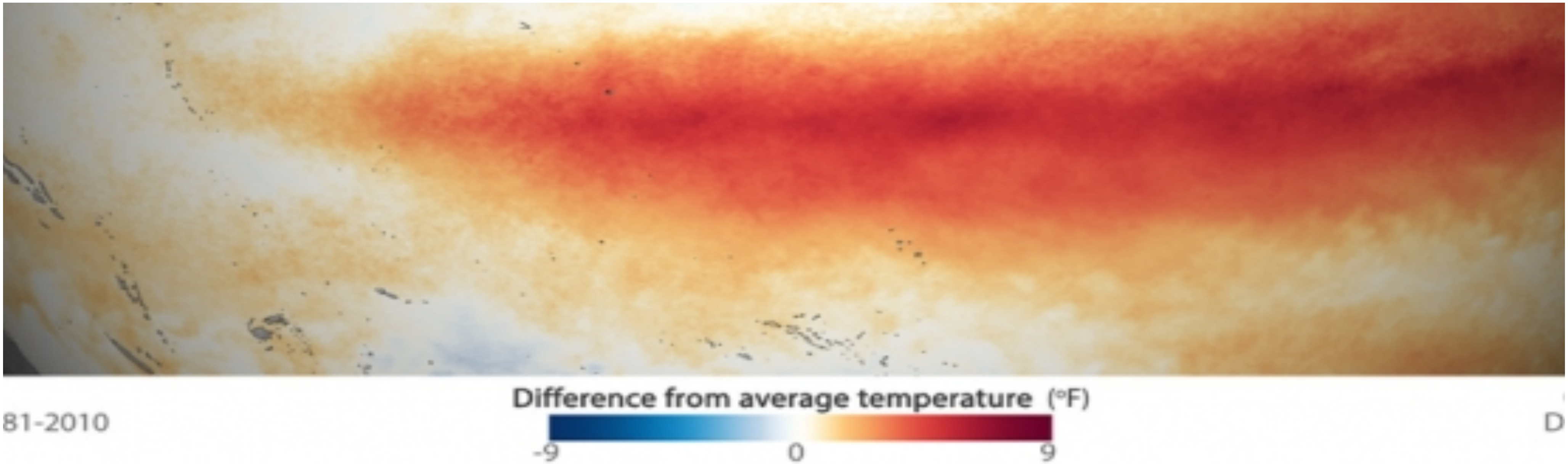
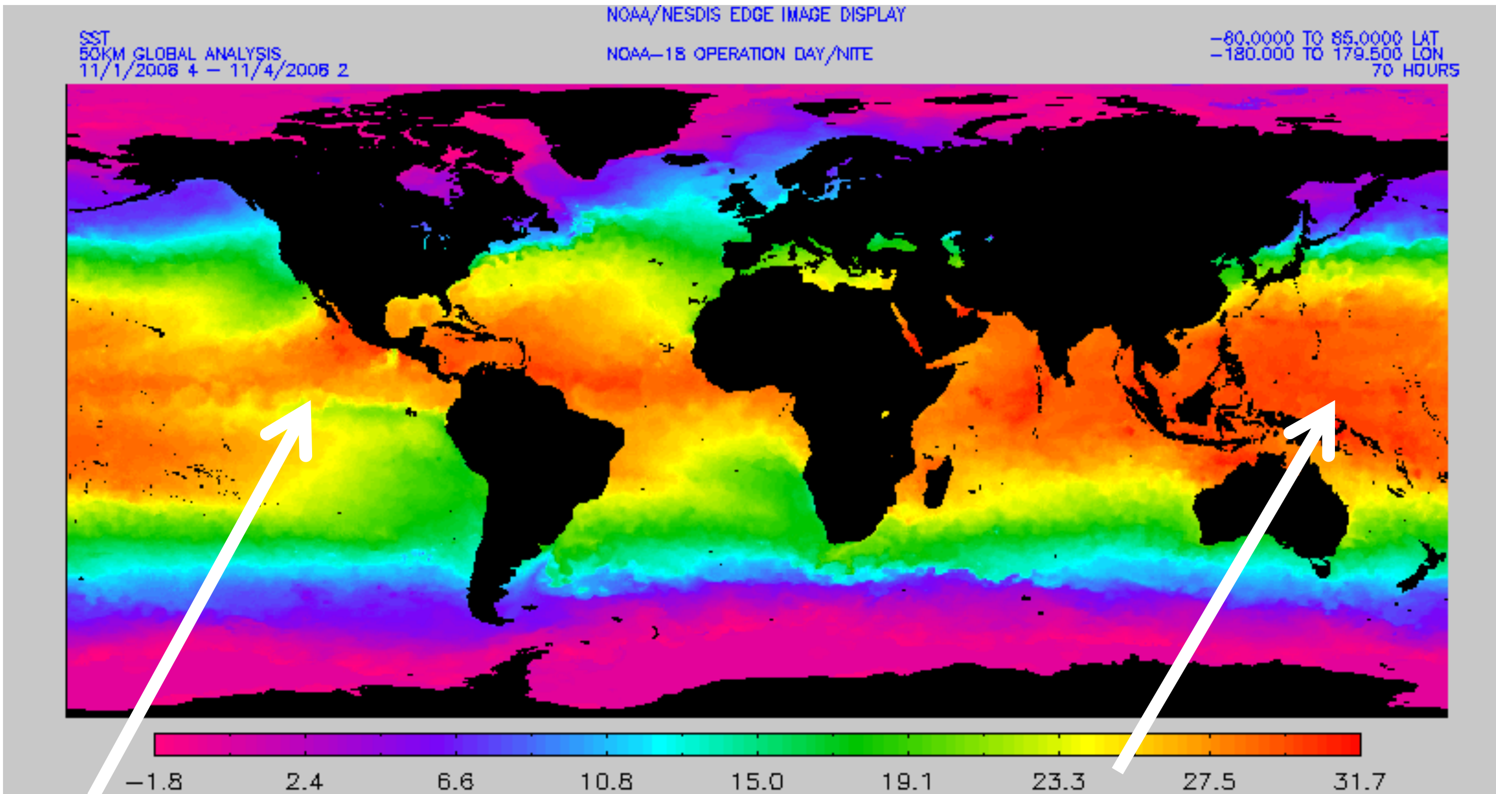


SIOC 210: Equatorial circulation

- Pacific equatorial circulation
- (Atlantic, Indian equatorial circulations)
- El Niño/Southern Oscillation (ENSO)

- Reading: DPO S7.9 (dynamics) or 7.9, and 10.7, 10.8 (Pacific circulation and ENSO)

Sea surface temperature (satellite)

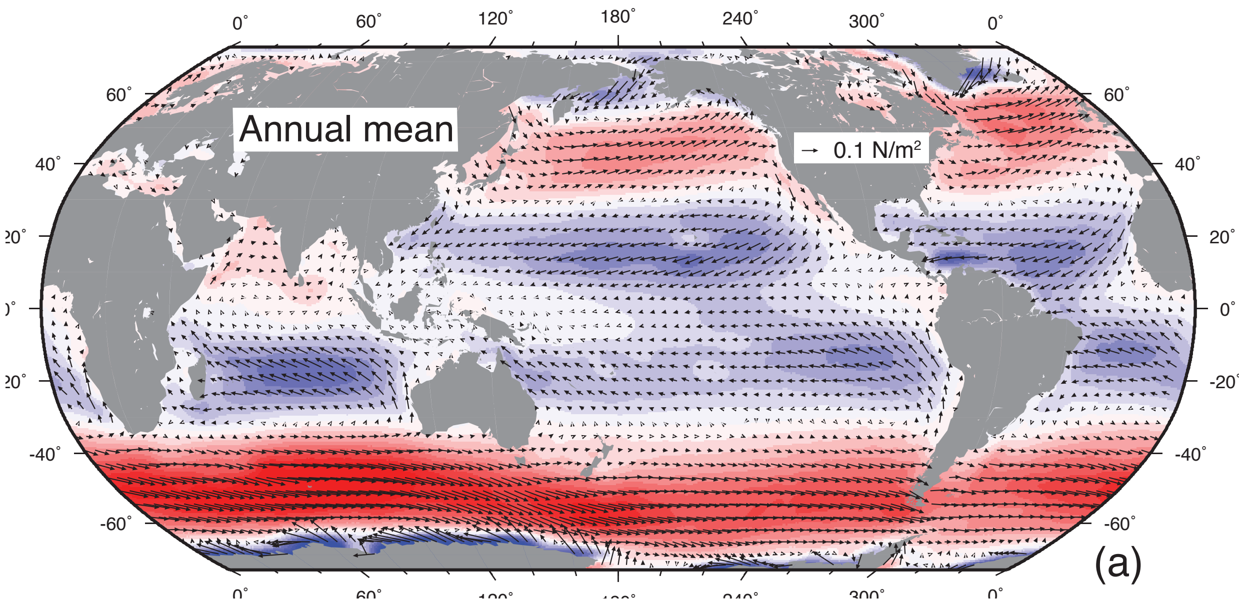


Cold tongue (colder water along equator in east)

Warm pool (warmer water along equator in west)

http://www.osdpd.noaa.gov/PSB/EPS/SST/sst_anal_fields.html

Global surface wind stress



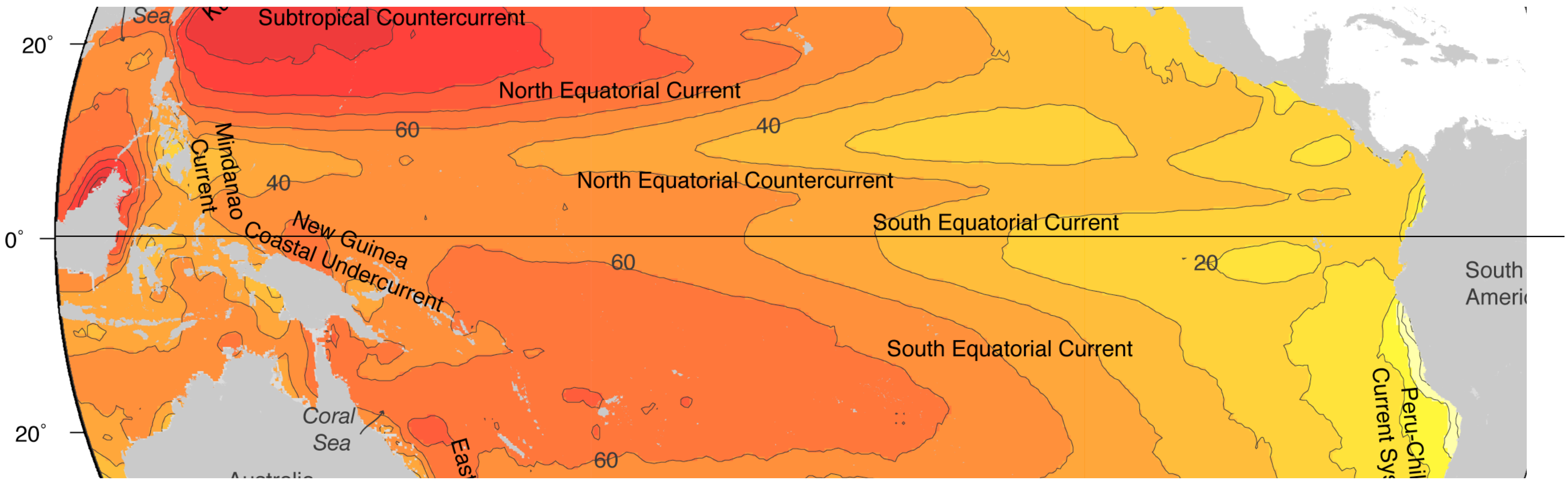
Trade winds in tropical Pacific and Atlantic.

Resulting in:

(1) poleward Ekman transport and hence equatorial upwelling

(2) Westward (downwind) frictional flow right at equator, hence more upwelling in east and pile of water in west

Tropical Pacific surface currents



DPO Fig. S10.1

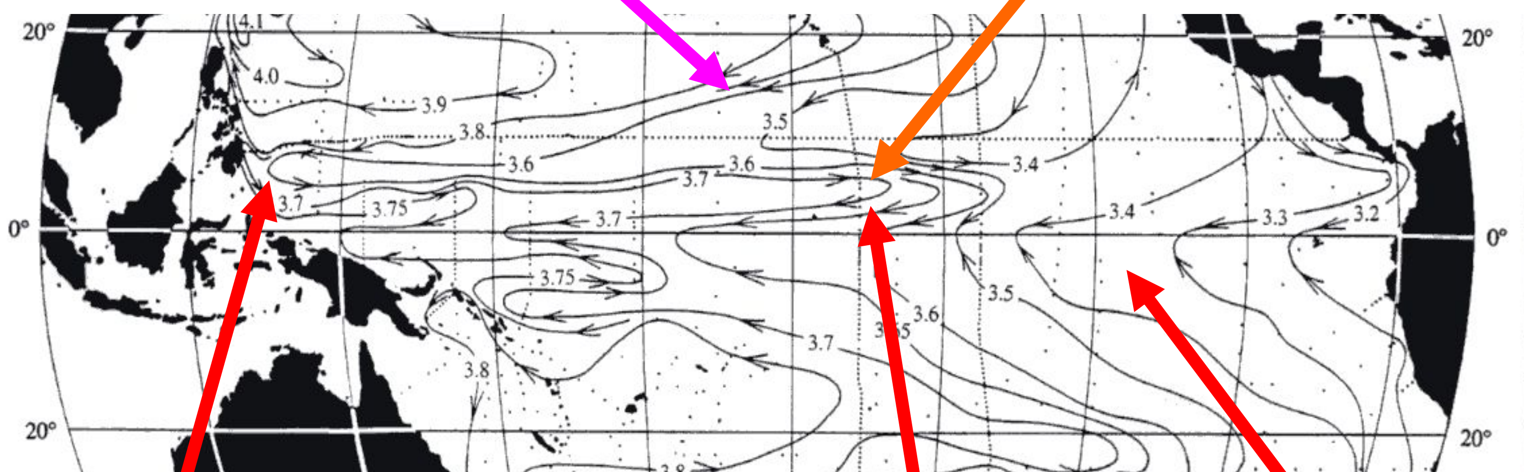
Surface height (cm) anomaly from global mean, from Niiler et al., 2003

Tropical Pacific surface steric height

(Reid, 1997)

North Equatorial Current (westward)

North Equatorial Countercurrent (eastward)



Mindanao Current (western boundary current for the NEC/NECC cyclonic circulation)

South Equatorial Current (westward)

NOTE: The mean surface flow on the equator is westward

(DPO Fig. 10.1)

Equatorial Undercurrent

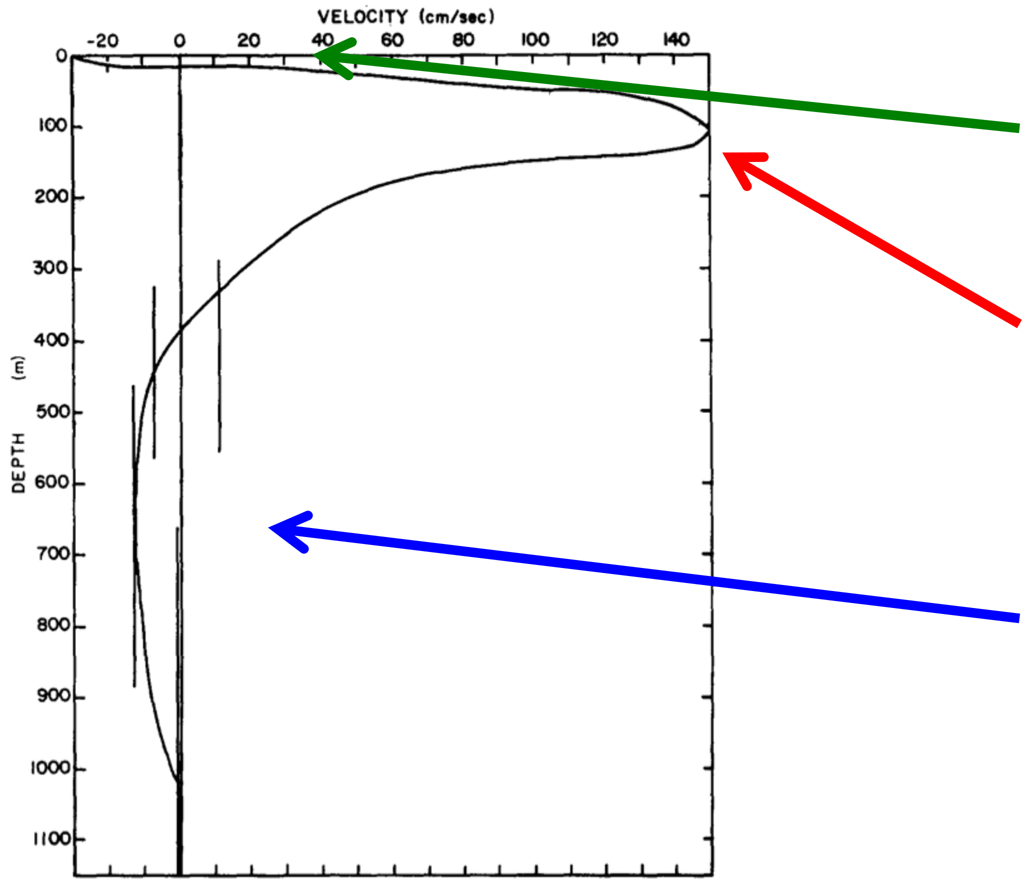


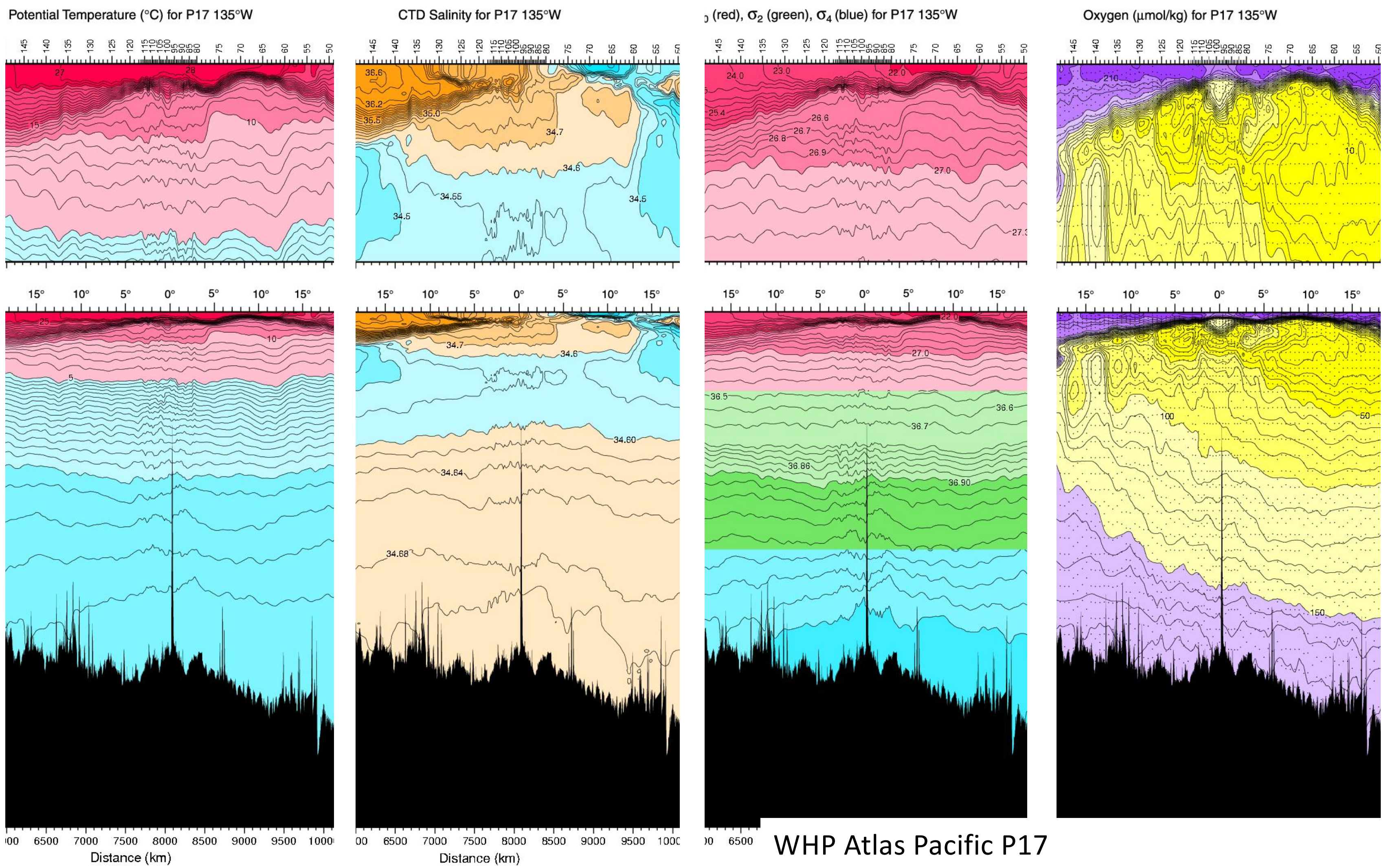
FIG. 4. A composite east-west velocity current profile, 0–100 m, at the equator at 140 °W, based on Roberts current meter and Swallow current floats. Uncertainty in depth of Swallow floats is indicated by vertical lines.

Just beneath the surface westward flow (SEC), there is a powerful eastward undercurrent, called Equatorial Undercurrent (EUC).

Beneath the EUC there is a weaker westward flow called the Equatorial Intermediate Current

(Knauss, DSR 1960)

Vertical structure across equator (Pacific)



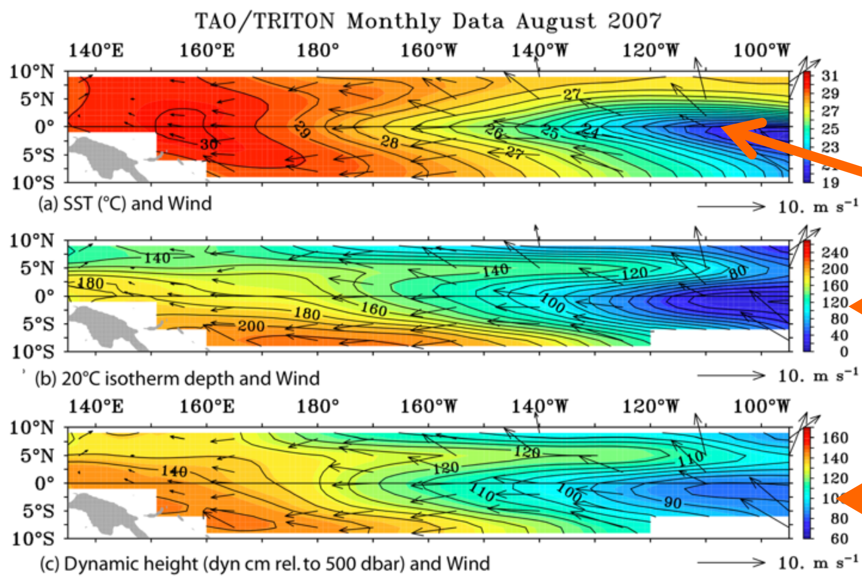
WHP Atlas Pacific P17

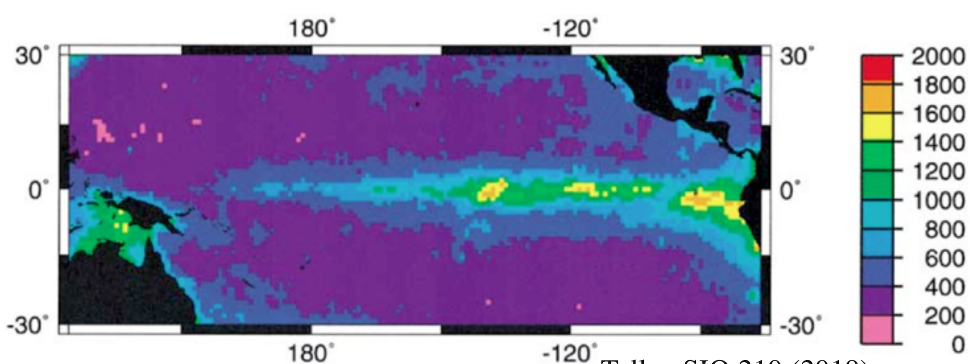
http://whp-atlas.ucsd.edu/pacific_index.html

Dynamics IX: Equatorial dynamics in brief (slide 1): Momentum balances (forces)

1. Flow AT the equator cannot be geostrophic (Coriolis = 0; f=0)
2. Equatorial flow (f=0) consists of 2 parts:
   A. Wind stress drives viscous flow pushed directly downwind: without pressure gradient force (Analog of the shallow Ekman layer, but with no Coriolis force)
   B. Pressure gradient force drives down-gradient flow from high pressure to low pressure (balanced by either acceleration, advection or viscous terms). (Analog of geostrophic flow.)
3. Flow that is slightly off the equator (more than 1/4° latitude): Coriolis important
   A. Wind stress creates Ekman layer, poleward transport, with slight downwind component, high SSH off the equator
   B. PGF balanced by Coriolis (geostrophic flow): westward surface currents, becoming more and more geostrophic with increasing latitude (fully geostrophic after about 1° from equator)

Normal equatorial conditions





https://www.pmel.noaa.gov/tao/drupal/disdel/

Trade winds

Cold tongue

Thermocline deep in west, shallow in east

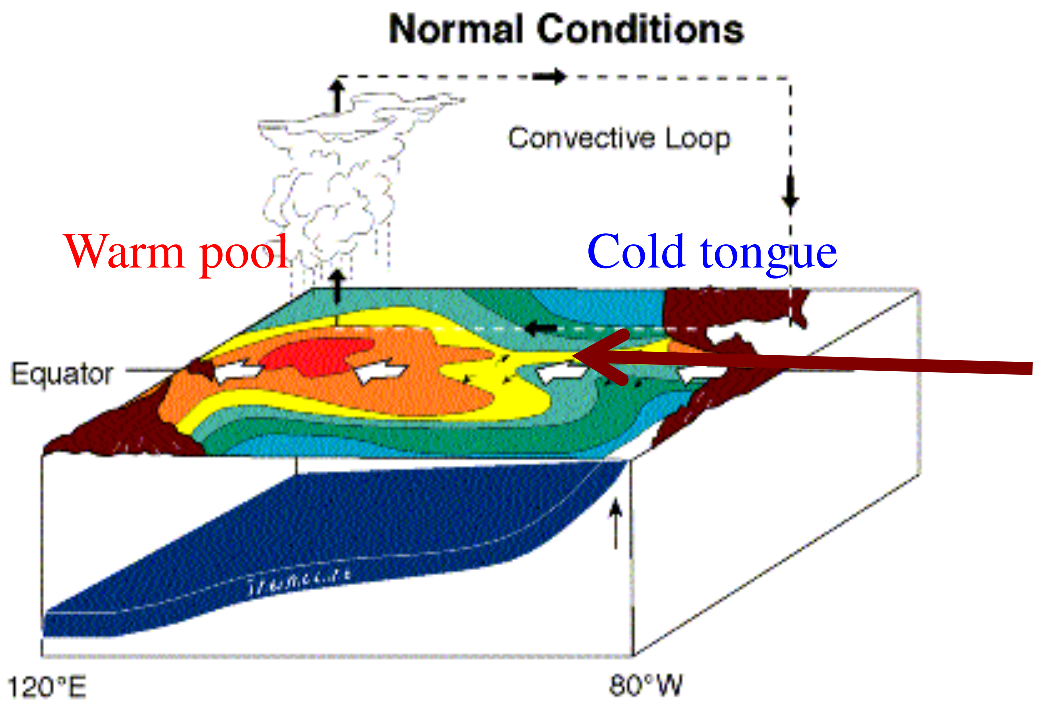
Dyn. Ht. and SSH high in west, low in east

High productivity (ocean color) in cold tongue

La Niña phase is very similar

DPO Fig. 10.22

Pacific equatorial structures (upper ocean) (normal conditions)



("normal" compared with El Niño conditions)

DPO Fig. 10.27 from

http://www.pmel.noaa.gov/tao/elnino/nino-home.html)

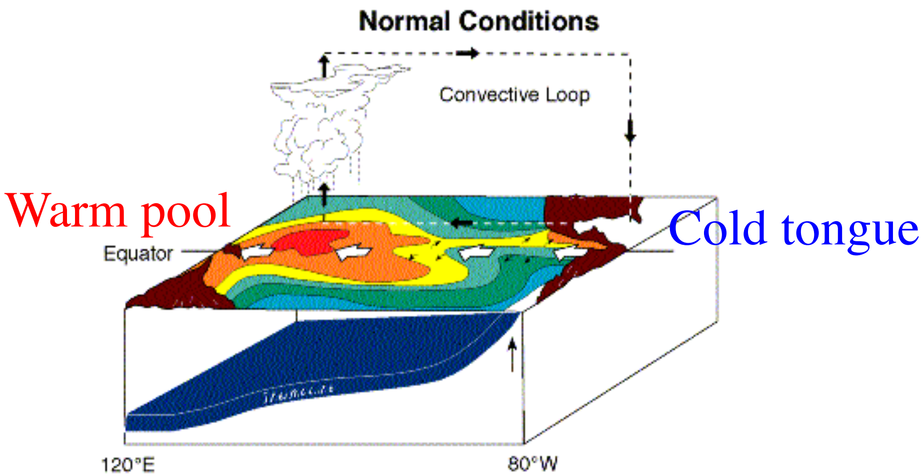
1. Easterly winds (Walker circulation)

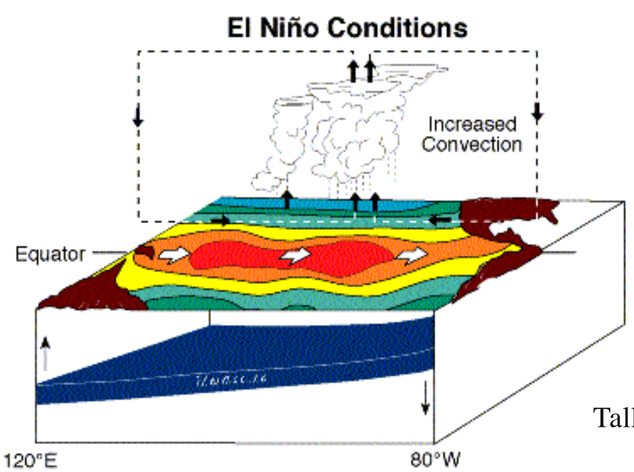
2. Poleward Ekman transport creates meridional pgf: westward geostrophic surface flow NOT at equator

3. Downwind surface flow on equator due to (1) and westward near equator due to (2)

4. Equatorial upwelling due to (1) westward flow (cold tongue vs. warm pool) and (2) poleward flow (upwelling at all longitudes)

Pacific equatorial structures (upper ocean) (ENSO)





Tropical Pacific: we refer often to
- "normal"
- "El Niño"
- "La Niña"

conditions, which alternate irregularly every 3 to 7 years. This is natural climate variability (interannual).

El Niño is a warm equatorial phase.
La Niña is similar to normal, but more extreme.

DPO Fig. 10.27

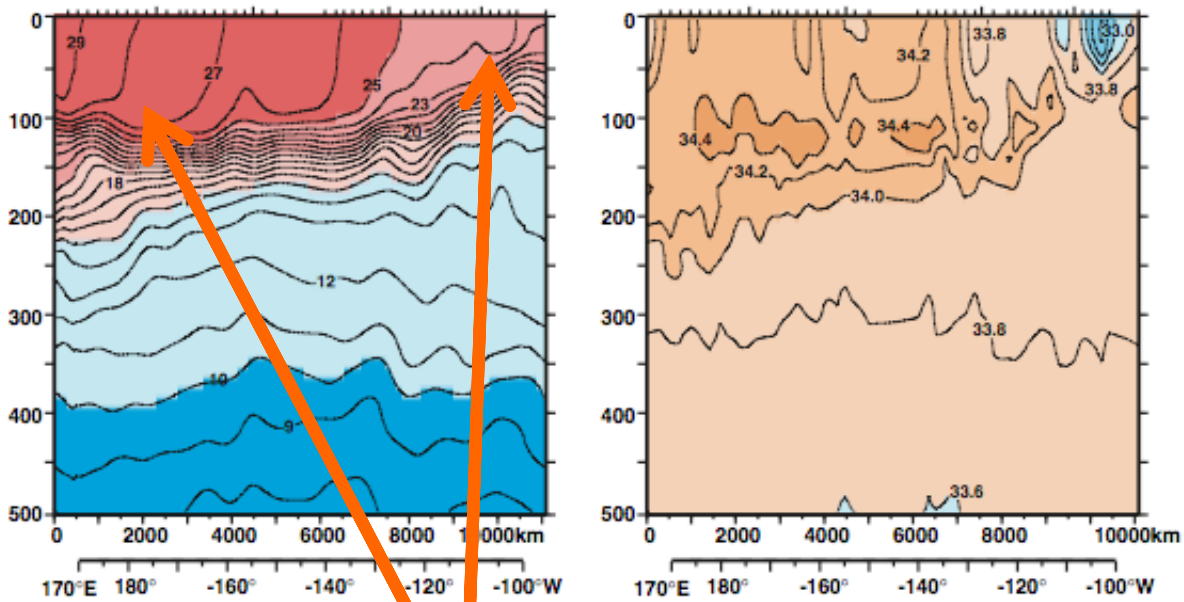
Dynamics IX: Equatorial dynamics in brief (slide 2): Equatorial upwelling

1. Upwelling 1: caused by downwind VISCOUS westward flow along the equator (one part of the South Equatorial Current), due to the easterly Trade Winds, creating upwelling in the east at the continent (S. America) and piling up in the west at the land (Indonesia)

   a) Upwelling creates the Cold Tongue in the eastern equatorial region. Pileup of warm water creates the Warm Pool in the western equatorial region. (Both are SST features; Cold Tongue accompanied by shallow thermocline, Warm Pool by deeper thermocline)
   b) The equatorial surface flow causes high pressure (high sea level) in the west and low pressure (low sea level) in the east, therefore an eastward PGF.

2. Upwelling 2: caused by off-equatorial Ekman transport driven by the easterly Trade Winds. Where thermocline is shallow, this upwells cold to surface. Where thermocline is deep (in warm pool), upwells warm to surface so does not result in cold surface water

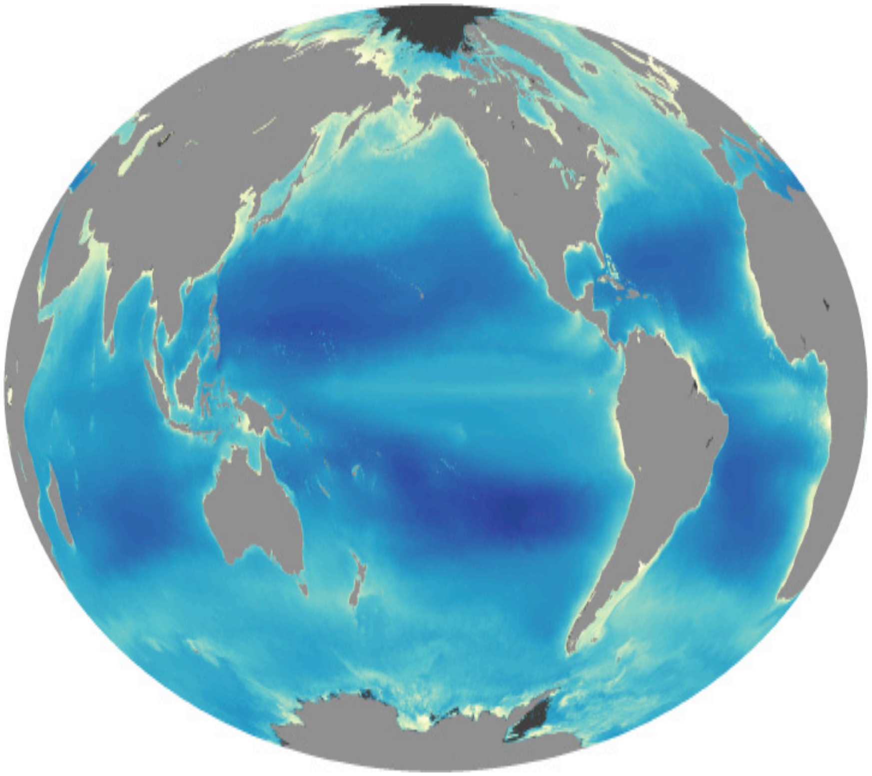
Along-equatorial (zonal) temperature and salinity sections: Pacific



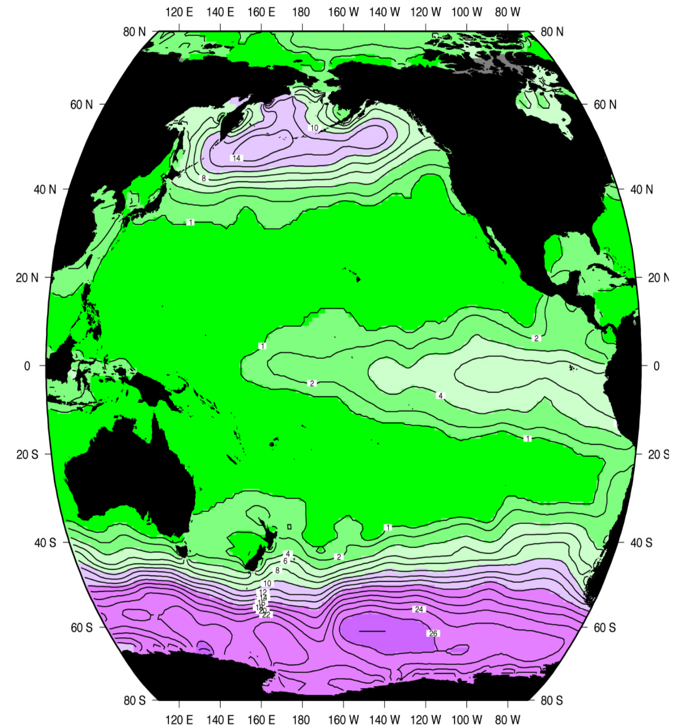
Thick warm layer in west (warm pool)
Thermocline surfaces to east, cooler water at surface (cold tongue)

"Alize" cruise (France, 1991)

Ekman-induced upwelling/downwelling, effect on surface nutrients



Ocean color: chlorophyll



Nitrate at 10 m depth

http://earthobservatory.nasa.gov/Features/Phytoplankton/page4.php

Equatorial upwelling brings nutrients to sea surface, enhanced in cold tongue in the mean

Dynamics IX: Equatorial dynamics in brief (slide 3): flows driven by the pressure gradient force

1. Equatorial PGF: high in west and low in east because water is piled up in the west by the winds. This causes eastward flow from high to low pressure along the equator. This is called the Equatorial Undercurrent. The strongest current in the global ocean > 150 cm/sec, but very thin and restricted to very close to the equator. (The surface equatorial flow is the westward South Equatorial Current, driven directly by the wind, as already stated.)

2. Meridional PGF: low along equator and high north and south of equator due to off-equatorial transport driven by the winds). Causes westward geostrophic flow north and south of equator in both hemispheres: South Equatorial Current (off-equatorial portion, in BOTH hemispheres – confusing nomenclature)

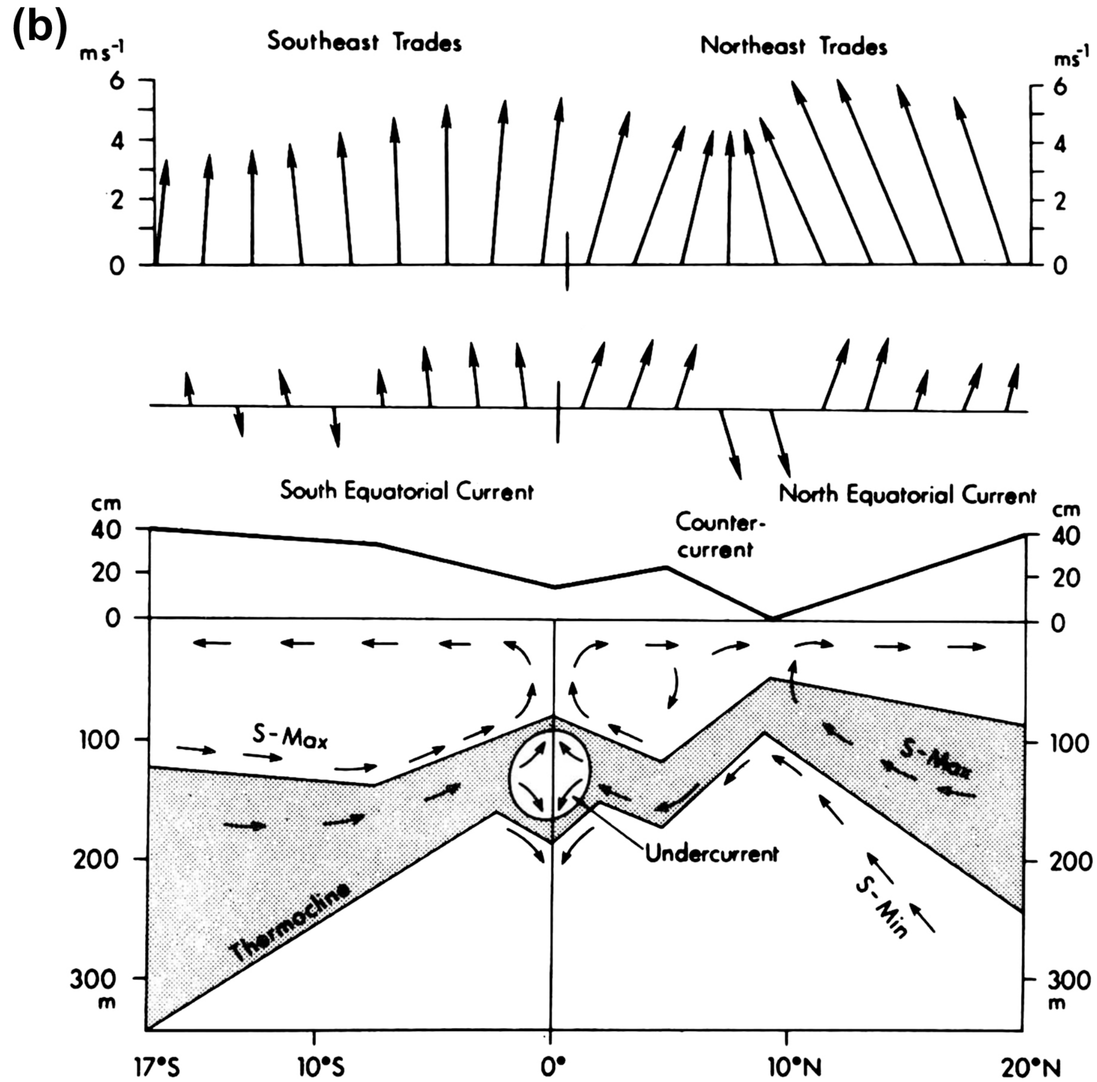
Subsurface equatorial currents (Wyrtki and Kilonsky, 1984)

Trade winds

Meridional PGF

Poleward Ekman

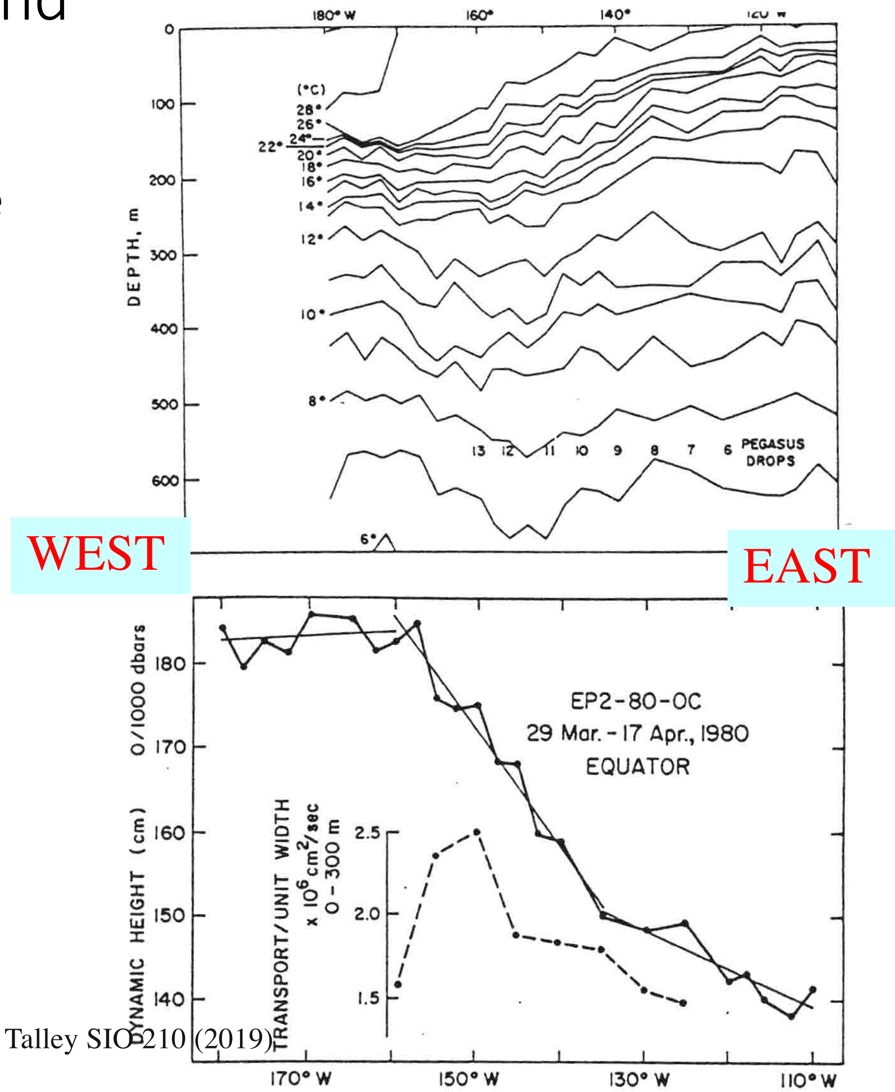
Equatorial upwelling (type 2)



DPO FIGURE 10.20b

Along-equatorial temperature and dynamic height

Warm pool in west, shoaled thermocline in east with cooler surface waters



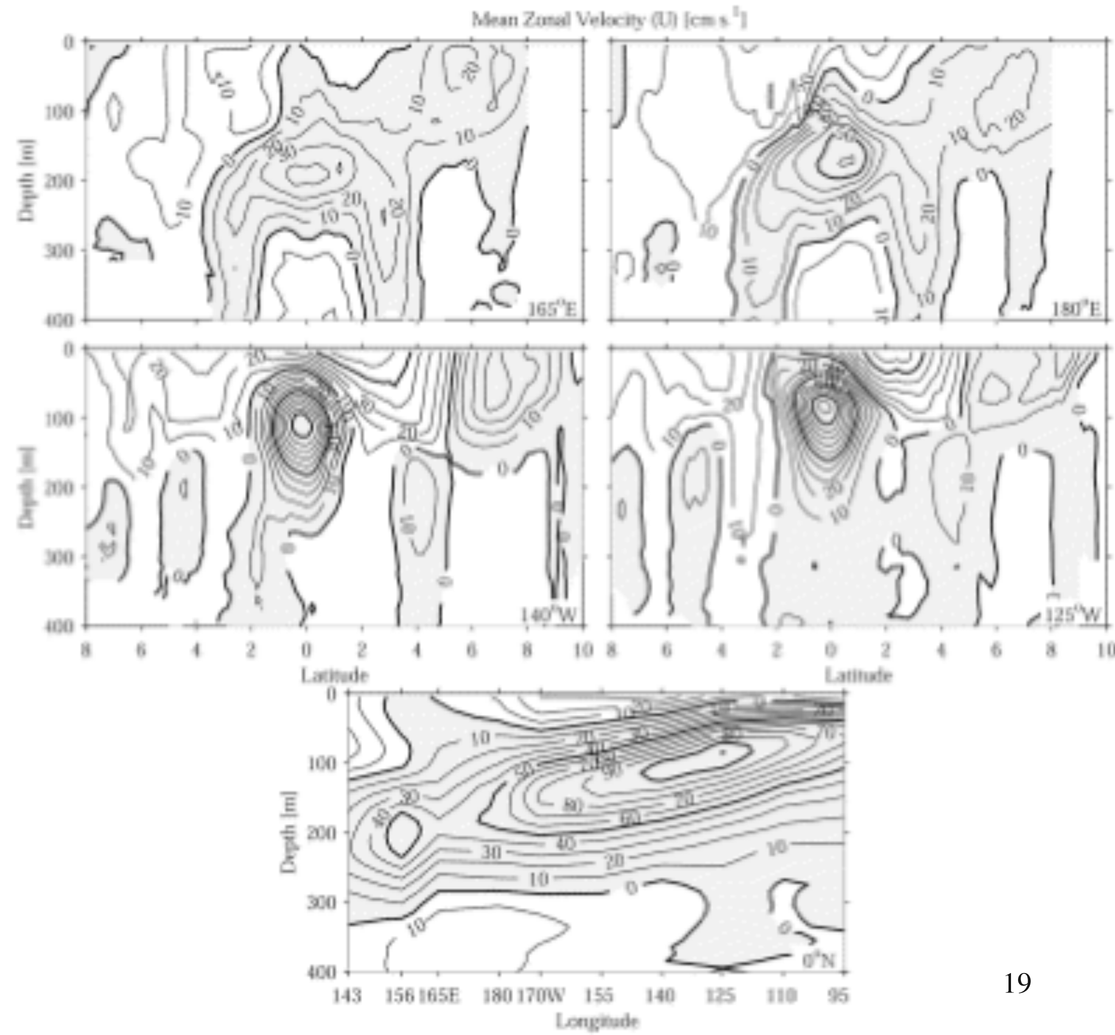
Surface dynamic height along equator

(Leetmaa and Spain, 1981)

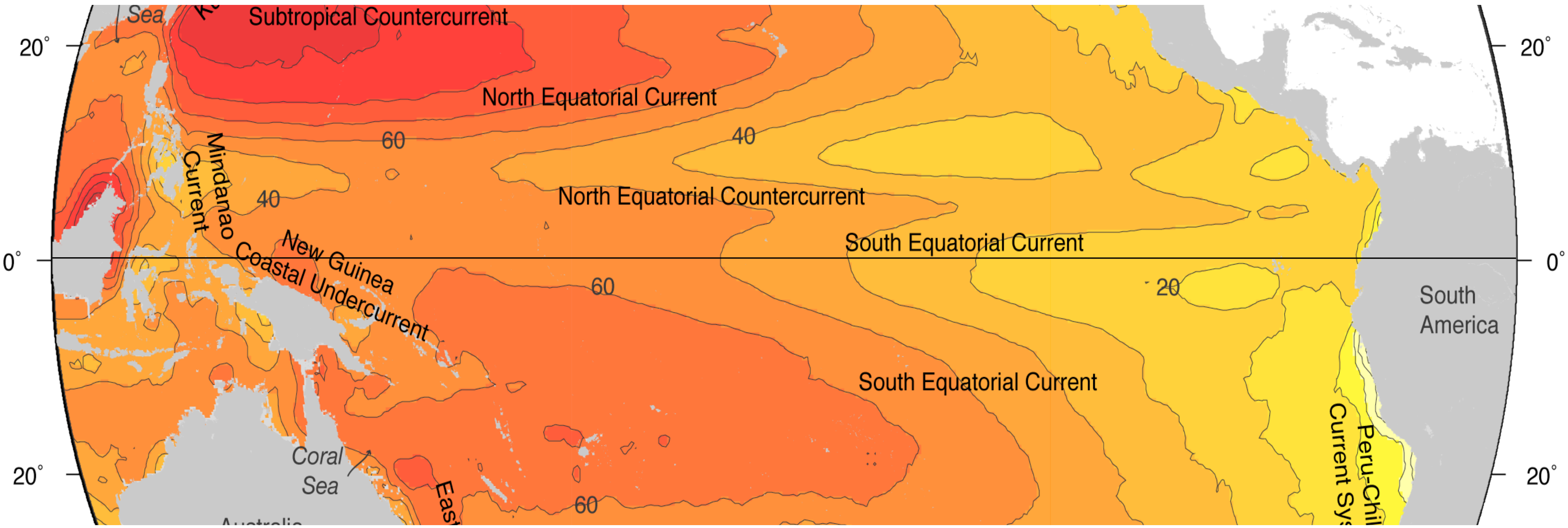
Equatorial Undercurrent: shoaling to east

Velocity structure at several longitudes and along equator

(Johnson et al., 2002)

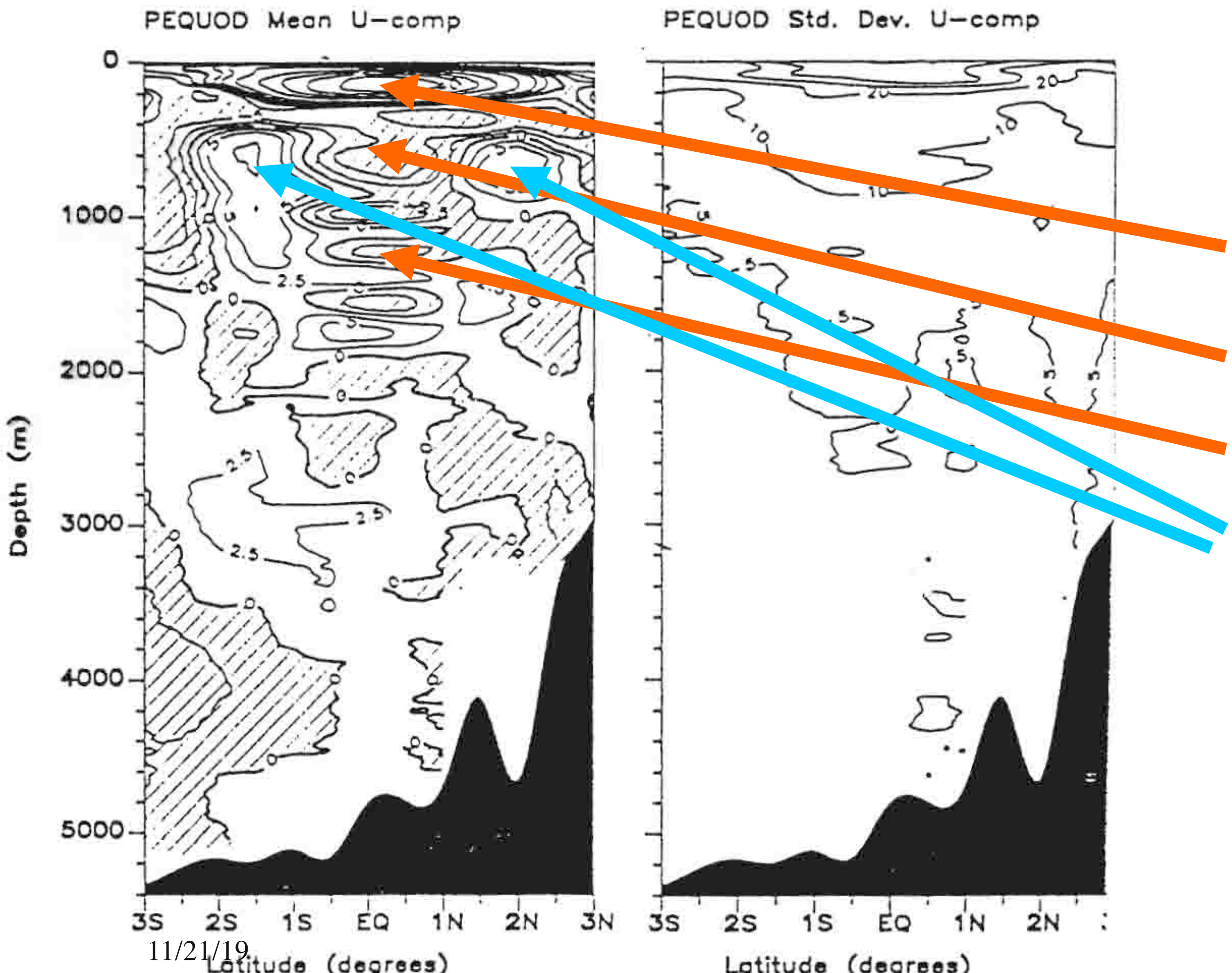


Pacific surface currents: revisit to summarize



DPO Fig. S10.1

Equatorial current structure: deep jets



Meridional section of velocity structure in central equatorial Pacific.

Equatorial Undercurrent

Equatorial Intermediate Current

Stacked jets

Tsuchiya jets

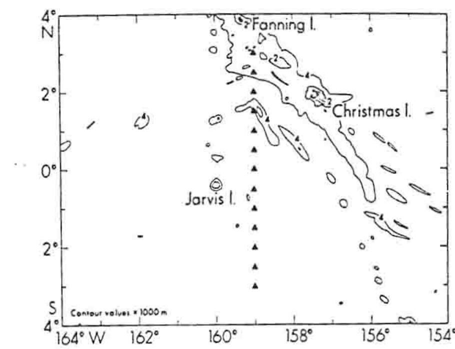
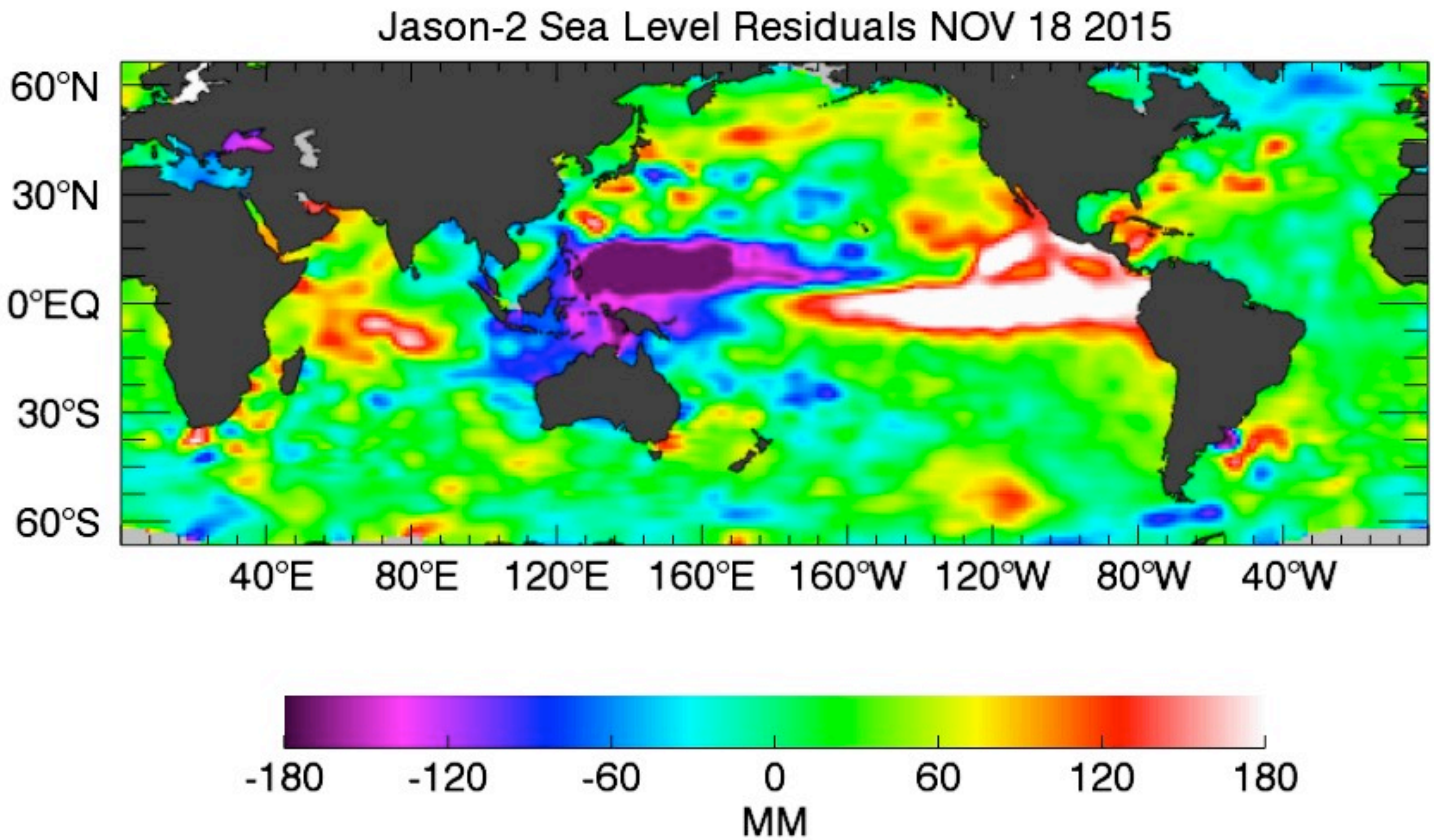


Fig. 1. Line Islands Profiling Project station locations. The Christmas Island Ridge blocks deep zonal flow north of 1°S.

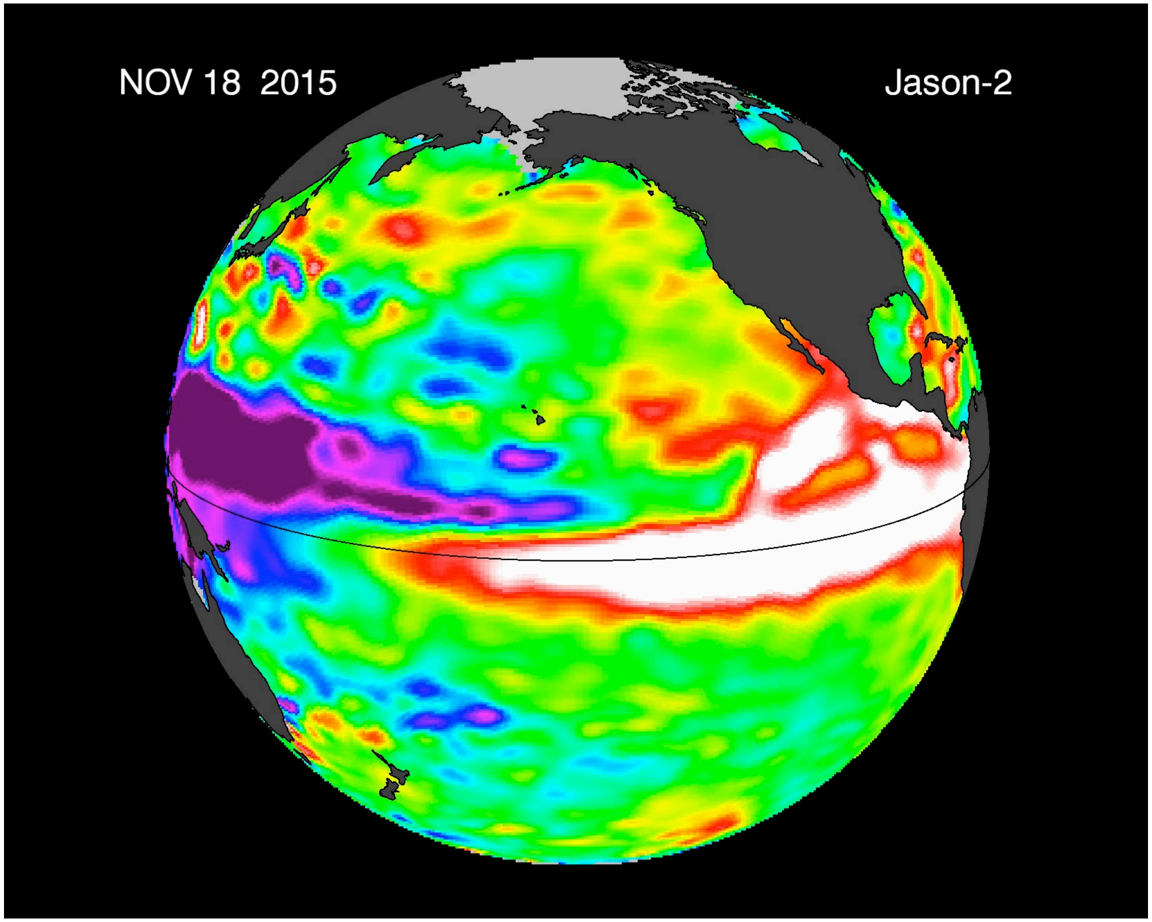
Firing (JGR, 1989)

(Firing, 1989)

ENSO: last El Nino http://sealevel.jpl.nasa.gov/science/elninopdo/

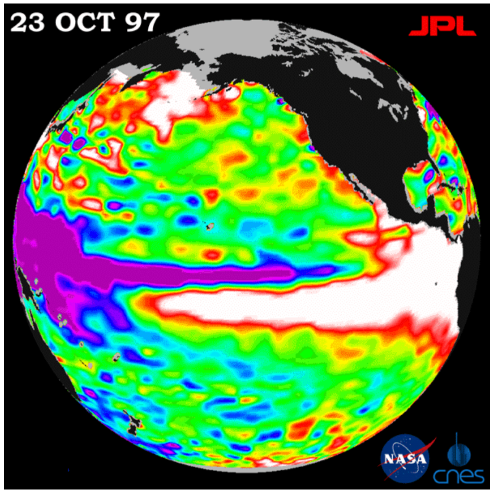


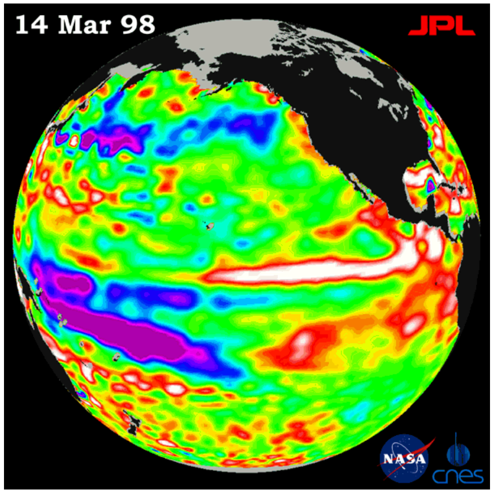
ENSO: last El Nino (it was BIG) http://sealevel.jpl.nasa.gov/science/elninopdo/



ENSO: sea surface height

http://topex-www.jpl.nasa.gov/elnino/index.html



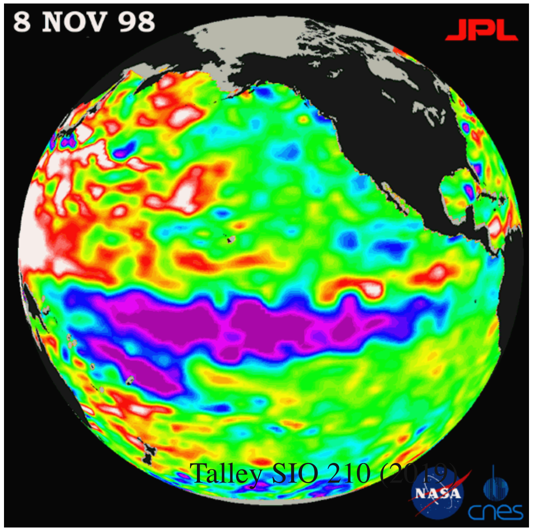


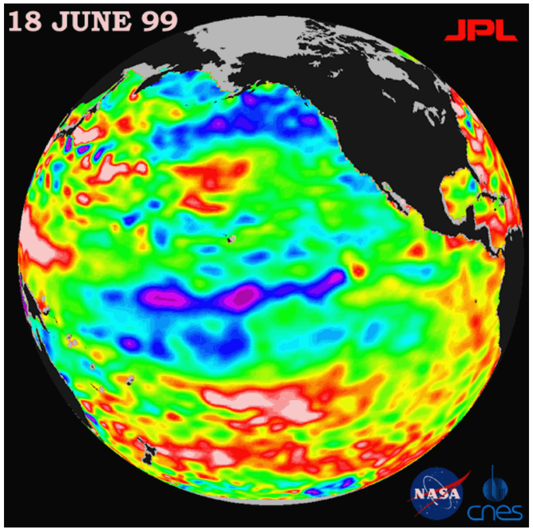
Full El Niño condition

El Niño retreating

Full La Niña condition

La Niña fading





El Niño/Southern Oscillation (ENSO)

- Climate:
  - Variability (Natural modes, times scales of interannual, decadal, centennial, millenial)
  - Change (anthropogenic) – search for trend that is attributable to external forcing

El Niño/Southern Oscillation (ENSO)

- Climate:
  - Variability (Natural modes, times scales of interannual, decadal, centennial, millenial)
  - Change (anthropogenic) – search for trend that is attributable to external forcing

- ENSO is an interannual climate variation
- 3-7 year time scale, not predictable (chaotic process with underlying physics that creates repetition that is not precisely cyclic)

El Niño/Southern Oscillation (ENSO)

- Climate:
  - Variability (Natural modes, times scales of interannual, decadal, centennial, millenial)
  - Change (anthropogenic) – search for trend that is attributable to external forcing

- ENSO is an interannual climate variation
- 3-7 year time scale, not predictable (chaotic process with underlying physics that creates repetition that is not precisely cyclic)

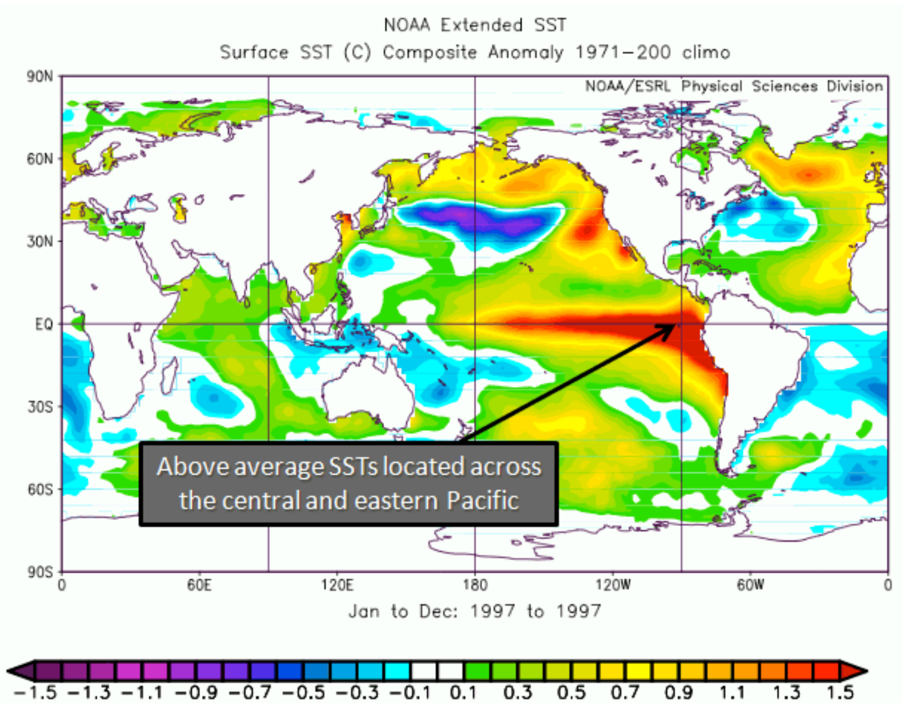
- Coupled ocean-atmosphere interaction with feedback (coupling is strong in tropics, weak at higher latitudes)

- Nearly global impacts, certainly in the tropics

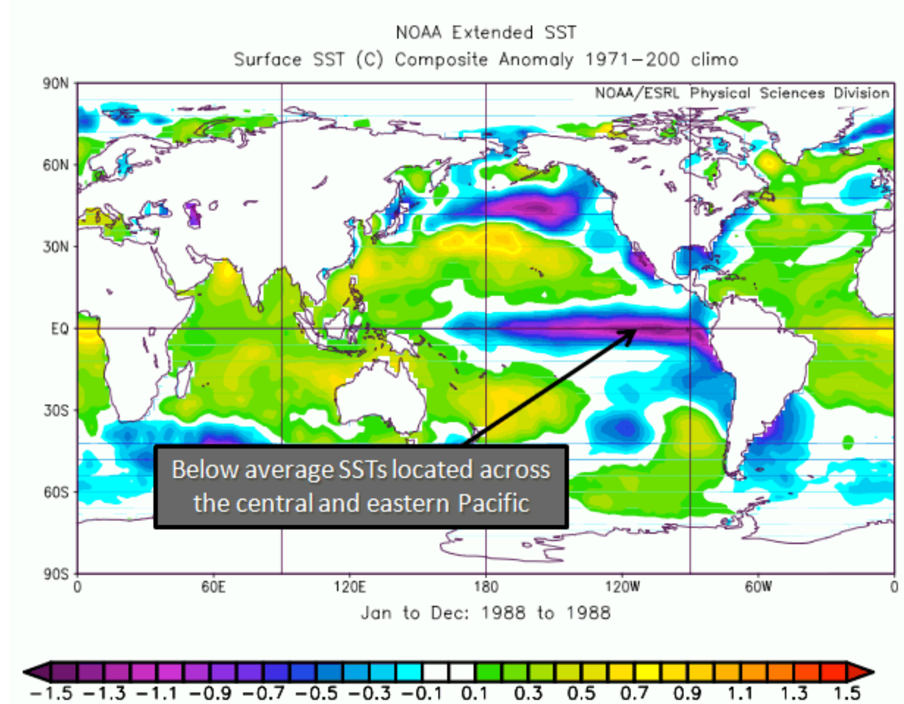
- Strongest impacts in eastern tropical Pacific - Peruvian upwelling, eastern tropical surface temperatures, tropical rainfall

ENSO surface temperature anomalies

El Niño



La Niña



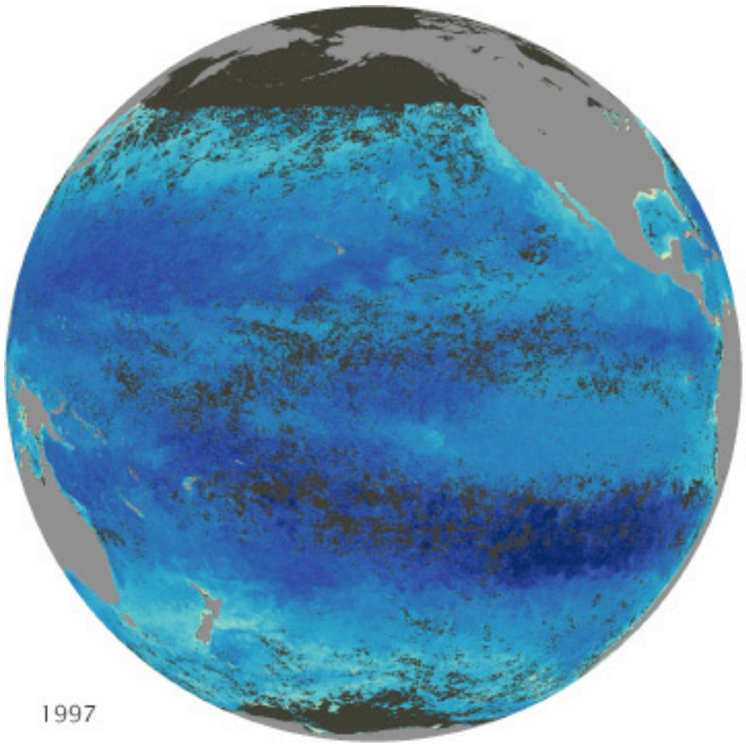
El Niño has anomalously warm cold tongue.

La Niña has anomalously cold cold tongue (hence “super-normal”)

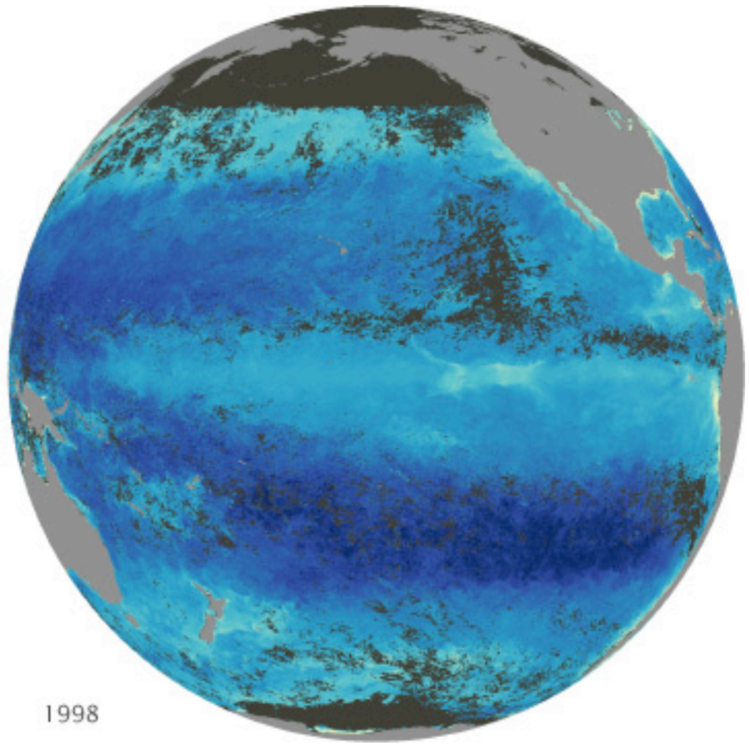
http://www.nc-climate.ncsu.edu/climate/patterns/ENSO.html

ENSO effect on surface chlorophyll

El Niño



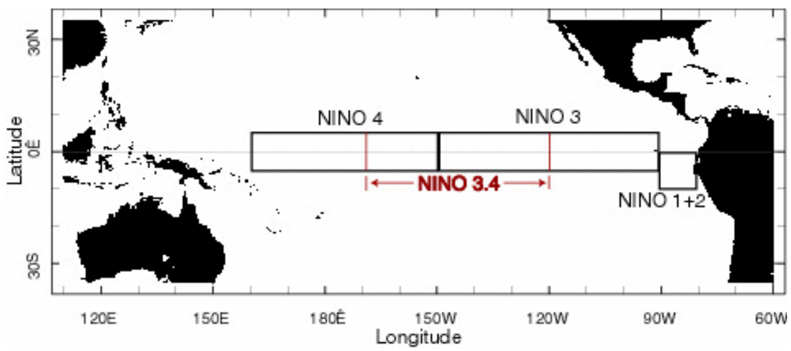
La Niña



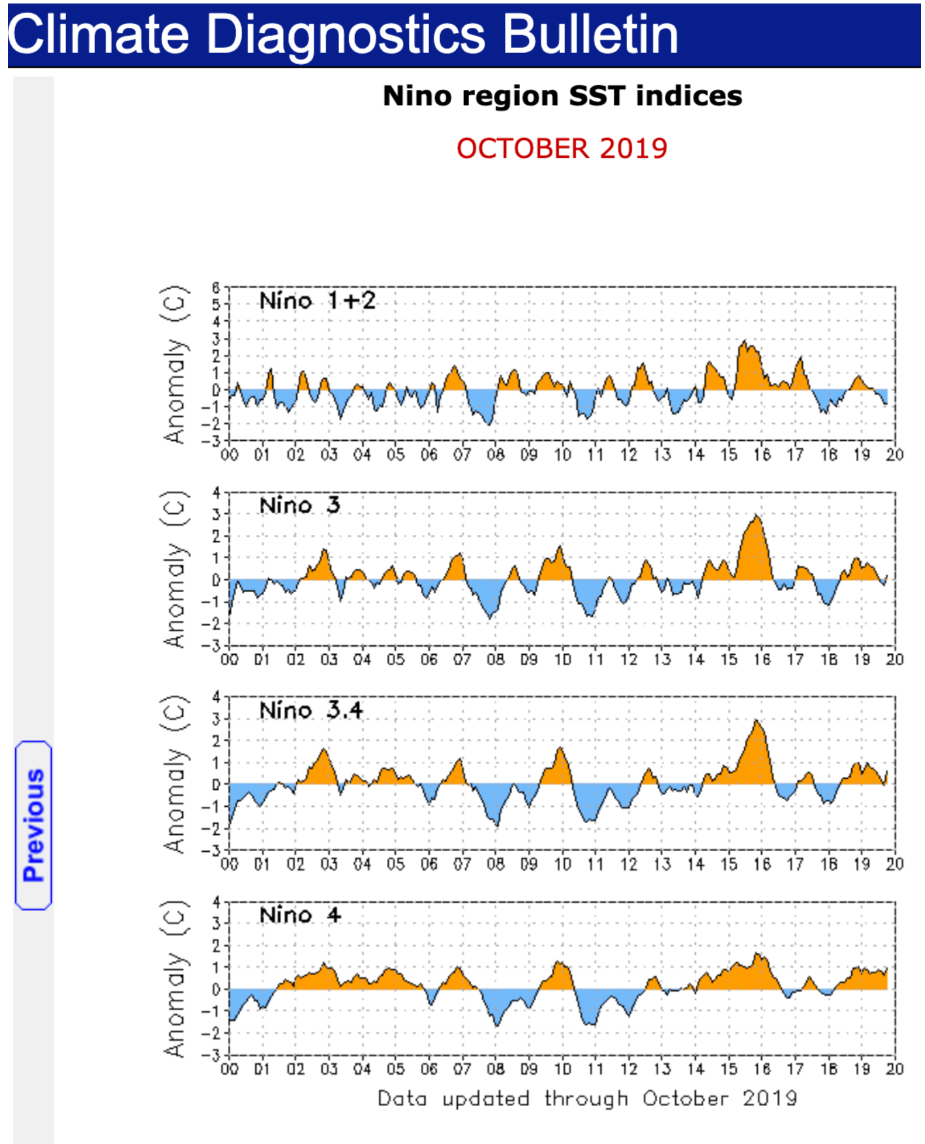
Equatorial upwelling brings nutrients to sea surface, enhanced in cold tongue in the mean; upwelling from warm, nutrient depleted water during El Niño

http://earthobservatory.nasa.gov/Features/Phytoplankton/page4.php

ENSO SST indices: Most commonly used is the Nino3 or Nino3,4

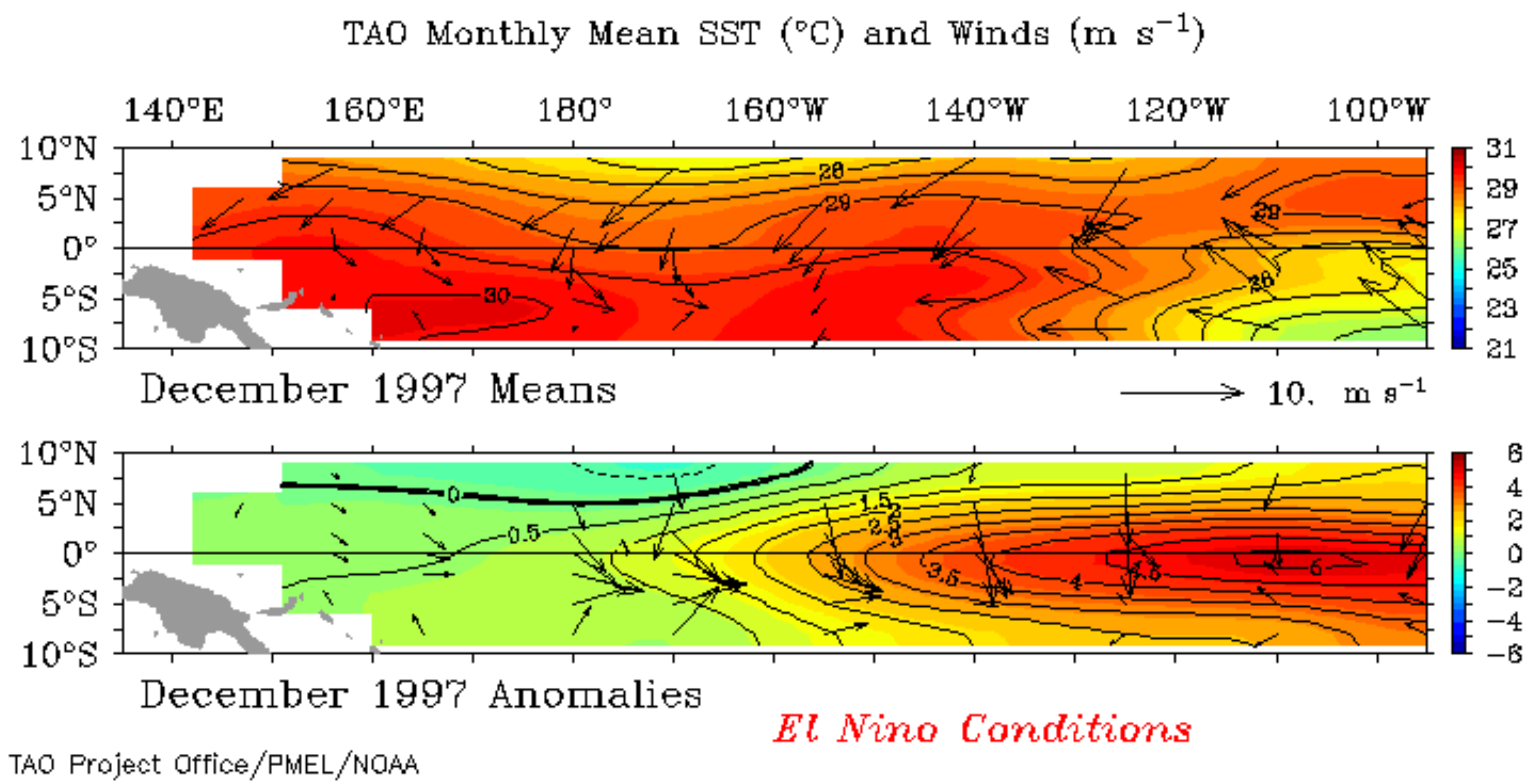


Fall 2013: conditions neutral (mildly La Niña)

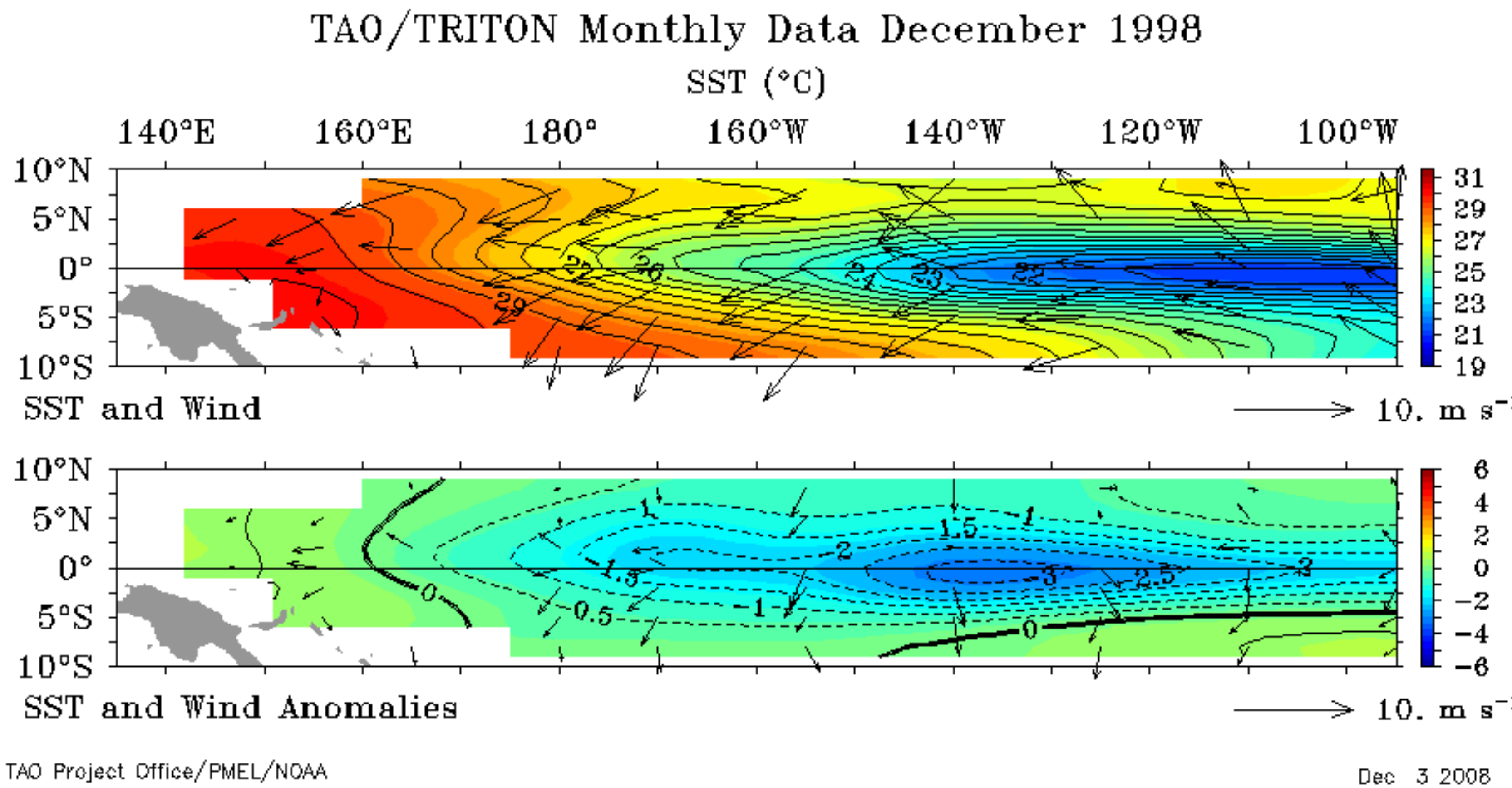


http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/bulletin

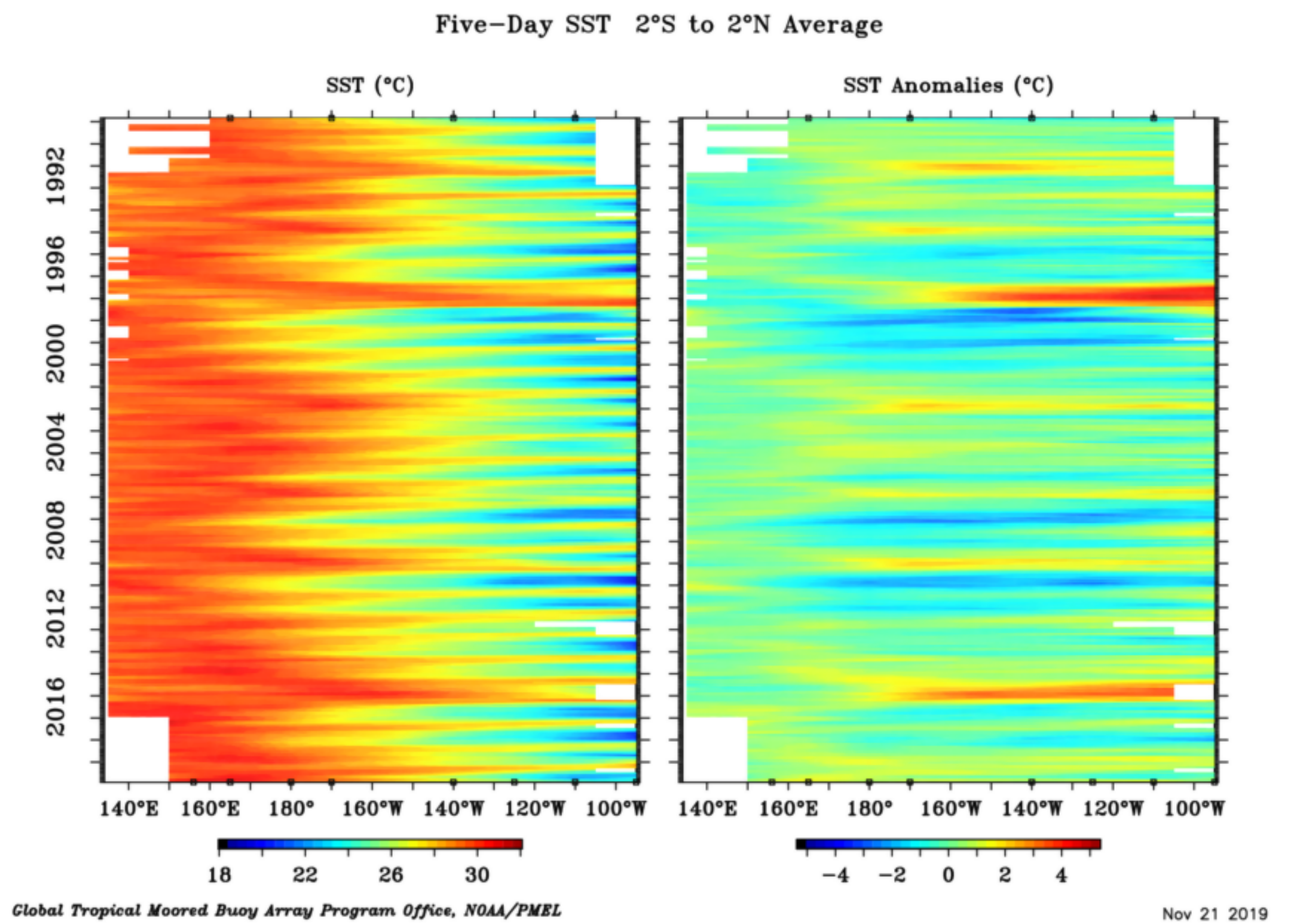
El Niño SST and wind conditions in the tropical Pacific



La Niña SST and wind conditions in the tropical Pacific



Time series: SST at equator

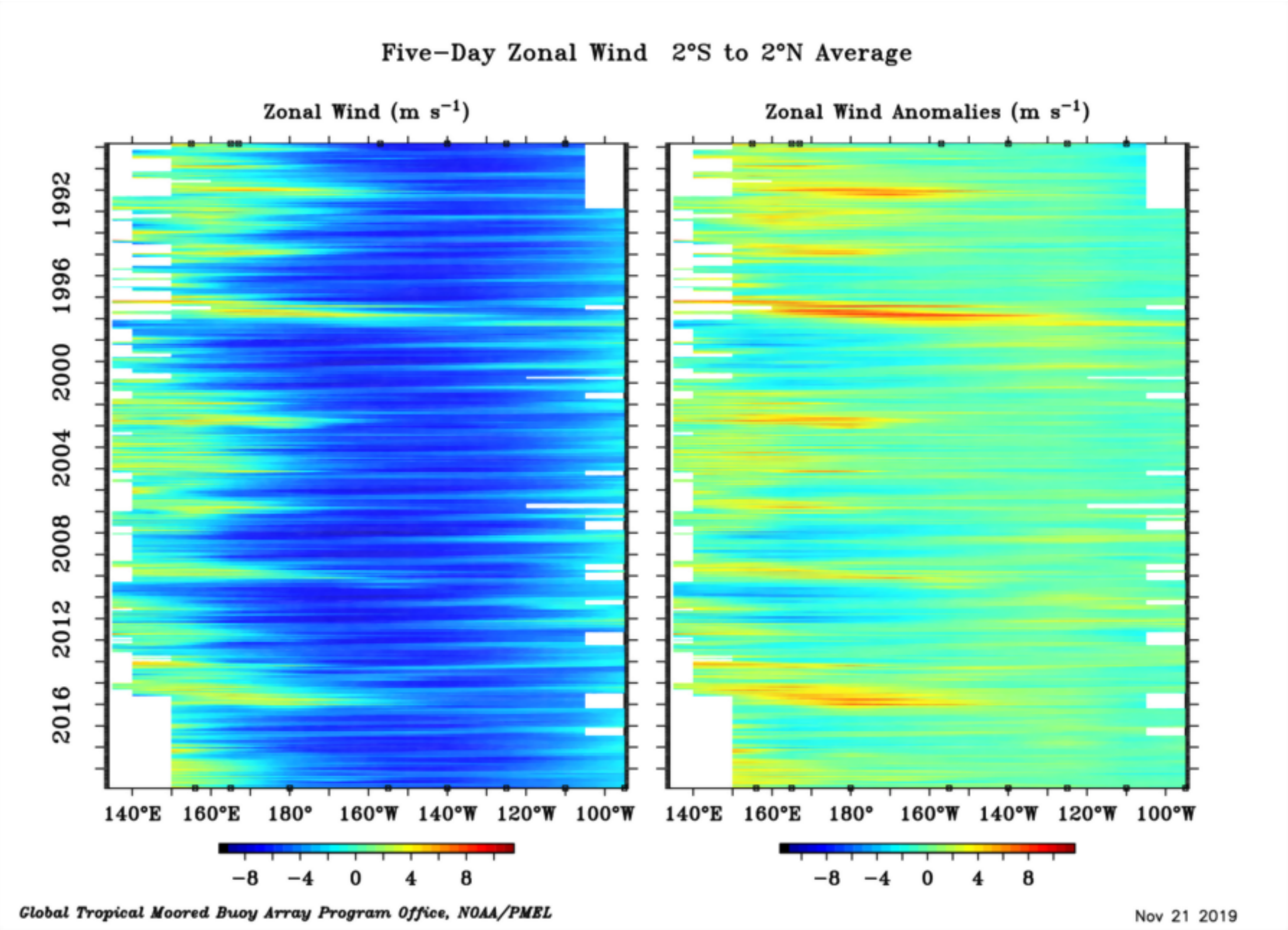


El Niño

La Niña

El Niño

Time series: zonal wind at equator

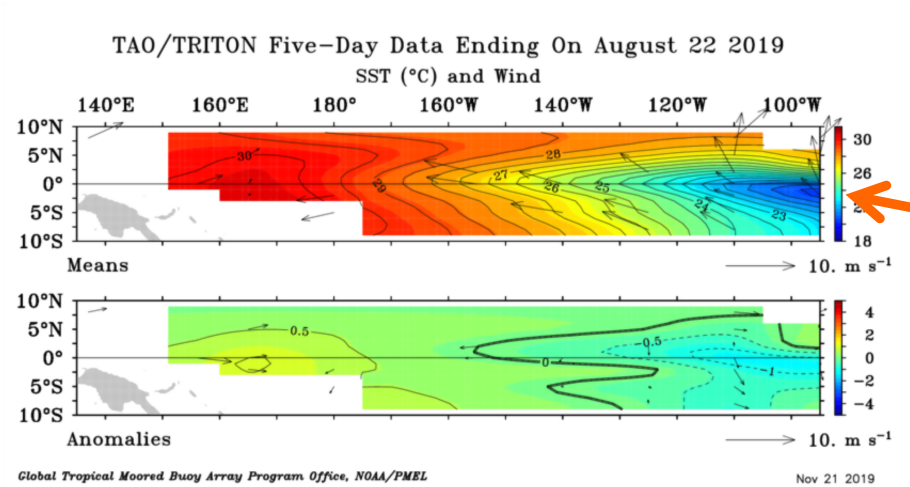


El Niño

La Niña

El Niño

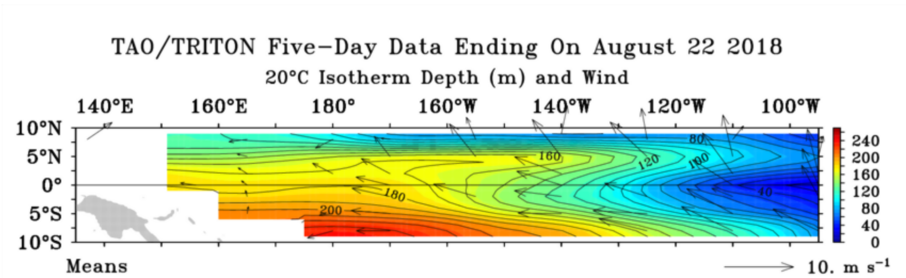
Today’s equatorial conditions (normal conditions)



https://www.pmel.noaa.gov/tao/drupal/disdel/

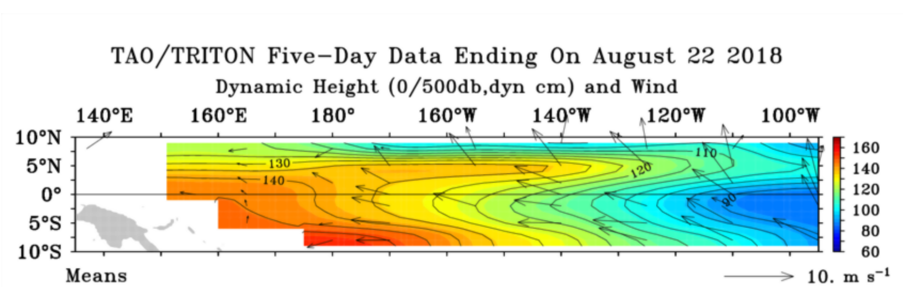
Trade winds (vectors)

Warm pool and cold tongue

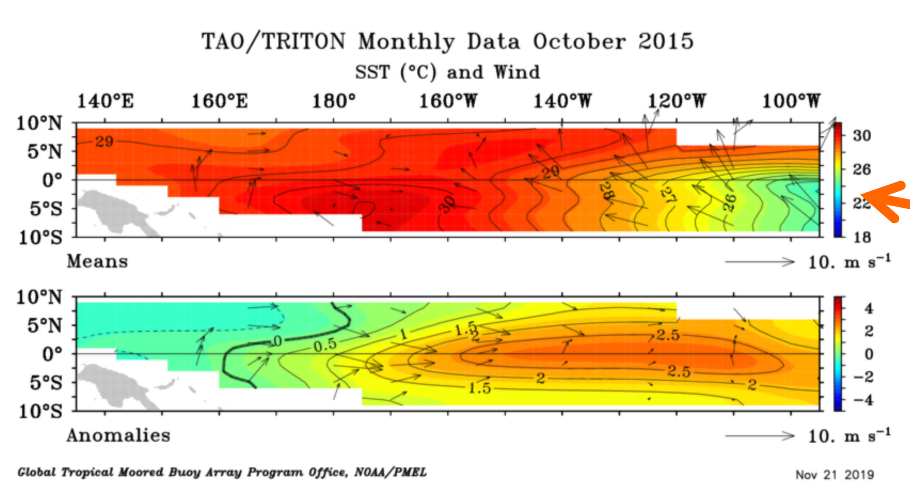


Thermocline deep in west, shallow in east

Dyn. Ht. and SSH high in west, low in east



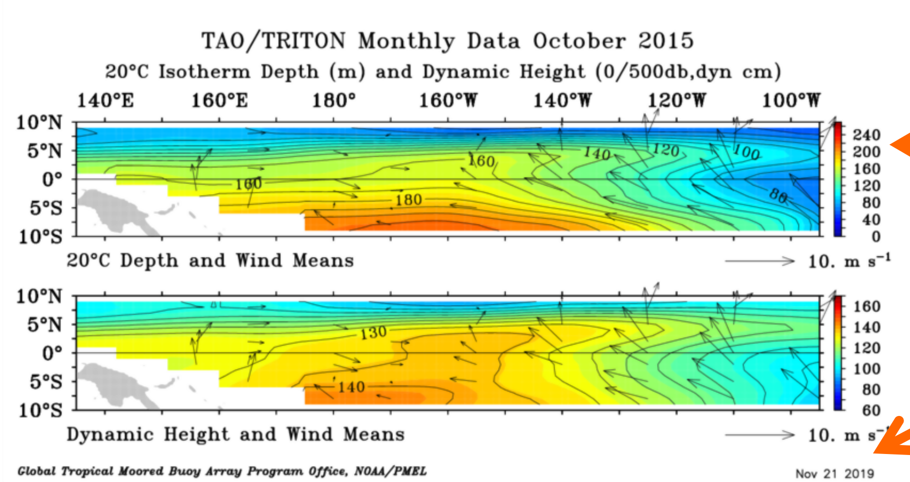
Last big El Nino (2015) equatorial conditions



https://www.pmel.noaa.gov/tao/drupal/disdel/

Trade winds (vectors)

Warm pool and cold tongue



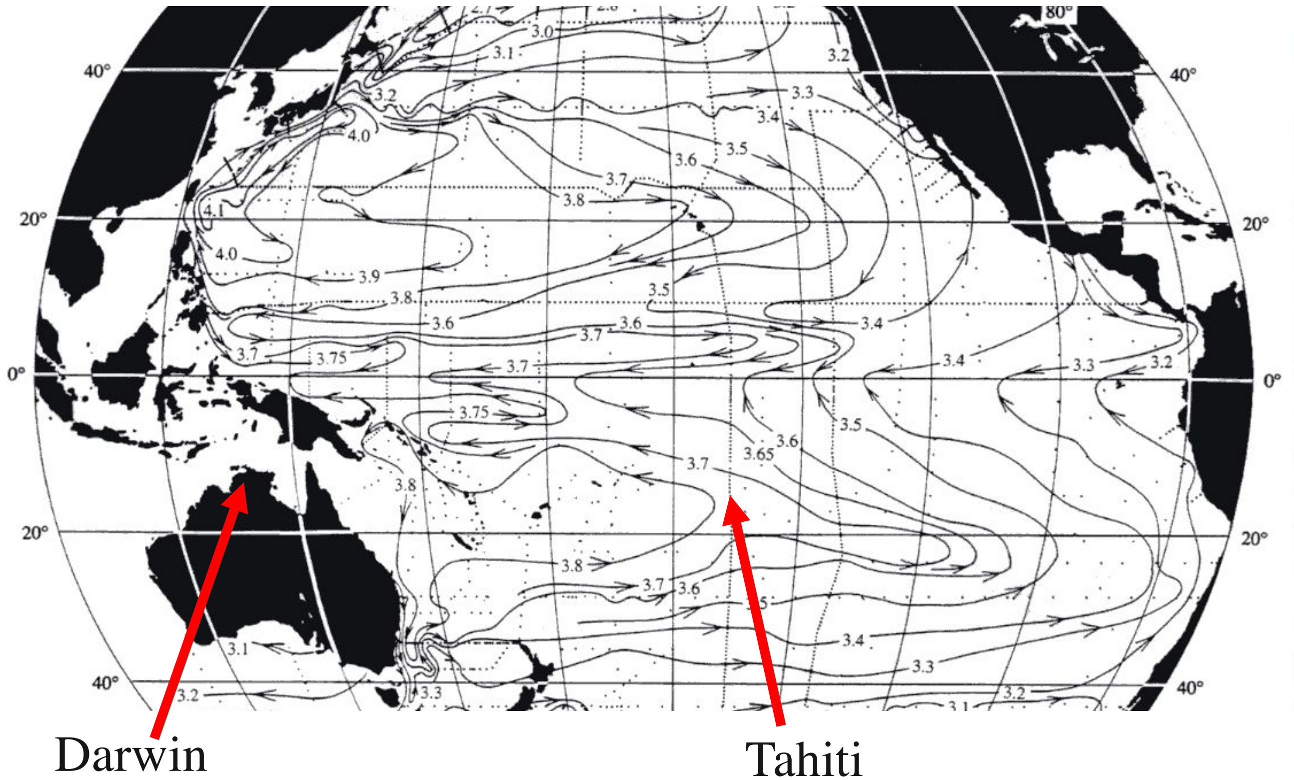
Thermocline deep in west, shallow in east

Dyn. Ht. and SSH high in west, low in east

ENSO pressure index: the "Southern Oscillation"

Walker cell: low pressure in west, high pressure in east

Southern Oscillation Index measures strength of Walker cell: Tahiti sea level pressure (SLP) minus Darwin SLP



Southern Oscilllation index (NCEP)

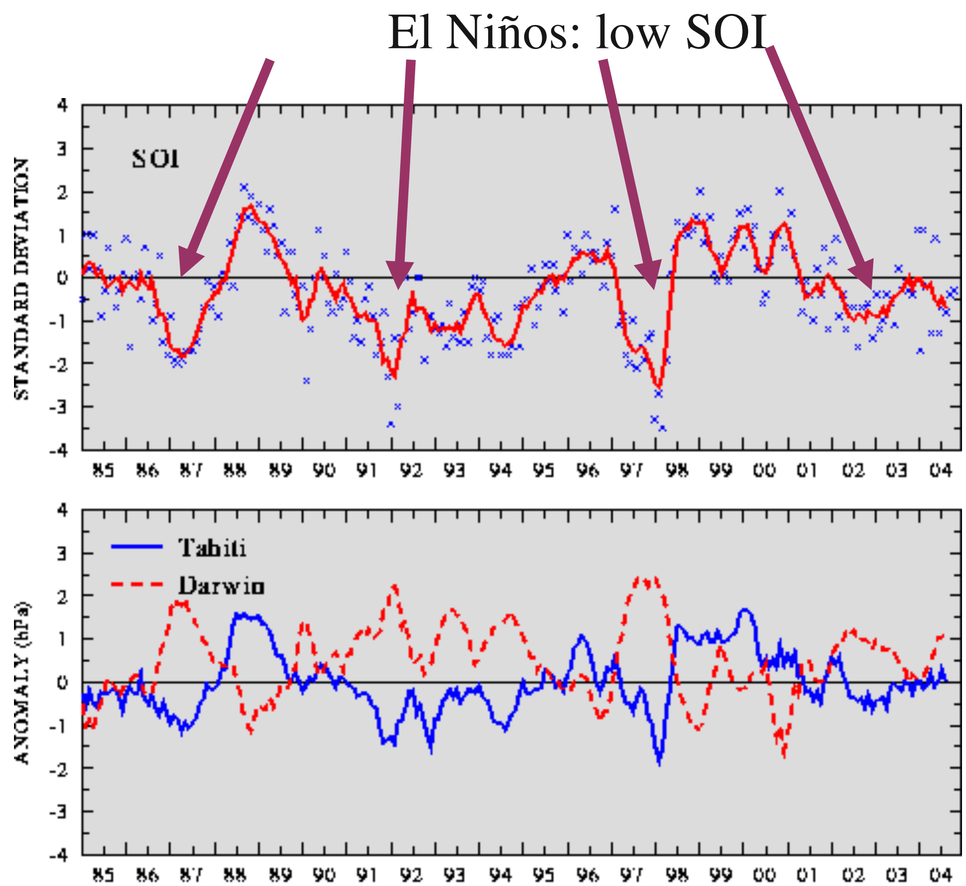
During El Niño:

SOI is low:

Tahiti minus Darwin SLPA is low, meaning that the pressure difference between them is reduced.

Therefore the trade winds are weaker during ENSO.

Note that Darwin and Tahiti anomalies are out of phase



http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/bulletin/index.html

Southern Oscilllation index

El Niños: low SOI

La Niñas: high SOI

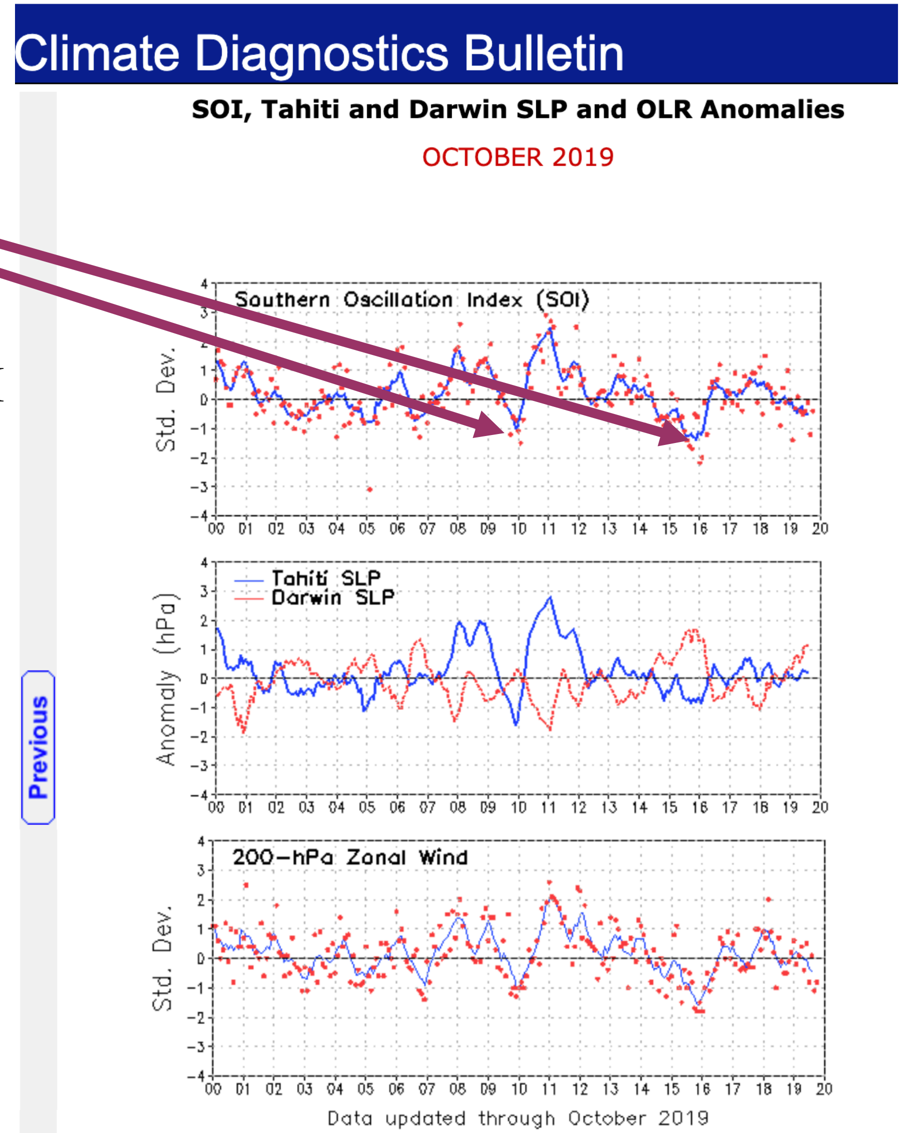
During El Niño:

SOI is low:

Tahiti minus Darwin SLPA is low, meaning that the pressure difference between them is reduced.

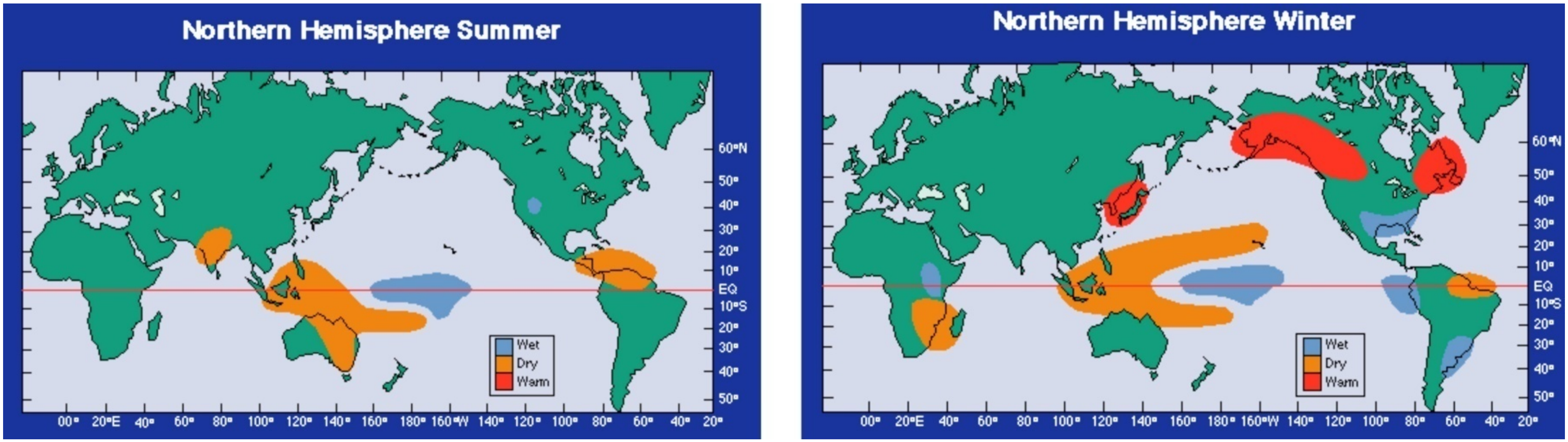
Therefore the trade winds are weaker during ENSO.

Note that Darwin and Tahiti anomalies are out of phase



http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/bulletin/index.html

El Niño precipitation changes

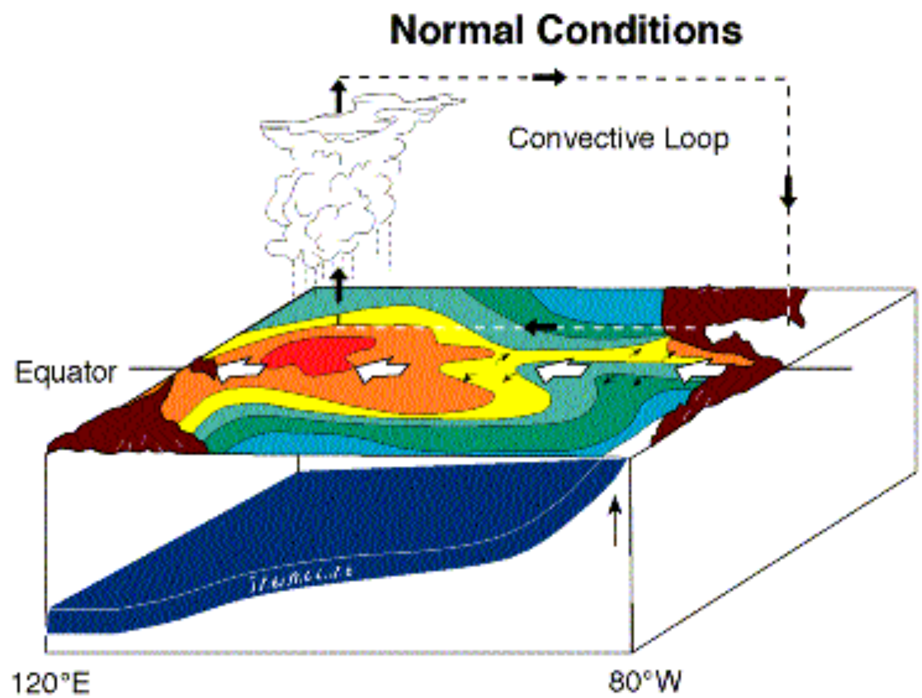


Global precipitation anomalies for Northern Hemisphere summer (left) and winter (right) during El Niño. *Source: From NOAA PMEL (2009d).*

DPO Figure S10.24

Dynamics IX: ENSO elements (slide 1):
Bjerknes feedback between wind and SST
Walker circulation and upper ocean circulation

1. Walker circulation: trade winds blow westwarc
2. South Equatorial Current: surface water on equator pushed westwards by trades
3. Warm pool in west, cold tongue in east as a result
4. Warm water in west heats atmosphere, rising air
5. Cold tongue in east cools atmosphere, sinking air
6. This causes the Walker circulation



Dynamics IX: ENSO elements in brief (slide 2): El Niño mechanism

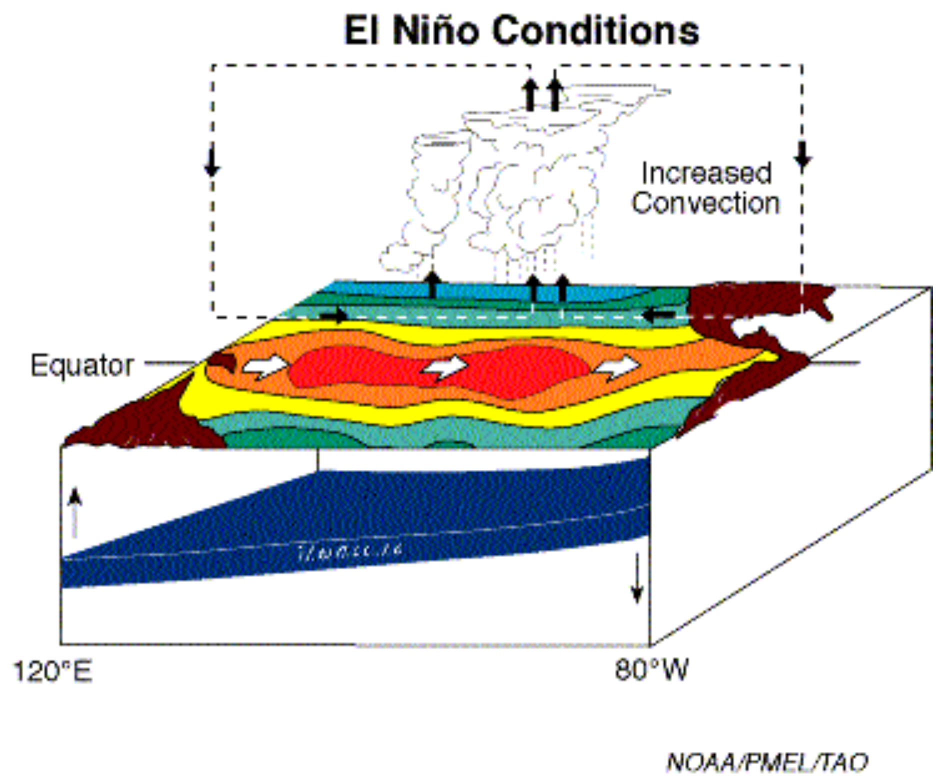
If trade winds weaken, then

(1) Westward surface flow (SEC) weakens, allowing western Pacific warm waters to move eastward

(2) cold tongue in eastern equatorial Pacific warms

(3) Equatorial SST gradient is thus reduced and this further reduces the tradewinds.

(4) This then becomes the El Niño condition.



http://www.pmel.noaa.gov/tao/elnino/nino-home.html)

Dynamics IX: ENSO elements in brief (slide 2)
La Niña mechanism

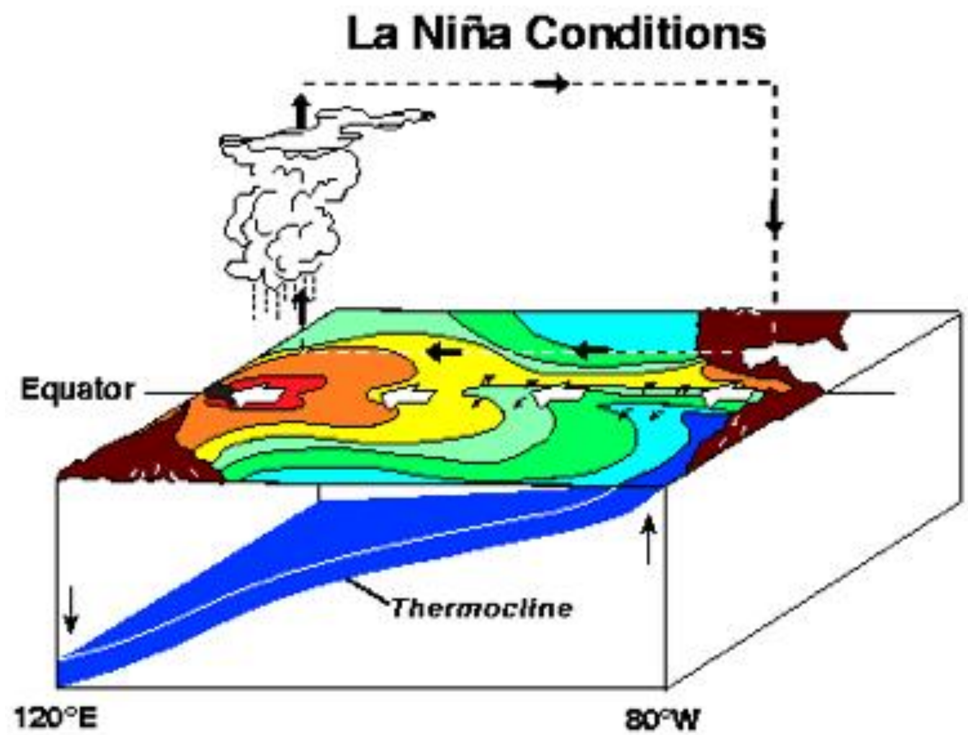
If trade winds strengthen, then

(1) Westward surface flow (SEC) strengthens, warm pool stays in west

(2) Upwelling in east provides cold surface water there

(3) Equatorial SST gradient is thus increased and this further increases the tradewinds.

(4) This then becomes the La Niña condition.



http://www.pmel.noaa.gov/tao/elnino/nino-home.html)

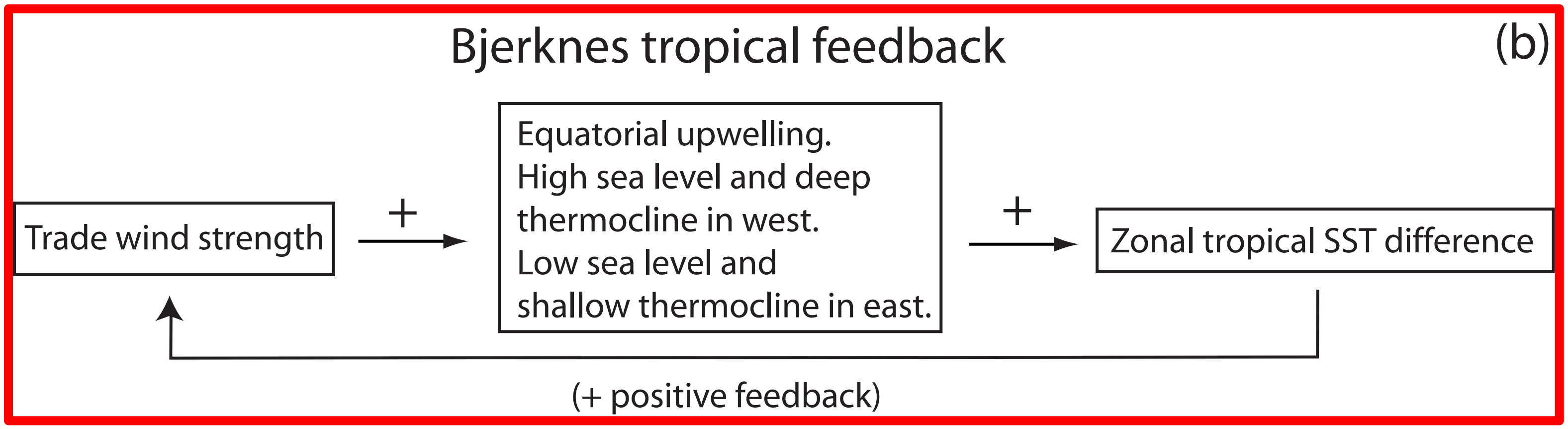
Dynamics IX: climate feedback

Write down each process and how it impacts another process.

Couplings:

\+ an increase in one creates an increase in the other

\- an increase creates a decrease (not on this example)



DPO Fig. S10.36

Dynamics IX: climate feedback

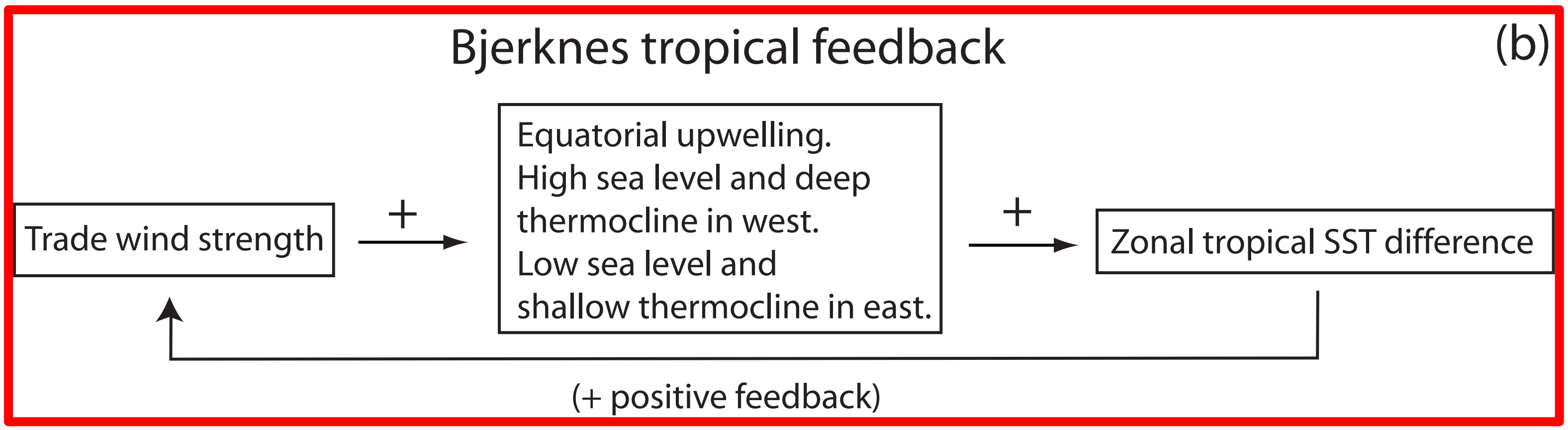
Assign +1 or -1 to each + and -. Multiply them all together.

If product > 0 (positive): feedback is positive, which means growth ("runaway feedback")

If product < 0 (negative): feedback is negative, which means damping, return to initial state. (no growth)

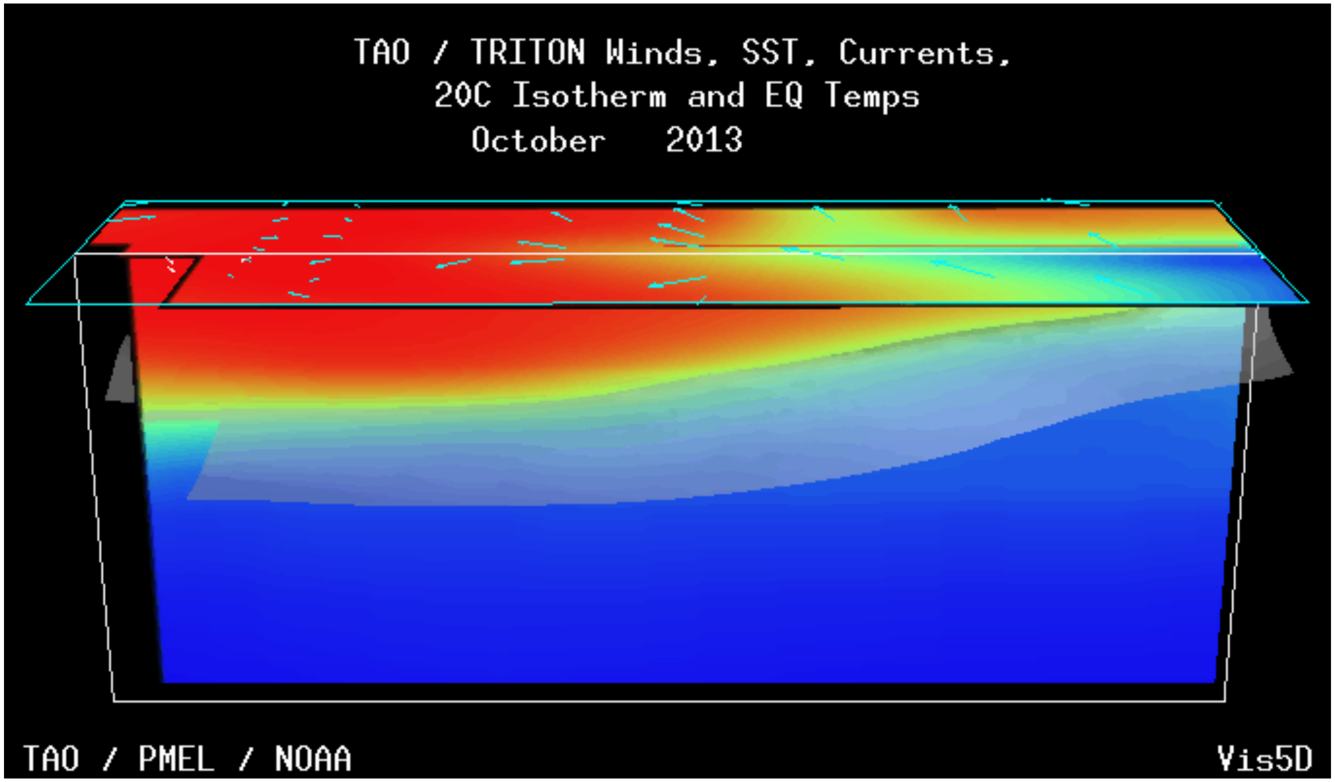
The Bjerknes feedback example has 2 +:

(+1)*(+1) = 1 > 0, so runaway feedback



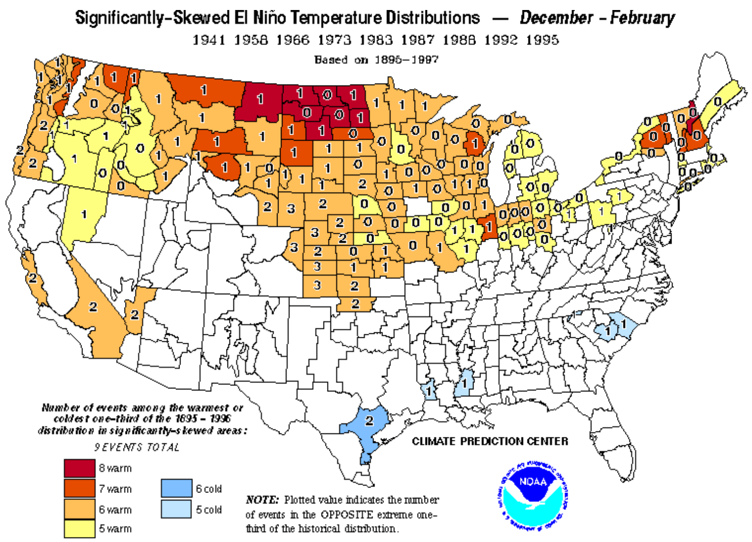
DPO Fig. S10.36

El Niño animation

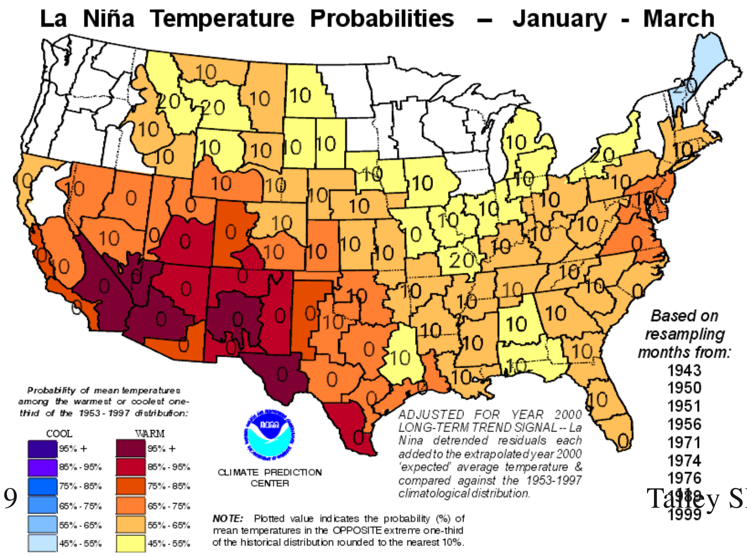


NOAA/PMEL/TAO: 2009-2012. All of these data come from the Tropical Atmosphere Ocean (TAO) network of moored ocean buoys in Equatorial Pacific. (DATA) Time scale - several years. Space scale - width of Pacific.

USA impacts of El Niño and La Niña: temperature

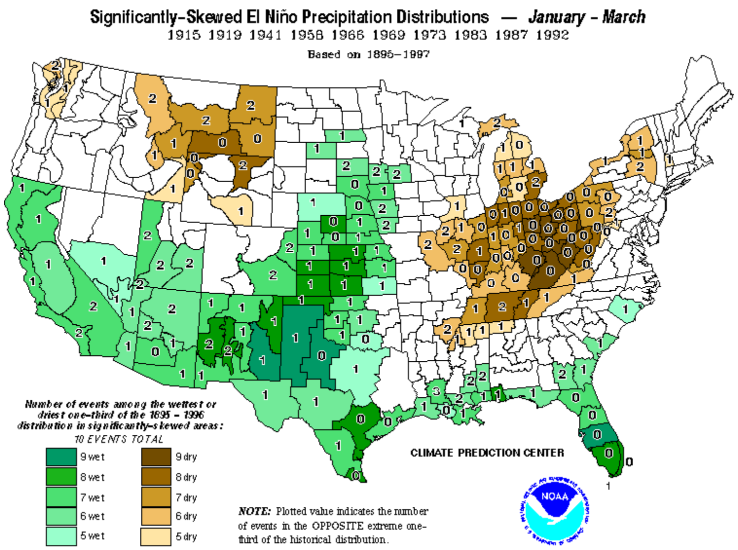


El Niño winter T anomaly

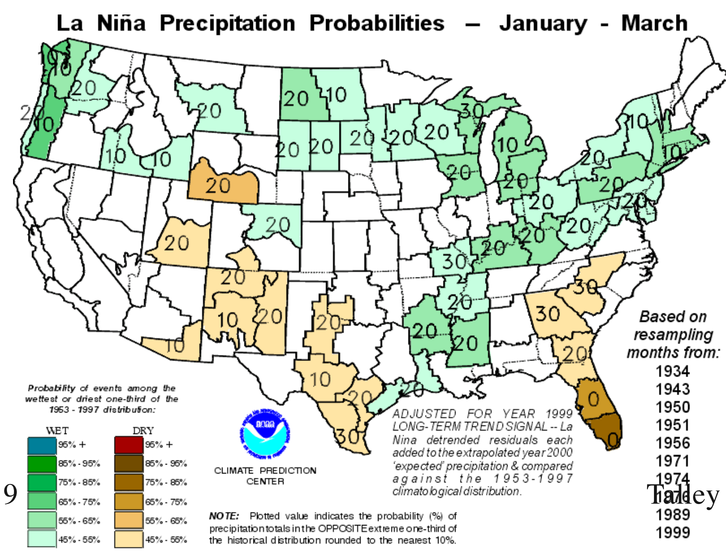


La Niña winter T anomaly

USA impacts of El Niño and La Nina: precipitation



El Niño winter precip anomaly



La Niña winter precip anomaly

African maize yield, relation to ENSO