Latest results of variational bias correction in LAM DA systems

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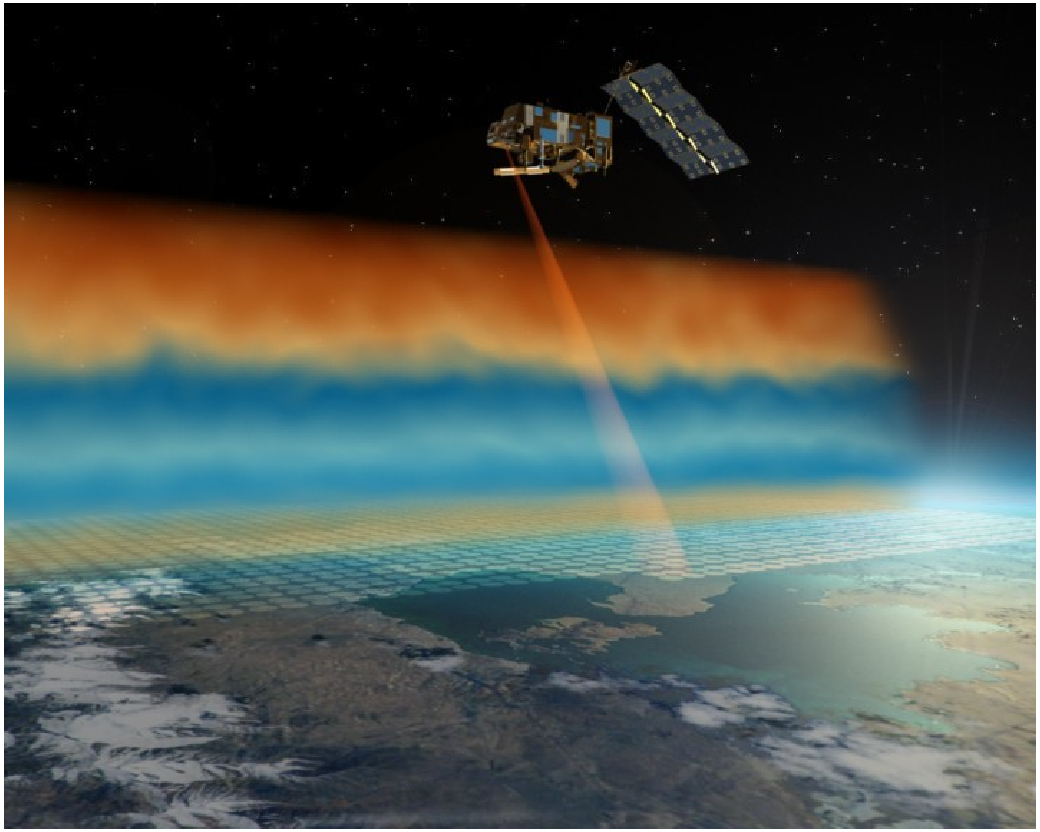
Máté Mile (HMS)



DAWD, Ljubljana
19.9.2017

Bias correction scheme is essential for a satellite data assimilation into NWP models.

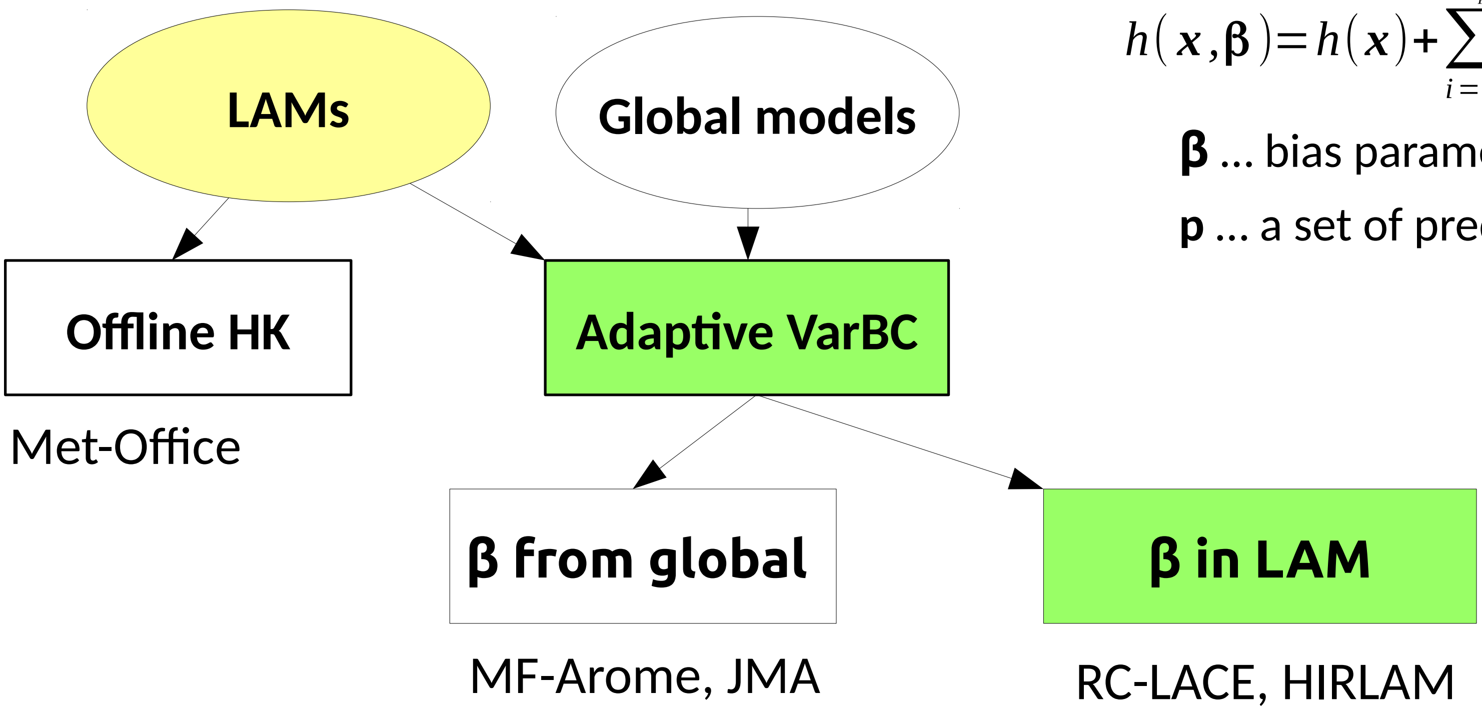
Observation bias: $b_0 = \langle \mathbf{y} - h(\mathbf{x}) \rangle$

Bias prediction model: $b_0 = \langle \mathbf{y} - h(\mathbf{x}, \boldsymbol{\beta}) \rangle = 0$

$$h(\mathbf{x}, \boldsymbol{\beta}) = h(\mathbf{x}) + \sum_{i=1}^{N_p} \beta_i p_i$$

β ... bias parameters

p ... a set of predictors



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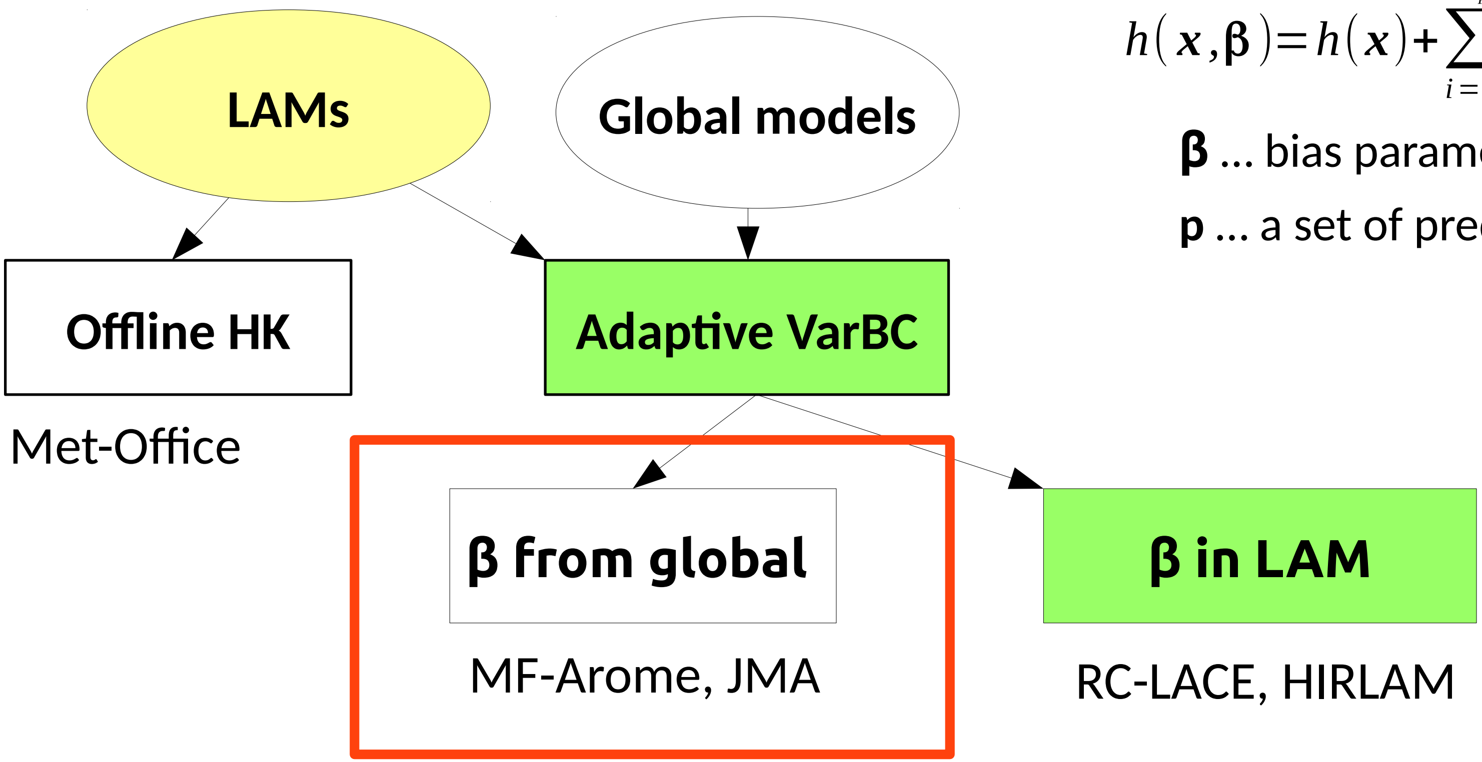

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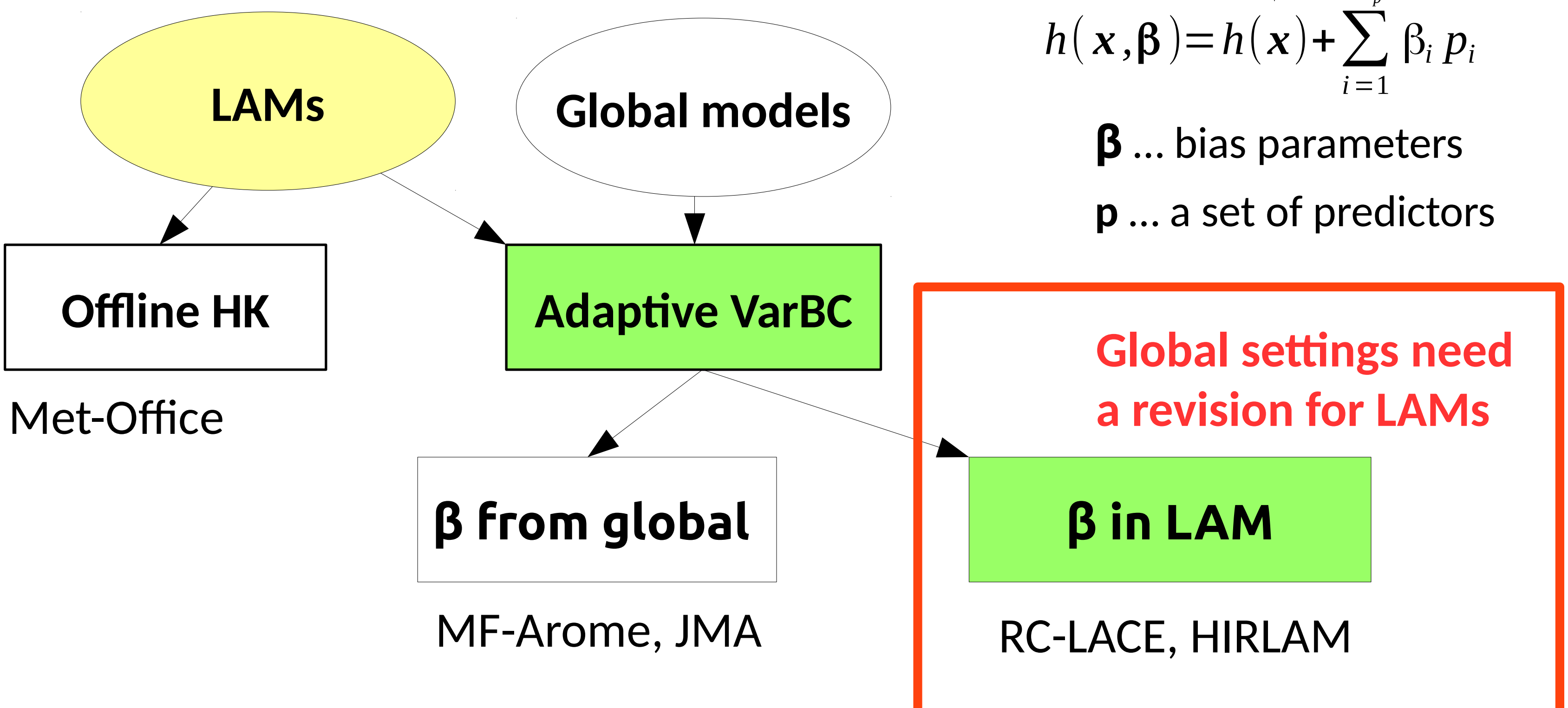
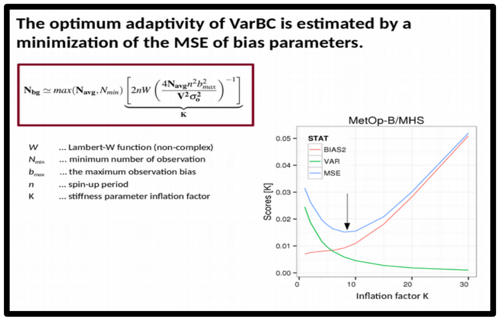
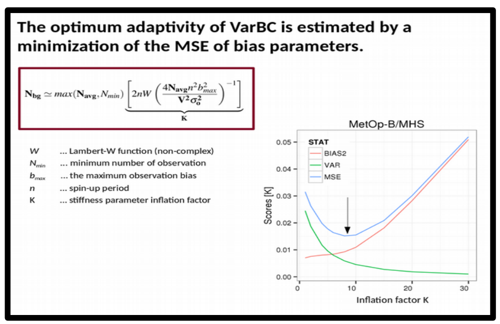


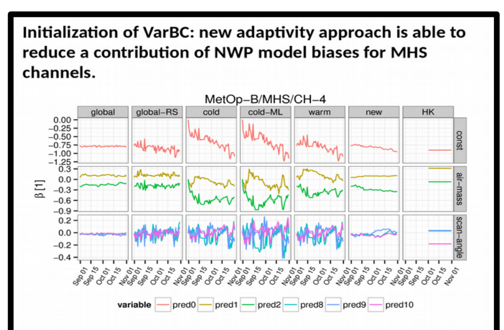
This presentation introduces a behavior of the VarBC scheme in LAMs and suggests a new adaptivity setting.



Sampling issues in LAMs

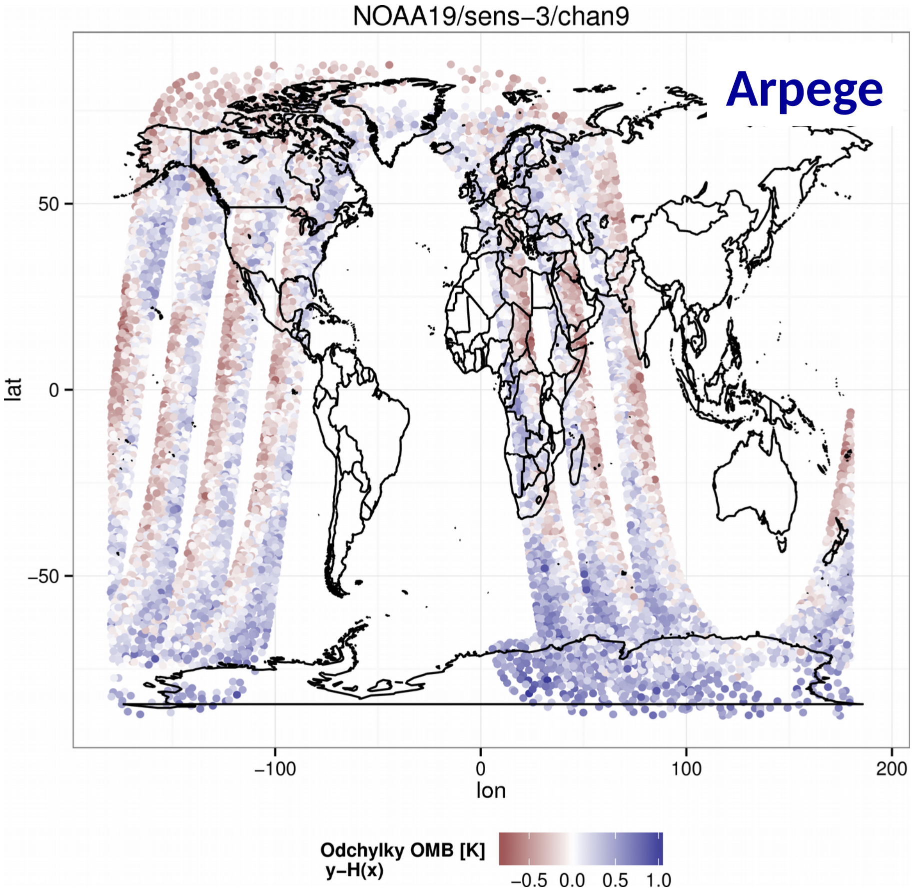


The VarBC scheme and a new adaptivity setting



Evaluation of bias correction

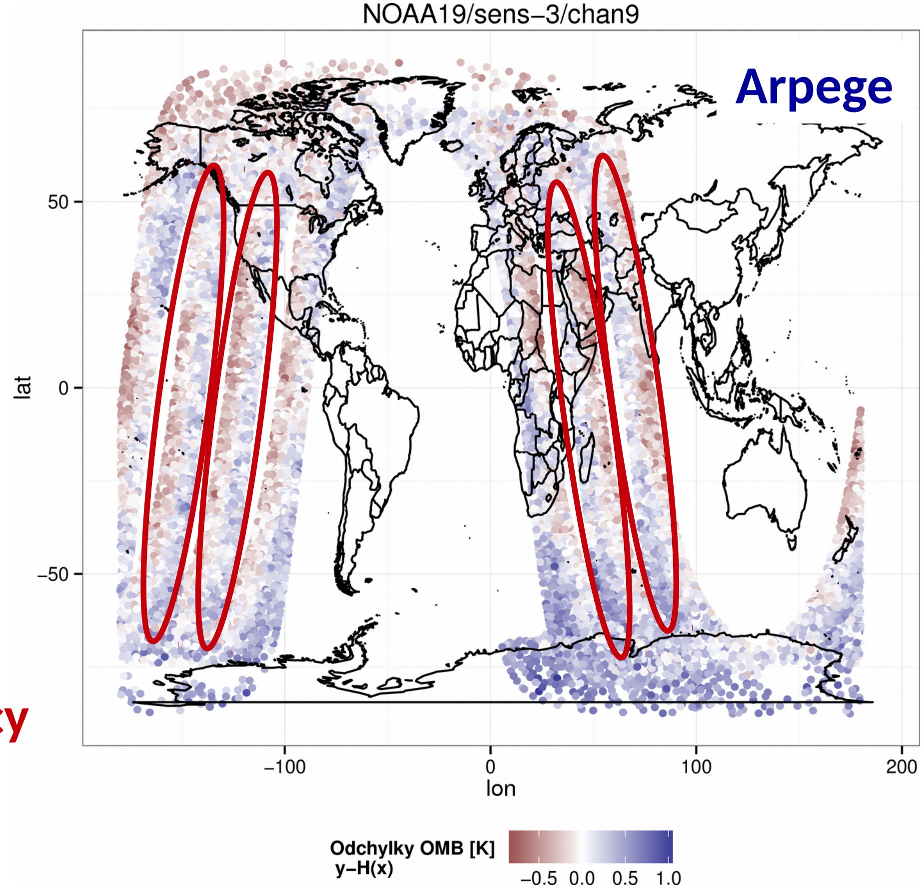
Satellite bias detection is statistically meaningful provided normally distributed random sample of observations.



OmG of AMSU-A channel 9 for a particular day

Satellite bias detection is statistically meaningful provided normally distributed random sample of observations.

Satellite scan angle bias dependency



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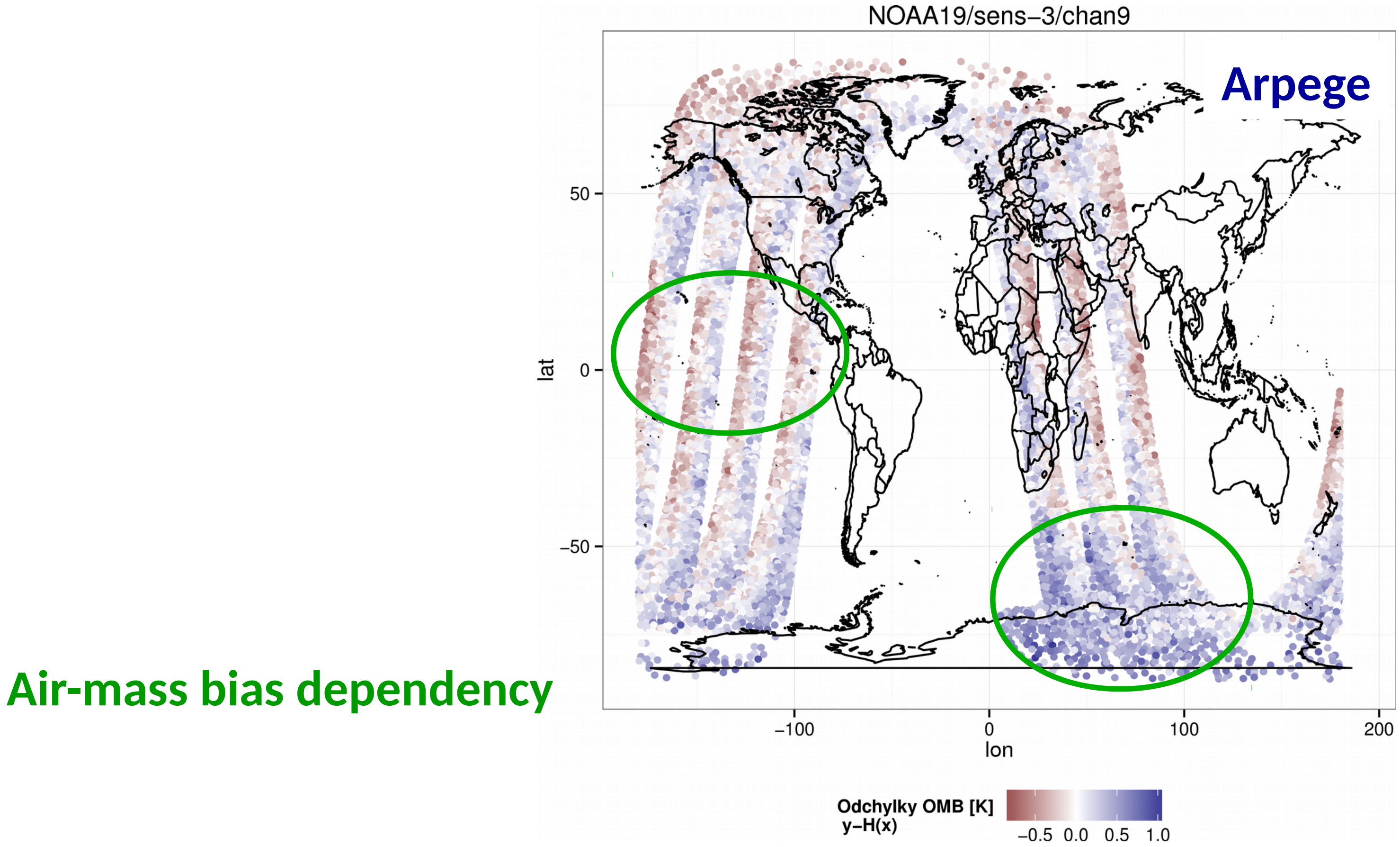
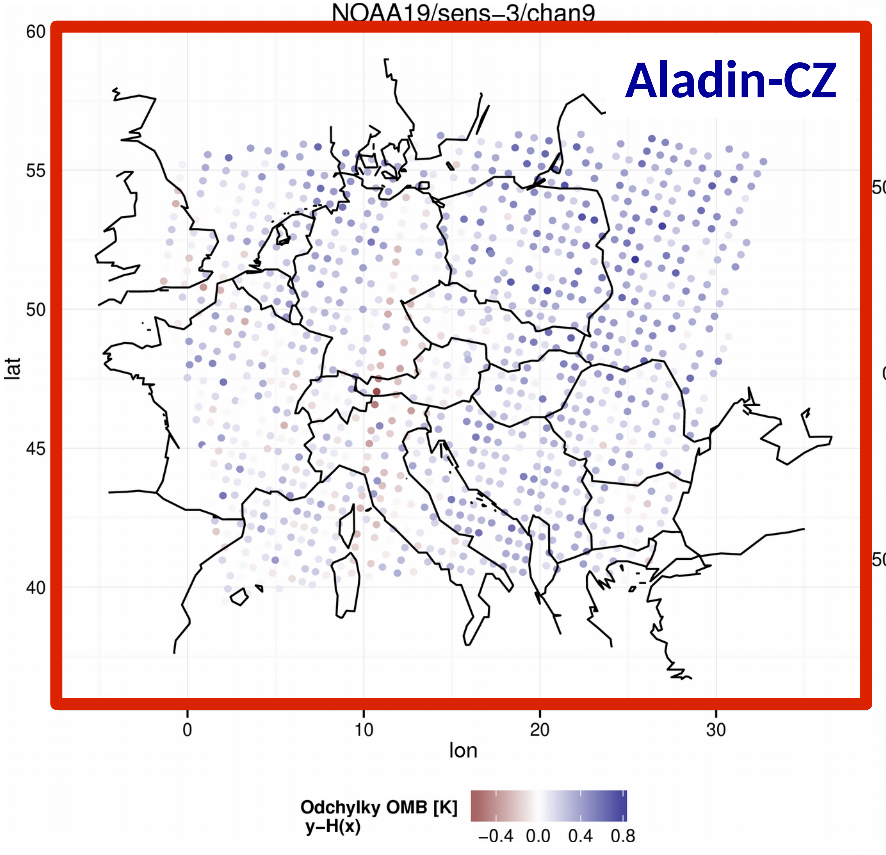
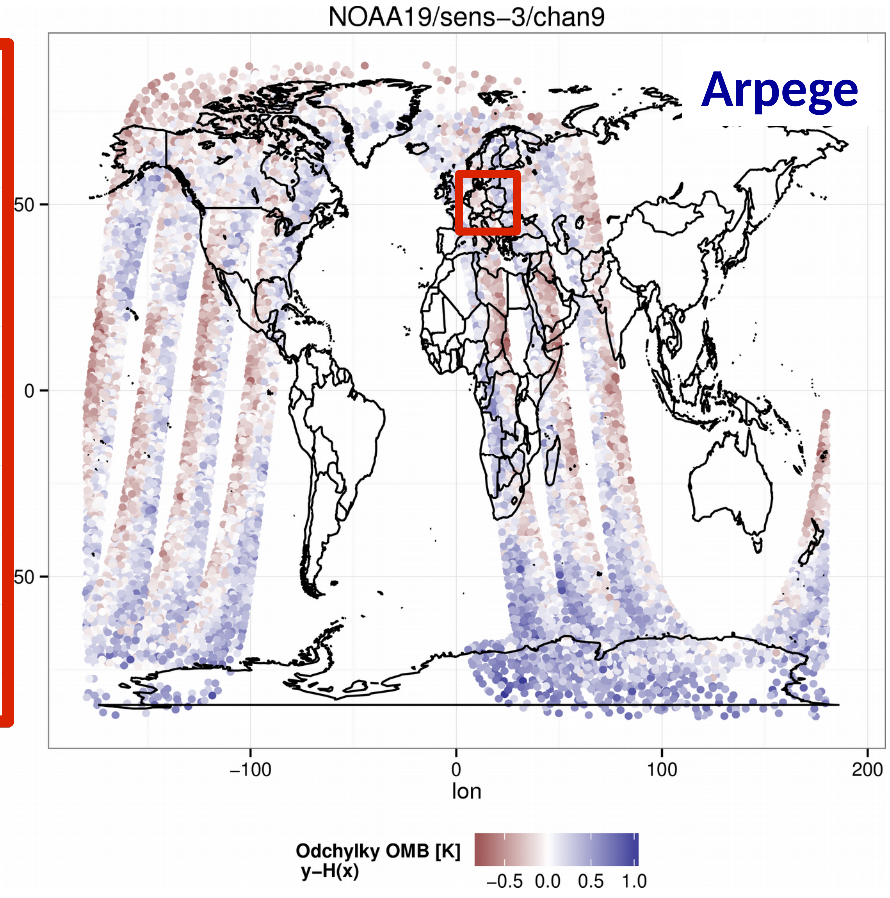


OmG of AMSU-A channel 9 for a particular day

The observation sample is non-uniform, spatially and time dependent in LAMs.





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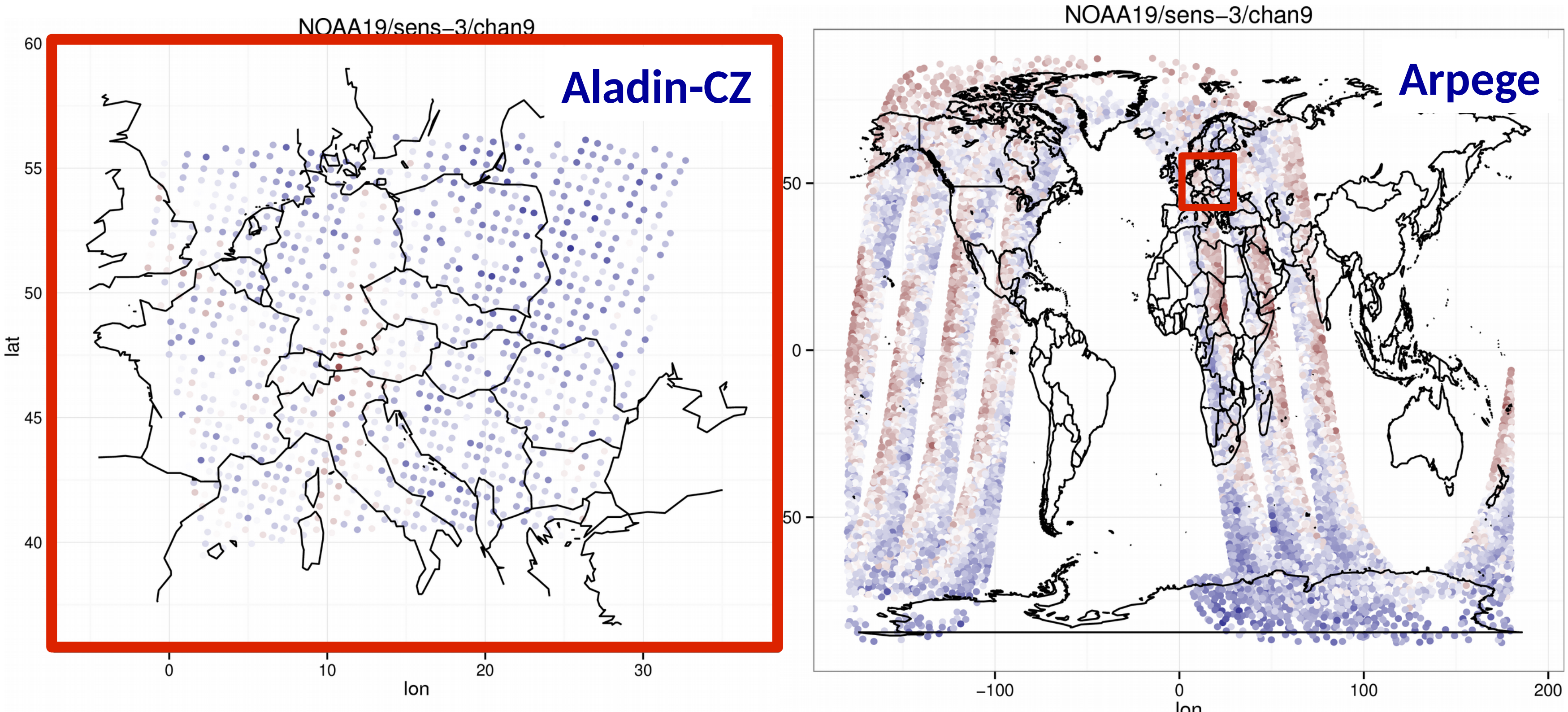


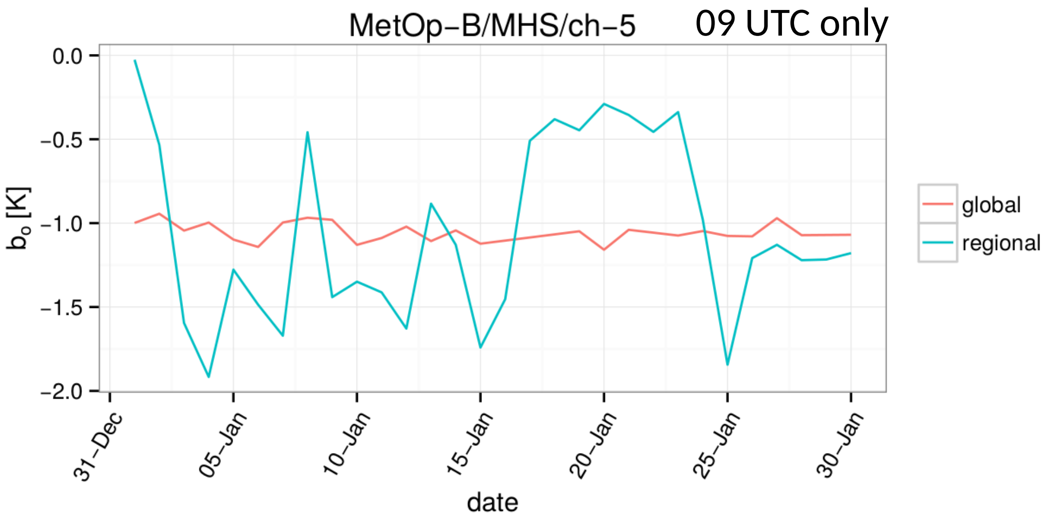
Two possibilities how to detected a meaningful satellite bias:
1) gathering the data over a long-time (the offline method)
2) cycling satellite bias information in time (the VarBC method)

Sampling variance of the observation bias is negligible in a global model but inflated in LAMs because of the spatially dependent observation sample.

Sampling variance of the mean of observation bias:

Global $$\sigma_{b_o}^2 = \frac{\sigma_o^2}{N_{avg}}$$

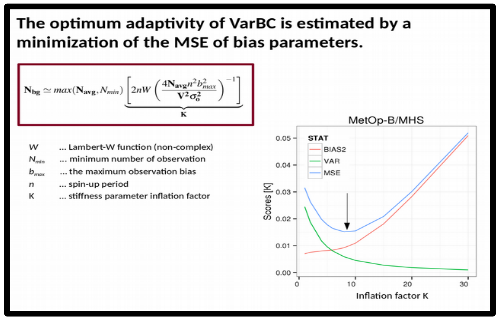
LAM $$\sigma_{b_o}^2 = \frac{\sigma_o^2 \cdot V^2}{N_{avg}}$$



The inflation factor *V* corresponds to a contribution of NWP model biases:

$$V = \sqrt{\frac{N_{avg}}{\sigma_o^2} \frac{1}{n} \sum_{i=1}^{n} (b_{o_i} - \overline{b_o})^2},$$

This presentation introduces a behavior of the VarBC scheme in LAMs and suggests a new adaptivity setting.



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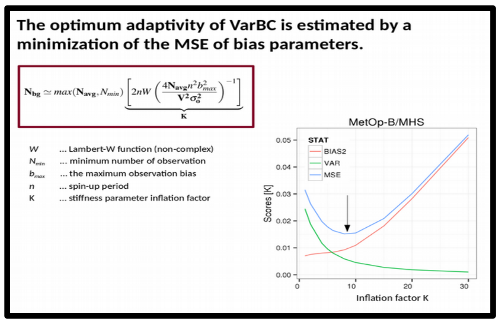
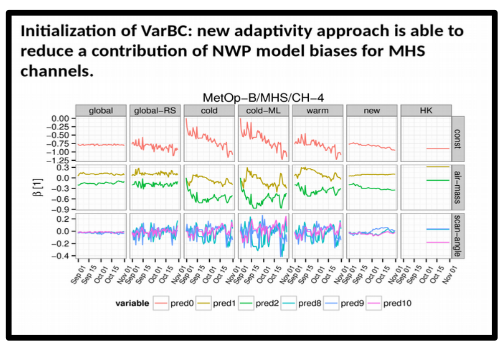


The VarBC scheme and a new adaptivity setting



Evaluation of bias correction

The VarBC scheme advantages: maintenance, an adaptive bias correction WRT time, observation, analysis.

The VarBC scheme implementation:

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

$\boldsymbol{\beta}_\mathbf{b}$ … background bias parameters

$\mathbf{B}_\beta$ … background bias parameter error covariance matrix

Diagonal B_β with elements: $\sigma^2_{\beta_b} = \frac{\sigma^2_o}{N_{bg}} \longrightarrow \sigma^2_{\beta_b} = \frac{\sigma^2_o}{N_{bg} V^2}$

$\mathbf{N_{bg}}$ … stiffness parameter (5000) ~ adaptivity of VarBC

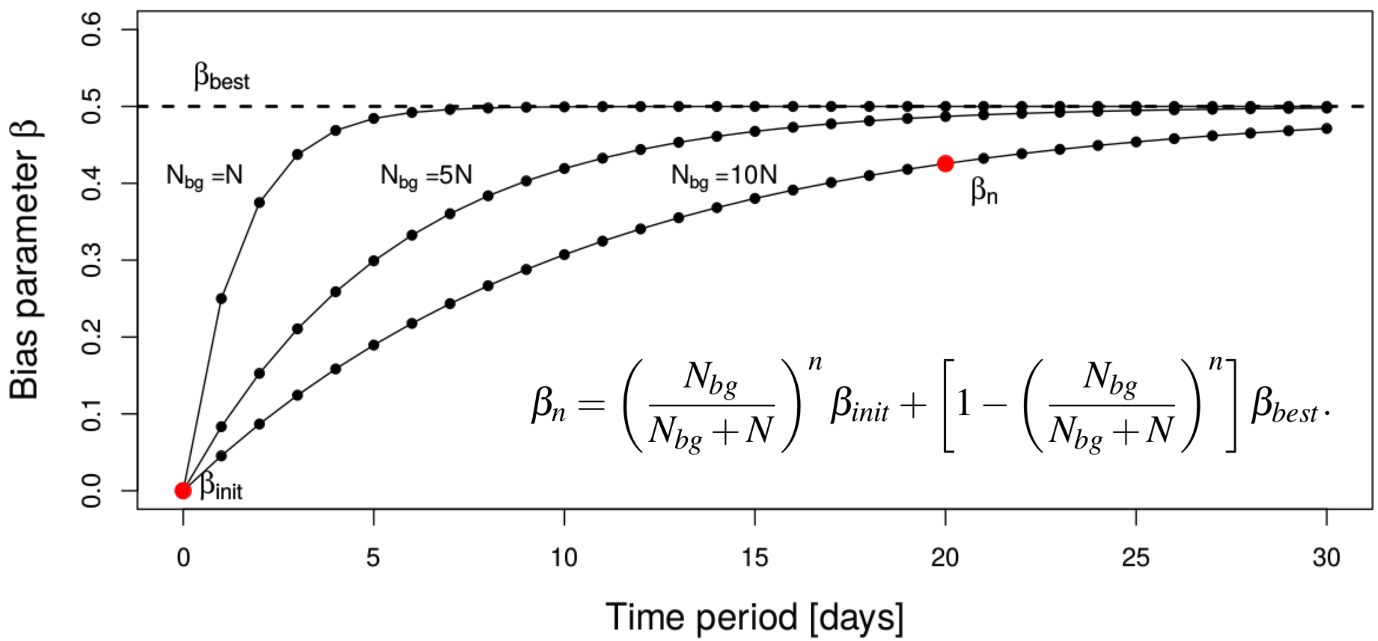
How set optimal stiffness parameters in LAMs ??

The optimum adaptivity of the VarBC is a trade-off between the variance and bias of bias parameters.

The concept of a variance-bias trade-off

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

See Cameron and Bell (2016)



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

The optimum adaptivity of VarBC is a trade-off between the variance and bias of bias parameters.

The concept of a variance-bias trade-off

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

$$bias(\beta_{best}, \beta_n) = \beta_{best} \left(\frac{N_{bg}}{N_{bg} + N} \right)^n$$

$$var(\beta_n) = var(\beta_{best}) \left[1 - \left(\frac{N_{bg}}{N_{bg} + N} \right) \right]^2$$

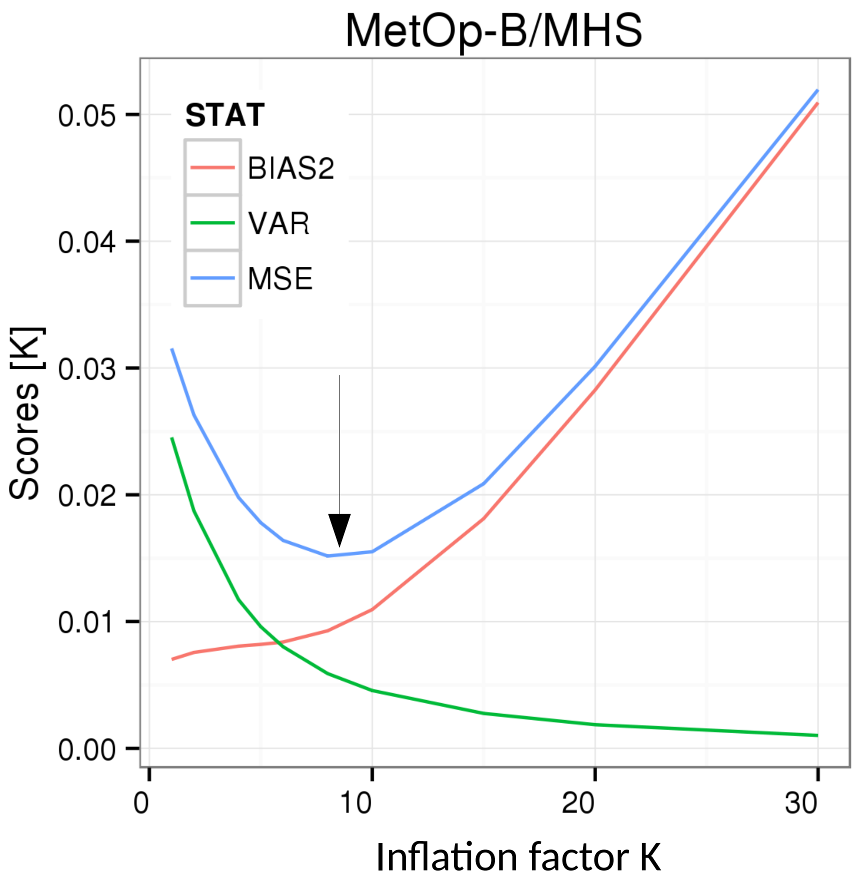
Optimum N_{bg} is estimated by minimizing the MSE:

$$\frac{dMSE}{dN_{bg}} = 0$$

The optimum adaptivity of VarBC is estimated by minimizing of the MSE of bias parameters.

$$\mathbf{N_{bg}} \simeq max(\mathbf{N_{avg}}, N_{min}) \underbrace{\left[2nW\left(\frac{4\mathbf{N_{avg}}n^2 b_{max}^2}{\mathbf{V}^2\sigma_{\mathbf{o}}^2}\right)^{-1}\right]}_{\mathbf{K}}$$

W	… the Lambert-W function (non-complex)
N_{min}	… the minimum number of observation
b_{max}	… the maximum observation bias
n	… the length of spin-up period
K	… a stiffness parameter inflation factor

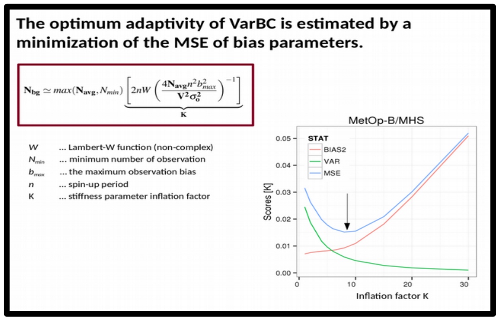


Estimating of K for the ATOVS in the LAM model Aladin-CZ.

Instrument	σ_o [K]	V	passive N_{avg}	passive K_{30}	passive N_{bg} [$\times 10^3$]	active N_{avg}	active K_{120}	active K_{10}
AMSUA-5	0.25	4	380	6	2	60	20	3
AMSUA-6	0.18	4	460	6	3	70	20	3
AMSUA-7	0.22	4	480	6	3	75	20	3
AMSUA-8	0.22	4	920	6	6	130	20	3
AMSUA-9	0.22	6	920	6	6	130	20	3
AMSUA-10	0.26	9	920	7	6	130	20	3
AMSUA-11	0.30	14	920	8	7	130	30	5
AMSUA-12	0.66	16	920	10	9	130	40	8
AMSUA-13	1.44	22	910	14	13	130	50	15
MHS-3	3.0	6	6970	9	63	570	30	7
MHS-4	2.5	6	6690	8	54	540	30	7
MHS-5	2.0	11	6460	9	58	520	30	7

The factor *V* is estimated based on the period in October 2015. The remaining parameters are set to b_{max} = 0.3 K, N_{min} = 100 and *n* = 10, 30 and 120 days.

This presentation introduces a behavior of the VarBC scheme in LAMs and suggests a new adaptivity setting.



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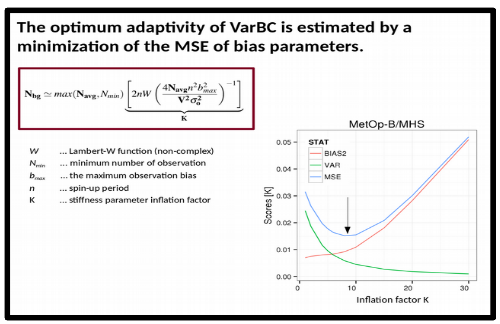

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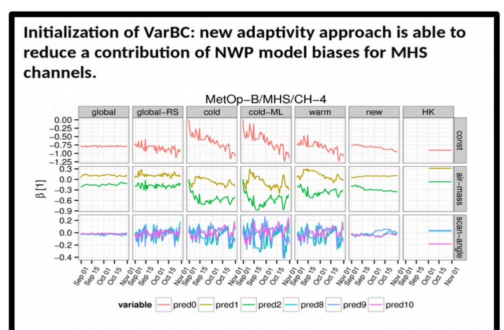


Evaluation of bias correction

The setting of evaluation

Model

The LAM Aladin-CZ with 3D-Var upper-air DA at 9 UTC only; the ATOVS on MetOp-A and -B

Period

Training (spin-up): September 2015
Testing: October 2015

Passive DA experiments

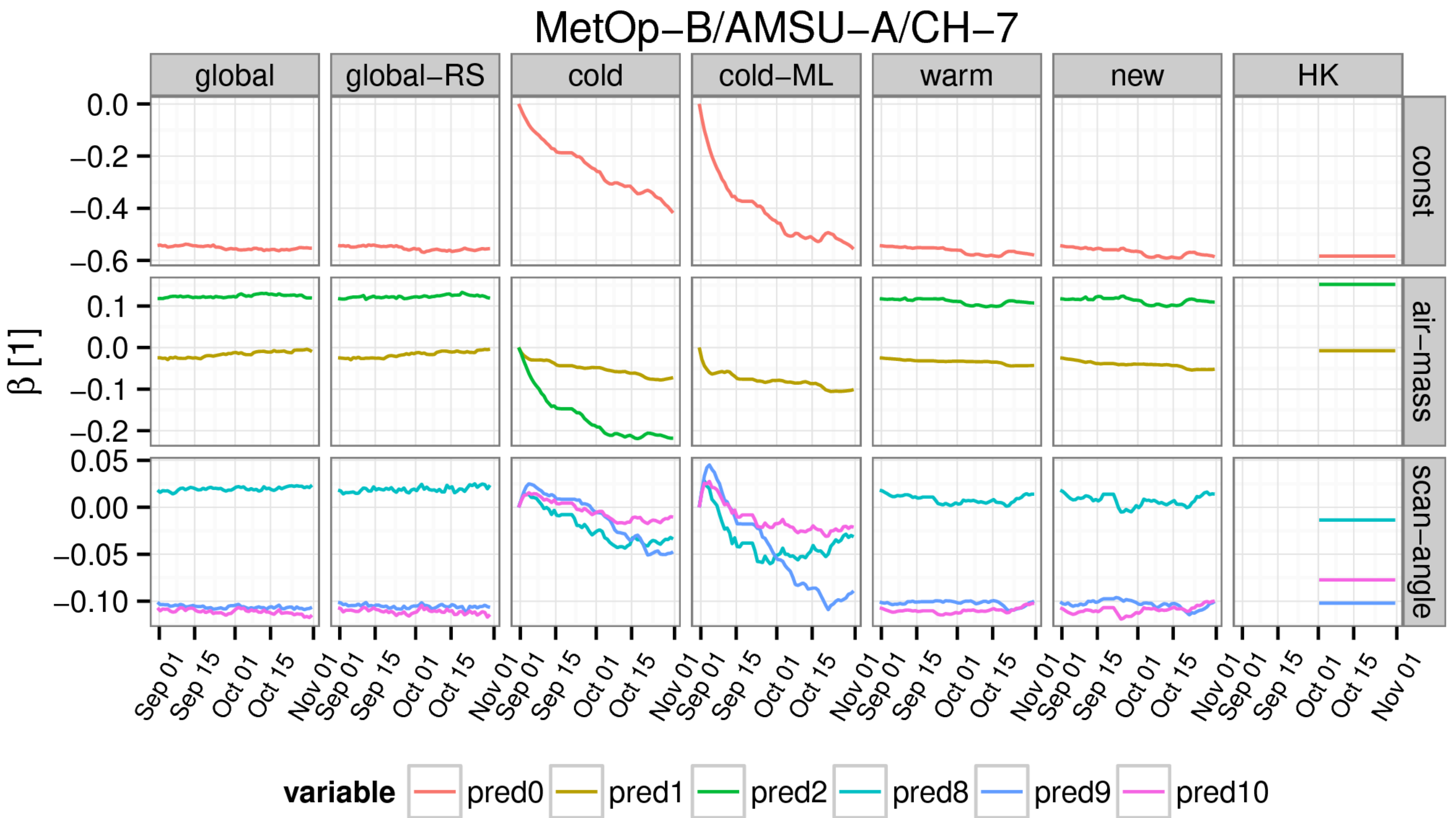
Method	Description	N_{bg}
Global	Raw global β	---
Global-RS	Global β adopted to LAM at each analysis time	5000
Cold	Initial β set to zero	5000
Cold-ML	Tuned cold proposed by Lindskog et al. (2012)	2500
Warm	Initial global β + cycling β in LAM	5000
New	Initial global β + cycling β in LAM	new formulation
HK	Offline method based on Harris & Kelly (2001)	---

Active DA experiments

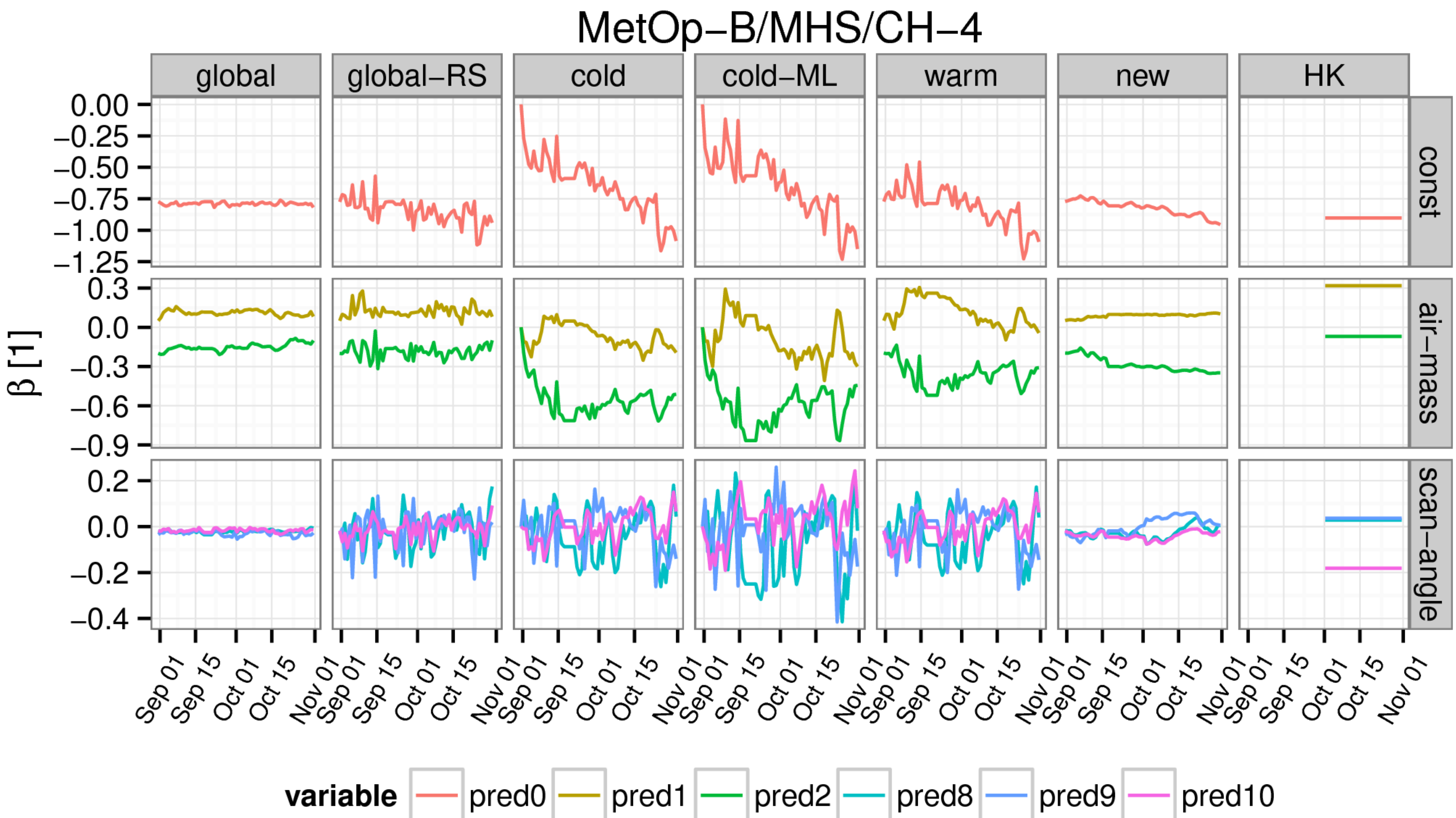
Warm_ACT70 default N_{bg} set to 5000

New_ACT70 new formulation

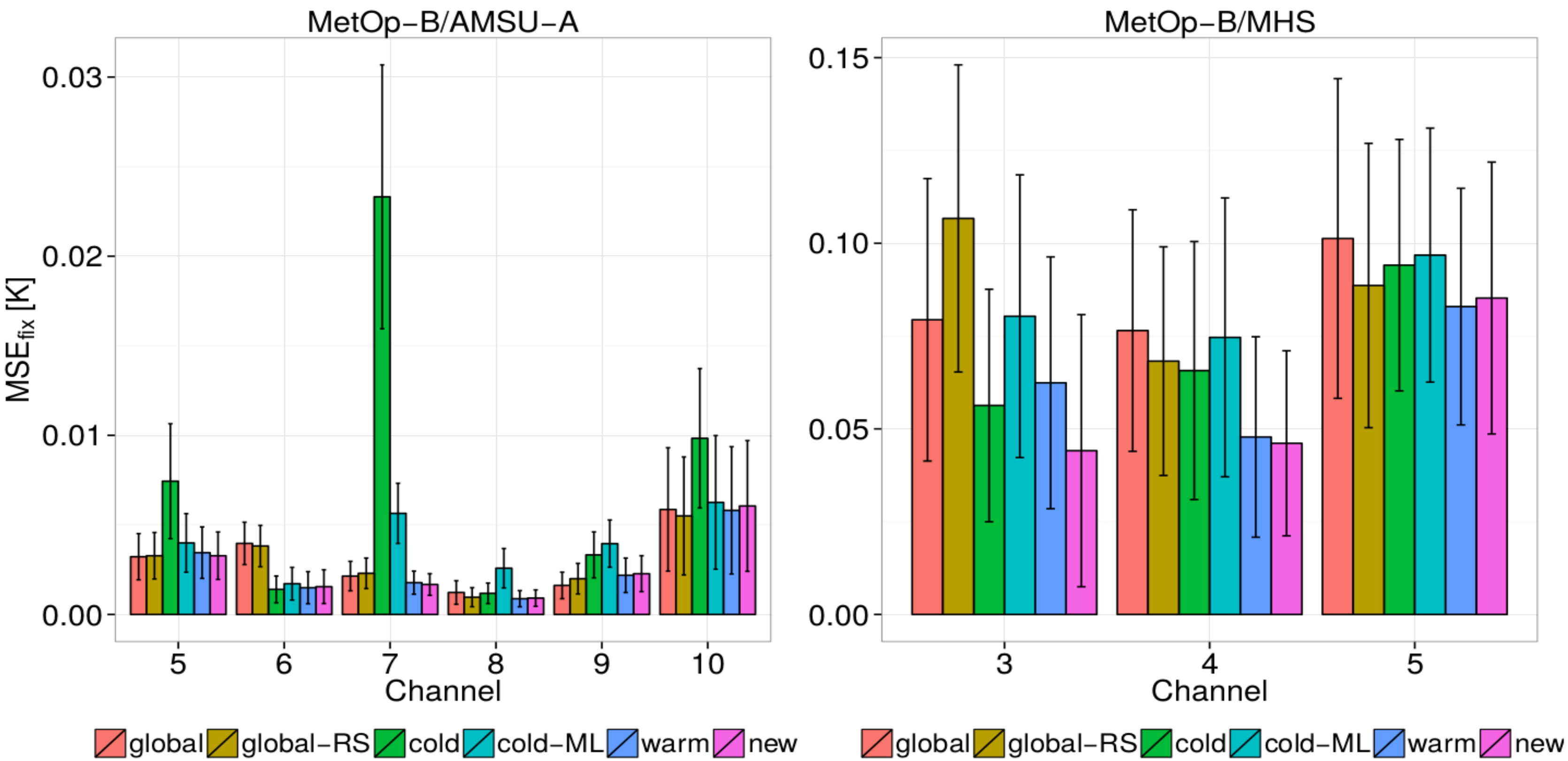
Initialization of VarBC: coldstart methods require excessive spin-up period to initialize bias dependencies for particular AMSU-A channels.



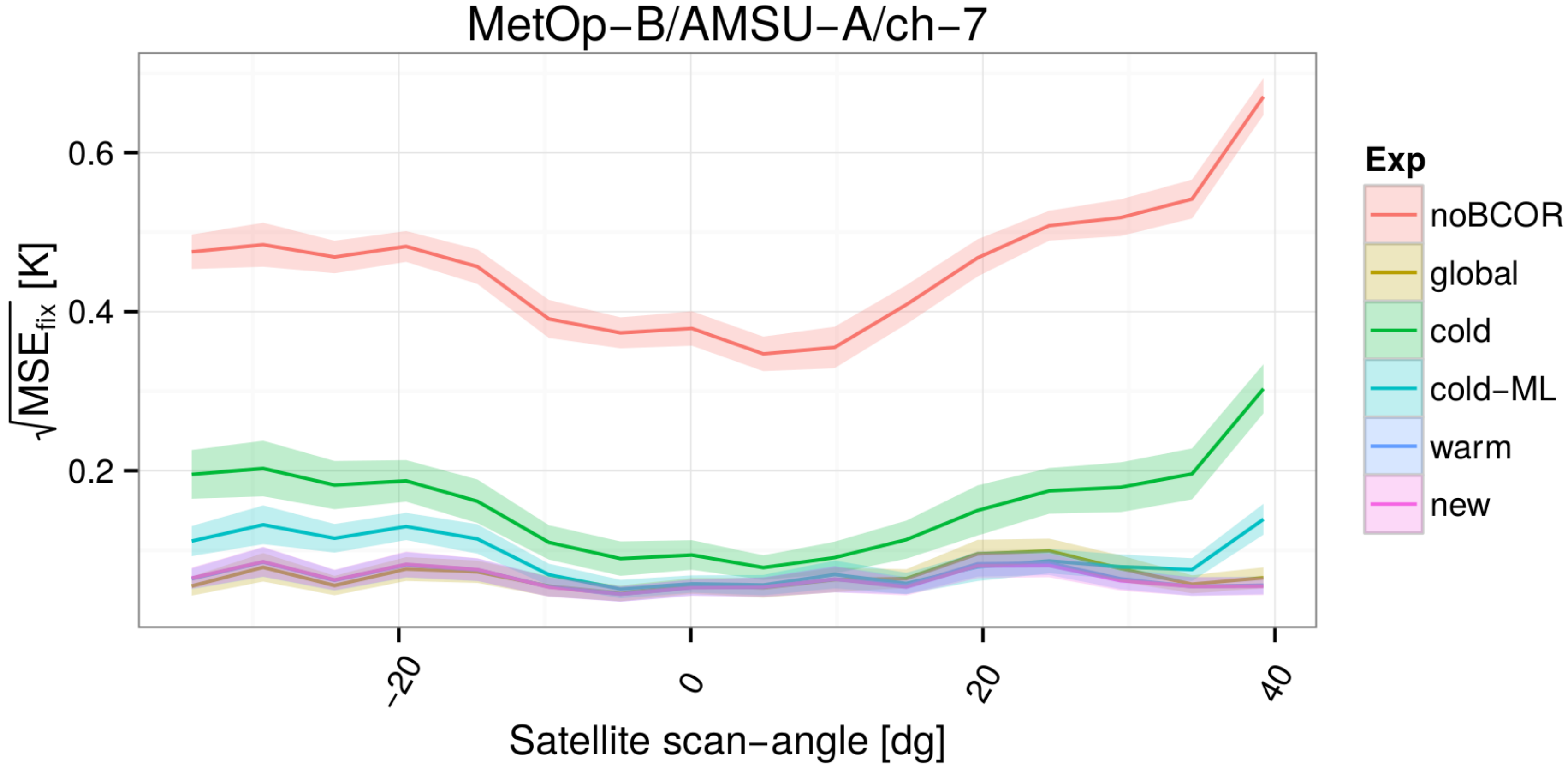
Initialization of VarBC: the new adaptivity formulation is able to reduce a contribution of NWP model biases.



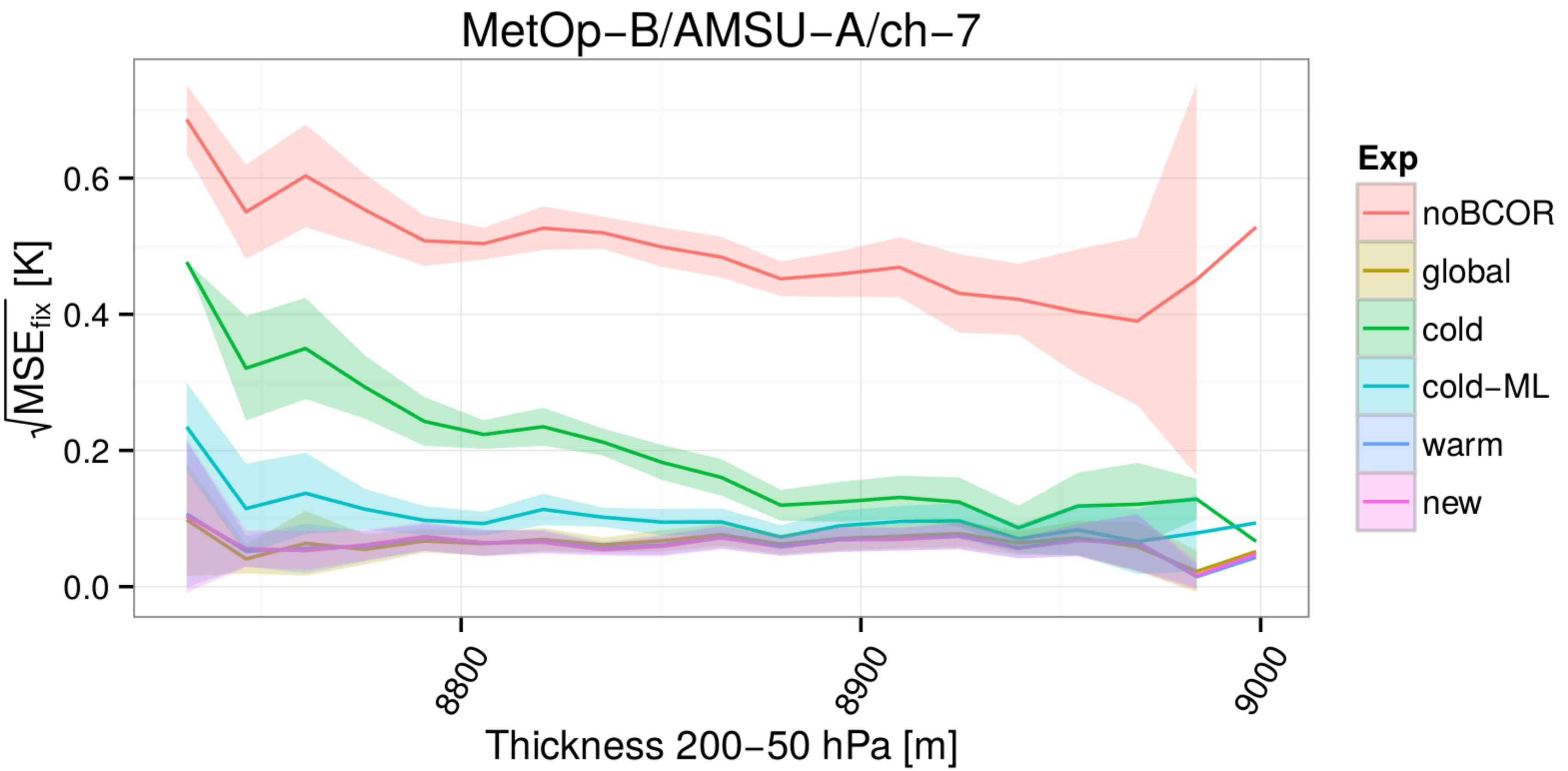
The coldstart and global-RS methods provide worse quality of bias correction (MSE) than the warmstart and new methods.



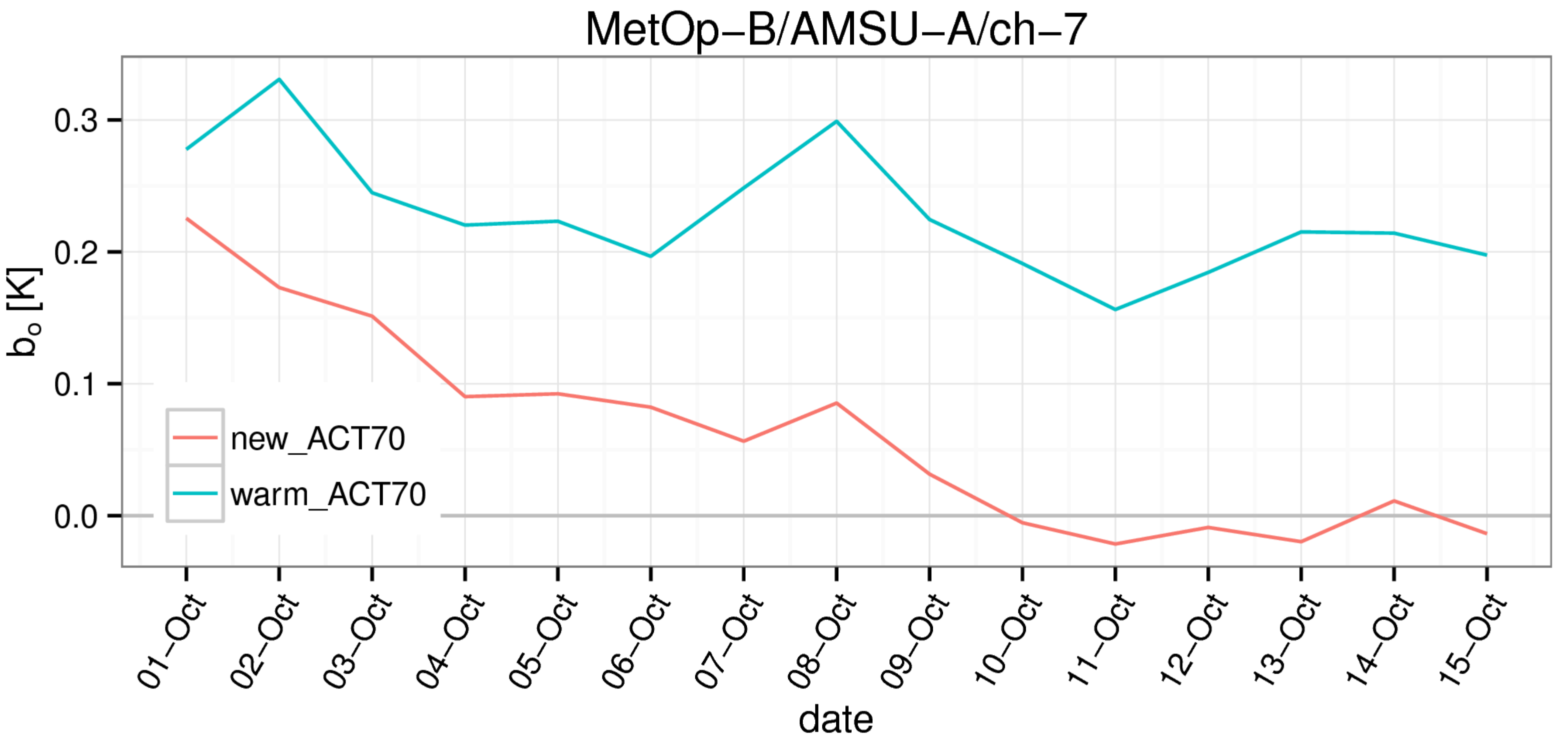
The initialization methods based on global bias parameters provide a better satellite scan-angle bias correction.



The initialization methods based on global bias parameters provide a better air-mass bias correction.



In active DA, the default setting of stiffness parameter has too slow response to satellite bias changes for particular AMSU-A channels.



The VarBC response to an artificial bias (0.3 K) during October 2015.

Summary

- VarBC advantages: a maintenance, an adaptive bias correction WRT time, analysis and available observations.
- Initialization of VarBC:
  - use global-RS if observation bias differences between global and LAM models are not large,
  - use warmstart instead of the coldstart methods,
  - use the new formulation of N_{bg} to estimate the adaptivity of VarBC → especially for the active data assimilation!!
- Preliminary results on RC-LACE webpage:
  - *Mate Mile, Patrik Benacek, 2016: Comparison of different VARBC initialization approaches*
- Latest results – submitted manuscript to the MWR journal:
  - *in a peer review process (08/2017)*

Future plans

- Forecast impact studies
- How to deal with marginal data coverage
- Testing 6h/24h cycling
- Summarize the up to now results concerning:
  - channel selection (IASI, ATOVS, SEVIRI),
  - VarBC scheme,
  - thinning distance,
  - observation error setting.

Thank you for your attention.

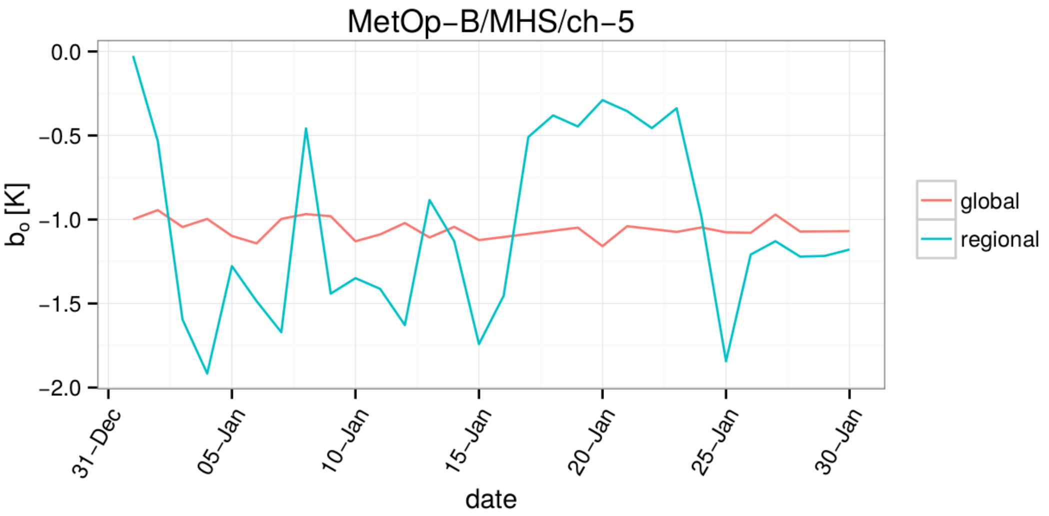
Setting of the stiffness parameter determines a response of VarBC to satellite bias changes as well as NWP model biases.

$$\sigma^2_{\beta_b} = \sigma^2_{b_o} = \frac{\sigma^2_o}{N_{bg}}$$

How set N_{bg} in LAMs??

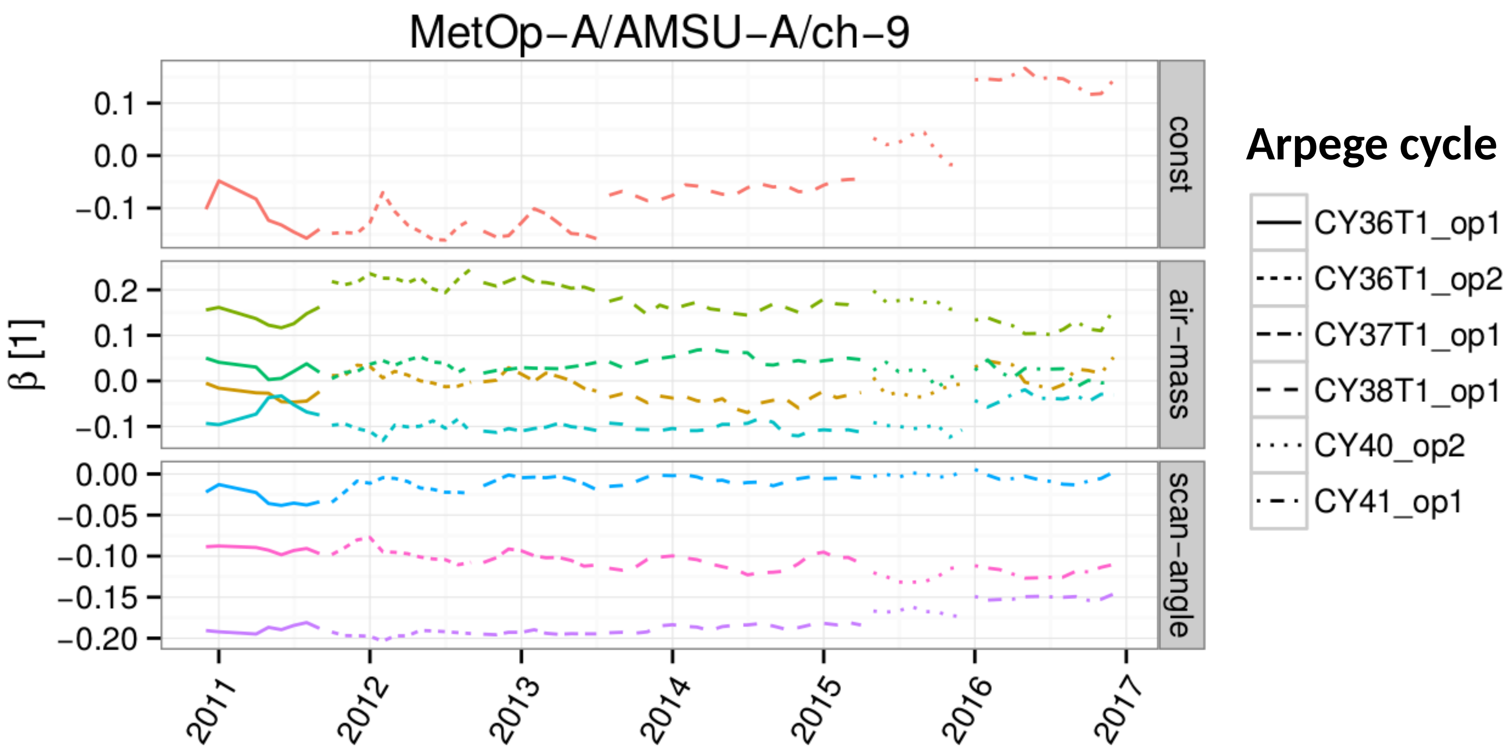
"A statistically meaningful estimate of the observation bias is obtained if the bias parameters vary slowly in time and space." Dee (2005).

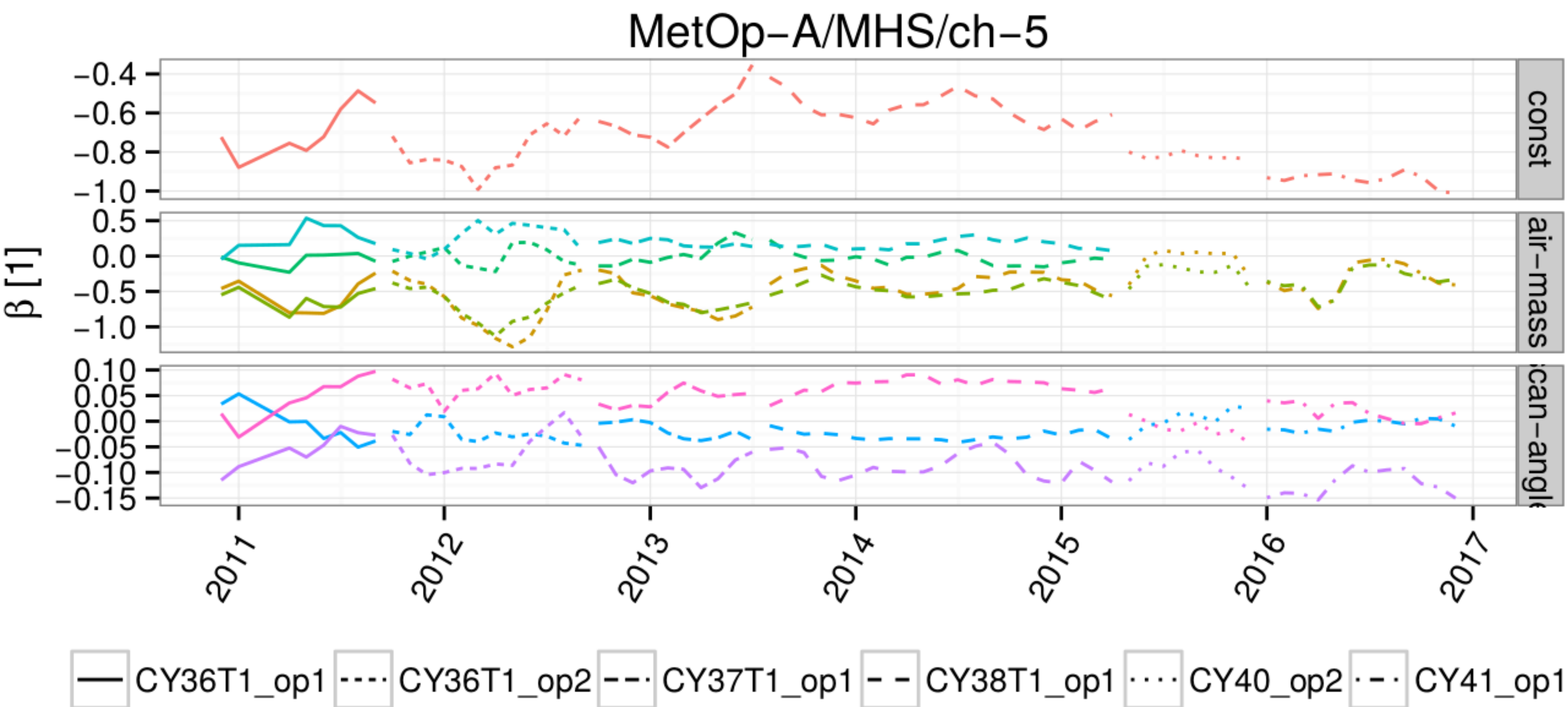
$$\sigma^2_{\beta_b} = \frac{\sigma^2_o}{N_{bg} V^2}$$



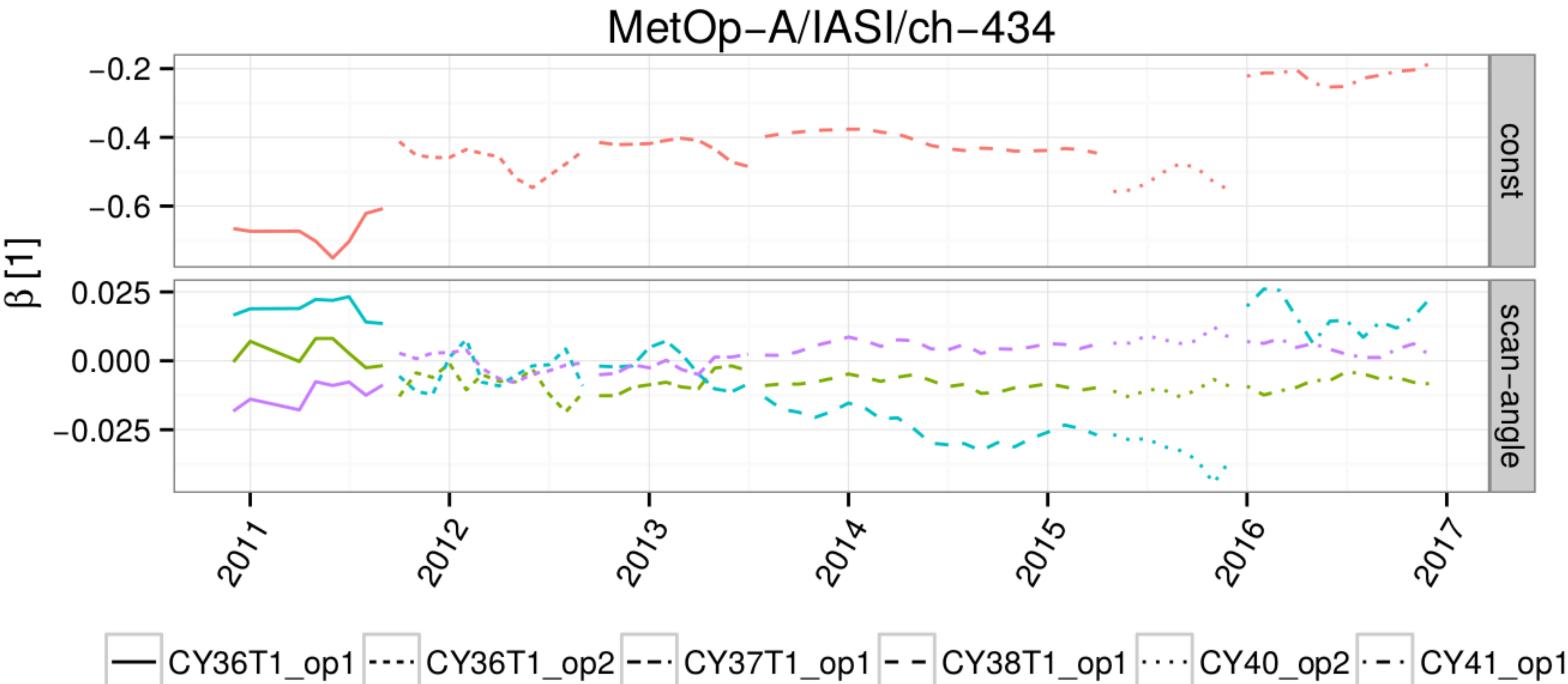
Initialization of bias parameters from a global model requires a consistency between global and LAM systems.

- set of predictors,
- the RTTOV and satellite data pre-processing,
- differences between the radiance bias are not large.





MetOp−A/MHS/ch−5
β [1]
const
air−mass
scan−angle
−0.4
−0.6
−0.8
−1.0
0.5
0.0
−0.5
−1.0
0.10
0.05
0.00
−0.05
−0.10
−0.15
2011
2012
2013
2014
2015
2016
2017
CY36T1_op1
CY36T1_op2
CY37T1_op1
CY38T1_op1
CY40_op2
CY41_op1



MetOp−A/IASI/ch−434
β [1]
−0.2
−0.4
−0.6
0.025
0.000
−0.025
const
scan−angle
2011
2012
2013
2014
2015
2016
2017
CY36T1_op1
CY36T1_op2
CY37T1_op1
CY38T1_op1
CY40_op2
CY41_op1

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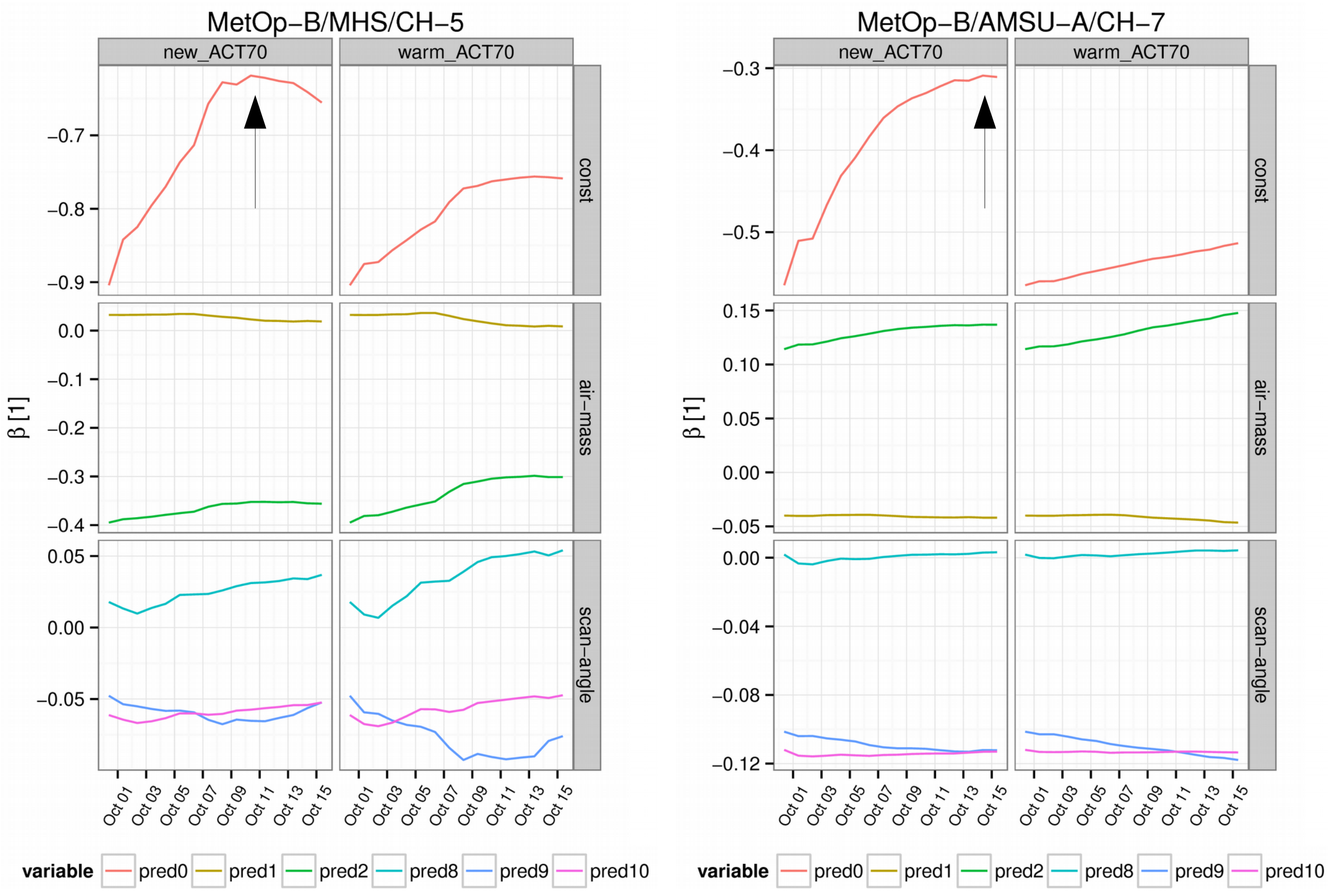

The VarBC response to an artificial bias 0.3 K in terms of bias parameters during October 2015.