A Linear Inverse Model of Tropical and South Pacific Seasonal Predictability

EGU Assembly 2020

CL3.2: Predictions of climate from seasonal to (multi)decadal timescales (S2D) and their applications

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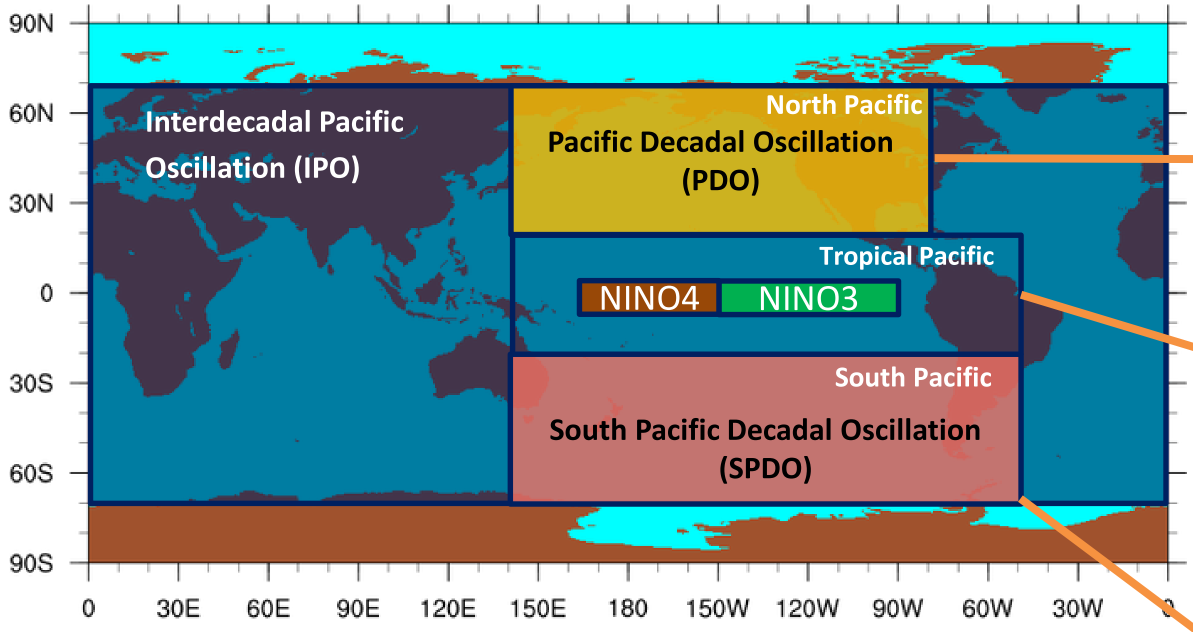
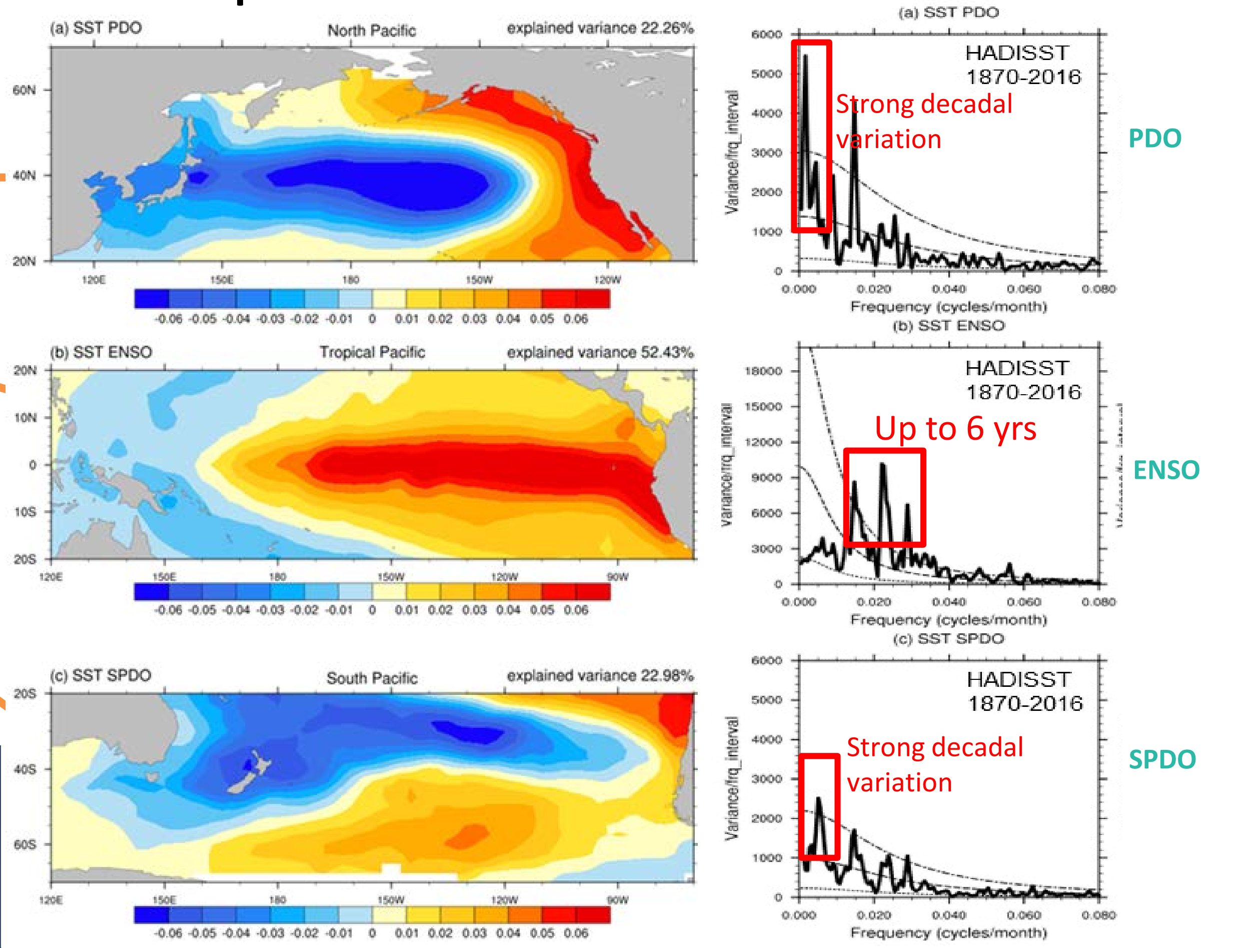
Background: The leading climate modes of variability in Pacific Ocean



Spatial Patterns

Temporal Variability



Definitions:

1. El Nino-Southern Oscillation (ENSO): NINO3, NINO4, NINO3.4, NINO1+2, etc. Area averaged sea surface temperature in some boxes in the Tropical Pacific.

2. Pacific Decadal Oscillation (PDO): The first EOF mode of Pacific sea surface temperature poleward of 20ºN (Mantua et al. 1997).

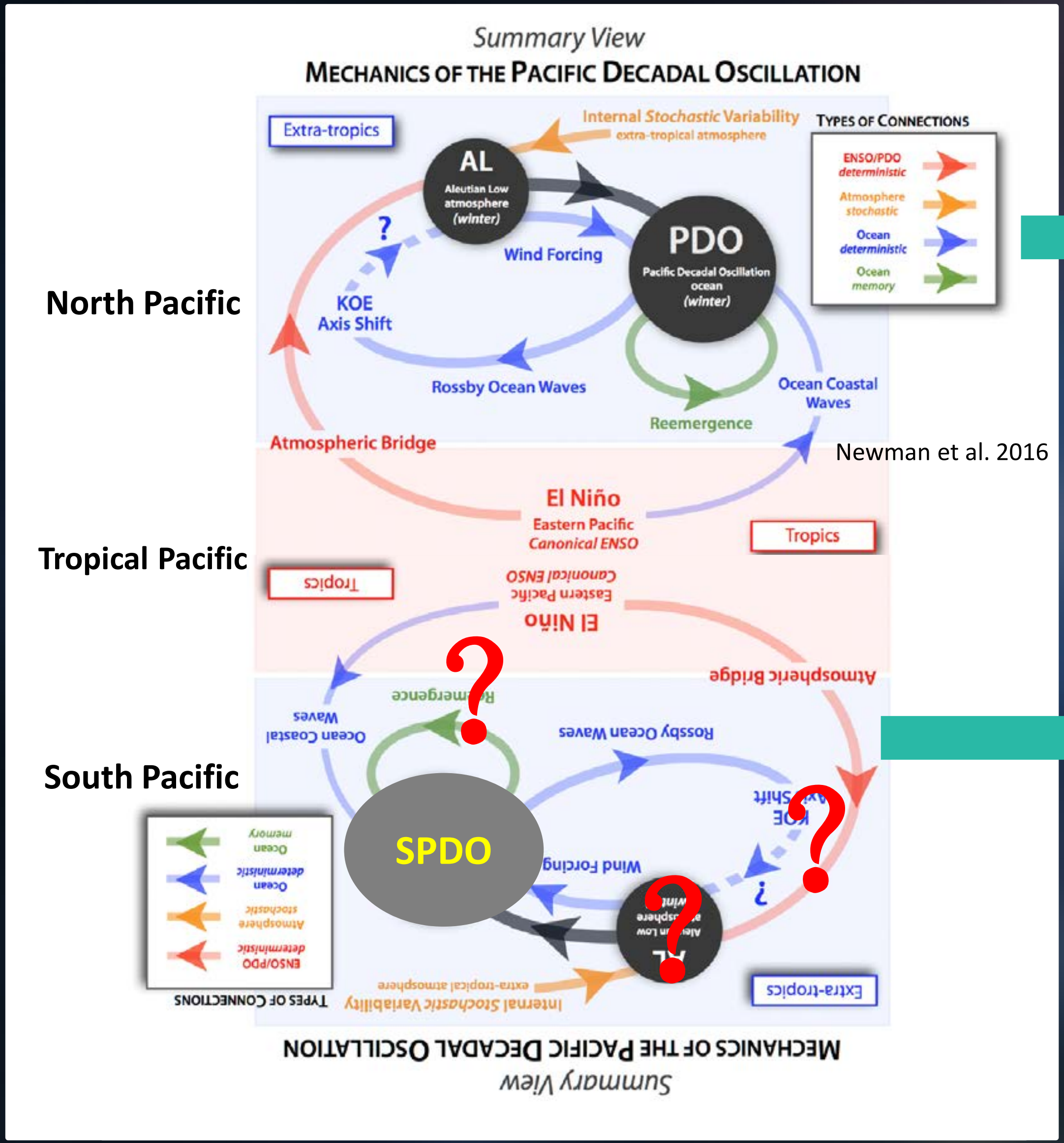
3. South Pacific Decadal Oscillation (SPDO): The first EOF mode of Pacific sea surface temperature poleward of 20ºS (Chen and Wallace 2015).

4. Interdecadal Pacific Oscillation (IPO): The third EOF mode of the low-frequency global sea surface temperature (Power et al. 1999).

Spatial patterns: The PDO and SPDO patterns look very much like the ENSO pattern, but meridionally broader than ENSO over equatorial Pacific.

Temporal variability: ENSO fluctuates in the order of years. The PDO and SPDO fluctuate in the order of decades.

Background: The region of interest— South Pacific



The PDO in the North Pacific

It has been recognised that the PDO is not simply a single physical mode but instead largely represents the combination of different processes operating on different time scales. These multiscale processes include **white noise atmospheric forcing**, **ENSO teleconnections** and **oceanic processes** **(Newman et al. 2016)**.

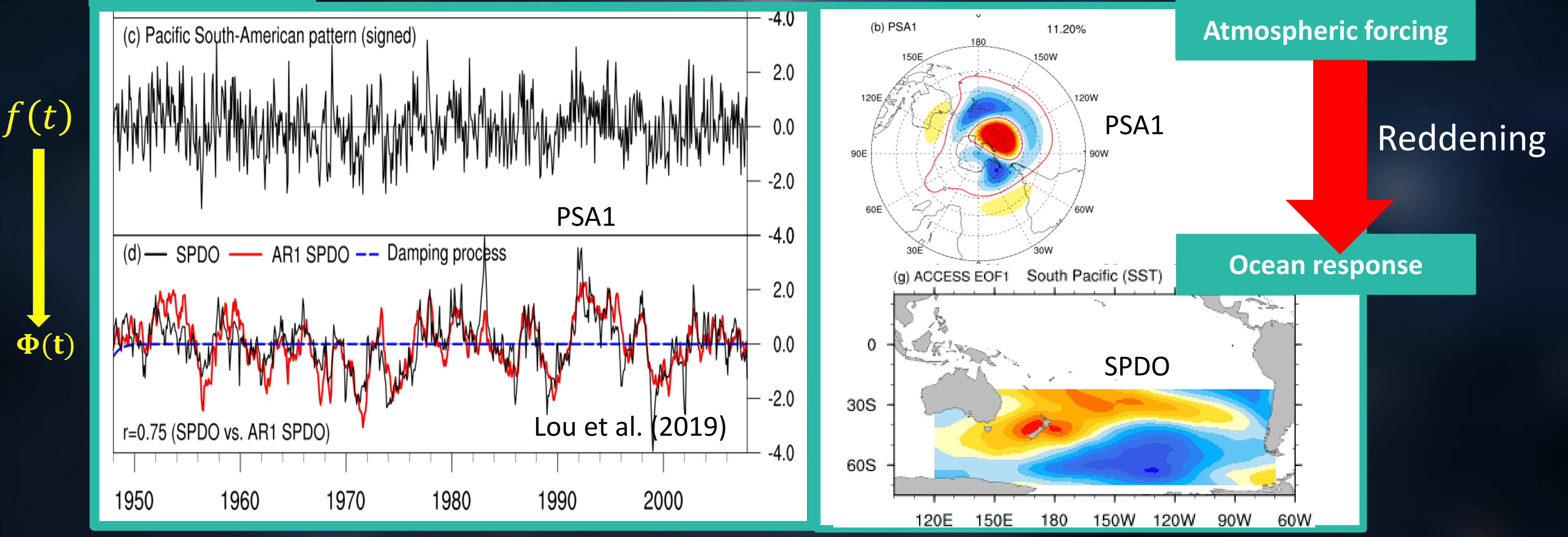
The SPDO in the South Pacific

Hypothesis: The SPDO also integrates multiple dynamics of the atmospheric forcing, ENSO teleconnections and oceanic processes in the Southern Hemisphere.

The role of atmospheric forcing

The first-order of autoregressive (AR1) model: $$\frac{d\Phi(t)}{dt} = f(t) - \frac{\Phi(t-\Delta t)}{\tau_{sur}} \quad (1)$$

South Pacific



The PSA1 is the key atmospheric driver for the SPDO over South Pacific (Lou et al. 2019).

What is the linear inverse model (LIM)?

LIM is the multivariate generalization of univariate AR1 model.

Stochastic forcing term (fast processes)

Time-continuous equation: $$\frac{d\mathbf{x}}{dt} = \boxed{\mathbf{Lx}} + \boxed{\xi}$$

Linear deterministic feedback term (slow processes)

Time-discrete equation: $$\mathbf{x}_{t+\tau} = \boxed{\mathbf{G}_\tau \mathbf{x}_t} + \boxed{\xi dt}$$

Green Function: $$\mathbf{G}_\tau = \exp(\mathbf{L}\tau) = \langle \mathbf{x}_{t+\tau}\mathbf{x}_t^T \rangle \langle \mathbf{x}_t \mathbf{x}_t^T \rangle^{-1}$$

τ-lag covariance matrix of **x**

Inverse matrix of 0-lag covariance of **x**

LIM design

Whether a LIM works or not depends on how we define the state vector $\mathbf{x}$

- Madden-Julian Oscillation (Cavanaugh et al. 2014)
- Atlantic Multidecadal Variability (Zanna 2012)
- North Pacific Decadal Variability (Alexander et al. 2008)
- ENSO (Penland and Sardeshmukh 1995)
- Tropical-North Pacific coupled system (Newman 2007)

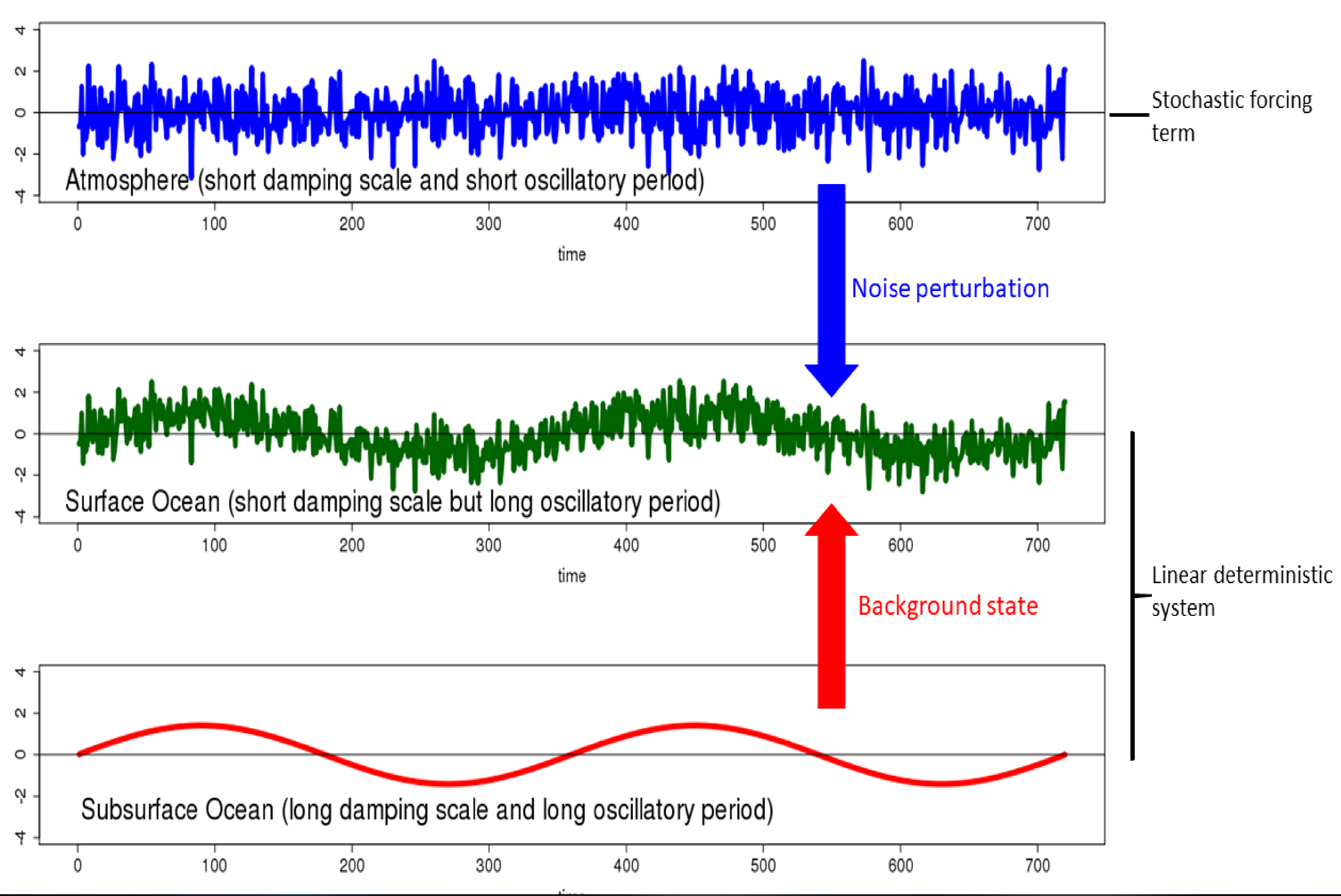
➢ In our work:

$$\frac{d\mathbf{x}}{dt} = \mathbf{L}\mathbf{x} + \xi \begin{cases} \mathbf{x} = \begin{bmatrix} \text{TP SST} \\ \text{SP SST} \end{bmatrix} & \text{SST-only experiment} \\ \mathbf{x} = \begin{bmatrix} \text{TP SST} \\ \text{SP SST} \\ \text{SP VAT} \end{bmatrix} & \text{SST+VAT experiment} \end{cases}$$

➢ Due to nonlinearity, instability or non-stationarity of the true processes and imperfections of observational data, it is very likely to run into singular issues (data matrix $\mathbf{x}$ is not invertible) if the observational data are used directly.

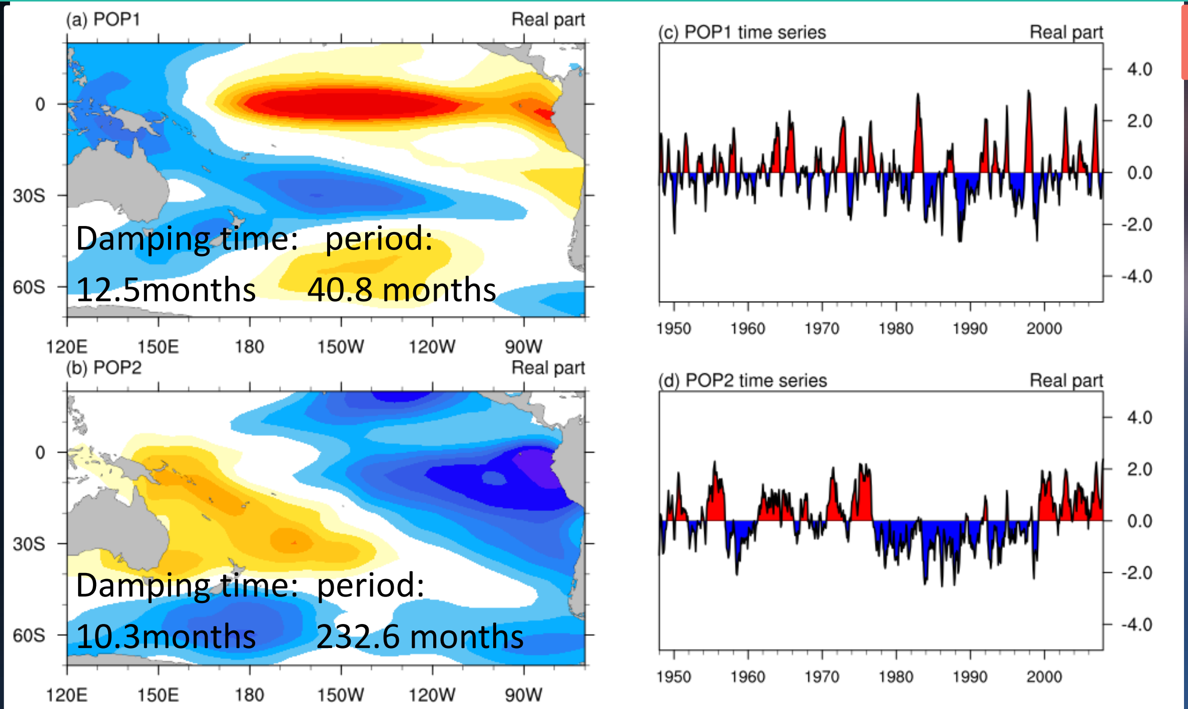
➢ In order to avoid singular issues, we need to reduce the freedom of the data first by applying the Empirical Orthogonal Function (EOF) analysis. In my study, 10 leading PCs have been used.

Basic concepts: Damping time scales & Oscillatory Period

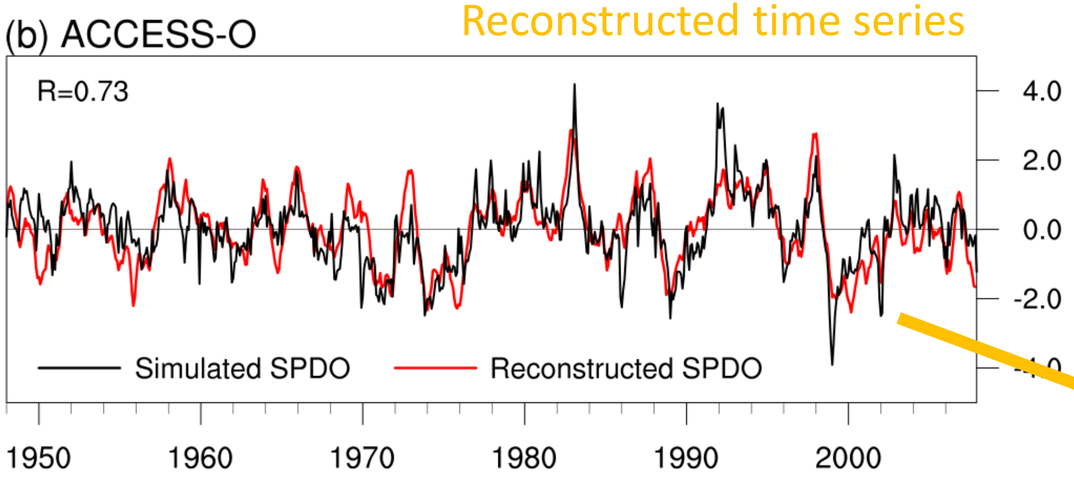


A schematic shows how the SST variability in the extratropical South Pacific can be considered as the superposition of atmospheric variability and subsurface processes.

LIM – The least damped modes (signal modes)



Reconstructed time series

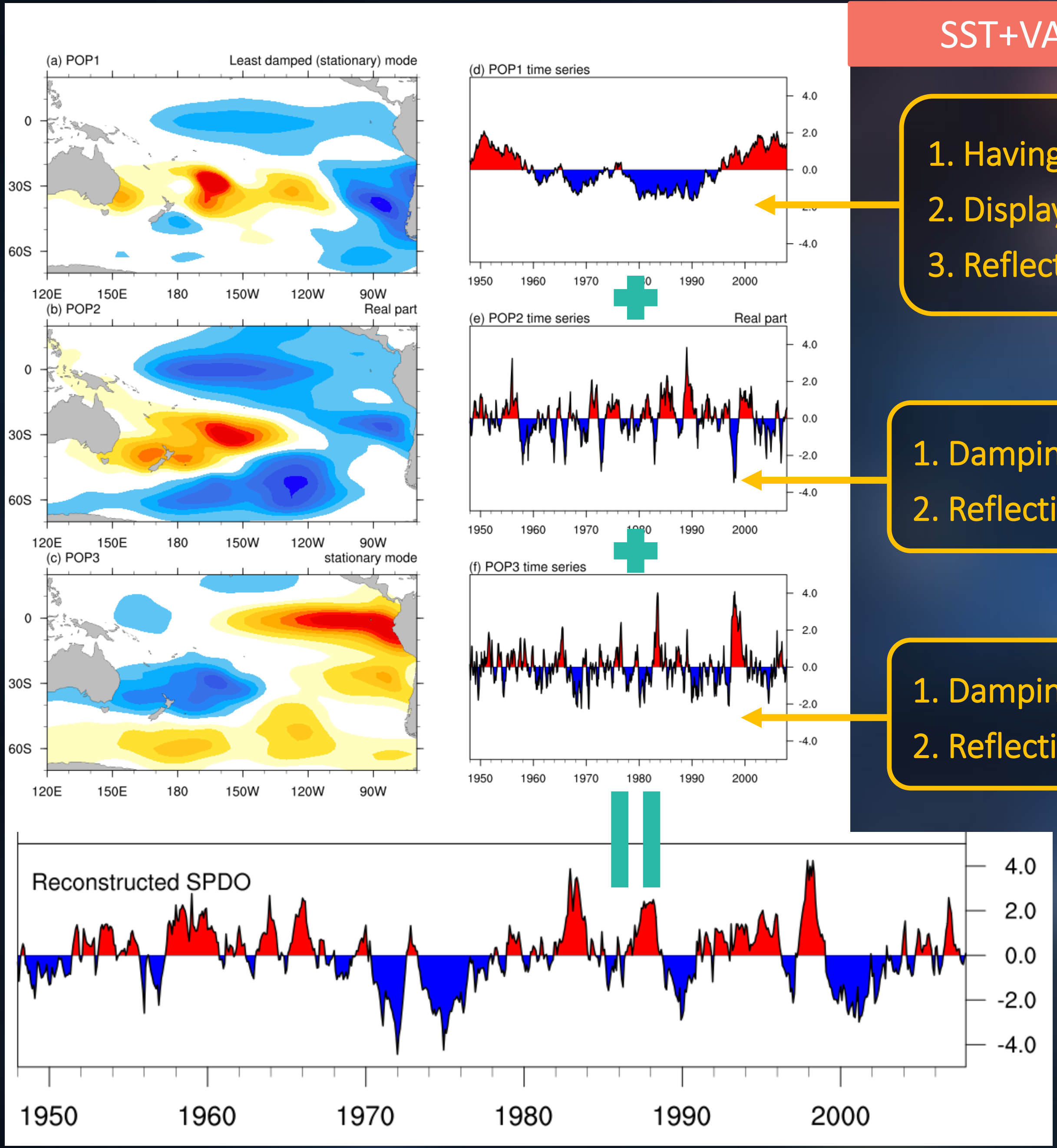


Lou et al. (2020)

SST-only Experiment (ACCESS-O)

- The dynamics of the SST variability have been separated into at least two distinct time scales with one operating on interannual and one on (inter-)decadal.
- The mode associated with the interannual variability dominates its signals narrowly in the equatorial Pacific and remains very similar to the ENSO variability. The corresponding POP time series is related to the simulated TP-PC1 (i.e. ENSO) with a correlation of 0.67.
- The mode associated with the (inter-)decadal variability has a meridionally broader structure compared to its interannual counterpart. The corresponding time series is consistent with the so-called 'climate regime shift' in the mid- to late 1970s and late 1990s.
- The interaction between the interannual ENSO mode and the (inter-)decadal SPDO mode plays a large part in giving rise to the overall SPDO variability.

LIM – The least damped modes (signal modes)



SST+VAT Experiment (ACCESS-O)

1. Having A considerably longer damping time scale: 102 months;
2. Displaying the greatest persistence;
3. Reflecting the subsurface signal.

1. Damping time scale: 20 months and oscillatory period 179 months;
2. Reflecting the (inter)decadal SPDO variability.

1. Damping time scale: 8 months;
2. Reflecting the (inter)annual ENSO variability.

Decadal variability is maintained/enhanced by subsurface processes in the South Pacific Ocean;

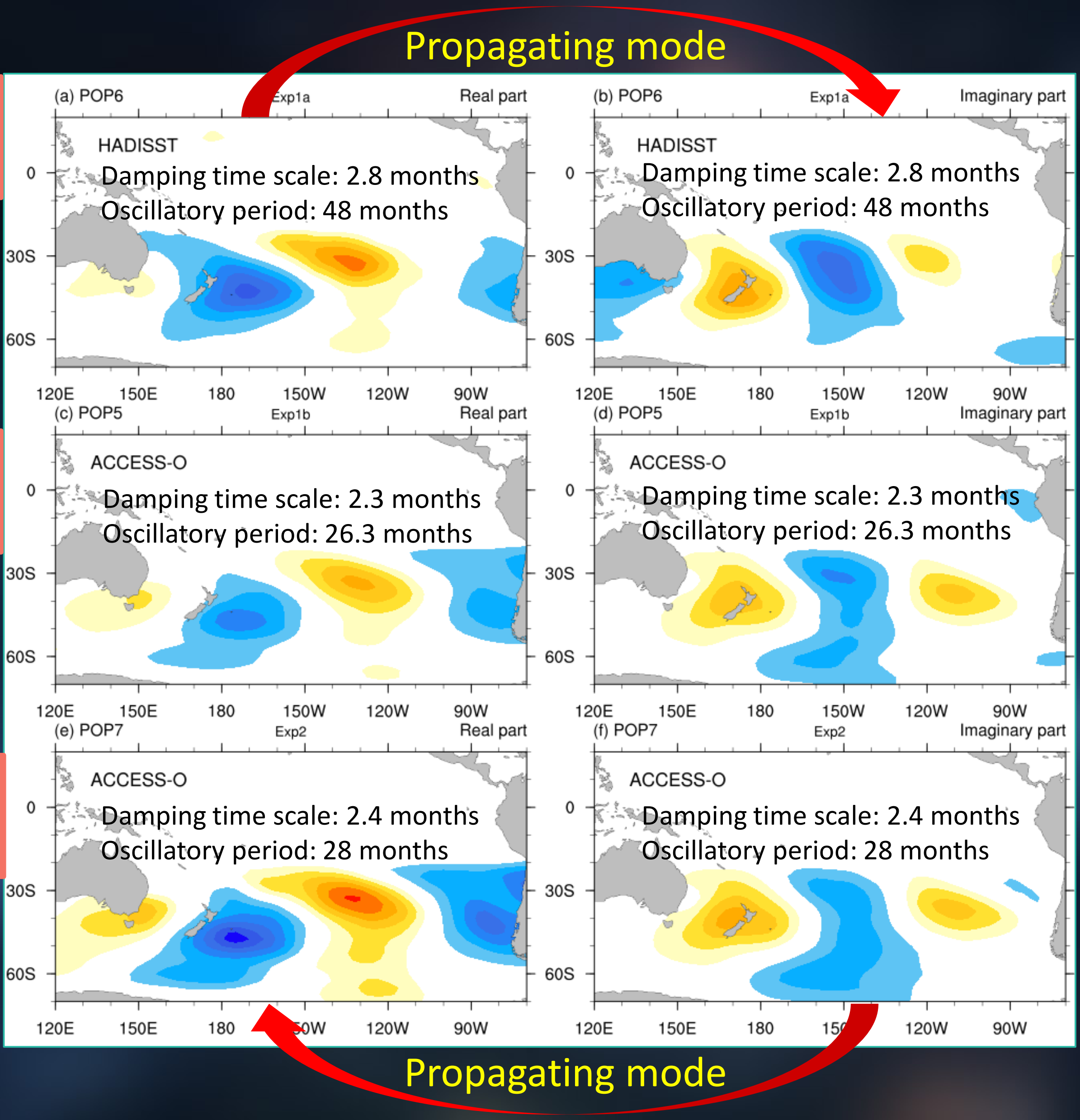
The dynamics of the entire SPDO variability can be decomposed into different processes operating on different time scales.

LIM – The most damped modes (noise modes)

SST-only Experiment HADISST

SST-only Experiment ACCESS-O

SST+VAT Experiment ACCESS-O



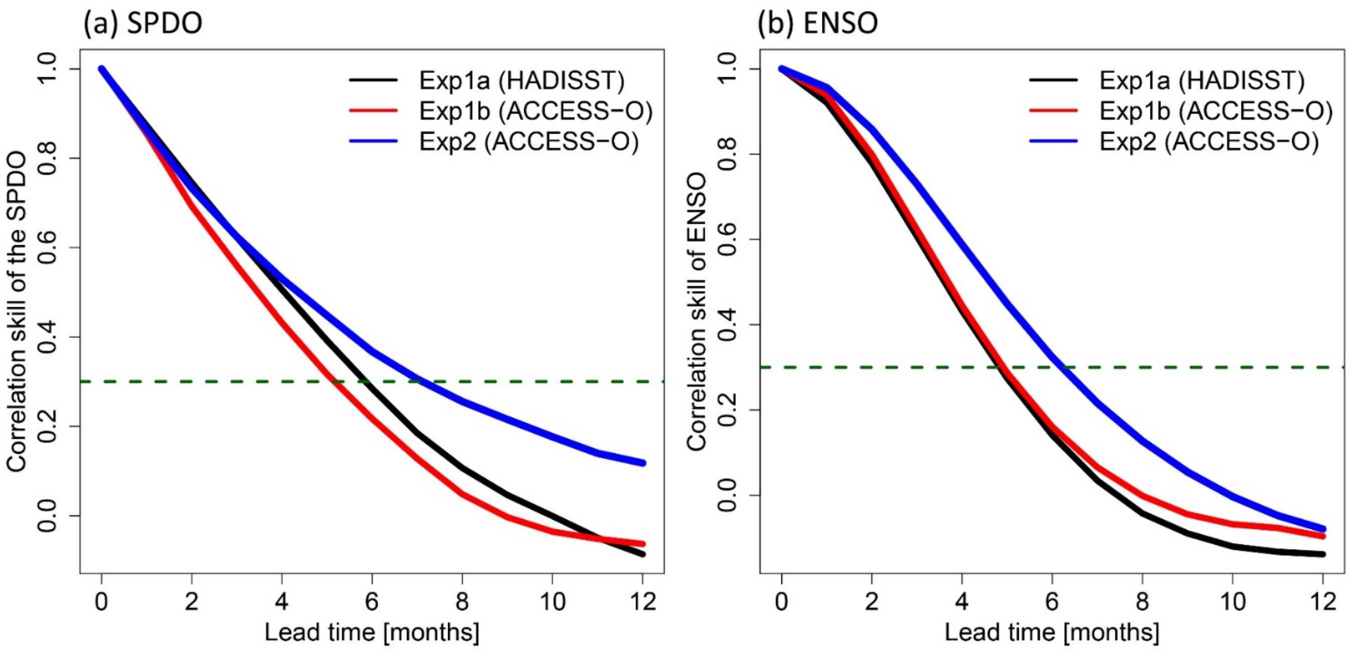
The damping time scales of the most damped modes in each experiment were 2.8, 2.3, and 2.4 months respectively with corresponding oscillatory periods of 4.0, 2.2, and 2.4 years. Those modes with shortest damping time scales reflect the least predictable noise components in the system.

- The noise modes are propagating;
- Reflecting atmospheric eastward-propagating Rossby wave train variability, which imprints its signal onto the surface ocean.

LIM – Predictive skill of the SPDO and ENSO

LIM: $\mathbf{x}_{t+\tau} = \mathbf{G}_\tau \mathbf{x}_t + \xi dt$

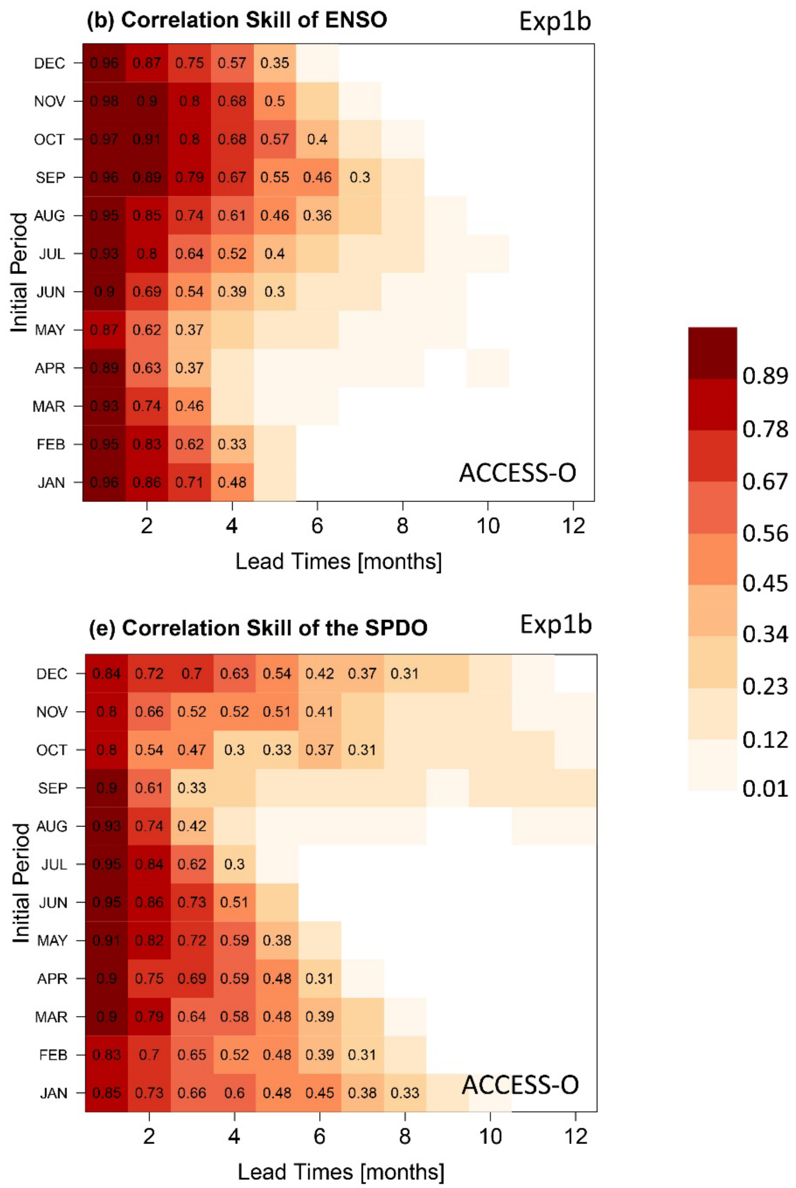
LIM prediction: $\mathbf{x}_{t+\tau} = \mathbf{G}_\tau \mathbf{x}_t$



The correlation skill between the observed/simulated SPDO and ENSO and the corresponding predicted time series.

- By including subsurface processes in the South Pacific, the prediction skill of both the SPDO and ENSO is increased.
- **SPDO prediction**: replacing higher-order SST PCs with subsurface processes in the LIM does not improve the prediction skill of the SPDO for shorter leads (i.e., each experiment has very similar prediction skill for leads up to 4 months). For longer leads (4 months), the subsurface variability starts adding more predictability to the SPDO.
- **ENSO prediction:** the ENSO predictions have been improved throughout all forecast lead times from 0–12 months where subsurface processes in the South Pacific are incorporated.

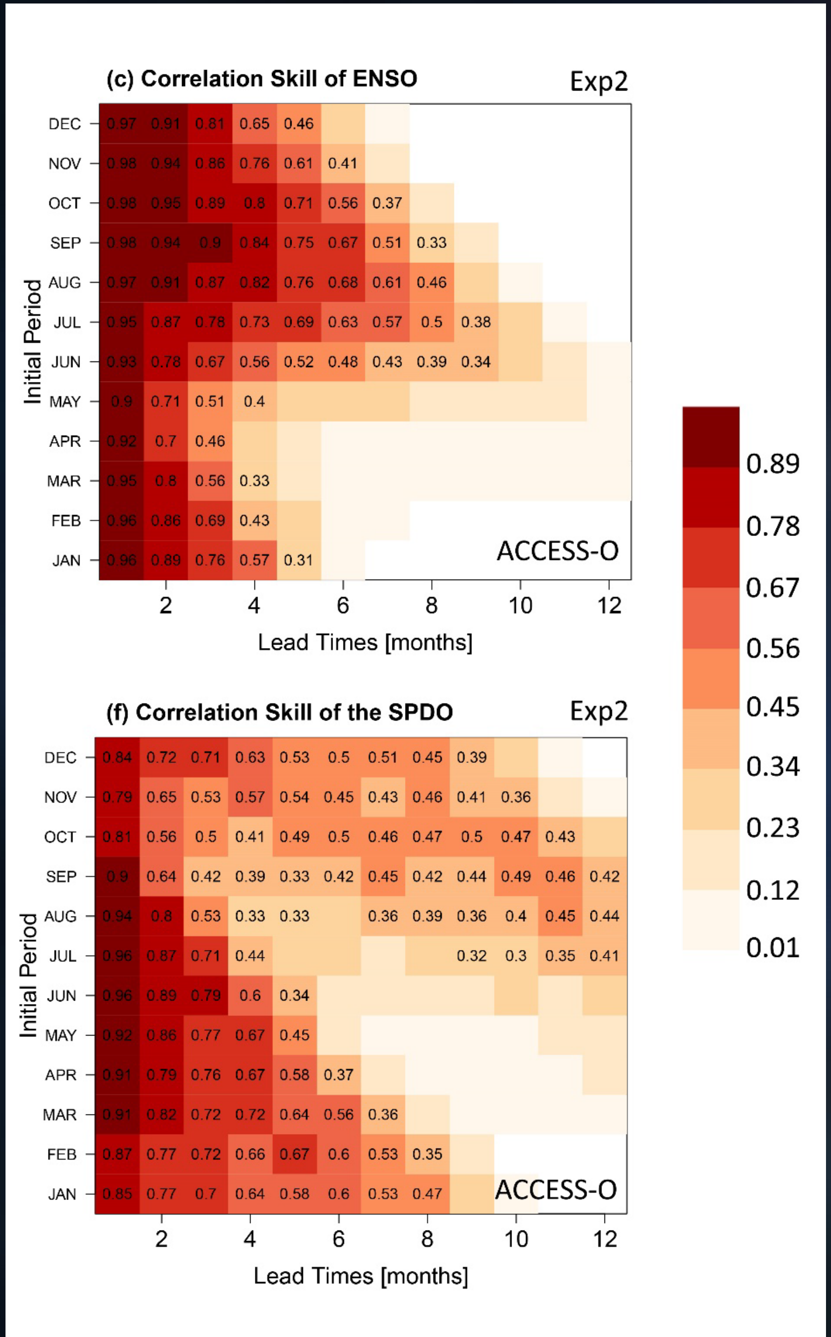
LIM – Predictive skill of ENSO and the SPDO in the SST-only Experiment



Lou et al. (2020)

- The ENSO prediction skill is relatively low (~3 months) when initiated in the boreal spring (i.e., MAM) primarily due to the boreal spring predictability barrier when ENSO often emerges or decays.
- The SPDO has longer predictability relative to ENSO. However, the SPDO exhibits shorter predictability (~3-4 months) when the predictions are initiated in austral winter (JAS), which might be due to the delayed influences from tropical ENSO variability.

LIM – Predictive skill of ENSO and the SPDO in the SST+VAT Experiment



- The ENSO prediction skill has been improved throughout all the seasons when subsurface processes in the South Pacific are included. Moreover, ENSO correlation skill is significantly higher for predictions starting after June, with skill of up to ~9 month in austral winter (i.e., JJA) when the subsurface contribution is incorporated.
- In general, the SPDO has longer predictability relative to ENSO, especially when the subsurface processes are considered.
- Forecast skill of the LIM is comparable to the GCMs. However, the reduced-order LIM is much cheaper. These LIM forecasts are competitive with that of comprehensive nonlinear GCMs.

Summary

- The Pacific-South American (PSA) pattern is the key atmospheric driver of the South Pacific decadal Oscillation (SPDO);
- The least damped modes (signal modes) resemble El Niño–Southern Oscillation (ENSO) and the SPDO.
- The most damped modes (noise modes) reflect atmospheric eastward-propagating Rossby wave train variability.
- Although the oscillatory periods of ENSO and SPDO are distinct, they have very close damping time scales, indicating that the predictive skill of the surface ENSO and SPDO is comparable.
- The ENSO spring predictability barrier is apparent in linear inverse model (LIM) predictions initialized in March–May (MAM) but displays a significant correlation skill of up to ~3 months.
- For the SPDO, the predictability barrier tends to appear in June–September (JAS), indicating remote but delayed influences from the tropics.
- Subsurface processes in the South Pacific Ocean are the main source of decadal variability and further that by characterizing the upper ocean temperature contribution in the LIM, the seasonal predictability of both ENSO and the SPDO variability is increased.

Lou J., T. J. O'Kane, and N. J. Holbrook (2020). A Linear Inverse Model of Tropical and South Pacific Seasonal Predictability. *Journal of Climate, 33*(11), 4537-4554. doi:10.1175/jcli-d-19-0548.1

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THANK YOU! STAY SAFE AND HEALTHY!

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