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

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Contents

1 Introduction

The previous experiments with 3D-Var data assimilation scheme for the double-nested limited area model ALADIN/Hungary have been performed in order to establish the best strate-gy for the application of the scheme. We had to choose between many options, such as: different first-guesses, lateral boundary conditions (from the global model or limited area model), initialization methods (digital filter initialization, incremental digital filter initialization, no initialization), coupling techniques (time-consistency, space-consistency), etc. These investigations are summarized in an earlier ALATNET report (Alexandru [1], 2002).

The next step was to select some interesting meteorological situations, when on the one hand, the operational model (in dynamical adaptation) failed to provide a good prediction and on the other hand, when the operational (reference) forecast was reasonably good. In the first case the improvements were checked, and in the latter one, whether the 3D-Var scheme is able to keep the good performance of the reference model. Therefore we started with a case (the 17-18th of July 2002), when the operational forecast was extremely bad.

The present paper is organized in the following way: 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

A short description of the synoptic situation of this case is presented below. On 13.07, a cold trough spread over Western Europe on 500 hPa. From this, a cold drop isolated on 14.07, moved to East, whirled over Northern Italy on 16.07, at noon, and filled slightly in between. From noon of 17.07, it got a cold supply on the backside, which made the cyclone to strengthen again and to move to East from 18.07. Between the 18-20th of July the cyclone moved over the Carpathian Basin. On 18.07, large quantity of precipitation (40-70 mm) has been measured over the central part of Hungary, along the Danube river (Figure 1). In the morning of 18.07, a steady direction and speed convergence evolved in the wind field, that probably played an important role as a trigger effect in the rainstorm (with precipitation on a large area).

Also before 17.07, this cyclone had significant influence on the weather of Hungary. The forecasters predicted some showers and thunderstorms, in the period 12.07 - 17.07, especially in the afternoon or evening, which also occurred in reality. In these days, the temperature predicted by the numerical models had an underestimation of $3-5\,^{\circ}$C. According to ECMWF model (16.07 12 UTC run), the humidity at 700 hPa did not show maximum values over Hungary, and no closed cloudiness was expected over the country. The quantity of predicted precipitation reached 5 mm in a few places. The northwesterly stream in the lower atmosphere would have rather went against to the thunderstorms. Relying on the forecasts above and knowing the underestimation of the models from the previous days, the forecasters predicted frequent cloudiness and showers, thunderstorms at any places, and they moderated the temperature forecast. First in 17.07, they predicted $26-31\,^{\circ}$C, late, in the dawn of 18.07, they decreased the temperature at $24-29\,^{\circ}$C. But

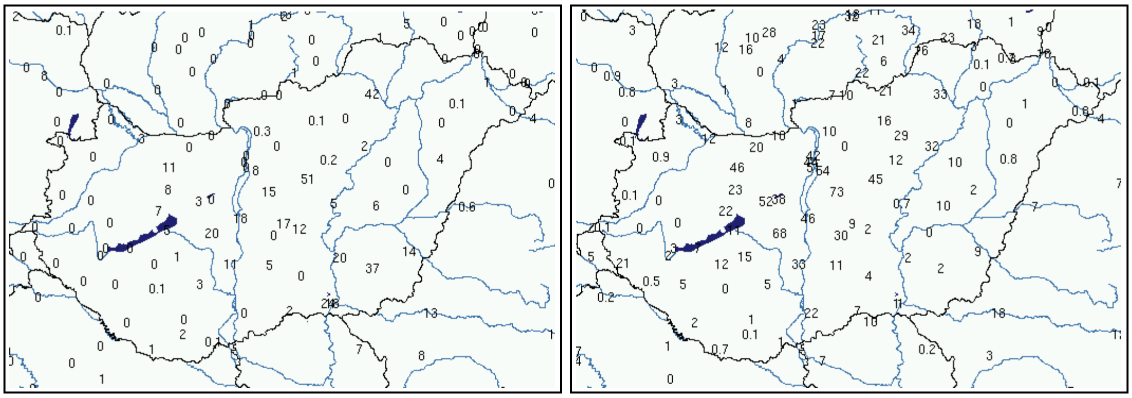

Figure 1: The quantity of precipitation (mm/24h) measured over Hungary between 17.07 06 UTC - 18.07 06 UTC (left) and 18.07 06 UTC - 19.07 06 UTC (right)

they did not expect significant fall in temperature (till 19 °C, as it was in reality). (HMS, 2002).

3 3D-Var experiments

To produce a good forecast with a numerical weather prediction model, a good description of the initial conditions is necessary. The objective of data assimilation is to define the best initial state of the model taking into account all the 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. 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. 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).

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 mesoscale limited area models. In dynamical adaptation mode, the initial and lateral boundary conditions for ALADIN are obtained through the interpolation of the ARPEGE analyses and forecasts onto the high-resolution grid of the limited area model (Horányi et al., 1996). Because of the fine resolution and of the noise produced by the interpolation from the global to limited area geometry, the ALADIN model is using the 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 is preceeded by the digital filter initialization (DFI) of the initial fields (Lynch and Huang, 1992; Lynch et al, 1997).

Other interpolation method used to obtain the initial conditions, as for the ALADIN/LACE model, is the DFI-blending technique. 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 latter are expected to be more realistic than those obtained by interpolation from the global model. A digital filter initialization (DFI) is applied on both analysis of the global model and forecast (or first-guess) of the limited area model, on the final grid of the mesoscale model, but at a lower resolution. The difference between the filtered fields provides a blending large-scale increment, which is added on the final grid, i.e. at the full resolution, to the forecast of the limited area model. So the role of the DFI is to filter out the global analysis increments at the smaller scales. Digital filter initialization ensures an "implicit and smooth" transition function to blend the spectra of the coupled models (Giard, 2001).

The ALADIN/LACE is a "simple-nested" limited area model (LAM), being driven by the global model. At its turn, the "simple-nested" LAM can provide the lateral boundary conditions to another LAM, which has a smaller domain and a higher resolution. The operational ALADIN/Hungary model (the reference in these experiments) is a "double-nested" LAM, its lateral boundary conditions being provided by the ALADIN/LACE model.

For this case study, three sets of experiments with 3D-Var data assimilation scheme were chosen to be performed using different sets of observational data and different lateral boundary conditions (from ALADIN/LACE and ARPEGE models). For the background term, standard NMC (National Meteorological Center) statistics (Parrish and Derber, 1992) have been used, and for the observation term, SYNOP and TEMP data available at the Hungarian Meteorological Service, and data from Météo-France, zoomed over the ALADIN/Hungary domain. From SYNOP observations, temperature and relative humidity have been considered, and from TEMP observations, wind, geopotential, temperature and relative humidity.

As coupling strategy, time-consistency has been chosen both in cycling and in production (Alexandru [2], 2002). 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 (Široká, 2001). Digital filter initialization (DFI) was applied in cycling and in production, at the beginning of the integration.

The assimilation cycle was started from 15.07.2002 06 UTC, i.e. three days before the event. The pictures with different forecasts (Figures 3-17, 19-21, 23-24) have a zoom over the integration domain.

The first set of experiments was carried out using SYNOP and TEMP data available at the Hungarian Meteorological Service (HMS) and the operational lateral boundary conditions for ALADIN/Hungary (from ALADIN/LACE model). Hereafter the name of this set of experiments is "*3dvar*".

The second set of experiments was performed with data from HMS, and lateral boundary conditions (LBC) from the ARPEGE model, interpolated over the ALADIN/Hungary domain. The notation is "*3dvar ARP*". This set of experiments was carried out, to see the implications of the simple-nesting, versus double-nesting, on the 3D-Var results.

For the third set, data from Météo-France (which include SYNOP, AIREP, SATOB, TEMP and PILOT observations) have been used in the assimilation cycle, and the operational LBC (from ALADIN/LACE model) for the first-guess and forecast. It was called "*3dvar TLS*". The same variables have been considered from SYNOP and TEMP observations as in the previous experiments, besides, from AIREP, wind and temperature, and from SATOB and PILOT, wind.

In Figure 2 the typical geographical distribution of the data available over the ALADIN/Hungary domain is plotted for 18.07 00 UTC and 06 UTC. Number **1** represents the location of SYNOP observations, **2** for AIREP, **3** for SATOB, **5** for TEMP, and **6** for PILOT data.

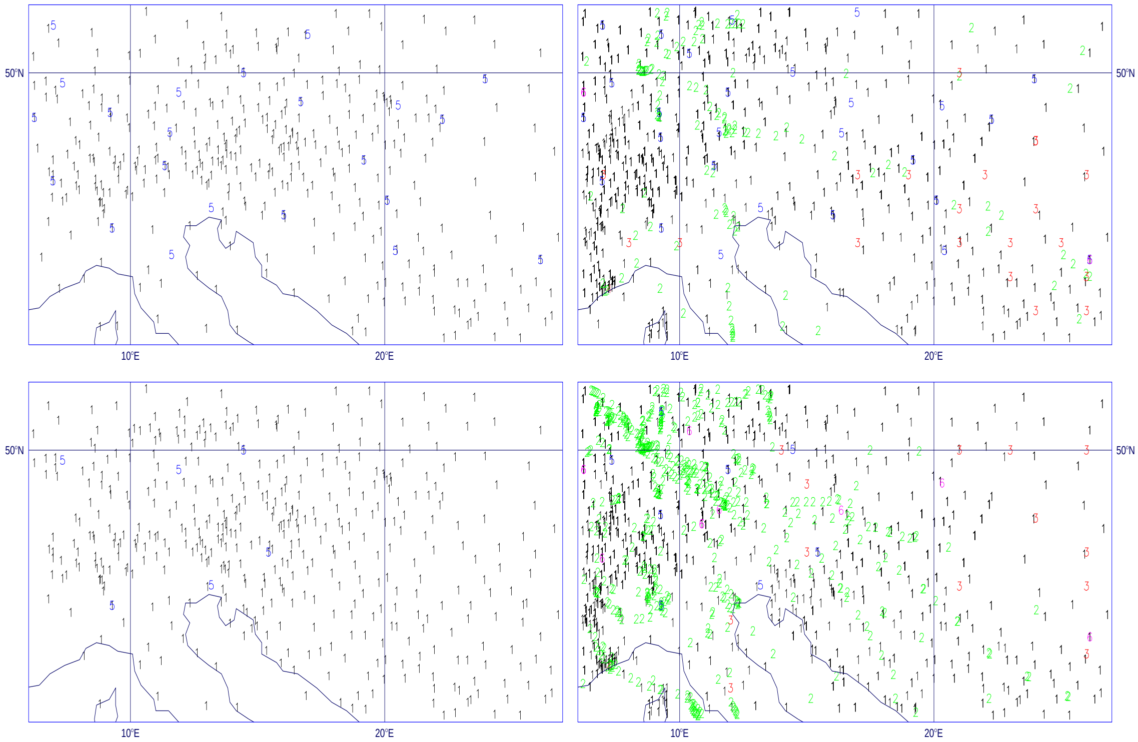

Figure 2: The typical geographical distribution of the available observational data over the ALADIN/Hungary domain from HMS (left) and from MF (right) for 18.07 00 UTC (top) and 18.07 06 UTC (bottom)

As we can see, almost the same TEMP data can be found in the two data sets. Data from HMS have more SYNOP observations over the central part of the domain. For data from Météo-France (MF) one can see numerous AIREP and SYNOP observations, especially in the western part of the domain.

4 Results

In this chapter the results of the 3D-Var experiments are compared to the operational forecast (in dynamical adaptation) of the ALADIN/Hungary model ("*oper*"). Mainly the forecasts of different fields from 17.07. 00 UTC, 12 UTC and 18.07 00 UTC model runs, valid at 18.07 12 UTC are described. Temperature increments of the 3D-Var analysis are studied, and at the end, the impact of different observations over the forecast is described.

4.1 17.07 00 UTC run

For this run, the 36h forecasts of geopotential, temperature, wind, relative humidity at different levels have been compared. The precipitation was cumulated for 24h, between 17.07 06 UTC and 18.07 06 UTC.

The operational forecast from 17.07 00 UTC run shows that the cold air is streaming from north-west in the lower troposphere, bringing some instability in the western part of Hungary (Figure 3, left column).

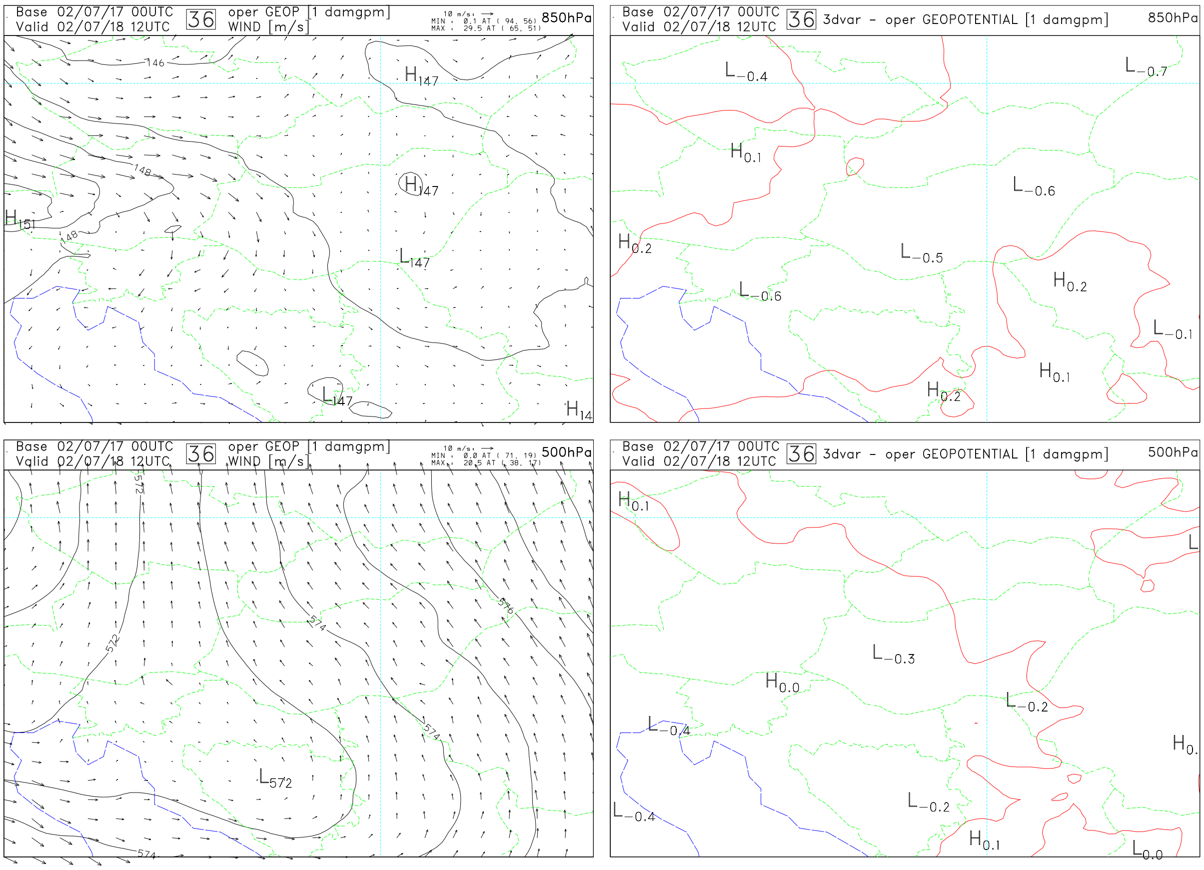

Figure 3: The operational forecast (*oper*) for geopotential and wind (left column) and the differences between the geopotential forecasts of the *3dvar* set and *oper* (right column), from 17.07 00 UTC model run, valid at 18.07 12 UTC, at 850 and 500 hPa

The operational forecast of relative humidity at 700 hPa indicates the availability of moisture at the right place, especially in the western and central parts of the country (Figure 4, top). However the quantity of precipitation cumulated in 24h is not bigger than 6 mm (Figure 5, left-upper panel). Compared to the real measurements (Figure 1, left), we can see that the operational model underestimated the quantity of precipitation.

All three sets of experiments with 3D-Var scheme have a similar forecast to that of the model in dynamical adaptation. The differences between the geopotential forecasts for some upper-levels of the models, with and without data assimilation, are very small (Figures 3, 6).

The relative humidity field indicates that the area of the Danubian Basin is mostly cloudy. However the vertical velocity field does not show any strong motion of the air

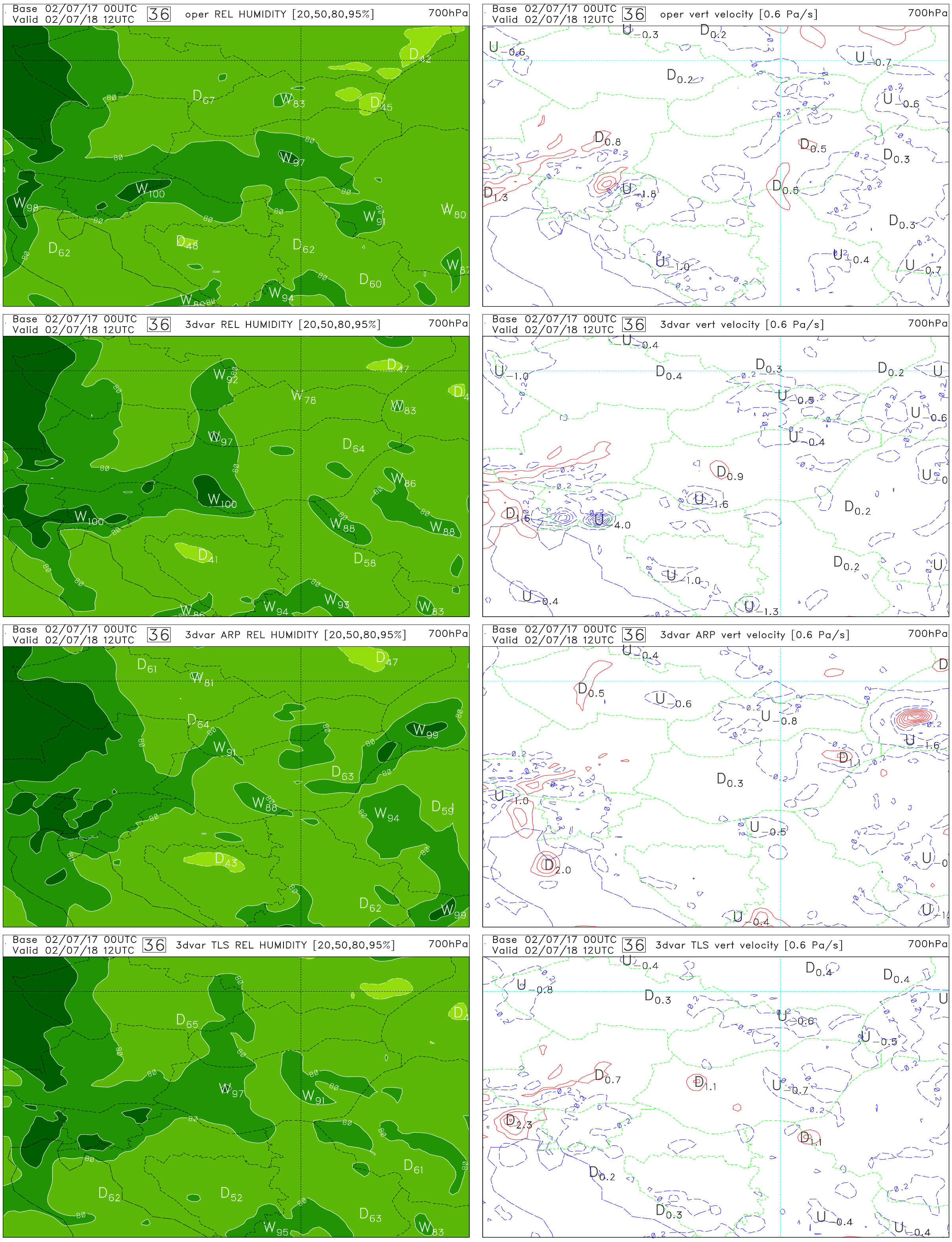

Figure 4: The operational forecast (*oper*) and using 3D-Var scheme with different data and LBC (*3dvar*, *3dvar ARP*, *3dvar TLS*), for relative humidity and vertical velocity at 700 hPa, from 17.07 00 UTC model run, valid at 18.07 12 UTC

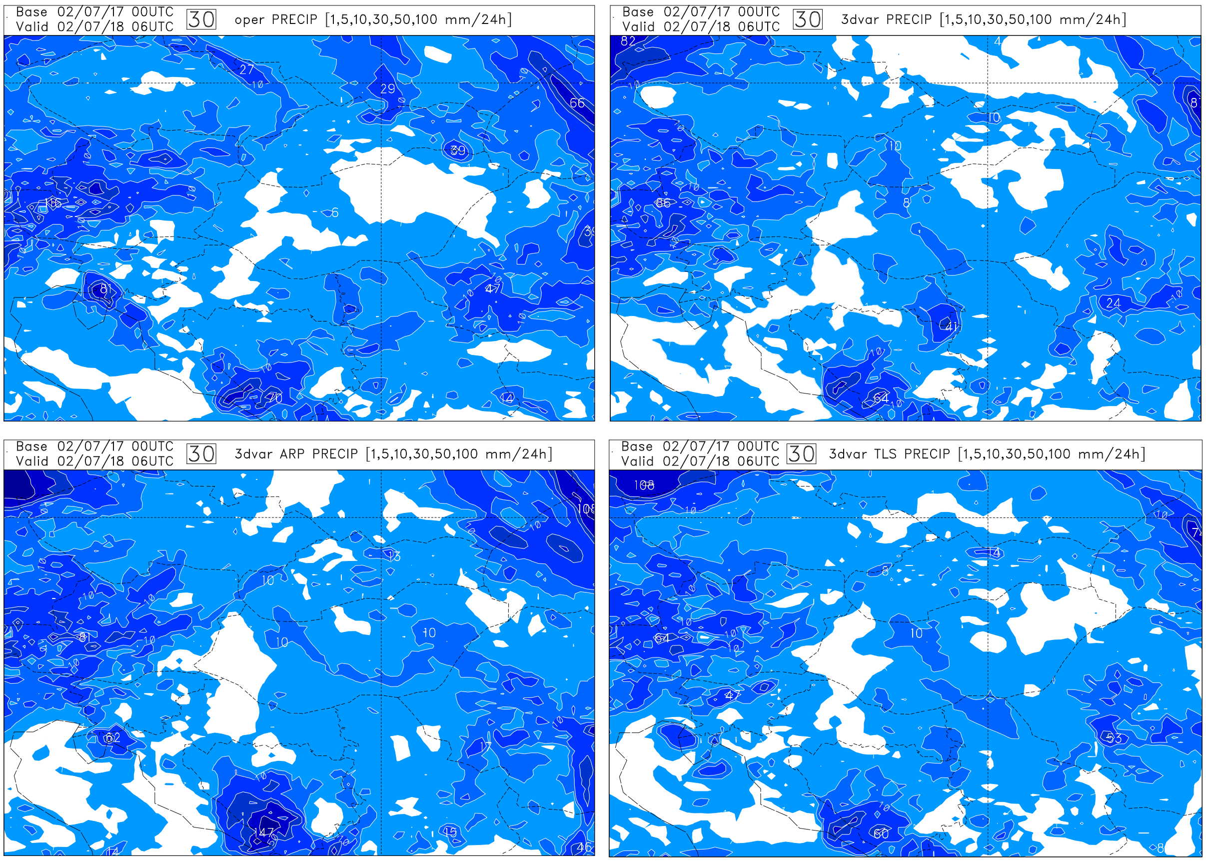

Figure 5: The quantity of precipitation (mm/24h) forecasted by operational model (*oper*) and using 3D-Var scheme with different data and LBC (*3dvar*, *3dvar ARP*, *3dvar TLS*) between 17.07 06 UTC - 18.07 06 UTC, from 17.07 00 UTC model run

masses through the 700 hPa surface (Figure 4). So a heavy rainfall is not likely to occur. The quantity of predicted precipitation is very small (around 10 mm in 24h), but on a larger area than the operational model forecasted (Figure 5).

Comparing the vertical velocity fields from the Figure 4, the downward motion in the eastern part of the domain, when LBC from ARPEGE have been used, looks suspiciously. First it has been tried to see for how long it appears. In the Figure 7, the forecasts valid between 18.07 11UTC - 18.07 14UTC are plotted. And one can see that the downward motion appeared only for two hours. Another idea was that maybe the information is coming through the coupling data, and in this case also the model in dynamical adaptation, using the same LBC as in *3dvar ARP* set, should have the same features. But this is not indicated in the Figure 8 (top). In that area the vertical motion of the air is rather upward. Then an experiment using 3D-Var scheme with LBC from ARPEGE model, but on a bigger domain, has been performed. It can be seen in Figure 8 (bottom) that there is no intensive vertical motion. So this feature appeared at the edge of the domain, because of the coupling, being amplified by the 3D-Var scheme.

In conclusion, the models (in dynamical adaptation or with data assimilation) did not predict the event with more than 24h before. But the 3D-Var scheme gave an indication that rainfall is expected to be occurred over the entire Hungary.

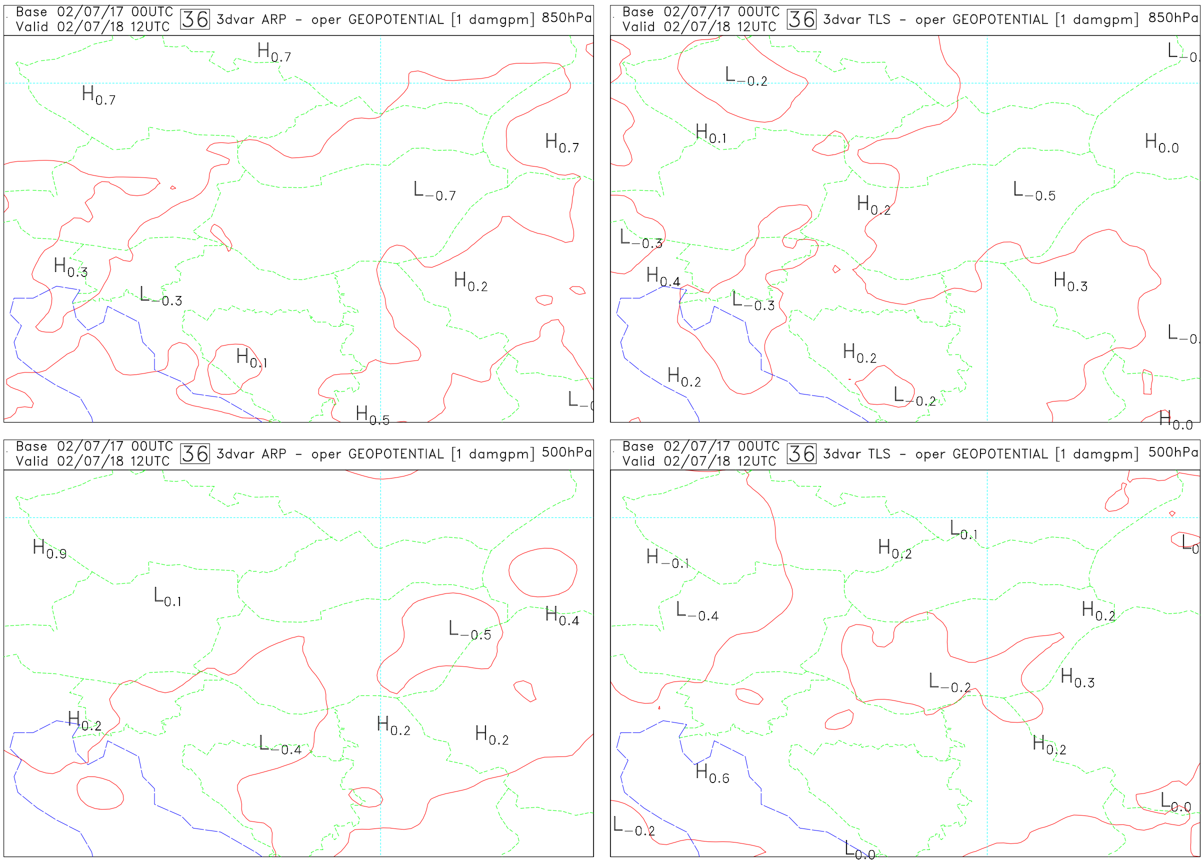

Figure 6: The differences between the geopotential forecasts of the *3dvar ARP* set and *oper* (left column), and of the *3dvar TLS* set and *oper* (right column) from 17.07 00 UTC model run, valid at 18.07 12 UTC, at 850 and 500 hPa

4.2 17.07 12 UTC run

The 24h forecasts of different fields from this run have been plotted, and also the precipitation cumulated for 24 hours, between 18.07 06 UTC and 19.07 06 UTC, which were compared to the measurements valid at the same time (Figure 1, right panel).

The 17.07 12 UTC run of the operational model did not show significant changes in the geopotential forecast, over the Danubian Basin, comparing to 17.07 00 UTC run. The difference is around 1 dampgm (not shown). The direction of the cold air remained north-westerly, the sky was predicted to be partly cloudy and no precipitation to be occurred (Figures 9, 10).

Instead in the eastern part of Hungary, a low geopotential height was forecasted (Figure 9, left column). One can see in that part an intensive vertical motion of the air masses, and the availability of moisture, which indicate a high likelihood of precipitation. Unfortunately, the quantity (around 101 mm in 24h) and also the location of the precipitation were not well predicted, being farther from the place of the event.

The differences between the operational forecast for geopotential, and those using data assimilation, for some upper-levels are plotted in Figures 9, 12, and it can be seen that the values are rather small (not bigger than 1 dampgm).

In the vertical velocity field do not appear big differences between experiments over the

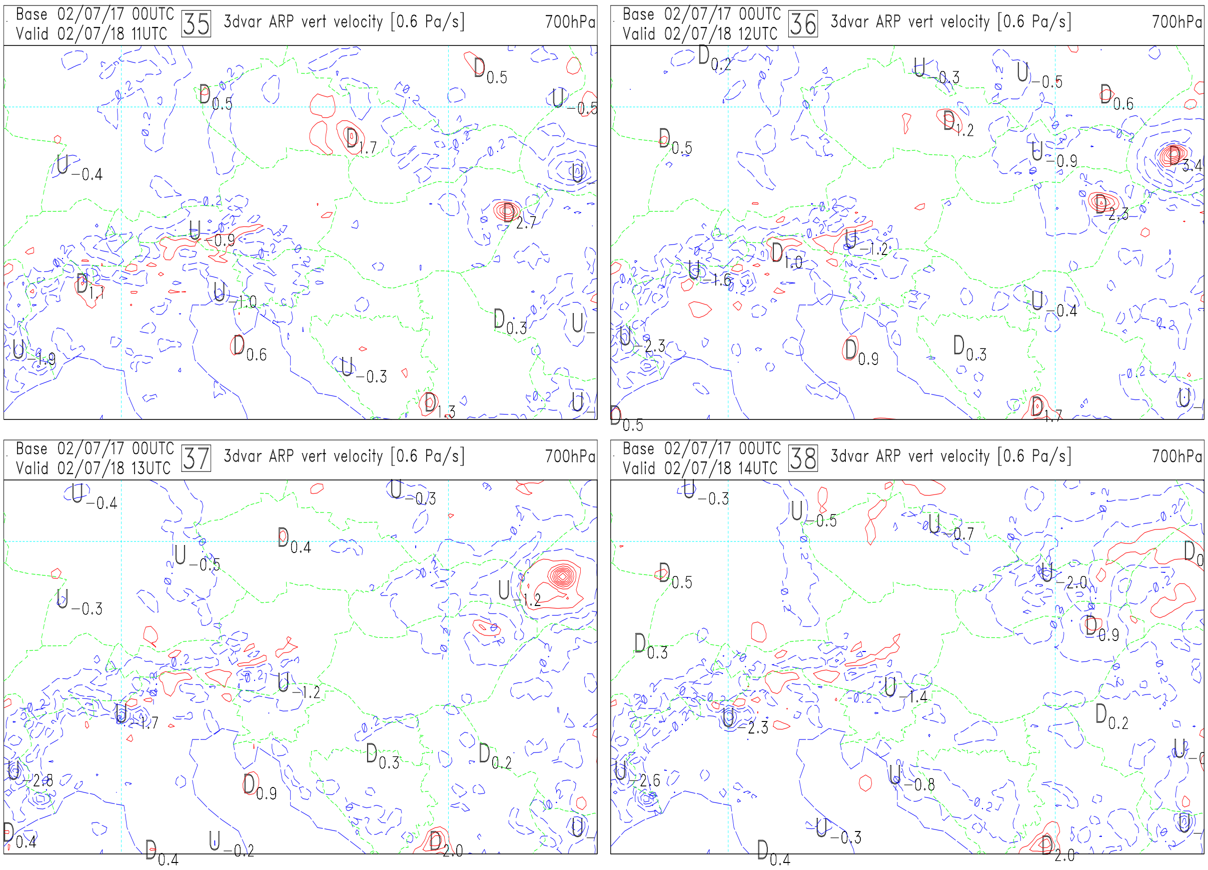

Figure 7: The forecast using 3D-Var scheme with data from HMS and LBC from ARPEGE (*3dvar ARP*), for vertical velocity at 700 hPa, from 17.07 00 UTC model run, valid between 18.07 11UTC - 18.07 14UTC

Danubian Basin. Unlike the operational model, the 3D-Var experiments with data from HMS (*3dvar* and *3dvar ARP* sets) predicted in the right place, high values of relative humidity (Figure 10). This was the main difference, which helped the model with 3D-Var scheme to give a good forecast. Comparing the forecasts of the model using 3D-Var scheme, one can see that the areas of high moisture have almost the same shape, when the observations from HMS were assimilated. The less extended area from the forecast of the *3dvar TLS* experiments is probably due to the smaller number of surface observations available in the data from Météo-France.

The quantity of precipitation using 3D-Var scheme, is important quantitatively (more than 50 mm in 24h), which is much higher than the operational model predicted. The areas of rainfall forecasted by the different versions of the 3D-Var experiments are slightly different. When the LBC are coming from the ALADIN/LACE model (*3dvar* and *3dvar TLS* sets), the location and the maximum values of precipitation are too much to east. The best forecast has been given by the *3dvar ARP* experiments, both as location, and as quantity of precipitation.

An intensive motion of the air masses can be seen east to Hungary, in the forecasts of the operational model, and using 3D-Var scheme with LBC from ALADIN/LACE model (Figure 10, right column). In the *3dvar ARP* experiments, this vertical motion appears in an earlier forecast (not shown). It means that this information is coming from the large

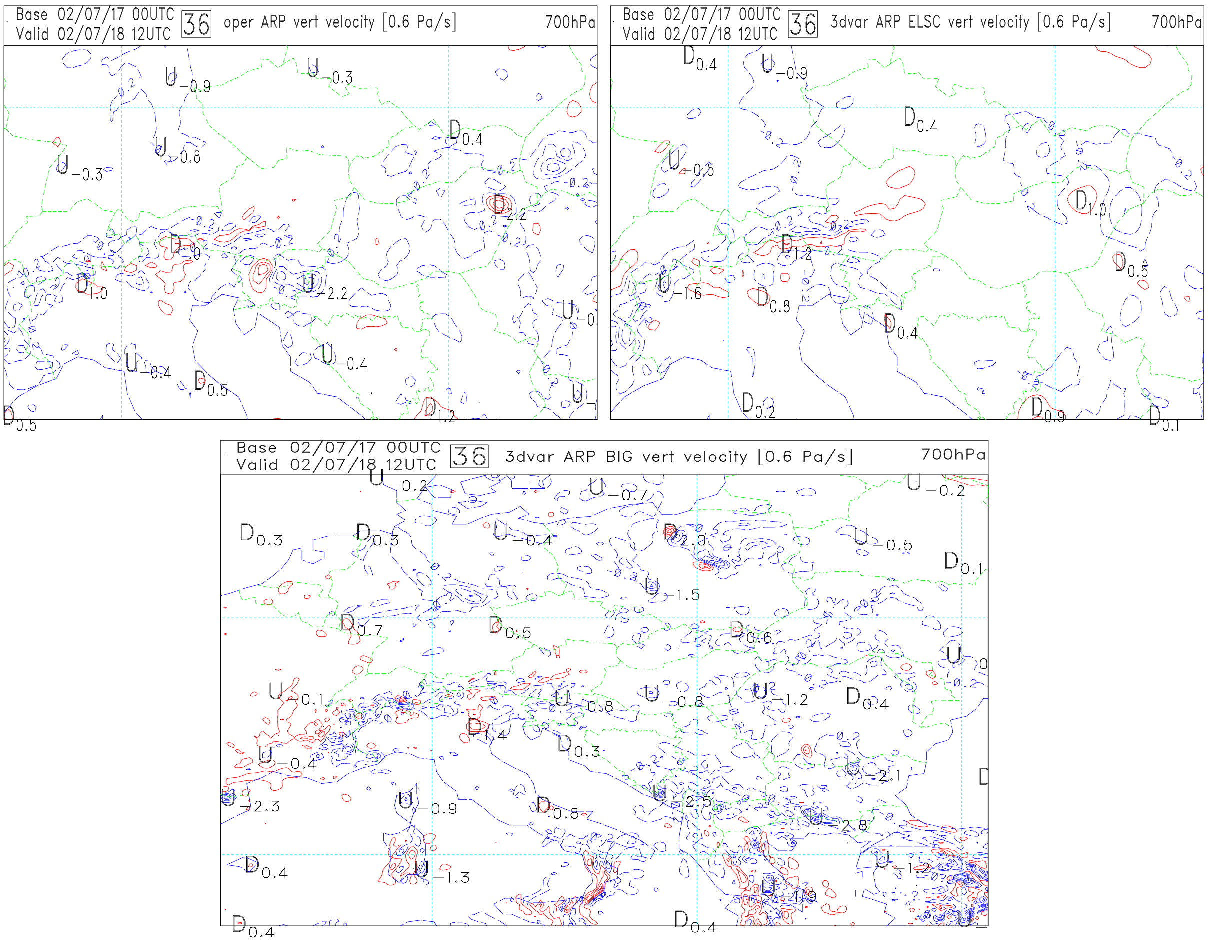

Figure 8: The operational forecast using LBC from ARPEGE (*oper ARP*), the forecast of the LBC from ARPEGE (*3dvar ARP ELSC*) and using 3D-Var scheme with LBC from ARPEGE, but on a bigger domain (*3dvar ARP BIG*), for vertical velocity at 700 hPa, from 17.07 00 UTC model run, valid at 18.07 12 UTC

scale from the ARPEGE model, through the ALADIN/LACE boundary conditions. So after 24h integration, the effect of the observational data assimilated at the beginning of the forecast period start to decrease, and the most important features are coming from the lateral boundary conditions.

The main difference between the two models (in dynamical adaptation and with data assimilation) appeared starting with this run. Comparing the experiments with the 3D-Var scheme, one can say that the closest forecast to reality was that using lateral boundary conditions from ARPEGE model, and data from the Hungarian Meteorological Service. The other two sets of experiments with data assimilation, predicted the area of rainfall too much to east.

4.3 18.07 00 UTC run

This last run is the nearest one to the moment of the real event. The 12h forecasts of the fields are plotted and the precipitation is cumulated between 18.07 06 UTC - 19.07 06 UTC (to be compared to Figure 1, right panel).

The operational model still did not give any sign about the future event. The air is

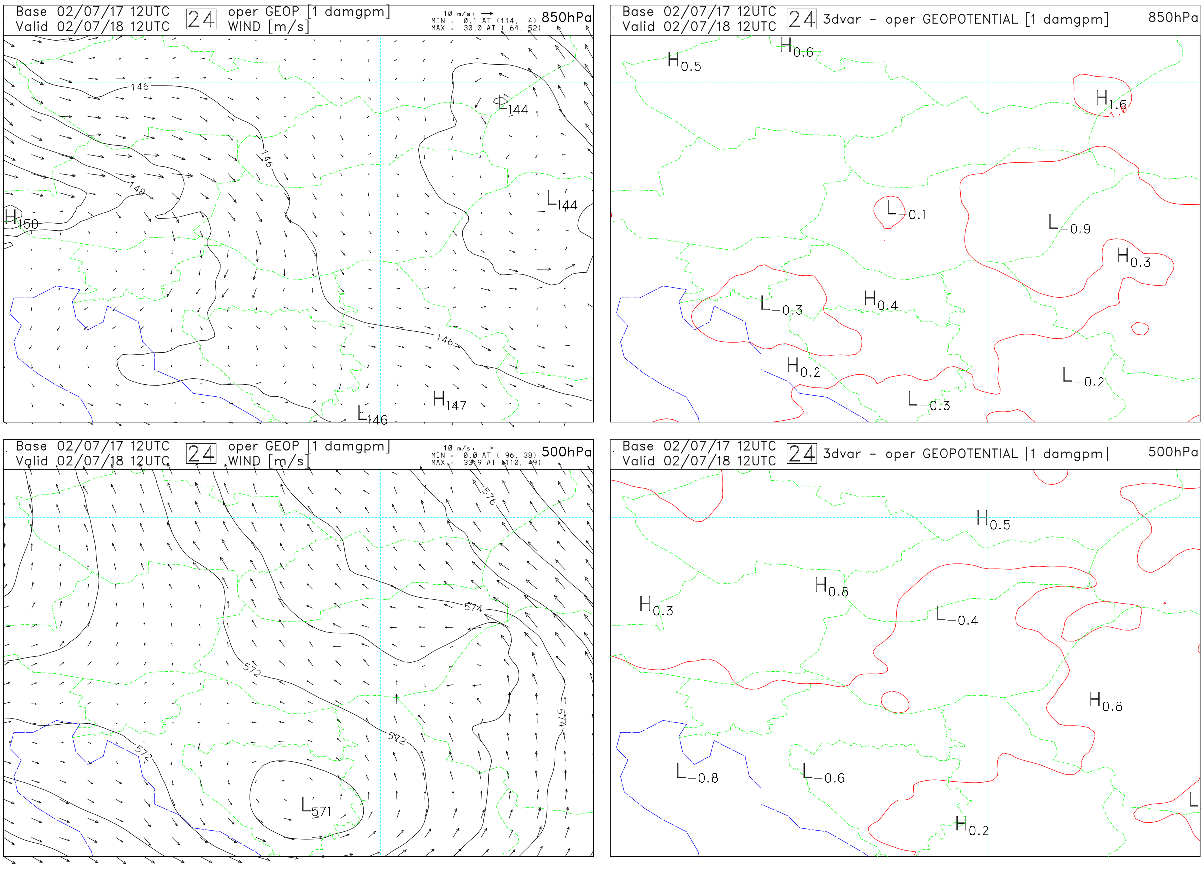

Figure 9: The operational forecast (*oper*) for geopotential and wind (left column) and the differences between the geopotential forecasts of the *3dvar* set and *oper* (right column), from 17.07 12 UTC model run, valid at 18.07 12 UTC, at 850 and 500 hPa

streaming from north-west, bringing cooler air especially in the western part of Hungary (Figure 13, left column).

The forecast of relative humidity at 700 hPa shows that the moisture is available more in south-west, where the air masses have a rising motion (Figure 14). But over the Danubian Basin, no indication of heavy rainfall was given. The quantity of precipitation predicted by the operational model is still very small (less than 5 mm in 24h) (Figure 15).

Comparing the geopotential forecasts of the model with and without data assimilation, one can see the big differences which appeared in the lower half of troposphere (almost 3 damgpm), over Hungary (Figures 13, 16). The positive influence of the observations over the forecast is bigger as the time is nearer to the moment of the event.

The area where the moisture is available covers almost entire country, in the experiments when 3D-Var scheme has been used, with a high likelihood of precipitation in the central part. Also the forecasts of vertical velocity field at 700 hPa show an intensive vertical motion of the air masses (Figure 14). All these fields, together with the forecast of the low geopotential height gave an indication of the heavy rainfall to be occurred over the central part of Hungary.

The precipitation forecast of *3dvar* experiments has a good location generally, but too much extended to south (area with more than 50 mm in 24h). The quantity of rainfall

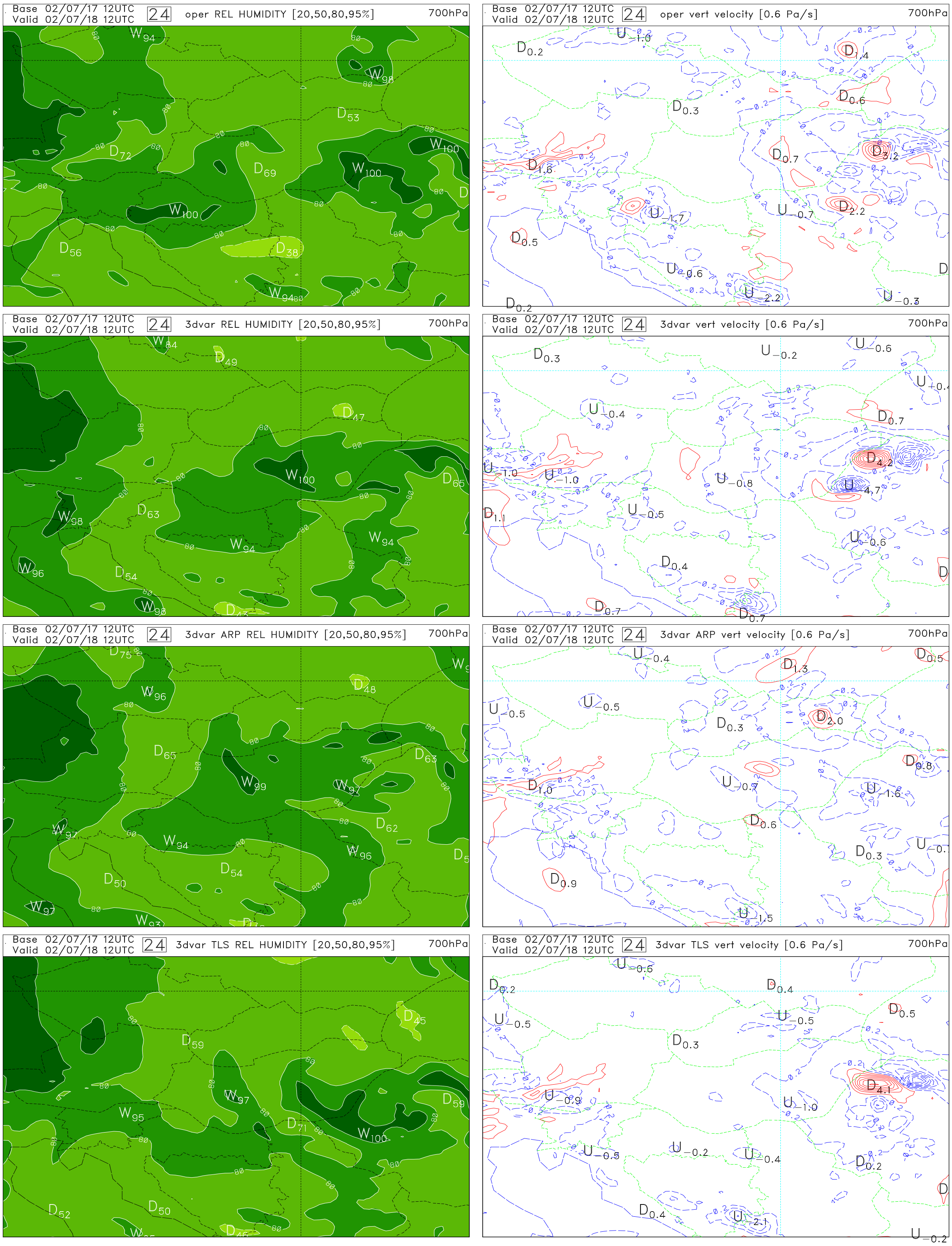

Figure 10: The operational forecast (*oper*) and using 3D-Var scheme with different data and LBC (*3dvar*, *3dvar ARP*, *3dvar TLS*), for relative humidity and vertical velocity at 700 hPa, from 17.07 12 UTC model run, valid at 18.07 12 UTC

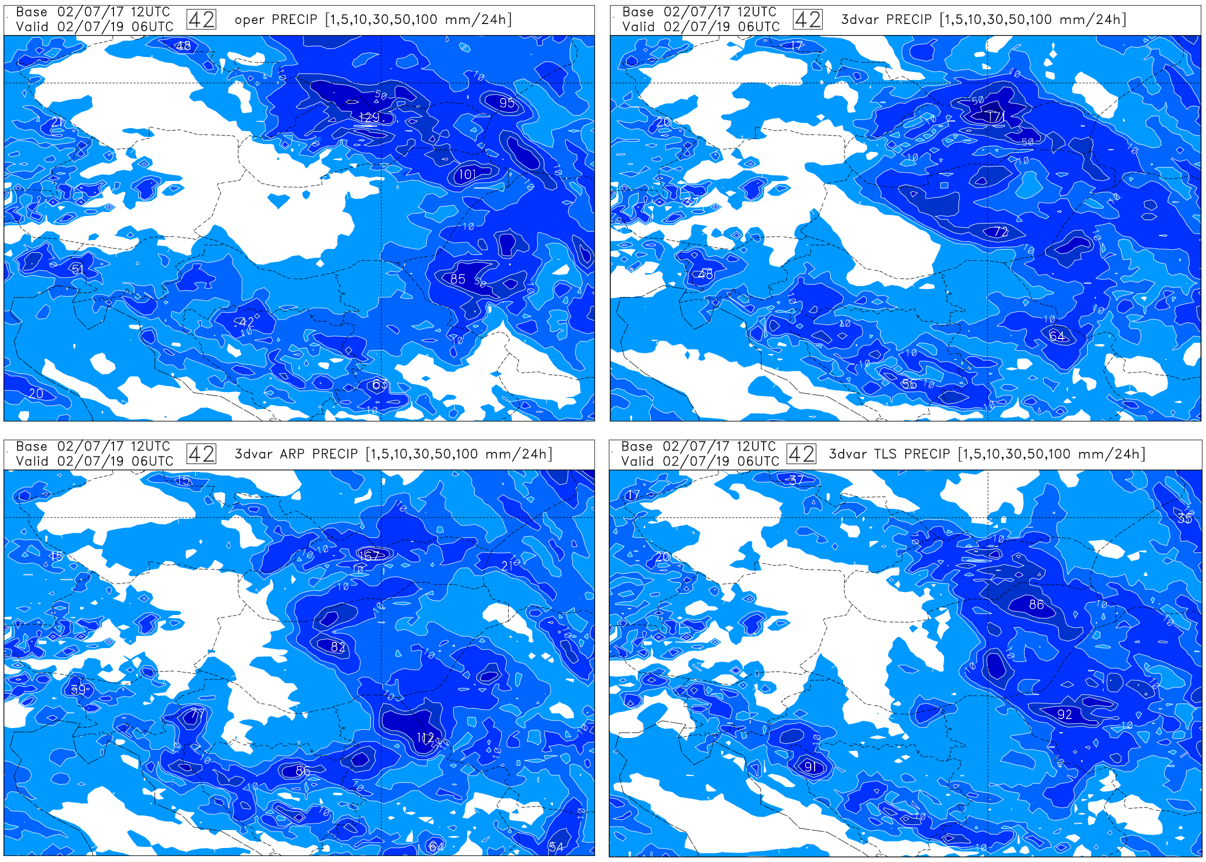

Figure 11: The quantity of precipitation (mm/24h) forecasted by operational model (*oper*) and using 3D-Var scheme with different data and LBC (*3dvar*, *3dvar ARP*, *3dvar TLS*) between 18.07 06 UTC - 19.07 06 UTC, from 17.07 12 UTC model run

(almost 170 mm) is twice bigger than in reality. The model with 3D-Var scheme and LBC from ARPEGE (*3dvar ARP*), predicted two small areas with more than 100 mm, and a good location of large precipitation. Indeed the maximum value of measured rainfall was about 73 mm in 24h, but we can consider that the predicted quantity is acceptable in reasonable limits (Figure 15). Also the *3dvar TLS* experiments had a good forecast of the precipitation. The quantity of rainfall is closer to the real measurements (around 72 mm in 24h over the Danubian Basin), and the location is good predicted.

Probably the good forecast given by the *3dvar ARP* set is due to the observations and moreover to the information from the ARPEGE model. In the *3dvar TLS* experiments, the bigger influence came from the observations (especially AIREP, SATOB), as they have been nearer to the moment of the event.

In Figure 17 the divergence at different upper-levels from the *3dvar ARP* experiments is plotted. One can see the strong divergence at 300 hPa located in the central part of Hungary. In this area the vertical velocity at 700 hPa is around -5.2 hPa/s, and also the moisture is available (Figure 14). Usually, strong divergence at upper-levels, associated with large areas of rising air in the middle troposphere, indicate heavy rainfall.

As a conclusion from this run, it can be said that the operational model, even with 6 hours before the event, was not able to predict any features of the phenomenon. All experiments with data assimilation forecasted large quantities of precipitation. Among

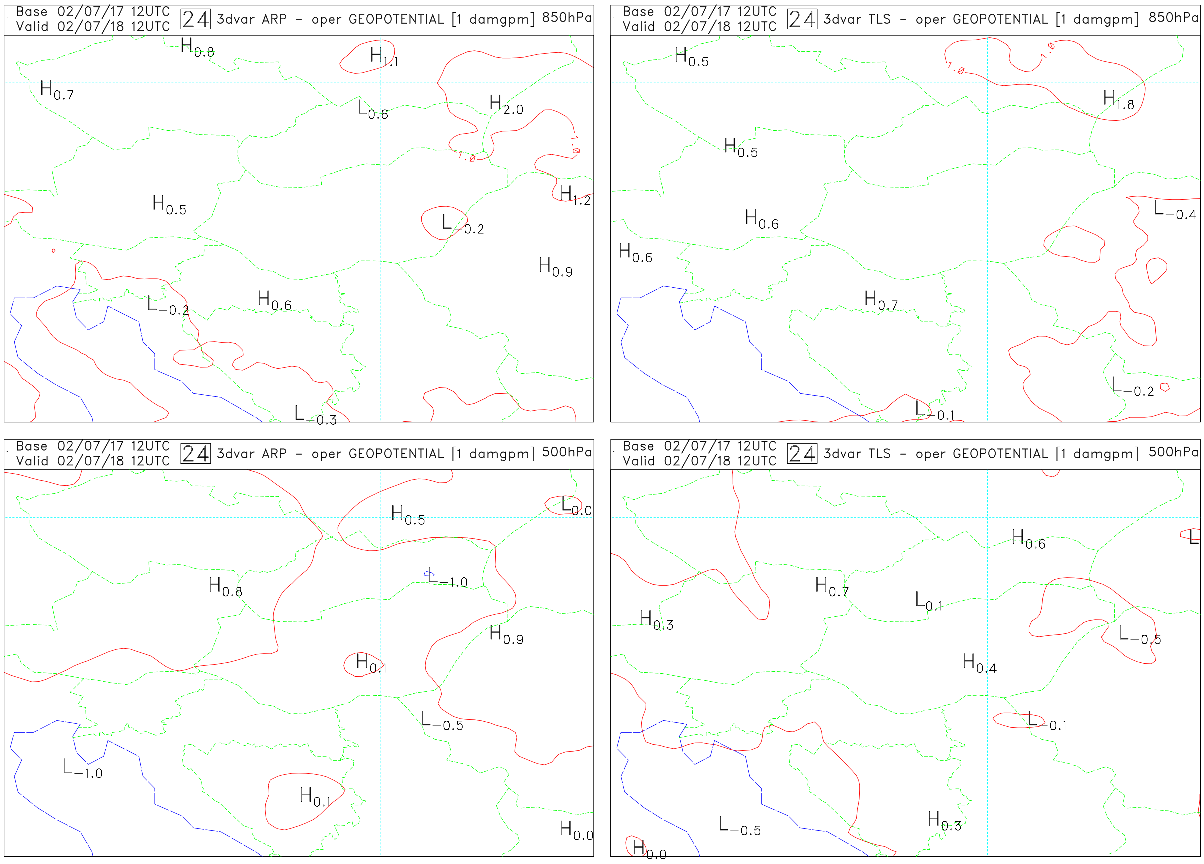

Figure 12: The differences between the geopotential forecasts of the *3dvar ARP* set and *oper* (left column), and of the *3dvar TLS* set and *oper* (right column) from 17.07 12 UTC model run, valid at 18.07 12 UTC, at 850 and 500 hPa

these, the *3dvar ARP* and *3dvar TLS* sets have been the closest ones to reality.

4.4 Maps of increments

For all 3D-Var experiments maps with the temperature increments (3D-Var analysis - first guess) have been plotted on two model levels: 18 (around 500 hPa) and 28 (around 850 hPa) over the entire domain of ALADIN/Hungary, including also the extension zone (Figure 18).

Comparing the temperature increments of the experiments using the same data (from HMS) and different LBC (*3dvar* and *3dvar ARP*), on the model level 24, the features are almost the same, but smaller values are for *3dvar*, which means that the background was closer to observations. The effect of observations near Hungary is coming from Brno, Szeged and Vienna stations. The features have remained similarly, when different observational data have been used, and the same LBC (*3dvar* and *3dvar TLS*), especially in the northern part of the domain. The differences in the southern part are probably due to the AIREP observations.

On the model level 15, smaller values of the temperature increments can be seen for *3dvar* experiments. The main difference appears in the north-east corner of the domain. Using LBC from ALADIN/LACE, the information from the background was far from

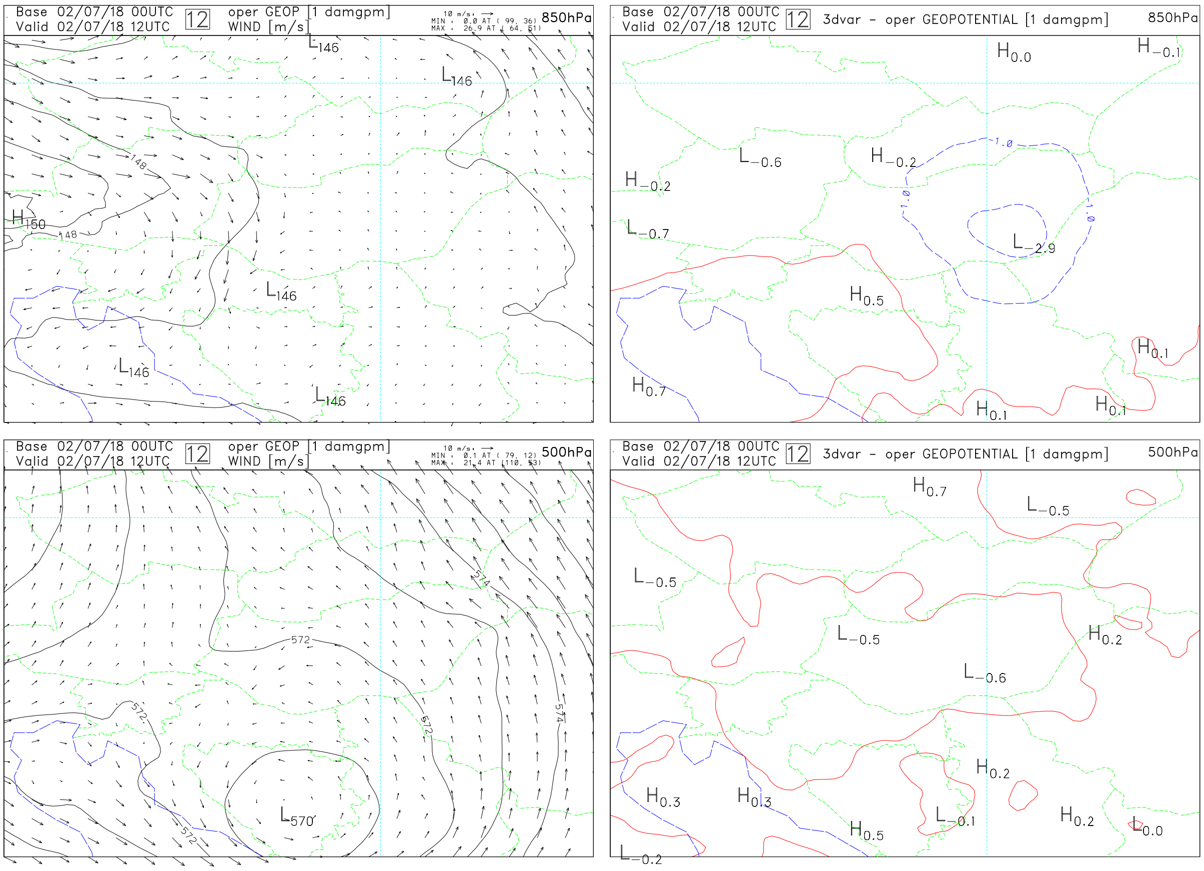

Figure 13: The operational forecast (*oper*) for geopotential and wind (left column) and the differences between the geopotential forecasts of the *3dvar* set and *oper* (right column), from 18.07 00 UTC model run, valid at 18.07 12 UTC, at 850 and 500 hPa

observations, while the model using ARPEGE LBC has been able to fit the first-guess very close to observations. But this difference do not appear on the model level 24.

The most worrying feature of the increments is that they are looking bi-periodic near the boundaries of the domain. For the future, we have to find out a solution for this problem, because some spurious features could appear near the lateral boundaries.

4.5 The impact of observations over forecast

Working at this case study, we tried to understand how the observations used, influenced the quantity and the location of precipitation. So some experiments were carried out, similar to the *3dvar* set, except that only SYNOP or TEMP observations available at HMS have been used, all along the assimilation cycle. The new sets of experiments are called "*3dvar SYNOP*" and "*3dvar TEMP*". Then the closest TEMP stations to Hungary have been removed, and the name of this set is "*3dvar TEMP test*". For another set of experiments, the observations between $10^\circ - 26^\circ$ longitude have not been used, remaining around 5-6 stations in the western part of the domain ("*3dvar TEMP test2*"). And the last experiment has been performed using only one station (Milan) in the assimilation cycle ("*3dvar TEMP test3*"). Figure 20 show the precipitation cumulated in 24h (between 18.07 06 UTC - 19.07 06 UTC) from the experiments described above, from 18.07 00

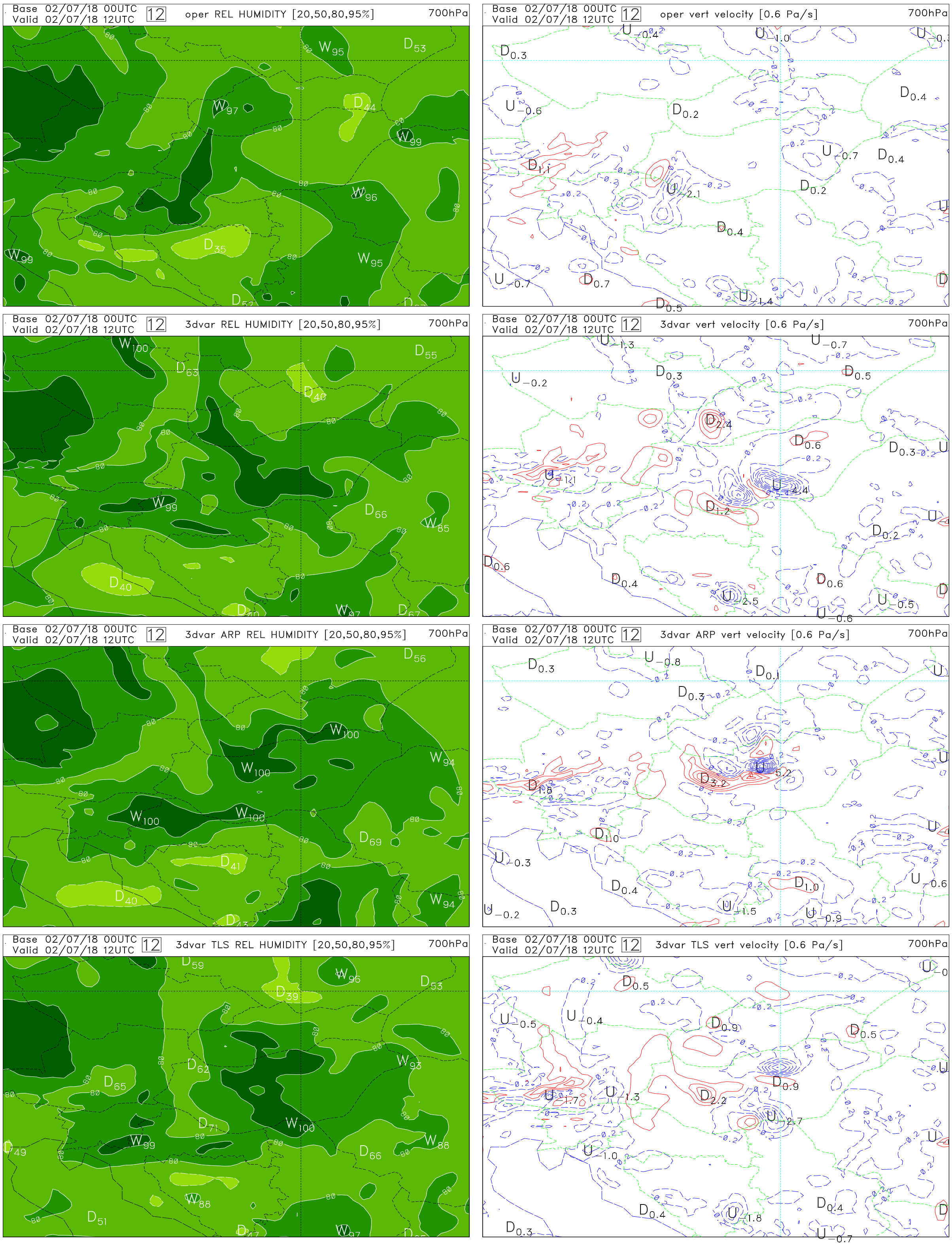

Figure 14: The operational forecast (*oper*) and using 3D-Var scheme with different data and LBC files (*3dvar*, *3dvar ARP*, *3dvar TLS*), for relative humidity and vertical velocity at 700 hPa, from 18.07 00 UTC model run, valid at 18.07 12 UTC

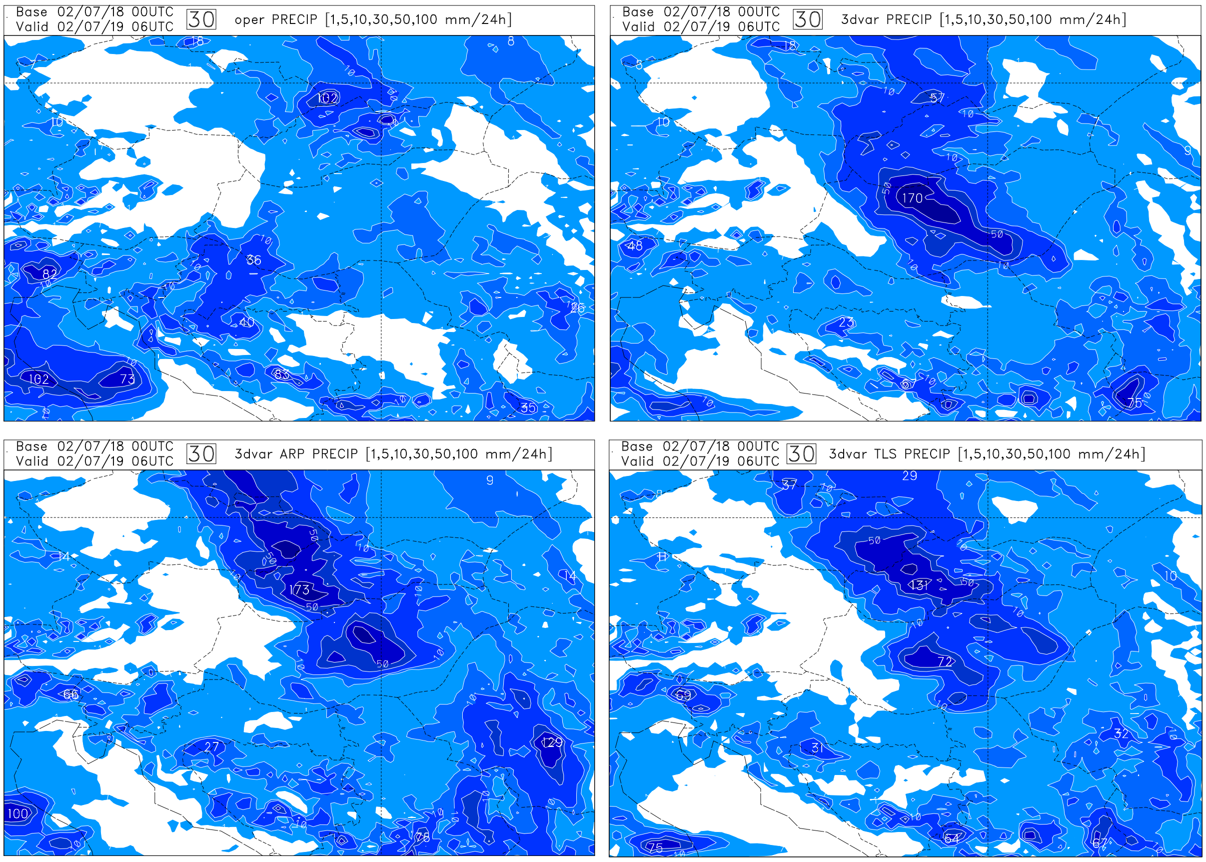

Figure 15: The quantity of precipitation (mm/24h) forecasted by operational model (*oper*) and using 3D-Var scheme with different data and LBC (*3dvar*, *3dvar ARP*, *3dvar TLS*) between 18.07 06 UTC - 19.07 06 UTC, from 18.07 00 UTC model run

UTC model run. The picture of precipitation forecast from *3dvar* experiments is plotted as reference.

Over the Danubian Basin, the moisture is available for the experiments performed with all SYNOP or TEMP observations. In the central part of Hungary also the ascent of air masses through the 700 hPa surface is predicted, which give a clue for heavy rainfall to be occurred (Figure 19).

It can be seen that the location of the maximum precipitation is related to the area of intensive motion, when the moisture is available (Figure 20). Compared to real measurements, the precipitation forecast of the *3dvar SYNOP* experiments has reasonable values (more than 50 mm in 24h). But these areas with heavy rainfall appeared in the north and in the south, which was not in reality. In the previous model run (from 17.07 12 UTC), the quantity of rainfall using only SYNOP observations has been overestimated, and also the location was much in the south. Using only TEMP data, the quantity of precipitation has good values and moreover the location is well predicted, which means that the measurements about the vertical structure of the atmosphere are important. But in these experiments, another maximum (around 108 mm in 24h) was forecasted in the south-eastern part of Hungary, which was not in reality.

Decreasing the number of TEMP observations near Hungary, the forecasts show the sky mostly cloudy, a weak motion of the air through 700 hPa surface, so a small probability

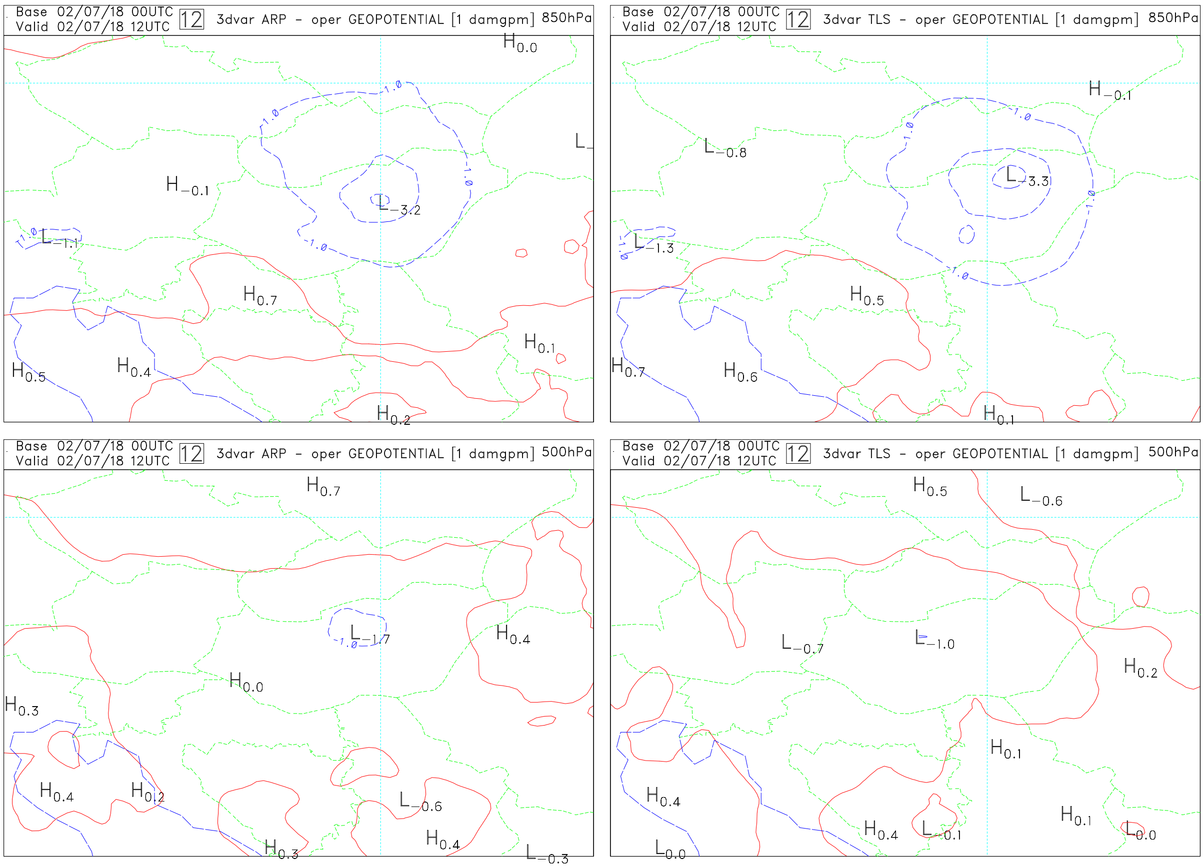

Figure 16: The differences between the geopotential forecasts of the *3dvar ARP* set and *oper* (left column), and of the *3dvar TLS* set and *oper* (right column) from 18.07 00 UTC model run, valid at 18.07 12 UTC, at 850 and 500 hPa

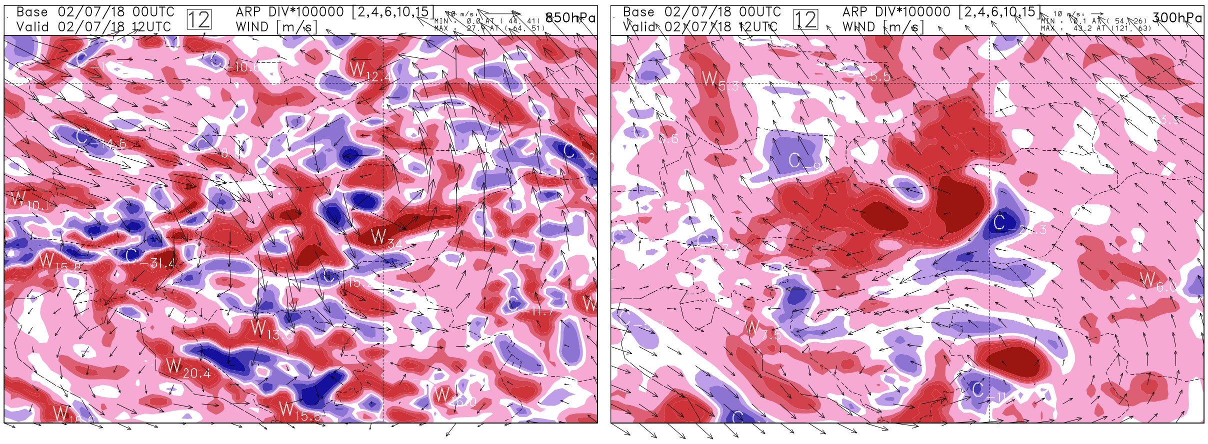

Figure 17: The forecast using 3D-Var scheme, with data available at HMS and ARPEGE LBC (*ARP*), for divergence and wind at 850 (left) and 300 hPa (right) from 18.07 00 UTC model run, valid at 18.07 12 UTC

of rainfall over the Danubian Basin (Figure 21). The areas of heavy precipitation started to decrease and to move more to east. The *3dvar TEMP test3* predicted a huge quantity of precipitation in the south-east. So the results of the model with data assimilation became

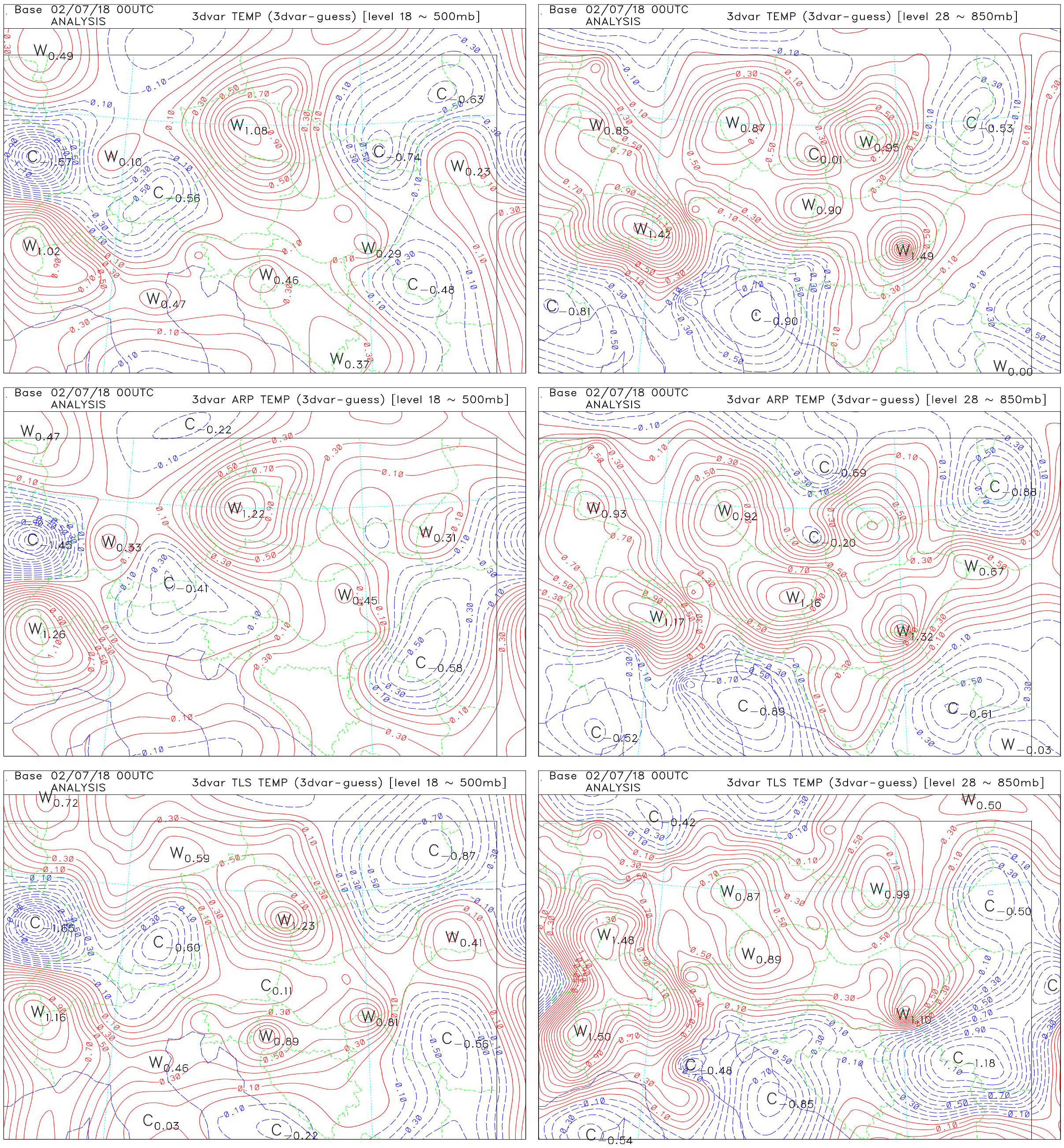

Figure 18: The temperature increments on the model levels 18 and 28 for the 3D-Var experiments with different data and LBC (*3dvar*, *3dvar ARP*, *3dvar TLS*), from 18.07 00 UTC model run

more and more unrealistic, as less observations near Hungary have been used.

The temperature increments (3D-Var analysis - first guess) from *3dvar TEMP test2* and *3dvar TEMP test3* experiments, on the model levels 18 and 28 from 18.07 00 UTC run, have been plotted in Figure 22. Again the increments look bi-periodic. Even when only the stations located west to 10° longitude have been used, the increments influenced the fields on the other side of the domain, especially at the middle troposphere. The area of influence of the single observation seems to appear also in the eastern part of the domain, but it is not very big, the station being not located near the lateral boundary. So

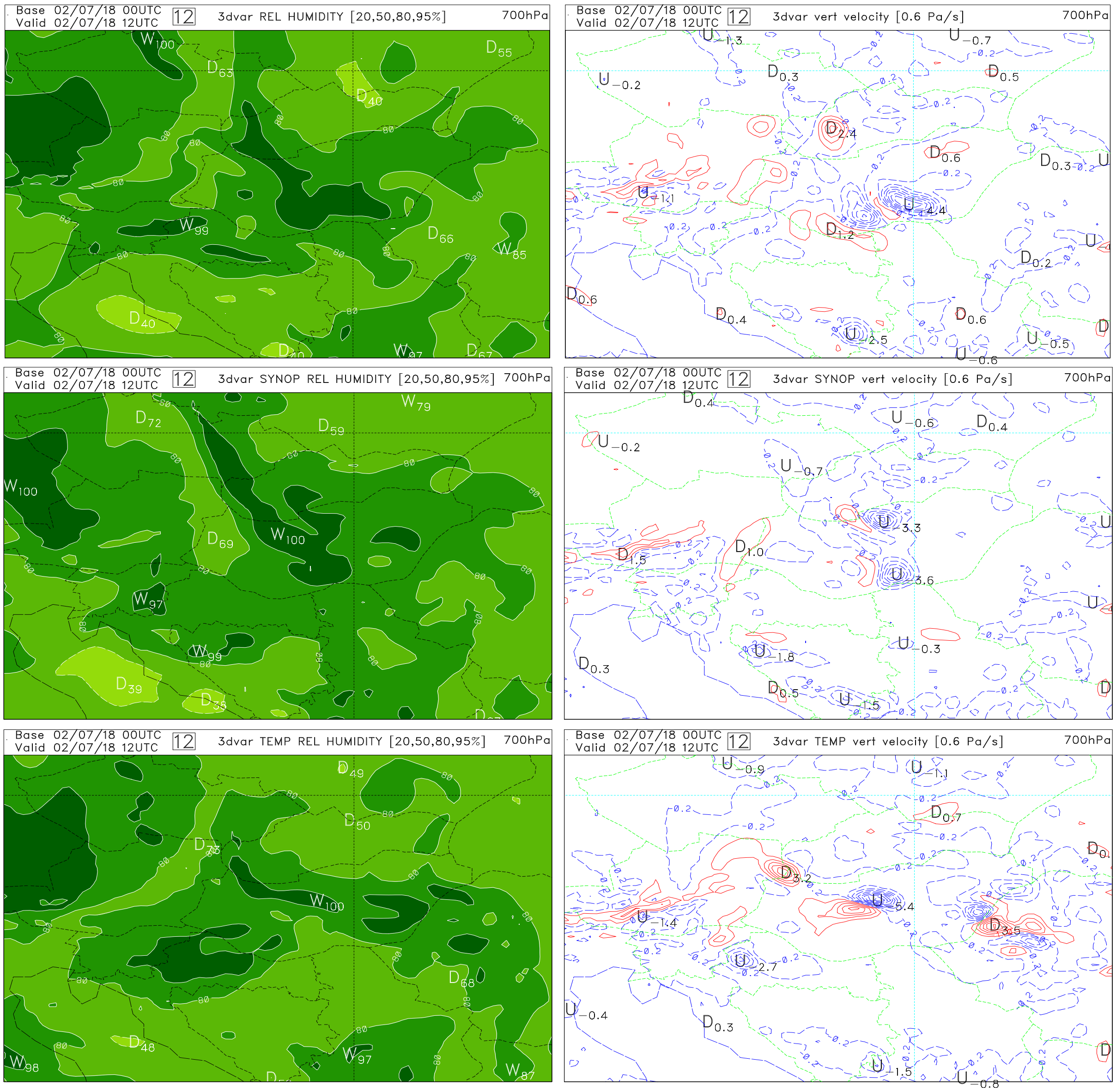

Figure 19: The forecast using 3D-Var scheme with all data (*3dvar*), only SYNOP (*3dvar SYNOP*), only TEMP (*3dvar TEMP*) for relative humidity and vertical velocity at 700 hPa, from 18.07 00 UTC model run, valid at 18.07 12 UTC

in principle, excluding data near the boundaries, these spurious effects can be avoided.

These experiments showed that using only SYNOP data, the precipitation forecast and the location are not well predicted. Compared to *3dvar* results, the experiments when TEMP observations have been assimilated, gave a better location of precipitation and with reasonable quantities over the Danubian Basin. But also some maximums appeared in the south-eastern part of Hungary, with very big values. So the most important features for the forecast are coming from the upper-air observations. As less and less data near Hungary have been used the maximum of precipitation is decreasing gradually and it is moving to east. So generally it cannot be said that only one type of observations, or only some data are responsible for the precipitation forecast. Most probably, the event had occured due

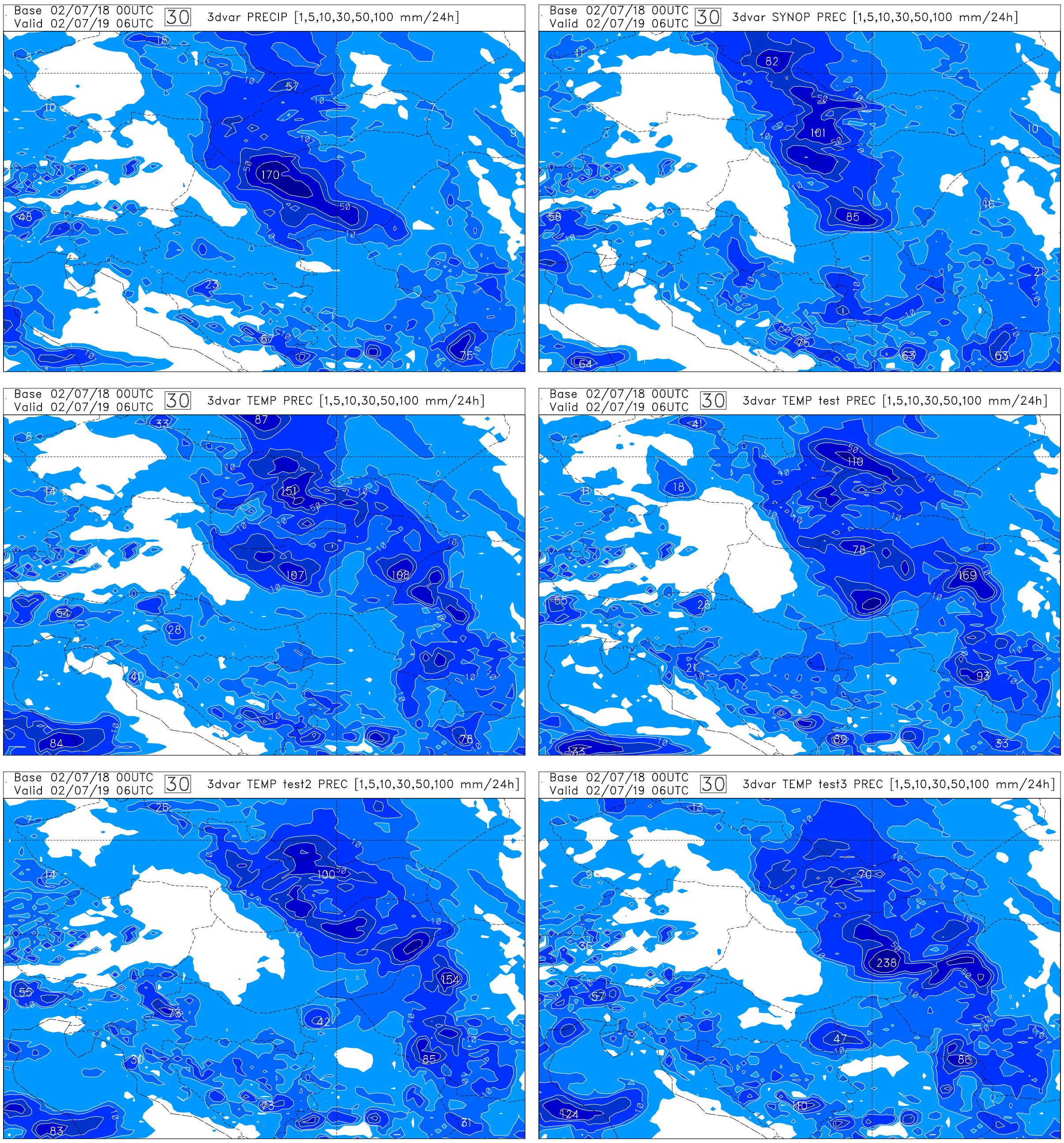

Figure 20: The quantity of precipitation (mm/24h) forecasted by the model using 3D-Var scheme with all data (*3dvar*), all SYNOP (*3dvar SYNOP*), all TEMP (*3dvar TEMP*) and less and less TEMP data (*3dvar TEMP test*, *3dvar TEMP test2*, *3dvar TEMP test3*) between 18.07 06 UTC - 19.07 06 UTC, from 18.07 00 UTC model run

to a special interaction between surface and upper-air atmospheric caracteristics.

The temperature increments from the experiments with observations near the lateral boundaries look bi-periodic, influencing the fields on the opposite part of the domain.

These experiments performed only with SYNOP or TEMP data confirm that for this case it is important to use together observations from surface and upper-air, and the location of the data to be as close as possible to the area of interest.

Another set of experiments which has been performed, was similar to the *3dvar* set,

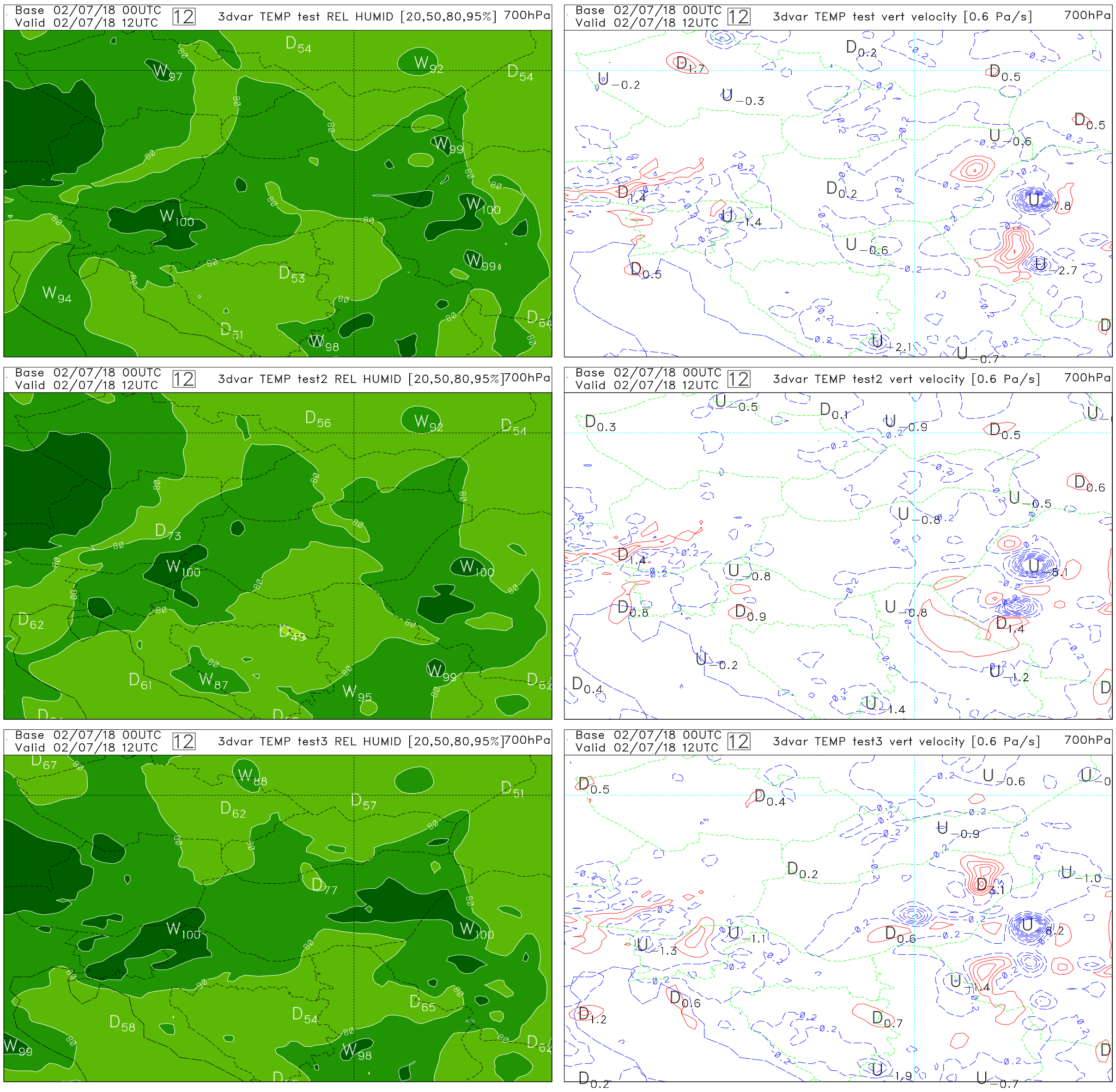

Figure 21: The forecast using 3D-Var scheme with ALADIN/LACE LBC and less and less TEMP data (*3dvar TEMP test*, *3dvar TEMP test2*, *3dvar TEMP test3*) for relative humidity and vertical velocity at 700 hPa, from 18.07 00 UTC model run, valid at 18.07 12 UTC

with LBC from ALADIN/LACE model and data from HMS, keeping the same variables from TEMP, but using different observed variables from SYNOP. So in turn, geopotential, temperature and relative humidity (*3dvar (Z,T,RH)*) have been assimilated from the surface observations, then geopotential and temperature (*3dvar (Z,T)*), only temperature (*3dvar (T)*), and finally only geopotential (*3dvar (Z)*). One can see in Figure 23 that the quantity and the distribution of the precipitation have been changed. It appears that for this case the geopotential measurements had a bigger influence on the rainfall forecast in the northern part of the country (Figure 23, right column), and the temperature, in the southern part. Figure 24 shows the precipitation cumulated in 24h from the *3dvar ARP* and *3dvar TLS* experiments, when from the SYNOP observations, only geopotential has

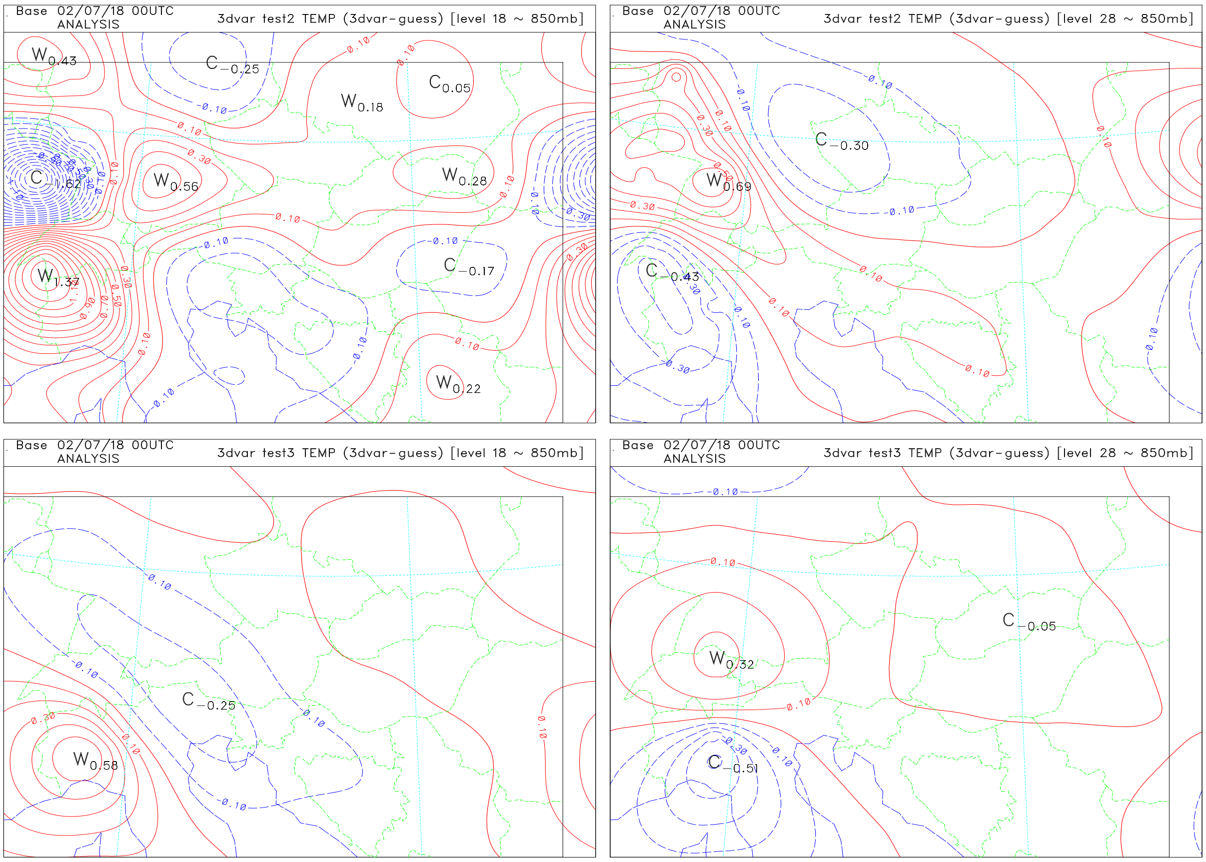

Figure 22: The temperature increments on the model levels 18 and 28, for the *3dvar TEMP test2* (top) and *3dvar TEMP test3* (bottom) experiments, from 18.07 00 UTC model run

been considered. Both sets predicted high values of rainfall too much in the north. The forecast from these experiments has not been improved, but still it is better than the one of the model in dynamical adaptation.

5 Conclusions

A case from the 17-18th of July 2002 has been studied in this report. The operational model (in dynamical adaptation) did not forecast the heavy rainfall which happened over the Danubian Basin. It has been tried to see how the assimilation of observations can change the actual forecast. For these experiments two different sets of data (from Hungarian Meteorological Service and Météo-France) have been used, and different lateral boundary conditions (from ARPEGE and ALADIN/LACE models).

The operational model was the reference for the new experiments. Three main runs have been compared, from 17.07 00 UTC and 12 UTC, and 18.07 00 UTC.

The 17.07 00 UTC runs did not show any indication about the large quantity of precipitation to be occurred. All experiments gave around 10 mm in 24h, which is a strong underestimation, compared to real values as 51 mm, or 42 mm. The difference is that the 3D-Var experiments predicted small precipitation, but over a larger area than the operational model, covering almost entire Hungary.

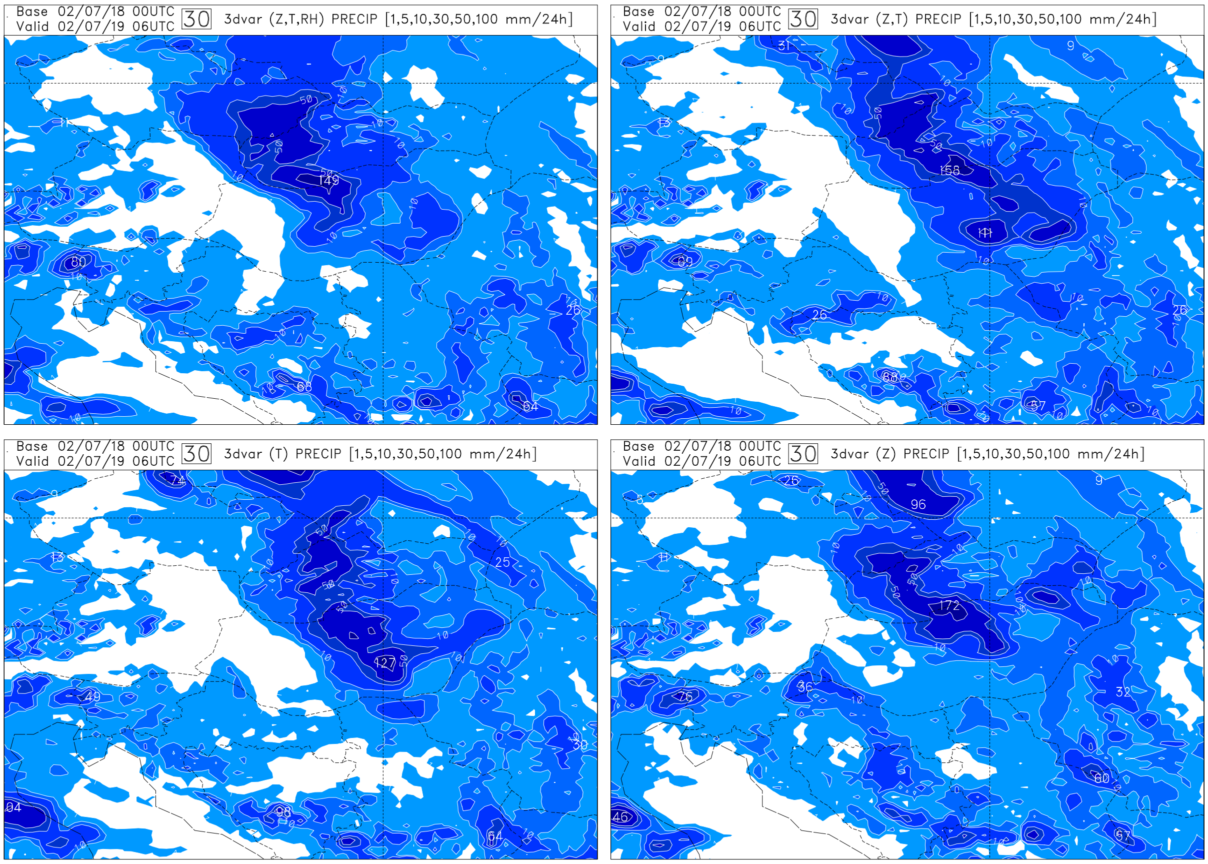

Figure 23: The quantity of precipitation (mm/24h) forecasted by the model using 3D-Var scheme with all data but different observed variables from SYNOP (*3dvar (T,Z,RH)*, *3dvar (T,Z)*, *3dvar (T)* and *3dvar (Z)*), between 18.07 06 UTC - 19.07 06 UTC, from 18.07 00 UTC model run

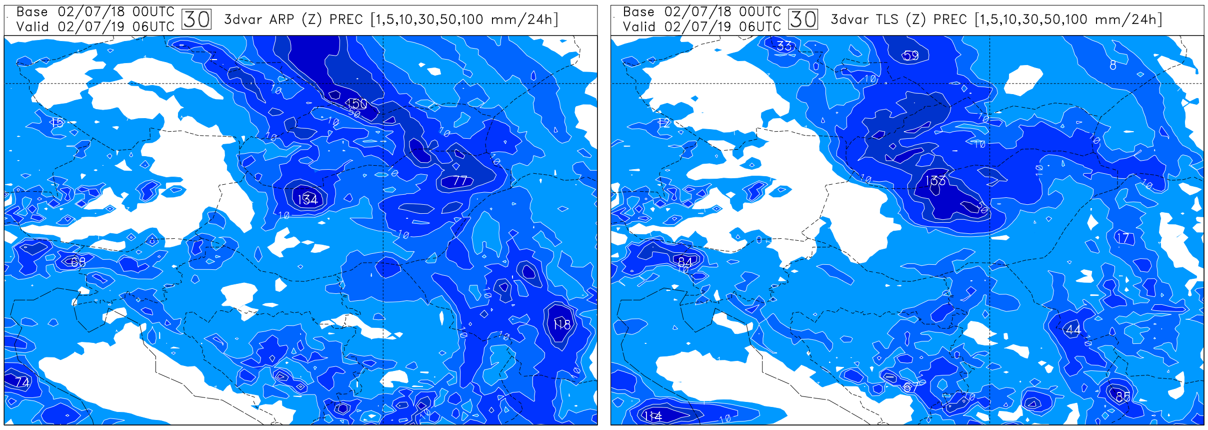

Figure 24: The quantity of precipitation (mm/24h) forecasted by the model using 3D-Var scheme with data from HMS and ARPEGE LBC (*3dvar ARP (Z)*), data from MF and ALADIN/LACE LBC (*3dvar TLS (Z)*) with geopotential from SYNOP observations, between 18.07 06 UTC - 19.07 06 UTC, from 18.07 00 UTC model run

The operational forecast from 17.07 12 UTC run did not predict any precipitation over the Danubian Basin. All three sets of experiments with 3D-Var data assimilation scheme forecasted heavy rainfall in the central part of Hungary. The best location and quantity were given by the *3dvar ARP* set, with lateral boundary conditions from ARPEGE, and data from Hungarian Meteorological Service. The other two sets of experiments with data assimilation, predicted the area of rainfall too much to east. This run showed the first indication about the future occurrence.

The experiments with 3D-Var scheme from 18.07 00 UTC run gave a good forecast of the event, compared to the operational model. When lateral boundary conditions from ALADIN/LACE model and data from the Hungarian Meteorological Service have been used (*3dvar*), the quantity of precipitation seems to be overestimated (with maximum value as 170 mm in 24h). A better forecast of the rainfall was performed by the model with 3D-Var scheme using lateral boundary conditions from ARPEGE and observational data from HMS (*3dvar ARP*), respectively with LBC from ALADIN/LACE and data from Météo-France (*3dvar TLS*). The quantity of rainfall is closer to the real measurements (bigger than 50 mm in 24h over the Danubian Basin), and the location is good predicted. Probably the good forecast given by the *3dvar ARP* set is due to the observations and moreover to the information from the ARPEGE model. In the *3dvar TLS* experiments, the bigger influence came from the observations (especially AIREP, SATOB), as they have been nearer to the moment of the event. From the point of view of the forecasters, this run would not help them to elaborate a new forecast, because the time when the new information became available, was too late.

The maps with temperature increments showed that generally on the model level 28 the features are similarly for all the 3D-Var experiments. Smaller values are for the *3dvar* set, which means that the background was closer to observations. The effect of observations near Hungary is coming from Brno, Szeged and Vienna stations. Slightly differences appeared in the southern part of the domain are probably due to the AIREP observations, for the experiments with the same lateral boundary conditions, but with different observational data (*3dvar* and *3dvar TLS*). On the model level 15, the main difference between the temperature increments appeared in the north-east corner of the domain. Using lateral boundary conditions from ALADIN/LACE, the information from the background was far from observations, while the model using ARPEGE LBC has been able to fit the first-guess very close to observations. A worrying feature of the increments is that they look as being bi-periodic. In principle, excluding data near the boundaries, these spurious effects can be avoided.

The experiments performed only with SYNOP or TEMP data showed that we cannot identify a set of observations, which are uniquely responsible for the improved prediction of the rainfall event. The most important features for the forecast are coming from the upper-air observations. However, for this case it is better to use together observations from surface and upper-air. As more and more data near Hungary have been removed the results became more unrealistic. So for this case also the location of the data has to be as close as possible to the area of interest.

For the 3D-Var experiments using all the TEMP data, but different observed variables from SYNOP (geopotential, temperature, relative humidity), the quantity and the distribution of the precipitation have been changed. It appears that for this case the geopotential measurements had a bigger influence on the rainfall forecast in the northern part of the country, and the temperature, in the southern part. The forecast from these experiments has not been improved, but still it is better than the one of the model in dynamical adaptation.

As we could see the 3D-Var data assimilation scheme helped to improve the forecast of the model. The quantity of precipitation was significant, compared to what the operational model predicted. The next step will be to study a case when the model in dynamical adaptation had a very good forecast, to be sure that the 3D-Var scheme does not deteriorate the good features.

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