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)

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

+6 000 000 data used daily
Variational bias correction

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)

\[ J_b: \text{background constraint for } x \quad J_o: \text{observation constraint} \]
\[ J(x) = (x_b - x)^T B_x^{-1} (x_b - x) + [y - h(x)]^T R^{-1} [y - h(x)] \]

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

\( J_\beta: \text{background constraint for } \beta \)

Find optimal bias correction given all available information

Predictors:
- constant offset
- scan
- air-mass
NOAA-9 MSU Ch3 disruption (cosmic storm)

A graph showing the standard deviation bias (K) for NOAA-9 MSU Ch 3 Tropics and 200 hPa RS temperature Tropics. The graphs display data from September to December 1986, with clear visual disruptions around November 4 and December 6, potentially indicating a cosmic storm.
Performance of the VarBC
reduction of bias wrt RS temperature data
ERA Interim experimentation
Stratospheric model bias

NOAA-10 HIRS-3
Observation

NOAA-10 MSU-4
Observation

NOAA-10 MSU-4
Departures &
Bias Correction

Model bias wrongly attributed to observations

S. Hemisphere

20 K

1 K
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
## Operational parametric form

- **γ** correction to the RT model: \( \gamma = \text{fractional error in layer absorption coefficient} \)
- Scan correction: 3\(^{rd}\) order polynomial of Scan Angle
- Air-mass regression
  
  Linear regression with a limited set of predictors \( P_i \), derived from the NWP model

<table>
<thead>
<tr>
<th>Instruments</th>
<th># of preds</th>
<th>Predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIRS, AMSU-A, AMSU-B, AIRS</td>
<td>4</td>
<td>1000-300, 200-50, 10-1, 50-5 hPa thicknesses</td>
</tr>
<tr>
<td>GEOS (GOES, Meteosat)</td>
<td>3</td>
<td>1000-300, 200-50 hPa, TCWV</td>
</tr>
<tr>
<td>SSMI</td>
<td>3</td>
<td>Tskin, TCWV, Surface Wind Speed</td>
</tr>
</tbody>
</table>
Estimation of the $\gamma$ coefficient in VarBC
Relevant bias predictors

Property 1 = help reduce the first-guess departures

ΔTb (K)

Latitude (or scan, …)

Uncorrected departures

Bias-corrected departures

STD
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

\[
J_b: \text{background constraint for } x \\
J_o: \text{bias-corrected observation constraint} \\
J_\beta: \text{background constraint for } \beta \\
\text{Weight decay regularization}
\]

\[
J(x,\beta) = (x_b - x)^T B_x^{-1} (x_b - x) + [y - b(x,\beta) - h(x)]^T R^{-1} [y - b(x,\beta) - h(x)] \\
+ (\beta_b - \beta)^T B_{\beta}^{-1} (\beta_b - \beta) + \beta^T (\nu J) \beta
\]
Relevant bias predictors

Property 1 = help reduce the first-guess departures

*Diagnostic 1 = absolute value of (normalized) parameters*
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)
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*
• LW Temperature  
• SW Temperature  
• Water Vapour

Abs($\gamma$-1) in %  
$\Delta\gamma$ VarBC/Offline in %
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

STD background departures
STD analysis departures
Mean background departures
Mean analysis departures
Static bias corrections (offset = 0.99)

NOAA-18 AMSU-A Ch5 Tropics

Coefficients from VarBC
Introduction of the VarBC in operations: first step

100 hPa RS temperature Tropics

500 hPa RS temperature Tropics
AIRS operational bias predictors

Diagnostic 1
Abs(Param)

Diagnostic 2
VarBC/Offline disagreement

1000-300 hPa
200-50 hPa
10-1 hPa
50-5 hPa

- LW Temperature
- SW Temperature
- Water Vapour
Weight decay regularization

AIRS

Bias correction variance

Variance explained

AIRS: fraction of variance explained by the bias correction with the weight decay constraint

- \( n_0 = 0 \)
- \( n_1 = 1 \) → Reduction of 19.3\% for bias parameters
- \( n_5 = 10 \) → Reduction of 53.1\% for bias parameters