El Niño - Southern Oscillation (ENSO)

Ocean-atmosphere interactions

ENSO

“EN” = El Niño; “SO” = Southern Oscillation
El Niño is a warming of the tropical eastern Pacific
Southern Oscillation is a see-saw in atmospheric pressure
The ocean-atmosphere work together (are “coupled”) to produce ENSO climate variability
ENSO is an Ocean-Atmosphere “dance” involving:
- Surface and upper level winds
- East-west SST gradients
- Upwelling and ocean productivity
- Thermocline depth
- Sea surface height

Global Atmospheric Circulation

Trade winds

The key is to appreciate how odd the “normal” state is!

Q1: A strong east-west SST gradient in the Pacific Ocean is partly responsible for:
A. Rain over Indonesia
B. The Hadley circulation
C. The Walker circulation
D. Answers A, B, C
E. Answers A, C

Trade winds on the equator bring cold waters to surface

Eastern tropical Pacific is cooler than west for two reasons:
1) Trade winds pile up warm water in the west
2) Wind-driven upwelling in the east
Normal Conditions

Note features:
- East-west SST gradient
- Eastern upwelling
- E-W Thermocline depth
- E-W Sea surface height
- Surface pressure
- Trade winds

Normal Conditions in the tropical Pacific

Hadley and Walker winds vary in phase: when Hadley cell is strong, so is the walker circulation

Transition to El Niño

What are changes in:
- East-west SST
- Upwelling
- Thermocline depth
- Sea surface height
- Surface pressure
- Trade winds
- Rainfall?

Full El Niño conditions

El Niño Conditions

What are changes in:
- East-west SST
- Upwelling
- Thermocline depth
- Sea surface height
- Surface pressure
- Trade winds
- Rainfall?
El Niño SST anomaly movie

Anomalies
Blue = cold
Red = warm

Largest El Niños of 20th century

1982
1997

La Niña Conditions

What are changes in:
- East-west SST
- upwelling
- Thermocline depth
- Sea surface height
- Surface pressure
- Trade winds
- rainfall?

La Niña SST anomaly movie

Anomalies
Blue = cold
Red = warm

No two events alike...

La Niña

Historically Speaking

El Niño and La Niña events tend to develop during the period Apr-Jul and they:
- Tend to reach their maximum strength during Nov-Feb
- Typically persist for 6-12 months, though occasionally persisting for up to 2 years
- Sometimes form or weaken 3 to 5 years
Walker Circulation

British mathematician, director general of observations for India (formed after monsoon failure of 1877 - worst famine in Indian history).
Arrived in 1904, shortly after huge famine caused by drought.
Goal to predict Indian Monsoon.
Found that many global climate variations, including Monsoon rains in India, were correlated with the Southern Oscillation.

Q2: Place in order of low to high surface atmospheric pressure.

A. A, B, C
B. C, B, A
C. B, C, A
D. A, C, B
E. Can't tell
Southern Oscillation Index

- SOI is a “proxy” for El Nino - La Nina state
- High SOI = Tahiti SLP > Darwin SLP = La Nina
- SOI is the ATMOSPHERIC expression of ENSO.
- The OCEANIC expression of ENSO: SSTs, upwelling, thermocline, SST height, ocean productivity

SOI

La Nina: SOI (JAN/FEB/MAR) > +5.0
El Nino: SOI (JAN/FEB/MAR) < -5.0

January SST anomalies
Prescribed: 1983 - 1956

Difference in Jan. SST between the two extreme ENSO episodes of this century

ENSO: Physical coupling between the ocean and atmosphere

Blue = Atm pressure at Darwin
Red = SST anomaly for the NINO3 region
Connecting El Niño and the SO (ENSO)

The link between SO and El Niño was made convincingly by Bjerknes. Made extensive use of data gathered during 1957 (strong El Niño year). Realized that unusual events separated by half the circumference of Earth could be linked together as parts of a huge coupled phenomenon ENSO—involving both the ocean and the atmosphere.

Prof. Jacob Bjerknes

General Description of ENSO Processes

Bjerknes established the empirical connection between EN and SO. He also provided a hypothesis about the mechanism that underlies our present understanding.

The key is to appreciate how odd the “normal” state is:
- The easterly trades drive westward currents, bringing the cold waters of the Peru Current from the South American coast.
- The Coriolis force turns westward surface currents poleward, causing divergence and upwelling.
- The trade winds push the warm upper layer waters poleward as well as westward, pulling the thermocline to the surface in the east.
- All are due to the easterly winds, but the easterly winds are also due to temperature contrasts along the equator. Thus there are positive feedbacks to reinforce both El Niño and La Niña phases.

Why does ENSO State tend to Oscillate?

Equatorial ocean dynamics
Key observations by Klaus Wyrtki in 1970’s
- El Niño is preceded by a transfer of warm water from west to east
- This transfer is thought to trigger a warm event
- What triggers the movement of water?
  - In cold phase, waters cold (and low) in east, warm (and high) in west
  - Warm water from west sloshes back and overshoots equilibrium—positive feedbacks mentioned before set of El Niño conditions

Why does ENSO State tend to Oscillate?

Shortest Answer:
- Differing timescales of Kelvin and Rossby Wave propagation

Longer answer:
- The oscillation is made possible due to the asymmetry between eastward and westward oceanic motions (see 2D Animation in notes).
- Along the equator there is a relatively fast eastward motion called an equatorial Kelvin wave. Peaking somewhat off the equator are westward motions called Rossby waves.
- Time scale: <1 yr for the Kelvin waves to shift the warm pool eastward; 2 yrs for Rossby waves to return the warm pool to the west, to await another wind relax.

Here is a 3D animation of the tropical Pacific as it cycles through an El Niño then La Niña event. The surface shown is sea-level (in cm) and the surface is colored according to the SST anomalies associated with each event.
Prediction for Winter '08

Global SST anomalies - last week

“normal”

http://iridl.ldeo.columbia.edu

ENSO and Global Warming

Still no consensus

Persistent El Niño?
Surface ocean warms uniformly.
Warming penetrates to thermocline.
Ocean-atm coupling sustains El Niño mode.

Persistent La Niña?
Surface ocean warms differentially; West warms more.
WEP SST warming drives convection there
Strengthens Walker Cell.
Ocean-atm coupling sustains La Niña mode.

El Niño Forecasting

Still no consensus

Stephen E. Zebiak
Director General
International Research Institute
for Climate Prediction

Mark Cane
Chair, DEES
Vetlesen Professor