THE EFFECT OF TWO-WAY COUPLING IN A CLIMATE-HYDROLOGICAL SETUP

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Summary. This study is a part of an on-going Danish research project HYACINTS. A key outcome of the project is a fully coupled model setup using the HIRHAM regional climate model and the MIKE SHE hydrological model with the intent of improving hydrological predictions. We here present results from the initial studies prior to the coupling performed to aid in the decision of optimal climate model domain size and resolution as well to parameterize the hydrological model.

These studies showed that the size of the domain is more important than resolution in producing accurate simulations of precipitation and temperature by the HIRHAM model over Northern Europe. The HIRHAM simulations also showed better results for temperature compared to precipitation. Further, the initial studies showed the sensitivity of parameters in the MIKE SHE model to be highly dependent on the vegetation type and groundwater table depth, which is essential information in the calibration of the distributed hydrological model.

1 INTRODUCTION

Traditionally, distributed hydrological and climate models have been regarded as two separate disciplines. Hydrological models have utilized input data from observations or climate simulations and the description of atmospheric exchange have been limited to a surface-near layer. Similarly, in climate models very simplistic descriptions of surface/subsurface hydrological components have been included. In recent years efforts have been made to reduce these limitations in the modelling of the hydrological cycle by the coupling of models each describing a component in the complex system of water and energy exchange between the soil, water and atmosphere components[1,2,3,4].

Both climate and hydrological models components are likely to gain from the coupling. Climate models are likely to provide improved simulations from the more detailed description of soil water content and water table depths as generated in the hydrological model since climate models in general are not considering lateral redistribution of subsurface energy and moisture fluxes[4] and due to the strong relationship between the latent heat flux the soil water distribution[3,5] . In addition to soil water, the impact of land use and vegetation on the land surface energy fluxes will also be described in more details since a land-surface model component is often added in the coupled setup as well as the possibility to include human processes such as pumping and irrigation. On the other hand the hydrological model may benefit from the horizontal redistribution of sensible energy made possible through the climate model.

This study is a part of the Danish HYACINTS project[6], where a fully coupled dynamic climate-hydrological modelling system is developed consisting of the HIRHAM regional climate model (Danish Meteorological Institute) and the MIKE SHE hydrological model (DHI). The coupled modelling system is to be established for a domain within the national water resources model for Denmark (Geological Survey of Denmark and Greenland).

Presented here are:

1. An initial study prior to the coupling investigating the atmosphere component where the optimal domain characteristics of the HIRHAM regional climate model were assessed by analyzing seven different setups with combinations of resolutions between 5.5 and 12 km and domain sizes between 1350x1350 km and 5500x5200 km.
2. An initial study prior to the coupling on the land and subsurface component where three sites with extensive monitoring and each representing distinct surface types within the catchment were modelled and calibrated in MIKE SHE in 1D setups. This overall parameterisation was thereby transferred to a distributed MIKE SHE setup in an attempt to minimize the number of parameters in the distributed calibration.
3. A specification on input data and the configuration of the coupled setup.

1 THE ATMOSPHERE COMPONENT

HIRHAM model version 5[7] simulations were performed on seven different domains with varying model resolution, domain size and domain placement as outlined in Table 1. Reanalysis data were used at the model boundaries. The simulations were assessed on a seasonal basis for the variables precipitation and temperature in terms of both model absolute error and using bootstrap statistics.

Simulation	Cell size (km)	Domain size (km)	Cell extent
SIM1	5.5	1400x1400	252x252
SIM2	11	1350x1350	122x122
SIM3	11	2800x2800	252x252
SIM4	5.5	1400x1400	252x252
SIM5	5.5	2000x2000	362x362
SIM6	11	4000x2800	362x252
SIM7	12	5500x5200	452x432

Table 1. The domain characteristics of the HIRHAM model runs. All domains are placed with a 60% extent to the west except SIM4 having a 60% eastern extent.

The error analysis was performed by subtracting observation data from the simulation outputs. For this, the observations were bilinearly interpolated to match the grids of the simulation runs. The observation data were supplied by The Danish Meteorological Institute in

10 and 20 km resolution for precipitation and temperature respectively[8,9]. An outcome of the bootstrap test is significance levels to which the simulations perform better compared to a random sample from the observation data set. The random sampling was done in subdomains corresponding to the decorrelation length of the variable and season in question and was performed with 25000 replications to create the summed square residual (SSR) distribution. The bootstrap significance was then calculated as the SSR percentage of the random sampling above the SSR of observation-simulation grid pairs from the same cell.

The results from the error and bootstrap analysis are shown in Figure 1. The results generally show a slight increase in bootstrap levels and decrease in absolute error as a function of higher resolution but the main effect is seen with increasing domain size. It can also be seen from both the bootstrap and error analysis that the HIRHAM simulations perform better in the winter, fall and to some extent spring seasons compared to the summer season and that precipitation is more difficult to simulate compared to temperature.

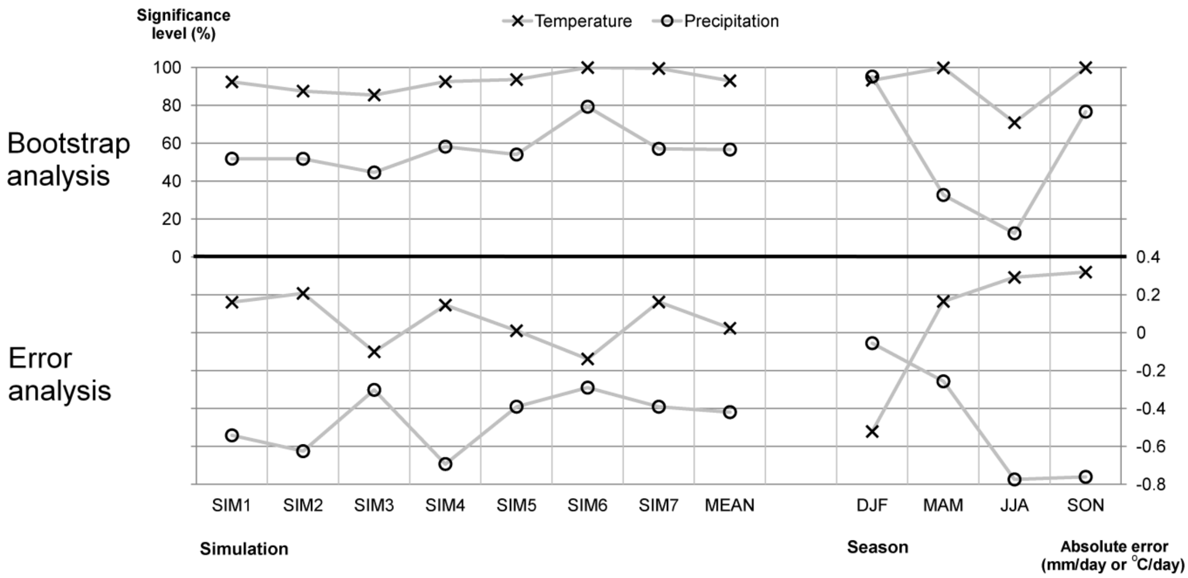

Figure 1. The upper panel shows the results from the bootstrap test and the lower panel shows the error analysis. The left sections shows the yearly averaged results for each simulation and the right section shows the seasonal results as averaged over all simulations.

3 THE SURFACE/SUBSURFACE COMPONENT

The coupled setup is initially tested on the Skjern catchment of approximately 2500 km^2 (Figure 2). It is located in Denmark in the western part of the Jutland peninsula with western winds dominating the climate. The mean annual measured precipitation within the catchment is in the range of approximately 750-900 mm for the latest climate reference period 1961-90[10] and somewhat follows the gently increasing topography ranging from seal level in the west to 130 m towards the east. In the same period the mean annual temperature was 8.3 ^{o}C and the monthly mean temperatures range between 0.7 and 16.1 ^{o}C[11]. Within the catchment three intensively monitored sites are placed at the three most distinct surface types; agriculture (55%), meadow/grass/heath (35%) and forest (7%) with the remaining 3% being urban or other. The measurements at these sites includes radiation and energy fluxes, precipitation, temperature, soil water content, humidity, soil characteristics among many others.

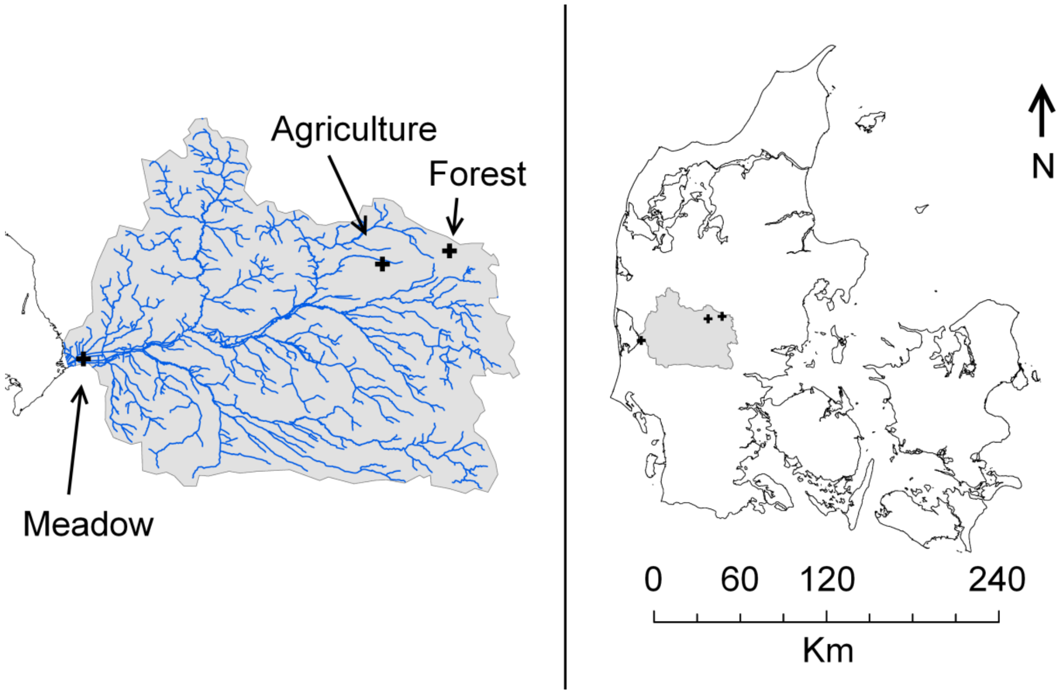

Figure 2. The Skjern catchment and the location of the three sites with extensive monitoring used to calibrate the MIKE SHE setup.

The hydrological model of the coupled setup is the fully distributed MIKE SHE model[12]. Prior to running the distributed MIKE SHE setup three 1D models for ET and soil water flow were applied to test parameter sensitivities and identify optimum parameter values for the three surfaces. Richards' equation is used to simulate water flow in the unsaturated zone using measured groundwater levels as a lower boundary condition. Included in this MIKE SHE setup is the SW ET land-surface component (Shuttleworth and Wallace Evapotranspiration) modified to also include latent and sensible energy fluxes from ponded water on leafs and soil[12]. The SW ET component is a two-layer model separating energy and moisture fluxes between the canopy and the soil. The required input data to the model are all measured at the three sites: precipitation, air temperature, wind speed, global radiation, net radiation, relative humidity and air pressure. Soil parameterisation in the setup is based on the Van Genuchten functional relationship[14] and is derived from distributed soil maps for texture on a 250 m grid basis for the upper two soil horizons; 0-25 cm, 25-75 cm and 500 m for the 75-130 cm horizon[15].

To keep the number of parameters in the optimization on a reasonable level, seasonal variations were included by keeping a constant ratio between different periods of the year. These ratios were specified according to simulations performed in the soil plant atmosphere model DAISY capable of simulating vegetation characteristics as a function of climate, soil and plant/crop type[16]. Especially for the agricultural surfaces a precise knowledge on the anthropogenic induced seasonality can be considered essential. As for the ratio between parameters experiencing seasonality, the knowledge on the ratio between the Van Genuchten parameters between the horizons for each of the three setups was used thereby necessitating only optimization of a single parameter throughout the entire soil profile.

The sensitivity analysis was performed for the year 2010 against all relevant parameters in the MIKE SHE/SW ET setup using initial and lower- and upper bound values from the literature and the DAISY simulations described above. The analysis was performed against output measures of latent and sensible heat fluxes and soil water content at 2-3 depths in the upper 70cm of the profile using the AUTOCAL tool delivered with MIKE SHE[17]. The results can be seen in Figure 3. For agriculture and forest the key vegetation parameters are minimum stomata resistance and leaf area index and the key soil parameters are Van Genuchten α and n and for the forest also hydraulic saturated conductivity. For the meadow having a high groundwater table, soil parameters have the highest sensitivities.

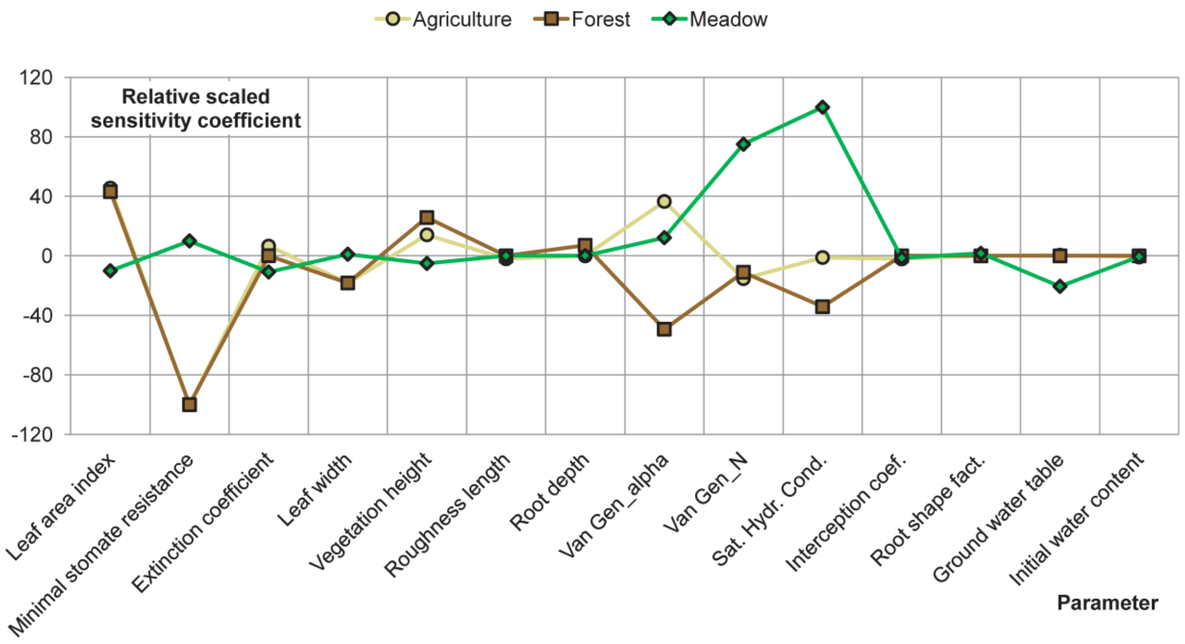

Figure 3. The results from the sensitivity analysis performed in MIKE SHE/SW ET at the three sites.

4 SPECIFICATIONS OF THE COUPLED SETUP

After having performed the above two studies determining the characteristics of each of the atmosphere, land-surface and subsurface components the coupling is to be performed. The models are coupled using the Open Modelling Interface (OpenMI) developed by the OpenMI Association. Both MIKE SHE and HIRHAM have recently been made compliant with OpenMI. Some of the challenges in coupling the two model codes include large differences in the horizontal grid resolutions, i.e. 0.5 and 11 km in MIKE SHE and HIRHAM, respectively, the different regular/irregular grid structure and different time steps. Also, MIKE SHE requires a Windows platform to run, whereas HIRHAM is installed on a Linux based Cray supercomputer located at The Danish Meteorological Institute. A schematic of the model coupling is shown in Fig. 4, illustrating how meteorological data derived from HIRHAM and energy fluxes returned from MIKE SHE are exchanged. As shown in the figure MIKE SHE and OpenMI are installed on the same system along with a proxy for HIRHAM, which handles the data exchange with the remote system using shared data storage.

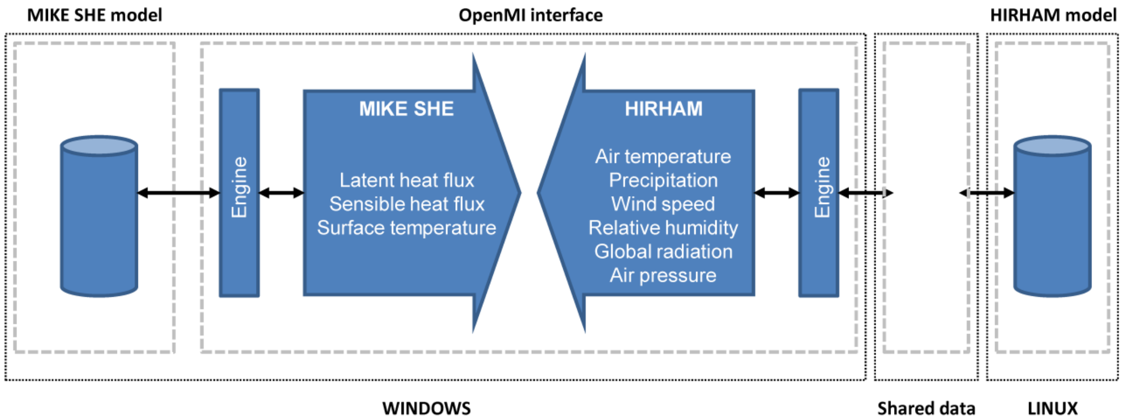

Figure 4. A schematic overview of the components in the coupled setup and the data exchange.

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