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

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Presentation outline

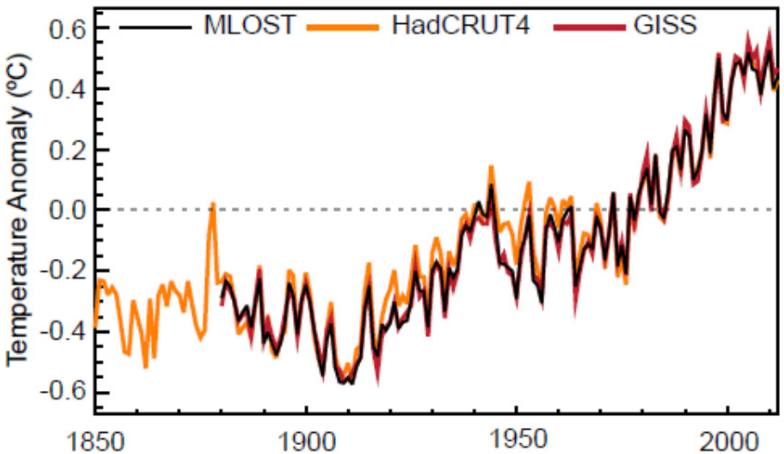
- General introduction to the subject of coupling of models
- HIRHAM setup and preparation
- MIKE SHE setup and calibration
- Coupled studies
- Conclusions and perspectives

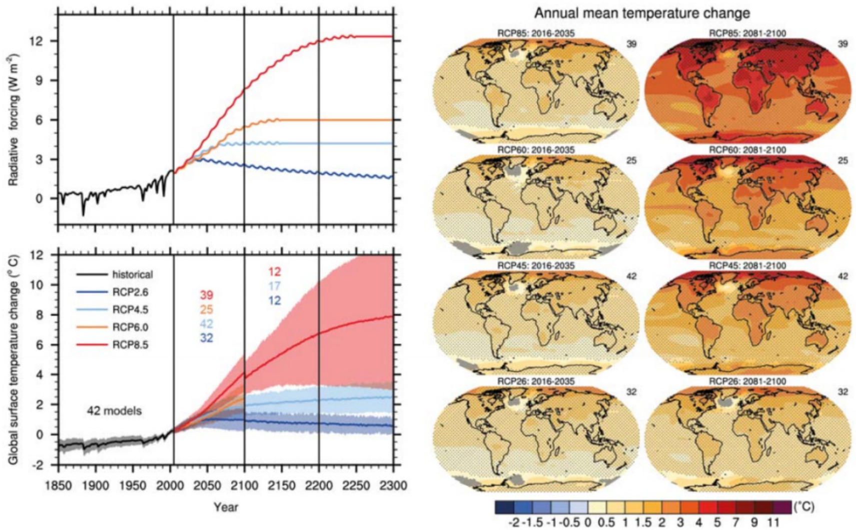
Setting of study

”Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems.”

”Need for knowledge on the interaction between water resources and the climate in support of general decision making and management.”

”Underlined in the light of the expected global warming and increased extreme event frequency to ensure proper climate adaption strategies.”





Water and climate (change) implications

Agriculture/food production/water resources

Ecosystems (e.g. eutrophication and invading species)

Extreme precipitation/floods /infrastructure

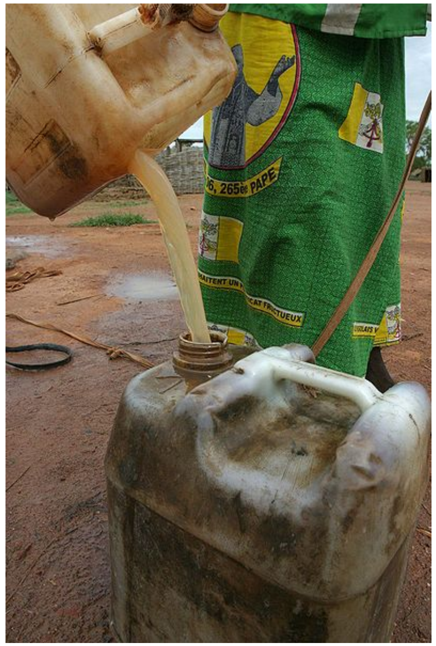
Water resources/water quality/availability

Water and climate (change) - globally

Ecosystems (e.g. eutrophication and invading species)

Agriculture/food production/water resources

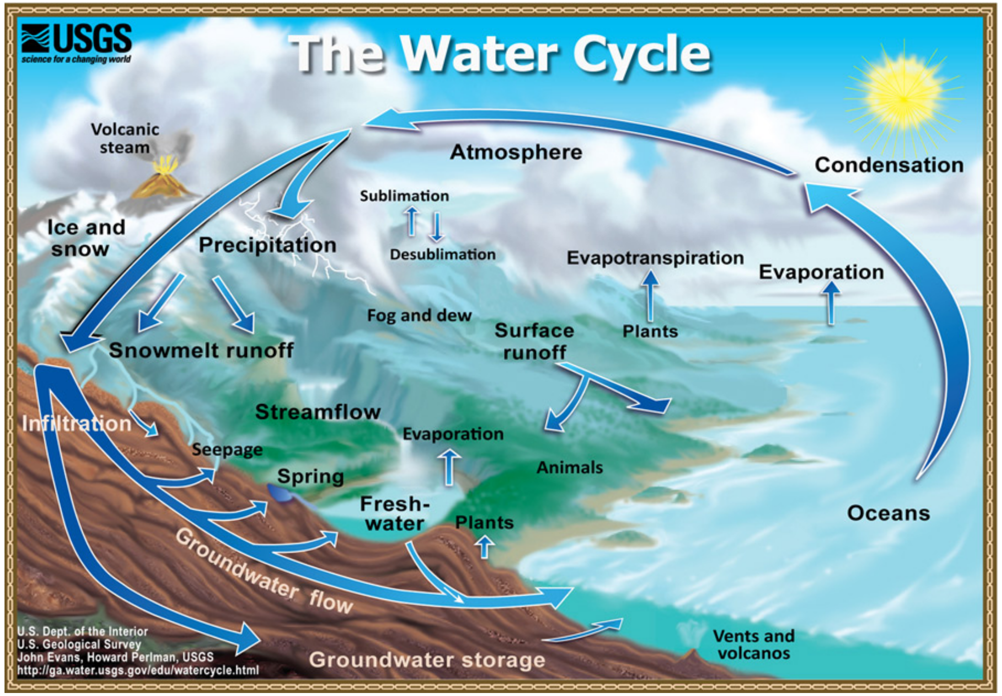
Extreme precipitation/floods



Water resources/quality

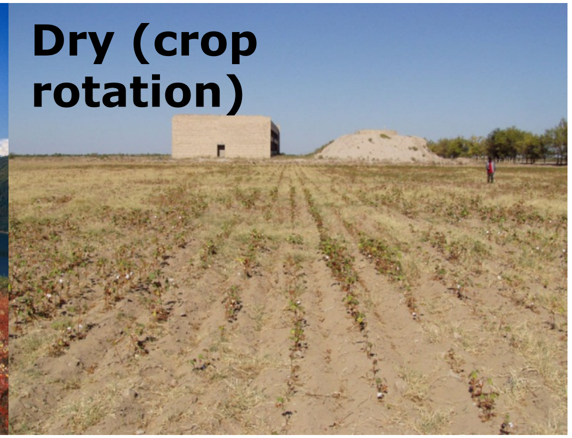
Water and climate (change)

"The ability to achieve realistic projections of both present and future climate and water resources depends largely on the ability to numerically simulate the processes of hydrology, energy and ecology between the atmosphere, the land surface and the subsurface. It is commonly recognized that these processes are explicitly interconnected and that their interaction is highly complex."



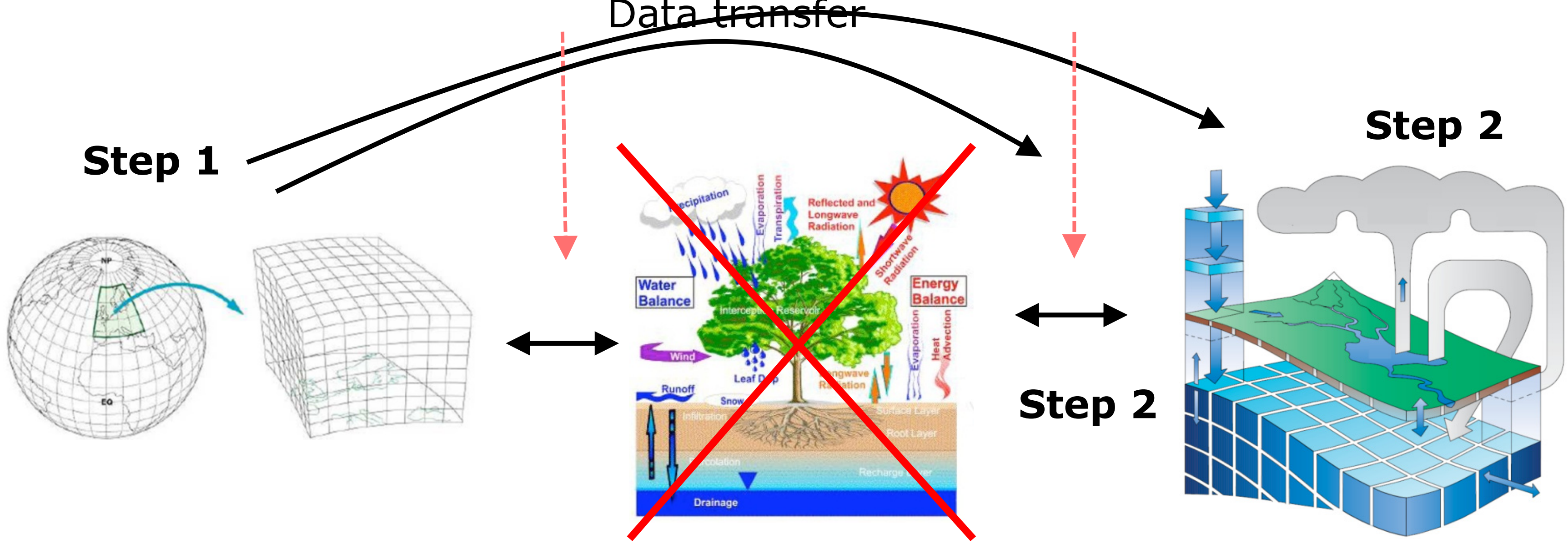
→ **Complex parallel series of interrelated events in time and space**

Landscapes and dynamics



Aim of study: To improve the overall simulation of climate and hydrology processes by the coupling of models

Simultaneous simulation – fully dynamic 2-way data exchange



Climate model

Land surface model

Hydrology model

Traditionally

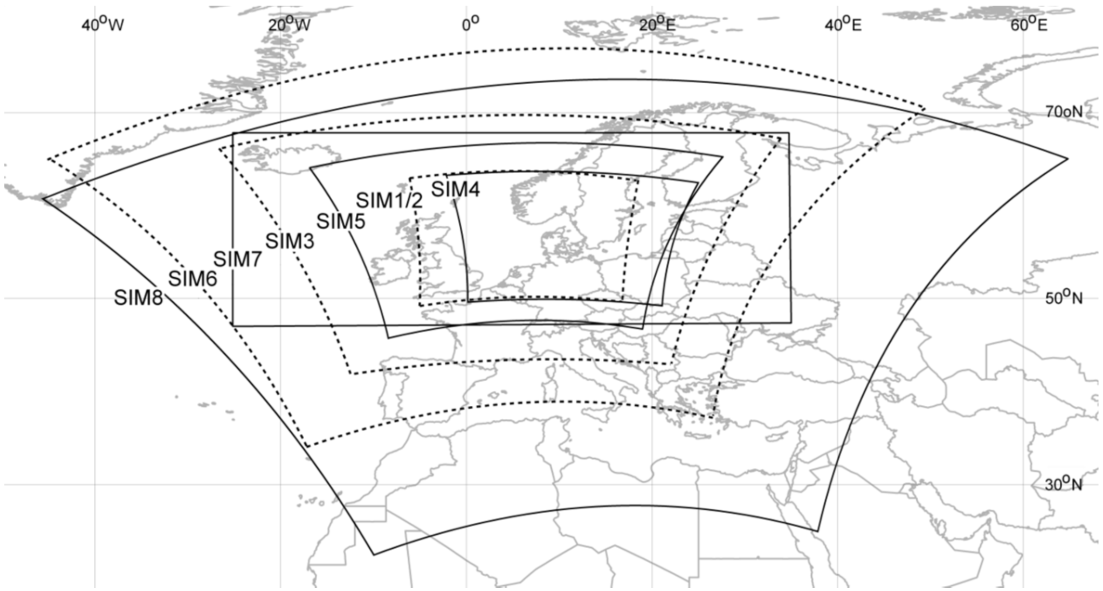
Coupled approach

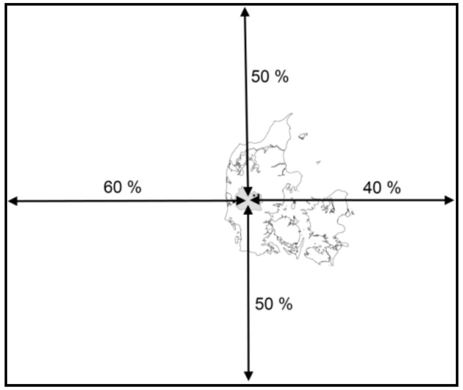
Includes inter-model feedback

Improved hydrology and land surface descriptions

HIRHAM – setup study - domains

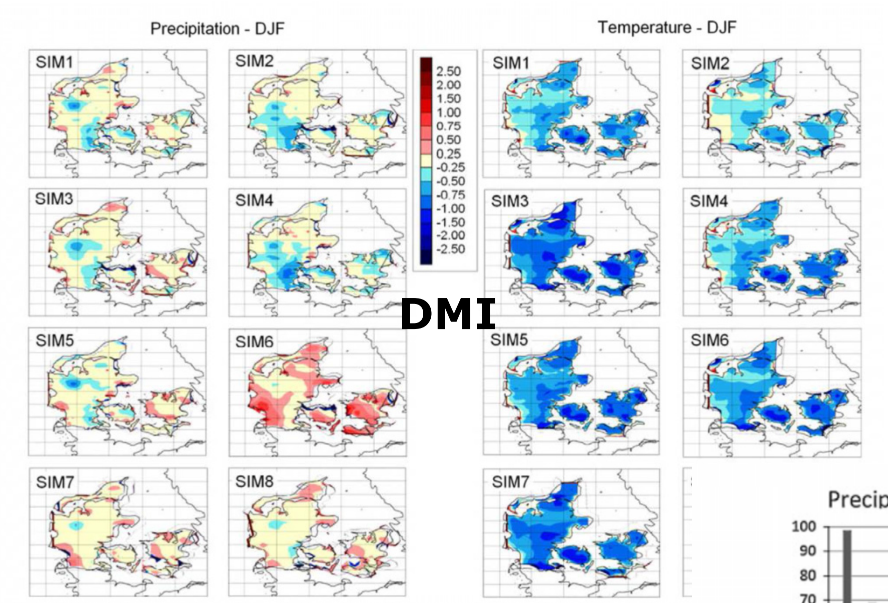
1. Find the optimal HIRHAM domain characteristics for the coupled setup
2. No definite rules on domain size, location and resolution

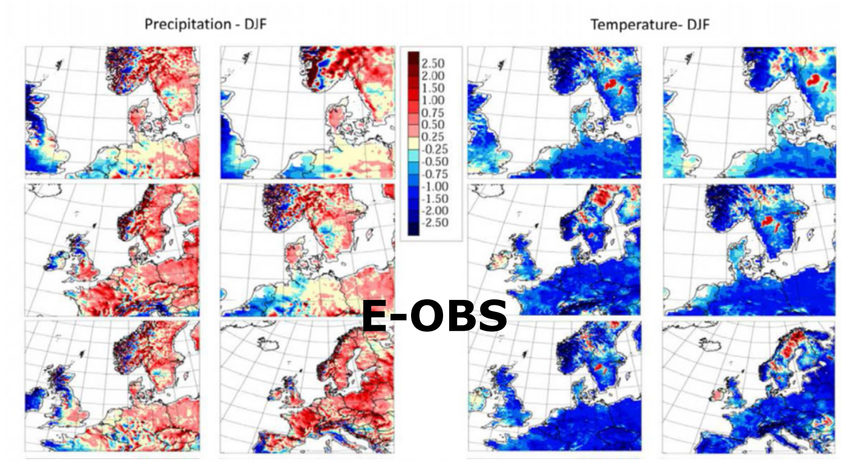


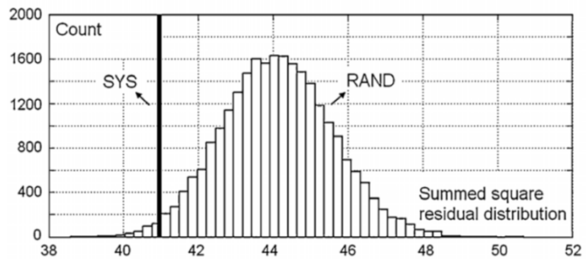


Model run	Resolution (km)	Domain size (km - lon x lat)	Number of cells
SIM1	5.5	1400x1400	252
SIM2	11	1350x1350	122
SIM3	11	2800x2800	252
SIM4	5.5	1400x1400	252
SIM5	5.5	2000x2000	362
SIM6	11	4000x4000	362
SIM7	11	4000x2800	362
SIM8	12	5500x5200	452x432

HIRHAM – setup study – Error/significance







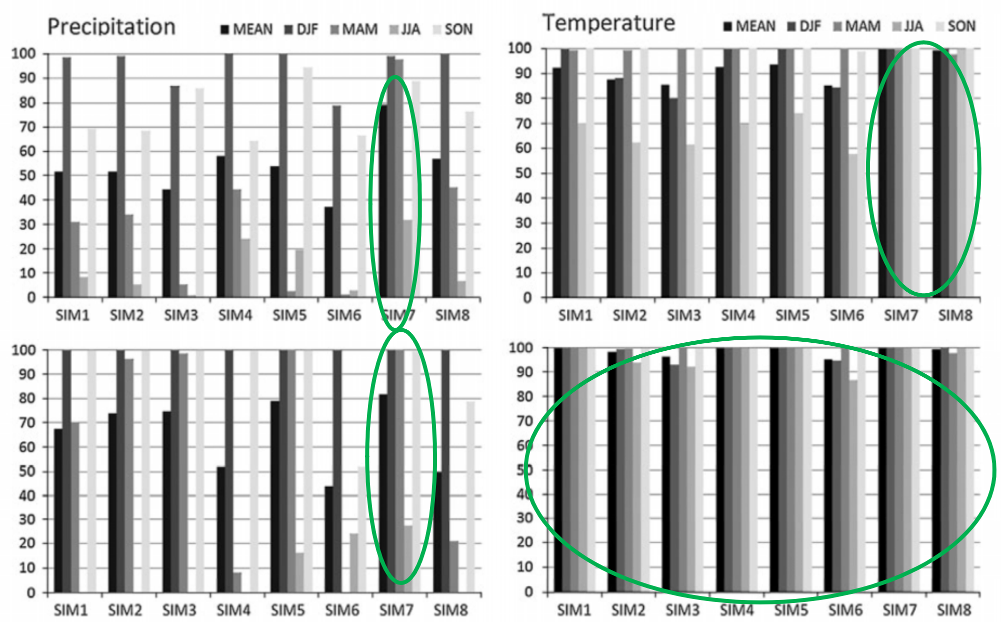


Fig. 10 The significance levels of the bootstrap test. *Upper row* with random resampling in moving blocks, *lower row* with random resampling all over Denmark

HIRHAM - Low pressure occurences

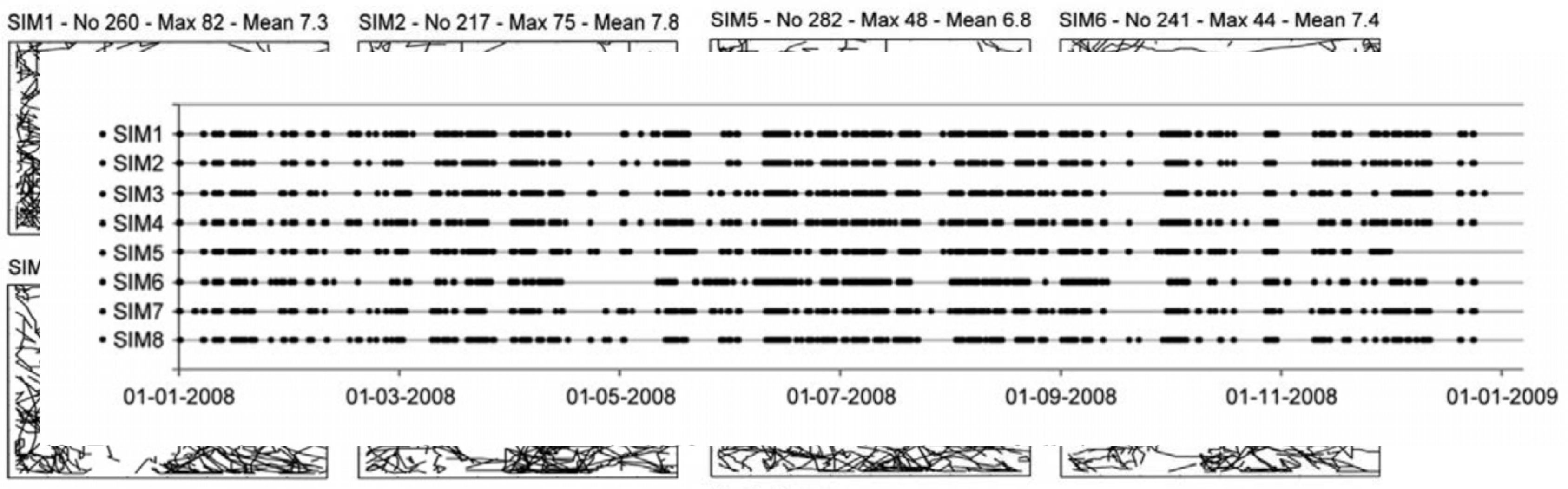


Fig. 11 The movement of low pressures in 2008 in the area shared by all simulations. *Each line* shows the path of the centre of a low pressure event. No, max and mean represent number of occurrences within the domain, maximum travel time (h), mean travel time (h) respectively

<u>-> Best domain for the coupling: 11 km resolution and 4000x2800 km size</u>

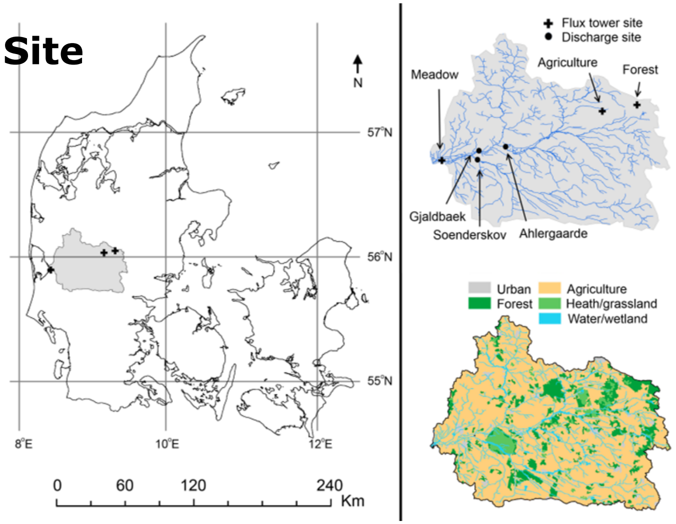
<u>HIRHAM setup study</u>: Larsen, M. A. D., Thejll, P., Christensen, J. H., Refsgaard, J. C., and Jensen, K. H. (2013). On the role of domain size and resolution in the simulations with the HIRHAM region climate model, Clim. Dynam., 40, 2903–2918, doi:10.1007/s00382-012-1513-y.

MIKE SHE/SWET – setup study

Calibrate MIKE SHE including SWET land surface model component

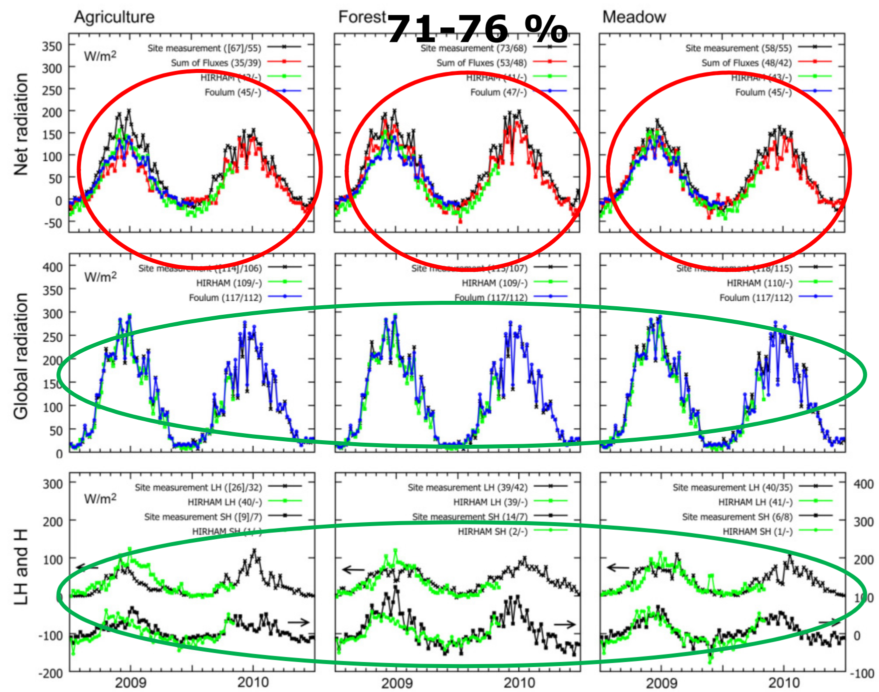
Water balance – energy fluxes – spinup – sensitivity

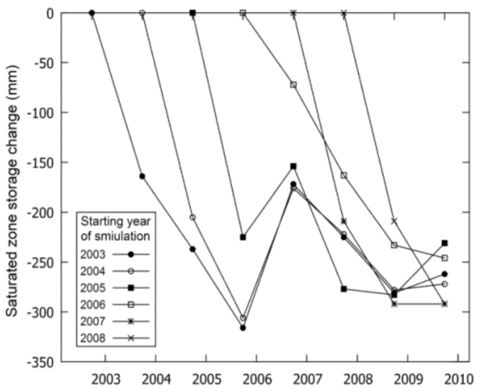
Site



Energy balance

71-76 %



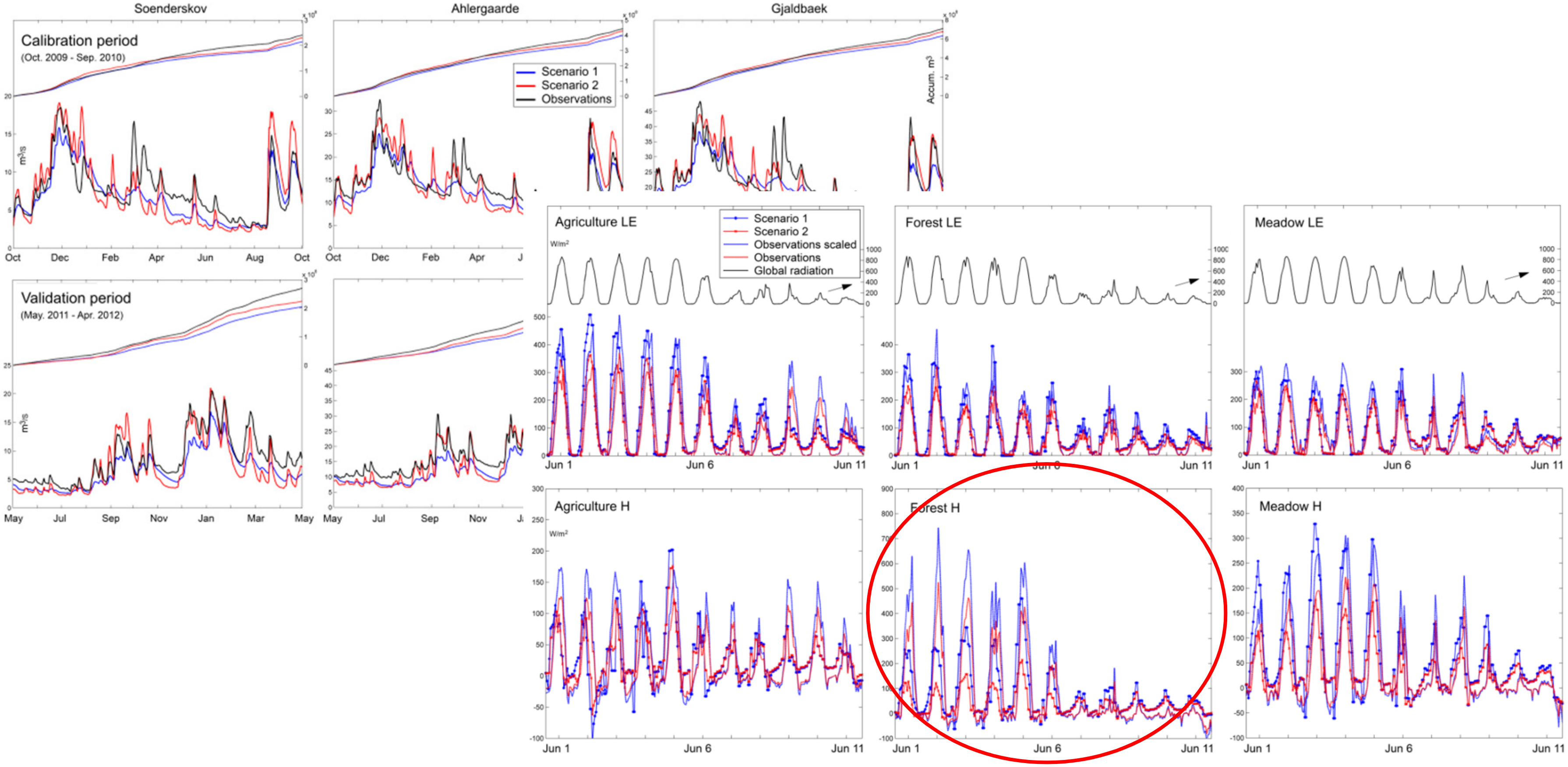


Spinup

(saturated)

- **Oct 1, 2009 -> Sep 30, 2010**
- **5-10 months spinup (unsaturated)**

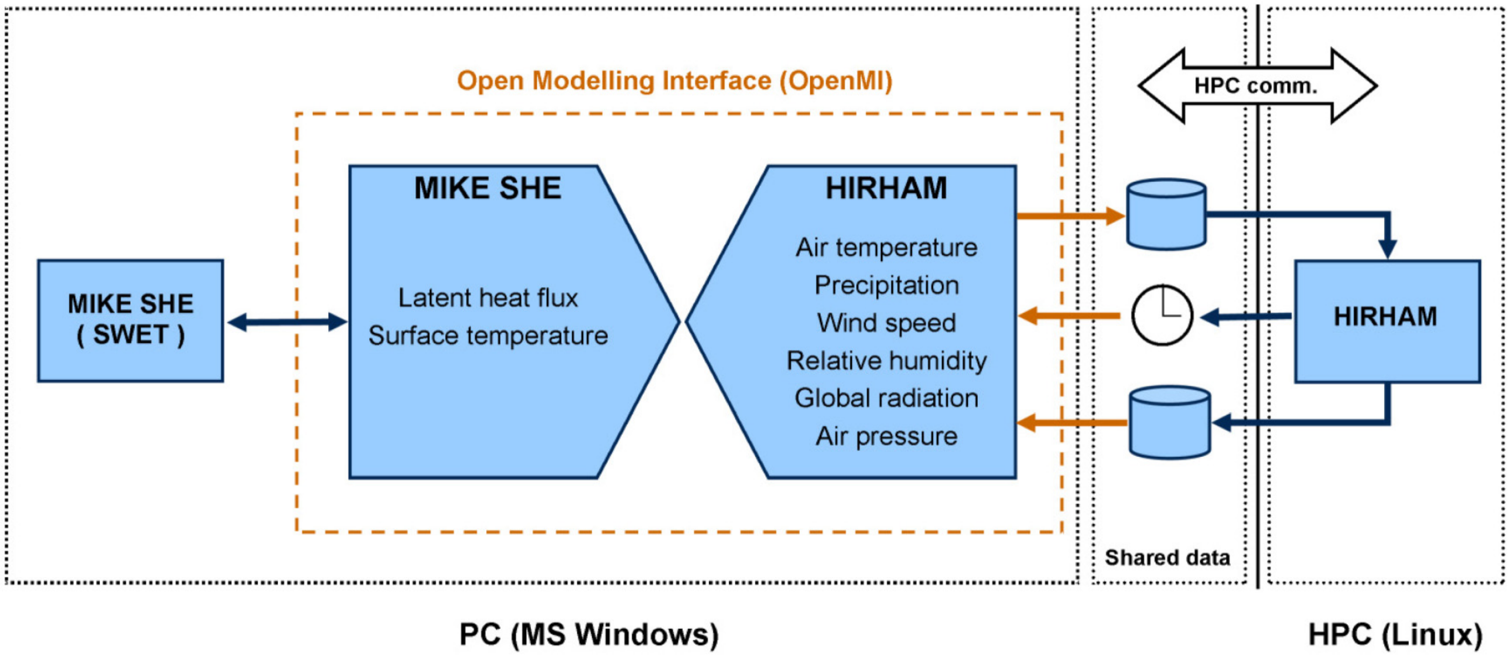
MIKE SHE/SWET – setup study – Q, LE and H



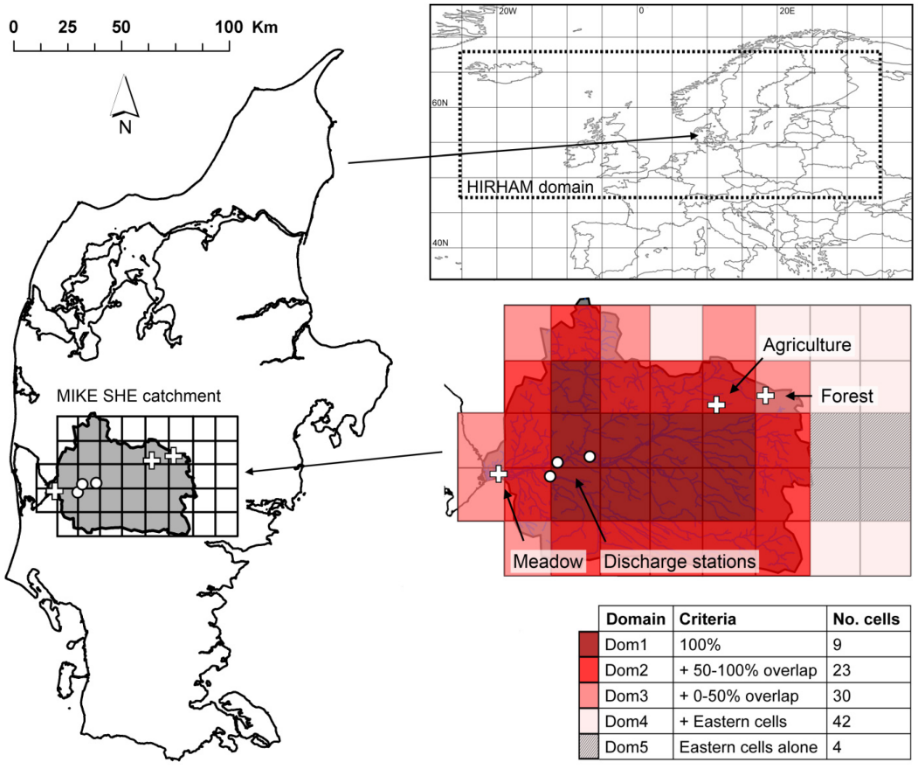
Calibration completed under conditions of lacking energy balance closure

Coupled study

1. Couple models to include land surface-atmosphere interaction
2. Effect of coupling - data transfer interval – variability – extreme events



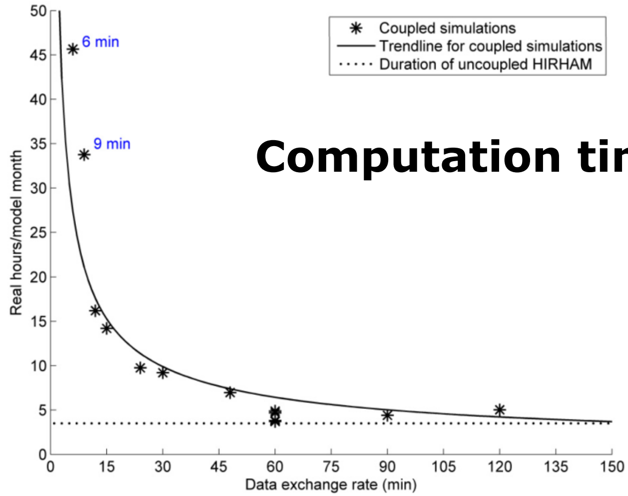
Coupled study



Domain	Criteria	No. cells
Dom1	100%	9
Dom2	+ 50-100% overlap	23
Dom3	+ 0-50% overlap	30
Dom4	+ Eastern cells	42
Dom5	Eastern cells alone	4

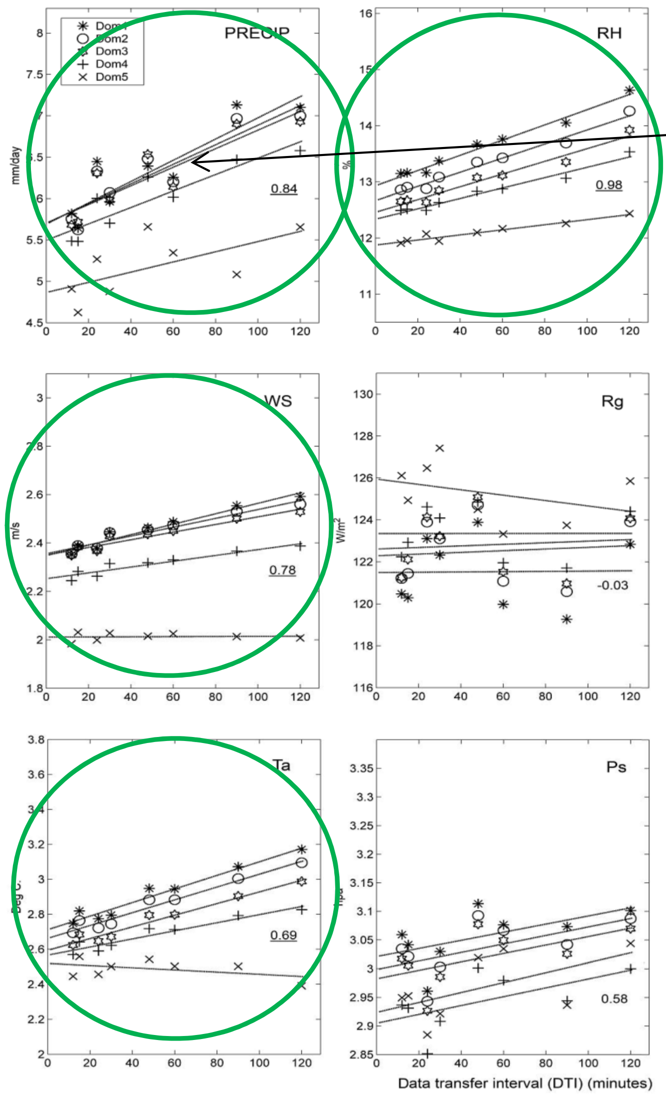
26 simulations

- 8 – Coupled/Data transfer interval/ 6-12->120min.
- 8 – Coupled/60 min./perturbed
- 8 – Uncoupled/pertubed
- 2 – <u>MIKE SHE</u>. Coupled one-way/Observation input

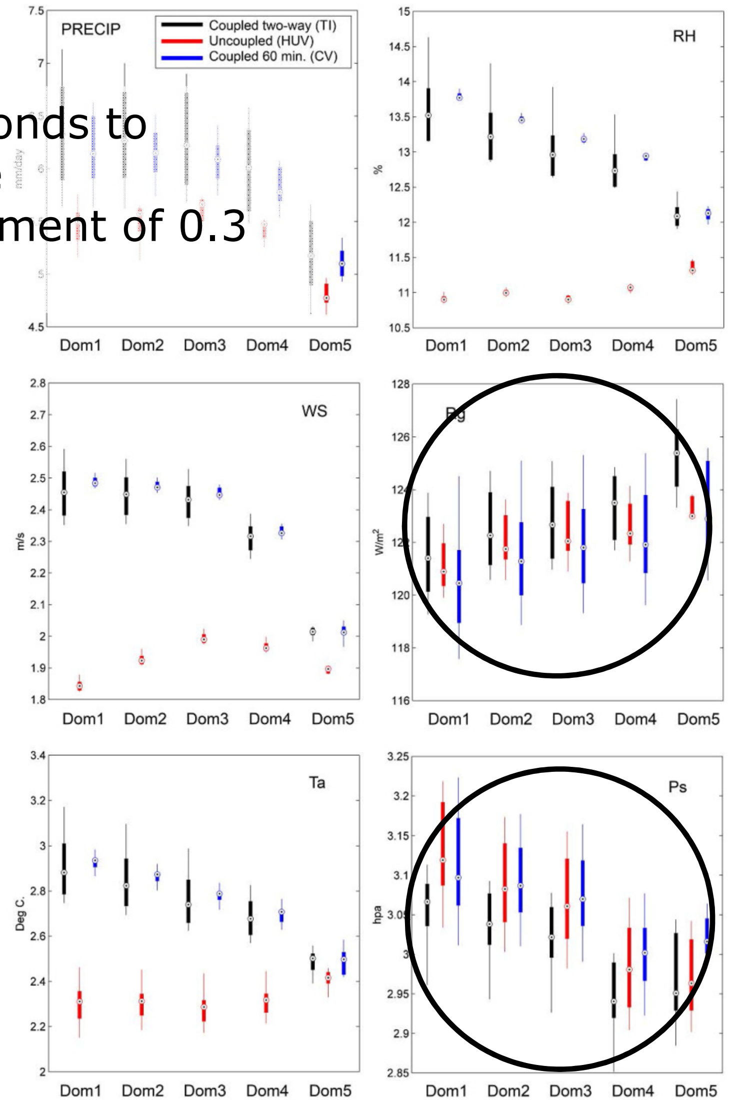


Computation time

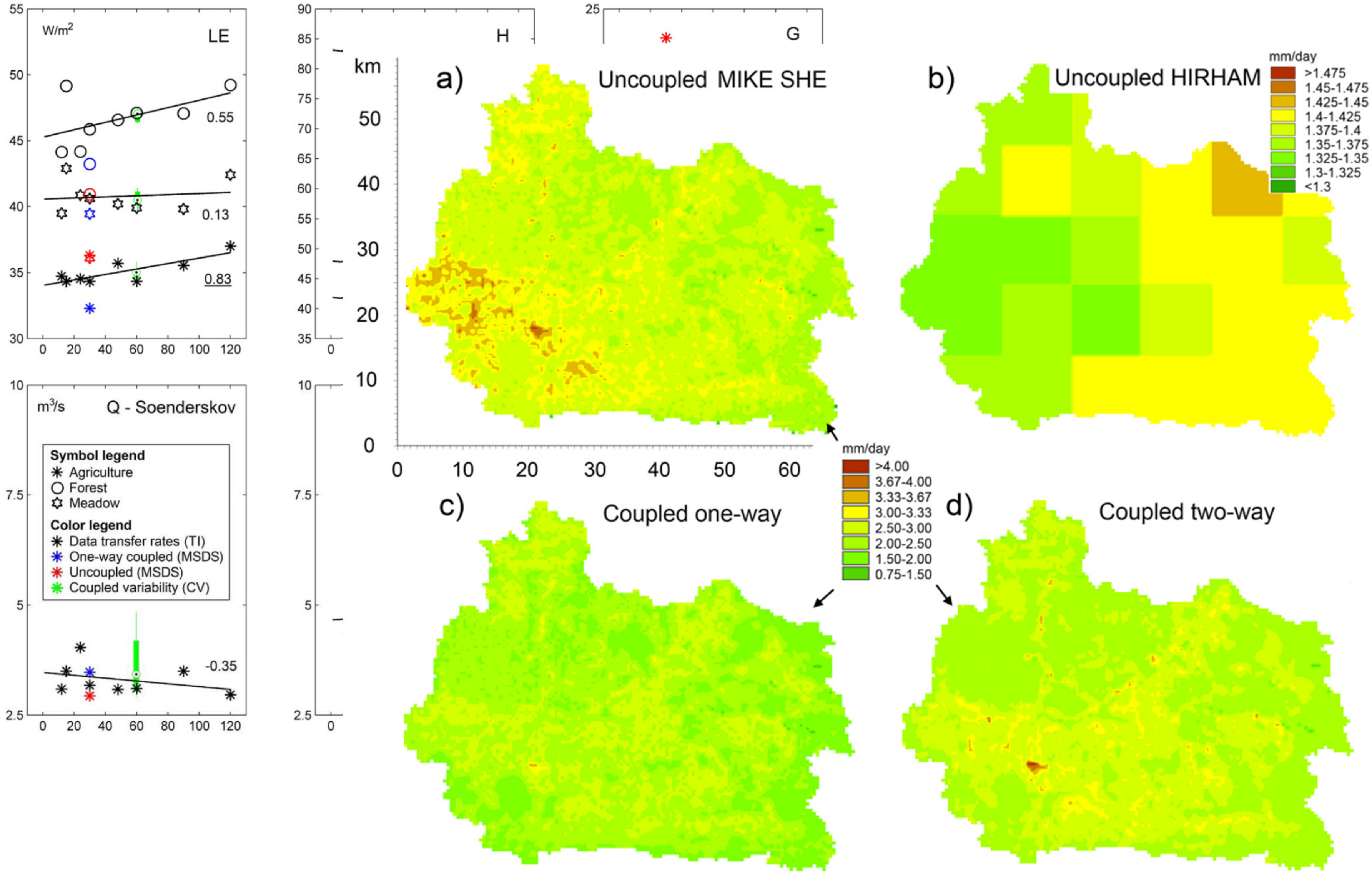
Coupled study – HIRHAM output



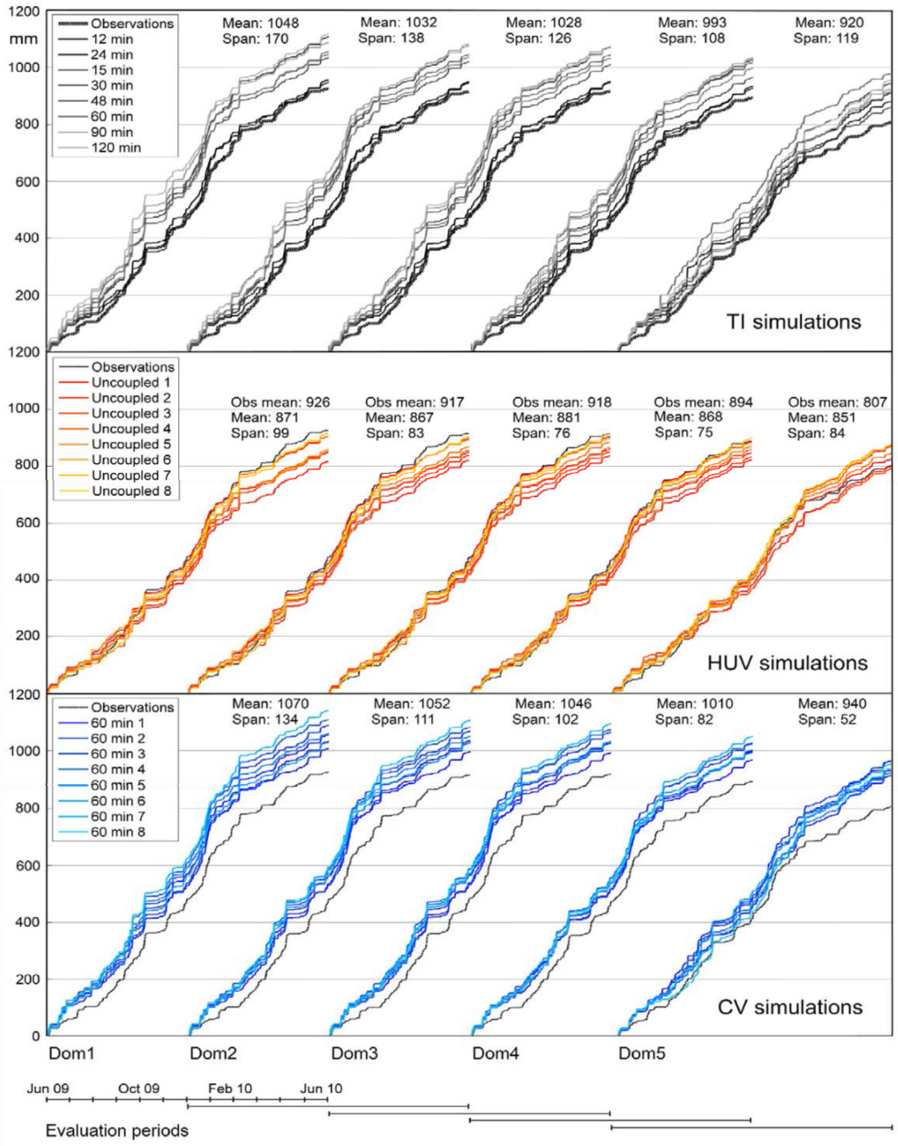
Corresponds to absolute improvement of 0.3 mm/day



Coupled study – MIKE SHE output



Coupled study – Precipitation



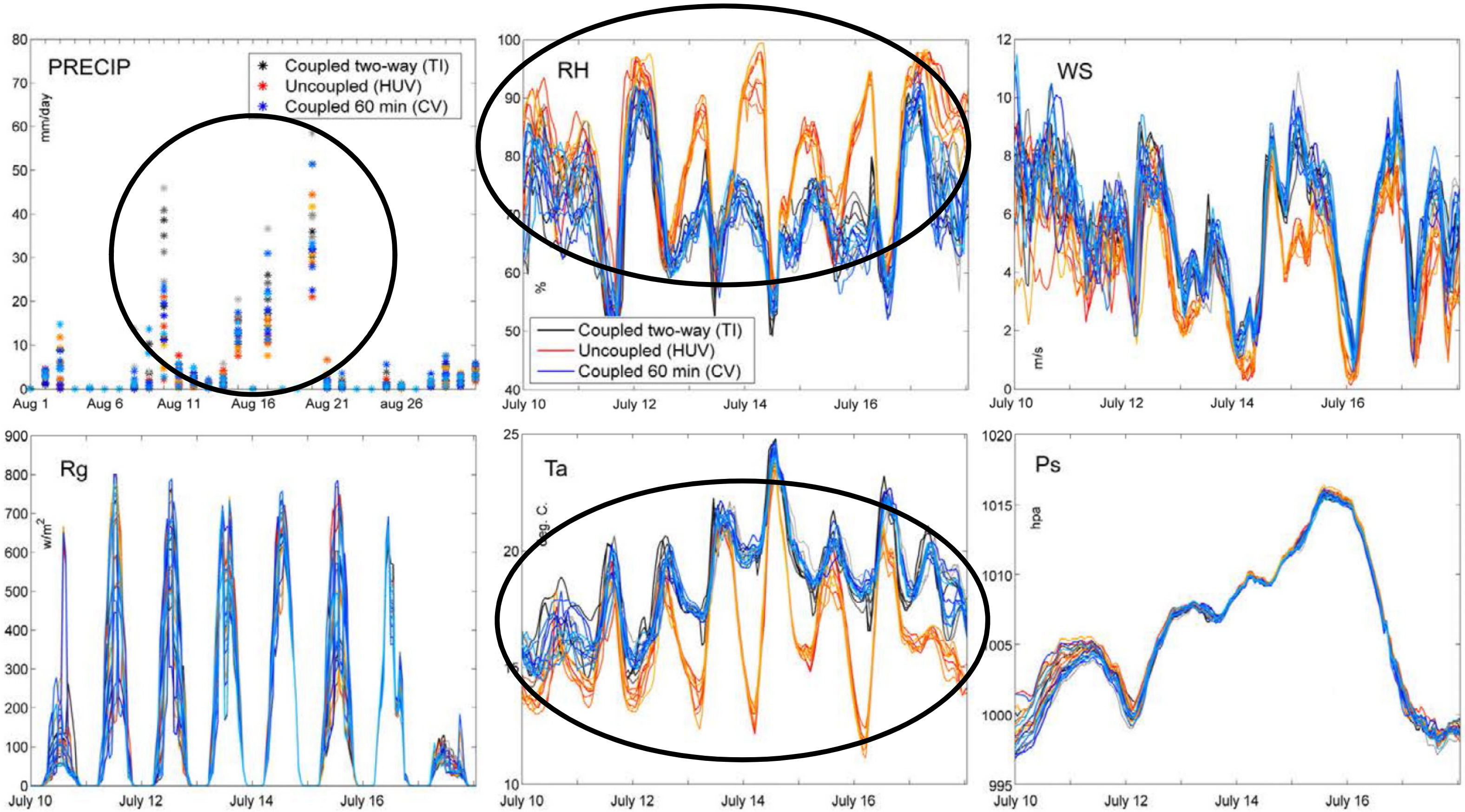
Mean sum	Dom5->Dom1	Mean span
1004	128	132
892	119	83
1027	130	96

(mm)

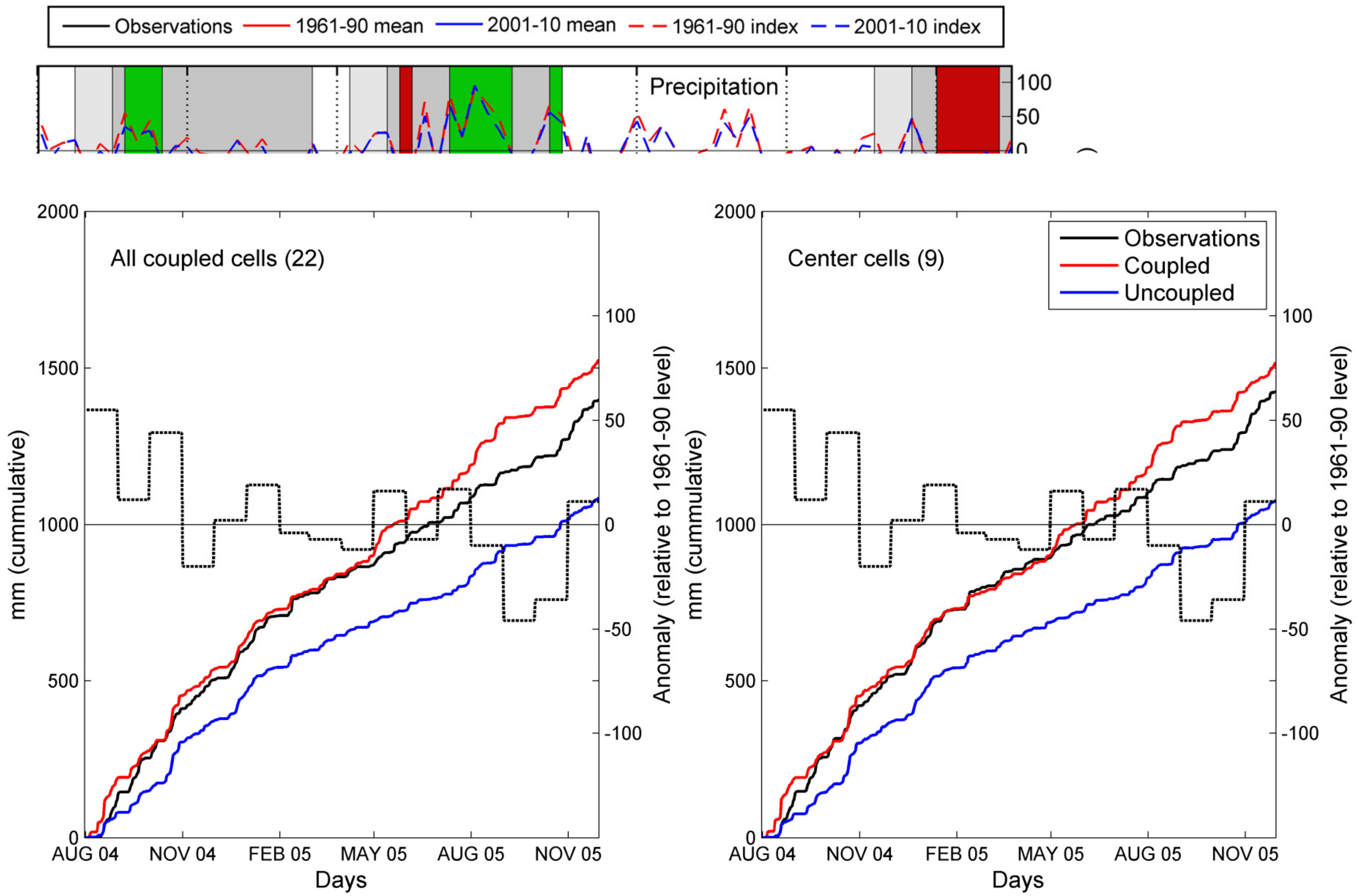
↓

Well known east-west gradient

Coupled study – Time plots



Coupled study – More extreme periods



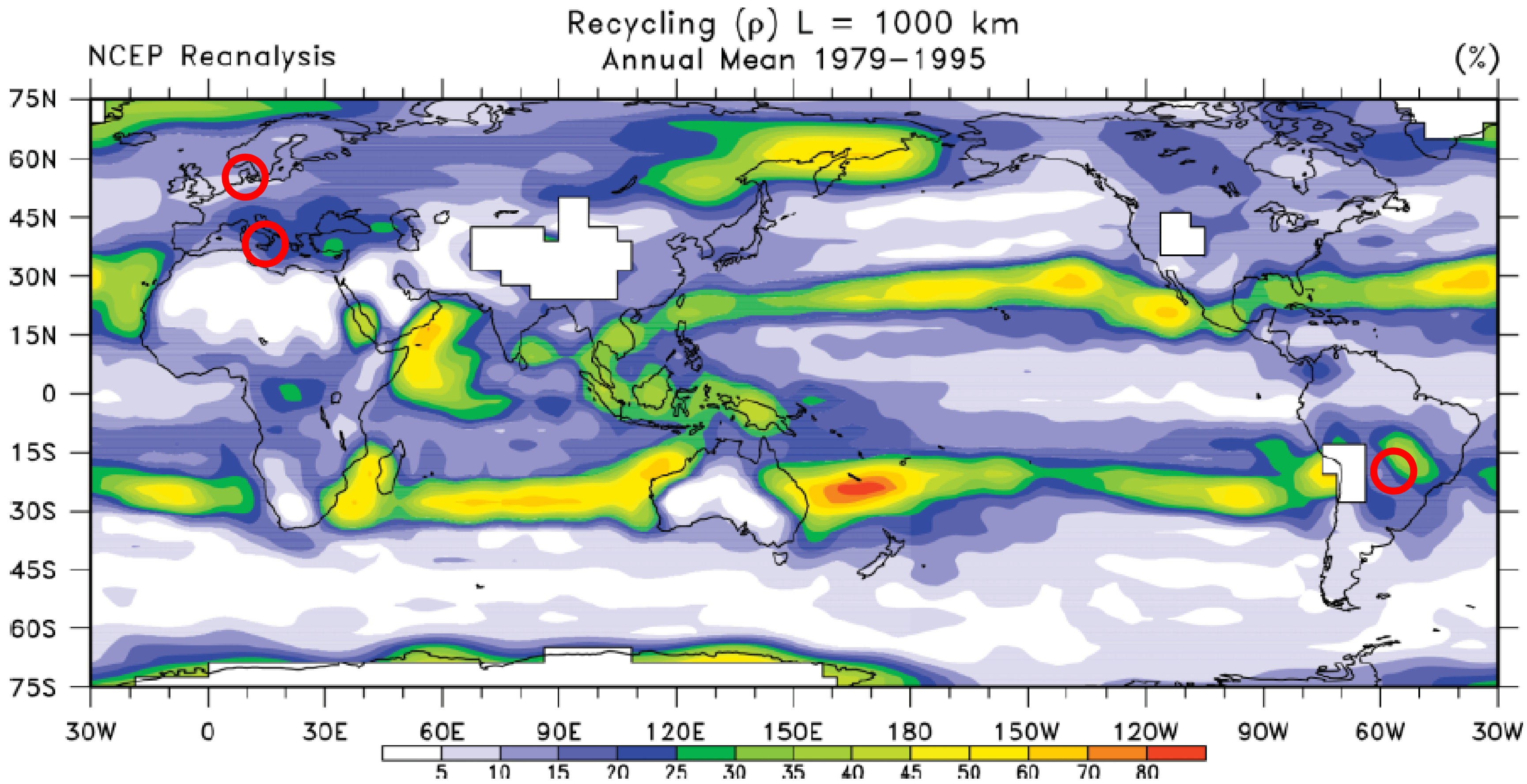
Coupled study – Conclusions

- **In general; coupled results are poorer than uncoupled**
  - HIRHAM and MIKE SHE calibrated and refined individually to reproduce observations
  - However -> the setup is feasible -> early stage study
  - Promising results for periods of higher rainfall
- **Four of six climatic variables show improvements with higher frequency exchange**
  - Precipitation is among these (difficult)
- **No improvement noticable for MIKE SHE**
- **Variability is significant – Covers 47% of improvement due to data exchange rate**

Coupled study – Perspectives

- **Coupled calibration**
- **Tested in non-severe conditions. Improvement in wet/dry conditons?**
    - Different moisture regime (arid, tropics etc.)
- **Climate projections (assess hydrological response including feedback)**
- **Anthropogenic effects**
    - Land use changes
    - Irrigation/pumping
- **Larger scale (larger catchment)**
    - Larger scale processes (global radiation and surface pressure)
- **Memory based data exchange -> computation speed**
- **Code improvments**
    - Snow melt
    - Streamlining -> GUI, ease of use, stability

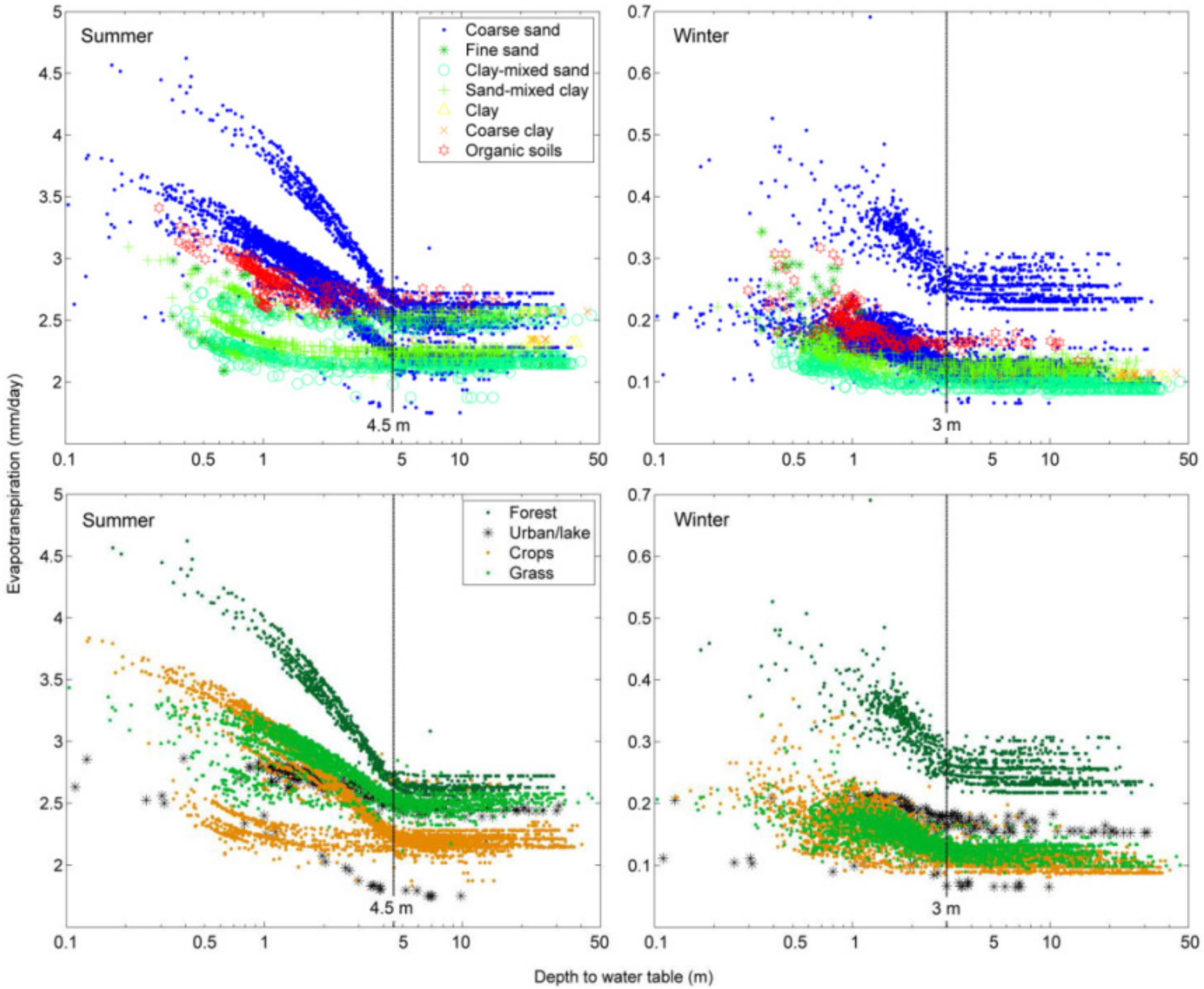
Location / moisture regime



Trenberth (1999)

The end

Thank you



Daily JJA and DJF evapotranspiration as a function of depth to water table

Results – statistics

			Discharge			Latent (LE) and Sensible (H) heat fluxes					
			Soenderskov	Ahlergaarde	Gjaldbaek	Agri.	Forest	Meadow	Agri.	Forest	Meadow
			Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	LE (W/m^2)	LE (W/m^2)	LE (W/m^2)	H (W/m^2)	H (W/m^2)	H (W/m^2)
RMSE	SCN1	2009/2010	2.2	2.8	4.9	52.1	55.5	48.0	52.2	*87.3*	56.1
	SCN2	2009/2010	2.8	3.4	4.8	37.4	35.4	39.5	35.8	*67.7*	42.3
MAE	SCN1	2009/2010	1.6	2.2	3.5	29.7	32.4	29.4	37.2	62.5	40.7
	SCN2	2009/2010	2.1	2.7	3.5	21.8	21.0	24.9	26.2	45.4	29.5
Nash S (NS)	SCN1	2009/2010	0.61	0.63	0.61	0.42	0.58	0.58	0.23	*0.44*	0.44
	SCN2	2009/2010	0.35	0.48	0.61	0.44	0.66	0.46	0.33	*0.32*	0.40
Mean values	SCN1	2009/2010	6.8 (7.6)	12.7 (14.1)	20.1 (22.5)	51.0 (43.5)	48.6 (59.0)	52.7 (48.2)	20.1 (9.5)	*34.8 (9.9)*	25.3 (7.8)
	SCN2	2009/2010	7.3 (7.6)	13.6 (14.1)	21.5 (22.5)	40.4 (31.8)	38.8 (41.7)	46.9 (35.0)	16.3 (7.0)	*13.4 (7.0)*	9.8 (5.7)

Paper 3+4 - results

	Variable	MAE absolute change	MAE percentage change	MAE CV variability	MAE HUV variability	RMSE absolute change	RMSE percentage change	RMSE CV variability	RMSE HUV variability
HIRHAM output variables	PRECIP (mm/day)	0.3	8.3	0.2	0.2	1.1	16.4	0.7	0.6
	RH (%)	0.8	7.9	0.3	0.1	1.1	8	0.3	0.2
	WS (m/s)	0.1	5.4	0.0	0.0	0.2	5.8	0.5	0.1
	Rg (W/m^2)	-0.1	-0.2	2.6	1.3	-0.1	-0.1	6.0	3.2
	Ta (Deg. C)	0.2	10.1	0.1	0.1	0.3	8.8	0.1	0.2
	Ps (hPa)	0.0	1.8	0.1	0.1	0.1	2.7	0.2	0.2
MIKE SHE output variables	LE (W/m^2)	1.9	6.9	0.9	-	1.9	4.5	1.5	-
	H (W/m^2)	-2.3	-7.4	0.5	-	-3.1	-6	1.5	-
	G (W/m^2)	-0.1	-3.1	0.2	-	-0.7	-7.9	0.7	-
	Q (W^3/s)	-0.4	-12.2	0.7	-	0.1	-0.1	2.2	-