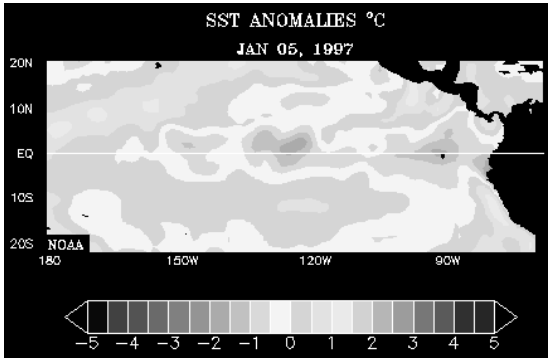
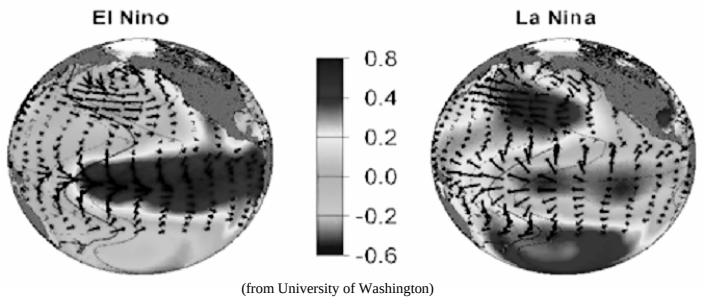
Lecture 10: El Nino Southern Oscillation (ENSO)



- ❑ General Properties and Mechanism
- ❑ Why only Pacific Ocean has El Nino

El Nino-Southern Oscillation



(from University of Washington)

❑ ENSO is the largest interannual (year-to-year) climate variation signal in the coupled atmosphere-ocean system that has profound impacts on global climate.

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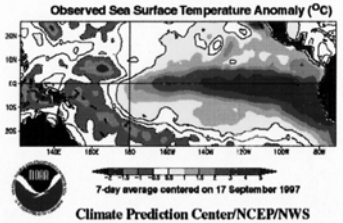
El Niño: originally, an oceanic phenomenon

- Every two to seven years, the waters warm up along the western-most shores of South America.
- Peruvian sailors who fished in this region, were the first to notice and to give a name to this phenomenon.
- Because the phenomenon would usually begin to peak around the Christian Christmas holiday, the sailors named the odd phenomenon "El Niño" meaning "the Christ Child."



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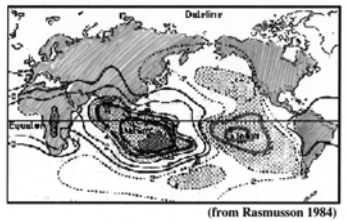
Southern Oscillation: an atmospheric phenomenon

In 1910s, Walker found a connection between barometer readings at stations on the eastern and western sides of the Pacific (Tahiti and Darwin). He coined the term Southern Oscillation to dramatize the ups and downs in this east-west seesaw effect.



(from Rasmusson 1984)

Sir Gilbert Walker

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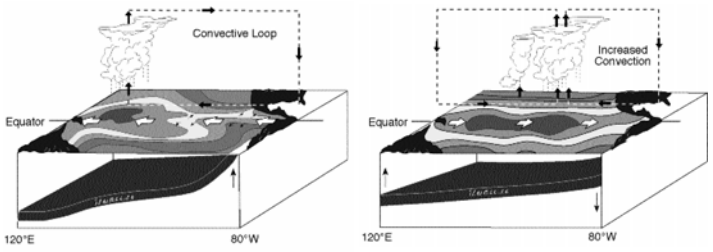
Coupled Atmosphere-Ocean System

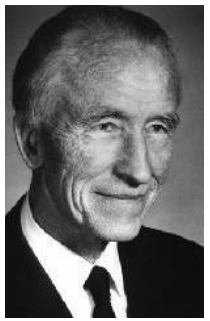
Normal Condition **El Nino Condition**



(from NOAA)

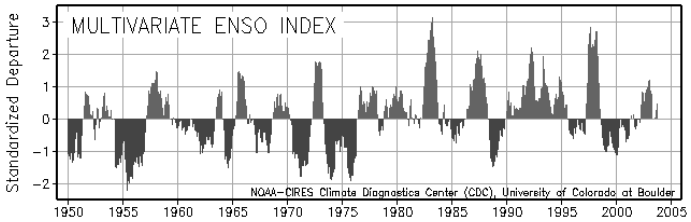
El Nino and Southern Oscillation

- Jacob Bjerknes was the first one to recognizes that El Nino is not just an oceanic phenomenon (in his 1969 paper).
- In stead, he hypothesized that the warm waters of El Nino and the pressure seasaw of Walker's Southern Oscillation are part and parcel of the same phenomenon: the ENSO.
- Bjerknes's hypothesis of coupled atmosphere-ocean instability laid the foundation for ENSO research.



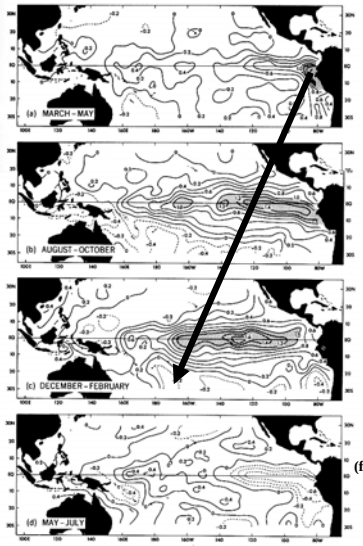
Jacob Bjerknes

The ENSO Cycle



- El Nino and La Nina tends to appear in cycle, with one follows the other.

➔ The ENSO Cycle.



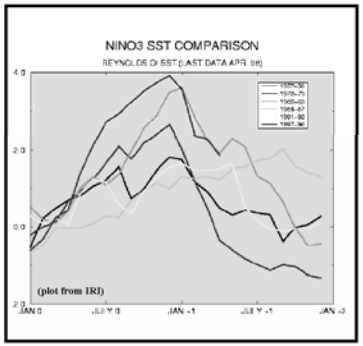
Onset Phase

Growing Phase

Mature Phase

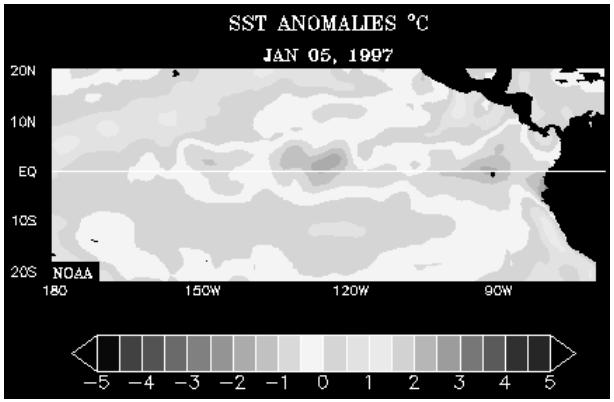
(from Rasmusson and Carpenter 1982)

ENSO's Phase-Lock to the Annual Cycle



- Composition analyses have shown that ENSO events tend to onset, grow, and decay at certain seasons of the year (Rasmusson and Carpenter 1982).

1997-98 El Nino



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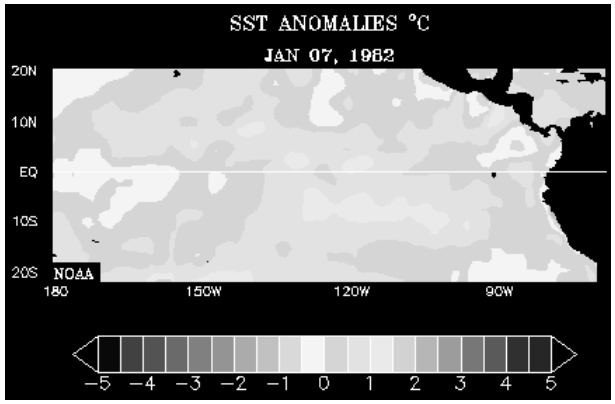
1982-83 El Nino



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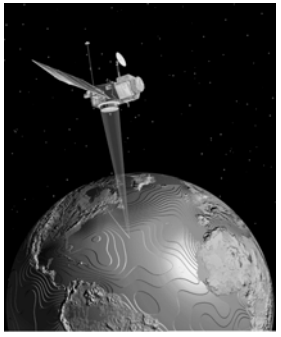
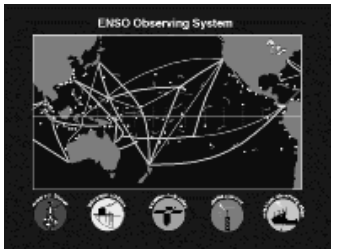
"Measuring" ENSO

Space-Based Observations



In-Situ Observations



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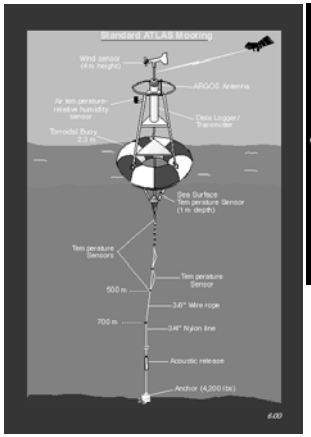
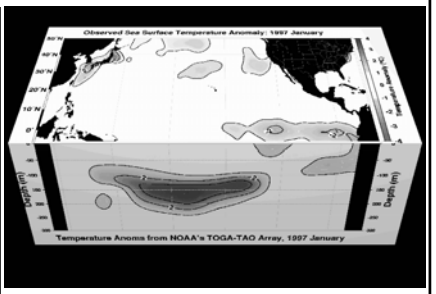
Subsurface Ocean Observation





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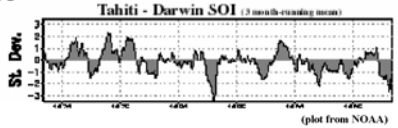
Basic Issues

- The Basic Mechanism of the ENSO
  - growth mechanism
  - phase-transition mechanism
  - onset triggering mechanism



(plot from NOAA)

- The Irregularity of the ENSO
  - deterministic chaos associated with ENSO-annual cycle interactions
  - stochastic forcing by weather noise
  - nonlinear interactions between coupled atmosphere-ocean modes
  - external forcing from Indian Ocean and the extratropical Pacific
- Seasonal Cycle and ENSO
  - Is the seasonal cycle necessary for ENSO to be realized?
  - Is the seasonal cycle fundamental to the irregularity in the ENSO events?
  - Why ENSO is phase-locked with the annual cycle?

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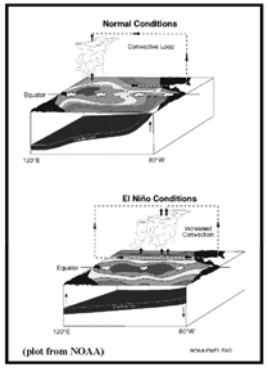
Growth Mechanism



(plot from NOAA)

The growth mechanism is responsible for amplifying SST anomalies during both the warm and cold phases of the ENSO cycle.

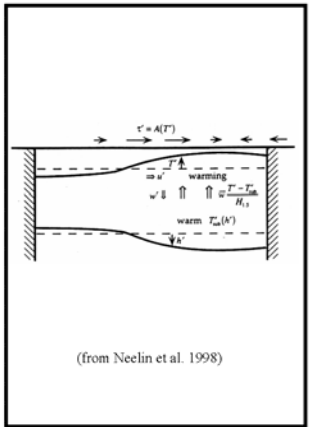
- Positive feedbacks from the interaction between the atmosphere and ocean provide a mechanism for SST anomalies to grow in the tropical Pacific during ENSO events.
- This coupled instability mechanism was first proposed by Bjerknes (1966, 1969) based on statistical correlations and was later demonstrated by many modeling studies.

Phase-Transition Mechanism

Any successful theory for the phase-transition mechanism has to be able to (1) provide a negative feedback to reverse the phase of the ENSO cycle, and (2) account for the long period associated with the cycle.

- Delay Oscillator Theory (Schopf and Suarez 1988; Battisti and Hirst 1989)
  - Ocean memory is carried by thermocline depth through reflection and propagation (i.e., the delay) of ocean waves (i.e., subsurface ocean dynamics dominants).
  - ENSO period is determined by the wave propagation and reflection time.
- Slow SST-Fast Wave theory (Neelin 1991; Neelin and Jin 1993; Jin and Neelin 1993a,b)
  - ocean memory is provided by SST through heat storage in the mixed layer (i.e., surface thermodynamics dominants).
  - ENSO period is determined by air-sea interaction and surface ocean advections.
- Recharge Oscillator Theory (Wyrkti 1975, 1985; Cane et al. 1986; Zebiak 1989; Jin 1997)
  - ocean memory is carried by the zonal-mean ocean thermocline depth, which is constantly in non-equilibrium with equatorial wind stress on ENSO timescales (i.e., subsurface ocean dynamics dominants).
  - ENSO period depends on the time needed to adjust the non-equilibrium mean thermocline depth at the equator throughout the tropical Pacific basin-wide.

SSTA Tendency Equation



(from Neelin et al. 1998)

- SSTA tendency =
  surface thermodynamical processes
  + subsurface thermocline process

Surface thermodynamical processes
- thermal feedback from the atmosphere ($-cT'$)
- wind-forced horizontal advection ($-u'*\overline{T}_x$ or $b\tau$)
- wind-induced vertical advection ($-w'*\overline{T}_z$ or $c\tau$)

Subsurface thermocline process
- upwelling associated with thermocline depth anomaly ($-w*\Delta T/\Delta z$ or Ah')

$$\frac{\partial T'}{\partial t} = -cT' + (b+c)\tau + Ah'$$

(Jin-Yi Yu 1999)

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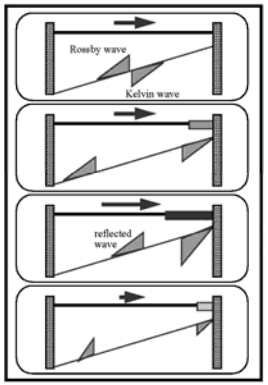
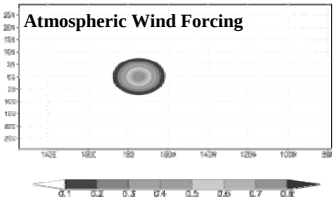
Delayed Oscillator Theory

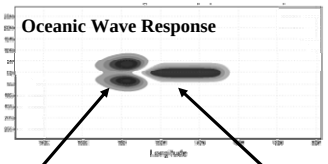


- Wind forcing at the central Pacific: produces a downwelling Kevin wave propagating eastward and a upwelling Rossby wave propagating westward.
- wave propagation: the fast kelvin wave causes SST warming at the eastern basin, while slow Rossby wave is reflected at the western boundary.
- wave reflection: Rossby wave is reflected as a upwelling Kelvin wave and propagates back to the eastern basin to reverse the phase of the ENSO cycle.
- ENSO period: is determined by the propagation time of the waves.

Delayed Oscillator: Wind Forcing



(Figures from IRI)



- The delayed oscillator suggested that oceanic Rossby and Kevin waves forced by atmospheric wind stress in the central Pacific provide the phase-transition mechanism (I.e. memory) for the ENSO cycle.
- The propagation and reflection of waves, together with local air-sea coupling, determine the period of the cycle.

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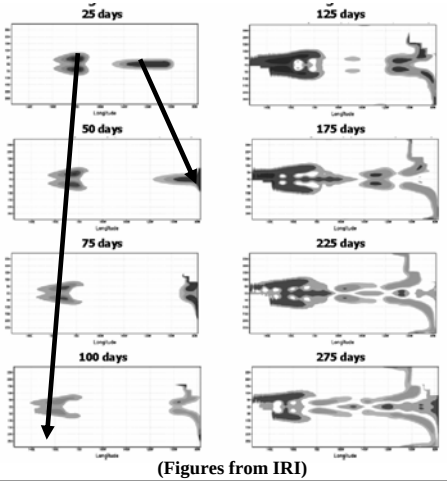
Wave Propagation and Reflection



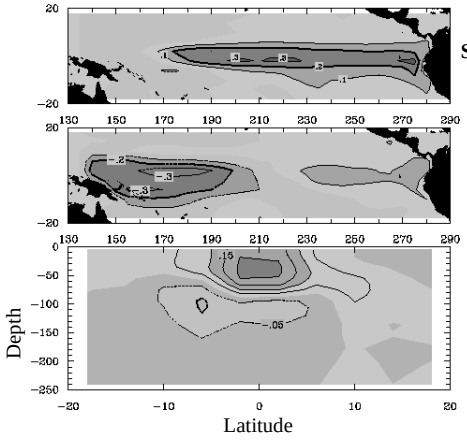
(Figures from IRI)

- It takes Kevin wave (phase speed = 2.9 m/s) about 70 days to cross the Pacific basin (17,760km).
- It takes Rossby wave about 200 days (phase speed = 0.93 m/s) to cross the Pacific basin.

Why Only Pacific Has ENSO?

- Based on the delayed oscillator theory of ENSO, the ocean basin has to be big enough to produce the "delayed" from ocean wave propagation and reflection.
- It can be shown that only the Pacific Ocean is "big" (wide) enough to produce such delayed for the ENSO cycle.
- It is generally believed that the Atlantic Ocean may produce ENSO-like oscillation if external forcing are applied to the Atlantic Ocean.
- Although the Indian Ocean is considered too small to produce ENSO.

ENSO Simulation by ESS CGCM

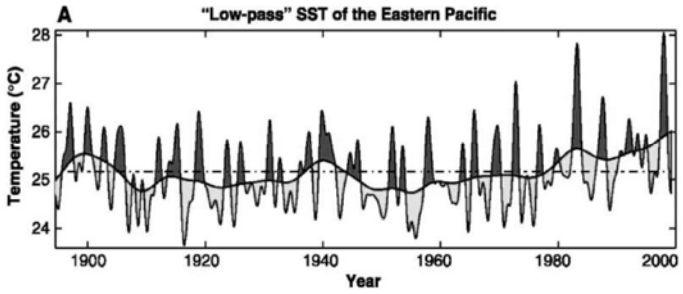


Surface Ocean Temperature

Sub_Surface Temperature

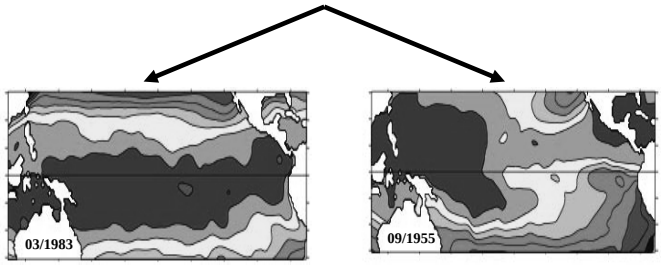
Vertical Cross Section

Decadal Changes of ENSO



(Figure from Fedorov and Philander 2000)

How El Nino Changes When Climate Warms?



❑ **Hypothesis 1: Permanent El Nino**
(Philander 2003)
When global climate warms
➔ El Nino / La Nina alternations disappear
➔ El Nino forever.

❑ **Hypothesis 2: Stronger ENSO Activity**
(Huber and Gaballero 2003)
When global climate warms
➔ Stronger El Nino / La Nina lternations
➔ Stronger ENSO events.

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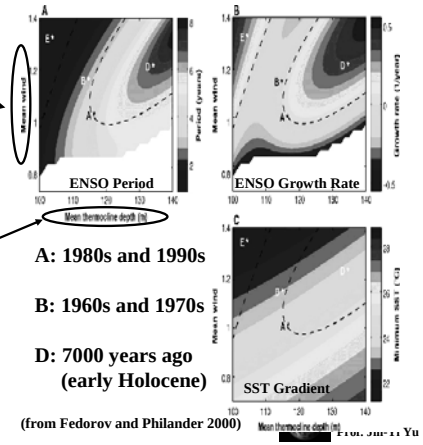
How Global Changes Affect El Nino?

How strong the wind is?

How deep the thermocline is?



A: 1980s and 1990s

B: 1960s and 1970s

D: 7000 years ago (early Holocene)

(from Fedorov and Philander 2000)