Diagnosing the Dynamics of ENSO Flavors using Linear Inverse Models

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This work explores the dynamics of ENSO flavors using a Linear Inverse Model (LIM) applied to a 2000-year pre-industrial simulation from GFDL CM2.1 coupled GCM. The results show how CM2.1's various ENSO flavors diverge from nearby initial states, with a potential predictability horizon of 6 months. We further introduce a new measure, based on historical data, to facilitate probabilistic forecasts of ENSO flavors.

1. Defining ENSO flavors

Neutral: - std(NINO3.4) < NINO3.4 < std(NINO3.4)
El Niño : NINO3.4 > std(NINO3.4)
La Niña : NINO3.4 < - std(NINO3.4)
Eastern Pacific (EP) /Central Pacific (CP) flavor
EP El Niño : El Niño & NINO3 > NINO4
CP El Niño : El Niño & NINO3 < NINO4
EP La Niña : La Niña & NINO3 < NINO4
CP La Niña : La Niña & NINO3 > NINO4

2. Precursors of ENSO flavors

Precursors of two El Niño flavors originate from nearby initial states in the neutral state reservoir. Difference between the precursors (measured in PC1-PC2 space) grows exponentially in time, so that two flavors become distinguishable in the final mature state. The predictability of the flavors is around 6 months.

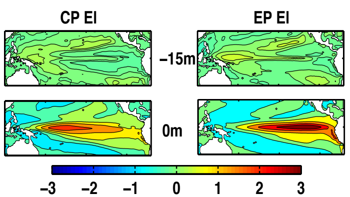
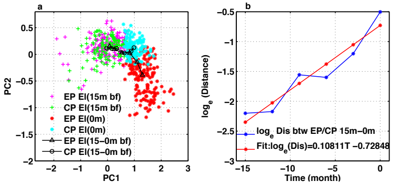


Fig1: Composite of EP/CP El Niño at final state (0m) & 15 months before (-15m).

Fig2: El Niño flavors color coded in PC1-PC2 space & composite trajectory for each flavor (a), difference between composite trajectories (defined as distance in PC1-PC2 space) generally fit exponential function in time (b).



3. How to build a LIM

Simple version procedure

1. Choose variable SST or SST+TZ, do multivariate EOF analysis using historical data and use multivariate PC as the state vector X.
2. Fit propagation matrix G (Tau) using historical data which satisfies X (t+Tau) = G (tau) X (t). Do Singular Vector analysis for G (tau) to observe the non-normal growth and optimal initial pattern and evolved final pattern.
3. Tune and verify the model by doing forecast with independent data to achieve optimal forecast skill in several metrics.
4. Apply LIM. Given initial condition X(t), forecast future X(t+Tau) and NINO indices at certain lead time Tau.

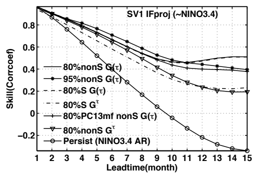


Fig3: skill comparison between a series of model. Leaping propagator G(Tau) algorithms achieve optimal forecast skill.

4. Dynamics of ENSO flavors

How to diagnose the dominant dynamics along diverging trajectories of ENSO flavors using LIM?

We construct two LIMs: one using tropical Pacific SST only (to capture fast ocean-atmosphere feedbacks), and another using tropical Pacific SST plus ocean heat content (TZ, to capture additional slower feedbacks from ocean thermocline dynamics). Forecast of two individual EP/CP El Niño event suggests slow oceanic thermocline feedbacks largely control the EP El Niño. CP El Niño seems more dominated by fast surface feedback. However, there is no clear separation of their dynamics.

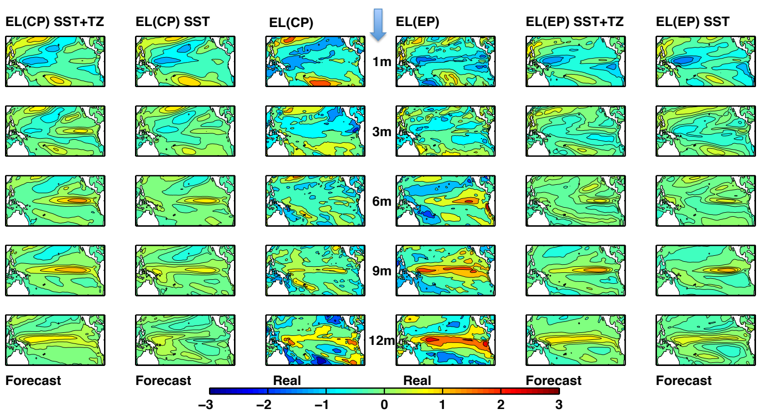


Fig4: 12 months real EP/CP El Niño events(3&4 column) & forecasted evolution from two types LIM (1&5 column using SST+TZ, 2&6 column using SST only).

5. Probabilistic forecasts of ENSO flavors

Given historical data and current state, how to forecast after 6 months, how much% to become El Niño, how much% to be La Niña, how much % to be Neutral, or even tell EP/CP flavors?

We use historical data to project on initial Singular Vectors of G (Tau=6, SST+TZ, DIM=18), then color code 6-month later real ENSO flavors on this SV1-SV2 diagram. We divide the SV1-SV2 space into boxes, and count different types within each box to provide probability. Once we have the probability diagram, we could project current SST+TZ map on 6-month lead initial SVs, then we can tell the percentage probability of different ENSO flavors from which box it locates in SV1-SV2 diagram.

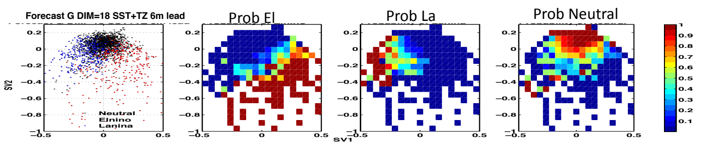
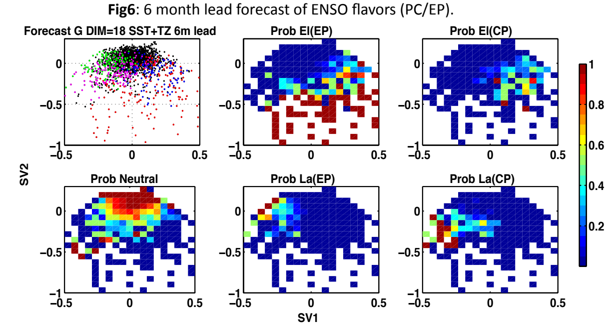


Fig5: 6 month lead forecast of El Niño/La Niña/Neutral with percentage.

Fig6: 6 month lead forecast of ENSO flavors (PC/EP).



6. Summary

Diverse ENSO flavors emerge spontaneously from an unforced run of the GFDL-CM2.1 coupled GCM. Linear inverse models (LIMs) are powerful tools to diagnose and predict the evolution of these flavors, including their probability of emergence from a given initial state. LIM experiments suggest that ENSO events whose peak SST anomalies appear in the east Pacific involve a greater role for subsurface thermocline feedbacks, than do those whose peak SST anomalies appear in the west Pacific. Chen Chen* cchen@ldeo.columbia.edu

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