Rapid development of systematic ENSO-related seasonal forecast errors

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Introduction

El Niño-Southern Oscillation (ENSO) is an important driver of global seasonal climate, yet seasonal forecast models exhibit systematic biases in its representation. In this study we examine these biases in six operational seasonal forecast models to characterise their spatial structure and temporal evolution as a function of forecast lead and seasonal cycle.

Data and methods

- Multi-decade hindcasts from eleven seasonal forecast models: ECMWF SEAS5, DWD GCFS2.1, ECCC CanCM4i, ECCC GEM5-NEMO, CMCC SPS3.5, GFDL-SPEAR, NASA GEOS-S2S, UKMO GloSea6-GC3.2, Meteo-France System 8, NCEP CFSv2 and JMA CPS3
- Hindcasts have initialisation dates from July to February
- Models are verified against ERA5 reanalysis
- "ENSO-related" error is defined as the regression of forecast error against the observed (ERA5) Niño3.4 index

Results

1) ENSO explains a large percentage of SST and rainfall error variance

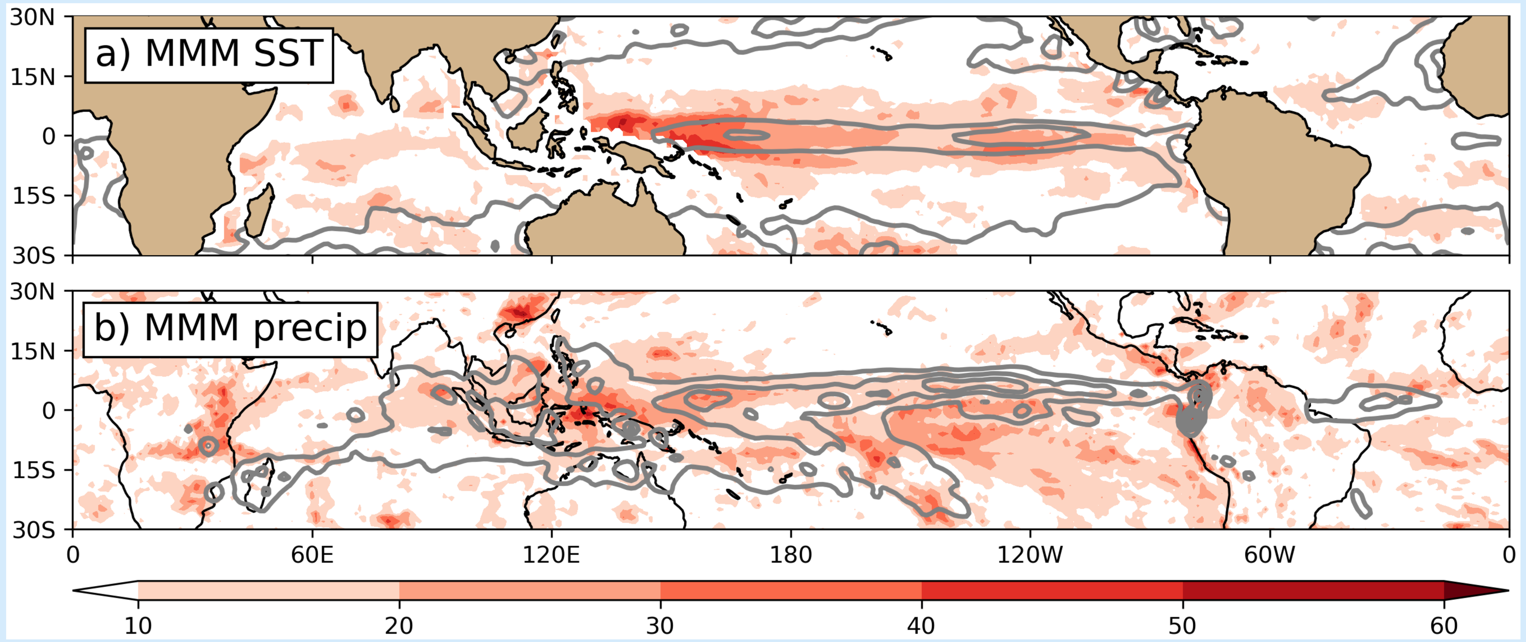


Figure 1: Shading shows the DJF MMM percentage of error variance explained by the observed Niño3.4 index for (a) SST and (b) rainfall. Grey contours show the variance of the model error in each variable.

- ENSO explains up to 50% or more of the MMM SST error variance in the equatorial Pacific (Figure 1a)
- ENSO explains slightly less of the rainfall error variance, but still greater than 40% in the west Pacific (Figure 1b)
- This indicates that errors in SST and rainfall in the tropical Pacific are strongly linked to ENSO

3) Forecast error depends primarily on seasonal cycle and less on forecast lead time

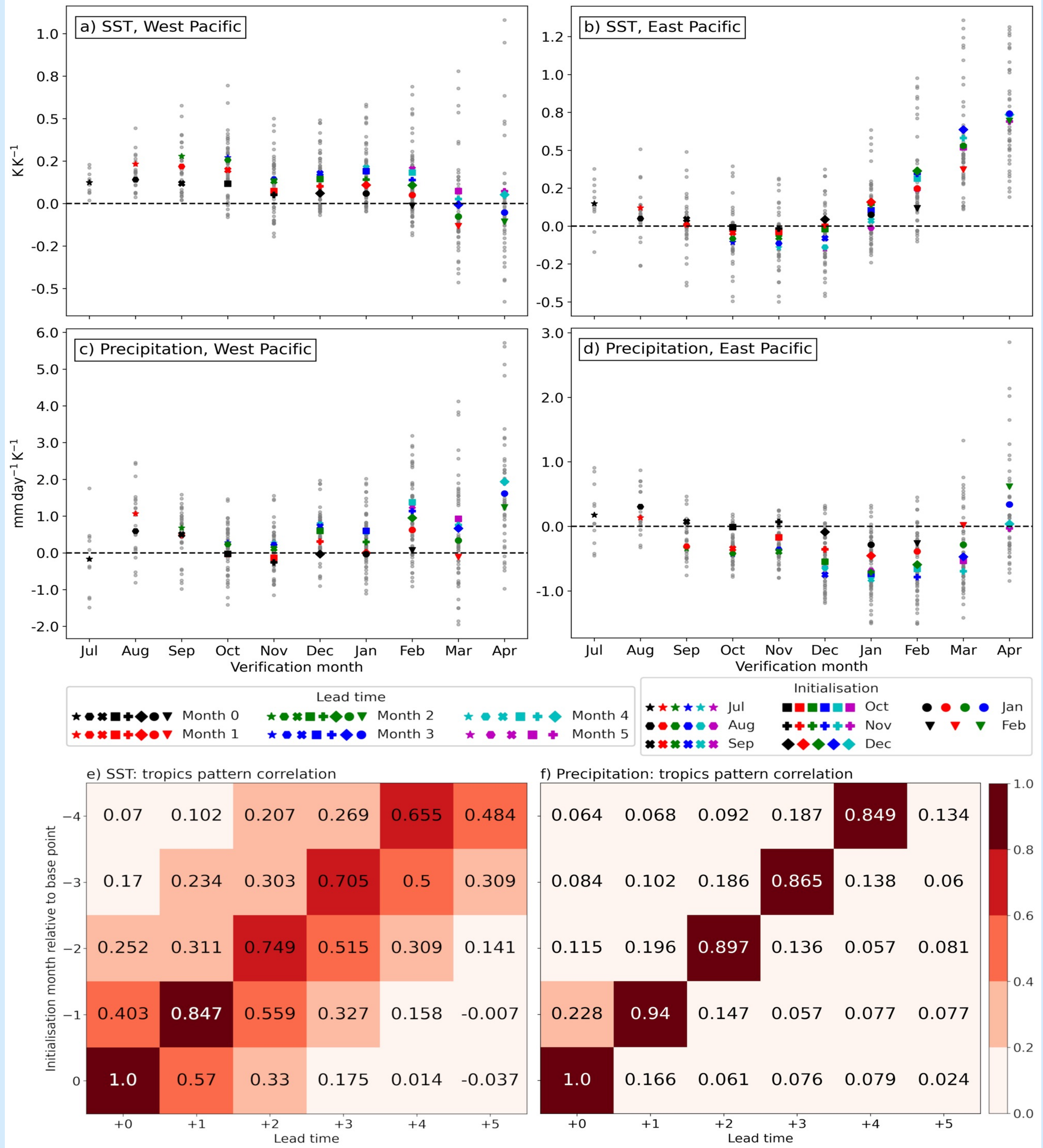


Figure 3: MMM (a, b) SST error and (c, d) precipitation error regressed against the observed Niño3.4 index averaged over (a, c) the West Pacific and (b, d) the East Pacific. Regions used for averaging are shown in Fig 2. Different colours represent different lead times, and different symbols represent different initialisations. Grey dots indicate individual model simulations. (e, f) show the pattern correlations for tropical ENSO-related SST and precipitation errors for four different base months as a function of lead and initialisation.

- The magnitude of ENSO-related error depends primarily on verification month, although there is some intensification with lead time (Figure 3a-d)
- This suggests that the errors are developing so rapidly that the forecast quickly enters the climate model state
- As well as the magnitude, the patterns of ENSO-related error are also very similar for a range of lead times for a given verification month (Figure 3e-f)

4) ENSO-related seasonal forecast errors develop very rapidly

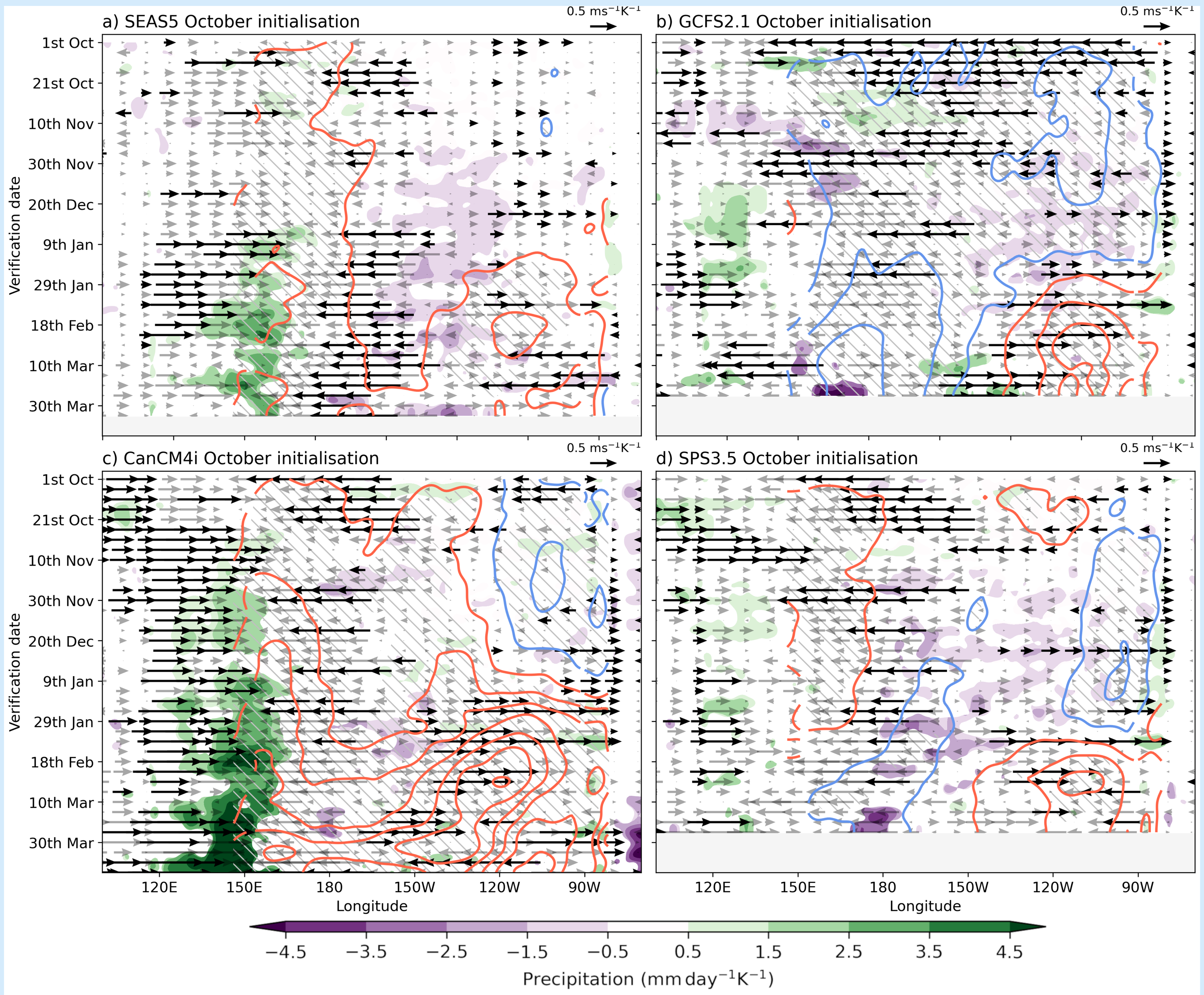
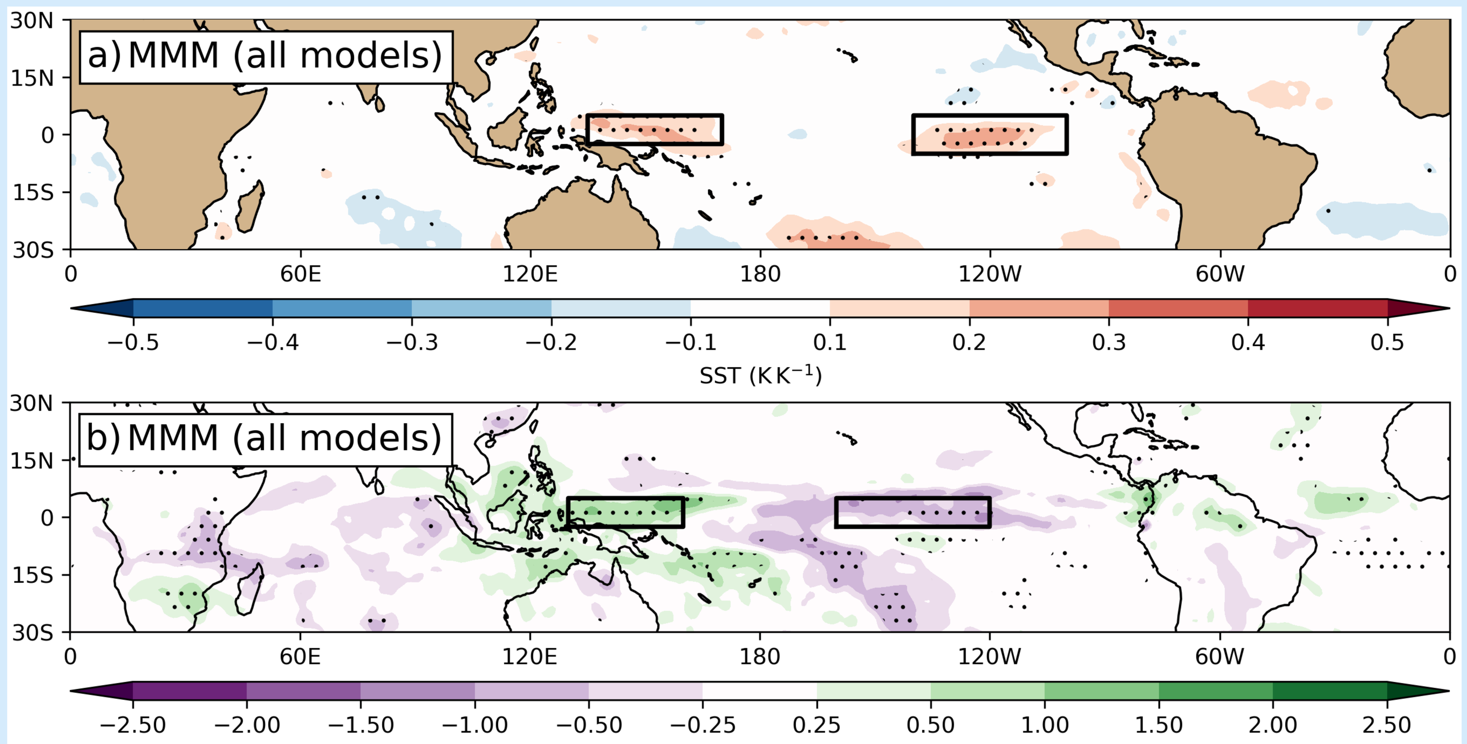


Figure 4: Hovmöller diagrams showing the evolution of the pentad-averaged ENSO-related error for October initialisations for SST (contours), precipitation (shading) and 10 m zonal wind (vectors) averaged between 5°N-5°S for (a) ECMWF SEAS5 (b) DWD GCFS2.1 (c) ECCC CanCM4i and (d) CMCC SPS3.5. For precipitation, only significant values are plotted. Significant wind vectors are shown in black. Significance for SST is shown by the grey hatching. Contours for SST are every 0.2 K K^{-1}, including contours for -0.1 and 0.1 K K^{-1} (blue for negative, red for positive).

- All four models (those with daily data) develop ENSO-related errors within the first pentad following initialisation (i.e. Days 1-5 mean)
- Positive errors in west Pacific SST and easterly wind errors appear rapidly in three of the models, followed by rainfall errors, which arise due to anomalous convergence
- There is some indication that errors appear first in the near-surface wind, before subsequently inducing the SST errors, although this requires further analysis

2) There are systematic errors in ENSO simulation for both SST and rainfall in the tropical Pacific



- Positive ENSO-related SST errors are apparent in both the western and eastern Pacific (Figure 2a)
- The west Pacific error is indicative of an extension or westward shift of ENSO SST anomalies
- The east Pacific error is related to slow model decay of ENSO events in late winter and spring
- ENSO-related rainfall errors indicate a westward shift of ENSO rainfall anomalies towards the west Pacific (Figure 2b)
- This shift is largely consistent across all eleven models

Figure 2: (a) Multi-model mean DJF SST error for forecasts initialised in October regressed on the observed Niño3.4 index (b) Same as (a), but for precipitation.

Summary and conclusions

- **Seasonal forecast models exhibit systematic errors in their representation of ENSO events in the equatorial Pacific**
- **These include a westward extension or shift of ENSO SST anomalies, and a too-slow decay in late winter and early spring**
- **These errors develop so rapidly – within the first two weeks following forecast initialisation – that the forecast anomalies quickly transition from nature's attractor to the climate model attractor, leading to the errors becoming a function of the seasonal cycle rather than lead time**
- **These errors are likely to have important impacts on extratropical seasonal forecast skill, through driving errors in Rossby wave propagation**
- **This work has recently been accepted for publication in Geophysical Research Letters (Beverley et al., 2023)**

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