Radiance bias correction in the ALADIN-CZ:
comparison of different VarBC configurations

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Motivation

- random, zero-mean, Gaussian errors of observations $\mathbf{y}$ and the model background $\mathbf{x_b}$ (3D-VAR assumptions),
- *bias detection:* based on a sample of observation increments $\boldsymbol{\delta y} = \mathbf{y} - h(\mathbf{x})$,
- *bias prediction/correction:* Variational Bias Correction (VarBC) scheme based on a multiple linear regression and implemented into the 3D-VAR scheme:

$$f(\mathbf{x}, \boldsymbol{\beta}) = \sum_{k=0}^{N_p-1} \beta_k p_k(\mathbf{x}).$$

The bias coefficients $\boldsymbol{\beta}$ are:

- adopted from a global NWP model (VarBC-global):
  - the same set of predictors p_k ($\checkmark$),
  - differences between observation biases in regional and global models are not large ($\dagger$),
- estimated/cycled in regional models (VarBC-LAM):
  - data sample issues.

VarBC-LAM: data sample issues

The accuracy of β strongly depends on a miscellaneous data sample obtained under different:

- meteorological conditions (the spatially/serially correlated data sample in LAMs),
- satellite scan-positions (the non-uniform data sample in LAMs).

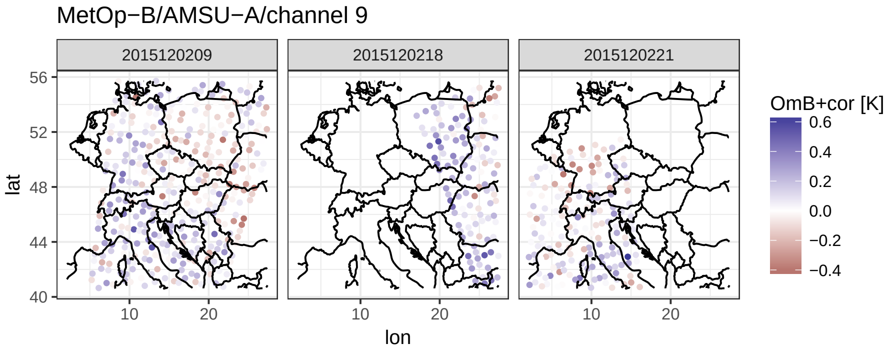

Figure : The non-uniform polar-satellite data sample in the ALADIN-CZ assimilation cycle.

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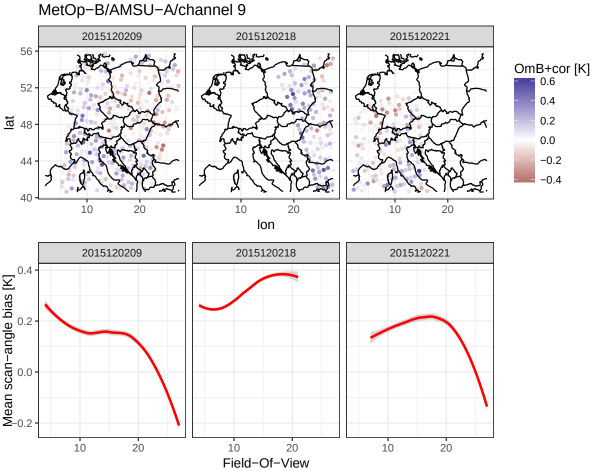

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The VarBC introduction

β are estimated within the 3D-VAR data assimilation scheme:

$$\begin{aligned} J(\mathbf{x},\boldsymbol{\beta}) = & (\mathbf{x}-\mathbf{x_b})^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x_b}) \\ & +(\mathbf{y}-h(\mathbf{x},\boldsymbol{\beta}))^T\mathbf{R}^{-1}(\mathbf{y}-h(\mathbf{x},\boldsymbol{\beta})), \\ & +(\boldsymbol{\beta}-\boldsymbol{\beta_b})^T\mathbf{B}_{\boldsymbol{\beta}}{}^{-1}(\boldsymbol{\beta}-\boldsymbol{\beta_b}) \end{aligned}$$

Assuming m-observations, p-predictors, $\boldsymbol{x}=\boldsymbol{x_b}$, $\mathbf{B}_{\boldsymbol{\beta}} = diag(\sigma_{\beta_1},\ldots,\sigma_{\beta_p})$ and $\sigma^2_{\boldsymbol{\beta}} = \frac{\sigma_o^2}{N_{bg}}$, optimal $\boldsymbol{\beta}$ are estimated by minimizing:

$$\min_{\boldsymbol{\beta}} J(\boldsymbol{\beta}) = \min_{\boldsymbol{\beta}} \left(\frac{1}{2\sigma_o^2}\sum_{i=1}^{m}[\delta y - f(\boldsymbol{\beta})]^2 + \frac{N_{bg}}{2\sigma_o^2}\sum_{j=0}^{p}(\beta_j-\beta_j^b)^2 \right) \tag{1}$$

Regularization term (J_β) penalizes large changes of $\boldsymbol{\beta}$ from $\boldsymbol{\beta_b}$. Regularization parameter (N_{bg}) determines the VarBC adaptivity.

The VarBC demonstration: toy model

Let's assume $\boldsymbol{\beta}$ ($p = 3$) associated with scan-angle predictors (θ, θ^2, θ^3):

$$f(\boldsymbol{\beta}) = \beta_0 + \beta_1\theta + \beta_2\theta^2 + \beta_3\theta^3.$$

Minimizing the cost function in (1):

N_{bg}	β	$J(\beta)$
0	$(0.0, 0.0, 0.0, 1.0) \rightarrow \boldsymbol{\beta}_b$	0.3

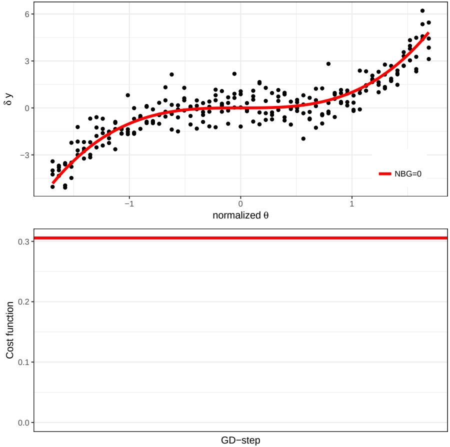

Figure : Illustration of the VarBC application for the scan-angle bias correction using β_b (red) and β with regularization terms $N_{bg} = 0$ (blue) and $N_{bg} = m$ (green). The toy model is based on GD-method: $m = 244$, $p = 4$, $iter = 50$, $\alpha = 0.1$

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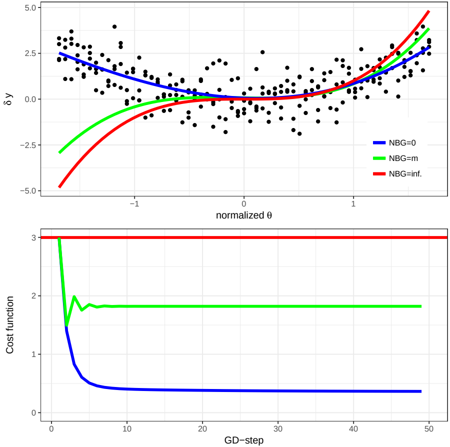
N_{bg}	β	$J(\beta)$
-	$(0.0, 0.0, 0.0, 1.0) \leftarrow \boldsymbol{\beta}_b$	3.0
0	$(0.1, -0.2, 1.0, 0.1)$	0.3
m	$(0.1, -0.1, 0.2, 0.8)$	1.9

N_{bg} determines an adaptivity of $\boldsymbol{\beta}$:

- $N_{bg} \gg m$ (less adaptive)
- $N_{bg} \ll m$ (more adaptive)
- $N_{bg} = m$ (a half weight of β_b)



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VarBC-LAM adaptivity approaches

Exp	**Parameter N_{bg}**	**Reference**
NBG5000	5000	AROME-MF
NBG2000	2000	HIRLAM (Lindskog et al. (2012))
CAM	$max(m_{avg}, N_{min})\left(2^{\frac{1}{n_h}} - 1\right)^{-1}$	Met-Office (Cameron and Bell (2016))
NEW	$max(m_{avg}, N_{min})2n\left[W\left(\frac{4n^2\sigma_o^2}{var(b_o)}\right)\right]^{-1}$	ALADIN-CZ (Benacek and Mate (2018))

m_{avg}	...	expected #observations at analysis time
n_h	...	#analysis steps to reduce half-bias
n	...	#analysis steps to reduce bias
$var(b_o)$	...	time-variance of the mean observation bias (model error constraint)
σ_o	...	observation error (instrument error constraint)

VarBC-LAM adaptivity approaches: comparison

Regularization term for MHS/channel-5 on MetOp-B in ALADIN-CZ ($m_{avg} = 250$).

Exp	N_{bg}	β	$n[days]$
NBG5000	$20m_{avg}$	$\boldsymbol{\beta}$	-
NBG2000	$8m_{avg}$	$\boldsymbol{\beta}$	-
CAM	$7m_{avg}$	$\boldsymbol{\beta}$	10 ($2n_h$)
NEW	$3m_{avg}$	β_0	10
NEW	$21m_{avg}$	$\beta_{1,\dots,p}$	30

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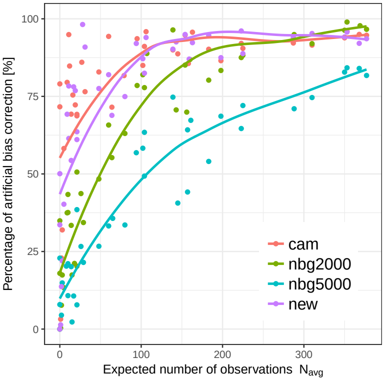

Figure : Artificial bias correction (constant bias-offset of σ_o) after 15-day spin-up period with regards to m_{avg}. Performance of different VarBC approaches is represented by a moving average line.

VarBC initialization

- VarBC-LAM: 24-hour cycling; 45-days initalization (passive DA, warmstart)
- VarBC-global (ARP100): β from ARPEGE; no initialization

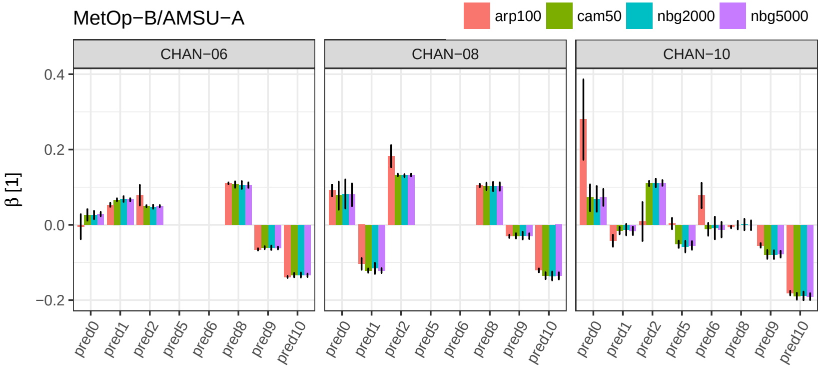

Figure : Mean bias coefficients for particular AMSU-A channels estimated after the initialization period for different VarBC-LAM methods and for VarBC-global as a reference. The mean bias coefficients are evaluated from 1 to 31 Dec 2015. Error bars represent the standard error of the mean of bias coefficients.

Quality of the model background

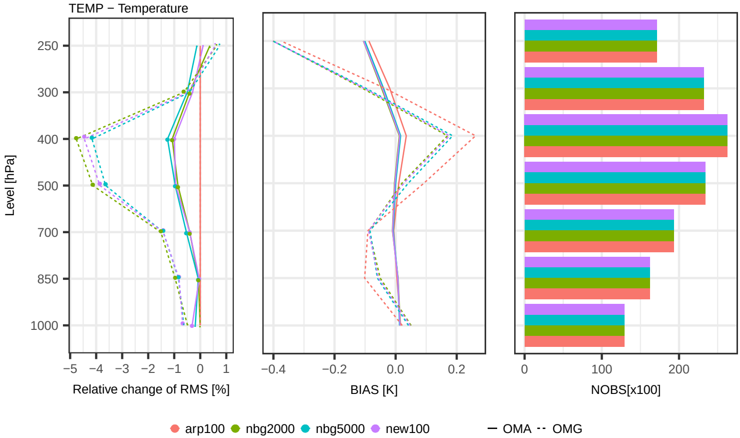

Figure : Evaluation of a quality of the analysis/first-guess in assimilation cycle for different VarBC-LAM methods and VarBC-global (reference) with N_{min} set to 100. Vertical profile of relative RMS (left) and BIAS (middle) scores of OMA and OMG differences are evaluated with respect to TEMP-T (temperature) based on 3-hour analysis cycle from 01 Dec 2015 to 31 Jan 2016. Dots represent statistically significant differences on the 95% confidence level with respect to the reference. The number of observations is presented in bar plots (right).

Quality of analysis: VarBC overfitting

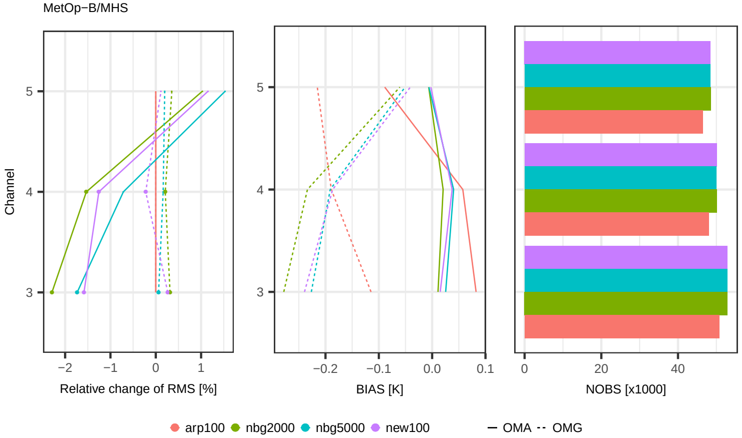

Figure : As Fig. 5 but with respect to the instruments MHS on MetOp-B.

Scan-angle bias correction quality

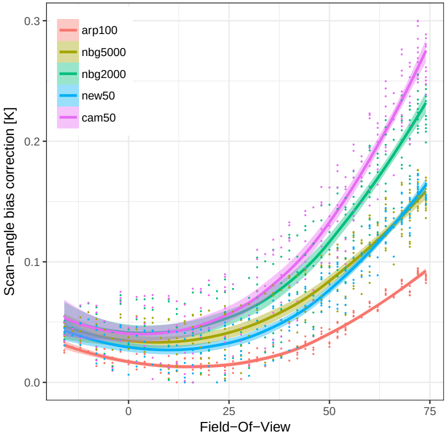

Figure : The scan-angle bias correction using different VarBC-LAM methods and VarBC-global as a reference represented by moving average lines. A position of the satellite scan is represented by Field-Of-View (FOV). The bias correction is shown for the IASI channel 267 on MetOp-B for a particular day on 26 Dec 2015 at 21 UTC.

Forecast impact study: no instrument bias changes

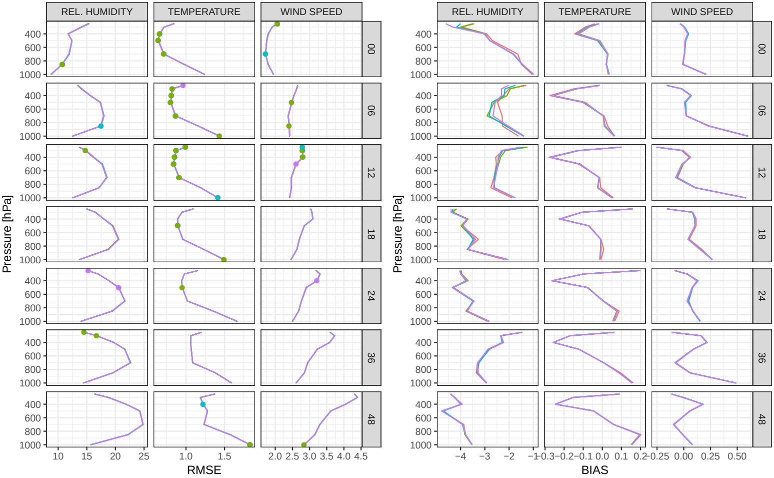

Figure : Vertical profile of relative RMSE using VarBC-LAM methods NBG5000, NBG2000, NEW100 and VarBC-global ARP100 as a reference. The scores are evaluated with respect to combined AMDAR+TEMP observations during the validation period. Dots represent statistically significant differences on the 95% confidence level.

Artificial bias correction quality

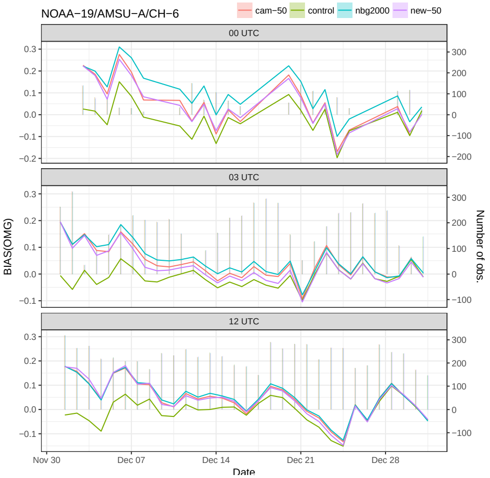

Figure : Reaction of different VarBC-LAM methods on artificially biased AMSU-A channel 6 on NOAA-19 (0.1 K) monitored by the time-evolution of mean OMG values. The length of spin-up period is evaluated with regards to particular analysis times 00 (top), 03 (middle) and 12 UTC (bottom) during a one-month spin-up period. Bar plots represent the number of observations used in the DA-system.

Conclusion

- the VarBC-global may not be consistent with LAM conditions:
  - global-offset/air-mass (†),
  - geometric correction (✓),
- VarBC-global: a small degradation of the background/analysis and the short-range forecast,
- the VarBC-LAM configurations:
  - NBG2000, CAM (overfitting problem),
  - NBG5000 (underfitting problem),
  - CAM/NEW allow assimilation of small data samples ($\geq$ 50 obs):
    - small improvment of BIAS for the RH profile,
    - adjusting β to instrument bias changes on a short-time scale.

Thank you for your attention.