Project: **722**
Project title: **High Order Schemes for the COSMO model**
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Report period: **01.01.2017 - 31.12.2017**

In 2016 higher order schemes were implemented in COSMO model version, 'cosmo_'. The 4th order 'symmetric' advection (advS4) together with 4th 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 15 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.

Stability and performance of non-dissipative high order scheme (HOS)

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 2nd 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.
The performance of the AdvS4p4 scheme was found to be the same as for the AdvC3p2 scheme after application of the tools offered by DKRZ and an improvement of the implementation of the AdvS4 scheme in cosmo_5.0 (see previous report). 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. The implementation of the new schemes was thus considered successful.

Comparison of climatologies of HOS and reference scheme

First results are published in Will et al (2017). Table 1 gives an overview of the configurations investigated, of the simulation IDs and the initial and boundary conditions (IBCs) used. ECMWF's ERA-INT reanalyses data were used as IBC for the CORDEX-EU-LR (50km) configuration over Europe. The results (TEU006 and TEU007) have been used as IBC for the CORDEX-EU-MR (18km), CORDEX-EU-HR (12km) and COSMO-EU (7km) configurations. The 7km runs (CEU011 and CEU012) have been used as IBC for the convection permitting configurations COSMO-DE-LR (4.5km) and COSMO-DE (2.8km).

Simulation ID	IBC	Configuration	Hor. Resolution [km]	Grid
TEU006	ERAint	CORDEX-EU-LR	50	131x141x40
TEU007	ERAint	CORDEX-EU-LR-HOS	50	131x141x40
CEU011	TEU006	COSMO-EU	7	657x605x40
CEU012	TEU007	COSMO-EU-HOS	7	657x605x40
CDE011	CEU011	COSMO-DE	3	421x461x50
CDE012	CEU012	COSMO-DE-HOS	3	421x461x50
CDE014	CEU012	COSMO-DE-LR-HOS	5	247x269x50

Table 1: **Overview of simulations presented.** Each simulation has been conducted over a time span of 15 years.

We found a significant impact of the HOS scheme on the climatology for all configurations and a strong impact in the Alpine region if the deep convection parameterization is switched off. Figure 2 to 6 show differences between HOS and reference scheme simulations at 50km, 7km and 2.8 km horizontal resolution together with the comparison between the 2.8km HOS simulation and a reference data set (ECAD or ERA interim). Figures 1 and 2 show the mean daily minimum and maximum 2m temperature differences. Figure 3 shows the maximum horizontal wind speed differences. Figure 4 shows additionally the maximum wind speed difference between HOS at 4.5km resolution and referece scheme at 2.8km resolution. Figures 5 and 6 show the mean positive vertical velocity (mean (W>0)) at different model levels corresponding to different mean pressure levels of a standard atmosphere for HOS and reference scheme at 7km and 2.8 km respectively.

The results can be interpreted as follows. The HOS allows a more intensive grid scale dynamics and a subsequent stronger vertical turbulent mixing (due to dependency of the turbulence parameterization on grid scale velocity). This leads to a stronger vertical mixing in the boundary layer and stronger vertical transport in the troposphere. The numerical diffusion and deep 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 in particular the potential to substantially improve the simulation of extreme events at convection permitting scales. However, the vertical transport in the boundary layer needs to be retuned. In particular the minimum diffusion coefficient and the thickness of the laminar layer for sensible and latent heat flux. This work is ongoing.

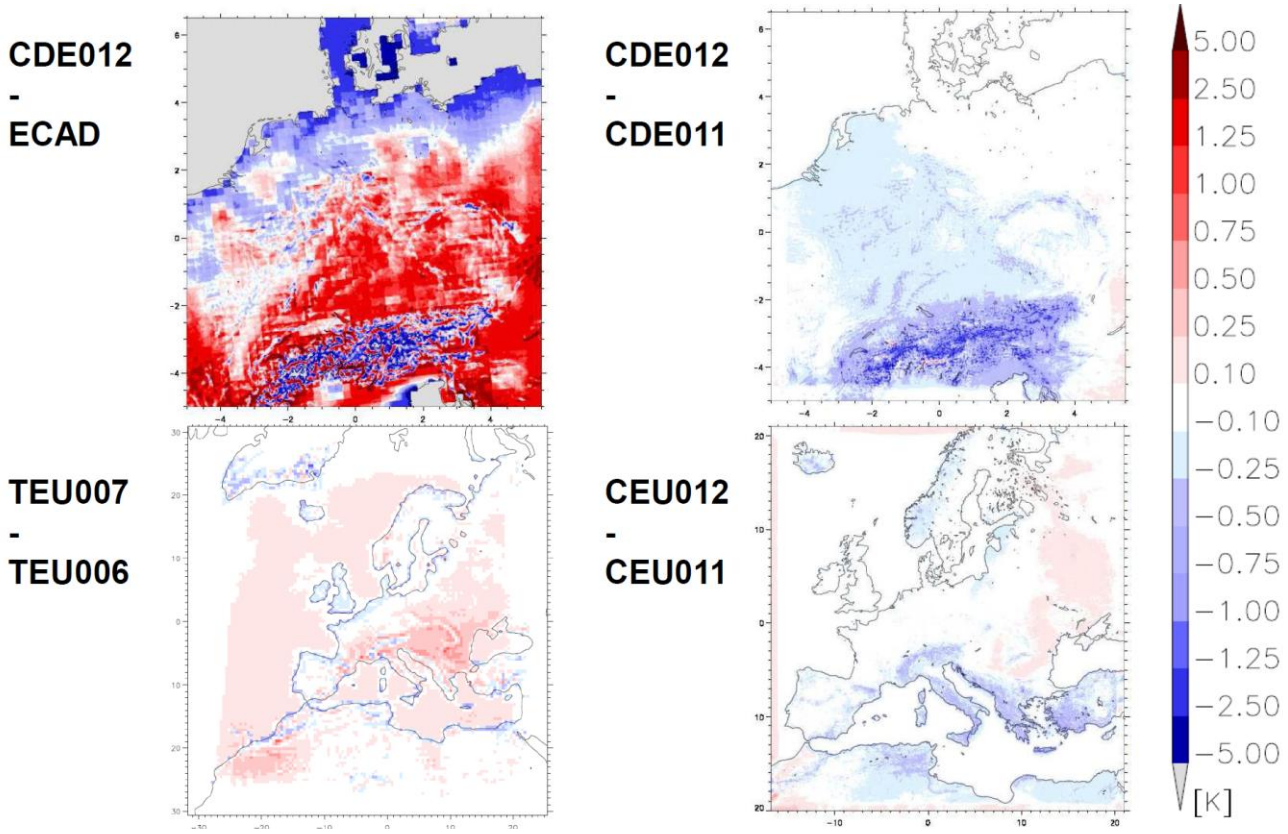

Figure 1: Mean daily minimum 2m temperature differences for 2000−2010.

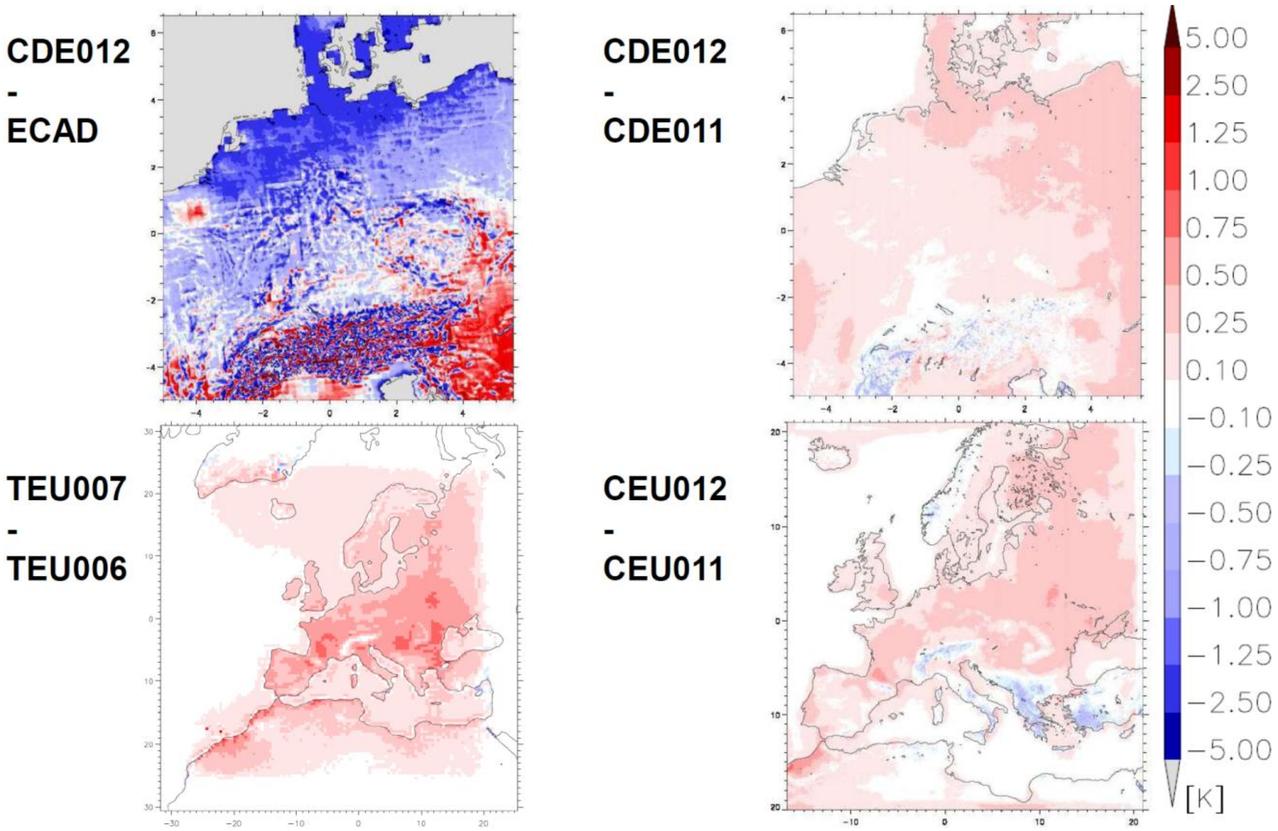

Figure 2: Mean daily maximum 2m temperature differences for 2000-2010.

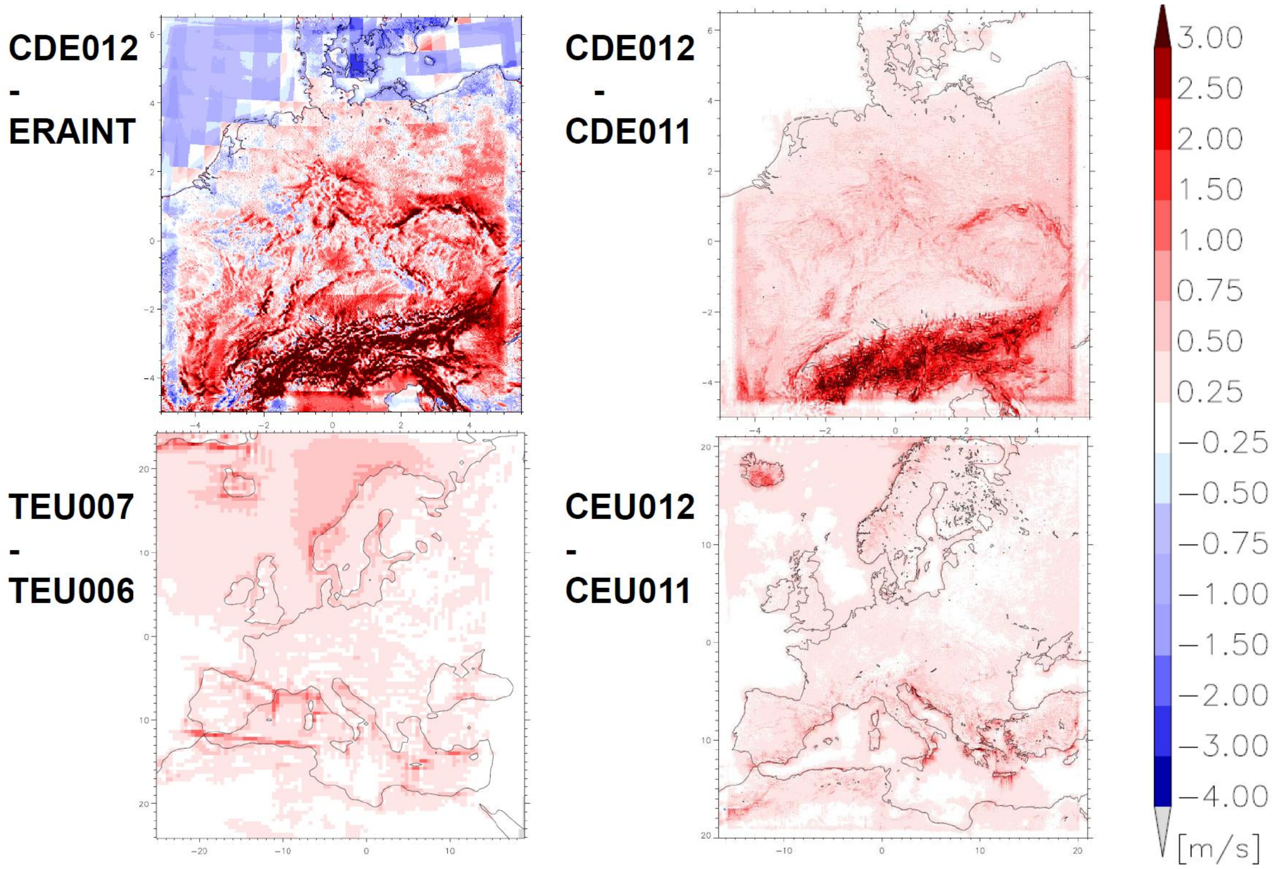

Figure 3 Mean maximum horizontal velocity differences (with gusts) for 2000-2010.

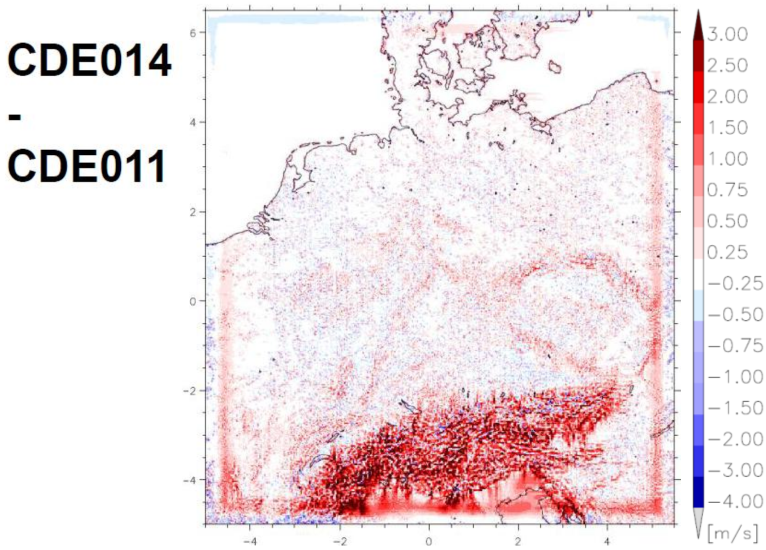

Figure 4: Mean maximum horizontal velocity difference (with gusts) for 2000-2010.

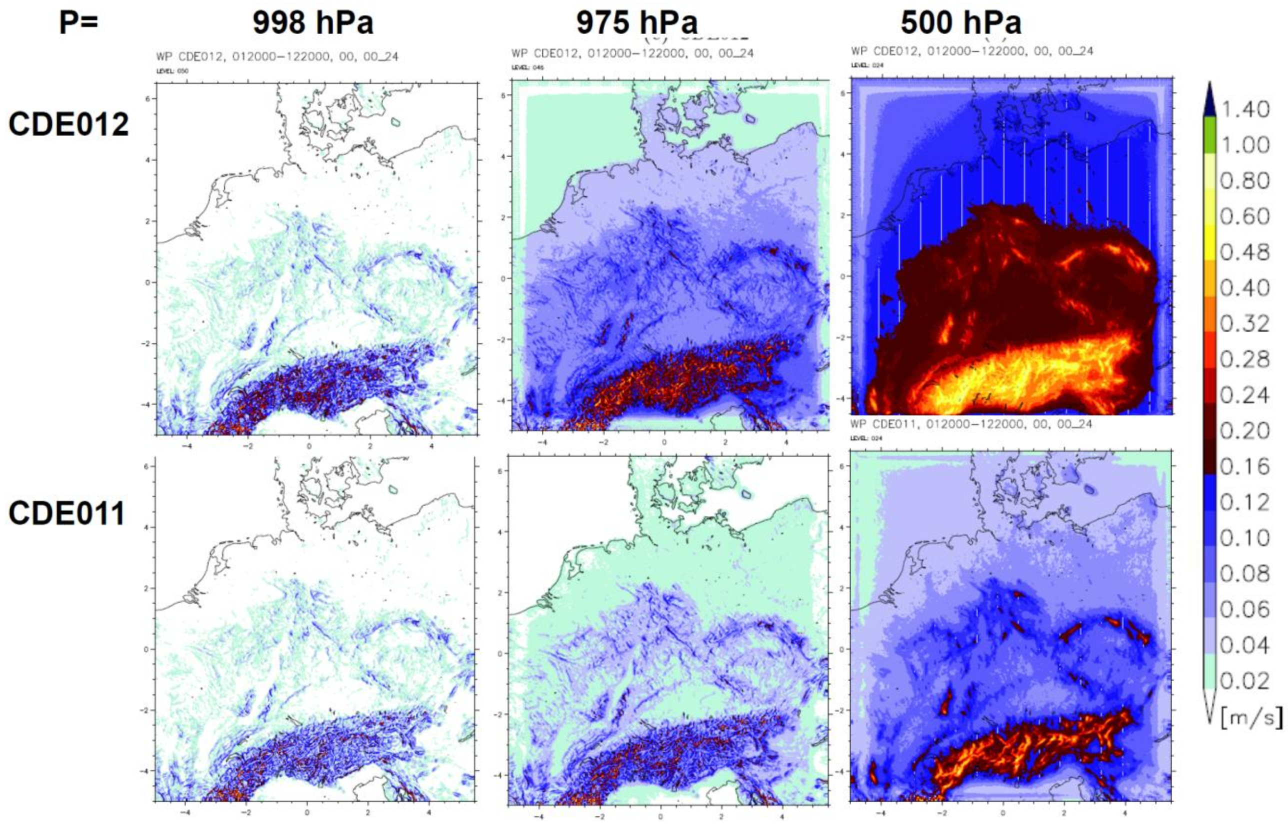

Figure 5 Mean positive vertical velocity for 2000.

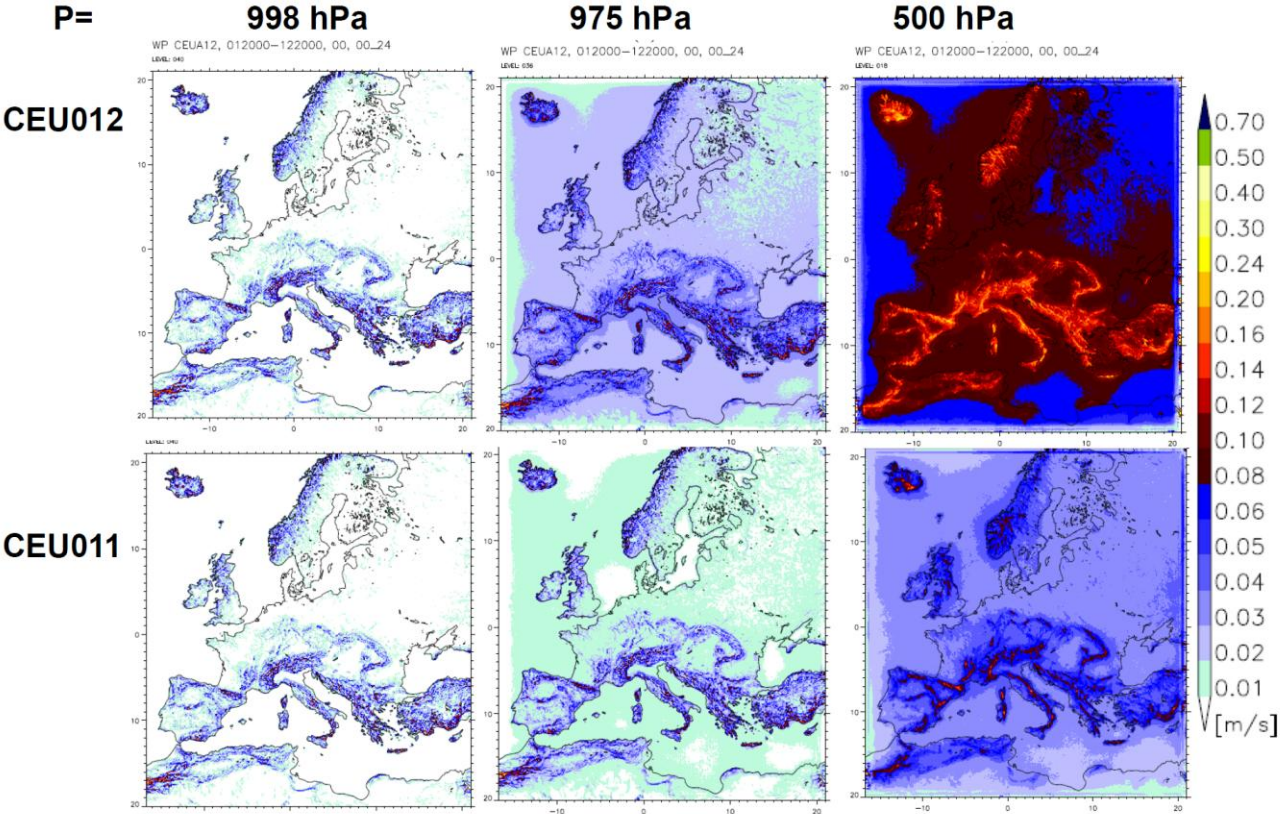

Figure 6 Mean positive vertical velocity for 2000.

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