Climate Dynamics: Why Does Climate Vary?

Pacific Decadal Oscillation: Noise Integration, Nonlinear Rectification, and Scale Interaction

http://www.esrl.noaa.gov/psd/people/dezheng.sun/lectures/ATOC7500.html
The Pacific Decadal Oscillation

**a**

Positive phase vs. negative phase of the Pacific Decadal Oscillation

**b**

Graph showing the PDO index (sum of May-Sep) from 1930 to 2000

NOAA / NWFSC

Steven Hare
The 1976 Regime Shift

Trenberth (1990)
The 1976 Regime Shift
Epoch 1977–93 minus epoch 1950–76
PDO: Spatial Patterns

regressions on GR

SST

stress

SLP
PDO and Other Pacific Basin Climate Indices
The PDO and Alaskan salmon production

TABLE 3: Percent change in mean catches of four Alaskan salmon stocks following major PDO sign changes in 1947 and 1977.

<table>
<thead>
<tr>
<th>salmon stock</th>
<th>1947 step</th>
<th>1977 step</th>
</tr>
</thead>
<tbody>
<tr>
<td>western Alaska sockeye</td>
<td>-37.2%</td>
<td>+242.2%</td>
</tr>
<tr>
<td>central Alaska sockeye</td>
<td>-33.3%</td>
<td>+220.4%</td>
</tr>
<tr>
<td>central Alaska pink</td>
<td>-38.3%</td>
<td>+251.9%</td>
</tr>
<tr>
<td>southeast Alaska pink</td>
<td>-64.4%</td>
<td>+208.7%</td>
</tr>
</tbody>
</table>

Mantua et al. 1997
Spatial Patterns of PDO and ENSO: Similarity and Differences
The Hasselmann Mechanism for SST Variability

Heat fluxes associated with weather events, “random forcing”

Ocean response to flux back heat which slowly damps SST anomalies

\[ \frac{dT'}{dt} = -\lambda T' + Q' \]

\[ Q' = \sum A e^{i\omega t} \]

\[ |T'(\omega)|^2 = \left| A \right|^2 \frac{1}{\omega^2 + \lambda^2} \]
The Simple Ocean’s SST Anomaly Variability

Complex behavior with decadal anomalies!

\[ \text{SST}_{n+1} = \lambda \cdot \text{SST}_n + \eta \]

\( \lambda = \text{constant}; \ \eta = \text{Random number} \)

Log plot of SSTA Spectra

No damping

Atm forcing

Period

10 yr 1 yr 1 mo
Simple Ocean Model: correspondence to the real world? Observed and Theoretical Spectra for a location in the North Atlantic Ocean

Atmospheric forcing and ocean feedback estimated from data
“The Atmospheric Bridge”

Meridional cross section through the central Pacific

(Alexander 1992; Lau and Nath 1996; Alexander et al. 2002 all J. Climate)
Mechanism for Atmospheric Circulation Changes due to El Nino/Southern Oscillation

Latent heat release in thunderstorms

Atmospheric wave forced by tropical heating

“Decadal” variability in the North Pacific: tropical (ENSO) Connection?


Tropical Pacific Decadal Variability: A Consequence of the Rise and Fall of ENSO Activity?
The time-mean effect of ENSO
(or the Rectification of ENSO)

While ENSO has two phases, in reference to the long-term mean climate, the integrated effect of ENSO over a decade or longer is not zero, but a significant warming effect on the eastern tropical Pacific, with a spatial pattern that highly resembles the pattern of tropical Pacific decadal variability.
Methodologies

• Compare the equilibrium state of the coupled tropical ocean-atmosphere system with the time-mean state of the system, though the use of a box model whose unstable equilibrium can be analytically obtained.

• Force an Ocean GCM using surface forcing with and without ENSO fluctuations

• Perturbation Experiments with coupled GCMs with and without equatorial coupling between surface winds and SST gradients
Equilibrium State Versus Time-Mean State

The System:
\[ \frac{dA}{dt} = f(A, \lambda) \]  \hspace{1cm} (1)

Equilibrium State:
\[ f(A_0, \lambda) = 0 \]  \hspace{1cm} (2)

Time Mean State:
\[ f(\bar{A} + A', \lambda) = 0 \]  \hspace{1cm} (3)

When \( f(A, \lambda) \) is nonlinear, \( \bar{A} \neq A_0 \)  \hspace{1cm} (5)
A Box Model for the ENSO System

\[
\frac{dT_1}{dt} = c(T_e - T_1) + sq(T_2 - T_1)
\]

\[
\frac{dT_2}{dt} = c(T_e - T_2) + q(T_{sub} - T_2)
\]

\[
q = \frac{\alpha}{\alpha} (T_1 - T_2)
\]

\[
T_{sub} = \Phi(-H_1 + h_2')
\]

\[
\Phi(z) = T_e - \frac{T_e - T_b}{2} (1 - \tanh\left(\frac{z + z_0}{H^*}\right))
\]

\[
h_2' - h_1' = -\frac{H_1}{H_2} \frac{\alpha}{b^2} (T_1 - T_2)
\]

\[
1 \frac{dh_1'}{r \ dt} = -h_1' + \frac{H_1}{2H_2} \frac{\alpha}{b^2} (T_1 - T_2)
\]

Tropical Pacific Climate as a Function of $T_e$.

(a) Equilibrium and Time-Mean SST

(b) Amplitude of ENSO
Forced Ocean GCM Experiments with and without ENSO in the Forcing

- The long-term mean winds are identical for A and B, but A has interannual variations and B does not.
- The thermal BCs for A and B are identical -- both are restored to a prescribed potential SST.
Upper T Difference Between Experiments with/without ENSO

Time mean (1950–2011) upper ocean temperature differences
fluctuating wind runs – fixed wind runs

SST Difference Between Experiments with/without ENSO

Sun et al. 2012
Upper T Difference Between Experiments with/without ENSO

Sun et al. 2012
SST Difference Between Experiments with/without ENSO

Sun et al. 2012
Difference in convergence of $V'T'$ (with ENSO minus without ENSO)

Sun et al. 2012
Difference in convergence of $VT'$

(with ENSO minus without ENSO)

NDH DIFF with ENSO - without ENSO 1950-2011

Sun et al. 2012
Two Emerging Scenarios for TPDV

- Stochastic forcing from weather events over the western Pacific warm-pool results in a decadal component in the long-term variability in the level of ENSO activity, which in turn results in TPDV through the nonlinear rectification of ENSO.

- TPDV results from an interaction between the variance of ENSO variability and the decadal background state.
A Mechanism for Decadal Variability in the Level of ENSO Activity: Forcing form Weather Events From the Warm-pool

\[ \frac{dT'}{dt} = -\lambda T' + Q' \]

\[ Q' = \sum Ae^{i\omega t} \]

\[ |T'(\omega)|^2 = \frac{|A|^2}{\omega^2 + \lambda^2} \]
Oscillations in the Model different regimes

Homework

• Through the “atmospheric bridge”, a tropical SST anomaly can exert its impact on the extratropical ocean and cause a SST anomaly there. Based on what you know about the atmosphere and ocean dynamics, can you envision a mechanism that may do the reverse – allowing an extratropical SST anomaly to cause a change in the tropical SST?

• Do you expect to see a counterpart of PDO in the Atlantic sector? Why?
Recommended Reading For the Next Lecture

Seasonal cycle of Temperature & MLD in N. Pacific
Reemergence Mechanism

• Winter Surface flux anomalies
• Create SST anomalies which spread over ML
• ML reforms close to surface in spring
• Summer SST anomalies strongly damped by air-sea interaction
• Temperature anomalies persist in summer thermocline
• Re-entrained into the ML in the following fall and winter