An Advanced Framework for Disentangling Deterministic Dynamics and Stochastic Processes in ENSO Predictability

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MOTIVATION

- ENSO is the dominant mode of climate variability in the tropical Pacific and plays an essential role in modulating the global through its numerous teleconnections.
- As a coupled phenomenon, ENSO is inherently multivariate
- Debate persists on which initiation mechanism dominates, and consequently a lack of consensus in its predictability.
- Coupled feedbacks are important in the tropical Pacific, but **the role of atmospheric noise remains unclear.**

BACKGROUND

- Previous studies demonstrate that suppressing ENSO variability, thereby isolating coupled instabilities, provides a baseline for understanding the tropical system's natural variability without ENSO.
- Figure 1 shows that ENSO-like events can be initiated without ENSO cycle preconditioning.

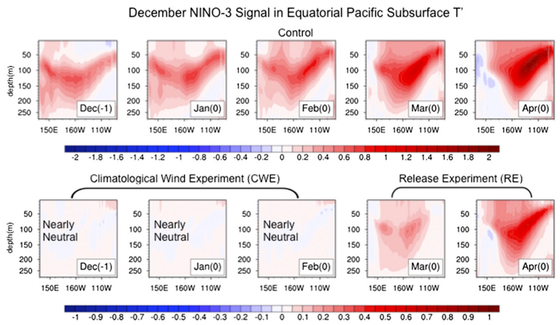


Figure 1. Anomalous subsurface temperature evolution in a CCSM4 Control, CWE (ENSO-neutral simulation), and a Release Experiment. (Larson and Kirtman 2005).

- One interpretation of this result is that reinstating dynamic coupling from an ENSO-neutral initial condition documents the unpredictable component of ENSO.
- Predictability may not hinge on subsurface preconditioning—underscoring the importance of including noise-driven processes in predictability estimates.

CESM2 EXPERIMENTS

- Four **CESM2** simulations and experiments:
  a) Control — 2000 years
  b) NoENSO — 500 years
  c) March RE
  d) September RE
- **NoENSO** is built by decoupling the momentum flux severs the Bjerknes feedback, rendering the ocean incapable of responding to any anomalous wind stress variability.
- **Release Experiment (RE)** ensembles are comprised of 60 unconstrained and freely evolving one-year forecasts, each initialized with different, but sequential, March or September initial conditions from the ENSO-neutral reference climatology (NoENSO).

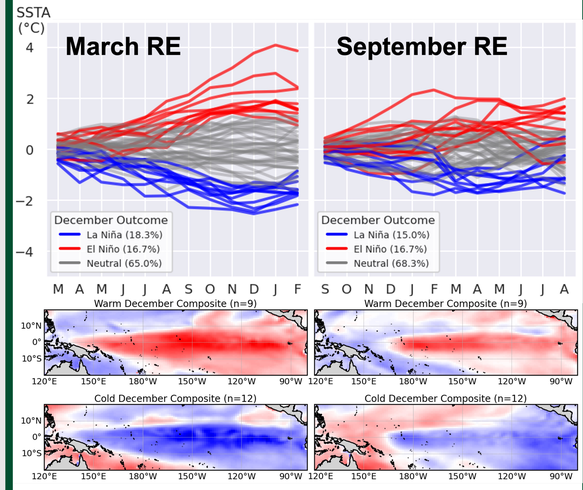


Figure 2. (top) Niño-3.4 Error Swath and (bottom) December warm and cold composites for (left) the March RE and (right) the September RE. Red (blue) lines indicate El Niño (La Niña) events, defined when the December Niño-3.4 SSTA exceeds + (–) one standard deviation.

- Figure 2 demonstrates that a lot of ENSO develops from coupled instability induced errors alone — *the unpredictable component of ENSO.*
- Regardless of initialization month, ENSO-like growth can be initiated and grow to substantial amplitude without ENSO cycle preconditioning in the CESM2 release experiments.

RESULTS & DISCUSSION

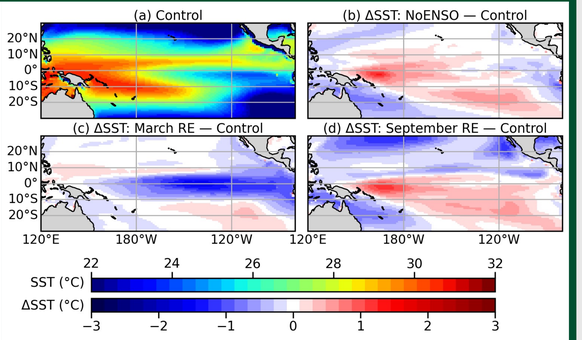


Figure 4. Mean December (a) SST for the Control simulation and the mean December ΔSST relative to the Control for (b) NoENSO, (c) the March RE, and (d) the September RE.

- **NoENSO** warm bias implies that without ENSO, the tropical Pacific favors warmer December SSTs.
- Varied mean December SST structure between **March- and September-REs** suggest coupled dynamics and noise interactions differ, with March leading to cooler outcomes by December.

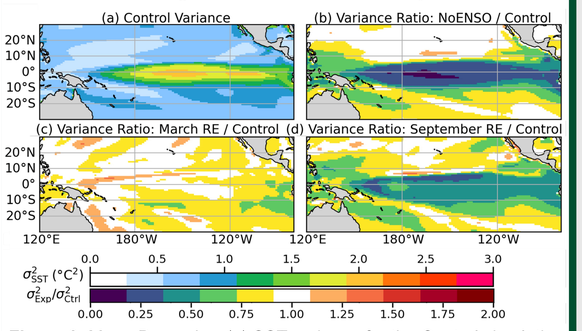


Figure 3. Mean December (a) SST variance for the Control simulation and the mean December SST variance ratio relative to the Control for (b) NoENSO, (c) the March RE, and (d) the September RE.

- December SST variance ratios (diagnostic metric of coupled feedback strength):
  - Confirms suppressing ENSO drastically reduces SST variability in **NoENSO**.
  - Show that unstable coupled feedbacks, nonlinearities, or ocean dynamics may be important (likely so in the western Pacific) in the **March RE**.
  - Indicate SST variability is forced by atmosphere (especially across near-equatorial Pacific) in **September RE**.

POSTER IN FOUR

- Coupled feedbacks are important in the tropical Pacific, but **the role of atmospheric noise remains unclear.**
- Decoupling the momentum flux—severing the Bjerknes feedback—successfully suppresses SST variability in the CESM2 NoENSO.
- ENSO-like growth can (and does) occur without ENSO cycle preconditioning in CESM2 and with a clear seasonal influence on SST evolution and SST variability.
- To enhance our understanding of the mechanistic drivers of ENSO variability, future work will prioritize separating stochastic influences from underlying dynamics drivers.

FUTURE WORK

- ❑ Develop a machine learning-based diagnostic tool to identify noise, and to assess whether subsurface precursors or atmospheric noise play a more dominant role in determining ENSO event outcomes.
- ❑ Integrate the interactive ensemble (IE) coupling approach within a predictability framework to diagnose the mechanisms driving ENSO growth with minimized interference from uncoupled atmospheric noise.

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