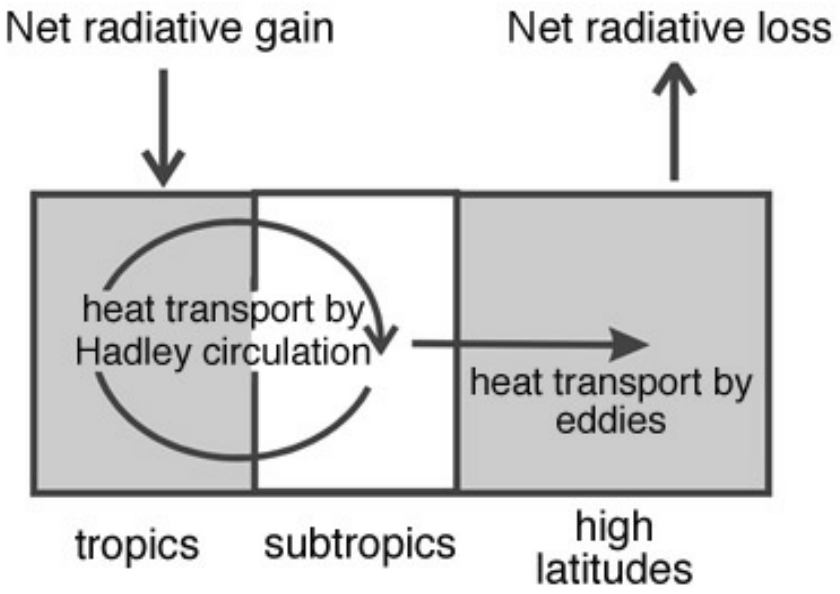
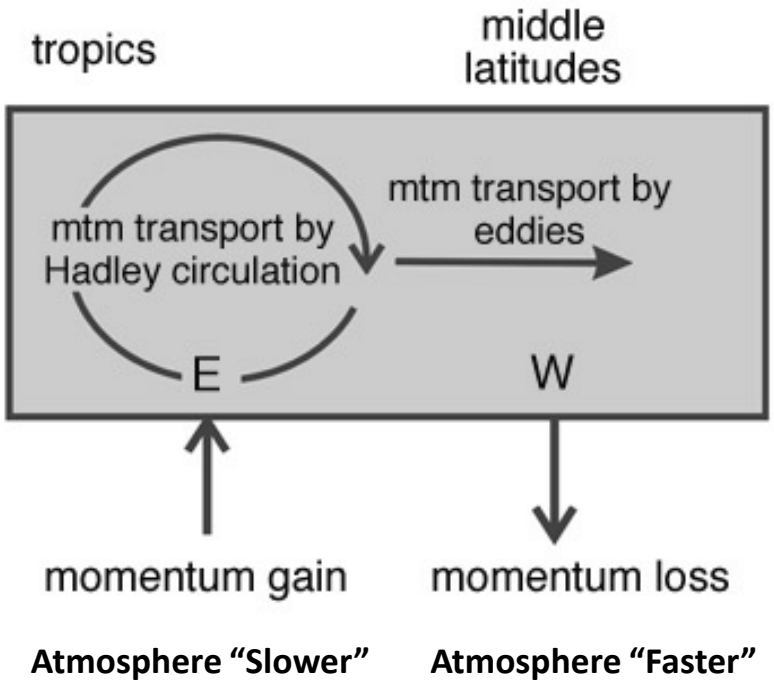
Large-Scale Circulation: Three Big Ideas

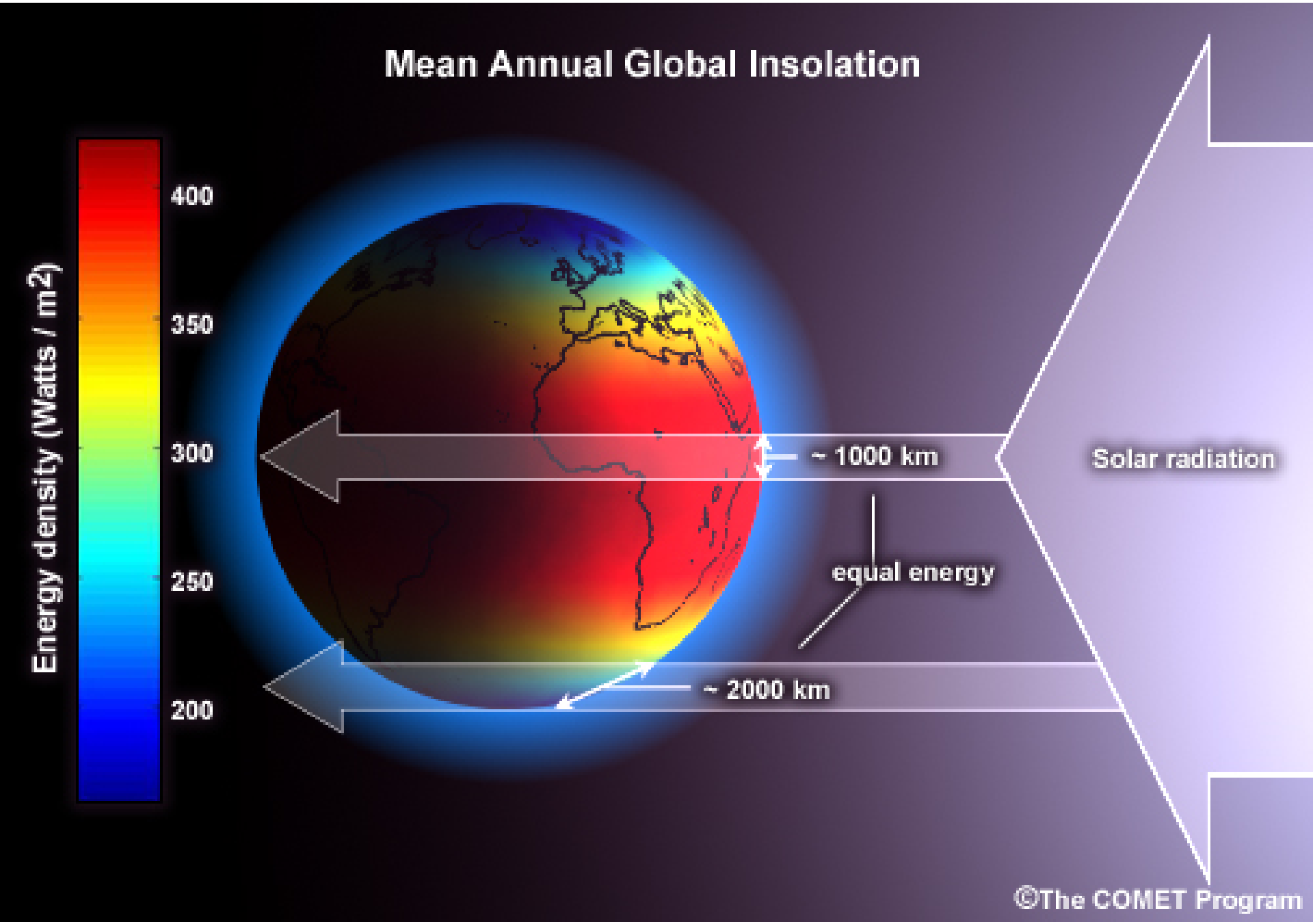
1) **Meridional Temperature and Momentum Transport (Mean Meridional Circulation)**
   - Stationary and Transient Eddies
2) **Large-Scale Tropics**
   - ENSO
3) **Climate Change**
   - Weaker Overturning Circulation

1) Meridional Temperature and Momentum Transport

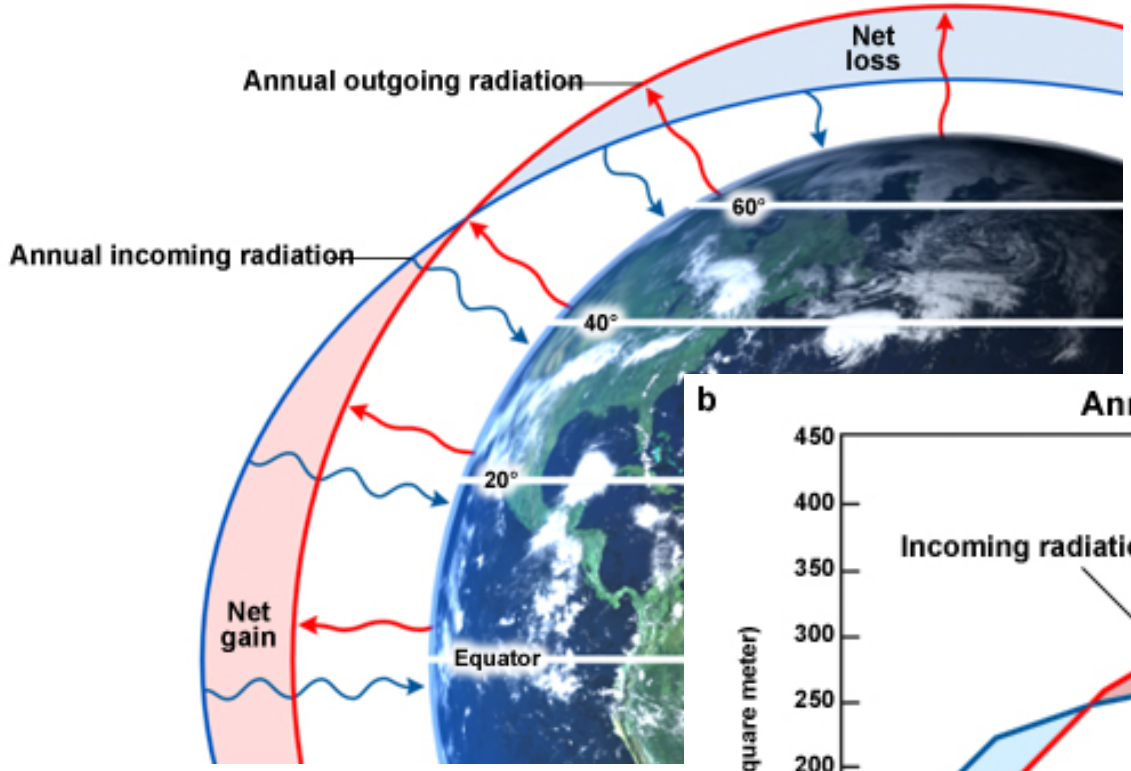




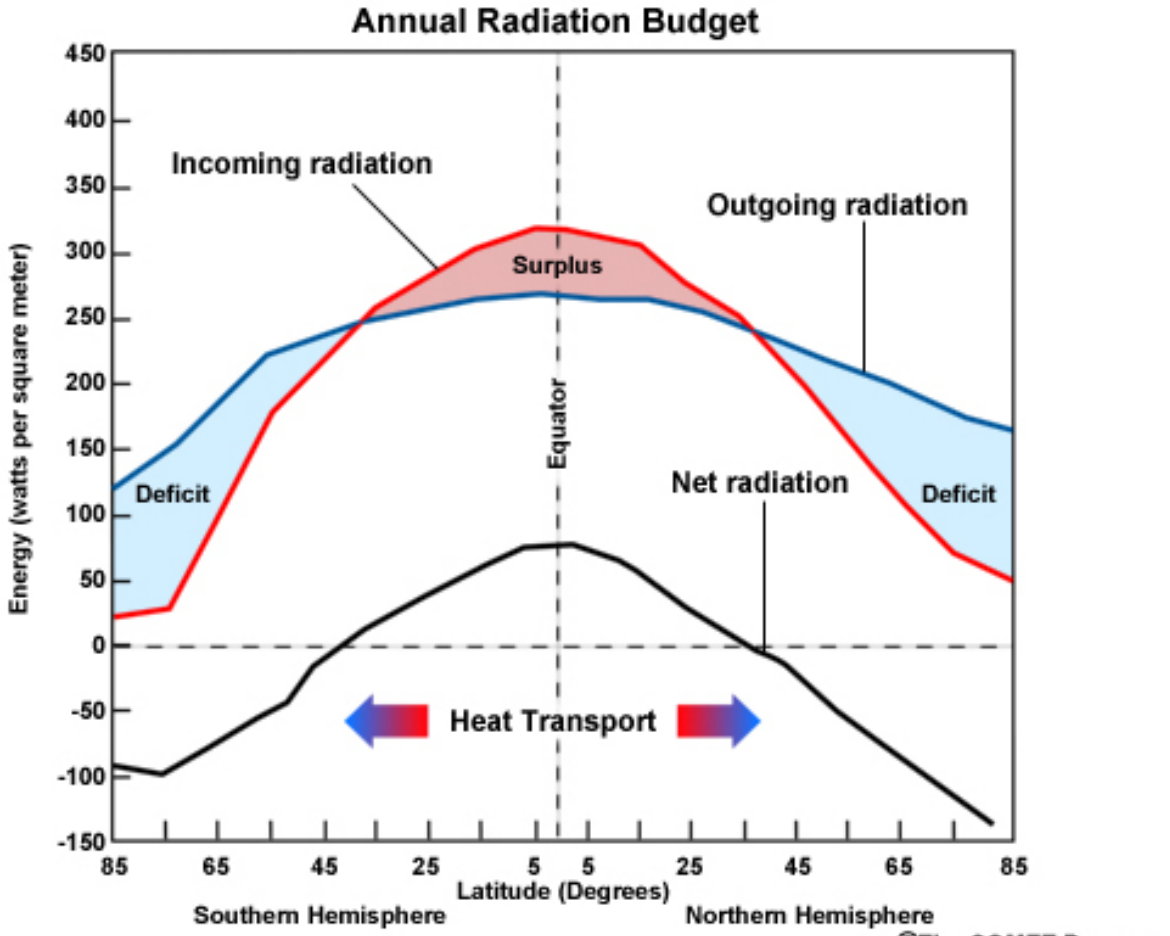
Atmosphere "Slower" **Atmosphere "Faster"**

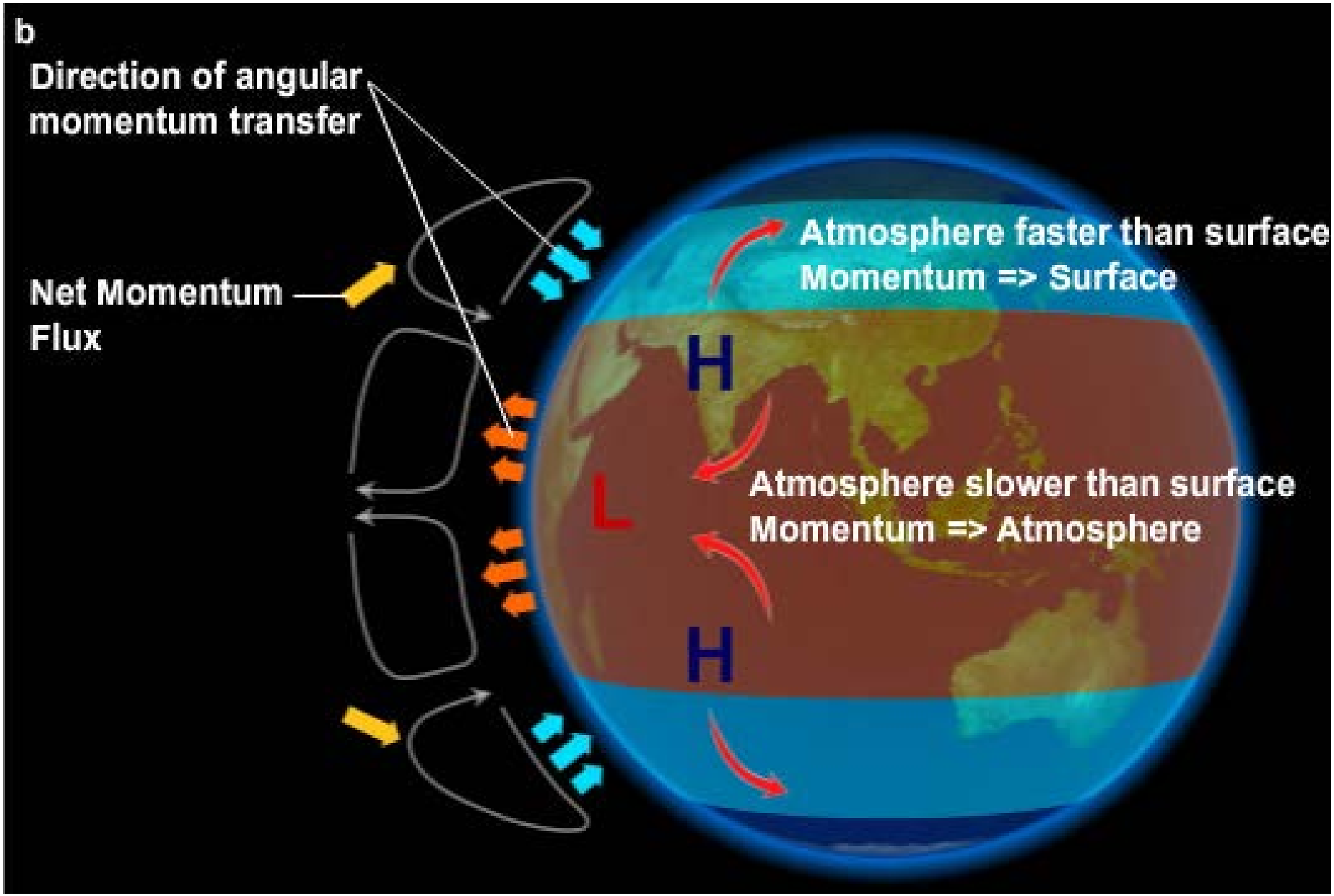

Mean Annual Global Insolation
Energy density (Watts / m2)
400
350
300
250
200
~ 1000 km
Solar radiation
equal energy
~ 2000 km
©The COMET Program

a

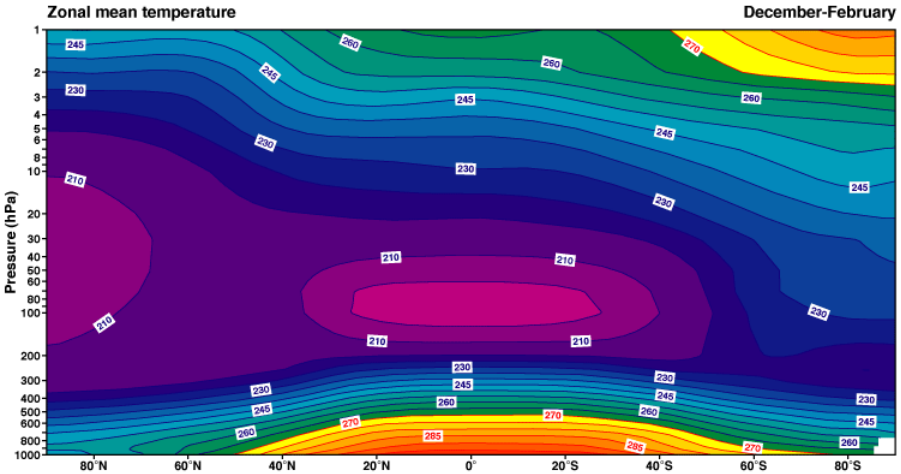


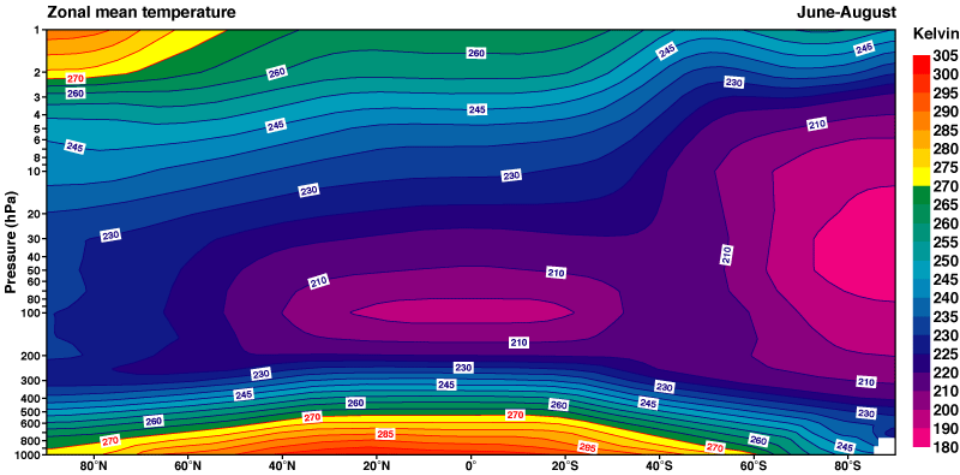
b

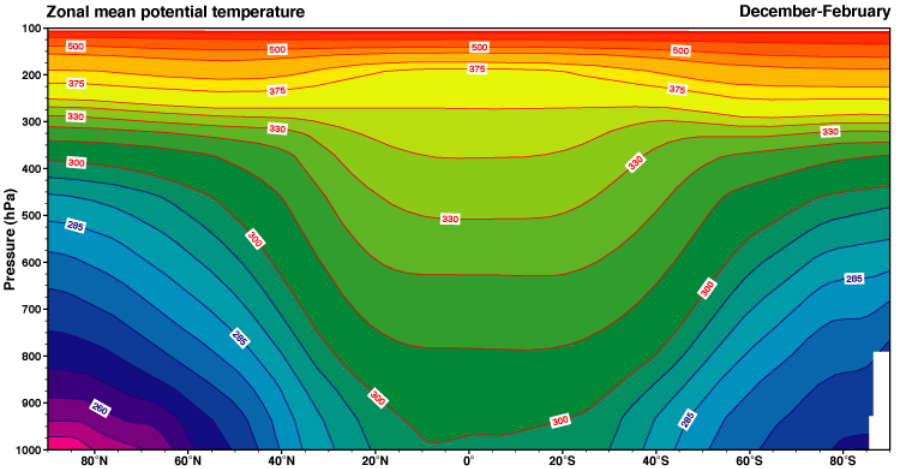


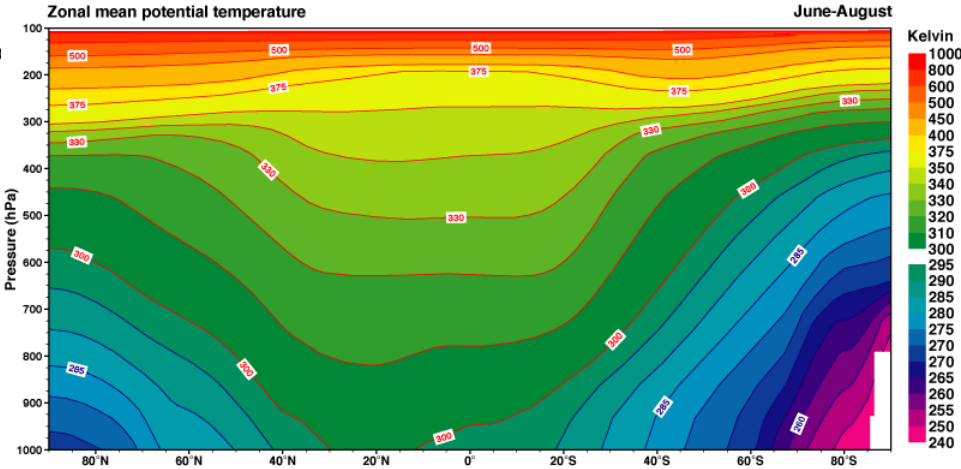

b
Direction of angular momentum transfer
Net Momentum Flux
Atmosphere faster than surface
Momentum => Surface
H
L
Atmosphere slower than surface
Momentum => Atmosphere
H

Temperature and Potential Temperature Structure of the Atmosphere

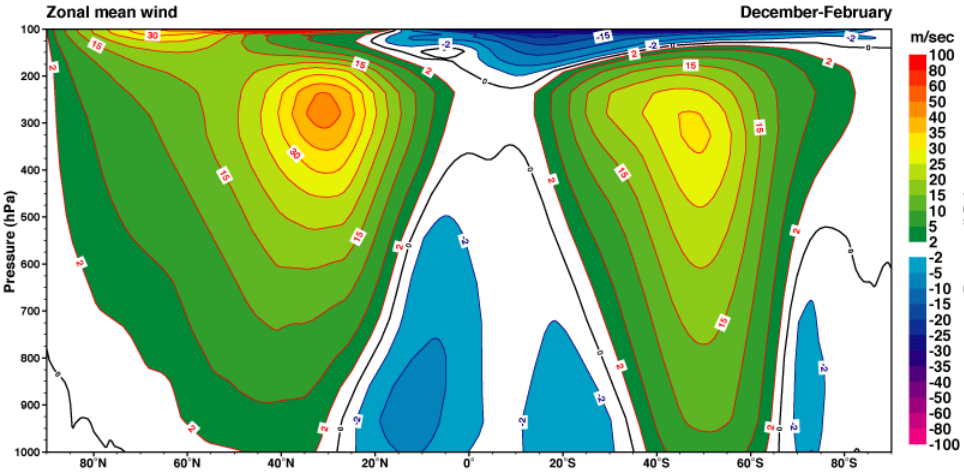


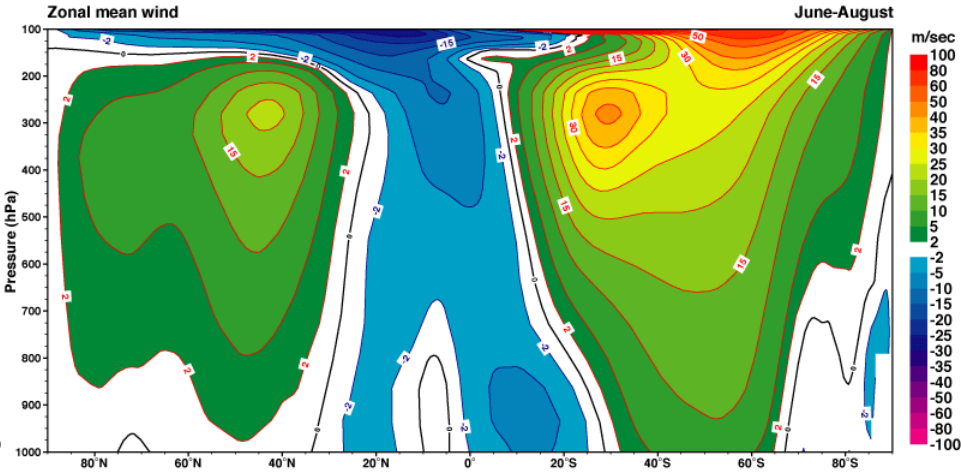


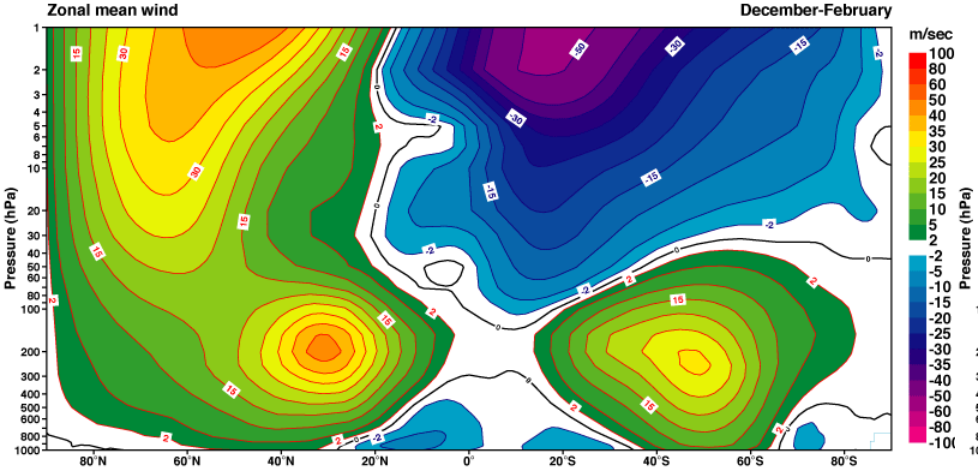


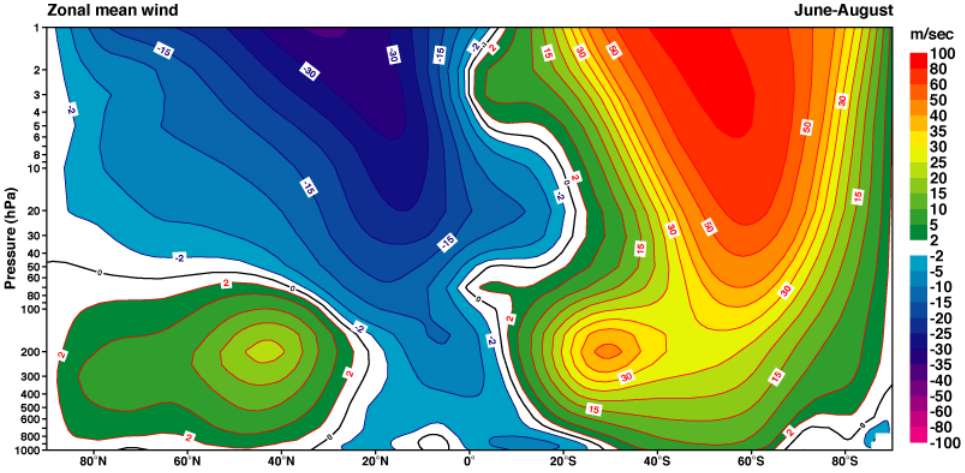


Zonal Wind Sturcture Structure of the Atmosphere



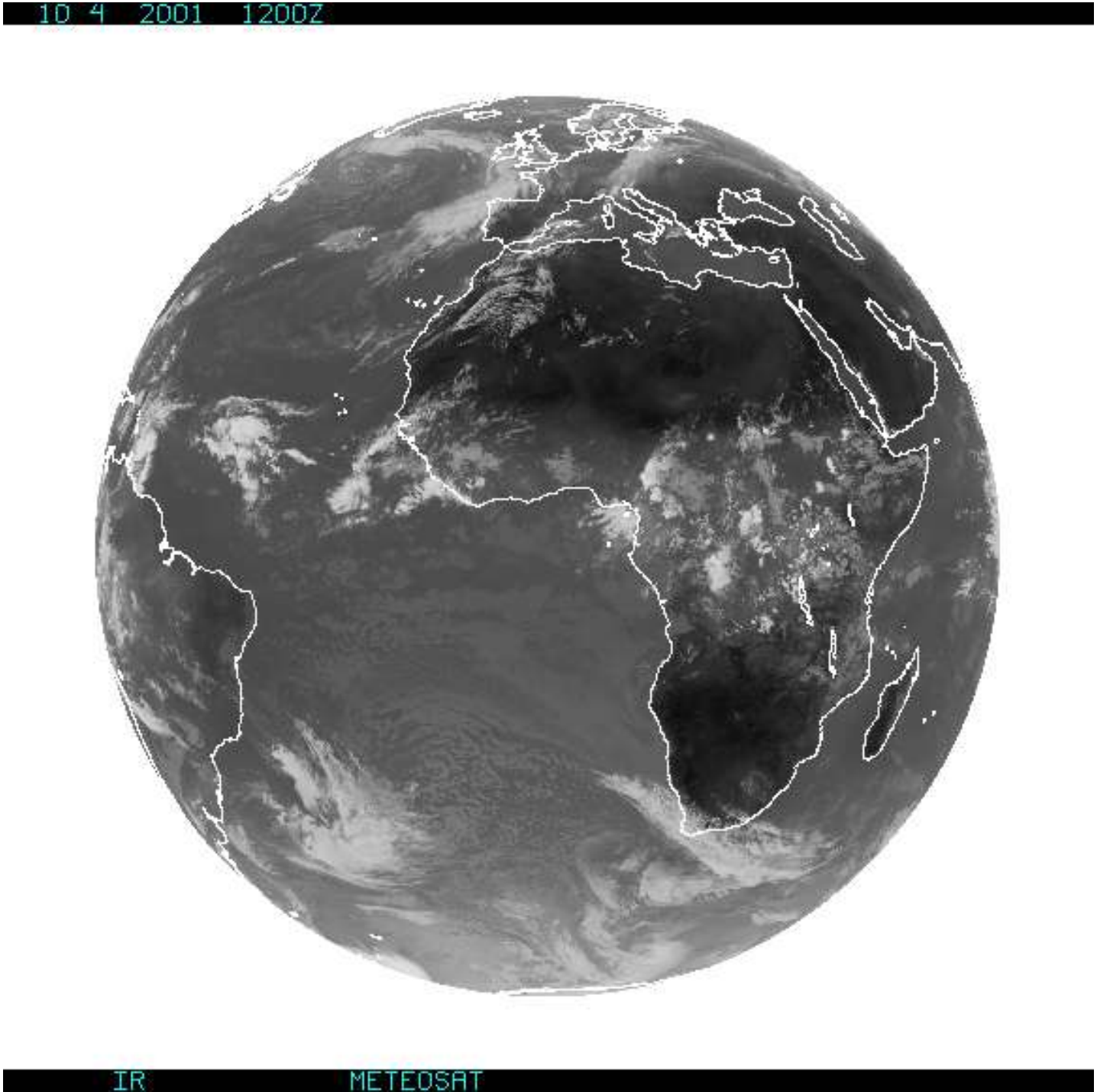


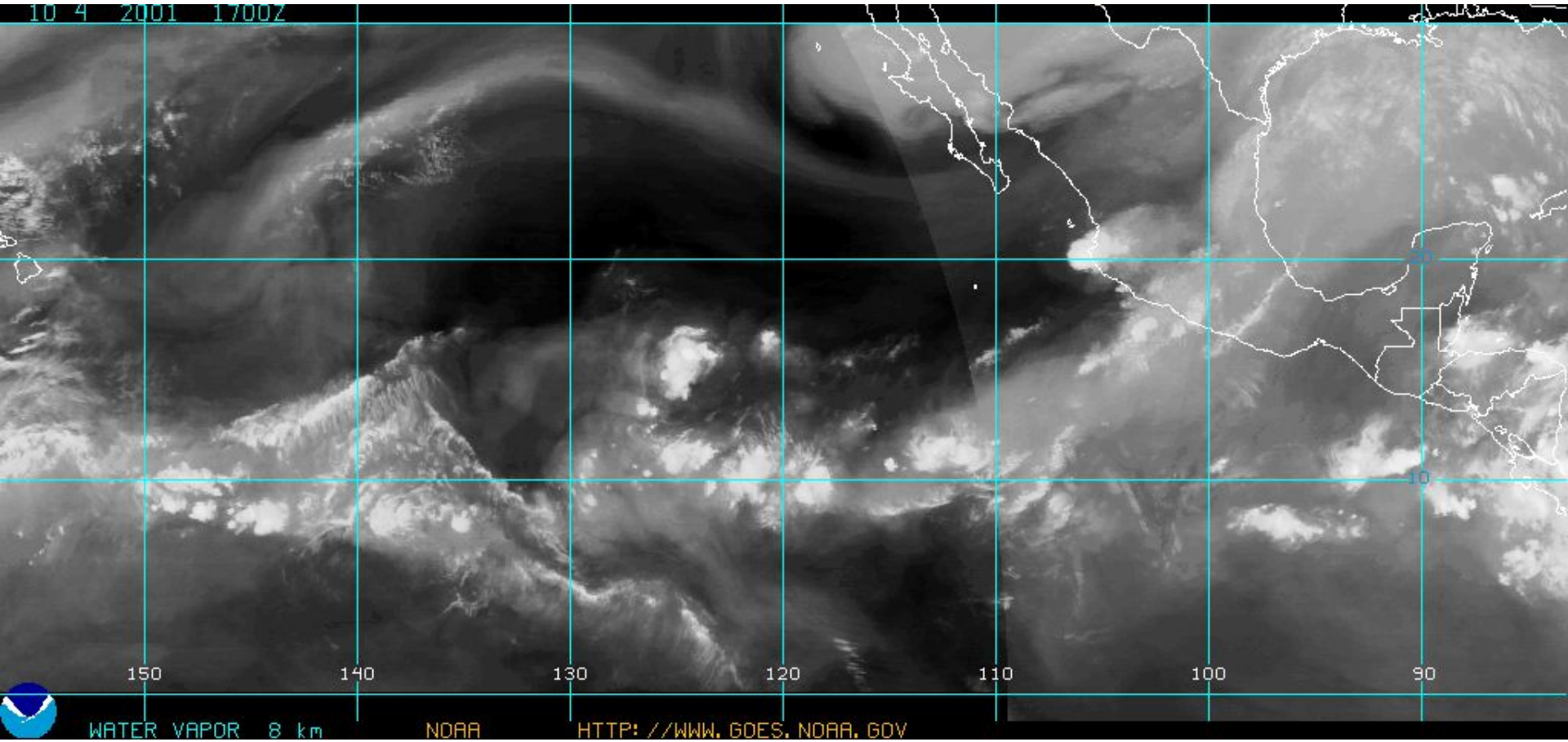


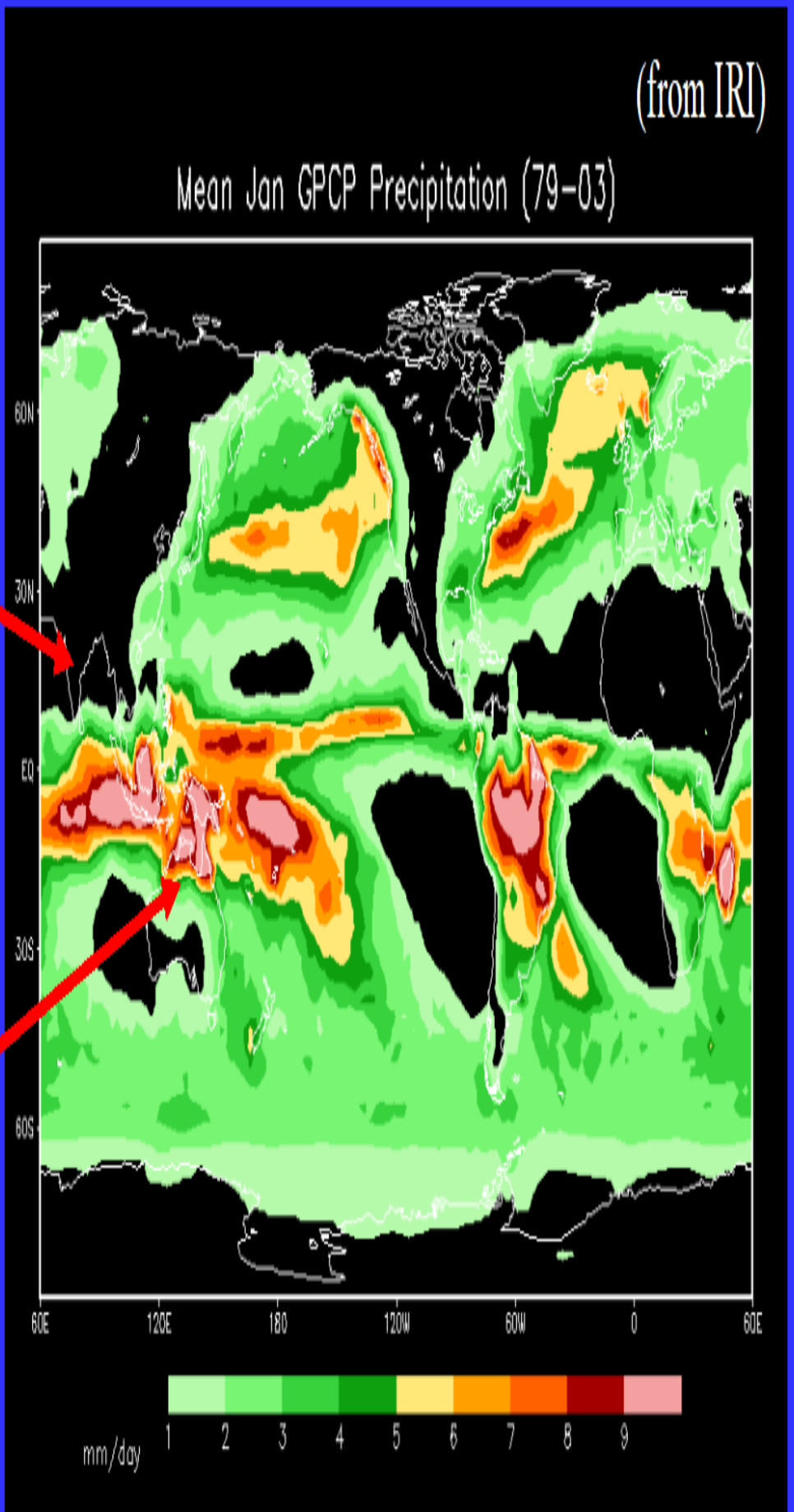


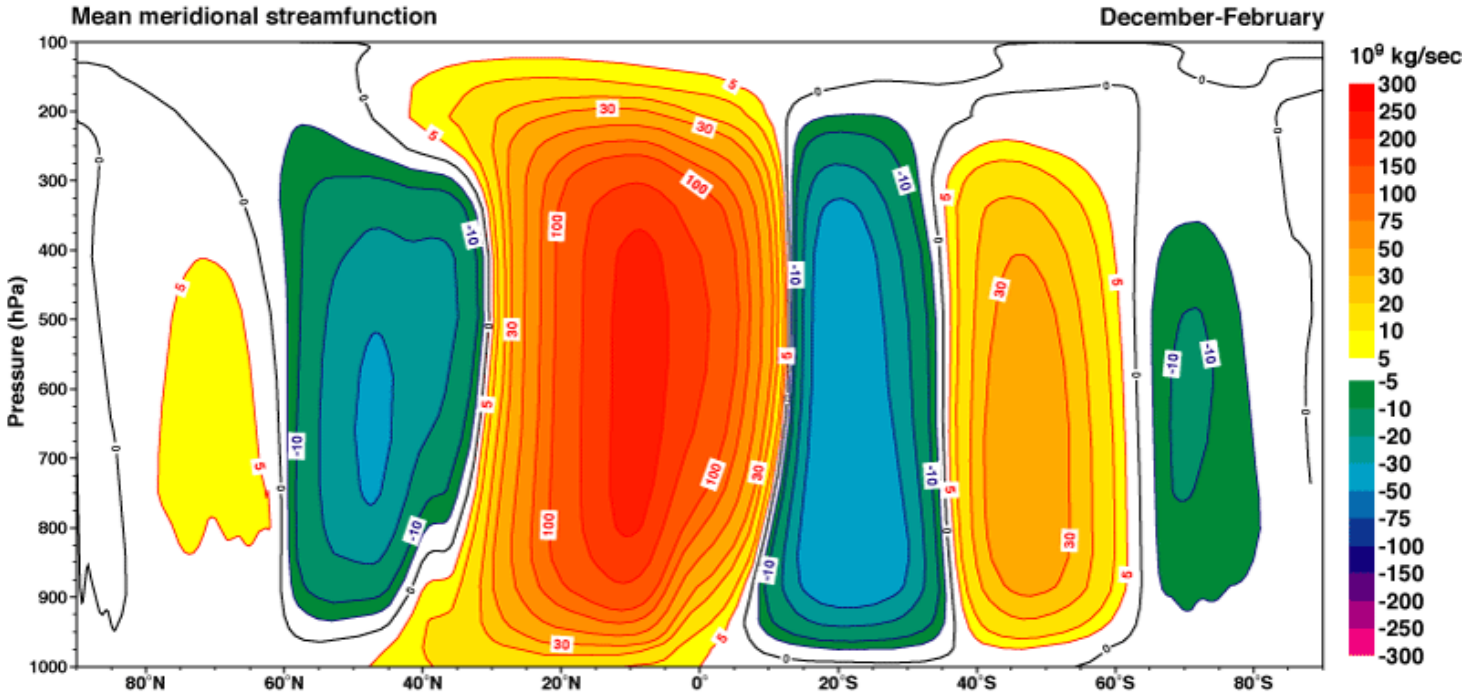
ITCZ Intertropical Convergence Zone

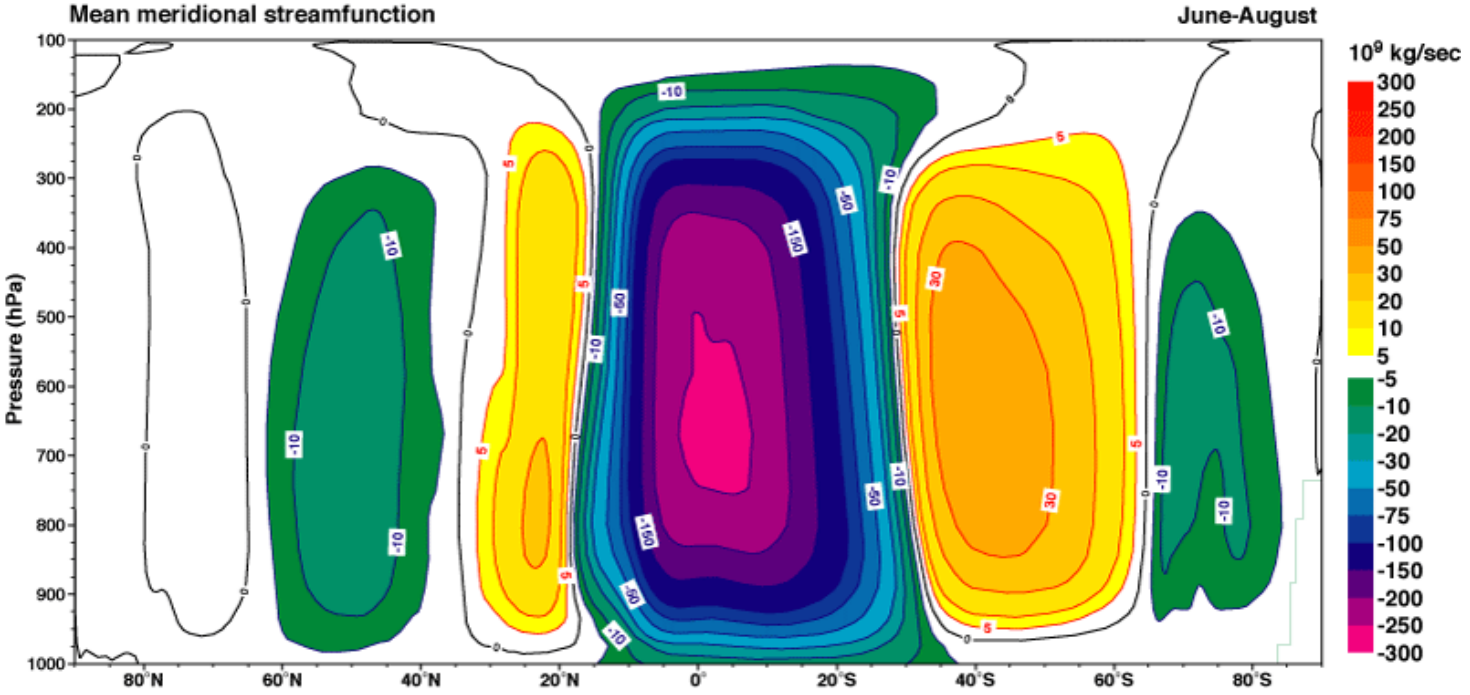
- Latitude of Tropical Precipitation Maximum
- Not Necessarily Latitude of Maximum Rising Motion

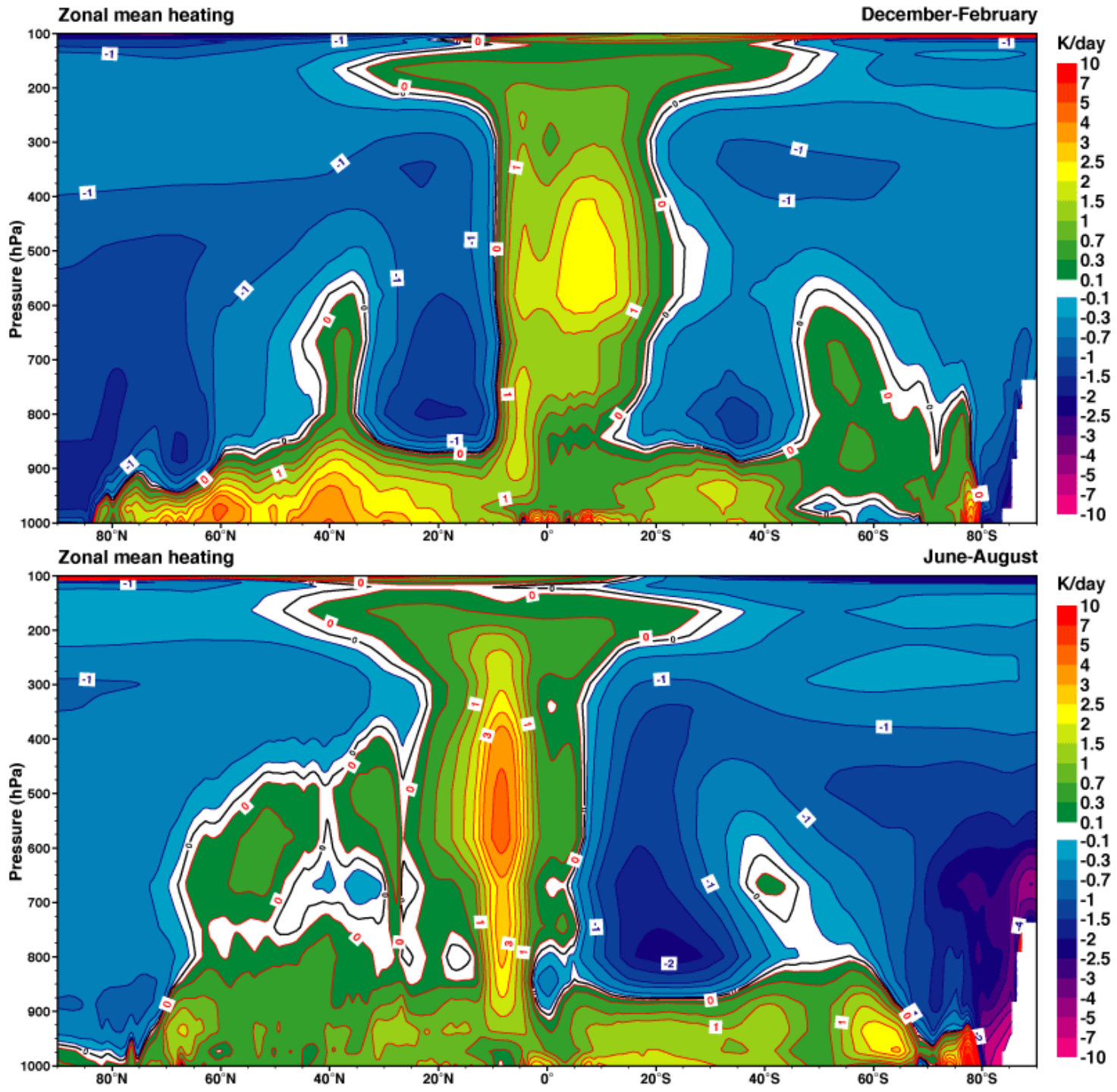

10 4 2001 1200Z
IR METEOSAT


10 4 2001 1700Z
30
10
150
140
130
120
110
100
90
WATER VAPOR 8 km
NOAA
HTTP://WWW.GOES.NOAA.GOV


(from IRI)
Mean Jan GPCP Precipitation (79-03)
Indian Monsoon
Australian Monsoon
60N
30N
EQ
30S
60S
60E
120E
180
120W
60W
0
60E
1
2
3
4
5
6
7
8
9
mm/day

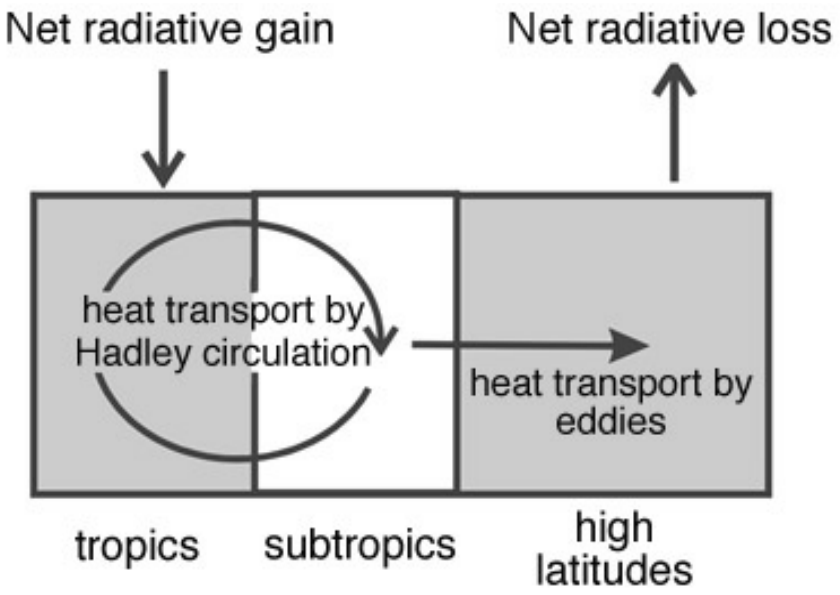

Mean meridional streamfunction
December-February
Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
10⁹ kg/sec
300
250
200
150
100
75
50
30
20
10
5
-5
-10
-20
-30
-50
-75
-100
-150
-200
-250
-300

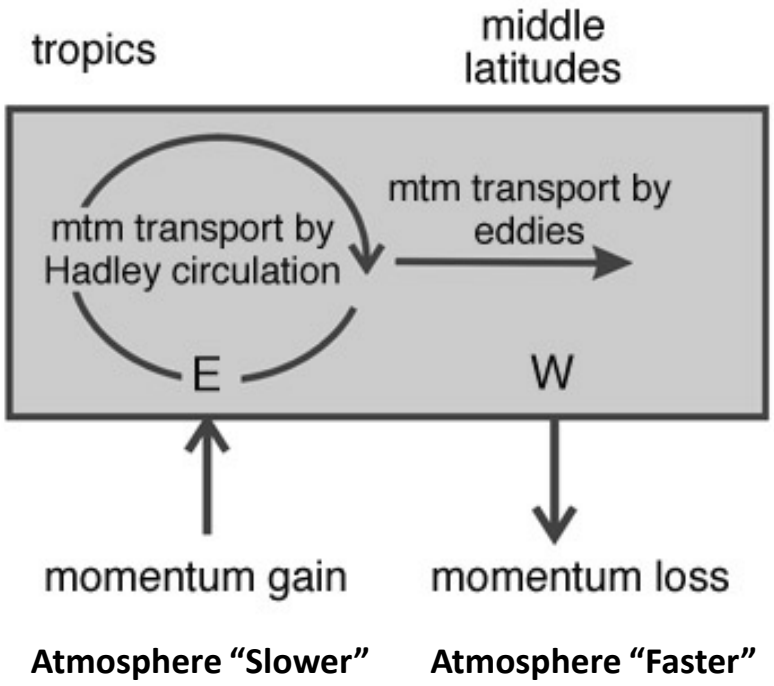

Mean meridional streamfunction
June-August
Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
10⁹ kg/sec
300
250
200
150
100
75
50
30
20
10
5
-5
-10
-20
-30
-50
-75
-100
-150
-200
-250
-300


Zonal mean heating
December-February
K/day
10
7
5
4
3
2.5
2
1.5
1
0.7
0.3
0.1
-0.1
-0.3
-0.7
-1
-1.5
-2
-2.5
-3
-4
-5
-7
-10
Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
Zonal mean heating
June-August
K/day
Pressure (hPa)

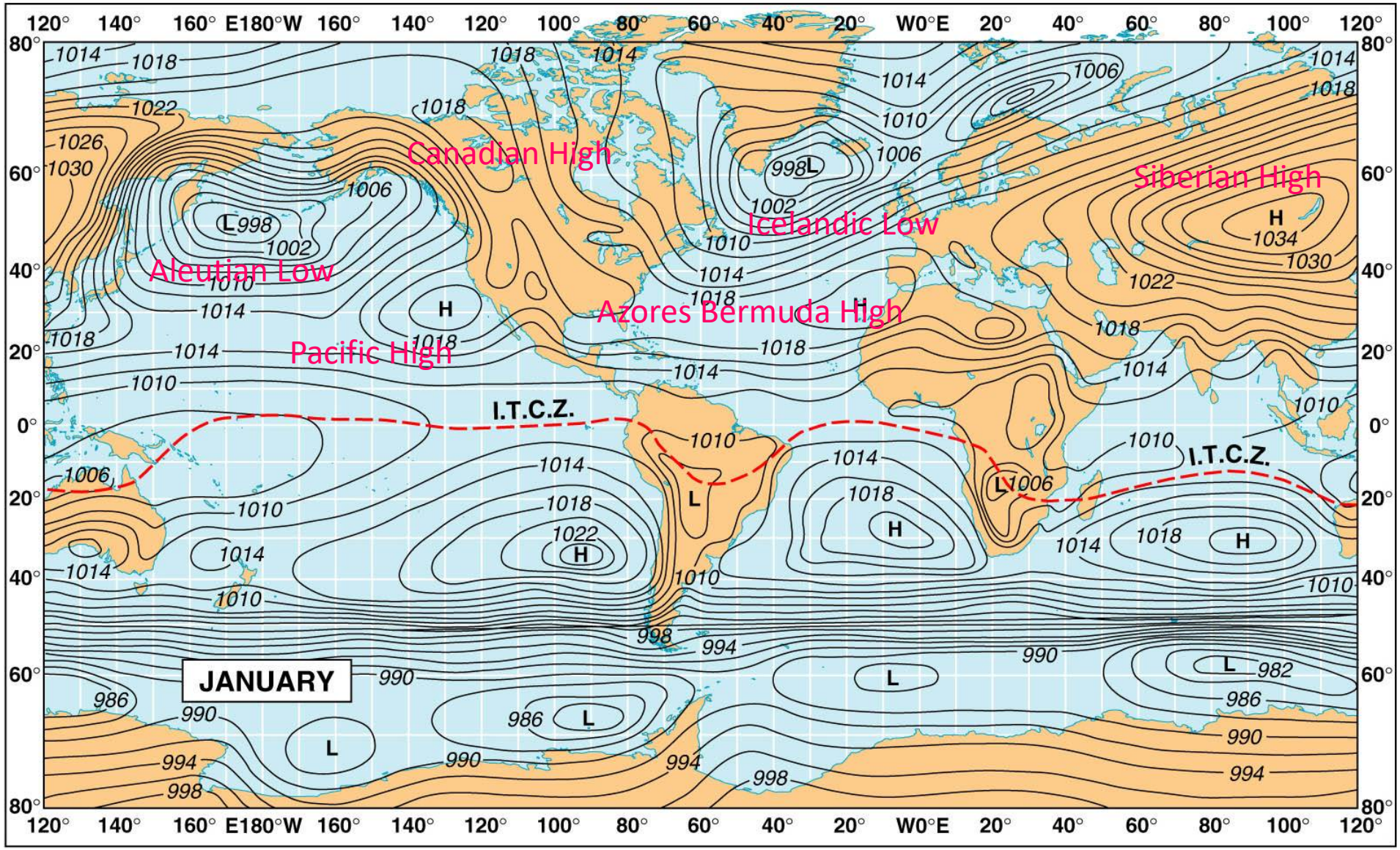
1) Meridional Temperature and Momentum Transport

- **Stationary Eddies and Transient Eddies**

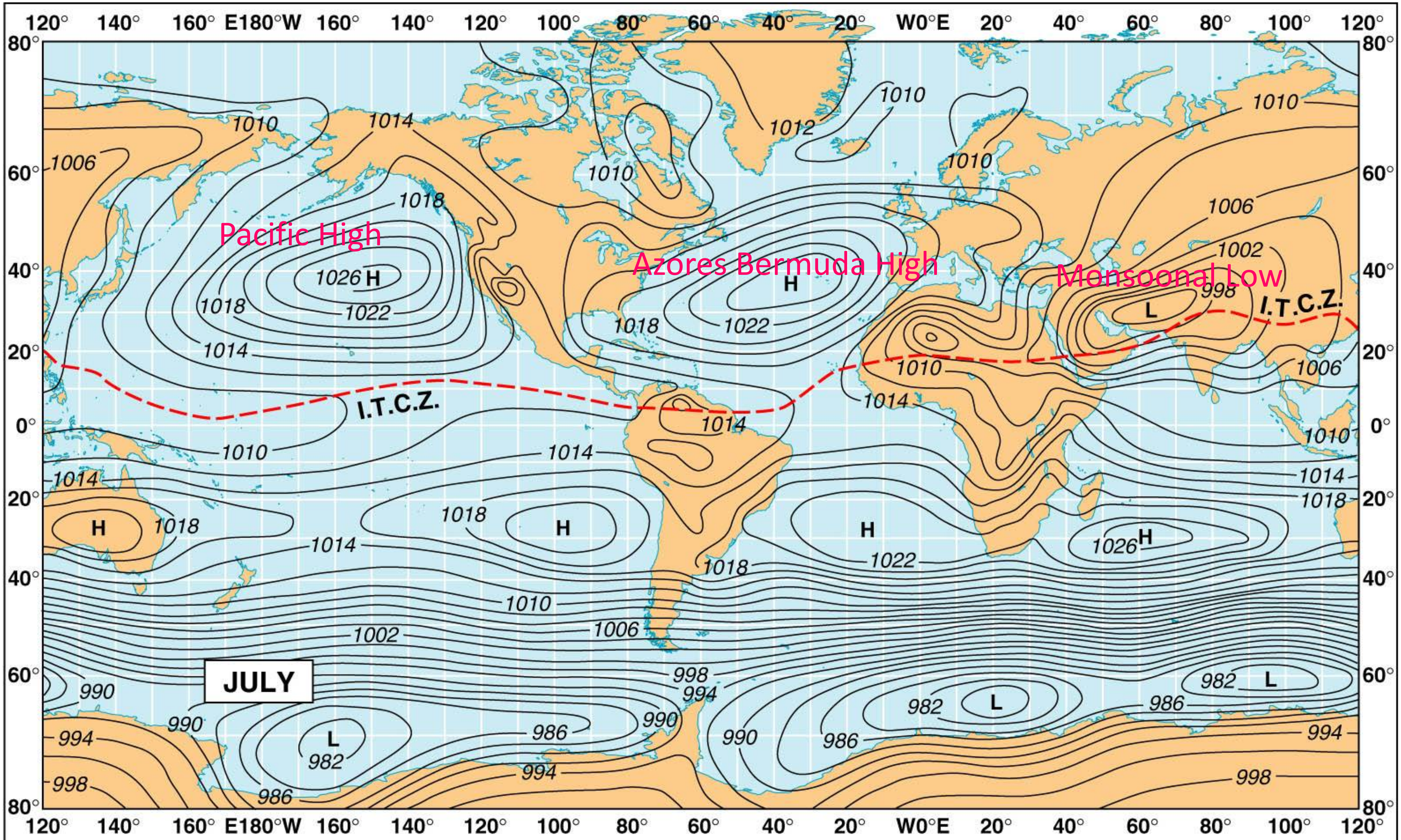




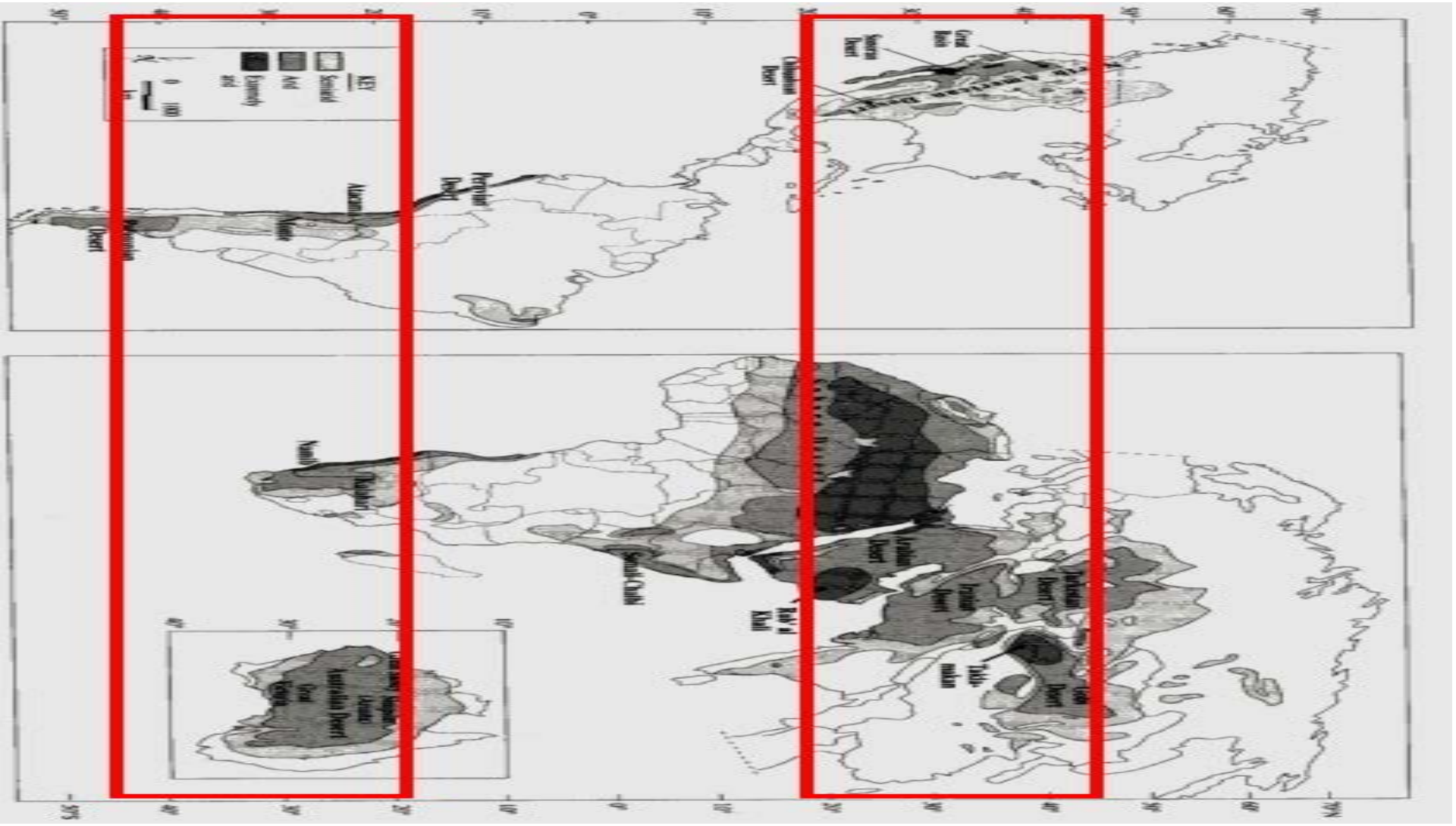
Atmosphere "Slower" **Atmosphere "Faster"**


Canadian High
Siberian High
Icelandic Low
Aleutian Low
Azores Bermuda High
Pacific High
I.T.C.Z.
I.T.C.Z.
JANUARY
120° 140° 160° E180°W 160° 140° 120° 100° 80° 60° 40° 20° W0°E 20° 40° 60° 80° 100° 120°
80° 60° 40° 20° 0° 20° 40° 60° 80°

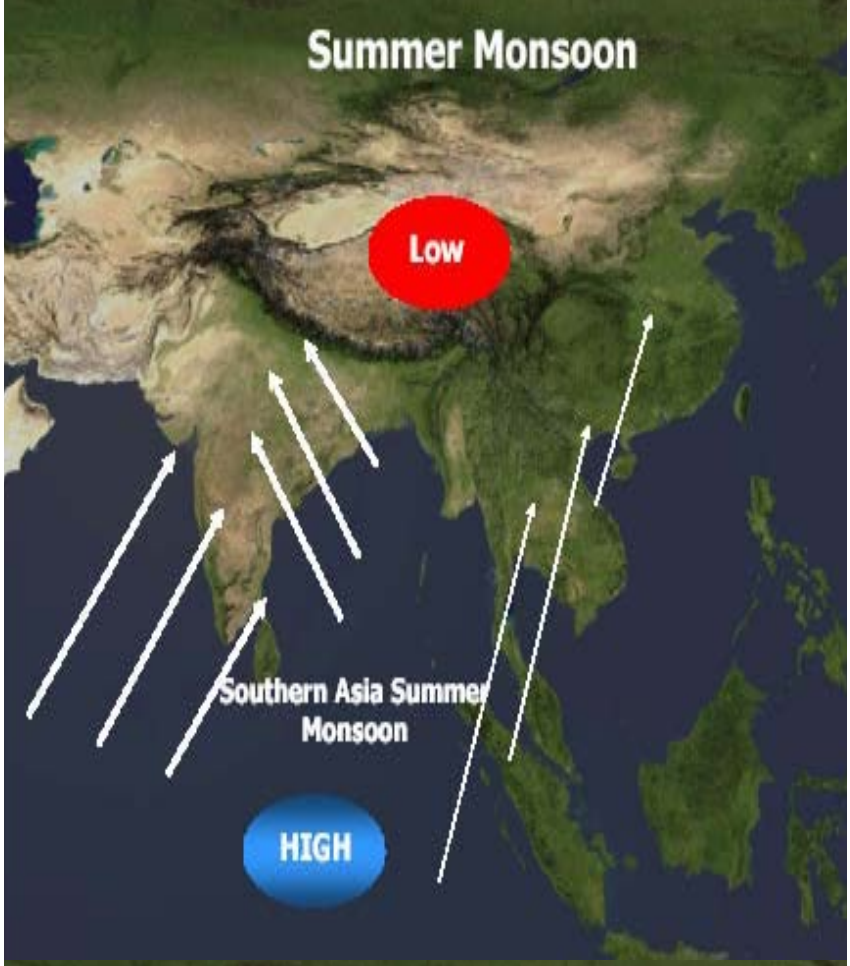
(a)

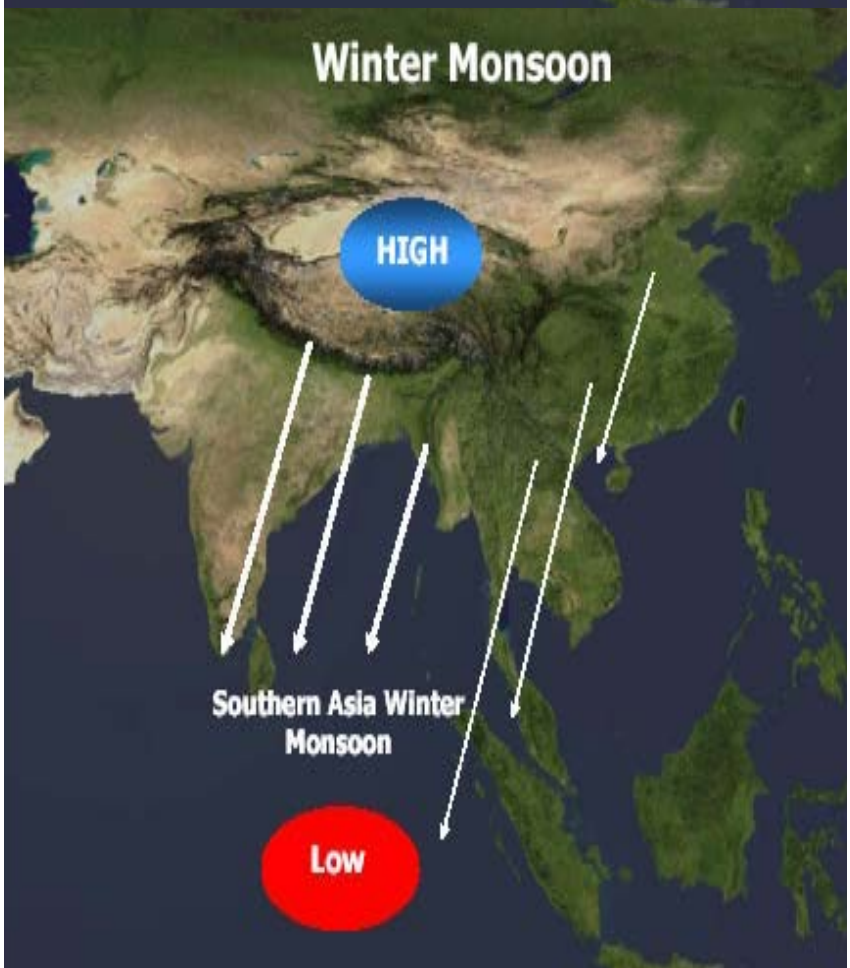

Pacific High
Azores Bermuda High
Monsoonal Low
I.T.C.Z.
JULY
1026 H
1022
1018
1014
1010
1006
1002
998
994
990
986
982
(b)

Global Deserts



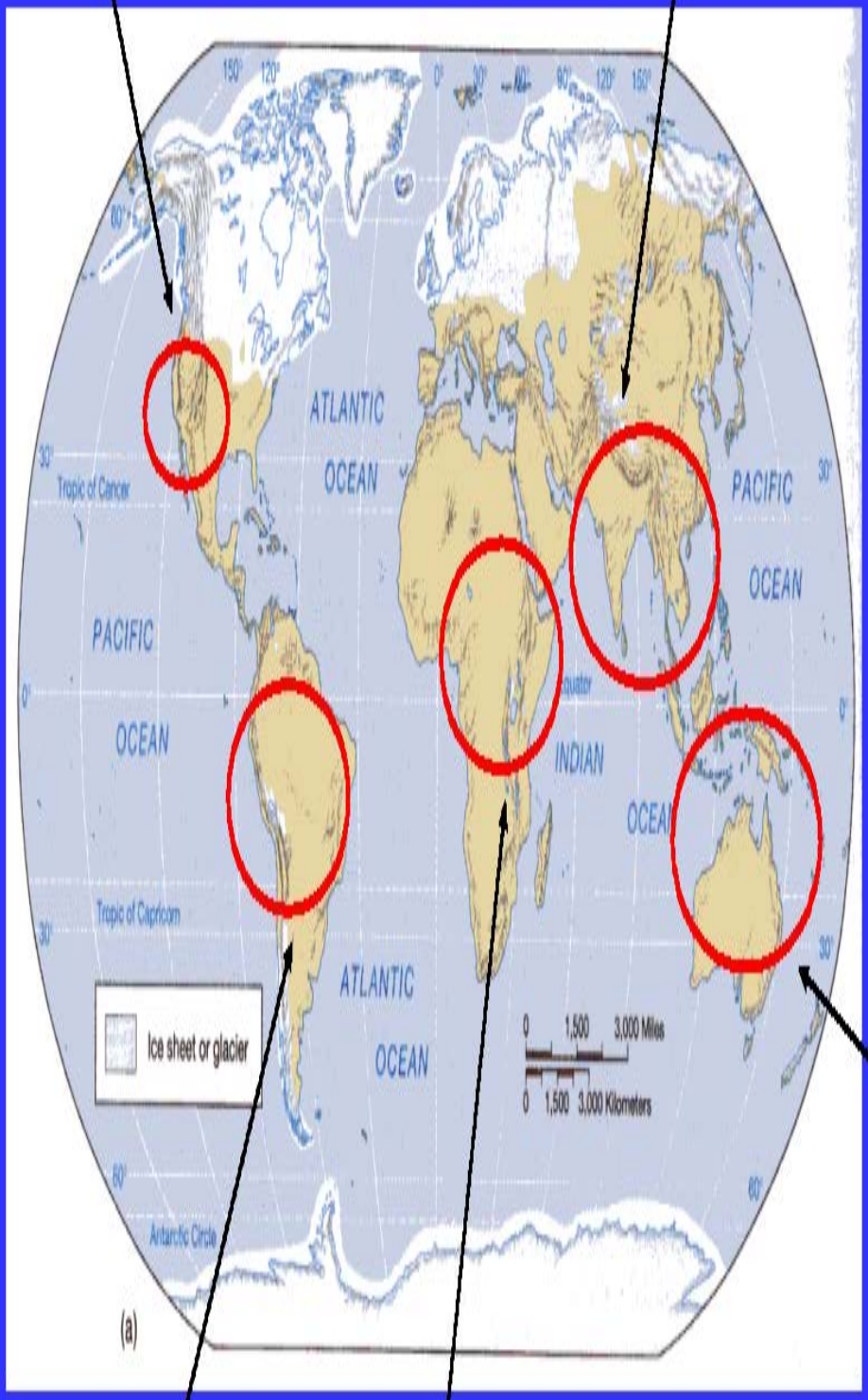
Monsoons


Summer Monsoon
Low
Southern Asia Summer Monsoon
HIGH


Winter Monsoon
HIGH
Southern Asia Winter Monsoon
Low

North America Monsoon

Asian Monsoon



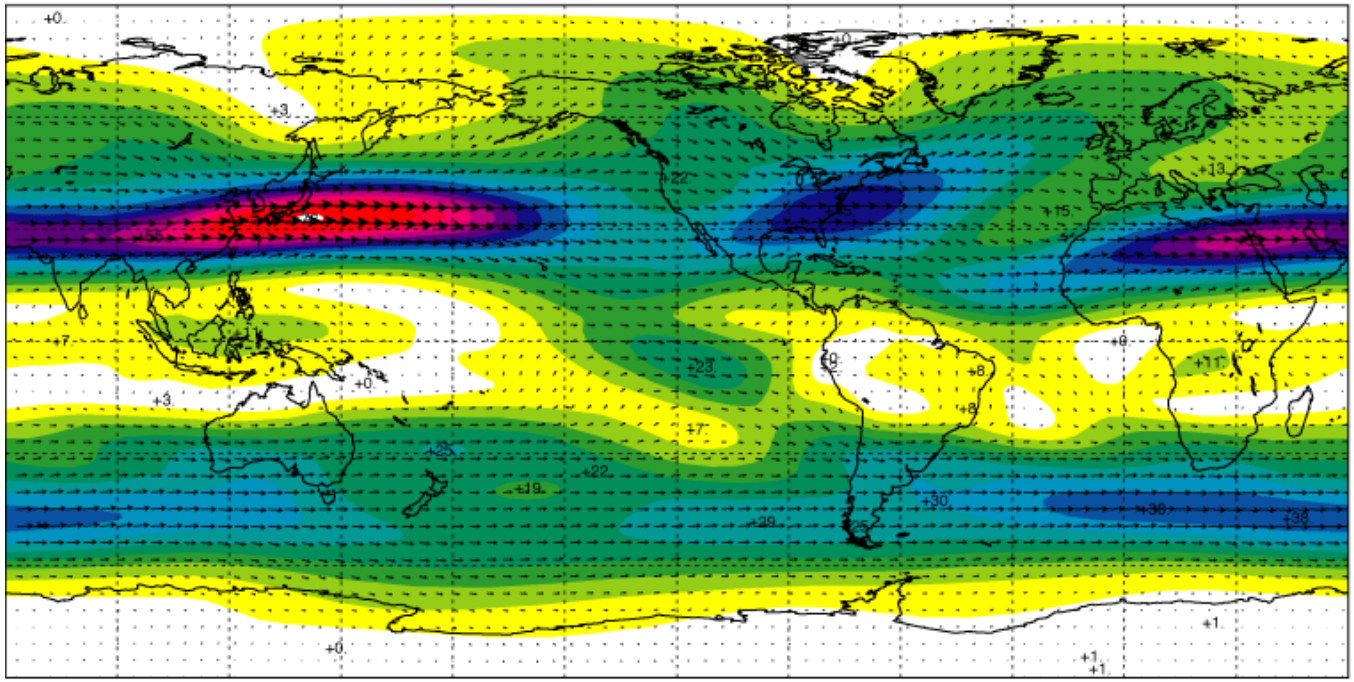
Australian Monsoon

South America Monsoon

Africa Monsoon

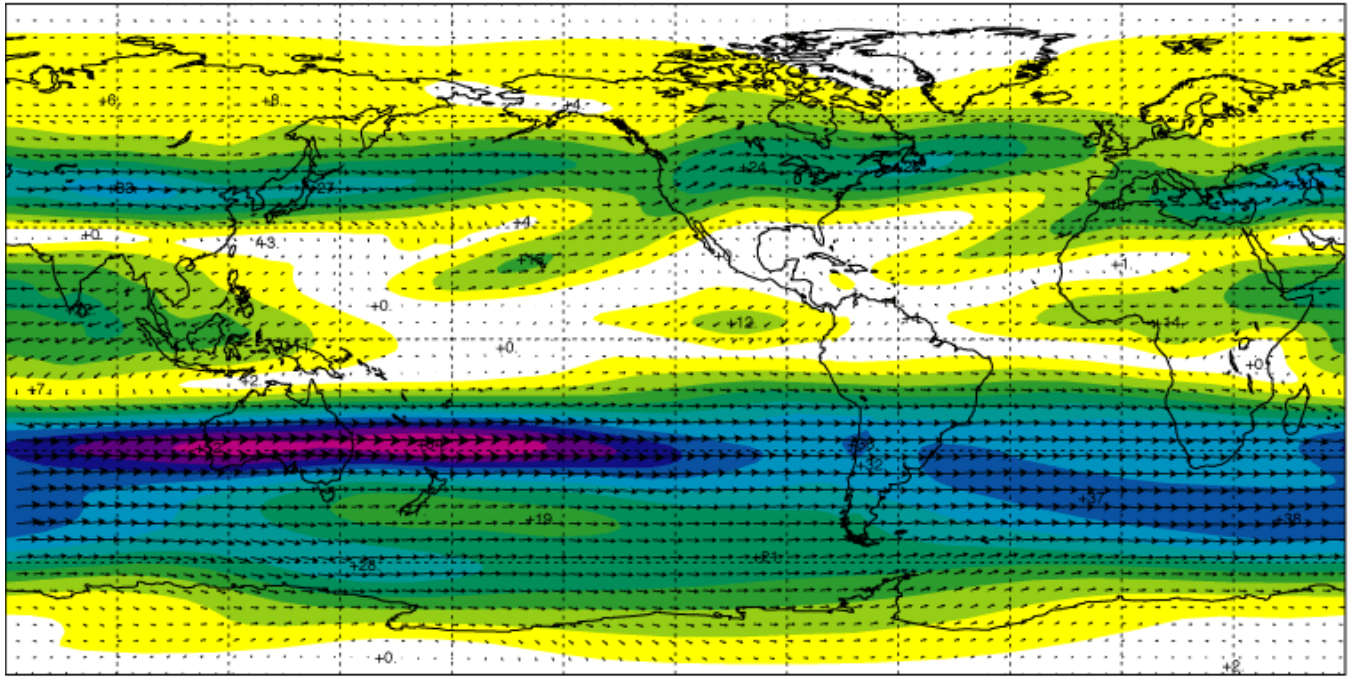
Wind vector and isotachs at 200 hPa

December-February



Wind vector and isotachs at 200 hPa

June-August



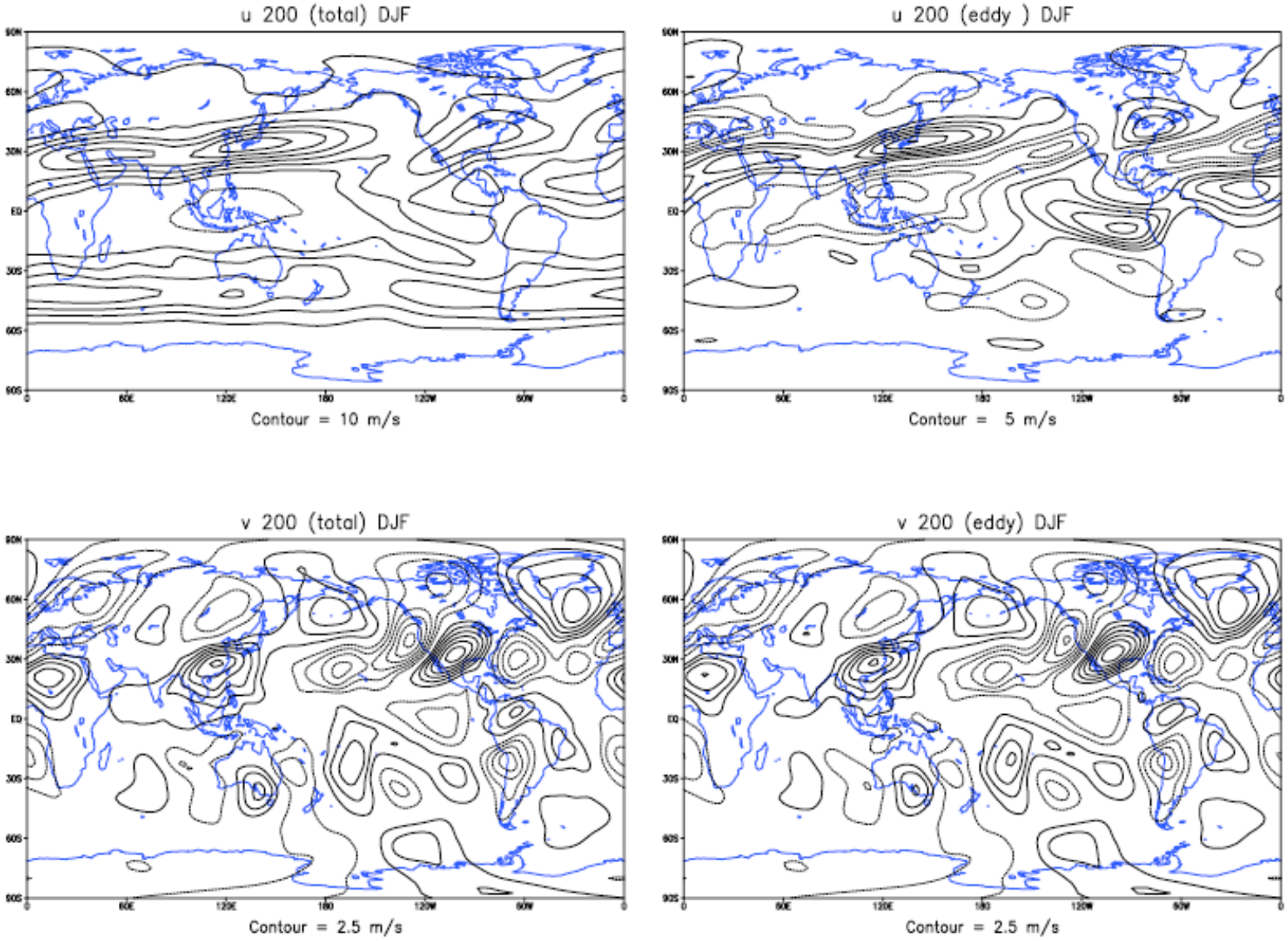


Figure 1: **DJF 200 hPa u and v wind, total and eddy.**

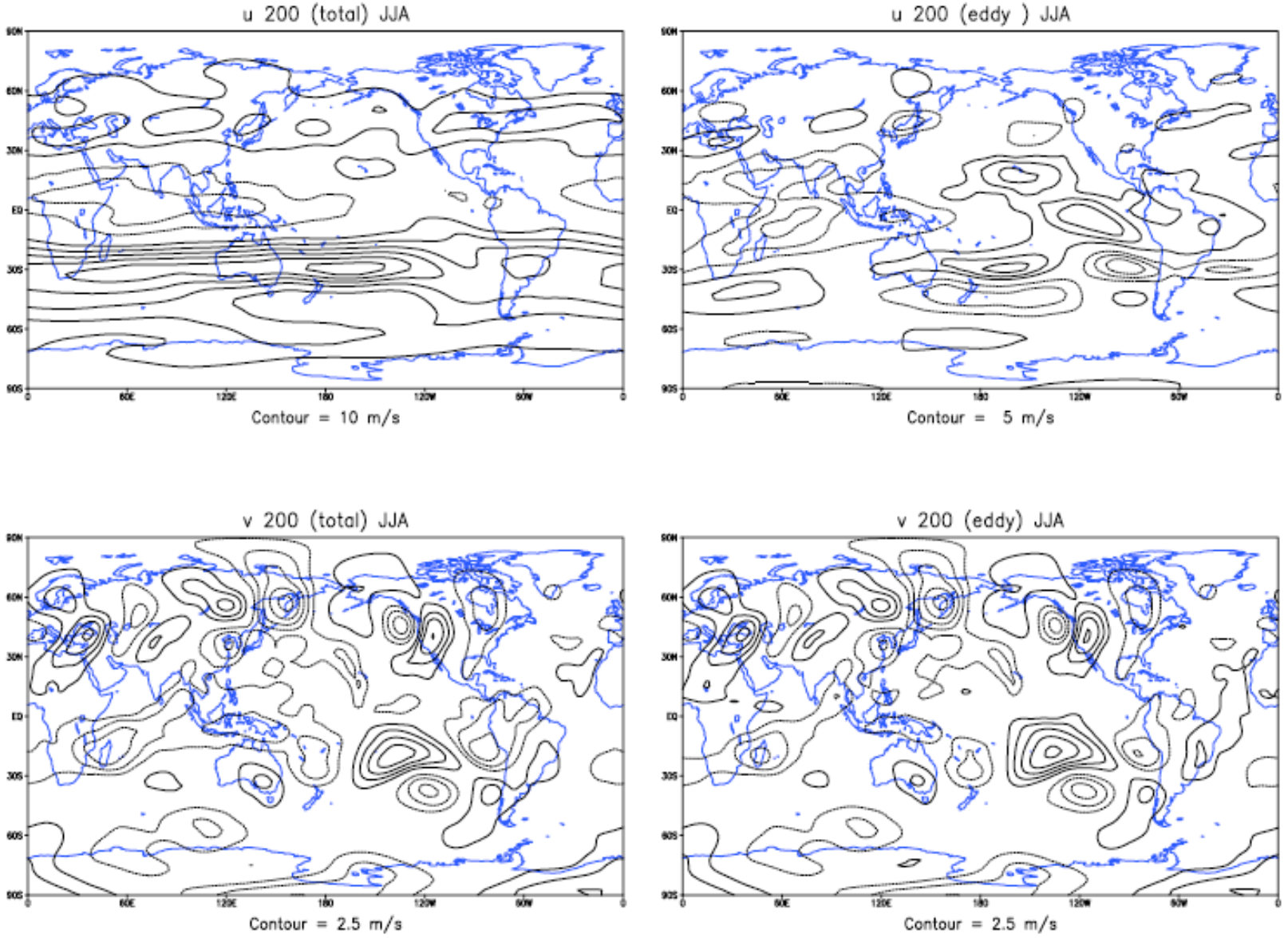


Figure 2: **JJA 200 hPa u and v wind, total and eddy.**

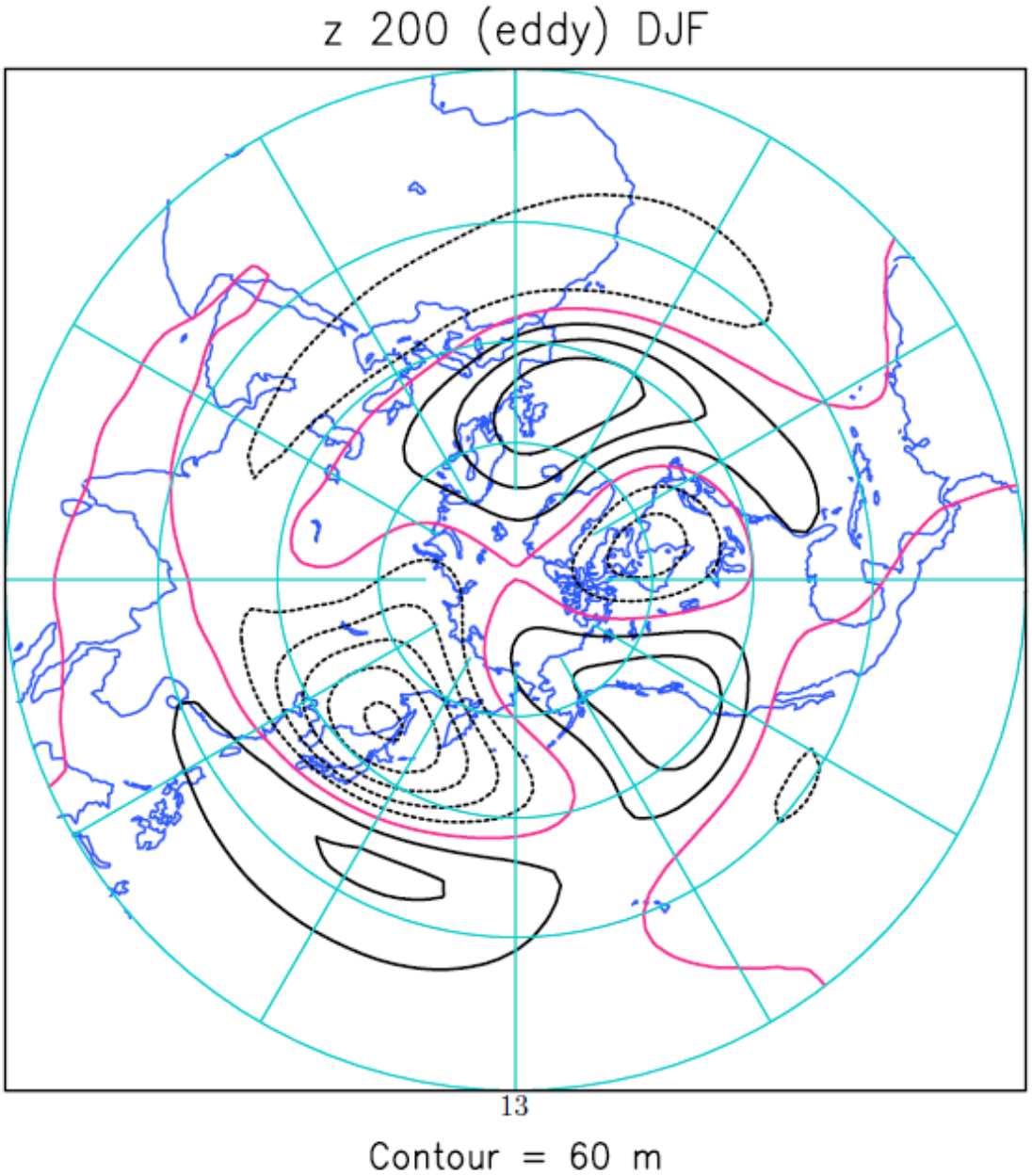


Figure 3: **DJF 200 hPa Z eddy.**

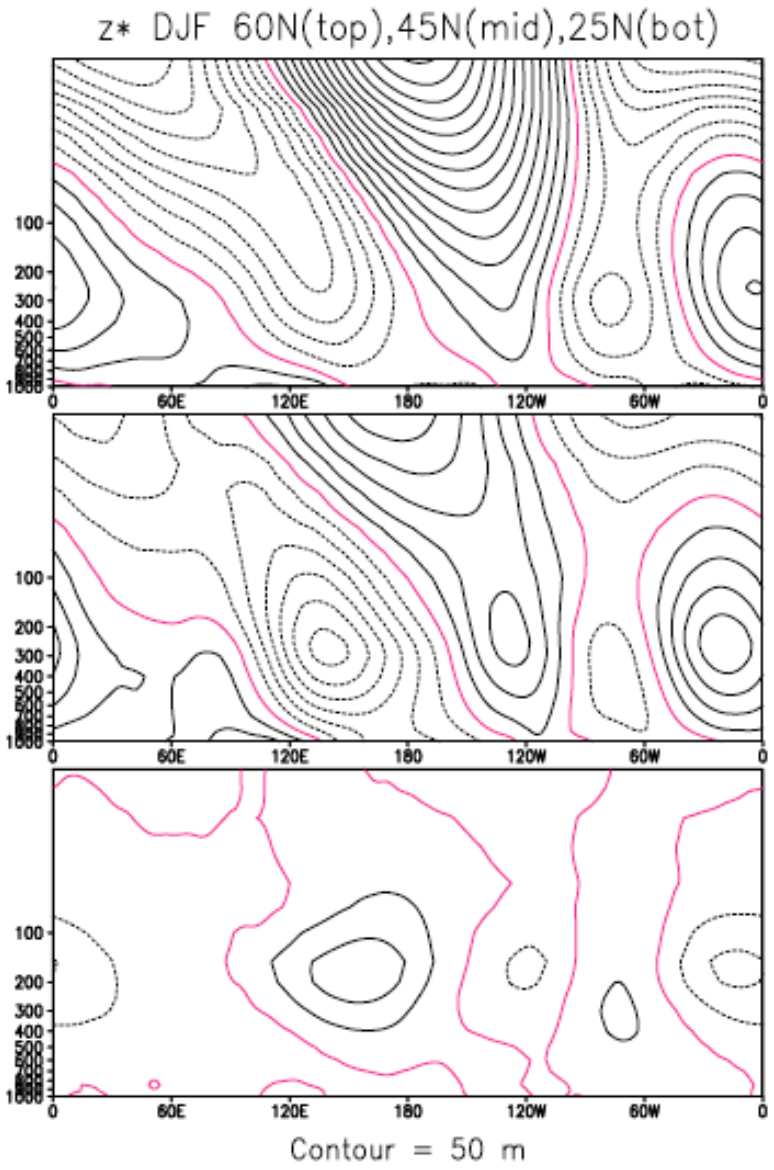


Figure 4: **Longitude/Pressure sections of DJF Z* at 60N (top), 45N(mid), and 25N(lower) .**

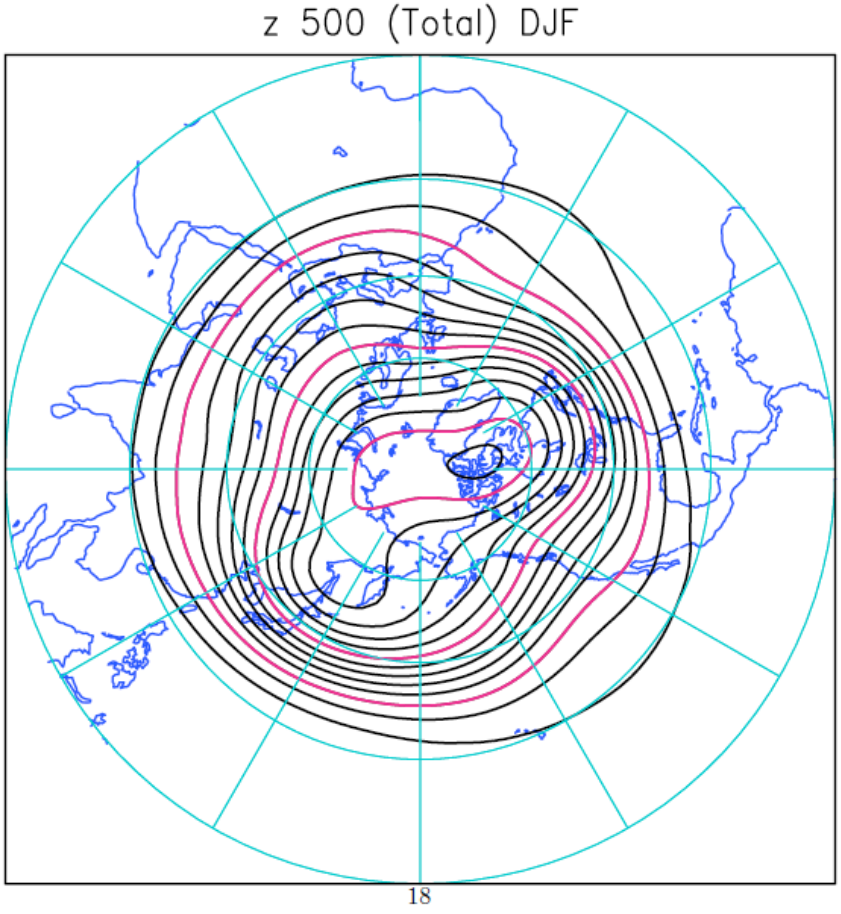


Figure 6: **DJF 500 hPa Z NH.**

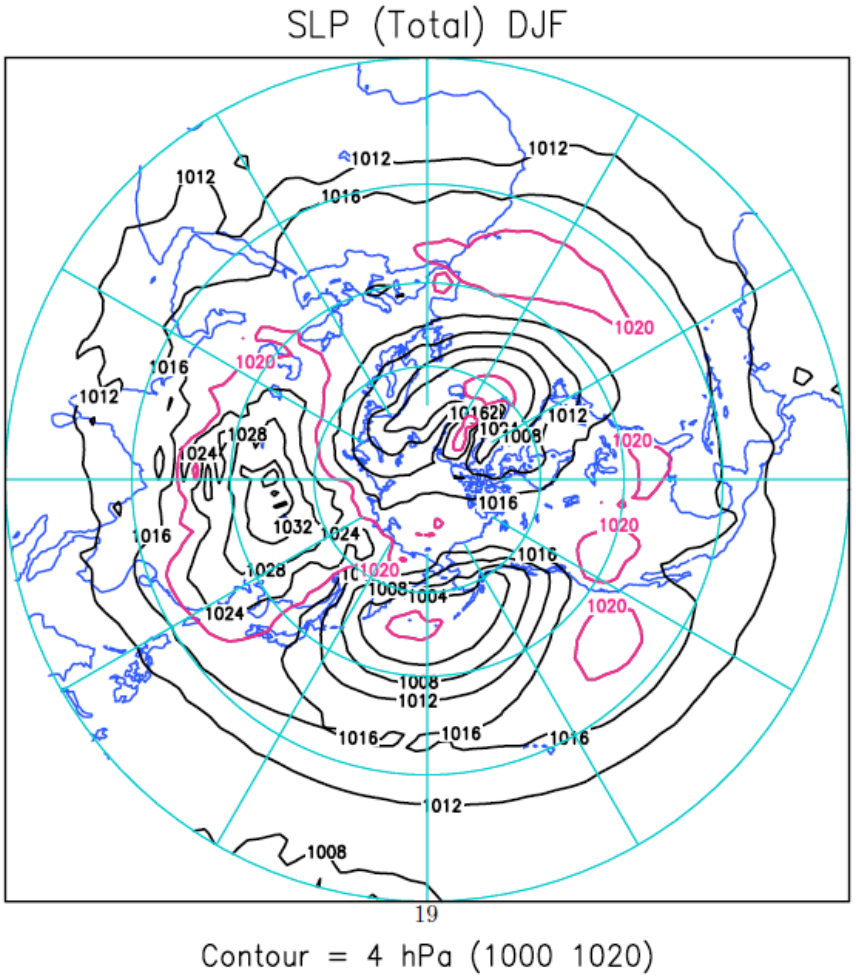
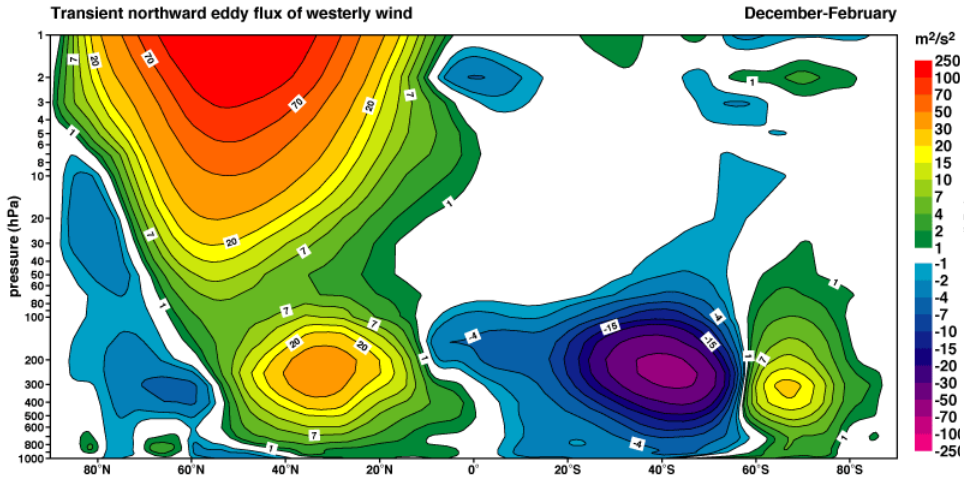
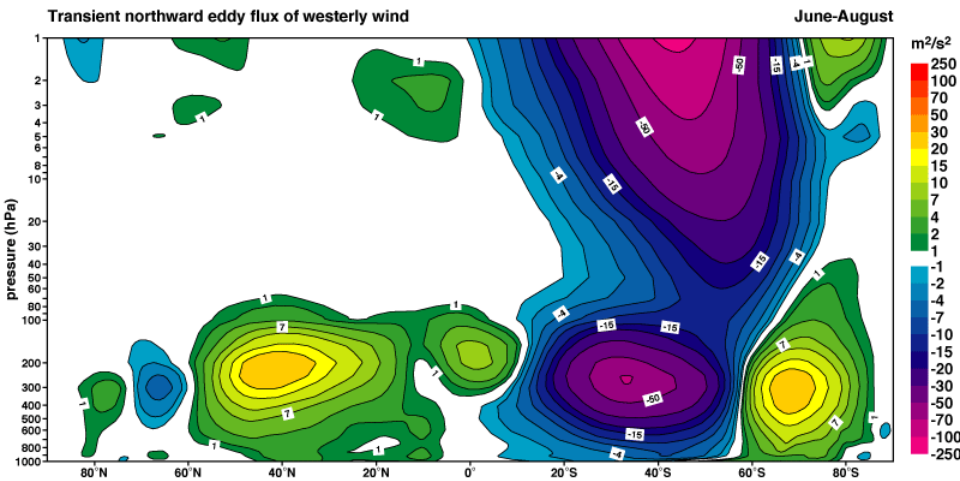
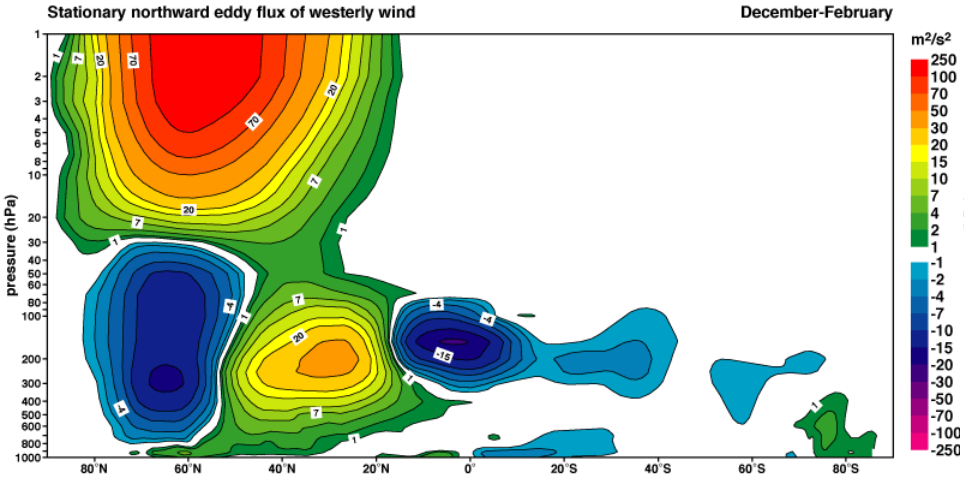


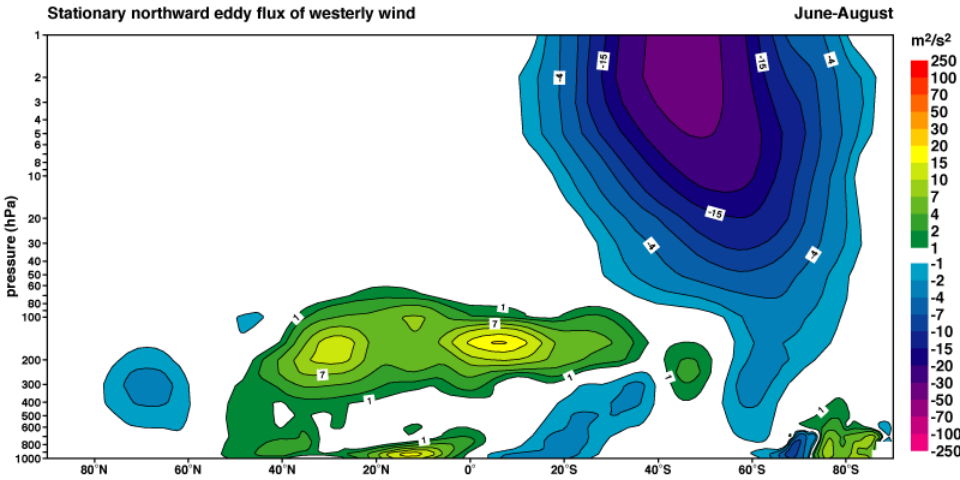
Figure 7: **DJF SLP NH.**

Transient and Stationary Eddy Flux of Westerly Momentum

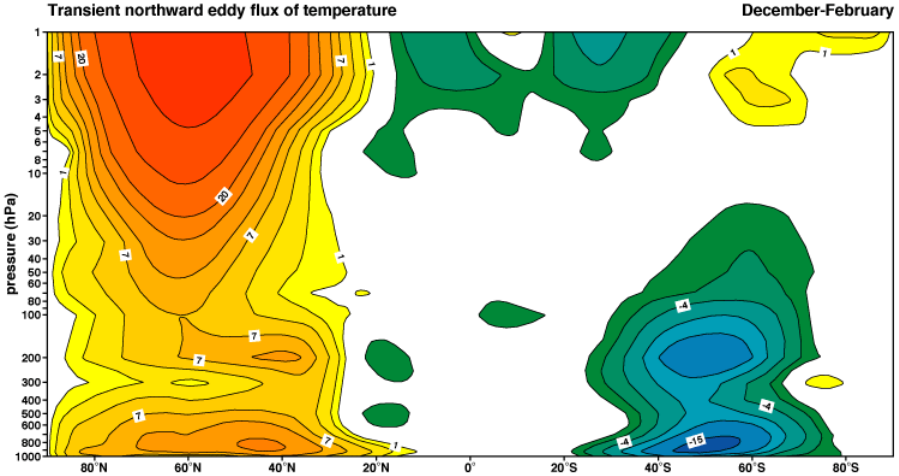


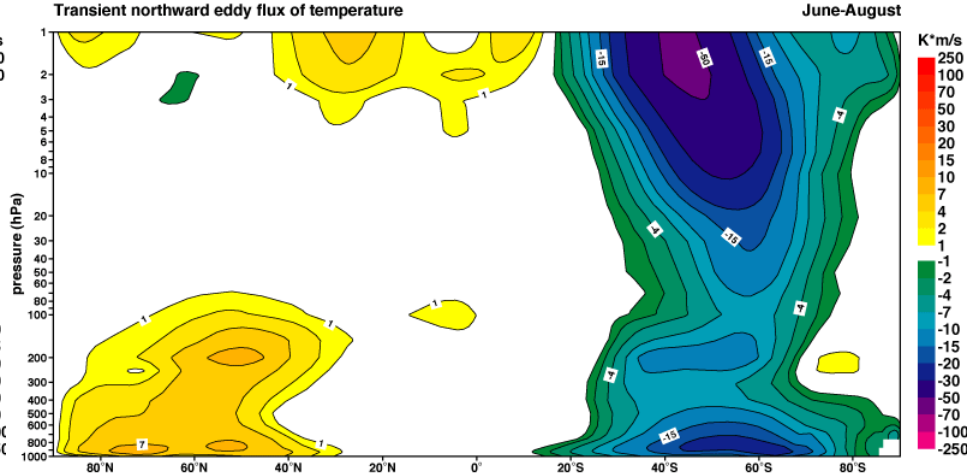


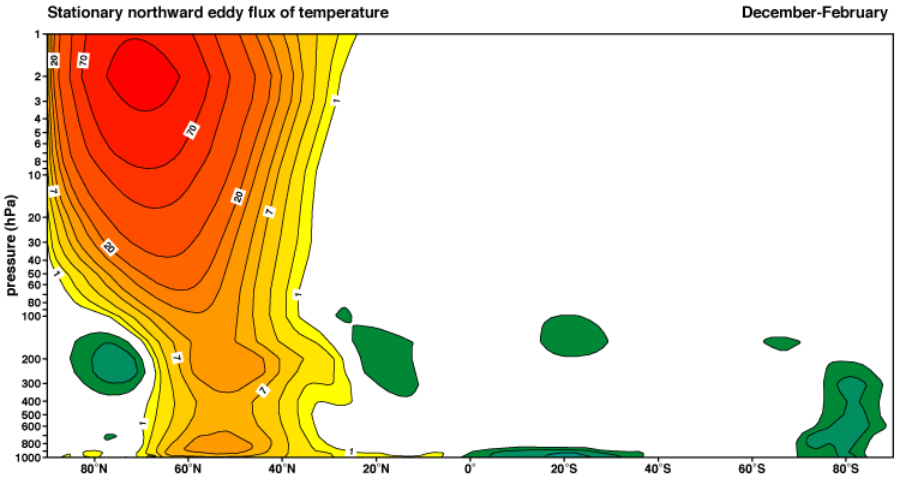


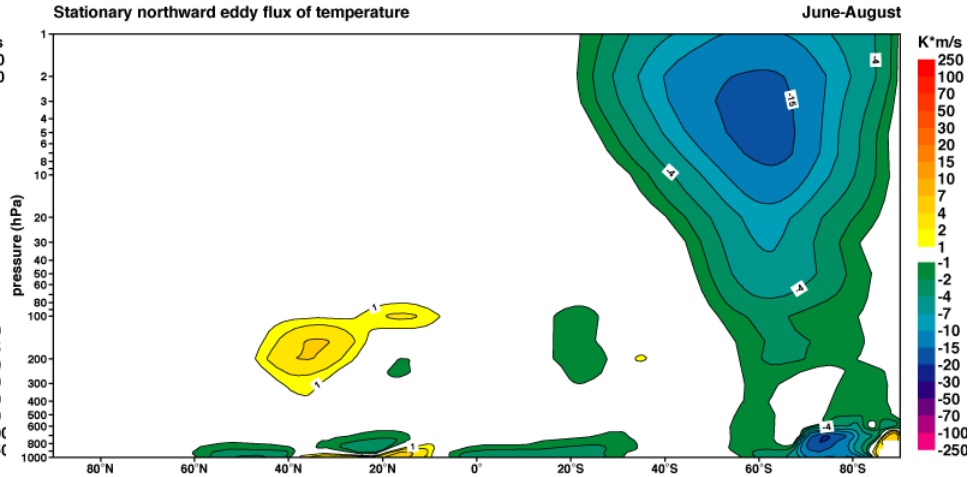


Transient and Stationary Eddy Flux of Temperature





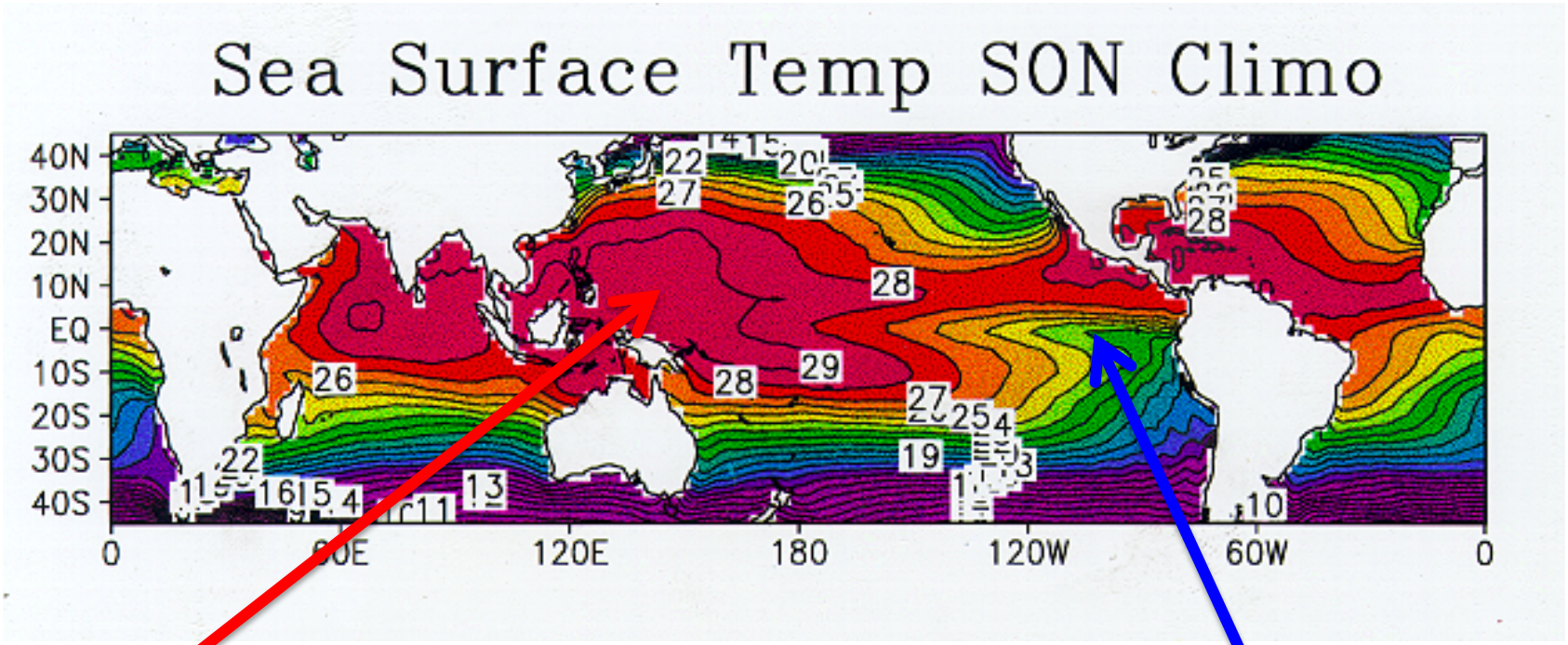




Large-Scale Circulation: Three Big Ideas

1) **Meridional Temperature and Momentum Transport (Mean Meridional Circulation)**
   - Stationary and Transient Eddies
2) **Large-Scale Tropics**
   - ENSO
3) **Climate Change**
   - Weaker Overturning Circulation

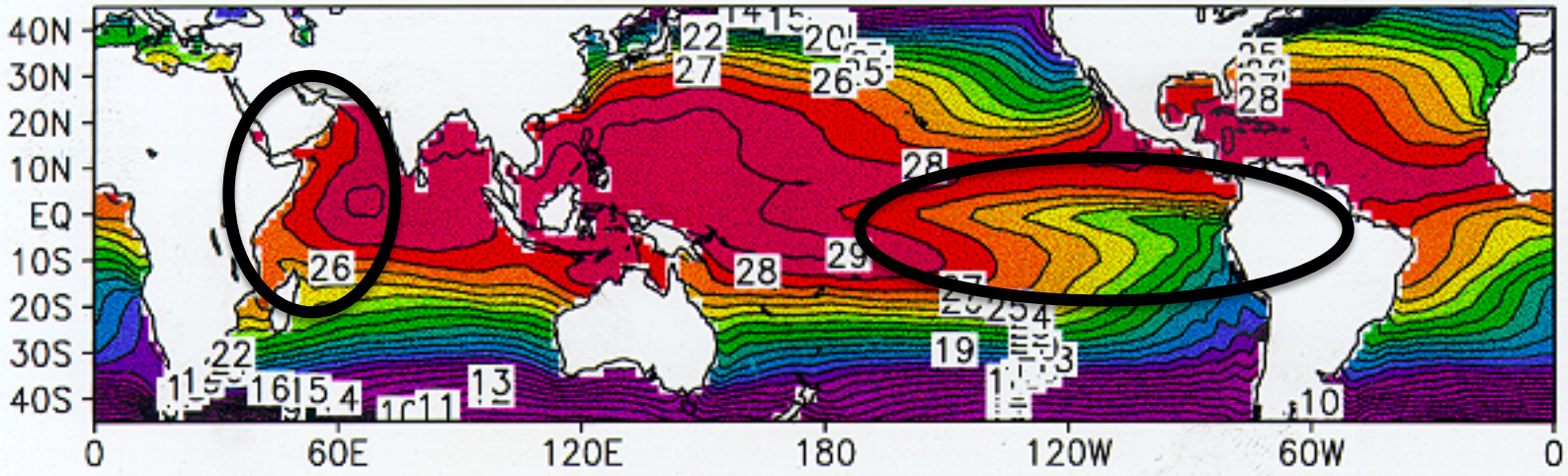
September-October-November
Sea Surface Temperature Climatology



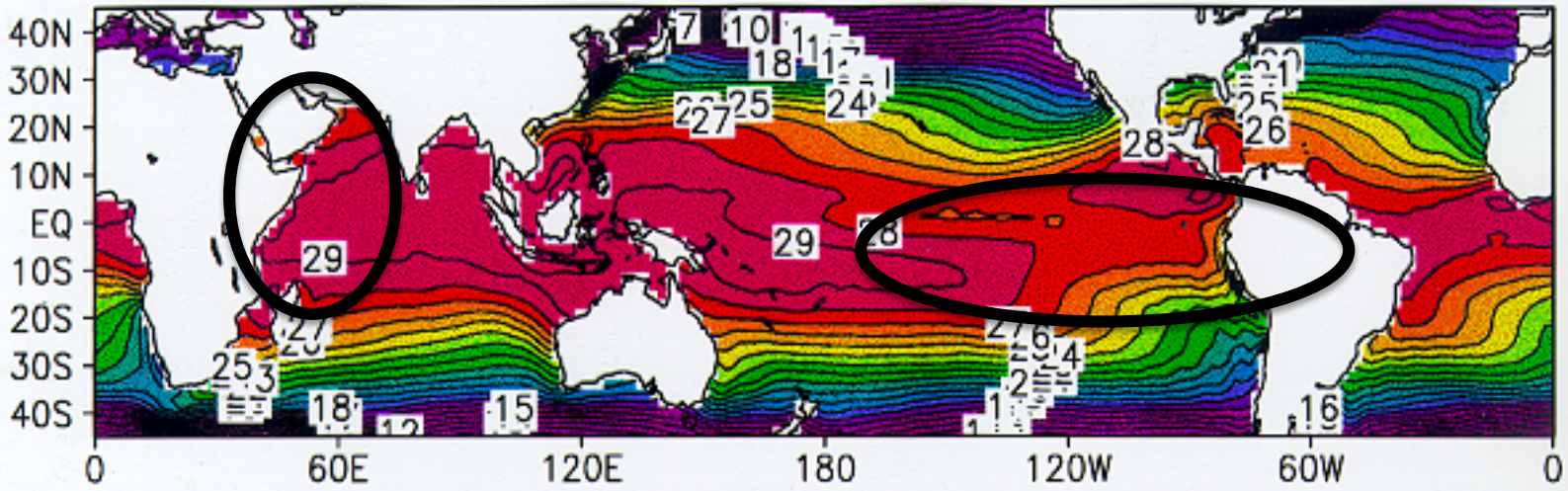
Warm Pool

Cold Tongue

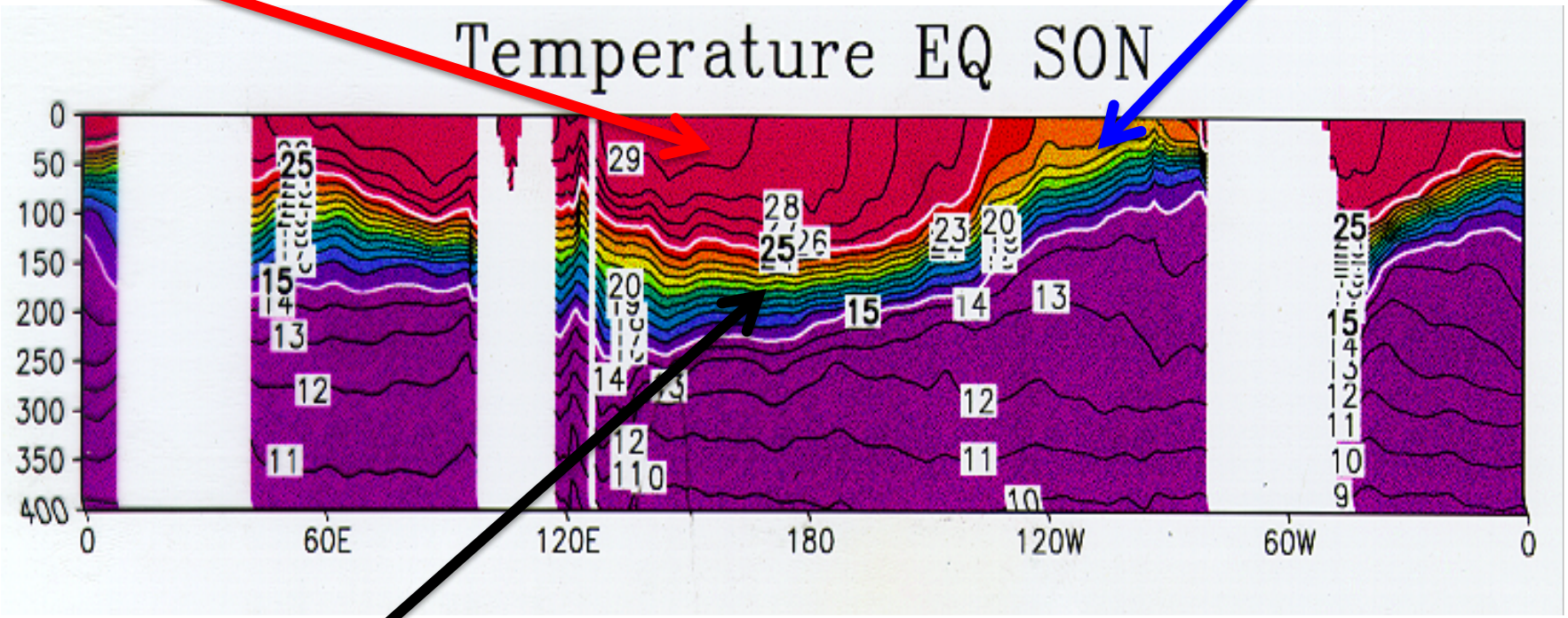
Sea Surface Temp SON Climo

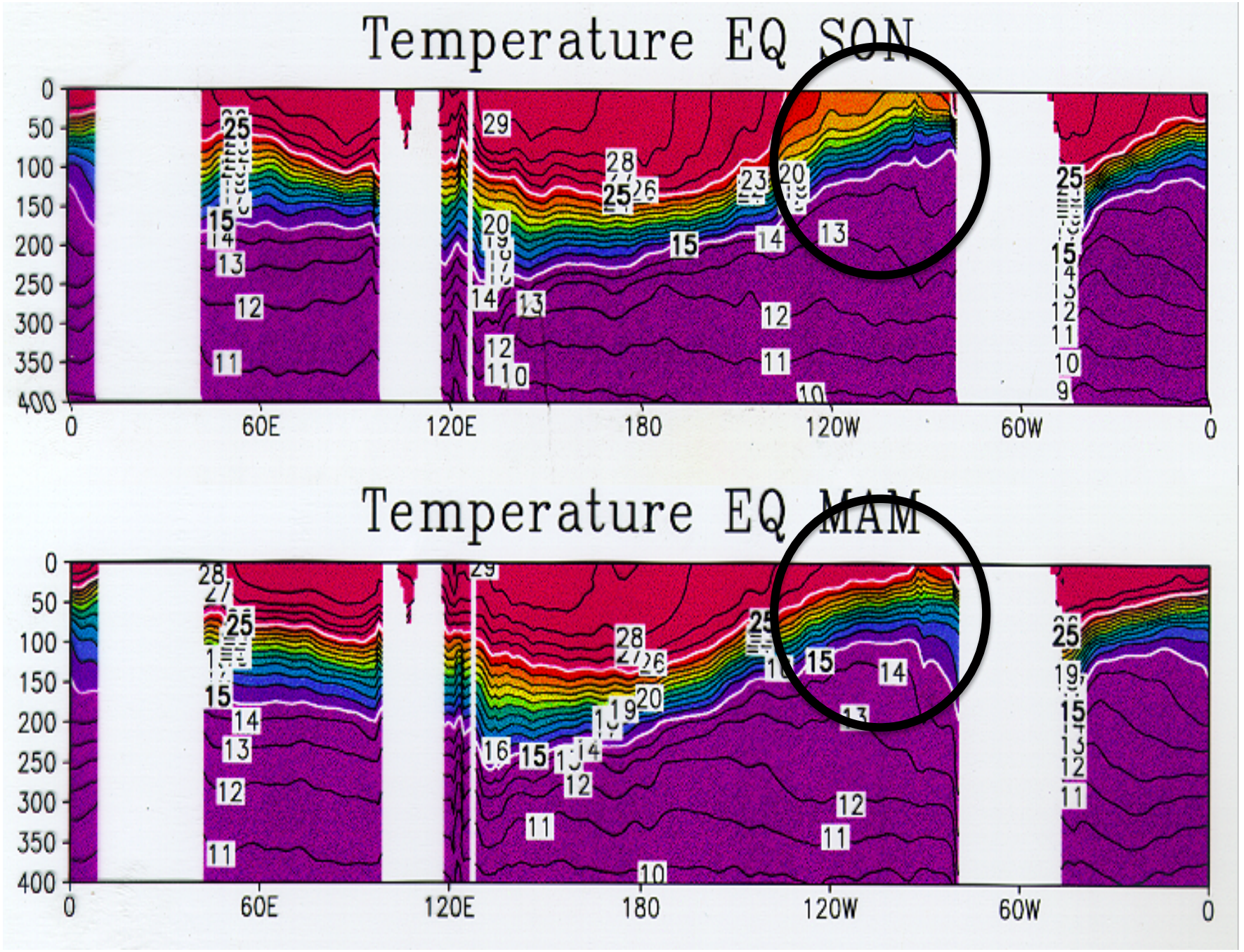


Sea Surface Temp MAM Climo

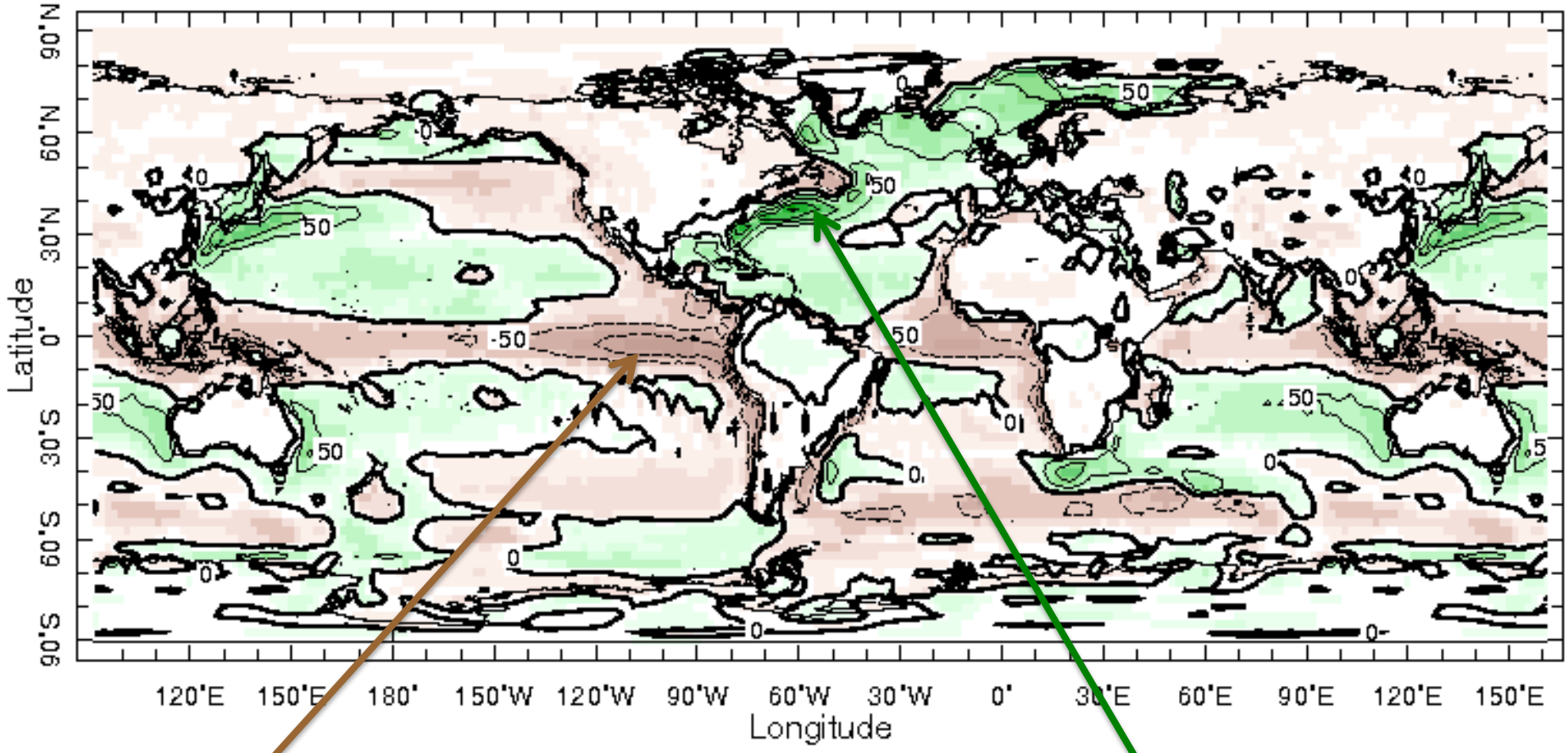


September-October-November
Equatorial Temperature Climatology




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



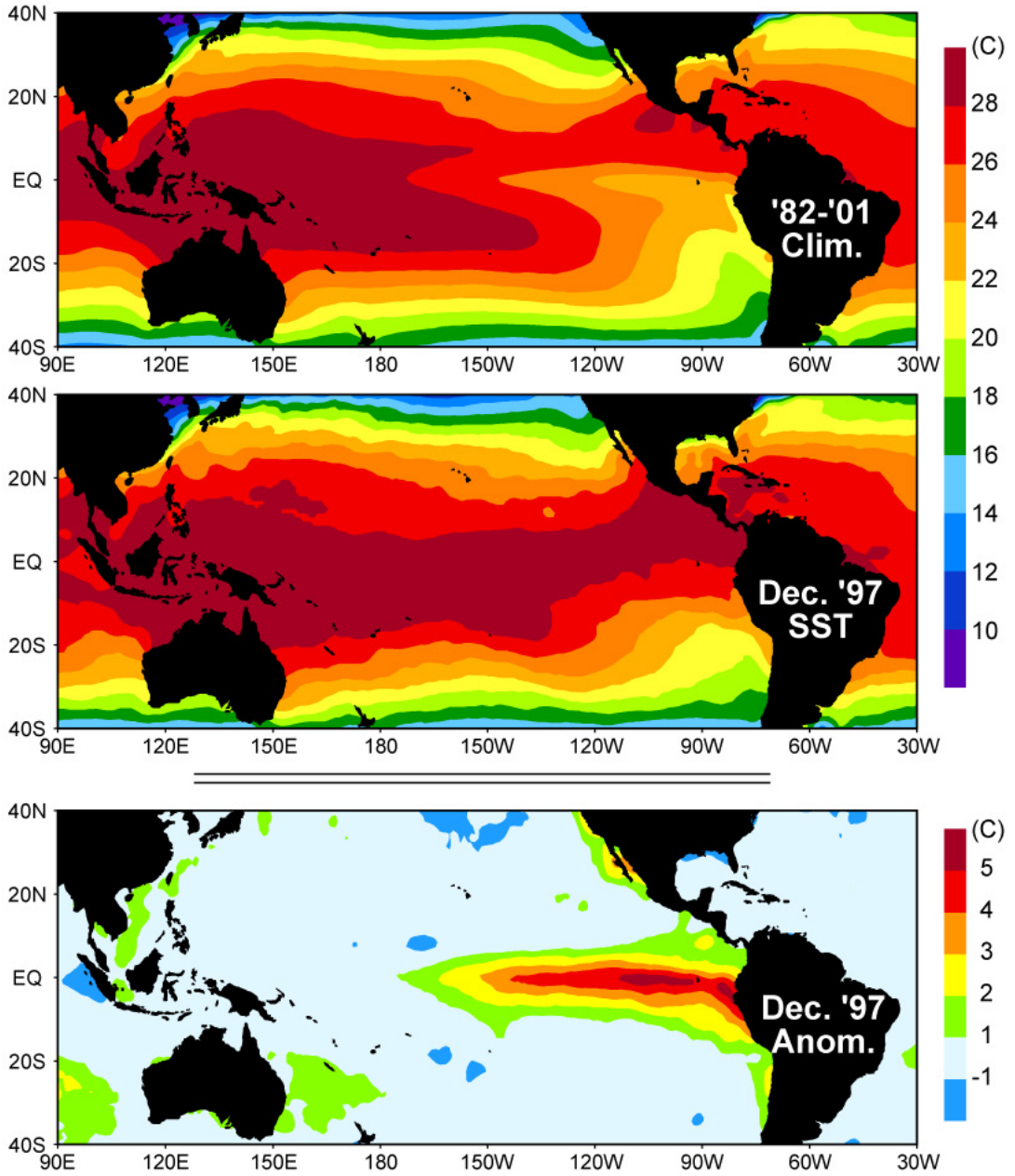
Heat Flux INTO the Ocean

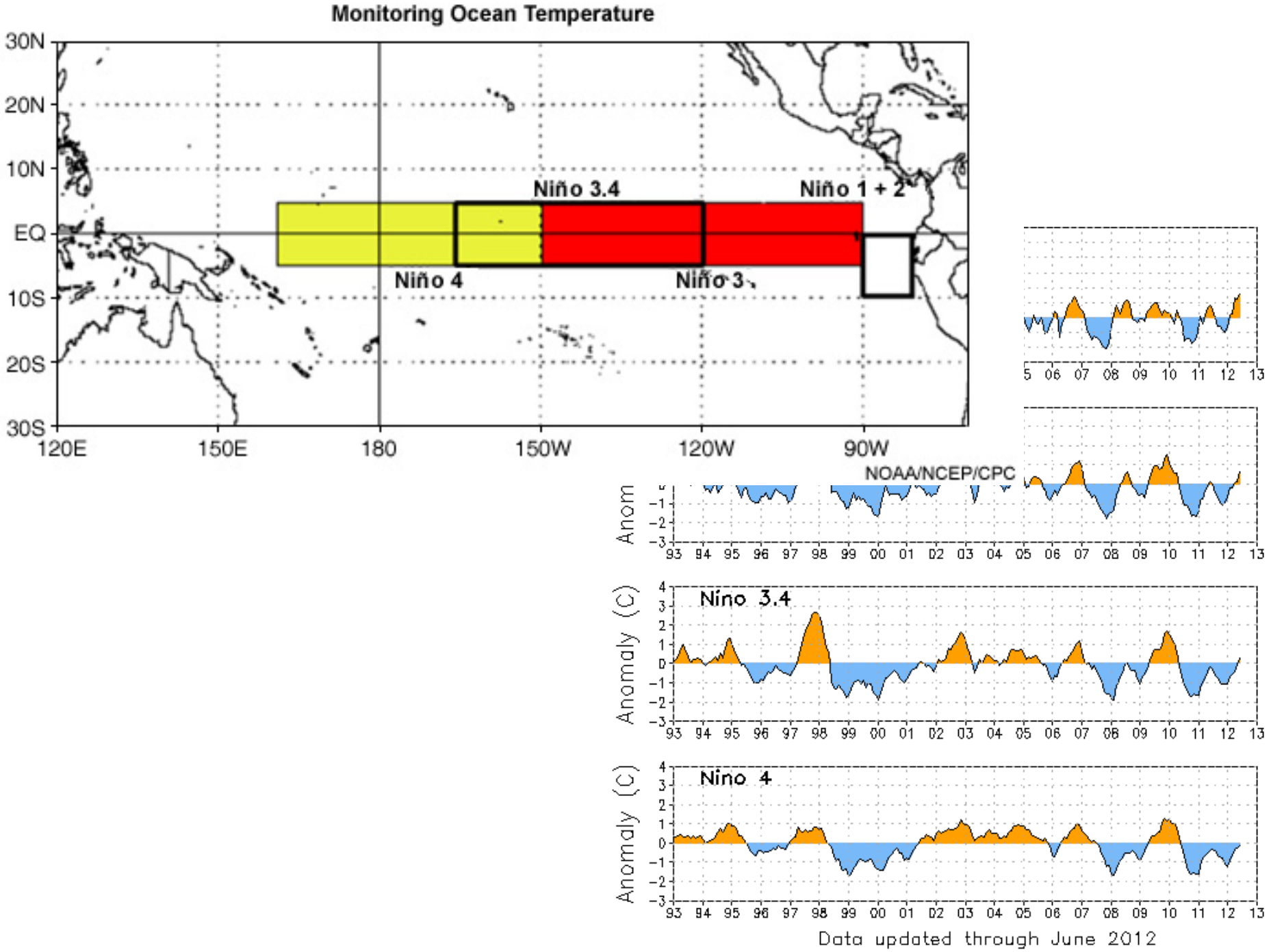
Heat Flux OUT OF the Ocean

December 1982-2001
SST Climatology

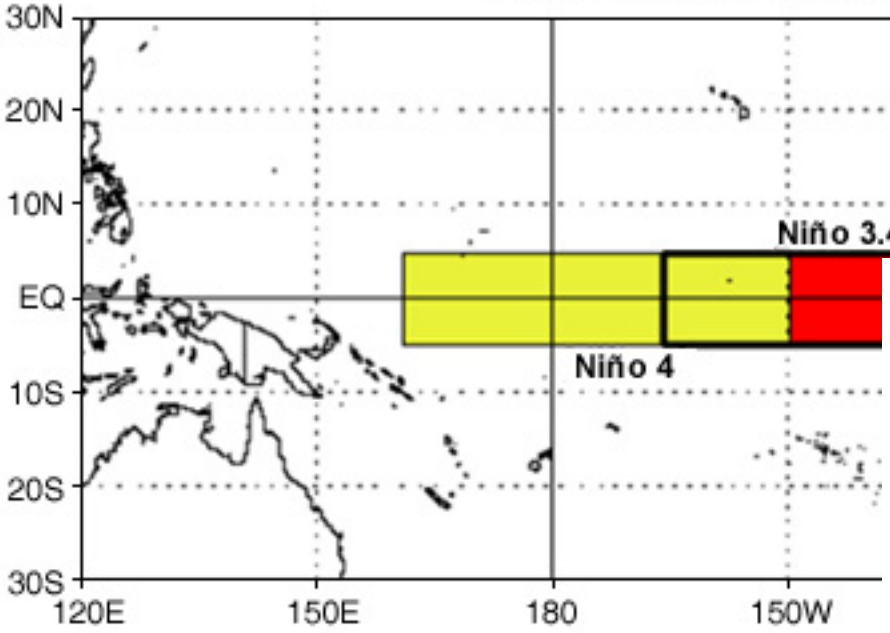
December 1997
Total SST

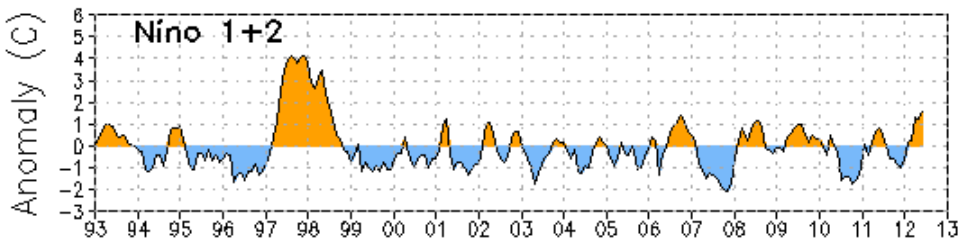
December 1997
SST Anomaly

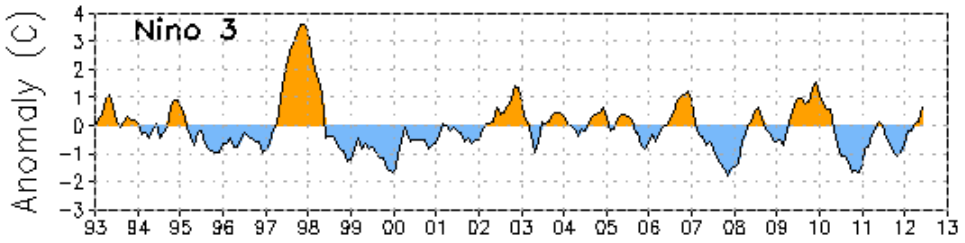


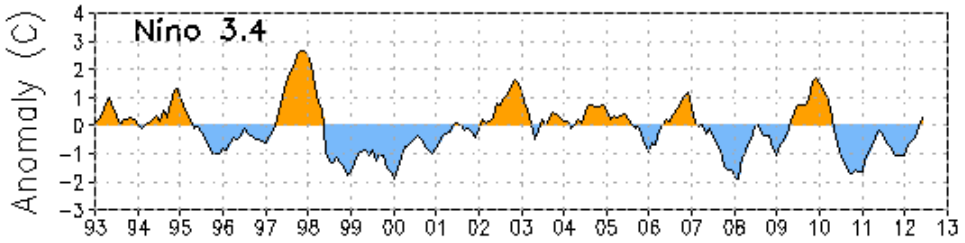

Monitoring Ocean Temperature
30N
20N
10N
EQ
10S
20S
30S
120E
150E
180
150W
120W
90W
Niño 3.4
Niño 1 + 2
Niño 4
Niño 3
NOAA/NCEP/CPC
Anom
Nino 3.4
Anomaly (C)
Nino 4
Anomaly (C)
93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13
Data updated through June 2012

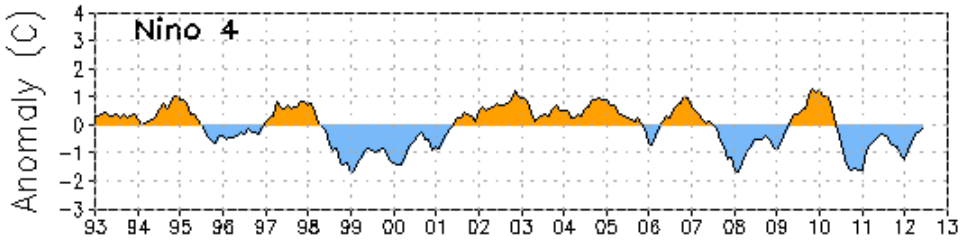
Monitoring Ocean Temperature



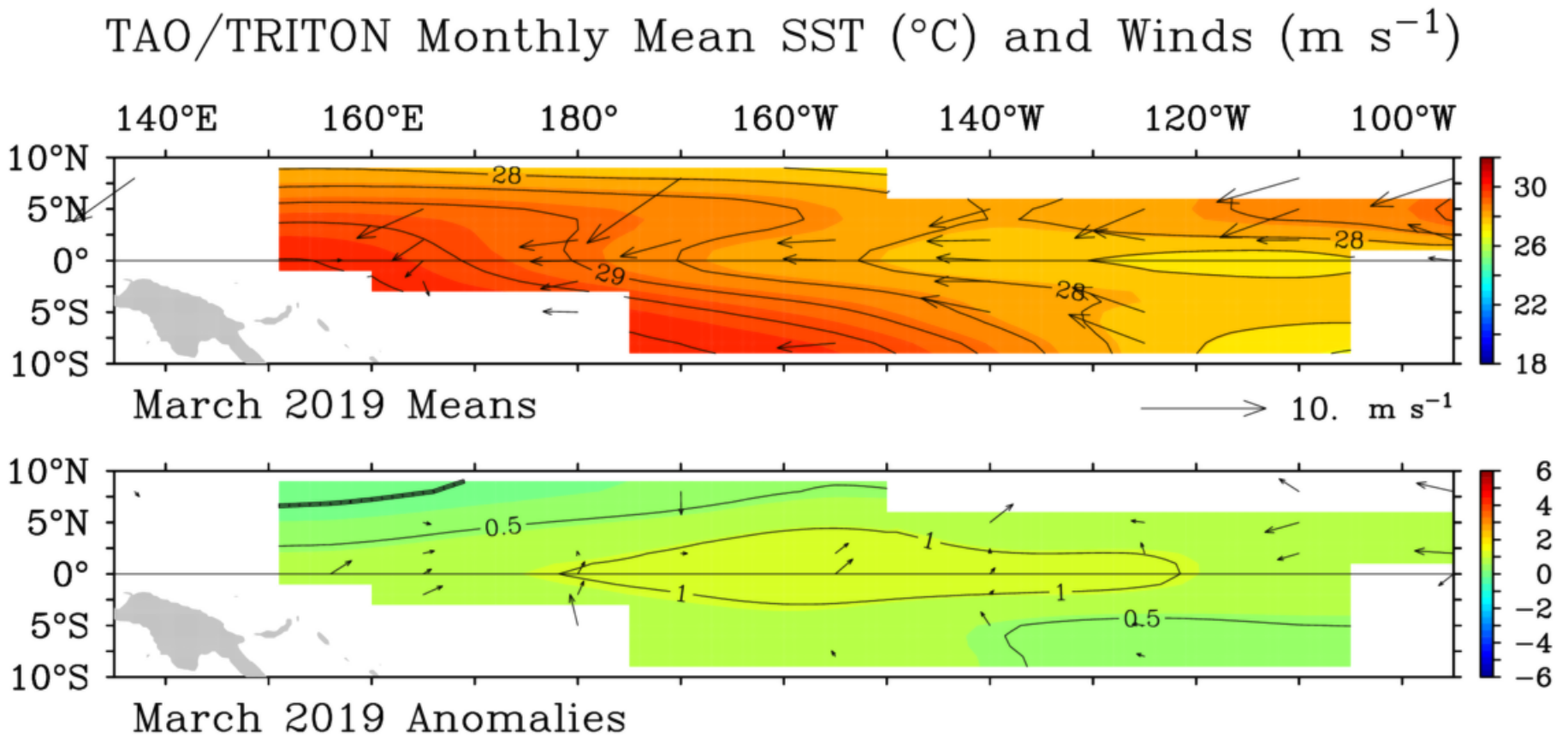






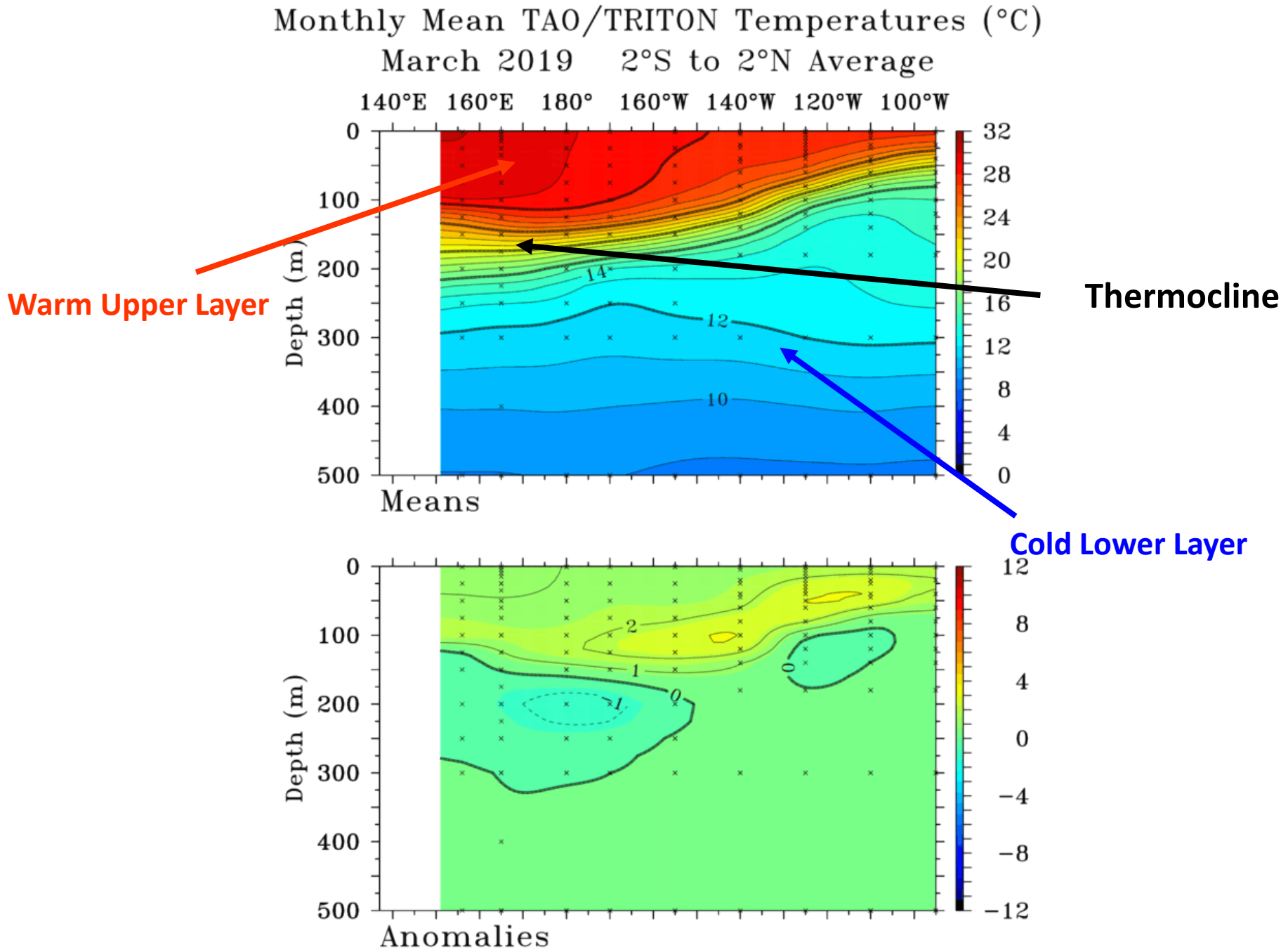


Data updated through June 2012

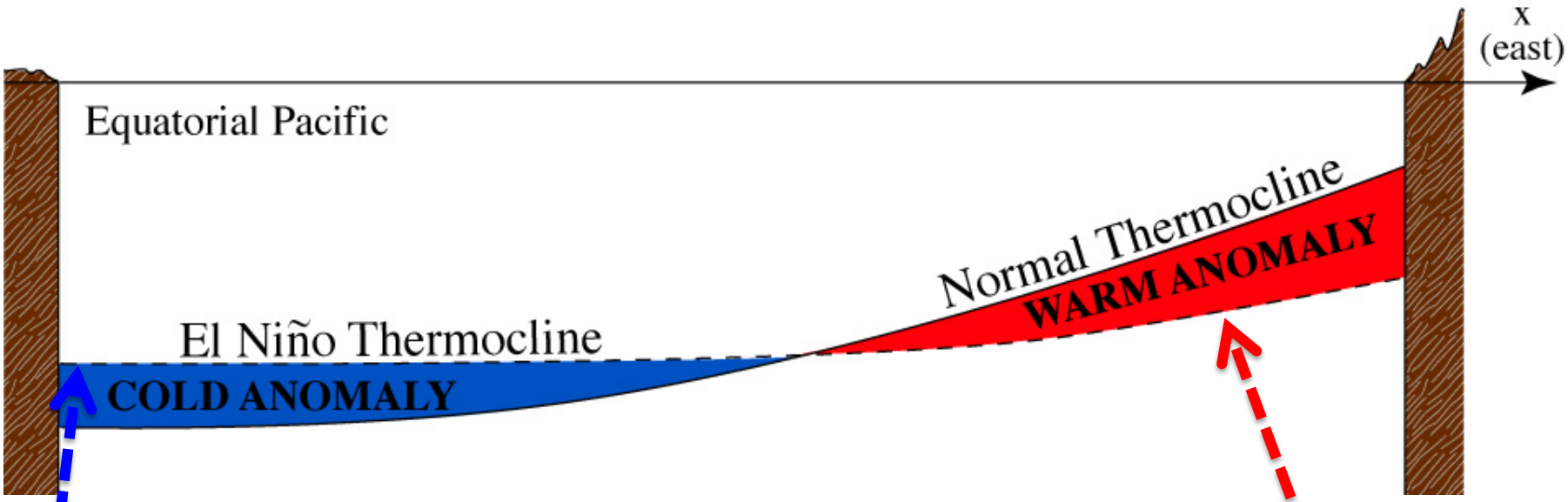


Global Tropical Moored Buoy Array Program Office, NOAA/PMEL

Apr 29 2019


Monthly Mean TAO/TRITON Temperatures (°C)
March 2019 2°S to 2°N Average
140°E 160°E 180° 160°W 140°W 120°W 100°W
Depth (m)
0
100
200
300
400
500
14
12
10
32
28
24
20
16
12
8
4
0
Means
Warm Upper Layer
Thermocline
Cold Lower Layer
2
1
0
-1
12
8
4
0
-4
-8
-12
Anomalies
Global Tropical Moored Buoy Array Program Office, NOAA/PMEL
Apr 29 2019

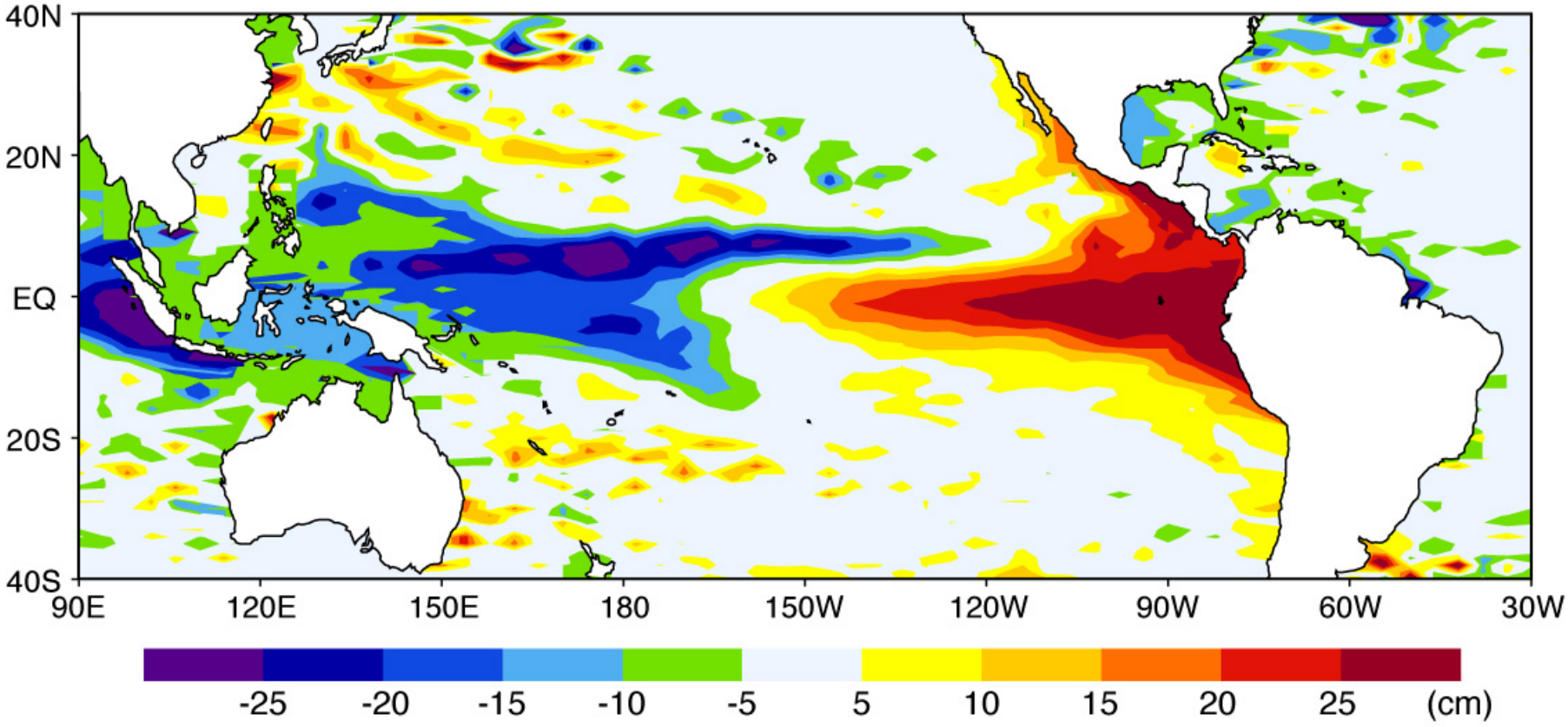
El Nino vs. Normal Thermocline Depth

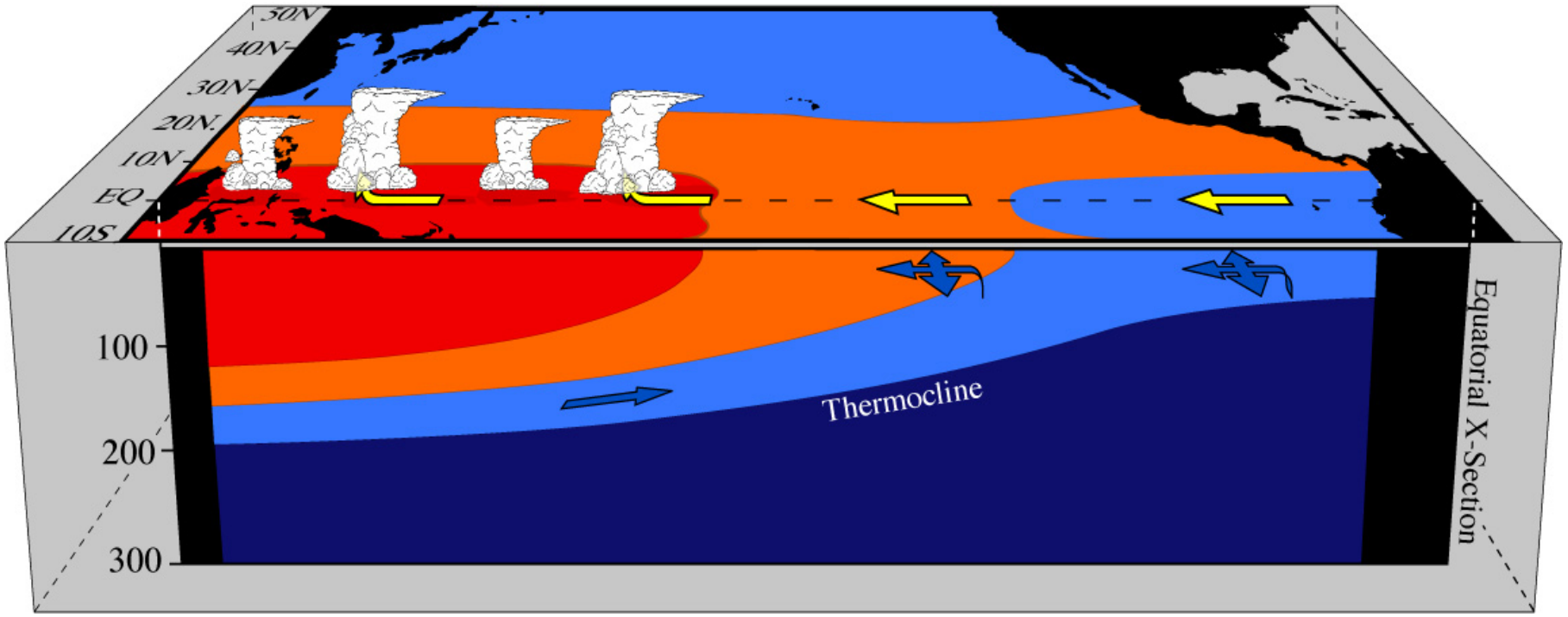


Thermocline is Shallower than Normal
Negative Depth Anomaly

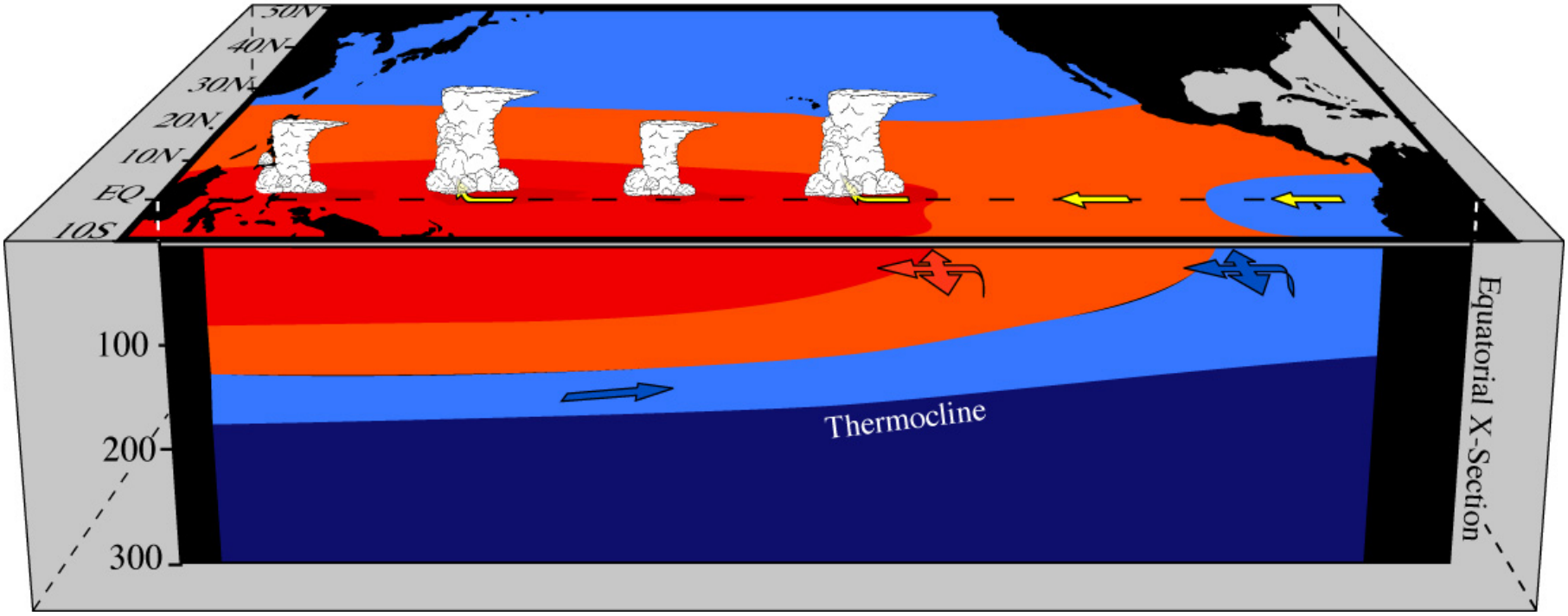
Thermocline is Deeper than Normal
Positive Depth Anomaly

December 1997 (El Nino) Thermocline Depth Anomalies)

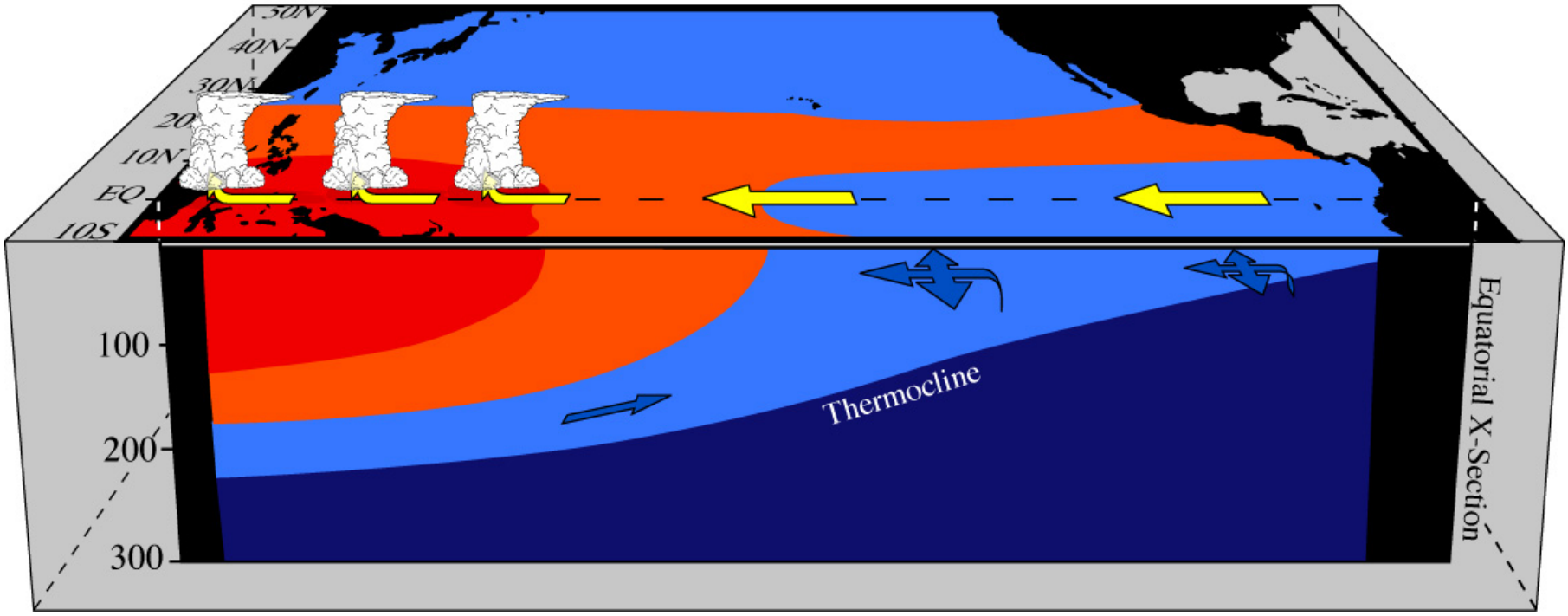




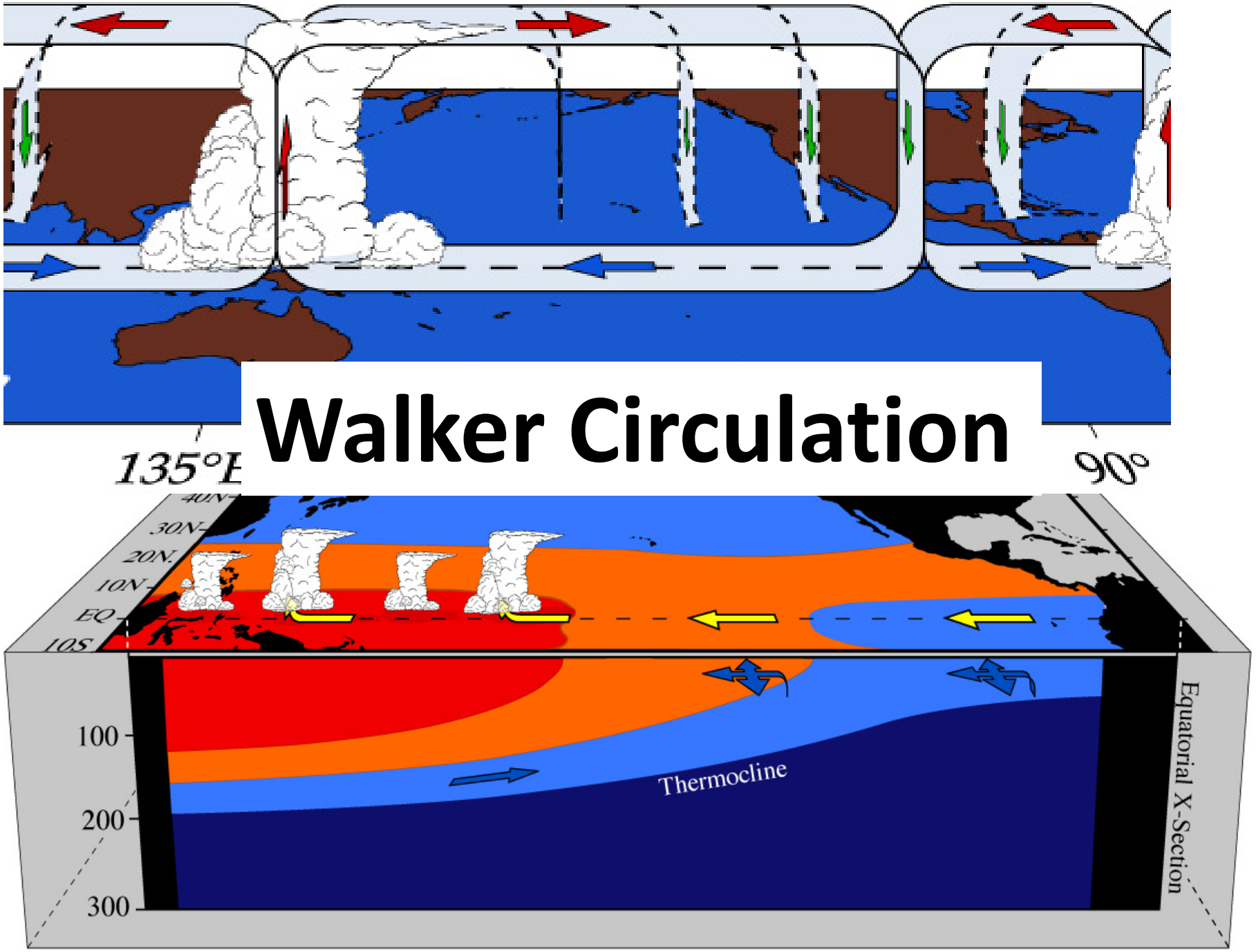
Normal Conditions in the Tropical Pacific



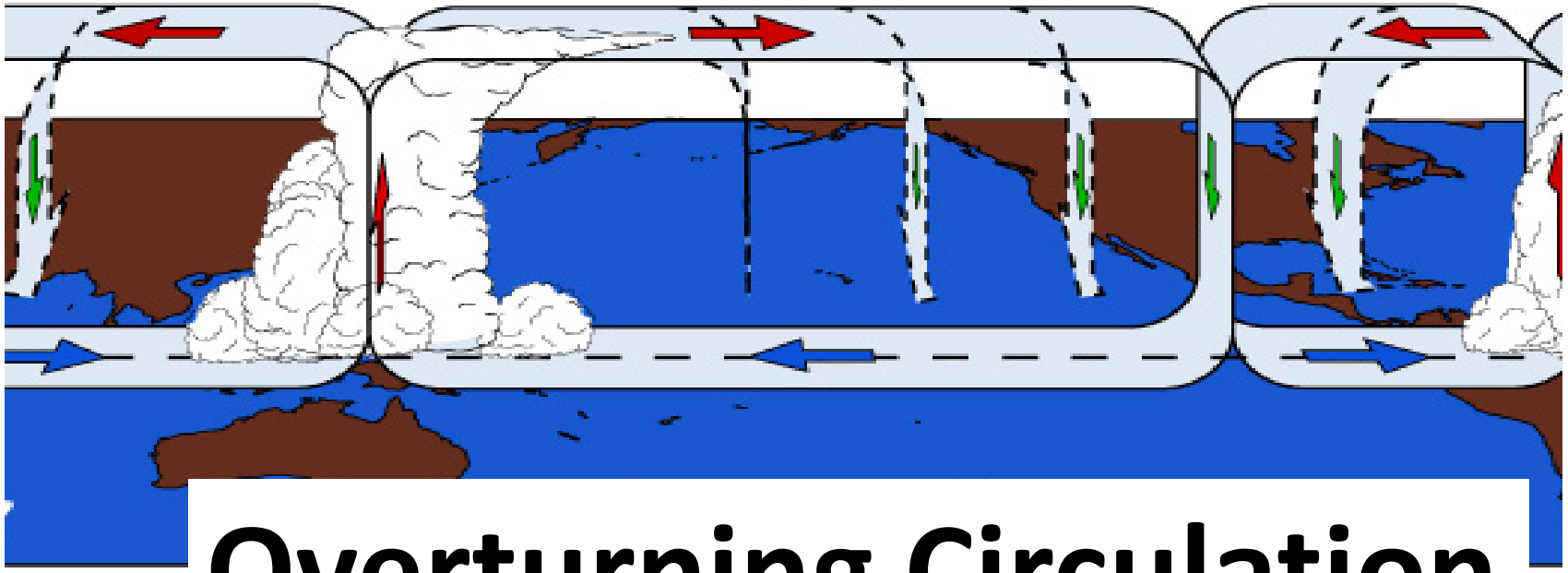
Warm (El Nino) Conditions in the Tropical Pacific



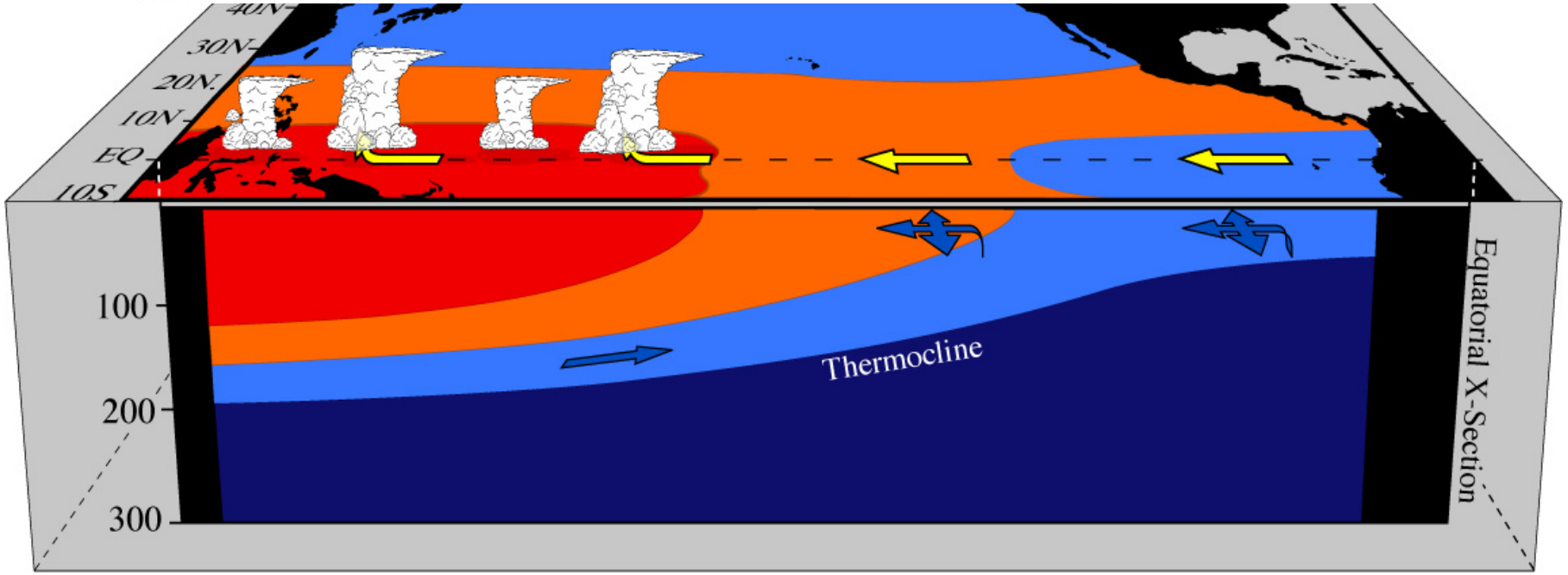
Cold (La Nina) Conditions in the Tropical Pacific

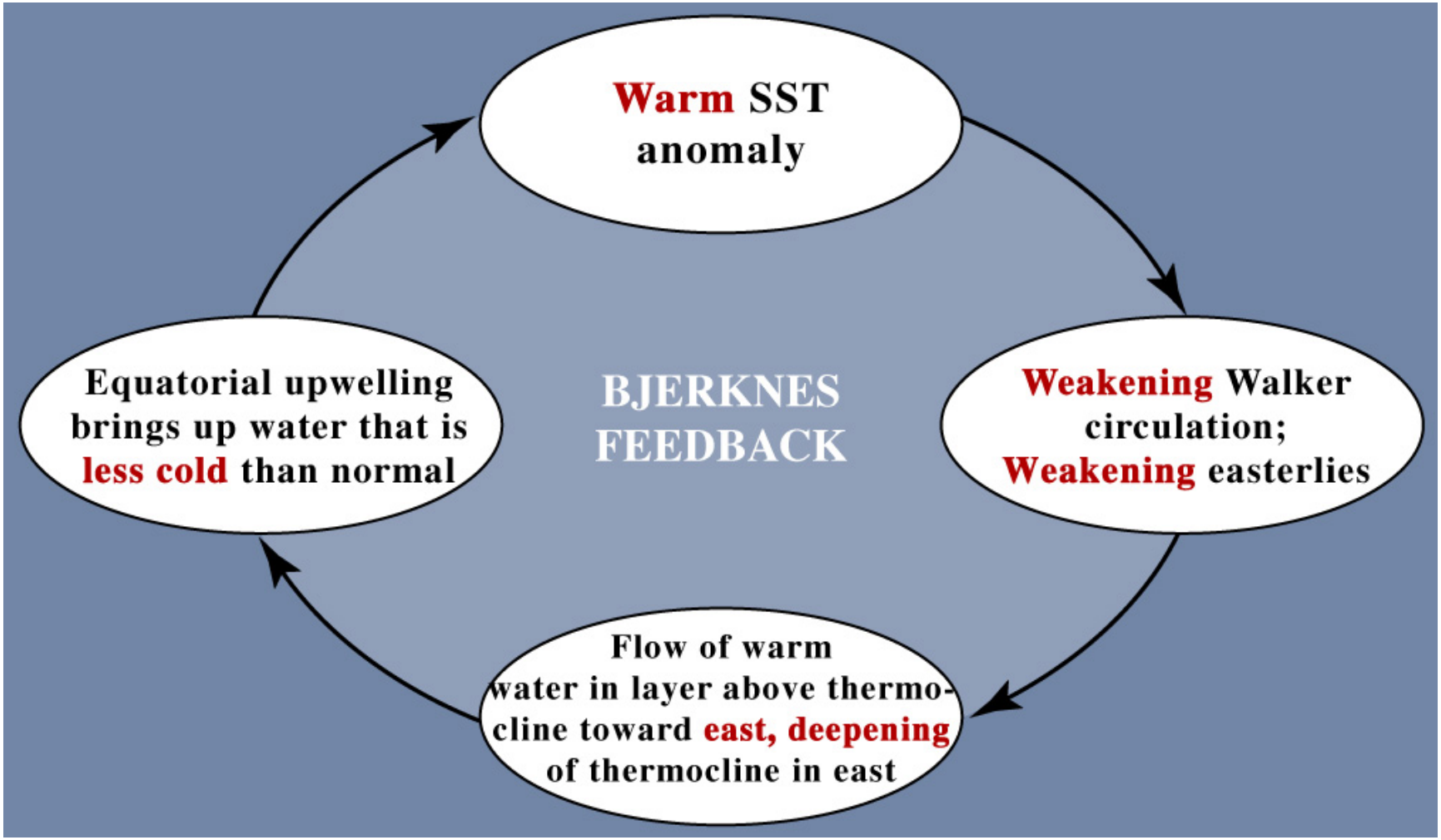


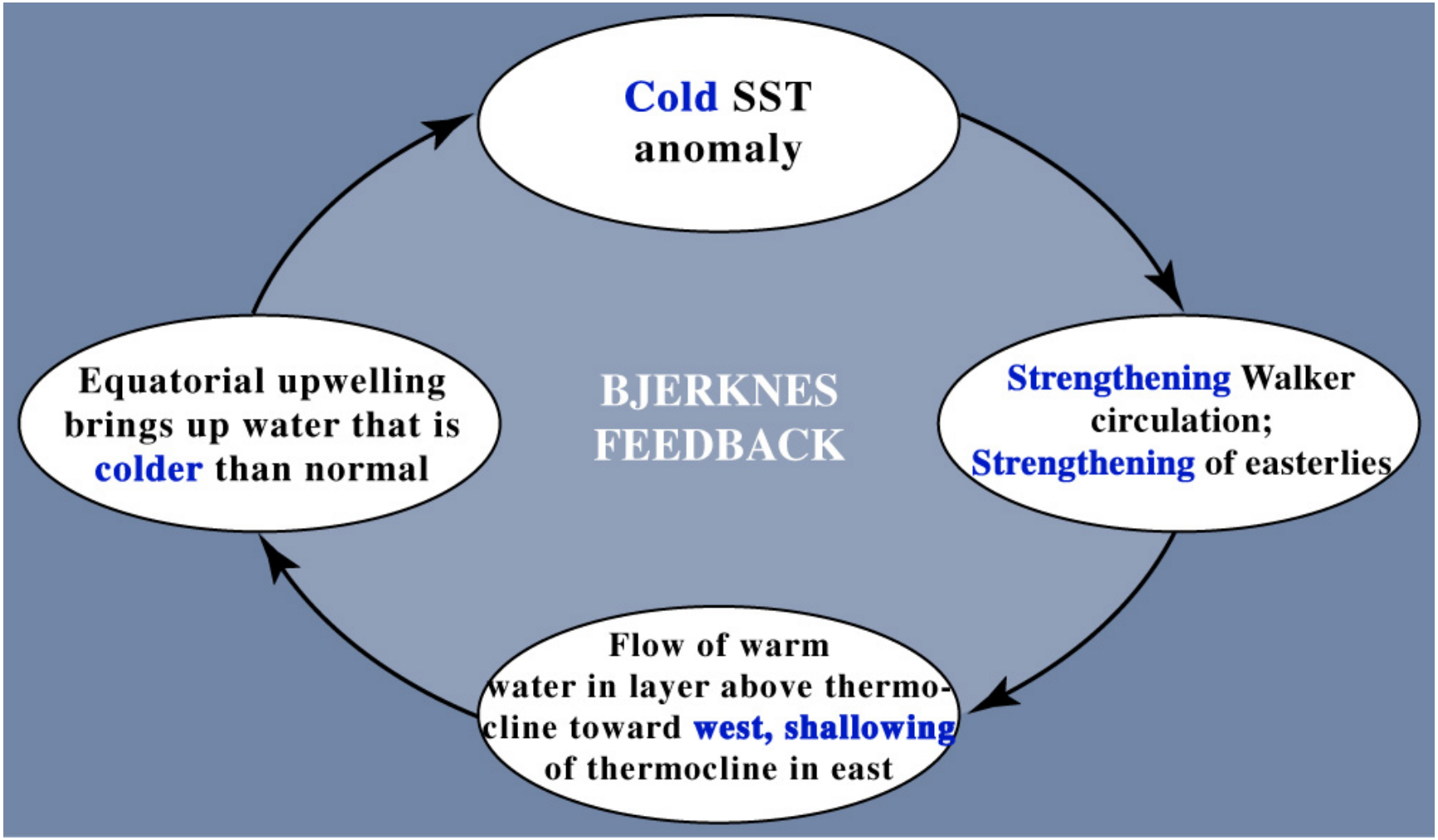
Walker Circulation



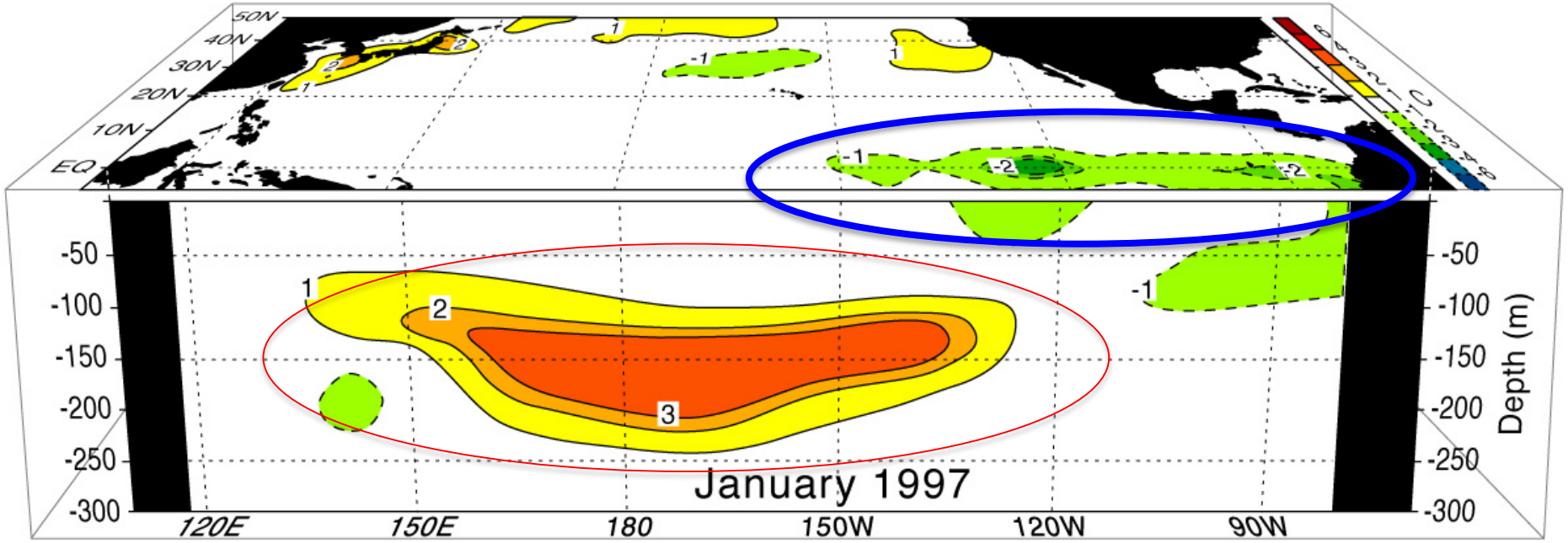
Overturning Circulation



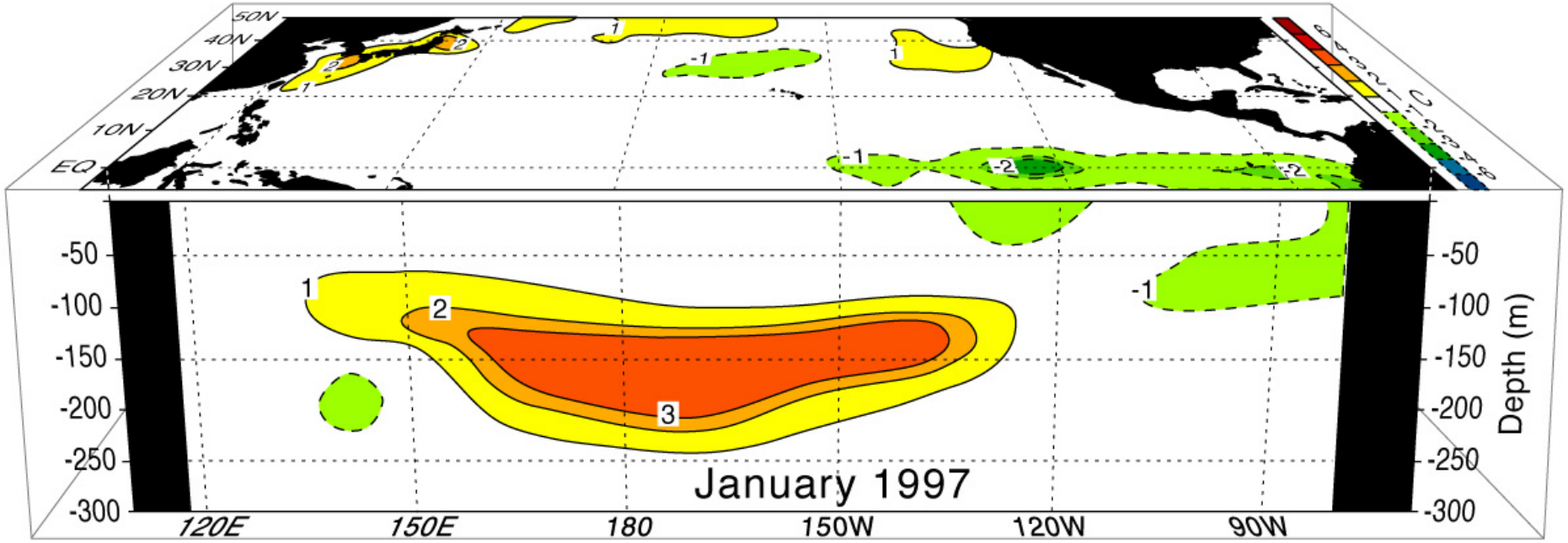

Warm SST anomaly
Weakening Walker circulation; Weakening easterlies
Flow of warm water in layer above thermo-cline toward east, deepening of thermocline in east
Equatorial upwelling brings up water that is less cold than normal
BJERKNES FEEDBACK

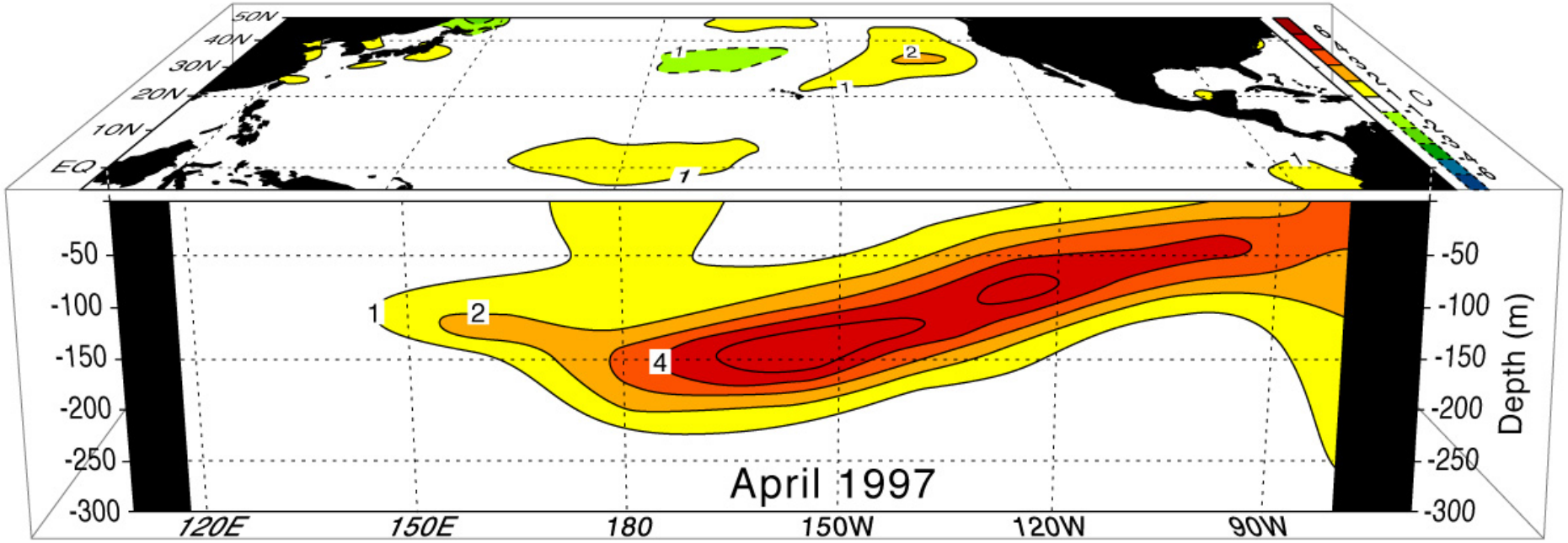

Cold SST anomaly
Strengthening Walker circulation; Strengthening of easterlies
Flow of warm water in layer above thermo-cline toward west, shallowing of thermocline in east
Equatorial upwelling brings up water that is colder than normal
BJERKNES FEEDBACK

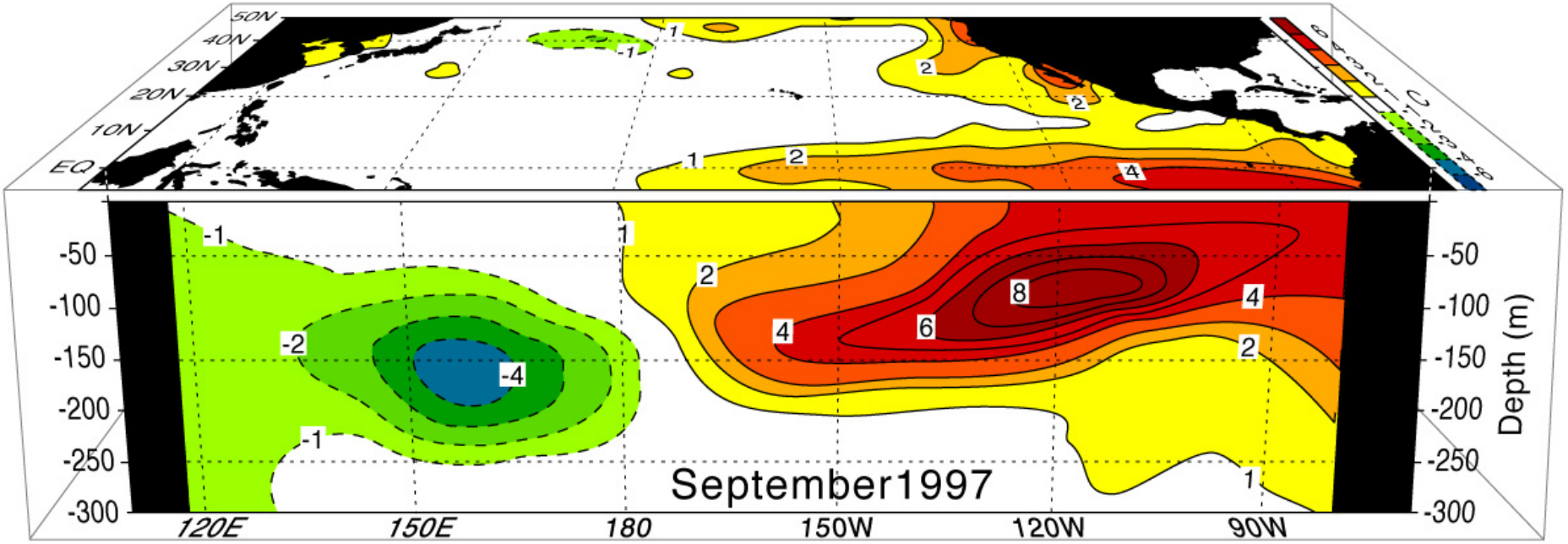
Evolution of the 1997-98 ENSO Event



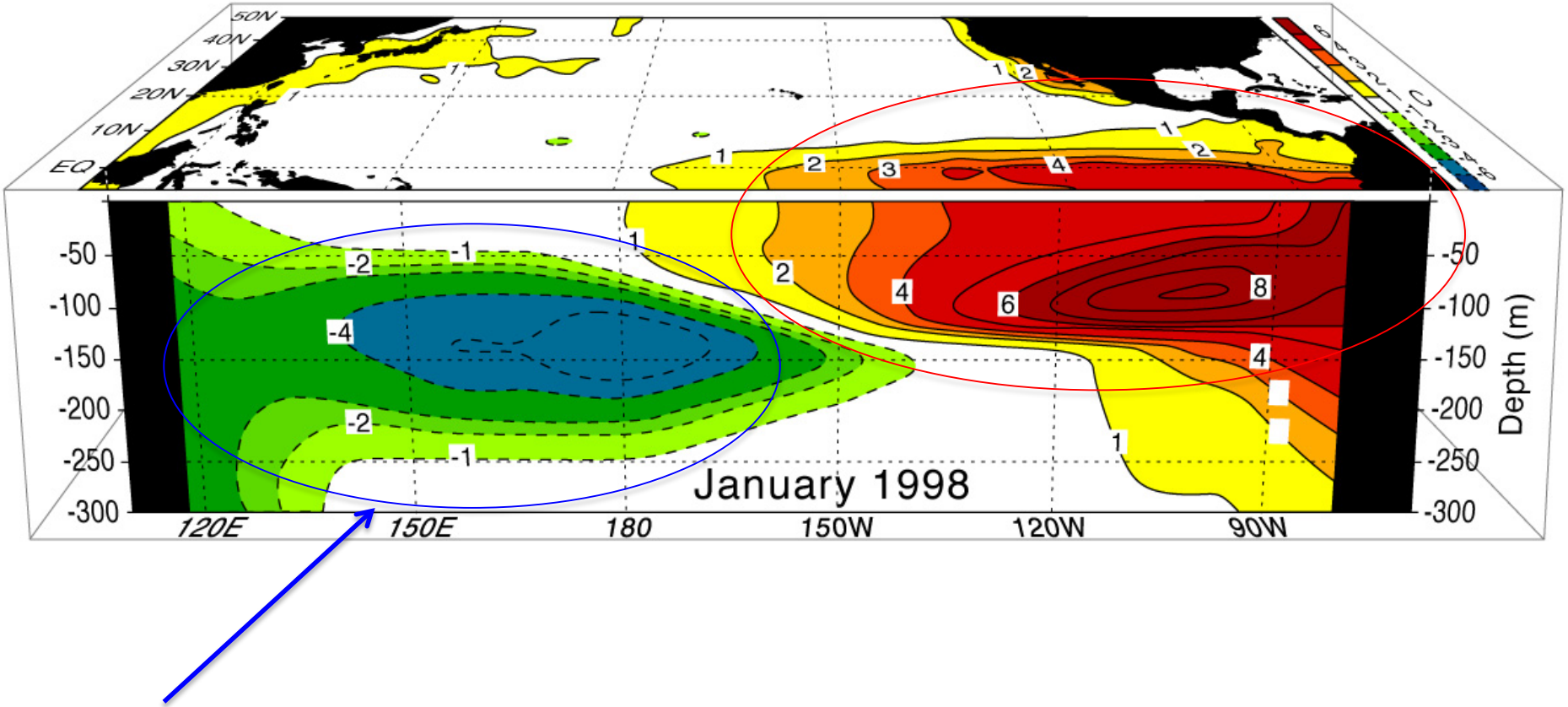
Warm Sub-Surface Temperature (Deeper Thermocline) Anomaly is the Precursor of the Coming Warm Event – Why We Can Predict


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

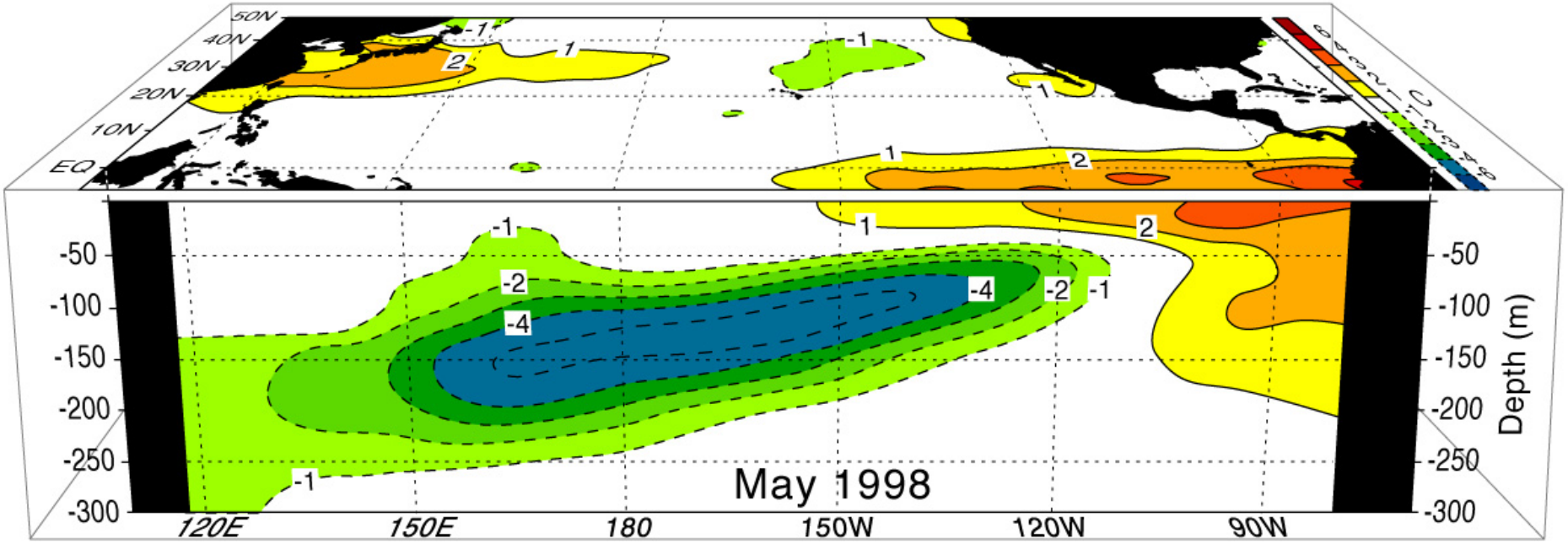

50N
40N
30N
20N
10N
EQ
1
2
1
1
1
-50
-100
-150
-200
-250
-300
1
2
4
April 1997
120E
150E
180
150W
120W
90W
Depth (m)

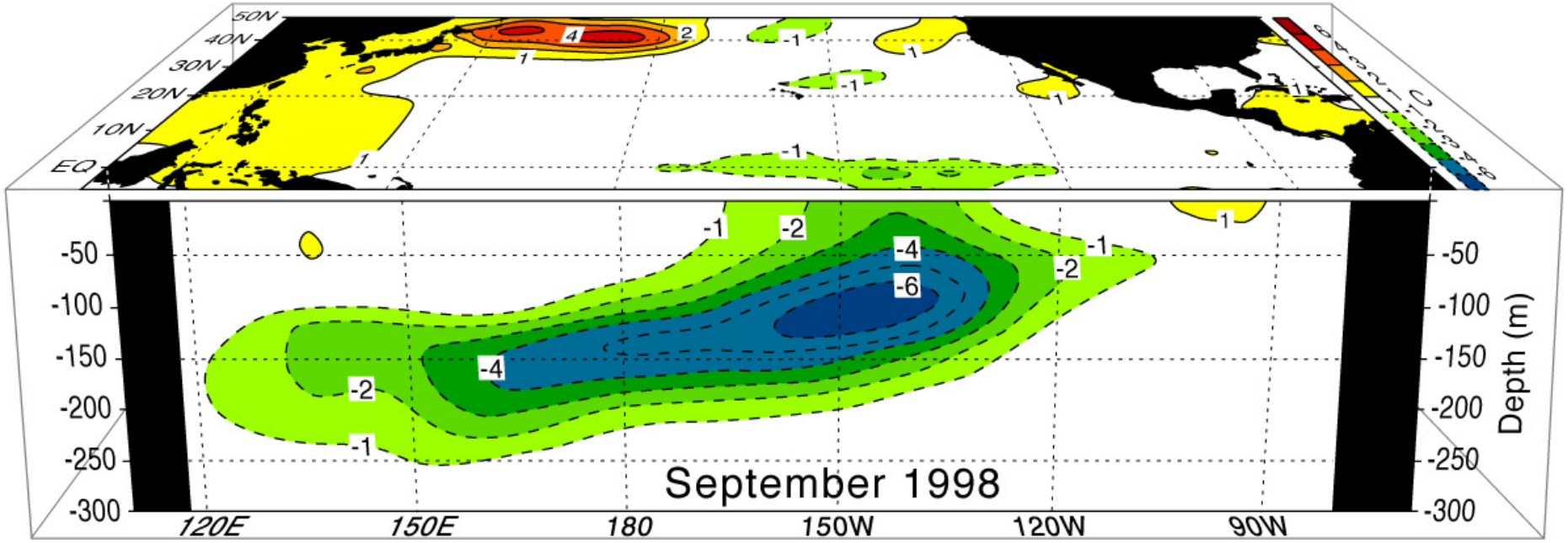

50N
40N
30N
20N
10N
EQ
-1
1
2
4
-50
-100
-150
-200
-250
-300
-2
-4
6
8
Depth (m)
September1997
120E
150E
180
150W
120W
90W

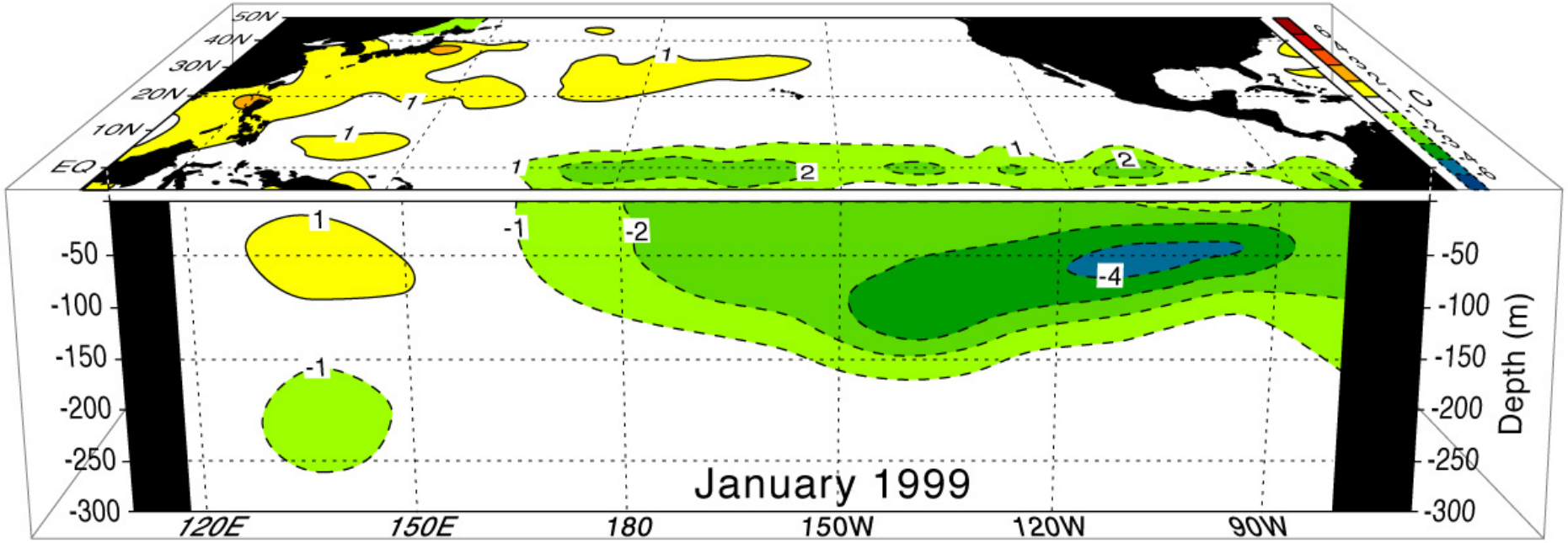
Mature Warm Event

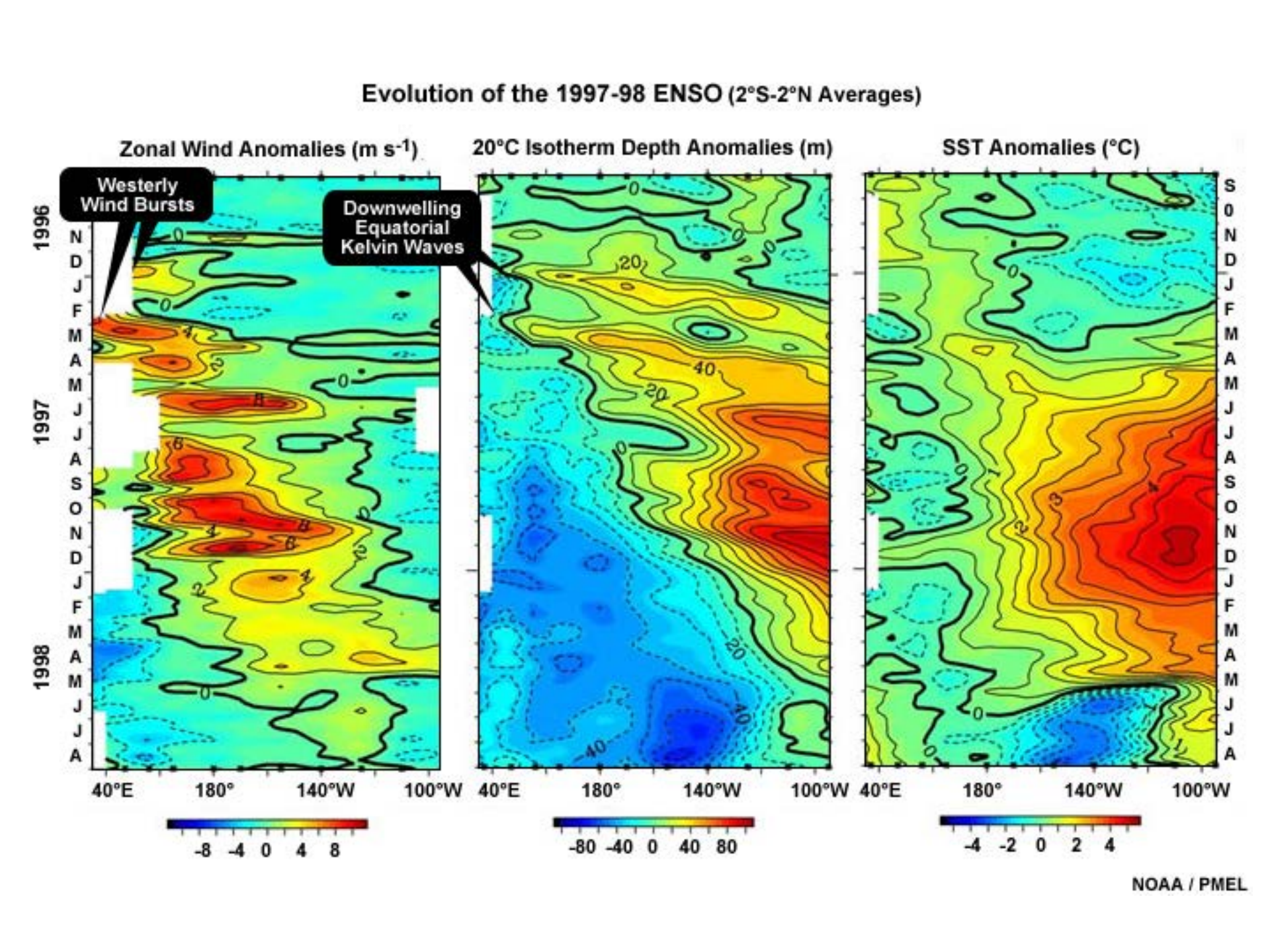


The Precursor of the Coming Cold Event


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

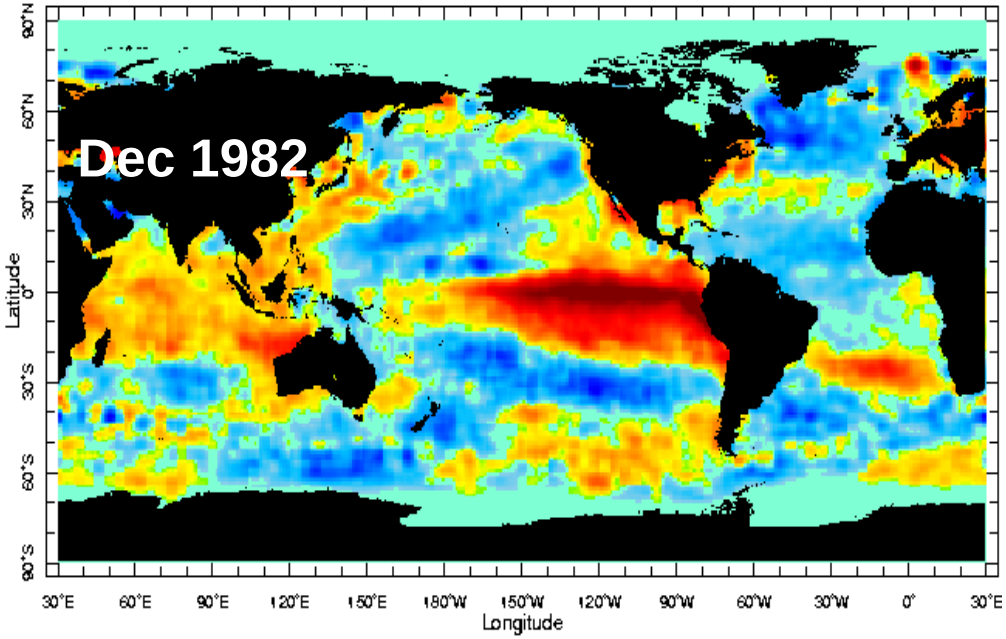

50N
40N
30N
20N
10N
EQ
4
2
1
-1
-50
-100
-150
-200
-250
-300
-6
-4
-2
Depth (m)
September 1998
120E
150E
180
150W
120W
90W

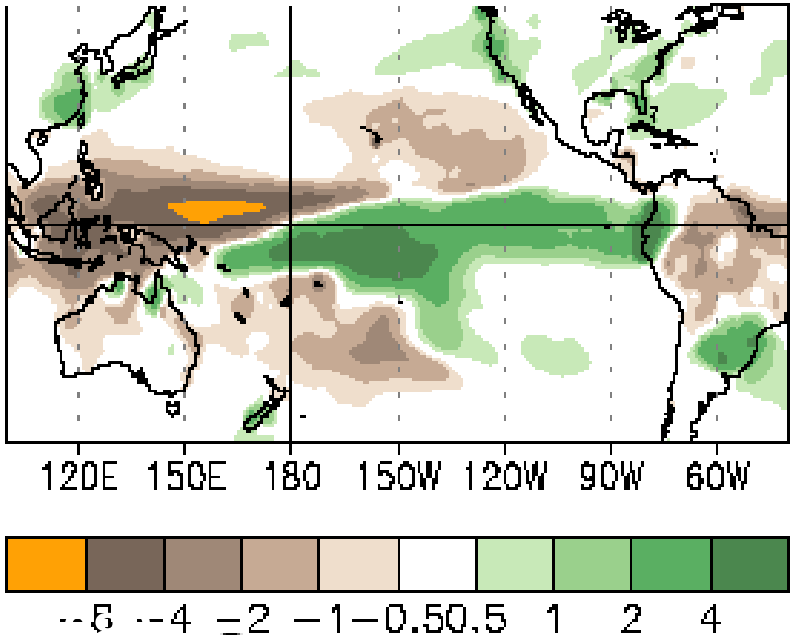

50N
40N
30N
20N
10N
EQ
120E
150E
180
150W
120W
90W
-50
-100
-150
-200
-250
-300
Depth (m)
January 1999

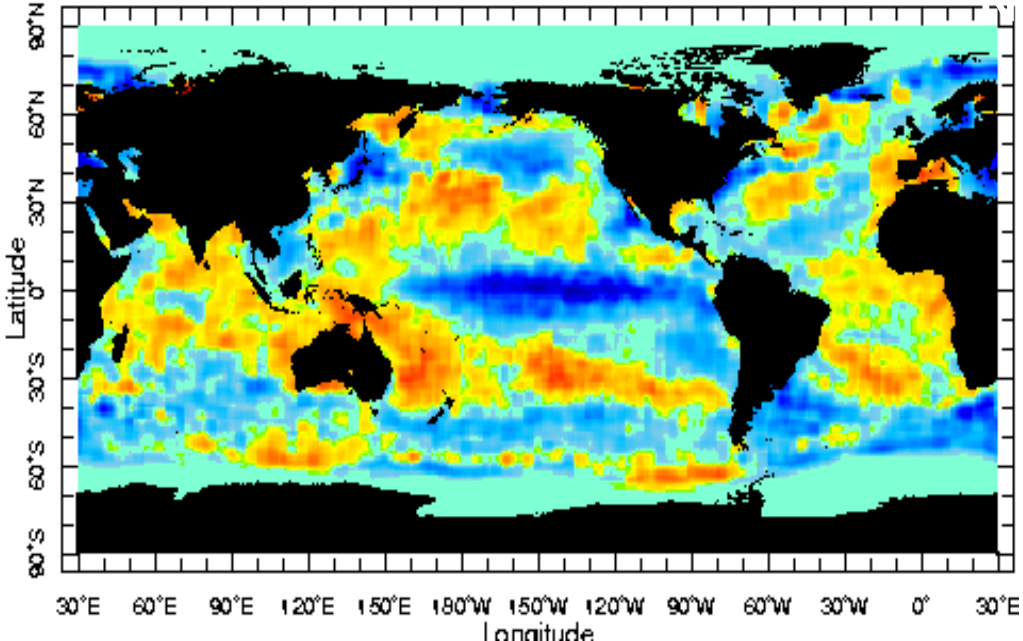

Evolution of the 1997-98 ENSO (2°S-2°N Averages)
Zonal Wind Anomalies (m s-1)
20°C Isotherm Depth Anomalies (m)
SST Anomalies (°C)
Westerly Wind Bursts
Downwelling Equatorial Kelvin Waves
1996
1997
1998
N D J F M A M J J A S O N D J F M A M J J A
S O N D J F M A M J J A S O N D J F M A M J J A
40°E
180°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

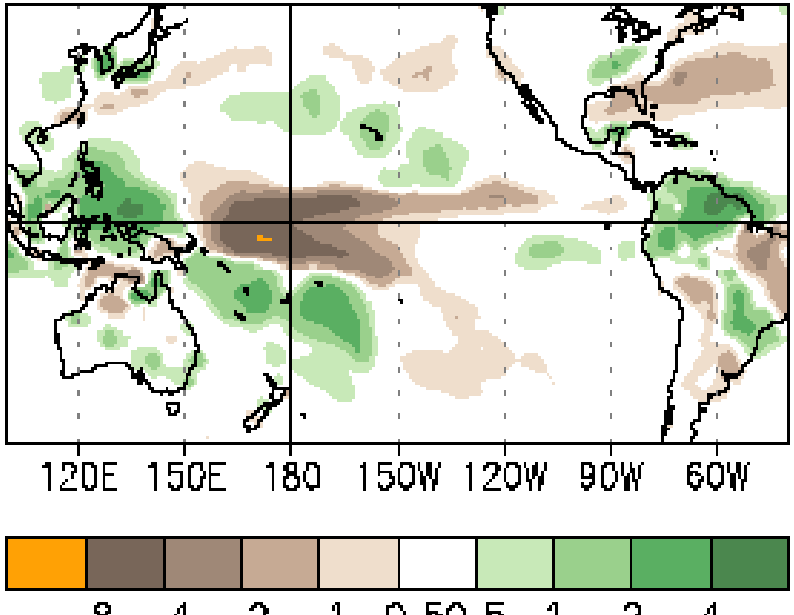
Teleconnections

SST ⇒ Rainfall







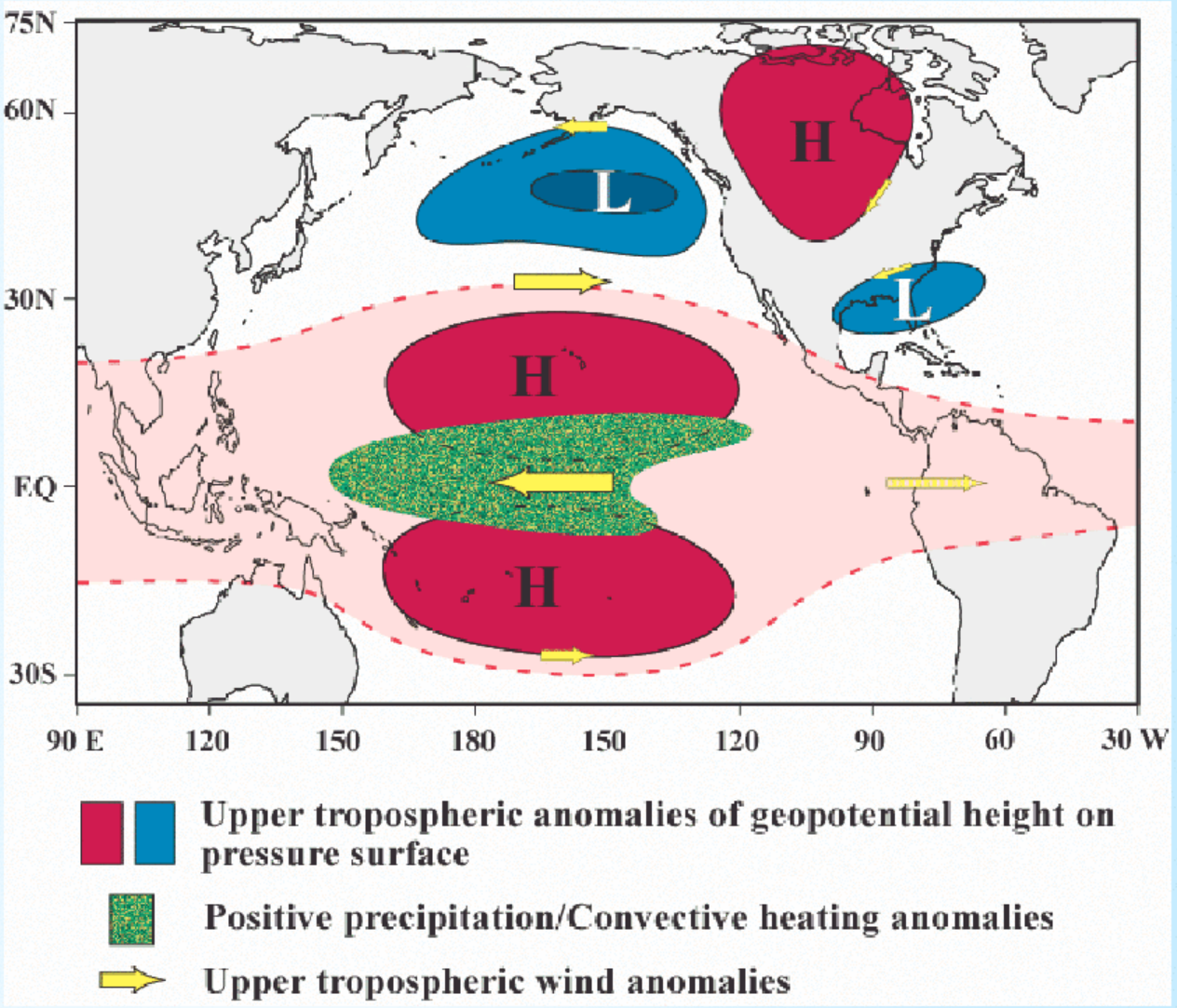


Pacific - North American sector Response to El Niño

La Niña: opposite sign to a first approximation
(but weaker, esp. over N. America)

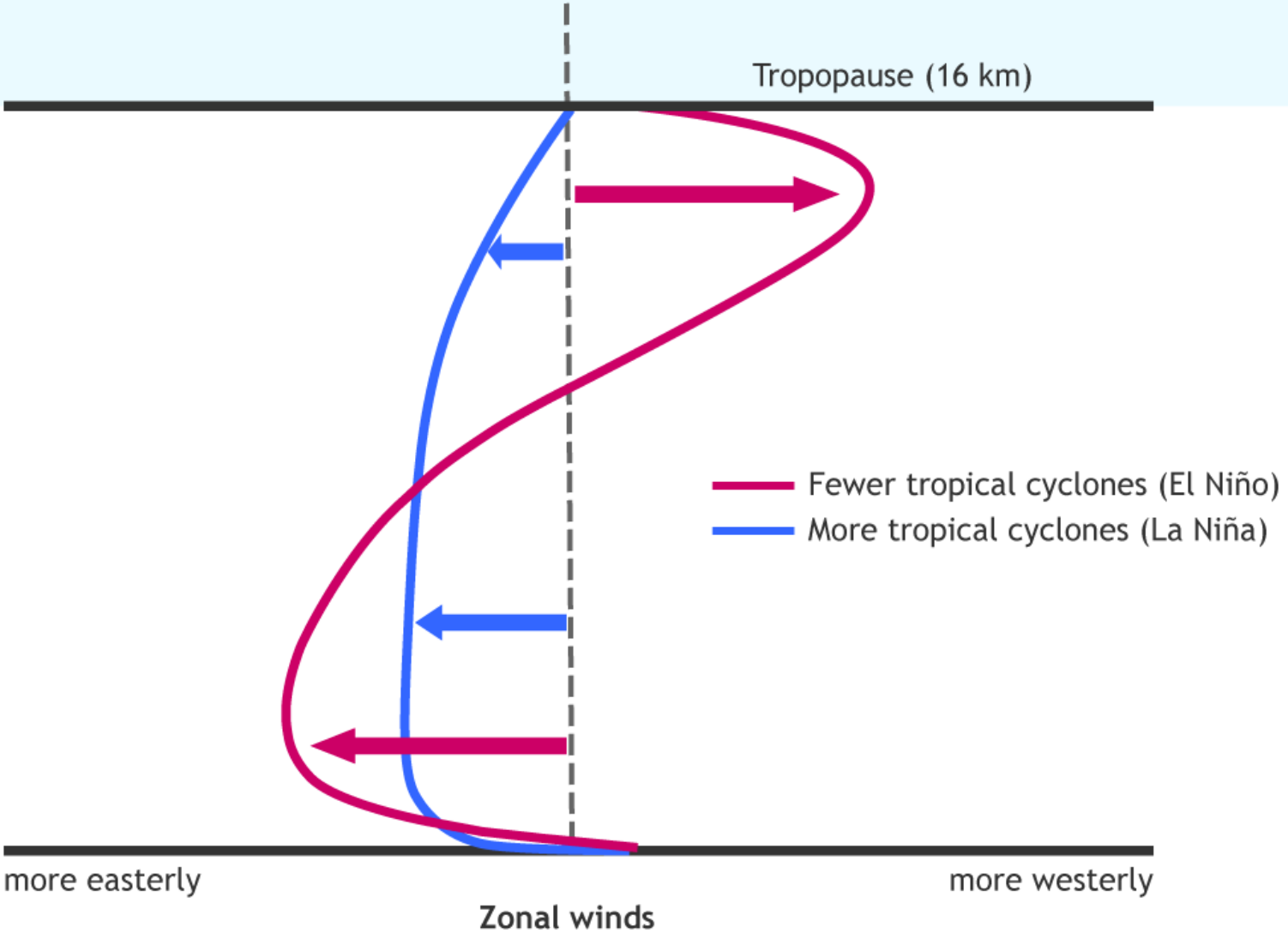
Mid-latitude response:
barotropic, same sign through depth of troposphere

Tropical response:
baroclinic, opposite sign at low levels



Refs: J.M. Wallace et al 1998,
K. Trenberth et al 1998

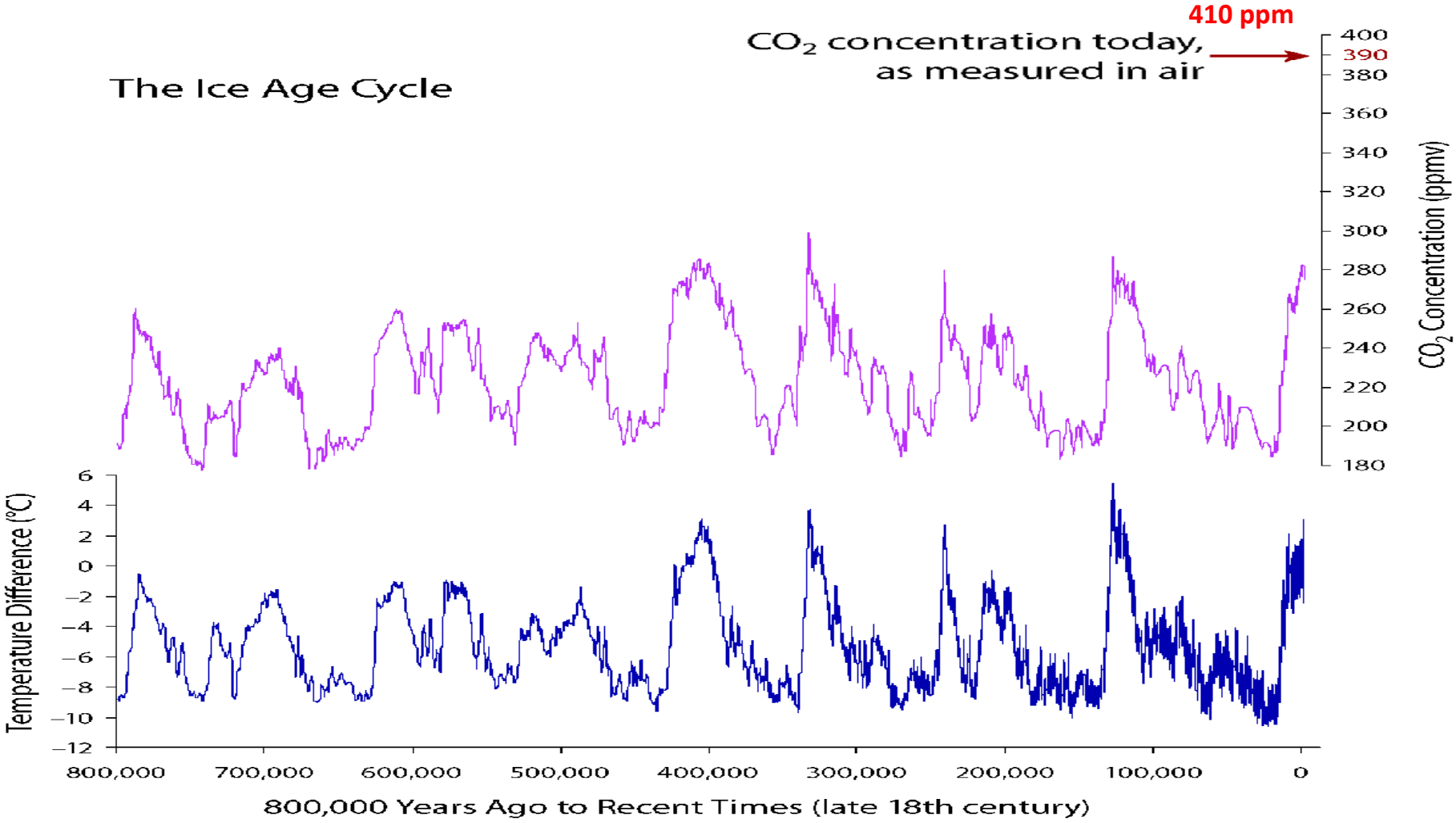
Vertical wind profile in the western tropical Atlantic



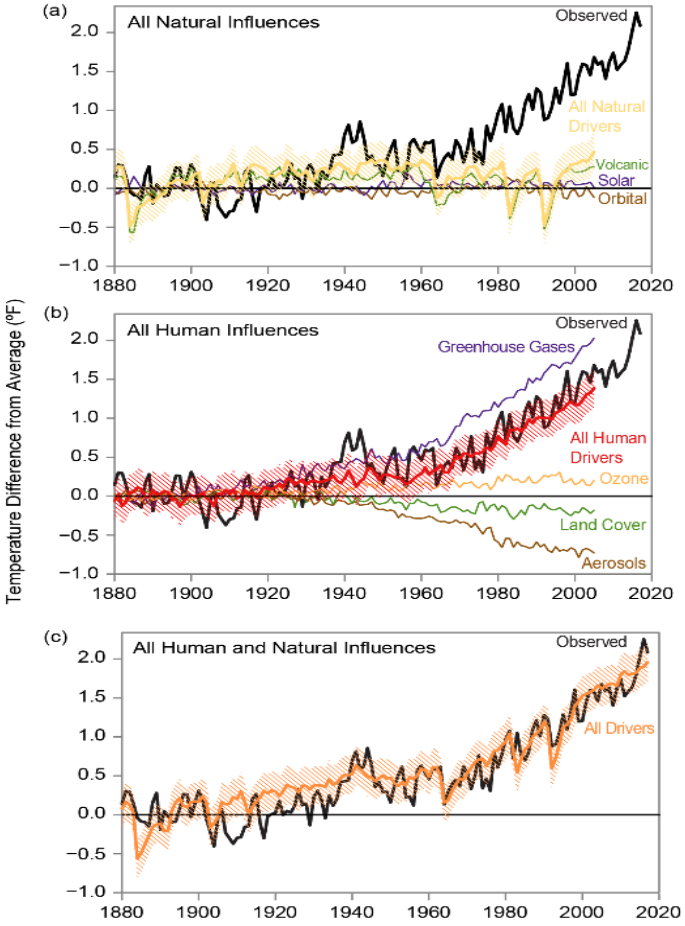
NOAA.gov

Large-Scale Circulation: Three Big Ideas

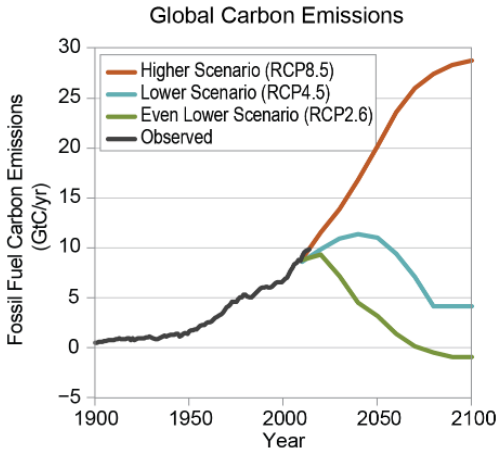
1) **Meridional Temperature and Momentum Transport (Mean Meridional Circulation)**
   - Stationary and Transient Eddies
2) **Large-Scale Tropics**
   - ENSO
3) **Climate Change**
   - Weaker Overturning Circulation

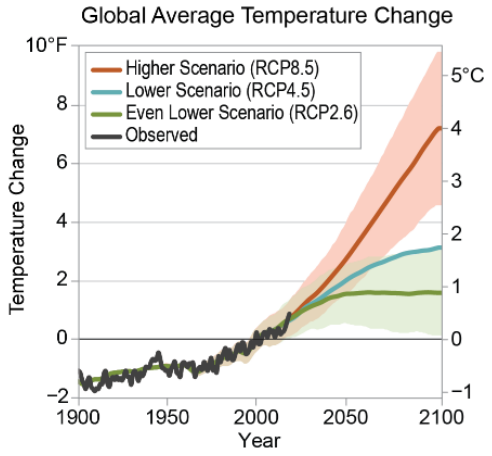

410 ppm
The Ice Age Cycle
CO2 concentration today, as measured in air
400
390
380
360
340
320
300
280
260
240
220
200
180
CO2 Concentration (ppmv)
6
4
2
0
−2
−4
−6
−8
−10
−12
Temperature Difference (°C)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
800,000 Years Ago to Recent Times (late 18th century)

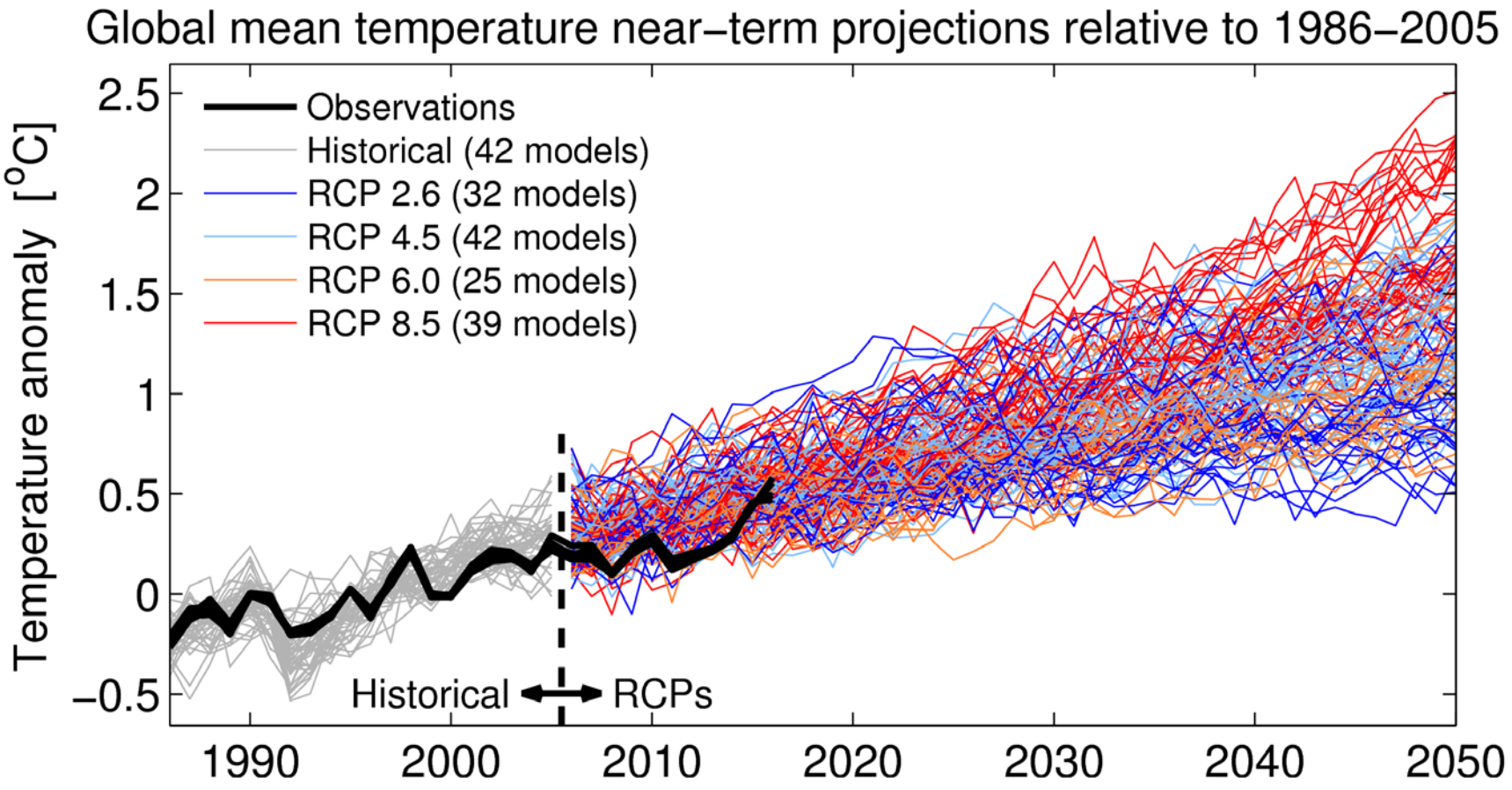
How We Understand Human Influence on Climate



Projections of Future Human Influence on Climate

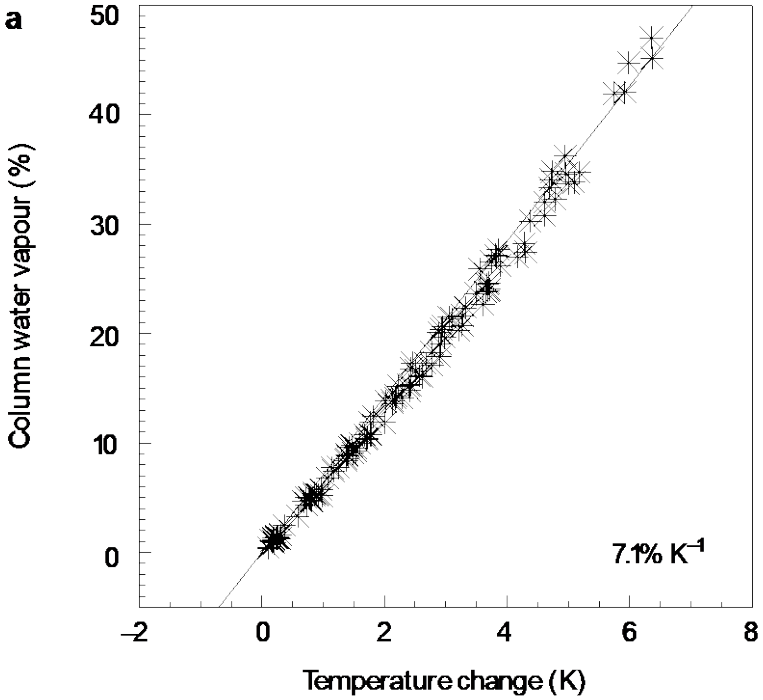





Global mean temperature near–term projections relative to 1986–2005
Temperature anomaly [°C]
Observations
Historical (42 models)
RCP 2.6 (32 models)
RCP 4.5 (42 models)
RCP 6.0 (25 models)
RCP 8.5 (39 models)
Historical
RCPs
2.5
2
1.5
1
0.5
0
−0.5
1990
2000
2010
2020
2030
2040
2050

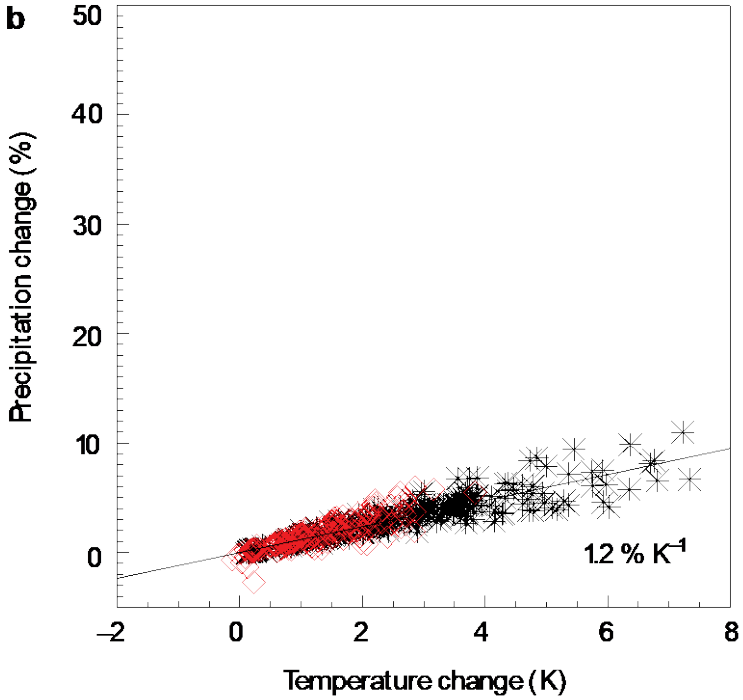
Global Changes with Warming

Increase in Water Vapor

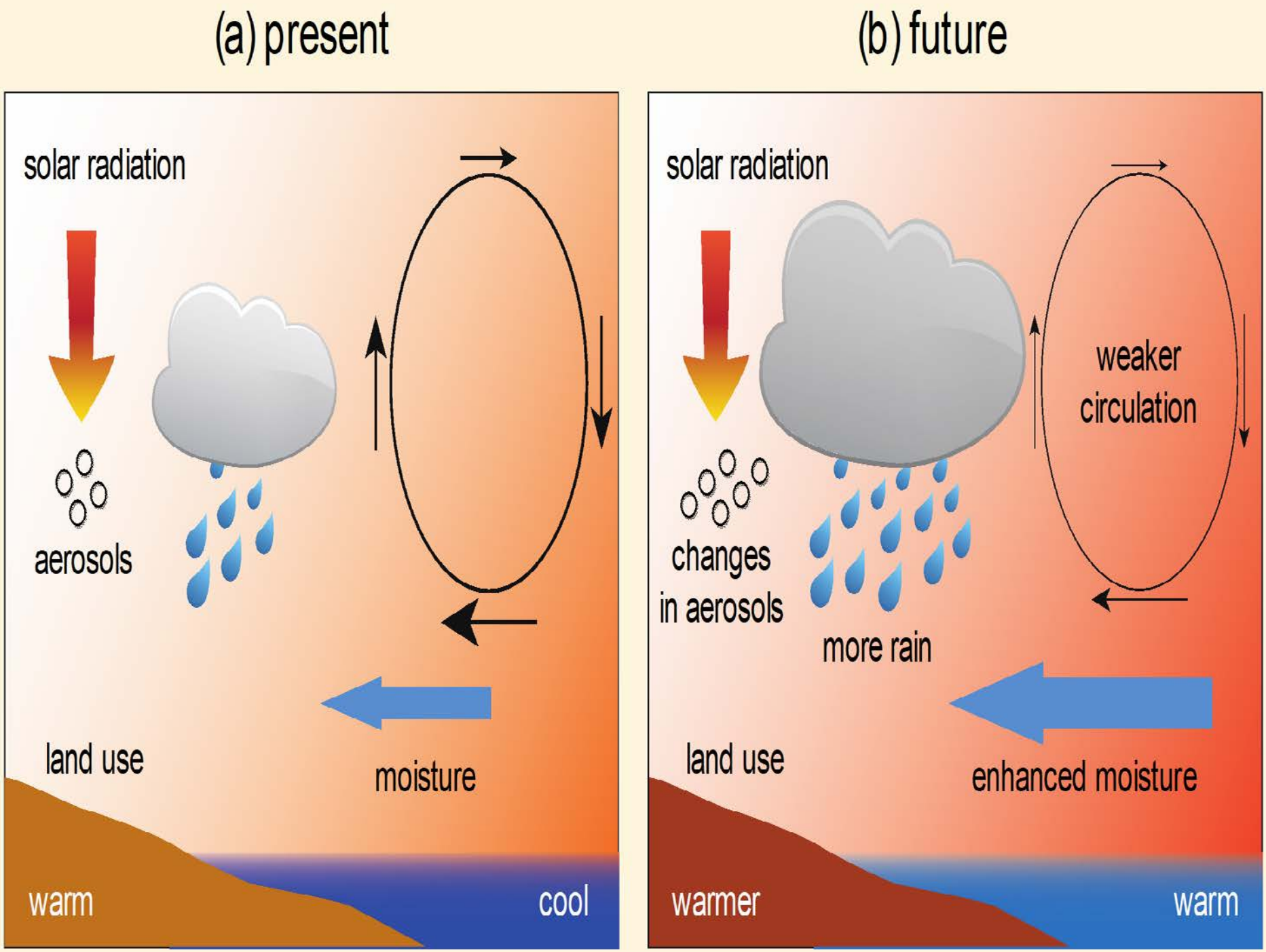


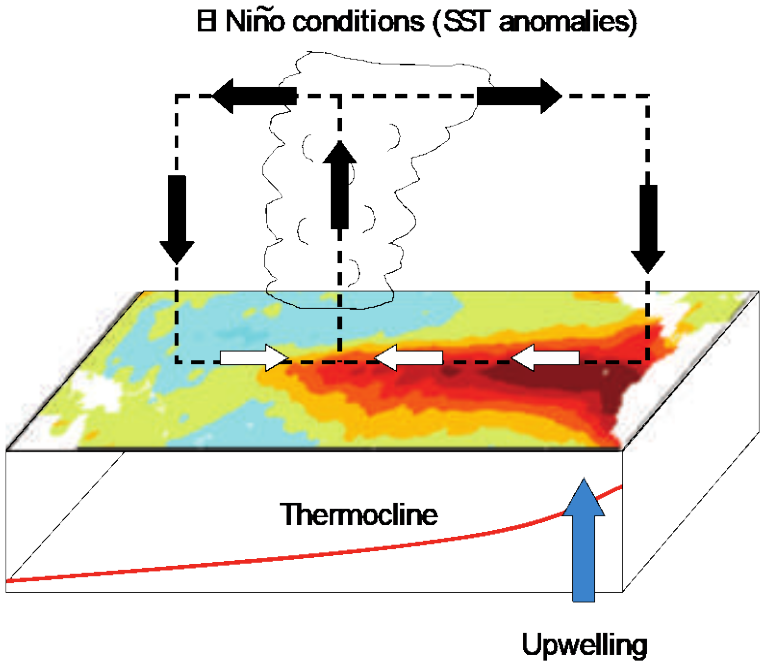
Expected From Clausius-Clapeyron

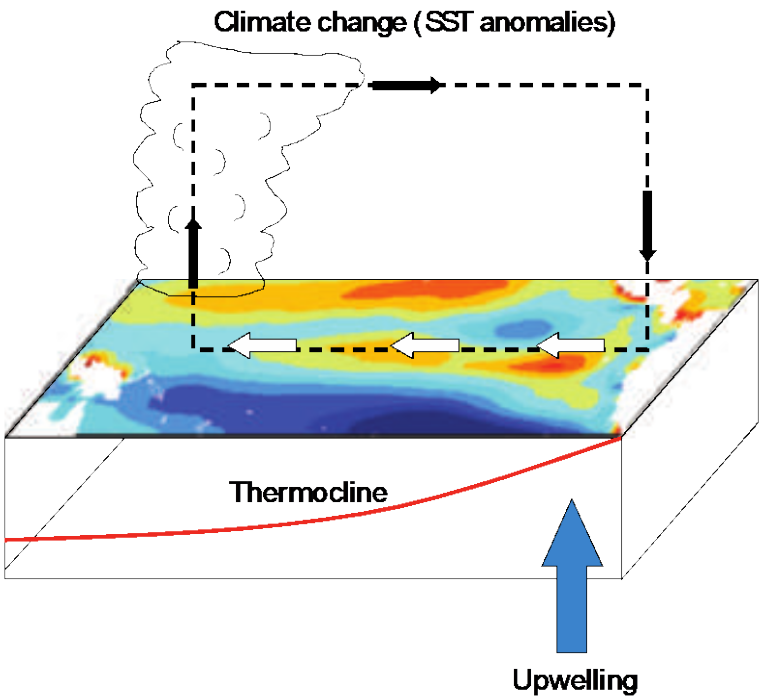
Changes in Precipitation



Smaller than Expected -> Decrease in Overturning Circulation

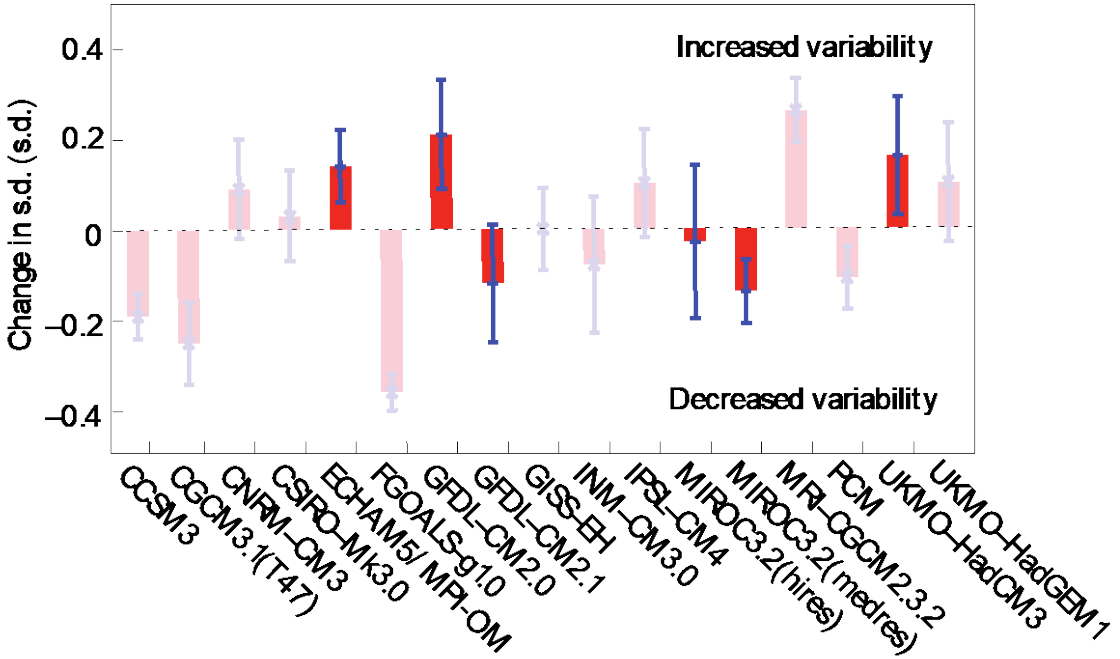

(a) present
solar radiation
aerosols
land use
moisture
warm
cool
(b) future
solar radiation
weaker
circulation
changes
in aerosols
more rain
land use
enhanced moisture
warmer
warm



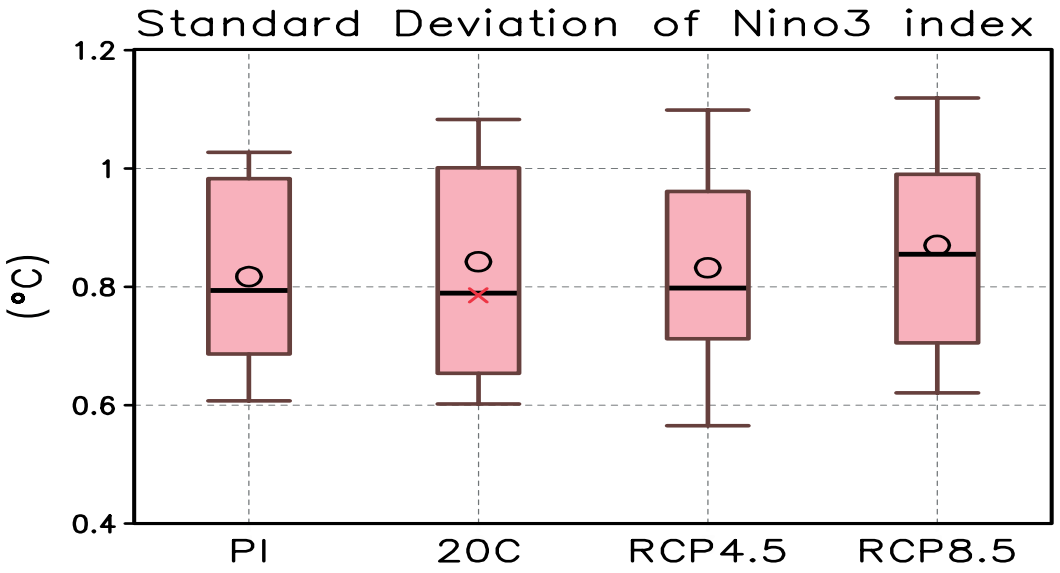


Not El Nino-Like

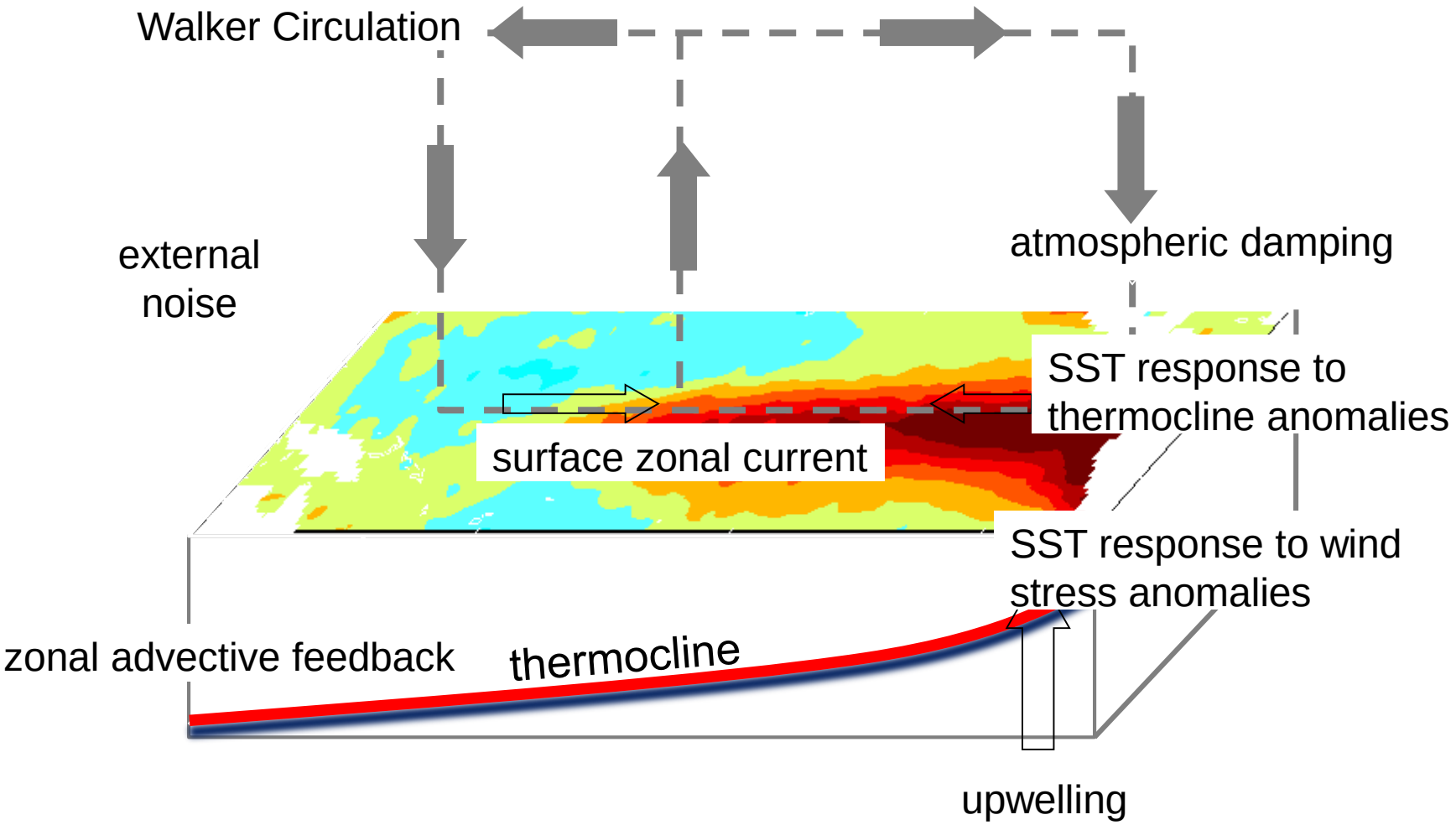
CMIP3

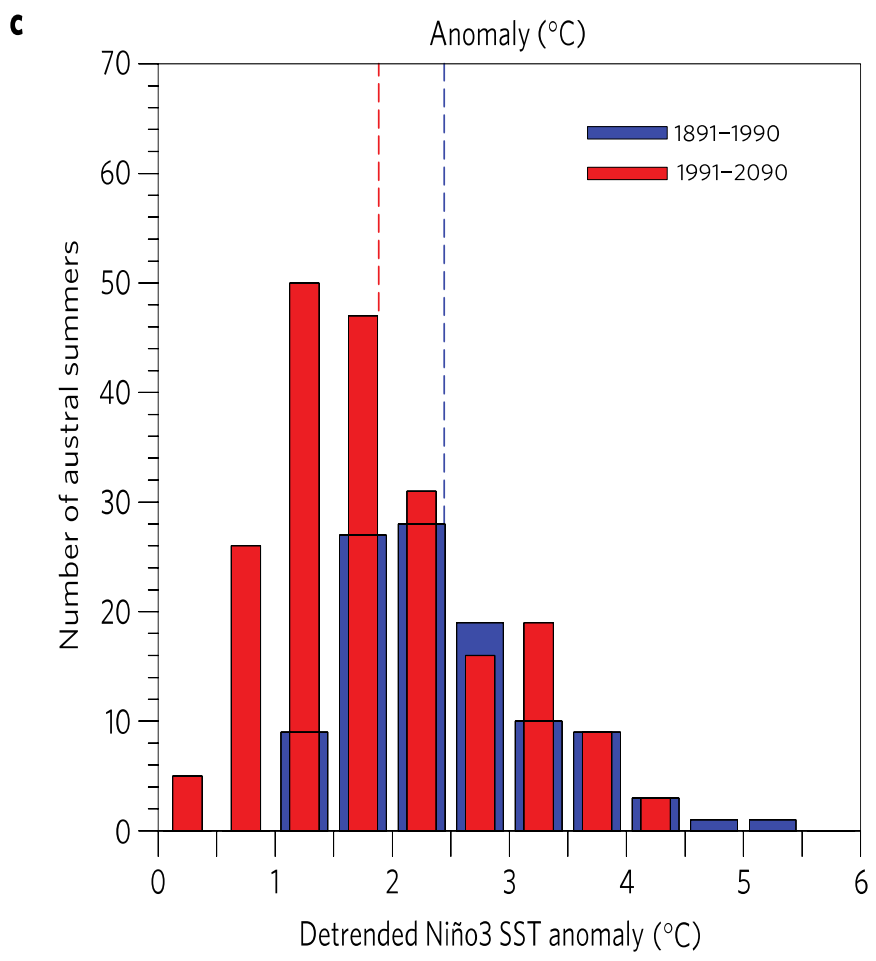

Increased variability
Decreased variability
Change in s.d. (s.d.)
0.4
0.2
0
–0.2
–0.4
CCSM3
CGCM3.1(T47)
CNRM-CM3
CSIRO-Mk3.0
ECHAM5/ MPI-OM
FGOALS-g1.0
GFDL-CM2.0
GFDL-CM2.1
GISS-EH
INM-CM3.0
IPSL-CM4
MIROC3.2(hires)
MIROC3.2(medres)
MRI-CGCM2.3.2
PCM
UKMO-HadGEM1
UKMO-HadCM3

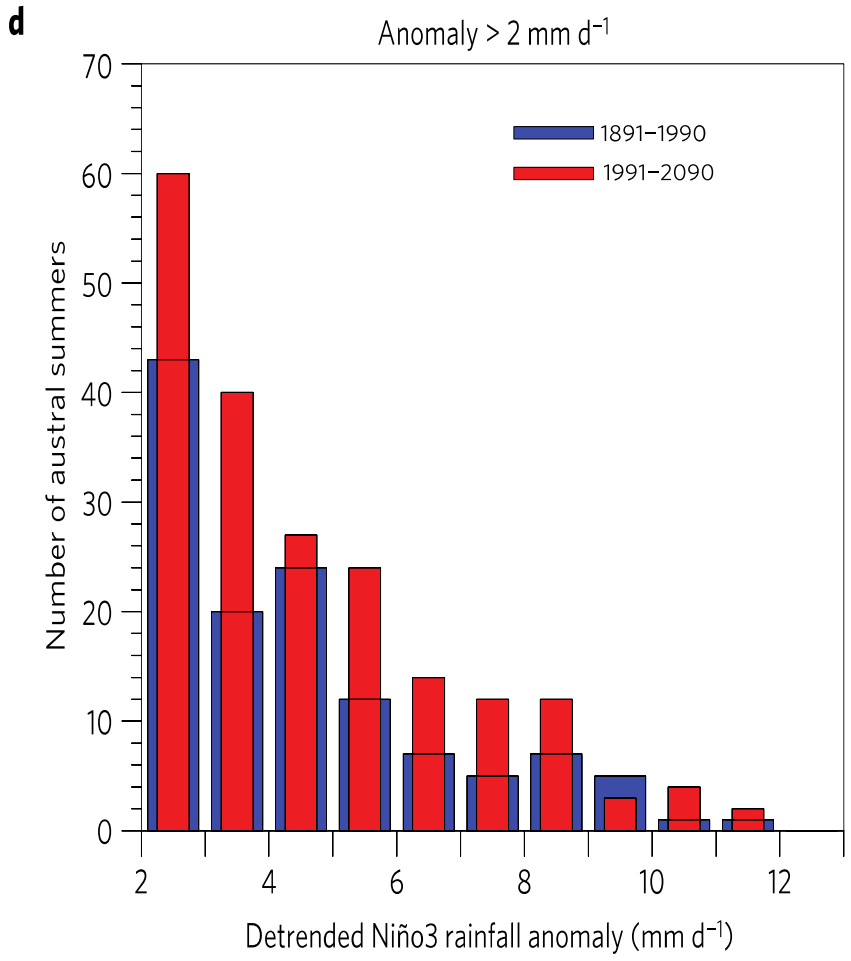
CMIP5

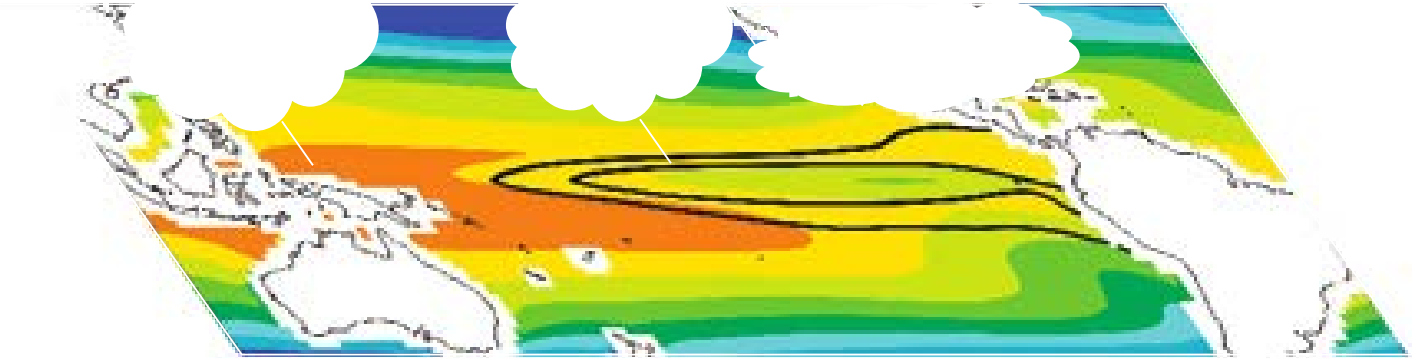

Standard Deviation of Nino3 index
(°C)
1.2
1
0.8
0.6
0.4
PI
20C
RCP4.5
RCP8.5

El Niño Features and Processes




c
Anomaly (°C)
1891–1990
1991–2090
Number of austral summers
Detrended Niño3 SST anomaly (°C)
0
10
20
30
40
50
60
70
0
1
2
3
4
5
6


d
Anomaly > 2 mm d−1
1891–1990
1991–2090
Number of austral summers
Detrended Niño3 rainfall anomaly (mm d−1)
0
10
20
30
40
50
60
70
2
4
6
8
10
12



Large-Scale Circulation: Three Big Ideas

1) **Meridional Temperature and Momentum Transport (Mean Meridional Circulation)**
   - Stationary and Transient Eddies
2) **Large-Scale Tropics**
   - ENSO
3) **Climate Change**
   - Weaker Overturning Circulation