5. El Niño Southern Oscillation

Ocean-Atmosphere Coupling

Tropical atmosphere/ocean, large-scales strongly controlled by boundary conditions imposed by other scales.

Large-scale upper ocean determined by past history of wind stress

Major features of tropical atmospheric circulation (averaged over months) largely determined by SSTs.

At interannual timescales, zonal gradient of equatorial thermocline and overlying Trade Wind stress approximately in balance.

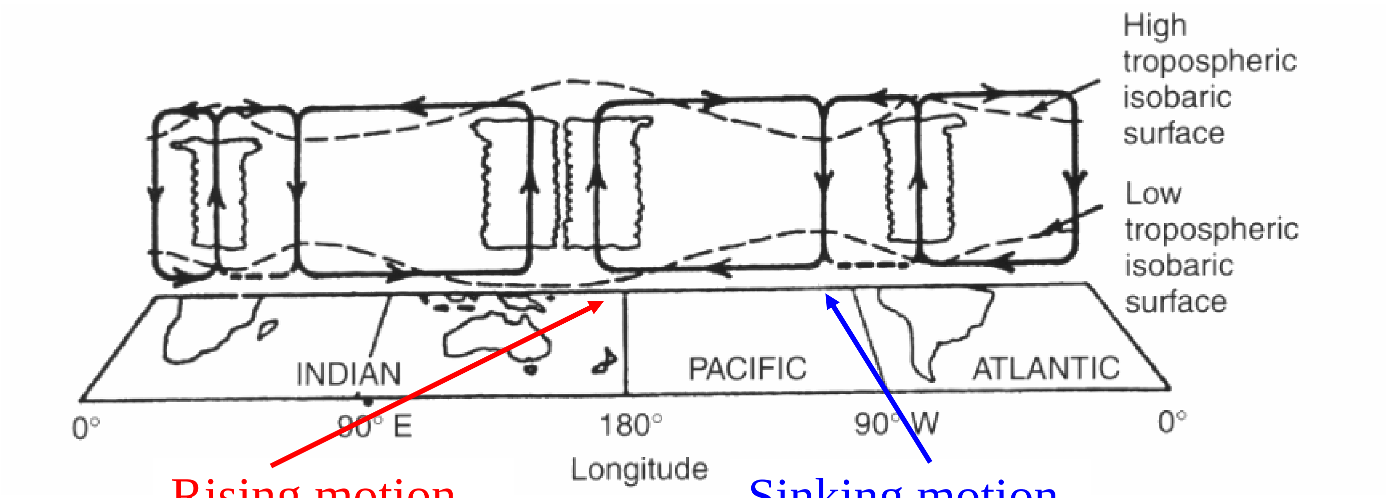
Hadley Circulation

Meridional circulation, rising air (moist) in ITCZ (usually 5-10°N), descending air (dry) in desert regions (20-30°).

Walker circulation

Pattern of diabatic heating in equatorial region: strong departures from zonal symmetry.

East-West overturning along the equator

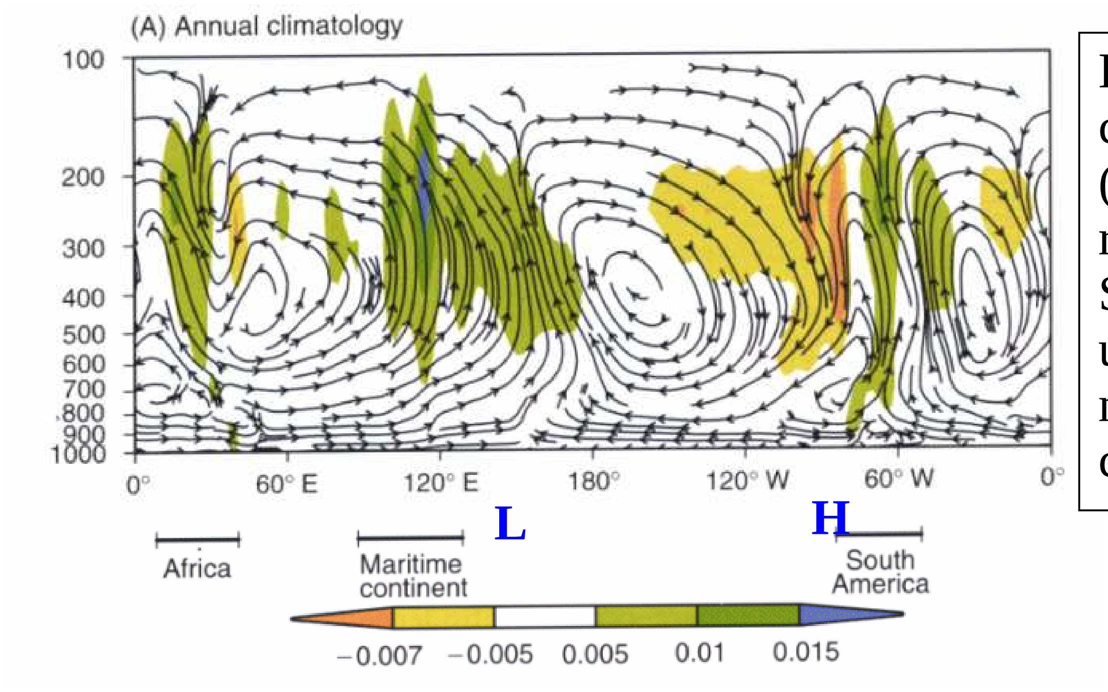


Rising motion over warm water

Sinking motion over cold water

Several overturning cells associated with diabatic heating over equatorial Africa, Central & South America and the Maritime Continent (ie Indonesian region). Dominant cell in both zonal scale and amplitude is equatorial Pacific: **Walker circulation**.

Longitudinal variations in sea surface temperature due mainly to the effects of wind-driven ocean currents.



Equatorial circulation (NCEP reanalysis). Strong up/downward motion coloured.

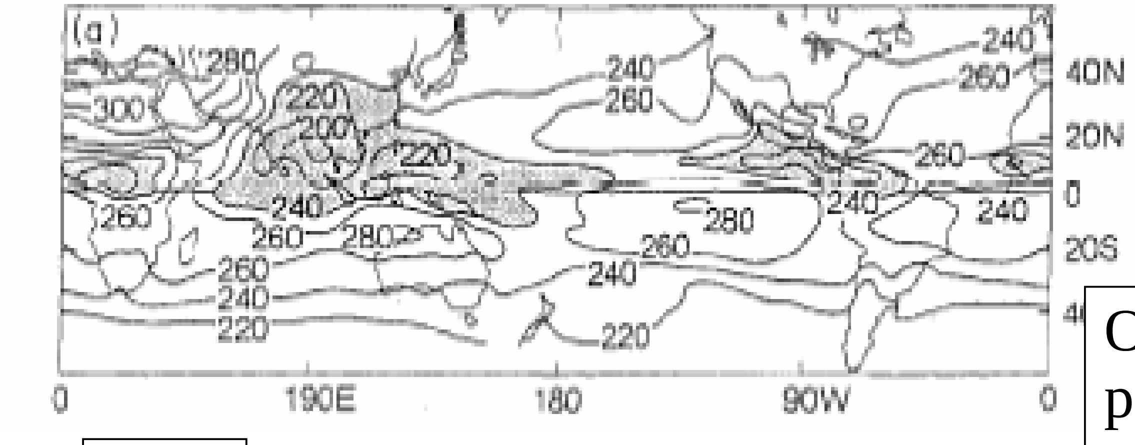
Low sea level pressure (SLP) in western Pacific and high SLP in eastern Pacific

Westward-directed pressure gradient force drives mean surface easterly winds in equatorial Pacific

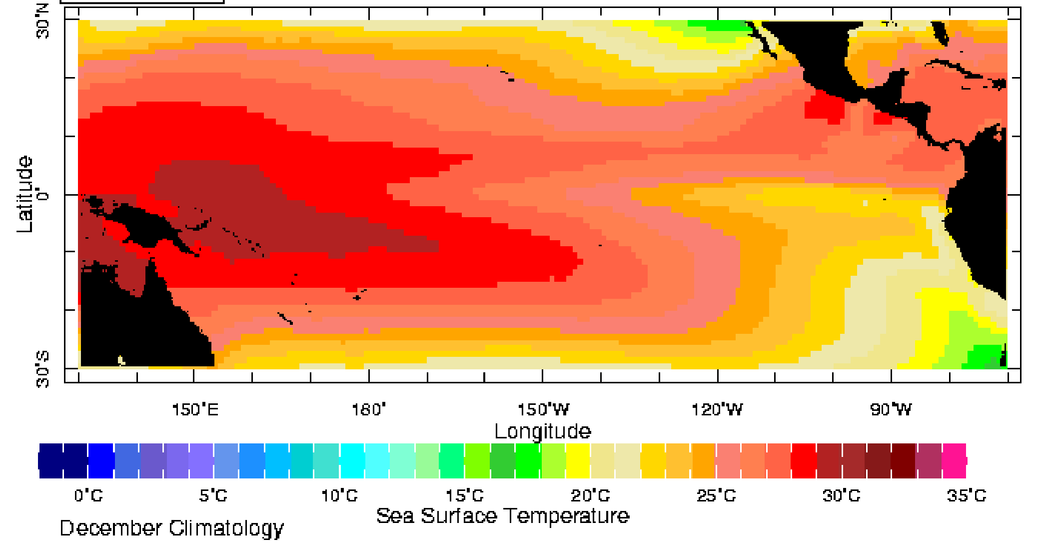
Horizontal vapour transport + high evapouration rates caused by the high SSTs provide moisture source for convection in western Pacific

Ascending (*descending*) branch warm (*cold*): thermally-direct circulation – converts available potential energy to kinetic energy.

OLR



SST



OLR pattern ~ warm water.

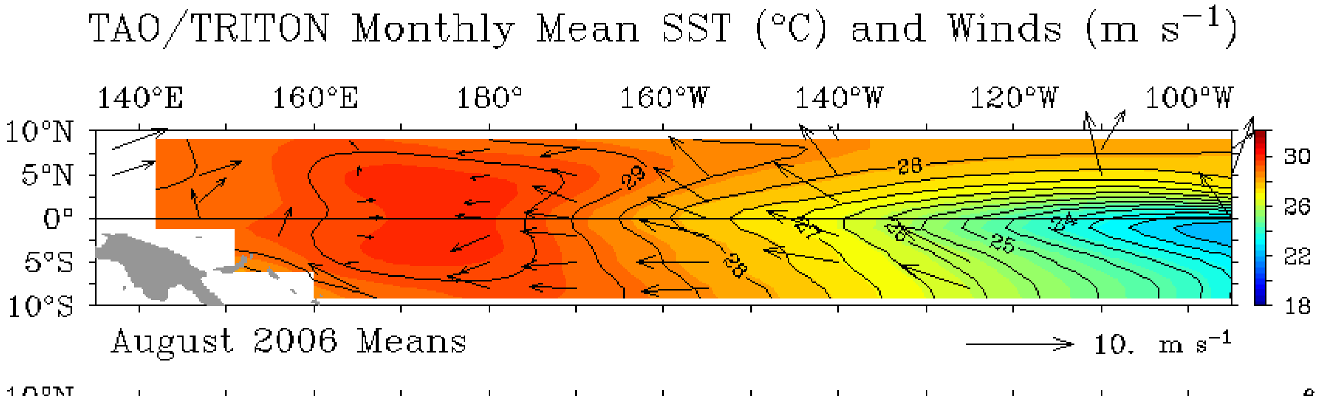
Note also cold strip at E. Pacific

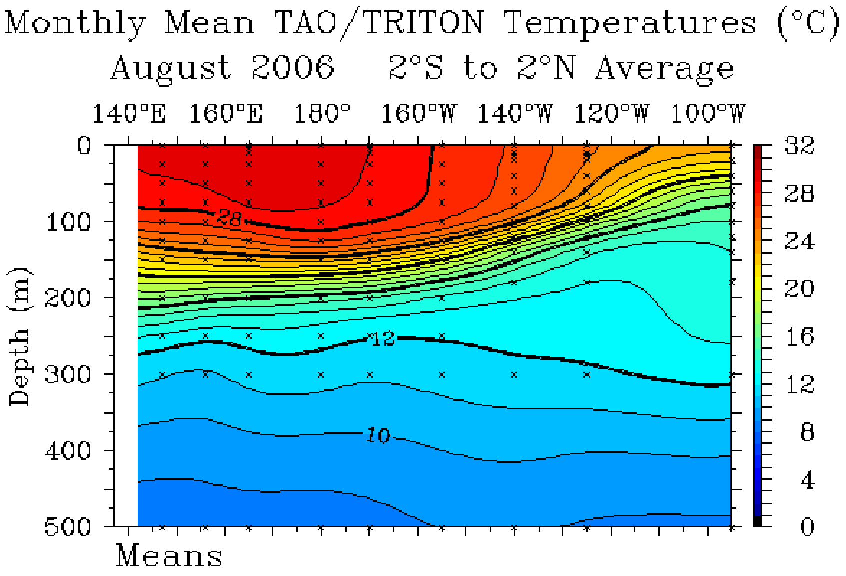
Westward wind stress τ gives Ekman flow in ocean mixed layer (depth H) poleward: $-fv = \tau / \rho H$.

Induces upwelling of cold deep water along equator: raises thermocline. Gives geostrophic flow westward:

$$\beta u = \frac{1}{\rho_0}\frac{\partial^2 p'}{\partial y^2} \qquad y \to 0$$

. Also stress driven at surface.





Since boundaries, E-W pressure gradient in ocean.

Deep, warm mixed layer in west, tilted thermocline.

Below surface (away from effects of wind stress):

1. away from equator - geostrophic equatorward

2. at equator - eastward 'jet' down pressure gradient - equatorial undercurrent (Atlantic & Pacific).

Interannual fluctuations of Walker Circulation

East-west SLP gradient associated with the Walker circulation undergoes an irregular interannual variation.

Global-scale ‘see-saw’ in pressure & associated changes in patterns of wind, temperature & precipitation named **southern oscillation** by Walker.

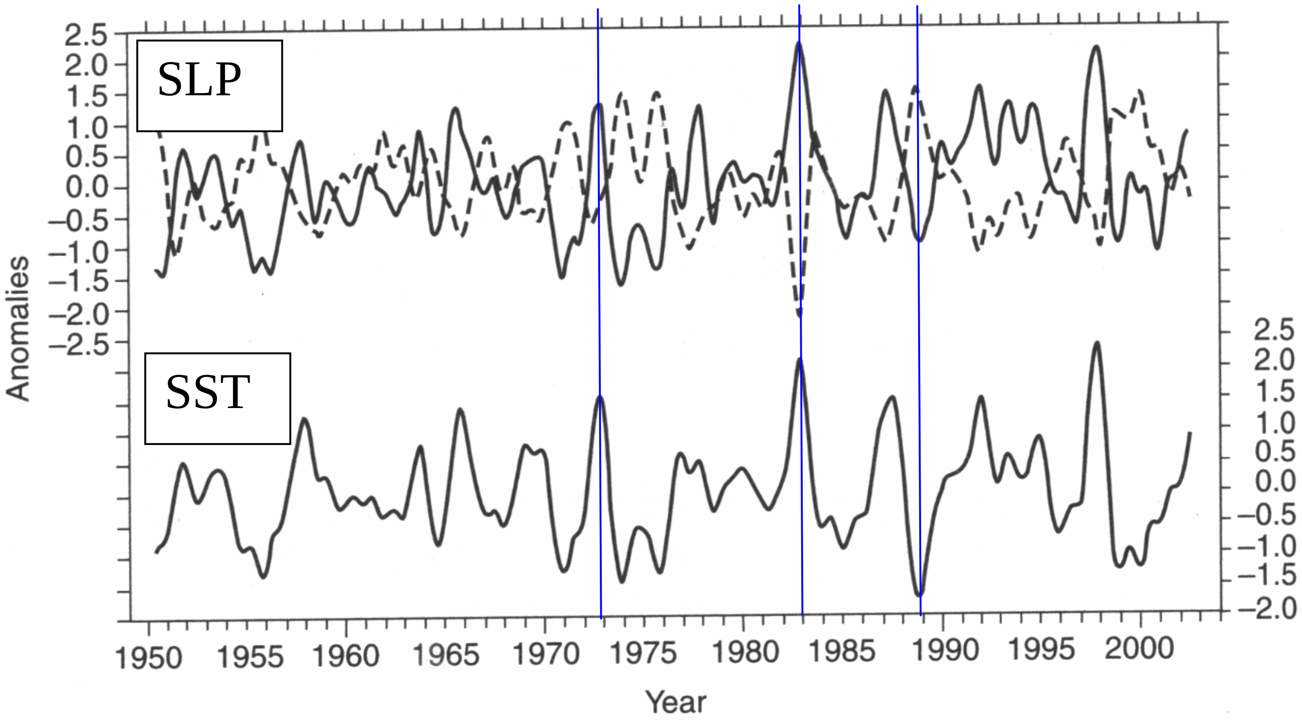
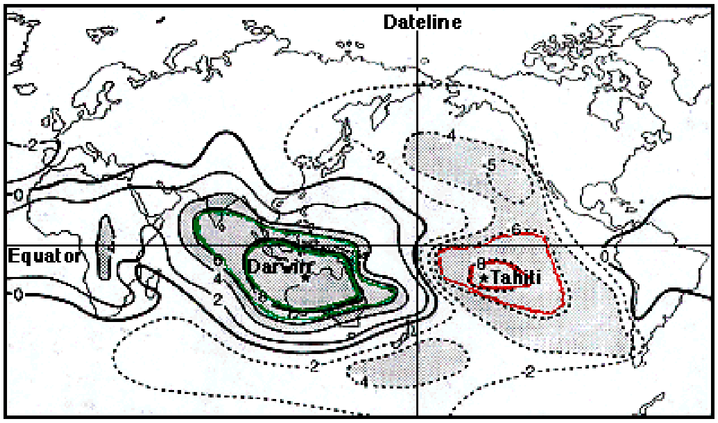


Fig. 11.11 Time series showing SST anomalies (°C) in the eastern Pacific (lower curve) and anomalies in sea level pressures (hPa) at Darwin (upper solid curve) and Tahiti (upper dashed curve). Data are smoothed to eliminate fluctuations with periods less than a year. Figure courtesy of Dr. Todd Mitchell, University of Washington.

Also correlated with SSTs.

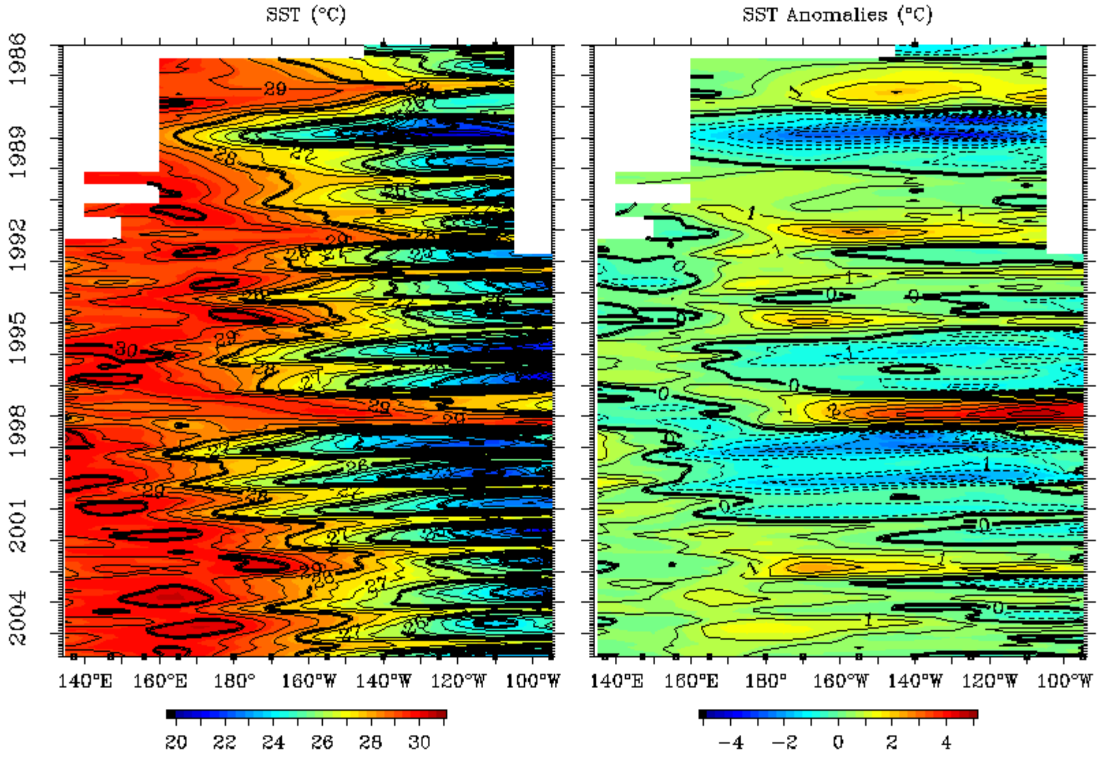
SOI: Tahiti and Darwin as "centers of action",
mslp correlations between two locations



Tahiti and Darwin are at opposite ends of the Southern Oscillation's seesaw, and so the difference in pressure between them is used to measure the Southern Oscillation. The numbers represent a statistical measure called the correlation coefficient. The figure shows that the pressure variation at Tahiti is as closely related to Darwin as are locations near to Darwin, but with the opposite sign (i.e., if the Pressure is high at Darwin, it is low at Tahiti and vice versa). (After Rasmusson, 1984.)

Surface pressure anomalies at Darwin Austraila and Tahiti are negatively correlated and have strong variations in the period range of 2-5 years.

Monthly SST 2°S to 2°N Average



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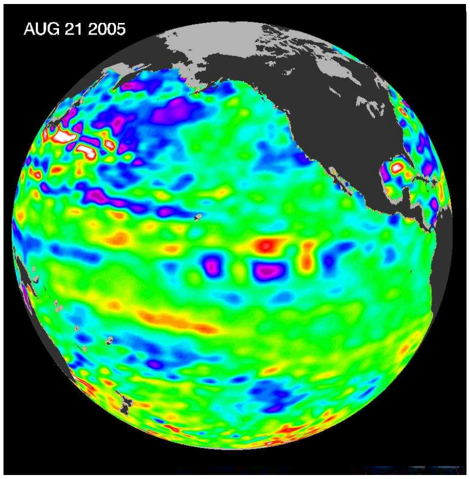
Sep 22 2005

Usually W-E decrease in SSTs, but in some years less.

Warm events **El Niño**.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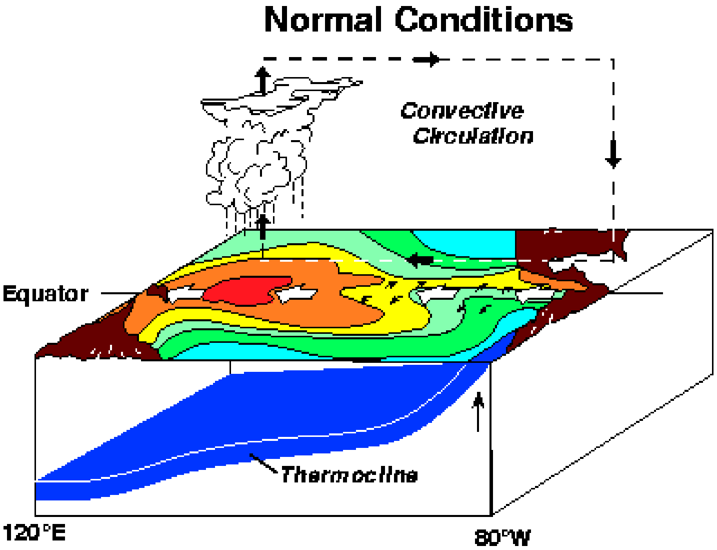
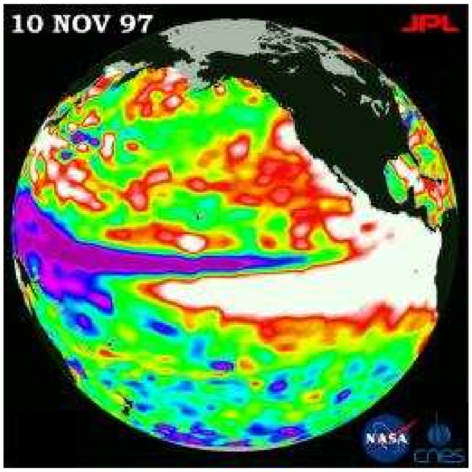
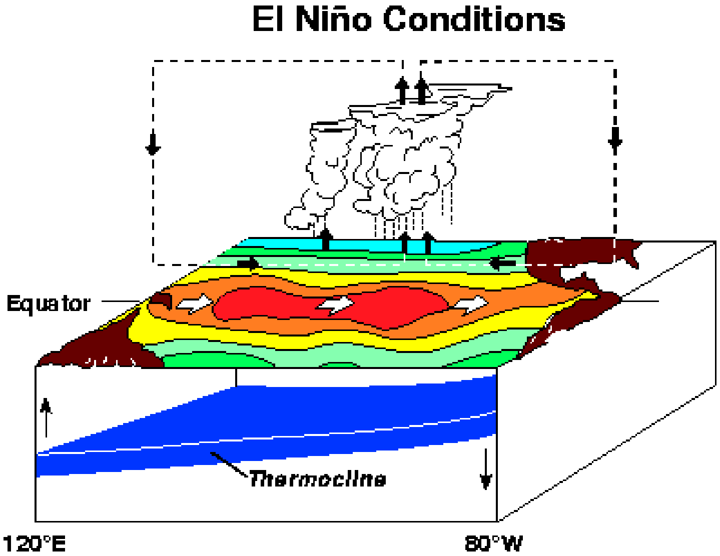
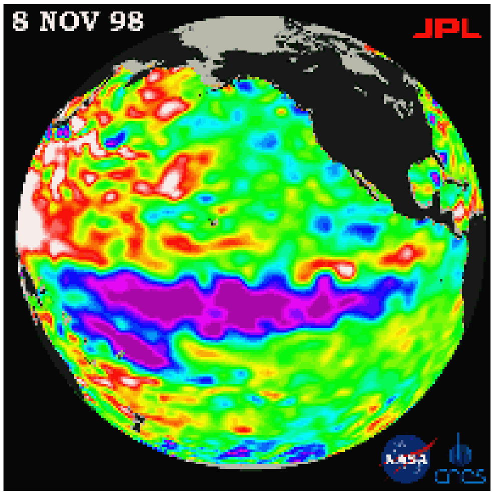
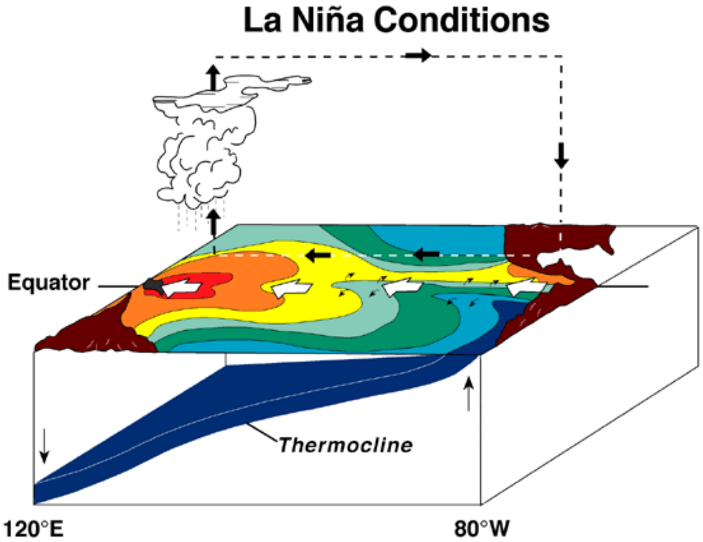

Normal Conditions
Convective Circulation
Equator
Thermocline
120°E
80°W


10 NOV 97
JPL

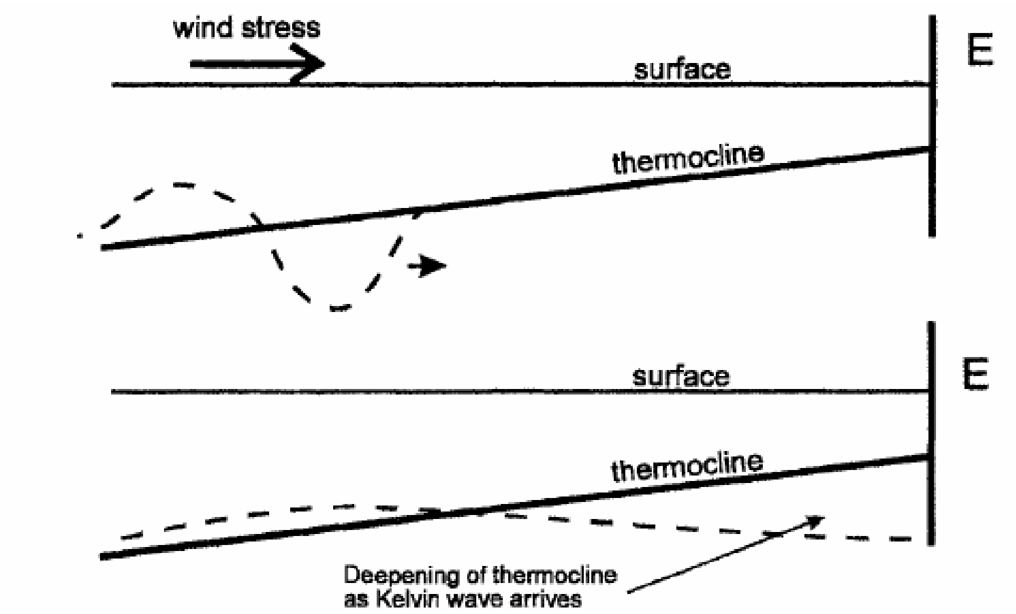

El Niño Conditions
Equator
Thermocline
120°E
80°W


8 NOV 98
JPL


La Niña Conditions
Equator
Thermocline
120°E
80°W

Ocean forces atmospheric behaviour: response to changed boundary conditions associated with El Niño SST fluctuations [demonstrated hierarchy of models].

Atmosphere forces oceanic behaviour: oceanic fluctuations response to changed wind stress distribution associated with SO.

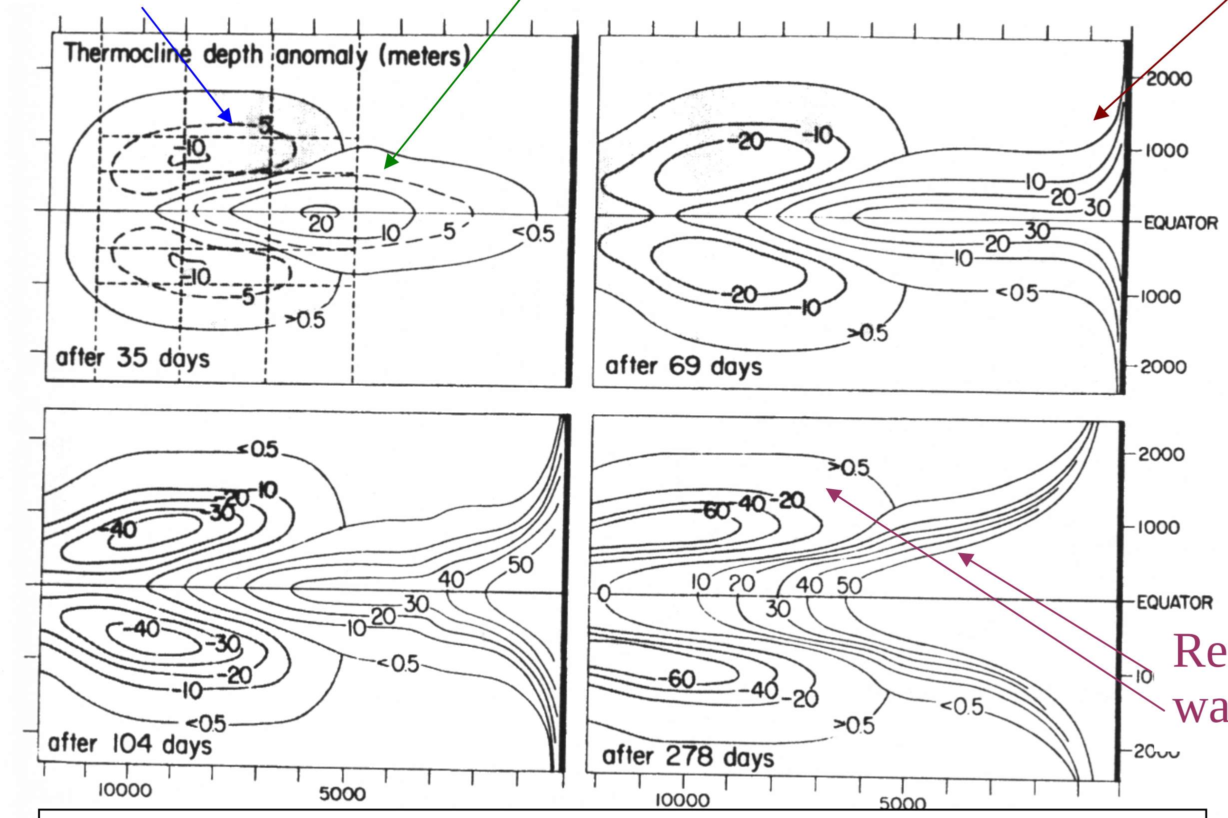


Bjerknes: collapse of trades in W Pacific drives oceanic Kelvin wave (of thermocline depression) eastward – deepen thermocline in E Pacific 2 months later (speed 2ms^{-1}). Raises SST in east (warmer water upwelled). Atmosphere/ocean coupling – **ENSO**.

Wave propogation

Response to longitudinally isolated heating at equator: wave propagation beyond localised heating. Rossby wave (westward), Kelvin wave (eastward). Fastest Rossby wave group velocity ~1/3 of Kelvin wave.

Suppose warm SST anomaly over E Pacific. Implies westerly wind anomaly over central Pacific. Waves excited in ocean.



Rossby wave (slow to West)

Kelvin wave (rapid to East)

Poleward coastal waves on E-boundary

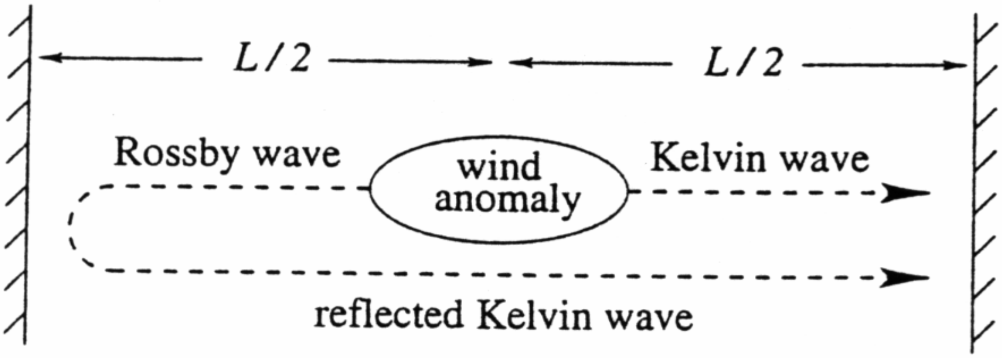
Reflected waves

Time development of thermocline depth anomaly in response to wind anomaly (eastward stress) limited in space to region of dashed lines.

Oscillations

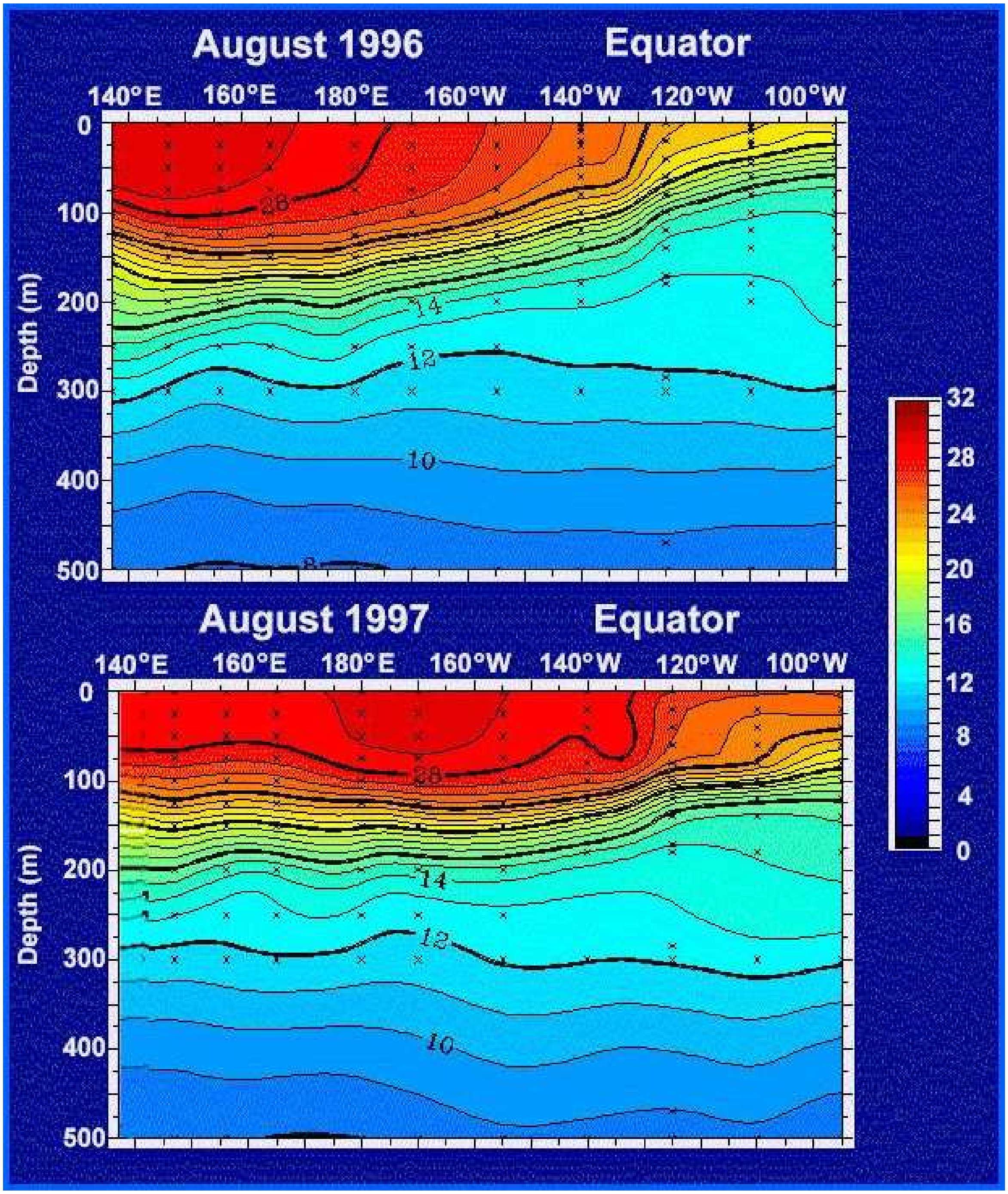
Downwelling Kelvin wave propagates eastward. Reinforces initial warm SST anomaly in E Pacific. **Positive feedback.**

Upwelling Rossby wave propagates westward and reflected as an upwelling Kelvin wave. Reduces initial SST anomaly. **Negative feedback**.



Propagation times – feedbacks **delayed**. Ocean never catches up with its current state – implies oscillations.

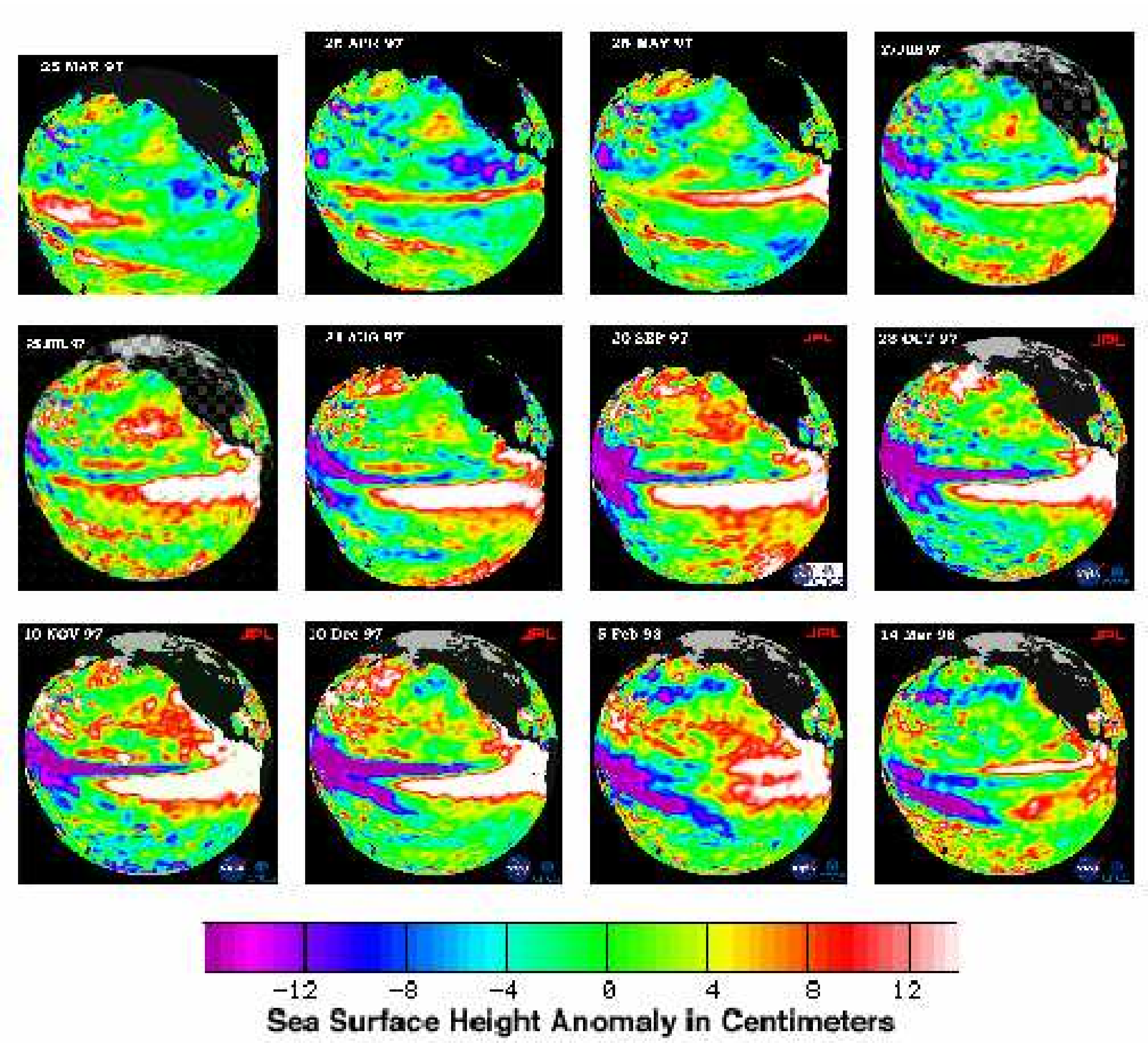
[When Kelvin wave strikes eastern NS boundary, some energy reflected, rest divided between Nth/Sth coastal Kelvin waves.]



Also movies at

http://nsipp.gsfc.nasa.gov/enso/visualizations/

El Nino 1997



Evolution of sea surface height during the development of the 1997 El Nino event (March ’97 to May ’98). Kelvin waves are triggered by wind anomalies blowing over the central Pacific, and propagate warm (raised sea surface) anomalies to the eastern Pacific.

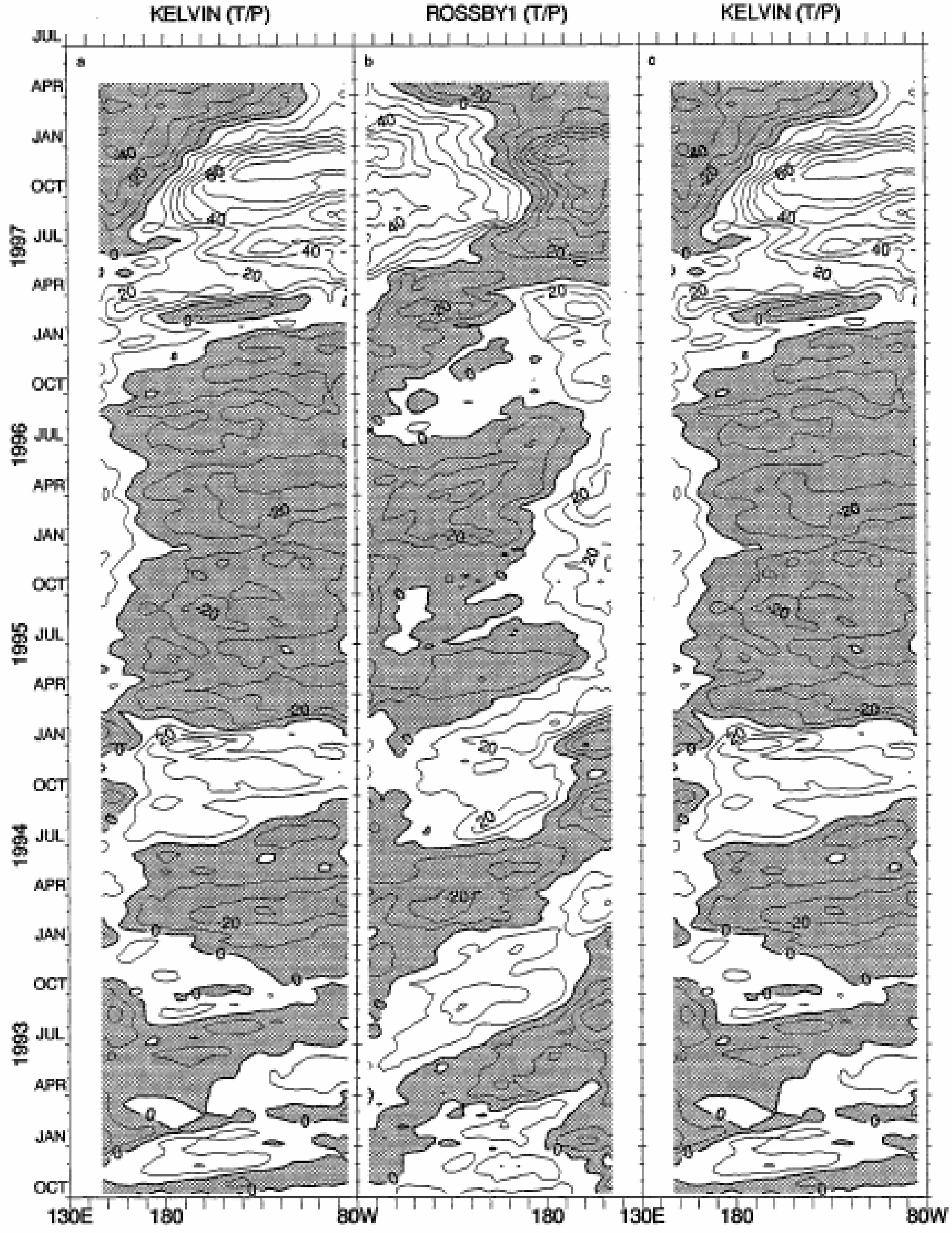


Fig. 6 a longitude-time plots of the TOPEX/POSEIDON Kelvin wave coefficient (from 130°E to 80°W), b the first-mode Rossby wave coefficient (in reverse display from 80°W to 130°E), and c the Kelvin wave coefficient (from 130°E to 80°W; repeated for comparison). Contour interval is 10 units for both coefficients. *Positive* (*negative*) coefficients are *white* (*gray*)

Longitude-time sections of projections of TOPEX-POSEIDON sea-level anomalies into Kelvin (left and right panels) and n=1 Rossby waves (middle)

Delayed Oscillator model

Simple heuristic model of El Nino including time-delayed +ve/-ve feedbacks. Many variants (following from Tziperman et al 1994).

$$\frac{dh}{dt} = aF\left[h\left(t-\tau_1\right)\right] - bF\left[h\left(t-\tau_2\right)\right]$$

+ve feedback -ve feedback

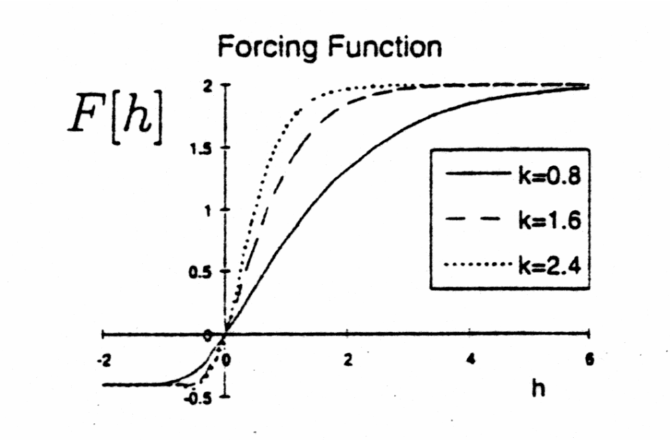
h is thermocline depth in the E.Pacific,

$$F\left[h\right] = \begin{cases} 0.4\tanh\left(\dfrac{kh}{0.4}\right) & h<0 \\ 2\tanh\left(\dfrac{kh}{2}\right) & h>0 \end{cases}$$

nonlinear function that limits max/min values of h (i.e. allows h to saturate)

k is strength of atmosphere-ocean coupling

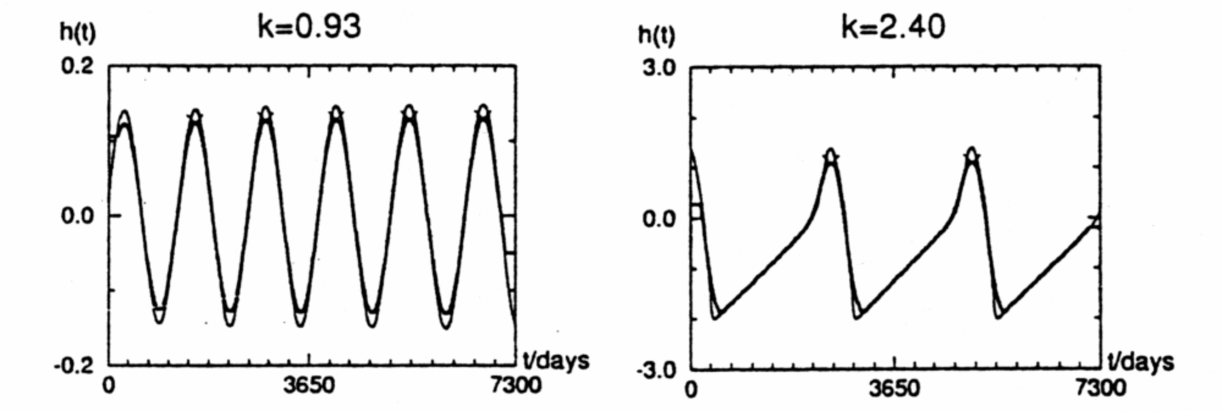
a & b control growth/decay rates



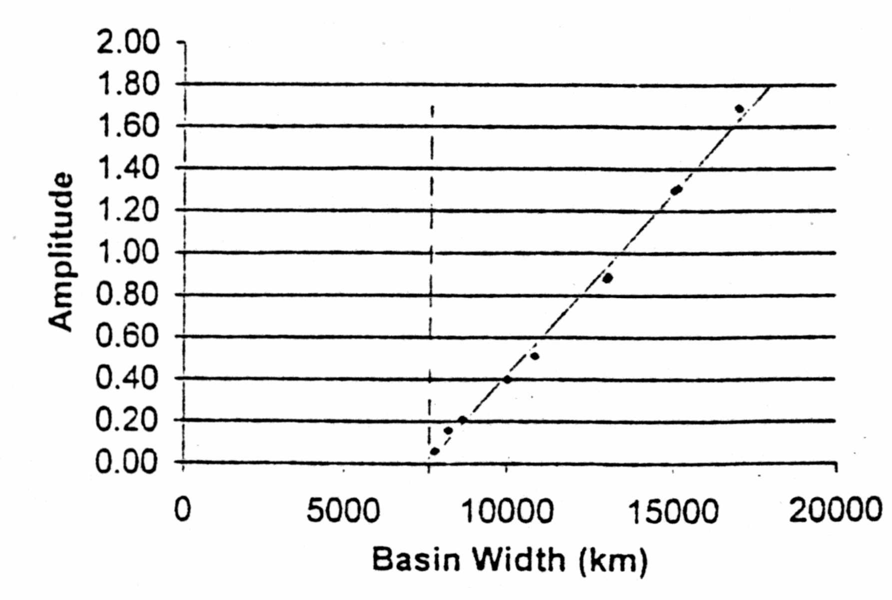
τ_1 & τ_2 are time-delays set by Kelvin/Rossby wave transit times

Highly tunable, but produces several robust features:

1. oscillations with period of ~2-10 years (>> τ_1, τ_2)

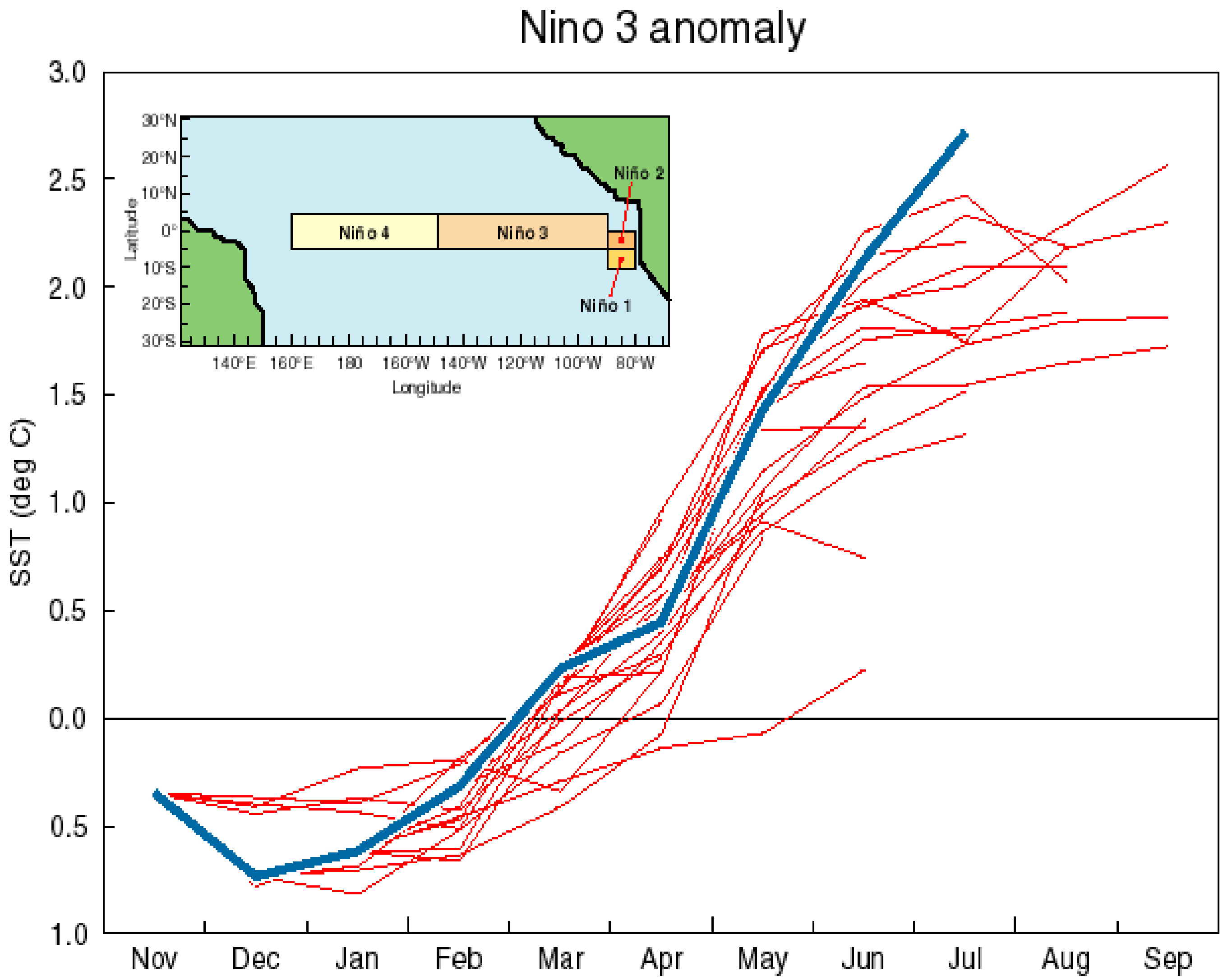


2. oscillations dependent on basin width, hence no/weak oscillation in the Atlantic

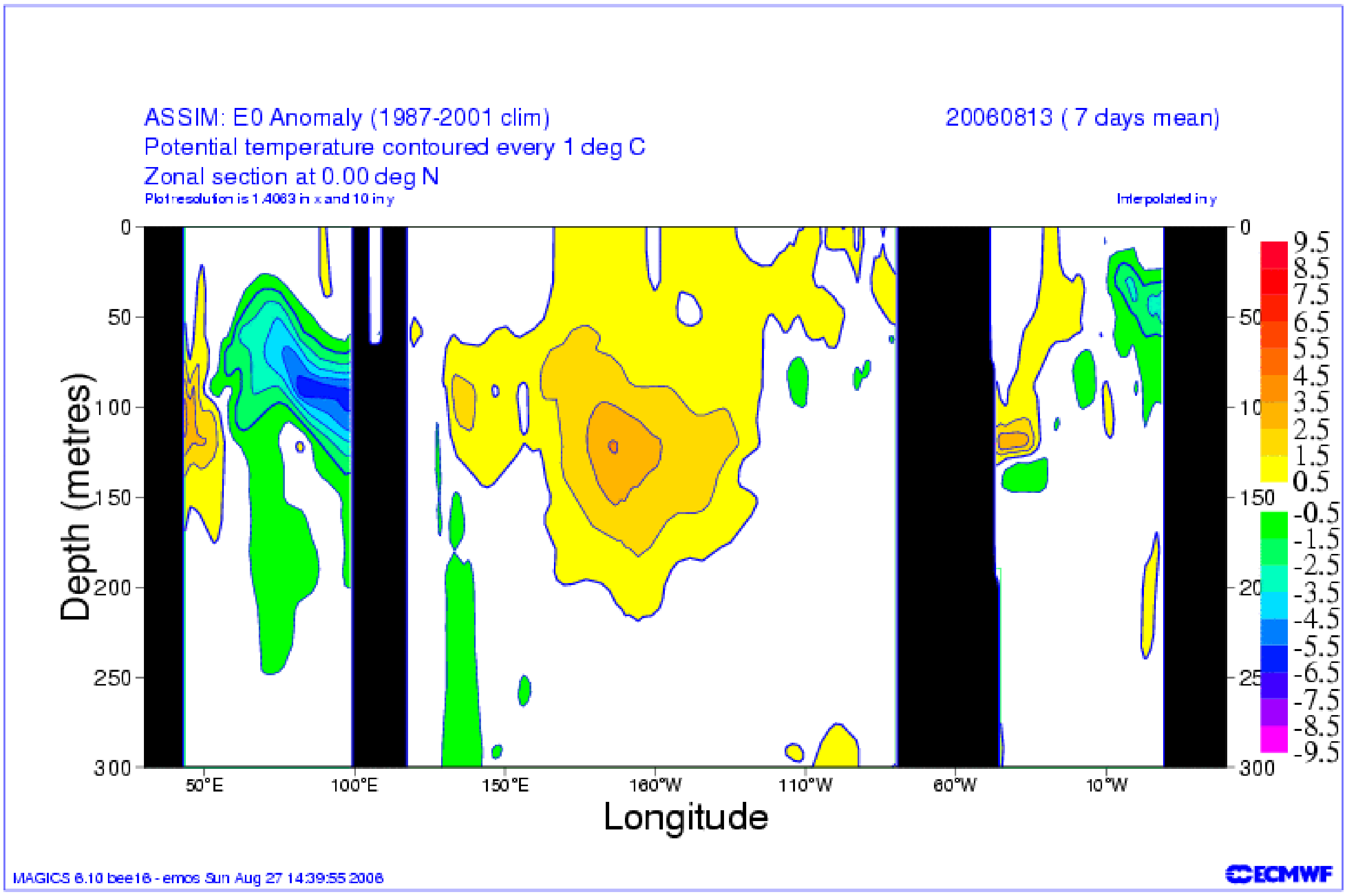


Forecasting ENSO

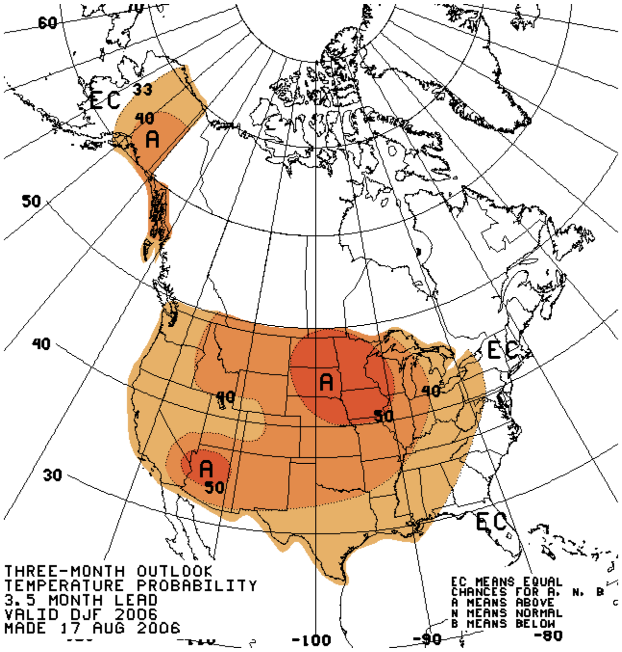
NINO 3 Index, which is departure in monthly sea surface temperature from its long-term mean averaged over NINO 3 region.


Nino 3 anomaly

Current Conditions



Current US Forecast

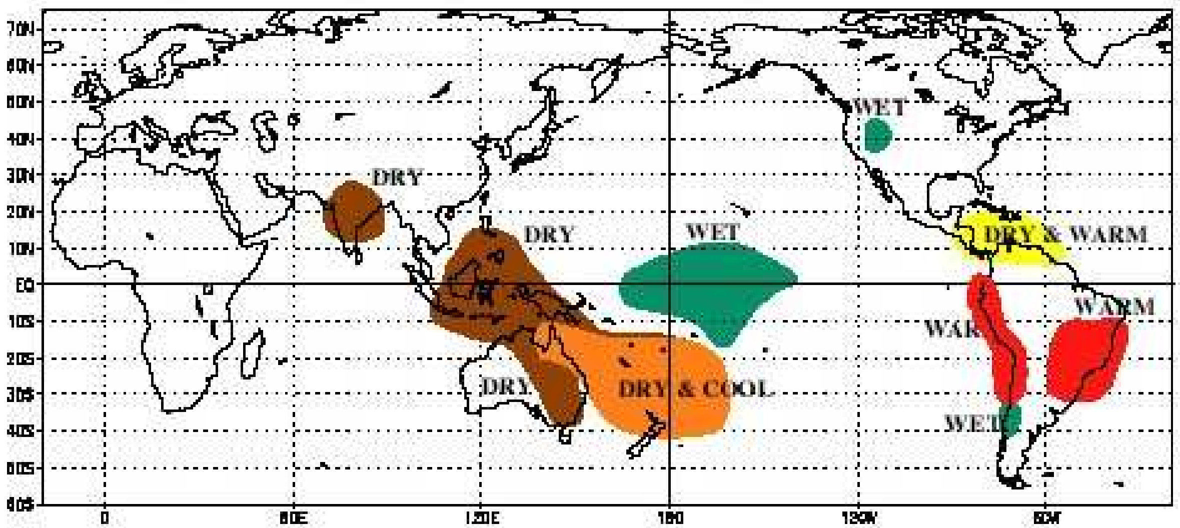


ENSO impacts

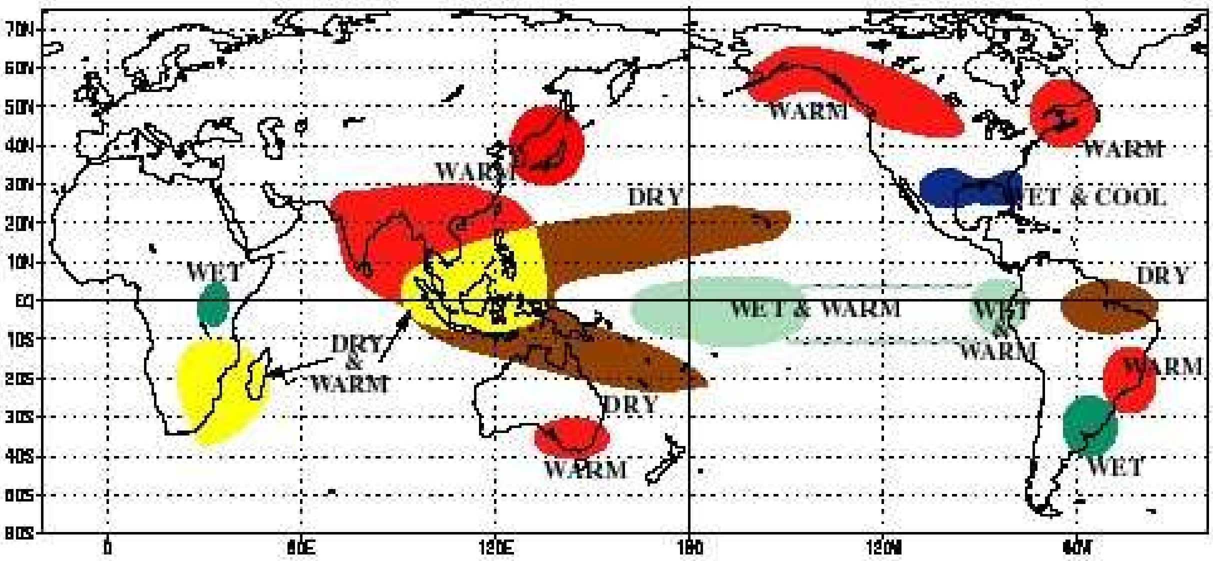
Global impacts on weather:

El Nino

WARM EPISODE RELATIONSHIPS JUNE - AUGUST

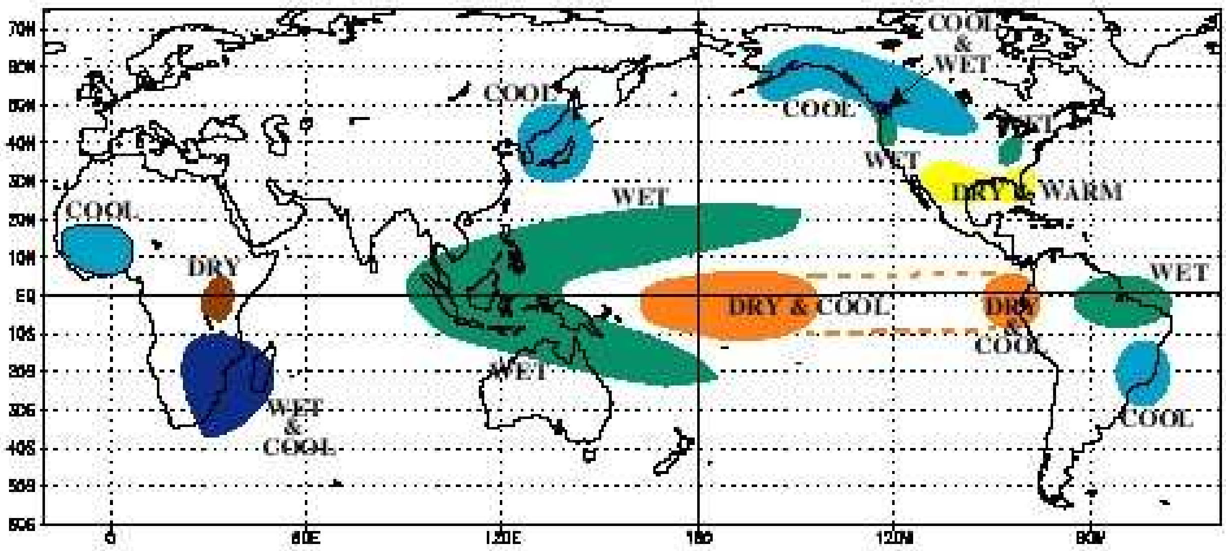


WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



La Nina

COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



COLD EPISODE RELATIONSHIPS JUNE - AUGUST