Coupled data assimilation with TerrSysMP

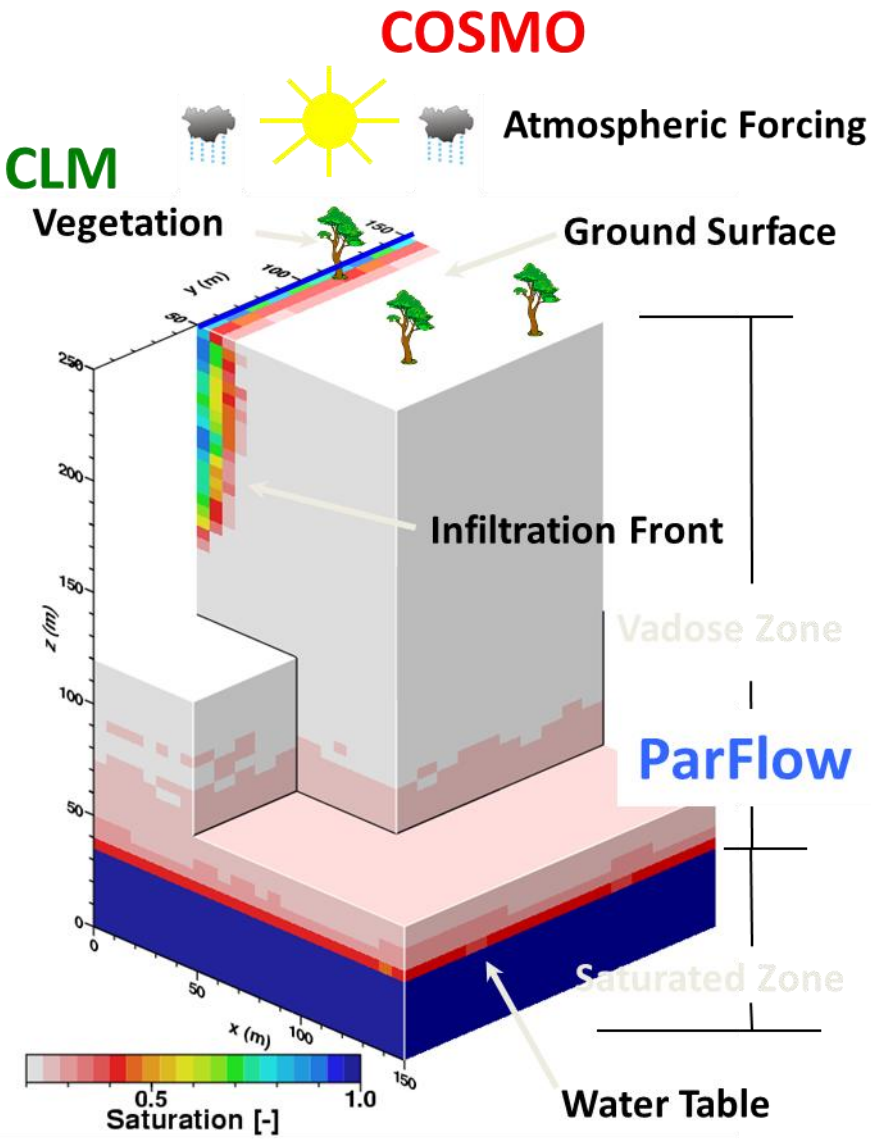
Harrie-Jan Hendricks-Franssen[1,2], Prabhakar Shrestha[3], Wolfgang Kurtz[1,2], Bibi Naz[1,2], Hongjuan Zhang[1,2], Stefan Kollet[1,2], Clemens Simmer[3], and Harry Vereecken[1,2]

[1] Forschungszentrum Jülich, Agrosphere (IBG 3), Leo-Brandt-Strasse, 52425 Jülich, Germany

[2] HPSC-TerrSys, Geverbund ABC/J, Jülich, Germany

[3] Meteorological Institute, Bonn, Germany

TerrSysMP



- 3D Variably saturated subsurface flow and energy transport (Jones & Woodward, 2001; Kollet et al., 2009)
- Integrated overland flow, terrain following grid (Kollet & Maxwell, 2006; Maxwell, 2013)
- Integrated land surface and regional climate model (Shrestha et al., 2014)

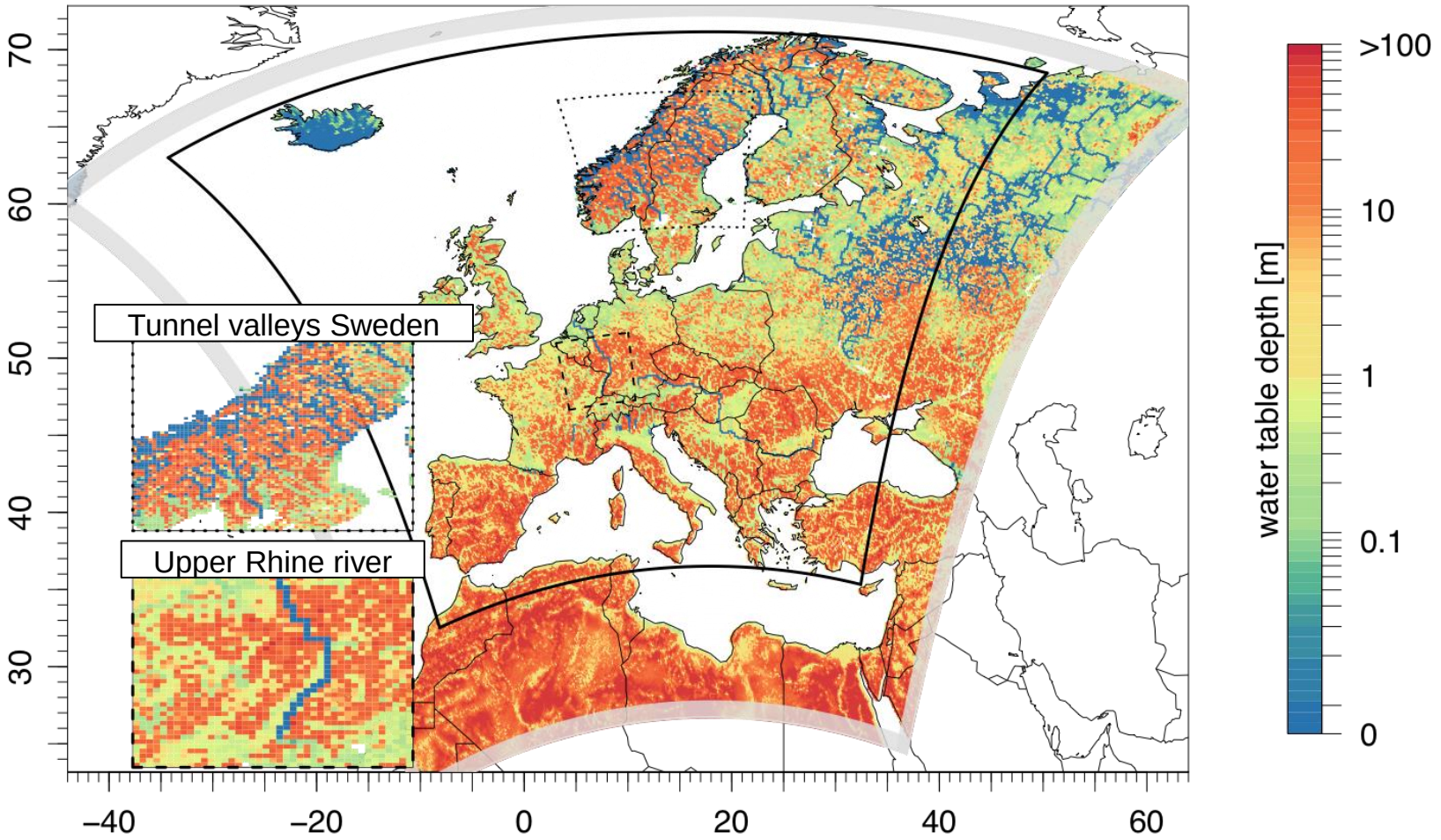
  External coupling via OASIS3: Multiple Program Multiple Data Execution Model (Shrestha et al., 2014)
- Atmospheric downscaling algorithm (Schomburg et al., 2010)

TerrSysMP

- Lateral subsurface transport of water and energy via groundwater
- PDE-based description of two-way interactions between groundwater, vadose zone, surface water, vegetation and atmosphere
- Land surface (CLM3.5) component still has large potential to be improved (e.g., beta-function for drought stress, photosynthesis types, plant traits)
- Overland flow process very non-linear → very high spatial resolution needed
- In general, many unknown parameters, initial states and forcings → data assimilation

Simulations up to continental scale

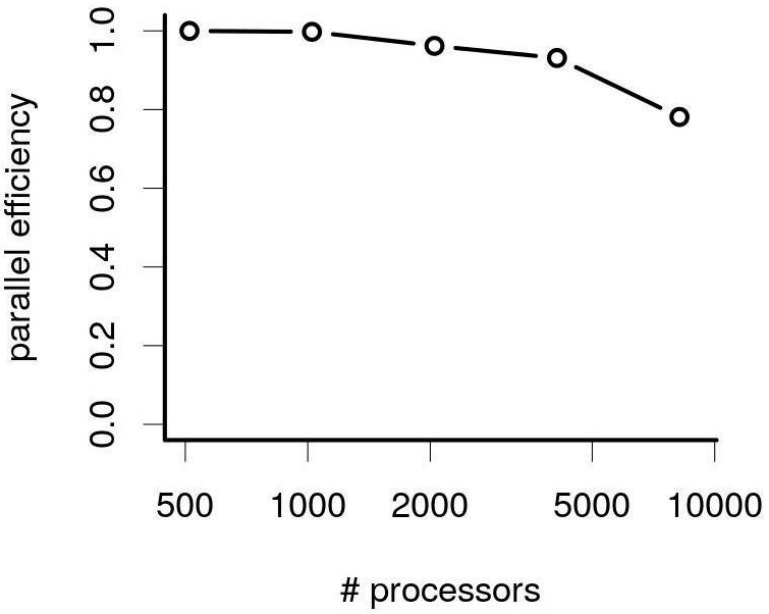
- Groundwater depth calculated over Europe
- Problem: long spin-ups needed related to slow groundwater dynamics.

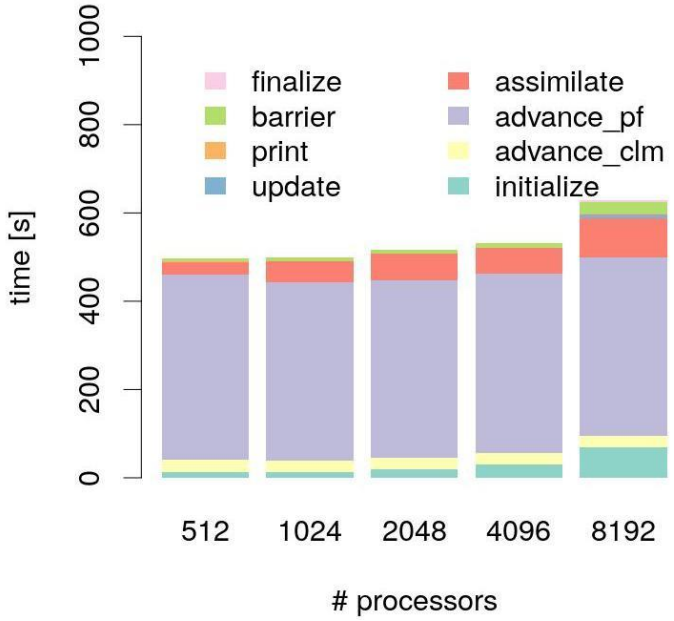


Keune et al., 2016

TerrSysMP and PDAF

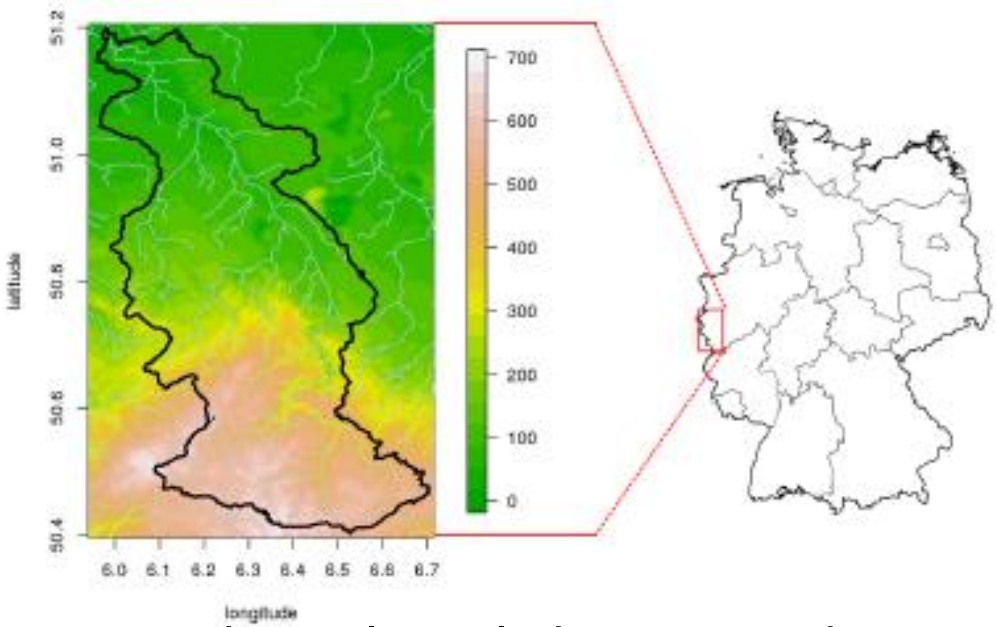
- PDAF (Nerger and Hiller, 2013) was coupled to TerrSysMP
- COSMO, CLM and ParFlow are parallel, DA in addition also parallel
- DA system is fully integrated (no I/O, no model reinitializations)
- Good scalability through effective use of domain decomposition
- Different DA-algorithms activated (EnKF, local EnKF, LETKF)
- Multiscale SM, GW levels and river water levels can be assimilated

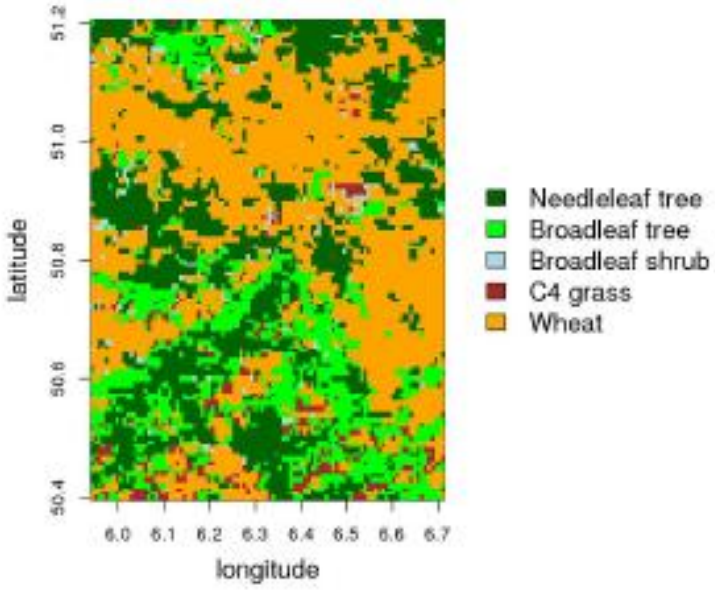




Kurtz et al. (2016), GMD

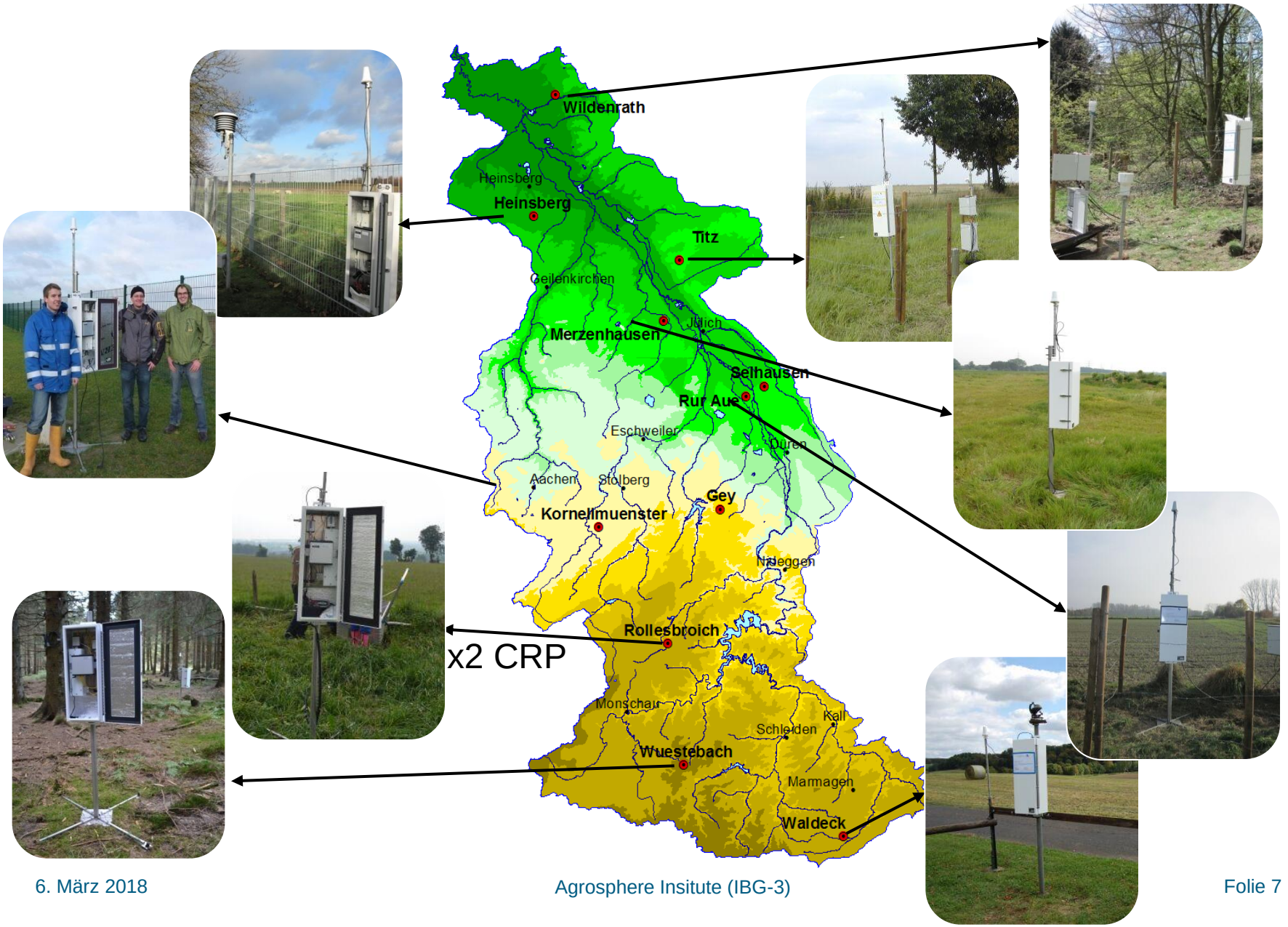
1st Example: Soil moisture Rur catchment



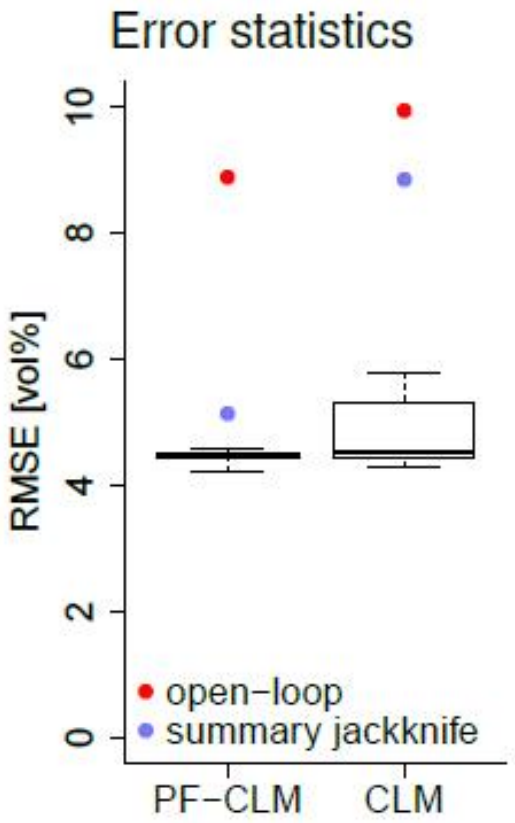


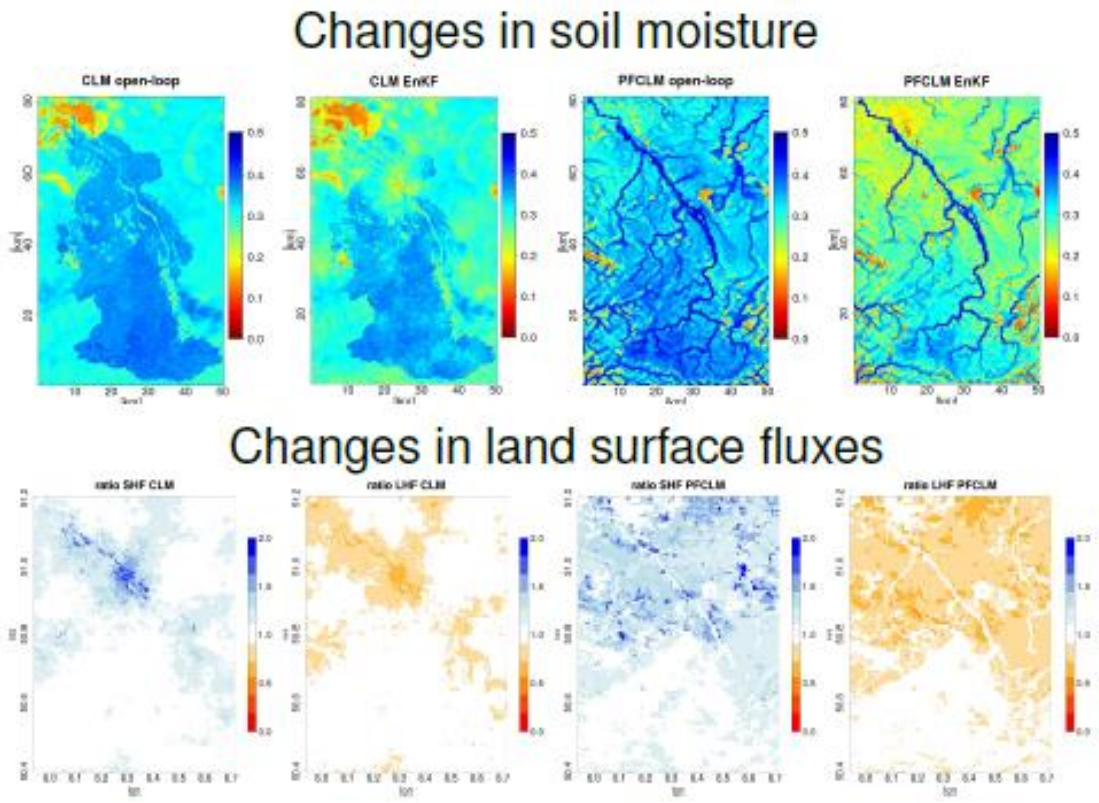
- Horizontal resolution: 500 m (100x162 cells)
- Vertical resolution 2cm-136 cm, 30 layers (30 m total thickness)
- Vegetation classification from MODIS
- Model forcings from COSMO-DE reanalysis
- Subsurface properties from European Soil data base

Cosmic Ray Probe Network Rur catchment



RMSE soil moisture



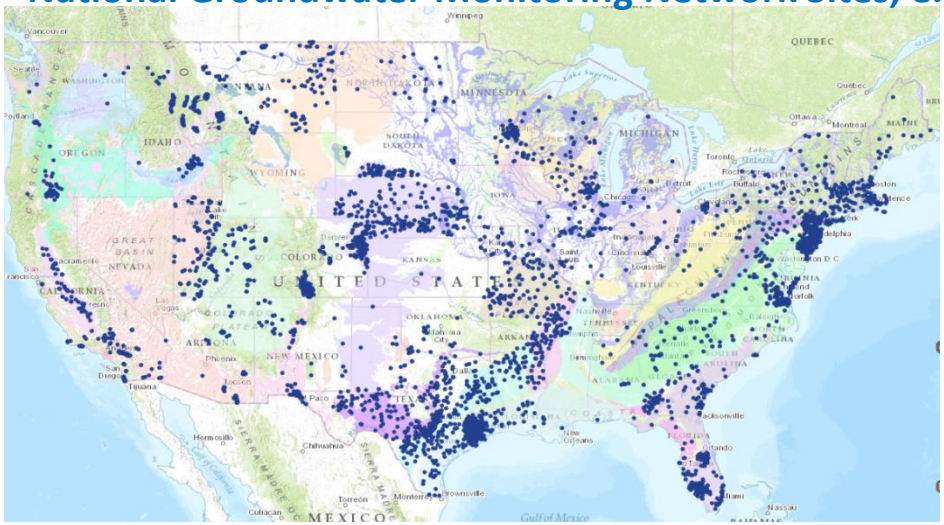


- Assimilation of soil moisture data from cosmic-ray probe network is effective for catchment wide soil moisture characterization
- Subsurface conceptualization affects update of soil moisture data

2nd example: GW-level assimilation

Aim is to update (root zone) soil moisture above groundwater table.

National Groundwater Monitoring Network Sites, e.g. USA

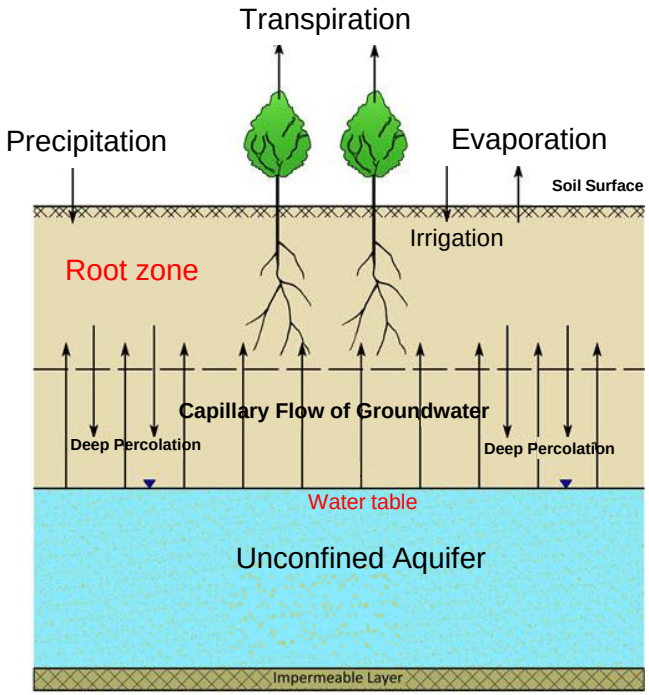


Good data source:

- low cost
- high accuracy
- widely available

May contain valuable information about root zone soil moisture:

- Especially for shallower GW tables
- Deeper GW tables generally indicate drier areas



(Source: Modified from Smedema and Rycroft, 1983)

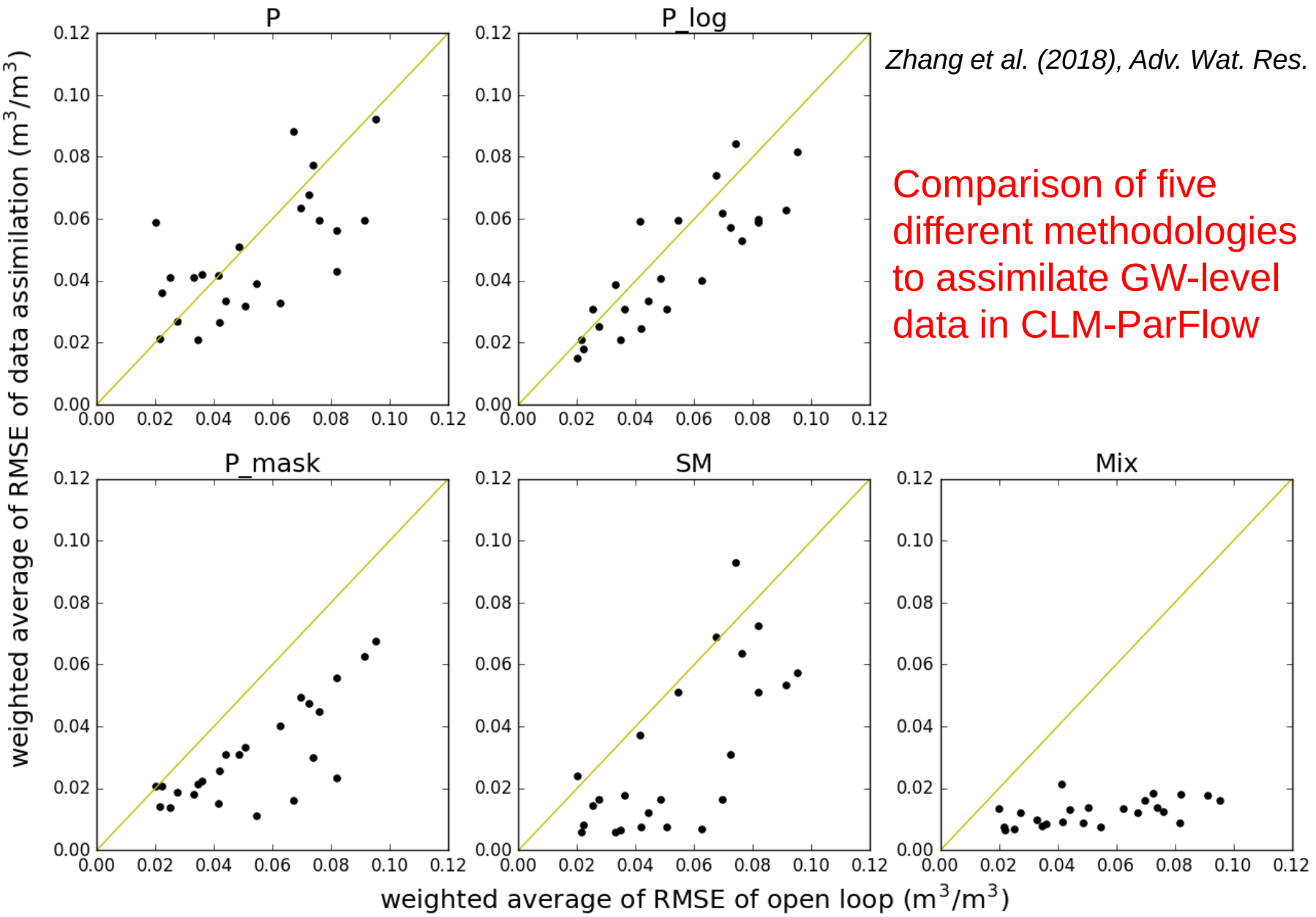
2nd example: GW-level assimilation

- Complication: state variable is pressure and shows for drought conditions in upper vadose zone strongly skewed, non-Gaussian pdf´s.

- Solution: if GW-level is assimilated, saturated grid cells are updated in terms of pressure but unsaturated grid cells in terms of soil moisture.

- Performance evaluated for large number of synthetic experiments (75 cases: 3 soil types x 5 PFT´s x 5 climate types).

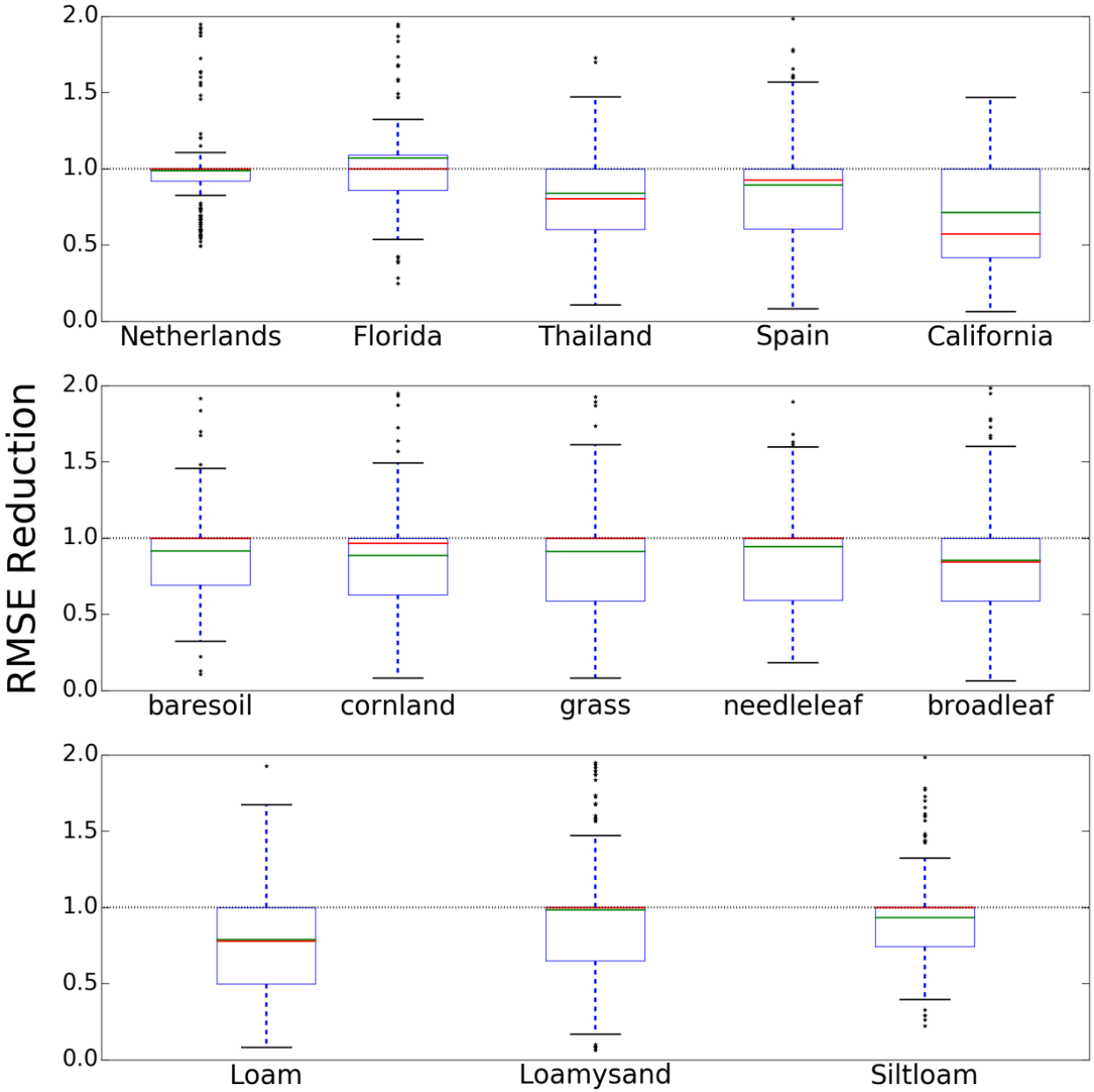
Methodology to incorporate GW-levels



Zhang et al. (2018), Adv. Wat. Res.

Comparison of five different methodologies to assimilate GW-level data in CLM-ParFlow

RMSE Reduction vs. Climate/PFT/Soil



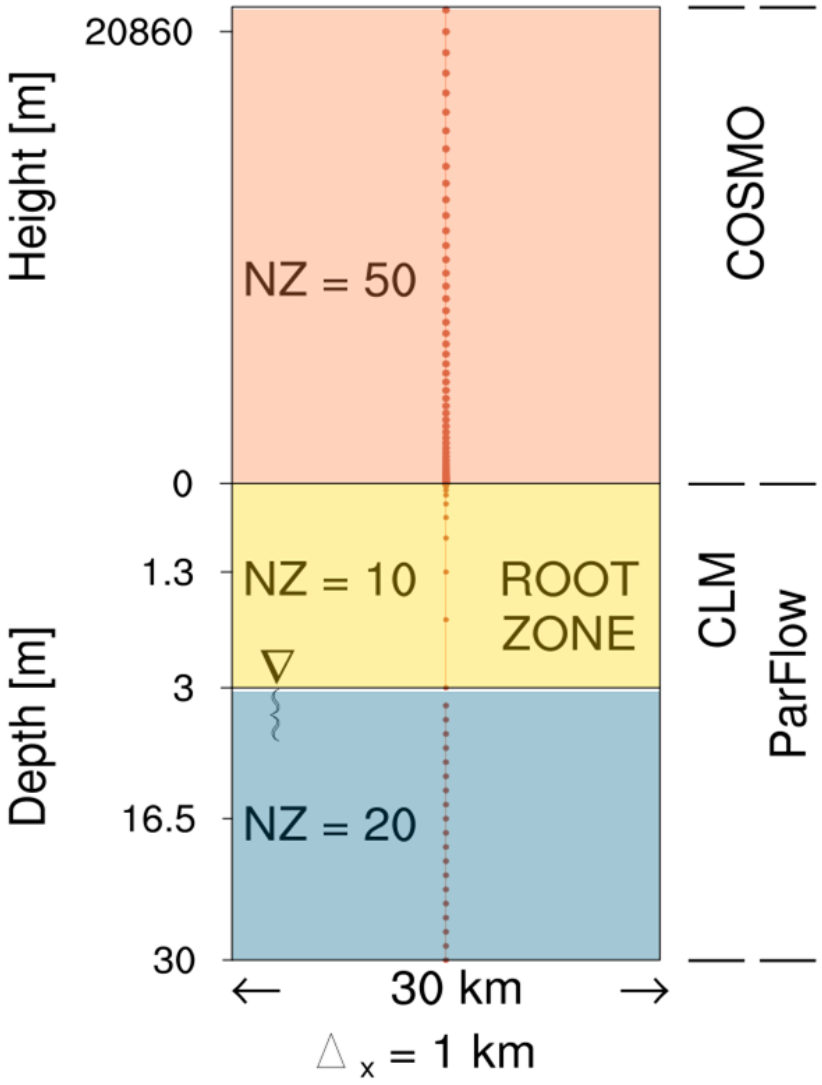
green: mean
red: median

If GW-level is not very shallow or very deep, assimilation shows clear benefit

Better results for loam soils.

Better results for broadleaf trees.

3rd example: atmosphere-land surface DA



- Homogeneous land surface & subsurface.
- 30 x 20 km^2 and resolution of 1km.
- Atmosphere has 50 vertical layers, with 20m resolution near surface.
- Subsurface has 30 vertical layers stretching until 30m.
- Periodic lateral BCS /impermeable lower BCS,

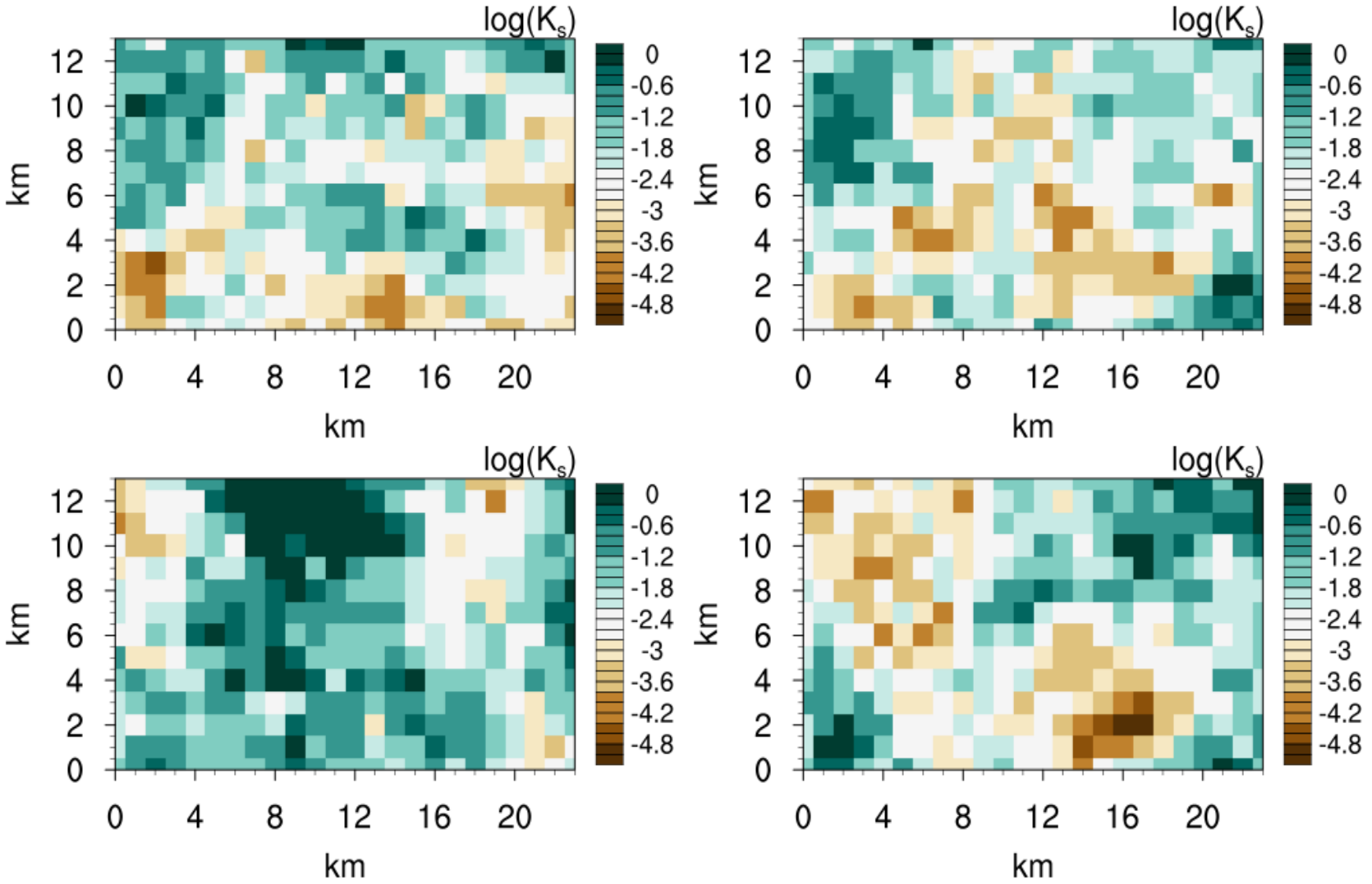
Spin-up

- 100 days of spin-up (Feb 1- May 7, 2008).
- Initial ground and vegetation temperature 283 K.
- Initial groundwater table depth 3m, hydrostatic profile.
- External forcing by COSMO-DE reanalysis data.
- Other parameters deterministic.

Ensemble generation

- 48 ensemble members.
- Spatially variable fields of saturated hydraulic conductivity.
- LAI, soil color, clay percentage, leaf carbon-nitrogen ratio randomly perturbed (but spatially constant).
- Turbulent mixing scale parameter.
- Other parameters deterministic.

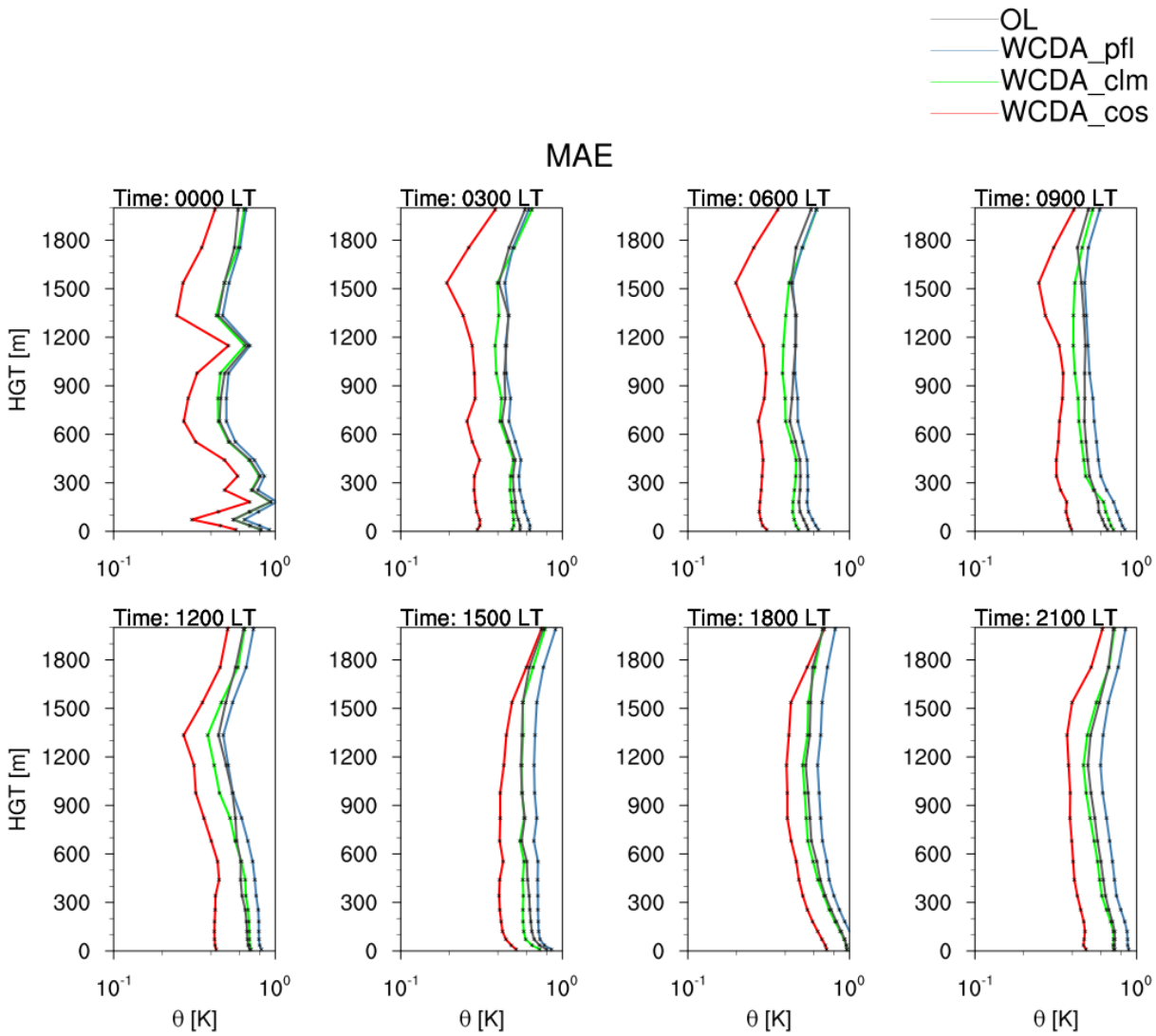
Spatially variable hydraulic conductivity



DA experiments

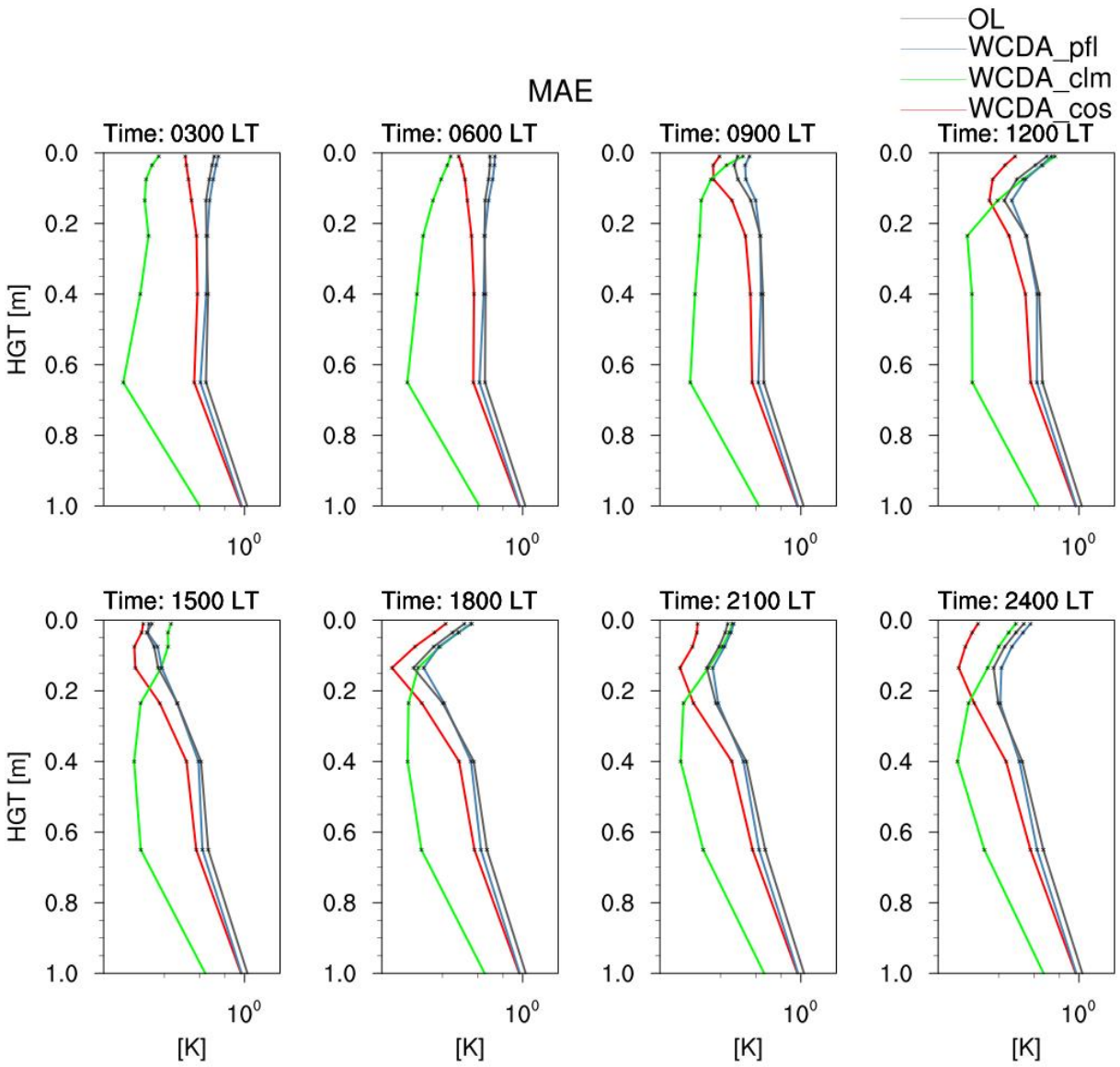
- Atmospheric DA: Atmospheric temperature at 10, 100, 200, 500, 1000, 3000 and 5000m.
- Land surface DA: Soil temperature at 2, 6, 10, 20, 30, 50, 80 cm depth.
- Subsurface DA: Soil moisture at 2, 6, 10, 20, 30, 50 and 80 cm depth.
- Observation variances: 0.60 K^2, 0.10 K^2 and 0.005.
- Daily assimilation for 10 locations in space.

Characterization atmospheric states



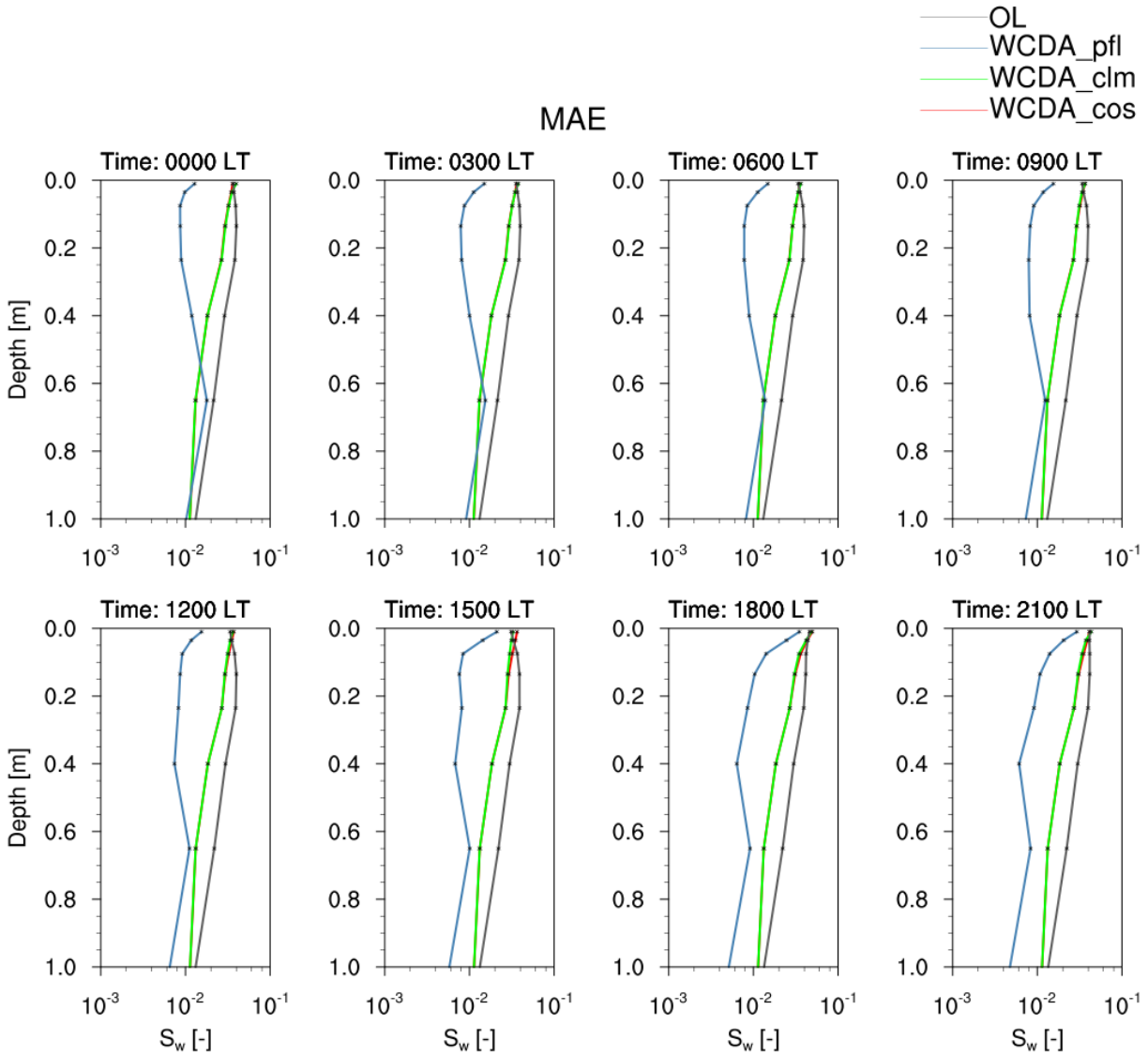
- Only atmospheric DA improves characterization of boundary layer potential temperature.

Characterization soil temperature



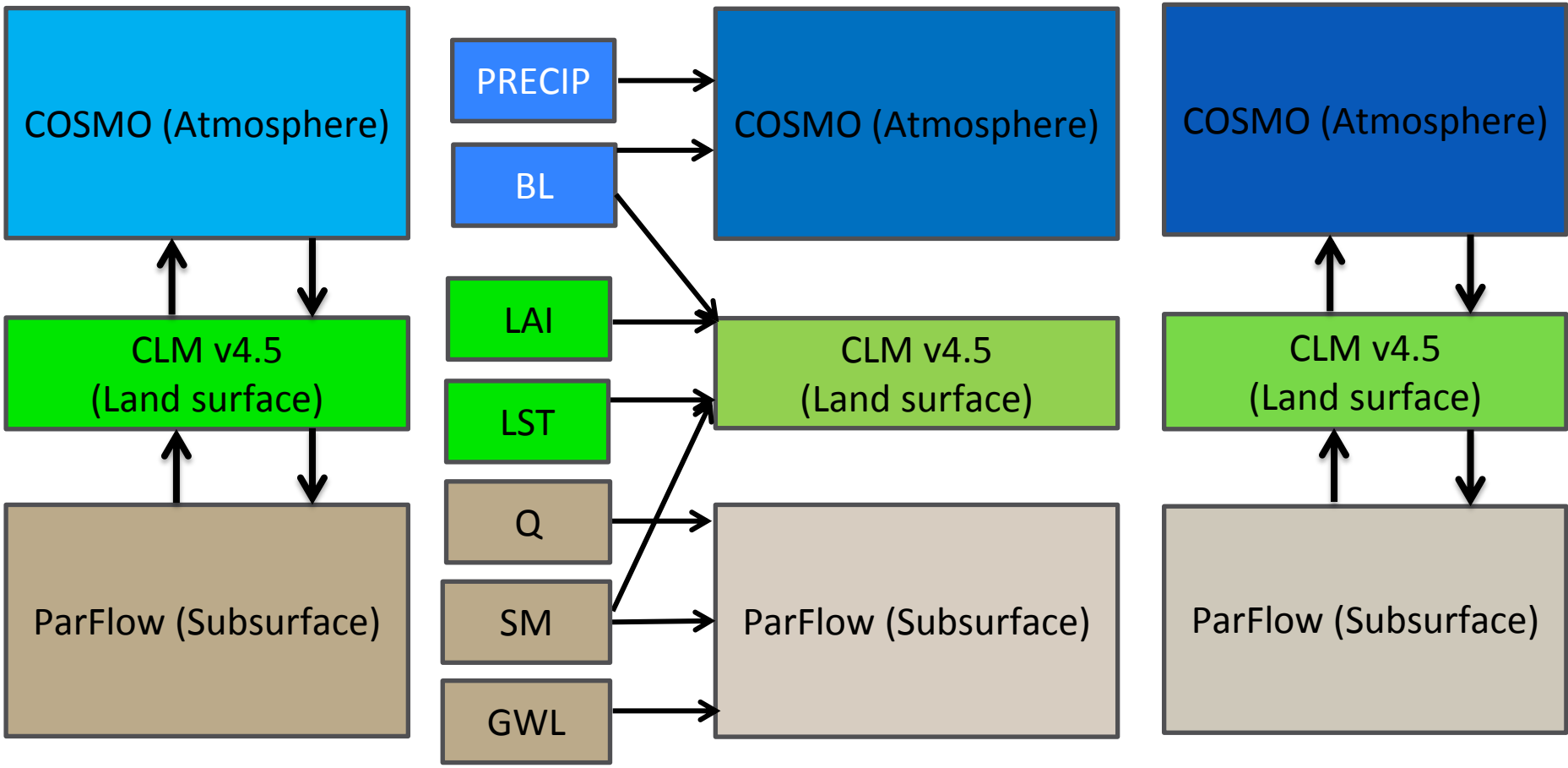
- Assimilation of soil temperature improves soil temperature, but less for upper 20 cm.
- Assimilation of atmosperic temperature improves soil temperature for upper layers.

Characterization soil moisture



- Assimilation of soil moisture improves soil moisture.
- Assimilation of soil temperature has also an impact on improving soil moisture characterization.

Outlook: coupled DA?



Example: Only some of the measurement data are used to update (sensitive) states in other compartments

Conclusions and outlook

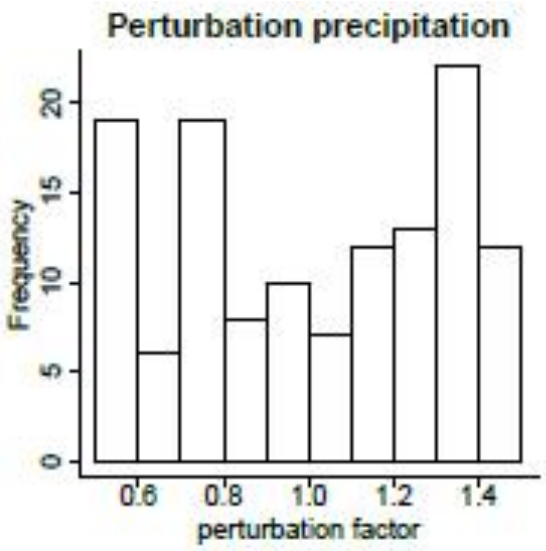
- TerrSysMP-PDAF: highly efficient DA-framework
- Soil moisture from cosmic ray probes, with about one probe per ~ 200 km^2 was found to reduce RMSE of soil moisture at not-assimilated locations in the catchment from 0.09 cm^3/cm^3 to 0.05 cm^3/cm^3.
- GW-level data show high potential to improve root zone soil moisture characterization under certain climatic conditions.
- Coupled atmospheric-land surface- subsurface DA shows largest impact of atmospheric temperatures. New test for drier conditions show larger impact of soil moisture/soil temperature. Ensemble spread should be improved.
- Current work: extension of coupled DA.

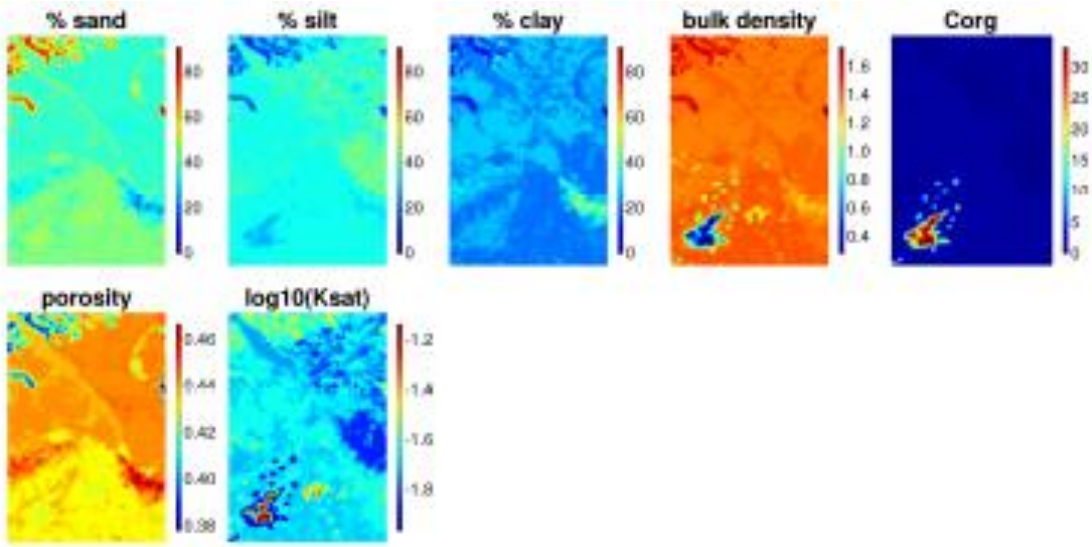
JÜLICH
FORSCHUNGSZENTRUM

Thanks for your attention!

DA-experiments Rur catchment

- 128 ensemble members
- Perturbation of precipitation, incoming short wave and long wave radiation and air temperature
- Perturbation of porosity and log(K_{sat})

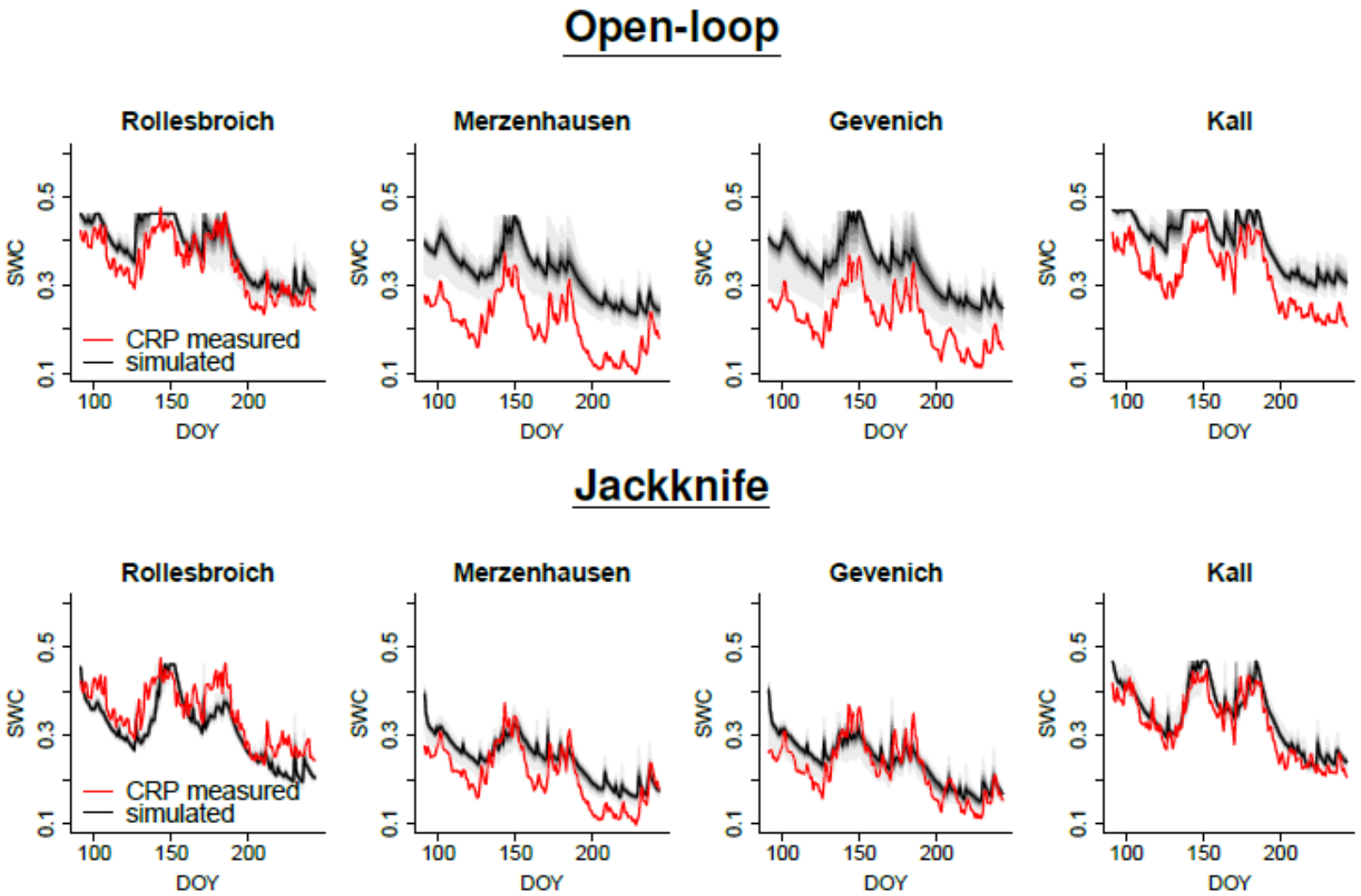




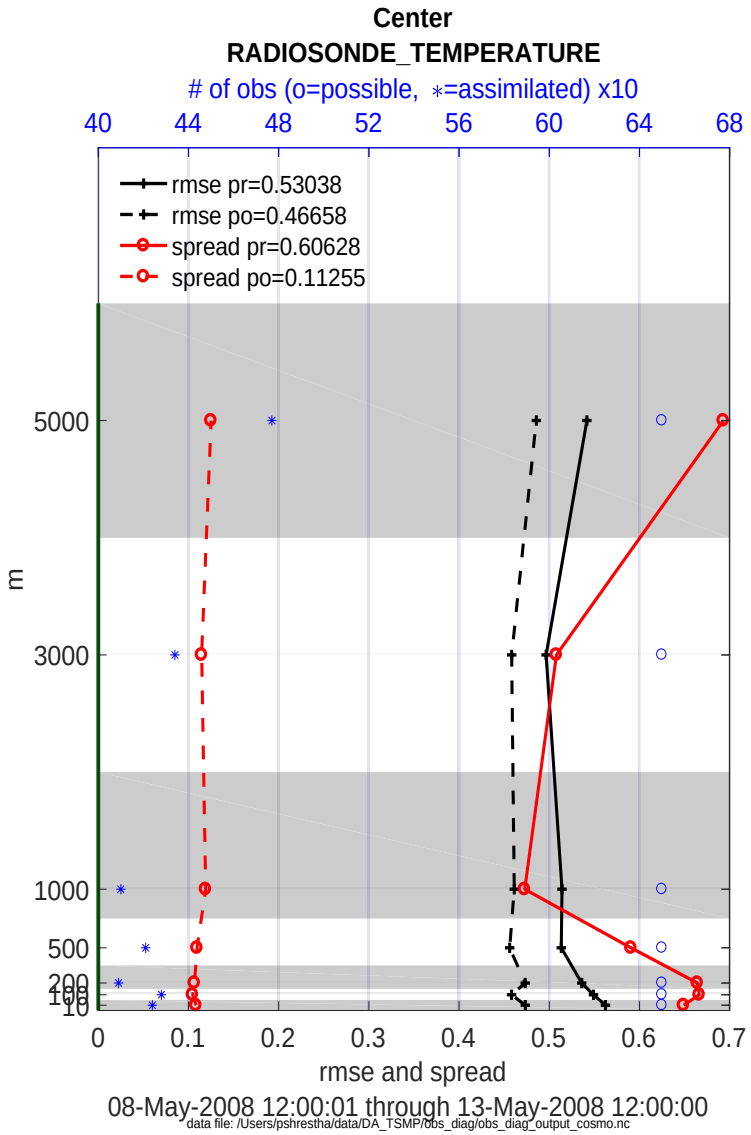
DA-experiments Rur catchment

- Assimilation period April – September 2013.
- Assimilation of soil moisture from 8 cosmic ray probes with EnKF.
- Probe left out in assimilation used for verification (jackknife).
- Repeated 9 times (all probes once left out).
- CLM v3.5 versus ParFlow-CLM assimilation.
- State updating and joint state-parameter updating

ParFlow-CLM jackknifing examples

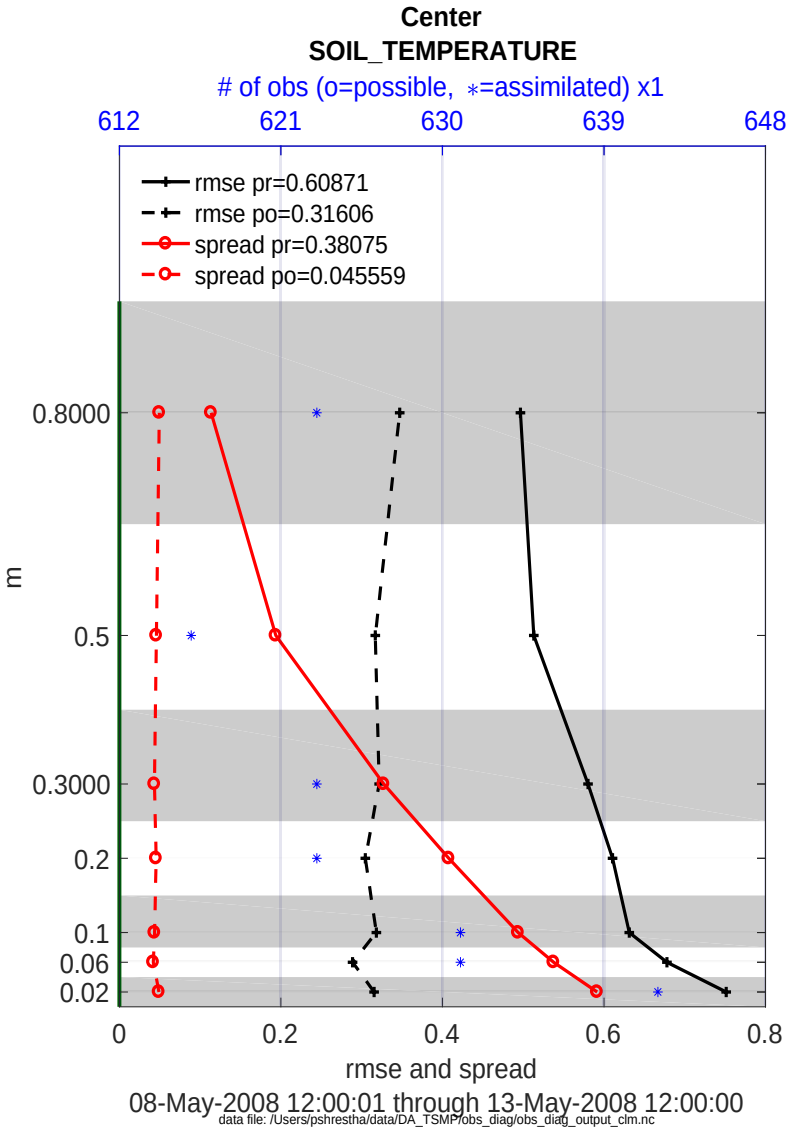


Atmospheric DA



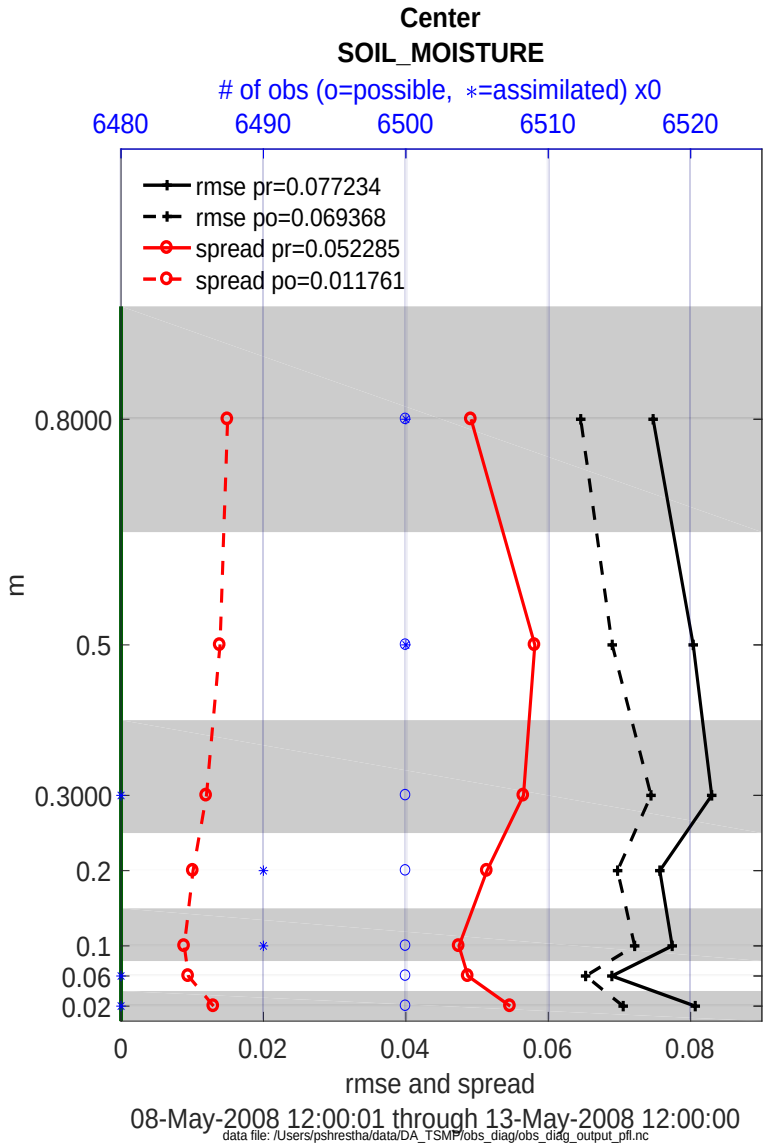
- Reduction in RMSE of Tair from 0.53 K to 0.47 K.
- Strong reduction ensemble spread.
- Inbreeding is an issue.

Land surface DA



- Reduction in RMSE of Tsoil from 0.61 K to 0.32 K.
- Strong reduction ensemble spread.
- Inbreeding is an issue.

Subsurface DA



- Reduction in RMSE of SWC from 0.077 to 0.069 cm^3/cm^3.
- Strong reduction ensemble spread.
- Inbreeding is an issue.