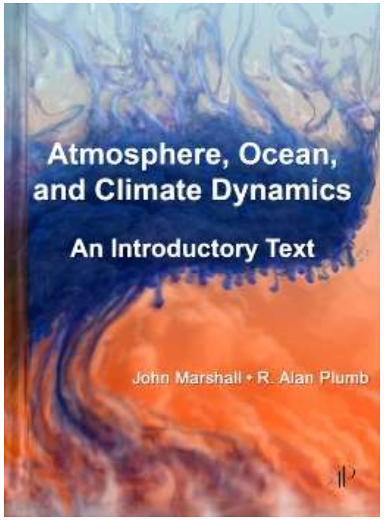
GEF 1100 – Klimasystemet

Chapter 12: Climate and climate variability - I



Prof. Dr. Kirstin Krüger (MetOs, UiO)

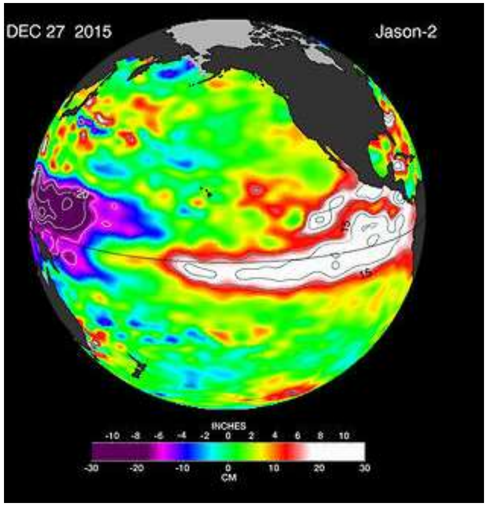
UiO : University of Oslo

Lecture Outline – Ch. 12

Ch. 12 – Climate and climate variability – Part I

Ch. 12 - Part II: “Paleo-climate” by Wolfram Kürschner

1. Introduction
2. The ocean as a buffer of temperature change
3. El Niño and the Southern Oscillation (ENSO)*
    - 2.1 Internal variability
    - 2.2 Normal conditions
    - 2.3 ENSO
4. Other modes of variability
    - 3.1 North Atlantic Oscillation*
5. Summary
6. Take home message



*Plus add-ons, not in the book.

Weather and Climate variations

Timescale

Processes	days			years			thousands of years		millions of years		
	h/d	w	m	y	10 y	10^2y	10^3y	10^4y	10^5y	10^6y	10^9y
Weather	■	■									
Land surface	■	■	■								
Ocean mixed layer	■	■	■								
Sea ice		■	■	■							
Volcanos		■	■	■							
Vegetation	■	■	■	■	■	■	■	■	■	■	
Thermocline				■	■	■					
Mountain glaciers					■	■					
Deep ocean						■	■	■			
Ice sheets						■	■	■	■		
Orbital forcing								■	■		
Tectonics										■	■
Weathering									■	■	■
Solar "constant"				■	■	■	■	■	■	■	■

Marshall and Plumb (2008)

Ocean: buffer of temperature change

Heat capacity:

- «Slab» ocean heat capacity: $\gamma_O = \rho_{ref}\, c_w\, h$
- Atmosphere heat capacity: $\gamma_A = \rho_s\, c_p\, H$
- $\gamma_O / \gamma_A \approx 40$ if $h = 100$ m
- $\gamma_O / \gamma_A \approx 2000$ if $h = 5000$ m

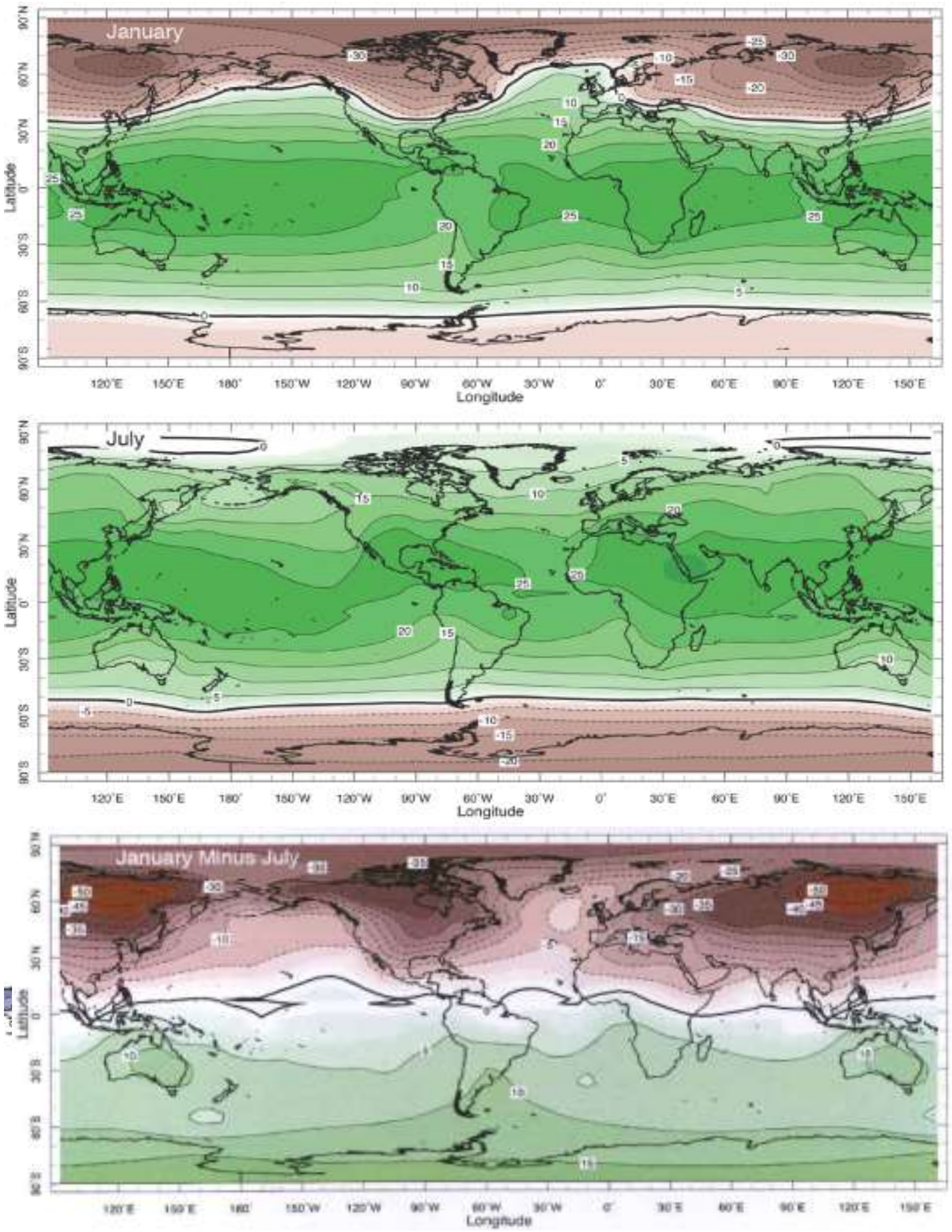
Thermal adjustment timescales:

- Ocean: 300 d ≈ 10 month, if *h*=100 m (40 y if *h* = 5000 m;
  in reality more like 1000 y)
- Atmosphere: ≈ 1 month

Energy storage:

- Oceans absorb and store more energy than continents.

Monthly mean surface air temperature (^oC)



January

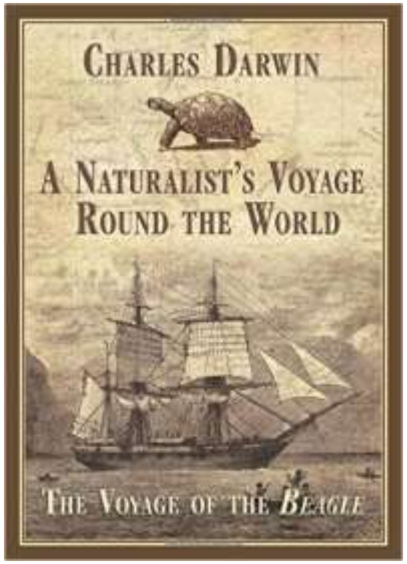
July

Jan-Jul

- Winter: continents are colder than the surrounding oceans at the same latitude
- Summer: continents are warmer than the ocean.

Marshall and Plumb (2008)

Tropics: pronounced internannual climate variability



- Charles Darwin („Voyage of the Beagle", 1831-1836) noted simultaneous climate anomalies in tropics.
- First described in the 1920s by Gilbert Walker → Southern Oscillation (SO).
- „El Nino" (EN), Spanish the child (or Christ child), phenomena known since centuries by the Peruvians, originally referred to a warm current occurring off the Peruvian coast during Christmas.
- Only since the 1960s Jacob Bjerknes argued that EN and the SO are linked → ENSO.

Assume: Simplified two-layer ocean model, no continents, zonal steady state wind stress, independent of longitude

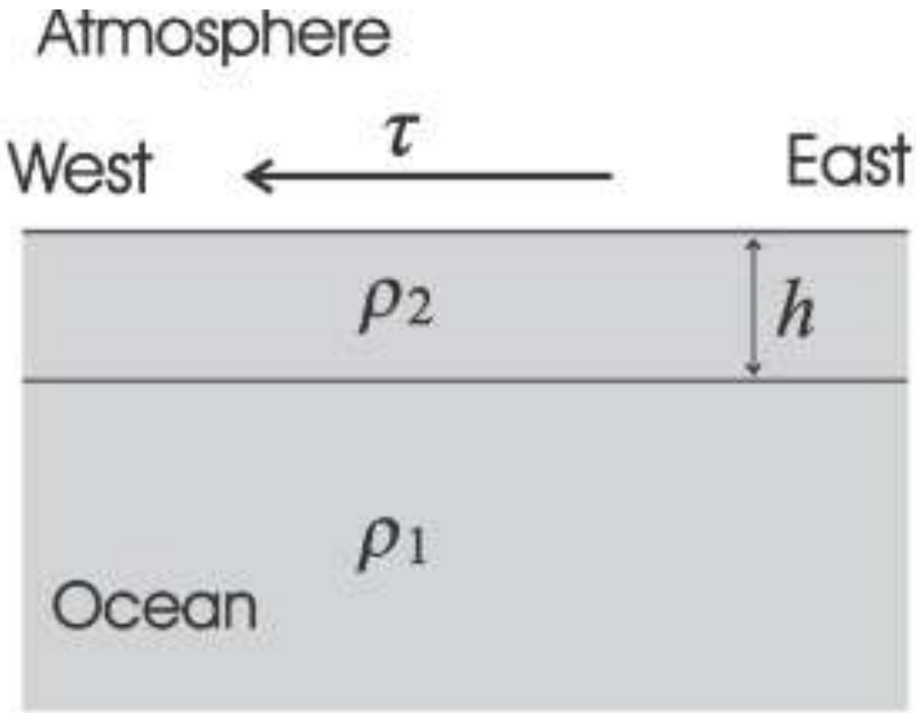
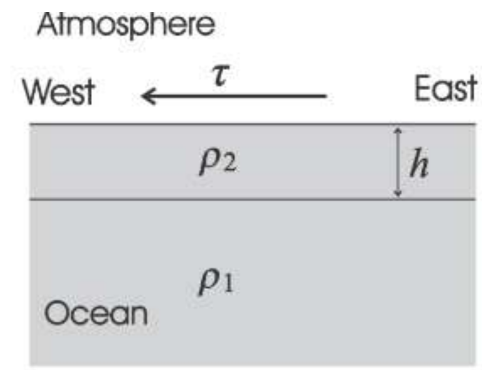


Figure 12.4: Schematic of a two-layer ocean model: the upper layer of depth *h* has a density $\rho 2$, which is less than the density of the lower layer, $\rho 1$. A wind stress blows over the upper layer.

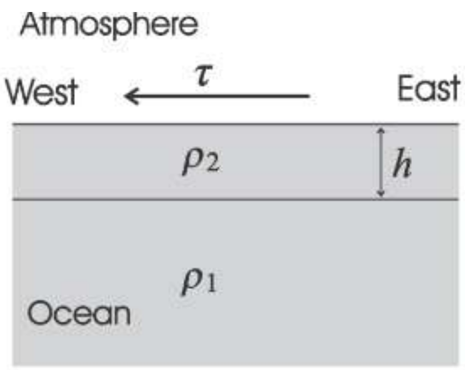
Marshall and Plumb (2008)

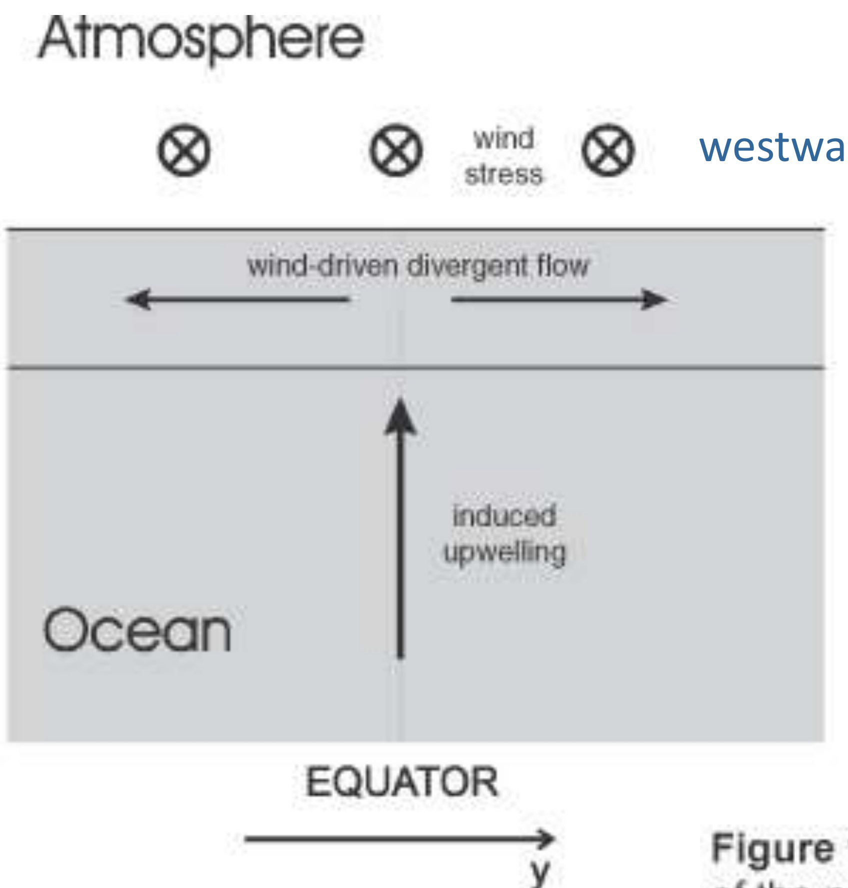


Ekman driven eq. upwelling

- In response to the westward wind stress (τ <0) associated with the easterly tropical trade winds,
- ocean flow above the thermocline must be driven northward/ southward north/ south of the equator *($f \approx \beta y$; y distance north of the equator; β gradient of Coriolis parameter at the eq.)*,
- divergent of the ocean flow and consequently upwelling near the equator (within ±2.25 of latitude, see equatorial deformation radius PP. 267).

Equatorial oceanic upwelling



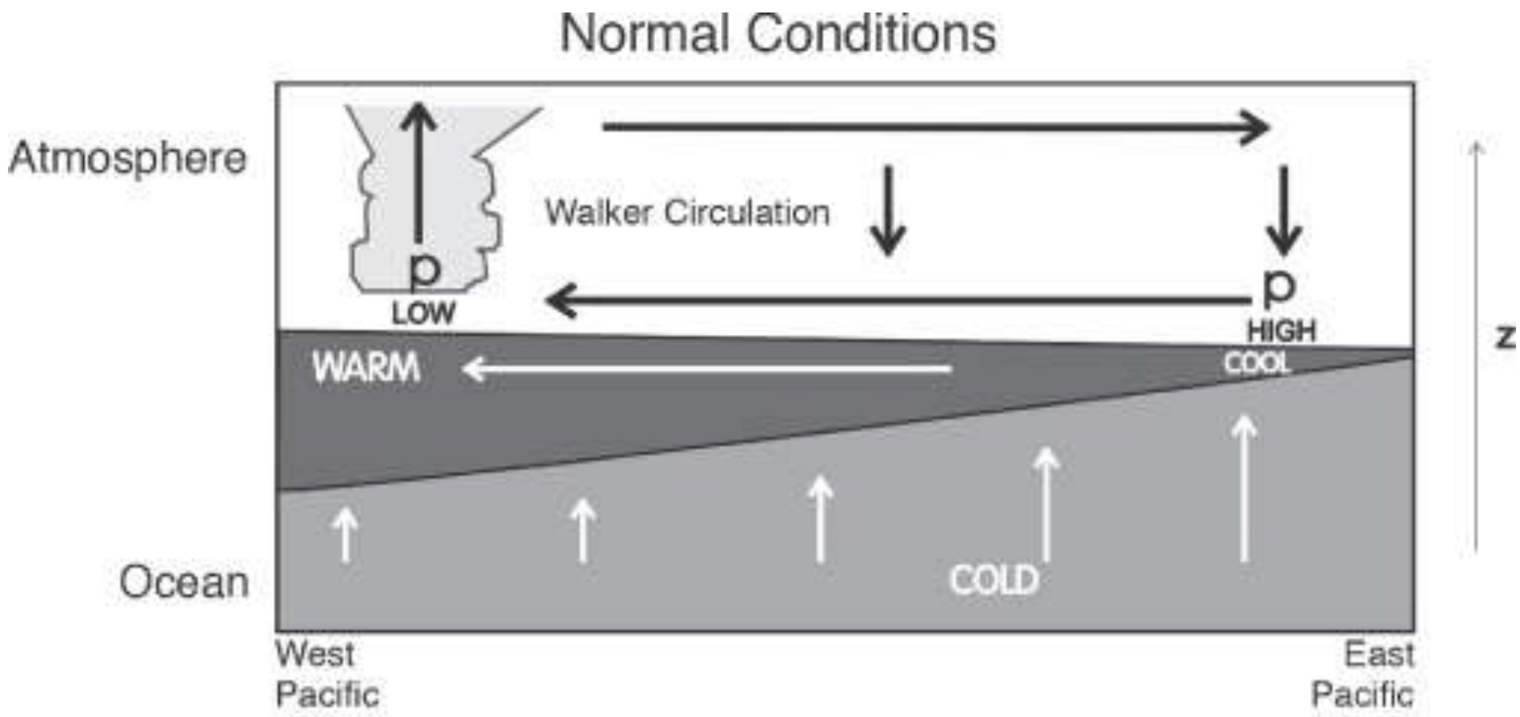


westward wind stress

Figure 12.5: Schematic meridional cross section of the near-equatorial up-welling induced by a westward wind stress near the equator. Since the upper-layer flow is divergent, mass continuity demands upwelling through the thermo-cline.

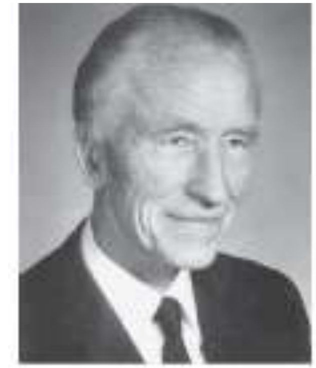
Marshall and Plumb (2008)

In reality: tropical Pacific is bounded to the East (South America) and to the West (shallow seas of Indonesia)…

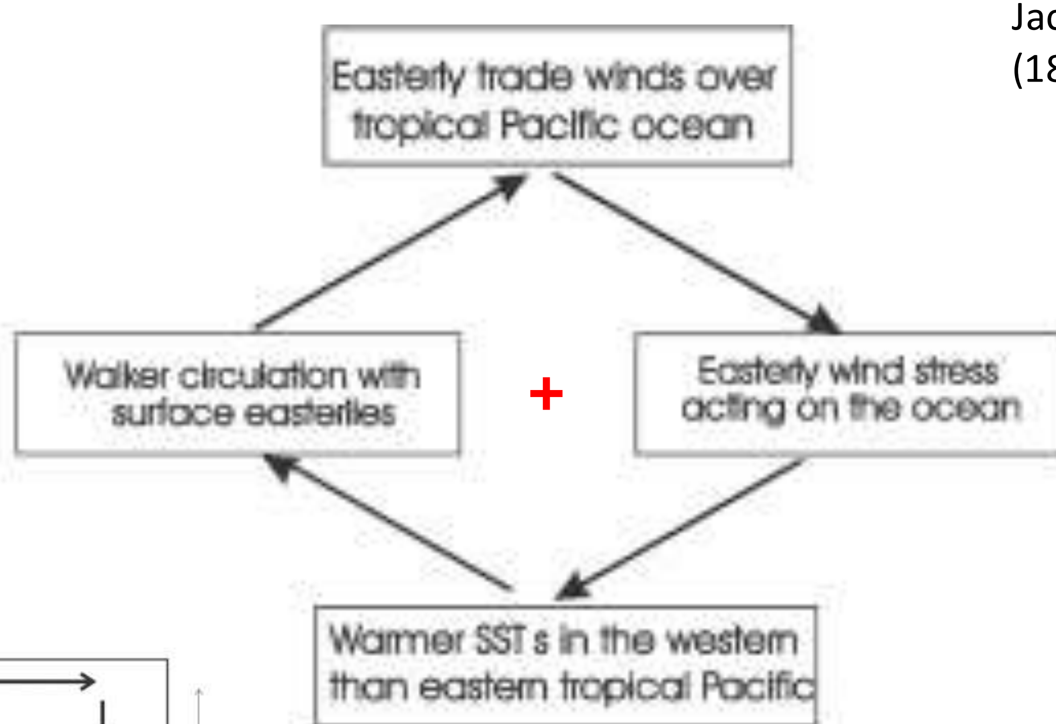


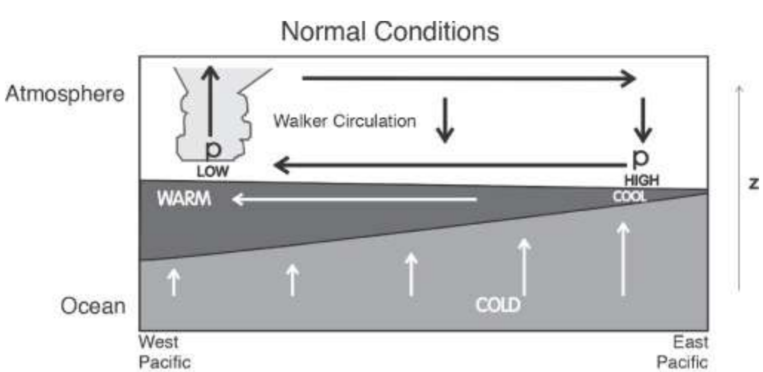
Marshall and Plumb (2008)

Bjerknes feedback



Jacob Bjerknes
(1897-1975)

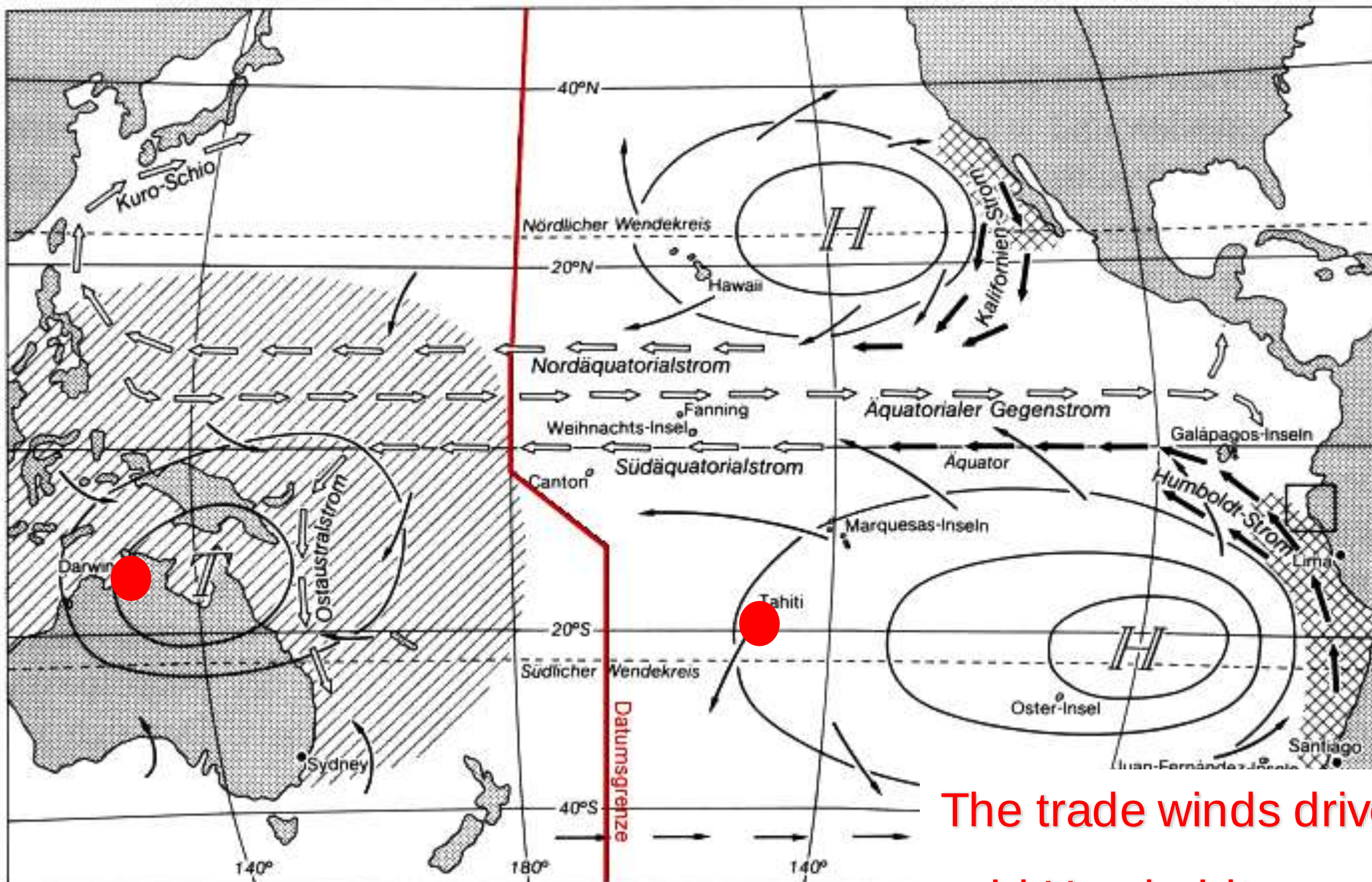




Marshall and Plumb (2008)

Walker circulation – atmospheric phenomena

W



E

The trade winds drive the cold Humboldt current

● Southern Oscillation Index (SOI): for the most part $p_{\text{Tahiti}} - p_{\text{Darwin}} > 0$

Kalte Meeresströmungen — Warme Meeresströmungen

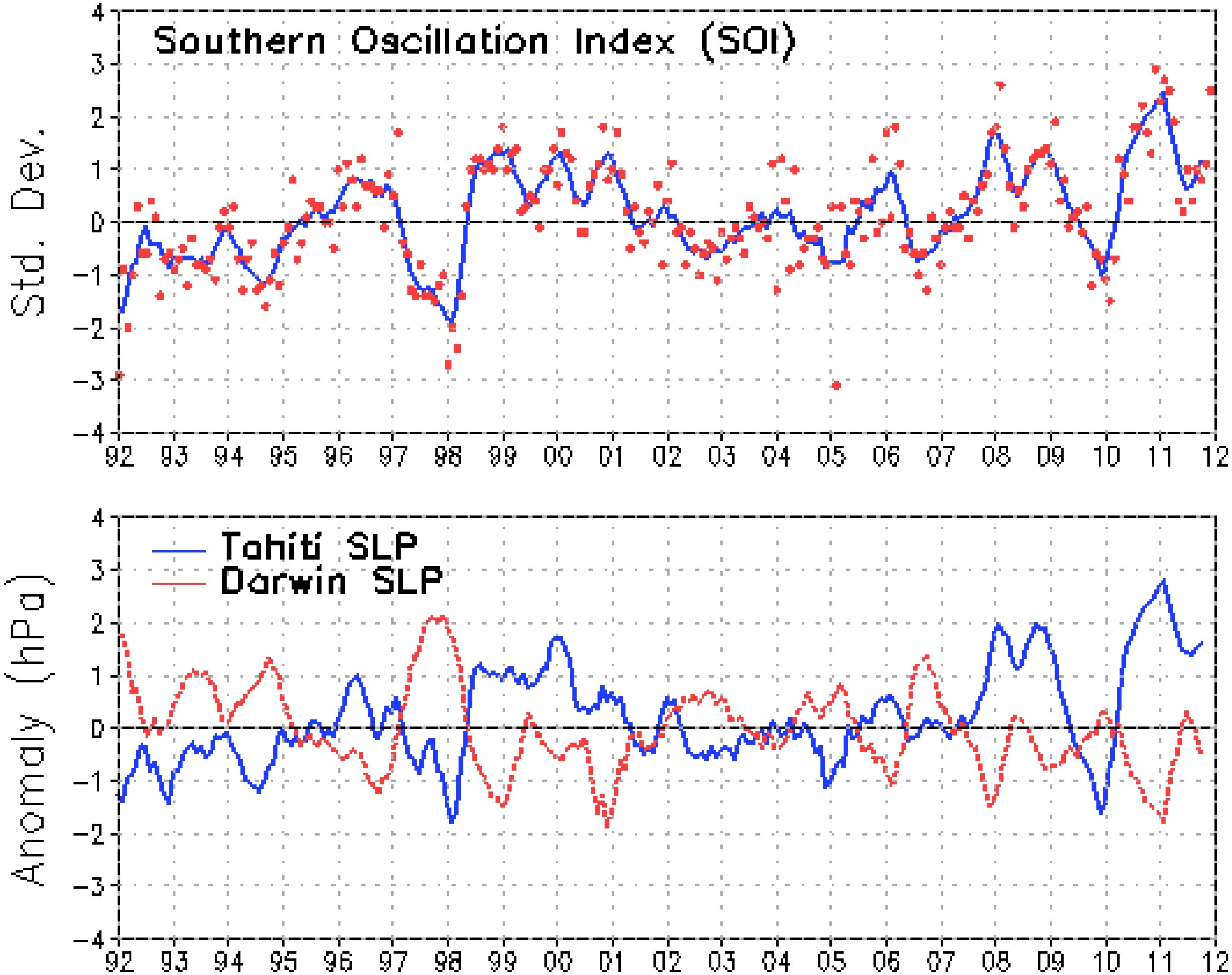
Niedrige Meeresoberflächentemperaturen (Aufquellendes Tiefenwasser, Niederschlagsneigung gering)

Hohe Meeresoberflächentemperaturen (Tropisch-warmes Oberflächenwasser, konvektives Niederschlagsgeschehen)

Persistente Luftdruckgebilde — Vorherrschende Windrichtungen

www.enso.info/enso.html

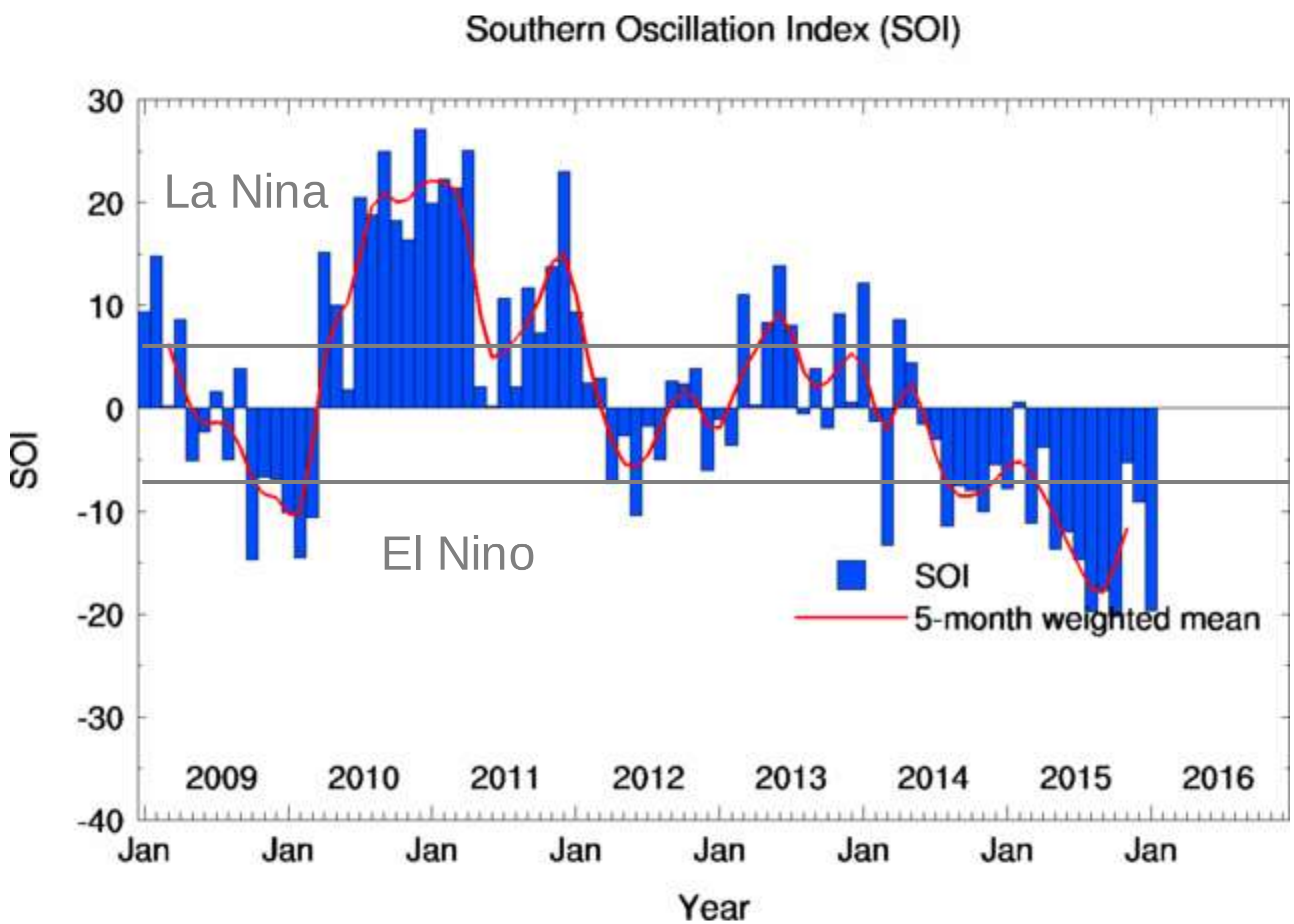
SOI: 1992–2011



SOI = (Standardized SLP Tahiti - Standardized SLP Darwin) / Monthly Standard Deviation of ΔSLP

www.cpc.ncep.noaa.gov

SOI: 2009–2016



SOI>0:
below normal air pressure at Darwin and above normal air pressure at Tahiti

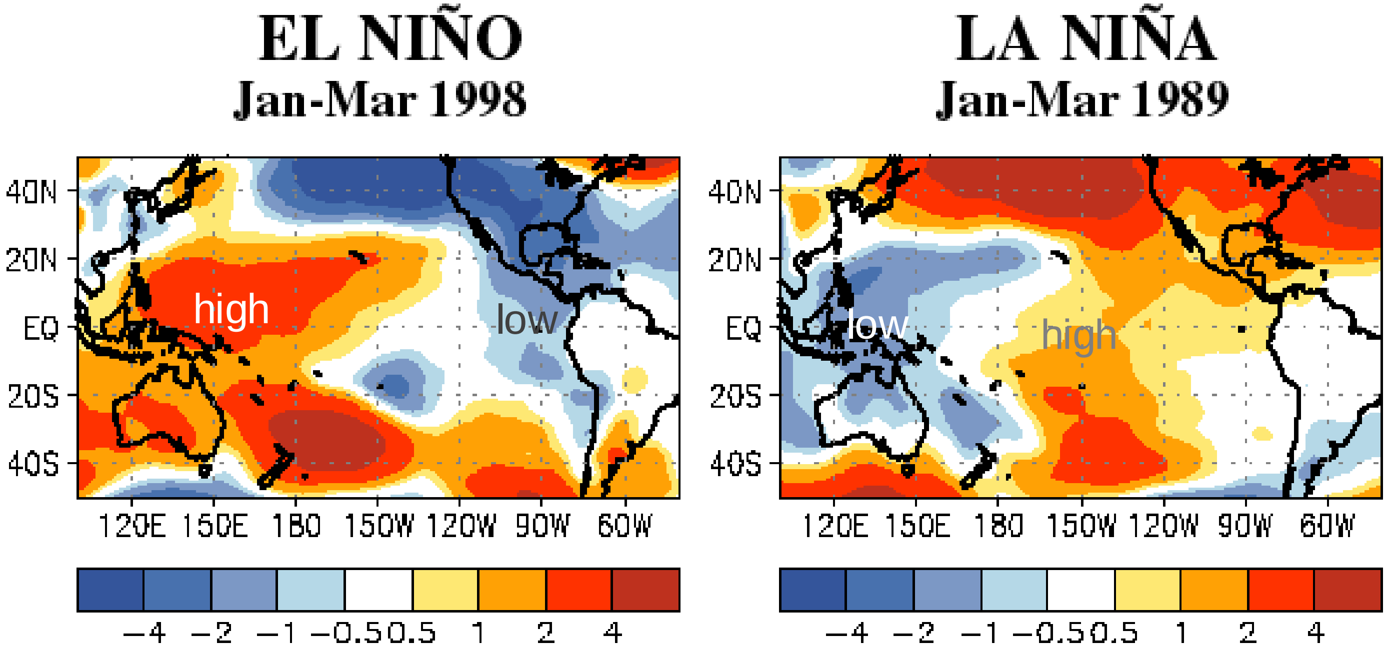
SOI<0 : below normal air pressure at Tahiti and above-normal air pressure at Darwin.

$$SOI = 10 \cdot \frac{\Delta P - \Delta P_{avg}}{s_{\Delta P}}$$

www.bom.gov.au/climate/glossary/soi.shtml

ΔP = (average Tahiti MSLP for the month) - (average Darwin MSLP for the month),
ΔP_{avg} = long term average of ΔP for the month in question, and
$s_{\Delta P}$ = long term standard deviation of ΔP for the month in question.

Southern Oscillation: Sea Level Pressure (SLP) anomalies (hPa)

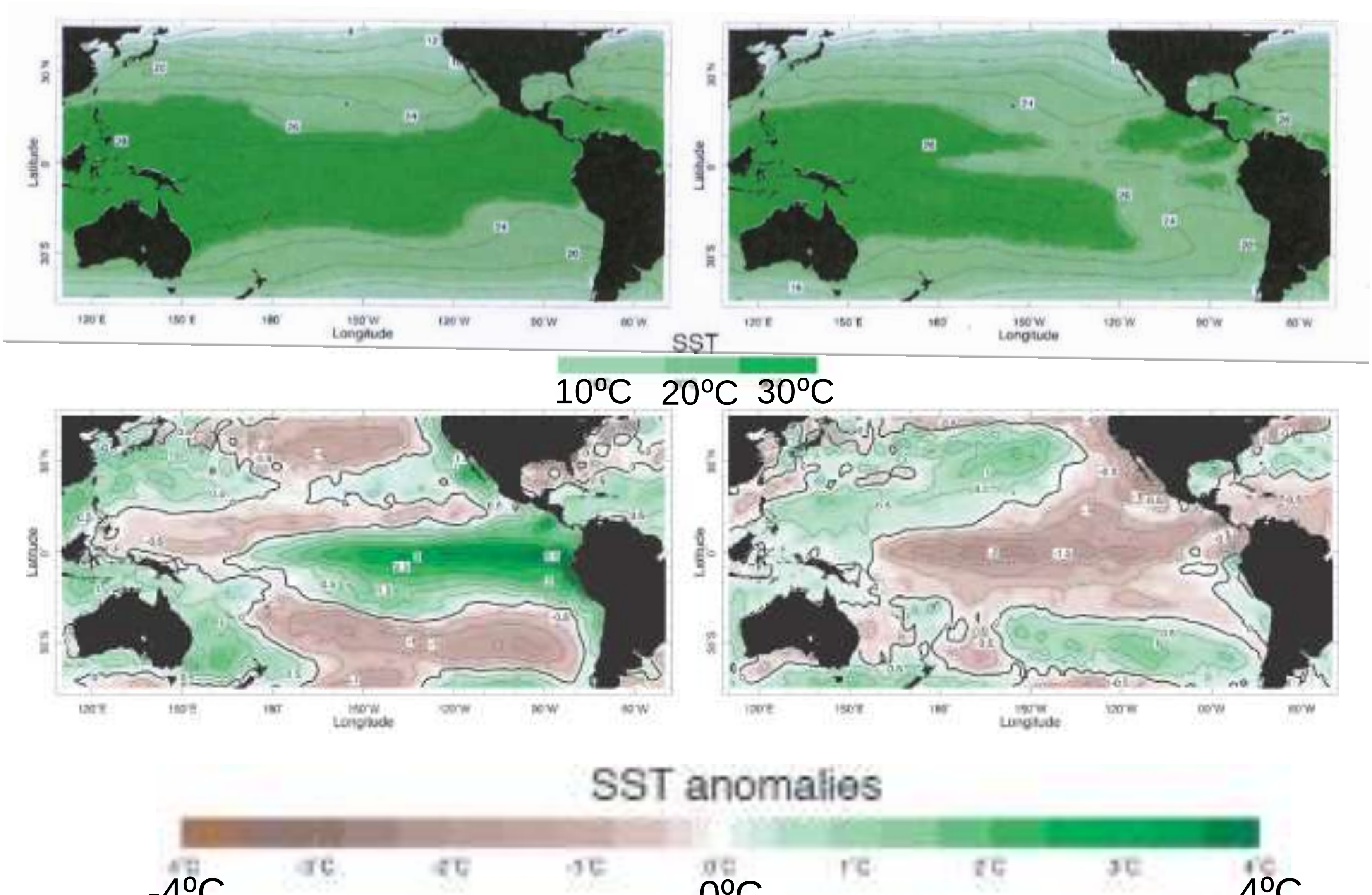


-Negative phase of the Southern Oscillation occurs during El Niño.
-Positive phase of the Southern Oscillation occurs during La Niña.

www.cpc.ncep.noaa.gov

El Niño Jan-Mar 1998

La Niña Jan-Mar 1989



Marshall and Plumb (2008)

SOI and SST anomalies (K) in equatorial East Pacific

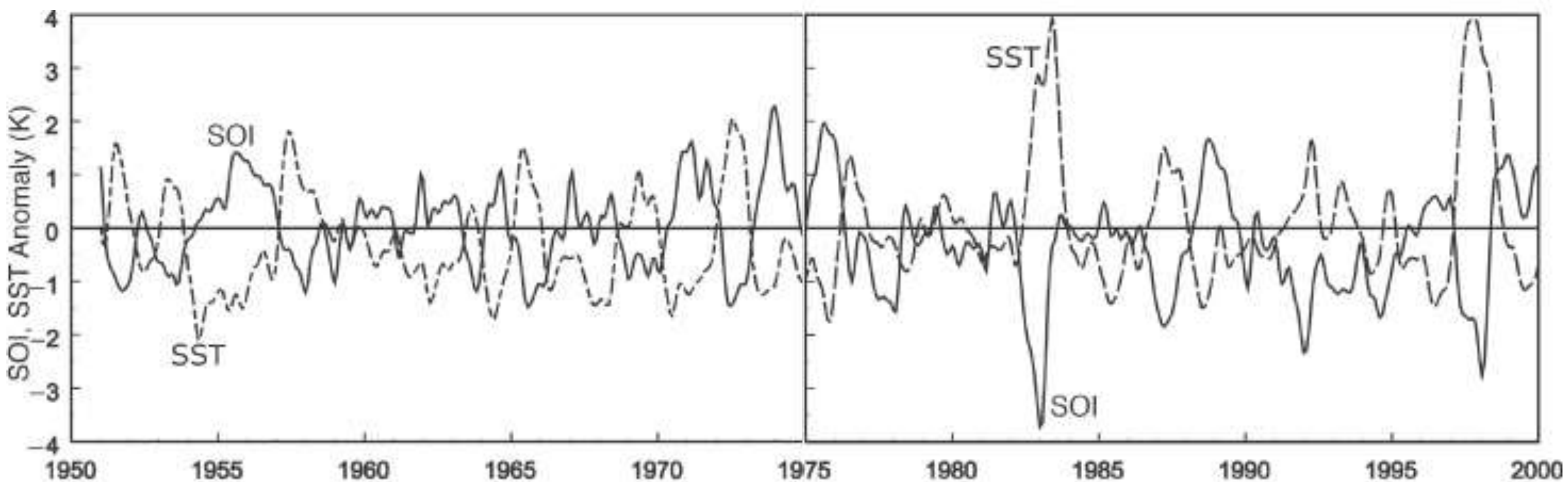


Figure 12.10: The Southern Oscillation index (solid) and sea surface temperature (SST) anomaly (K) in the equatorial east Pacific Ocean (dashed), for the period 1951–2000. The SST anomaly refers to a small near-equatorial region off the coast of South America. The two time series have been filtered to remove fluctuations of less than about 3 months.

Marshall and Plumb (2008)

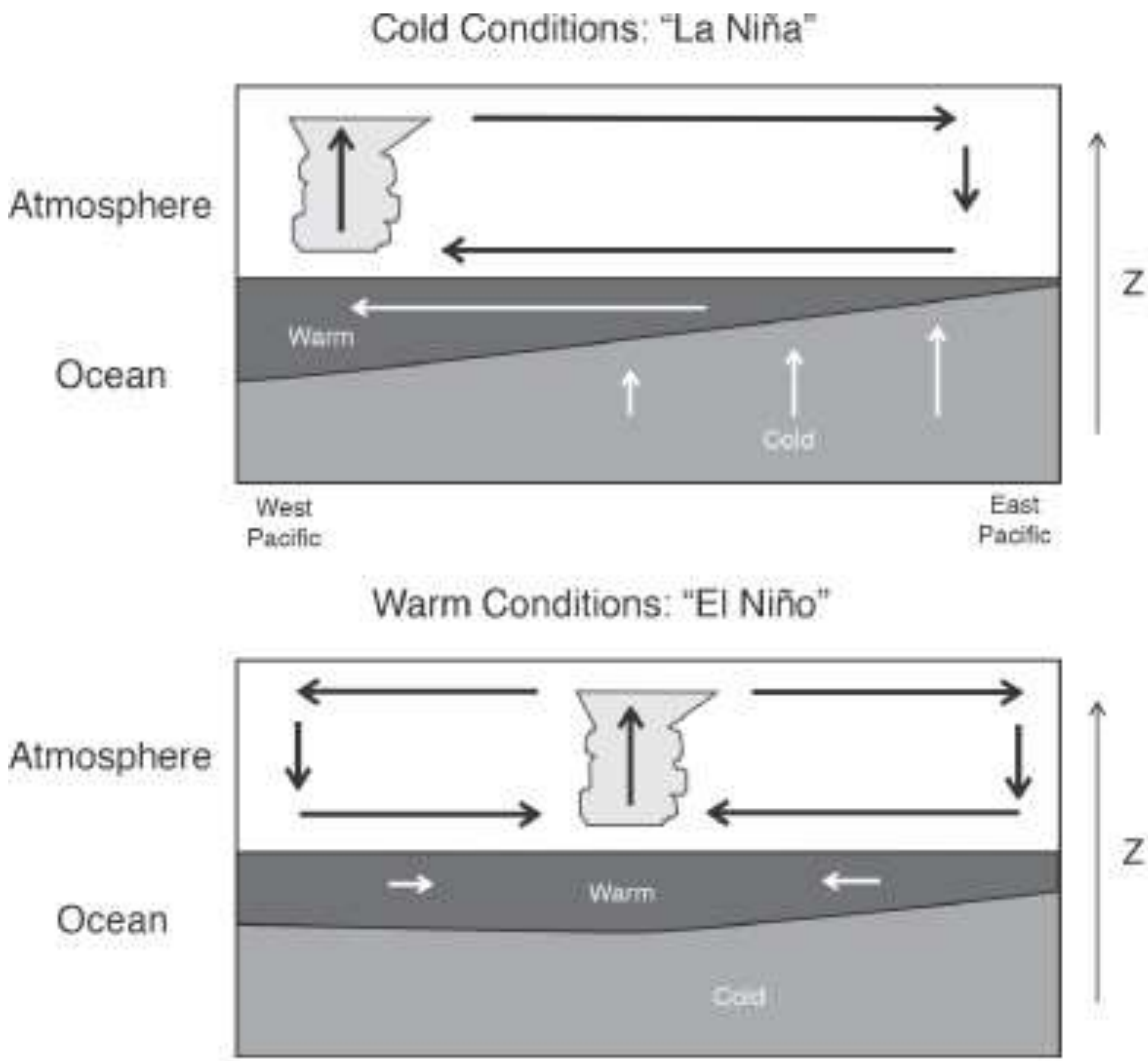


Figure 12.11: Schematic of the Pacific Ocean-Atmosphere system during (top) cold La Niña and (bottom) warm El Niño conditions.

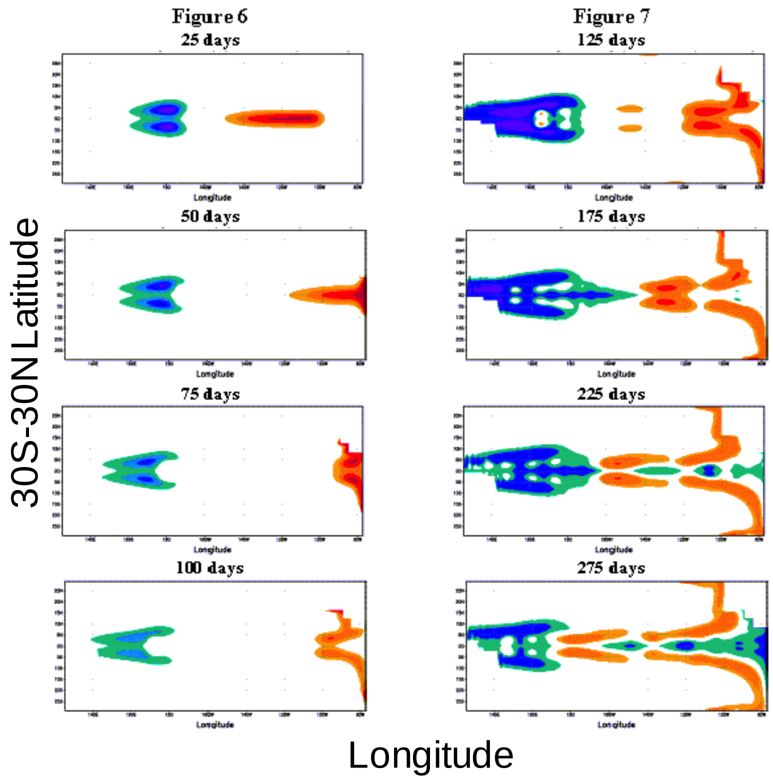
Marshall and Plumb (2008)

Onset of El Nino - **Bjerknes Feedback**

- Deepening of the thermocline in the Equatorial Eastern Pacific (EEP),
- reduced west-east SST-gradient,
- anomalous wind blowing from west to east,
- shift of convection cell to central Pacific,
- flow of warm surface waters from west to east Pacific (= positive Bjerknes feedback.)

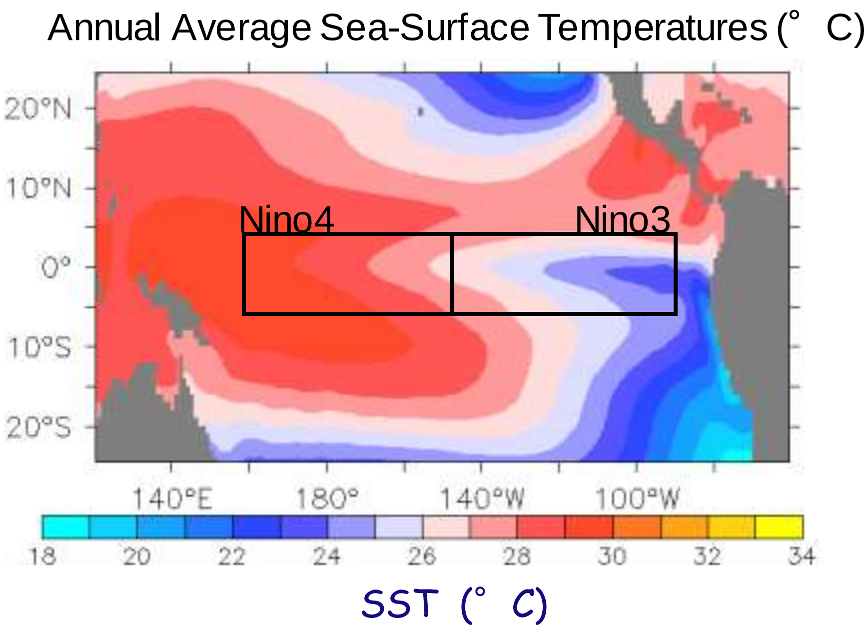
Termination of El Nino - **Delayed Oscillator**

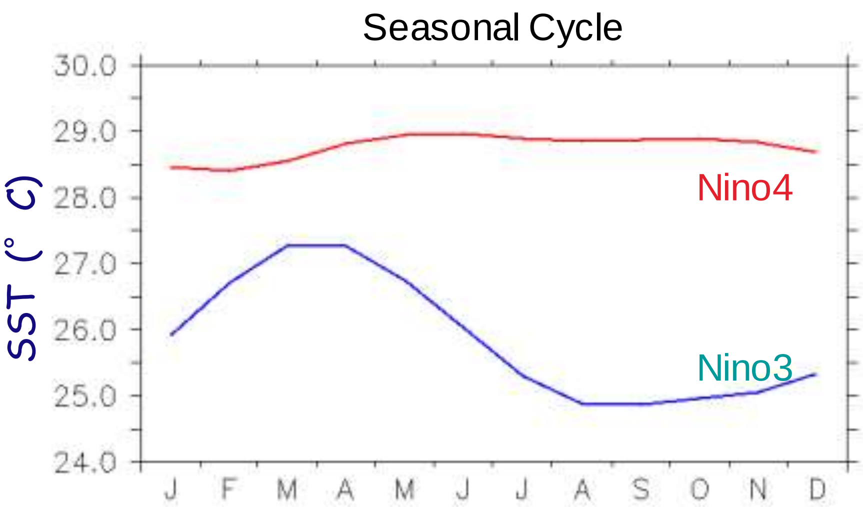
- Initial wave deepening the EEP thermocline also generates a shoaling westward wave.
- This wave reflects at the western boundary of the Pacific and propagates back toward the east -> thermocline shoaling.
- This shoaling wave arrives the EEP about 7-9 months later, terminating El Nino.



orca.rsmas.miami.edu/~melicie/krw2.gif

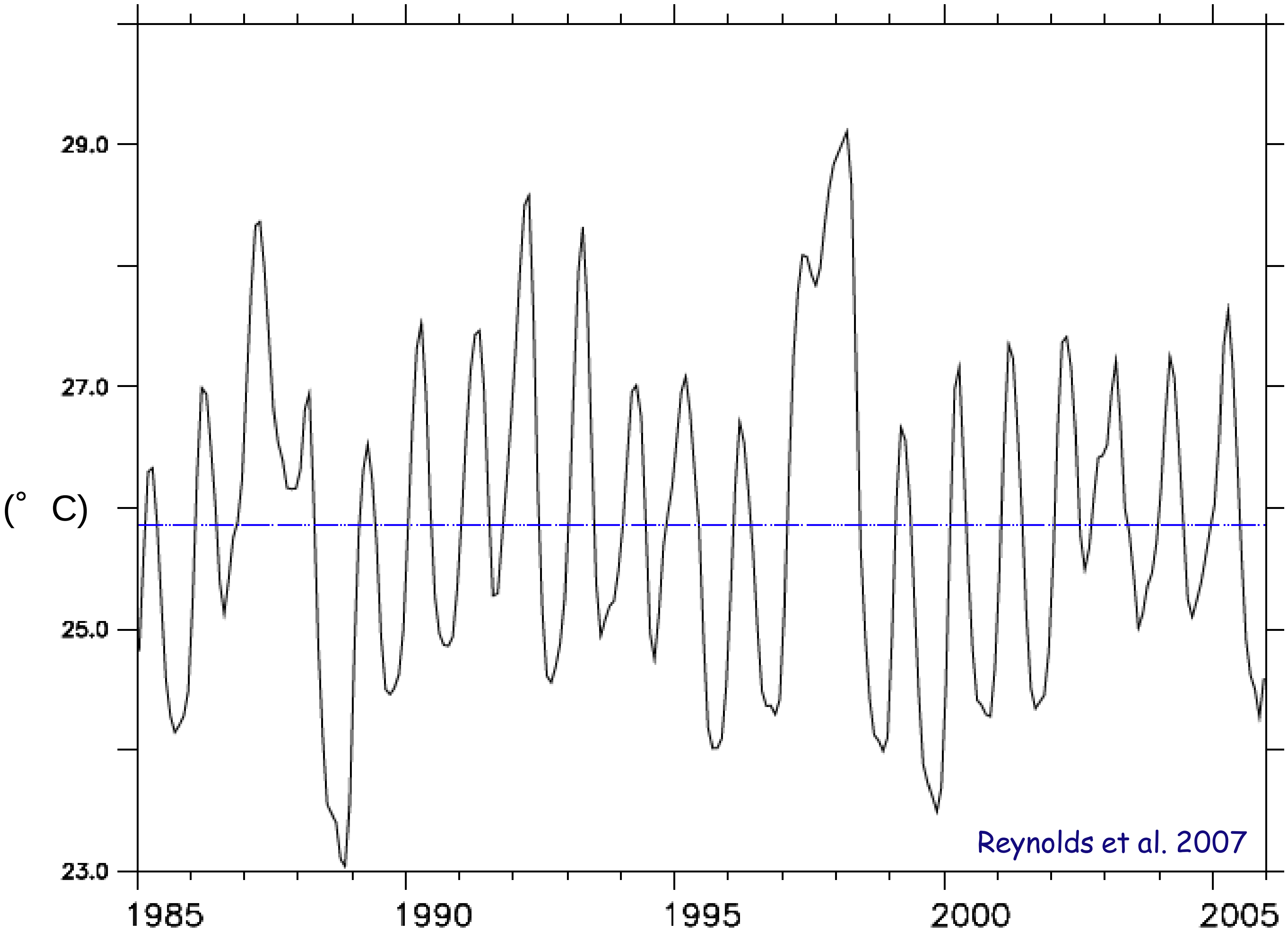
Modern Equatorial Pacific SST Variability



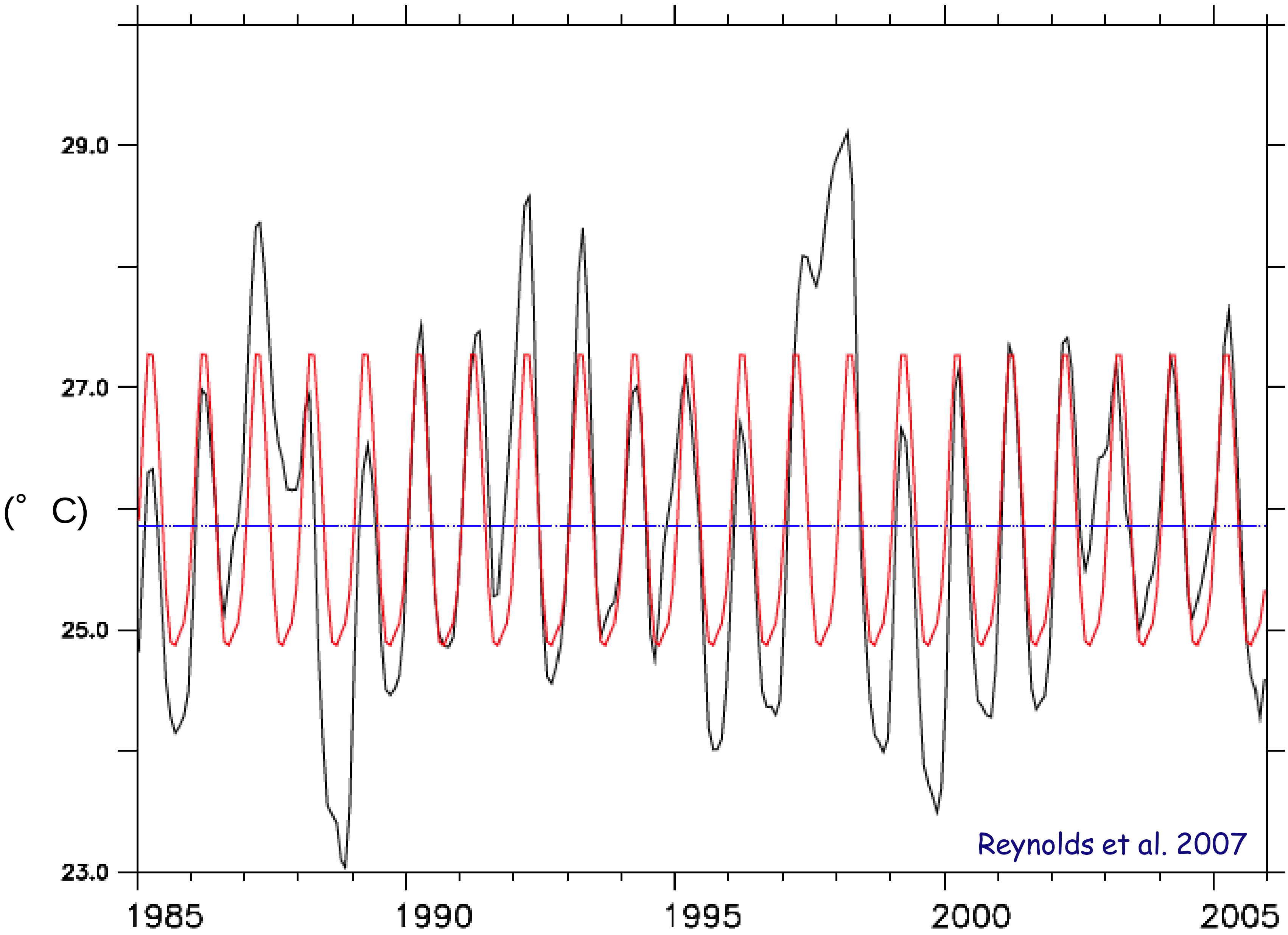


Data from Reynolds et al. 2007

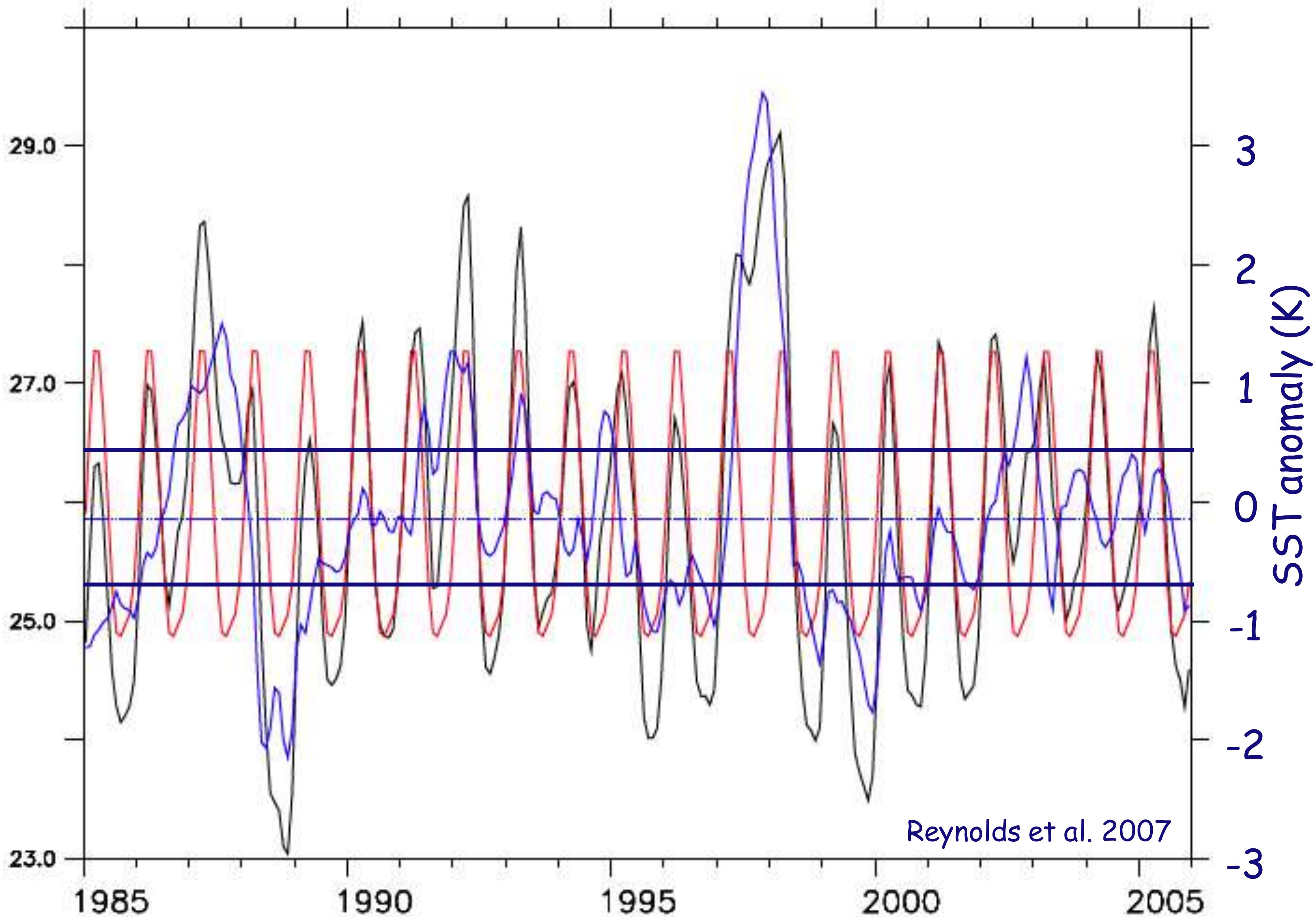
Nino3-SST



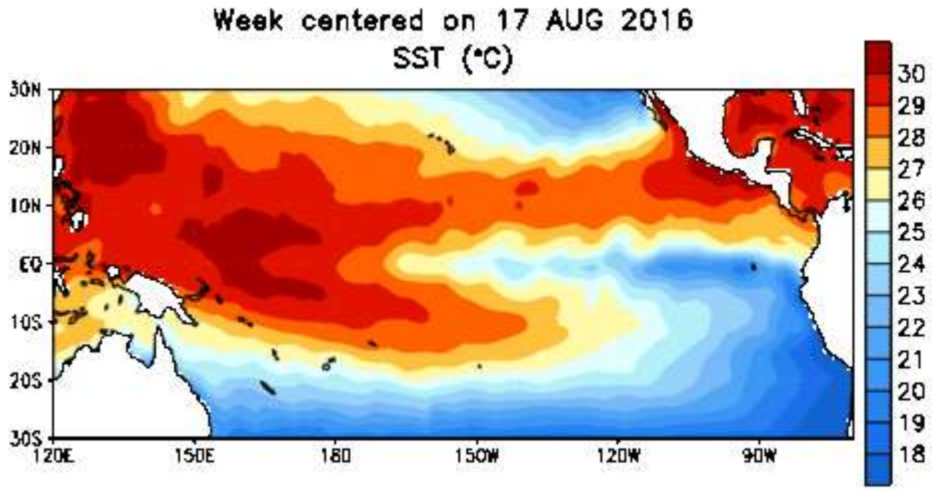
Nino3-SST

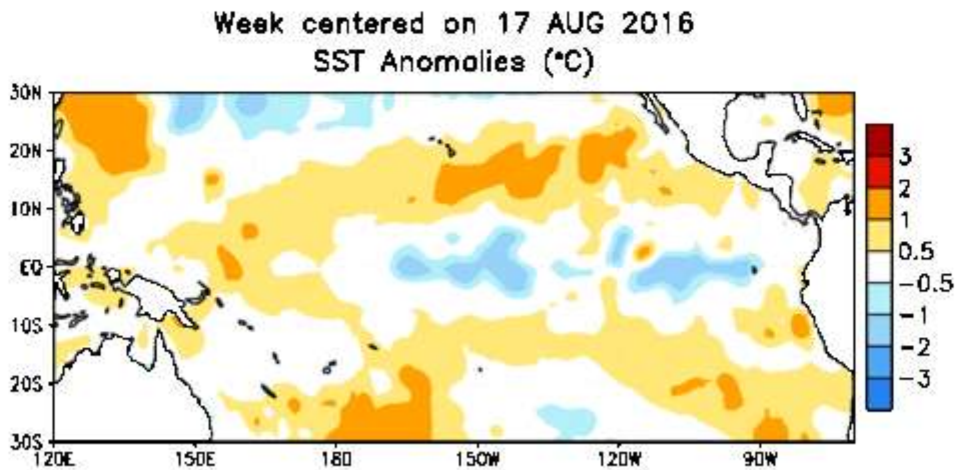


Nino3-SST


29.0
27.0
25.0
23.0
3
2
1
0
-1
-2
-3
SST anomaly (K)
1985
1990
1995
2000
2005
Reynolds et al. 2007

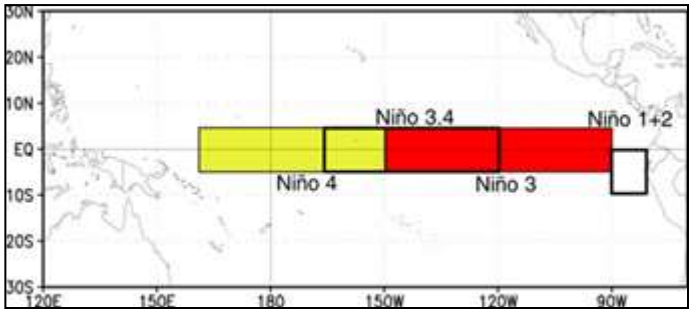
What is the current ENSO situation?





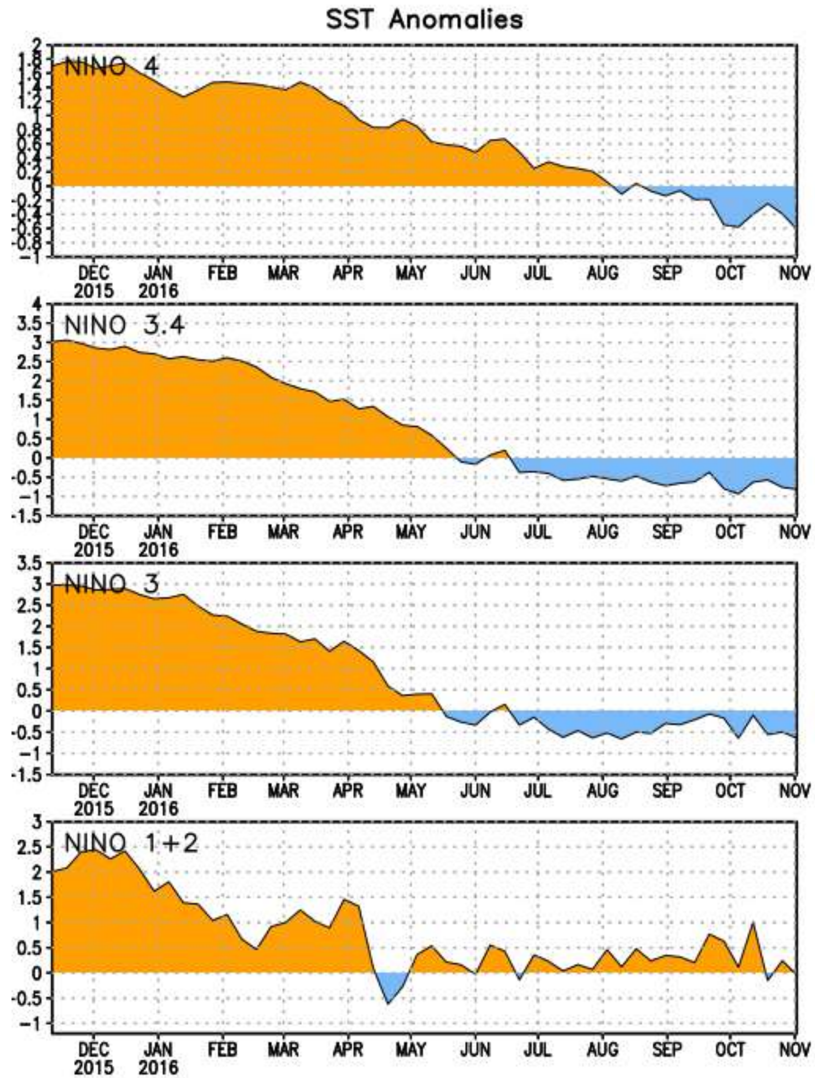
www.cpc.ncep.noaa.gov

Current ENSO conditions



The latest weekly SST departures are:

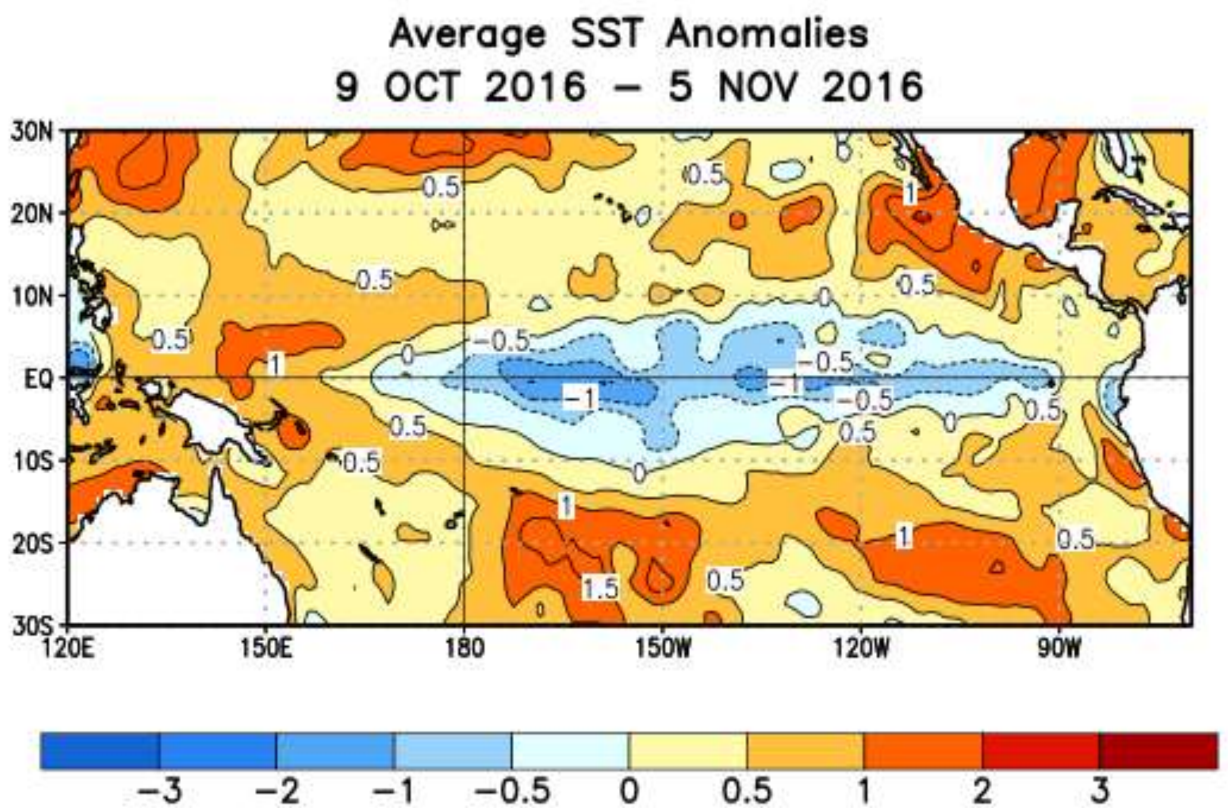
Niño 4	-0.6°C
Niño 3.4	-0.8°C
Niño 3	-0.6°C
Niño 1+2	0.0°C

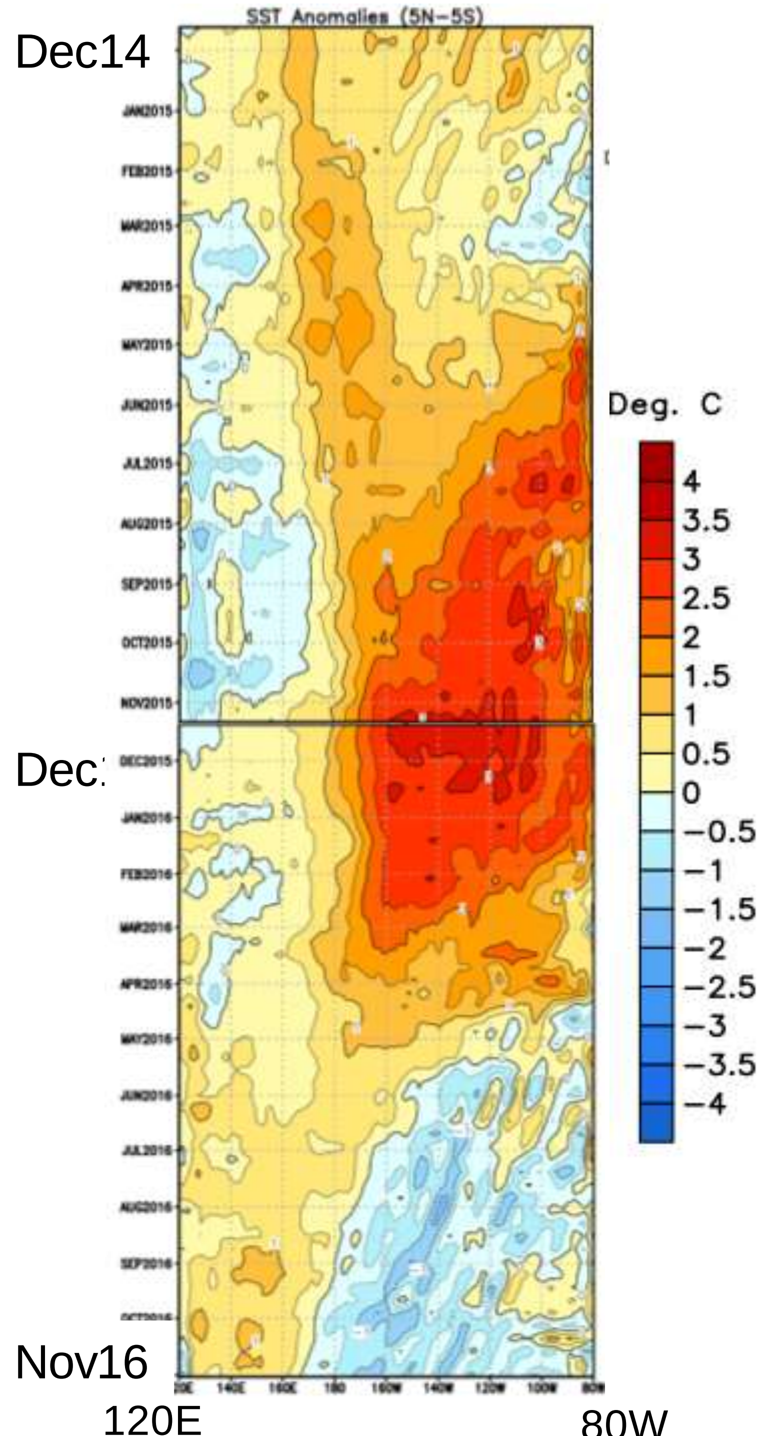


Update prepared by:
Climate Prediction Center / NCEP
7 November 2016

SST Departures (°C) in the Tropical Pacific During the Last Four Weeks

During the last four weeks, equatorial SSTs were below average across the central and east-central Pacific, and near average in the far eastern Pacific.





SST anomalies 5N – 5S

Dec 2014 – November 2016

- From winter 2014 until June 2016 El Nino conditions were prevailing.

-Since mid-April 2016, near-to-below average SSTs have expanded westward toward the Date Line. > ENSO neutral conditions.

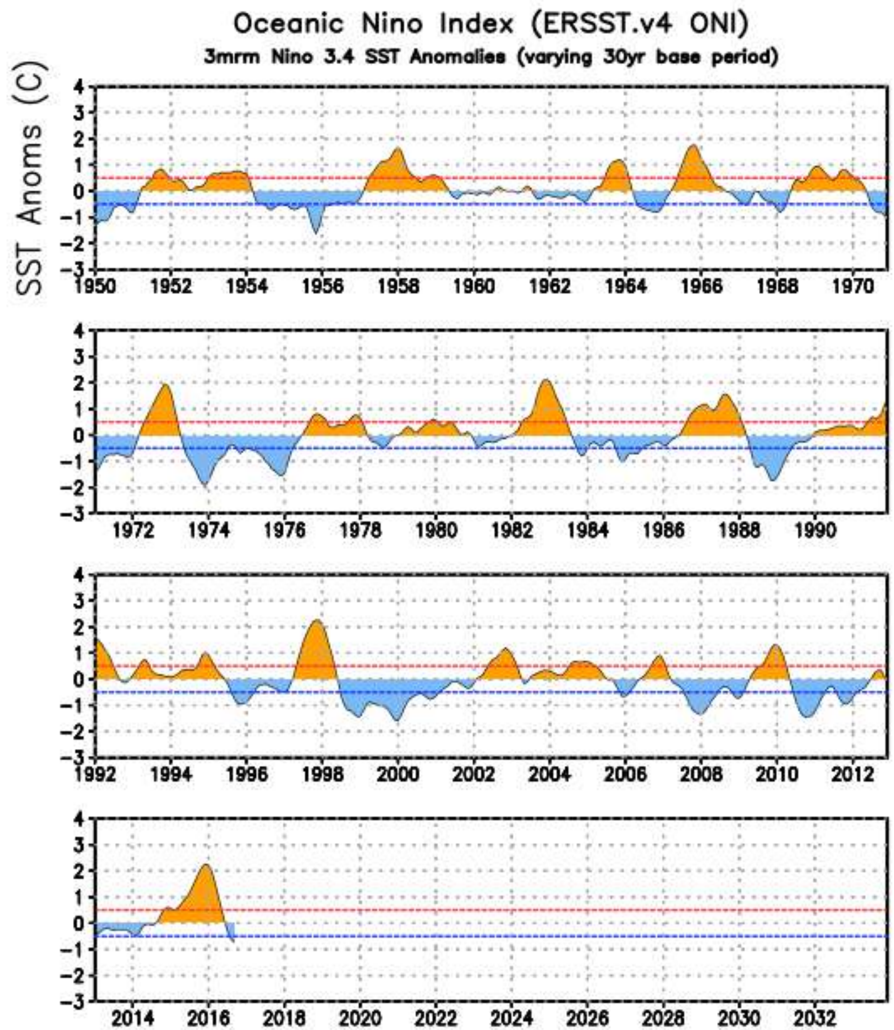
- Over the last month, negative SST anomalies have persisted in the central and east-central Pacific, while SST anomalies in the eastern Pacific have been more variable.

www.cpc.ncep.noaa.gov

El Nino evolution since 1950

The most recent ONI value (August - October 2016) is -0.7°C

Weekly ENSO updates

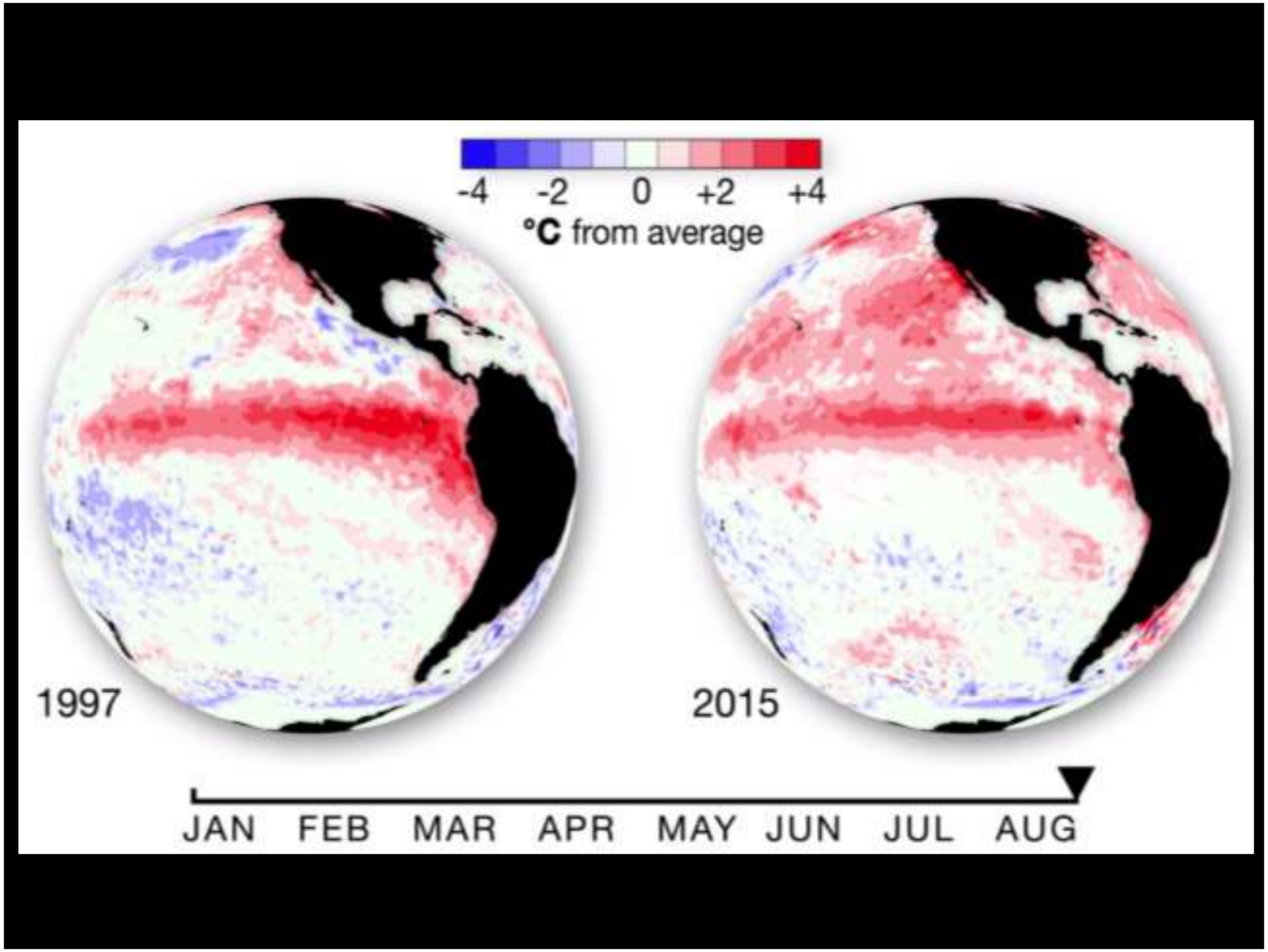


El Niño ↑
Neutral
La Niña ↓

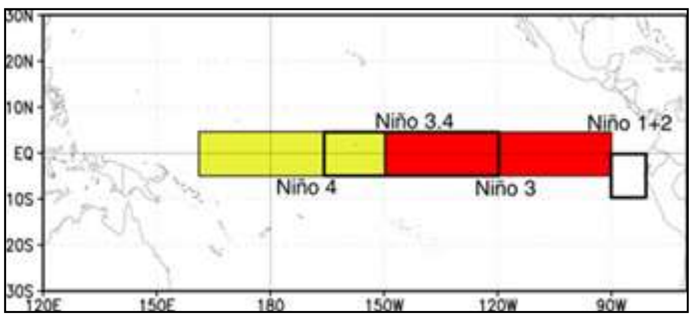
CPC considers El Niño or La Niña conditions to occur when the monthly Niño3.4 ONI departures meet or exceed +/- 0.5° C along with consistent atmospheric features. These anomalies must also be forecasted to persist for 3 consecutive months.

(www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml)

El Nino 1997 and 2015 developments



Pacific Niño 3.4 SST Model Outlook



Most multi-model averages indicate weak La Niña conditions during the Northern Hemisphere fall and early winter 2016-17.

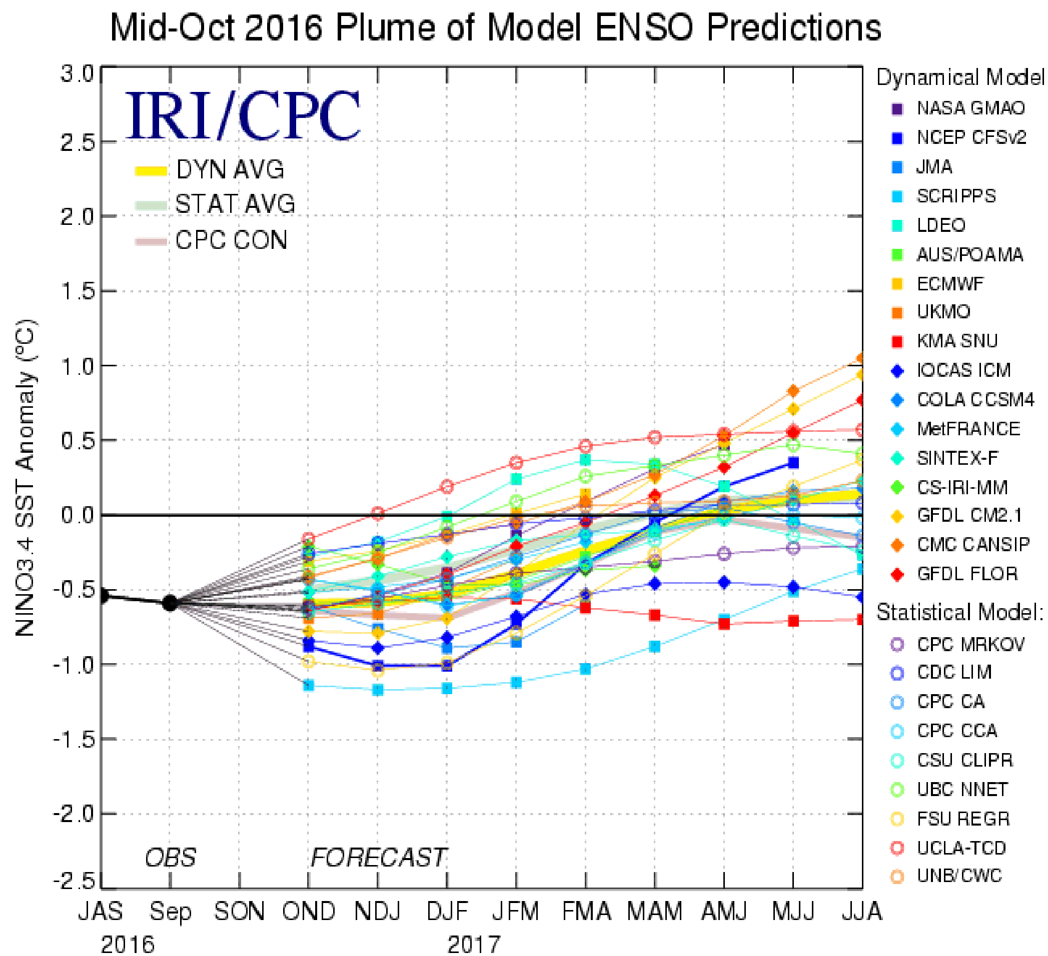
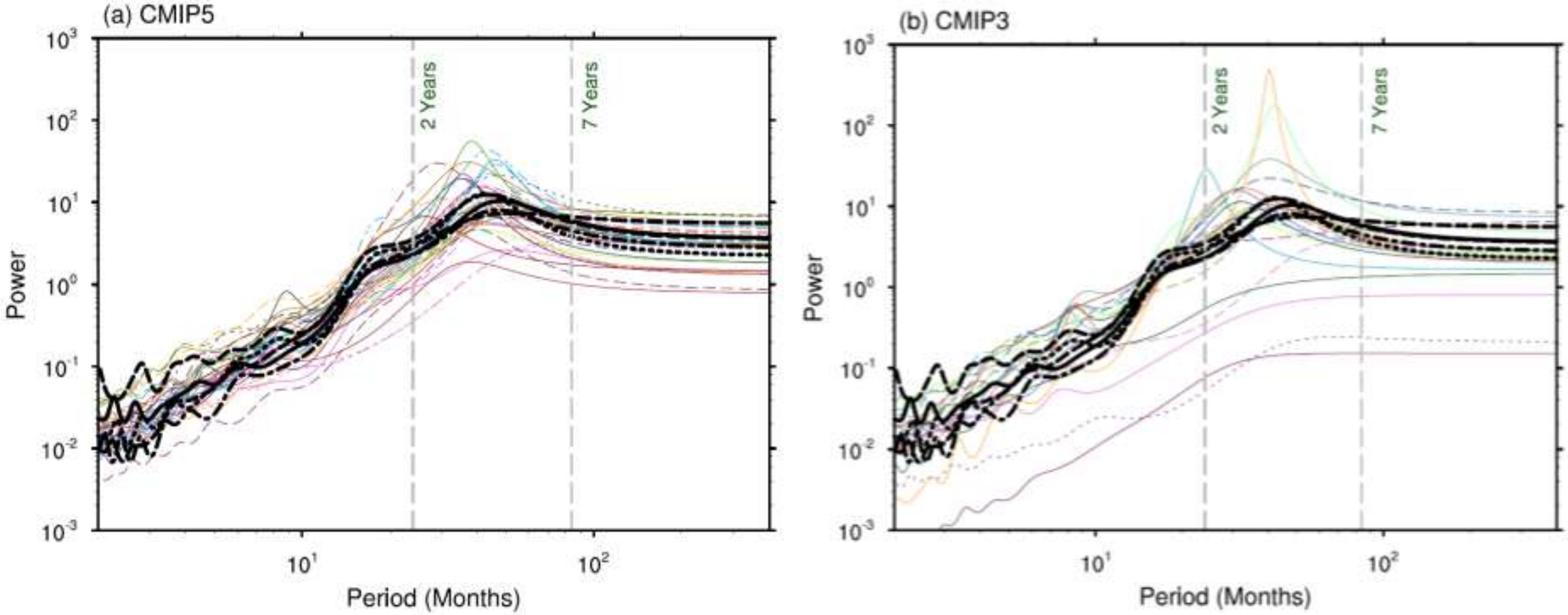


Figure provided by the International Research Institute (IRI) for Climate and Society (updated 18 October 2016).

Update prepared by:
Climate Prediction Center / NCEP
7 November 2016

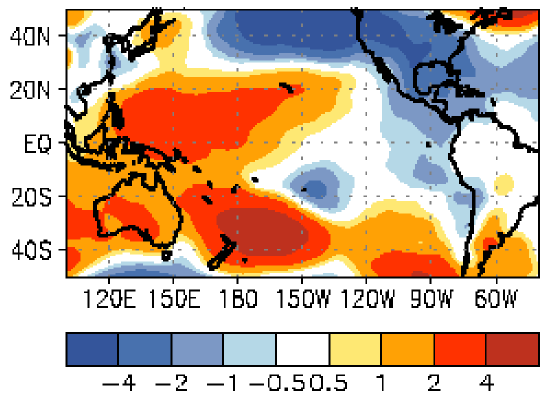
ENSO frequency: observations and CMIP3/5 models

Maximum entropy power spectra of surface air temperature averaged over the NINO3 region (5° N to 5° S, 150° W to 90° W)

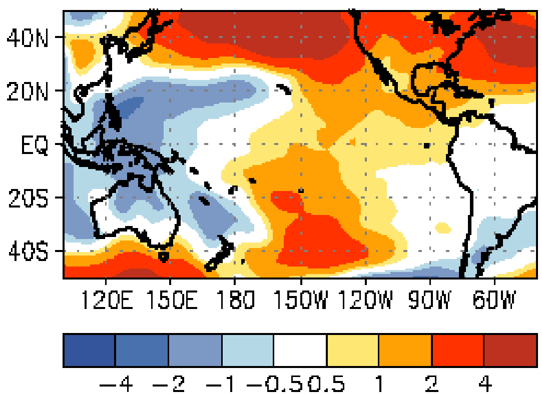


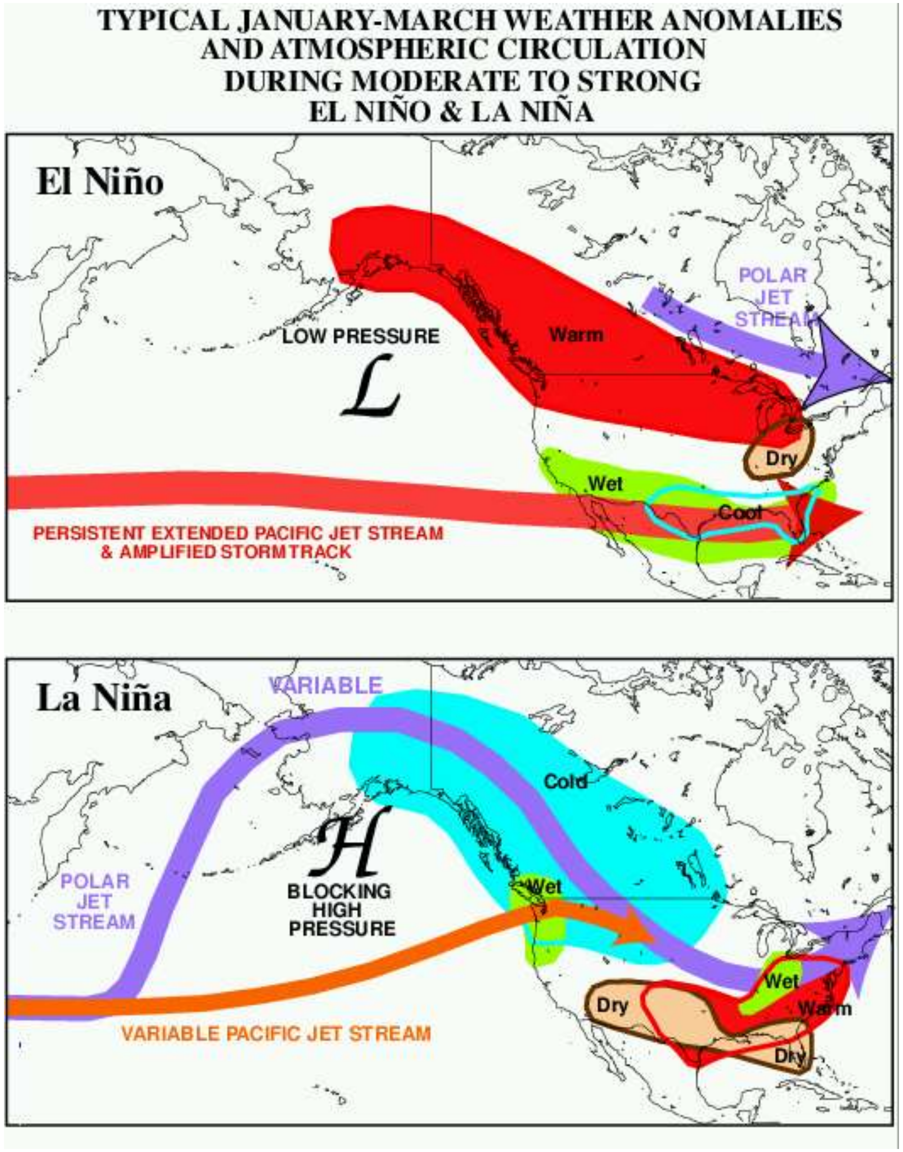
"There is high confidence that the multi-model statistics of ENSO have improved since the AR4." (IPCC, 2013)

EL NIÑO
Jan-Mar 1998



LA NIÑA
Jan-Mar 1989





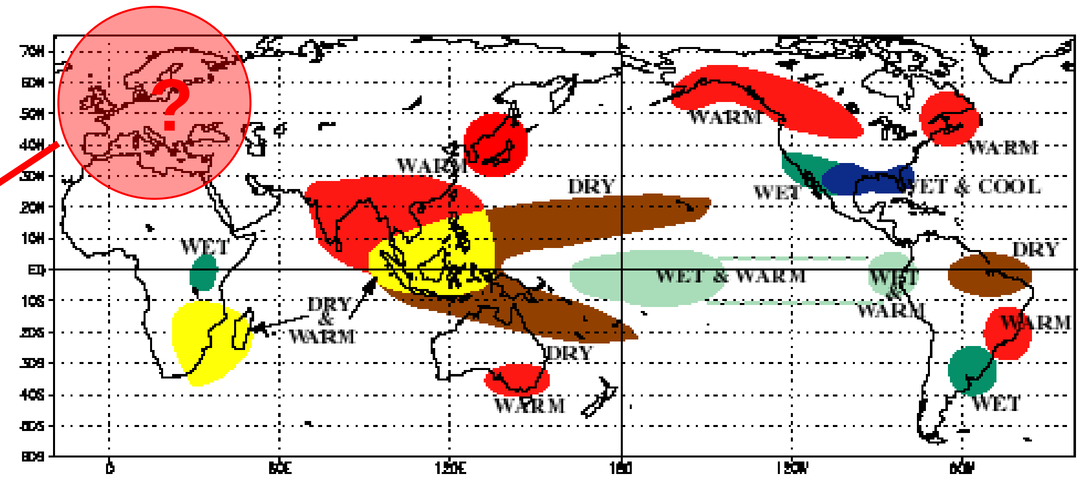
www.cpc.noaa.gov

ENSO warm events: global weather anomalies

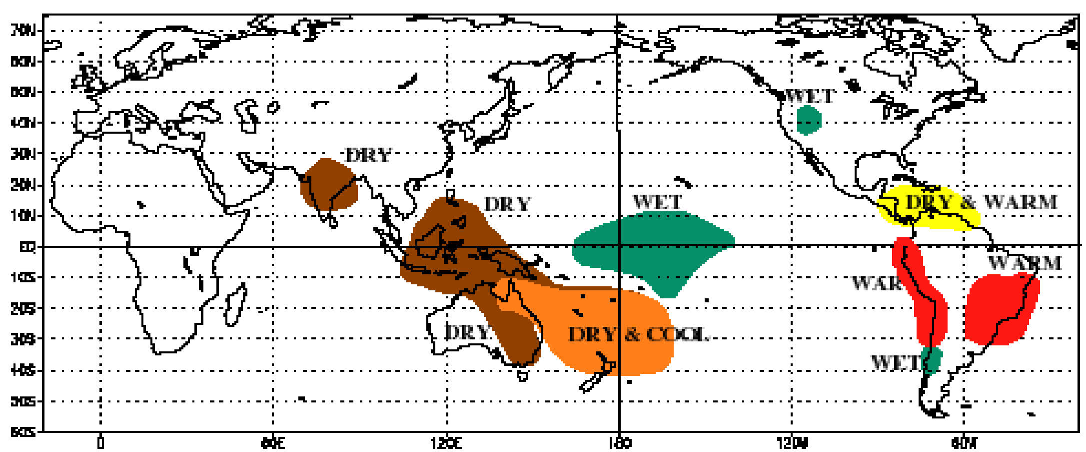
Temperature and precipitation anomaly

Current topic of research

WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



WARM EPISODE RELATIONSHIPS JUNE - AUGUST

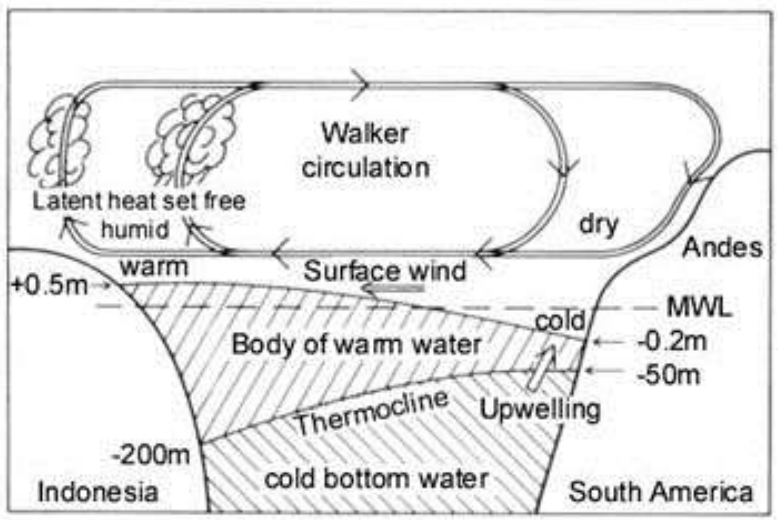


Teleconnections: global remote effects

http://apollo.lsc.vsc.edu/classes/met130/notes/chapter11/gen_circ.html

Walker circulation – normal condition

W



E

Roedel, 1992

1. **Trade winds** transport the warm equatorial **seawater to the west**, which in turn accumulates at the eastern coasts of Indonesia.

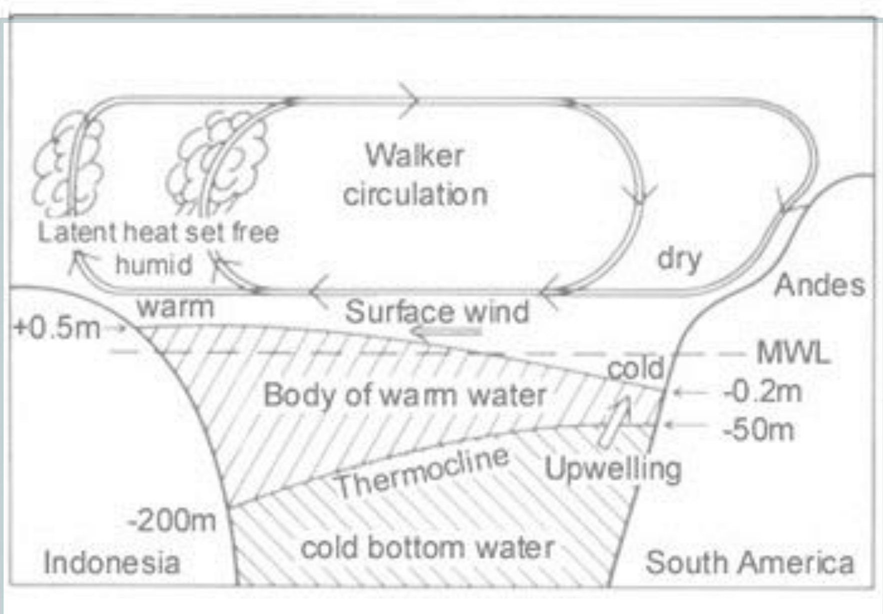
2. As a consequence, upwelling cold water from the depths of the eastern Pacific can rise at the **coast of South America**, and the **Humboldt Current's cold water from Antarctica can flow in.**

3. This causes an air circulation: while the warm water accumulated in the **western Pacific** leads to an **ascent of the air masses** (**low pressure area, precipitation**),

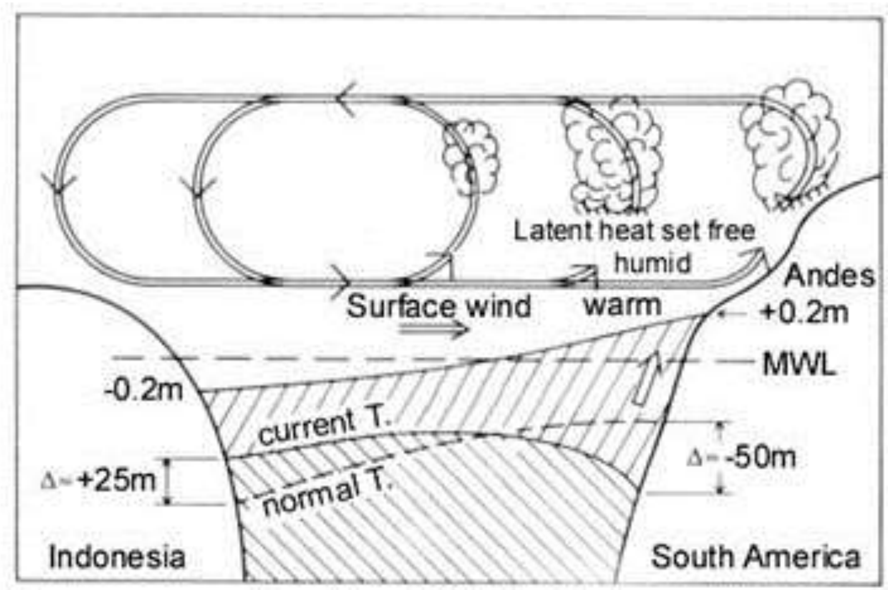
4. the **cold water in the eastern Pacific** leads to **a descent of the air masses** (**high pressure area, drought,** e.g. Atacama desert).

El Niño - Summary

Normal condition



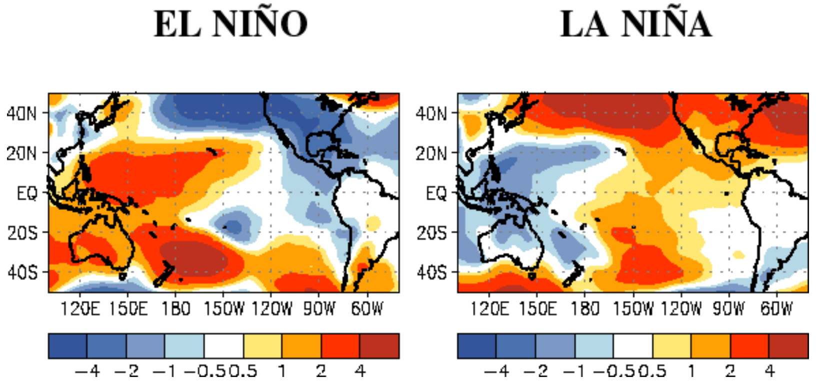
El Niño



- Deepening of the thermocline in the Equatorial Eastern Pacific (EEP),
- reduced west-east SST-gradient,
- anomalous wind blowing from west to east,
- shift of convection cell to the east (Central or East Pacific),
- flow of warm surface waters from west to east Pacific (= **positive Bjerknes feedback**.)

Southern Oscillation - Summary

- Swing in sea level pressure over the tropical Pacific.
- Normal conditions = Walker circulation: low pressure over tropical West Pacific (Darwin) and high pressure over tropical East Pacific (Tahiti).
- Southern Oscillation Index (SOI) based on Tahiti - Darwin SLP.
- El Niño: negative phase of SOI.
- La Niña: positive phase of SOI.



ENSO summary

- **El Niño** and the **S**outhern **O**scillation (**ENSO**) describe a complex coupled circulation system between the atmosphere and ocean in the tropical Pacific.

- El Niño represents the oceanic components,

- while the Southern Oscillation represent the atmospheric components.

- ENSO has three phases:

  ENSO warm event: El Niño SOI < 0
  ENSO cold event: La Niña SOI > 0
  ENSO neutral: SOI ≈ 0 (normal Walker circulation)

- La Niña is an enhanced neutral phase!

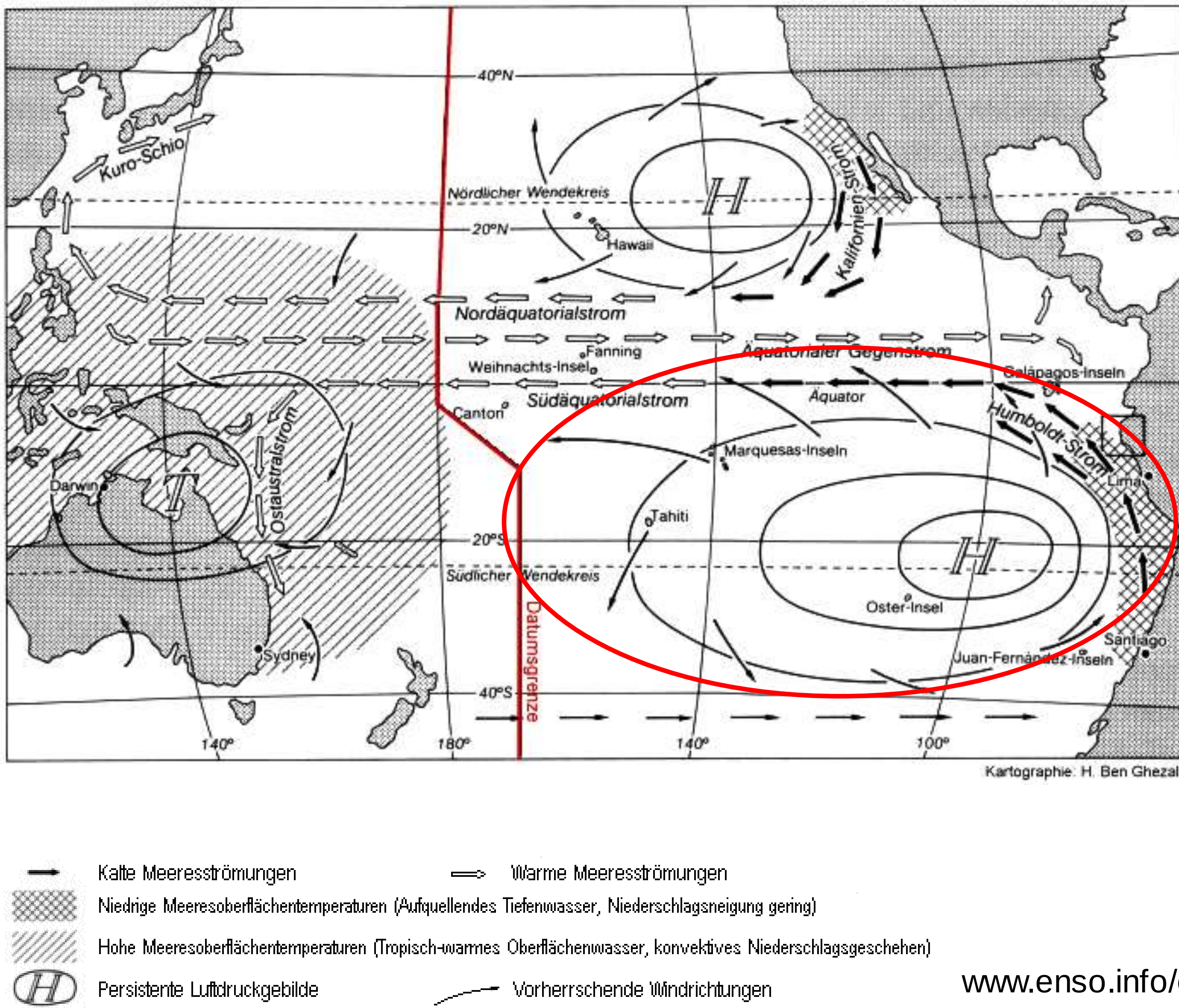
Take home message

- Walker circulation is a zonal atmospheric circulation in the tropical Pacific (SOI).
- ENSO: complex coupled atmosphere-ocean system in the tropical Pacific.
- ENSO dominates the variability in the tropics (Pacific); global teleconnections; relevant for weather and climate.
- ENSO has seasonal and interannual variations (2-7 year period).
- Onset of El Nino → “Bjerknes feedback”; termination of El Nino → “delayed oscillator”.

Quiz

Weather – climate: are there always SE winds in the subtropics of the SH?

W



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www.enso.info/enso.html

Multiple choice questions

- What is El Nino?

a) An oceanic phenomena.

b) A weather phenomena.

c) A warming of sea surface temperatures at the west coast of Peru during Christmas time.

d) A warming of the eastern equatorial Pacific impacting weather and climate worldwide.

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Questions

- The Atacama desert blooms, what are the likely reasons for this unusual phenomena?