Assimilation of data from groundwater and cosmic-ray neutron soil moisture sensor networks into the integrated Terrestrial System Modeling Platform TSMP - The Rur catchment case study

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Introduction

Cosmic-ray neutron sensors (CRNS) measure soil moisture (SM) in real-time at the field scale, bridging the gap between in situ measurements and remote sensing products. This is promising and has the potential to enhance hydrological model predictions through the assimilation of CRNS data and improve the estimation of model parameters. In this study, soil moisture measurements from a network of 12 CRNS in the Rur catchment (~2000km^2, Germany) were assimilated into the Terrestrial Systems Modelling Platform (TSMP) by the ensemble Kalman filter (EnKF). The objectives of this study are to investigate:

- How effective a CRNS network can be in improving soil moisture characterization with fully integrated terrestrial models such as TSMP at the catchment scale;
- Whether the assimilation of CRNS soil moisture data can result in better prediction of ET;
- How data assimilation (DA) performance can vary between years with different hydrological conditions (wet versus dry).

Materials, methods and model settings

- Reanalysis dataset COSMO-REA6 as atmospheric forcing.
- High-resolution (1:50,000) regional soil map BK50 to estimate soil hydraulic properties.
- Meteorological forcings, hydraulic conductivities (K_s), and porosity were perturbed to generate the ensemble (128 members).
- SM from CRNS was assimilated and ET from eddy covariance stations, together with SM from CRNS were used for verification (jackknife experiments).
- DA was conducted for a wet year (2016) and a dry year (2018); the state update frequency was daily; the parameter update frequency was 3 days with damping factor 0.1, and the measurement error was 0.03 cm^3/cm^3.

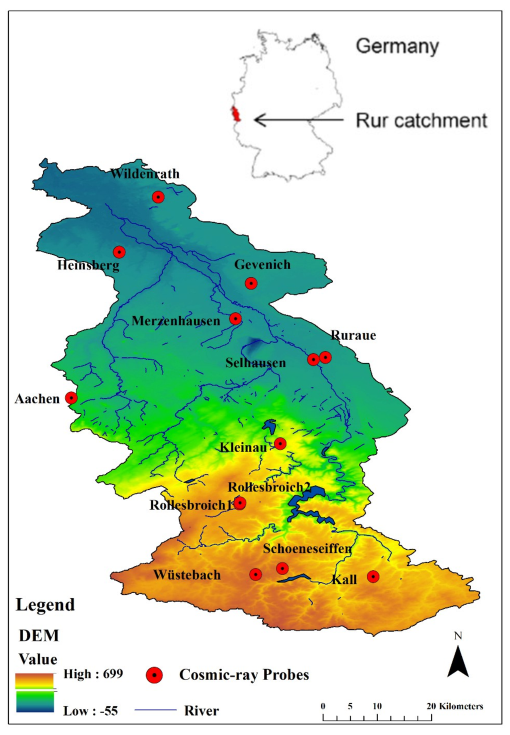

Fig 1. Map of the Rur catchment.

Assimilation methodology

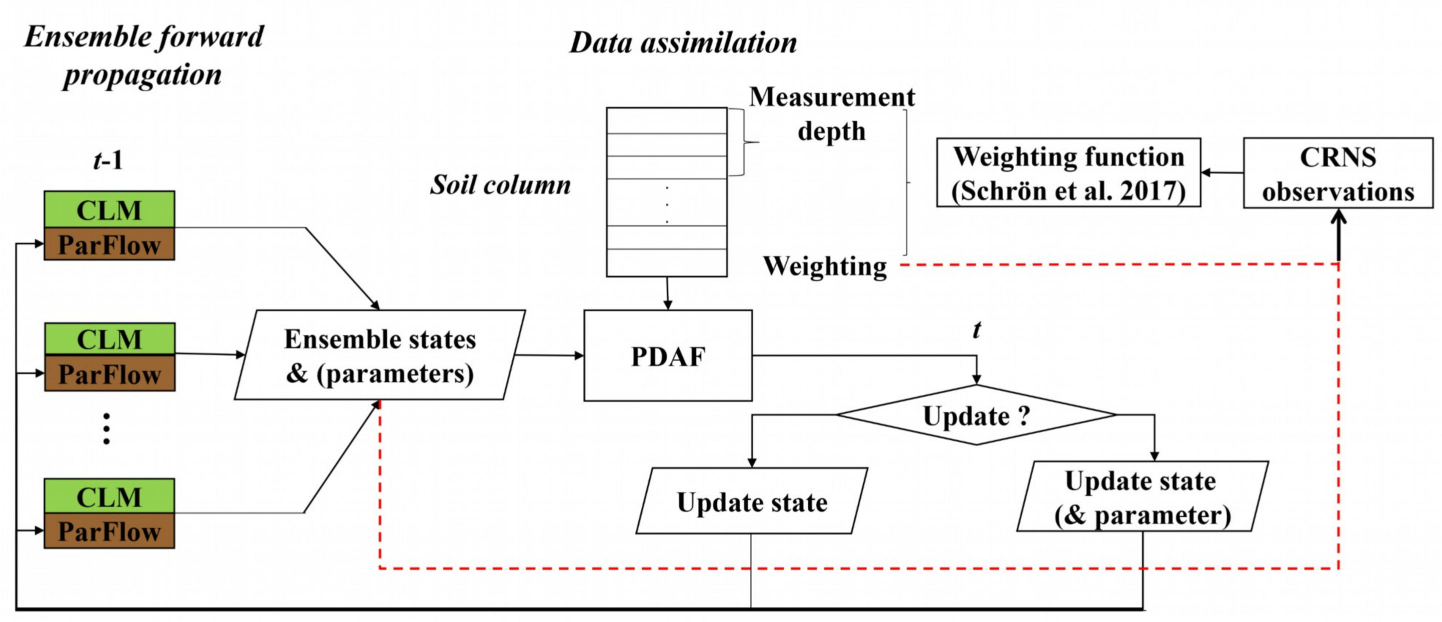

Fig 2. Schematic overview of the assimilation of SM from CRNS with PDAF into TSMP.

Results

Table 1. Error statistics for open loop (OL), data assimilation with state updates (State), joint state-parameter updates (Joint), and jackknife simulations with joint state-parameter updates (Jackknife) for the assimilation periods of 2016 and 2018.

Year	Simulation	BIAS (cm^3/cm^3)	MAE (cm^3/cm^3)	R	RMSE (cm^3/cm^3)	ubRMSD (cm^3/cm^3)
2016	OL	-0.051	0.062	0.795	0.077	0.058
	State	-0.024	0.034	0.918	0.044	0.037
	Joint	-0.004	0.023	0.942	0.031	0.031
	Jackknife	-0.012	0.036	0.879	0.046	0.045
2018	OL	0.005	0.054	0.739	0.069	0.069
	State	-0.008	0.032	0.895	0.044	0.043
	Joint	0.001	0.024	0.944	0.033	0.033
	Jackknife	0.008	0.046	0.816	0.058	0.058

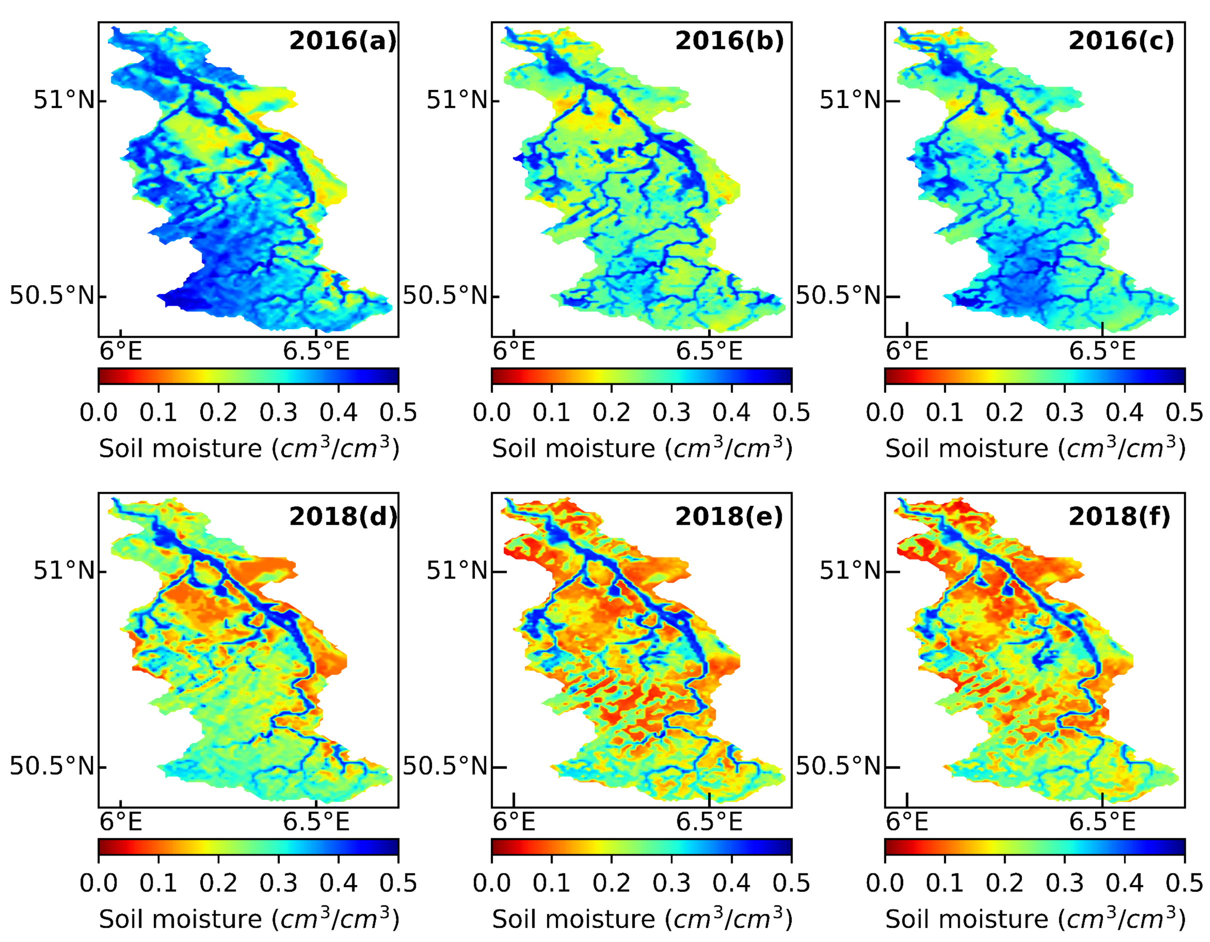

Fig 3. Examples of the simulated SM distribution over the Rur catchment on the 22nd of July in 2016 and 2018. Subplots a) and d) are from the OL, b) and e) are from DA with state update, and c) and f) are from joint state-parameter update simulations.

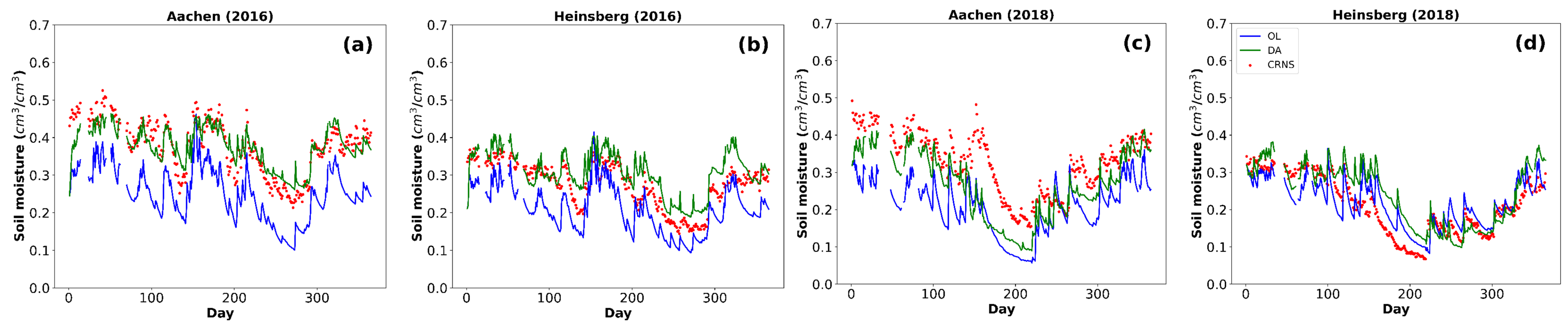

Fig 4. Temporal evolution of simulated SM from the mean (blue) and jackknife simulation mean (DA, green), together with the observed SM from the CRNS (red), for 2016 (a, b) and 2018 (c, d) at the CRNS sites

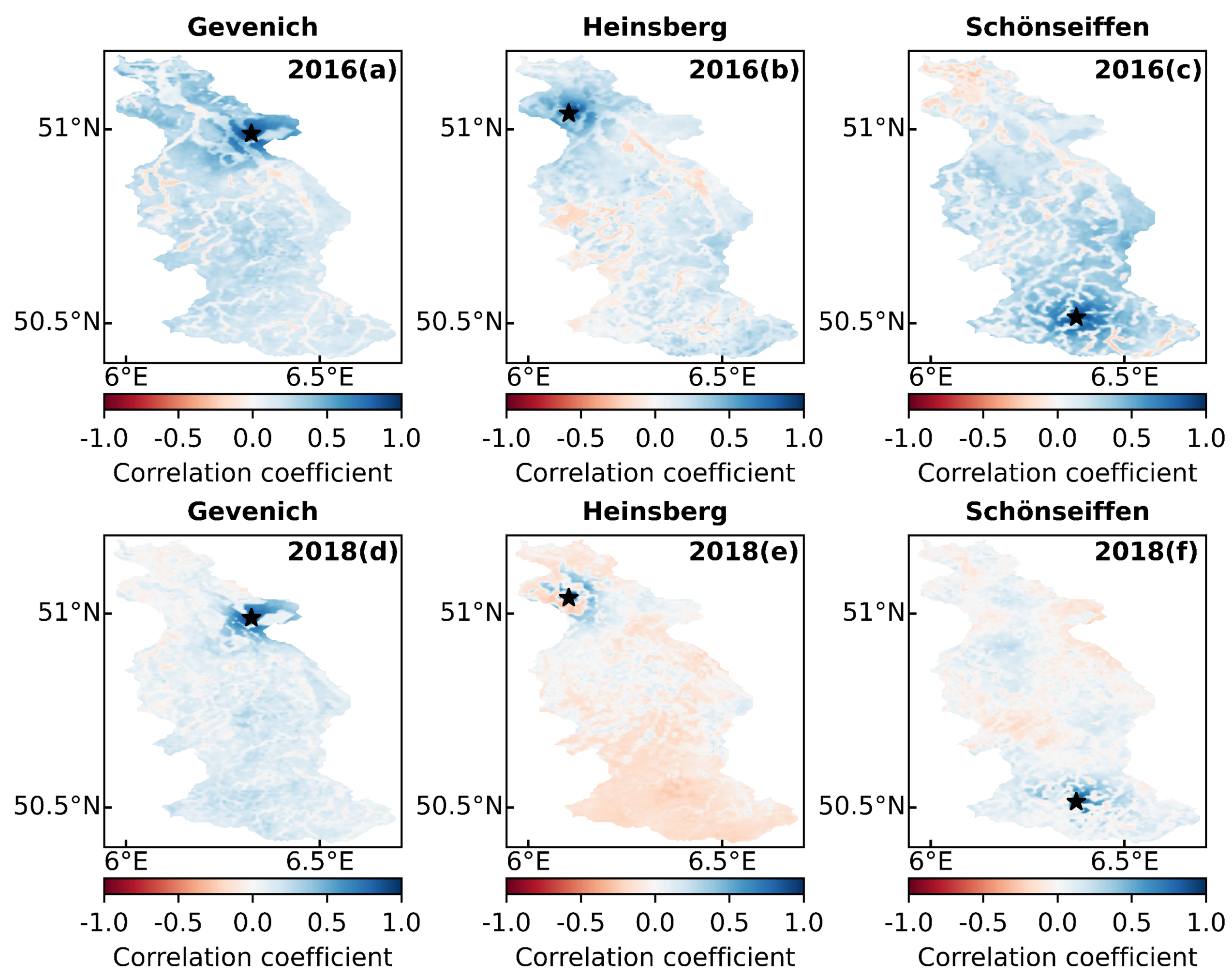

Fig 5. Examples of the spatial correlations of SM between CRNS sites and other grid cells over the Rur catchment, for the OL run. Subplots a) and d) are from Gevenich on the 29th of June in 2016 and 2018, b) and e) are from Heinsberg on the 2nd of August in 2016 and 2018, and c) and f) are from Schönseiffen on the 28th of July in 2016 and 2018. The black asterisk is the location of the CRNS sites.

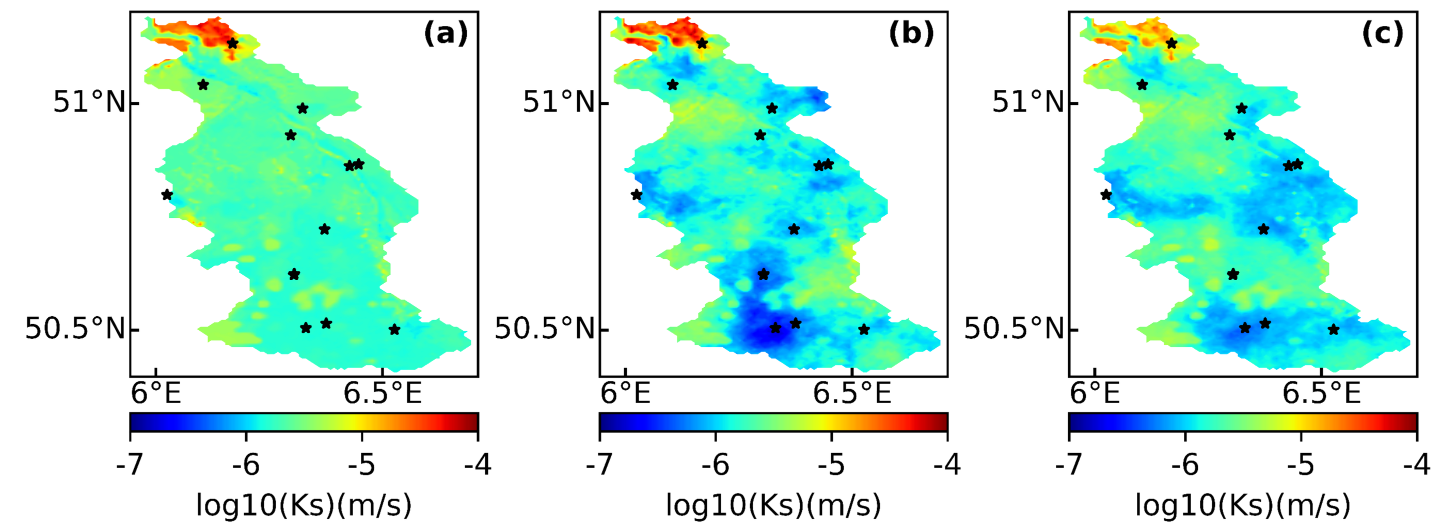

Fig 6. Ensemble averaged $\log_{10}K_s$ fields of the soil at 2cm depth: (a) prior field; (b) DA with joint state-parameter updates at the end of 2016; (c) DA with joint state-parameter updates at the end of 2018. The black asterisk is the location of the CRNS sites.

Conclusions

1. EnKF assimilation of SM from CRNS improves SM estimation at measurement sites strongly in both dry and wet years, up to 60% RMSE reduction.
2. Jackknife experiments show limited improvement in SM characterization at independent verification locations (an RMSE reduction of 40% in 2016 and 16% in 2018), indicating that the measurement network (~1 site per 200 km^2) is not dense enough.
3. SM assimilation improved ET simulation to a lesser degree than soil moisture, less than 15% RMSE reduction of monthly ET, indicating the possible role of model structural errors.

Outlook

Accurate information on the spatio-temporal variability of groundwater level (GWL) and root zone SM is essential for a better understanding of hydrological processes and the coupled terrestrial water and energy cycles. We are currently investigating the potential to assimilate the groundwater depth and SM observations simultaneously into the TSMP for the Ruhr catchment, including state updates only or state and parameter updates jointly. Initial results from the DA experiments are as follows:

1. Multiple site assimilation requires careful screening of assimilated sites and the use of a damping factor to limit state updates for the first assimilation steps;
2. Joint state-parameter estimation gives slightly better results for GWL than state estimation alone;
3. Weakly coupled DA (saturated zone states are updated by GWL measurements) shows better GWL simulations than fully coupled DA (all subsurface states are simultaneously updated).

In the following, a new DA strategy (unsaturated zone states are updated by SM measurements and saturated zone states are updated by GWL measurements) will be implemented into the model to evaluate the potential to improve further the subsurface characterization, land-atmosphere exchange fluxes (e.g., evapotranspiration), and discharge.

References and acknowledgements

Schrön, M., Köhli, M., Scheiffele, L., Iwema, J., Bogena, H. R., Lv, L., Martini, E., Baroni, G., Rosolem, R., Weimar, J., Mai, J., Cuntz, M., Rebmann, C., Oswald, S. E., Dietrich, P., Schmidt, U., and Zacharias, S.: Improving calibration and validation of cosmic-ray neutron sensors in the light of spatial sensitivity, Hydrology and Earth System Sciences, 2017.

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