Forecasting soil moisture at 600m resolution over Germany using the hydrologic model ParFlow/CLM with ECMWF atmospheric forcing

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Introduction

Monitoring and forecasting the terrestrial water budget becomes increasingly important, especially for **stakeholders from the agricultural sector**, in the context of

- Resilience to **extreme weather events** like the droughts of 2018, 2019, and 2020,
- Adaptation to **climate change**,
- Sustainable management of soil and **water resources**.

Daily forecasts available at **www.adapter-projekt.de**

Atmospheric forcing – ECMWF

- Hourly forecast data for **eight (near-) surface parameters**, i.e. t2m, tp, sp, q, u10, v10, ssrd, strd
- From three forecast products (**HRES, ENS, and SEAS**)
- Reference time series (climatology) calculated with first 24h from each daily **deterministic forecast** (forced with HRES)
- Each forecast is **initialized** on the basis of the forecast at h+24 from the previous day

Model – ParFlow/CLM

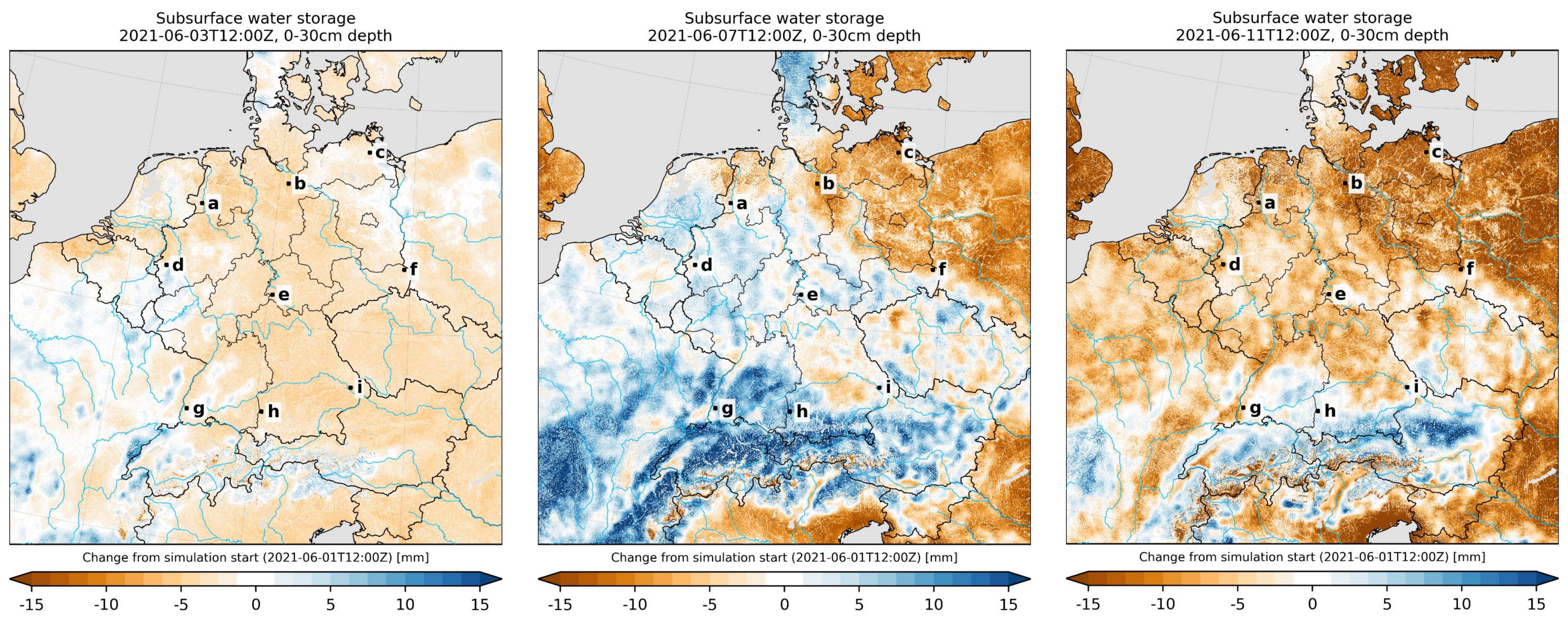
ParFlow/CLM (www.parflow.org)

Hydrological model that simulates 2D/3D **hydrological processes in the saturated and unsaturated zone**, including groundwater and overland flow [1,2].
Its integrated land surface module CLM (Common Land Model) allows for a representation of the **interactions at the surface** (water and energy fluxes) [2].

Experiment setup

- 2000 x 2000 grid points over **Central Europe**
- **611m resolution** – hourly time step
- **15 depth layers** from surface to 60m, with increasing thickness
- **Soil types**: SoilGrids250m texture grouped in 12 USDA classes and International Hydrogeologic Map of Europe below depth to bedrock
- **Land cover**: CLC2018 (Corine Land Cover) reclassed in 18 IGBP types
- Run on **GPUs** of the JUWELS HPC system at Jülich Supercomputing Centre (JSC) [3]

10-day deterministic forecast (HRES) and ensemble prediction (ENS)



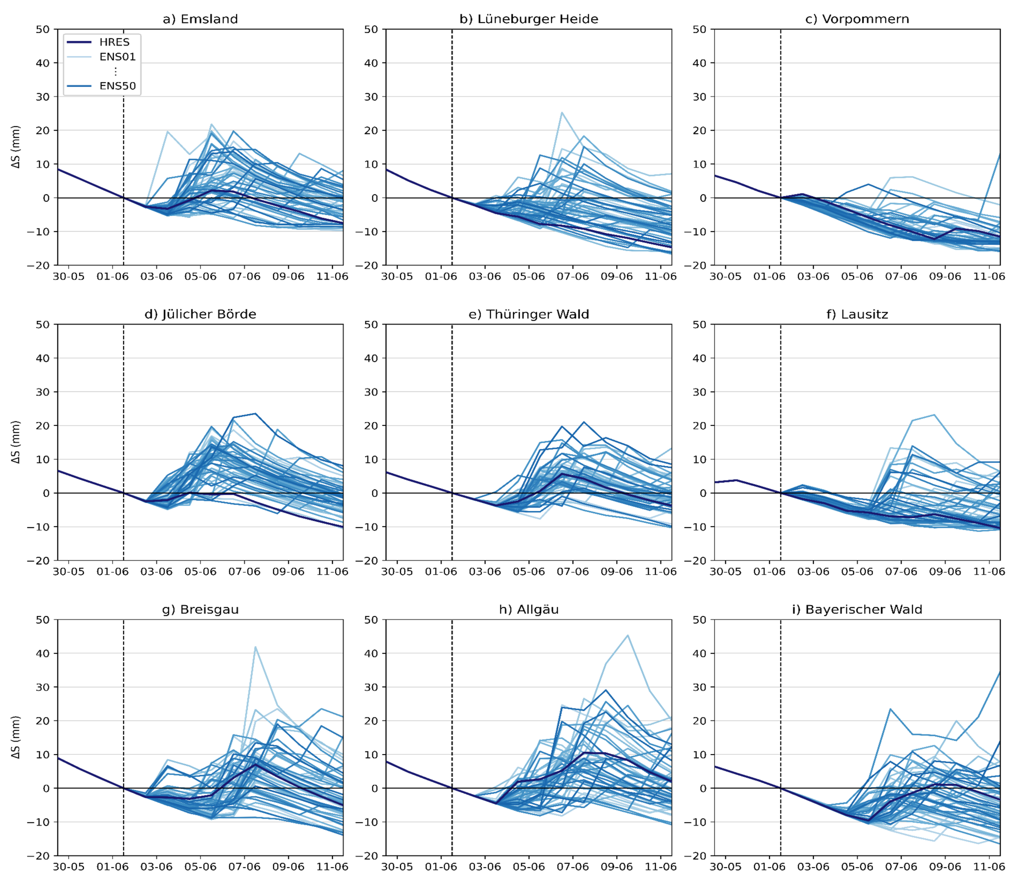


Figure 1

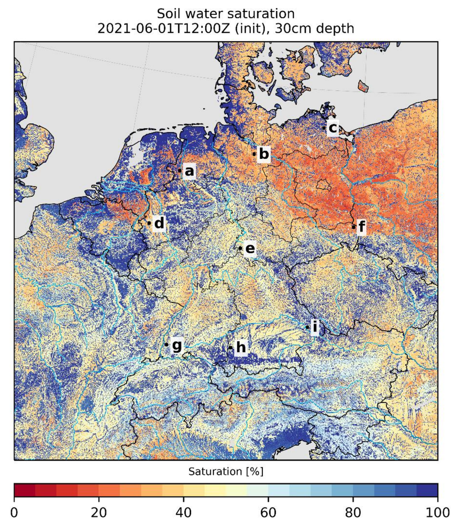
Top: Change (in mm) in the subsurface water storage in 0-30cm depth with respect to simulation start (2021-06-01, 12UTC) for three selected time steps (+48h, +144h, +240h) for the deterministic forecast forced with HRES.

Bottom: Change (in mm) in the subsurface water storage in 0-30cm depth with respect to simulation start (2021-06-01, 12UTC, dashed line) for every 24h (12UTC) for nine selected grid points (shown on the maps) for the deterministic forecast forced with HRES (thick dark blue line) and 50 ensemble members forced with ENS (light to medium blue lines).

The **subsurface storage increase** in the upper 30cm of the soil due to precipitation appears very clearly on the maps of **Figure 1** (blue shades). On the other side, in regions where no precipitations occurred over the forecast period, e.g. north-eastern Germany, Poland, and Hungary, the **water loss increases over time**. As the soil was already dry in these regions, percolation did not occur anymore and the subsurface storage loss was mainly **due to evapotranspiration**. This kind of diagnostic gives useful information to the stakeholders, for example on the necessity to **irrigate the fields** and on the **amount of water** that might be added to the soil to compensate the loss through evapotranspiration.

Figure 1 (bottom) highlights the **added value of the 50 ensemble members**, especially in a situation with **convective precipitation** as shown here. For example, in northern and eastern Germany (plots b, c, f), the HRES-based deterministic forecast predicted almost no precipitation, while a significant number of ensemble members forecasted precipitation. The ensemble also gives valuable information to the user on both the accuracy over time of the deterministic forecast and the **amount of precipitation** that might be expected, and its impact on the soil water storage.

4-month probabilistic seasonal ensemble prediction (SEAS)



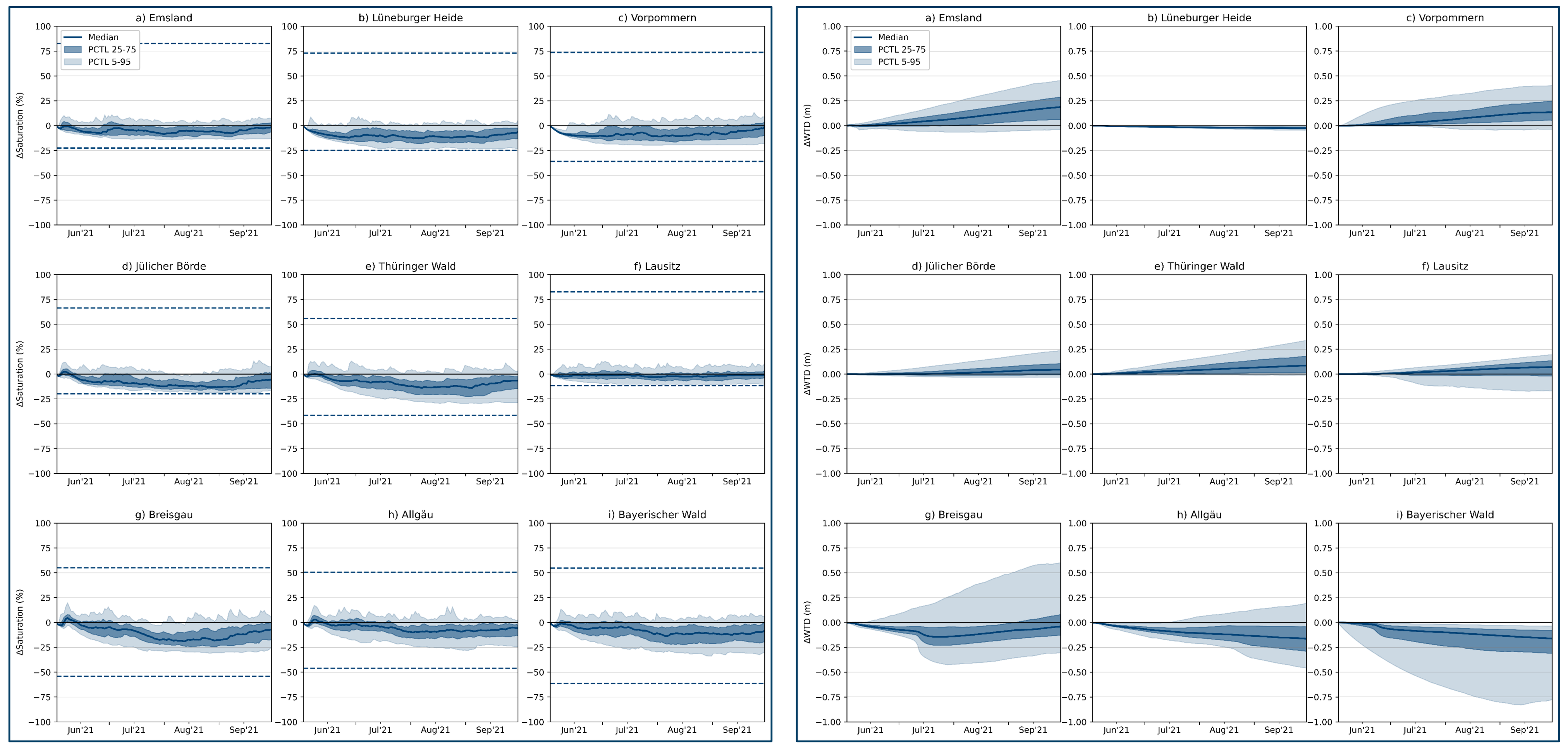


Figure 2

Left: Soil water saturation (%) at simulation start (2021-06-01, 12UTC).

Middle: Change in saturation (%) at 30cm depth over 4 months with respect to simulation start for the 50 member ensemble forced with SEAS for nine selected 5x5 grid points (shown on the map). The dark blue line shows the ensemble median and the shaded areas show the 25-75 (medium blue) and 5-95 (light blue) percentile intervals. The dashed horizontal lines represent the maximum and minimum change possible, i.e. the change to reach the full saturation and residual saturation, respectively.

Right: same as middle but for the change in water table depth (m).

The **seasonal prediction of the soil water saturation** change in 30cm depth shows for almost all regions a further drying of soil reaching its maximum during the first half of August (**Figure 2, middle**). In some regions, e.g. b, d, and f, the saturation might even reach the residual saturation. It is interesting to note that both the 25-75 and the 5-95 **intervals do not increase over time**. On the contrary, they even slightly decrease towards the end of the forecasting period.

The situation is more complex for the **change in water table depth** (**Figure 2, right**). Depending on soil and topographic properties, the predicted change is more or less pronounced. Further, while the ensemble indicates a clear **increase in water table depth** for all six northern regions (plots a – f), the water table is predicted to rise in south-eastern Germany. The trend is less clear for the Rhine valley (plot g), where the abrupt decrease in the water table depth around mid-July and the following recovery until end of September contrast with the very linear changes forecasted for the other regions.

Figure 3 shows that the **probability that the plant available water decreases below 30%** (water stress for plants) will further increase over wide parts of central and western Germany over the summer, and that the situation might even remain critical until end of September in the Land of Saxony-Anhalt.

Such seasonal predictions on the **evolution of the soil water resources** might help the stakeholders to manage these resources and to adapt their activities to mitigate the risk of yield loss through water stress.

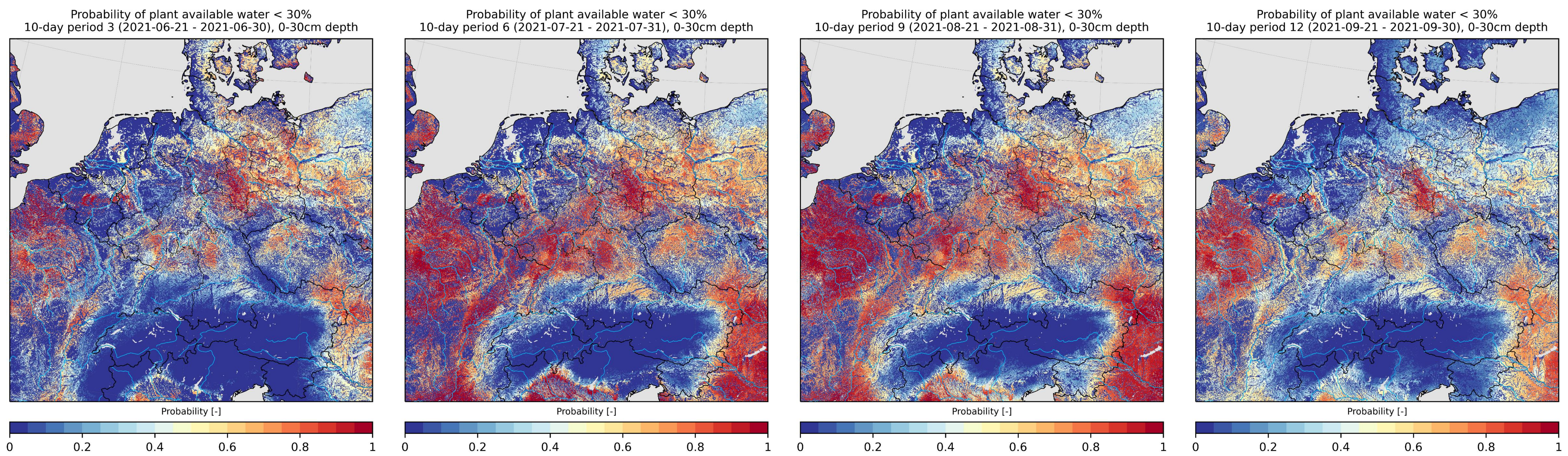


Figure 3

Probability of plant available water below 30% for 10-day periods 3, 6, 9, and 12 on the basis of the 50 member ensemble seasonal prediction forced with SEAS and initialized on 2021-06-01, 12UTC.

Acknowledgments

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References

[1] Kollet S., Maxwell R., 2006, Integrated surface-groundwater flow modeling: A free-surface overland flow boundary condition in a parallel groundwater flow model, *Advances in Water Resources*, 29, 945-958, doi: 10.1016/j.advwatres.2005.08.006

[2] Kuffour B., Engdahl N., Woodward C., Condon L., Kollet S., Maxwell R., 2020, Simulating coupled surface-subsurface flows with ParFlow v3.5.0: capabilities, applications, and ongoing development of an open-source, massively parallel, integrated hydrologic model, *Geoscientific Model Development*, 13, 1373-1397, doi: 10.5194/gmd-13-1373-2020

[3] Hokkanen J., Kollet S., Kraus J., Herten A., Hrywniak M., Pleiter D., 2021, Leveraging HPC accelerator architectures with modern techniques – hydrologic modeling on GPUs with ParFlow, *Computational Geosciences*, 1-13, doi: 10.1007/s10596-021-10051-4

[4] Jülich Supercomputing Centre, 2019, JUWELS: Modular Tier-0/1 Supercomputer at the Jülich Supercomputing Centre. *Journal of large-scale research facilities*, 5, A135, doi: 10.17815/jlsrf-5-171