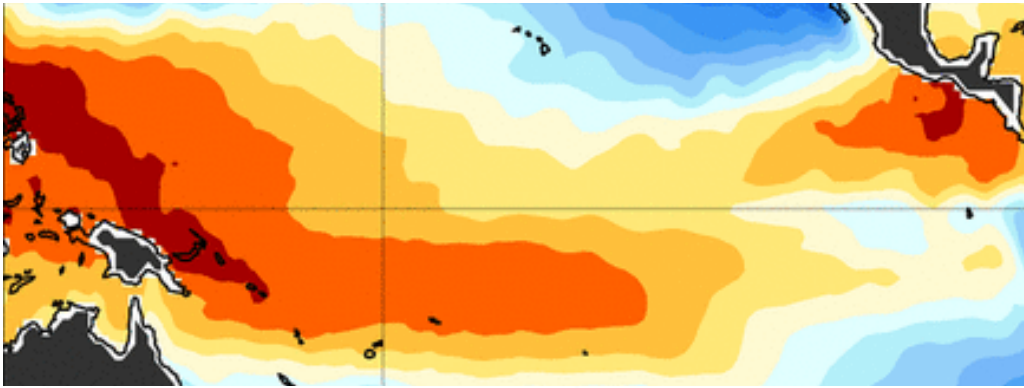
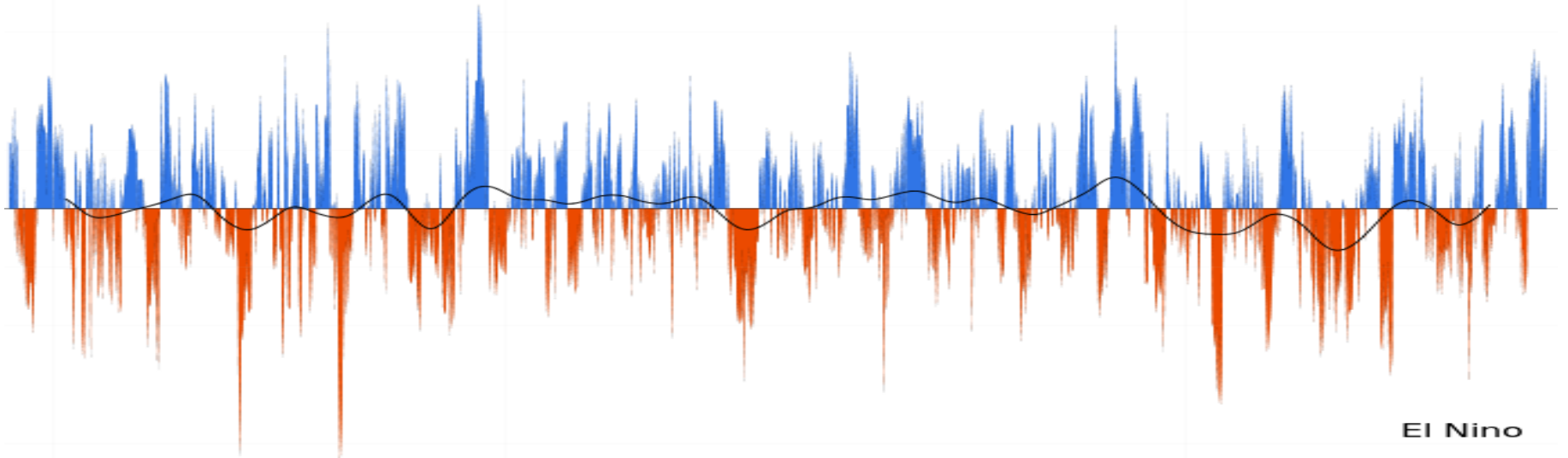


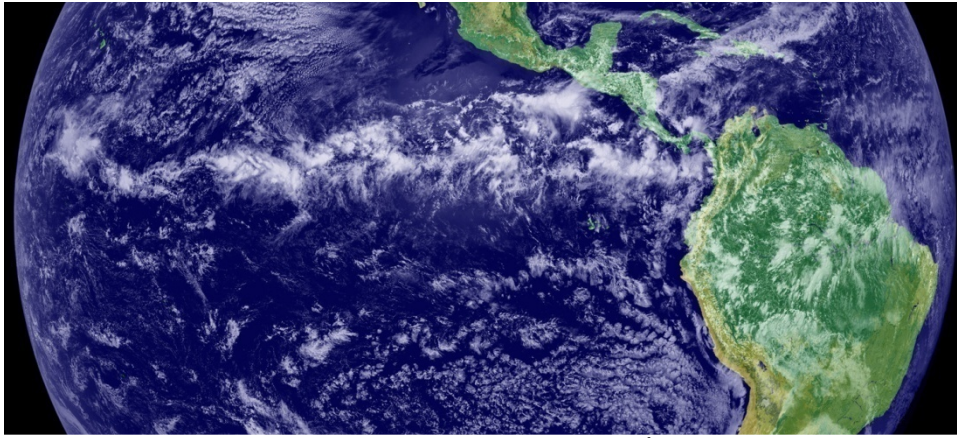


# Η δυναμική του ισημερινού ωκεανού και οι κλιματικές διακυμάνσεις



**10. Equatorial dynamics  
and climate variability**  
**Sarantis Sofianos**  
Dept. of Physics, University of Athens





Στον Ισημερινό:

$$\phi = 0 \Rightarrow \sin \phi = 0$$

$$\Rightarrow f = 2\Omega \sin \phi = 0$$

Όμως στη ζώνη του ισημερινού η επίδραση της περιστροφής είναι σημαντική λόγω  $\beta$ . Και:

**Equatorial  
beta-plane**

$$f = \beta y$$

$$\beta = \frac{\partial f}{\partial y} = \frac{\partial}{\partial y} 2\Omega \sin \phi = 2\Omega \cos \phi \frac{\partial \phi}{\partial y} = \frac{2\Omega \cos \phi}{R_{earth}} = \frac{2\Omega}{R_{earth}}$$

$$\Omega = 7.29 \times 10^{-5} \text{ sec}^{-1}, R_{earth} = 6371 \text{ km}$$

$$\beta = 2.28 \times 10^{-11} \text{ m}^{-1} \text{ sec}^{-1}$$

Για να ορίσουμε την “Ισημερινή Ακτίνα” ( $R_{eq}$ ), χρησιμοποιούμε τη ακτίνα Rossby:

$$R = \frac{\sqrt{g'H}}{f} = \frac{c}{f}$$

ώστε

$$R_{eq} = R \quad \text{at} \quad y = R_{eq}$$

$$\Rightarrow R_{eq} = \sqrt{\frac{c}{\beta}}$$

Για  $c=1.4 \text{ m/sec}$  (for the tropical ocean\*; Philander, 1990)

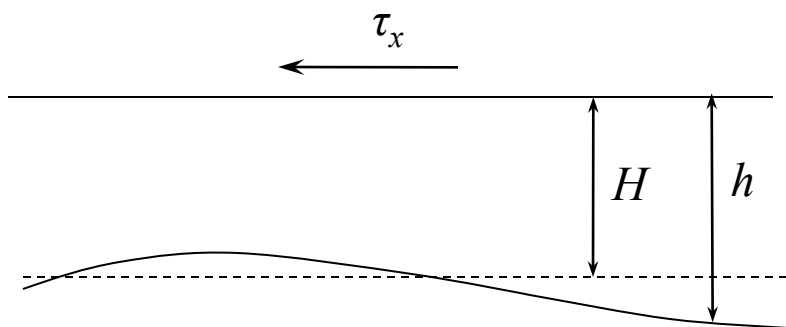
$$R_{eq} = 248 \text{ km} / 2.23^\circ$$

$$\text{και } T_{eq} = \frac{R_{eq}}{c} = \frac{1}{\sqrt{\beta c}} \approx 2 \text{ days}$$

\* ( $\Delta\rho/\rho_0=0.002; H=100 \text{ m}$ )

$$\text{και } R_{eq}^{ex} \approx 20^\circ$$

## Equatorial Circulation

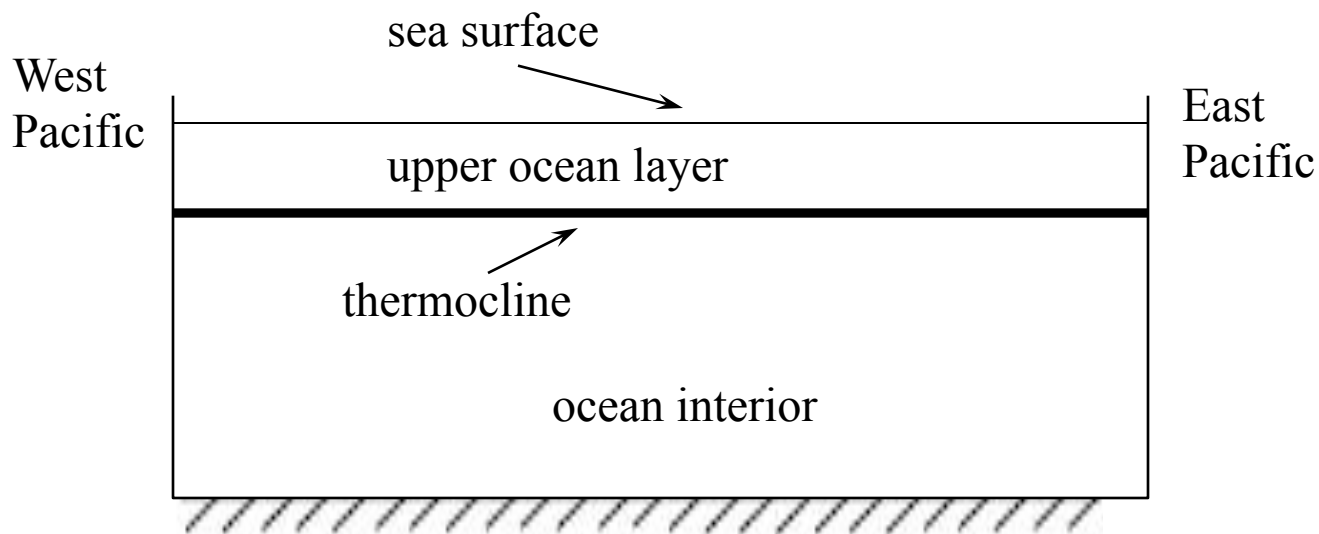


One-layer reduced gravity model

$$\frac{\partial u}{\partial t} - \beta y v = -g' \frac{\partial h}{\partial x} + \frac{\tau_x}{\rho_0 H} - Ru$$

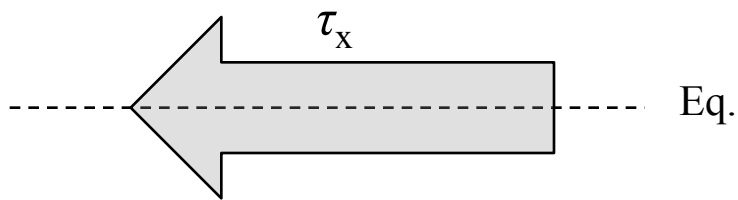
$$\frac{\partial v}{\partial t} + \beta y u = -g' \frac{\partial h}{\partial y} + \frac{\tau_y}{\rho_0 H} - Rv$$

$$\frac{\partial h}{\partial t} + H \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) = 0$$



## The steady state solution

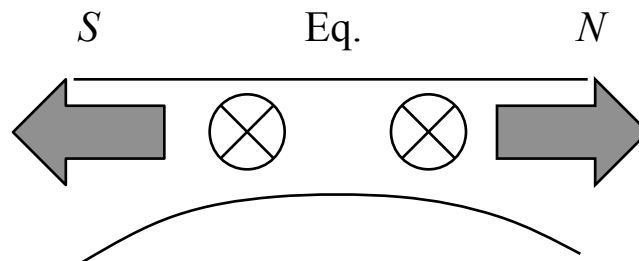
$$\left. \begin{aligned} \frac{\partial u}{\partial t} - \beta y v &= -g' \frac{\partial h}{\partial x} + \frac{\tau_x}{\rho_0 H} \\ \frac{\partial v}{\partial t} + \beta y u &= -g' \frac{\partial h}{\partial y} + \frac{\tau_y}{\rho_0 H} \\ \frac{\partial h}{\partial t} + H \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) &= 0 \end{aligned} \right\} \begin{aligned} -\beta y v &= -g' \frac{\partial h}{\partial x} + \frac{\tau_x}{\rho_0 H} \quad (1) \\ \beta y u &= -g' \frac{\partial h}{\partial y} \quad (2) \quad \left( \frac{\partial}{\partial t} = 0, \tau_y = 0, \tau_x \propto y, R = 0 \right) \\ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} &= 0 \quad (3) \end{aligned}$$



**i. Infinite ocean**  $\left( \frac{\partial}{\partial x} = 0 \right)$

$$v = -\frac{1}{\beta y} \frac{\tau_x}{\rho_0 H}$$

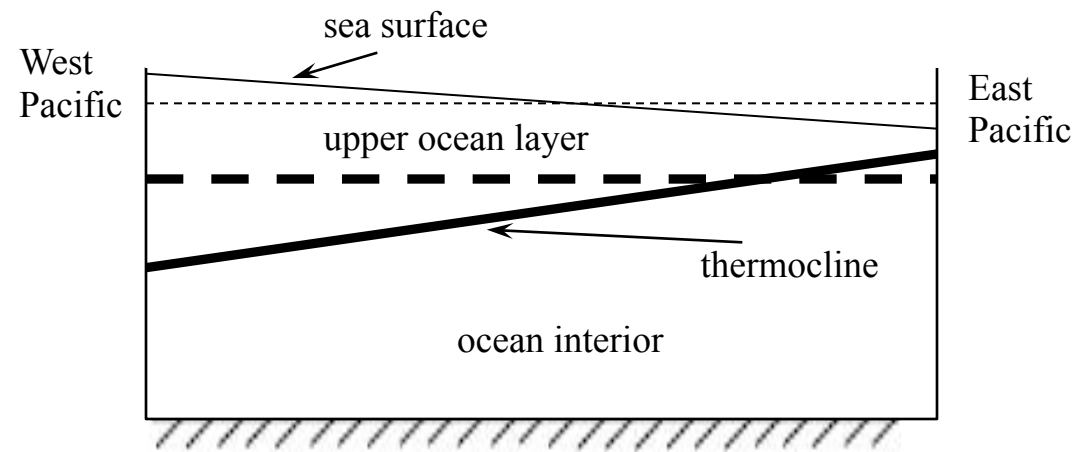
$$u = -\frac{g'}{\beta y} \frac{\partial h}{\partial y}$$



## ii. Bounded ocean

Πολύ κοντά στον Ισημερινό ( $y \rightarrow 0$ ) οι παραπάνω λύσεις δεν έχουν νόημα. Χρειάζεται ειδική μελέτη του συστήματος (αλλάζουμε τις οριακές συνθήκες).

$$\left. \begin{aligned} \frac{\partial(1)}{\partial y} &\Rightarrow -\beta v - \beta y \frac{\partial v}{\partial y} = -g' \frac{\partial^2 \eta}{\partial x \partial y} + \frac{1}{\rho_0 H} \frac{\partial \tau_x}{\partial y} \\ \frac{\partial(2)}{\partial x} &\Rightarrow \beta y \frac{\partial u}{\partial x} = -g' \frac{\partial^2 \eta}{\partial x \partial y} \end{aligned} \right\} \text{ - και λόγω (3) } \quad v = -\frac{1}{\beta \rho_0 H} \frac{\partial \tau_x}{\partial y} \equiv 0$$



Χρησιμοποιώντας την (3) και λόγω “bounded” equator ( $u = \text{const}$  και 0 στα όρια)

$$u = 0$$

Ισορροπία: 
$$g' \frac{\partial \eta}{\partial x} = \frac{\tau_x}{\rho_0 H}$$

## Equatorial Pacific Temperature (World Ocean Atlas, 1998)

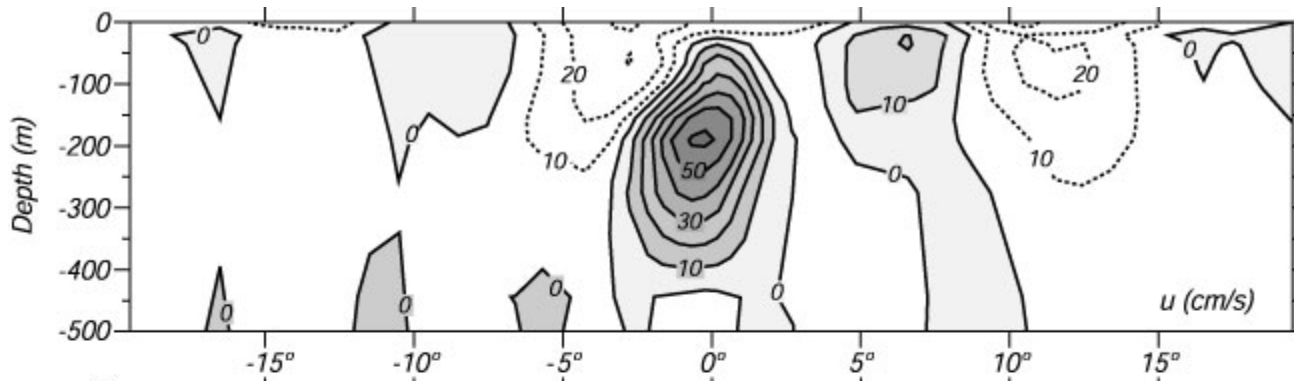
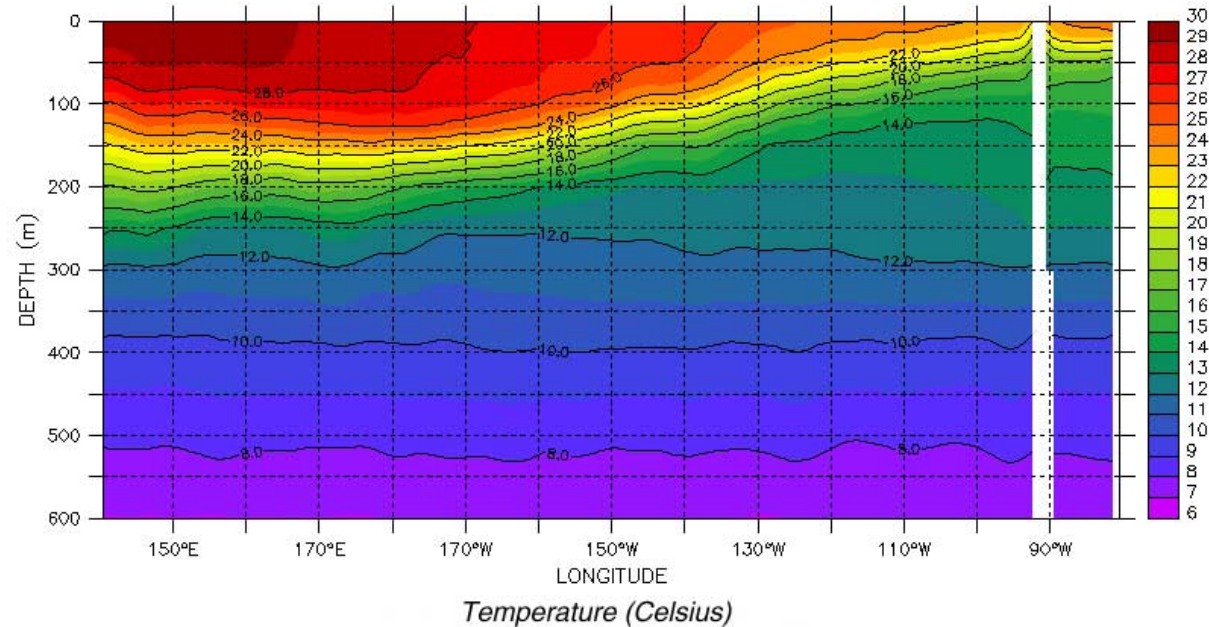
Σε βάθη μεγαλύτερα από  $D_e$ , η επίδραση του ανέμου είναι αμελητέα και η βαθμίδα πίεσης δεν αντισταθμίζεται.

$$\frac{\partial u}{\partial t} - \cancel{\beta \gamma v} = -g' \frac{\partial h}{\partial x} + \frac{\tau_x}{\rho_0 H}$$

Επίσης, στον Ισημερινό  $y=0$  και δεν υπάρχει γεωστροφική ισορροπία.

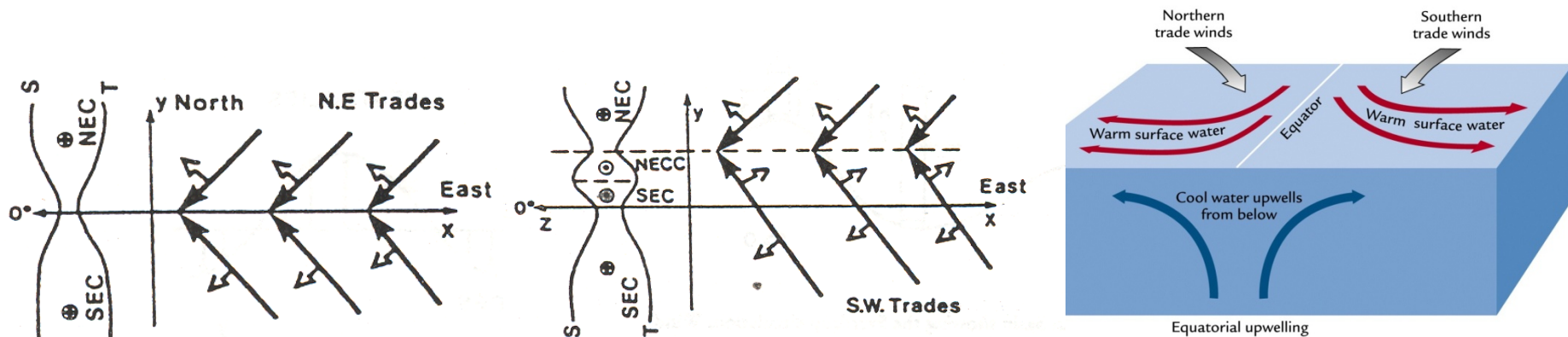
Η βαθμίδα πίεσης δημιουργεί επιτάχυνση μέχρι να αναπτυχθούν ισχυρά ρεύματα και η ισορροπία να επέλθει μέσω δυνάμεων τριβής:

$$-g' \frac{\partial h}{\partial x} - Ru = 0 \Rightarrow u = -\frac{g'}{R} \frac{\partial h}{\partial x}$$

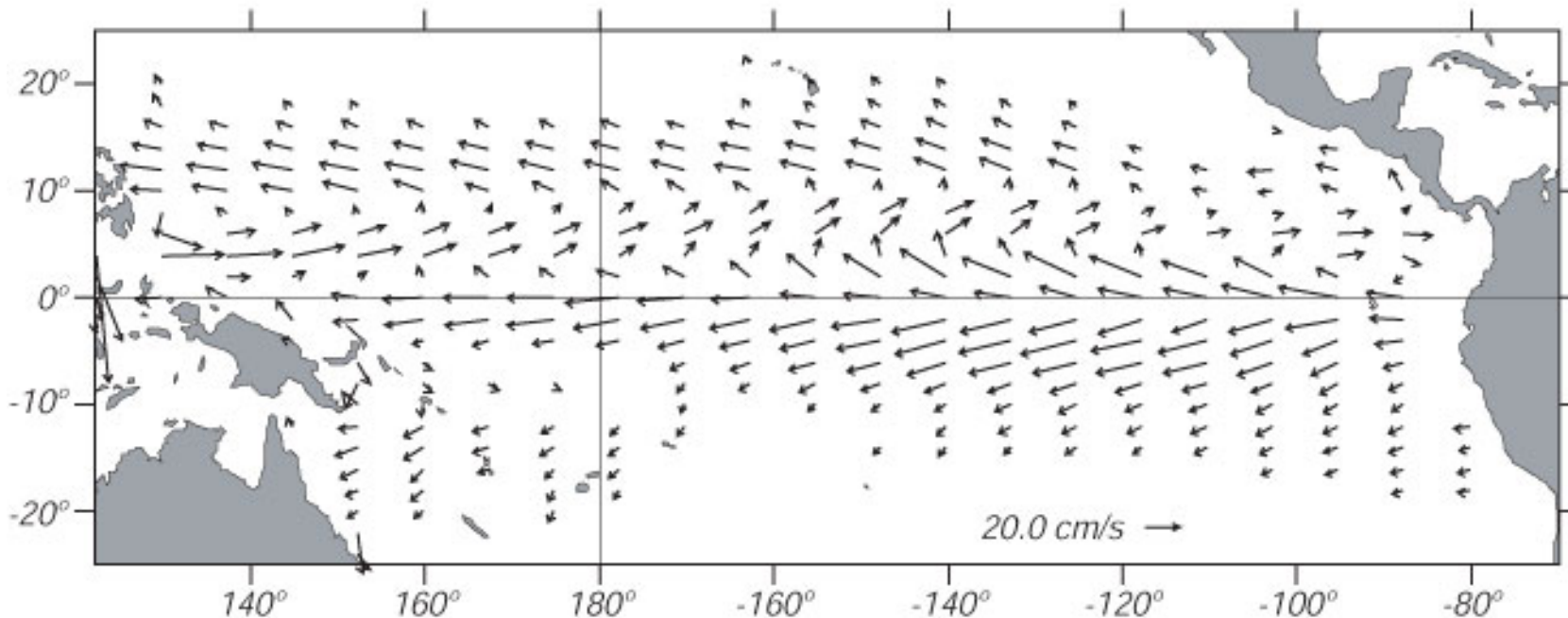


## Equatorial Undercurrent

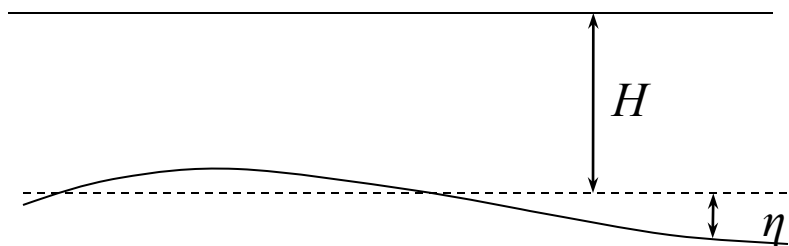
Το ισημερινό σύστημα ρευμάτων αναπτύσσεται λόγω της σύγκλισης του συστήματος των αλλαγών ανέμων και της επίδρασης του Ekman Transport



Average Velocity at 10 m Jan 1981 – Dec 1994



## Equatorial Linear Wave Theory (Free Waves)



One-layer reduced gravity model

General wave solution:

$$\begin{cases} u = U(y) \cos(kx - \omega t) \\ v = V(y) \sin(kx - \omega t) \\ \eta = A(y) \cos(kx - \omega t) \end{cases}$$

Αποδεικνύεται ότι η λύση έχει τη μορφή:  $V(y) = H_n \left( \frac{y}{R_{eq}} \right) e^{\frac{-y^2}{R_{eq}^2}}$  όπου  $H_n$  είναι πολυώνυμο τάξης  $n$ .

και υπάρχει λύση μόνο όταν

$$\frac{\omega^2}{c^2} - \frac{\beta k}{\omega} - k^2 = \frac{2n+1}{R_{eq}^2}, \quad n = 0, 1, 2, \dots$$

$$\frac{\partial u}{\partial t} - \beta y v = -g' \frac{\partial \eta}{\partial x}$$

$$\frac{\partial v}{\partial t} + \beta y u = -g' \frac{\partial \eta}{\partial y}$$

$$\frac{\partial \eta}{\partial t} + H \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) = 0$$

Αντικαθιστώντας στο σύστημα εξισώσεων και λύνοντας ως προς μια συνάρτηση ( $V$ ):

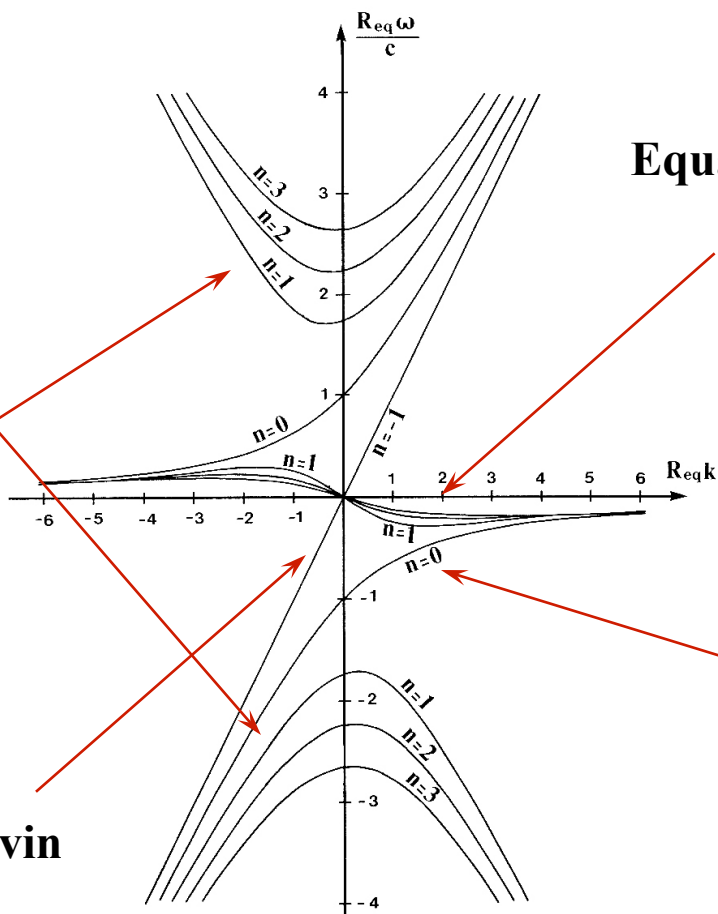
$$\frac{d^2 V}{dy^2} + \left( \frac{\omega^2 - \beta^2 y^2}{c^2} - \frac{\beta k}{\omega} - k^2 \right) V = 0$$

όπου  $H_n$  είναι πολυώνυμο τάξης  $n$ .

**Equatorial wave dispersion relationship**



# Equatorial Rossby Waves



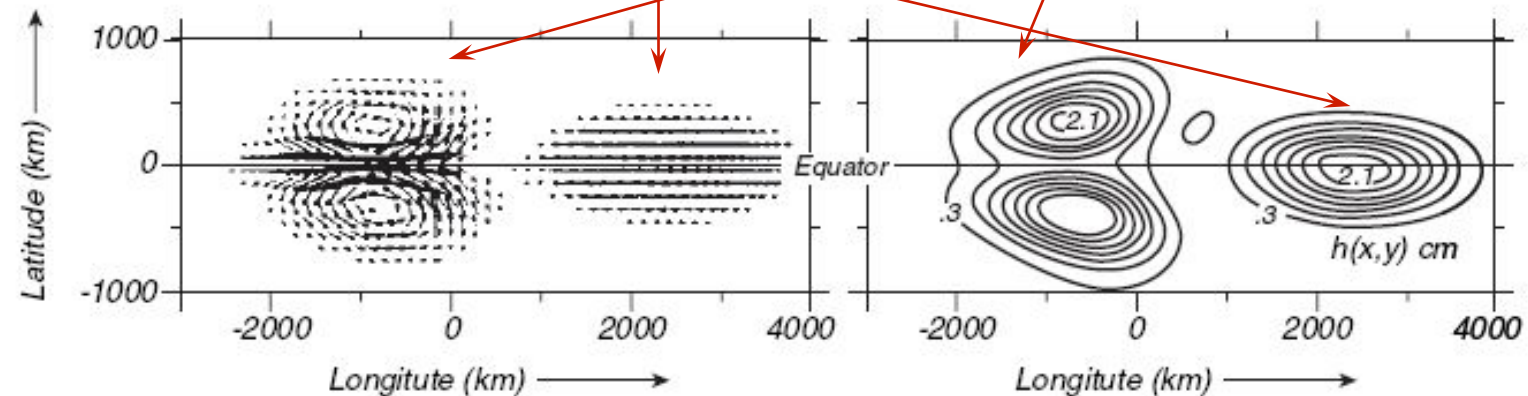
mixed inertia-gravity waves (low latitude)

μικτά gravity/planetary (Yanai Waves)

# Equatorial Kelvin Waves

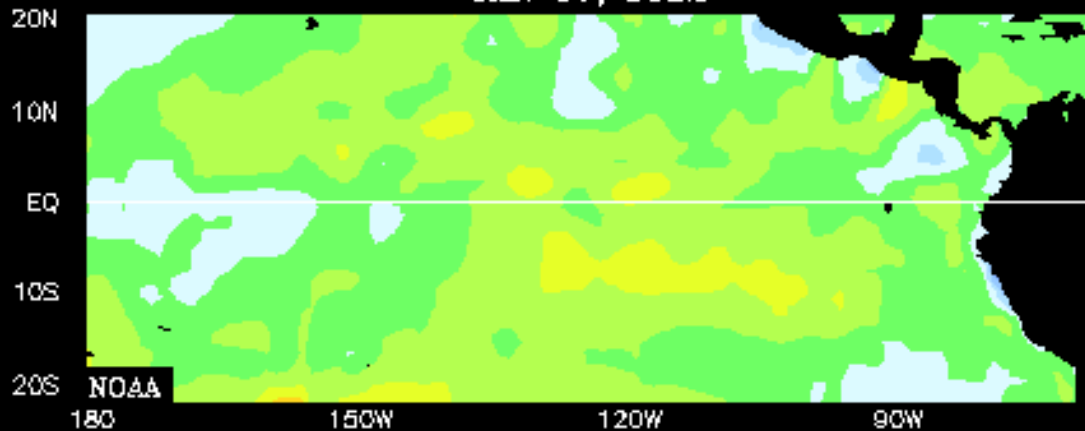
# Equatorial Kelvin Wave

# Equatorial Rossby Wave

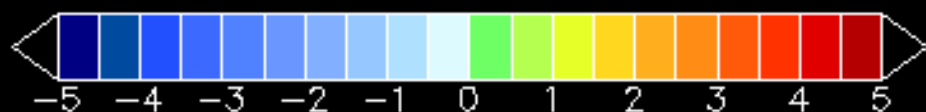


# SST ANOMALIES °C

JAN 07, 1982



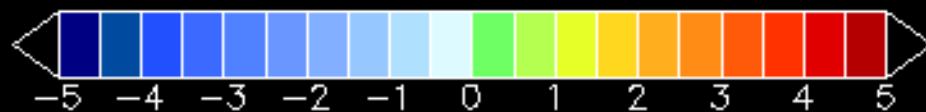
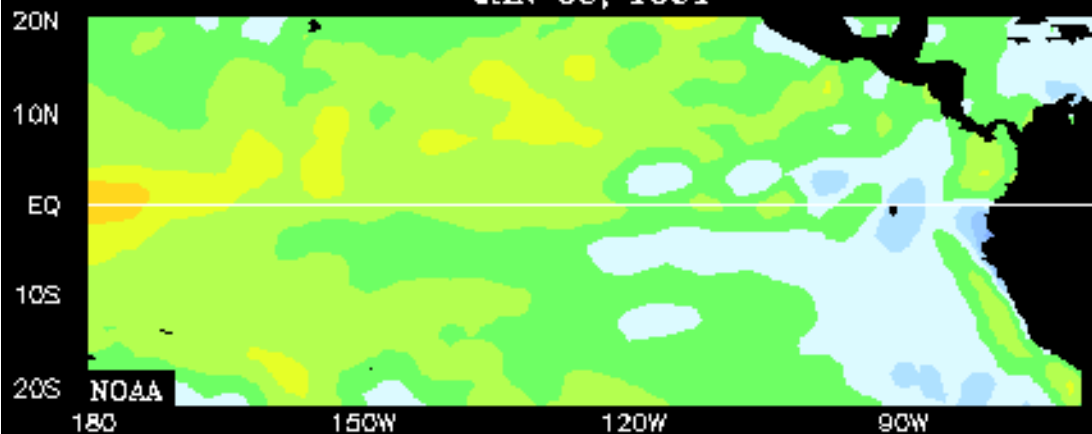
**Eastern Equatorial Pacific  
Warm Anomaly**



**El Nino**

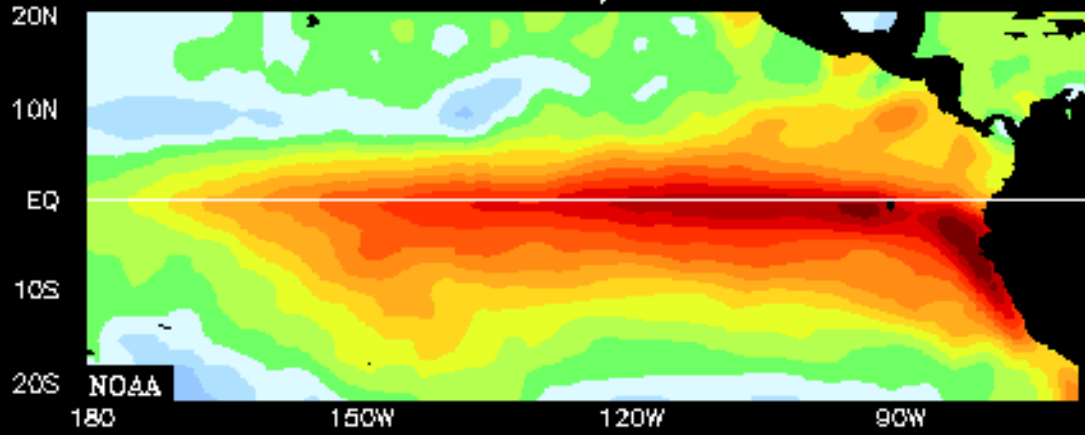
# SST ANOMALIES °C

JAN 06, 1991



SST ANOMALIES °C

JAN 04, 1998

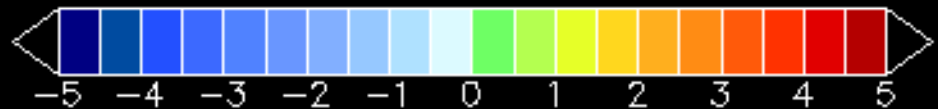
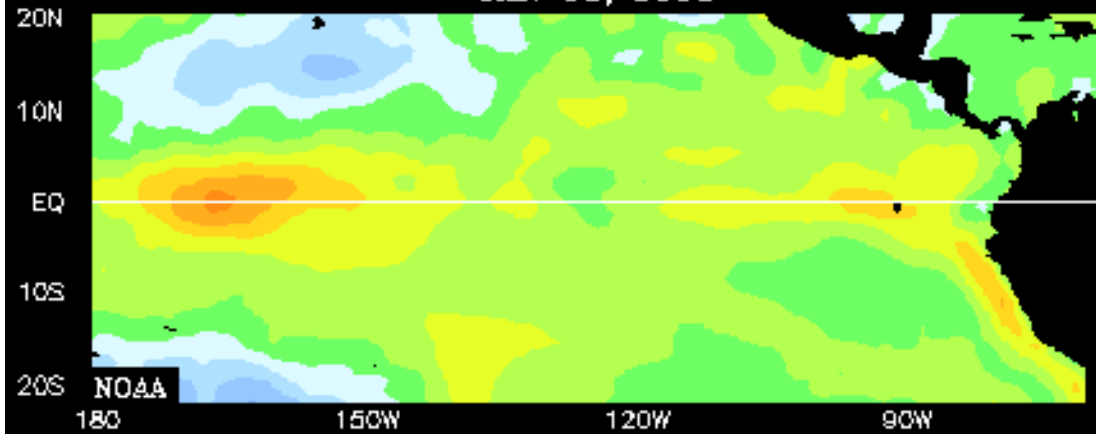


**Eastern Equatorial Pacific  
Cold Anomaly**

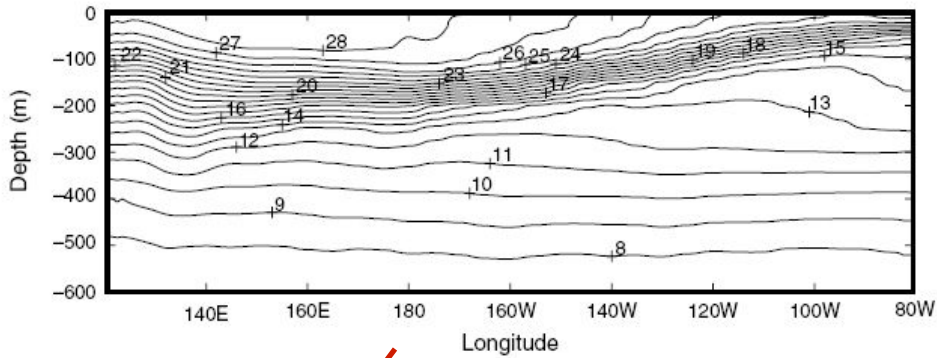
**La Nina**

SST ANOMALIES °C

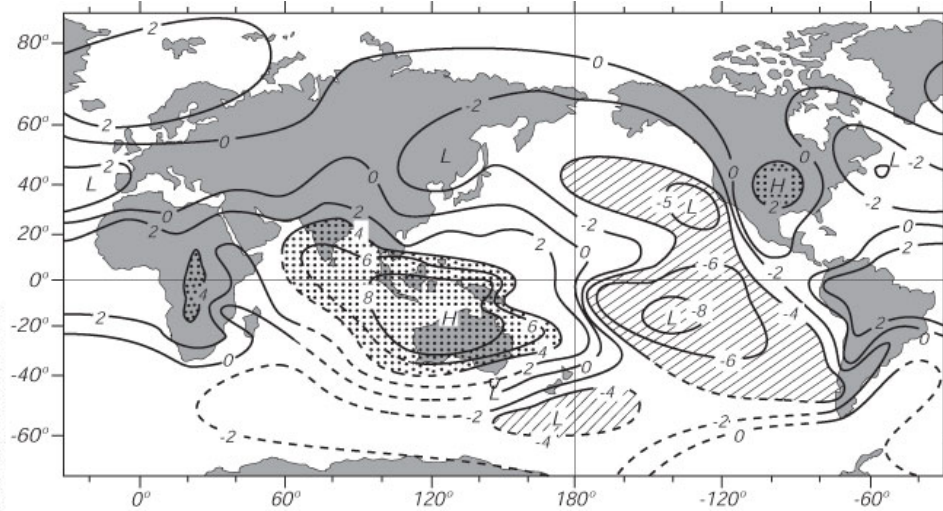
JAN 01, 1995



# *SST Anomaly*

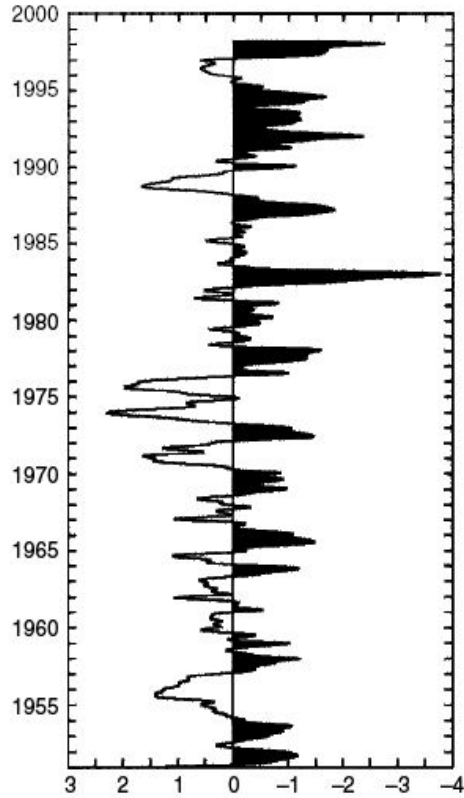
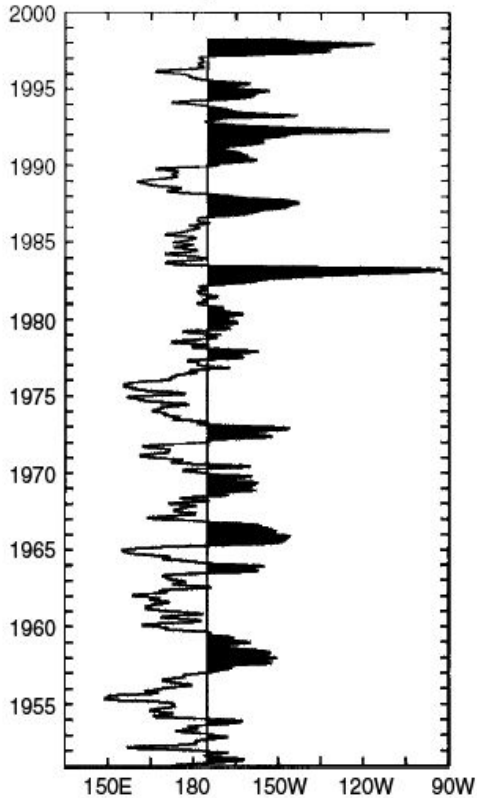


# *El Nino and the Southern Oscillation*



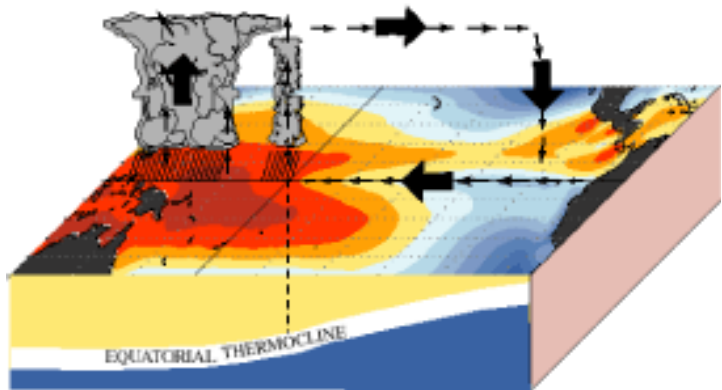
Eastern edge of the 28.5°C SST

Southern oscillation index



*Pressure difference between Darwin (Australia) and Tahiti*

December - February Normal Conditions

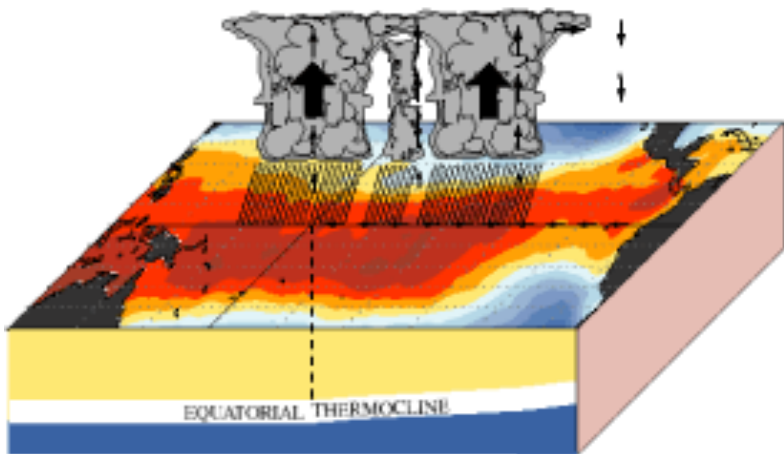


*El Niño and the Southern Oscillation*

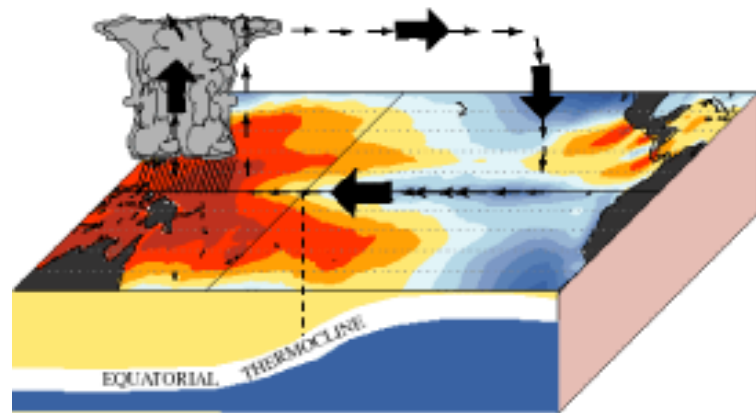
*Positive SST Anomaly travels eastward*

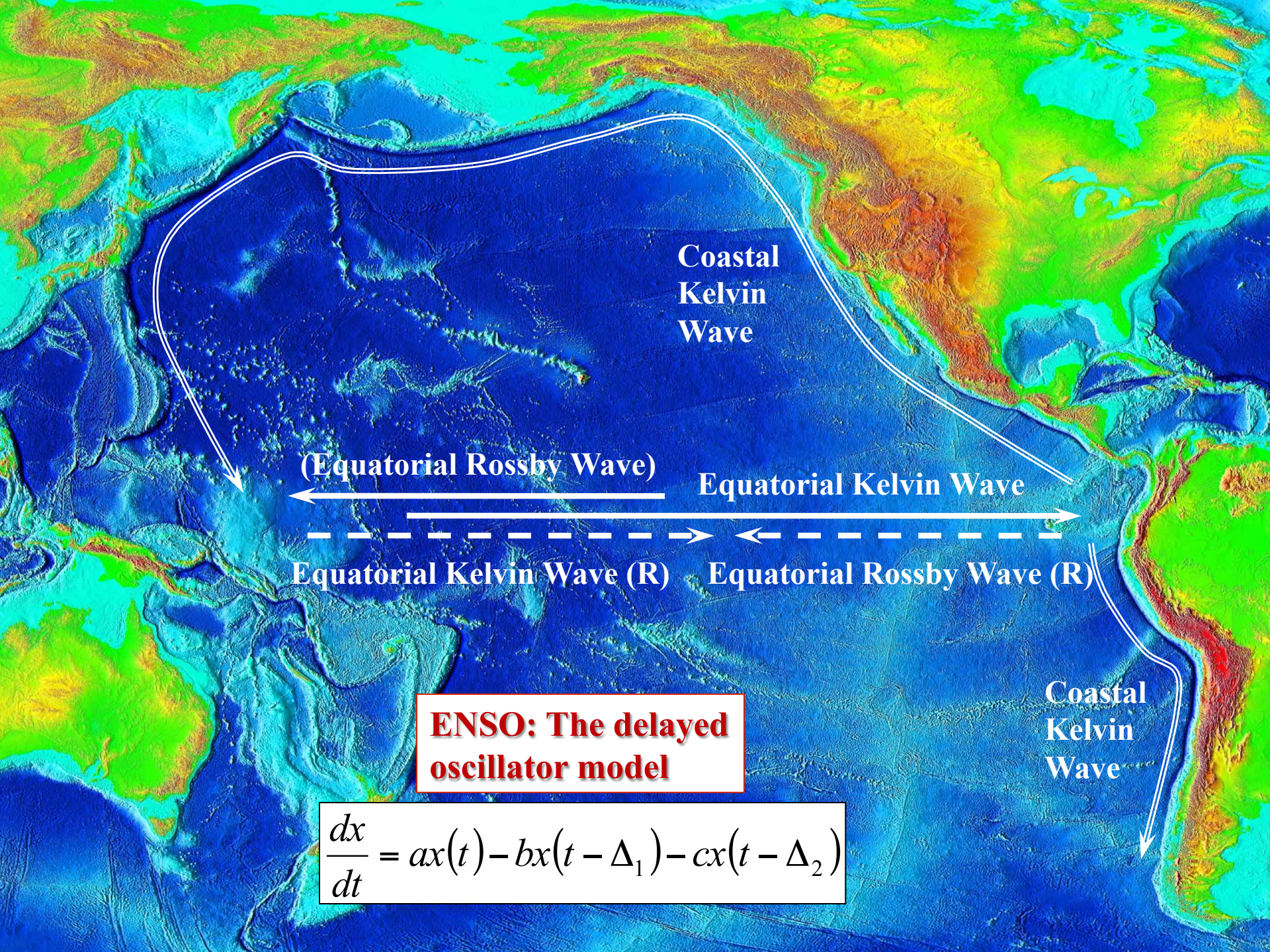
*Slackening/reversal of the Trade Winds*

December - February El Niño Conditions



December - February La Niña Conditions





Coastal  
Kelvin  
Wave

(Equatorial Rossby Wave)

Equatorial Kelvin Wave

Equatorial Kelvin Wave (R)

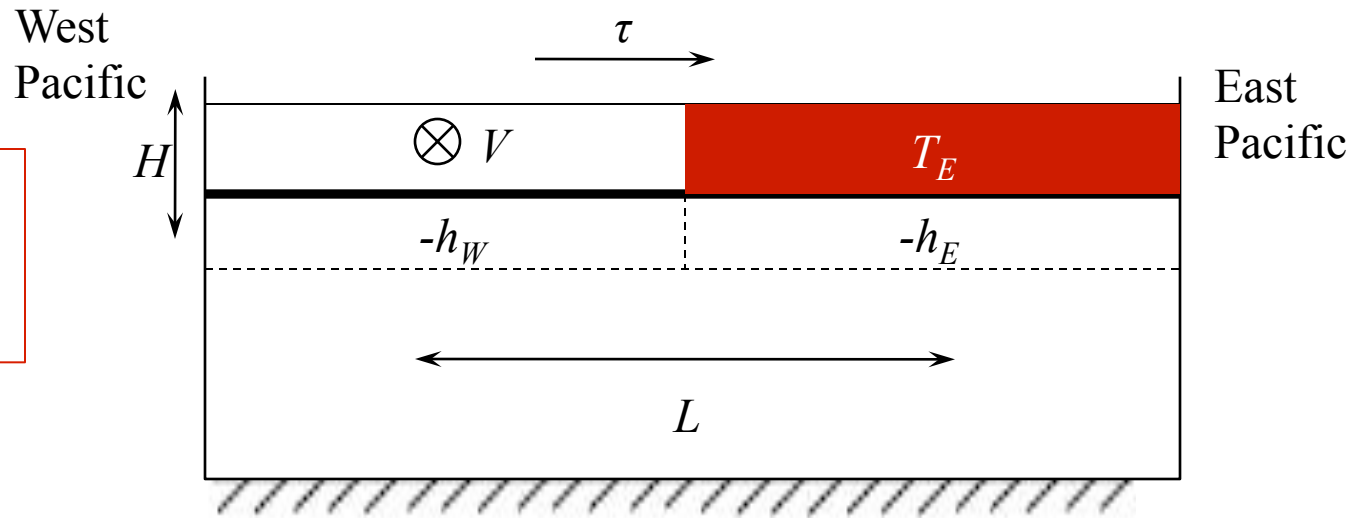
Equatorial Rossby Wave (R)

Coastal  
Kelvin  
Wave

**ENSO: The delayed oscillator model**

$$\frac{dx}{dt} = ax(t) - bx(t - \Delta_1) - cx(t - \Delta_2)$$

**ENSO: The recharge oscillator model**



**• Dynamics**

*pressure-gradient/wind-stress balance:*

$$g' \frac{h_E - h_W}{L} = \frac{\tau}{\rho_0 H}$$

Jin (1997)

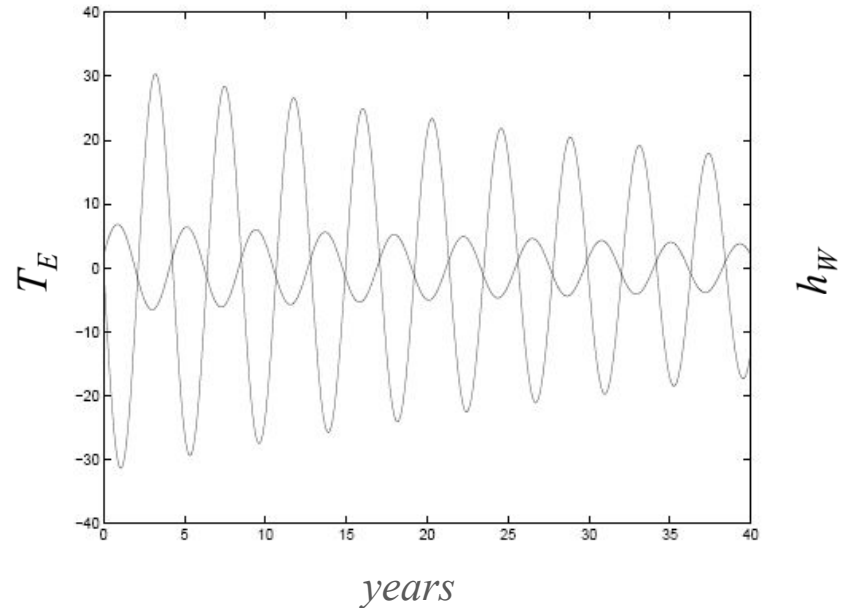
**• Conservation of volume**

*compensating meridional flux:  
(from each side of the equatorial zone)*

**• Heat budget**

- a. *Advection of temperature*
- b. *Vertical advection*

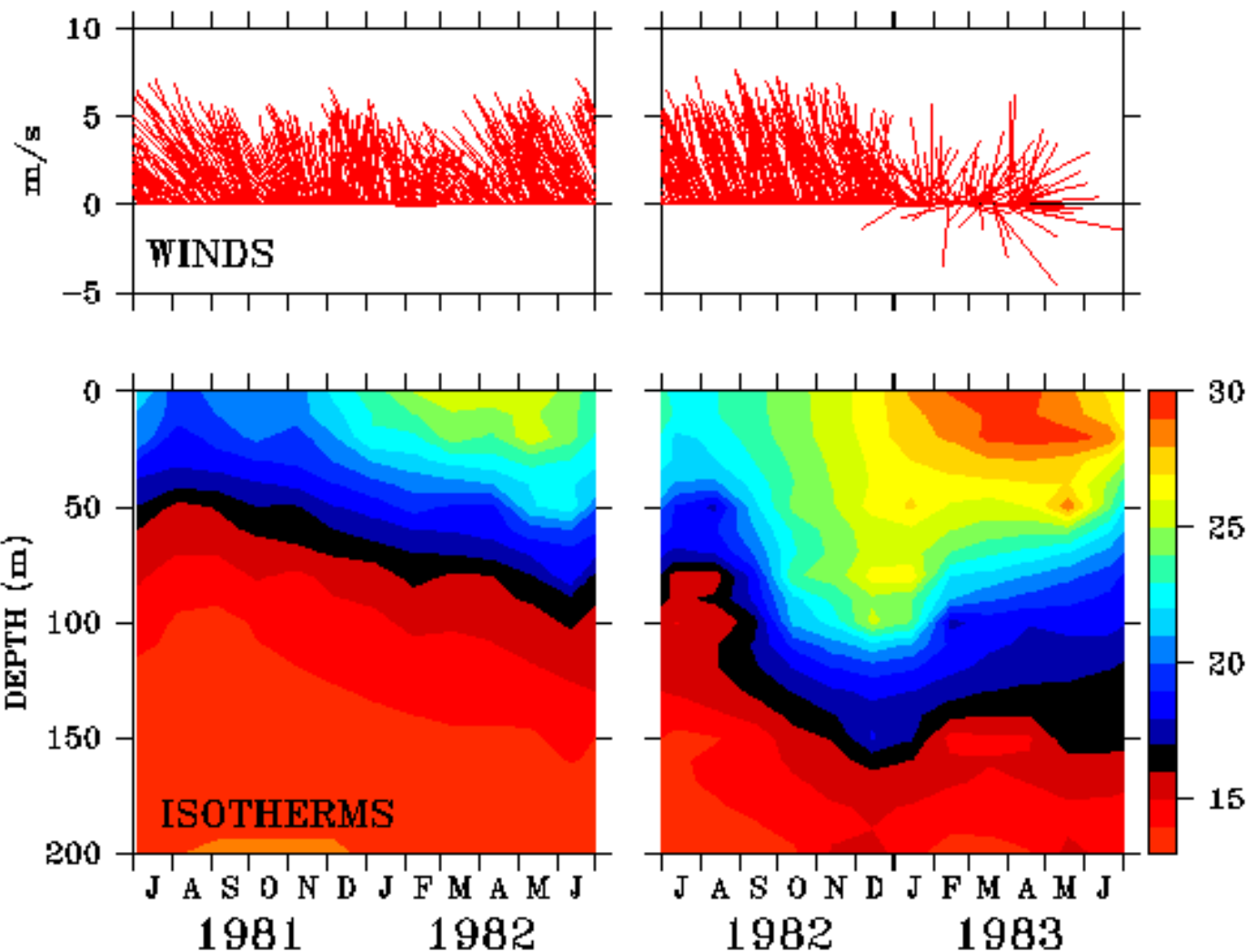
*Assuming the **atmosphere** adjust immediately to temperature anomaly  $T_E$*



# Wind and Temperature at EQ, 110°W

## NORMAL

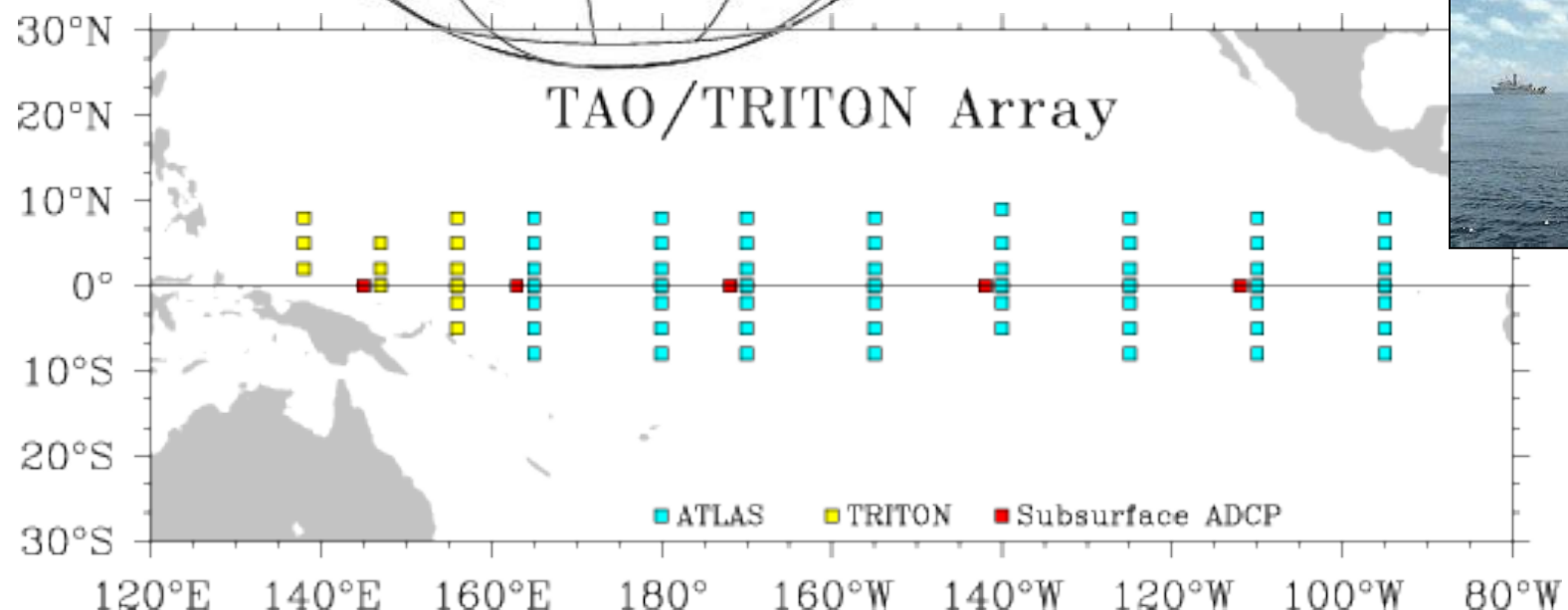
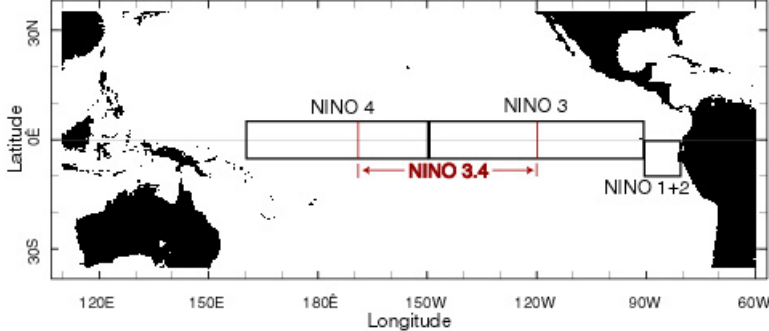
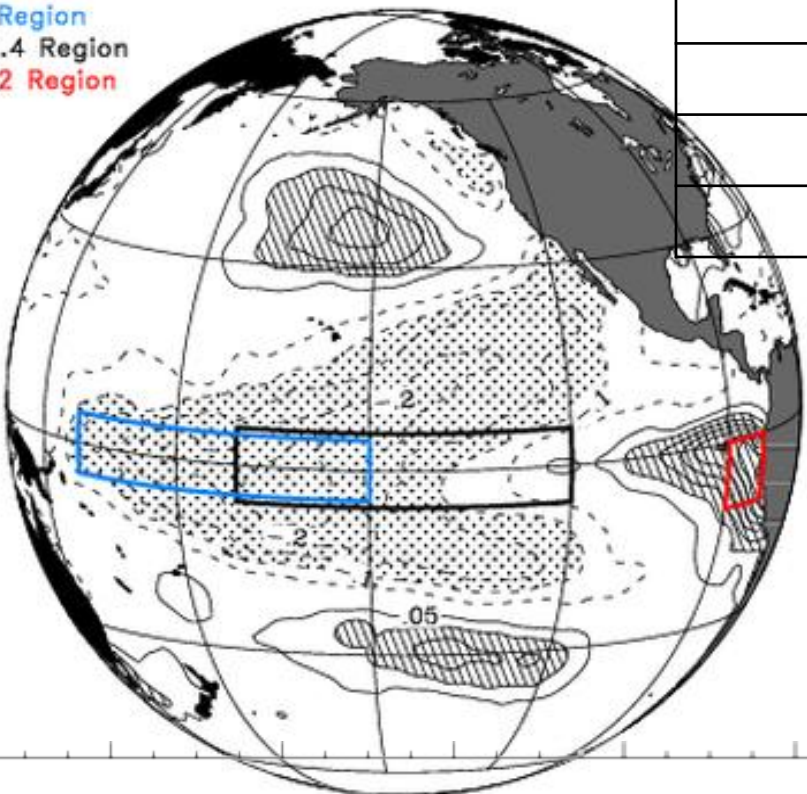
## EL NINO



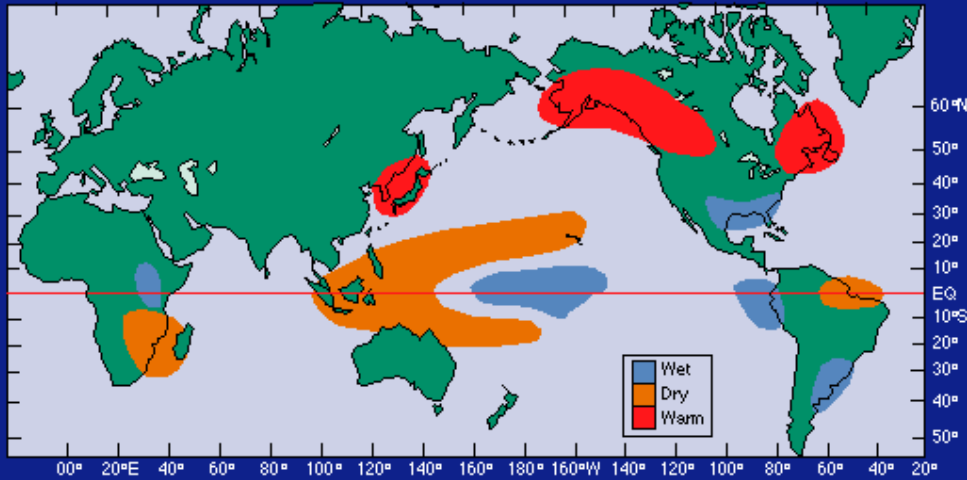


Niño Region	Range Longitude	Range Latitude
1+2	90°W-80°W	10°S-0°
3	150°W-90°W	5°S-5°N
3.4	170°W-120°W	5°S-5°N
4	160°E-150°W	5°S-5°N

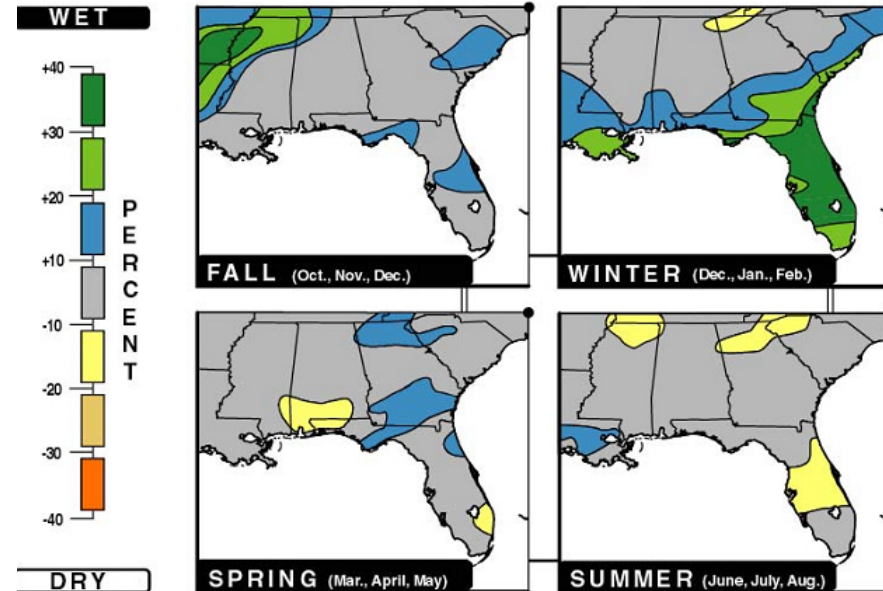
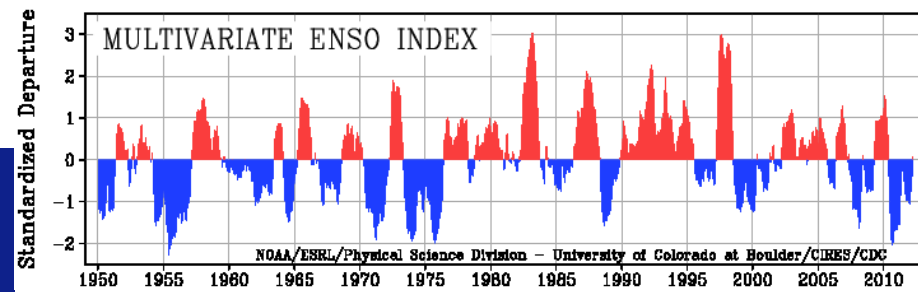
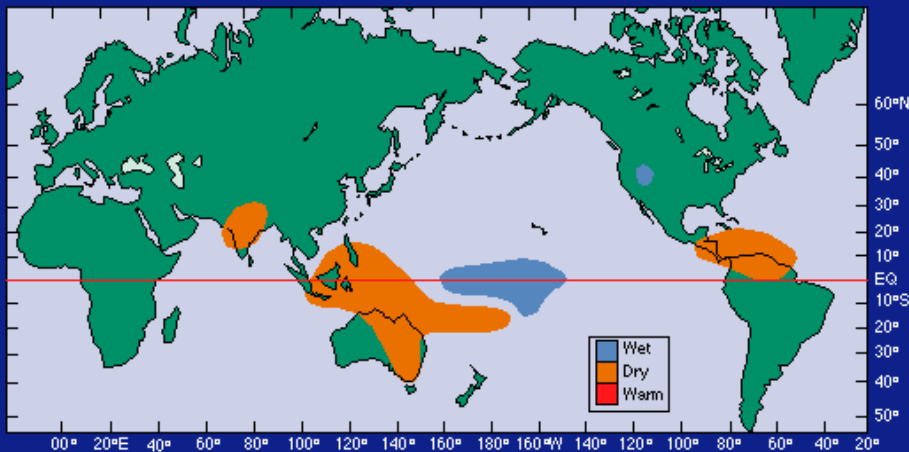
Blue = Niño 4 Region  
 Black = Niño 3.4 Region  
 Red = Niño 1+2 Region



### Northern Hemisphere Winter



### Northern Hemisphere Summer



## *ENSO Teleconnections*

*Chance of 2 hurricanes hitting the U.S.:*

- 28% in El Niño
- 48% in Neutral
- 66% in La Niña

*Precipitation anomalies during El Niño in  
Winter and Summer*

Week centered on 29 FEB 2012  
SST (°C)

