Locally improved land surface feedback by dynamically coupling a hydrology model to an RCM improves simulated precipitation – also the extreme tail

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CRES Centre for Regional Change in the Earth System

HYACINTS Hydrological Modelling for Assessing Climate Change Impacts at different Scales

HOBE Center for Hydrology Hydrological Observatory

Motivation

Dynamically couple existing state-of-the-art models to utilize improvements in process representation and spatio-temporal scale in the subsurface/land surface/atmosphere water and energy feedback loop

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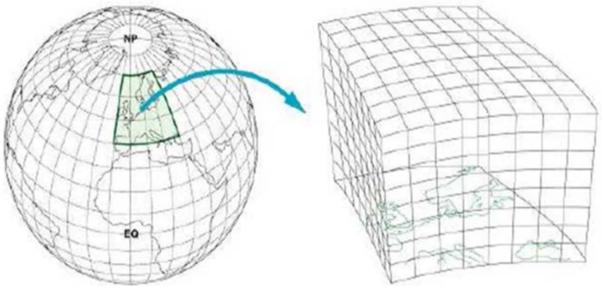
- Diminished bias
- Improved reliability in future projections

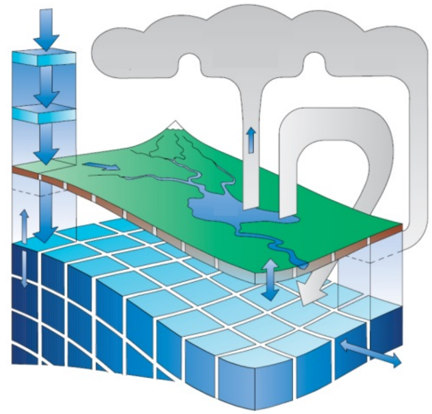
Models are largely developed in separate communities (hydrology or climate) and the research field of coupling models has only emerged (quite) recently

Land surface <–> atmosphere interaction

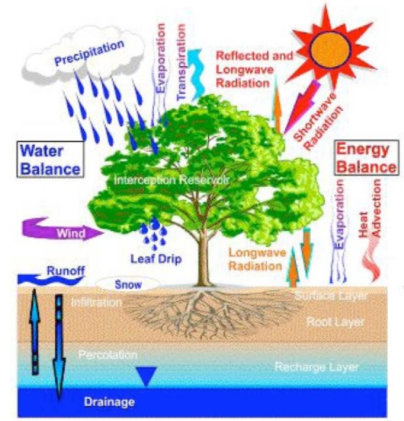
Models:



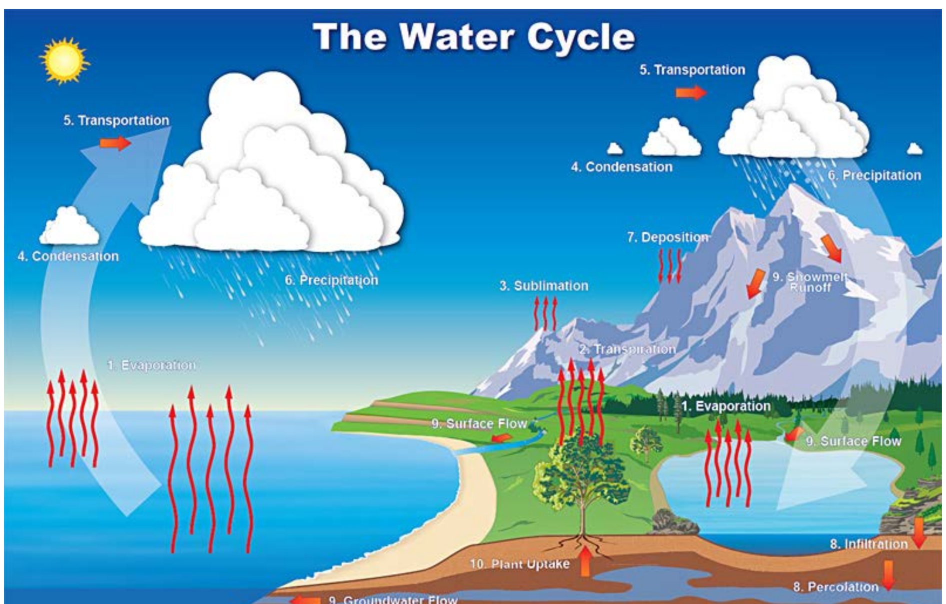
Regional climate model



Distributed hydrology model



Land surface model

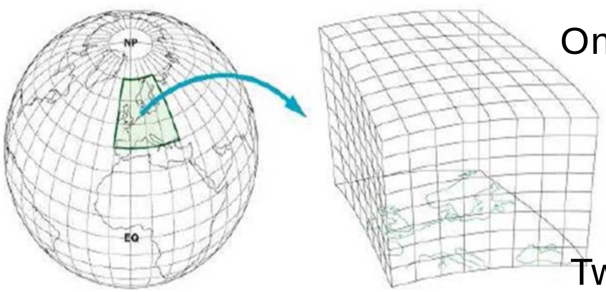


Complex series of interrelated events in time and space

Source:
http://www.education.noaa.gov/Freshwater/Water_Cycle.html

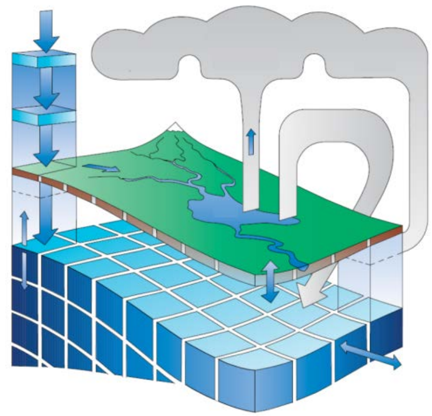
Land surface <–> atmosphere interaction

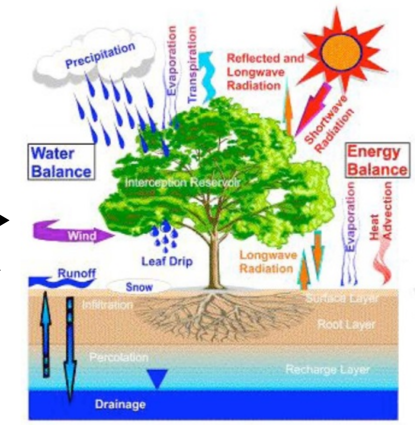
Models:



One-way

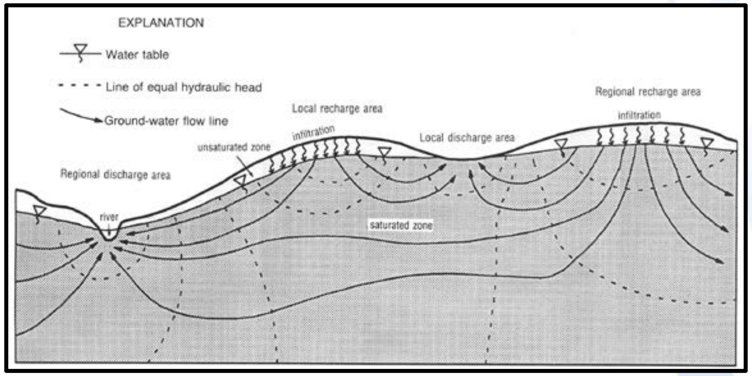
Two-way

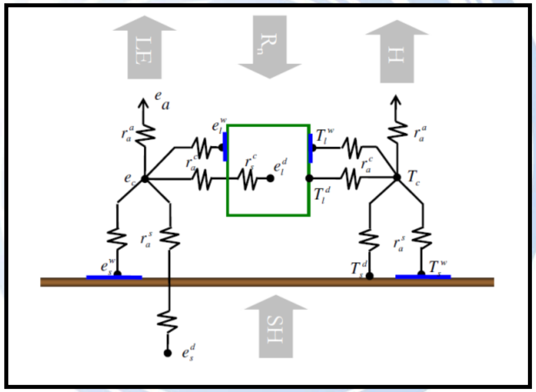




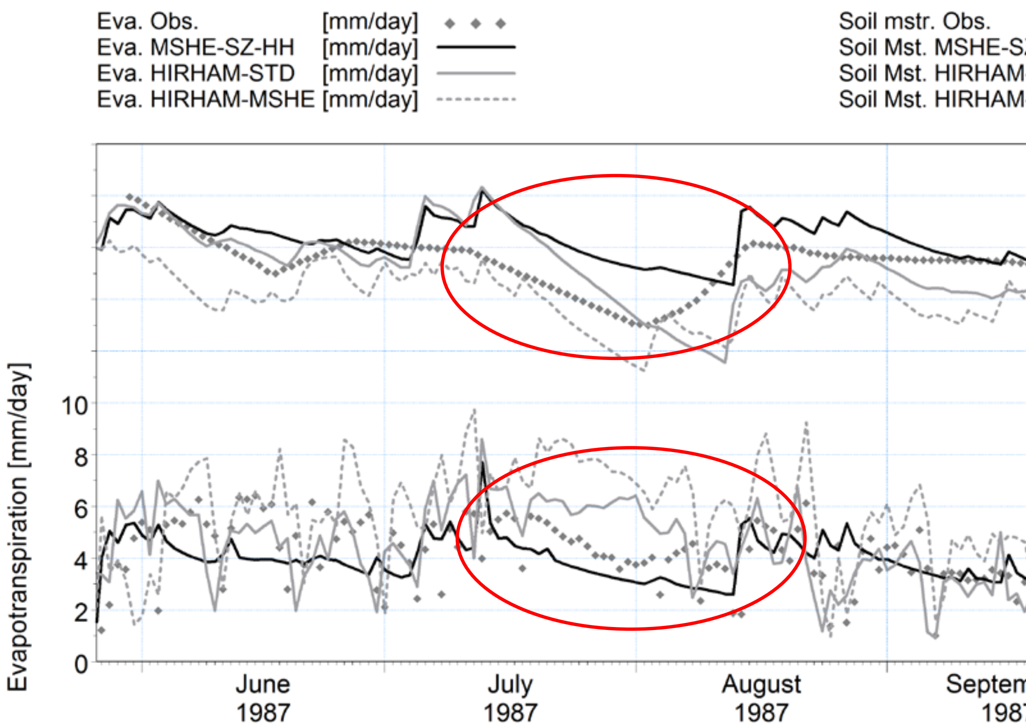
Regional climate model Distributed hydrology model Land surface model

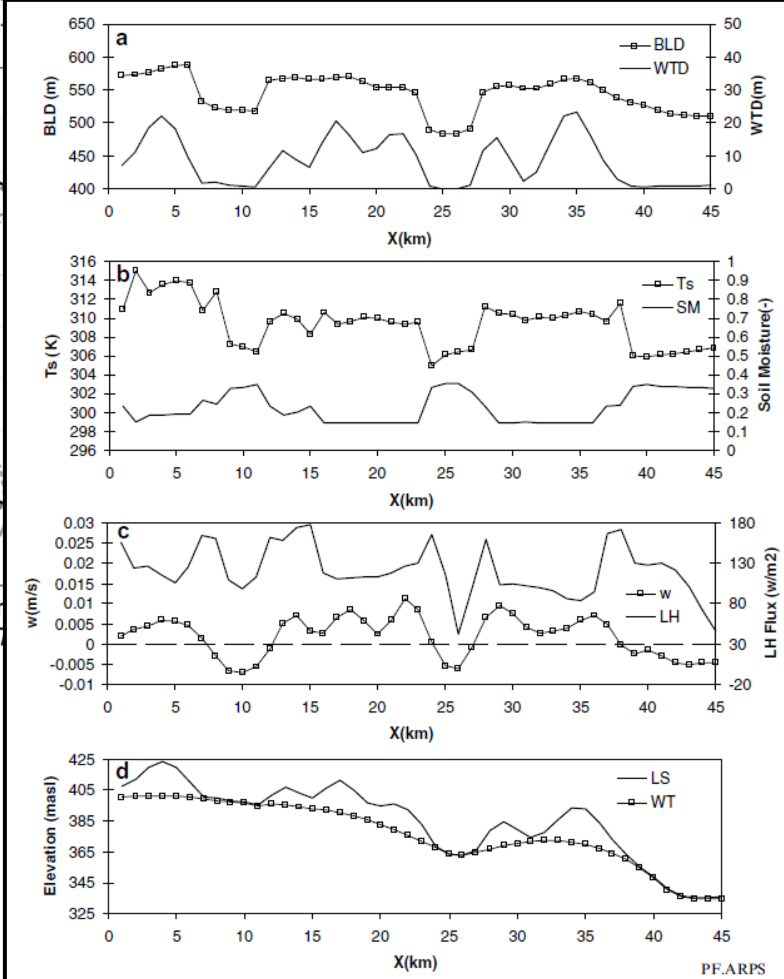
Processes:





Land surface <–> atmosphere interaction
(Proof of concept)





Larsen MAD, Rasmussen SH, Drews M, Butts MM, Christensen JH, Refsgaard JC. Assessing the influence of groundwater and land surface scheme in the modelling of land surface–atmosphere feedbacks over the FIFE area in Kansas, USA. Environ Earth Sci (2016) 75:130, doi:10.1007/s12665-015-4919-0.

Maxwell RM, Chow FK, Kollet SJ. The groundwater–land–surface–atmosphere connection: soil moisture effects on atmospheric boundary layer in fully coupled simulations. Adv Water Resour 2007;30:2447–66. doi:10.1016/j.advwatres.2007.05.018.

Larsen et al. coupled research - flow chart

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DK case (Skjern River catchment)

Climate model preparation

Larsen et al. (2013): On the role of domain size and resolution in the simulations with the HIRHAM region climate model. Journal: Climate dynamics.

Hydrology model preparation

Larsen et al. (2016): Calibration of a distributed hydrology and land surface model using energy flux measurements. Journal: Agricultural and Forest Meteorology.

Coupled methodology

Butts, Larsen et al. (2014): Embedding complex hydrology in the regional climate system – Dynamic coupling across different modelling domains. Journal: Advances in Water Resources.

Coupled test runs

Larsen et al. (2014): Results from a full coupling of the HIRHAM regional climate model and the MIKE SHE hydrological model for a Danish catchment. Journal: Hydrology and Earth System Sciences.

Coupled long term simulations

Larsen et al. (2016): Local control on precipitation in a fully coupled climate-hydrology model. Journal: Scientific Reports.

Other cases

USA case

Larsen et al. (2016): Assessing the influence of groundwater and land surface scheme in the modelling of land surface-atmosphere feedbacks over the FIFE area in Kansas, USA. Journal: Environmental Earth Sciences.

Mediterranean case

Larsen et al. (In progress): Preparing for fully coupled climate-hydrological modelling in data-sparse regions applied over the Crati river catchment in Southern Italy.

Larsen et al. coupled research - flow chart

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Climate model preparation

Larsen et al. (2013): On the role of domain size and resolution in the simulations with the HIRHAM region climate model. Journal: Climate dynamics.

- Physically based (then why needed?)
- Often referred to as tuning (not calibration):
    - Parameters related to processes not represented at the model grid resolution, i.e. land surface and convective precipitation
    - Often related to energy/radiation balances
    - Tuning is not highly site-specific

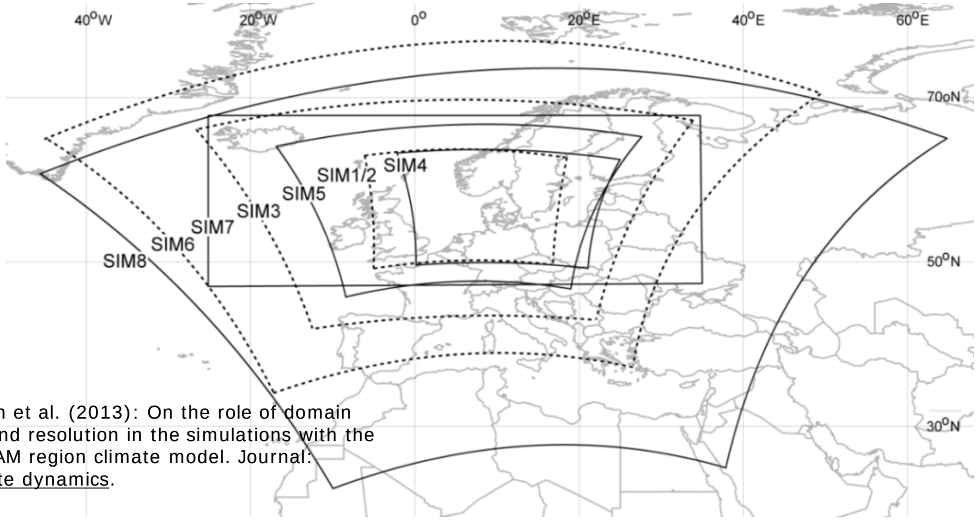
Hydrology model preparation

Larsen et al. (2015?): Calibration of a distributed hydrology and land surface model using energy flux measurements. Journal: Agricultural and Forest Meteorology (in review).

- Physical
- Complex geology and land surface (represented by grid boxes)
- Calibration often on Q, head, soil water, evapotranspiration etc.
- 100% site specific

HIRHAM – setup study - domains

1. Tuning already done!
2. Find the optimal HIRHAM domain characteristics for the coupled setup
3. No definite rules on domain size, location and resolution

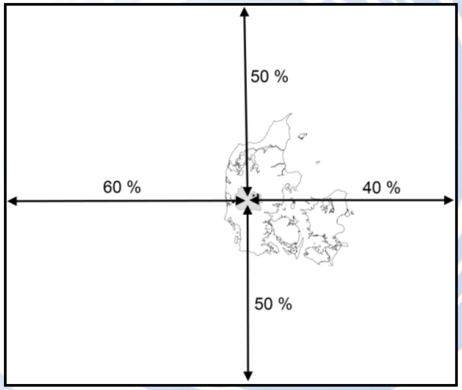


Larsen et al. (2013): On the role of domain size and resolution in the simulations with the HIRHAM region climate model. Journal: Climate dynamics.

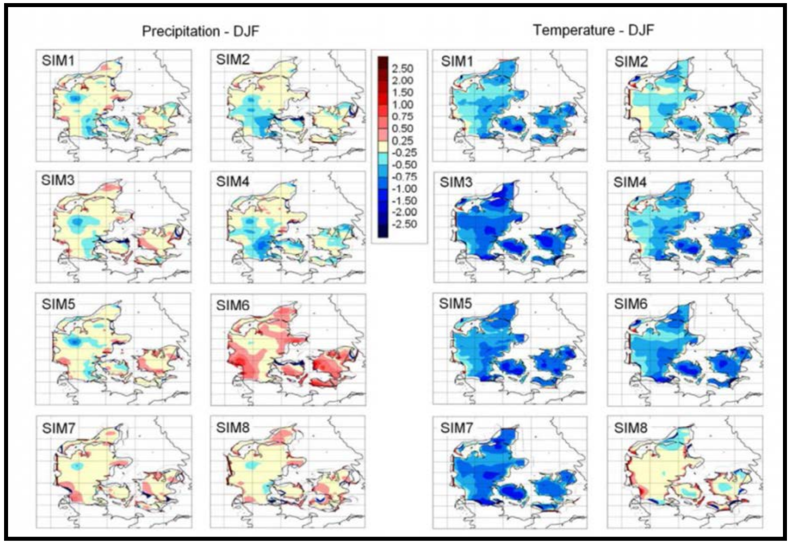
Specifications
- DMI-HIRHAM (5)
- ERA-Interim
- 1 Jan 2008 – 30 Apr 2010

Assessment
- Seasonal precip. and temp.
- E-OBS and DMI observation data

Model run	Resolution (km)	Domain size (km - lon x lat)	Number of cells
SIM1	5.5	1400x1400	252
SIM2	11	1350x1350	122
SIM3	11	2800x2800	252
SIM4	5.5	1400x1400	252
SIM5	5.5	2000x2000	362
SIM6	11	4000x4000	362
SIM7	11	4000x2800	362
SIM8	12	5500x5200	452x432



HIRHAM – setup study – error/significance



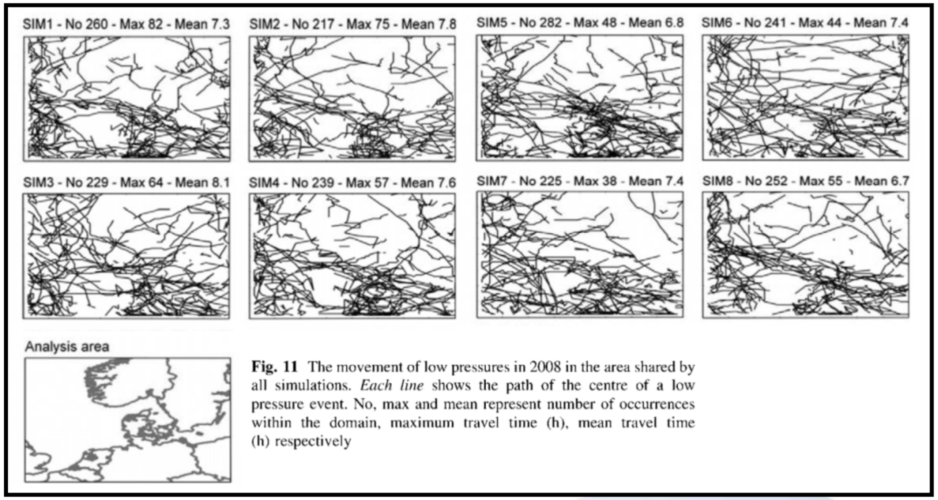


Fig. 11 The movement of low pressures in 2008 in the area shared by all simulations. *Each line* shows the path of the centre of a low pressure event. No, max and mean represent number of occurrences within the domain, maximum travel time (h), mean travel time (h) respectively

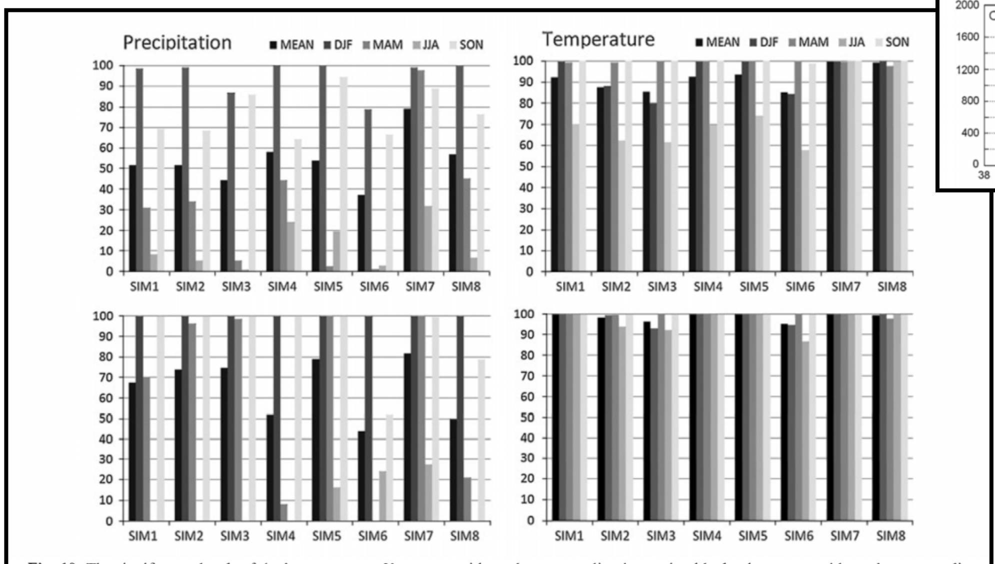
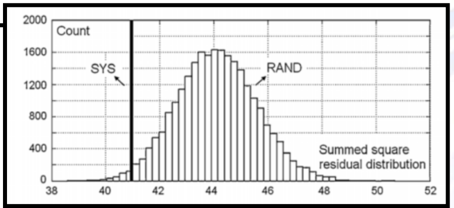


Fig. 10 The significance levels of the bootstrap test. *Upper row* with random resampling in moving blocks, *lower row* with random resampling all over Denmark

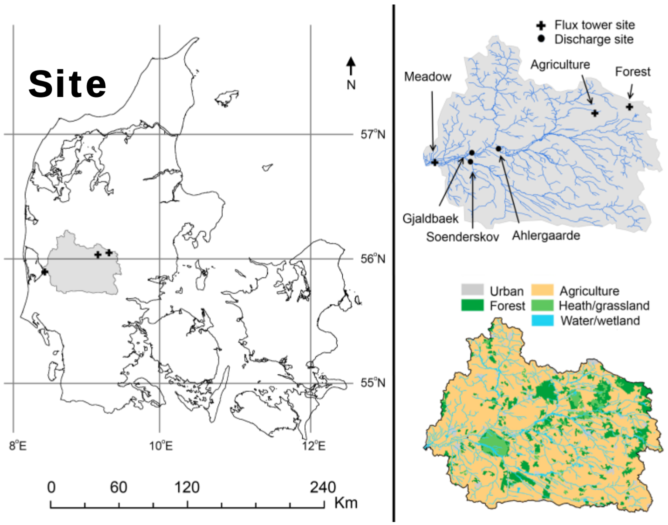


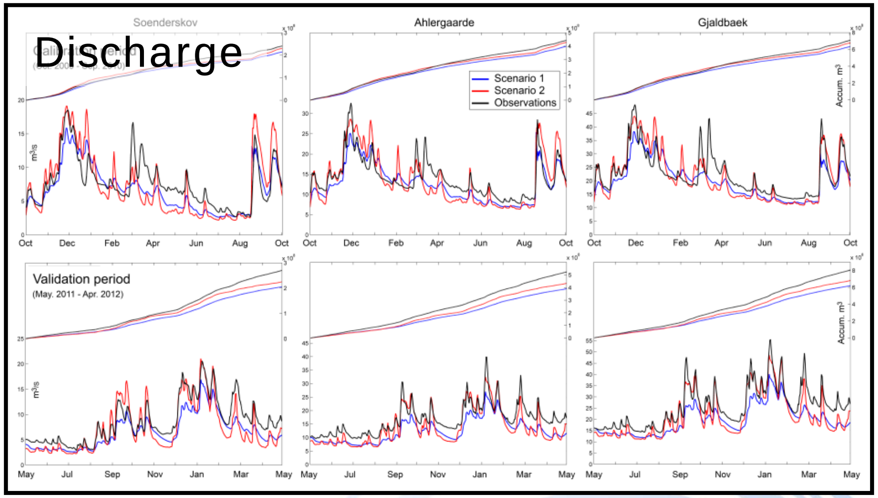
Best domain: 11 km resolution and 4000x2800 km size

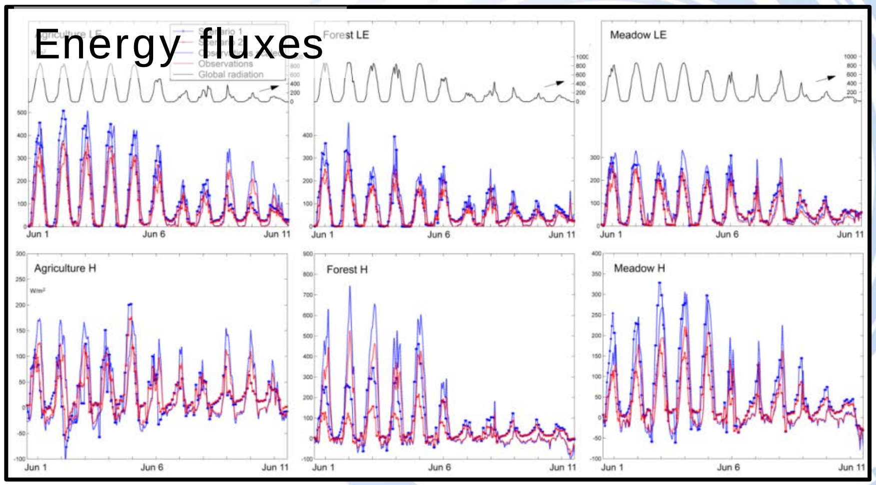
Larsen, M. A. D., Thejll, P., Christensen, J. H., Refsgaard, J. C., and Jensen, K. H. (2013). On the role of domain size and resolution in the simulations with the HIRHAM region climate model, Clim. Dynam., 40, 2903–2918, doi:10.1007/s00382-012-1513-y.

MIKE SHE / SWET – setup study

Calibrate MIKE SHE including SWET land surface model component







Specifications

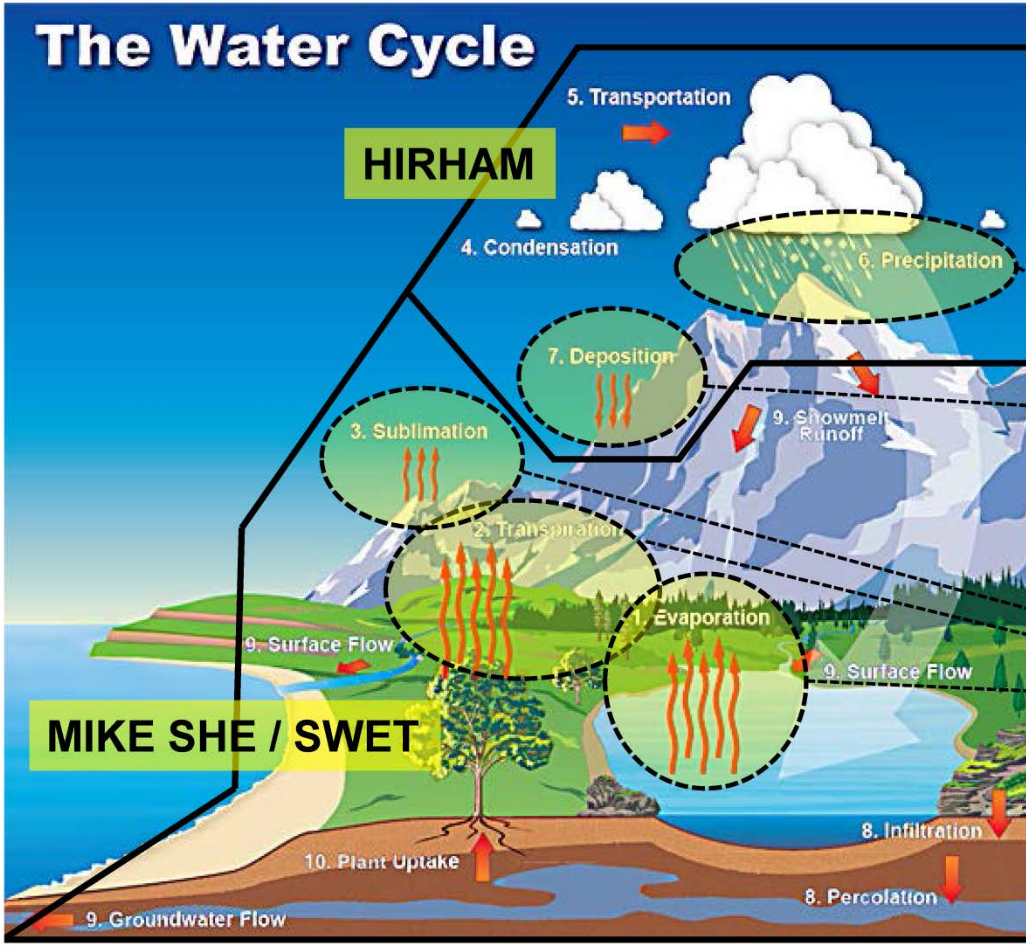
- MIKE SHE (2011)
- 500 m resolution
- Calibrated against observation data
- Calibration: 1 Oct 2009 – 30 Sep 2010
- Validation: 1 May 2011 – 30 Apr 2012

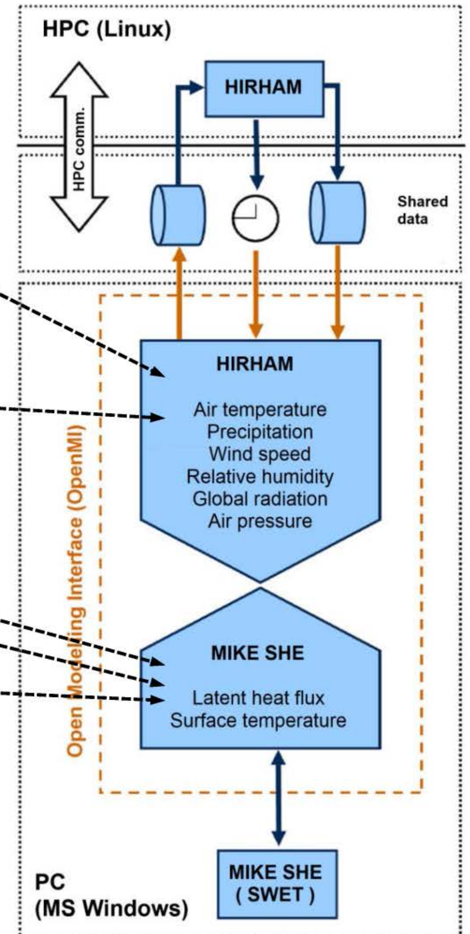
Assessment

- Energy fluxes (LE, H and G)
- Discharge (water balance)
- Spinup sensitivity

Larsen et al. (2016): Calibration of a distributed hydrology and land surface model using energy flux measurements. Journal: Agricultural and Forest Meteorology.

Coupling approach

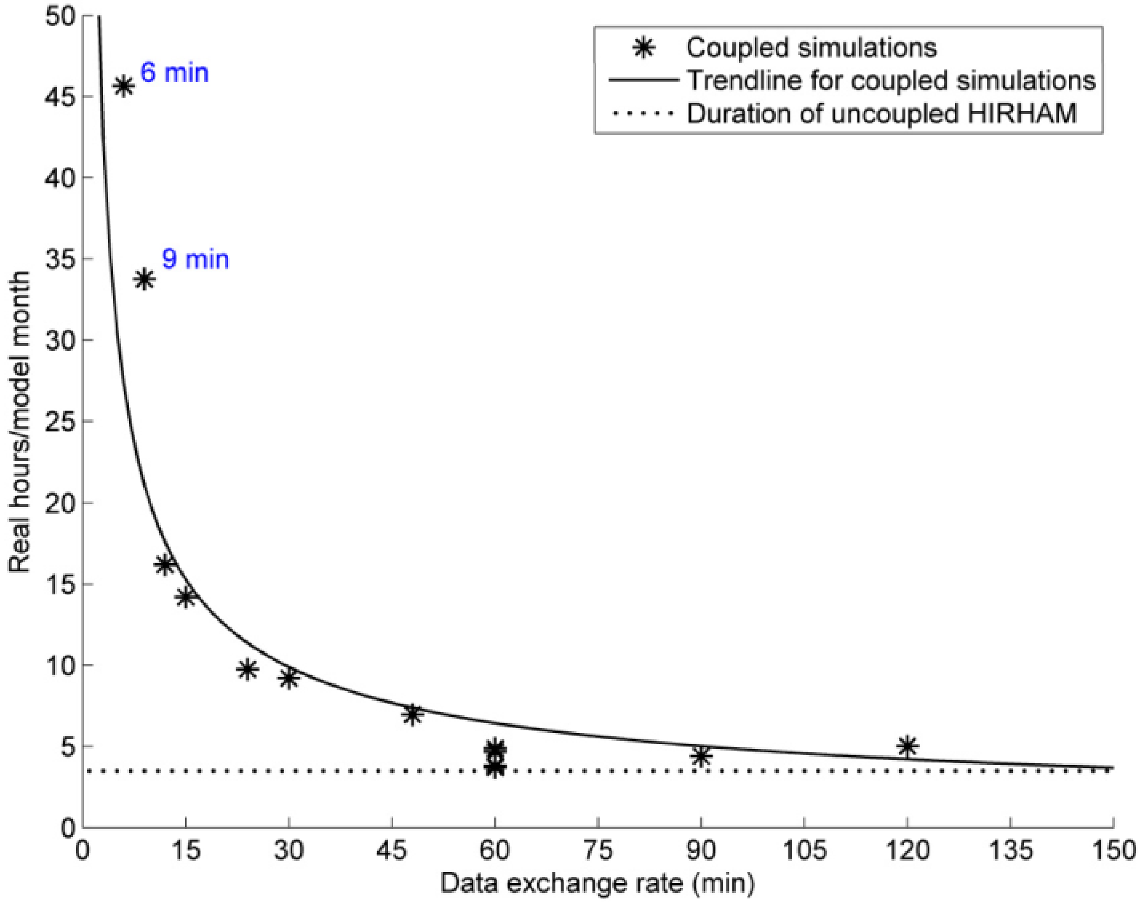




Butts, Larsen et al. (2014): Embedding complex hydrology in the regional climate system – Dynamic coupling across different modelling domains. Journal: Advances in Water Resources.

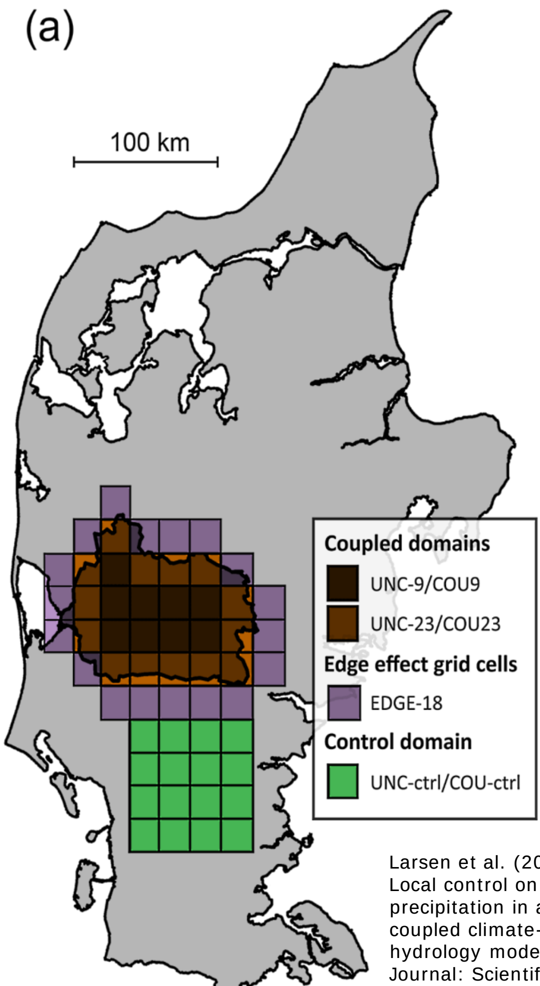
- Timing (wait/go)
- Mapping (interpolation)
- Temporal interpolation
- Unit conversion

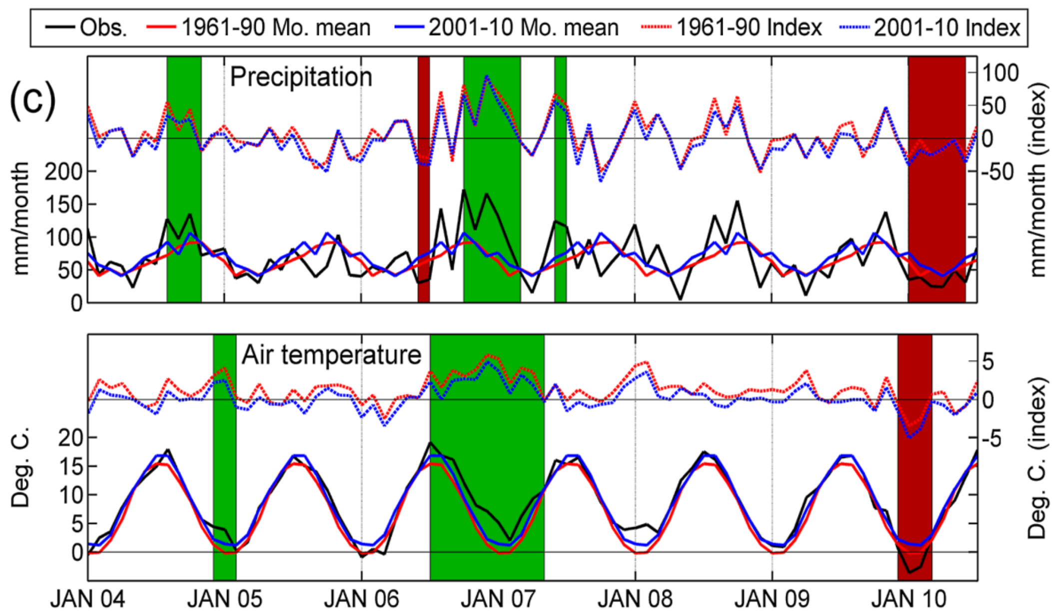
Data transfer interval



Butts, Larsen et al. (2014): Embedding complex hydrology in the regional climate system – Dynamic coupling across different modelling domains. Journal: Advances in Water Resources.

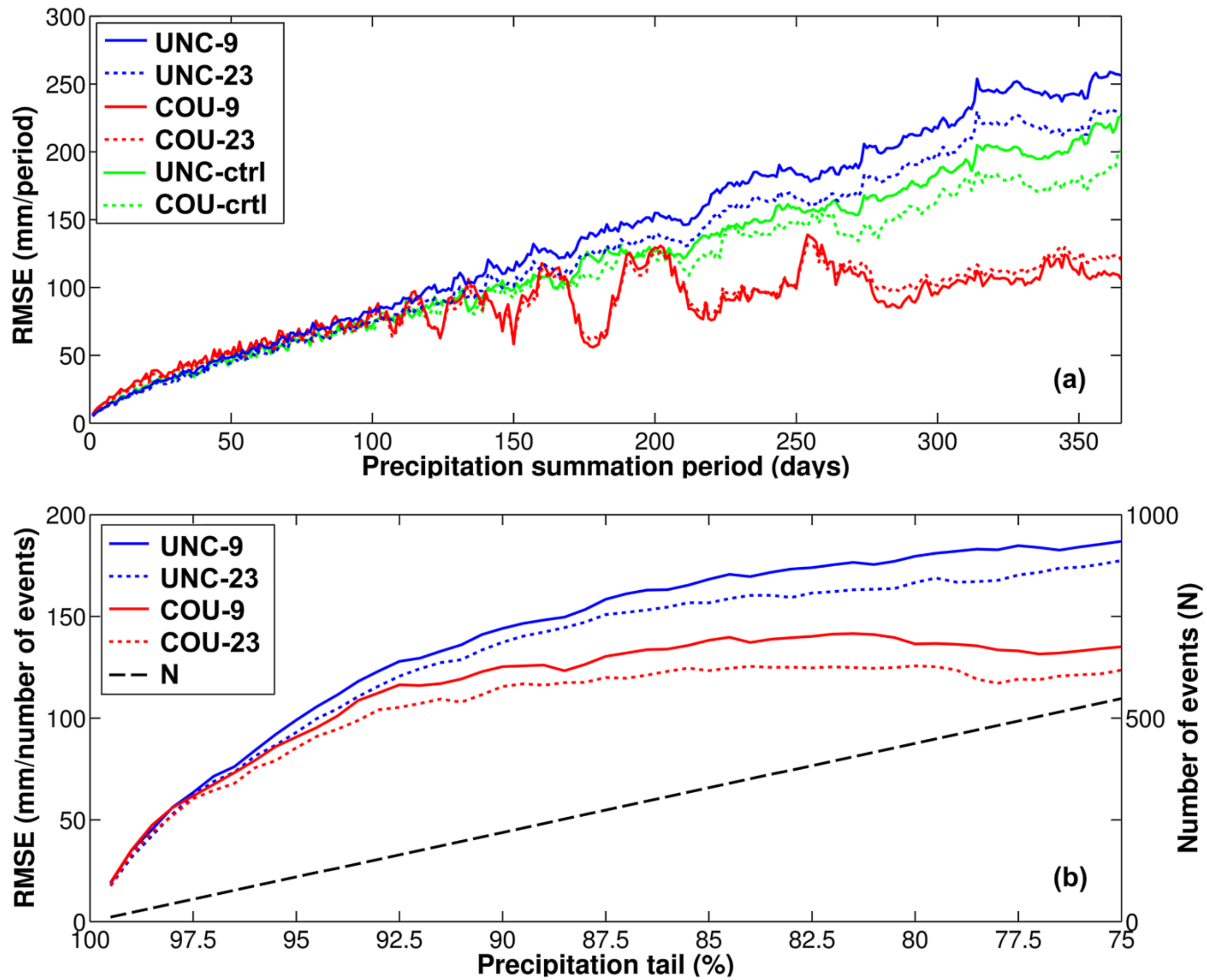
Hydrology catchment, RCM domain and observed T and P in simulated period





Larsen et al. (2016): Local control on precipitation in a fully coupled climate-hydrology model. Journal: Scientific Reports. Scientific Reports | 6:22927 | DOI: 10.1038/srep22927

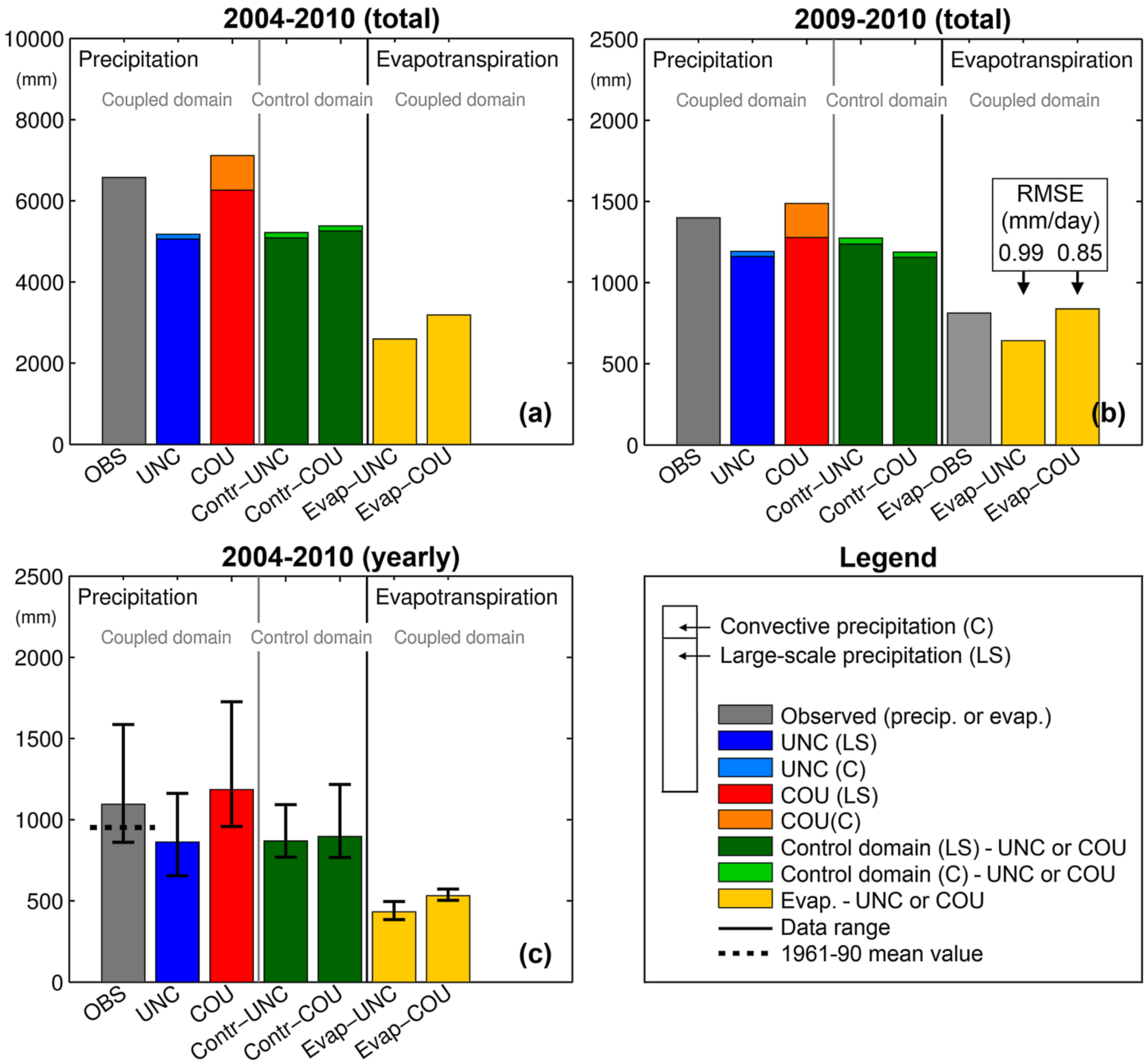
Simulation RMSE as a function of period length and precipitation intensity



Larsen et al. (2016): Local control on precipitation in a fully coupled climate-hydrology model. Journal: Scientific Reports. Scientific Reports | 6:22927 | DOI: 10.1038/srep22927

(a) Root mean square errors (RMSE) of observed and simulated precipitation after summation in periods of 1-365 days for the entire data range and (b) RMSE as a function of the precipitation sum from the 75-99.5% percentile (sorted by observation data) as well as the sample size (entitled N).

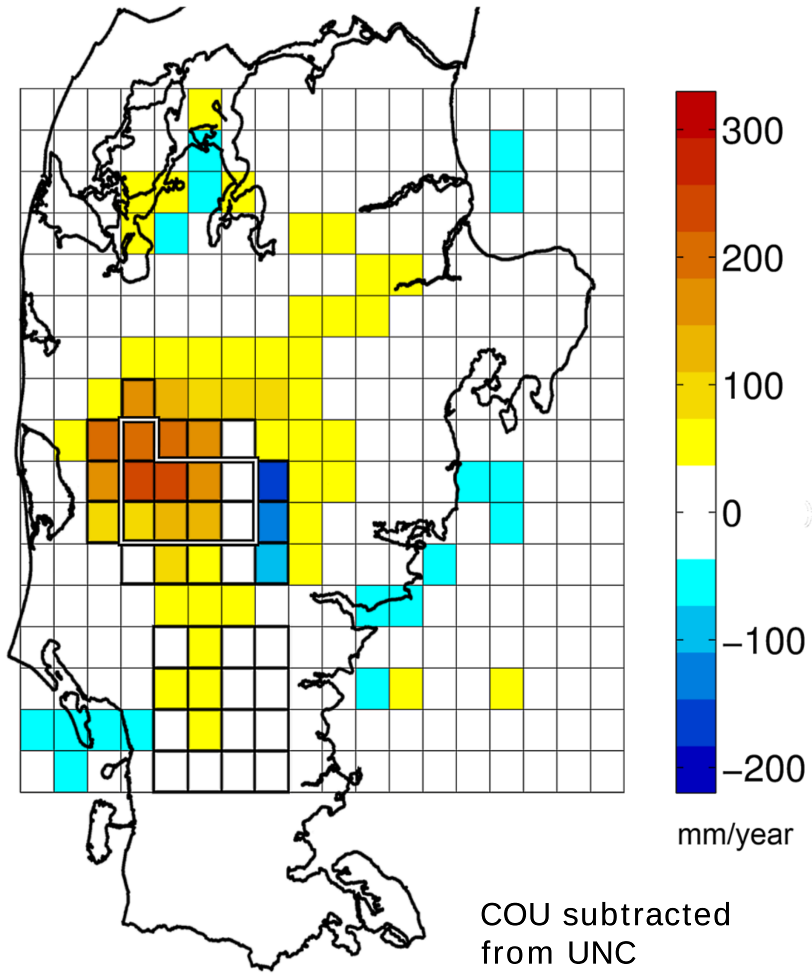
Precipitation and evapotranspiration amounts and variability



Plots of the observed total and simulated large-scale (LS) and convective (C) precipitation (stacked to show simulated total) as well as the observed (2009-2010 only) and simulated evapotranspiration. Results are shown as summation plots for (a) the total period, (b) for the 2009-2010 period and (c) yearly averages (Aug to Jul). Plot (b) includes observed evapotranspiration and corresponding RMSE values for COU and UNC daily evapotranspiration and plot (c) includes the total observation and simulation range for the six years and the 1961-90 mean (the gauge undercatch is corrected by monthly factors[37]). All non-control results show average levels from the 9 cell coupled domain.

Larsen et al. (2016): Local control on precipitation in a fully coupled climate-hydrology model. Journal: Scientific Reports. Scientific Reports | 6:22927 | DOI: 10.1038/srep22927

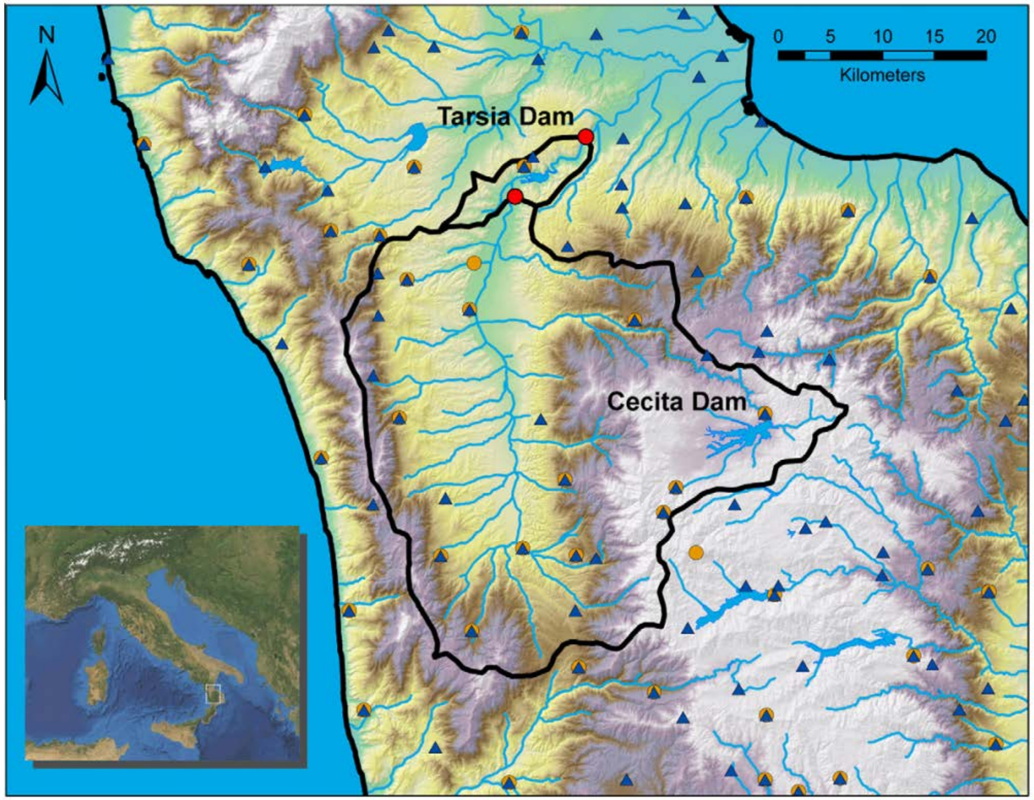
Distributed plot of RMSE difference between coupled and uncoupled simulations



Larsen et al. (2016): Local control on precipitation in a fully coupled climate-hydrology model. Journal: Scientific Reports. Scientific Reports | 6:22927 | DOI: 10.1038/srep22927

Distributed plot of the difference in RMSE levels of UNC and COU (COU subtracted from UNC) for a 365 day summation period for the entire Jutland peninsula. The colour scale intervals and the white colour (centred on 0 mm/year) reflects the internal model variability (+/- 36 mm/year), as described in the method sections. The plot was created using MATLAB and QGIS software.

New study – Italy, Crati River catchment



Thank you

Conclusions

- More realistic treatment of subsurface processes becomes important when approaching climate time scales (3 months+)
  - Likely in DK with where groundwater exerts a high control on soil moisture
  - Corresponds to groundwater system response times
- Precipitation more accurate -> convective share is increased
- Extreme precipitation also more accurate
- Increased confidence in RCM simulations of projected changes in the hydrological cycle
- Need for bias correction is largely diminished

- **Perspective**: Increased coupled area -> contribution of validity -> also a vast increase in setup and calibration effort AND a likely decline in detail