Satellite Bias Correction in Limited-Area Model ALADIN

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Introduction

Bias correction of satellite radiances is an essential component of data assimilation system in Numerical Weather Prediction (NWP). Variational Bias Correction (VarBC) schemes are widely used by global NWP centers (NCEP, ECMWF), but there are still open questions regrading their use in limited-area models (LAMs). We shall present a study of VarBC adaptivity in the limited-area 3D-Var system using the state-of-the-art NWP system ALADIN, which shares its model code with the global system IFS/ARPEGE, and is operationally used at Czech Hydrometeorological Institute.

1. Model ALADIN/CZ

- Central Europe domain (Fig.1),
- $\delta x \sim 4.7$ km, 87 vertical levels up to 0.1 hPa,
- BlendVar for upper-air fields (DF Blending + 3D-Var),
- 6-hour analysis cycle at 0, 6, 12 and 18 UTC,
- Radiance observations:
  SEVIRI (Meteosat-10)
  ATOVS/IASI (NOAA, MetOp).

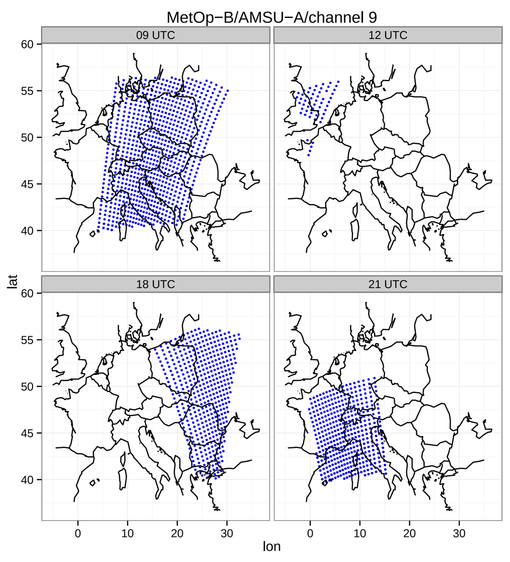

Figure 1: Data coverage of MetOp-B over ALADIN/CZ domain on Sep 7, 2015.

2. Variational Bias Correction

VarBC is an adaptive bias correction scheme implemented into the 3D-Var data assimilation system:

$$J(\mathbf{x},\beta) = (\mathbf{x}-\mathbf{x_b})^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x_b}) + (\beta-\beta_\mathbf{b})^T\mathbf{B}_\beta{}^{-1}(\beta-\beta_\mathbf{b}) + (\mathbf{y}-h(\mathbf{x},\beta))^T\mathbf{R}^{-1}(\mathbf{y}-h(\mathbf{x},\beta)),$$

where β are bias parameters associated with VarBC predictors, $\beta_\mathbf{b}$ are background bias parameters issued from the former analysis cycle and $\mathbf{B}_\beta$ is the background bias parameter error matrix simplified by diagonal elements:

$$\sigma^2_{\beta_\mathbf{b}} = \frac{\sigma^2_\mathbf{o}}{\mathbf{N_{bg}}}. \quad (1)$$

$\sigma^2_{\beta_\mathbf{b}}$ represents a sample variance of the mean of N_{bg} independent observations, whose individual error variance is $\sigma_o{}^2$. The adaptivity of VarBC scheme is controlled by a stiffness parameter $\mathbf{N_{bg}}$.

3. LAM sampling issues

The observation bias is detected at each analysis time based on observation-minus-model (OMG):

$$\mathbf{b_o} = \langle \mathbf{y} - h(\mathbf{x}) \rangle. \quad (2)$$

Estimate of $\mathbf{b_o}$ is statistically meaningful provided a normal independent sample of OMG. In LAM, the sample of polar satellites is spatial/time dependent caused by:

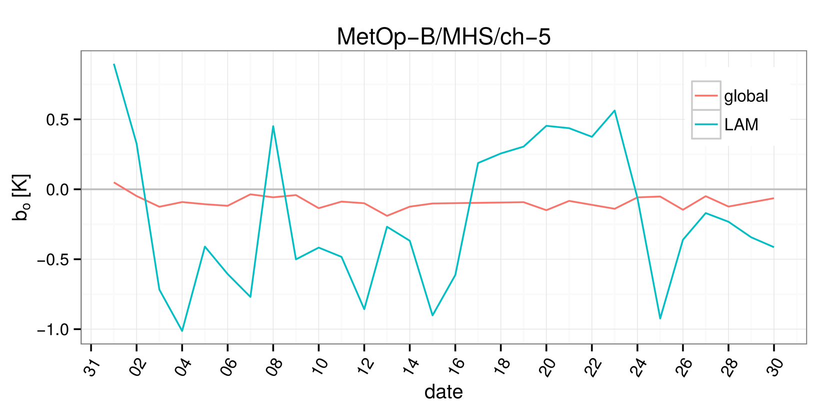

Figure 2: Time evolution of observation bias for the MHS channel 5 on MetOp-B in ARPEGE (12 UTC) and ALADIN/CZ (9 UTC) in 01/2016.

- **non-uniform data coverage** (Fig.1),
- **regional weather conditions**: different NWP model biases for typical weather regimes, seasons or diurnal cycle.

The higher sample variance of $\mathbf{b_o}$ is detected in LAM's analysis cycle (see Fig.2).

Conclusion

- Higher sample variance of the observation bias is detected in LAM.
- Optimal stiffness of VarBC proposed (Eq. 5) in order to:
  - reduce impact of LAM sampling issues on VarBC (Fig.5),
  - optimize the response of VarBC to satellite bias changes (Fig.6).
- VarBC initialization in ALADIN/CZ:
  - **coldstart**: requires an excessive spin-up period (Fig.5); underestimates scan-angle/air-mass bias correction (Fig.6),
  - **global** β**'s** (ARPEGE): not fully representative for particular AMSU-A/IASI channels due to model cycle, resolution (not shown),
  - **warmstart**: seems to be the best option in combination with the new formulation of N_{bg} (Eq. 5).

References

[1] J. Cameron and W. Bell. The testing and planned implementation of variational bias correction (varbc) at the met office. 2016.

[2] L. Lindskog, M. Dahlbom, S. Thorsteinsson, P. Dahlgren, R. Randriamampianina, and J. Bojarova. Atovs processing and usage in the harmonie reference system. HIRLAM Newsletter 59, HIRLAM, 2012.

4. VarBC adaptivity in LAM

The key parameter for the VarBC adaptivity is the stiffness parameter N_{bg} (Eq. 1). The default N_{bg} setting (5000) is not flexible for all satellite instruments/channels providing rapid or too slow adaptation of β (Fig.5). Cameron and Bell (2016) suggested a harmonized stiffness parameter provided N independent observation sample when initial bias parameter β_{init} decreases exponentially towards the best fit β_{best} (red-line; Fig.3):

$$\beta_n = \left(\frac{N_{bg}}{N_{bg}+N}\right)^n \beta_{init} + \left[1 - \left(\frac{N_{bg}}{N_{bg}+N}\right)^n\right]\beta_{best}. \quad (3)$$

The lack of independence in LAM implies a higher sample variance of β (blue-line; Fig.3) invalidating (3). Therefore, we propose a new formulation of N_{bg} that is able to reduce the sample variance with respect to the satellite bias component. This concept is based on the variance-bias trade-off considering the Mean-Square Error (MSE) of β at n^{th} time step:

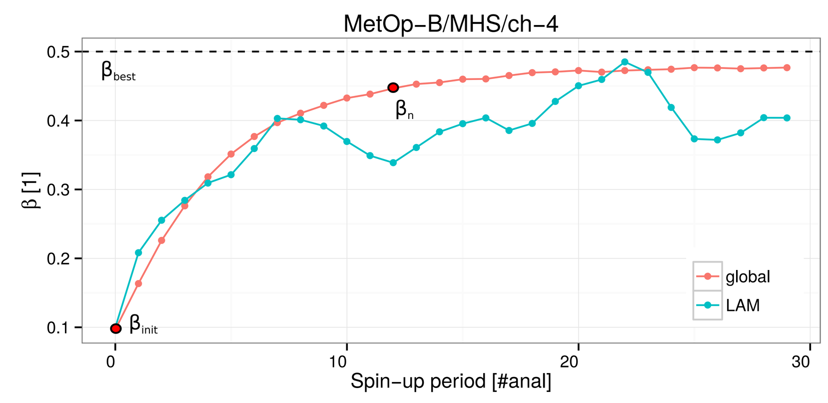

Figure 3: Initialization of β during a 30-day spin-up period wrt independent (global) and dependent (LAM) observation sample.

$$MSE(\beta_n) = var(\beta_n) + bias(\beta_{best}, \beta_n)^2. \quad (4)$$

The optimum stiffness parameter is estimated by minimizing the MSE function (Fig.4) with respect to N_{bg} such that:

$$\mathbf{N_{bg}} \simeq max(\mathbf{N_{avg}}, N_{min}) \underbrace{\left[2nW\left(\frac{4n^2b^2_{max}}{var(b_o)}\right)^{-1}\right]}_{K}. \quad (5)$$

K is stiffness inflation factor, $\mathbf{N_{avg}}$ is expected observation number per analysis, N_{min} is minimum observation sample, $var(b_o)$ is sampling variance of the observation bias, b_{max} is the maximum satellite bias, n is a spin-up period and W is the Lambert-W function.

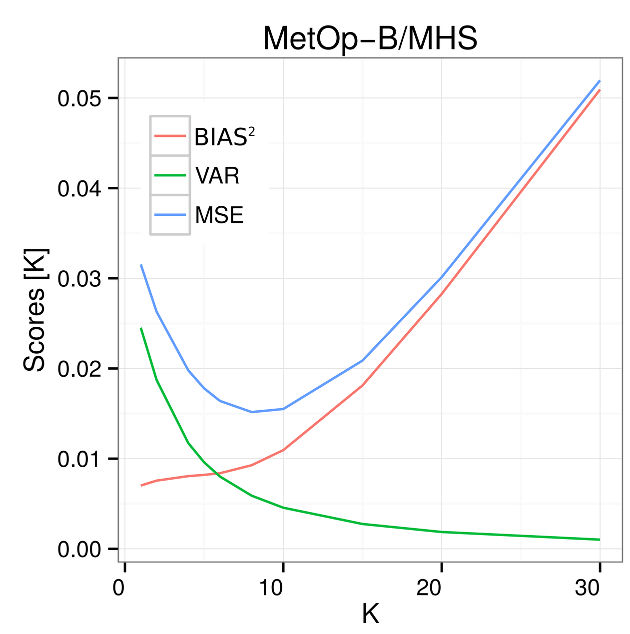

Figure 4: Variance-bias components of MSE (4). The optimum K corresponds to the minimum MSE representing the best correction of b_o with respect to LAM sampling issues.

Instrument	N_{avg}	K_{30}	K_{10}
AMSUA-5	380	6	3
AMSUA-6	460	6	3
AMSUA-7	480	6	3
AMSUA-8	920	6	3
AMSUA-9	920	6	3
AMSUA-10	920	7	3
MHS-3	6970	9	7
MHS-4	6690	8	7
MHS-5	6460	9	7

Table 1: Estimate of K for particular ATOVS channels in ALADIN/CZ considering b_{max} = 0.3 K and N_{min} = 100. The K_{10} and K_{30} corresponds to spin-up periods n = 10 and 30.

5. Evaluation of VarBC

Different VarBC initialization method are compared during a spin-up period in 09/2015 (Fig.5) during which the radiance observations do not influence the model's initial state (passive mode). A quality of VarBC is evaluated using different β (after initialization) during a validation period in 10/2015 (Fig.6).

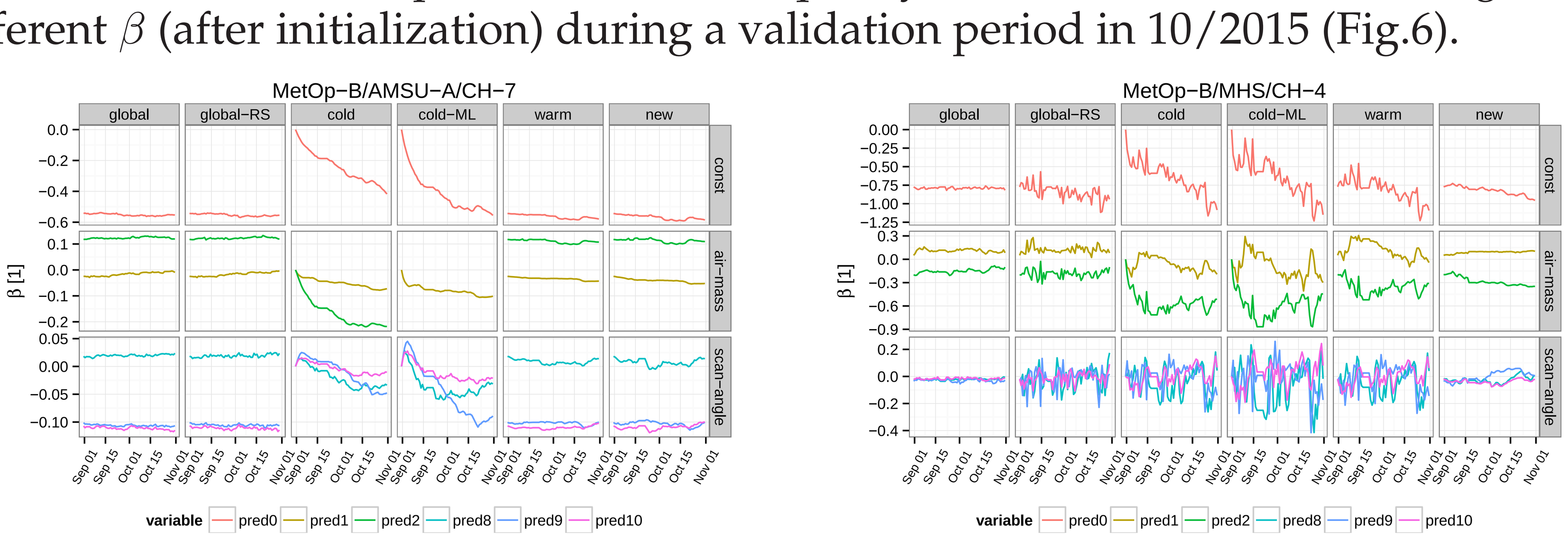

Figure 5: Initialization of β associated with constant (top), air-mass (middle) and scan-angle (bottom) predictors using methods: coldstart (cold), coldstart as proposed by Lindskog et al. (2012)(cold-ML), default warmstart (warm) and warmstart with adjusted N_{bg} (new). The ARPEGE bias parameters (global) are used as a reference. Scores are calculated for the AMSU-A channel 7 (left) and MHS channel 4 (right) on MetOp-B at 9 UTC during 09-10/2015.

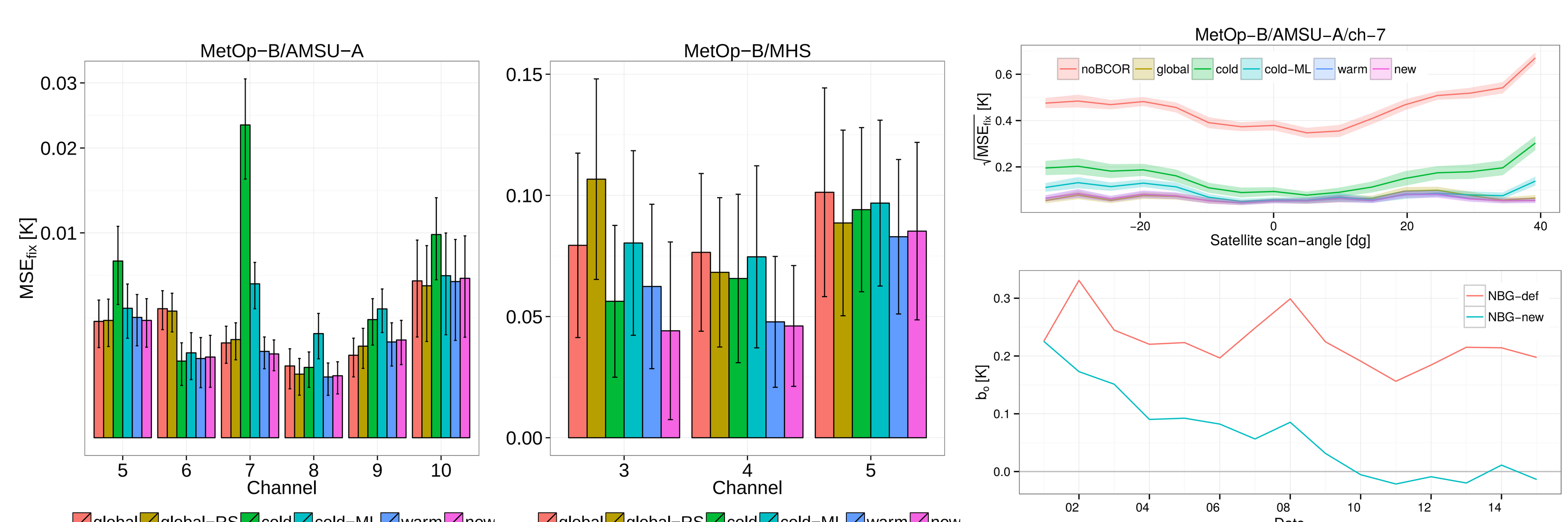

Figure 6: The bias correction quality measured by MSE of the corrected observation bias (95% confidence level) wrt VarBC initialization methods. Overall scores are calculated for AMSU-A (left) and MHS (middle) channels. Top-right: The MSE scores wrt the satellite scan-angle. Bottom-right: The VarBC response to an artificial satellite bias 0.3 K using default N_{bg} (5000) and new N_{bg} (Eq. 5). Both the scores are calculated for the AMSU-A channel 7 on MetOp-B at 9 UTC during 10/2015.