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Extended abstract

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Publication date:
2014

1st European Fully Coupled Atmospheric-Hydrological Modeling and WRF-Hydro Users workshop
Rende (Cosenza, Italy), June 11-13, 2014
Extended Abstracts

Integrated Climate and Hydrology Modelling - Catchment Scale Coupling of the HIRHAM Regional Climate Model and the MIKE SHE Hydrological Model

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***Keywords* - Coupled modelling, catchment scale hydrological modelling, regional climate modelling, atmosphere – land surface feedback**

I. ABSTRACT

Applying regional climate models (RCM) at finer scales, down to even a few kilometres, representing the complex atmosphere/land-surface/subsurface hydrology interactions is crucial for understanding climate feedbacks. The ability of many current climate models to fully represent the terrestrial water cycle is however limited and particular true for surface and subsurface processes.

We here present a dynamically coupled version of the MIKE SHE (Graham and Butts 2005) hydrology model nested inside the DMI-HIRHAM RCM (Christensen et al. 2006). A major challenge in the coupling resides in the vastly different philosophies between such model codes as RCM's generally implement primary physical equations while hydrological models typically require substantial calibration. Further challenges include differences in spatial and temporal resolutions and computational platform differences (Windows and Linux based codes) necessitating the use of the OpenMI cross-platform model interface.

The coupled model is evaluated for a catchment in Denmark embedded within the RCM domain. Inside the shared model domains the coupled model enables two-way atmosphere/land-surface interactions via the energy-based land-surface model (SWET) (Overgaard 2005) embedded in MIKE SHE in the current configuration. In this manner the simpler DMI-HIRHAM land-surface scheme is effectively replaced by the superior land-surface component of the combined MIKE SHE/SWET model, which includes a wider range of processes at the land-surface and 3D subsurface flows as well as higher temporal and spatial resolution. The setup has proven stable and has been used for simulations of several years.

II. METHOD

The task of individually calibrating and preparing each of the two modelling systems is performed in two studies preceding the coupled simulations: (i) In Larsen et al. (2013) the DMI-HIRHAM performance of simulated seasonal precipitation and air temperature is investigated through systematic variations in domain size (1350x1350 km to 5500x5200 km), domain location and model grid resolution (5.5 to 11 km) in a total of eight simulations. The coupled RCM domain is chosen based on the DMI-HIRHAM results from these eight domains (Figure 1). (ii) In Larsen et al. (*submitted*) the MIKE SHE hydrology model is calibrated

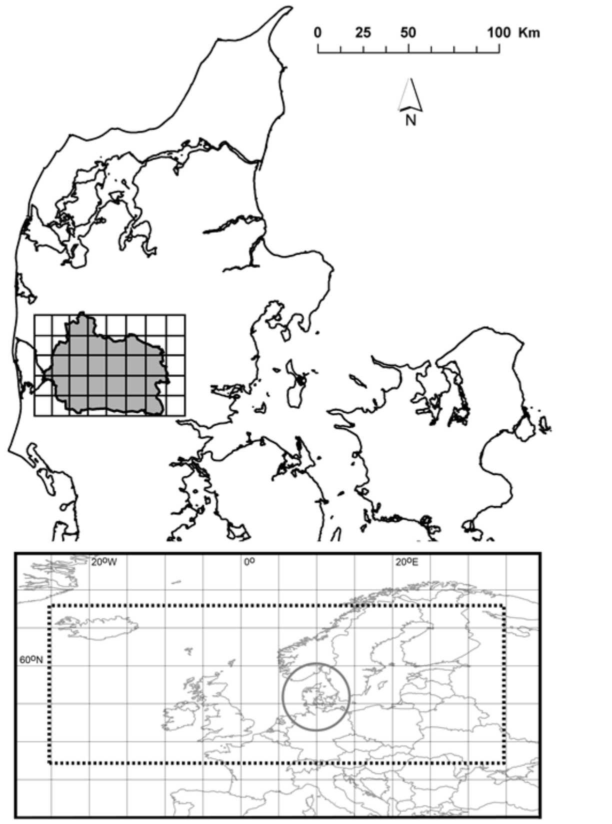

Fig. 1 The DMI-HIRHAM regional climate model domain used in the coupled simulations and the Skjern River catchment location within Denmark. Also shown is the DMI-HIRHAM grid cells of the overlapping area.

against energy flux components (sensible and latent heat), discharge and soil moisture focusing on both water balance closure and atmospheric exchange.

After the successful preparation of each of the two models the coupled simulations between the DMI-HIRHAM RCM and the MIKE SHE hydrological model are performed. To facilitate communication between the differing computation platforms the OpenMI external coupling software is used in the Windows environment (personal workstation) whereas additional code is developed in the Linux environment (Cray XT5). The coupling codes handle the temporal 'wait-execute' timing between the models, define the exchange variables and the related unit conversion factors, handle the spatial mapping and interpolation as well as handling the interpolation of variables with regard to the individual time step of the models in relation to the data exchange frequency.

In the coupled setup DMI-HIRHAM is used as the climatic forcing for MIKE SHE supplying six climatic variables (Precipitation, air temperature, relative humidity, surface pressure, global radiation and wind speed). In the present MIKE SHE setup the SWET energy-based (Shuttleworth-Wallace scheme) land-surface model is used within MIKE SHE to facilitate the exchange of energy fluxes to DMI-HIRHAM (latent heat and surface temperature – the latter recalculated to sensible heat).

The DMI-HIRHAM domain covers app. 2800 km x 4000 km in 11 km resolution with the coupling area located with a 60 % stretch to the west wherefrom most weather systems originate. The MIKE SHE model setup embedded within the RCM domain covers the groundwater-dominated Skjern river catchment in Denmark (Jutland peninsula) consisting of mainly sandy soils and agricultural land (61 %) and having a water balance of roughly 1050 mm precipitation (gauge undercatch corrected), 500 mm discharge, 475 mm evapotranspiration and 75 mm pumping.

The coupled simulations are performed for two different periods with differing aims:

(1) 26 simulations are performed for a one-year period (1 May 2009 to 30 Apr 2010) to investigate the influence of the inter-model data transfer interval on model performance and computation time (varied from 12 to 120 min) as well as the influence DMI-HIRHAM coupled and uncoupled model variability.

(2) 8 simulations (ongoing and therefore subject to increase) are performed in selected periods from 2000-2010 having good observation data, evaluating the coupled model performance, as opposed to uncoupled, with regard to more severe events of drought, high precipitation and warm/cold periods.

III. RESULTS

The data transfer interval between the two models greatly influenced the computation time which was partly related to the data exchange being file-based as opposed to memory-based due to security constraints at the computation facility. A drastic increase in computation time was seen with more frequent data exchange (Figure 2). An optimal data transfer interval in terms of model output statistics and computation time was therefore seen for data transfer rates of

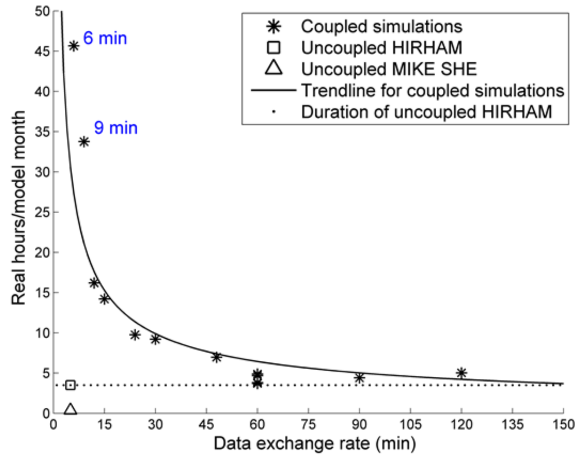

Fig. 2 The computation time for different data transfer intervals between the coupled models, DMI-HIRHAM and MIKE SHE, expressed in units of wall time per month of simulation time. The dashed line is the uncoupled DMI-HIRHAM simulation time.

approximately 30 min, which was chosen for the coupled runs performed hereafter.

The resulting spatial patterns of evapotranspiration from MIKE SHE (Figure 3a) (uncoupled – observation driven), DMI-HIRHAM (Figure 3b) (uncoupled), one-way coupled (figure 3c) (DMI-HIRHAM input to MIKE SHE without feedback) and two-way coupled (Figure 3d) for a one week summer period is shown in figure 3. The plots raise several issues: (i) The higher detail in resolution when extracting results from MIKE SHE is obvious whereas the feedback to DMI-HIRHAM is aggregated into the RCM grids. (ii) The regional distribution of evapotranspiration minima and maxima varies between model runs (e.g. between figure 3a and 3b), whereas an inspection of the geographical precipitation patterns in this and preceding weeks (not shown)

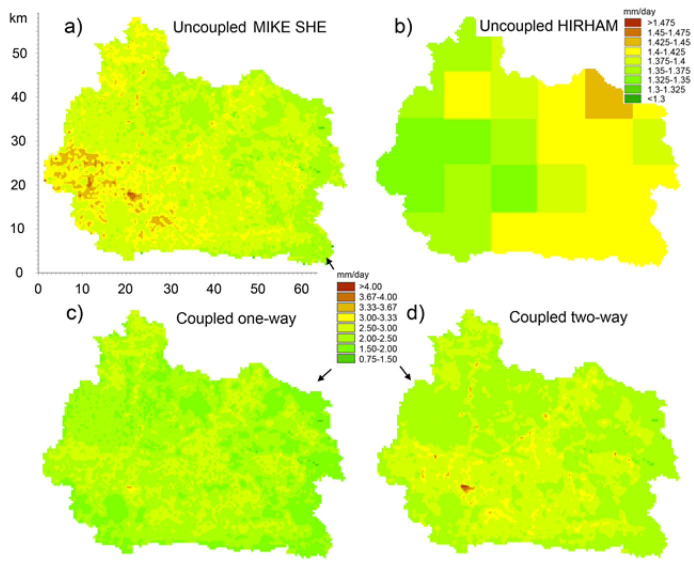

Fig. 3 The simulated spatial distribution of mean daily evapotranspiration for the period June 5-11, 2009, from MIKE SHE alone (a) (observed forcing data), DMI-HIRHAM alone (b), coupled one-way (c) (MIKE SHE simulation with DMI-HIRHAM forcing data and no feedback to DMI-HIRHAM) and fully two-way coupled with dynamic feedback (d).

shows a clear correlation between the geographical distribution of higher precipitation and corresponding evapotranspiration. (iii) MIKE SHE is greatly influenced by the driving variables (observations or RCM – figure 3a and 3c) and the two-way coupled runs with MIKE SHE feedback into DMI-HIRHAM (3d) is higher as compared to one-way coupled (3c) reflecting the general higher evapotranspiration rate from MIKE SHE.

The coupled runs were assessed against the same six climatic variables exchanged from DMI-HIRHAM to MIKE SHE as these were available as gridded high resolution observation data for the periods in question. Four of these show statistical improvements with an increase in the data transfer frequency; precipitation, air temperature, wind speed and relative humidity whereas global radiation and surface pressure remain largely unaffected. Figure 4 shows time series plots of these six variables for a summer period. A high degree of variability is related to the simulated precipitation with general higher precipitation levels in the one-year period (summarized – not shown) for the coupled simulations (1048 mm) compared to uncoupled simulations (926 mm). Also, relative humidity, air temperature and wind speed is clearly more affected by method (coupled/uncoupled) than by variability. For all of these six variables however, the coupled simulations show poorer output statistics as compared the uncoupled results.

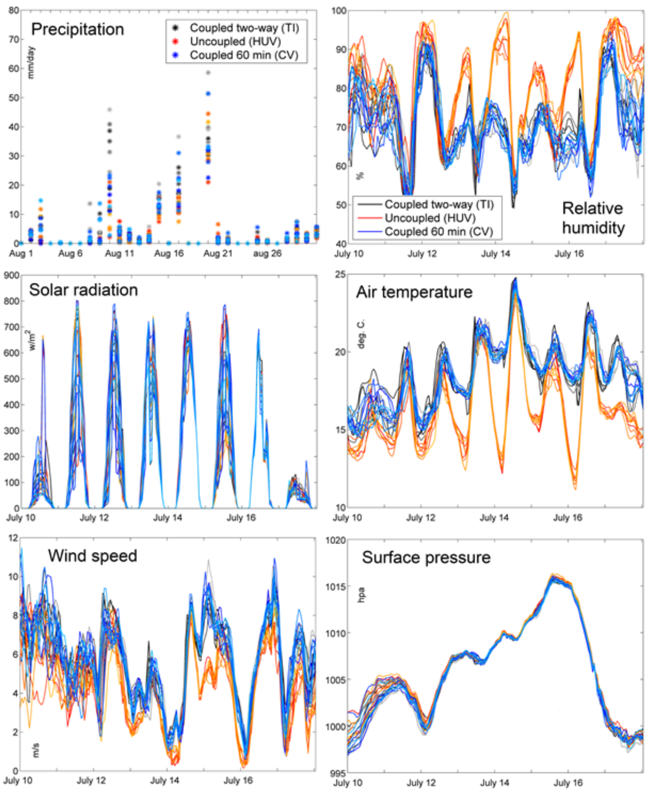

Fig. 4 The six climatic variables used in the assessment of the coupled setup for the 10-18 July period, 2009, (precipitation is 1-31 August). The TI, HUV and CV runs each represent groups of eight simulations varying the data transfer interval of 12-120 minutes (TI), assessing HIRHAM uncoupled variability (HUV) as well as fully coupled variability (CV).

IV. DISCUSSION AND CONCLUSIONS

We here present the results from two full studies employing a fully dynamic coupling performed on several years with a sub-diurnal data exchange frequency between the DMI-HIRHAM RCM and the MIKE SHE/SWET hydrology-land-surface model including full 3D subsurface flow, river flow and an energy flux based atmospheric exchange.

The poorer performance of the coupled model setup, as compared to the uncoupled setup, is explained by the calibration and refinement of both DMI-HIRHAM and MIKE SHE over a number of years, or even decades, to reproduce observations. These alterations however, are completely ignored by imposing a new model over the shared domain which inevitably results in model deterioration.

Further, the results clearly show the need to account for the RCM induced variability in the assessment methodology: The higher evapotranspiration rates from the downstream river-near areas in figure 3a/d are clearly related to the higher detail in the hydrological processes included in MIKE SHE as opposed to the 'bucket type' hydrology in DMI-HIRHAM (Figure 3b) but a strong influence is also induced by temporal and geographical variations in mainly precipitation.

With regards to coupled model performance an important aspect for future studies is to pursue a strategy for calibrating the coupled model setup as a whole to overcome the danger of having the model calibration compensate for biases in the other model. Further experiments would also benefit from utilizing a larger shared domain and simulating other regions. However, in the present study we emphasize the overall feasibility of the coupling tool and suggest that modelling studies of the future climate are likely to benefit from the coupled model setup.

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