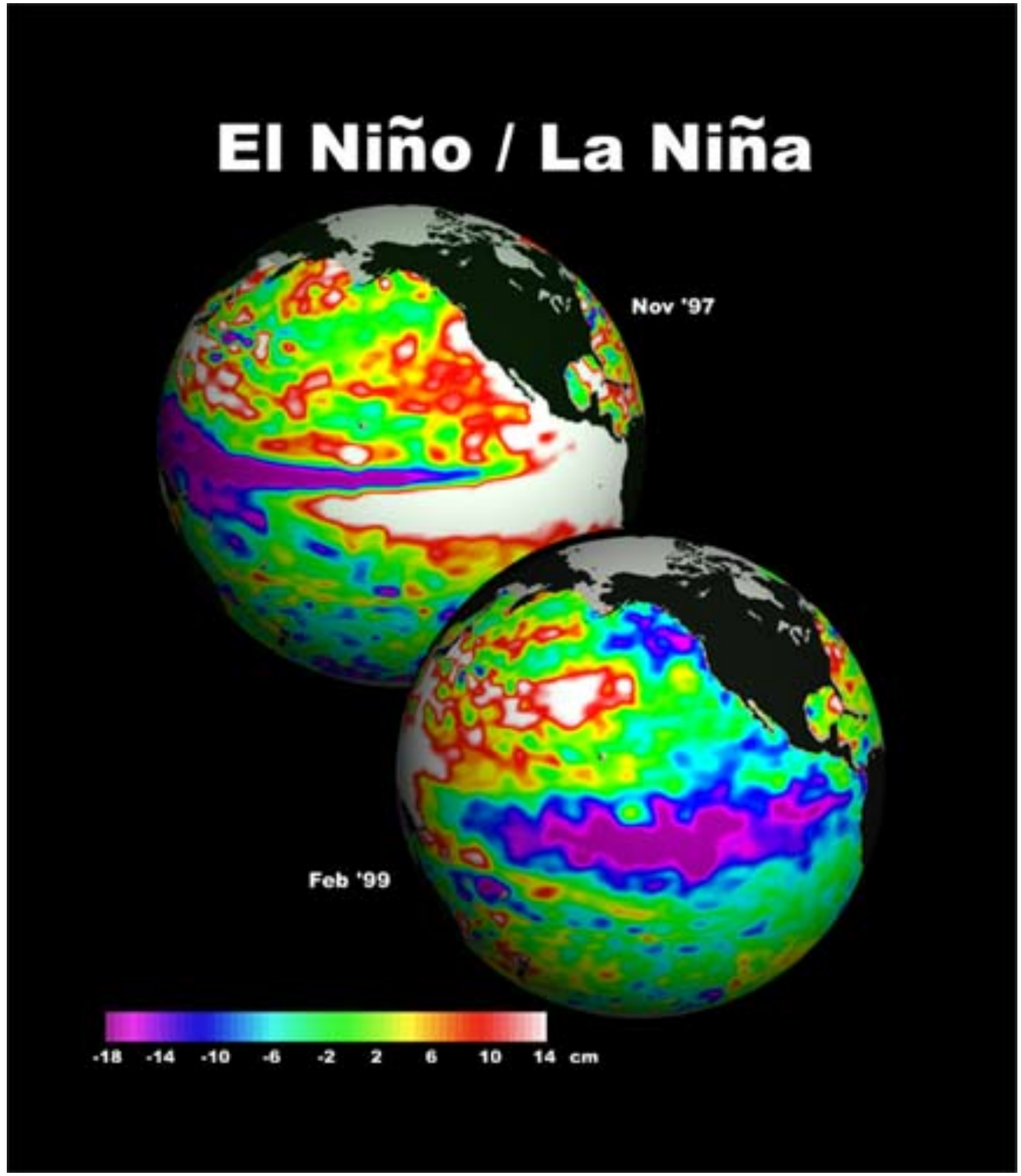
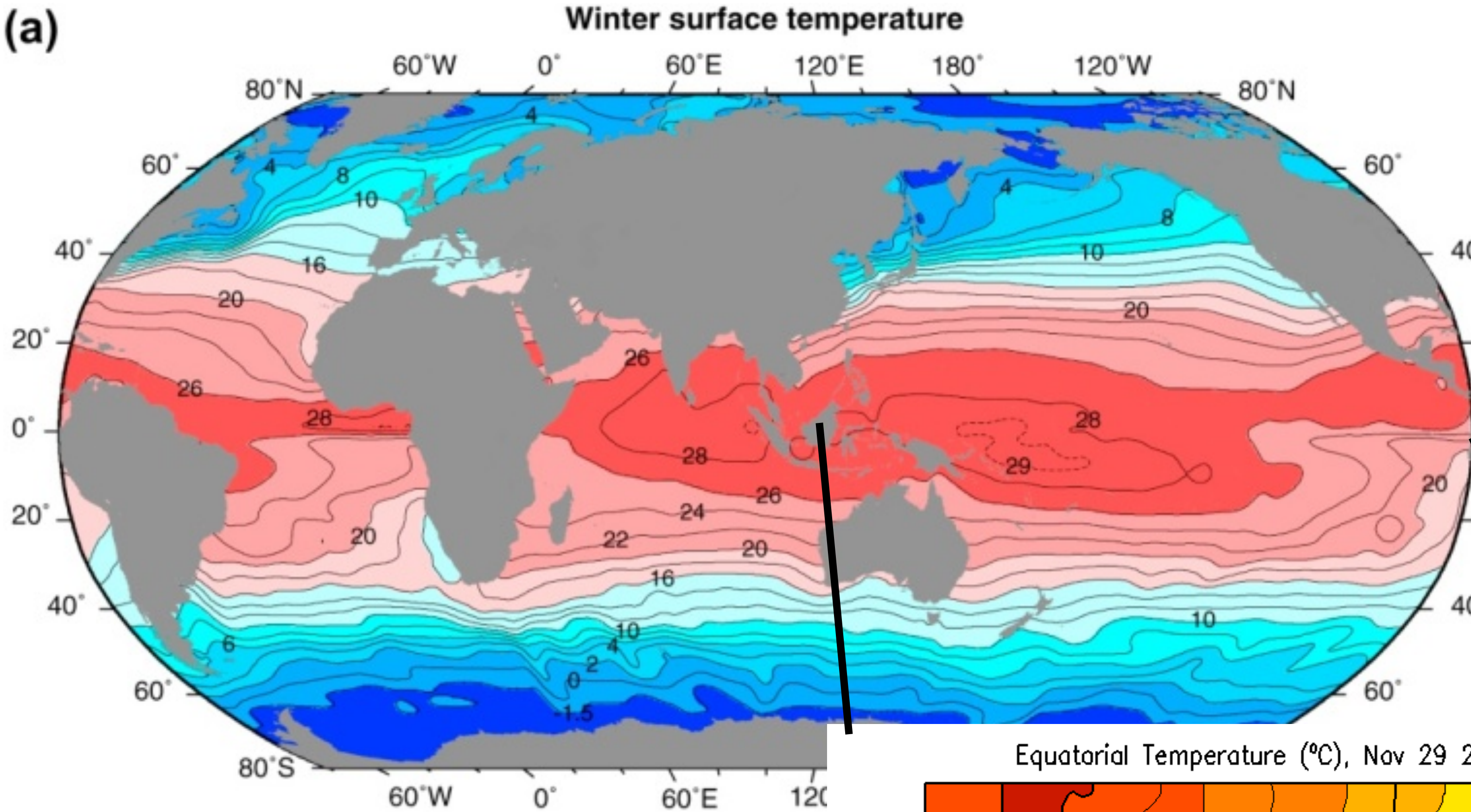
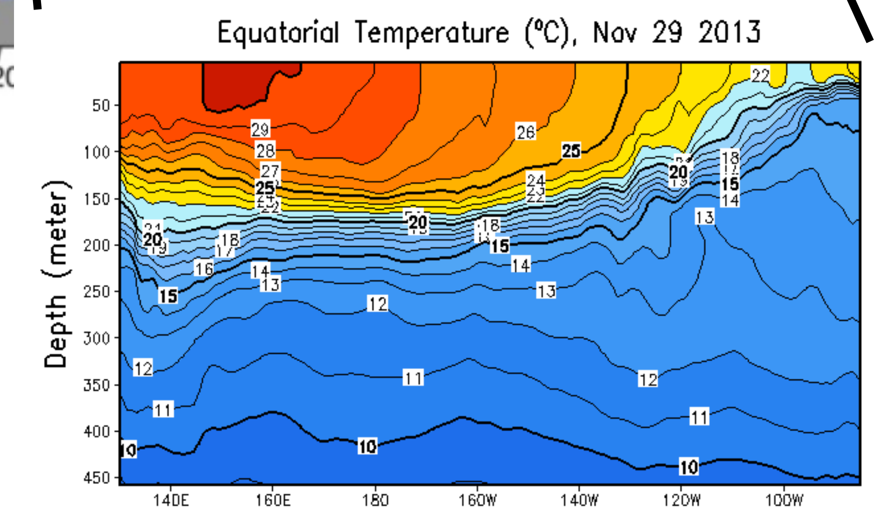
Coupled Modes of Variability

AOS660
Prof. McKinley
December 3, 2013



Sea level height anomalies from TOPEX/Poseidon





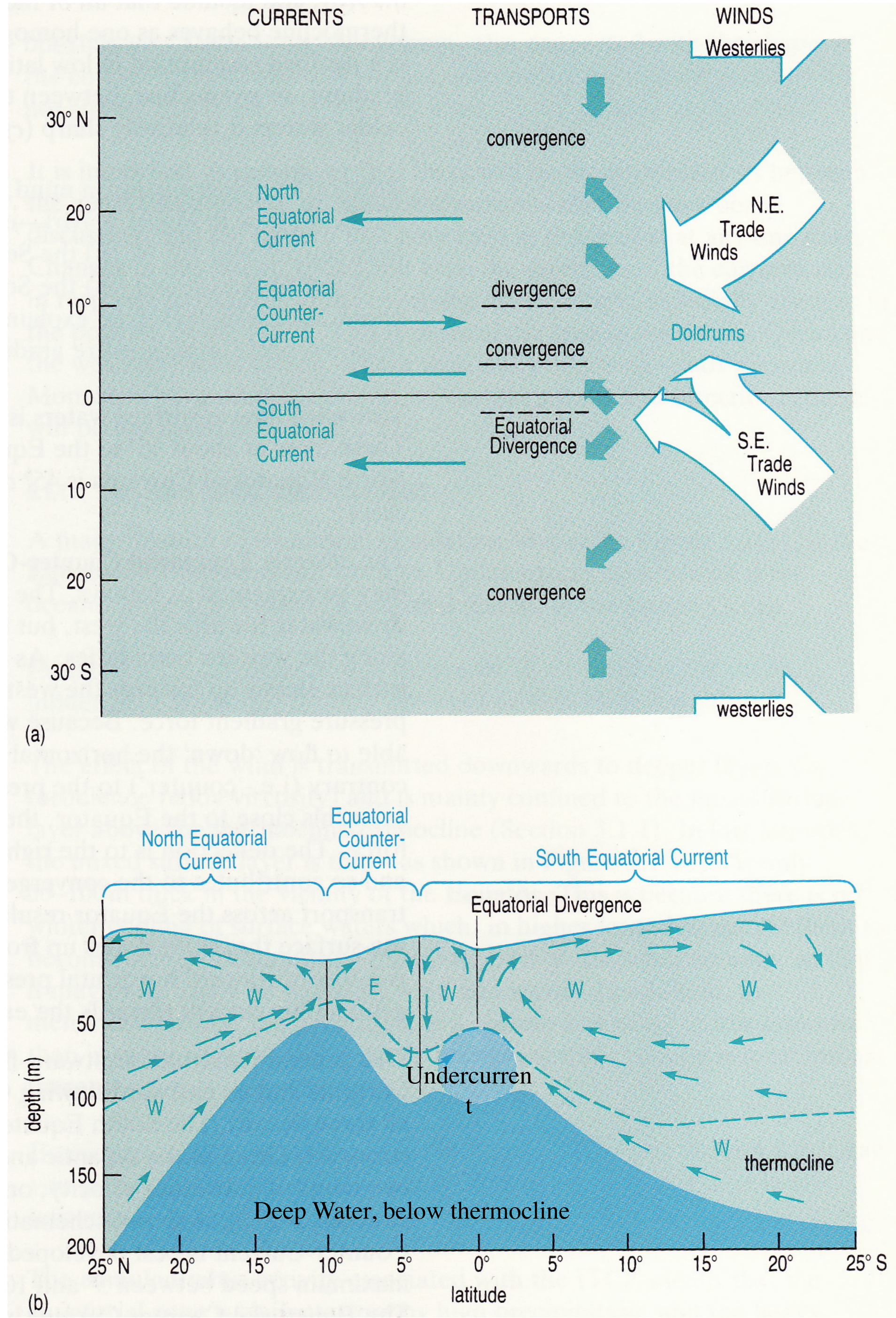
(a) Surface temperature (°C) of the oceans in winter (January, February, March north of the equator; July, August, September south of the equator) based on averaged (climatological) *data from Levitus and Boyer (1994)*.

TALLEY

Equatorial Pacific Currents

- Coriolis Force goes to zero at equator
  - But does have effect within ~1degree of equator
- Flow is more directly forced by the winds
- Undercurrent
  - Water piling up in west, then flowing down pressure gradient
  - And/or stabilization by coriolis

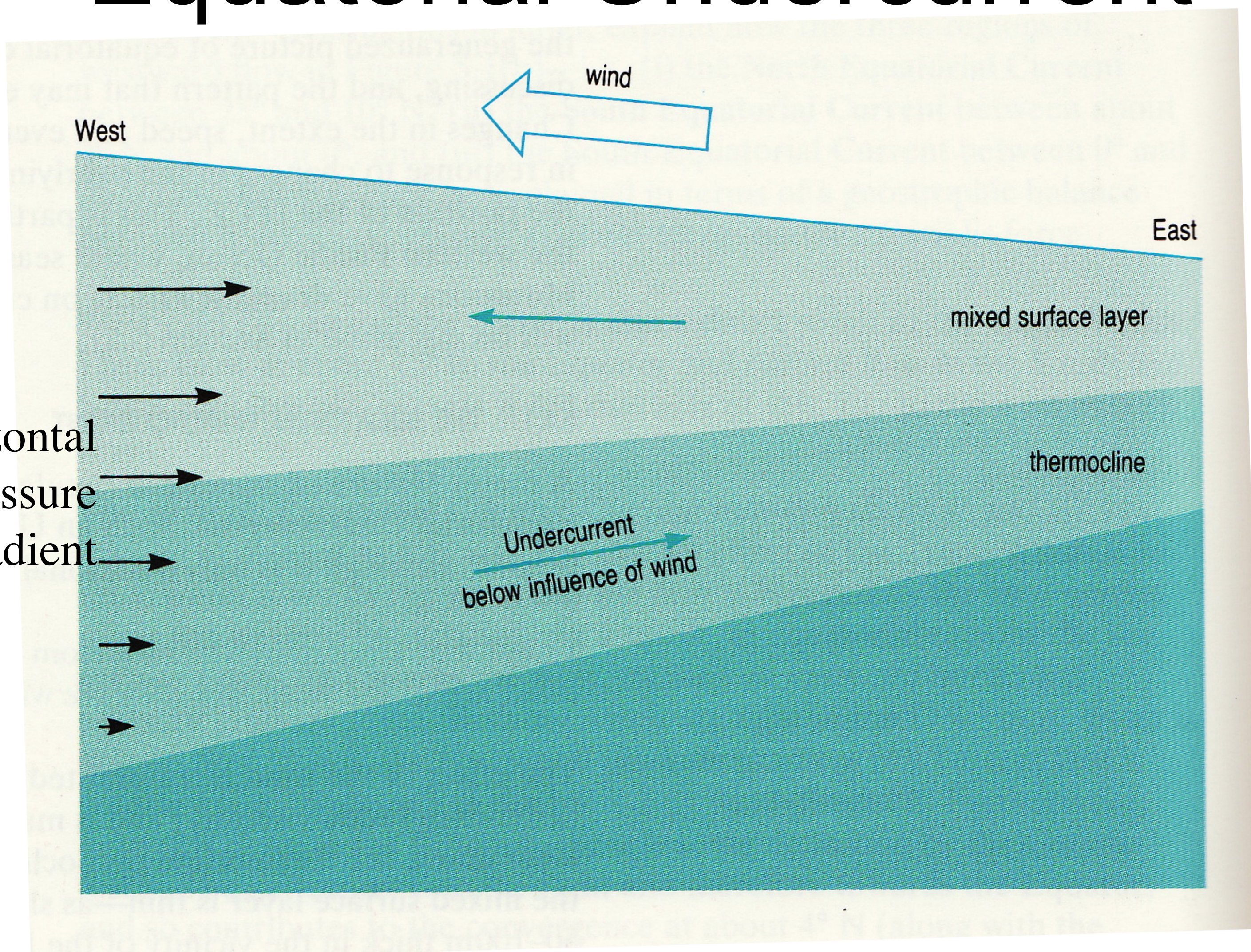
Equatorial divergence and current system



Open University, Ocean Circulation, Fig 5.1

Equatorial Undercurrent

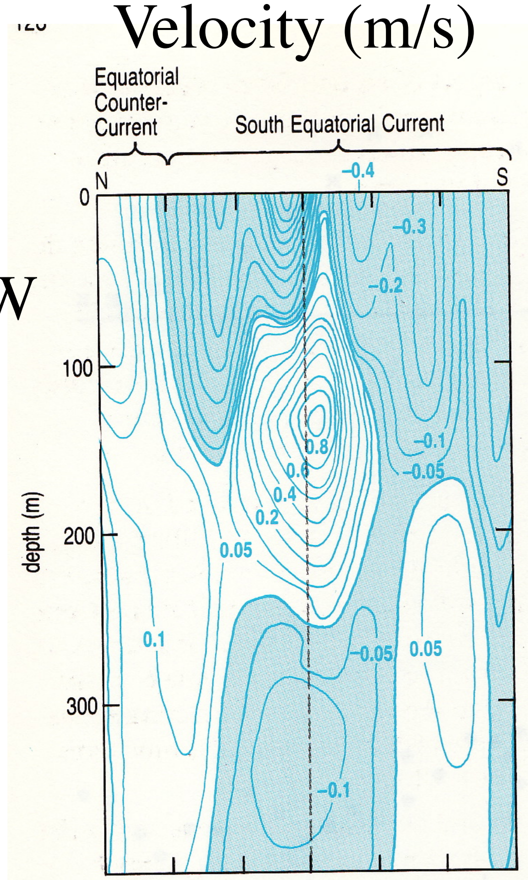
Horizontal
pressure
gradient

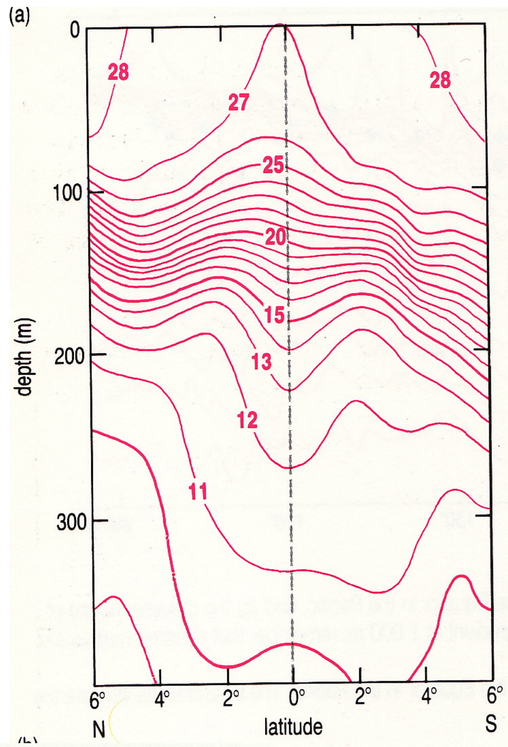


Open University, Ocean Circulation, Fig 5.2

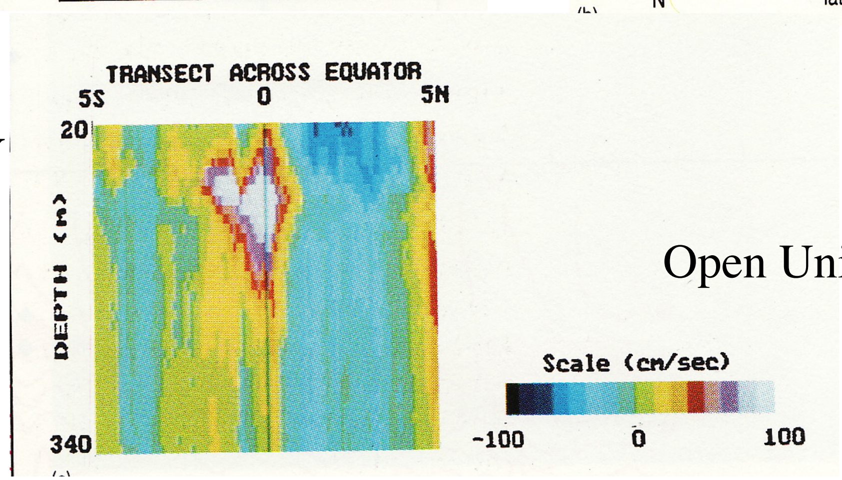
Velocity (m/s) Temp (degC)

At 150W

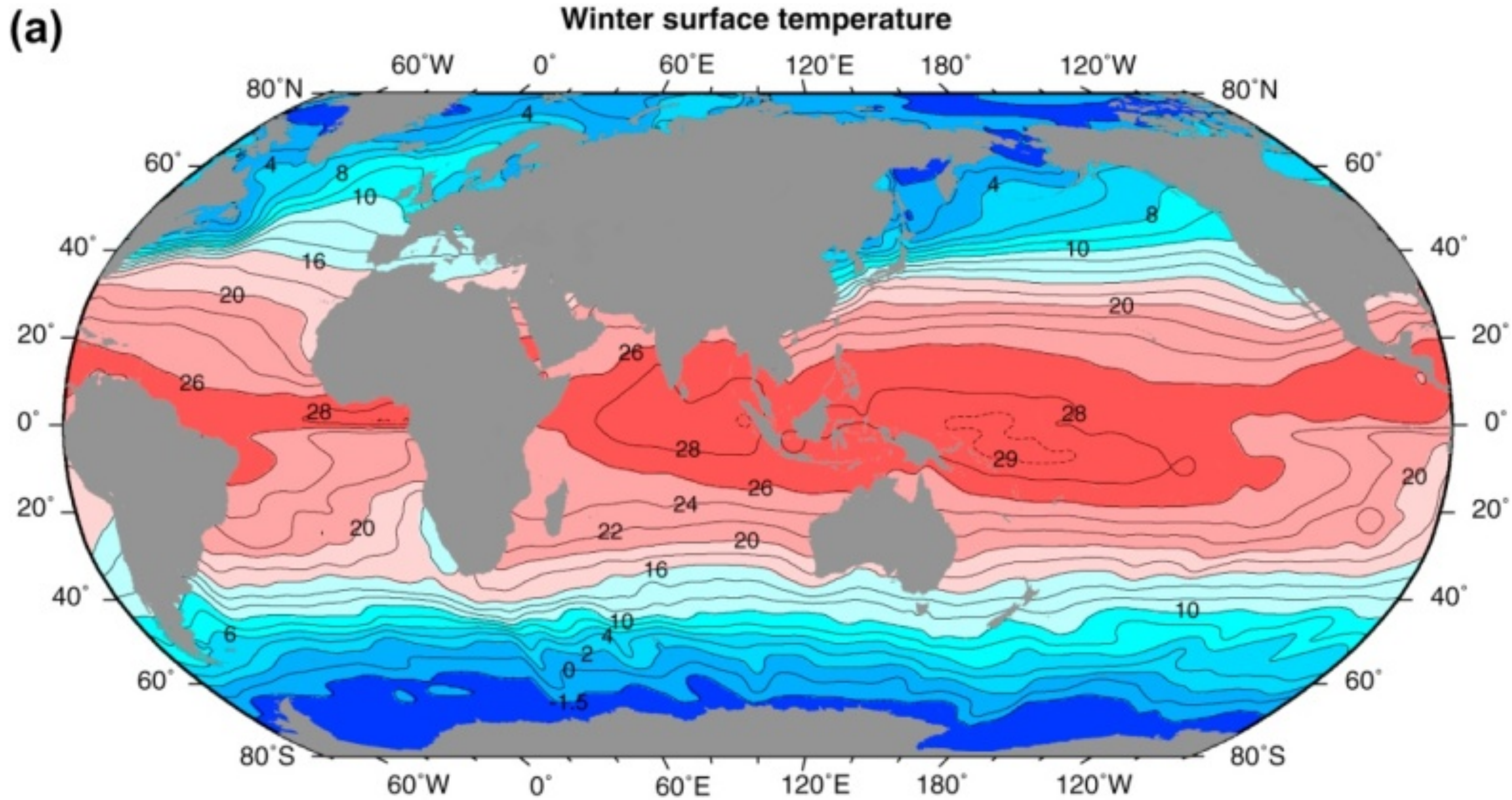




At 110W



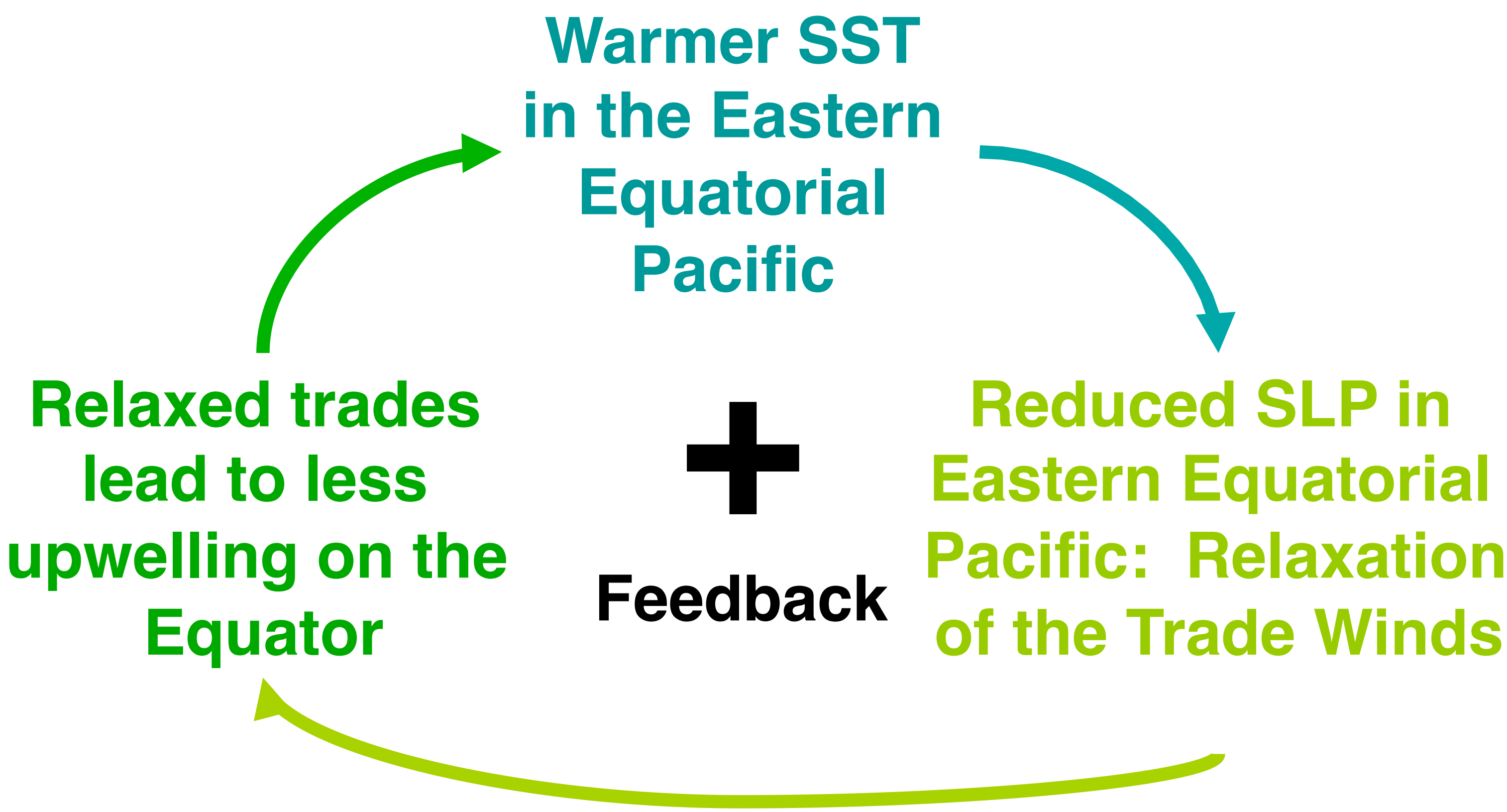
Open University, Ocean Circulation, Fig 5.4



(a) Surface temperature (°C) of the oceans in winter (January, February, March north of the equator; July, August, September south of the equator) based on averaged (climatological) *data from Levitus and Boyer (1994)*.

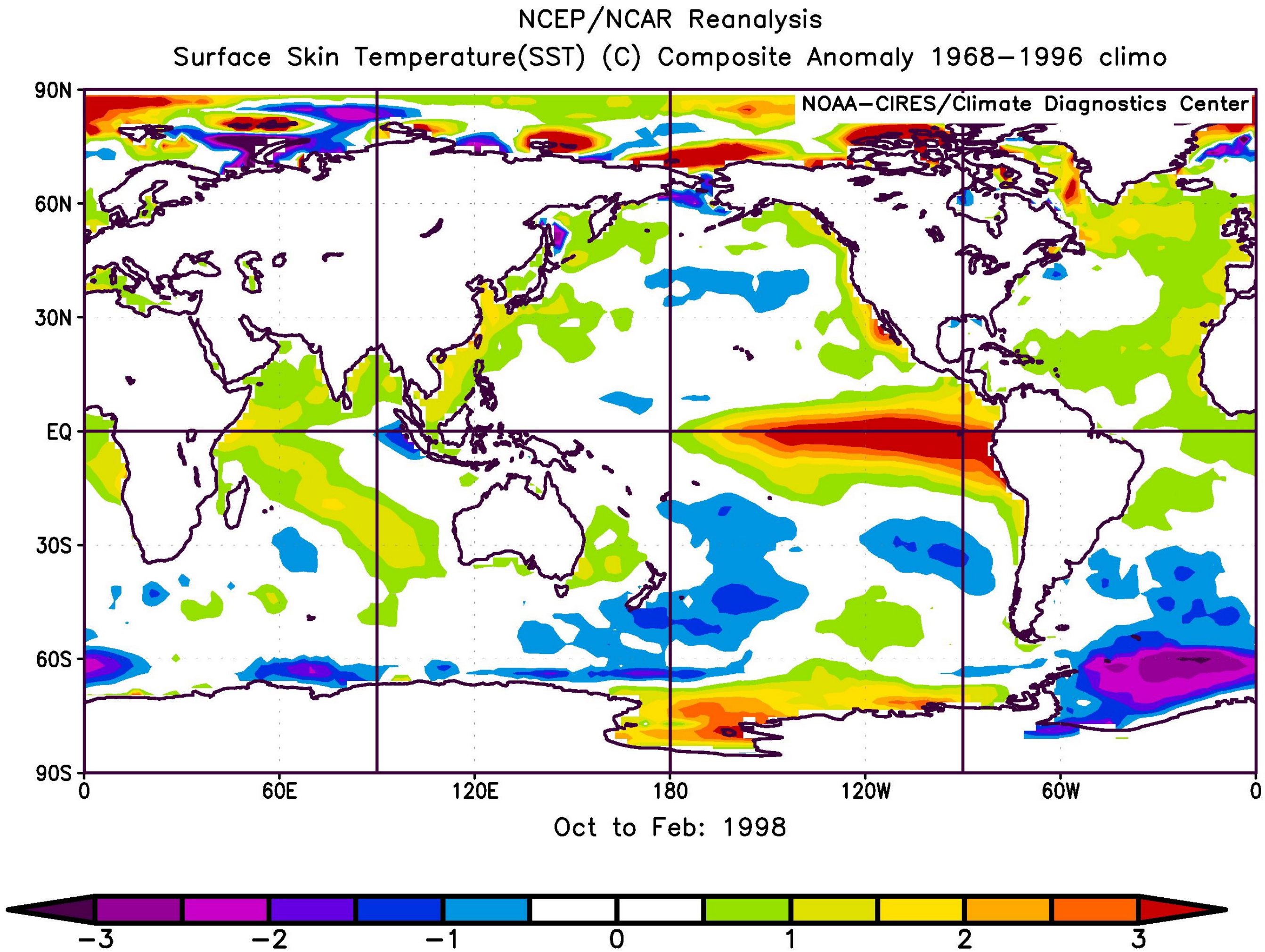
FIGURE 4.1

El Niño / Southern Oscillation



El Niño (warm phase)

El Niño / Southern Oscillation



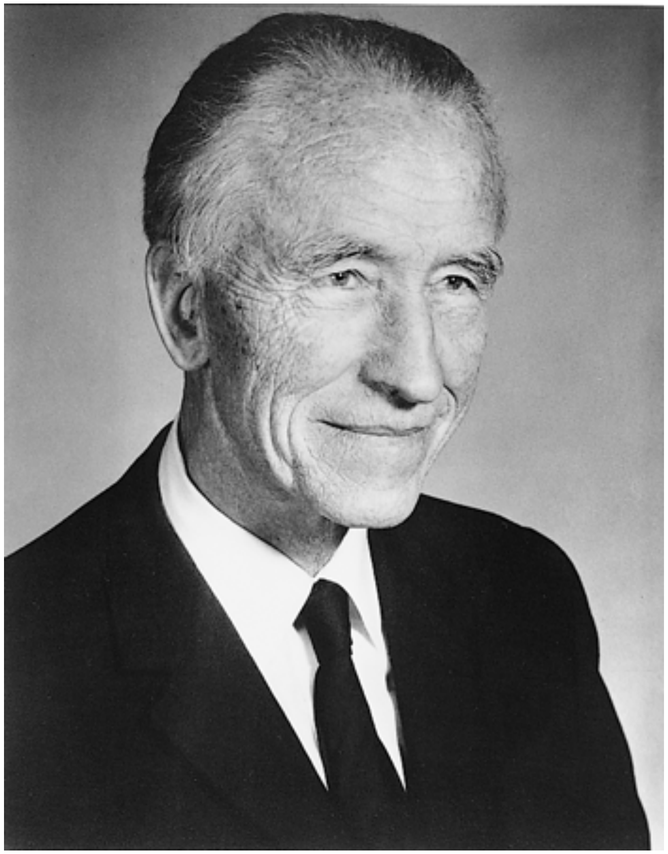
http://www.cdc.noaa.gov/

El Niño / Southern Oscillation

- Jacob Bjerknes (1969) **ENSO**:

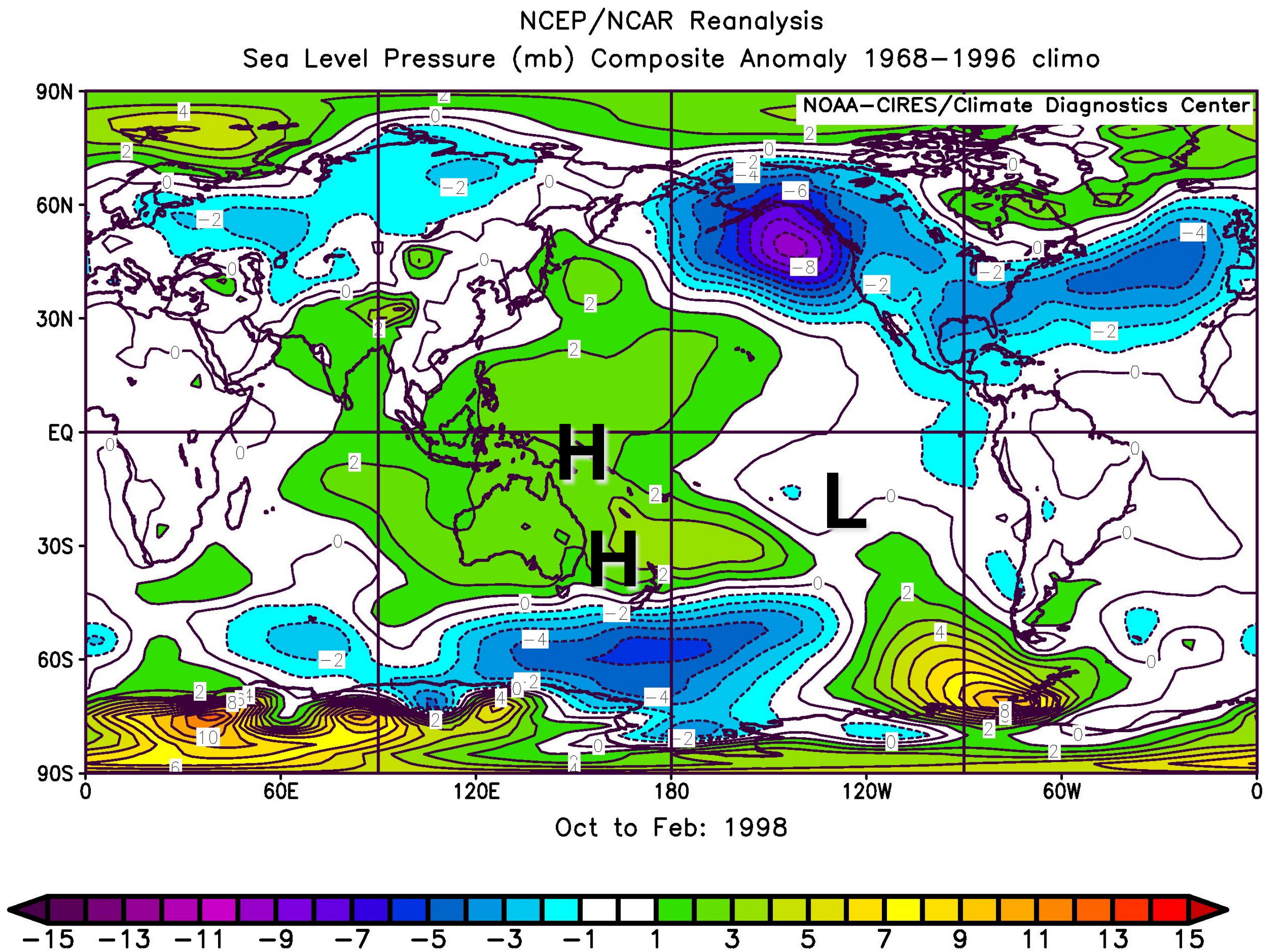
  "A change toward a steeper pressure slope at the base of the Walker Circulation is associated with an increase in the equatorial easterly winds and hence also with an increase in upwelling and a sharpening of the contrast of surface temperature between the eastern and western Pacific. This chain reaction shows that an intensifying Walker Circulation also provides for an increase in the east-west temperature contrast that is the cause of the Walker Circulation in the first place."

  Bjerknes, 1969. M. Wea. Rev.



La Niña (cool phase)

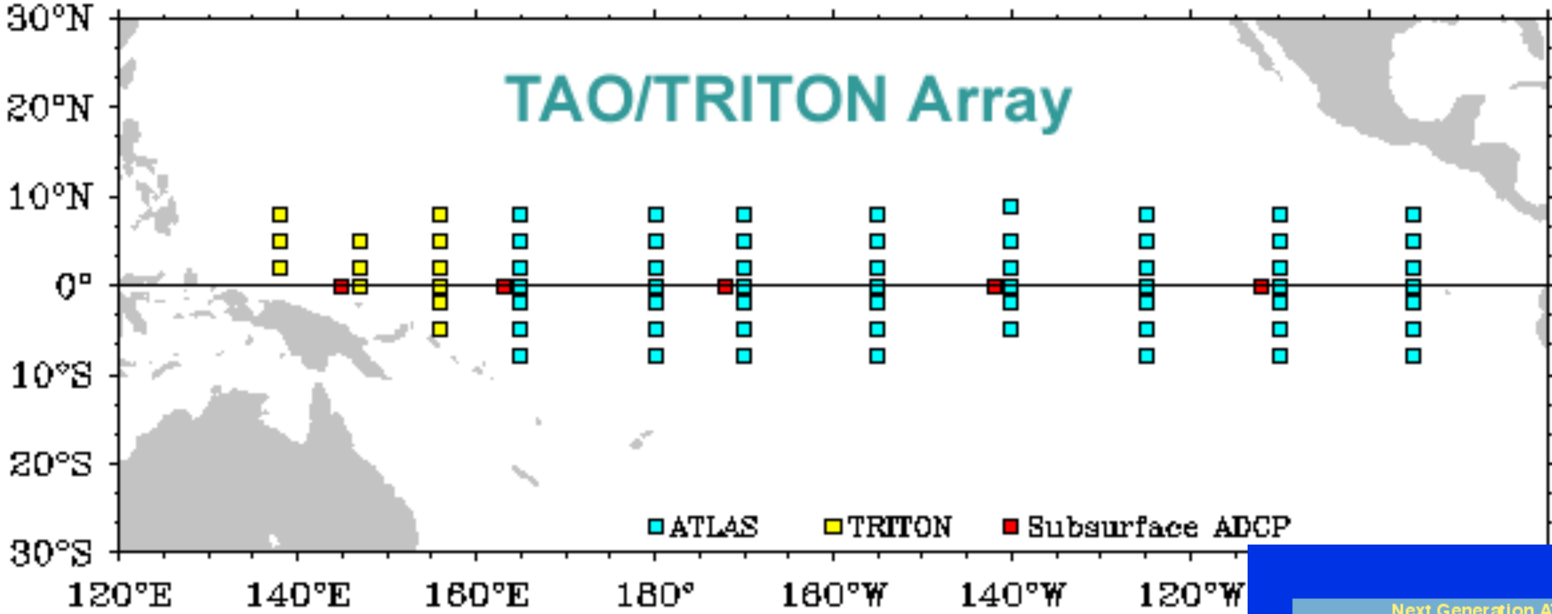
El Niño / Southern Oscillation



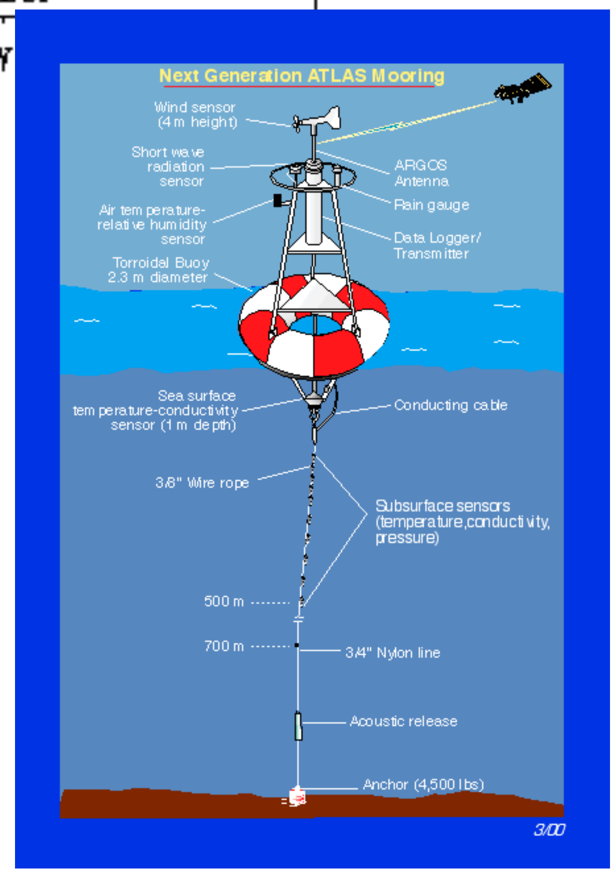
http://www.cdc.noaa.gov/

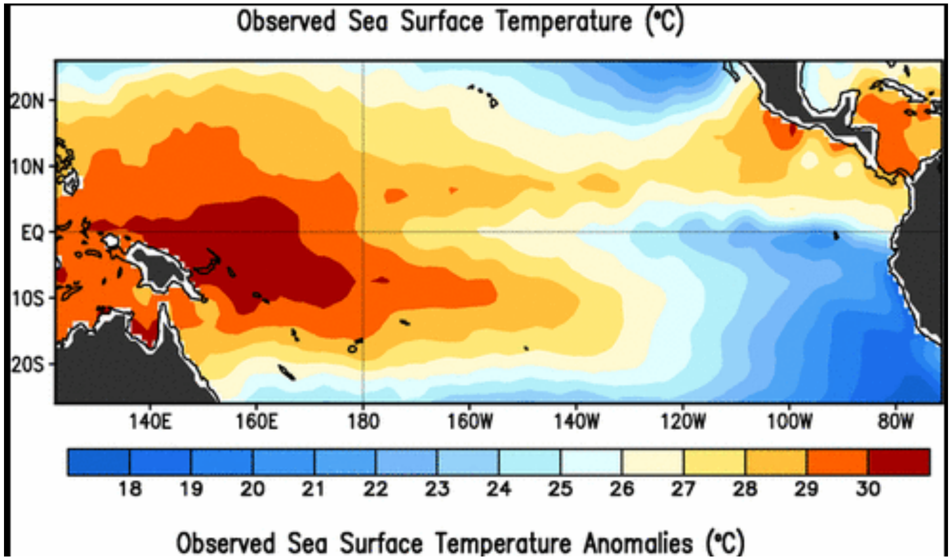
El Niño / Southern Oscillation

- The 1982-83 ENSO event
  - Largest ENSO event on record (until 1997-98)
  - Drought in Indonesia, floods in California and Peru. Globally, > 8 billion USD in damages
  - The world is completely caught by surprise - and it could have been predicted six months in advance, ***<u>if data was available real time.</u>***
- The TAO program was launched in response
  - The TAO array is deployed to provide real-time monitoring of the Tropical Pacific (intro slide)
  - ENSO dynamics are identified, the first ENSO predictions begin (now, no ENSO event goes unpredicted…)


TAO/TRITON Array
30°N
20°N
10°N
0°
10°S
20°S
30°S
120°E
140°E
160°E
180°
160°W
140°W
120°W
ATLAS
TRITON
Subsurface ADCP


NOAA
R 104


Next Generation ATLAS Mooring
Wind sensor (4 m height)
Short wave radiation sensor
Air temperature-relative humidity sensor
Torroidal Buoy 2.3 m diameter
ARGOS Antenna
Rain gauge
Data Logger/ Transmitter
Sea surface temperature-conductivity sensor (1 m depth)
Conducting cable
3/8" Wire rope
Subsurface sensors (temperature,conductivity, pressure)
500 m
700 m
3/4" Nylon line
Acoustic release
Anchor (4,500 lbs)
3/00



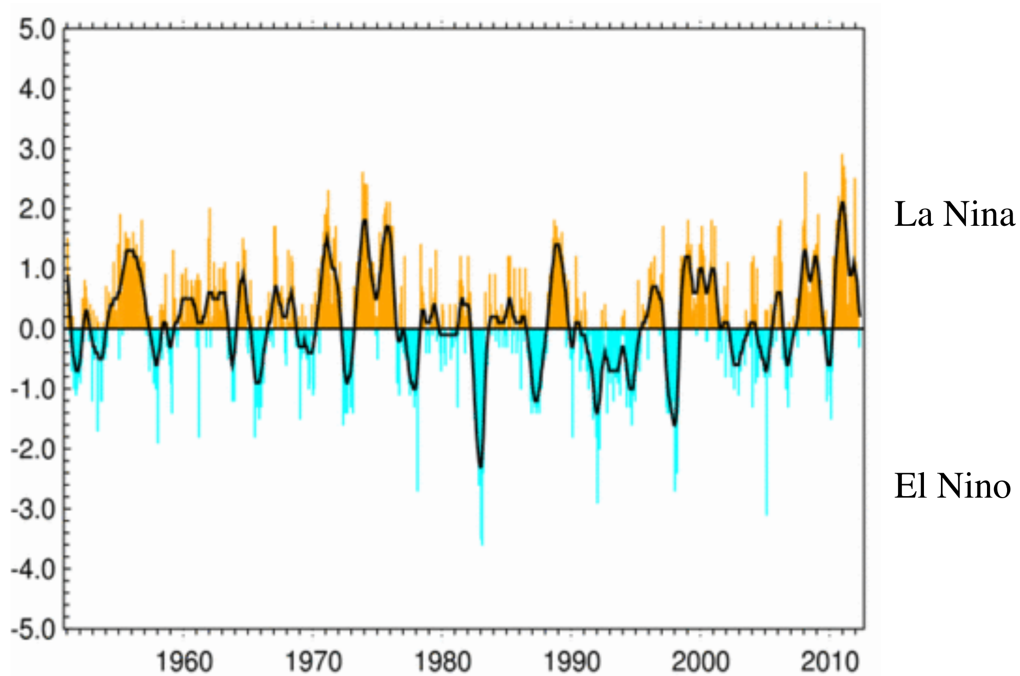
7 day average, centered 27 November 2013

We now monitor closely El Niño / Southern Oscillation

http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml

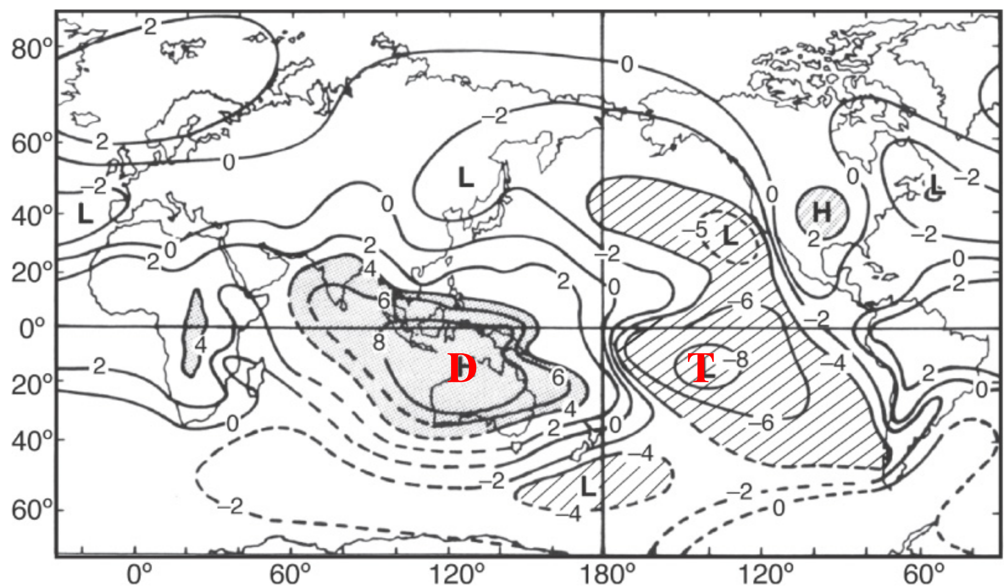
http://www.cpc.noaa.gov/

- Current conditions?
  - SOI is positive, but only weakly so
  - Neutral

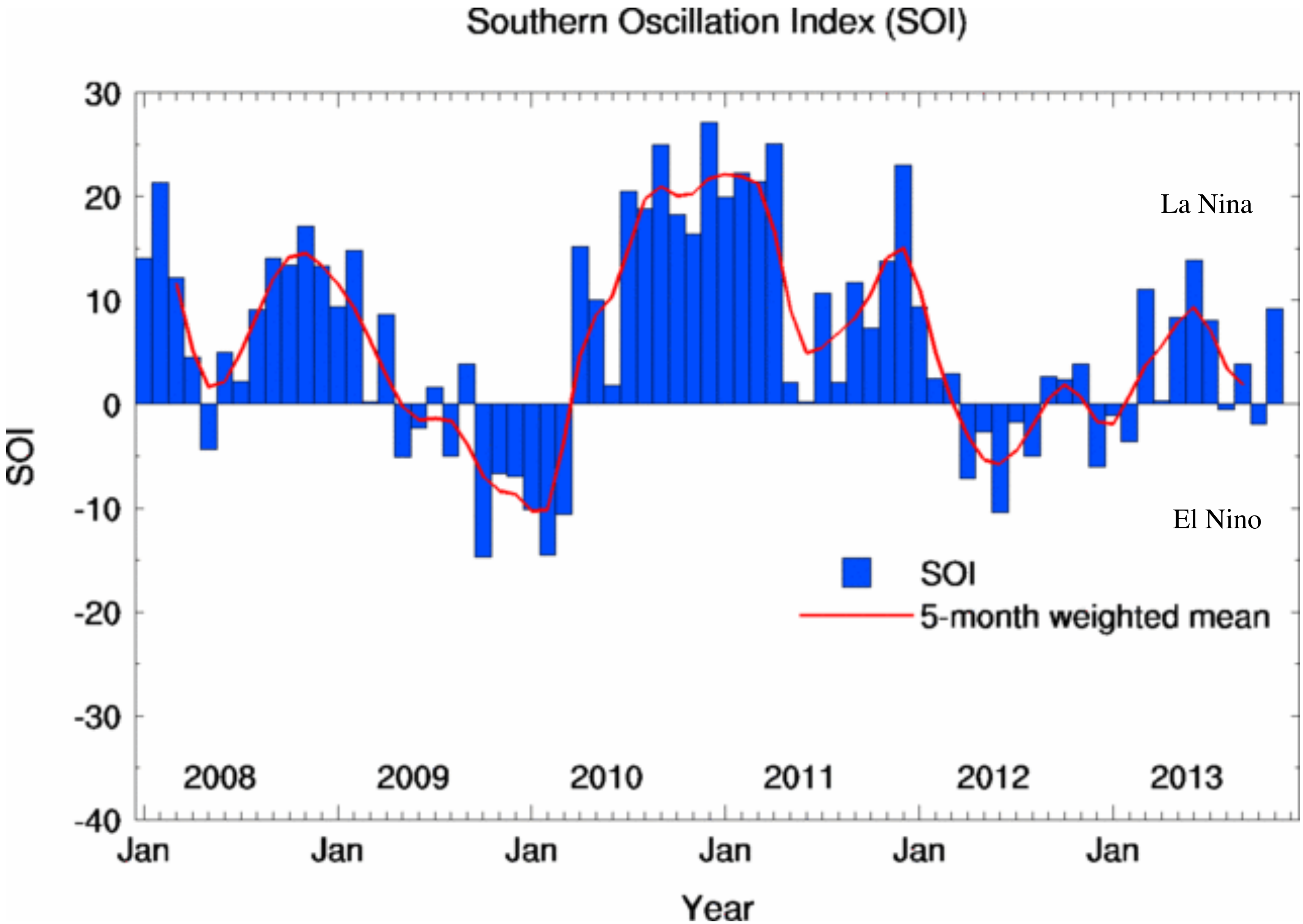


Southern Oscillation Index

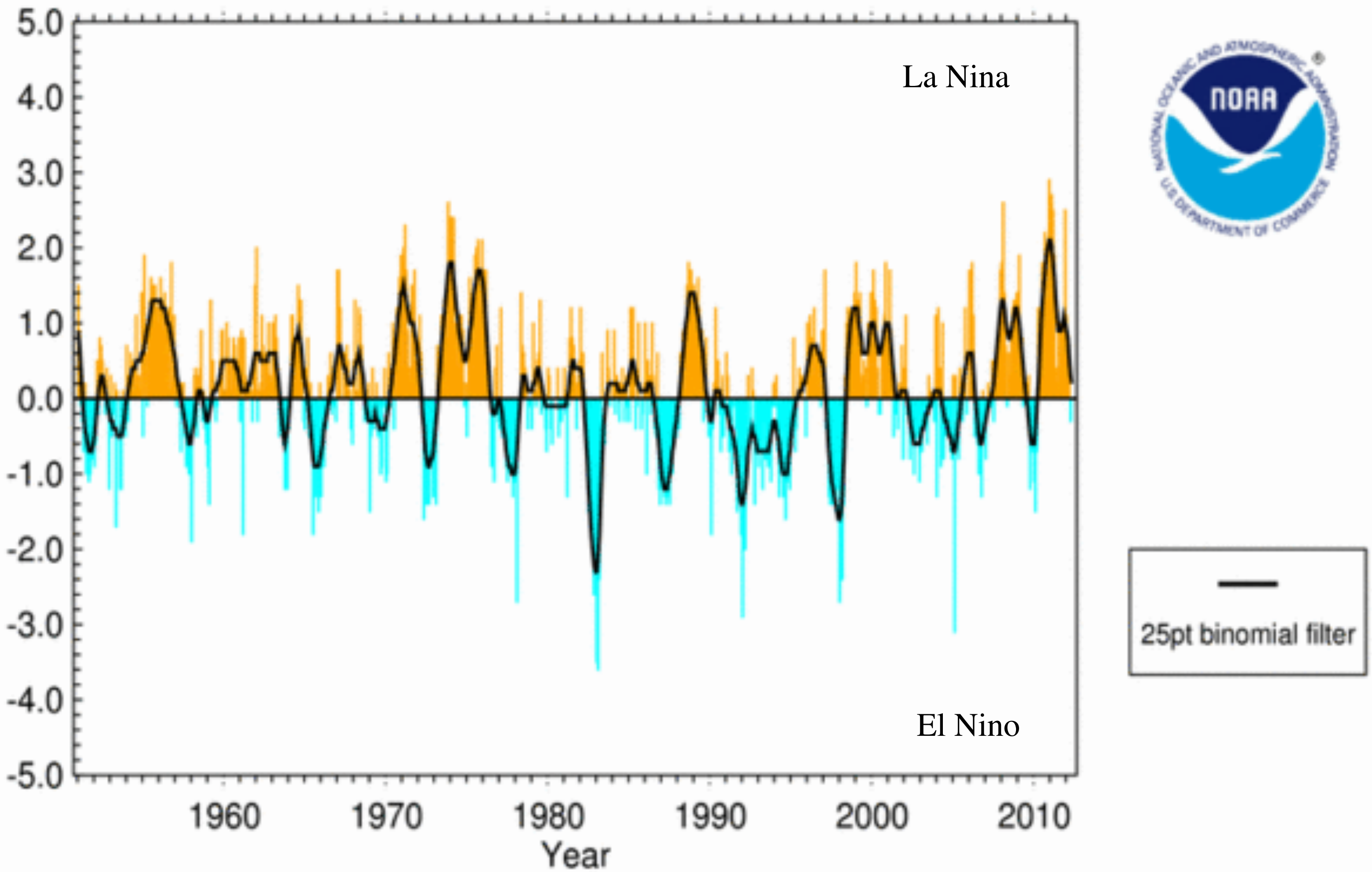
$$SOI = 10 \times \frac{SLP_{Tahiti} - SLP_{Darwin}}{\sigma_{difference}}$$



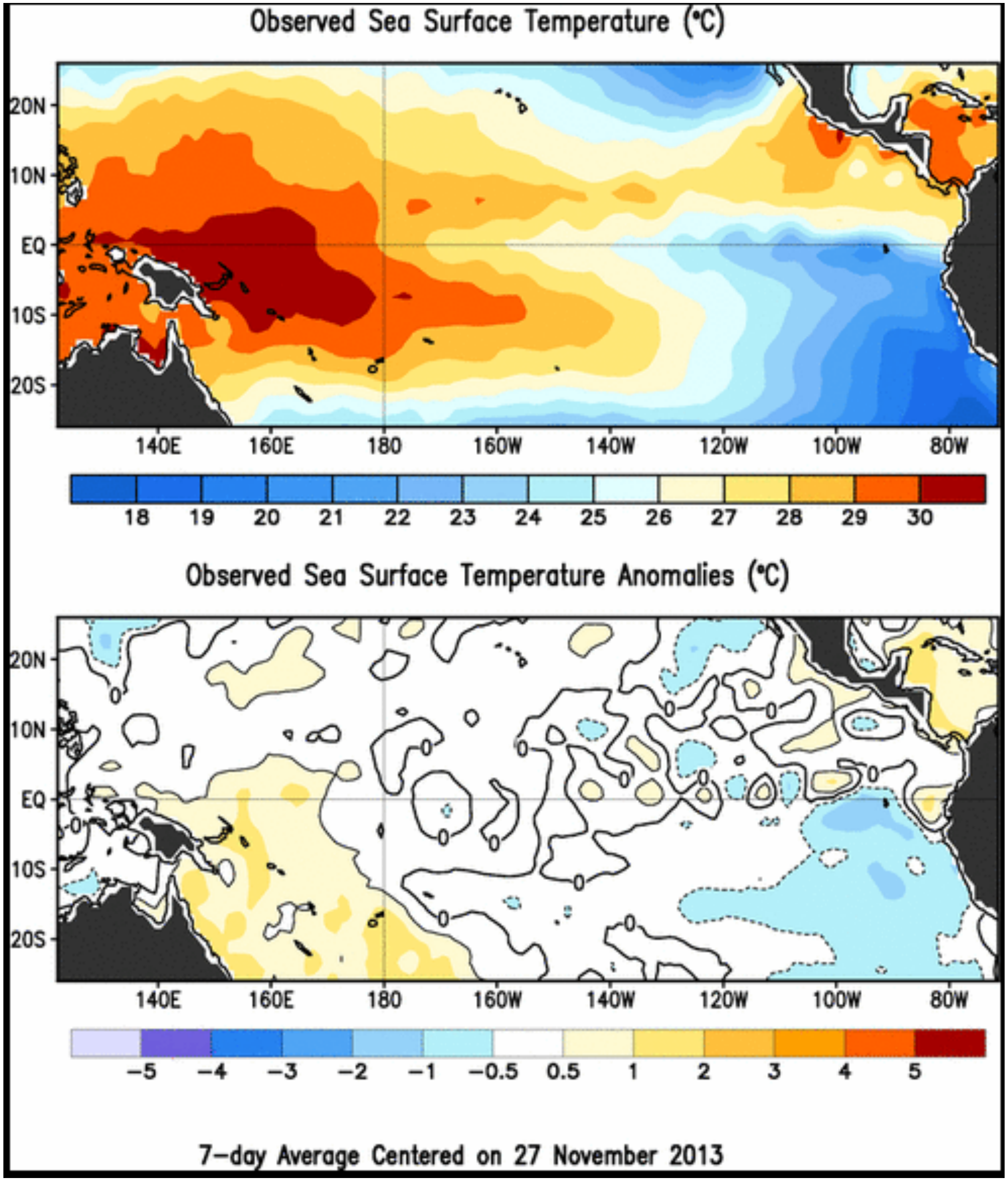
negative = Weaker Walker Circ = El Niño
positive = Stronger Walker Circ = La Niña

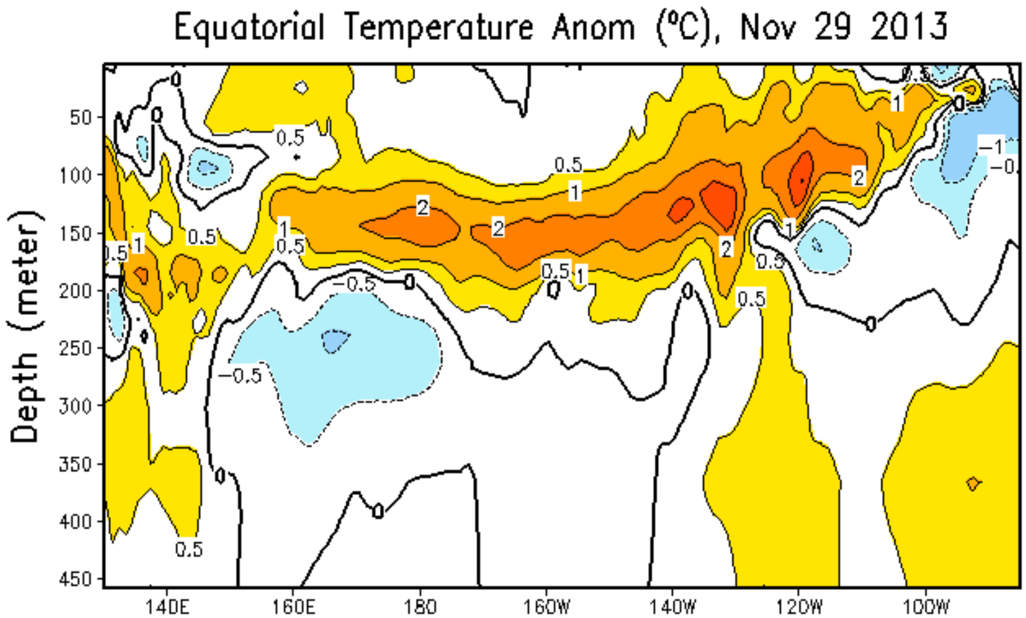

Southern Oscillation Index (SOI)
30
20
10
0
-10
-20
-30
-40
SOI
La Nina
El Nino
SOI
5-month weighted mean
2008
2009
2010
2011
2012
2013
Jan
Jan
Jan
Jan
Jan
Jan
Year

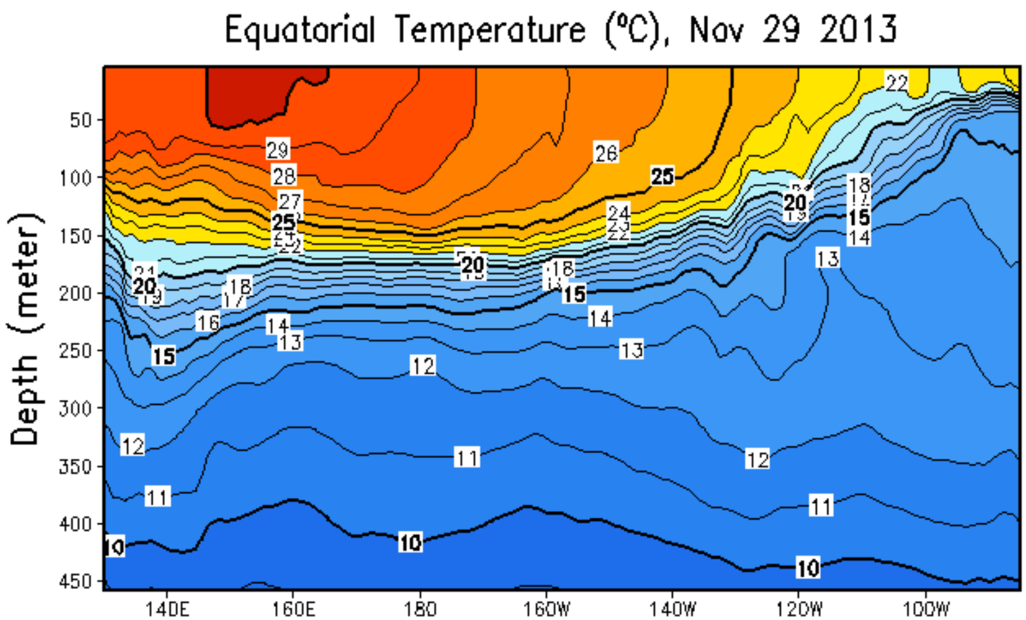
Standardized Southern Oscillation Index (SOI)



National Climatic Data Center / NESDIS / NOAA


Observed Sea Surface Temperature (°C)
20N
10N
EQ
10S
20S
140E
160E
180
160W
140W
120W
100W
80W
18 19 20 21 22 23 24 25 26 27 28 29 30
Observed Sea Surface Temperature Anomalies (°C)
−5 −4 −3 −2 −1 −0.5 0.5 1 2 3 4 5
7-day Average Centered on 27 November 2013

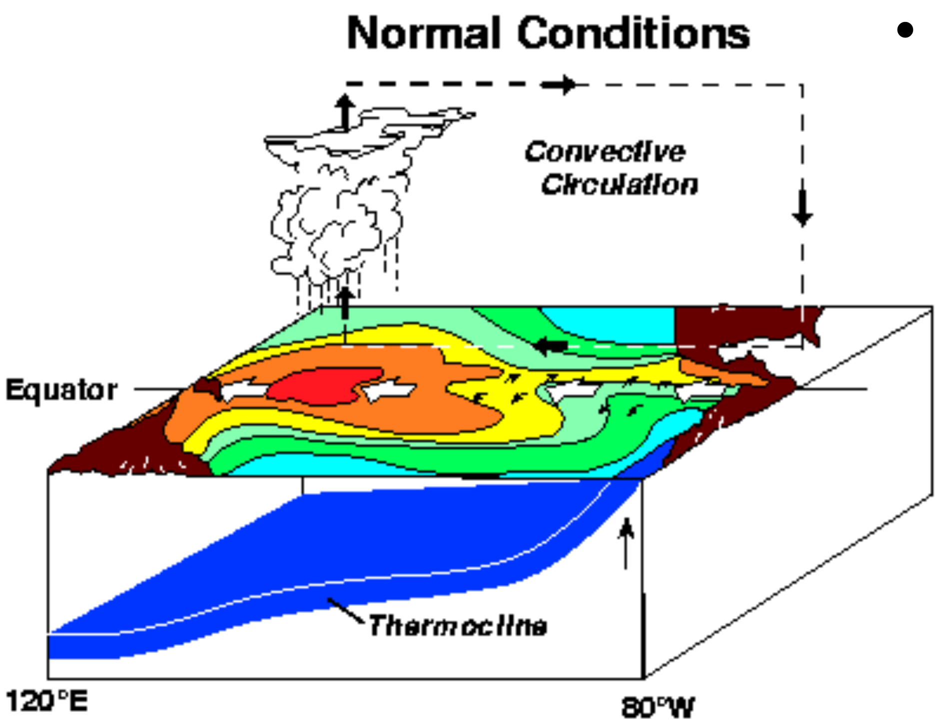




http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ocean/

Dynamics of ENSO

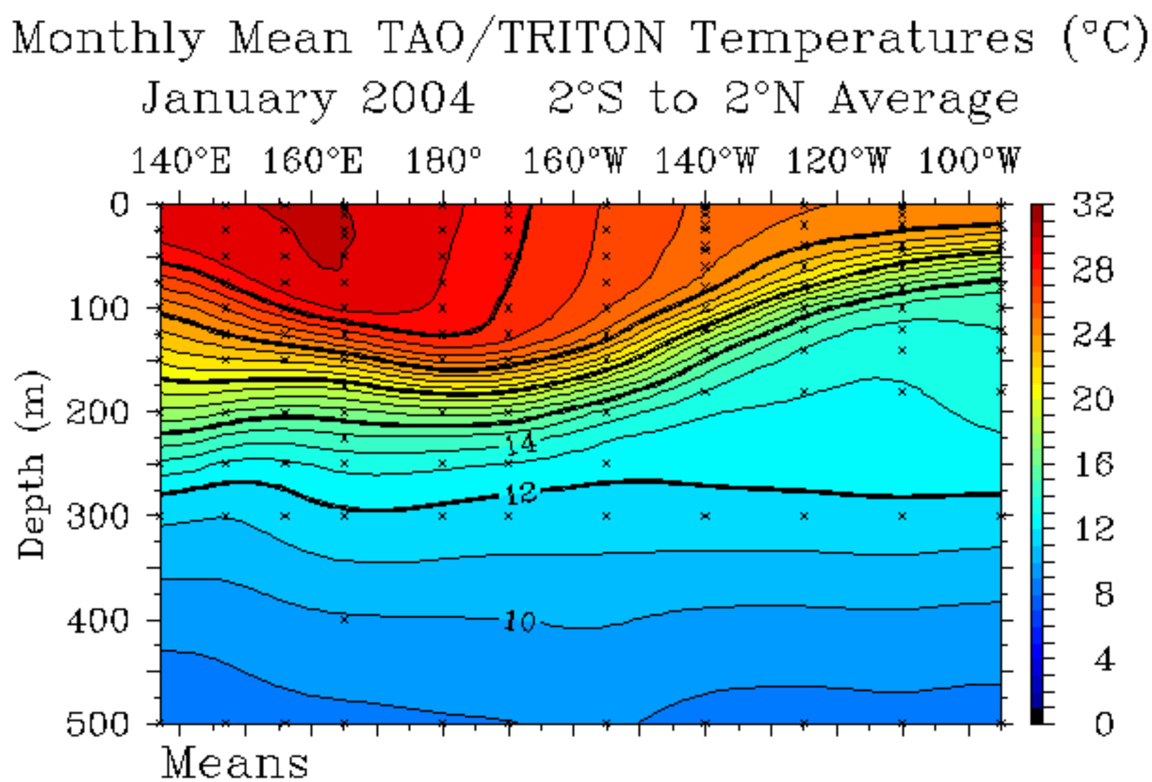
ENSO Dynamics:
Tropical Pacific Mean State



http://www.pmel.noaa.gov/tao/elnino/nino_normal.html

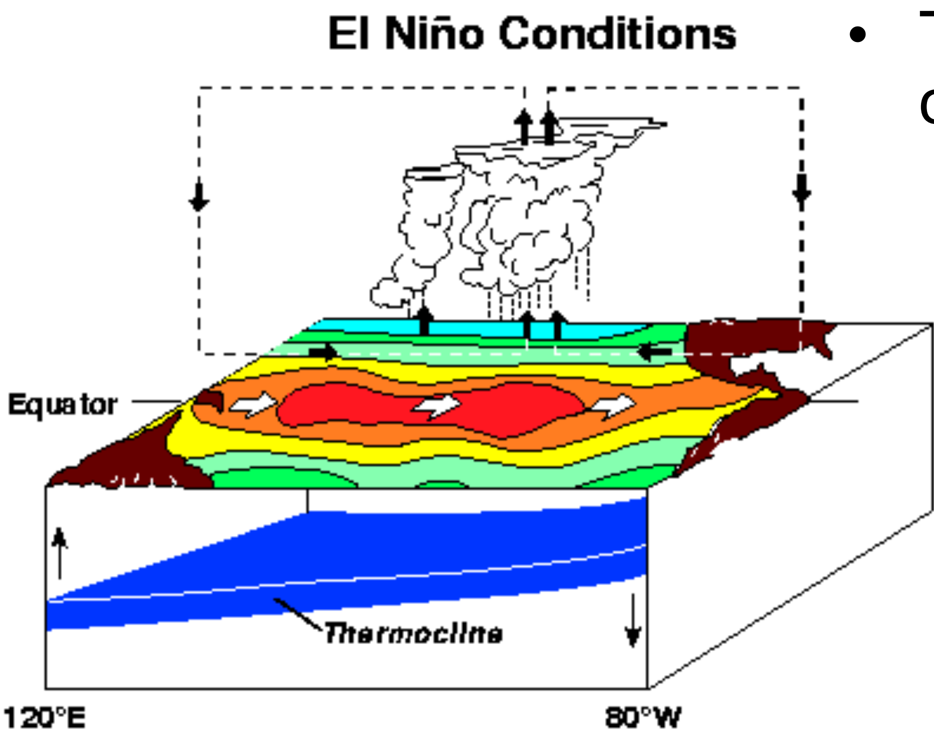
- Tropical Pacific normal conditions
  - Easterly trades cause thermocline to deepen in the west, shoal in the east
  - Winds also cause Ekman upwelling along the equator, bringing cooler subsurface water to the surface
  - Cooling from upwelling is most pronounced in the east, where the thermocline is close to the surface

ENSO Dynamics:
Tropical Pacific Mean State



http://www.pmel.noaa.gov

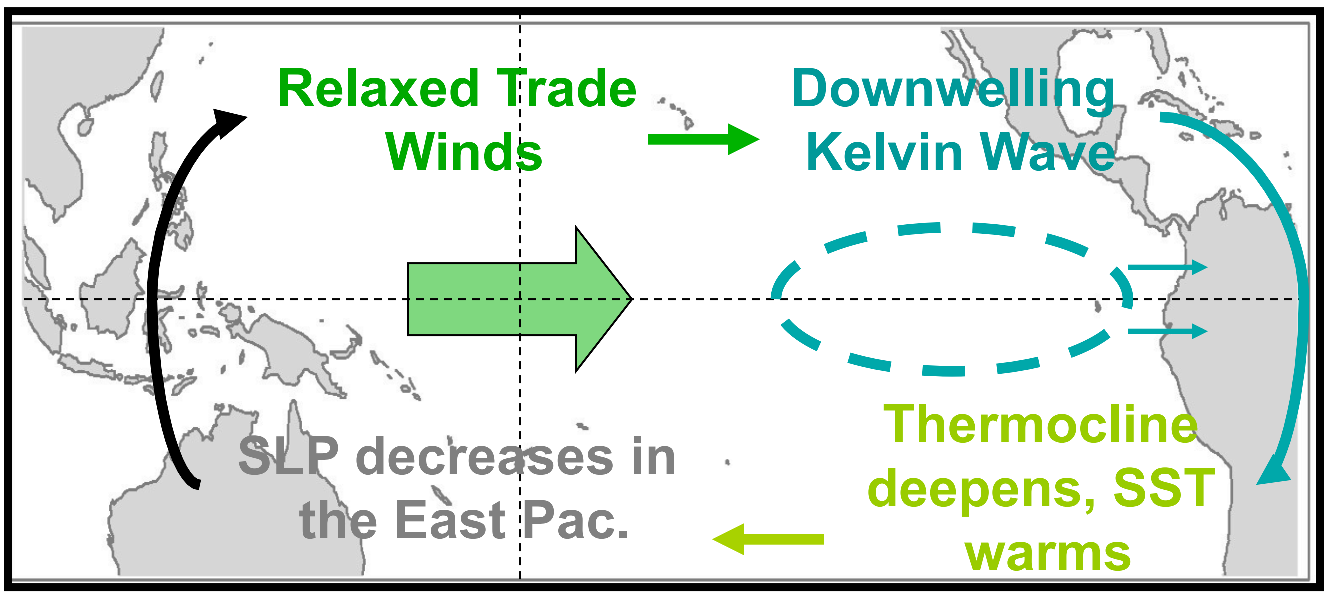
ENSO Dynamics:
Positive “Bjerknes” Feedback



- Tropical Pacific El Niño conditions
  - Relaxed trades force ***downwelling Kelvin signal*** along the thermocline
  - In the east, the surface warms as upwelling brings warmer water (from above the thermocline) to the surface
  - Warmer SSTs in the east cause further relaxation of the trades - a positive feedback

http://www.pmel.noaa.gov/tao/elnino/nino_normal.html

ENSO Dynamics:
Positive "Bjerknes" Feedback



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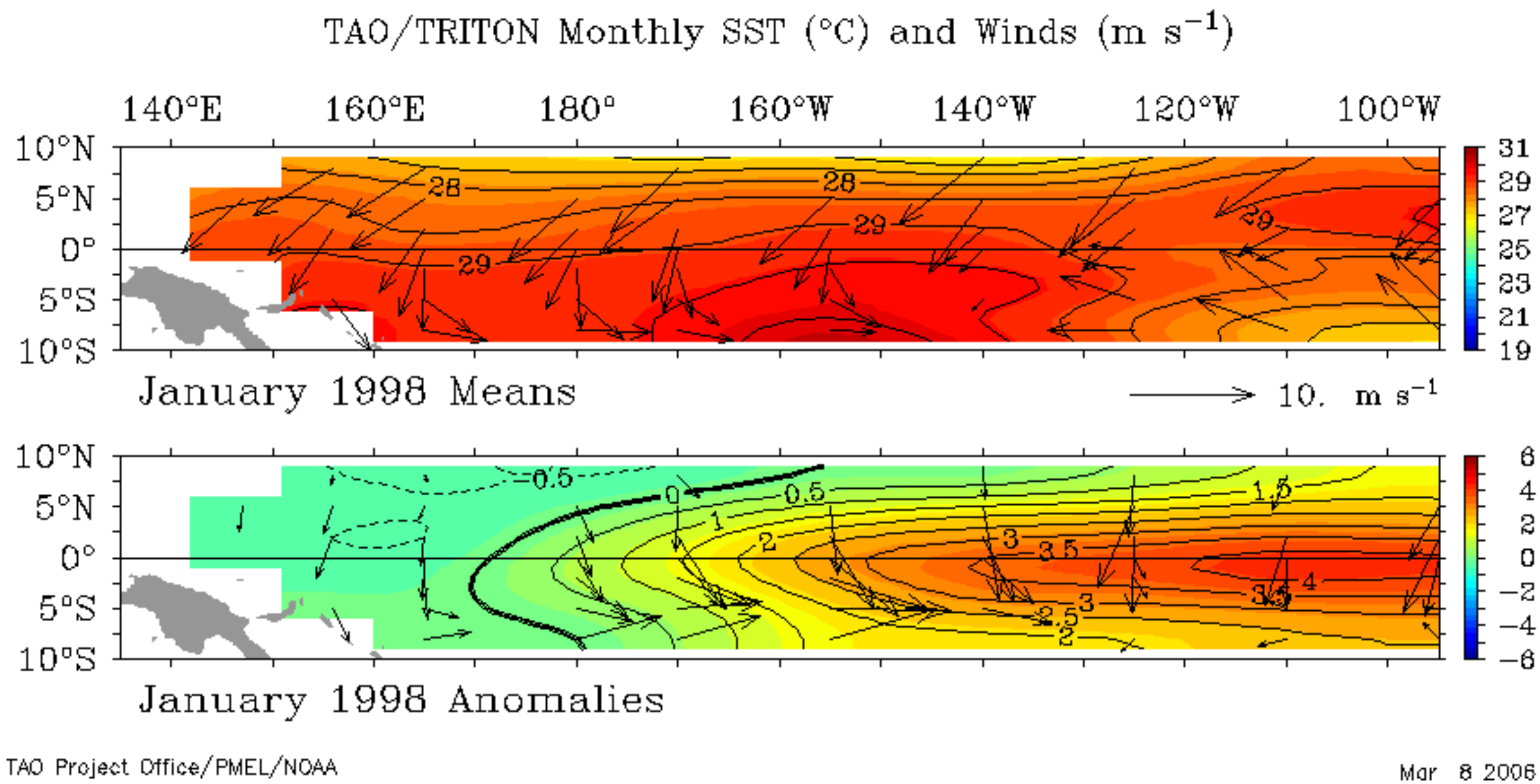
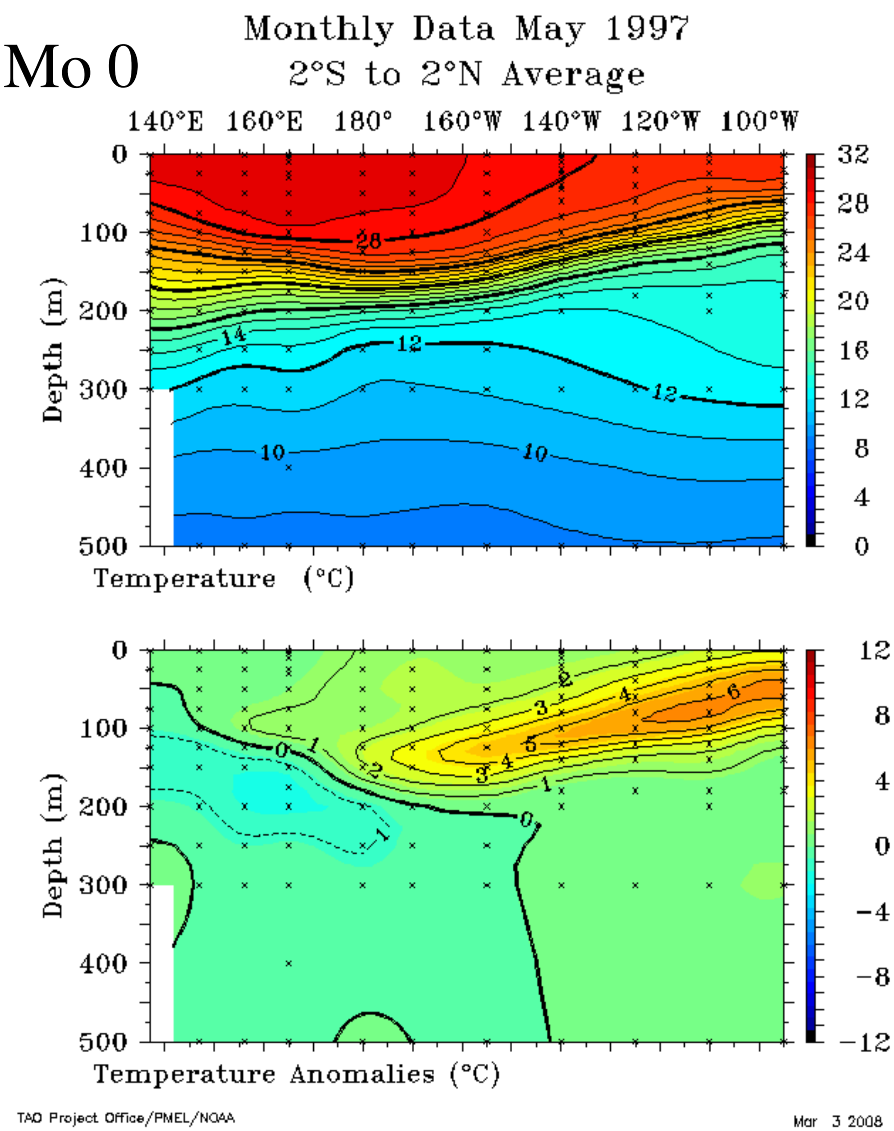


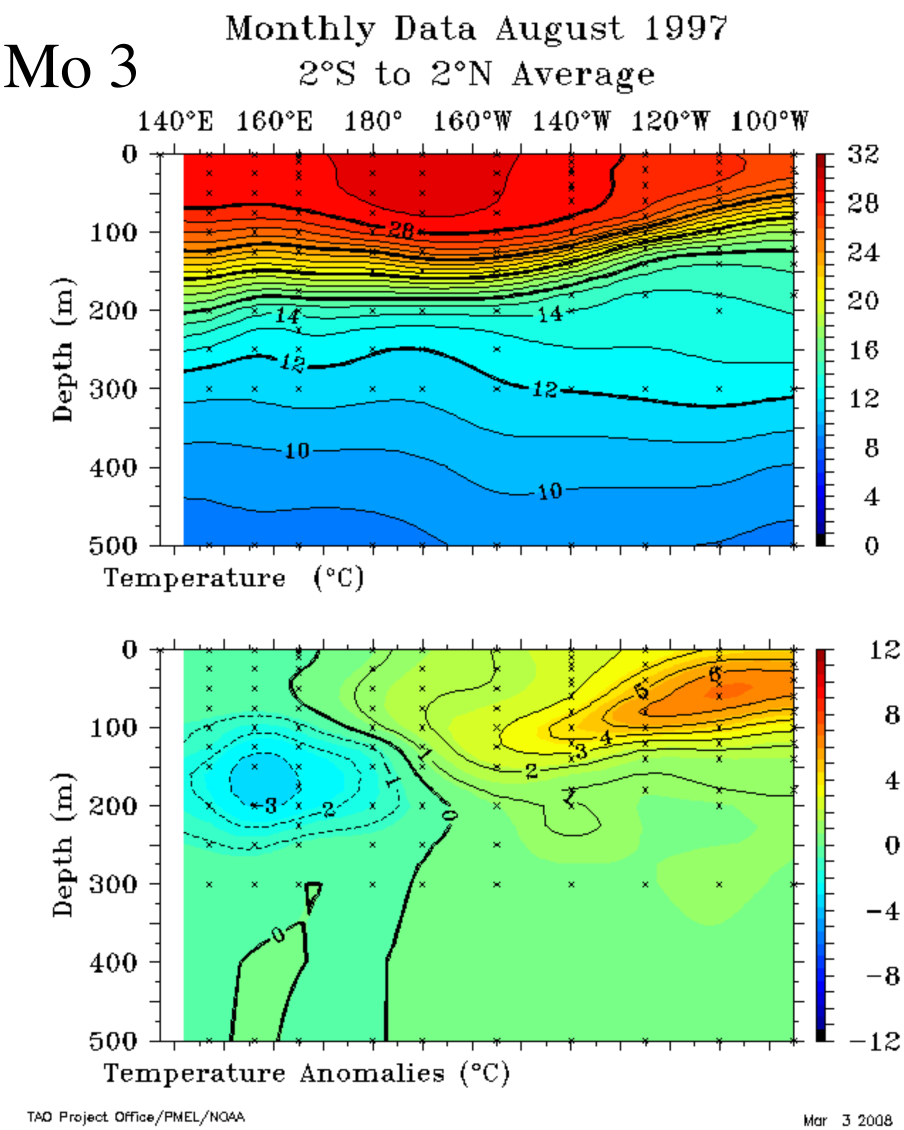
http://www.pmel.noaa.gov

ENSO Dynamics:
Positive "Bjerknes" Feedback

Mo 0

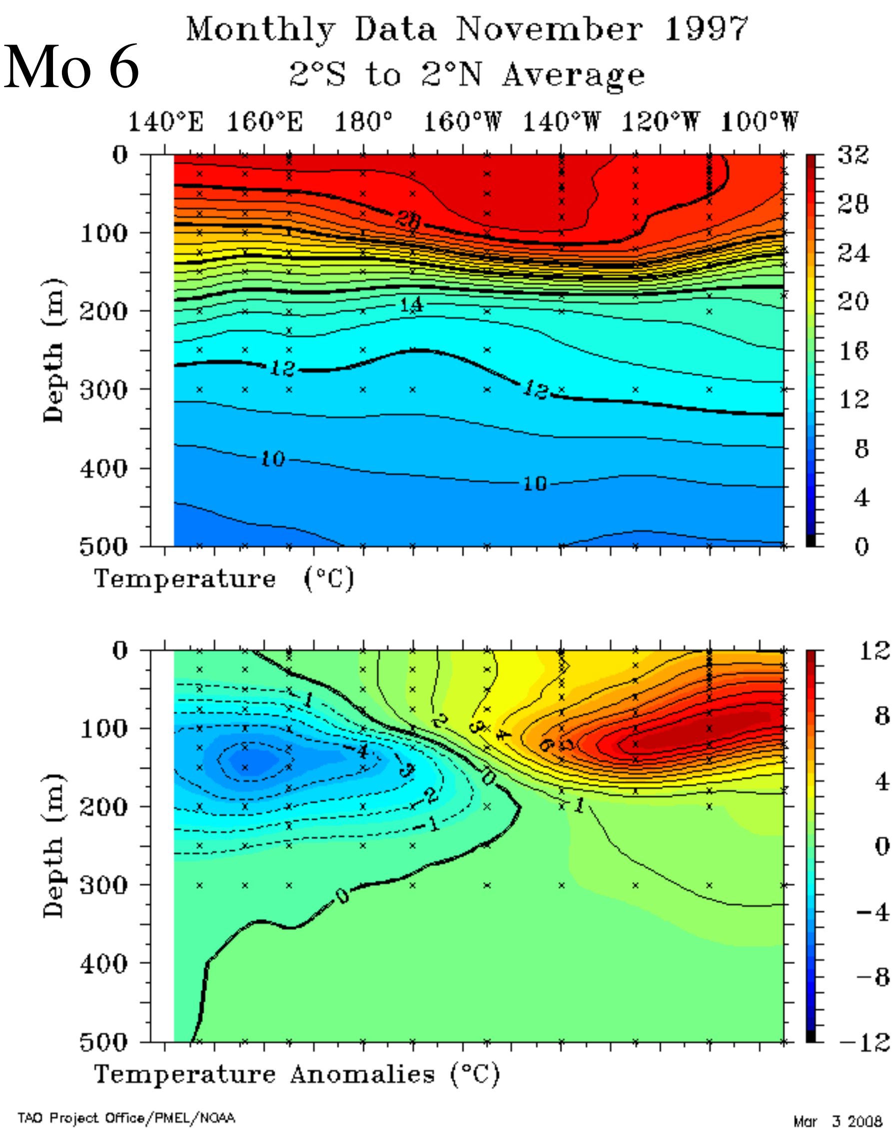


Mo 3

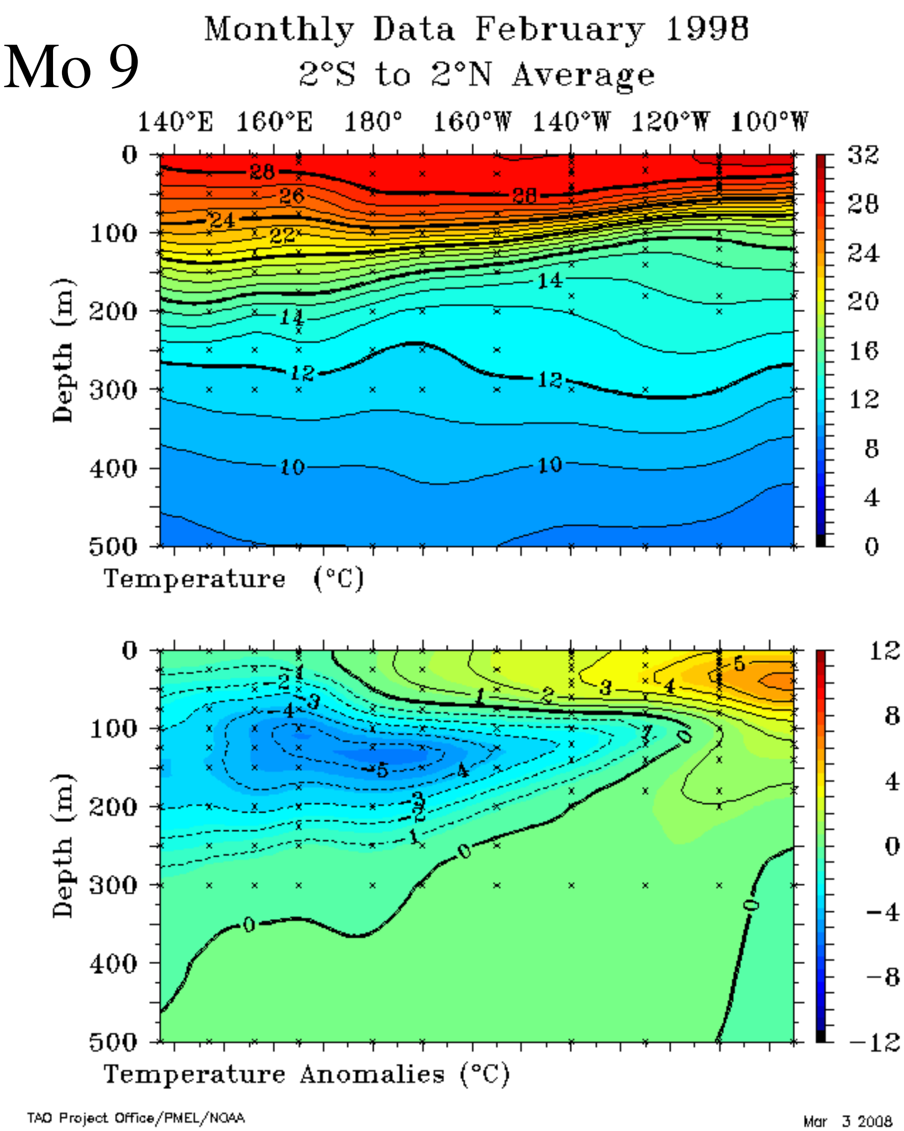


ENSO Dynamics:
Positive "Bjerknes" Feedback

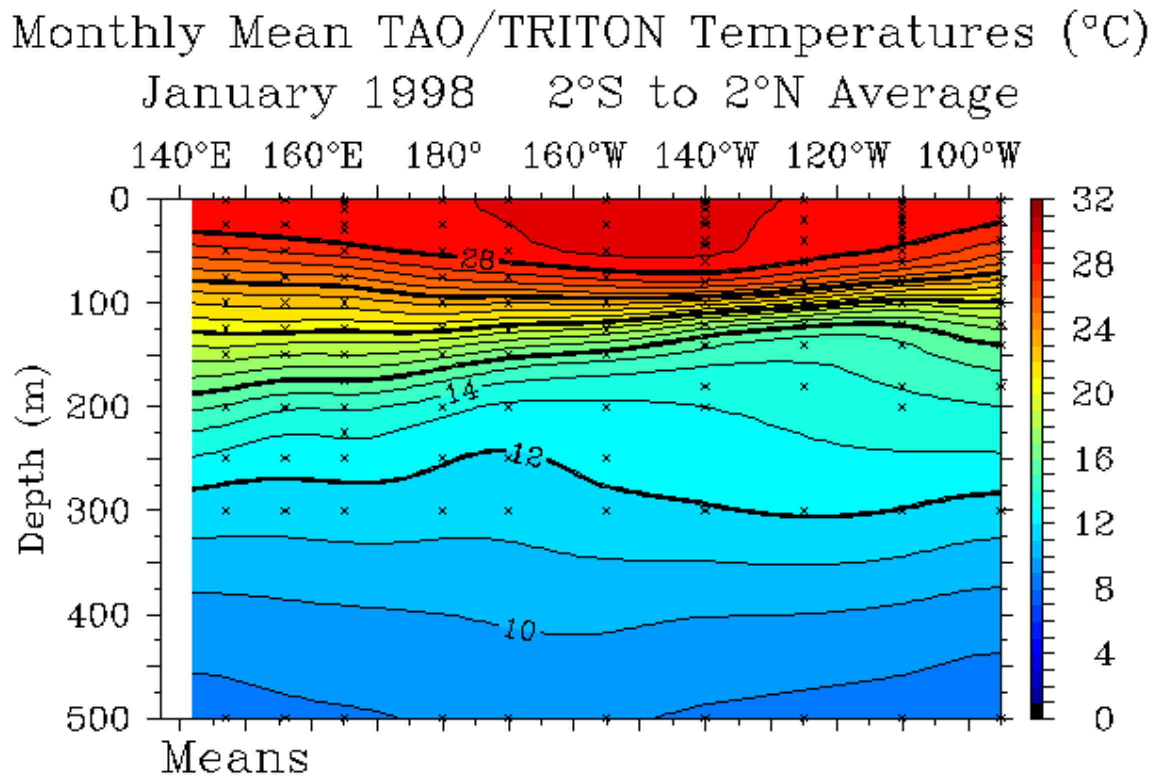
Mo 6



Mo 9

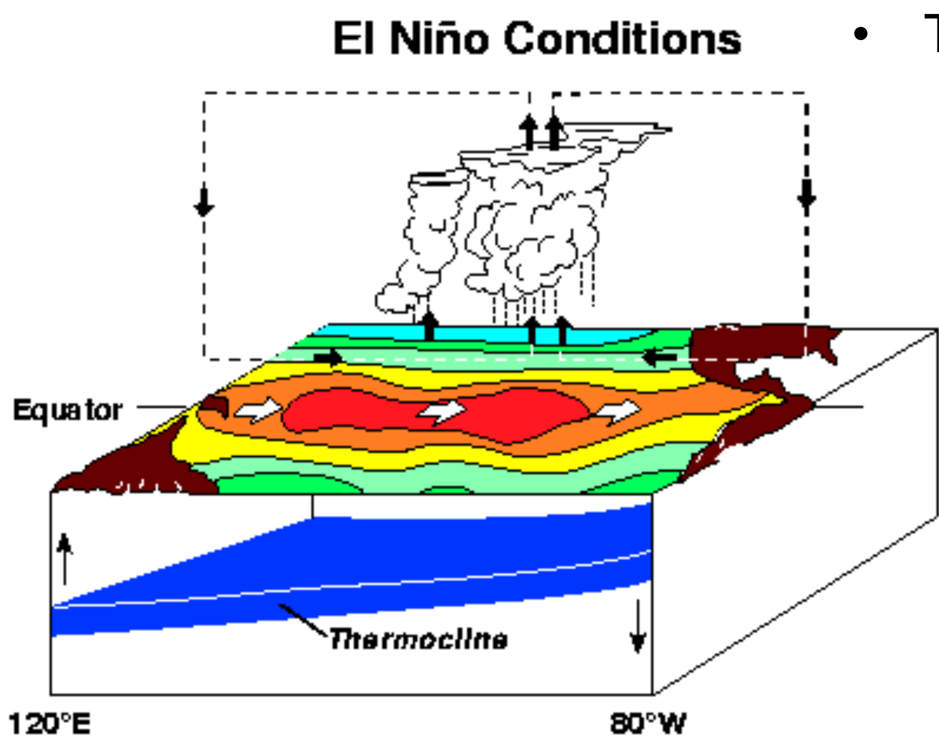


ENSO Dynamics:
Positive "Bjerknes" Feedback



http://www.pmel.noaa.gov

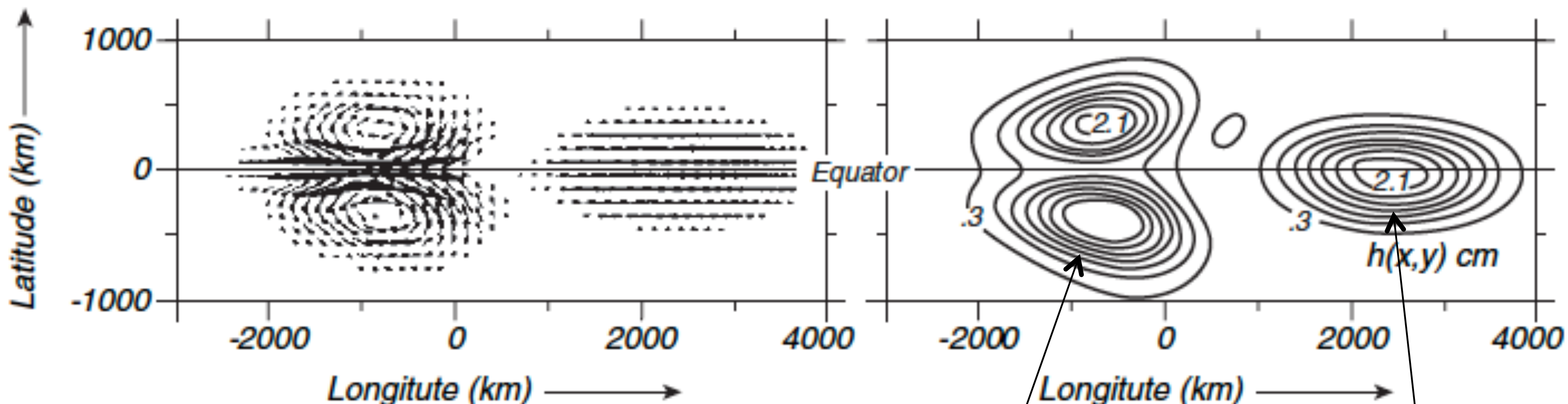
ENSO Dynamics:
Negative "Ocean Memory" feedback



- Tropical Pacific El Niño conditions
  - At the same time, relaxed trades force ***upwelling Rossby signals*** which reflect off the western boundary as ***upwelling Kelvin signals***
  - These upwelling Kelvin signals bring the thermocline back to the surface in the east, shutting off an El Niño event
  - Often times, the thermocline overshoots in the east, resulting in cool conditions after an El Niño event: La Niña conditions

http://www.pmel.noaa.gov/tao/elnino/nino_normal.html

From an initial bell-shaped disturbance of the thermocline in Central Pacific, after 20 days

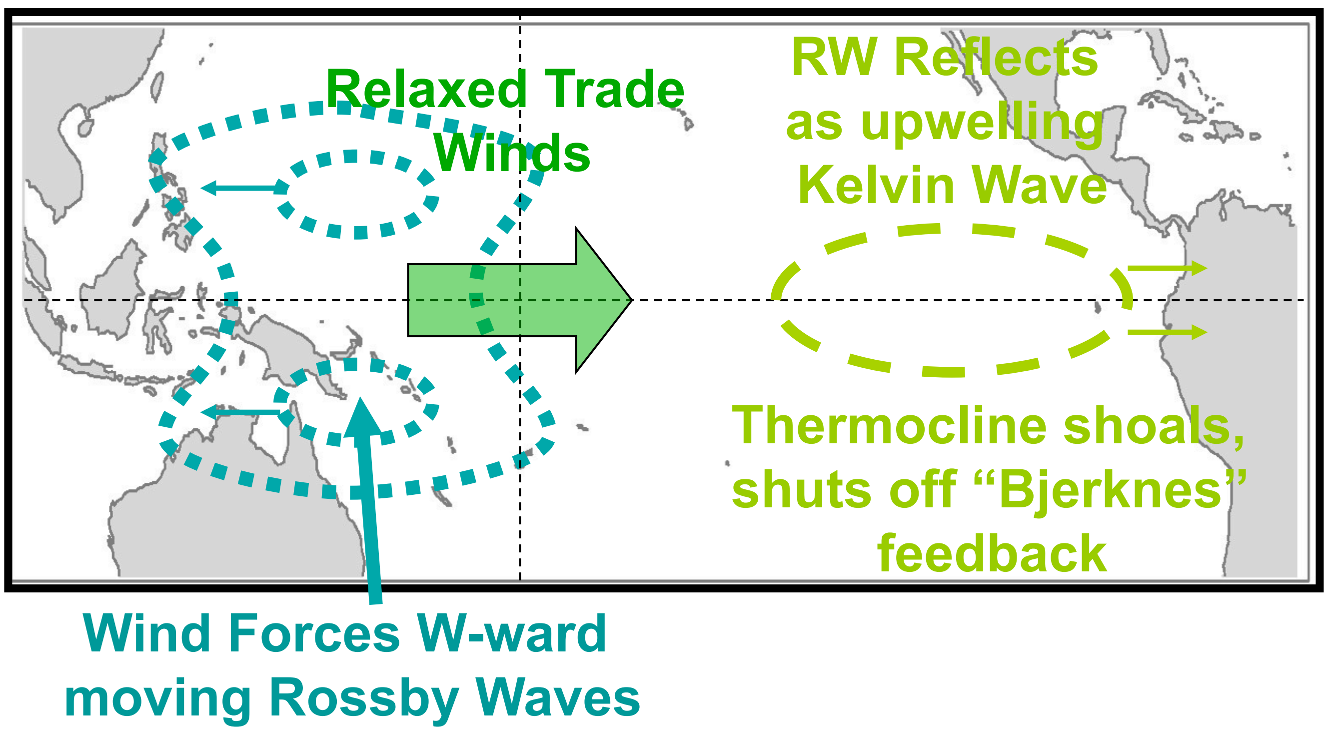


Westward Rossby
$c_{max} = 0.8$ m/s
2-4 mo to west

Eastward Kelvin
$c_{max} = 2\text{-}3$ m/s
2-3 mo to east

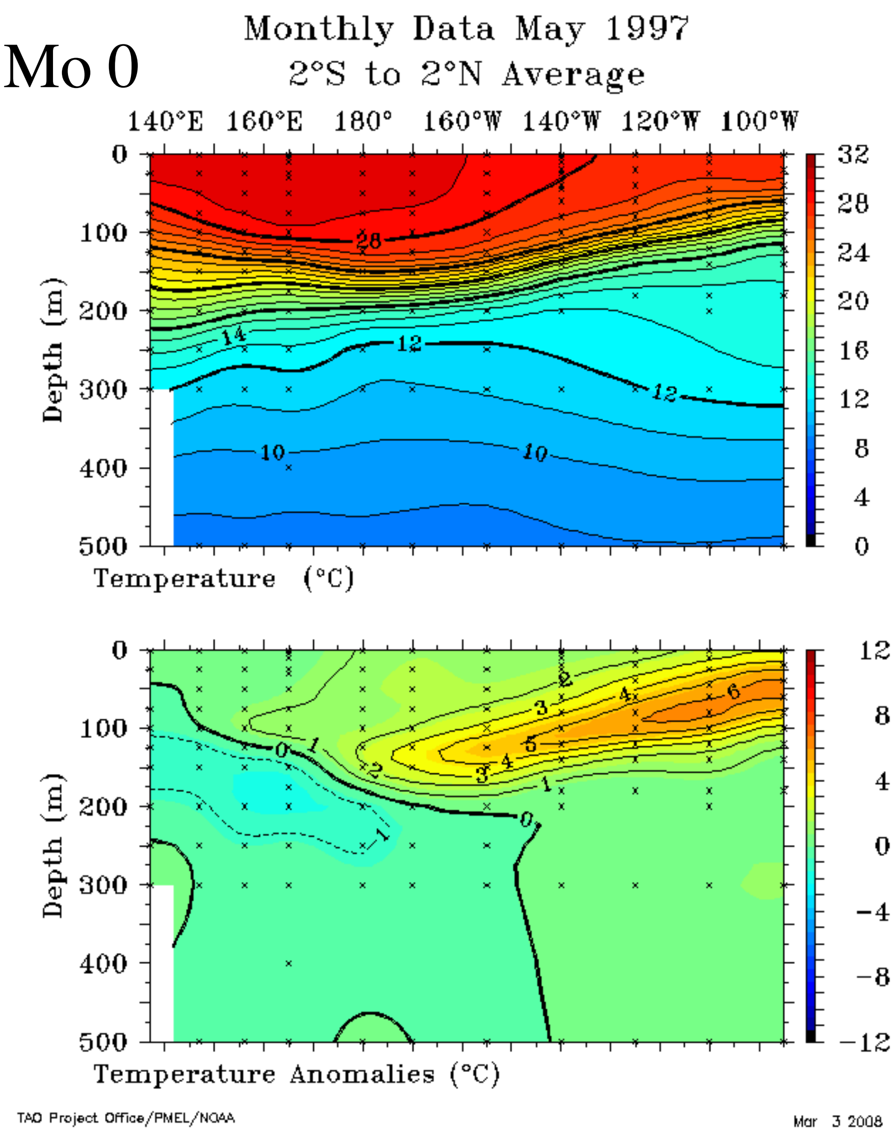
Satellite observations indicate Rossby waves propagate at 1/5 – 1/7 speed of Kelvin wave (Fu and Cazanave, 2001)

ENSO Dynamics:
Negative "Ocean Memory" Feedback

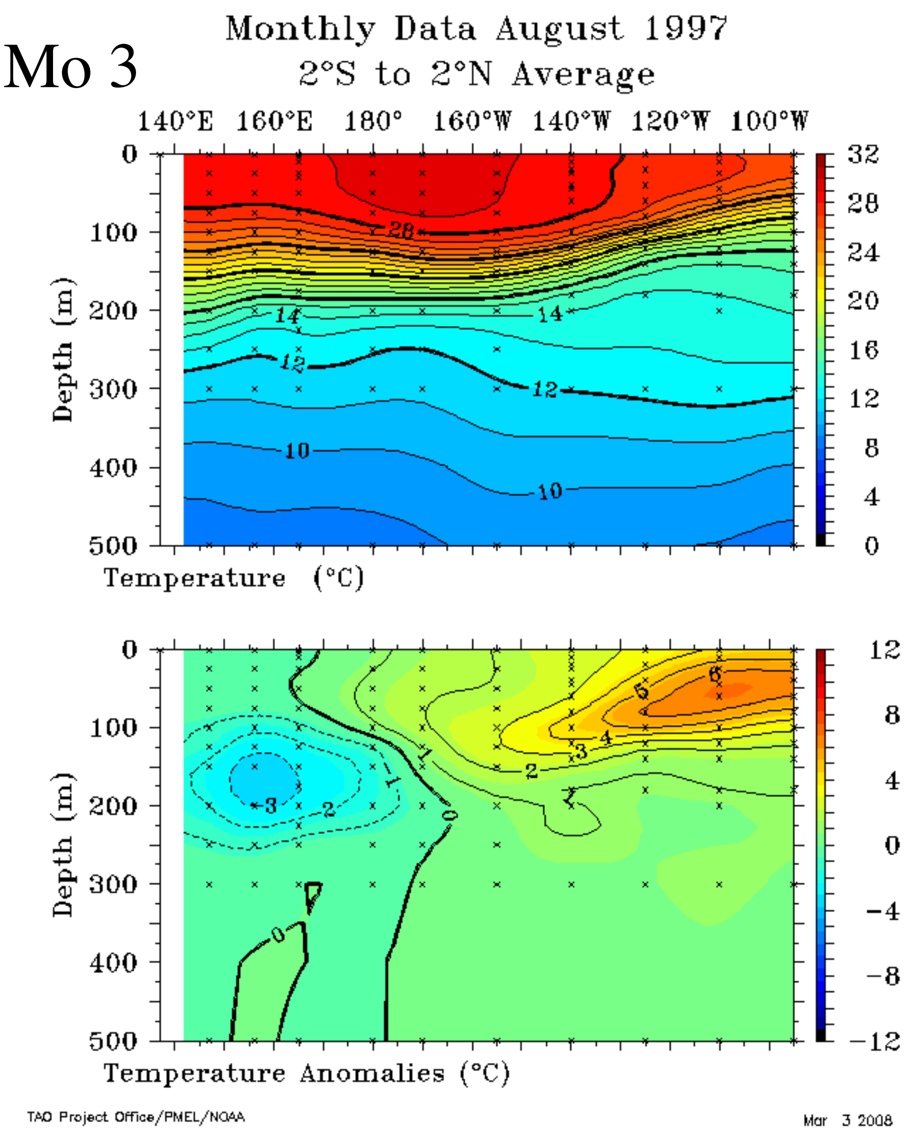


ENSO Dynamics:
Negative "Ocean Memory" Feedback

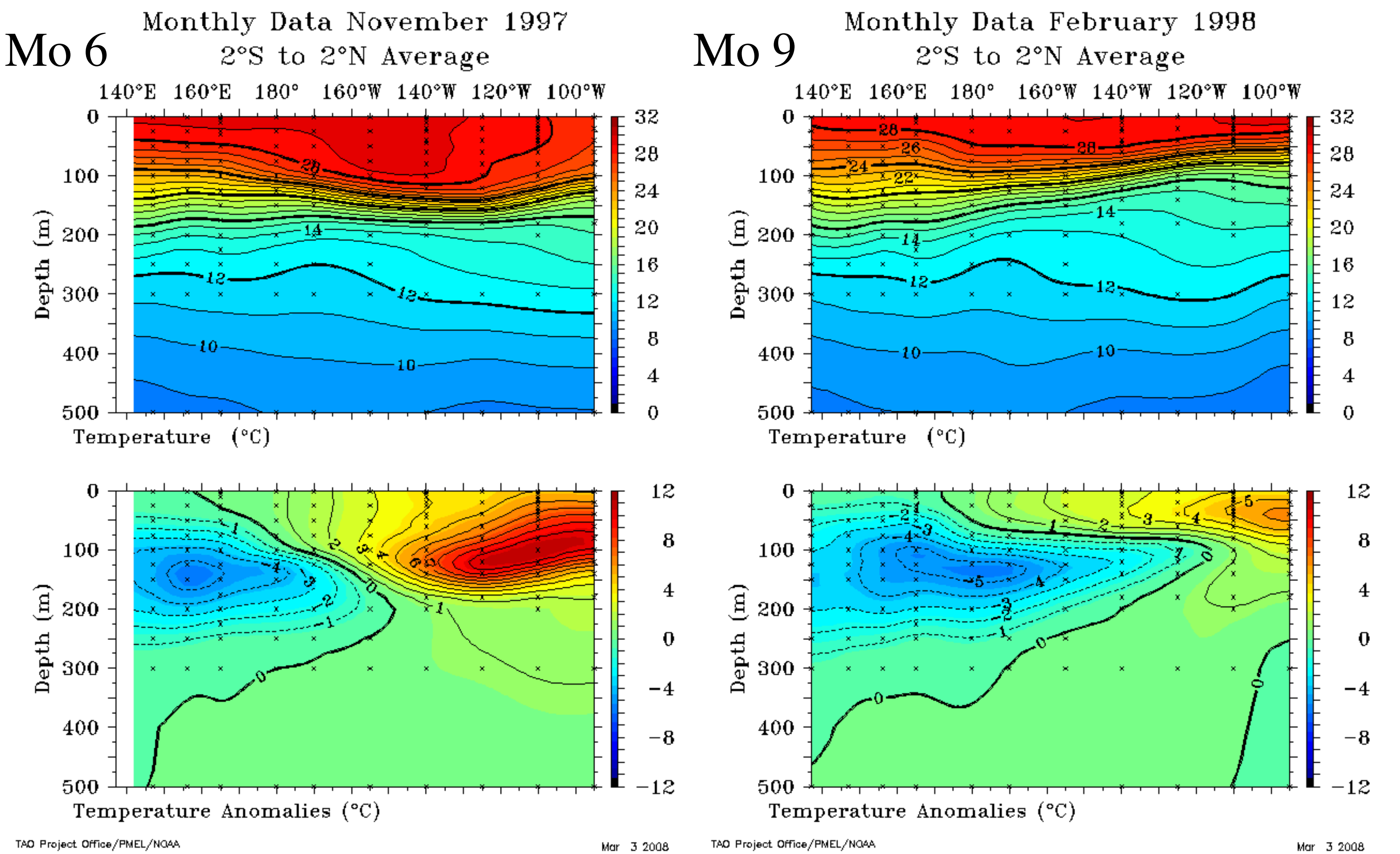
Mo 0



Mo 3

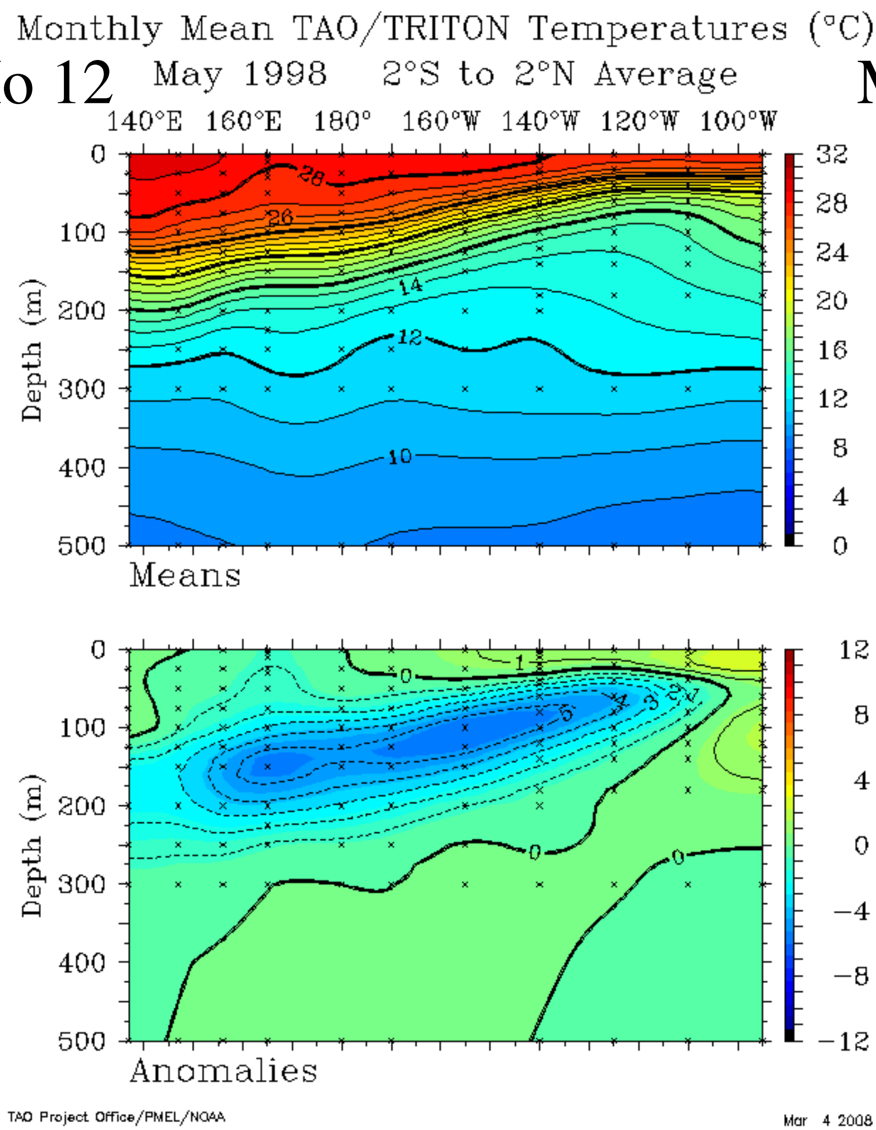


ENSO Dynamics:
Negative “Ocean Memory” Feedback

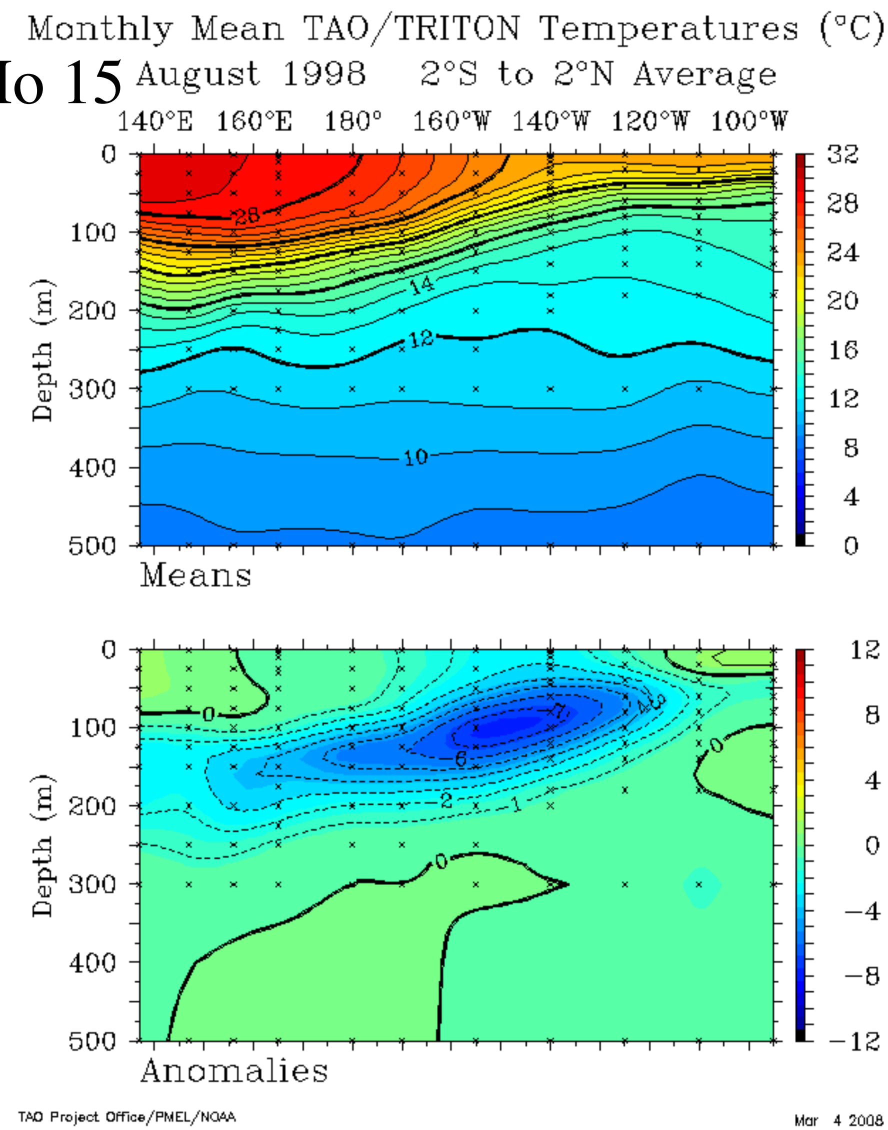


ENSO Dynamics:
Negative "Ocean Memory" Feedback

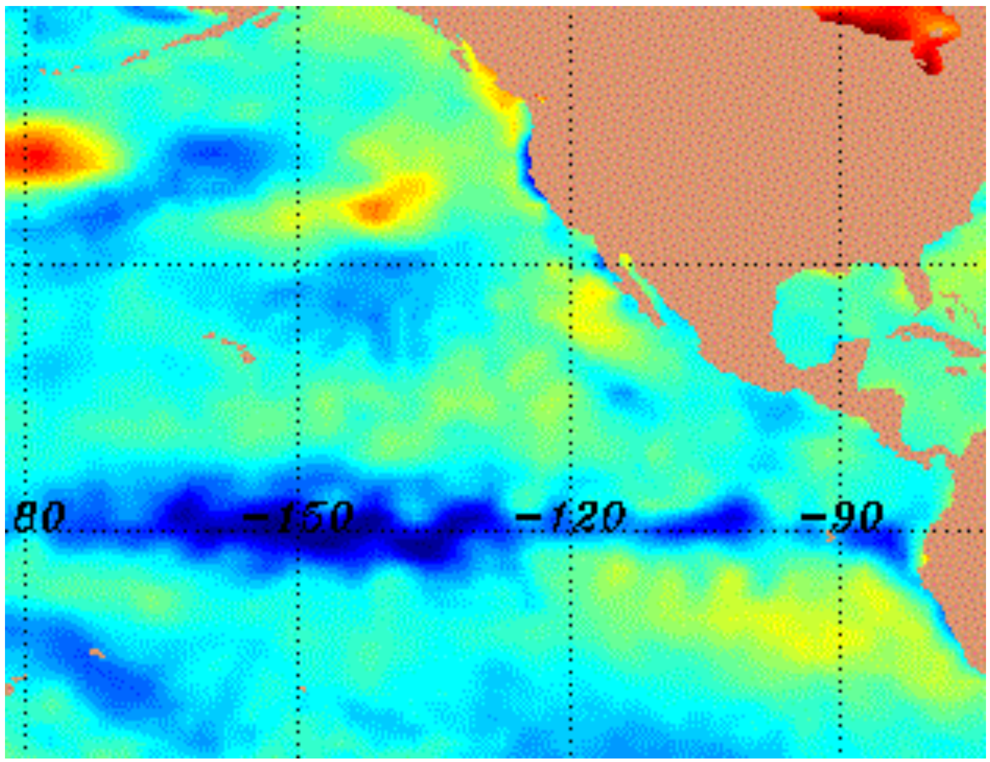
Mo 12



Mo 15

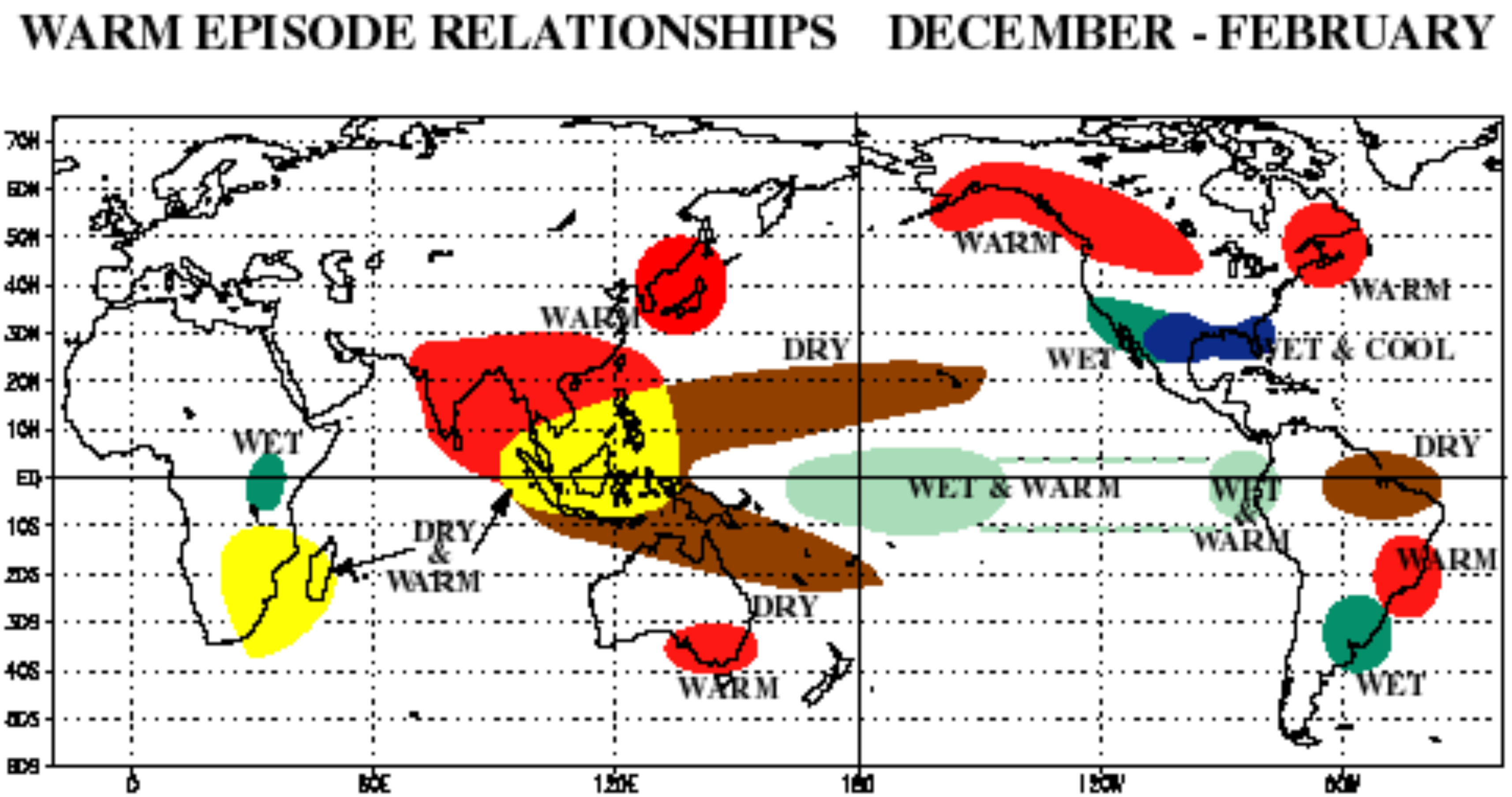


Negative SST’ in August 1998



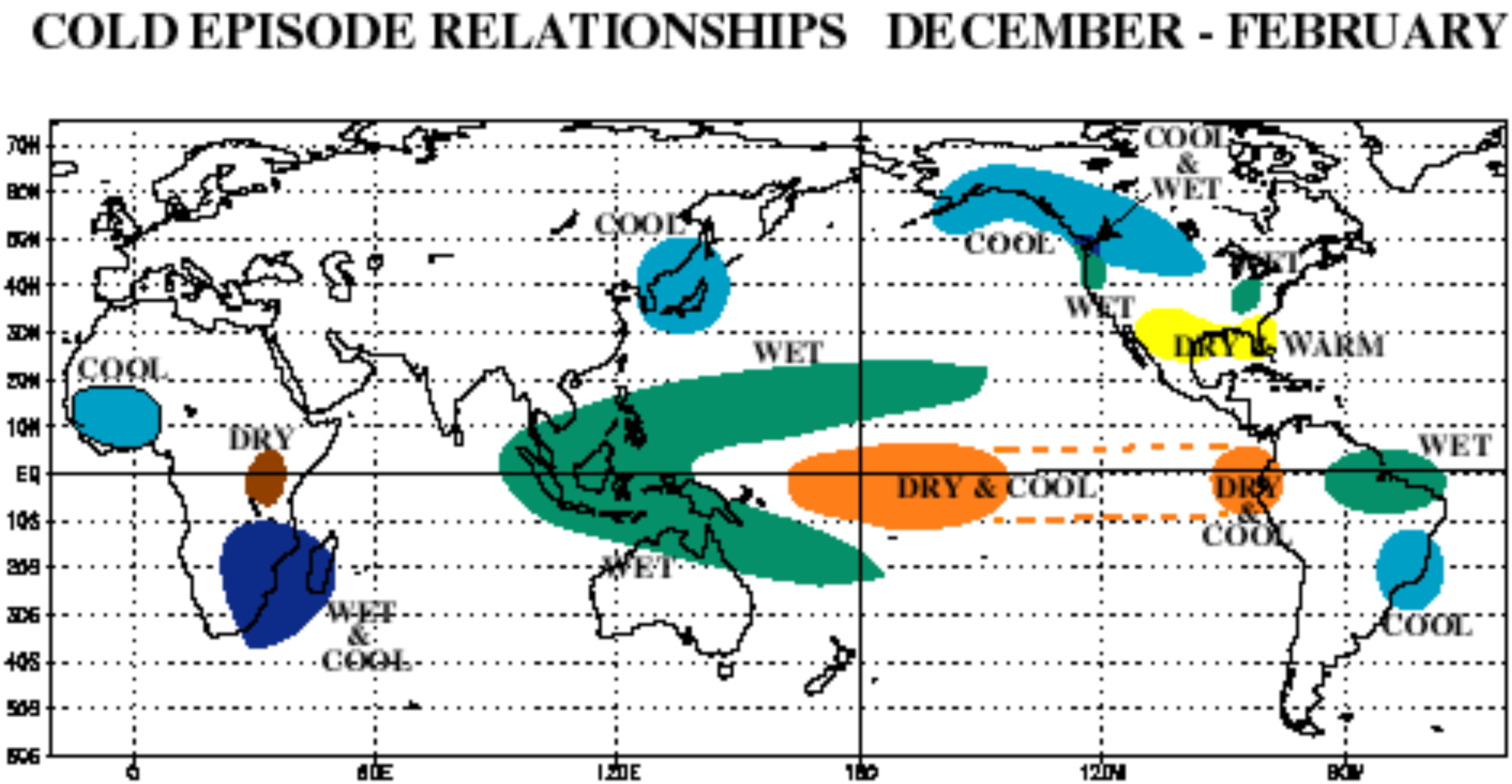
ENSO Impacts

El Niño Impacts: DJF

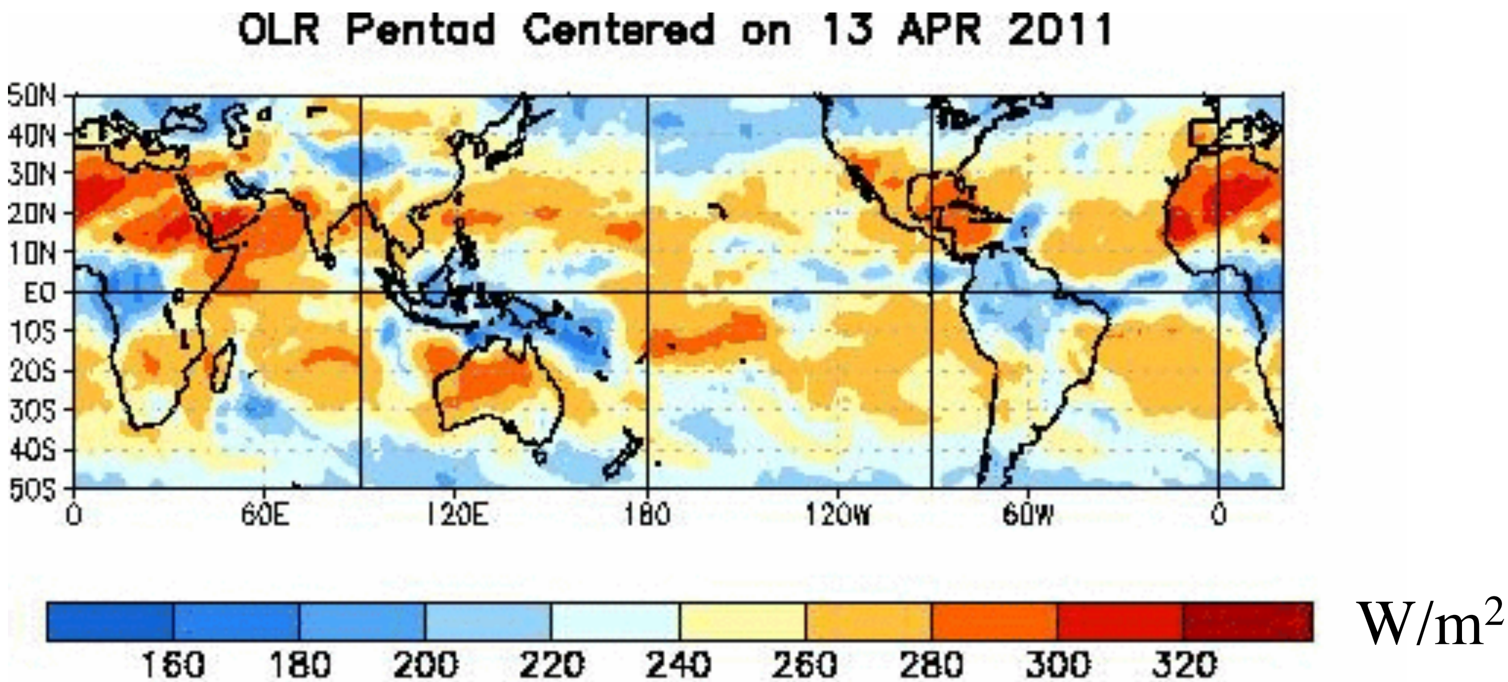


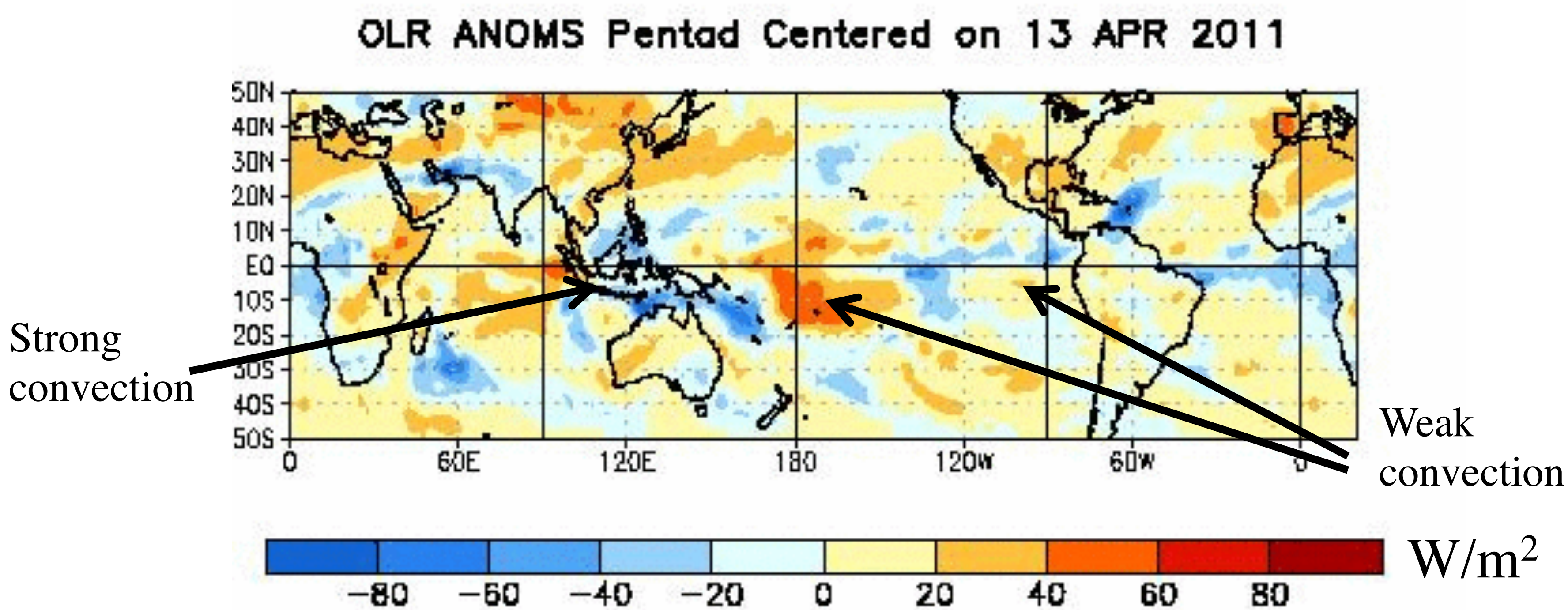
http://www.cpc.ncep.noaa.gov/

La Niña Impacts: DJF

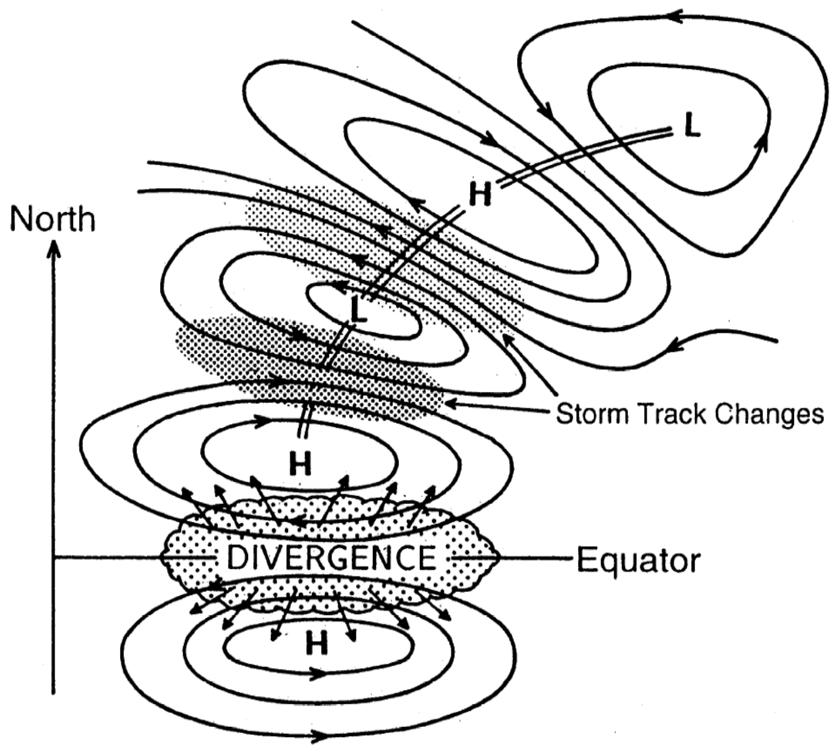


La
Nina
OLR
Apr’11





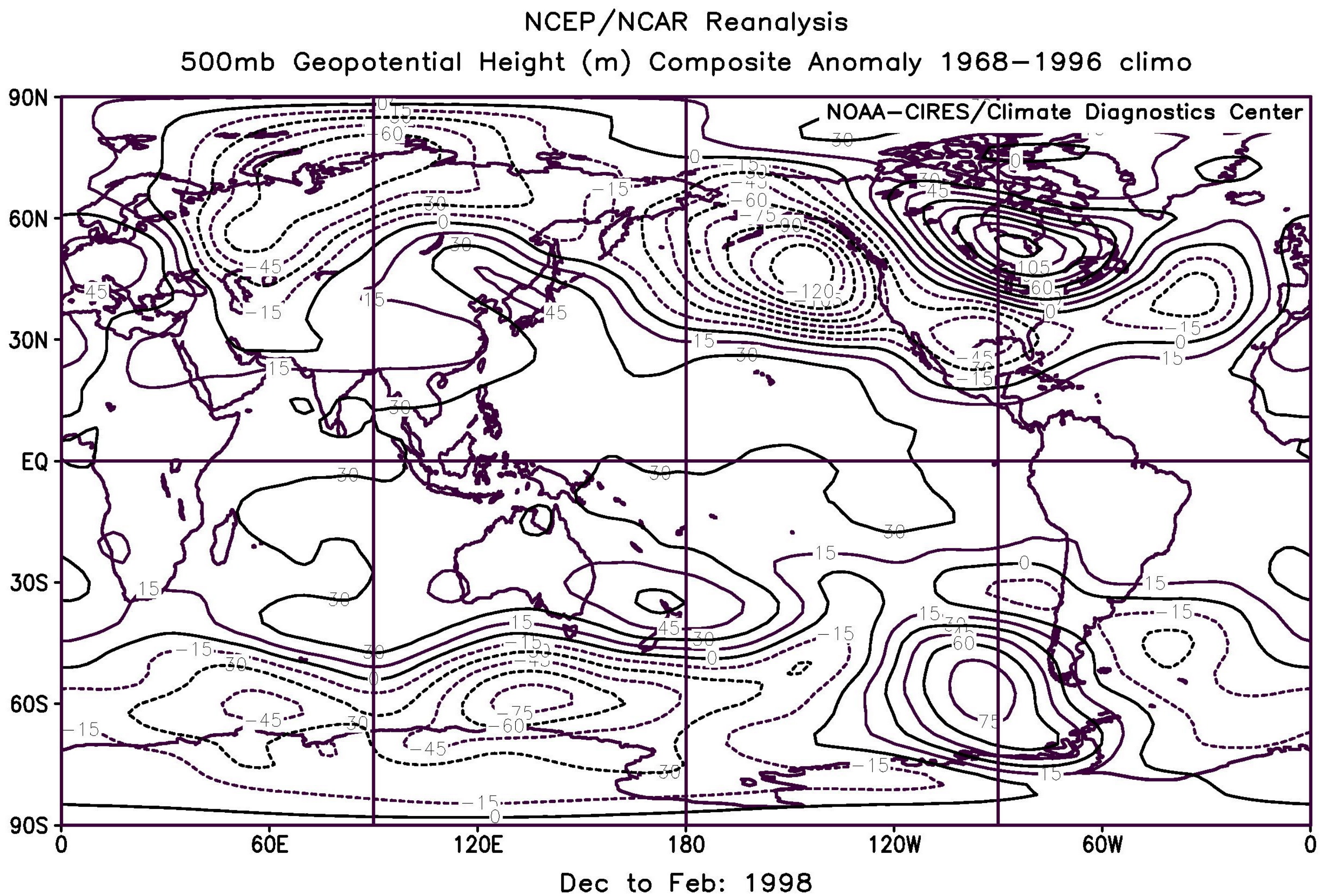
ENSO Impacts: Mid-latitudes



- Changes in the location of convection lead to changes in upper level divergence in the tropics
- Upper level divergent flow provides forcing for poleward-propagating Rossby waves: "teleconnections"
- Interactions with mean state and storm tracks alter the teleconnections

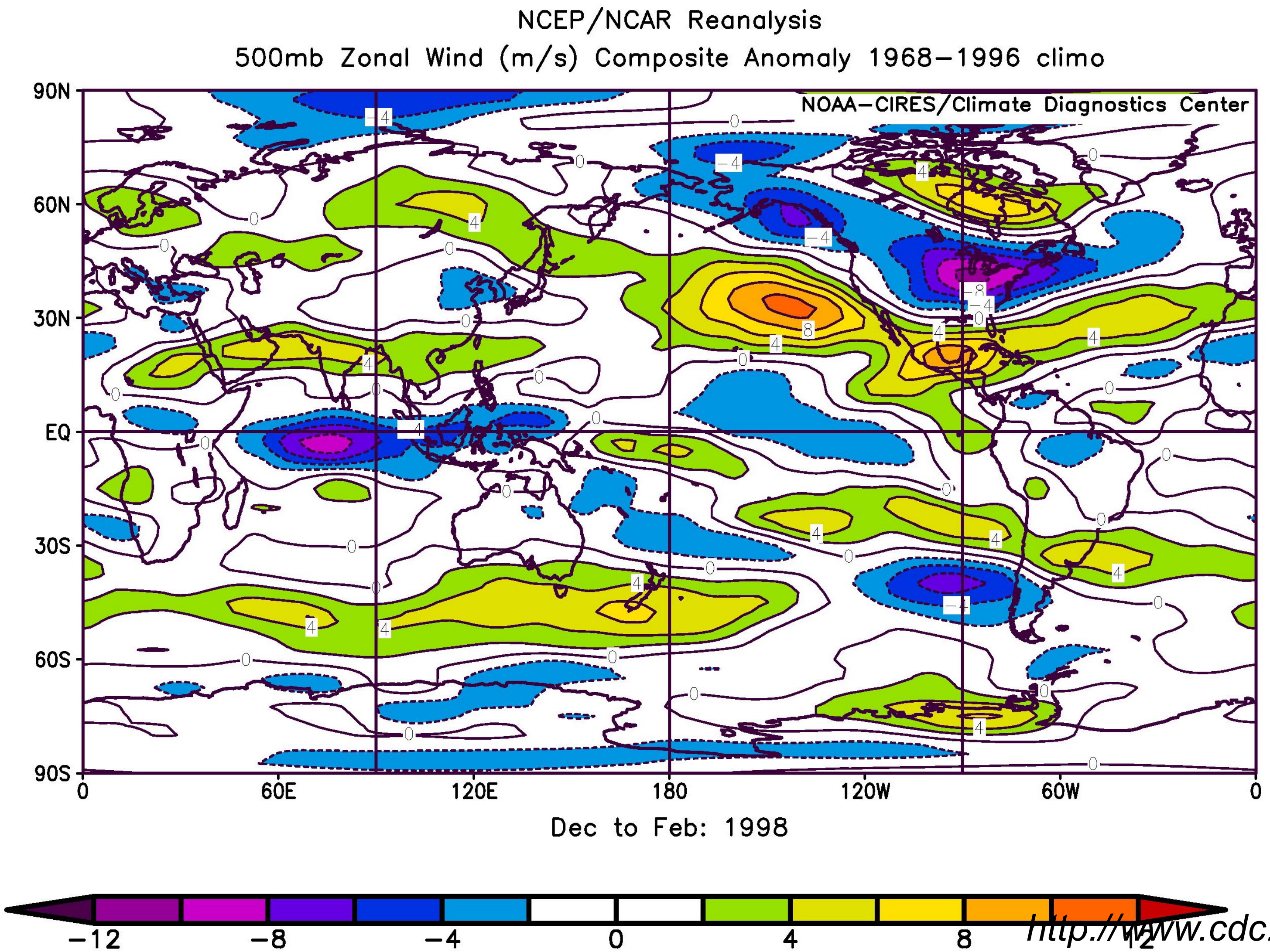
Trenberth et al., 1998

El Nino Impacts: Mid-latitudes



http://www.cdc.noaa.gov

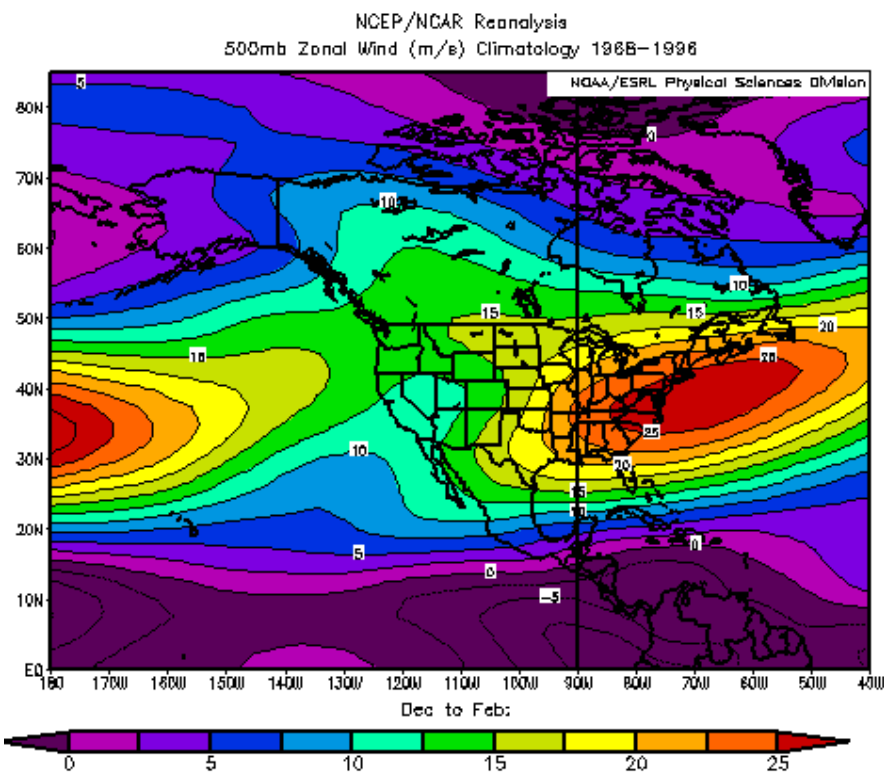
El Nino Impacts: Mid-latitudes



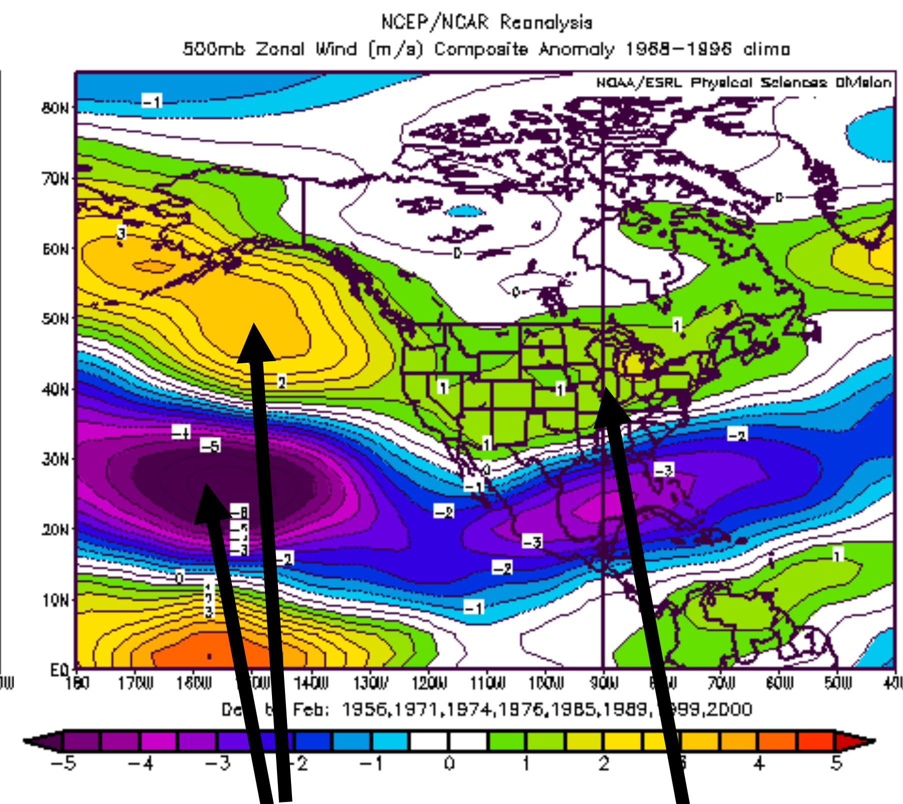
http://www.cdc.noaa.gov

La Niña Impacts: Mid-latitudes

Climatology



La Niña Composite

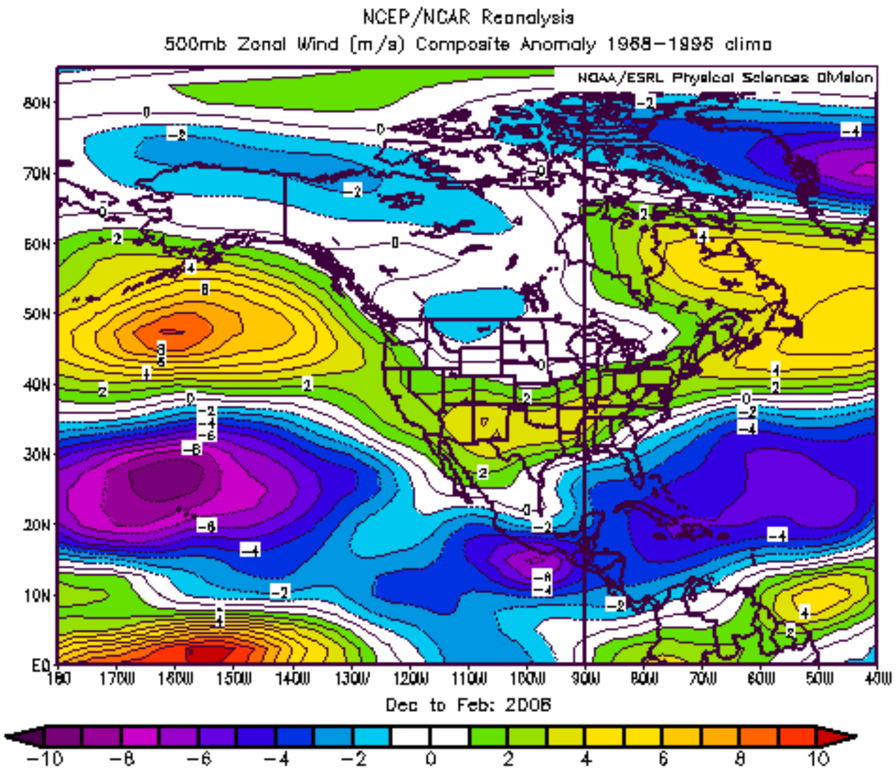


Blocking Pattern

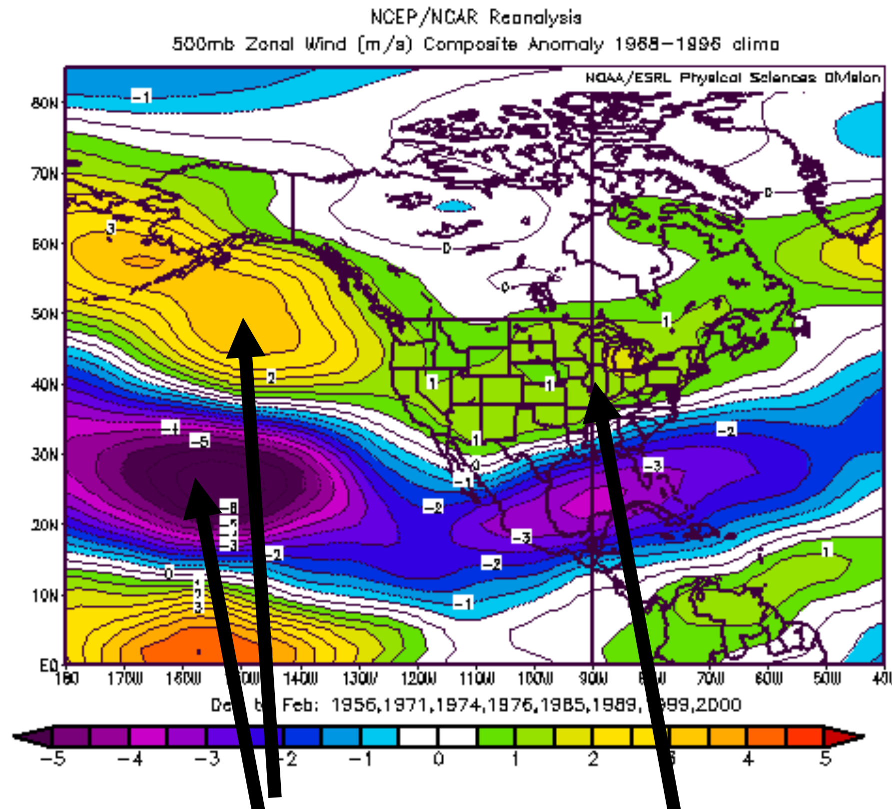
Northward Jet shift

La Niña Impacts: Mid-latitudes

DJF 2008



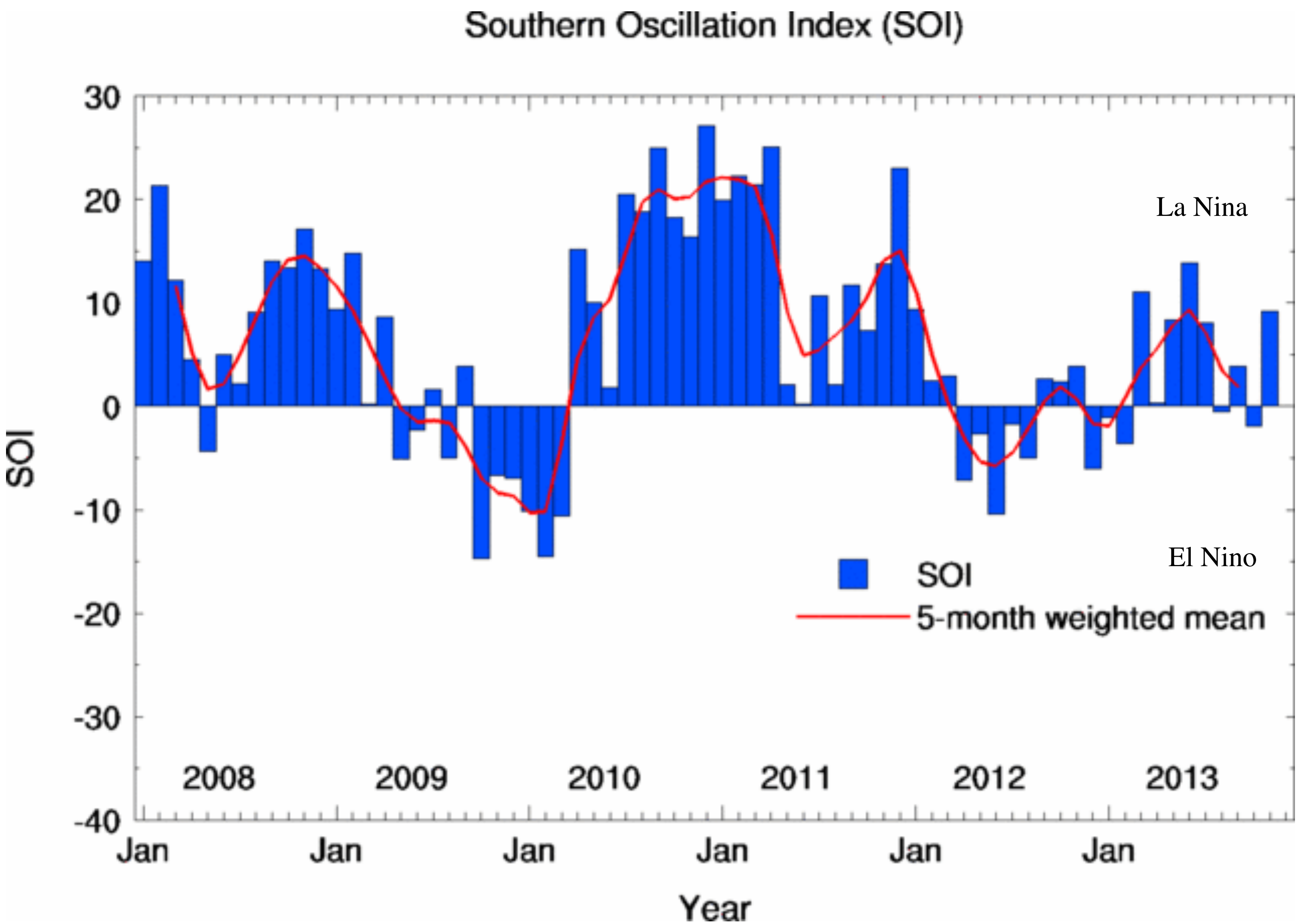
La Niña Composite



Blocking Pattern

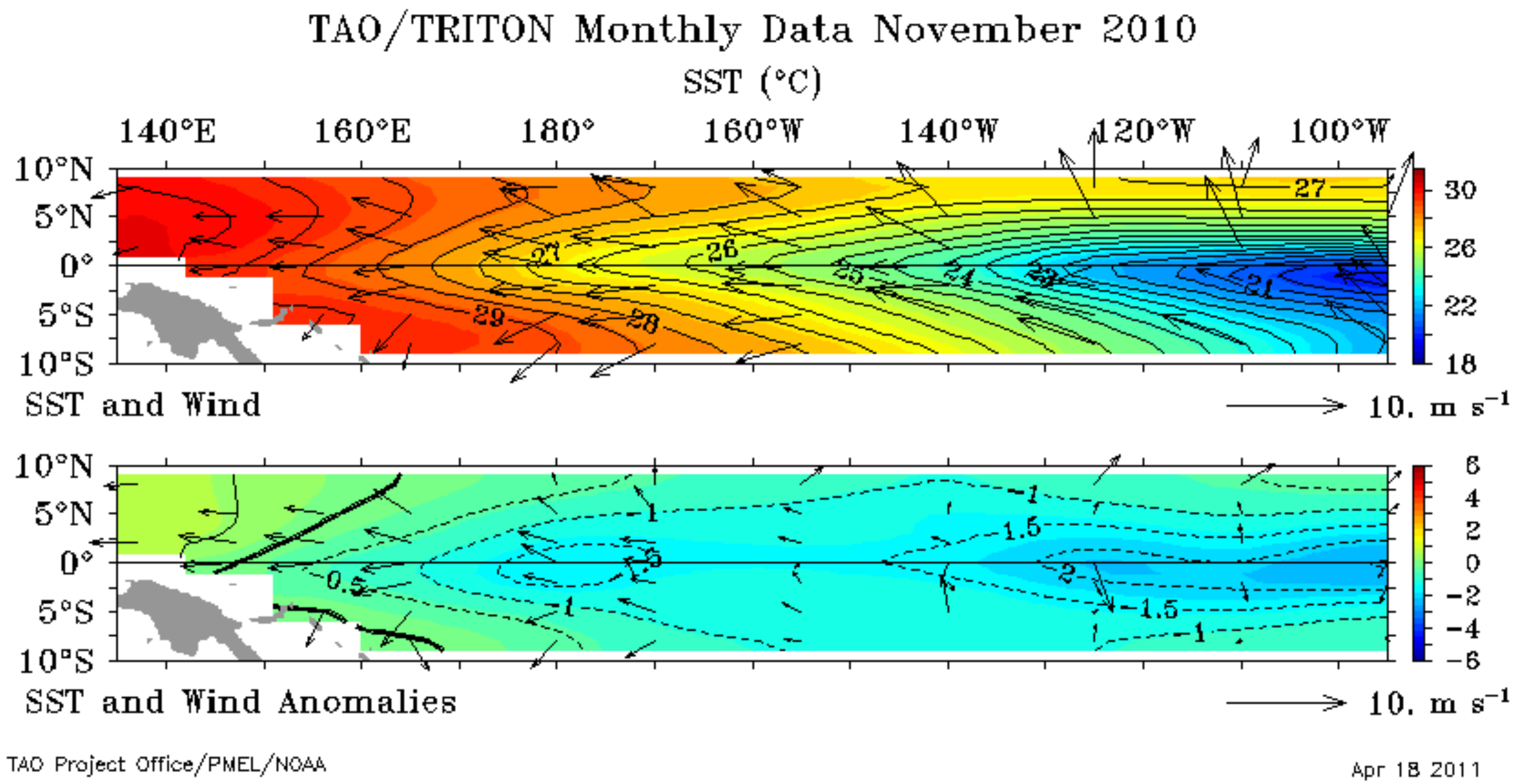
Northward Jet shift

ENSO Current Status and Seasonal Impacts



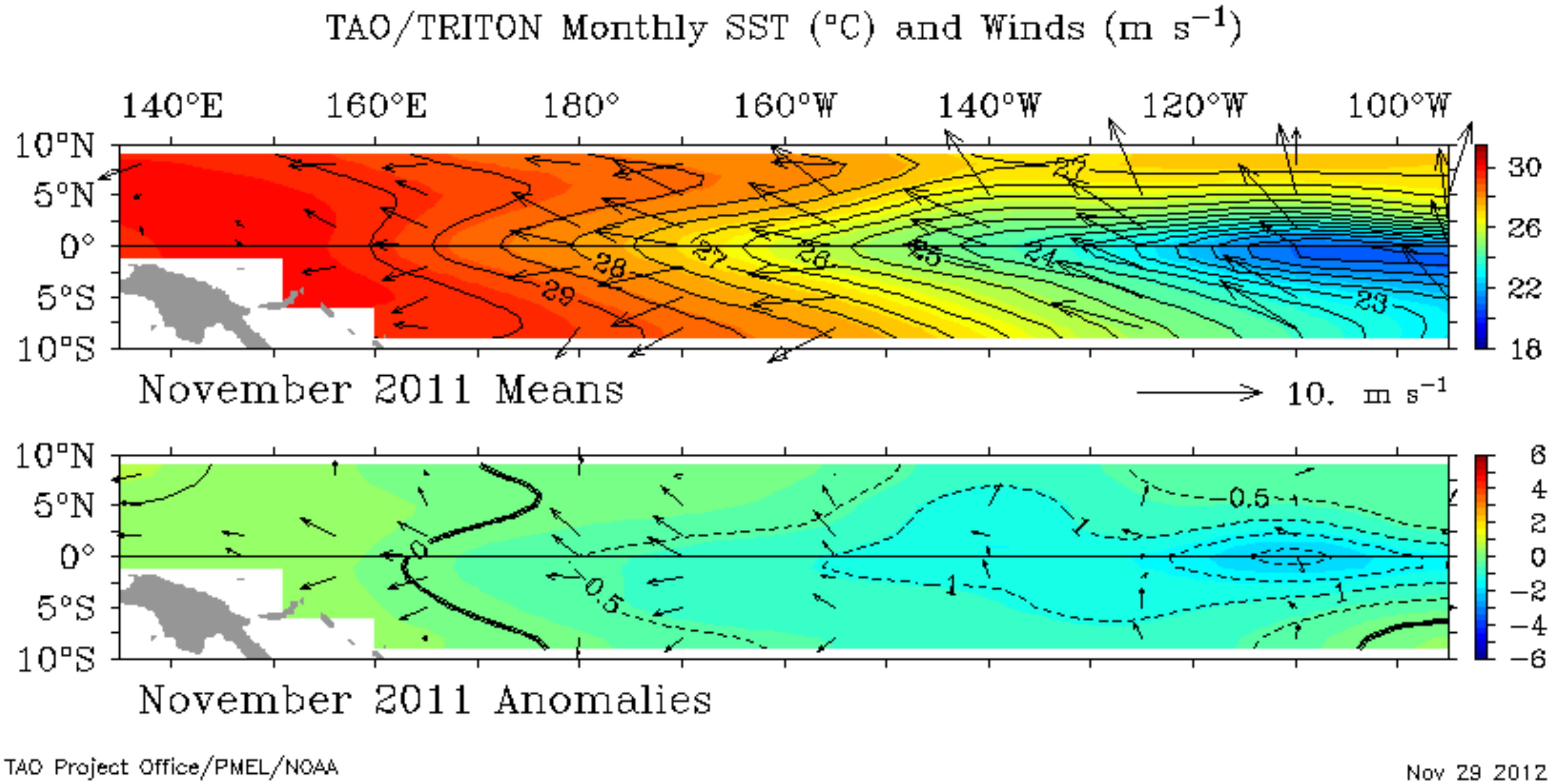
Southern Oscillation Index (SOI)
30
20
10
0
-10
-20
-30
-40
SOI
La Nina
El Nino
SOI
5-month weighted mean
2008
2009
2010
2011
2012
2013
Jan
Jan
Jan
Jan
Jan
Jan
Year

El Niño / Southern Oscillation



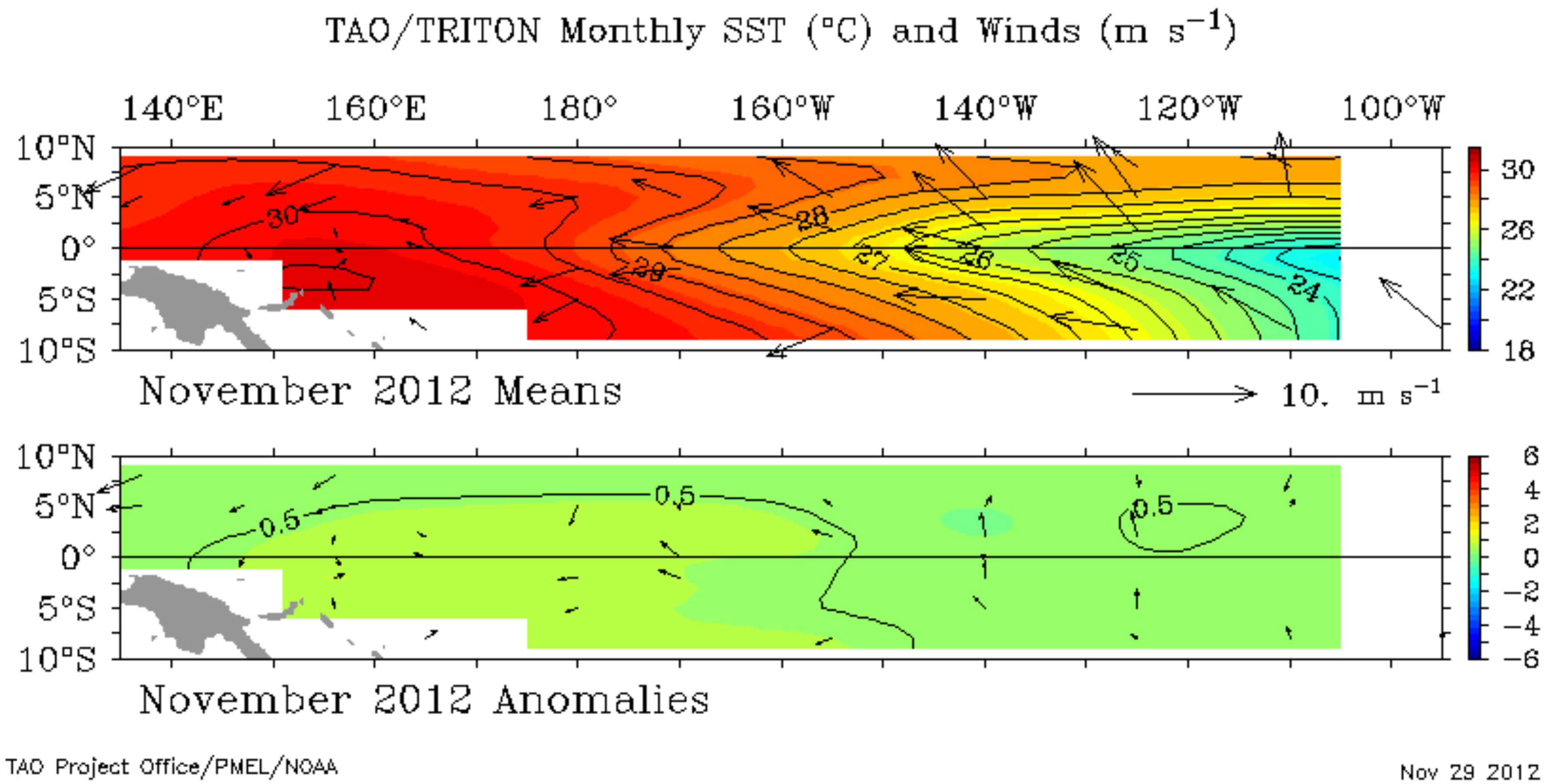
Fall-Winter 2010: La Nina

El Niño / Southern Oscillation



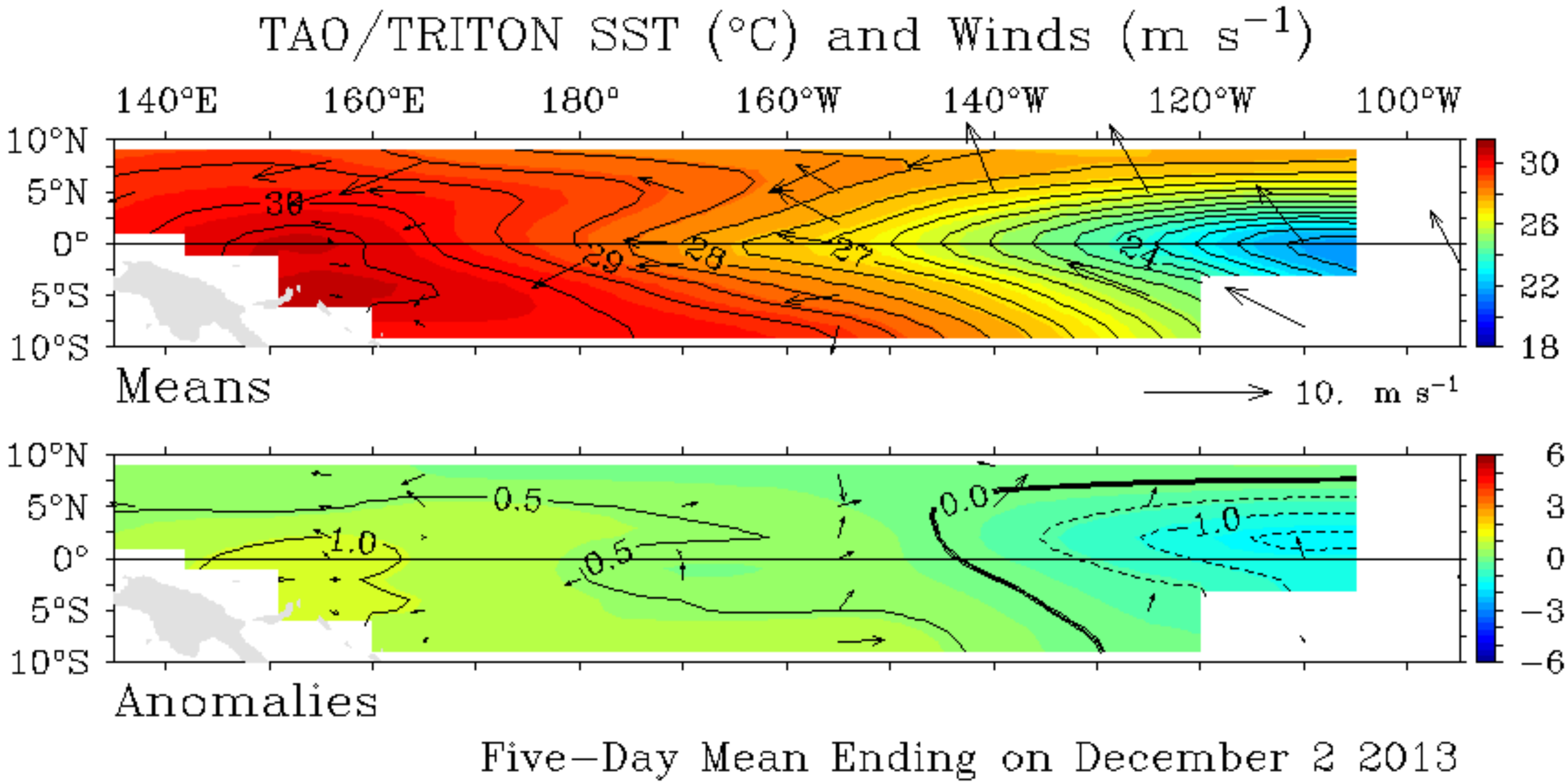
Fall-Winter 2010-11: La Nina
Fall-Winter 2011-12: La Nina

El Niño / Southern Oscillation



Fall-Winter 2010-11: La Nina
Fall-Winter 2011-12: La Nina
Fall 2012: Neutral

El Niño / Southern Oscillation



Fall-Winter 2010-11: La Nina

Fall-Winter 2011-12: La Nina

Fall 2012: Neutral

Fall 2013: Neutral

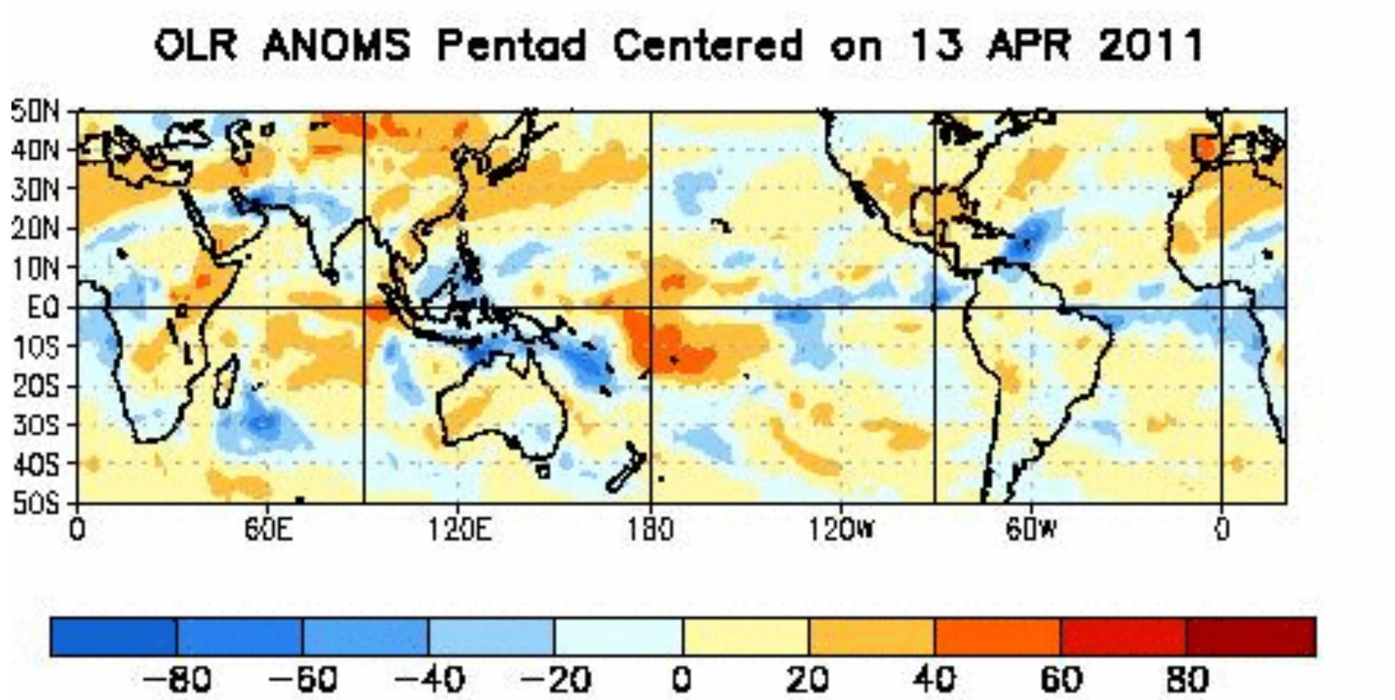
Animations

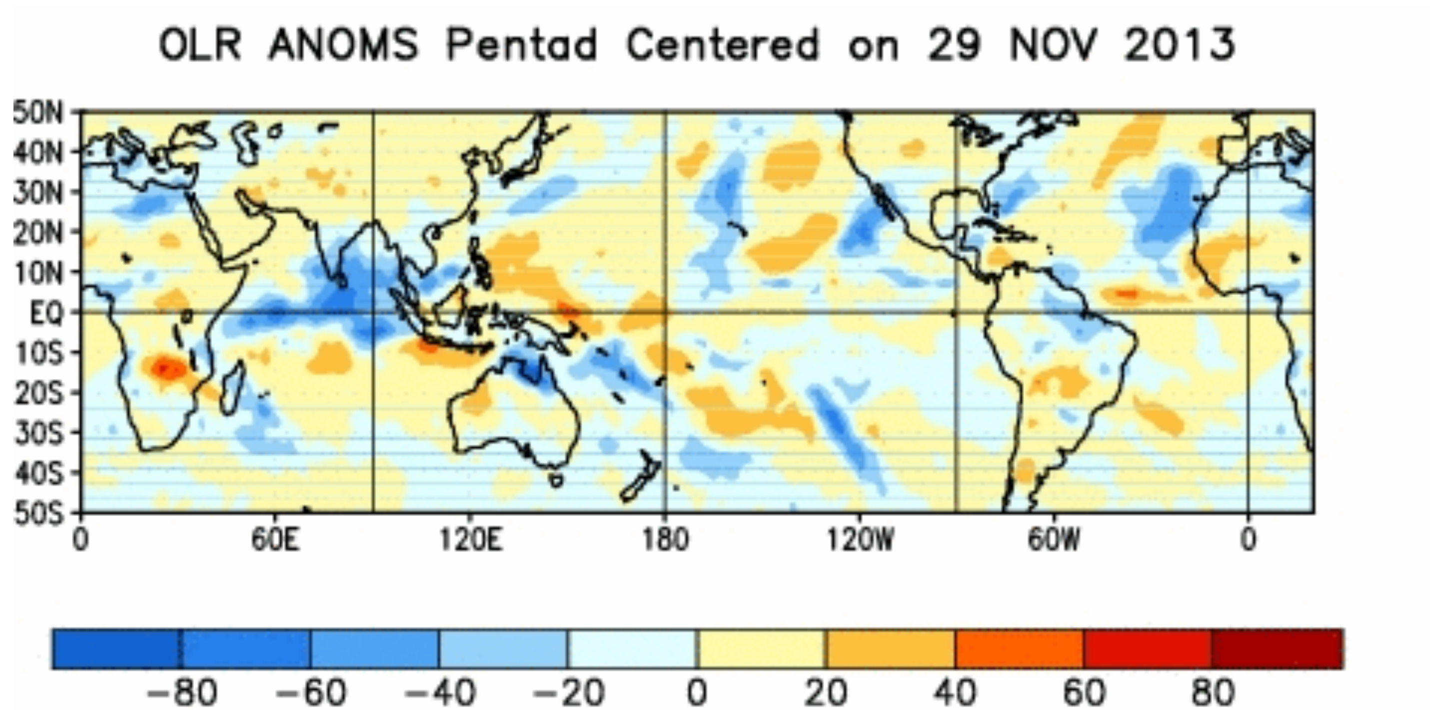
NOAA CPC http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml

NOAA PMEL http://www.pmel.noaa.gov/tao/jsdisplay/ani.html

OLR
Anomaly

April 2011
La Nina
(top)
vs.
Nov 2013
Neutral
(bottom)





Seasonal Prediction

- State of the art for climate prediction =

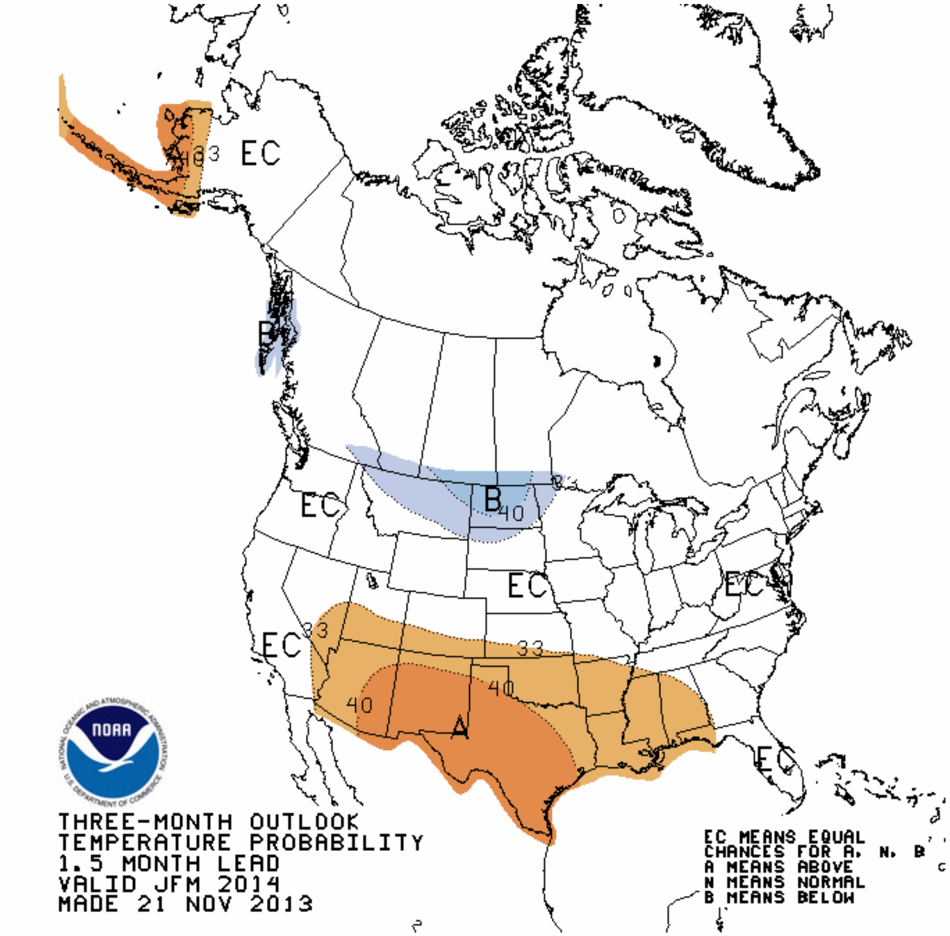
  statistical variability from ENSO + soil moisture + warming trend

- NOAA Climate Prediction Center (CPC)

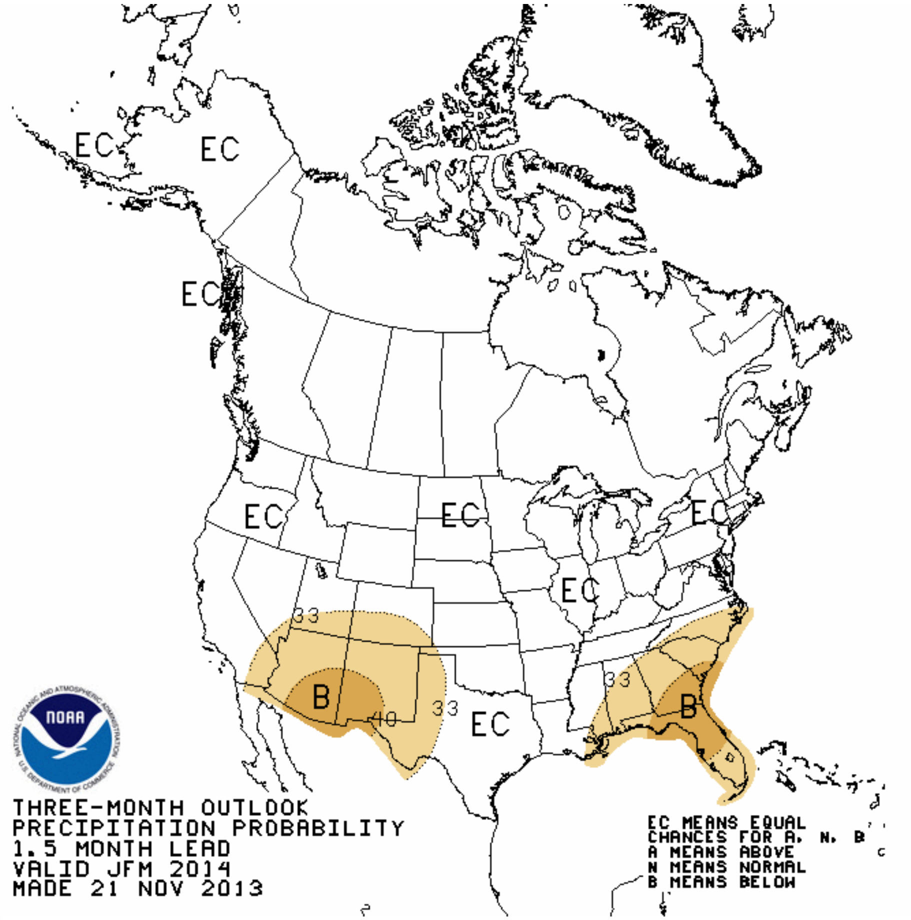
http://www.cpc.ncep.noaa.gov/products/forecasts/month_to_season_outlooks.shtml

Seasonal Prediction, JFM 2014

Temp



Precip



A = warmer, wetter; B = colder, drier

Shading = probability > 33.33%

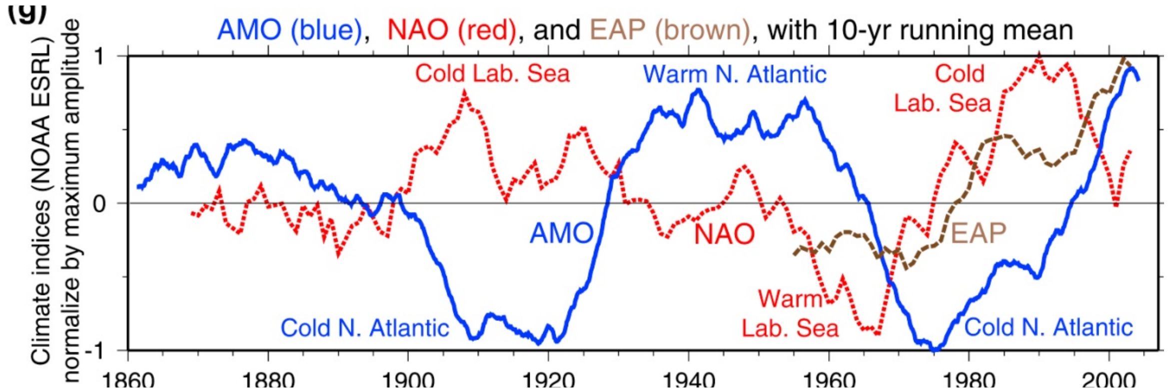
http://www.cpc.ncep.noaa.gov

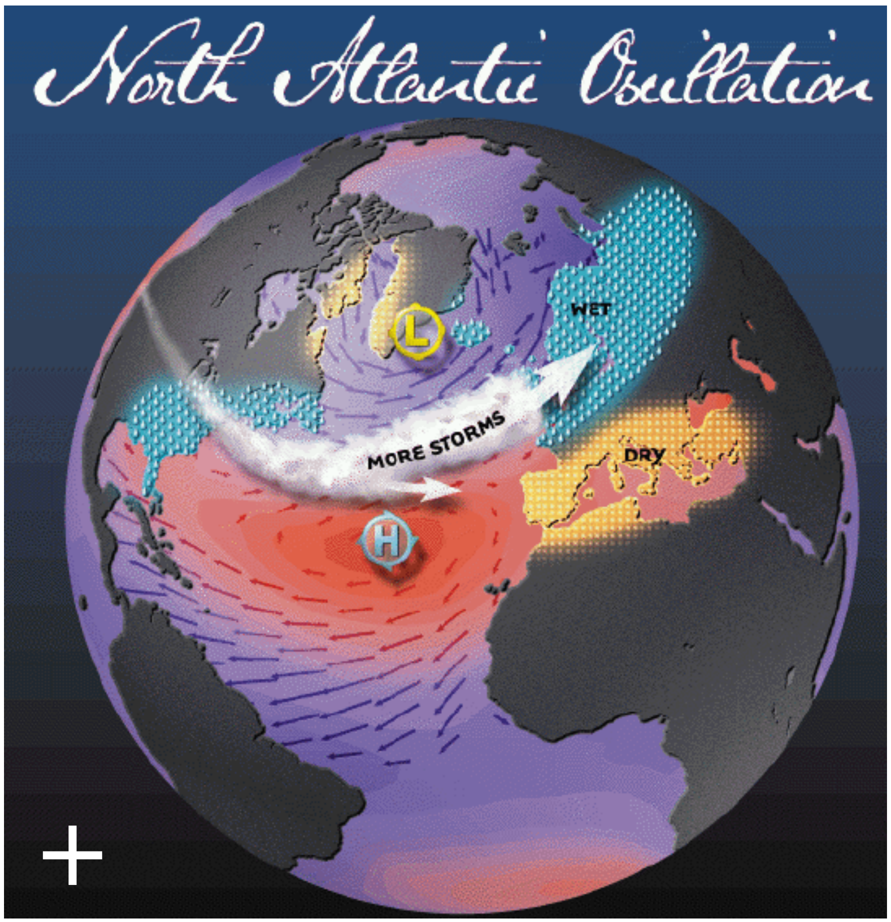
ENSO Summary

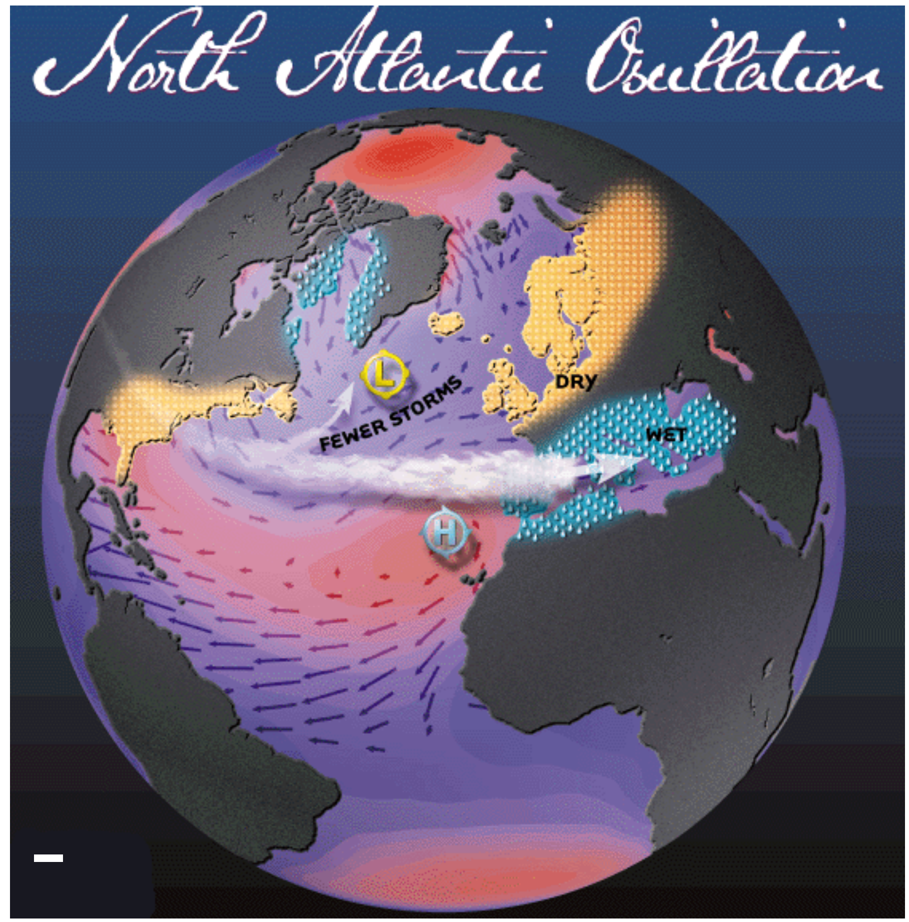
- ENSO dynamics involve a positive feedback (by which the event amplifies) and a delayed negative feedback (which eventually “shuts off” an ENSO event)
- ENSO impacts the global climate
- Monitoring in the Equatorial Pacific (TOGA/TOA) is now operational. This is a significant component in modern seasonal climate prediction.

Other Coupled Modes

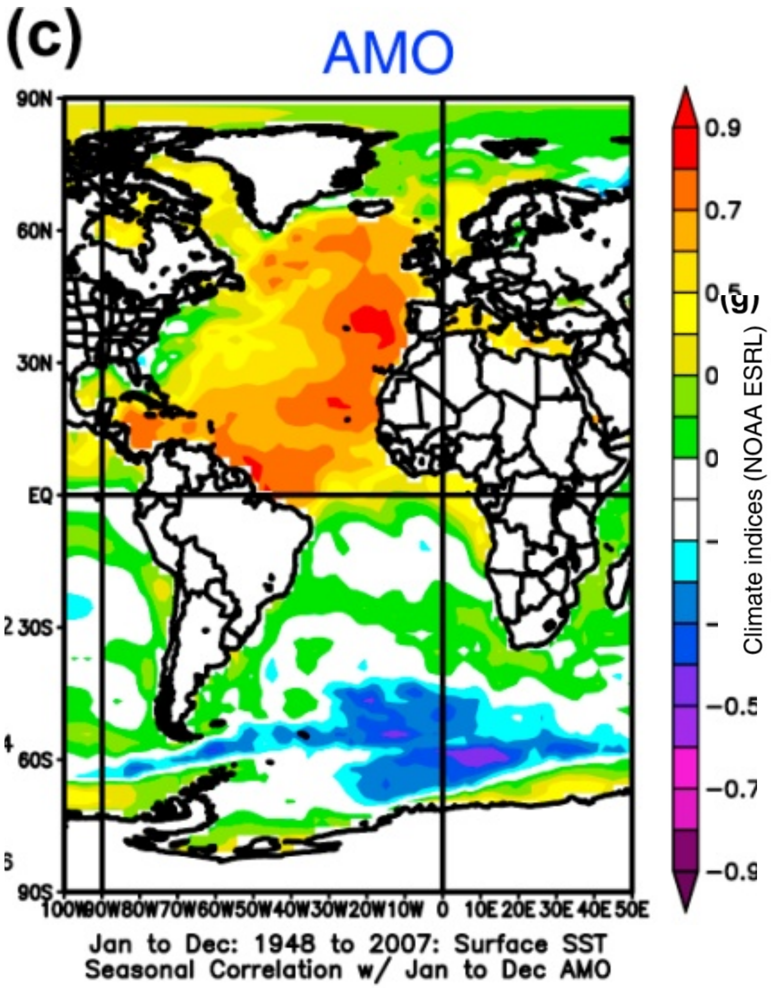
North Atlantic Oscillation

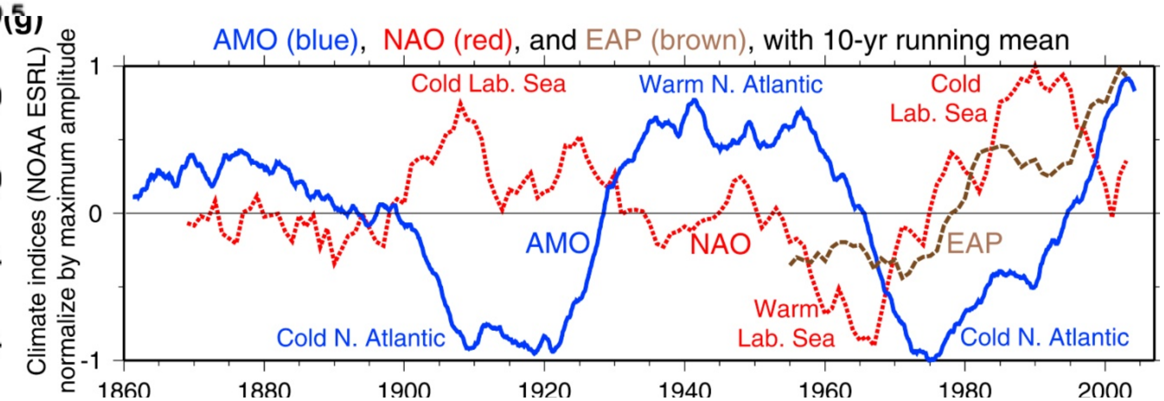






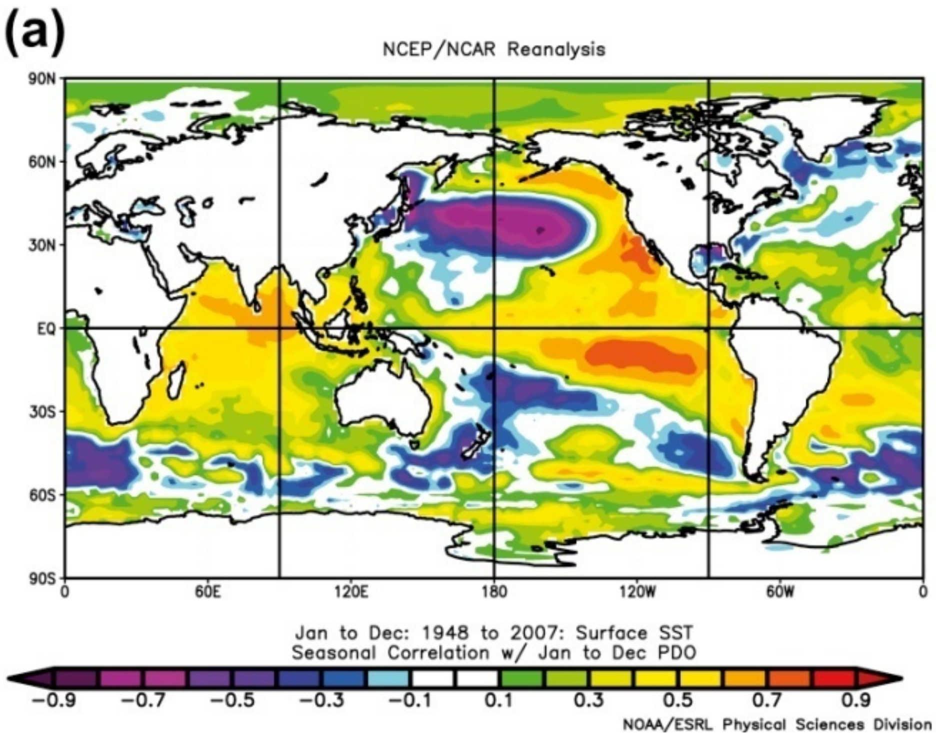
Atlantic Multidecadal Oscillation

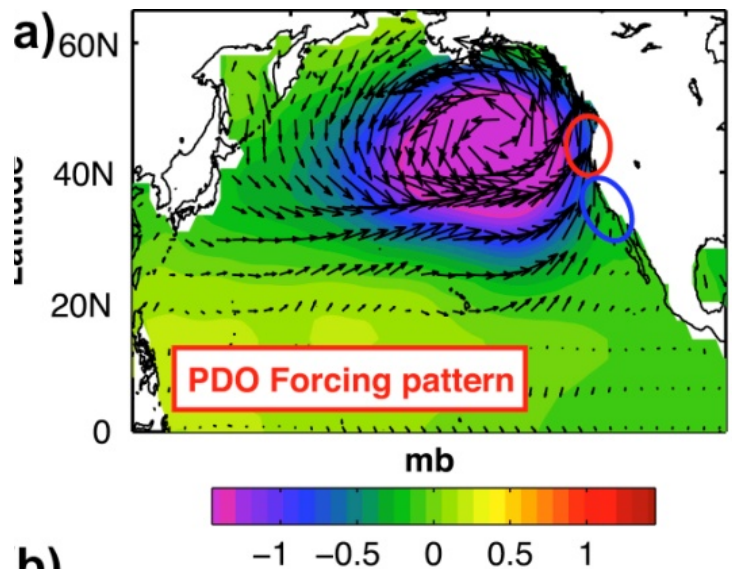


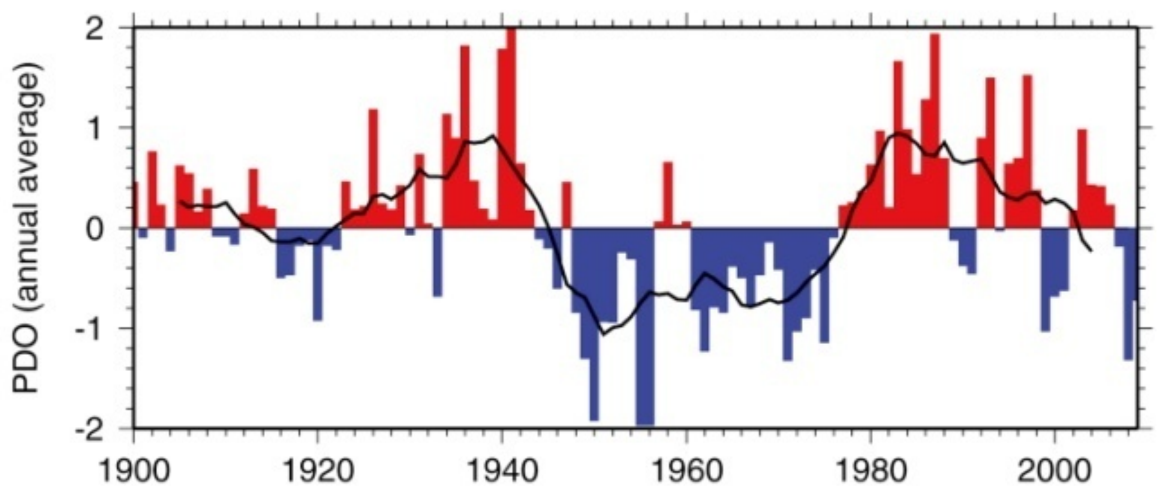


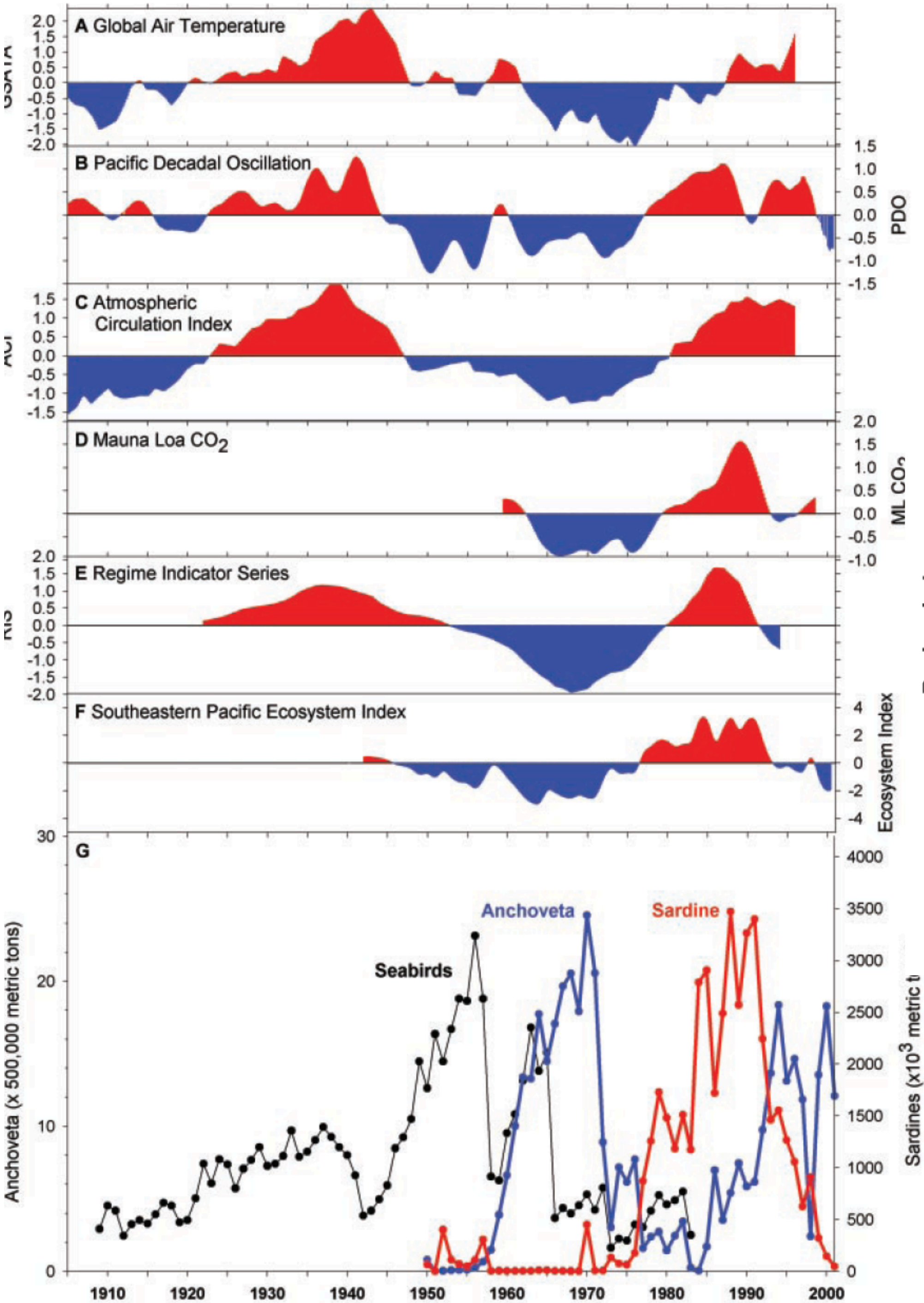
AMO connection to MOC variability is hypothesized

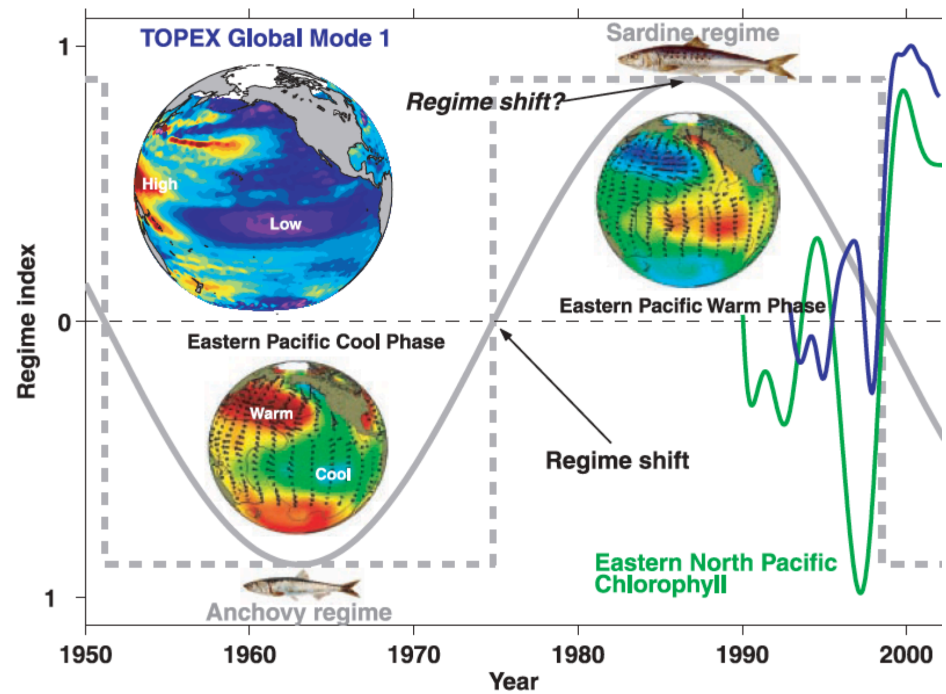
Pacific Decadal Oscillation











Chavez et al. 2003