The Abdus Salam
International Centre
for Theoretical Physics

2356-14

Targeted Training Activity: ENSO-Monsoon in the Current and Future Climate

30 July - 10 August, 2012

Everything You Want to Know About ENSO, But Were Afraid to Ask

KIRTMAN Benjamin Paul

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ATMOSPHERIC SCIENCE

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UNIVERSITY OF MIAMI

Everything You Want to Know About ENSO, But Were Afraid to Ask

Ben Kirtman
University of Miami – Rosenstiel School

Outline

- **Role of the Ocean (Dynamics)**
  - Mean State, Air-Sea Fluxes,Mixed Layer
  - Rossby, Kelvin Waves, Sverdrup Balance
- **Predictability**
  - Error Growth, Stochastic Forcing (WWB)
  - Low Frequency Variations in Predictability
- **Prediction**
  - Ingredients, Quality, Uncertainty
- **ENSO in Models**
  - IPCC Class Models

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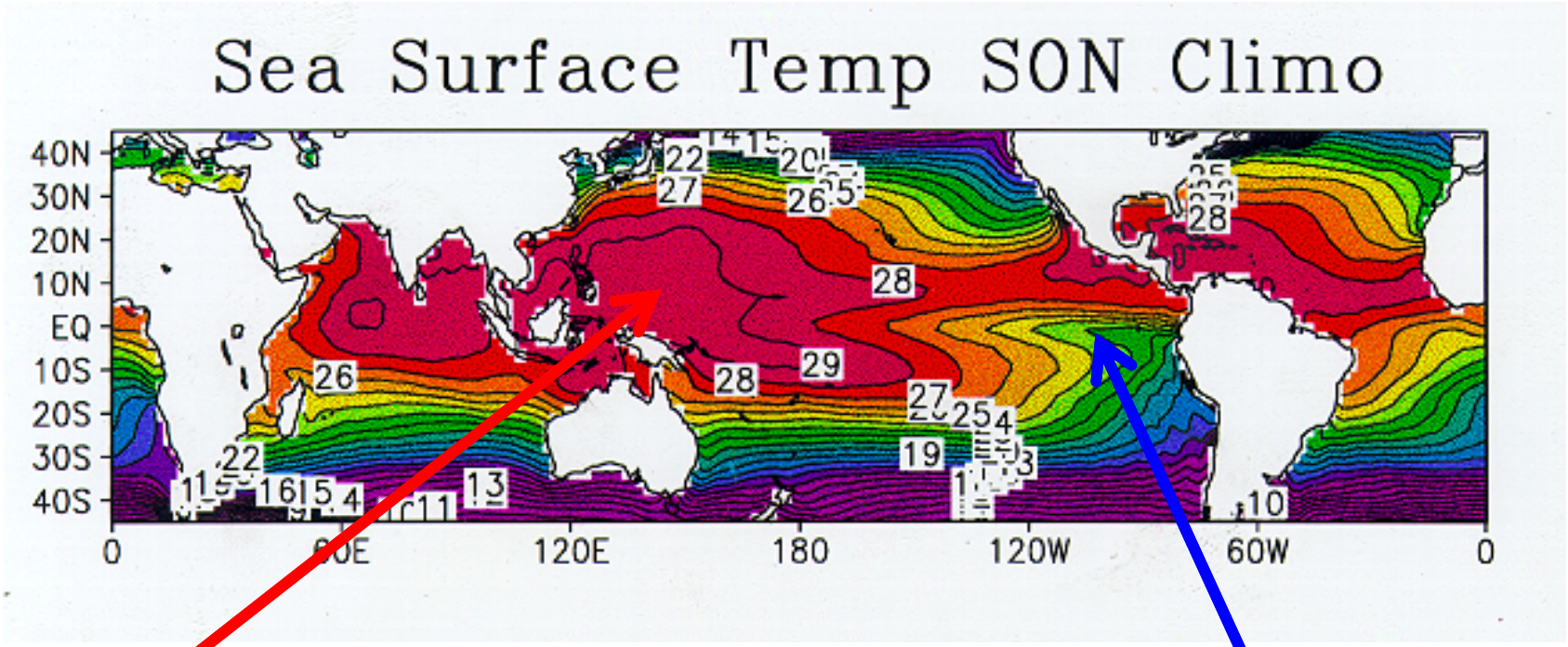
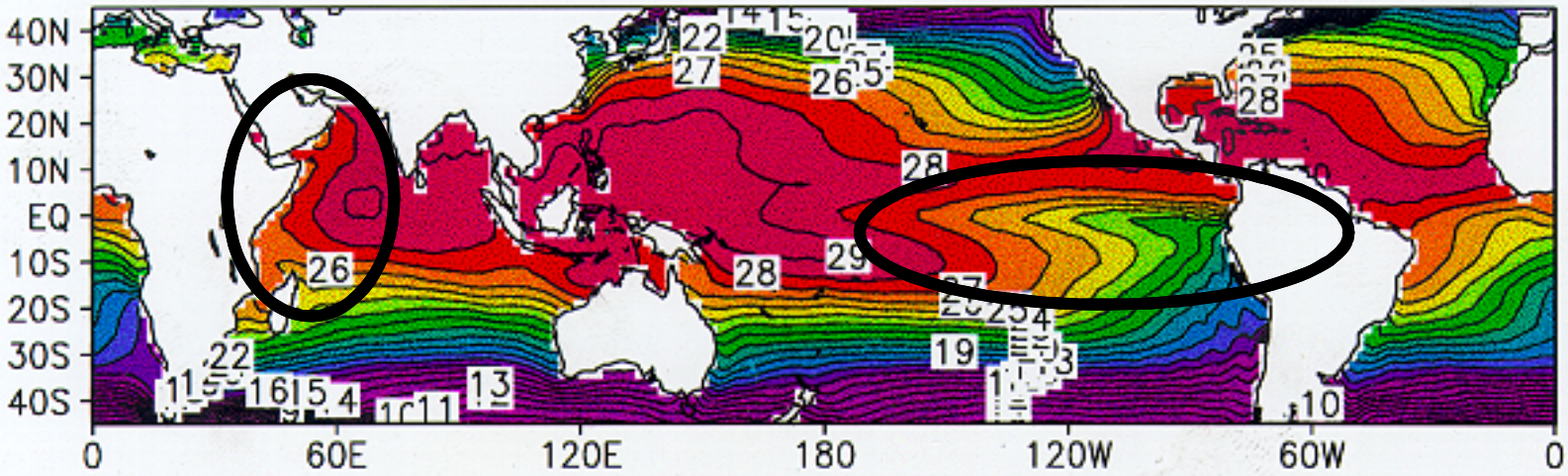
September-October-November
Sea Surface Temperature Climatology



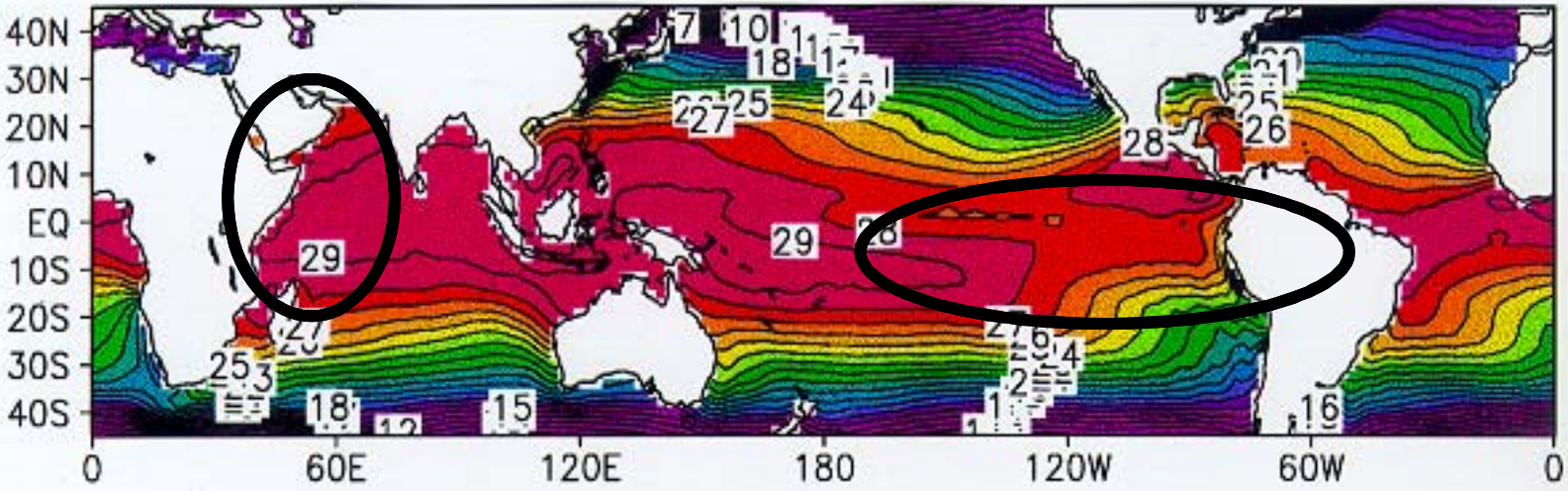
Warm Pool

Cold Tongue

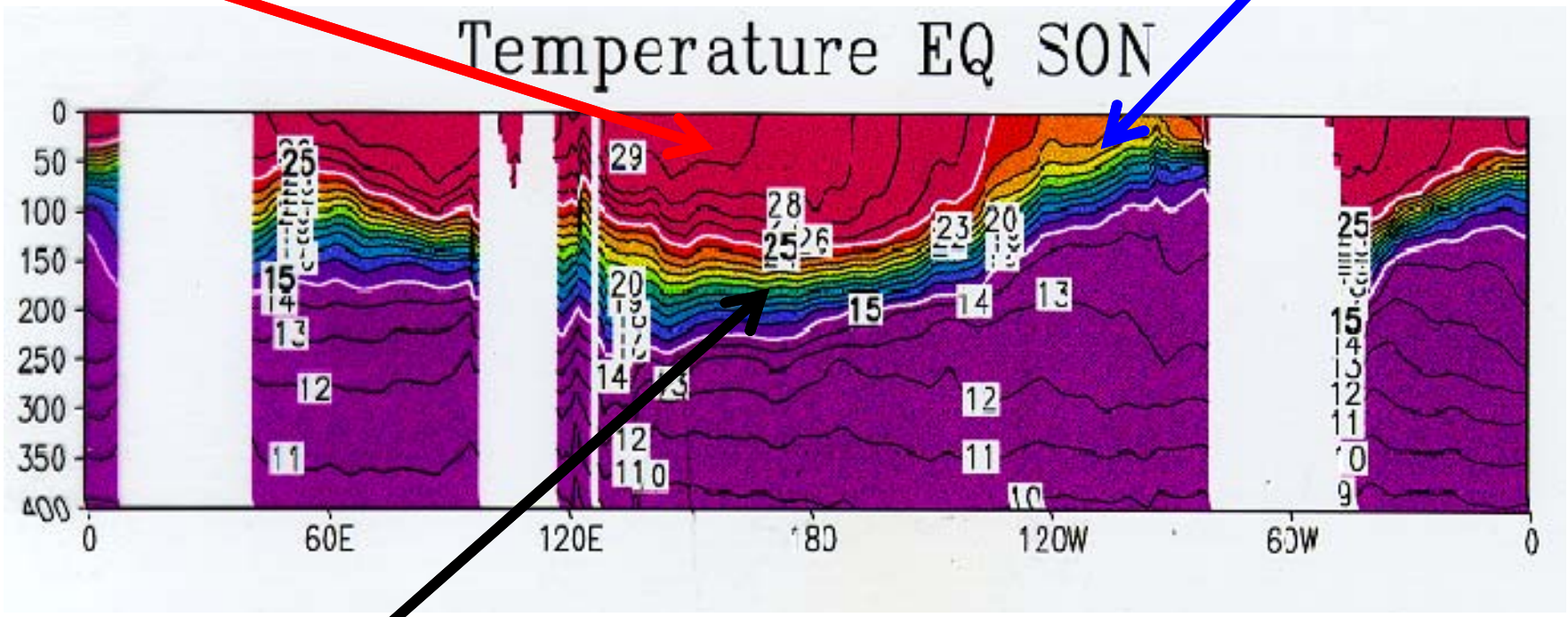
Sea Surface Temp SON Climo

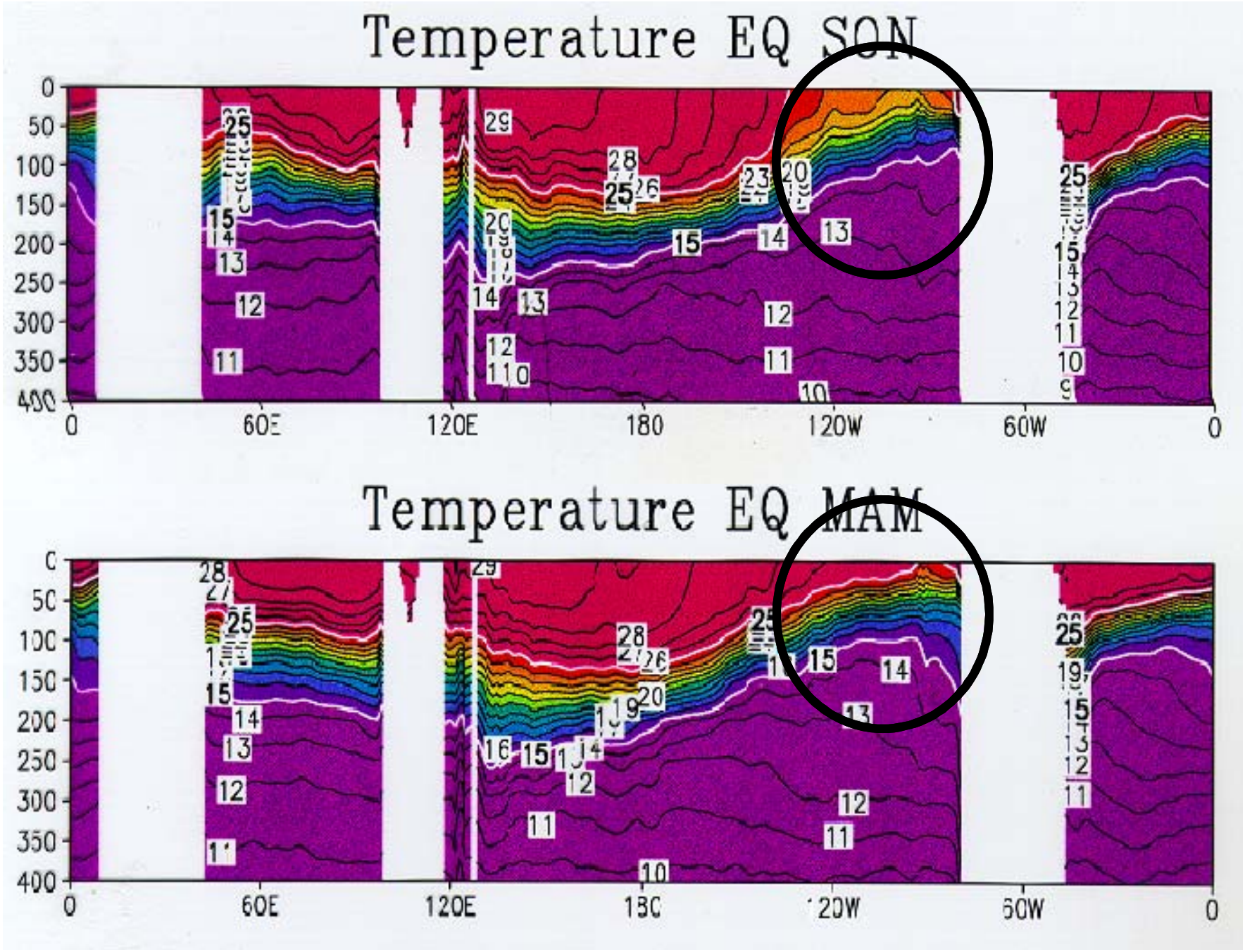


Sea Surface Temp MAM Climo

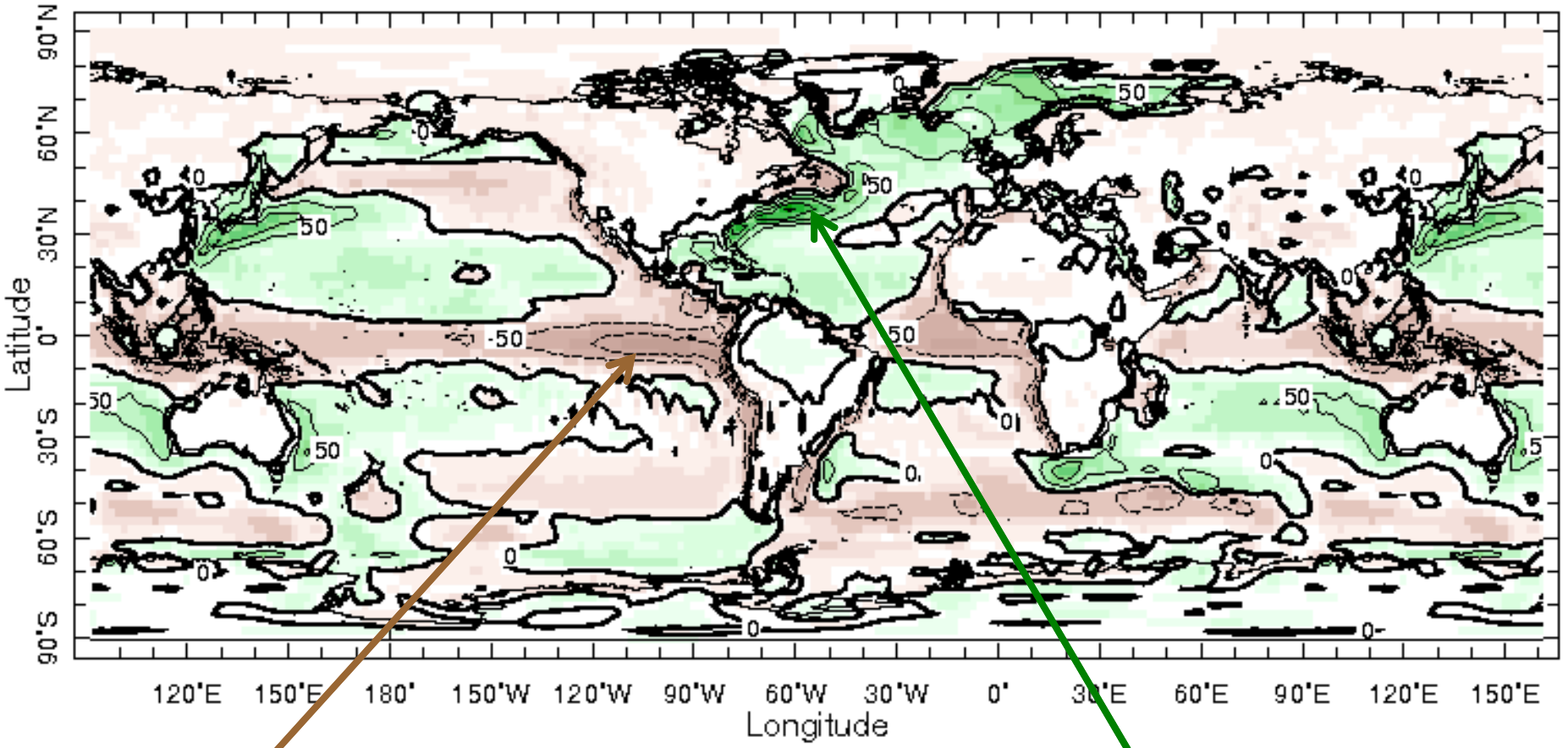


September-October-November
Equatorial Temperature Climatology




Temperature EQ SON
0
50
100
150
200
250
300
350
400
0
60E
120E
180
120W
60W
0
Temperature EQ MAM
0
50
100
150
200
250
300
350
400
0
60E
120E
180
120W
60W
0

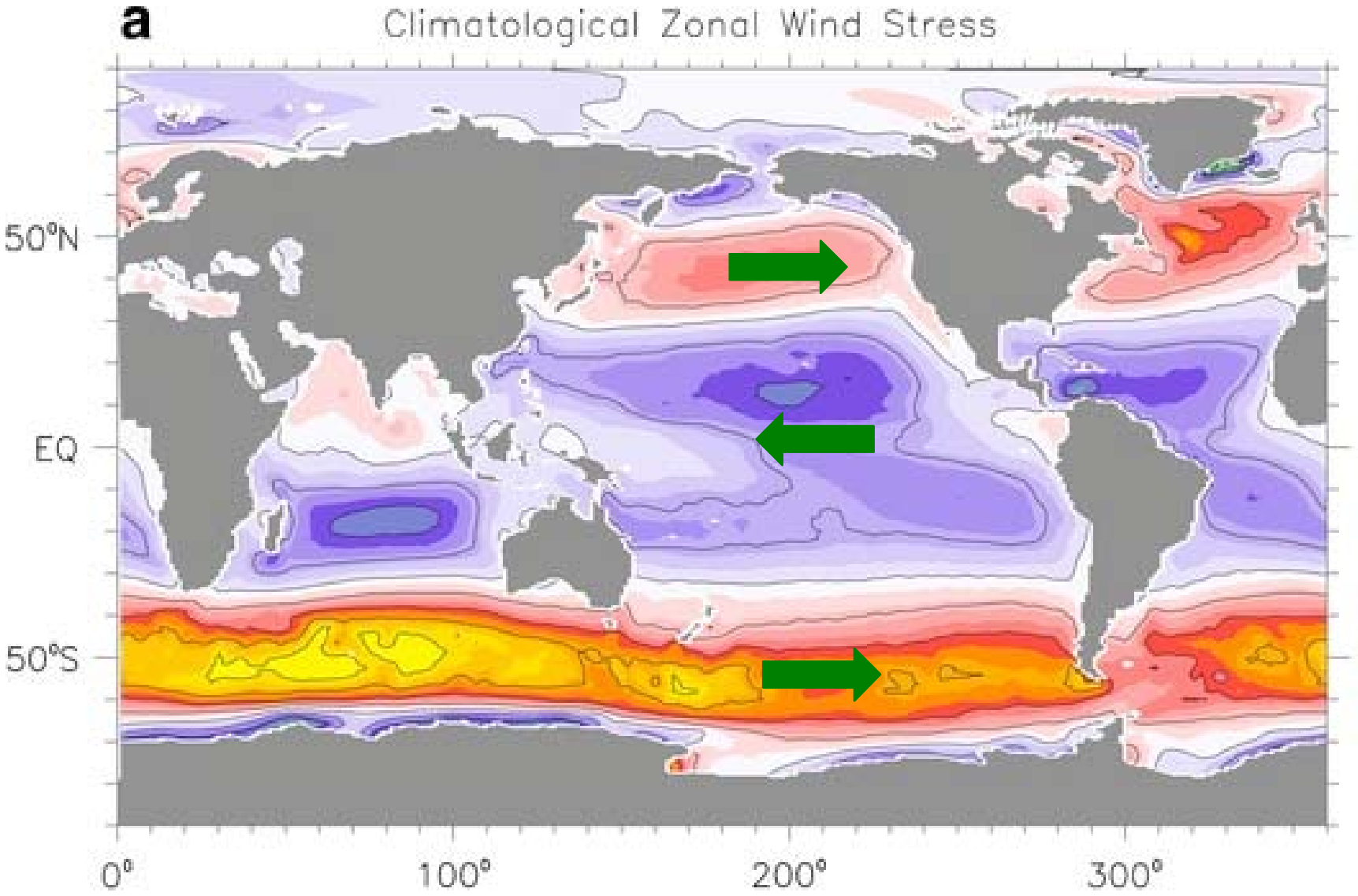
Air-Sea Heat Flux



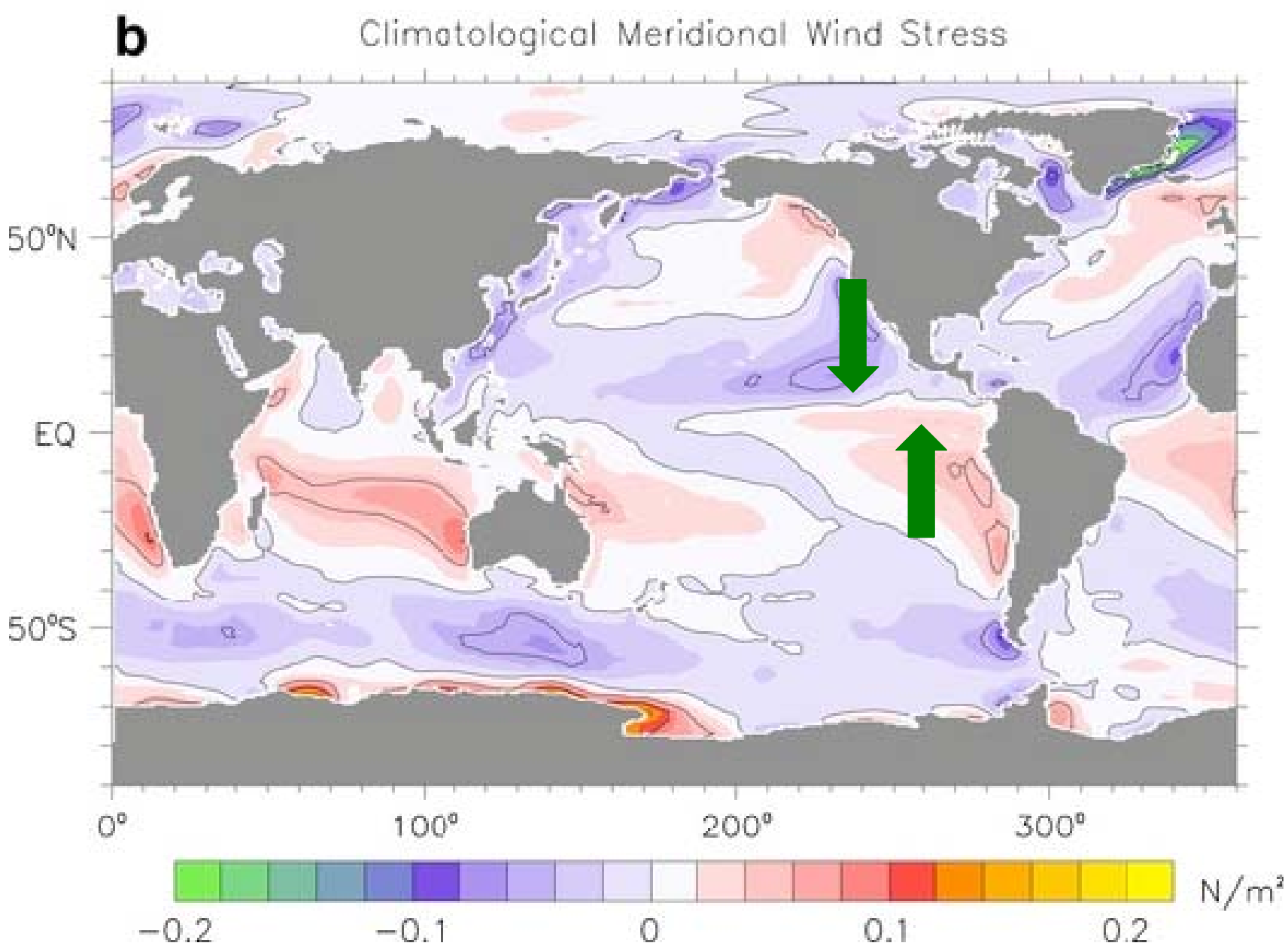
Heat Flux INTO the Ocean

Heat Flux OUT OF the Ocean

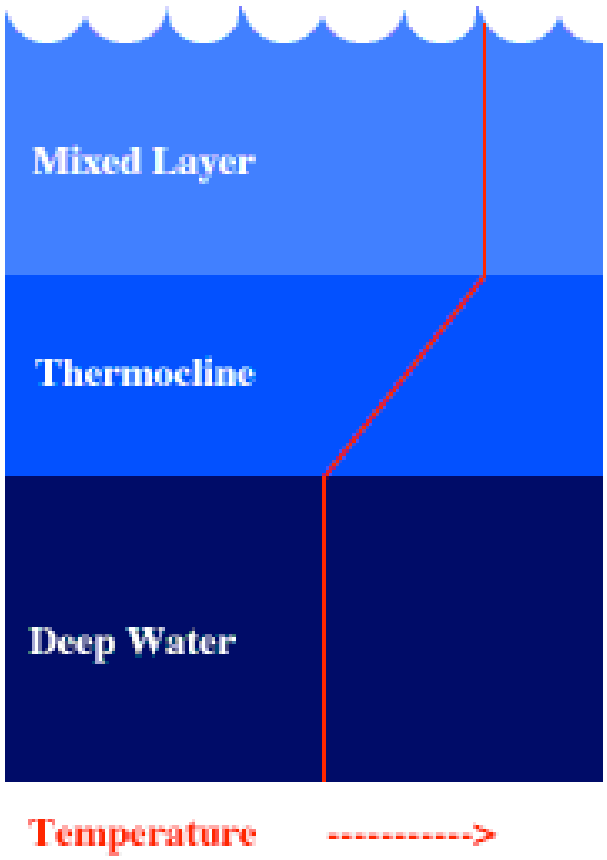
Zonal Momentum Flux (Wind Stress)



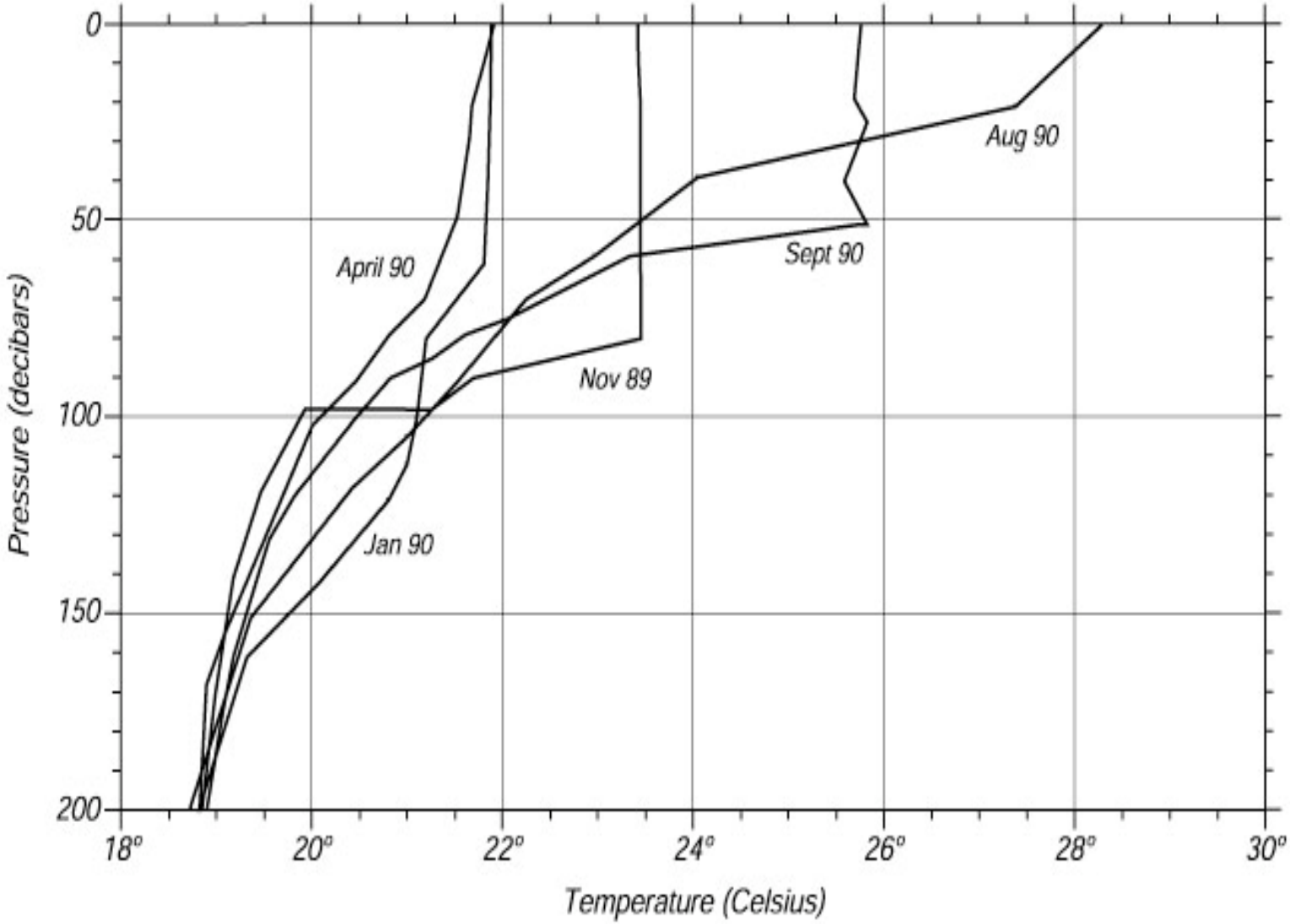
Meridional Momentum Flux



Ocean Mixed-Layer



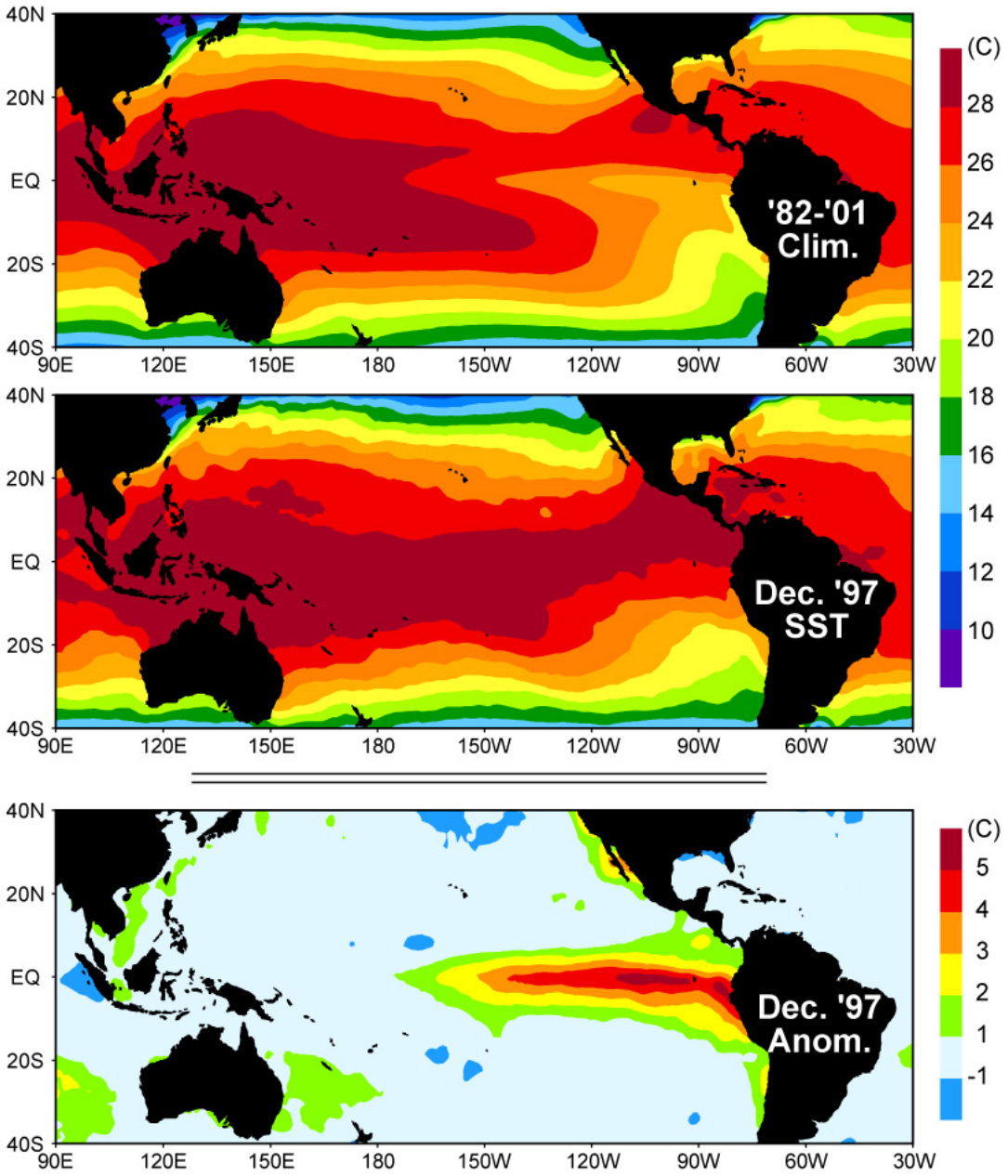
Ocean Mixed-Layer

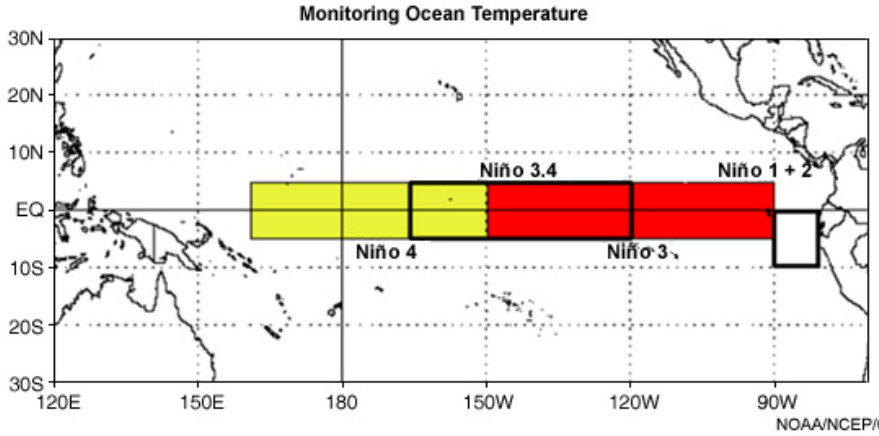


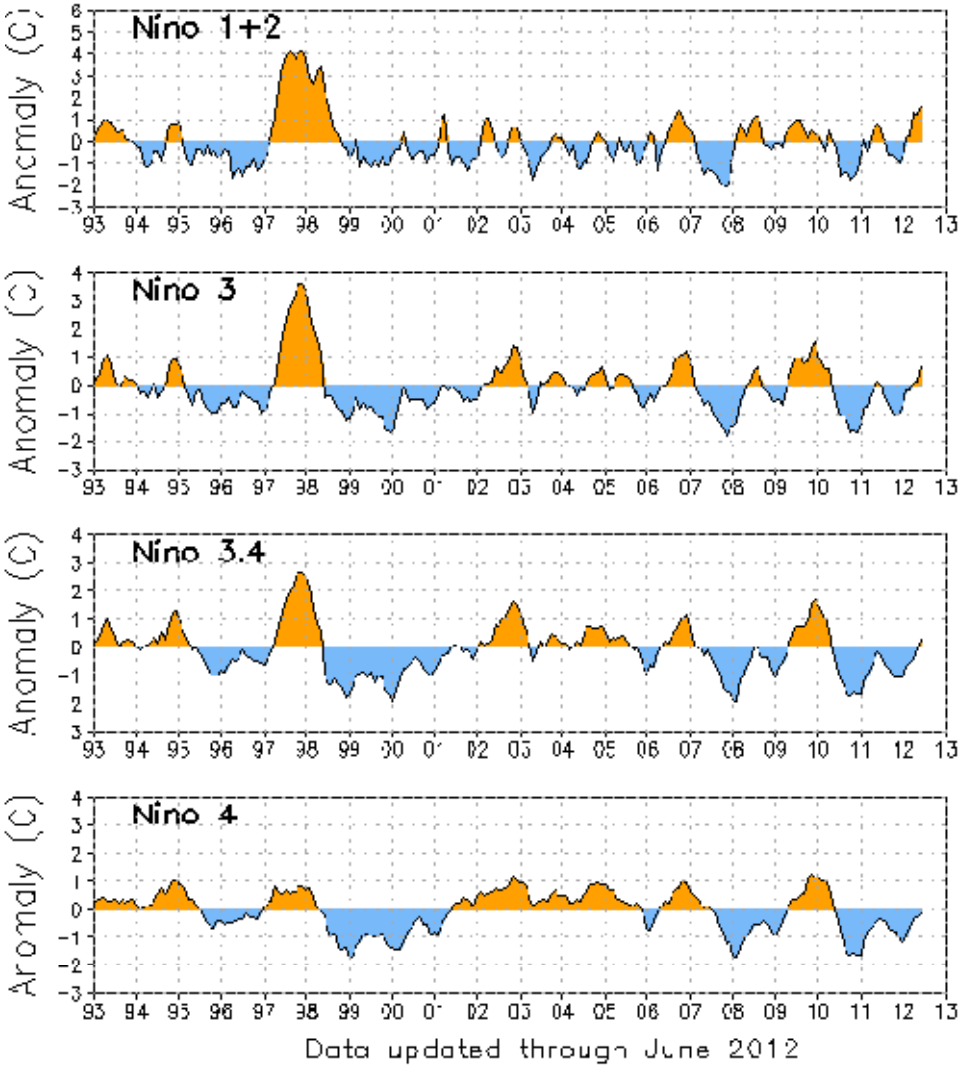
December 1982-2001
SST Climatology

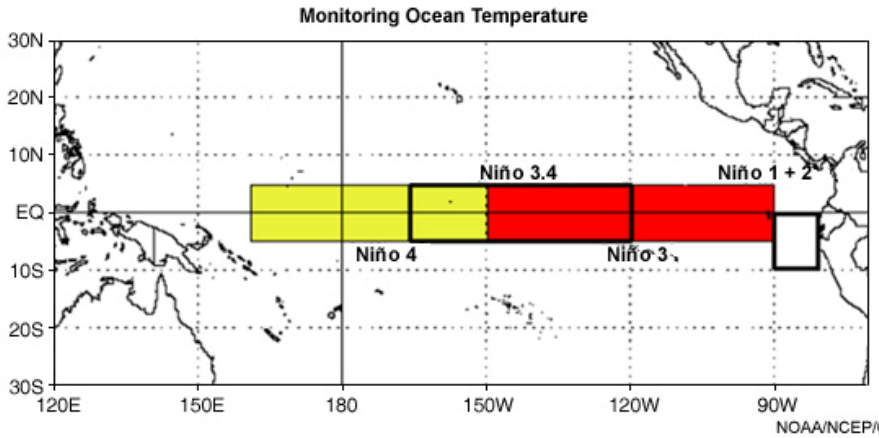
December 1997
Total SST

December 1997
SST Anomaly




Monitoring Ocean Temperature
30N
20N
10N
EQ
10S
20S
30S
120E
150E
180
150W
120W
90W
Niño 3.4
Niño 1 + 2
Niño 4
Niño 3
NOAA/NCEP/CPC


Nino 1+2
Anomaly (C)
Nino 3
Anomaly (C)
Nino 3.4
Anomaly (C)
Nino 4
Anomaly (C)
93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13
Data updated through June 2012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30N
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Niño 3.4
Niño 1 + 2
Niño 4
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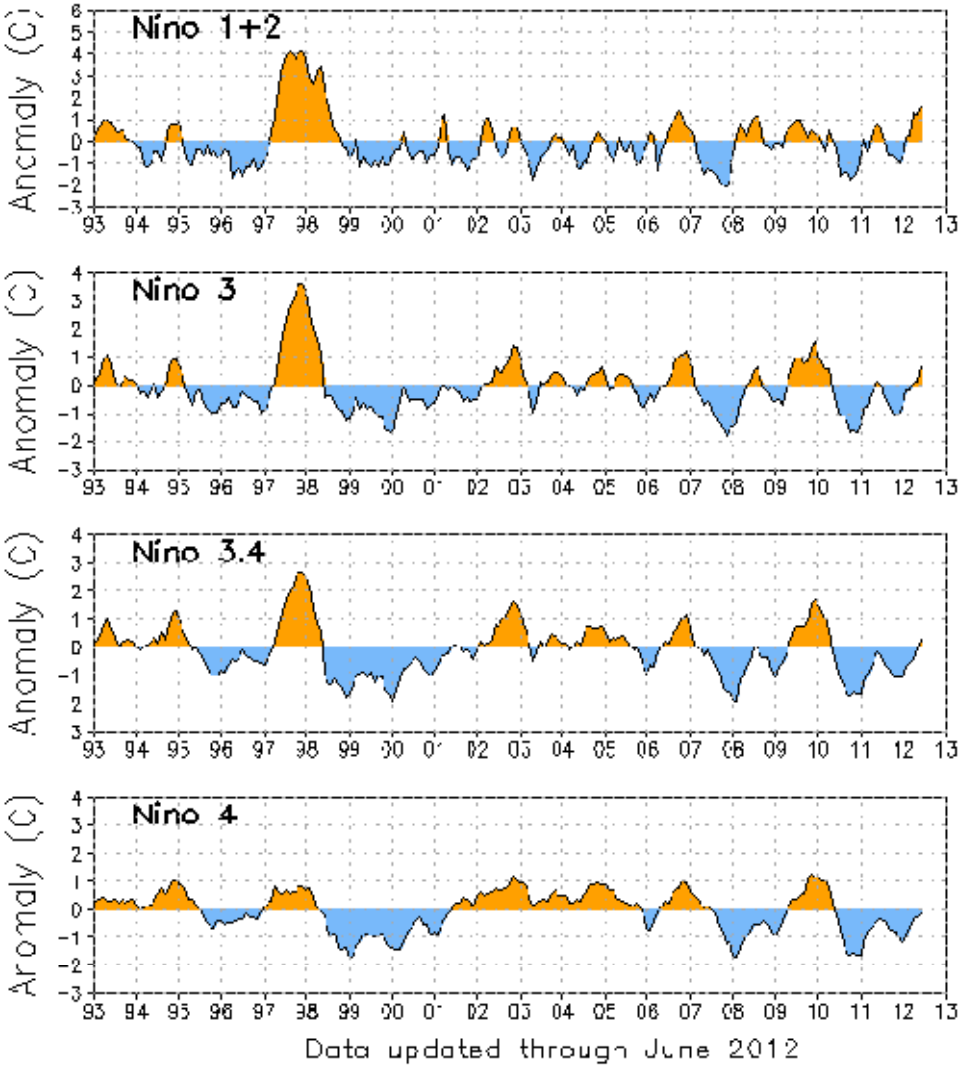
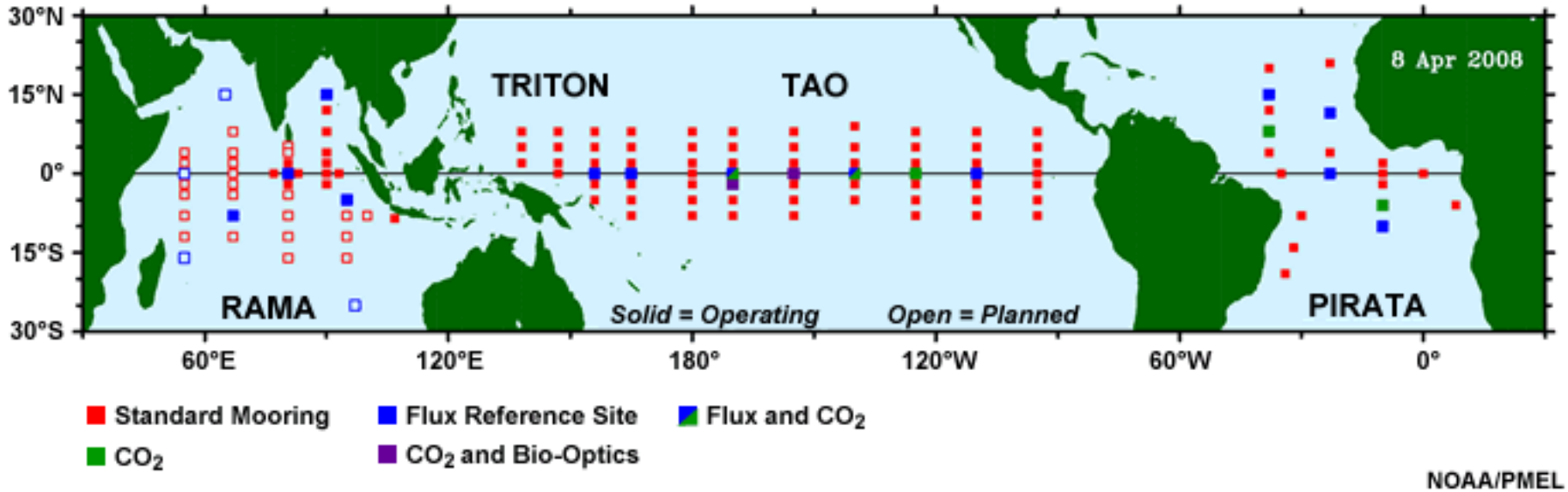
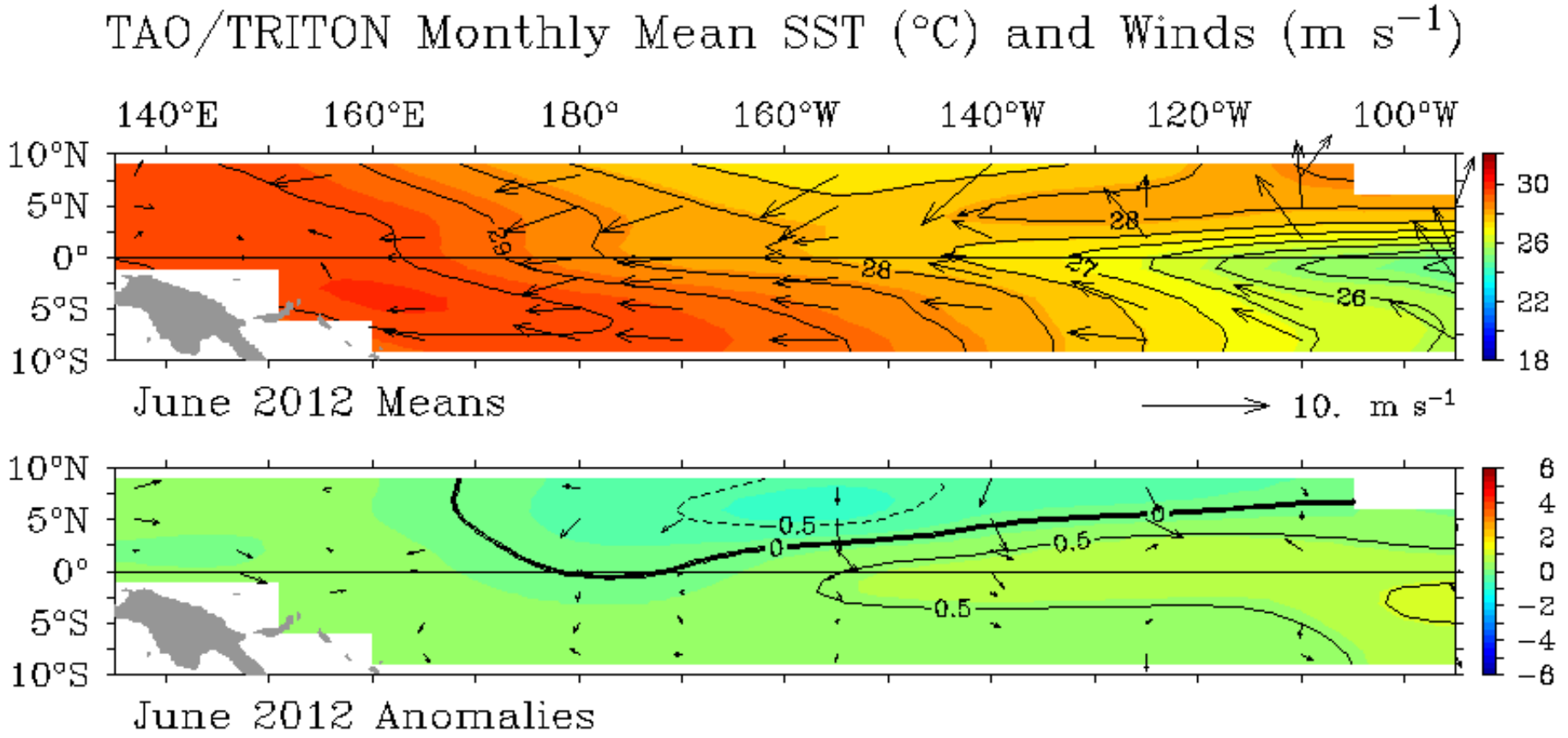

Nino 1+2
Anomaly (C)
Nino 3
Anomaly (C)
Nino 3.4
Anomaly (C)
Nino 4
Anomaly (C)
93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13
Data updated through June 2012

Global Tropical Moored Buoy Array

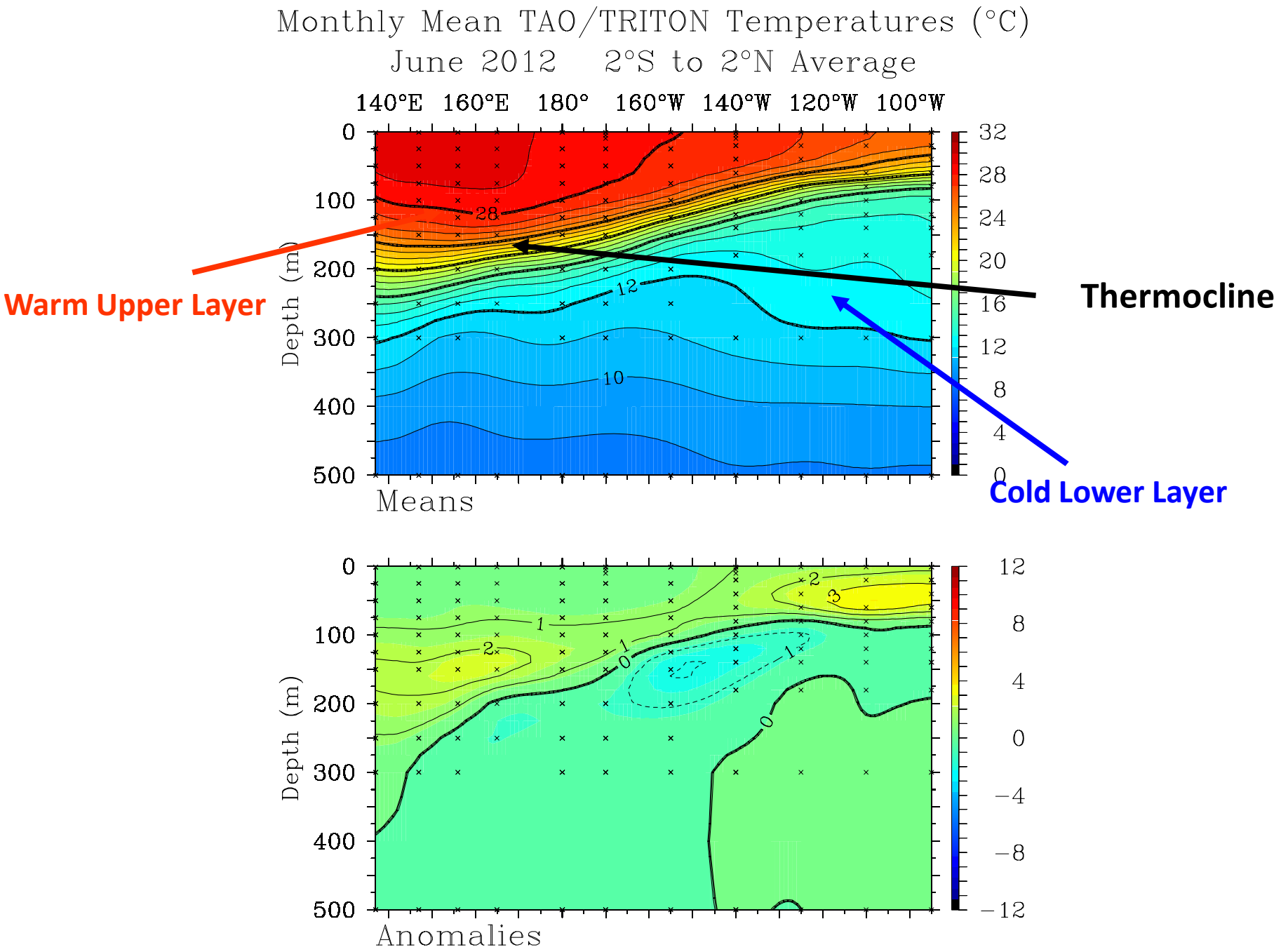


NOAA/PMEL

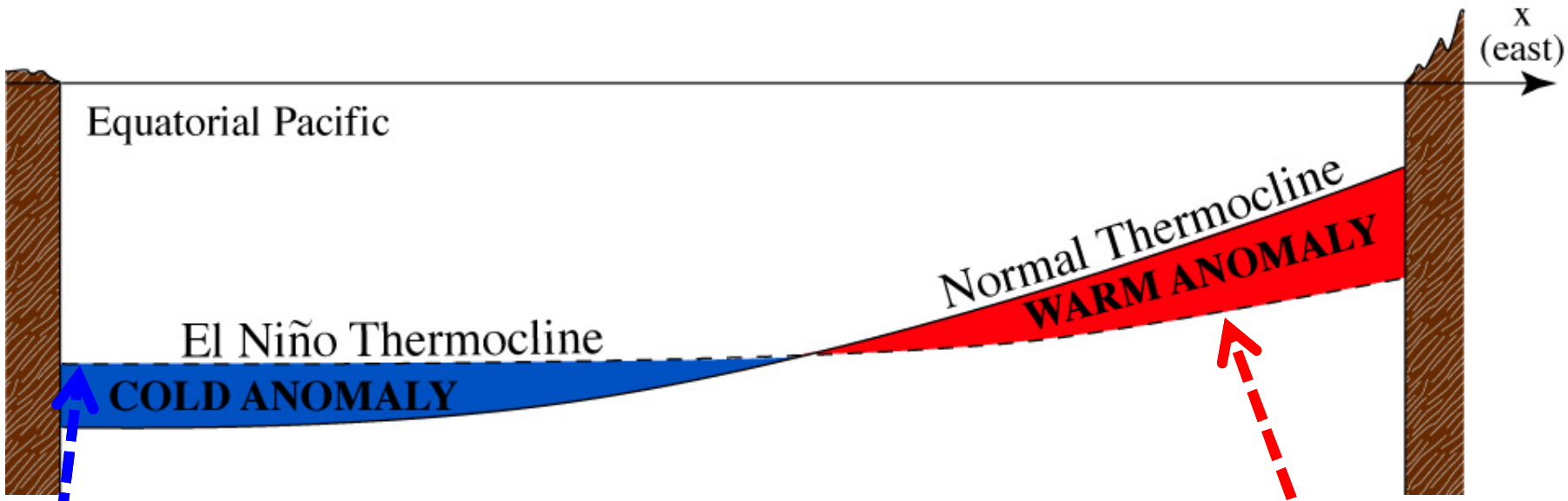


TAO Project Office/PMEL/NOAA

Jul 26 2012


Monthly Mean TAO/TRITON Temperatures (°C)
June 2012 2°S to 2°N Average
140°E 160°E 180° 160°W 140°W 120°W 100°W
Depth (m)
Means
Anomalies
Warm Upper Layer
Thermocline
Cold Lower Layer
TAO Project Office/PMEL/NOAA
Jul 26 2012

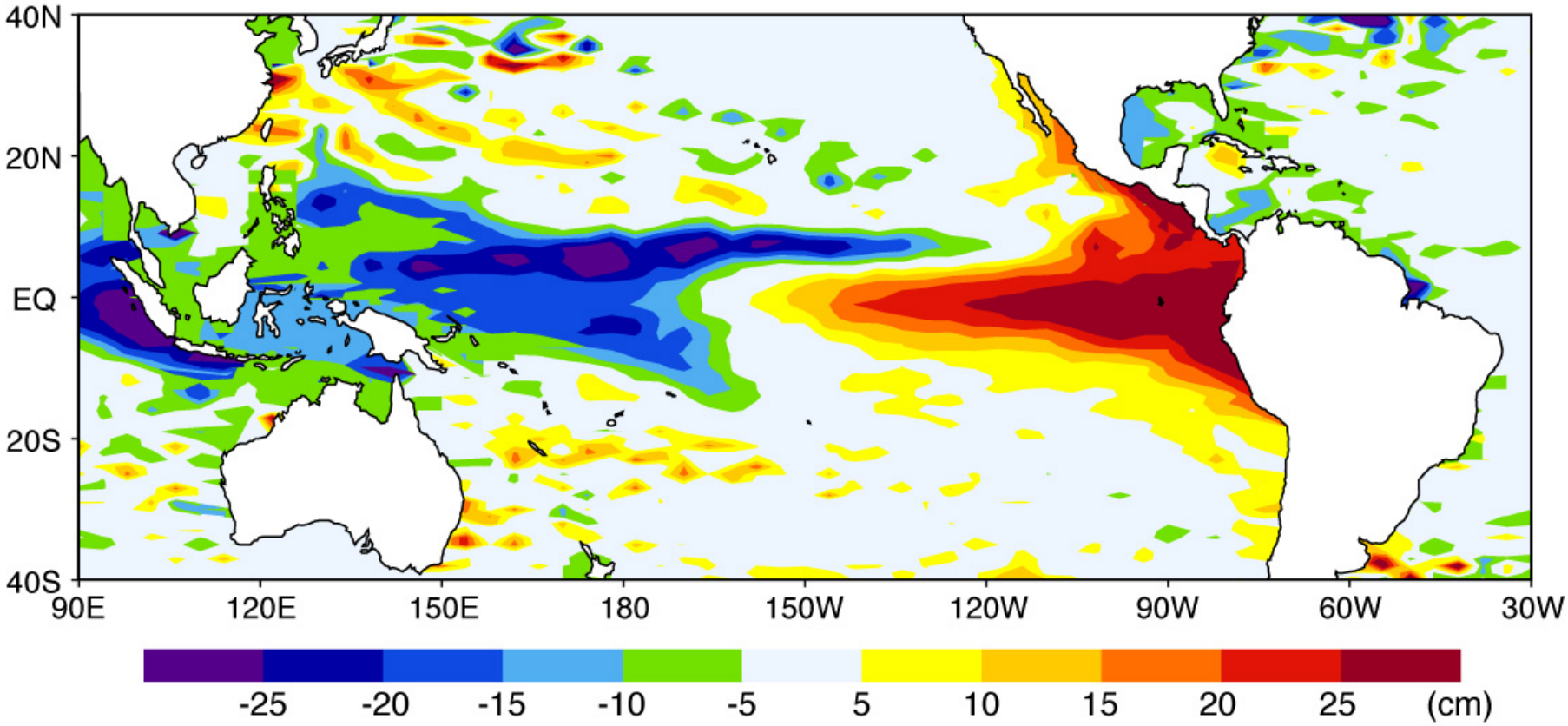
El Nino vs. Normal Thermocline Depth

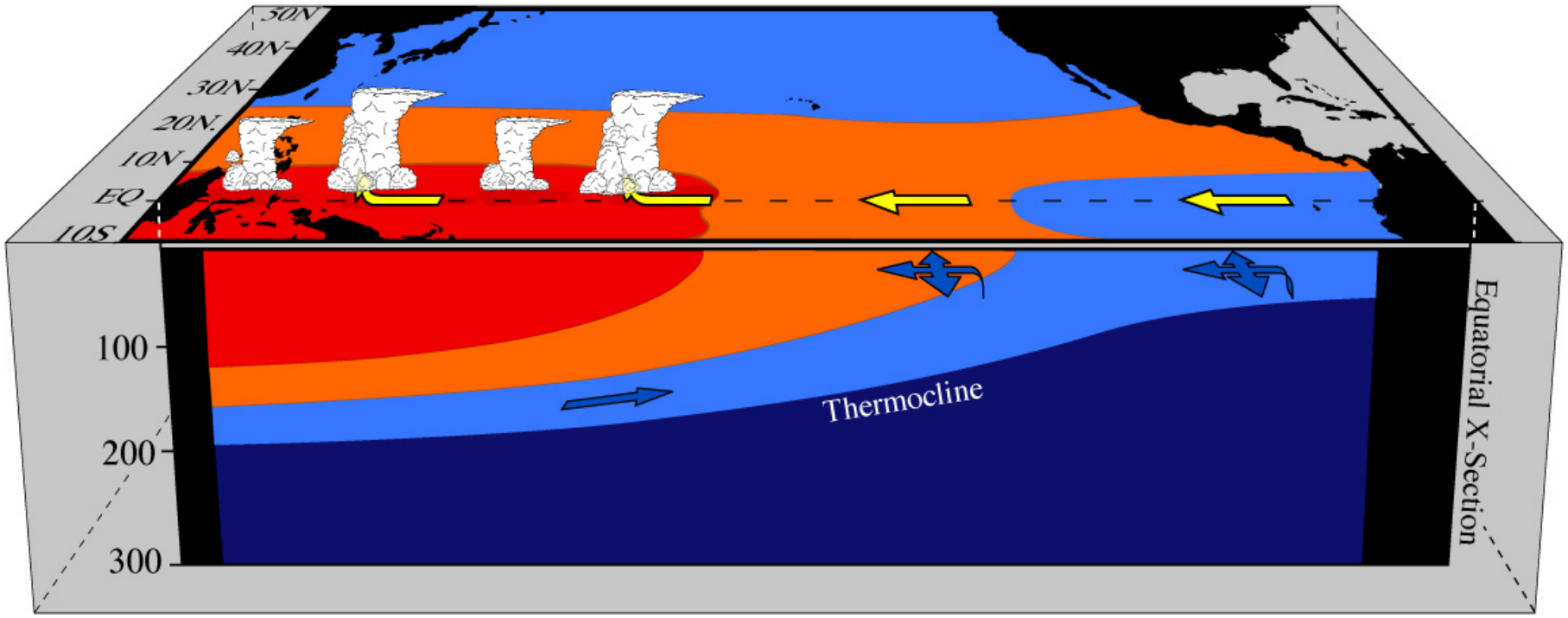


Thermocline is Shallower than Normal
Negative Depth Anomaly

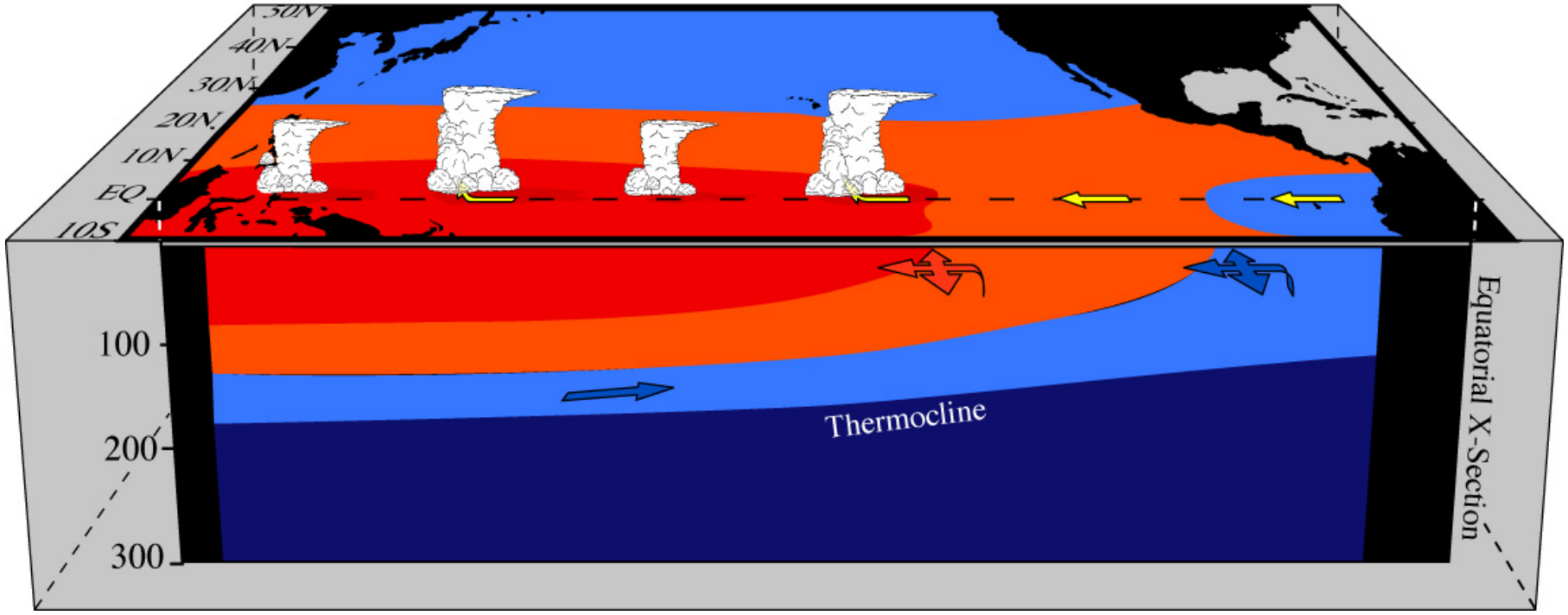
Thermocline is Deeper than Normal
Positive Depth Anomaly

December 1997 (El Nino) Thermocline Depth Anomalies)

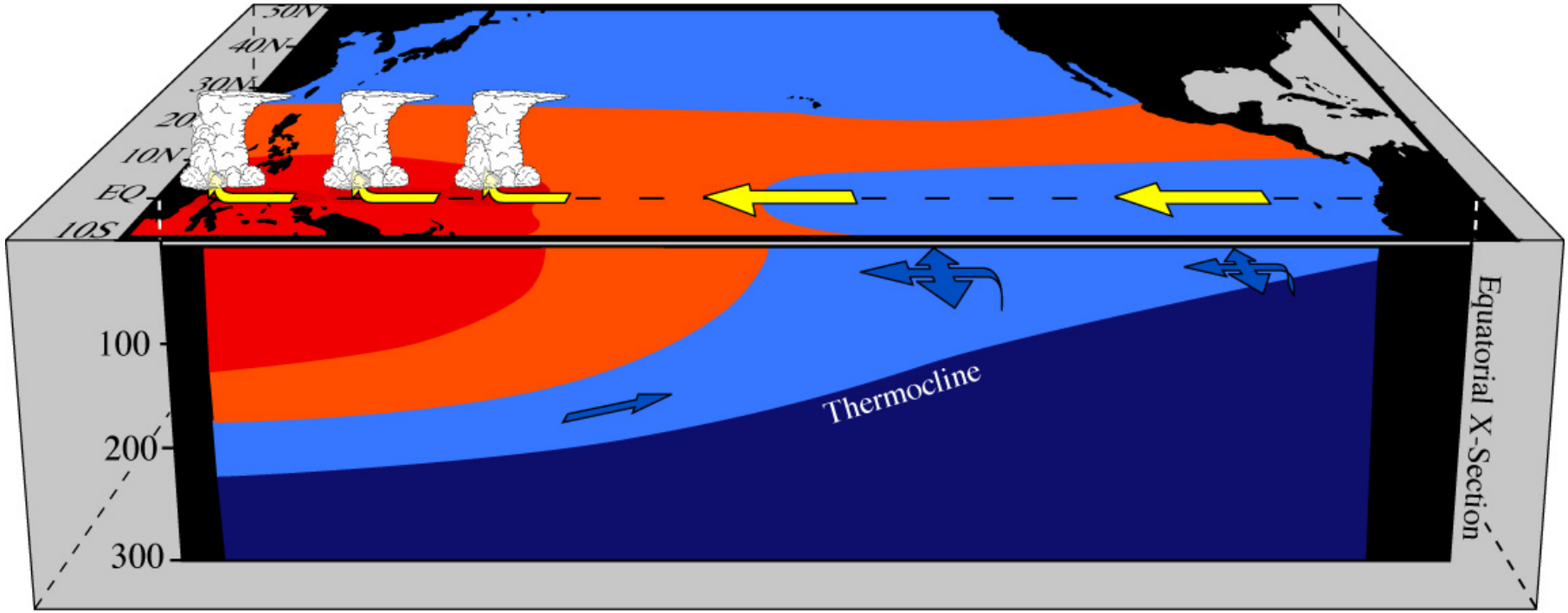




Normal Conditions in the Tropical Pacific

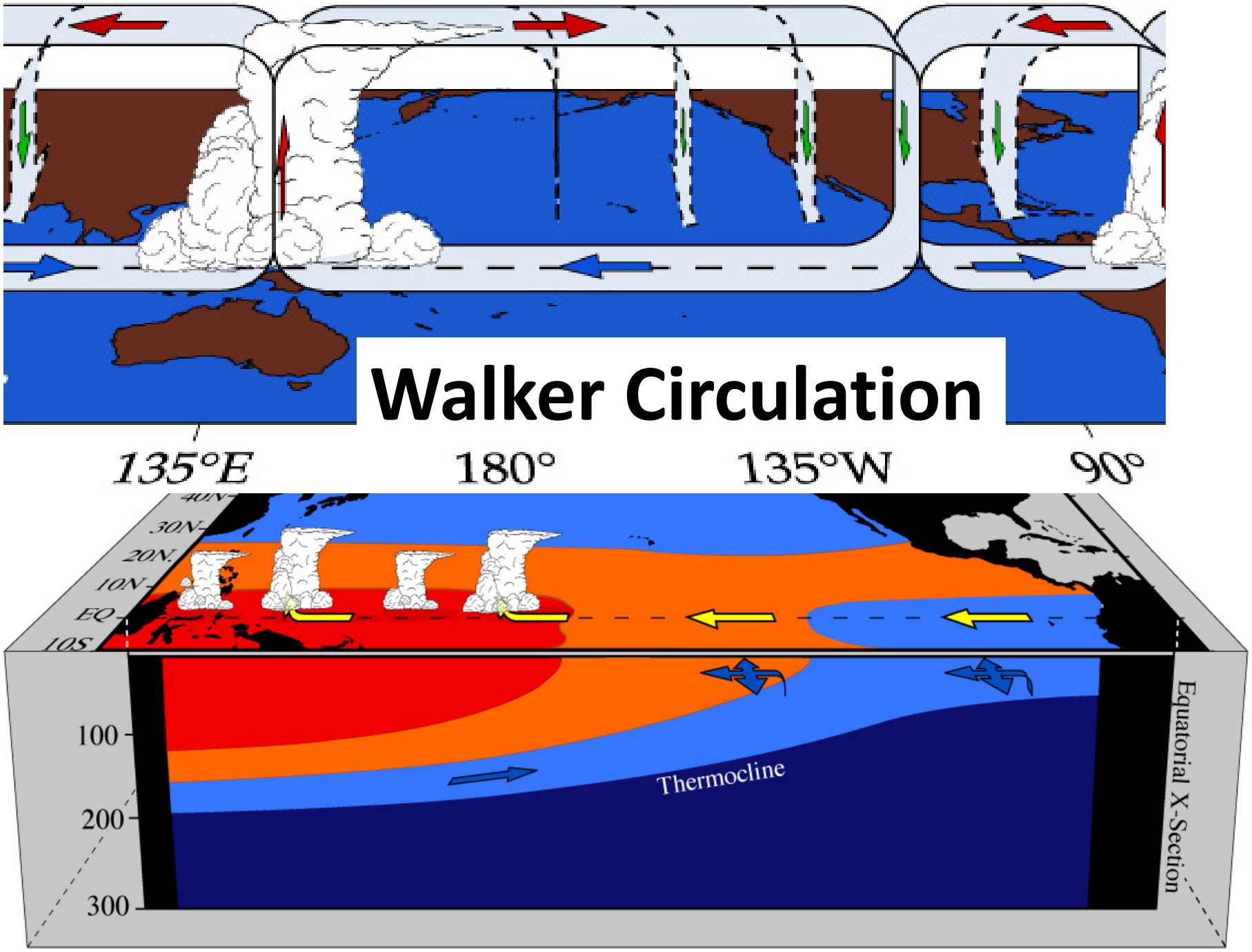


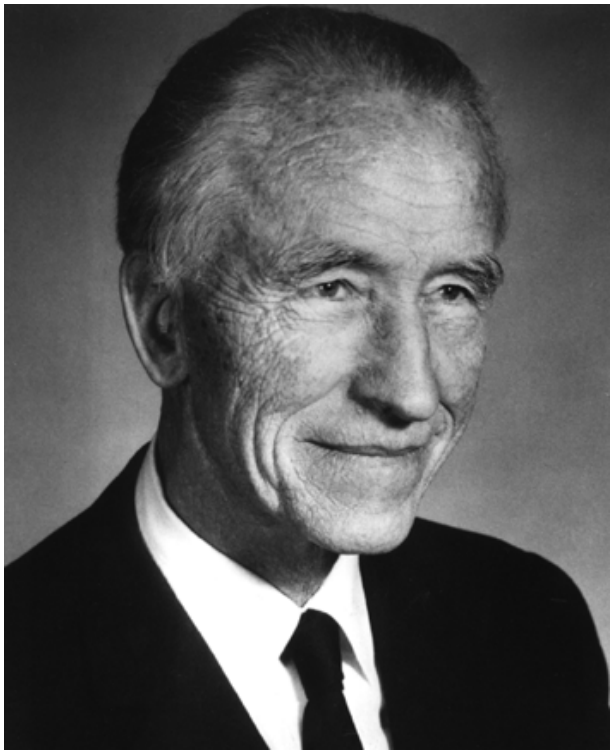
Warm (El Nino) Conditions in the Tropical Pacific



Cold (La Nina) Conditions in the Tropical Pacific

Walker Circulation

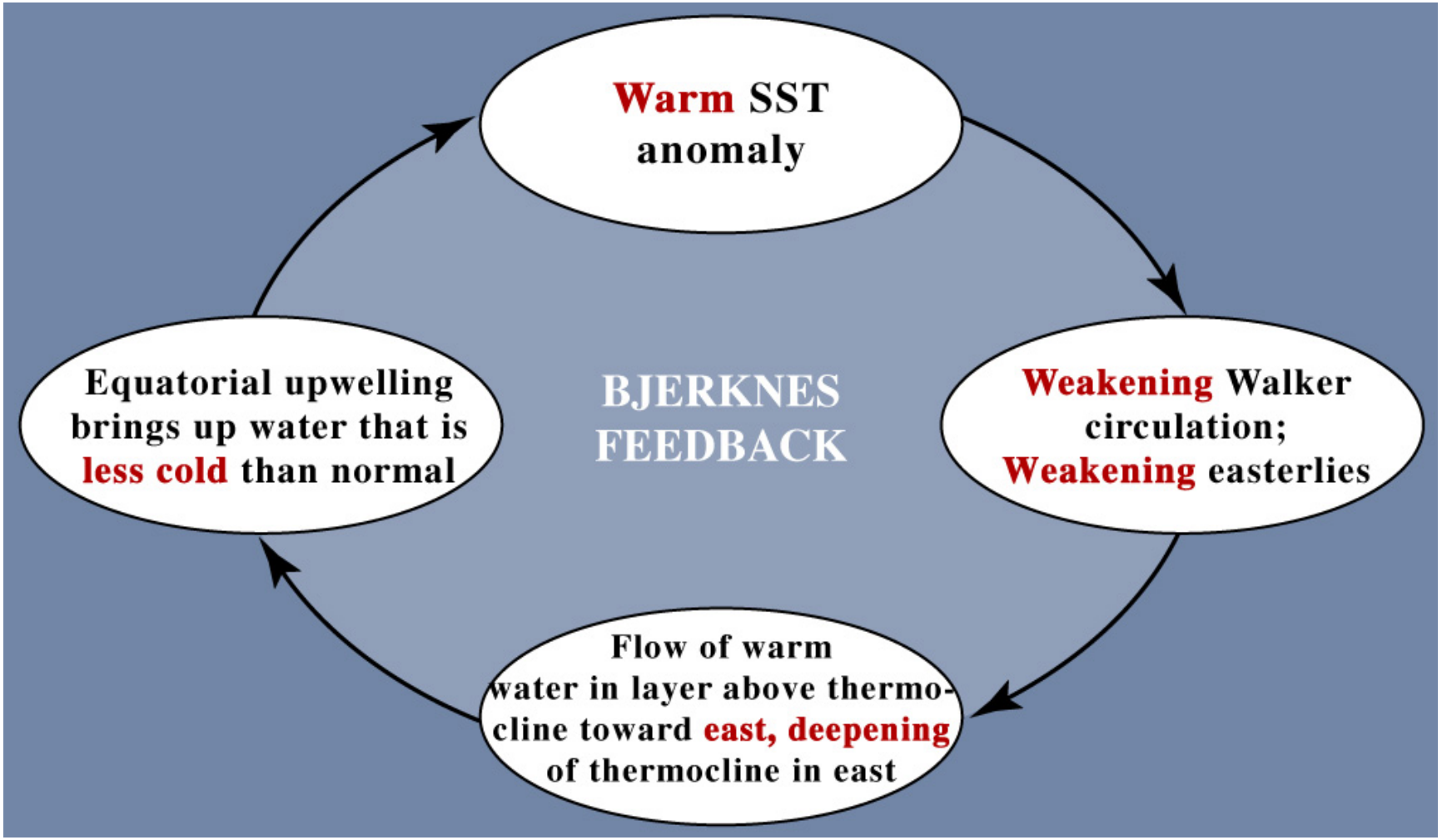


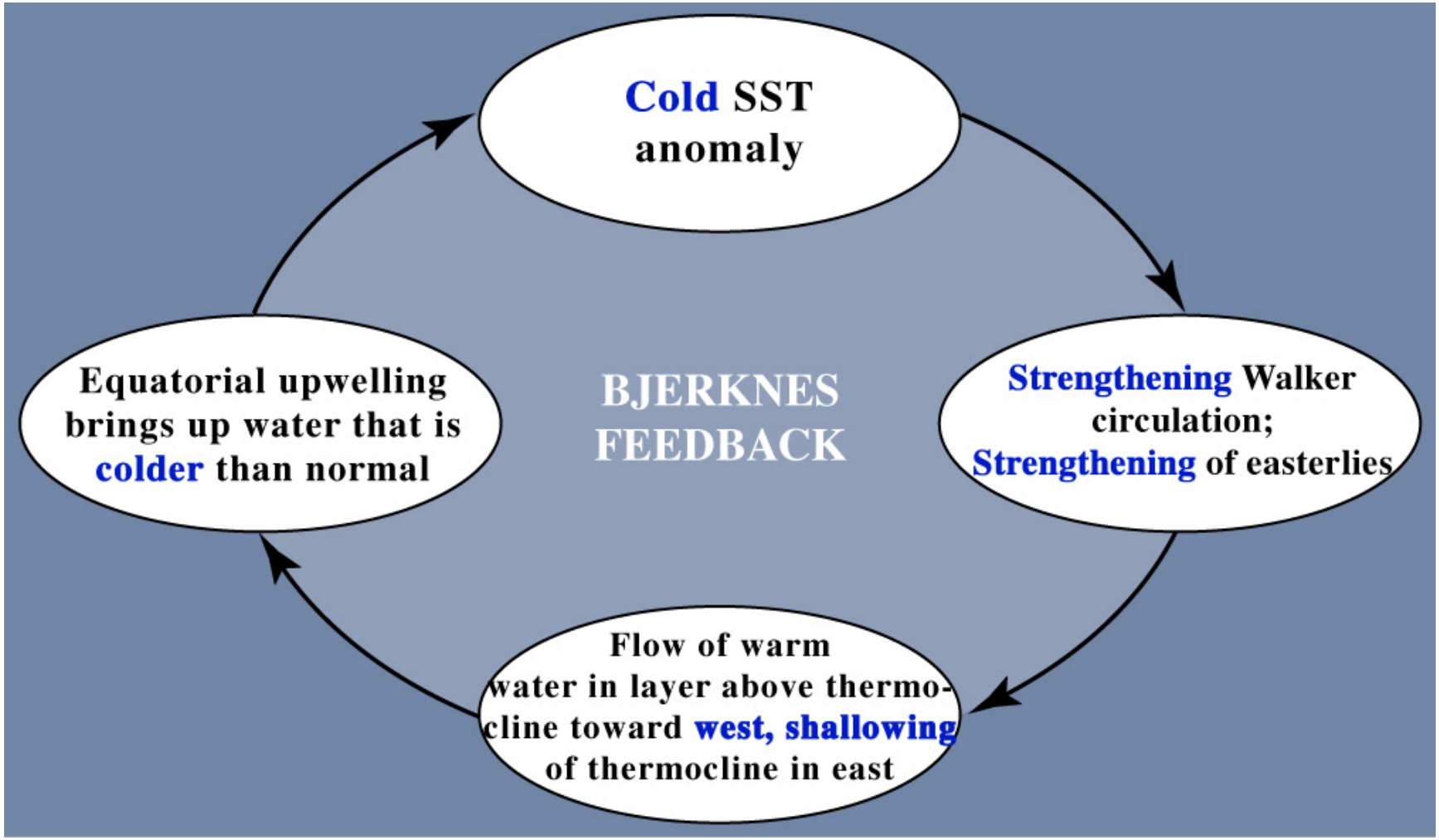


Jakob Bjerknes

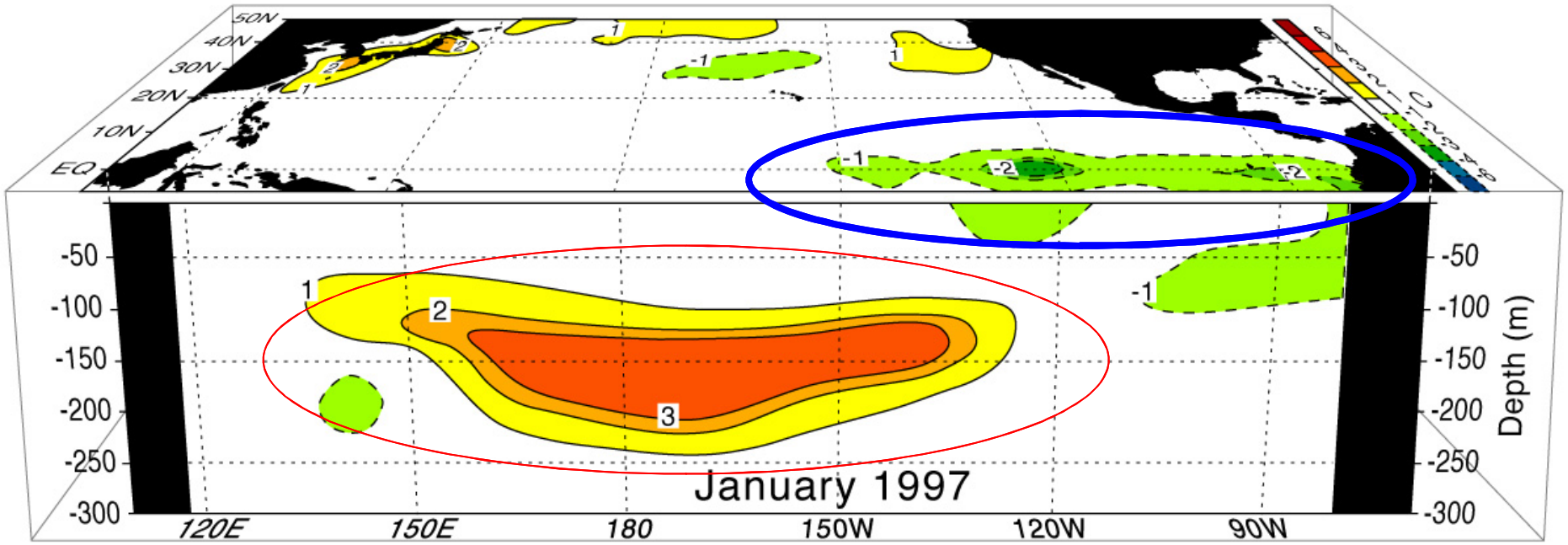
"It is the gradient of SST along the equator which is the cause of [...] the Walker circulation. An increase in equatorial easterly winds [is associated with] an increase in upwelling and an increase in the east-west temperature contrast that is the cause of the Walker circulation in the first place. [...] On the other hand, a case can also be made for a trend of decreasing speed [...] There is thus ample reason for a never-ending succession of alternating trends by air-sea interaction in the equatorial belt, but just how the turnabout between trends takes place is not yet clear." 1969

The Role of the Ocean

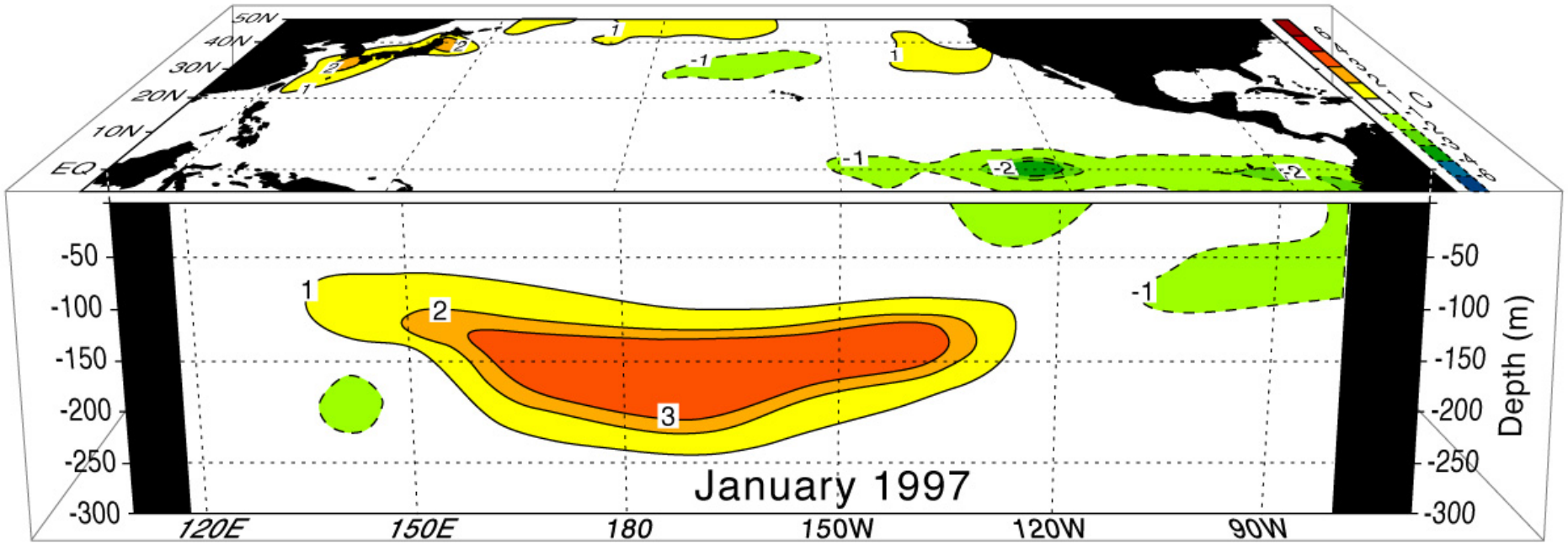

Warm SST anomaly
Weakening Walker circulation; Weakening easterlies
Flow of warm water in layer above thermo-cline toward east, deepening of thermocline in east
Equatorial upwelling brings up water that is less cold than normal
BJERKNES FEEDBACK

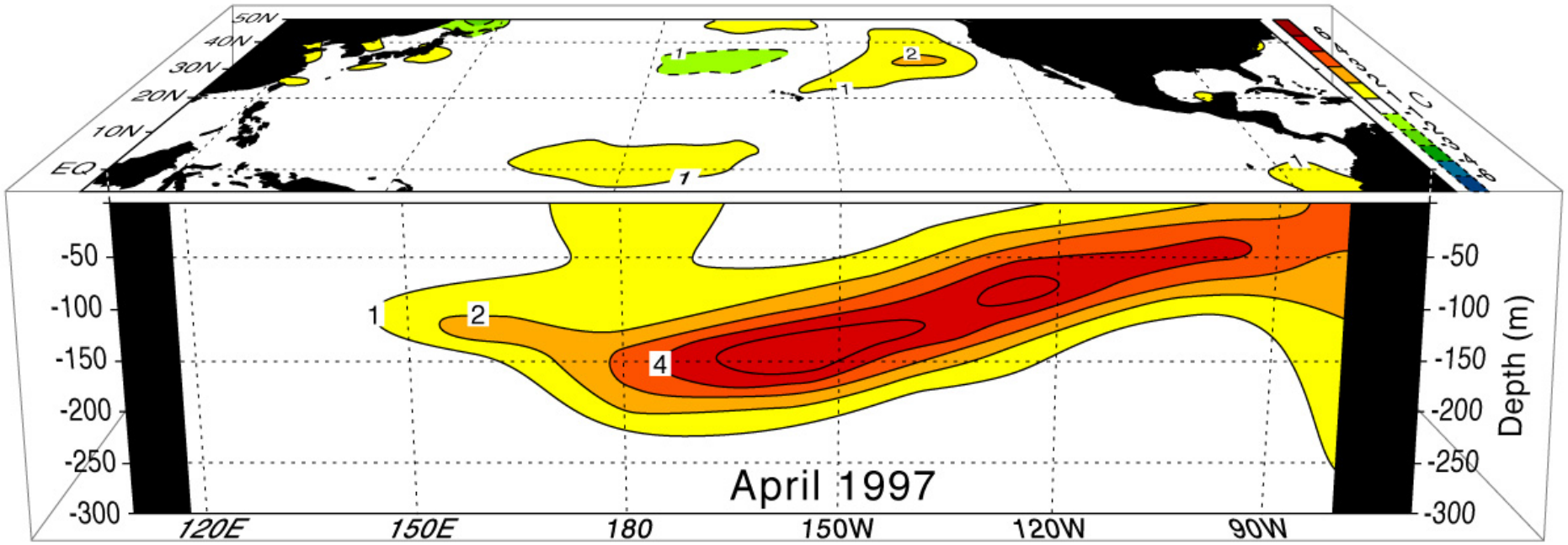

Cold SST anomaly
Strengthening Walker circulation; Strengthening of easterlies
Flow of warm water in layer above thermo-cline toward west, shallowing of thermocline in east
Equatorial upwelling brings up water that is colder than normal
BJERKNES FEEDBACK

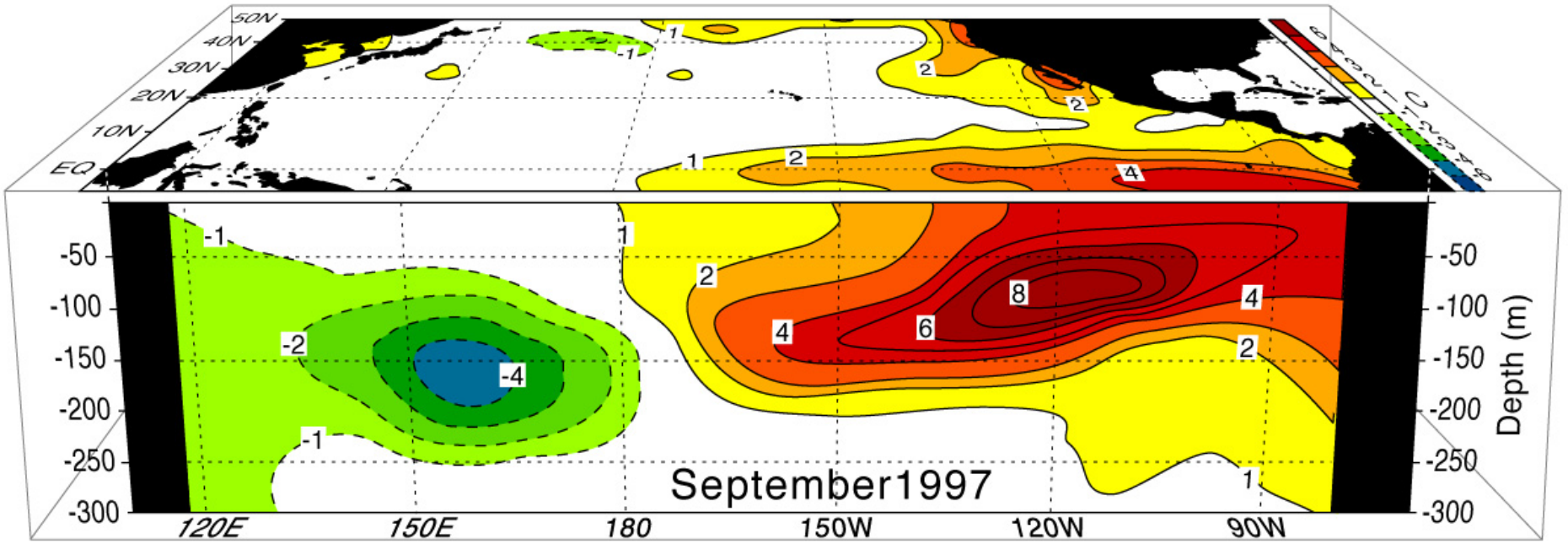
Evolution of the 1997-98 ENSO Event



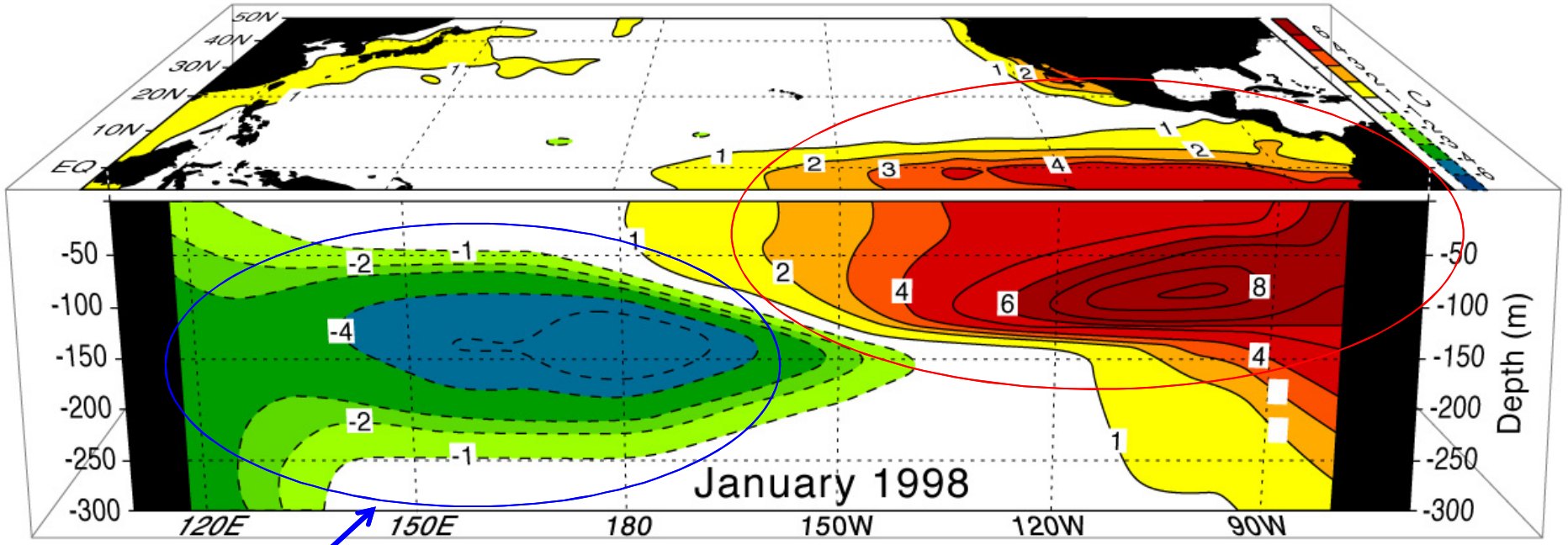
Warm Sub-Surface Temperature (Deeper Thermocline) Anomaly is the Precursor of the Coming Warm Event – Why We Can Predict


50N
40N
30N
20N
10N
EQ
-50
-100
-150
-200
-250
-300
Depth (m)
120E
150E
180
150W
120W
90W
January 1997

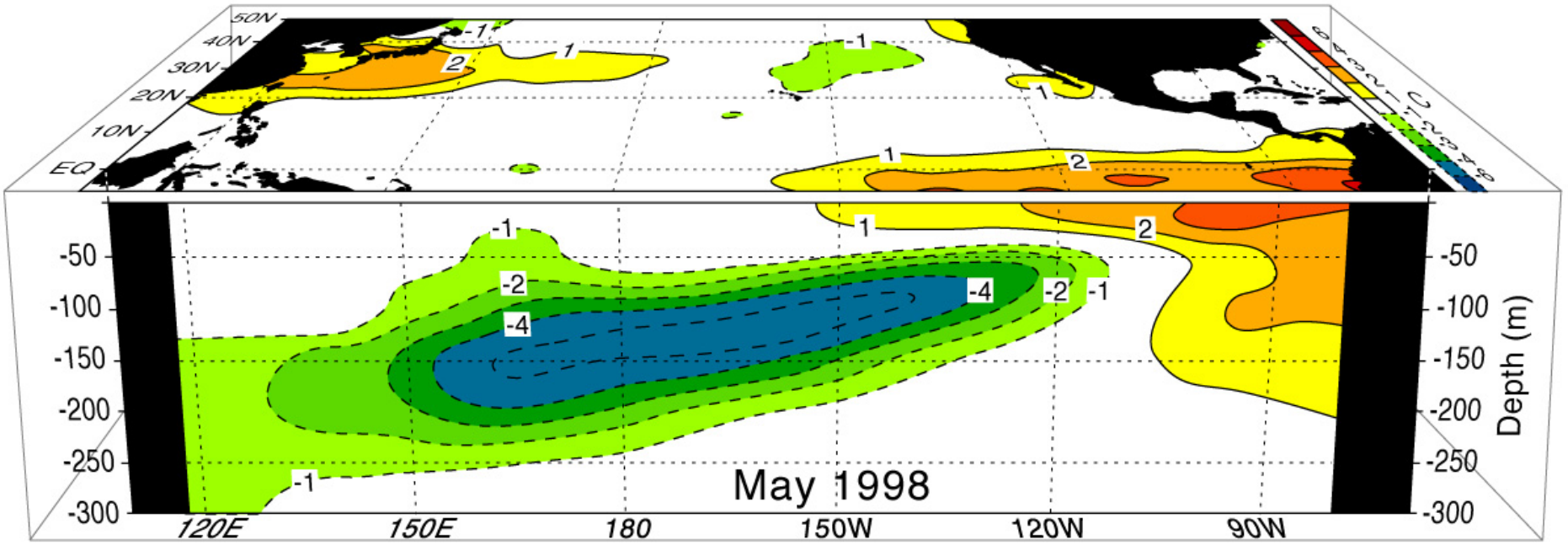

50N
40N
30N
20N
10N
EQ
1
2
1
1
-50
-100
-150
-200
-250
-300
1
2
4
April 1997
120E
150E
180
150W
120W
90W
Depth (m)

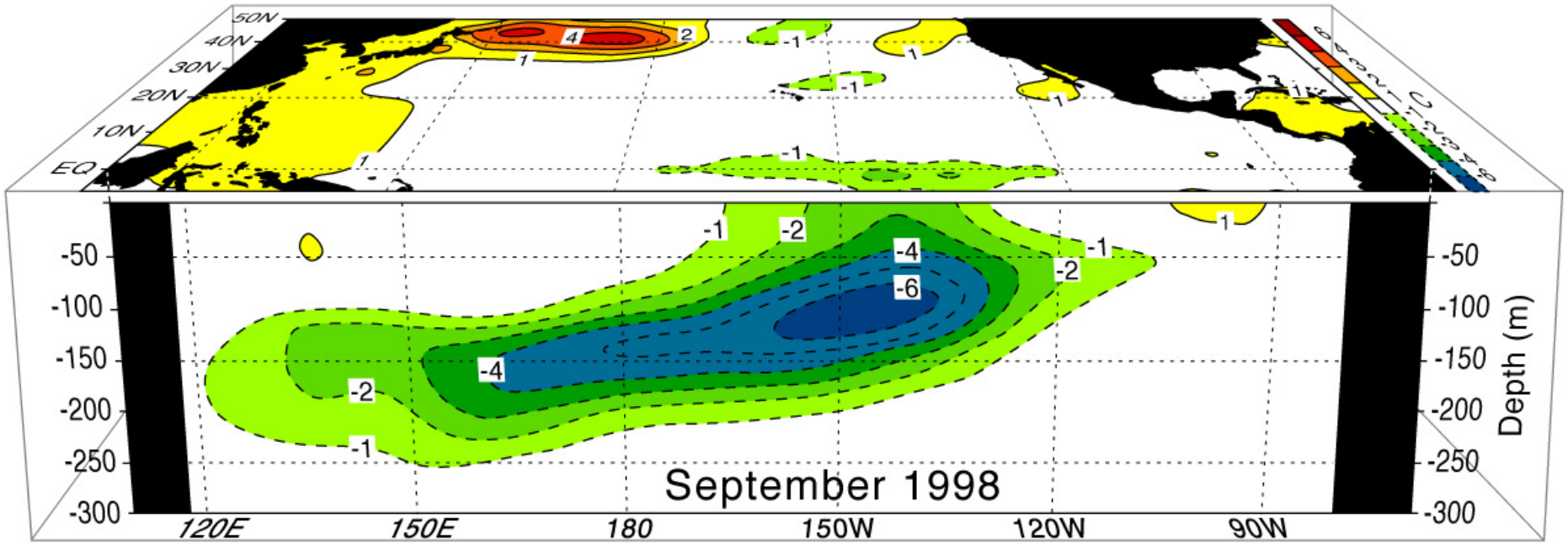

50N
40N
30N
20N
10N
EQ
-50
-100
-150
-200
-250
-300
120E
150E
180
150W
120W
90W
Depth (m)
September1997

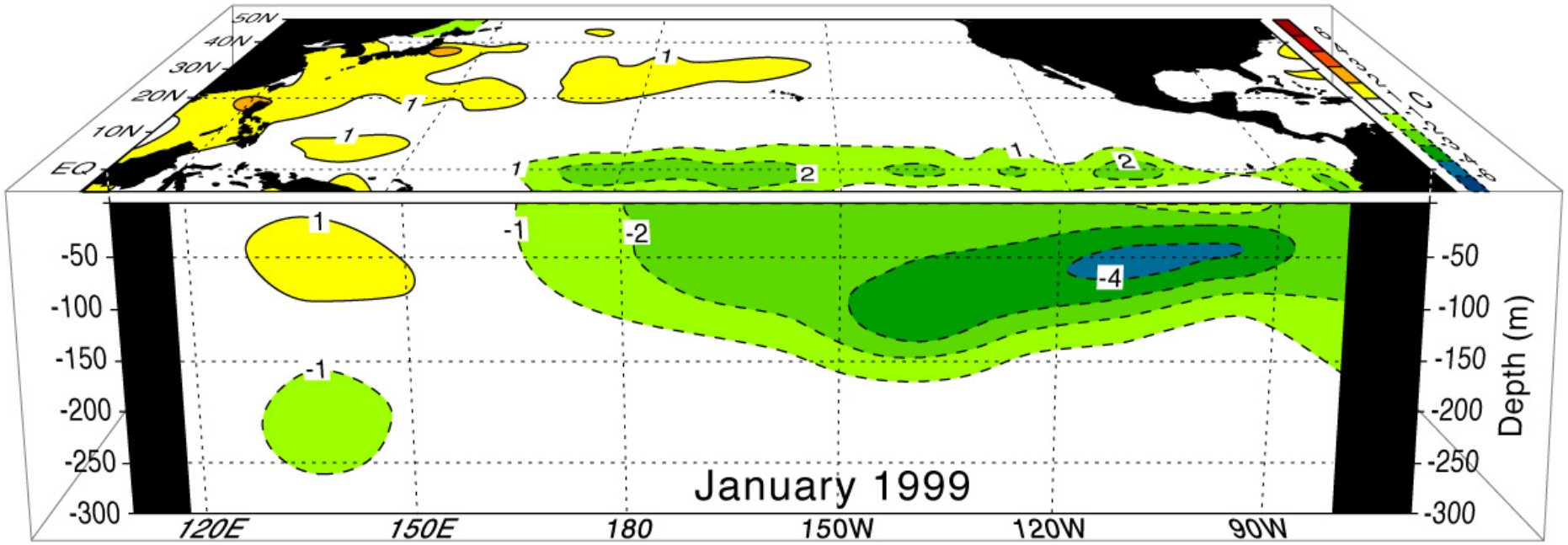
Mature Warm Event



The Precursor of the Coming Cold Event

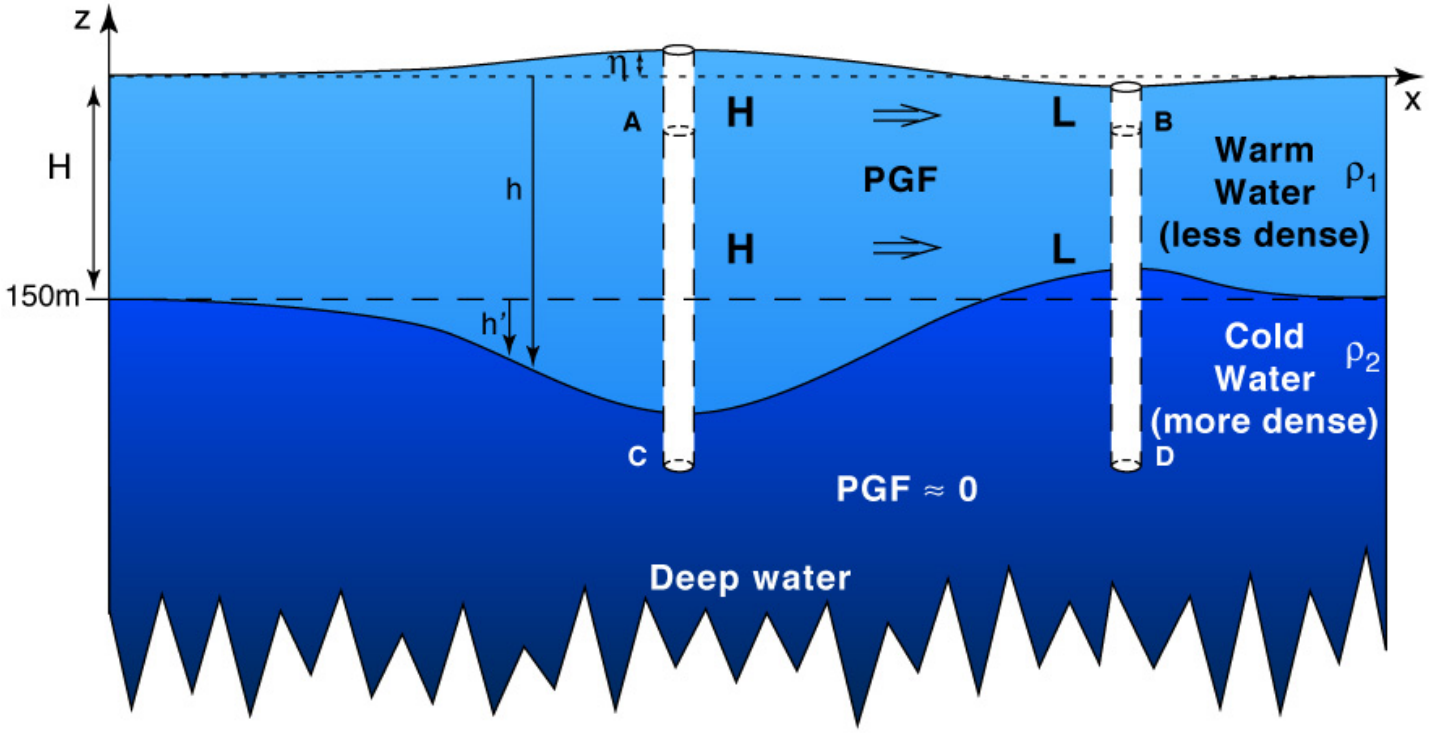

50N
40N
30N
20N
10N
EQ
-1
1
2
-1
1
1
2
-1
-2
-4
-4
-2
-1
1
2
-1
-50
-100
-150
-200
-250
-300
120E
150E
180
150W
120W
90W
Depth (m)
May 1998


50N
40N
30N
20N
10N
EQ
120E
150E
180
150W
120W
90W
-50
-100
-150
-200
-250
-300
Depth (m)
September 1998


50N
40N
30N
20N
10N
EQ
120E
150E
180
150W
120W
90W
-50
-100
-150
-200
-250
-300
Depth (m)
January 1999

Pressure gradients in an idealized upper layer

Idealized upper ocean layer



- **Pressure ∝ mass above**
- **At A ocean surface high so PGF from A toward B in upper ocean**
- **Deeper thermocline balances higher sea surface ⇨ PGF small below thermocline**
- **Sea surface height ∝ thermocline depth [cm vs. m]**

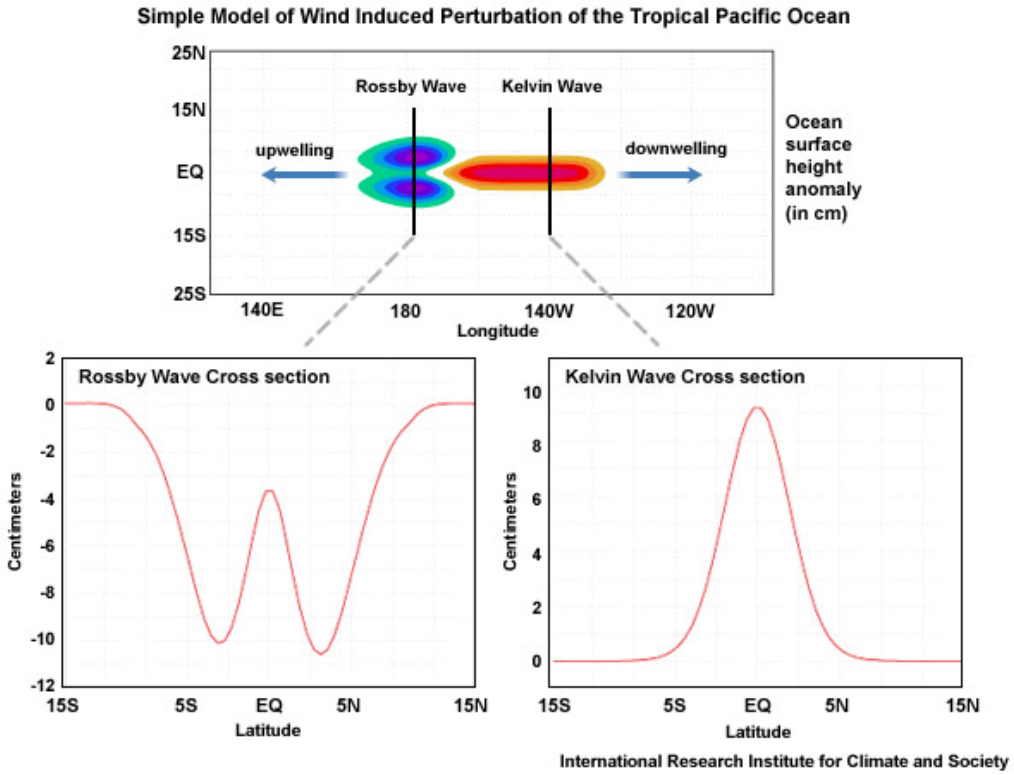
Equatorial Ocean Wave Dynamics

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

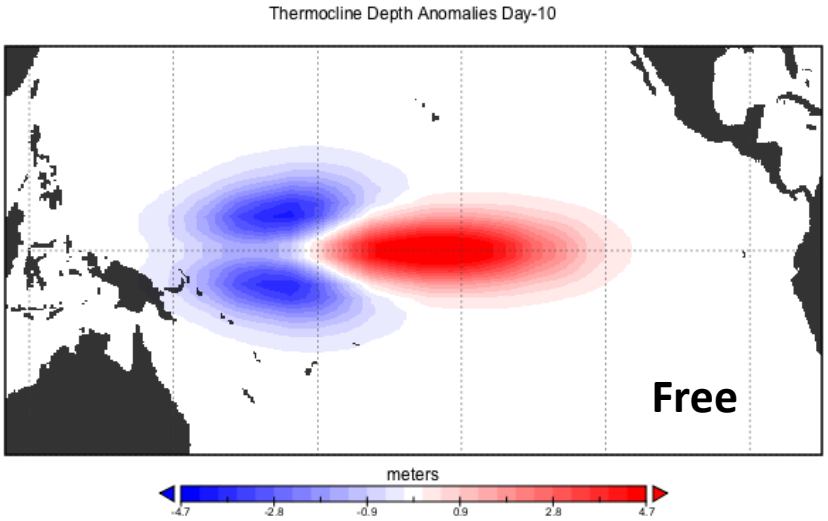
$$\frac{\partial v}{\partial t} + \beta y u = g' \frac{\partial h}{\partial y}$$

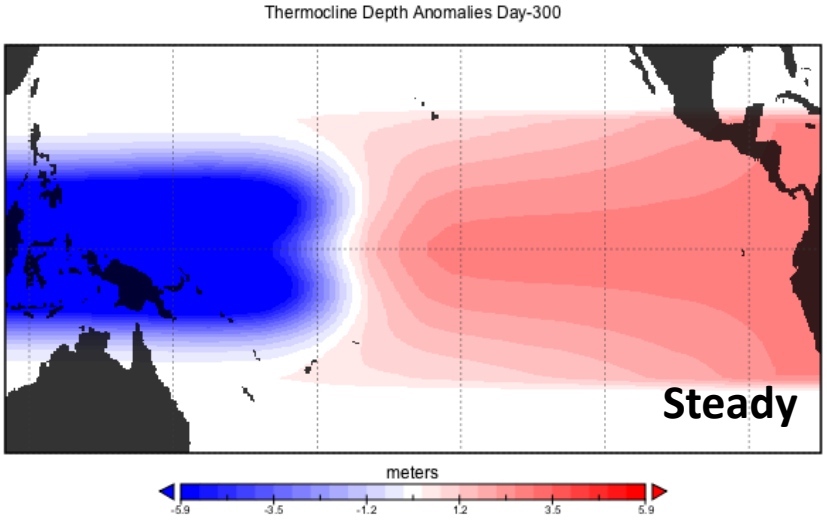
$$\frac{\partial h}{\partial t} + H\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = 0$$

Free Kelvin and Rossby Waves



Equatorial Ocean Wave Dynamics





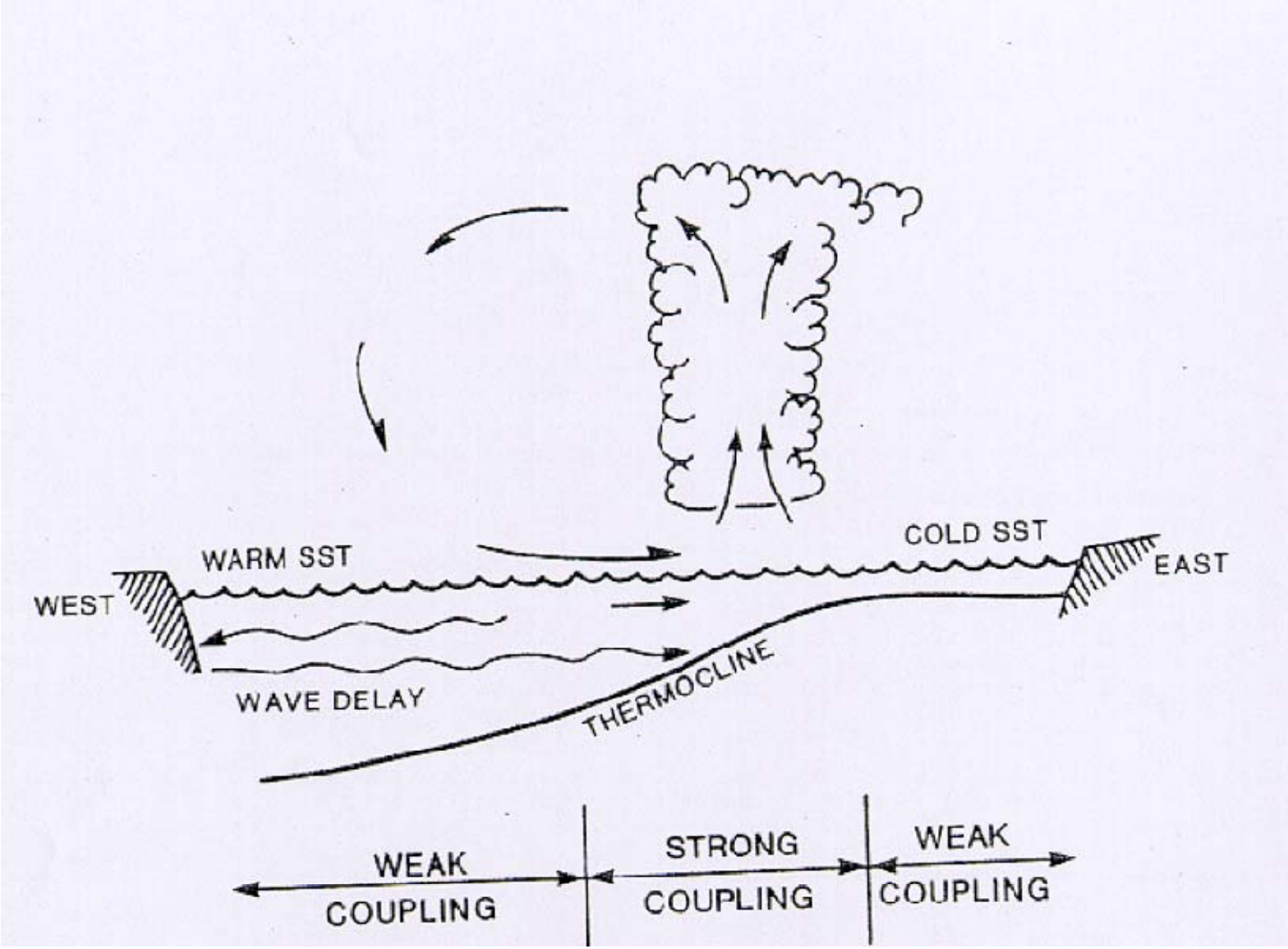
$$\frac{\partial u}{\partial t} - \beta y v = g' \frac{\partial h}{\partial x} - \varepsilon u + \frac{\tau_x}{\rho_0 \bar{h}}$$

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

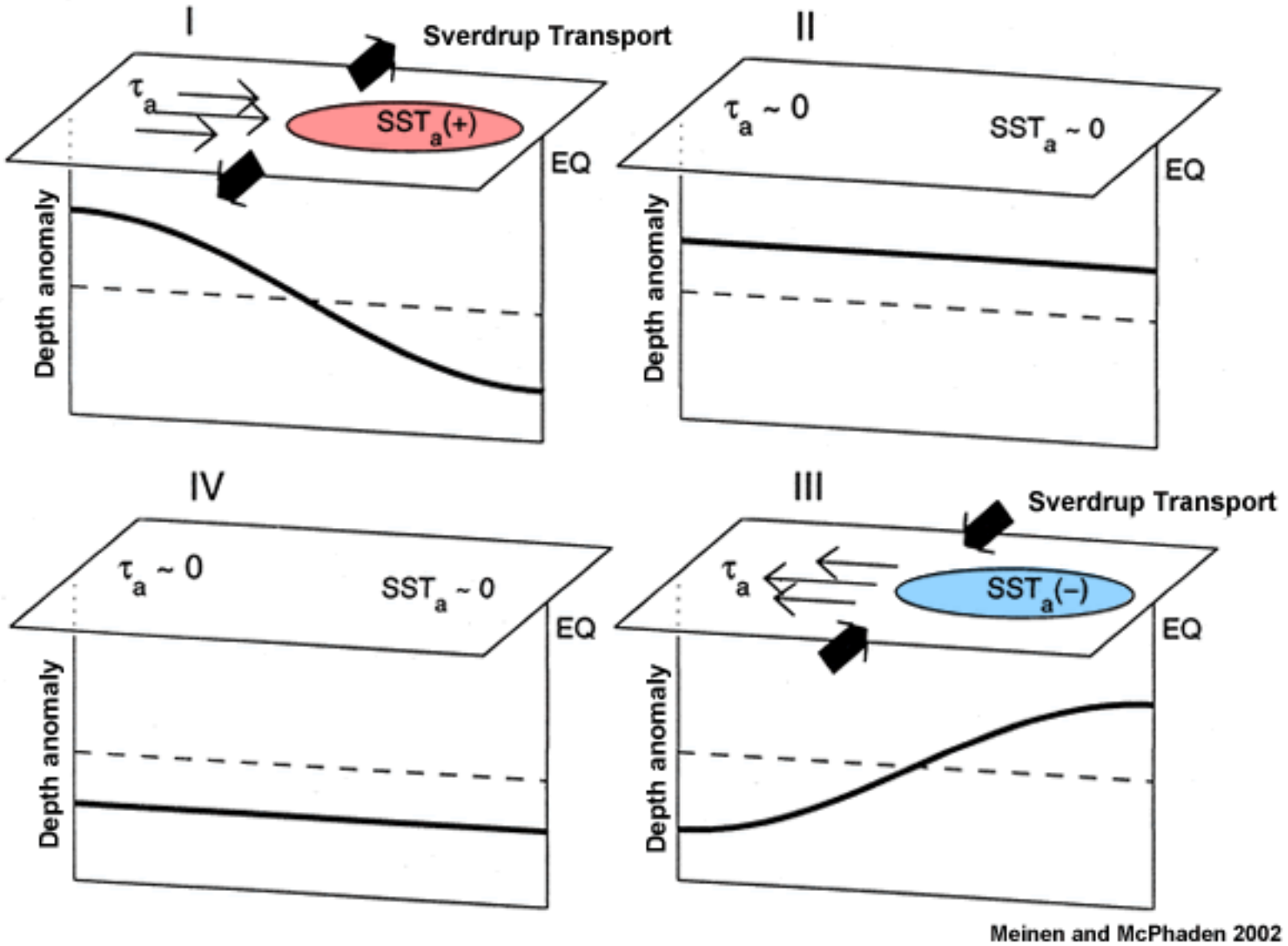
$$\frac{\partial h}{\partial t} + H\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = -\varepsilon h$$

Free vs. Steady Response

Role of the Ocean in the Delayed Oscillator Theory for ENSO

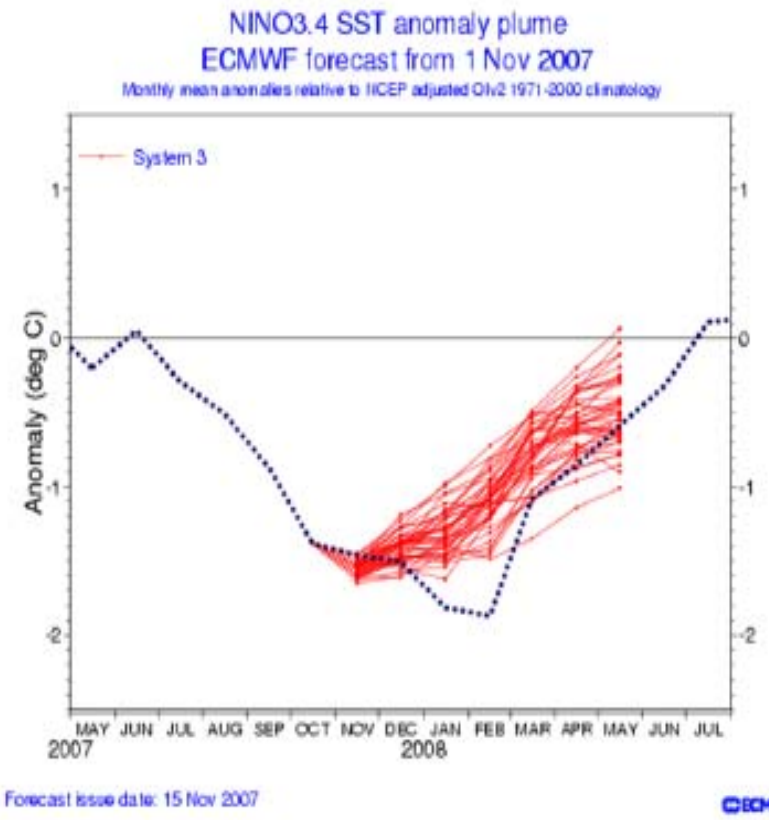


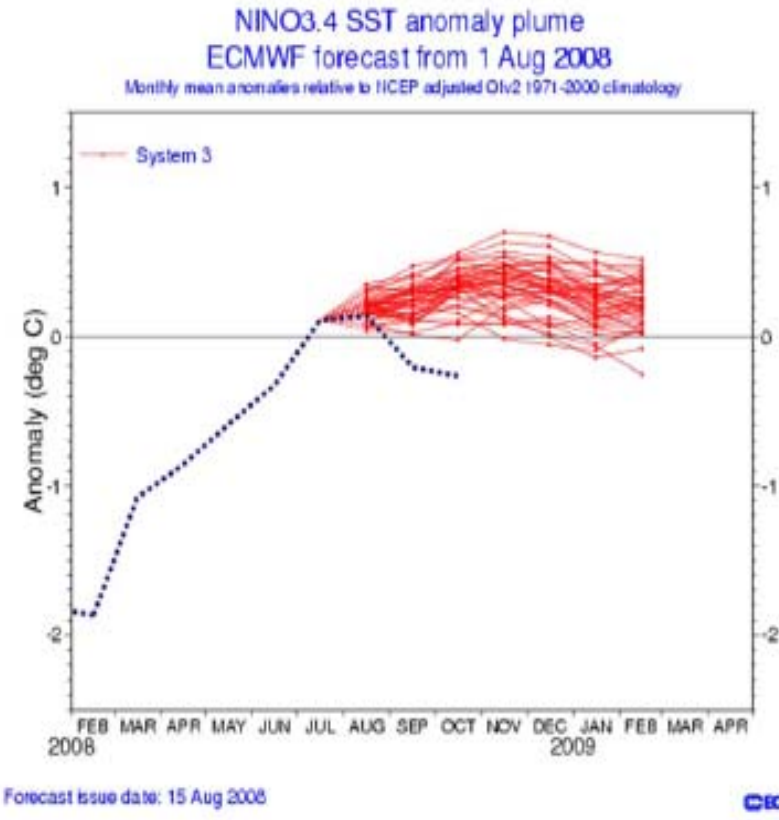
Schematic of the Recharge/Discharge Theory of ENSO

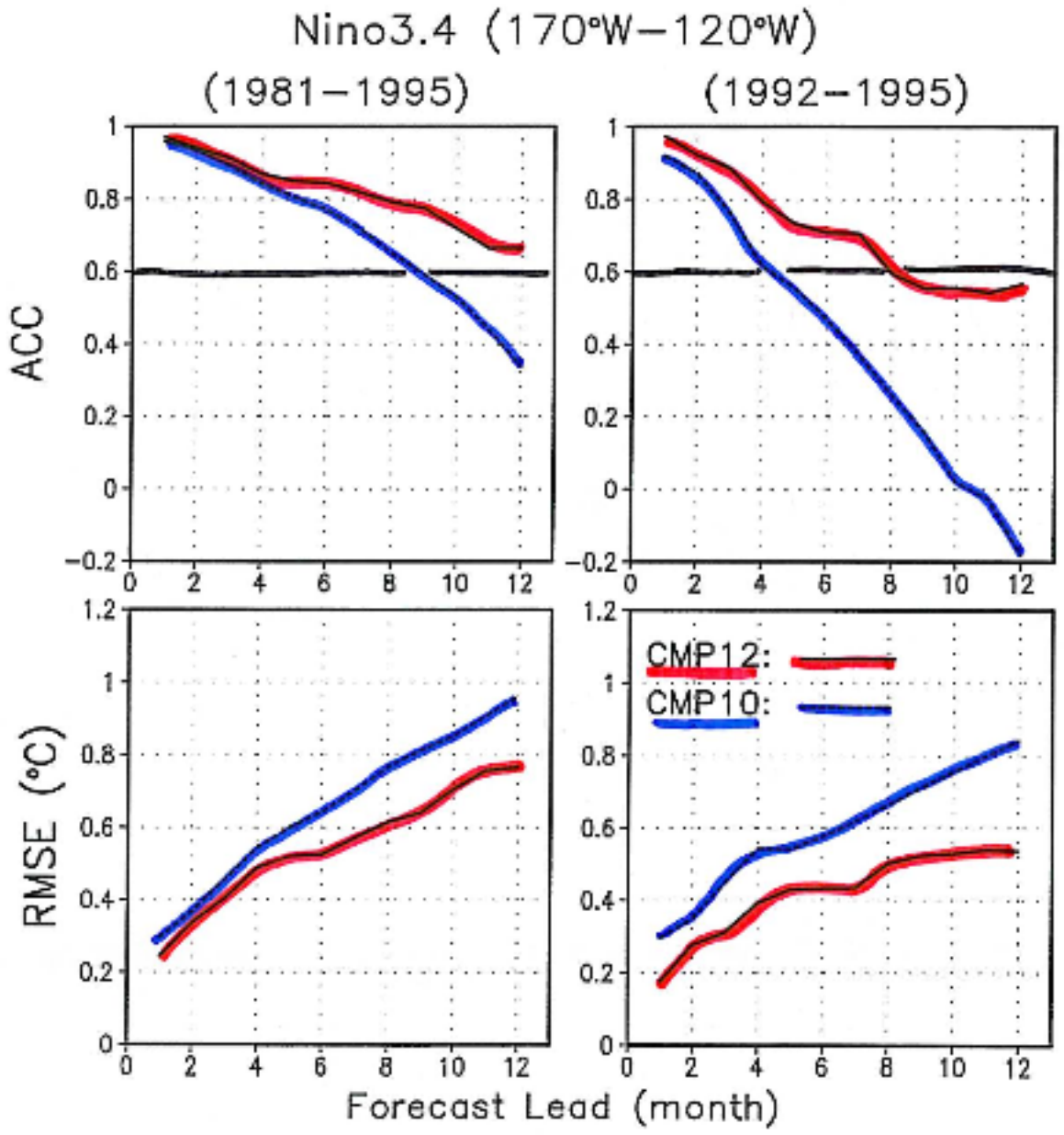


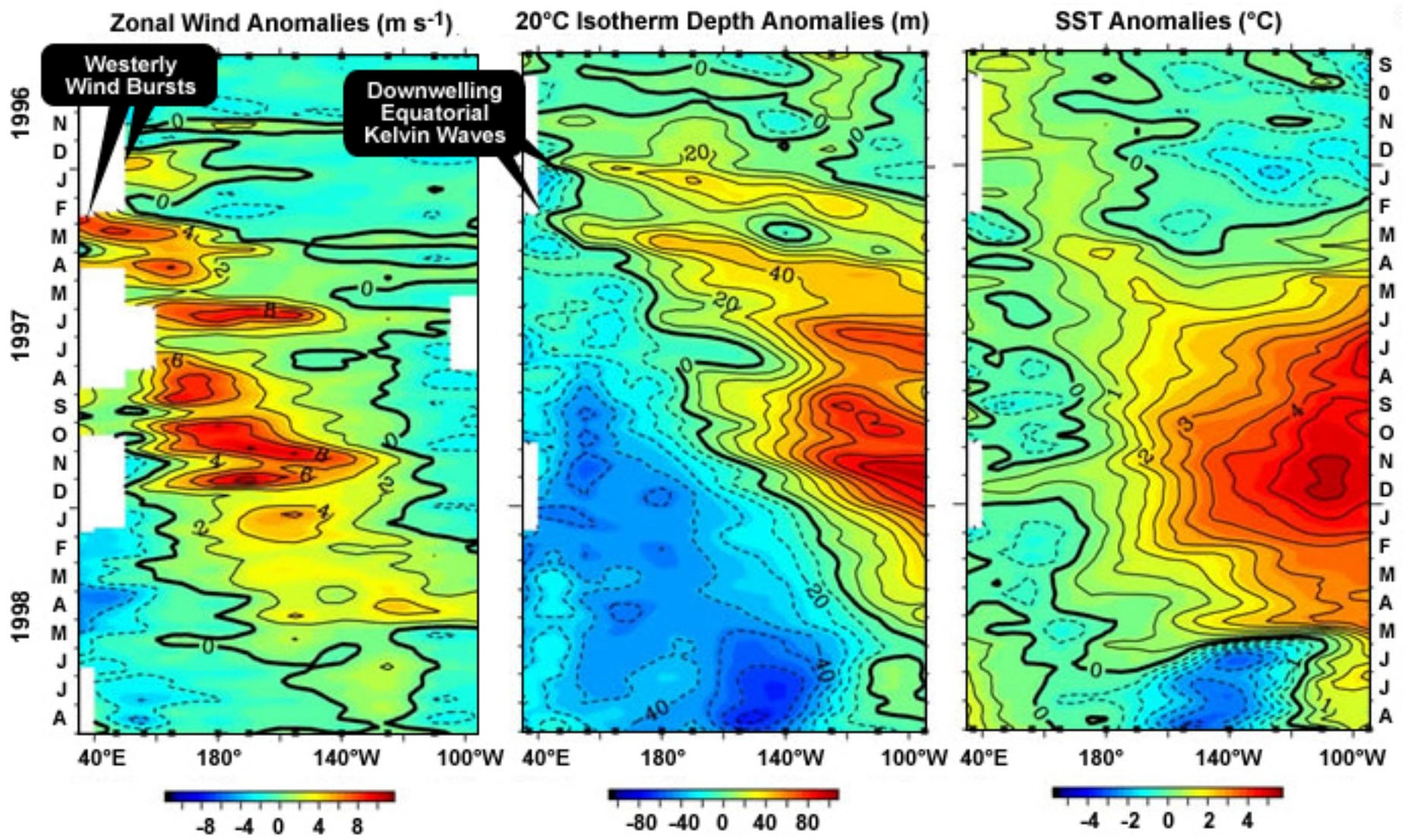
Meinen and McPhaden 2002

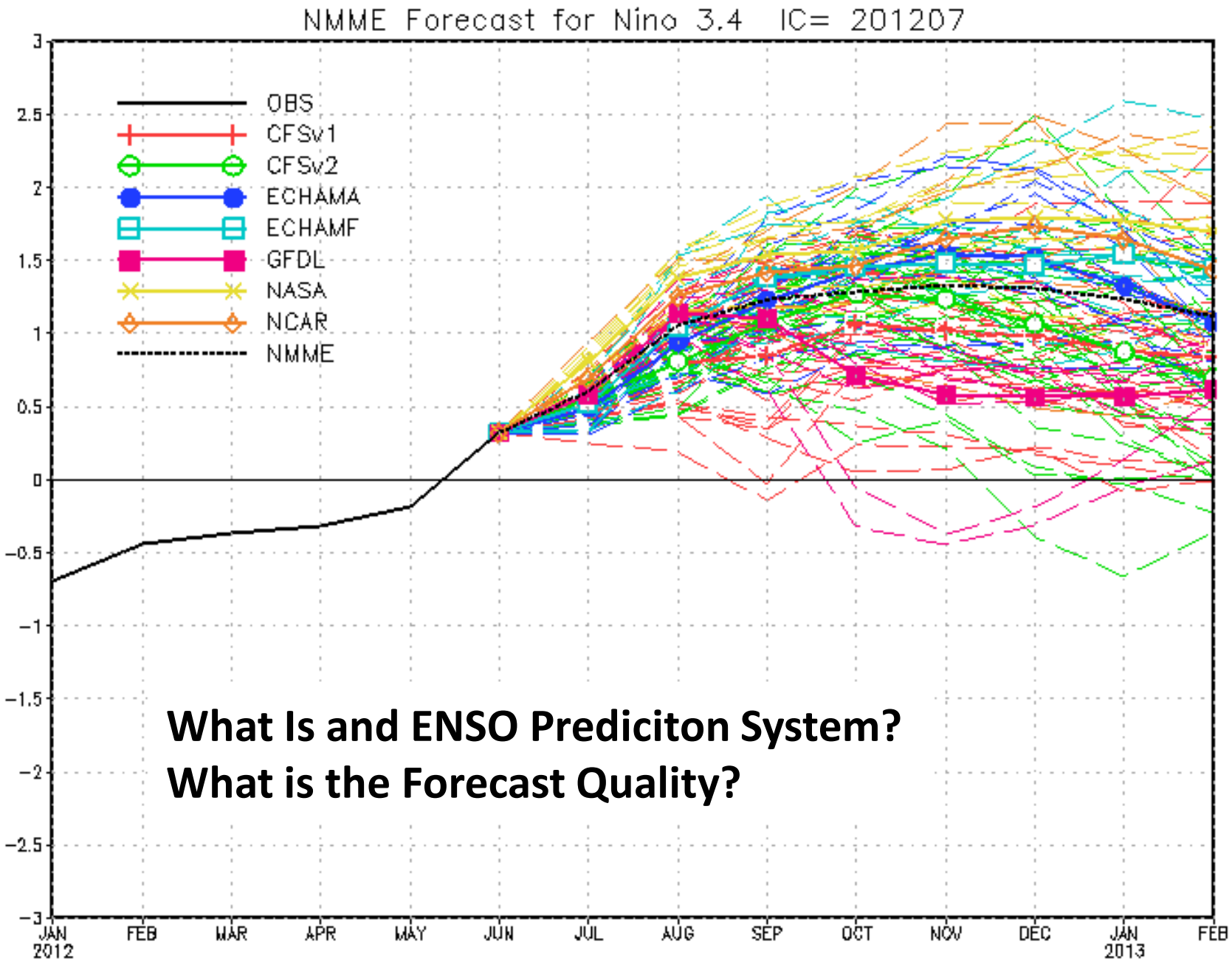
Prediction vs. Predictability





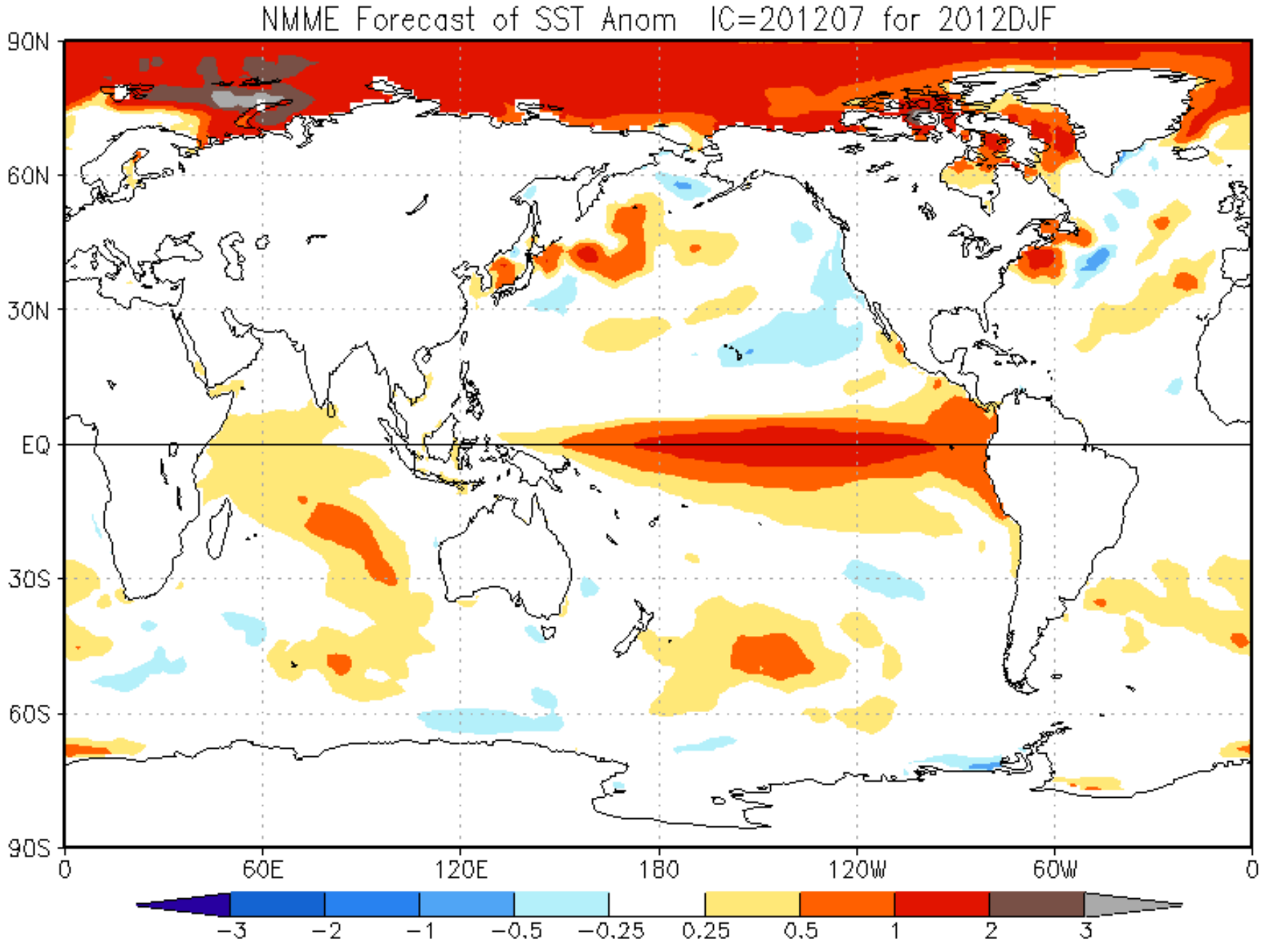

Nino3.4 (170°W–120°W)
(1981–1995)
(1992–1995)
ACC
RMSE (°C)
CMP12:
CMP10:
Forecast Lead (month)

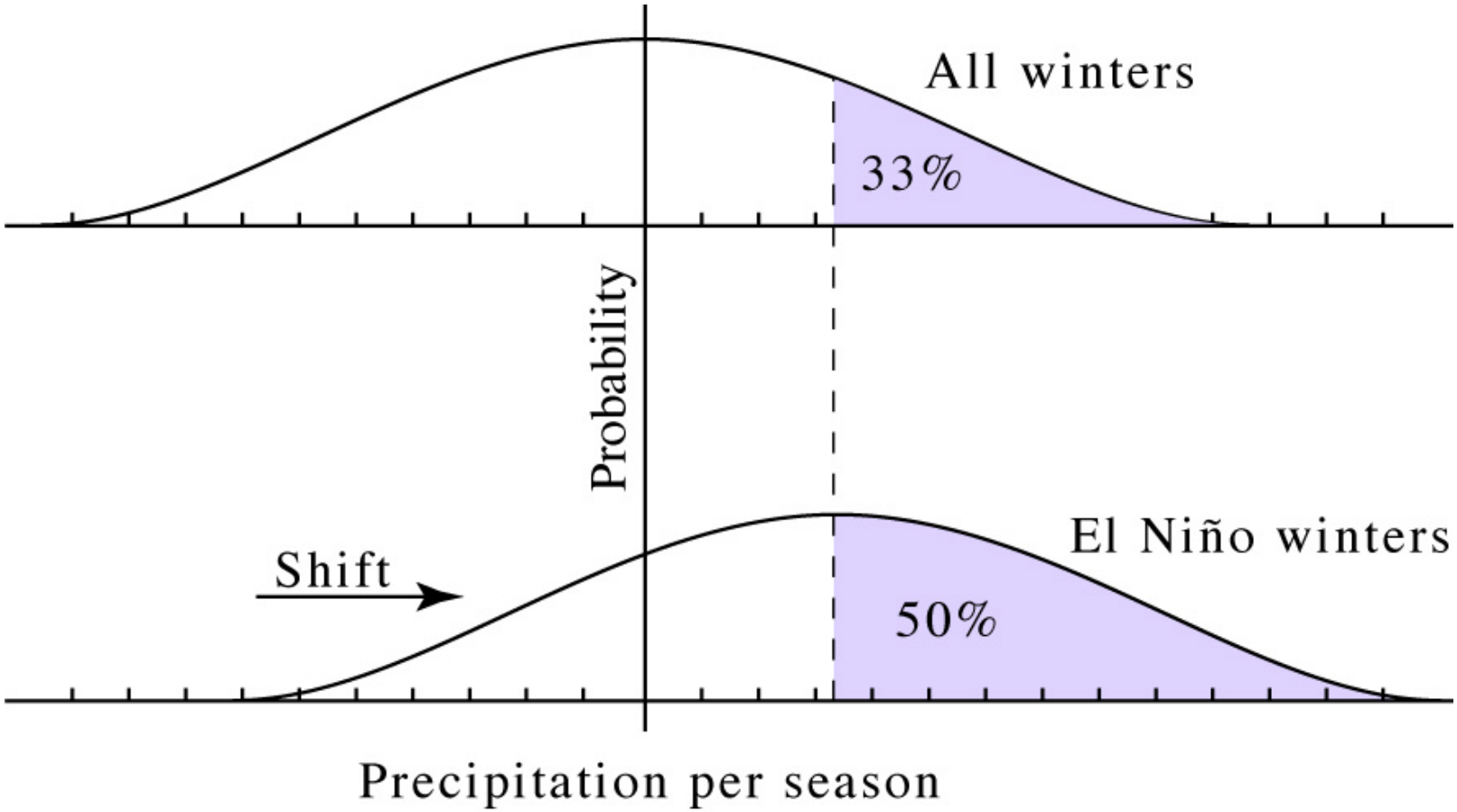

Evolution of the 1997-98 ENSO (2°S-2°N Averages)
Zonal Wind Anomalies (m s-1)
20°C Isotherm Depth Anomalies (m)
SST Anomalies (°C)
Westerly Wind Bursts
Downwelling Equatorial Kelvin Waves
1996
1997
1998
N D J F M A M J J A S O N D J F M A M J J A
S O N D J F M A M J J A S O N D J F M A M J J A
40°E 180° 140°W 100°W
-8 -4 0 4 8
-80 -40 0 40 80
-4 -2 0 2 4
NOAA / PMEL

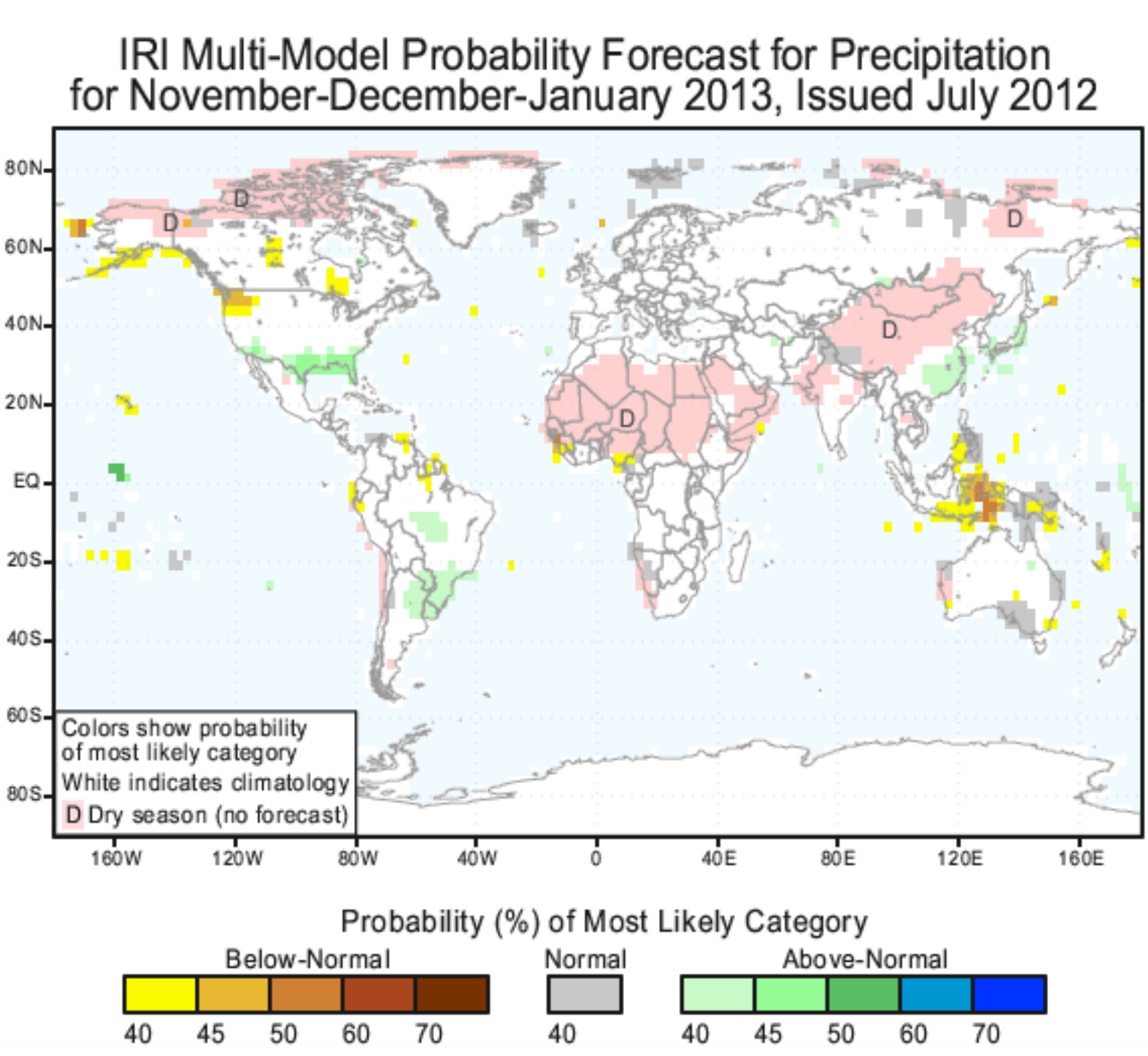


What Is and ENSO Prediciton System?

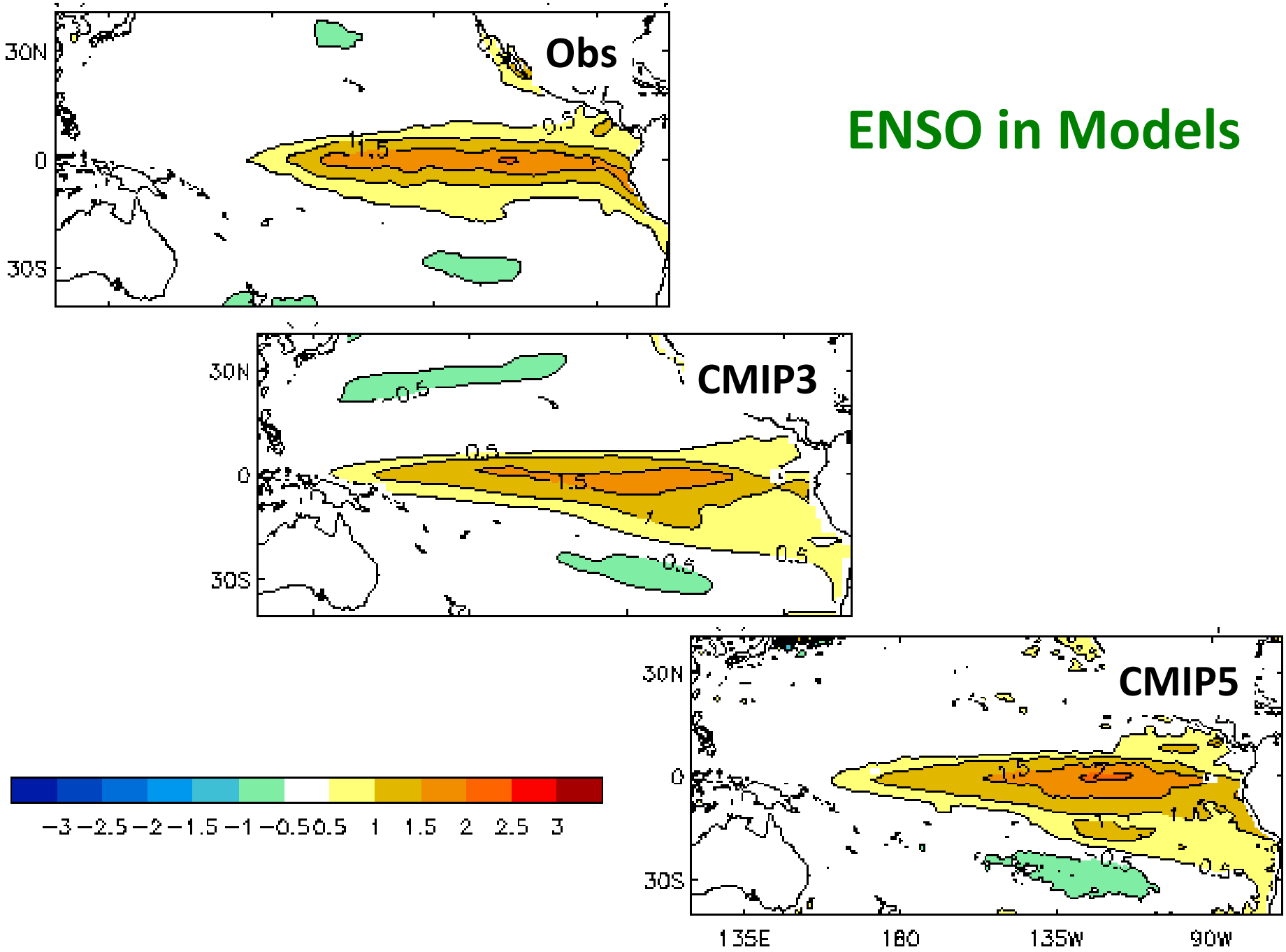
What is the Forecast Quality?


NMME Forecast of SST Anom IC=201207 for 2012DJF
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
−3
−2
−1
−0.5
−0.25
0.25
0.5
1
2
3


All winters
33%
Probability
Shift
El Niño winters
50%
Precipitation per season


IRI Multi-Model Probability Forecast for Precipitation
for November-December-January 2013, Issued July 2012
80N
60N
40N
20N
EQ
20S
40S
60S
80S
160W
120W
80W
40W
0
40E
80E
120E
160E
D
D
D
D
D
Colors show probability
of most likely category
White indicates climatology
D Dry season (no forecast)
Probability (%) of Most Likely Category
Below-Normal
40
45
50
60
70
Normal
40
Above-Normal
40
45
50
60
70

ENSO in Models



Outline

- **Role of the Ocean (Dynamics)**
  - Mean State, Air-Sea Fluxes,Mixed Layer
  - Rossby, Kelvin Waves, Sverdrup Balance
- **Predictability**
  - Error Growth, Stochastic Forcing (WWB)
  - Low Frequency Variations in Predictability
- **Prediction**
  - Ingredients, Quality, Uncertainty
- **ENSO in Models**
  - IPCC Class Models

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