26th International Congress on Modelling and Simulation, Adelaide, SA, Australia, 30 Nov–4 Dec 2025
mssanz.org.au/modsim2025

Stream J – Invited keynote

Bending time and space to predict hydrological extremes at decadal timescales

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Abstract: We live in an era where models can simulate the climate many decades into the future, embracing intertwined dynamics, rich initial conditions, and exponentially expanding computing power that allows multiple ensembles and uncertainty quantification. These models, however, are coarse, approximate and uncertain, with past attempts at direct use leading to limited success as they lose the plot a few months into the future.

What can, then, be the solution to our hydrological predictability barrier? The answer to this question may lie in asking why predictability deteriorates with lead time. In our investigations of this problem, we realised a key reason for poor long-lead predictability is that the climate predictors being used exhibit a markedly different spectrum than the hydrological response being predicted. While spectral mismatches can be overcome through the use of filters (such as the catchment store in a hydrological model which changes rainfall into streamflow, or a de-noising filter in a mobile phone camera that makes blurry images appear perfect), designing a generic filter is complex and fraught with limitations of generalisability that all hydrologic modellers would attest to.

Can use be made then of a mathematical filter designed to re-create a spectrally mismatched predictor to one that is more suitable? By re-weighting the power associated with different frequencies of the predictor spectrum, we re-cast the mismatched predictor into a new incarnation that is spectrally consistent with the response. In other words, if we were attempting to predict seasonal rainfall in Adelaide using the NINO3.4 Index that represents climate anomalies in the middle of the Pacific, we present an alternative that transforms the NINO3.4 Index to a version specific for Adelaide which exhibits the same spectrum as the response being modelled. We show that this spectral modification alone can improve predictability, although the improvement comes at the cost of the complexity the resulting model now exhibits.

We next present a way around this model complexity barrier by generalising the prediction model while using the same spectral transform as above. This generalisation utilises the learning abilities of a Machine Learning model by substituting space for time while using the localised predictors obtained based on the spectral transformation. This method increases complexity in the model structure, needing larger data input to give steadier predictions. At each lead, we pool spatial samples together with lead-dependent temporal windows to enlarge the effective training set and stabilise estimates. This enables the machine learning framework to optimize our robust and high-performance hydrologic prediction platform. We show that this platform is able to increase the predictability horizon of seasonal rainfall to an average of 48 months and expands the area exceeding our skill criterion to nearly the entire Australian continent. This is a significant increase from 12 months for the North Monsoon Region (NMR) that was first reported by us in (Choudhury et al, 2019), later enhanced to 24 months for most regions in Australia in (Jiang et al, 2025) that first used the spectral transformation as a pre-processing tool. Given this result uses default climate model simulations, there is scope for further improvement by choosing models sensitively, and even more so by refining the models to exhibit greater accuracy as they evolve with enhancements in our understanding, data and computational abilities.

REFERENCES

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Keywords: *Hydrologic forecasting; Decadal forecast; Spectral transformation*

