Forecast of the Czech floods using the 3D-Var scheme for the ALADIN mesoscale limited area model

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ALATNET Internal Report
June 2003

Hungarian Meteorological Service

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1 Introduction

Data assimilation is an analysis technique by which the observational meteorological data are merged together with a dynamical model of the atmosphere in order to obtain as much as possible an accurate and consistent description of the atmospheric state. The data assimilation schemes applied to the numerical weather prediction (NWP) models takes into account all the available information, i.e. the observations, the first-guess or background (in the form of an a priori estimation of the atmospheric state), the error statistics of these two types of information, the physical laws governing the atmospheric flow.

A data assimilation system is being developed for the 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 initial experiments was to get a general idea about the applicability of the system for a double-nested LAM and moreover to establish the best possible strategy for its design (Alexandru [1], 2002). These experiments provided the best framework for a more detailed study of the application of the 3D-Var scheme.

Further experiments were concentrated on case studies, comparing the forecasts of the model using the 3D-Var scheme and the one in dynamical adaptation (which is the operational system of the ALADIN/Hungary model at the moment). Thus some interesting meteorological situations have been selected, on the one hand, when the operational model failed to provide a good prediction and on the other hand, when the operational forecast was reasonably good. In a previous ALATNET report (Alexandru, 2003) a case study from the first category has been presented. From the second one, the Czech floods from the 11-13 th of August 2002 have been chosen to be analyzed using 3D-Var scheme. The forecasters considered that the operational ALADIN/Hungary model had a good forecast of the event.

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

2 Synoptic situation

The floods in August 2002 were caused by very intensive and large rainfall that hit the southern and western part of Bohemia mainly. There were two events, the first one on the 6-7 th of August and the second one, on the 11-13 th of August 2002. A short description of the synoptic situation of these events is presented below.

On the 6 th of August a high altitude low pressure system from the Gulf of Genoa reached the area of Alps causing rain showers and thunderstorms in Austria. As an effect of the moist air with unstable stratification in the cyclone, the quantity of precipitation was high, 50-100 mm in the Alps, but in some places of the central part of Austria it exceeded even 200 mm during the two days.

The quantity of precipitation decreased temporarily between the 8-10 th of August in the Alps. Rain showers, thunderstorms continued to occur but large quantity of precipitation fell only locally. A new active cyclone reached however the upper parts of the Danube on the 11 th of August. The motion of the cyclone slowed down on an unusual

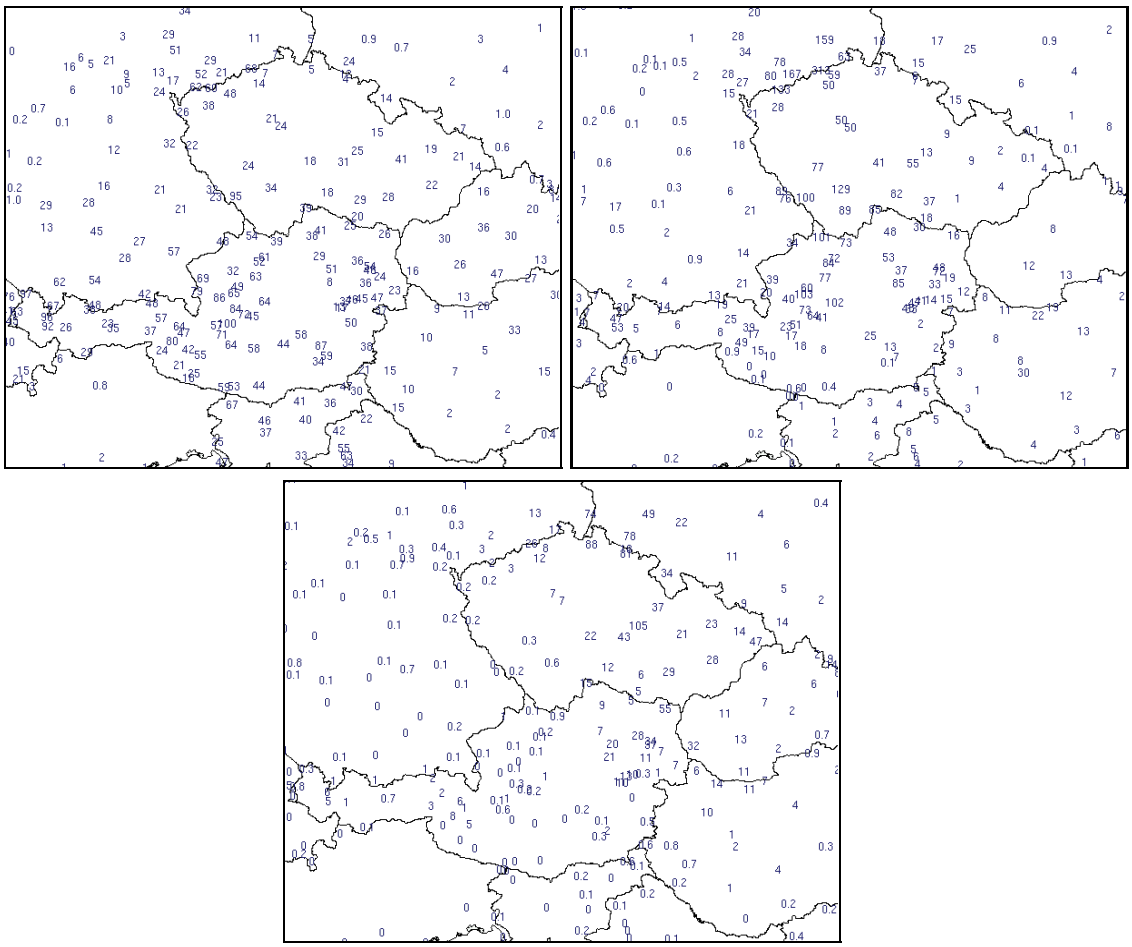

Figure 1: The quantity of precipitation (mm/24h) measured between 11.08 06 UTC - 12.08 06 UTC (top, left), 12.08 06 UTC - 13.08 06 UTC (top, right) and 13.08 06 UTC - 14.08 06 UTC (bottom)

way in the region and its occluded front spread over the central part of Austria and the Czech basin three days almost immobile. As an effect of this stationary front, the quantity of precipitation was again significant in Austria, Bavaria and Bohemia, i.e. 100-150 mm in 24h, but locally 200 or in some places more than 300 mm (Figure 1). (IABM, 2002).

3 3D-Var experiments

3D-Var data assimilation scheme consists of the minimization of a cost-function in order to get the best fit to the available information sources. This function is a sum of three terms, the background term, representing the departures from the first-guess (usually, the 6h forecast from the previous integration of the model), the observation term, representing the departures from the observations, and the constraint term, measuring the departure of the analysis from a filtered model state. At the moment for ALADIN model, only the first two terms are defined.

For the observation term of the cost function, only the surface (SYNOP) and upper-air (TEMP) observations were considered, and the standard NMC statistics for the background term. The NMC (National Meteorological Center, now called National Centers for

Environmental Prediction) method estimates the background error statistics using a set of differences between forecasts valid at the same time, but at different ranges (usually 36h - 12h differences). (Parrish and Derber, 1992).

The experiments have been performed with 3D-Var data assimilation scheme for a *double-nested limited area model* (ALADIN/Hungary). This means that the boundary conditions of the model are provided by another limited area model (ALADIN/LACE), which has a bigger domain, and a lower resolution. At its turn, ALADIN/LACE model is driven by the French global model, ARPEGE. The domain of ALADIN/Hungary model covers mostly the Central European area, at 8 km resolution.

Because of the fine resolution and of the noise produced by the interpolation from the simple-nested LAM to double-nested LAM geometry, the ALADIN/Hungary model is using initialization to remove the fast propagating inertia-gravity waves from the initial conditions which would cause numerical instability at the beginning of the integration. Therefore the time integration (in cycling and in production) is preceded by the digital filter initialization (DFI) of the initial fields (Lynch et al, 1997).

For this case study, two sets of experiments using 3D-Var scheme were carried out. The first set of experiments was performed 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 have been considered, and from TEMP observations, wind, geopotential, temperature and relative humidity. Hereafter the name of this set of experiments is "*3dvar (T,RH)*".

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 from the SYNOP observations is not analyzed in the assimilation cycle for ARPEGE model, because it can cause some spurious features in the upper troposphere. For the time being, neither the observation operator nor the background term do uncouple the planetary boundary layer from the troposphere successfully. As the first set of experiments has been already performed at that time, we decided to present here these results also.

As coupling strategy, time-consistency has been chosen both in cycling and in production (Alexandru [2], 2002). Time-consistency means that the lateral boundary conditions 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 (Široká, 2001).

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.

4 Results

For this case study, mainly the forecasts of different fields from 11.08 - 12.08, 00 UTC and 12 UTC model runs have been analyzed. For these model runs, the maps with

the forecasts of the geopotential and wind have been plotted over the entire domain of the ALADIN/Hungary model. In order to point out the location of the event, the maps with the 24h cumulated precipitation, relative humidity and vertical velocity at 700 hPa have a zoom between 45 °- 52 ° latitude and 10 °- 20 ° longitude. For each model run, the 24h forecasts of the geopotential, relative humidity and vertical velocity fields have been plotted.

4.1 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.

In Figure 2, one can see a low-pressure system located in the southern part of the Czech Republic predicted by the operational model. The differences between the operational forecast for geopotential, and those using data assimilation, for some upper levels are rather small, not bigger than 1.5 dampgm (Figure 2, middle, bottom).

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 (till 6.5 Pa/s). So there is an increased likelihood that heavy precipitation will develop. All three experiments show almost the same pattern of high humidity (Figure 3).

For this run, the precipitation was cumulated for 24h, between 11.08 06 UTC - 12.08 06 UTC (Figure 4). All three experiments overestimated in some places in Austria the quantity of precipitation, predicting more than 200 mm in 24h (the real measurements being around 100 mm). But the location of the rainfall is well forecasted. Moreover this model run gave the first indication of the new location of the heavy rainfall over the border of Germany and Czech Republic. Comparing to reality, the *oper* and *3dvar (Z)* sets predicted very well the quantity of precipitation in this area, but the *3dvar (T,RH)* experiment seems to overestimate it (almost twice bigger).

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

4.2 11.08 12 UTC run

In Figure 5 the operational forecast shows 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. Comparing the forecasts of the geopotential, with and without 3D-Var scheme, one can see some differences (almost 2 damgpm) between the models.

The operational and 3D-Var forecasts of the relative humidity at 700 hPa surface show the same shape of the areas where the moisture is available. So the sky is mostly cloudy over the northern and western parts of Austria, Bohemia and Saxony. An intensive vertical motion of the air masses can be seen in Figure 6, reaching values as 5 hPa/s. These indicate that a heavy rainfall is likely to occur.

In the southern part of Austria the sky is partly cloudy and the air has a descending motion, which are generally associated to areas of fair weather. So it is expected that the precipitation will end soon.

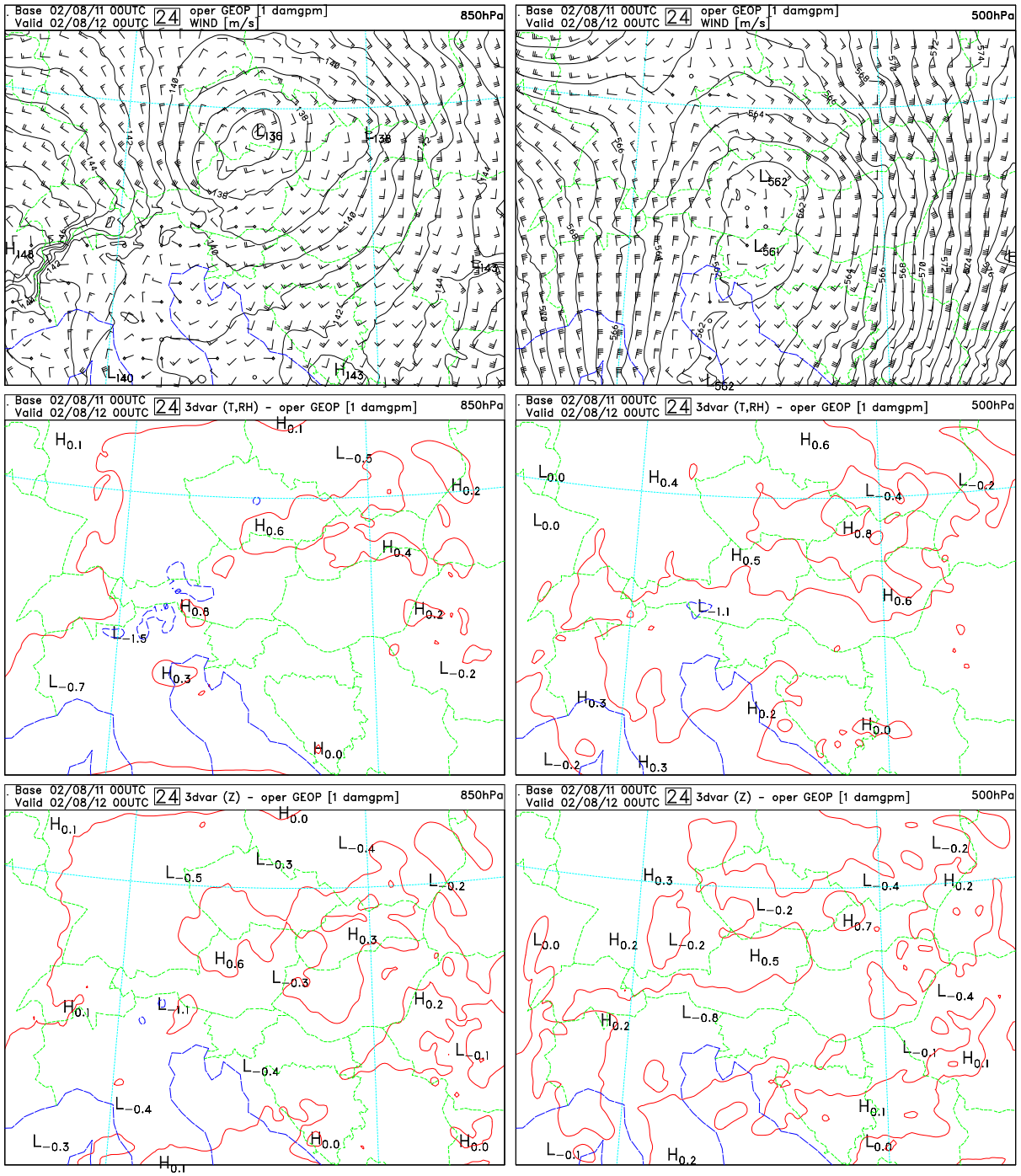

Figure 2: The 24h operational forecast (*oper*) for geopotential and wind (upper row) and the differences between the geopotential forecasts of the *3dvar (T,RH)*, *3dvar (Z)* sets and *oper*, from 11.08 00 UTC model run, valid at 12.08 00 UTC, at 850 and 500 hPa

The quantity of precipitation, cumulated for 24h, between 12.08 06 UTC and 13.08 06 UTC (Figure 7), reaches values bigger than 100 mm in Austria, which have been very close to reality. All three experiments predicted over the border of Germany and Czech Republic, some places with a significant quantity of precipitation (more than 100 mm in 24h). Indeed in that region the real maximum was 313 mm, so the forecast was

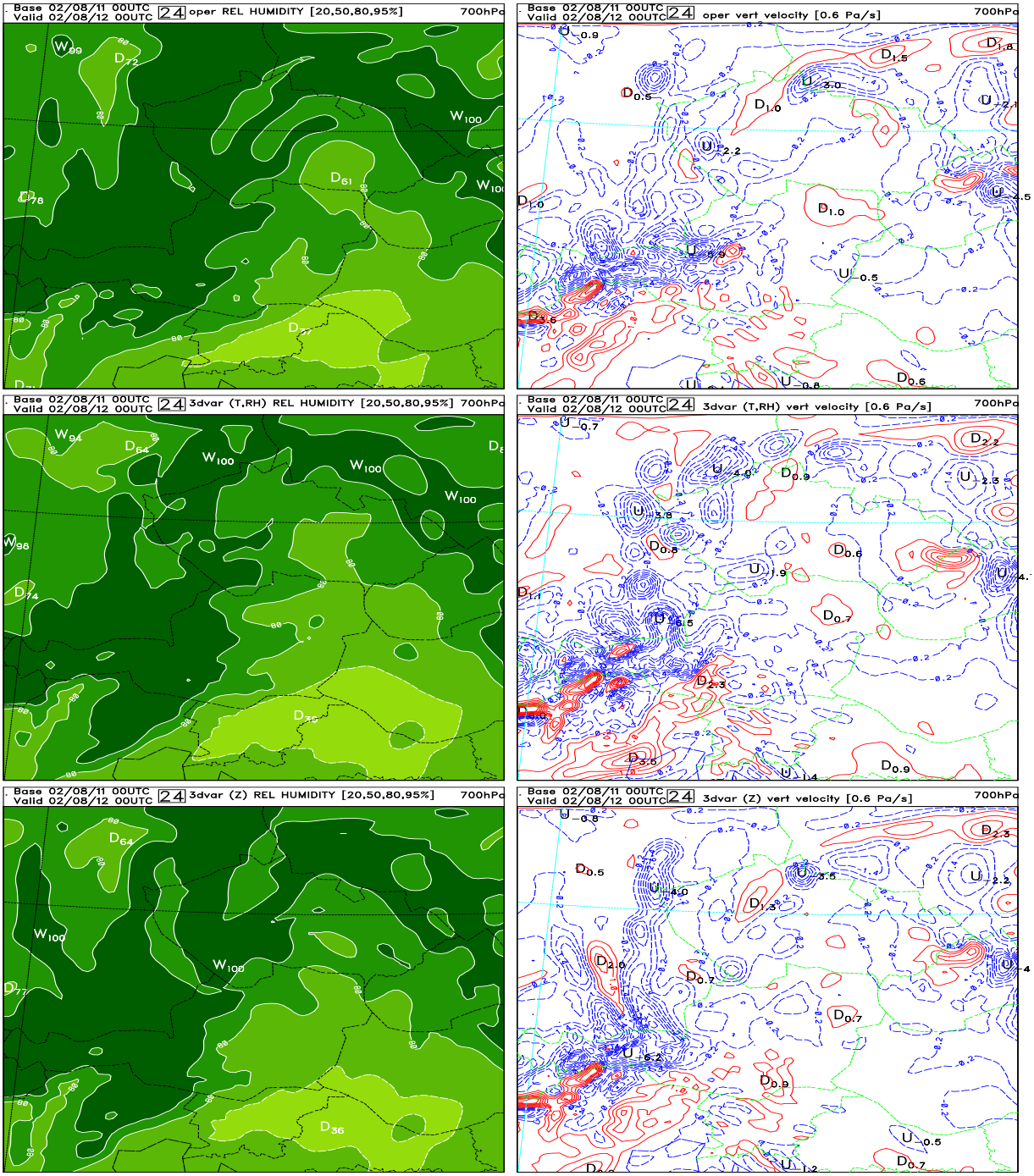

Figure 3: The 24h operational forecast (*oper*) and using 3D-Var scheme (*3dvar (T,RH)*, *3dvar (Z)*), for relative humidity and vertical velocity at 700 hPa, from 11.08 00 UTC model run, valid at 12.08 00 UTC

underestimated, but still the models gave an indication of the intensive rainfall. More to the west, 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, significant quantity of precipitation has been forecasted.

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

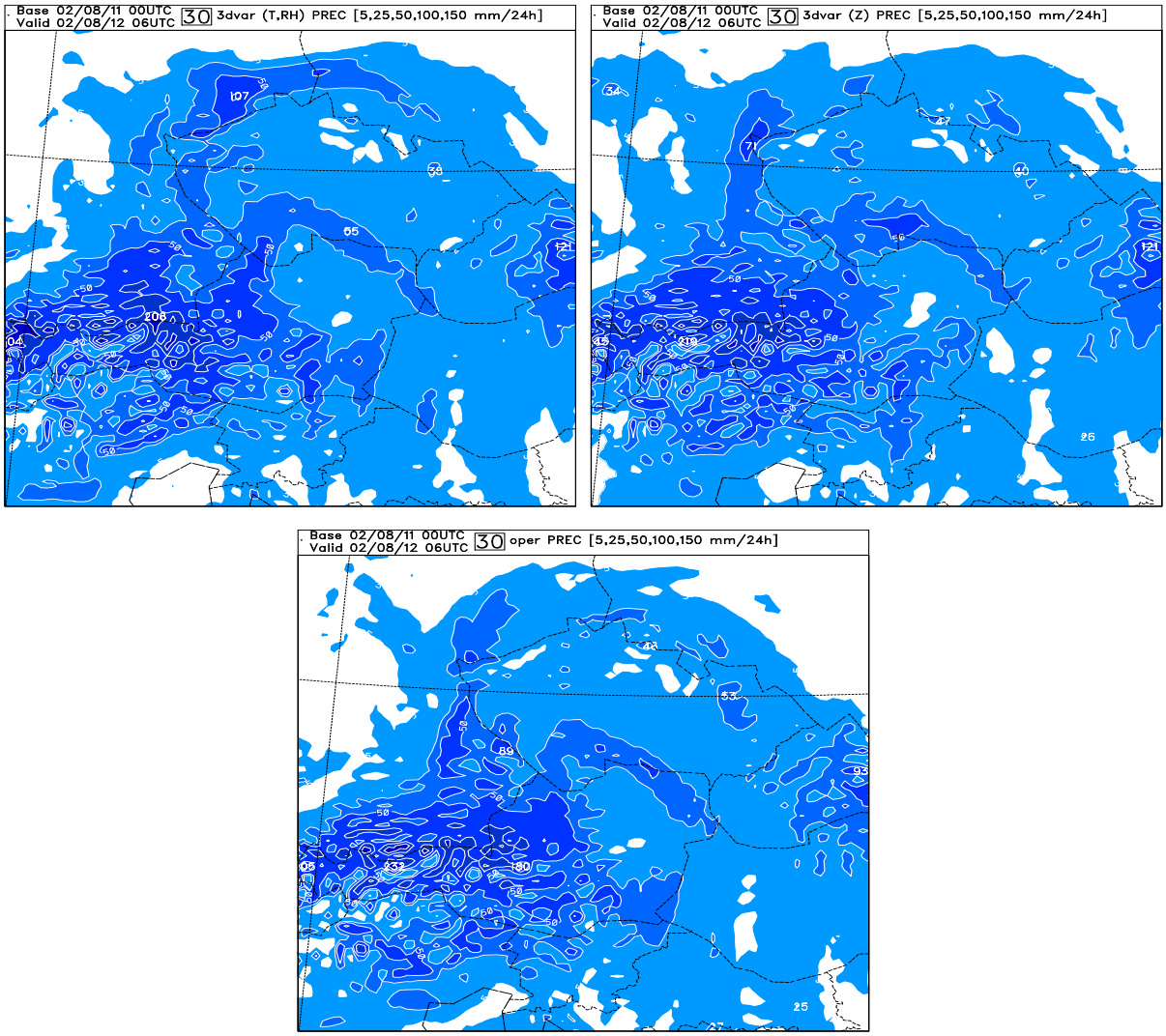

Figure 4: The quantity of precipitation (mm/24h) forecasted by the operational model (*oper*) and using 3D-Var scheme (*3dvar (T,RH)*, *3dvar (Z)*) between 11.08 06 UTC - 12.08 06 UTC, from 11.08 00 UTC model run

over the border of Germany and Czech Republic, but still this was more than 100 mm in 24h. The location of the maximum of the event was forecasted more to the west.

4.3 12.08 00 UTC run

The direction of the cold air remains north-westerly. The low-pressure system began to fill in, progressing on a northeastward track. The differences between the operational forecast and those using the 3D-var scheme for geopotential are less than 2 damgpm (Figure 8).

The area of high humidity started 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 can be seen in these regions, where heavy precipitation are expected to occur (Figure 9).

Figure 10 shows the precipitation cumulated in 24h between 12.08 06 UTC and 13.08

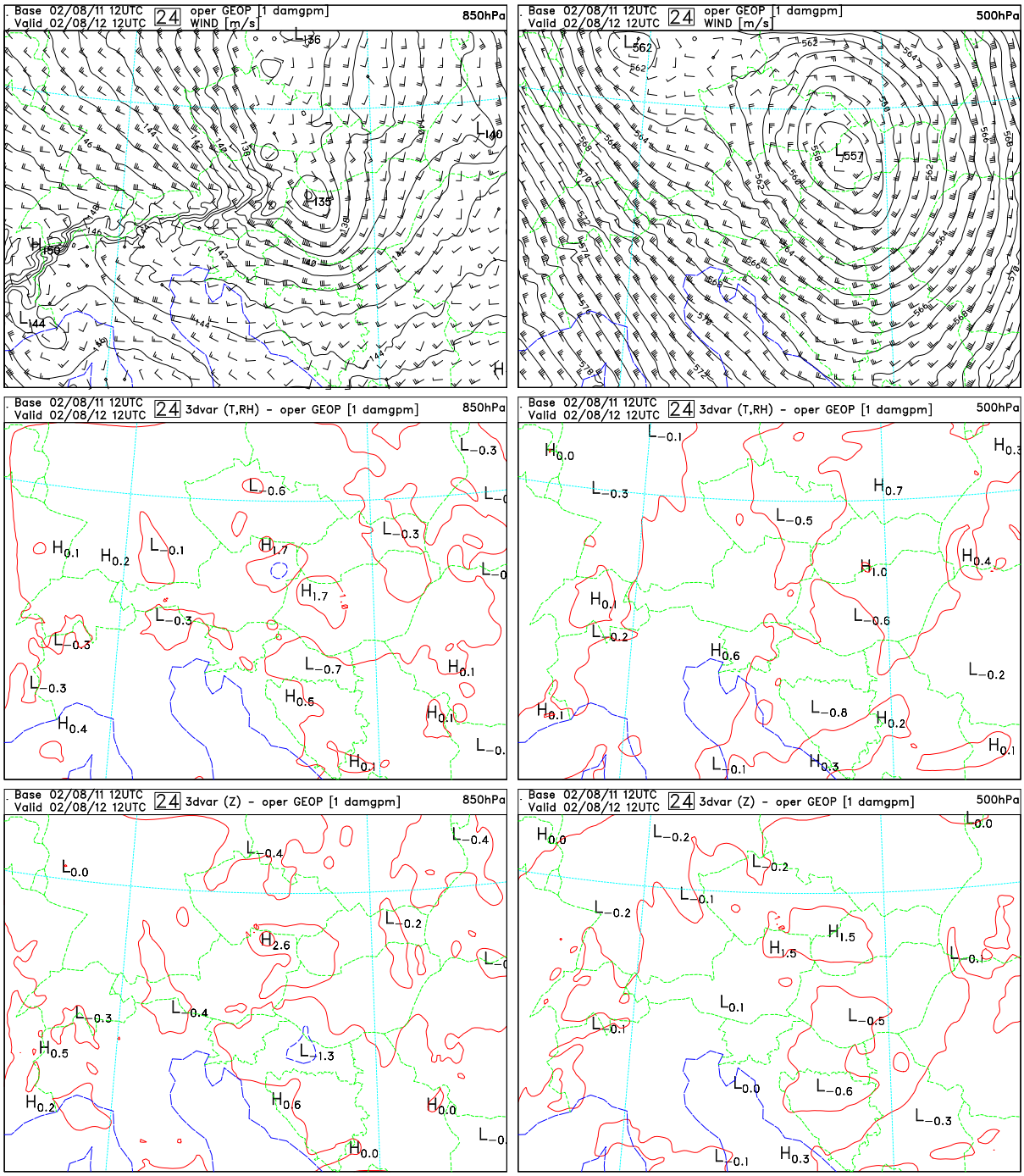

Figure 5: The 24h operational forecast (*oper*) for geopotential and wind (upper row) and the differences between the geopotential forecasts of the *3dvar (T,RH)*, *3dvar (Z)* sets and *oper*, from 11.08 12 UTC model run, valid at 12.08 12 UTC, at 850 and 500 hPa

06 UTC. In some places in Austria, the quantity of precipitation is more than 100 mm in 24h, which is a slight overestimation, compared to real measurements. Unlike the previous run, all the models predicted the right place of the rainfall in Saxony, where values as 296 mm in 24h are shown. The operational forecast has the closest value to reality. But also the 3D-Var experiments predicted an important quantity in that area. A good prediction

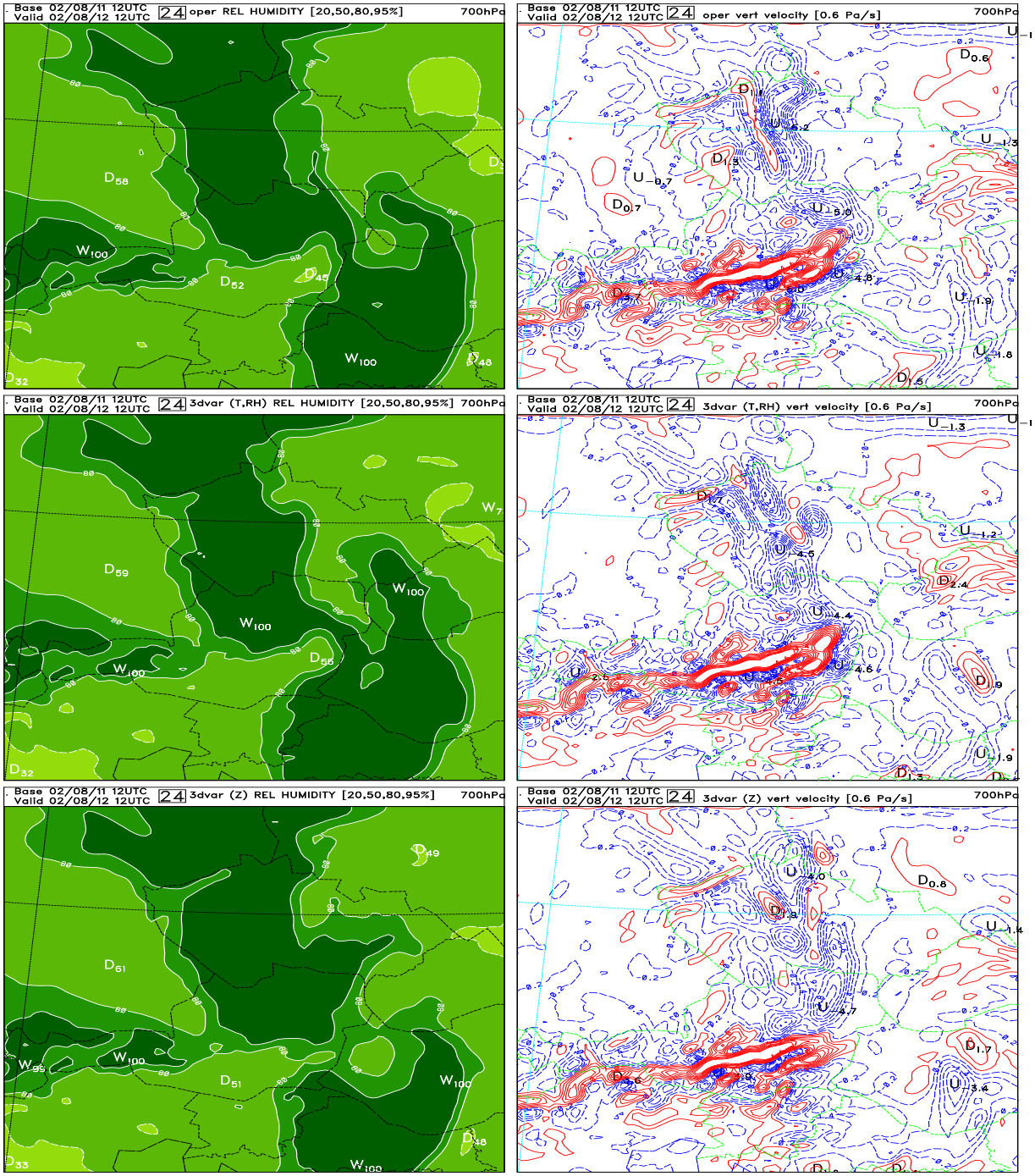

Figure 6: The 24h operational forecast (*oper*) and using 3D-Var scheme (*3dvar (T,RH)*, *3dvar (Z)*), for relative humidity and vertical velocity at 700 hPa, from 11.08 12 UTC model run, valid at 12.08 12 UTC

of the rainfall over Bohemia has been performed by the *3dvar (Z)* experiment. The *oper* and *3dvar (T,RH)* sets overestimated the quantity of precipitation, predicting more than 150 mm, comparing with real measurements as 50 mm.

In Figure 10, 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

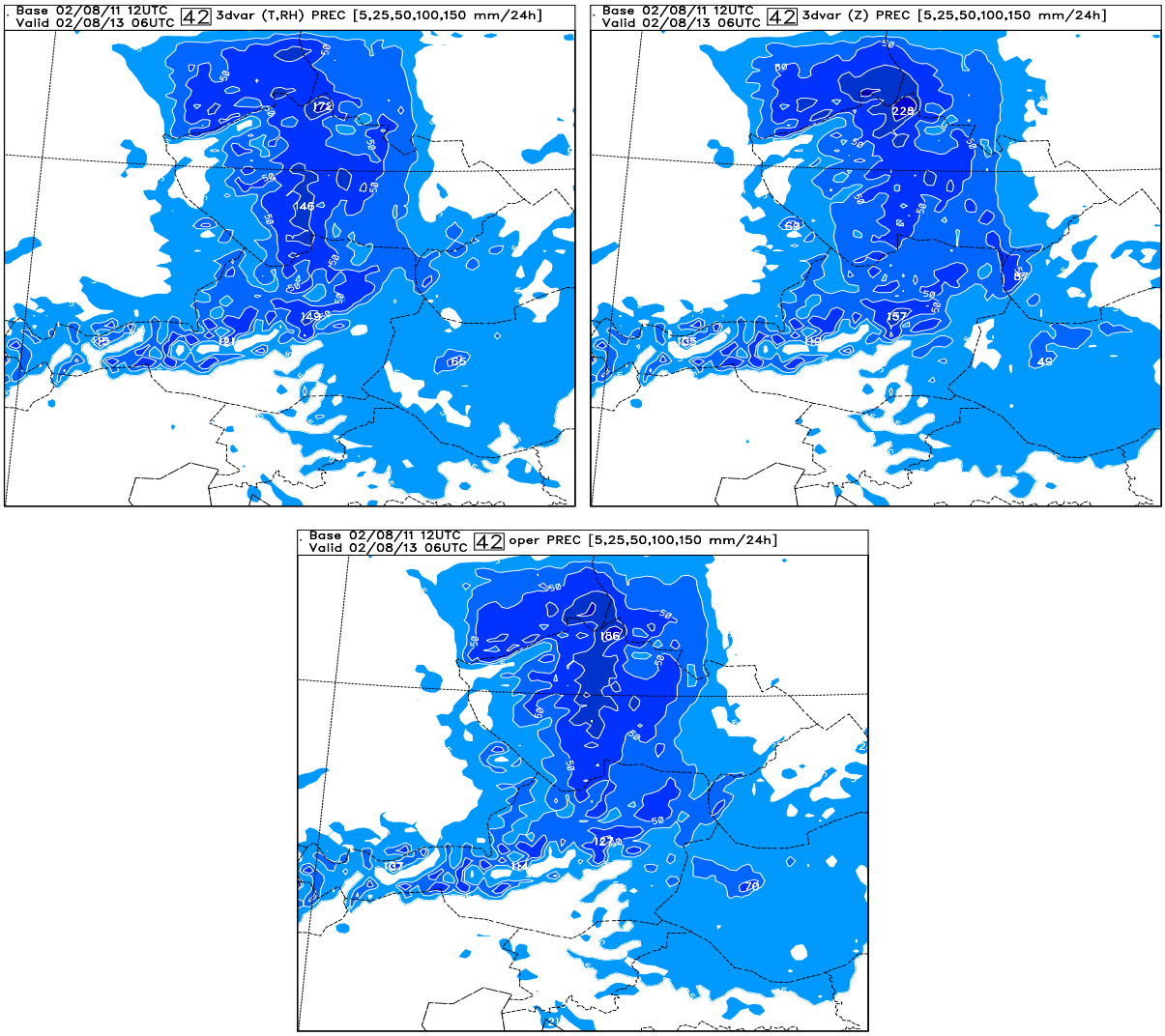

Figure 7: The quantity of precipitation (mm/24h) forecasted by the operational model (*oper*) and using 3D-Var scheme (*3dvar (T,RH)*, *3dvar (Z)*) between 12.08 06 UTC - 13.08 06 UTC, from 11.08 12 UTC model run

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.

4.4 12.08 12 UTC run

The operational forecast of the geopotential from the last model run presented in this paper, shows that the low-pressure system continued to move in a northeastward direction (Figure 11). 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 scheme are very small, less than 1 damgpm.

Now in the south-western part of Poland, Czech Republic, the west of Hungary, the moisture is available. All three experiments predicted the same shape of the area where

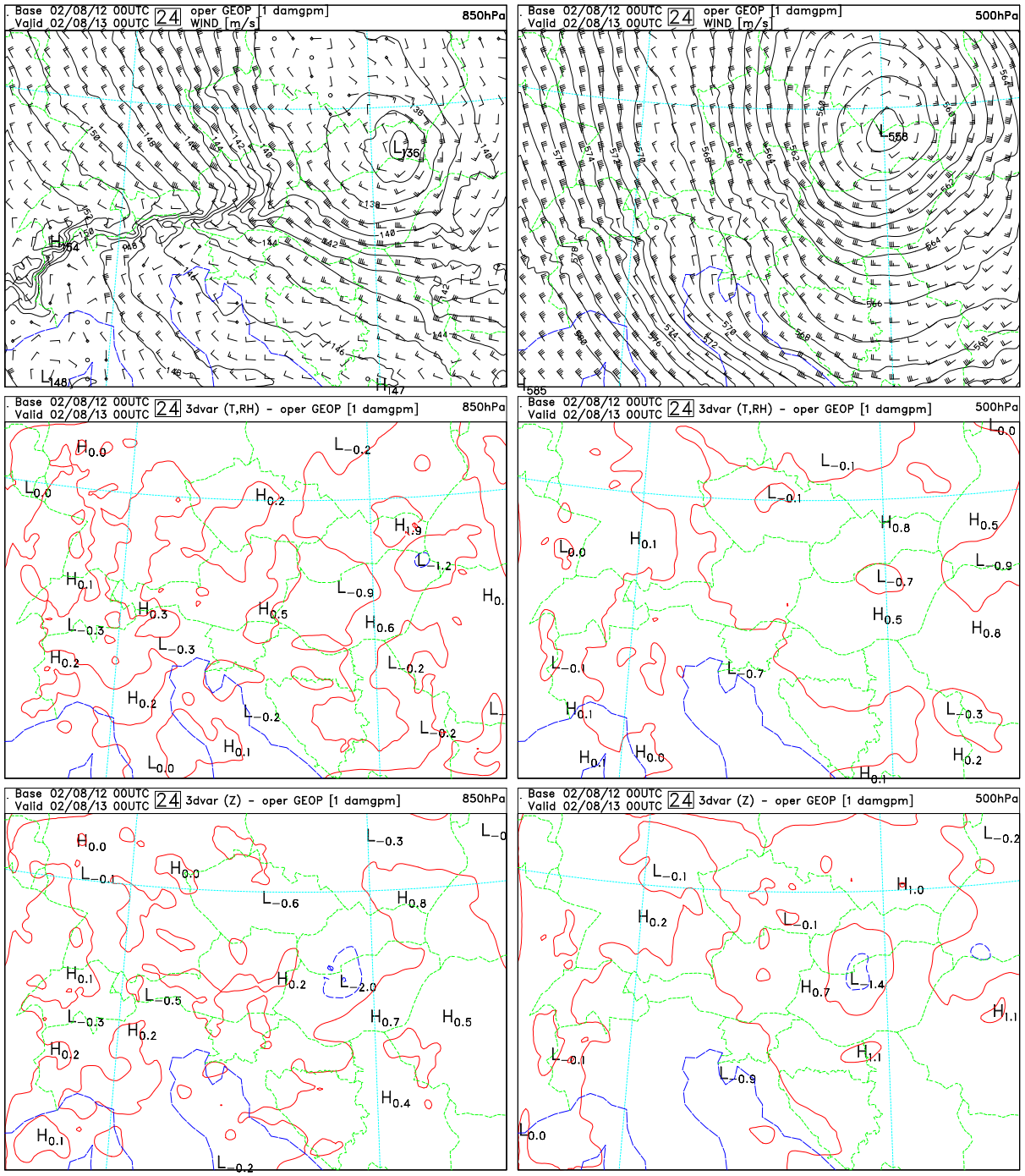

Figure 8: The 24h operational forecast (*oper*) for geopotential and wind (upper row) and the differences between the geopotential forecasts of the *3dvar (T,RH)*, *3dvar (Z)* sets and *oper*, from 12.08 00 UTC model run, valid at 13.08 00 UTC, at 850 and 500 hPa

the humidity is high (Figure 12). The vertical motion of the air masses is less intense, reaching values as 2.6 Pa/s.

The precipitation cumulated in 24h between 13.08 06 UTC and 14.08 06 UTC is shown in Figure 13. One can see now that the models predicted almost the same quantity of precipitation, and the location is also similar. Comparing to reality, the models in

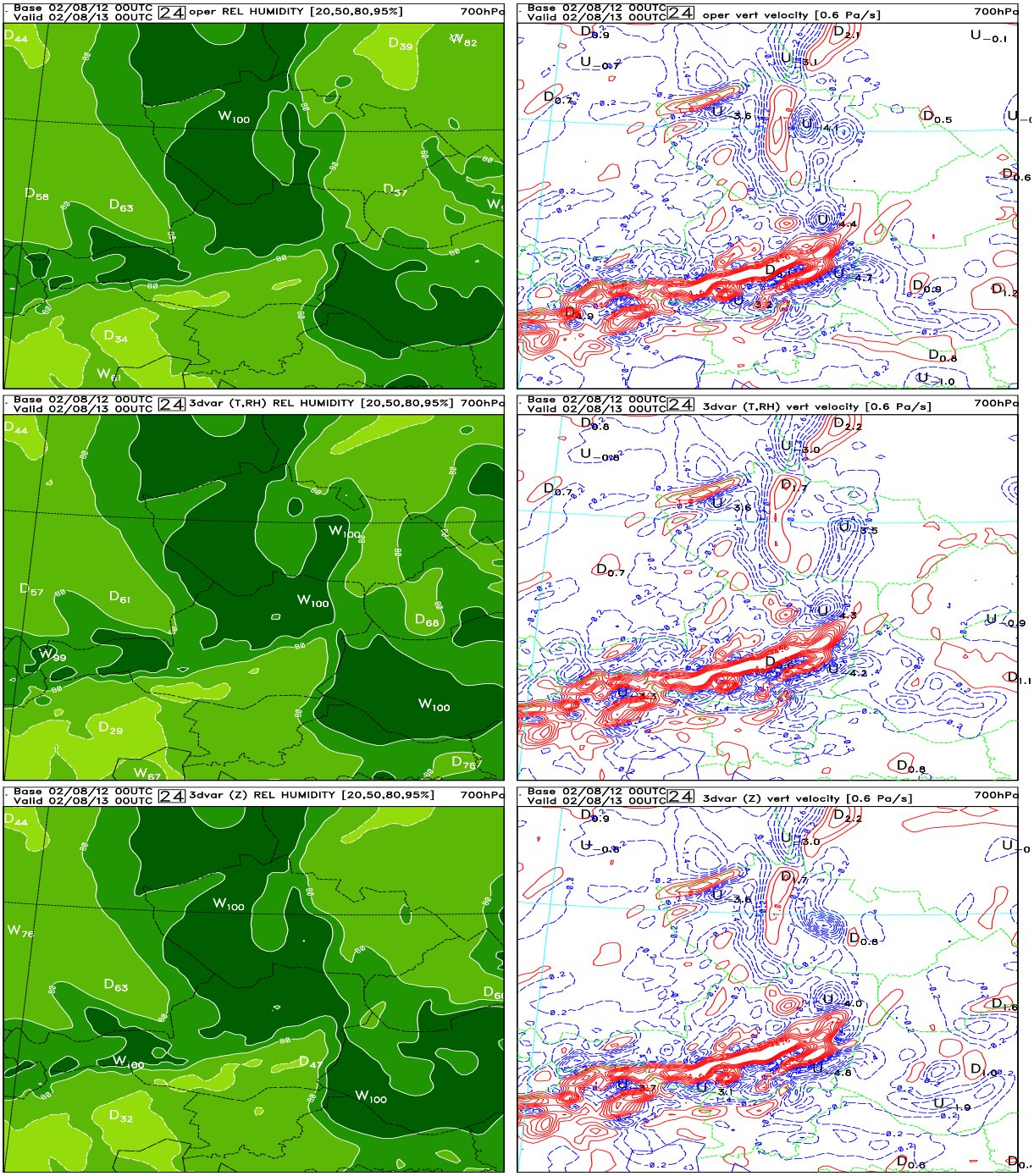

Figure 9: The 24h operational forecast (*oper*) and using 3D-Var scheme (*3dvar (T,RH)*, *3dvar (Z)*), for relative humidity and vertical velocity at 700 hPa, from 12.08 00 UTC model run, valid at 13.08 00 UTC

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.

At the end we can conclude that the models succeeded to give a good forecast for the

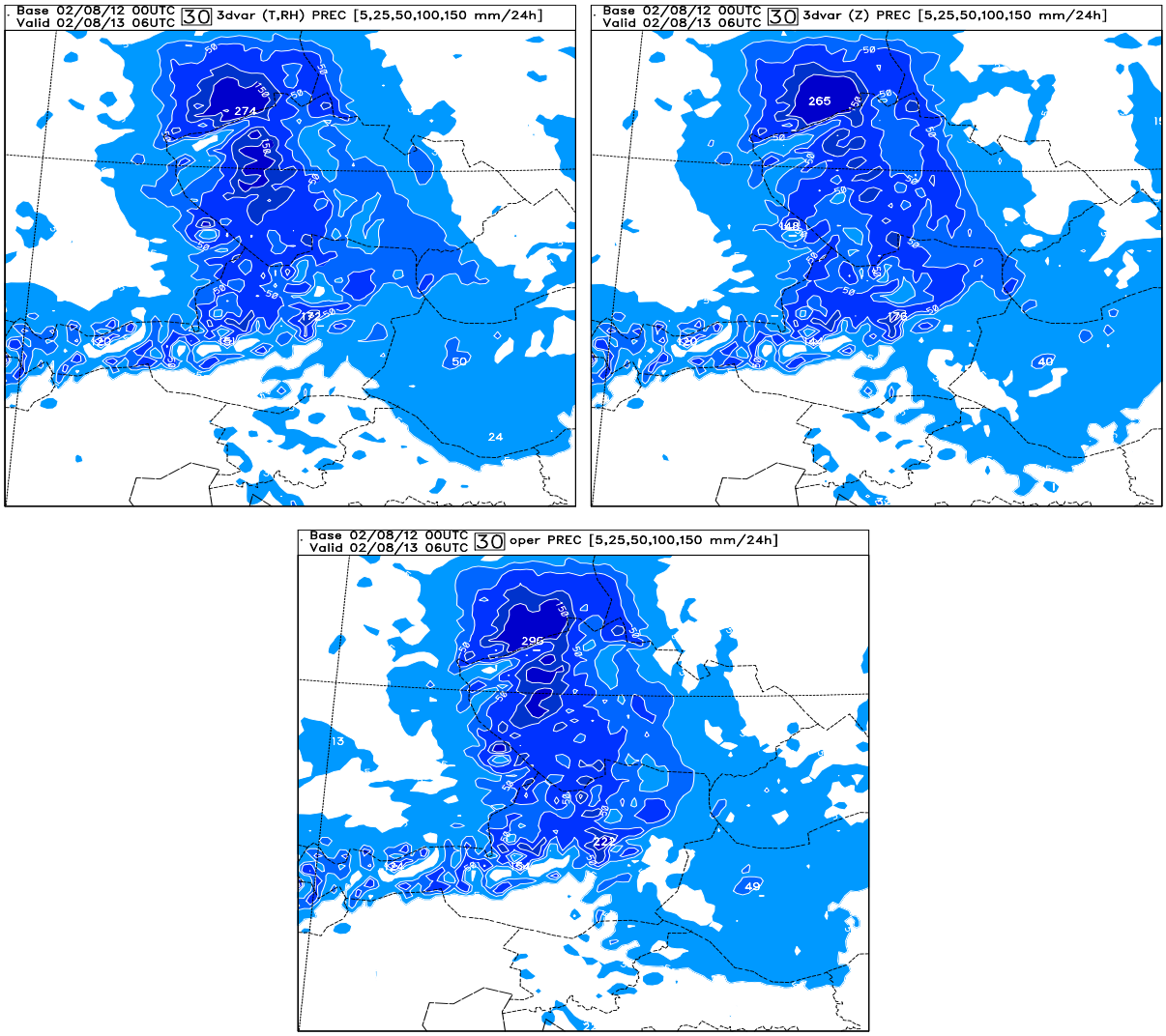

Figure 10: The quantity of precipitation (mm/24h) forecasted by the operational model (*oper*) and using 3D-Var scheme (*3dvar (T,RH)*, *3dvar (Z)*) between 12.08 06 UTC - 13.08 06 UTC, from 12.08 00 UTC model run

end of these floods. The quantity of precipitation started to decrease, and the location to move in the eastern part of Czech Republic.

5 Conclusions

In this paper, the Czech floods from the 11-13 th of August 2002 have been analyzed 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 dif-

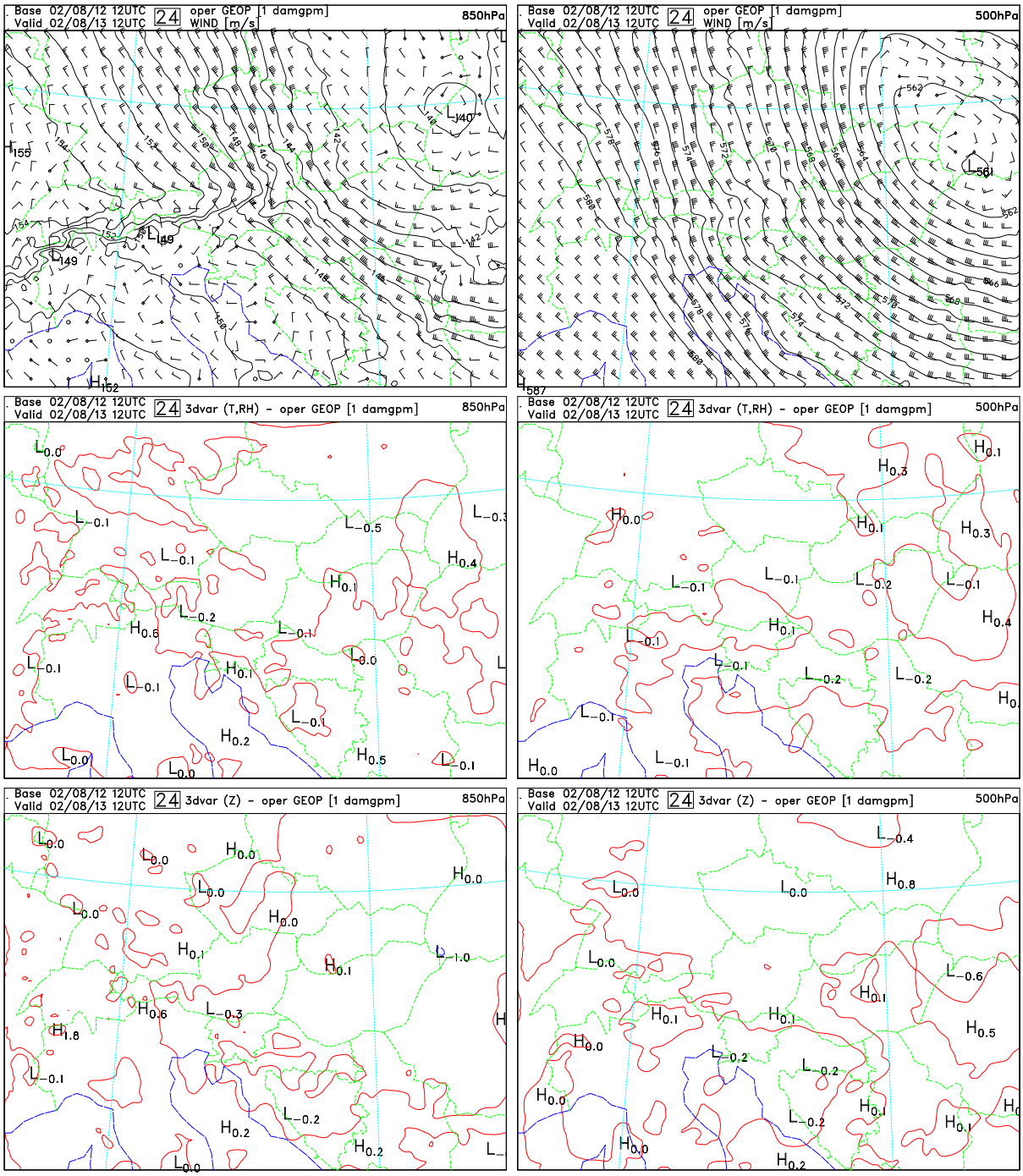

Figure 11: The 24h operational forecast (*oper*) for geopotential and wind (upper row) and the differences between the geopotential forecasts of the *3dvar (T,RH)*, *3dvar (Z)* sets and *oper*, from 12.08 12 UTC model run, valid at 13.08 12 UTC, at 850 and 500 hPa

ference between the experiments is that one analyzed 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. Four model runs have been compared, from 11.08 00 UTC and 12 UTC, 12.08 00 UTC and 12 UTC.

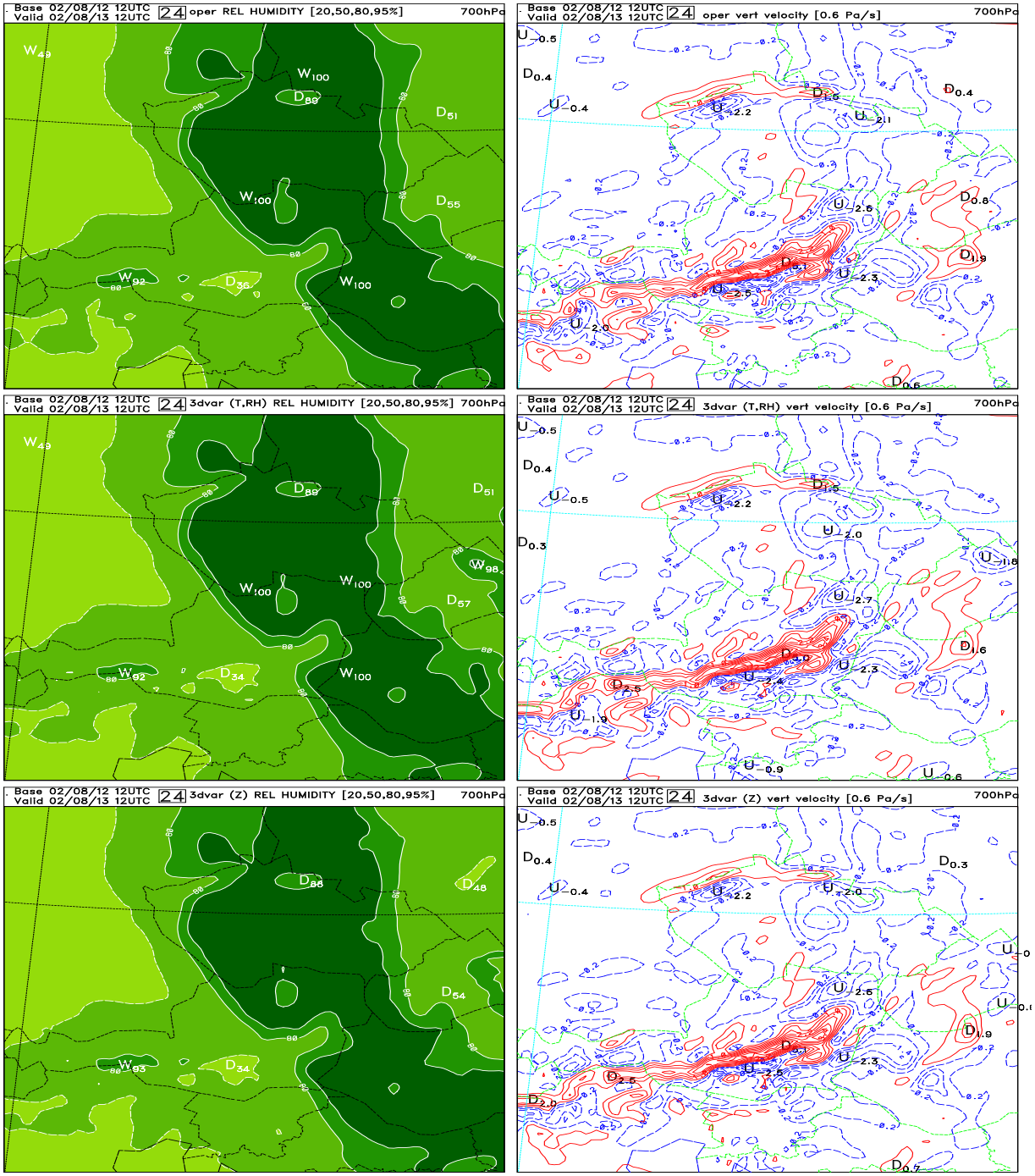

Figure 12: The 24h operational forecast (*oper*) and using 3D-Var scheme (*3dvar (T,RH)*, *3dvar (Z)*), for relative humidity and vertical velocity at 700 hPa, from 12.08 12 UTC model run, valid at 13.08 12 UTC

The forecasts from the 11.08 00 UTC model run show the beginning of the event, with an intensive rainfall started over Austria, and moving to the Czech Republic. All three experiments overestimated the quantity of precipitation in Austria, predicting more than 200 mm in 24h (the real measurements being around 100 mm). The location of the rainfall is well forecasted. This model run gave the first indication of the new location of

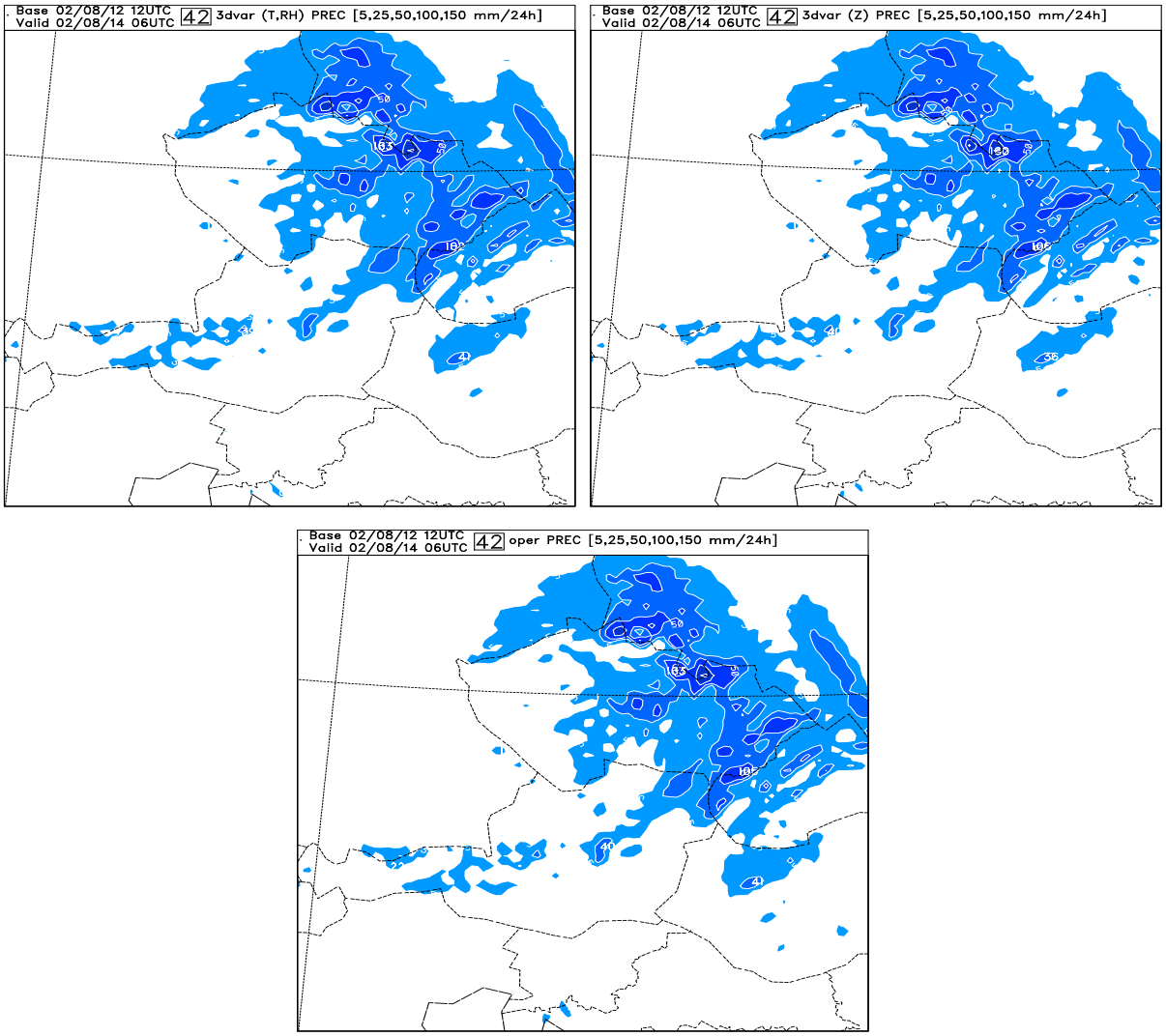

Figure 13: The quantity of precipitation (mm/24h) forecasted by the operational model (*oper*) and using 3D-Var scheme (*3dvar (T,RH)*, *3dvar (Z)*) between 13.08 06 UTC - 14.08 06 UTC, from 12.08 12 UTC model run

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, had a good forecast of precipitation in Austria and in the central part of Czech Republic. Also a significant quantity of precipitation (more than 100 mm in 24h) has been predicted over the border of Germany and Czech Republic. But comparing to real measurements, the forecast was underestimated, the maximum of precipitation reaching 313 mm. Despite this, the models gave an indication of the intensive rainfall. Both models (with and without data assimilation) predicted heavy precipitation more to the west, 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, around 300 mm in 24h, 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. The great quantity of precipitation has not been predicted exactly, but it was large enough, to give warning about the future flood.

The main difference between experiments appeared in this run, in the forecasting of the rainfall over Bohemia. The *3dvar (Z)* experiment succeeded to give a good prediction, while the *oper* and *3dvar (T,RH)* sets overestimated the quantity of precipitation (more than 150 mm, comparing with 50 mm, as it was in reality).

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 NWP 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.

As we could see from these four runs, both models, in dynamical adaptation and using the 3D-Var scheme had similar forecasts.

The good prediction 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.

But 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, excepting for one model run.

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.

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