Impact of different PBL parameterizations on the resolved deep convection in the AROME model

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Introduction

At the Hungarian Meteorological Service (HMS) the AROME model is used operationally to predict high-impact weather. The quality of the AROME forecasts is evaluated with subjective and objective methods since the beginning of 2010. The gathered experience shows that the simulation of convective precipitation is highly sensitive to the applied turbulence and shallow convection parameterization. Consequently, the aims of the present study are the following:

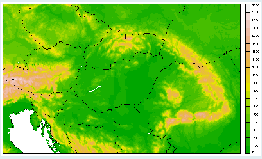
- Show the impact of different turbulence and shallow convection parameterizations on the resolved deep convection in AROME, by analyzing case studies and a longer continuous period
- Understand the link between turbulence, shallow convection and deep convection based on the investigation of vertical profiles
- Introduce the SAL verification as a useful method for quantifying the differences in the forecasted precipitation fields

AROME experiments

AROME is a non-hydrostatic numerical weather prediction model developed by Meteo France (Seity et al., 2010). It consists of the non-hydrostatic ALADIN dynamical core, the physical parameterization package of Meso-NH and the Surfex land surface model.

The main features of the AROME model used in the experiments are the following:

- Model version: CY35T1
- 2.5 km horizontal resolution (500*320 points)
- 60 vertical model levels
- Upper-air initial and lateral boundary conditions from ECMWF/IFS
- Surface analysis interpolated from ALADIN/HU
- 3 hour coupling frequency of LBCs
- All runs started at 00 UTC
- 36 hour simulation
- No data assimilation



The operational AROME domain used at the Hungarian Meteorological Service.

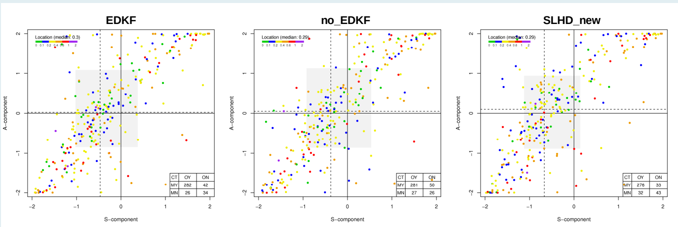
To test the impact of turbulence and shallow convection parameterizations on the resolved deep convection, three experiments were performed:

1. Turbulence and shallow convection are **parameterized separately**. For turbulence the CBR scheme is applied (Cuxart et al., 2000), for shallow convection the Kain-Fritsch scheme is used (further referred to as the „noEDKF" run). As in the operational AROME configuration at HMS, the non-linear, flow dependent Semi-Lagrangian horizontall diffusion sheme (SLHD) is applied to all (falling and non-falling) hydrometeors.
2. Turbulence and shallow convection are parameterized with the **Eddy Diffusivity – Mass Flux** method, which combines these two approaches. In the present AROME configuration the CBR scheme is used for turbulence. The mass-flux contribution follows an original approach in the dry part of the boundary-layer. In the cloudy part of the updraft the Kain-Fritsch scheme is utilized ("EDKF" run; Pergaud et al., 2009). SLHD settings are same as for the previous experiment.
3. This experiment tests the impact of **horizontal diffusion**. As compared to the first two experiments, SLHD is applied to alll dynamical fields (temperature, wind, vater vapour), but not to the falling hydrometeors („SLHD_new" run; Bengtsson et al, 2011). The supporting spectral diffusion is switched off below 100 hPa in this experiment.

Verification of a one-month summer period

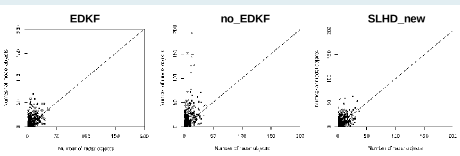
Next to the case studies a longer period period, between 17th July 2010 and 17th August 2010, has also been investigated. Compared to the long-year average the summer of 2010 was very wet, consequently, the number of convective cases to be verified was rather high during this one month. Standard verification techniques (comparing the model with Synop and TEMP observations in a grid-point manner) have not shown significant differences between the three experiments. Therefore, new verification techniques were implemented at HMS using the precipitation measurements of weather radars.

Here, results of the SAL verification (Wernli et al., 2008) are presented. In the case of the SAL verification, precipitation objects are defined both on the forecasted model precipitation field and the radar field, however, these objects are not associated, but relative differences between the characteristics of the model and radar objects are calculated. These characteristics are the Amlitude (A), Structure (S) and Location (L), which are visualized together on the SAL-plot. For the definition of objects a dynamic threshold was used, i.e. the threshold was chosen as 1/15 of the maximum of the precipitation field.



SAL-plots for the three AROME experiments for the one-month period. Calculated using three hourly accumulated precipitation. All lead times (between +3h and +36h) are verified together. Dashed lines account for the medians of A and S, the shaded area shows the 25% and 75% percentiles.

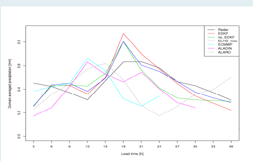
Results show, that the area averaged precipitation (averaged for the whole forecast range, A component) is very well forecasted by AROME, and no significant differences are detected between the three experiments. The S component is negative, which means that the size of precipitation objects is underestimated by the model. Largest negative values of the S component are seen for the "SLHD_new" experiment. The Location component (in colors) is similar for the three runs.



Scatter plots for the observed and predicted number of precipitation objects in the SAL verification.

As shown also for the case study of 22nd July the „no_EDKF" run strongly overestimates the number of precipitation objects during flat anticyclonic situations. A slight overestimation can also be detected for the „EDKF" run, while the „SLHD_new" run has practically now bias for this characteristic. This further reduction of cells is attributed to the stronger horizontall diffusion in the case of the „SLHD_new" settings.

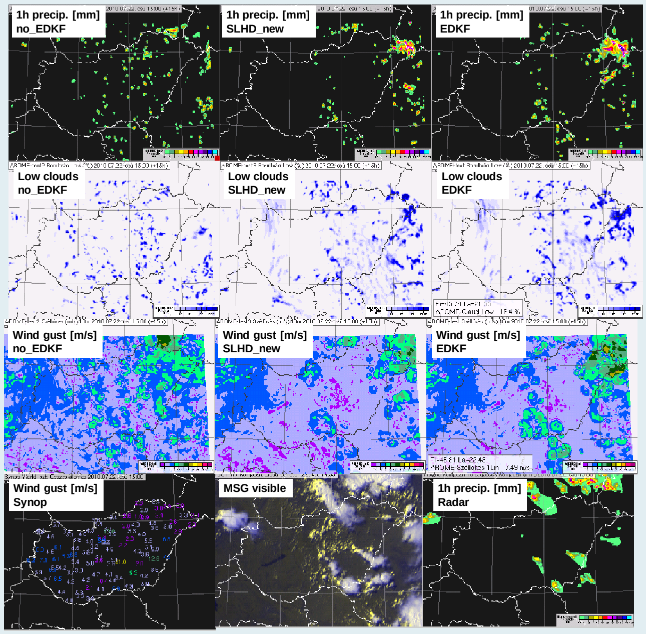
An important characteristic in forecasting heavy precipitation events is the ability of the NWP model in forecasting the timing of convection. For the one-month period the simulated diurnal cycle of precipitation was compared to radar measurements. Models with a parameterized deep convection (ECMWF/IFS, ALADIN, ALARO) initiate convection too early. The AROME model with resolved deep convection performs much better in this respect. The problem of the „no_EDKF" run (too many cells) is also present in this plot (overestimation between +12h and +15h). Among the three AROME experiments the „SLHD_new" run performs best.



Observed and predicted diurnal cycle of precipitation for the one-month prediod (domain averaged precipitation).

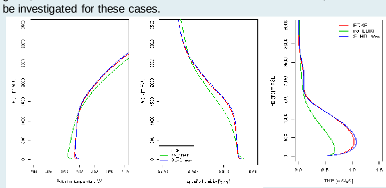
Case study – 22nd July 2010

The three AROME experiments were first compared on selected case studies. Largest differences between the experiments were detected during synoptic situations with weak large scale forcing. In the following, a case study for the 22nd July 2010 is presented. On this day the weather situation over Hungary was characterized by an anticyclone. In the early afternoon light to medium strength showers were observed which developed to heavy thunderstorm in the evening.



Forecasted fields of the three AROME experiments and measurements for 22nd July 2010 at 15 UTC (+15 h forecasts).

As presented on the figures above, the "no_EDKF" run significantly overestimates the number of convective cells during early afternoon, while during the evening it fails to simulate the heavy thunderstorms (not shown here). Also convection itself is initiated too early (around 8 UTC) in this experiment. The "EDKF" and "SLHD_new" runs are more successful in predicting the diurnal evolution of precipitation, by reducing the number of convective cells. The application of Semi-Lagrangian horizontal diffusion on the dynamical fields ("SLHD_new" run compared to "EDKF" run) slightly reduces the number of cells, however, it also decreases the convective wind gusts, which leads to an underestimation for this case. However, the role of the applied wind gust parameterization in AROME is still to be investigated for these cases.



Domain averaged vertical profiles of the three AROME experiments for 22nd July 2010 at 13 UTC (+15 h forecasts).

The reason why the "no_EDKF" run produces too many convective cells is given by the early afternoon profiles. As opposed to the two other experiments, this run simulates a too shallow Planetary Boundary Layer (PBL) with weak turbulence. This is attributed to the fact, that here only a local turbulence scheme (CBR) is applied, which fails to simulate the non-locat nature (large eddies) of the convective PBL. The hybrid EDKF scheme accounts for these non-local effects through the mass-flux contribution. Consequently, with the EDKF scheme more energy is dissipated in the PBL which hinders the development of small cells, and delays the initiation of convection.

Conclusions

Based on the detailed investigation of case studies and the verification results of the one-month period, the following conclusions can be drawn:

- The choice of the PBL scheme has a significant impact on the resolved deep convection in AROME
- The higher PBL mixing resulted by using the EDKF scheme reduces the number of cells and improves the timing of convection
- Even with using EDKF (current operational setting at HMS) the number of convective cells is still slightly overestimated
- The application of Semi-Lagrangian horizontal diffusion reduces the number of cells and also the precipitation peak during early afternoon, which corresponds better to radar observations
- The diurnal cycle of convective precipitation is well forecasted by the AROME model, as compared to other NWP models with a parameterized deep convection

References

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Acknowledgement: Discussions through the COST Action ES0905 are acknowledged.