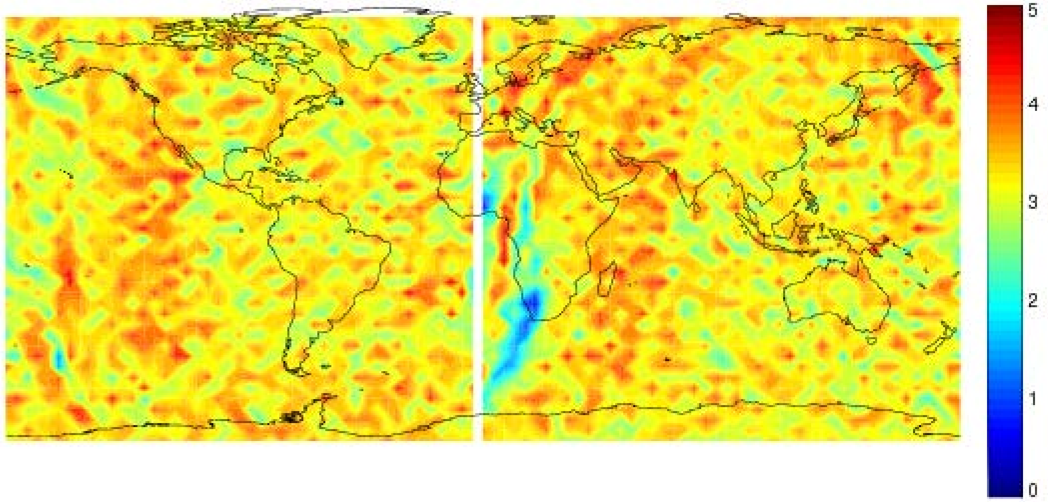


Temperature bias at 1hPa

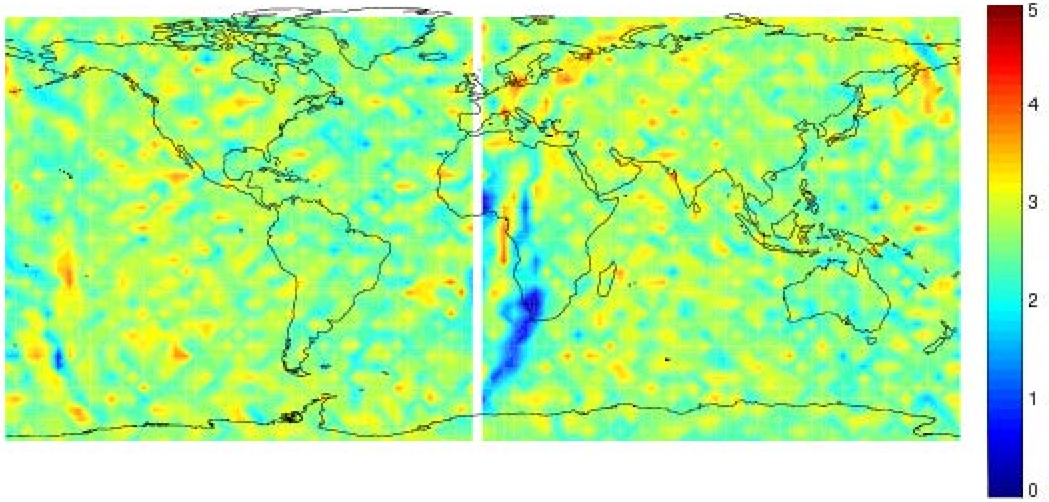
MEAN(MLS-CNTL),2014D15JF



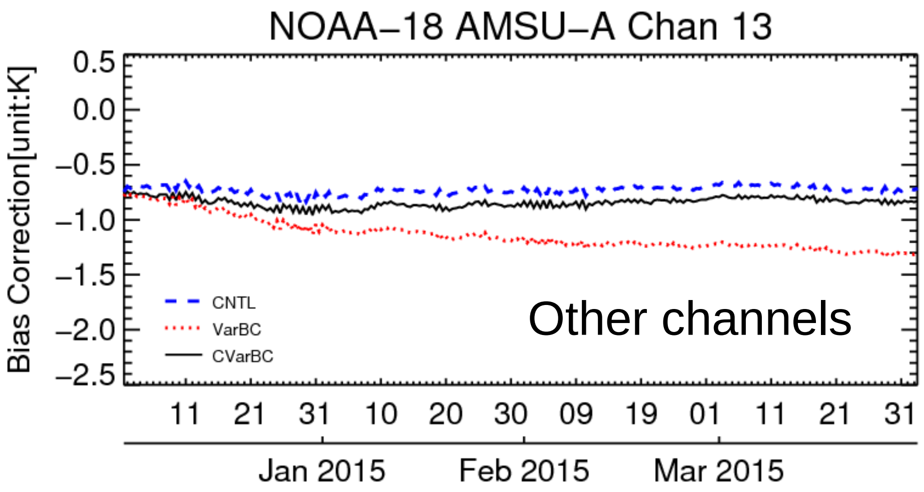
MEAN(MLS-CNTL),2014D15JF

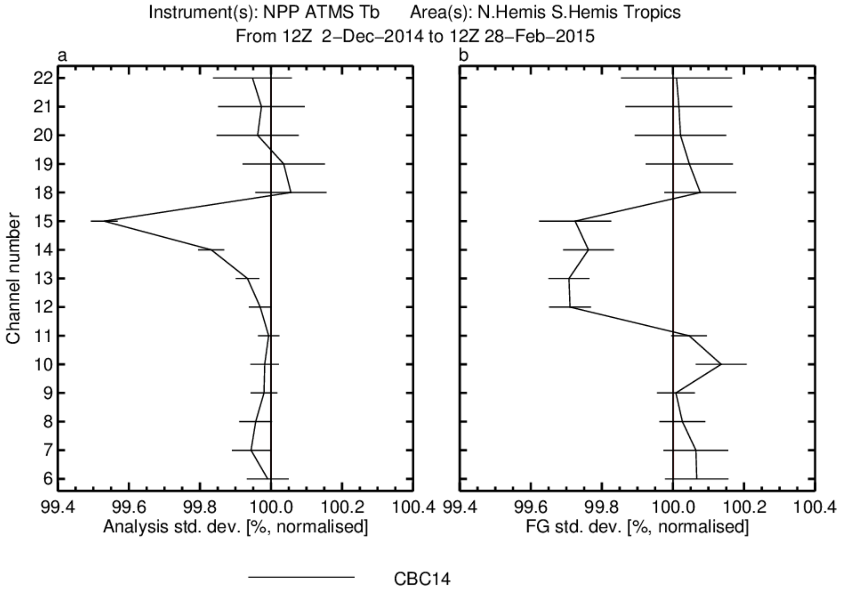


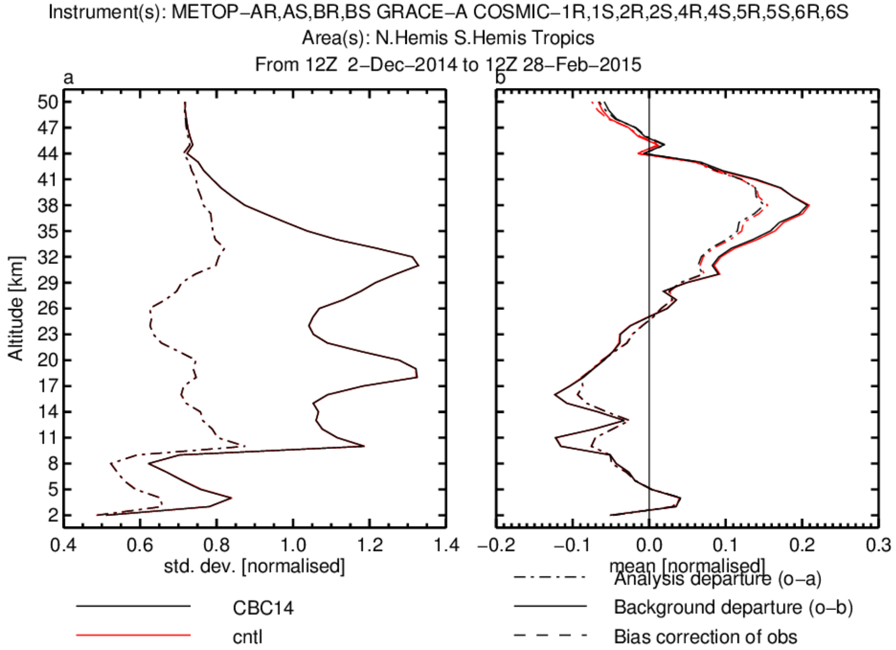
MEAN(MLS-CVarBC), 2014D15JF

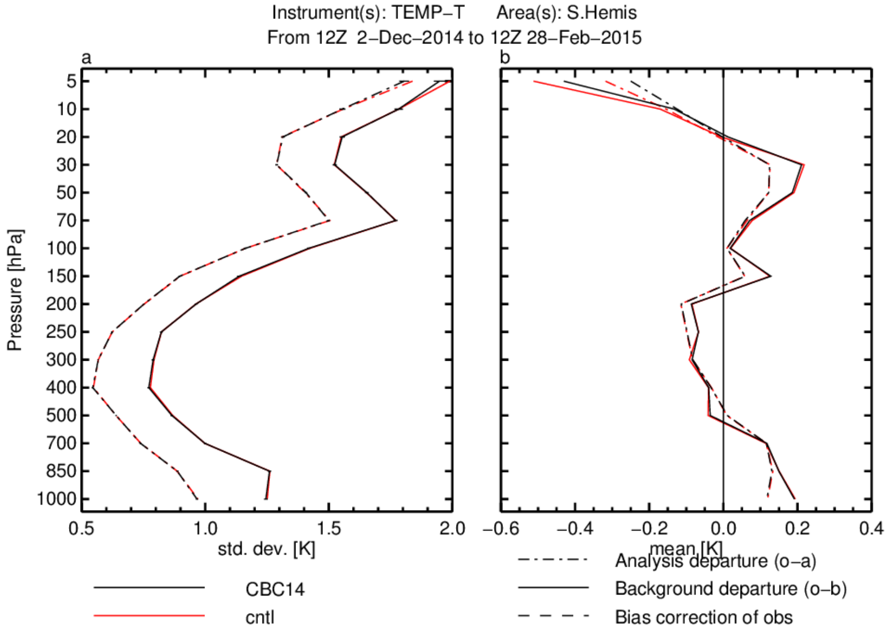


Impact on the fit of other observations



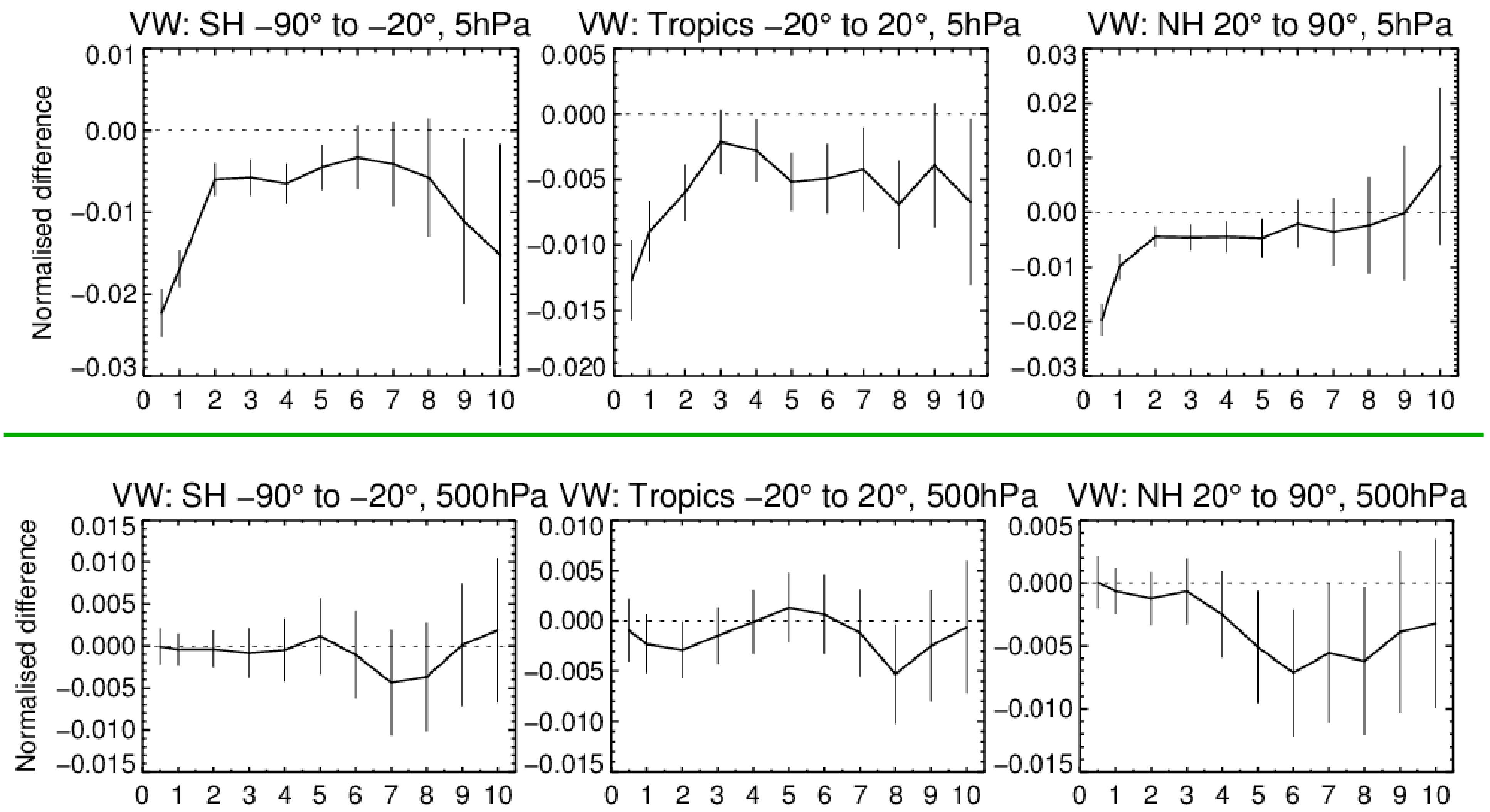


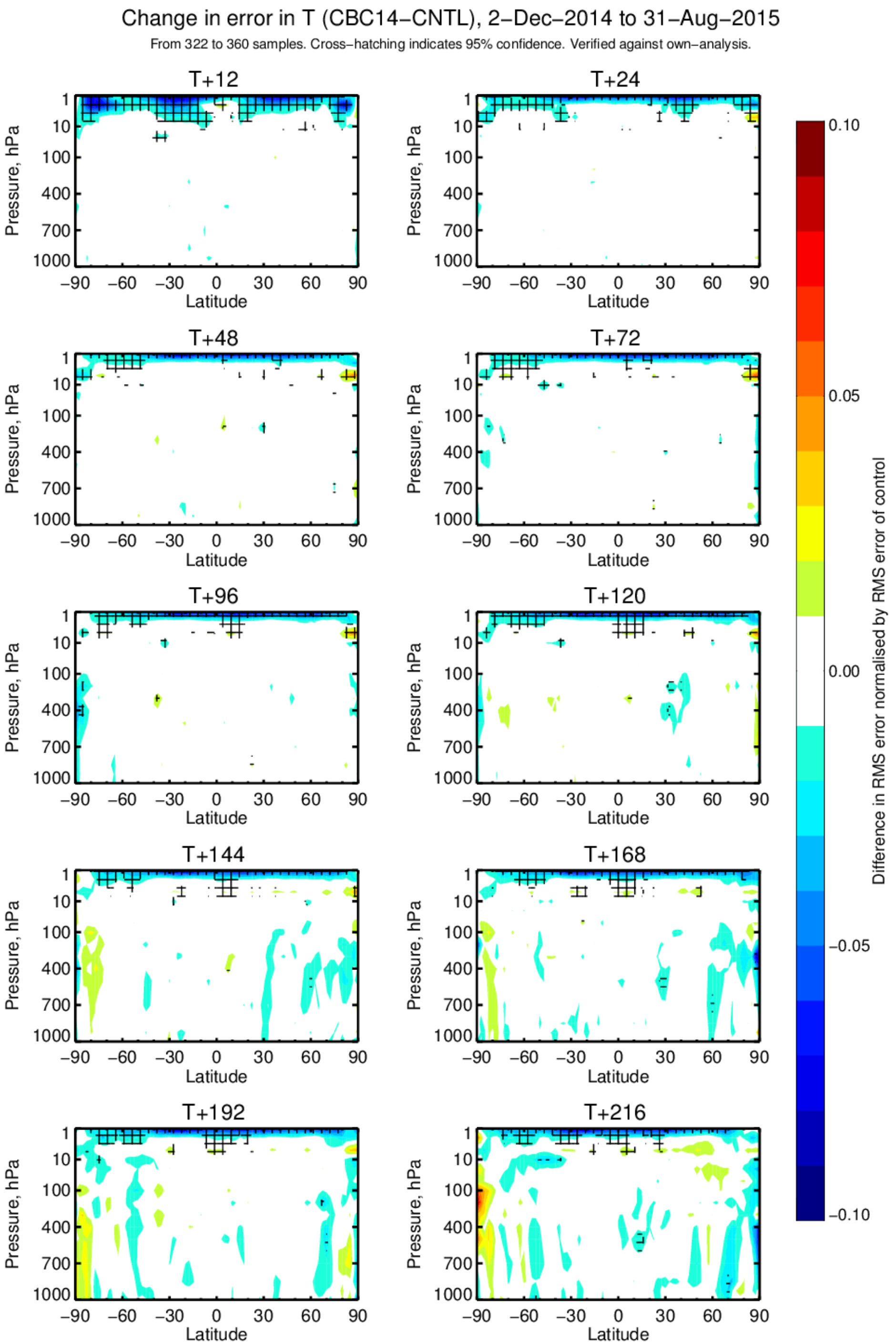


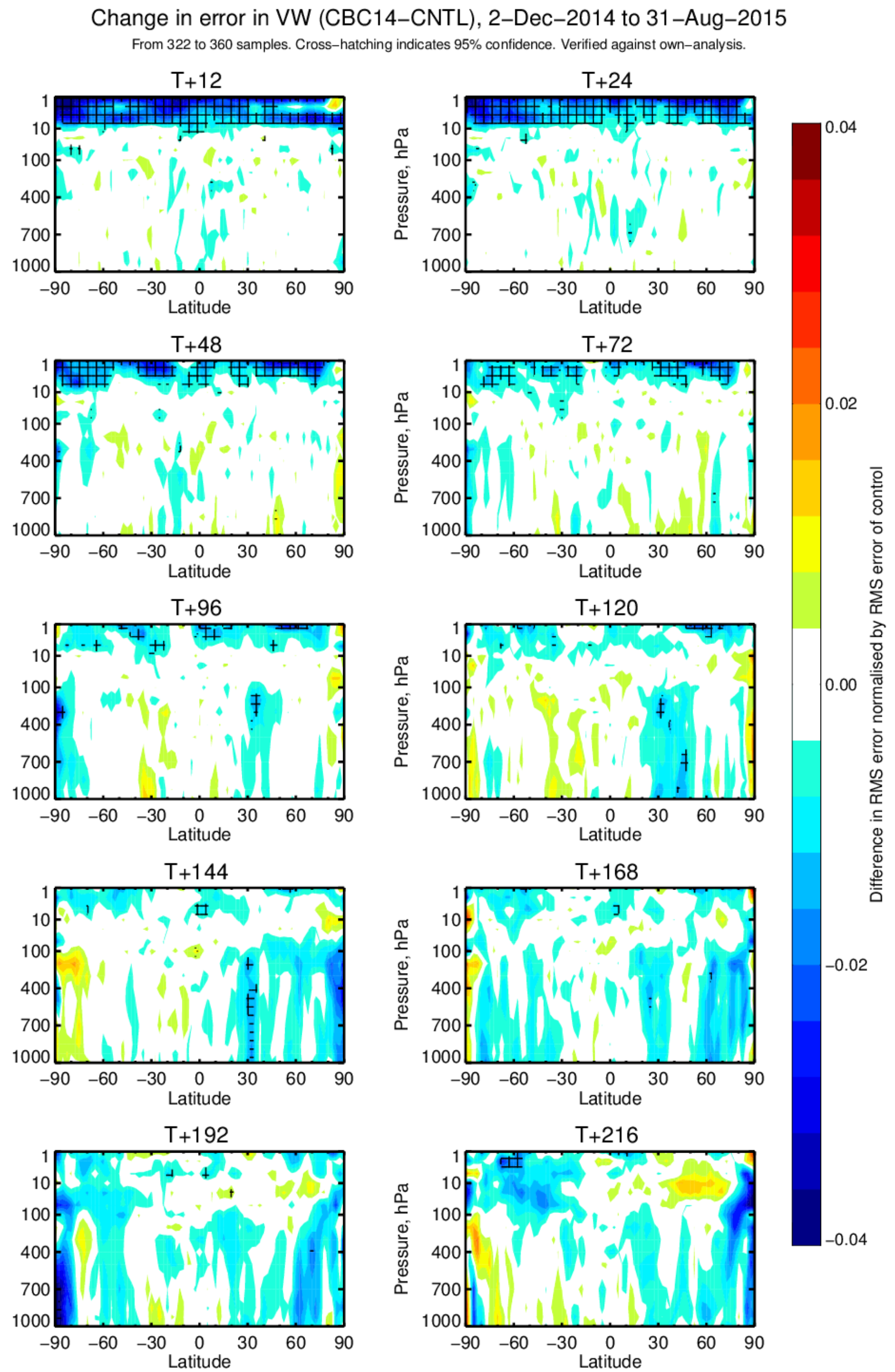


Impact of Constrained VarBC on AMSUA CH14 on Forecast (2014D15JF and 2015JJA)

2–Dec–2014 to 31–Aug–2015 from 322 to 360 samples. Confidence range 95%. Verified against own–analysis.



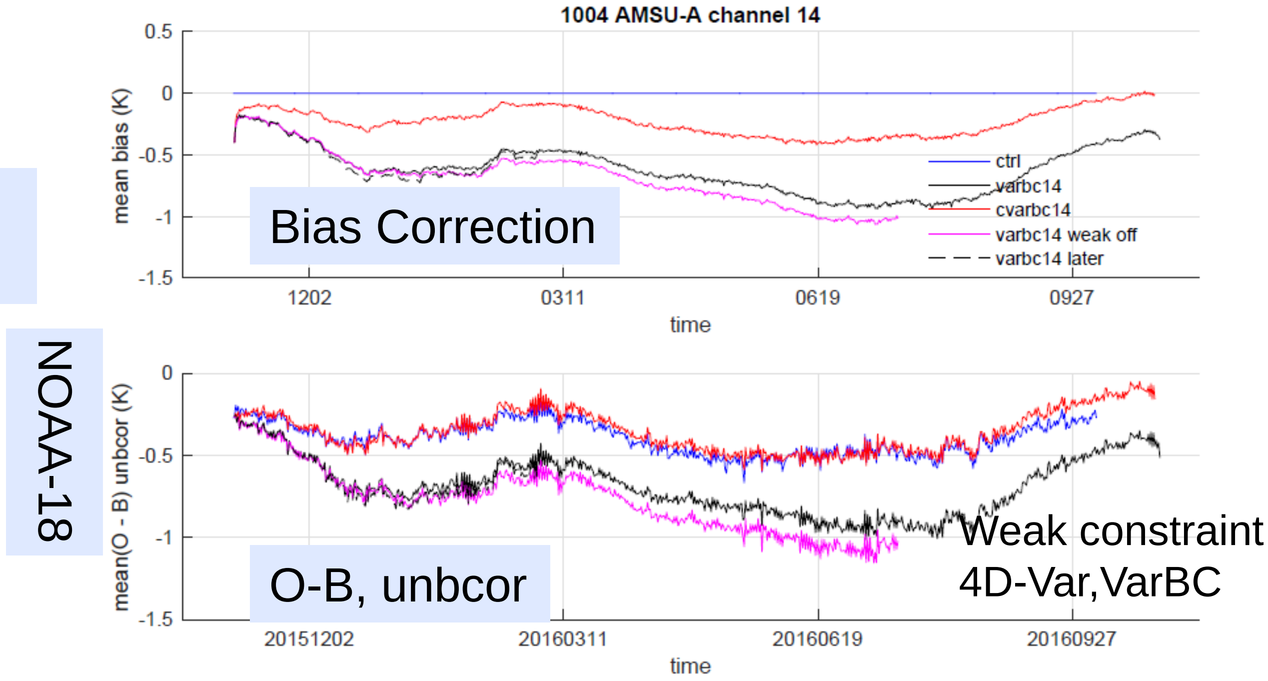

Change in error in T (CBC14−CNTL), 2−Dec−2014 to 31−Aug−2015
From 322 to 360 samples. Cross−hatching indicates 95% confidence. Verified against own−analysis.
T+12
T+24
T+48
T+72
T+96
T+120
T+144
T+168
T+192
T+216
Pressure, hPa
Latitude
Difference in RMS error normalised by RMS error of control


Change in error in VW (CBC14−CNTL), 2−Dec−2014 to 31−Aug−2015
From 322 to 360 samples. Cross−hatching indicates 95% confidence. Verified against own−analysis.
T+12
T+24
T+48
T+72
T+96
T+120
T+144
T+168
T+192
T+216
Pressure, hPa
Latitude
Difference in RMS error normalised by RMS error of control

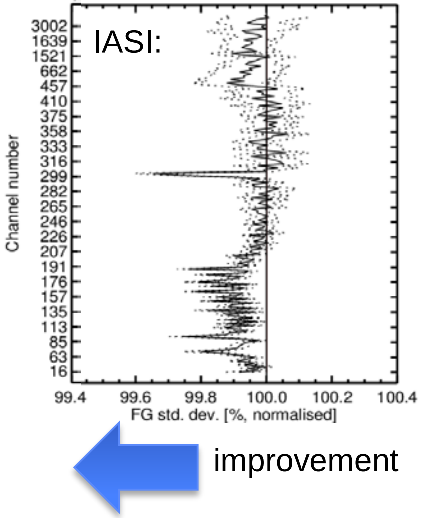
One year experiments

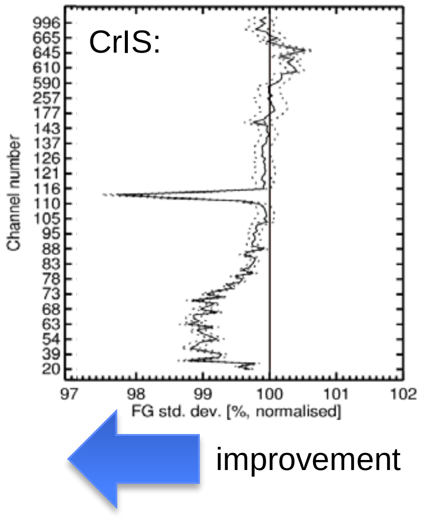
- Test the implementation for a long time series and with weak constraint 4D-Var

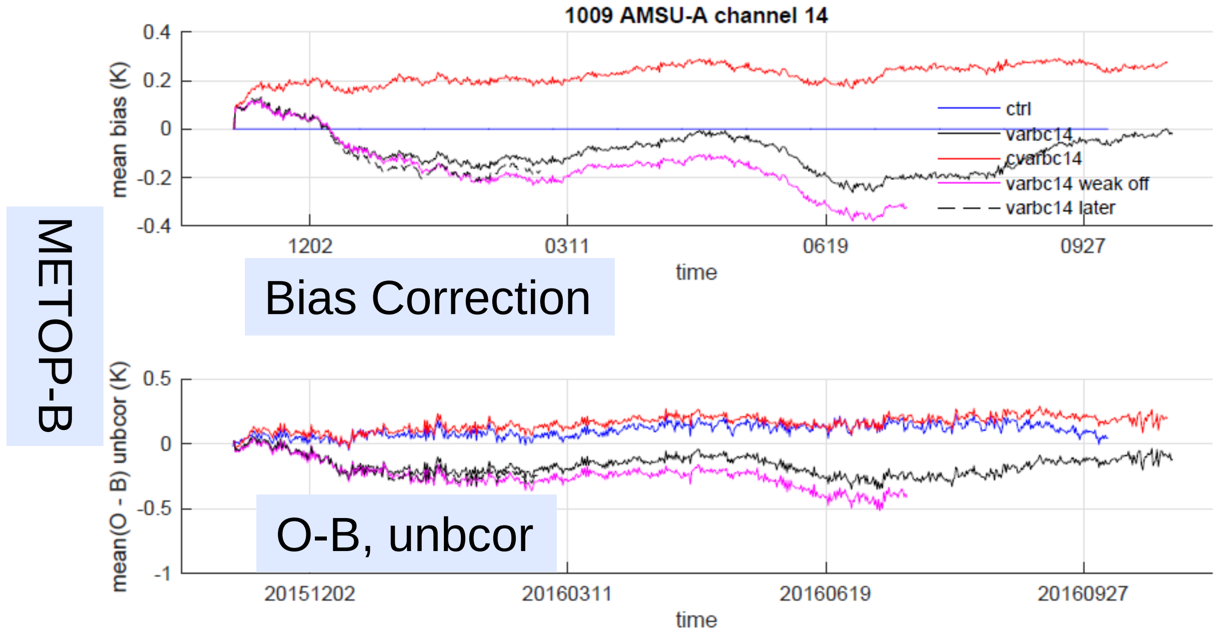
$$
\begin{aligned}
2J(\mathbf{x},\boldsymbol{\beta},\eta) = & (\mathbf{x}_b-\mathbf{x})^T\mathbf{B}_x^{-1}(\mathbf{x}_b-\mathbf{x}) \\
& + (\boldsymbol{\beta}-\boldsymbol{\beta}_b)^T\mathbf{B}_\beta^{-1}(\boldsymbol{\beta}-\boldsymbol{\beta}_b) \\
& + [\mathbf{y}-H(\mathbf{x})-h(\mathbf{x},\boldsymbol{\beta})]^T\mathbf{R}^{-1}[\mathbf{y}-H(\mathbf{x})-h(\mathbf{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



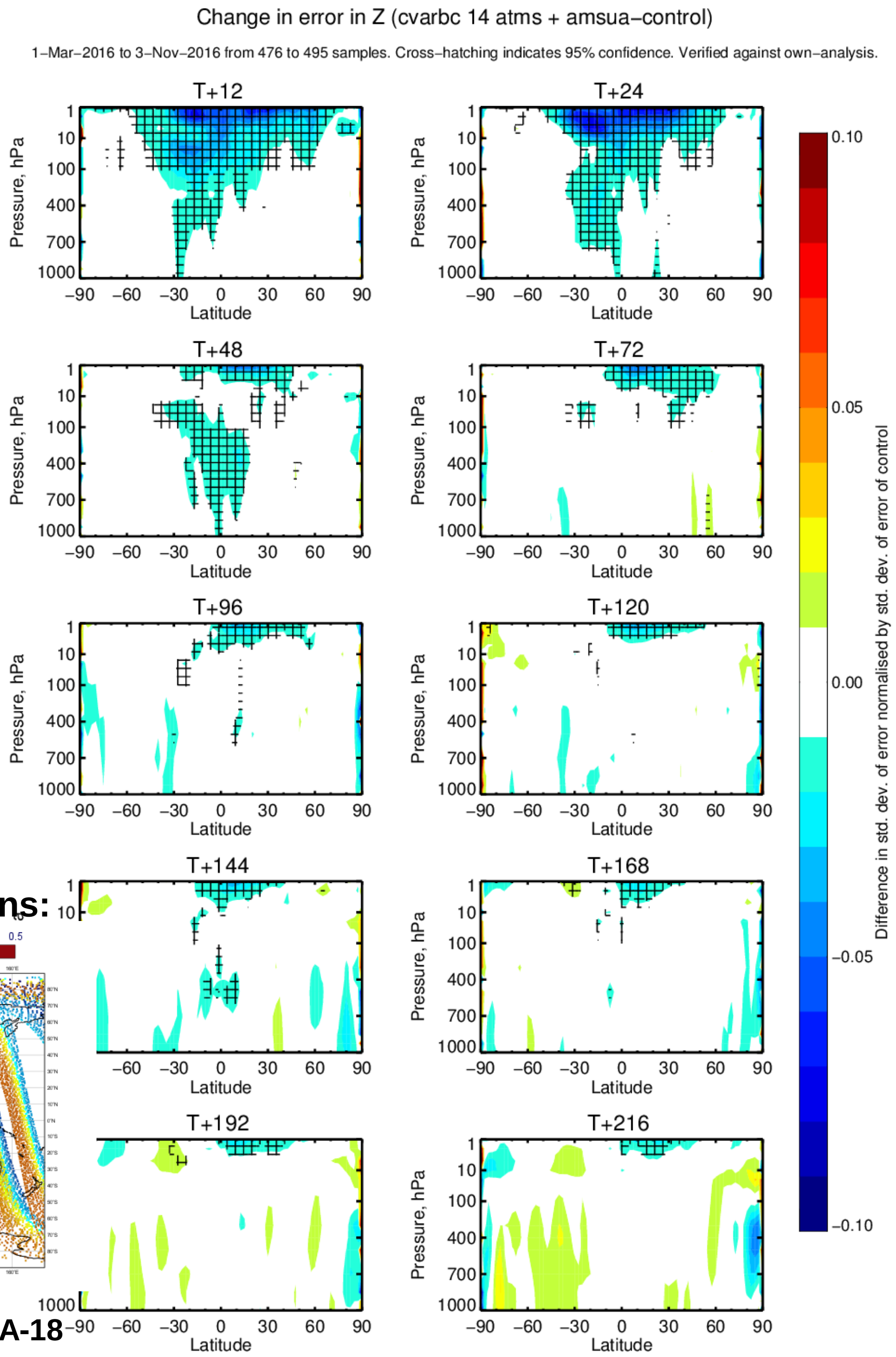
STDEV O – B:

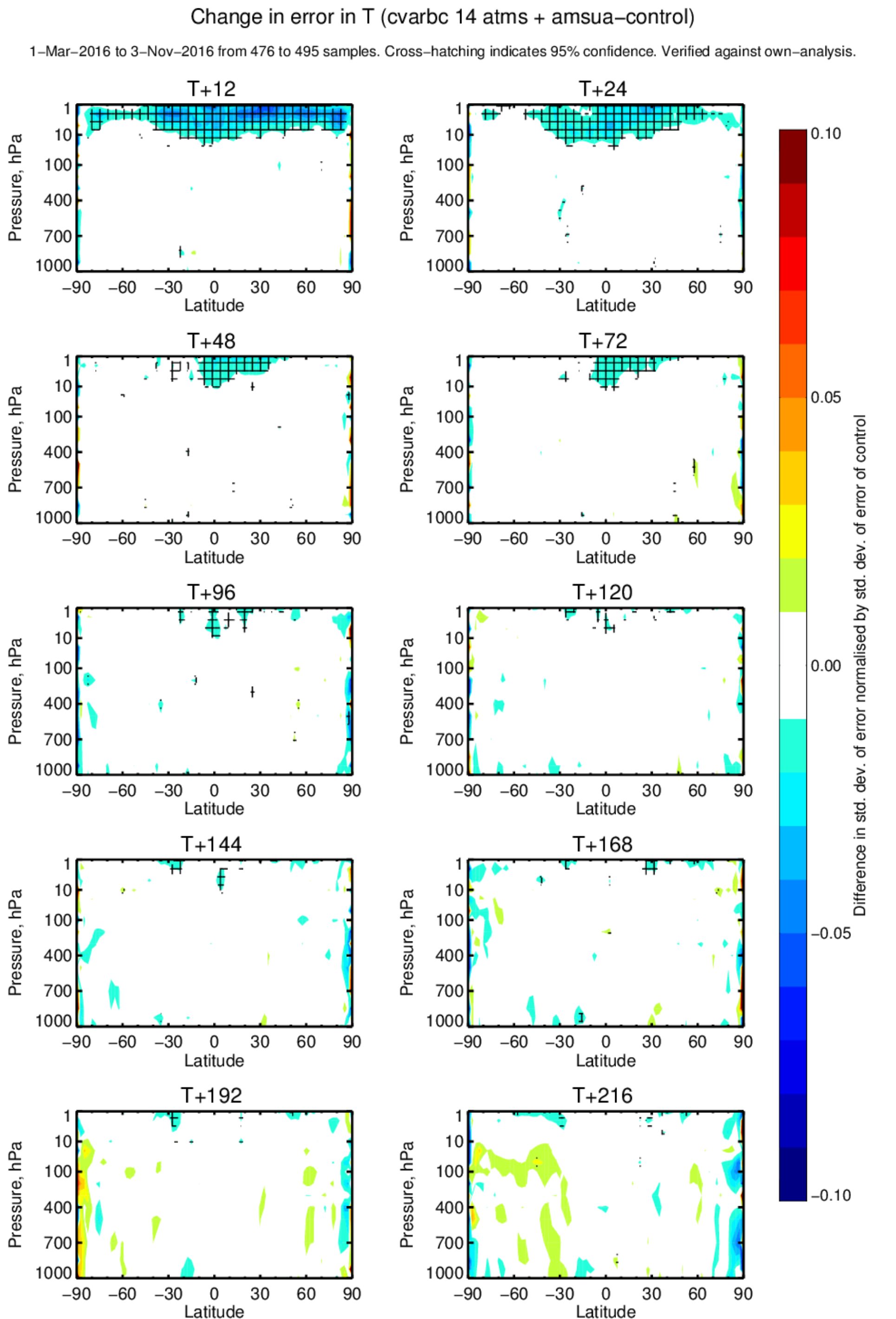




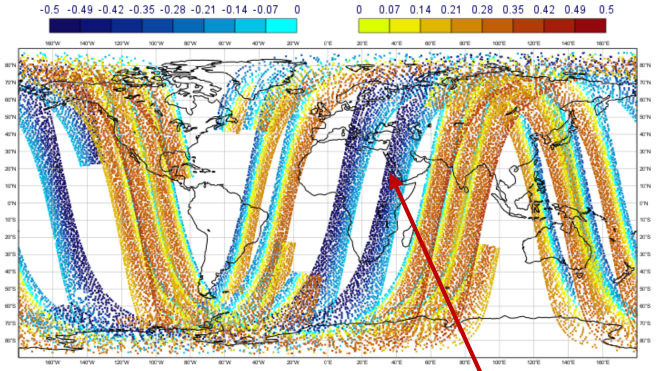


Impact on forecasts





New AMSU-A 14 bias corrections:



NOAA-18

Summary and Discussions

- **Potential use of CVarBC**
  - Reanalysis
  - Window channels
  - Stratosphere sounding
  - Humidity sounding (and trace gases)
  - All-sky?

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

- **Priori information of observation Bias**
  - Systematic bias $\mathbf{b}_0$
  - Uncertainty $\mathbf{R}_b$
  - GSICS, GAIA-CLIM?

Quantitive use of RU and RT uncertainty

- **How to determine the regularization parameter?** α
  - Posteriori estimation ?
  - Balance with anchor observations?
  - Deal with model bias?

Acknowledgment

The implementation of CVarBC at ECMWF
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The discussions at ITSC are really appreciated.