On the use of bias correction method and full grid AMSU-B data in a limited area model

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Abstract

In the frame of the continuous development of the 3D-Var system at the Hungarian meteorological Service our aim is to use as many data and in as fine resolution as possible. The AMSU-A data are already implemented in the data assimilation system of the limited area model ALADIN Hungary (ALADIN/HU) and used operationally. Our recent work consists of studying the impact of E-AMDAR, atmospheric motion vectors (AMV) and full grid AMSU-B data on the model analysis and short-range forecasts. We handle the locally received ATOVS data as well as the ones pre-processed and transmitted through the EUMETcast broadcasting system. In this paper we discuss our experience on the choice of the proper bias correction for a limited area model (LAM). Thus, bias corrections computed using the French global ARPEGE and the ALADIN/HU limited area models background are compared. Results on the implementation of the AMSU-B data in the LAM ALADIN/HU are also presented.

Introduction

In most numerical weather prediction (NWP) centres satellite data are assimilated in the form of raw radiances. For the efficient use of raw (ATOVS in our case) radiances biases between the observed radiances and those simulated from the model states (first-guess) must be removed.

Many investigations were carried out on the removal of these biases. *Eyre* (1992) introduced the radiance bias as the combination of the scan-angle dependent (originating form the measurement quality) and air mass dependent errors. *Harris and Kelly* (2001) showed that scan angle biases vary with the geographical latitude bands. *Dee* (2004) proposed an adaptive bias correction scheme that can automatically sense the change in the bias of a given channel and responses correspondingly. *Watts and McNally* (2004) introduced a bias correction scheme, which is based on a modification of the transmittance coefficients in the radiative transfer model (RTTOV), involving two global parameters for each channel that can be adjusted to reduce the systematic errors in the RTTOV calculations.

The proposed bias correction schemes, however, were developed for global models. Thus, their adaptation to limited area models (LAMs) raises further questions. The quality of the bias correction coefficients - scan-angle biases and coefficients for air-mass predictors - depends on the amount of the observation-minus-model-first-guess, obtained at each satellite (AMSU-A) scan position. The amount of satellite measurements along the scan line is much smaller in case of a limited domain (LAM) compared to global models, because satellite paths are likely to be cut at different scan positions during their pre-processing. This can cause problems when evaluating the scan-angle biases for a limited area model.

In ARPEGE/ALADIN (*Horányi et al*., 1996) model the method described by *Harris and Kelly* (2001) is used for correcting radiance-biases (see section 2.1). Scan-angle biases depend on the number of samples obtained at each scan position. When computing scan angle biases using a limited area model (LAM), it is not likely to have the same number of samples for all scan positions in a given channel. To illustrate this, two satellite paths - a complete one on the right and a portion of a second path on the left side of the domain - are shown in Fig. 1. The inadequacy in the number of samples leads to fluctuating bias curves along the scan-lines

(Fig. 2/a) instead of well-smoothed ones. Due to sufficient number of samples, this problem does not appear when computing the scan-angle biases for global models.

Figure 2/a demonstrates the statistics computed for a one month period for the old domain (Fig. 3/a) of the ALADIN Hungary (ALADIN/HU) model, which is relatively small compared to the new one (Fig. 3/b). Enlarging the domain, smoother curves were obtained (Fig. 2/b). Less but still valuable fluctuation, however, was still observed for several channels - see, for example, the curve representing the scan-angle bias for channel 9 of AMSU-A (red triangles in Fig. 2/b). This indicates, that further efforts have to be done to improve the bias correction method for the ALADIN/HU LAM model.

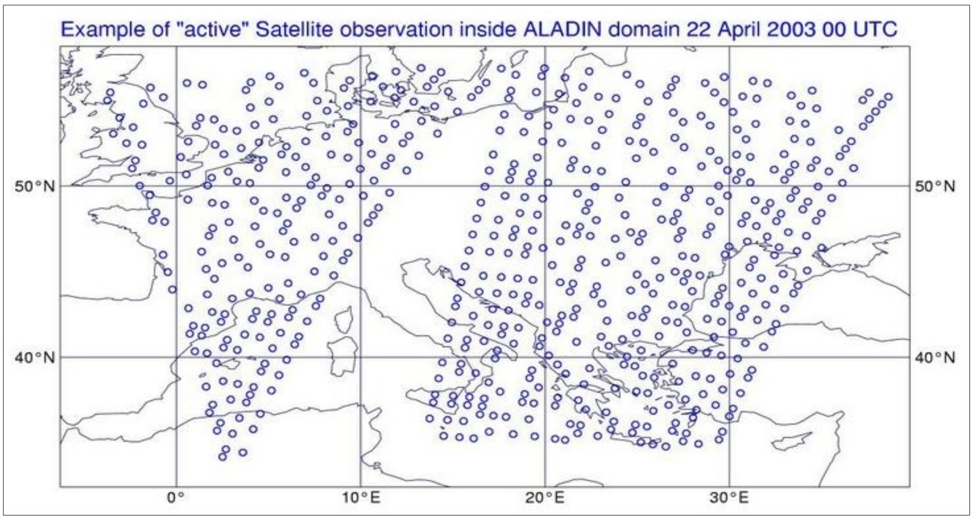


Figure 1. Example of satellite paths inside the ALADIN/HU domain (C+I zone) observed on 22 April 2003 at 00 UTC.

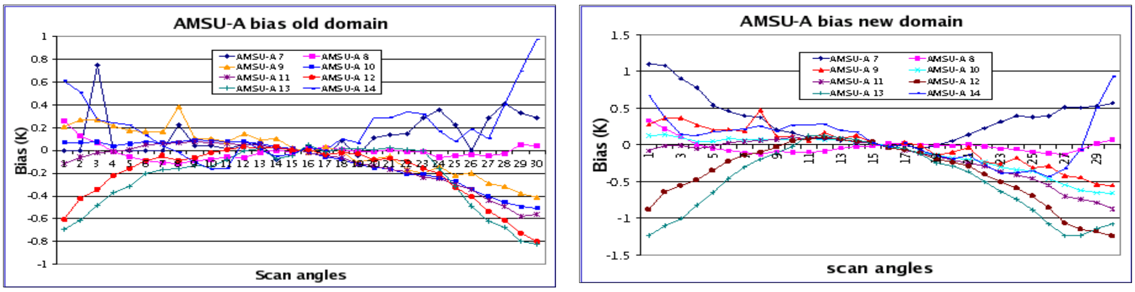
Bias correction coefficients, computed for the French global (ARPEGE) model and for the ALADIN limited area model, and many of their combinations were tested. The impact of bias-correction coefficients, computed for the restricted LAM domain was then compared with influence of one, calculated for the coupling[1] global model. The importance of removing air-mass related biases when assimilating the ATOVS observations in a limited area model was also investigated.

Many investigations have been performed to evaluate the impact of the AMSU-B data in a limited area model (Jones et al, 2002; Candy, this volume). These studies showed positive impact in the analysis of moisture and short-range forecast of precipitation. Our goal is to improve our short-range forecast of precipitation, assimilating the AMSU-B data in as fine resolution as possible. Thus, full grid AMSU-B (one by one field of view (FOV)) data were investigated in the 3D-Var ALADIN/HU, using different thinning distances in the assimilation process.

This paper investigates different bias correction coefficients in order to find the best method for processing raw radiance satellite data and presents the preliminary results of the study related to the assimilation of full grid AMSU-B data in the ALADIN limited area model.

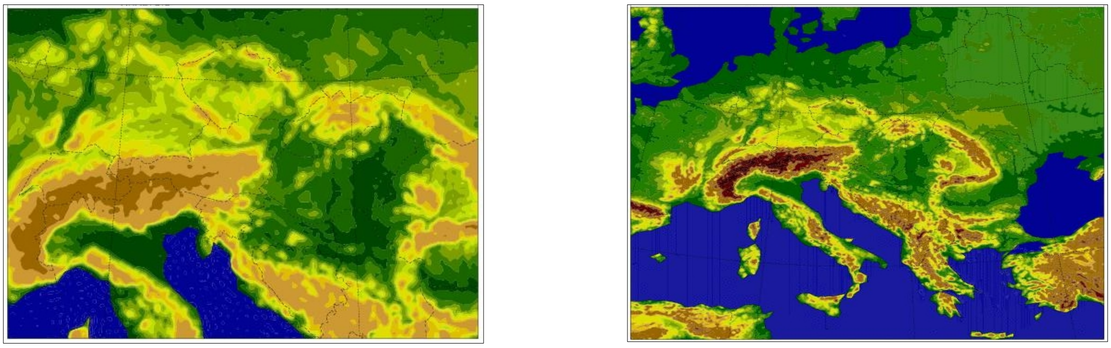
1The integration of a limited area model needs information about its lateral boundary conditions - the coupling files. In the case of ALADIN model, we use file from the global ARPEGE model, which is referred here as a coupling model.

Section 2 describes the main characteristics of ALADIN/HU model and its assimilation system. Section 2.1 illustrates the local pre-processing of satellite data, while section 2.2 provides a short description of the bias correction method used in ALADIN/HU. Section 3. gives a detailed description of the investigation of radiance-bias correction file for LAM. Section 4. presents the preliminary results of the investigation of full grid AMSU-B data, and in section 5. we draw some conclusions of the results presented in this paper.



(a) (b)

Figure 2/a-b. Scan-angle biases computed for the old (left) and new (right) ALADIN/HU domains. Note that the corresponding domains are presented in Fig. 3/a-b



(a) (b)

Figure 3/a-b. Topography of the old (left) and new (right) ALADIN/HU domains

The ALADIN/HU model and its assimilation system

At the Hungarian Meteorological Service (HMS) the ALADIN/HU model runs in its hydrostatic version. Different versions of the ARPEGE/ALADIN codes have been used in the investigations (see table 1. for more details). In this study we used the model with 12-km horizontal resolution (Fig.3/b), and with 37 vertical levels from the surface up to 5 hPa. The three-dimensional variational data assimilation (3D-Var) system was applied to assimilate both conventional (SYNOP and TEMP) and satellite (ATOVS) observations. As the variational technique computes the observational part of the cost function in the observational space, it is necessary to simulate radiances from the model parameters. In ARPEGE/ALADIN we use the RTTOV (see table 1) radiative transfer code to perform this transformation (*Saunders et al.,* 1998), which has 43 vertical levels. Above the top of the model, an extrapolation of the profile is performed using a regression algorithm (*Rabier et al.,* 2001). Below the top of the model, profiles are interpolated to RTTOV pressure levels. A good estimation of the background error covariance matrix is also essential for the variational technique to be successful. The background error covariance - the so-called "B" matrix - is computed using the standard NMC method (*Parrish and Derber,* 1992; *Široká et al.,* 2003).

The specific humidity was assimilated in univariate form to avoid certain problems, related to its assimilation in al25/cy24t1 (see *Randriamampianina and Szoták,* 2003 for more details). An optimal interpolation scheme was used to analyse the surface fields (*Radi and Issara,* 1994). The AMSU-A data were assimilated at 80km resolution. The 3D-Var is running in 6-hour assimilation cycle generating an analysis at 00, 06, 12 and 18 UTC. In this study, we performed a 48-hour forecast once a day (see Table 1.).

Table 1: The ALADIN/HU 3D-Var applied in the investigations

		Investigation of radiance-bias correction for LAM	Investigation of full grid AMSU-B data
Model	- Hydrostatic version - Horizontal res.: 12km - 37 vertical levels	al25/cy24t1	al28/cy28t3
3D-Var	- Cov. Matrix B: std NMC - 6 hour assim. Cycling - RTM model: RTTOV - Coupling files: ARPEGE long cut-off files - Satellite observations: - Selected channels - Humidity assimilation	RTTOV-6 Coupling: every 6h NOAA-15&16 AMSU-A AMSU-A (5-12) univariate	RTTOV-7 Coupling: every 3h NOAA-15,16&17 AMSU-A&B AMSU-A(5-12), AMSU-B(3-5) multivariate
O.I:	- Surface analysis	Yes	No, copy of ARPEGE surface fields to ALADIN grid
Forecast:	- 48 hour	From 00 UTC	From 12 UTC

Pre-processing of satellite data

The ATOVS data are received through our HRPT antenna and pre-processed with the AAPP (ATOVS and AVHRR Pre-processing Package) software package. We used AMSU-A, level 1-C radiances in our experiments.

For technical reasons our antenna is able to receive data only from two different satellites. To acquire the maximum amount of satellite observations the NOAA-15 and the NOAA-16 satellites were chosen, which have orbits perpendicular to each other and pass over the ALADIN/HU domain at about 06 and 18 UTC and 00 and 12 UTC, respectively.

For each assimilation time we used the satellite observations that were measured within ±3 hours. The number of paths over the ALADIN/HU domain within this 6-hour interval varies up to three.

Bias correction

The direct assimilation of satellite measurements requires the correction of biases computed as differences between the observed radiances and those simulated from the model first guess. These biases arising mainly from instrument characteristics or inaccuracies in the radiative transfer model can be significant. The method developed by *Harris and Kelly* (2001) was used to remove this systematic error. This scheme is based on separation of the biases into scan-angle dependent bias and state dependent components. The air-mass dependent bias is expressed as a linear combination of set of state-dependent predictors.

Four predictors computed from the first-guess fields were selected (p1 - the 1000-300hPa thickness, p2 - the 200-50hPa thickness, p3 - the skin temperature and p4 - the total column water) for the AMSU-A data used in our experiments.

A carefully selected sample of background departures for the AMSU-A and channel set was used to estimate the bias, in a two-step procedure. First, scan bias coefficients were computed by separating the scan-position dependent component of the mean departures in latitude bands. Secondly, after removing the scan bias from the departures, the predictor coefficients for the state-dependent component of the bias were obtained by linear regression. At the end of this estimation procedure, bias coefficients for the AMSU-A were stored in a file. The data assimilation system could then access the coefficients in order to compute bias corrections for the latest observations, using update state information for evaluating the air-mass dependent component of the bias. The brightness temperatures were corrected accordingly, just prior to assimilation.

As ARPEGE model uses every second pixel of ATOVS measurements, it has zero scan-angle coefficients at non-used pixels, which may cause a large remaining bias when using one by one field of view of the AMSU-A data. To overcome this problem, the values of the two adjacent pixels were interpolated into pixels with zero coefficients.

Investigation of radiance-bias correction for LAM

Description of the experiments

In order to estimate the impact of different bias correction coefficients on the model analysis and forecasts the scores of different experiments were compared with those from the run (NT80U) performed using the bias correction file, computed for the ALADIN/HU LAM model.

A twenty-day period (18.04.2003-07.05.2003 - denoted as first period later on) was used for the first impact study that consisted of four experiments. A fifteen-day period (20.02.2003-06.03.2003 - denoted as second period later on) was chosen for the second impact study in order to confirm the main results of the first one by repeating some of the experiments.

The radiosonde (TEMP), surface (SYNOP) and AMSU-A observations were used in all the experiments, applying different bias correction methods:

NT80U: The bias correction coefficients were computed for the ALADIN/HU domain (control run)

T8B1I: The bias correction coefficients were computed for the ARPEGE model

T8B2I: The scan angle coefficients were computed for the ARPEGE model, but no air-mass correction was applied

T8B3I: The ARPEGE scan-angle coefficients and the air-mass bias correction coefficients computed for the ALADIN/HU were used

NOT8U: The same as NT80U for the second period

O8B1I: The same as T8B1I for the second period

O8B3I: The same as T8B3I for the second period.

Results and discussion

Bias correction coefficients computed for the global ARPEGE and limited area ALADIN/HU models and their combinations were compared in order to find the best solution for processing the AMSU-A data in the ALADIN/HU model. The impact of the bias correction methods was either slightly positive or negative, but to a very small extent. The main impact of the bias correction coefficients was expressed on the temperature fields.

The results are classified as follows:

Comparison of biases using different bias correction files

The particularity of the data assimilation system at the HMS is that is has different (positive or negative) bias on temperature profile at different model levels. For example, clear positive and negative bias can be observed at the 1000hPa and 850 hPa levels, respectively (Fig. 4). The bias on humidity profile is slightly positive for all the model levels (not shown).

According to our results, the bias coefficients for the global ARPEGE model (mentioned as global bias correction file later on) had a heating effect above and a cooling effect under the 500hPa level (Fig. 4) compared to the control run. Our verification concerned only the levels below 100hPa.

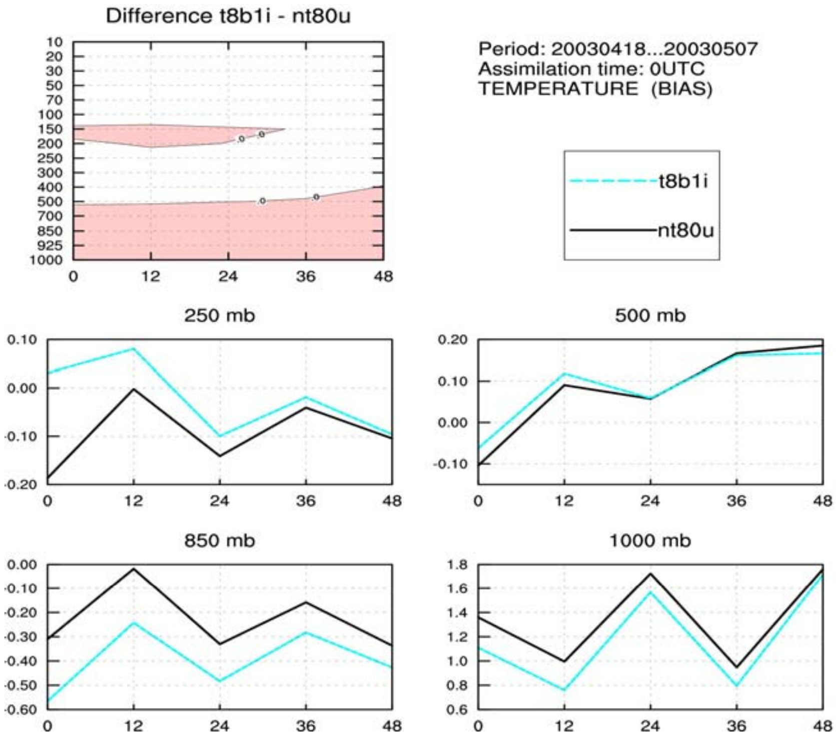


Figure 4. Temperature biases, computed using the global (ARPEGE) bias correction coefficients (T8B1I) against biases, computed using the LAM coefficients (NT80U) for the first period. The coloured area (upper left picture) shows negative values in difference between biases.

Impact of the global bias correction file

Thought the ALADIN/HU model had different biases on temperature in different model layers, the systematic cooling or heating did not necessarily yield an overall positive impact on temperature forecasts. For example, a clear positive impact on the forecast of temperature could be observed in the troposphere (500hPa level) during the second period, although there was a negative impact at 850hPa during the first period (Fig. 5). Thus, the behaviour of the limited area model was not fully "controllable" when applying the global bias correction file in the assimilation system to process satellite observations. Consequently, no stable impact on the model analysis and forecast could be obtained.

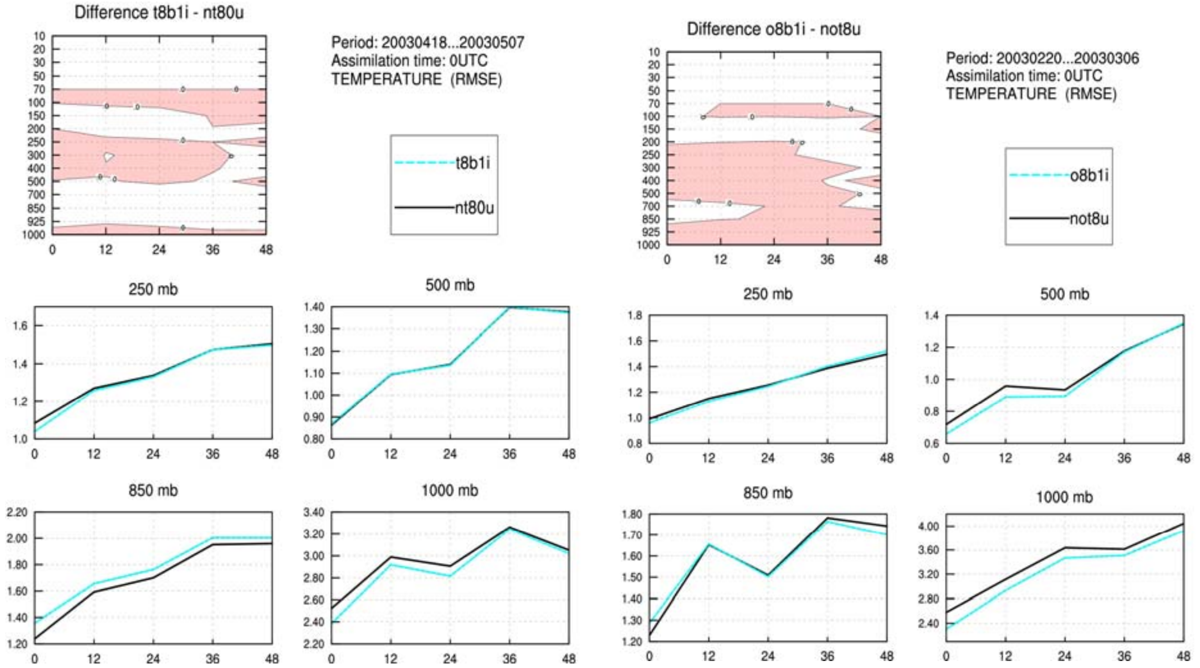


Figure 5. Temperature root-mean-squares errors (RMSEs) for run with global bias correction coefficients (ARPEGE) (T8B1I and O8B1I, for the first and the second period, respectively) against run with LAM coefficients (NT80U and NOT8U, for the first and the second period, respectively). The coloured area (upper left picture) shows negative values in difference between biases.

Impact of no air-mass bias correction in the processing of AMSU-A

In order to assess the importance of air-mass bias correction, model runs with and without application of air-mass correction were compared. Thus, in the experiment T8B2I, no more than the interpolated ARPEGE scan-angle bias correction was used since using a global model we could compute better representation of the scan-angle bias. Without air-mass bias correction, satellite measurements warmed the model fields to a larger extent, which indicated that there was a residual bias in the temperature field shifted by satellite data (not shown). Accordingly, the verification scores showed a slightly negative or neutral impact on all the variables, including temperature forecast, in which the positive impact completely disappeared (Fig. 6). It seemed likely that we needed air-mass bias correction to assimilate radiances, since the ARPEGE scan-angle bias correction itself was not satisfactory.

Combining the scan-angle bias correction of the global model with the air-mass bias coefficients of the LAM

Assuming that the air-mass bias correction was important, we combined the interpolated ARPEGE scan-angle bias correction with the ALADIN/HU air-mass bias correction in the experiment T8B3I. The combination of the global and the local bias correction coefficients showed structurally similar results to those obtained in the experiment with ARPEGE bias correction file only (see Fig. 5.), but both negative and positive impacts were negligible (Fig. 7). This revealed that using the global scan-angle bias correction with LAM air-mass bias correction coefficients did not improve the impact significantly.

The sensitivity of channels 5, 6, 7, 10, 11 and 12 to the bias correction files was evaluated analysing the number of assimilated satellite data (Fig. 8). More observation was available in the troposphere (channels 5, 6 and 7), while less data were used for channels 10, 11 and 12 when applying the global air-mass bias coefficients in data processing. We assumed, that the use of channels 5-7 was more efficient when applying the global bias coefficients compared to the local ones probably because the analysis of the surface fields in the ARPEGE model was more accurate than that in the LAM.

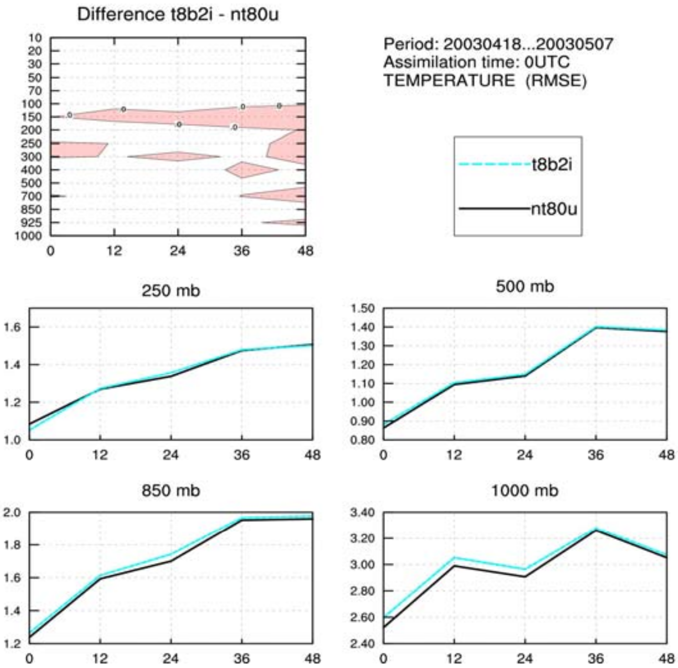


Figure 6. Temperature root-mean-square errors (RMSEs) for run with global bias correction coefficients (ARPEGE) (T802I - no air-mass bias correction) against run with LAM coefficients (NT80U), differences between them are illustrated in upper left picture, where coloured area presents negative values.

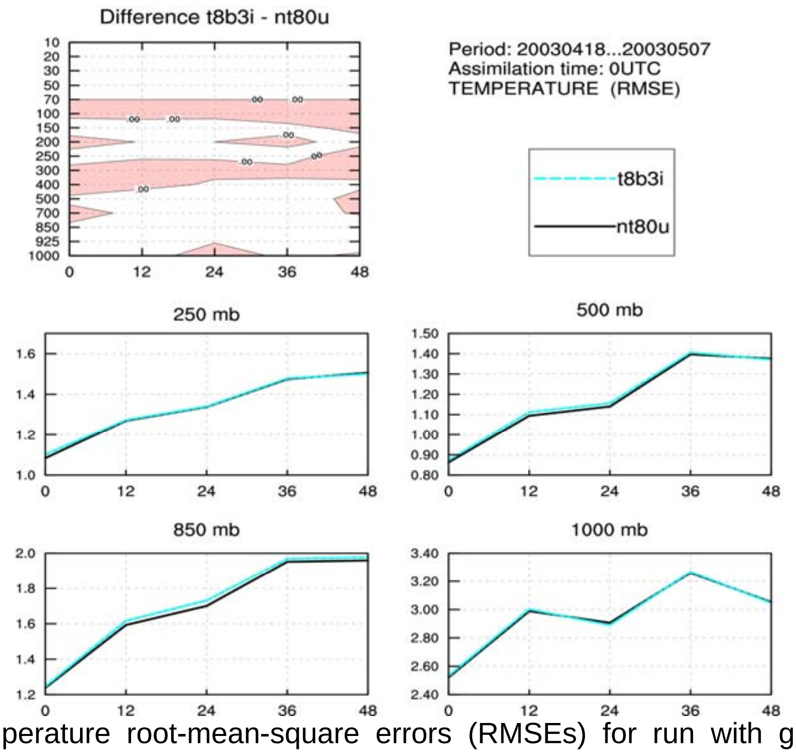


Figure 7. Temperature root-mean-square errors (RMSEs) for run with global (ARPEGE) scan-angle bias correction coefficients and with LAM air-mass bias correction coefficients (T803I) against run with LAM bias correction coefficients (NT80U). The coloured area (upper left picture) shows negative values in difference between biases.

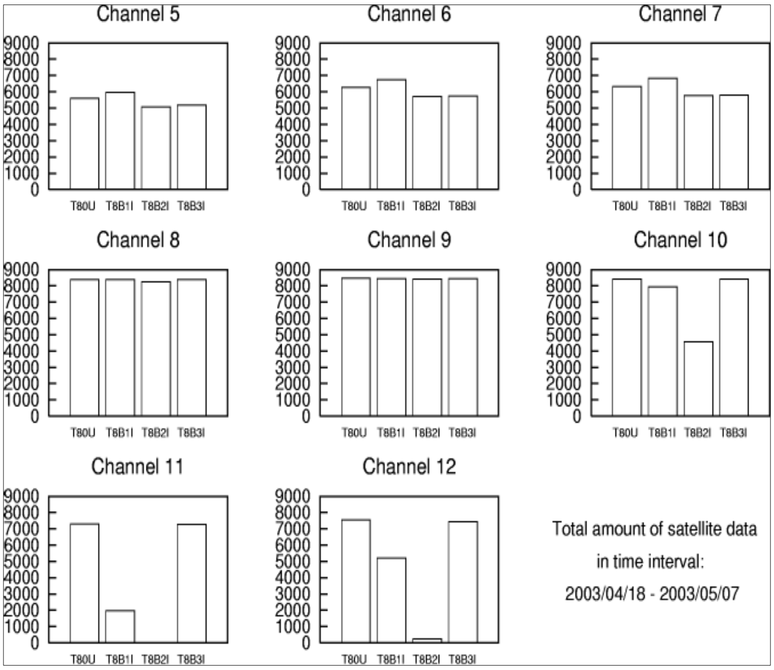


Figure 8. Total number of assimilated satellite observations (active data) for the period 18.04.2003 - 07.05.2003.

Investigation of full grid AMSU-B data

Description of the experiments

The aim of this investigation was to exploit the AMSU-B data in as fine resolution as possible. From technical point of view the use of these data in 3x3 FOV resolution (same resolution as the AMSU-A data) is the simplest way. This run was compared to the ones with AMSU-B data assimilated in full grid as follows:

NAMV- using surface, radiosonde, aircraft (AMDAR) and satellite (AMSU-A) observations (control observations) in assimilation. This was the control run.

SBX3- using control observations and AMSU-B data reduced in 3x3 FOV, thinned in 80km resolution in the assimilation.

SFB8- using control observations and AMSU-B data in full grid (1x1 FOV), thinned in 80km resolution in the assimilation.

SFB6- using control observations and AMSU-B data in full grid, thinned in 60km resolution in the assimilation.

SFB1- using control observations and AMSU-B data in full grid, thinned in 120km resolution in the assimilation.

A two-week period (07.02.2005-21.02.2005) was chosen to evaluate the impact of different settings of the AMSU-B data in the assimilation system. The scores of each run were evaluated objectively. The bias and root-mean-square error (RMSE) were computed from the differences between the analysis/forecasts and observations (surface and radiosondes). The accumulated amount of precipitation was also compared to the one computed from the surface measurement for a few interesting situations within the period of study.

Results and discussion

The impact of the AMSU-B data was estimated comparing the runs with and without the assimilation of these data. The performance of the different settings in the assimilation of the AMSU-B data was evaluated comparing the scores of runs to each other. The main results are classified as follows:

Influence of the assimilation of AMSU-B data on temperature and humidity bias

The use of the AMSU-B in the assimilation process caused a weak heating and cooling effect in the troposphere and around the tropopause, respectively (Fig.9) and resulted in more moist conditions in the troposphere in the analysis and forecast. As it was found during the everyday subjective verification, the forecasts issued from the 3D-Var cycles were more “dry” than those of the spin-up model (or dynamical adaptation). This “drying” effect of the 3D-Var resulted in overestimated temperature and worsened forecast in certain cases. In such situations the “wetting” effect of the AMSU-B data could increase the forecast accuracy. From the other hand, the only humidity observation we had and used was from radiosonde measurements.

Impact of AMSU-B data on the analysis and short-range forecasts

According to the above discussion, the systematic addition of moisture in the model leaded to a positive impact not only in the analysis and forecast of temperature, except for the 6-hour forecast when we observe a remarkable difference in the RMSE (Fig. 10), but also the forecast of relative humidity. Figure 11 shows clear positive impact in the 48-hour forecast of the relative humidity.
The impact on the analysis and forecasts of geopotential, wind speed and wind direction was found to be neutral (not shown).

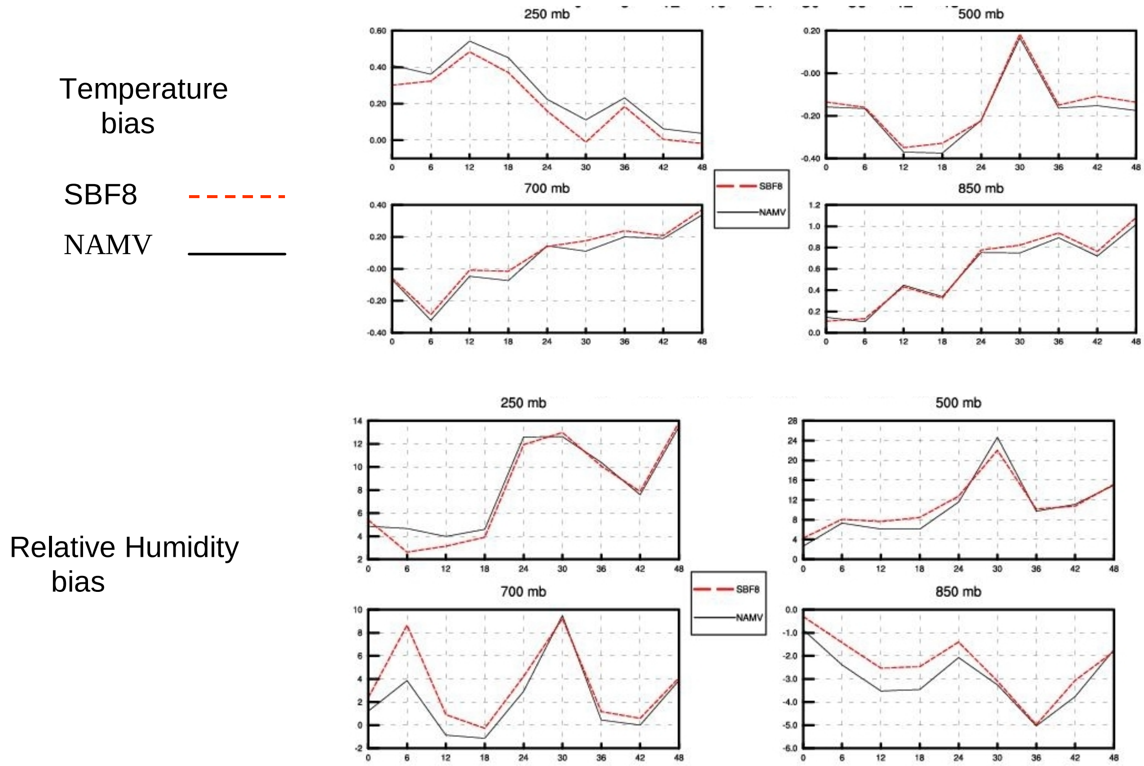


Figure 9. Temperature and relative humidity biases for the runs with (SBF8: dashed line) and without (NAMV: solid line) AMSU-B data at the analysis (0) and subsequent forecast times.

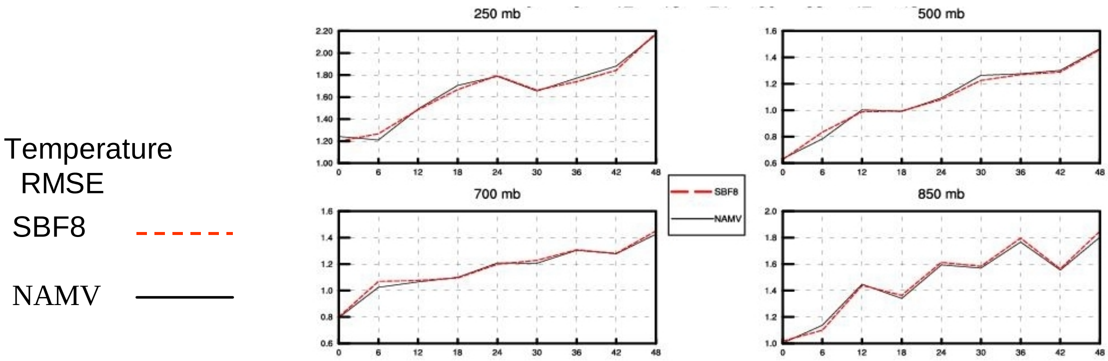


Figure 10. Root-mean-square error (RMSE) of temperature for the runs with (SBF8: dashed line) and without (NAMV: solid line) AMSU-B data at the analysis (0) and subsequent forecast times.

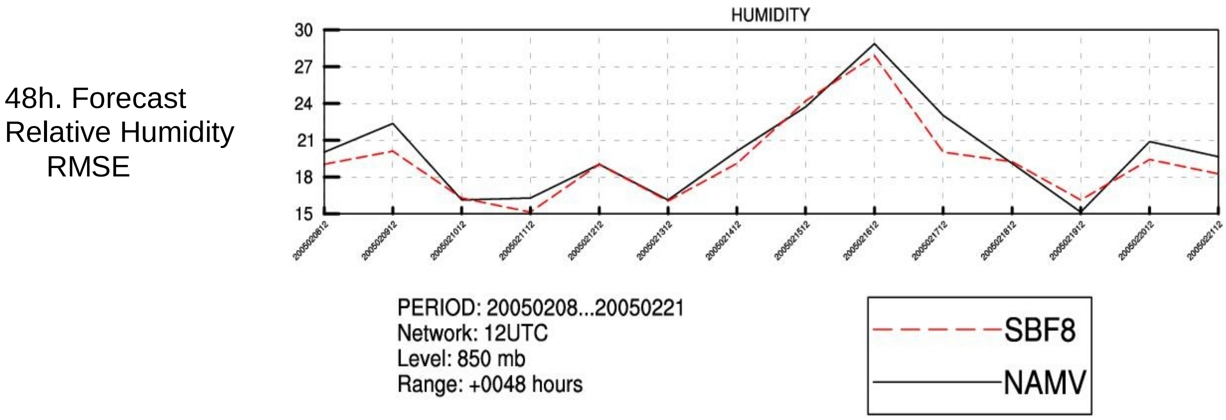


Figure 11. RMSE for the 48-hour forecast of relative humidity for the runs with (SFB8) and without (NAMV) assimilation of AMSU-B data.

Evaluation of the different usage of the AMSU-B data

To find the best usage of the AMSU-B in the assimilation system, four settings were compared: three runs with full grid using different thinning distances (SFB8: 80 km, SFB6: 60 km and SBF1: 120 km) in the assimilation, and one run with reduced (3x3 FOV) number of observations (SBX3, thinning distance: 80 km). Using full grid AMSU-B data in 80 km resolution (run SBF8) improved the forecast of all the parameters (see Fig. 12). Nevertheless, we have to mention that SBF8 provides less accurate 6-hour forecasts of temperature than SBF6, SBF1 or SBX3. Comparing the scores of individual daily 6-hour forecasts, it was found that experiments with full grid AMSU-B “failed” to predict (on the 6-hour forecast, valid for 18UTC 18 February 2005) the presence of a low-pressure region over the Southern part of Italy, causing large bias in the forecast of geopotential and temperature (not shown).

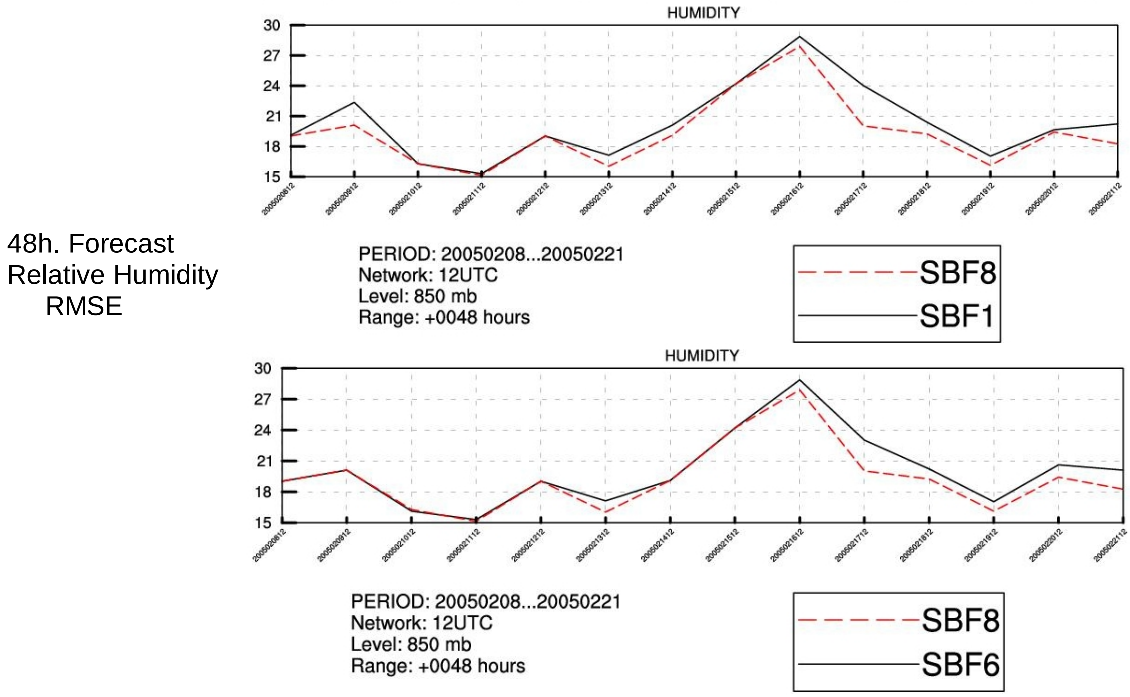


Figure 12. RMSE for relative humidity of individual runs

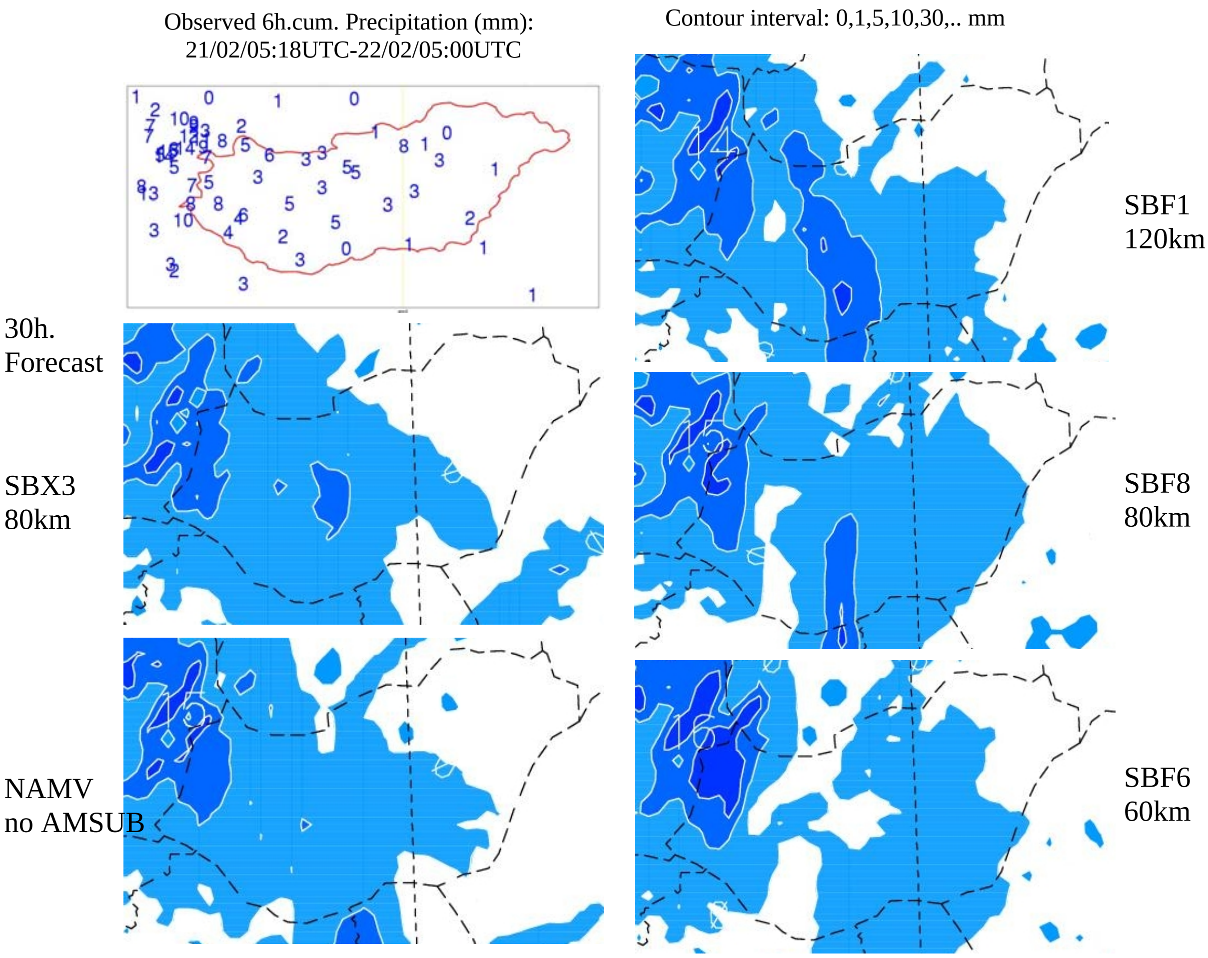


Figure 13. Comparison between observation (top, upper left) and predictions of 6-hour accumulated precipitation amount valid for 00 UTC 22nd Feb. 2005.

Comparison of 6-hour precipitation forecasts

Figure 13. shows the observed and predicted cumulative precipitation for the territory of Hungary. All the runs (with and without AMSU-B data) gave quite good prediction of the rainfalls observed in the Western part of the country. The precipitation patterns in the Eastern part, however, were only predicted by runs that used the AMSU-B data in full grid. Further studies, however, should be carried out to explain the rapid reduction of rainfall amount in the central part of Hungary with increase of resolution from 120km to 60km.

Conclusions

Our experiments showed the importance of bias correction coefficients in the processing of AMSU-A data in the ALADIN/HU limited area model.

The use of the global bias correction file showed different impacts on short-range forecasts, especially in the lower troposphere, which is very important for synoptic meteorology. LAM bias correction coefficients provided a "stable" impact on the analysis as well as on the short-range forecasts.

Although the ARPEGE and the ALADIN models use basically the same parameterisation of physical processes, and the bias correction coefficients are available from the global model, it is recommended to use bias correction, computed separately for the ALADIN model to ensure better processing of the AMSU-A data in the analysis system. It was found, that despite of smaller observation-minus-first-guess samples, bias correction coefficients computed for the limited area were more suitable and reliable when assimilating radiances in a LAM.

It was proved, that the air-mass bias correction must be included in the processing of AMSU-A data in the limited area model.

It seems that the processing of the channels 10-12 in LAM was very sensitive to the bias coefficients computed for a global model.

Our preliminary results showed that the resolution of input AMSU-B data is important for their better use in a LAM. The assimilation of AMSU-B data in full grid is preferable.

The impact of AMSU-B data on the analysis and short-range forecast of temperature, geopotential and wind fields was found to be rather slightly positive than neutral. Positive impact on the forecast of relative humidity was observed.

It seems that the “optimal thinning distance” for our system is 80km. Further investigations, however, should be performed for recommendations on operative use of AMSU-B data.

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