# Bias correction of satellite data at ECMWF

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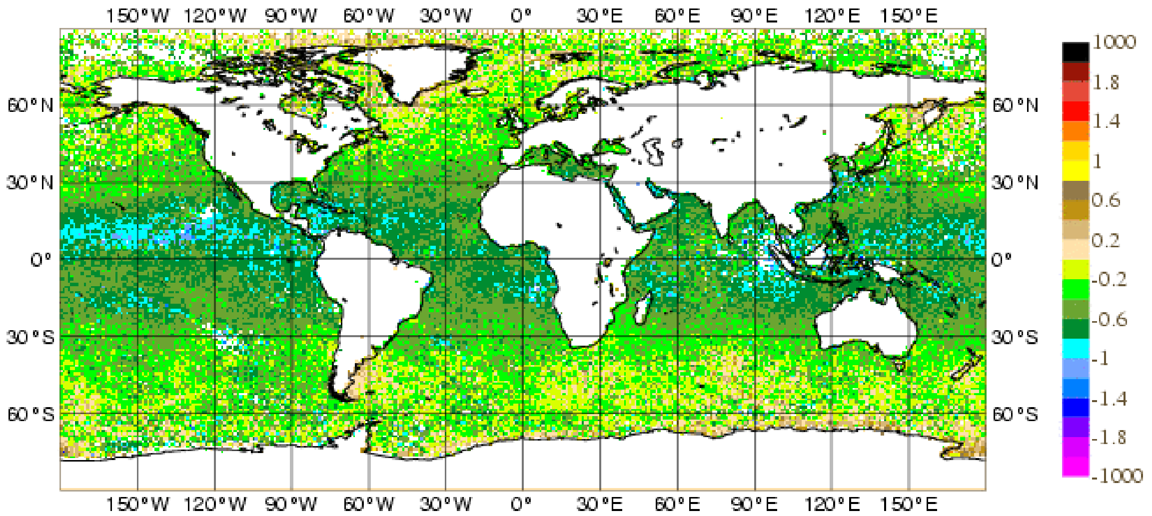
**Bias estimation and correction in data assimilation**
**8 - 11 November 2005**

# Introduction

ECMWF 4DVar assimilation system requires that model and observations are unbiased with normally distributed errors.

But first-guess departures (*i.e.* observation minus equivalent from the model guess) show systematic errors.




Average departures over 2 weeks for NOAA17/HIRS14

## OUTLINE:

- Bias model
- Adaptive bias correction
- Variational bias correction

# Operational bias model

- Scan correction (latitude bands)

- Air-mass regression (Harris & Kelly)

  Linear regression with a limited set of predictors $P_i$ derived from the NWP model:

$$\text{Bias} = \Sigma\beta_i.P_i(x)$$

| Instruments | Predictors |
|---|---|
| HIRS | 1000 - 300 hPa thickness<br>200 - 50 hPa thickness |
| AMSUB | 1000 - 300 hPa thickness<br>200 - 50 hPa thickness |
| SSMI | 1000 - 300 hPa thickness<br>200 - 50 hPa thickness<br>Total Column Water Vapor |
| GEOS (GEOS, Meteosat) | 1000 - 300 hPa thickness<br>200 - 50 hPa thickness<br>Total Column Water Vapor |

# Operational bias model

- Scan correction (latitude bands)

- Air-mass regression (Harris & Kelly)

- [$\gamma$,$\delta$] model: Radiative Transfert Model correction

(for errors in absorbing gas density, SRF, absorption coefficient).

For each channel, definition of
$\delta$: global constant
$\gamma$: fractional error in layer absorption coefficient

Transmittance from level p to space: $\Gamma(p) \rightarrow \Gamma(p)^{\gamma}$
Physically based scheme, discriminating observation bias from model error.

# Operational bias model

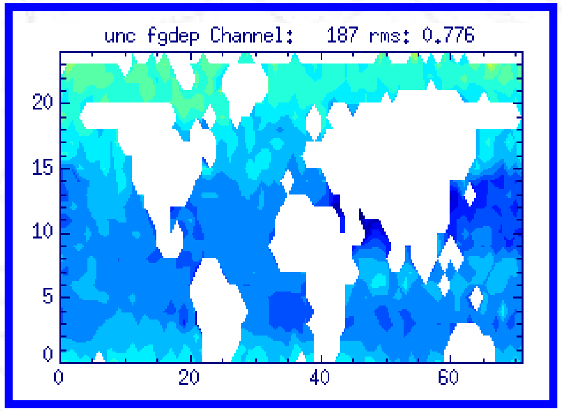
Simulate $\gamma = +5\%$ transmission error – air-mass dependent bias: A

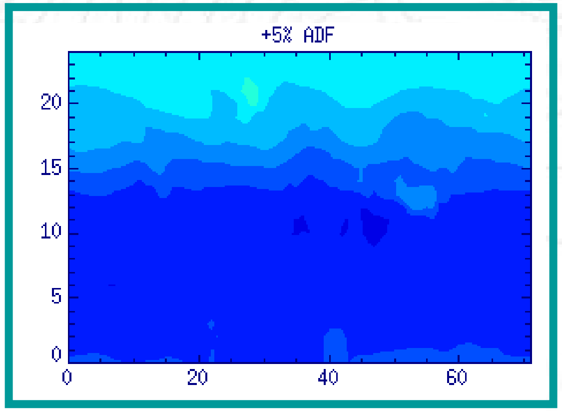
Monitor biases in operational System: B

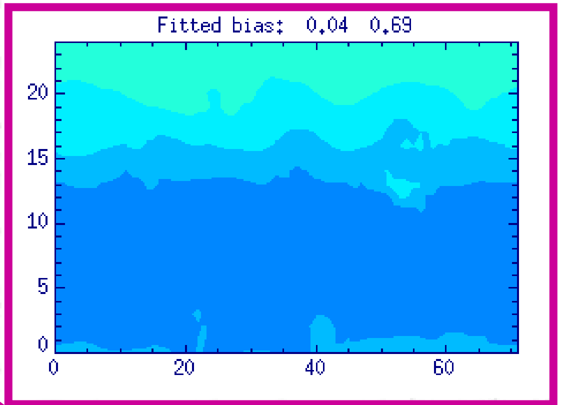
Assume bias model:

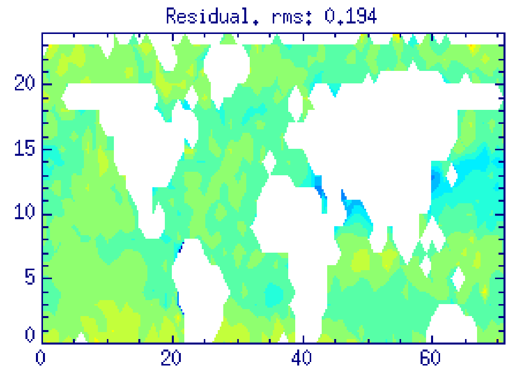
$$B = \delta + \gamma .\ A$$

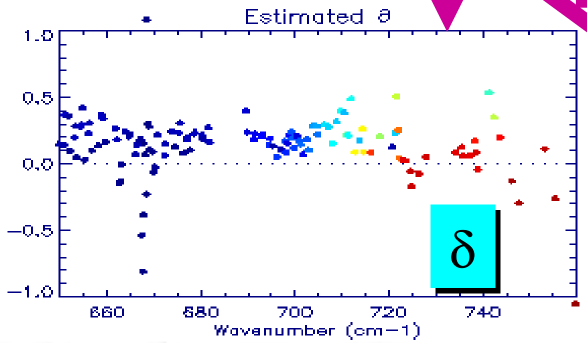
Get best estimates of $\delta$ and $\gamma$

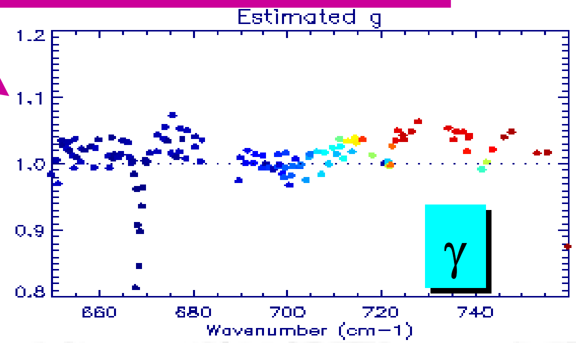



AIRS 15 μm channels

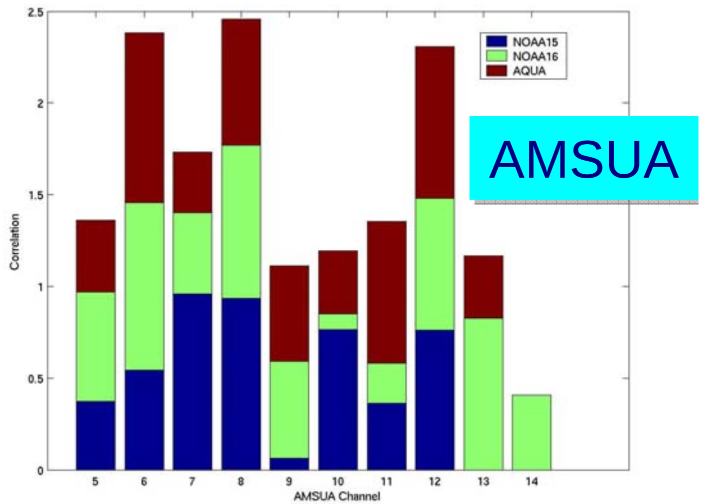
Credits: P. Watts

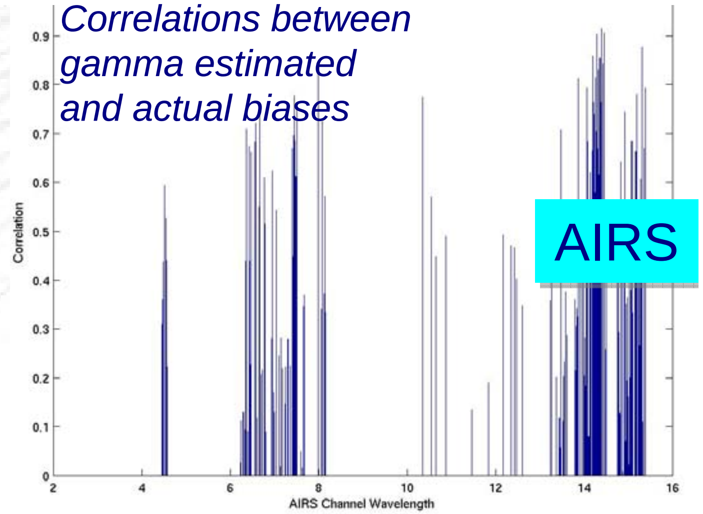
# Operational bias model

Systematic evaluation of air-mass variability and γ correlations for sounding instruments

| Instruments | Bias model |
|---|---|
| HIRS | H&K 2 predictors |
| AMSUB | H&K 2 predictors |
| SSMI | H&K 3 predictors |
| GEOS (GEOS, Meteosat) | H&K 3 predictors |
| AMSUA | [γ,δ] |
| AIRS | [γ,δ] |

*NOAA18 AMSUA14 FG departures Hovmoeller plot*




*Correlations between gamma estimated and actual biases*

What we have **NOT** attempted to correct bias patterns due known model error (e.g. stratosphere ringing)

# Adaptive bias correction

A static bias correction cannot correct an instrument failure/drift. Problem of identifying manually a drift within hundreds of data types in real time.

Adaptive bias correction = bias estimate is updated for every cycle.

***Pros**:*

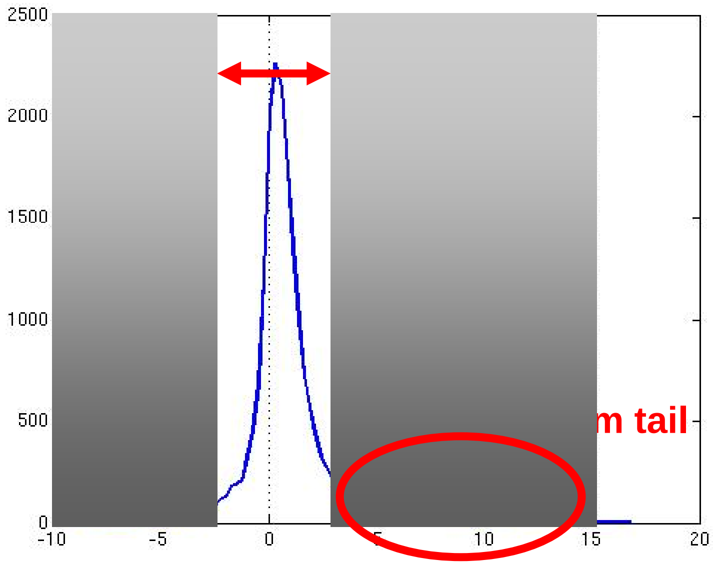
Based on the same bias model: Harris&Kelly or [$\gamma$,$\delta$] ($\gamma$ *kept constant*). Automatic, much easier to handle for new instruments or drifts. Continuity in time series (interesting for climate simulations).

***Cons**:*

Prone to wrongly mapping systematic errors of the NWP model into radiance bias correction. Relies even more on the ability of the bias model to separate observation bias from model error.
Need for a background term : reduces the reactivity of the system.

# Adaptive bias correction

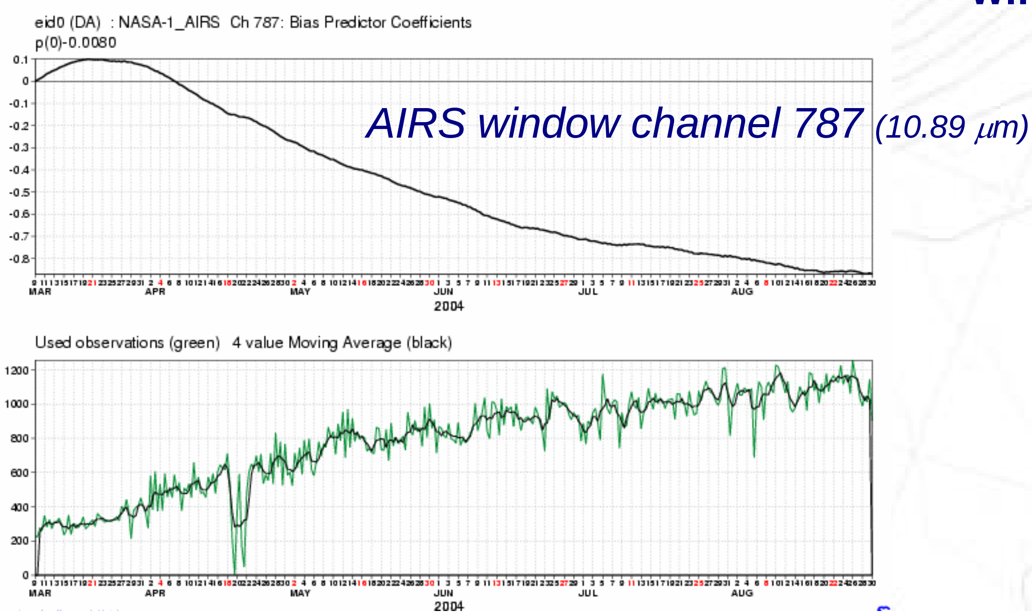
*NOAA18*
*AMSUA*
*Channel4*

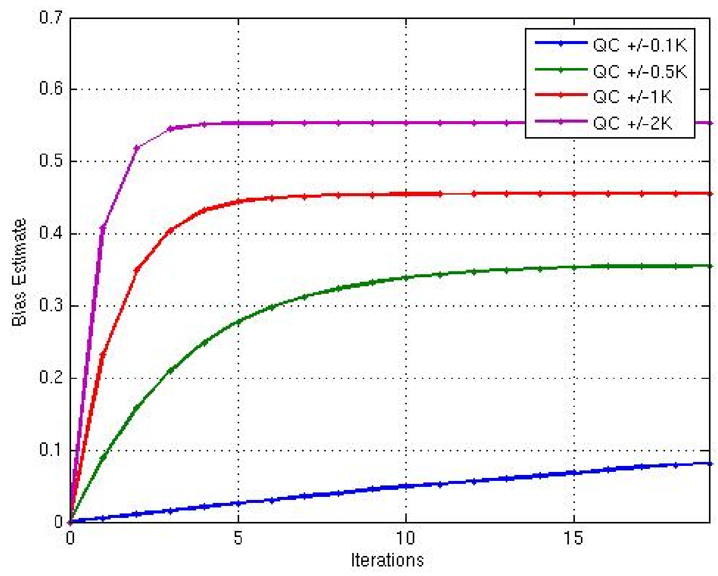



## Interaction with QC

Distribution of departures have a cold/warm tail (IR/MW) due to cloud contamination.
Quality Control (QC) based on departures is often applied to remove outliers (bad quality data) BEFORE estimating the bias.

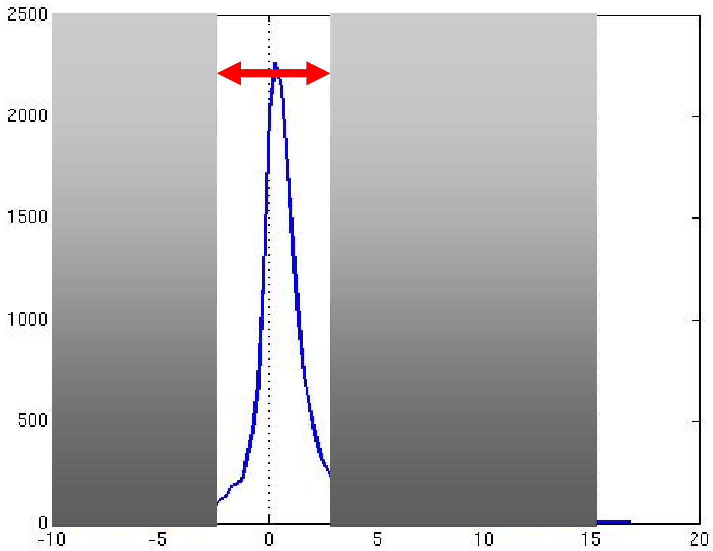
**FEEDBACK PROCESS**
**The speed of convergence and value of the estimate depend on the size of the boxcar window QC.**

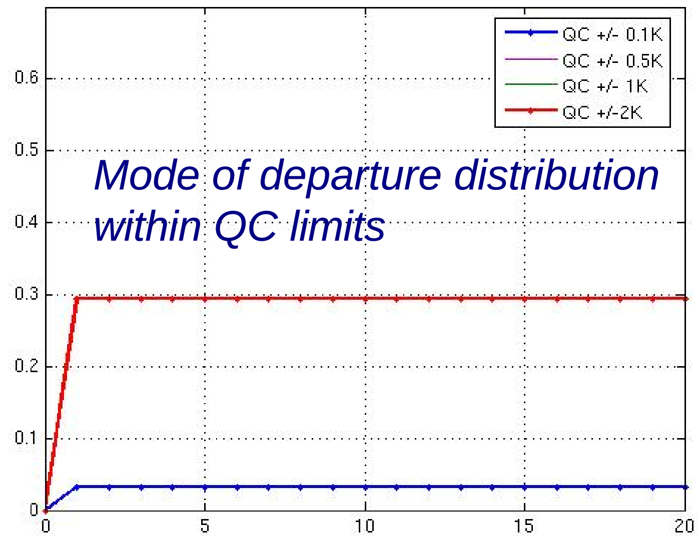


# Adaptive bias correction

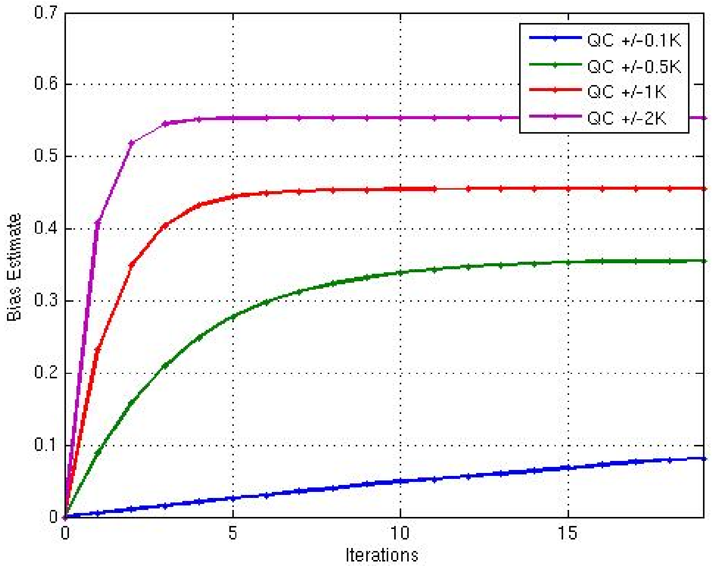
*NOAA18*
*AMSUA*
*Channel4*



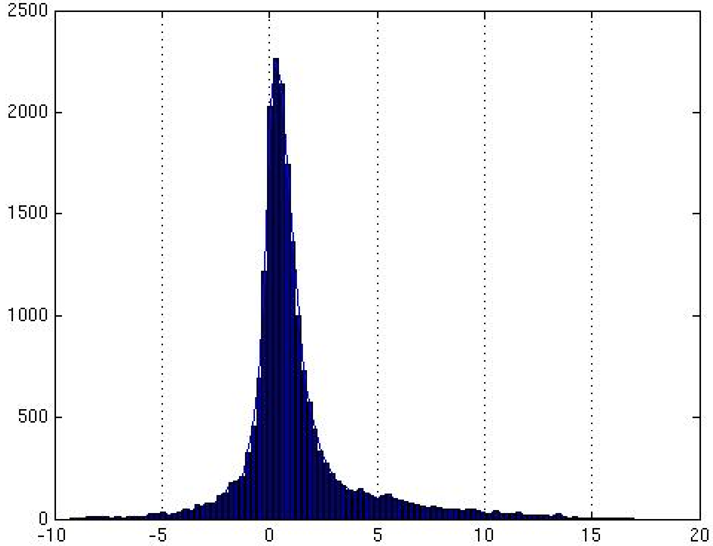

FEEDBACK PROCESS
The speed of convergence and value of the estimate depend on the size of the boxcar window QC.

To combat this we are evaluating the use of the MODE for bias estimation as opposed to the mean.



# Adaptive bias correction

*NOAA18*
*AMSUA*
*Channel4*

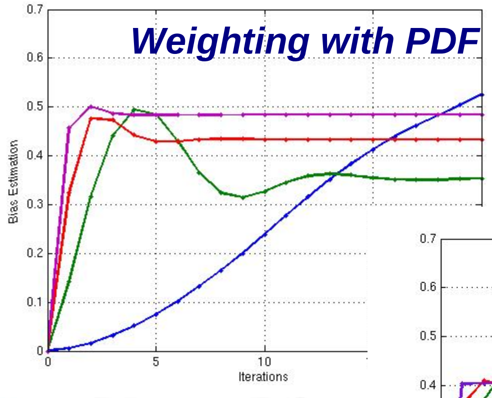


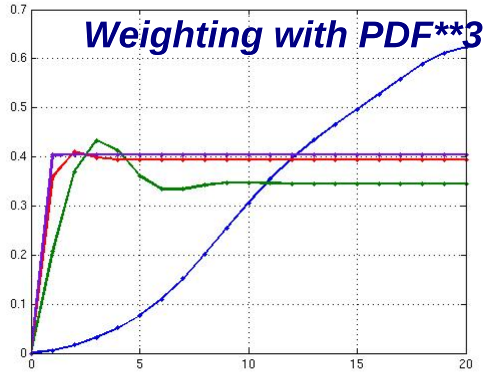

Weighting the contributions to the bias with the PDF of first-guess departures.

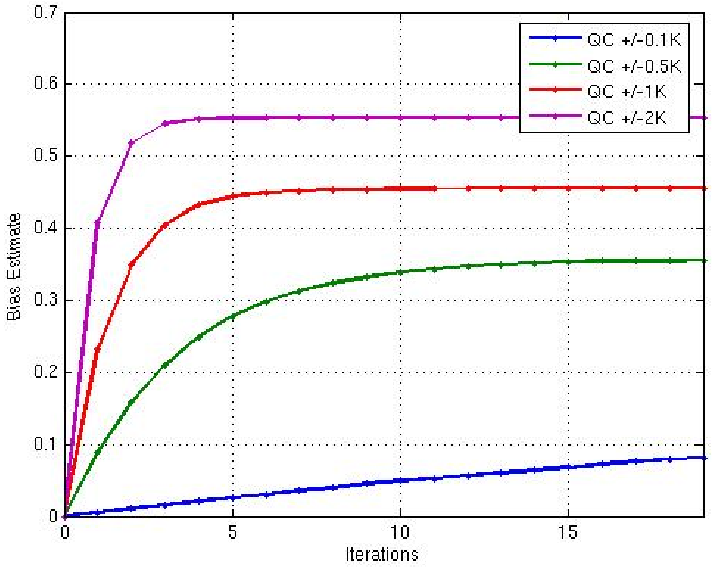
•Using PDF as a confidence estimation for the observations (cf Huber norm).

•Can be used adaptively in VarBC
(→ separation in the sources of bias ).

•Less sensitive than the mean to QC width and remaining outliers.

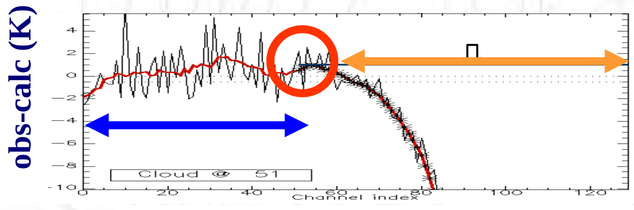


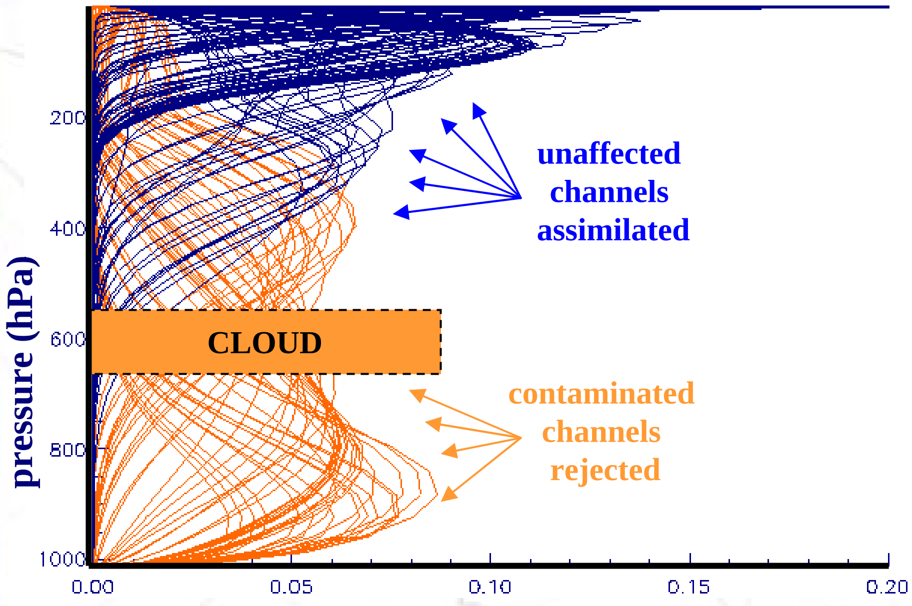
# Adaptive bias correction

## Interaction with AIRS cloud detection

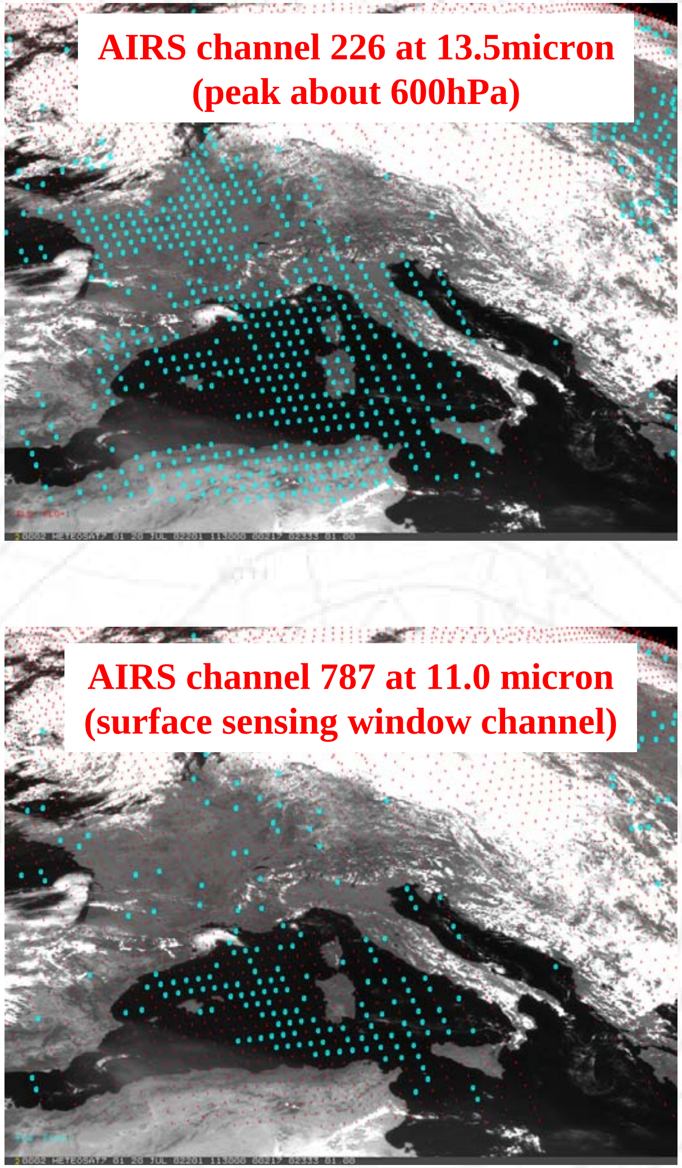



Vertically ranked channel index

The characteristic signal of cloud is identified within departures of the observed radiance spectra from a computed clear-sky background spectra.

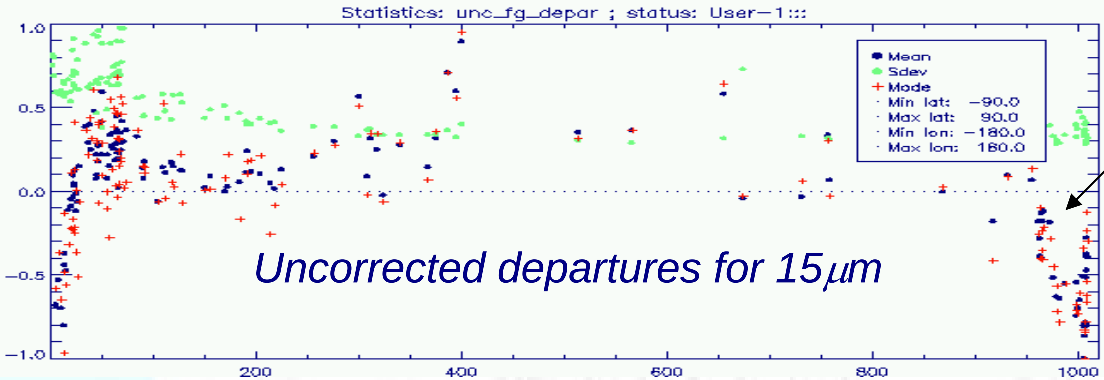



temperature jacobian (K)

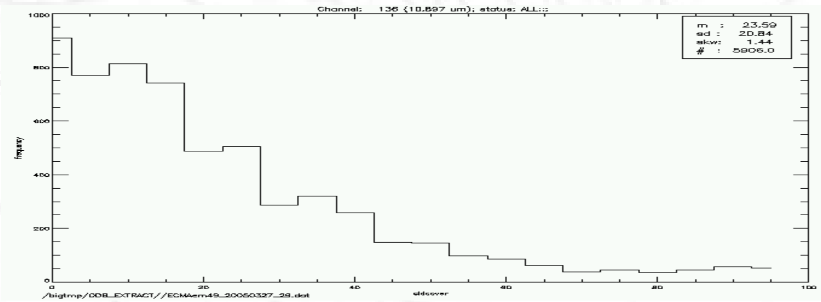


# Adaptive bias correction

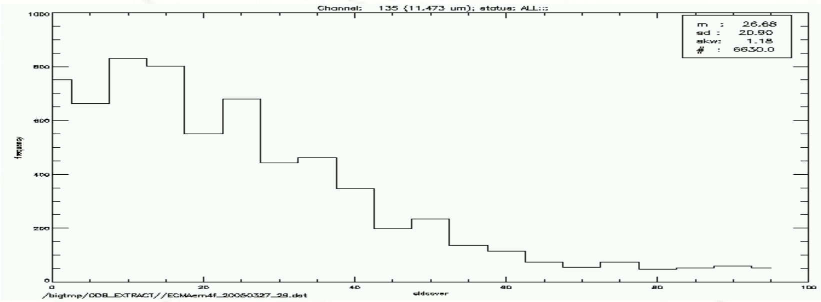
## Interaction with cloud detection scheme for AIRS




*Population clear for **VISNIR** imager*

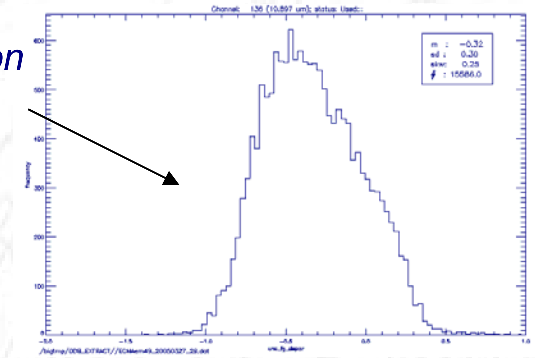



*VISNIR cloud percentage for clear AIRS787*

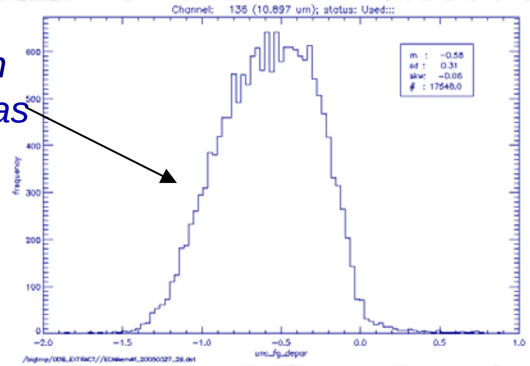



*Uncorrected departures for AIRS window channel 787 (10.89 $\mu$m)*

*Active population with **Static** bias correction*

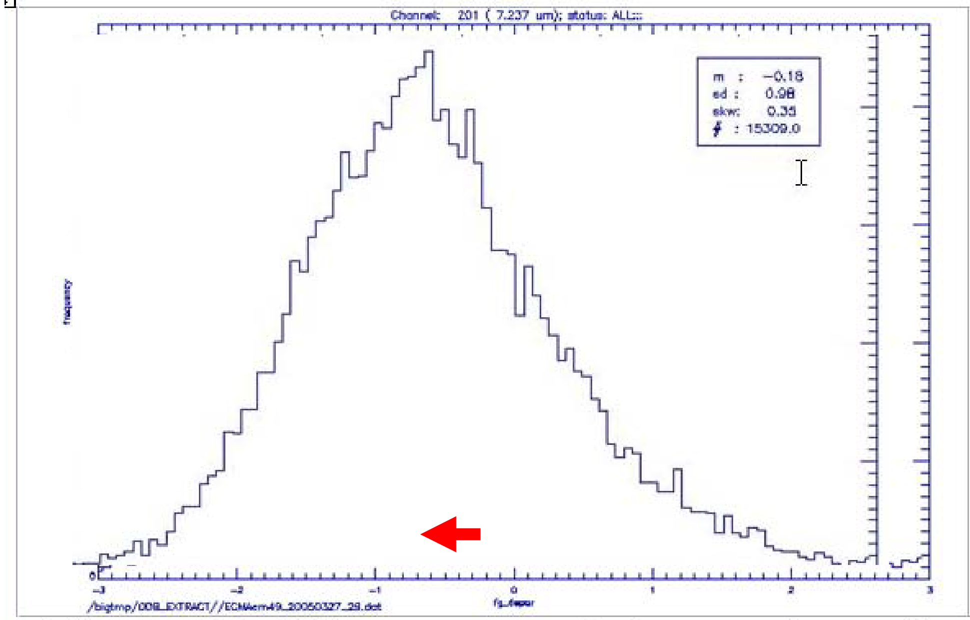



*Active population with **adaptive** bias correction*

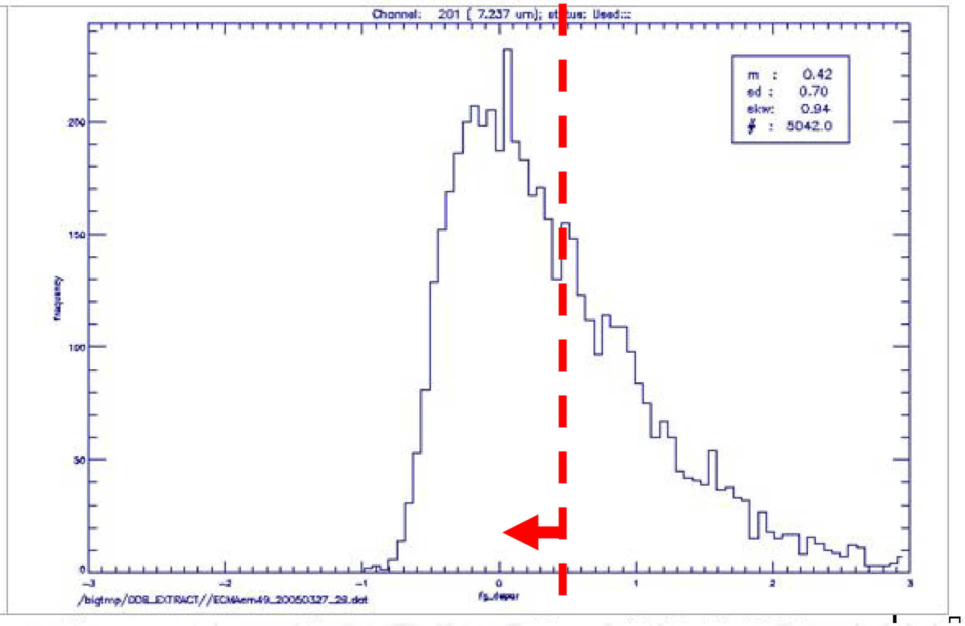


# Adaptive bias correction

## Interaction with cloud detection scheme for AIRS




*All data*

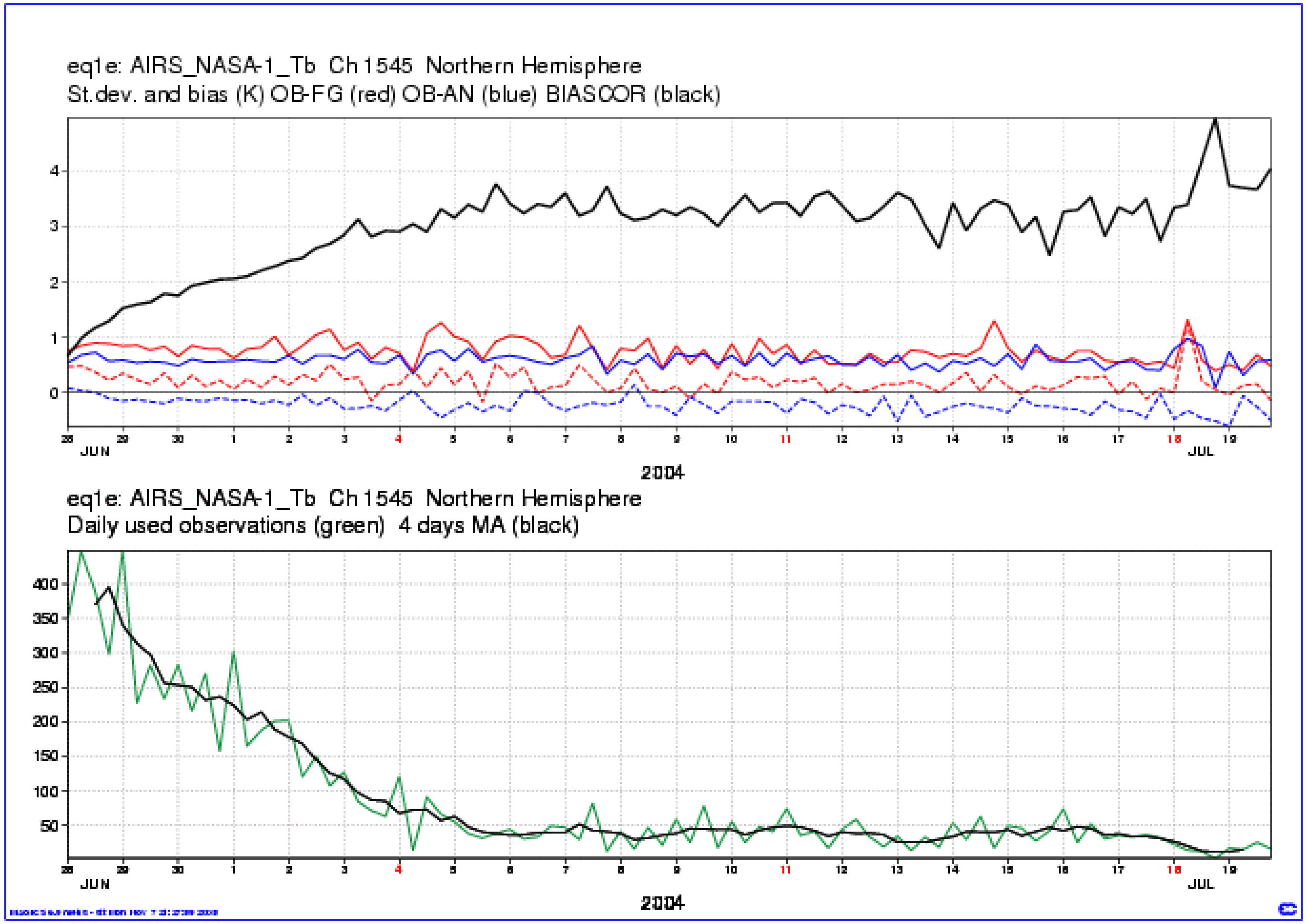



*Active data*

First-guess departures for AIRS WV channel 1545 (7.23 μm)

# Adaptive bias correction

## Interaction with cloud detection scheme for AIRS




Bias correction

FG departure
AN departure

Number of active obs

# Variational bias correction

Work of Dick Dee at NASA and ECMWF showed some promise for adaptive bias correction **INSIDE** the assimilation system
(currently done by NCEP operation).

**VarBC** = bias parameters $\beta_i$ (*i.e.* coefficients for the bias model) become part of the 4DVar control variable

$\underline{H}(x,\beta) = H(x) + \sum \beta_i . P_i(x)$ (H: observation operator, $P_i$: predictors)

*Pros:*
Estimation of biases can follow instrument drifts/jumps automatically and is **CONSTRAINED** by other information inside the analysis (*i.e*. model, other data).

*Cons:*
(Small) overhead of computer calculation during NWP assimilation.
Data used for QC but not assimilated must go through minimisation to estimate the bias.

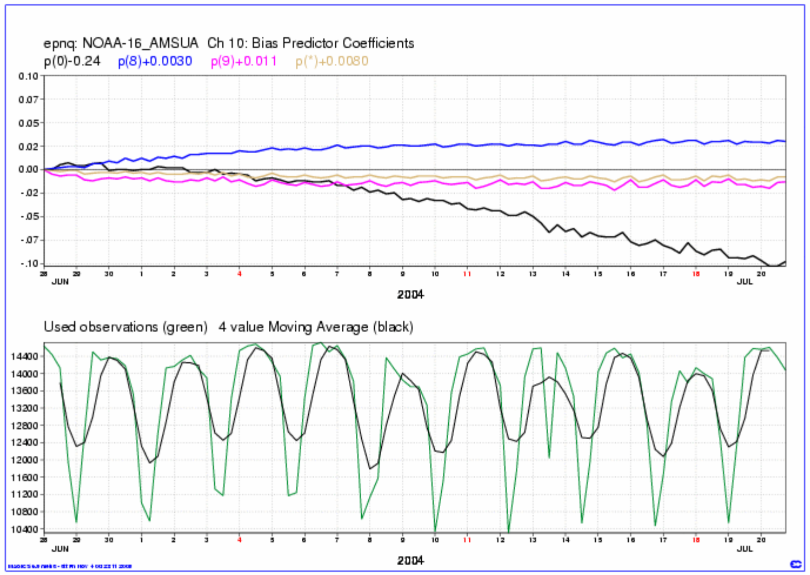
# Variational bias correction

## Technical implementation

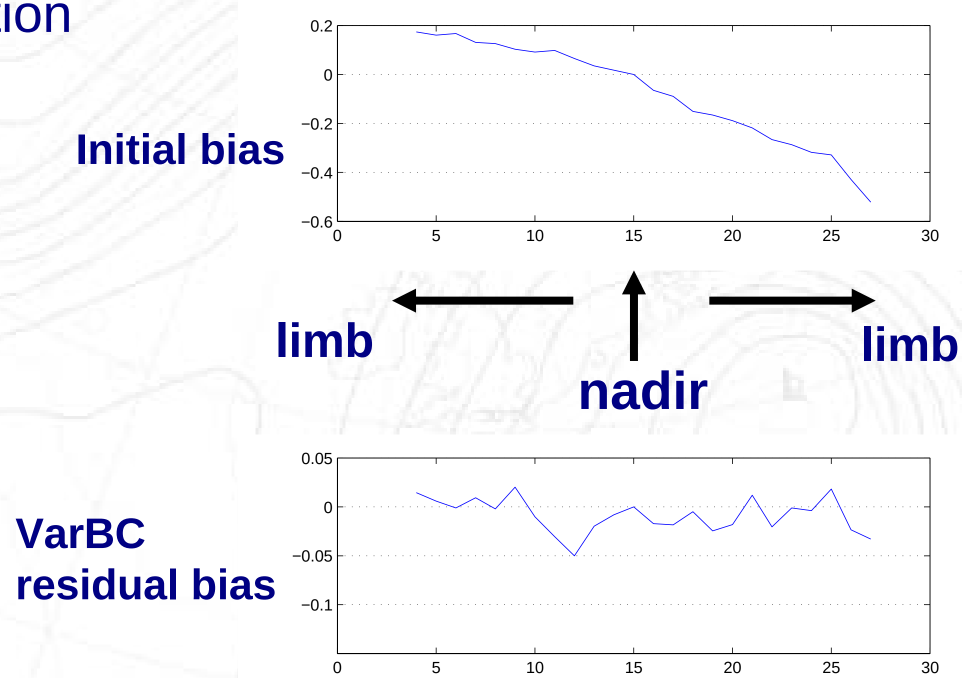
• Background term (=inertia defined with an equivalent number of observations)

•Different dataset for bias correction: Inflation of obs error stats for passive data. Possibility to use a mask (*e.g.* near radiosondes, or AIRS VISNIR-clear data)

• Incorporation of scan correction
(as a 3rd order polynomial regression)




*NOAA16 AMSUA channel 10*



# Variational bias correction

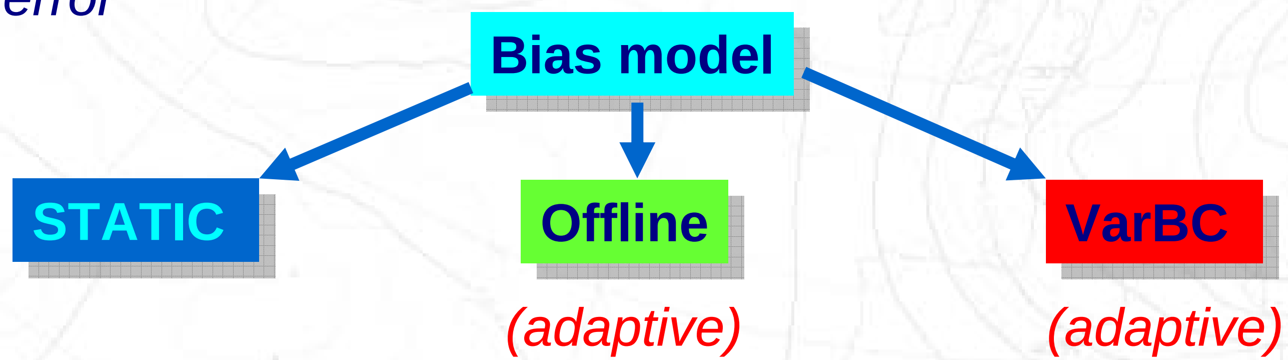
## Separation between sources of bias

Usually assigned to the bias model, BUT…

...VarBC exploits the redundancy of information between observations.

Non-satellite data (radiosondes, aircraft, surface, etc) constrain the bias estimation for satellite observation (they must not be corrected adaptively !).

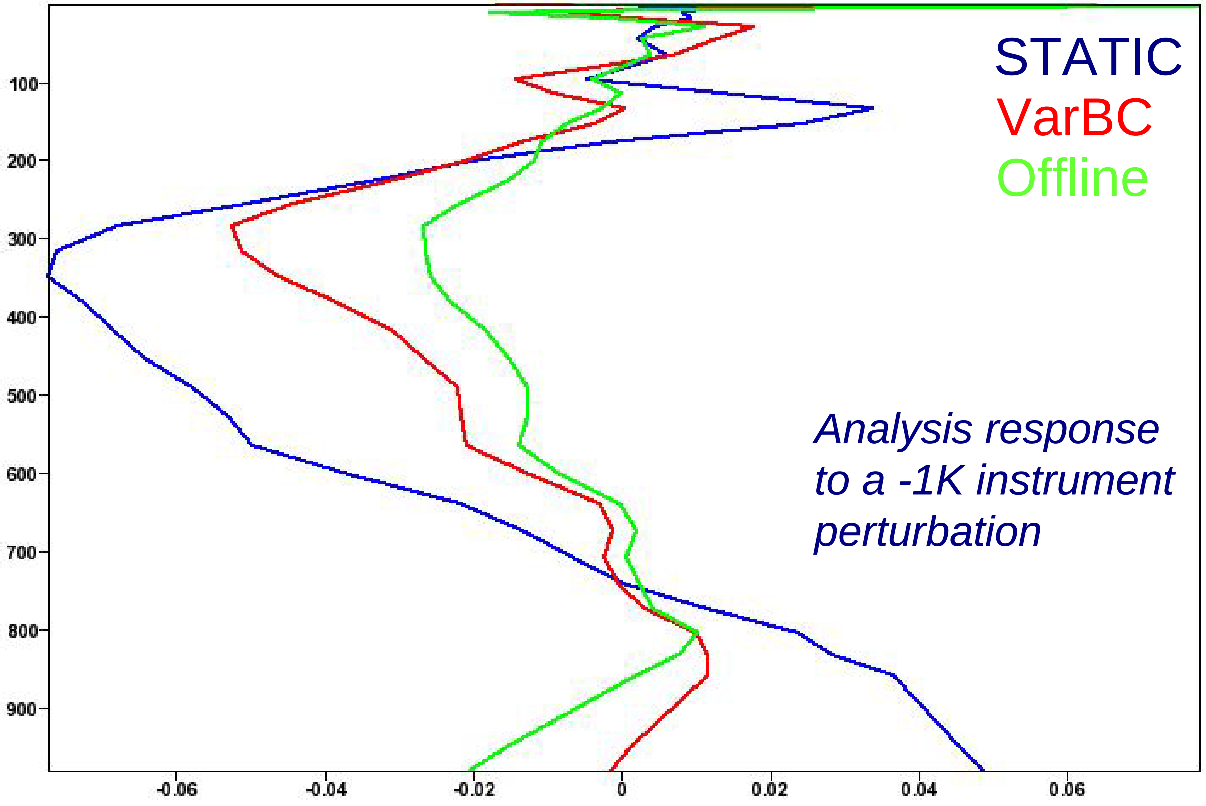
→*Potential ability of **VarBC** to discriminate observation bias from NWP model error*



# Variational bias correction

## **Artificial perturbation:** coherent with bias model

• Instrument step: -1K for NOAA16 AMSUA channel 6 (tropospheric temp)
→ VarBC close to Offline scheme. *Limitation by background term and QC*



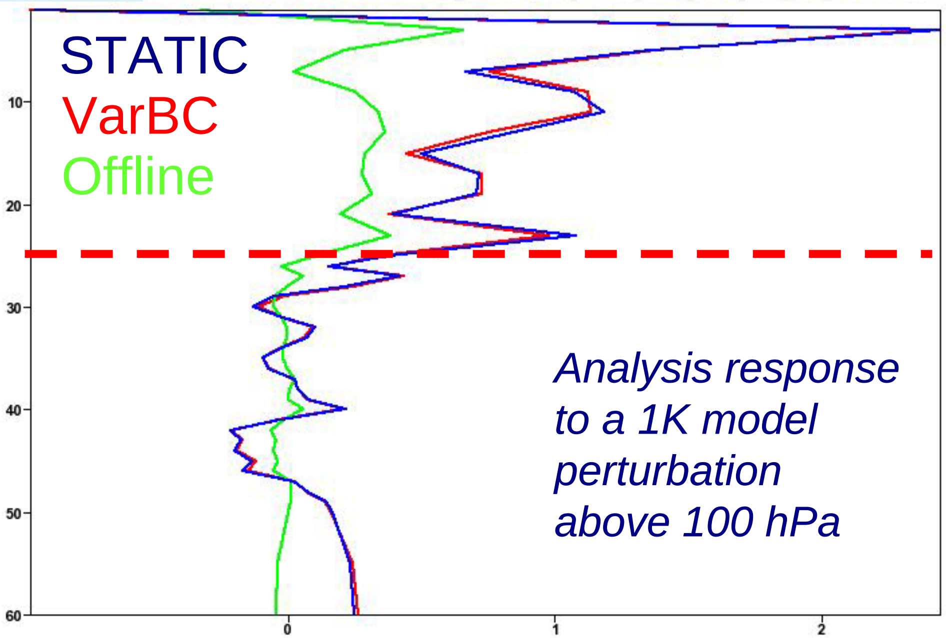
# Variational bias correction

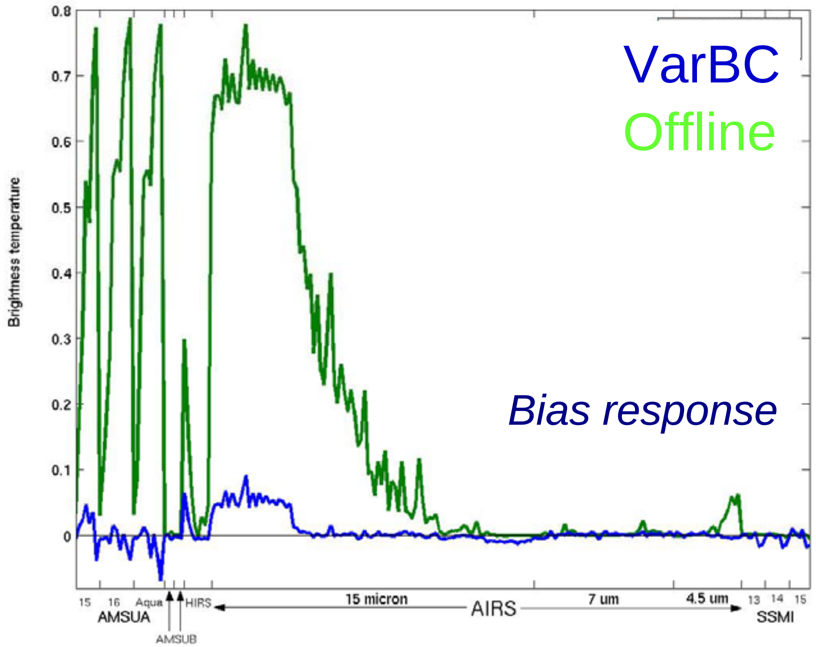
## **Artificial perturbation:** coherent with bias model

• Instrument step: -1K for NOAA16 AMSUA channel 6 (tropospheric temp)
→ VarBC close to Offline scheme. *Limitation by background term and QC*

• Model step: 1K above 100 hPa
→VarBC ignore most of the model error

**VarBC = good compromise between Static and Offline bias schemes**

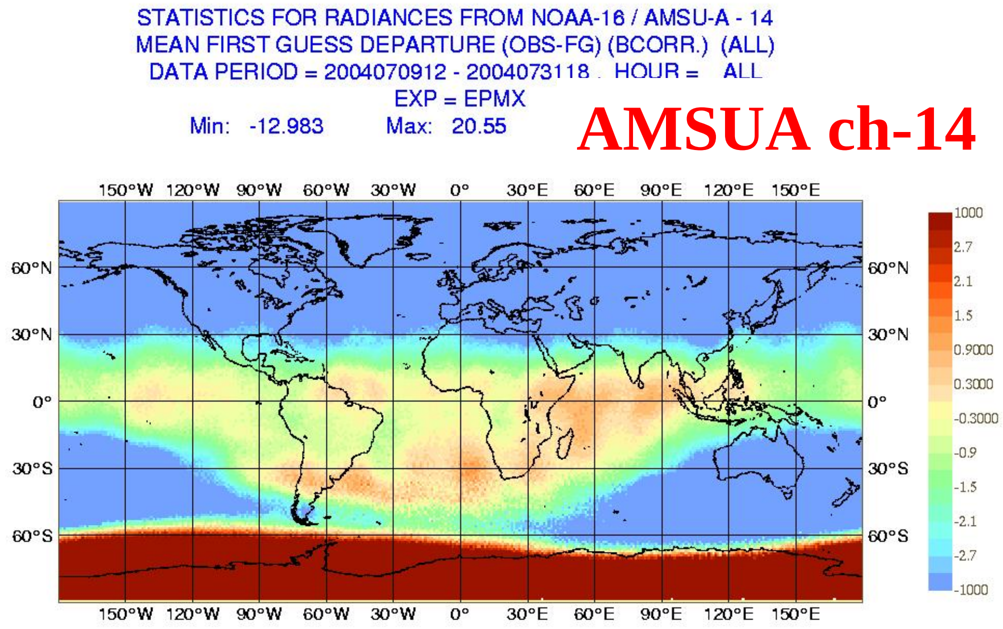


# Variational bias correction

## Versatile bias model

Cold **bias in the NWP model**
in the stratospheric polar night




**No statistical assumption on the bias shape**

**Full versatility of the bias model to correct ANY bias**

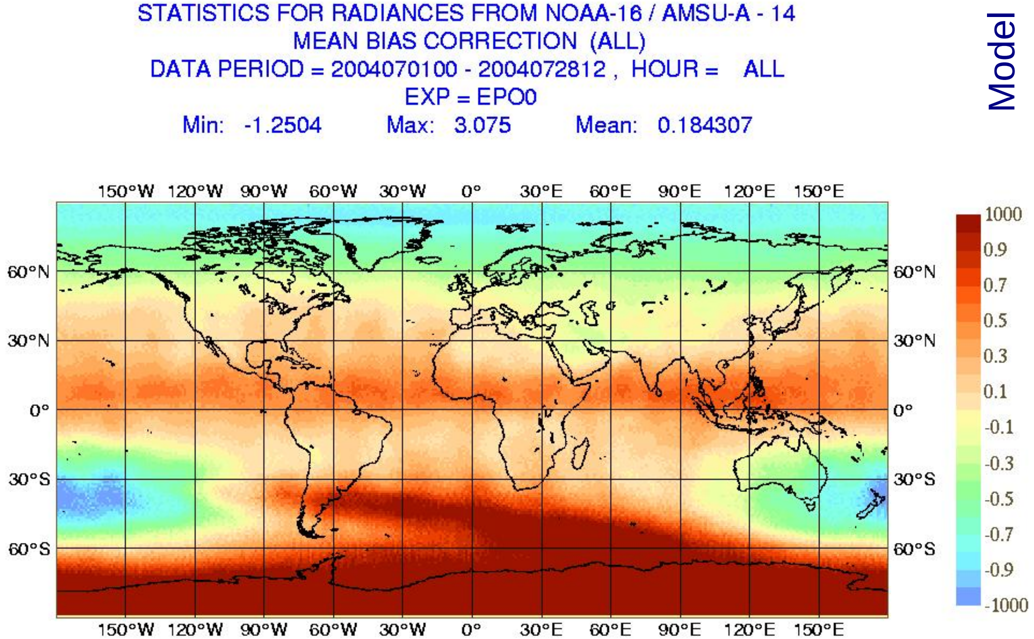
**New bias model** = **Temperature profile**
**Humidity profile**
**Skin Temperature**
**(87 predictors)** → **VarBC**

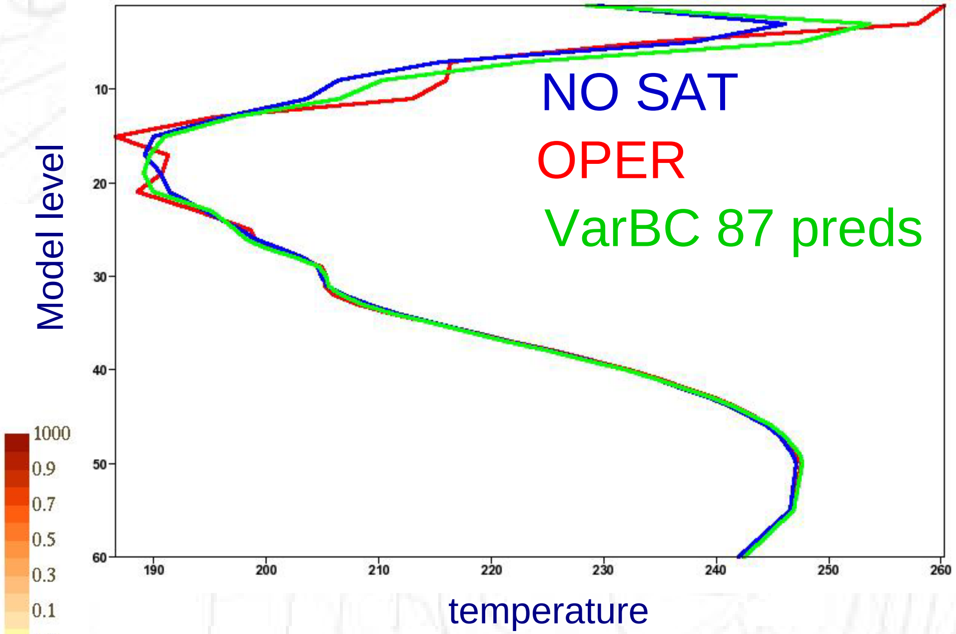
*(adaptive)*

# Variational bias correction

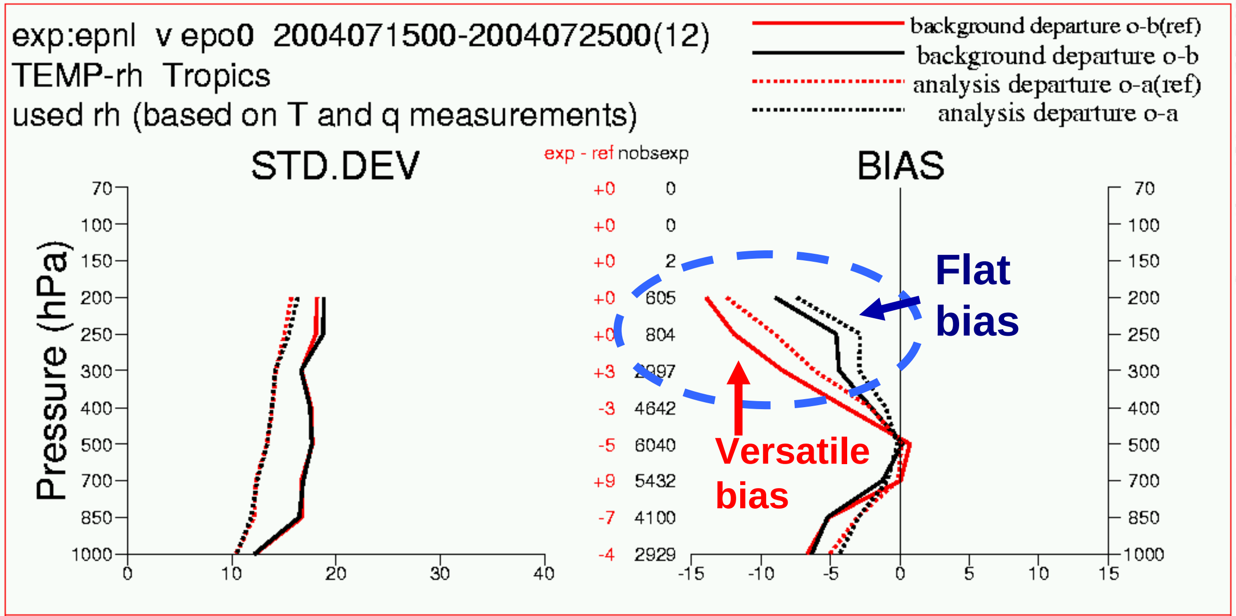
## Versatile bias model

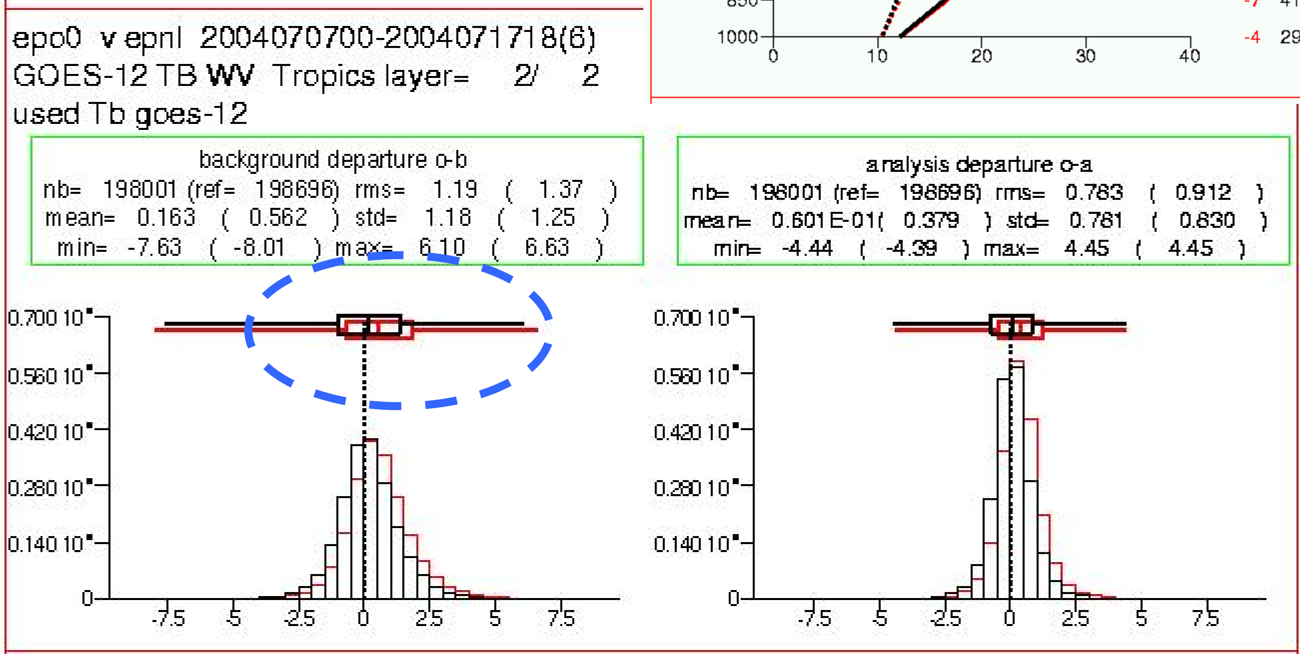
- The NWP model top is drawn back to the NOSAT experiment
- The winter pole temperature oscillations are greatly reduced



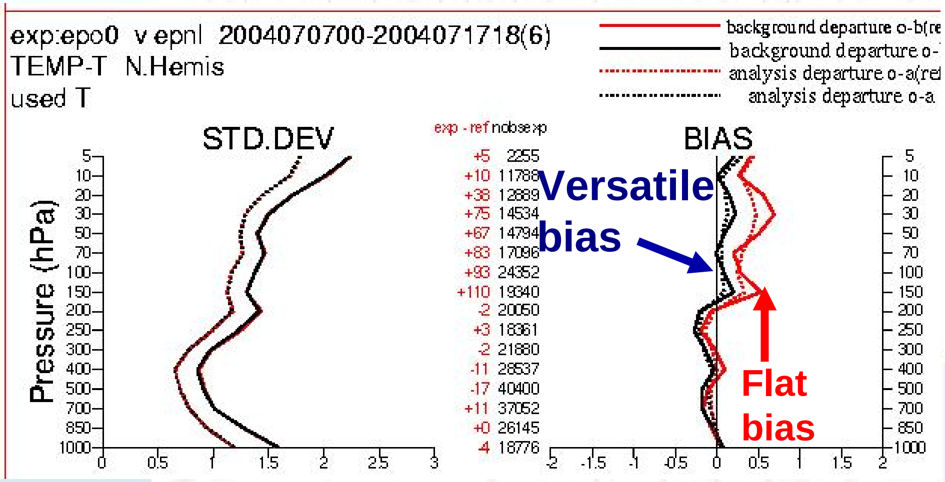
# Variational bias correction



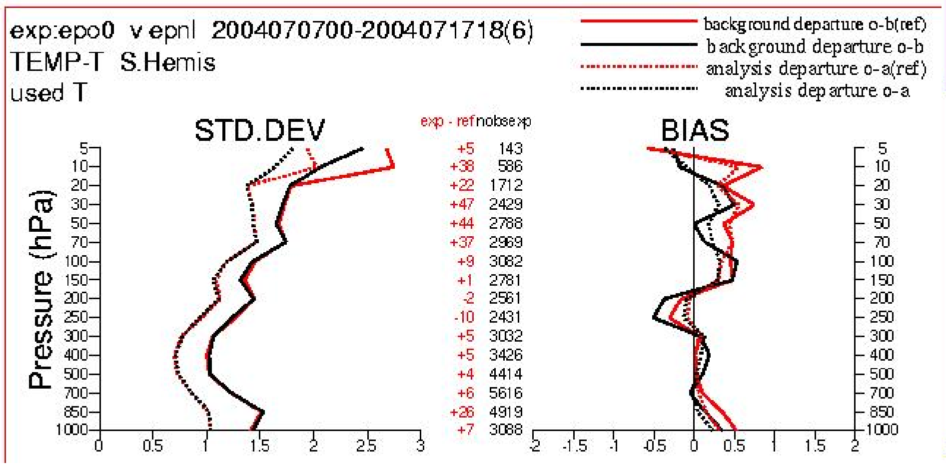



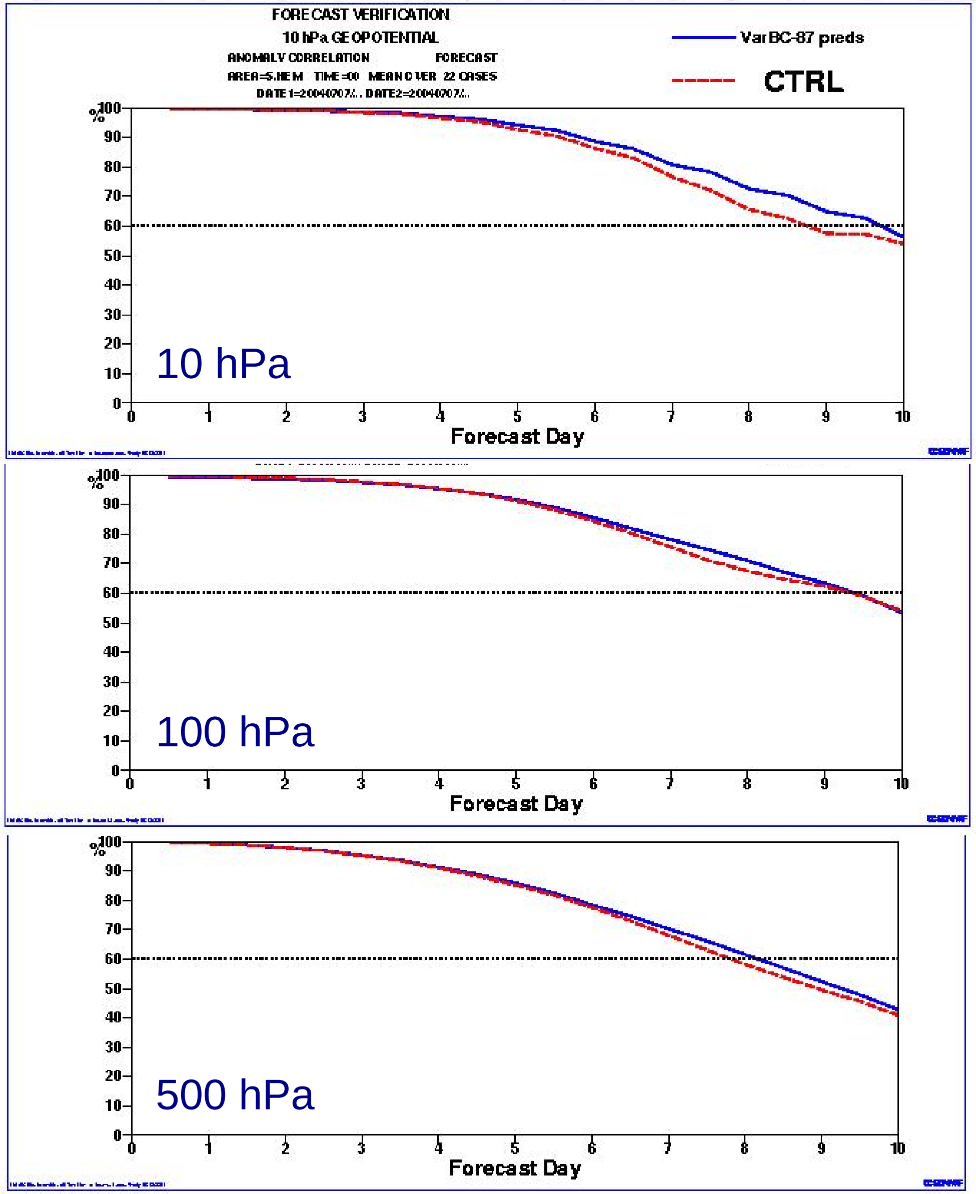

**Humidity bias in the NWP model** is less constrained by the satellite data

# Variational bias correction




Temperature fit to RS



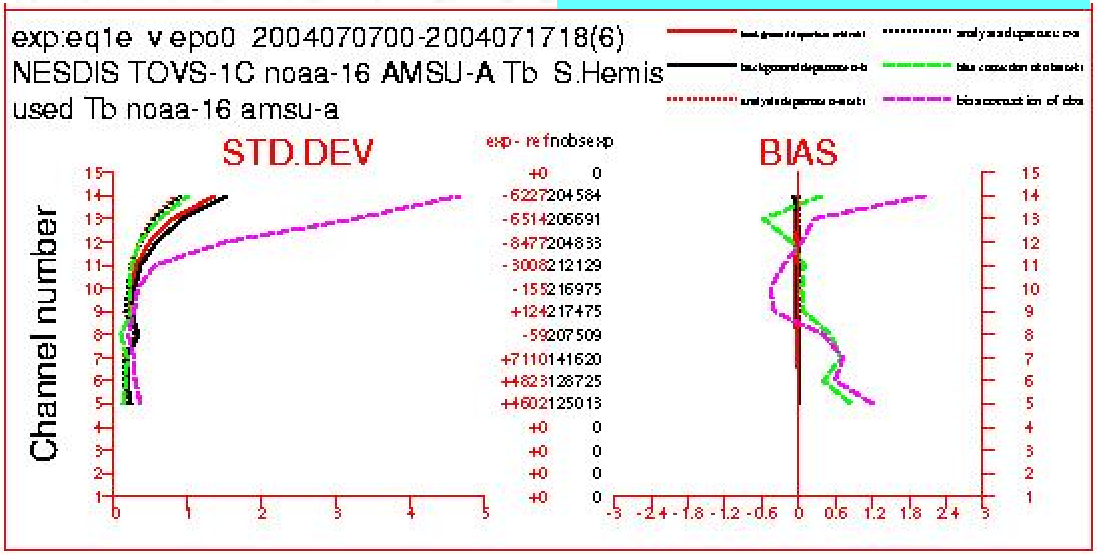
# Variational bias correction

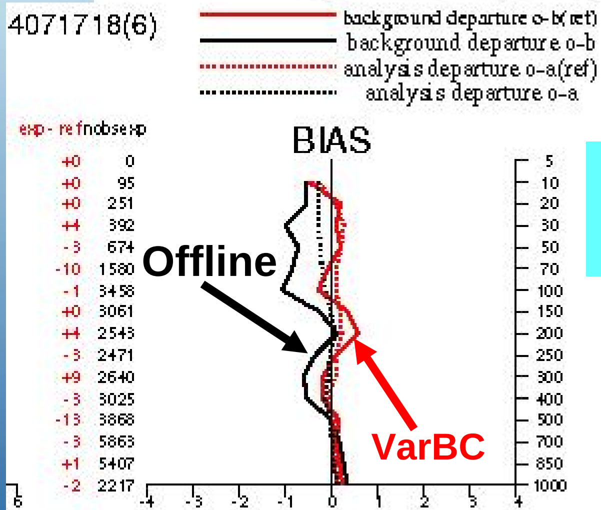
**Versatile bias model (87 preds)**

**VarBC** *(adaptive)*

**Offline** *(adaptive)*

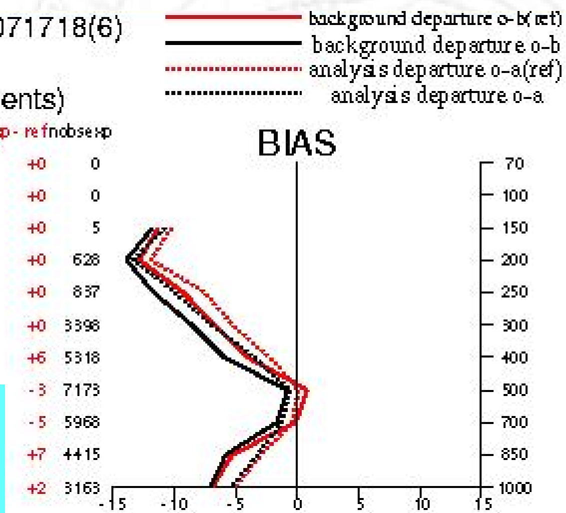
Fit to NOAA16 AMSUA



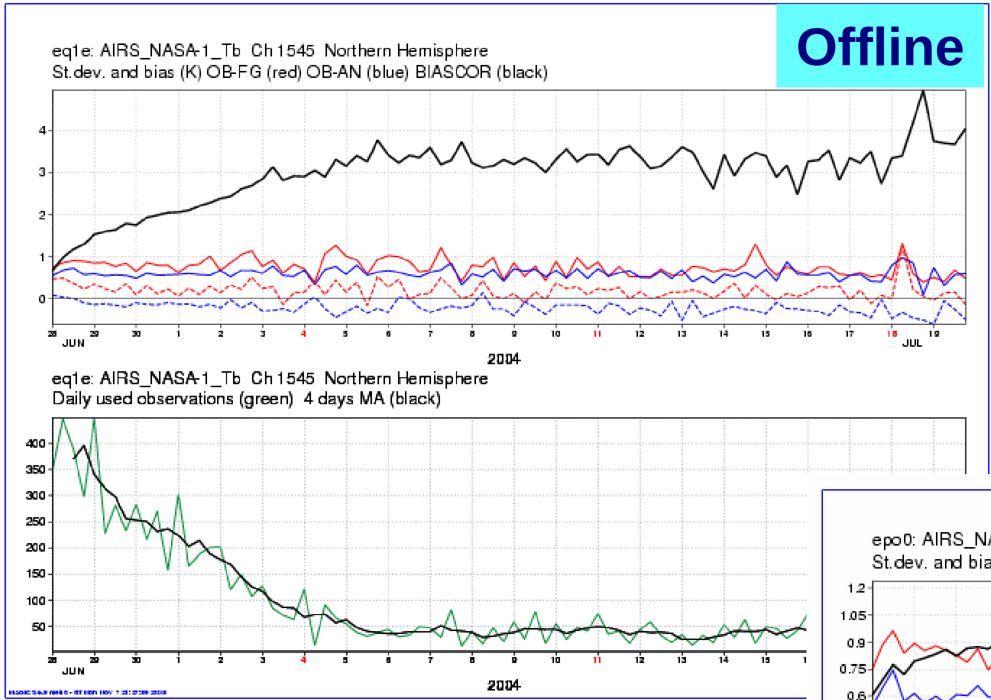




Fit to PILOT U wind - SH

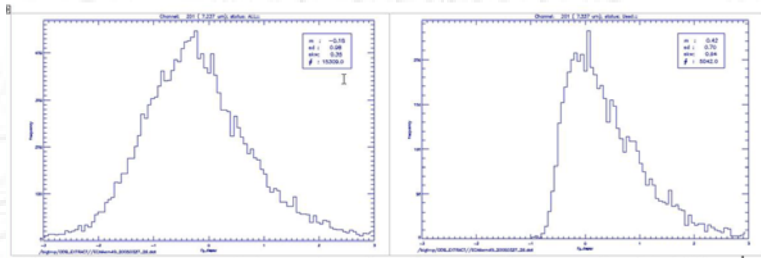
Fit to RS RH - Trop

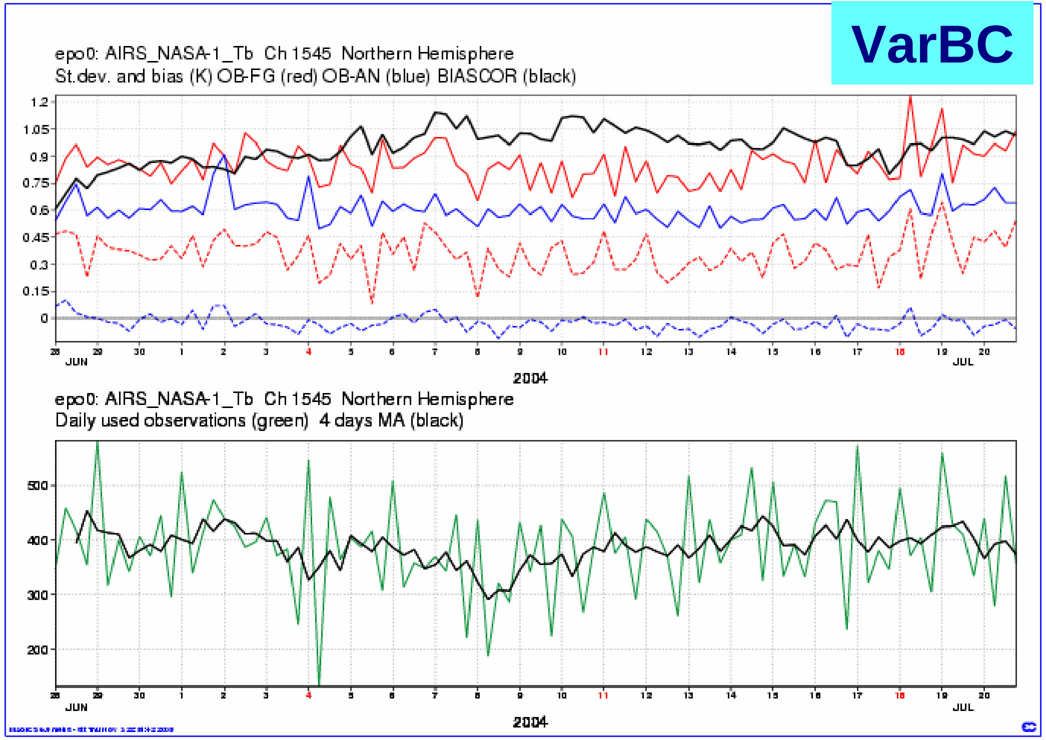


# Variational bias correction




***AIRS WV channel 1545 (7.23 $\mu$m)***






**Feedback process with cloud detection scheme for AIRS WV channels does not happen in VarBC**

# Conclusion

[$\gamma$,$\delta$] bias model used operationally for AIRS and AMSUA. Linear regression for HIRS, AMSUB, SSMI, GEOS.

Technical and scientific advantages of adaptive bias correction.

Feedback process b/w QC (first-guess check, cloud detection) defining the active population and adaptive bias correction modifying next cycle's departures. Reduced when using the mode of the distribution of departures as bias estimate.

Mapping of NWP error into adaptive bias estimate is reduced with VarBC, due to the constraint of other data (radio-sondes, aircraft, …).

Still need for a bias model that understands the sources of bias.

Investigate the explicit use of redundancy of information within data.

Thank you for your attention…

… bon appetit