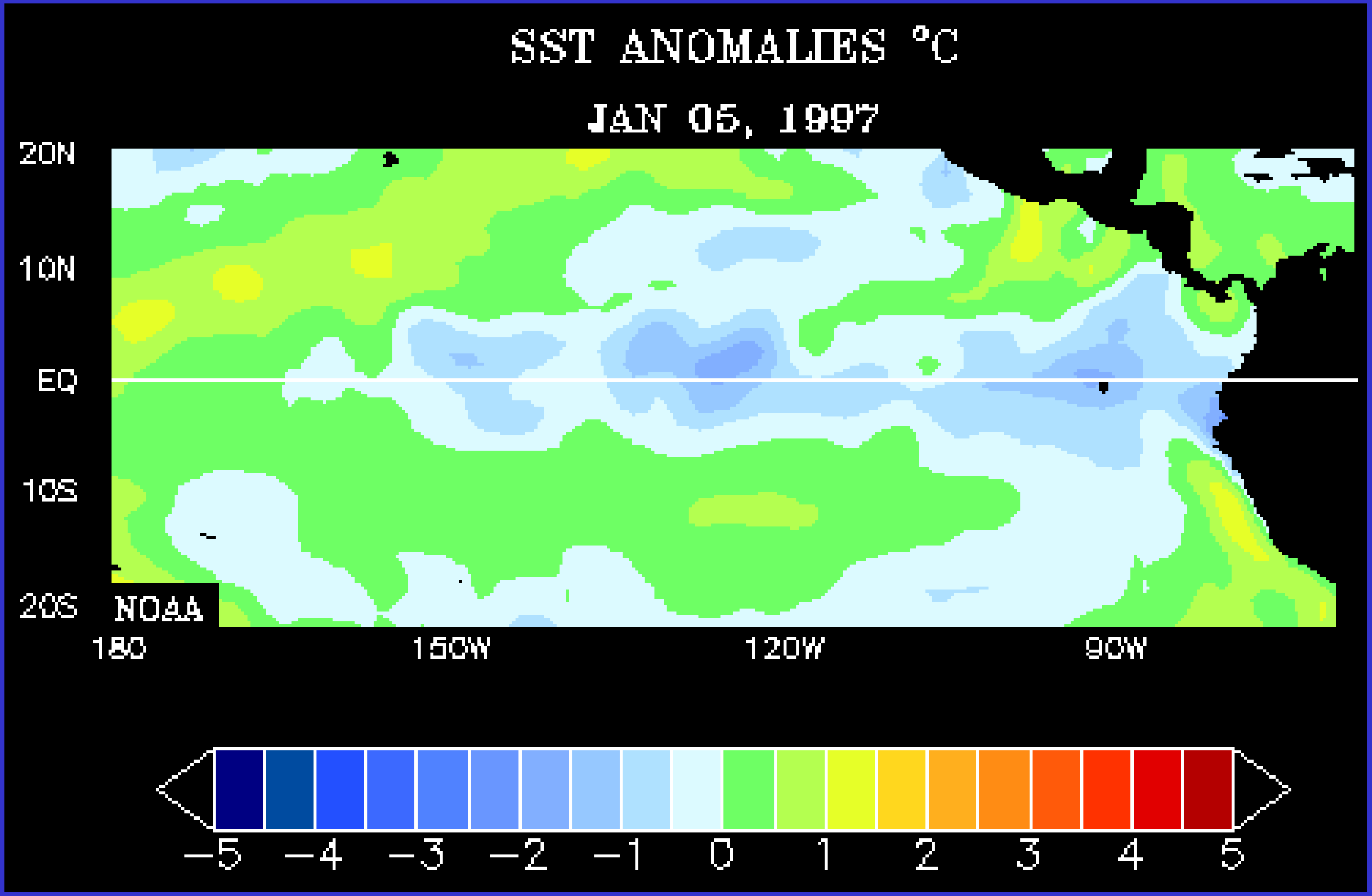
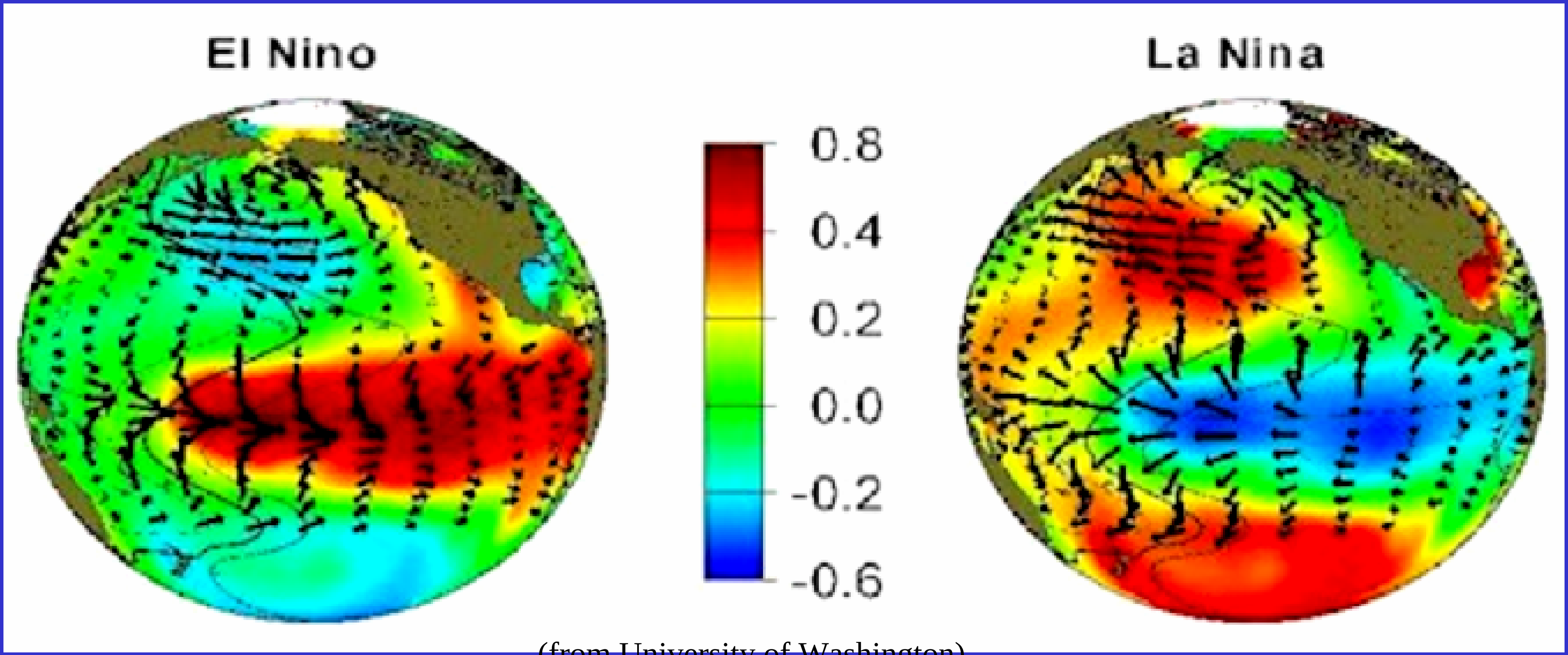
Lecture 10: El Nino Southern Oscillation (ENSO)



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

El Nino-Southern Oscillation



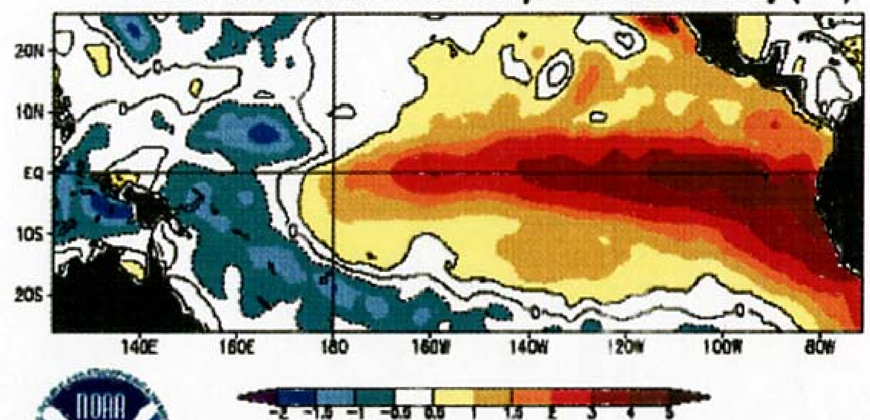
(from University of Washington)

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

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."

Observed Sea Surface Temperature Anomaly (^oC)

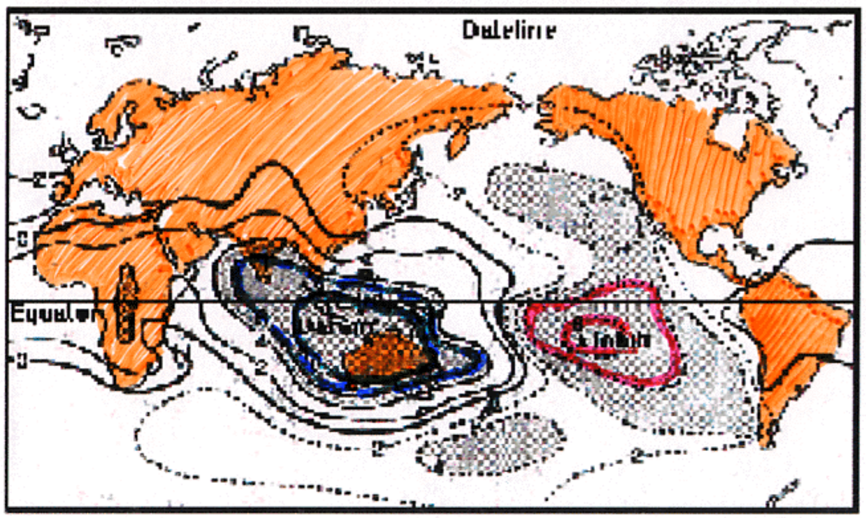


7-day average centered on 17 September 1997

Climate Prediction Center/NCEP/NWS

Southern Oscillation: an atmospheric phenomenon

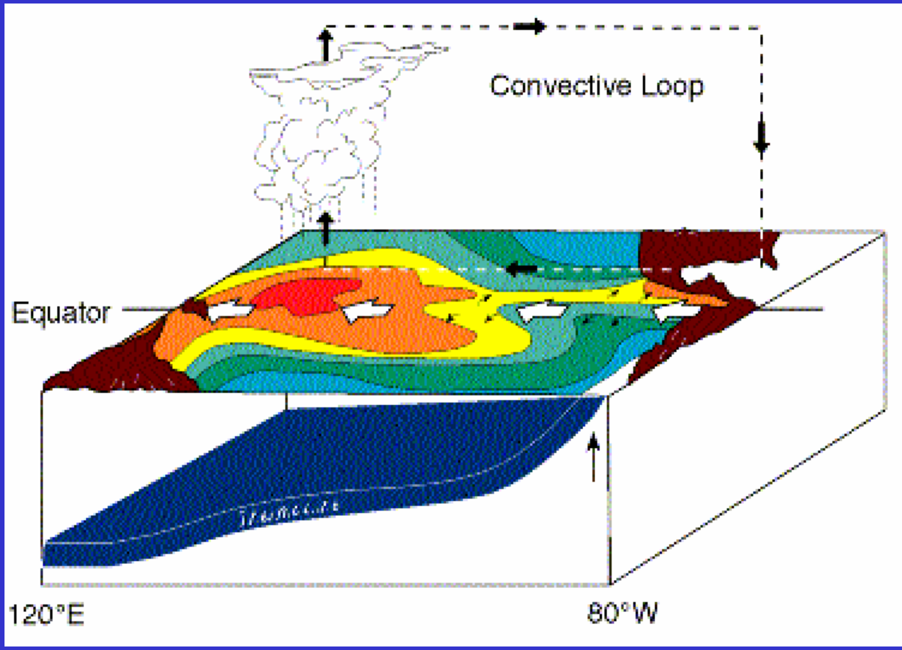
In 1910s, Walker found a connection between barometer readings at stations on the eastern and western sides of the Pacific (Tahiti and Darwin). He coined the term **Southern Oscillation** to dramatize the ups and downs in this east-west seesaw effect.

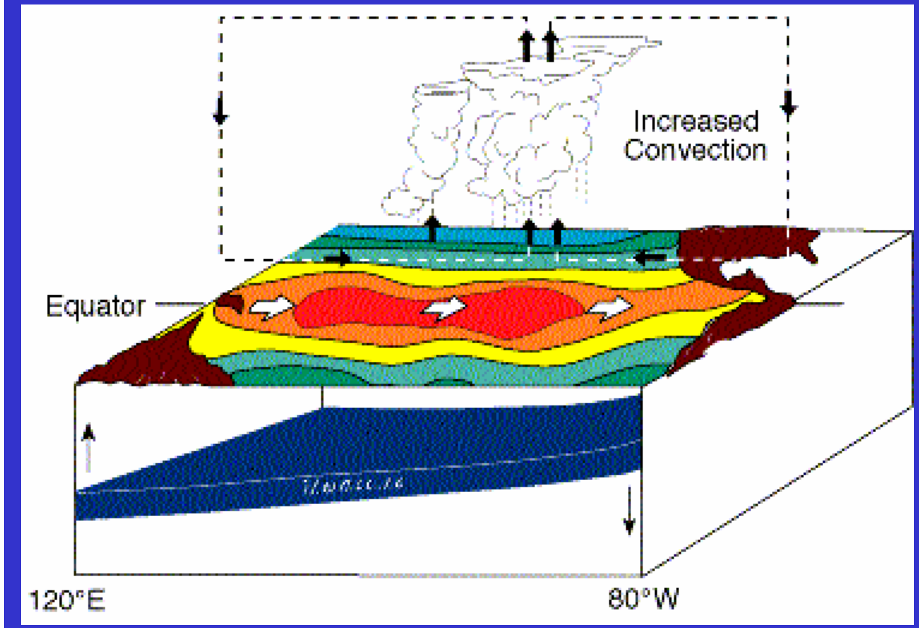


(from Rasmusson 1984)

Sir Gilbert Walker

Coupled Atmosphere-Ocean System

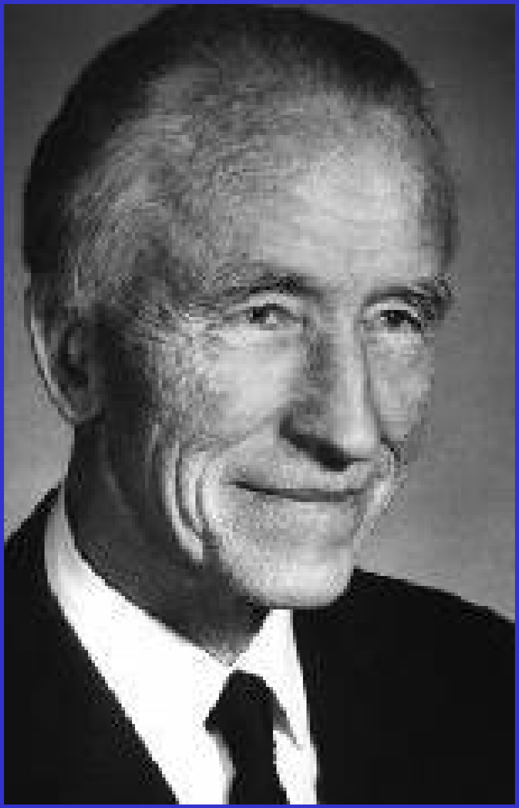




(from NOAA)

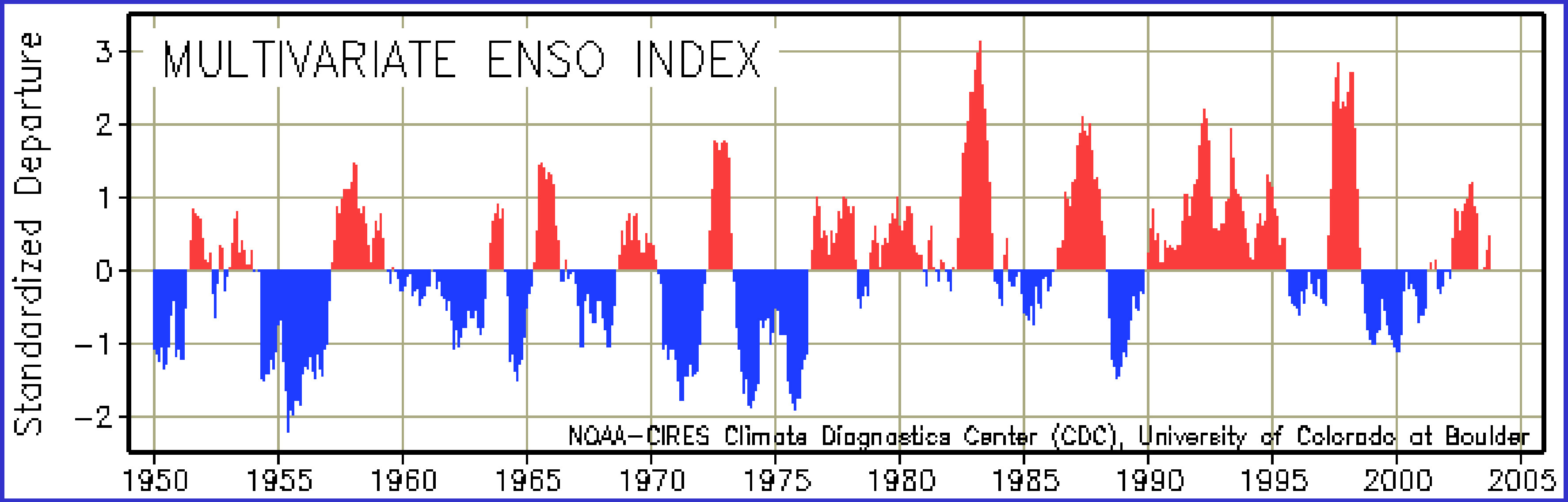
El Nino and Southern Oscillation

- 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.



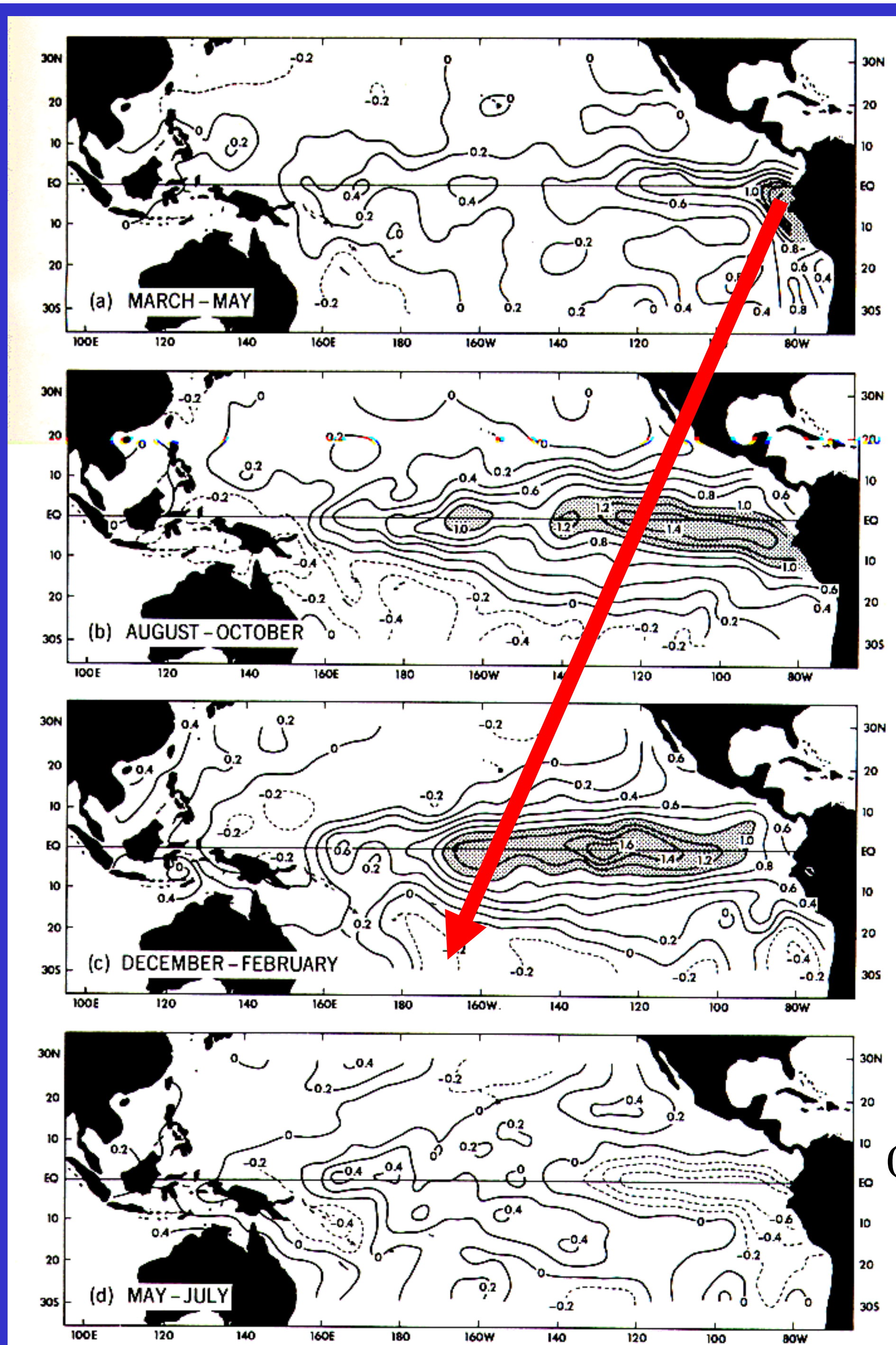
Jacob Bjerknes

The ENSO Cycle



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

➔ The ENSO Cycle.



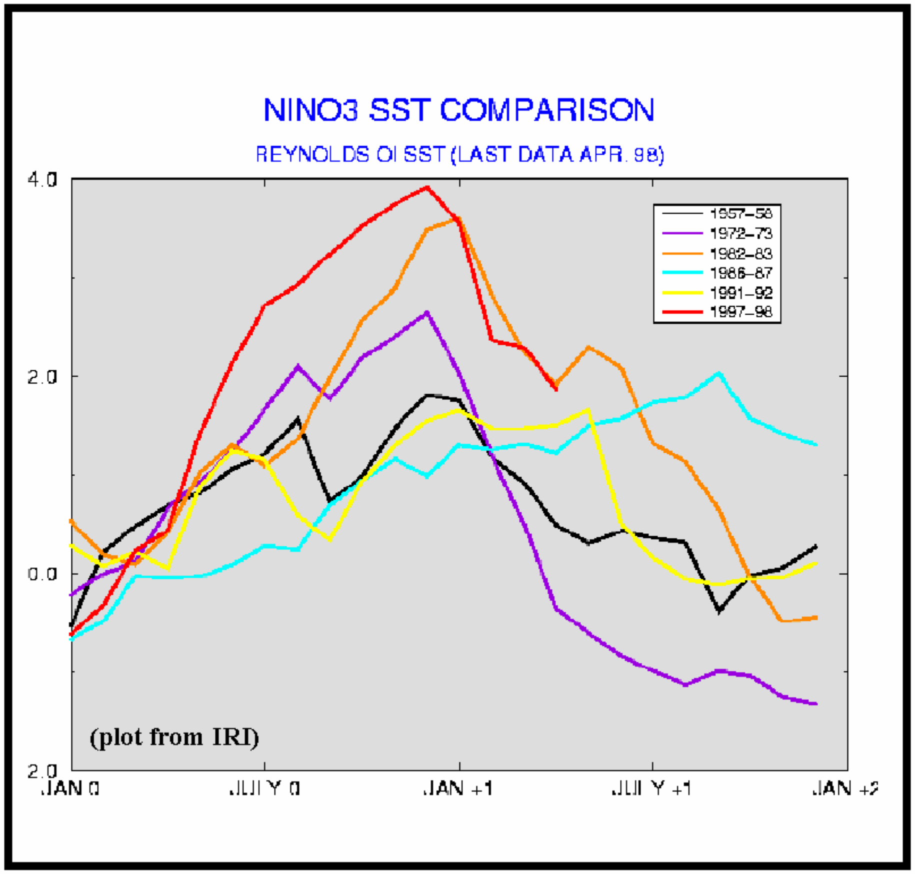
Onset Phase

Growing Phase

Mature Phase

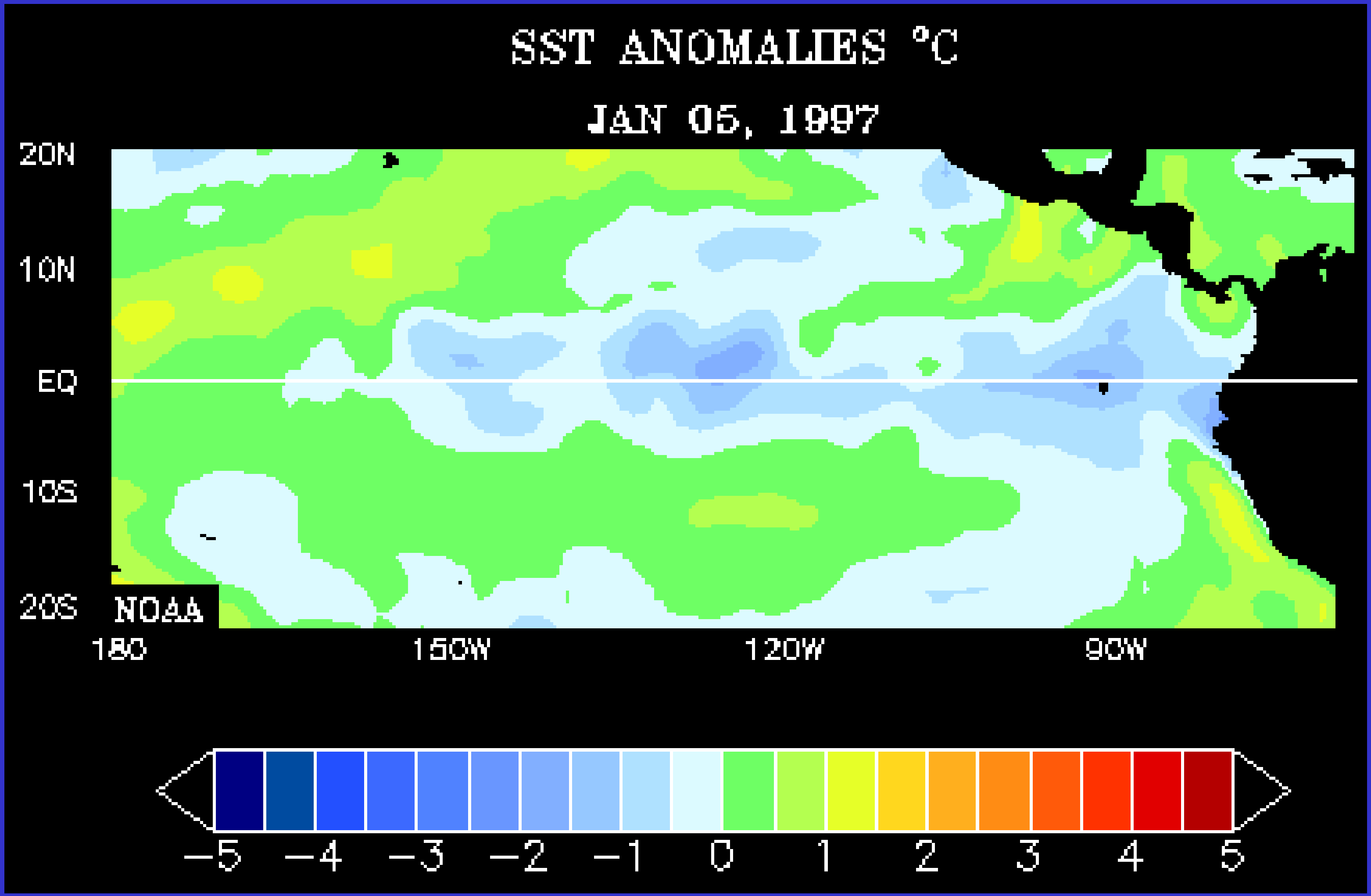
(from Rasmusson and Carpenter 1982)

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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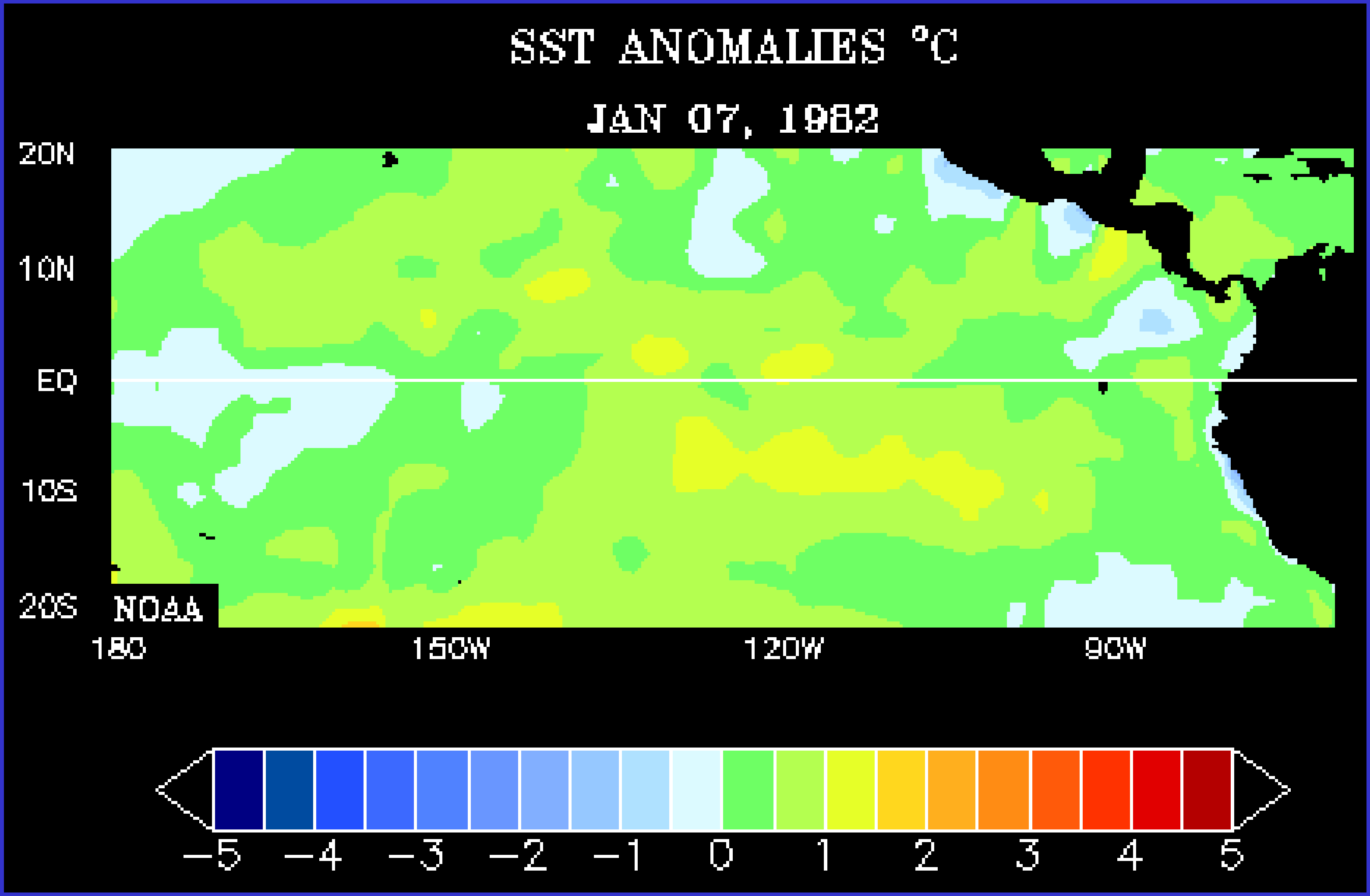
1982-83 El Nino



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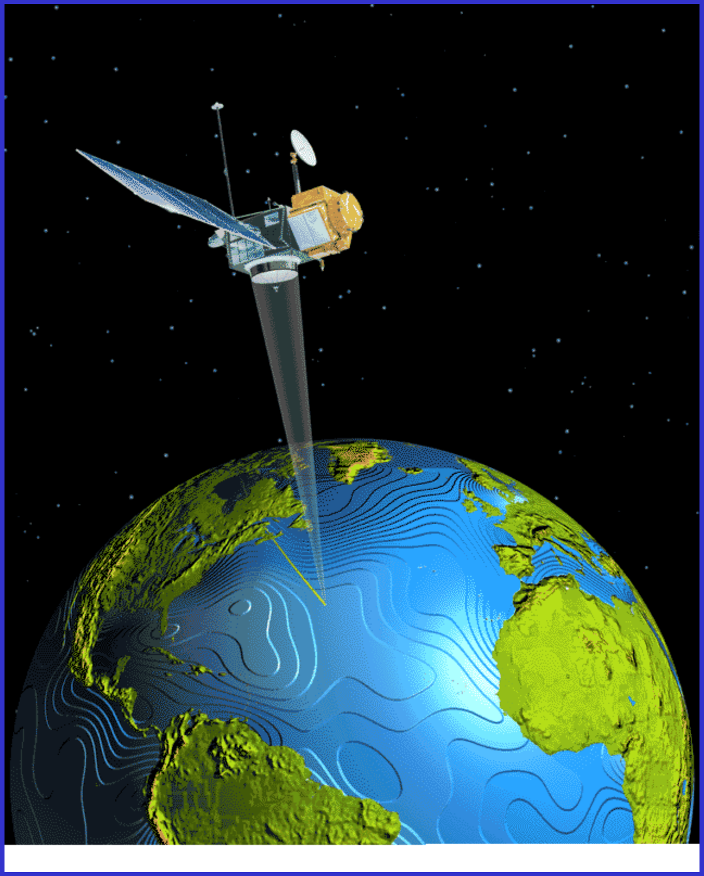
"Measuring" ENSO

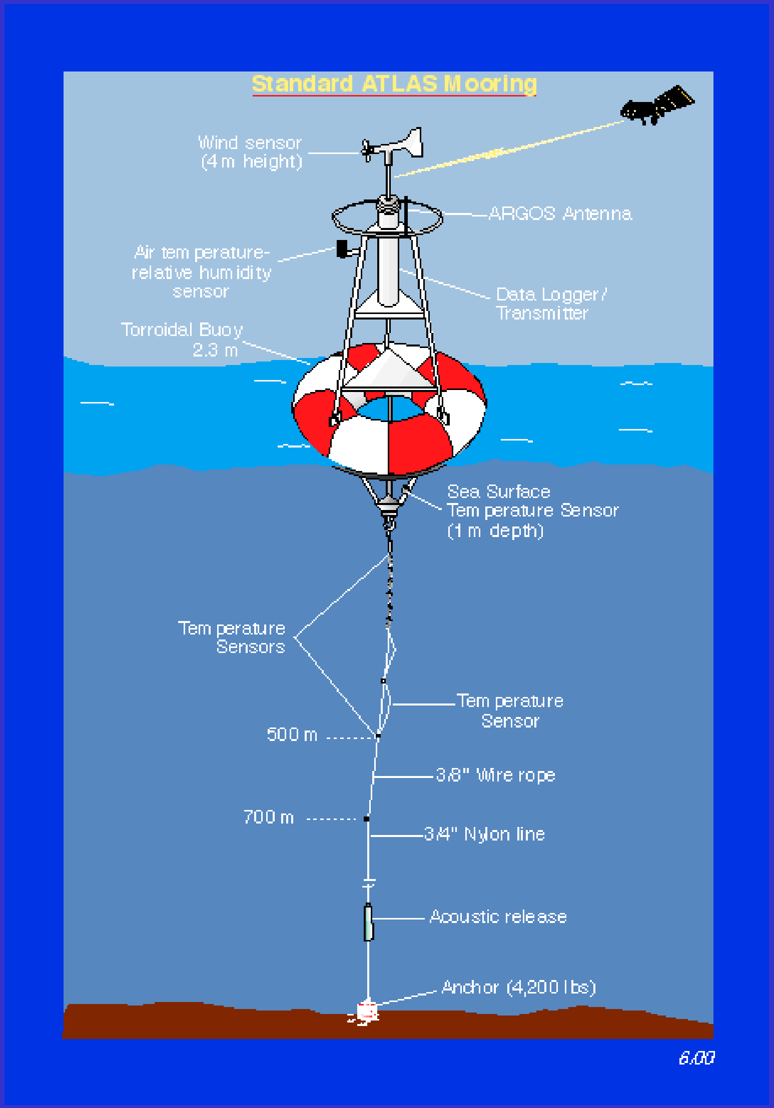
Space-Based Observations

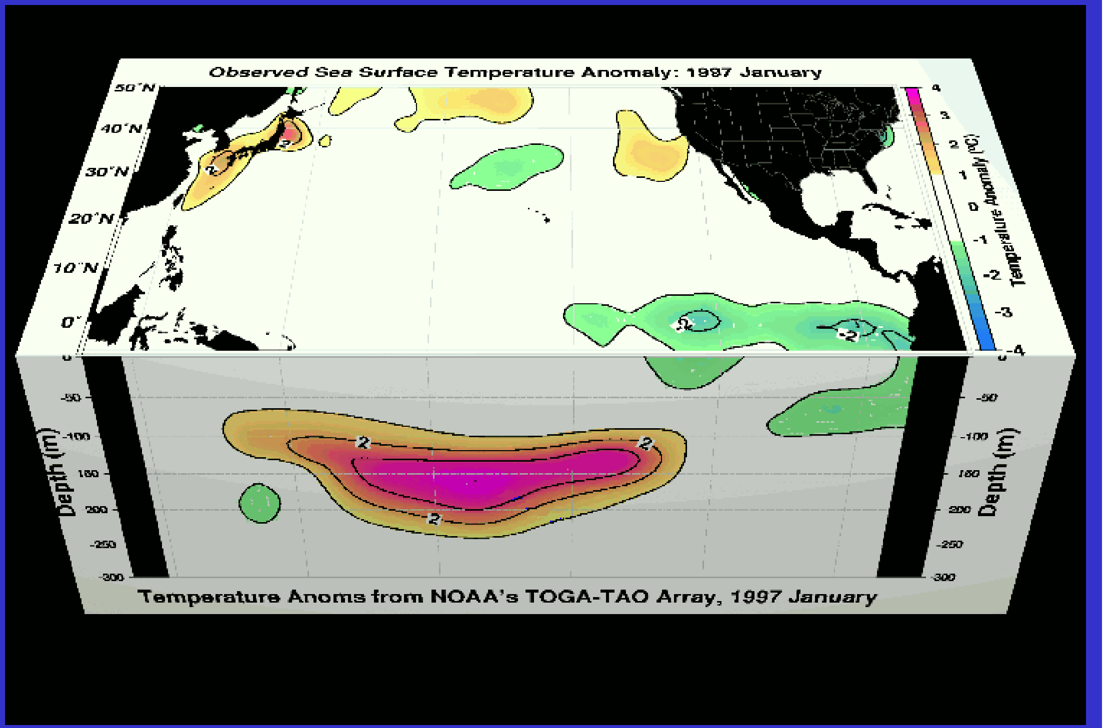


In-Situ Observations


ATLAS

Subsurface Ocean Observation





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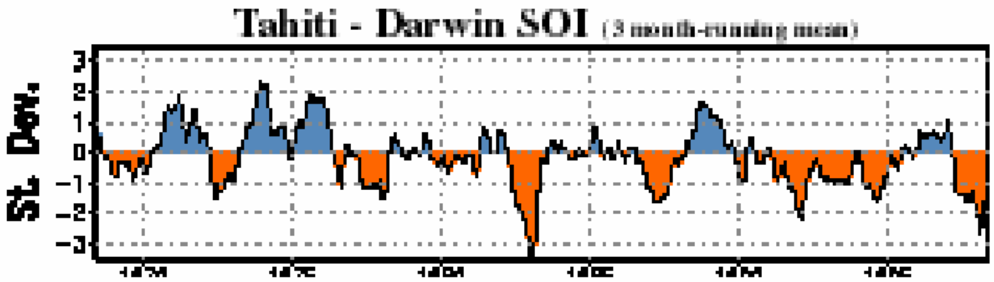
Basic Issues

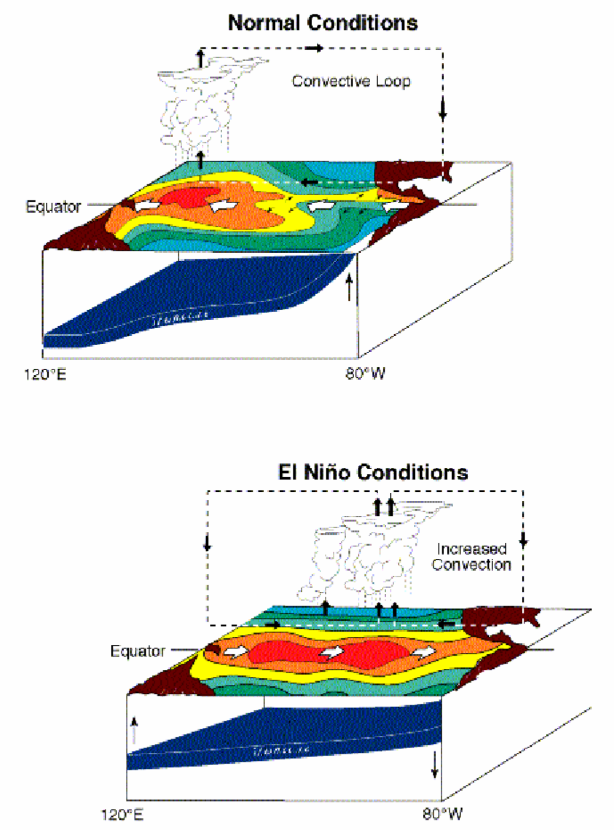
- The Basic Mechanism of the ENSO
  - growth mechanism
  - phase-transition mechanism
  - onset triggering mechanism



(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?

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.

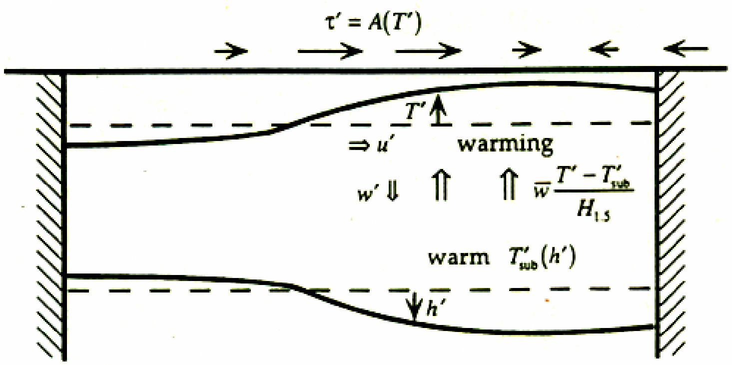
- This coupled instability mechanism was first proposed by Bjerknes (1966, 1969) based on statistical correlations and was later demonstrated by many modeling studies.

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 $c\tau$)

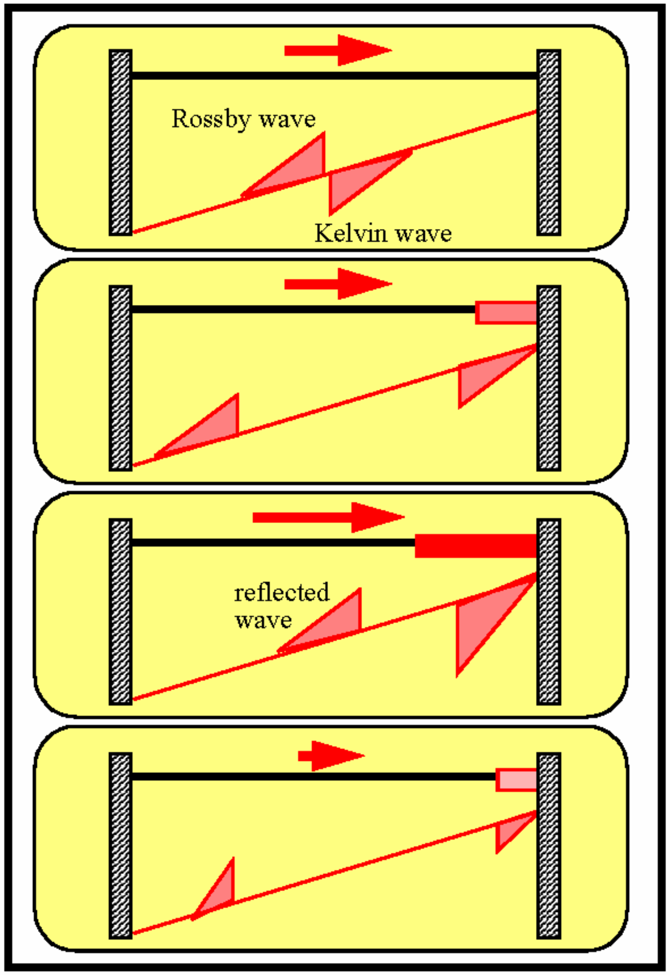
Subsurface thermocline process

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

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

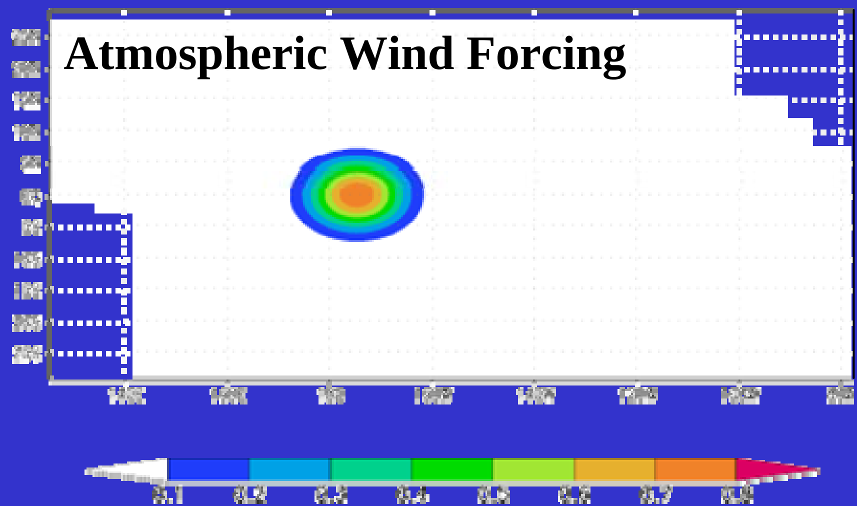
(Jin-Yi Yu 1999)

Delayed Oscillator Theory

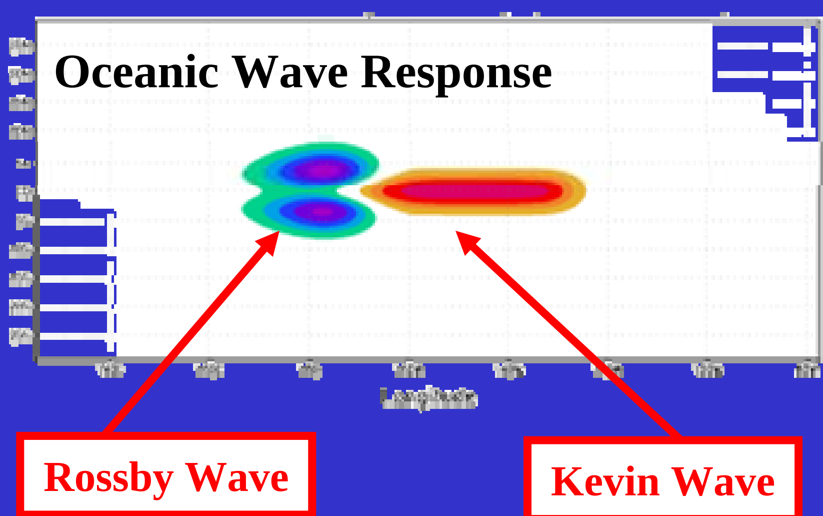


- Wind forcing at the central Pacific: produces a downwelling Kevin wave propagating eastward and a upwelling Rossby wave propagating westward.
- wave propagation: the fast kelvin wave causes SST warming at the eastern basin, while slow Rossby wave is reflected at the western boundary.
- wave reflection: 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

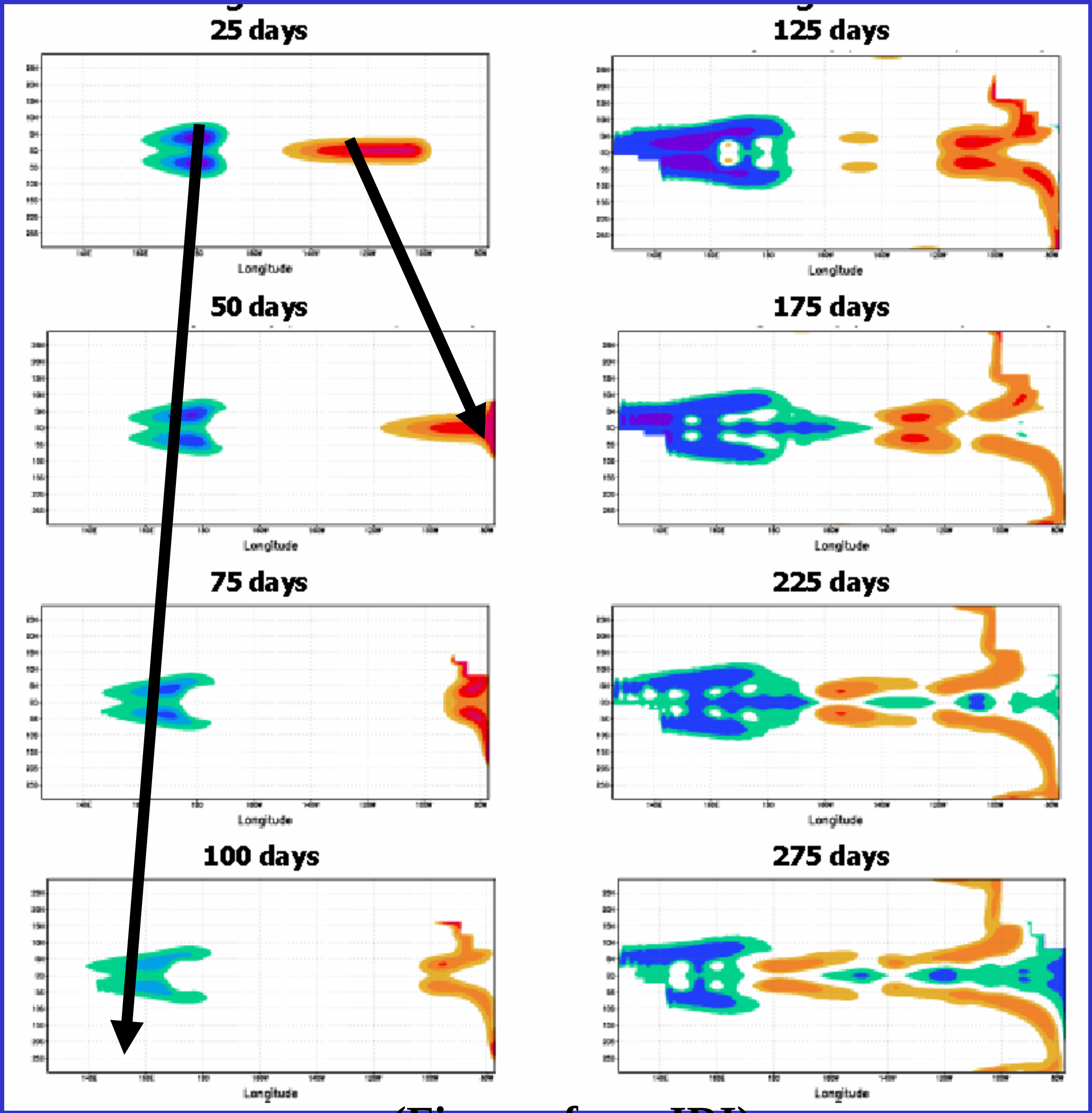


(Figures from IRI)



- 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.

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?

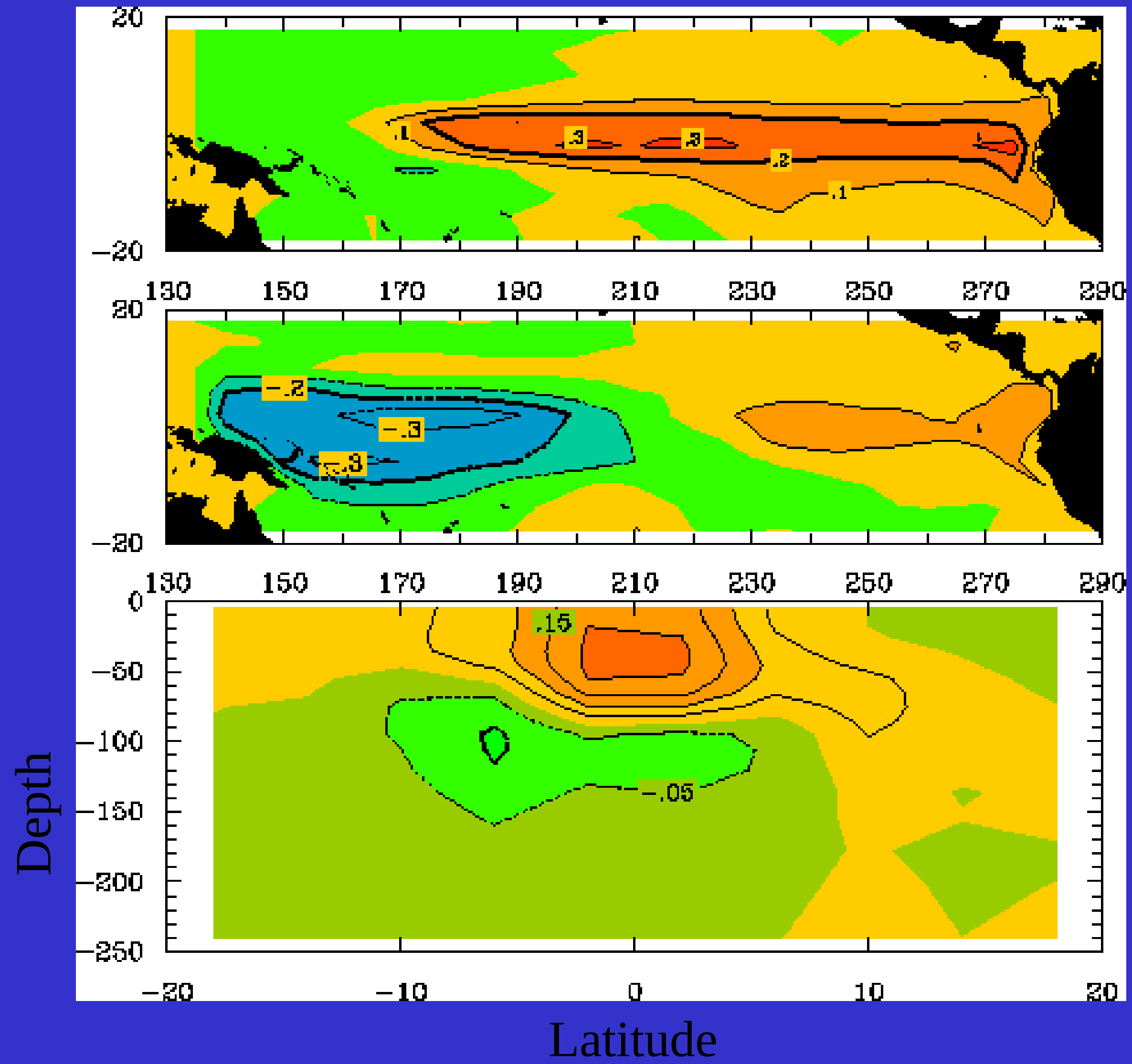
- Based on the delayed oscillator theory of ENSO, the ocean basin has to be big enough to produce the "delayed" from ocean wave propagation and reflection.

- It can be shown that only the Pacific Ocean is "big" (wide) enough to produce such delayed for the ENSO cycle.

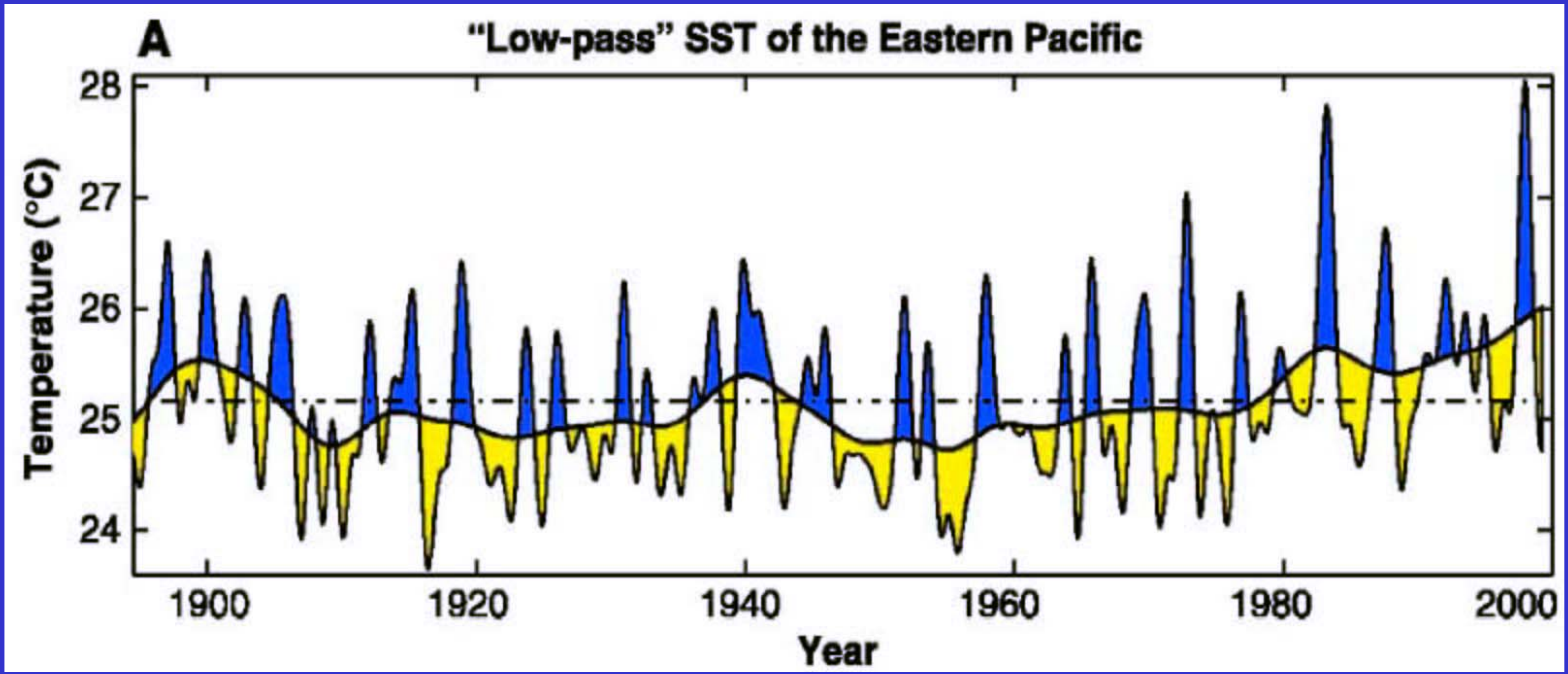
- It is generally believed that the Atlantic Ocean may produce ENSO-like oscillation if external forcing are applied to the Atlantic Ocean.

- Although the Indian Ocean is considered too small to produce ENSO.

ENSO Simulation by ESS CGCM



Decadal Changes of ENSO



(Figure from Fedorov and Philander 2000)

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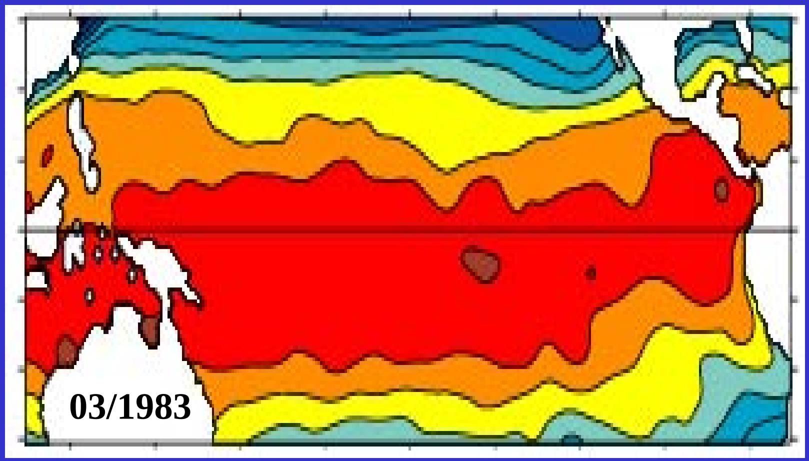
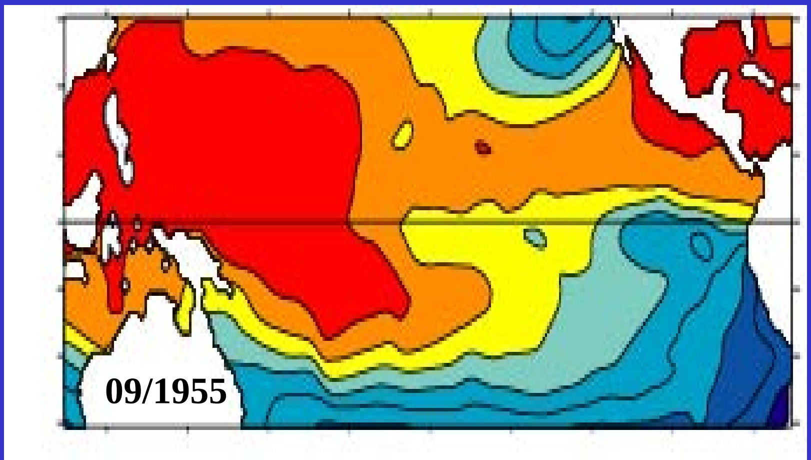
How El Nino Changes When Climate Warms?





- **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**

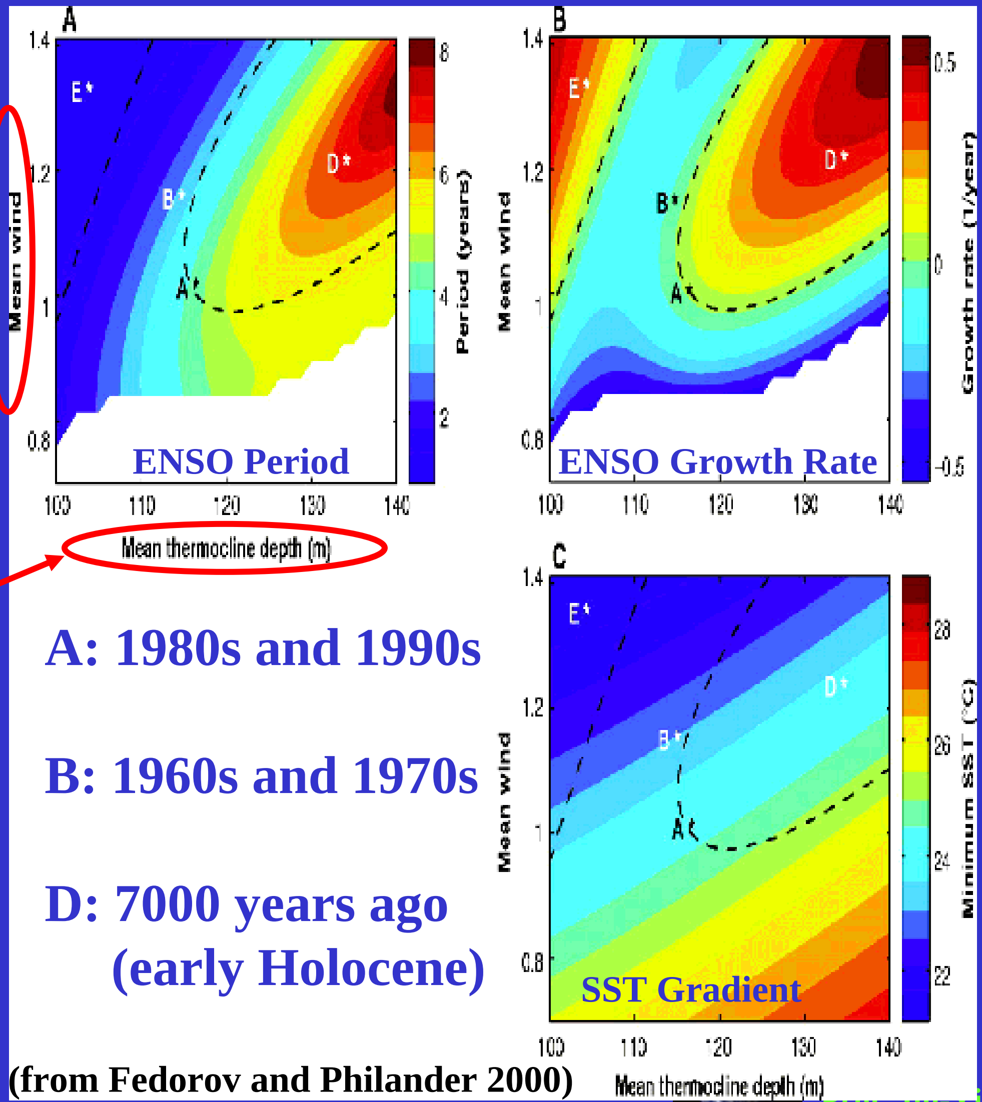
  (Huber and Gaballero 2003)

  When global climate warms

  ➔ Stronger El Nino / La Nina lternations

  ➔ Stronger ENSO events.

How Global Changes Affect El Nino?



A: 1980s and 1990s

B: 1960s and 1970s

D: 7000 years ago
(early Holocene)

(from Fedorov and Philander 2000)