A high-resolution forecasting system of the terrestrial water cycle over Germany and surrounds using the hydrologic model ParFlow/CLM

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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, 2020, and 2022
- Adaptation to **climate change**,
- Sustainable management of soil and **water resources**.

Daily forecasts available at **www.adapter-projekt.de** and **www.wasser-monitor.de**

Monitoring and forecasting system

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** over **15 depth layers** from surface to 60m, with increasing thickness → 6x10^6 grid points
- **611m resolution** – hourly time step
- **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

Monitoring and forecasting system workflow

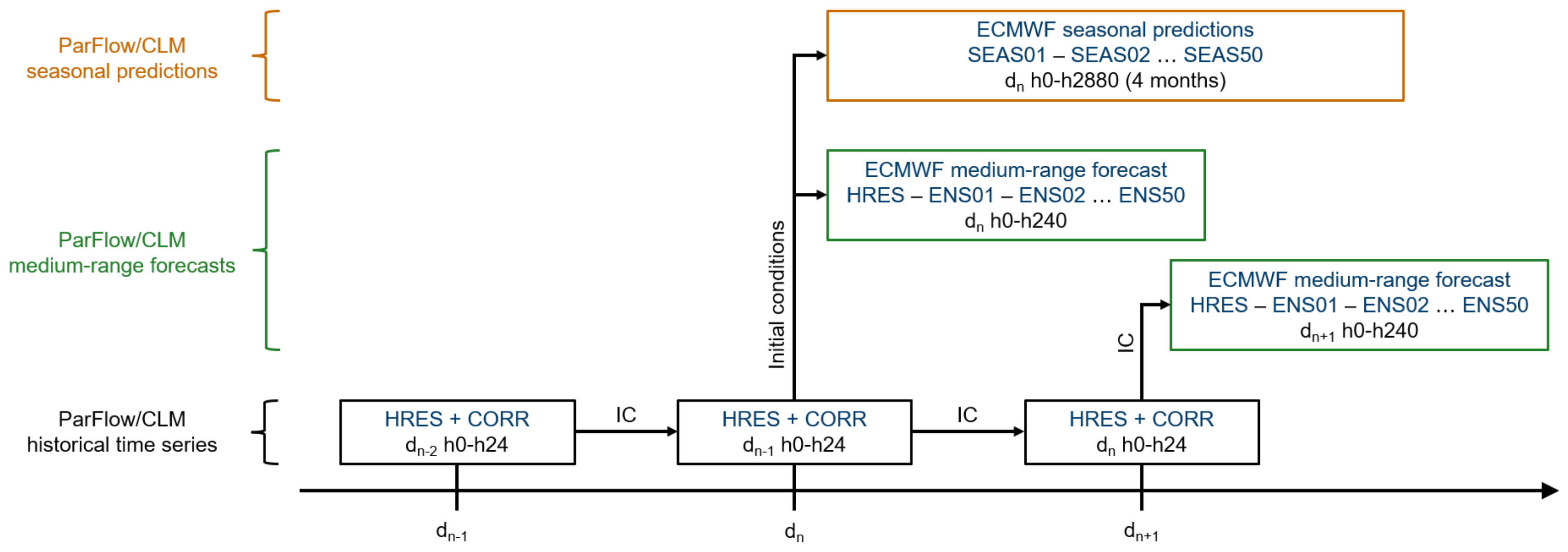
Fully automatised workflow producing every day 10-day forecasts driven by **ECMWF** weather forecasts

→ **Deterministic** forecast forced with HRES

→ 50-member ensemble forced with ENS for **uncertainty**, every two days

\+ 50-member ensemble **seasonal forecast** over four months driven by SEAS, every three months

- Each forecast is **initialized** with the deterministic forecast at h+24 from the previous day
- **Reference time series** (climatology) calculated with first 24h from each daily deterministic forecast



ParFlow/CLM
seasonal predictions

ParFlow/CLM
medium-range forecasts

ParFlow/CLM
historical time series

ECMWF seasonal predictions
SEAS01 – SEAS02 … SEAS50
d_n h0-h2880 (4 months)

ECMWF medium-range forecast
HRES – ENS01 – ENS02 … ENS50
d_n h0-h240

ECMWF medium-range forecast
HRES – ENS01 – ENS02 … ENS50
d_{n+1} h0-h240

Initial conditions

IC

HRES + CORR
d_{n-2} h0-h24

IC

HRES + CORR
d_{n-1} h0-h24

IC

HRES + CORR
d_n h0-h24

d_{n-1}

d_n

d_{n+1}

Figure 1
Workflow of the monitoring and forecasting system. CORR = correction run with observation-based precipitation product; HRES = ECMWF deterministic medium-range forecast; ENS = ECMWF medium-range probabilistic 50-member ensemble forecast; SEAS = ECMWF seasonal probabilistic 50-member ensemble forecast.

Performance on JUWELS Booster

- Run on GPUs of the JUWELS Booster HPC system at Jülich Supercomputing Centre (JSC)
- Using the new highly efficient **GPU capability** of the ParFlow code [3]
- Each simulation runs on **one single node** (4 GPU cores), needing 6-10 hours wall time

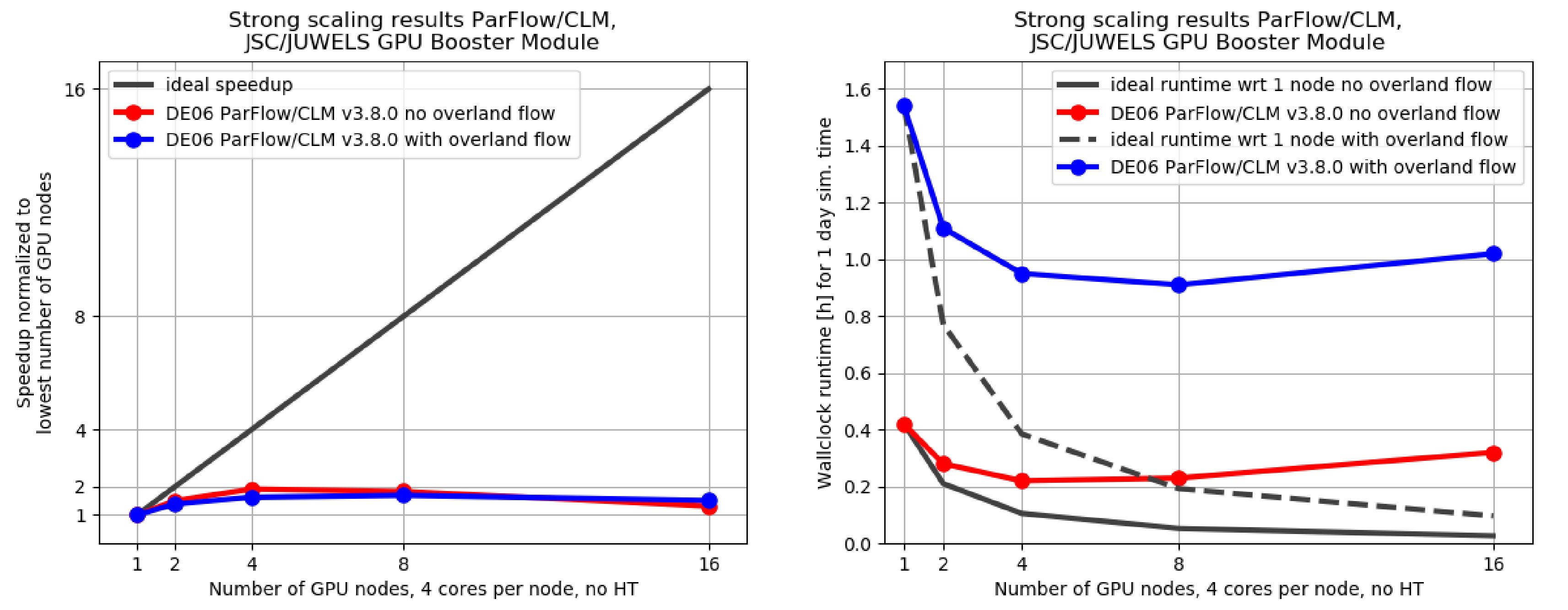


Figure 2
Strong scaling experiment with ParFlow/CLM v3.8.0 for one simulation day (24 hourly time steps) with and without explicit overland flow routing on the JUWELS GPU Linux Booster Module at JSC.

Acknowledgments

The authors gratefully acknowledge the Earth System Modelling Project (ESM) for funding this work by providing computing time on the ESM partition of the supercomputer JUWELS [4] at Jülich Supercomputing Centre (JSC).

References

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[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

Medium-range forecasts

Forecasts of the **state and fluxes** of the terrestrial water cycle allow for

- Deriving indicators and **diagnostics** relevant for stakeholders,
- Calculated for different (root-) **depths**,
- **Information** for water stress, trafficability, nutrient leakage, irrigation, etc.

Presented as **maps** (deterministic forecast) and **time series** for 3x3km² tiles everywhere over Germany (deterministic + ensemble forecast)

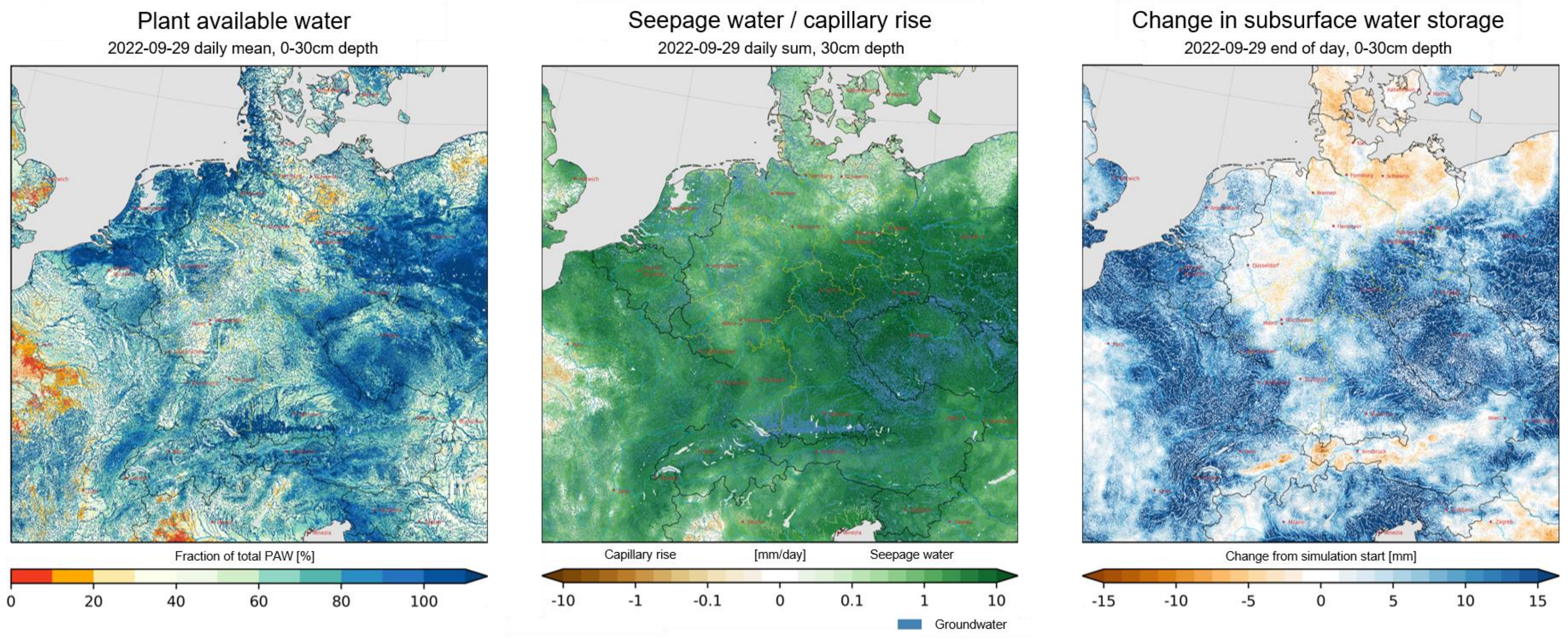


Figure 3
Examples of diagnostics based on the deterministic forecast for the upper 30cm / in 30cm depth. Forecast for the 29th of September 2022 from the run initialized at 2022-09-21, 12UTC.

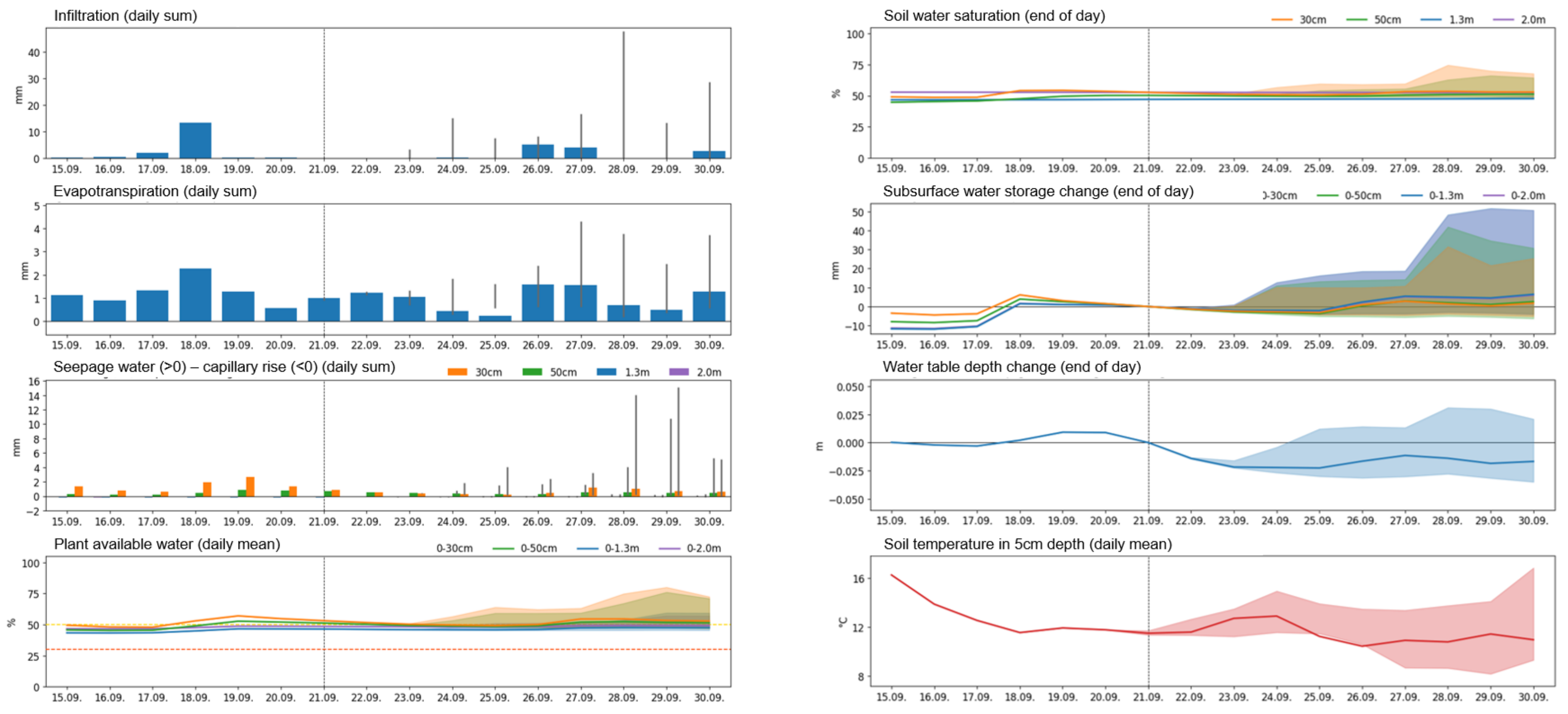
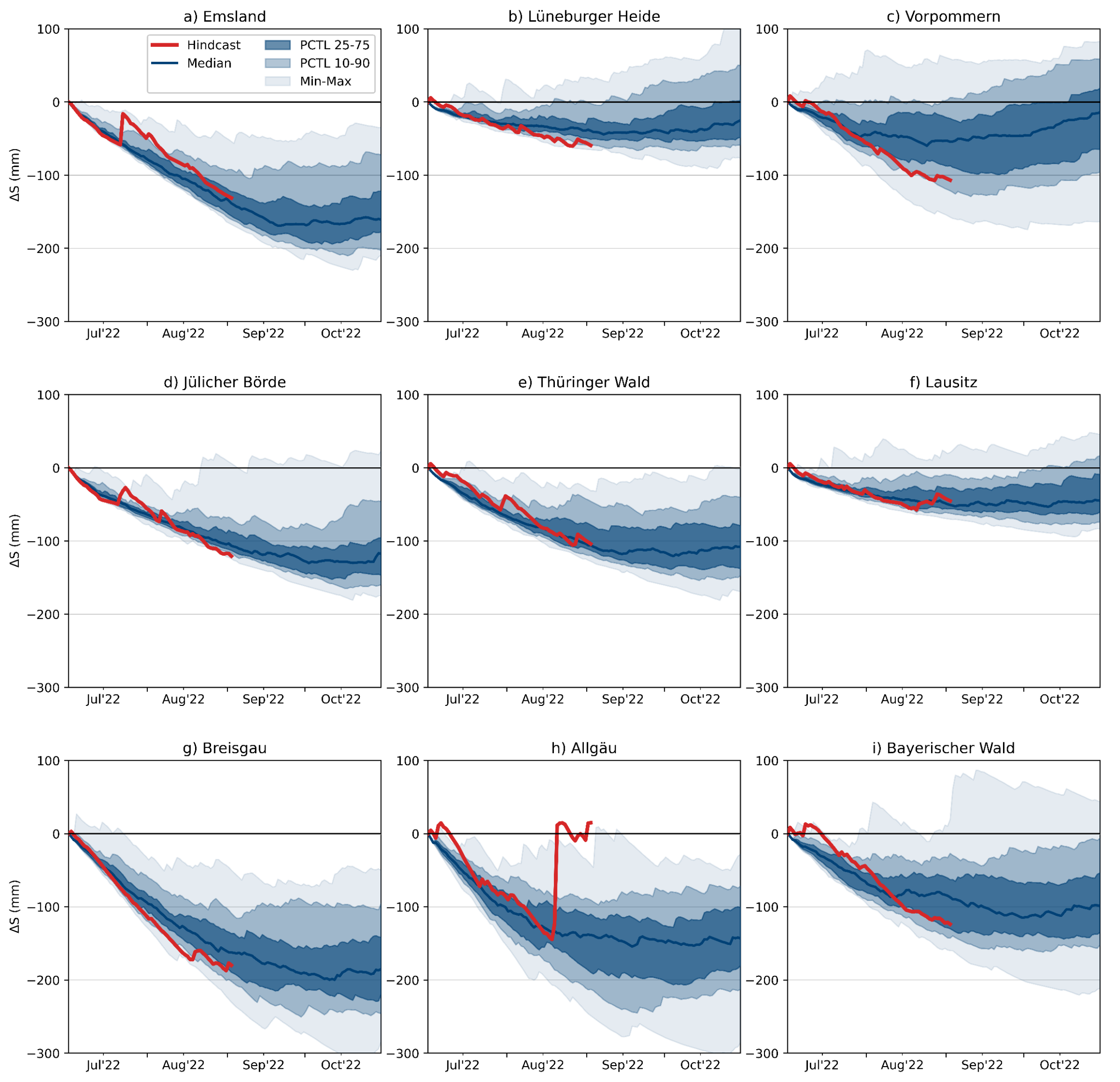


Figure 4
Time series for 50.9055°N 6.3824°E (Jülich, North Rhine-Westphalia) hindcast + forecast initialized at 2022-09-21, 12UTC.

Seasonal probabilistic forecasts



Information for

- **Water resources management**
- Adaptation & mitigation strategies

Via **indicators** assessing

- The risk of water stress/scarcity
- Water resources depletion/recovery

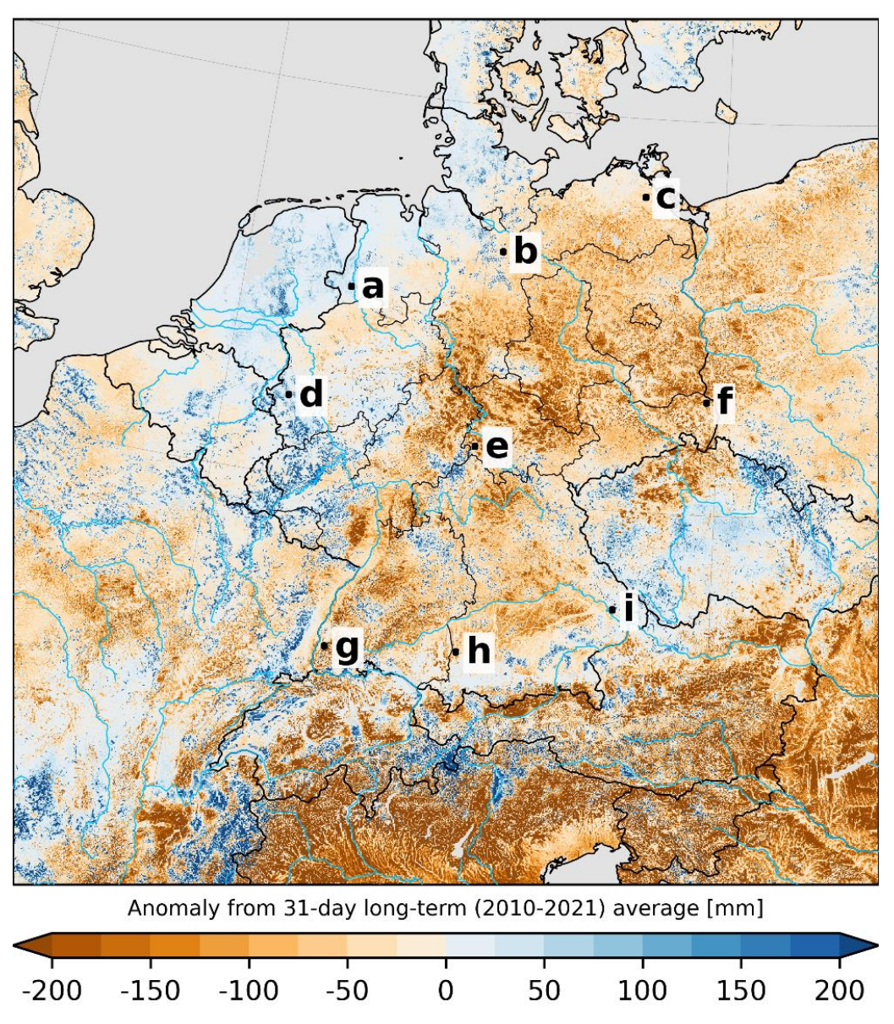


Figure 5
Right: Total subsurface water storage anomaly (mm) for 2022-07-01 compared to the 31-day long-term average (2010-2021).
Left: Change in daily total subsurface water storage (mm) over four months with respect to simulation start (2022-07-01, 12UTC) for the 50-member ensemble forced with SEAS for nine selected grid points. The red line shows the deterministic hindcast (HRES-driven +12h for each day). The dark blue line shows the ensemble median and the shaded areas show the 25-75 percentile (dark blue), 10-90 percentile (medium blue), and min-max (light blue) intervals.

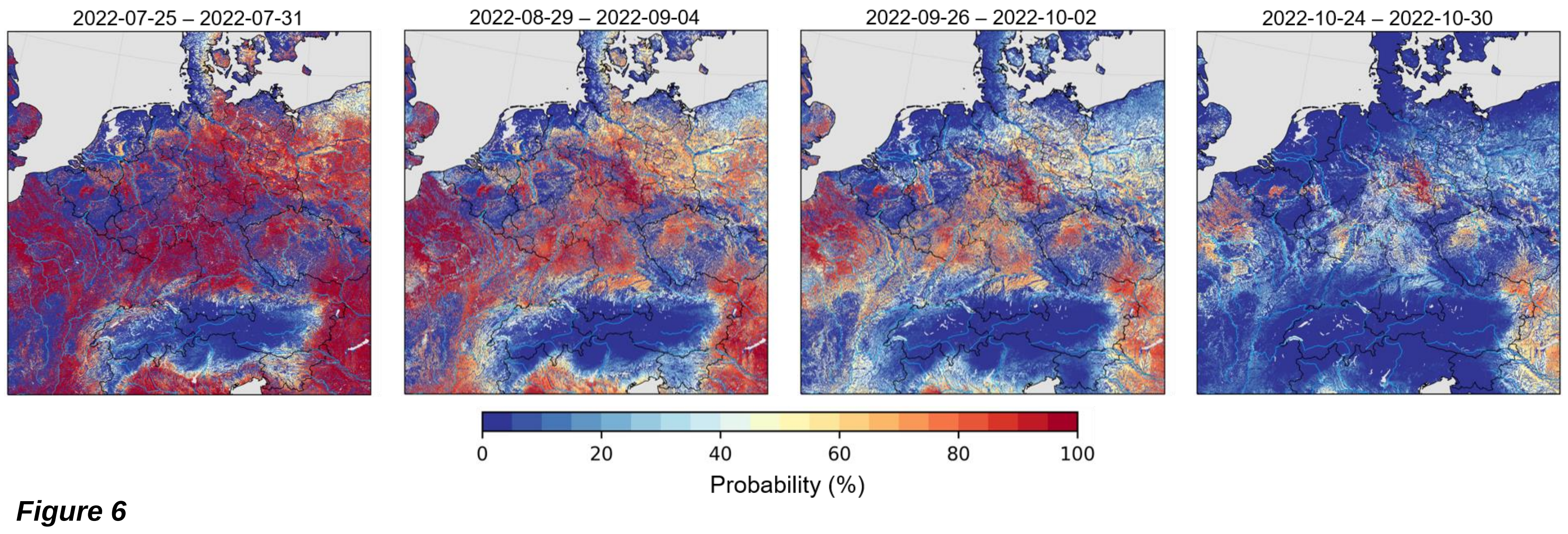


Figure 6
Probability of plant available water below 30% over 0-30cm depth for different weeks on the basis of the 50-member ensemble seasonal prediction forced with SEAS and initialized on 2022-07-01, 12UTC.