ERA-Interim bias correction of satellite radiance brightness temperatures

Algorithm, performance, and limitations

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Outline (map view)

1. Re-analysis & ERA-Interim

2. Data assimilation

3. Bias-correction in ERA-Interim

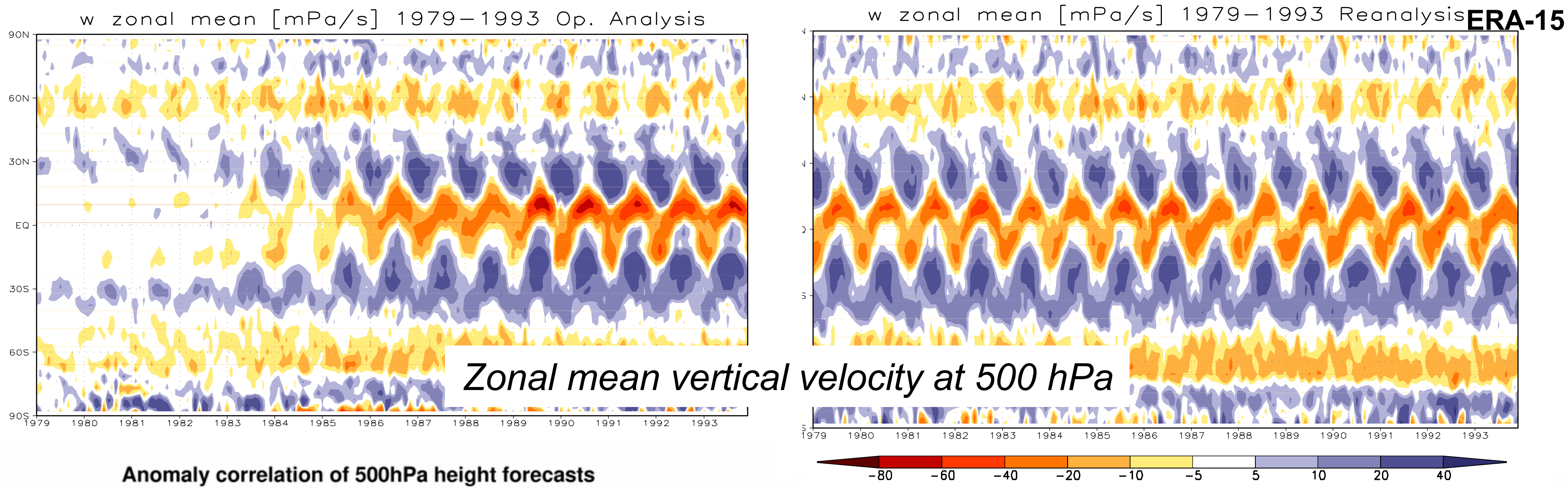
4. Strengths and limitations (from the hypotheses)

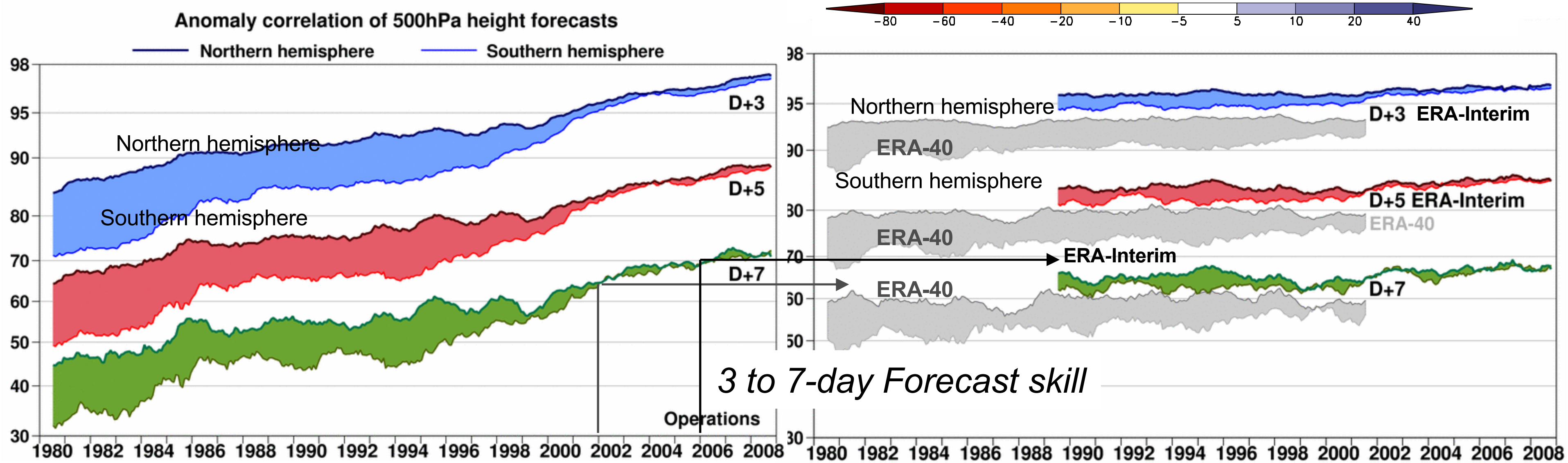
5. Performance (strong points)

6. Limitations (weak points)

7. Conclusions and next steps

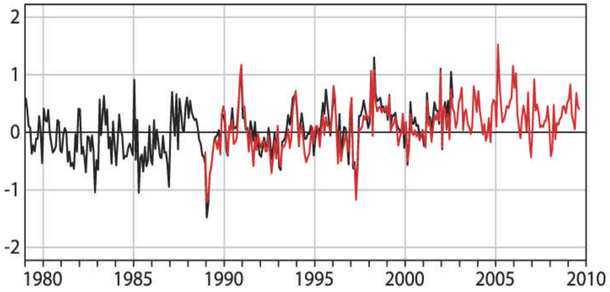
Operational NWP **products vs.** ***reanalysis*** **products**





Reanalysis quality is more uniform in time than that of operational products

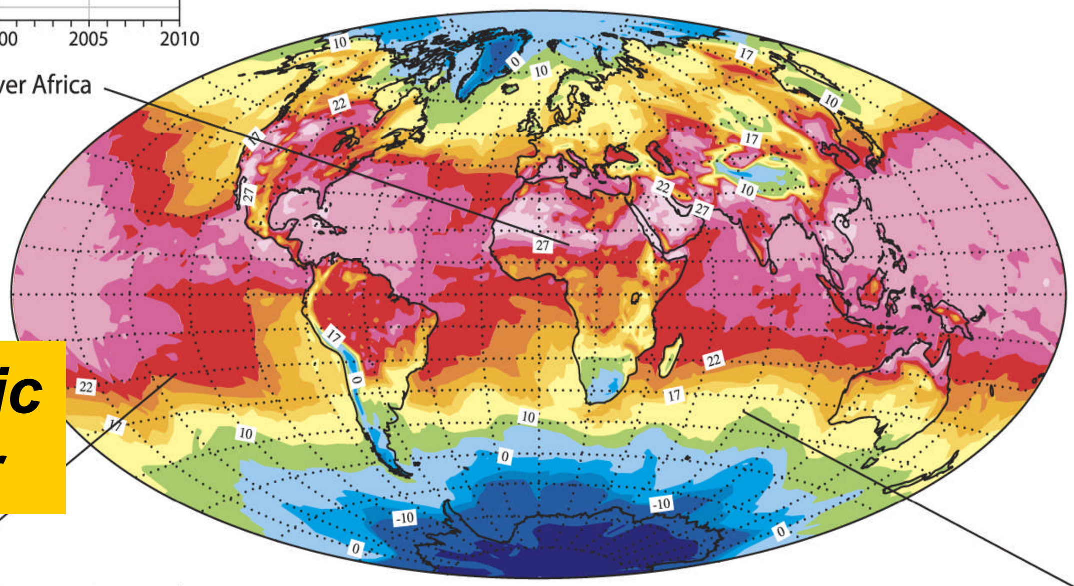
Re-analyses attempt to create a consistent picture of the Earth atmosphere

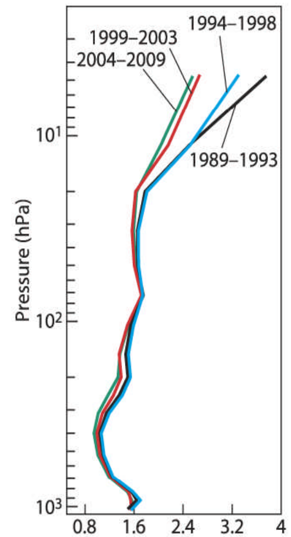


2-metre temperature anomaly (°C) over Africa

(Time)

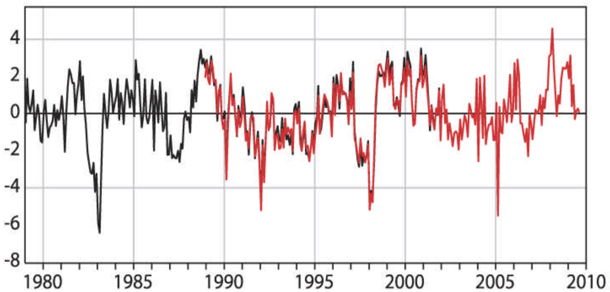
ERA-Interim 2-metre temperature (°C)
15 August 2003 03 UTC





Atmospheric parameter

Southern Oscillation Index (hPa)



Horizontal

Standard deviation of differences between ERA-Interim and radiosondes temperature (°C) in the southern hemisphere

Vertical

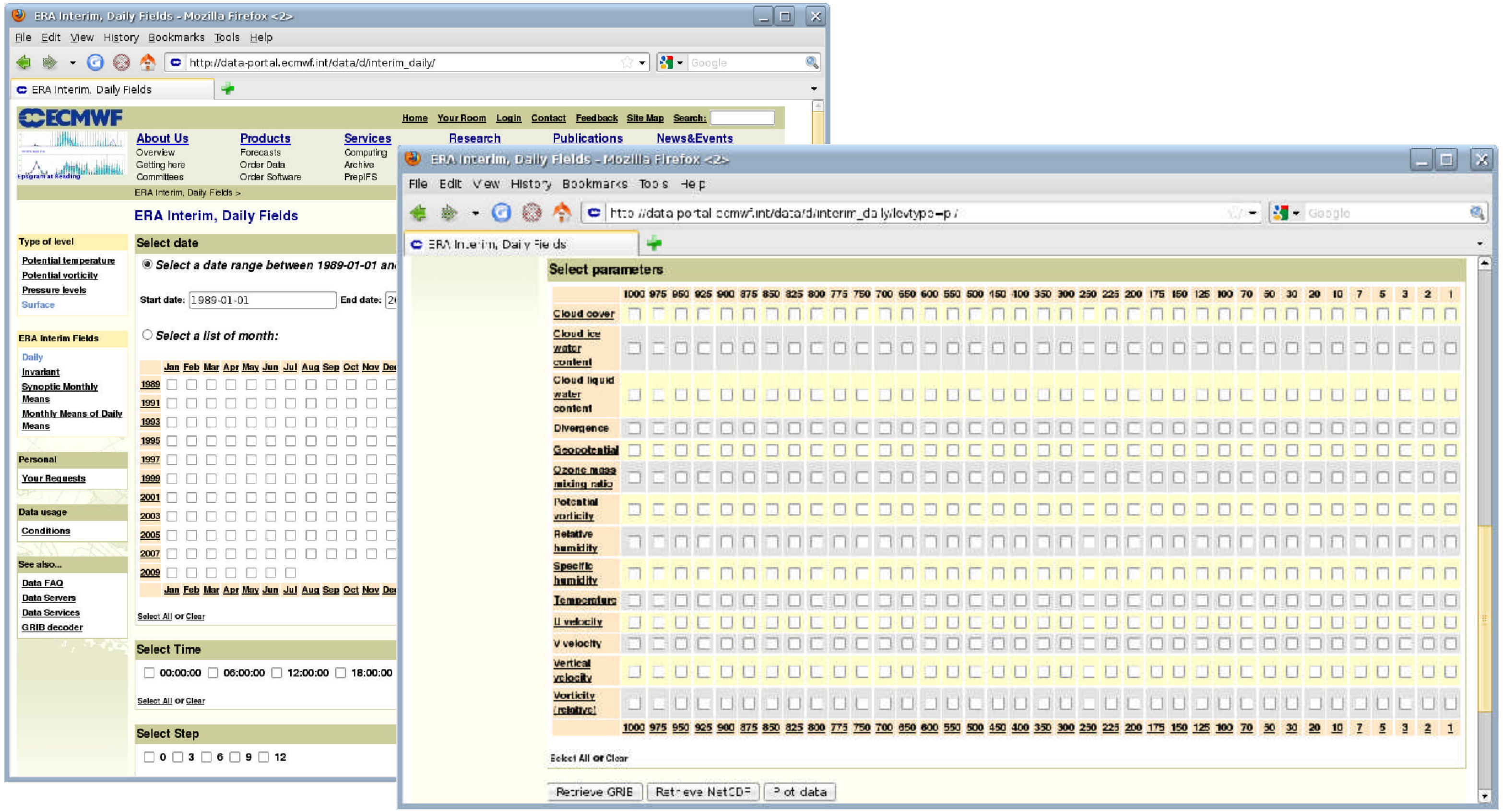
ECMWF

Latest ECWMF re-analysis: ERA-Interim

- January 1989-present — Continues in near-real-time
Now updated monthly
- Horizontal resolution — T255 (~80 km or 0.7 deg)
- Vertical resolution — L60 (top 0.1 hPa ~65 km altit.)
- Temporal resolution: — 6 hr for upper-air fields
3 hr for surface fields
Model time-step: 30 minutes
- Access:
  - ECMWF member states: full archive access (MARS)
  - US education and research users: access via UCAR http://dss.ucar.edu/datasets/ds627.0/
  - All users: web access via ECMWF Data Server http://data-portal.ecmwf.int/data/d/interim_daily/

ERA-Interim Data Server

Information: http://www.ecmwf.int/research/era
Products: http://data-portal.ecmwf.int/data/d/interim_daily/
Data available in NetCDF or GRIB

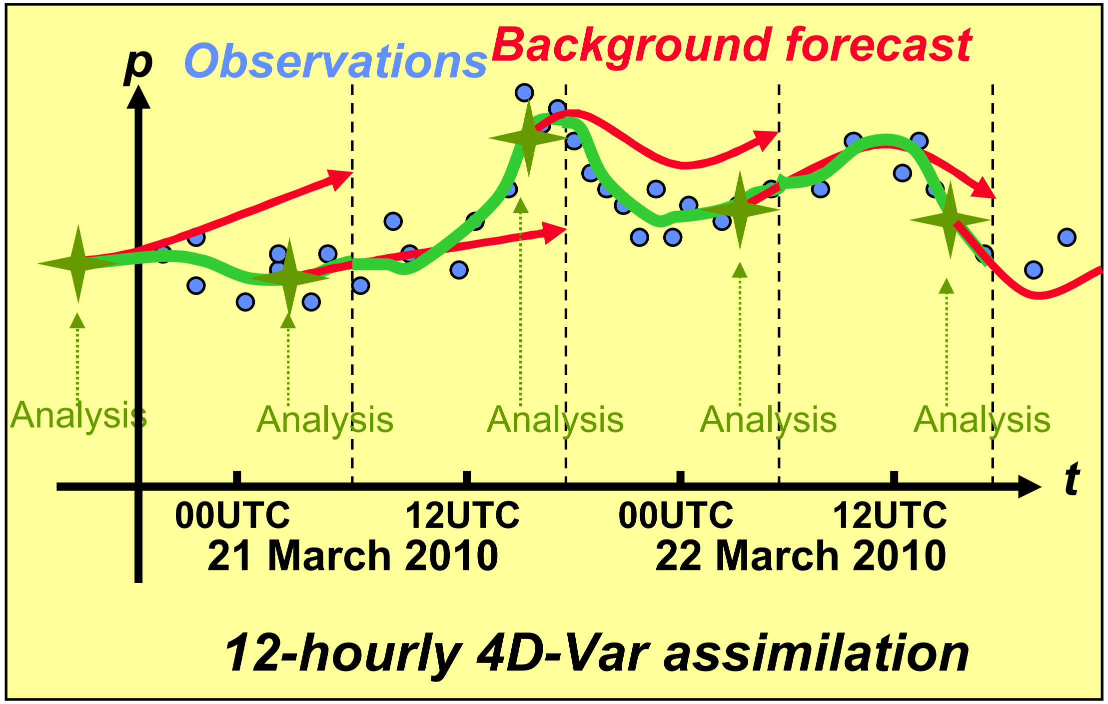


General characteristics of ECMWF re-analyses (so far)

- Aim to construct the *best* estimate of the state of the atmosphere at any given time, any given location
- Use the techniques of Numerical Weather Prediction (NWP) as employed at ECMWF
- N times daily (N=2 in ERA-Interim), run an assimilation (now 4DVAR) to determine the most likely state of the atmosphere at a given time, so-called analysis
- This state is then propagated in time until the next analysis time, at which point a new data assimilation procedure is carried out
- The consistency across variables, in space, and in time (during 12-hour intervals) is thus ensured by the atmospheric model and its error characteristics as specified in the assimilation

Brief primer on data assimilation

- **Combine information from**
  - **Observations**
  - **Background forecast (propagates the information extracted from prior observations)**
  - **Error statistical models**
  - **Relationships to build-in dynamical and physical consistency between various meteorological parameters**



- **To produce the "most probable" estimate of the atmospheric state**
  - **And some estimate of uncertainty**

There's no free lunch… Hypotheses are required to get the smoothing illustrated above…

Determination of the analysis state

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

- The input x_b represents past information propagated by the atmospheric forecast model (the background)
- The input $[y - h(x_b)]$ represents the new information (observations) entering the system (the background departures)
- The function $h(x)$ represents a model for simulating observations; this includes the forecast model in 4DVAR (the observation operator)
- Minimising the cost function $J(x)$ produces an adjustment to the model background based on all used observations (the analysis)
- **Hypotheses typically used to solve this** (and/or buried in this approach):

  The background and the observation errors are independent, Gaussian with zero means (**unbiased**), and properly specified in B and R; the model errors are negligible within the analysis window.

Variational bias correction

First proposed and implemented by Derber and Wu, 1998

- **Solve for analysis and bias parameters at the same time**

Minimise $\mathbf{J(x)} = (\mathbf{x_b} - \mathbf{x})^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x_b} - \mathbf{x}) + [\mathbf{y} - \mathbf{h(x)}]^{\mathrm{T}}\mathbf{R}^{-1}[\mathbf{y} - \mathbf{h(x)}]$

The bias parameters: β

The bias model: $b(x,\beta)$: Typically a linear combination of bias parameters with robust predictors to characterize air mass or observation geometry

Minimise $\mathbf{J(z)} = (\mathbf{z_b} - \mathbf{z})^{\mathrm{T}}\mathbf{B}_z^{-1}(\mathbf{z_b} - \mathbf{z}) + [\mathbf{y} - \tilde{\mathbf{h}}(\mathbf{z})]^{\mathrm{T}}\mathbf{R}^{-1}[\mathbf{y} - \tilde{\mathbf{h}}(\mathbf{z})]$

$$\mathbf{z}^{\mathrm{T}} = [\mathbf{x}^{\mathrm{T}}\boldsymbol{\beta}^{\mathrm{T}}] \qquad \tilde{\mathbf{h}}(\mathbf{z}) = \mathbf{h}(\mathbf{x}) + \mathbf{b}(\mathbf{x}, \boldsymbol{\beta})$$

- **The aim is to correct for observation *and* observation operator (radiative transfer) error bias – altogether**
- **Assuming that these biases are constant during the duration of the analysis window**

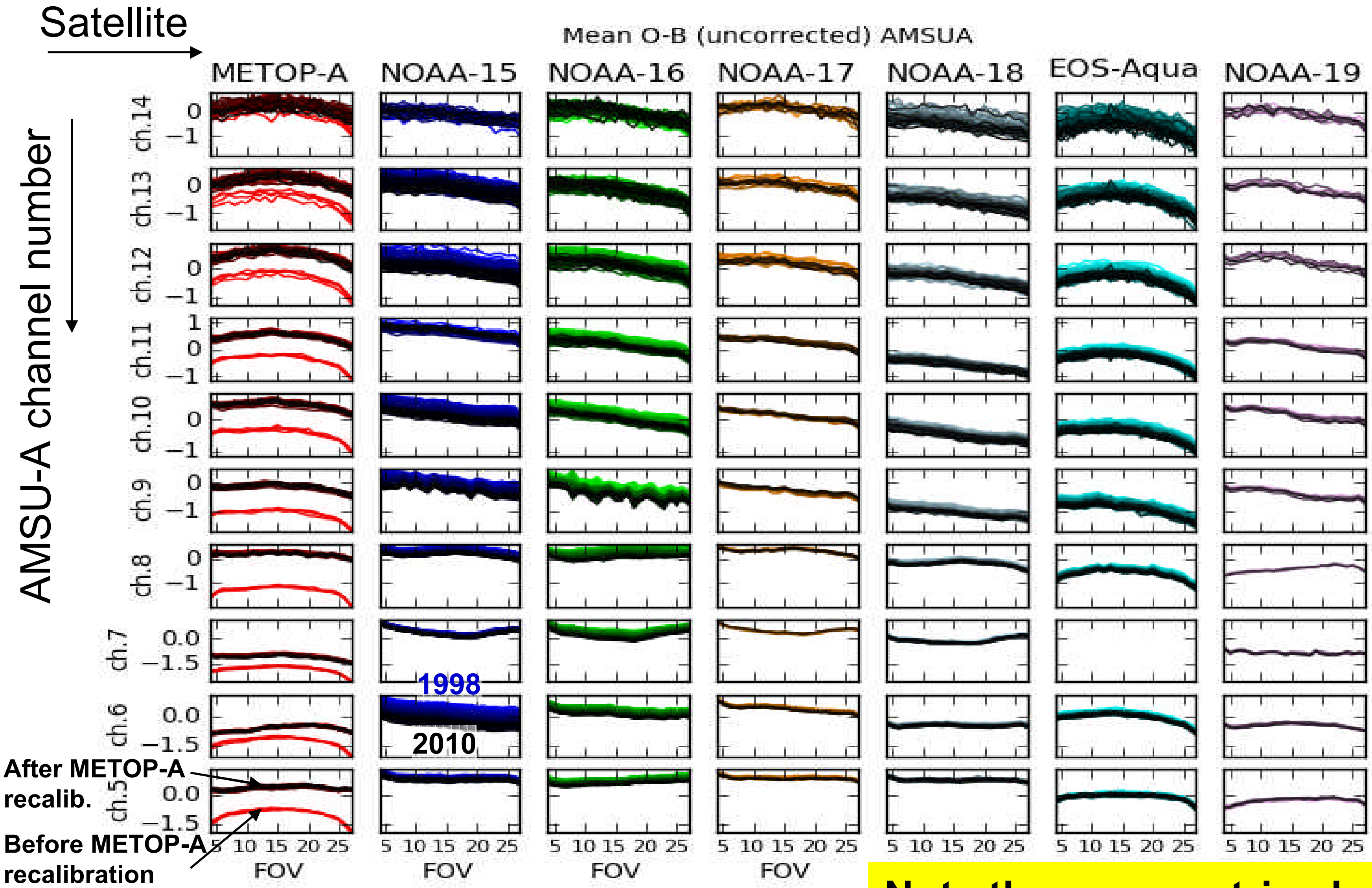
Bias predictors in ERA-Interim for radiances

Sensor	Bias predictors											
	offset	Δz 1000 -300mb	Δz 200 -50 mb	Δz 10 -1 mb	Δz 50 -5 mb	Total col wv	Skin Temp.	Sfc wind speed	Nadir view angle NVA	NVA **2	NVA **3	NVA **4
HIRS												
AIRS												
GEO IMG												
SSU	Except channel 3											
MSU												
AMSU-A	Except channel 14											
AMSU-B												
MHS												
SSM/I												
SSM/I-S												
AMSR-E												

Central node of this talk: Strengths and limitations of the variational bias correction

- **Strengths:**
  - Benefit from all the other observations to determine the most likely bias estimate
  - "Quick" updates (12 hours) are possible
  - Automatic procedure
  - Dot not assume that observations present consistent bias characteristics over the life-time of each instrument
- **Limitations:**
  - When/where there are few observations with independent biases, or
  - When/where the only observations available present similar biases as compared to the model,
  - Then the model bias can contaminate the bias estimate

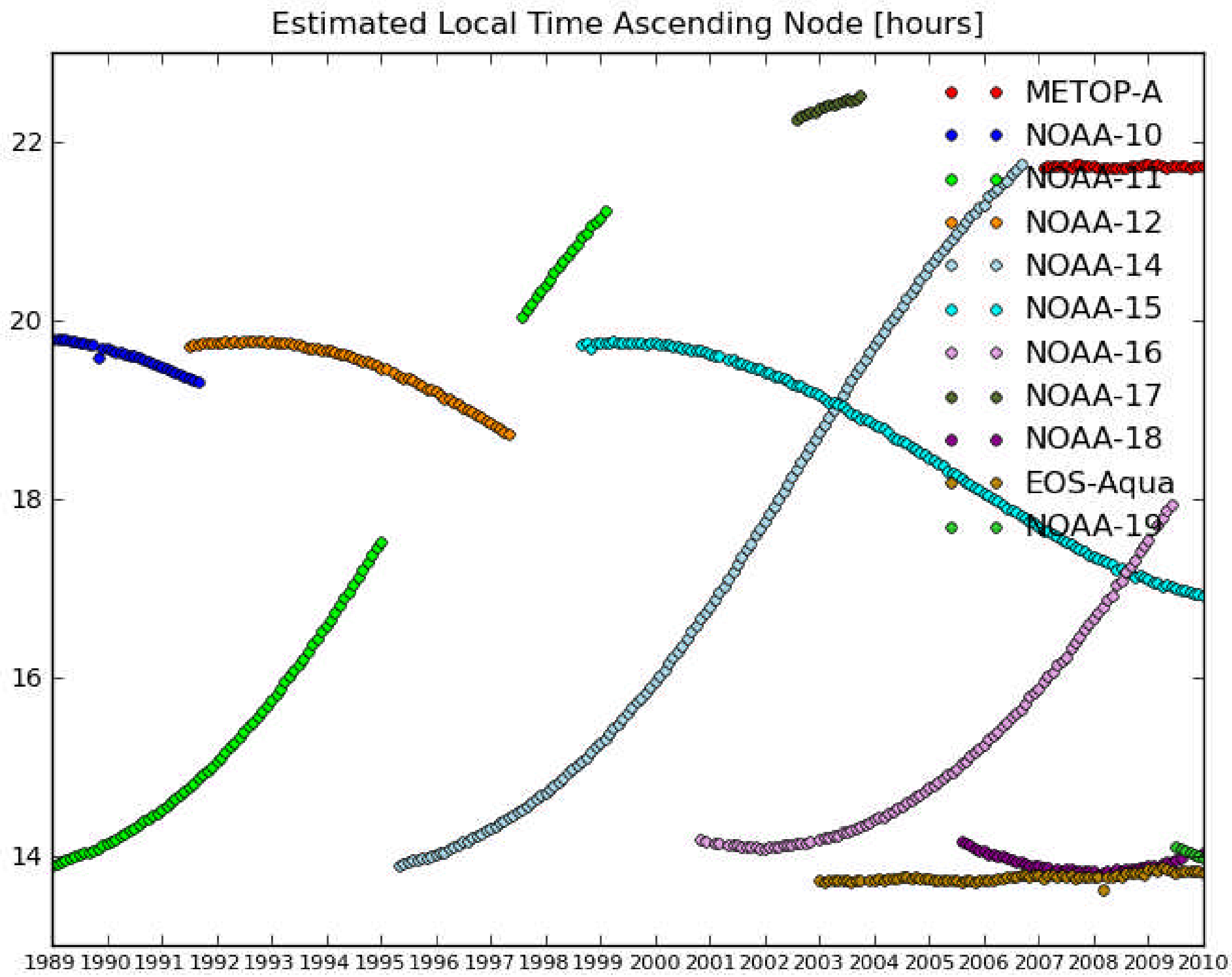
Example 1: AMSU-A Scan-angle bias



Latitudes 20S-20N, ocean only

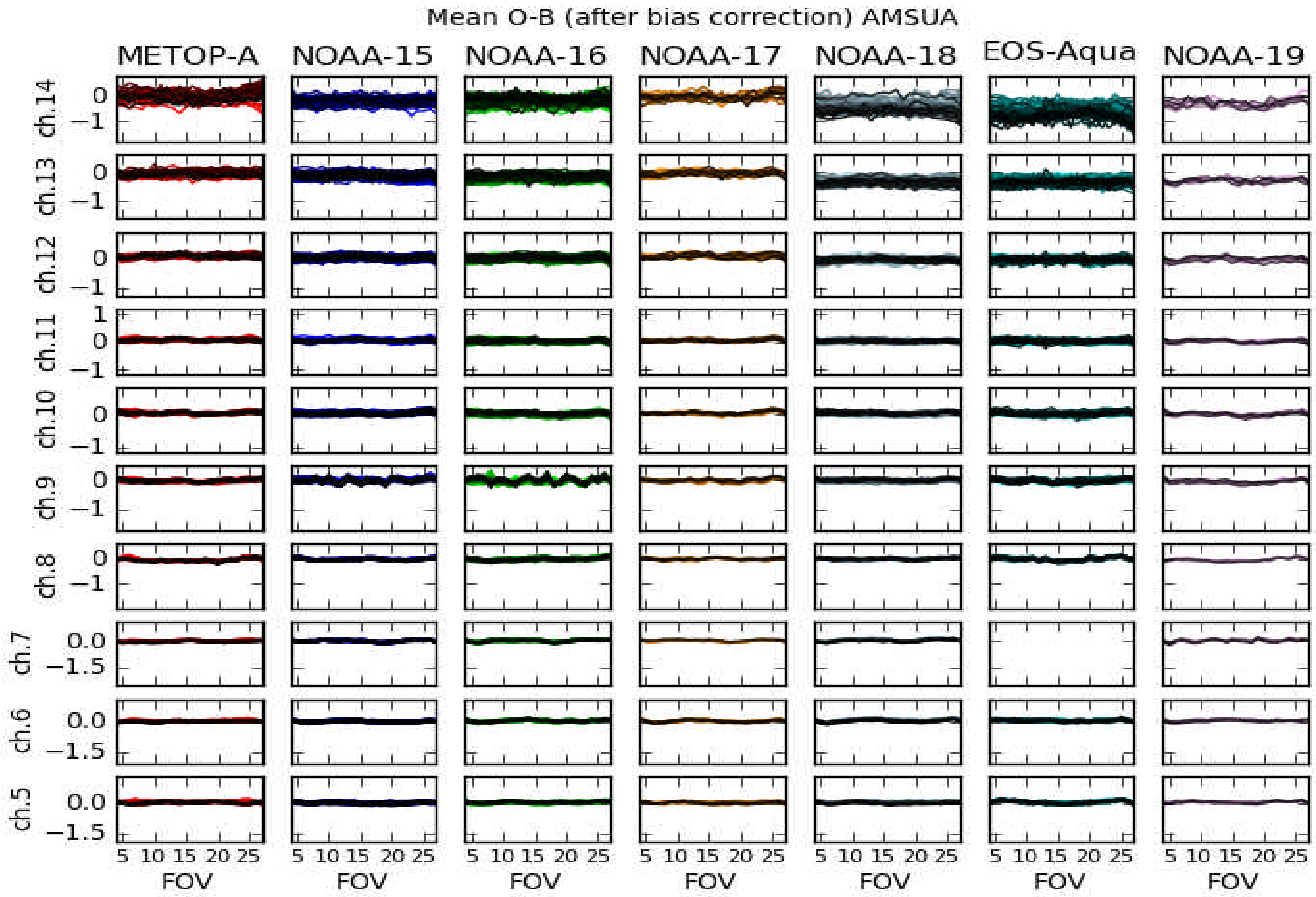
Note the asymmetric shapes

Satellite orbital drift, as estimated from the data at 1-month intervals



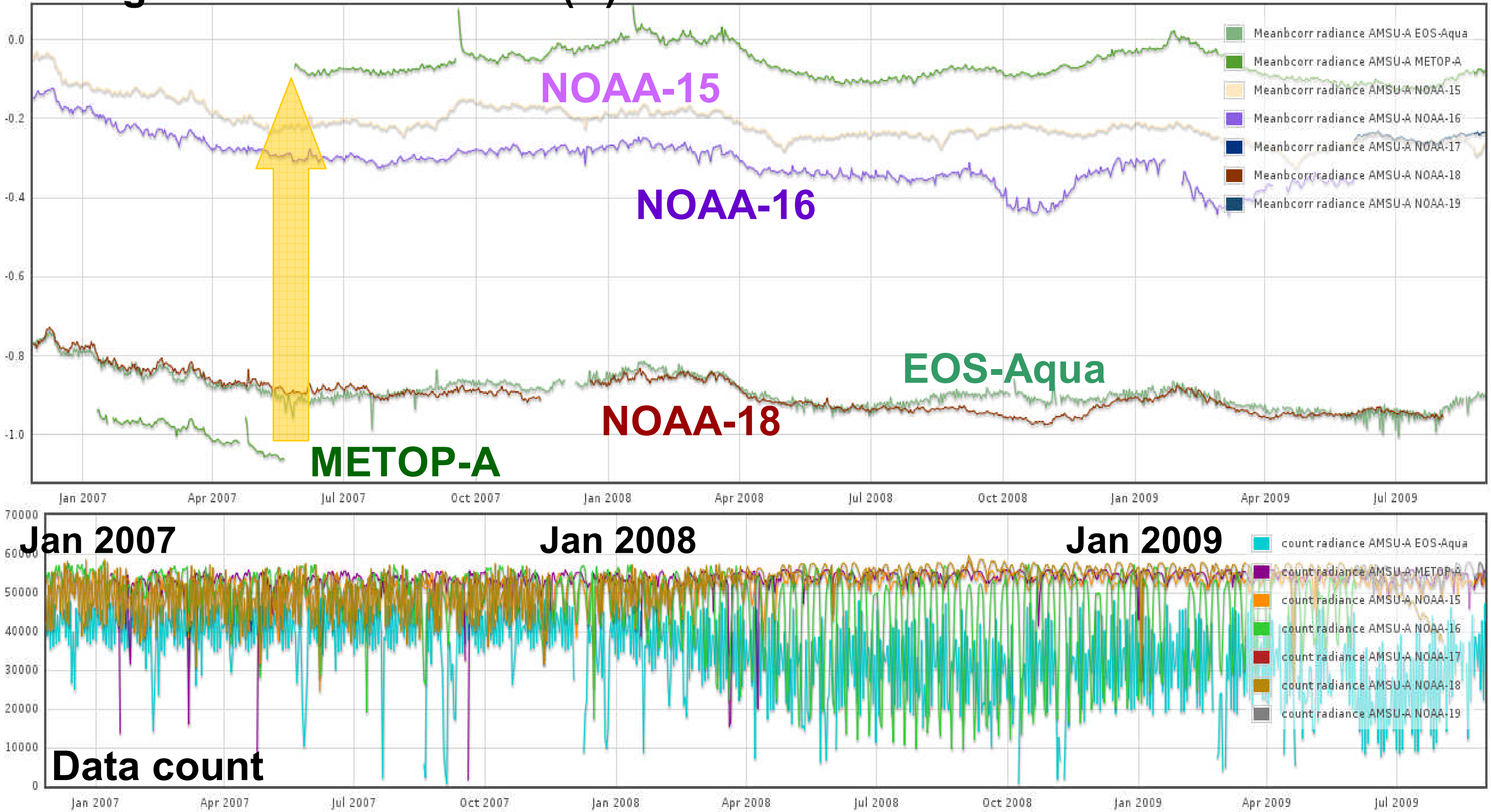
1989 **2010**

Example 1 (cont): AMSU-A biases, after variational bias corr.



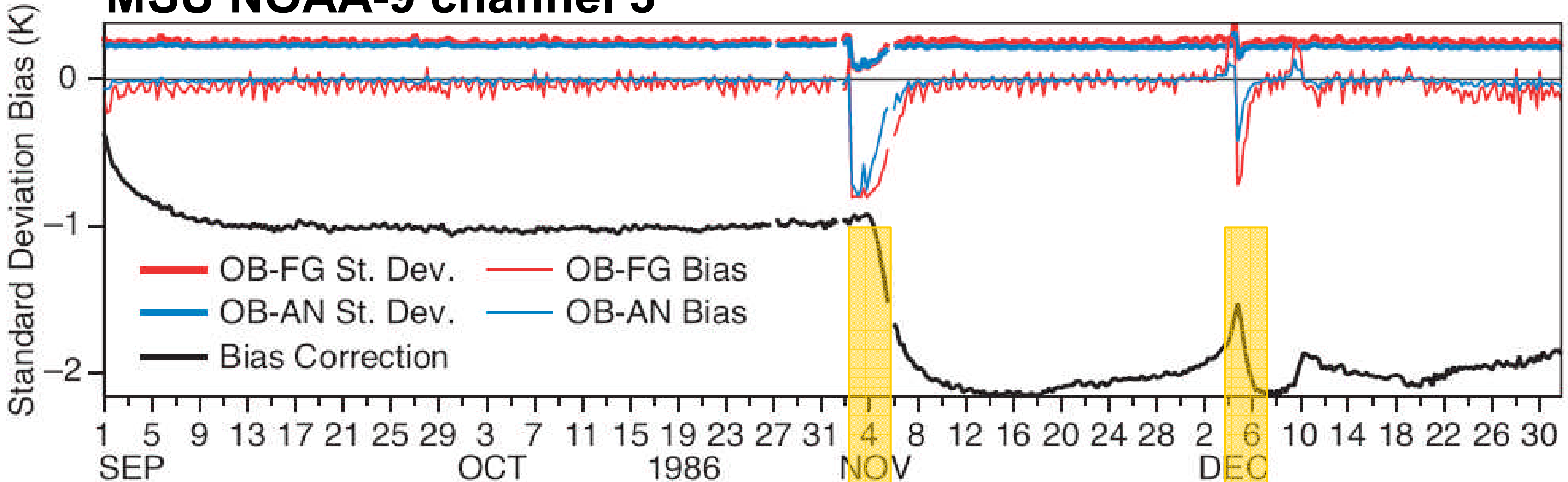
Example 2: AMSU-A METOP-A recalibration after launch

Mean global bias correction (K) for channel 9

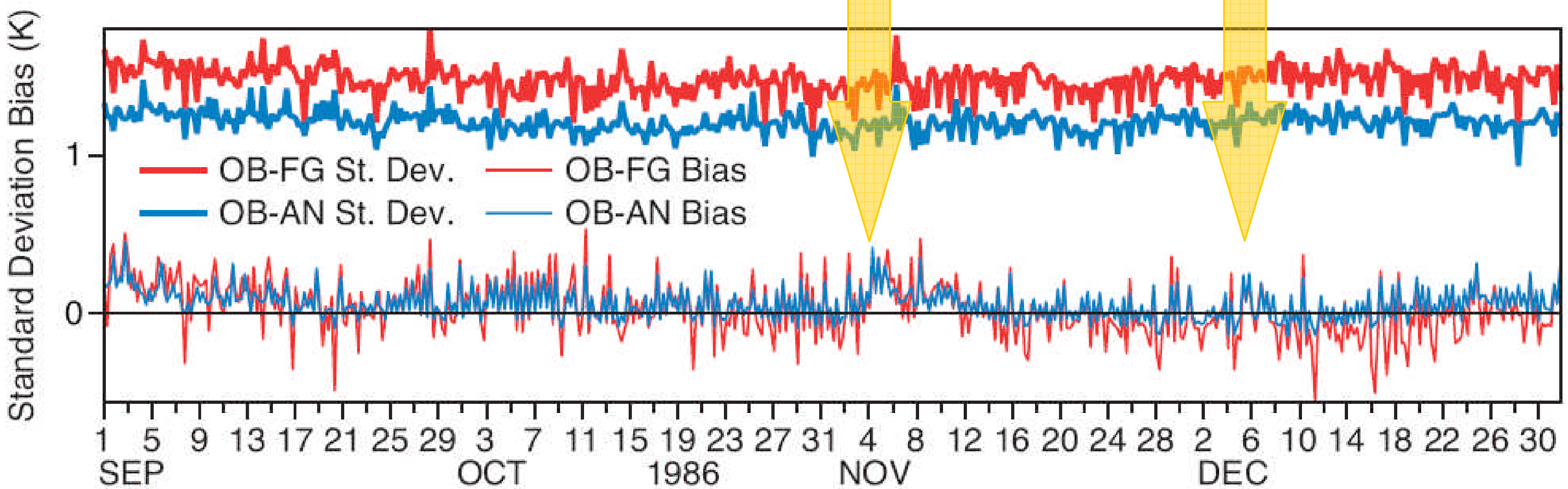


Example 3: Magnetic storms

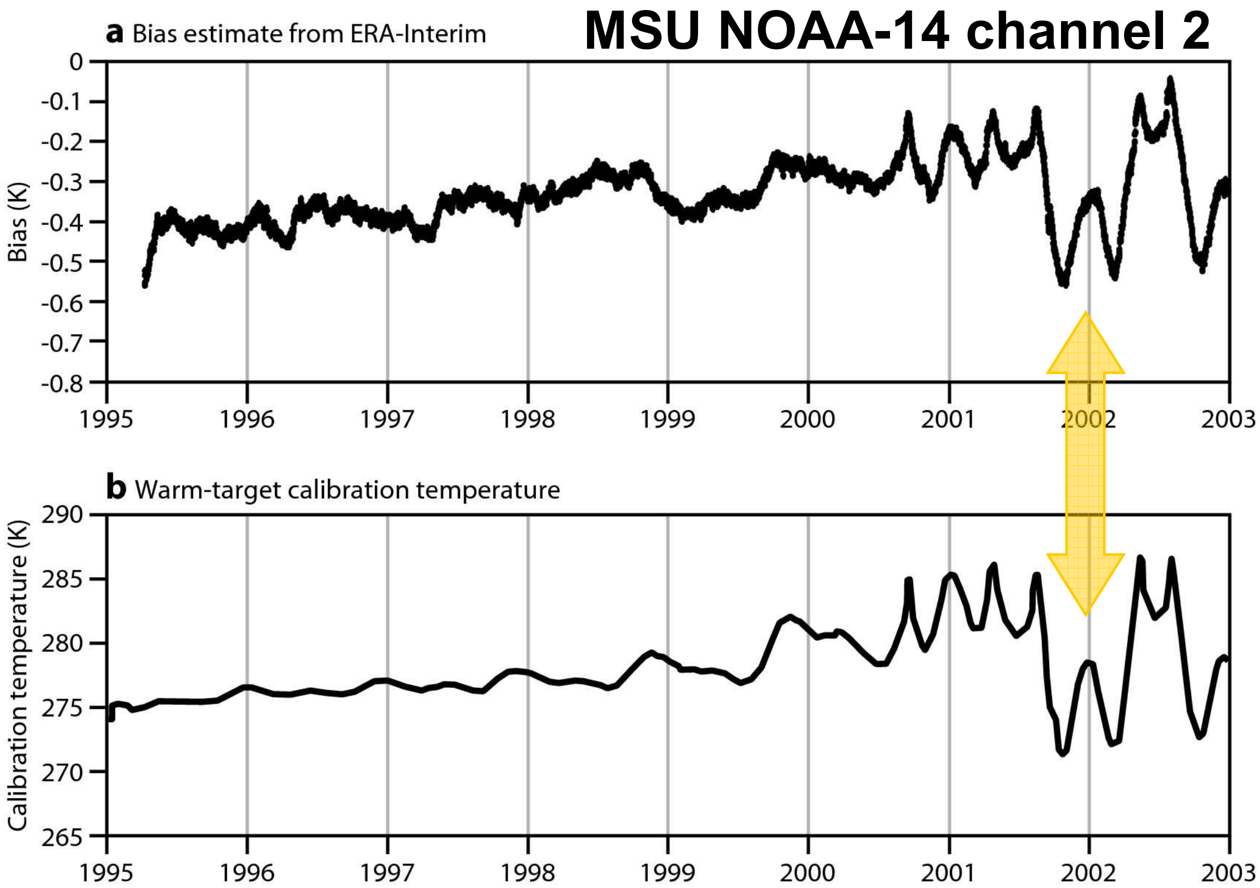
MSU NOAA-9 channel 3



200 hPa temperature departures from radiosonde observations



Example 4: Reference blackbody calibration fluctuations



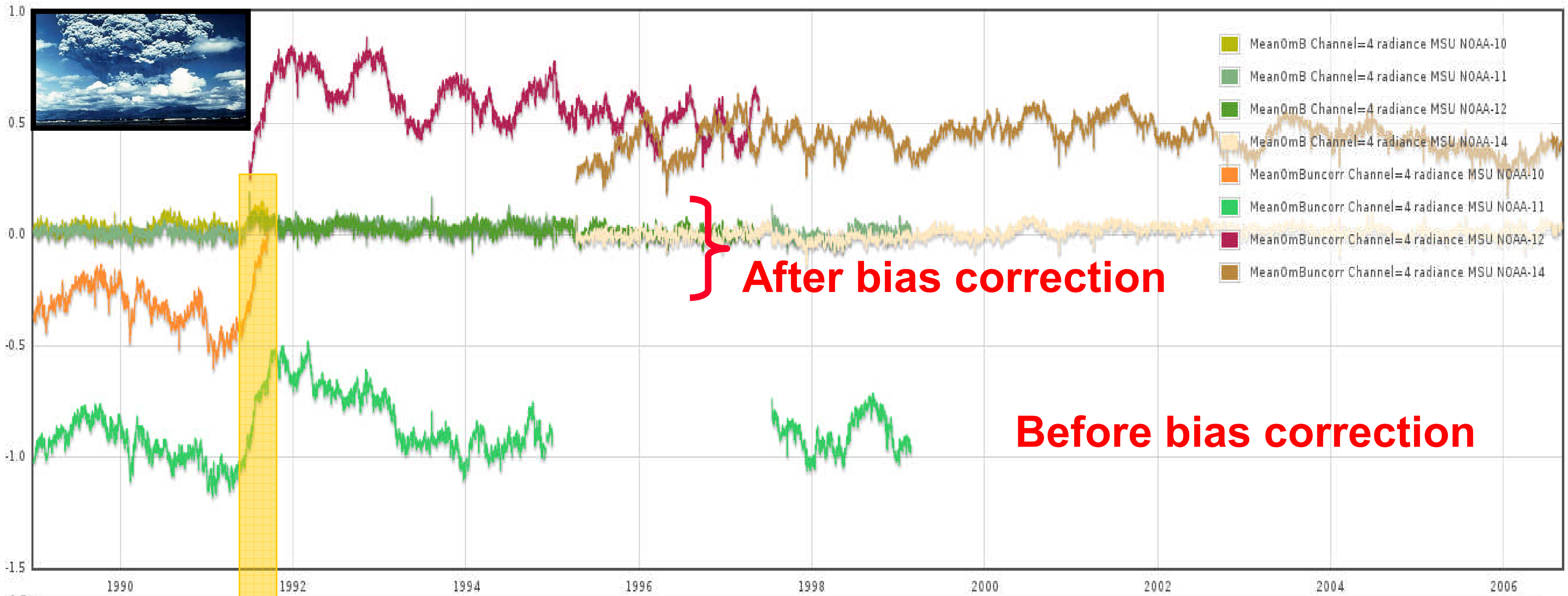
Variational bias estimates for NOAA-14

Actual warm-target temperatures on board NOAA-14 (Grody *et al.* 2004)

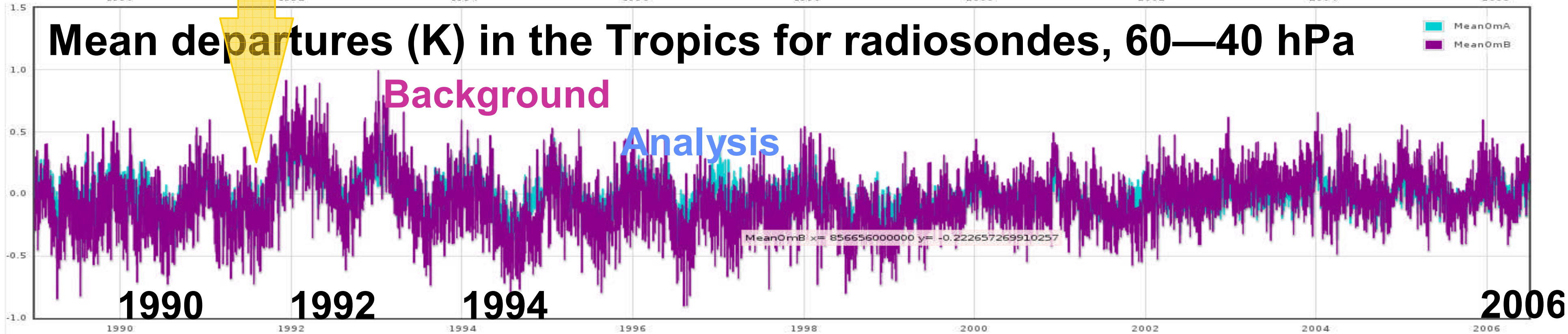
Dee and Uppala, 2009

Example 5 : Mt Pinatubo eruption

Mean obs-background departures (K) in the Tropics for MSU channel 4



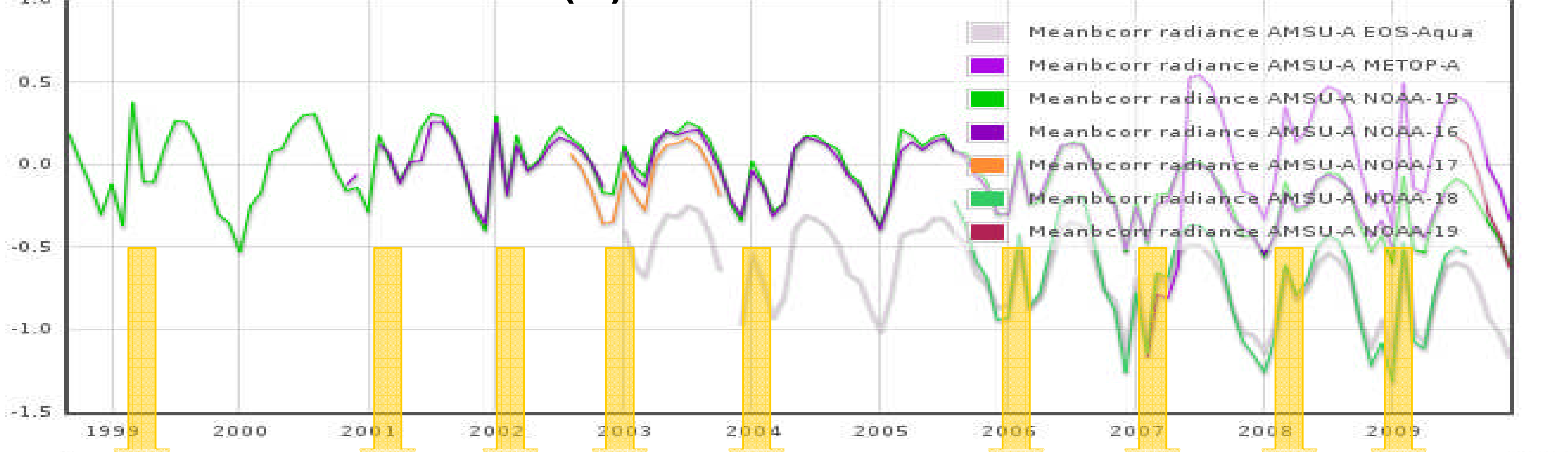
Mean departures (K) in the Tropics for radiosondes, 60—40 hPa



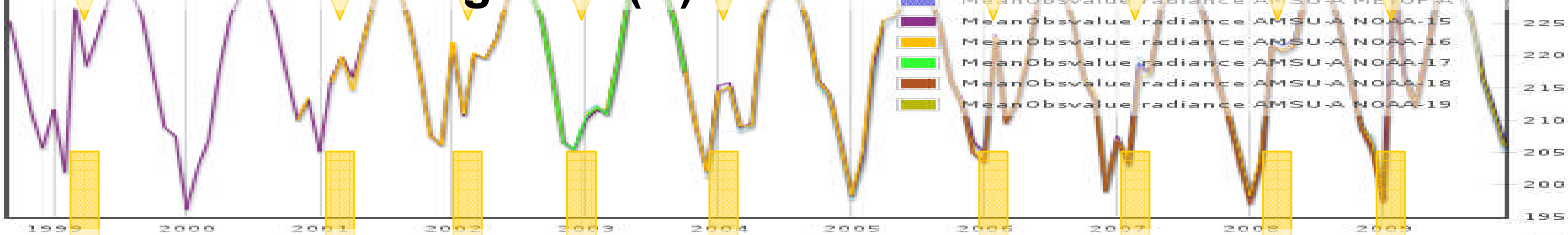
ECMWF

Example 6: Sudden stratospheric warming events

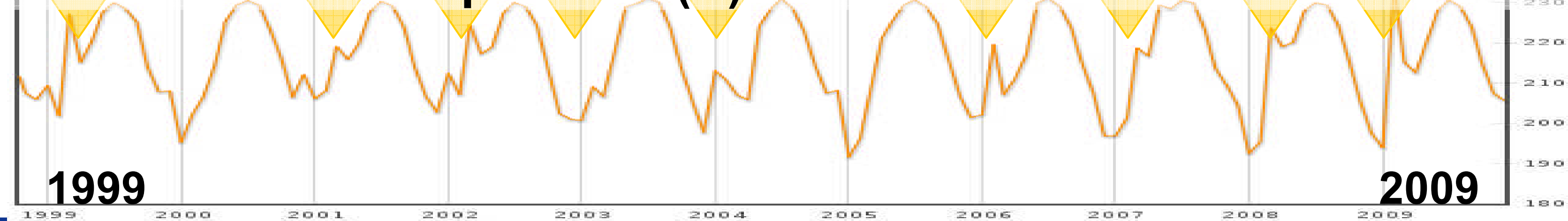
Mean bias correction (K) in the Arctic for AMSU-A channel 10



Mean observed Bright. T. (K) in the Arctic for AMSU-A channel 10



Mean observed temperature (K) in the Arctic radiosondes 40—25 hPa



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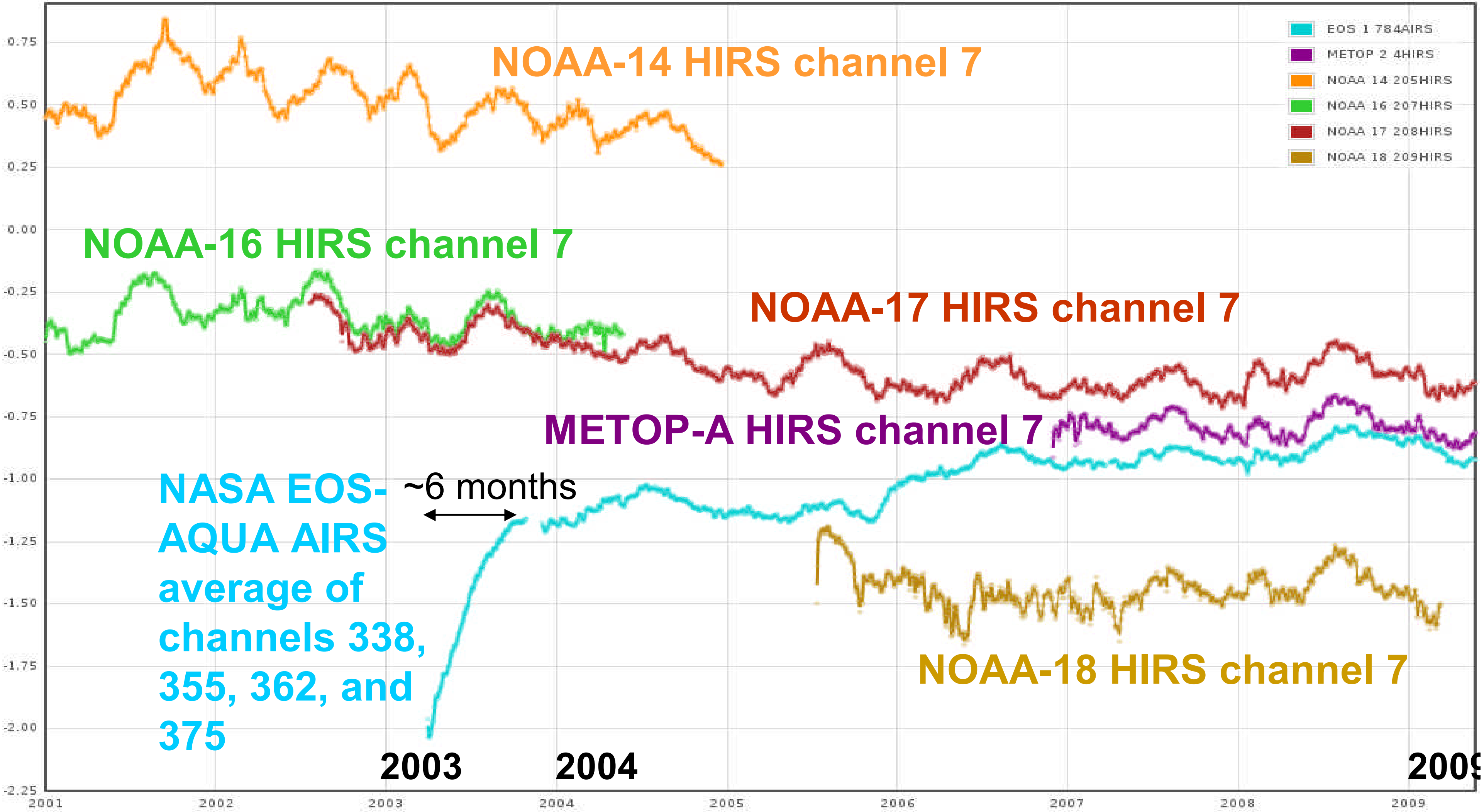
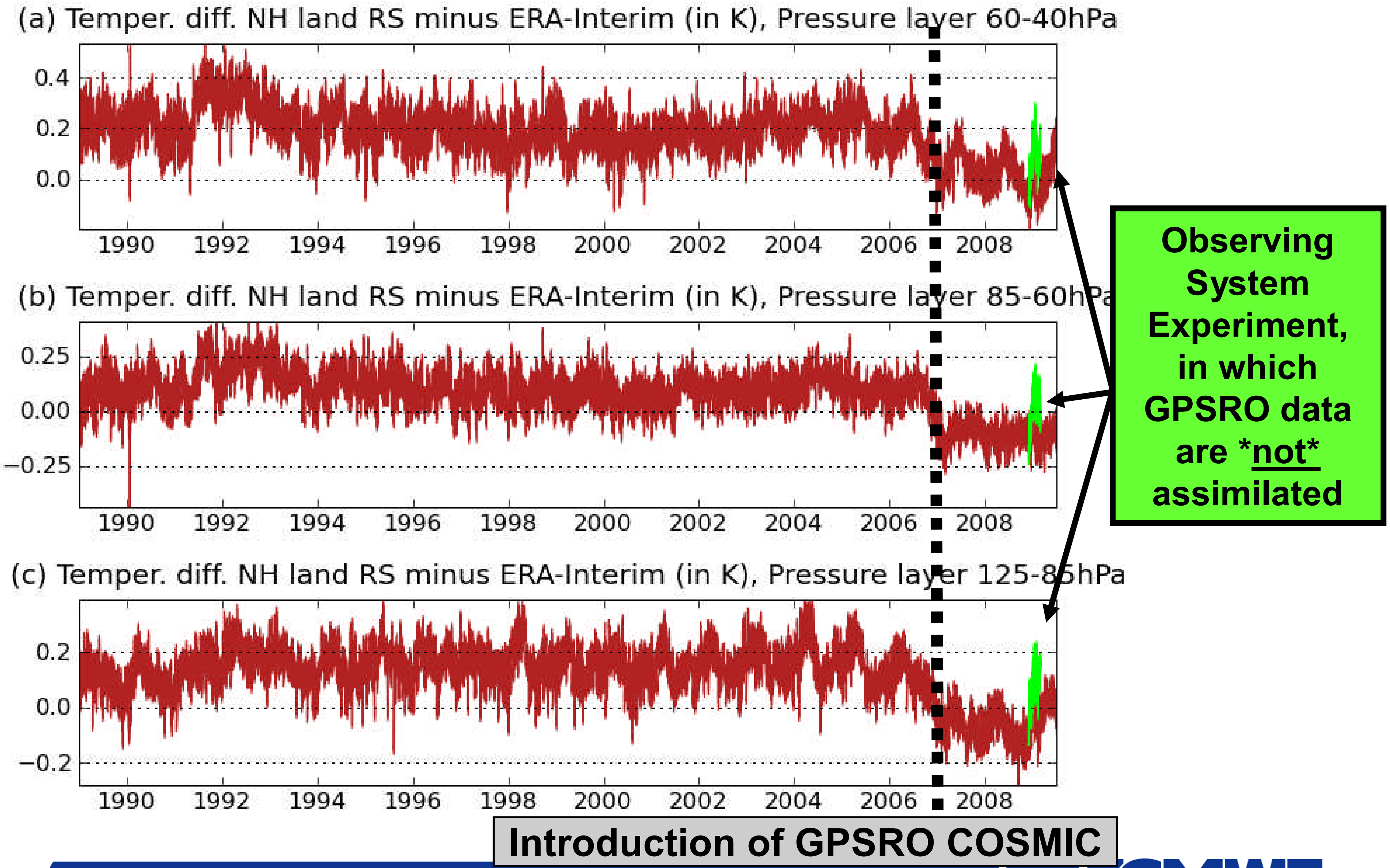
Example 7: Slow spin-up for AIRS

Mean global bias correction (K)



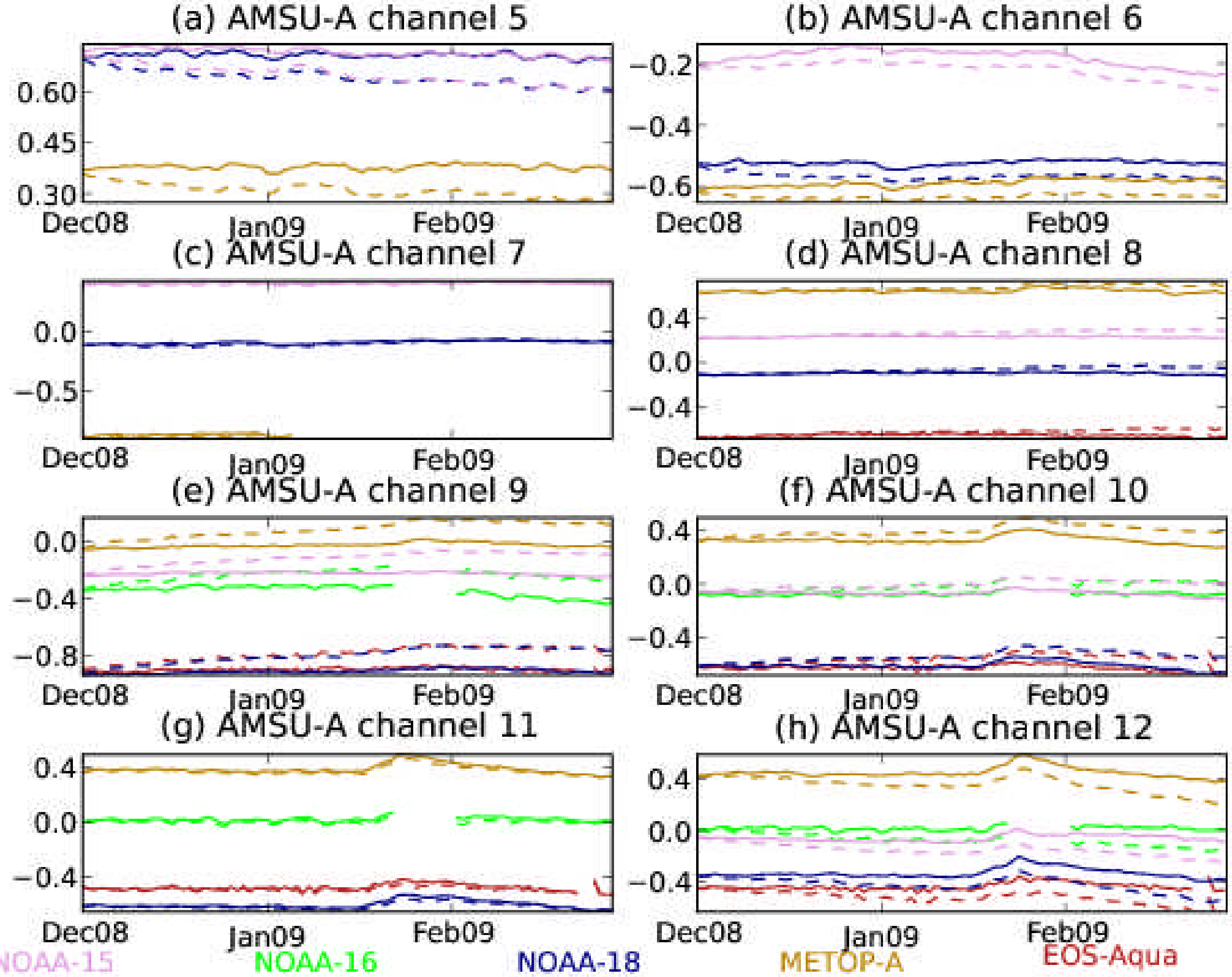
Example 8: Sensitivity to changes in the "anchoring" obs. system: GPSRO



ECMWF

Example 8 (cont.): Sensitivity to changes in the "anchoring" obs. system: GPSRO

Bias correction estimates (global means)



Observing System Experiment, in which GPSRO data are *<u>not</u>* assimilated

——— ERA-Interim - - - - ERA-Interim *without* GPSRO assimil.

Summary: Variational bias correction (1) Weak points

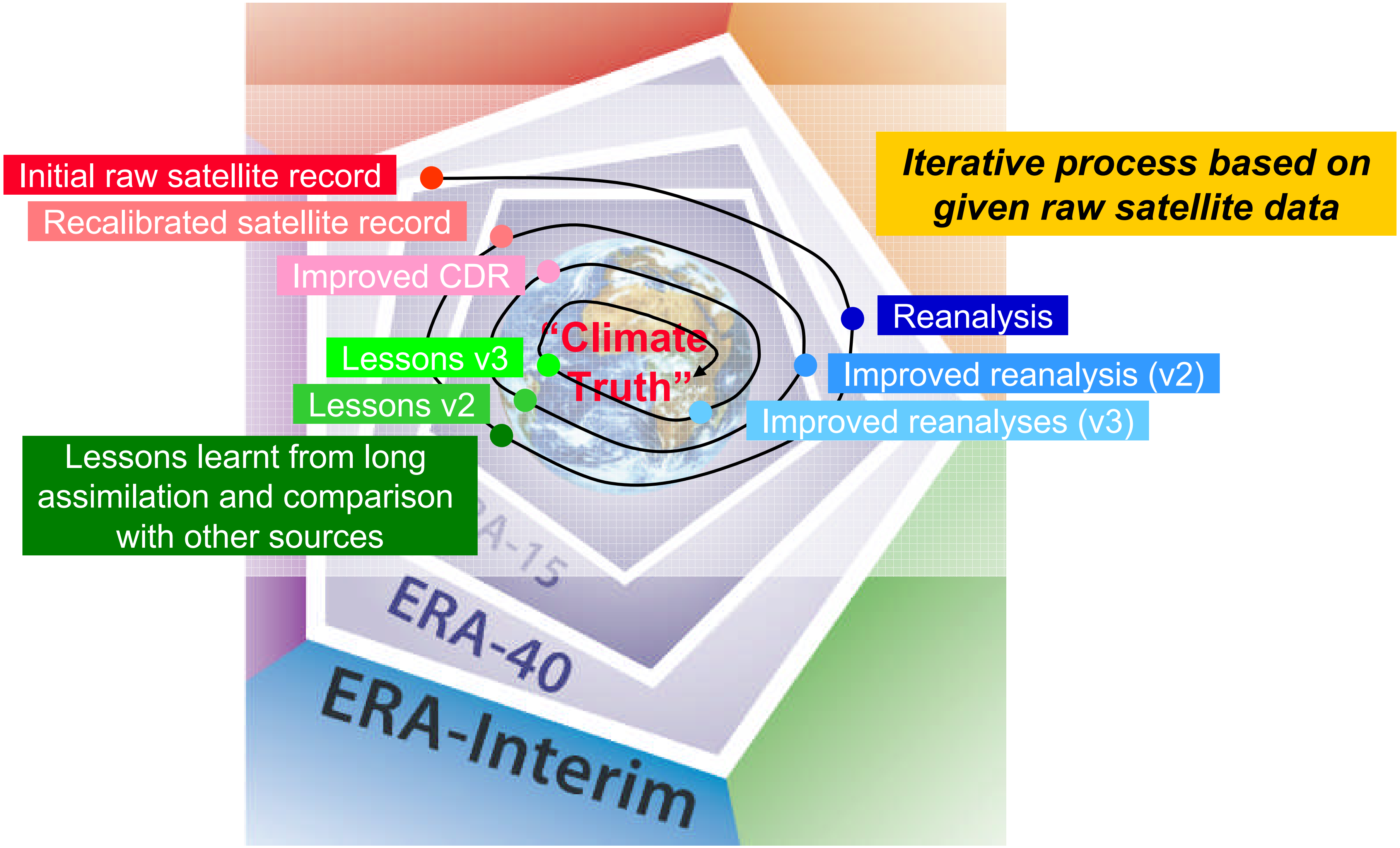
- **Sensitive to changes in the "reference" obs. system:**
  - Aircraft data assimilated in ERA-Interim are biased warm, and increasingly numerous; These data need to be bias corrected in the next ERA
  - Introduction of a large number of GPSRO soundings introduces a break in the time-series of temperatures at the tropopause
- **The variational bias correction cannot do everything!**
  - "Some" handling of <u>model biases</u> is definitely required for the next ERA; aerosols need better handling in particular
- **Spin-up can sometimes be slow:**
  - This seems to happen when a sensor probes a sub-space not observed by other instruments; the model state then takes a while to adjust

Summary: Variational bias correction (2) Strong points

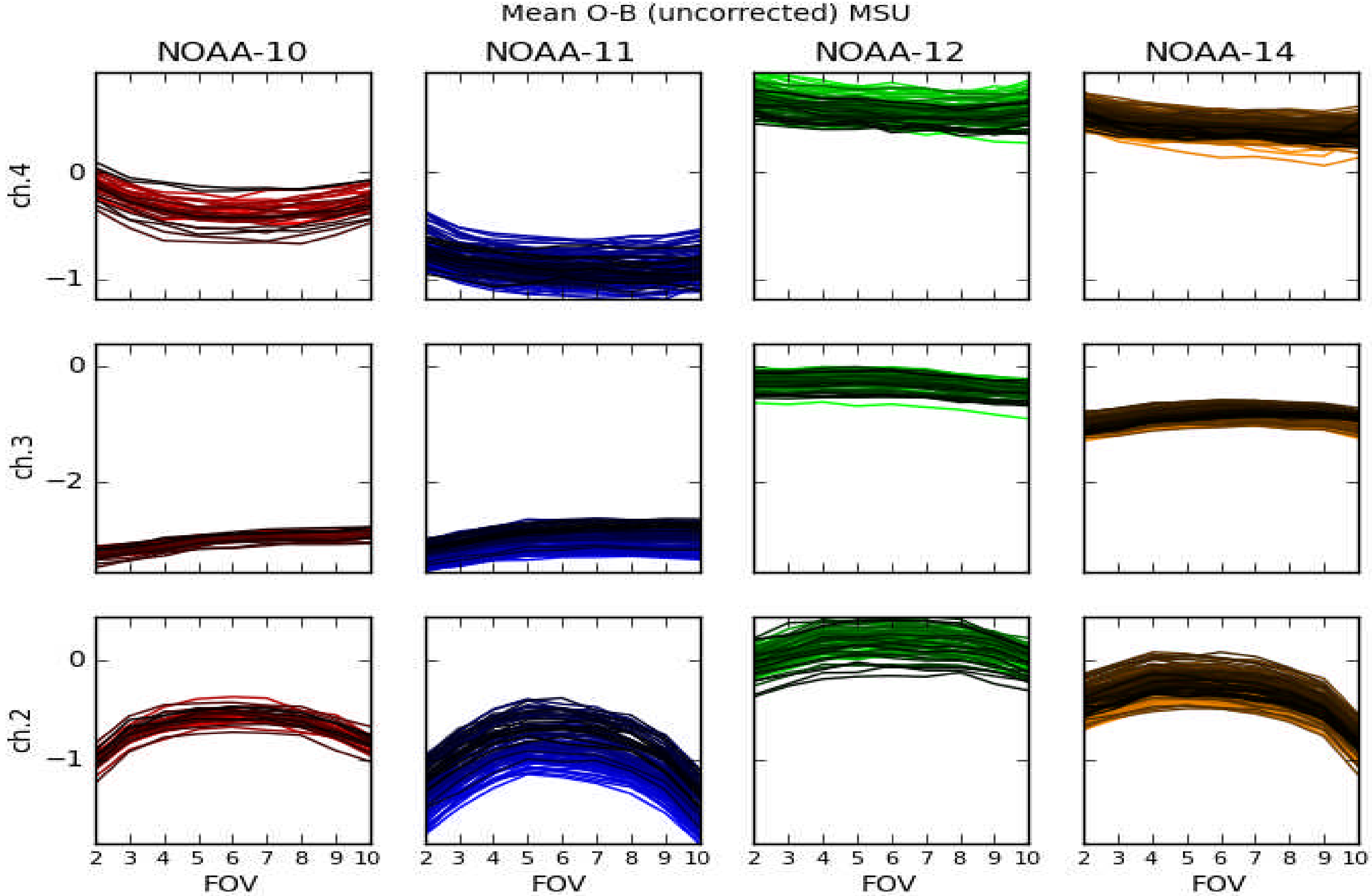
- Successfully correct for scan-angle dependent biases
  - These cannot be explained simply by model or radiative transfer model biases
- Manage to anchor the reanalysis system to observations which *we* specify as references
  – it's not black magic anymore where the mean behavior is the "sum" of all the observations
  - Opens the possibility to run several reanalyses where various observing systems are specified as references; the spread being an indication of how well we understand the observing systems and the past climate
- The shocks introduced by new satellite radiances, as found in ERA-40, are greatly reduced
- The technical complexity of satellite data assimilation has been greatly reduced

Next steps

- The experience gained with ERA-Interim will be valuable to feed back findings and verify whether the bias estimates are consistent with other estimates
- *Biases asymmetric with respect to scan angle* seem to point to phenomena still to be better corrected
  -- do antenna corrections need improving?
- Bias correction is likely to stick around for a while, but we hope to run various reanalyses with different types of observing systems as references
- Look forward to assimilating recalibrated observations – to continue the improvement loop…

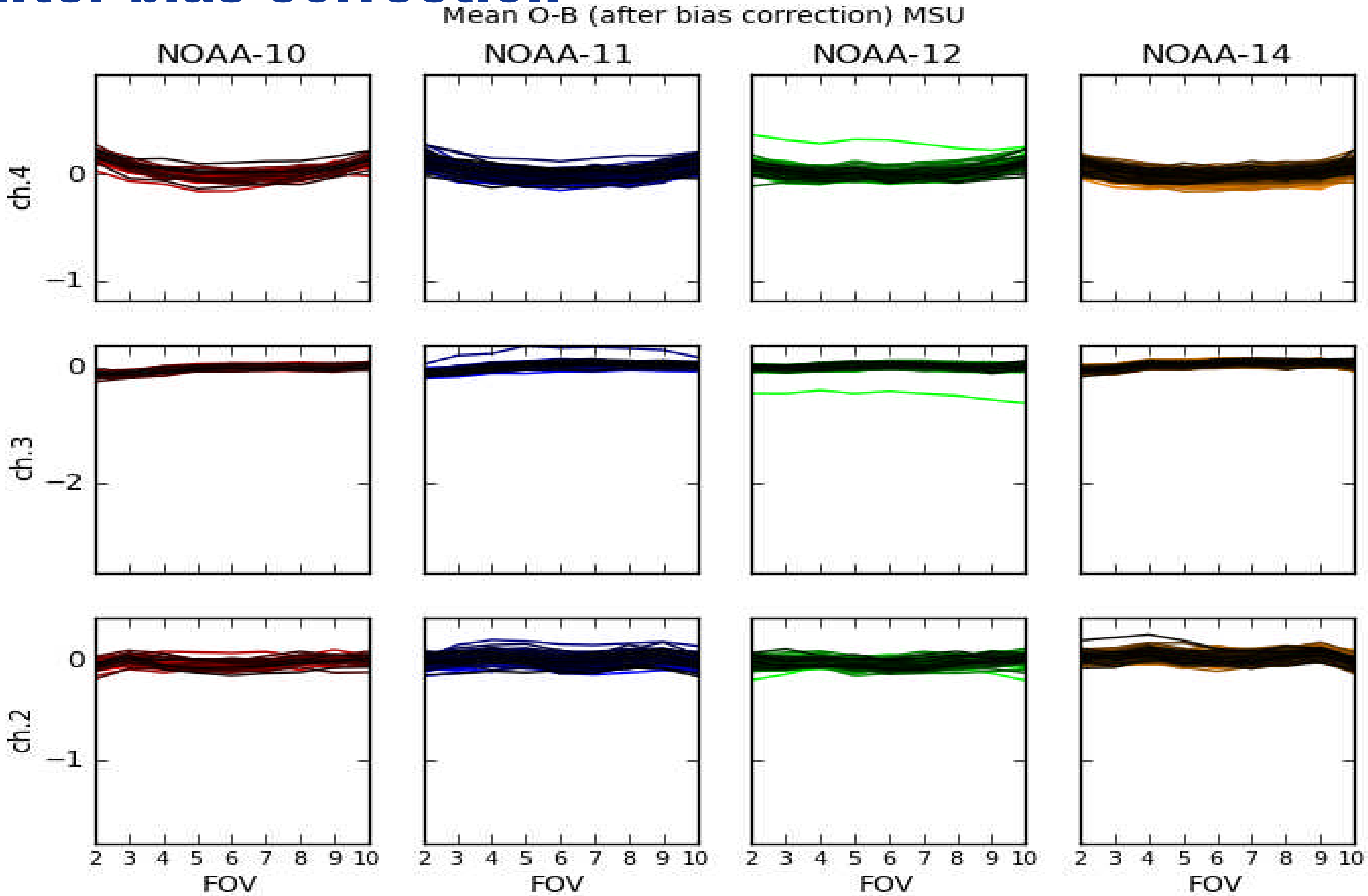

Initial raw satellite record
Recalibrated satellite record
Improved CDR
"Climate Truth"
Lessons v3
Lessons v2
Lessons learnt from long assimilation and comparison with other sources
Reanalysis
Improved reanalysis (v2)
Improved reanalyses (v3)
Iterative process based on given raw satellite data
ERA-40
ERA-Interim

Scan-angle dependence of the MSU biases



Curves get darker as the dates increase

Scan-angle dependence of the MSU biases after bias correction



Curves get darker as the dates increase