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Radiance-bias correction for a limited area model

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Abstract—Direct assimilation of satellite measurements requires correction of biases caused by both measurement problems and errors in the radiative transfer model. The bias correction is based on finding the difference between the observed radiances and those simulated from the model states. Since the bias correction method was originally developed for global models, its 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 sample 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. This can cause problems when evaluating the scan-angle biases for a limited area model. This paper investigates different bias correction coefficients in order to find the best method for processing satellite data in the ALADIN limited area model. Bias correction coefficients, computed for the French global (ARPEGE) model, and one computed for the ALADIN limited area model, and many of their combinations were tested. The impact of the bias correction coefficients computed for the ALADIN limited area model was found to be more "stable" in both the analysis and short-range forecasts. The impact of the bias correction coefficients computed for the global model depended on the synoptic situation of the investigated period, especially in the important for the synoptic meteorology 850 to 500 hPa layer.

Key-words: limited area model, radiance-bias correction, data assimilation, ATOVS/AMSU-A.

1. Introduction

In most numerical weather prediction (NWP) centres, satellite data are assimilated in the form of raw radiances. For the efficient use of raw radiances (in our case from ATOVS), 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. The bias parameters are then updated jointly and simultaneously with the model state during the variational analysis, and are fully consistent with all observational information available to the analysis. *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 model (*Horányi et al*., 1996), the method described by *Harris* and *Kelly* (2001) is used for correcting radiance-biases (see Section 2.2). 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. 2a)* 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.

Fig. 2a demonstrates the statistics computed for a one month period for the old domain (*Fig. 3a*) of the ALADIN Hungary (ALADIN/HU) model, which is relatively small compared to the new one (*Fig. 3b*). Enlarging the domain, smoother curves were obtained (*Fig. 2b*). Less but 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 (triangles in *Fig. 2b*). This indicates, that further efforts have to be done to improve the bias correction method for the ALADIN/HU LAM model.

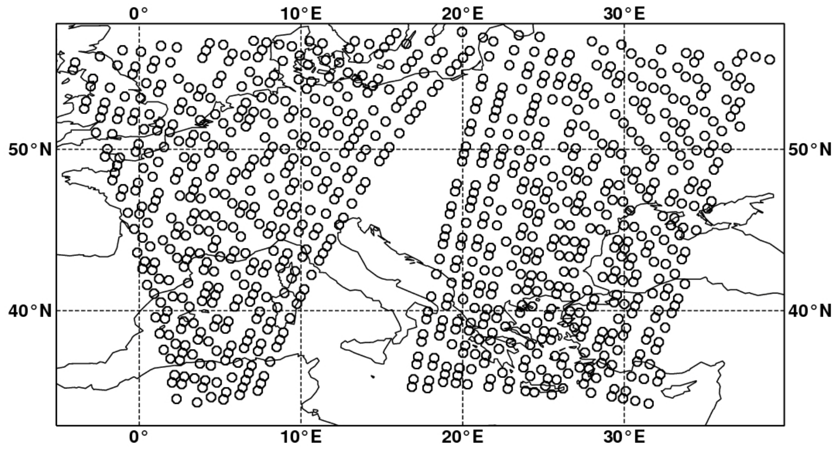

Fig. 1. Example of satellite paths inside the ALADIN/HU domain observed on April 23, 2003, 00 UTC.

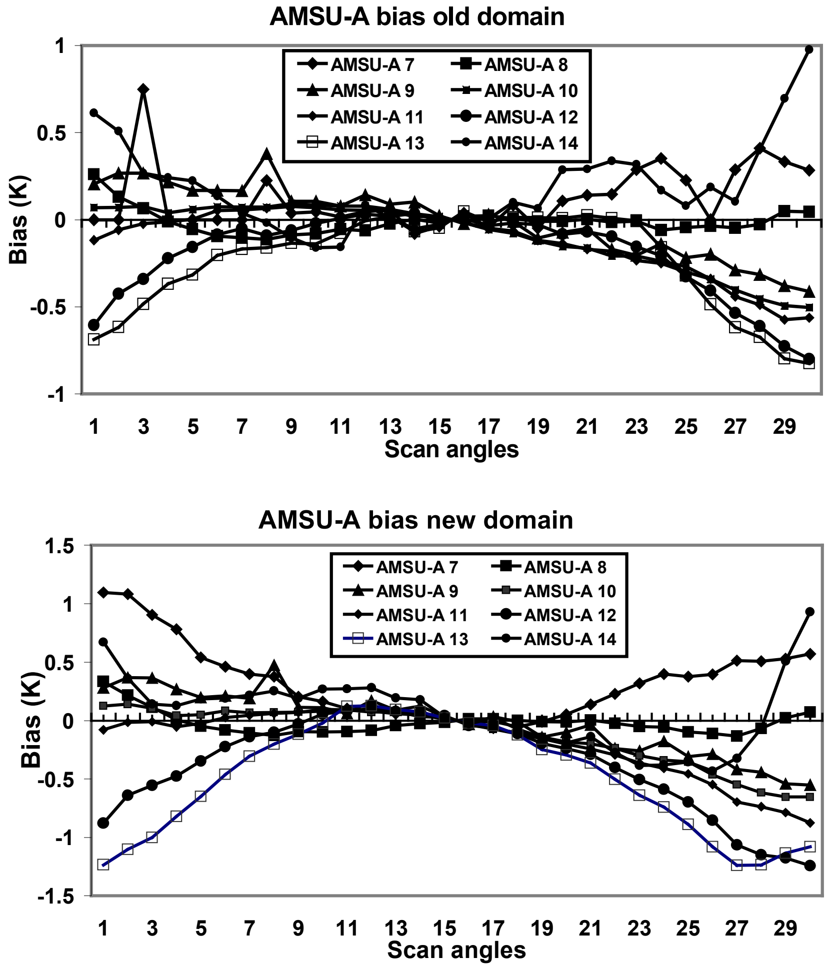

Fig. 2. Scan-angle bias computed for the old (*a*) and new (*b*) ALADIN/HU domains. Note that the domains of the ALADIN/HU model are presented in Figs. 3a and 3b.

This paper investigates different bias correction coefficients in order to find the best method for processing raw radiance satellite data in the ALADIN limited area model.

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

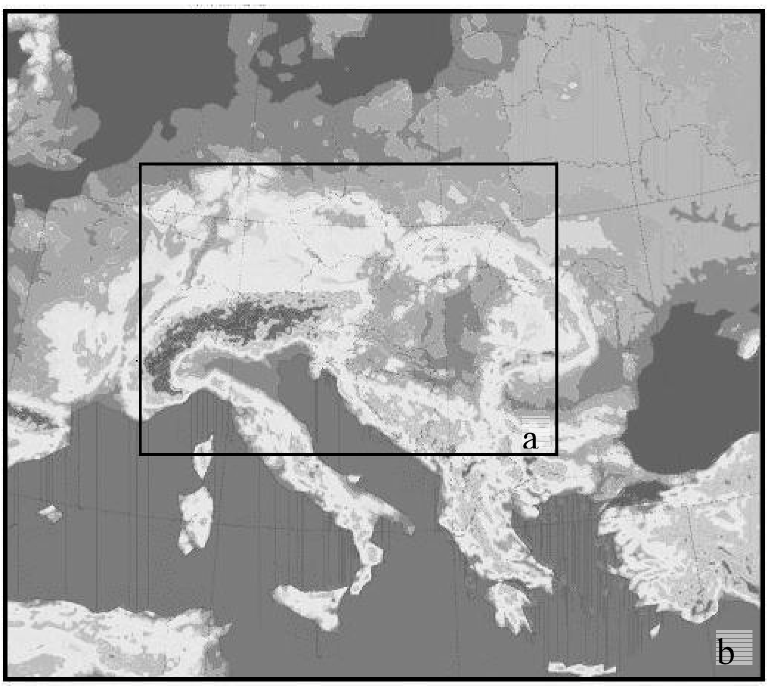

Fig. 3. Topography of the old (*a*) and new (*b*) ALADIN/HU domains, respectively.

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 experiments performed with various bias correction files. Section 4 reviews the results of the experiments, and in Section 5 we draw some conclusions of the results presented in this paper.

2. The ALADIN/HU model and its assimilation system

At the Hungarian Meteorological Service (HMS), the ALADIN/HU model runs in its hydrostatic version. The model used in this investigation was the

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

al15/cy24t1 version of the ARPEGE/ALADIN codes (http://www.cnrm.-meteo.fr/aladin/concept/historycycles.html). In this study we used the model with 12 km horizontal resolution (*Fig. 3b*) and 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 (al15/cy24t1) we use the RTTOV6 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 (see *Randriamampianina* and *Szoták,* 2003 for more details). An optimal interpolation scheme was used to analyze the surface fields (*Radi* and *Issara,* 1994). The AMSU-A data were assimilated at 80 km 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, starting from 00 UTC.

2.1 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 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 varied up to three.

2.2 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 the set of state-dependent predictors.

Four predictors computed from the first-guess fields were selected (p1 – the 1000–300 hPa thickness, p2 – the 200–50 hPa 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.

3. 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. 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).

A twenty-day period (April 18, 2003–May 07, 2003 – denoted as first period later on) was used for the first impact study that consisted of four experiments. A fifteen-day period (February 20, 2003–March 06, 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.

OT8B1I: The same as T8B1I for the second period.

OT8B3I: The same as T8B3I for the second period.

4. 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. Almost neutral impact of bias correction methods on the analysis and forecast of relative humidity, geopotential height, and wind speed was found.

Concerning the impact on the temperature, the results are classified as follows.

4.1 Comparison of biases using different bias correction files

The particularity of the data assimilation system at the HMS is that it 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 1000 hPa 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) have a heating effect above and a cooling effect under the 500 hPa level (*Fig. 4*) compared to the control run. Our verification concerns only the levels below 100 hPa.

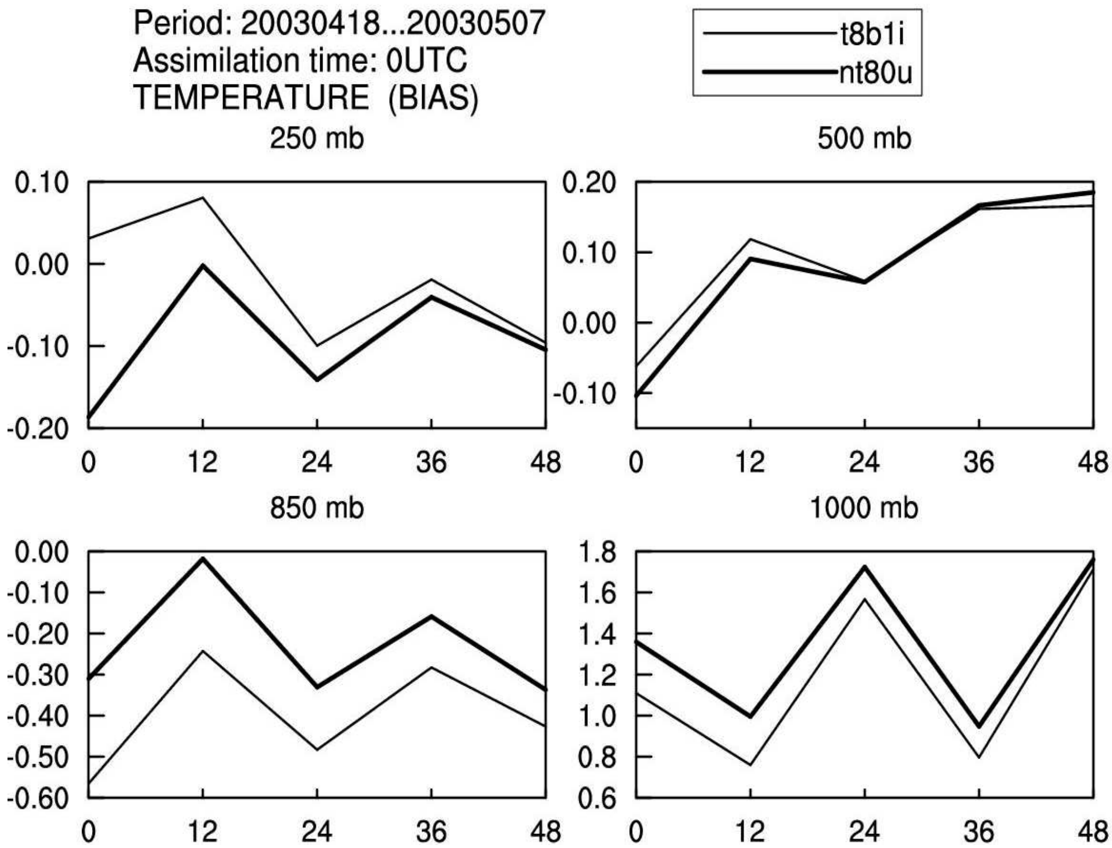

Fig. 4. Temperature biases, computed using the global (ARPEGE) bias correction coefficients (T8B1I) against biases, computed using the LAM coefficients (NT80U) for the first period.

4.2 Impact of the global bias correction file

Though the ALADIN/HU model has different biases of temperature in different model layers, the systematic cooling or heating does not necessarily yield an overall positive impact on temperature forecasts. For example, a clear positive impact on the forecast of temperature can be observed in the troposphere (500 hPa level) during the second period, although there was a negative impact at 850 hPa during the first period (*Fig. 5*). Thus, the behavior of the limited area model is 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 can be obtained.

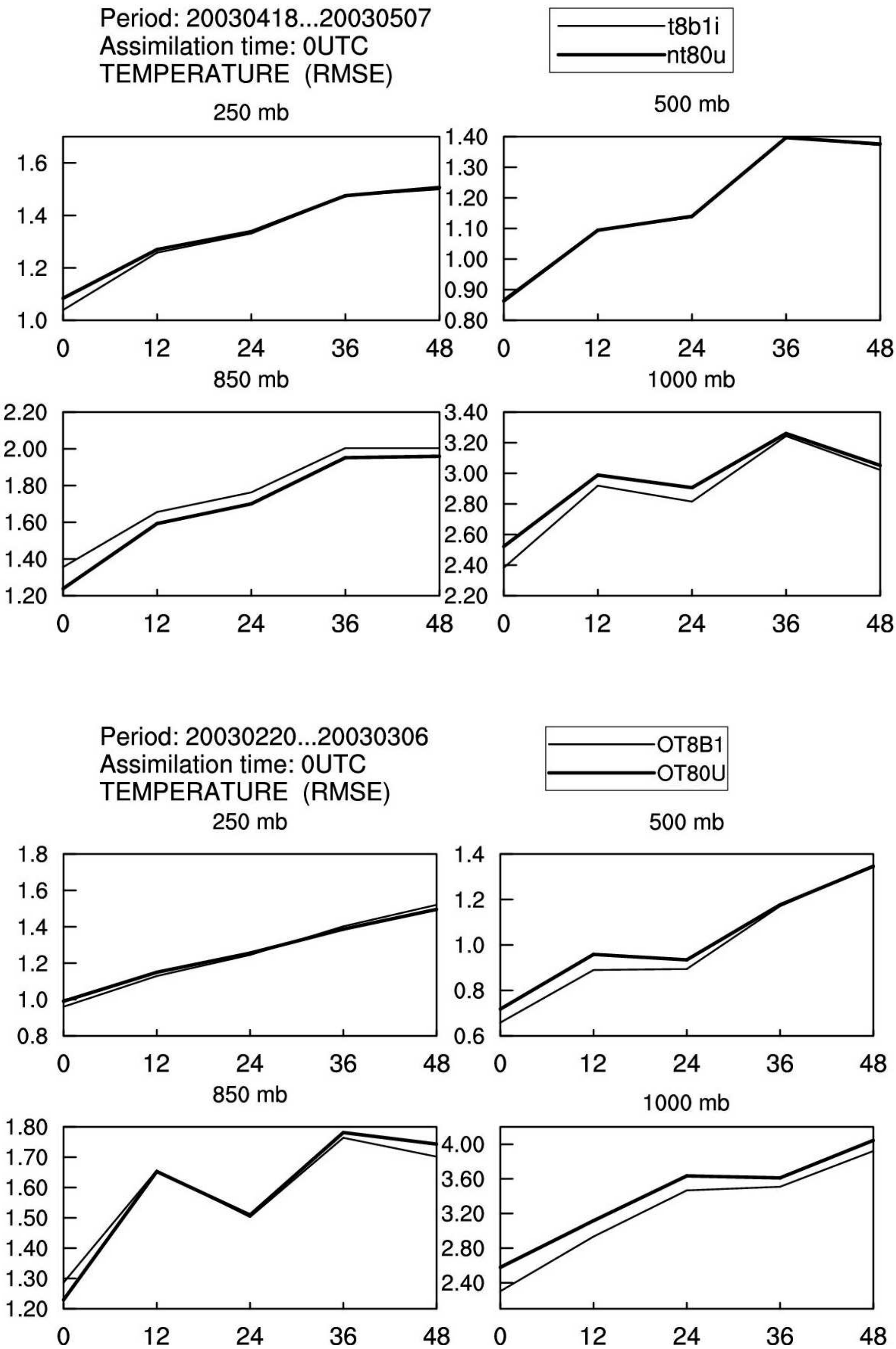

Fig. 5. Temperature root-mean-squares errors (RMSEs) for run with global bias correction coefficients (ARPEGE) (T8B1I and OT8B1I, for the first and the second period, respectively) against run with LAM coefficients (NT80U and OT80U, for the first and the second period, respectively).

4.3 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 can compute better representation of the scan-angle bias.

Without air-mass bias correction, satellite measurements warmed the model fields to a larger extent, which indicates 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 seems likely that we need air-mass bias correction to assimilate radiances, since the ARPEGE scan-angle bias correction itself was not satisfactory.

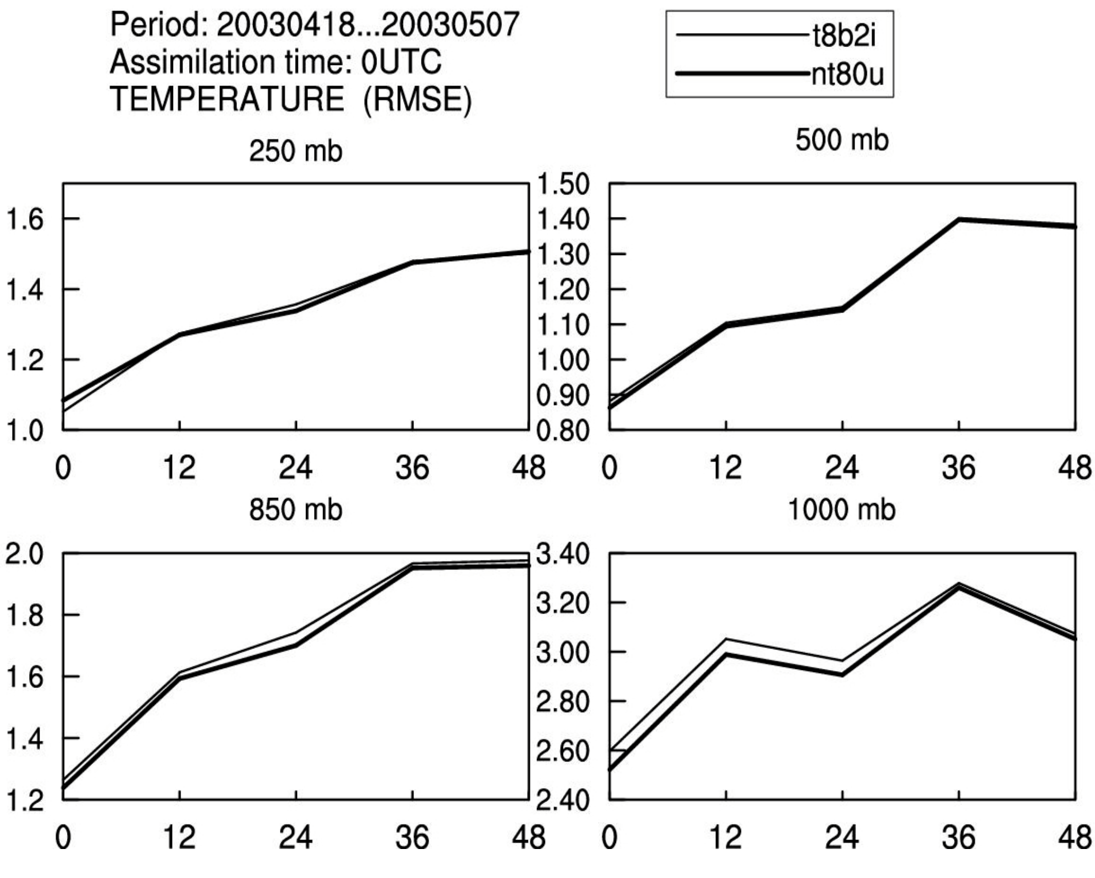

Fig. 6. Temperature root-mean-square errors (RMSEs) for run with global bias correction coefficients (ARPEGE) (T8B2I – no air-mass bias correction) against run with LAM coefficients (NT80U).

4.4 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 is 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 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 reveals that using the global scan-angle bias correction with LAM air-mass bias correction coefficients did not improve the impact significantly.

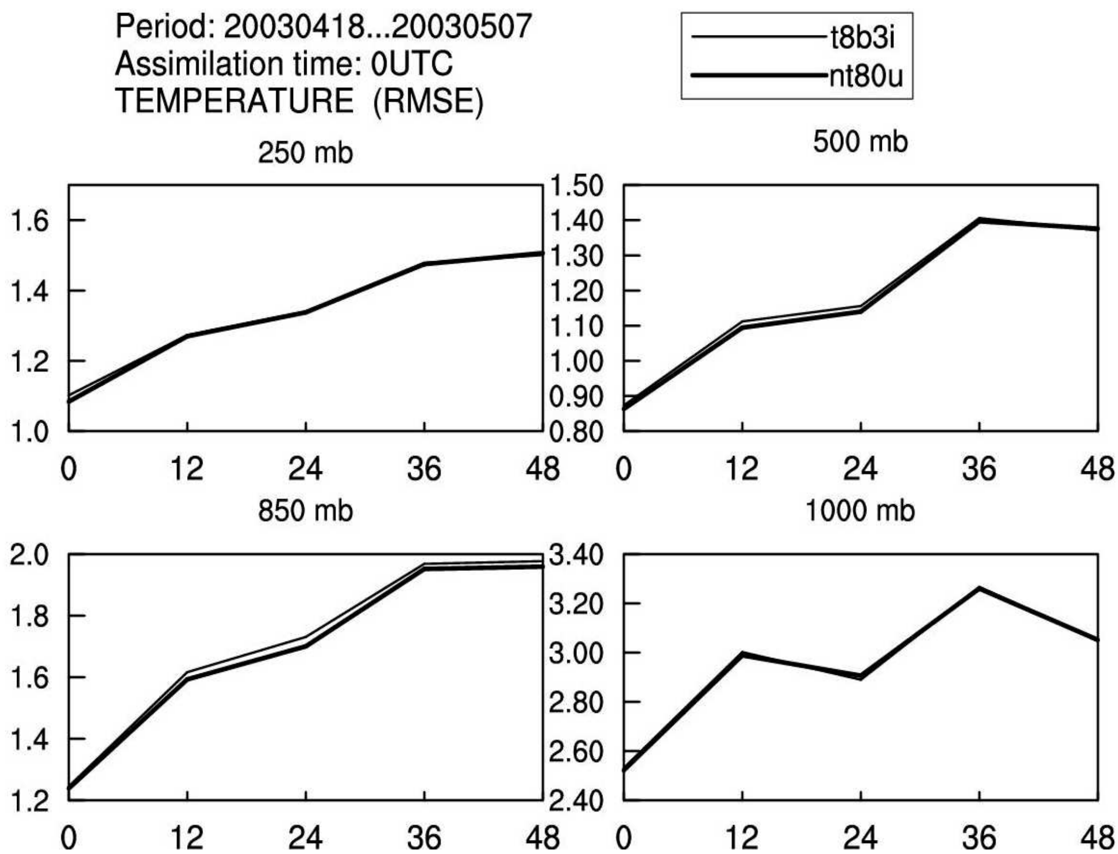

Fig. 7. Temperature root-mean-square errors (RMSEs) for run with global (ARPEGE) scan-angle bias correction coefficients and with LAM air-mass bias correction coefficients (T8B3I) against run with LAM bias correction coefficients (NT80U).

The sensitivity of channels 5, 6, 7, 10, 11, and 12 to the bias correction files was evaluated analyzing 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 assume, 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 is more accurate than that in the LAM.

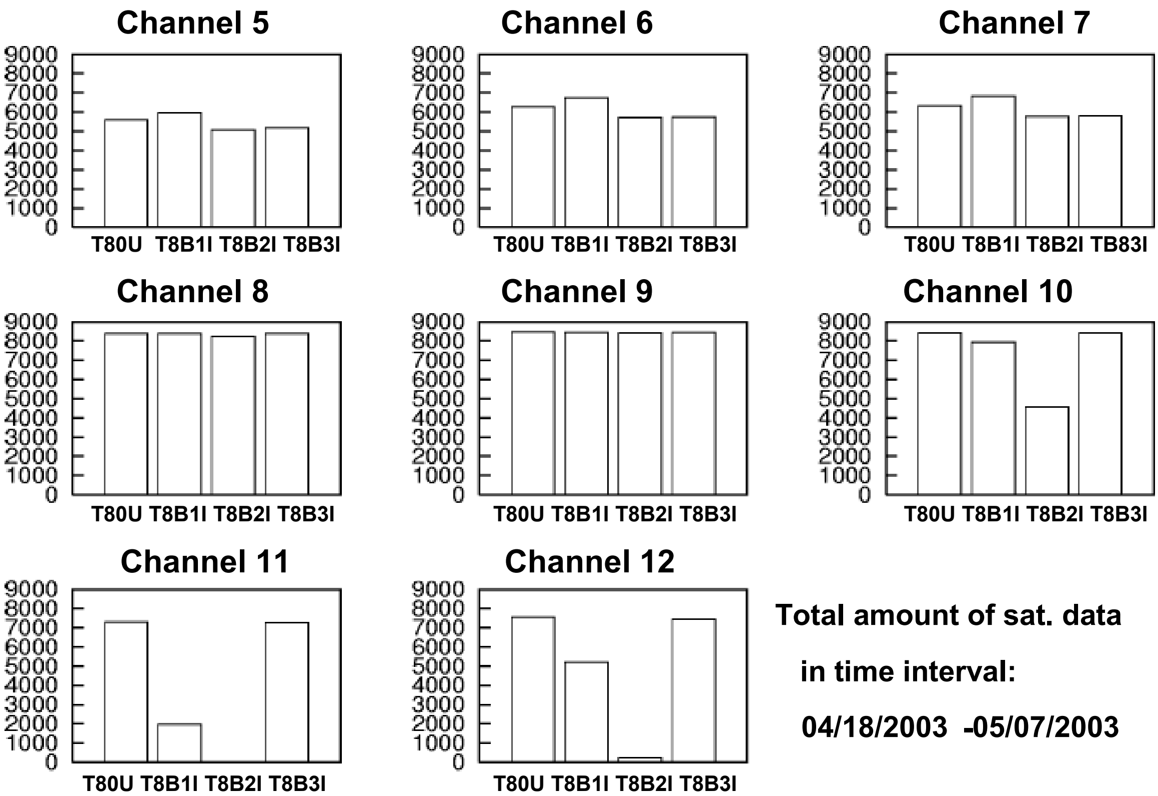

Fig. 8. Total number of assimilated satellite observations (active data) for the period April 18, 2003–May 07, 2003.

5. Conclusions

Our experiments show 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 provide 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 parameterization 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 are 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 is very sensitive to the bias coefficients computed for a global model.

At the Hungarian Meteorological Service, a 3D-Var system became operational this year (from May 17, 2005). In this system the pre-processing of the AMSU-A data uses bias correction coefficients computed locally according to the method, presented in this paper.

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