Project: **722**
Project title: **High Order Schemes for the COSMO model**
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In 2016 higher order schemes were implemented in COSMO model version, 'cosmo_'. The 4^{th} order 'symmetric' advection (advS4) together with 4^{th} order fast-waves solver (p4) discretisation has been shown to conserve the kinetic energy a priori. The advS4p4 scheme was found to allow stable simulations without any implicite or explicite horizontal numerical diffusion (d0.00). A series of 2 to 5 year simulations was conducted to investigate the stability properties and the climatology in comparison with the reference scheme (AdvC3p2d0.25) for the standard domain Europe at horizontal resolutions 0.44, 0.165, 0.11 and 0.0625 degrees using the recommended configuration of the CLM-Community and for the domain Germany at 0.04 and 0.025 resolution using the reference configurations of Deutscher Wetterdienst at convection permitting scales COSMO-DE.

We found that all AdvS4p4d0.00 simulations were running stably. However, the reference scheme AdvC3p2 required additional explicit horizontal diffusion at all resolutions. This was also the case if AdvS4 was used together with 2^{nd} order fast waves solver (p2). As shown by Ogaja & Will (2016) this is consistent with the theoretical analysis of energy conservation and implicite alias error removal of the schemes.
An investigation of the performance of the AdvS4p4 scheme showed that the symmetric advection scheme consumed 20 times more computing hours than the reference scheme AdvC3p2 resulting in a doubling of the cost of computation. The application of the tools offered by DKRZ allowed to identify the additional boundary exchange used in the implementation for the additional interpolation to be responsible for that. A carefull analysis of the scheme showed, that this additional boundary exchange can be avoided. A new implementation of the AdvS4 scheme was introduced in cosmo_5.0_clm9 and the performance tests have been repeated. As shown in Figure 1, the new implementation exhibits no increase in computing time anymore. This makes the AdvS4p4d0.00 scheme a candidate for a new generation of non-dissipative dynamical cores of atmospheric dynamics.

The scheme advS4p4v2 also indicated improved stability from the time series of its L1 error norms. All these results can be seen in Fig. 1. The implementation of the new schemes was thus considered successful.

For the real test simulations, ECMWF's ERA-INT reanalyses data were used as the boundary conditions to perform long time (at least 1 year) simulations using the new COSMO higher order schemes in a domain covering Europe. The configuration included 257x271x40 grid points with a time step of 150s and grid spacing of 16km in zonal and meridional directions. Sensitivity study on the artificial diffusion was conducted and from the results, advS4p4v2 scheme exhibits significant differences for mean temperature after one year of simulation (see Fig. 2). The simulation has been extended to run for 5 years for further analysis of the means and higher order statistics.

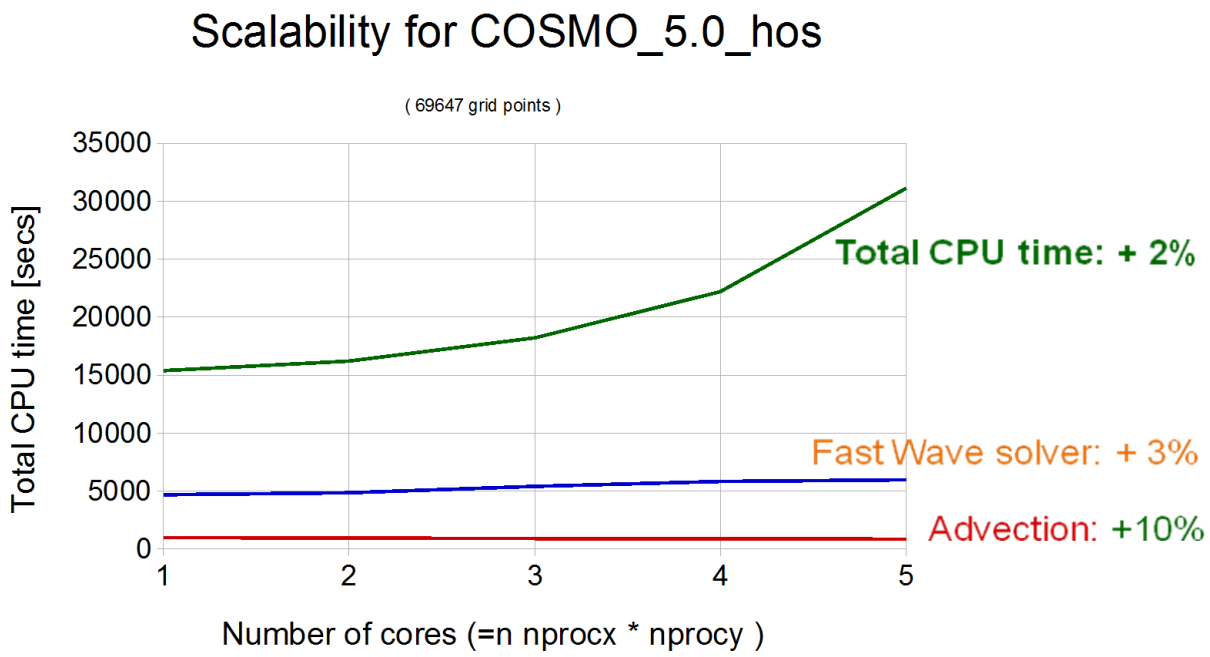

Figure 1: Simulation cost in CPU seconds (lines) and the additional cost of S4p4 scheme in comparison with C3p2 scheme (numbers right) in dependence on the number of nodes (24 processors each) on mistral for the total computing cost, advection and fast waves solver only.

Fig. 2 shows the difference of July 2000-2001 mean of daily maximum of the horizontal windspeed in 10m above ground between the AdvS4p4d0.00 and AdvC3p2d0.25. Interestingly, the difference is moderate at 0.44 and 0.0625 horizontal resolution but large (3m/s) at 0.025 (=2.8km) horizontal resolution. Additonal simulations have shown that the difference is large if the deep convection parameterization is switched off. This indicates, that numerical diffusion and convection parameterization redistribute conserved quantities very fast such that nothing is left to do for the grid scale dynamics. If the parameterizations are switched off, the grid scale dynamics is transporting momentum and energy. Thus, the AdvS4p4 scheme has the potential to substantially improve the simulation of extreme events at convection permitting scales. These results are in preparation for publication. However, the numerical artefact visible as stripes in the 0.44 simulation at individual positions need to be investigated and the results need to be confirmed by longer simulation periods.

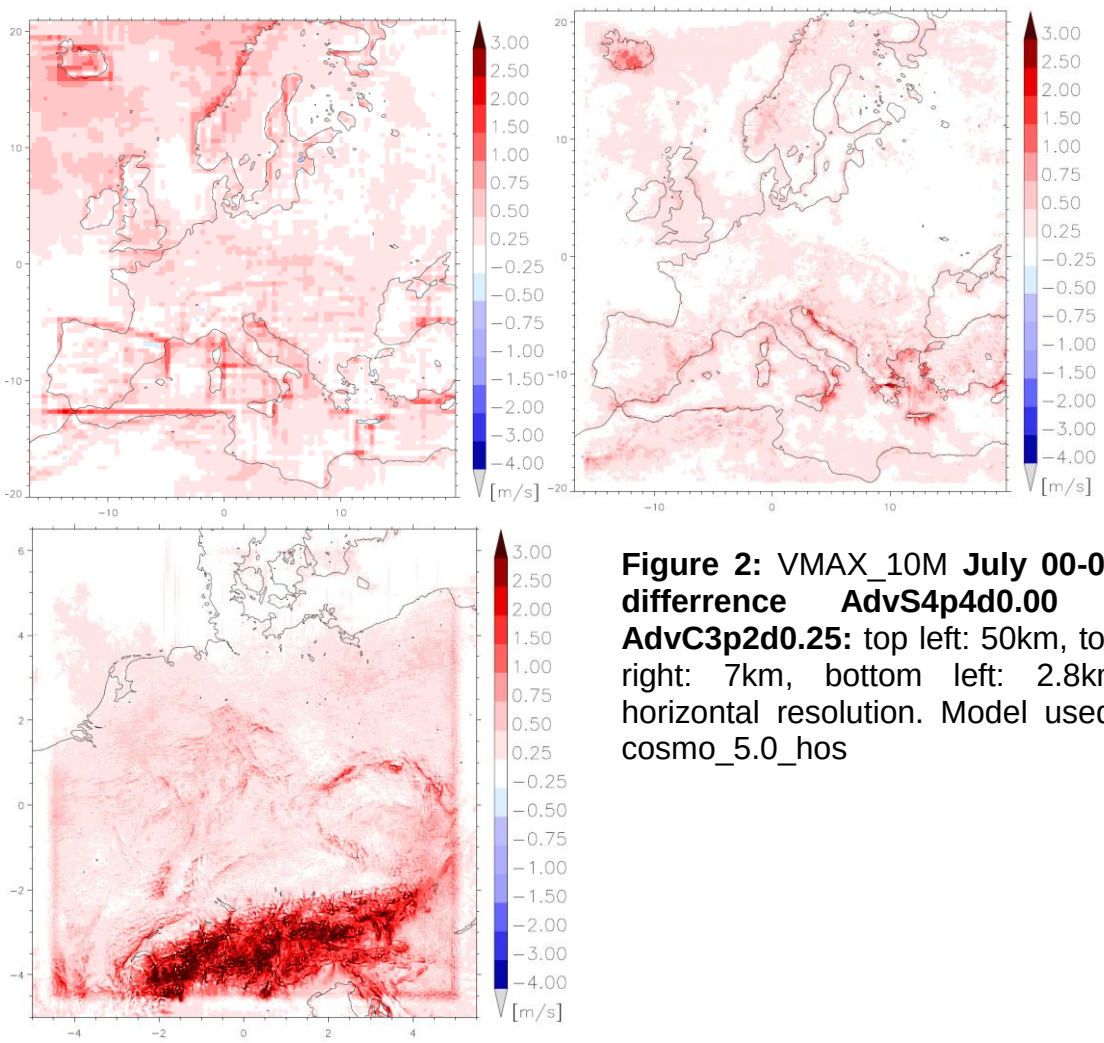

Figure 2: VMAX_10M **July 00-01 difference AdvS4p4d0.00 - AdvC3p2d0.25:** top left: 50km, top right: 7km, bottom left: 2.8km horizontal resolution. Model used: cosmo_5.0_hos

Literature:

Ogaja, J., A. Will (2016): Will Fourth order, conservative discretization of horizontal Euler equations in the COSMO model and regional climate simulations. *Met.Z.*, DOI 10.1127/metz/2016/0645