An integrated package for convection, clouds and precipitation

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Context

Our 4-years research effort aiming at integrating the main ”moist” parametrizations – deep convection, resolved condensation, microphysics – into a coherent package, has now reached the maturity. It succeeds at producing realistic behaviours at all resolutions, from grid meshes larger than 20km (where deep convection is subgrid) to 2km (where deep convection is mostly resolved), including the intermediate resolutions (typically 4km); and most important, the forecasts at these different resolutions are consistent with each other. The package, developed in the frame of the Arpège-Aladin Model, includes:

- A large-scale condensation scheme base on Smith (1990).
- A prognostic mass-flux scheme for the convective updraught, which is an extension of the scheme described in (Gerard and Geleyn 2005). The new scheme detrains condensates which are combined with the resolved condensates before entering the microphysics. It affects the resolved model variables through a convective transport flux and convective condensation fluxes (Piriou 2005).
- Microphysical routines widely derived from the scheme of Lopez (2002). We use cloud ice and droplets as model prognostic variables (advected by the model dynamics), while the precipitation contents (solid and liquid) are simply diagnosed together with the precipitation fluxes. Lopez’ original routines have been refined to have a completely coherent treatment of the heat and water fluxes. We added a parametrization of the Bergeron effect.
- A prognostic mass-flux parametrization of a moist downdraught, driven by the evaporative cooling of the precipitation estimated in the microphysics.

The core principle of the package is the use of a cascading approach, avoiding double counting of the sources of condensation. We also introduced a coherent treatment of the turbulent diffusion based on conservative variables. The use of the Semi-Lagrangian Horizontal Diffusion (SLHD) developed by F. Váňa was found beneficial. We were able to reduce drastically the main scaling parameter SLHDA0 by a factor 300 when using our integrated package, which suggests a better behaviour of the energy spectrum than in the operational model.

Technical challenges

The acute verification of the functioning and the behaviour of such a large package required to make tri-dimensional experiments, because the closure of the convective updraught, based on the moisture convergence towards a grid box, and the use of prognostic variables, induce 3-D feedbacks that are absent from single-column model tests. The evolution of up- and downdraught profiles as well as the evolution of the internal variables passing through the microphysical routines, had to be assessed thoroughly.

The key was the development of specific software to be able to follow internal variables within the physics package without being submerged under data.

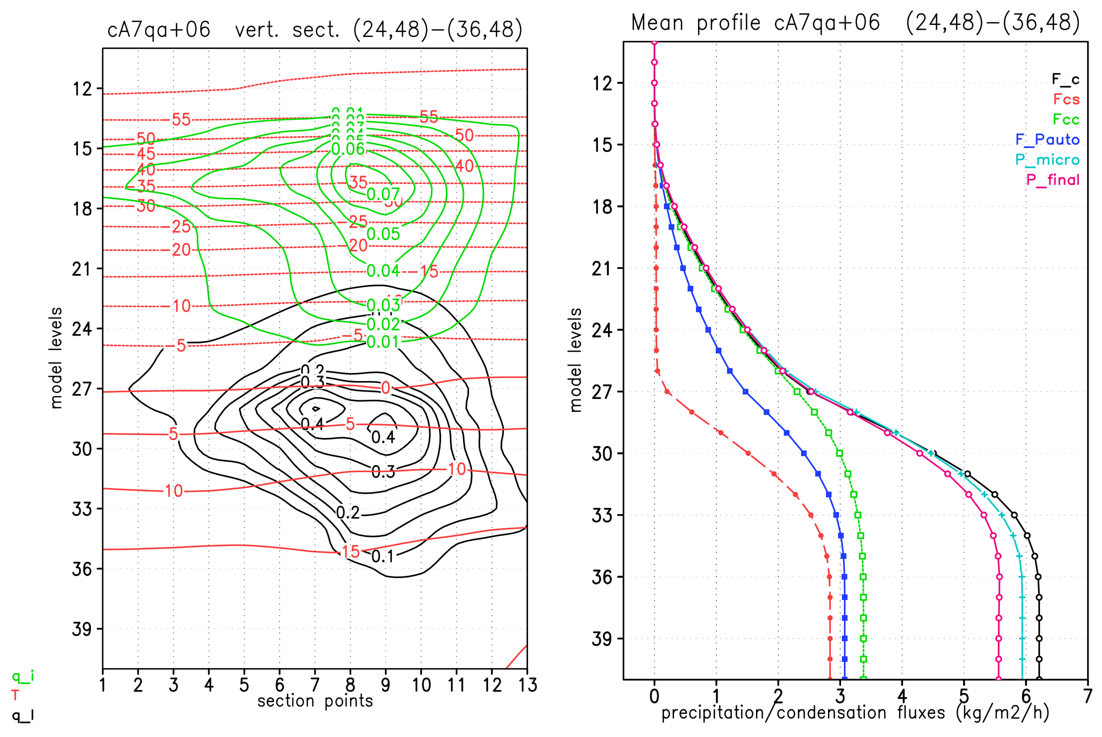

Figure 1: **Vertical cross section in a 3-D run. Left: temperature (°C, red), cloud ice (g/kg, green), cloud droplets (g/kg, black). Right: mean profile over the same section of the resolved condensation flux (red dashes), the convective condensation flux (green dots), their sum (black), the auto-conversion flux (blue), the total precipitation from auto-conversion, collection and evaporation in microphysics (cyan), and the final precipitation flux after the downdraught (magenta).**

Varying the model resolution

We show below a situation of active thunderstorms that caused very intense showers over Belgium on 10 September 2005. The operational model (no microphysics, diagnostic convection) missed most of the episode.

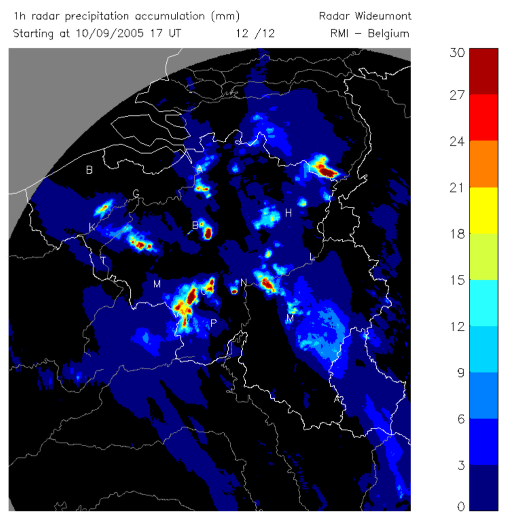

Figure 2: **Radar observation: 1-h accumulated precipitation (mm/h)**

The next pictures show a same forecast at 6.97, 4.95 and 2.18km with the new integrated scheme (left) and when switching off the deep convection scheme (right). Apart from geometry, all model tunings were identical, e.g. the model was run in hydrostatic mode.

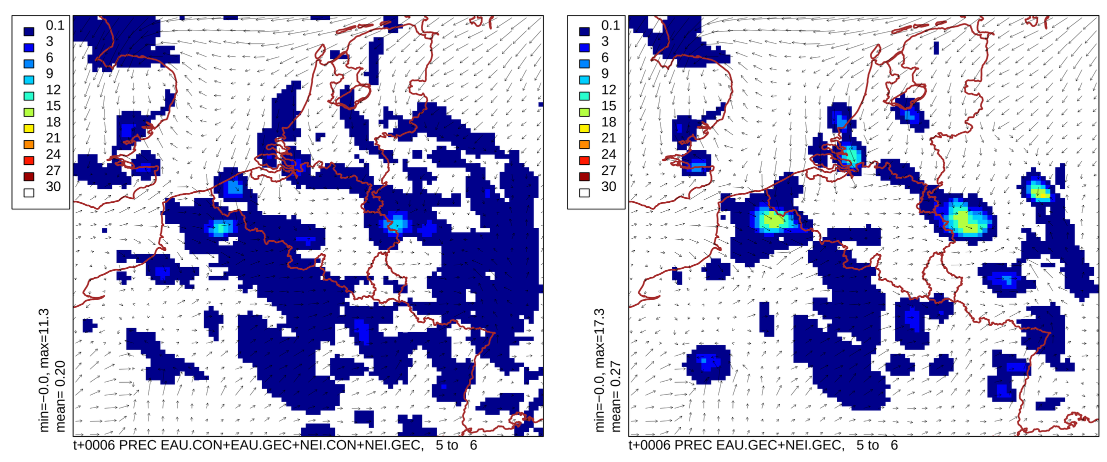

Figure 3: **Forecast at 7 km resolution. 1-h accumulated precipitation (mm/h), 10-m wind. Left: Integrated package, right: with no convection scheme.**

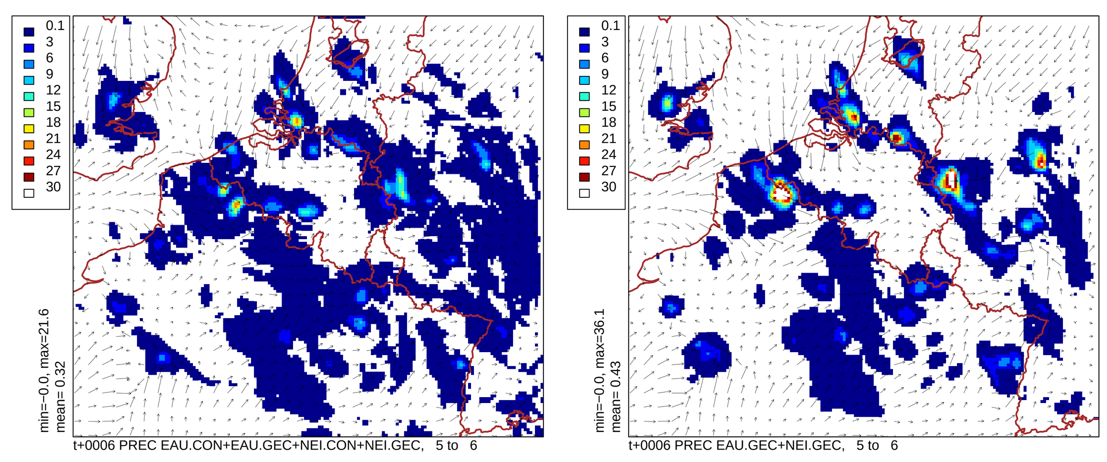

Figure 4: **Same as Fig. 3 for 4km resolution**

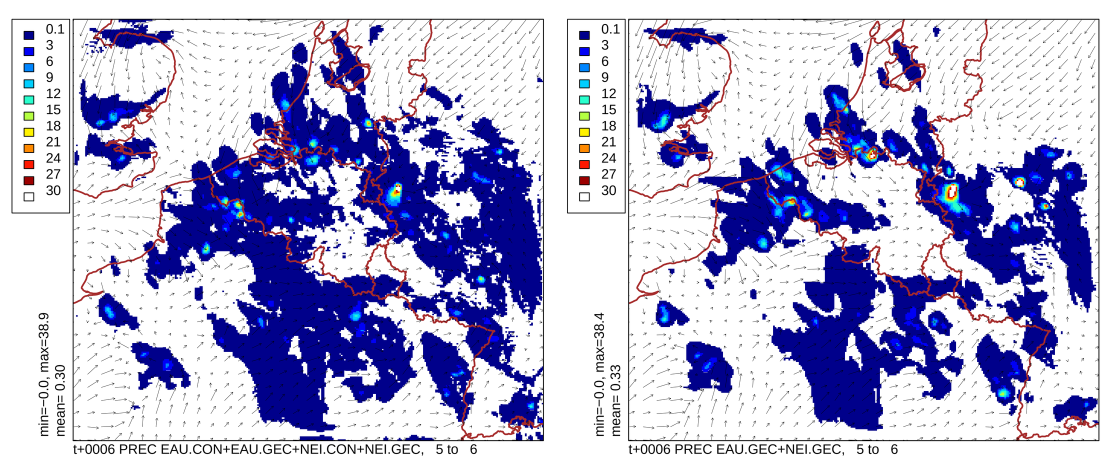

Figure 5: **Same as Fig. 3 for 2.18 km resolution**

The integrated scheme results at the different resolutions are consistent, i.e. the location of the maxima are the same and the amounts increase regularly with increasing resolution. The smaller precipitation amounts at coarser resolution come first from a wider averaging area. The smoother model orography and the bigger uncertainty on the correlation between vertical velocity and water vapour contents are additional sources of differences.

This case also illustrates the importance of using a parametrization of deep convection (and one which is fit for high resolution): when we switch it off (right of Fig. 3 to 5), the convective updraughts are forced to a coarser-than-realistic scale, producing a too strong atmospheric response (Deng and Staufer, 2006): the areas of intense precipitation are much wider than observed. In the 2.18-km run, the convection scheme still produces significant condensation, while without it the resolved scheme alone takes over the totality.

The prognostic convection scheme is by construction non-hydrostatic: in the frame of the hydrostatic model dynamics, it appears that it continues to enhance the forecast down to the 2-km resolution.

Benefits at 7-km resolution

This is a first demonstration that our scheme may be beneficial at coarser resolutions. The prediction of our operational Aladin model for 17 August 2006 (using diagnostic schemes and no cloud water variables) was particularly unrealistic, showing intense precipitation over all Belgium, and the birth around 18:00utc of a local depression in the South of Belgium, which deepened and moved slowly to the North-East (to be on the North of Netherlands 12h later).

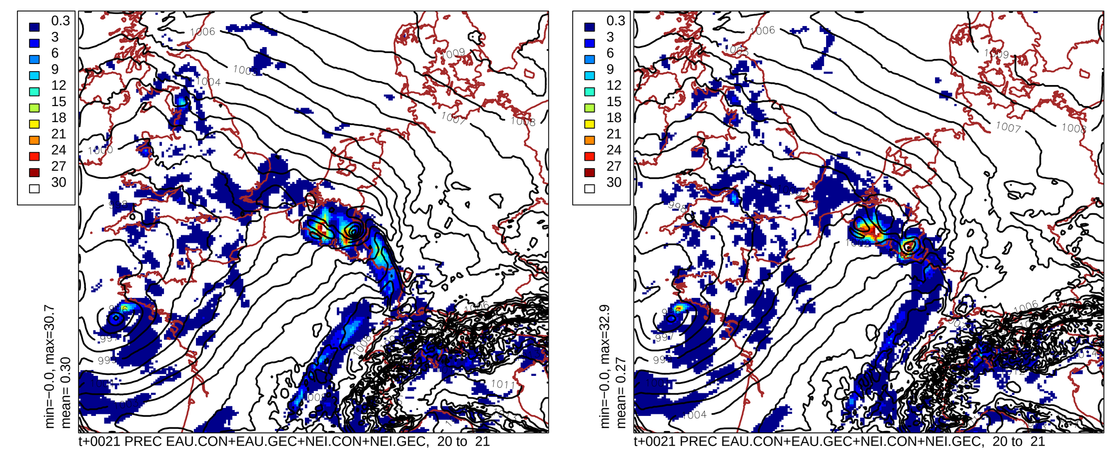

Figure 6: **2006-08-17, 21:00 utc. 1-h accumulated precipitation (mm), mean sea-level pressure (hPa). Left: operational Aladin-Belgium model (7-km grid mesh, 46 vertical levels). Right: same with SLHD.**

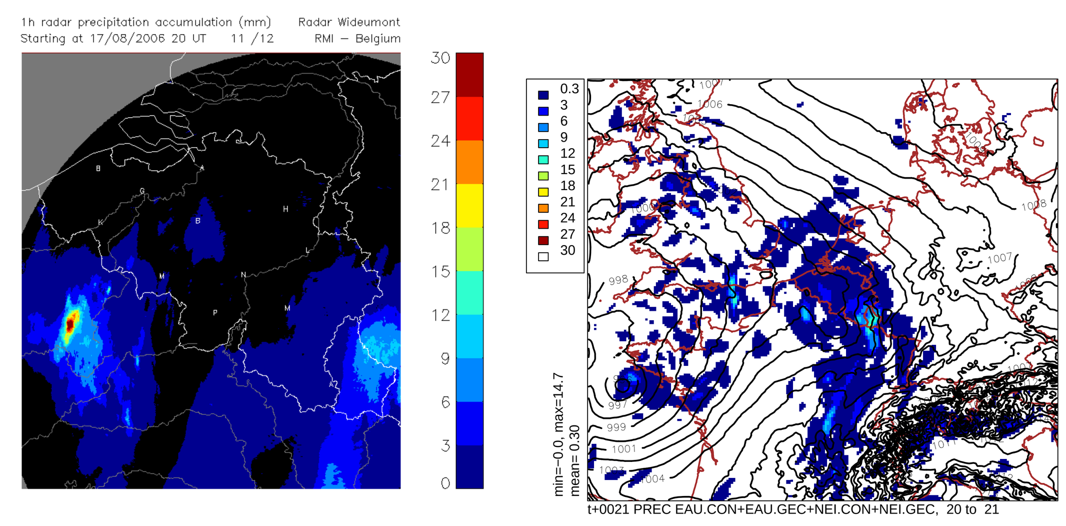

Figure 7: **2006-08-17, 21:00 utc. Left: Radar picture: 1-h accumulated precipitation. Right: new integrated package, same geometry as operational.**

On Fig. 6 the operational forecast for 21:00 utc presents intense precipitation over South of Belgium and the bogus surface low around 997 hPa.

Using the Semi-Lagrangian Horizontal Diffusion scheme smoothes the low to around 1000 hPa, but the maximum precipitation is even bigger (32.9 mm/h instead of 30.7)

On the contrary, with our new integrated package (Fig. 7, right), the bogus depression has completely disappeared, while the accumulated precipitation (5 to 9 mm/h on Belgium) is much more acceptable compared with the location and amounts given by the radar picture (left).

Perspectives

This research will be the object of a publication in the coming months. The integrated package is presently being included in the new ALARO-0 version of the ALADIN model, where it will also be able to use different resolved-clouds or precipitation schemes. Thorough validation tests in this frame are programmed for this autumn. Some more refinements are being tested, like the use of a prognostic mixing in the updraught parametrization.

References

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