Reanalysis applications of GPS radio occultation measurements

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ECMWF

GRAS SAF Workshop on Applications of GPS radio occultation measurements
ECMWF, 16-18 June 2008

Outline

- ERA-Interim and GPSRO data
- Bias issues in the reanalysis context
- Variational bias correction of radiance data (VarBC)
- Effect of COSMIC data on VarBC
- Impact of CHAMP in ERA-Interim

ERA-Interim: Preparation for a new European reanalysis

ERA-Interim: Atmospheric reanalysis from 1989 onward

- **Currently processing 2004; real-time by the end of 2008**
- Will continue as a Climate Data Assimilation System

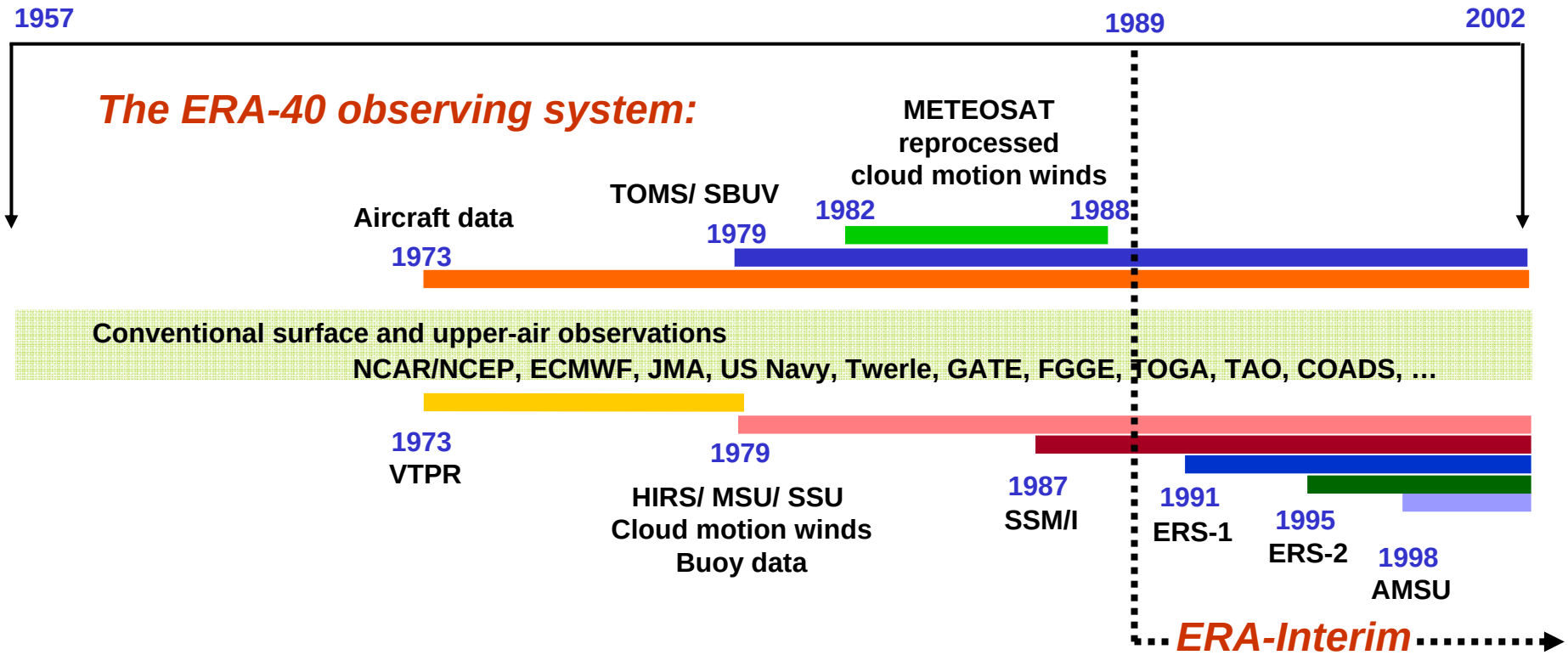
Main system characteristics:

- **T255 (~80km) horizontal resolution**
- 60 vertical layers; top level at 0.1 hPa
- Improved model physics (ECMWF model cycle 31r2)
- **4D-Var analysis using a 12h time window**
- Completely revised humidity analysis
- Wavelet-based background error covariances
- **Variational bias correction of radiance data**

Many product improvements compared to ERA-40:

- Better fit to observations
- Much better hydrological cycle
- Improved stratospheric transport
- Improved forecast skill

- *See ECMWF Newsletters 110, 115 for additional details*
- *Contact ECMWF Data Services for access to ERA-Interim data products*



Observations used in ERA-Interim:

- **ERA-40 observations until August 2002**
- **ECMWF operational data after August 2002**
- Reprocessed altimeter wave-height data from ERS
- Humidity information from SSM/I rain-affected radiance data
- Reprocessed METEOSAT AMV wind data
- Reprocessed ozone profiles from GOME
- ***Reprocessed GPSRO data from CHAMP***

Use of GPSRO in ERA-Interim (currently August 2004)

• CHAMP:	2001 – 2009 (?)	~ 150 profiles/day
• COSMIC:	2006 – 2011 (?)	~ 1500 profiles/day
• GRAS:	potentially from 2006	~ 650 profiles/day
• GRACE:	potentially from 2006	~ 150 profiles/day

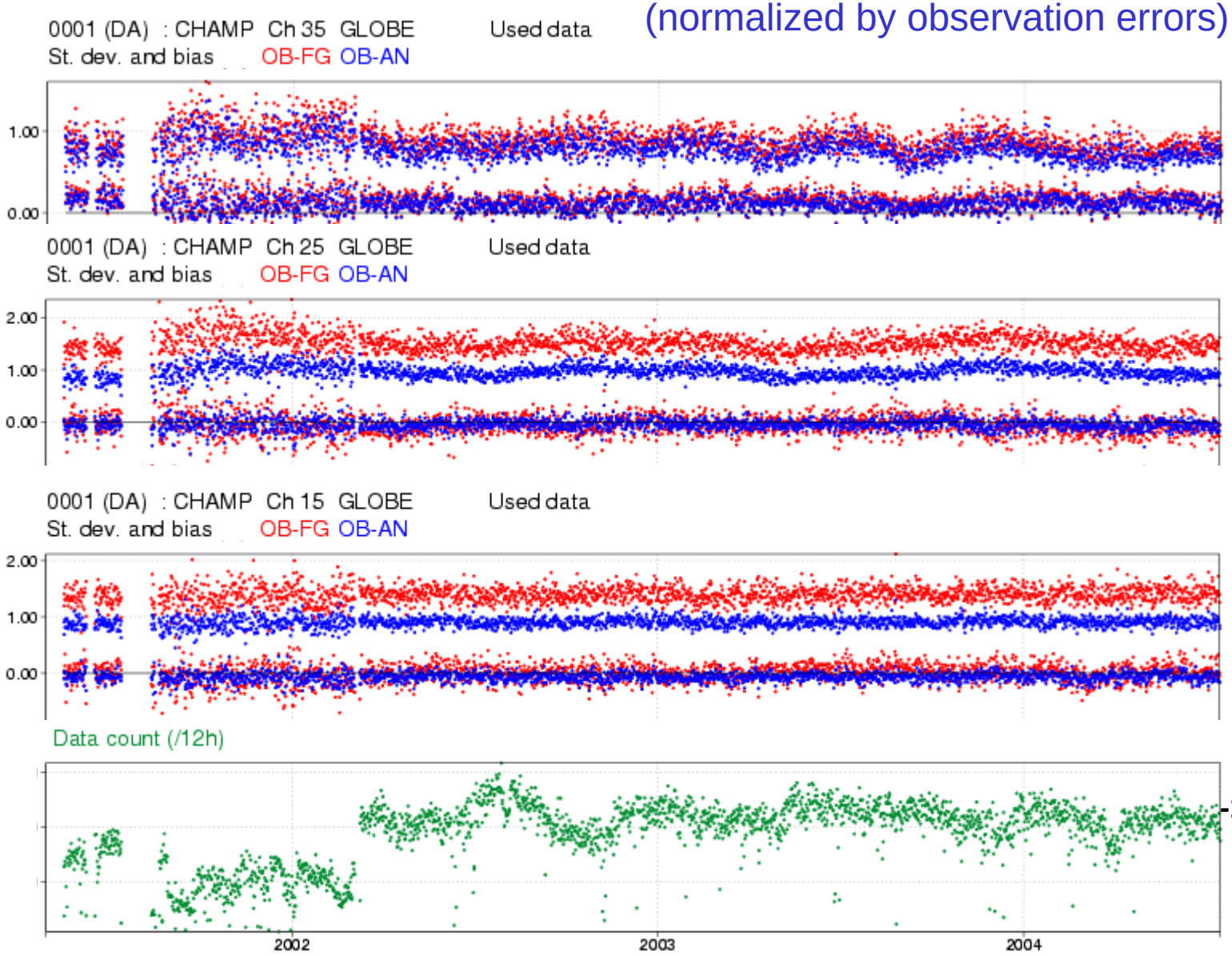
Expectations from a reanalysis perspective:

- GPS data should be especially valuable because they
  - resolve scales not well observed by other instruments,
  - provide global uniform sampling, and
  - do not require bias correction

Can GPS data provide a baseline for bias corrections of other instruments ?

CHAMP data in ERA-Interim: bending angle departures

(normalized by observation errors)



Binned at ~35 km

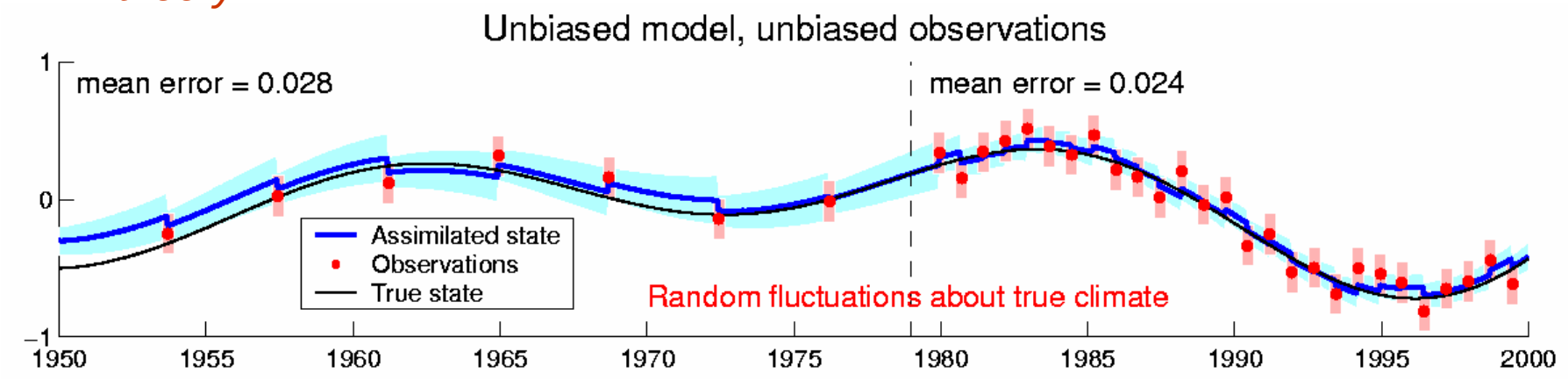
~25 km

~15 km

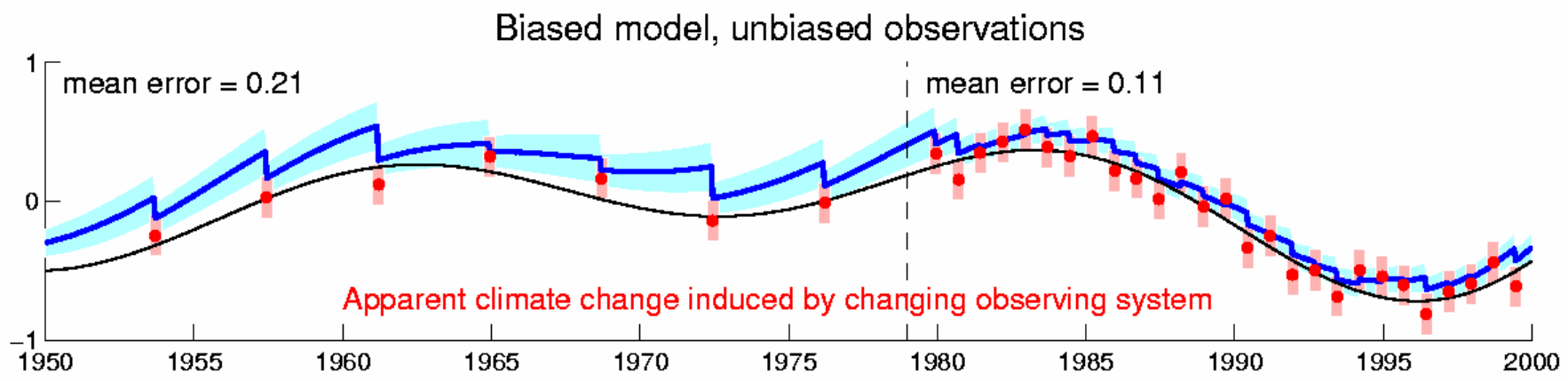
-150 profiles per day

The bias problem in a reanalysis context

In theory:



In practice:



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Variational bias correction (VarBC) applied to radiance data

The data assimilation system optimizes the bias corrections,
using all available information from observations and model

- Global radiance bias expressed in terms of *bias predictors*:
  - A constant offset
  - Instrument scan position
  - Functions of the observed atmospheric column (e.g. integrated lapse rate)
- Separately for each satellite/sensor/channel: $b(\beta, x) = \beta_0 + \sum_i \beta_i p_i$
- Estimate the bias parameters in the variational analysis (Derber and Wu 1998)

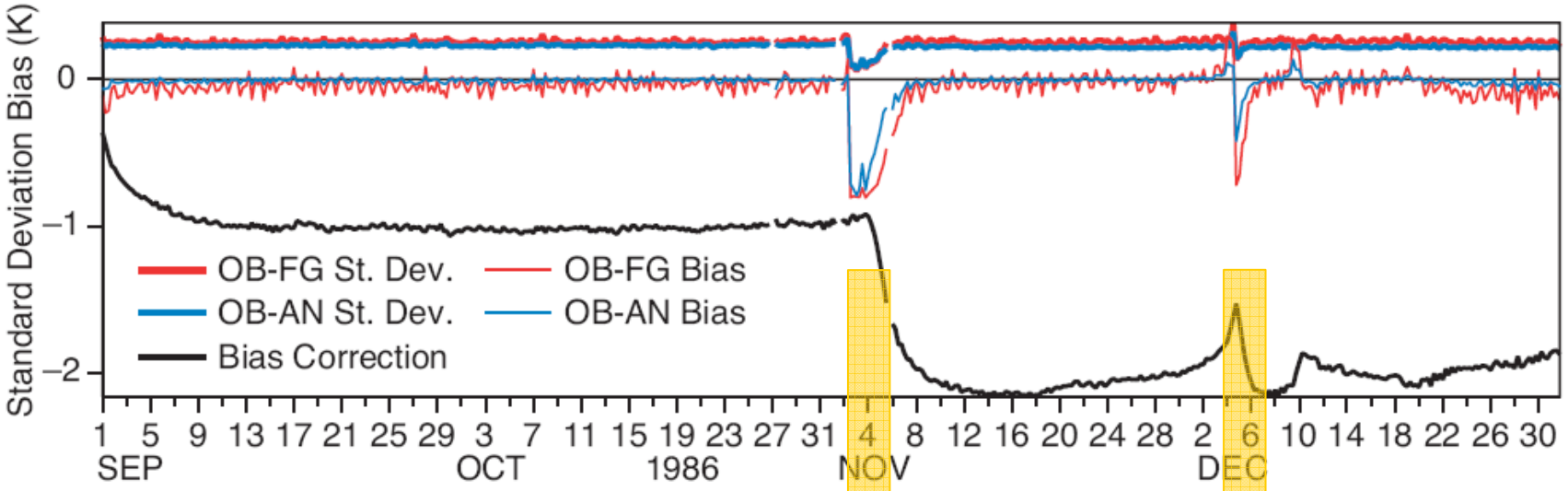
J_b: background constraint for x

J_β: background constraint for β

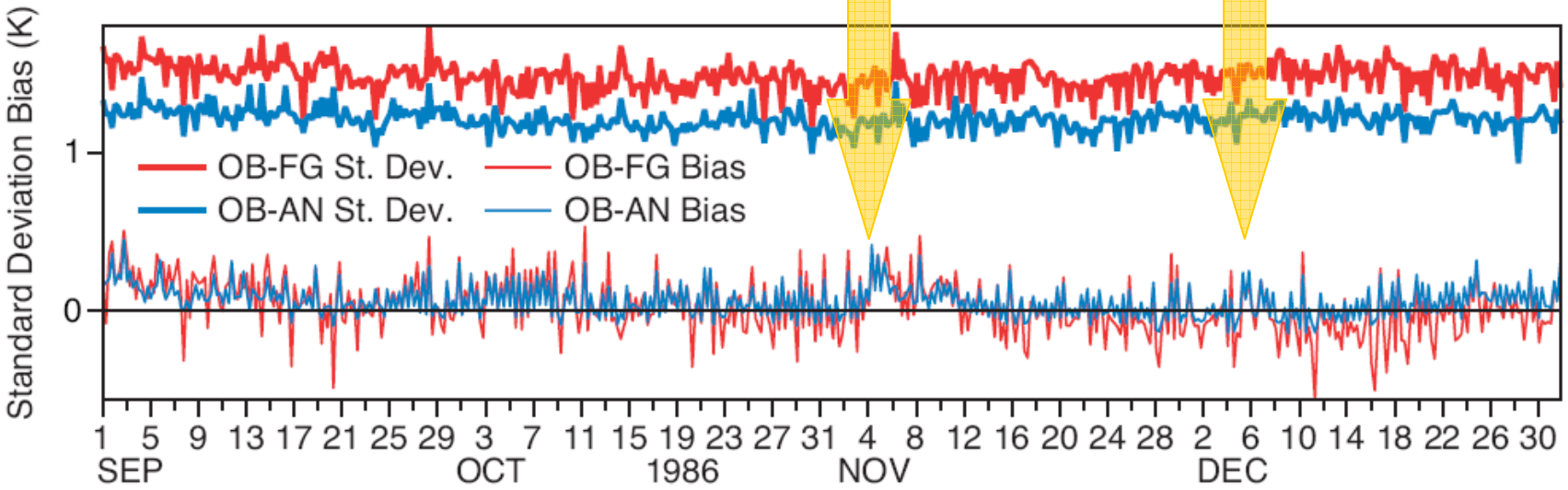
$$J(x,\beta) = (x_b - x)^T B_x^{-1} (x_b - x) + (\beta_b - \beta)^T B_\beta^{-1} (\beta_b - \beta) + [y - b_o(x,\beta) - h(x)]^T R^{-1} [y - b_o(x,\beta) - h(x)]$$

J_o: bias-corrected observation constraint

Example: NOAA-9 MSU channel 3, solar flare disruption

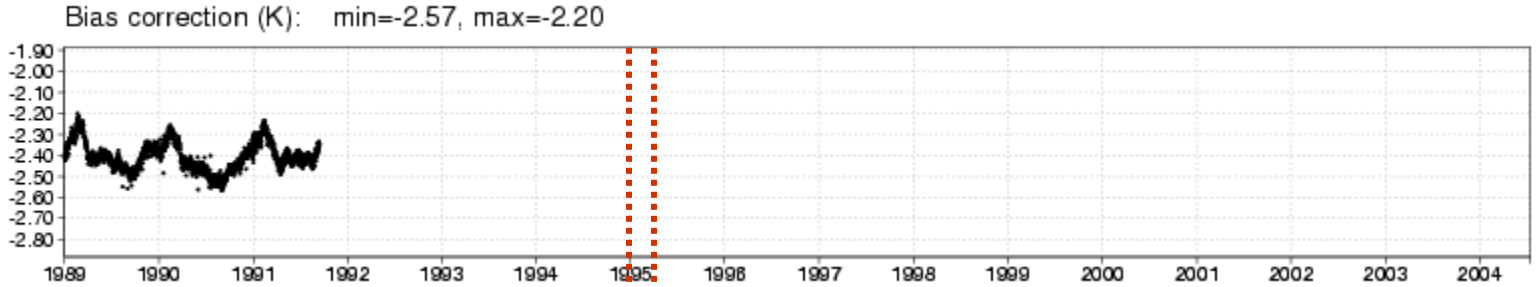


200 hPa temperature departures from radiosonde observations

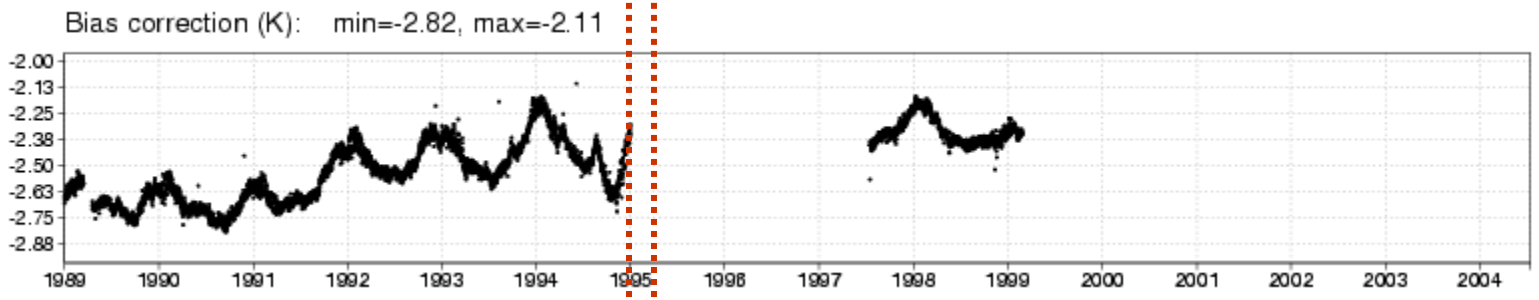


MSU Ch3 variational bias corrections in ERA-Interim

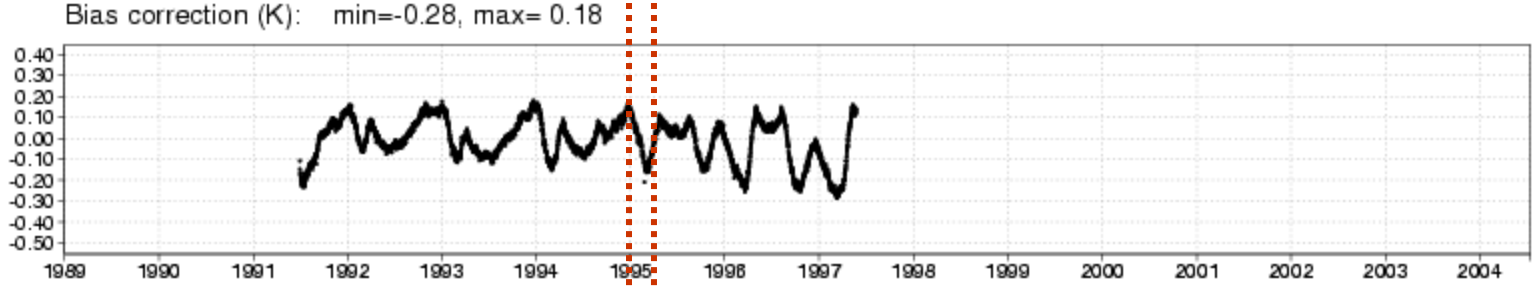
NOAA-10



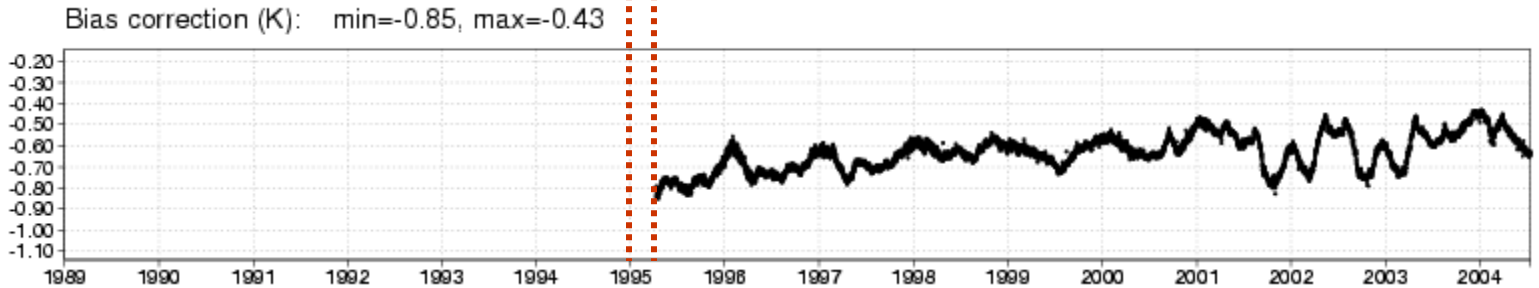
NOAA-11



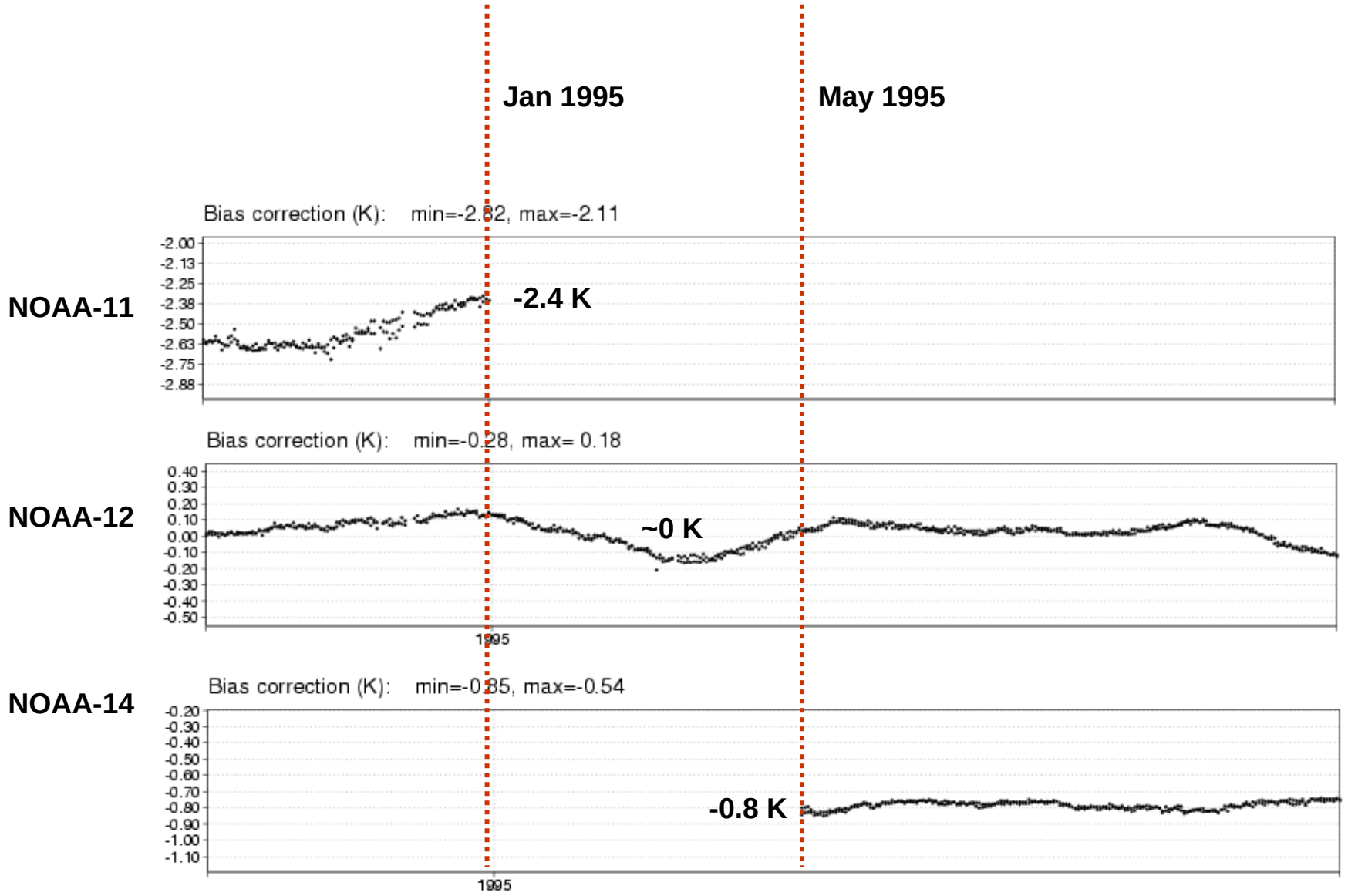
NOAA-12



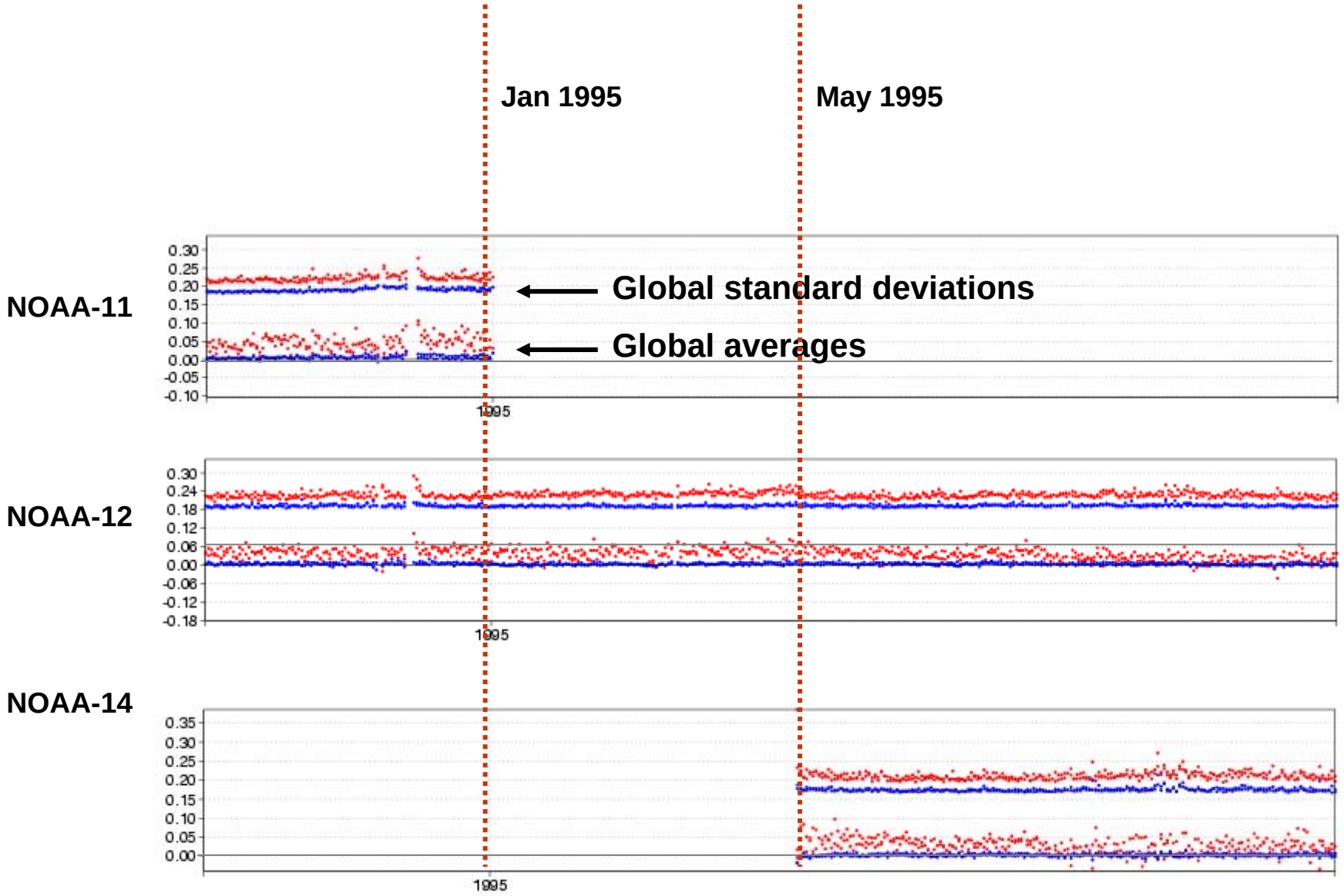
NOAA-14



Inter-satellite calibration based on VarBC

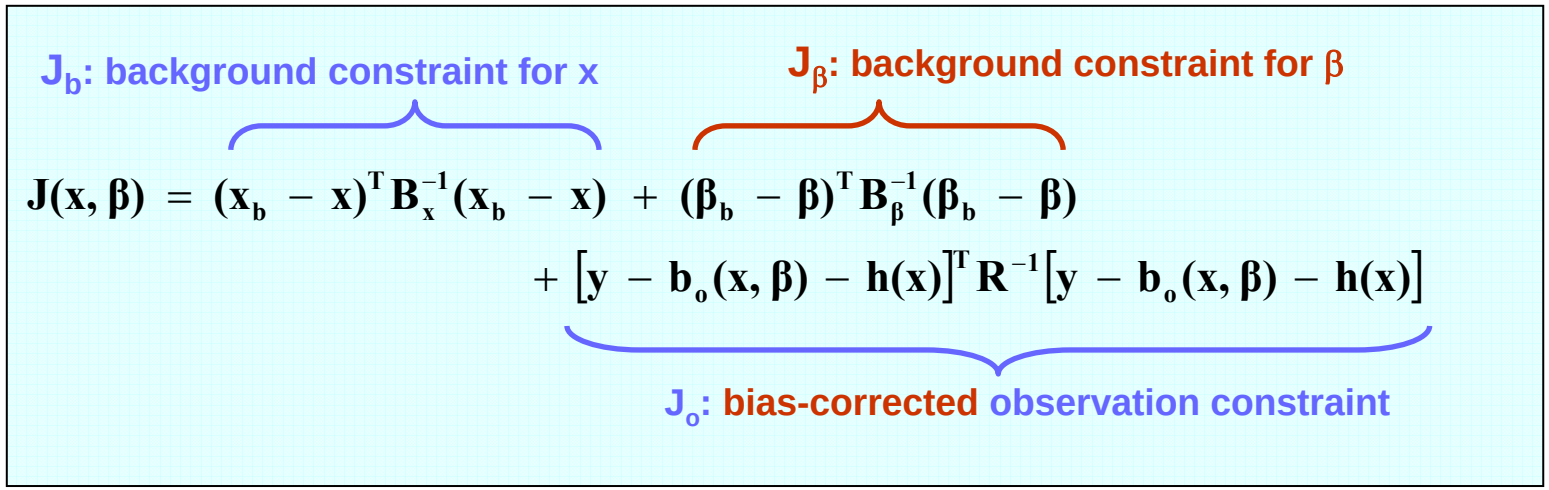


MSU Ch3 bias-corrected Tb departures



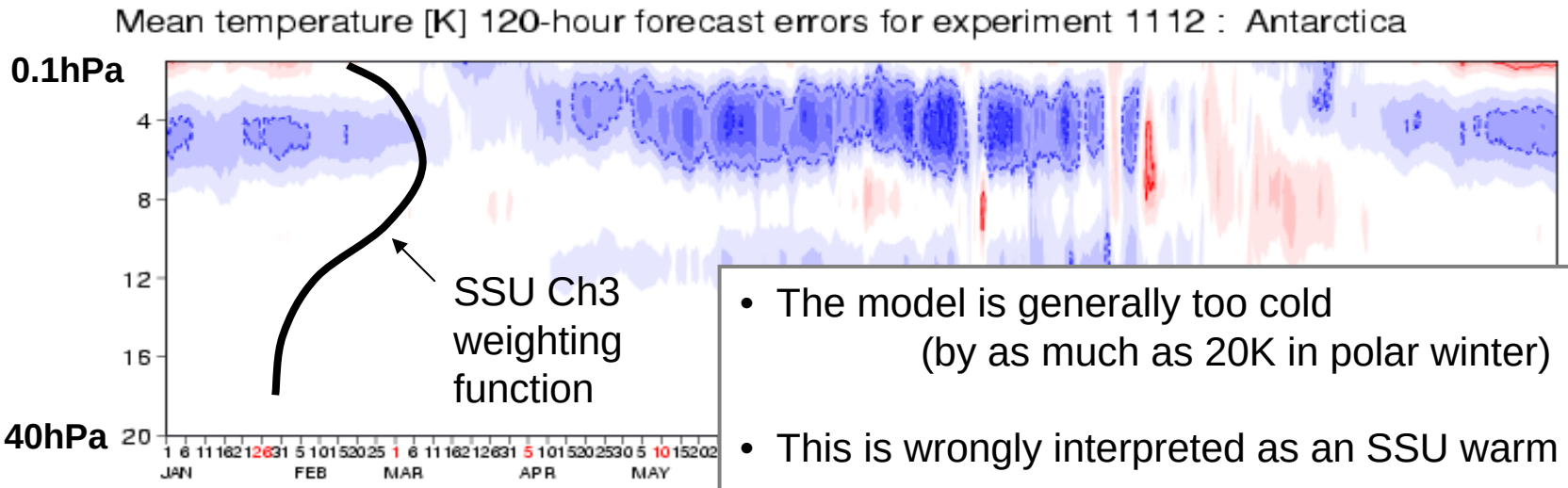
Limitations of variational bias correction

The analysis adjusts the bias parameters in order to optimize the consistency among the various information sources:

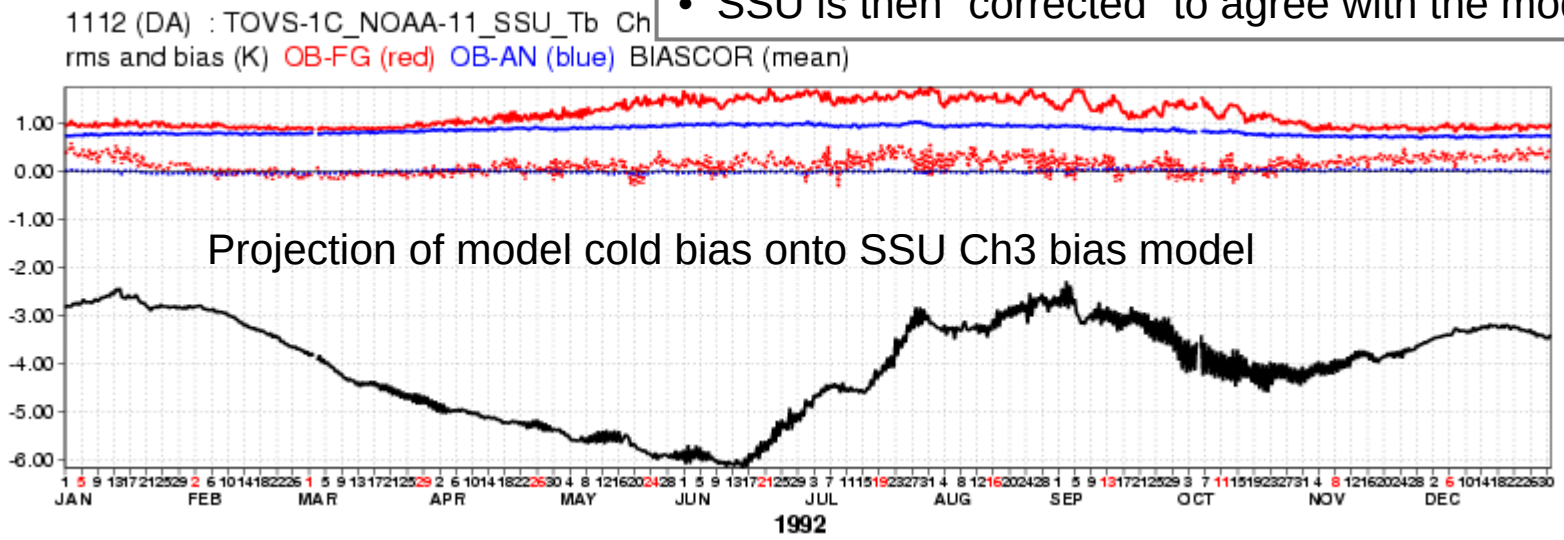


- One has to be careful about which (and how many) sources to correct
- It won't work unless there is sufficient information to anchor the system
- Since VarBC corrects the (mean) departures, systematic errors in the forecast model may interfere

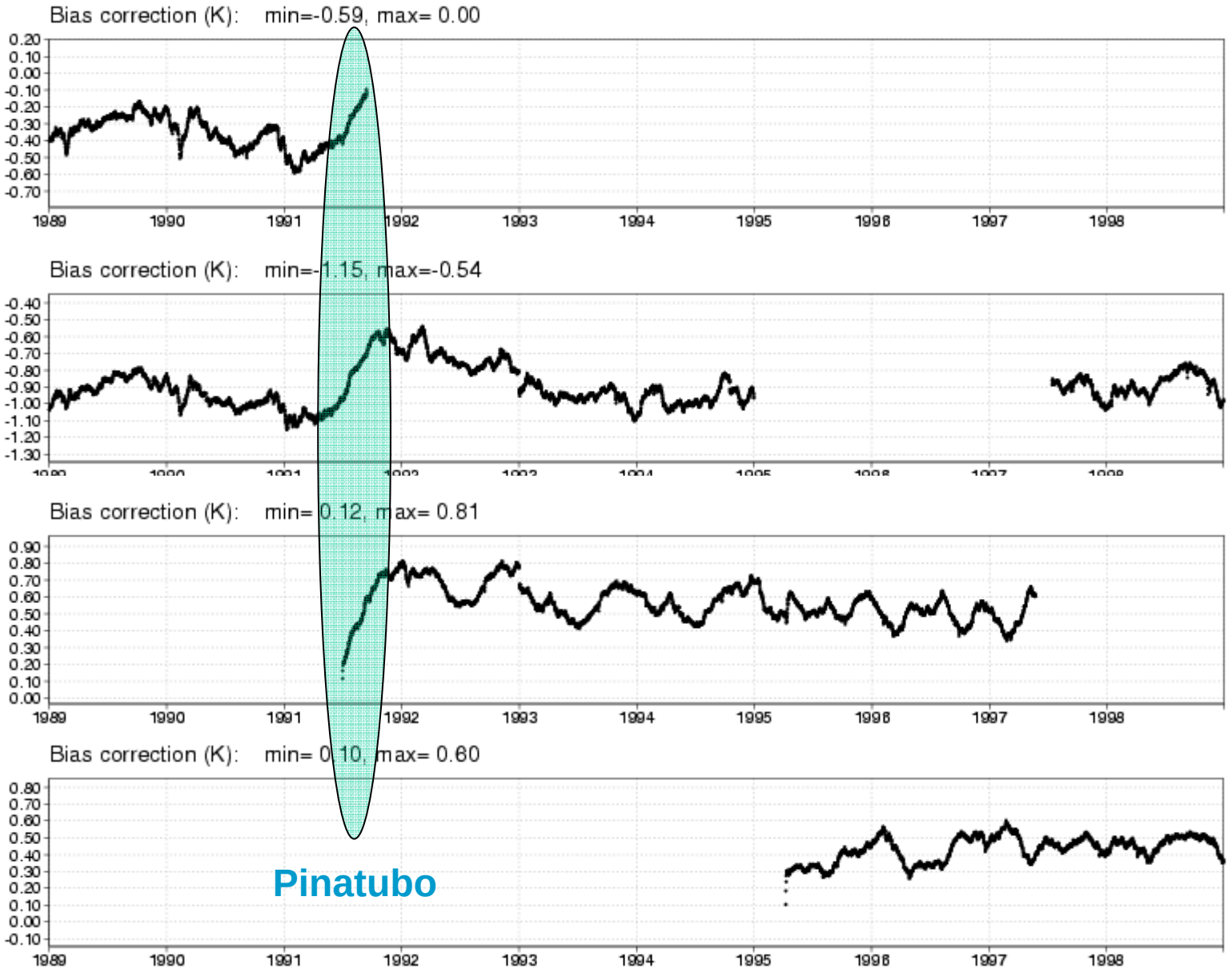
Limitation of VarBC: Interaction with model bias



- The model is generally too cold (by as much as 20K in polar winter)
- This is wrongly interpreted as an SSU warm bias
- SSU is then “corrected” to agree with the model



MSU Ch4: Tropical mean bias corrections



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GPS as a baseline for other instruments

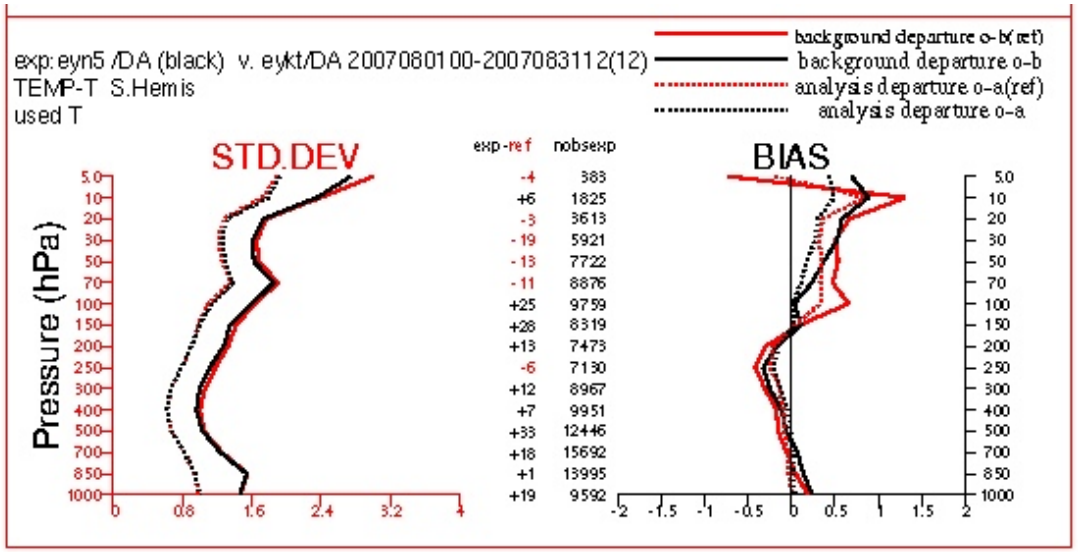
How do GPS data affect the bias corrections of other instruments?

Experiment in a simplified NWP system (Sean Healy):

- Period: June 15th to August 31st, 2007
- T511/159 Cy32r3
- **CONTROL**: Assimilates all conventional measurements + AMSU-A and MHS instruments from the METOP-A satellite
- **COSMIC**: As control, but with all COSMIC measurements assimilated
- **VarBC switched on**. How do the COSMIC measurements modify the evolution of the bias correction of AMSU-A radiances?

Fit to radiosonde and COSMIC measurements (SH)

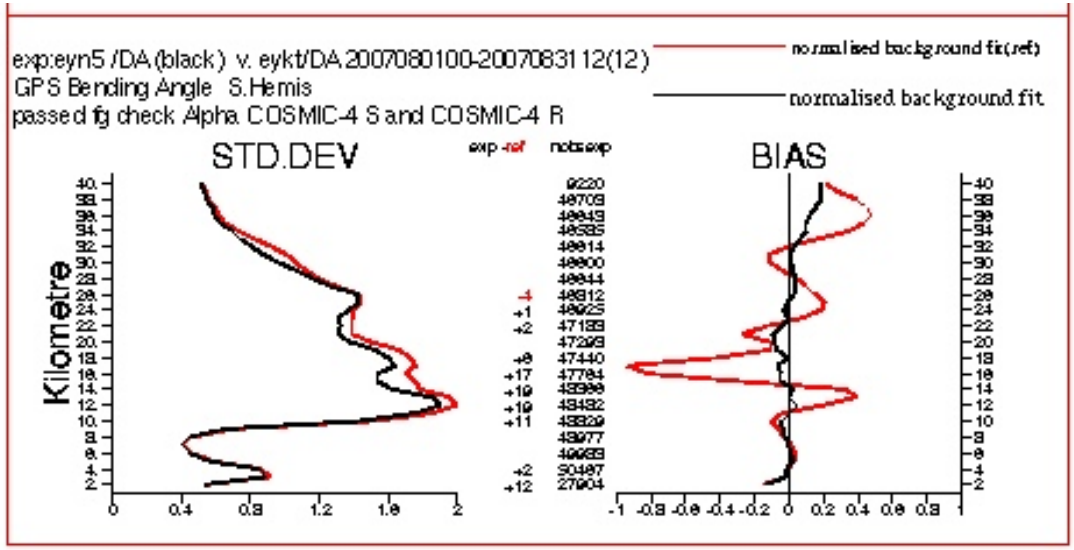
Radiosonde temperature

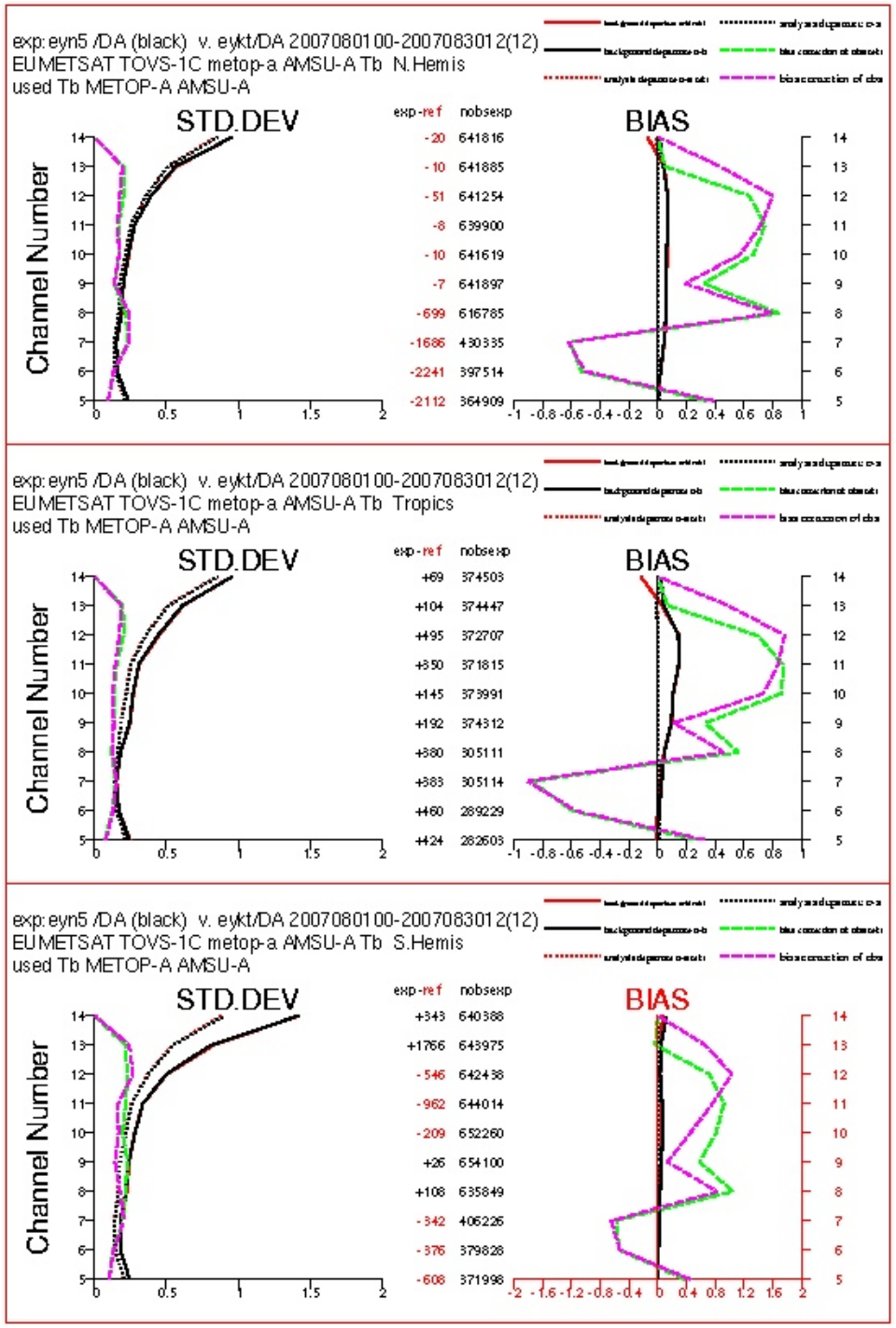


CONTROL: red
COSMIC: black

Bending angle COSMIC-4

(normalised O-B departures)





Bias correction applied to AMSU-A radiances for August 2007

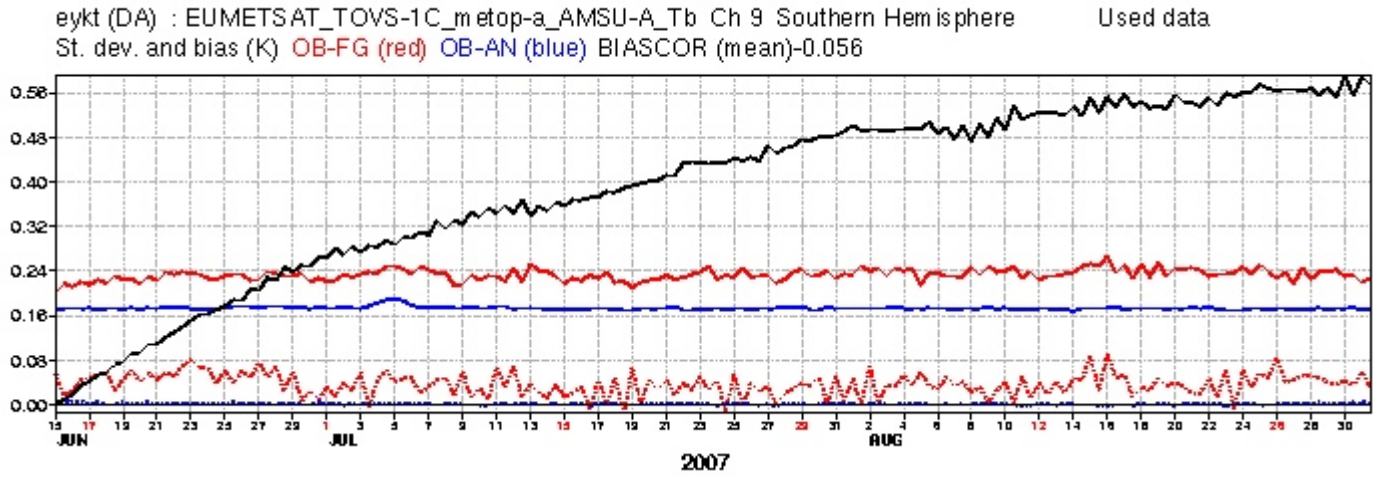
Green = Control
Pink = COSMIC

Bias correction applied to channels 8,9,10,11 generally smaller with COSMIC assimilated.

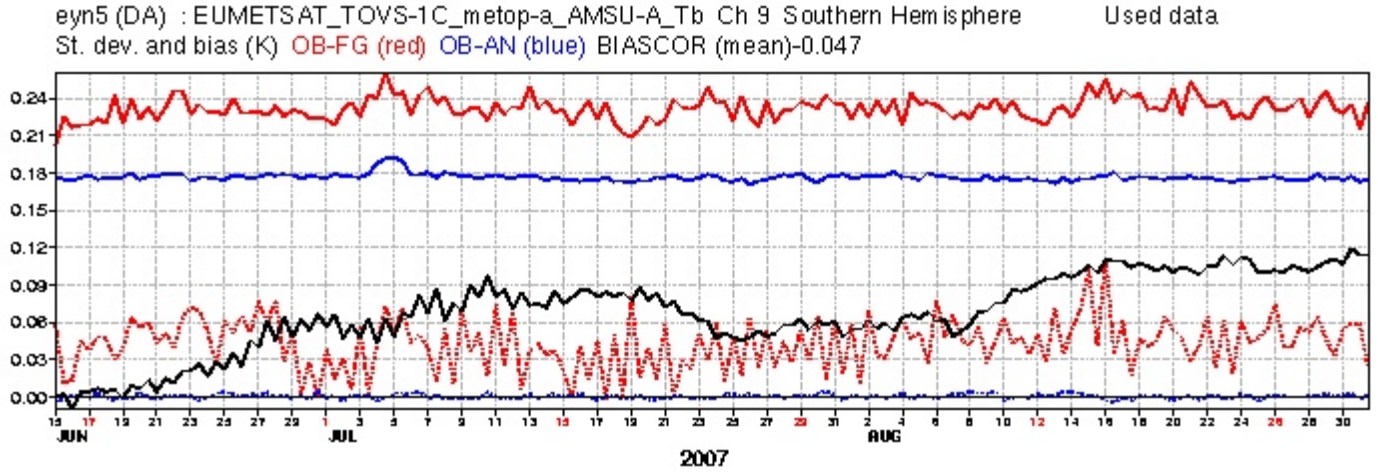
Larger for channels 12,13.

Evolution of the bias correction for AMSU-A, channel 9 (Southern Hemisphere)

CONTROL (NO COSMIC MEASUREMENTS)

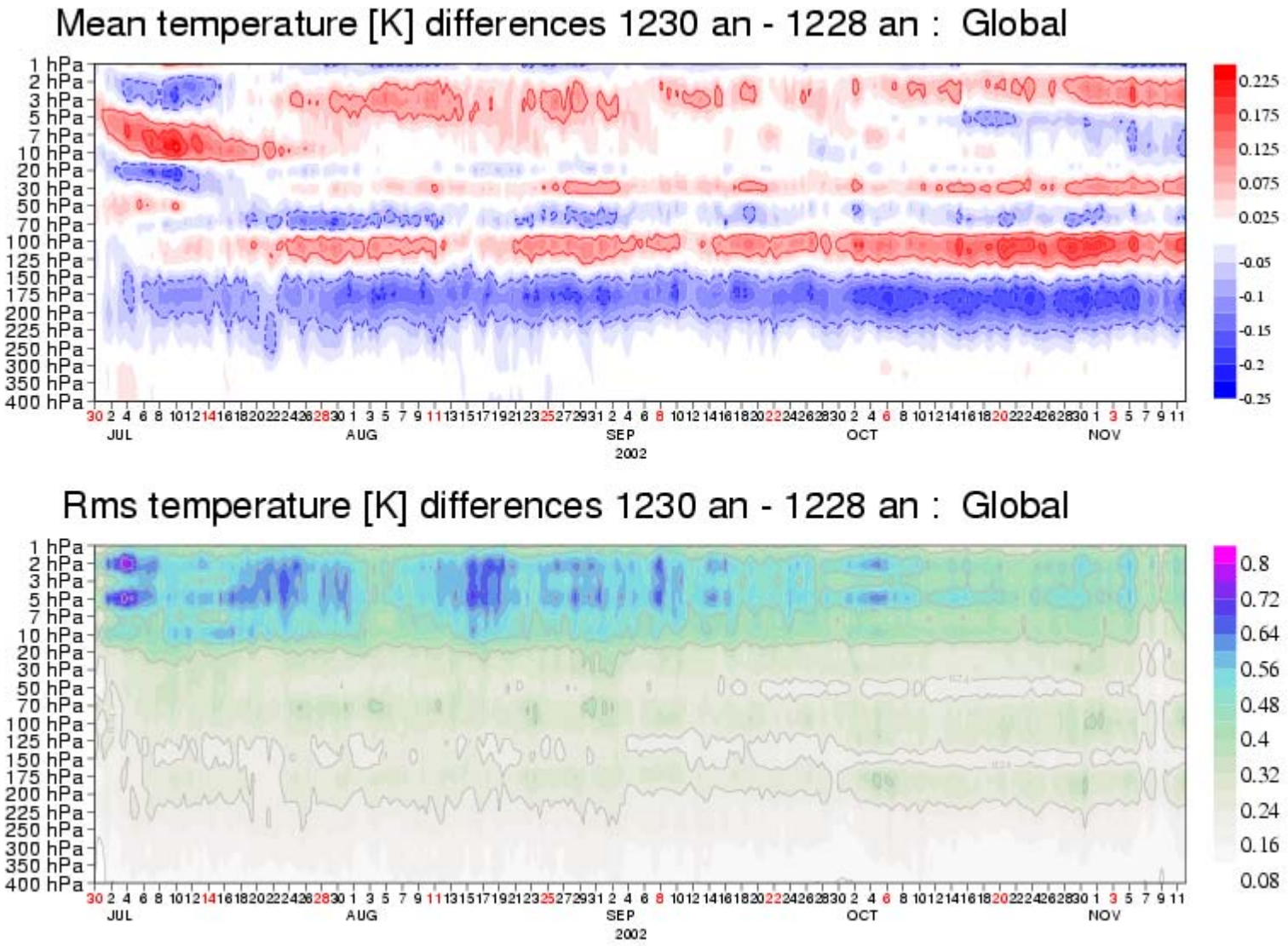


COSMIC MEASUREMENTS ASSIMILATED



Impact of CHAMP data in ERA-Interim

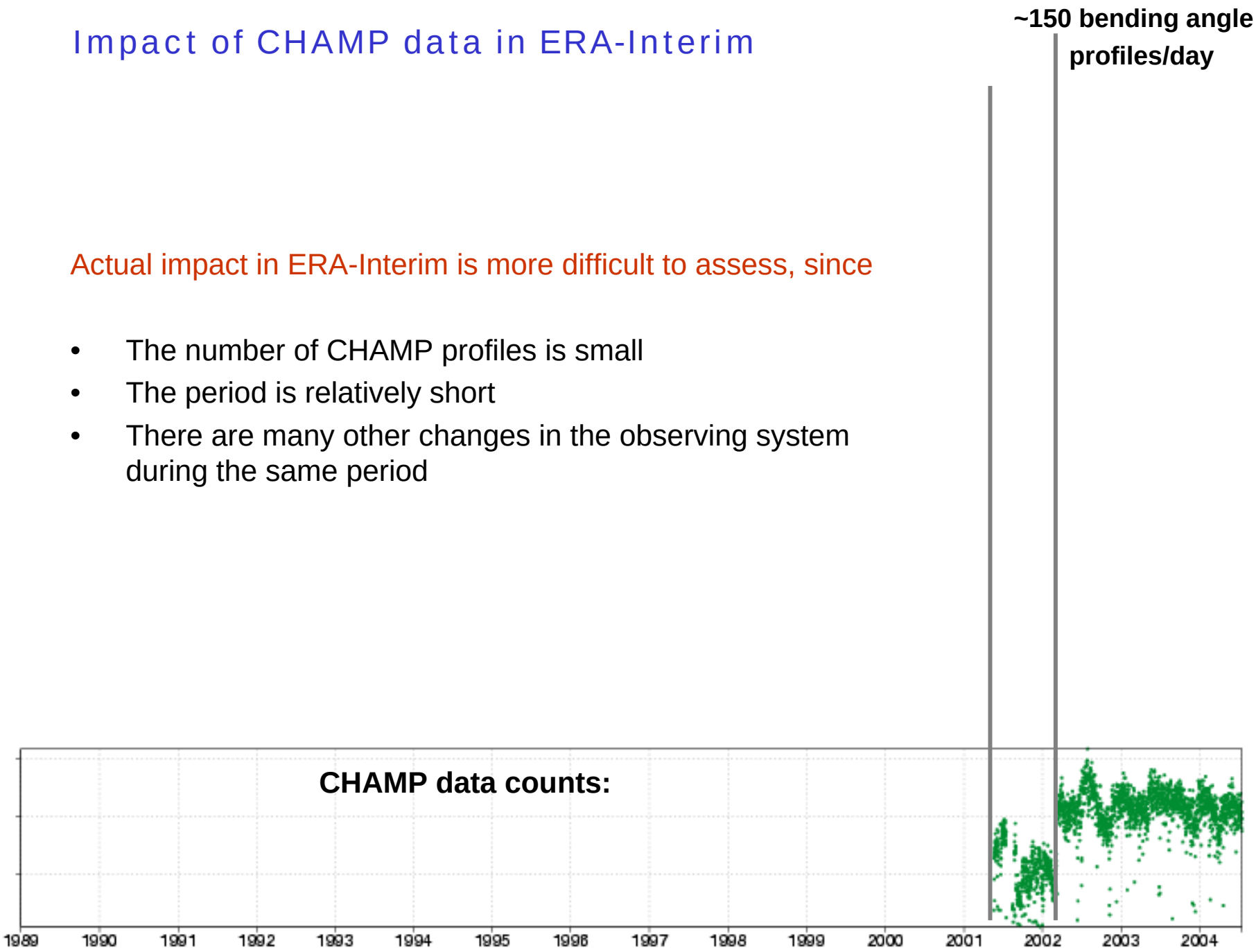
A preliminary impact experiment was performed ahead of ERA-Interim:



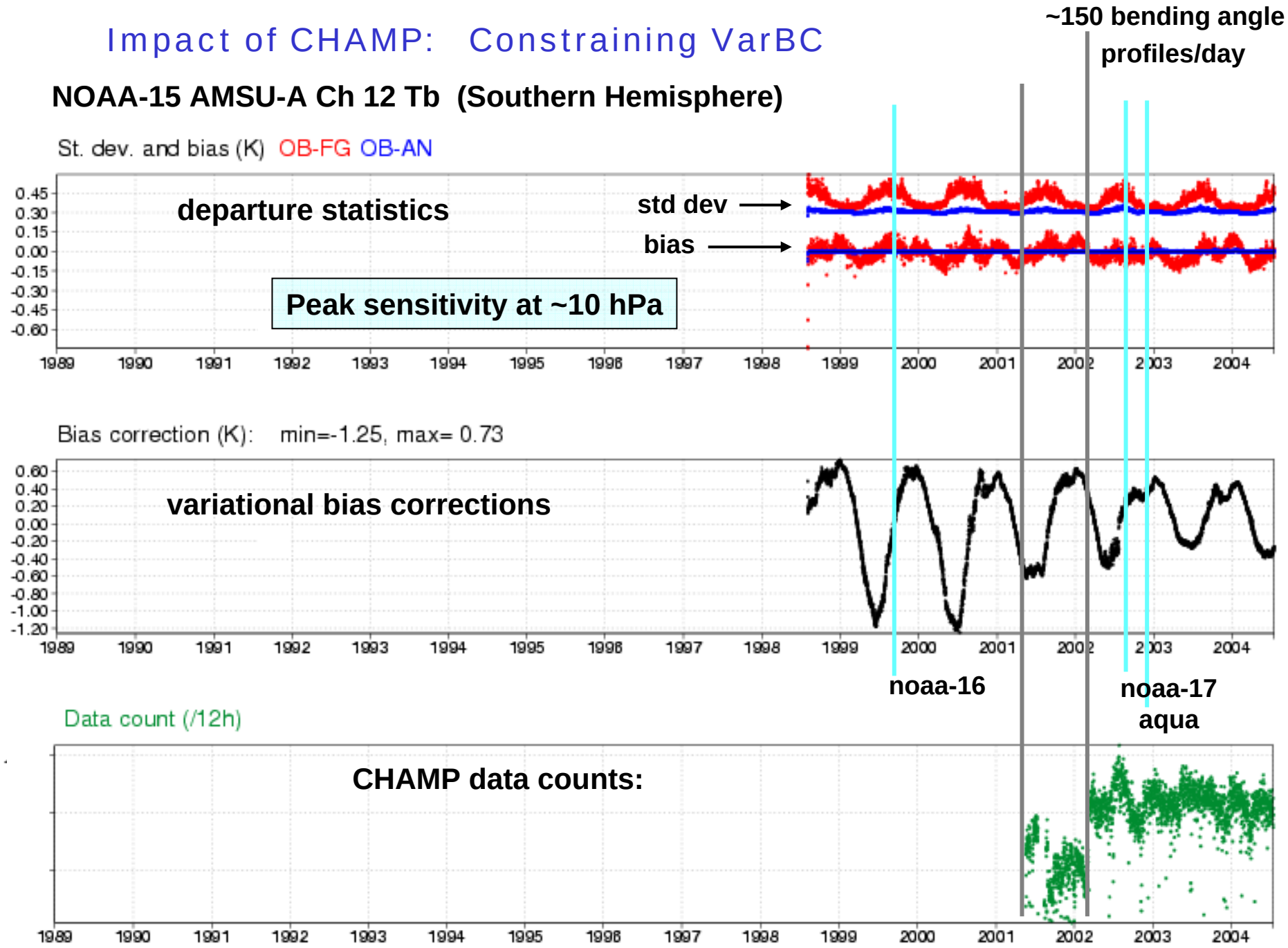
Impact of CHAMP data in ERA-Interim

Actual impact in ERA-Interim is more difficult to assess, since

- The number of CHAMP profiles is small
- The period is relatively short
- There are many other changes in the observing system during the same period



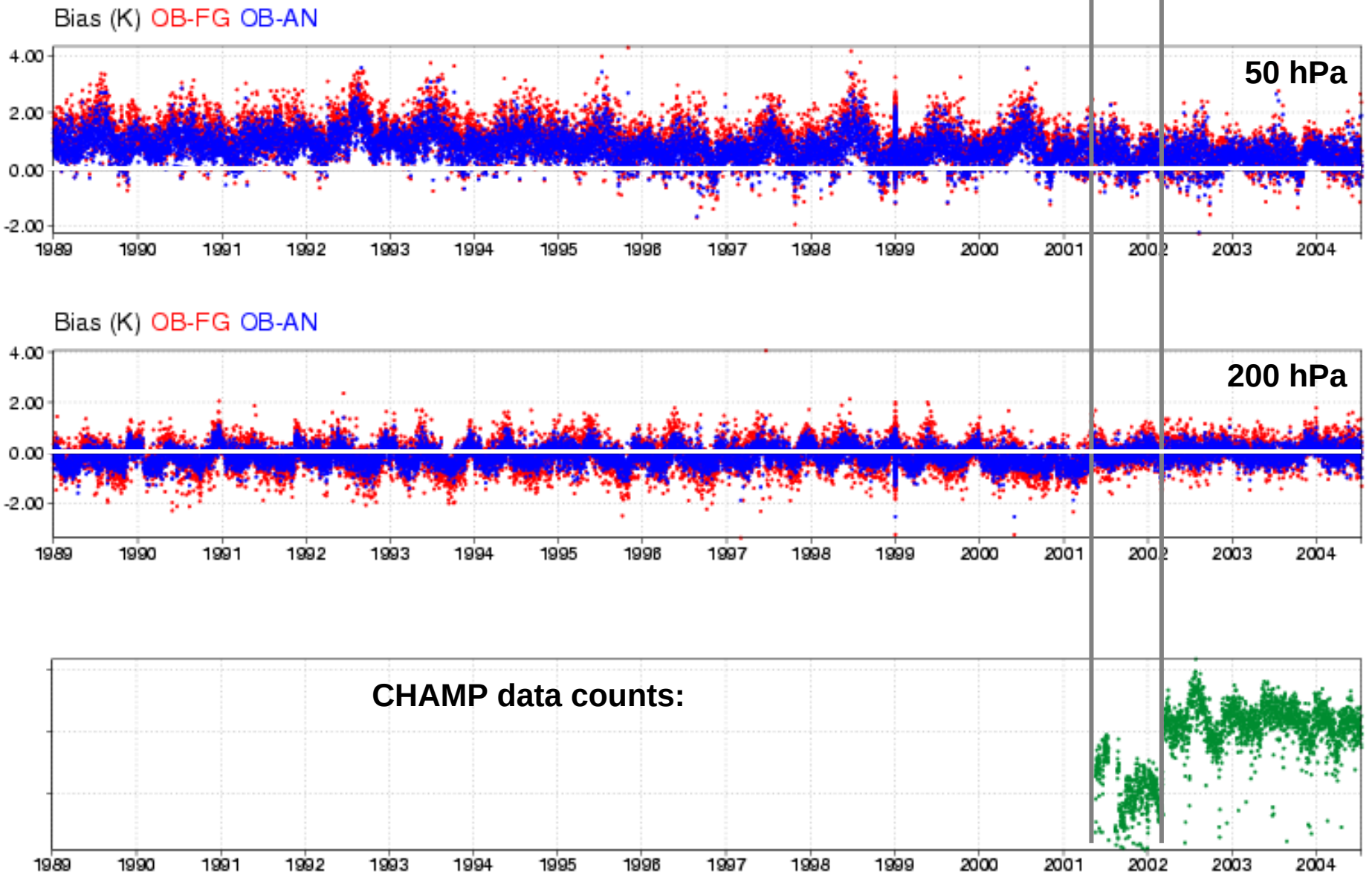
Impact of CHAMP: Constraining VarBC



Impact of CHAMP: Better fit to radiosonde data

~150 bending angle profiles/day

Radiosonde temperature mean departures (S Polar Cap)



Summary

Expectations from the reanalysis perspective:

GPS data should be especially valuable because they

- resolve scales that are not well observed by other instruments,
- provide global uniform sampling, and
- do not require bias correction

Can GPS data provide a baseline for bias corrections of other instruments ?

- Early experience with ERA-Interim seems to confirm these points.
- Potential of GPSRO for climate monitoring: *no inter-satellite biases?*
- Reprocessing activities are extremely valuable and should be encouraged