Bias correction of satellite data at ECMWF

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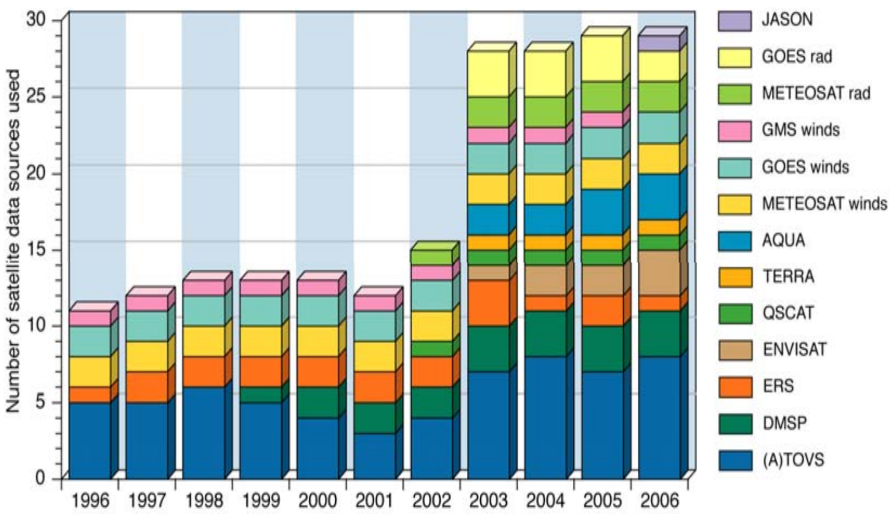
Motivation for an adaptive system

- Simplify the bias correction process of manual tuning / retuning
- Automatically handle:
  - Instrument problem / contamination
  - New version of RT Model
  - Appearance of new instruments
- Reanalysis issue: remove inconsistencies due to changes in the observing system
- Large increase in the number of satellite data (currently 29 instruments, ~500 channels, ~3000 bias parameters)



+6 000 000 data used daily

Prone to wrongly mapping systematic errors of the NWP model into radiance bias correction

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Variational bias correction

Predictors:
- constant offset
- scan
- air-mass

Bias for each satellite/sensor/channel: $b(\beta, x) = \sum_i \beta_i p_i$

Add the bias parameters β_i to the control vector in the variational analysis
→ joint estimation of bias and model state (Derber and Wu 1998) (Dee 2005)

J_b: background constraint for x J_o: observation constraint

$$\mathbf{J(x)} = \underbrace{(\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x})}_{J_b} + \underbrace{[\mathbf{y} - \mathbf{h(x)}]^T \mathbf{R}^{-1} [\mathbf{y} - \mathbf{h(x)}]}_{J_o}$$

↓

J_b: background constraint for x J_o: bias-corrected observation constraint

$$\mathbf{J(x,\beta)} = \underbrace{(\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x})}_{J_b} + \underbrace{[\mathbf{y} - \mathbf{b(x,\beta)} - \mathbf{h(x)}]^T \mathbf{R}^{-1} [\mathbf{y} - \mathbf{b(x,\beta)} - \mathbf{h(x)}]}_{J_o}$$
$$+ \underbrace{(\beta_b - \beta)^T \mathbf{B}_\beta^{-1} (\beta_b - \beta)}_{J_\beta}$$

J_β: background constraint for β

Find optimal bias correction given all available information

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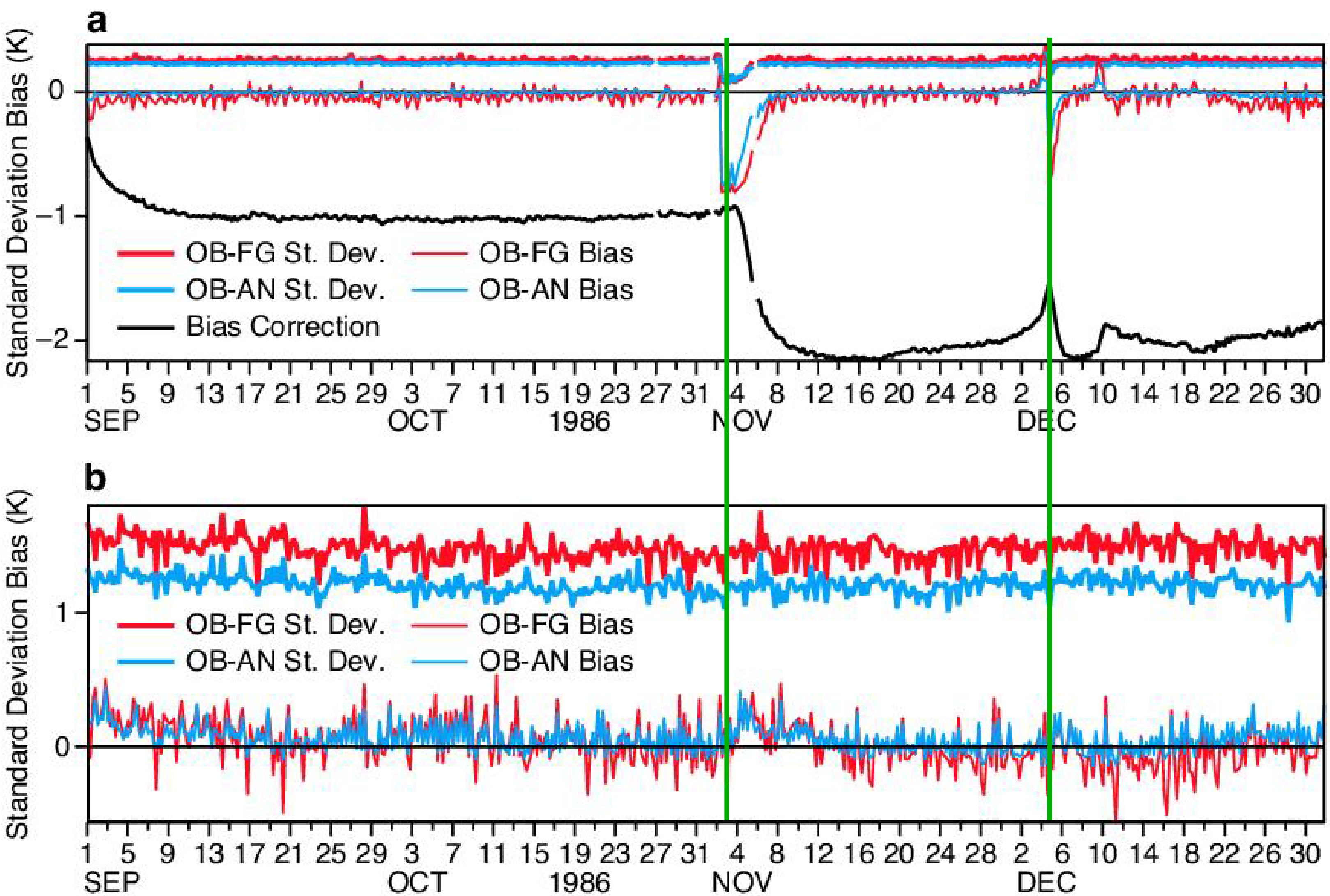
NOAA-9 MSU Ch3 disruption (cosmic storm)

NOAA-9
MSU Ch 3
Tropics

200 hPa RS
temperature
Tropics



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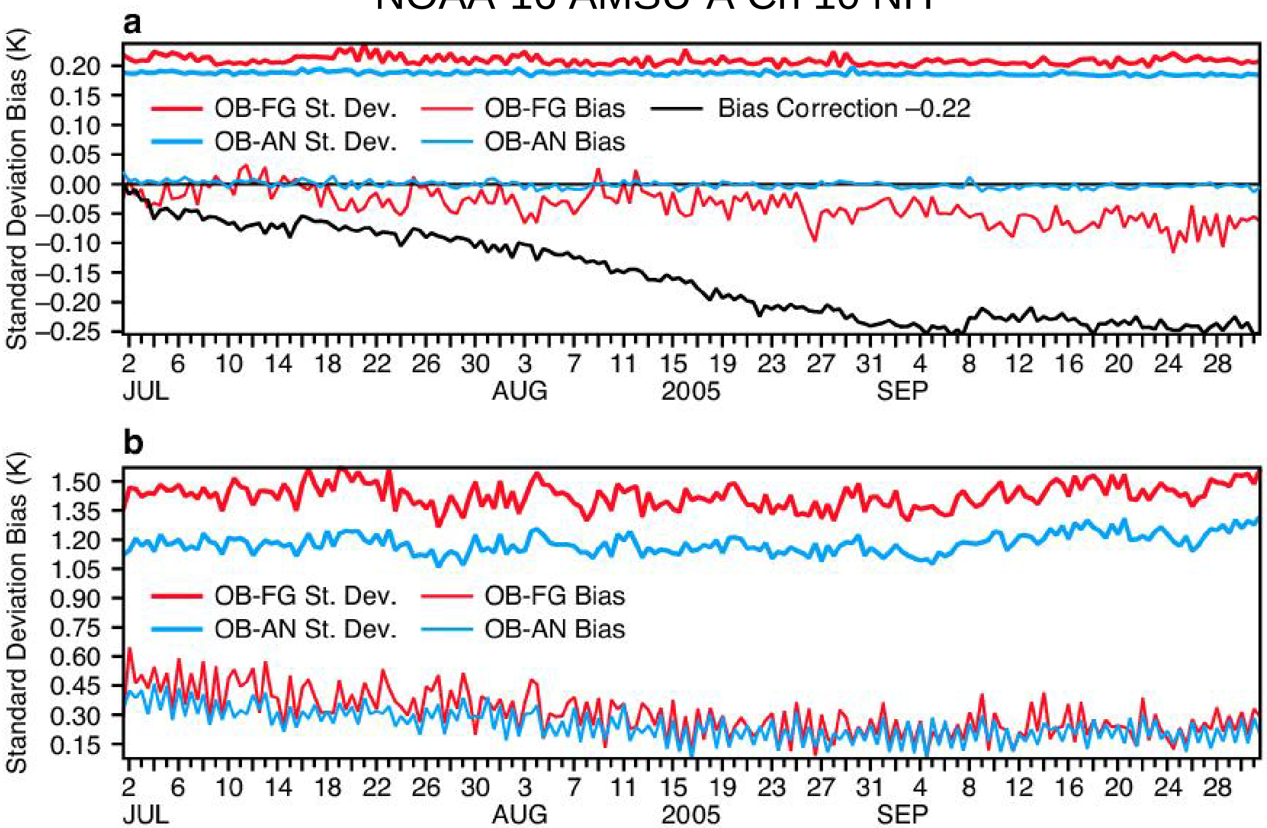
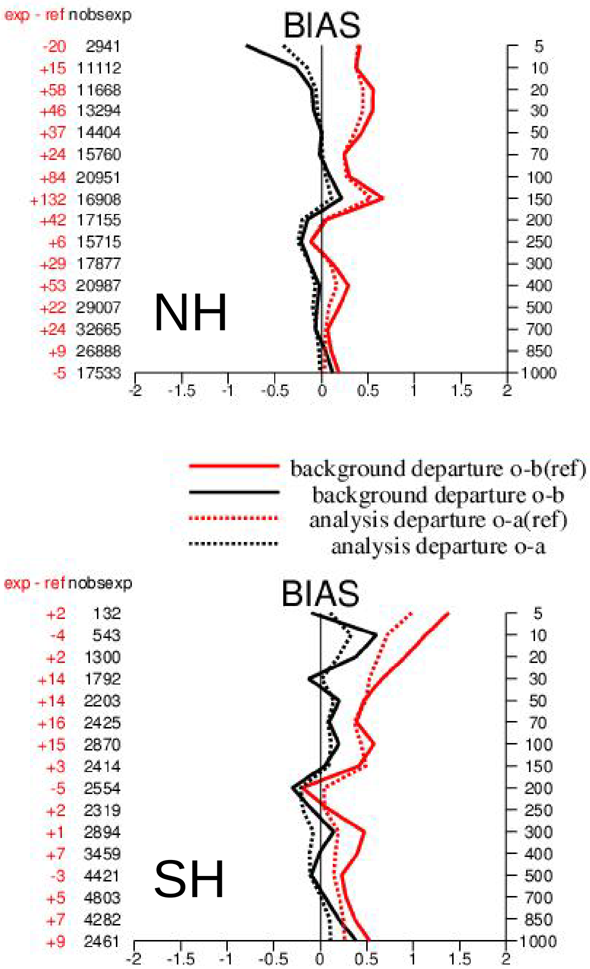
Performance of the VarBC
reduction of bias wrt RS temperature data

VarBC **Control**

NOAA-16 AMSU-A Ch 10 NH



50 hPa RS temperature NH



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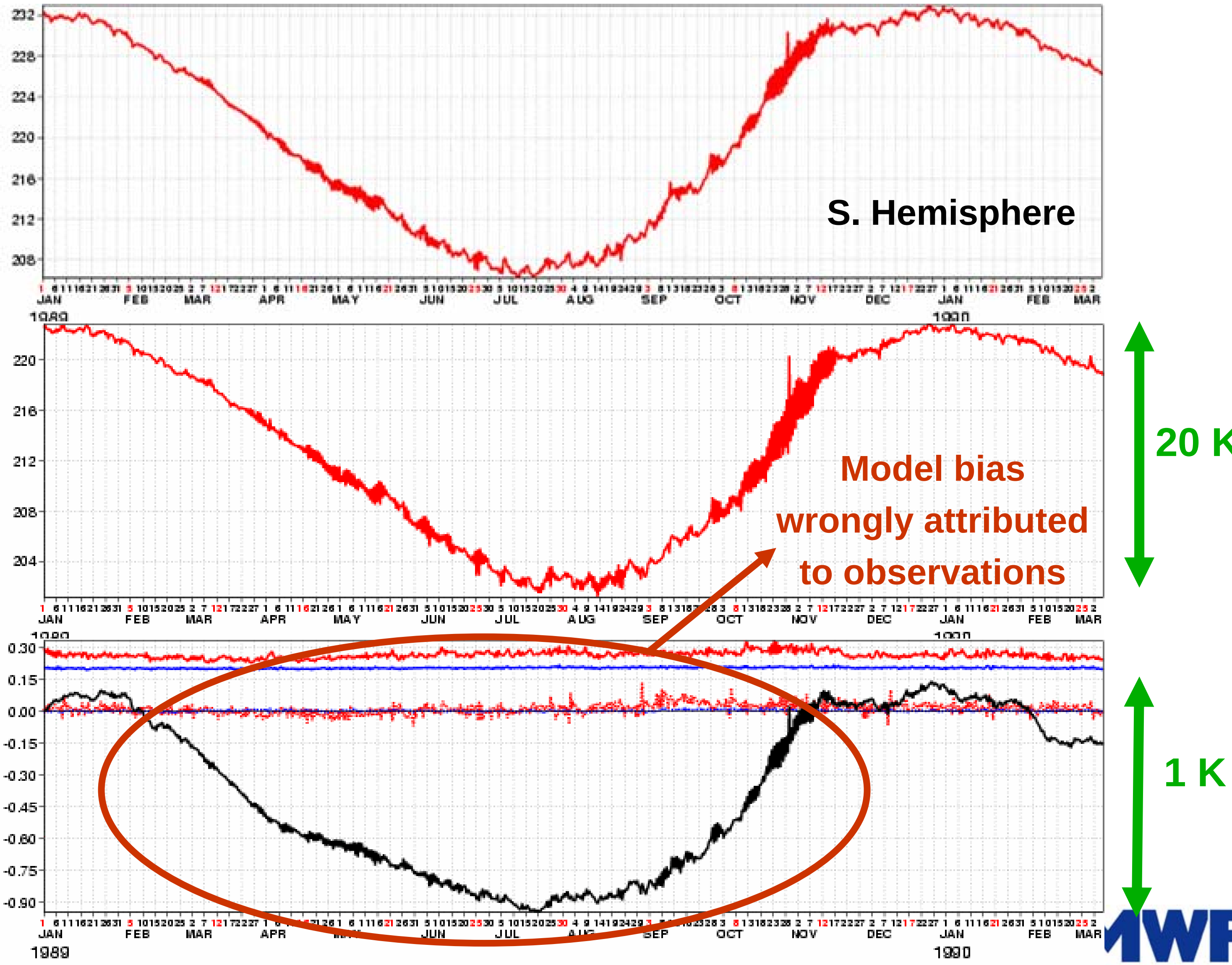
ERA Interim experimentation
Stratospheric model bias

NOAA-10 HIRS-3 Observation

NOAA-10 MSU-4 Observation

NOAA-10 MSU-4 Departures & Bias Correction



Conclusion on VarBC

- **Automation = big practical advantage**
- **Ability to handle sudden instrument shifts and slow drifts**
- **New sensors can be integrated easily**
  (reasonable bias within 1-7 days)
- **Consistency within the observing system**
  (better fit to RS temperatures)
- **Ability to (partially) discriminate between observation bias and systematic NWP model error relies on:**
  - **availability of unbiased data source (anchoring network)**
  - **observational coverage**
  - **parametric form**

Parametric form to represent observation bias

Definitions

It is essential to distinguish…

PARAMETRIC FORM = the predictors chosen to characterize the bias
(*e.g.* constant offset, NWP model preds, gamma, …)

ADAPTIVITY = how the bias coefficients are updated:

Static *vs* **Adaptive** → **VarBC** / **Offline**

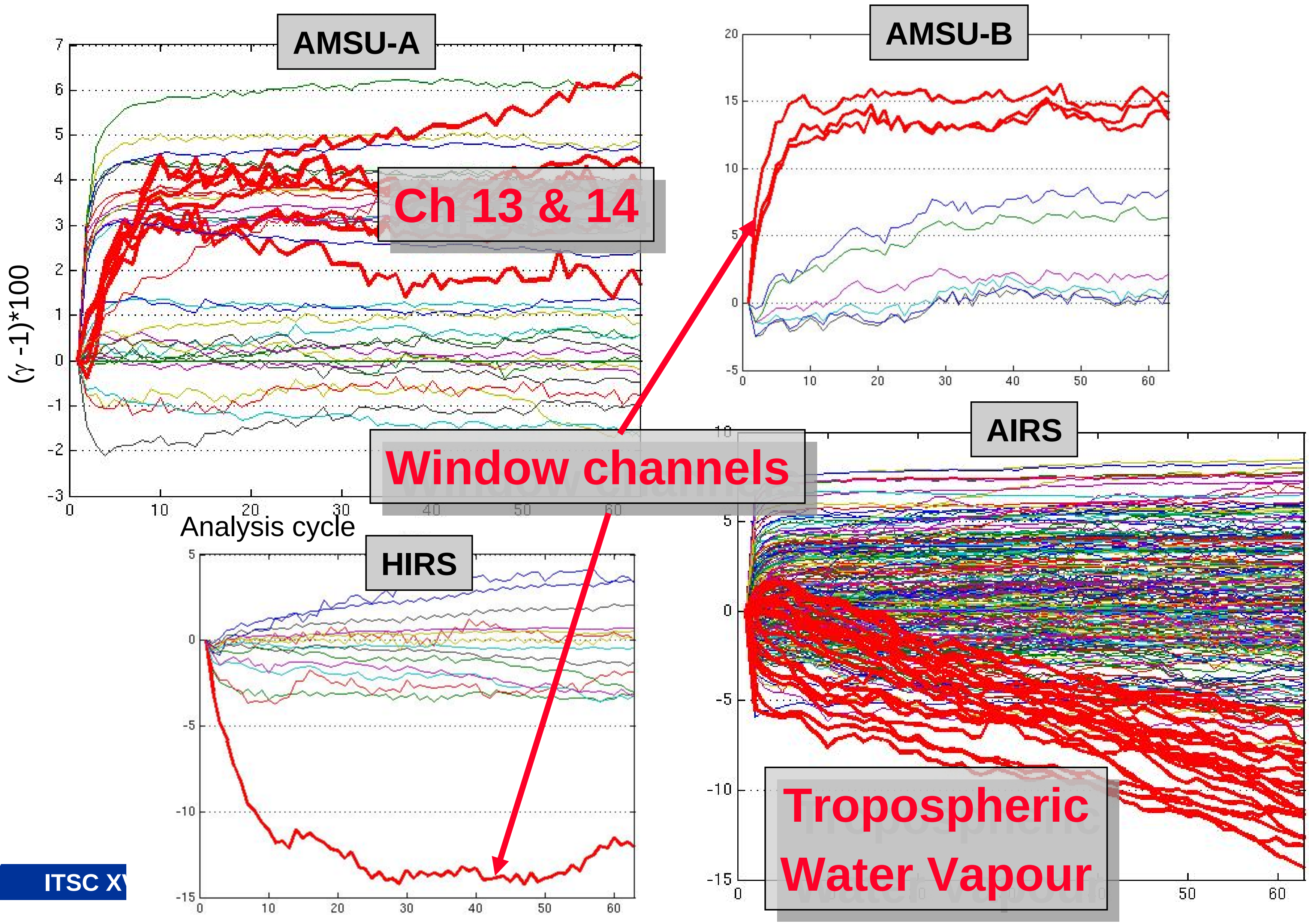
Operational parametric form

- γ correction to the RT model: γ = fractional error in layer absorption coefficient **STATIC**
- Scan correction: 3rd order polynomial of Scan Angle **ADAPTIVE**
- Air-mass regression

  Linear regression with a limited set of predictors P_i derived from the NWP model **ADAPTIVE**

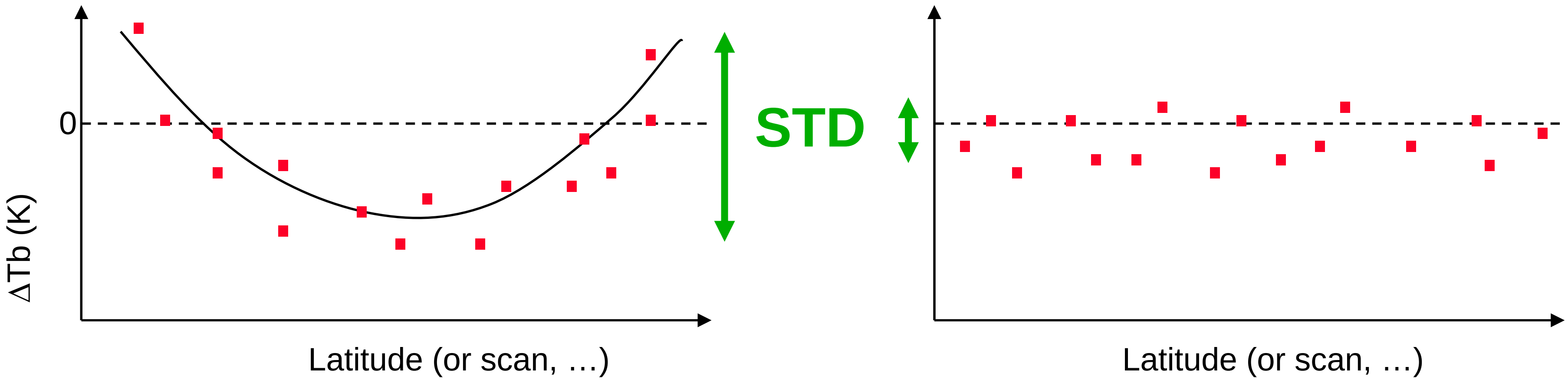
Instruments	# of preds	Predictors
HIRS, AMSU-A, AMSU-B, AIRS	4	1000-300, 200-50, 10-1, 50-5 hPa thicknesses
GEOS (GOES, Meteosat)	3	1000-300, 200-50 hPa, TCWV
SSMI	3	Tskin, TCWV, Surface Wind Speed

Estimation of the γ coefficient in VarBC



Relevant bias predictors

Property 1 = help reduce the first-guess departures



Uncorrected departures **Bias-corrected departures**

Relevant bias predictors

Property 1 = help reduce the first-guess departures

- Compute the variance explained for each potential predictor: not very convenient
- The predictors are normalized (mean=0, std=1). The parameter values from **VarBC** can be compared to **discard “useless” predictors**
- A “compensation” effect can happen b/w predictors that are correlated

Weight decay regularization

J_b: background constraint for x

J_o: bias-corrected observation constraint

$$J(\mathbf{x},\boldsymbol{\beta}) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x}) + [\mathbf{y} - \mathbf{b}(\mathbf{x},\boldsymbol{\beta}) - \mathbf{h}(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - \mathbf{b}(\mathbf{x},\boldsymbol{\beta}) - \mathbf{h}(\mathbf{x})]$$
$$+ (\boldsymbol{\beta}_b - \boldsymbol{\beta})^T \mathbf{B}_\beta^{-1} (\boldsymbol{\beta}_b - \boldsymbol{\beta}) + \boldsymbol{\beta}^T (\nu . I) \boldsymbol{\beta}$$

J_β: background constraint for β

Weight decay constraint for β

Relevant bias predictors

Property 1 = help reduce the first-guess departures

Diagnostic 1 = absolute value of (normalized) parameters

Relevant bias predictors

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Property 2 = focus on observation bias
(and not systematic NWP model error)

Relevant bias predictors

Property 1 = help reduce the first-guess departures

Diagnostic 1 = absolute value of (normalized) parameters

Property 2 = focus on observation bias
(and not systematic NWP model error)

- VarBC is **constrained** by all other observation sources (*e.g.* RS)
- Offline adaptive BC tries to fully correct signal in the departures
- A parametric form only explaining for observation bias only should be updated identically in both schemes

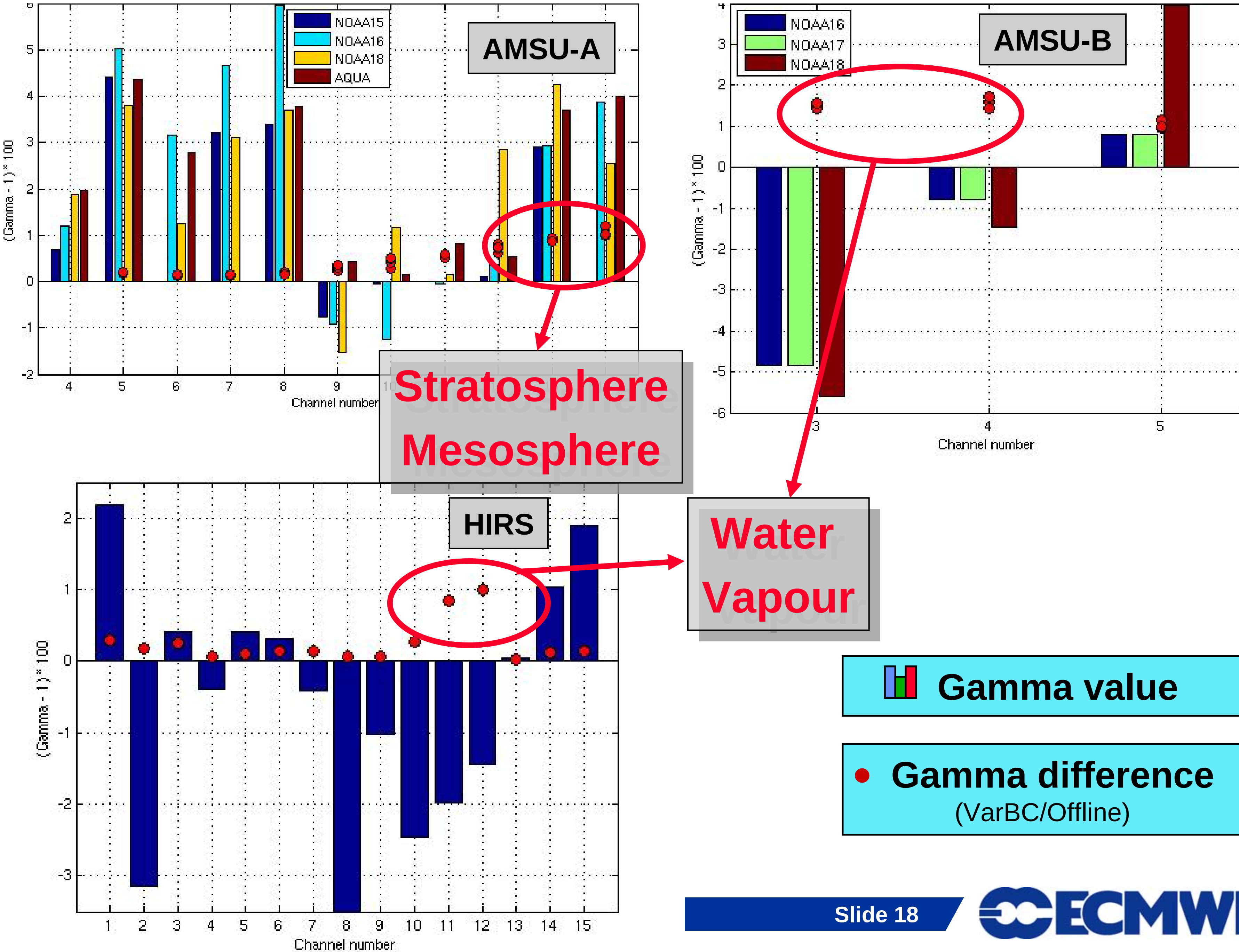
Relevant bias predictors

Property 1 = help reduce the first-guess departures

Diagnostic 1 = absolute value of (normalized) parameters

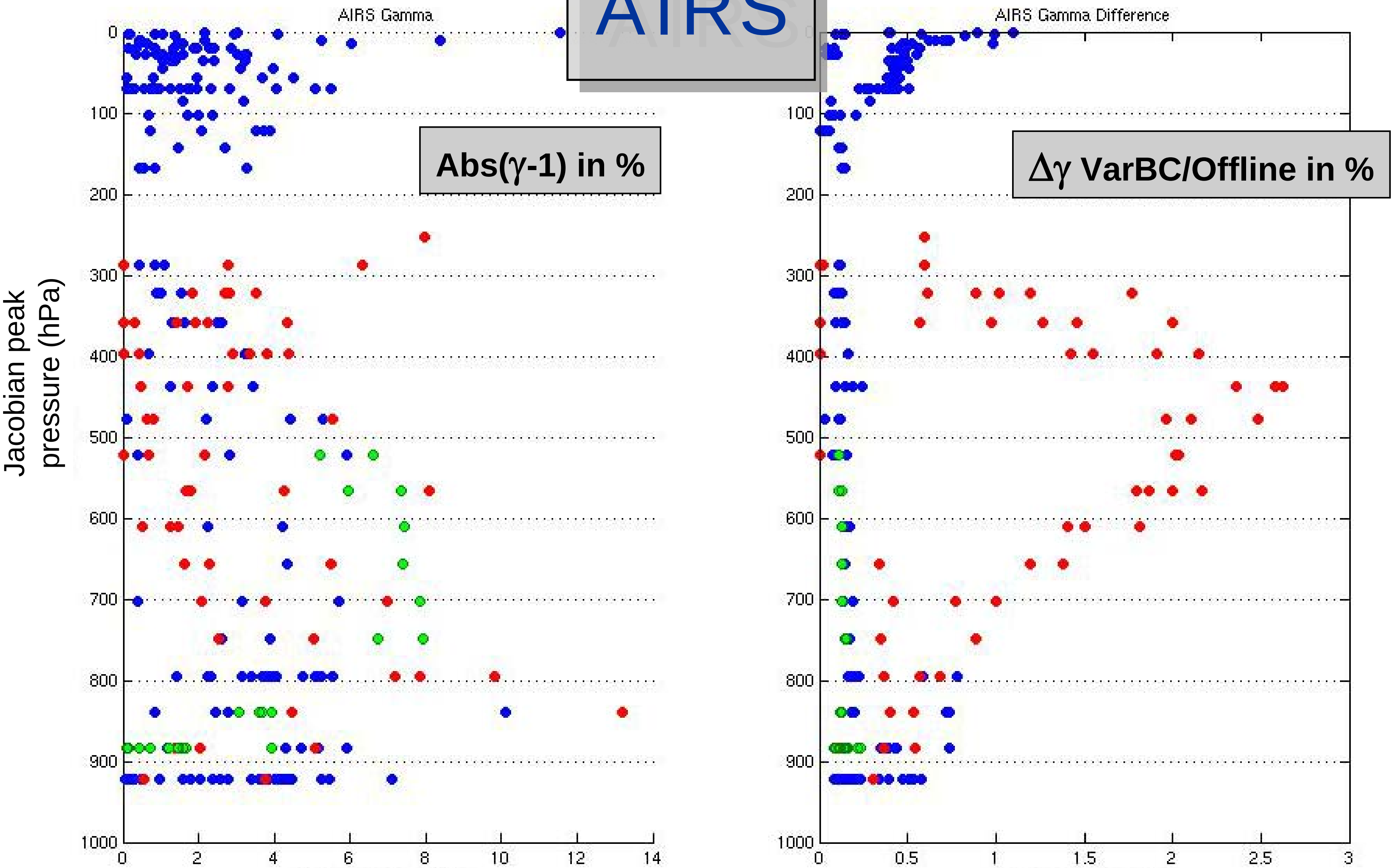
Property 2 = focus on observation bias
(and not systematic NWP model error)

Diagnostic 2 = (dis)agreement b/w VarBC and Offline Adaptive BC


AMSU-A
NOAA15
NOAA16
NOAA18
AQUA
(Gamma - 1) * 100
Channel number
AMSU-B
NOAA16
NOAA17
NOAA18
(Gamma - 1) * 100
Channel number
HIRS
(Gamma - 1) * 100
Channel number
Stratosphere
Mesosphere
Water
Vapour
Gamma value
Gamma difference
(VarBC/Offline)

AIRS

- LW Temperature
- SW Temperature
- Water Vapour



Conclusion & future work

- VarBC operational at ECMWF since September 12th 2006 and in ERA-Interim reanalysis

- Works well in many respects. Needs close attention to:
  - **NWP model error mapping *(e.g.* stratosphere)**
  - **feedback process with Quality Control & Cloud Detection (*e.g.* window channels)**

- Enables diagnostics to evaluate bias predictor relevance

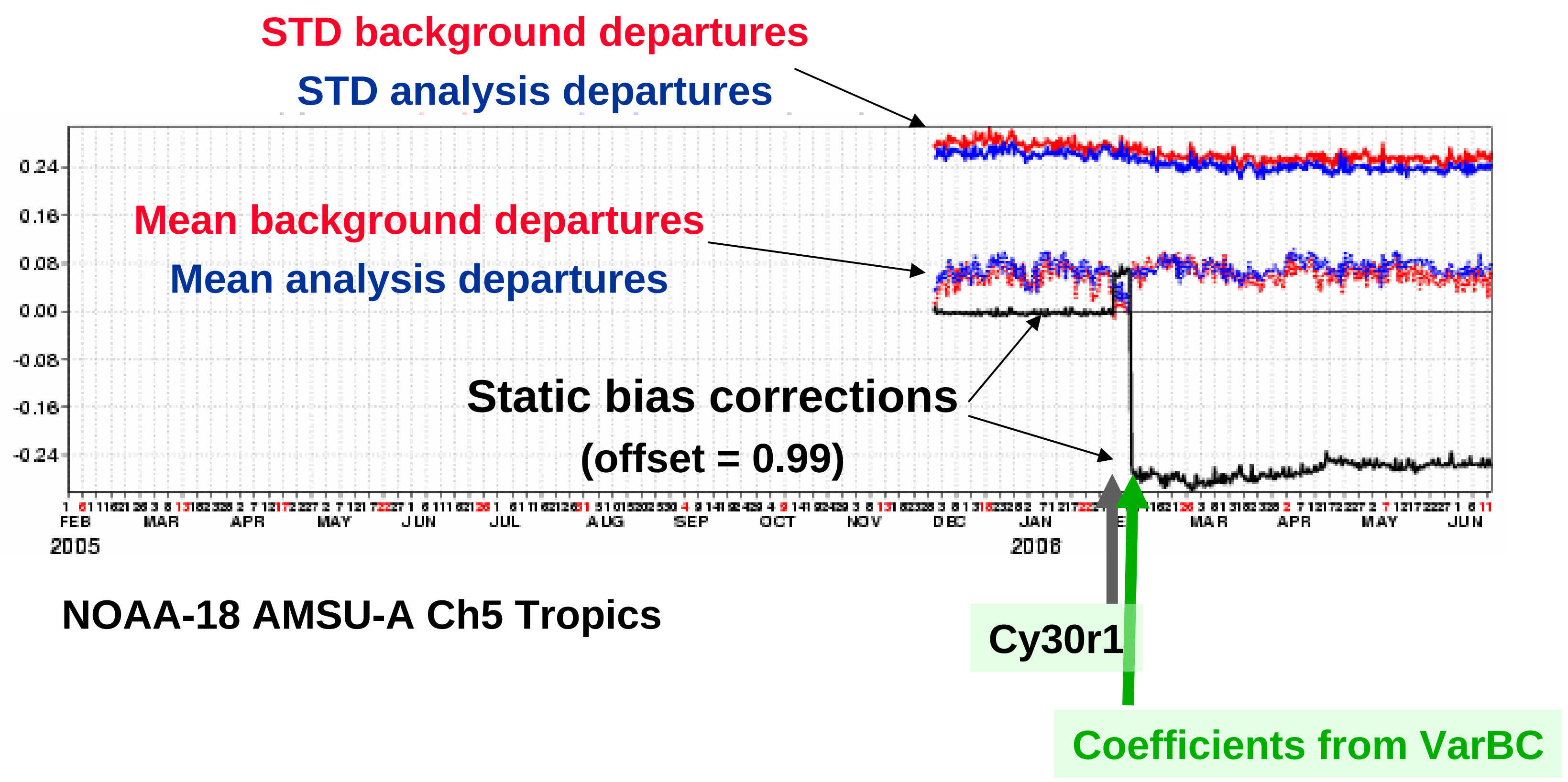
- These can be used in an objective method to select predictors

END

Thank you…

Introduction of the VarBC in operations: first step

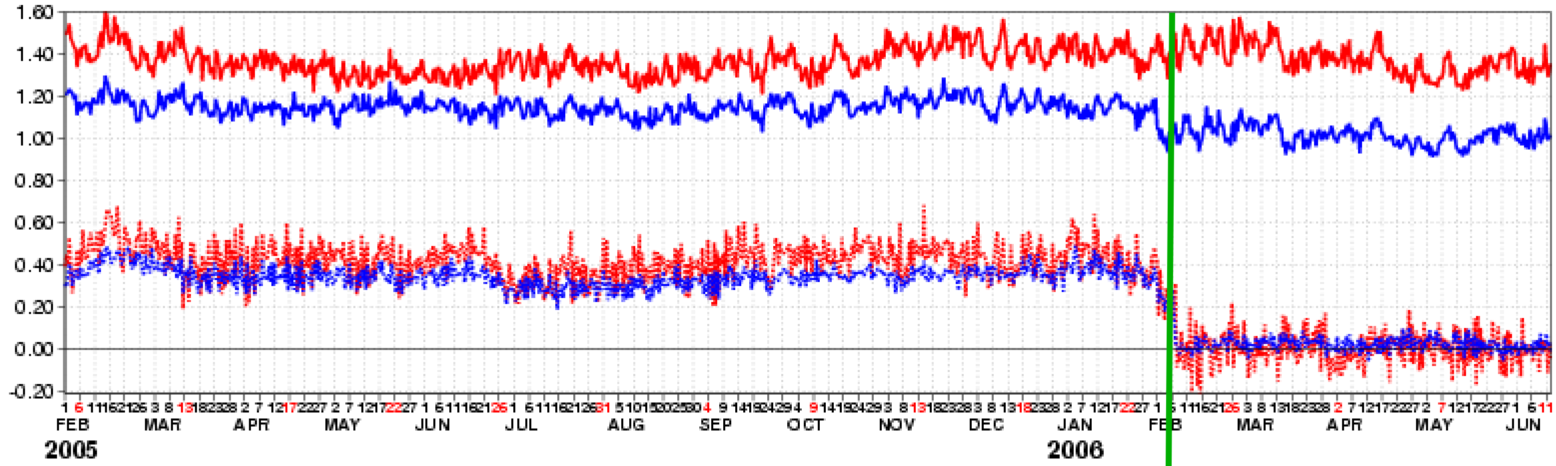
Feb 2006: implementation of a static bias correction derived from a VarBC experiment



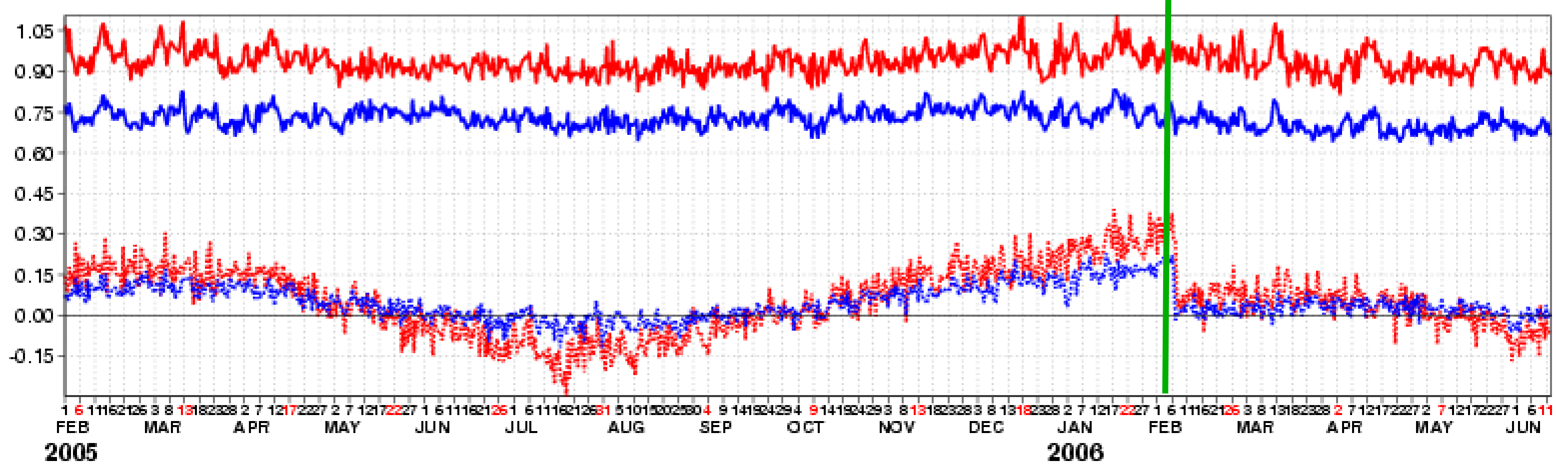
NOAA-18 AMSU-A Ch5 Tropics

Introduction of the VarBC in operations: first step

100 hPa RS temperature Tropics



500 hPa RS temperature Tropics



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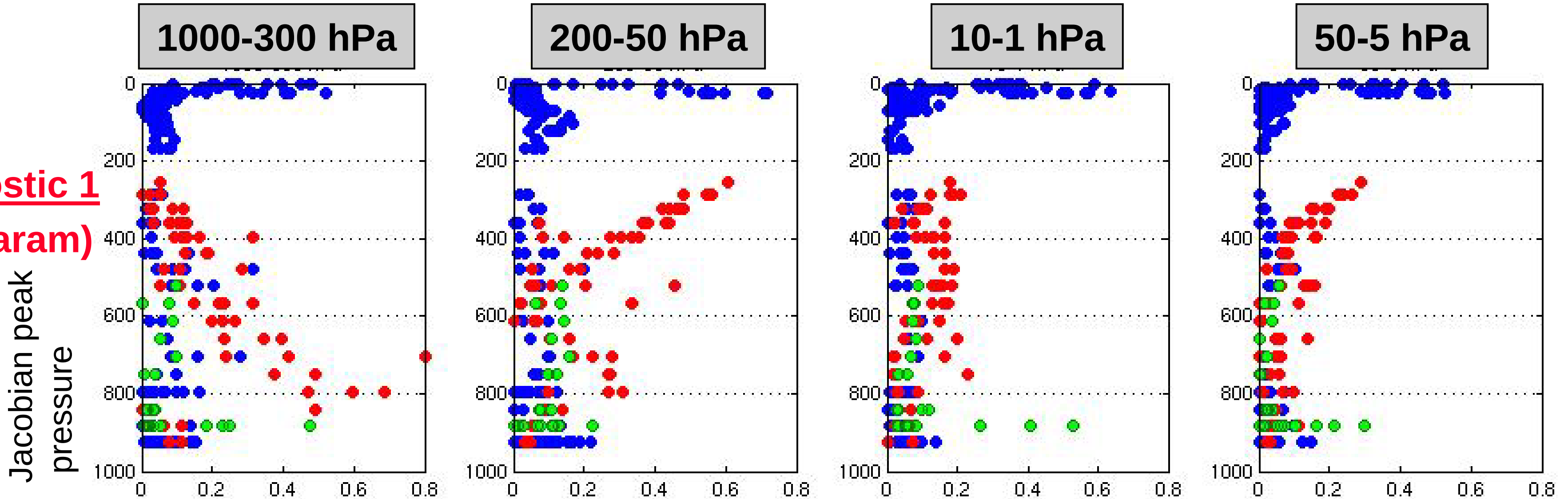
AIRS operational bias predictors

Diagnostic 1

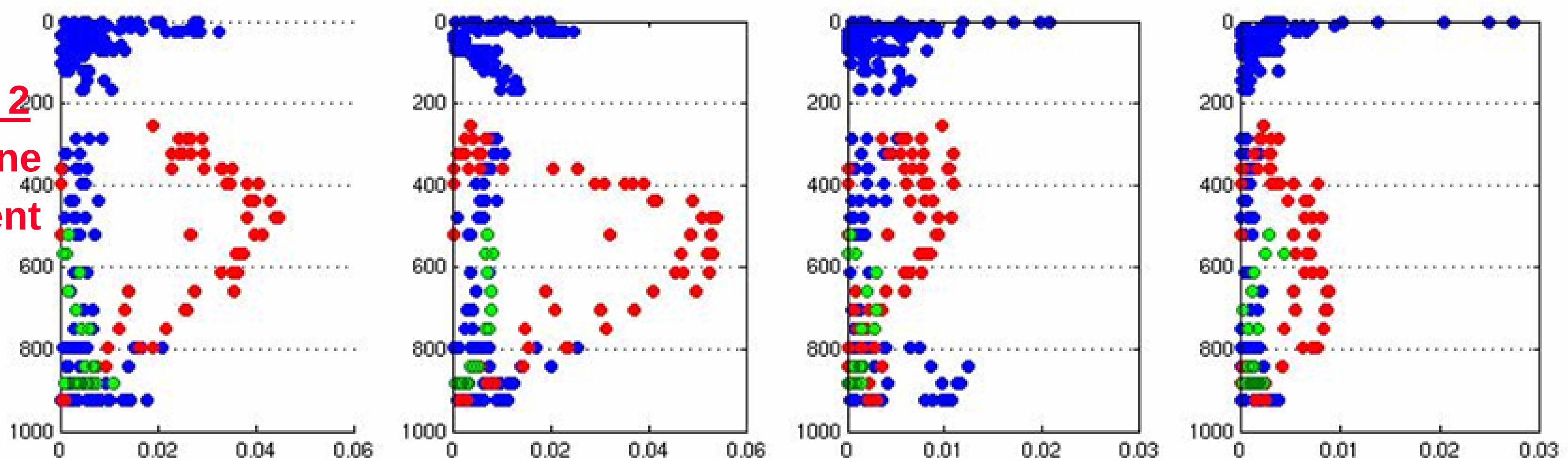
Abs(Param)



• LW Temperature • SW Temperature • Water Vapour

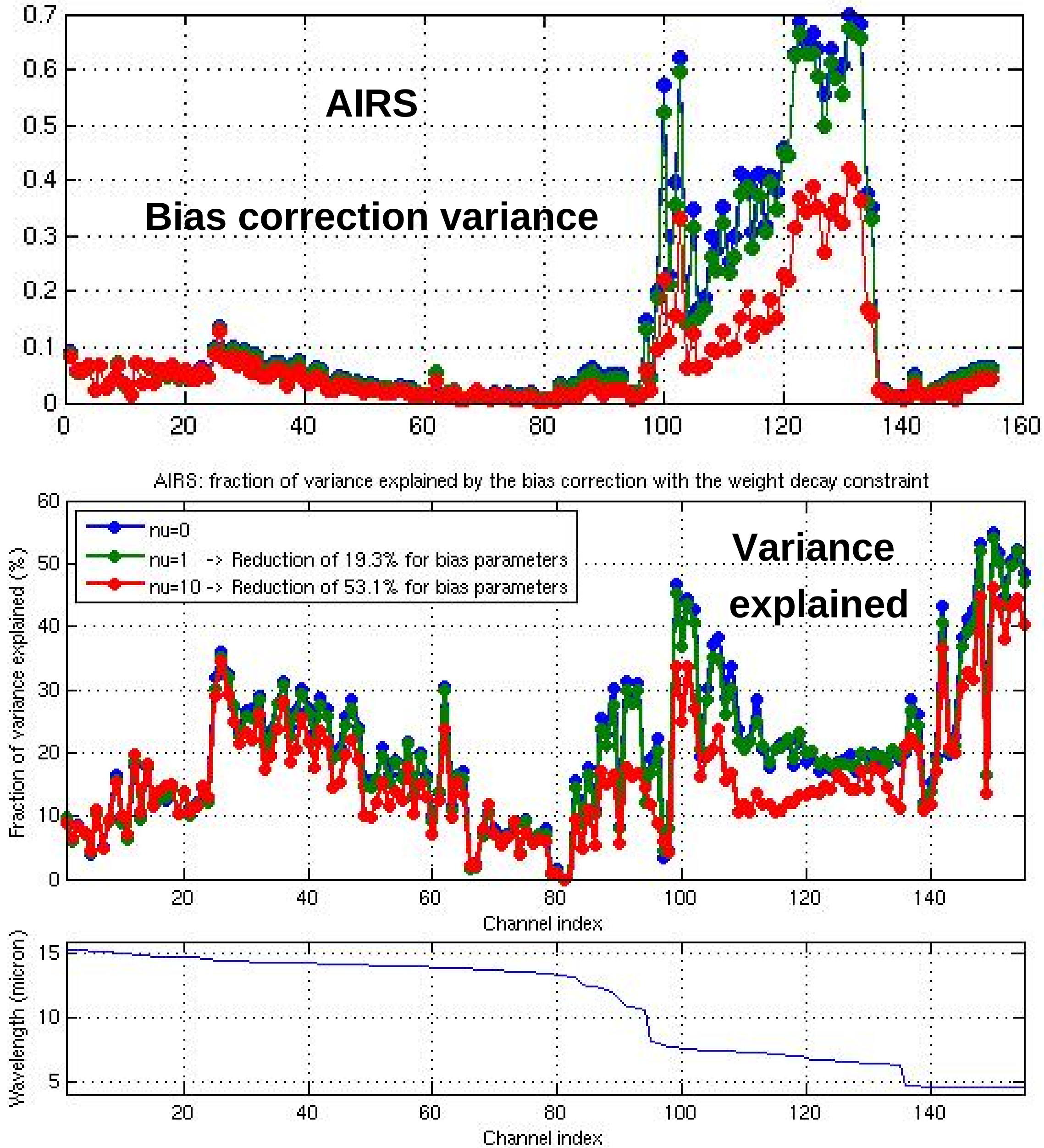
Diagnostic 2

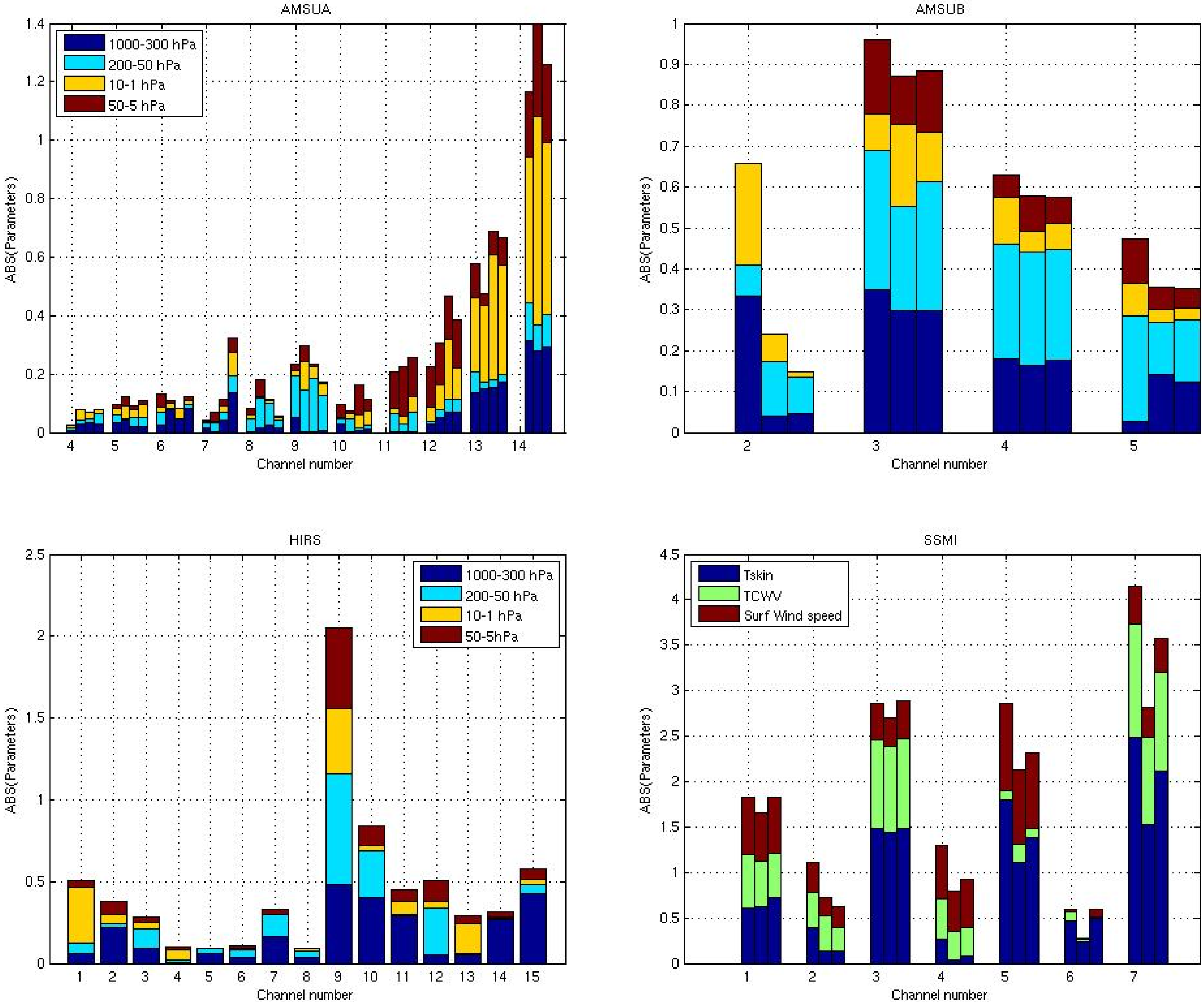
VarBC/Offline disagreement



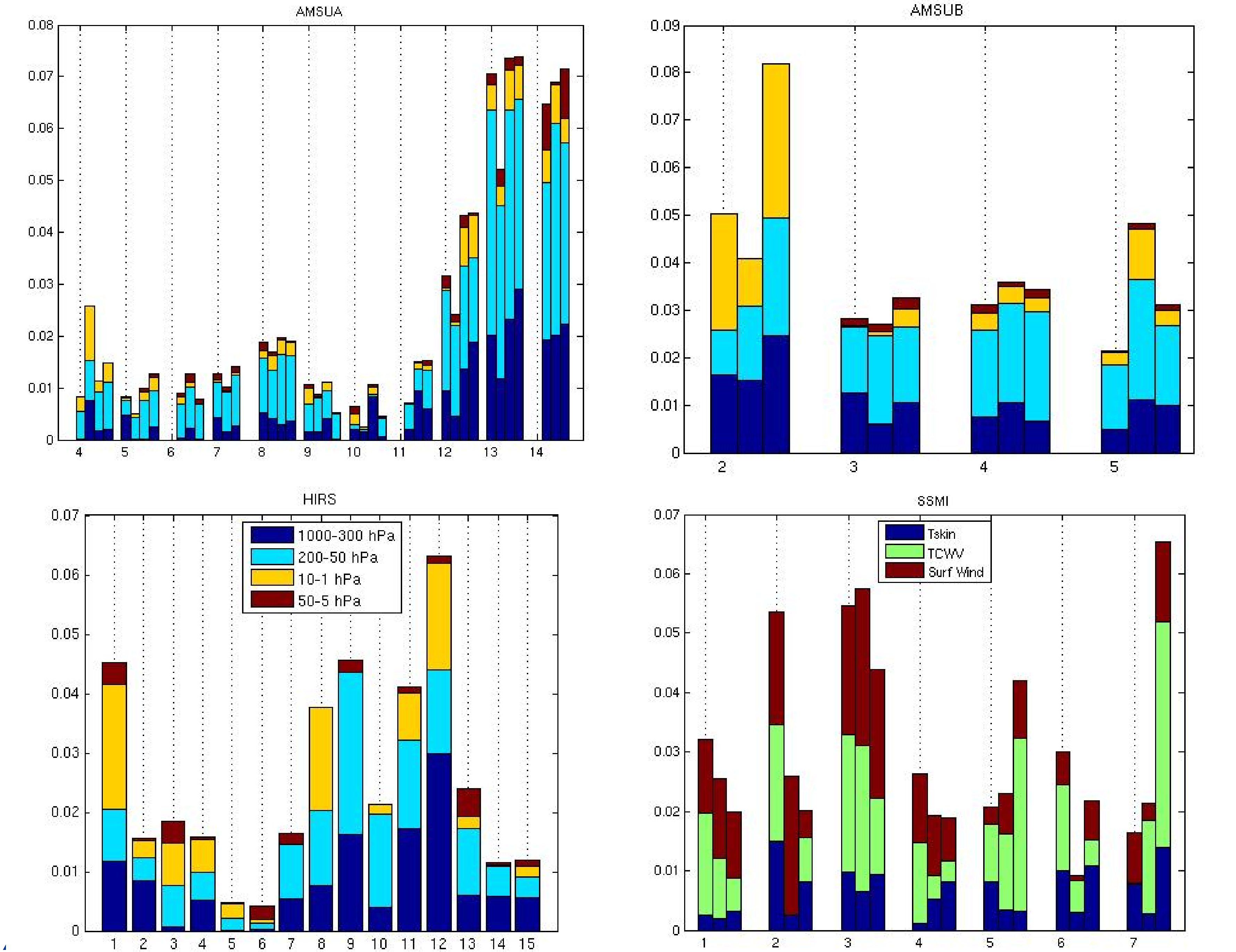
ITSC

Weight decay regularization





AMSUA
AMSUB
HIRS
SSMI
1000-300 hPa
200-50 hPa
10-1 hPa
50-5 hPa
50-5hPa
Tskin
TCWV
Surf Wind speed
ABS(Parameters)
Channel number


AMSUA
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Surf Wind