

Assessment of the skill of seasonal probabilistic water table depth forecasts with the hydrological model ParFlow/CLM over central Europe

2025-06-26 | A. Belleflamme^{1,2}, S. Hammoudeh^{1,2}, K. Goergen^{1,2}, S. Kollet^{1,2}

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There is a need for (sub-) seasonal forecasting of water resources

Especially in relation to droughts

Repeated droughts in central Europe (2018, 2019, 2020, 2022)

Multi-year droughts

→ insufficient regeneration of (ground) water resources

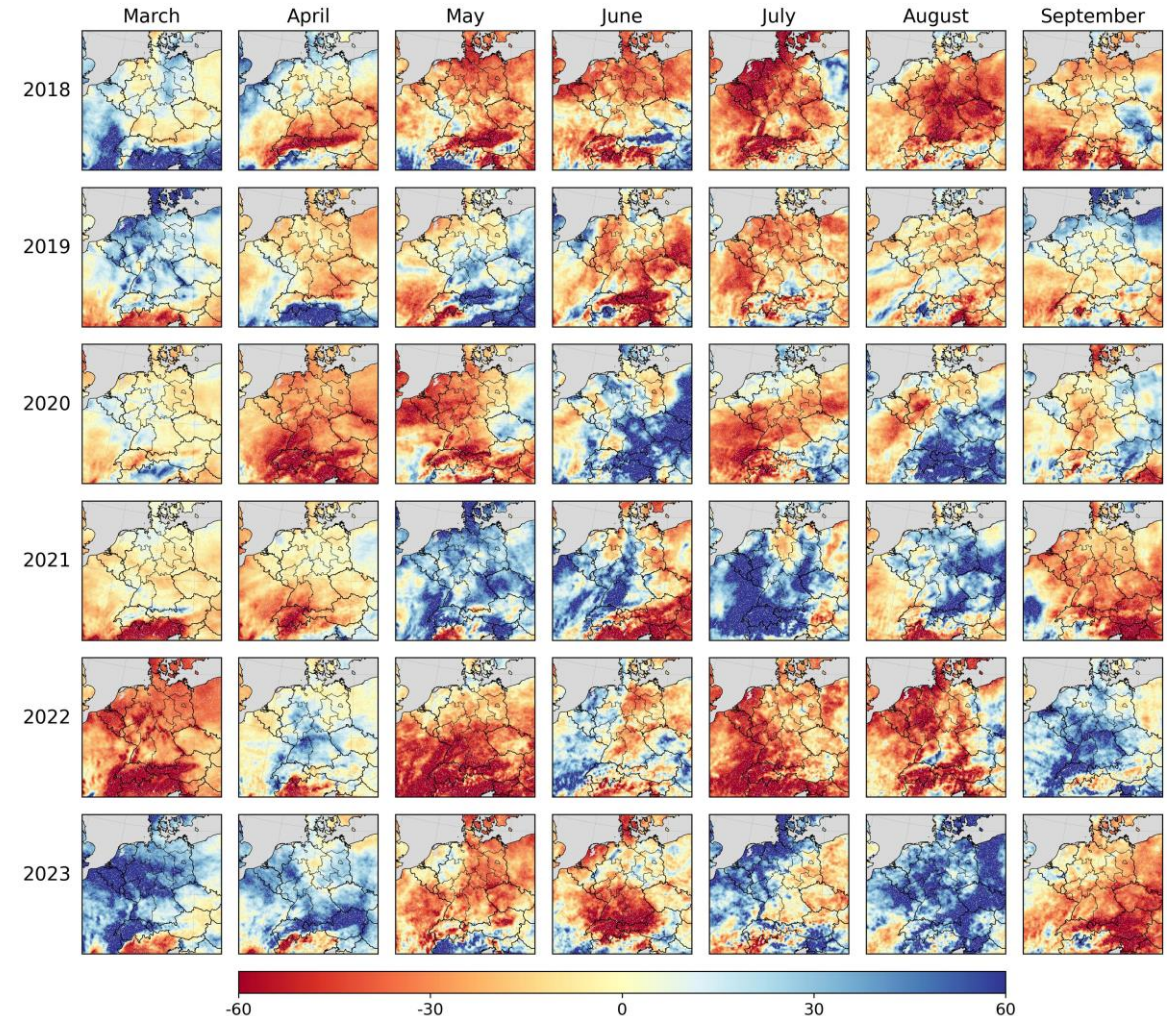
→ Seasonal forecasts

Upcoming drought (risk)

Regeneration of water resources

Water management strategies dealing with reduced water resources

Agriculture, forestry, water management



Monthly anomalies (mm) of precipitation sum compared to 2013-2023

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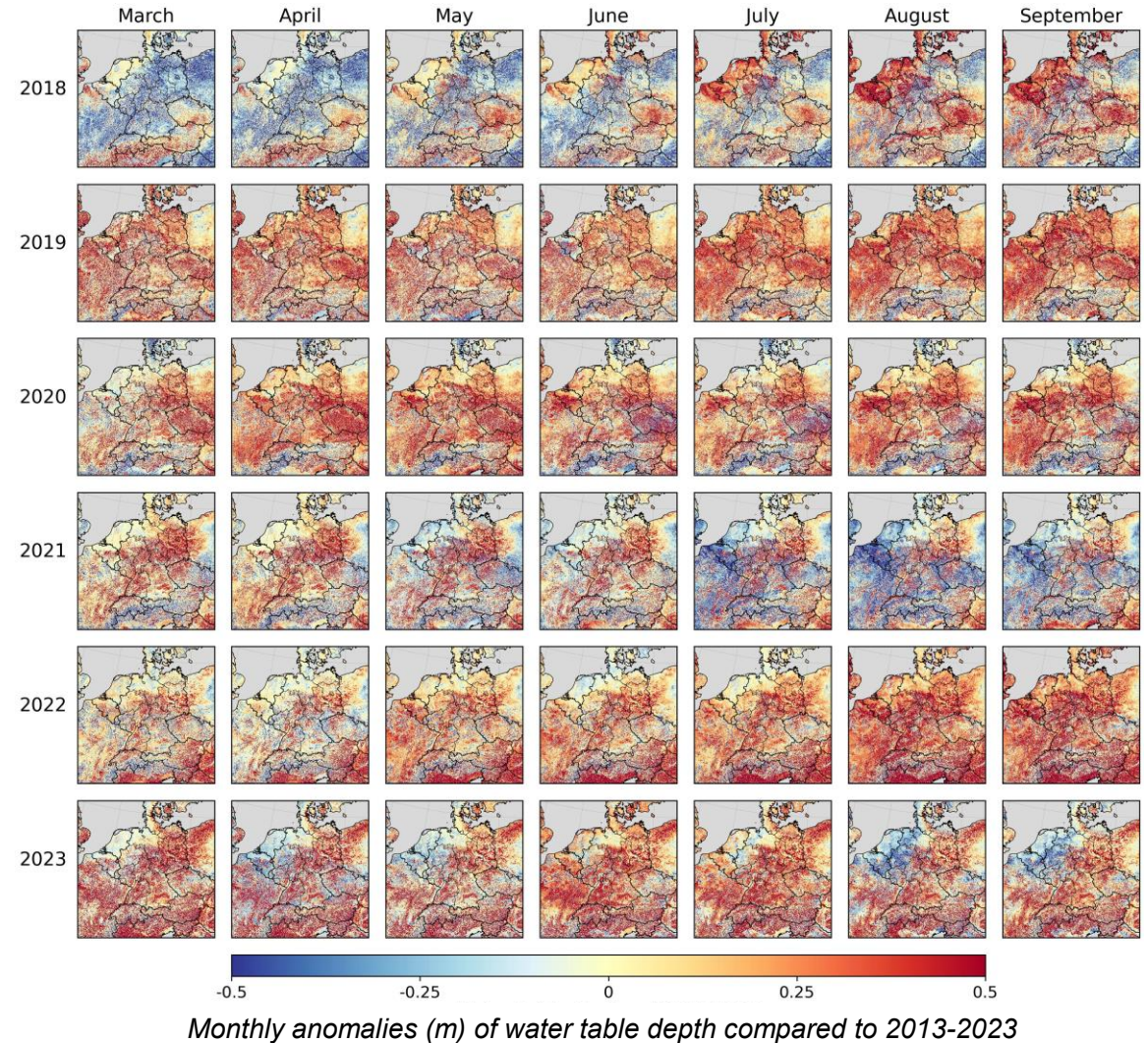
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Experimental Water Resources Bulletin: information for water resources management

www.adapter-projekt.de/bulletin/index.html - seasonal probabilistic predictions of subsurface water storage

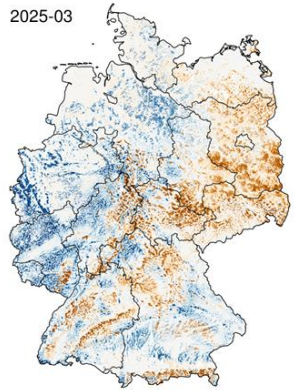
FZJ Experimental Water Resources Bulletin for Germany, Summer 2025

www.adapter-projekt.de/bulletin Release date: 2025-06-12, the eWRB Team

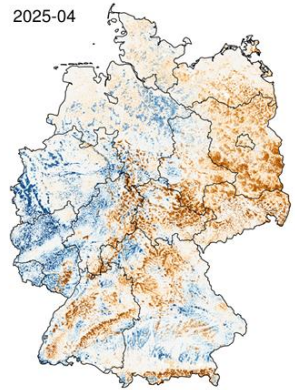
The **Forschungszentrum Jülich (FZJ) experimental water resources bulletin (eWRB)** gives a **regular seasonal update** on the **current state and the upcoming potential evolution of terrestrial near-surface water resources**. The eWRB is an open access research data product for an expert environmental sciences and stakeholder audience as well as the interested public.



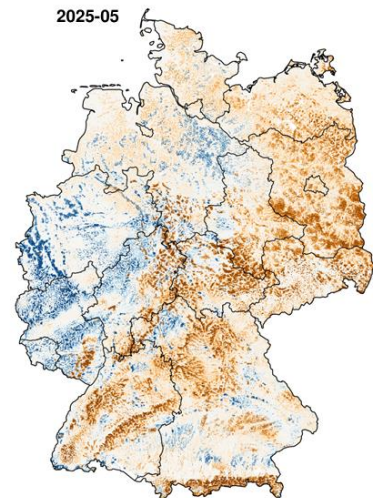
2025-03



2025-04



2025-05



Subsurface monthly water storage anomaly from individual long-term (2010-2024) monthly means [mm]

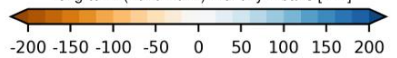
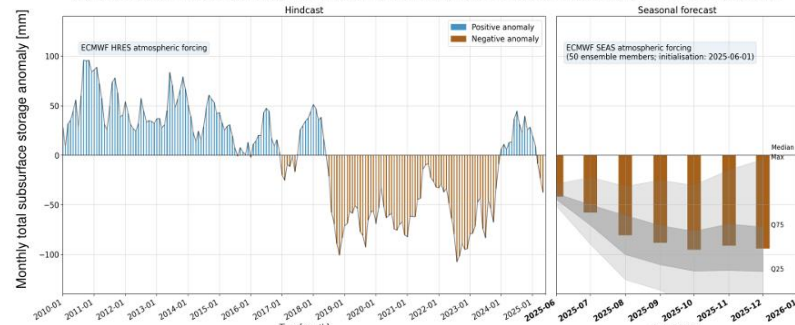


Fig. 1: Monthly anomalies of total subsurface water storage, i.e. shallow groundwater, for the past season with respect to long-term monthly means from 2010-2024 in mm water column. With the eWRB, the total subsurface water storage includes the shallow soil zone and groundwater to a depth of 60m. Data: Hindcasts from ParFlow/CLM simulations with ECMWF HRES atmospheric forcing.

7-months forecast based on 50-member ensemble

State and possible developments: During Spring, subsurface water storage continued to decline, stronger than forecasted in the April 2025 eWRB. Increasing summer deficits are expected in the south, middle, and east of Germany. Nation-wide means seem comparable with simulation results for drought years 2018 and 2020. Basis: 50-member ensemble forecast from 2025-06-01.

Monthly total water storage anomaly from long-term (2010-2024) monthly means [mm] for Germany; ParFlow/CLM; DE06



2025-06 2025-08 2025-10 2025-12

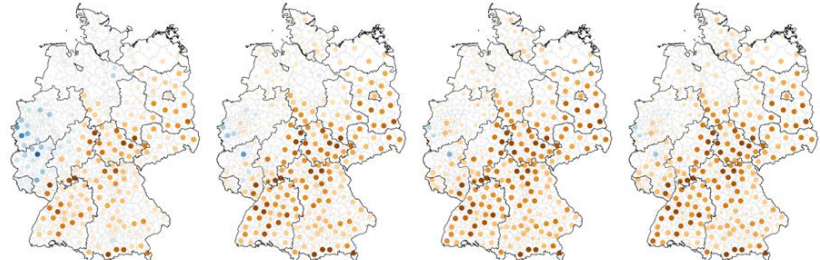


Fig. 2: Past evolution of monthly total subsurface water storage anomalies as spatial means for Germany from 2010-Jan to 2025-May as simulated at 611m resolution with the ParFlow/CLM (www.parflow.org) integrated hydrological model based on daily forecasts driven by ECMWF HRES deterministic atmospheric forcing ("hindcast"), and 7-months forecast from 2025-Jun to 2025-Dec based on ECMWF SEAS 50-member ensemble ("seasonal forecast").

Fig. 3: Seasonal forecasts (2025-Jun to 2025-Dec); mean of total subsurface water storage anomalies from 50-member ParFlow/CLM ensemble (initialized on 2025-06-01), ECMWF SEAS seasonal ensemble prediction driven. Dots: NUTS-3 level administrative regions; dot size: proportional to how many members agree in their sign.

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monthly anomalies of previous season

How reliable and accurate are seasonal hydrological forecasts of subsurface water resources?

Given the skill of weather forecasts and especially precipitation

7-months forecast based on 50-member ensemble

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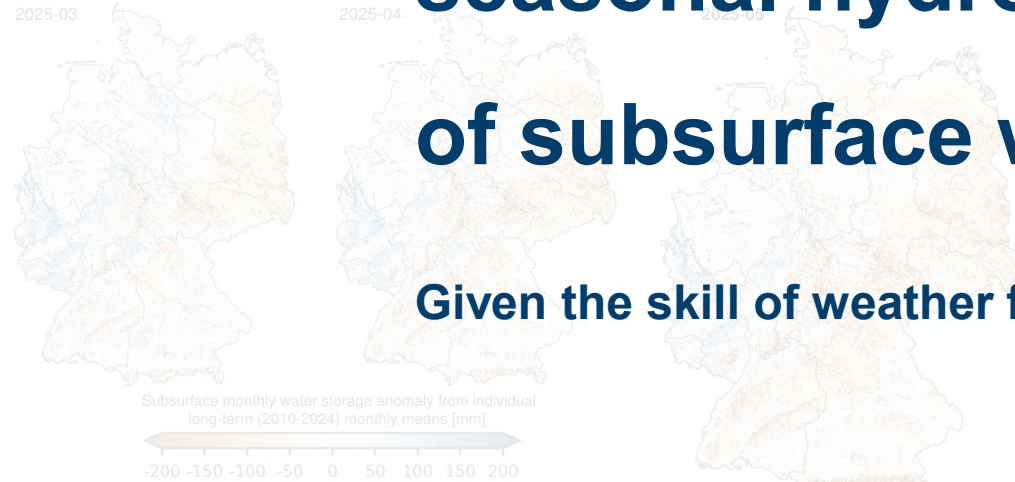
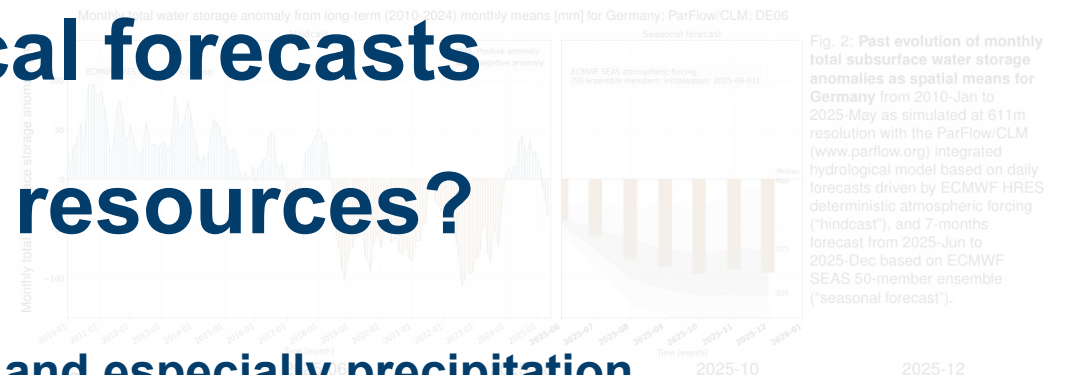


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monthly anomalies of previous season

Seasonal forecast skill of water table depth with ParFlow/CLM

How do we perform the forecasts?

What is the overall skill of the forecasts?

Are we able to forecast droughts?

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ParFlow allows for a complete representation of the soil water budget

With interactions at the land surface

ParFlow

Integrated hydrological model

Fully coupled, 2D/3D dynamical representation of the hydrological processes in the variably saturated zone, including groundwater and overland flow

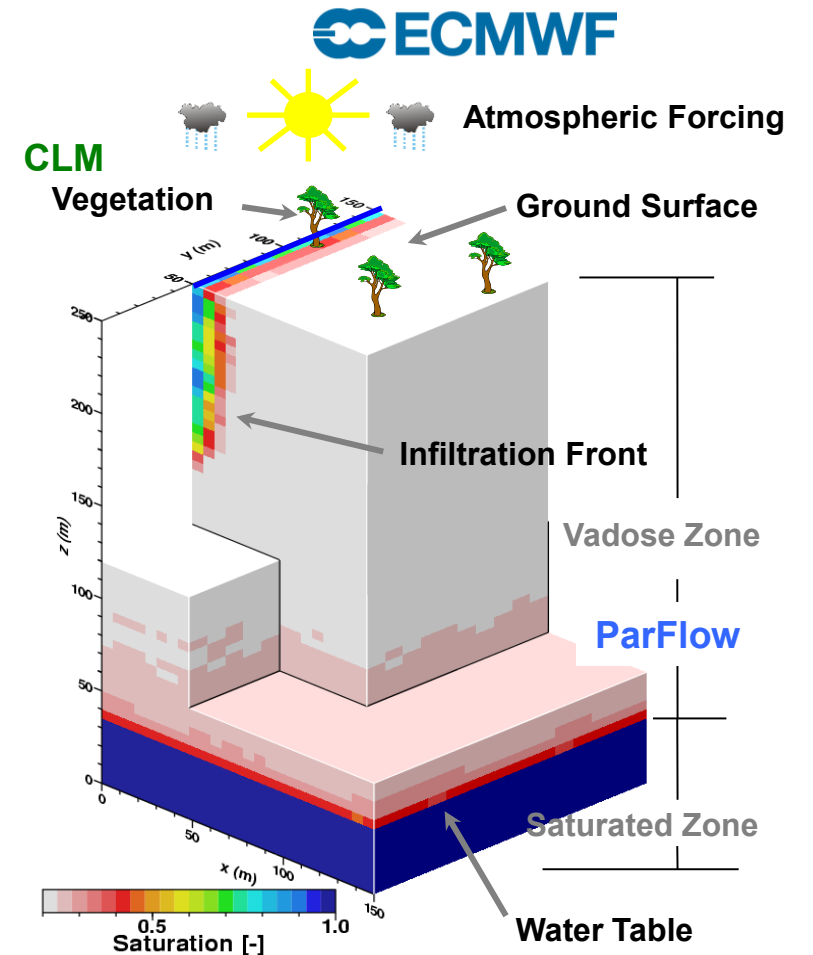
CLM (Common Land Model)

Subroutine land surface module

Representation of the interactions at the surface (water and energy fluxes)

HPC: JUWELS Booster (GPUs) (Jülich Supercomputing Centre)

Overland flow routing turned off to decrease computing time



A 50-member probabilistic forecast is calculated four times per year

Starting from the climatology

Atmospheric forcing

ECMWF seasonal probabilistic forecast SEAS5

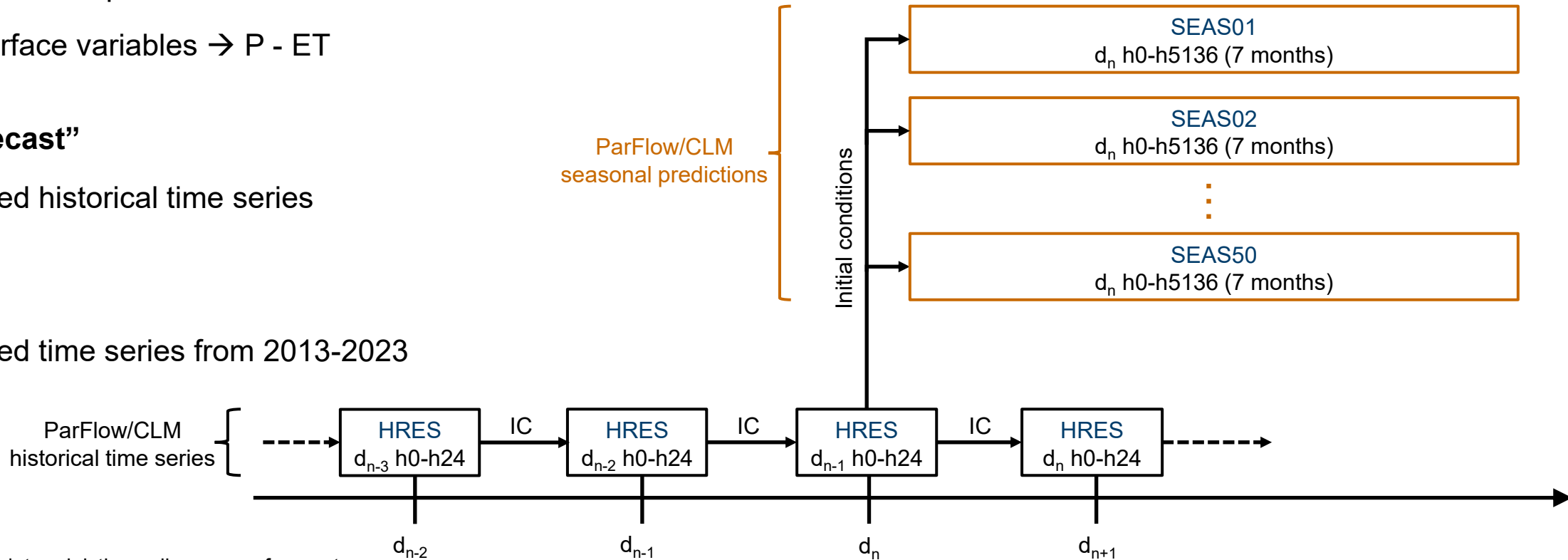
8 (near) surface variables \rightarrow P - ET

“Perfect forecast”

HRES-based historical time series

Climatology

HRES-based time series from 2013-2023



HRES = ECMWF deterministic medium-range forecast

SEAS = ECMWF seasonal probabilistic 50-member ensemble forecast

Seasonal forecast skill of water table depth with ParFlow/CLM

How do we perform the forecasts?

What is the overall skill of the forecasts?

Are we able to forecast droughts?

Seasonal forecast shows higher skill than climatology-based forecast for WTD

Except when stronger change in anomaly

Continuous Ranked Probability Skill Score

→ General skill of ensemble distribution

→ Compares the distribution with the expected value

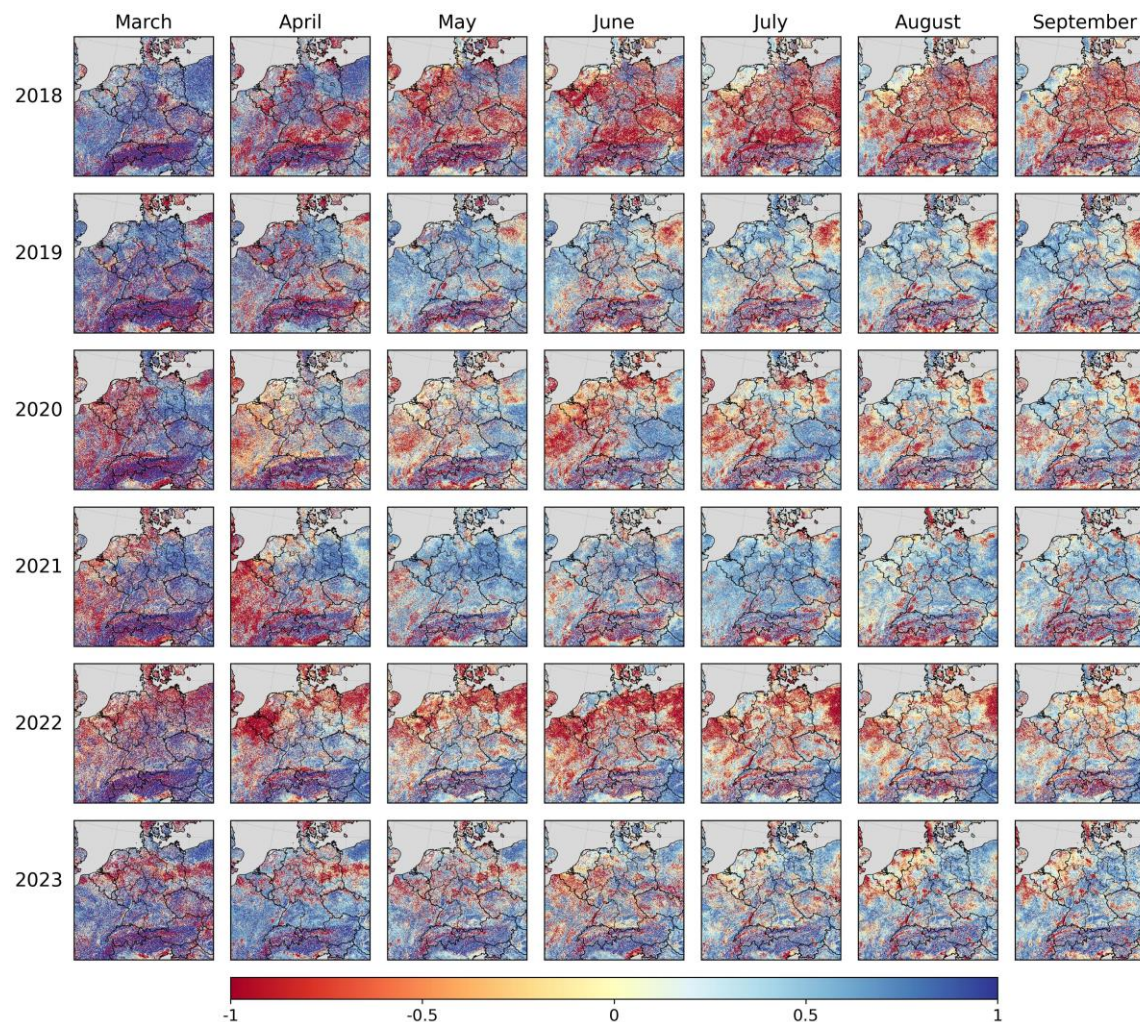
→ Seasonal forecast ensemble vs
climatology-based “pseudo-forecast”

→ > 0 = good skill, < 0 = bad skill

Underrepresentation of extremely dry members

Role of **memory effect**

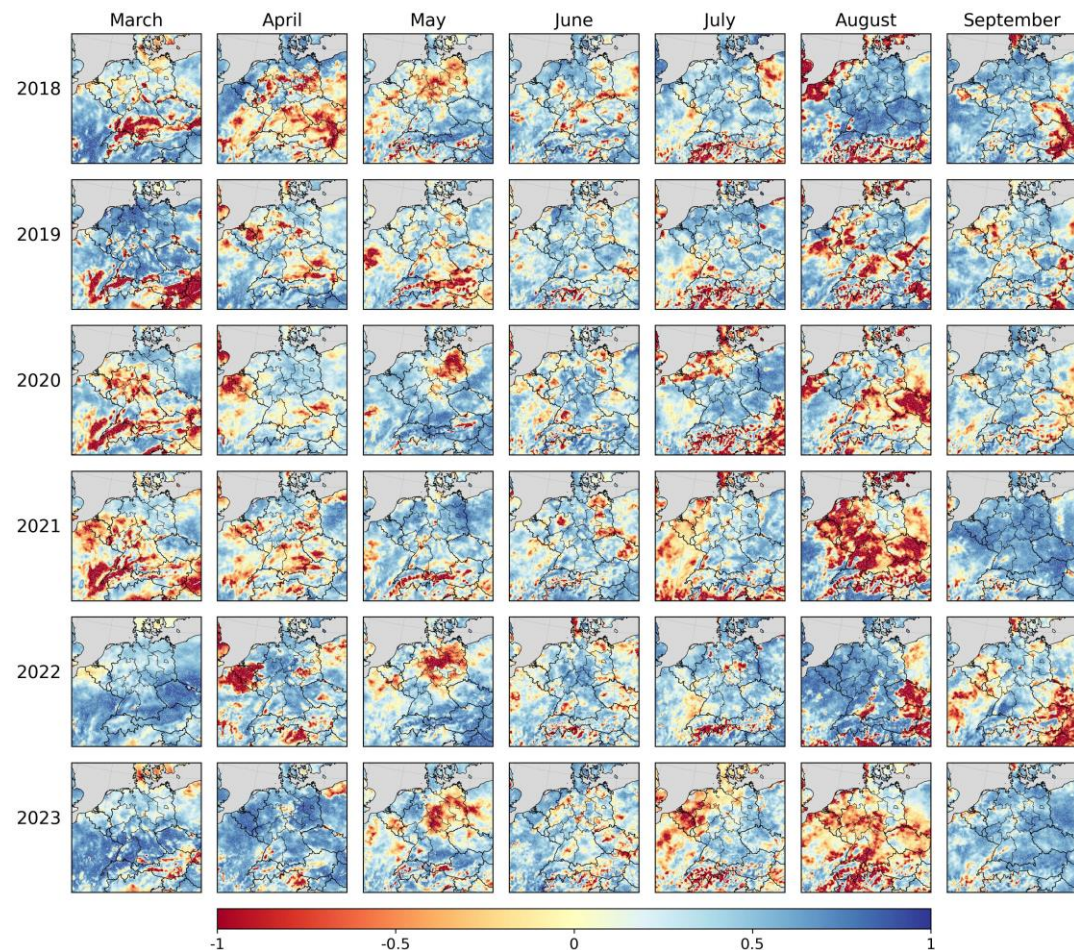
Only **slight decrease in skill** after first month



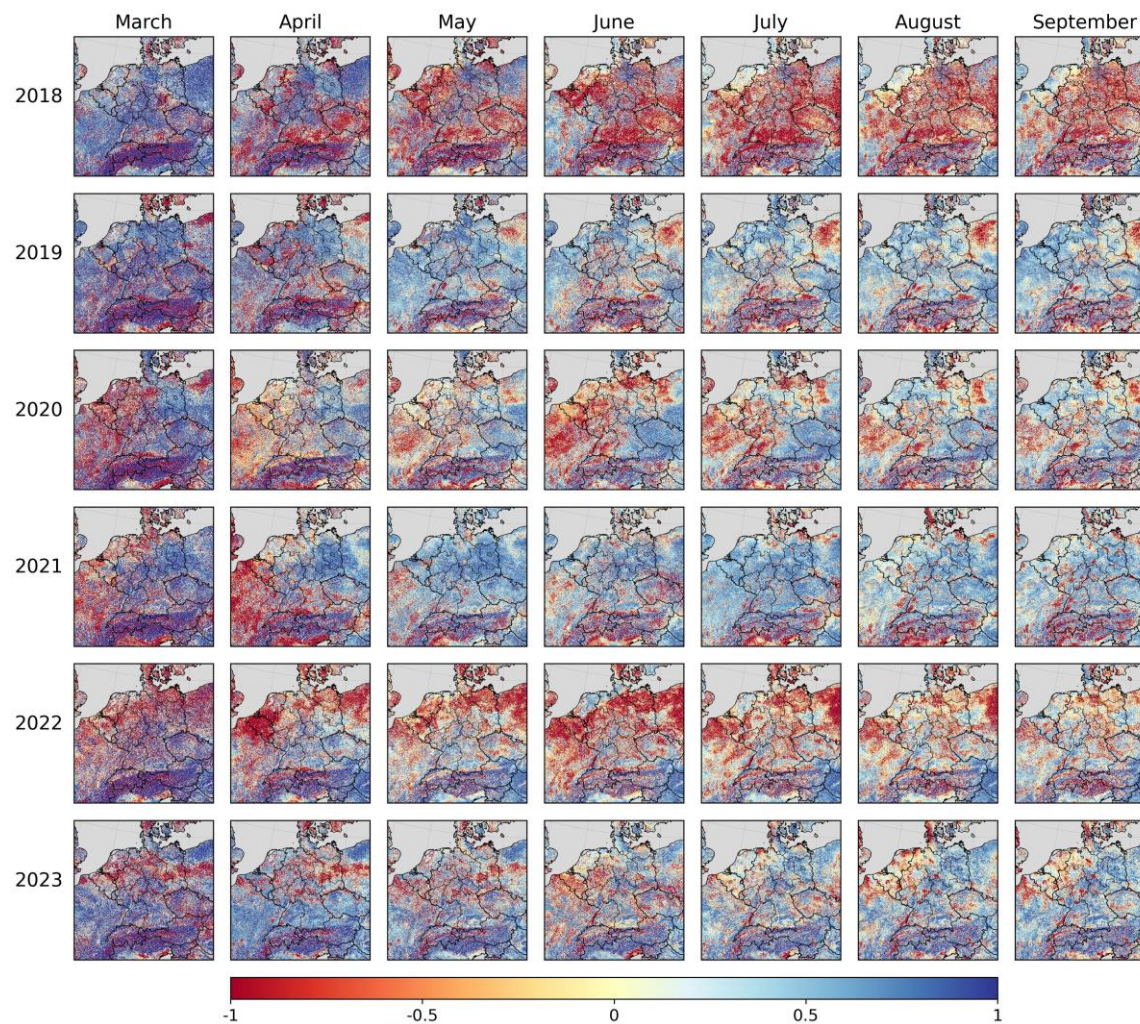
Monthly CRPSS for water table depth from seasonal forecast compared to 2013-2023 climatology-based “pseudo-forecast”

Seasonal forecast shows higher skill than climatology-based forecast for WTD

Skill much more variable for precipitation

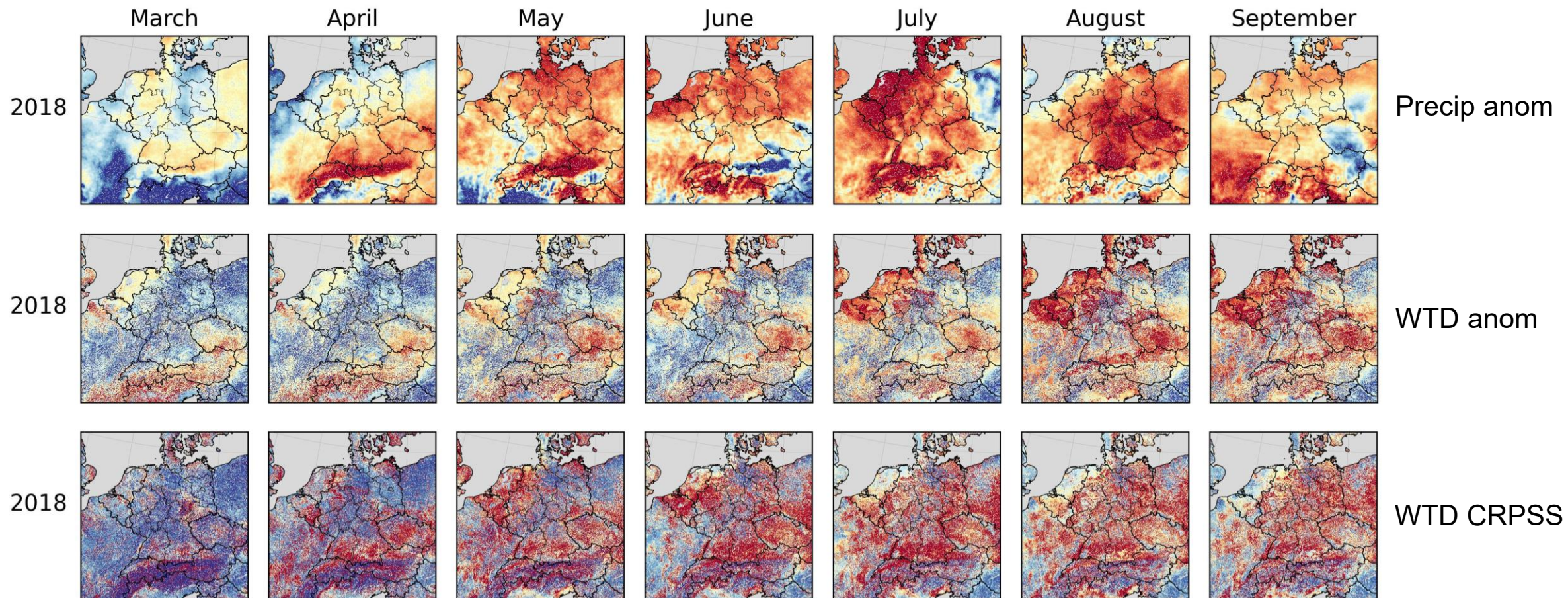


Monthly CRPSS for precipitation sum from seasonal forecast compared to 2013-2023 climatology-based "pseudo-forecast"



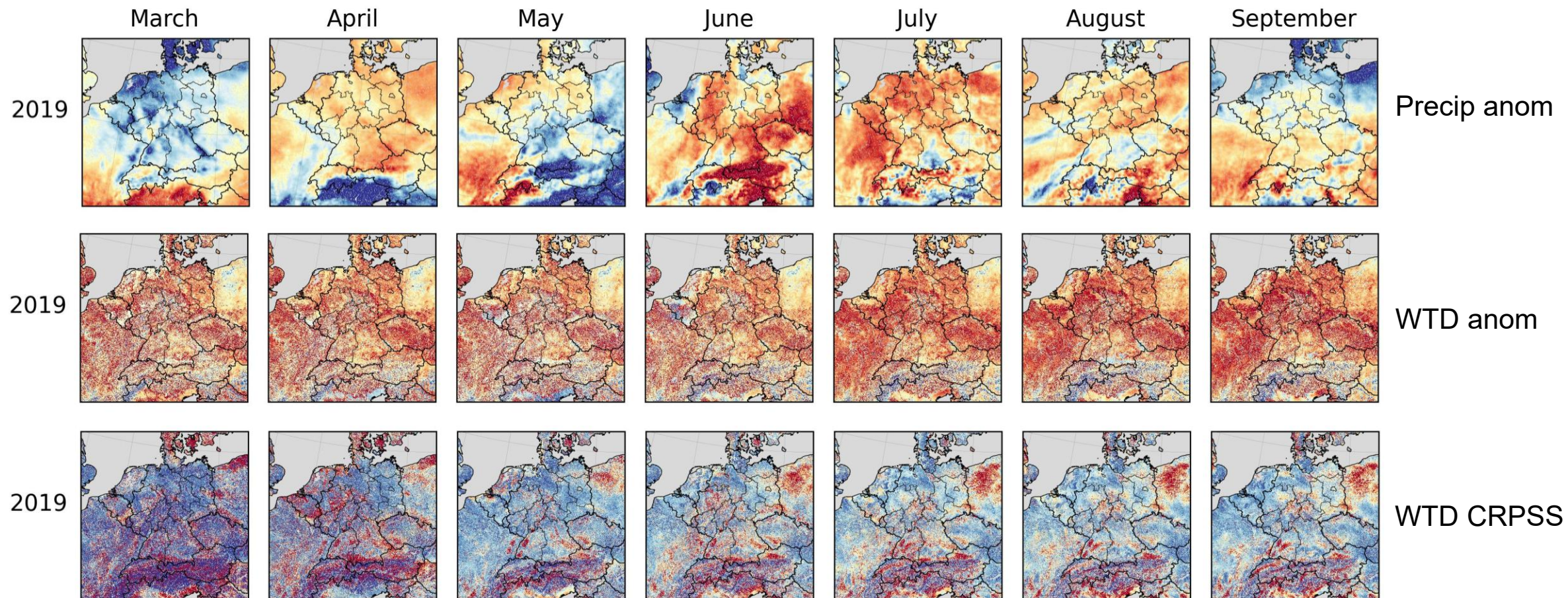
Monthly CRPSS for water table depth from seasonal forecast compared to 2013-2023 climatology-based "pseudo-forecast"

Seasonal forecast shows higher skill than climatology-based forecast for WTD



wet conditions in spring + strong meteorological drought
→ agricultural drought onset → low skill

Seasonal forecast shows higher skill than climatology-based forecast for WTD



dry conditions in spring + less pronounced precipitation deficit
→ agricultural drought continuing → higher skill

Seasonal forecast skill of water table depth with ParFlow/CLM

How do we perform the forecasts?

What is the overall skill of the forecasts?

Are we able to forecast droughts?

Dry conditions are generally well forecasted

Even if the skill decreases after the first month

Area Under Curve of the Relative Operating Characteristic

→ Skill for dry extreme events

→ Probabilistic contingency table for lower quintile of distribution

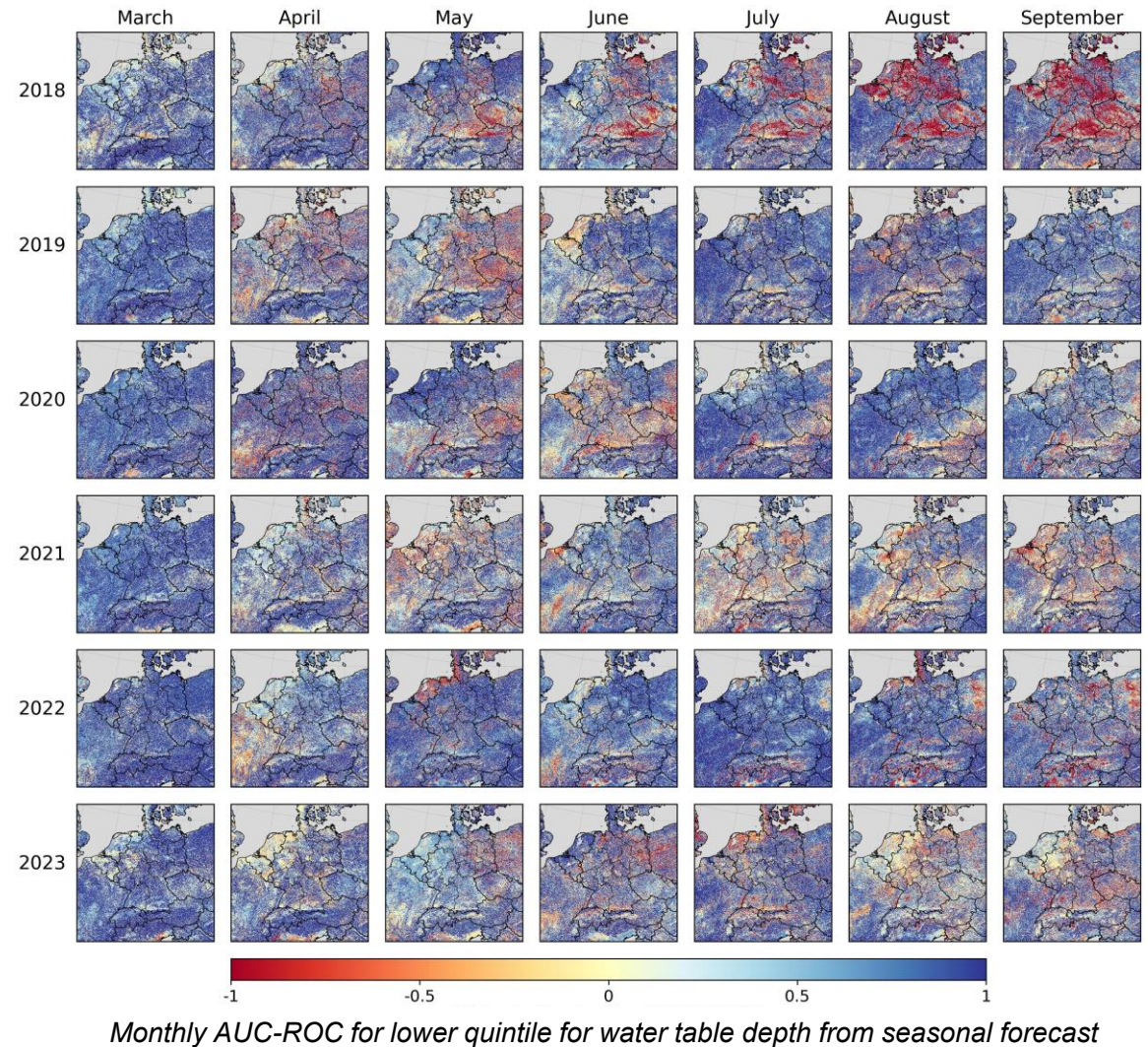
→ 1 = high skill, ~ 0 = no skill

More extreme, **drier conditions are represented** in the probabilistic ensemble

Skill decreases in 2018, spring 2019 and 2020, etc.

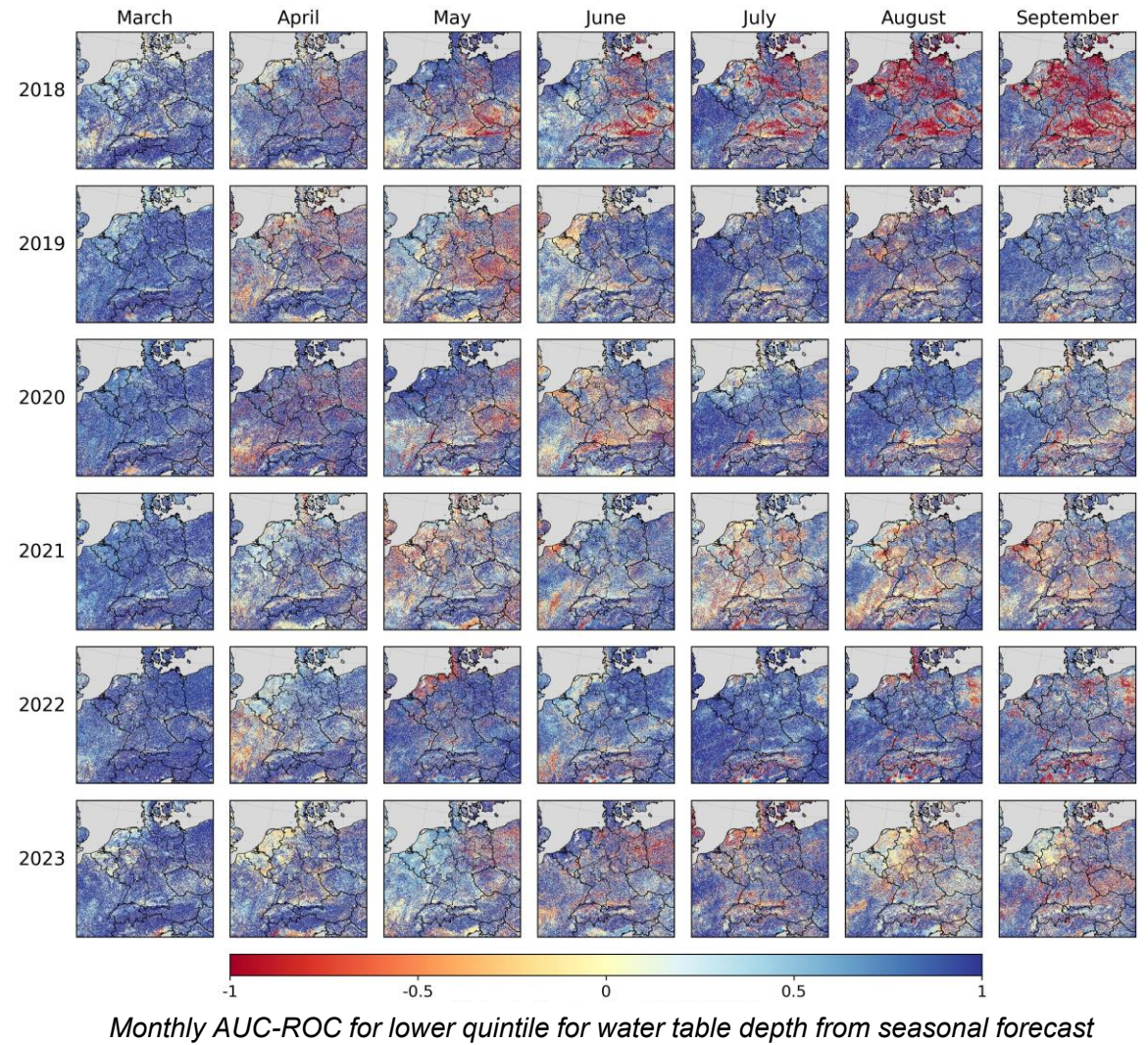
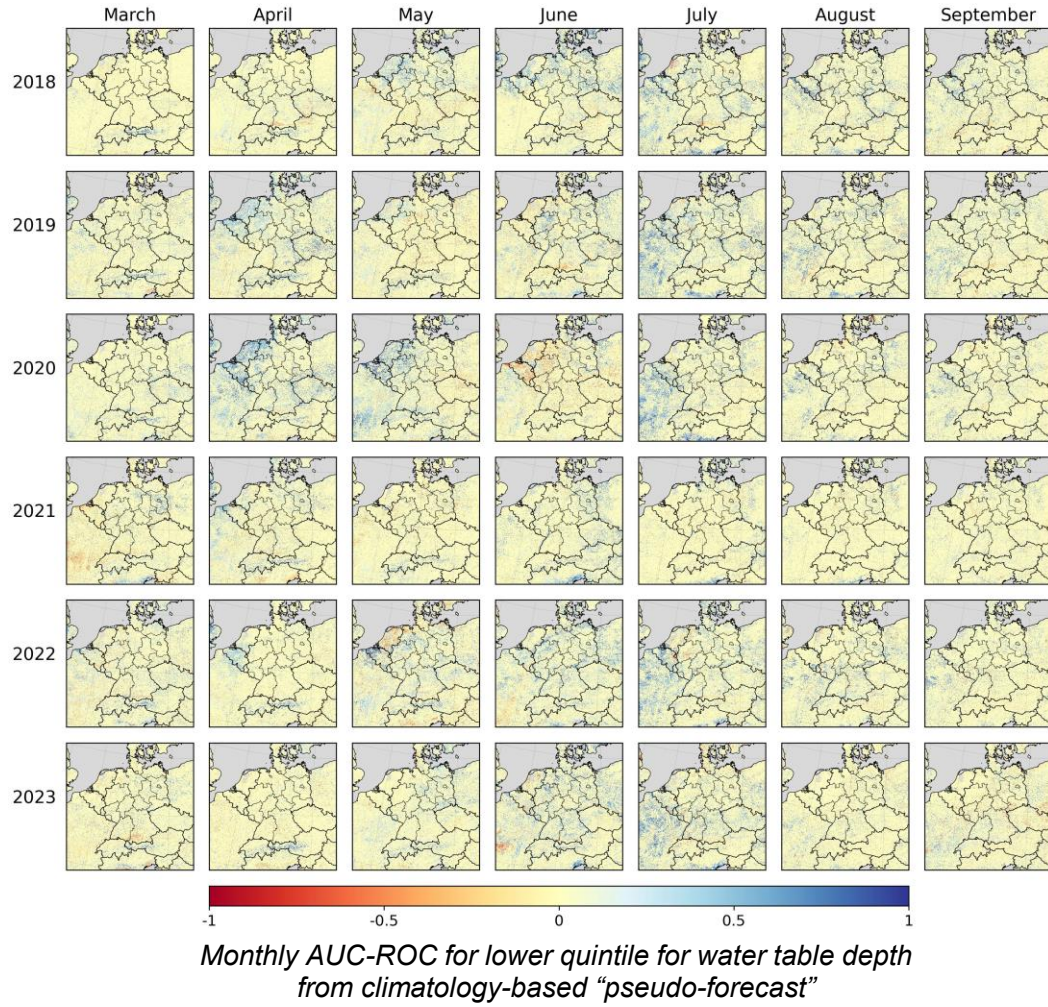
Climatology-based “pseudo-forecast” shows **no skill**

Precipitation from seasonal forecast and climatology also shows **no skill**



Dry conditions are generally well forecasted

Even if the skill decreases after the first month



Seasonal forecast skill of water table depth with ParFlow/CLM

How do we perform the forecasts?

- Hydrological model ParFlow driven by ECMWF forecast
- 50-member probabilistic forecast with different atmospheric forcings

What is the overall skill of the forecasts?

- Seasonal forecast generally outperforms climatology-based “pseudo-forecast”
- Mainly due to the memory effect
- WTD skill highly dependent from atmospheric forcing skill

Are we able to forecast droughts?

- Yes, but needs further investigation
- Ensemble analysis not sufficient, need to focus on tail of distribution



More information, seasonal and daily forecasts:

→ www.wasser-monitor.de

→ www.adapter-projekt.de

Acknowledgement

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