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Quantifying the Sub-seasonal Predictability Limit of 1-km Soil Moisture Drought in Germany

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Skillful sub-seasonal to seasonal (S2S) hydrologic forecasts are essential for proactive, risk-based water management, yet the practical boundary of their usefulness - the predictability limit - remains poorly quantified for high-resolution drought indicators. Here, we use the operational High-resolution Sub-seasonal Hydroclimatic Forecasting System, HS2S (https://www.ufz.de/HS2SForcasts4Germany), providing daily ensemble soil-moisture forecasts for Germany since 2020, and quantify predictability limits with CRPS (Continuous Ranked Probability Score), a strictly proper scoring rule for probabilistic forecasts.

HS2S couples the mesoscale Hydrologic Model (mHM; https://mhm-ufz.org) with ECMWF extended-range ensemble meteorological forecasts. In the latest version of the forecasting system (Hs2S v0.2), 51 atmospheric ensemble forecasts are interpolated from 10~km to 1~km using external drift kriging and subsequently bias-corrected, enabling near-real-time hydrologic forecasting and uncertainty estimates.

We quantify predictability limits for recent drought conditions in Germany, focusing on the persistent multi-year drought of 2018--2022 and the acute drought conditions observed in 2025. Using the Soil Moisture Index (SMI; total soil column), we diagnose how forecast skill decays with lead time (up to 42~days) and how this decay varies across space. To contextualize the added value of meteorological forcing versus hydrologic persistence, we benchmark HS2S against (i) an Ensemble Streamflow Prediction (ESP)-style reference that propagates initial hydrologic conditions with historical meteorological sequences and (ii) a purely statistical ARIMA baseline. We further isolate the contribution of initial hydrologic conditions, derived from high-density German Weather Service (DWD) station observations, and show how land-surface "memory'' can extend useful predictability beyond that provided by meteorological forcing alone. The results provide a benchmark for further impact-based drought early warning studies and identify actionable windows of opportunity in which high-resolution forecasts add decision-relevant value.