

# Impact of the ATOVS data on the Mesoscale ALADIN/HU Model

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## Abstract

At the Hungarian Meteorological Service for the last few years we have been investigating the three-dimensional variational (3D-Var) data assimilation technique in the limited area model ALADIN (ALADIN/HU). Our main objective is to change the so-called dynamical adaptation (initial file from the global model ARPEGE) that is recently in operational use, to a 6-hour data assimilation cycle. Another important task is to use as many observations as possible.

Data from radiosonde and surface observations are already prepared for data assimilation. At present, we are investigating the use of data from aircraft (AMDAR) and satellite (ATOVS) observations. The impact of ATOVS data is studied in two resolutions (80 and 120km). In the ALADIN 3D-Var, the specific humidity is assimilated together with vorticity, divergence, temperature and surface pressure (in multivariate formulation). According to the preliminary results, it is better to assimilate the specific humidity separately (univariate formulation) from all other control variables.

We got promising results when assimilating ATOVS data at 80 and 120 km resolutions.

## Introduction

In 2001 a complex study was performed to compare the quality of locally pre-processed ATOVS radiances (level 1d) from CMS (Centre de la Météorologie Spatiale, Météo France) in Lannion with those from NOAA/NESDIS<sup>1</sup> (Randriamampianina and Rabier, 2001). According to the results of this study, the quality of the locally pre-processed ATOVS data is better than the quality of NESDIS data. Moreover, the positive impact of the locally pre-processed ATOVS data on the forecast of the ARPEGE model over Europe (Lannion reception area) was more significant than that of NESDIS.

These encouraging results were one of the reasons to choose the ATOVS data as potential observation to complete the observational database at the Hungarian Meteorological Service (HMS). In 2002 the implementation of the locally pre-processed ATOVS data was performed. Hence, a new concept of data pre-processing was worked out followed by the implementation of a bias correction program to estimate the systematic errors of the local ATOVS data. More information about the pre-processing and the implementation of ATOVS data into the ALADIN three-dimensional variational (3D-Var) data assimilation at the Hungarian Meteorological Service (HMS) is described in Randriamampianina (2003).

This report presents the first results of the study on the impact of ATOVS data on the analyses and forecasts of the ALADIN model. Section 2 gives a brief description of the characteristics of the ALADIN/HU model. Section 3 introduces the pre-processing of ATOVS data. A description of the performed experiments for the impact study is given in Section 4. Section 5 presents the results of the impact study, followed by some selected cases in Section 6. In Section 7 we draw some conclusions and discuss further tasks.

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

The hydrostatic version of the ALADIN model was used in this study. The horizontal resolution of the ALADIN/HU is 6.5 km. ALADIN/HU has 37 vertical levels from surface up to 5 hPa. We use the 3D-Var technique as an assimilation system. An important advantage of the variational technique is that the cost function for the observation part is computed in the observation space. Consequently, for

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<sup>1</sup> NOAA/NESDIS- National Oceanic and Atmospheric Administration/National Environmental Satellite Data and Information Service

assimilation of radiances, we have to be able to determine them from the model parameters. For this purpose we need a radiative transfer code. In ARPEGE/ALADIN we use the RTTOV code (Saunders et al., 1999), which uses 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. Assimilation systems require good estimation of the background error covariance - the so-called "B" matrix. The B matrix was computed using the "standard NMC method" (Parrish and Derber, 1992). A 6 hour assimilation cycling was chosen, consequently the 3D-Var is running 4 times a day at 00, 06, 12 and 18 UTC. We perform a 48 hour forecast one time a day from 00 UTC.

### **Data pre-processing**

We receive the ATOVS data through an HRPT antenna. The AMSU-A, level 1C, data are pre-processed by the AAPP (ATOVS and AVHRR Pre-processing Package) package.

### **Choice of Satellite**

Because of its technical specification, our antenna is able to receive data from only two satellites at the same time. Data from NOAA-15 are available over the ALADIN/HU domain at about 06 and 18 UTC, while data from NOAA-16 are available around 00 and 12 UTC. The orbit of the NOAA-17 is between the orbits of the other two satellites a bit closer to that of NOAA-16. We know that NOAA-15 has problems not only with the AVHRR instruments but also with some microwave channels (AMSU-A-11 and AMSU-A-14). Nevertheless, NOAA-15 and NOAA-16 were chosen for the impact study to guarantee the maximum amount of observation at each assimilation time.

### **Extraction of ATOVS data**

Satellite data observed and pre-processed in the interval of  $\pm 3$  hours from the assimilation time are treated. The maximum number of the orbits found at one assimilation time varies up to 3 (see Fig. 1).

### **Bias correction**

The systematic error of the satellite data can be shown by comparing the observed radiances with the computed (simulated) ones. The systematic error arises mainly from errors in the radiative transfer model, instrument calibration problems or biases in the model fields. The bias correction coefficients for data from NOAA15 and NOAA16 were computed for the study period according to Harris and Kelly (2001). Note, that the bias coefficients were computed for different latitude bands. Fig. 2 demonstrates the bias, computed for the same latitude band for NOAA-15 and NOAA-16.

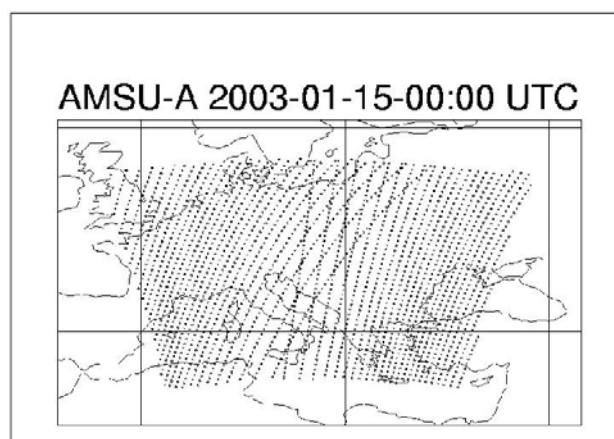


Figure 1: Satellite data over the ALADIN-HU domain (central + inner zone).

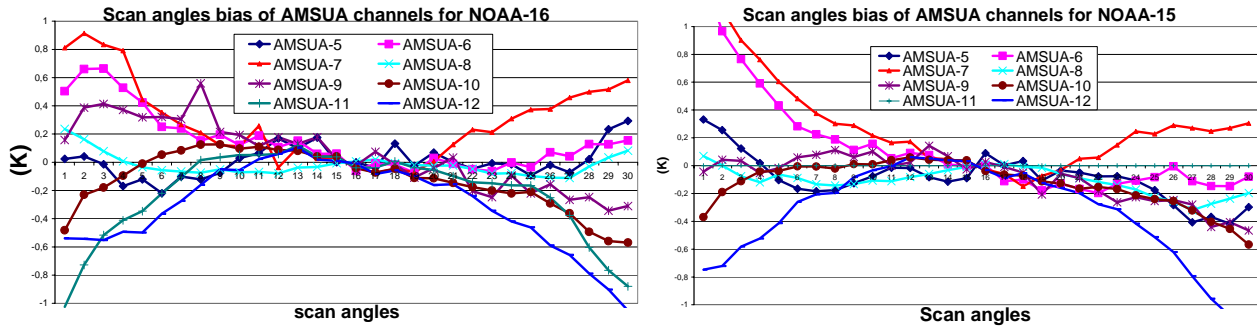


Figure 2: Bias (in degree Kelvin) specific to the scan angles varies with latitude band. Figures present cases, when the biases were computed for the same latitude band.

### Channel selection

Analysing the bias of the brightness temperature, specific for each AMSU-A channel, inside all possible latitude bands, we decided to keep the same number of channels as they were used in the ARPEGE model (see Table 1.).

Table 1.:The use of AMSU-A channels

Channel number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Over Land					x	x	x	x	x	x	x	x			
Over Sea					x	x	x	x	x	x	x	x			
Over Sea ice							x	x	x	x	x	x			
Cloudy pixel								x	x	x	x	x			

Note, that over land channels 5 and 6 are used when the model orography is less than 500m and 1500m, respectively

Our study is interesting from the point of view of using AMSU-A data over land (see Table 1.), because the percentage of land over the ALADIN-HU domain is more than 70%.

### Observation statistics and assimilation of radiances

It is necessary to check the efficiency of the statistics (observation error) used to handle the observation in case of new data and, in our case, "new model configuration" (more examples can be seen in Randriamampianina and Rabier, 2001). The observation (AMSU-A radiances) minus guess (computed radiances) were compared with the observation minus analysis for this purpose (see Fig. 3). These graphs show statistics computed from a few days (2003.02.20-2003.02.25) cycling. The distance between the two curves indicates how the addition of the AMSU-A data could modify the first-guess fields during the assimilation. The larger the distance, the bigger the impact of the observation (so, of the AMSU-A) on the analysis. These results are comparable to those computed in Randriamampianina and Rabier (2001). Thus, we decided to keep the original values of the theoretical standard deviation at this stage as it is used in ARPEGE.

### Experiments design

In the experiments, two thinning techniques (80 and 120 km resolutions) were investigated. The impact of ATOVS data was studied for a two-week period (from 2003.03.20 to 2003.03.06). Surface (SYNOP) and radiosonde (TEMP) observations were used in the control run. The impact was evaluated comparing the control run with runs with TEMP, SYNOP and ATOVS data. Examining the first results, we found that the impact of ATOVS data on analysis and forecasts depended on the way the control variables (vorticity, divergence, temperature and surface pressure and the specific humidity) were handled. In particular, the assimilation of the specific humidity in univariate form or with all control variables using the multivariate formulation was focused on.

**The following experiments were carried out:**

- T8000** - TEMP, SYNOP and AMSU-A data were assimilated. The AMSU-A data were thinned at 80km resolution. The multivariate formulation was used for all control variables.
- T1200** - TEMP, SYNOP and AMSU-A data were assimilated. The AMSU-A data were thinned at 120km resolution. The multivariate formulation was used for all control variables.
- Aladt** - TEMP and SYNOP were assimilated - control run. It is our 3D-Var cycling running in parallel suite. The multivariate formulation was used for all control variables.
- Touhu** - TEMP, SYNOP and AMSU-A data were assimilated. The AMSU-A data were thinned at 80km resolution. The specific humidity was assimilated as a univariate control variable, while the other control variables were assimilated using multivariate formulation.
- 12uhu** - TEMP, SYNOP and AMSU-A data were assimilated. The AMSU-A data were thinned at 120km resolution. The specific humidity was assimilated as a univariate control variable, while the other control variables were assimilated using multivariate formulation.
- Aluhu** - TEMP and SYNOP were assimilated - the control run. The specific humidity was assimilated as a univariate control variable, while the other control variables were assimilated using multivariate formulation.

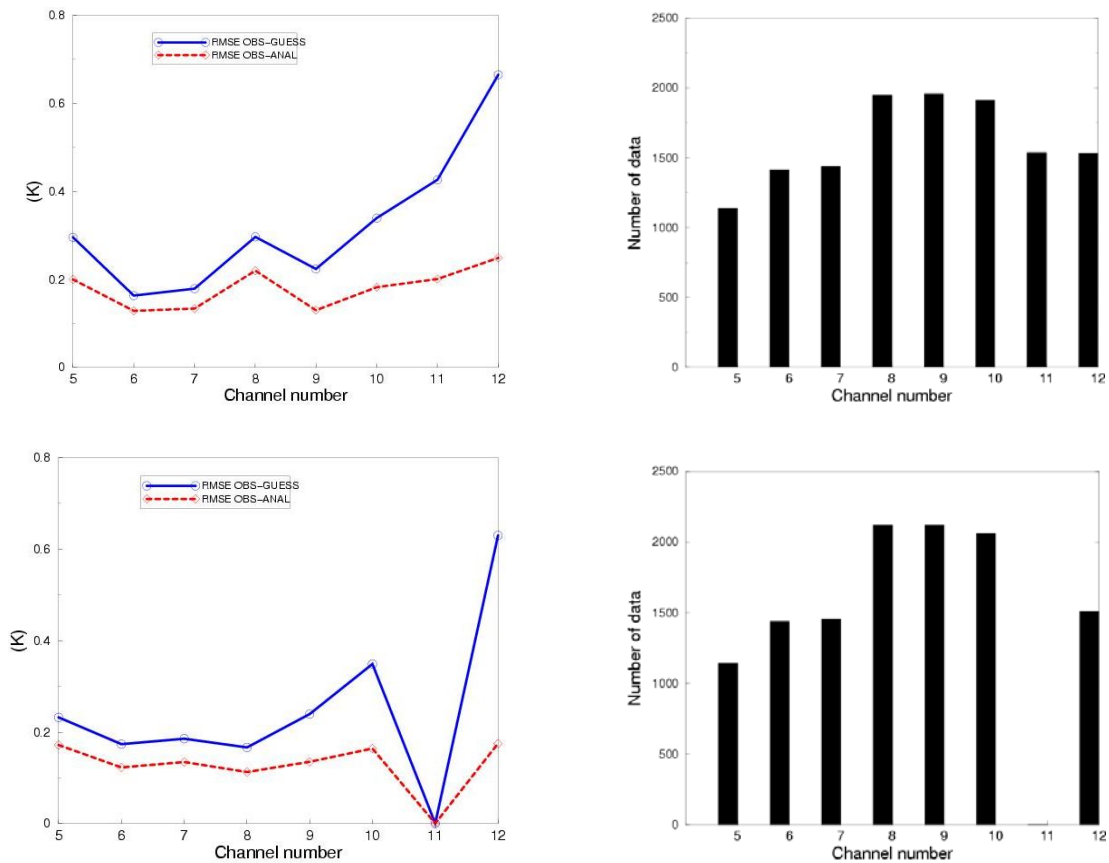


Figure 3: Example of statistics of observation minus guess (solid line) and observation minus analysis (dashed line) for AMSU-A at 00 UTC (upper graphs) and 06 UTC (lower graphs) for a five-day cycling (from 2003.02.20 to 2003.02.25) (left hand side). On the right one can find the number of data used in the computation of the statistics.

**Objective verification**

The bias and the root mean square error (RMSE) were computed from the differences between the analysis/forecasts and the observations (SYNOP and TEMP) and also with the long cut-off analyses of the global model ARPEGE.

## Most important results

### Using multivariate formulation

- We found that AMSU-A data have positive impact on the analyses and forecasts of geopotential height when assimilating them in both 80 and 120 km resolutions. Especially, on lower levels (i.e. below 700 hPa), the impact was positive for all forecast ranges. Positive impact on the short-range (until 12 hour) forecast was observed for all model levels (see Fig. 7)
- A neutral impact on the analysis and forecasts of wind speed was observed.
- A neutral impact of AMSU-A data on the temperature profile was found.
- Regarding the relative humidity fields, clear negative impact was observed.

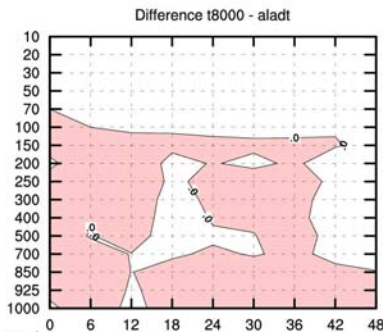


Figure 7: Difference between the root mean square errors for geopotential height:  $RMSE_{T8000} - RMSE_{aladt}$ .

Negative value (coloured) means that the error of run with ATOVS data is less than that of control run, thus the ATOVS data have positive impact. X and Y axes present the forecast ranges (in hour) and the model levels respectively (in hPa)

The "stability" of the negative impact of AMSU-A data on relative humidity fields showed that the source might have come from the way the humidity data had been assimilated. We decided to separate the specific humidity from the multivariate formulation and assimilate it alone (univariate form).

### Assimilating the humidity in univariate form

- The impact of AMSU-A data on forecast of geopotential height was somewhat less, but positive compared to the run with multivariate formulation.
- Positive impact on the temperature above 700 hPa was observed from the 24 hour forecast range (see Fig. 8)
- Concerning the impact on relative humidity, improvement could be observed (Fig. 9). It is important to mention that we found big improvement at all model levels when assimilating the humidity data in univariate form, especially for levels around the tropopause (Fig. 10). It can be also observed on the run without ATOVS data (Fig. 10).
- A neutral impact was found for the wind speed.

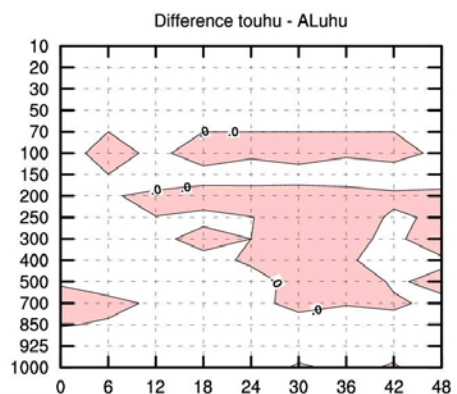


Figure 8: Difference between the root mean square errors of temperature in case of assimilating the humidity data in univariate form:

$RMSE_{touhu} - RMSE_{aluhu}$ . Negative value (coloured) means that the error of run with ATOVS data is less than that of control run, thus the ATOVS data have positive impact. X and Y axes present the forecast range (in hour) and the model levels respectively (in hPa).

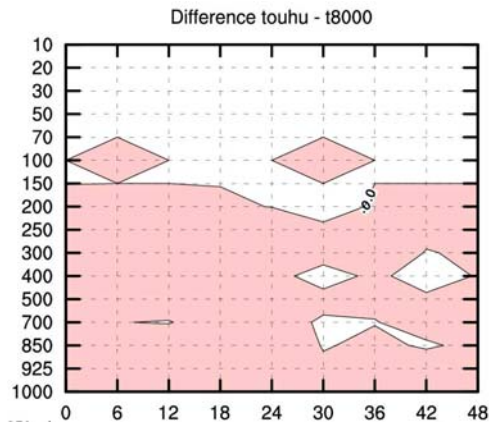


Figure 9: Difference between the root mean square errors of relative humidity:  $RMSE_{touhu} - RMSE_{T8000}$ . Negative value (coloured) means that the error is reduced when assimilating the specific humidity in univariate form.

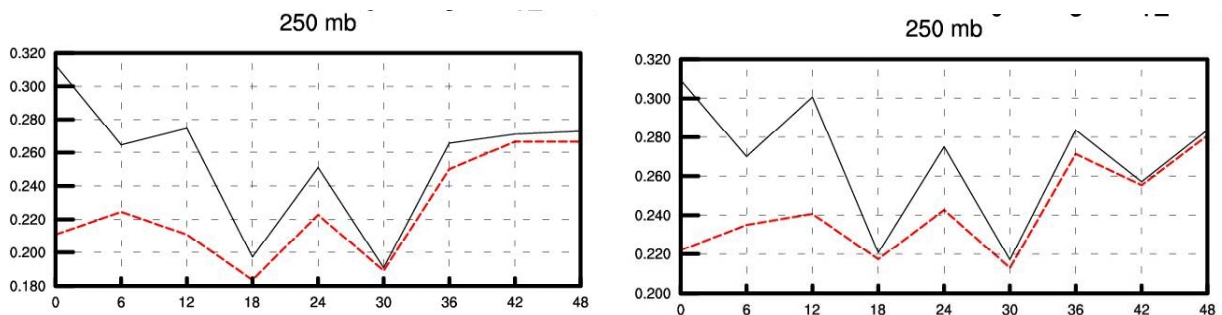


Figure 10: Root mean square forecast errors of relative humidity (in percent) at 250 hPa level against radiosonde observation. Comparison of two 3D-Var runs with ATOVS data assimilated in 80 km resolution (left hand side graph) and runs with TEMP and SYNOP data (right hand side graph). Solid line: when the multivariate formulation was used for all control variables. Dashed line refers to case, when the specific humidity was assimilated in univariate form. X axis presents the forecast ranges in hour.

### Influence of resolution

We performed comparisons to evaluate the influence of resolution of ATOVS data on the analysis and forecast. In general, the positive impact of ATOVS data on geopotential and temperature was stronger in case of finer (80 km) resolution of ATOVS data. The 120 km resolution gave "better" impact on relative humidity, wind speed and wind direction when using multivariate formulation. Assimilating the humidity data in univariate form, the finer resolution gave "better" impact on relative humidity (see Fig. 11).

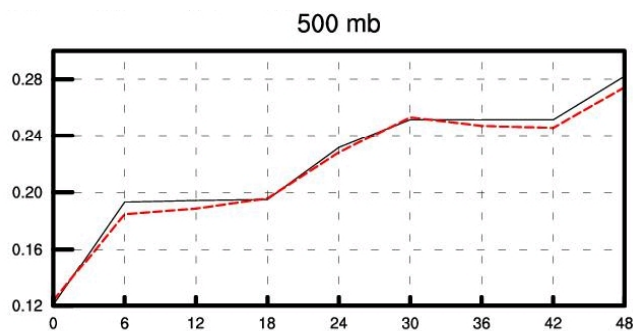


Figure 11: Root mean square forecast errors of relative humidity (in percent) at 500 hPa level against radiosonde observation. Comparison of two 3D-Var runs with ATOVS data when the humidity was assimilated in univariate form. Dashed line: thinning in 80 km (touhu). Solid line: thinning in 120 km (120uhu). X axis presents the forecast ranges in hour.

We concluded, that the positive impact was somewhat stronger in general when ATOVS data were assimilated at finer resolution, especially when the specific humidity was assimilated in univariate form.

### Selected cases

As it was shown above, the impact of ATOVS data on the forecast on different parameters was slightly positive or neutral in general. In the following, we chose certain cases within the study period to compare the runs with and without ATOVS data with a special attention on forecast of precipitation.

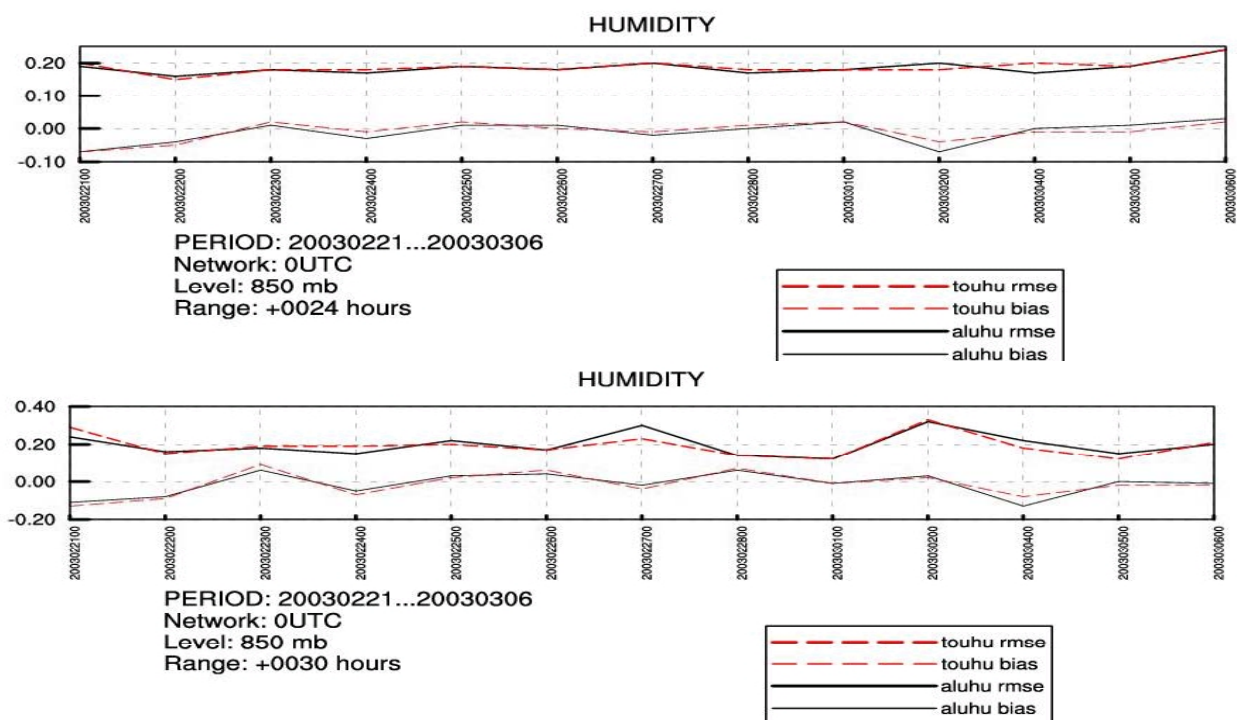


Figure 12: Day-to-day root mean square forecast errors (in percent) (upper curves) and biases (lower curves) of relative humidity at 850 hPa model level. Comparison of 3D-Var run with ATOVS data assimilated in 80 km (touhu, dashed line) with the control one (with TEMP and SYNOP only) (aluhu, solid line) for 24 (upper graphic) and 30 (lower graphic) hour forecast ranges.

Exploring the reasons of negative impact on the forecast of humidity it was ascertained that in some cases no ATOVS data was available at all (e.g. 24 February, see Fig. 12), or the negative impact was characteristic for territories, located rather far from the satellite pass (e.g. 28 February). It indicates that the negative impact may refer to the absence of ATOVS data, so that the ATOVS data did not have the possibility to correct the "bad quality" first-guess fields.

We examined what differences we receive in the spatial distribution of cumulative precipitation depending on the use (here we mean inclusion or exclusion) of ATOVS data in 3D-Var runs. The results of this study are given in Figures 13-15.

Figure 13 shows that from synoptical point of view there is no big difference between the maps, created from results of the runs without (left) and with (right) ATOVS data. The objective verification, however, showed positive impact on 24-hour and neutral impact on 30-hour forecasts (Fig. 12) of ATOVS data on the humidity on this particular day (2 March). Figures 14 illustrates differences in cumulative precipitation between the runs without (left) and with (right) ATOVS data at the Eastern coast of Poland and Western part of Byelorussia. According to the real situation, presented in Figure

15, there was some precipitation over the mentioned area. One can see that the run with ATOVS data could slightly better describe this situation (4 March).

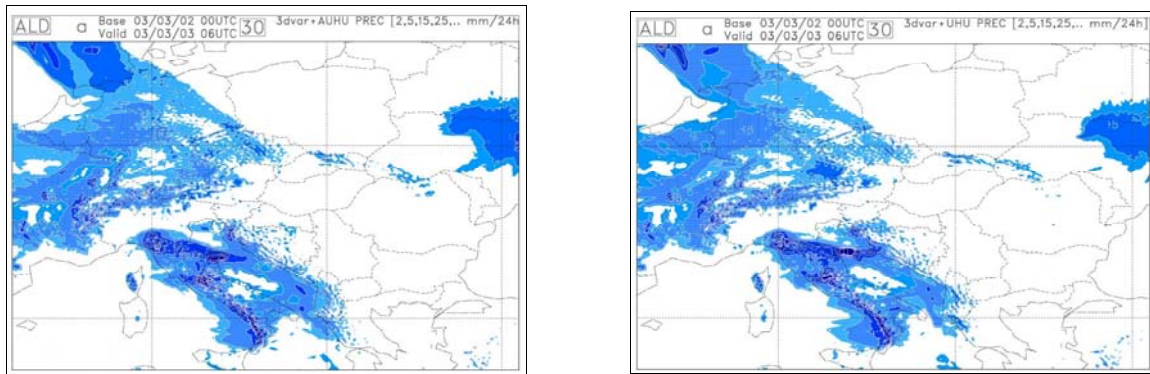


Figure 13: The 24 hour cumulative precipitation (in mm) predicted over the ALADIN/HU domain from 2003.03.02 00 UTC. On the left: control run (with TEMP and SYNOP). On the right: 3D-Var run with ATOVS assimilated in 80 km resolution. In both runs the humidity was assimilated in univariate form. Note that the 24-hour cumulated precipitation is the difference between the cumulative precipitation predicted at 6 and 30 hour forecast ranges.

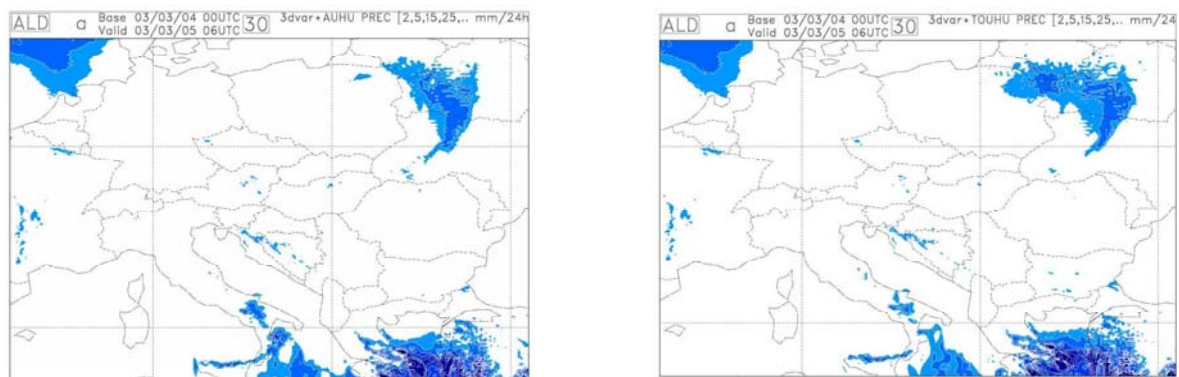


Figure 14: The 24 hour cumulative precipitation (in mm) predicted over the ALADIN/HU domain from 2003.03.04 00 UTC. Upper picture: control run (with TEMP and SYNOP). Lower picture: 3D-Var run with ATOVS assimilated in 80 km resolution. In both runs the humidity was assimilated in univariate form. Note that the 24-hour cumulated precipitation is the difference between the cumulated precipitation predicted at 6 and 30 hour forecast ranges.

We examined also a situation when ATOVS data were available over a very small part of the ALADIN/HU domain (case of Feb. 28). Analysing the 24-hour cumulative precipitation, we found that the run with ATOVS data gave poorer results than the run without ATOVS data for cases, when the rainy territories were located far away from the satellite pass. Moreover (see the 24 h. forecast on Feb. 28 as an example), the impact of ATOVS data was slightly negative.

Detailed analyses of the above mentioned cases provide important additional information for the impact study compared to statistical evaluation. Thus, the indexes of the objective verification sometimes might not be enough for thorough assessment of the impact of satellite data on analysis and forecast.



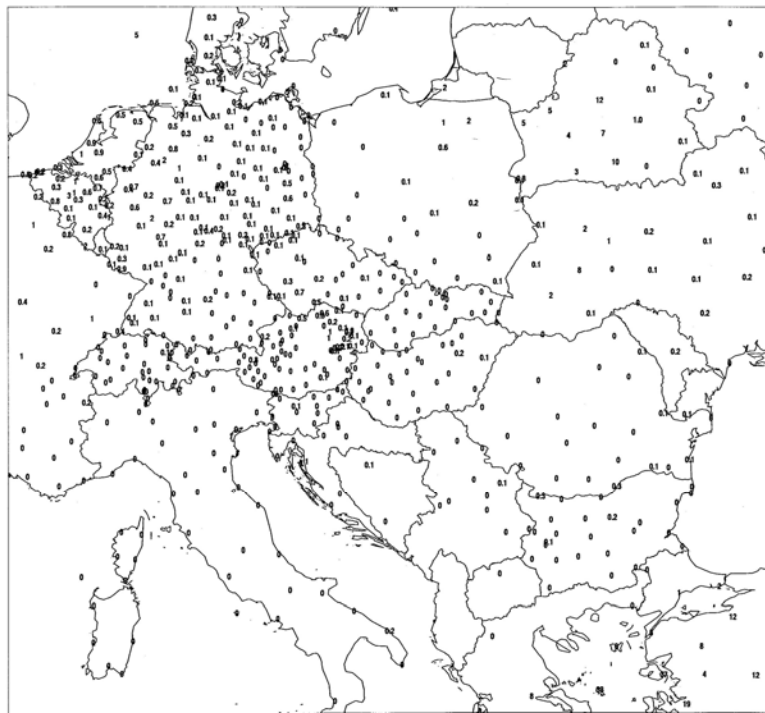


Figure 15: The 24 hour cumulative precipitation (in mm) extracted from SYNOP telegrams for 2003.03.05 06 UTC (upper picture) and the distribution of the ATOVS pixels at 2003.03.04 00 UTC (situation after screening - active observation) (lower picture).

### ***Comparison with the French global model (ARPEGE) long cut-off analyses***

We compared the forecasts from runs with and without ATOVS data with the ARPEGE long cut-off analyses at 4 forecast ranges (12, 24, 36 and 48 hours). The objective of this comparison is to have the horizontal distribution of the impact over the ALADIN/HU domain.

Figure 16 indicates that positive impact is dominating all over the ALADIN/HU domain. However, when comparing the average statistics for the 2 cases (Fig. 17), the impact might be slightly positive (36 hour forecast, 500 hPa) or slightly negative (12 hour forecast, 500 hPa) (Fig 17). We found similar results when comparing statistics for other variables.

### **Summary, further suggestions and experiments**

- The assimilation of the ATOVS data into the limited area model ALADIN/HU gave neutral impact in general (the positive and negative impacts were slight) but the positive impact is dominating all over the domain.
- Because of the problems related to the humidity, it is recommended to assimilate the humidity data in univariate form. We changed the assimilation of the humidity from multivariate to univariate in the version of 3d-Var, running actually in parallel suite in Budapest.
- The impact of the ATOVS data on the forecast of temperature was slightly negative in the lower levels. To avoid this, we decided to investigate the use of channels sensitive to the lower atmospheric layers (channels 5, 6 and 7) before performing any further experiments.
- The impact of ATOVS data with finer (80 km) resolution was somewhat "better", than that of 120 km resolution data. It is recommended to perform the further assimilation of ATOVS data in finer resolution.
- Further experiments should be done to clarify what kind of expectations we can have with respect to assimilation of ATOVS data.
- Similar results were obtained when performing the impact study on other 2-week period. It is recommended to perform further experiments to study the changes in the impact of ATOVS data on the forecast in extreme weather conditions.

To sum up, we can state that at the present stage no definite positive impact of ATOVS data on the forecast can be proved in the 3D-Var data assimilation system of the ALADIN model, so it is necessary to continue the experiments.

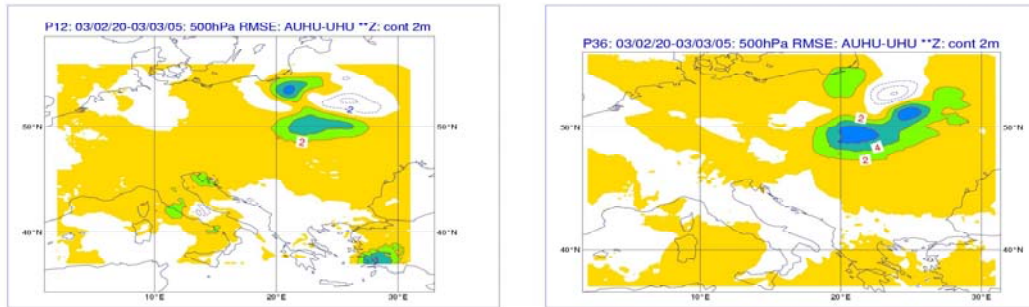


Figure 16: Difference between the root mean square forecast errors ( $RMSE_{aluhu} - RMSE_{touhu}$ ) on geopotential field when comparing the forecasts with the ARPEGE long cut-off analyses. One can see the 12 hour (left-hand side) and 36 hour (right hand-side) forecasts. Coloured areas (positive values) indicate, that run without AMSU-A has bigger error, so the impact of AMSU-A is positive.

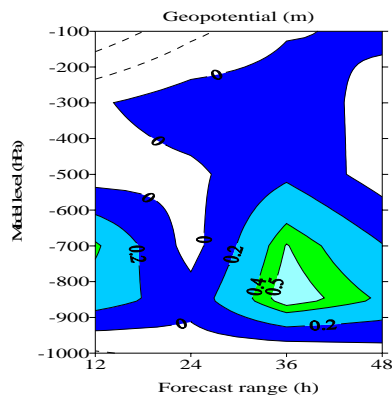


Figure 17: Difference between the root mean square forecast errors ( $RMSE_{aluhu} - RMSE_{touhu}$ ) of geopotential field when comparing the forecasts with the ARPEGE long cut-off analyses. In coloured areas we have positive impact of the AMSU-A data on forecasts

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