# On the hydrological performance in preparation for fully coupled climate-hydrology modelling in a data-sparse region


M.A.D. Larsen[1], A. Senatore[2], M. Drews[1] and G. Mendicino[2]

[1] Technical University of Denmark, Dep. of Management engineering

[2] University of Calabria, Department of Environmental and Chemical Engineering

Technical University of Denmark

UNIVERSITÀ DELLA CALABRIA

# Motivation and background

Successful study in Denmark (Skjern river, 2500km$^2$) dynamically coupling MIKE SHE (hydrology+land surface) and HIRHAM (RCM) utilizing improvements in process representation and spatio-temporal scales in the subsurface/land surface/atmosphere water and energy feedback loop

= *Diminished precipitation bias (long term and extreme)*

SCIENTIFIC REPORTS | 6:22927 | DOI: 10.1038/srep22927

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SCIENTIFIC REPORTS

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## Local control on precipitation in a fully coupled climate-hydrology model

Received: 30 June 2015
Accepted: 25 February 2016
Published: 10 March 2016

Morten A. D. Larsen[1], Jens H. Christensen[2], Martin Drews[1], Michael B. Butts[3] & Jens C. Refsgaard[4]

The ability to simulate regional precipitation realistically by climate models is essential to understand and adapt to climate change. Due to the complexity of associated processes, particularly at unresolved

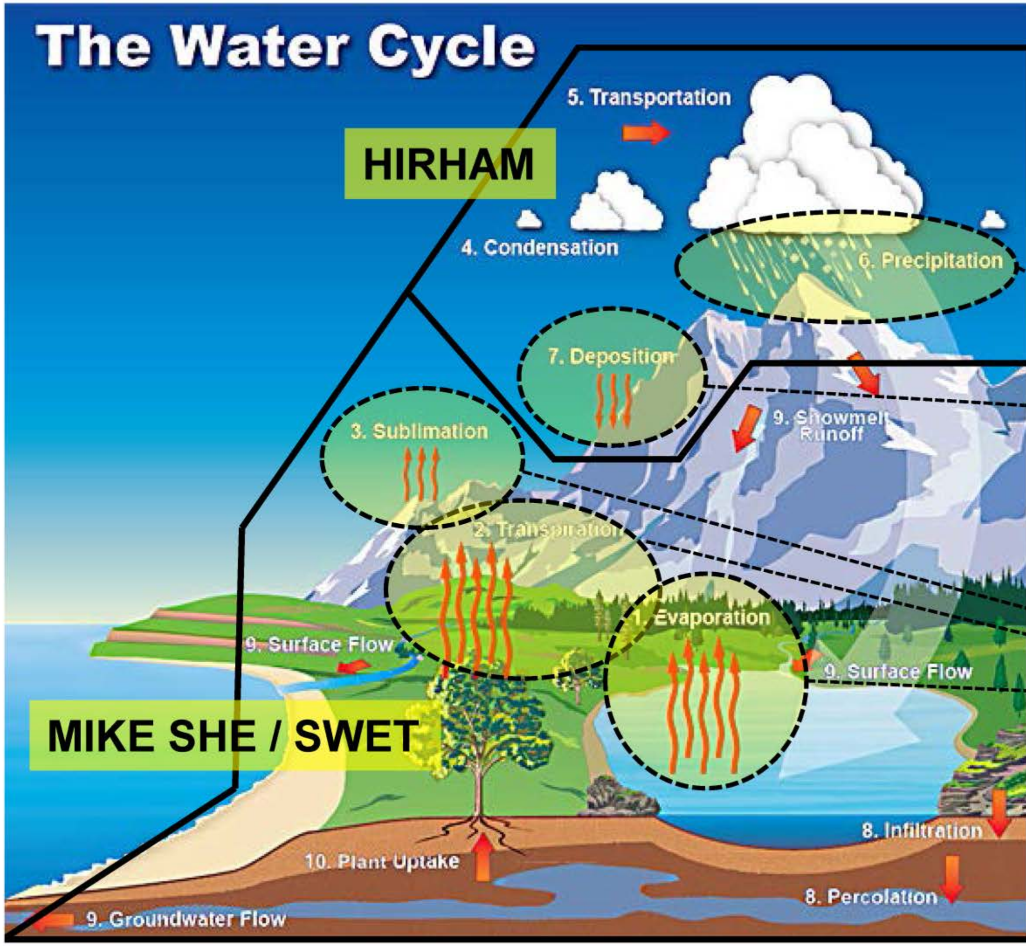
# Motivation and research questions

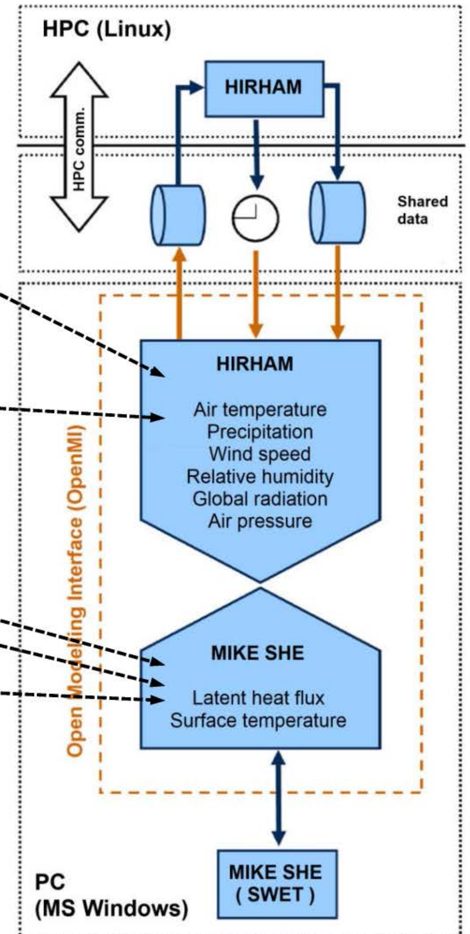
- Coupled and advanced atmosphere-hydrology models require a wide range of data for both forcing and validation.
- High quality is required; 1) spatial coverage and resolution, 2) temporal resolution, 3) representation of local attributes and, of course, 4) truthfulness. *Garbage in = garbage out.*
- Studies often for areas with good data coverage.

In this light;

1. <u>What are the prospects of doing coupled hydrology-climate runs for areas of poorer data availability and quality?</u>
2. <u>Is it feasible to even apply coupled modelling if only large scale gridded data sets are available?</u>
3. <u>Can the coupled setup perform equally well in a non-groundwater dominated catchment (Italy vs Denmark)?</u>

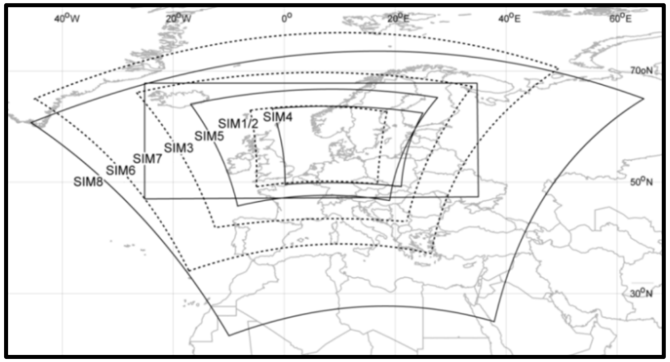
# Danish MIKE SHE-HIRHAM studies – model concept



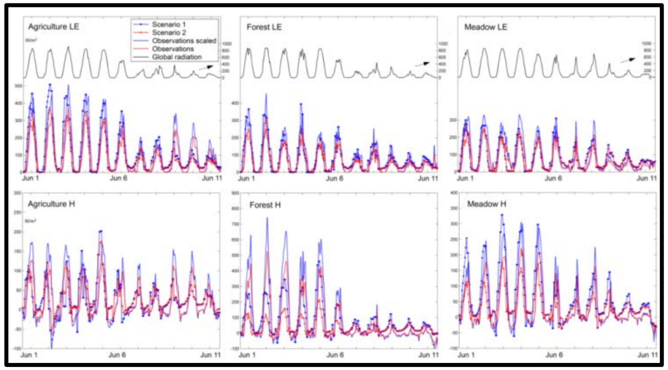




- Timing (wait/go)
- Mapping (interpolation)
- Temporal interpolation
- Unit conversion

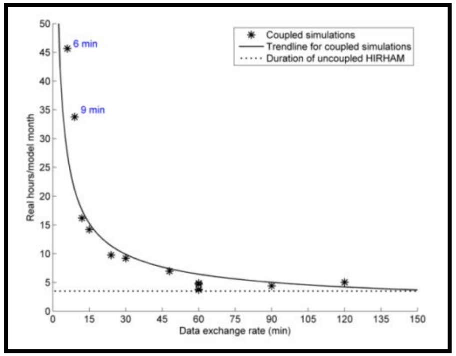
# Danish MIKE SHE-HIRHAM studies (1)



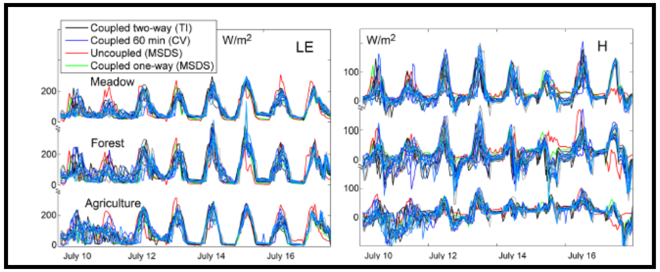

**HIRHAM domain selection:** Larsen, MAD et al. (2013): On the role of domain size and resolution in the simulations with the HIRHAM region climate model. Clim. Dyn. 40, 2903-2918



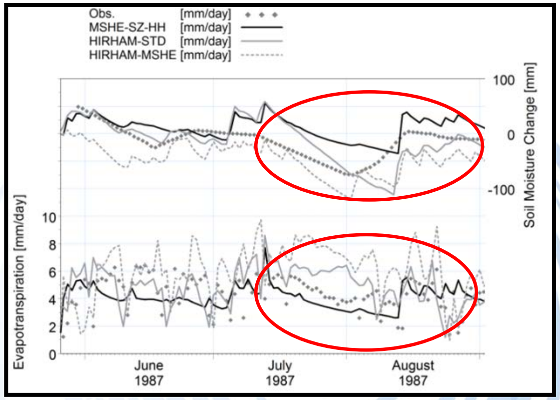

**MIKE SHE calibration:** Larsen, MAD et al. (2016): Calibration of a distributed hydrology and land surface model using energy flux measurements. Agr. Forest Meteorol. 217, 74–88




**Coupled methodology:** Butts, M et al. (2014): Embedding complex hydrology in the regional climate system – Dynamic coupling across different modelling domains. Adv. Water Resour. 74, 166–184

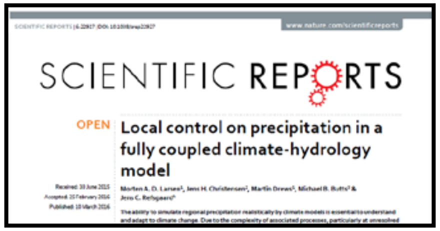



**Coupled setup benchmarking, tests and variability:** Larsen, MAD et al. (2014): Results from a full coupling of the HIRHAM regional climate model and the MIKE SHE hydrological model for a Danish catchment. Hydrol. Earth Syst. Sci. 18, 4733–4749




**Proof of concept:** MIKE SHE more skilfully reproduces soil moisture and evapotranspiration compared to HIRHAM. Larsen MAD 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. Environ. Earth. Sci., 75:130

# Danish MIKE SHE-HIRHAM studies (2)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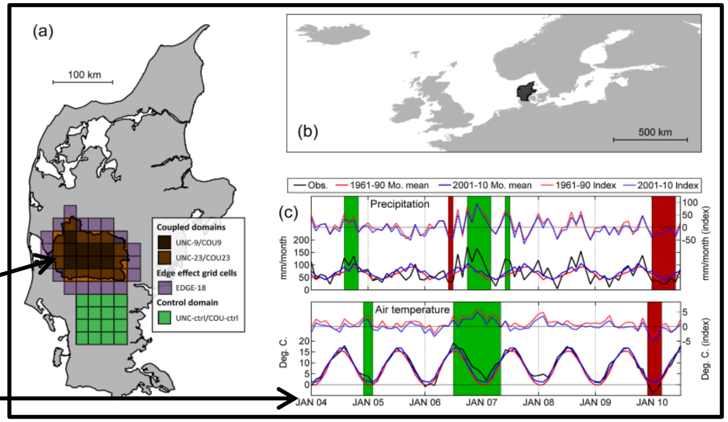
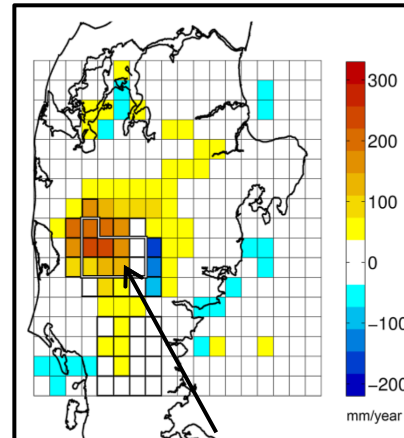
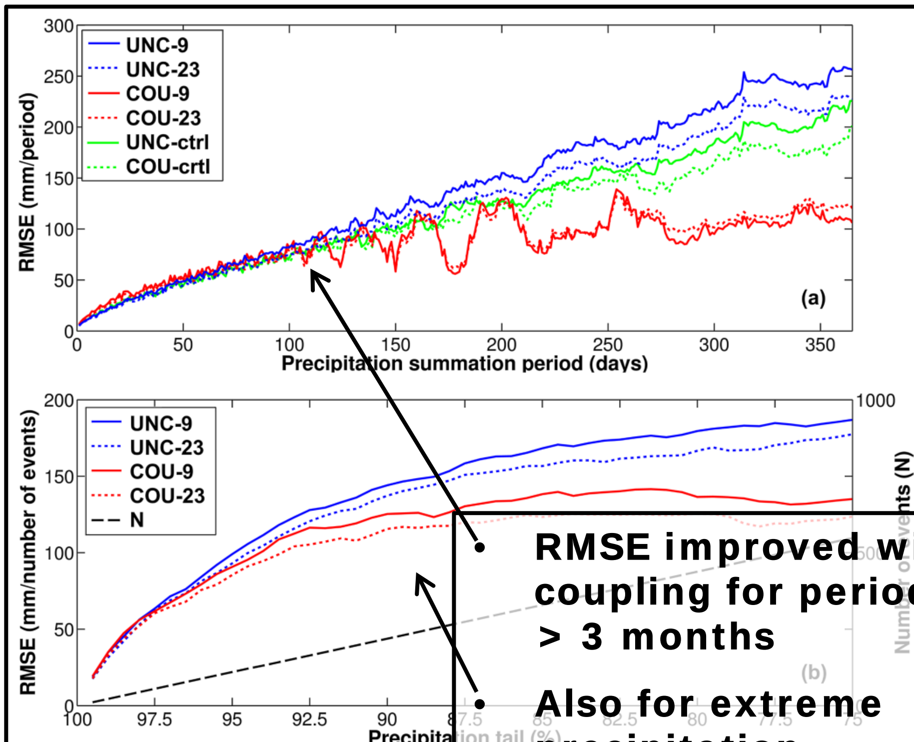
OPEN Local control on precipitation in a fully coupled climate-hydrology model



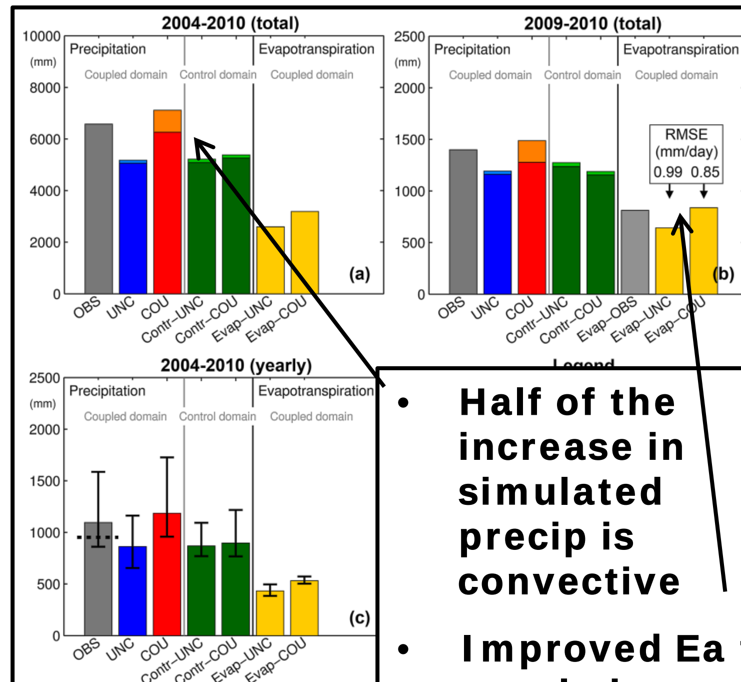

- 2500 km² coupled area
- Six-year run




Local influence



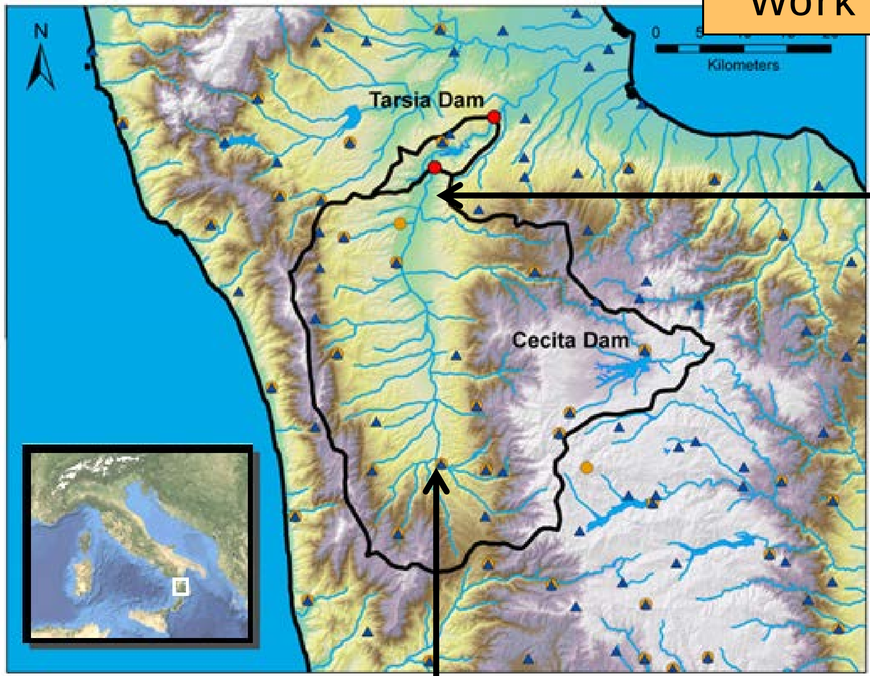

- RMSE improved with coupling for periods > 3 months
- Also for extreme precipitation

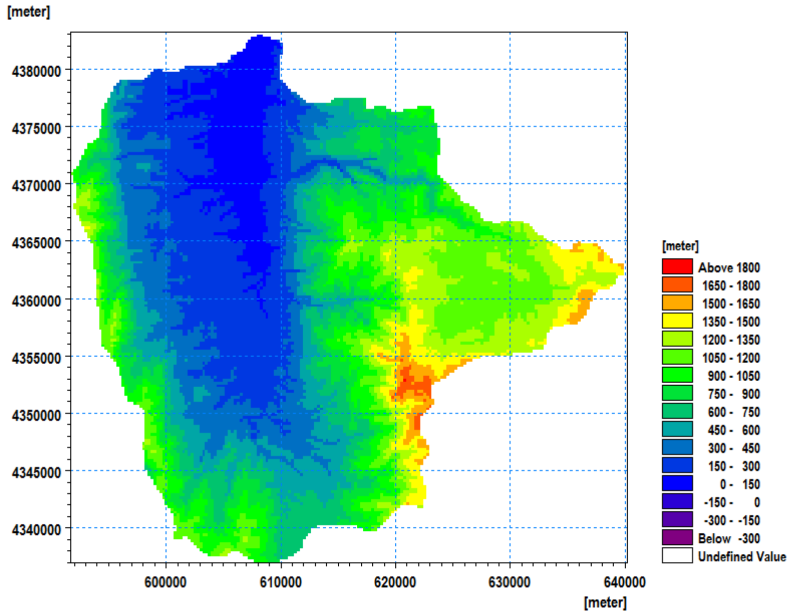



- Half of the increase in simulated precip is convective
- Improved Ea for coupled run

# Crati River catchment

Work in progress!



# Study area

Crati river (1260 km$^2$) used to highlight the above due to:

1. Reasonable data availability (discharge, a flux tower station, climate stations and gridded data products such as ERA-I, E-OBS, SWBM and RCM output) – although with problems (lack of temporal overlap, gap filling, availability, hydrogeological interpretations and land use)
2. The location (the Mediterranean) previously been shown to exhibit biases which potentially could be reduced in a coupled setup
3. Complicated orography/microclimate test case (poorly represented in models)
4. WRF-Hydro model runs have been performed enabling the possibility for comparisons

# MIKE SHE model

## Processes

- Overland flow (finite difference)
- Rivers/lakes (fully dynamic Saint-venant equation)
- Unsaturated flow (2D Richards equation)
- Evapotranspiration (Shuttleworth.Wallace 2 layer equations)
- Saturated flow (3D finite difference)
- Dynamic reduction of time step for precipitation events

## Setup

- 1 hour time step (*4 hour for saturated flow*) (reduced with rainfall)
- 250m resolution

# MIKE SHE calibration steps

- Parameter intervals from literature

- Local sensitivity analysis (manually investigating parameter space) and also including correlation matrix

- RMSE output measure – weighted sum of squares objective function

- Relatively short calibration period (5 months with 6 months unsat/sat spinup)

- Inverse modelling based on a maximum of 72 model evaluations (computation time) and 2 parameters (at a time)

= Focus (here) more on performance in relation to forcing than best possible model (that could follow later on)

# Data

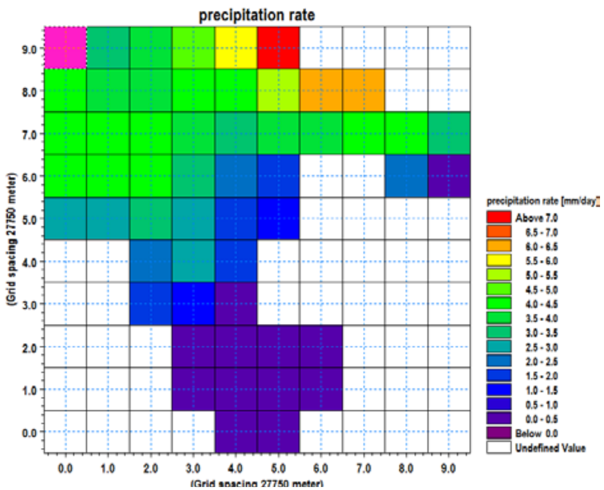
| FORCING | Variable | Resolution | | Comments |
|---|---|---|---|---|
| | | spatial | Temporal | |
| **EOBS** | Precip | 0.25 deg | Daily | |
| **EOBS** | Air Temp | 0.25 deg | 3h | |
| **EOBS** | Surf. Pres. | 0.5 deg | Daily | |
| **ERAI** | Global Rad. | Single cell | 12h | |
| **ERAI** | Wind speed | Single cell | Monthly | |
| **HADISDH** | Rel Humidity | Single cell | Monthly | |
| **Station based** | All six | 2-10 in catchment | Hourly | |
| **Cali / Vali** | | | | |
| **SWBM** | Ea | 0.5 deg | Daily | Model based |
| **Flux tower** | LH | Point | 30 min | ONLY 2012 AND located just outside the catchment! |
| **Local obs.** | Q | Point downstream | Hourly | ONLY 2001-2006! |

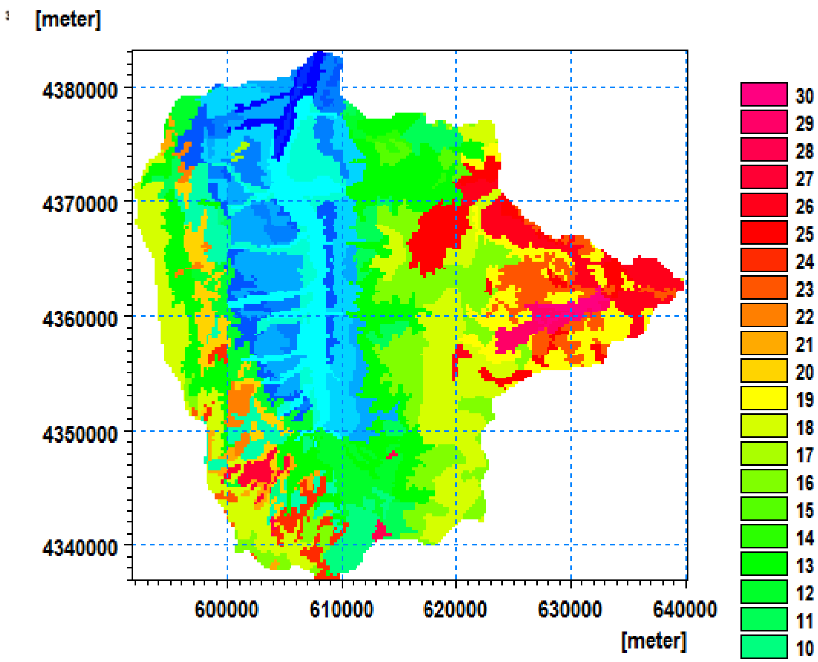
More? Satelite data?

Complication

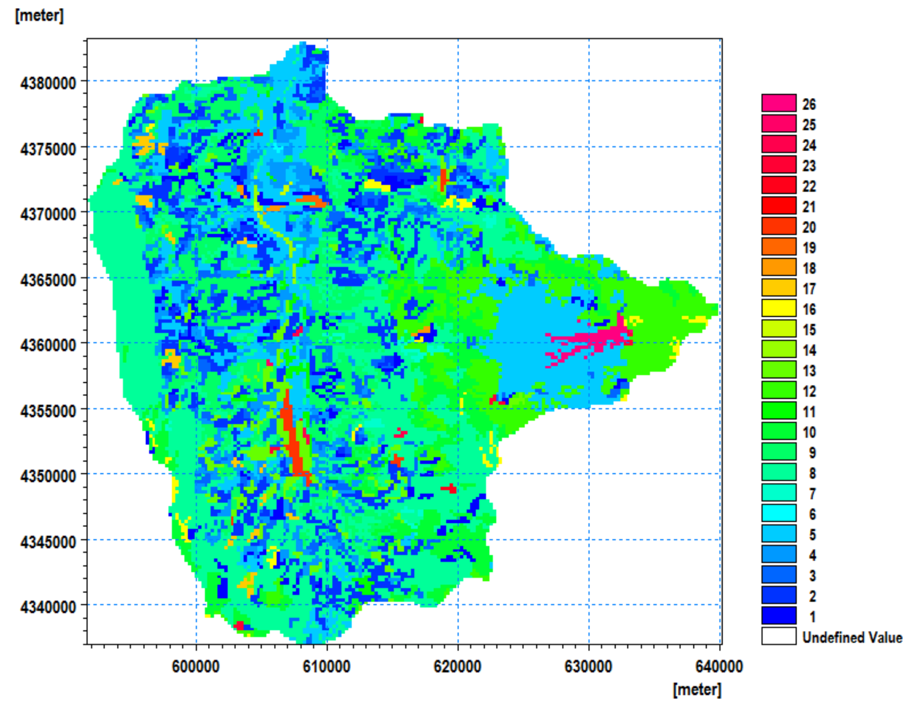
# Input data examples

E-OBS (0.25º)




Corine land cover




Unsaturated soil classes

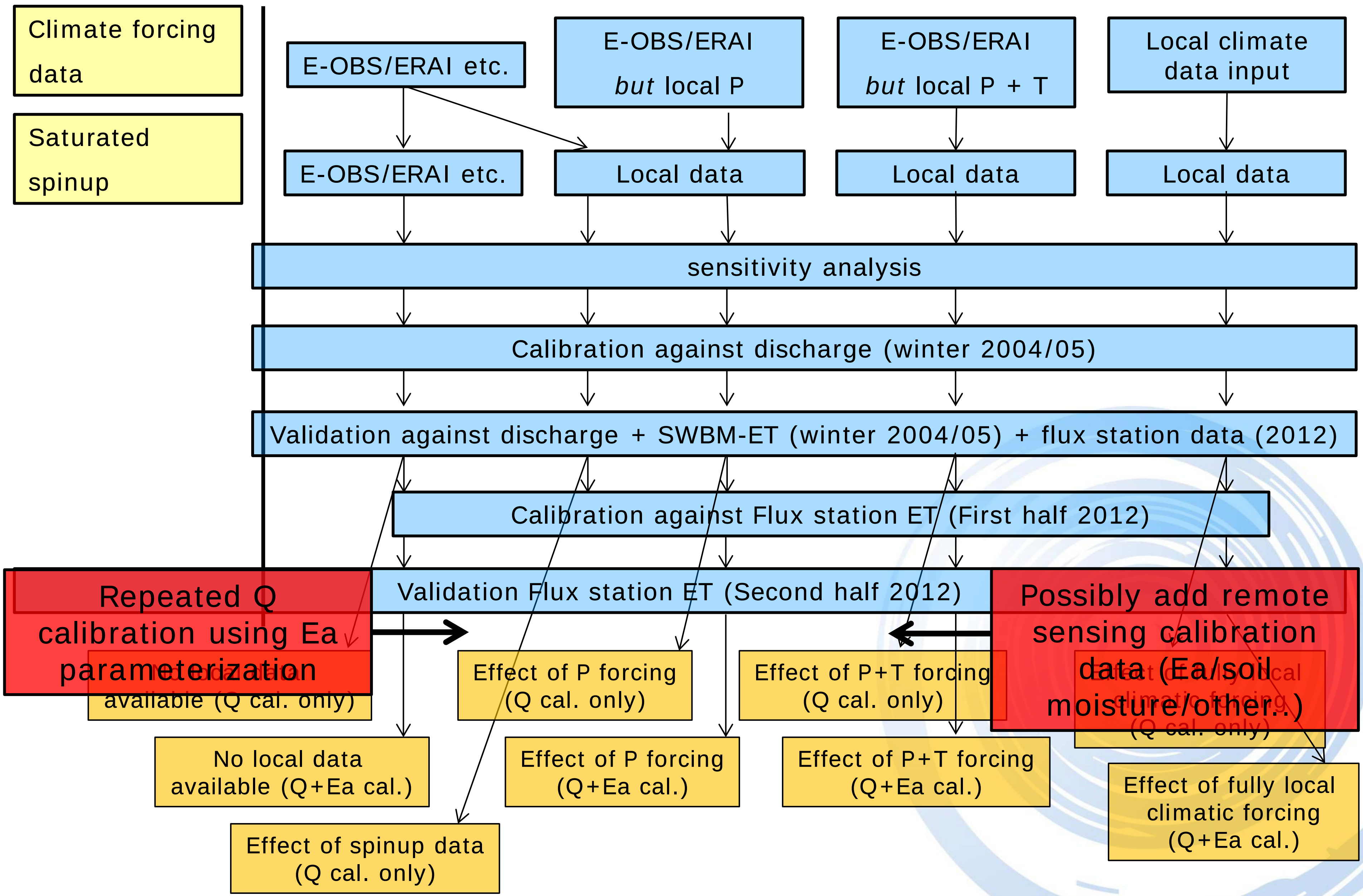
# Vegetation parameterization

## Corine land cover (initial) land surface parameterization

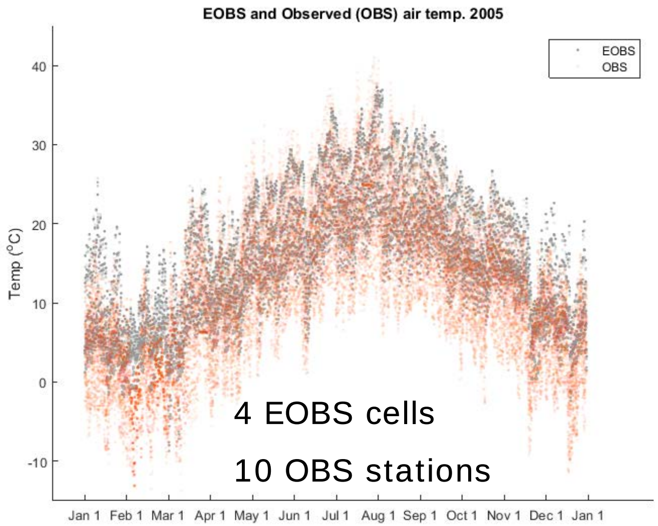
Ratios are kept constant in the calibration proces

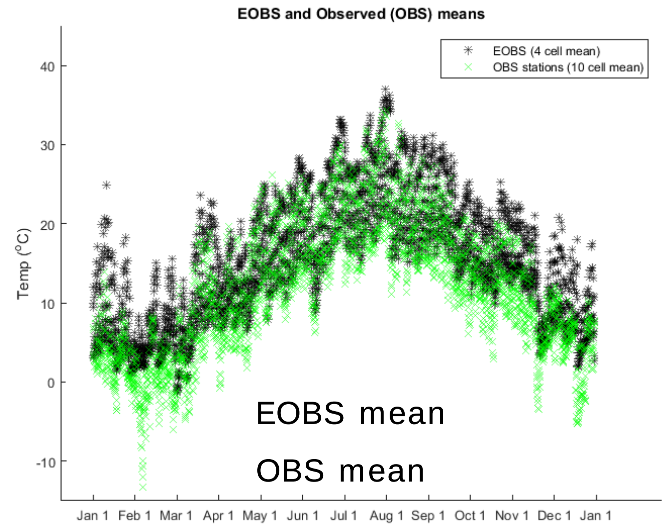
| | Land use | Albedo | Min stomata resistance | LAI | z0s | Root depth | Ext. factor | Vegetation height |
|---|---|---|---|---|---|---|---|---|
| | % | | m/s | $m^2/m^2$ | m | mm | | m |
| Transitional woodland-shrub | 3.2 | 0.175 | 150 | 4.5 | 0.84 | 2 | 0.66 | 4 |
| Annual crops associated with permanent crops | **9.1** | 0.125 | 130 | 3 | 0.05 | 0.5 | 0.5 | 0.5 |
| Land principally occupied by agriculture, with significant areas of natural vegetation | **5.4** | 0.125 | 150 | 3 | 0.05 | 0.5 | 0.5 | 0.5 |
| Complex cultivation patterns | **5.6** | 0.125 | 100 | 2.5 | 0.05 | 0.5 | 0.5 | 0.5 |
| Non-irrigated arable land | **13.9** | 0.125 | 90 | 3 | 0.025 | 0.25 | 0.5 | 0.25 |
| Vineyards | 0.0 | 0.2 | 140 | 1.5 | 0.2 | 1 | 0.25 | 2 |
| Sclerophyllous vegetation | 0.5 | 0.175 | 200 | 4.2 | 1.23 | 4 | 0.5 | 12.3 |
| Broad-leaved forest | **26.3** | 0.175 | 150 | 4.5 | 1.23 | 4 | 0.5 | 12.3 |
| Olive groves | **11.6** | 0.15 | 240 | 3.5 | 1 | 2 | 0.33 | 10 |
| Mixed forest | **8.8** | 0.175 | 215 | 4.5 | 1.23 | 4 | 0.5 | 12.3 |
| Industrial or commercial units | 0.6 | 0.175 | 100 | 0.1 | 0.01 | 0.1 | 0.5 | 0.1 |
| Coniferous forest | **8.7** | 0.175 | 150 | 4.5 | 1.23 | 4 | 0.5 | 12.3 |
| Discontinuous urban fabric | 2.9 | 0.25 | 100 | 1 | 0.2 | 1 | 0.5 | 2 |
| Beaches, dunes, sands | 0.2 | 0.4 | 100 | 0.1 | 0.01 | 0.01 | 0.1 | 0.1 |
| Fruit trees and berry plantations | 0.1 | 0.175 | 240 | 3.5 | 1.23 | 4 | 0.5 | 12.3 |
| Natural grasslands | 0.8 | 0.16 | 120 | 2 | 0.04 | 0.4 | 0.5 | 0.4 |
| Pastures | 0.7 | 0.175 | 190 | 3 | 0.025 | 0.25 | 0.5 | 0.25 |
| Mineral extraction sites | 0.1 | 0.3 | 100 | 0.1 | 0.01 | 0.1 | 0.5 | 0.1 |
| Sparsely vegetated areas | 0.1 | 0.3 | 100 | 0.25 | 0.02 | 0.1 | 0.1 | 0.2 |
| Continuous urban fabric | 0.5 | 0.175 | 100 | 0.1 | 0.01 | 0.1 | 0.5 | 0.1 |
| Permanently irrigated land | 0.0 | 0.125 | 85 | 4 | 0.05 | 0.5 | 0.5 | 0.5 |
| Burnt areas | 0.0 | 0.3 | 100 | 0.1 | 0.02 | 0.1 | 0.1 | 0.2 |
| Sport and leisure facilities | 0.1 | 0.15 | 100 | 2 | 0.03 | 0.3 | 0.5 | 0.3 |
| Road and rail networks and associated land | 0.1 | 0.2 | 100 | 0.1 | 0.01 | 0.1 | 0.5 | 0.1 |
| Construction sites | 0.0 | 0.2 | 100 | 0.1 | 0.01 | 0.1 | 0.5 | 0.1 |
| Water bodies | 0.6 | 0.1 | 1 | 0 | 0 | 0 | 0 | 0 |

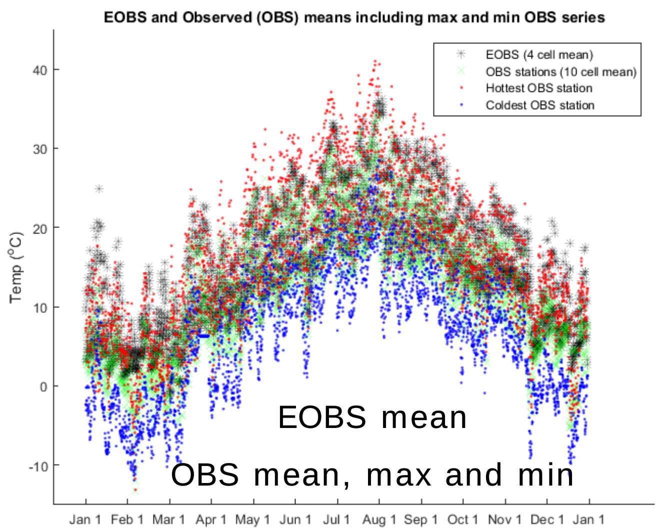
# Model runs (scenarios for data availability)



# Input data – Air Temp (2005 example)

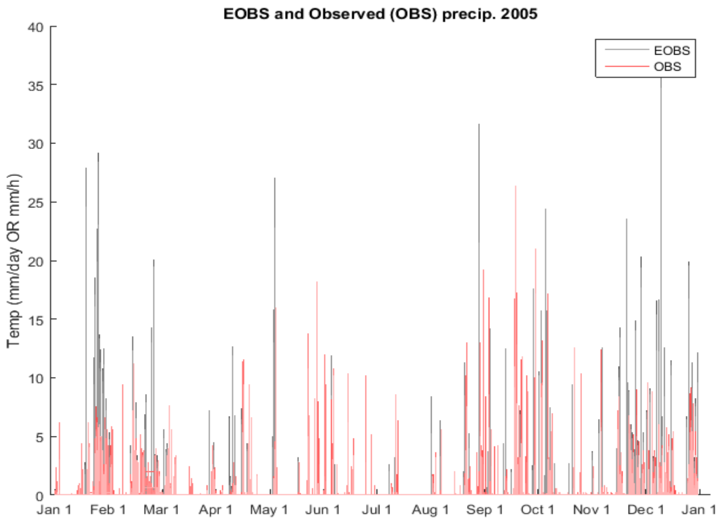


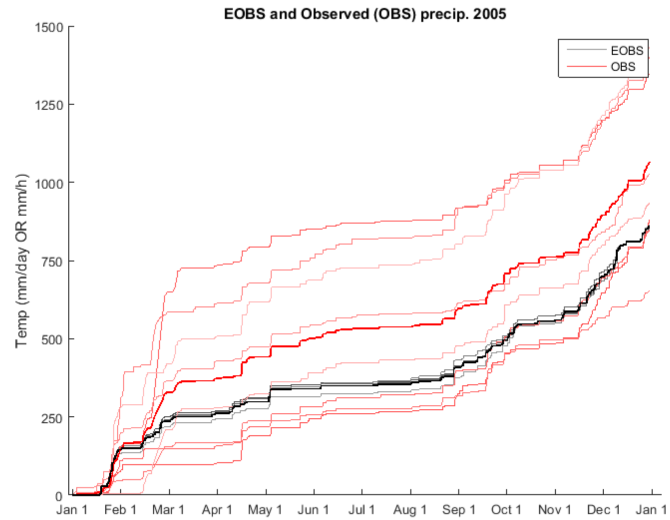




Quite some variation within the station data that is not captured by the EOBS data set

# Input data – Precip (2005 example)




~1400 mm

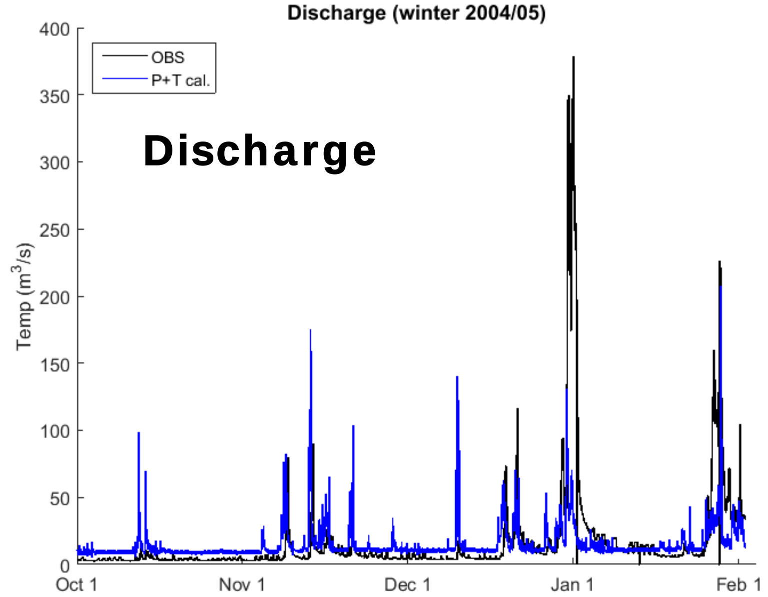
~1060 mm

~860 mm

EOBS somewhat resembles 7 precip stations (with 200 mm/year) whereas 3 stations are consistently higher (app. 550 mm/year)

*All for 2005*

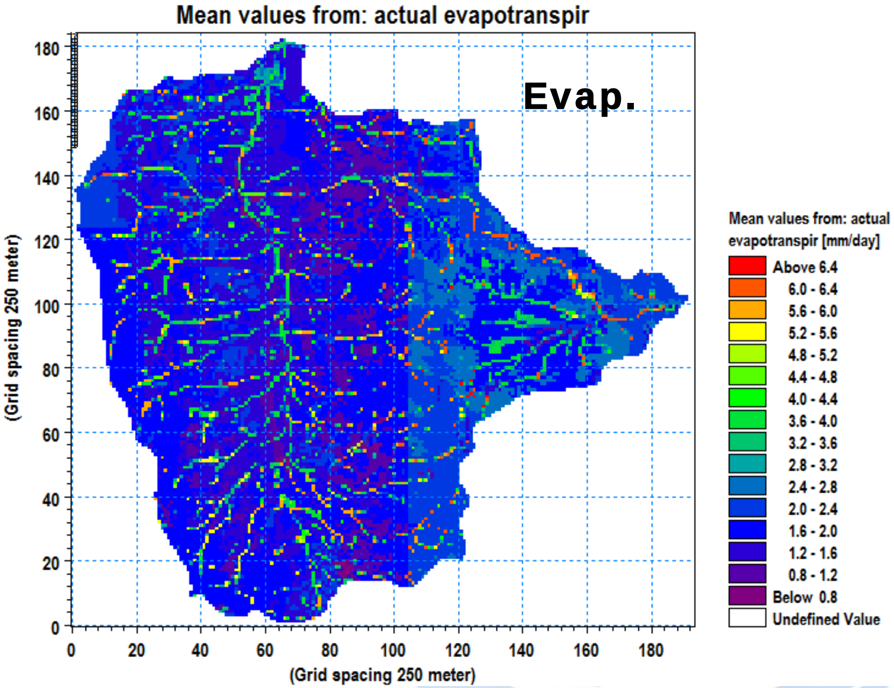
# Output




Nash Sutcliffe ≈ 0.3 with run using local P+T and large scale Wind, Glob Rad, RH and Surf Pres

## Steps for improvement

- 5 months calibration (short)
- Simple geology
- Not calibrated for Ea (only Q)
- Still need to add four locally observed variabled



# Conclusions

- Data input severely affects model outcome (no surprise)
- Several factors are likely to inhibit the land surface performance of the Crati river case as compared to the Danish study:
  1. Knowledge on hydrogeology
  2. Surface data; number of Q gauging- and flux tower stations
  3. 'Man hours in calibration / funding'

- Possibility for satisfying daily, as opposed to sub-daily, water/energy reproduction also with further model refinements (geology)
  1. Studies on the influence of the land surface temporal resolution on RCM simulations remains for this setup

Thank you