STOCHASTIC FORCING OF CP AND EP ENSO EVENTS: OBSERVATIONS VS CESM-LE

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What is Stochastic Forcing?

- Forcing that is white \textit{in time} (not space)
- Physical systems contain processes on many time scales
  - Approximate the ‘fast’ processes (chaotic & non-linear) as white noise

Why is it important?

- Many physical model experiments show ENSO is sensitive to natural variability
  - Initial conditions
  - Noise forcing

[Graphs and diagrams are included here.]
Role of Noise Forcing in Generating ENSO Diversity

- Observational evidence for *optimal initial conditions* that maximize EP and CP growth

**Optimal Initial Conditions, and Final Conditions**

- What noise forcing can *lead to the generation* of these optimals?
Methods

1. Estimate Dynamics - Linear Inverse Model (LIM)
2. Identify Optimal Initial Conditions
3. Calculate Noise Forcing

Observations
1982-2015
SST: monthly + daily IOSST
Thermocline depth (20° Isotherm depth): monthly + daily GODAS
Daily NCEP Reanalysis

CESM Large Ensemble
1982-2015
35 Ensemble Members
SST: monthly + daily
SSH: monthly + daily
Daily Atmospheric Variables
Using Linear Inverse Modeling (LIM) to Estimate Noise Forcing

1) Calculate Dynamics,
2) Identify the Optimal Initial Conditions,
3) Estimate Noise Forcing

Final State: CP or EP ENSO event
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Final State: CP or EP ENSO event

- 850mb Zonal Wind (shaded)
- Optimal Initial Condition
- Noise
- Deterministic Dynamics + Noise
- EP Optimal
- SST (shaded)
- Thermocline Depth (contours)
Dynamics: Linear Inverse Model

General linearized model describes the Tropical Pacific:

\[ \frac{dX}{dt} = LX + \xi \]

- **White Noise Forcing**
  - (does not include atmospheric noise)

**Deterministic Dynamics**

\[ X = \text{State Vector [SST; Thermocline Depth or SSH]} \]
\[ L = \text{Linear Operator describing the slow, linear dynamics of the system} \]
\[ \xi = \text{Noise Forcing} \]

**Solution:**

\[ X(\tau) = \exp(L\tau)X(0) \]

Calculate Linear Dynamics \( L \) from **statistics** of observations:

\[ C(\tau) = \exp(L\tau)C(0) \]

\[ L = \frac{\ln(C_\tau/C_0)}{\tau} \]
Optimal Initial Conditions

\[ X(\tau) = \exp(L\tau) \, X(0) = G_\tau \, X(0) \]

Solve generalized eigenvalue problem for **optimal** initial conditions \( (p) \) that maximize growth \( (\mu) \) in the direction specified by \( \text{Norm} \ (N) \)

\[ G_\tau^T N G_\tau \, p = \mu(\tau)p \]

“CP” or “EP Norm” defines direction of growth

Maximized Growth

Optimal Initial Condition
Optimal Initial Conditions

Observations

6mo CP Optimal

6mo EP Optimal

CESM-LE

6mo CP Optimal

6mo EP Optimal

PMM

Thermocline contour interval: 4m

SSH contour interval: 2cm
Final Conditions

Observations

CP Final

EP Final

CESM-LE

CP Final

EP Final

Thermocline contour interval: 8m

SSH contour interval: 4cm
Noise Forcing

\[ \frac{dX}{dt} = LX + \xi \]

\[ \xi(t) = \frac{[x(t+\Delta t) - x(t-\Delta t)]}{2} - Lx(t) \]

- \( x \) = High Frequency (pentad) State Vector
- \( L \) = Linear Dynamics of the system
- \( \xi(t) \) = Noise Forcing (time and space dependent)

Observations

Regress \( \xi(t) \) onto the spatial patterns of optimal initial conditions
Noise Forcing

Seasonal Cycle of Noise Variance

Observations

CESM-LE
CP Noise: Sea Level Pressure

Observations

DJF

JJA

ANN

CESM-LE

symmetric

NPO

ANN

DJF

JJA
EP Noise: Sea Level Pressure

Observations

CESM-LE

ANN

weaker

ANN
Noise: EP 850mb Zonal Wind

Observations

CESM-LE

WWB

MAM

JJA

WWB in CESM?

MAM

JJA
Noise: EP OLR

Observations

ANN

MAM

JJA

CESM-LE

ANN

MAM

JJA
Final Remarks:

1. **Central Pacific:**
   - Optimal initial condition: **Pacific Meridional Mode**
   - Noise forcing: **North Pacific Oscillation (DJF)**

2. **Eastern Pacific:**
   - Optimal initial condition: SST anomalies in Eastern Pacific, depressed thermocline
     - Kelvin Wave / Thermocline
   - Noise forcing: Zonal Wind anomalies (MAM)
     - WWB

3. Differences in CESM-LE analysis:
   - CP Optimal + final
   - EP Optimal + final
   - EP Noise Variance: peaks in JJA
   - EP Wind Structures: JJA

Thank you!