Predicting ENSO Events and their Regional Impacts Beyond a Year

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1. Introduction

The El Niño–Southern Oscillation (ENSO) is a major driver of global and regional climate. El Niño (warm) and La Niña (cold) phases — typically last 9–12 months but can persist longer.

Prolonged ENSO events beyond a year can cause severe regional impacts – e.g., 2010–12 and 2020–23 multi-year La Niña events brought prolonged rainfall and severe flooding in eastern Australia, while the 2014–16 and 2018–20 multi-year El Niño events triggered heatwaves, bushfires, and droughts across Australia.

Reliable multi-year ENSO forecasts are critical for building climate resilience and managing risks. However, lack of long-term seasonal hindcast records and high computational costs, makes the climate prediction beyond a year challenging.

How well can ENSO events and their regional impacts be skilfully predicted beyond a year in real-world?

2. Objectives

This study evaluates the potential for long-lead dynamical climate prediction beyond a year, focusing on the predictability of multi-year El Niño and La Niña events, and their regional impacts in Australia.

Additionally, we assess the predictability of key ocean–atmosphere processes driving ENSO asymmetry and identify sources of uncertainty that limit long-range forecasts.

3. Data & Method

Model: ECMWF - SEAS5-20C *(Weisheimer et al. 2022)*
State-of-the-art Coupled Model & Data Assimilation System

- ECMWF's IFS coupled model – similar to SEAS5
- SEAS5 low-resolution configuration - coupled data assimilation
- Start dates per year: 1 May and 1 November
- Forecast lead time : 24-months with 10 ensemble members
- Hindcast period: 1901-2010, 110 years
- Initialization with CERA-20C *(Laloyaux et al. 2018).*

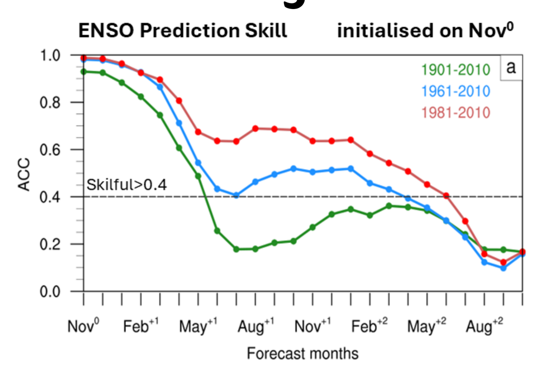
Data for Verification

- Monthly gridded ERSST.v5 SST (Huang et al. 2017)
- Monthly CERA-20C ocean heat content (OHC) *(Laloyaux et al. 2018)*
- Monthly ERA-20C 10-m wind (Poli et al. 2016).

Selection of ENSO events - based on observed [Nino3.4] Indices
El Niño(EN): normalised [Nino3.4] ≥ +0.5
La Niña(LN): normalised [Nino3.4] ≤-0.5
Multi-year events → when [Nino3.4] threshold persists beyond a year.

4. Key Results & Discussions

I. Long-lead ENSO prediction skill



Based on Anomaly Correlation Coefficient (ACC) metrics:

SEAS5-20C has high predictive skill for ENSO events with a lead time beyond a year when initialised on 1st November.

Best skill in recent period.

The model shows better ENSO prediction skill when the forecasts are initialised on 1st November near mature El Niño state.

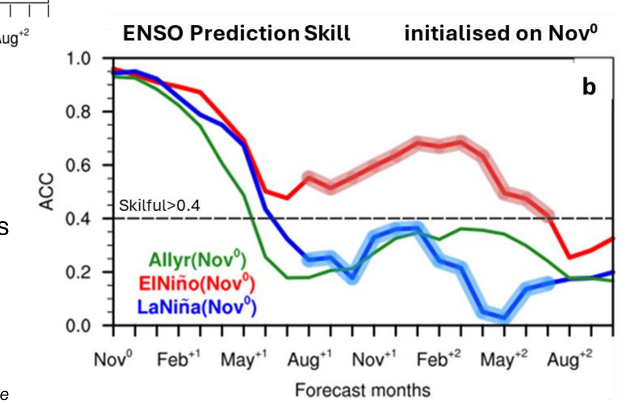
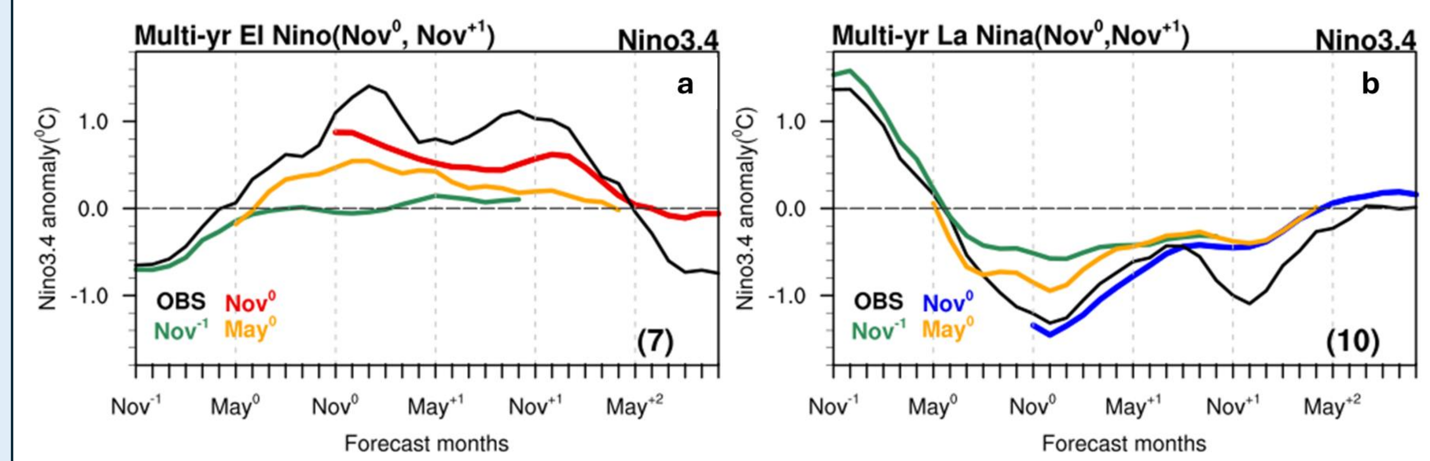


Fig. 1 *Sharmila et al. (2023), J. Climate*

II. Prediction of Multi-year ENSO events

Composited time series of Niño3.4 indices for all initialised forecasts relative to ERSST



The model can predict multi-year El Niño events up to 18 months when initialized near a mature El Niño state (Nov⁰), but underestimates Niño3.4 SST anomalies in the subsequent year (Nov⁺¹).

Predicting the multi-year La Niña events are challenging from a La Niña state, but more robust when initialised from peak El Niño state .

Fig. 2 *Sharmila et al. (2025), under review*

III. Prediction of Key Processes in Equatorial Pacific

Composited temporal evolution of SST, 10m wind anomalies in the equatorial Pacific (5°S-5°N) for multi-year ENSO events based on a) observation, b) Nov0 forecasts initialized at the peak ENSO state, and model forecast errors (c).

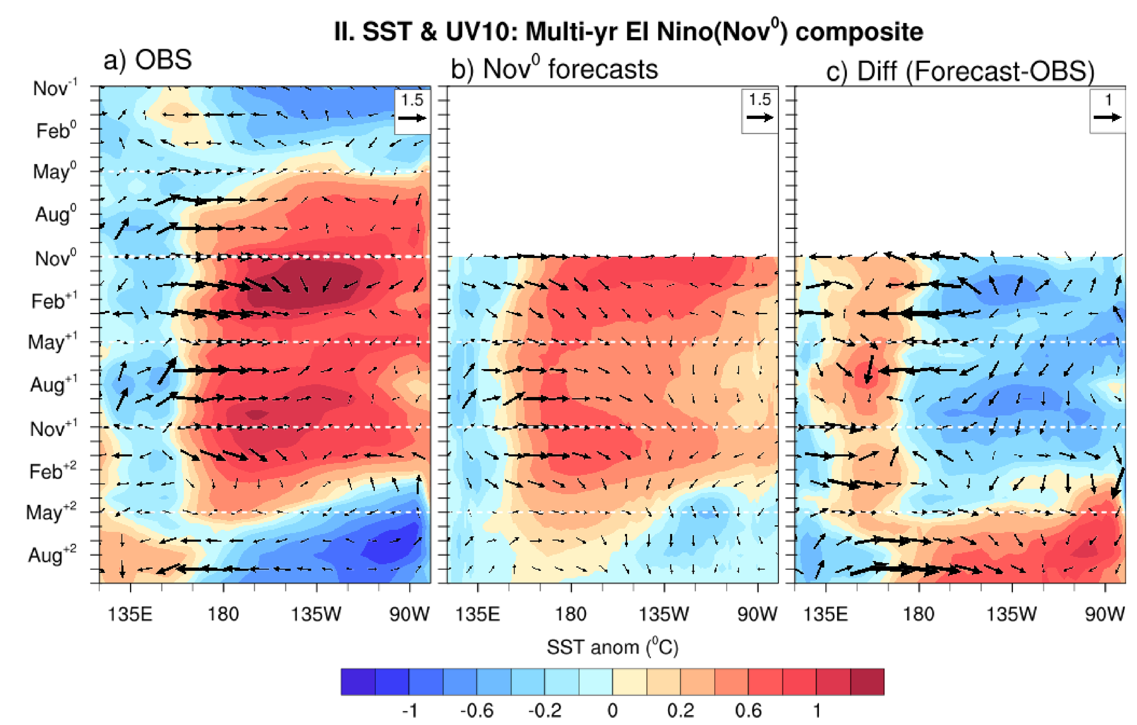
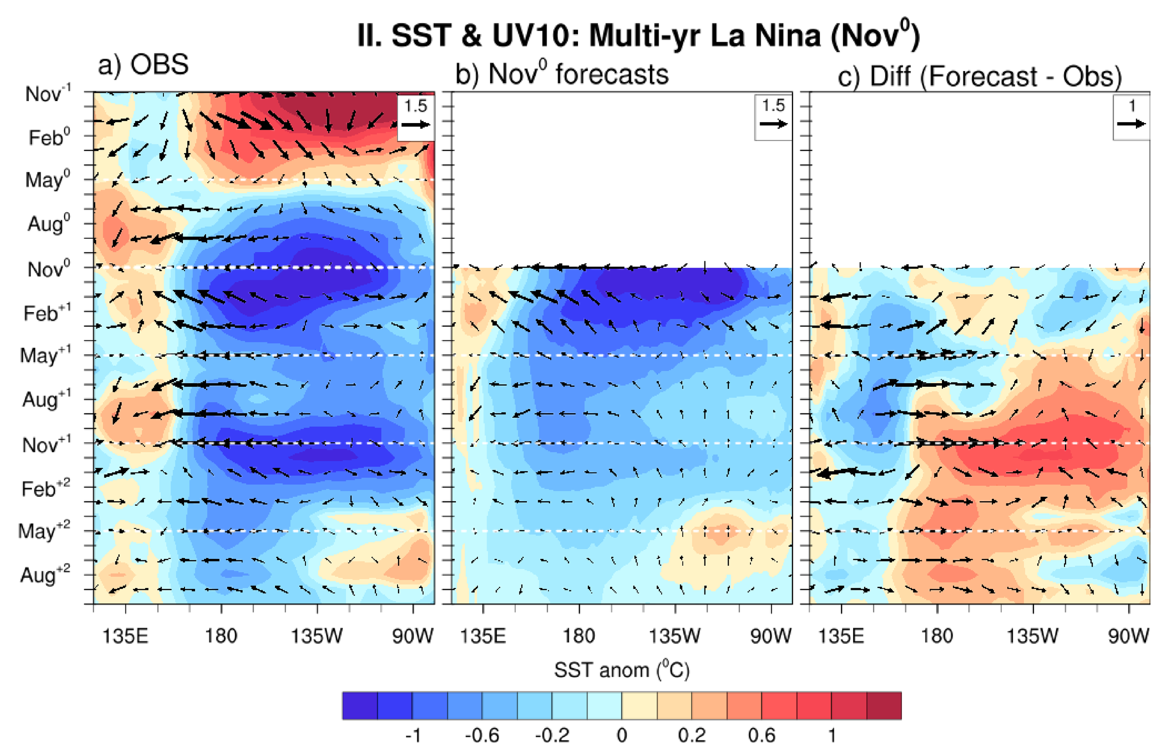


Fig. 3

Nov⁰ initialised forecast well predicts SST and wind anomalies during first and second peak of multi-year El Niño event but underestimates their magnitudes during the second peak in year +1.

However, both the predicted equatorial ENSO SST anomalies and associated near-surface wind anomalies are more westward displaced compared to the observation, dur to well-known cold-tongue bias.

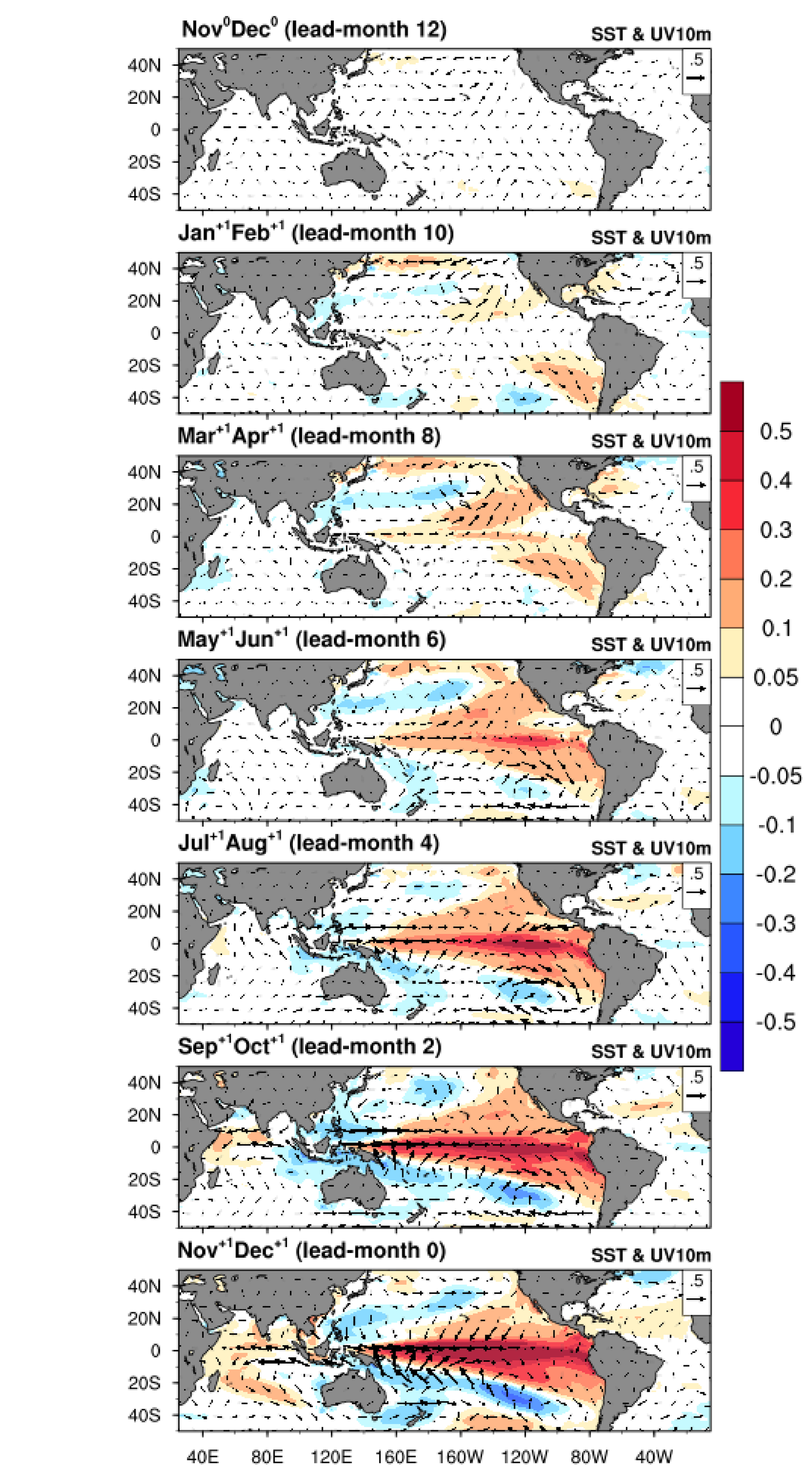


For multi-year La Niña, Nov⁰ initialised forecast well predicts SST and wind anomalies during first peak but struggles to predict the second peak at the end of year +1.

Fig. 4 *Sharmila et al. (2025), under review*

V. Sources of prediction uncertainty

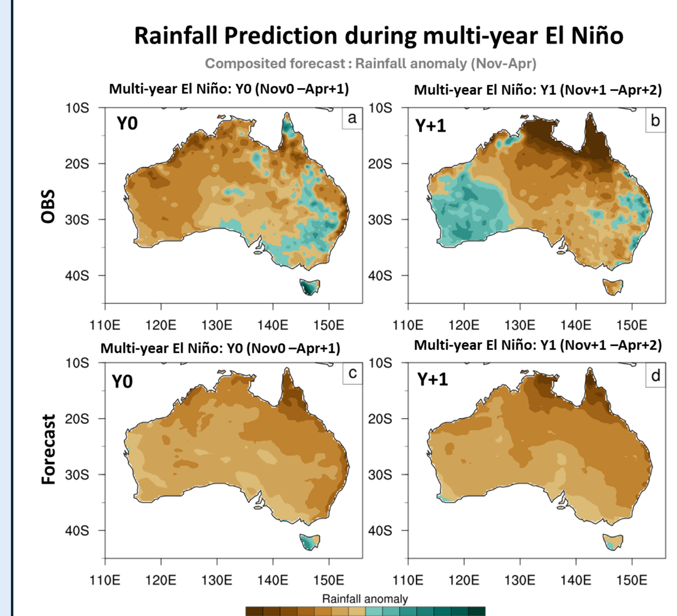
Lag-Regressed maps based on ensemble spread in next year Niño3.4 SST index (Nov⁺¹, 12-month lead) and ensemble spread in SST (shaded) and UV-10m (vectors) anomaly in the preceding months from Nov⁰ forecasts.



Subseasonal atmospheric noise in the subtropical Pacific and its interaction with the equatorial ocean—via the seasonal footprint mechanism—is the main source of second-year prediction uncertainty.

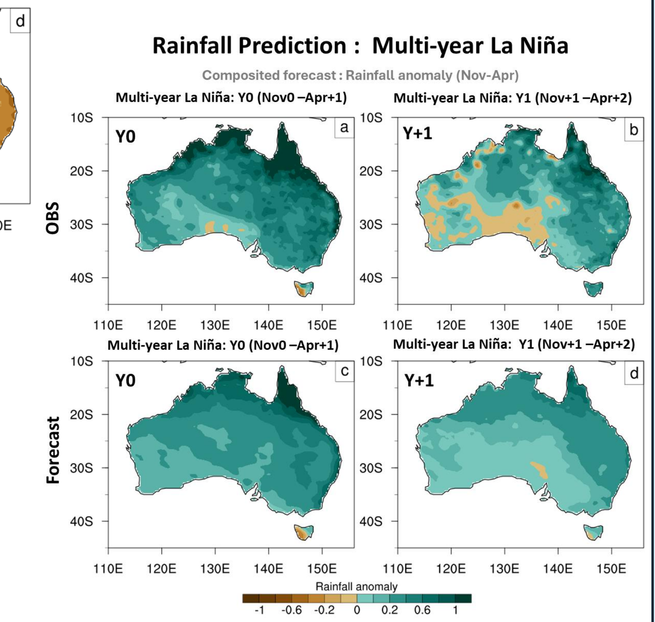
Fig. 6 *Sharmila et al. (2025), under review*

IV. Prediction of Regional Impacts



Based on Nov0 initialised forecasts:

Model predicts overall dry conditions across Australia during 1st (Y0) and 2nd (Y+1) wet-season of multi-year El Nino events but underestimates the rainfall magnitude.



Model predicts overall wet conditions during 1st (Y0) and 2nd (Y+1) wet-season of multi-year La Nina events across Australia but underestimates the rainfall magnitude.

The model also predicted the asymmetry in 2nd wet-season (Y+1) to some extent.

Fig. 5 *Sharmila et al. (in prep.)*

5. Conclusions

- SEAS5-20C can skilfully predict ENSO events with a lead time beyond a year up to 18 months when initialised on 1st November.
- Multi-year El Niño and La Niña events can be predicted up to 18 months when initialised at peak El Niño state.
- Predicting the duration of La Niña events is difficult when starting from a La Niña state.
- The model captures the multi-year ENSO-related processes in the equatorial Pacific in the following year.
- The model could predict the multi-year ENSO-related wet/dry rainfall anomalies during wet-season across Australia to some extent – providing prospects for regional climate forecasting beyond a year.
- Subseasonal subtropical atmospheric noise and associated air-sea interaction in the equatorial region limit predictive capacity beyond this time-frame.
- Overall, the study shows good prospects for extending climate predictions up to 2 years.

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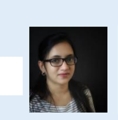

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