The data assimilation framework TerrSysMP-PDAF

HPSC TerrSys

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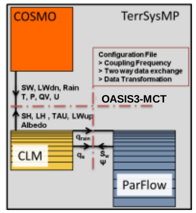
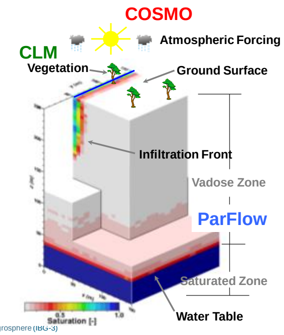
G2A: Terrestrial System Modeling Platform TerrSysMP

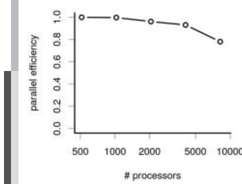


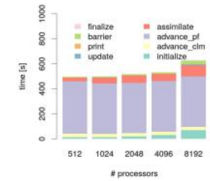
TerrSysMP schematic
Shrestha et al. 2014



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



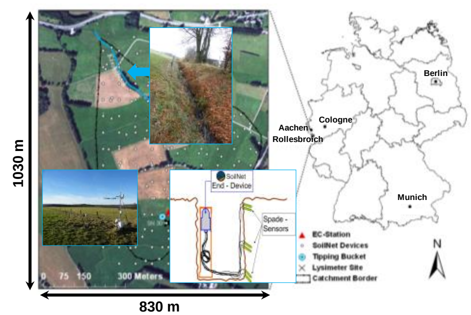


Kurtz et al. (2016), GMD

Why TerrSysMP-PDAF?

- Hydrological, meteorological and agricultural predictions.
- Consistent re-analysis for subsurface-land surface-atmosphere system.
- Improve model on the basis of detected systematic DA-increments.
- Determine value of measurement data and implications for design of monitoring networks.
- Parameter estimation → Important for long-term predictions/scenarios.

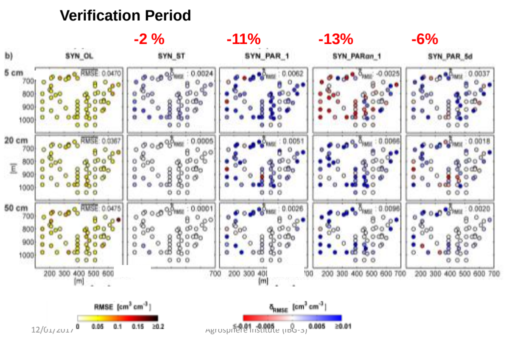
First Example: TERENO study site Rollesbroich (CZO)



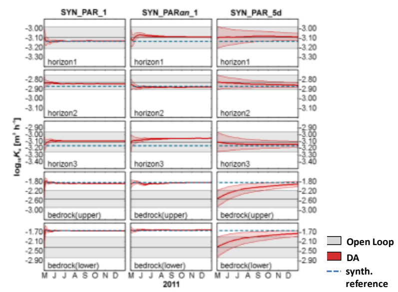
Research questions

- Can hillslope hydrology be characterized with a physically based model, containing many unknowns?
- Is the update of saturated hydraulic conductivity only enough to adjust the model simulations closer to the observations?
- Simulations are performed for the real-world case and a synthetic case which mimics the real-world. Is there a systematic difference in performance?

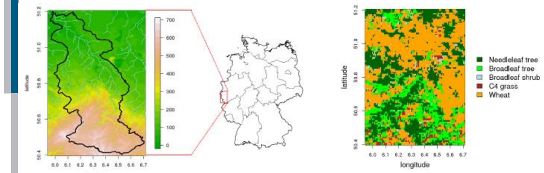
Soil Water Contents (synthetic)



Estimated Hydraulic Conductivity (synthetic)

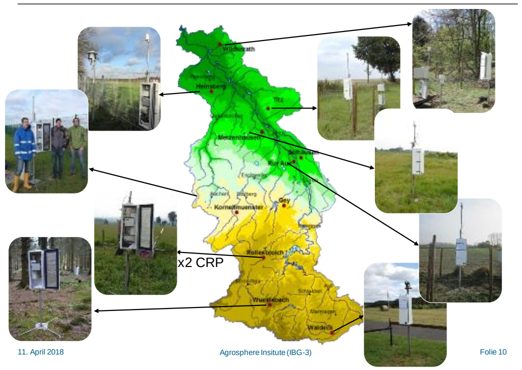


2nd Example: Soil moisture Rur catchment

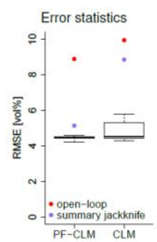


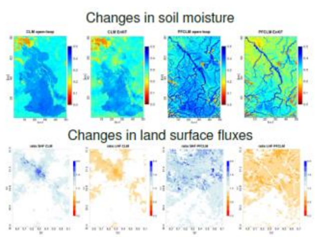
- Horizontal resolution: 500 m (100x162 cells)
- Vertical resolution 2cm-136 cm, 30 layers (30 m total thickness)
- Vegetation classification from MODIS
- Model forcings from COSMO-DE reanalysis
- Subsurface properties from European Soil data base

Cosmic Ray Probe Network Rur catchment



RMSE soil moisture



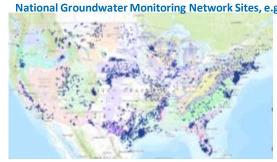


- Assimilation of soil moisture data from cosmic-ray probe network is effective for catchment wide soil moisture characterization
- Subsurface conceptualization affects update of soil moisture data

Third example: GW-level assimilation

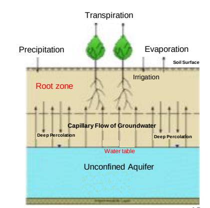
Aim is to update (root zone) soil moisture above groundwater table.

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)

Third example: GW-level assimilation

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- 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

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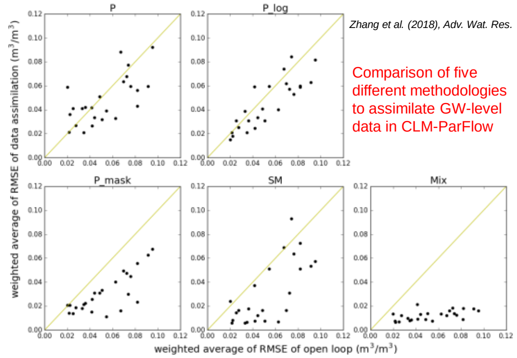

Zhang et al. (2018), Adv. Wat. Res.

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

RMSE Reduction vs. Climate/PFT/Soil

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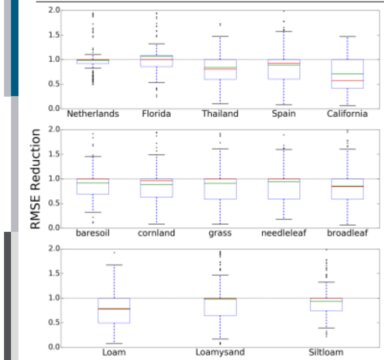

green: mean
red: median

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

Better results for loam soils.

Better results for broadleaf trees.

Outlook: coupled DA

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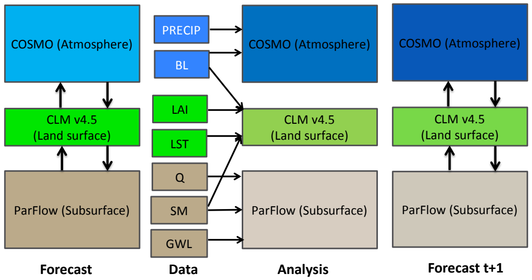

Example: Only some of the measurement data are used to update (sensitive) states in other compartments

Conclusions and outlook

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- TerrSysMP-PDAF: highly efficient DA-framework
- Hillslope example: ~40% of RMSE soil moisture related to model structural errors (e.g., missing preferential flow paths in soil, enhanced drainage subsurface, systematic parameter bias)
- Catchment example: cosmic ray probes useful to update catchment-wide soil moisture contents
- GW-level data show high potential to improve root zone soil moisture characterization under certain climatic conditions.
- Current work: extension of coupled DA.

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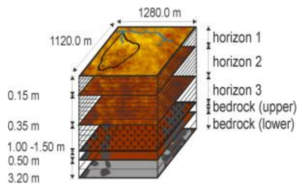
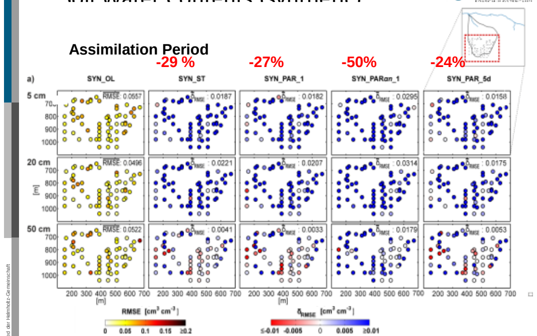
Thanks for your attention!

TerrSysMP Model Setup

- **Model domain discretization:**
  - 20 vertical layers with 0.025 – 0.58 m resolution
  - 128 x 112 horizontal grid cells with 10 x 10 m resolution → 0.3 million unknowns
- **Domain Extent:** 1280 x 1120 m, with 3.2 m total depth
- **Boundary conditions:** No flux at lateral boundaries and lower boundary



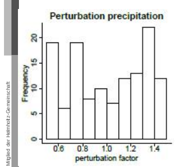
Soil Water Contents (synthetic)

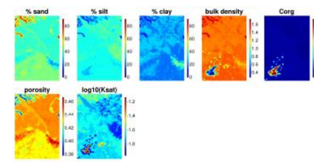


Open loop synthetic has overall 42% smaller RMSE than open loop real-world

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