# Detailed case study of a dramatic winter temperature overestimation in the ALADIN/HU model

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## 1. Introduction

The ALADIN/HU model usually produces wrong forecasts near the surface in strong inversion cases. In these situations the 2 meter temperature and the daily temperature fluctuation are overestimated systematically. The experiences show that in case of large snow surface these overestimations become larger. Our aim was to examine and declare the reasons of the errors through a representative example. In January and February 2003 there were some cold air pad situations with strong inversions and principally the 2 m temperature forecasts suffered from the largest systematic and RMSE errors.

At the beginning of February (13th and 14th) the operational ALADIN/HU model had a large minimum temperature overestimation in the Carpathian Basin. The measured 2 m minimum temperature was around -10 - -15 °C and in some places even lower (-20 °C over the central part of Hungary). A large anticyclone extended over central and northern Europe without considerable cloudiness and precipitation. At the same time there was a big amount of snow cover over almost the whole country, which originated from the previous snow-fall at the beginning of February (Fig. 1). The snow field and the clear sky together produced extreme cold nights due to the long-wave radiation.

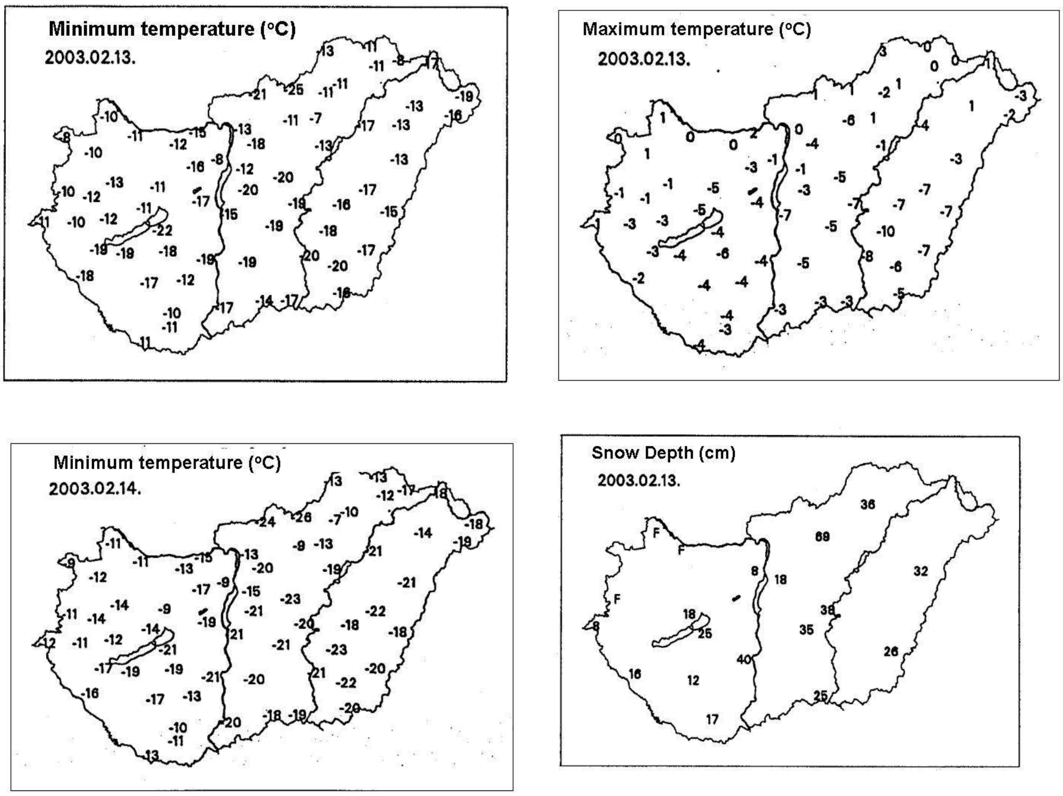



Figure 1. Temperature and snow depth measurements over Hungary on 13th – 14th February

## 2. Models

The operational ALADIN/HU model was not able to forecast this extreme cooling event, the average overestimation of the 2 m minimum temperature was about 8 - 10 °C for both nights, but the forecaster and even the ECMWF model predicted smaller minimum temperatures and their errors were about 2 - 4 °C. The largest temperature overestimations occurred in the coldest southern and central part of Hungary, where the snow field was the deepest (the observations were more than 25 cm). The north-western part of the country was the "warmest" region with –11 °C and with spotted snow cover, and the ALADIN/HU model produced the smallest error over this region. The large snow field in Hungary appeared as a large radiative surface, and the main problem was that the operational model did not contain sufficient amount of snow (Fig. 2a) compared to the measurements, especially over the southern part of the country. This erroneous configuration of the snow surface had two reasons, on the one hand there is no operational snow analysis in ARPEGE (only the ARPEGE forecast keeps the snow from the previous precipitation events), and on the other hand the February "climate" file contains almost no snow field all over the Carpathian Basin. Both problems led to this failure in the description of snow cover and depth in the initial conditions of the model.

Beside this the operational 2 m temperature analysis was also not too successful at the border of southern and eastern part of Hungary (Fig. 2b), e.g. the analyzed value was -7.6 °C whereas the observed one was -16.3 °C in Szeged (N: 46.25°, E: 20.10°), so the initial error was about 9 °C. This difference was kept during the model integration, and moreover at +30 hour forecast time the error came up to 11 °C (-7.4 °C forecasted, -18.6 °C observed).

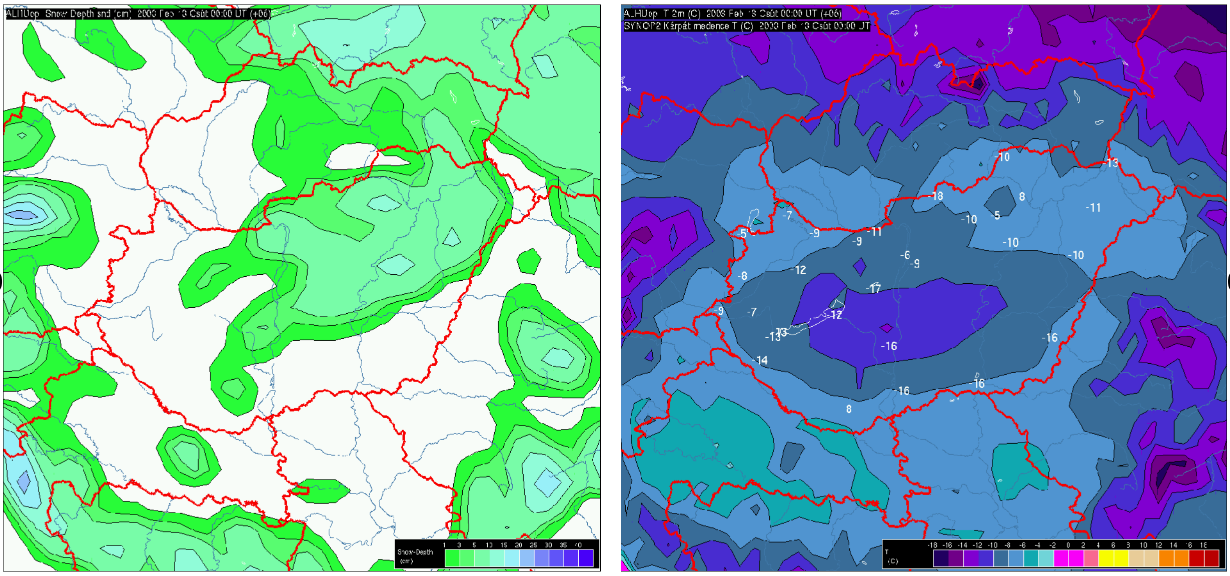
(a)  (b)

Figure 2. ALADIN/HU dynamical adaptation : a) snow and b) 2m temperature analysis at 00 UTC, 13 February 2003. Figures are plotted with the HAWK visualization system of HMS. The white numbers represent the measured values.

The 2 meter temperature is a diagnostic variable calculated as an interpolation between the surface and the lowest model level, taking into account the stability near the surface. The surface temperature is determined by the radiation budget, the latent and sensible heat transport between the atmosphere and the ground and the heat transport between the different ground layers (Gerard, 2001) :

$$\frac{\partial T_s}{\partial t}=\delta_{land} C_T (Q_R+Q_{sens}+Q_{lat}-F_{sp}-L_{w-i}(F_n-F_{si})) \qquad (1),$$

where :

- $\delta_{land}$ is the land-sea mask,
- $C_T$ is the ground thermal coefficient which depends on the ground type,
- $Q_R$ is the surface net radiative energy flux,
- $Q_{sens}$ is the surface sensible heat flux,
- $Q_{lat}$ is the surface latent heat flux associated to liquid and solid water,
- $F_{sp}$ is the heat flux between the surface and deep ground,
- $F_n$ is the snow melting flux,
- $L_{w-i}$ is the melting heat,
- $F_{si}$ is the surface freezing flux.

Equation (1) considers some important processes connected to the snow properties, for instance the depth and the equivalent water content. Beside this, the long-wave emission near the surface also depends on the ground type (vegetation, snow) via the albedo. Above the snow surface the saturated water vapour can be easier condensed from the air to the ground than above bare ground and in dry air the outgoing radiation is increased. The gain from the raised latent heat flux derived from the condensation is too small compared to the deficit coming from the cooling by long-wave radiation, the average ratio is about 1/20 to the benefit of radiation in a chosen snow covered point in central Hungary (Fig. 3). In this picture only the period of surface temperature decrease was examined. In this case the radiation has the biggest influence to the evolution of the surface temperature and the second most important process is the heat flux between the surface and the deep ground, which is negative that means the deep ground warms the surface above.

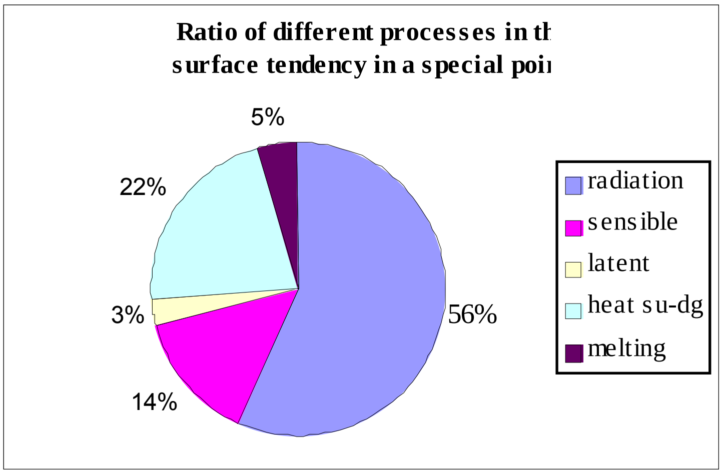



Figure 3. Ratio of different processes in the surface temperature tendency (radiation, sensible heat, latent heat, heat flux between the surface and the deep ground, snow melting/freezing flux)

## 3. 3D-VAR experiments

First of all we tried to perform an experiment using a 3D-VAR data assimilation cycle with CANARI surface analysis to get more realistic 2 m temperature analysis and forecast. So a "3D-VAR+CANARI" cycle was run from 00 UTC, 12th of February, with 6 hours assimilation range. In CANARI the 2 m temperature and relative humidity and the 10 m wind analyses were activated, however the snow analysis was not switched on at that stage. We got a very promising 2 m temperature analysis (Fig. 4), the south-east and central part of the country was the coldest area and the northern part the warmest one.

Unfortunately, after some hours of integration the corresponding forecast became worse than the dynamical adaptation one, especially at the southern part of the country. It seems that the forecast with "3D-VAR+CANARI" produced smaller 2 m relative humidity forecasts in the studied area at 12 UTC 13th of February (12 hours forecast), which allowed more incoming short-wave and more outgoing long-wave radiation, with raising 2 m temperature :

dyn. ad. : relative humidity 67%, short-wave radiation 307 W/m$^2$ and –1.2 $^o$C,
assim. : relative humidity 44%, short-wave radiation 361 W/m$^2$ and +0.1 $^o$C,
at Szeged, while the observed temperature was –5.1 °C at that time.

This difference between the operational dynamical adaptation and the forecast with 3D-VAR was kept for the entire integration time, which means that the 3D-VAR based forecast was even worse than the operational one (Fig. 5). After 30 hours integration 2 - 4 °C differences could be noticed.

The main problem can be identified in the unbalanced fields at the initial time, for example a too strong and considerable correction was brought to the surface and 2 m temperatures by the analysis process, which deteriorated the humidity field near the surface.

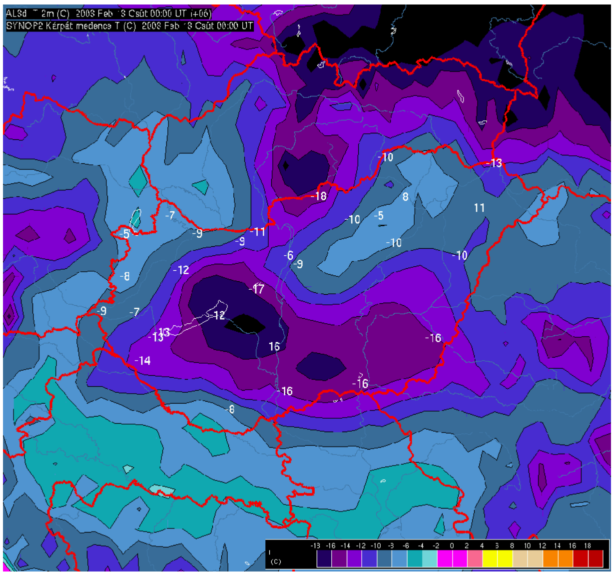


Figure 4. 2m temperature analysis at 00 UTC 13th of February, 2003. obtained with3D-VAR+CANARI

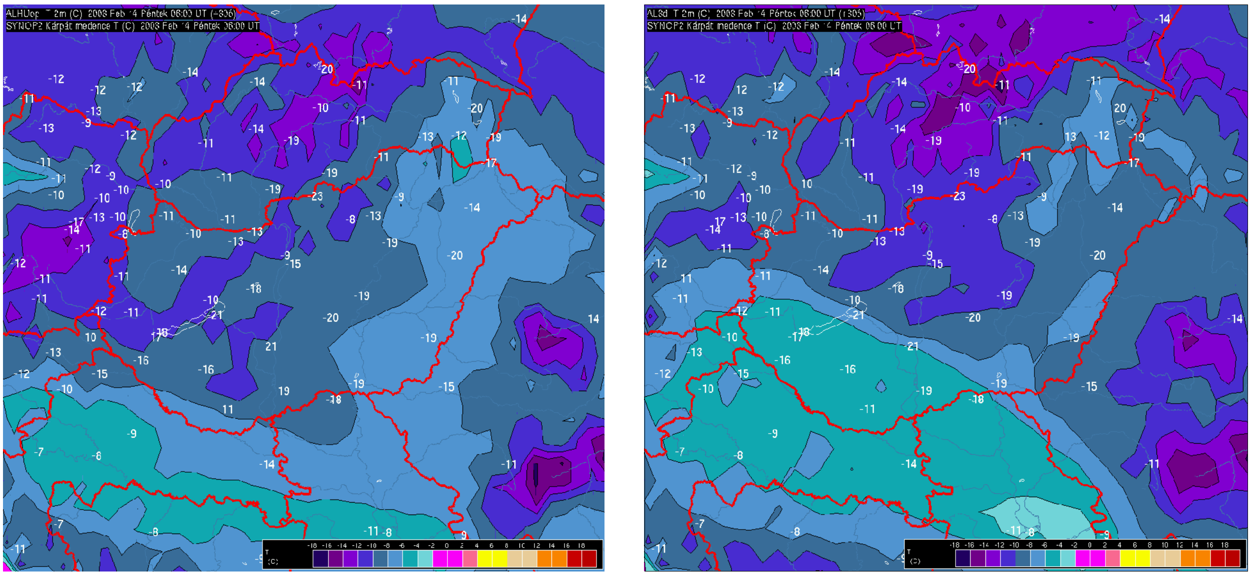


Figure 5. 2m temperature 30 hours forecasts with dynamical adaptation (left) and 3D-VAR+CANARI (right).

Beside this, as was mentioned, snow analysis was not carried out in the previous experiments, which could cause some negative effects on the surface temperature forecast. Therefore a "3D-VAR+CANARI+SN" analysis cycle and 48 hour forecast were performed including snow analysis in the cycle. The initial snow depth was more correct than in the operational dynamical adaptation, especially on the south-western part of the country, but the south-eastern part was not well represented (Fig. 6), and the snow was melting continuously. The 2 m temperature analysis was almost the same as without snow analysis. The forecast was a little bit worse at the beginning, which means that the atmosphere warmed at night apart from the reality, but after 12 hours the forecast turned into a bit better. The temperature difference between the two kinds of runs came about 3 °C after 30 hours integration at station Szeged : "3D-VAR+CANARI "produced -6.9 °C, "3D-VAR+CANARI+SN" –9.8 °C. But the measurement was –18.6 °C at 06 UTC 14th, so the overestimation remained still unacceptably huge.

It seems that the model broke the very stable air mass near the surface by the intensive wind in the planetary boundary layer. This can be confirmed by visualization of the 10 m wind and gust forecasts (Fig. 7). The weakest wind and gust were generated by the dynamical adaptation especially in the central part of Hungary (wind speed is 1 m/s, gust 1.2 m/s at Szeged), and "3D-VAR+CANARI" predicted the strongest ones, 2 m/s wind speed and 2.8 m/s gust. These results were in agreement with the 2 m temperature forecast : if the "3D-VAR+CANARI+SN" had produced smaller wind forecast the temperature would have been smaller too.

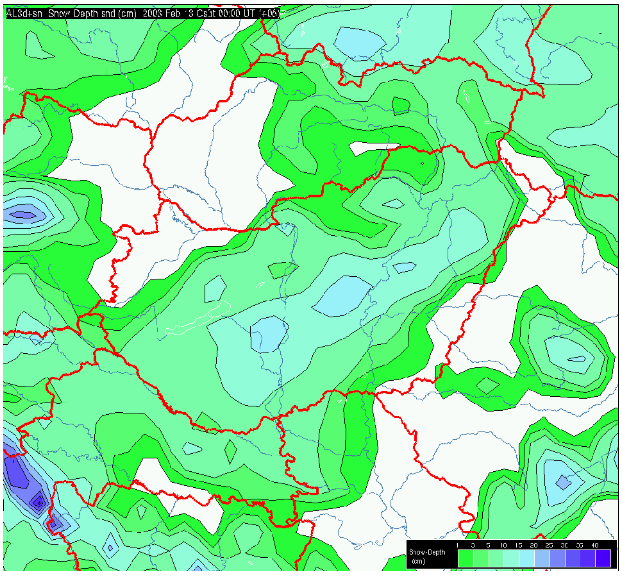


Figure 6. Snow analysis at 00 UTC 13th of February, using 3D-VAR+CANARI+SN cycle

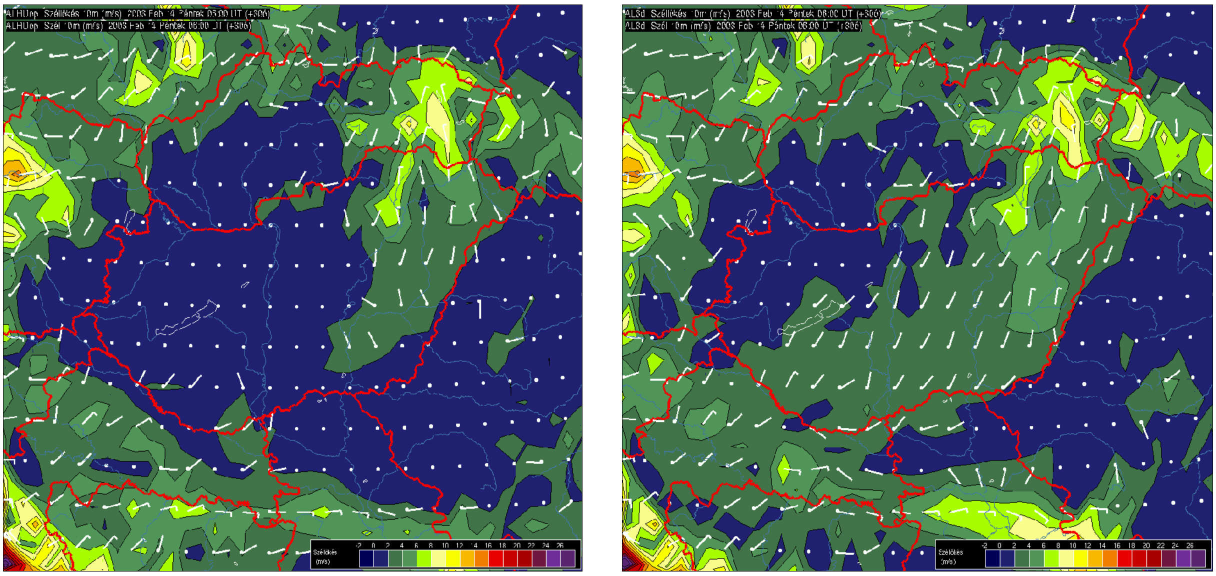


Figure 7. Wind forecasts obtained with dynamical adaptation (left) and 3D-VAR+CANARI (right)

If this speculation is correct, it is worth to do some experiments with improved physical parametrization processes in the planetary boundary layer. So first of all we tried to make a forecast using the operational package but with some modified parameters with respect to stable conditions, namely to reduce the vertical turbulent transport, e.g. with a change of the inverse critical Richardson number, from 0.25 into 0.175.

A "3D-VAR+CANARI+SN+NPAR" cycle and then a 48 hours forecast were performed using "3D-VAR+CANARI" with snow analysis and new sets of turbulence parameters in the calculation of the guess. Then another experiment, "3D-VAR+CANARI+SN+NPHYS", was carried out using a new physical-parametrization package advised by experts from Toulouse (Geleyn, 2003). In this package the *cloudiness* (Xu-Randall), *radiation* (EWS), *deep convection*, *vertical turbulent transport* computations are improved, and the *stability parameters* are also changed, and used in addition to the "3D-VAR+CANARI+SN" experiment. The best results were obtained with this last settings, especially at the beginning of the integration. After 3 hours the most realistic temperature distribution was found compared to other experiments, which means that the new process description produced more realistic states near the surface. This latter fact was also proven by the evaluation of the 10 m wind fields. However at the end of the integration we had still 4 - 5 °C errors in 2 m temperature.

Since the snow analysis was not as successful as desired, some other treatments were carried out related to the extension of the snow surface. Some parameters had to be modified in the optimal interpolation namelist, either increasing the guess error (the operational value for the snow equivalent water content is 5 $kg/m^2$ which approximately corresponds to a snow depth of 5 cm) resulting in the use of more observations, or increasing the radius of influence of observations (the operational value is 50 km). The first modification means that our confidence in the guess is diminished and the second one results in the increased reliability on the observations. These two properties need to be enlarged, therefore the guess error was set to 20 $kg/m^2$ because the differences between the observations and the guess was quite big in a lot of points.

A new "3D-VAR+CANARI+SN+NPHYS" cycle was carried out with modification of the two parameters, but the analysis was still unrealistic because of the deficiency of observation operator for the snow quantity in ARPEGE/ALADIN. The calculation of the corrected model equivalent of snow quantity is called twice, first time for calculating the observation departure (obs-guess) and second time for the determination of the analysis differences (obs-analysis) (Gaytandjieva, 2000). If the weather situation is extreme, and the observations are far from the "climate" fields, the correction doesn't work properly, as can be seen from its formulation :

$$Sn=\frac{1}{2}(276-T_{clim})+\frac{1}{3}(276-T_{mod})(Sn_{mod}-Sn_{clim}) \qquad (2),$$

where :

- $Sn$ is the corrected model equivalent at the observation point, $Sn_{clim}$ and $Sn_{mod}$ the "climate" and model fields just interpolated at the observation point, for snow;
- $T_{clim}$ is the "climate" and $T_{mod}$ the model 2 m temperatures interpolated at the observation point;
- threshold 276 K refers to the consideration of avoiding snow surface where the surface temperature is higher than 3 $^{o}$C.

In our case the temperature and the snow depth were both too far from the climatology, so we got extreme values for $Sn$ in the calculation of obs-guess and this values are overwritten into 0 at the obs-analysis calculation. To avoid this problem we suppressed the corrections in Eq. (2), using the simpler observation operator : $Sn = Sn_{mod}$ .

With this new formulation in a "3D-VAR+MOD_CANARI+SN+NPHYS" cycle and 48 hours forecast we got very good snow depth analysis, and the best 2 m temperature forecast (Fig. 8).

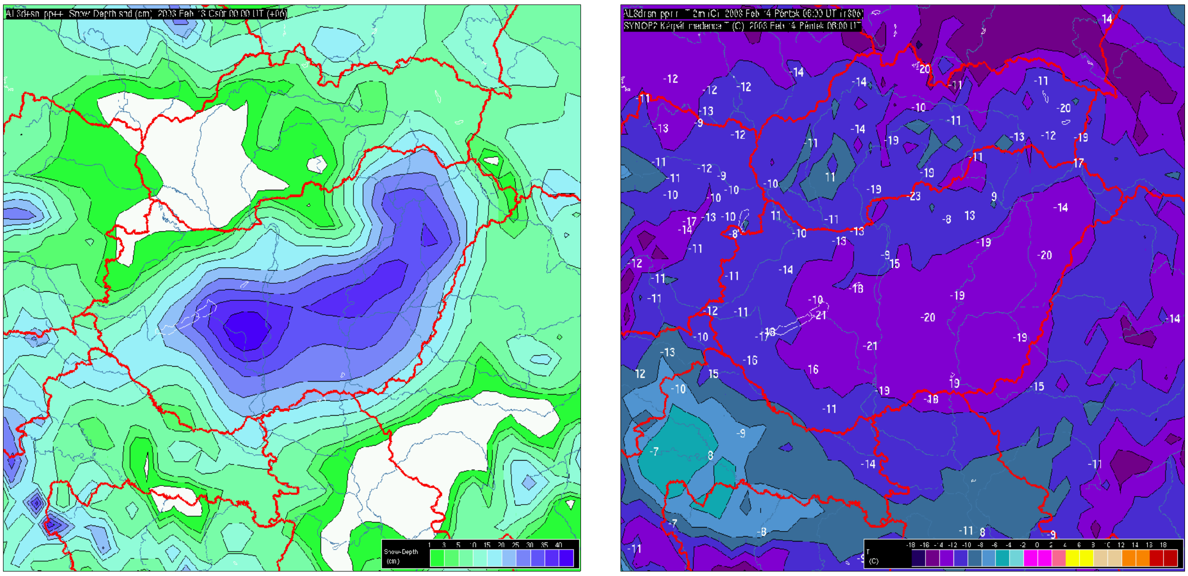


Figure 8. Snow depth analysis at 00 UTC 13th February, 2003 (left), 30 hour 2 m temperature forecast (right) made by 3D-VAR+MOD_CANARI+SN+NPHYS

## 4. Summary and conclusions

At the beginning of February 2003 ALADIN/HU model strongly overestimated the 2 m temperature, our aim was to investigate the reason of this deficiency and correct this error by some improvement of the model.

Our results are illustrated by Fig. 9, which shows the evaluation of 2 m temperature forecast s from our different integrations at a critical station, Szeged (which is by the way also my birth place). The dark blue curve is the SYNOP observations, which should be reached. Let's see the model forecast in the order of the experiments :

- It can be seen that the operational dynamical adaptation (orange) had a very big, 10 °C, overestimation.
- The simple "3D-VAR+CANARI" (bright blue) experiment without snow analysis got correct initial fields, but after 12 hours integration the result became worse than the operational one, because of the unbalances in the initial fields and the lack of snow.
- A little bit better forecast was produced by "3D-VAR+CANARI+SN" which contains snow analysis (purple), but the difference remains still too huge. Similar quality of prediction was performed using different sets of physical parametrizations, "3D-VAR+CANARI+SN+NPAR" (brown) where some vertical stability parameters were changed, and "3D - VAR+CANARI+SN+NP" (green), where some processes (radiation, cloudiness, vertical turbulent transport, deep convection) were modified. This last one was a little bit more correct at the beginning of the integration than the others.
- The best forecast was carried out with the modified snow analysis applied on the previous, improved physical parametrization run, "3D-VAR+MOD_CANARI+SN+NP" (blue), but still there were about 4 –5 °C of error.

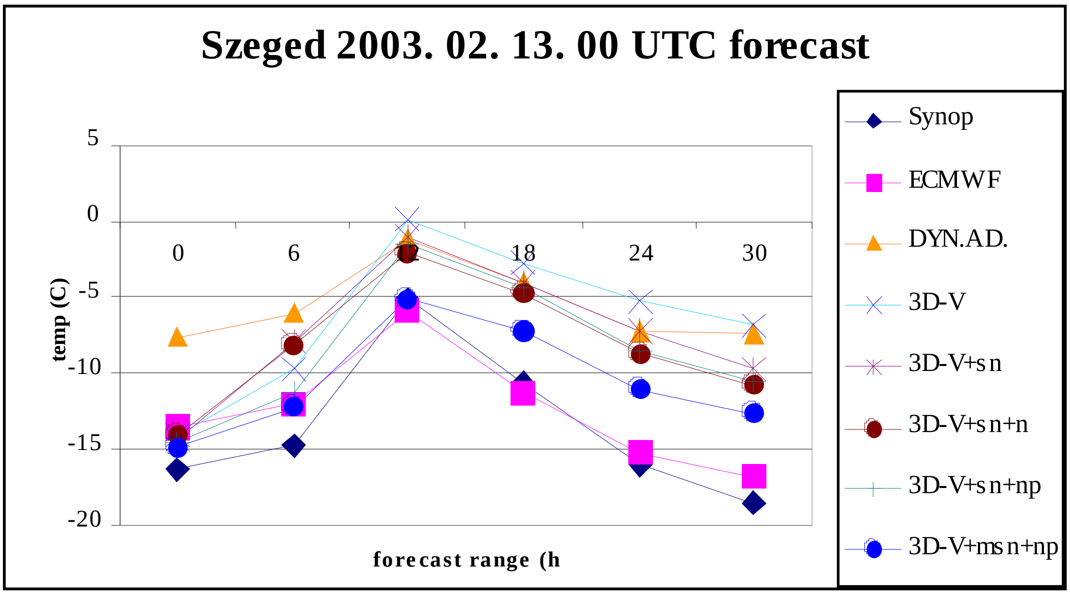



Figure 9. 2 m temperature forecast (2003. 02. 13. 00 UTC + 30 h) made by different model runs.

It was shown that basically all added ingredients to the operational model slightly corrected the unsuccessful forecast but the predictions were still not sufficiently successful. We got the nicest result with using all the possibilities we can apply, however the results of the ECMWF model was still much nearer to the reality than the ALADIN one. The problem was connected to the absence of snow analysis and the deficiencies in physical parametrization in ALADIN. From the treatments it was turned out that with better analysis we didn't certainly got more realistic result. The interaction between the ground and the atmosphere is also need to be largely improved.

## 5. References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