Predicting the complete coupled terrestrial water and energy cycles

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Introduction

- The Terrestrial Systems Modeing Platform TSMP (Shrestha et al., 2014) consists of the atmospheric circulation model COSMO (Baldauf et al., 2011), or alternatively ICON, the land surface CLM (Oleson et al., 2004) and the subsurface flow model ParFlow (Jones and Woodward, 2011; Kollet and Maxwell, 2006). ParFlow solves the 3D Richards´ equation for water flow in the unsaturated zone (soils), saturated zone (aquifers) and routing of surface runoff. The three models are coupled via OASIS-MCT (Valcke, 2013). TSMP models therefore the complete terrestrial water cycle including aquifers, soils, rivers, snow and ice, vegetation and atmospheric water.
- TSMP shows a very favourable scalability on supercomputers and ParFlow has recently be adapted to run with GPU processors.
- Data assimilation methods (e.g. Ensemble Kalman Filter (Evensen, 1994)) can be used to merge observations with simulations by TSMP (Shrestha et al., 2014), using the Parallel Data Assimilation Framework PDAF (Nerger & Hiller, 2013, Kurtz et al., 2016). Currently the assimilation of soil moisture (in situ, from satellite), groundwater levels (in situ), land surface temperature (remote sensing), river stages (in situ) and air temperature has been implemented. TSMP-PDAF can also be used to estimate model parameters like saturated hydraulic conductivity, using an augmented state vector approach.
- TSMP is used for different kind of predictions, with and without data assimilation, and at different spatial scales ranging from fields, via (large) catchments and the national scale, to the continental scale.

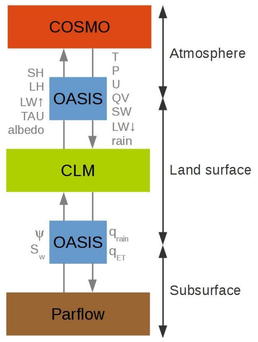


Fig. 1: Coupling scheme of TSMP

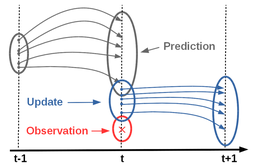


Fig. 2: Basic concept of the Ensemble Kalman filter. Arrows represent model state trajectories and circles represent uncertainty.

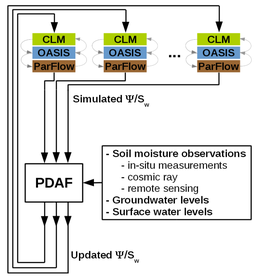


Fig. 3: Data flow for the data assimilation with TSMP and the Parallel Data Assimilation framework PDAF.

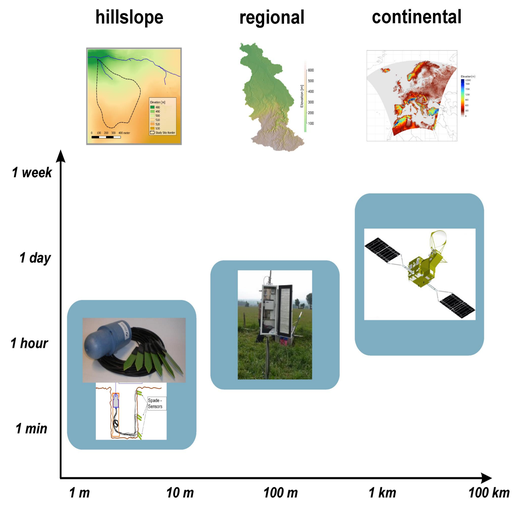


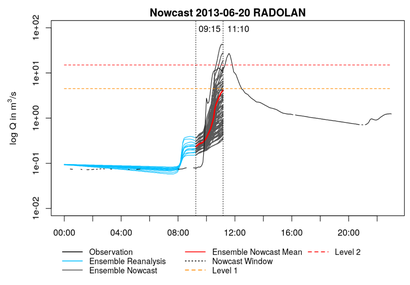
Fig. 4: Example of the use of observations to be assimilated at different scales: soil moisture. TDR-measurements at the hillslope scale, cosmic ray neutron sensor measurements at the larger catchment scale and remotely sensed soil moisture for the continental scale.

Example 1: Flash flood predictions

- The subsurface component of TSMP, ParFlow, is used for evaluating quantitative precipitation estimation (QPE), nowcast (QPN) and forecast (QPF) in a flashflood nowcasting framework.

Fig. 5 (left): Flash flood event in Wachtberg, near Bonn, Gemany on the 20th of June 2013.

Fig. 6 (right): Measured discharge and ensemble-based modelled discharge at Wachtberg for the flash flood event. The critical discharge levels are also indicated in the figure.



- The framework has been tested for flash flood cases like Wachtberg (Pomeon et al., 2020).
- The framework will be applied over Germany.
- Polarimetric radar information is ingested to improve QPE and QPN, and flash flood prediction.
- The assimilation of soil moisture data (e.g., initial soil moisture content from satellite or in situ probes) or stage information is foreseen.

Example 2: Yield prediction for regions in Germany and Australia

- The land surface component of TSMP, CLM5.0, was set up over North-Rhine-Westphalia (NRW), Germany and Victoria, Australia (VIC).
- **Input**: *soil texture and soil organic carbon information* from SoilGrids, *soil hydraulic and thermal properties* estimated by pedotansfer functions; *land cover* from Sentinel-2A and Landsat-8 (NRW), or MODIS and Victorian Land Use Information System (VIC).
- **Simulation experiments**: for boreal summer seasons of 2017, 2018, 2019 and 2020. Forcings: ECMWF seasonal weather predictions, from the 1st of April and for the next seven months (CLM-S), from the 1st of April (prediction three months) followed by further four months of prediction issued on the 1st of July (CLM-SUB) and a simulation forced by bias adjusted reanalysis data (CLM-WFDE5).
- **Verification data**: *Simulated yields* were compared with observed yields from state-wide agricultural statistics; *simulated leaf area index and evapotranspiration* with MODIS products; simulated *soil moisture* with soil moisture observed by SMAP.

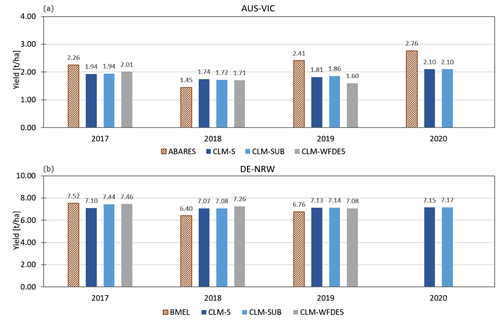


Fig. 7: CLM-S, CLM-SUB, and CLM-WFDE5 simulated crop yield compared to corresponding official yield records (a) from ABARES (2020), averaged for all analysed winter crops (wheat, barley, and canola) within the AUS-VIC domain, and (b) from BMEL (2020a, b), averaged for all analysed crops (wheat, corn, and canola) within the DE-NRW domain, for the years 2017 to 2020. 2020 not yet available for NRW.

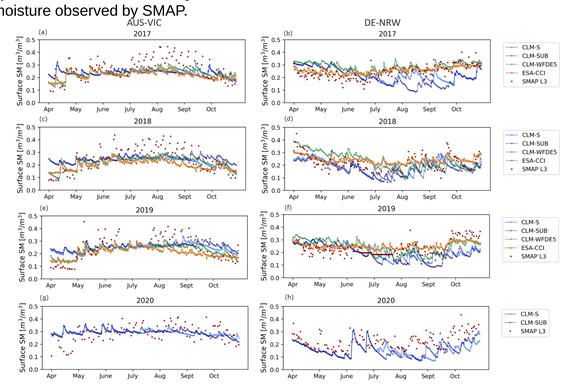


Fig. 8: CLM-S, CLM-SUB and CLM-WFDE5 simulated soil moisture for 0 – 0.05 m from April to October of 2017, 2018, 2019 and 2020, averaged over (left) the AUS-VIC domain and (right) the DE-NRW domain, compared to ESA-CCI and SMAP L3 soil moisture data.

Example 3: Terrestrial system model predictions over EUROCORDEX

- TSMP (COSMO-CLM-ParFlow) is setup over EURCORDEX at 12.5km resolution, with FAO soil maps, MODIS land use and lateral forcings from ECMWF HRES. It runs operationally with daily new forecasts, with increased resolution (500m) over a smaller domain (around North-Rhine-Westphalia, Germany).
- Simulations with TSMP, use as initial conditions forecasts from past day, but precipitation is corrected by radar data, and hydrolgy is updated based on radar-corrected precipitation. ECMWF HRES forecast drives TSMP along boundaries and provides 10-day forecasts for EUROCORDEX and NRW.

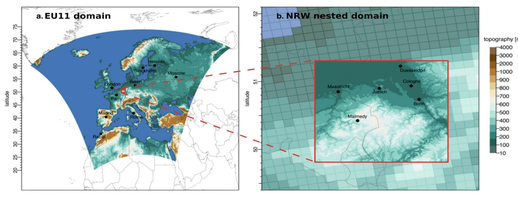


Fig. 9: TSMP Forecasting system (TSMP-M) domains: EU11 cordex domain (12.5 km spatial resolution) driven by the ECMWF HRES forecast data and nested domain (1 km atmospheric resolution, 500m surface and subsurface resolution).

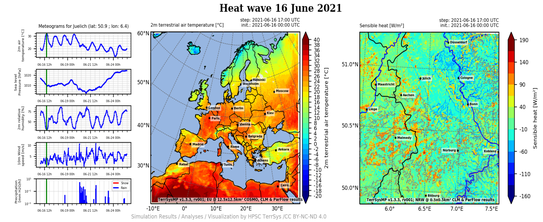


Fig. 10: Part of the TSMP forecast for June 16, 2021, when the heatwave was observed. Left figure shows air temperature over the EU11 cordex domain at 17:00 UTC. Right figure demonstrates sensible heat flux over the NRW model domain.

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Acknowledgements

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