Testing of bias correction schemes for satellite data assimilation

a short report based on the master thesis
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Abstract: Satellite sensor AMSU-A provides passive measurements of the radiation emitted from the earth's surface and the atmosphere. The radiances contain temperature and humidity information, but in order for this information to be directly assimilated in a numerical weather prediction (NWP) system, biases between the observed radiances and those simulated from the model first guess must be corrected. After the introduction we recall a notion of analysis, data assimilation and implementation in numerical model ALADIN, which is used by the Czech Hydrometeorological Institute. Then we introduce two radiance-bias correction schemes so-called Harris and Kelly method and variational correction method VarBC. In the last part of my thesis are presented the results of both correction methods for satellite measurements, available in one month periods, and effect of correction is demonstrated on the figures.

Title: Study of bias correction for data assimilation in NWP model ALADIN
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Keywords: analysis, 3DVAR, data assimilation, satellite measurements, bias, Harris a Kelly method, VarBC.

Contents

1 Introduction

In most numerical weather prediction (NWP) centers satellite data are assimilated with the positive impact on the analysis. Like any other measurement system, satellite instrument are not perfect and are prone to error. Random errors are significantly reduced within a data assimilation scheme (spectral, spacial and temporal filtering), but systematic errors (biases) require more sophisticated methods to detect and correct. Biased observation can systematically damage the data assimilation scheme and ultimately the quality of the forecasting system.

The main aim of this work is to set going correction methods in model ALADIN/CE, verify and compare some results of experiments and find some advantages and disadvantages of correction methods.

All experiments were based on the model ALADIN/CE, with following main model characteristics:

- cycle 35t1lentch
- 9 km horizontal resolution and 43 vertical levels
- domain covers roughly the same area as the formal LACE domain (shows fig.1)
- 3h coupling interval, time step 360 s
- 6h assimilation cycle (00, 06, 12, 18 UTC)
- B matrix was computed by the lagged NMC method

Assimilation system is named BlendVar and consist of surface analysis, DFI blending and 3DVAR.

Surface analysis – is based on optimal interpolation method and combine information from report SYNOP, SST analysis from ARPEGE and any others parameters, that are not analyzed, are initialized from ALADIN first guess with the relaxation to climatology

DFI blending – combine upper-air analysis of global model ARPEGE with ALADIN first guess in high resolution

3DVAR – balanced field from DFI blending is assimilated with observation SYNOP and TEMP by variational methods

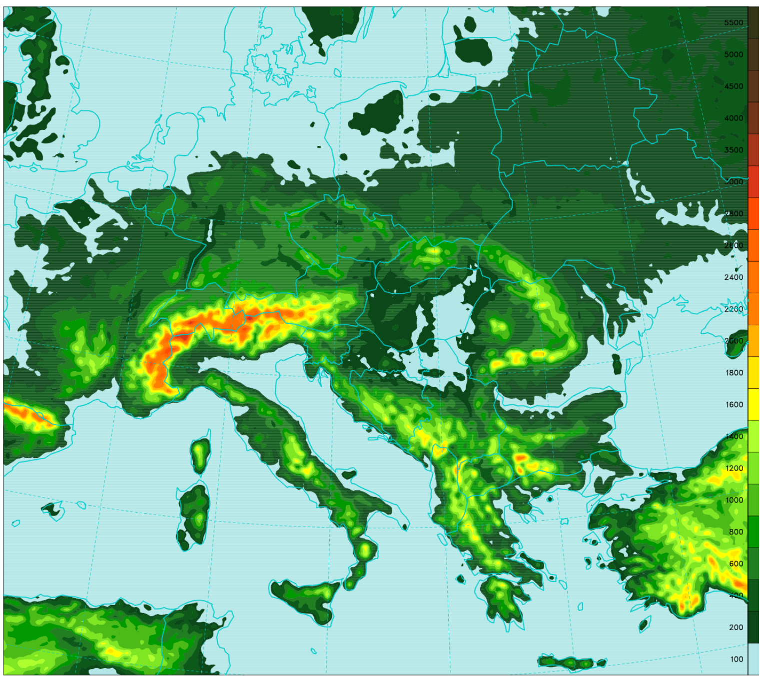

Figure 1: Computational LACE domain of model ALADIN/CE

Before we use satellite data in 3DVAR, it's important to correct biases between observation and first guess. Biases are mainly from instrument characteristic, inaccuracies of the radiative transfer model and of the assimilating model. Correction methods differ in manner of modeling bias, in time, computational and technical support consumption.

We focused on *offline method* by Harris and Kelly and *VarBC method* in my thesis. Methods were tested for polar satellite NOAA15, NOAA16 and NOAA18 for sensor AMSU-A. Data used were available in format OBSOUL from OPLACE system in Hungary.

2 Bias correction methods

2.1 Offline method

It was described by Harris and Kelly (2001) a method to correct radiance biases before using in data assimilation system. The method is able to correct a scan bias (originated from varying scanning angle) and an air-mass bias (arisen from different thermodynamics properties of scanned athmosphere and the surface). An example of bias varation with scan-angle can be seen on figure 2 for satellite NOAA18

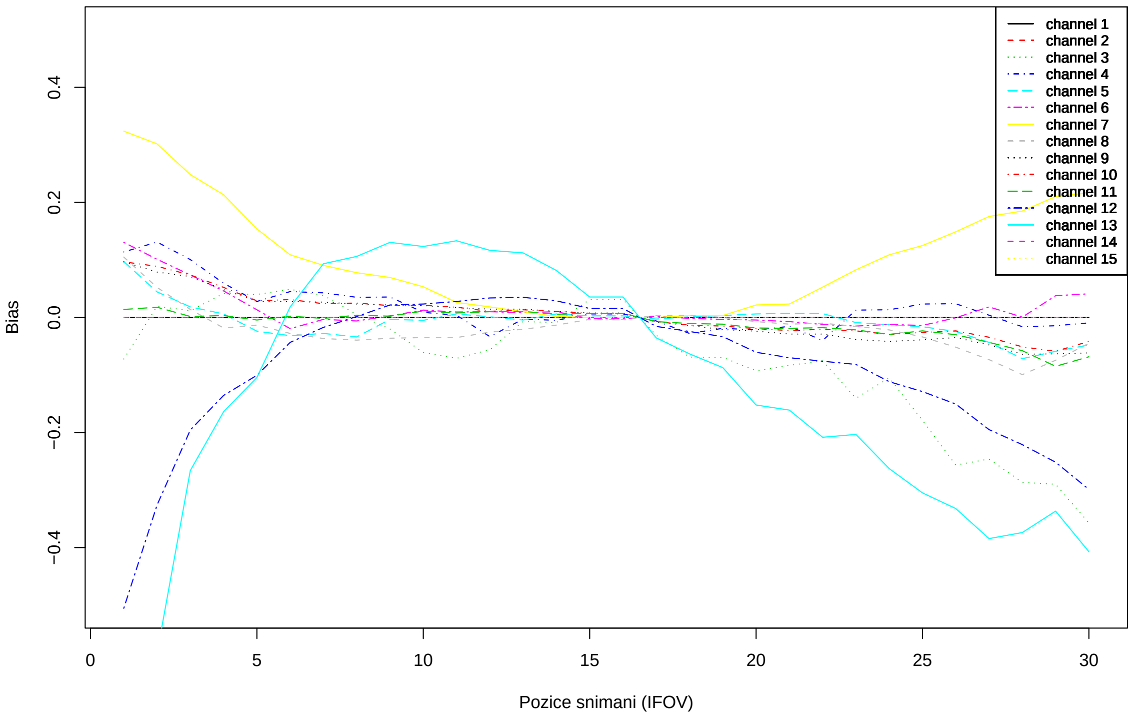

Figure 2: Scan-angle bias dependency of satellite NOAA18 for sensor AMSUA. Y-axis represent size of bias and x-axis represent scan position IFOV. Different color and pattern line is assignment channel of sensor.

The air-mass bias b^{air} is obtained by linear regression of the relation:

$$b^{air} = \beta_0 + \sum_{i=1}^{N} \beta_i p_i(\mathbf{x})$$

where β_i is a weight of N suitable air-mass predictor $p(i)$, that are composed of the following geophysical quantities from the model first-guess: thicknesses pressure levels (1000-300 hPa and 200-50 hPa), skin temperature and total column of water vapor.

Application of offline method: at first we apply correction method to a period (usually 30 days) before run assimilation. During this period are prepared the bias coefficients $\boldsymbol{\beta}$ in ASCII file *bcor_noaa.dat*. The bias coefficients from *bcor_noaa.dat* are used during of all tested periods to compute bias departure.

2.2 VarBC method

Is adaptive method implemented into variational assimilation system. It is adaptive in the sense that the bias parameters are recalculated at each new analysis cycle. VarBC is based on minimization cost function:

$$\boldsymbol{J}_{VarBC} = \boldsymbol{J_o} + \boldsymbol{J}_b + \frac{1}{2}(\boldsymbol{\beta}_b - \boldsymbol{\beta})^T \mathbf{B}_{\beta}{}^{-1}(\boldsymbol{\beta}_b - \boldsymbol{\beta})$$

, where the member $\mathbf{J_0}$ (or $\mathbf{J_b}$) minimizes square errors between observation (or first guess) and analysis. The third member is bias corrected, which adjust coefficients β in each assimilation cycle to take optimally unbiased analysis. Coefficients $\beta_{\mathbf{b}}$ are obtained from previously analysis stored in file VARBC.cycle. When we start assimilation cycle, we can use an initial coefficients $\beta_{\mathbf{b}}$ from:

1. Offline method (stored *bcor_noaa.dat*)
2. VARBC.cycle - available from global model ARPEGE
3. set up $\beta_{\mathbf{b}} = 0$

This method require satellite data to be assimilated. In order to eliminate impact of biased data into analysis, we set up flag EXPERIMENTAL for satellite data in blacklist. This flag increase data observation error to 100.00K, so the contribution weight of observation to cost function J_o is minimal for satellite data, hence data are not used in analysis. More information about settings method VarBC is in APPENDIX A.

3 Setup of experiments

Bias correction was tested on month period of February 2009 (1.2.2009-28.2.2009) and the work comprises in total 6 experiments:

Reference experiment **EP01** – we turn off both correction methods (set up coefficients β equal zero in bcor_noaa.dat) and compute departures between observation and analysis during tested period. This experiment is used as the reference for verification of bias correction method in the following experiments.

Offline method – we don't use satellite data in assimilation and initial coefficients β are computed by offline method during previously month: 1.1.2009-31.1.2009. We run 2 experiments varying in number of use predictors:

- **EP02** – use predictors 1 and 2 from table.
- **EP03** – use predictors 1, 2 and 3 from the table.

Predictor	Character
1	thicknesses of pressure level 1000-300 hPa
2	thicknesses of pressure level 200-50 hPa
3	skin temperature

VarBC – we use satellite data in analysis, but the observation error is set up $100K$. We chose following VarBC predictors in VarBC:

Predictor	Character
1	thicknesses of pressure level 1000-300 hPa
2	thicknesses of pressure level 200-50 hPa
6	thicknesses of pressure level 5-50 hPa
8	Scan angle
9	Scan angle**2
10	Scan angle**3

Method VarBC was tested in 3 experiments from 3 independent initial β_b coefficients, described above:

- **EP04** – from VARBC.cycle (ARPEGE)
- **EP05** – from initial file compute by offline methods
- **EP06** – from $\beta_\mathbf{b} = 0$

4 Results of experiments

In order to evaluate bias corrected methods we have used observation monitoring to check:

- behavior of satellite observation during the tested period against first guess or analysis (example figure 3 top)
- behavior of satellite observation for each satellite channel averaged in tested period against first guess or analysis (example figure 3 bottom)

There is quantitative table of amount of observation, result of quality control (active, passive, ...) and obs-guess (O-G) and obs-analysis (O-A) mean at the end of each satellite monitoring.

It was found that both correction methods have almost no impact on bias reduction for channels 12 and 13. We rejected those channels from figures in all experiments, because of huge bias, which shift dynamically created axis and make monitoring more difficult to evaluate. The values of bias can be found in observation monitoring tables.

In the end of this section is behavior of O-G and O-A departures on tested period for channel 6 of satellite NOAA18 at 12UTC (figure 11), where you can see the influence of different initial conditions for bias correction of VarBC (EP04, EP05 and EP06).

4.1 Offline method EP02 and EP03

NOAA15 - Offline

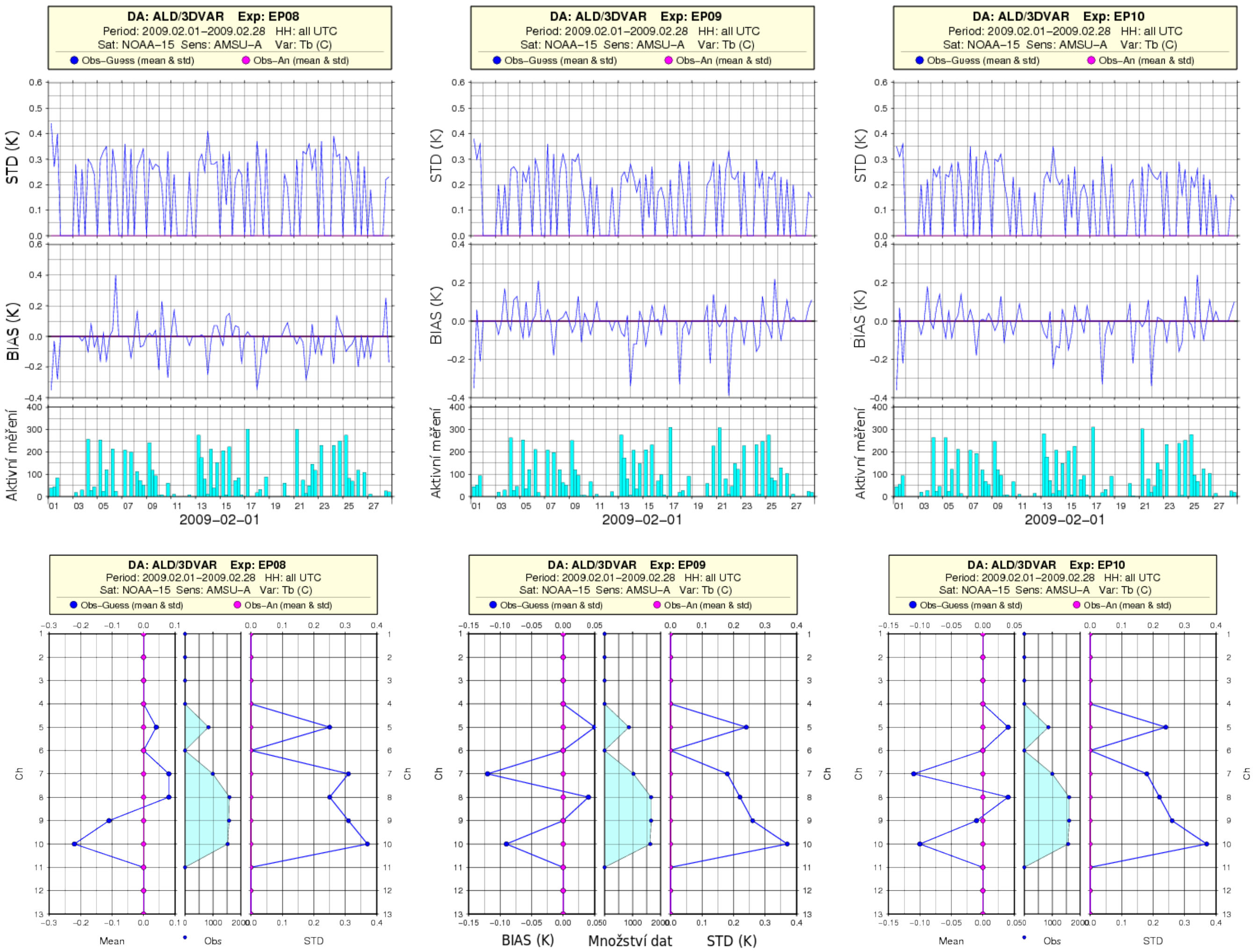

Figure 3: Monitoring of satellite NOAA15. Figures above show time evolution of mean and standard deviation of obs-guess for experiments (from left): reference EP01 and offline methods EP02 and EP03. Figures below show mean and standard deviation of obs-guess for each channel of sensor AMSU-A.

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	89590	0	0	100	89590	0.00	0.00	0.00	0.00
2	89602	0	0	86	89602	0.00	0.00	0.00	0.00
3	88214	0	0	0	88214	0.00	0.00	0.00	0.00
4	88278	0	0	0	88278	0.00	0.00	0.00	0.00
5	88274	837	0	29661	70394	0.04	0.00	0.25	0.00
6	88254	0	0	44316	88254	0.00	0.00	0.00	0.00
7	88560	996	0	22128	69688	0.08	0.00	0.31	0.00
8	88278	1584	0	70684	16110	0.08	0.00	0.25	0.00
9	88268	1573	0	70961	16116	-0.11	0.00	0.31	0.00
10	88264	1522	0	72476	16114	-0.22	0.00	0.37	0.00
11	0	0	0	0	0	0.00	0.00	0.00	0.00
12	88040	1169	0	76887	16070	-0.24	0.00	1.06	0.00
13	87224	723	0	80449	16126	0.53	0.00	1.84	0.00
14	20	0	0	20	20	0.00	0.00	0.00	0.00
15	88272	0	0	0	88272	0.00	0.00	0.00	0.00

Table 1 NOAA-15 AMSU-A observation summary of EP01

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	92122	0	0	104	92122	0.00	0.00	0.00	0.00
2	92134	0	0	90	92134	0.00	0.00	0.00	0.00
3	90746	0	0	0	90746	0.00	0.00	0.00	0.00
4	90810	0	0	0	90810	0.00	0.00	0.00	0.00
5	90806	868	0	31196	72494	0.05	0.00	0.24	0.00
6	90786	0	0	45430	90786	0.00	0.00	0.00	0.00
7	91092	1031	0	18437	71628	-0.12	0.00	0.18	0.00
8	90810	1656	0	72594	16572	0.04	0.00	0.22	0.00
9	90800	1657	0	72635	16578	-0.00	0.00	0.26	0.00
10	90796	1630	0	73216	16576	-0.09	0.00	0.37	0.00
11	0	0	0	0	0	0.00	0.00	0.00	0.00
12	90572	1399	0	78367	16532	0.02	0.00	1.11	0.00
13	89696	751	0	83581	16956	0.35	0.00	1.85	0.00
14	20	0	0	20	20	0.00	0.00	0.00	0.00
15	90804	0	0	0	90804	0.00	0.00	0.00	0.00

Table 2 NOAA-15 AMSU-A observation summary of EP02

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	89590	0	0	100	89590	0.00	0.00	0.00	0.00
2	89602	0	0	84	89602	0.00	0.00	0.00	0.00
3	88214	0	0	0	88214	0.00	0.00	0.00	0.00
4	88278	0	0	0	88278	0.00	0.00	0.00	0.00
5	88274	864	0	30096	70102	0.04	0.00	0.24	0.00
6	88254	0	0	44304	88254	0.00	0.00	0.00	0.00
7	88560	1000	0	18066	69498	-0.11	0.00	0.18	0.00
8	88278	1600	0	70576	16110	0.04	0.00	0.22	0.00
9	88268	1601	0	70619	16116	-0.01	0.00	0.26	0.00
10	88264	1568	0	71210	16114	-0.10	0.00	0.37	0.00
11	0	0	0	0	0	0.00	0.00	0.00	0.00
12	88040	1373	0	75933	16070	0.02	0.00	1.08	0.00
13	87224	843	0	80683	16490	0.60	0.00	1.80	0.00
14	20	0	0	20	20	0.00	0.00	0.00	0.00
15	88272	0	0	0	88272	0.00	0.00	0.00	0.00

Table 3 NOAA-15 AMSU-A observation summary of EP03

NOAA18 - Offline

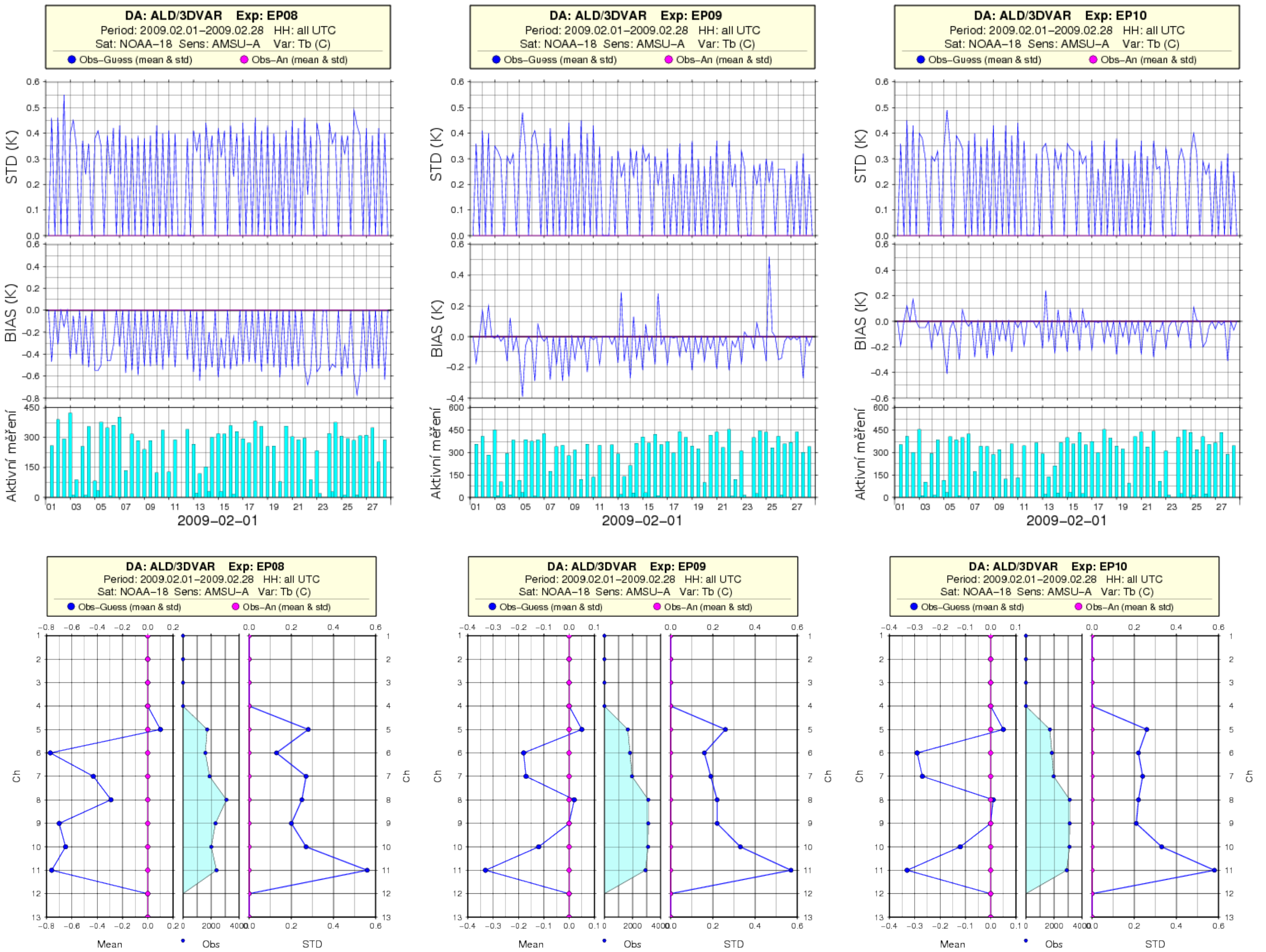

Figure 4: Monitoring of satellite NOAA18. Figures above show time evolution of mean and standard deviation of obs-guess for experiments (from left): reference EP01 and offline methods EP02 and EP03. Figures below show mean and standard deviation of obs-guess for each channel of sensor AMSU-A.

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	151193	0	0	67	151193	0.00	0.00	0.00	0.00
2	151197	0	0	64	151197	0.00	0.00	0.00	0.00
3	150857	0	0	0	150857	0.00	0.00	0.00	0.00
4	149606	0	0	0	149606	0.00	0.00	0.00	0.00
5	150857	1722	0	51677	120776	0.10	0.00	0.28	0.00
6	150857	1591	0	63123	119232	-0.77	0.00	0.13	0.00
7	150857	1890	0	37281	119111	-0.43	0.00	0.27	0.00
8	150857	3096	0	119546	28360	-0.29	0.00	0.25	0.00
9	150857	2319	0	128879	28360	-0.70	0.00	0.20	0.00
10	150857	2016	0	131280	28360	-0.65	0.00	0.27	0.00
11	150857	2381	0	129240	28360	-0.76	0.00	0.56	0.00
12	150857	2016	0	133551	28360	-0.59	0.00	1.02	0.00
13	150857	1416	0	138611	29512	0.24	0.00	1.80	0.00
14	150857	0	0	88412	150857	0.00	0.00	0.00	0.00
15	150857	0	0	0	150857	0.00	0.00	0.00	0.00

Table 4 NOAA-18 AMSU-A observation summary of EP01

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	151193	0	0	67	151193	0.00	0.00	0.00	0.00
2	151197	0	0	62	151197	0.00	0.00	0.00	0.00
3	150857	0	0	0	150857	0.00	0.00	0.00	0.00
4	149606	0	0	0	149606	0.00	0.00	0.00	0.00
5	150857	1660	0	50485	122213	0.05	0.00	0.26	0.00
6	150857	1818	0	51138	120834	-0.18	0.00	0.16	0.00
7	150857	1957	0	28226	120700	-0.17	0.00	0.19	0.00
8	150857	3121	0	119420	28360	0.02	0.00	0.22	0.00
9	150857	3124	0	119375	28360	0.00	0.00	0.22	0.00
10	150857	3104	0	119853	28360	-0.12	0.00	0.33	0.00
11	150857	2915	0	122459	28360	-0.33	0.00	0.57	0.00
12	150857	2457	0	131730	28360	0.00	0.00	1.11	0.00
13	150857	1356	0	140378	28580	0.27	0.00	1.83	0.00
14	150857	0	0	88413	150857	0.00	0.00	0.00	0.00
15	150857	0	0	0	150857	0.00	0.00	0.00	0.00

Table 5 NOAA-18 AMSU-A observation summary of EP02

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	151193	0	0	67	151193	0.00	0.00	0.00	0.00
2	151197	0	0	62	151197	0.00	0.00	0.00	0.00
3	150857	0	0	0	150857	0.00	0.00	0.00	0.00
4	149606	0	0	0	149606	0.00	0.00	0.00	0.00
5	150857	1703	0	50990	121506	0.05	0.00	0.26	0.00
6	150857	1845	0	51678	120255	-0.29	0.00	0.22	0.00
7	150857	1976	0	29320	120158	-0.27	0.00	0.24	0.00
8	150857	3115	0	119420	28360	0.01	0.00	0.22	0.00
9	150857	3118	0	119385	28360	0.00	0.00	0.21	0.00
10	150857	3099	0	119850	28360	-0.12	0.00	0.33	0.00
11	150857	2908	0	122489	28360	-0.33	0.00	0.58	0.00
12	150857	2550	0	130881	28360	0.01	0.00	1.09	0.00
13	150857	1540	0	139676	28598	0.39	0.00	1.84	0.00
14	150857	0	0	88428	150857	0.00	0.00	0.00	0.00
15	150857	0	0	0	150857	0.00	0.00	0.00	0.00

Table 6 NOAA-18 AMSU-A observation summary of EP03

4.2 VarBC method EP04, EP05 and EP06

NOAA15 - VarBC

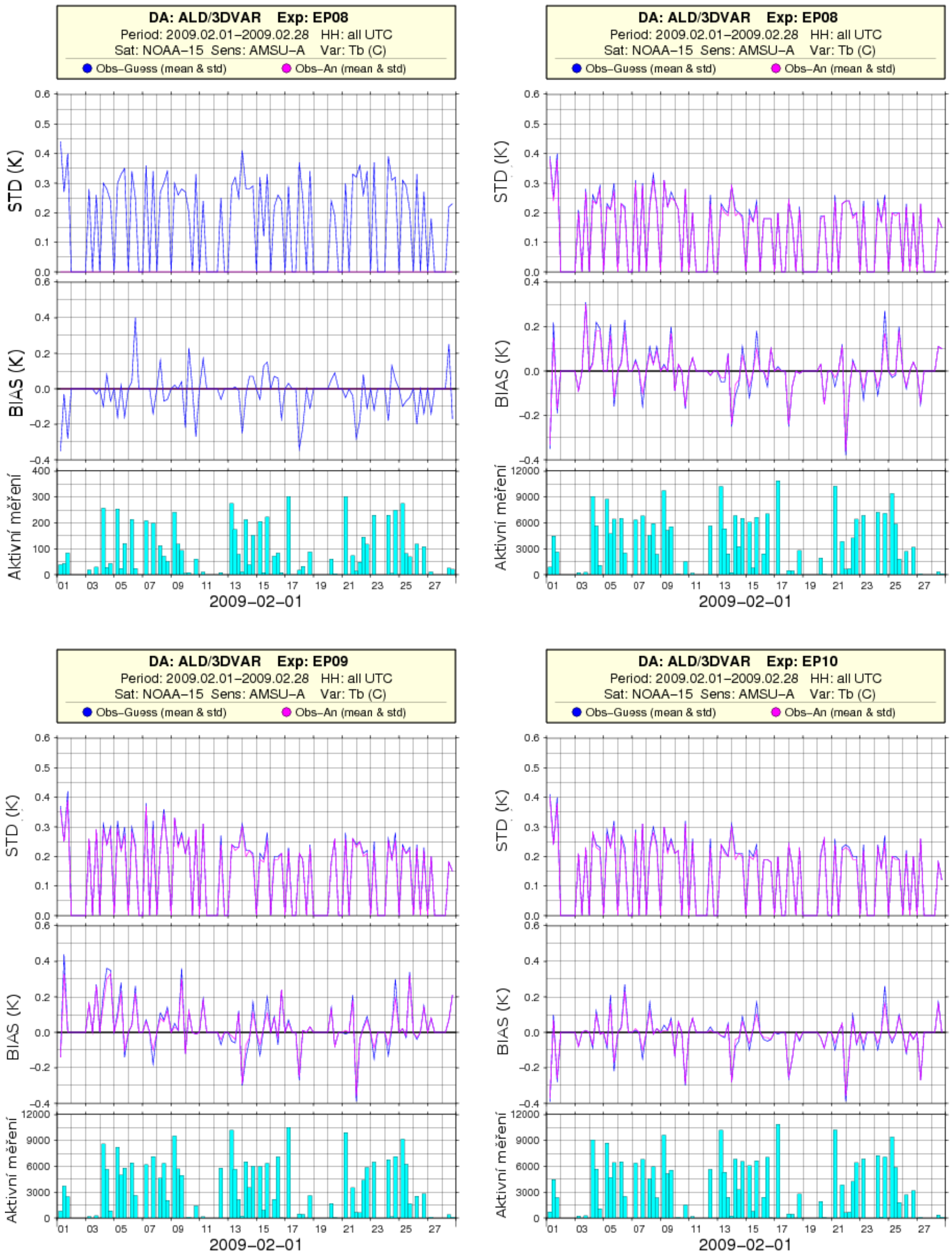

Figure 5: Monitoring of satellite NOAA15. Figures show time evolution of mean and standard deviation of obs-guess (blue) and obs-analysis (red) for experiments (from left above): reference EP01, EP04 and (from left below) EP05 and EP06.

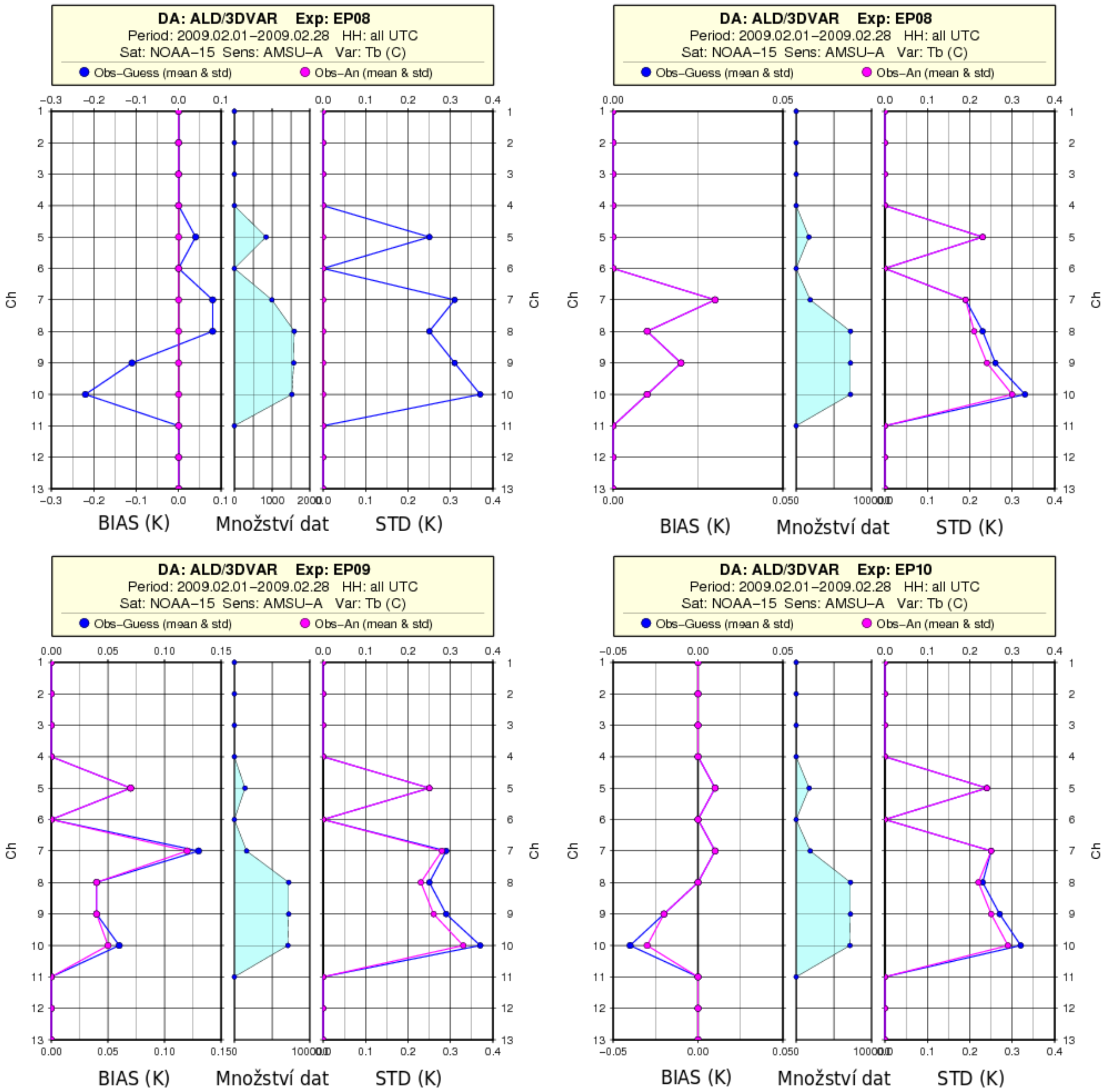

Figure 6: Monitoring of satellite NOAA15. Figures show mean and standard deviation of obs-guess (blue) and obs-analysis (red) for each channel AMSUA for experiments (from left): reference EP01, EP04 and (from left below) EP05 and EP06.

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	89590	0	0	100	89590	0.00	0.00	0.00	0.00
2	89602	0	0	86	89602	0.00	0.00	0.00	0.00
3	88214	0	0	0	88214	0.00	0.00	0.00	0.00
4	88278	0	0	0	88278	0.00	0.00	0.00	0.00
5	88274	837	0	29661	70394	0.04	0.00	0.25	0.00
6	88254	0	0	44316	88254	0.00	0.00	0.00	0.00
7	88560	996	0	22128	69688	0.08	0.00	0.31	0.00
8	88278	1584	0	70684	16110	0.08	0.00	0.25	0.00
9	88268	1573	0	70961	16116	-0.11	0.00	0.31	0.00
10	88264	1522	0	72476	16114	-0.22	0.00	0.37	0.00
11	0	0	0	0	0	0.00	0.00	0.00	0.00
12	88040	1169	0	76887	16070	-0.24	0.00	1.06	0.00
13	87224	723	0	80449	16126	0.53	0.00	1.84	0.00
14	20	0	0	20	20	0.00	0.00	0.00	0.00
15	88272	0	0	0	88272	0.00	0.00	0.00	0.00

Table 7 NOAA-15 AMSU-A observation summary of EP01

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	89590	0	0	89590	89590	0.00	0.00	0.00	0.00
2	89602	0	0	89602	89602	0.00	0.00	0.00	0.00
3	88214	0	0	88214	88214	0.00	0.00	0.00	0.00
4	88278	0	0	88278	88278	0.00	0.00	0.00	0.00
5	88274	17082	17860	71192	70414	-0.00	-0.00	0.23	0.23
6	88254	0	0	88254	88254	0.00	0.00	0.00	0.00
7	88560	18838	18840	69722	69720	0.03	0.03	0.19	0.19
8	88278	72128	72168	16150	16110	0.01	0.01	0.23	0.21
9	88268	72098	72152	16170	16116	0.02	0.02	0.26	0.24
10	88264	71810	72150	16454	16114	0.01	0.01	0.33	0.30
11	0	0	0	0	0	0.00	0.00	0.00	0.00
12	88040	60914	71970	27126	16070	0.07	0.07	1.08	0.99
13	87224	0	0	87224	87224	0.00	0.00	0.00	0.00
14	20	0	0	20	20	0.00	0.00	0.00	0.00
15	88272	0	0	88272	88272	0.00	0.00	0.00	0.00

Table 8 NOAA-15 AMSU-A observation summary of EP04

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	89590	0	0	89590	89590	0.00	0.00	0.00	0.00
2	89602	0	0	89602	89602	0.00	0.00	0.00	0.00
3	88214	0	0	88214	88214	0.00	0.00	0.00	0.00
4	88278	0	0	88278	88278	0.00	0.00	0.00	0.00
5	88274	13986	15542	74288	72732	0.07	0.07	0.25	0.25
6	88254	0	0	88254	88254	0.00	0.00	0.00	0.00
7	88560	16396	16650	72164	71910	0.13	0.12	0.29	0.28
8	88278	72090	72168	16188	16110	0.04	0.04	0.25	0.23
9	88268	72106	72152	16162	16116	0.04	0.04	0.29	0.26
10	88264	70786	72150	17478	16114	0.06	0.05	0.37	0.33
11	0	0	0	0	0	0.00	0.00	0.00	0.00
12	88040	62304	71970	25736	16070	-0.01	0.01	1.06	0.97
13	87224	0	0	87224	87224	0.00	0.00	0.00	0.00
14	20	0	0	20	20	0.00	0.00	0.00	0.00
15	88272	0	0	88272	88272	0.00	0.00	0.00	0.00

Table 9 NOAA-15 AMSU-A observation summary of EP05

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	89590	0	0	89590	89590	0.00	0.00	0.00	0.00
2	89602	0	0	89602	89602	0.00	0.00	0.00	0.00
3	88214	0	0	88214	88214	0.00	0.00	0.00	0.00
4	88278	0	0	88278	88278	0.00	0.00	0.00	0.00
5	88274	17110	17888	71164	70386	0.01	0.01	0.24	0.24
6	88254	0	0	88254	88254	0.00	0.00	0.00	0.00
7	88560	18862	18876	69698	69684	0.01	0.01	0.25	0.25
8	88278	72114	72168	16164	16110	0.00	0.00	0.23	0.22
9	88268	72008	72152	16260	16116	-0.02	-0.02	0.27	0.25
10	88264	71330	72150	16934	16114	-0.04	-0.03	0.32	0.29
11	0	0	0	0	0	0.00	0.00	0.00	0.00
12	88040	59286	71970	28754	16070	0.03	0.03	1.09	1.00
13	87224	0	0	87224	87224	0.00	0.00	0.00	0.00
14	20	0	0	20	20	0.00	0.00	0.00	0.00
15	88272	0	0	88272	88272	0.00	0.00	0.00	0.00

Table 10 NOAA-15 AMSU-A observation summary of EP06

NOAA16 - VarBC

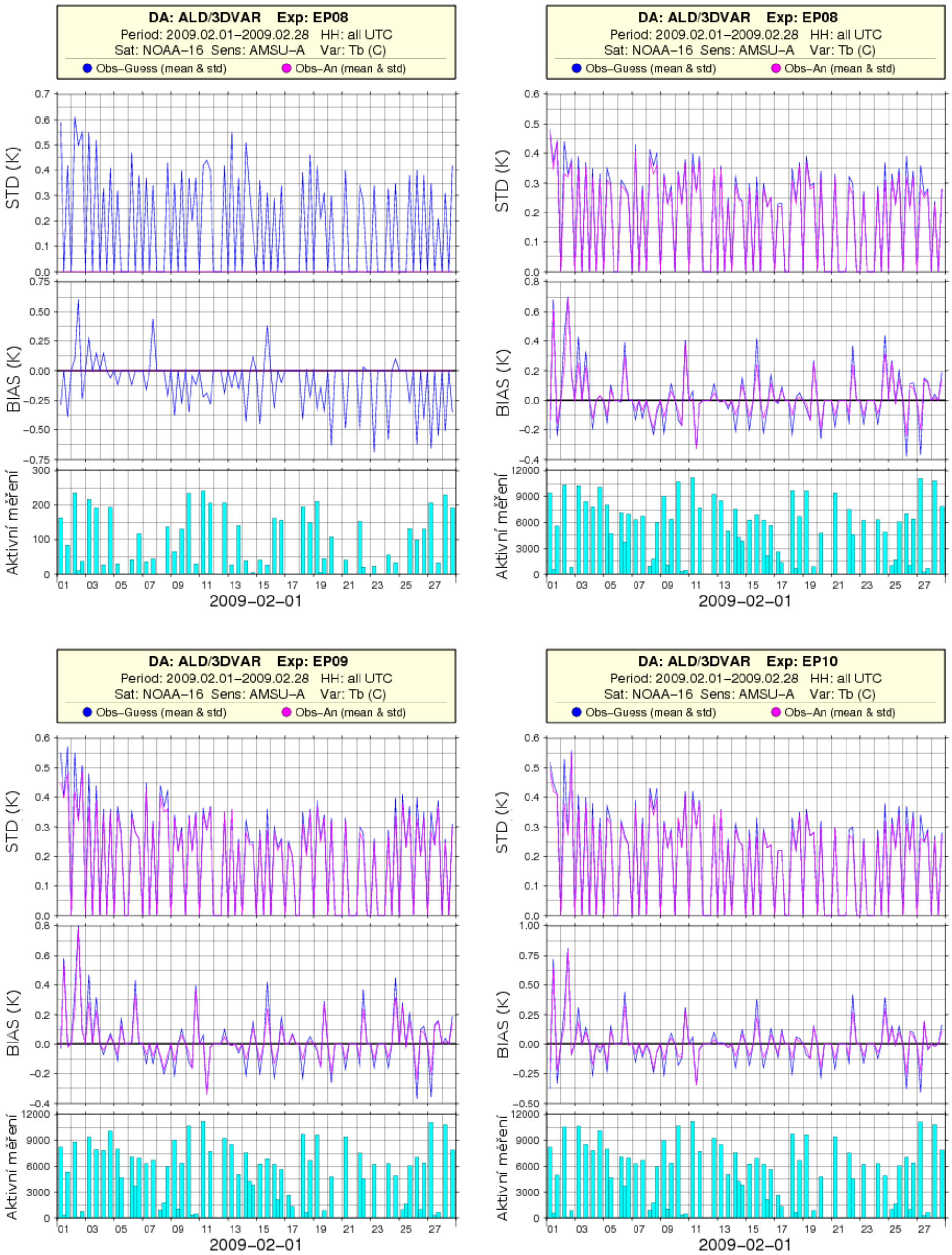

Figure 7: Monitoring of satellite NOAA16. Figures show time evolution of mean and standard deviation of obs-guess (blue) and obs-analysis (red) for experiments (from left): reference EP01, EP04 and (from left below) EP05 and EP06.

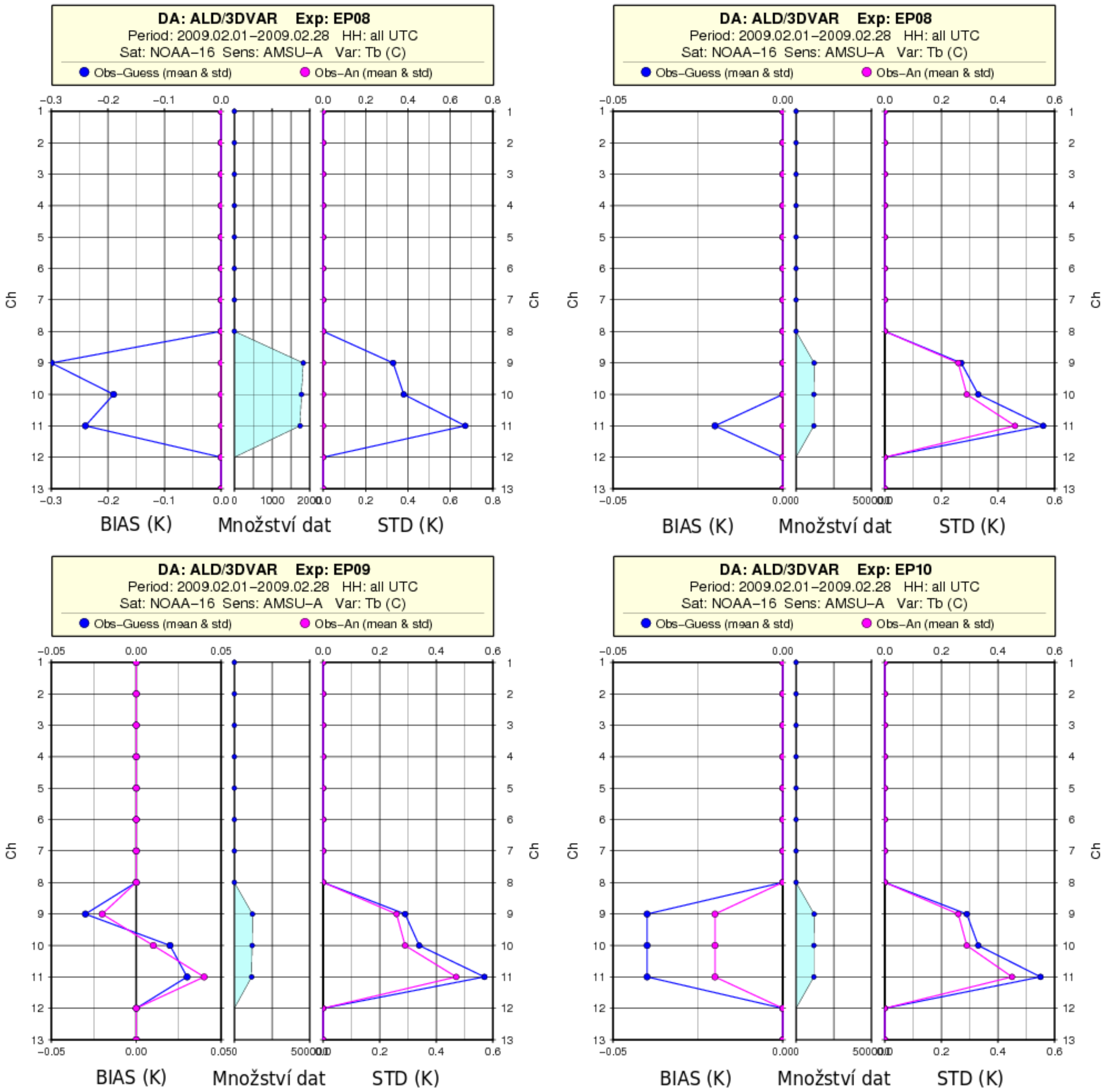

Figure 8: Monitoring of satellite NOAA16. Figures show mean and standard deviation of obs-guess (blue) and obs-analysis (red) for each channel AMSUA for experiments (from left): reference EP01, EP04 and (from left below) EP05 and EP06.

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	148060	0	0	50	148060	0.00	0.00	0.00	0.00
2	148060	0	0	42	148060	0.00	0.00	0.00	0.00
3	148044	0	0	0	148044	0.00	0.00	0.00	0.00
4	0	0	0	0	0	0.00	0.00	0.00	0.00
5	148044	0	0	22026	148044	0.00	0.00	0.00	0.00
6	148044	0	0	44624	148044	0.00	0.00	0.00	0.00
7	148044	0	0	6204	148044	0.00	0.00	0.00	0.00
8	145646	0	0	10176	145646	0.00	0.00	0.00	0.00
9	148044	1828	0	121062	27736	-0.30	0.00	0.33	0.00
10	147308	1779	0	122133	27584	-0.19	0.00	0.38	0.00
11	148044	1744	0	122436	27736	-0.24	0.00	0.67	0.00
12	147658	1319	0	130995	27638	-0.52	0.00	1.02	0.00
13	147934	813	0	136981	28176	0.21	0.00	1.72	0.00
14	148044	0	0	92230	148044	0.00	0.00	0.00	0.00
15	147188	0	0	0	147188	0.00	0.00	0.00	0.00

Table 11 NOAA-16 AMSU-A observation summary of EP01

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	148060	0	0	148060	148060	0.00	0.00	0.00	0.00
2	148060	0	0	148060	148060	0.00	0.00	0.00	0.00
3	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
4	0	0	0	0	0	0.00	0.00	0.00	0.00
5	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
6	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
7	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
8	145646	0	0	145646	145646	0.00	0.00	0.00	0.00
9	148044	120144	120308	27900	27736	-0.00	0.00	0.27	0.26
10	147308	118942	119724	28366	27584	-0.00	0.00	0.33	0.29
11	148044	118082	120308	29962	27736	-0.02	-0.00	0.56	0.46
12	147658	99676	120020	47982	27638	-0.02	0.00	1.09	0.96
13	147934	0	0	147934	147934	0.00	0.00	0.00	0.00
14	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
15	147188	0	0	147188	147188	0.00	0.00	0.00	0.00

Table 12 NOAA-16 AMSU-A observation summary of EP04

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	148060	0	0	148060	148060	0.00	0.00	0.00	0.00
2	148060	0	0	148060	148060	0.00	0.00	0.00	0.00
3	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
4	0	0	0	0	0	0.00	0.00	0.00	0.00
5	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
6	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
7	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
8	145646	0	0	145646	145646	0.00	0.00	0.00	0.00
9	148044	119228	120308	28816	27736	-0.03	-0.02	0.29	0.26
10	147308	118582	119724	28726	27584	0.02	0.01	0.34	0.29
11	148044	114812	120308	33232	27736	0.03	0.04	0.57	0.47
12	147658	99274	120020	48384	27638	0.10	0.09	1.12	1.02
13	147934	0	0	147934	147934	0.00	0.00	0.00	0.00
14	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
15	147188	0	0	147188	147188	0.00	0.00	0.00	0.00

Table 13 NOAA-16 AMSU-A observation summary of EP05

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	148060	0	0	148060	148060	0.00	0.00	0.00	0.00
2	148060	0	0	148060	148060	0.00	0.00	0.00	0.00
3	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
4	0	0	0	0	0	0.00	0.00	0.00	0.00
5	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
6	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
7	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
8	145646	0	0	145646	145646	0.00	0.00	0.00	0.00
9	148044	119156	120308	28888	27736	-0.04	-0.02	0.29	0.26
10	147308	118286	119724	29022	27584	-0.04	-0.02	0.33	0.29
11	148044	118772	120308	29272	27736	-0.04	-0.02	0.55	0.45
12	147658	97166	120020	50492	27638	-0.05	-0.02	1.09	0.97
13	147934	0	0	147934	147934	0.00	0.00	0.00	0.00
14	148044	0	0	148044	148044	0.00	0.00	0.00	0.00
15	147188	0	0	147188	147188	0.00	0.00	0.00	0.00

Table 14 NOAA-16 AMSU-A observation summary of EP06

NOAA18 - VarBC

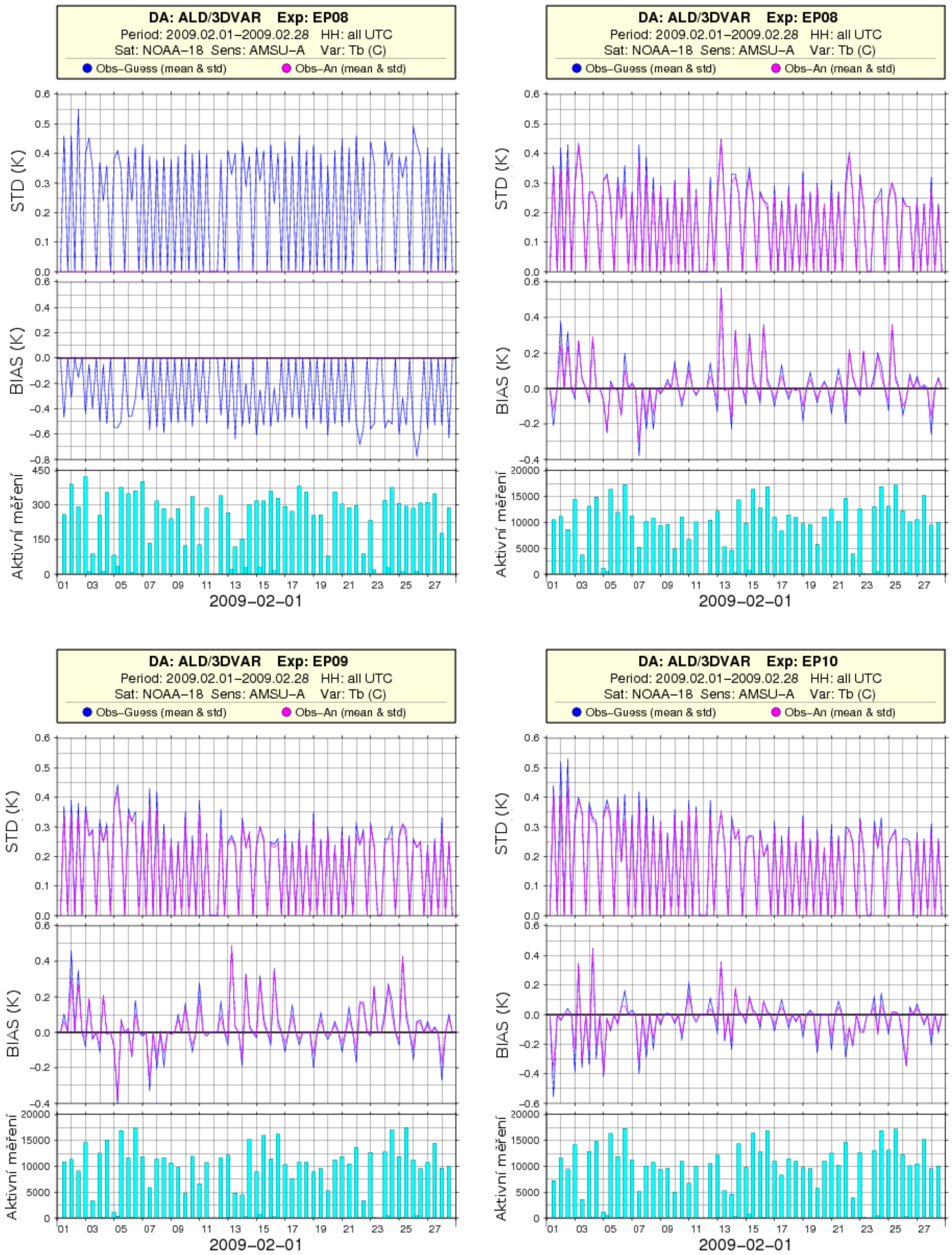

Figure 9: Monitoring of satellite NOAA18. Figures show time evolution of mean and standard deviation of obs-guess (blue) and obs-analysis (red) for experiments (from left): reference EP01, EP04 and (from left below) EP05 and EP06.

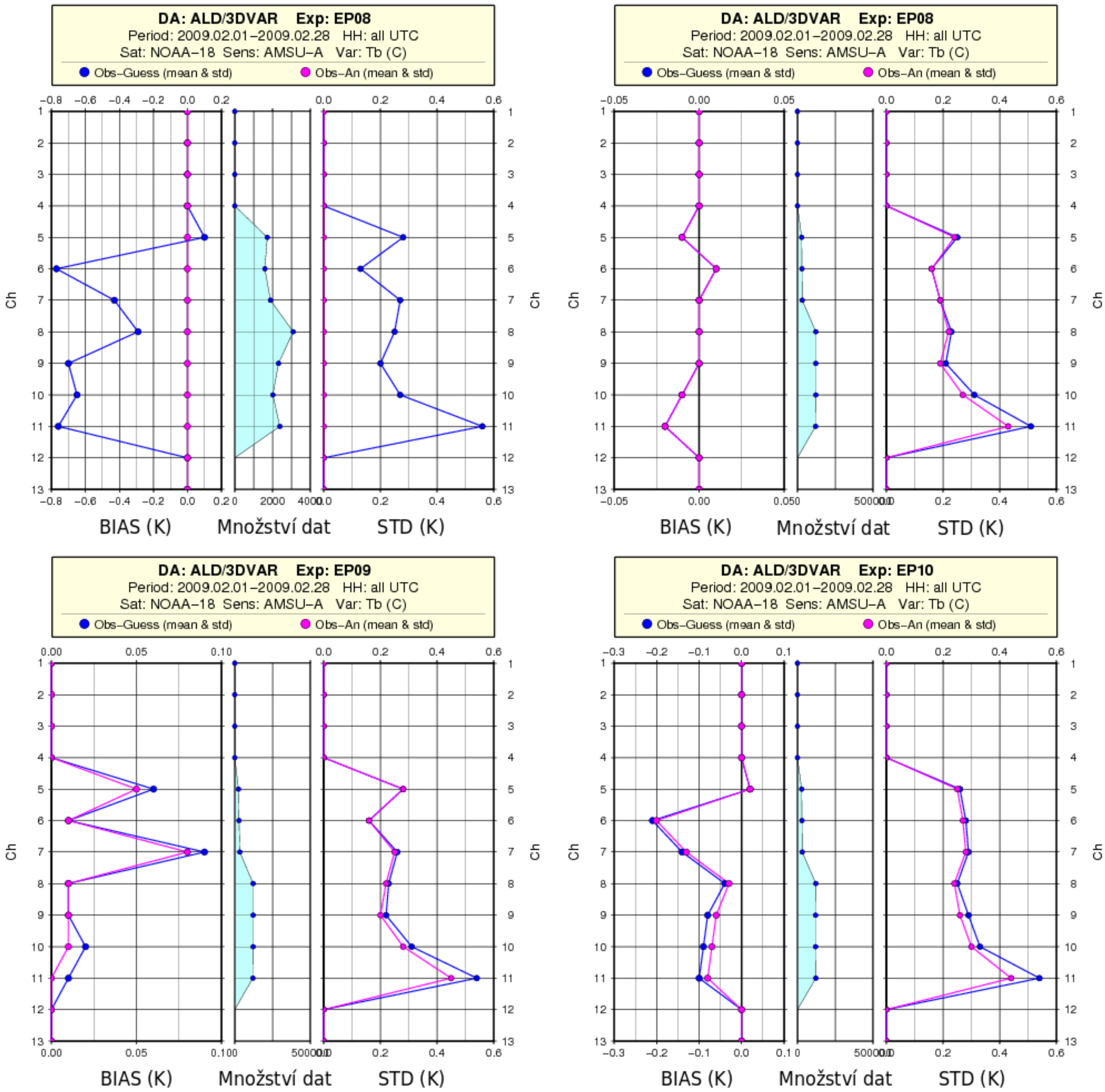

Figure 10: Monitoring of satellite NOAA18. Figures show mean and standard deviation of obs-guess (blue) and obs-analysis (red) for each channel AMSUA for experiments (from left): reference EP01, EP04 and (from left below) EP05 and EP06.

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	151193	0	0	67	151193	0.00	0.00	0.00	0.00
2	151197	0	0	64	151197	0.00	0.00	0.00	0.00
3	150857	0	0	0	150857	0.00	0.00	0.00	0.00
4	149606	0	0	0	149606	0.00	0.00	0.00	0.00
5	150857	1722	0	51677	120776	0.10	0.00	0.28	0.00
6	150857	1591	0	63123	119232	-0.77	0.00	0.13	0.00
7	150857	1890	0	37281	119111	-0.43	0.00	0.27	0.00
8	150857	3096	0	119546	28360	-0.29	0.00	0.25	0.00
9	150857	2319	0	128879	28360	-0.70	0.00	0.20	0.00
10	150857	2016	0	131280	28360	-0.65	0.00	0.27	0.00
11	150857	2381	0	129240	28360	-0.76	0.00	0.56	0.00
12	150857	2016	0	133551	28360	-0.59	0.00	1.02	0.00
13	150857	1416	0	138611	29512	0.24	0.00	1.80	0.00
14	150857	0	0	88412	150857	0.00	0.00	0.00	0.00
15	150857	0	0	0	150857	0.00	0.00	0.00	0.00

Table 15 NOAA-18 AMSU-A observation summary of EP01

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	151193	0	0	151193	151193	0.00	0.00	0.00	0.00
2	151197	0	0	151197	151197	0.00	0.00	0.00	0.00
3	150857	0	0	150857	150857	0.00	0.00	0.00	0.00
4	149606	0	0	149606	149606	0.00	0.00	0.00	0.00
5	150857	28885	30085	121972	120772	-0.01	-0.01	0.25	0.24
6	150857	30312	31633	120545	119224	0.01	0.01	0.16	0.16
7	150857	31708	31752	119149	119105	-0.00	-0.00	0.19	0.19
8	150857	122319	122497	28538	28360	-0.00	-0.00	0.23	0.22
9	150857	122495	122497	28362	28360	-0.00	-0.00	0.21	0.19
10	150857	122069	122497	28788	28360	-0.01	-0.01	0.31	0.27
11	150857	120255	122497	30602	28360	-0.02	-0.02	0.51	0.43
12	150857	100227	122497	50630	28360	0.01	-0.01	1.02	0.92
13	150857	0	0	150857	150857	0.00	0.00	0.00	0.00
14	150857	0	0	150857	150857	0.00	0.00	0.00	0.00
15	150857	0	0	150857	150857	0.00	0.00	0.00	0.00

Table 16 NOAA-18 AMSU-A observation summary of EP04

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	151193	0	0	151193	151193	0.00	0.00	0.00	0.00
2	151197	0	0	151197	151197	0.00	0.00	0.00	0.00
3	150857	0	0	150857	150857	0.00	0.00	0.00	0.00
4	149606	0	0	149606	149606	0.00	0.00	0.00	0.00
5	150857	25546	30165	125311	120692	0.06	0.05	0.28	0.28
6	150857	29020	34200	121837	116657	0.01	0.01	0.16	0.16
7	150857	34149	34230	116708	116627	0.09	0.08	0.26	0.25
8	150857	122305	122497	28552	28360	0.01	0.01	0.23	0.22
9	150857	122495	122497	28362	28360	0.01	0.01	0.22	0.20
10	150857	121691	122497	29166	28360	0.02	0.01	0.31	0.28
11	150857	119089	122497	31768	28360	0.01	0.00	0.54	0.45
12	150857	100150	122497	50707	28360	-0.07	-0.07	1.02	0.92
13	150857	0	0	150857	150857	0.00	0.00	0.00	0.00
14	150857	0	0	150857	150857	0.00	0.00	0.00	0.00
15	150857	0	0	150857	150857	0.00	0.00	0.00	0.00

Table 17 NOAA-18 AMSU-A observation summary of EP05

Channel	Total	Active	Pass	Reject	Black	O-G Mean	O-A Mean	O-G STD	O-A STD
1	151193	0	0	151193	151193	0.00	0.00	0.00	0.00
2	151197	0	0	151197	151197	0.00	0.00	0.00	0.00
3	150857	0	0	150857	150857	0.00	0.00	0.00	0.00
4	149606	0	0	149606	149606	0.00	0.00	0.00	0.00
5	150857	28861	30054	121996	120803	0.02	0.02	0.26	0.25
6	150857	29987	31610	120870	119247	-0.21	-0.20	0.28	0.27
7	150857	31380	31729	119477	119128	-0.14	-0.13	0.29	0.28
8	150857	122277	122497	28580	28360	-0.04	-0.03	0.25	0.24
9	150857	120665	122497	30192	28360	-0.08	-0.06	0.29	0.26
10	150857	120360	122497	30497	28360	-0.09	-0.07	0.33	0.30
11	150857	121338	122497	29519	28360	-0.10	-0.08	0.54	0.44
12	150857	96647	122497	54210	28360	-0.05	-0.06	1.03	0.94
13	150857	0	0	150857	150857	0.00	0.00	0.00	0.00
14	150857	0	0	150857	150857	0.00	0.00	0.00	0.00
15	150857	0	0	150857	150857	0.00	0.00	0.00	0.00

Table 18 NOAA-18 AMSU-A observation summary of EP06

NOAA18 - VarBC - channel 6

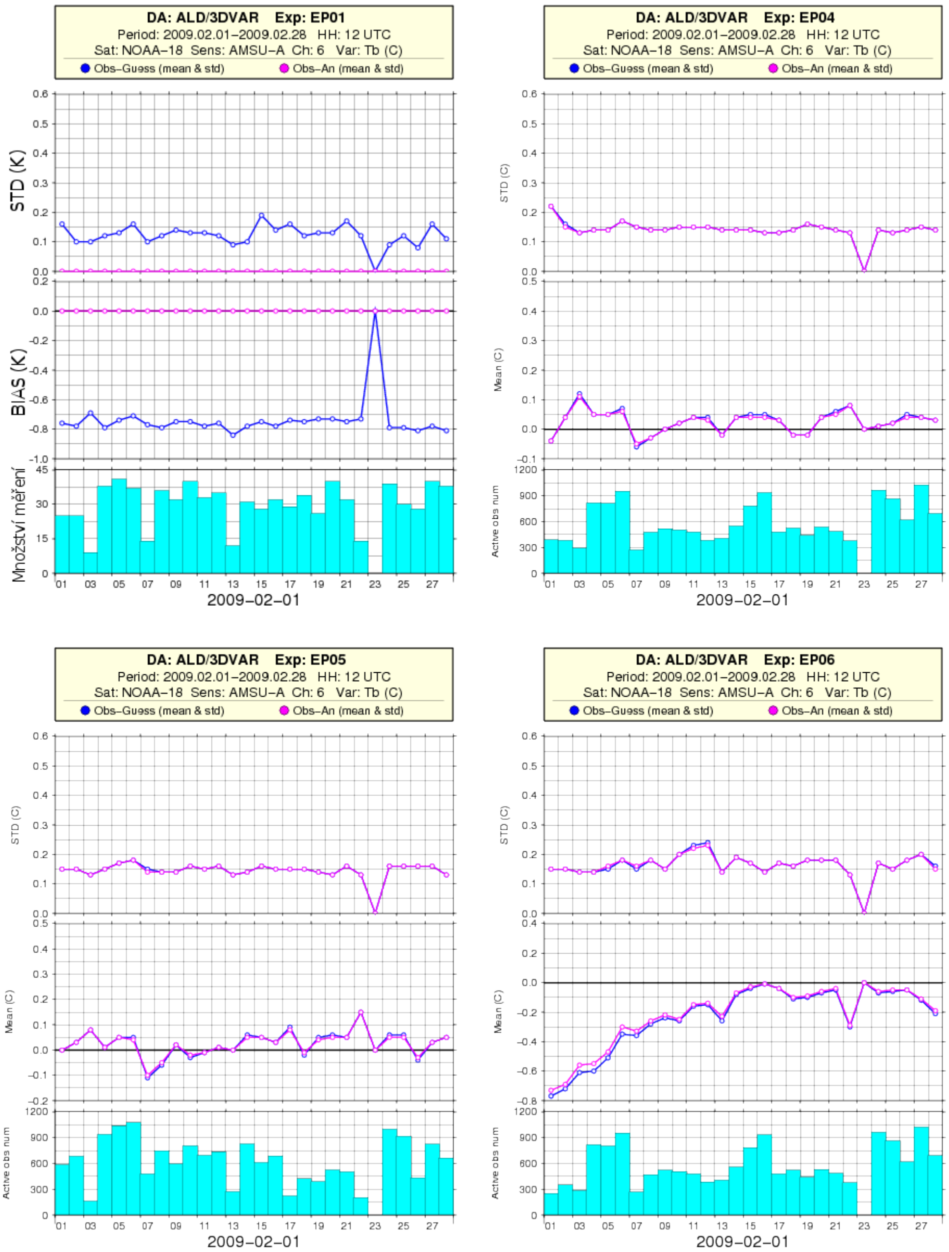

Figure 11: Monitoring of channel 6 satellite NOAA18 for analysis time 12UTC and VarBC experiments. Figures show time evolution of mean and standard deviation of obs-guess (blue) and obs-analysis (red) for experiments (from left above): reference EP01, EP04 and (from left below) EP05 and EP06. We can see bahaviour of bias correction during tested period in exeperiments, which differ in initializing of bias coefficient.

5 Summary and conclusions

Two correction methods - offline (H&K) and VARBC correction methods were successfully tested in model ALADIN/CE for sensor AMSU-A. There were some technical problems in code during preparation offline methods and VarBC (for more details see APPENDIX A), but finally both correction method behave very reliably during the month period. There are significant difference in bias between single channel, which is obvious if we compare averaged channel bias and bias averaged over tested period. Greater bias is detectable for the channel 11, 12, 13, which represent characteristics of the upper air levels.

5.1 Offline method EP02 and EP03

Almost no statistics for satellite observation NOAA16 were caused probably by modification set for offline method. Figures show time evolution and channel distribution of mean and standard deviation of obs-guess (blue line) for offline methods EP01, EP02 and EP03. Offline methods correct averaged bias half-times for satellite NOAA15 (figure 3) and for NOAA18 even on three-quarter of value (figure 4). The added predictor of skin temperature (in EP03) have neutral effect for bias correction both satellite NOAA15 and NOAA18.

5.2 VarBC method EP04, EP05 and EP06

VarBC methods use satellite data in analysis, so the figure include average mean and standard deviation of obs-guess (blue line) and moreover obs-analysis (red line), which can provide an information about how much are satellite data taken into account during analysis. Because an observation error of satellite data was setting in about $100.00K$, we expect, that both departure O-G and O-A will be almost identical.

The three experiments differ in initial set up of bias coefficients. All three experiments have big influence on the bias correction. Figure 11 shows, that VarBC initialized from ARPEGE's bias coefficients (EP04) have similar result as initialization from offline method (EP05). Both methods correct bias immediately in the beginning of period. When we used bias coefficients equal to zero (EP06), coefficients are in each assimilation cycle more accurately, but it takes about 15 days to get equivalent results of bias correction as in EP04 or EP05.

5.3 Bias dependence on date of observation

Behavior of bias during tested period is different for satellite NOAA15, NOAA16 and NOAA18. The main reason you can find in the orbital path and time of satellite fly over LACE domain. There are collected measurement from ± 3 assimilation window in data file. Accuracy of the observation data depend except another dependencies (accuracy of measurement instrument, sophistication of observation operator...) on the time of measurement. Polar satellites choose a sun-synchronous orbit: meanings each successive orbital pass occurs at the same local time of day. The orbital of polar satellite shift every day to east, so we can figure approximately time of satellite measurements in the middle of domain LACE and near the border of domain:

Satellite	Obs in the middle of domain (UTC)	Obs on border of domain (UTC)
NOAA15	15:00	16:30
		13:30
	04:30	06:00
		03:00
NOAA16	15:30	17:00
		14:30
	05:00	06:30
		03:30
NOAA18	12:00	13:30
		10:30
	01:00	**02:30**
		23:30

Observation outside of the LACE domain are rejected. If we take into account assimilation 6h-cycle (analysis time at 00, 06, 12 and 18UTC), it's obvious, that some satellites will produce old data with regard to the analysis time. Because correction methods are set to correction of scan-bias and air-properties (not 'age' of the measurement), we can expect for this analysis time and satellite worse bias correction. You can see this effect on the figure 12 above, where are observation from NOAA18 collect at analysis time 06UTC. There are filtered observation from overfly of satellite at 02:30UTC (bold font in the table). Otherwise on the same figure below you can see bias correction of the more accuracy data of NOAA18 from the analysis time 00UTC. Figure 12 shows application of offline method (EP02) and VarBC (EP04).

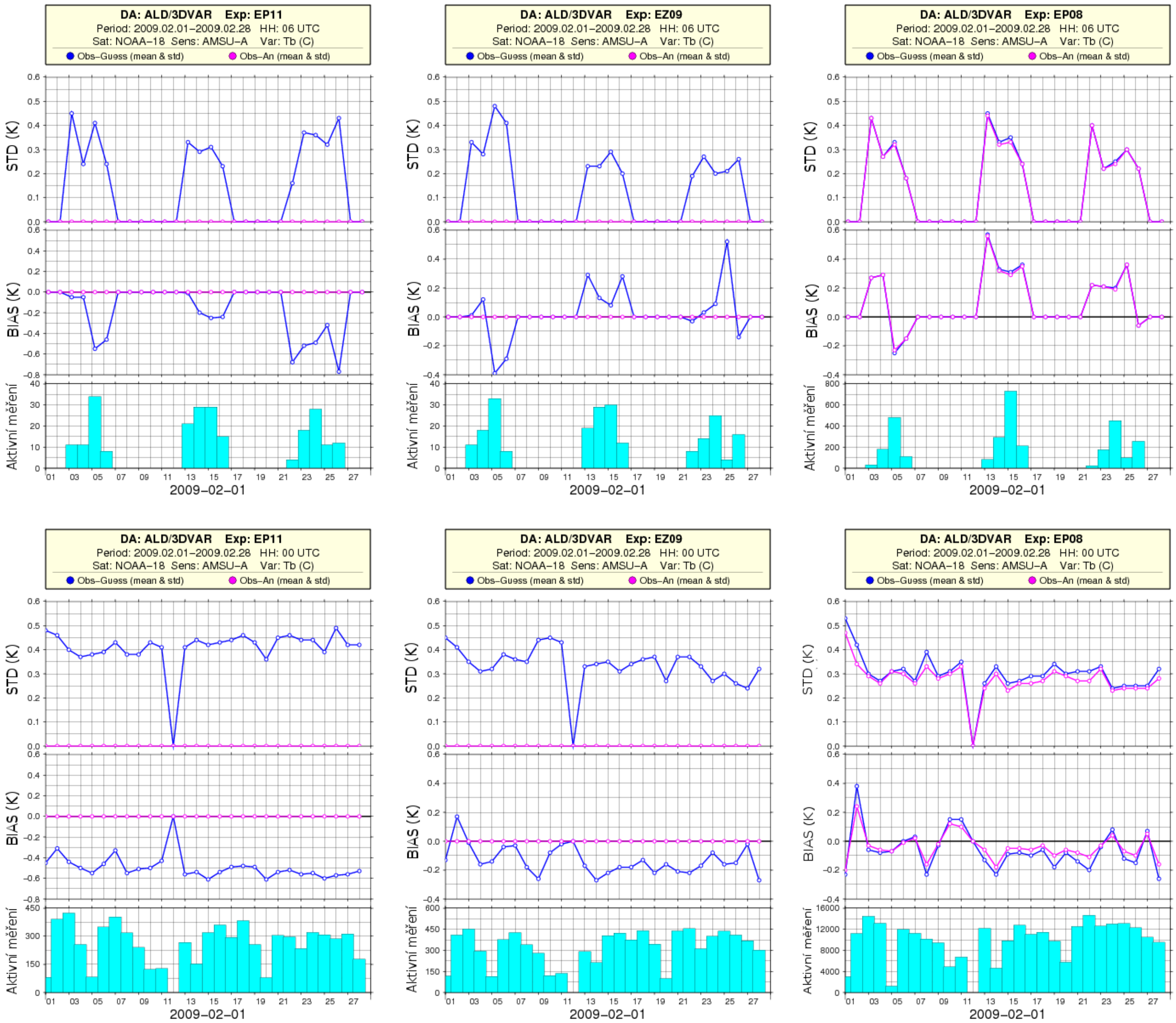

Figure 12: Bias correction of satellite data NOAA18 in the term of analysis 06UTC (above) and 00UTC (below). Data collect at 06UTC are older with regard to time of analysis, while analysis time 00UTC includes more accuracy data. We can see application correction methods (from left): reference EP01, offline method EP02 and VarBC experiment EP03. Ability of correction older observation is in a manner for used methods limited.

To conclude the H&K method provided slightly worse corrections in terms of total bias decrease compared to VARBC method. And although H&K method is quite efficent and cheap in CPU consumtion, considering an increasing number of operationally used sattelites and sensors, this method requires nonnegligible maintenance (regular recomputation of bias coefficients, maintenance of all 9 programs involved in computations, etc.) The VARBC method corrected biases more effectively and a big advantage is the automatic update of the coeficients during each analysis and thus the ability to adapt in case of an artificial instrument shift.

Appendix A

A Settings of VarBC

A.1 Blacklist

We have to add fail(EXPERIMENTAL) in blacklist to increase observation error up $100K$.

```
! AMSU-A selection --------------------------------------------

if (SENSOR = amsua) then

    if (STATID = "     206") and (PRESS in (6,11))    then fail(CONSTANT); endif;
    if (STATID = "     207") and (PRESS in (5,6,7,8)) then fail(CONSTANT); endif;
    if (STATID = "     222") and (PRESS in (7))       then fail(CONSTANT); endif;
    ...

    if PRESS in (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15) then fail(EXPERIMENTAL); endif;
endif;   ! SENSOR = AMSUA
```

We add the same fail in the end of IF statement SATEM:

```
if (OBSTYP = satem) then
  ...

  if STATID in ("     206","     207","     208","     209") then fail(EXPERIMENTAL); endif;
endif;
```

A.2 Namelist

We have to add some logical keys in namelist: namel_minim_al35t1 and namel_screen_al35t1:

```
 /
&NAMVAR
   LVARBC=.TRUE.,                  # activate VarBC
 /
&NAMVARBC
  LCONSTANT_VARBC=.FALSE.,
  LBC_PRED_RAD1C(3,3,5)=.FALSE.,   # don't use predictor 5 in VarBC
  LBC_PRED_RAD1C(3,4,5)=.FALSE.,   # predictor 5: 1-10 hPa thickness
  LBC_PRED_RAD1C(3,5,5)=.FALSE.,
  LBC_PRED_RAD1C(3,6,5)=.FALSE.,
  LBC_PRED_RAD1C(3,7,5)=.FALSE.,
  LBC_PRED_RAD1C(3,8,5)=.FALSE.,
  LBC_PRED_RAD1C(3,9,5)=.FALSE.,
  LBC_PRED_RAD1C(3,10,5)=.FALSE.,
  LBC_PRED_RAD1C(3,11,5)=.FALSE.,
  LBC_PRED_RAD1C(3,12,5)=.FALSE.,
  LBC_PRED_RAD1C(3,13,5)=.FALSE.,
  LBC_PRED_RAD1C(3,14,5)=.FALSE.,
  lbc_AIRS=.FALSE.,
  lbc_AMSUA=.TRUE.,                 # assimilate only sensor AMSUA
  lbc_AMSUB=.FALSE.,
  lbc_FY2=.FALSE.,
```

```
  lbc_GOESIMG=.FALSE.,
  lbc_HIRS =.FALSE.,
  lbc_METEOSAT=.FALSE.,
  lbc_MHS=.FALSE.,
  lbc_MSG=.FALSE.,
  lbc_MSU=.FALSE.,
  lbc_MTSATIMG=.FALSE.,
  lbc_SSMI=.FALSE.,
  lbc_SSU=.FALSE.,
  LBC_MSG_HR=.FALSE.,
 ncs_config=0,                  # changet initialization bias coefficients
  LCONSTANT_VARBC(3,13,0)=.TRUE.,  # don't use channel 13 in VarBC
  LCONSTANT_VARBC(3,13,1)=.TRUE.,
  LCONSTANT_VARBC(3,13,2)=.TRUE.,
  LCONSTANT_VARBC(3,13,3)=.TRUE.,
  LCONSTANT_VARBC(3,13,4)=.TRUE.,
  LCONSTANT_VARBC(3,13,5)=.TRUE.,
  LCONSTANT_VARBC(3,13,6)=.TRUE.,
  LCONSTANT_VARBC(3,13,7)=.TRUE.,
  LCONSTANT_VARBC(3,13,8)=.TRUE.,
  LCONSTANT_VARBC(3,13,9)=.TRUE.,
  LCONSTANT_VARBC(3,13,10)=.TRUE.,
  LCONSTANT_VARBC(3,13,11)=.TRUE.,
 /
```

A.3 Change in code

we have to change some code lists:

- **/arp/op_obs/biaspred.F90** – one of VarBC predictor compute thickness levels $1 - 10hPa$, but model ALADIN/CE have top pressure level in 5 hPa. So we have to reduce number of press level in variable *zplev* and in namelist switch off predictor 5 (see namelist).
- **/arp/var/surad.F90** – call CSVARBC after SUADVAR:

```
     IF ((LELAM).OR.(.NOT. LVARBC)) THEN
  !*    1.3 Call of suadvar which is the routine setting up the
  !*        constants for the radiative transfer code and calls
  !*        to routines to set satellite specific parameters
  !*        will handle multiple satellite series, satid's and
  !*        subtypes etc
  IF (MNSERIES /= 0) THEN
  ! The first two arguments should be removed from SUADVAR.
  ! Also the last one can be removed.
    CALL GSTATS(1954,0)
    IF(LSCREEN) CALL SUADVAR(IDUM,ZDUM,MSATDIM,MSUBDIM,MNSERIES,&
     & MNSATID,MNSUBTYPE,MKSERIES,MKSATID,MKSUBTYPE,NJPPF)
    CALL GSTATS(1954,1)
  ELSE
    WRITE(IU,*)'SURAD: NO SATEMS IN CMA'
  ENDIF
ENDIF
```

```
IF (LVARBC) THEN
  !*    1.3.5 Bias parameter estimation: handle cold start for
  !           variational bias parameters
  IF (lscreen) CALL CSVARBC
ENDIF
```

- **/arp/obs_preproc/upecma.F90** – we don't use observation from ECMWF, so we have to cancel IF statement:

  ```
  !  if (LECMWF) then
     ...
  ```

  we increase observation error for data with fail(EXPERIMENTAL) to $100K$ to ensure no influence in analysis:

  ```
   ROBODY(JNLV,MDBFOE)  = 100.00_JPRB
  ```