# Bias correction of satellite data at ECMWF

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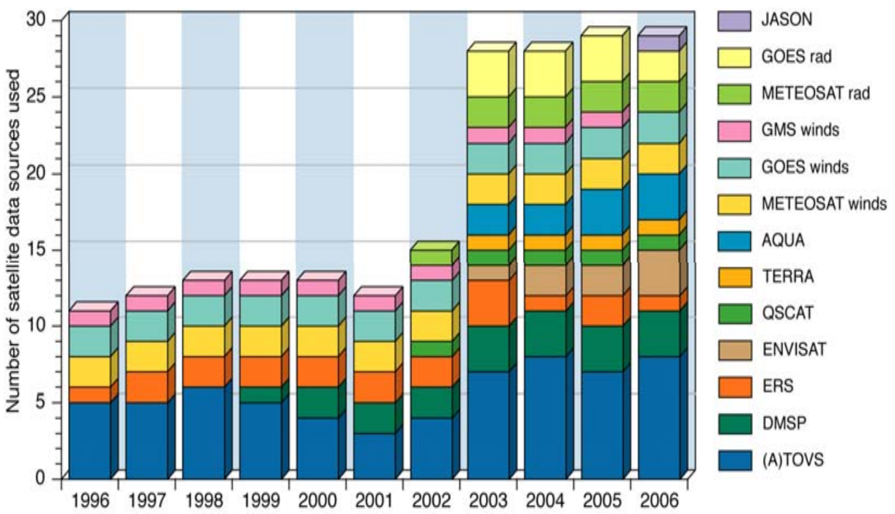
# Motivation for an adaptive system

- 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 $\beta_i$ 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

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

$J_\beta$: background constraint for $\beta$

***Find optimal bias correction given all available information***



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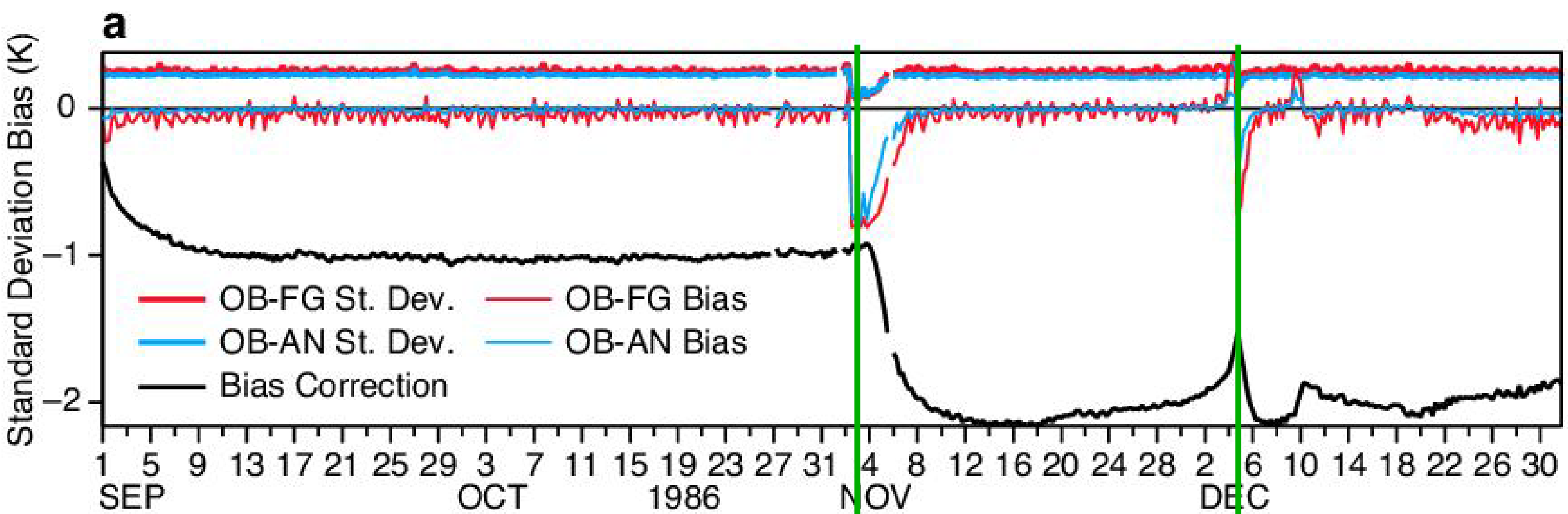
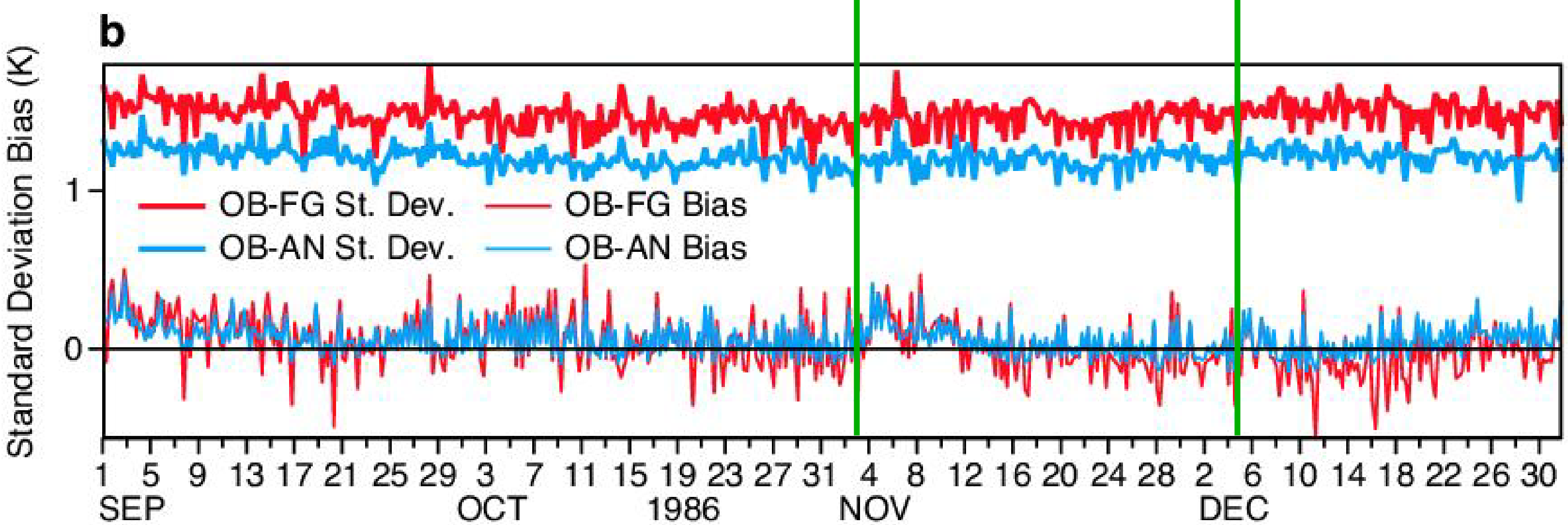
# NOAA-9 MSU Ch3 disruption (cosmic storm)

NOAA-9
MSU Ch 3
Tropics



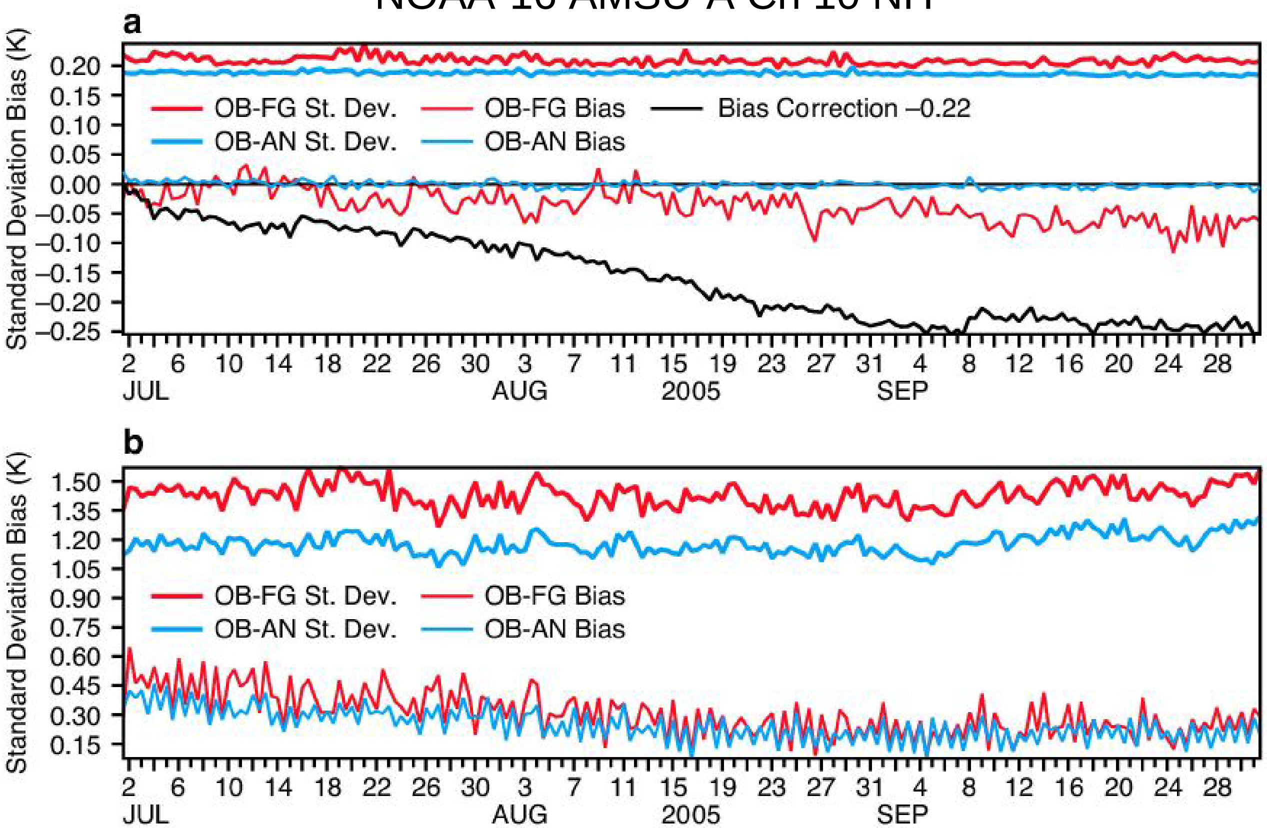

200 hPa RS
temperature
Tropics



# Performance of the VarBC

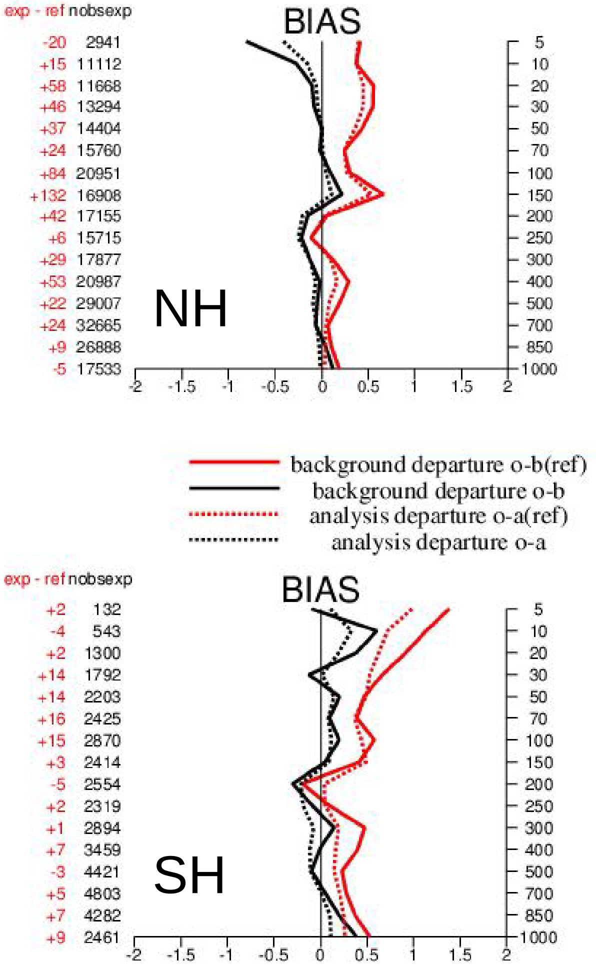
## reduction of bias wrt RS temperature data

NOAA-16 AMSU-A Ch 10 NH




50 hPa RS temperature NH

**VarBC** **Control**



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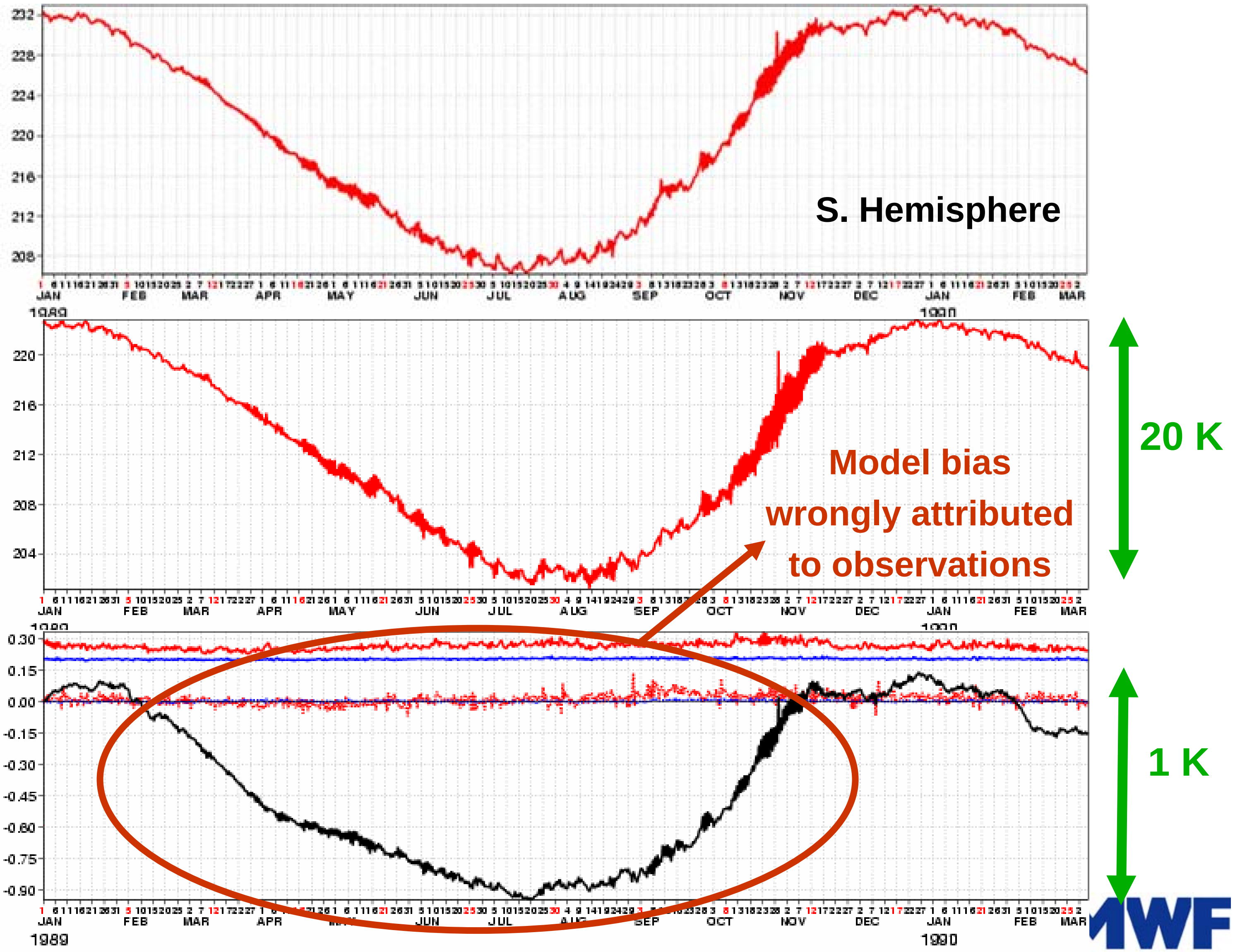
# ERA Interim experimentation
# Stratospheric model bias

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, …)

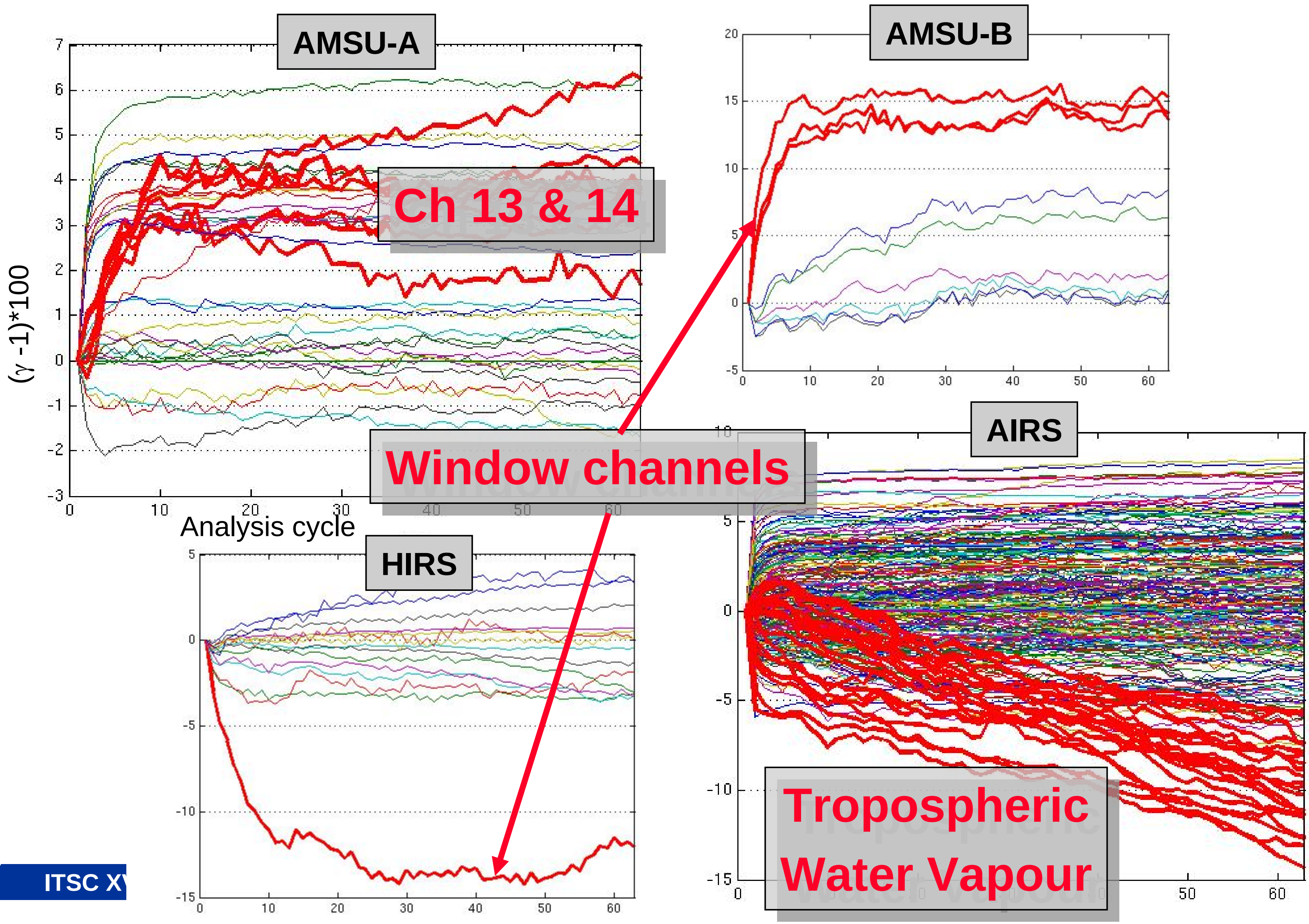
**ADAPTIVITY** = how the bias coefficients are updated:

# Operational parametric form

- $\gamma$ correction to the RT model: $\gamma$ = 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**

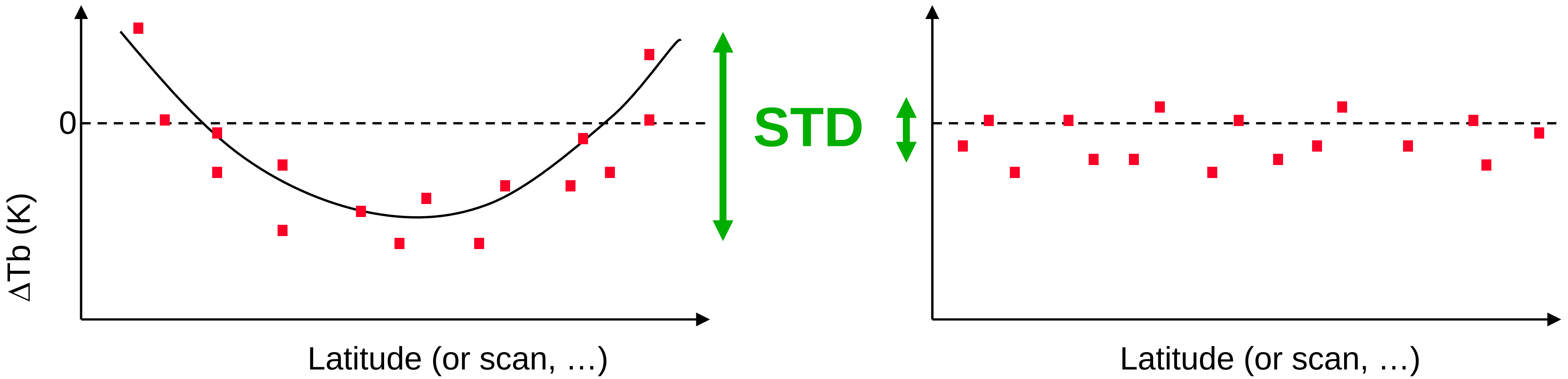
| Instruments | # of preds | Predictors |
| --- | --- | --- |
| HIRS, AMSU-A, AMSU-B, AIRS | 4 | 1000-300, 200-50, 10-1, 50-5 hPa thicknesses |
| GEOS (GOES, Meteosat) | 3 | 1000-300, 200-50 hPa, TCWV |
| SSMI | 3 | Tskin, TCWV, Surface Wind Speed |

# 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

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

$J_\beta$: background constraint for $\beta$ — Weight decay constraint for $\beta$

# Relevant bias predictors

Property 1 = help reduce the first-guess departures

*Diagnostic 1 = absolute value of (normalized) parameters*

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


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# 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



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# 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*



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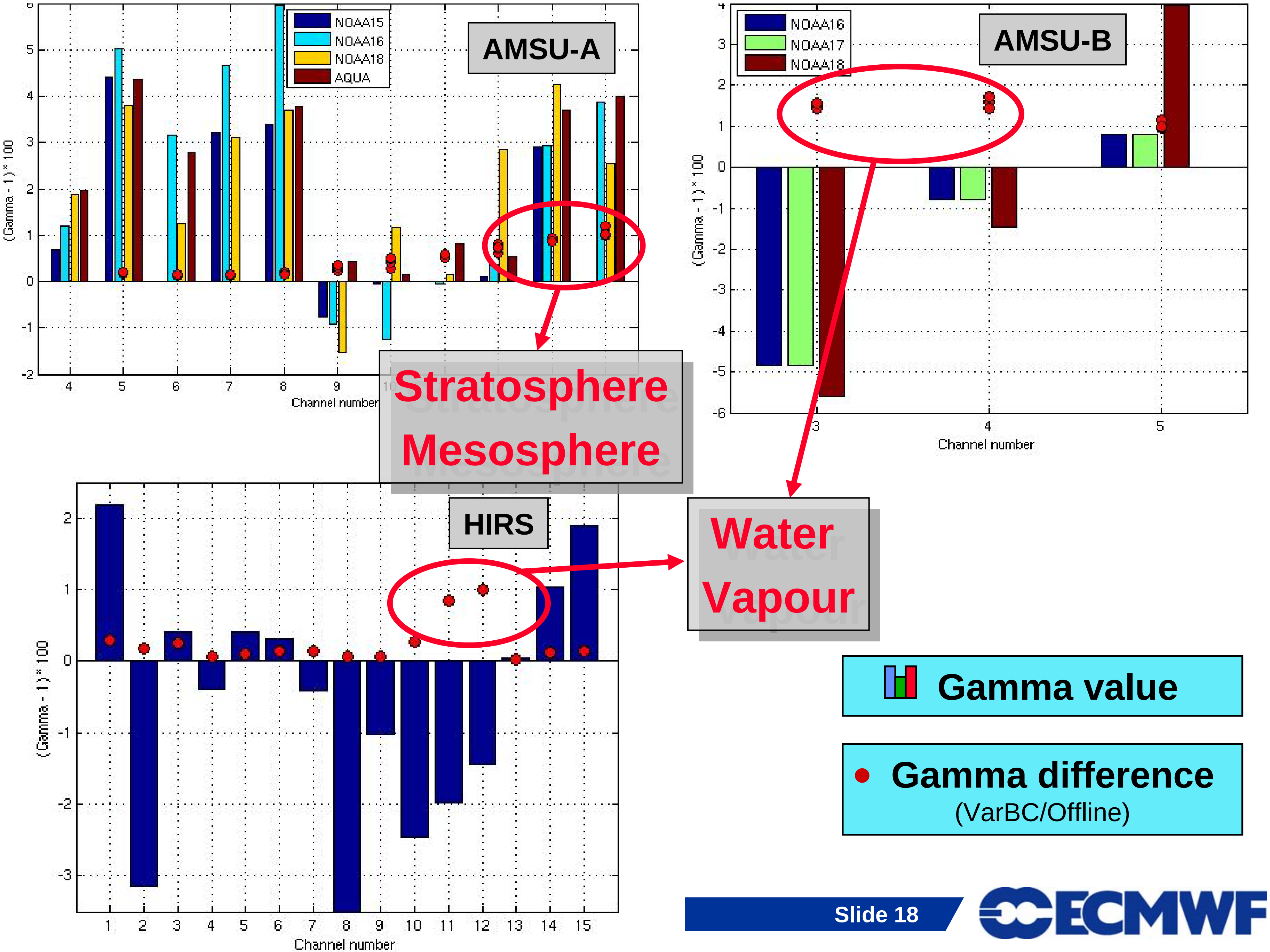
AMSU-A
NOAA15
NOAA16
NOAA18
AQUA
(Gamma - 1) * 100
Channel number
Stratosphere
Mesosphere
AMSU-B
NOAA16
NOAA17
NOAA18
(Gamma - 1) * 100
Channel number
HIRS
(Gamma - 1) * 100
Channel number
Water
Vapour
Gamma value
Gamma difference
(VarBC/Offline)
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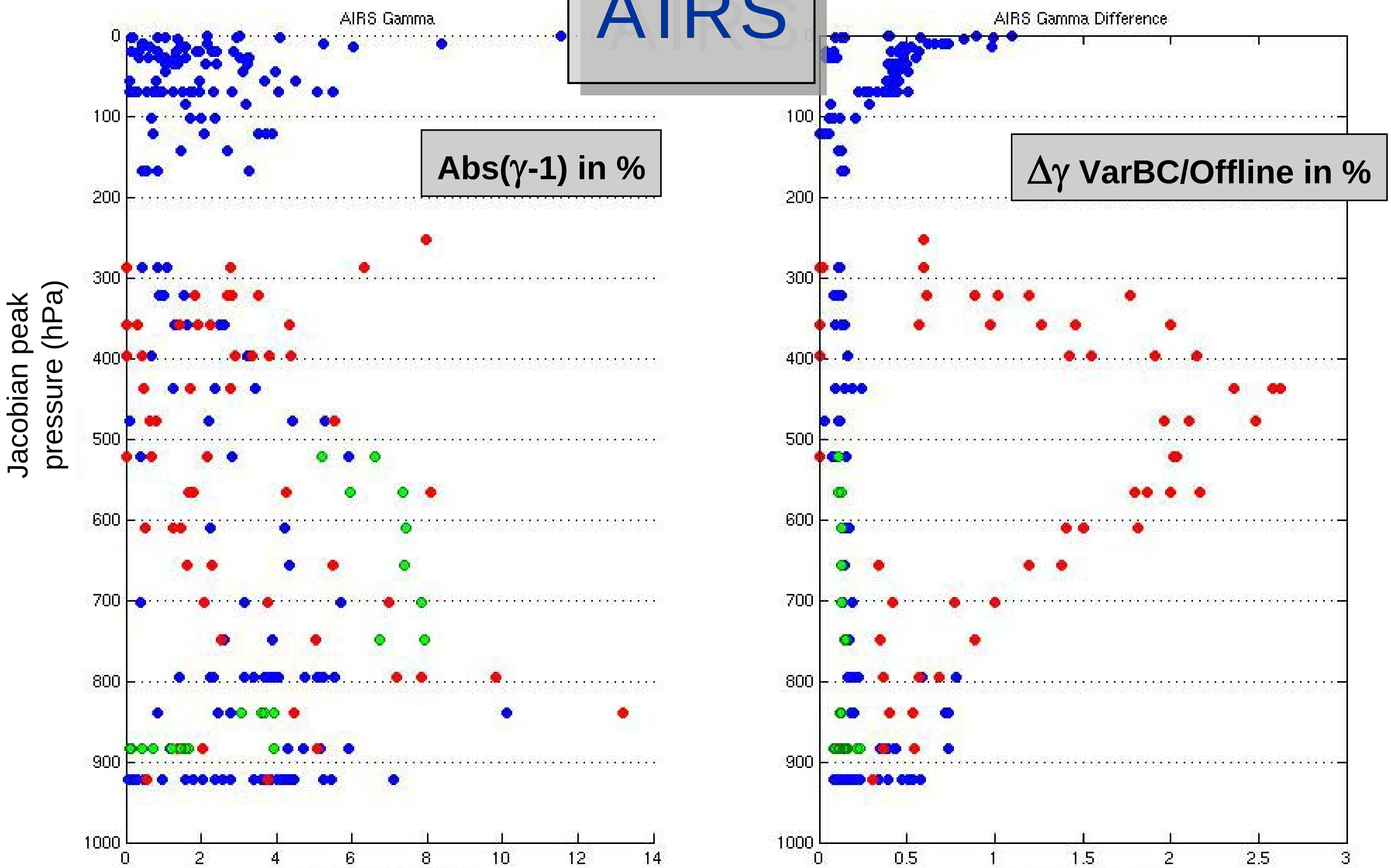
• LW Temperature • SW Temperature • Water Vapour

# AIRS



# 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

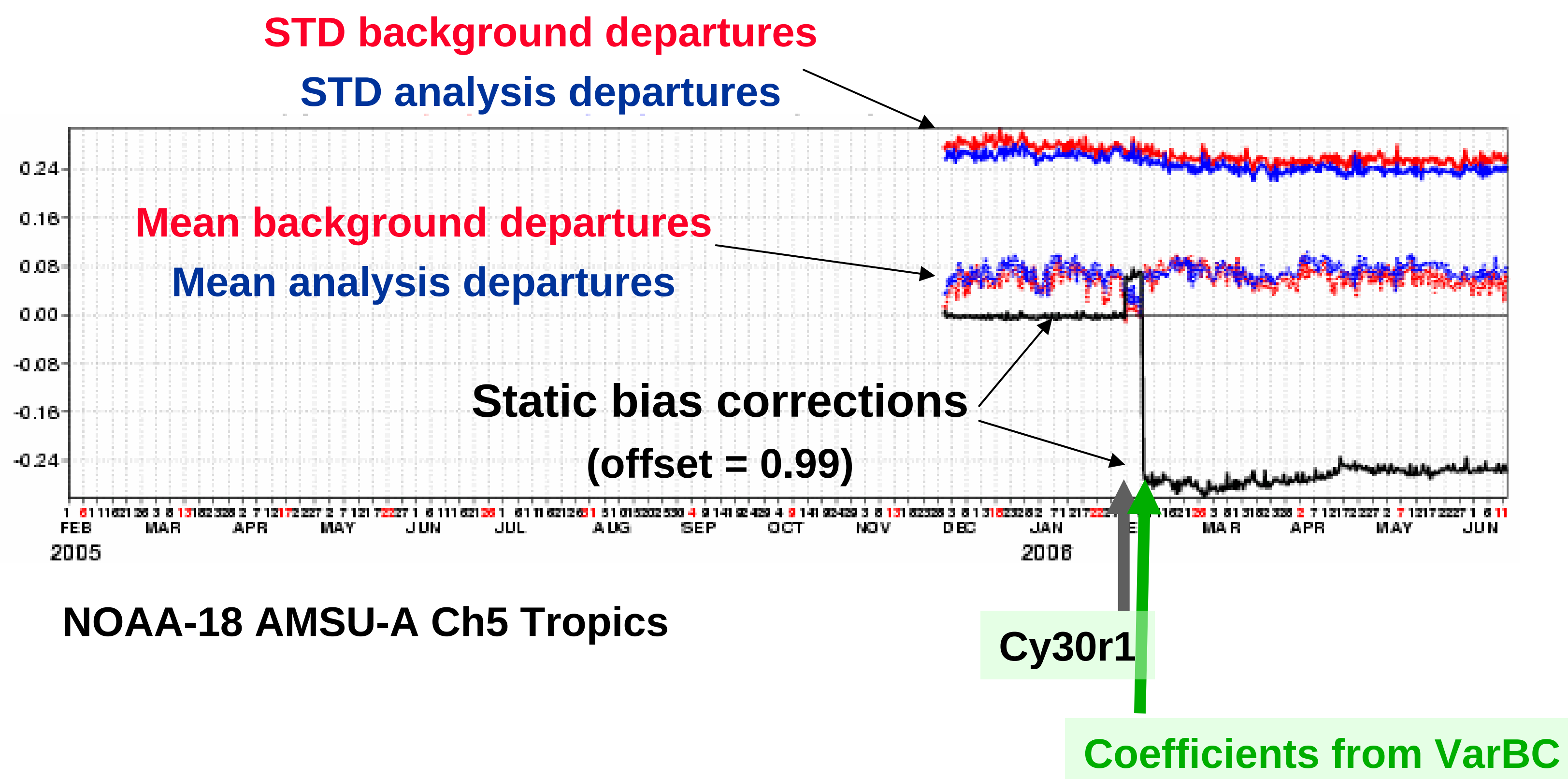
- These can be used in an objective method to select predictors

END

Thank you…

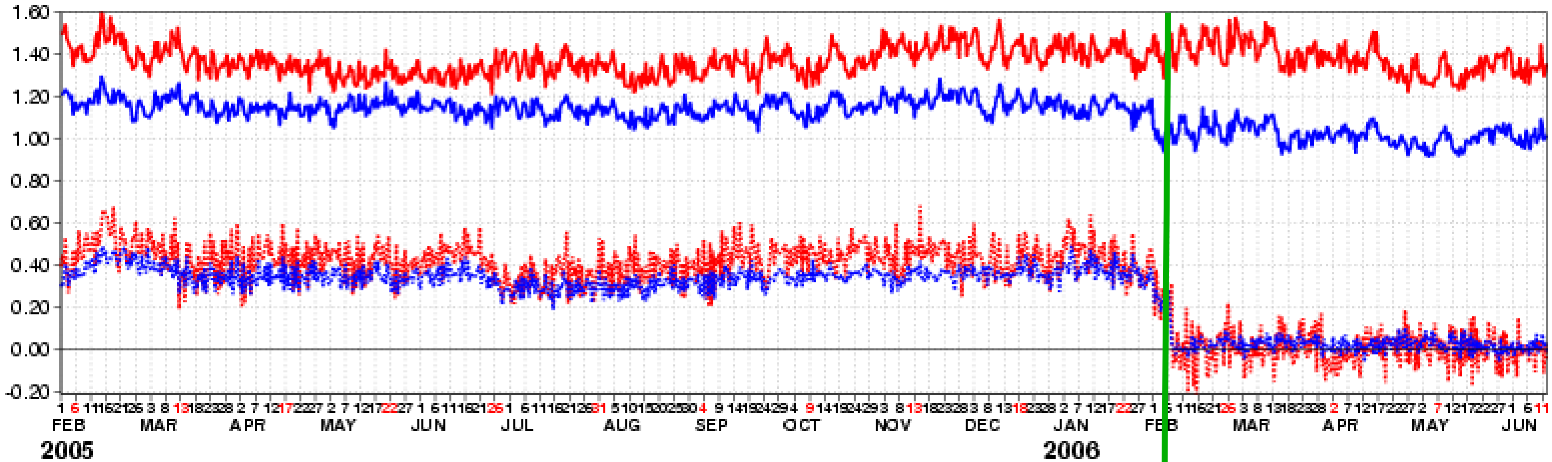
# Introduction of the VarBC in operations: first step

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

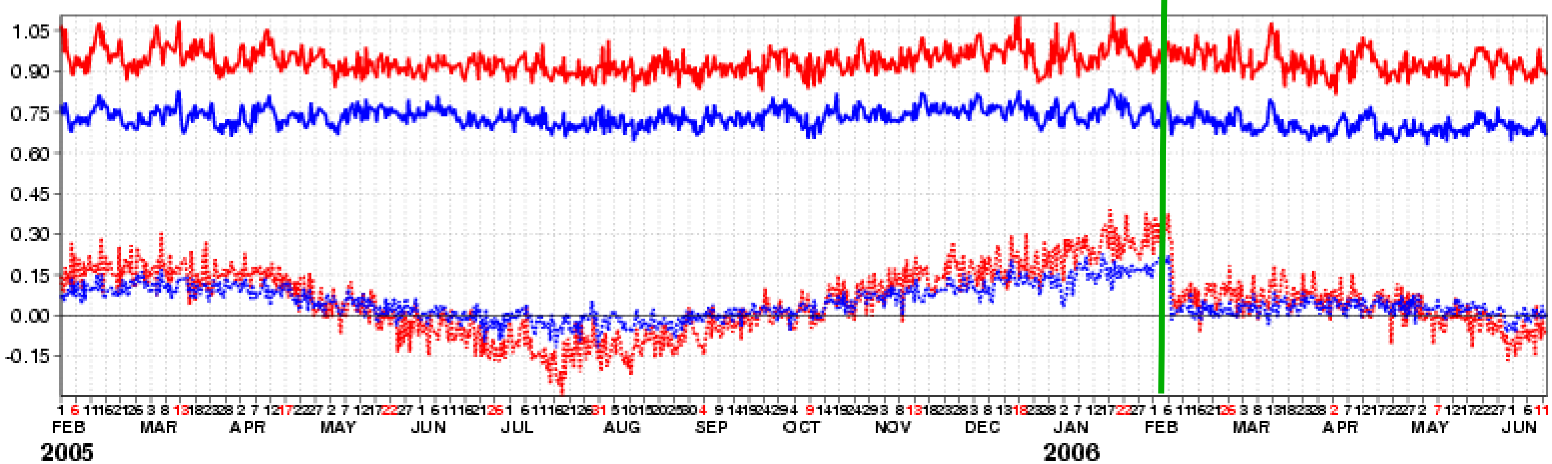


# Introduction of the VarBC in operations: first step

**100 hPa** RS temperature Tropics




**500 hPa** RS temperature Tropics



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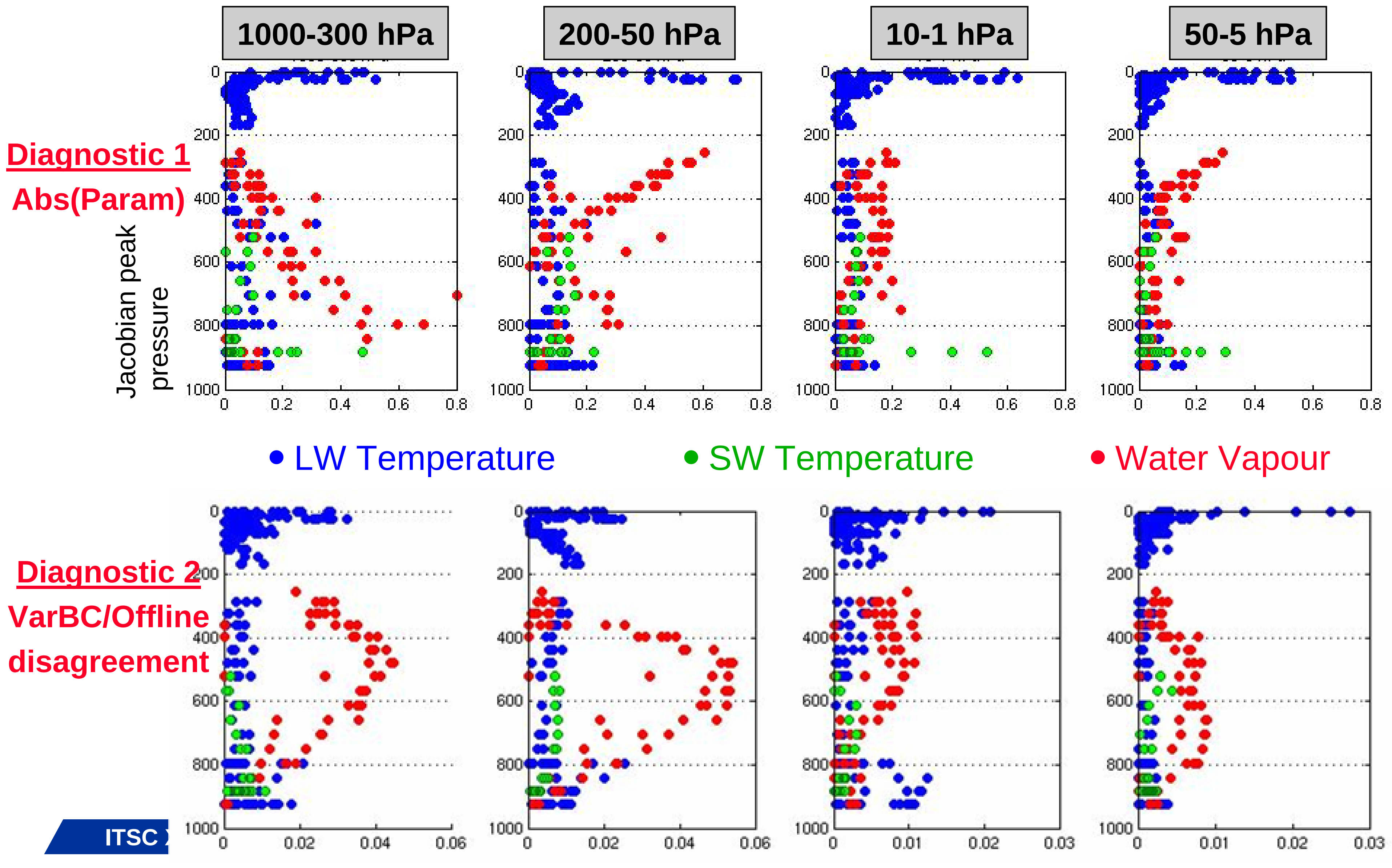
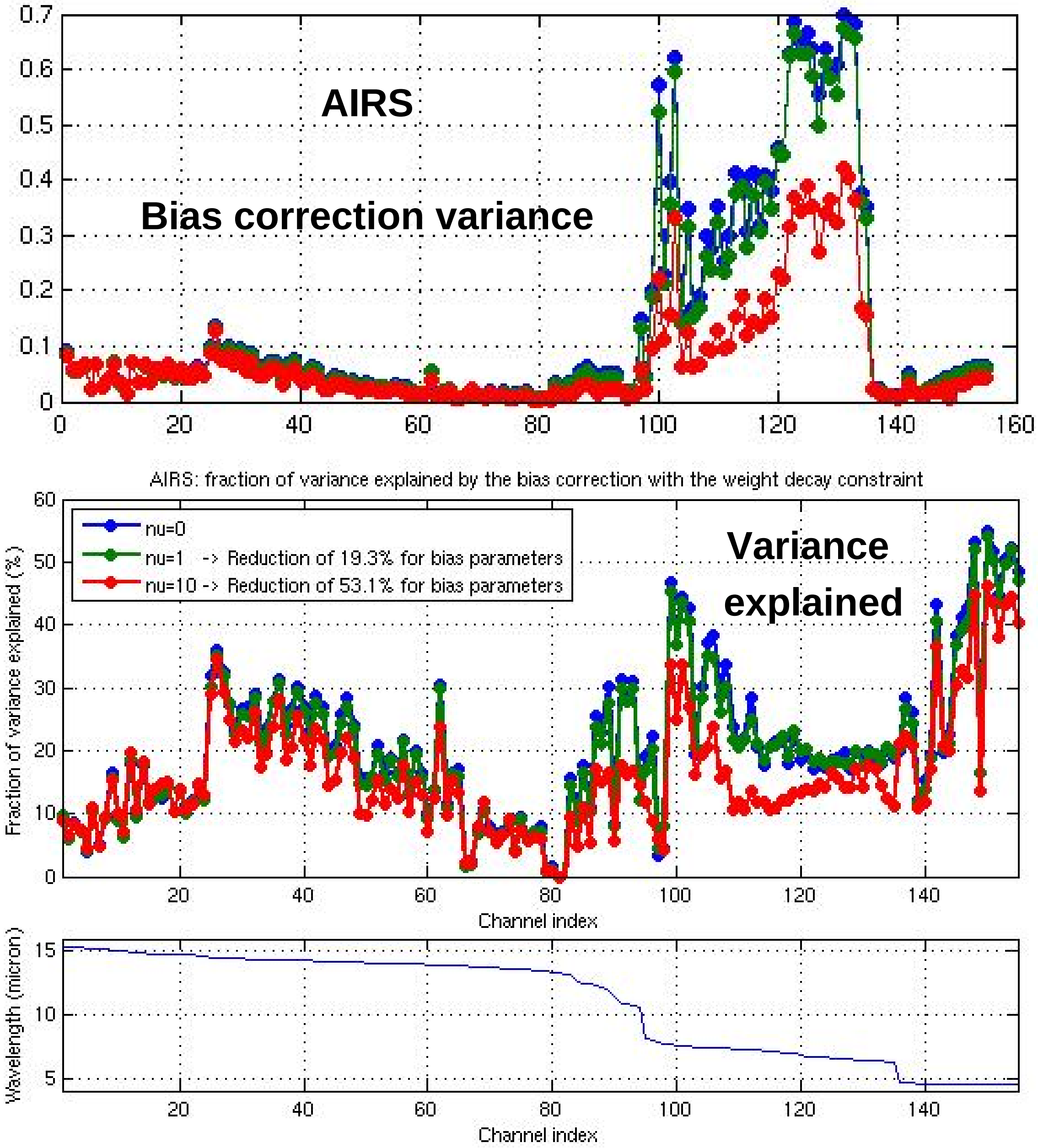
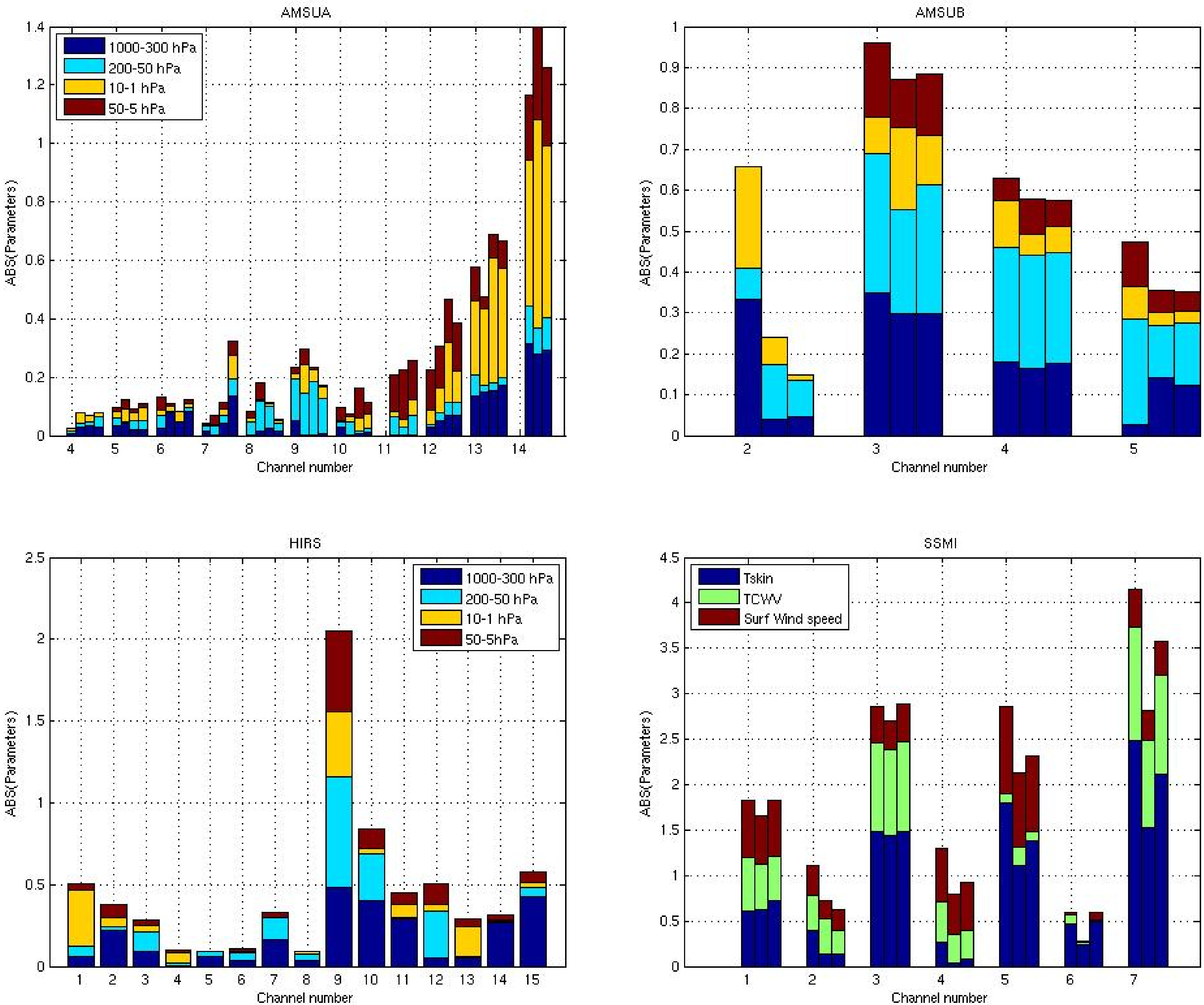
# AIRS operational bias predictors

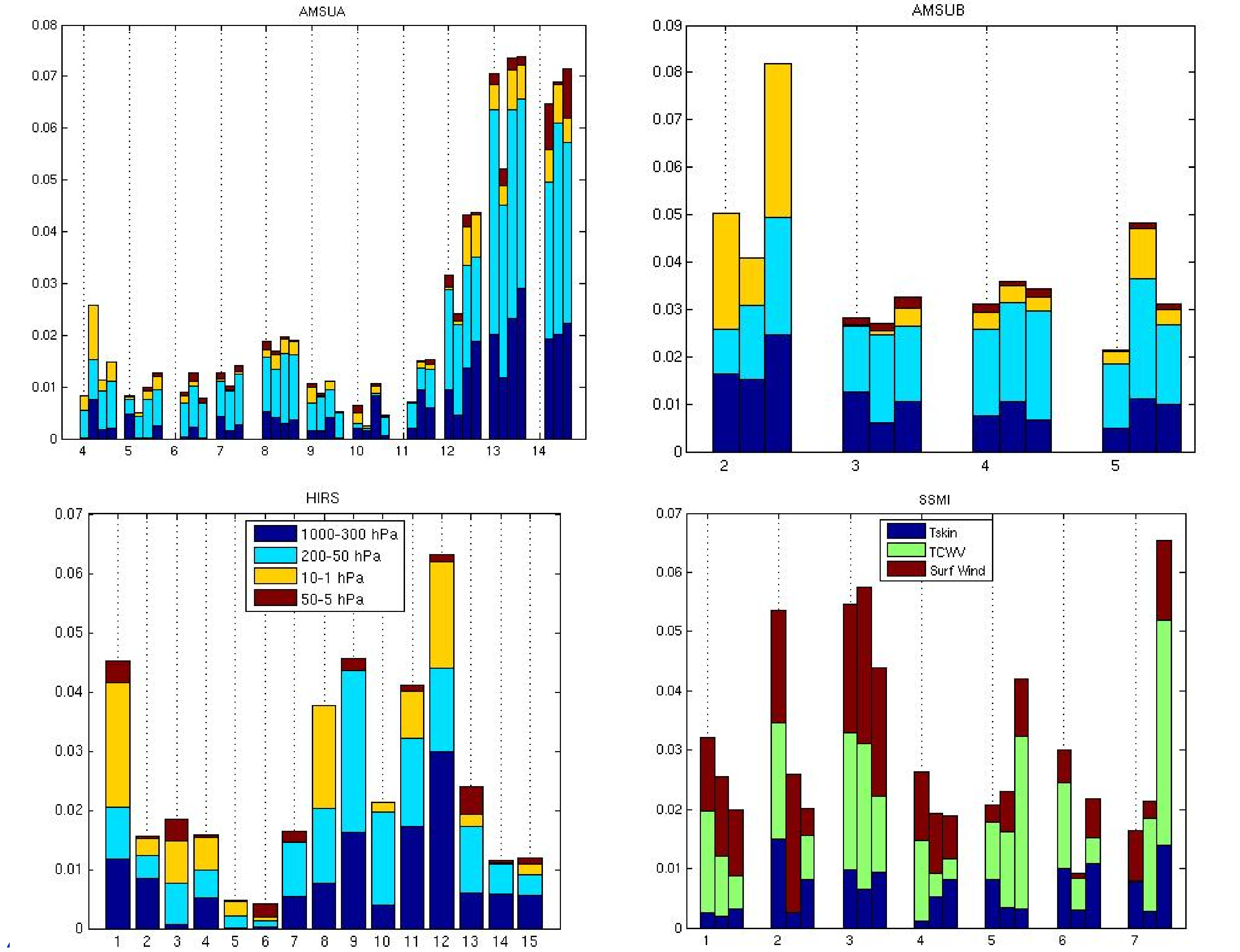


# Weight decay regularization





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


AMSUA
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
4 5 6 7 8 9 10 11 12 13 14
AMSUB
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2 3 4 5
HIRS
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1000-300 hPa
200-50 hPa
10-1 hPa
50-5 hPa
SSMI
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1 2 3 4 5 6 7
Tskin
TCWV
Surf Wind

International TOVS Study Conference, 15th, ITSC-15, Maratea,Italy, 4-10 October 2006
Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center,
Cooperative Institute for Meteorological Satellite Studies, 2006.