Project:

Project title: Climate change in central Europe using higher order numerics

Project leader: Andreas Will

Allocation period: 1.7.2015 - 31.12.2015

Project overview

Convection permitting climate simulations have been shown to provide a significant added value, in particular in the Alpine Region (Ban et al., 2015, Prein et al., 2015). However, the added value in medium size mountains is not clearly identified (Prein et al., 2015) and the precipitation climatology of the regions is not well captured (Prein et al., 2015). It is hypothesized that an important reason for that behavior is the substantial difference between the grid scale resolution applied to orography and physics and the effective resolution of approx. $8 \Delta x$ (see Ogaja et al, 2014, Report of project 722 for 2014) of model dynamics due to dissipative numerics and/or diffusion terms used to keep the simulation stable. In medium size mountains the flow field is not slaved by orographic forcing and locally organized internal model dynamics is more relevant.

Recently, a 4th order, energy conserving spatial scheme (S4p4d0.00) has been implemented in the COSMO-CLM and successfully applied over Europe at 18km resolution (Ogaja et al, 2014). It allows simulating the regional climate without any implicit or explicit dissipation and exhibits an effective model resolution close to its theoretical value of approximately $4dx$ (see Fig. 1). At the same time it needs the same storage and slightly more computing time. Thus, the 4th order numerics has the potential to reduce the necessary resolution by approximately a factor of two and to reduce the needs for computational resources by one order of magnitude. It is intended to apply the S4p4d0.00 numerics in a medium size mountain region already investigated in climate change and climate impact studies.
The Rhineland-Palatinate region with Eifel and Hunsrück mountains North and South of the Mosel river has a complex mesoscale meteorology, provides high resolution measurements and is subject of several climate impact studies in Germany, Belgium and Luxemburg. Thus, it is a good candidate for such a study.

**Range of planned work from the scientific point of view**

The project aims investigating the opportunities of reducing the necessary spatial resolution for convection permitting simulations and impact studies using regional climate model output for hydrological modelling, agricultural production and pests in crops. Currently, the letter require RCM output at km scale which is computationally extremely expensive.

The real case runs are planned for a model domain in Central Europe covering the German states of Rhineland-Palatinate and Saarland as well as Luxembourg and parts of northern France and eastern Belgium (see Figure 1). The region is characterised by a temperate semi-oceanic climate with mild winters and moderate summers (Goergen et al. 2013). It features some moderate topography (up to 750 m amsl.) and is prone to fully reveal the advantages of the new schemes at convection permitting scales down to a horizontal resolution of 1.4 km.

![Figure 2: Model domain for convection permitting climate simulation, showing model topography of COSMO-CLM at a resolution of 1.3 km with main cities indicated by the red dots (adapted from Junk et al., 2014)](image)

Appropriate configurations for different model resolutions down to 1km in mid-european climate have been developed within the CLM-Community and the COSMO consortium for the COSMO model. They shall be used within this study.

It is planned to analyse the relevance of the increased effective model resolution in S4p4d0.00 for different types of climate statistics and to assess the added value of higher resolution for climate impact studies.

**Mathematical and/or computational aspects**

Currently, the S4p4d.00 numerics in the COSMO-CLM is the only numerical method in RCMs, which allows simulating over climatological time scales in the range of stable time steps without
any implicite or explicite diffusion. The needs for storage and data communication during the calculation remain constant. The computational costs increase by approximately 20%.

**Algorithmic/mathematical/numerical methods and solution procedures**

The COSMO-CLM uses the 3rd order Runge-Kutta time integration method and finite difference explicite schemes in the horizontal and implicite in the vertical on a curvilinear grid. The model is subject of regular maintenance, is continuously optimised for new computing architectures and was one of the benchmark models for the new machine at DKRZ.

The newly implemented S4p4d0.00 scheme is being implemented in an operational model version, which is subject to performance analysis as well.

**Particular suitability to solve the problem with help of HLRE 2**

The limited area model COSMO participated in international model comparison projects and showed an overall high quality. The COSMO-CLM is a widely tested non-hydrostatic regional climate model and applicable at space scales down to 1km for real cases. The dynamical core has been extensively tested down to 50m resolution for idealised test cases on blizzard and NEC.

The size of the problem requires a computing time of order 500 000 CPUh. Such computing facilities are not available at BTU Cottbus.

**Performance benefits depending on the number of used CPUs (scalability)**

COSMO-CLM has been shown to run efficiently on blizzard using up to several thousand processors and was a benchmark model for mistral. The performance tests revealed similar results on blizzard and mistral.

**Required computing time and amount of storage space**

Real case simulations are planned in 2015 to quantify the numerical requirements for convection resolving simulations using non-dissipative 4th order dynamics in a medium size mountain region of Rhineland-Palatinate, Saarland and Luxembourg (RPSL). Climate change time slice projections are planned aiming to investigate the added value of convection resolving simulations in such regions for impact studies.

We aim to investigate the 4th order symmetric scheme configuration in comparison with the reference configuration of the CLM-Community and to simulate the climate change signal at
convection resolving scales using the optimum configuration found.

The reference climate and climate change simulations for Europe at 18km (CCLM-EU18) and 11km (CCLM-EU11) resolution (Keuler et al, 2015) and a reference climate simulation using the S4p4d0.00 scheme (CCLM-E18-S) will be used as boundary conditions for the simulations at higher resolutions.

It is planned to simulate a series of 5 JJA simulations aiming to investigate the numerical requirements: C3p2d0.25 and S4p4d0.00 in COSMO-DE domain at 5 km (nx x ny x nz= 210x230x50) gand in CCLM-RPSL domain at 2.8 km resolution (nx x ny x nz= 140x140 x 60), and the C3p2d0.25 in CCLM-RPSL domain at 1.3 km resolution (nx x ny x nz= 220x220x60) nested in the COSMO-DE 5km simulation.

It is expected to achieve similar quality using the CCLM-RPSL2.8 configuration using S4p4d0.00 as for CCLM-RPSL1.3 using C3p2d0.25. Thus, the climate change simulations are planned to be simulated at 2.8 km resolution. Using a larger domain allows nesting in a coarse resolution run, which is planned to be the 11km CORDEX-EU simulation over Europe available from the DKRZ server. The RCP8.5 and RCP2.6 scenarios for the time slices 2001-2010, 2041-2050 and 2091-2100 shall be simulated. In 2015 the RCP8.5 for 2001-2010 and 2091-2100 are planned to be conducted together with the evaluation run using ERAINT boundary conditions for 2001-2010.

The resulting needs for computational resources are:

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Unit</th>
<th>CPUh/ Time unit</th>
<th>Nr of units</th>
<th>CPUh</th>
<th>HPSS [TB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSMO-DE5</td>
<td>1 mon</td>
<td>350</td>
<td>60</td>
<td>21 000</td>
<td>0,4</td>
</tr>
<tr>
<td>CCLM-RPSL2.8</td>
<td>1 mon</td>
<td>1,3 *350</td>
<td>90</td>
<td>40 950</td>
<td>0,6</td>
</tr>
<tr>
<td>CCLM-RPSL1.3</td>
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<td>30</td>
<td>90 300</td>
<td>0,3</td>
</tr>
<tr>
<td>CCLM-RPSL2.8</td>
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<td>2,6*350</td>
<td>360</td>
<td>327 600</td>
<td>2,5</td>
</tr>
<tr>
<td>All simulations</td>
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<td></td>
<td></td>
<td>479 850</td>
<td>3,8</td>
</tr>
<tr>
<td>Total request</td>
<td>( x 1.2 )</td>
<td></td>
<td></td>
<td>575 820</td>
<td>4,8</td>
</tr>
</tbody>
</table>

The total amount of CPU time is **479 850 CPUh**. For pre-processing of the initial and boundary
conditions, the model output and post-processing 1 TB GPFS are needed and 20% additional resources.

**Additional value compared to other projects**

The project aims to contribute to reduction of the need for computational resources by regional climate modelling by exploring the potentials of new numerical methods. There is no other RCM which has this opportunity.

The CCLM-RPSL2.8 (CL) will serve as input to climate change impact studies in the region covered by the model domain. The hourly output of relevant meteorological variables and their resolution allows for a detailed assessment and quantification of such impacts. Areas of investigation will include:

- Water cycle (e.g. influence of projected climate change conditions on the precipitation and reference evapotranspiration conditions)
- Agricultural production (e.g. yield production under changed climatological conditions based on APSIM model, McCown, 1995)
- Impacts on pests in economic relevant crops (e.g assessing the multi-trophic interaction between host plants and their pests under climate change conditions)

In order to assess the spread of the climate change signal, a combination with CORDEX runs (18 km) will be done, in a similar way to Junk et al., 2014. Additionally, the usage of two different scenarios (i.e. RCP8.5 and RCP2.6) will allow quantifying the impact of mitigation efforts during the two future time periods being investigated.

**References**


Ogaja, J. And A. Will (2014), Fourth order, non-dissipative discretisation of horizontal Euler
equations in the COSMO model and regional climate simulation over Europe, Meteorologische Zeitschrift, submitted