Continental-scale evaluation of a fully distributed coupled land surface and groundwater model ParFlow-CLM over Europe

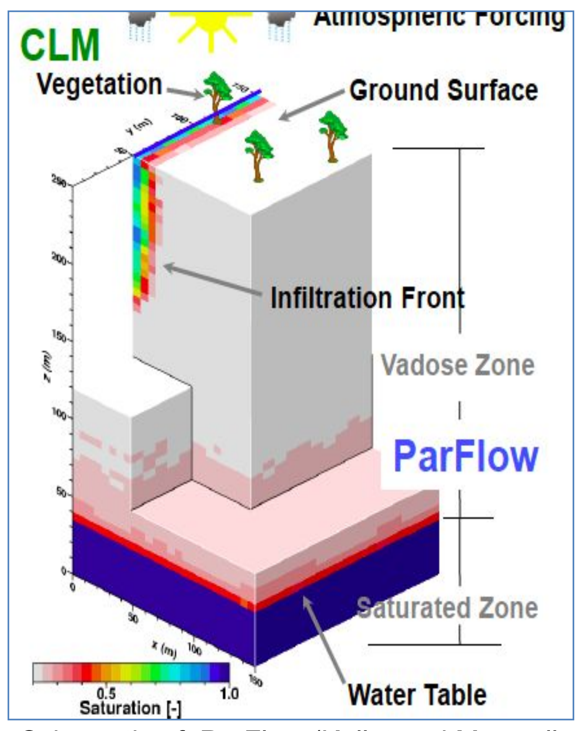
Bibi S. Naz[1,2], Wendy Sharples[3], Klaus Goergen[1,2] and Stefan Kollet[1,2]

(1) Agrosphere (IBG-3), Forschungszentrum Jülich; (2) Centre for High-Performance Scientific Computing in Terrestrial Systems, Geoverbund ABC/J, (3) Bureau of Meteorology, Melbourne, Australia

Background

High-resolution large-scale predictions of hydrologic states and fluxes are important for many regional-scale applications and water resource management. However, because of uncertainties related to forcing data, model structural errors arising from simplified representations of hydrological processes or uncertain model parameters, model simulations remain uncertain. To quantify this uncertainty, model simulations were performed at 3 km resolution over the European continent using the ParFlow hydrologic model and validated with in-situ and remote sensing observations including discharge, surface soil moisture (SM), evapotranspiration (ET) and water table depth..

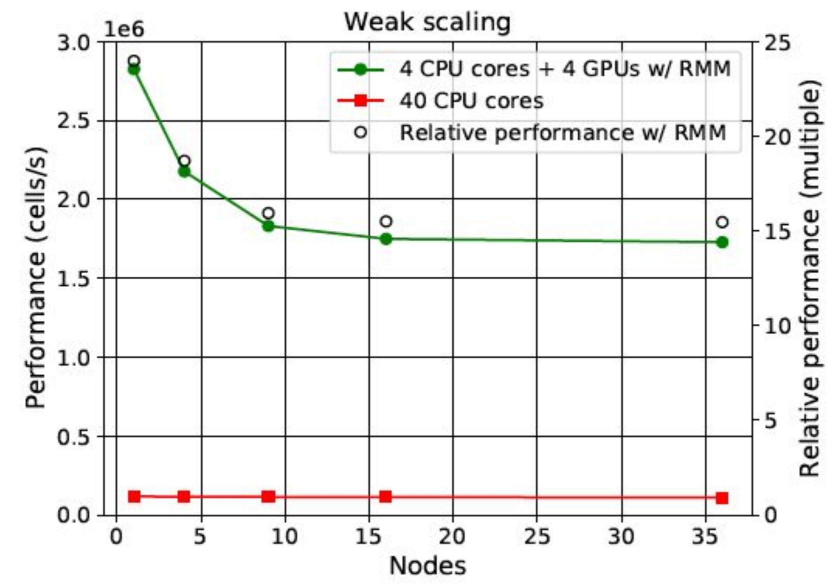
ParFlow model



Schematic of ParFlow (Kollet and Maxwell, 2006) model .

- ParFlow simulates three-dimensional variably saturated groundwater flow solving Richards equation and overland flow with a two-dimensional kinematic wave approximation.
- Model was setup at 3 km resolution over Europe (problem size of 1544x1592x15)
- Simulation period: 1 January 1997 – 31 December 2006 (hourly time step)
- ParFlow runs on JURECA-DC (16 GPU distributed over 4 nodes).

ParFlow-GPU Implementation



The performance evaluation suggests good scaling across multiple nodes with 15-16 times increase in the performance from using GPU accelerat Hokkanen et al., 2021

Results

Fig 1. Evaluation of ParFlow-CLM simulated monthly streamflow

- Overall, the comparison shows that the streamflow dynamics are well captured for the selected 16 large rivers.
- There is an overestimation of the winter flow by the model and an underestimation of summer flow for most gauging stations.

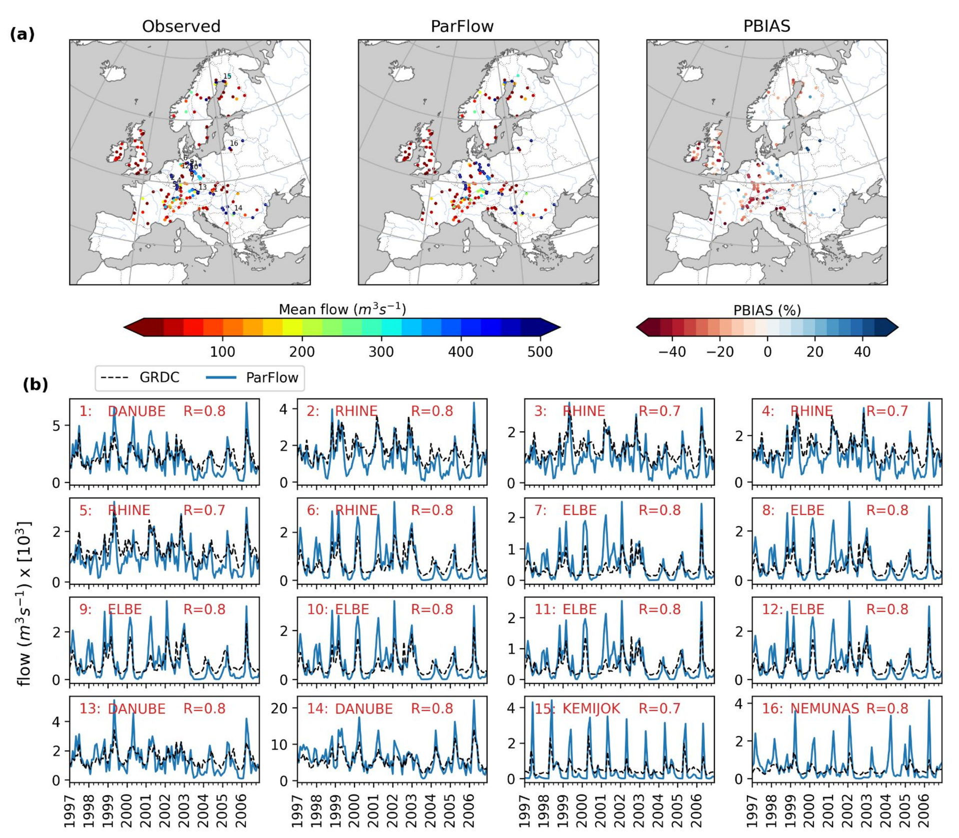


Fig 2. Evaluation of ParFlow-CLM simulated surface soil moisture

- Comparison with surface moisture from ESACCI shows ParFlow overall overestimates surface soil moisture.
- Regionally, SWC anomalies from both ParFlow and ESSMRA compare well with the ESA CCI anomalies.
- Overall, ESSMRA estimates much stronger dry anomalies than both ParFlow and ESACCI, particularly in drought years.

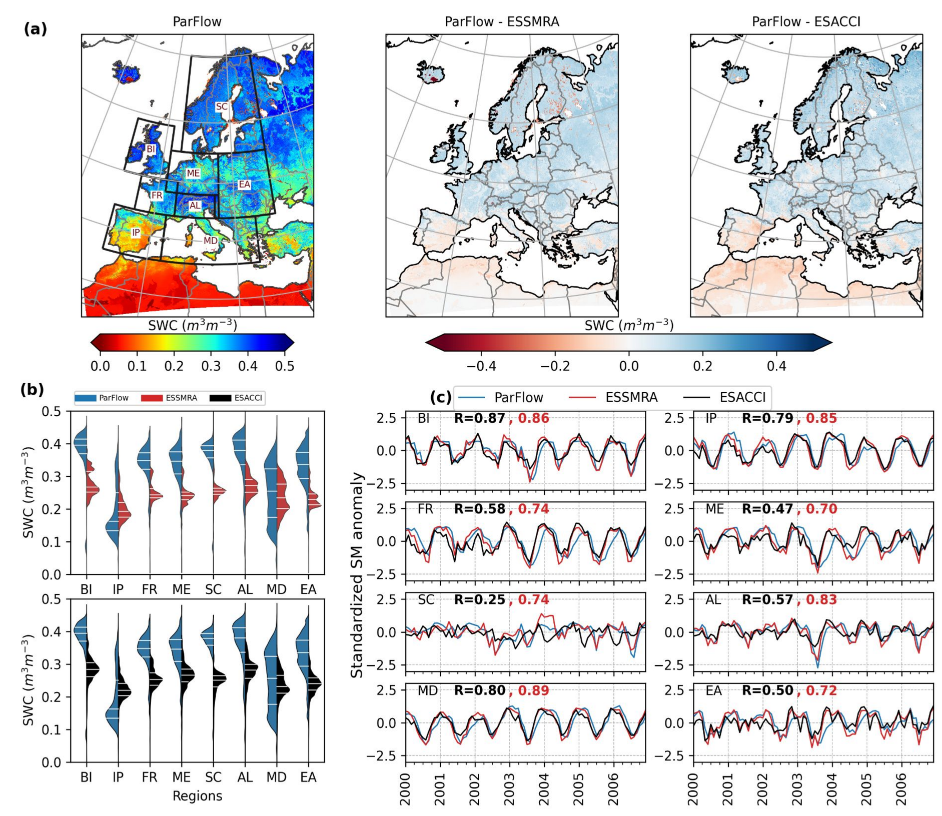


Fig 3. Evaluation of ParFlow-CLM simulated Evapotranspiration

- ParFlow-CLM simulated ET is lower than both remotely sensed GLASS and reanalysis GLEAM ET over most areas in the EURO-CORDEX domain, however over PRUDENCE regions, it is highly correlated with both GLASS and GLEAM dataset (R > 0.9).
- The main differences in ET are mostly detected in summer where GLASS estimated ET is larger than both GLEAM and ParFlow-CLM simulated ET.

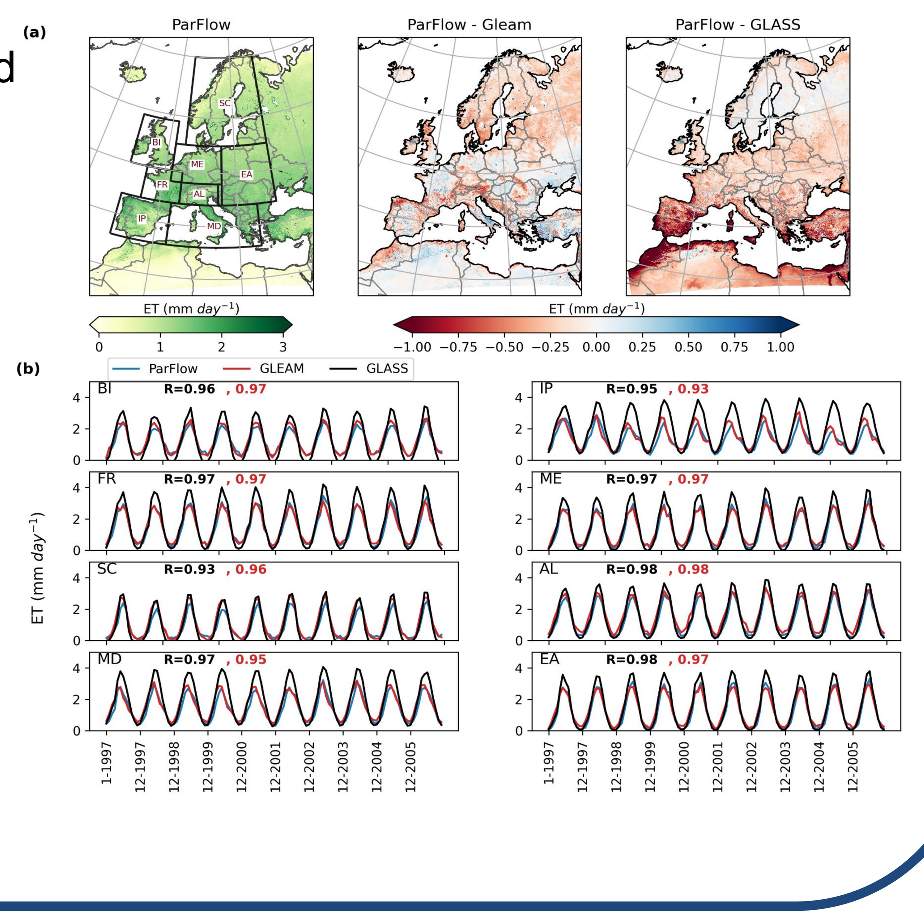
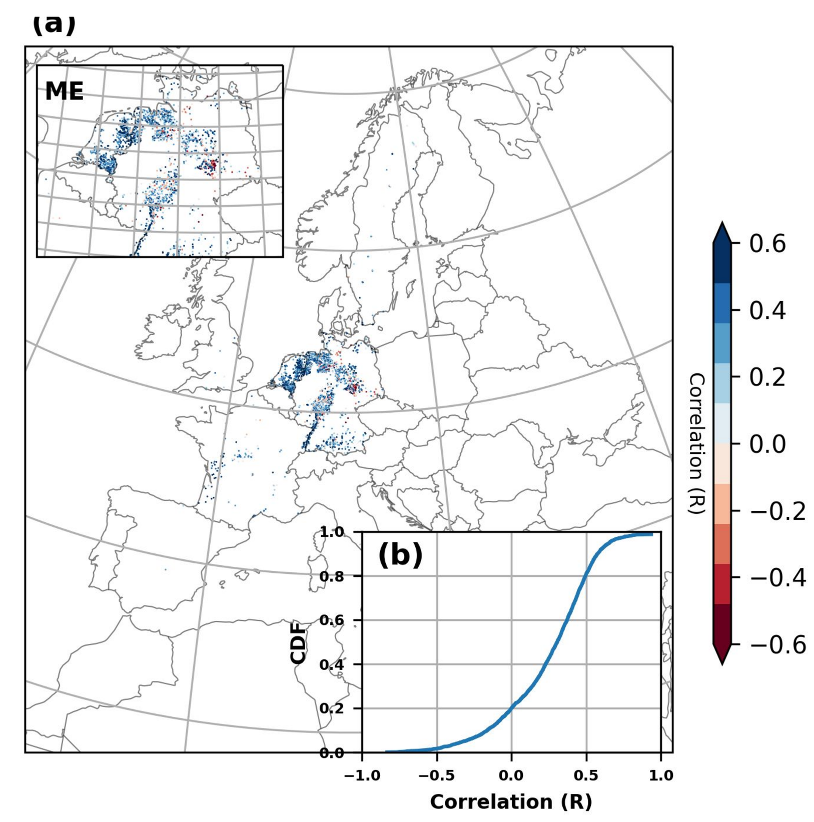
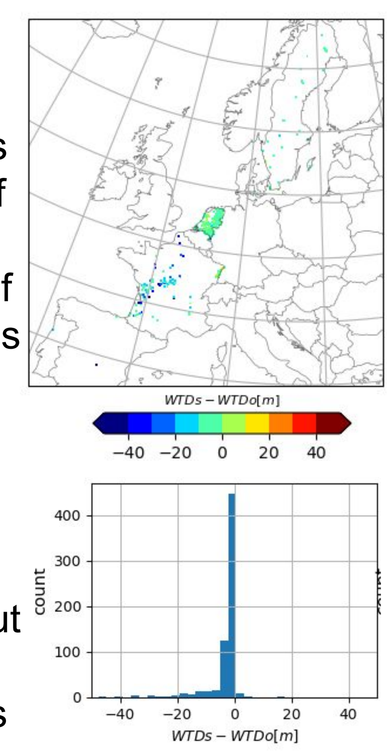


Fig 4. Evaluation of ParFlow-CLM simulated groundwater



- In general ParFlow-CLM model appropriately captures the seasonal cycles of water table depth anomalies with 80% of stations show R values above zero.
- On average, the difference in absolute water table depth between observation and simulation is about -3.6 m and RSME is 4.25 m for the stations where WTD data is provided.



Summary

- ParFlow-CLM simulates more realistic spatial distribution of hydrological variables, where local drainage is better resolved with shallow groundwater system.
- At the regional level, our simulations capture the interannual variability in the hydrologic states and fluxes well when compared with observational data of water table depth, ET, surface soil moisture and discharge.
- Increase in horizontal resolution would be important to improve our model results, particularly for river flows.
- In future, uncertainties arise from groundwater flow representation and soil moisture and its control on latent and sensible heat fluxes, runoff and water table depth will be explored.

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Contact

Bibi S . Naz
b.naz@fz-juelich.de

Agrosphere (IBG-3)
Institute of Bio- and Geosciences
Jülich Research Centre (FZJ)
Jülich, Germany

Centre for High-Performance Scientific, Computing in Terrestrial Systems (HPSC TerrSys)
Geoverbund ABC/J (Germany)

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