Alternative approaches for moisture convergence computation in Aladin

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1 Motivation

During extensive evaluation of the new Aladin/CE model domain with increased resolution (Δx=4.7 km, 87 vertical levels and dt=180 s compared to reference operational version with Δx=9 km, 43 model levels and dt=360 s) some spurious granularity in precipitation fields was observed (for typical example see figure 1). The presence of this pattern was concluded to be relatively weather dependent, being exclusively linked to the existence of weak or medium convection activity. However the relative organization and large wide character of the phenomena led originally to its wrong association with the model dynamics. (The turbulence and shallow convection schemes have been finally found to be the primary sources explaining this noise.) Related to this, among some other tests of model dynamics, the so called moisture convergence delivered by model dynamics to closure the convection scheme was also reviewed with respect.

The present method of computing the moisture convergence is in a way Eulerian advection of moisture. Like that it might be affected by aliasing in the presence of linear truncation. Moreover it also requires the moisture field (i.e. specific humidity) to be transformed to spectral space in order to deliver horizontal derivatives. This when considering the moisture field as very inhomogeneous may lead to erroneous computation of its derivatives.

This report aims to summarize the experiments done for the moisture convergence computation. They all were done with the "noisy" turbulence scheme (using Louis function and inter-time-step memory through diagnosed

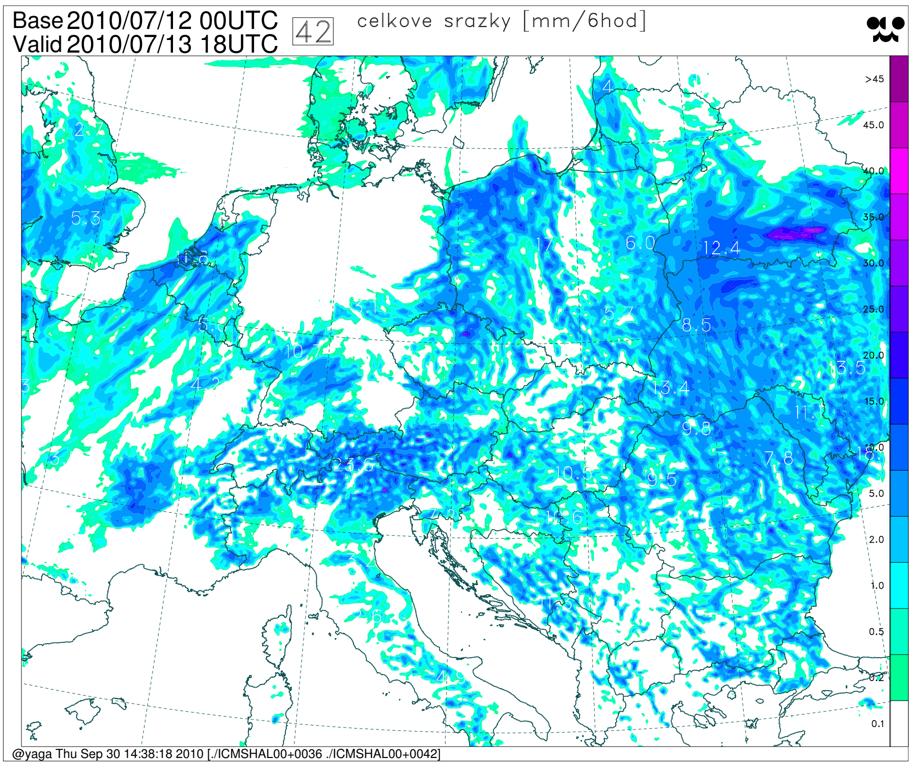

Figure 1: 6 hours cumulative precipitation after 42 hours of forecast of Aladin/CE 4.7km

and advected and diffused TKE). Like that the precipitation fields as generated by the model were very sensitive to the way of moisture processes parametrization, including the moisture convergence computation.

Although all results presented hereafter are from one particular simulation (LACE domain, Alaro physics) the conclusions were confirmed to be generally valid. This case was however selected for its very spectacular results in all discussed aspects.

2 Methods

As the alternative to the existing way of computation moisture convergence through spectral moisture (NCOMP_CVGQ=0) four other ways were explored:

1. To compute moisture convergence in (3D) Lagrangian way at the end of previous timestep (using the code under model option NCOMP_CVGQ=2 and storing it between timesteps in the GFL field YCVGQ). In such a case there is no need to transform moisture to spectral space so it is treated as pure grid-point field only here.
2. The same as above just the GFL field keeping the advected moisture is in addition smoothed by the SLHD diffusion.
3. New option NCOMP_CVGQ=3 has been coded offering the possibility to compute the horizontal components of moisture advection by grid-point formula of 4th order using pseudo-staggering (to comply with A-grid). The used formula can be illustrated by following expression of x-component of the moisture convergence (indexes stay here for the grid point positions):

$$u\frac{\partial q}{\partial x}\bigg|_i = \frac{1}{4}\left[(u_i+u_{i-1})\frac{(27(q_i-q_{i-1})-(q_{i+1}-q_{i-2}))}{24\Delta x} + (u_i+u_{i+1})\frac{(27(q_{i+1}-q_i)-(q_{i+2}-q_{i-1}))}{24\Delta x}\right]$$

   The vertical part is then computed in the exactly same way as in the reference solution. The beauty of this option is that it doesn't require that the specific humidity field is treated as a spectral field. Hence it is also treated as pure grid-point quantity in this case.
4. The same as the previous option with the difference that the moisture is treated as spectral field. This means that the moisture field is converted to the spectral space and back being slightly affected by the spectral fit deleting the $2\Delta x$ waves.

Note that options 1 and 2 are theoretically free from any aliasing. In a case it plays some role, one should detect it as the difference between those results and the reference. Option 4 then compared to the reference shows the impact of spectral derivatives which might be subject of Gibbs effect in association with steep inhomogeneities. Comparison of options 3 and 4 then gives the idea about the impact of spectral fit and $2\Delta x$ waves cut-off on specific humidity field.

3 Results

Figure 2 illustrates the different results obtained with the settings 1-4. They can be compared with the reference result of the 1 figure.

The plots on figure 2 are too small to allow detailed investigation of the results. However two points can be seen already there (justifying the reason why figure 2 is presented here): First, in general the areas of precipitations are very similar for all tested ways of moisture convergence. Knowing that this specific case is

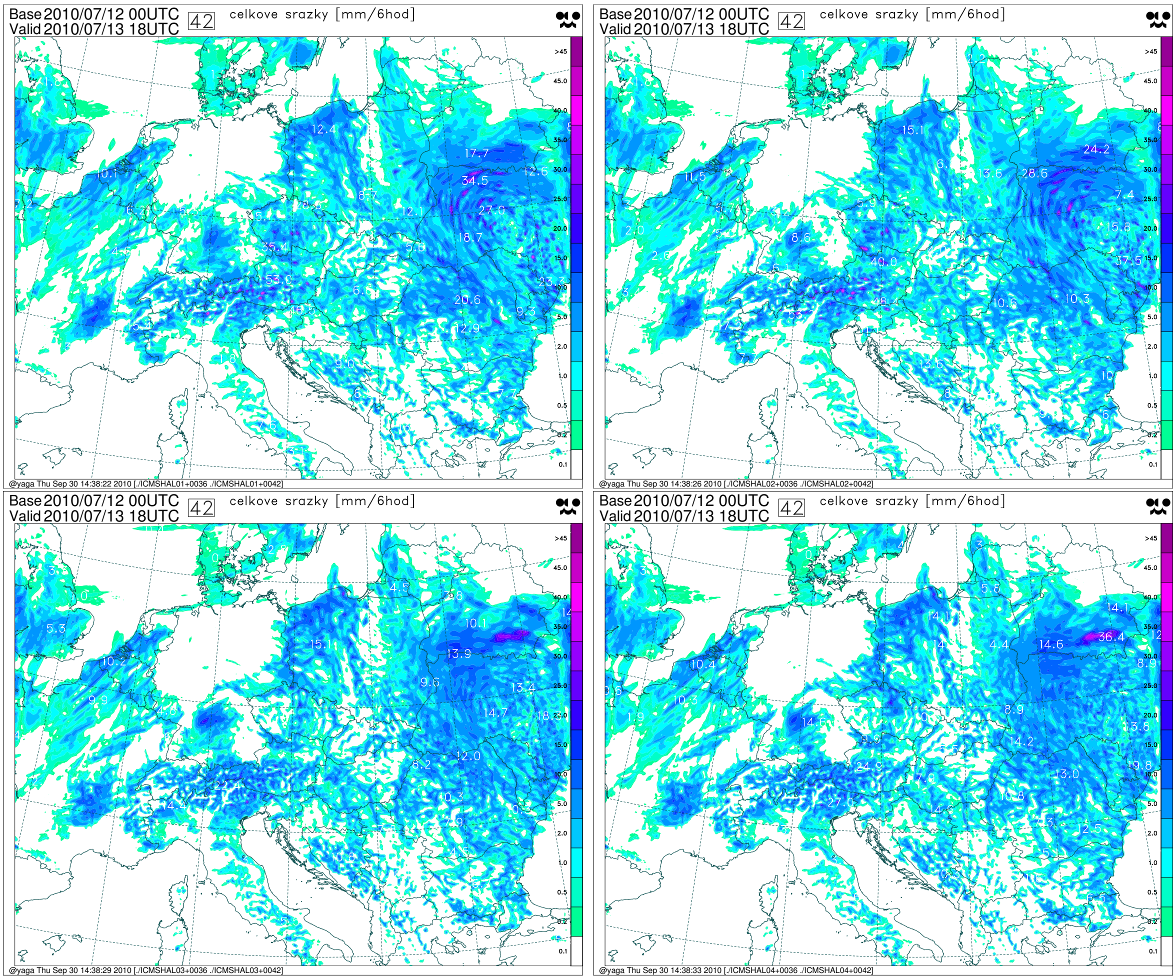

Figure 2: 6 hours cumulative precipitation after 42 hours of forecast of Aladin/CE 4.7km with tests 1-4 from top left to down right.

very sensitive to any change in the model setup (with respect to simulated convection) just illustrates that all methods are offering very comparable results. The second issue to be noticed here is however the ability of the Lagrangian methods to create some flow-dependent structures in precipitation field. This especially can be noticed in rotating cyclonic area over the western Ukraine. There the precipitation patterns evidently follow wind streams. The Eulerian methods quite missing those rotating character in the same area. This is evidently the consequence of the fact that the CFL criterion is broken there. To support this assumption, the reference run was re-launched with half timestep (i.e. 90s instead of 180s). As it can be seen in figure 3 in this case also the Eulerian methods starts to deliver some flow-dependent bands of precipitation in a way similar to those computed by Lagrangian way. The noisy pattern of the Eulerian runs than perhaps can be associated to the aliasing.

Previous seems to favored the Lagrangian way of computation. However closer look to the mountainous regions or places with active development (like above the Ukraine in the relatively flat area) as illustrated by zoomed figure 3 shows some strange spots in precipitations when computed by Lagrangian way. This seems to be rather result of the Lagrangian method associating moisture convergence from previous time-step (thus computed from $t - \Delta t$ model variables) with the physics based on model variables from time t. This tendency is even further amplified by SLHD applied to moisture convergence (being once again driven by flow deformation computed at $t - \Delta t$) in experiment 2. This is in a way just confirmation of the origin of the mentioned inconsistency.

The differences between experiment 1 and 2 are otherwise very small, so it is evident that despite pronouncing the mentioned inconsistency, impact of SLHD to smoothing moisture convergence has just cosmetic character.

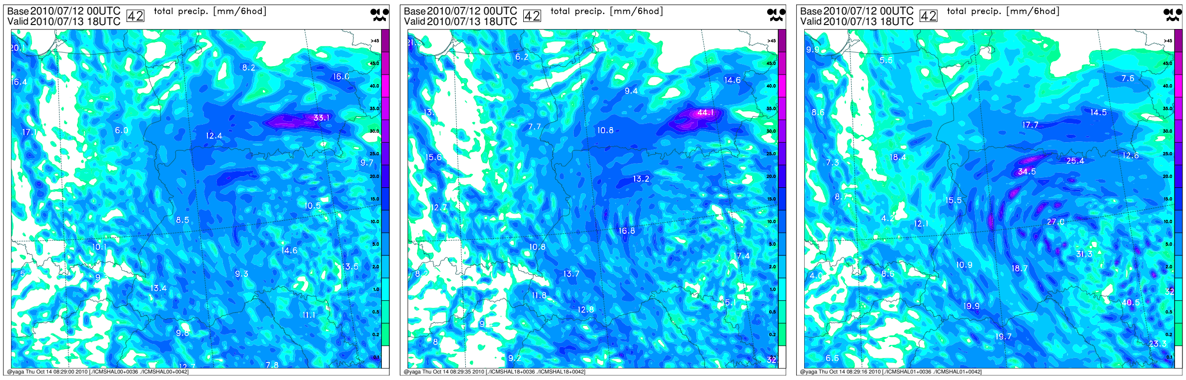

Figure 3: 6 hours cumulative precipitations (zoomed area) after 42 hours of forecast of Aladin/CE 4.7km with reference method (dt=180 s) on left, the same with halved time step (dt=90 s) in the middle and Lagrangian way of moisture computation (experiment 1) on right.

Perhaps more tests (or parallel runs for longer period) would be desirable to make any conclusion about that.

Perhaps more surprising seems to be the good consistency between reference run and experiments 3 and 4. It is evident that at least based on this sensitivity experiment the three ways are very comparable. This in a way also confirms that spectral method doesn't seem to be contaminated by Gibbs waves in terms of the moisture convergence computation. The spectral fit with the cut-off of the shortest $2\Delta x$ wave has evidently nearly no impact to the results.

All four methods were also further evaluated with respect to their performance (correctness) in lower resolution. In this respect they all seem to deliver comparable results with their higher resolution simulations. This is

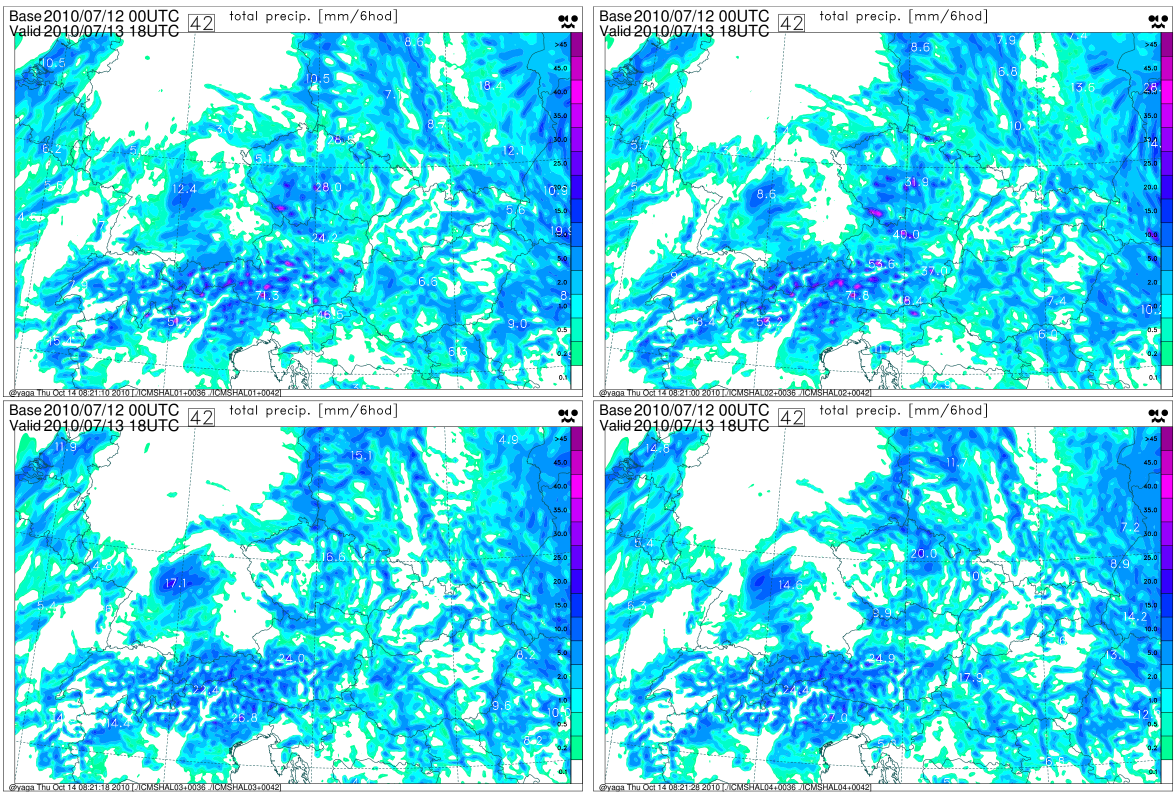

Figure 4: 6 hours cumulative precipitations (zoomed area) after 42 hours of forecast of Aladin/CE 4.7km with tests 1-4 from top left to down right for zoomed area.

especially surprising for the methods 3 and 4, using relatively wide stencil (5 times 5 points) for moisture so one would expect to find there some reduction of convection activity being result of smoothing over those wide stencils. Perhaps 45 km wide stencil for the 9 km resolution is still "small" enough to be not affected by this effect.

4 Conclusion

Five different ways of moisture convergence computation were evaluated here for the Aladin model (and its time step organization). None of them was found fully appropriate to every situation. The Eulerian way seem to be affected by broken CFL criterion, so it doesn't perform well for areas with strong wind. (For both investigated model configuration the limiting horizontal speed over which the moisture criterion starts to deliver incorrect results is around 25 m/s. And perhaps in this case the vertical CFL is even more important, with steep slopes and very high vertical resolution with 87 model levels.) In addition the small scale information might be also consequence of aliasing.

The Lagrangian way suffers from the inconsistency between moisture convergence and model physics. This could be improved by rearranging the time-step organization in the way that physics is computed after dynamics, so both moisture convergence and physics are computed by using the same time level model variables (like it is the case in IFS or Hirlam models). But this is indeed out of the scope of this study.

The Eulerian way perhaps seems to be still preferable solution out of the two. It delivers inaccurate results only for areas with strong (large scale) vertical motions or horizontal wind exceeding 25 m/s. For those there's further a hope that convection is not the dominating forcing there. The Lagrangian way for Aladin time-step organization with higher resolution means that the inconsistency might play increasing role. This was also experimentally confirmed by detecting much more "spotty" areas in higher resolution run compared to the lower resolution one.

It is evident that none of the two methods is ideal. Natural cure would be to rearrange time-step organization and apply the Lagrangian method. But perhaps much simpler way to solve the existing problem would be to introduce a prognostic treatment for the convective closure as it is planned for the 3MT scheme.

Another outcome from this study shows that the grid-point and spectral methods are both scientifically fully appropriate for investigated scales. While however spectral method is relatively efficient (requiring only several transpositions prior to computations in various model spaces) the 5x5 points stencil required for grid-point derivatives implies either additional communication or multiplication of model arrays when aiming the distributed computing architectures. Like that the spectral solution is still the most efficient one[1].

[1] For the reason of complicated data-flow and not really useful results (i.e. offering no extra quality on top of the existing model options) the NCOMP_CVGQ=3 code was not promoted to the common source code.