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MPIOM-REMO
A Coupled Regional Model for the North Sea

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A Coupled Regional Model for the North Sea

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1 Objectives of the Cooperation

The objective is to provide meteorological and oceanic data for climate projections over North Europe to the KLIWAS project. The future climate conditions are prescribed from the A1B scenario MPI-ECHAM5_T63L31 MPI-OM_GR1.5L40 SRESA1B run no.3 produced by the Max Planck Institute for Meteorology (MPI-Met) for the fourth Intergovernmental Panel on Climate Change (IPCC) assessment report (AR4) (phase 3 of the Coupled Model Intercomparison Project (CMIP3)). The scenario has been regionalized by the MPI-Met using a dynamically downscaling technique. For this purpose the atmosphere-ocean coupled regional model REMO/MPIOM is prepared to produce high resolution climate simulations over central and north Europe, with special interest on the North Sea and Baltic Sea region, where the resolution of the non-homogeneous oceanic grid reaches up to 5 to 13 km. The model output is then validated and analyzed jointly with the Bundesamt fuer Seeschifffahrt und Hydrographie (BSH) which also compares the results in terms of the climate and extreme events trends for the hydro-meteorologically relevant parameters for all involved modelling groups (Kliwas Schriftenreihe, Band 27, 2014).

2 Model Description

2.1 Brief description of model components (coupled and uncoupled), boundary conditions, driving records, initial conditions.

The regionally coupled climate model consists of the regional atmosphere model REMO and the Max-Planck-Institute for Meteorology ocean model (MPI-OM).

The REgional atmosphere MOdel (REMO) is based on the `Europa-Modell' of the German Weather service (Majewski, 1991) and the physical parameterizations are taken from the global climate model ECHAM-4 (Roeckner et al., 1996). REMO is a hydrostatic model and can be used for a horizontal resolution up to 10km. REMO as a ‘Limited Area Model’ needs lateral boundary forcing data like temperature, wind, surface pressure and moisture and as surface boundary conditions the temporal variable sea surface temperature and sea ice extent. The variable surface boundary conditions are taken from the respective MPI-OM run.

The HD Model (Hydrological Discharge) is a routing scheme, which accounts for the lateral waterflow on the land surface in global climate model applications. It is in charge inside the coupled model in providing the ocean component with freshwater input from the surface river system. The model describes the translation and retention of the lateral discharge within the river system as a function of spatially distributed land surface characteristics. The HD Model is applied on a regional scale with a fixed horizontal resolution of $1/2^{\circ}$ on a regular, non-rotated spherical grid, corresponding to an average grid box size of about 55 km x 55 km . The model requires surface runoff and subsurface drainage as input parameters and provides discharge values. [Hagemann and Duemenil, 1999, Hagemann and Jacob, 2007].

The Max-Planck-Institute Ocean Model (MPI-OM, formerly C-HOPE, Maier-Reimer, 1997; Marsland et. al, 2003) is a primitive equation model (z-level, with Boussinesq and incompressibility assumptions) formulated on an orthogonal curvilinear Arakawa C-grid. The model includes a dynamic-thermodynamic sea ice model with viscous-plastic rheology (Hibler, 1979). It has a free surface and uses a mass flux boundary condition for salinity. A simple bottom boundary layer scheme is included as well as the standard set of sub-grid scale parameterizations (e.g. isopycnal diffusion, Richardson number dependent vertical diffusivities, a simple mixed layer scheme including the effect of wind mixing at the surface, and eddy induced tracer transport according to Gent et, al., 1995). The calculation of tides was included.

The coupling between the REMO atmosphere model and the MPI-OM ocean model was carried out using the OASIS coupler developed by CERFACS (Valcke et. al., 2006). REMO calculates fluxes of heat, momentum and freshwater (mass) separately for the sea ice covered and ice free fractions of a grid box and receives in turn SST and sea ice properties from the ocean model. The coupling is updated every 2 hours.

2.2 List of the performed runs with a short description of the technical details

All the simulations have been performed with the following setup:

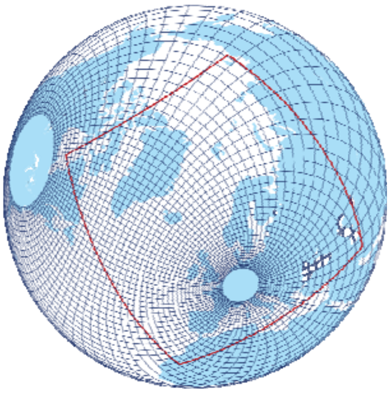

Figure 1: Global ocean domain and domain boundaries of the regional atmospheric model (in red). Please note that not all the grid lines were plotted.

Figure 1 shows the domains that have been used in the experiment. The atmospheric grid size is 181x181 grid boxes with 27 vertical levels with a horizontal resolution of 0.33 x 0.33 degrees (shown in the red box). The ocean domain is global with a bipolar projection (shown in the blue mesh). The poles are located at Central Europe and North America. The domain resolution is variable from approximately 300 km at the geographical South Pole up to 5 – 13 km in the North Sea.

The model time step for the atmosphere model is 150 seconds and 600 seconds for the ocean model. The model coupling has been run using the concurrent mode. The coupling time step is 2 hours.

2.3 Simulations

With this model setup, hindcast, historical and a future scenario simulations have been performed by Dmitry Sein. The hindcast simulation has been forced with NCEP reanalysis data. These simulations were used for model validation purposes. The historical and scenario simulations were driven with the output data from the global model ECHAM5/MPIOM from the IPCC CMIP3. The future climate simulation corresponds to the A1B scenario. Several runs were performed and optimized until a final run was chosen. A control simulation was performed to estimate the model drift and calculate only trends due to changes on CO2 concentrations.

Table 1: List of experiments carried out

Run ID	*Experiment ID*	*Forcing*	*Remarks*
261	Uncoupled Hindcast	NCEP reanalysis dataset 60 years	Historical simulation for model validation
253	Coupled Hindcast	NCEP reanalysis dataset 60 years	Historical simulation for model validation
251	CTRL	ECHAM5/MPI-OM control, 150 years from ECHAM5/MPIOM control simulation	Control simulation, necessary to estimate the model drift
215	20C	ECHAM5/MPI-OM 20C, 1920-2000 from simulation with historical forcings for this period.	Simulation for the period 1920-2000.
215	A1B	A1B scenario ECHAM5/MPI-OM, years 2001-2100 from ECHAM5/MPIOM A1B simulation	Emission scenario for the period 2001-2100

2.4 Methodology for coupling, tuning of parameters, sensitivity analysis

For the surface boundary, the treatment of soil hydrology is based on a simple bucket scheme, whereas, over the sea, REMO uses the sea surface temperature (SST) calculated on-line by the oceanic component and prescribed values in the rest of the ocean regions.

The coupling between the REMO atmosphere model and the MPI-OM ocean model was carried out using the OASIS coupler developed by CERFACS [Valcke, 2006]. OASIS is used for variables exchange and for coupling time synchronization only. A conservative bilinear interpolation routine is integrated in the MPIOM model to interpolate fields between REMO and MPIOM model grids. The HD model makes its own interpolation for REMO and ECHAM5 runoff and drainage variables. REMO calculates heat, freshwater and momentum fluxes for each grid box and receives in turn SST, sea ice thickness and compactness from the ocean model. The atmosphere-ocean coupling frequency is set to 2 hours and the calculation of the river routing is every 24 hours (Sein et al. 2012). A similar configuration without the river routing has been used for Indonesian rainfall [Aldrian et al., 2005] and Artic sea ice studies [Mikolajewicz, 2005].

3 Work performed

The regionalization of the ECHAM5/MPIOM CMIP3 A1B scenario was performed using the regional atmospheric-ocean coupled model REMO/MPIOM (Sein et al. 2012). Hindcast simulations were carried out using the same set-up either using NCEP forcing (run 261) or with the regional atmospheric-ocean coupled model REMO/MPIOM (run 253).

3.1 Hindcast simulations

Figure 2 shows the deviation of the modeled precipitation (driven with the NCEP reanalysis dataset) from observed climatological data within the period 1970-1999. In many parts of central and Eastern Europe, the atmospheric model simulates larger rainfall than observed, meanwhile at the south of the Alps the rainfall tends to be underestimated. This pattern is associated with a meridional shift of the mean position of the simulated westerly winds and therefore, the associated shift in the atmospheric moisture transport. According to the rainfall distribution in the mountain ranges regions, the water deposition by the orography precipitation processes seems to be overestimated by the model. This leads to larger values of rainfall on the windward side of the mountain range and a deficit on the lee side. The large values for rainfall in the northern region increase the continental runoff which implies larger freshwater discharge into the northwestern sea shelf areas. However, the annual cycle of the precipitation is very well reproduced by the model.

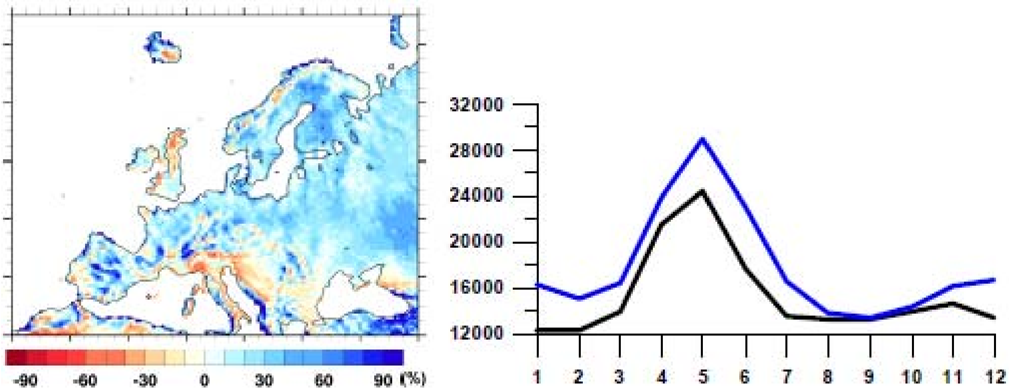

Figure 2: Left: 1970-1999 percentage difference of the simulated precipitation with respect CRU climatology (Climatic Research Unit, University of East Anglia) (CRU, 2008). Right: Baltic Sea Runoff climatology in m^3s^{-1} for river observations from GRDC (in black) (Duemenil et al 2000) and simulated (in blue) data.

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3.2 Downscaling of the IPCC A1B scenario

Figure 3 and figure 4 show the projected changes of the sea level at the North and Baltic Seas from the analysis performed by the BSH for run215. At the end of 21th Century, sea level is rising up to 0.2 to 0.3 meters. The distribution of the changes inside each of the North and the Baltic basins are quite homogenous, e. g. the already existing gradients and small-scale patterns within the basins are similar to those projected on the future climate simulation. The North Sea behaves slightly different to the Baltic Sea, the last one shows a general increase of the sea level up to 0.2 m higher. This can be explained by the increase of precipitation in the Baltic Sea basin and its catchment and the limited exchange of water flow through the Danish straits, which also limits the salt transport into the basin. As a result, the simulated salt concentrations decrease by up to 2 psu in the Baltic Sea, meanwhile the simulated decrease of salinity in the North Sea is about 0.5 psu (Figure 4). The Sea Surface Temperature (SST) time series for both North and Baltic Sea basins shows a positive trend particularly enhanced after year 2000.

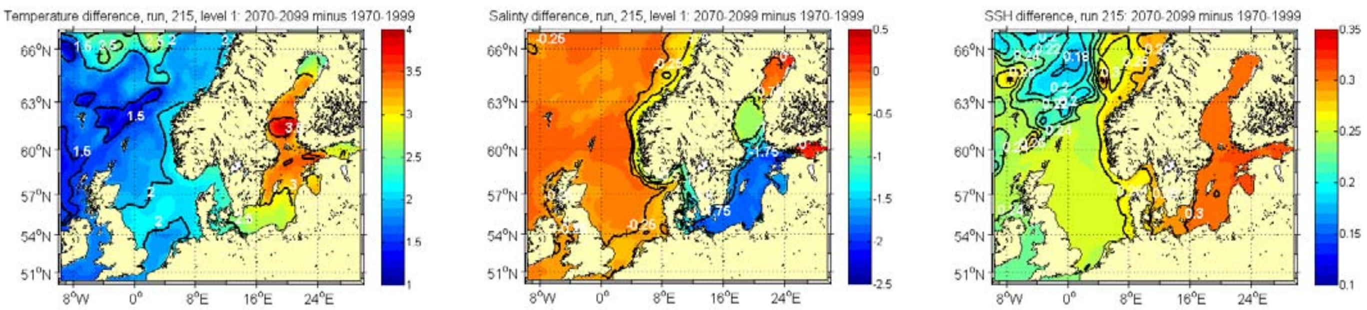

Figure 3: SST Anomalies in °C (left), sea surface salinity (middle) and steric effect in meters (right). Differences are calculated from the difference between the two 30 year periods at the end of the 21th and 20th centuries of the A1B scenario.

The sea level rise in the North Sea is less pronounced than in the Baltic Sea. The local changes on the basin are comparable to those on the North Atlantic area that could be explained by the influence of the thermal expansion effect on the water column (Fig 3 right). However, since the volume exchange with the open Atlantic remains stable, the increase of precipitation and changes in continental runoff play a rather insignificant role on the sea level rise.

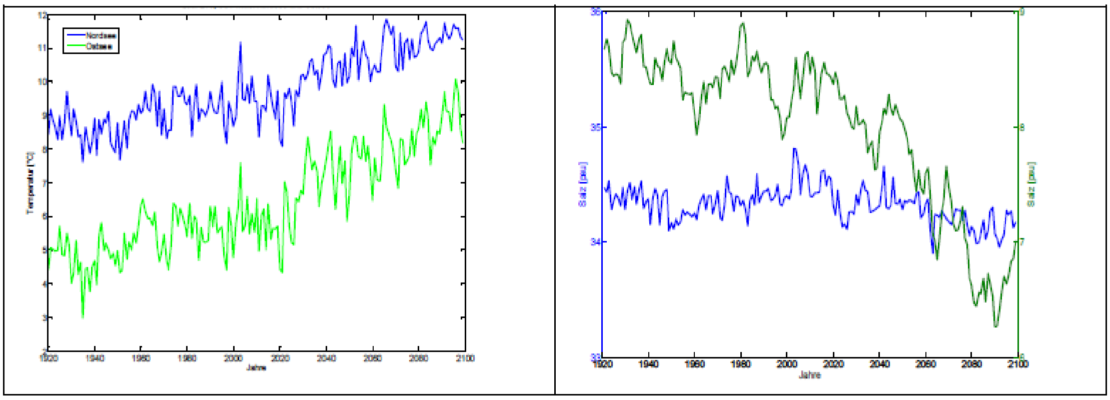

Figure 4: Time series for SST and Sea Surface Salinity averaged over the North Sea (in blue) and Baltic Sea (green).

3.3 Large-scale interaction

Apart from long-term trends due to climate change, the natural variability of the climate system is analyzed. In particular on regional scales, the natural variability is subject to pronounced oscillations, related to perturbations in the global ocean circulation and interactions with the atmosphere. An important mode of the natural variability in the North Sea region and the adjacent North Atlantic is driven by the North Atlantic Oscillation (NAO). The intensity of the NAO in the winter season, given by the NAO-Index, strongly influences the weather conditions over the North Atlantic ocean and the European continent and with this, the physical conditions of the near-surface water masses in the North Atlantic and the North Sea.

Evaluation of the historic 20th century control run for the IPCC SRES scenario runs shows that the coupled atmosphere-ocean regional circulation model REMO/MPIOM well reproduces the NAO influence on the strength of the general ocean circulation, sea surface temperature (SST), wind speed, and mixed layer depth (MLD). In figure 5, monthly regression coefficients of the winter NAO-Index and SST are shown for the North Atlantic (blue) and the northern North Sea (red). The regression coefficients indicate how much the SST is changing if the NAO-Index is changing by one standard deviation. Accordingly, a positive regression coefficient corresponds to a positive correlation coefficient, too. In the northern North Sea, the regression coefficients are about 0.2-0.4 K/std(NAO-I) in winter and spring, while in the North Atlantic, the NAO influence on SST is less pronounced. In figure 6, monthly regression coefficients are shown for the MLD. In the North Atlantic, a positive NAO phase comes along with a positive anomaly in the MLD of about 50-60 m/std(NAO-I) in spring, whereas in the northern North Sea, the MLD is hardly affected.

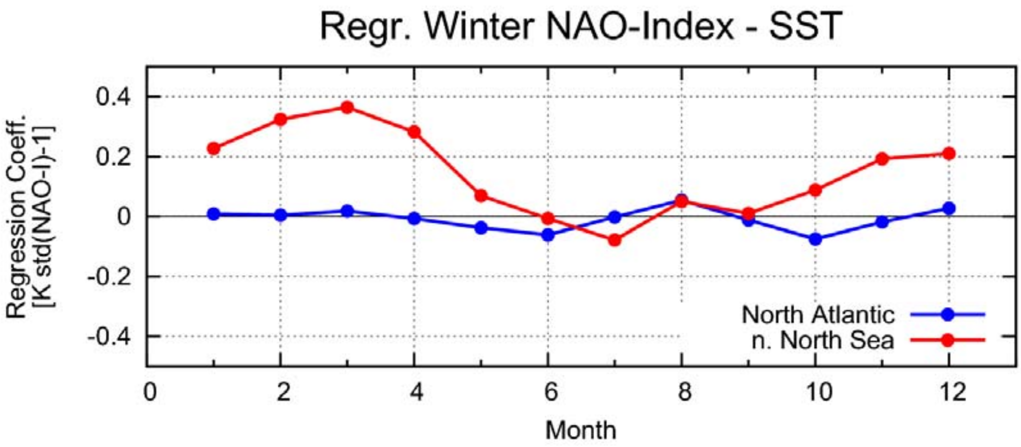

Figure 5: Monthly regression coefficients of winter NAO-Index and SST for the North Atlantic (blue) and the northern North Sea (red). Analysis of the 20th century control run for the IPCC SRES scenario runs, simulated with the coupled atmosphere-ocean regional circulation model REMO/MPIOM.

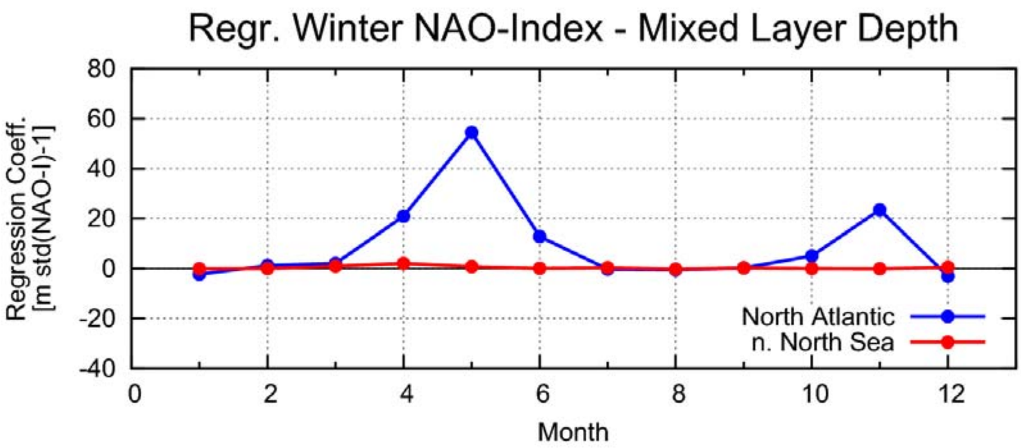

Figure 6: Monthly regression coefficients of winter NAO-Index and MLD for the North Atlantic (blue) and the northern North Sea (red). Analysis of the 20th century control run for the IPCC SRES scenario runs, simulated with the coupled atmosphere-ocean regional circulation model REMO/MPIOM.

4 Results in the form of key messages

4.1 Key points regarding the methodological and scientific progress achieved

For the first time, a Northern European climate simulation has been performed using a fully coupled atmosphere-ocean high resolution model which implies a free exchange of momentum, heat freshwater fluxes between the models at the air-sea interface. This represents an improvement with respect to previous simulations where surface conditions were prescribed, since the coupled model is able now to simulate freely small scale process important for the coastal areas. Moreover this technique is independent on imposed surface conditions at least over the coupled area, e.g. the coupled model is able to develop its own air-sea fluxes instead of those calculated if prescribed conditions by a driving model are given as in the uncoupled case. This becomes relevant when future climate scenarios are simulated. In this manner, the possible errors and uncertainties of the driving model are not directly transmitted to the coupled simulations.

4.2 Key messages to results

The coastal population and the marine ecosystems near the shore will be affected by climate change. On one hand side, changes on the hydraulic conditions and the thermal expansion of the water column cause an increase on the sea level. On the other hand, the examination of the NAO influence and its variability contributes to the central question concerning the relation of anthropogenic and natural variability in projected climate trends. Preliminary results of the A1B scenario run suggest that in the North Atlantic and northwest European shelf, the discussed influence of the NAO on various oceanic and atmospheric quantities remains significant during the 21st century.

5 Discussion and Outlook

The uncertainty of future climate trend is quite large and depends largely on human activity. The selected A1B scenario in this work is only one of the possible future climate change paths. For a better understanding of such trends, a set of different realizations of climate projects are necessary. The downscaling of the Representative Concentration Pathways (RCP) scenarios created for the IPCC AR4 becomes essential for a better climate change comprehension.

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