Choice for radiance-bias correction for a limited-area model

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1. Abstract

In order to assimilate satellite measurements directly we must correct biases between the observed radiances and those simulated from the model first guess, caused by systematic error of radiances and by the radiative-transfer model. The method used for bias correction was developed for global models, its adaptation to limited-area models 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 data obtained at each satellite (AMSU-A) scan position. In the case of a limited domain (limited-area model, LAM), we do not have the same amount of satellite measurements along the scan line, due to the fact that satellite paths might be cut at different scan positions during pre-processing in the analysis system. This might be a source of problems when evaluating of scan-angle biases for a LAM.

This paper investigates the use of different bias correction coefficients for the ALADIN limited-area model. In our study, the bias correction coefficients computed for the global ARPEGE model, those computed for the ALADIN limited-area model, and many of their combinations have been tested out in order to find the best one to process satellite data in a LAM.

The results of our experiments show that the impact of the bias correction coefficients computed for the ALADIN model is more "stable" in the analysis as well as in short-range forecasts, while the impact of the bias correction coefficients computed for the global model depends on the synoptic situation of the investigated period. This is especially true for the layers between 850 and 500 hPa, which is very important for synoptic meteorology.

2. Introduction

In most numerical weather prediction (NWP) centres satellite data are assimilated in the form of raw radiances. In order to efficiently use raw radiances (from ATOVS), biases between the observed radiances and those simulated from the model first-guess must be removed. A lot of articles deal with the removal of these biases (Eyre, 1992; Harris and Kelly, 2001). In general, these studies are based on global models and assume that radiance biases come from two different sources : from differences in measurement quality depending on the scan angle and from radiance and air-mass dependencies. In ARPEGE/ALADIN, we use the method described by Harris and Kelly (2001) to correct radiance biases. The main assumption of the above-mentioned study is that scan-angle biases vary with latitude, and air-mass predictors are composed of the following geophysical quantities from the model first-guess : two thicknesses (1000-300 hPa and 200-50 hPa), surface skin temperature and total column of water vapour.

Minor modifications had to be done in order to compute the radiance biases on a limited area. The most important modification concerns the consideration of the case of no satellite observation inside the "domain of interest" (central (C) + inner (I) zones).

In Fig. 1, one can see two satellite paths : a whole path can be seen on the right side of the domain and a portion of a second path is on the left side. Scan-angle biases depend on the number of samples obtained at each scan position. Due to the "problem" illustrated in Fig. 1, it is easy to understand that it is not possible to have the same number of samples for all scan positions in a given channel when computing scan-angle biases for a LAM. It leads to fluctuating curves instead of well-smoothed ones along scan lines (see Fig. 2a). In Fig. 2a we have the statistics computed for the old domain (Fig. 3a) of ALADIN-Hungary (ALADIN/HU), which is relatively small compared to the new one (Fig. 3b). When enlarging the domain, we get smoother curves, but we can still observe the above-mentioned problem for several channels. See, for example, the curve representing the scan-angle bias for channel 9 of AMSU-A (red triangle in Fig. 2b).

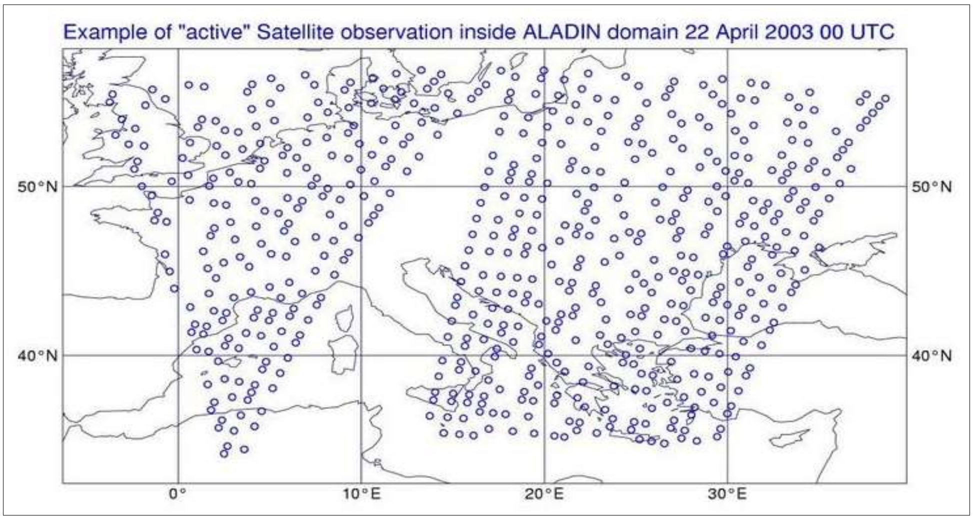


Figure 1 : Example of satellite paths inside the ALADIN/HU domain (C+I zone), observed on 22 April 2003 at 00 UTC.

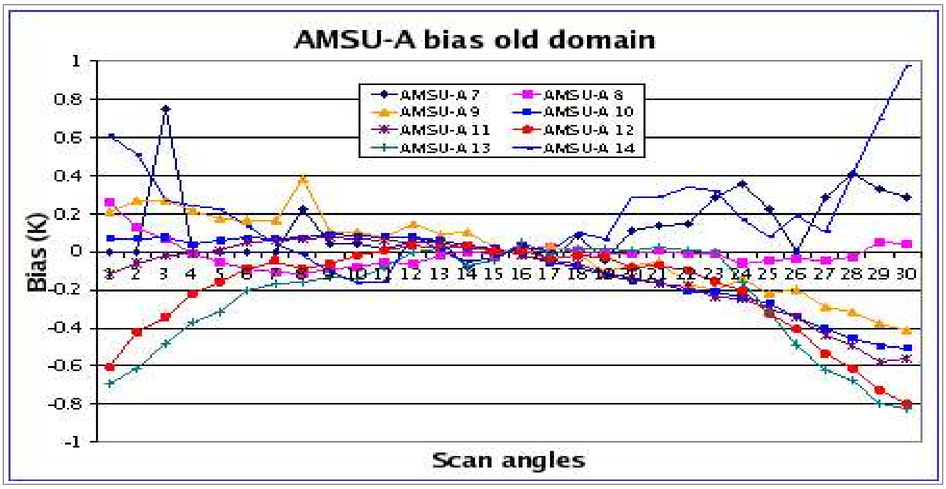


Figure 2a : Scan-angle biases computed for the old ALADIN/HU domain. Note that the domain is presented in Fig. 3a.

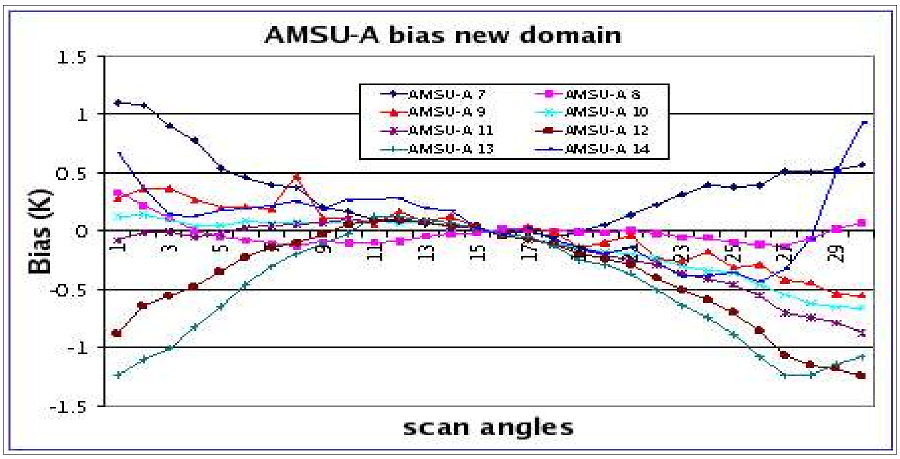
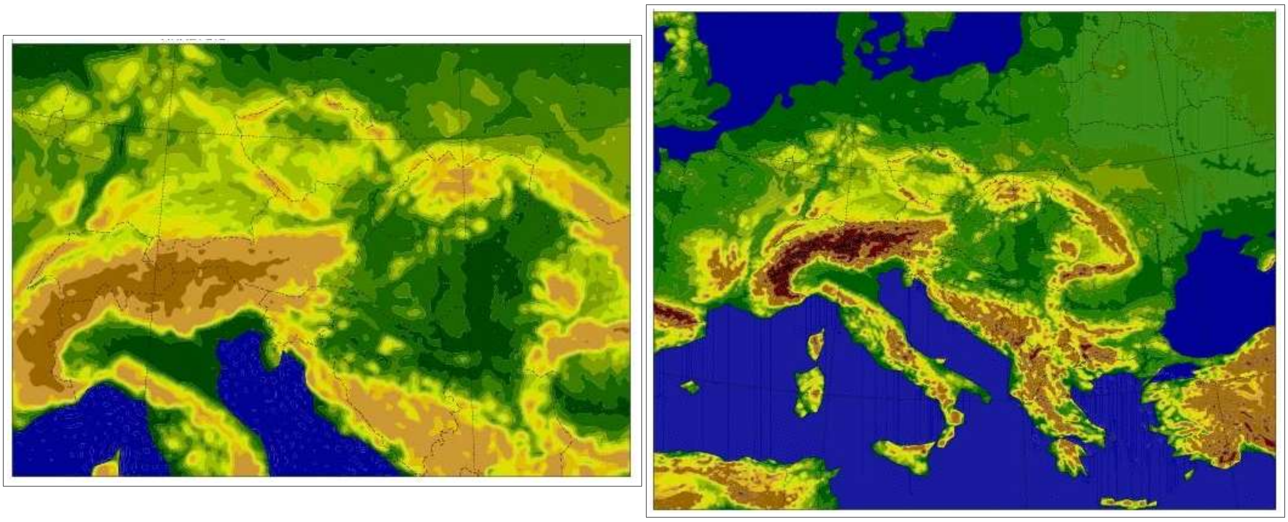


Figure 2b: Scan-angle bias computed for the new ALADIN/HU domain. Note that the domain of the latest ALADIN/HU version is presented on Fig. 3b.



(a) (b)

Figure 3 : Topography of the ALADIN/HU domains a) old, b) new.

We do not have the above-mentioned problems when doing the computation of scan-angle biases for global models, because there is a sufficient number of samples. A question arises concerning the bias correction coefficients to be used for the assimilation of ATOVS data in LAMs. Do we need to compute bias correction coefficients for the restricted domain of the LAM or can we use the ones computed for the coupling[1] global model? We have to pose another question regarding biases related to air-mass : is it at all necessary to remove biases related to air-mass to assimilate the ATOVS observations in a LAM?

The purpose of this paper is to answer these questions, investigating the impact of bias correction coefficients computed in two different ways : first using the coefficients of the ARPEGE global model, and second using those of the ALADIN/HU limited-area model. Bias correction coefficients computed for a global model cannot characterize radiances measured in a limited area as well as coefficients specifically computed for this domain. Despite smaller samples of observation-minus-first-guess, bias correction coefficients computed for the limited area is more suitable and reliable when assimilating radiances in a LAM.

Section 3 describes the main characteristics of ALADIN/HU model and its assimilation system. Section 4 illustrates the local pre-processing of satellite data, and provides a short description of the bias correction method used in ALADIN/HU. Section 5 gives a detailed description of the experiments performed with various bias-correction files. Section 6 reviews the results of the experiments, and in section 7 we draw some conclusions from the results presented in this paper.

3. Main characteristics of the ALADIN/HU model and its assimilation system

At the Hungarian Meteorological Service (HMS) the ALADIN/HU model runs in its hydrostatic version. In this study we used the model with 12-km horizontal resolution (Fig. 3b), and with 37 vertical levels from the surface up to 5 hPa. The three-dimensional variational data assimilation (3D-Var) 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 observation space, it is necessary to simulate radiances from the model fields. In ARPEGE/ALADIN we use the RTTOV radiative-transfer code, which has 43 vertical levels, to perform this transformation (Saunders et al. 1998). 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

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 file from the global ARPEGE model, referred here as coupling model.

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). Due to the problem related to the assimilation of specific humidity, it is assimilated in univariate form (see Randriamampianina and Szoták, 2003, for more details). The AMSU-A data are assimilated at 80 km resolution. The 3D-Var is running in 6-hour assimilation cycles generating an analysis at 00, 06, 12 and 18 UTC. We performed a 48-hour forecast once a day, from 00 UTC.

4. Pre-processing of satellite data

4.1 Selection

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 we have chosen the NOAA-15 and the NOAA-16 ones, 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.

4.2 Bias correction

The direct assimilation of satellite measurements requires the correction of biases between the observed radiances and those simulated from the model first guess. These biases are calculated to estimate the systematic error of satellite data. It may be significant and arise mainly from instrument characteristics or inaccuracies in the radiative transfer model. In order to remove this systematic error we used the method developed by Harris and Kelly (2001).

5. Description of the experiments

The purpose of our experiments was to study the impact of different bias correction coefficients, including coefficients computed for the global ARPEGE model and for the ALADIN/HU limited-area model.

As ARPEGE uses every second pixel of ATOVS measurements, it has zero scan-angle coefficients at non-used pixels, which may cause a large remaining bias. To overcome this problem, we interpolated the values of two adjacent pixels to pixels with zero coefficients.

In order to estimate the impact of different bias correction coefficients we compared the scores of all experiments with the run performed with our bias correction file (specific for ALADIN/HU).

We investigated the impact of each experiment over a twenty-day period (18.04.2003-07.05.2003 - to be denoted as first period later on). In order to confirm our main results we reran some experiments for another fifteen-day period (20.02.2003-06.03.2003 - to be denoted as second period later on).

The following experiments were carried out, all using radiosonde (TEMP), surface (SYNOP) and ATOVS observations :

NT80U: The bias correction file was computed for the ALADIN/HU domain (this was the control run in this study).

T8B1I: The bias correction coefficients were computed for the ARPEGE model (interpolated scan-angle coefficients, see explanation above).

T8B2I: The scan-angle coefficients were the interpolated ARPEGE ones, but no air-mass correction was applied.

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

T8B4I: We used the scan-angle biases as well as the air-mass correction coefficients computed for ALADIN/HU, but for channels with tropospheric peak (channel 5, 6 and 7) air-mass correction coefficients were the ARPEGE ones.

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.

6. Results and discussion

In this study we have compared the impact of our bias correction coefficients with the impact of bias correction coefficients computed for the global ARPEGE model in order to find the best solution to the processing of the AMSU-A in the ALADIN/HU model. In the previous section we have presented the main characteristics of the performed experiments. The results could be classified as follows :

6.1 Comparison of biases using different bias-correction files

Concerning the impact on biases in a temperature profile, we can emphasise that the use of bias coefficients for the global ARPEGE model (mentioned as global bias-correction file later on) have a cooling effect under 500 hPa and heating effect above this level (Fig. 4) compared to the control run. Unfortunately, our verification concerns only the levels below 100 hPa.

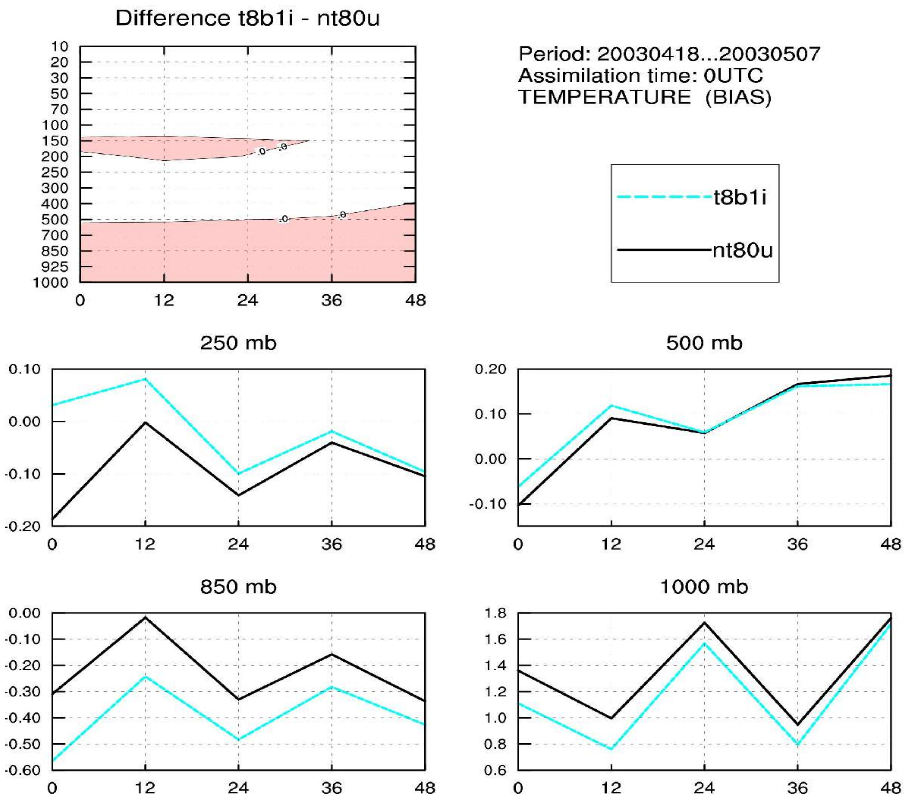


Figure 4.: Temperature biases for run with global (ARPEGE) bias correction coefficients (T8B1I) against run with LAM coefficients (NT80U) for the first period. In upper left picture we can see the difference between biases, where coloured area represents negative values.

6.2 Impact of the global bias correction file

The ALADIN/HU model has different biases (positive or negative) in different layers of the model. The systematic cooling or heating does not necessarily yield an overall positive impact on temperature forecasts. For example, one can see a definite positive impact on temperature forecasts at 500 hPa during the second period, though there was a definite negative impact at 850 hPa during the first period (see Fig. 5). So, the behaviour of the limited-area model is not really "controllable" when we apply the global bias-correction file in the assimilation system to process satellite observations.

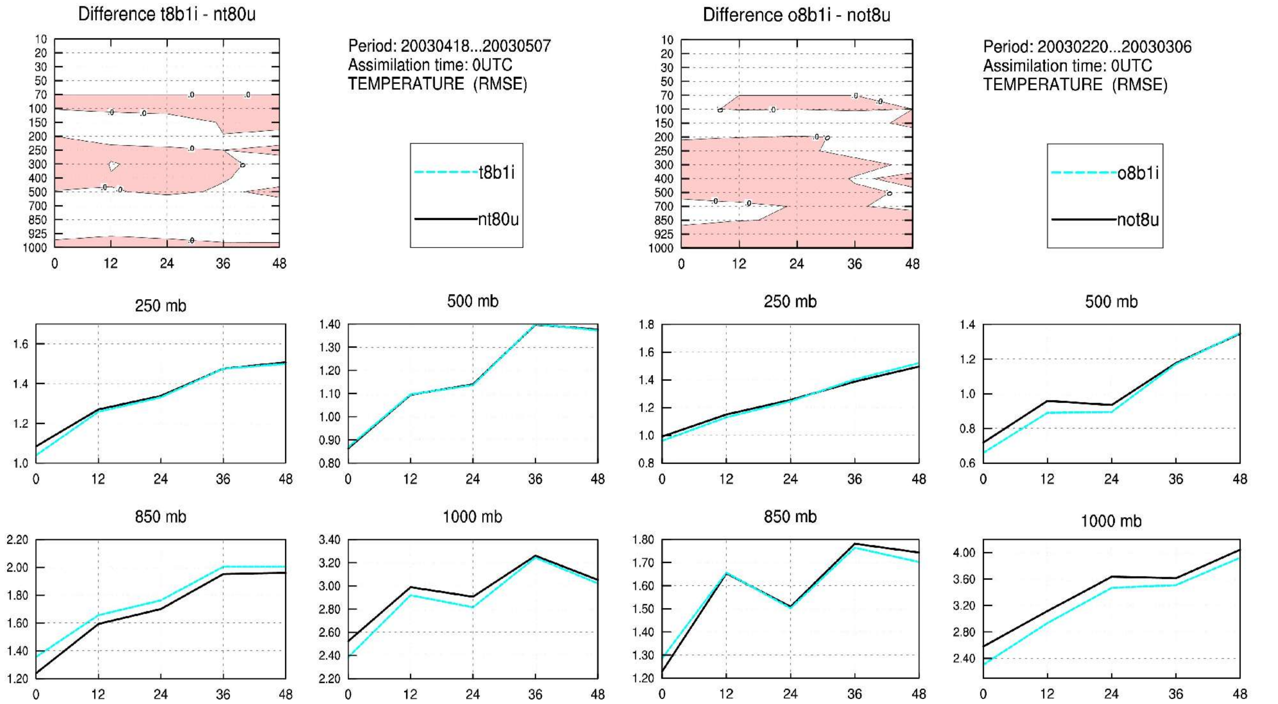


Figure 5.: Temperature root-mean-squares errors (RMSE) for run with global bias correction coefficients (ARPEGE) (T8B1I and O8B1I, for the first and the second period, respectively) against run with LAM coefficients (NT80U and NOT8U, for the first and the second period, respectively). In upper left picture we can see the difference between biases, where coloured area represents negative values.

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

It was an interesting question about bias correction whether the use of air-mass bias correction could be avoided in limited-area models or not. In order to assess the importance of air-mass bias correction, we did not apply air-mass correction in the experiment T8B2I, we used only the interpolated ARPEGE scan-angle bias correction. 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 negligible impact on all variables, including temperature for 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.

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

Based on the assumption that air-mass bias correction needs to be used, 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 of the experiment with only ARPEGE bias-correction file (see Fig. 5), but both negative and positive impacts were negligible (Fig. 7). This reveals that we cannot use the global scan-angle bias correction with LAM air-mass bias correction coefficients.

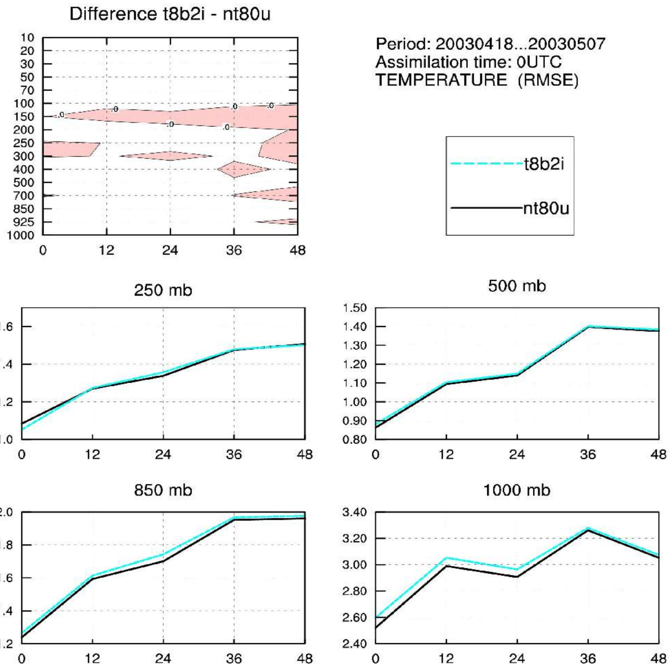


Figure 6.: Temperature root-mean-square errors (RMSE) for run with global bias correction coefficients (ARPEGE) (T802I - no air-mass bias correction) against run with LAM coefficients (NT80U), differences between them are illustrated in upper left picture, where coloured area presents negative values.

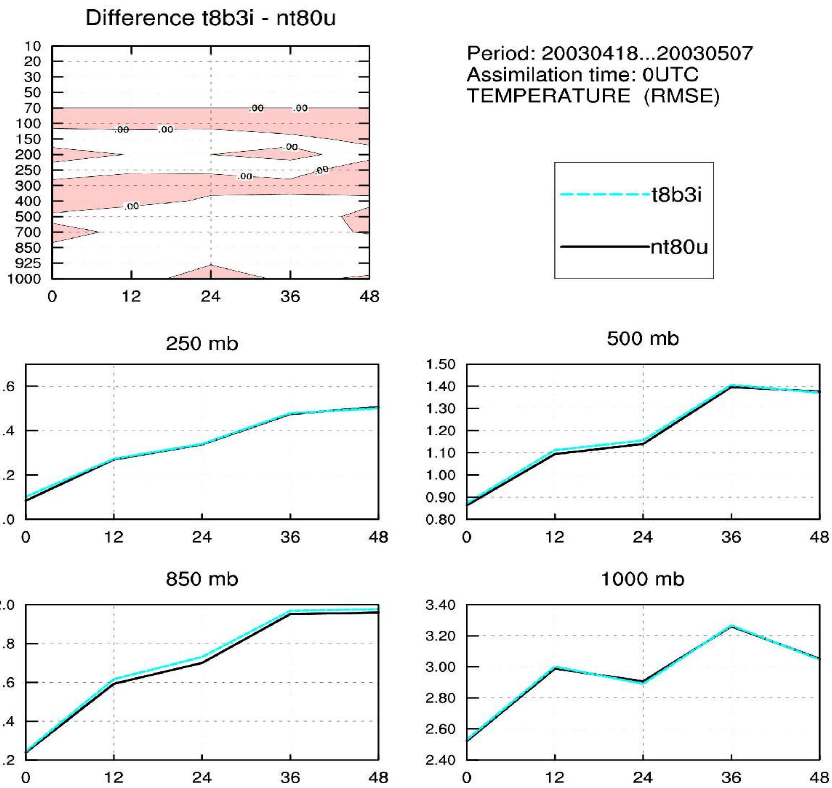


Figure 7.: Temperature root-mean-square errors (RMSE) for run with global (ARPEGE) scan-angle bias correction coefficients and with LAM air-mass bias correction coefficients (T803I) against run with LAM bias correction coefficients (NT80U). Upper left picture shows the difference between them, where coloured area presents negative values.

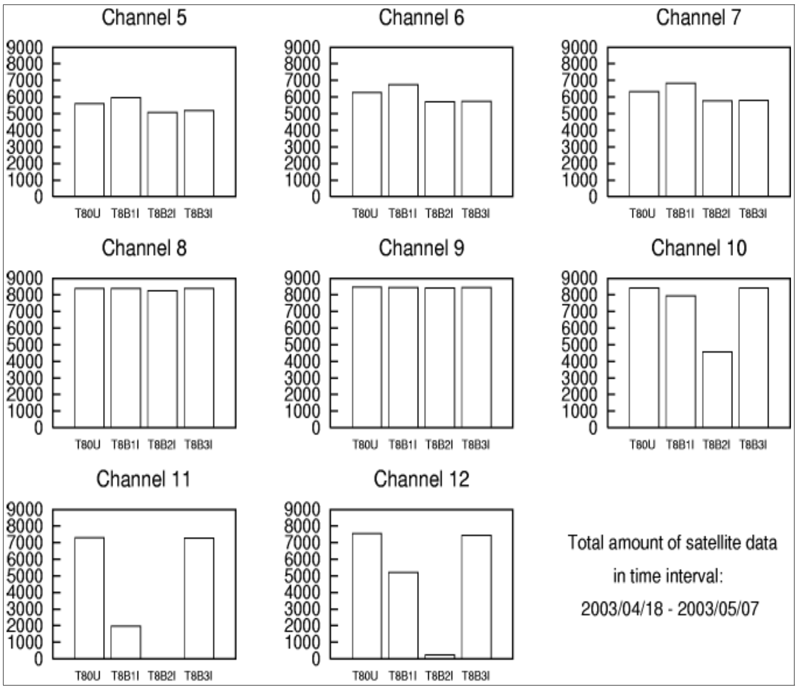


Figure 8: Total number of assimilated satellite observations (active data) for the period 18.04.2003 - 07.05.2003.

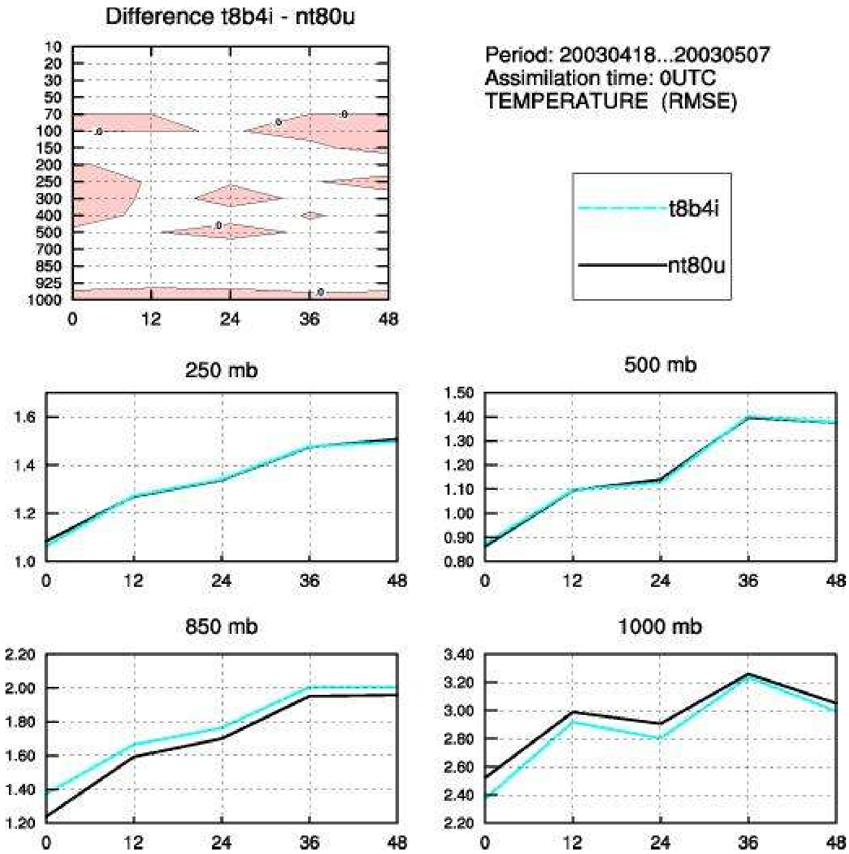


Figure 9.: Temperature root-mean-square errors (RMSE) run with LAM bias correction coefficients (NT80U) against run with LAM bias correction coefficients except the air-mass bias coefficients for AMSU-A channel 5, 6 and 7, which were the global (ARPEGE) ones (T804I). In upper left graph we can see the difference between their RMSE, coloured area presents negative values.

Analysing the number of assimilated satellite data (Fig. 8), we can see the sensitivity of channels 5, 6, 7, 10, 11 and 12 to the bias-correction files. We were able to use more observations 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. Taking into account that using the global air-mass bias correction we had significant positive impact at 1000 hPa for both periods, we decided to make an additional experiment (T8B4I), where we replaced some of the coefficients for air-mass bias of the LAM bias file (for channels 5, 6 and 7) with those computed for the global model (Fig. 9.). We got a positive impact at 1000 hPa, but unfortunately, we could not remove the negative impact at 850 hPa.

7. Conclusions

This set of experiments shows the importance of bias correction coefficients in the processing of AMSU-A data in the ALADIN/HU limited-area model. We have to underline the fact that the ARPEGE and ALADIN models use basically the same parametrization of physical processes. Nevertheless, we have to compute the bias-correction file for ALADIN to have better processing of the AMSU-A data in the analysis system.

The air-mass bias correction must be included in the processing of AMSU-A data for the LAM.

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. Consequently, we decided to keep the LAM bias-correction file in the processing of AMSU-A data.

8. Acknowledgements

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9. References

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