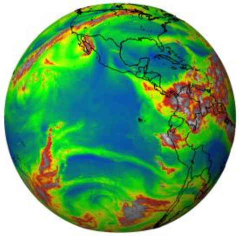
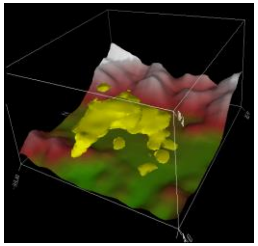
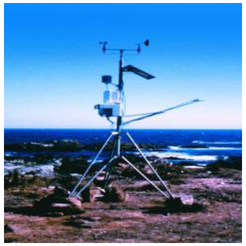
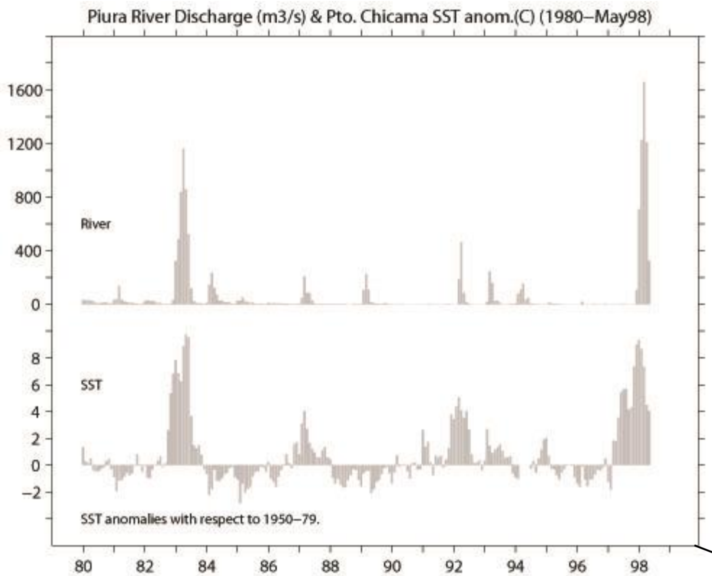





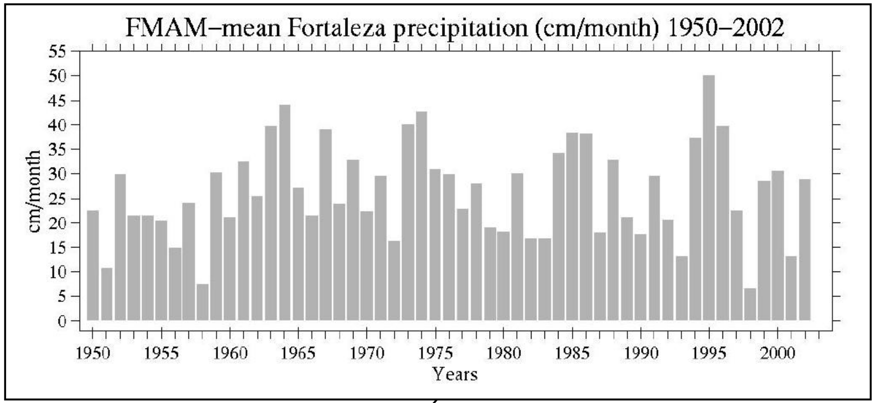

Universidad de Chile
Departamento de Geofísica

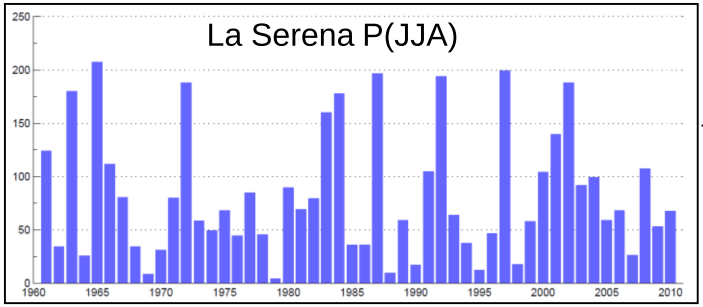
El Niño – Oscilación del Sur (ENSO)

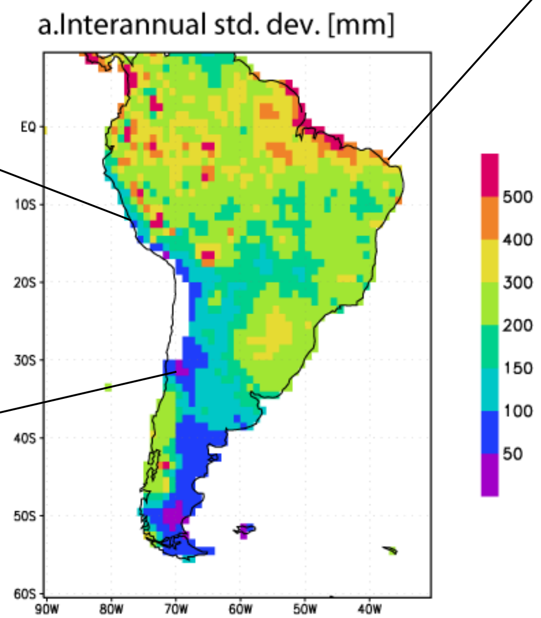
Prof. René Garreaud
www.dgf.uchile.cl/rene

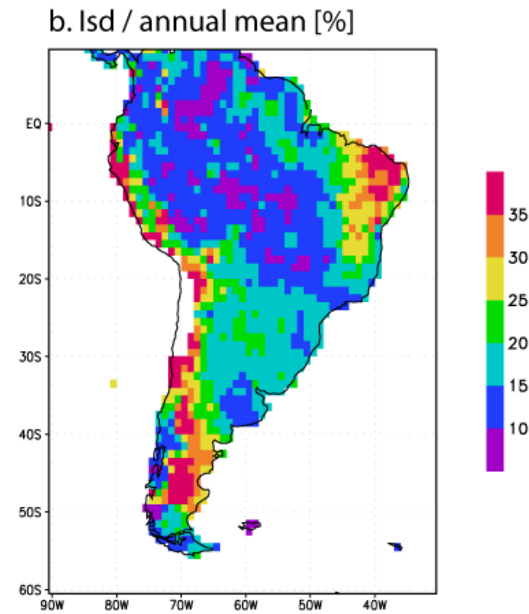
Interannual Precipitation Variability (UdW data)











Leadings modes of interannual (and longer) of atmospheric variability: ENSO – PDO(?) - AAO

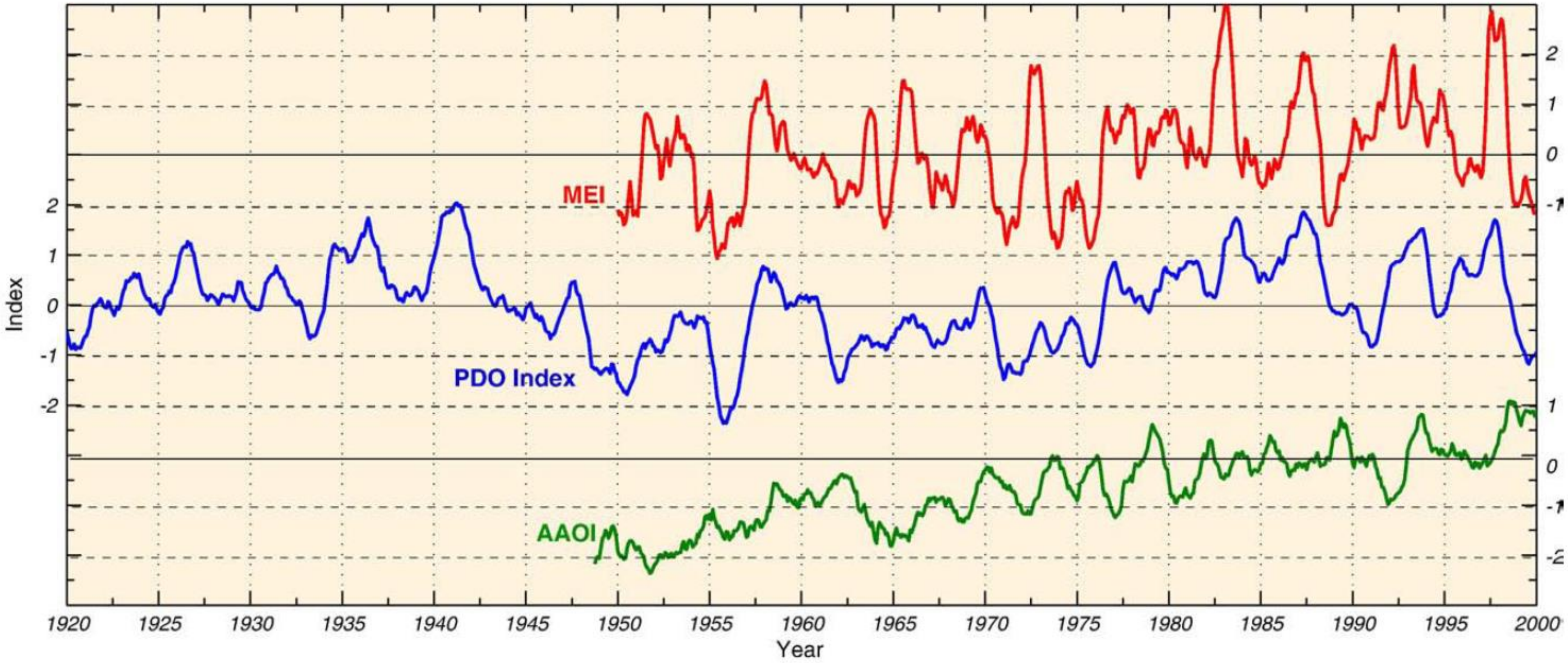


Fig. 5. Time series (1920–2000) of monthly mean Multivariate ENSO Index (MEI), PDO Index and AAO Index. All indexes were smoothed using a 5-month running mean filter. Original indices obtained from Climate Diagnostic Center (NOAA).

Desde cuando conocemos El Niño?

Hidrografía oceánica

DISERTACIÓN SOBRE LAS CORRIENTES OCEÁNICAS Y ESTUDIOS DE LA CORRIENTE PERUANA Ó DE HUMBOLDT, POR EL CAPITÁN DE NAVÍO D. CAMILO N. CARRILLO, VICE-PRESIDENTE DE LA SOCIEDAD GEOGRÁFICA; LEÌDA EN LA NOCHE DEL 27 DE MAYO EN EL SALÓN DE LA SOCIEDAD, Y PUBLICADA EN ESTA SECCIÓN POR ACUERDO DEL CONSEJO DIRECTIVO, PREVIA REVISIÓN DE SU AUTOR.

Carrillo, 1893
Bol. Soc. Geogr. Lima

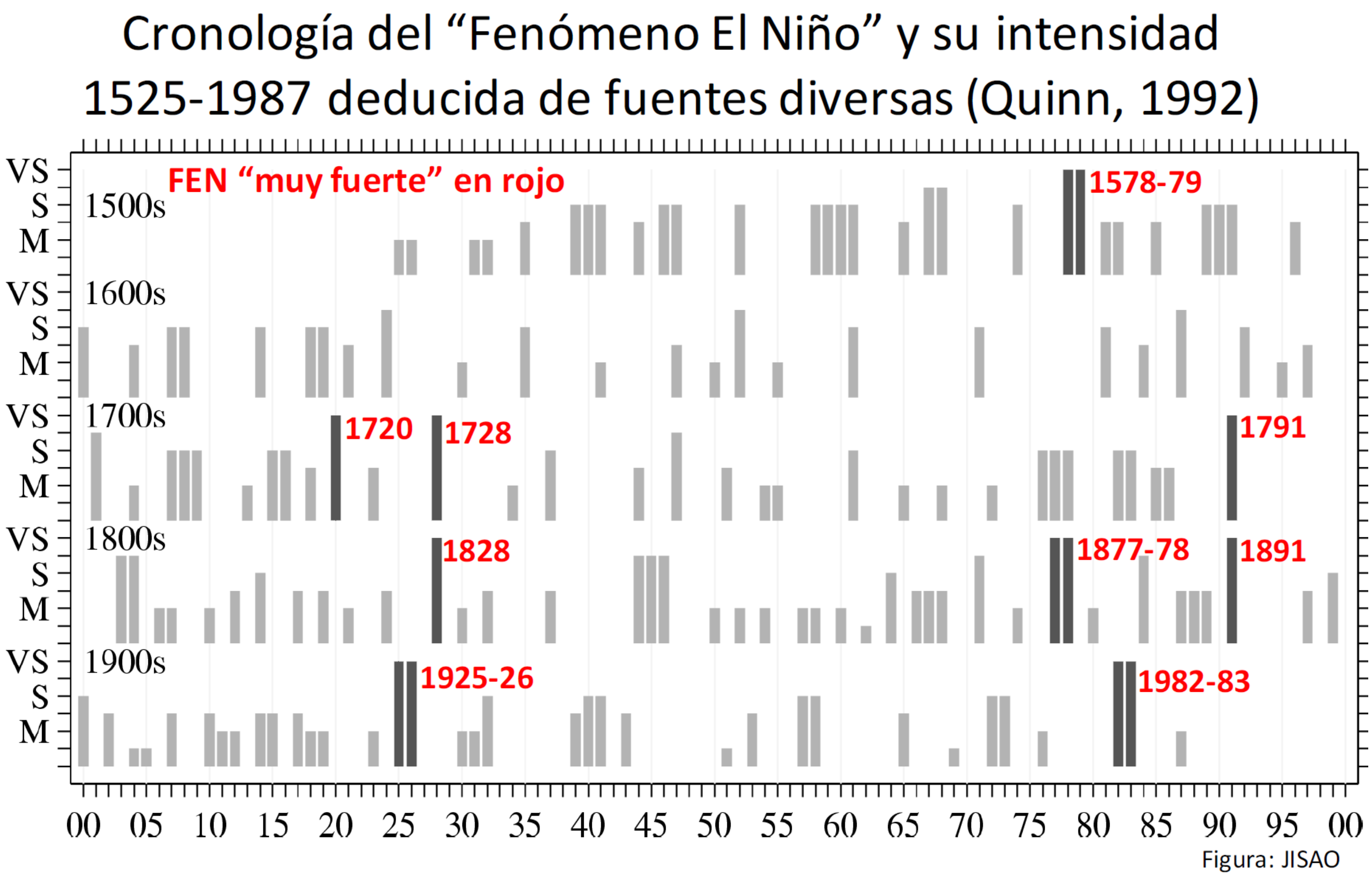
Está, pues, fuera de toda duda, que hay una contra-corriente que se dirije del Norte al Sur, en la costa del Perú, en oposición á la corriente de Humboldt.

Pero debo hacer notar que ellas son completamente independientes: la primera corre de norte á sur, siguiendo la dirección de la costa, y pegada á ella; mientras que la de Humboldt, tiene una dirección opuesta, según la descripción que de ella se ha hecho.

Los marinos paiteños que navegan frecuentemente cerca de la costa y en embarcaciones pequeñas, ya al norte ó al sur de Paita, conocen esta corriente y la denominan corriente del *Niño*, sin duda porque ella se hace mas visible y palpable después de la Pascua de Navidad. Esta contra-corriente me parece que tiene su origen cerca ó en el mismo golfo de Guayaquil; de manera que en ciertas épocas, particularmente en verano, se encuentran en las inmediaciones de la costa norte del Perú, hojas de palmeras, de platanos, naranjas y muchos otros objetos que las aguas del río Guayaquil y de Tumbes conducen al mar, y que la corriente del *Niño*, suelen arrastrar hasta la latitud de Sechura y Pacasmayo.

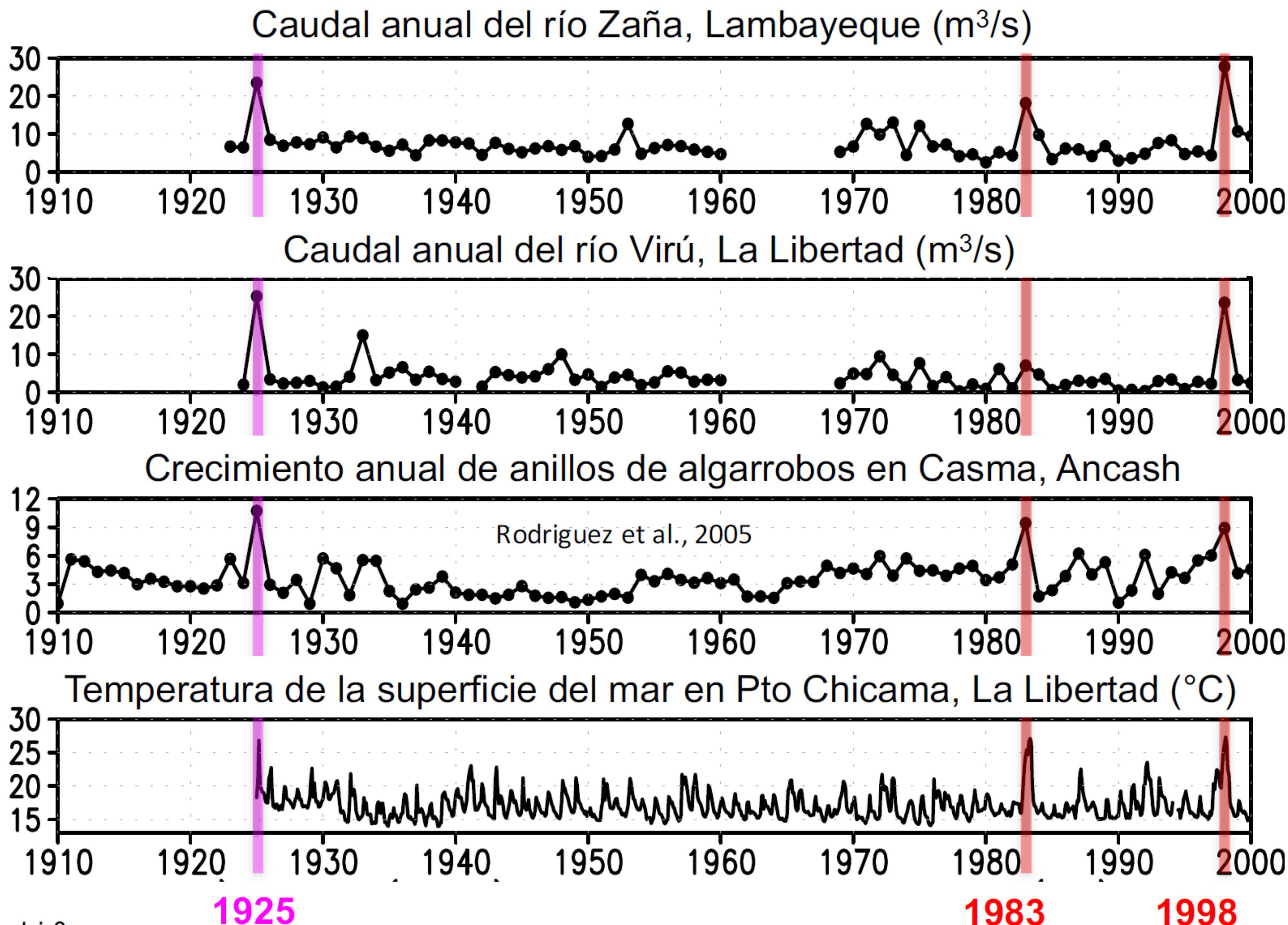
Gentileza de Ken Takahashi, IGP

Desde cuando conocemos El Niño?



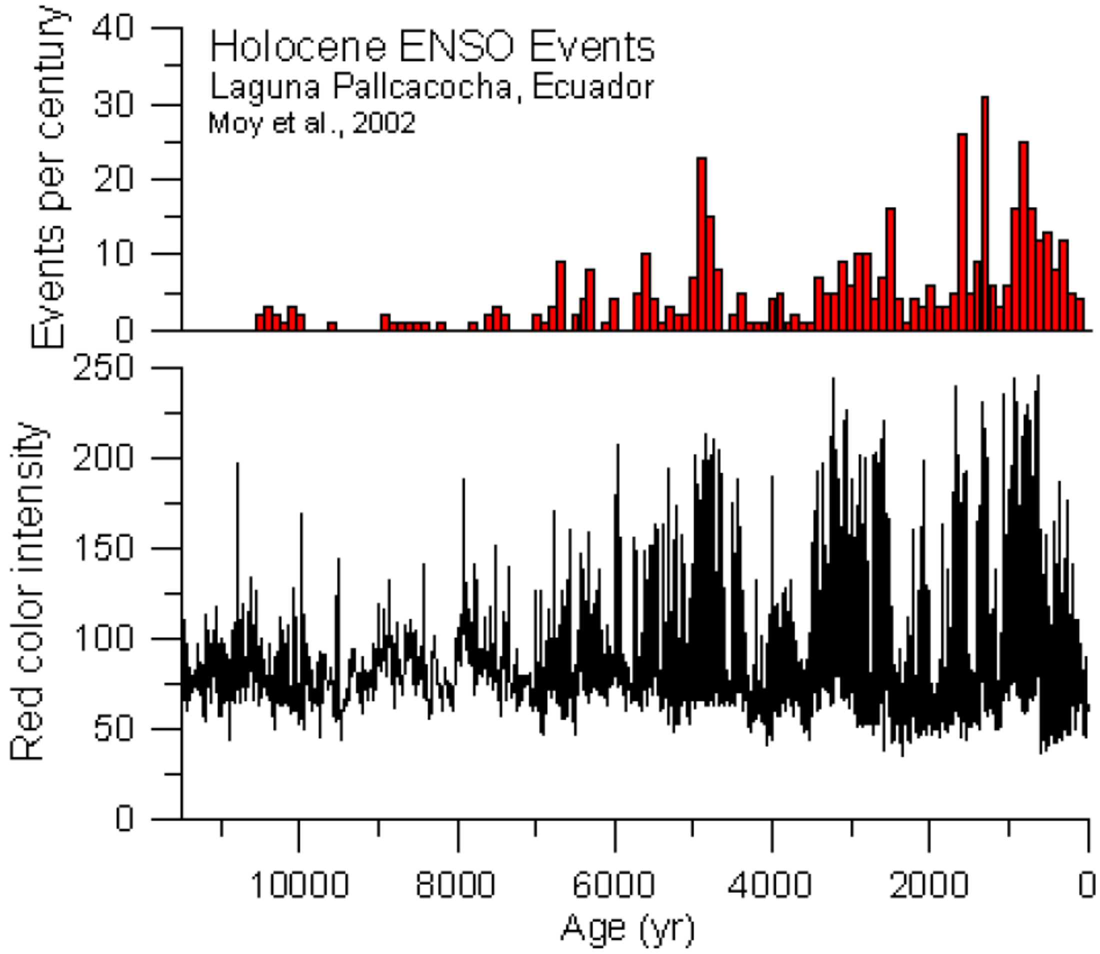
Gentileza de Ken Takahashi, IGP

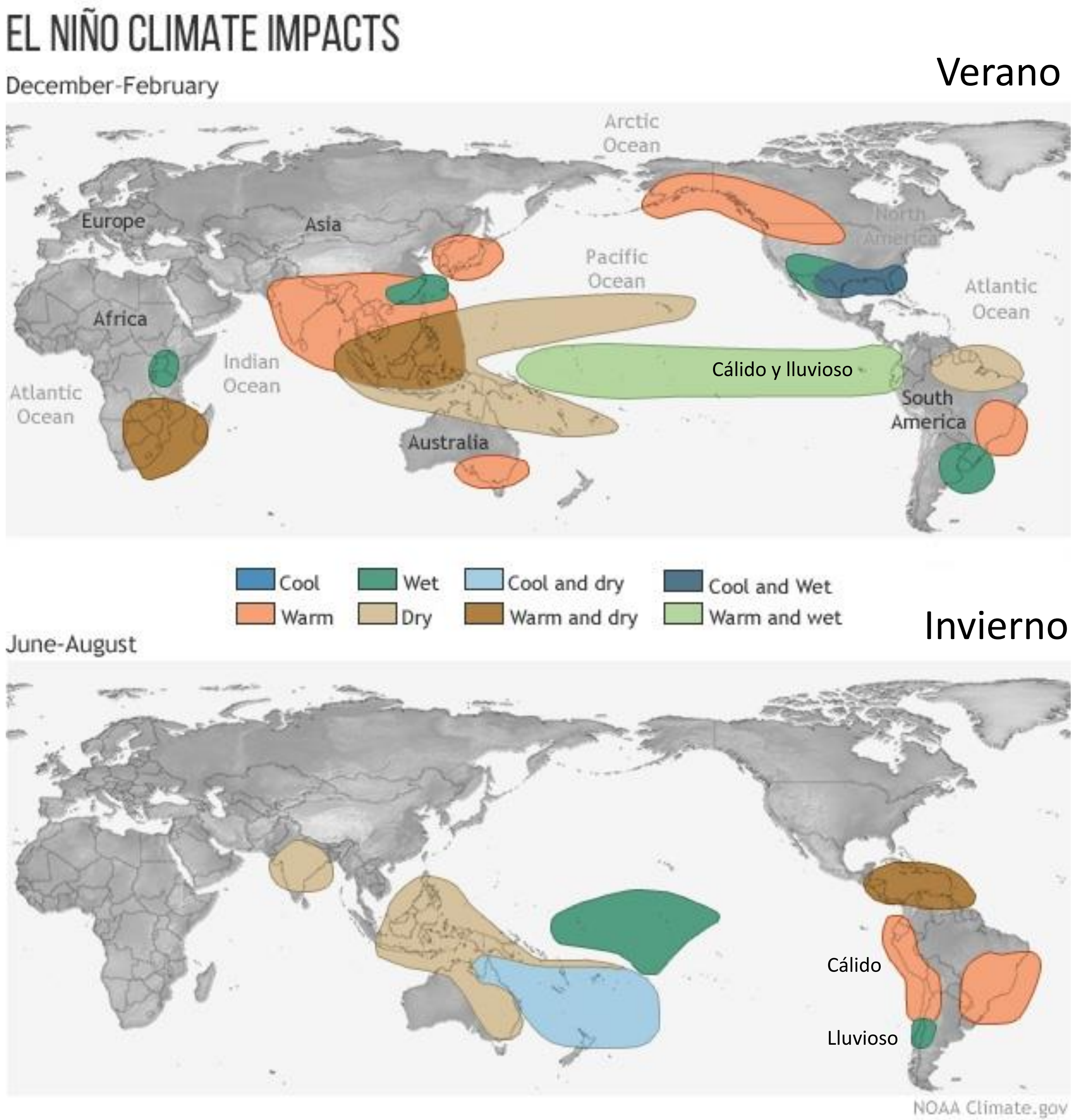
Desde cuando conocemos El Niño?



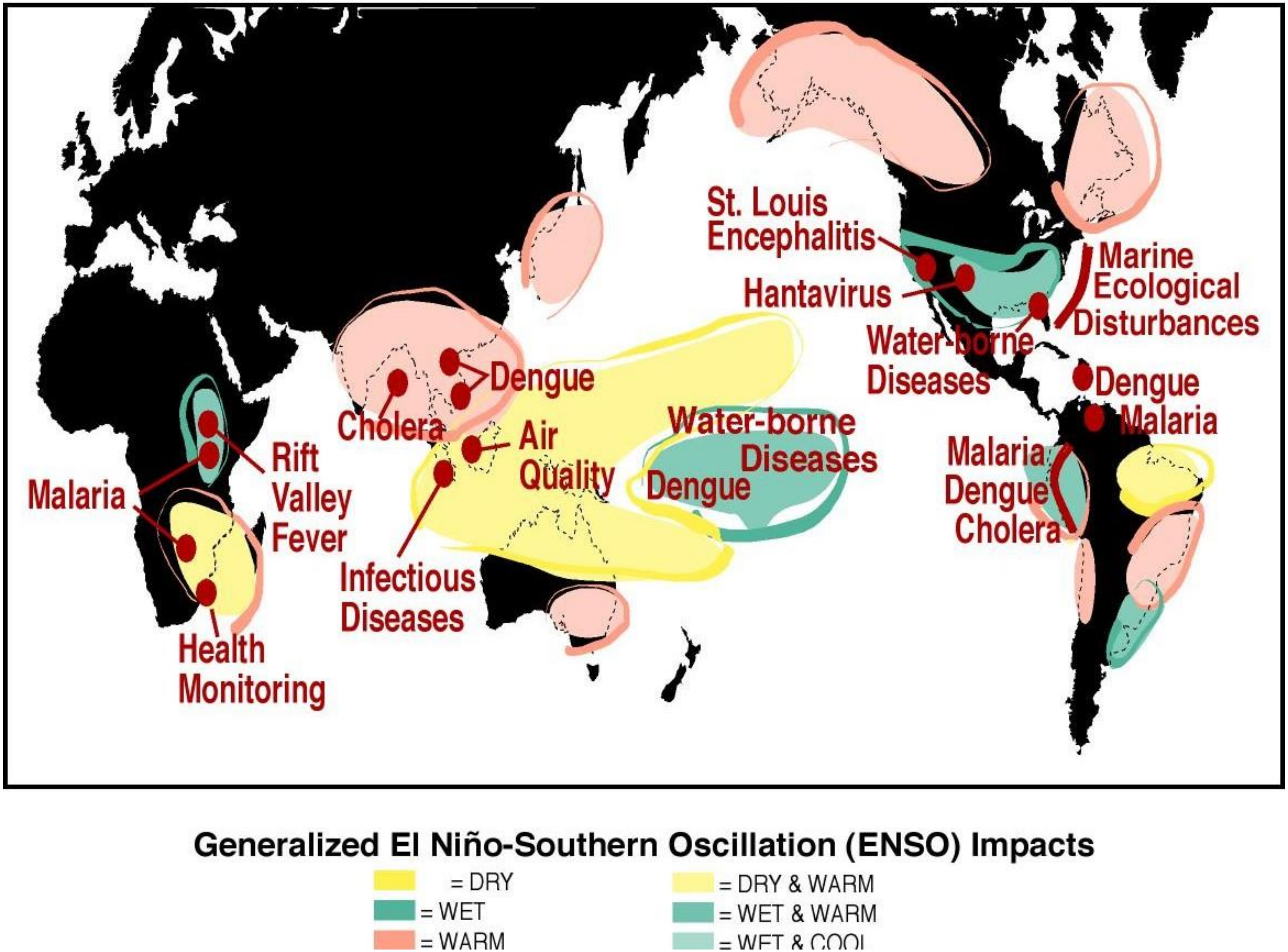
Takahashi & Martínez (2017)

Desde cuando conocemos El Niño?




EL NIÑO CLIMATE IMPACTS
December-February
Verano
Arctic Ocean
Europe
Asia
Pacific Ocean
North America
Atlantic Ocean
Africa
Indian Ocean
Atlantic Ocean
Cálido y lluvioso
South America
Australia
Cool
Warm
Wet
Dry
Cool and dry
Warm and dry
Cool and Wet
Warm and wet
June-August
Invierno
Cálido
Lluvioso
NOAA Climate.gov

Exploring the Linkages between the El Niño-Southern Oscillation (ENSO) and Human Health

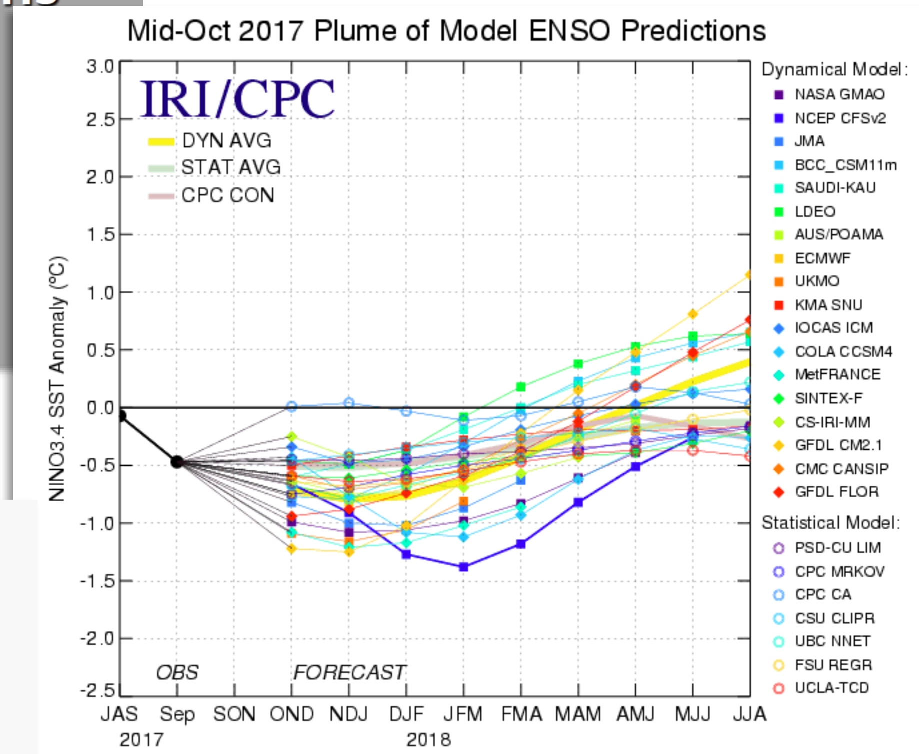


Ref: CPC/NCEP/NOAA

No es sorprendente entonces el gran interés en predicción de ENOS

ENSO: Recent Evolution, Current Status and Predictions

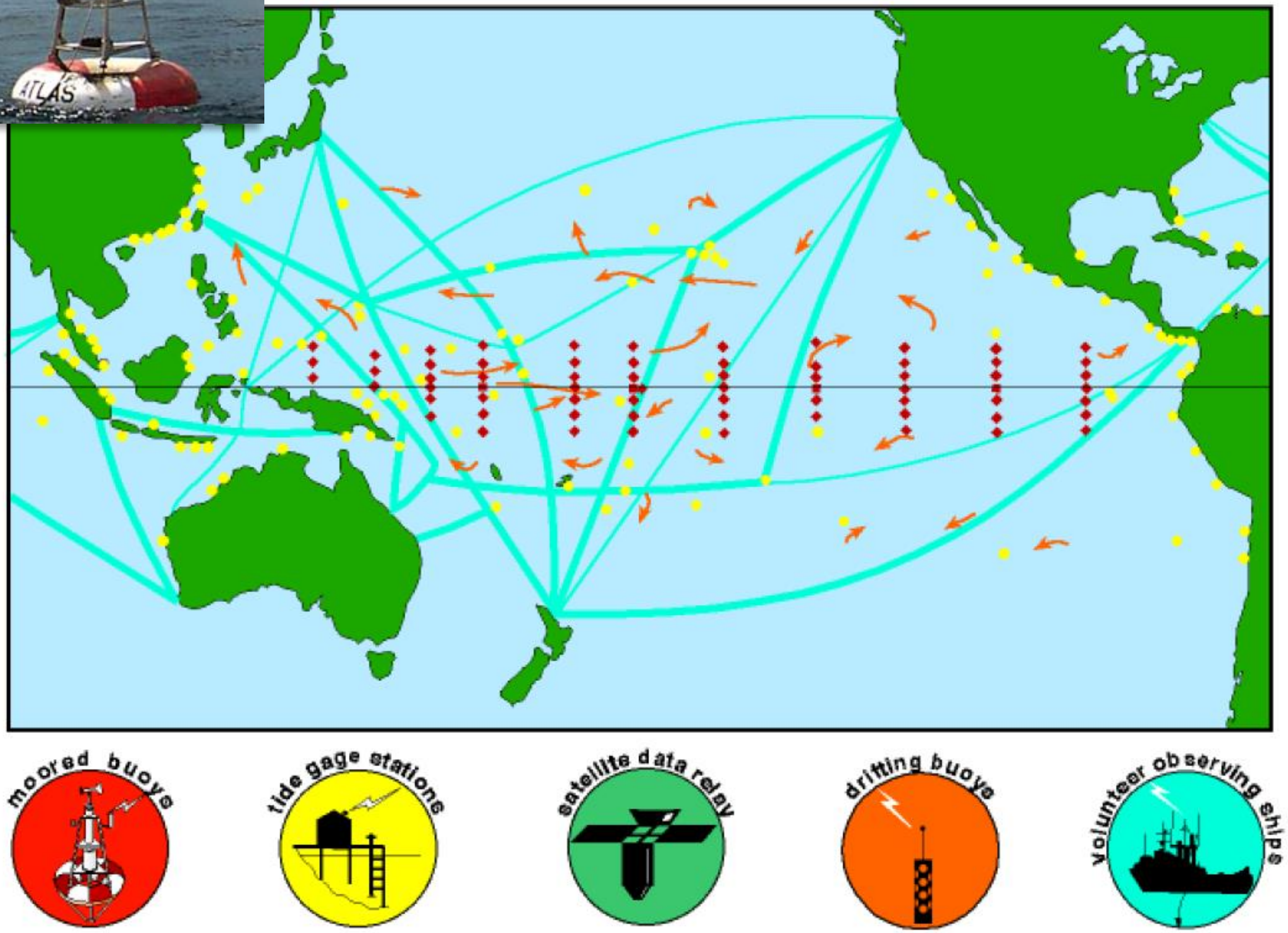
Update prepared by:
Climate Prediction Center / NCEP
23 May 2016



Boletines con información actualizada

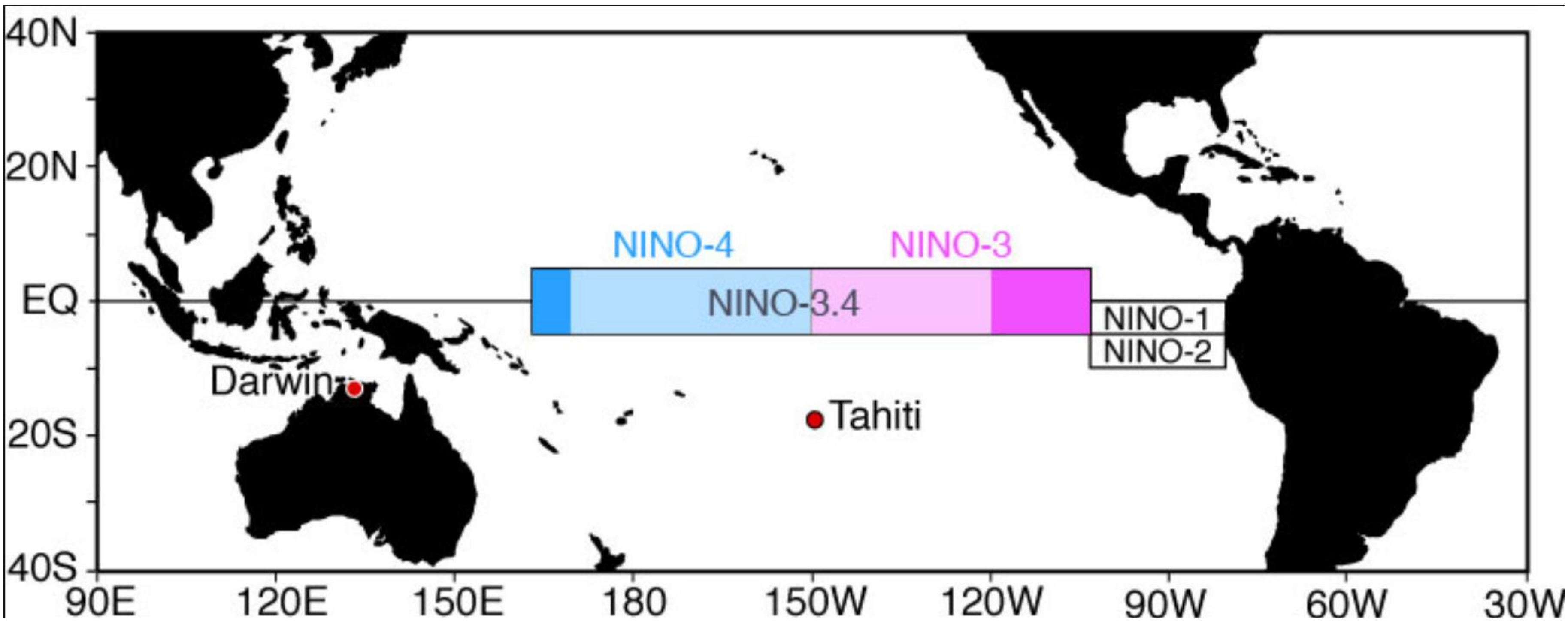
- Boletin de Alerta Climático (CPPS)
- Boletin de Alerta Climático (INOCAR)
- Boletin Oceanográfico (IMO)
- Boletin de Tendencias Climáticas (DMC)
- Boletin CIIFEN (CIIFEN)
- El Niño/Oscilación del Sur discusión diagnóstica (NOAA)
- El Niño/La Niña Hoy (OMM)
- ENSO Prediction (IRI)

ENSO Observing System



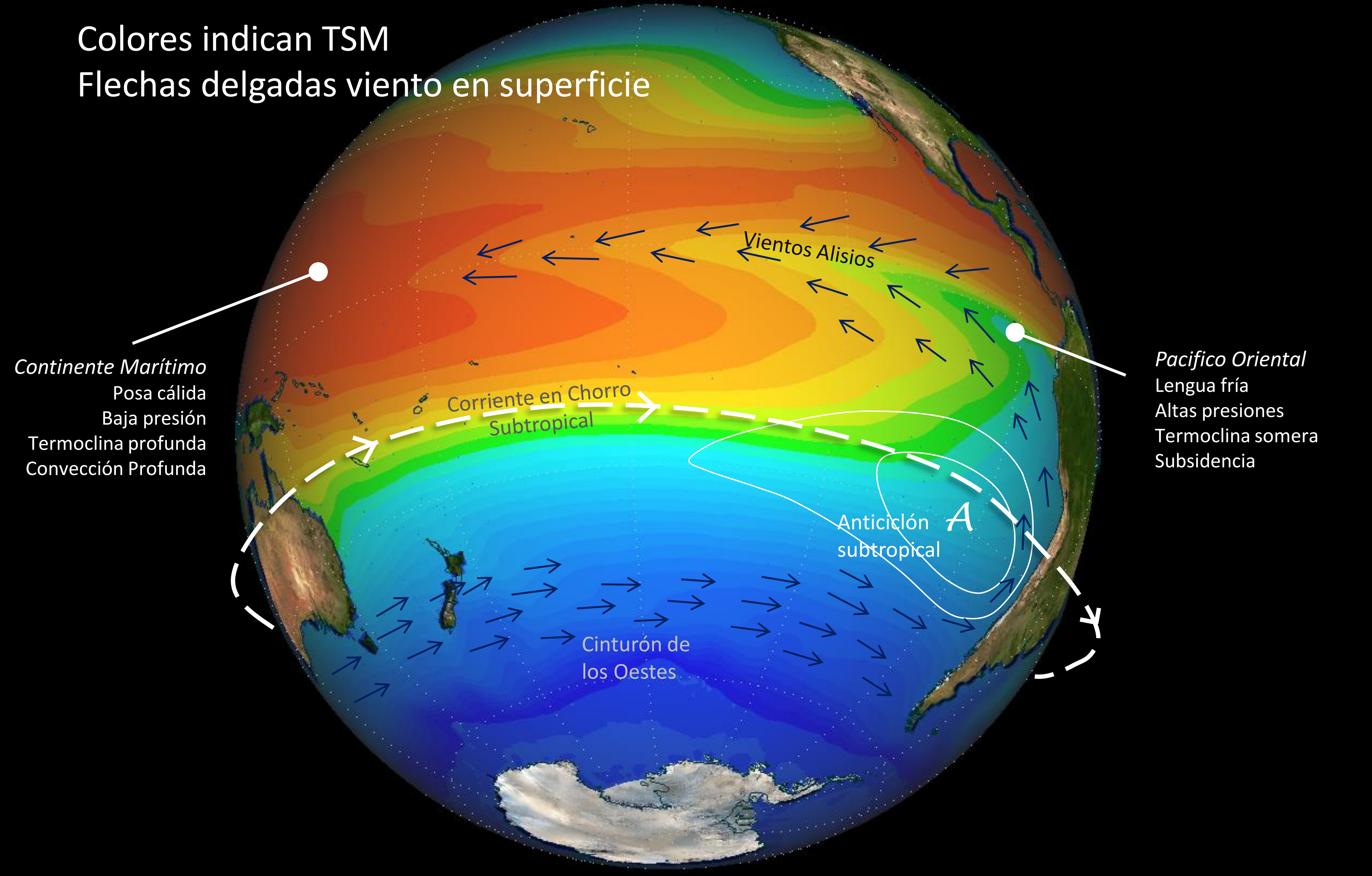
Regiones El Niño

Cada día se obtiene la temperatura superficial del mar y se le resta su promedio de largo plazo (anomalía de TSM)

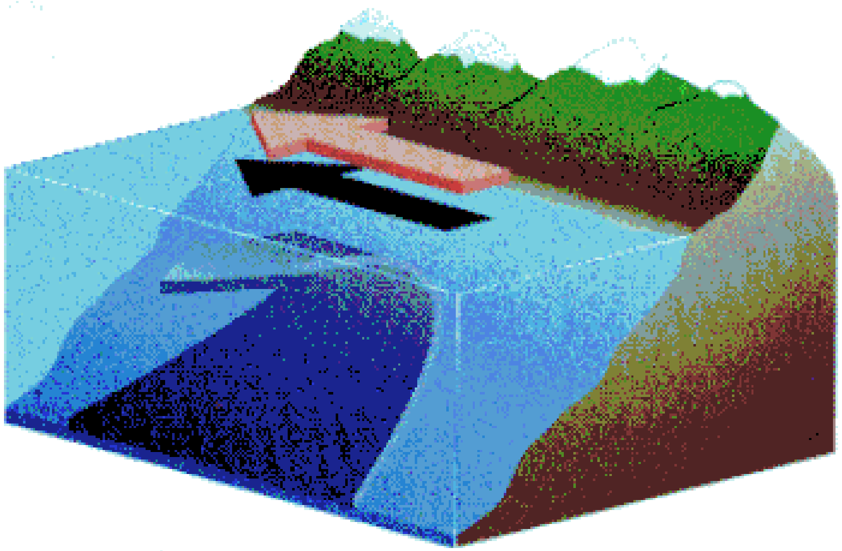


Condición media: Asimetría zonal y acoplamiento OA

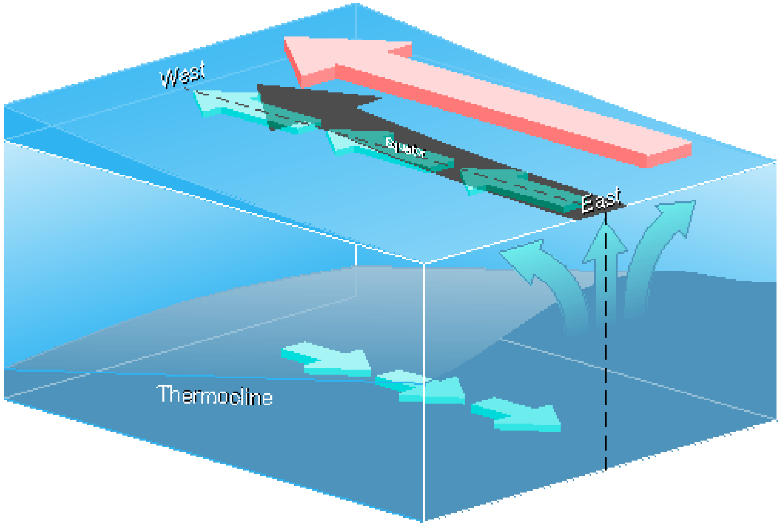
Colores indican TSM
Flechas delgadas viento en superficie



Surgencia: Afloramiento de aguas profundas (frías, ricas en O_2 y nutrientes) por efecto del viento



Surgencia costera



Surgencia ecuatorial

$$u = \bar{u} + \frac{\sqrt{2}}{\rho_0 f d}\, e^{z/d}\left[\tau^x \cos\left(\frac{z}{d} - \frac{\pi}{4}\right) - \tau^y \sin\left(\frac{z}{d} - \frac{\pi}{4}\right)\right], \tag{5-18a}$$

$$v = \bar{v} + \frac{\sqrt{2}}{\rho_0 f d}\, e^{z/d}\left[\tau^x \sin\left(\frac{z}{d} - \frac{\pi}{4}\right) + \tau^y \cos\left(\frac{z}{d} - \frac{\pi}{4}\right)\right], \tag{5-18b}$$

in which we note that the departure from the interior flow $(\bar{u}, \bar{v})$ is exclusively due to the wind stress. In other words, it does not depend on the interior flow. Moreover, this wind-driven flow component is inversely proportional to the Ekman-layer depth, d, and can be very large. Physically, if the fluid is almost inviscid (small ν, hence small d), a moderate surface stress can generate large velocities.

The wind-driven horizontal transport in the surface Ekman layer has components given by

$$U = \int_{-\infty}^{0} (u - \bar{u})\, dz = \frac{1}{\rho_0 f}\, \tau^y \tag{5-19a}$$

$$V = \int_{-\infty}^{0} (v - \bar{v})\, dz = \frac{-1}{\rho_0 f}\, \tau^x. \tag{5-19b}$$

Surprisingly, it is oriented perpendicular to the direction of the wind stress (Figure 5-5), to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This fact explains why icebergs, which have mass that is mostly underwater, systematically drift to the right of the wind in the North Atlantic.

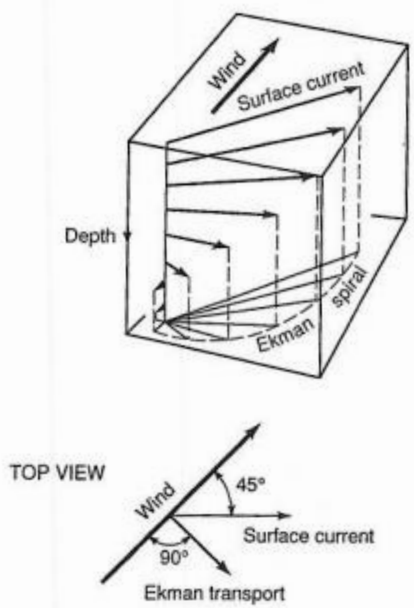


Figure 5-5 Structure of the surface Ekman layer. The figure is drawn for the Northern Hemisphere ($f > 0$), and the deflection is to the right of the surface stress. The reverse holds for the Southern Hemisphere.

The mathematical formulation of the Ekman layer begins by assuming a neutrally stratified fluid, a balance between the forces of pressure gradient, Coriolis and turbulent drag.

$$-fv = -\frac{1}{\rho_o}\frac{\partial p}{\partial x} + K_m\frac{\partial^2 u}{\partial z^2},$$
$$fu = -\frac{1}{\rho_o}\frac{\partial p}{\partial y} + K_m\frac{\partial^2 v}{\partial z^2},$$
$$0 = -\frac{1}{\rho_o}\frac{\partial p}{\partial z},$$

where u and v are the velocities in the x and y directions, respectively, f is the local Coriolis parameter, and K_m is the diffusive eddy viscosity, which can be derived using mixing length theory. Note that p is a modified pressure: we have incorporated the hydrostatic of the pressure, to take account of gravity.

There are many regions where an Ekman layer is theoretically plausible; they include the bottom of the atmosphere, near the surface of the earth and ocean, the bottom of the ocean, near the sea floor and at the top of the ocean, near the air-water interface. Different boundary conditions are appropriate for each of these different situations. Each of these situations can be accounted for through the boundary conditions applied to the resulting system of ordinary differential equations. The separate cases of top and bottom boundary layers are shown below.

Ekman layer at the ocean (or free) surface [edit]

We will consider boundary conditions of the Ekman layer in the upper ocean:[2]

$$\text{at } z = 0: \quad A\frac{\partial u}{\partial z} = \tau^x \quad \text{and} \quad A\frac{\partial v}{\partial z} = \tau^y,$$

where τ^x and τ^y are the components of the surface stress, τ, of the wind field or ice layer at the top of the ocean.

For the boundary condition on the other side, as $z \to \infty : u \to u_g, v \to v_g$, where u_g and v_g are the geostrophic flows in the x and y directions.

Solution [edit]

These differential equations can be solved to find:

$$u = u_g + \frac{\sqrt{2}}{fd}e^{z/d}\left[\tau^x\cos(z/d - \pi/4) - \tau^y\sin(z/d - \pi/4)\right],$$
$$v = v_g + \frac{\sqrt{2}}{fd}e^{z/d}\left[\tau^x\sin(z/d - \pi/4) + \tau^y\cos(z/d - \pi/4)\right],$$
$$d = \sqrt{2K_m/|f|}.$$

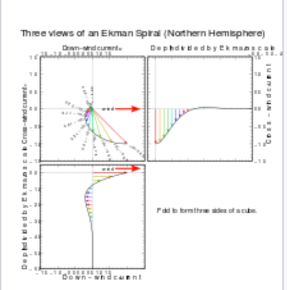
The value d is called the Ekman layer depth, and gives an indication of the penetration depth of wind-induced turbulent mixing in the ocean. Note that it varies on two parameters: the turbulent diffusivity K_m, and the latitude, as encapsulated by f. For a typical $K_m = 0.1m^2/s$, and at 45° latitude ($f = 10^{-4}s^{-1}$), then d is approximately 45 meters. This Ekman depth prediction does not always agree precisely with observations.

This variation of horizontal velocity with depth ($-z$) is referred to as the Ekman spiral, diagrammed above and at right.

By applying the continuity equation we can have the vertical velocity as following

$$w = \frac{1}{f\rho_o}\left[-\left(\frac{\partial\tau^x}{\partial x} + \frac{\partial\tau^y}{\partial y}\right)e^{z/d}\sin(z/d) + \left(\frac{\partial\tau^y}{\partial x} - \frac{\partial\tau^x}{\partial y}\right)(1 - e^{z/d}\cos(z/d))\right].$$

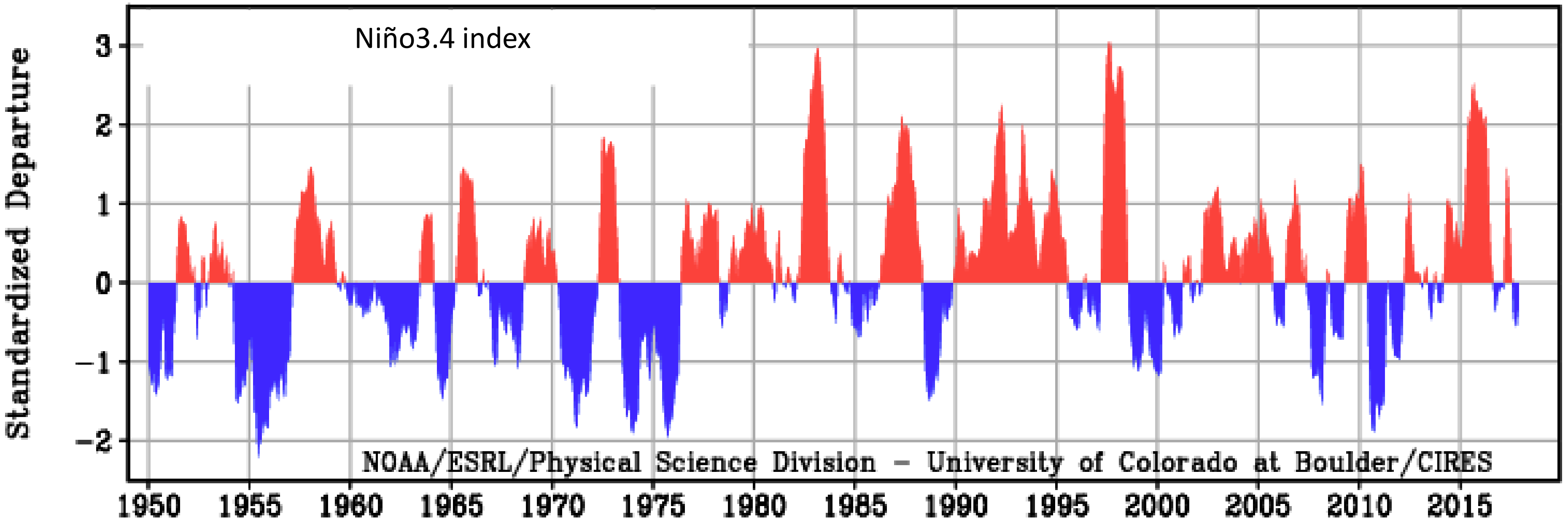
Note that when vertically-integrated, the volume transport associated with the Ekman spiral is to the right of the wind direction in the Northern Hemisphere.



Three views of the wind-driven Ekman layer at the surface of the ocean in the Northern Hemisphere. The geostrophic velocity is zero in this

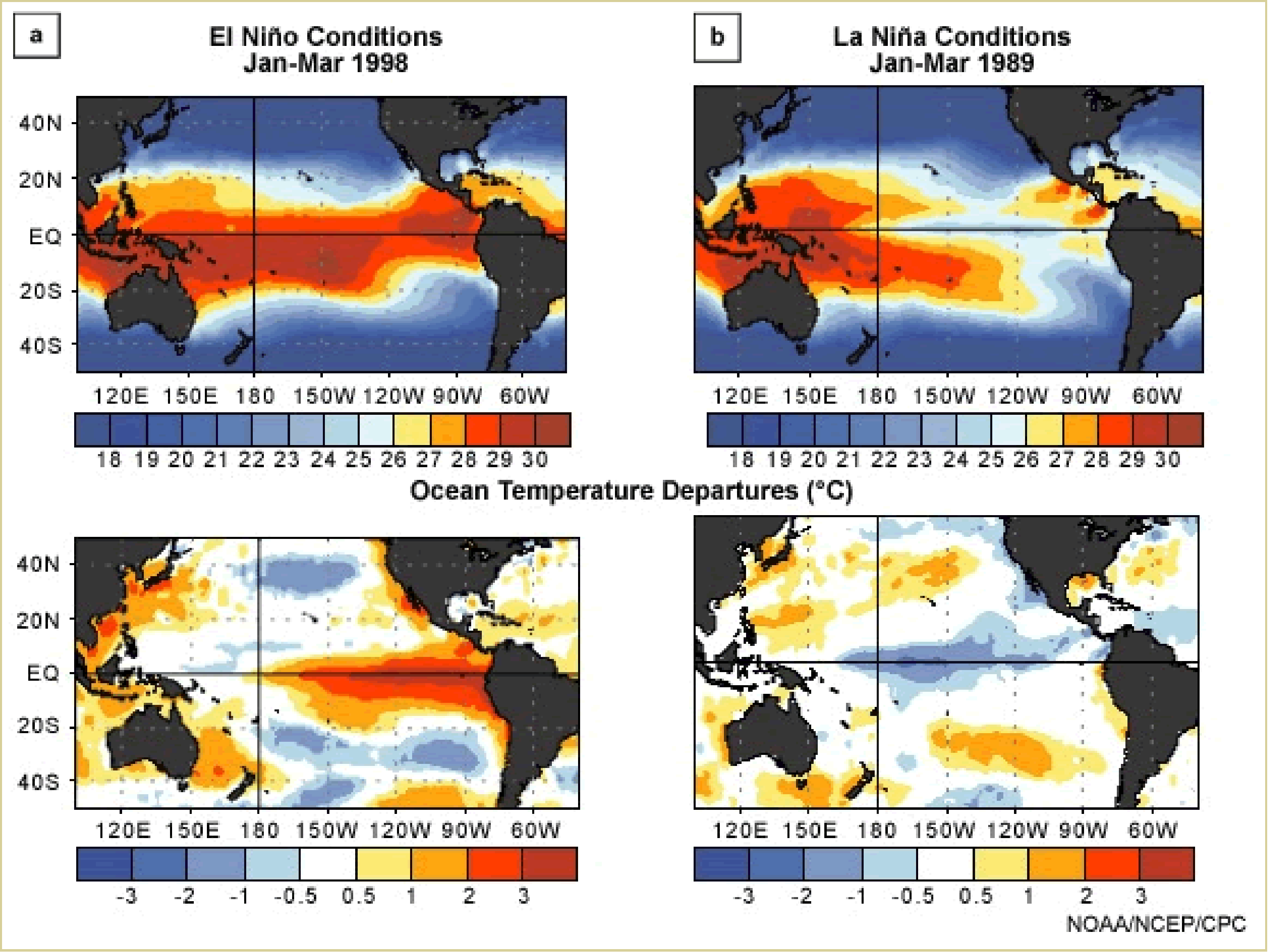
Variabilidad interanual en el Pacifico tropical

El Niño Global (aTSM >0.5°C por 3 meses en Nino3.4)
App 1 años de duración
Cada 3-7 años



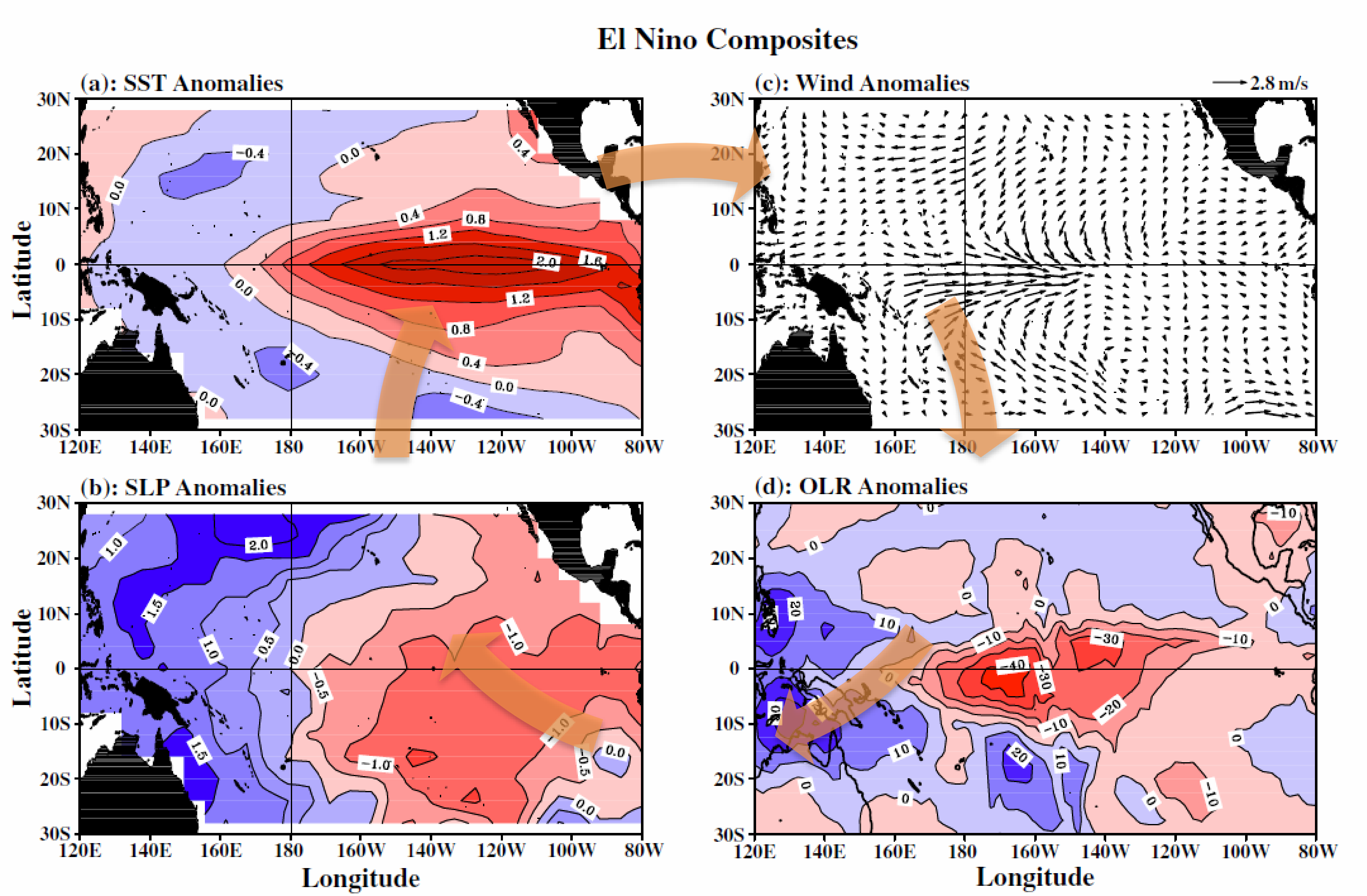
Variabilidad interanual en el Pacifico tropical

EN, LN (aT>0.5°C por 3 meses) : 1-2 años de duración, cada 3-7 años

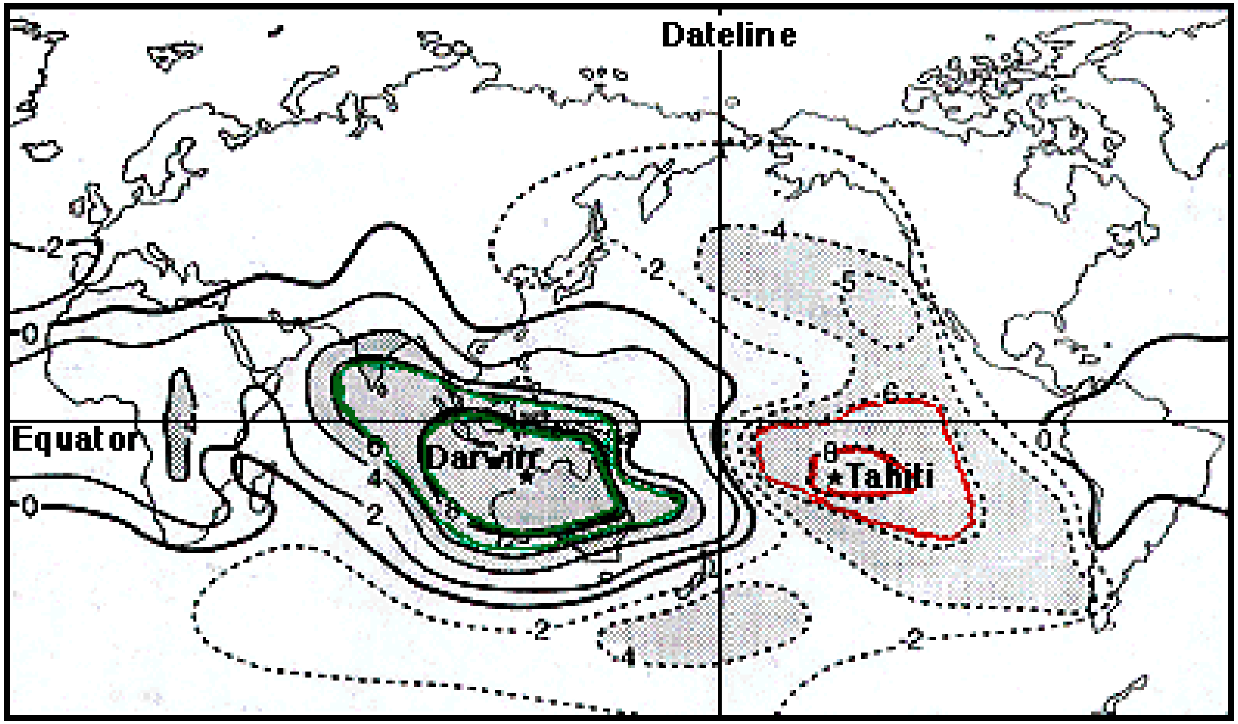


Mantención de El Niño: Mecanismo de Bjerknes

(También refleja acoplamiento O-A: SST, SLP, Viento)

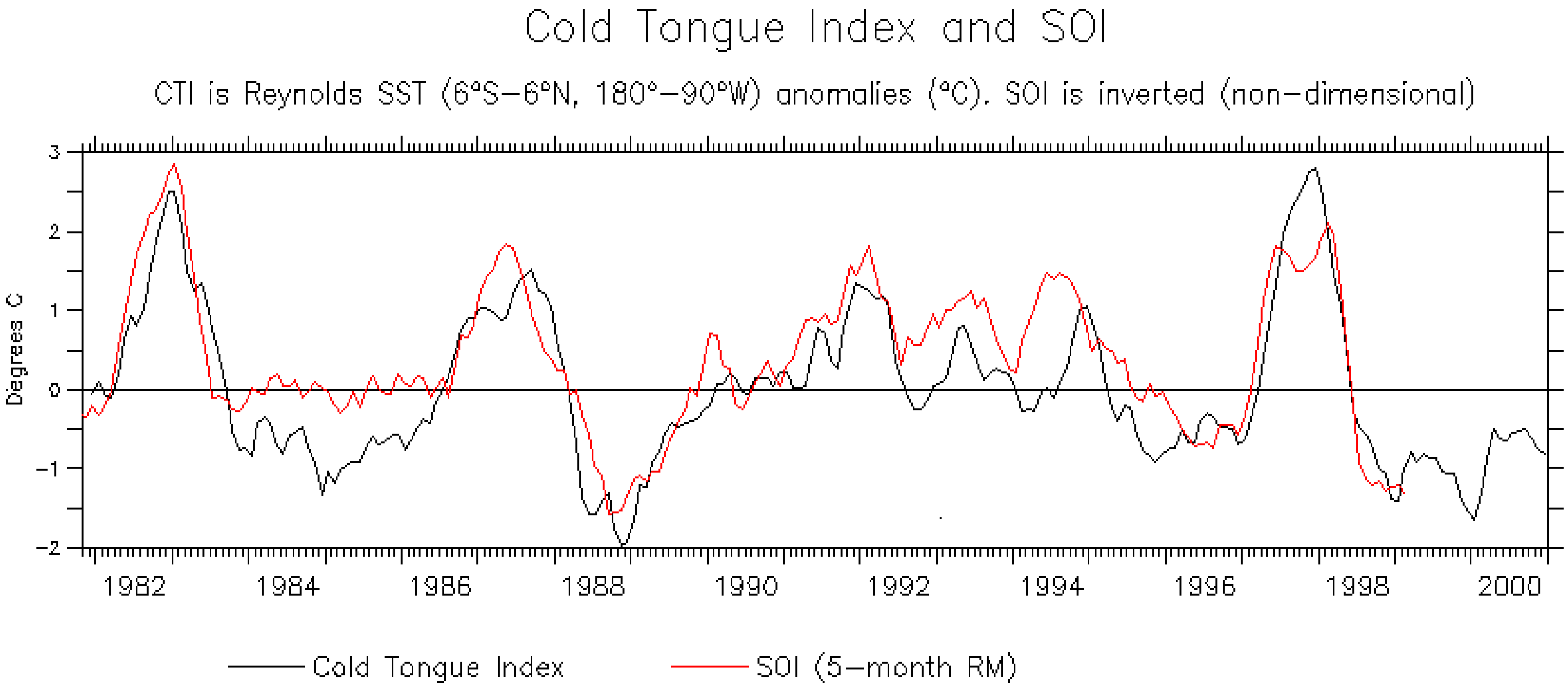


SOI: Tahiti and Darwin as "centers of action",
mslp correlations between two locations



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.)

Estan la OS y EN asociados? SI.....



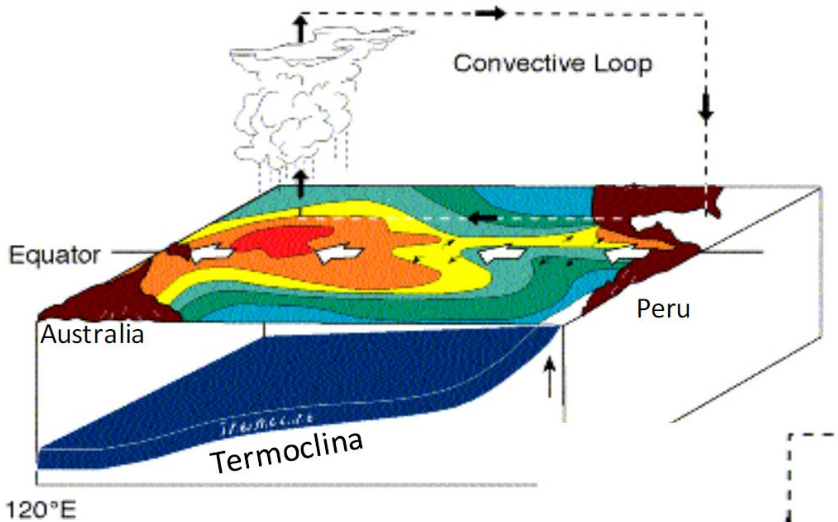
El Niño (TSM sobre el promedio) ⇔ Anticiclón del Pacifico relativamente bajo

La Niña (TSM bajo el promedio) ⇔ Anticiclón del Pacifico relativamente alto

Mantención de El Niño: Mecanismo de Bjerknes

(También refleja acoplamiento O-A: SST, SLP, Viento)

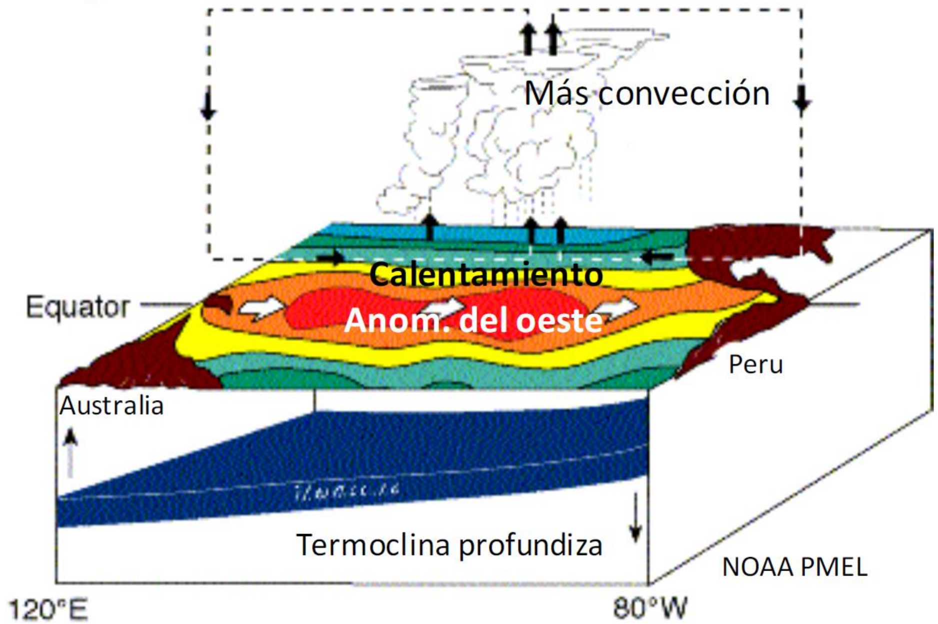
Condiciones normales



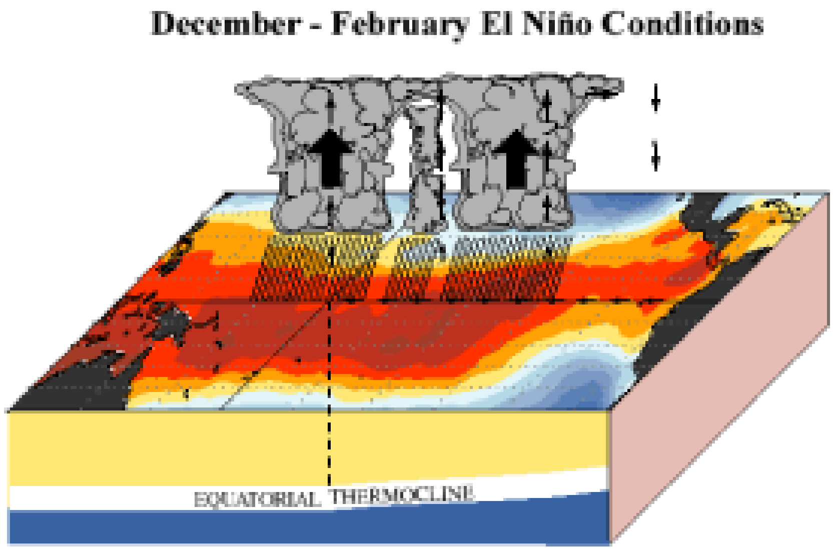
El Niño-Oscilación Sur (ENOS)

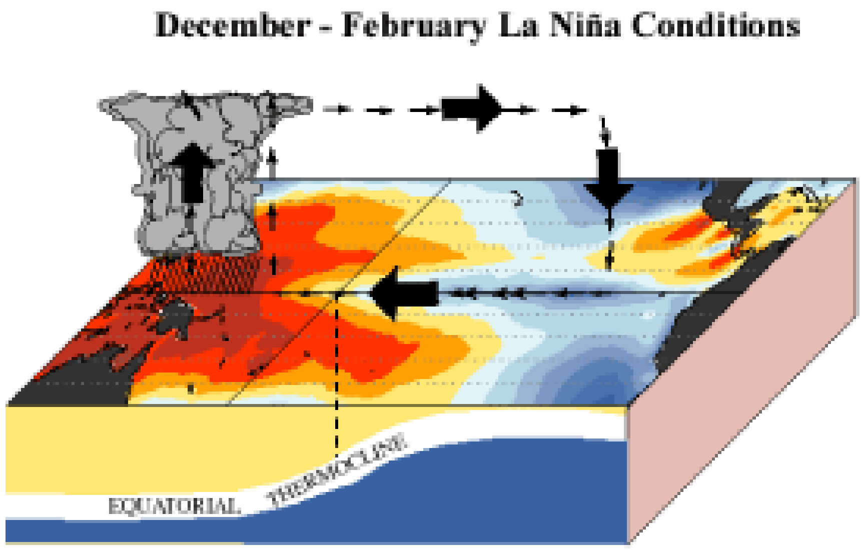
GLOBAL

El Niño global



Interacción océano-atmósfera en todo el Pacífico ecuatorial de **oeste a este**


December - February El Niño Conditions
EQUATORIAL THERMOCLINE


December - February La Niña Conditions
EQUATORIAL THERMOCLINE

FENOMENO EL NIÑO

- Disminuye la presión frente a la costa de Ecuador, Perú y norte de Chile, y aumenta en el Pacífico occidental (fase negativa de la OS)
- Los vientos alisios se debilitan por menor gradiente de presión.
- Se debilita la surgencia a lo largo del Pacífico ecuatorial, como resultado del debilitamiento de los alisios
- Aumenta la temperatura superficial del mar debido a la menor surgencia. La zona de ascenso de la celda de Walker se mueve hacia el Este.
- Aumenta el nivel del mar en la costa de América del Sur, y disminuye en Oceanía.
- El contraste térmico E-W disminuye a lo largo del Pacífico ecuatorial
- Lo anterior favorece un reforzamiento de las anomalías de presión y de los efectos asociados.
- El fenómeno persiste ! !

FENOMENO LA NIÑA

- Aumenta la presión frente a la costa de Ecuador, Perú y norte de Chile, y disminuye en el Pacífico occidental (fase positiva de la OS)

- Los vientos alisios se intensifican por el mayor gradiente de presión.

- Se fortalece la surgencia a lo largo del Pacífico ecuatorial, como resultado de la intensificación de los alisios.

- Disminuye la temperatura superficial del mar debido a la menor surgencia. La zona de ascenso de la celda de Walker se mueve hacia el Oeste.

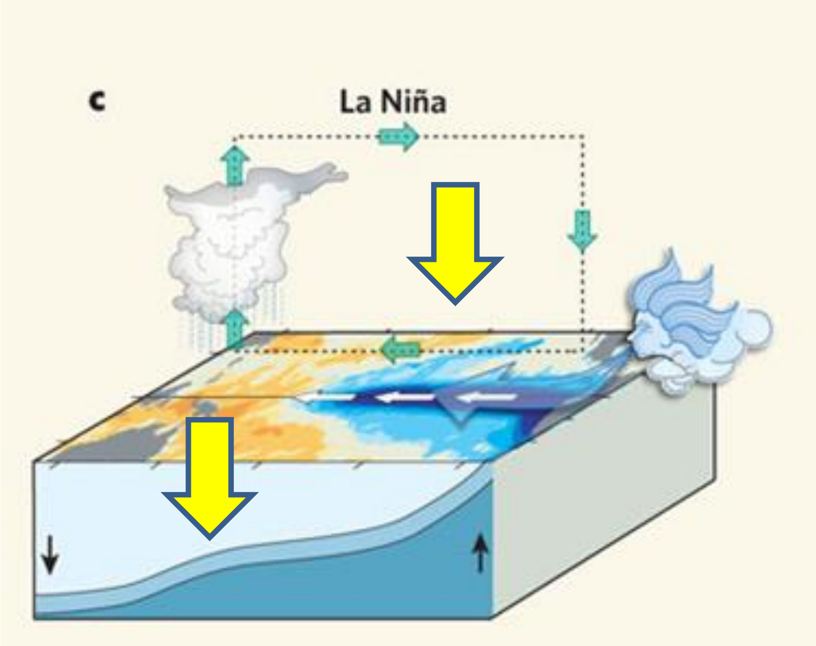
- Disminuye el nivel del mar en la costa de América del Sur, y aumenta en Oceanía.

- El contraste térmico E-W aumenta a lo largo del Pacífico ecuatorial

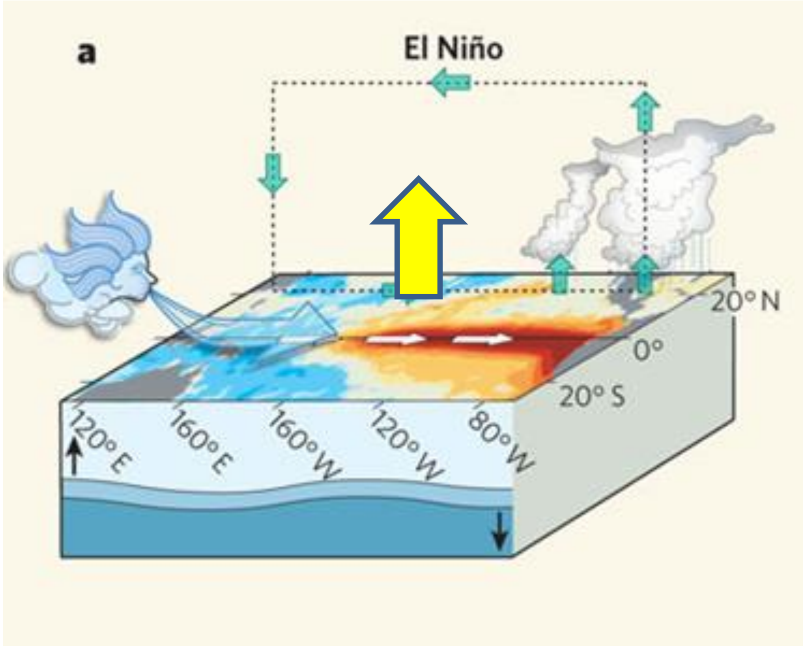
- Lo anterior favorece un reforzamiento de las anomalías de presión y de los efectos asociados.

- El fenómeno persiste ! !

Fases ENSO como un sistema de carga/descarga de Energía



Alisios más intensos / Mayor Insolación
Mayor surgencia en Pac. Oriental
Mayor hundimiento en Pac. Occidental
Energía ingresa al océano
Corrientes distribuyen el calor lateramente



Alisios más débiles
Menor surgencia en Pac. Oriental
Aumento de evaporación (LE)
Energía sale del océano
Atmosfera distribuye la energía globalmente

Karumuri Ashok & Toshio Yamagata
Nature 461, 481-484(24 September 2009)

Geophysical Research Letters

How the July 2014 easterly wind burst gave the 2015–2016 El Niño a head start

Aaron F. Z. Levine[1] and Michael J. McPhaden[1]

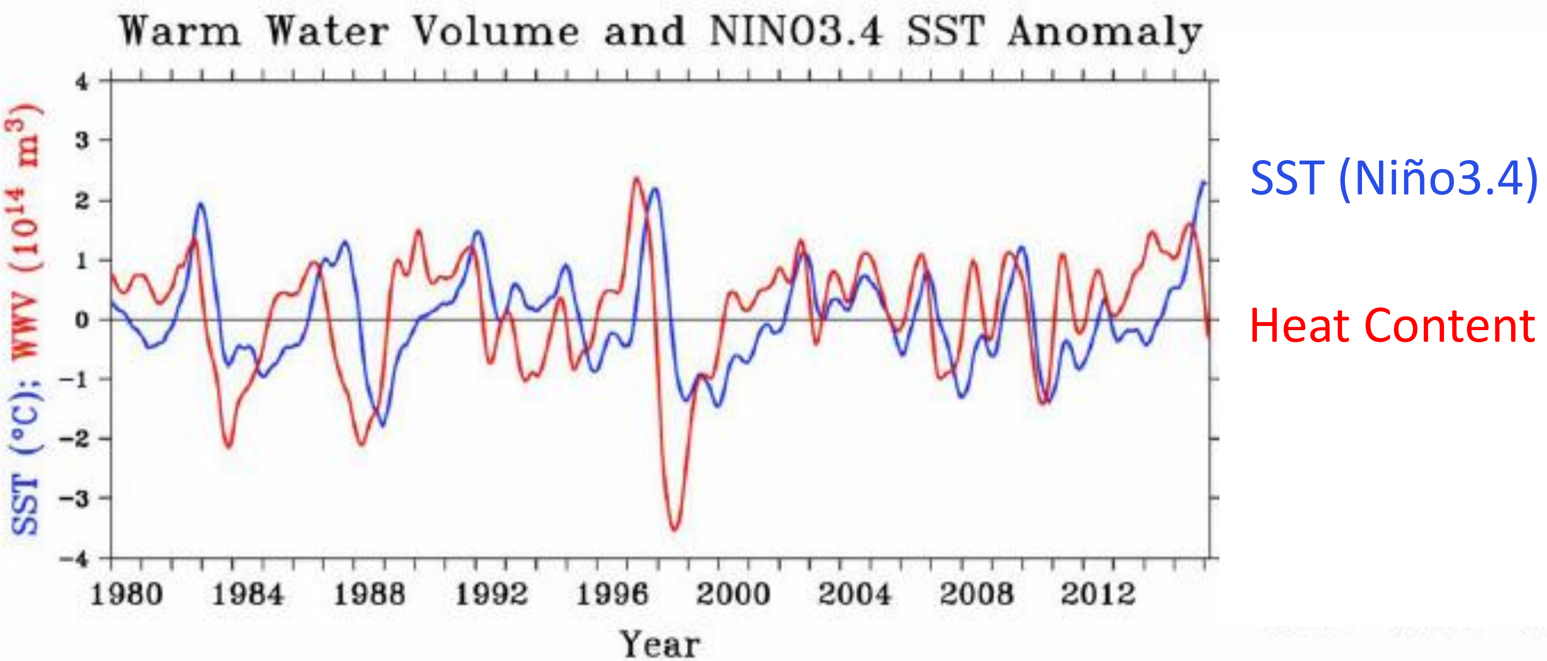


Figure 1. Time series of WWV and Nino3.4 from 1980-present using ERSSTv4. (left) Five month running means. (right) Monthly means since 2013, with the dashed blue line being the 0.5°C threshold for El Niño events and the dashed red line being 1×10^{14} m^3, a WWV threshold for the development of El Niño events.

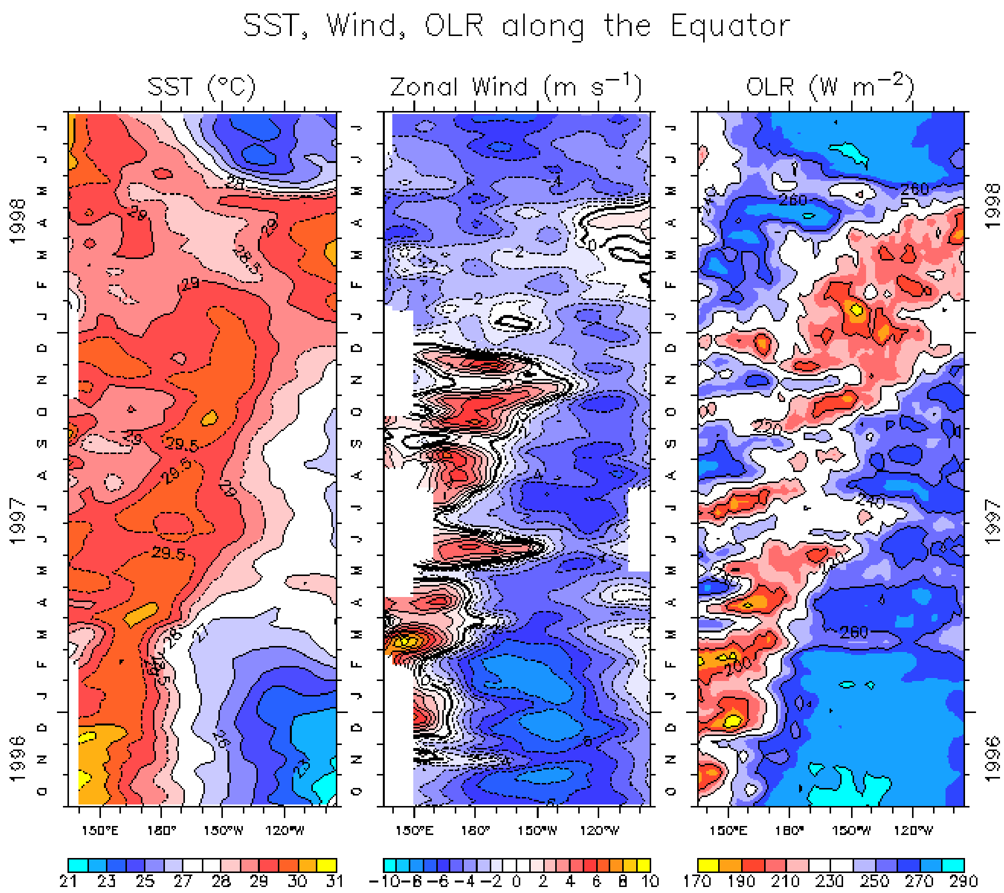
Dinámica de ENSO

Fase de crecimiento bien explicada por mecanismo de retroalimentación de Bjerknes (1966). Sin embargo hay varios aspectos que permanecen en debate:

1. Oscilación continua v/s fenómeno esporádico
2. Mecanismo de iniciación
3. Mecanismo de transición de fase

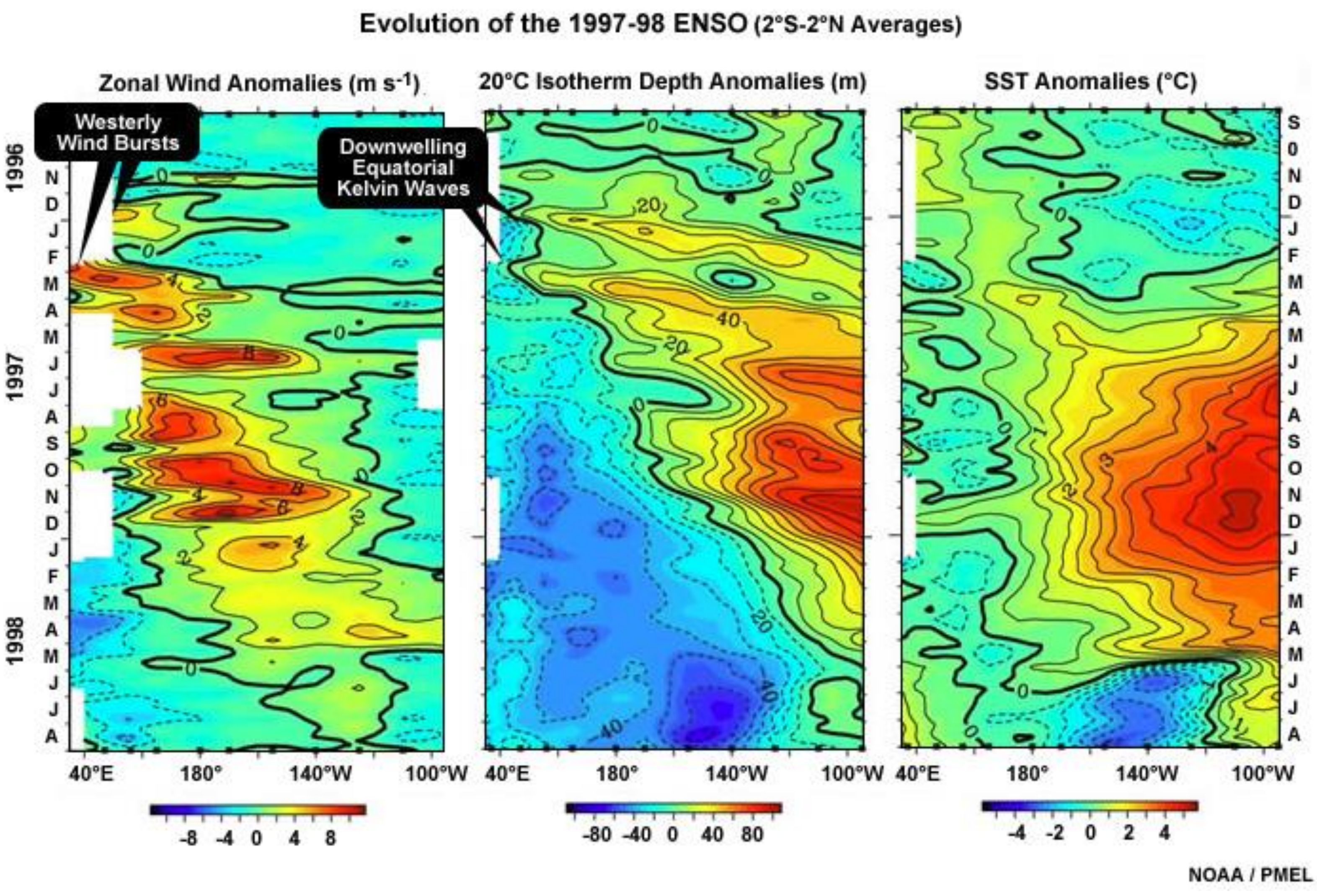
Iniciación de ENSO

- “Westerly wind bursts” asociados a MJO o Monzón del Asia
- Termoclina profunda en la región ecuatorial parece condición necesaria pero no suficiente



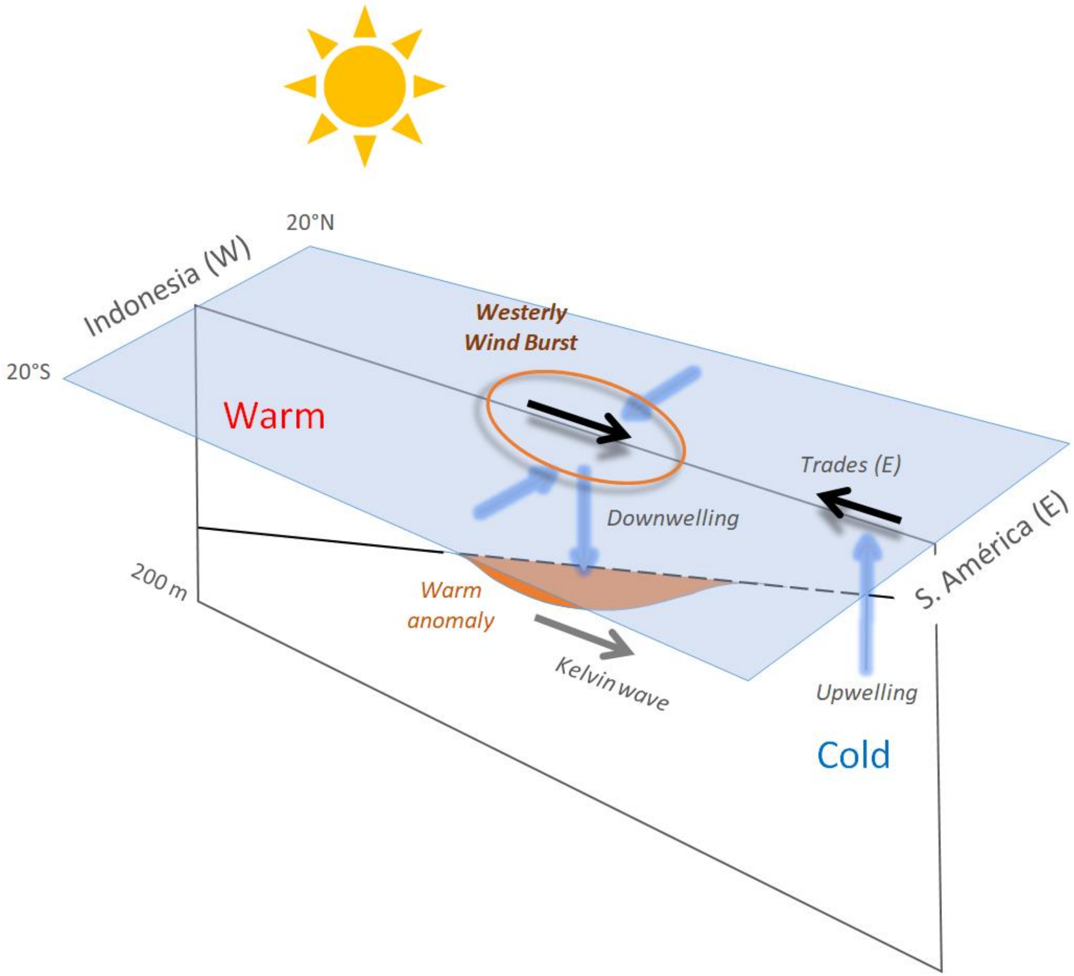
Mecanismo de Bjerknes explica mantención de EN(LN)… pero cual es el gatillo?

WWB: Westerly wind burst



Mecanismo de Bjerknes explica mantención de EN(LN)… pero cual es el gatillo?

WWB: Westerly wind burst



Westerly Wind Bursts: ENSO's Tail Rather than the Dog?

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ABSTRACT

Westerly wind bursts (WWBs) in the equatorial Pacific occur during the development of most El Niño events and are believed to be a major factor in ENSO's dynamics. Because of their short time scale, WWBs are normally considered part of a stochastic forcing of ENSO, completely external to the interannual ENSO variability. Recent observational studies, however, suggest that the occurrence and characteristics of WWBs may depend to some extent on the state of ENSO components, implying that WWBs, which force ENSO, are modulated by ENSO itself.

Satellite and in situ observations are used here to show that WWBs are significantly more likely to occur when the warm pool is extended eastward. Based on these observations, WWBs are added to an intermediate complexity coupled ocean–atmosphere ENSO model. The representation of WWBs is idealized such that their occurrence is modulated by the warm pool extent. The resulting model run is compared with a run in which the WWBs are stochastically applied. The modulation of WWBs by ENSO results in an enhancement of the slow frequency component of the WWBs. This causes the amplitude of ENSO events forced by modulated WWBs to be twice as large as the amplitude of ENSO events forced by stochastic WWBs with the same amplitude and average frequency. Based on this result, it is suggested that the modulation of WWBs by the equatorial Pacific SST is a critical element of ENSO's dynamics, and that WWBs should not be regarded as purely stochastic forcing. In the paradigm proposed here, WWBs are still an important aspect of ENSO's dynamics, but they are treated as being partially stochastic and partially affected by the large-scale ENSO dynamics, rather than being completely external to ENSO.

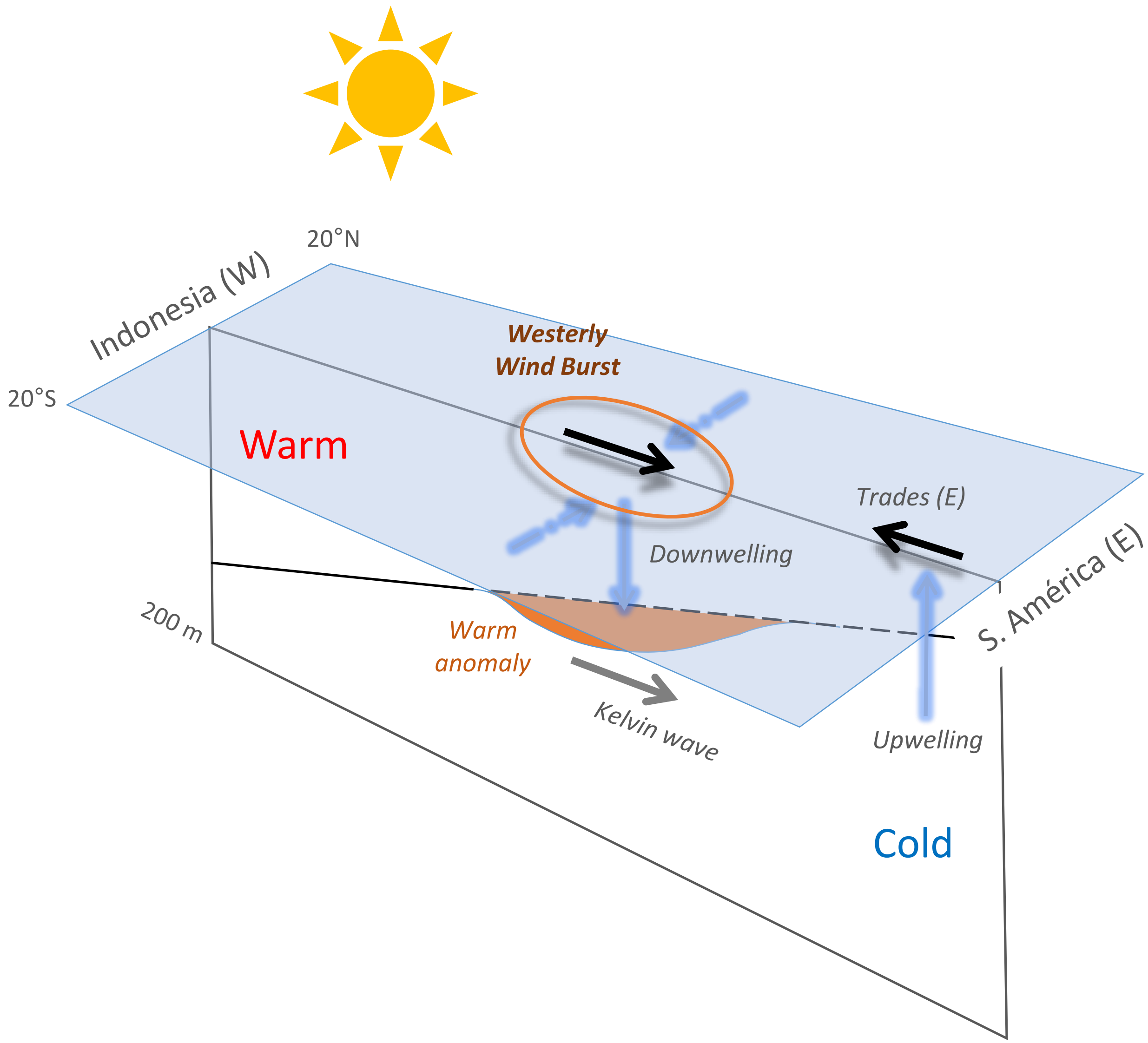
It is further shown that WWB modulation by the large-scale equatorial SST field is roughly equivalent to an increase in the ocean–atmosphere coupling strength, making the coupled equatorial Pacific effectively self-sustained.

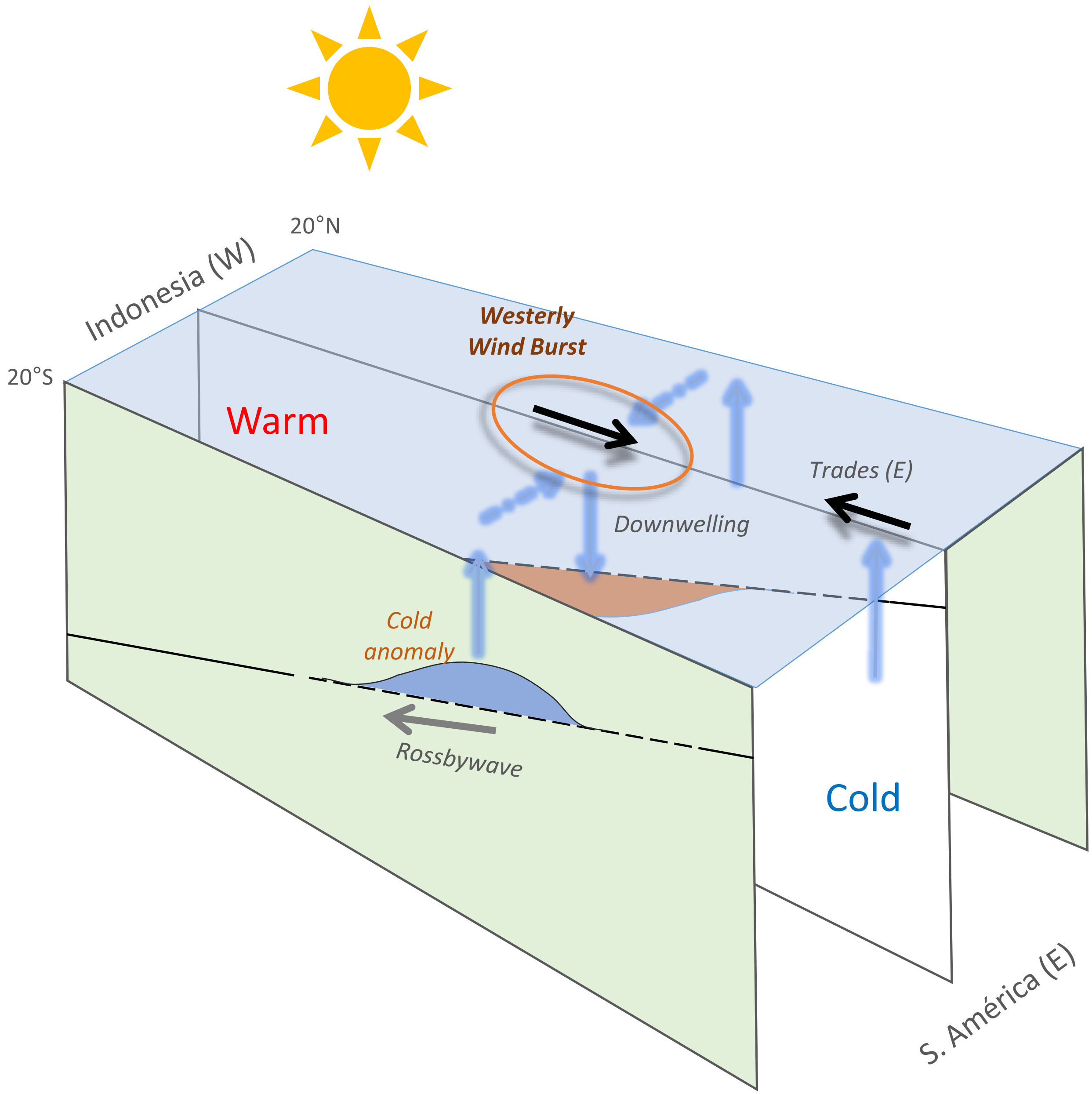
Mecanismos de transición de fase:

1. Teoría del oscilador retardado (Delayed Oscillator: Schopf and Suarez 1988; Battisti and Hirtz, 1989): La memoria del océano es provista por la profundidad de la termoclina mediante la propagación y reflexión de ondas oceánicas. En este caso, el periodo de ENSO es determinado por la velocidad de fase de las ondas en juego.

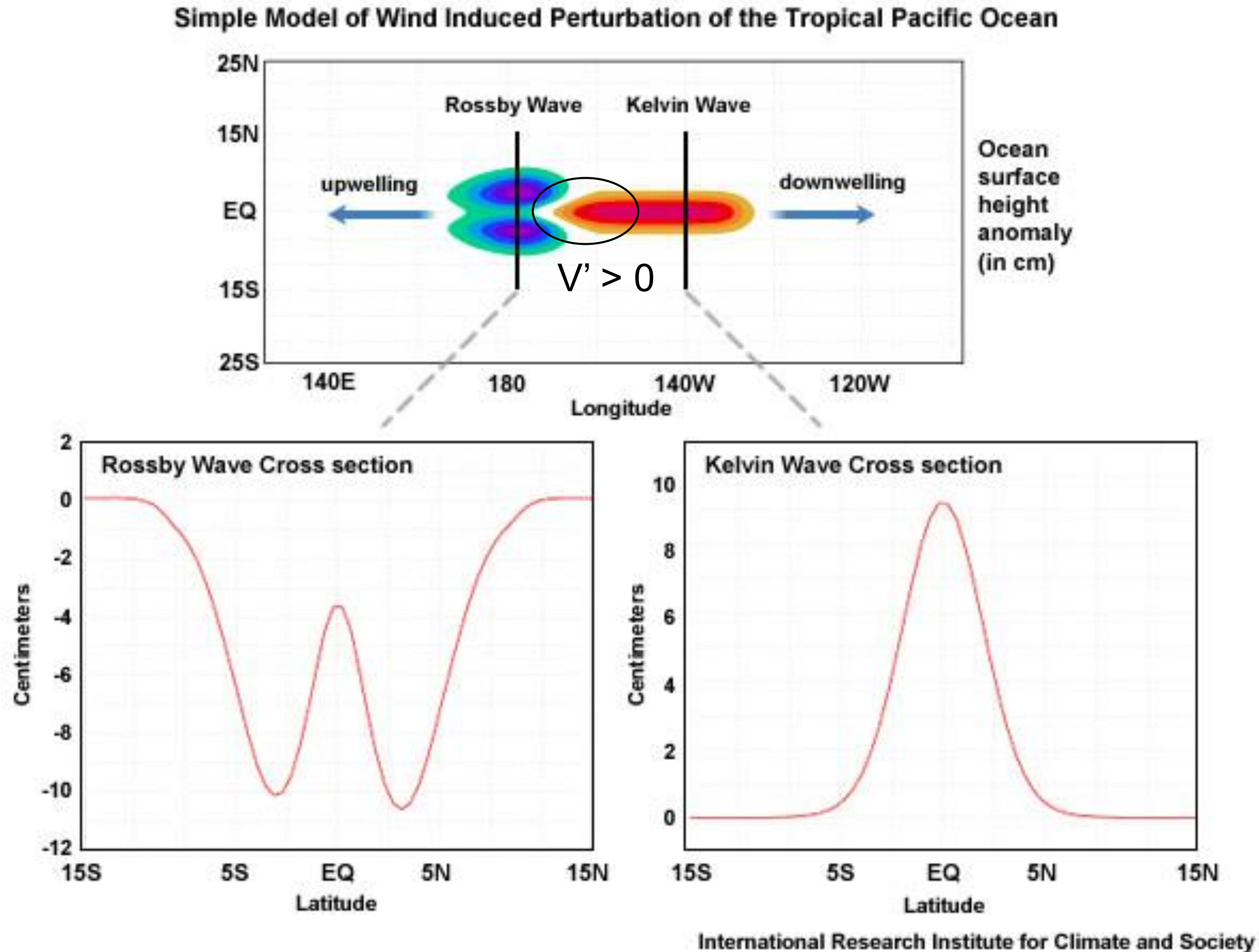
2. Teoría del oscilador recargado (Wyrtki 1975; Jin 1997): La memoria del océano es provista por la profundidad promedio de la termoclina la cual esta permanentemente fuera de equilibrio con el esfuerzo del viento en la franja ecuatorial.

3. Otras teorías (oscilador advectivo-reflectivo, oscilador unificado).


20°N
Indonesia (W)
20°S
Westerly
Wind Burst
Warm
Trades (E)
Downwelling
S. América (E)
200 m
Warm
anomaly
Kelvin wave
Upwelling
Cold



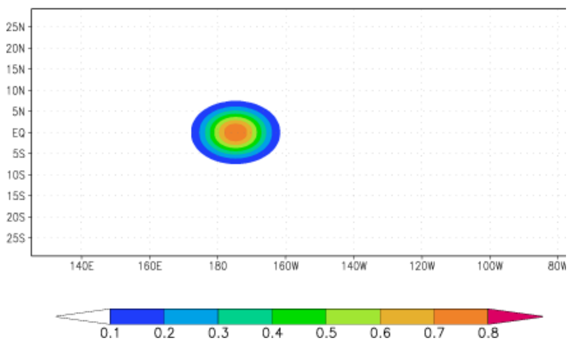
20°N
Indonesia (W)
20°S
Westerly
Wind Burst
Warm
Trades (E)
Downwelling
Cold
anomaly
Rossbywave
Cold
S. América (E)


Simple Model of Wind Induced Perturbation of the Tropical Pacific Ocean
25N
15N
EQ
15S
25S
Rossby Wave
Kelvin Wave
upwelling
downwelling
V' > 0
Ocean surface height anomaly (in cm)
140E
180
140W
120W
Longitude
Rossby Wave Cross section
Centimeters
Latitude
15S
5S
EQ
5N
15N
Kelvin Wave Cross section
International Research Institute for Climate and Society

How does El Nino End?

A growing El Nino contains the seeds of its own destruction.

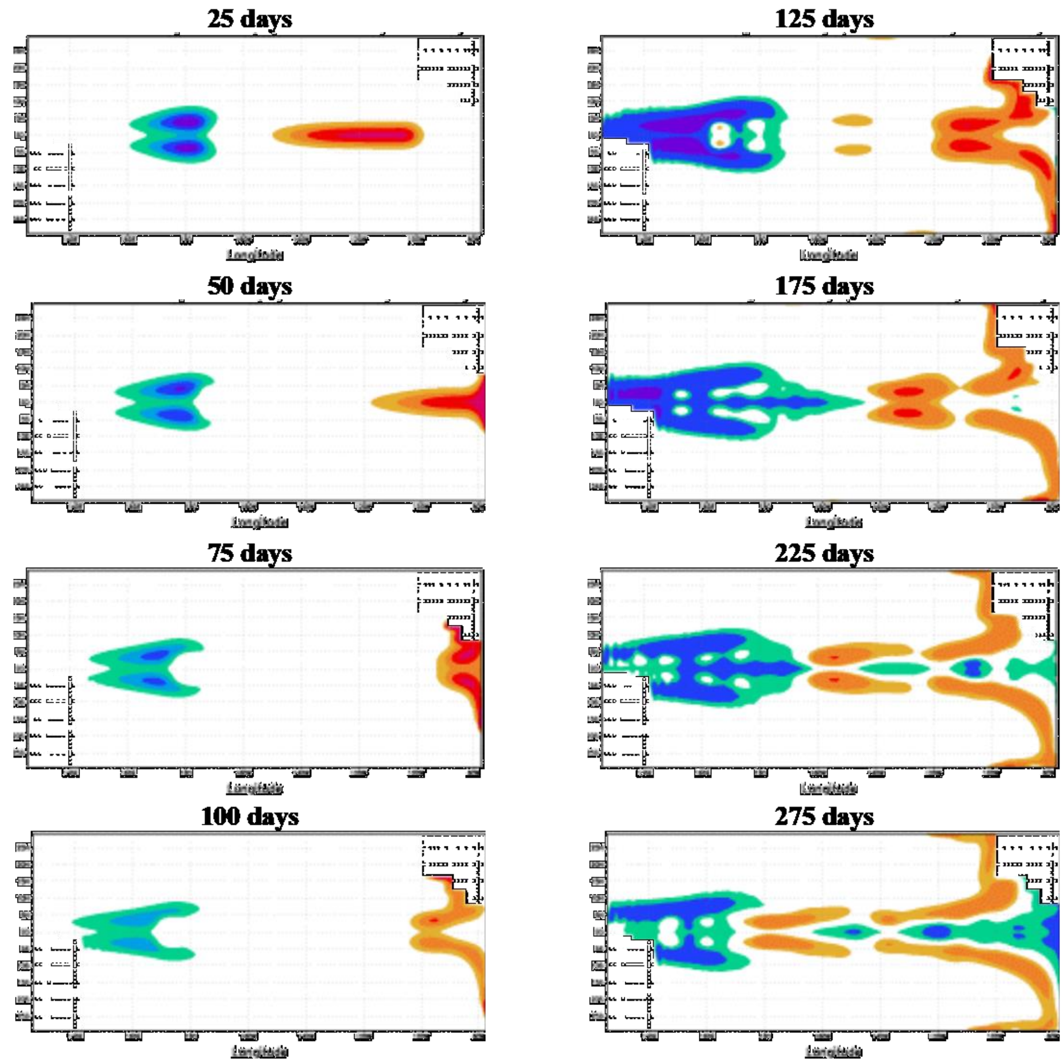
1. Hit ocean with a westerly wind stress pulse



2. Warm Kelvin waves propagate east along equator

➔ Event starts!

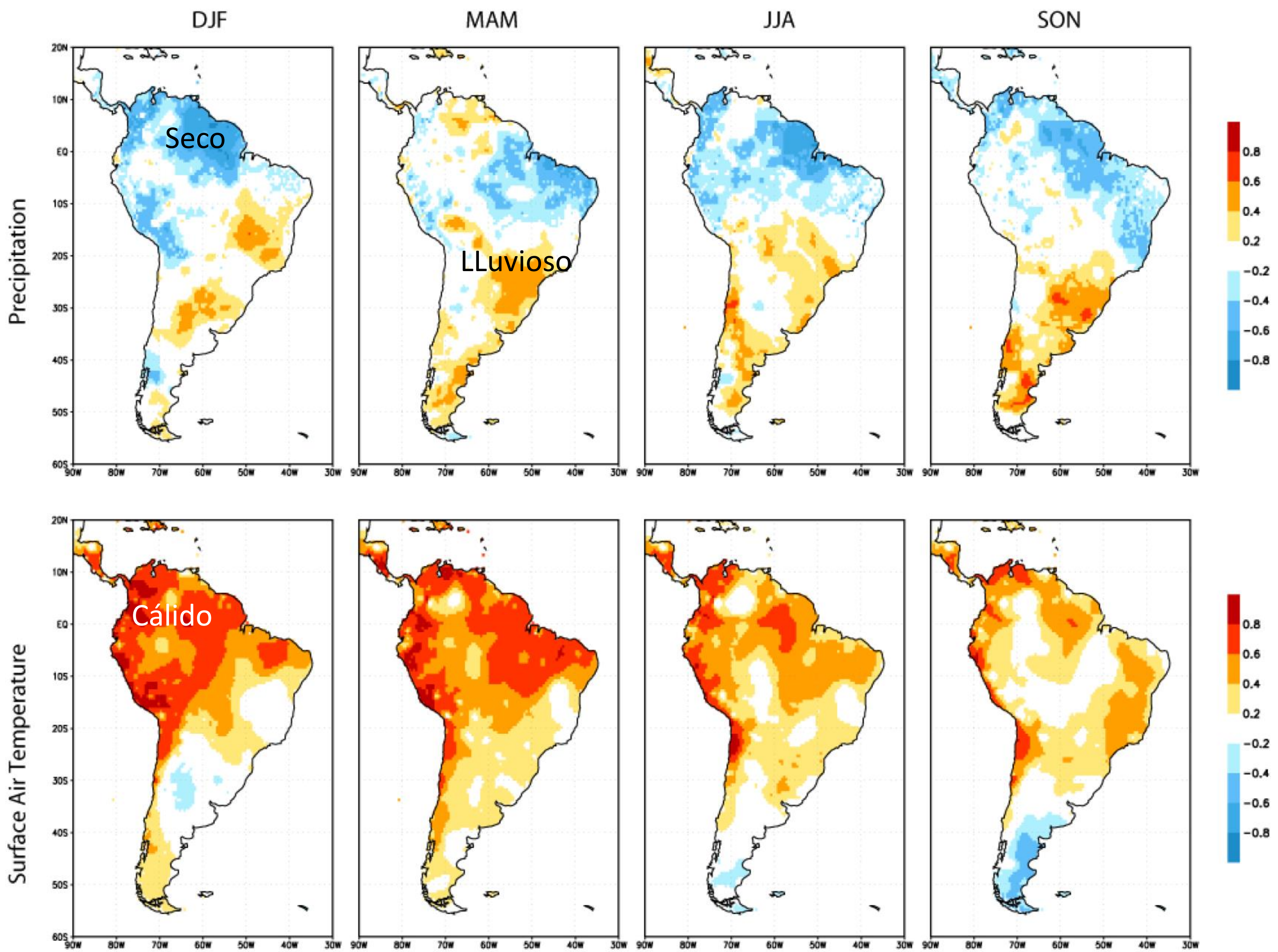
3. Cold Rossby waves propagate west at higher lat and reflect back eastward as Kelvin waves ➔ Event ends



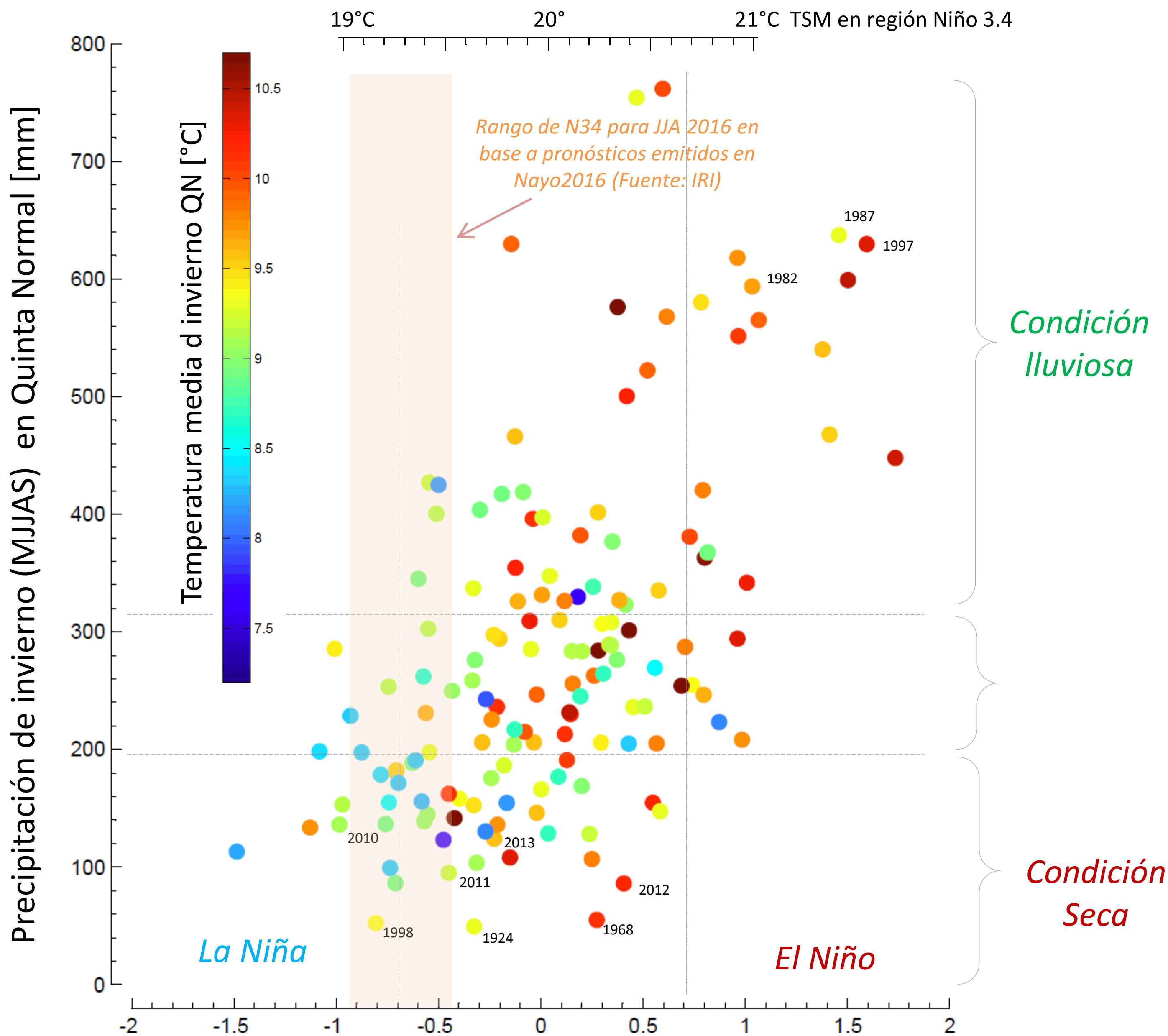
http://iri.columbia.edu/climate/ENSO/theory/

Principales impactos climáticos durante años El Niño

Correlación de Nino3.4 con precipitación y temperatura



Impactos ENOS en precipitación sobre Santiago



Fuentes: DMC (QN) y NOAA (EN)

Principales impactos climáticos durante años El Niño