SYSTEMATIC QUALITATIVE EVALUATION OF A HIGH RESOLUTION NON-HYDROSTATIC MODEL

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1. INTRODUCTION:

The presented work deals with the qualitative evaluation of numerical weather forecasts on very high resolution. Since non-hydrostatism plays an important role on natural phenomena that have a horizontal scale of 10km and lower it is a logical consequence that numerical weather prediction models should include non-hydrostatic dynamics when going to such high resolutions. Nevertheless one can hardly find direct comparisons of hydrostatic and non-hydrostatic models, because non-hydrostatic models are very often designed in a different way than their hydrostatic counterpart (e.g. type of vertical coordinate). This is not the case for the Aladin model , which allows a direct comparison of the two dynamics.
Therefore studies of the impact of non-hydrostatism can be obtained very easily from experiments with the Aladin model. The description of the results follows in chapter 4 of this report.

Additionally the fact that the model has to be run on very high resolution leads to other problems related to the resolution itself. The interaction of the orography and the flow introduces strange patterns for some near-surface fields, like precipitation. Some solution to cure this problems partially is also part of this work and will be presented in chapter 3.

In general the studies included several cases, where non-hydrostatic effects should be present. Therefore cases with heavy precipitation were choosen for the experiments, because vertical velocity and the resulting precipitation field should strongly depend on the used dynamics.

The 'Mesoscale Alpine Project' (MAP) provides a good database of observations. This was the reason that most of the studies were performed on events that happened during this period. Besides the MAP cases also experiments for the ALPIA domains were performed, which are often used for testing developments in non-hydrostatic dynamics.

2. GENERAL SETTINGS :

The experiments were peformed with Aladin Cycle25 and several domains with different characteristics were defined. The horizontal resolution for the experiments was 5km and 2.5km, respectively. The basic lateral boundary conditions and the initial conditions for the 5km runs were either taken from Aladin-Lace runs (horizontal resolution of 12.2 km) for the MAP cases or the results from a 10km run of some ALPIA experiment.

For the runs on higher resolution (2.5 km) additionally 5km results (hydrostatic and non-hydrostatic) were used to provide the necessary information at the domain borders.

The following figures (fig 2.1 - fig 2.8) show the choosen domains. Fig 2.1 shows the domain for the 5km runs for the MAP cases, while in fig 2.2 a large domain with resolution of 2.5km is displayed. The first one covers an area of 1000x1000 km (200x200 gridpoints), while the size of the second one is approximately 500x500km (also 200x200 gridpoints). The Alps are included in both of these domains to enable the analysis of the impact of high and steep mountains on the forecasts. It can be seen that on 2.5km larger alpine valleys (like the Inn-

valley) are resolved nicely, while this is hardly the case on the coarser resolution. Besides these big domains some smaller domains were choosen to take into account different types of landscape like only inner alpine areas (fig 2.3 and 2.4), a mixture of high mountains and coastal area (fig 2.5) or a region without high mountains (fig 2.6). These smaller domains have an extension of 90x90 gridpoints, which corresponds to 200x200km. Additionally to the above mentioned domains a 5km and a 2.5km resolution domain were added to allow investigation of the full forecasts on that domains, that are used for the ALPIA experiments (fig 2.7 and 2.8).

The length of the timestep for the 5km runs varied between 60 and 90 seconds, while for the higher resolution run it was decreased to a range between 30 and 60 seconds. Most integrations were performed up to 24hours or more in order to take into account the spin-up time. The generally drawn conclusions are not dependent on the domain and just a selection of cases can be presented here. The update frequency for the coupling files was 6hours for MAP and 3hours for ALPIA. Convection parametrisation was switched of for the 2.5km runs while the gravity wave drag was kept. 3 time-level semi-lagrangian advection was used for the non-hydrostatic runs.

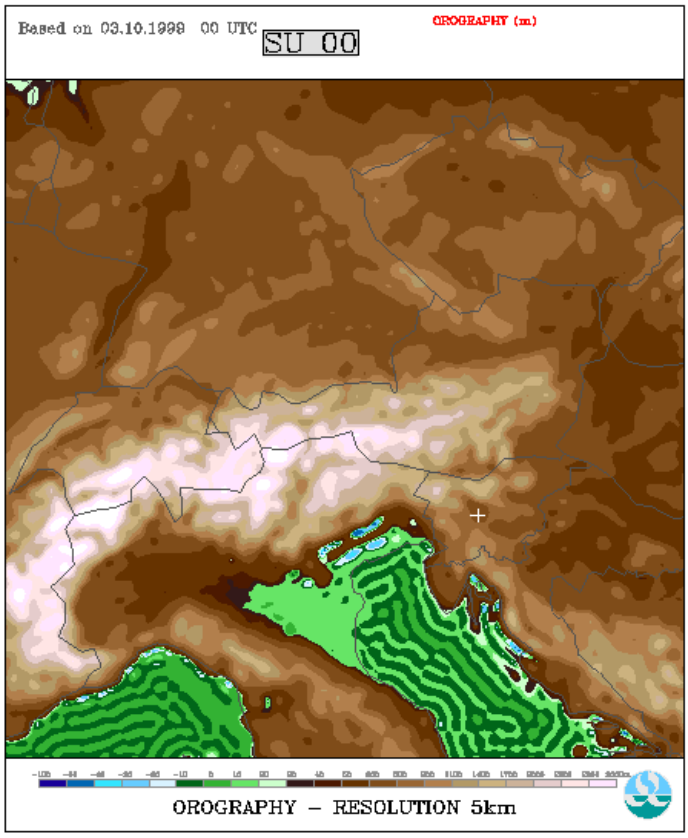

fig 2.1: 'MAP'-domain on 5km resolution

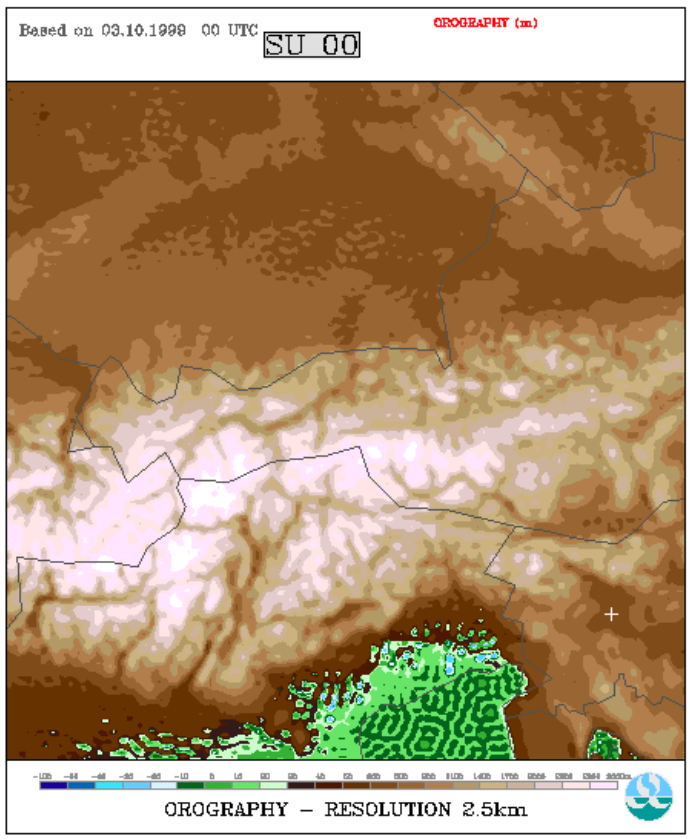

fig 2.2: 'MAP'-domain on 2.5km resolution

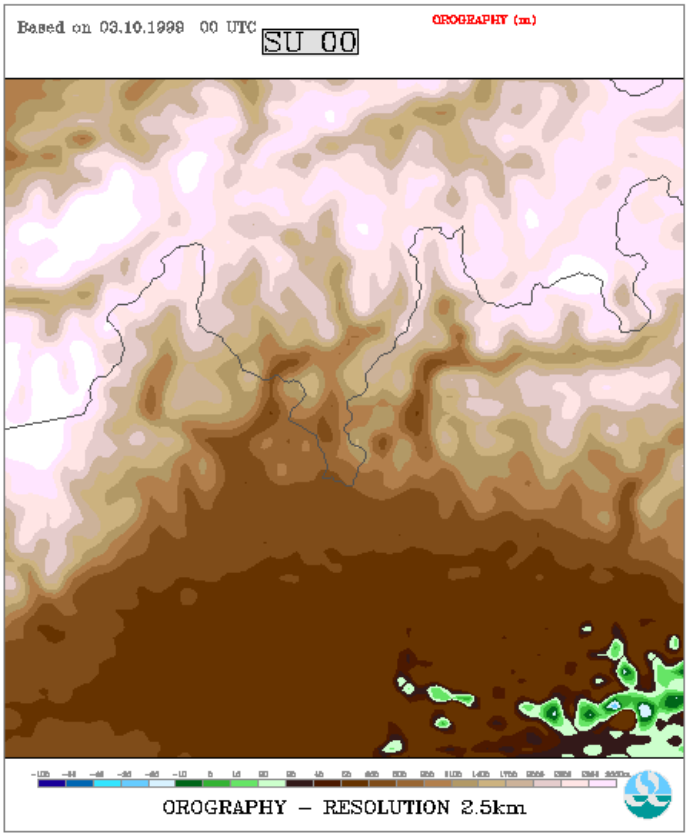

fig 2.3: Suisse-Italian Alps 2.5km resolution resolution

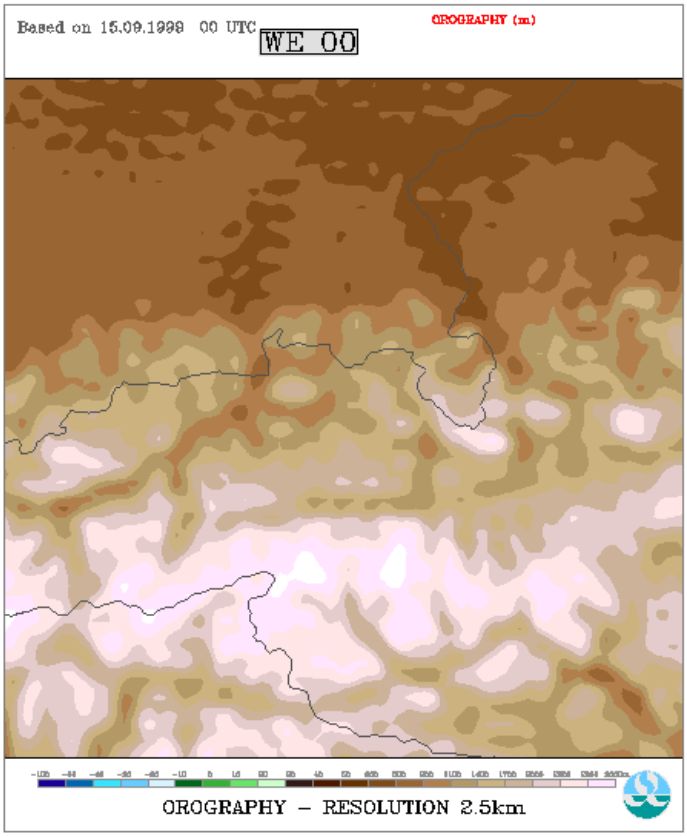

fig 2.4: Inner-alpine Austria 2.5km

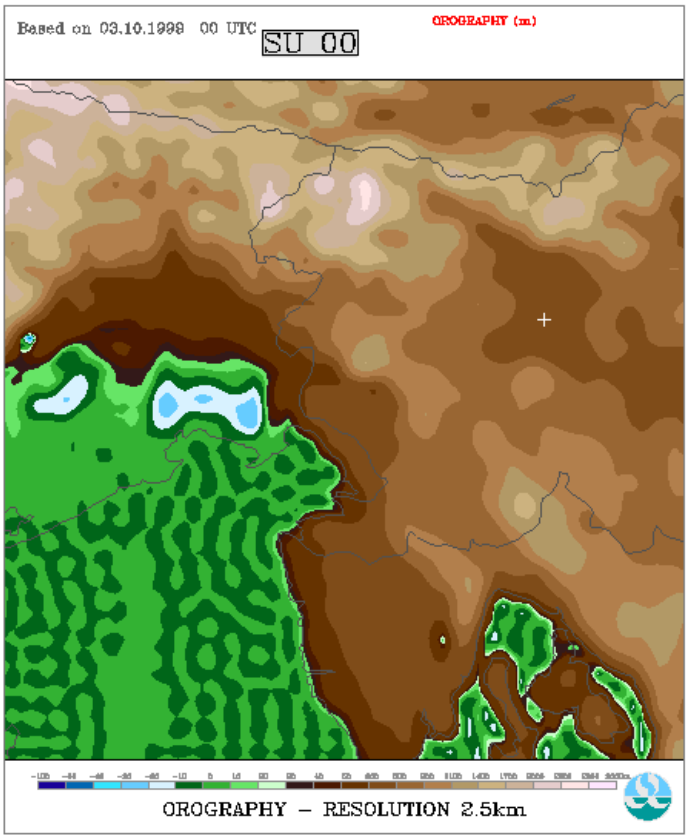

fig 2.5: Slovene Alps + parts of Adriatic Sea

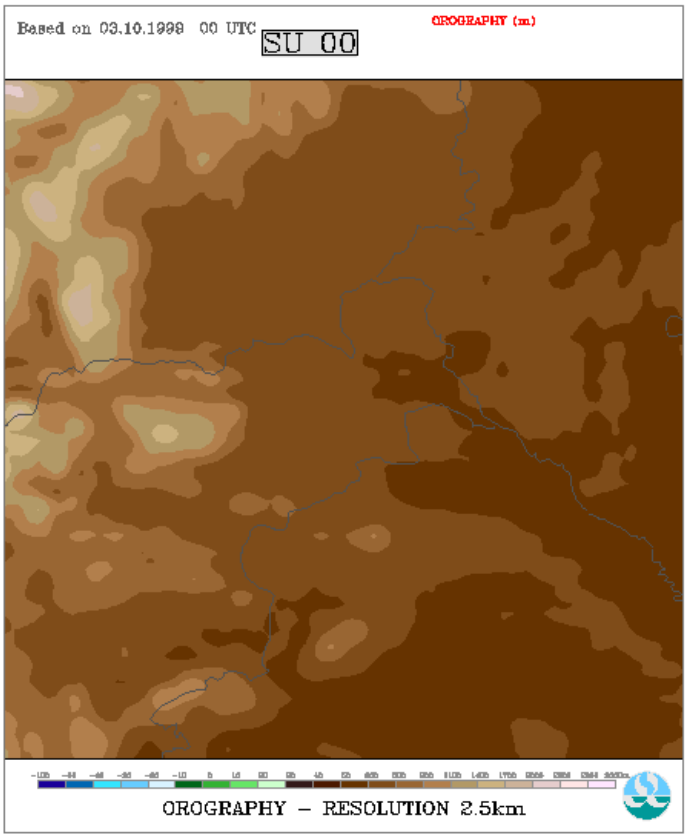

fig 2.6: E-Slovenia/W-Hungary

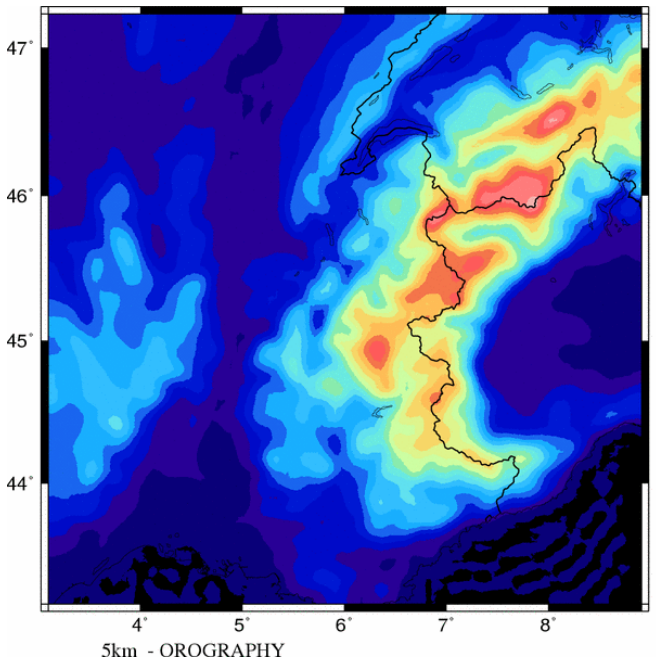

fig 2.7: 5km resolution – ALPIA domain

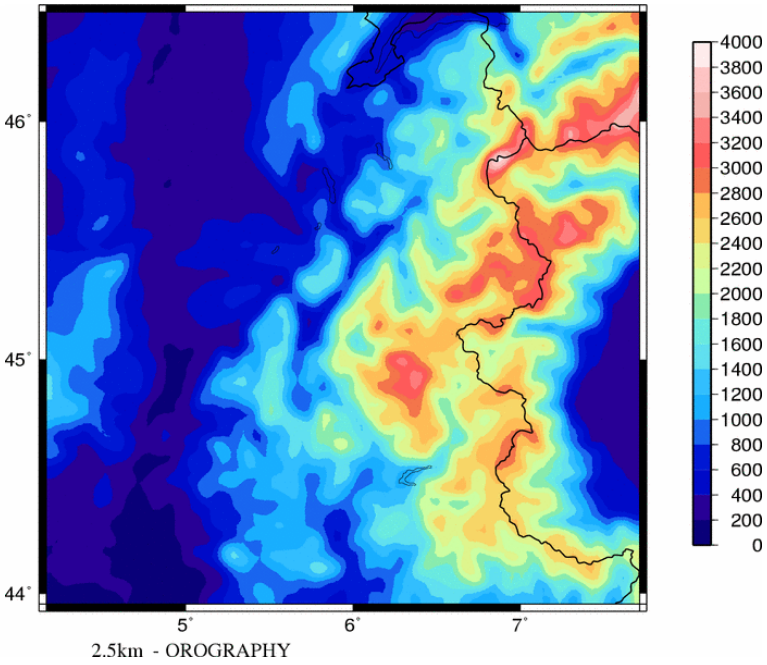

fig 2.8: 2.5 km resolution - ALPIA domain

3. OROGRAPHY ON HIGH RESOLUTION:

On high resolution a strong interaction between the flow and the orography occurs, which might lead to unrealistic precipitation patterns.
Besides this, it is a fact, that if a numerical spectral model is run on a linear grid the orography has to be at a lower spectral resolution than the other meteorological fields because a numerical instability is introduced, if the resolutions are kept the same. Linear grid seems a proper choice for running the model on high resolution so one has to deal with the orography problem mentioned above. One solution is to import the spectral orography on a quadratic grid truncation, when using a linear grid truncation for the other fields. Nevertheless it is a disadvantage, that this method sets the contribution from the smallest scales to zero abruptly (which means, that the last third of the spectrum is put to zero for orography). Therefore it seems reasonable to try a more flexible way of smoothing the orography. An additional spectral term is added to the cost function used to compute and optimize the spectral orography, which acts at damping the smallest scales. The idea is to put less weight to higher wavenumbers to reduce the variability and the steepness of the described orography and following a smoother influence of the orography to the flow.
It is obvious that the smoothing should not change the original orography too much, because a negative impact on the forecasted fields would have to be expected. The effect of such 'overdone' smoothing is shown in figures 3.1 and 3.2. Although the precipiation field looks better, huge information would be destroyed included in the other fields, if the orography is smoothed too much.

The effect of a realistic orography smoothing can be seen in the following pictures.
Figure 3.3 shows the 'original' orography, while in figure 3.4 the smoothed one is shown.
In figures 3.5 and 3.6, respectively the corresponding forecasted precipitation fields are presented. It is obvious that the smoothed orography has a positive impact on the quality of the precipitation field. On one hand the chaotic structure becomes more realistic and on the other hand the extreme high peak amounts on the luv-side are significantly reduced without a complete changing of their location.
Besides the changed precipitation fields also other near surface fields should be influenced by a different description of the orography. In figures 3.5 and 3.6 10m wind fields are shown for the two different orographies, while in figures 3.7 and 3.8 2m-temperature fields for the same case can be seen. Nearly no differences can be recognized for the wind field, while for the temperature the differences are a bit more obvious, which results on one hand directly from the smoother orography (the absolute elevation of the gridpoint changes) and on the other hand differences occur because mountain ridges and valleys are represented in a slight less quality than before. In general it still can be stated that the loss in information for the 2m-temperature field is very small compared to the gain for the precipitation and that the wind field does not change at all.

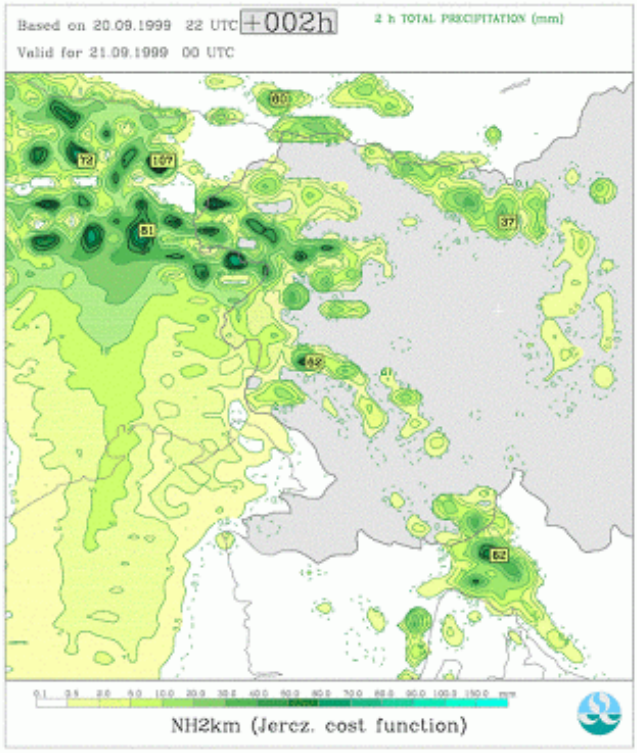

fig. 3.1: precipitation (original orography)

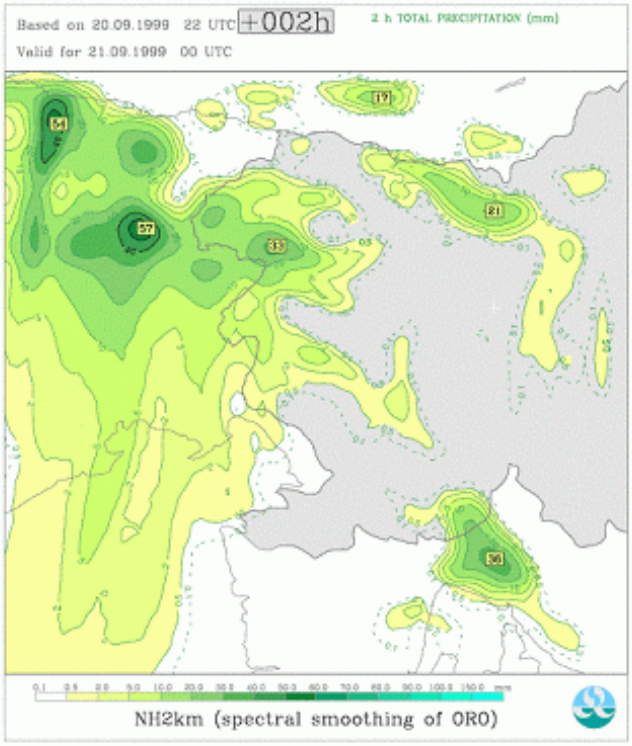

fig. 3.2: precipitation ('oversmoothed' orography)

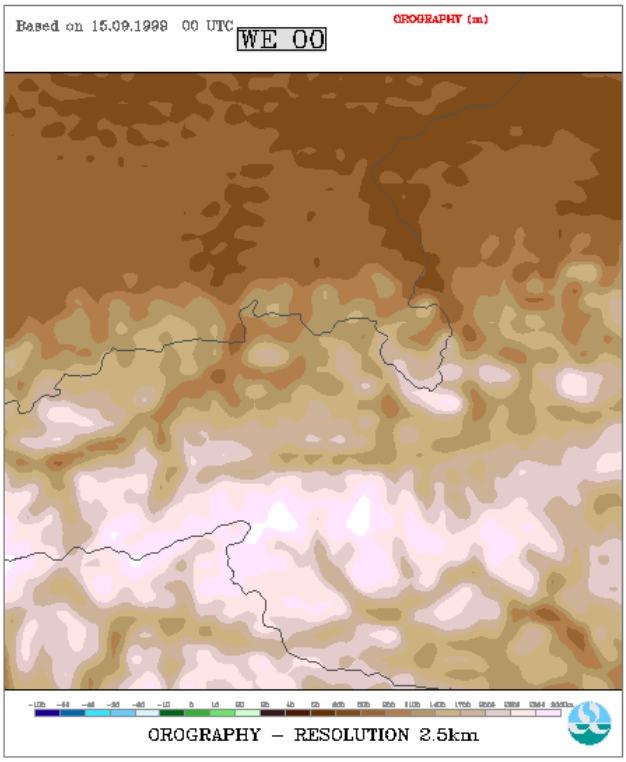

fig. 3.3: original orography

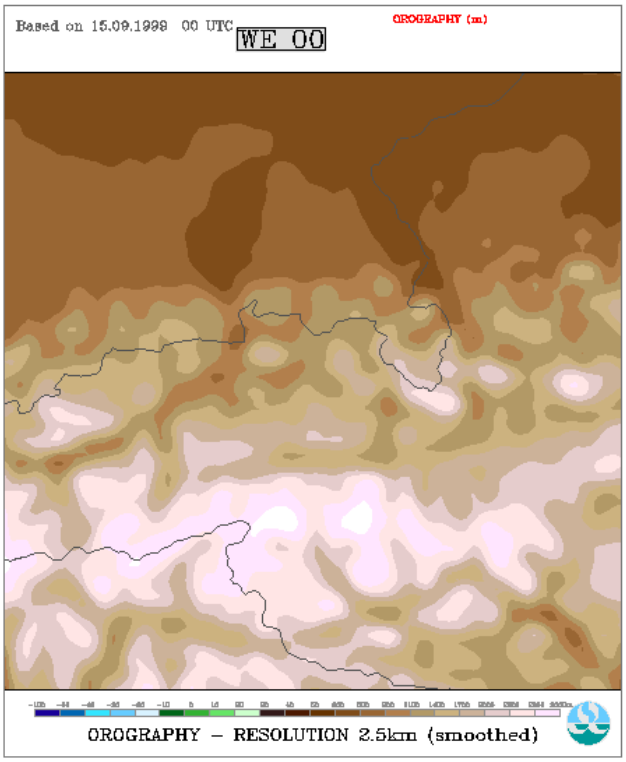

fig. 3.4: slightly smoothed orography

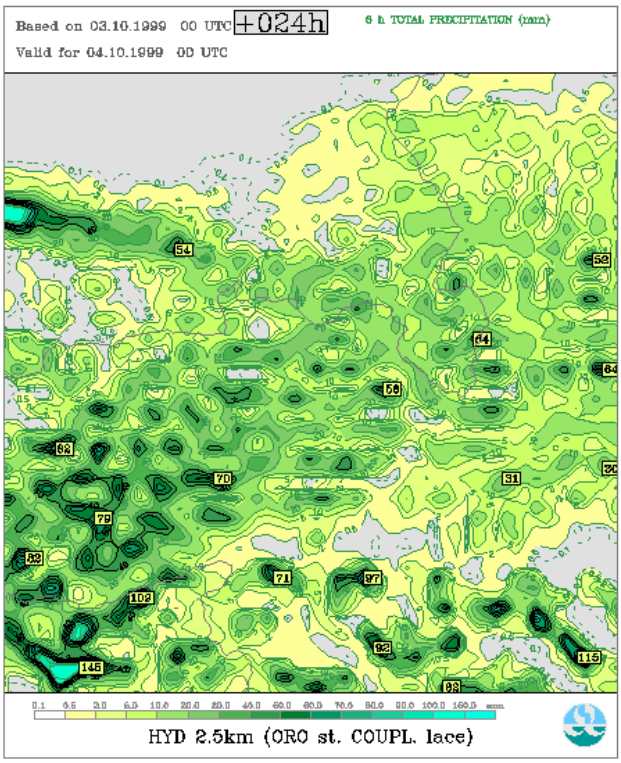

fig. 3.5: precipitation (original orography)

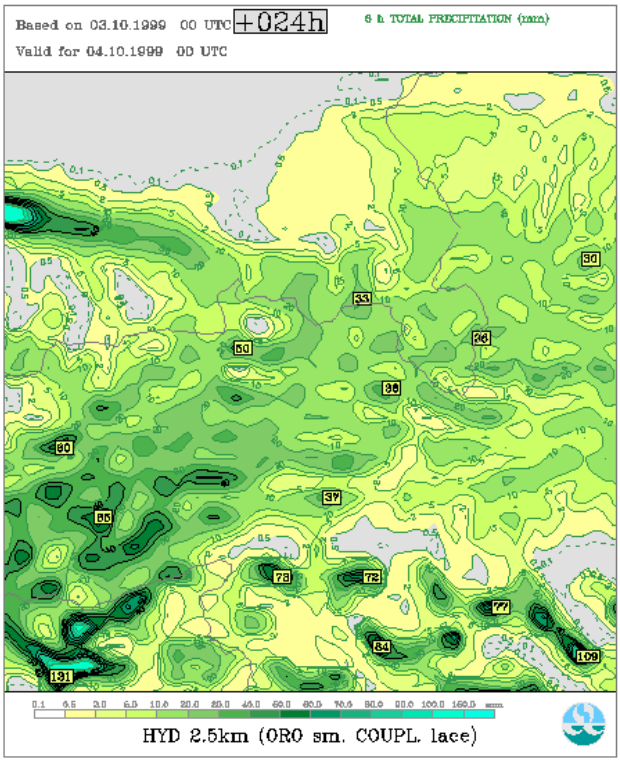

fig. 3.6: precipitation (smoothed orography)

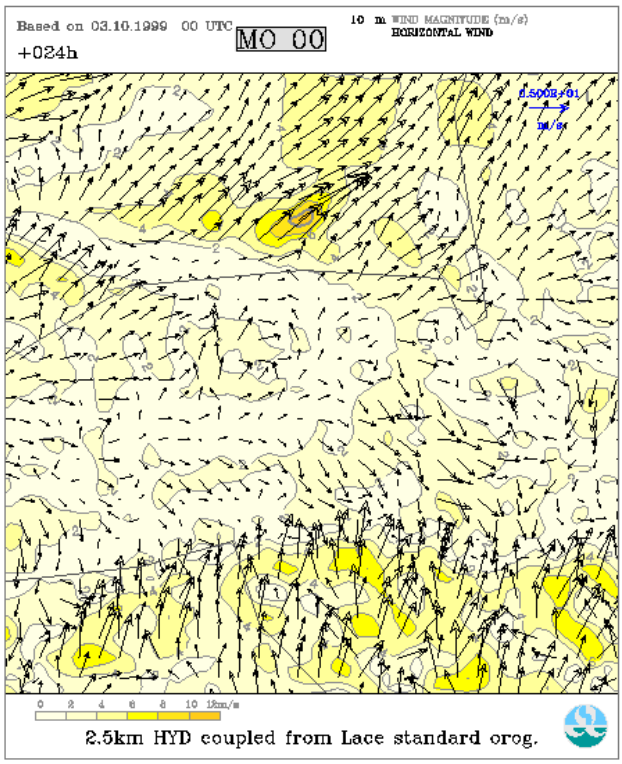

fig. 3.7: 10m-wind (original orography)

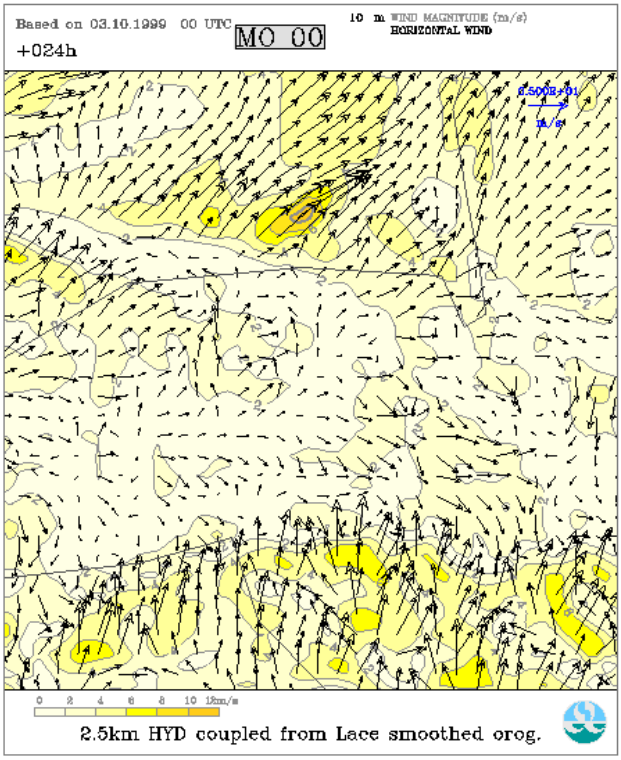

fig. 3.8: 10m-wind (smoothed orography)

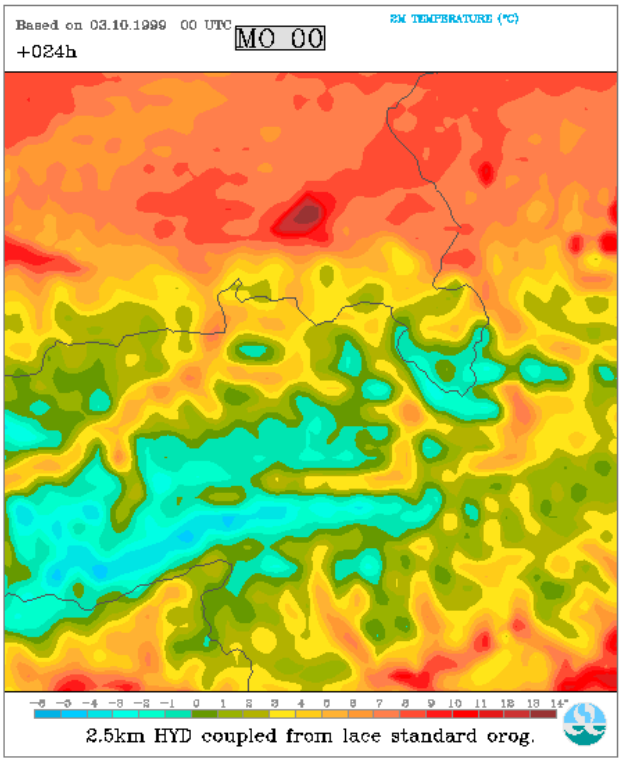

fig. 3.9: 2m-temp. (original orography)

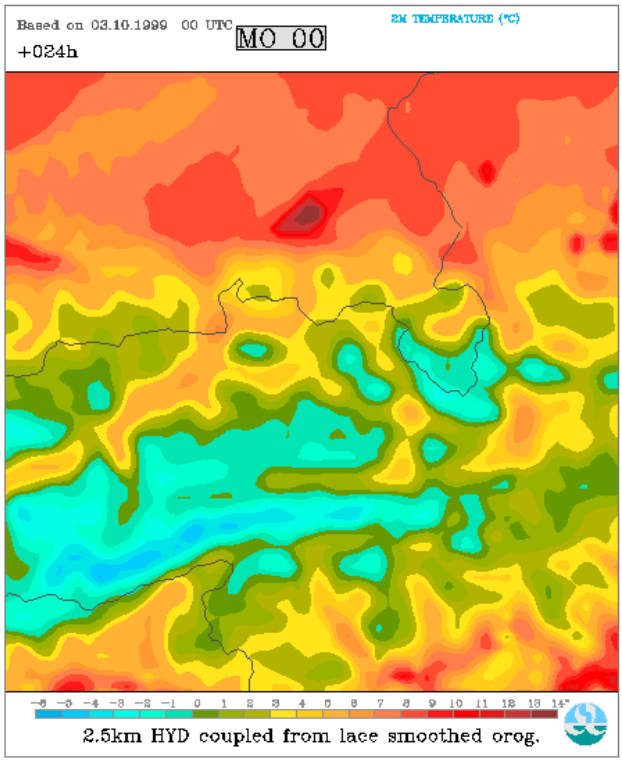

fig. 3.10: 2m-temp. (smoothed orography)

4. COMPARISON of HYDROSTATIC and NON-HYDROSTATIC DYNAMICS:

As already mentioned above the experiments for comparison of the hydrostatic and non-hydrostatic dynamics were carried out with Cycle25 of the Aladin model. This means that the used variables for vertical divergence and pressure departure were d3 and p2. Usage of older variables caused problems and for domains with complex terrain the model was not stable with these variables. Additionally the runs on domains with high and steep mountains (in this case the Alps) on 2.5km resolution were performed on linear grid with smoothed orography, cause other settings also often caused the model to blow up.

The results presented here are mainly taken from two cases with heavy precipitation.
One is the 3 October 1999, which was an event during the MAP-SOP (special observation period), that produced huge amounts of precipitation in mountainous areas, while the second one for the ALPIA domains is the 10 August 2002, which also includes heavy rainfall, this time in the most western part of the Alps.

The forecast for the ALPIA case is an 18 hour forecast and the displayed precipiation fields are 6hour sums, which means the amount between +12 up to +18 hours. In the MAP case the forecast time is +24 or +30 hours and the again the the sum of 6hours is shown. For the other comparisons (temperature in 700 and 850 hPa or vertical velocity in 700 hPa) lead times are between +18 and +30 hours.

The results should just be interpreted in a complete qualitative sense. It is not the aim of this report to prove that NH-dynamics are able to produce better forecasts than the hydrostatic run

or even vice versa, but just to identify general qualitative differences between the different dynamics. As it will be shown in several examples it is very difficult to give general statements, cause things are quite case sensitive.

Precipitation fields should be considered as very sensible to the used dynamics, cause they are directly driven by the vertical velocity field, which should be strongly influenced by the used dynamics. Additionally also temperature fields should be impacted as well.

Figures 4.1 and 4.2 display 30-hour forecasts of 6h precipitation amounts. On the left picture hydrostatic dynamics were used, while in the right picture the non-hydrostatic run is shown. Although the highest peaks are a bit lower and the field is a bit smoother for the NH case the differences are not very remarkable.

In 4.3 and 4.4 the same forecast on 2.5 km resolution can be seen. At the first sight precipitation fields also don't differ that much.

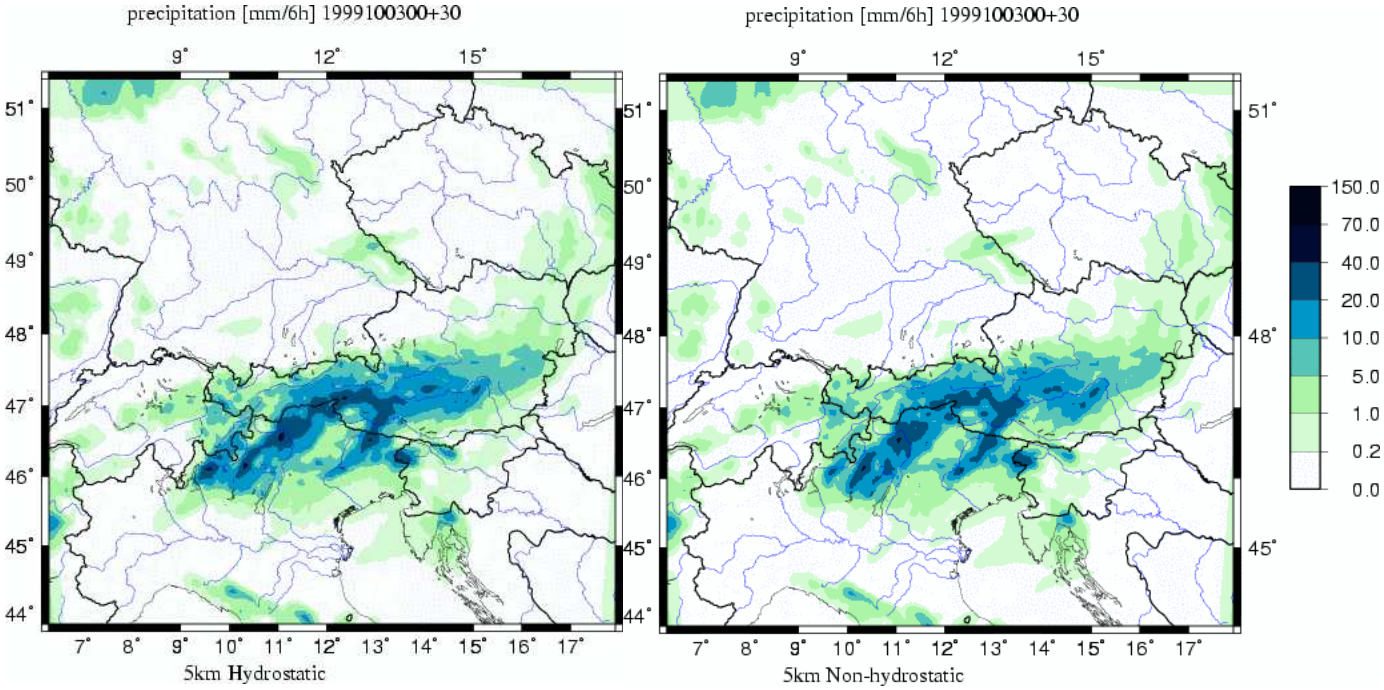

fig 4.1: 5km-res. precipitation HYD

fig 4.2: 5km-res. precipitation NH

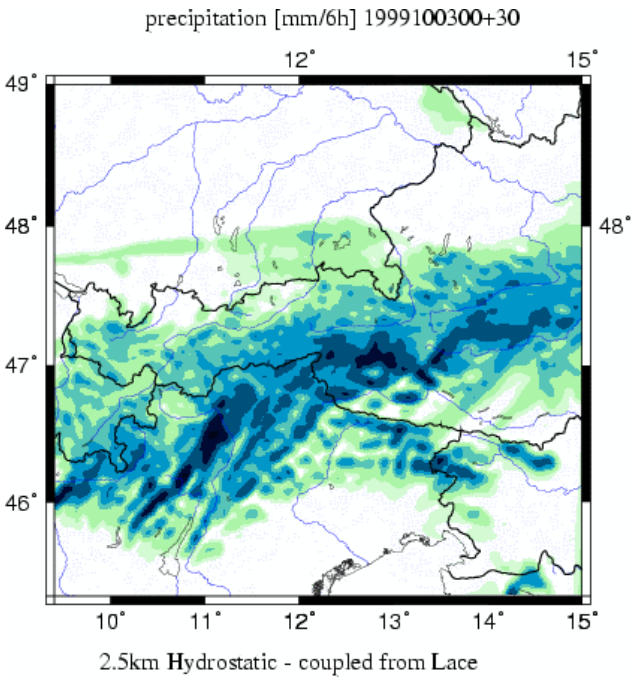

fig 4.3: 2.5km-res. precipitation HYD

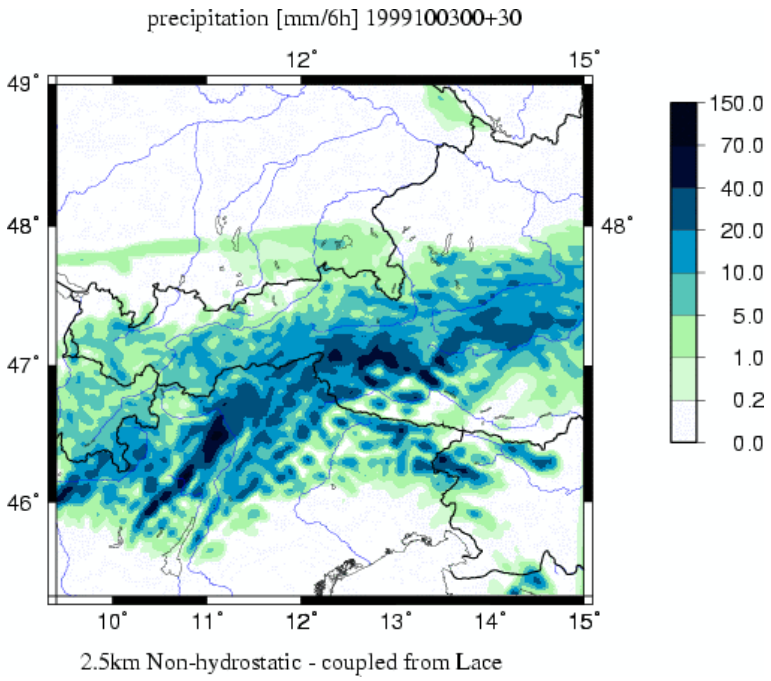

fig 4.4: 2.5km-res. precipitation NH

However if a smaller domain is chosen to reveal some details one can see that on 2.5 km resolution the differences are already obvious as is shown in figures 4.5 and 4.6, respectively.

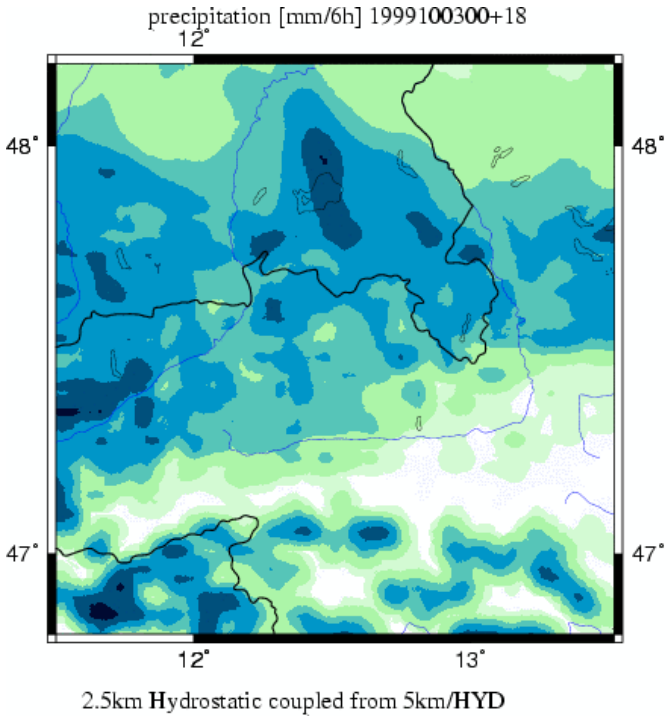

fig 4.5: 2.5km-res. precipitation HYD

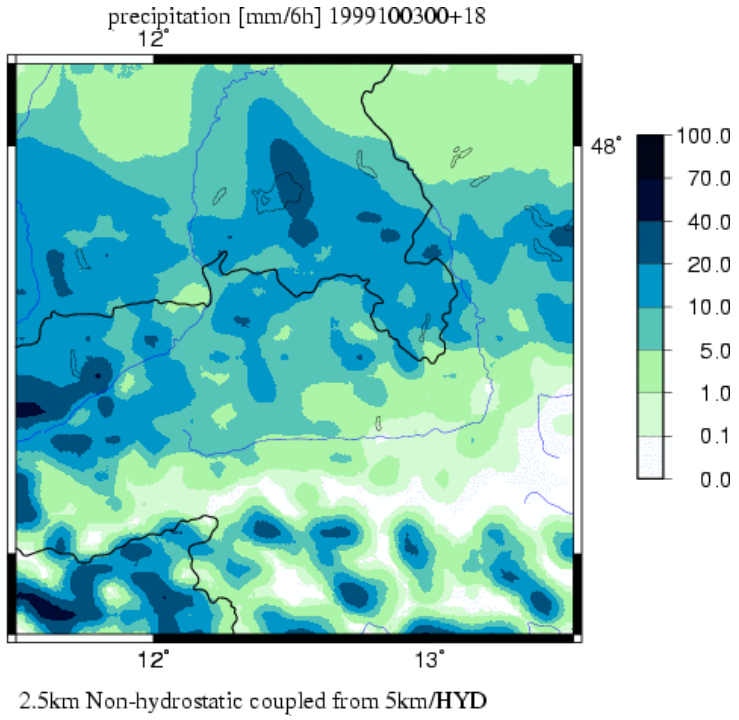

fig 4.6: 2.5km-res. precipitation NH

Besides a quite different structure of the peaks in the south-east of the domain it can be seen, that in the NH case the extension of the field is wider (the precipitation free area is smaller in the NH case) and also the small scale structures reveal significant differences.

In pictures 4.7 and 4.8, respectively the precipitation fields on 2.5km for the ALPIA domain are shown. The left one (fig 4.7) shows the hydrostatic forecast while the in the right one (fig 4.8) the corresponding non-hydrostatic forecast is shown. Peaks are significantly lower in the NH case, while the general structure of the field is similar. In figs 4.9 and 4.10. the same forecast is shown with the difference, that the coupling files here were on 10km resolution, while in the first case 5km resolution files were used for coupling. Again it can be seen that the NH amounts are lower (not that obvious as in the other case), but addtionally also that these runs show some clear differences to the runs from 5km coupling (in structure and amounts).

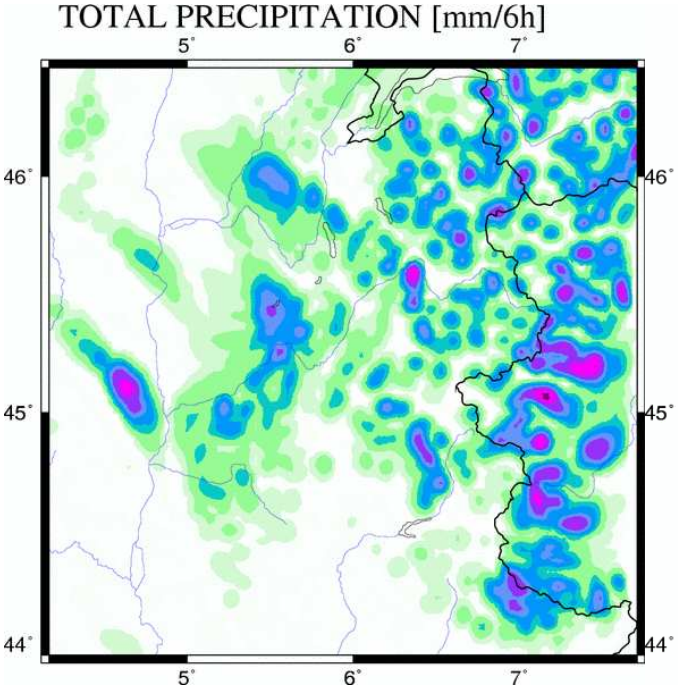

fig 4.7.: 2.5km-res. precipitation HYD coupled from 5km-Hyd

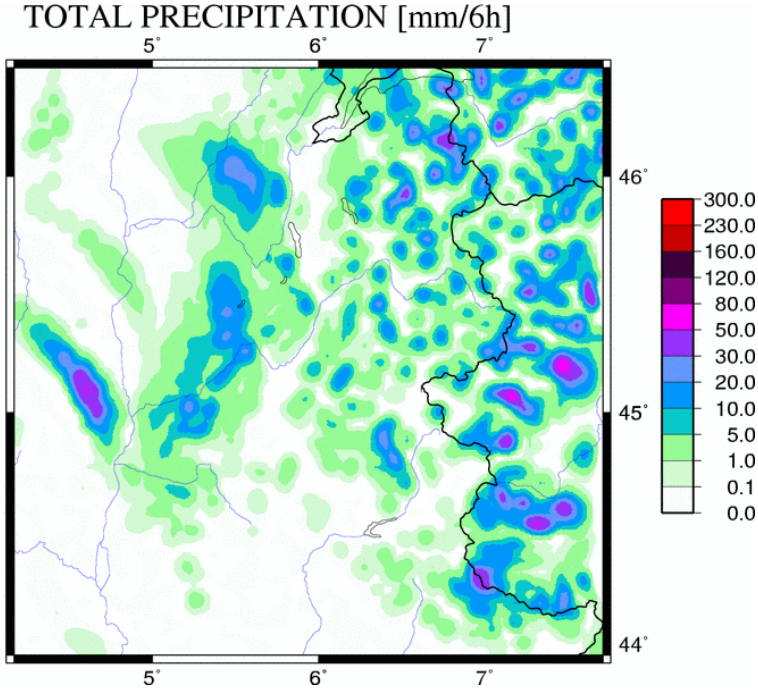

fig 4.8.: 2.5km-res. precipitation NH coupled from 5km-Hyd

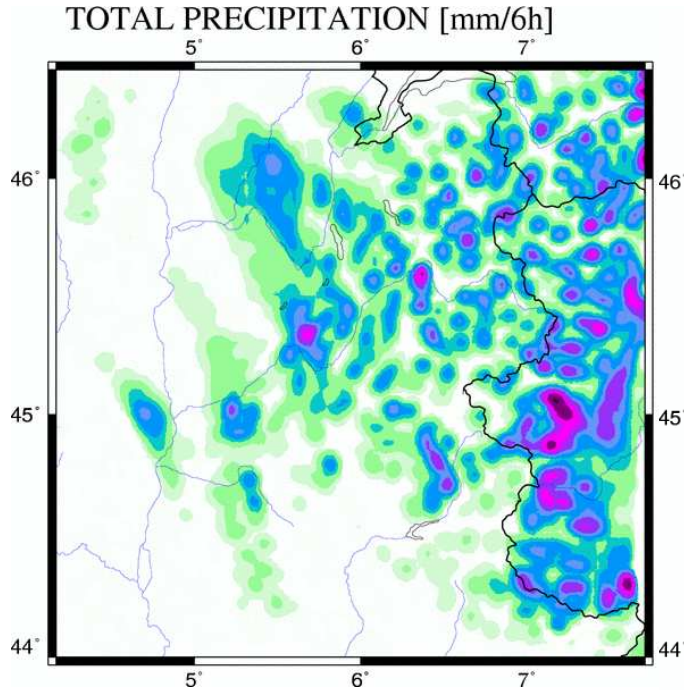

fig 4.9.: 2.5km-res. precipitation HYD coupled from 10km-Hyd

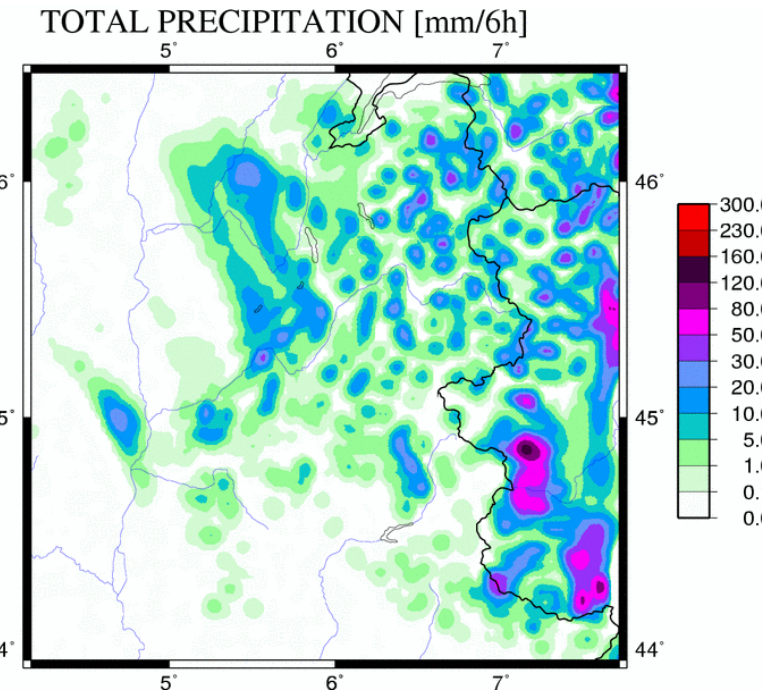

fig 4.10.: 2.5km-res. precipitation NH coupled from 10km-Hyd

If the non-hydrostatic is coupled to a 5km non-hydrostatic run, fig 4.11 (which means direct coupling of the non-hydrostatic variables) the result again differs from all other runs, but one

can guess, that changing the coupling resolution at least causes the same magnitude of differences than the use of different dynamics.

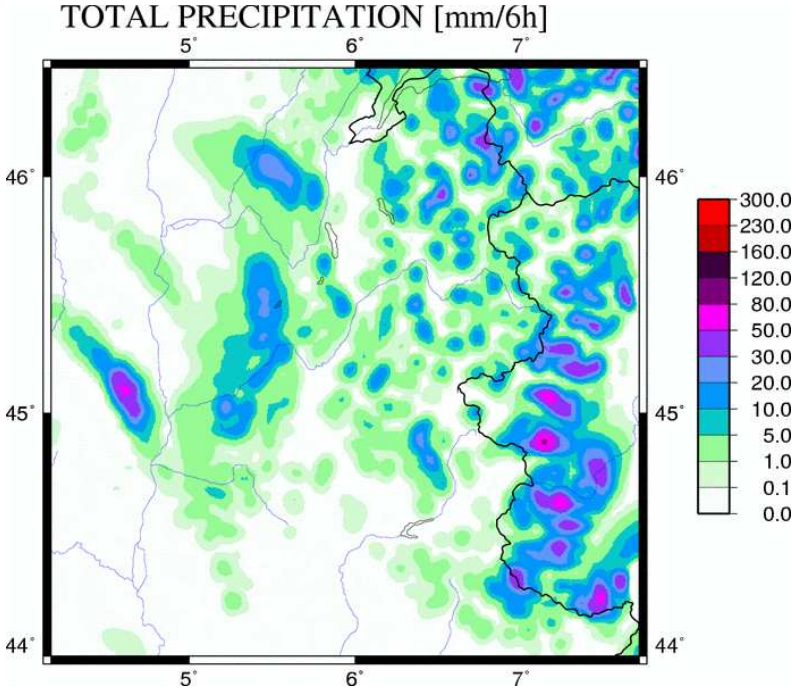

fig 4.11.: 2.5km-res. precipitation NH
coupled from 5km-NH

So this examples show, that besides the use of different dynamics other components (like the resolution of the coupling files) has an impact on the forecasted fields, when running the model on very high resolution, independent of the used dynamics.

For comparison of the dynamics also a closer look was done on the 5km results of the ALPIA case. Experiments were carried out for both dynamics and additionally different kinds of orography were used. The following 4 figures show some results of those experiments.

On the left side results for hydrostatic runs are displayed, while the non-hydrostatic counterparts are on the right side.

First pair shows the result, when using quadratic orography without enevelope (figs 4.12 and 4.13) while the next ones are the results for a linear grid run with smoothed orography (figs 4.14 and 4.15). Obviously all fields show differences, although the hydrostatic runs don't show that much sensitivity to the used orography as the non-hydrostatic runs. Both NH runs give less peak amounts and a slightly smoother field, although in the case of the smoothed orography one peak of the NH even exceeds the value of the corresponding HYD forecast (the most southern peak).

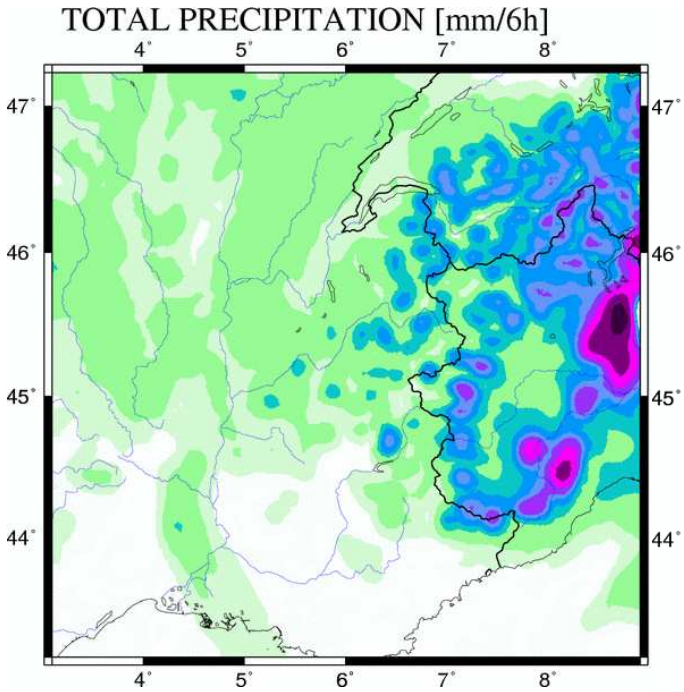

fig 4.12.: 5km-res. precipitation HYD quadratic grid - without envelope

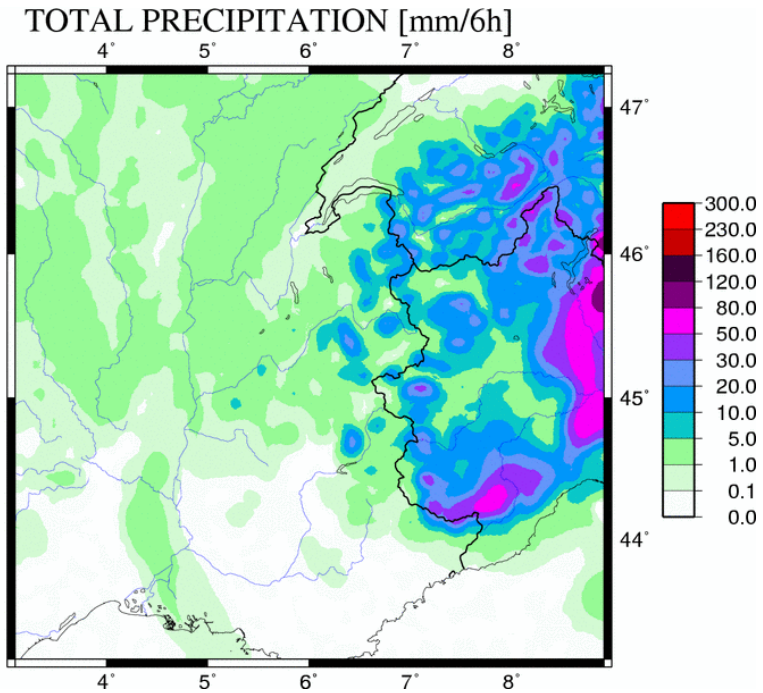

fig 4.13.: 5km-res. precipitation NH quadratic grid - without envelope

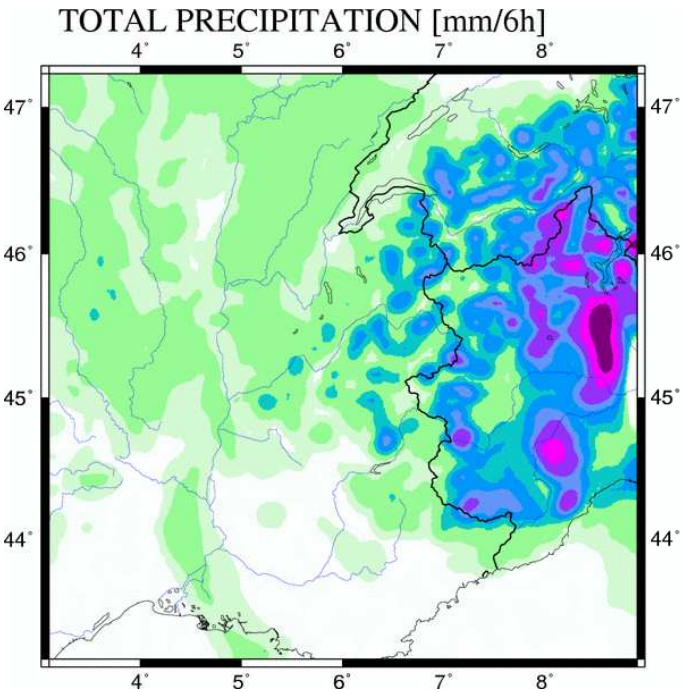

fig 4.14.: 5km-res. precipitation HYD linear grid - smoothed orography

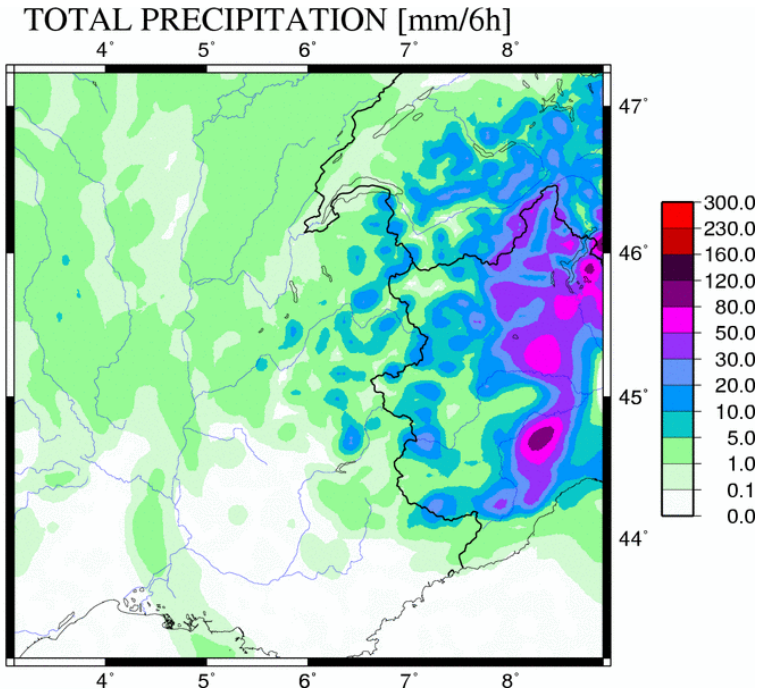

fig 4.15.: 5km-res. precipitation NH linear grid - smoothed orography

Besides these (expected) differences on high resolution, experiments were done to see the influence of the chosen domain size and the impact of different resolutions of the coupling files on other fields, like temperature. One time the 2.5 km runs were coupled to Lace files (~12km) or 10km resolution files for the ALPIA case, the other time they were coupled to the results from 5km runs For the latter also a distinction can be made between the hydrostatic and non-hydrostatic 5km runs providing the coupling information.

If the domain size is changed, no significant changes in the forecasted fields can be found with exception of the regions near the domain borders of the smaller domain.

The vertical velocity fields confirm the results from the precipitation forecasts. Figures 4.16 – 4.20 show 18hour forecasts of vertical velocity in 700hPa. Maxima and minima are lower for the NH cases and also locations can vary compared to the HYD ones. Again differences can be found dependent on the coupling files, showing smaller values when the model is coupled to the 10km run (figs 4.18 and 4.19).

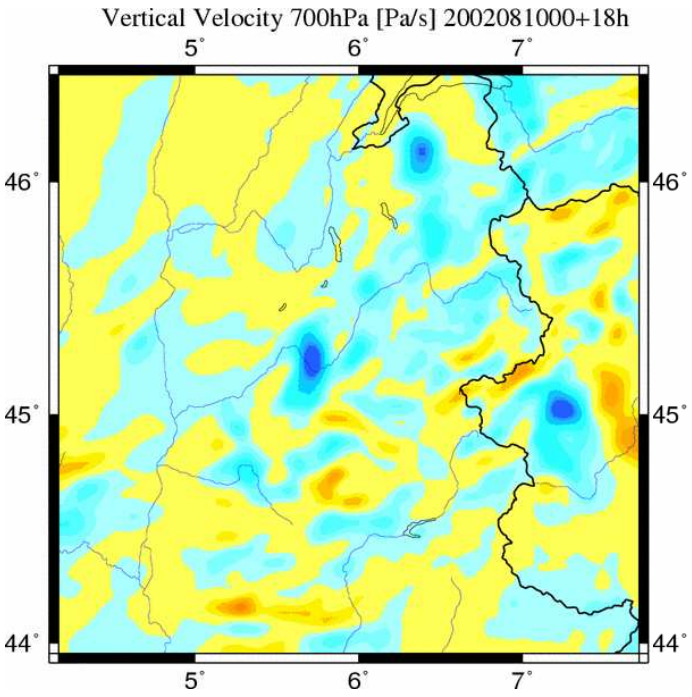

fig 4.16.:2.5km-res. vertical velocity HYD coupled from 5km-Hyd

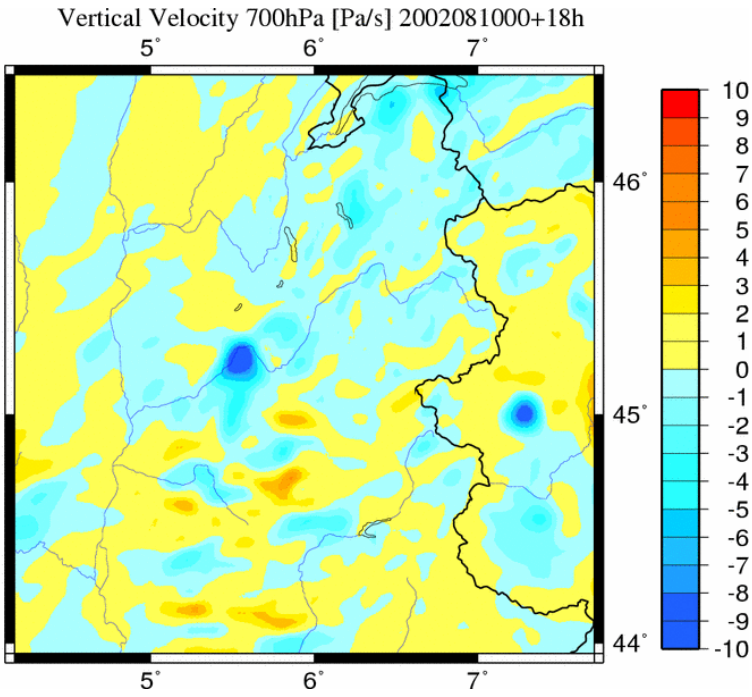

fig 4.17.: 2.5km-res. vertical velocity NH coupled from 5km-Hyd

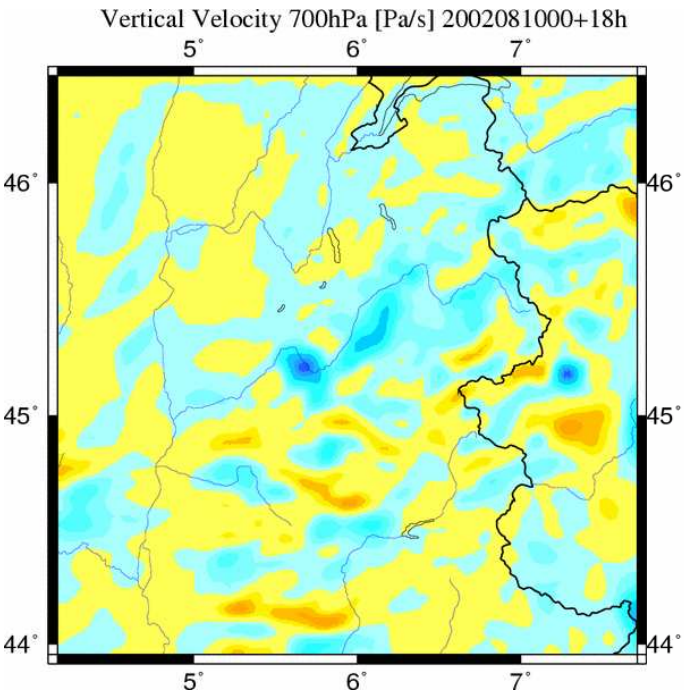

fig 4.18.:2.5km-res. vertical velocity HYD coupled from 10km-HYD

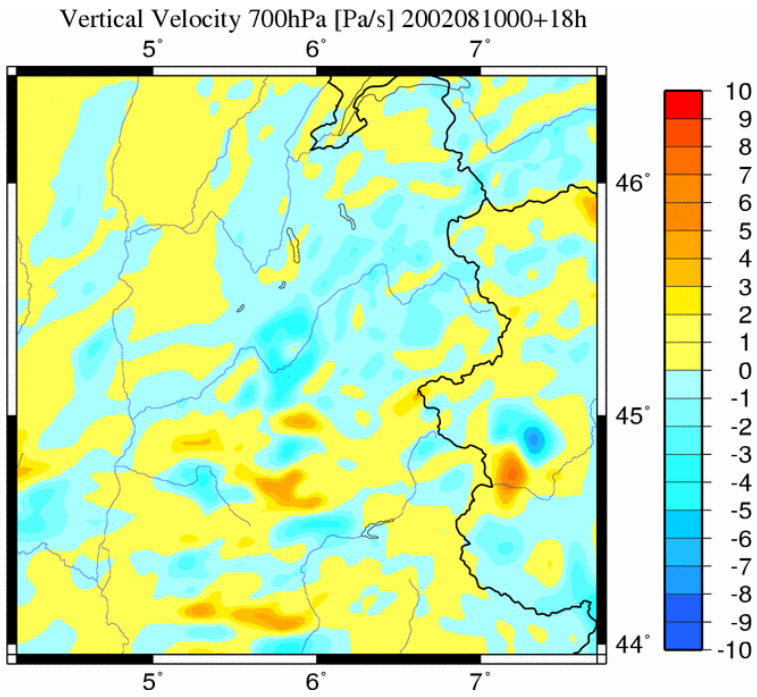

fig 4.19.: 2.5km-res. vertical velocity NH coupled from 10km-HYD

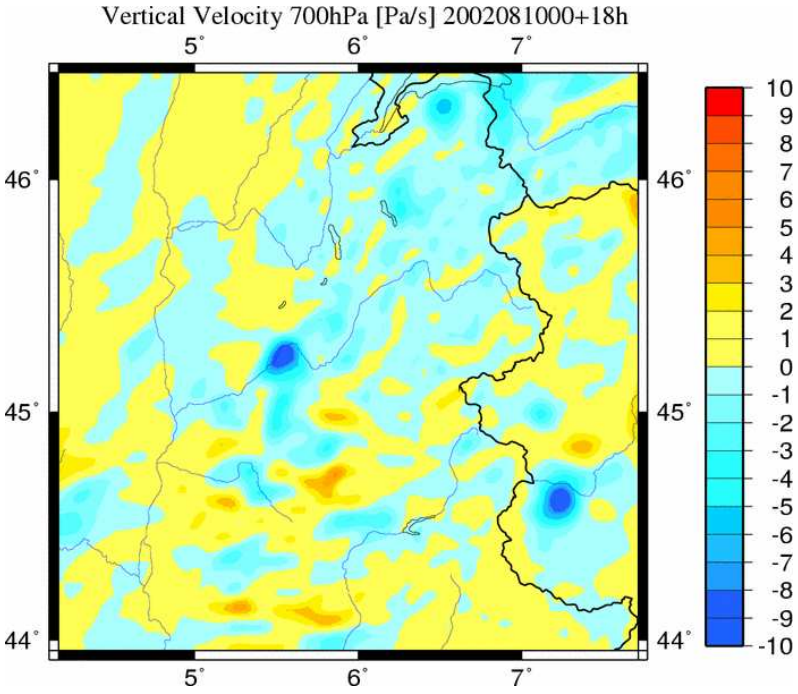

fig 4.20.:2.5km-res. precipitation NH coupled from 5km-NH

Another forecast parameter, that was examined is the temperature at 850hPa and 700hPa, respectively. Figures 4.21 and 4.22 show forecasted temperature fields at 850hPa from the NH model.
One time coupled to Lace (fig 4.21) the other time coupled to a 5km run (fig 4.22). Significant differences can easily be recognized in Bavaria.

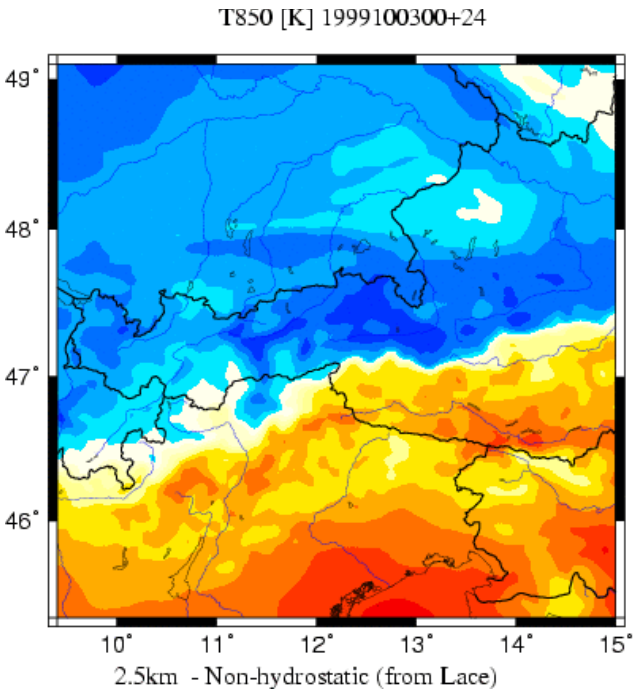

fig 4.21.: 2.5km-res. T850 HYD coupled from Lace

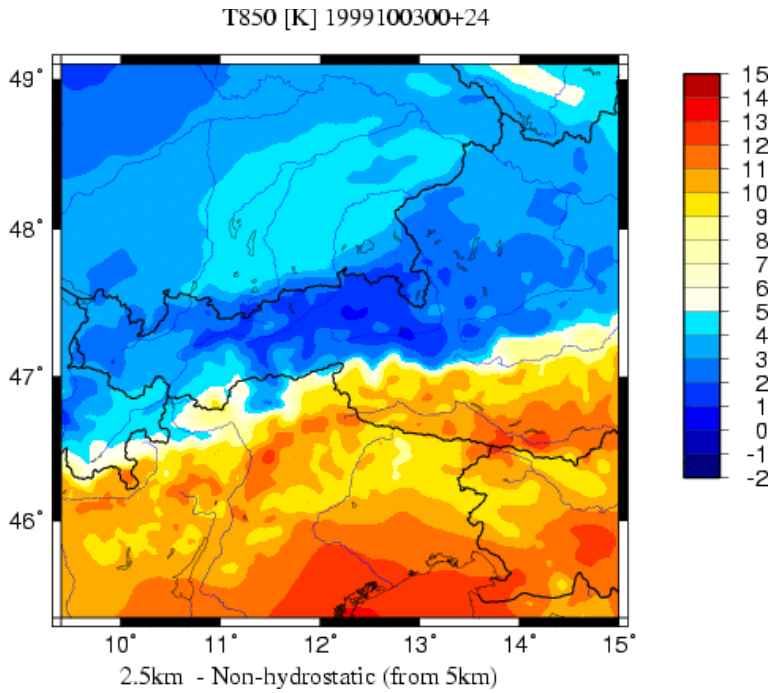

fig 4.22.: 2.5km-res. T850 NH coupled from 5km-Hyd

Figures 4.23 to 4.25 show the difference fields of 850hPa temperature. It is remarkable that besides the already mentioned difference in a larger Bavarian area the difference chart for different coupling resolutions reveals other regions with a significant signal. One reason might be, that already a small shift of the field in a region with a high horizontal temperature gradient can cause high difference values.
Nevertheless, if compared to the use of different dynamics, or coupling the NH model to a hydrostatic 5km or a NH 5km one, differences are more predicted for the different coupling resolutions.

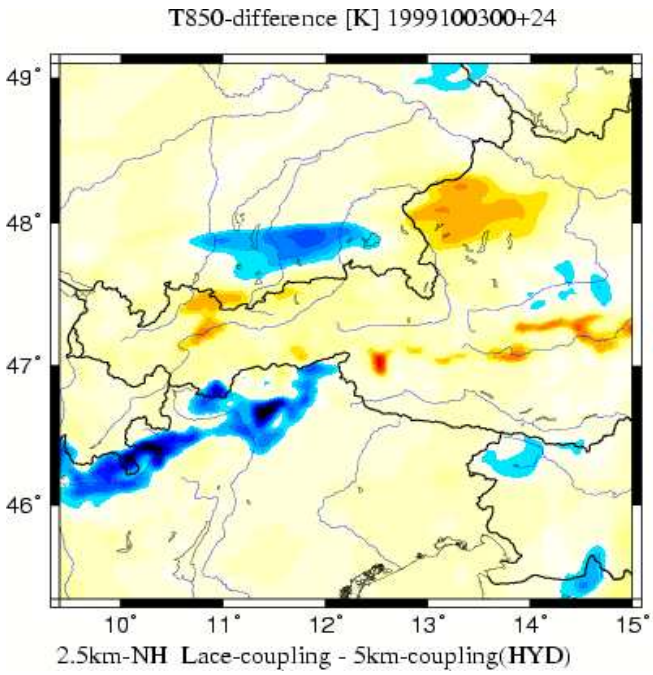

fig 4.23.:2.5km-res. T850-difference
different coupling resolutions
Lace - 5km-HYD

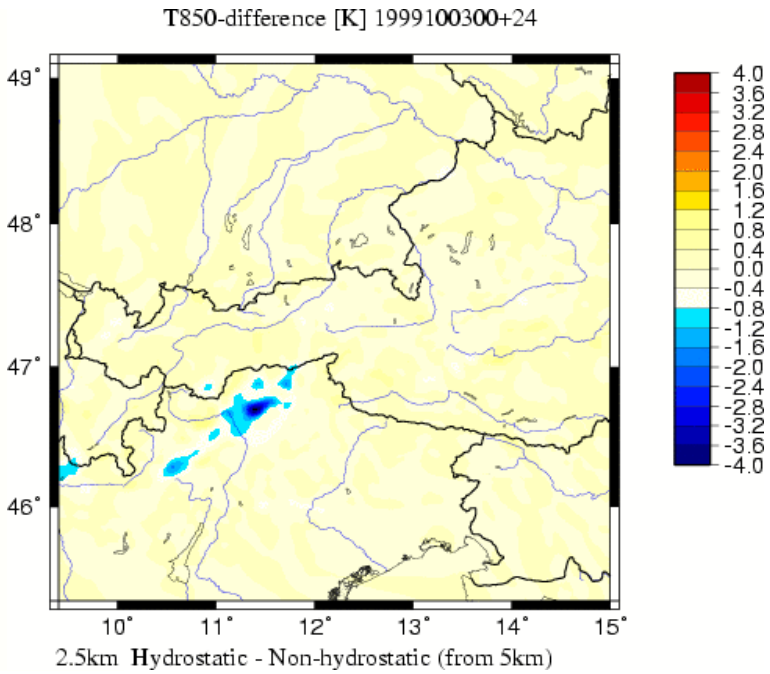

fig 4.24.: 2.5km-res. T850-difference
different dynamics (coupled from 5km-HYD)
HYD - NH

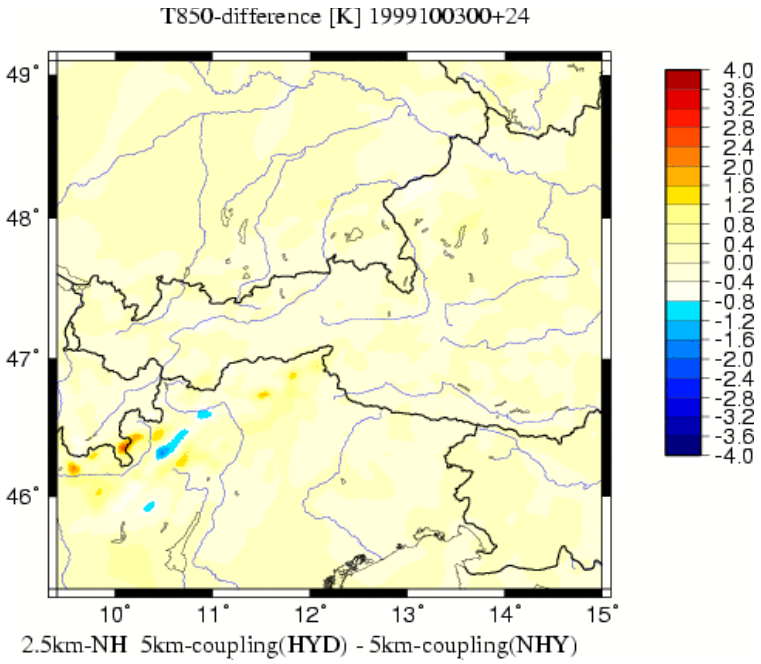

fig 4.25.: 2.5km-res. T850-difference
different dynamics of coupling files
5km-Hyd - 5km-NH

In the ALPIA case the temperature fields are more sensitive to the used dynamics. This is illustrated in figures 4.26 and 4.27. These examples also show that NH and HYD differ more, if they are coupled to 5km.

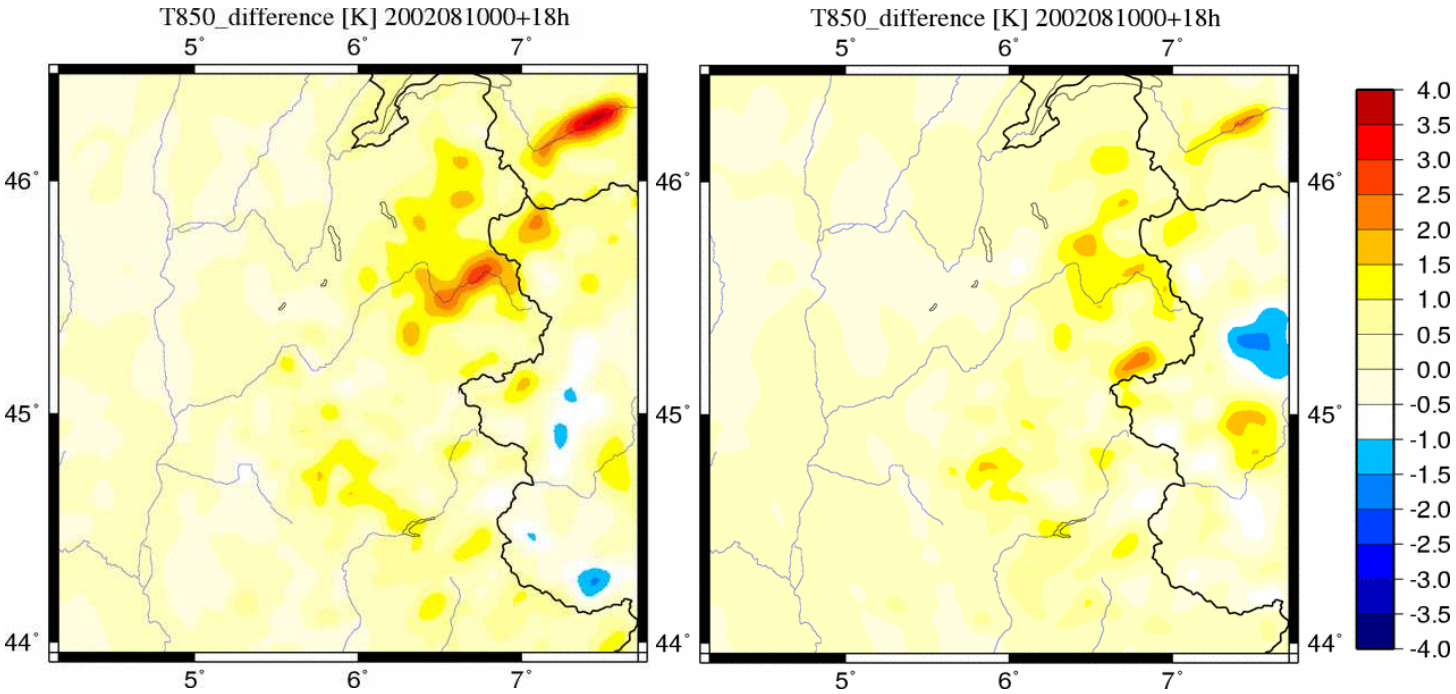

fig 4.26.:2.5km-res. T850-difference different dynamics (coupled from 5km-Hyd) HYD - NH

fig 4.27.: 2.5km-res. T850-difference different dynamics (coupled from 10km-Hyd) HYD - NH

The impact of the coupling resolution does not only appear in mountain regions, but can be found in flat regions as well, as is shown in figures 4.28 and 4.29. The domain covers parts of Hungary, Slovenia and Croatia and again coupling settings dominate the dynamics difference.

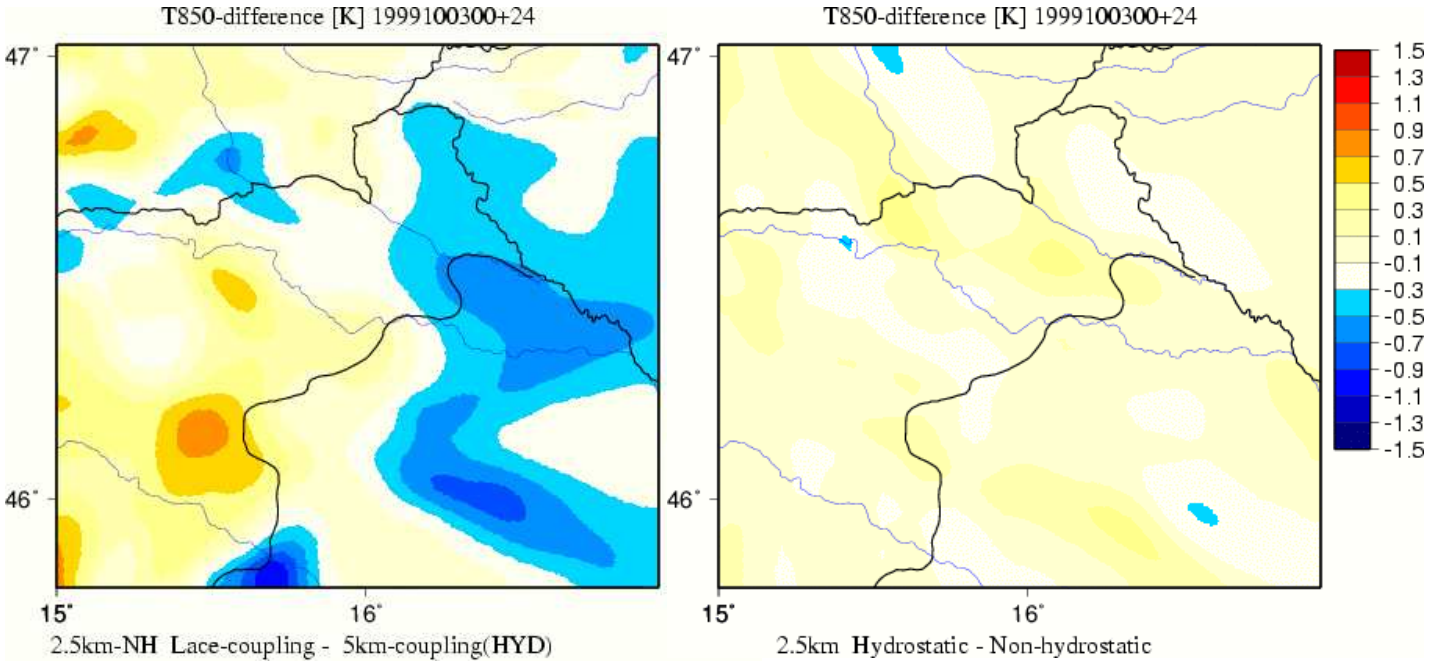

fig 4.28.:2.5km-res. T850-difference different resolutions of coupling files NH from 5km-HYD - NH from 10km

fig 4.29.: 2.5km-res. T850-difference different dynamics Hyd from5km-HYD - NH from 5km-HYD

Another look was taken at the temperature forecasts in 700hPa for the 5km runs of the ALPIA case, which clearly shows a larger signal concerning the different dynamics than the MAP case. The three following figures show the differences of the 18hour forecast. Fig 4.30 displays the difference field for the non-envelope quadratic orography, fig 4.31 the corresponding field with the usage of the envelope orography and finally 4.32 shows the result, if linear grid and smoothed orogrpahy are used. It is remarkable, that significant differences in the fields are present and that the used orography plays an important role for the magnitude and also the sign of the difference, respectively.

In this particular case the smoothed orography shows the largest differences.

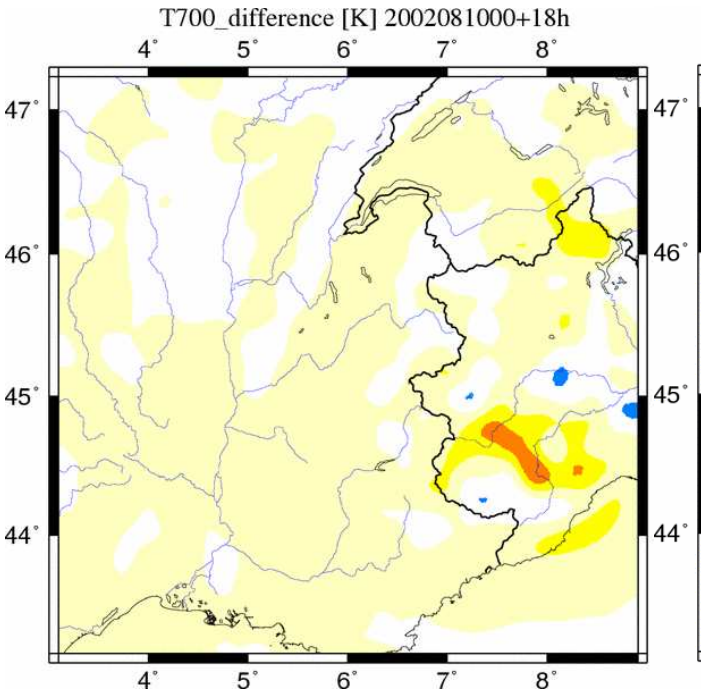

fig 4.30.:5km-res. T700-difference
different dynamics HYD-NH
quadratic grid orography without envelope

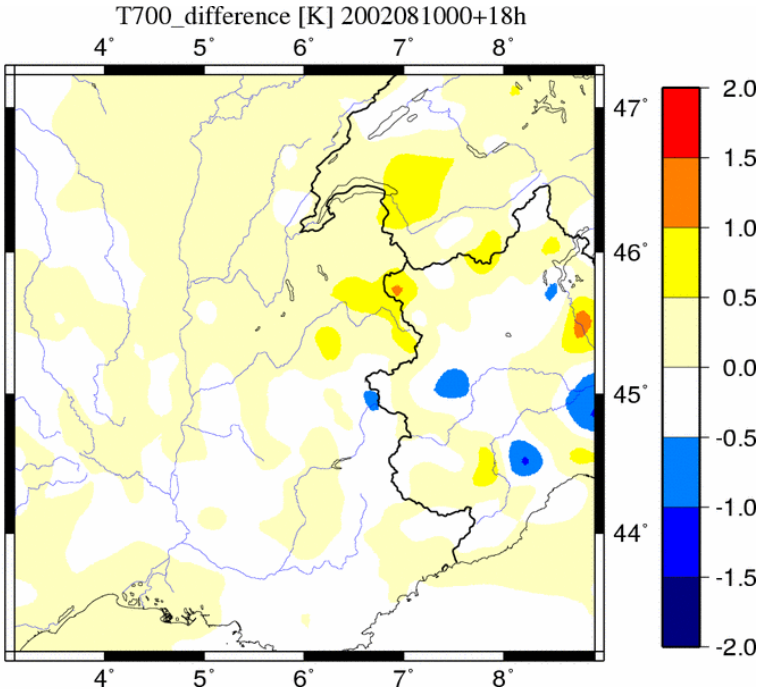

fig 4.31.: 5km-res. T700-difference
different dynamics HYD-NH
quadratic orography with envelope

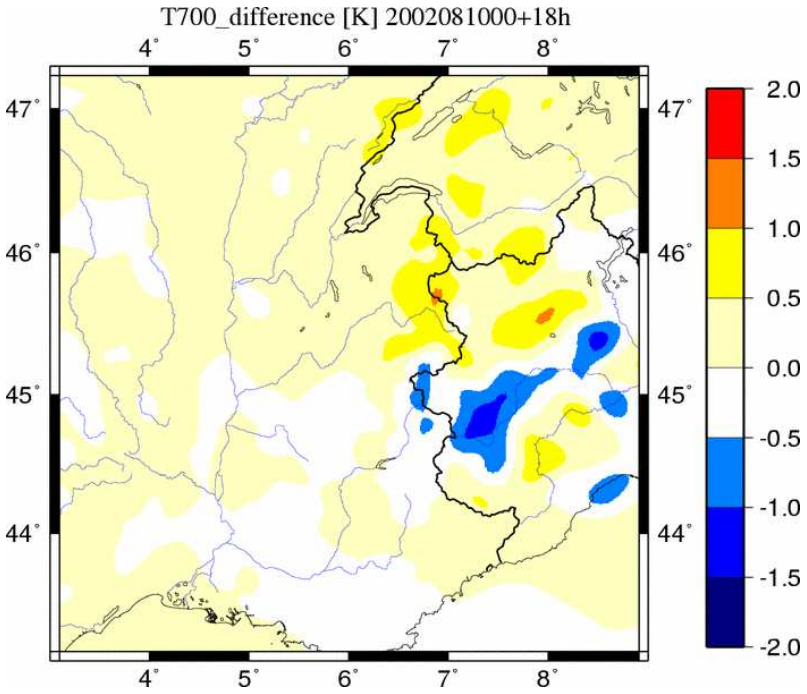

fig 4.32.:5km-res. T700-difference
different dynamics HYD-NH
linear grid smoothed orography

5. SUMMARY:

The work on the evaluation of the non-hydrostatic version of the ALADIN model on high resolution allows several conclusions.

Down to 5km resolution the model could be run without problems for both dynamics, while on 2.5km usage of a smoothed orography was necessary on domains with high and complex orography to keep the model stable.

Precipitation fields tend to become more and more unrealistic, if the resolution is decreasing. This is a general statement and valid for both, hydrostatic and non-hydrostatic version. One reason is probably, that liquid cloud water is not yet a prognostic variable in the model and therefore the amount of precipitation on the luv side of the mountains is too high, while on the lee side this precipitation is missing. This results in strange precipitation patterns in mountainous areas.

Additionally the usage of a linear grid seems a proper choice for running the model on resolutions below 10km.

If the model is run on a linear grid a modified description of the orography is required, because of numerical reasons. To apply an additional smoothing function in spectral space was tested and gave encouraging results. This orography smoothing also has a positive impact on the forecasted precipitation patterns, while the quality of the forecast for other near surface fields like 10m wind or 2m-temperature is not lost.

The cases that were used for comparison of the hydrostatic and non-hydrostatic dynamics did not reveal systematic differences on 5km resolution, but it turned out that things are strongly case-dependent. For the ALPIA case differences are much more evident compared to the MAP one. Non-hydrostatic runs show a tendency to reduce the peak amounts of precipitation and to generally smooth the precipitation field. On 2.5 km resolution the expected differences in the fields are more predicted (more extended fields and lower peak values).

For a quantitative analysis of the non-hydrostatic version several additional things have to be taken into account. This includes the resolution of the coupling data as well as the dynamics that were used for the run of the coupling model. The choice of the resolution of the coupling files is crucial and can cause the same magnitude of difference as the different dynamics. Additionally the kind of orography that is used for the forecasts has an impact on this difference. Different orographies (with or without envelope, smoothed orography for linear grid) have significant impact on the forecasted fields on high resolution.

6. PUBLICATIONS:

A.Beck,B.Ahrens,K.Stadlbacher
Impact of nesting strategies in dynamical downscaling of reanalysis data
submitted to Geophysical Research Letters (2003)

K. Stadlbacher
Contributions to ALADIN/ALATNET-newsletters 19/2,20/3,23/6,24/7
Systematic qualitative evaluation of a non-hydrostatic high resoluton model

Proceedings of 13th ALADIN-workshop in Prague (2003)
Experiences with the Aladin model on high resolution on different domains

Proceedings of ALATNETworkshop on Scientific Results in Kiralyret (2003)
Qualitative evaluation of Aladin non-hydrostatic dynamics on high resolution