1. Steluta ALEXANDRU : "Scientific strategy for the implementation of a 3D-VAR data assimilation scheme for a double nested limited area model"

Forecast of the Czech floods from August 2002 using the 3D-Var scheme for the ALADIN model

Introduction

A data assimilation system based on a three-dimensional variational (3D-Var) scheme is being developed for the ALADIN mesoscale limited area model (LAM). The scheme was applied for ALADIN/Hungary, which is a double-nested mesoscale LAM. 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 mode (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 a previous ALATNET report (Alexandru, [2] 2003) a case study from the first category has been presented. For the second one, the Czech floods from the 11-13th of August 2002 have been chosen to be analysed using the 3D-Var scheme.

A short description of the synoptic situation of these floods is presented below. There were two events. The first one was on the 6-7th of August, when a high altitude low-pressure system from the Gulf of Genoa reached the area of Alps causing heavy rain and thunderstorms in Austria. The quantity of precipitation decreased temporarily between the 8-10th of August in the Alps. Then the second event was between 11-13th of August, when a new active cyclone reached the upper parts of the Danube. The motion of the cyclone slowed down and its occluded front spread over the central part of Austria and the Czech basin for almost three days. As an effect of this stationary front, the quantity of precipitation was significant in Austria, Bavaria and Bohemia, i.e. 100-150 mm in 24 h, and in some places more than 300 mm (Fig. 1). (IABM, 2002).

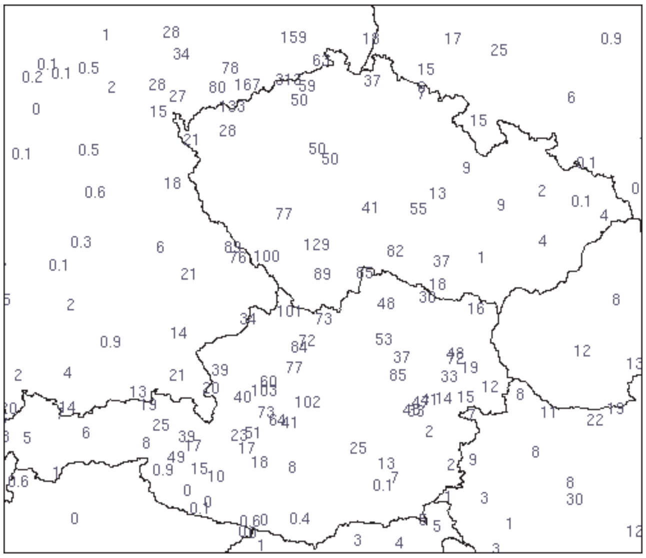

Figure 1 : The quantity of precipitation (mm/24h) measured over Austria and Czech Republic between 12.08 06 UTC - 13.08 06 UTC

3D-Var experiments

For this case study, two sets of experiments using 3D-Var were carried out. The first set was performed using the operational lateral boundary conditions (LBC) for ALADIN/Hungary (from the ALADIN/LACE model) and the SYNOP and TEMP data available at the Hungarian Meteorological Service (HMS). From SYNOP observations, temperature and relative humidity have been considered, and from TEMP ones, wind, geopotential, temperature and relative humidity. Hereafter the name of this set of experiments is "*3dvar(T,RH)*". As coupling strategy, time-consistency has been chosen both in cycling and in production (Alexandru, 2002).

The other set of experiments which has been carried out, was similar to the "*3dvar(T,RH)*" set, with LBC provided by the ALADIN/LACE model and data from HMS, keeping the same variables from TEMP, but using only geopotential from SYNOP observations. The notation is "*3dvar(Z)*".

Later we discovered that generally the temperature and relative humidity from the SYNOP observations is not analysed in the assimilation cycle for the ARPEGE model, because they can cause some spurious features in the upper troposphere. As the first set of experiments has been already performed at that time, we decided to present here these results also.

In both sets of experiments, the standard NMC statistics (Parrish and Derber, 1992) have been used. The reference of these experiments was the operational forecast of the model in dynamical adaptation ("*oper*"). The assimilation cycle was started from 07.08.2002 06 UTC, i.e. four days before the event. Further mainly the results from the "*3dvar(Z)*" set will be shown.

Results

For this case study, the forecasts for different fields from 11.08 - 12.08, 00 UTC and 12 UTC model runs, have been analysed. In order to point out the location of the event, the maps with the 24 h cumulated precipitation have a zoom between 45°-52° N in latitude and 10°-20° E in longitude.

11.08 00 UTC run

The forecast from this model run shows the beginning of the second flood, started over Austria, and moving to the Czech Republic. Both models, with and without data assimilation, predict a low-pressure system located in the southern part of the Czech Republic.

The area where the moisture is available, is very large, covering the western part of Austria, Bavaria, Saxony and the western part of Czech Republic. The air masses have here an intensive vertical motion (up to 6.5 Pa/s). So there is an increased likelihood that heavy precipitation will develop.

All three experiments overestimate in some places in Austria the quantity of precipitation, predicting more than 200 mm in 24 h (the real measurements being around 100 mm). But the location of the rainfall is well forecasted. Moreover this model run gives the first indication of the new location of the heavy rainfall over the border of Germany and Czech Republic.

One can say that the models, with and without data assimilation, succeeded to give a good forecast of the beginning of these floods.

11.08 12 UTC run

Both models show the air streaming from North-West, bringing cold air especially in the western part of Czech Republic. The low-pressure system has deepened in-between and moved more to the South, in the north-western part of Hungary.

The operational and 3D-Var forecasts of relative humidity at 700 hPa surface show the same pattern of high humidity (the northern and western parts of Austria, Bohemia and Saxony). The air masses have also an intensive vertical motion in those areas, reaching values as 5 hPa/s. These indicate that a heavy rainfall is likely to occur.

The quantity of precipitation, cumulated for 24 h, between 12.08 06 UTC and 13.08 06 UTC (Fig. 2), reaches values bigger than 100 mm in Austria, which is very close to reality. All experiments predict a significant quantity of precipitation in some places over the border of Germany and Czech Republic (more than 100 mm in 24 h). Indeed in that region the real maximum was 313 mm, so the forecast underestimate it, but still the models give an indication of the intensive rainfall. More to the East, one can see an area of heavy precipitation, forecasted by all experiments, probably, as the maximum of the event. Unfortunately the location is too far. In the central part of Czech Republic, a significant quantity of precipitation has been forecasted.

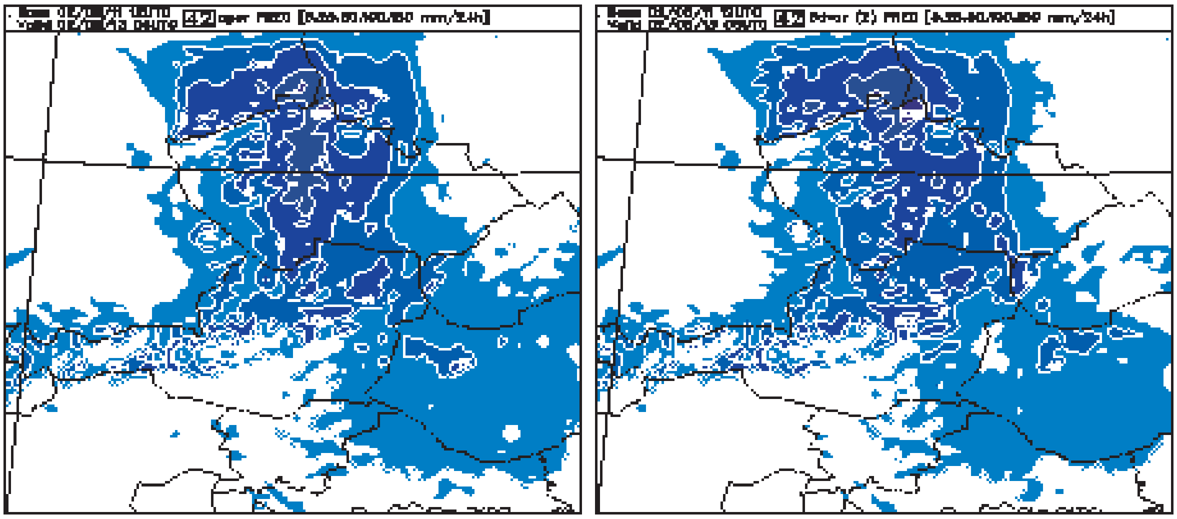

Figure 2 : The quantity of precipitation (mm/24h) forecasted by the operational model (*oper*) and using 3D-Var scheme (*3dvar(Z)*) between 12.08 06 UTC - 13.08 06 UTC, from 11.08 12 UTC model runs.

It can be concluded that the forecasts of the two models, with and without 3D-Var scheme, are comparable. They did not succeed to predict the real quantity of precipitation over the border of Germany and Czech Republic, but still this was more than 100 mm in 24 h. The location of the maximum of the event was forecasted more to the East.

12.08 00 UTC run

The direction of the cold air remains north-westerly. The low-pressure system begins to fill in, progressing on a north-eastward track. The differences between the operational forecast and those using the 3D-Var scheme for geopotential are less than 2 damgpm.

The area of high humidity starts to decrease comparing to the forecast from the previous run. But still in the northern and western parts of Austria, Saxony and Bohemia, the sky is mostly cloudy. Strong ascending motion has been forecasted in these regions.

Figure 3 shows the precipitation cumulated in 24 h between 12.08 06 UTC and 13.08 06 UTC. In some places in Austria, the quantity of precipitation is more than 100 mm in 24 h, which is a slight overestimation, compared to real measurements. Unlike the previous run, all the models predict the right place of the rainfall in Saxony, where values like 296 mm in 24 h are shown. The operational forecast has the closest value to reality. But also the 3D-Var experiments predict an important quantity in that area. A good prediction of the rainfall over Bohemia has been performed by the "*3dvar(Z)*" experiment. The other sets overestimate the quantity of precipitation, predicting more than 150 mm, comparing with real measurements like 50 mm.

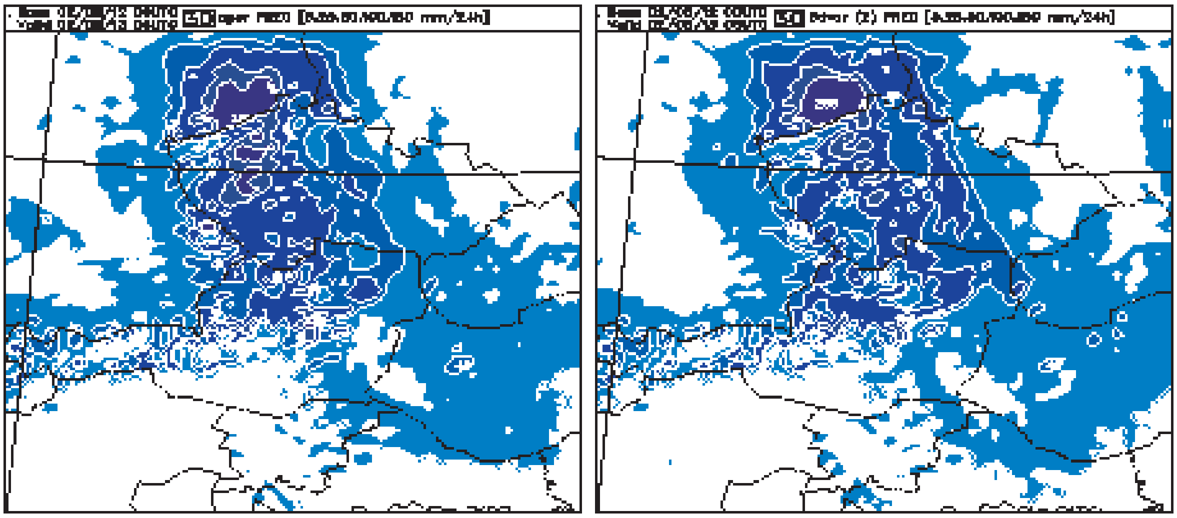

Figure 3 : The quantity of precipitation (mm/24h) forecasted by the operational model (*oper*) and using 3D-Var (*3dvar(Z)*) between 12.08 06 UTC - 13.08 06 UTC, from 12.08 00 UTC model runs.

One can see over the border of Poland and Czech Republic, an area with 100 mm precipitation forecast. The quantity is overestimated, in reality it hasn't been more than 37 mm. But it is an indication of the new place where significant rainfall is expected.

In conclusion one can say that all three sets of experiments had shown a good forecast of the event. The great quantity of precipitation has not been predicted exactly, but it was significant, giving warning to the forecasters about the future flood.

12.08 12 UTC run

The last model run showed that the low-pressure system continued to move in a north-eastward direction. The pressure gradients weakened and the winds subsided, so the cyclone begins to fill in. The differences between the operational forecast for geopotential and those using 3D-Var are very small, less than 1 damgpm.

The models predicted almost the same quantity of precipitation, and the location is also similar. Comparing to reality, the models in dynamical adaptation and using the 3D-Var scheme, showed an underestimation of the quantity of precipitation in some places and an overestimation in others. However the locations of the maximum values at the border of Czech Republic and Poland, and in Moravia were well predicted. So the forecast still can be considered good in reasonably limits.

So it can be concluded that the models succeeded to give a good forecast for the end of these floods. The quantity of precipitation started to decrease, and the location to move to the eastern part of Czech Republic.

Conclusions

In this paper, the Czech floods from the 11-13th of August 2002 have been analysed using the 3D-Var scheme for the ALADIN/Hungary model. The aim of these experiments was to show if the 3D-Var scheme is able or not to keep the good performance of the operational model (in dynamical adaptation). For this case, the forecasters considered that the operational model succeeded to predict correctly the event.

Two sets of experiments using 3D-Var scheme were carried out. For both of them, the operational lateral boundary conditions for ALADIN/Hungary and the SYNOP and TEMP data available at the Hungarian Meteorological Service have been used. The difference between them is that one analysed temperature and relative humidity from the SYNOP observations, and the other one, only geopotential. The reference of these experiments was the forecast of the operational model.

The forecasts from the 11.08 00 UTC model run show the beginning of the event, with an intensive rainfall started over Austria (more than 200 mm), and moving to the Czech Republic. This run gave the first indication of the new location of the heavy rainfall over the border of Germany and Czech Republic. There is no significant difference between experiments in the forecast of the rainfall.

All three experiments from the 11.08 12 UTC model run, predicted a significant quantity of precipitation (more than 100 mm in 24 h) over the border of Germany and Czech Republic. But comparing to real measurements (maximum as 313 mm), the forecast was underestimated. Despite this, the models gave an indication of the intensive rainfall. Both models predicted heavy precipitation more to the east, which has not happened in reality.

The forecast from the 12.08 00 UTC model run was the closest one to the maximum of the event, both as moment of time, and as significant rainfall. Large quantities of precipitation have been measured and predicted also. The operational forecast had the closest value to reality. But also the 3D-Var experiments predicted a significant rainfall in that area, giving warning about the future flood.

The last model run, from 12.08 12 UTC, did not show differences between the forecasts of the models in dynamical adaptation and using 3D-Var scheme. Similar locations and quantity of precipitation have been predicted. In some places the precipitation forecast of the models has been overestimated, and in others, it has been underestimated, comparing to real measurements. But the location of the most intensive rainfalls was well predicted.

The good forecast of the operational ALADIN/Hungary model is partly due to the good information provided through the lateral boundary conditions. Being a double-nested limited area model, it means that both ALADIN/LACE and mainly ARPEGE models had a good forecast for the floods. In the 4D-Var scheme for the global model ARPEGE more other observations have been assimilated, comparing to the 3D-Var scheme for ALADIN/Hungary model. So this fact explains the good performance of the global model.

The accurate information from the lateral boundary conditions, together with the assimilation of more SYNOP observations, helped the model with 3D-Var scheme to obtain a good prediction of the event. The influence of the new information coming from the SYNOP data was rather small, the first guess being close enough to the observations. Probably, that is why, there are not big differences between the two sets of experiments using the 3D-Var scheme.

Being a large scale phenomenon, the models with and without data assimilation predicted a similar evolution of the forecast. So it has been shown that the 3D-Var scheme do not deteriorate the good performance of the reference model. (Alexandru [1], 2003).

References

Alexandru, S., [1] 2003 : Forecast of the Czech floods from August 2002 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 Newsletter 6*.

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

IABM, 2002 : Up Front. *Newsletter of the International Association of Broadcast Meteorology* (IABM), 14, 2--4.

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

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

Introduction

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 4th of August 2002, when the operational model (in dynamical adaptation) has not been able to predict an important quantity of precipitation over Hungary.

The synoptic situation of this event is presented briefly. On the 4th of August 2002, a lower pressure field dominated over the central-eastern part of Europe. In altitude, the ridge of the anticyclone from North Africa was extended over the central-southern part of Europe, and a low cut-off was located more to the 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. Here the turbulence is severe, because of the violent updrafts and downdrafts. Thus rain showers and thunderstorms occur, with significant quantities of precipitation. Such an instability line 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. (Fig. 1).

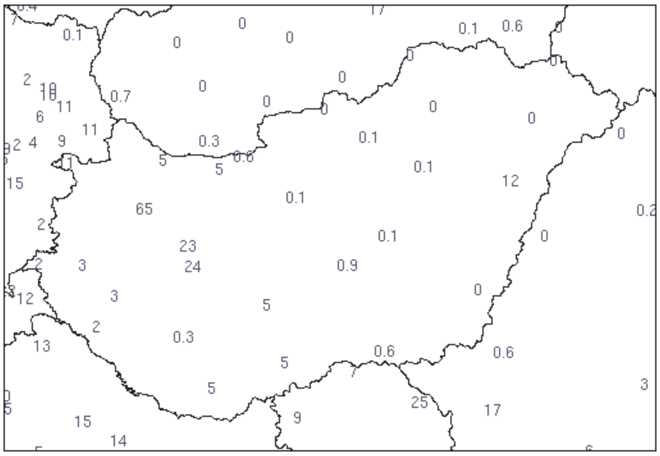

Figure 1 : The quantity of precipitation (mm/6h) measured over Hungary on 04.08, between 06 UTC - 12 UTC

3D-Var experiments

The ALADIN/Hungary model is using for the background term the standard NMC statistics, 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. 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). 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.

Results

In this chapter the forecasts of different fields from the model runs are described, then the impact of observations over forecast has been analysed. The maps with the cumulated precipitation have a zoom between 44°-50° N in latitude and 14°-25° E in longitude, in order to point out the location of the rainfall.

For the 04.08 00 UTC model run, both models, with and without data assimilation, did not predict the significant rainfall, either at the right moment, nor later. The quantity of precipitation do not exceed 6 mm, which is a strong underestimation, the real maximum being 65 mm. 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 coming from the observations did not give any indication about the future development of an instability line.

Also the results of the *3dvar* set were checked from the 04.08 06 UTC run, but still no indication about heavy precipitation. One reason of this misforecast could be the lack of any TEMP observation near to this region, so only information from SYNOP data were taken into account. Probably because the event has happened between 06 UTC and 12 UTC, especially to the end of the period, the surface observation at 06 UTC did not have information about the event.

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. 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. After 6 h integration, the difference between the models for the forecast of the geopotential is almost 3 damgpm.

The operational model predicted the sky partly cloudy over Hungary and no vertical motion of the air masses. So, no precipitation is expected to develop. The model using 3D-Var scheme (*3dvar*), forecasted an area in the western part of Hungary with high humidity. Also the air masses have an ascending vertical velocity, reaching values as 5 hPa/s.

In the north-western part of Hungary a significant rainfall has been forecasted by the experiments using 3D-Var scheme, the quantity reaching 173 mm in 6 h. However the operational model did not predict any precipitation. One can see in Fig. 2 the great difference between the operational forecast and that when data assimilation has been used.

Seeing the difference between the two models, another set of experiments has been proposed. It is similar to the *3dvar* set, but the lateral boundary conditions were provided by the ARPEGE model. The forecasts of same fields have been analysed, but they are rather similar. Only the quantity of precipitation is smaller than in the *3dvar* experiments, the maximum being around 126 mm in 6 h.

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. We tried to see how it was possible.

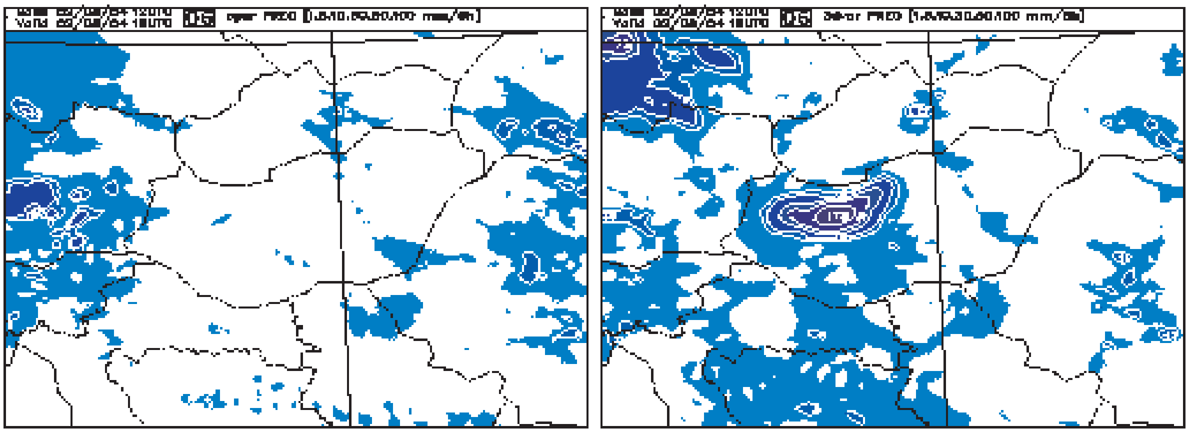

Figure 2 : The quantity of precipitation (mm/6h) forecasted by the operational model (*oper*) and using 3D-Var scheme (*3dvar*) between 04.08 12 UTC - 18 UTC, from 04.08 12 UTC model run

It was investigated if there are some imbalances between the models, with and without data assimilation. But the time evolution of the mean-sea-level pressure checked during 6 h integration in production, for the model in dynamical adaptation, and using 3D-Var, showed that the fields are in balance.

The impact of observations on 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 3*dvar TEMP* and *3dvar SYNOP(T,RH)*. In the last one, only the relative humidity and temperature variables have been assimilated.

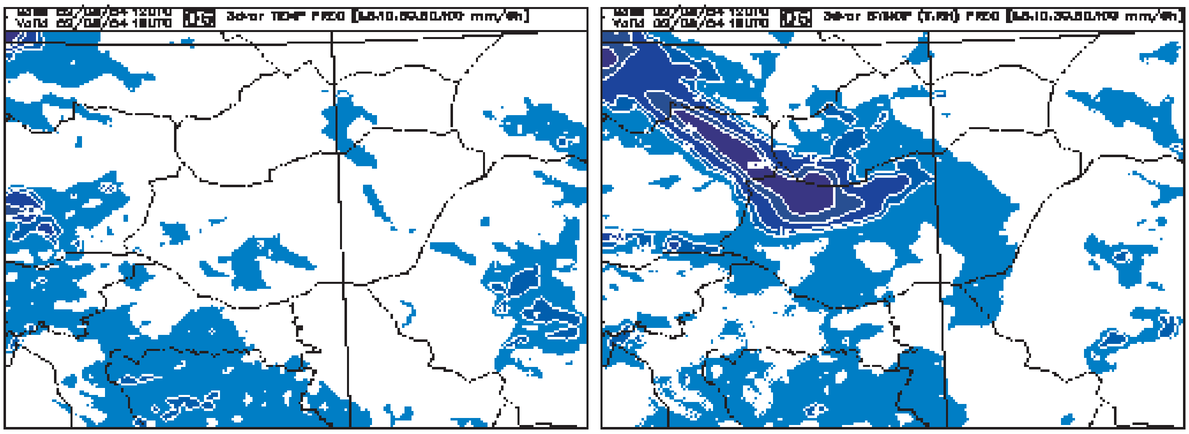

Figure 3 : The quantity of precipitation (mm/6h) forecasted by the model using 3D-Var with TEMP (*3dvar TEMP*) and SYNOP data (*3dvar SYNOP(T,RH)*) between 04.08 12 UTC - 18 UTC, from 04.08 12 UTC model runs

For all experiments, only the precipitation cumulated in 6 h, from the 04.08 12 UTC run, between 12 UTC and 18 UTC, has been plotted. As can be seen in Fig. 3, 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.

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, then geopotential and temperature, and finally geopotential, temperature and relative humidity. 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 observed variables from TEMP data are wind, geopotential, temperature and relative humidity. The conclusions from these experiments were that the geopotential and temperature measurements did not influence the rainfall forecast (not shown). The main information is coming from the relative humidity. As one can see in Fig. 4, when only relative humidity from surface observations has been assimilated, the quantity of precipitation is more than 260 mm in 6 h.

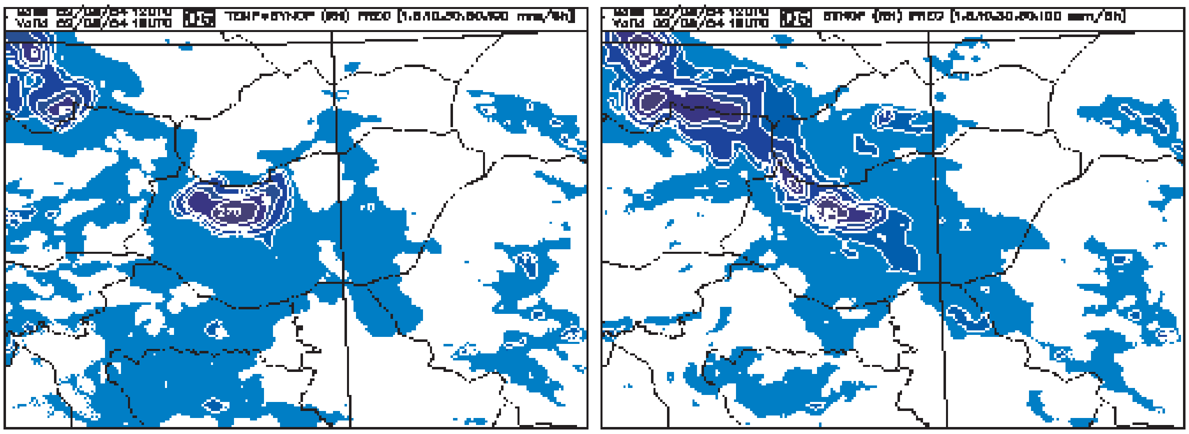

Figure 4 : The quantity of precipitation (mm/6h) forecasted by the model using 3D-Var with TEMP and SYNOP data (*3dvar TEMP+SYNOP(RH)*) and only SYNOP data (*SYNOP(RH)*) between 04.08 12 UTC - 18 UTC, from 04.08 12 UTC model runs

Few precipitation (around 29 mm) has been predicted also by the 3D-Var experiments when TEMP data together with the temperature and geopotential from the surface observations were assimilated. This can be an effect of the inefficient coupling between the planetary boundary layer and the troposphere, made by the observation operator. Thus the 2m temperature observation increment can 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 upperair observations, determined the prediction for some precipitation.

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.

The forecasts from the 04.08 00 UTC and 06 UTC runs showed that both models, with and without data assimilation, did not predict the intensive rainfall, neither at the right moment, nor later. It 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.

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 upperair 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 using 3D-Var scheme had good initial conditions, but it was beyond its capacity to predict such a rainstorm. (Alexandru, 2003).

References

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

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

Note : All the internal notes (5 up to now) written by Steluta Alexandru are available in its personal pages, on the ALATNET web site.