High resolution WRF simulations for climate change studies in Germany

ReKliEs-De
Regionale Klimaprojektionen Ensemble für Deutschland

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Introduction:

In WRFCLIM, high resolution climate simulations are carried out for Europe focusing on Germany, applying the Weather Research and Forcasting (WRF) model (Skamarock et al., 2008) within the the BMBF funded project **ReKliEs-De** (Regionales Klimaensemble für Deutschland; http://reklies.hlnug.de/startseite.html) and the DFG funded research unit on regional climate change **FOR 1695** (https://klimawandel.uni-hohenheim.de/).

Regionally climate change will have a large impact on:

- energy and water cycles
- intensity and frequency of extreme events
- yield and yield quality
- crop rotations
- water regime
- agricultural production systems
- land use

➢ **Climate informations on high resolution are required by end users!**

GCM +RCP	CCLM	REMO	WRF	WETTREG	STARS
MPI-ESM-LR 2.6					
MPI-ESM-LR 8.5					
CNRM-CM5 8.5					
HadGEM-ES 8.5					
EC-EARTH 8.5					
CanESM2 8.5					
MIROC5 8.5					

Table 1: model ensemble of ReKlEs-De (blue) and EURO-CORDEX (grey).

ReKliEs-De:
Robust climate change information on high spatial resolution for Germany and the large river catchments draining into Germany will be derived by carrying out climate simulations on 12 km resolution (Tab. 1).

FOR 1695:
The effects of global climate change on structure and functions of agricultural landscapes on a regional scale is investigated by running simulations on 3 km resolution, applying a crop model as well.

Method:

General circulation Models (GCMs) are able to represent the physical processes of Atmosphere, Ocean, Cryosphere and Land surface with a typical horizontal resolution of ~200 km.

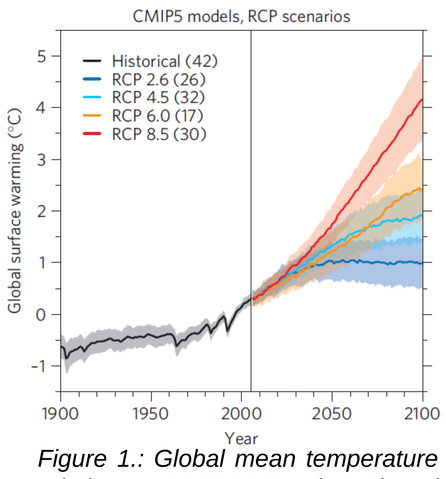
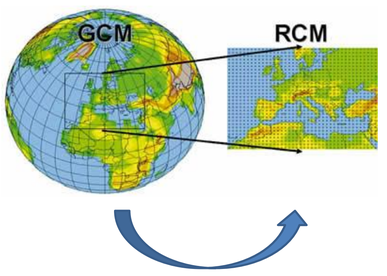


Figure 1.: Global mean temperature relative to 1986-2005 (Knutti and Sedlacek 2012).

Within the world wide coordinated effort of the Coupled Model Intercomparison Project Phase 5 (CMIP5, http://cmip-pcmdi.llnl.gov/cmip5/) the impact of emission scenarios based on Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011) on climate is simulated (Fig.1).

GCMs based on the different RCPs are dynamically downscaled using different Regional Climate Models (RCMs).
For Europe: EURO-CORDEX (EUROpe-COordinated Regional climate Downscaling Experiment; (http://www.euro-cordex.net).



Simulations at HLRS:

The WRF simulations are carried on the CRAY XC40 System at HLRS (Tab.2). Model domains and the land use for 12 and 3 km is shown in Figure 2.
The ERA-Interim reanalysis data (Dee et al., 2011) is used for evaluation of the historical runs. Climate projections are carried out from 1950-2100 (Tab.1 & Fig.1). The boundary forcing from the historical period (1950-2005) is based on observed atmospheric composition changes of anthropogenic and natural sources. The forcing of the RCP projections (2006-2100) is based on mitigation scenarios that assume policy actions will be taken into account to achieve certain emission targets (Taylor, 2012).
To ensure numerical stability by downscaling the coarse GCM simulations to the target resolution (12 and 3 km), an intermediate domain is required (50 km).

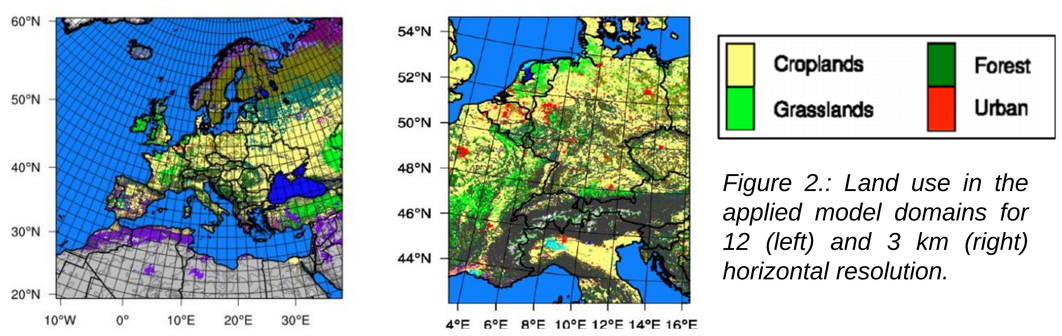


Figure 2.: Land use in the applied model domains for 12 (left) and 3 km (right) horizontal resolution.

GCM forcing	Resolution dx	Sim. Period	Forcing	Simulation Status	Archiving Status HPSS	WRF 3.6.1 setting
MIROC5	0.11° & 0.44° 12 km & 50 km	1958-2005 2005-2100	Historical RCP8.5	completed 2005-2076	completed ongoing	Land surface model: **NOAH/NOAHMP (at 3 km)**
EC-EARTH	0.11° & 0.44° 12 km & 50 km	1958-2005 2005-2100	Historical RCP8.5	completed completed	completed completed	Microphysics: **Morrison**
HadGEM-ES	0.11° & 0.44° 12 km & 50 km	1958-2005 2005-2100	Historical RCP8.5	completed completed	completed completed	PBL: **YSU**
MPI-ESM-LR	0.11° & 0.44° 12 km & 50 km	1958-2005 2005-2100	Historical RCP8.5/RCP2.6	completed completed	completed completed	Convection: **Kain-Fritsch-Eta**
ERA-Interim	0.11° / 12 km 0.03° / 3 km 0.03° / 3 km	1987-2014 2000-2010 2000-2010	Reanalysis Reanalysis Reanalysis+ GECROS	completed ongoing ongoing		Radiation: **CAM**

Table 2.: Summary of the simulations and their status carried out at HLRS.

Technical description:

Simulations on 50 and 12 km horizontal resolution are carried out with WRF model version 3.6.1. (www.wrf-model.org). For the 3 km simulations WRF 3.7.1 together with MP is applied.

Starting from 240 cores (10 nodes), the scaling is linear up to 1200 cores with a slight decrease and recovering when applying 1680 cores (Fig.3).
WRF is not primarily written for OpenMP applications, however simulations can be run in hybrid mode (MPI+OpenMP). Thus, the scaling performance in the speedup is not proportionally to the used time limitations.

- **External library**: NetCDF & PNetCDF
- **Software package:** CDO (Climate Data Operator), NCO (NetCDF Operator), NCL (NCAR Command Language).
- **Compiler**: PGI14.7

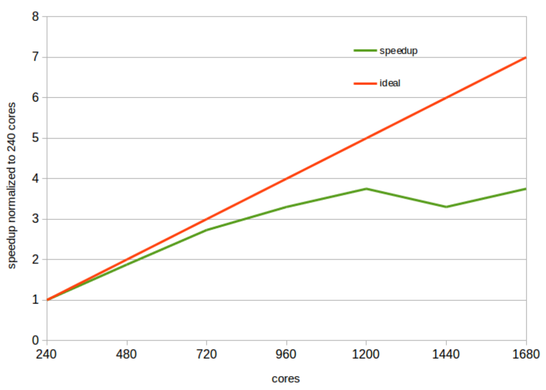


Figure 3: Scaling behavior of the non hybrid mode of WRF on the HLRS hazelhen system. This data was obtained with a domain size of 452x460 grid points and 50 vertical levels.

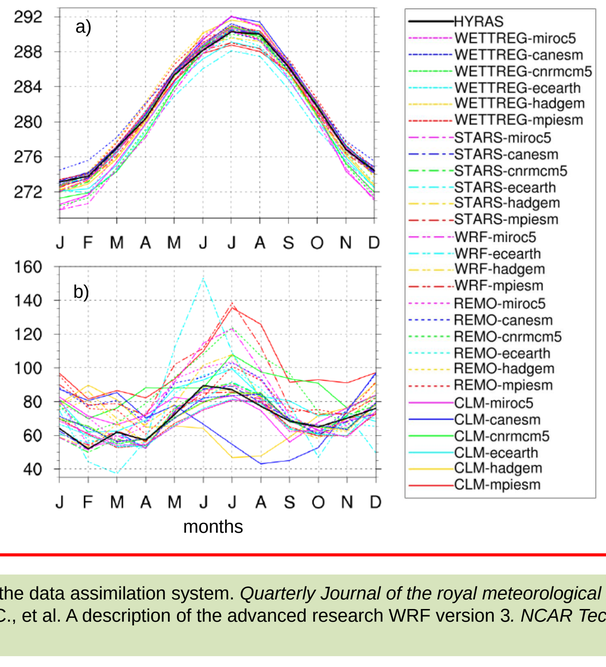
GCM forcing	Num. Simul.	Δx, Δy	Grid size	Storage in-terval [h]	wall-time/steps [s]	Cores/ run	Mio. Core-h
ERA-Interim	1 (10 years)	0.11°	460 x 425 x 50	3	0.15	5400	1
RCPs (projections)	5 (each 110 years)	0.11°	460 x 425 x 50	3	0.15	5400	64
Convection permitting ERA-Interim	2 (each 5 years)	0.03°	413 x 457 x 50	3	0.15	5400	1
Post-Proces-sing							0.01
Total							66

Table 3: Simulations and approximated computational resources for the WRFCLIM project between June 2016 and June 2017.

Results and Outlook:

ReKliEs-De: Most of the simulations until 2100 are completed. Special climate indices, representing climate change signals, will be analyzed using the whole ReKliEs-De model ensemble (Tab.1). Results of the project will be presented at a final workshop on 6th and 7th of December in Wiesbaden.
Figure 4 shows the evaluation of historical simulations 1971-2000 of the ReKliEs-De model ensemble. Models agree well in simulating the temperature (a). Precipitation (b) is more diverse, revealing difficulties of the models in simulating precipitation accurately.

Figure 4: annual cycle of temperature [K] (top) and precipitation [mm/day] (bottom) of the ReKliEs-De model ensemble and HYRAS gridded observational data between 1971 and 2000 for the ReKliEs-De domain (mainly Germany) (From: http://reklies.hlnug.de/infos.html, Newsletter No. 2).



FOR1695: Simulations are ongoing. Convection permitting simulations will be carried out and analyzed in the next step in order to reduce the current deficiencies of global and regional climate projections such as errors introduced by the parameterization of deep convection. Further, it will be possible to study the importance of land cover changes and greenhouse forcing.

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Final Kolloquium of ReKliEs-De
6th-7th December 2017
in Wiesbaden

Registration at
http://reklies.hlnug.de/startseite.html

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GEFÖRDERT VOM
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DFG Deutsche Forschungsgemeinschaft