Adaptive bias correction of radiance data

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Outline

- Biases in radiance data
- The need for an adaptive system
- Variational bias correction
- Performance:
  - Adaptive bias corrections in ERA Interim
  - Introduction of variational bias corrections in ECMWF operations
  - Asymptotic stability of the adaptive system
- Conclusion

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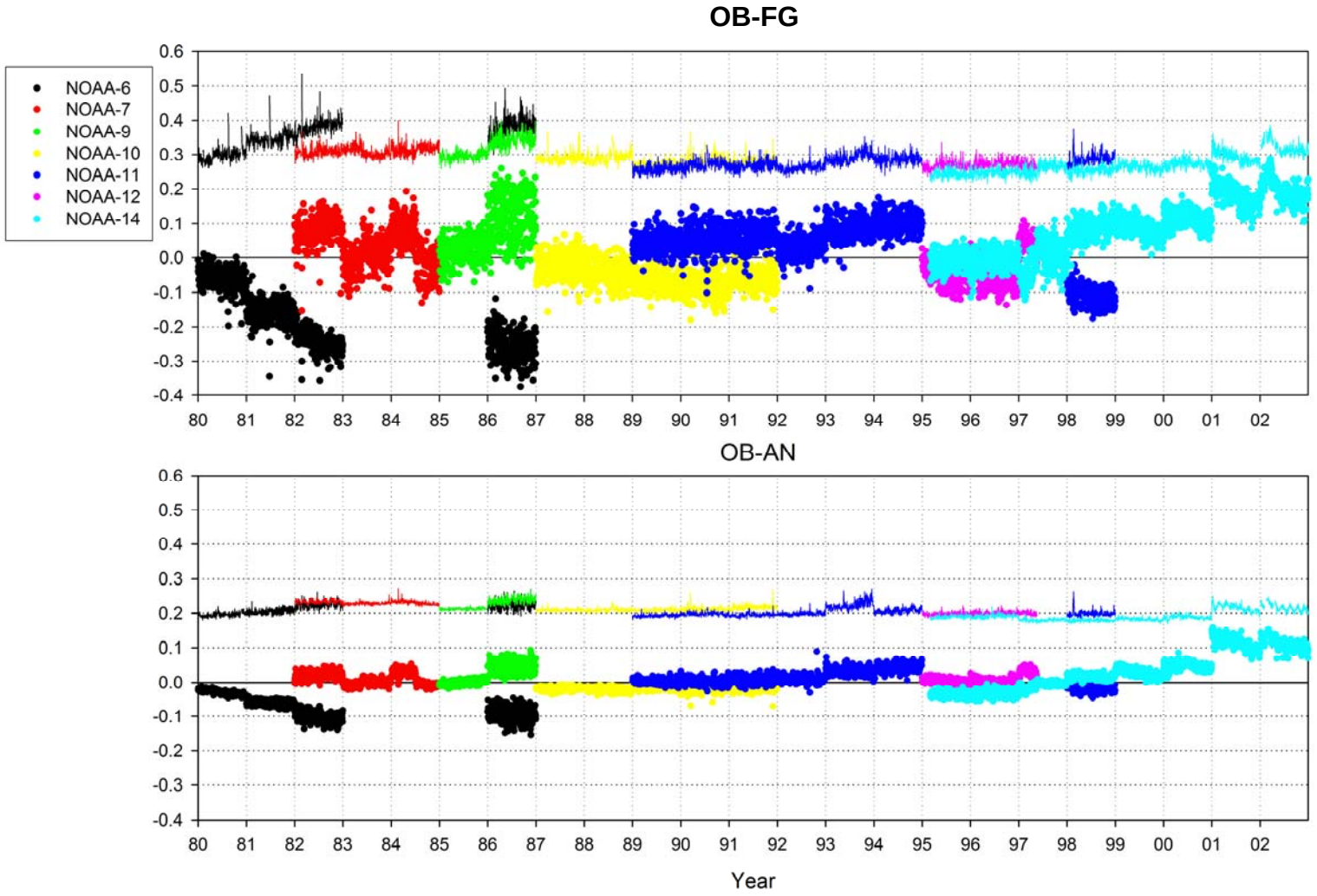
Global means and standard deviations of bias-corrected departures used in ERA-40

MSU Ch3

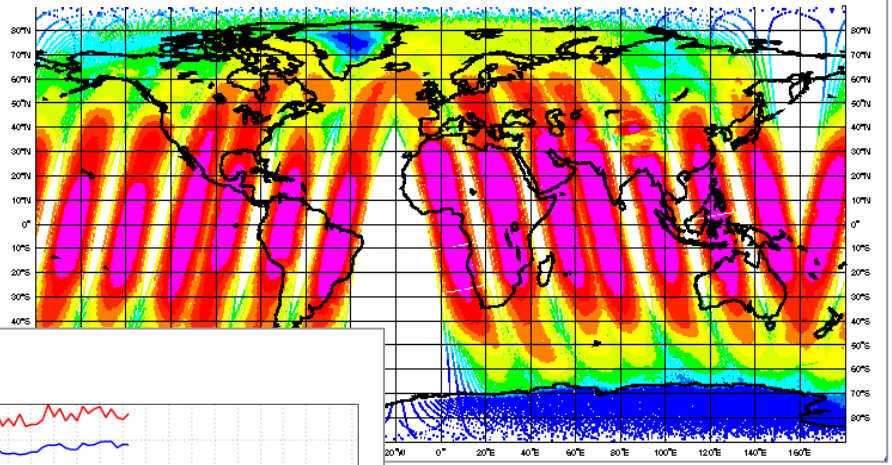


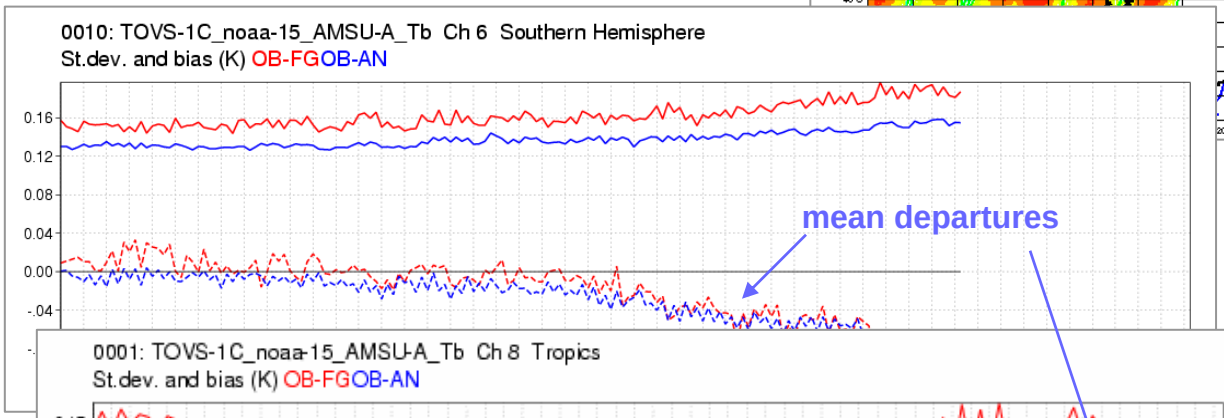
Biases in radiance data

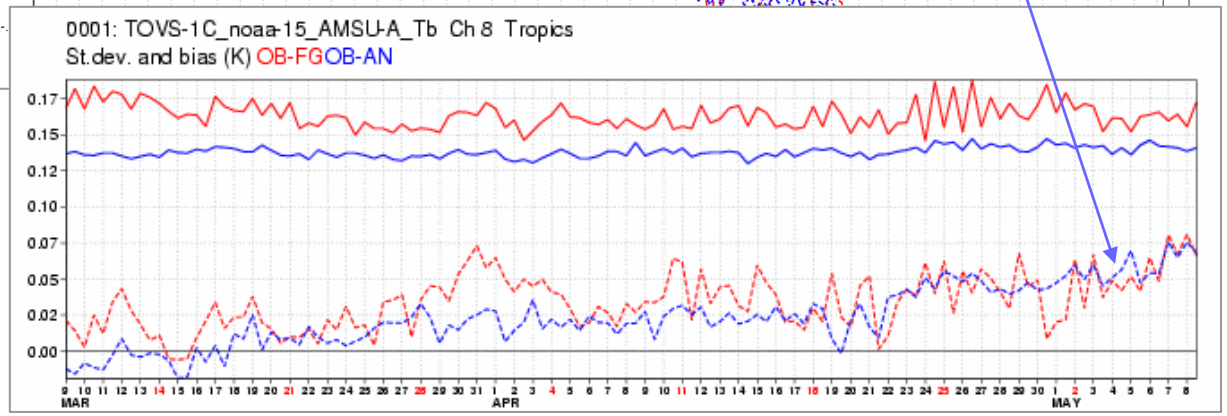
Non-physical scan-angle dependence of observed brightness temperatures

Shift in mean residuals between observed radiances and model-simulated radiances

AMSUA-channel 5 brightness temperatures







Instrument failure ?
Sensor calibration ?

Errors in radiative transfer model ?

Biases are complex, flow-dependent, and different for each satellite/sensor/channel

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The need for an adaptive system

- Manual tuning / retuning is tedious, subjective, and difficult to document
- Biases change, depending on the configuration of the observing system
- Need to retune often (change of instrument, radiative transfer model)
- Increasing number of sensors / channels is becoming unmanageable
- Special problems for reanalysis: Frequent restarts etc
- Need an objective basis for bias correction

Let the analysis procedure handle the bias corrections

- This would greatly simplify the bias correction of satellite data
- Estimate bias corrections in real time during the assimilation
- Adapt to slow changes in the bias, instrument drift, etc
- Cleanly handle abrupt changes (new sensors, sensor failure)
- Find the optimal bias corrections given all available information

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Variational bias correction

- Radiance bias expressed in terms of a small number of unknown parameters:
  - A constant offset
  - Predictors depending on instrument scan position (scan bias)
  - Predictors depending on model state x (air-mass dependent bias)

- Separately for each satellite/sensor/channel: $b(\beta, x) = \beta_0 + \sum_i \beta_i p_i$

- Add the bias parameters to the control vector in the variational analysis

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

- The analysis then estimates bias parameters jointly with model state variables (Derber and Wu 1998)

Advantages of variational bias correction

- Practical: Automates and simplifies bias adjustment procedures
- Theoretical: All available information is used to find the best bias corrections, consistent with analysis assumptions

Questions:

- Performance
- Robustness and stability
- Effect on climate signals

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Performance of the adaptive system

Technical aspects

- Simultaneously corrects all satellite radiance data (currently ~30 instruments, ~500 channels, ~3000 bias parameters)
- Automatically handles changes in the observing system (data gaps, appearance of new instruments)
- Flexible configuration of bias predictors for different instruments/channels
- Rapidly develops reasonable bias corrections for new sensors (1-7 days)

Scientific aspects

- Very effective in maintaining small mean radiance departures
- Enforces consistency among all data sources
- Improves the use of non-radiance data as well
- Damps artificial shocks due to changes in the observing system
- Ability to discriminate between observation bias and model bias depends on
  - nature of the bias model
  - observational coverage

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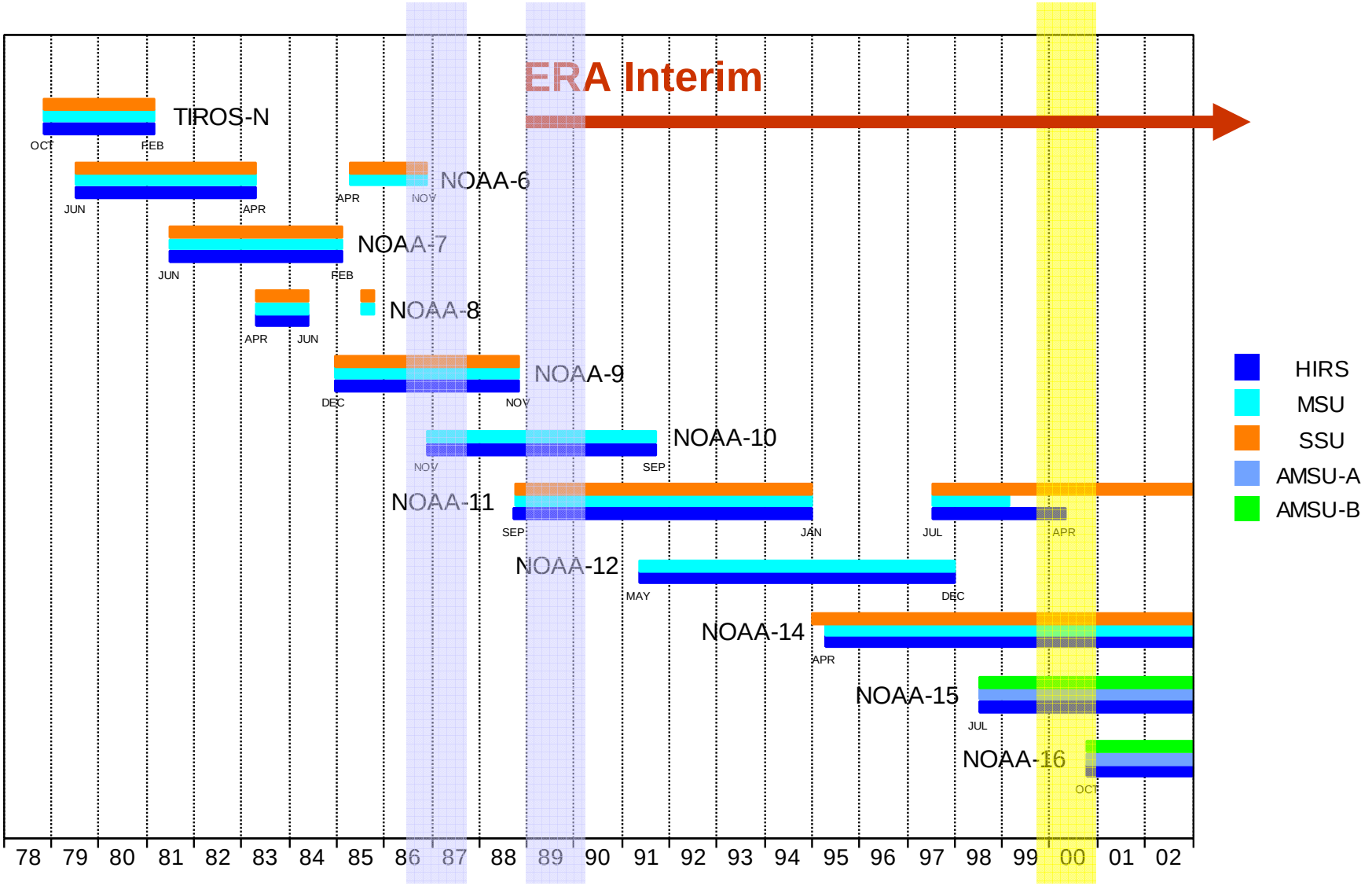
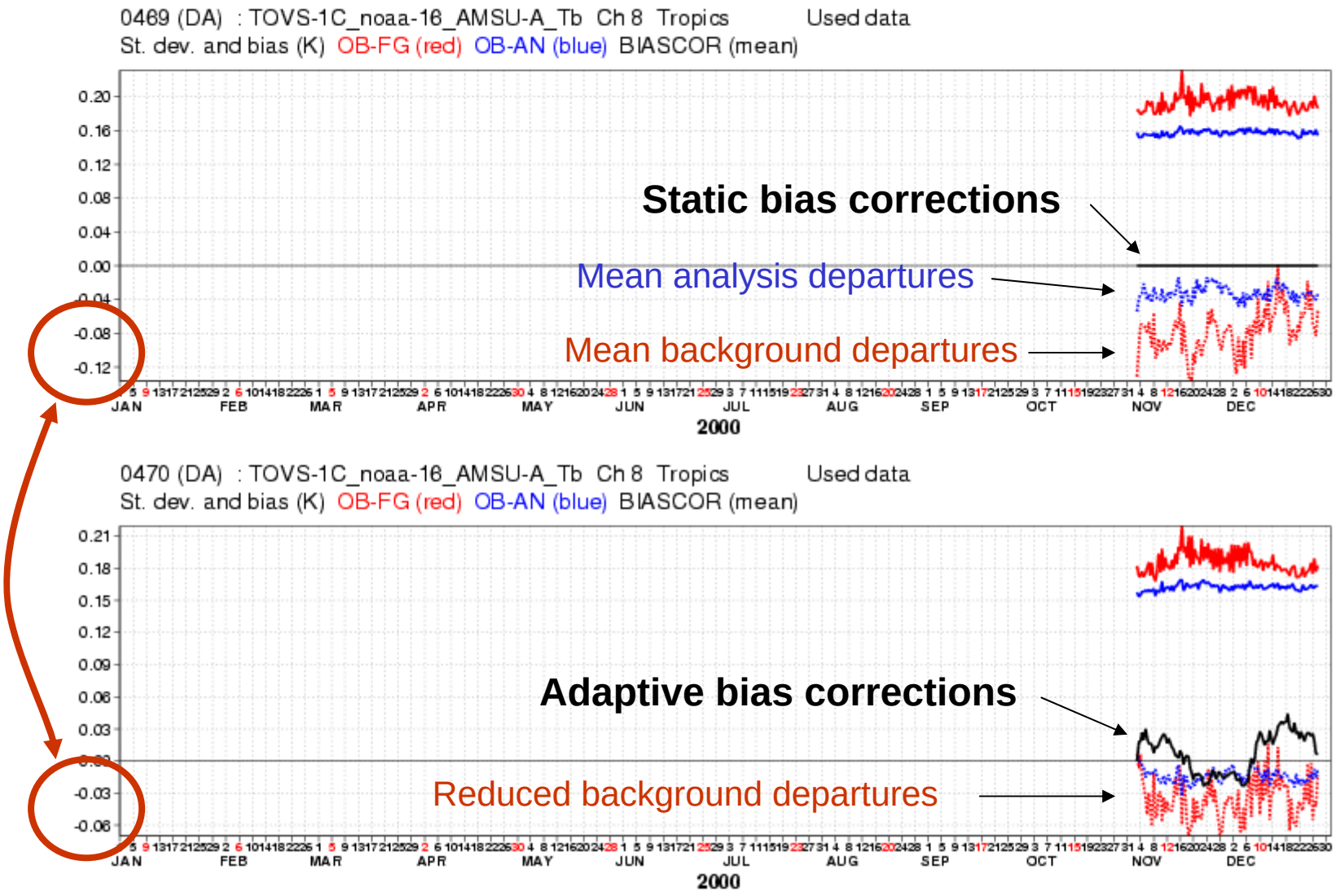
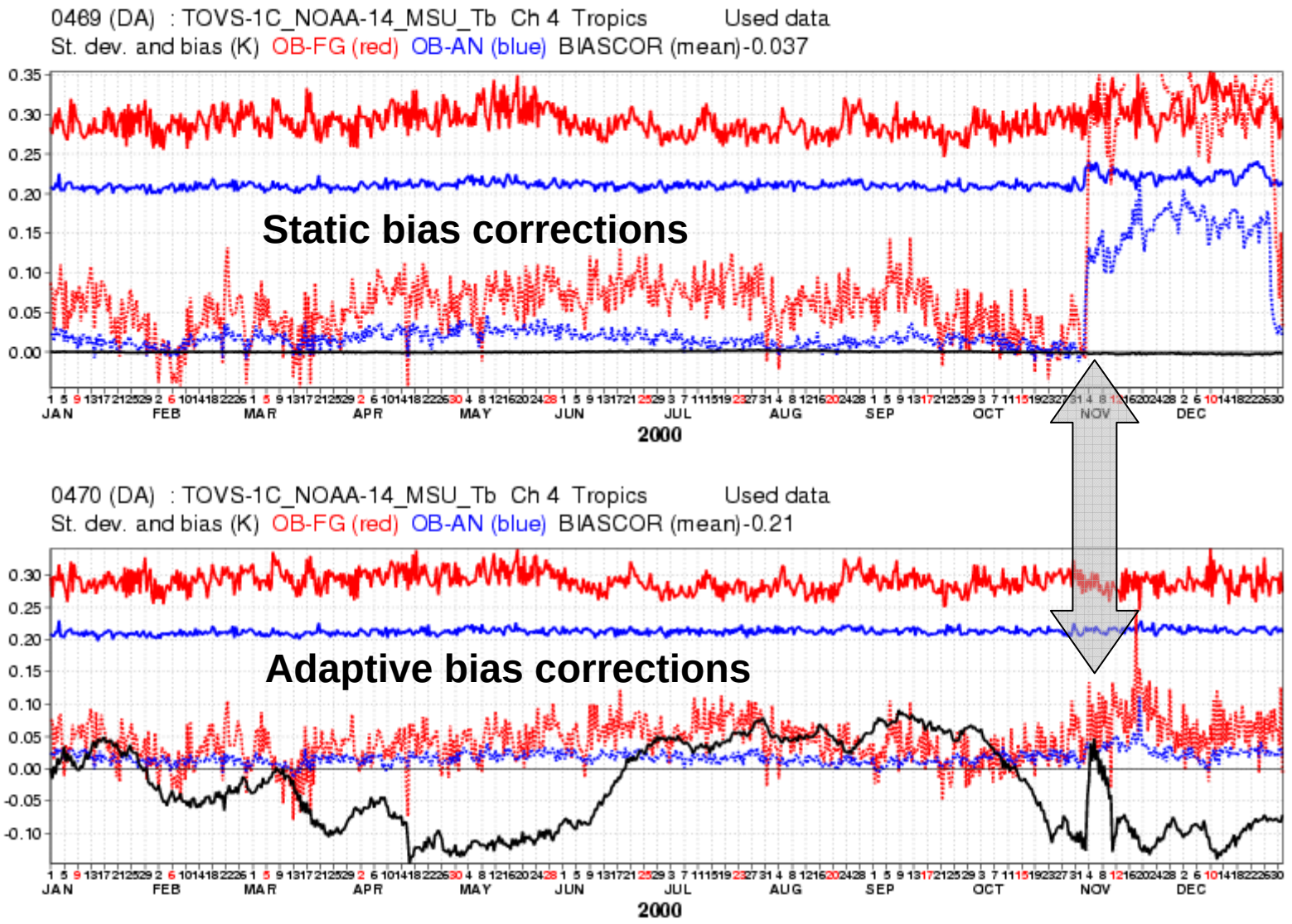
ERA Interim experimentation
Handling the introduction of NOAA-16



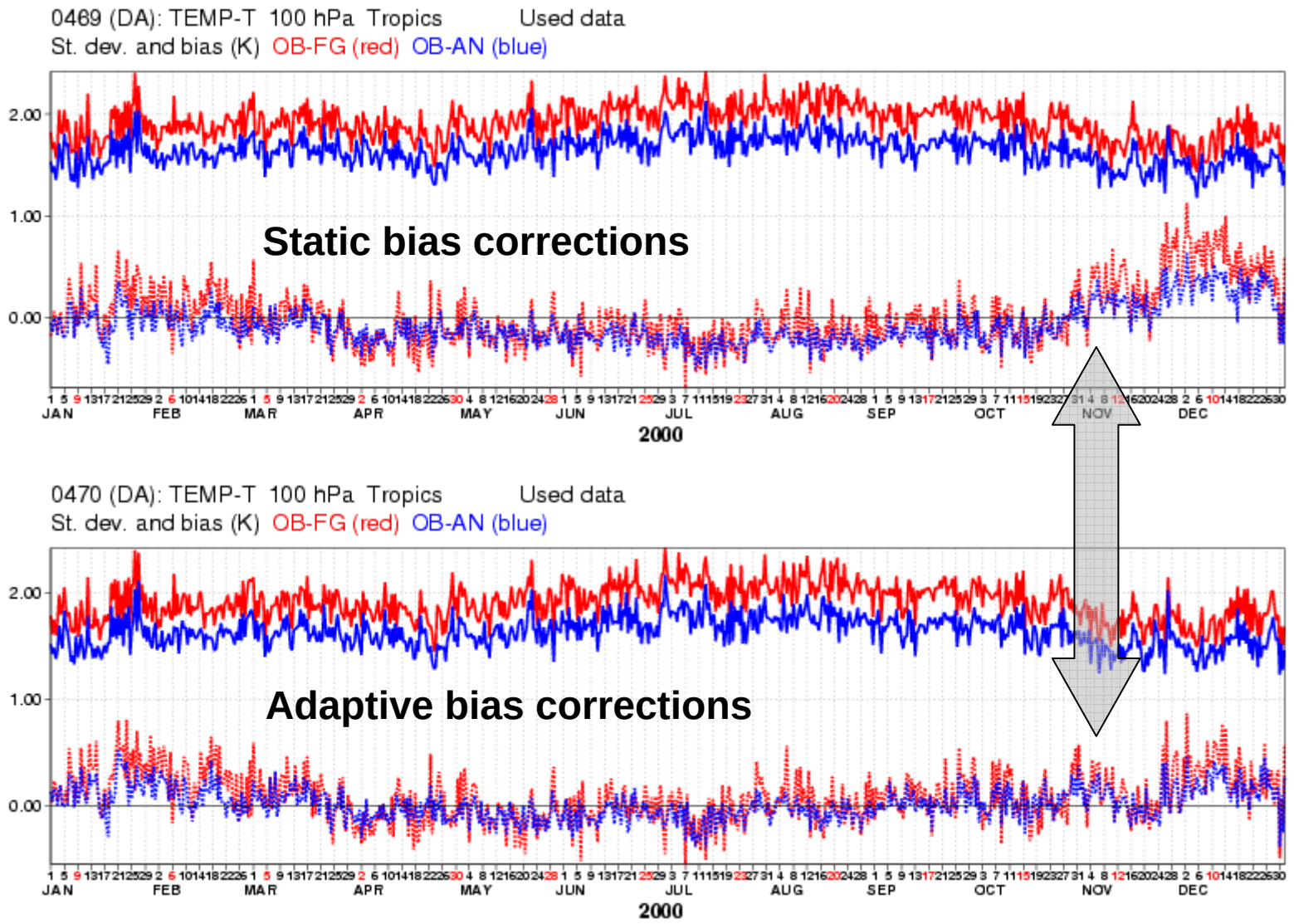
ERA Interim experimentation
Departures of NOAA-16 AMSU-A Ch 8



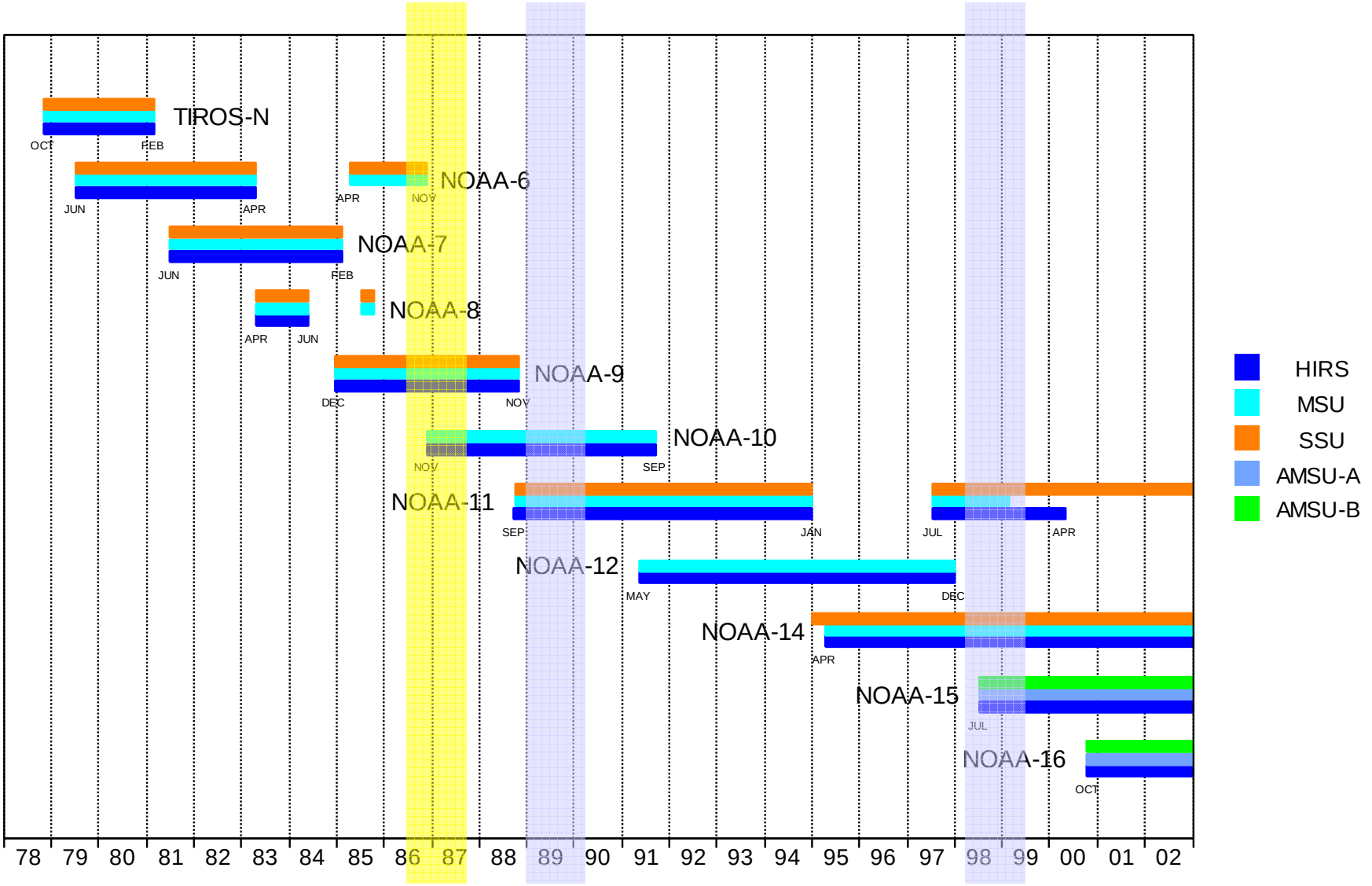
ERA Interim experimentation
Departures of NOAA-14 MSU Ch 4



ERA Interim experimentation
Departures of 100hPa radiosonde temperatures



ERA Interim experimentation
NOAA-9 MSU Ch3 disruption



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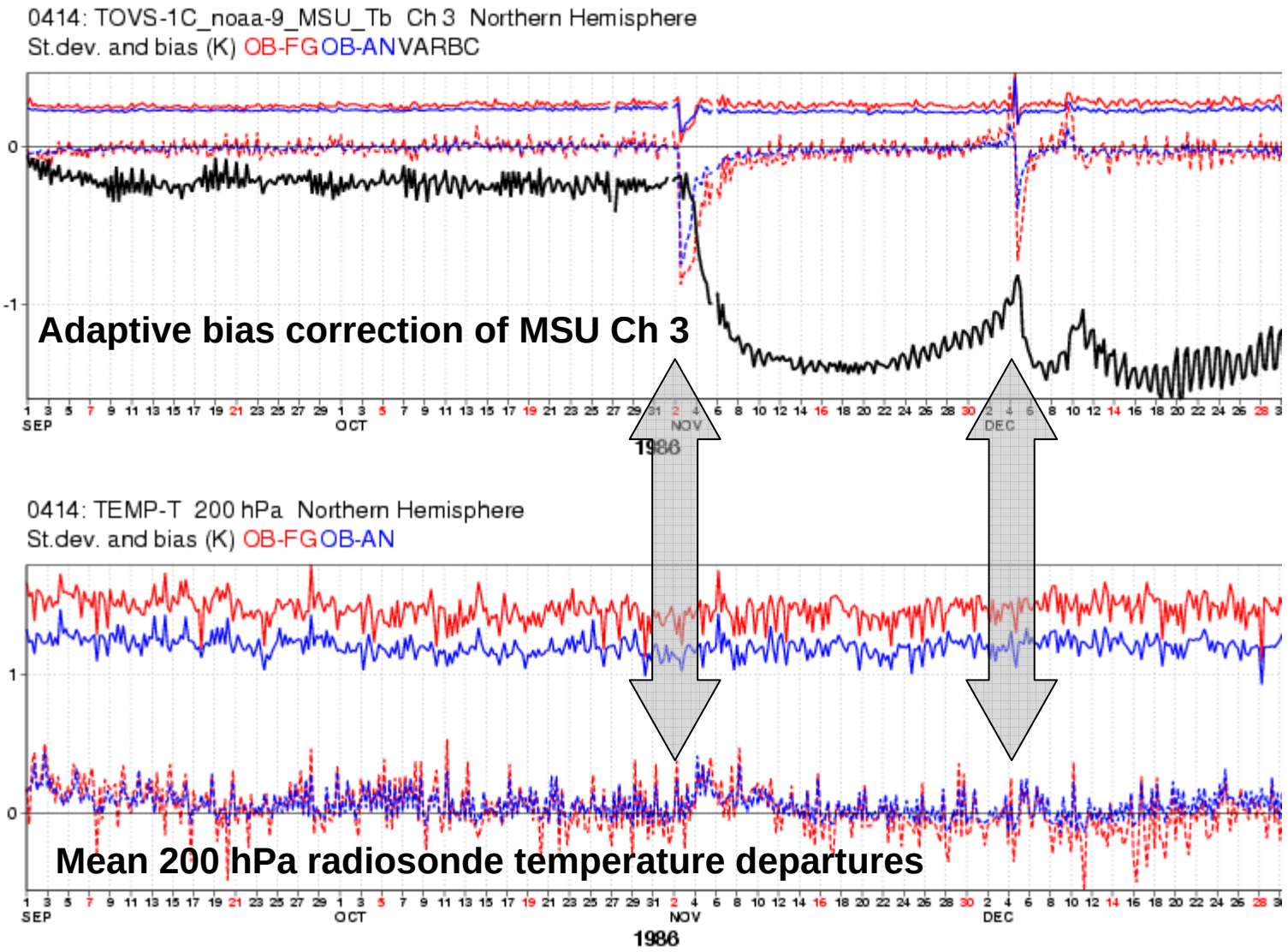
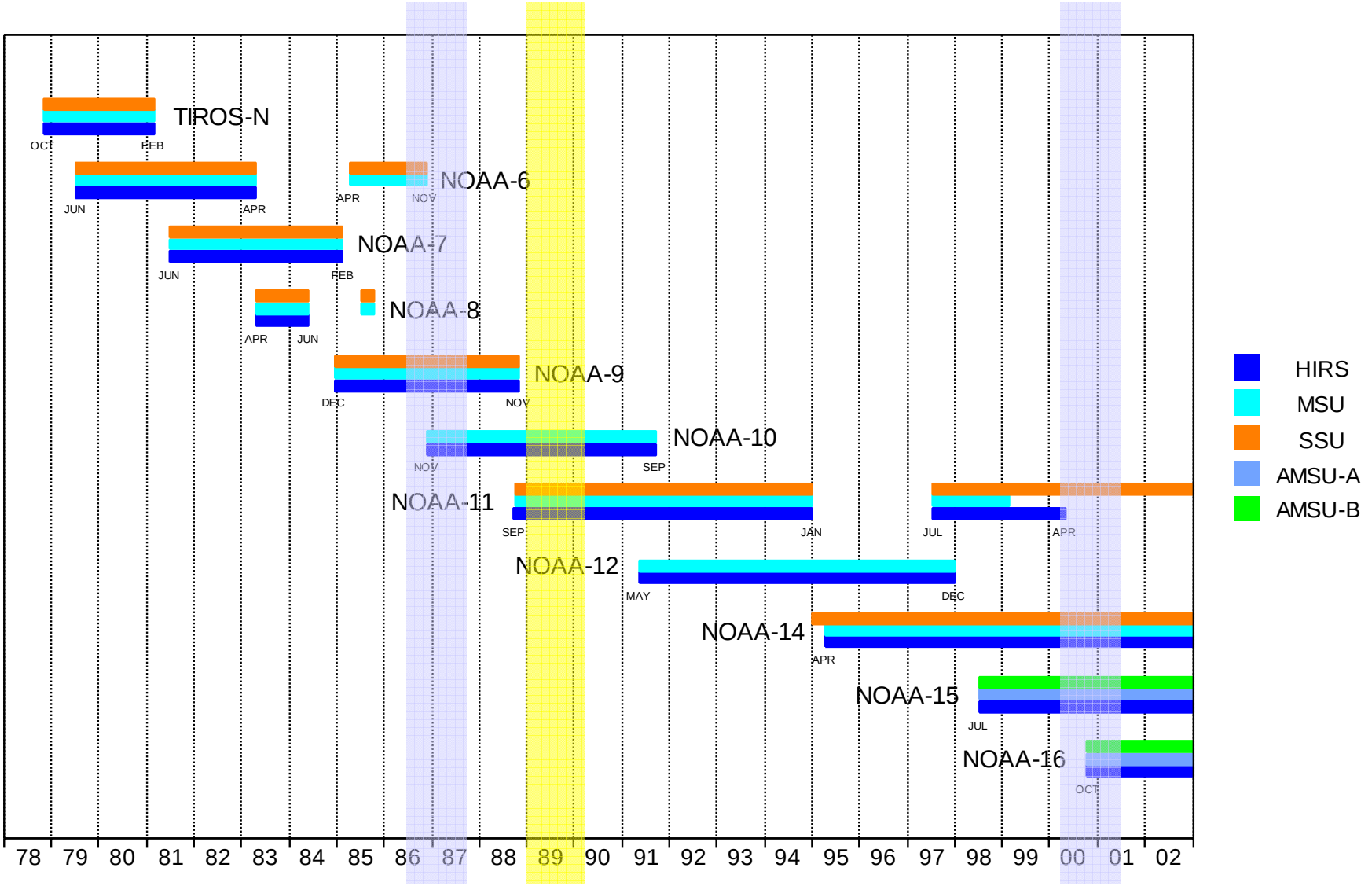


ERA Interim experimentation
NOAA-11 SSU – stratospheric model bias



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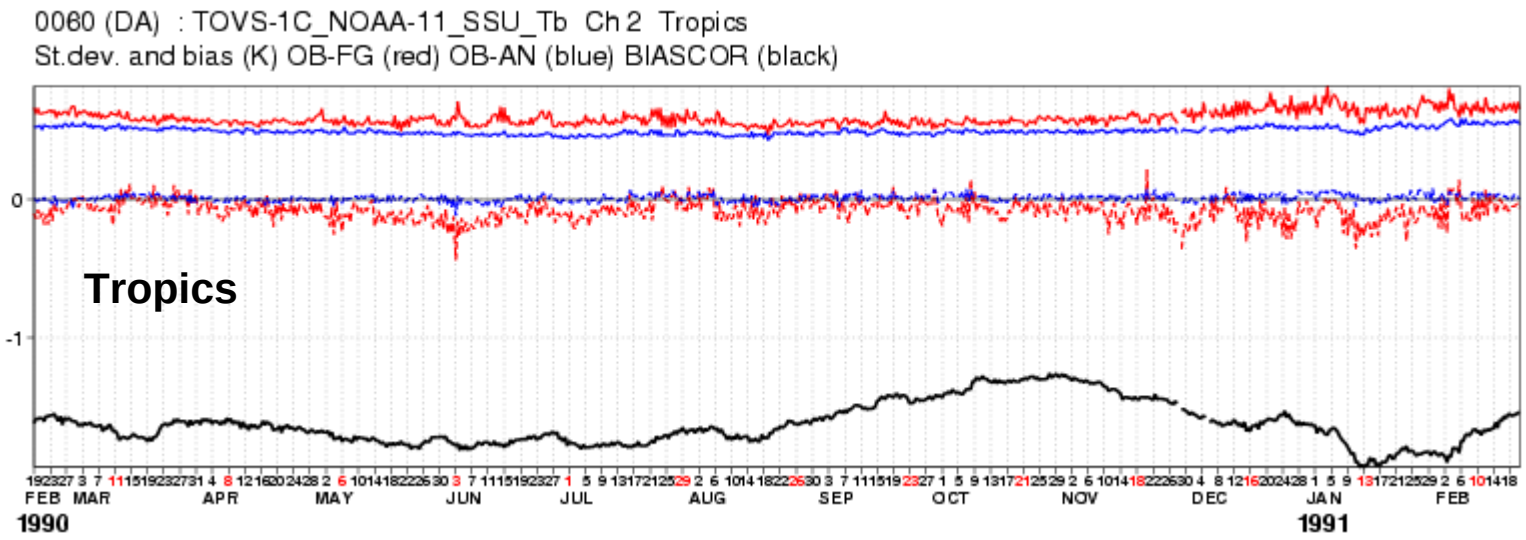

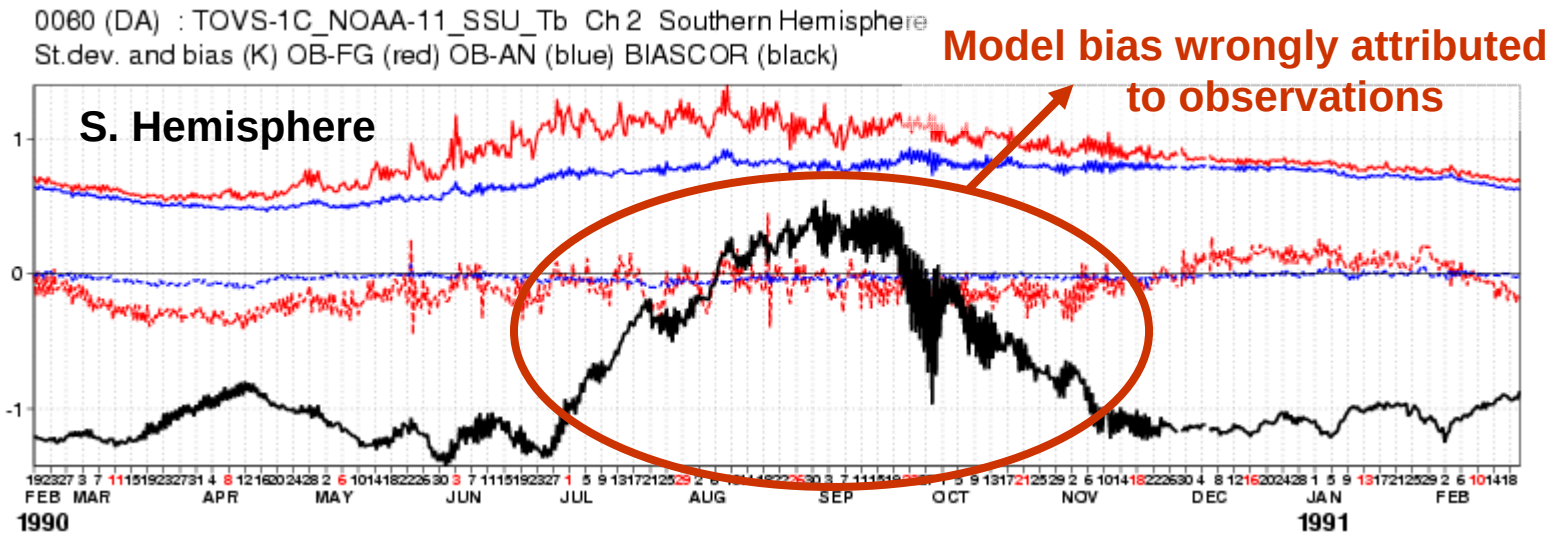

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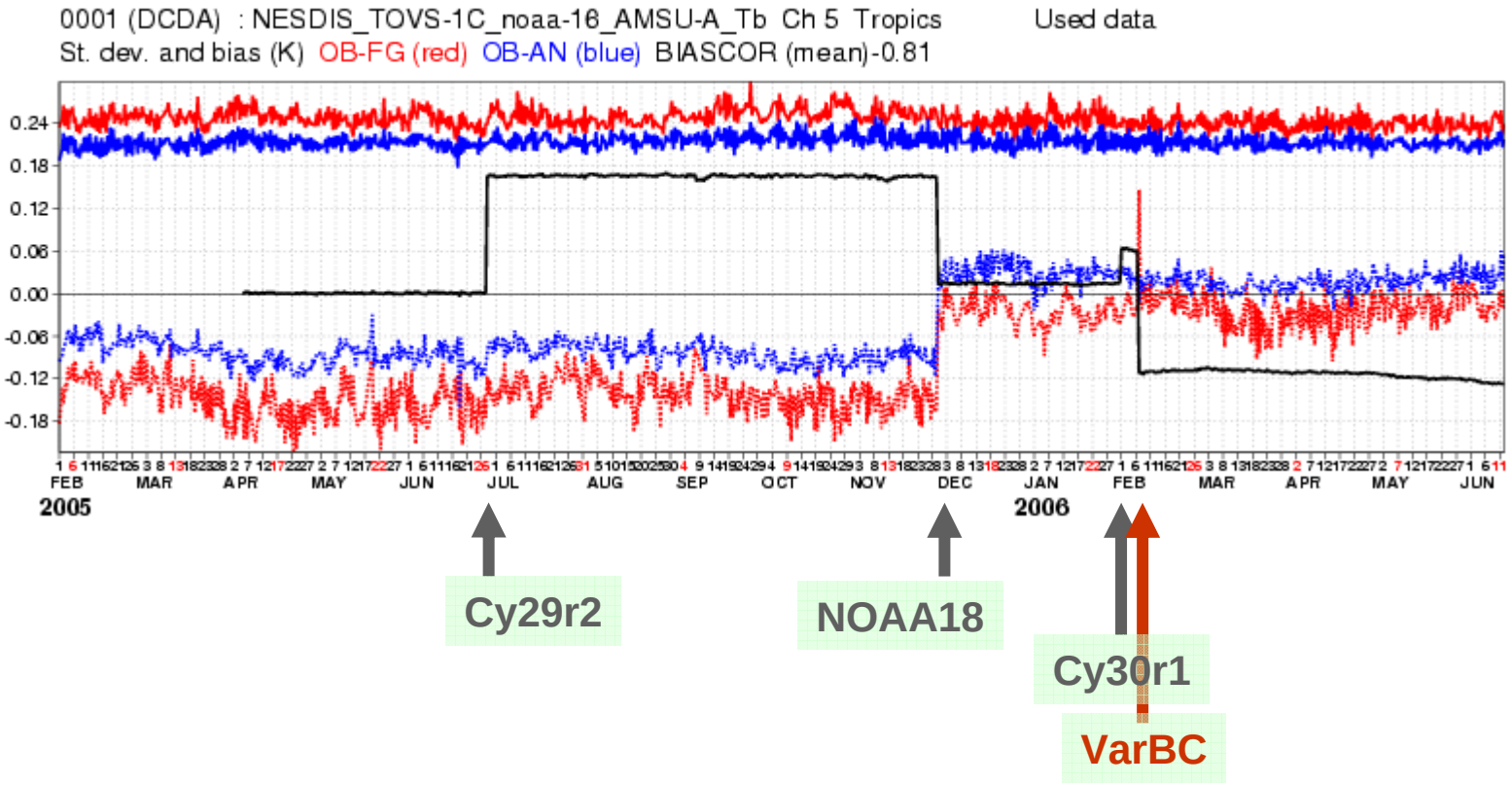
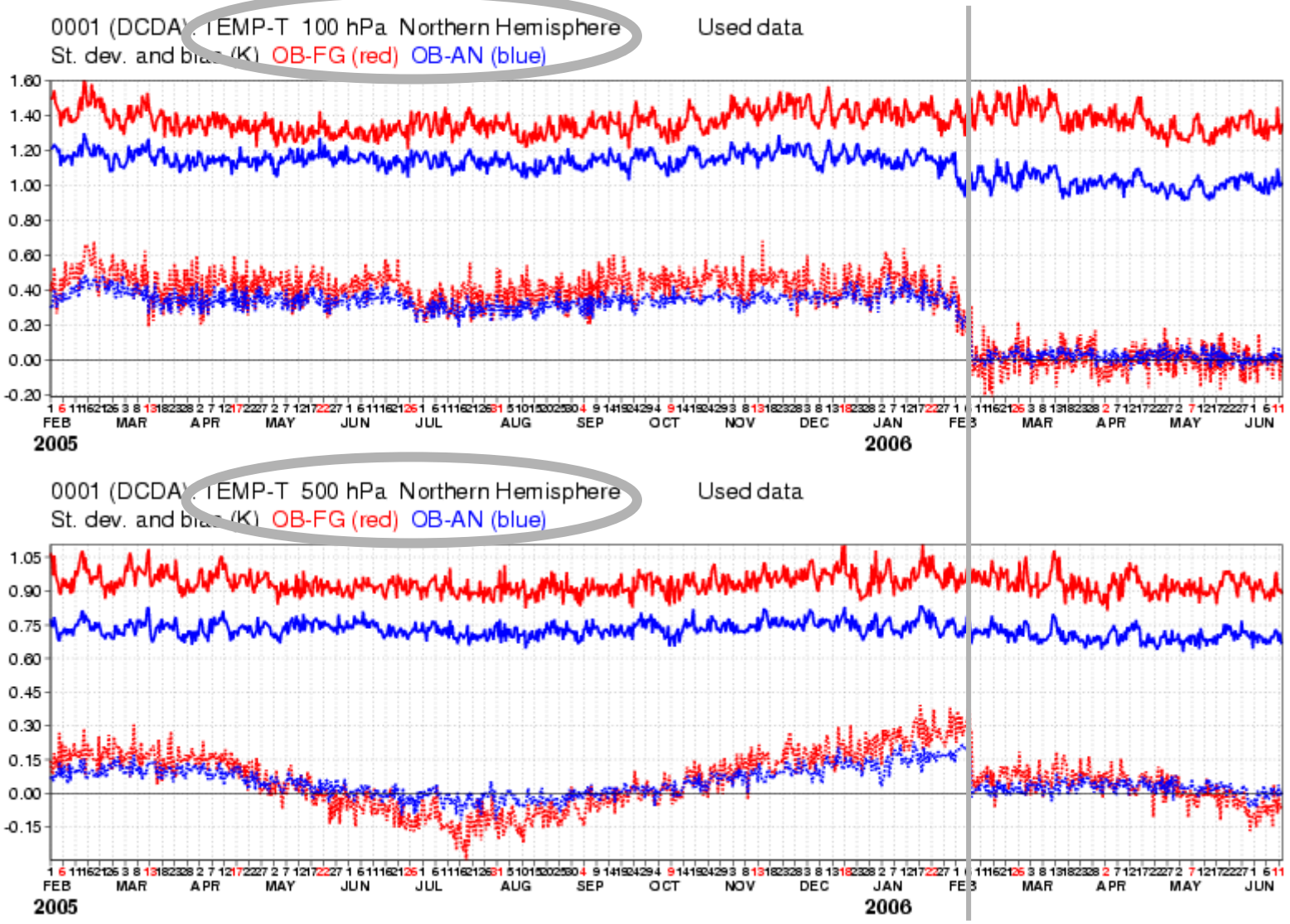
Introduction of variational bias corrections in operations

- Adaptive radiance bias correction will be implemented in the next release of the ECMWF operational forecast system
- Latest bias corrections in current operations derived from a VarBC experiment



Introduction of variational bias corrections in operations
Reduction of bias wrt radiosonde temperature data



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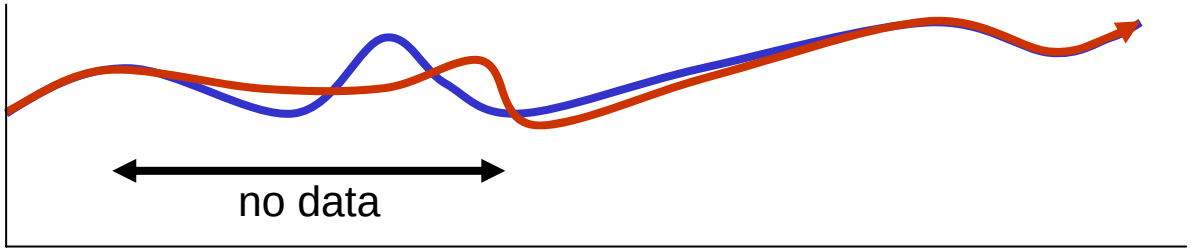
Asymptotic stability experiment

- In the adaptive system, the system state includes the bias parameters as well as the model state variables

- Does the adaptive system always converge to the same bias corrections, even when starting from very different states?

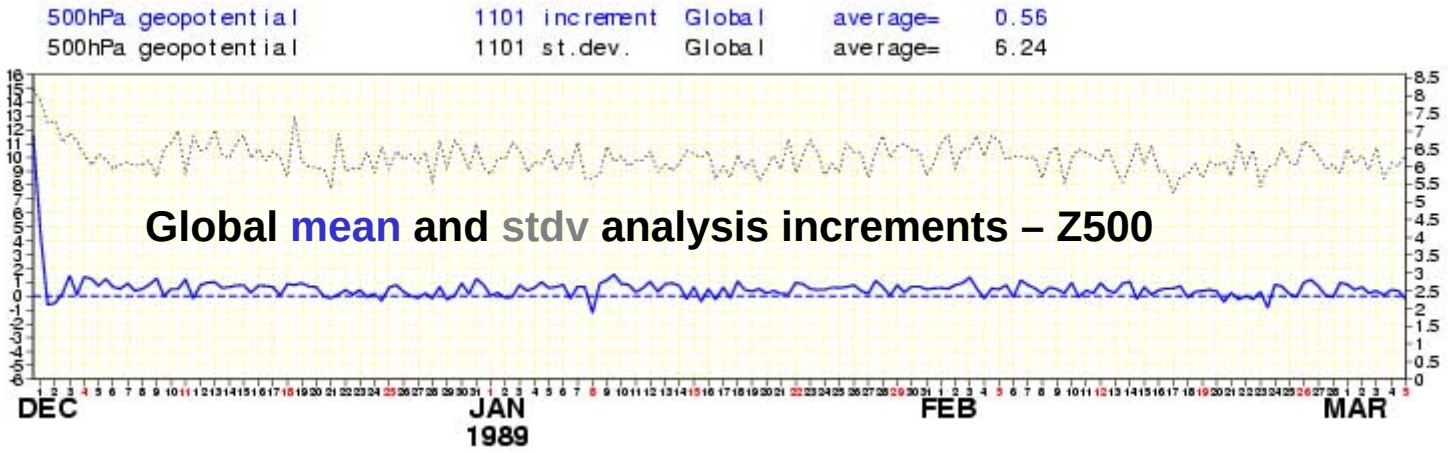
Experiment:

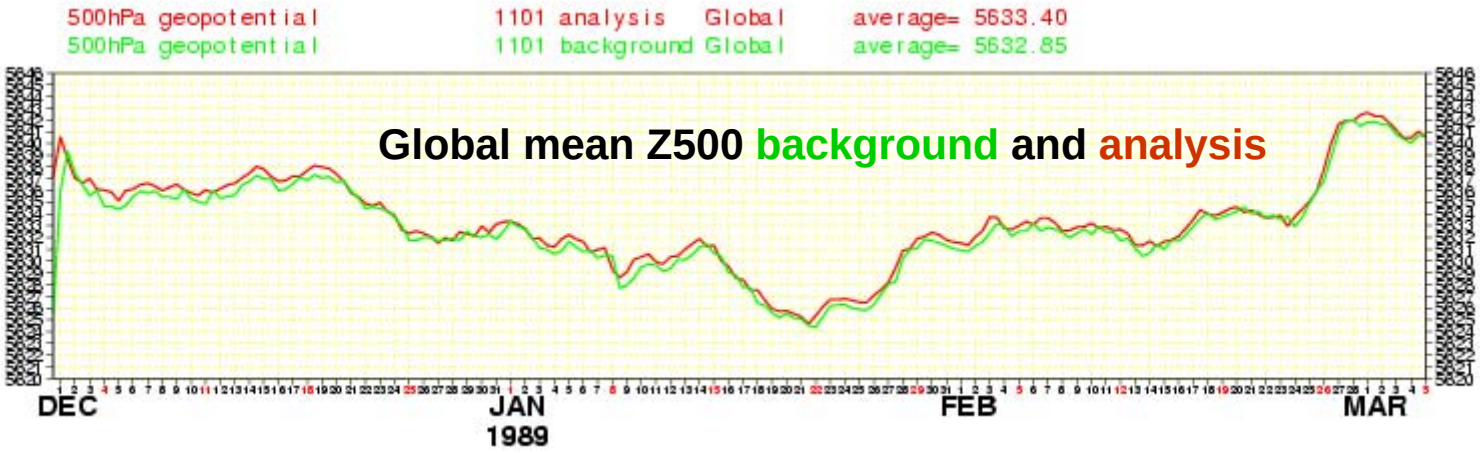
- Run a control assimilation with adaptive bias correction
- Repeat, but withhold all observations during a 2-week period
- See if the state variables and bias parameters re-converge



Asymptotic stability experiment

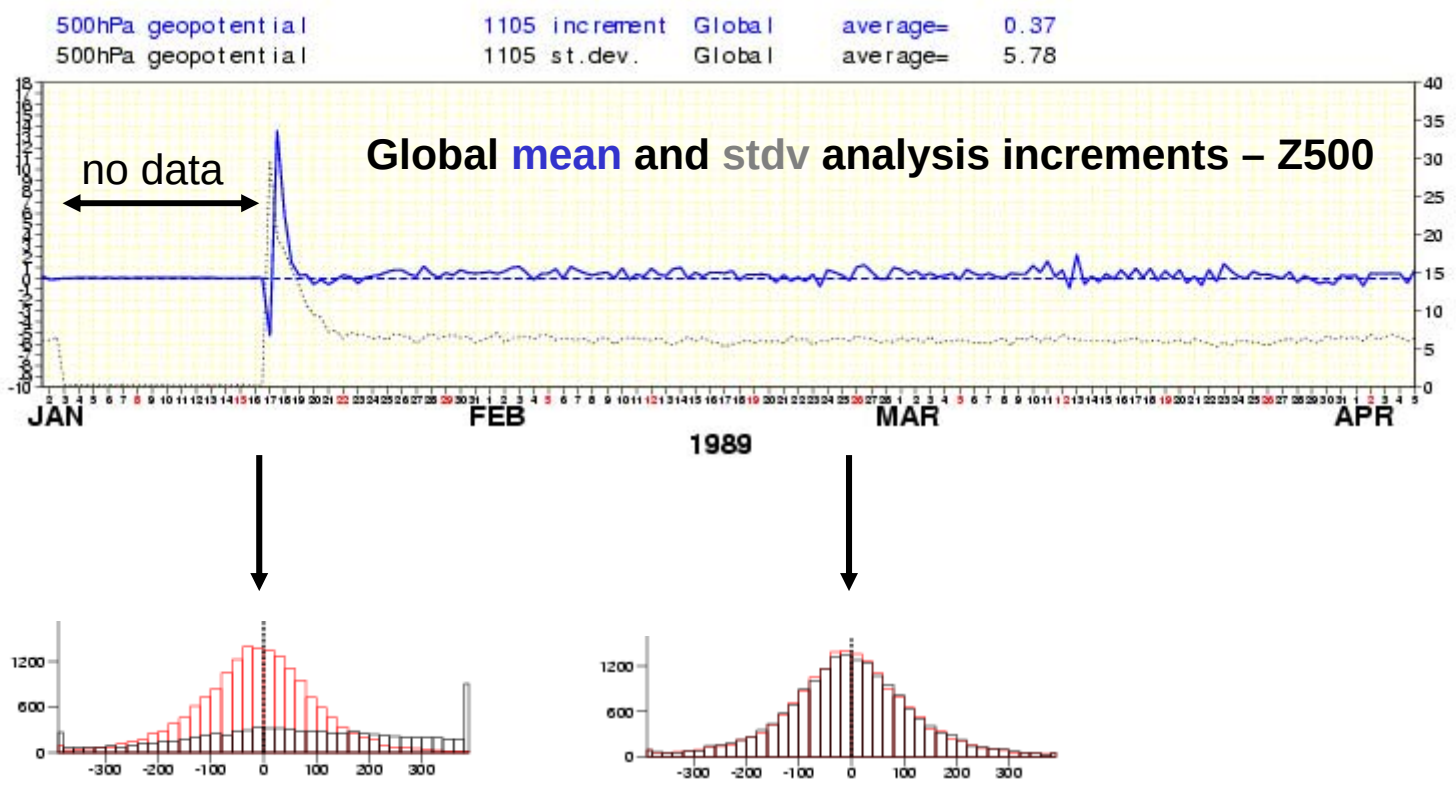
Control assimilation





Asymptotic stability experiment

Withhold all data during 2 weeks

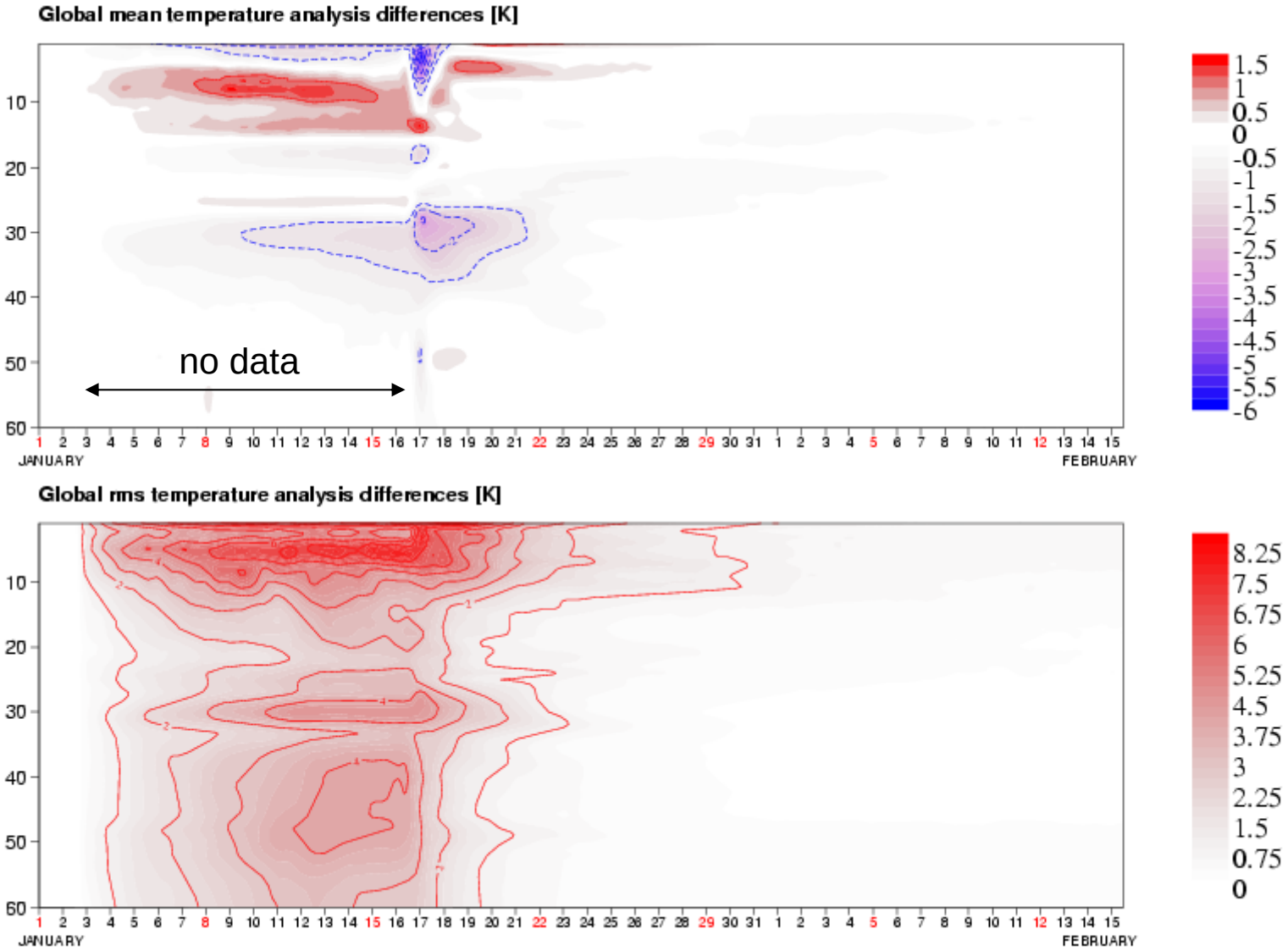


synop surface pressure departures

control (red) experiment (black)

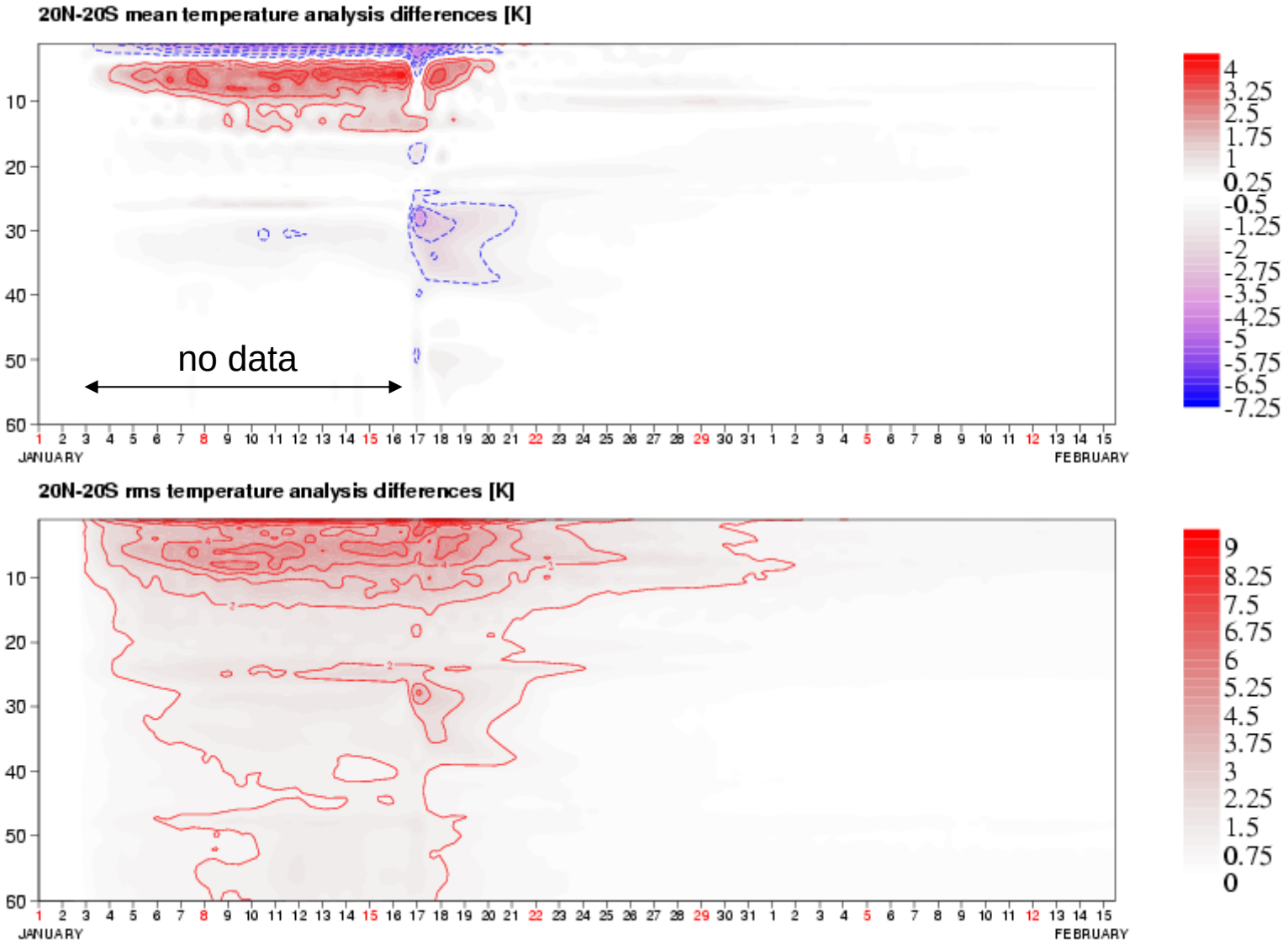
Asymptotic stability experiment

Convergence of the atmospheric state (global)



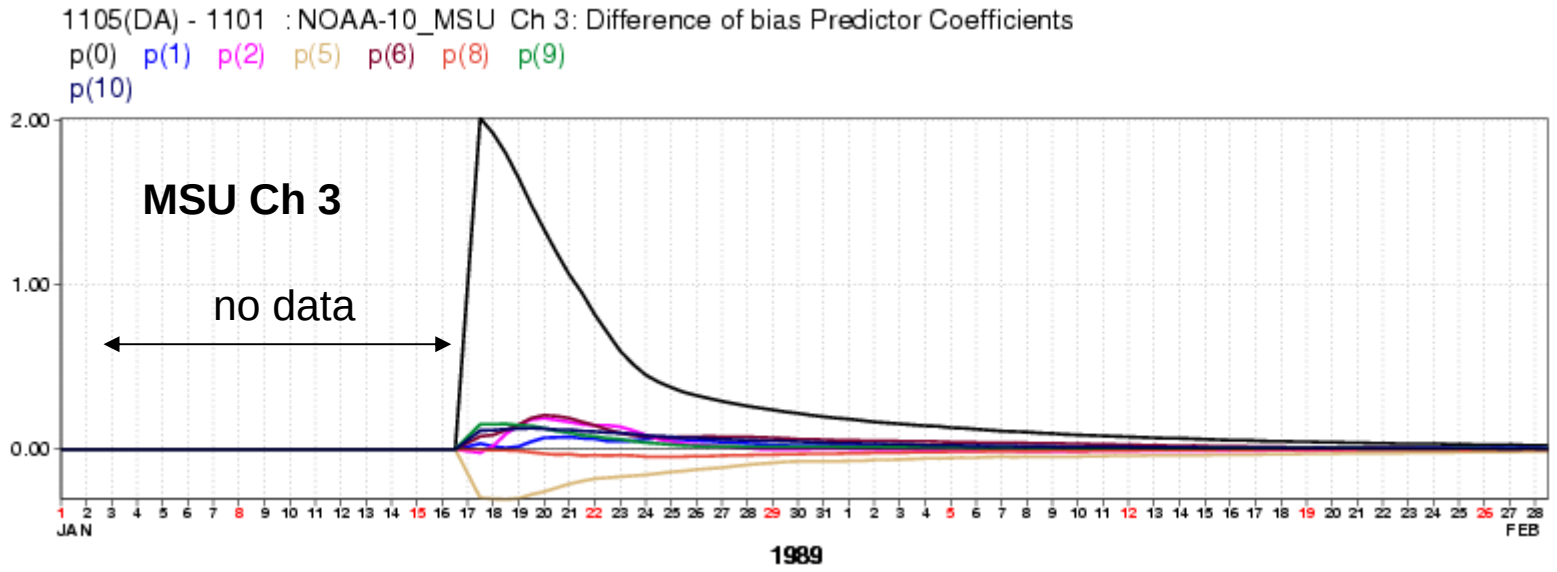
Asymptotic stability experiment

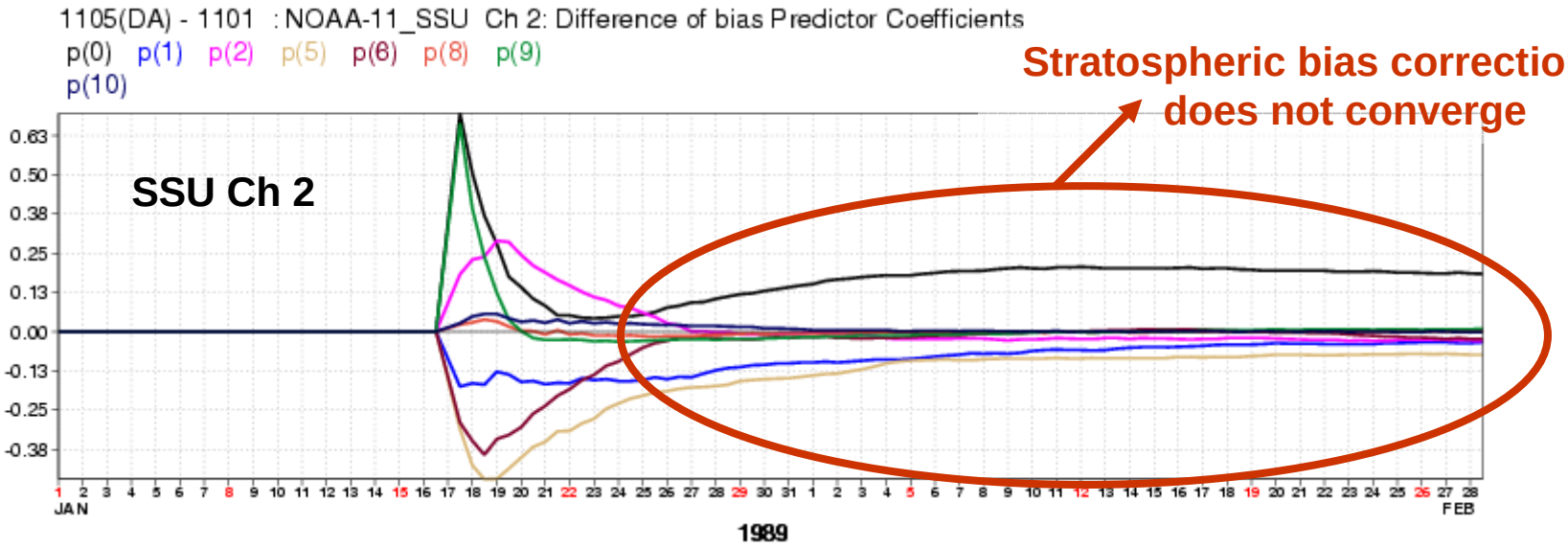
Convergence of the atmospheric state (tropics)



Asymptotic stability experiment

Convergence of the bias parameters





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- Automating the procedures for detection, estimation, and correction of biases in satellite radiances is a practical necessity, especially for reanalysis
- So far we have seen clear scientific advantages as well
- We wish to explore this approach for other data types (and the model)
- Bias-aware data assimilation will be **a major theme in the ERA Interim project**

- Variational bias correction is conceptually simple, and provides a solid scientific basis (maximum likelihood theory)
- But how will adaptive methods affect the representation of climate signals?
- **The key problem is to model the biases** such that they can be uniquely (and correctly) attributed to their source:

- Depending on the data coverage, variational bias correction may allow the system to drift to the model climate (e.g. SSU example)
- To solve this problem **we need to reduce the model bias**