OCN/ATM/ESS 587

Tropical ocean/atmosphere/climate interactions….

Forcing mechanisms

ENSO: basic cause-effect relations

Feedbacks….local

Feedbacks….N. Pacific

Feedbacks….global

General forcing mechanisms….

- **Narrow-band forcing (a single frequency forcing mechanism yields a single frequency response). Examples: Milankovich cycles, tides, etc.**

- **Broad-band forcing (forcing is spread out over a band [perhaps narrow] of frequencies, and response is similarly broad-band). Example: ENSO**

- **Other, such as red noise. Example: PDO.**

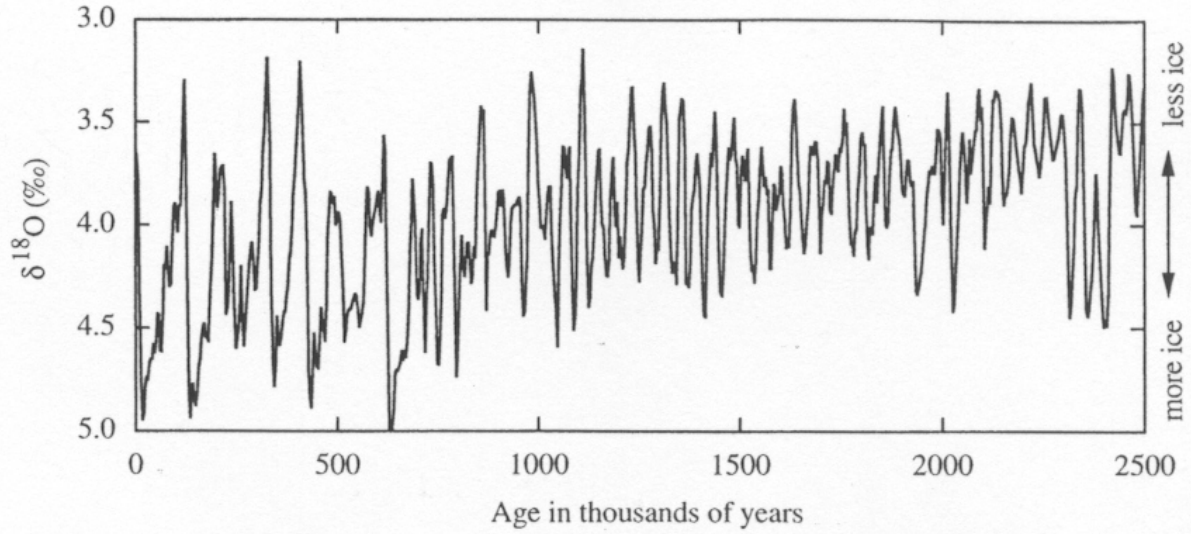
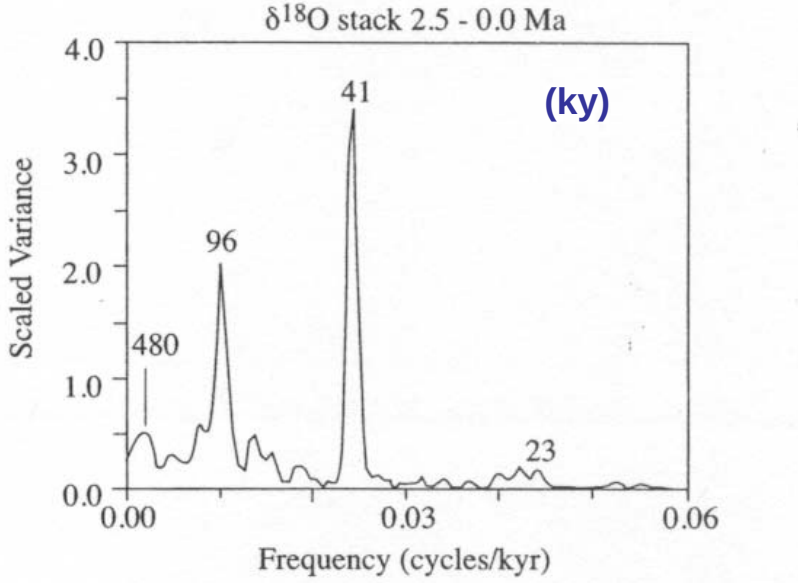
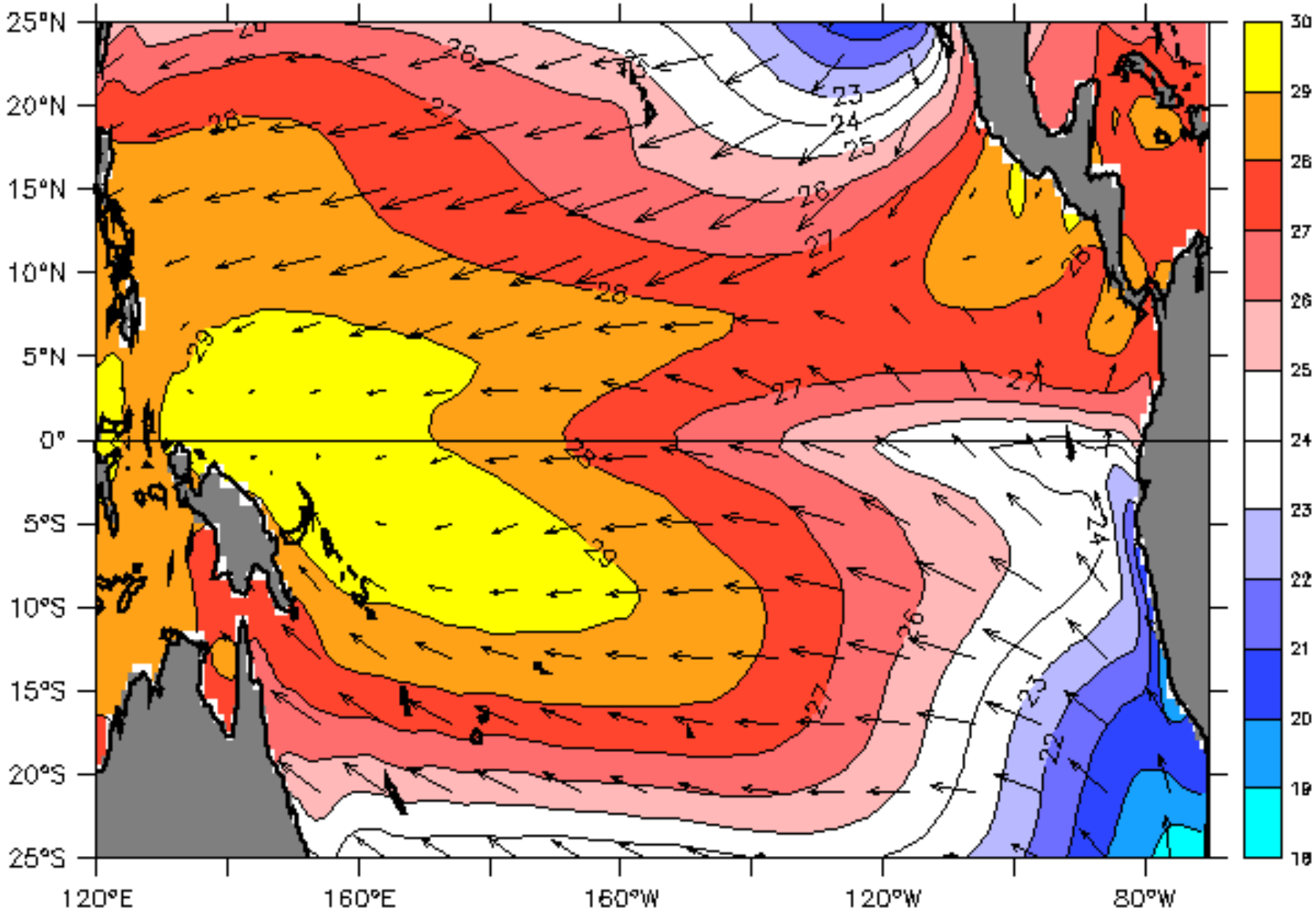


Fig. 8.6 History of $\delta^{18}O$ over the last 2.5 million years derived from several ice cores. [Plot made from data provided by M. E. Raymo and previously published in Raymo *et al.* (1990). Reprinted with permission from Elsevier Scientific Publishers.]

Fig. 8.7

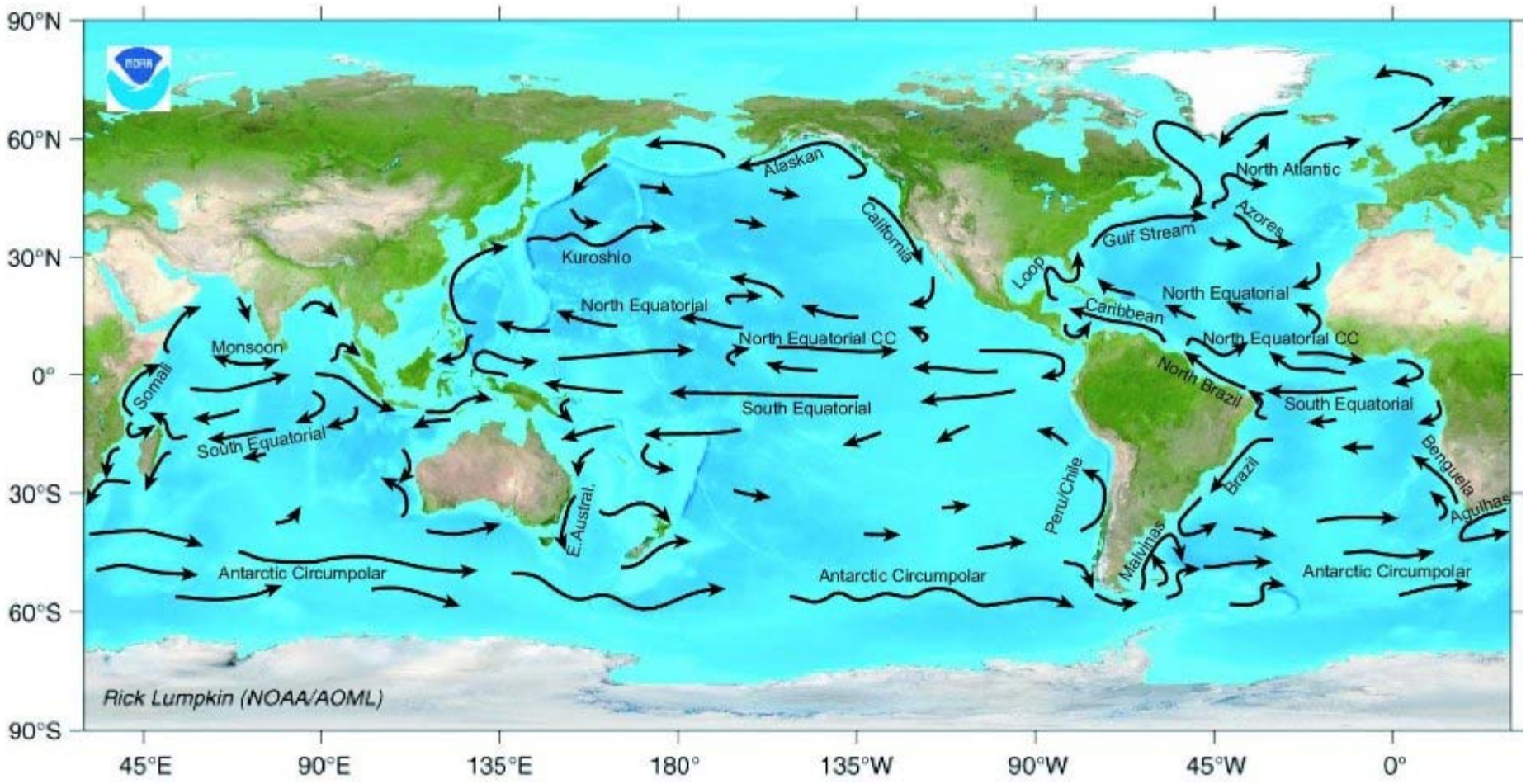


[from Hartmann]

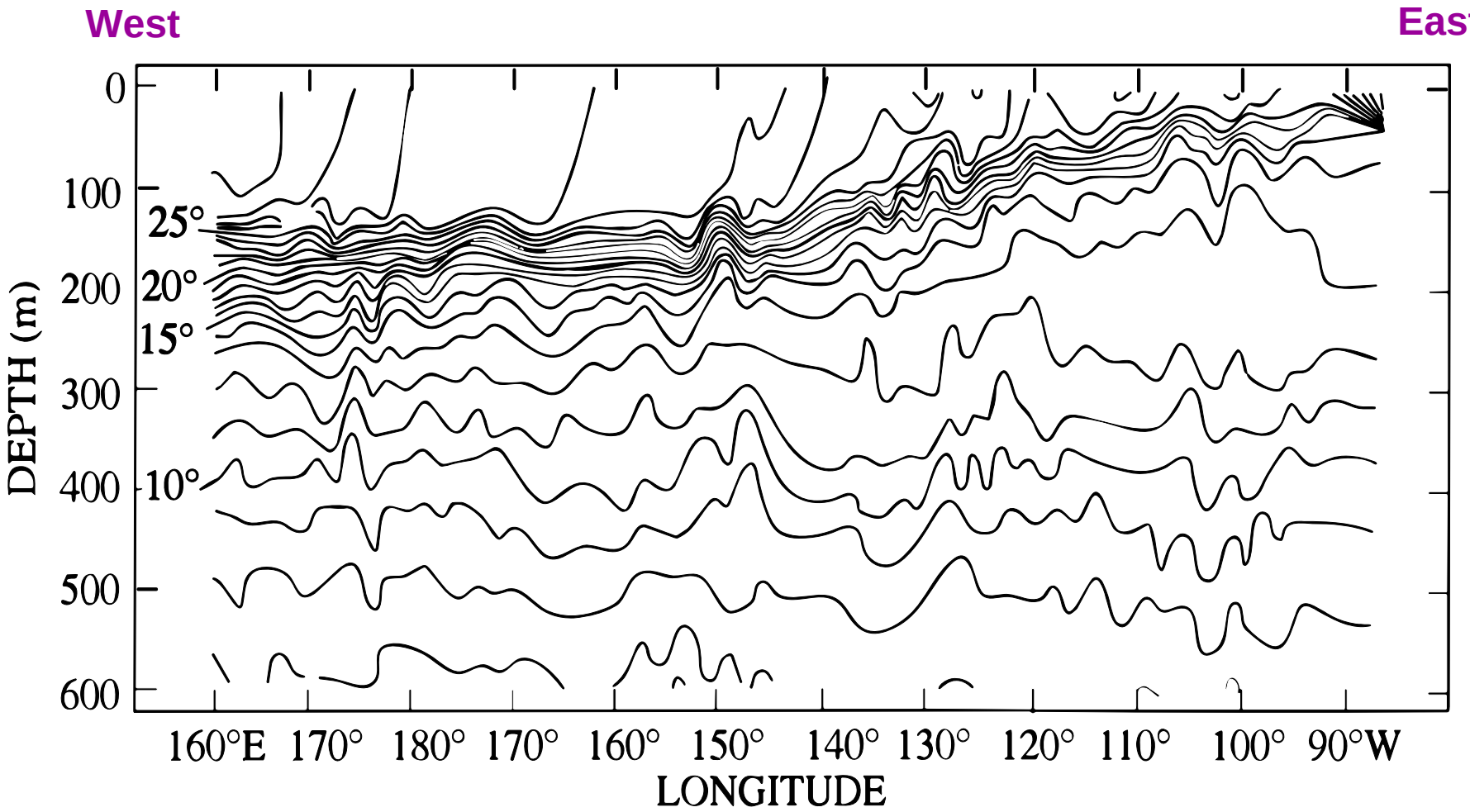


Mean SST and wind over the tropical Pacific

[from B. Kessler]

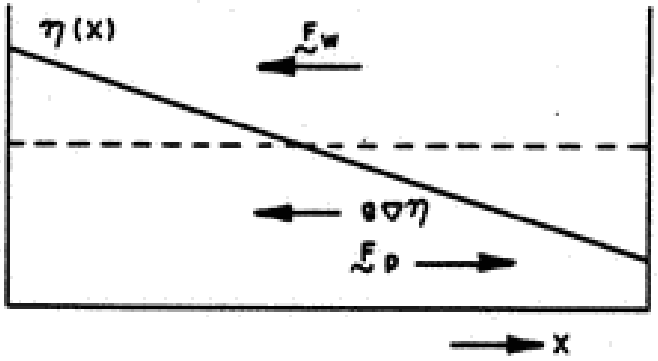


Normal surface currents in the Pacific



Temperature along the equator: normal conditions

Normal case for the Equatorial Pacific: balanced forces, wind and sea level gradient



$$\underset{\sim}{F}_w + \underset{\sim}{F}_p = \ddot{\underset{\sim}{X}} = 0$$

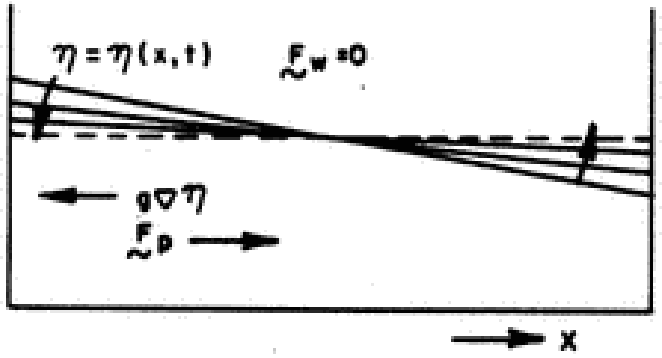
$$\underset{\sim}{F}_p = -g\Delta\eta$$

[forces balanced]

Pressure gradient = sea level gradient
$= -g\nabla\eta$

[forces unbalanced]

If the wind is removed, the sea level gradient attempts to propagate to a new equilibrium state

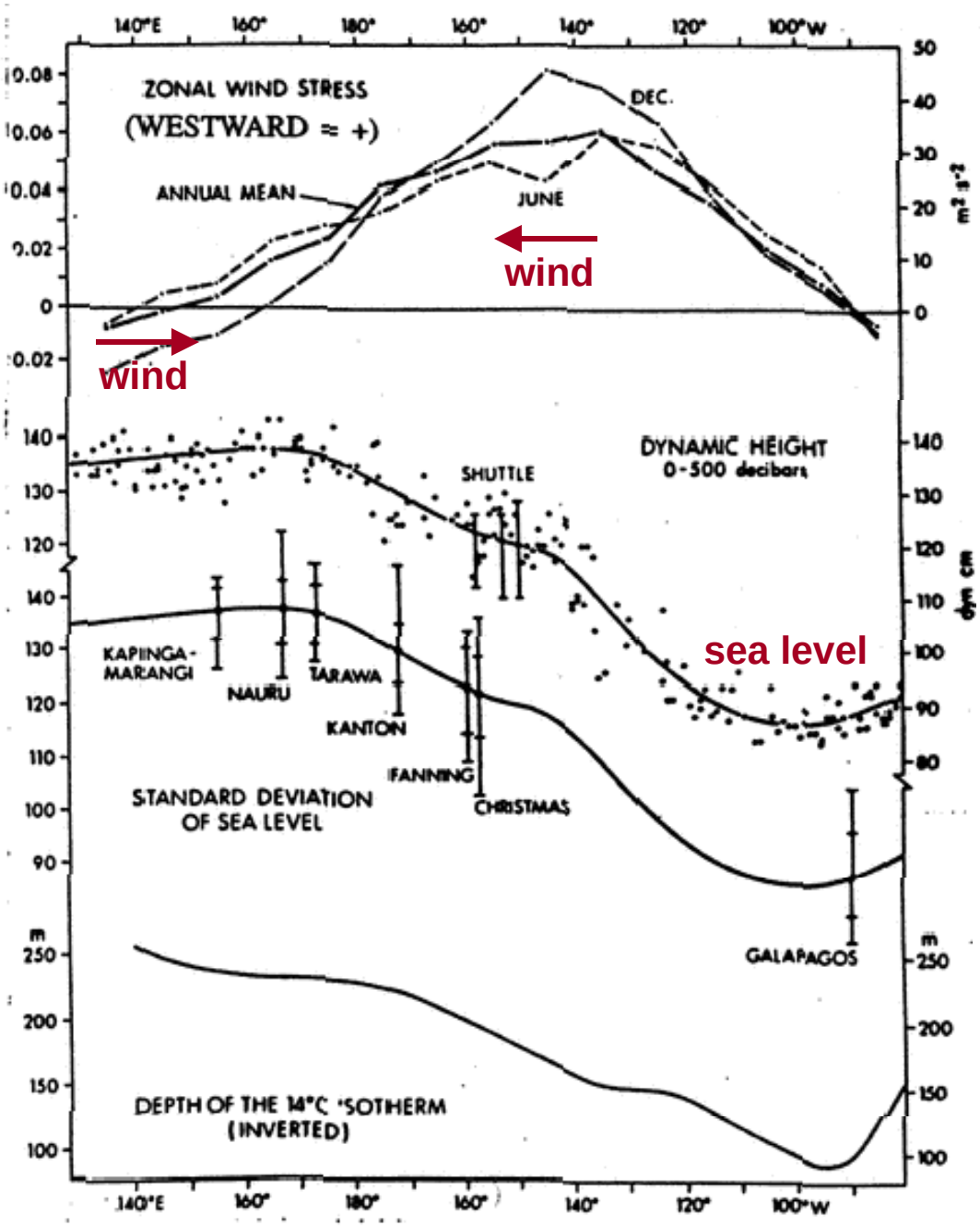


$$\underset{\sim}{F}_p = -g\nabla\eta = \ddot{\underset{\sim}{X}} > 0$$

ENSO….

Wind stress is east (pressure force to the west); sea level gradient yields ocean pressure force to the east.

140° E 100° W



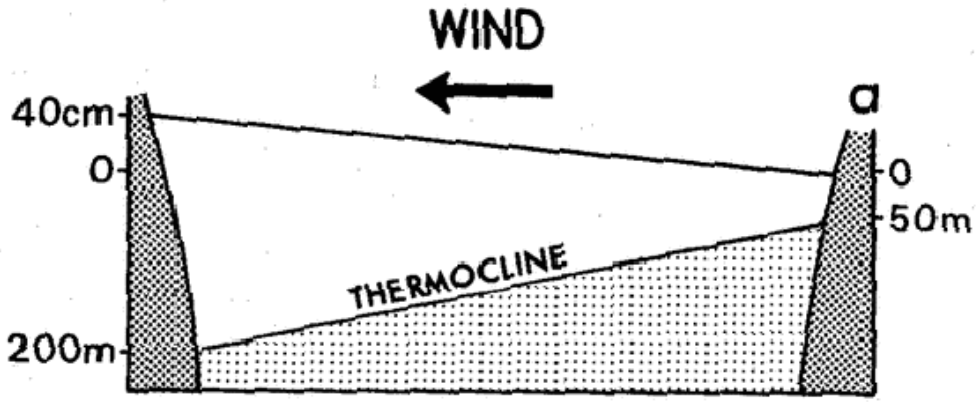
ENSO….an example of air-sea interaction and feedback

For reasons largely unknown, at intevals of ~ 5 years the easterly (ie, from the east) winds in the Equatorial Pacific disappear over the course of a few months, often reappearing as westerlies.

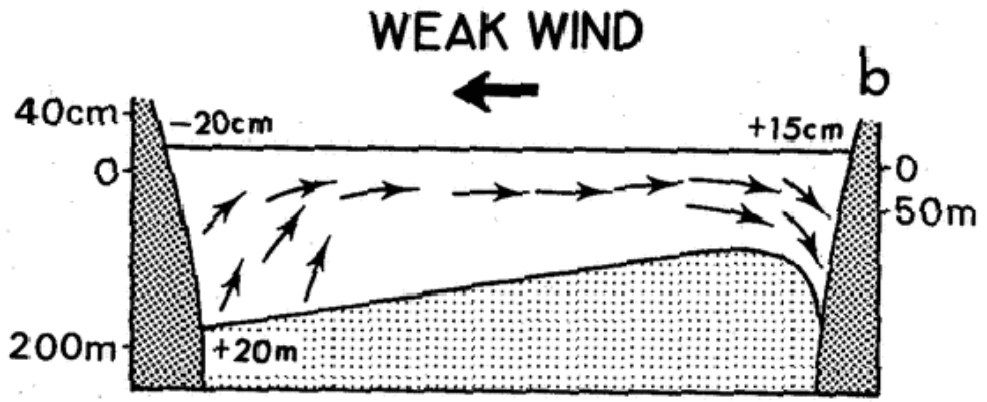
This causes the equatorial sea level gradient to be unbalanced, resulting in an oceanic flow to the east at the equator.

ENSO….

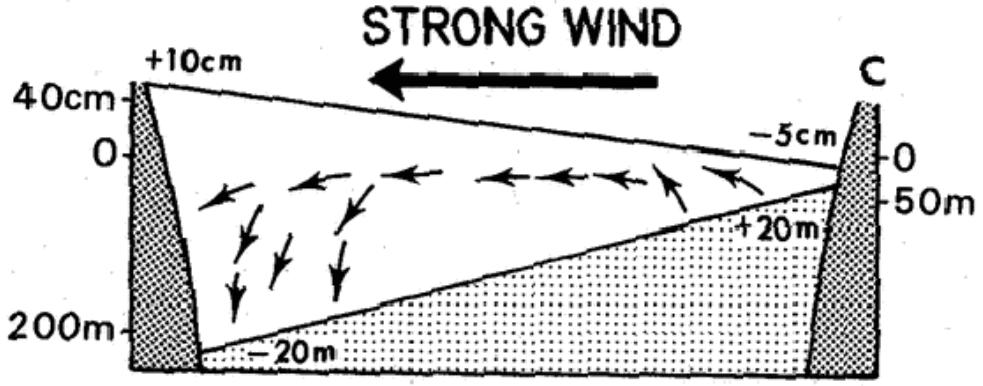
Atmosphere/ocean (normal)



Atmosphere/ocean (ENSO)

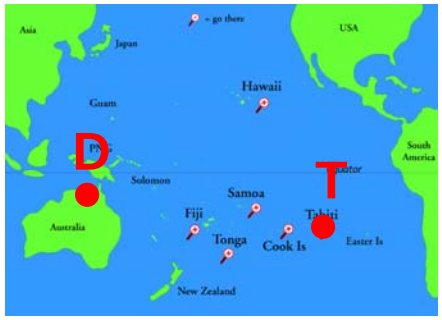


Atmosphere/ocean (La Niña)



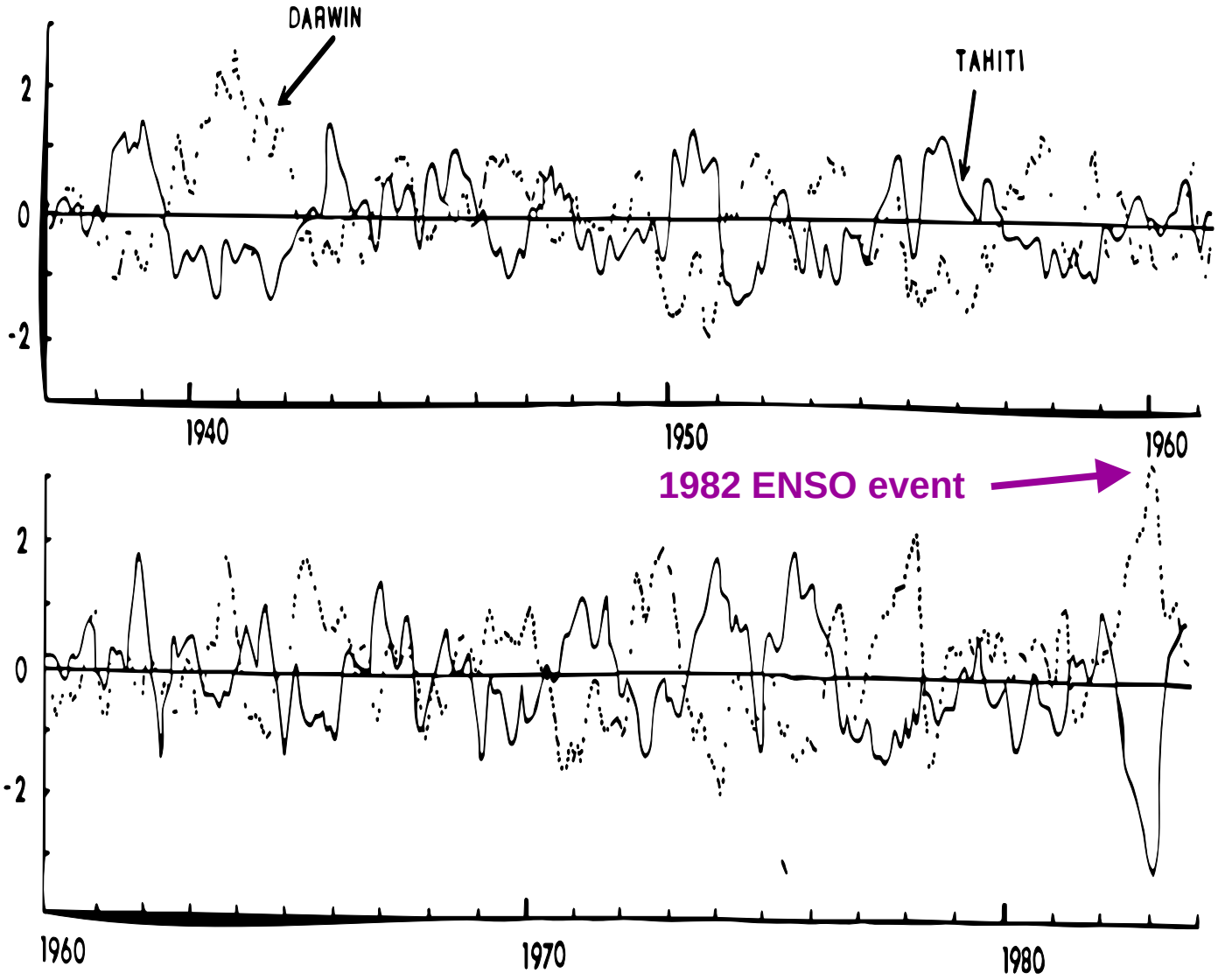
ENSO….

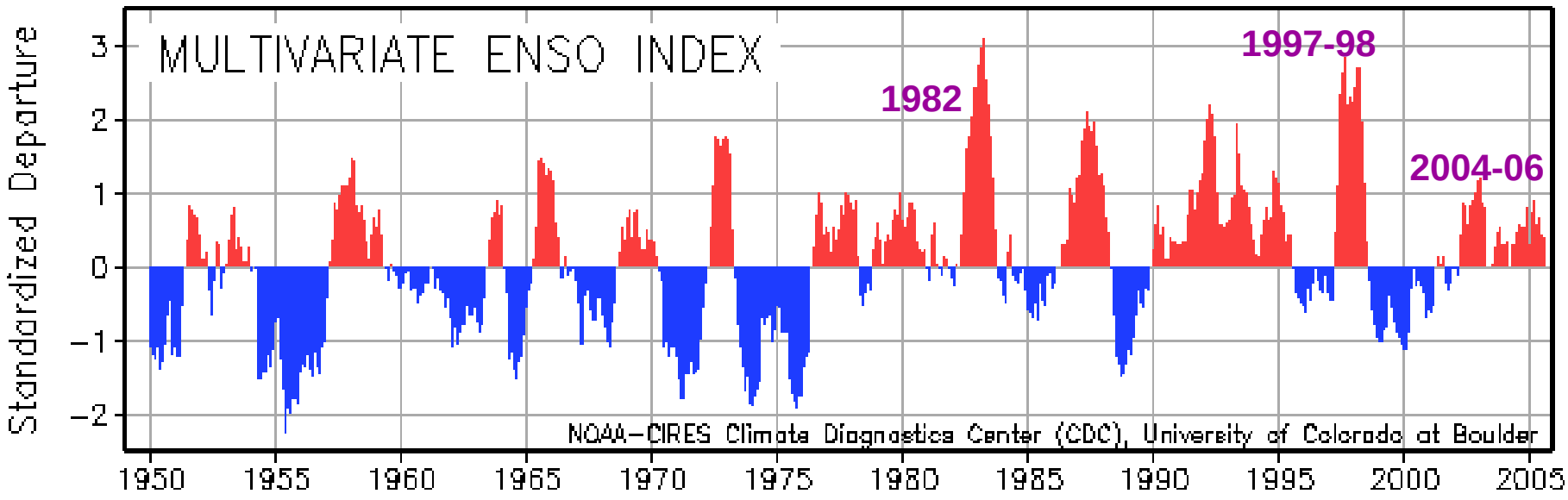
The ENSO Index: Darwin (Australia) minus Tahiti atmospheric presssure



D–T < 0
(normal)

D–T > 0
(ENSO)



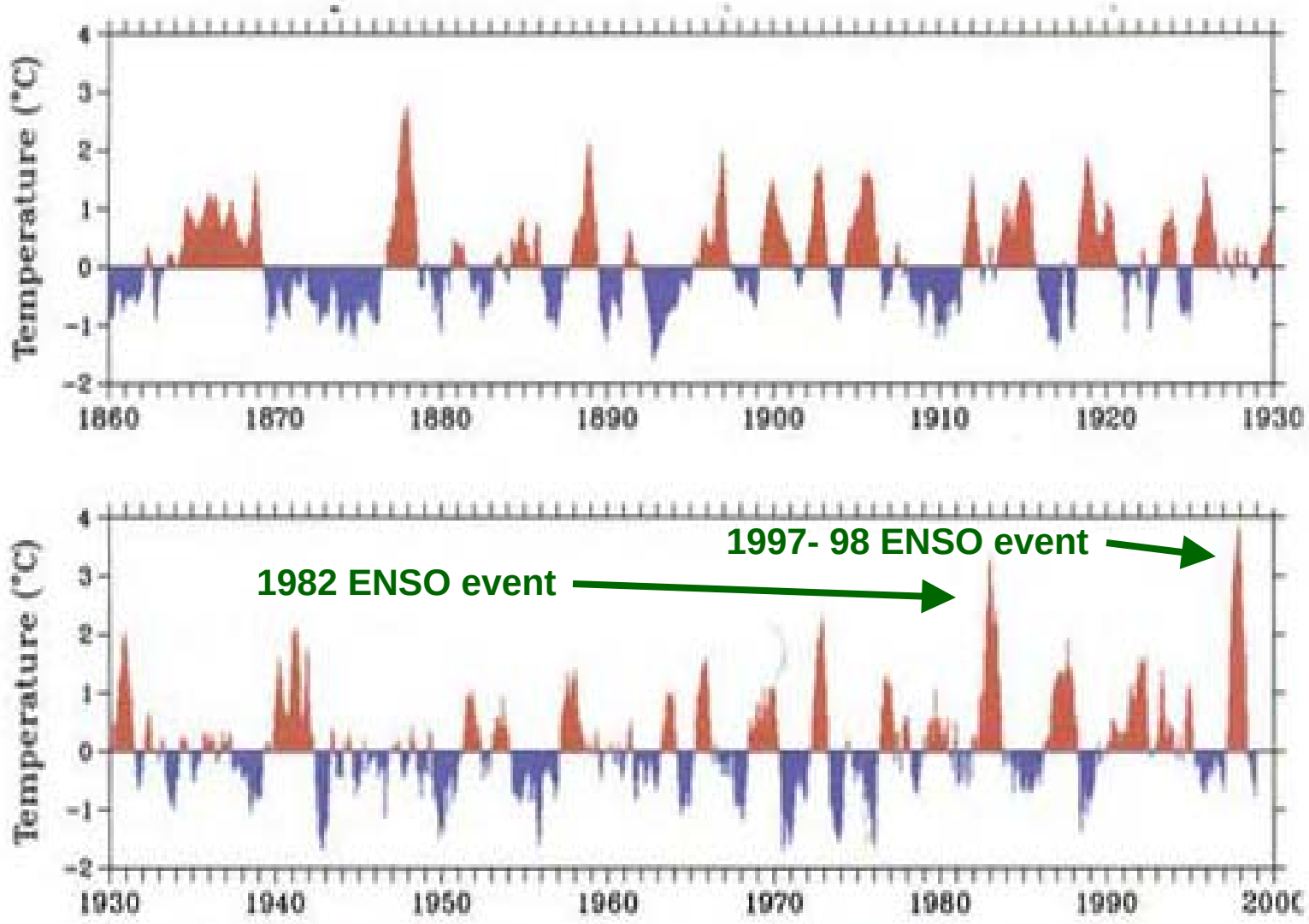


Present estimates of the ENSO index

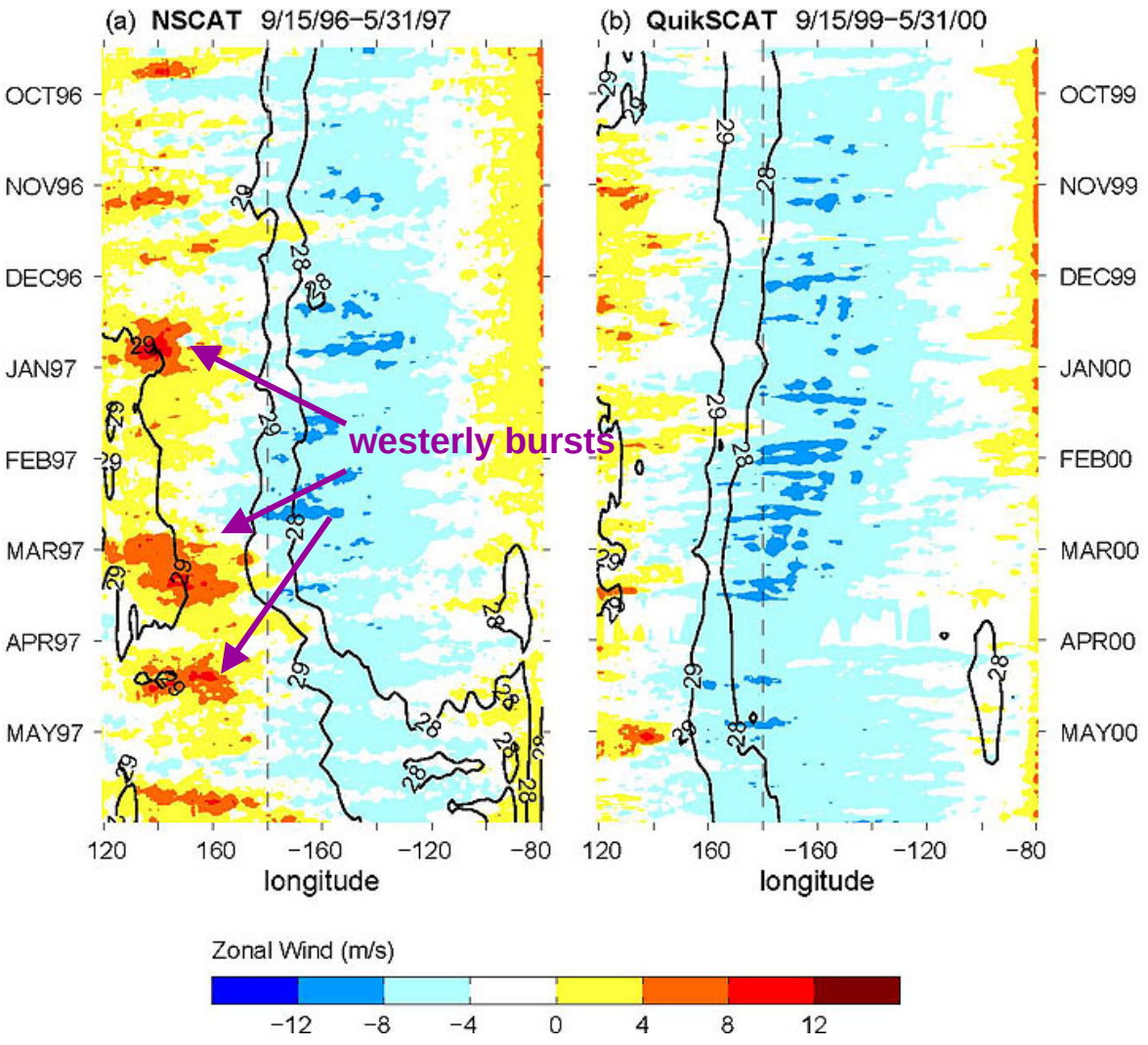
D–T < 0
(normal)

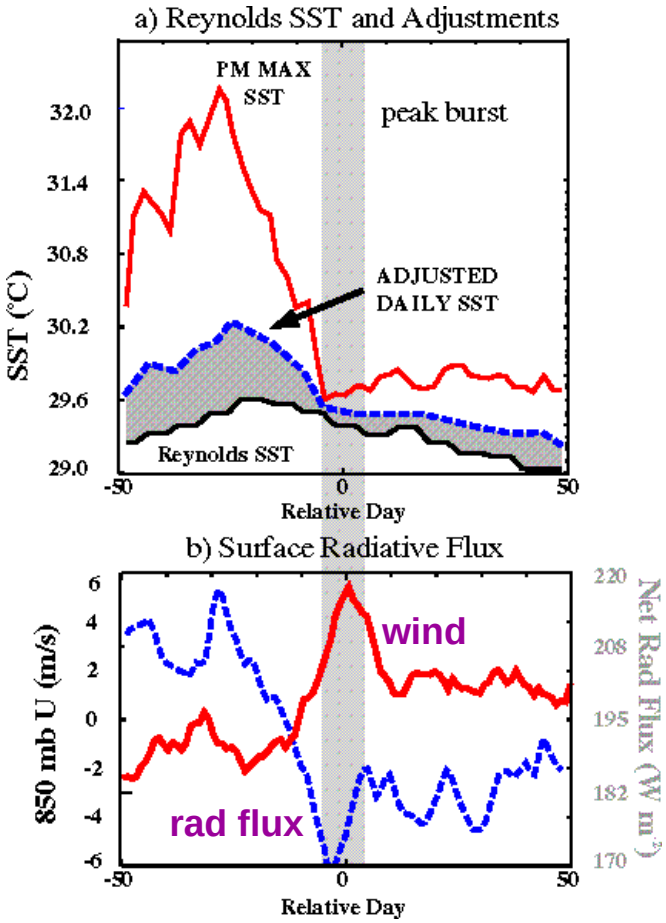
D–T > 0
(ENSO)

ENSO….



SST anomaly in the eastern equatorial Pacific, 1860-2000

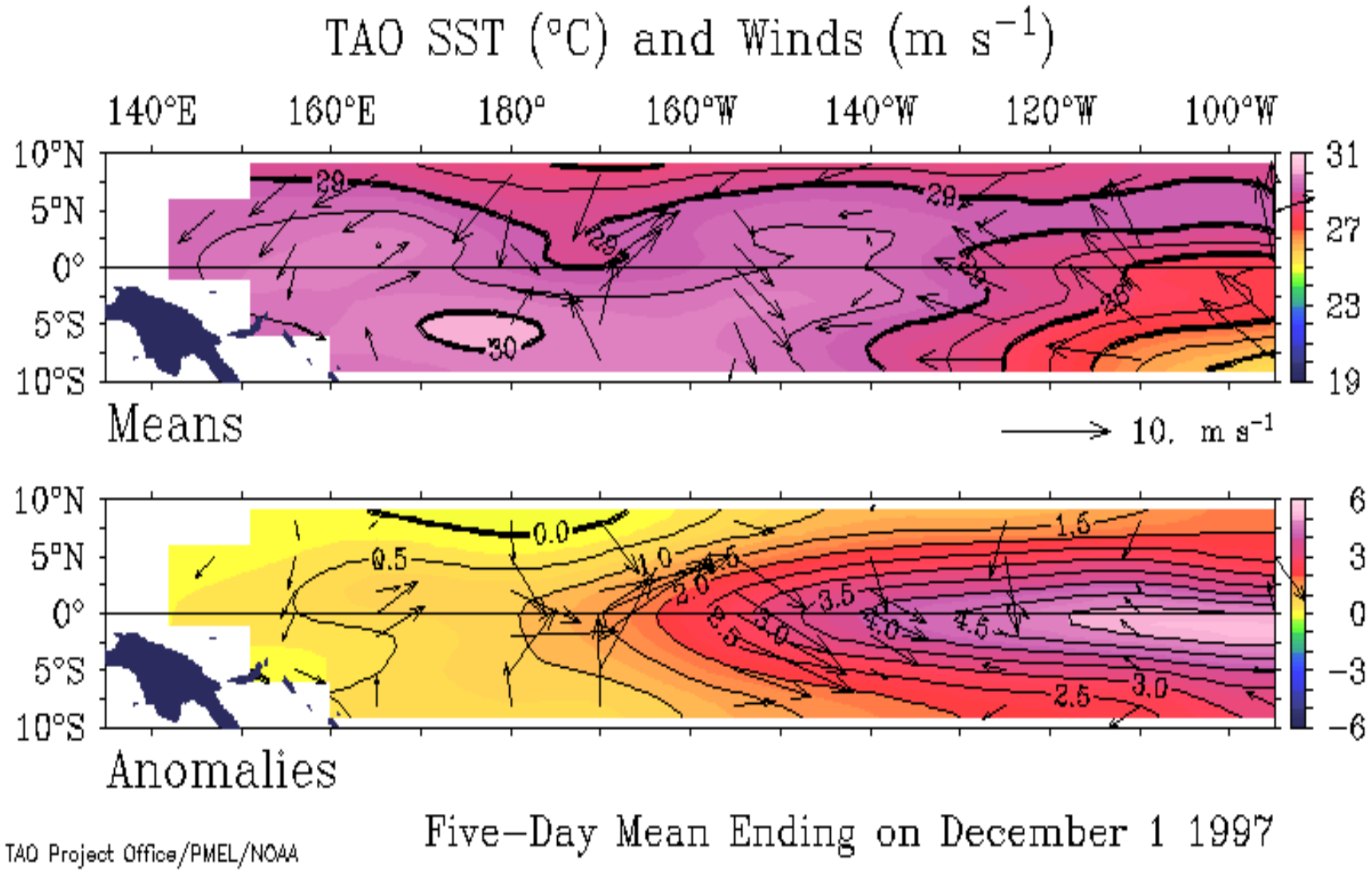




ENSO appears to often begin with westerly wind bursts in the western Pacific

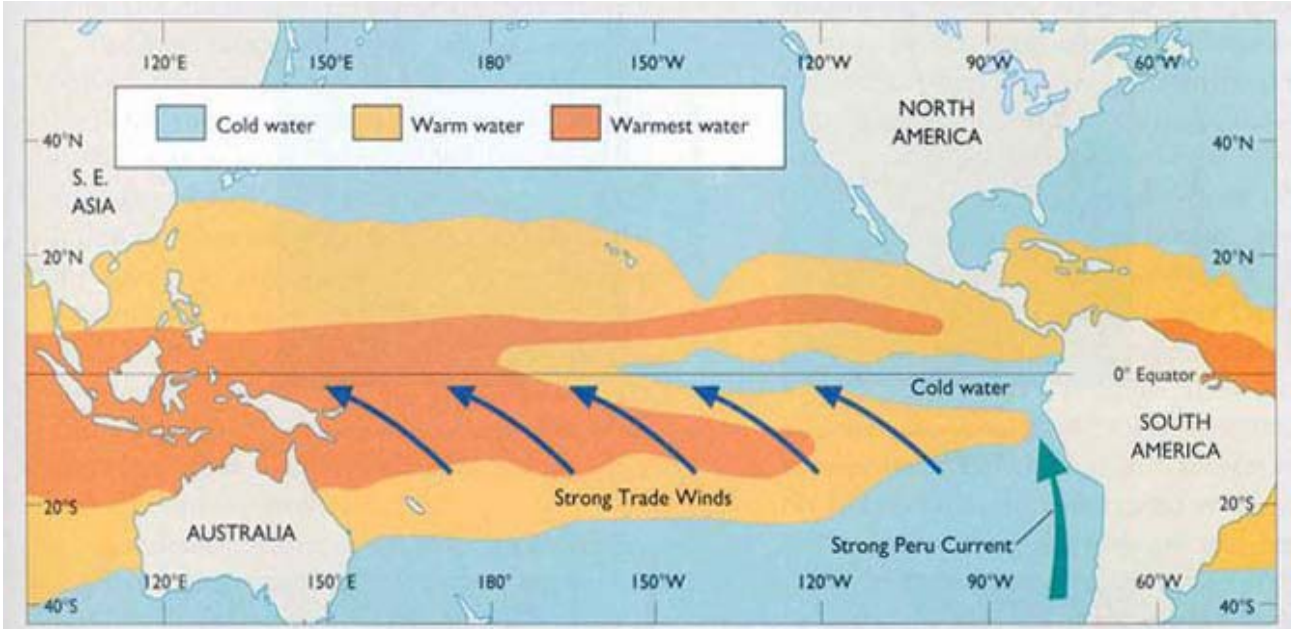
SST falls in conjunction with westerly wind bursts

ENSO….

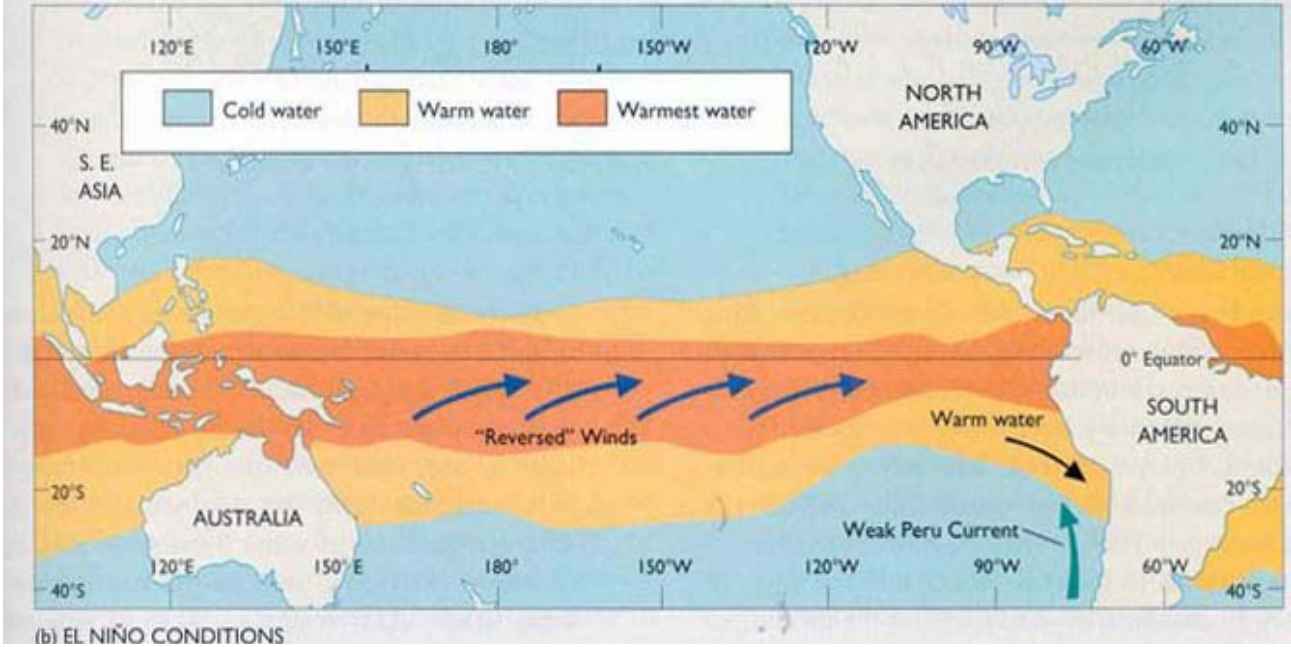


Wind and SST anomalies for the 1997-98 ENSO event

ENSO….

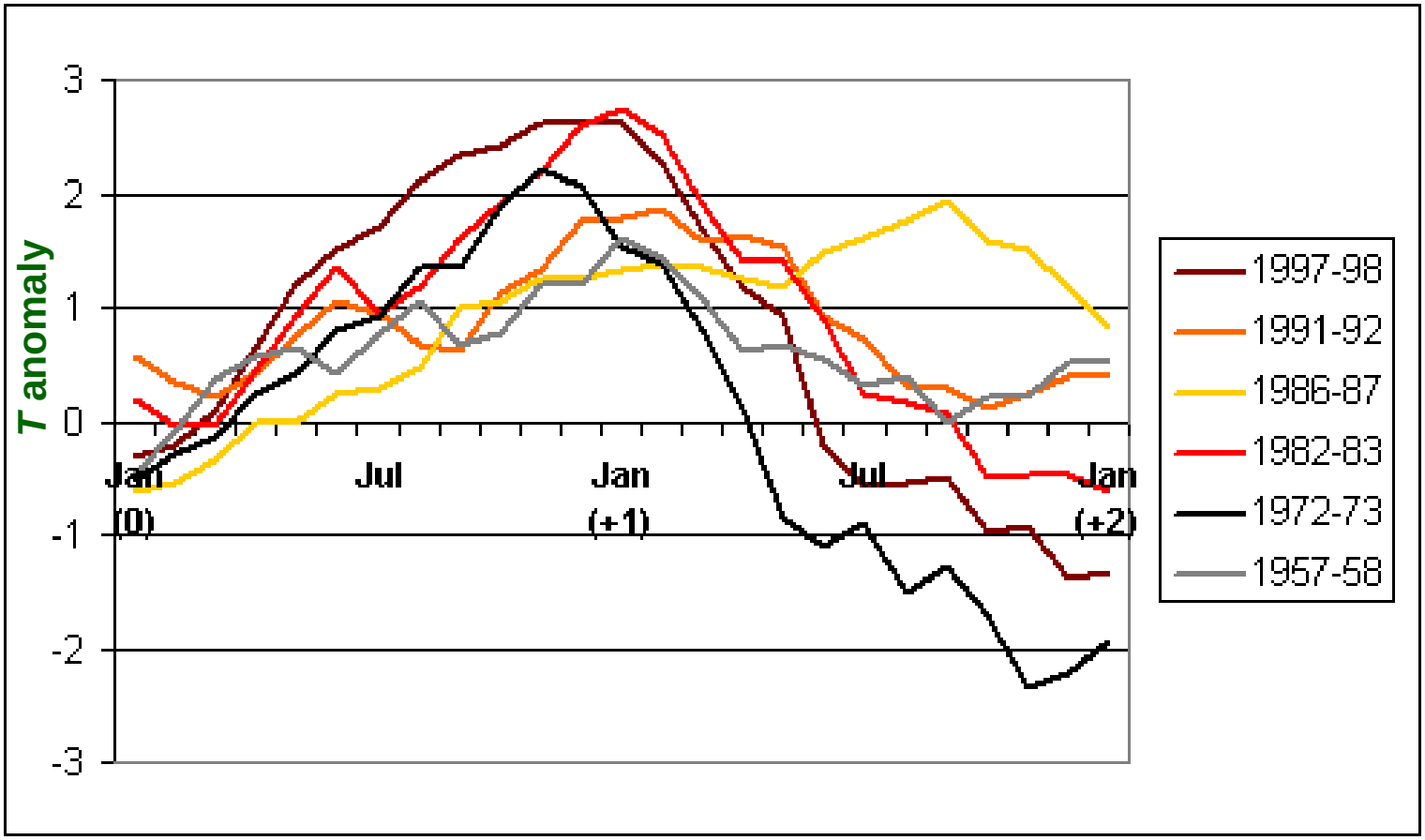


(a) NORMAL OCEANOGRAPHIC CONDITIONS



(b) EL NIÑO CONDITIONS

Examples of ENSO events during the past 50 years

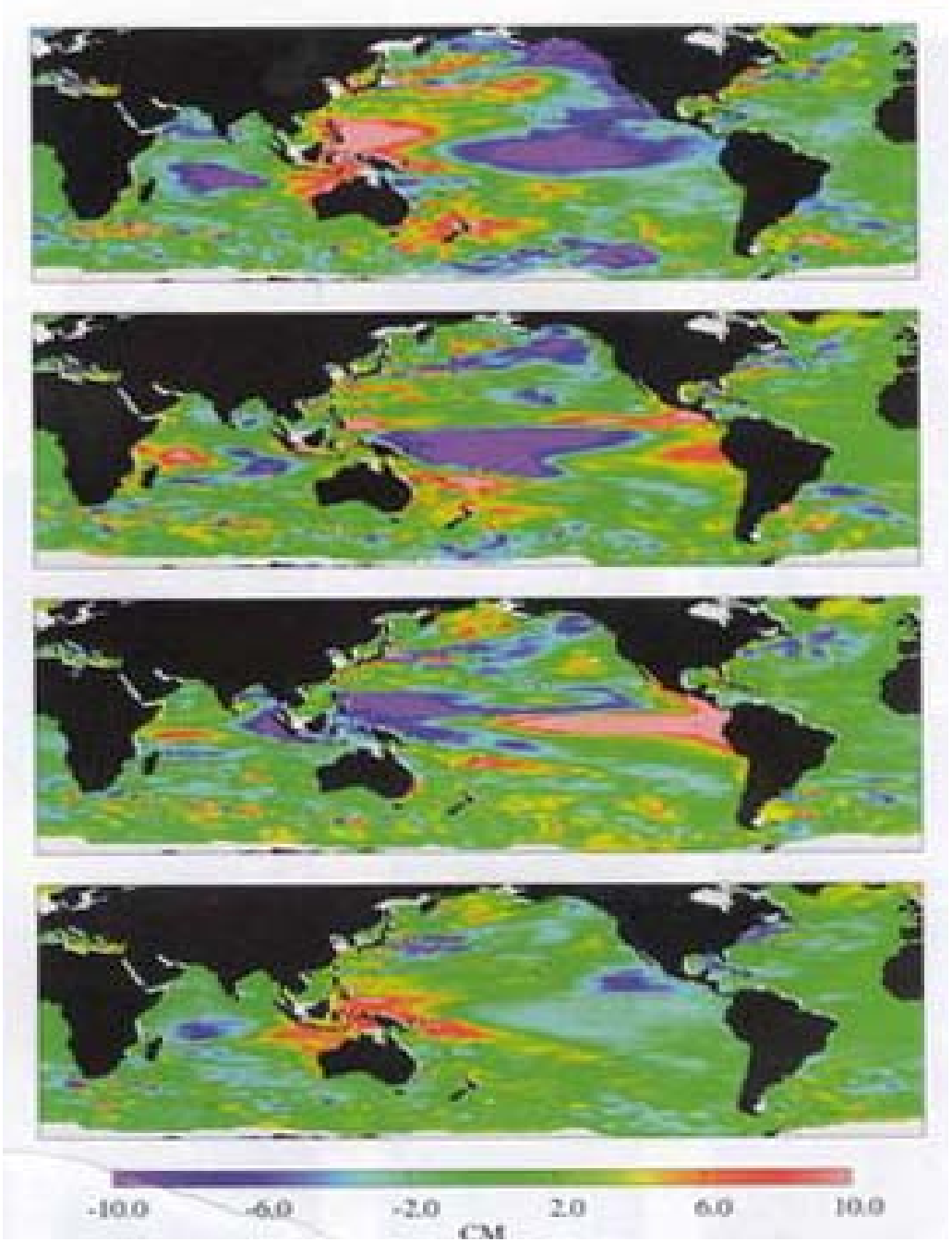


Warm events (EN): 1953, 1957-58, 1965, 1969, 1972, 1977, 1982, 1987, 1992-93, 1997-98, 2002

Cold events (LN): 1950, 1955-56, 1964, 1971, 1973-75, 1984, 1988, 1999-00, 2007

ENSO….

Sea level anomaly during the 1997-1998 event



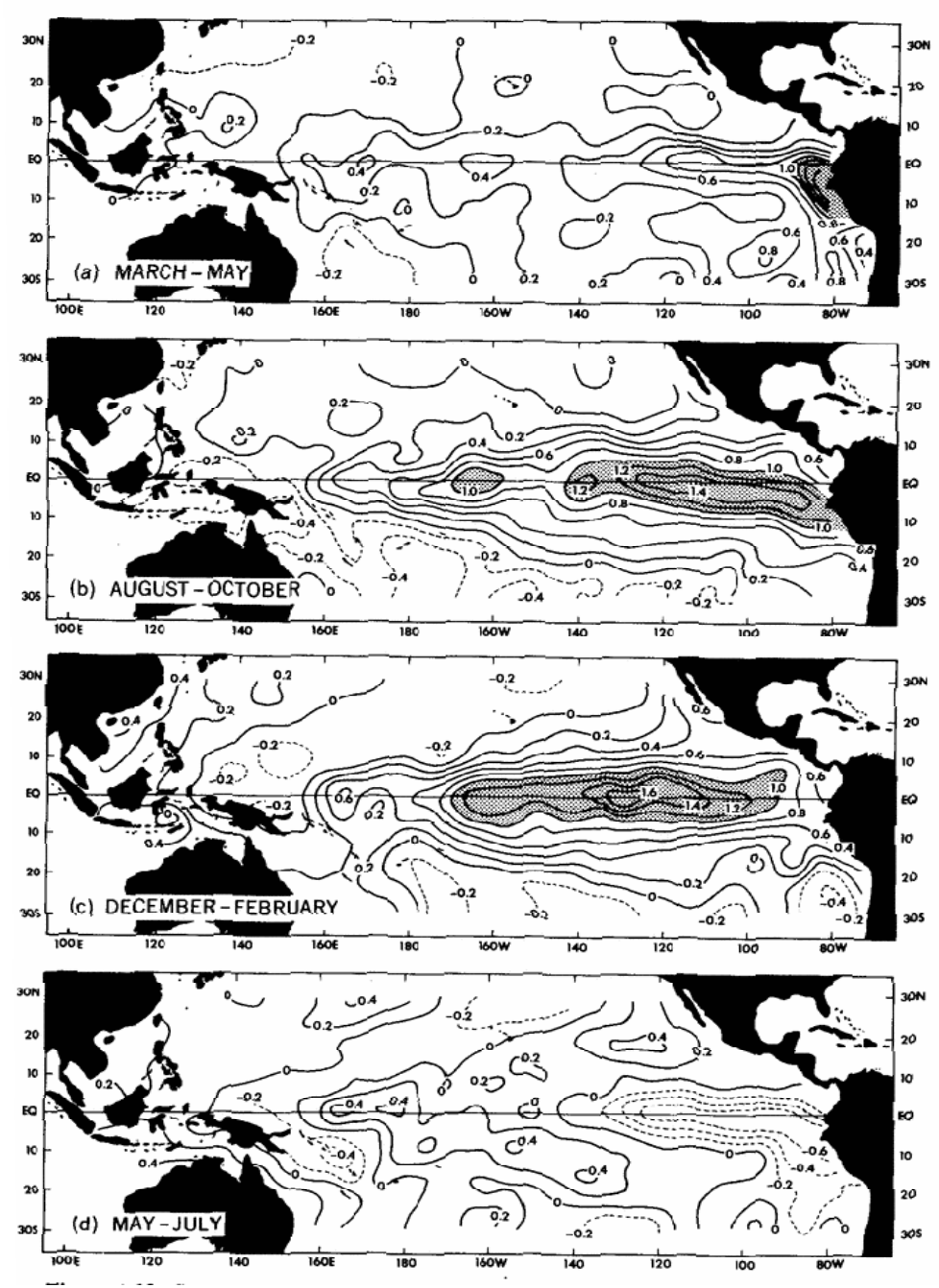
ENSO….

March-May before ENSO onset

August-October during ENSO onset

December-February mature phase

May-July returning to normal

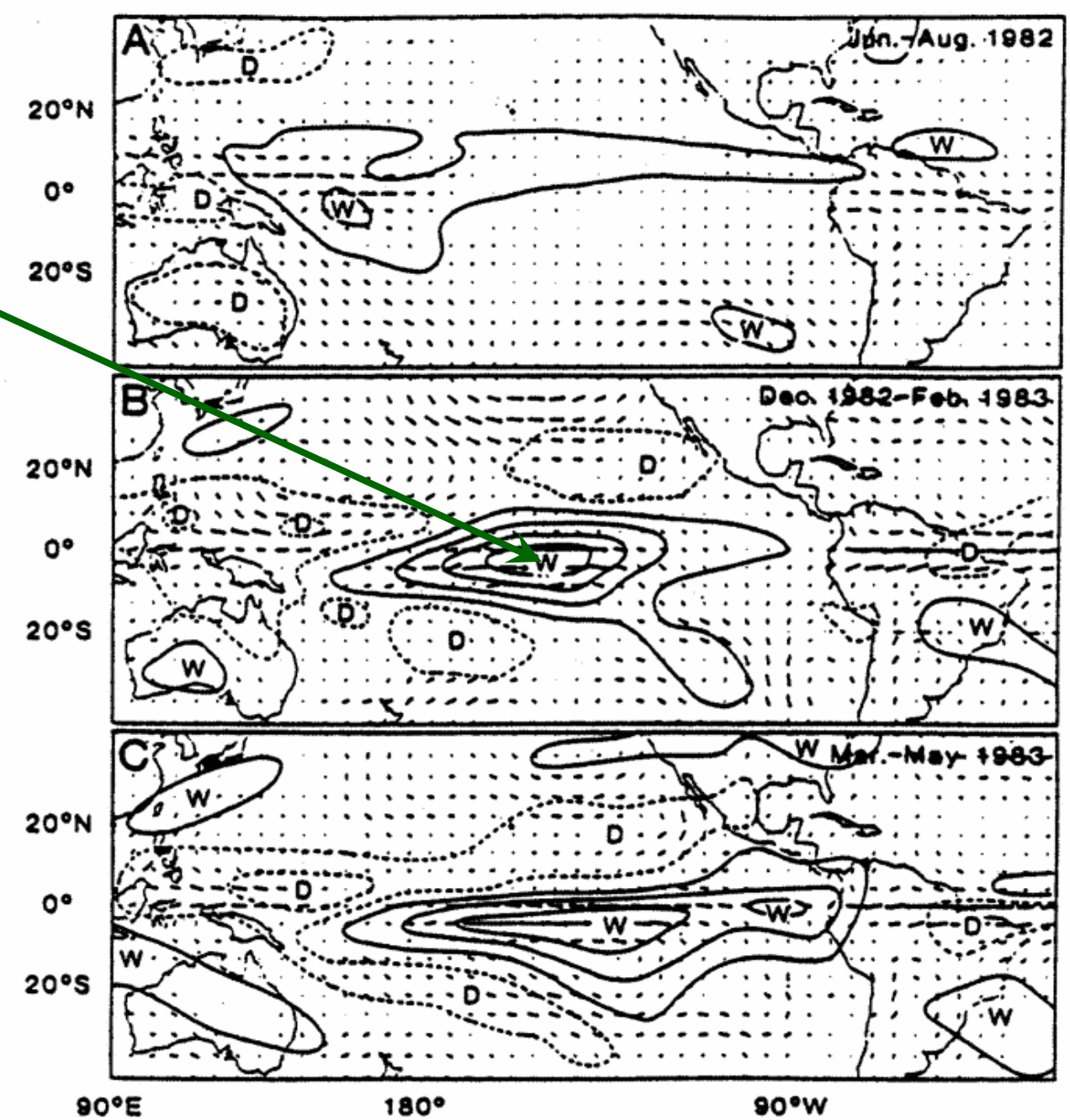


Composite ENSO SST anomaly

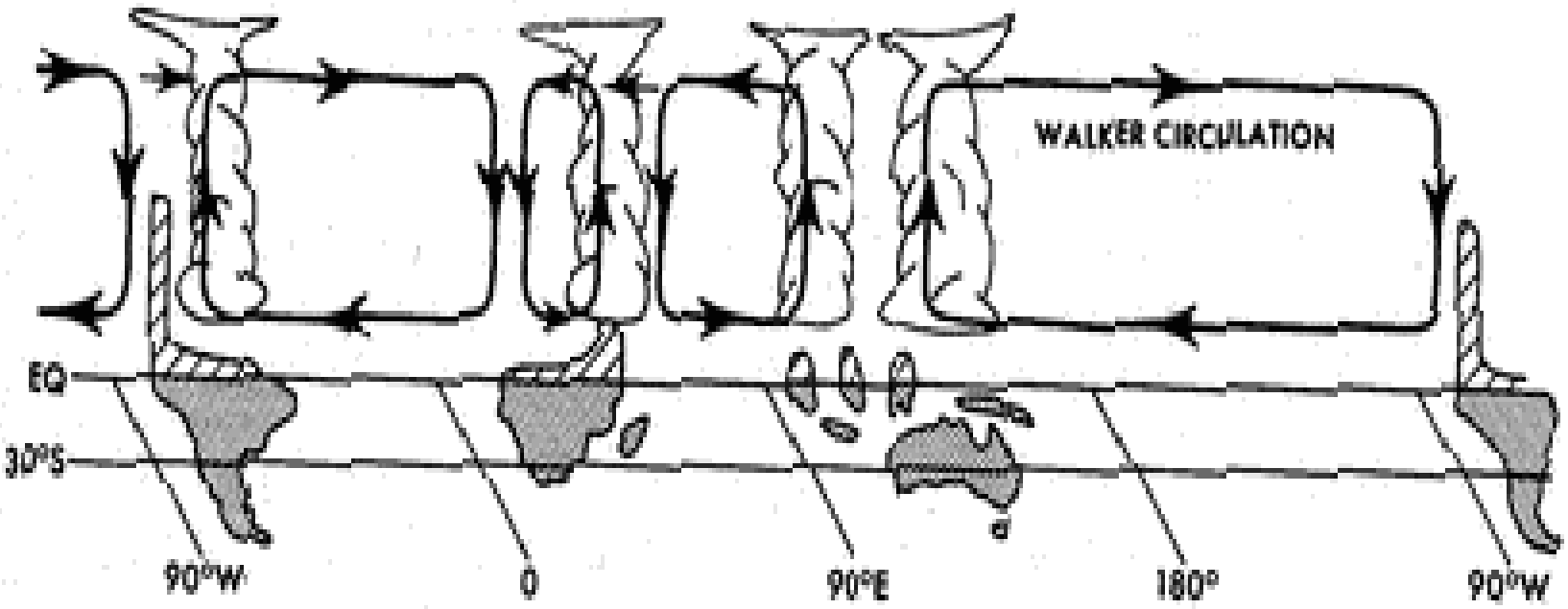
ENSO….

~20 watts/m^2

SST anomaly causes OLR anomaly (Q_B)



ENSO….

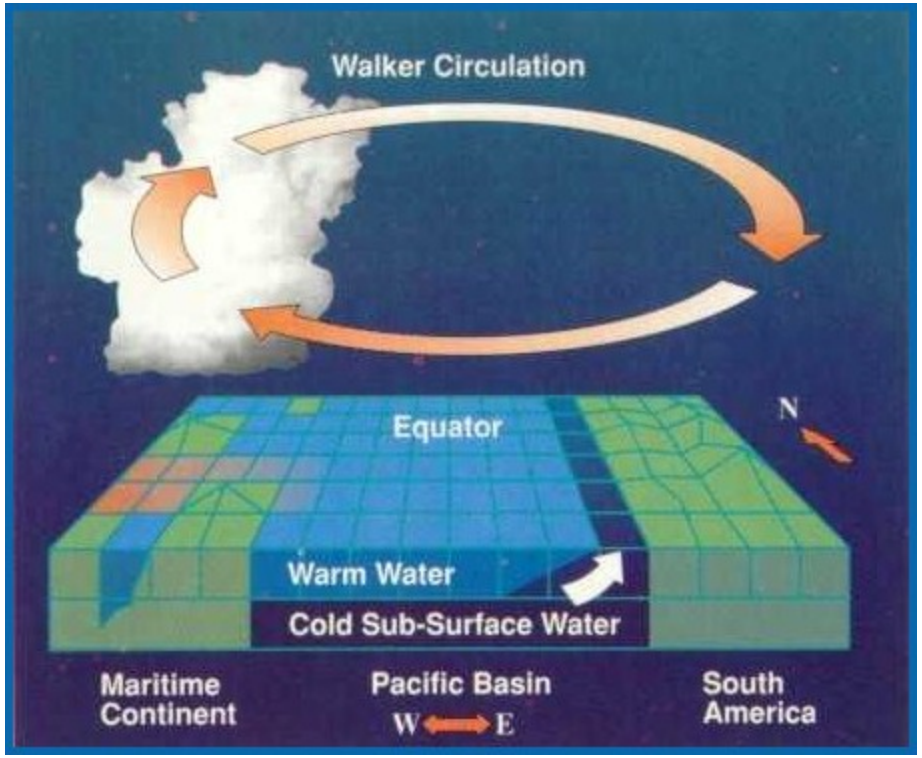


[rising = precipitation]

[sinking = deserts]

The Walker circulation is a system of upwelling and downwelling in the atmosphere.

ENSO OLR anomaly disrupts the Walker circulation

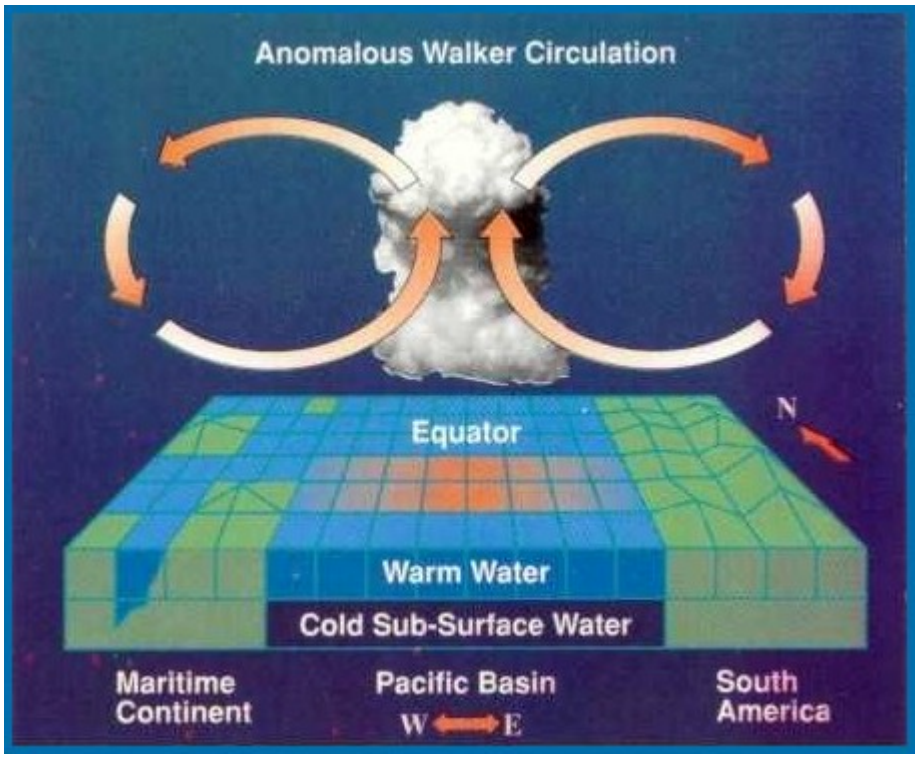


Normal Walker circulation

←

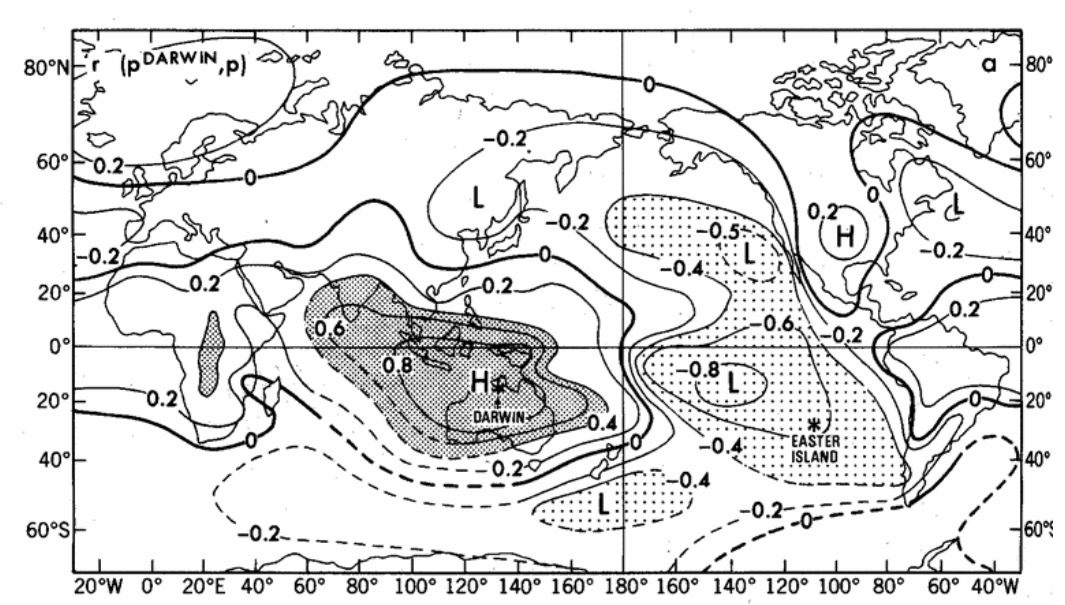
ENSO Walker circulation

→

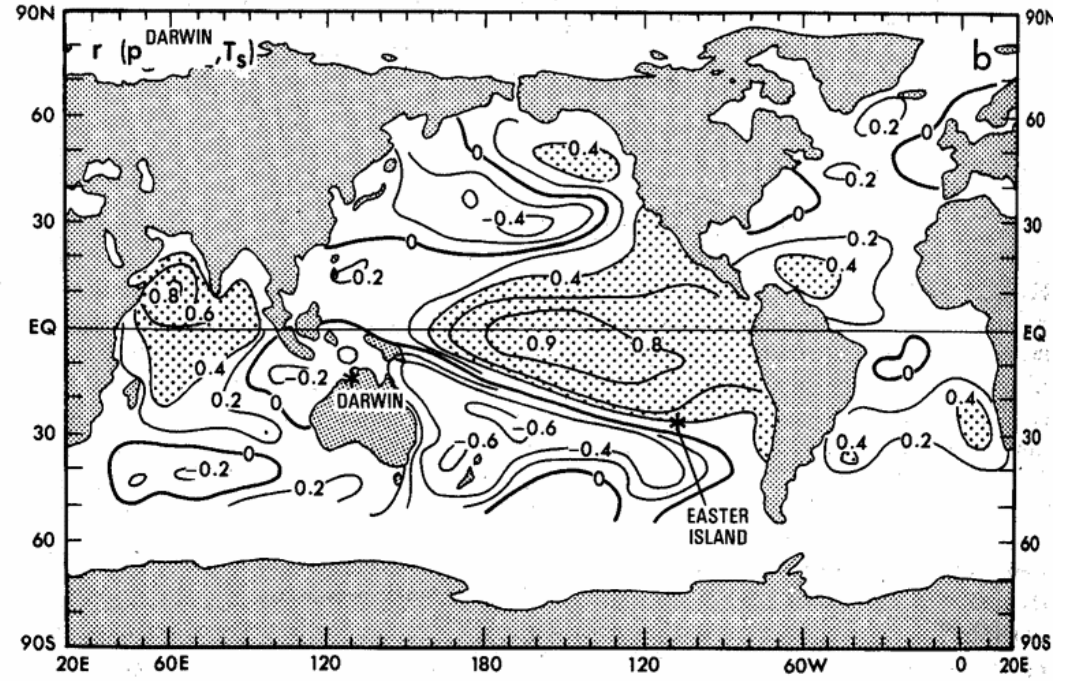


ENSO….

Correlation of Darwin surface pressure with global surface atmospheric pressure

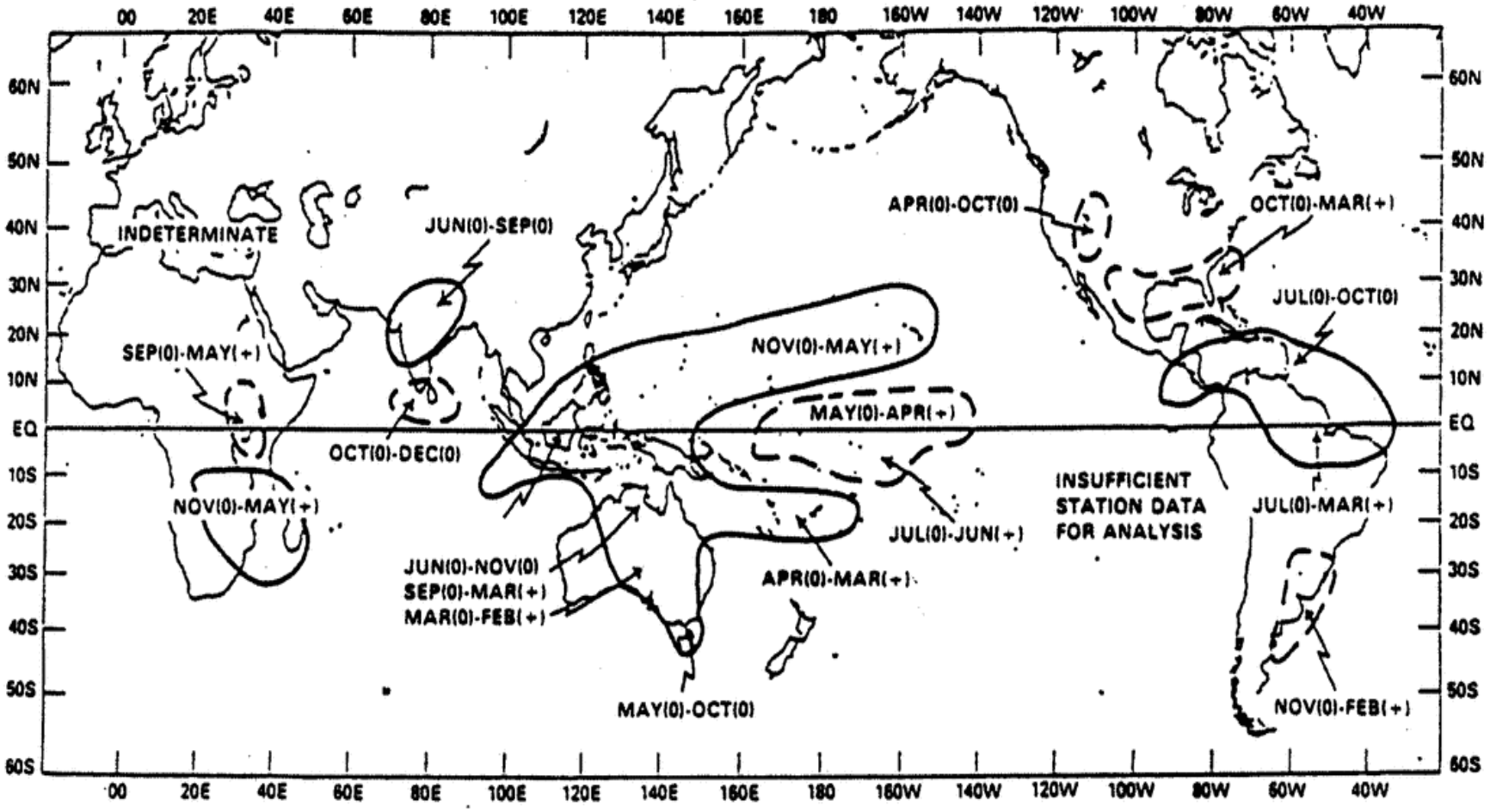


Correlation of Darwin surface pressure with global surface temperature



[Note large-scale correlations]

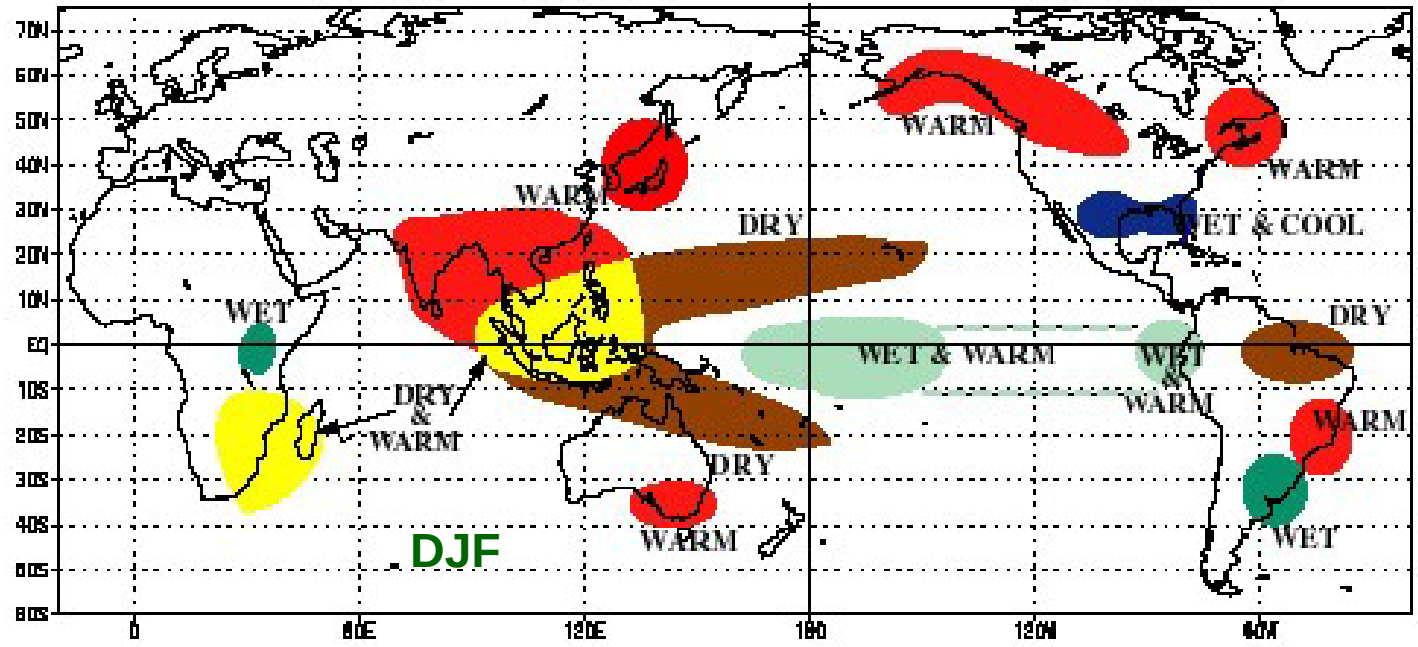
ENSO….

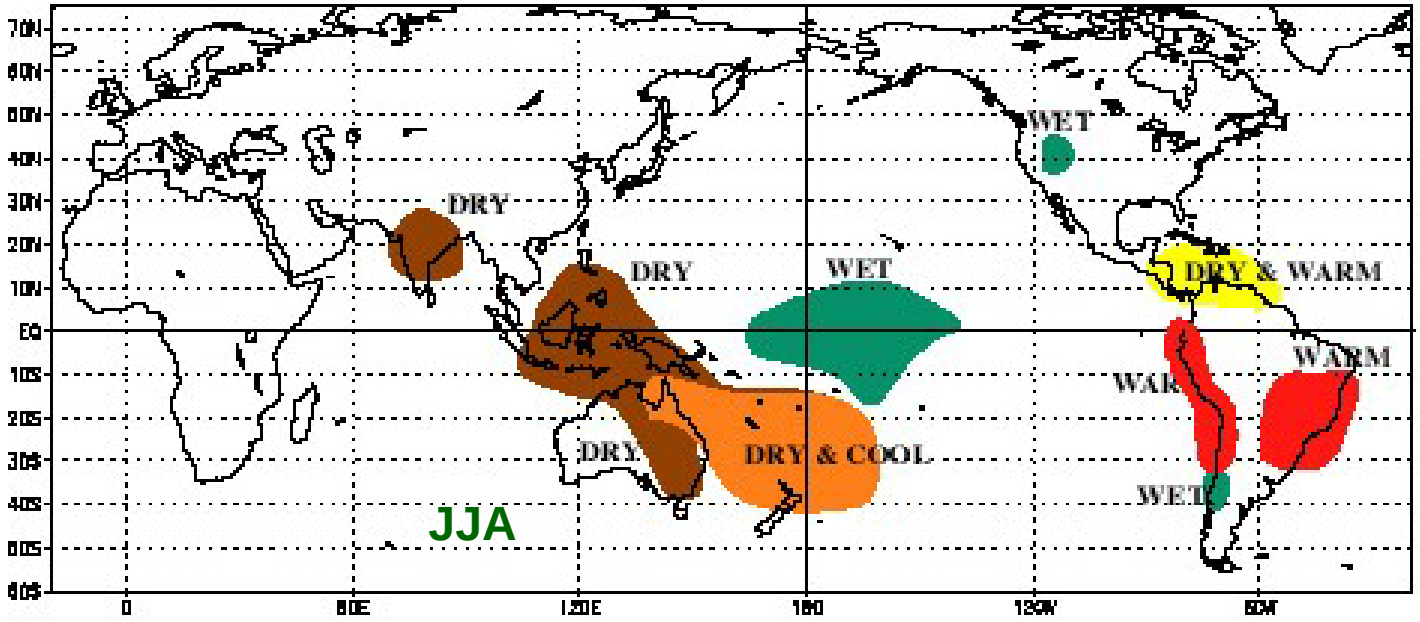


Precipitation correlations with Darwin pressure during ENSO events

ENSO….

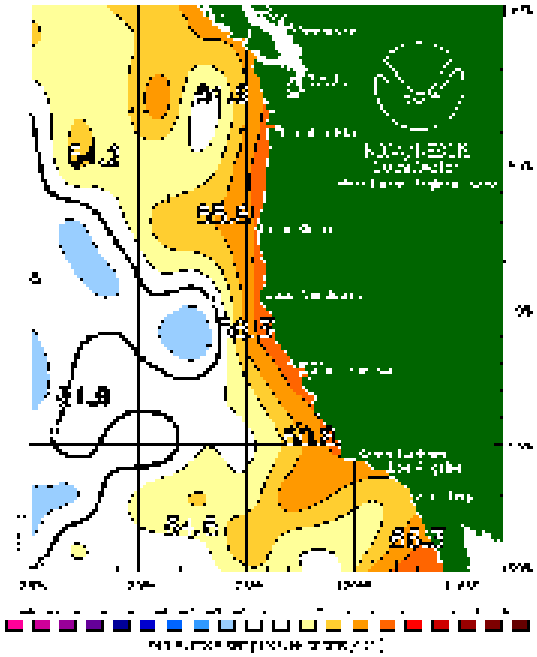
Precipitation anomalies



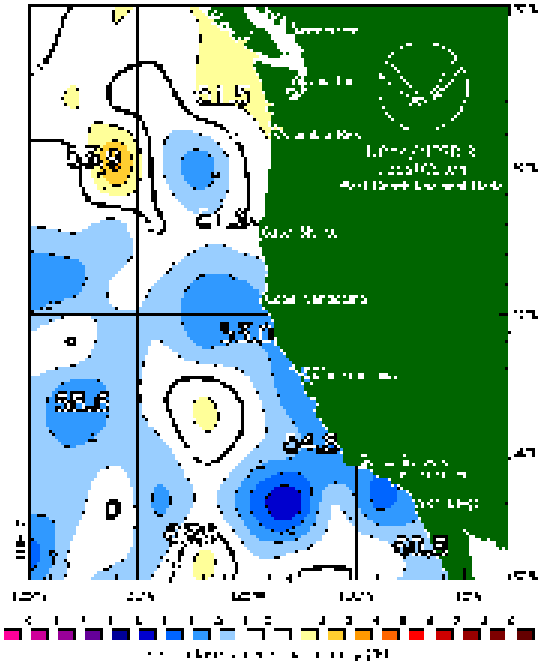


ENSO….

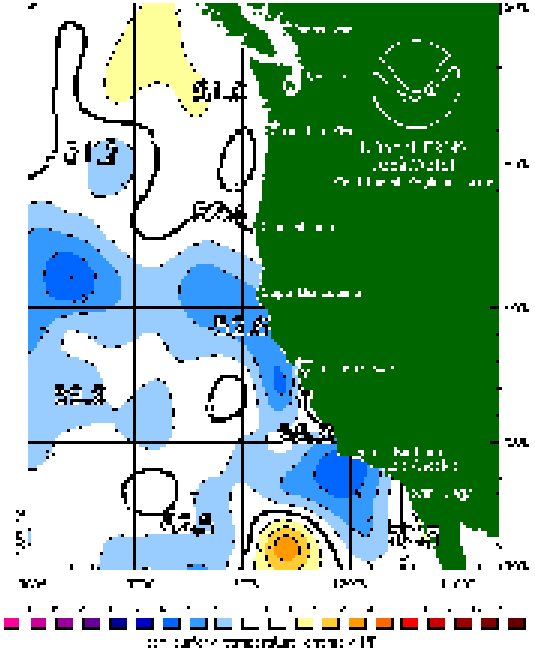
December 1997
El Niño year



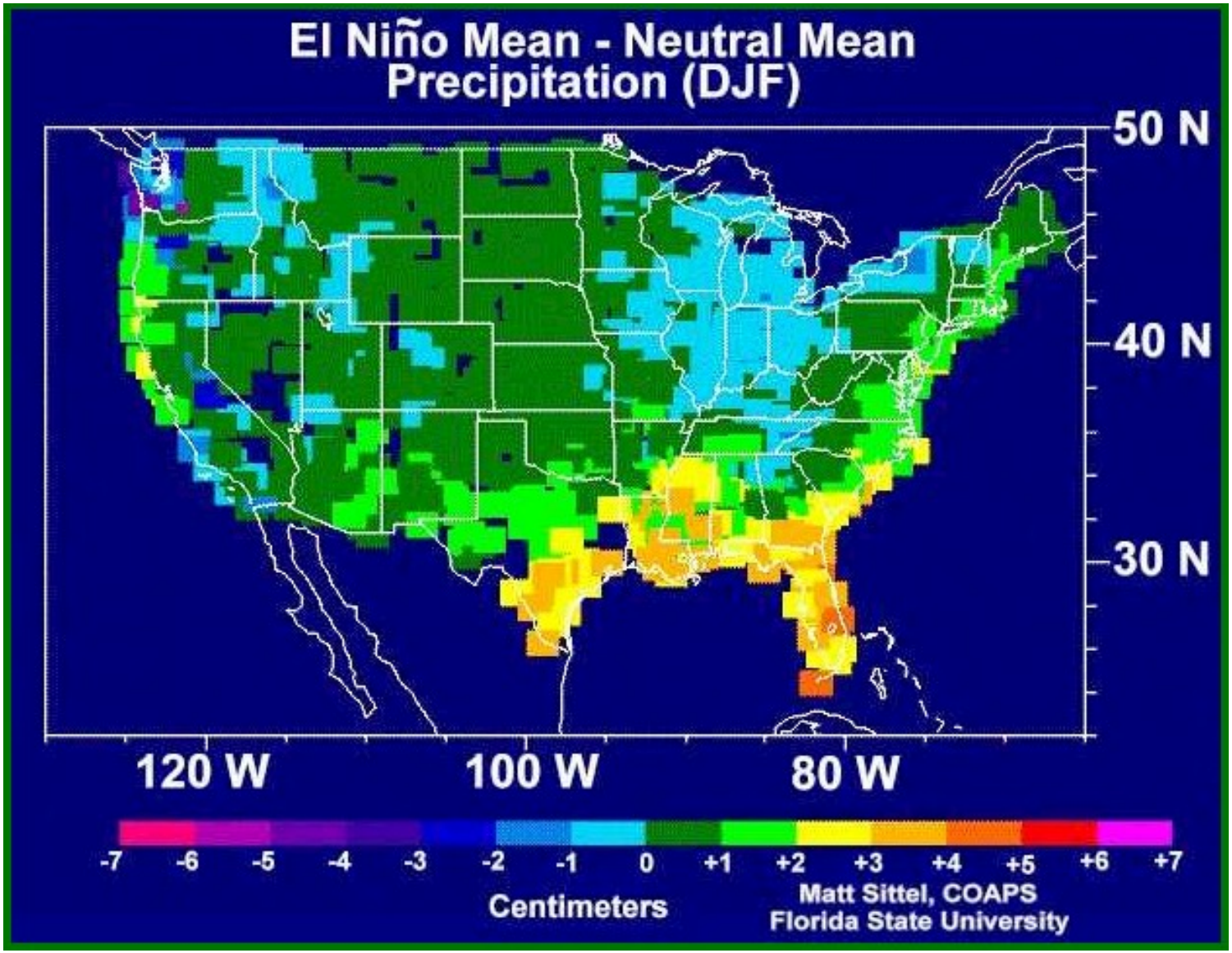
December 1998
La Niña year



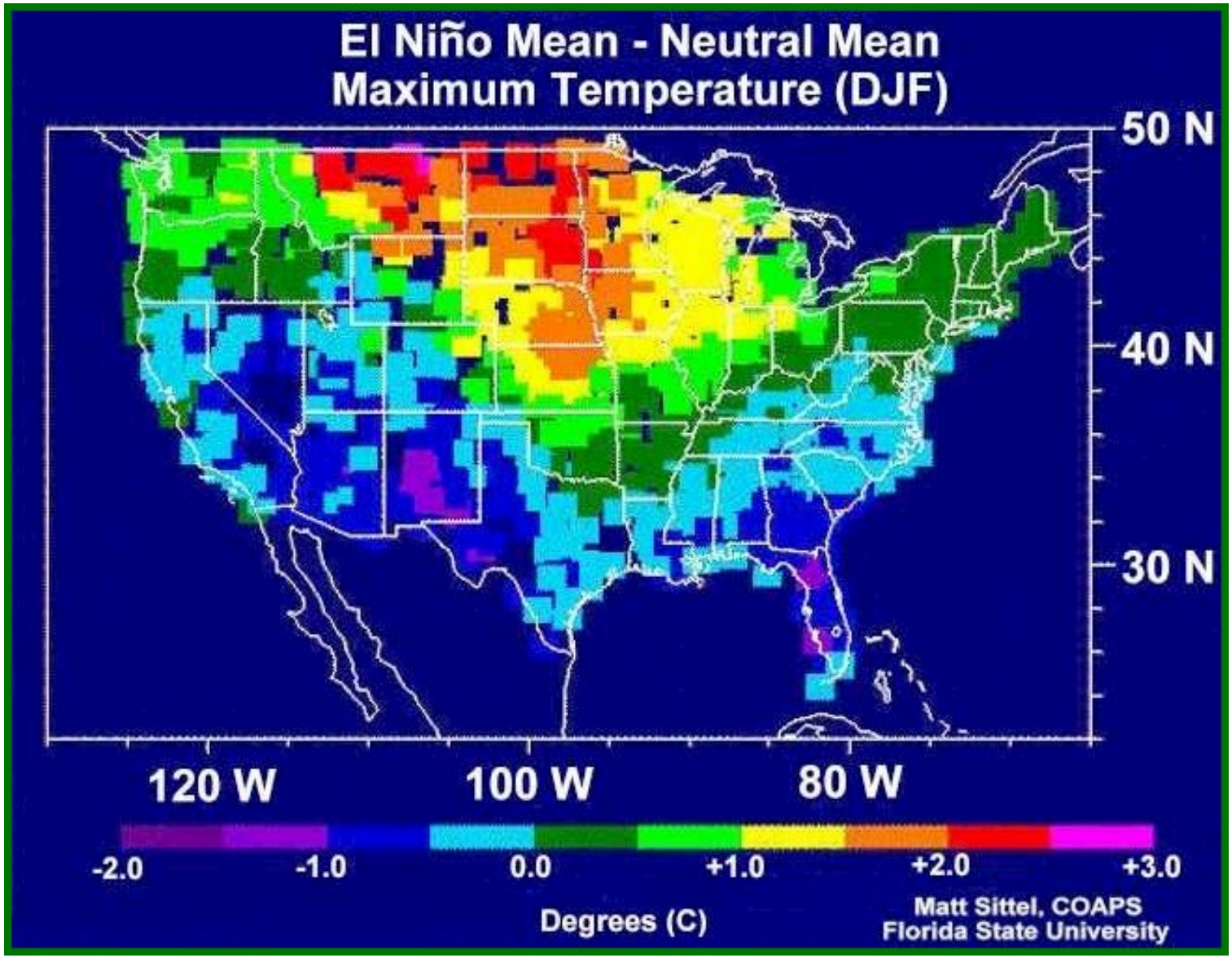
December 1999
La Niña year



Local SST effects from ENSO



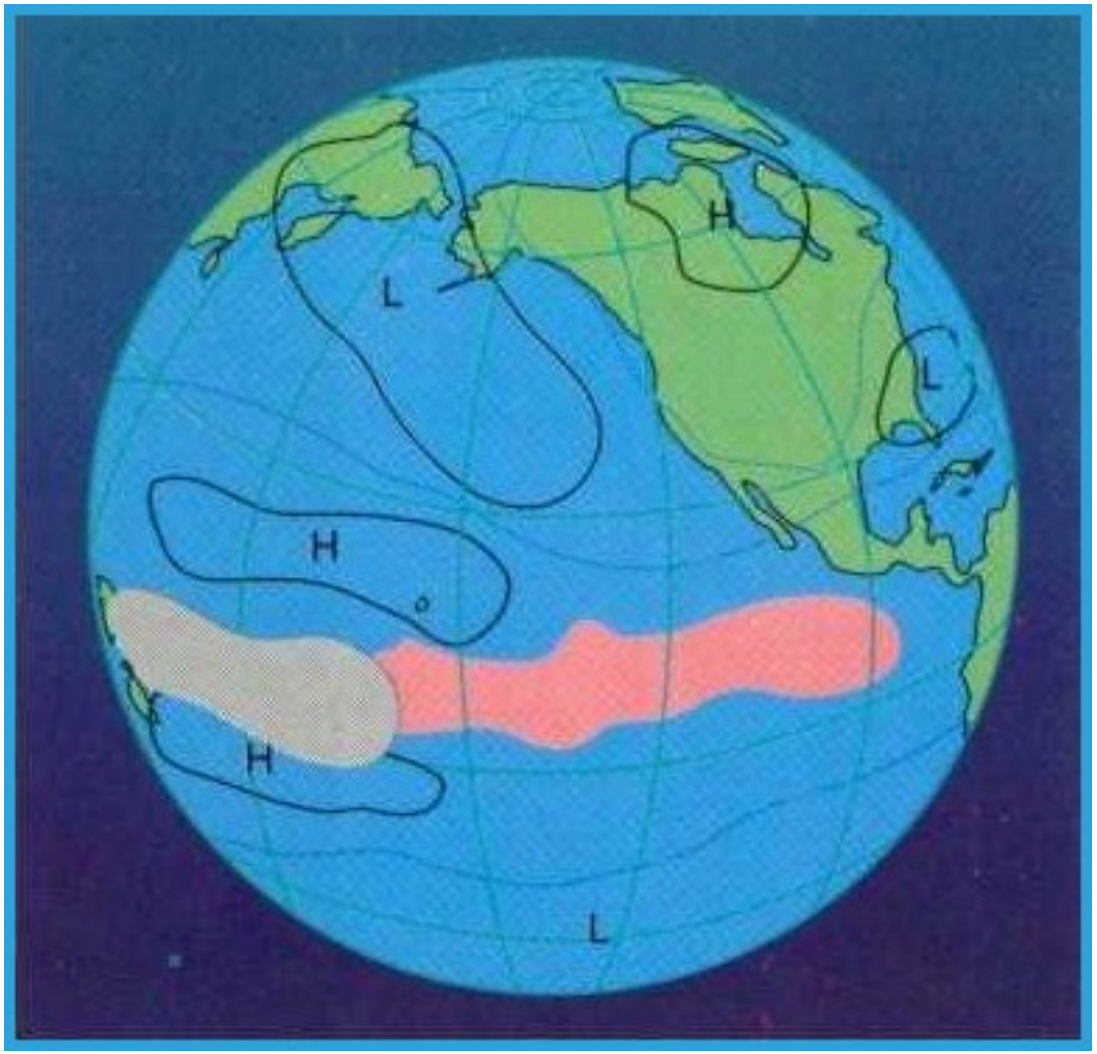
Typical precipitation anomalies from ENSO



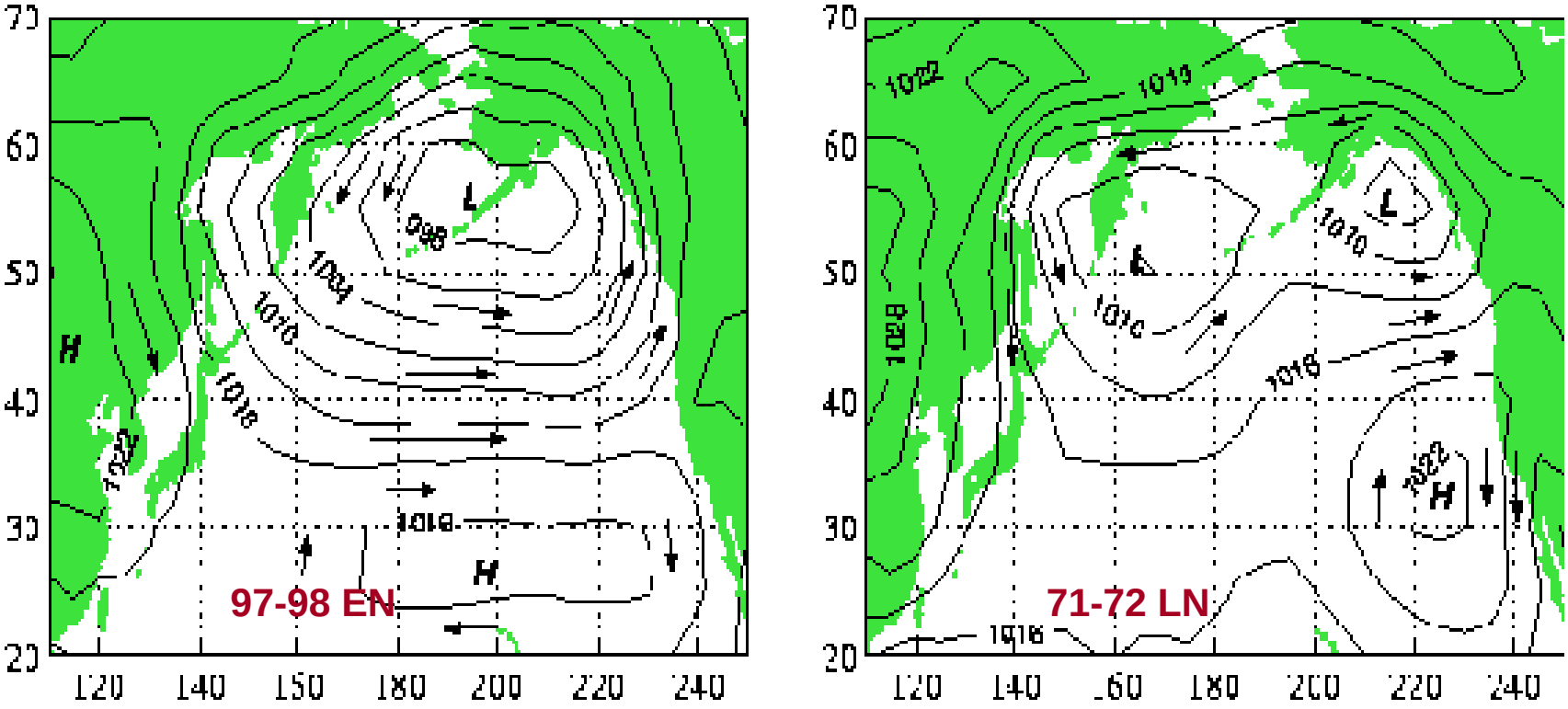
Typical air temperature anomalies from ENSO

ENSO….

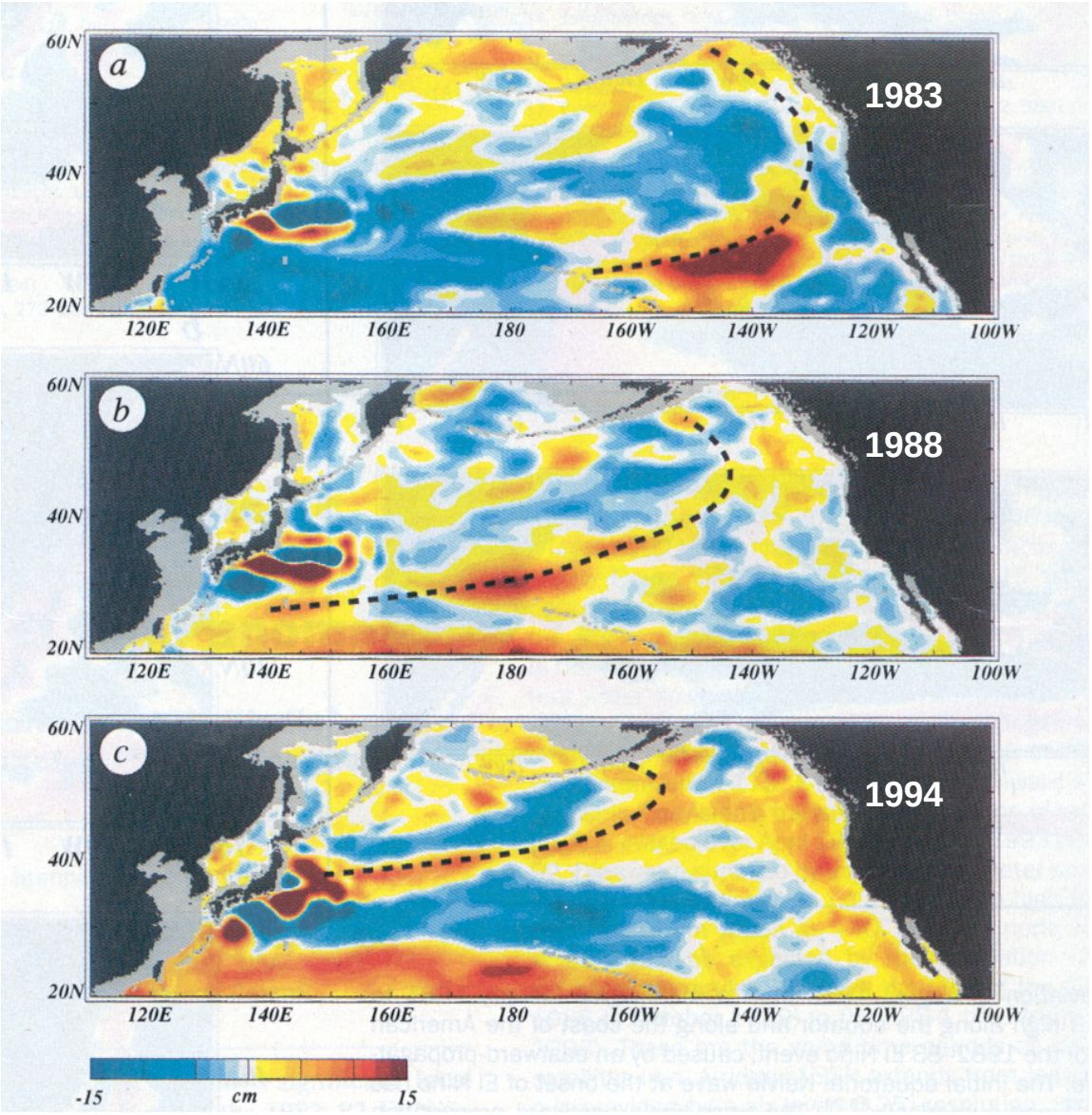
SST and OLR in the central equatorial Pacific generate atmospheric anomalies in the form of Rossby waves that communicate the warming at long distances

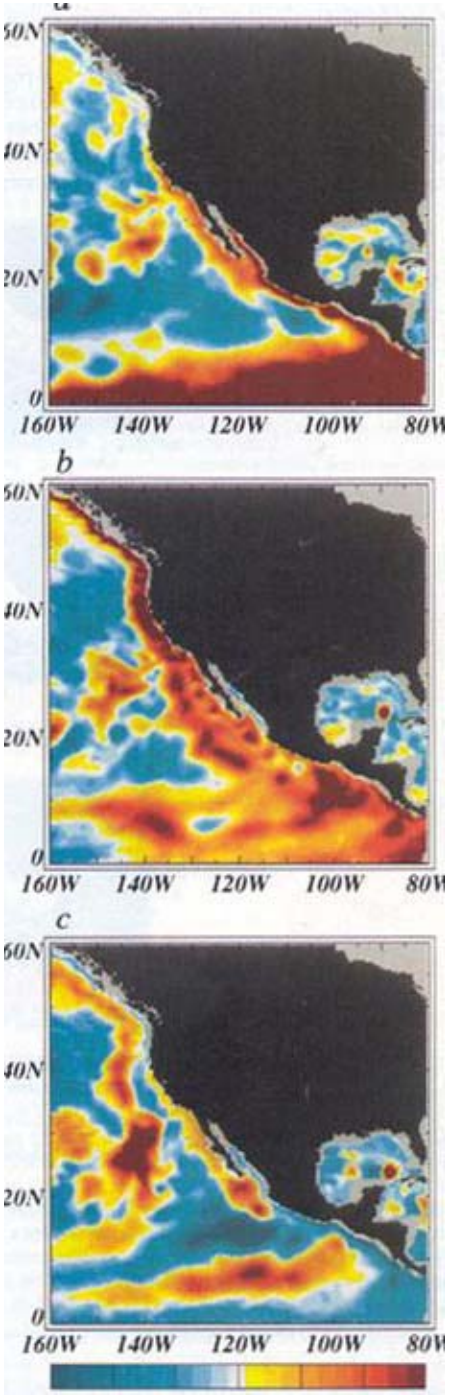


Local sequence of events: wind (atm) → SST (ocn) → OLR (ocn/atm) → P (atm)
Remote events: P (atm) → SST (ocn) ; P (atm) → precipitation



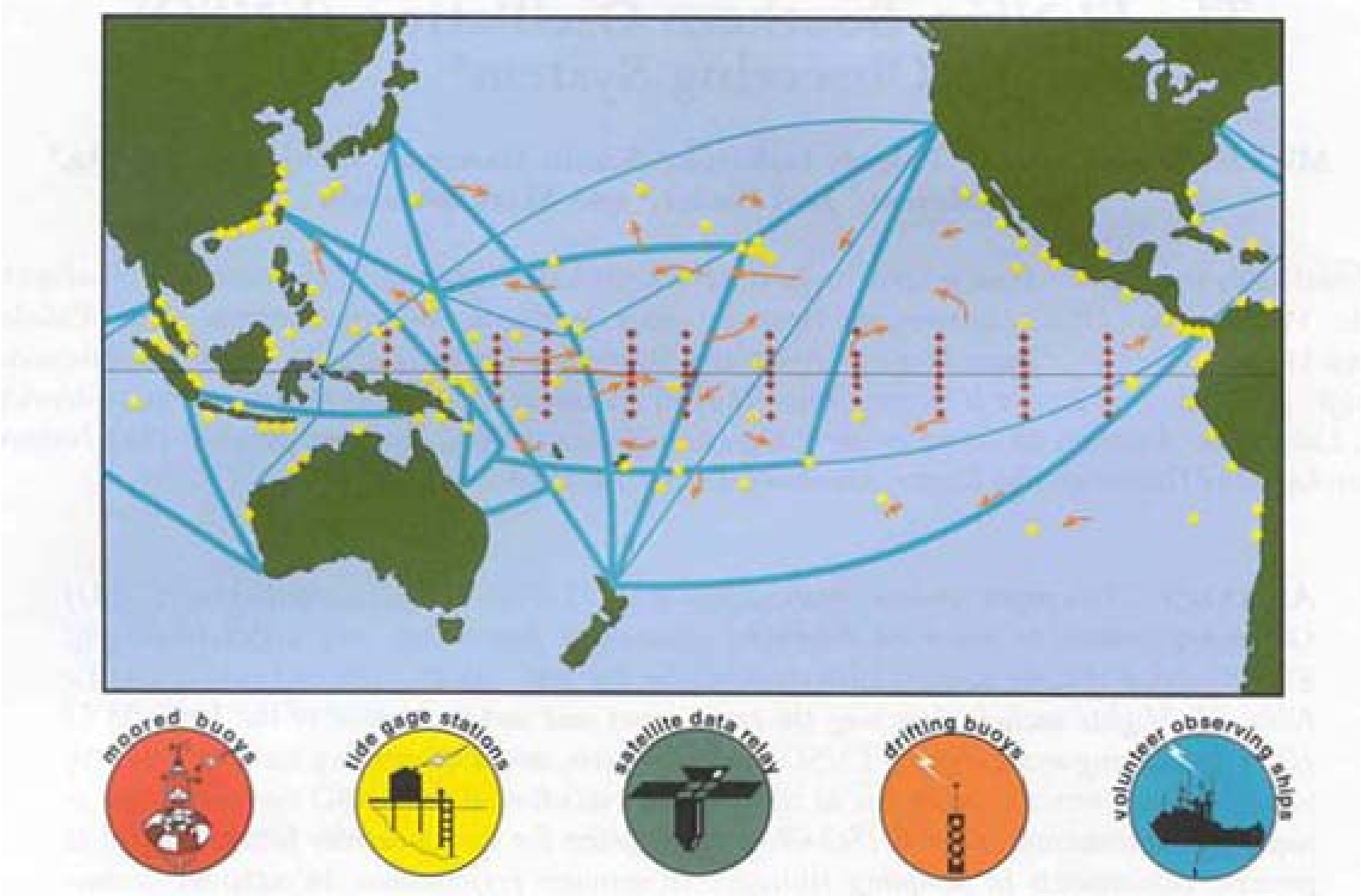
Position and strength of the Aleutian low pressure during 97-98 El Nino and 71-72 La Nina events



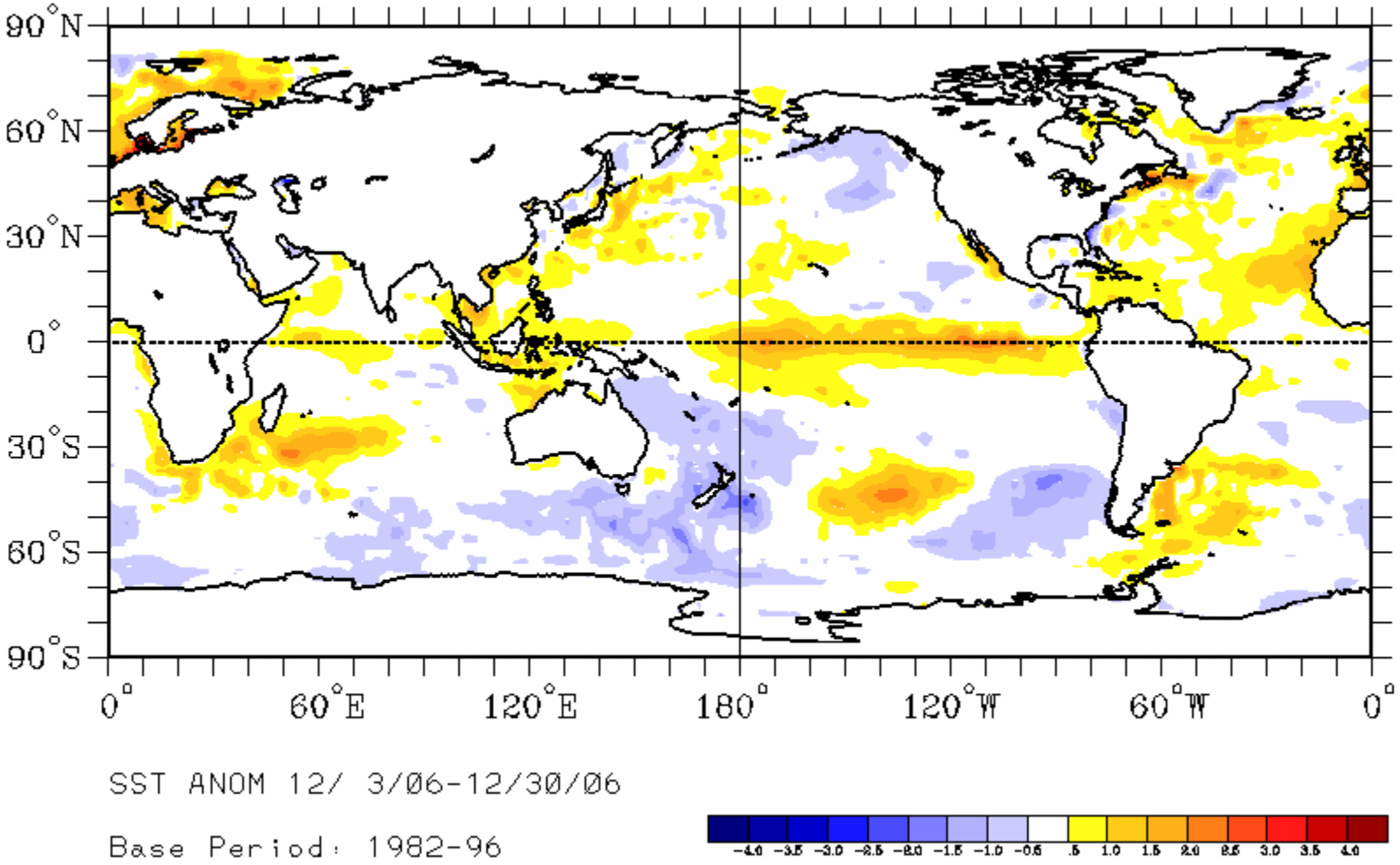


Jacobs et al. (1994) showed how a single ENSO event could affect the N. Pacific sea level, SST, and circulation over a long period.

ENSO….

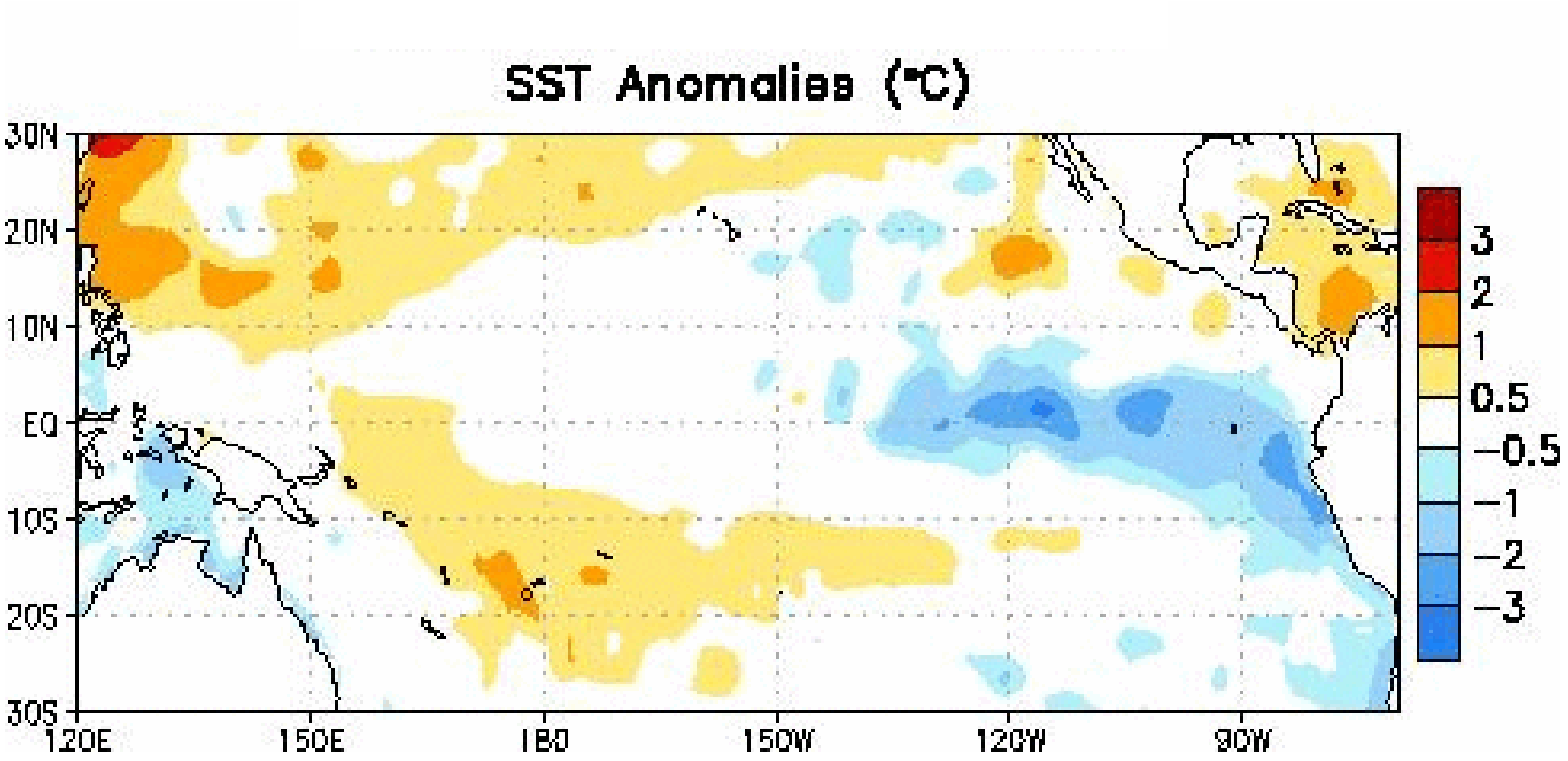


Equatorial Pacific observing system



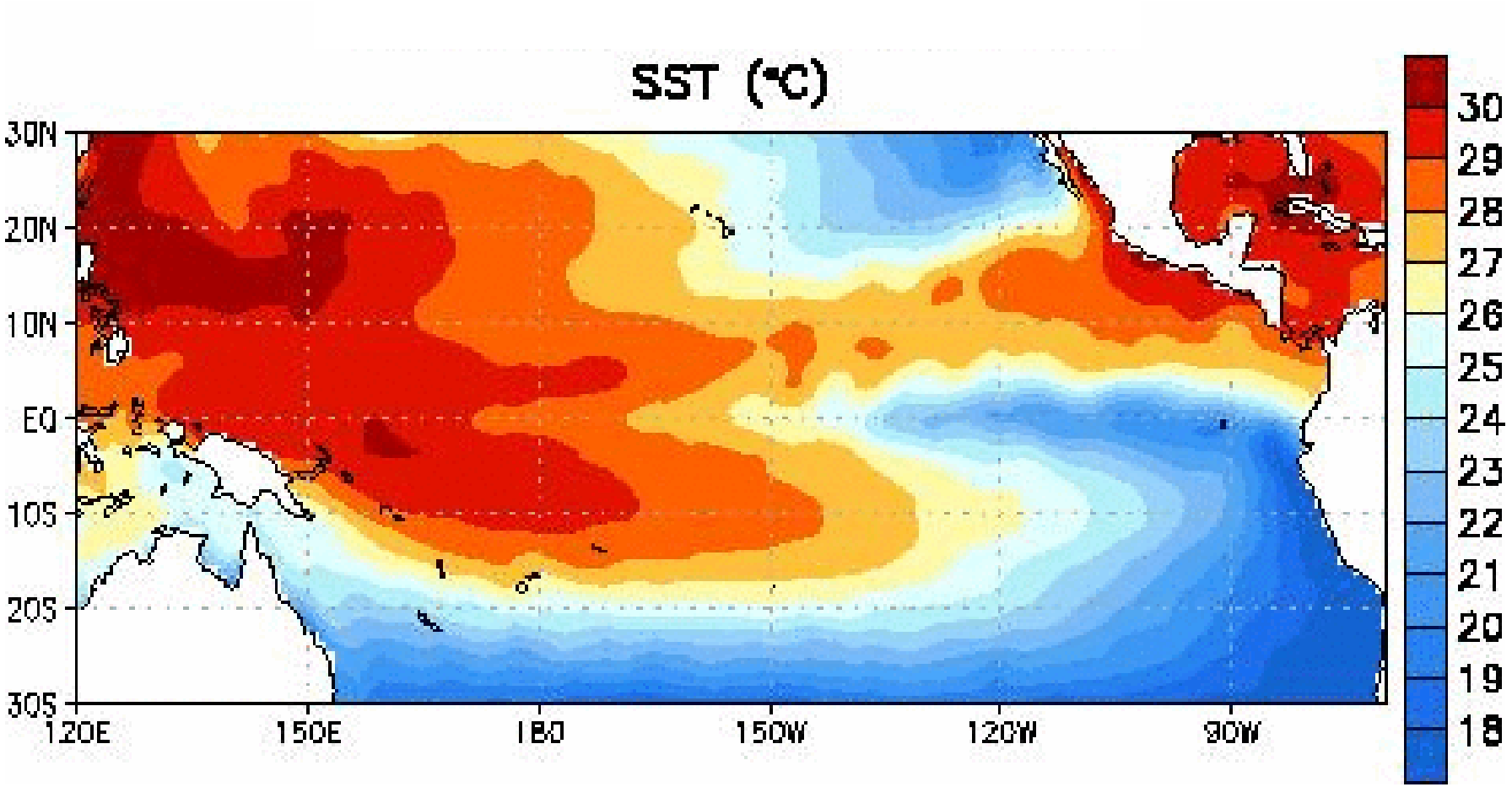
SST Anomaly, 12/2006

(El Niño conditions)



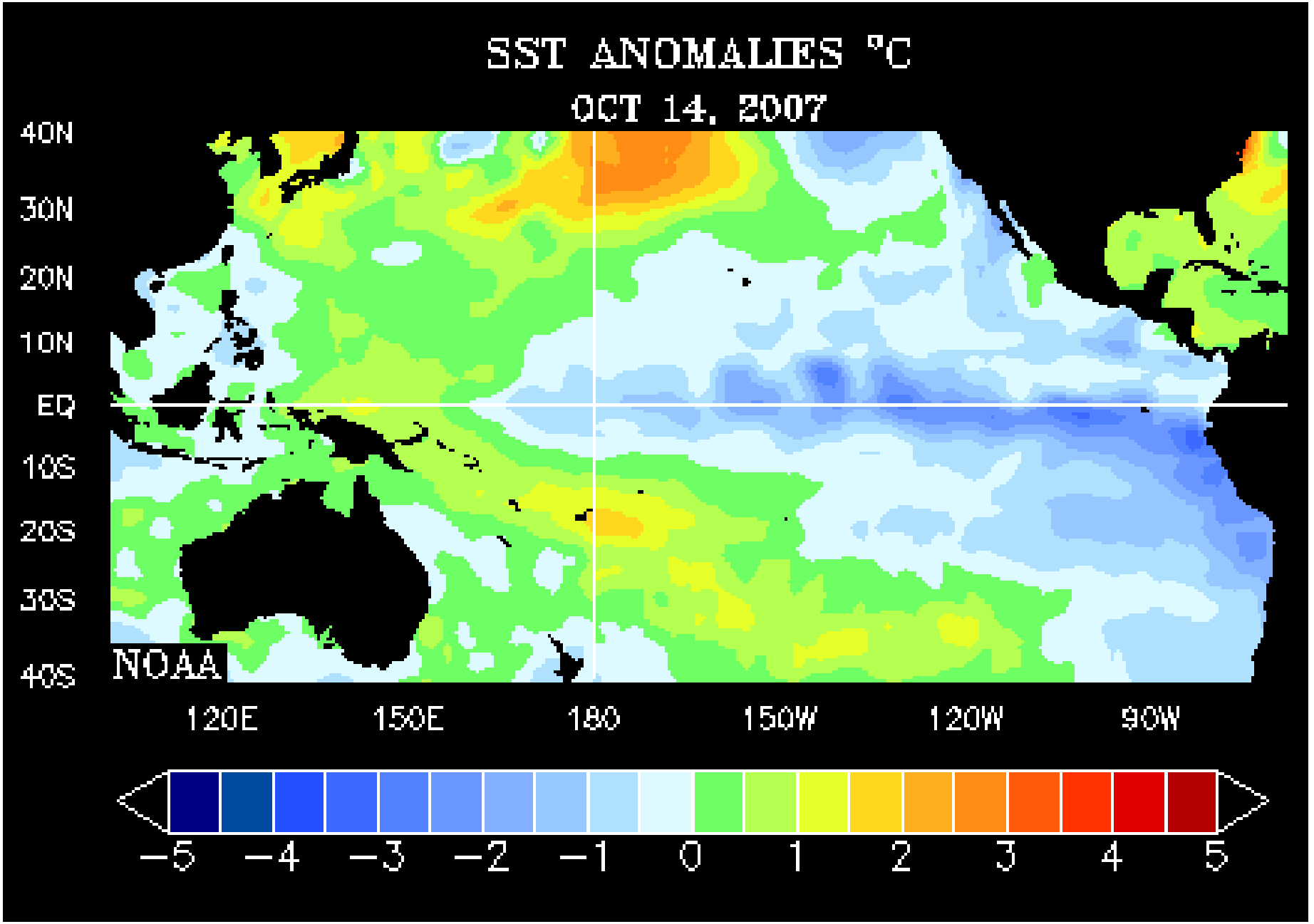
Pacific SST anomaly, 10/2007 (from NOAA)

(La Niña conditions)

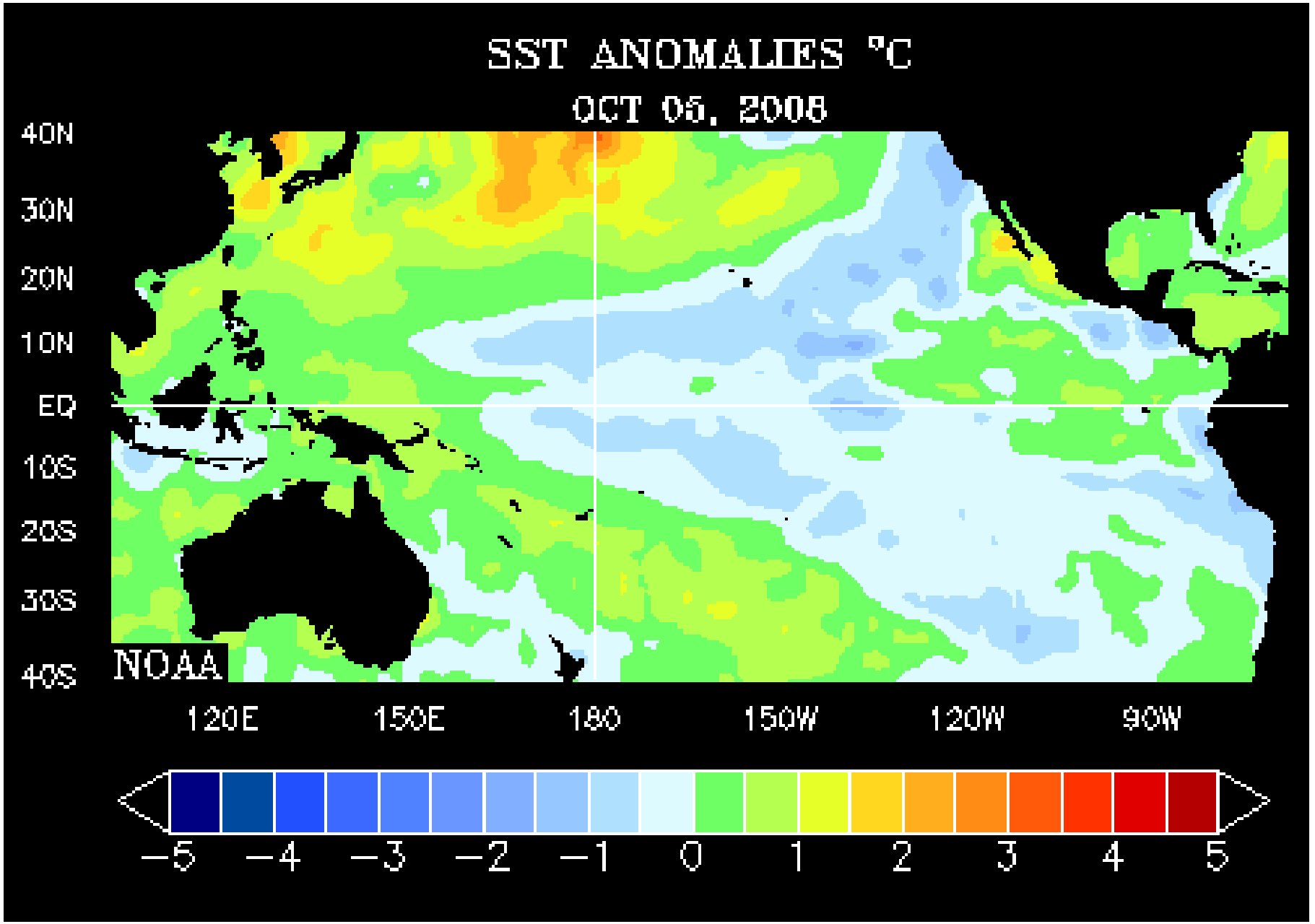


Pacific SST, 10/2007 (from NOAA)

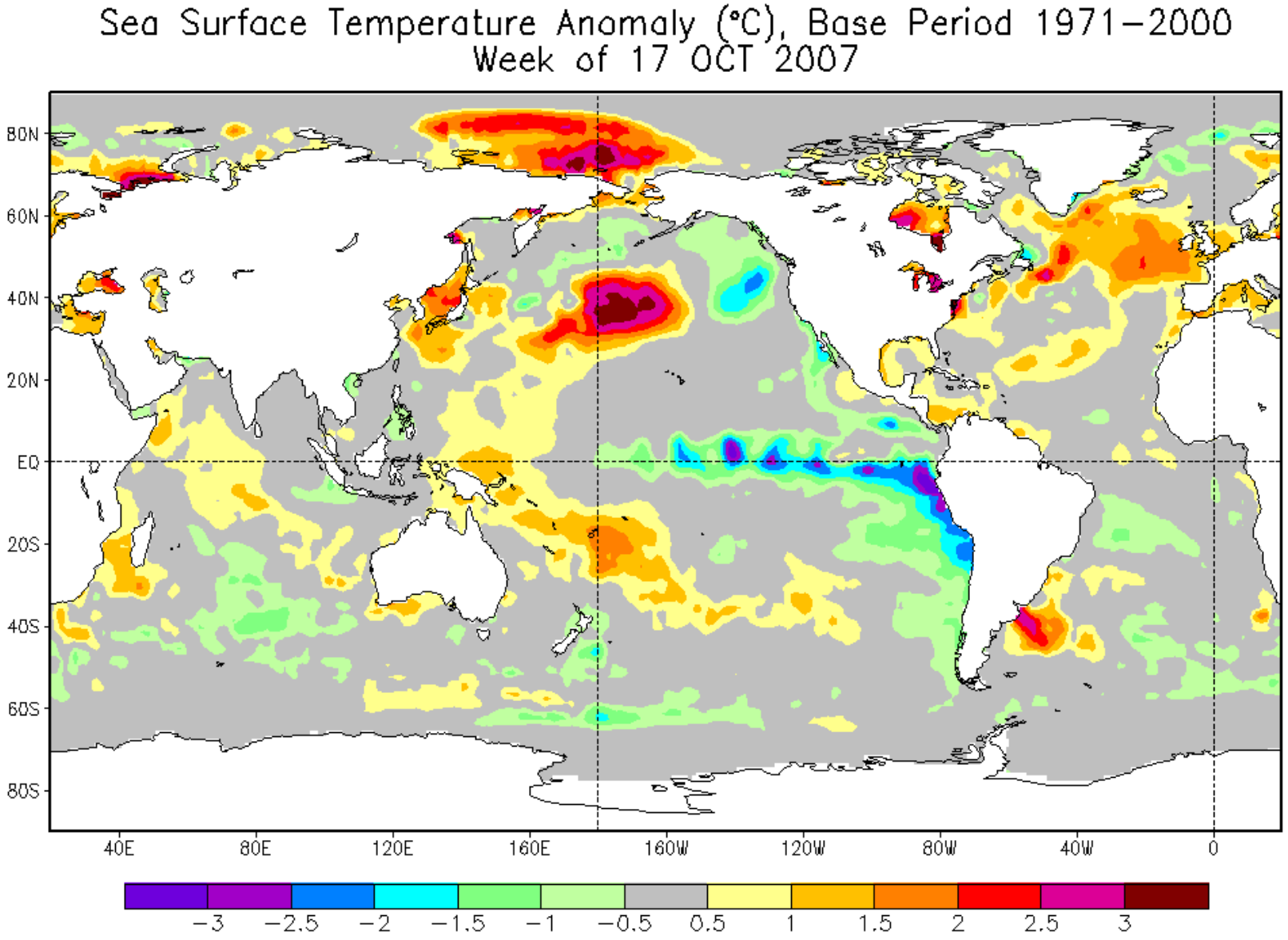
(La Niña conditions)



(SST anomalies, 10/07-10/08)



(SST anomalies, 10/08-10/09)



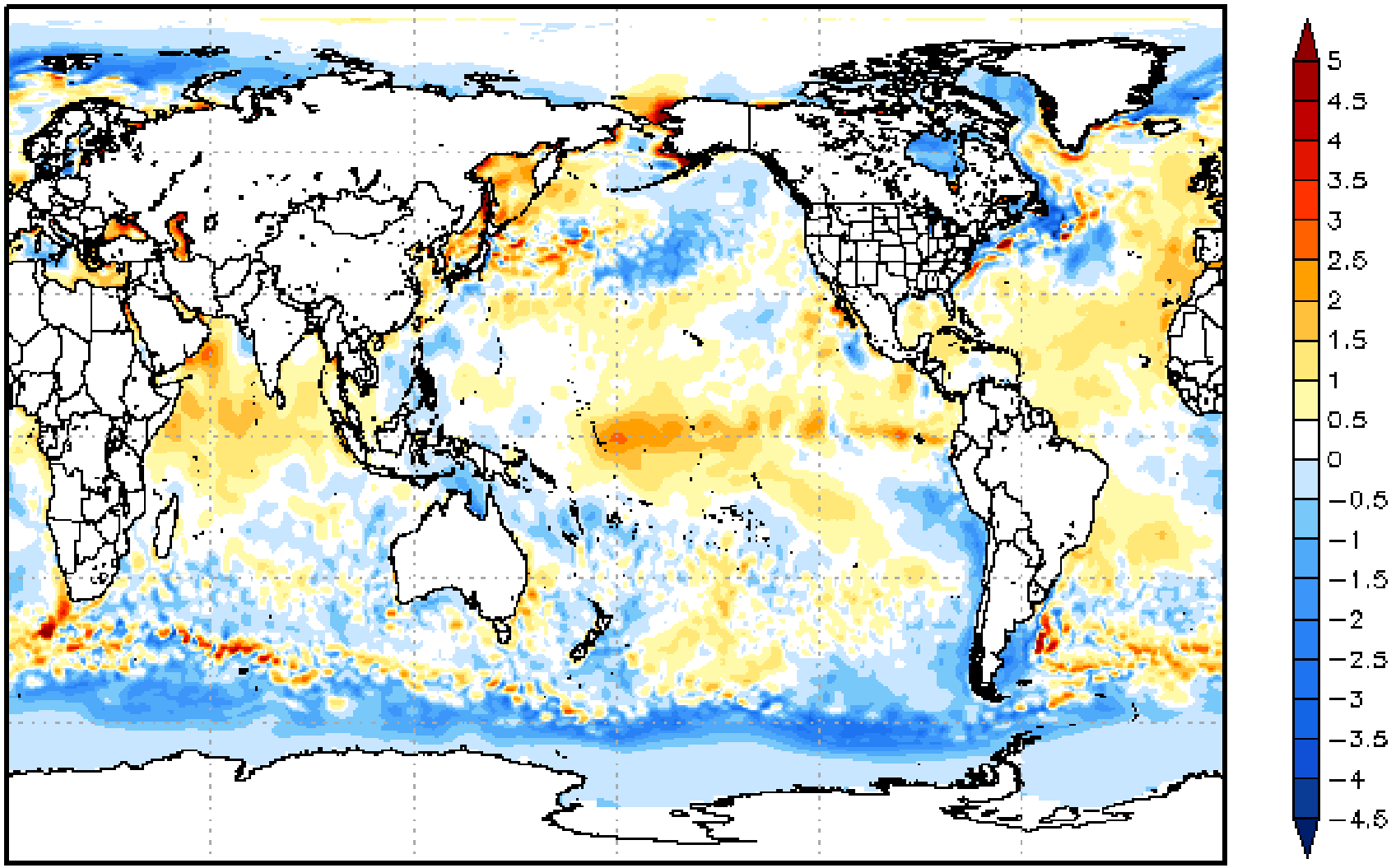
Global SST Anomaly, 10/17/07

(La Niña conditions)

weather zone

polar.ncep.noaa.gov

SST anomalies 2009-10-27



Global SST Anomaly, 10/27/09

(El Niño conditions)

Summary: ENSO is an atmosphere-ocean coupled mode of oscillation (broad-band):

(1) Genesis: ?? (atm or ocean)
(2) Atmospheric response: Pacific Eq. winds
(3) Ocean response: warming in the eastern and central Eq. Pacific; eastern upwelling suspended
(4) Atmospheric response: Eq. warming due to OLR anomaly from the ocean; Rossby wave generation
(5) Non-local response, atmosphere: anomalies in precipitation, wind, and temperature globally
(6) Non-local response, ocean: warming/cooling of boundary currents, ecosystem effects, ……
(7) Longer-term effects: relation to PDO, AO, NAO??