High-resolution pan-European multi-model simulations of hydrologic states and fluxes

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Motivation

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, multi-model simulations were performed at 3km resolution over the European continent using the Community Land Model (CLM3.5) (Naz et al., 2019, 2020) and the ParFlow hydrologic model.

Modeling setup

Modeling approach:

- ParFlow simulates three-dimensional variably saturated groundwater flow solving Richards equation and overland flow with a two-dimensional kinematic wave approximation.
- In ParFlow the soil column is divided into 15 soil layers (0–60 m), while in CLM 3.5, the soil profile is divided into 10 soil layers (0–3.8 m).

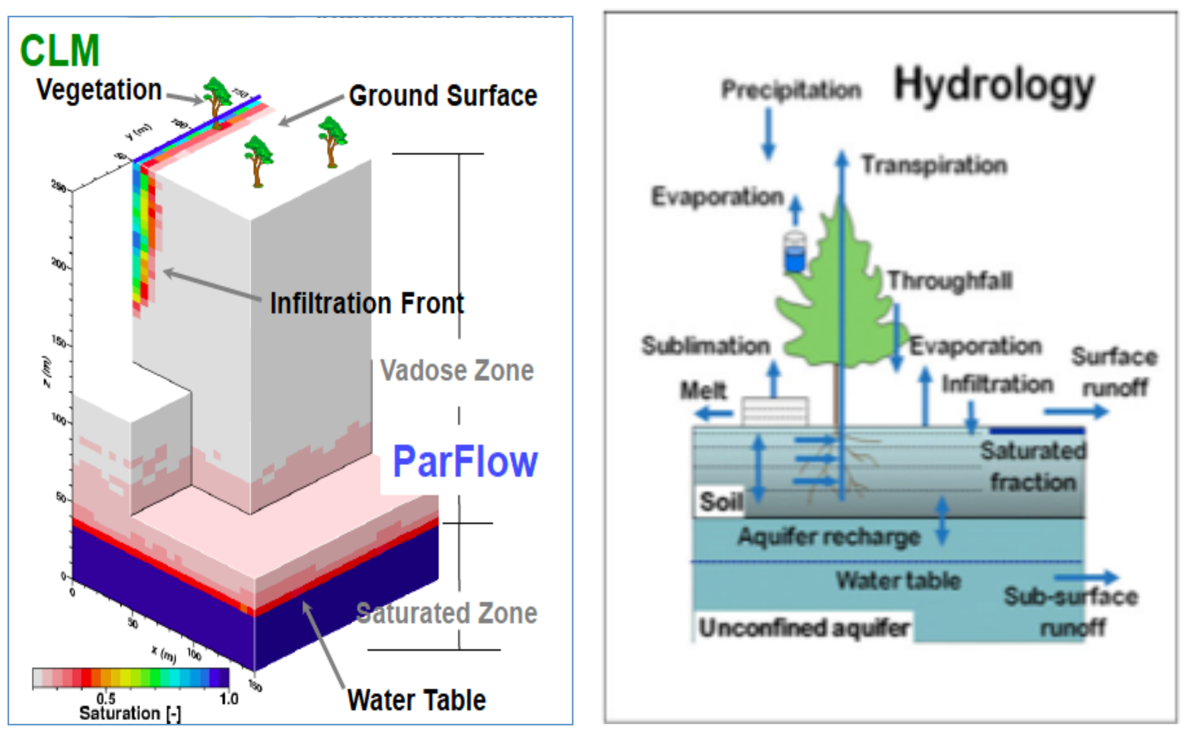

Figure 1: Schematic of standalone ParFlow (Kollet and Maxwell, 2006) and CLM3.5 (Oleson et al., 2008) models .

- CLM3.5 simulates movement of moisture between 10 soil layers is calculated using Richard's equation. The bottom soil layer is also coupled with an unconfined aquifer to account for groundwater recharge and discharge processes. There is no representation of the confined aquifer in the model.

Model Inputs:

Various key hydrologic model inputs were organized at 1/36 degree (~3 km) grid for the EU–CORDEX domain:

- Topography (GMTED2000 elevation) (Figure 2).
- Soil characteristics (FAO global dataset)
- In ParFlow, alluvial aquifers were represented using BGR Europe dataset plus CCMR global dataset.
- Vegetation LAI (MODIS LAI)
- Land surface classification (MODIS)
- Meteorological forcing (6km COSMO-REA reanalysis)
- Simulation period: 1 January 2000 – 31 December 2006.

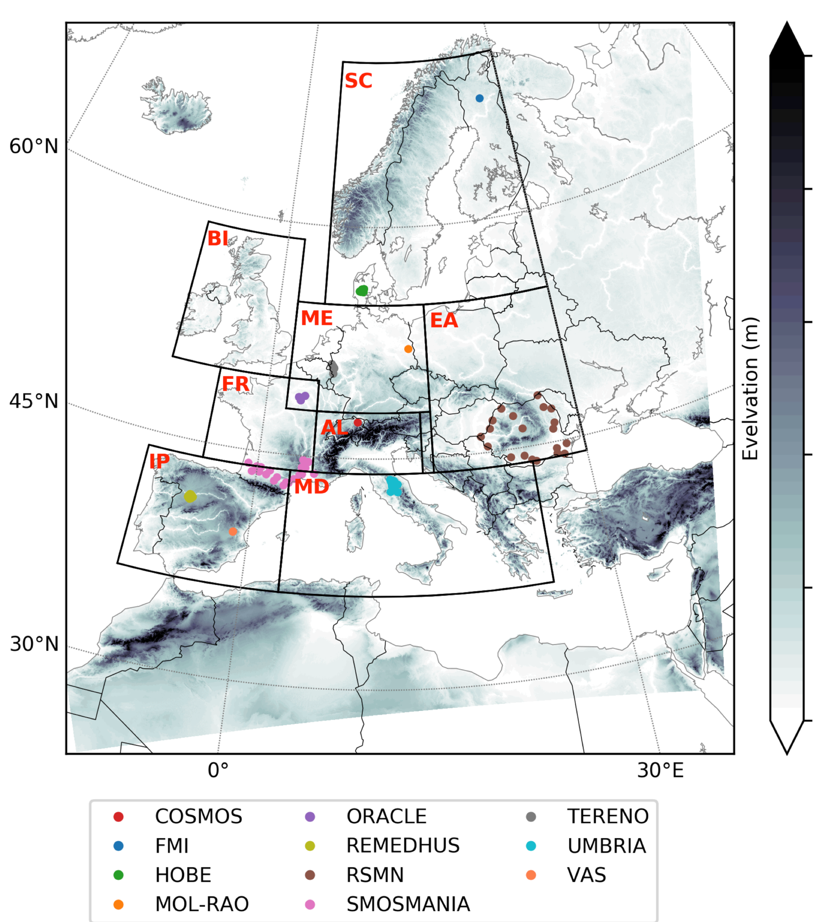

Figure 2: EURO-CORDEX domain (1544 × 1592 grid cells) showing surface elevation, boundaries of PRUDENCE regions and locations of International Soil Moisture Network (ISMN) stations used for data validation.

Model validation datasets:

- *In-situ* soil moisture (SM) from ISMN (red points in Figure 2.)
- Remotely sensed (RS) ESA CCI for SM, GRACE satellite for total water storage (TWS) comparison over PRUDENCE regions (regions in black color in Figure 2) were used.

Summary

- Overall, both ParFlow and CLM3.5 capture the interannual variability in the hydrologic states and fluxes well, however differences in performance between models showed the uncertainty associated with the representation of hydrological processes, such as groundwater flow and soil moisture.
- Comparison of ParFlow simulated soil moisture shows a good agreement with observations from ISMN network. However over PRUDENCE regions CLM3.5 show better match with ESA CCI dataset.
- TWS anomalies simulated by ParFlow and CLM 3.5 are consistent with GRACE satellite data.
- 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.

Surface SM validation with in-situ observations

- Surface soil moisture data between 2000–2006 at 4 ISMN networks for top 5 cm surface layer were collected and compared with the top two ParFlow and CLM soil layers (about 3 cm).
- ParFlow shows good agreement with observations for all stations than CLM 3.5.

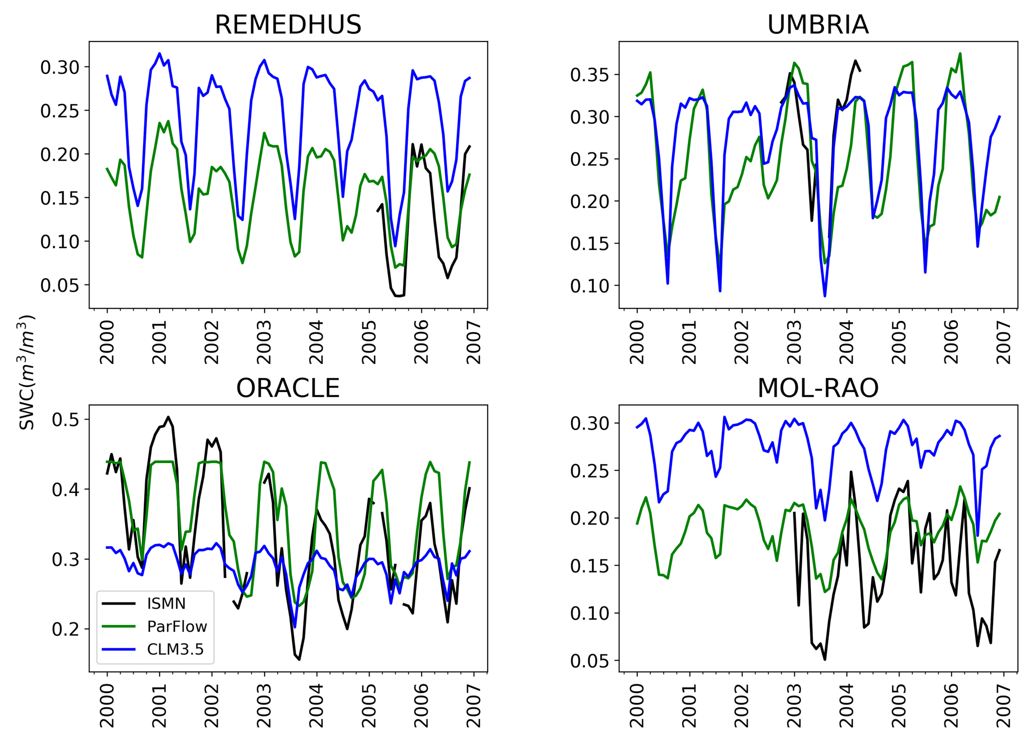

Figure 3 :Comparison of SM simulated by ParFlow, CLM with in-situ observations in four ISMN soil moisture network for 2000–2006.

Surface SM validation over PRUDENCE regions

- Over PRUDENCE regions both models followed the seasonal variations in SM fairly well when compared with RS SM ESA CCI dataset, indicating that the timing of SM at monthly and annual scales is reasonably accurate, however ParFlow simulated higher soil water content in most regions than ESA CCI and CLM SM.
- In the dryer regions such as IP and MD, the soil moisture estimates by both models shows good agreement with ESA CCI.

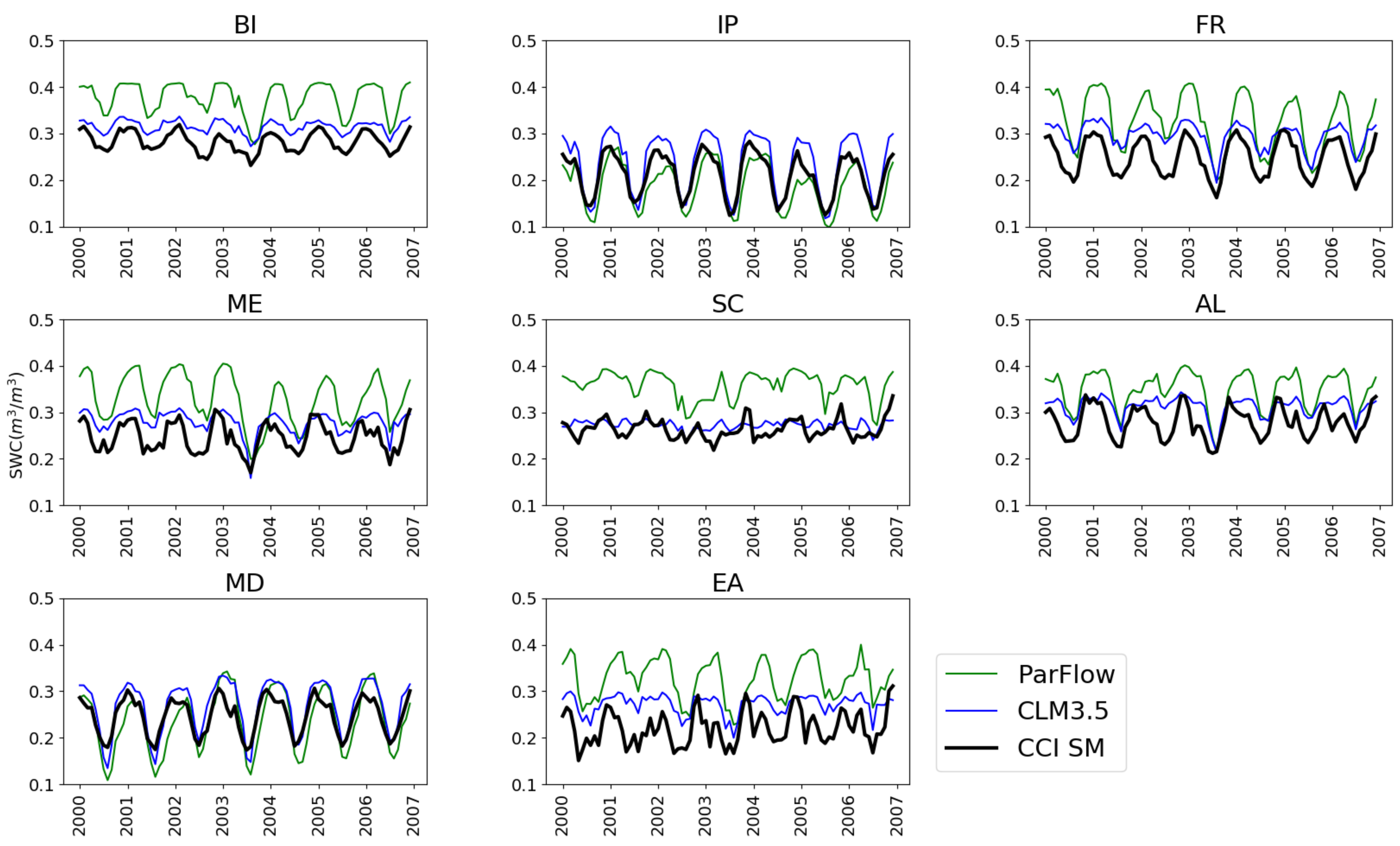

Figure 4: Comparison of the spatially aggregated SM simulated by ParFlow, CLM with ESA CCI satellite dataset over PRUDENCE regions for 2003–2006) period.

Total water storage anomaly

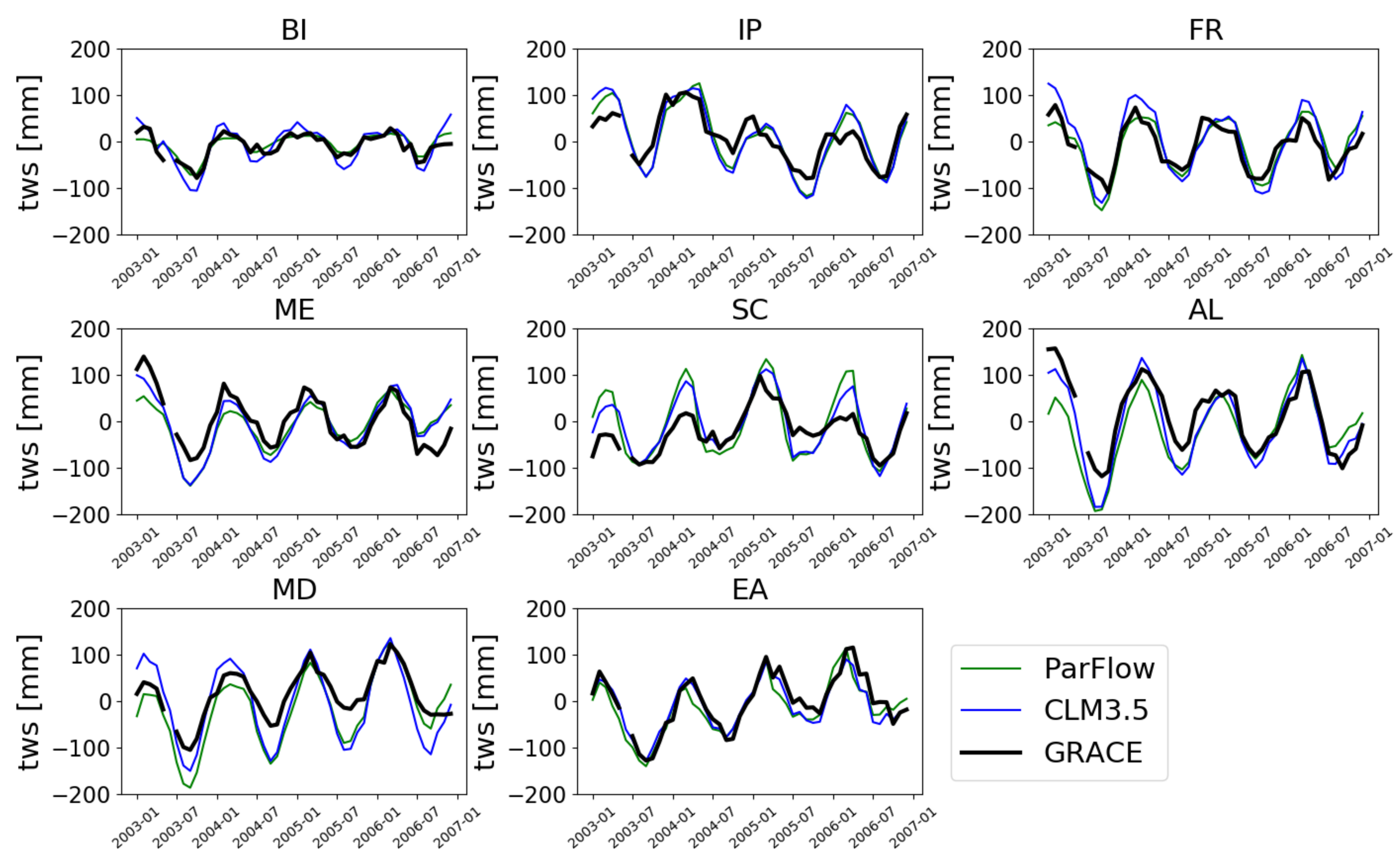

Figure 5 : Comparison of the total water storage anomaly (relative to 2003–2006) from ParFlow and CLM with GRACE satellite dataset.

The overall seasonal variation in TWS simulated by both models captured well when compared with the GRACE data, However, both model show much stronger negative anomalies in summer over most regions.

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