3D-Var experiments for the ALADIN/Hungary model: a case study (II)

Steluţa Alexandru

steluta.alexandru@meteo.inmh.ro

Supervisor:

András Horányi

horanyi.a@met.hu

ALATNET Internal Report

June 2003

Hungarian Meteorological Service

Contents

1 Introduction

A successful numerical forecast needs of a proper description of the initial conditions of the numerical weather prediction (NWP) model. The data assimilation schemes applied to the NWP models take into account all the available information about the atmosphere, i.e. observations, the first-guess or background (which can be a model forecast), any other information about the atmospheric flow and the reliability of all these ingredients.

One of the most recent data assimilation techniques is the variational data assimilation. A data assimilation system is being developed for ALADIN mesoscale limited area model (LAM), and applied for the ALADIN/Hungary, a double-nested mesoscale LAM, based on a three-dimensional variational (3D-Var) scheme.

The aim of the new experiments was to compare the forecast of the model using the 3D-Var scheme, with the one in dynamical adaptation (which is the operational system of the ALADIN/Hungary model at the moment), for some interesting meteorological situations. The case studies have been chosen on the one hand, when the operational model failed to provide a good prediction and on the other hand, when the operational forecast was considered reasonably good. In the first category the improvements were checked, and in the latter one, whether the 3D-Var scheme is able to keep the good performance of the operational model. Till now, two case studies from both categories have been investigated in the previous ALATNET reports (Alexandru [1], 2003; Alexandru [2], 2003). The main conclusions were that the model using 3D-Var scheme succeeded to predict a good forecast in both cases.

The research on the 3D-Var data assimilation scheme for a double-nested limited area model has been continued with another case study, from the 4^{th} of August 2002, when the operational model (in dynamical adaptation) has not been able to predict an important quantity of precipitation over Hungary.

The present paper is arranged thus: in section 2, the synoptic situation of the case is described, in section 3, the experiments performed with the 3D-Var scheme are presented, then the results are explained in section 4, and followed at the end by the conclusions.

2 Synoptic situation

The synoptic situation of this event is presented briefly. On the 4^{th} of August 2002, a lower pressure field dominated over the central-eastern Europe. In altitude, the ridge of the anticyclone from North-Africa was extended over central-southern Europe, and a low cut-off was located more to west. The temperatures in the western part of Hungary, were in the morning around 23 °C, increasing till 30 °C, at noon. The air in this area was very humid, which determined an unstable atmosphere.

A cold front was moving to the north-eastern part of Europe, through Austria and Hungary. So cold and dry air was streaming south-westerly. Advancing, the cold air moved the humid air upward, determining a convective instability. The non-frontal surface line, along which convective instability occurs, is called an instability line. This forms in advance of a cold front and is usually oriented roughly parallel to the cold front, moving in about the same direction as the cold front. Along the instability line, the turbulence is severe, because of the violent updrafts and downdrafts. Thus rain showers and thunderstorms occur, with significant quantities of precipitation.

Such instability line has been developed in the north-western part of Hungary, causing an intensive rainfall. Thus, in less than six hours, the quantity of precipitation reached a maximum of 65 mm. (Figure 1).

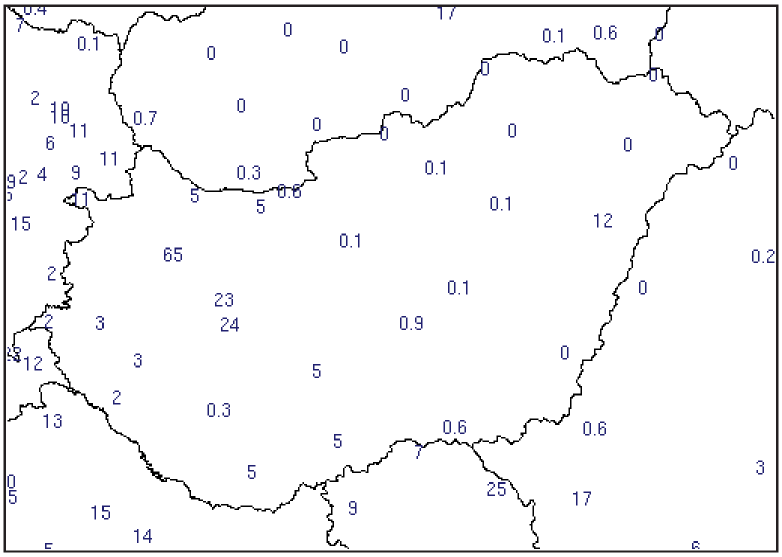

Figure 1: The quantity of precipitation (mm/6h) measured over Hungary on 04.08, between 06 UTC - 12 UTC

3 3D-Var experiments

ARPEGE is a global model, using 4D-Var (four-dimensional variational) data assimilation scheme (Thépaut and Courtier, 1991; Courtier et al, 1994), which provides the lateral boundary conditions for the ALADIN/LACE, a limited area model. The ALADIN/LACE is using the DFI-blending technique, to obtain the initial conditions. The idea of blending is to combine the large scale information from the ARPEGE analysis with the meso-scale features provided by the short-range ALADIN forecast. The ALADIN/LACE model can provide the lateral boundary conditions to another limited area model, which has a smaller domain and a higher resolution. So, the ALADIN/Hungary is a *double-nested limited area model*. The resolution of the ALADIN/Hungary model is around 8 km, and its domain covers mostly the Central European area.

The variational method consists of defining a cost function, which measures the departures of the analysis from the observations, from the background (the first-guess) information and possibly taking into account other physical constraints. Then the cost function is minimized in order to get the best fit to the available information sources, providing the best analysis for the model integration. The cost function is the sum of three terms:

$$J(x) = J_b(x) + J_o(x) + J_c(x)$$

where $J_b(x)$ (the background term) measures the distance between the analysis and the first-guess (usually, the 6h forecast from the previous integration of the model), $J_o(x)$ (the observation term) measures the distance between the analysis and the observations, and $J_c(x)$ (the constraint term) typically measures the departure of the analysis from a filtered model state. At the moment for ALADIN model only the first two terms are defined (Fischer, 2002).

The ALADIN/Hungary model is using for the background term, the standard NMC statistics (Parrish and Derber, 1992), and for the observation term, only SYNOP and TEMP data are considered in the assimilation cycle. As coupling technique, the time-consistency has been chosen both in cycling and in production. Time-consistency means that the lateral boundary data are coming from the same integration of the coupling model, thus the information is consistent in time. The initial file is the 3D-Var analysis, and the first two lateral boundary conditions are coming from the coupling model. Digital filter initialization (DFI) has been applied at the beginning of the integration, both in cycling and in production (Alexandru, 2002).

The 3D-Var experiments were carried out using the operational lateral boundary conditions (LBC) for ALADIN/Hungary (from ALADIN/LACE model) and the SYNOP and TEMP data available at the Hungarian Meteorological Service (HMS). From SYNOP observations, temperature and relative humidity information have been considered, and from TEMP data, wind, geopotential, temperature and relative humidity. Hereafter the name of this set of experiments is "*3dvar*".

The reference of these experiments was the operational forecast of the model in dynamical adaptation ("*oper*"). The assimilation cycle was started from 01.08.2002 06 UTC, i.e. three days before the event.

4 Results

In this chapter the forecasts of different fields from two model runs are described, then the time evolution of the mean sea level pressure during the 6h integration is plotted, and at the end, the impact of observations over forecast has been analyzed. The maps with the forecasts of relative humidity, vertical velocity and precipitation have a zoom between 44 °- 50 ° latitude and 14 °- 25 ° longitude, in order to point out the location of the rainfall. For the geopotential forecast, the maps have been plotted over the entire domain of the ALADIN/Hungary model.

The model runs from 03.08 have not been presented in this paper, because their forecasts did not give any indication about the rainstorm.

4.1 04.08 00 UTC run

For this model run, only the precipitation cumulated in 6h, between 06 UTC - 12 UTC and 12 UTC - 18 UTC is shown (Figure 2). One can see that both models, with and without data assimilation, did not predict the significant rainfall, either at the right moment, neither later. The quantity of precipitation do not exceed 6 mm, which is a strong underestimation, the real maximum being 65 mm. The location of the precipitation is slightly different between the two experiments. The operational forecast predicted the rain over an area in the south-western part, and the *3dvar* set, more in the north-western part of Hungary.

So the operational model, in dynamical adaptation, failed to predict the rainfall. The 3D-Var experiment did not have a better forecast, which means that the information

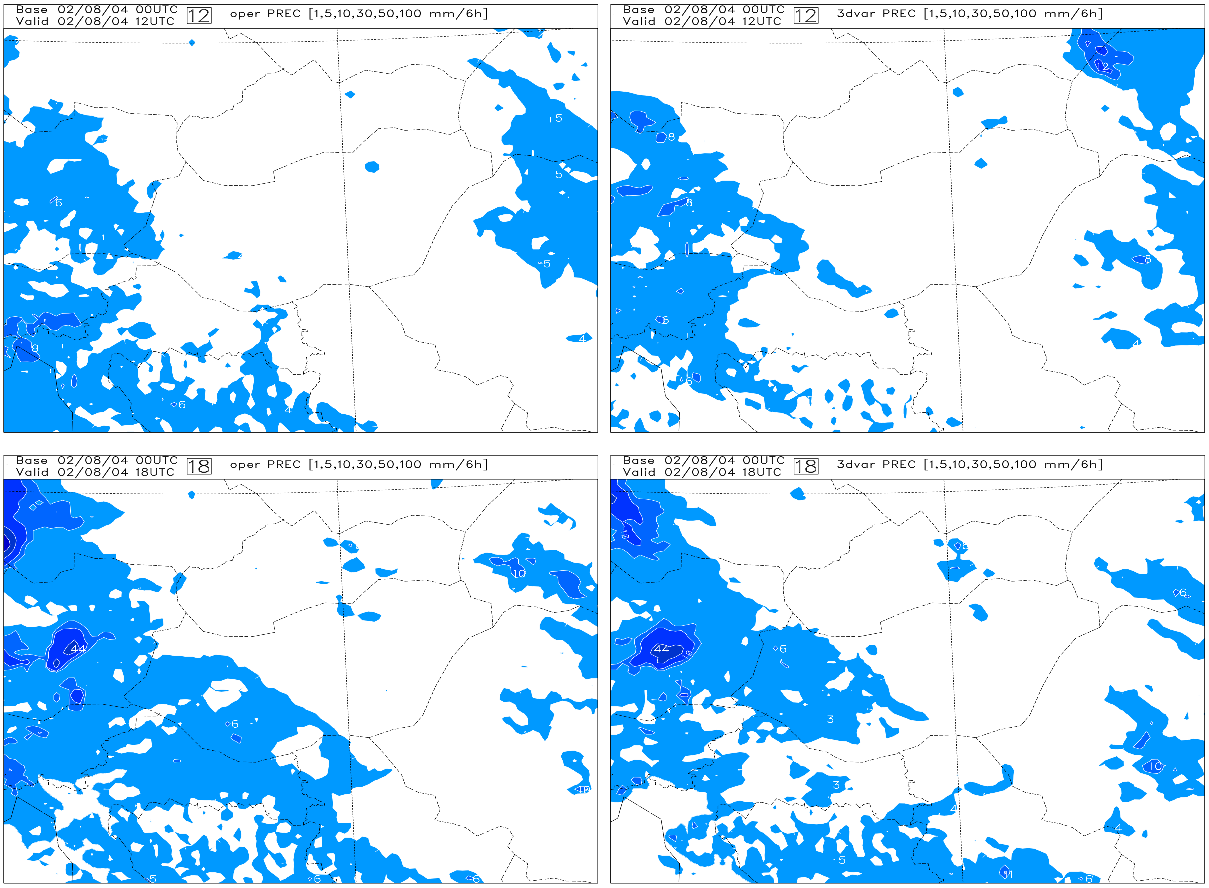

Figure 2: The quantity of precipitation (mm/6h) forecasted by the operational model (*oper*) and using 3D-Var scheme (*3dvar*) between 04.08 06 UTC - 12 UTC (top), and 12 UTC - 18 UTC (bottom), from 04.08 00 UTC model run

coming from the observations did not give any indication about the future development of an instability line.

4.2 04.08 12 UTC run

The main difference in the forecasts of the two models, with and without 3D-Var scheme, appeared in this run. To analyse this phenomenon, which has developed very fast, the analysis and 6h forecast of the geopotential, relative humidity and vertical velocity fields have been plotted. The precipitation has been cumulated for 6h, between 12 UTC - 18 UTC.

As it can be seen in the Figure 3 (top), the operational analysis shows the air streaming south-westerly. The pressure gradients are rather small, the wind is not too strong, over Hungary. The difference between the models, in the forecast of the geopotential, appeared since the beginning of the integration. The *3dvar* set predicted a lowest pressure over the western part of Hungary (Figure 3, middle).

The operational model predicted the sky partly cloudy over Hungary and no vertical motion of the air through the 700 hPa surface. So, no precipitation is expected to develop. The model using 3D-Var scheme (*3dvar* set), forecasted an area in the western part of Hungary with high humidity. Also the air masses have an ascending vertical velocity,

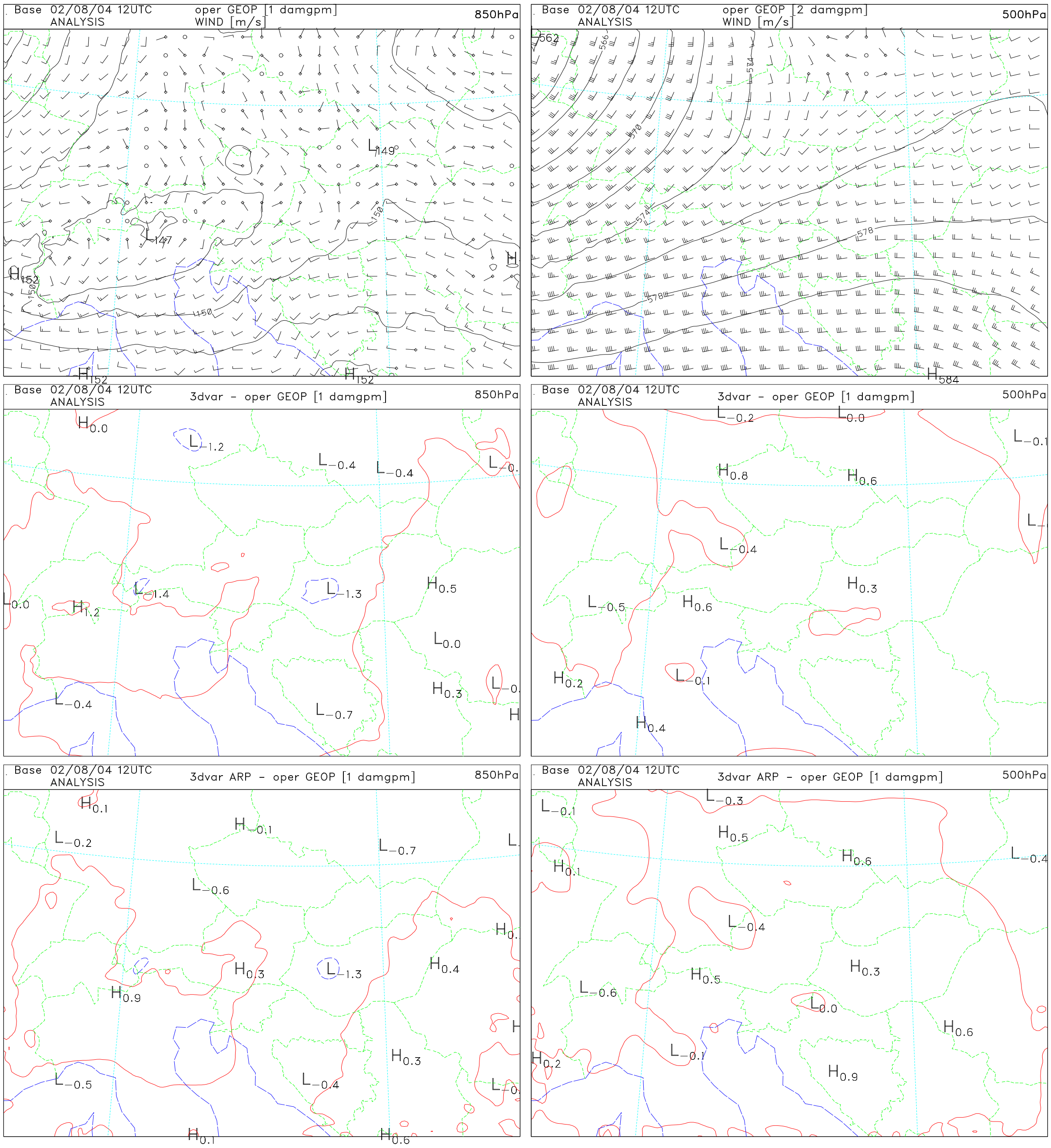

Figure 3: The operational analysis (*oper*) for geopotential and wind (upper row) and the differences between the geopotential analysis of the *3dvar*, *3dvar ARP* sets and *oper*, from 04.08 12 UTC model run, at 850 and 500 hPa

reaching values as 5 hPa/s. So significant rainfall is likely to occur in that region (Figure 4, top, middle).

After 6h integration, the operational forecast for geopotential predicted a low-pressure system located in the eastern part of Austria. The direction of the air is more westerly now, as it is shown in the Figure 5 (top, middle). The 3D-Var experiments showed a low-pressure system over the central part of Hungary. The difference between the models for the forecast of the geopotential is almost 3 damgpm.

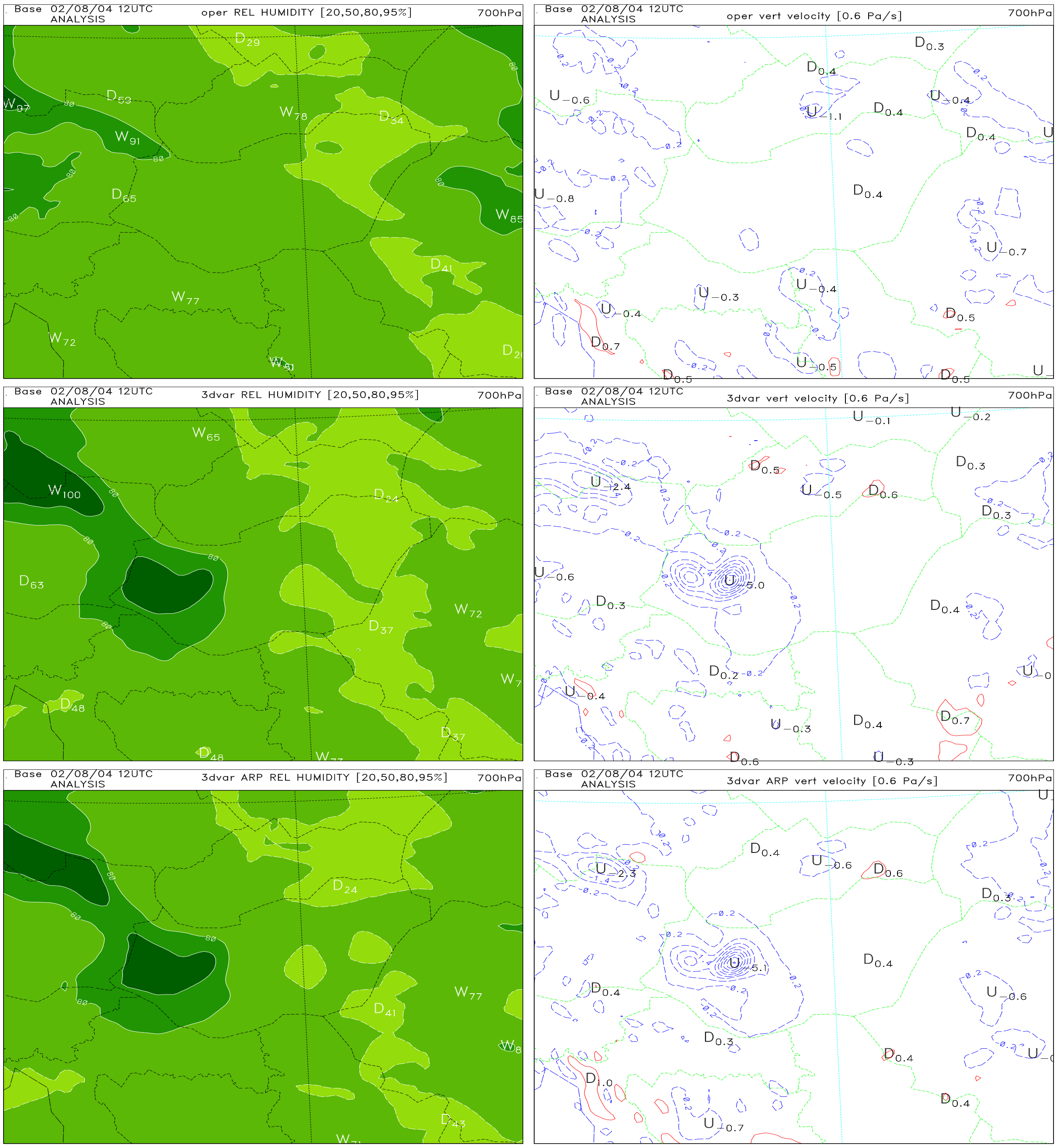

Figure 4: The operational analysis (*oper*) and using 3D-Var scheme (*3dvar*, *3dvar ARP*), for relative humidity and vertical velocity at 700 hPa, from 04.08 12 UTC model run

There are not important changes in the operational forecast of the relative humidity. The sky remains partly cloudy, and the vertical motion of the air is rather weak (Figure 6, top, middle). The area where the moisture is available, forecasted by the *3dvar* set, is located in the northern and central parts of Hungary. Here also an intensive ascending motion of the air masses is predicted, which indicates an increased likelihood of precipitation. Comparing to Figure 4 (top, middle), one can see how fast the moist air has been moved from the western to the northern part of Hungary.

In this, region a significant rainfall has been forecasted by the experiments using 3D-

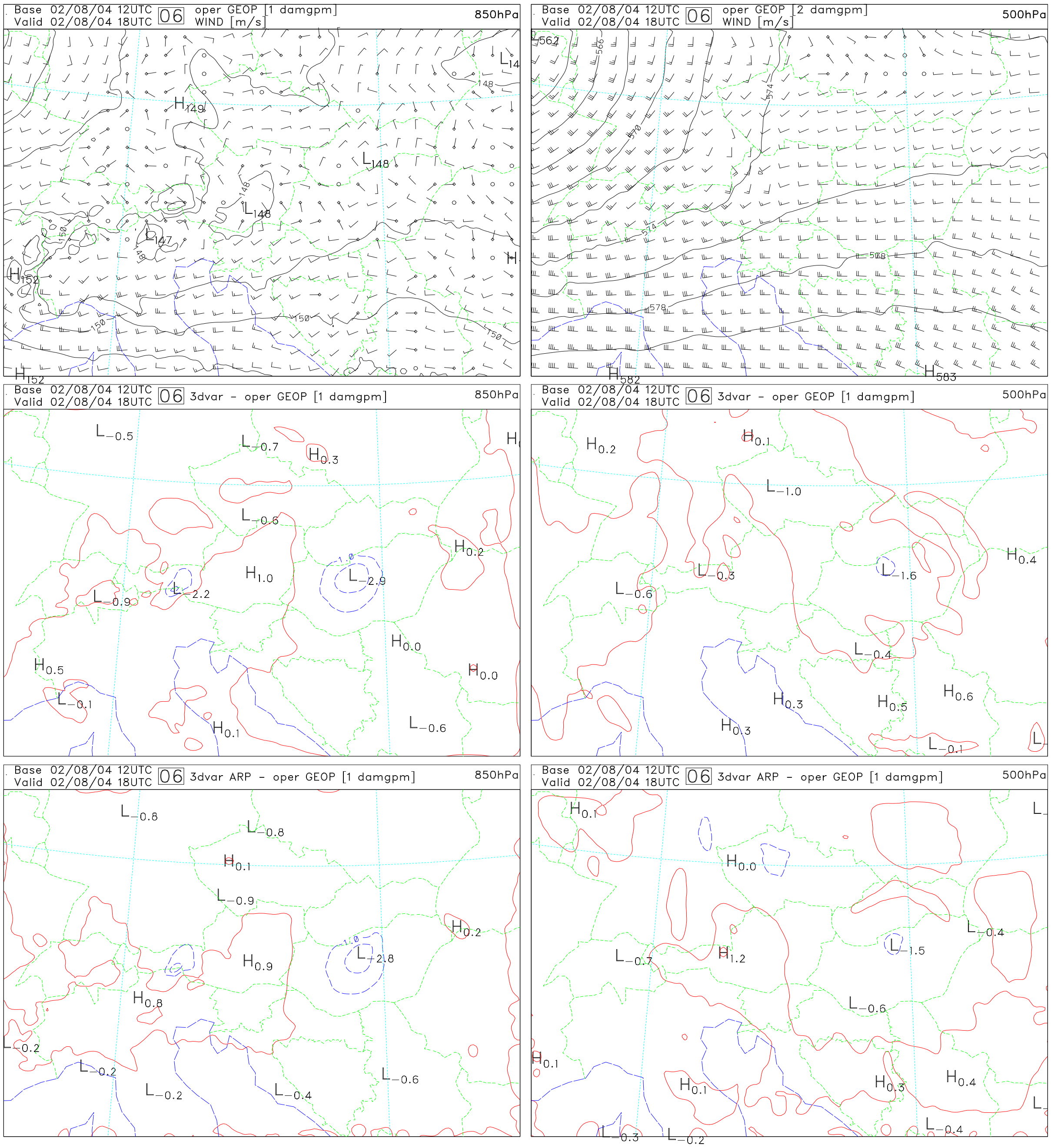

Figure 5: The 6h operational forecast (*oper*) for geopotential and wind (upper row) and the differences between the geopotential forecast of the *3dvar*, *3dvar ARP* sets and *oper*, from 04.08 12 UTC model run, valid at 04.08 18 UTC, at 850 and 500 hPa

Var scheme, the quantity reaching 173 mm in 6h. However the operational model did not predict any precipitation. One can see in the Figure 7 (top) the great difference between the operational forecast and that when data assimilation has been used.

Comparing to reality, one can say that for this particular period of time (on 04.08 between 12 UTC - 18 UTC), the operational model had a good forecast, the rainfall happening six hours earlier. But in the same time, it is also a failure of the operational model, which did not predict the precipitation at the right moment, but neither later.

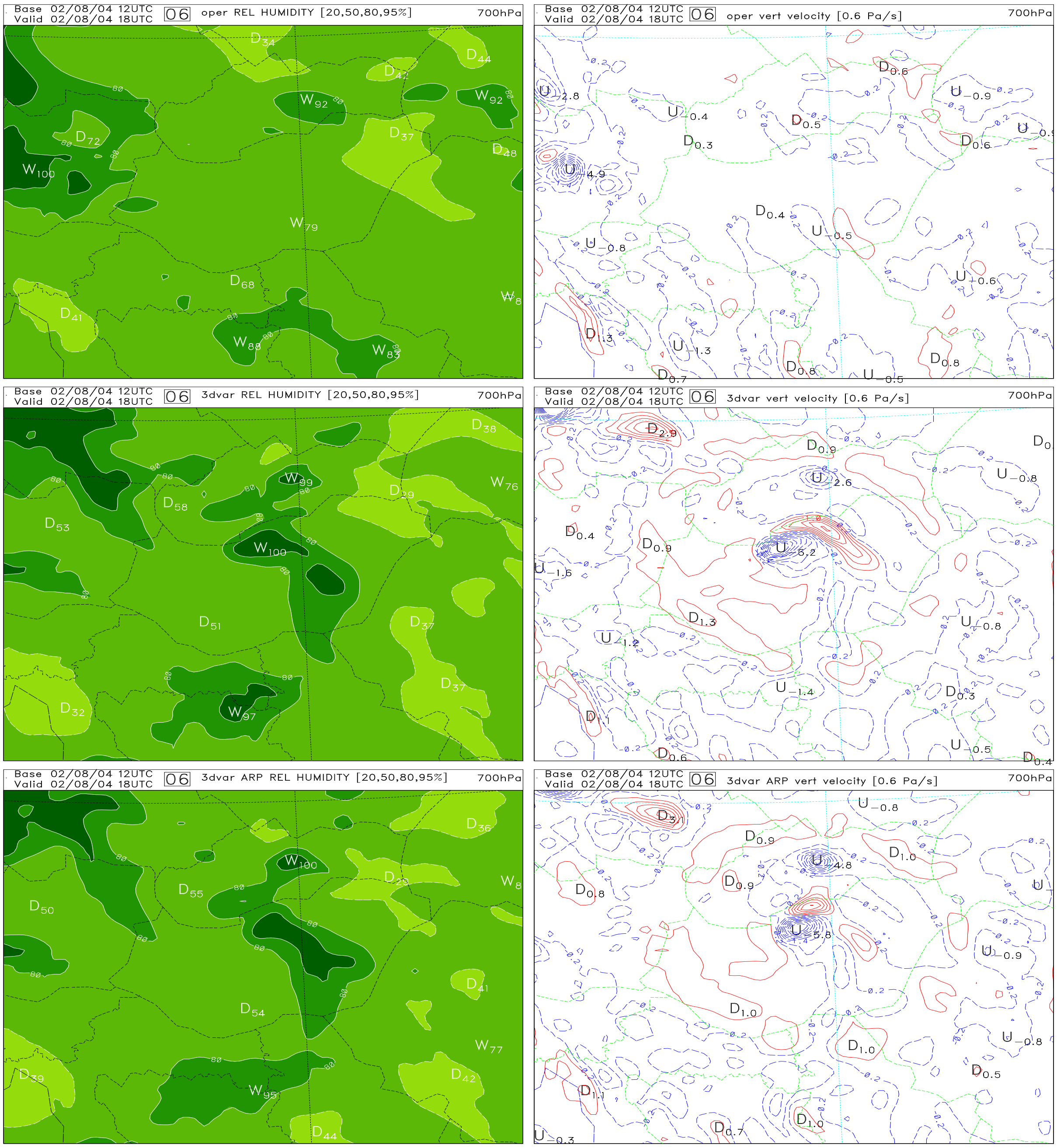

Figure 6: The 6h operational forecast (*oper*) and using 3D-Var scheme (*3dvar*, *3dvar ARP*), for relative humidity and vertical velocity at 700 hPa, from 04.08 12 UTC model run, valid at 04.08 18 UTC

Being a local phenomenon with a very fast evolution, it was not predicted either by the coupling model. So no information about it has been contained in the lateral boundary conditions from the ALADIN/LACE model.

Seeing the difference between the two models, another set of experiments has been proposed. It is similar to the *3dvar* set, only that the lateral boundary conditions were provided by the ARPEGE model. The name of these new experiments is "*3dvar ARP*". The forecasts of the same fields have been plotted. One can see that using different lateral boundary conditions, from the global model or from the limited area model, the forecasts

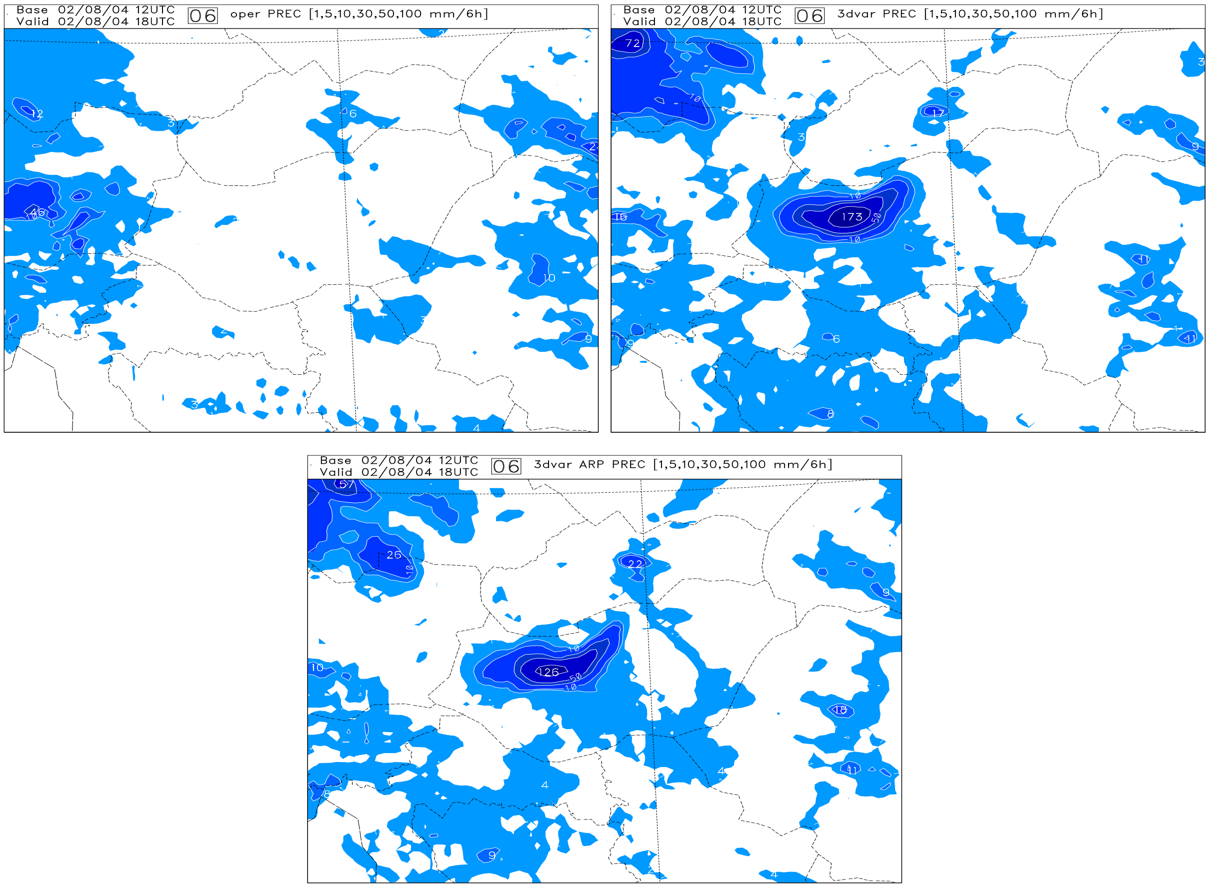

Figure 7: The quantity of precipitation (mm/6h) forecasted by the operational model (*oper*) and using 3D-Var scheme (*3dvar*, *3dvar ARP*) between 04.08 12 UTC - 18 UTC, from 04.08 12 UTC model run

for geopotential, relative humidity and vertical velocity are rather similar (Figures 3 - 6, middle, bottom). Also a significant rainfall has been predicted by the *3dvar ARP* set, but the quantity of precipitation is smaller than in the *3dvar* experiments, the maximum being around 126 mm in 6h (Figure 7, bottom).

So the experiments using 3D-Var scheme succeeded to forecast a huge quantity of precipitation, but with six hours delay. On the one hand, this represents a failure of the model, but on the other hand, the rainfall was still predicted. Now the question is how was it possible?

4.3 Time evolution of the fields

First it was investigated if there are some imbalances between the models, with and without data assimilation. The time evolution of the mean sea level pressure was checked during 6h integration in production, for the model in dynamical adaptation, and using 3D-Var scheme with LBC from the ALADIN/LACE model (*3dvar*), for the 04.08 12 UTC run.

The selected points over the domain in (x,y) coordinates are written below:

- ⋄ [5, 5] - a point in the coupling zone (bottom-left corner of the domain),

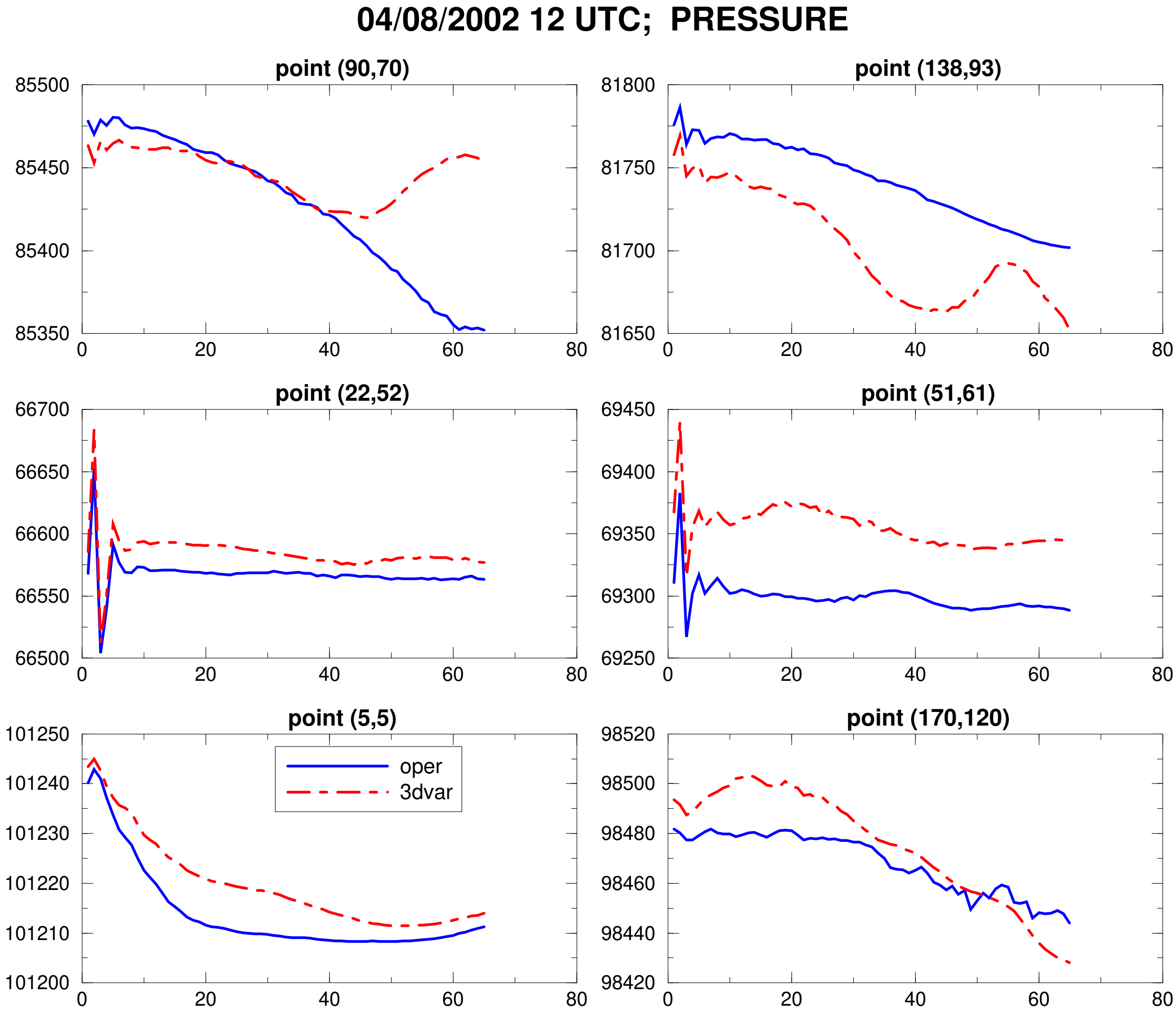

Figure 8: The time evolution of MSL for 04.08.2002 12 UTC, for six different points, for the operational forecast (*oper*), and using 3D-VAR scheme (*3dvar*)

- ◇ [22, 52] - a point over the mountains,
- ◇ [51, 61] - a point over the mountains,
- ◇ [90, 70] - a point in the middle of the domain,
- ◇ [138, 93] - a point over the mountains,
- ◇ [170, 120] - a point in the upper-right corner of the domain.

Comparing the the time evolution of the mean sea level pressure of the operational forecast (*oper*) to that using 3D-VAR scheme, one can say that generally, the curves are smooth. Only at the beginning of the integration, some big oscillations can be seen, especially for the points over the mountains. But this shows the noise which is eliminated from the initial fields. So it can be concluded that the fields are in balance (Figure 8).

4.4 The impact of observations over forecast

Trying to understand how the models using data assimilation forecasted the important quantity of precipitation, some experiments were carried out, similar to the *3dvar* set, except that different combinations of variables and data have been used, all along the assimilation cycle. In the first two sets of experiments only TEMP, respectively only SYNOP observations have been taken into account. The names are "*3dvar TEMP*" and "*3dvar SYNOP (T,RH)*". We have to mention that in the *3dvar SYNOP (T,RH)* experiment, the relative humidity and temperature variables have been assimilated.

For all experiments, only the precipitation cumulated in 6h, from the 04.08 12 UTC run, between 12 UTC - 18 UTC, has been plotted. As it can be seen in Figure 9, the *3dvar TEMP* set did not predict any rainfall, which means that all the information about it came from the surface observations. Indeed, using only SYNOP data, the quantity of precipitation is significant. The shape of the area of rainfall differs as it was predicted by the *3dvar* set, but still in the north-western part of Hungary more than 50 mm precipitation has been forecasted.

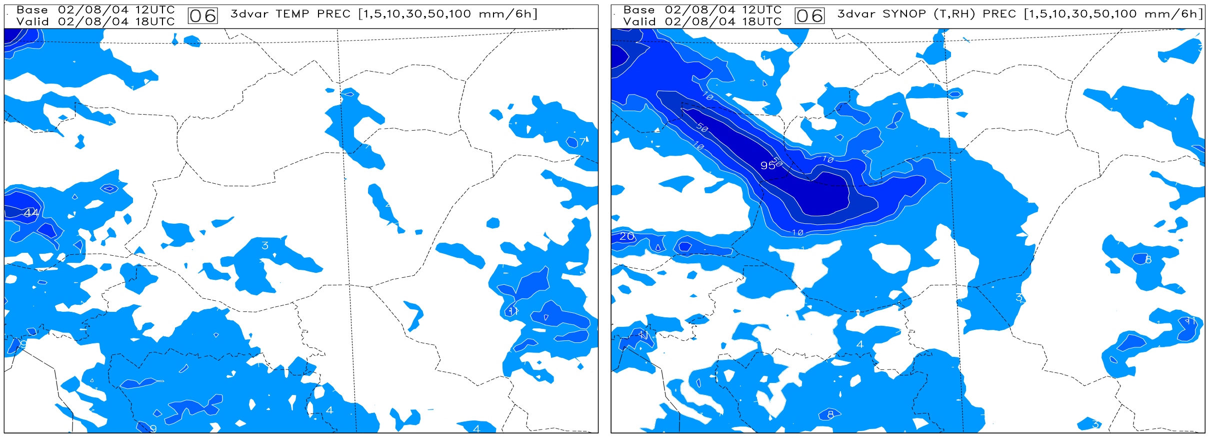

Figure 9: The quantity of precipitation (mm/6h) forecasted by the model using 3D-Var scheme with TEMP (*3dvar TEMP*) and SYNOP data (*3dvar SYNOP*) between 04.08 12 UTC - 18 UTC, from 04.08 12 UTC model run

The next experiments have been performed using different observed variables only from SYNOP data. So in turn, relative humidity (*SYNOP (RH)*) has been assimilated from the surface observations, then geopotential (*SYNOP (Z)*), geopotential and temperature (*SYNOP (Z,T)*), and finally geopotential, temperature and relative humidity (*SYNOP (Z,T,RH)*).

One can see in Figure 10 that the quantity and the distribution of precipitation have been changed, depending on what variables have been used. It appears that for this case the geopotential and temperature measurements did not influence the rainfall forecast. The main information is coming from the relative humidity. In the *SYNOP (RH)* set, when only relative humidity from surface observations has been assimilated, the quantity of precipitation reaches values as 264 mm in 6h. Using also the geopotential and temperature (*SYNOP (Z,T,RH)* set), a significant rainfall is predicted, but the maximum is much smaller. Comparing the shape of the area of precipitation, from the *3dvar SYNOP (T,RH)* and *SYNOP (Z,T,RH)* experiments, one can say that the geopotential measurements had

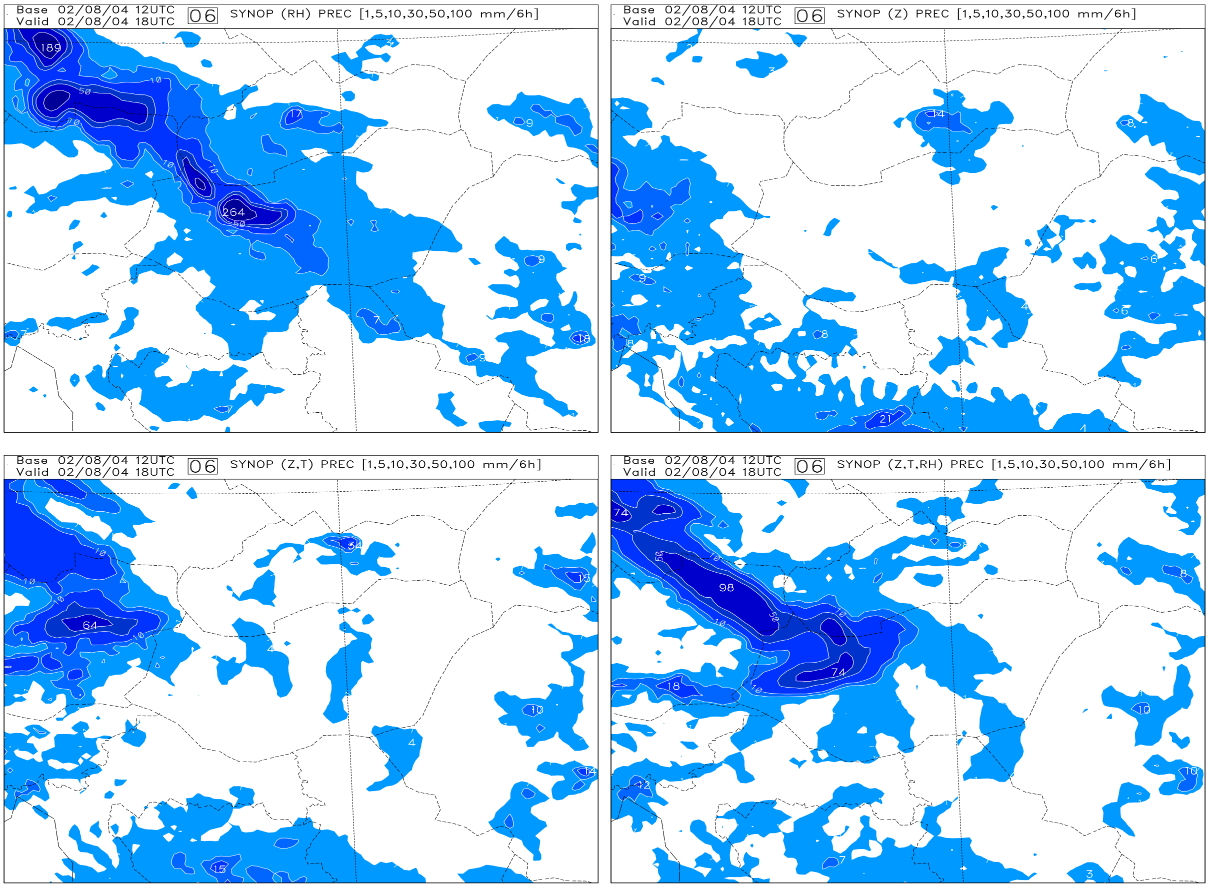

Figure 10: The quantity of precipitation (mm/6h) forecasted by the model using 3D-Var scheme with different observed variables from SYNOP data (*SYNOP (RH)*, *SYNOP (Z)*, *SYNOP (Z,T)*, and *SYNOP (Z,T,RH)*) between 04.08 12 UTC - 18 UTC, from 04.08 12 UTC model run

a slight influence.

Other experiments were carried out, being similar with the previous one's, only that TEMP observations have been added also in the assimilation cycle. The notation of these new experiments is *TEMP+SYNOP (RH)*, *TEMP+SYNOP (Z)*, *TEMP+SYNOP (Z,T)* and *TEMP+SYNOP (Z,T,RH)*. The observed variables from TEMP data are wind, geopotential, temperature and relative humidity. Figure 11 shows again an intensive rainfall over the Danubian Basin, in the experiments, when the relative humidity has been used from SYNOP observations (*TEMP+SYNOP (RH)* and *TEMP+SYNOP (Z,T,RH)* sets).

Comparing the experiments with and without TEMP observations, but when relative humidity from SYNOP data was assimilated (*SYNOP (RH)*, *TEMP+SYNOP (RH)*), it appears that the quantity of precipitation is still large, only the shape of the area of rainfall has been changed, being located especially over Hungary.

Looking on the forecasts from the *3dvar TEMP* and *SYNOP (Z,T)* sets, one can see only few precipitation, not exceeding 5 mm in 6h. But adding the TEMP data to the temperature and geopotential from the surface observations (*TEMP+SYNOP (Z,T)*), the quantity of precipitation increased (around 29 mm). This can be an effect of the ineffectively uncoupling between the the planetary boundary layer and the troposphere, made by the observation operator. Thus the 2m temperature observation increment can

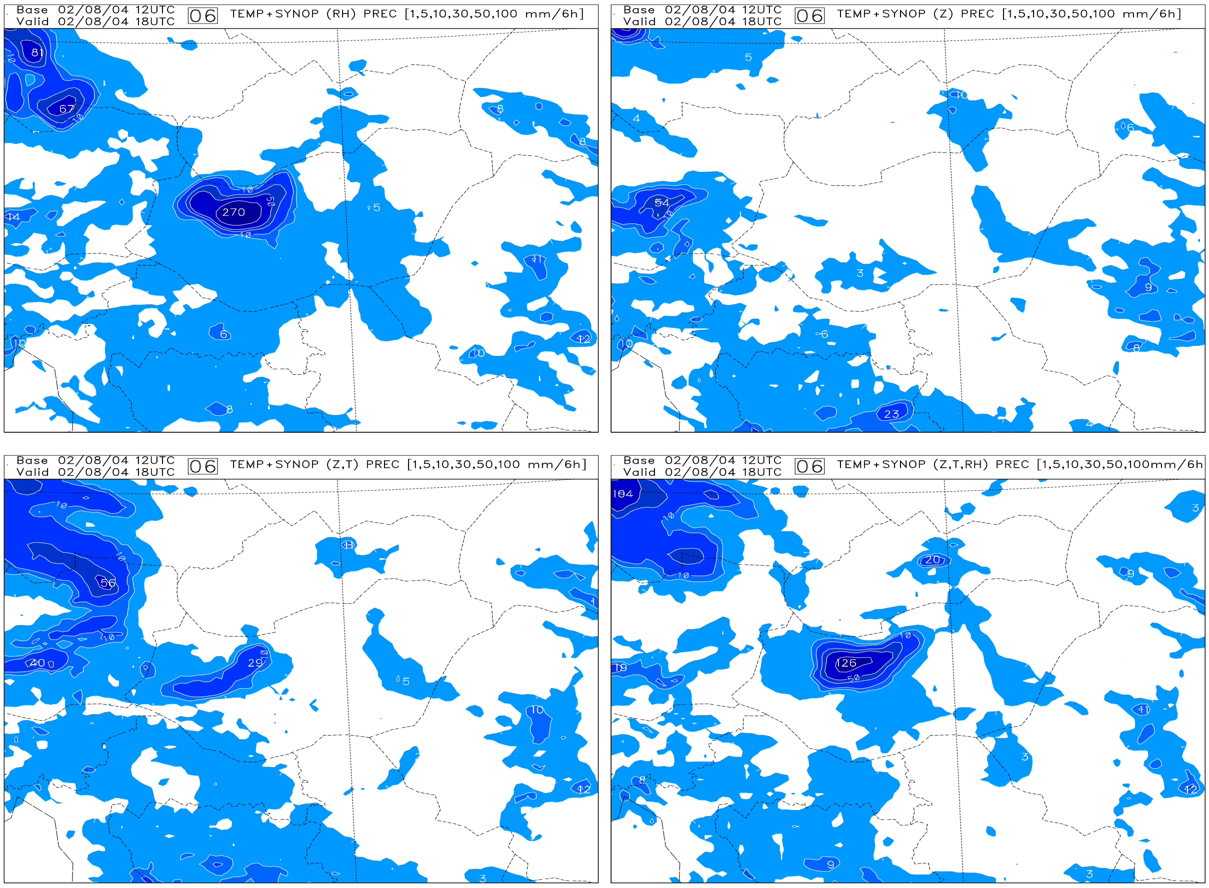

Figure 11: The quantity of precipitation (mm/6h) forecasted by the model using 3D-Var scheme with TEMP data and different observed variables from SYNOP data (*TEMP+SYNOP (RH)*, *TEMP+SYNOP (Z)*, *TEMP+SYNOP (Z,T)*, and *TEMP+SYNOP (Z,T,RH)*) between 04.08 12 UTC - 18 UTC, from 04.08 12 UTC model run

influence the temperature increments from the high troposphere.

In conclusion, the measurements of the 2 meter relative humidity have been responsible for the information introduced in the model, which caused the forecast of this significant rainfall. Also the temperature measurements, from the surface and upper-air observations, determined the prediction for some precipitation.

5 Conclusions

A case from the 4th of August 2002 has been presented in this paper. An instability line has been developed very fast in the morning, causing an intensive rainstorm. The operational model (in dynamical adaptation) was not able to predict this phenomenon. So new experiments have been performed in order to see whether the model using the 3D-Var scheme can have a better forecast.

For these experiments, different lateral boundary conditions (from the ARPEGE or ALADIN/LACE model) and SYNOP and TEMP observations available at the Hungarian Meteorological Service have been used. The reference of these experiments was the operational forecast of the model in dynamical adaptation. Two main model runs have been investigated, from 04.08 00 UTC and 12 UTC. The period when the precipitation fell over Hungary is between 06 UTC - 12 UTC, and its maximum value reached 65 mm.

The forecasts from the 04.08 00 UTC run showed that both models, with and without data assimilation, did not predict the intensive rainfall, neither at the right moment, nor later. The quantity of precipitation do not exceed 6 mm, which is a strong underestimation. The model using 3D-Var scheme failed to give a better forecast, which means that the information coming from the observations did not bring any indication about the future development of this instability line.

The 04.08 12 UTC run brought the main difference in the forecasts of the two models, in dynamical adaptation and with 3D-Var scheme. The operational model predicted fair weather, without any sign of rainfall. Comparing to reality, one can say that for this particular period of time, the operational model has a good forecast, the rainfall happening earlier than this model run. But in the same time, it is also a failure of the operational model, which did not predict the precipitation at the right moment, but neither later. Being a local phenomenon which has developed very fast, it was not forecasted by the coupling model. So no information about it came through the lateral boundary conditions from the ALADIN/LACE to ALADIN/Hungary model.

Instead, the experiments using 3D-Var scheme forecasted a huge quantity of precipitation (more than 100 mm), but with six hours delay. On the one hand, this represents a failure of the model, but on the other hand, the rainfall was still predicted.

Because the difference between the forecasts of the model, with and without data assimilation, was very big, we tried to investigate what caused the prediction of the rainstorm, and more than that, why later than in reality.

First, some imbalances in the time evolution of the mean sea level pressure forecasted by the two models were checked. But this hypothesis has proven false, the time evolution showing that the fields are in balance.

Other experiments were carried out using only SYNOP or TEMP data, in order to find out what observations could have influenced so much the precipitation forecast. Thus it was shown that the model using the 3D-Var scheme and only TEMP data, did not predict any rainfall, which means that all the information about it came from the surface observations. Indeed, assimilating only SYNOP data, the quantity of precipitation is significant.

The last experiments have been performed using different combinations of the observed variables from the SYNOP observations, with and without TEMP data in the assimilation cycle. The observed variables from SYNOP are the relative humidity, geopotential and temperature. From the TEMP data, the wind, temperature, relative humidity and geopotential have been assimilated. The precipitation forecasts from these experiments showed that the measurements of the 2 meter relative humidity have been responsible for the information introduced in the model, which caused the forecast of this significant rainfall. Also the temperature measurements, from the surface and upper-air observations, determined the prediction for some precipitation, but not so important.

So the information from the observations (from 04.08 at 12 UTC) reproduced the state of the atmosphere, with high humidity. Thus the analysis of the model caught the end of the storm. Because any other information from the lateral boundary conditions or from the first-guess did not give any indication about an existing storm, the model "said" that it is the beginning. So, one can say that the model had good initial conditions, but it was beyond the capacity of the 3D-Var scheme to predict such a rainstorm. Probably, we would have had better results, using the 3F-GAT or 4D-Var schemes, where information from the future having influence in the past, due to the adjoint model.

Acknowledgements

I would like to thank to Mrs. Katalin Ujváry Homokiné, who helped me to understand the synoptic situation of this case.

6 References

Alexandru, S., [1] 2003: Forecast of the Czech floods using the 3D-Var scheme for the ALADIN mesoscale limited area model. *ALATNET Internal Note.*

Alexandru, S., [2] 2003: 3D-Var experiments for the ALADIN/Hungary model: a case study (I). *ALATNET Internal Note.*

Alexandru, S., 2002: 3D-VAR data assimilation experiments for the double-nested limited area model ALADIN/Hungary. *ALATNET Internal Note.*

Courtier, P., Thépaut, J.N., and Hollingsworth, A. 1994: A strategy for operational implementation of 4D-Var, using an incremental approach. *Quart. J. Roy. Meteor. Soc.*, **120**, 1367–1387.

Fischer, C., 2002: The variational computations inside ARPEGE/ALADIN: cycle CY25T1. *ALADIN Internal Note.*

Parrish, D., and Derber, J., 1992: The National Meteorological Center's spectral statistical interpolation analysis system. *Mon. Weather Rev.*, **120**, 1747–1763.

Thépaut, J.N., and Courtier, P., 1991: Four-dimensional variational data-assimilation using the adjoint of a multilevel primitive-equation model. *Quart. J. Roy. Meteor. Soc.*, **117**, 1225–1254.