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TerrSysMP-PDAF: Technical concepts and application examples

Stefan Kollet[1,2], Dorina Baatz[1,2], Carina Furusho-Percot[1,2], Fabian Gasper[1,2], Klaus Görgen[1,2], Harrie-Jan Hendricks-Franssen[1,2], Jessica Keune[1,2,3], Ketan Kulkarni[2,4], Bibi Naz[1,2], Wolfgang Kurtz[1,2], Clemens Simmer[3], Wendy Sharples[2,4], Prabhakar Shrestha[3]

[1] Forschungszentrum Jülich, Agrosphere (IBG 3)
[2] HPSC-TerrSys, Geverbund ABC/J
[3] Meteorological Institute, Bonn University
[4] Jülich Supercomputing Centre

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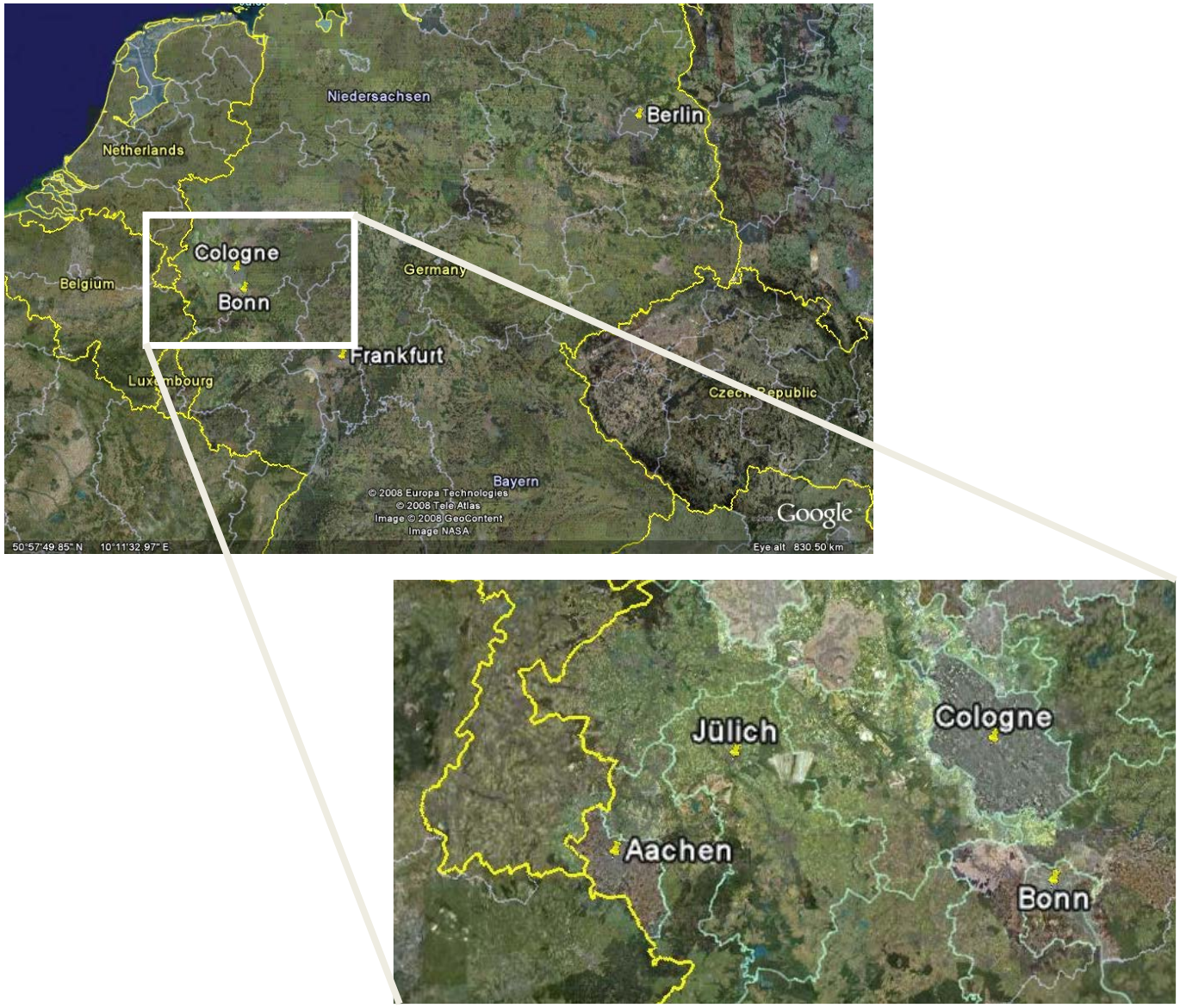
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Content

- Helmholtz Advanced Earth System Model Capacity

- Terrestrial Systems Modeling Platform, TerrSysMP
- TerrSysMP integrated with the Parallel Data Assimilation Framework, TerrSysMP-PDAF
- Application examples

- Potential contributions to CTMS

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Advanced Earth System Modelling Capacity (ESM)

Coordinated by

Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research

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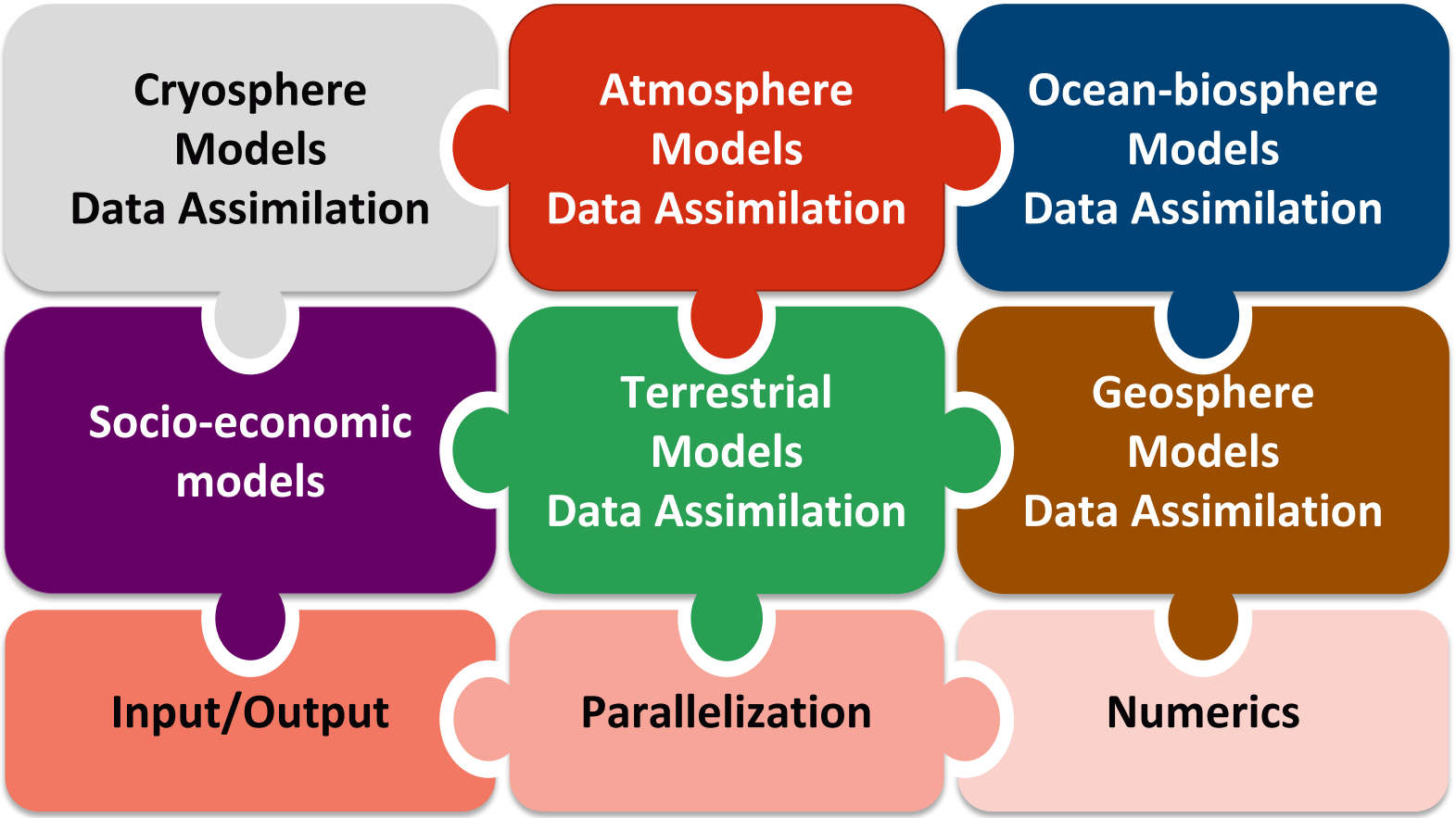
Helmholtz owns strong ESM expertise across Centers: AWI, DLR, FZJ, GEOMAR, GFZ, HZG, KIT, UFZ



How to mine great value across centers?

Background

- Evaluation of the Research Field “Earth and Environment”
- Recommendations of the Helmholtz Senate:
  - *“Modelling capabilities should be strengthened and a clear modelling strategy should be developed (e.g. referring to Earth system or climate modelling in the Programmes Geosystem, PACES-II, and ATMO).“*

HPSC TerrSys

ESM Advanced Earth System Modelling Capacity 2017-2020

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AWI

GFZ Helmholtz-Zentrum Potsdam

Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung

GEOMAR

HELMHOLTZ ZENTRUM FÜR UMWELTFORSCHUNG UFZ

KIT Karlsruher Institut für Technologie

DLR

- Main goal
  Develop, evaluate and apply an Earth system modelling infrastructure

Work Packages

- WP1: Earth System Model Development
- WP2: Data Assimilation
- WP3: Frontier Simulations
- WP4: ESM Strategy & education

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HPSC TerrSys

ESM Advanced Earth System Modelling Capacity 2017-2020

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- Main goal
  Develop, evaluate and apply a Earth system modelling infrastructure

Work Packages

- WP1: Earth System Model Development
  - Task 1.1 Atmospheric system
  - Task 1.2 Ocean-cryosphere-biosphere system
  - **Task 1.3: Terrestrial system**
  - Task 1.1 Geosphere
  - **Task 1.5: Model coupling**
- WP2: Data Assimilation
  - **Task 2.1: DA in ESM compartments**
  - **Task 2.2: DA of coupled ESM**
- WP3: Frontier Simulations
  - Task 3.1: Multiscale global change projections
  - Task 3.2: Monsoons in changing climate
  - **Task 3.3: European hydro-meteorological extremes**
  - Task 3.4: Matter cycling from land to sea
  - Task 3.5: Georeservoirs
  - Task 3.6: HPC and data management
- WP4: ESM Strategy & education
  - **Task 4.1: ESM strategy plan 2020-2040**
  - **Task 4.2: ESM implementation plan PoF IV 2020-2026**
  - **Task 4.3: Education**

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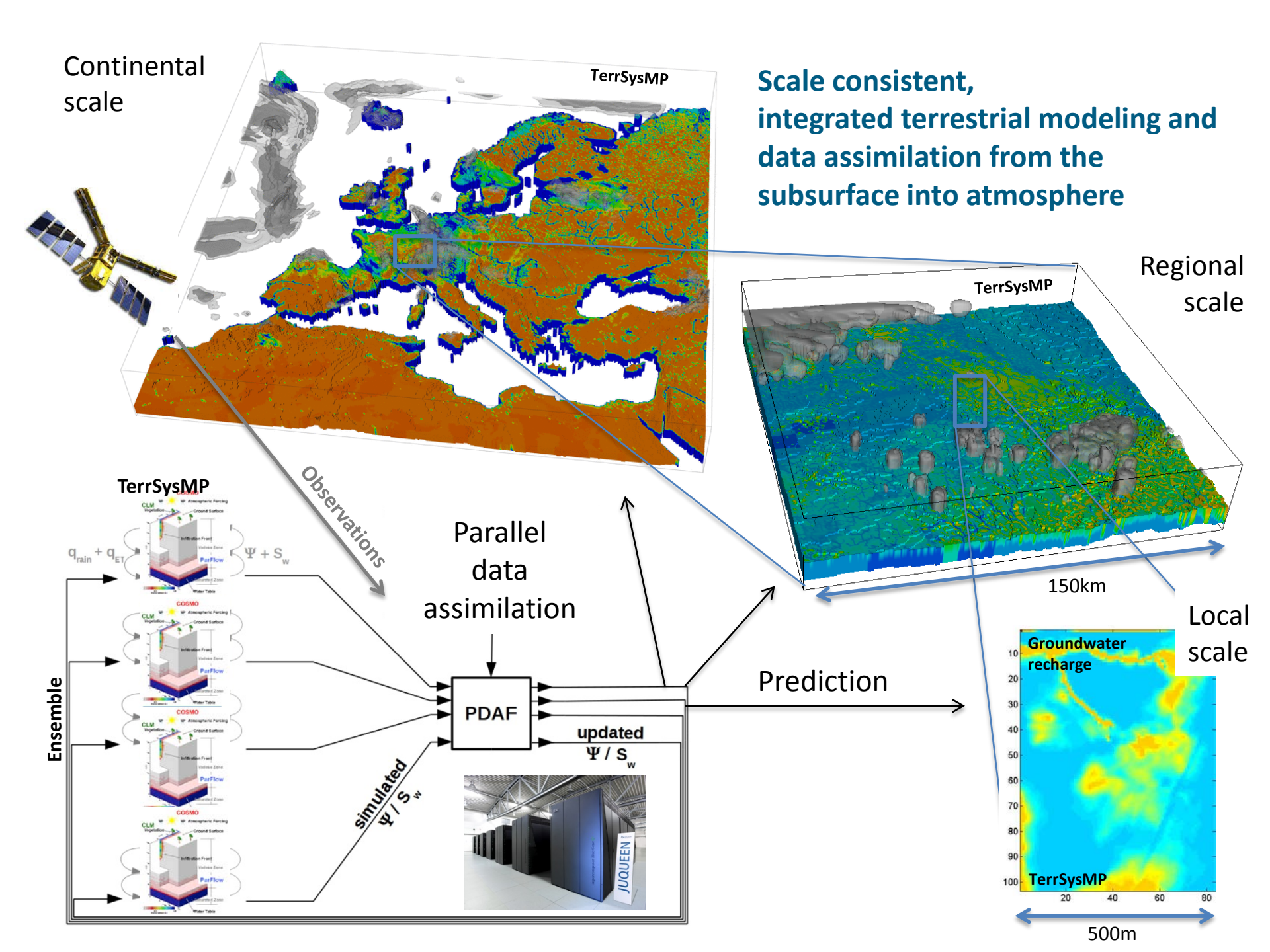
Continental scale
TerrSysMP
Scale consistent, integrated terrestrial modeling and data assimilation from the subsurface into atmosphere
Regional scale
TerrSysMP
150km
Observations
TerrSysMP
Parallel data assimilation
Ensemble
PDAF
updated Ψ / S w
simulated Ψ / S w
Prediction
Local scale
Groundwater recharge
TerrSysMP
500m

Terrestrial Systems Modeling Platform TerrSysMP-PDAF

SFB/TR32

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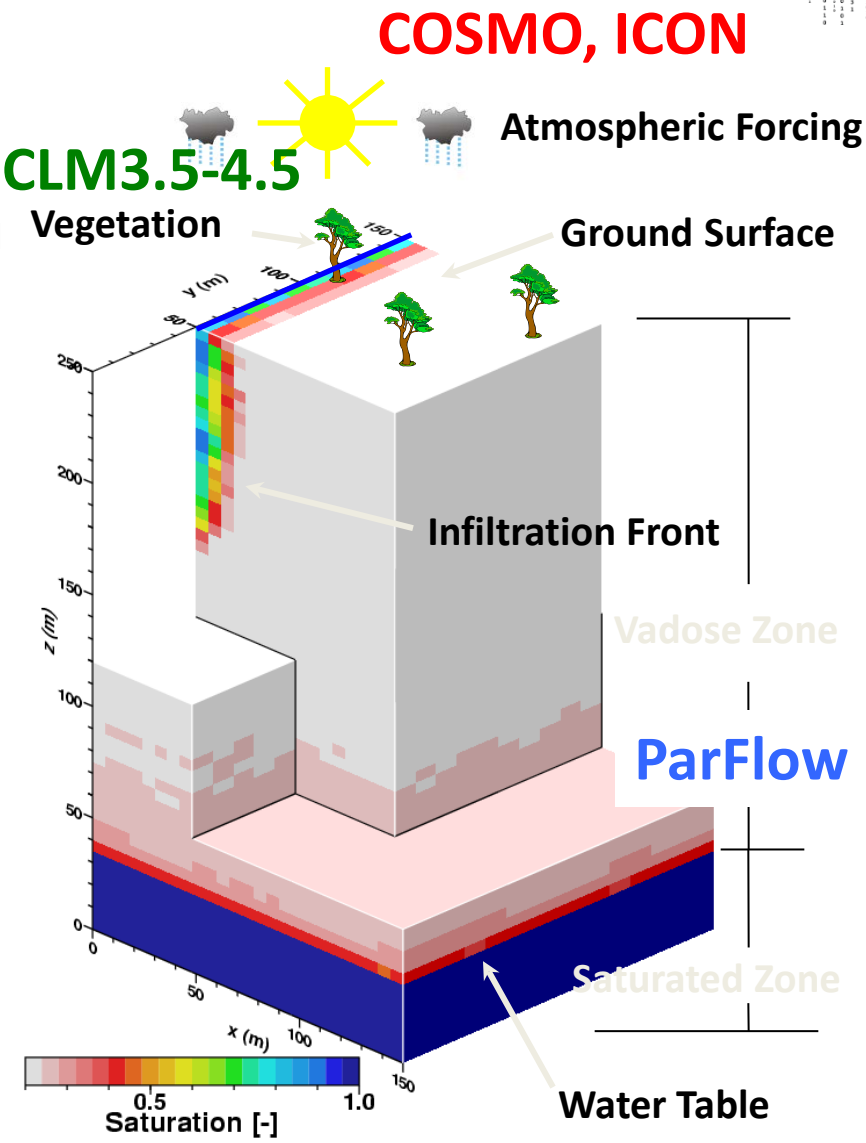
- 3D Variably saturated subsurface flow and energy transport (Jones & Woodward, 2001; Kollet et al., 2009)
- Integrated overland flow, terrain following grid (Kollet & Maxwell, 2006; Maxwell, 2013)
- Integrated land surface and regional climate model (Shrestha et al., 2014)
- Modular coupling via OASIS3-MCT: (Shrestha et al., 2014; Gasper et al., 2014)
- Explicit simulation of groundwater pumping and irrigation (Keune et al., 2018)
- Integrated Parallel Data Assimilation Framework, PDAF (Kurtz et al., 2016)
- Integrated with DART (Shrestha et al.,)



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Modular implementation

SFB/TR32

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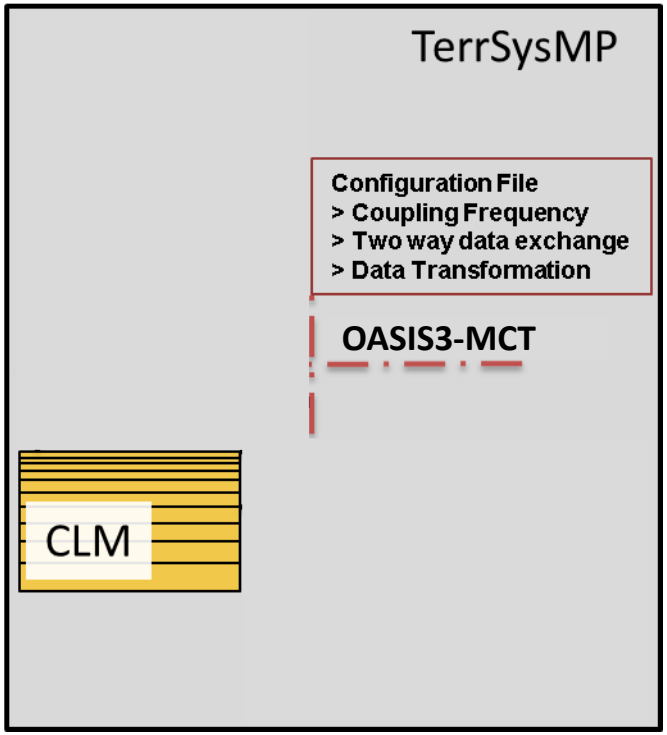
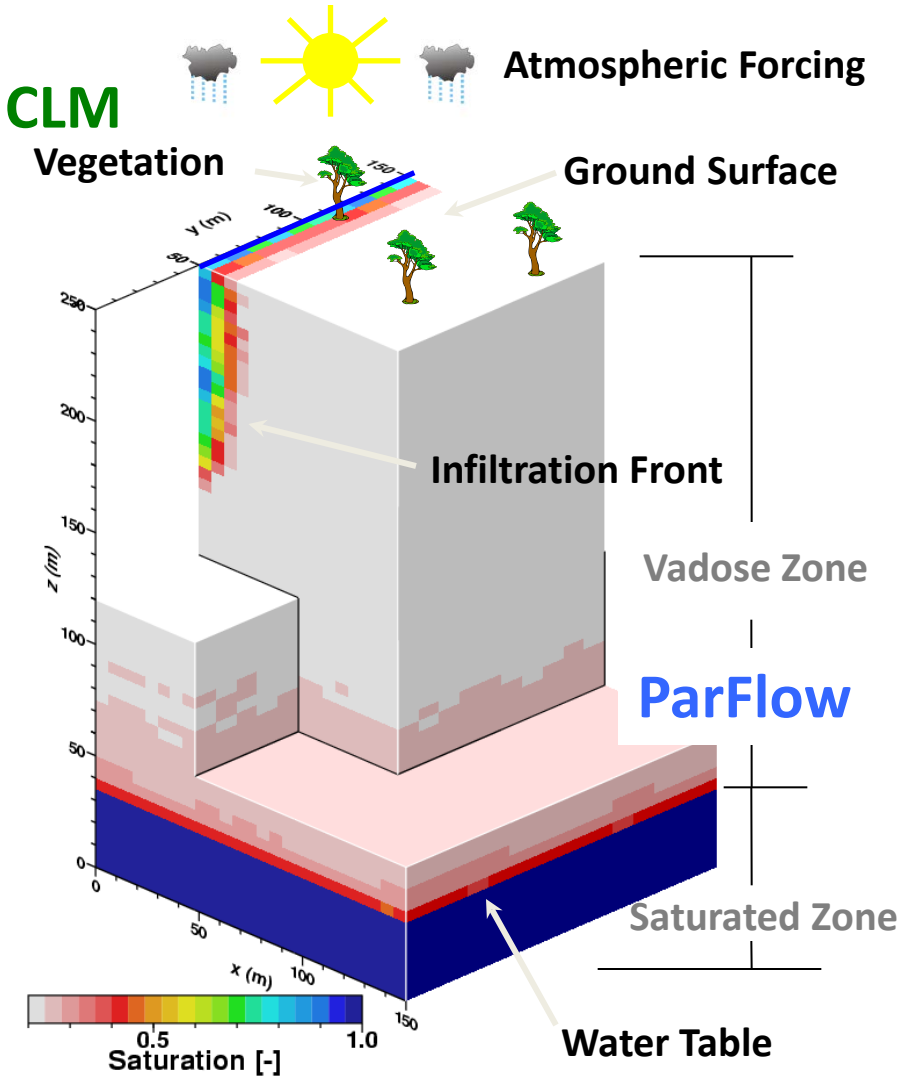


TerrSysMP schematic
Shrestha et al. 2014



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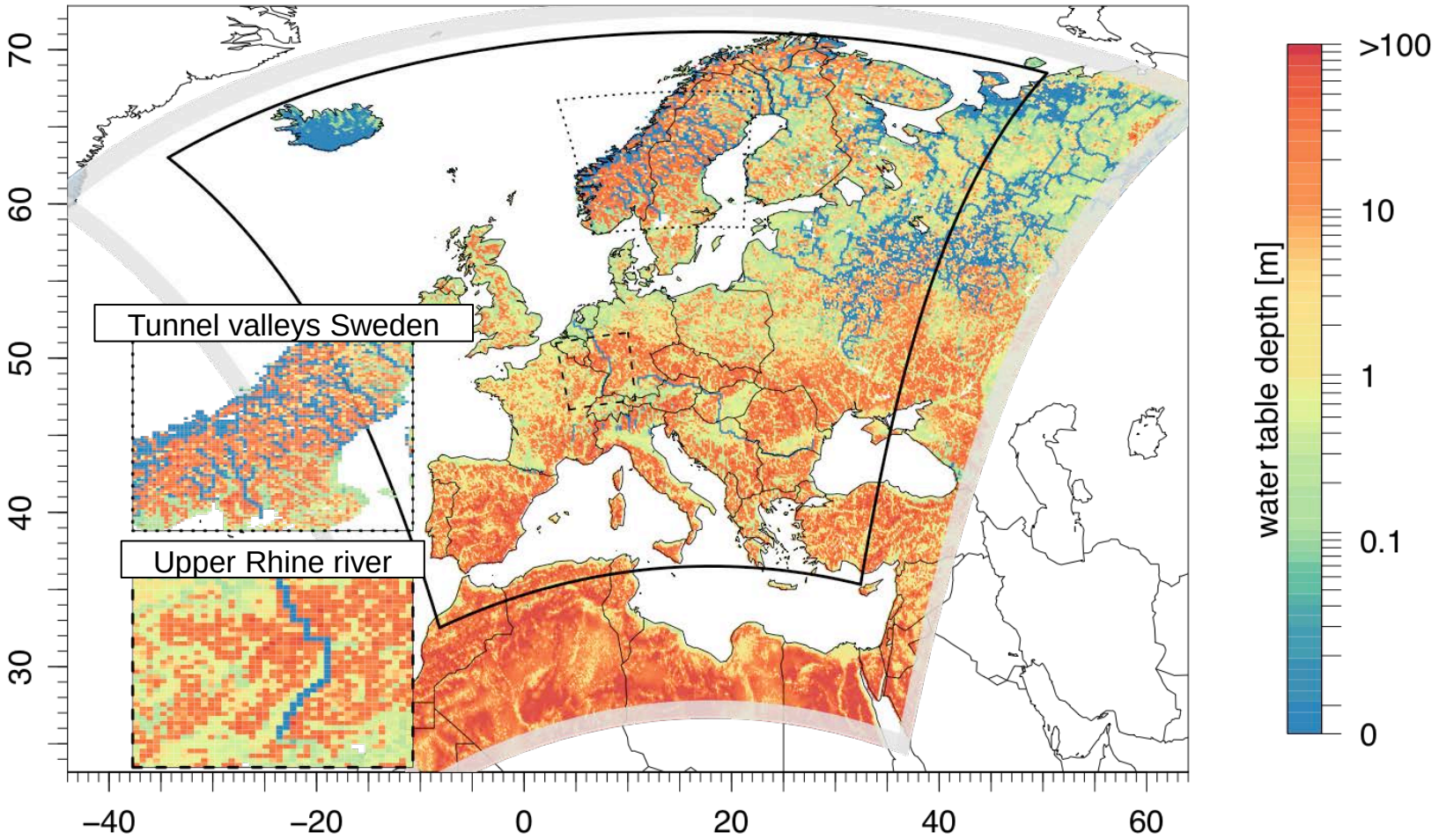
Simulations up to continental scale

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



Keune et al., 2016

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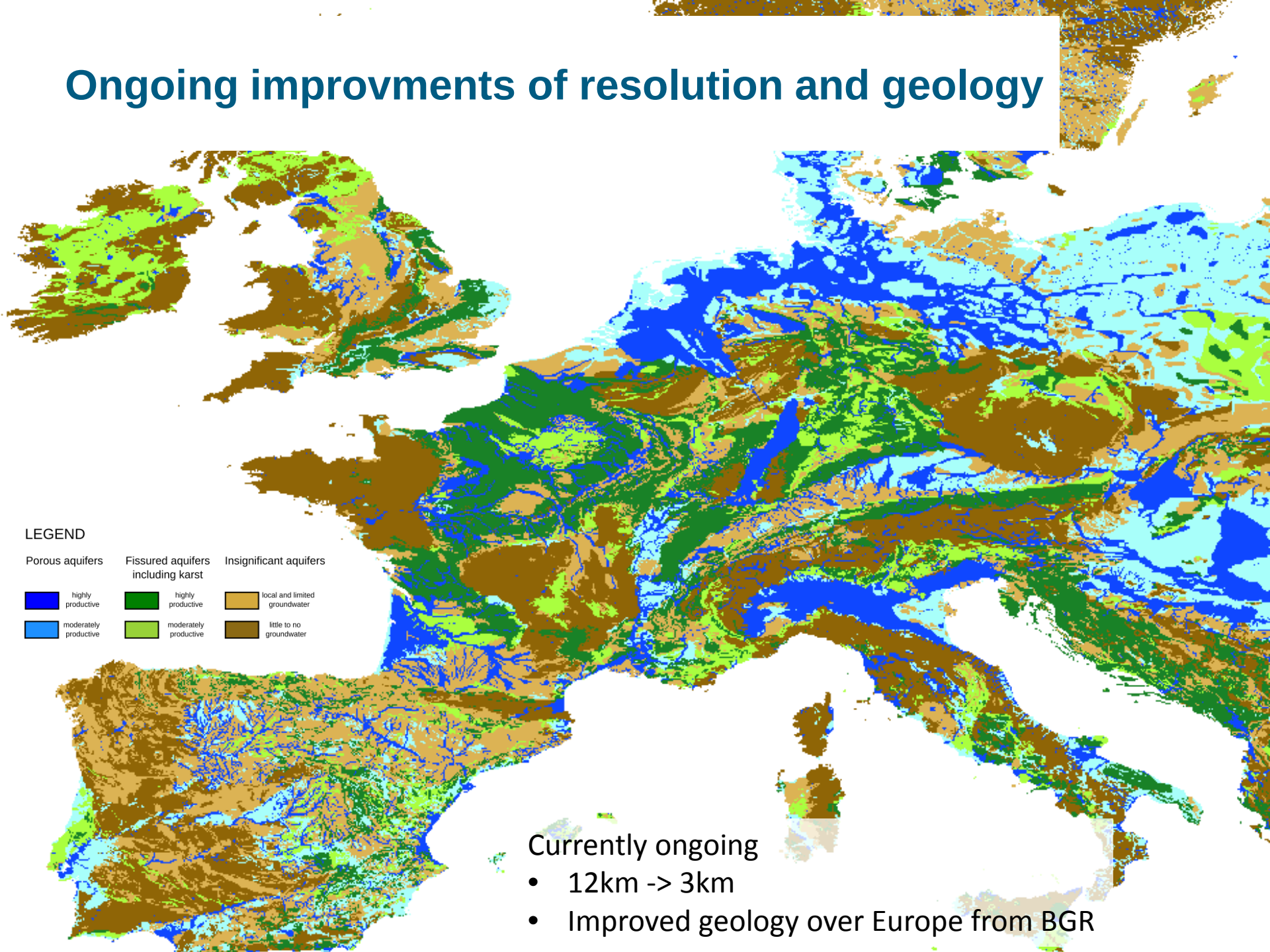
Ongoing improvments of resolution and geology



Currently ongoing

- 12km -> 3km
- Improved geology over Europe from BGR

Experimental TMS

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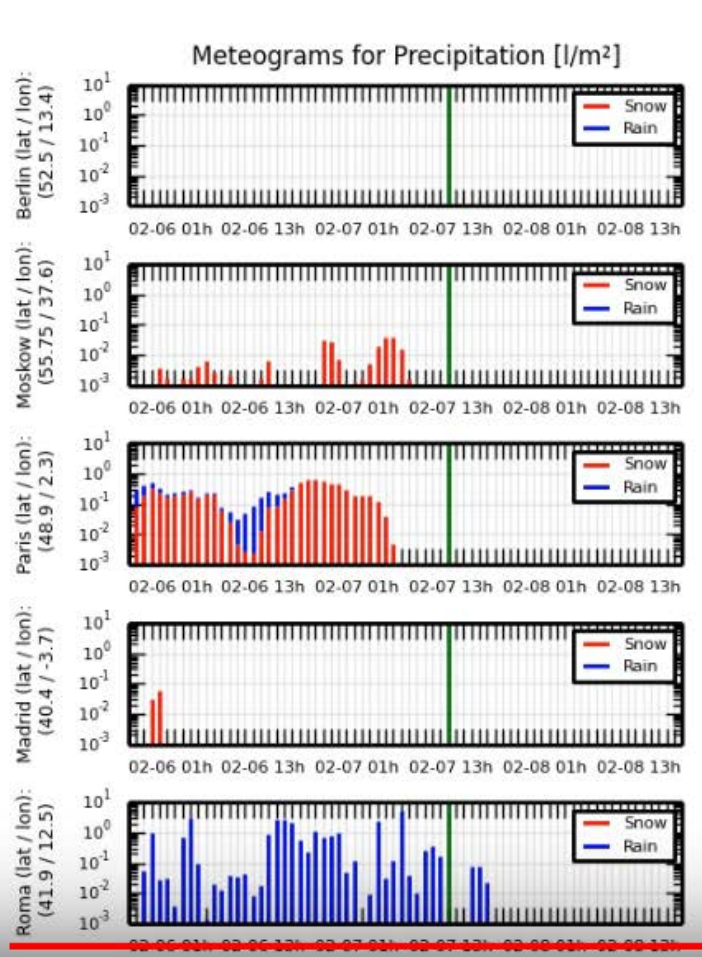
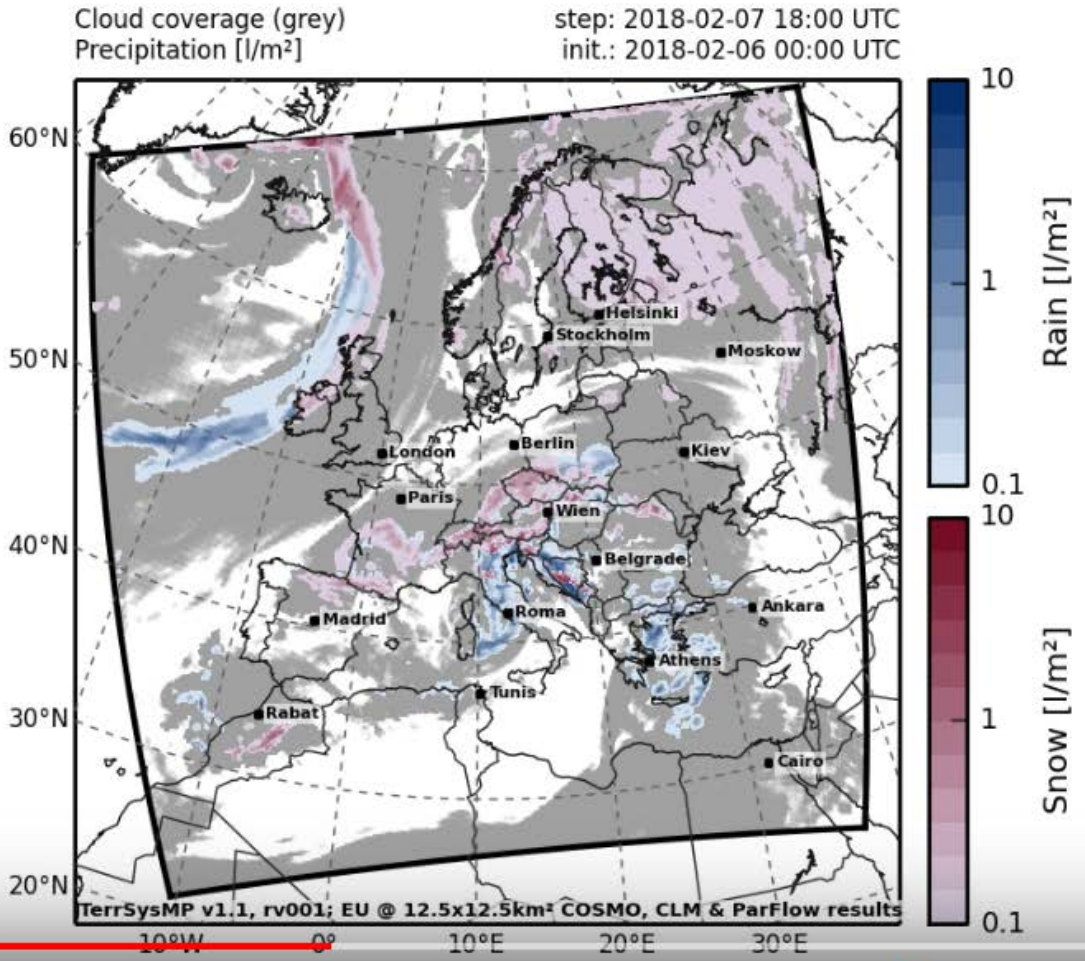
Nighlty runs w/o data assimilation
Fully coupled TerrSysMP: Europe EUR-11, 12km





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Simulation Results / Analyses / Visualization by HPSC TerrSys /

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Experimental TMS

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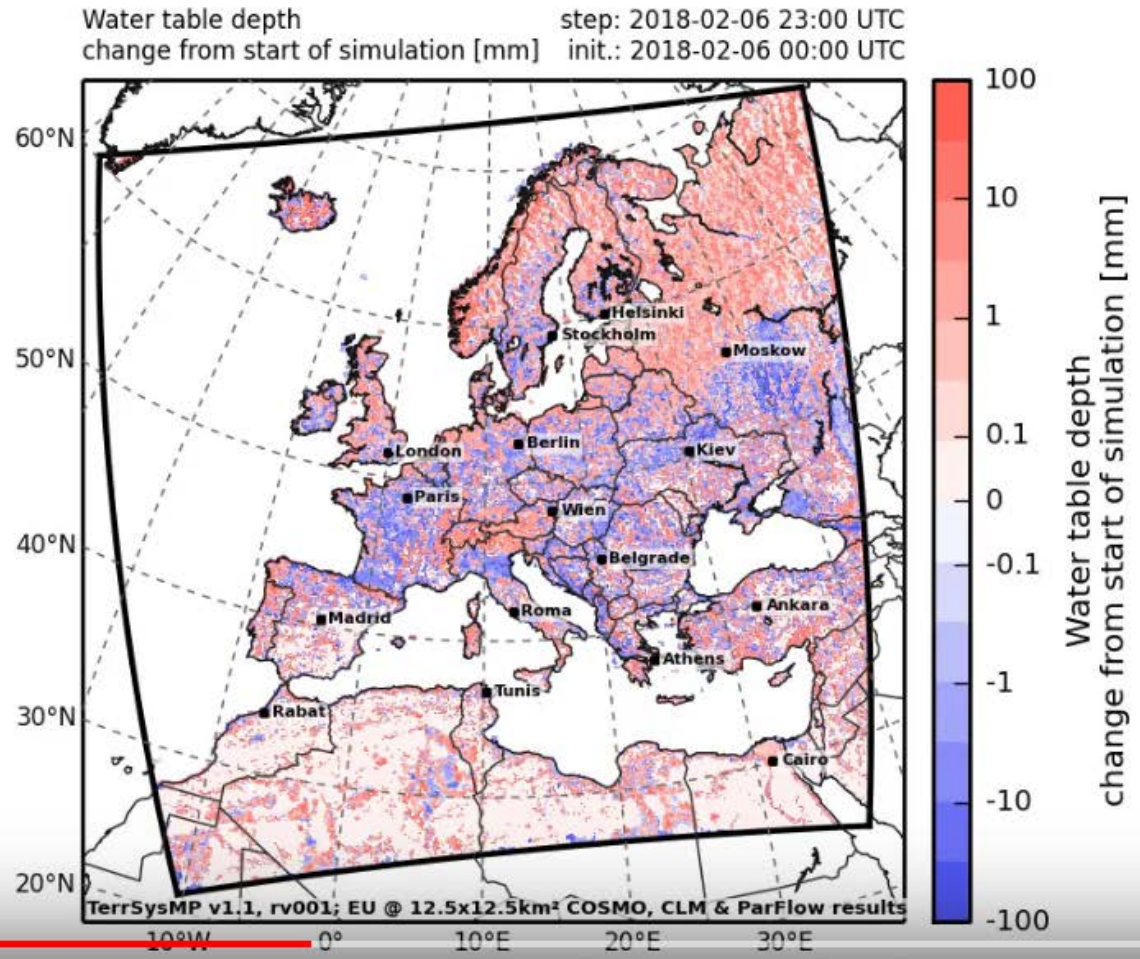
Terrestrial hydrologic and energy variables from the deep subsurface into the atmosphere



Thanks to
F. Pappenberger,
ECMWF

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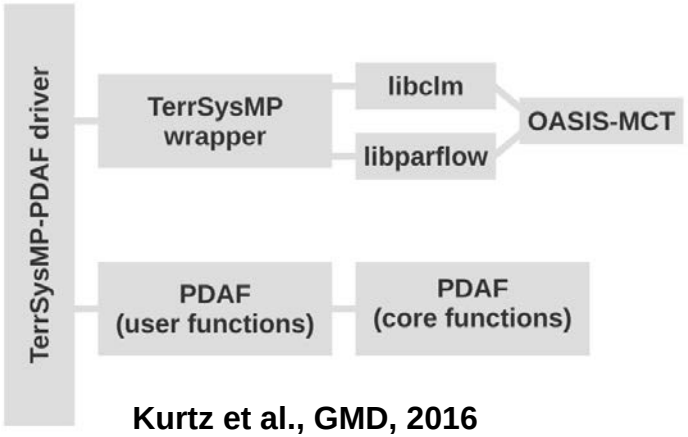
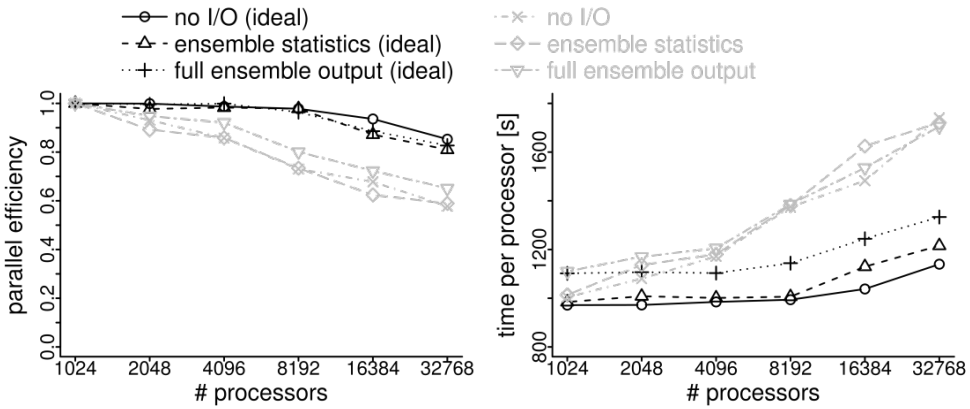
Simulation Results / Analyses / Visualization by HPSC TerrSys /CC BY-NC-ND 4.0

Implementation of Parallel Data Assimilation Framework, PDAF



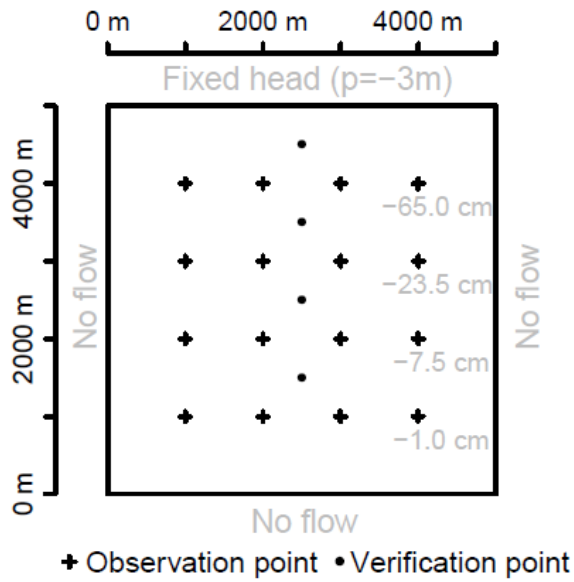
Kurtz et al., GMD, 2016



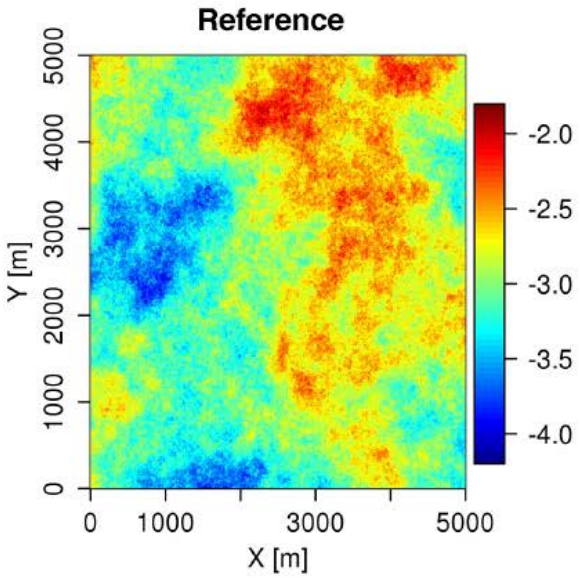
- TerrSysMP coupled with Parallel Data Assimilation Library (Nerger and Hiller, 2013)
- Currently implemented for land surface-subsurface part; COSMO integration ongoing
- Keeps modularity of TerrSysMP
- Fully parallel; good scalability
- Assimilation of pressure (GW-levels, discharge) and soil moisture data
- Parameter update: Saturated hydraulic conductivity, Manning‘s coefficients, texture, etc.

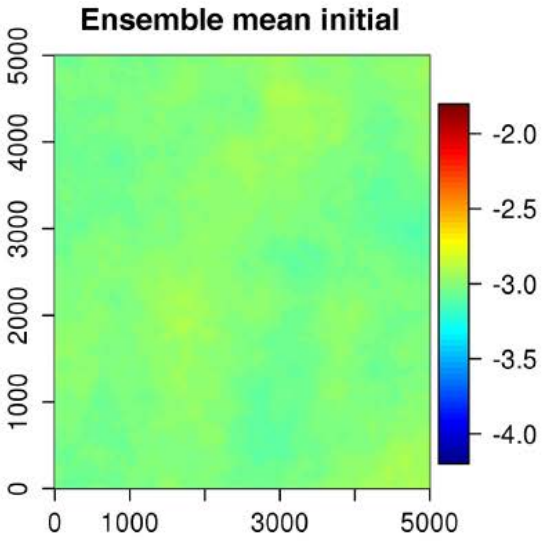
Kurtz et al., 2016

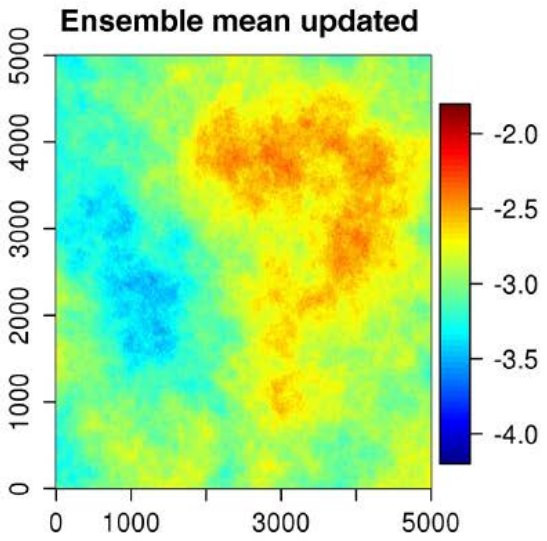
Extreme scaling: Update of $2x10^7$ parameters



- ParFlow-CLM
- 5000x5000x20m domain
- 5m lateral resolution
- 20 layers, variably thickness
- $2x10^7$ grid points
- Update of $2x10^7$ parameters (hydraulic conductivity)
- 66,000 compute cores

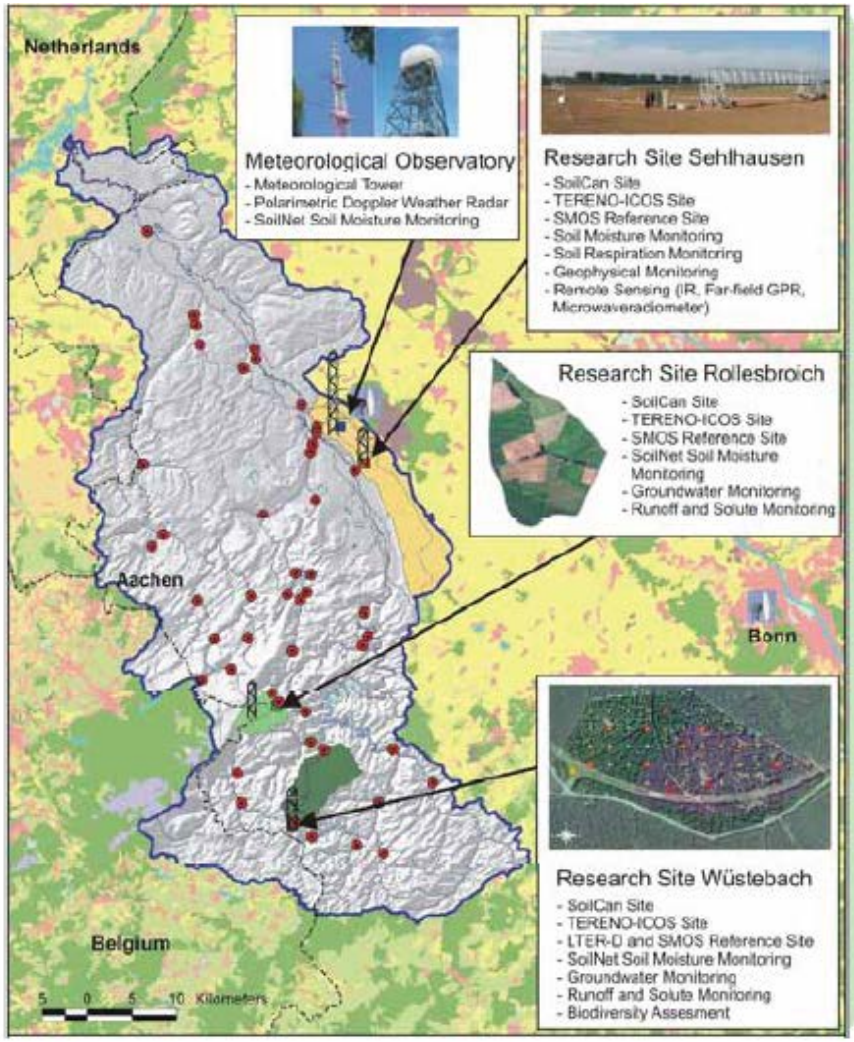


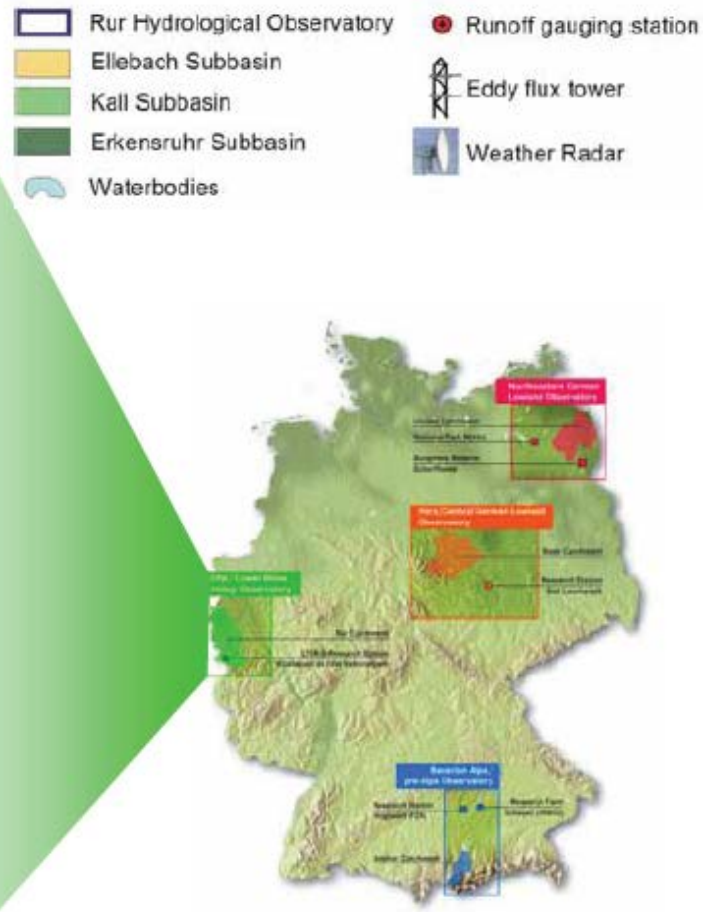




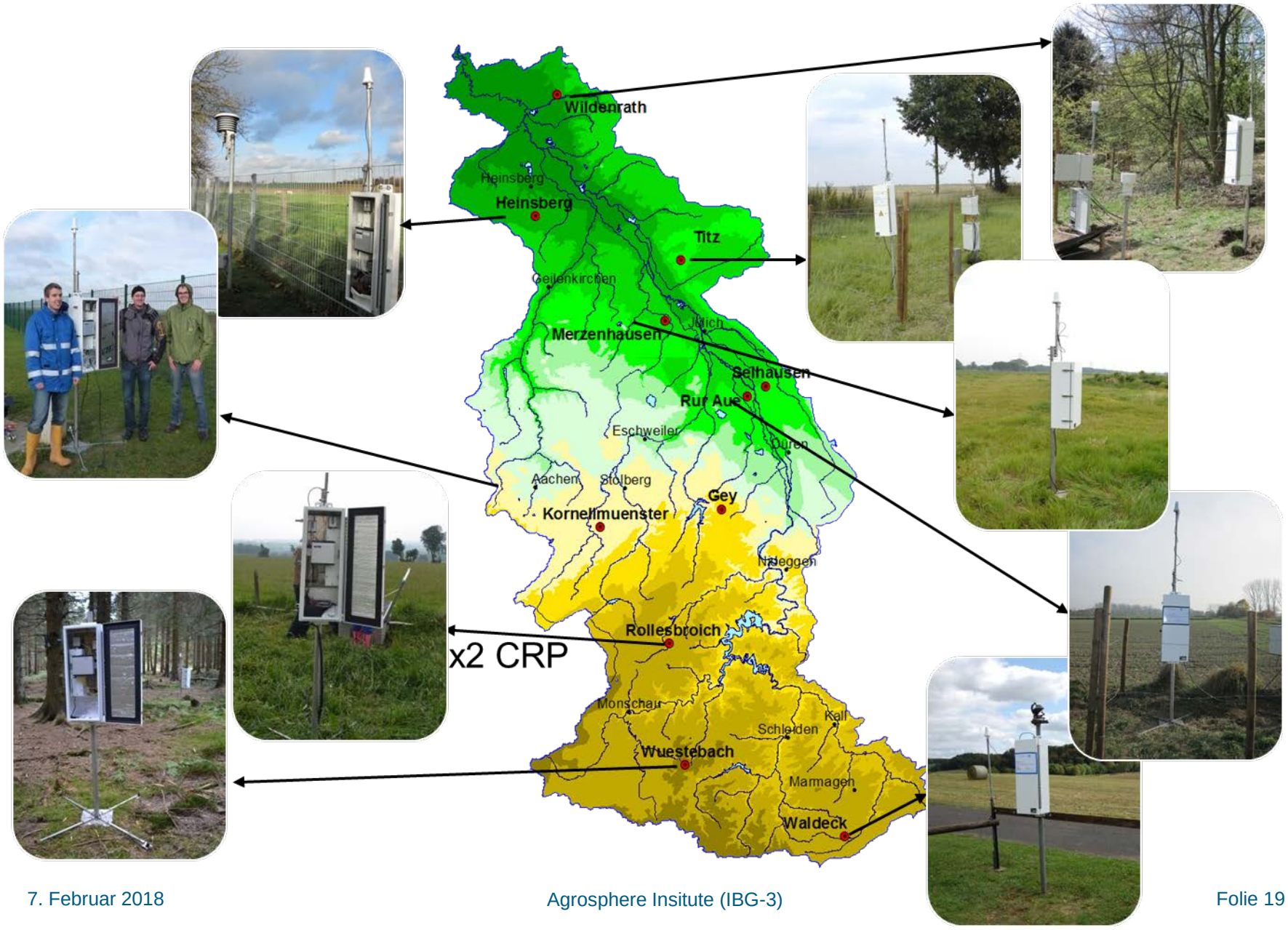
Kurtz et al., GMD, 2016

Application of the integrated modeling platform to the Rur catchment of TERENO and the SFB/TR32.





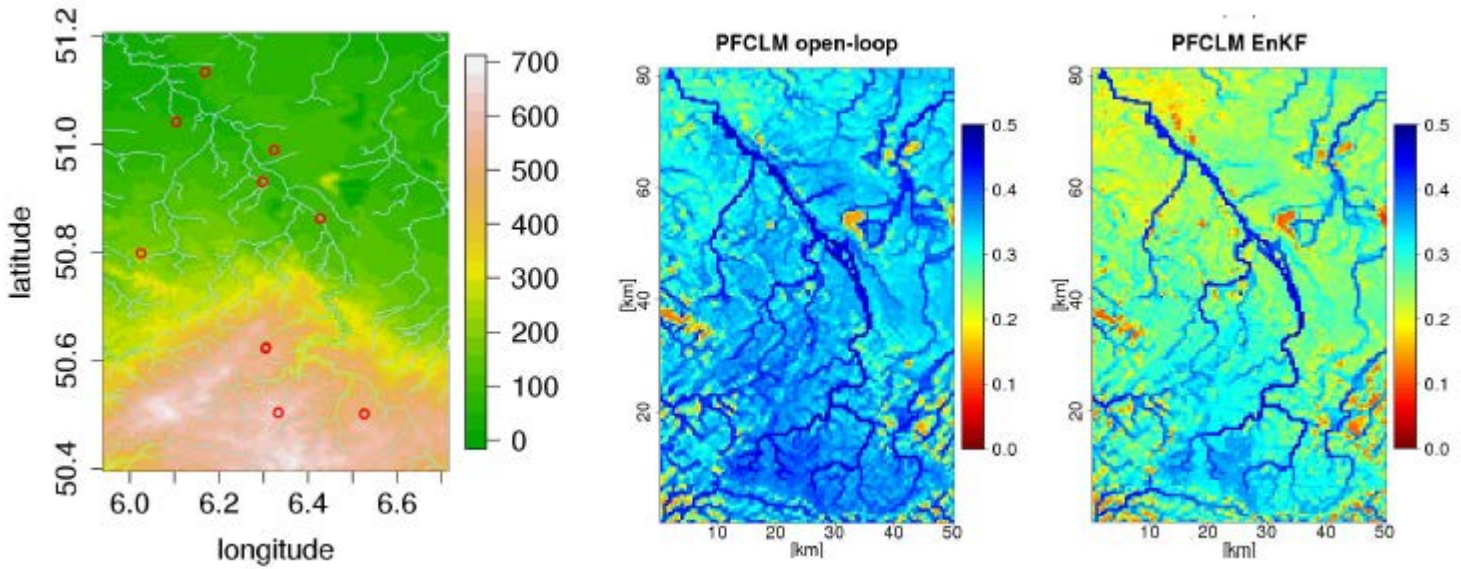
Cosmic Ray Probe Network Rur catchment



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

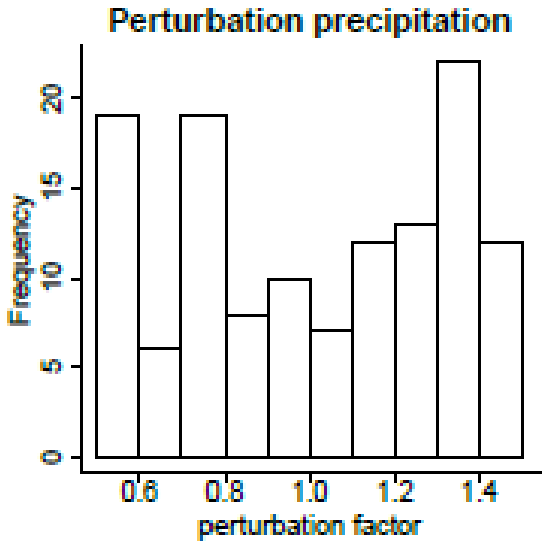
Soil moisture assimilation Rur catchment

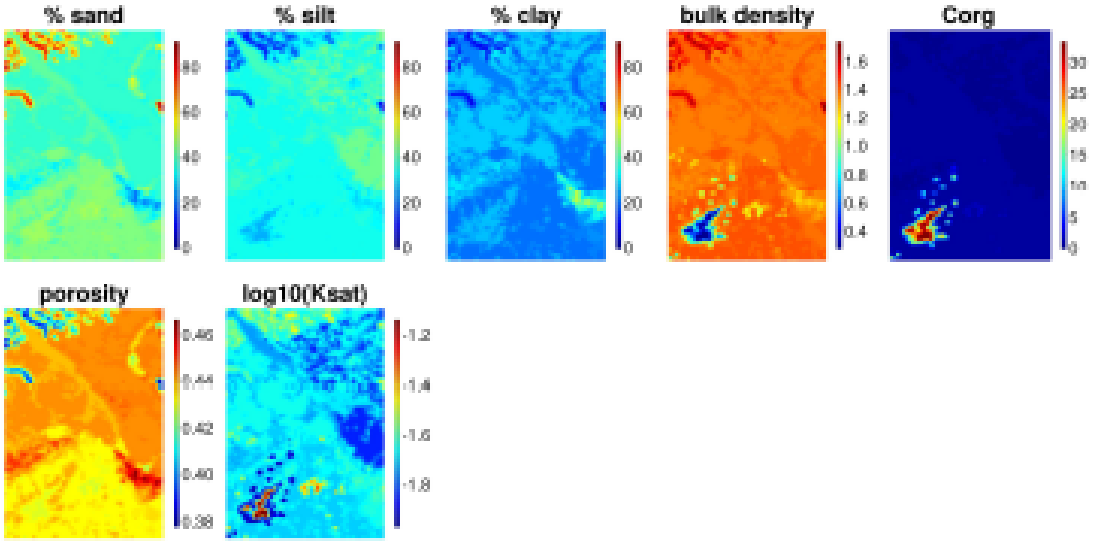


- Assimilation soil moisture (SM) data from a cosmic ray sensor network
- Effectiveness of SM assimilation is tested through cross validation
- Ensemble generation through perturbation of atmospheric input and soil hydraulic parameters
- Joint estimation of subsurface parameters
- Comparison of CLM and ParFlow-CLM

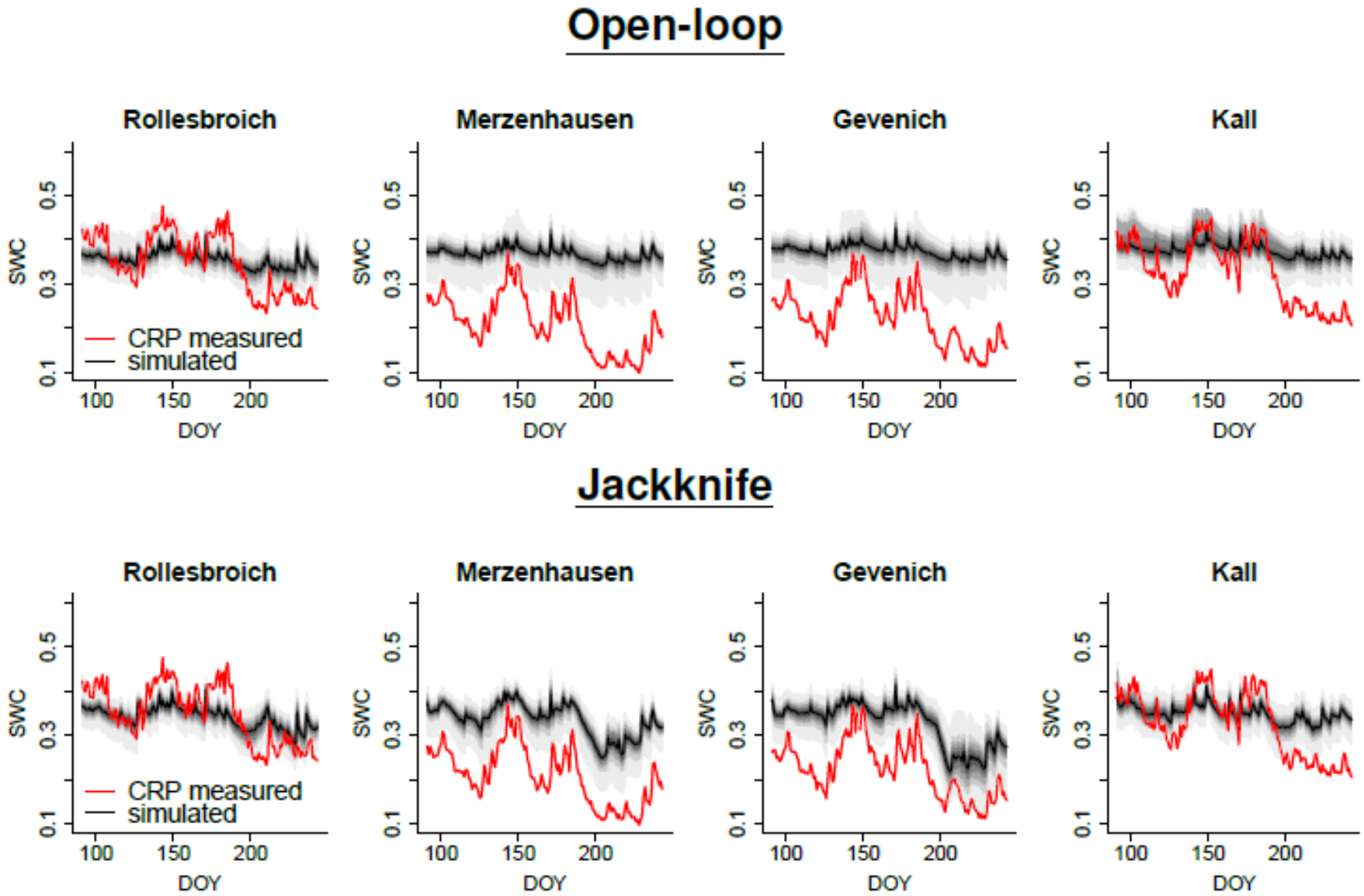
DA-experiments Rur catchment

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



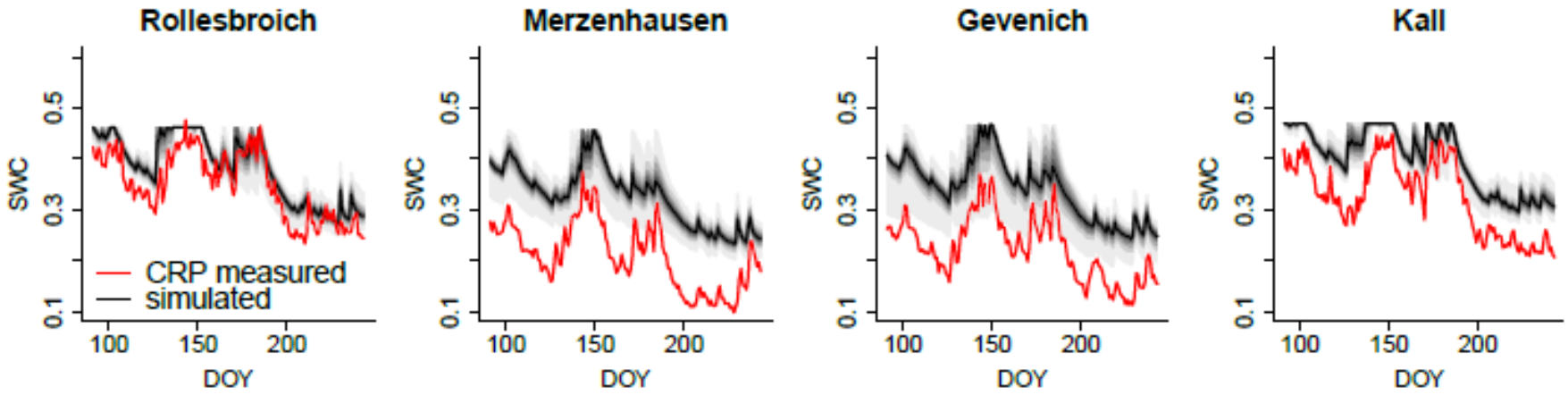


CLM jackknife examples

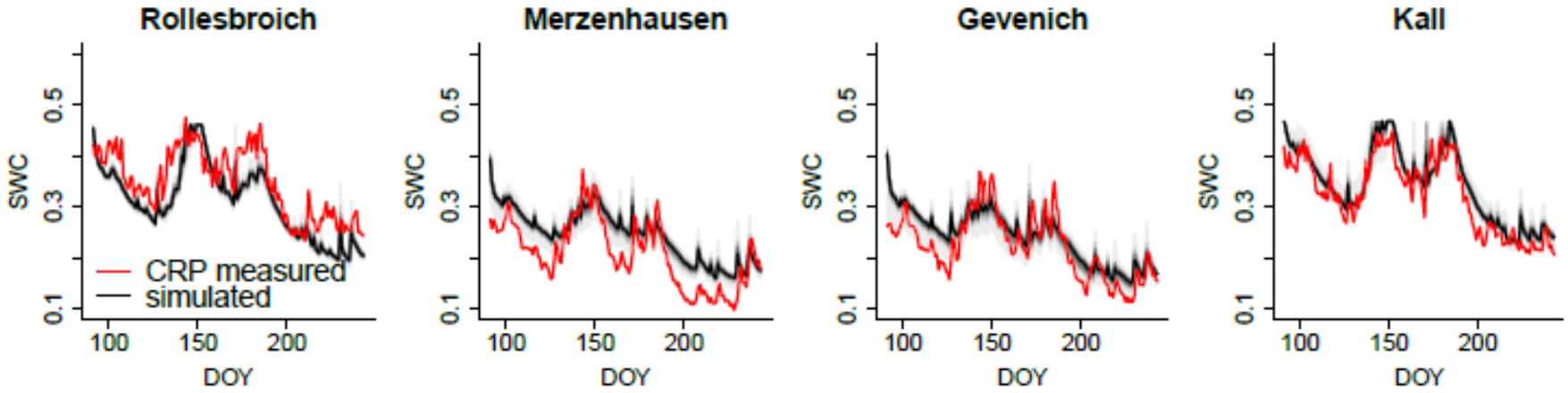


ParFlow-CLM jackknife examples

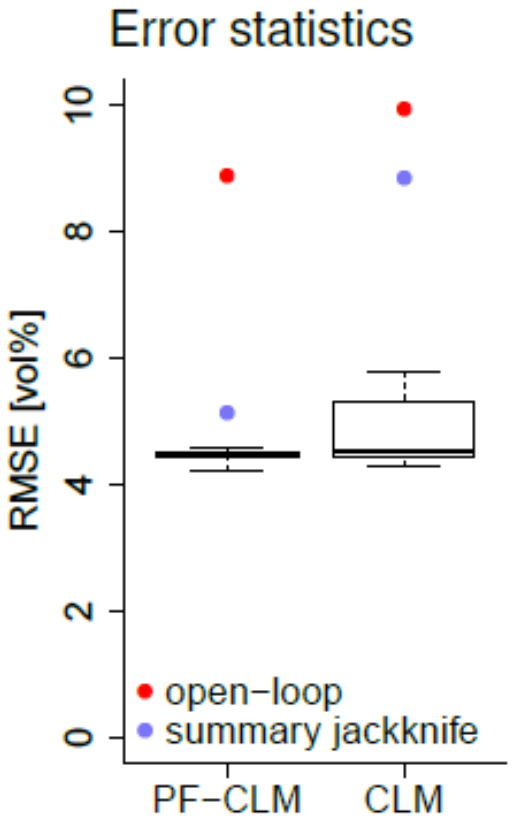
Open-loop

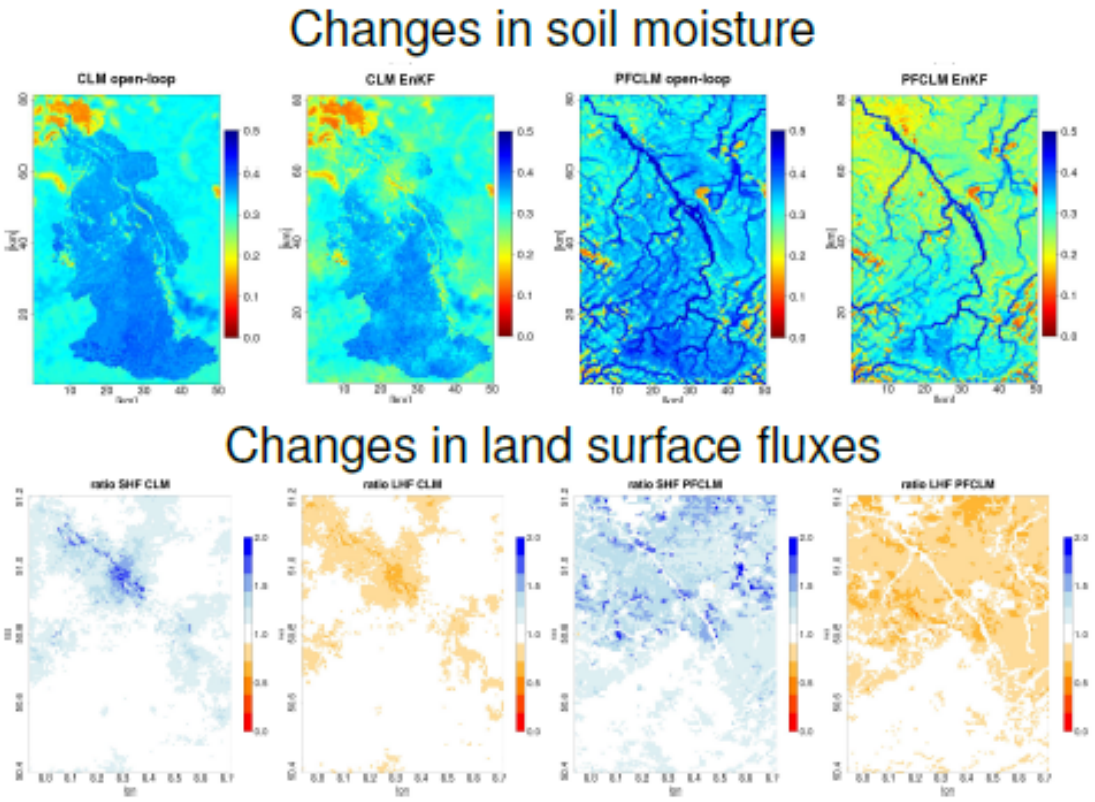


Jackknife



DA-experiments Rur catchment





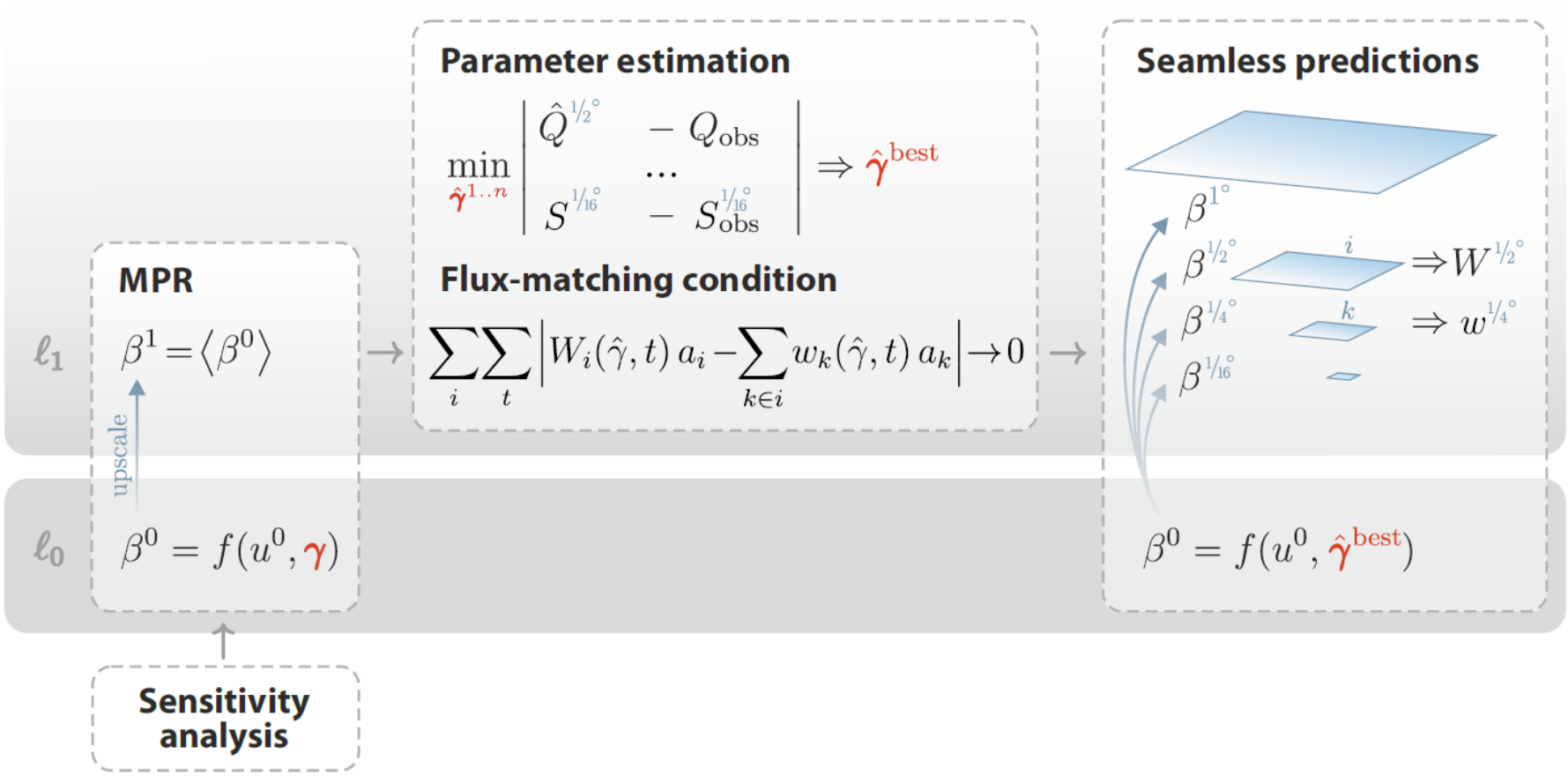
- Assimilation of soil moisture data from cosmic ray probe network is effective for catchment wide soil moisture characterization

- Subsurface conceptualization affects update of soil moisture data

Potential contributions ESM

- Physical and biogeochemical parameterizations
  - Rhizosphere modeling (water, biogeochem)
  - From root to shoot
  - Upscaled root water uptake
  - Isotope modeling
  - Groundwater flow and solute transport
  - Groundwater-surface water interactions
  - Human water use
  - …
- DA capabilities (cross-compartment, joint parameter-state updating)
- Coupling technology
- Software engineering, programming
- Parallel performance monitoring, tracing and tuning
- Multi scale parameter regionalization technologies (Luis Samaniego, UFZ)
- Scientific and applied use cases

Toward seamless predictions



Samaniego, L. et al.: Toward seamless hydrologic predictions across spatial scales, Hydrol. Earth Syst. Sci., 21, 4323-4346, https://doi.org/10.5194/hess-21-4323-2017, 2017.