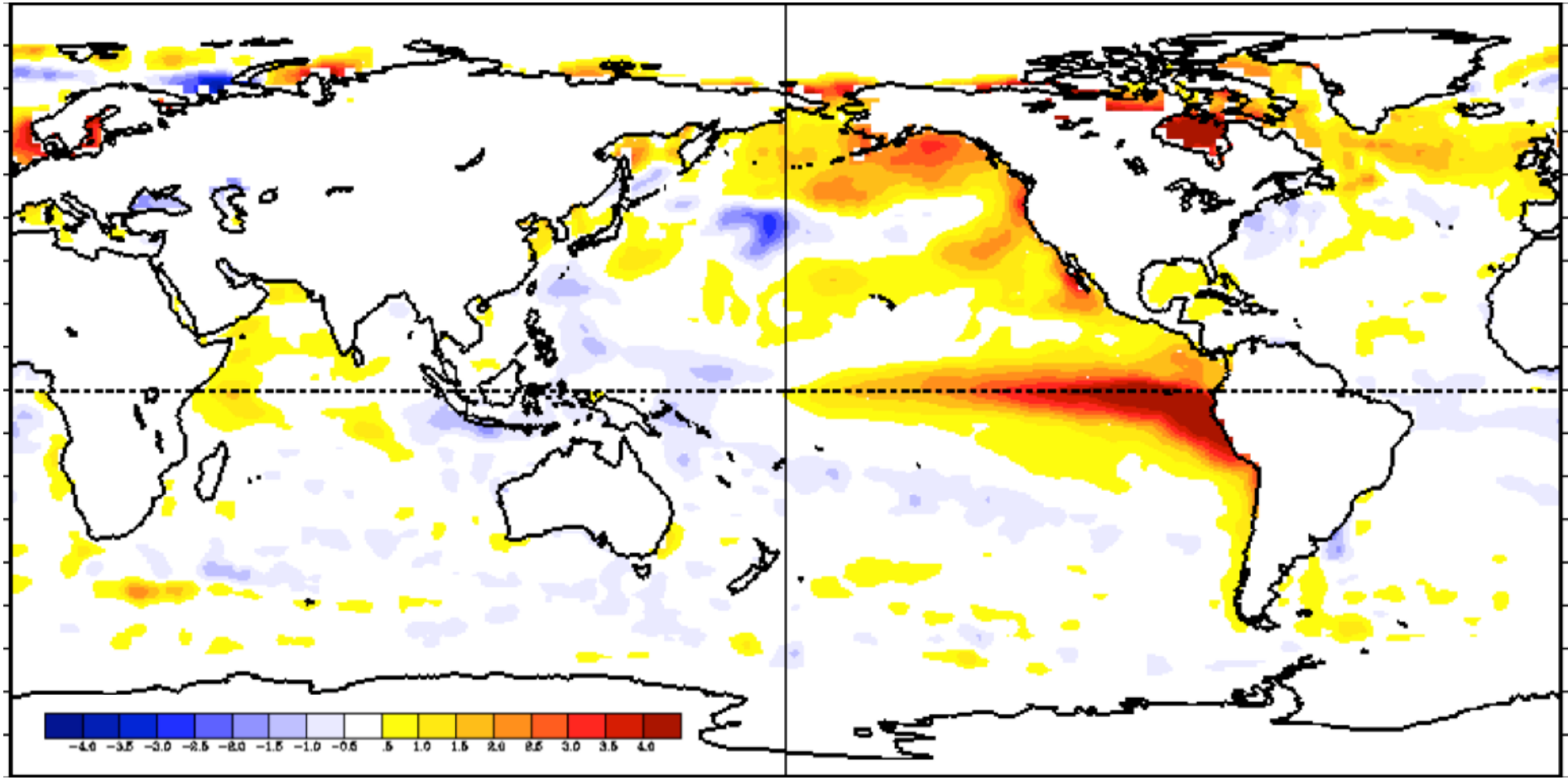
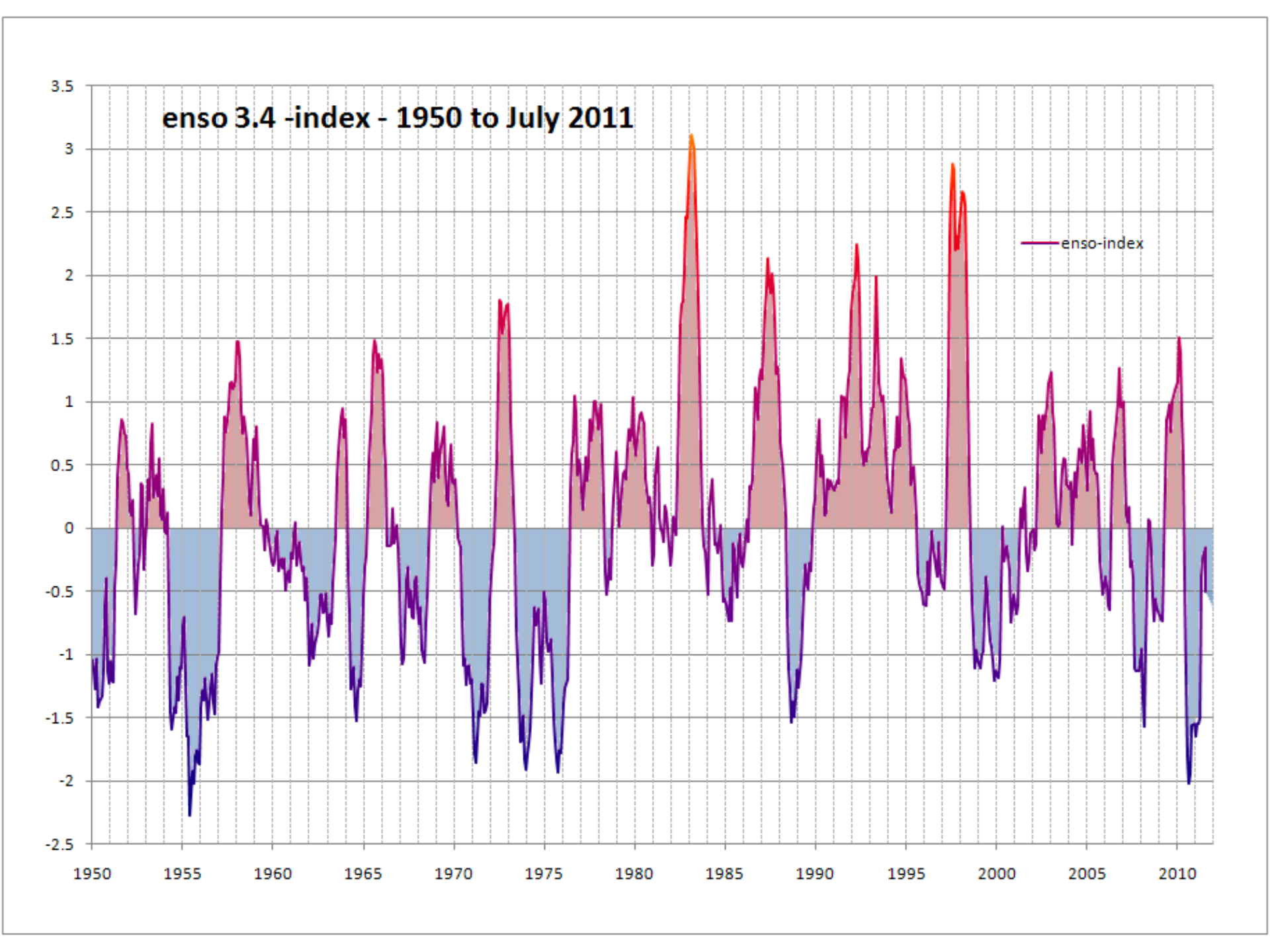
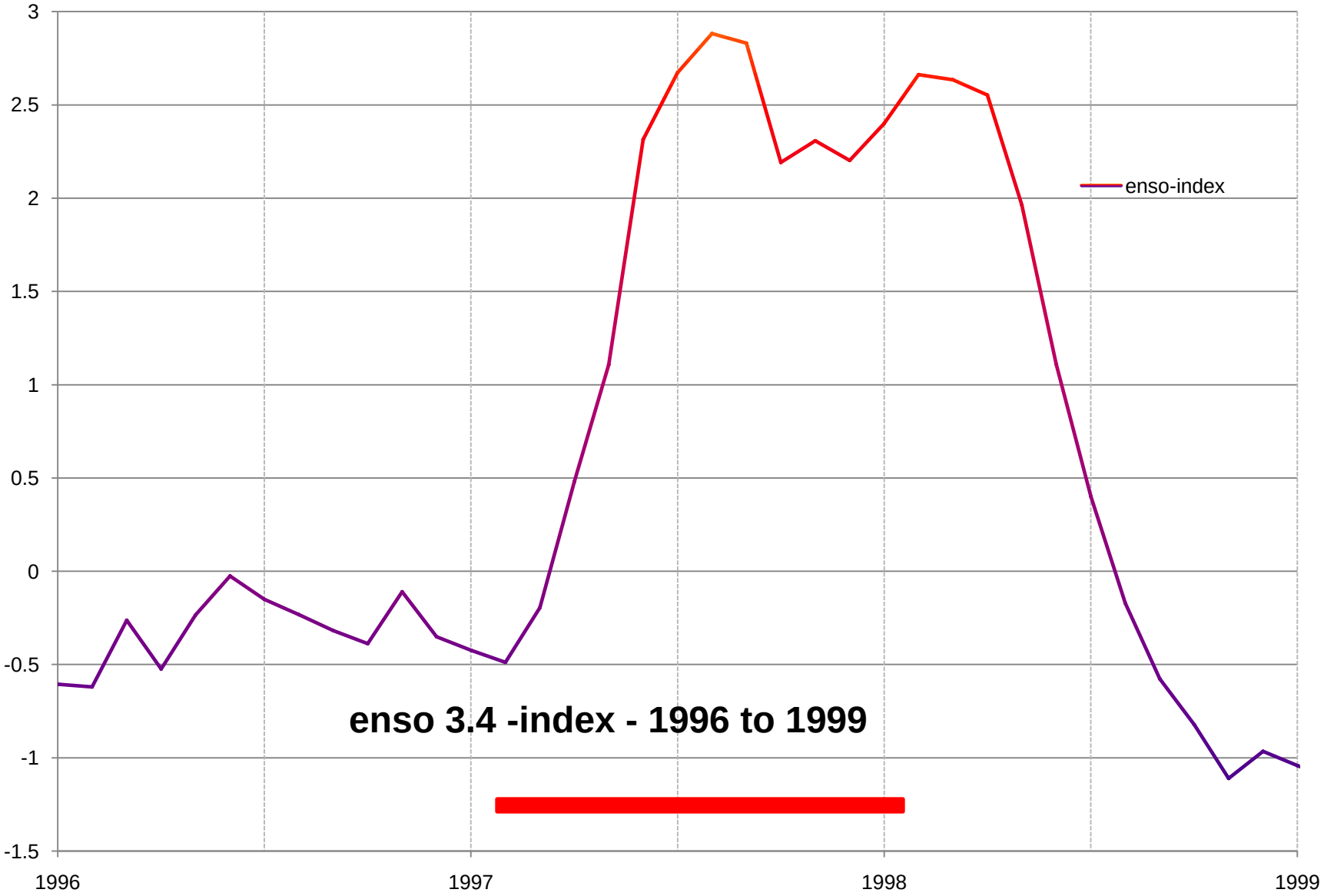
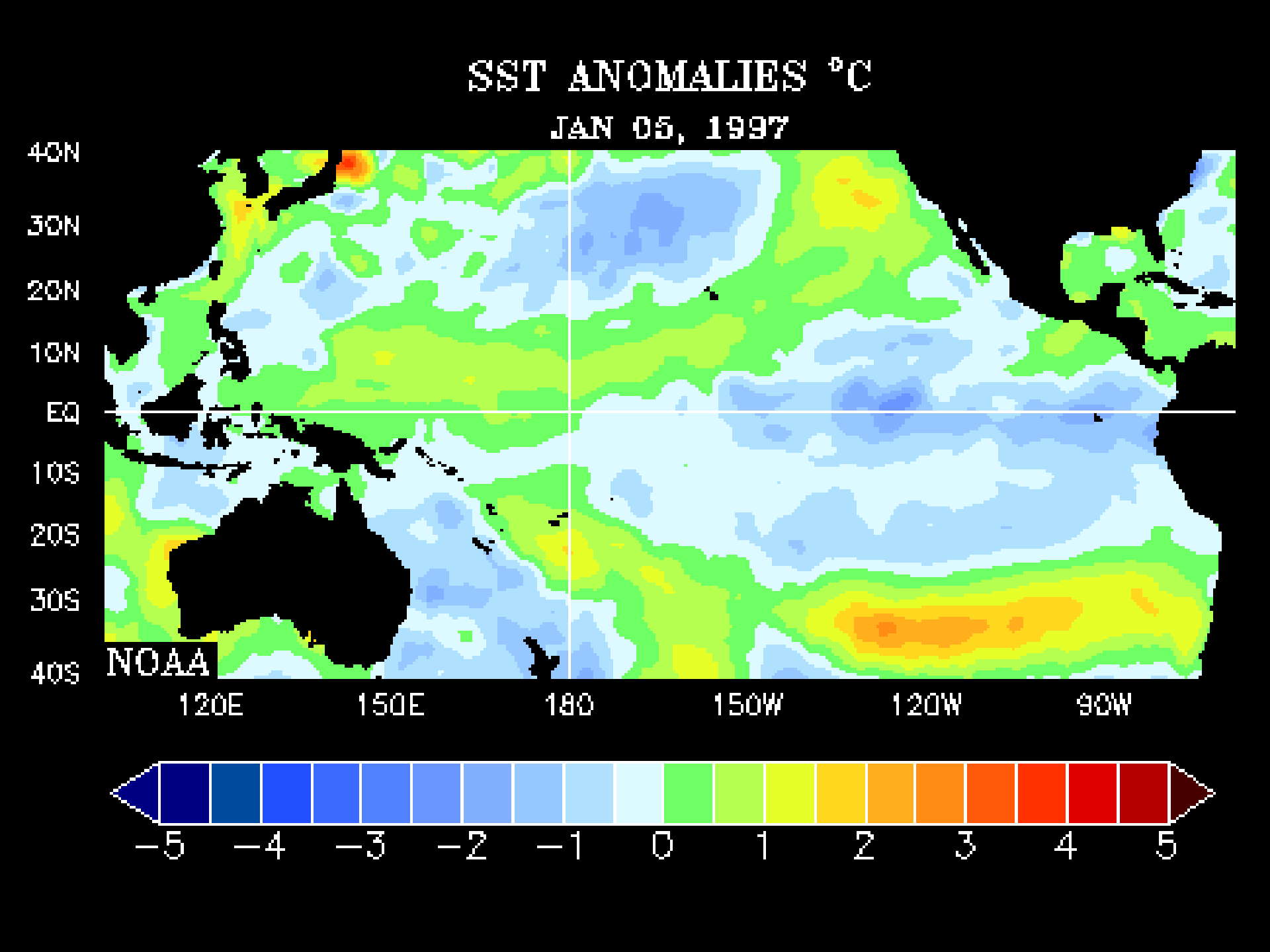
Ocean cycles and climate
ENSO, PDO, AMO, AO



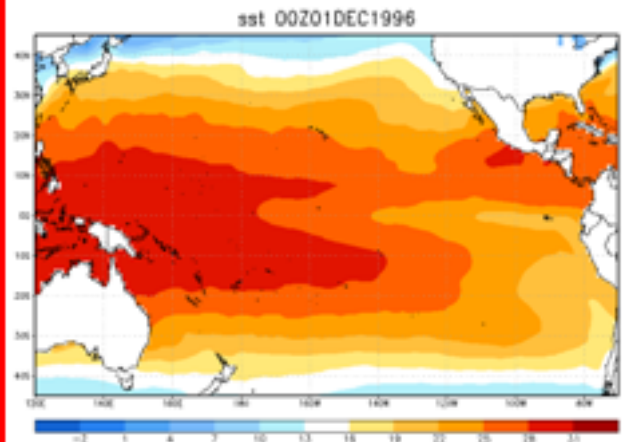

enso 3.4 -index - 1950 to July 2011
enso-index
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010


3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
1996
1997
1998
1999
enso-index
enso 3.4 -index - 1996 to 1999


SST ANOMALIES °C
JAN 05, 1997
40N
30N
20N
10N
EQ
10S
20S
30S
40S
NOAA
120E
150E
180
150W
120W
90W
−5
−4
−3
−2
−1
0
1
2
3
4
5

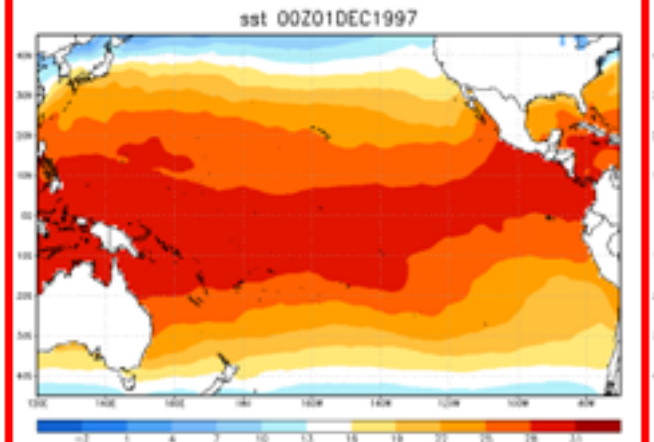
Three Phases Of ENSO - Pacific Sea Surface Temperatures

(a) ENSO Neutral



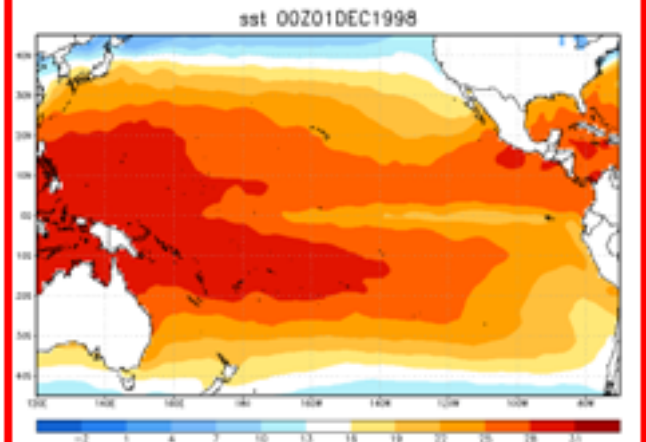
Dec 1996

(b) El Nino



Dec 1997

(c) La Nina



Dec 1998

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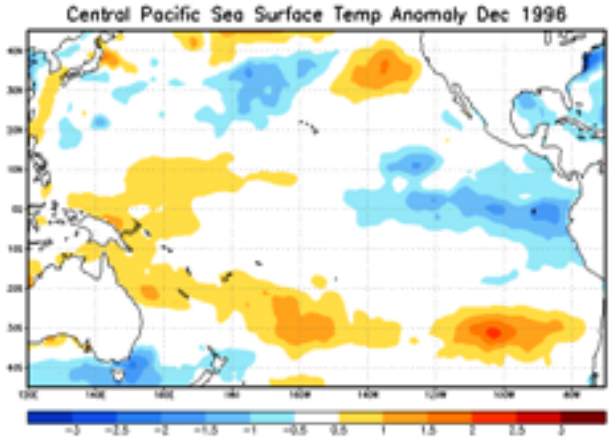
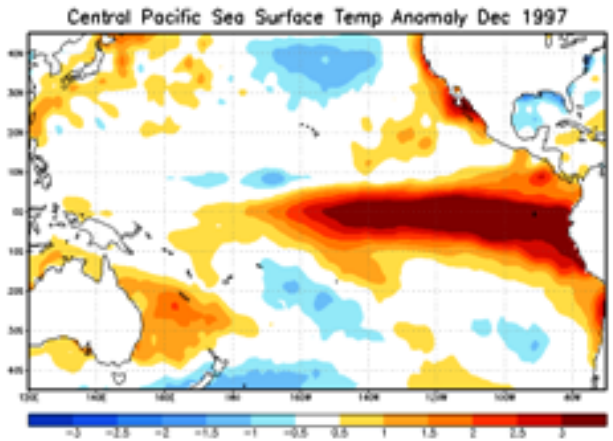
Three Phases Of ENSO - Pacific Sea Surface Temperature Anomalies

(a) ENSO Neutral



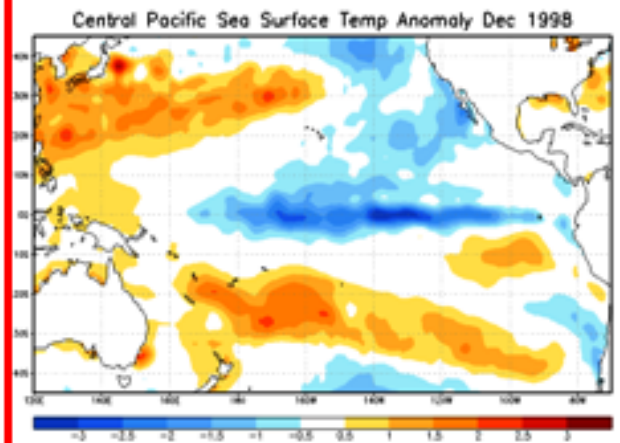
Dec 1996

(b) El Nino



Dec 1997

(c) La Nina



Dec 1998

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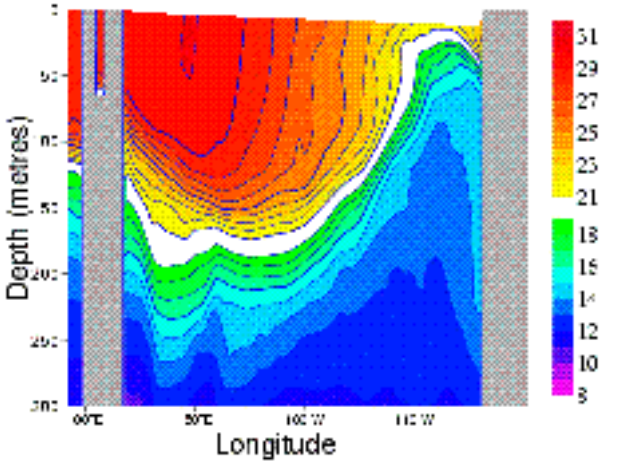
Three Phases Of ENSO - Equatorial Pacific Cross-Sections Showing Temperatures At Depth

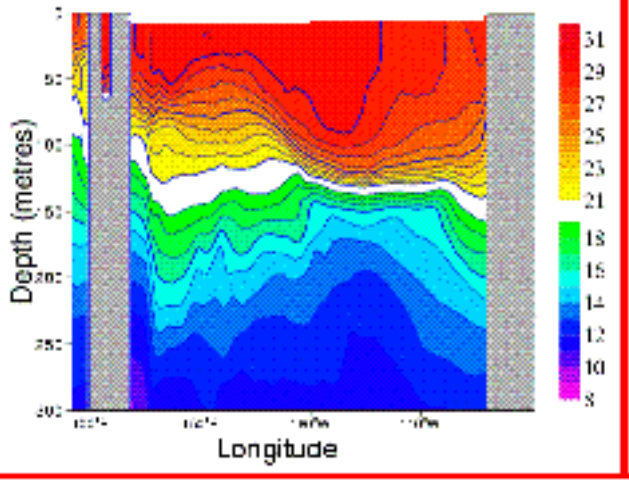
(a) ENSO Neutral (Dec 1996)

Trade Winds Cause Waters In West To Be Higher & Warmer Than In East



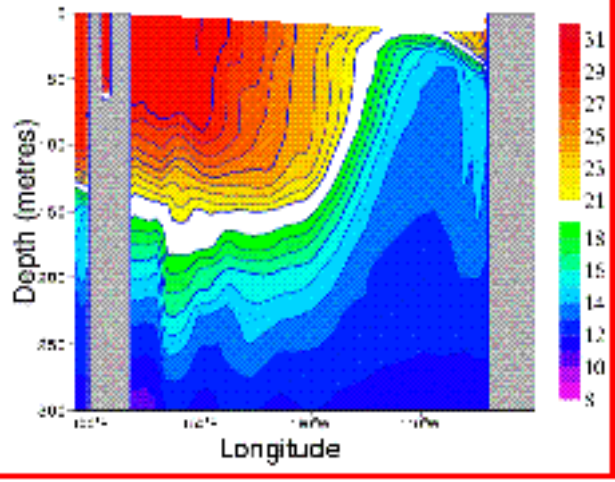
(b) El Nino (Dec 1997)

Trade Winds Relax And Allow Warm Water To "Slosh" To The East



(c) La Nina (Dec 1998)

Stronger Trade Winds Push Warm Water West And Expose Cool Water In East



Note: Illustrations are available through ECMWF website. Atlantic and Indian Oceans have been deleted to focus attention on Pacific. Surface height gradients have been added for illustration purposes.

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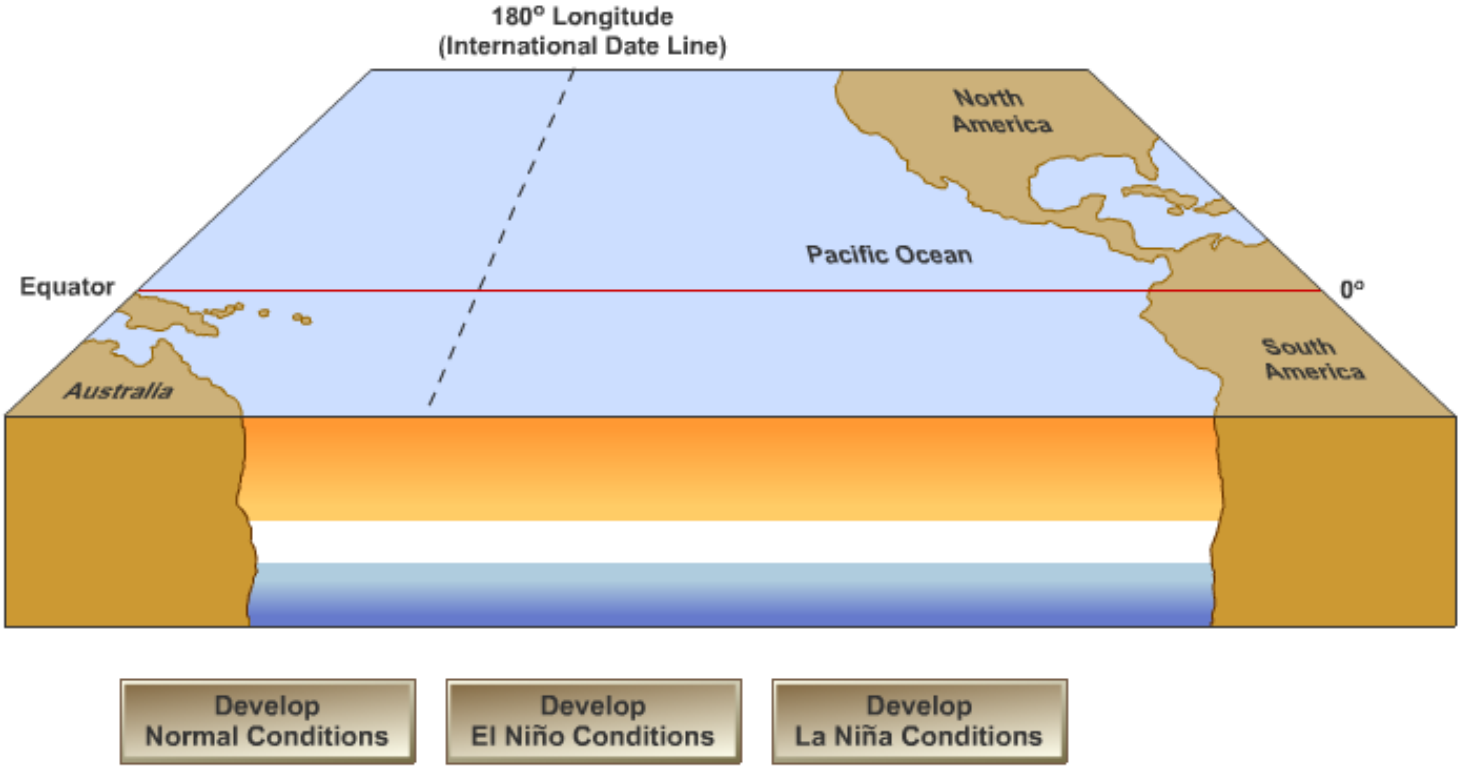
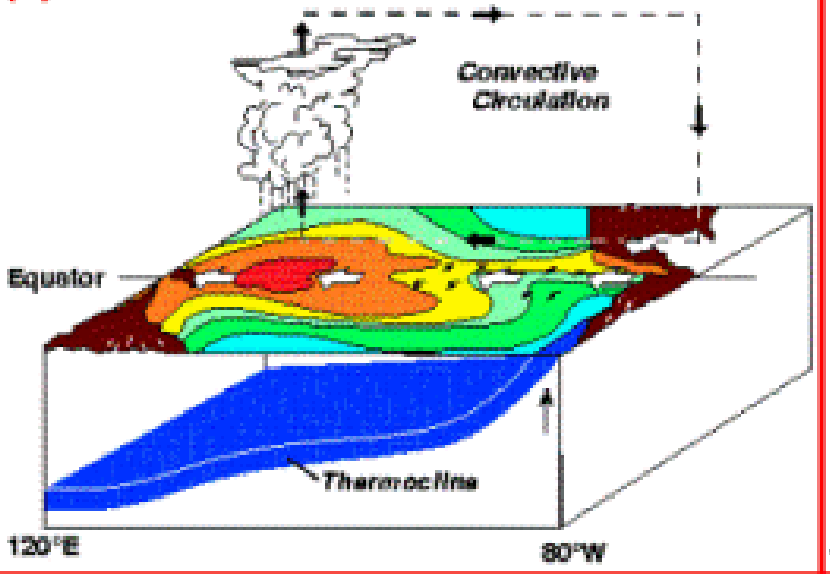
ENSO mechanisms animation

http://esminfo.prenhall.com/science/geoanimations/animations/26_NinoNina.html

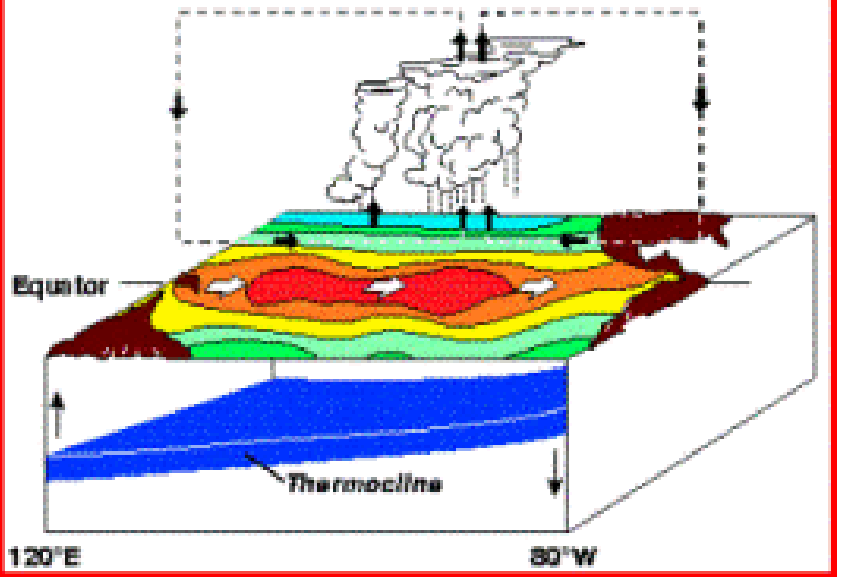


Three Phases of ENSO - Coupled Ocean-Atmosphere Processes

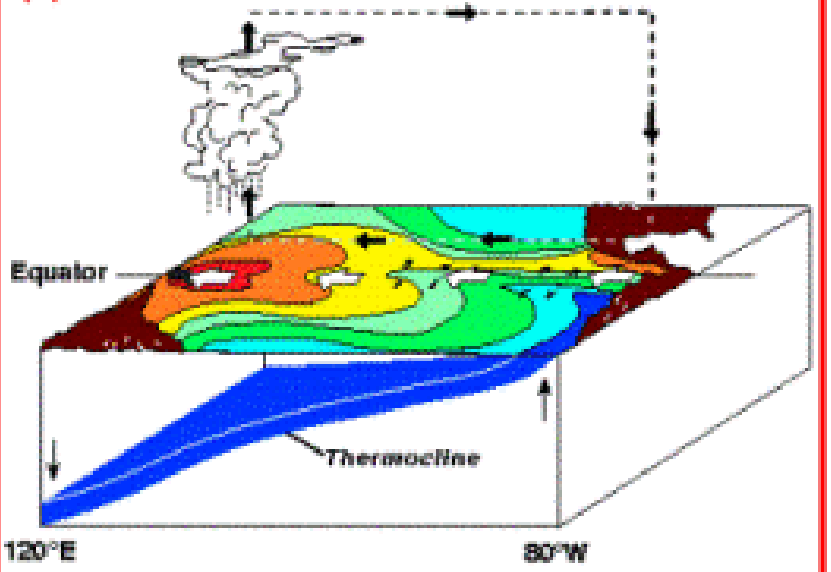
(a) Normal Conditions



(b) El Niño Conditions



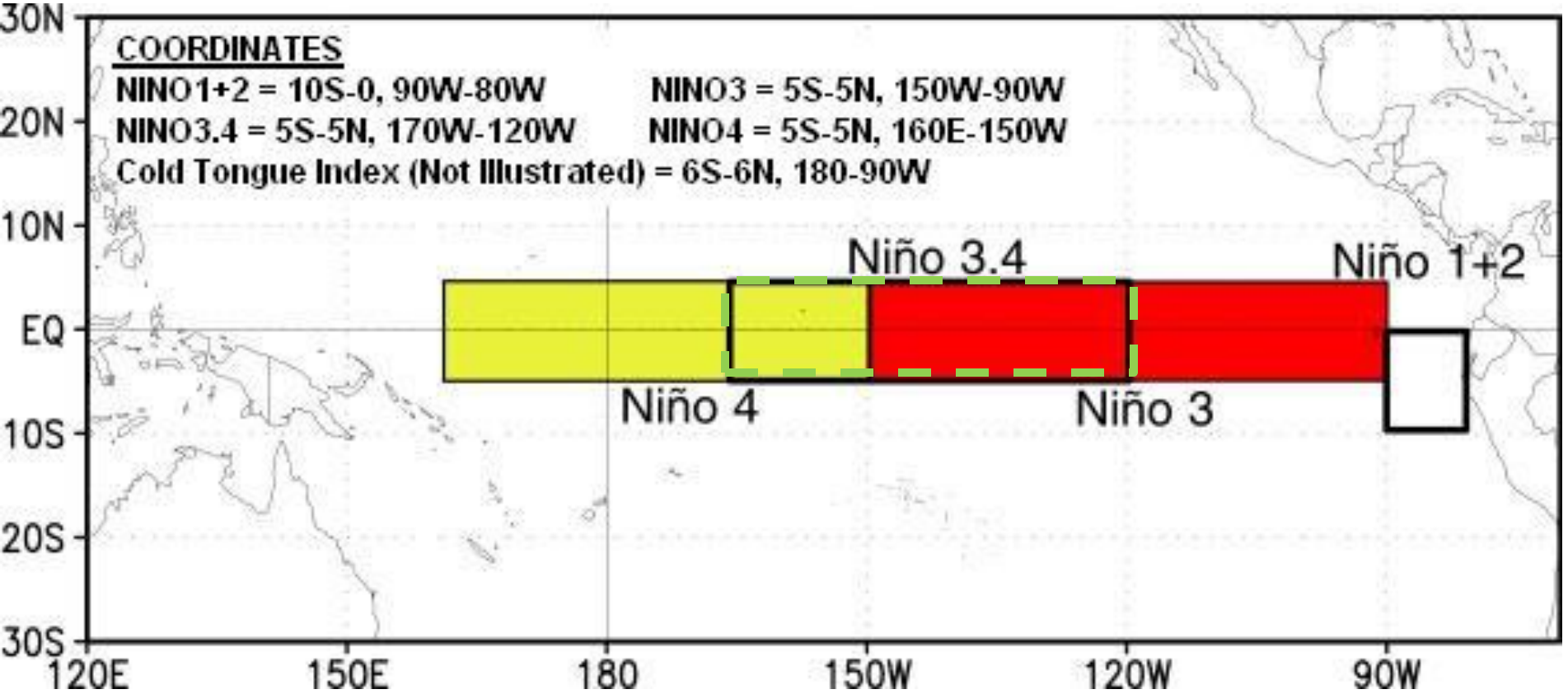
(c) La Niña Conditions



LEGEND

Dotted Lines -- Convection Cell
Black Arrows on Dotted Line -- Wind Direction
White Arrows -- Ocean Surface Current Direction

Where and how is ENSO measured?



SST (sea-surface temperature) is measured from space using IR radiometry.

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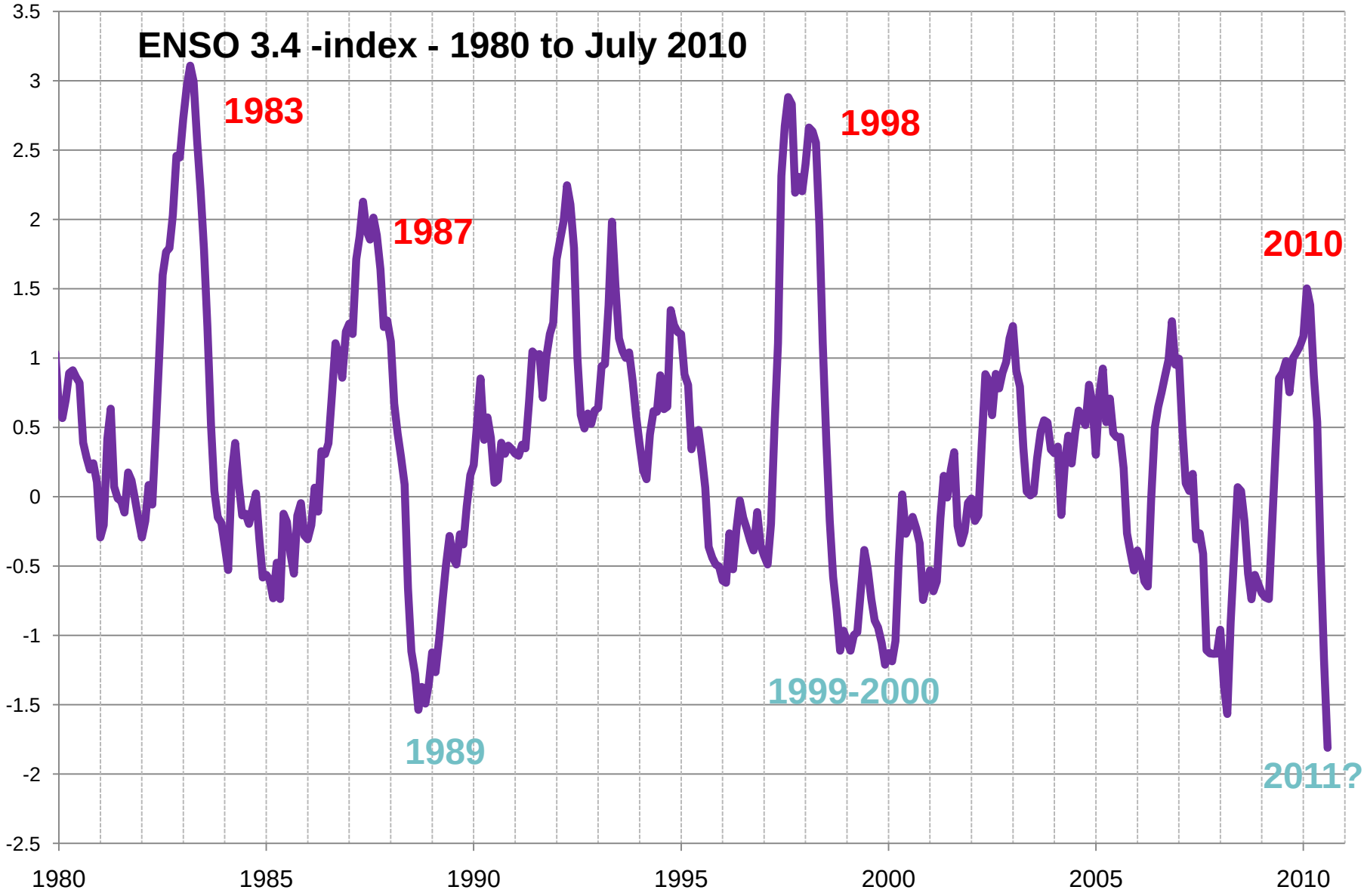
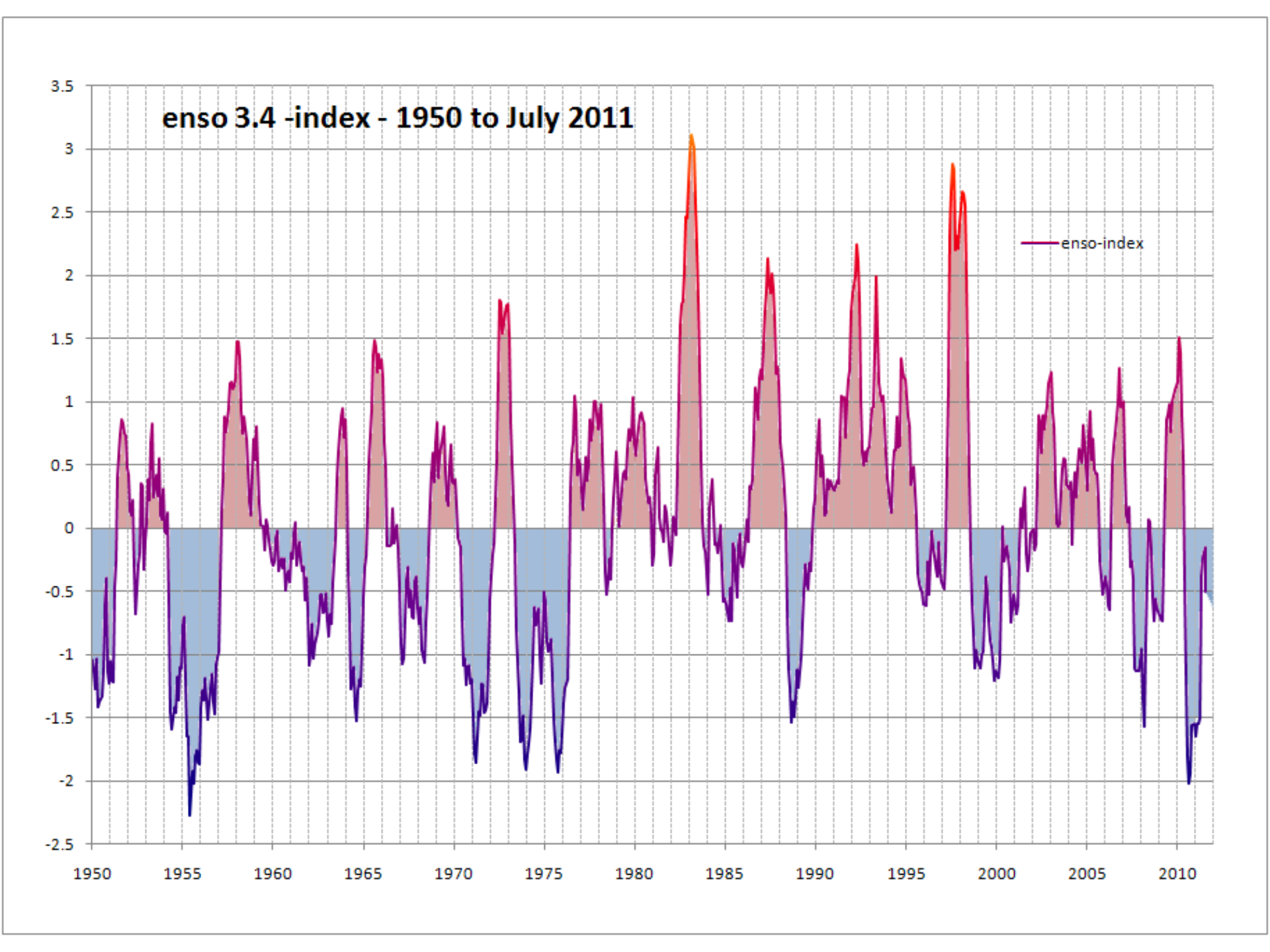


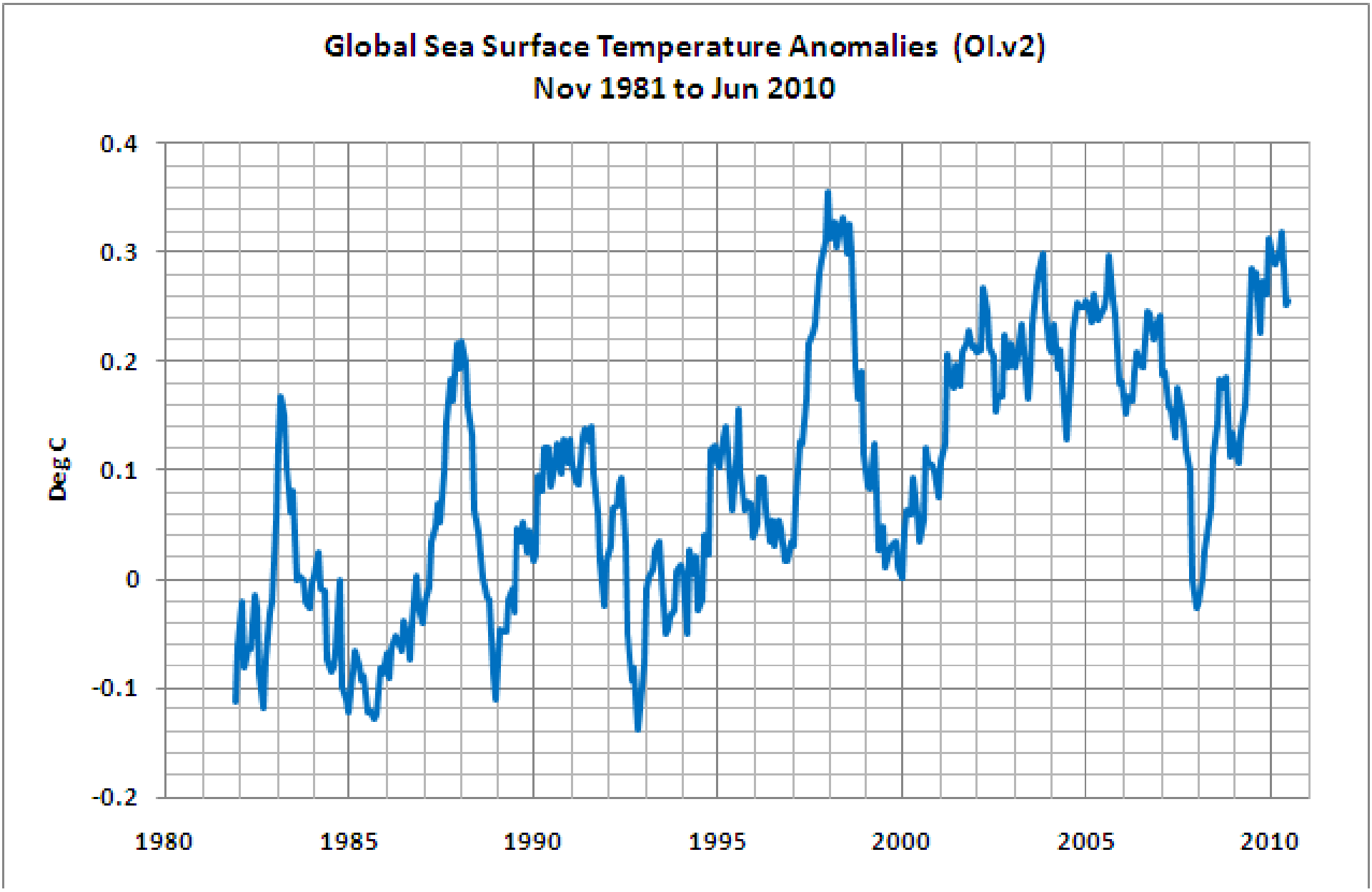
ENSO varies from positive (El Niño) to negative (La Niña) phases with a period of 4 to 6 years


enso 3.4 -index - 1950 to July 2011
enso-index
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

Current and future ENSO

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/index.shtml

How does ENSO affect the global climate?


Global Sea Surface Temperature Anomalies (OI.v2)
Nov 1981 to Jun 2010
Deg C
0.4
0.3
0.2
0.1
0
-0.1
-0.2
1980
1985
1990
1995
2000
2005
2010

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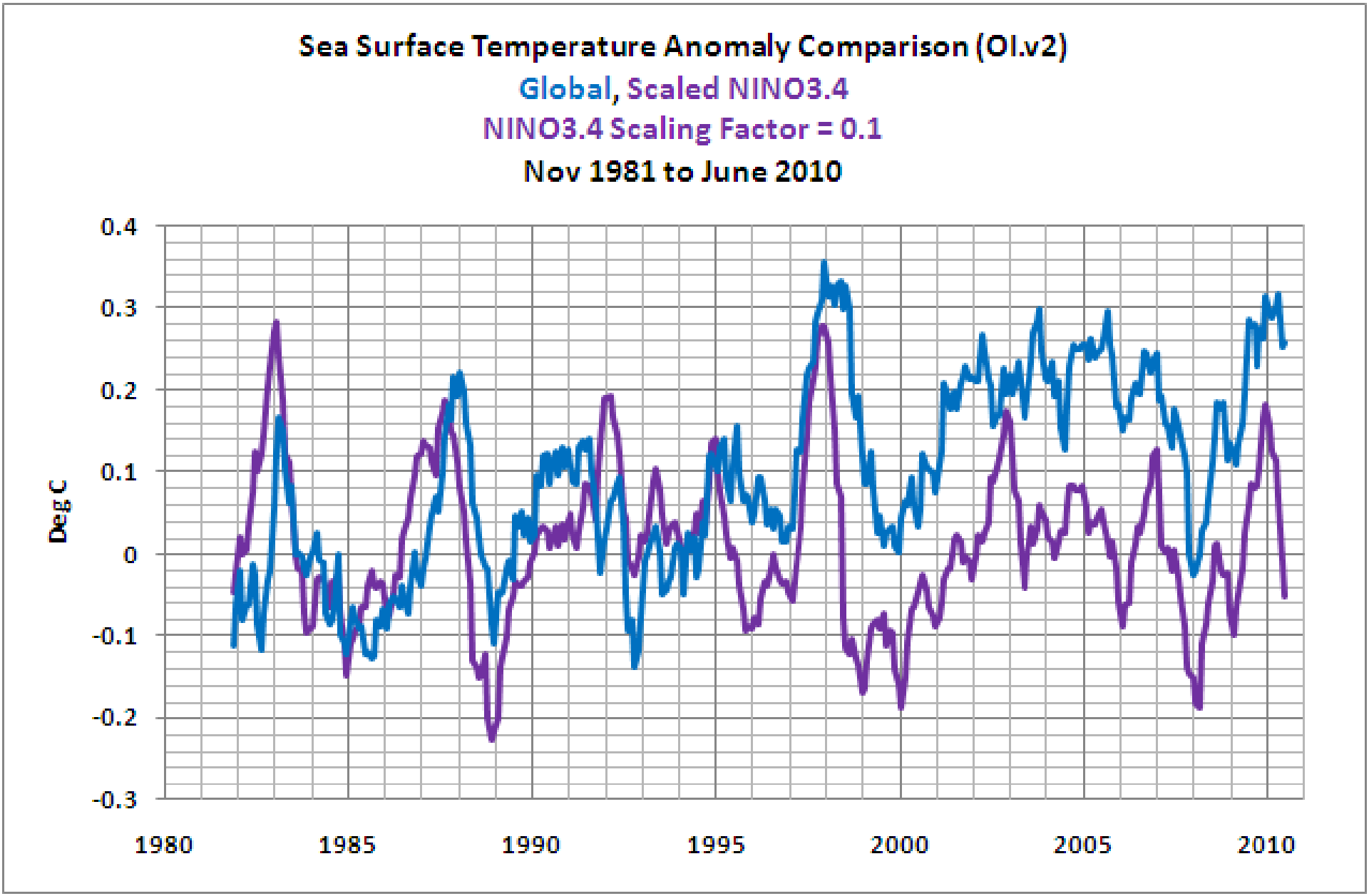
Sea Surface Temperature Anomaly Comparison (OI.v2)
Global, Scaled NINO3.4
NINO3.4 Scaling Factor = 0.1
Nov 1981 to June 2010
Deg C
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
1980
1985
1990
1995
2000
2005
2010

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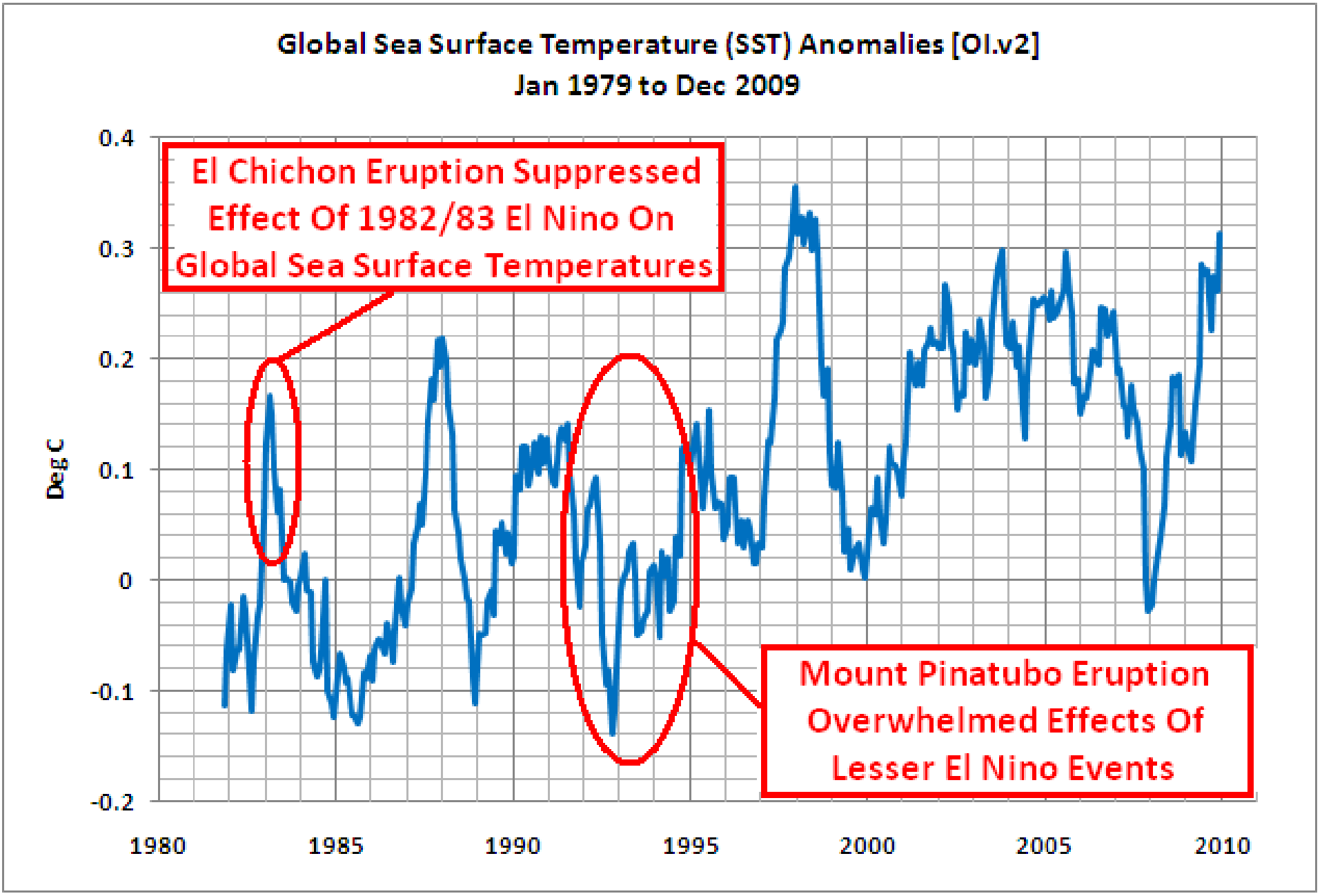
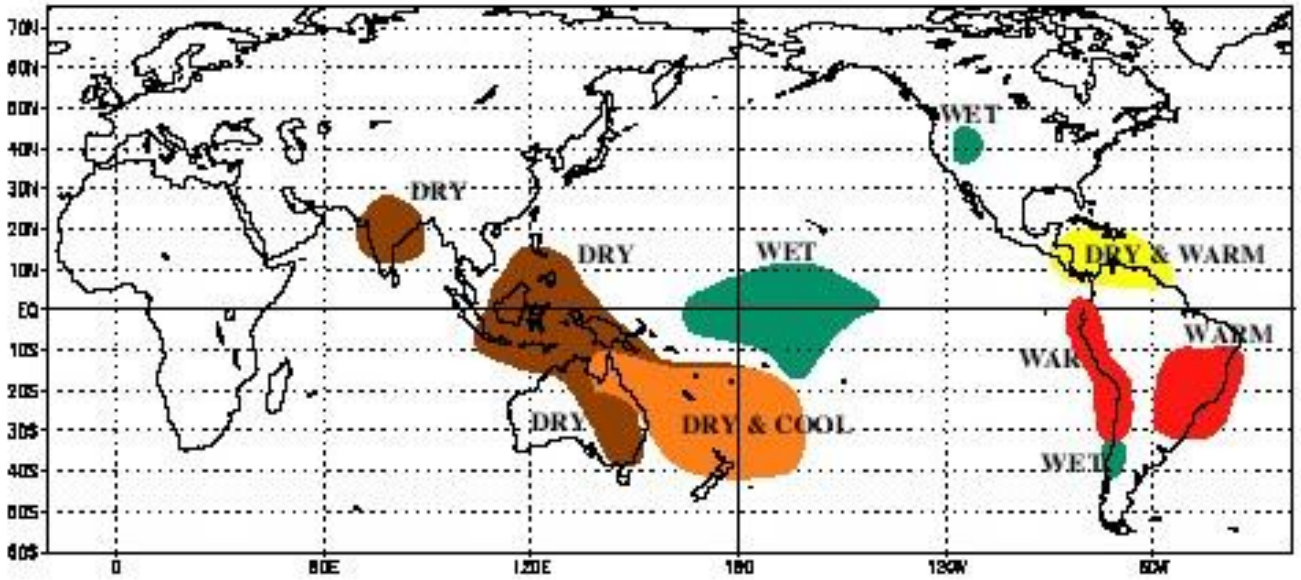
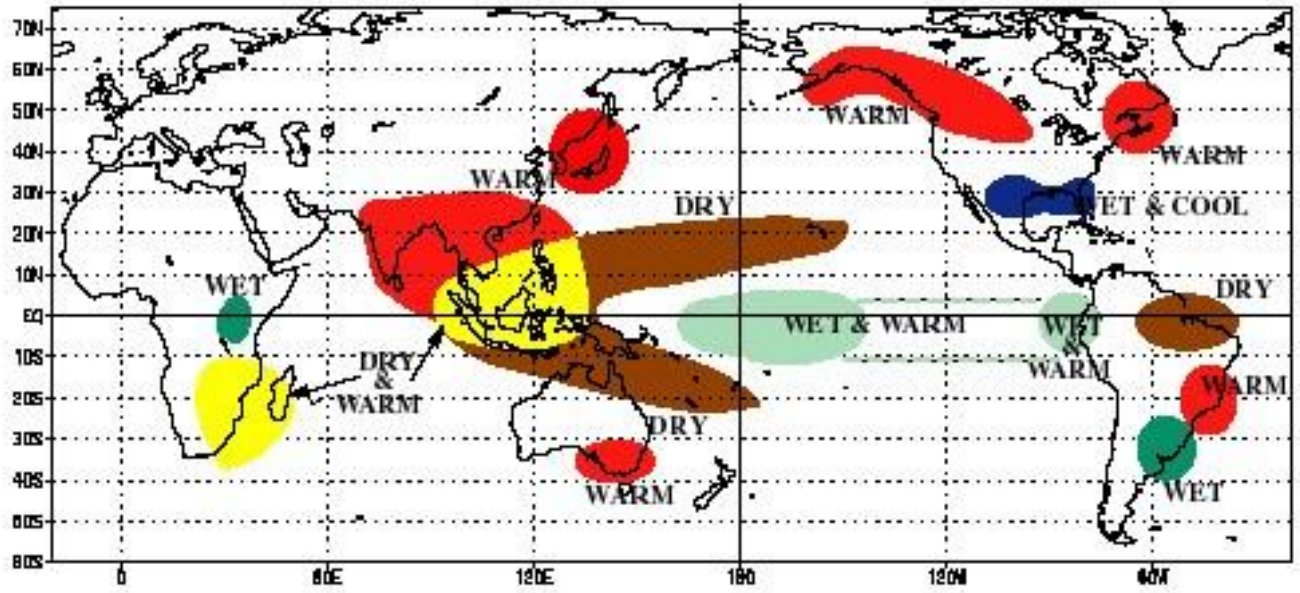

Global Sea Surface Temperature (SST) Anomalies [OI.v2]
Jan 1979 to Dec 2009
El Chichon Eruption Suppressed Effect Of 1982/83 El Nino On Global Sea Surface Temperatures
Mount Pinatubo Eruption Overwhelmed Effects Of Lesser El Nino Events
Deg C
0.4
0.3
0.2
0.1
0
-0.1
-0.2
1980
1985
1990
1995
2000
2005
2010

Bob Tisdale

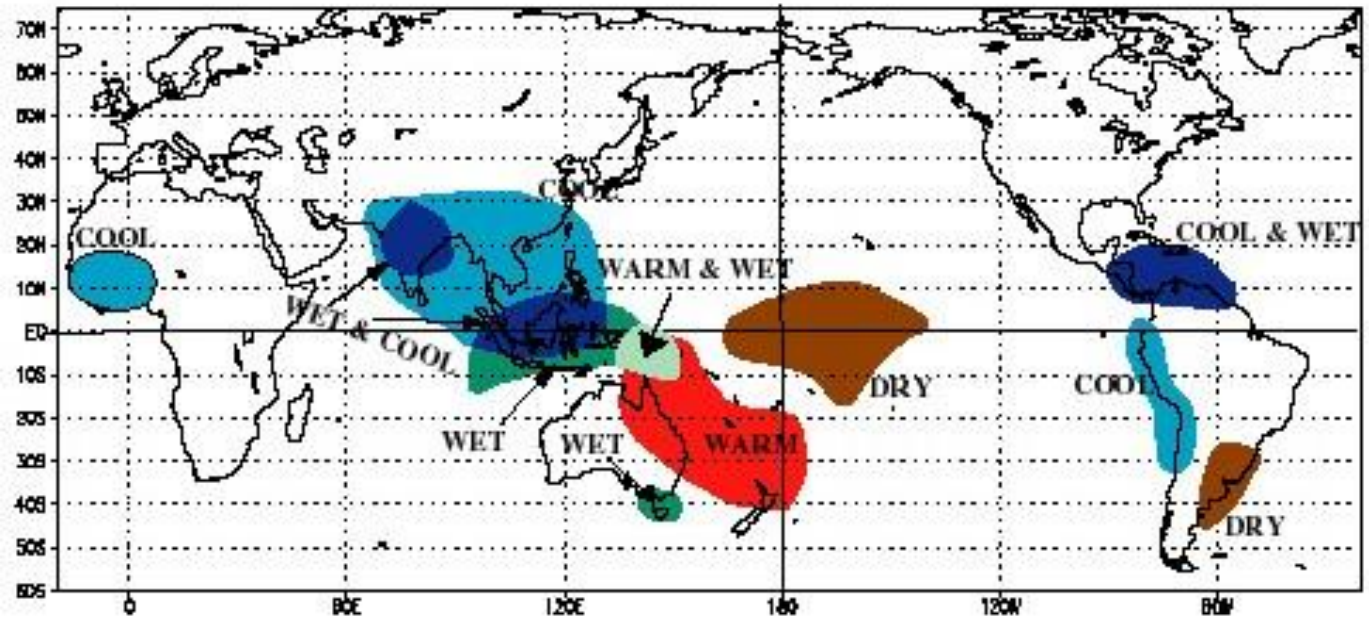
WARM EPISODE RELATIONSHIPS JUNE - AUGUST



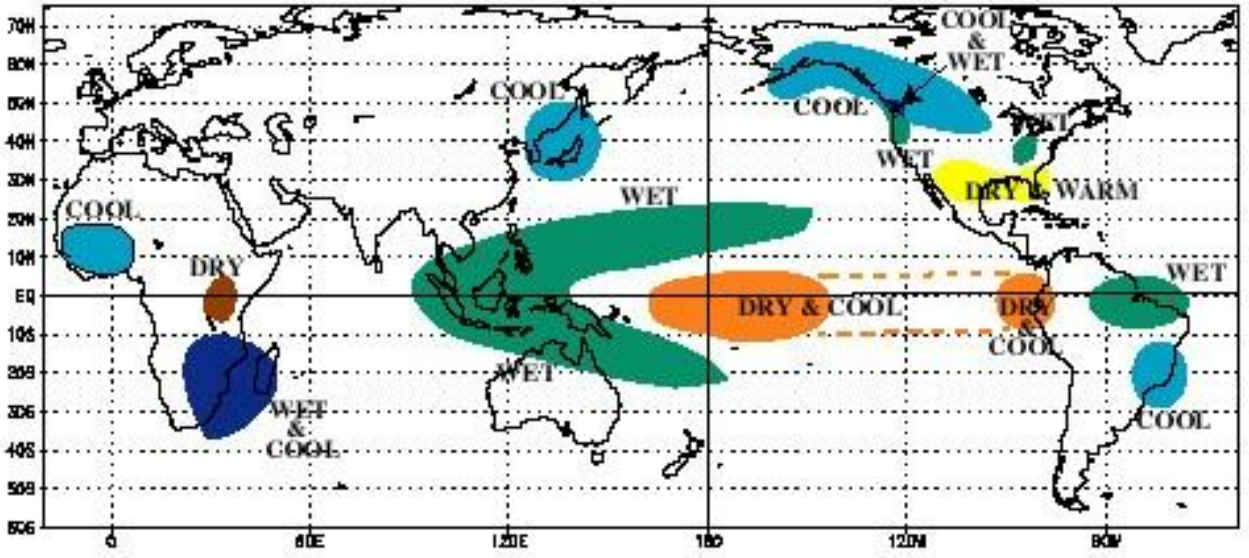
WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



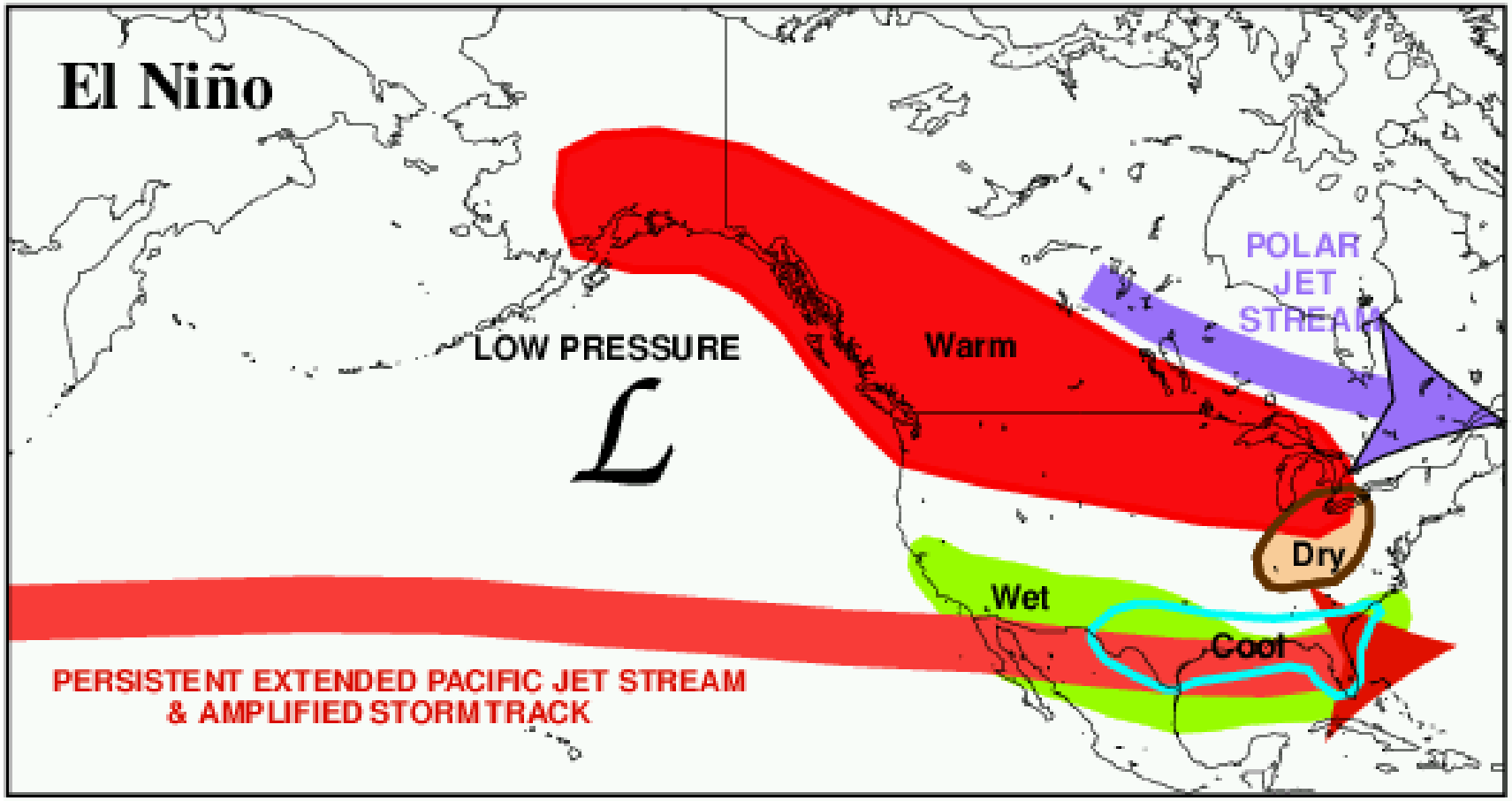
COLD EPISODE RELATIONSHIPS JUNE - AUGUST

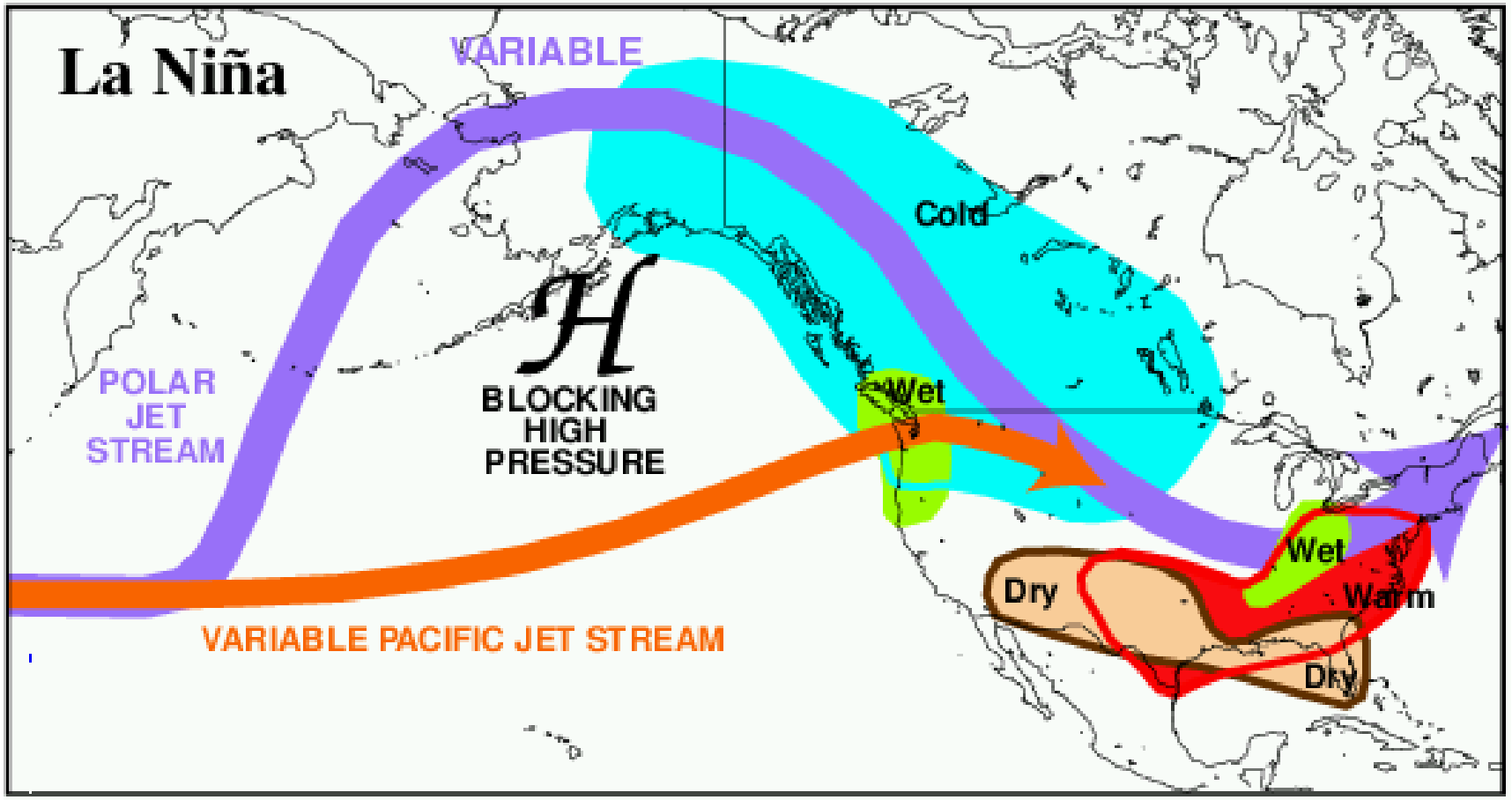


COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



TYPICAL JANUARY-MARCH WEATHER ANOMALIES AND ATMOSPHERIC CIRCULATION DURING MODERATE TO STRONG EL NIÑO & LA NIÑA

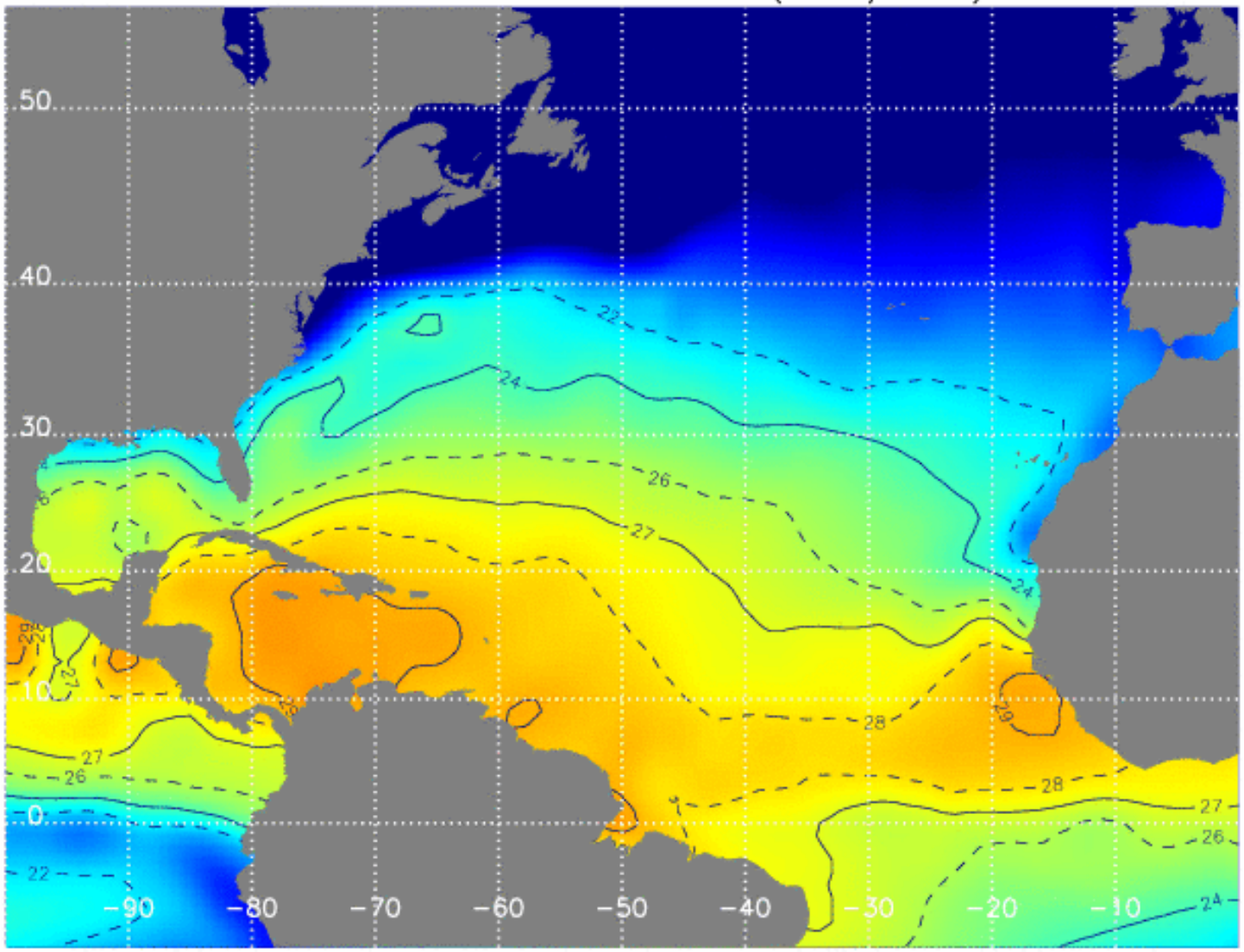



La Niña
VARIABLE
Cold
H
BLOCKING
HIGH
PRESSURE
POLAR
JET
STREAM
Wet
Dry
Wet
Warm
Dry
VARIABLE PACIFIC JET STREAM

ENSO and Atlantic hurricanes

- Tropical storms (hurricanes, cyclones, typhoons) are driven by heat in ocean water
- There is a link between the temperature of the equatorial Atlantic and the cumulative amount of energy in Atlantic hurricanes (meaning that the intensity of tropical storms can be linked to climate change)
- The development of tropical storms can be inhibited by vertical wind shear in the troposphere because wind shear inhibits cyclone development
- El Nino promotes Atlantic wind shear and so hurricanes tend to be less frequent
- La Nina conditions favour hurricanes, which partly explains why 2010 and 2011 have been such significant hurricane years (20 Atlantic tropical storms in 2010 and already 18 in 2011, typical average is less than 15)

NWS National Hurricane Center (NCEP/NOAA)

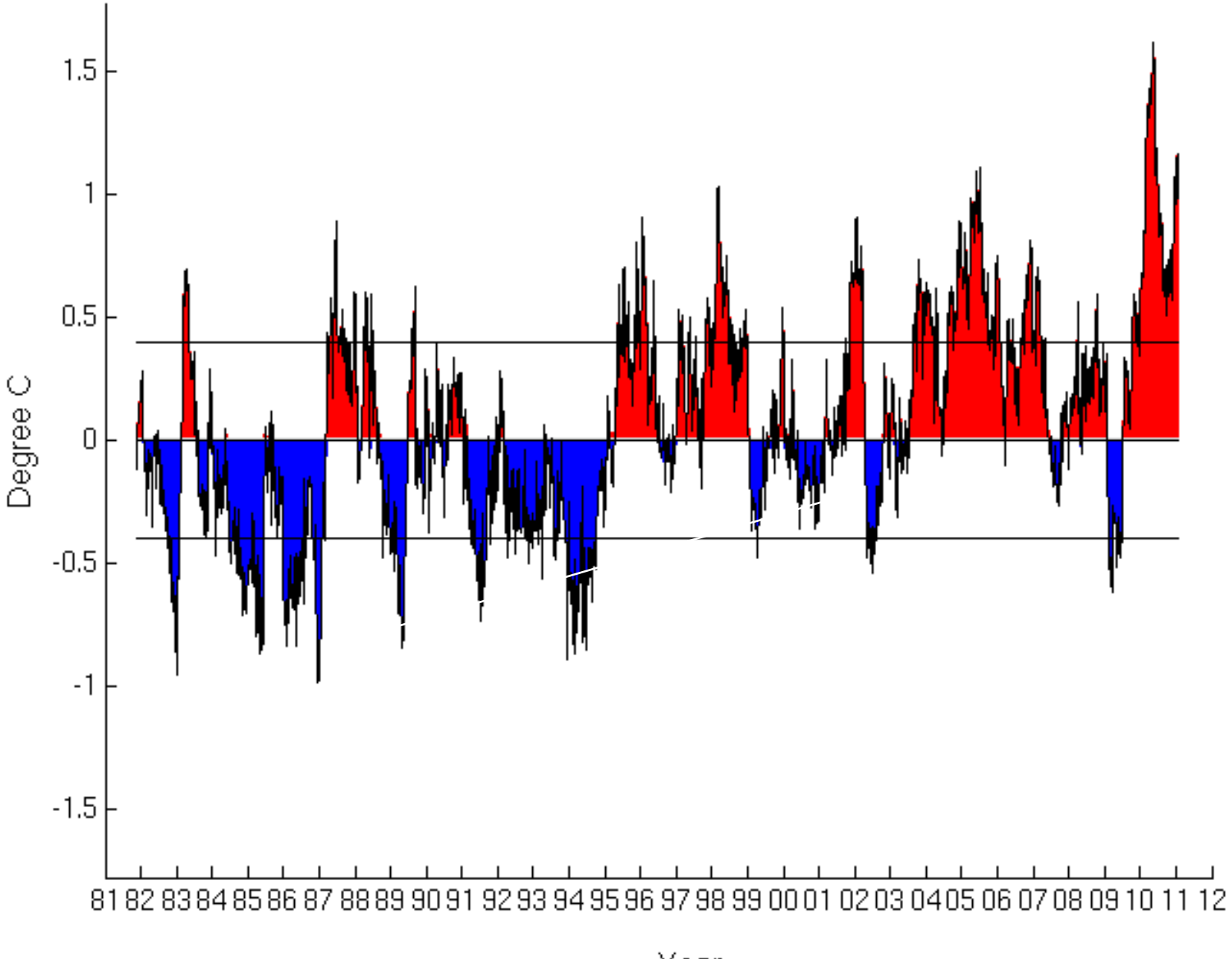


Ocean Analysis – Reynolds Weekly Sea Surface Temperature (7 day period ending on: 12–NOV–11)
degrees °C

15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0

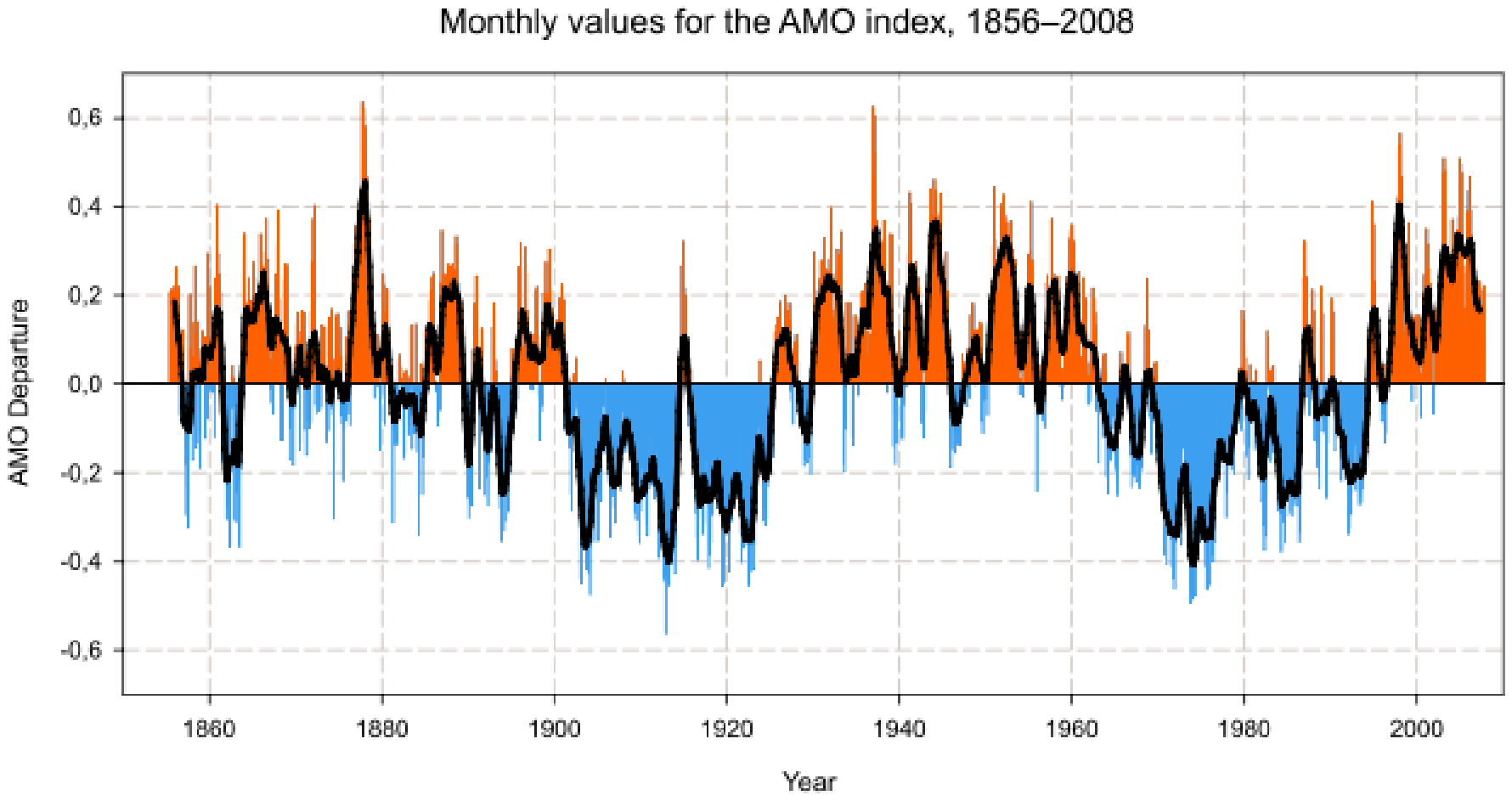
Data source: Environmental Modelling Center (NCEP/NOAA)

Tropical Atlantic basin SST anomalies



How does ENSO affect our climate?

Atlantic Multidecadal Oscillation



10-year running mean of the detrended Atlantic SST anomalies north of the equator

Atlantic Multidecadal Oscillation

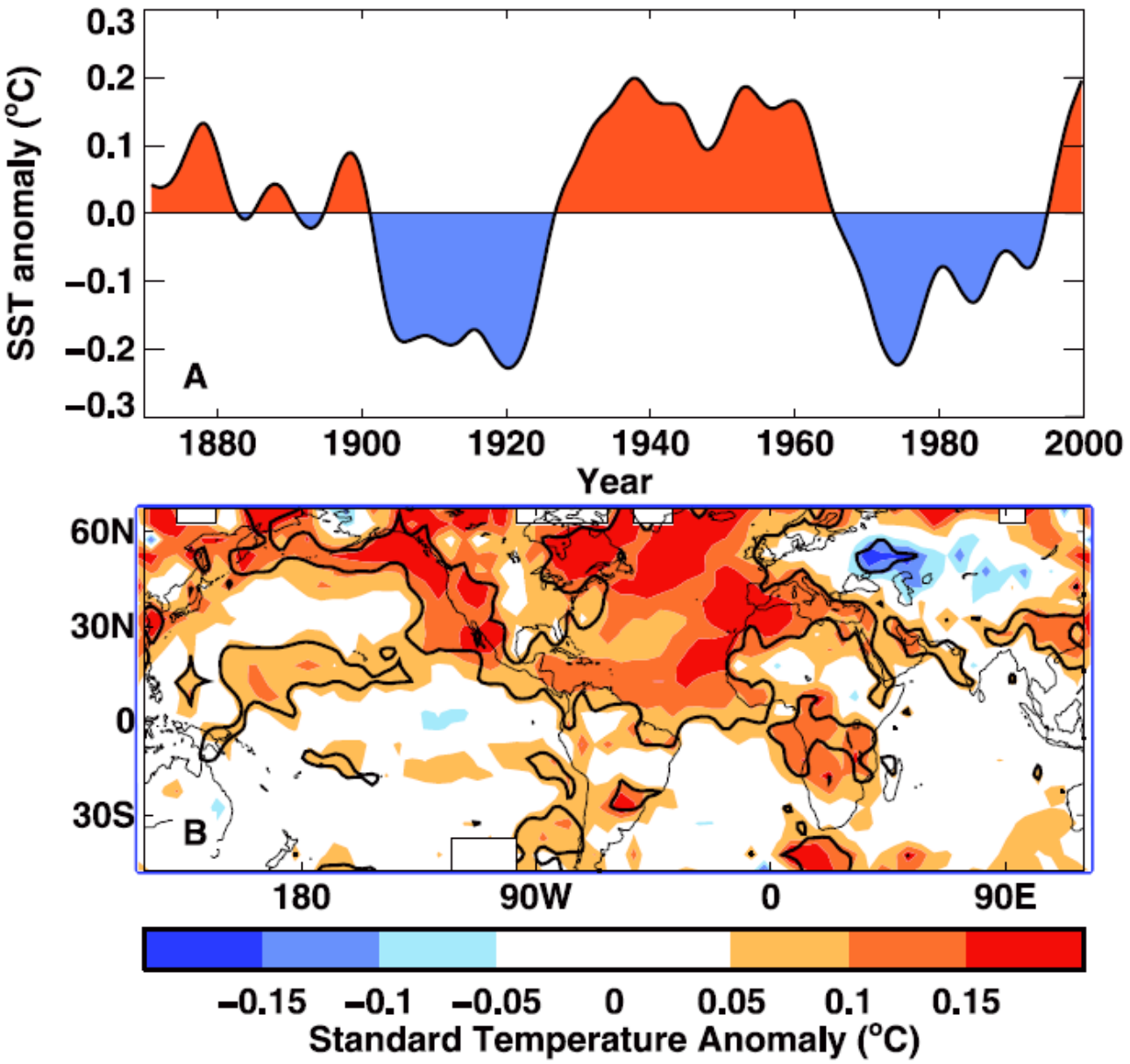
The AMO is a pattern of changes in the sea surface temperature of the North Atlantic Ocean with a period is around 70 y and a T difference of about 0.5°C between extremes. These changes are natural and have been occurring for at least the last 1,000 years.

The AMO affects air temperatures and rainfall over much of the Northern Hemisphere, in particular, North America and Europe. It is associated with changes in the frequency of North American droughts (large-scale droughts in the United States are likely to be associated with positive AMO) and is reflected in the frequency of severe Atlantic hurricanes (more hurricanes occur in the N. Atlantic during positive AMO periods).

The AMO obscures the human-induced global warming trend during AMO-cool periods and exaggerates the trend during AMO-warm periods.

Models of the ocean and atmosphere that interact with each other indicate that the AMO cycle involves changes in the south-to-north circulation and overturning of water and heat in the Atlantic Ocean – the **Atlantic Meridional Overturning Circulation** (a.k.a.: the Atlantic thermohaline circulation).
(In other words, this is a subdued expression of the mechanism for Dansgaard-Oeschger cycles.)
When the overturning circulation decreases, the North Atlantic temperatures become cooler.

Atlantic multi-decadal oscillation



Monitoring the Atlantic Meridional Overturning Circulation (MOC)

Harry L. Bryden

With Stuart Cunningham and Jochem Marotzke

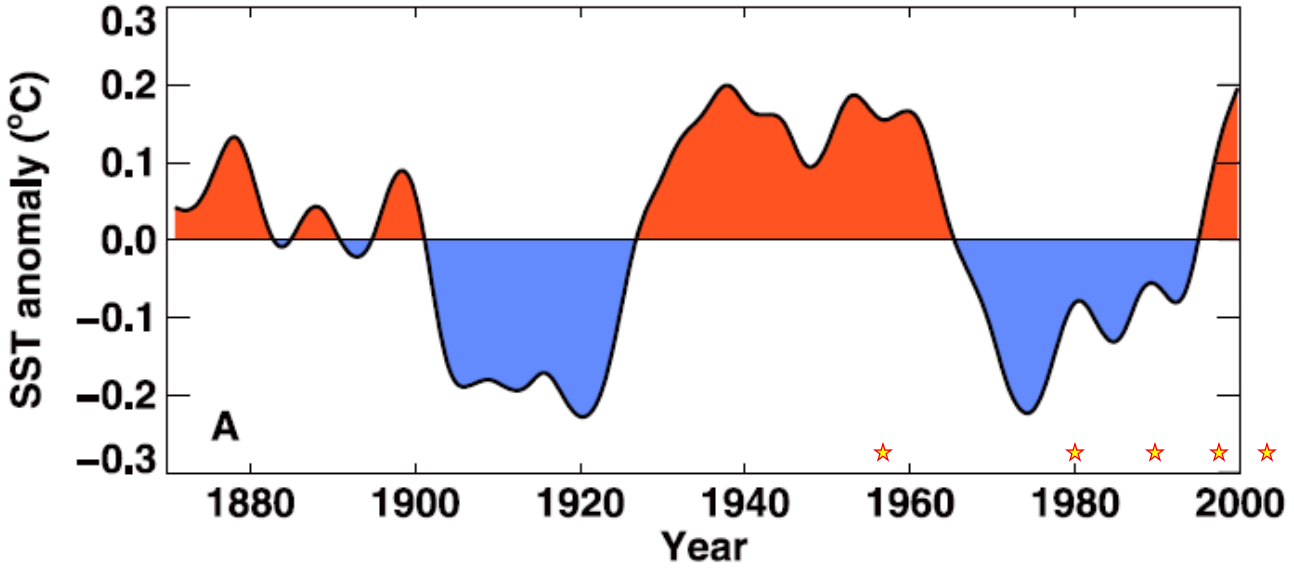
Slowing of the Atlantic meridional overturning circulation at 25° N

H.L. BRYDEN et al / Nature v.438 1dec2005

Harry L. Bryden[1], Hannah R. Longworth[1] & Stuart A. Cunningham[1]
[1]National Oceanography Centre, Empress Dock, Southampton SO14 3ZH, UK.

The Atlantic meridional overturning circulation carries warm upper waters into far-northern latitude
makes a s
and any sl

A transa
overtu
transat
decades
slowed b
Gulf Strea
cent large
per cent de
and 5,000 ... ... depth. In 2004, more of the northward Gulf Stream flow was recirculating back southward in the thermocline within the subtropical gyre, and less was returning southward at depth.

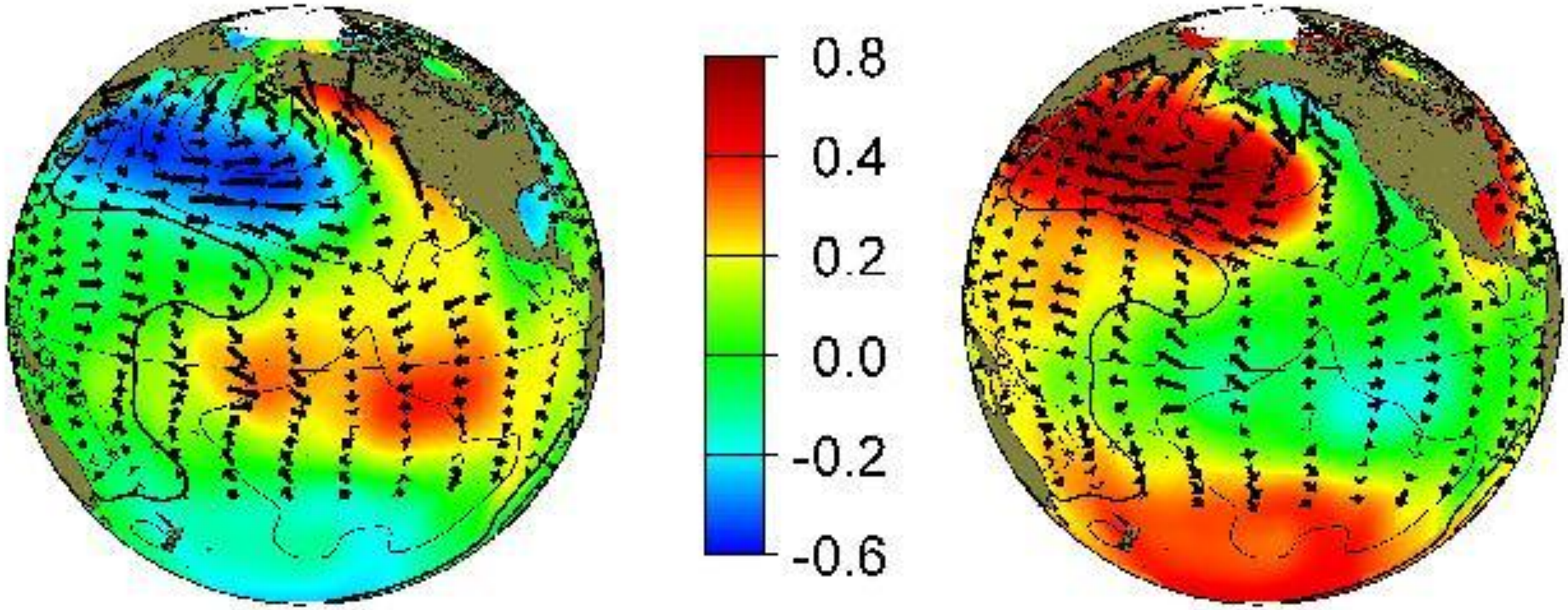


The decrease in net northward flow of warm upper waters and decrease in net southward flow of cold deep waters across the 25° N section result in a reduction of the northward heat transport across 25° N from 1.3–1.4 PW (1 PW = 10^{15} W) for the 1957, 1981 and 1992 sections to 1.1 PW for the 1998 and 2004 sections.

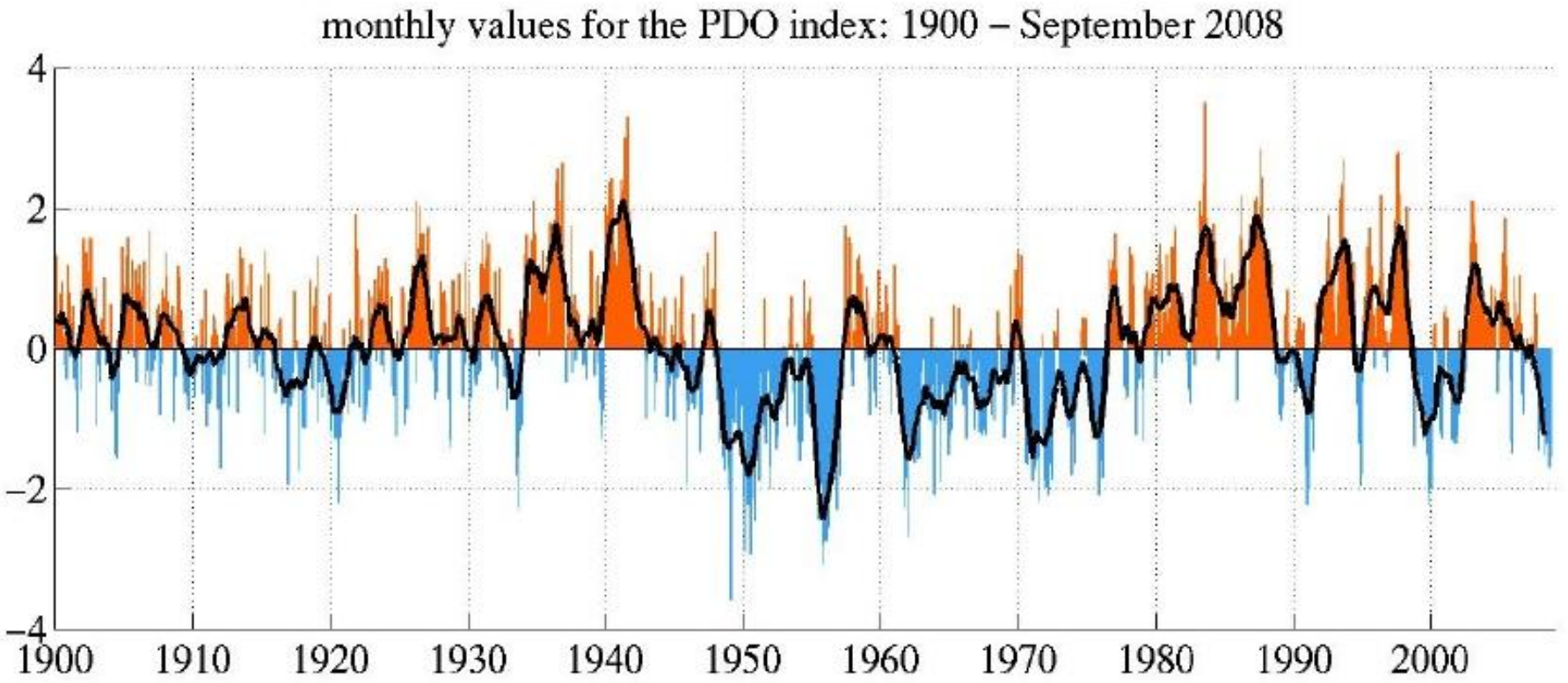
Pacific Decadal Oscillation

Warm phase

Cool phase

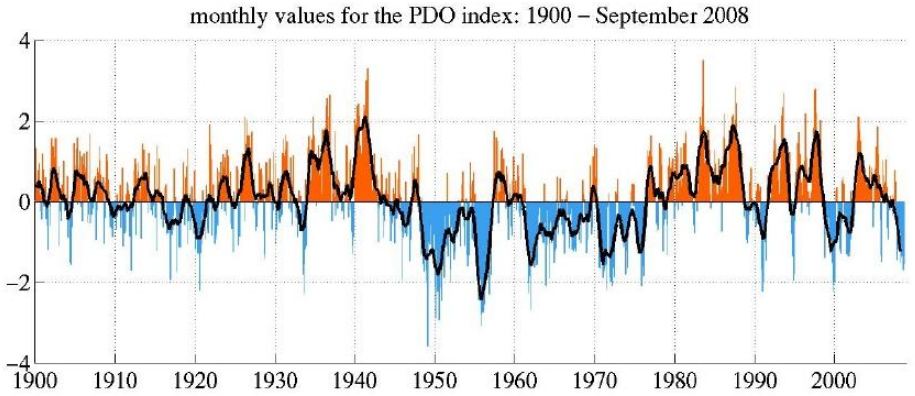


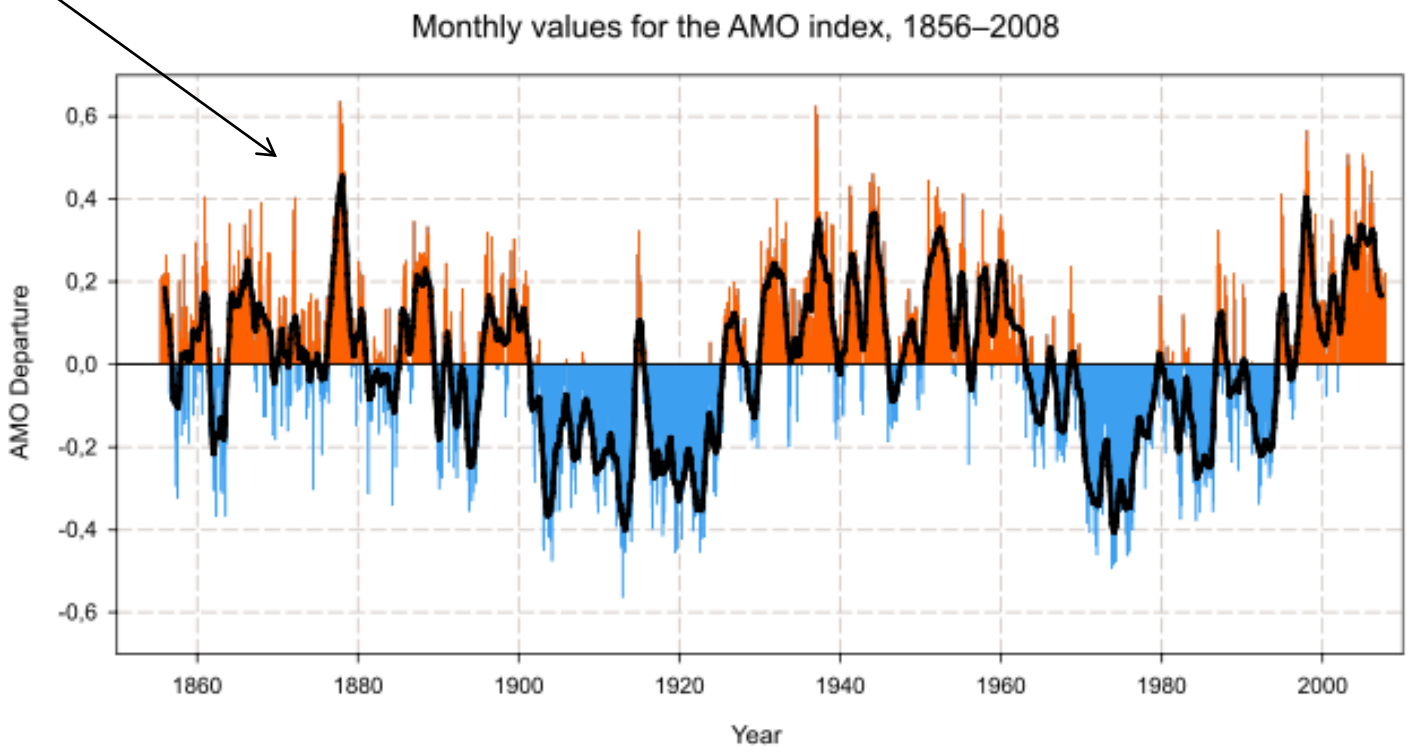
http://jisao.washington.edu/pdo/

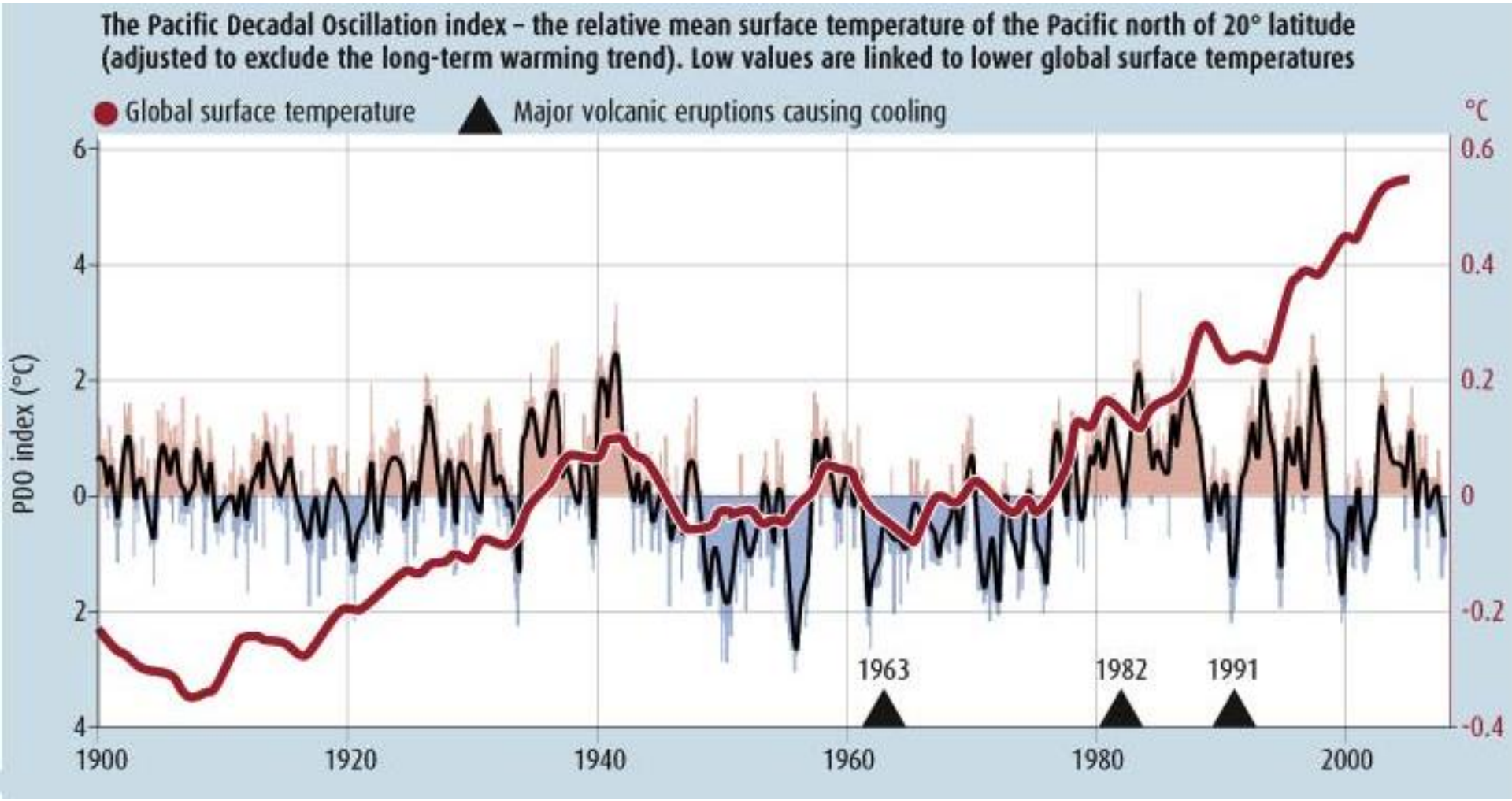


http://jisao.washington.edu/pdo/

PDO vs AMO


monthly values for the PDO index: 1900 – September 2008
4
2
0
−2
−4
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000


Monthly values for the AMO index, 1856–2008
AMO Departure
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
1860
1880
1900
1920
1940
1960
1980
2000
Year



From Pearce and LePage, New Scientist, August 2008

September 1915 (Pacific Fisherman 1915)

"Never before have the Bristol Bay [Alaska] salmon packers returned to port after the season's operations so early."

"The spring [chinook salmon] fishing season on the Columbia River [Washington and Oregon] closed at noon on August 25, and proved to be one of the best for some years."

1939 Yearbook (Pacific Fisherman 1939)

"The Bristol Bay [Alaska] Red [sockeye salmon] run was regarded as the greatest in history."

"The [May, June and July chinook] catch this year is one of the lowest in the history of the Columbia [Washington and Oregon]."

August/September 1972 (Pacific Fisherman 1972)

"Bristol Bay [Alaska] salmon run a disaster."

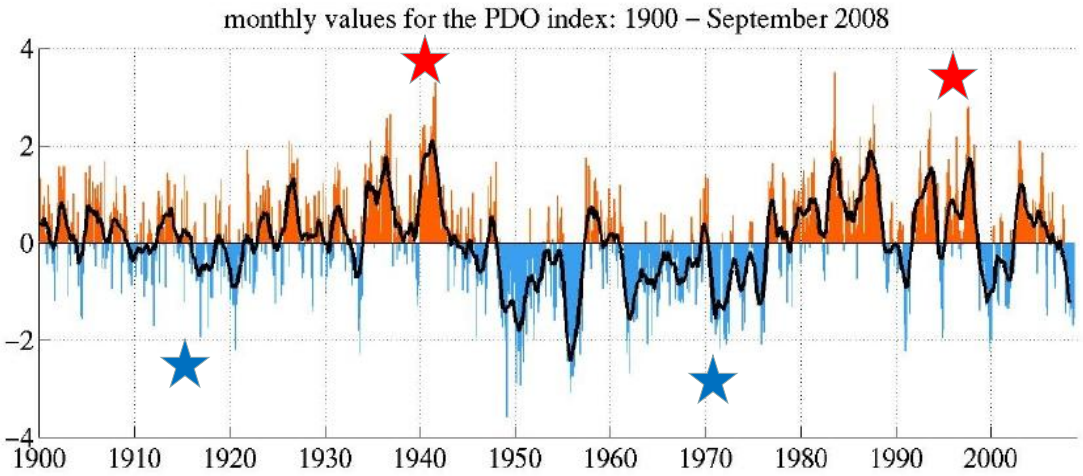
"Gillnetters in the Lower Columbia [Washington and Oregon] received an unexpected bonus when the largest run of spring chinook since counting began in 1938 entered the river."

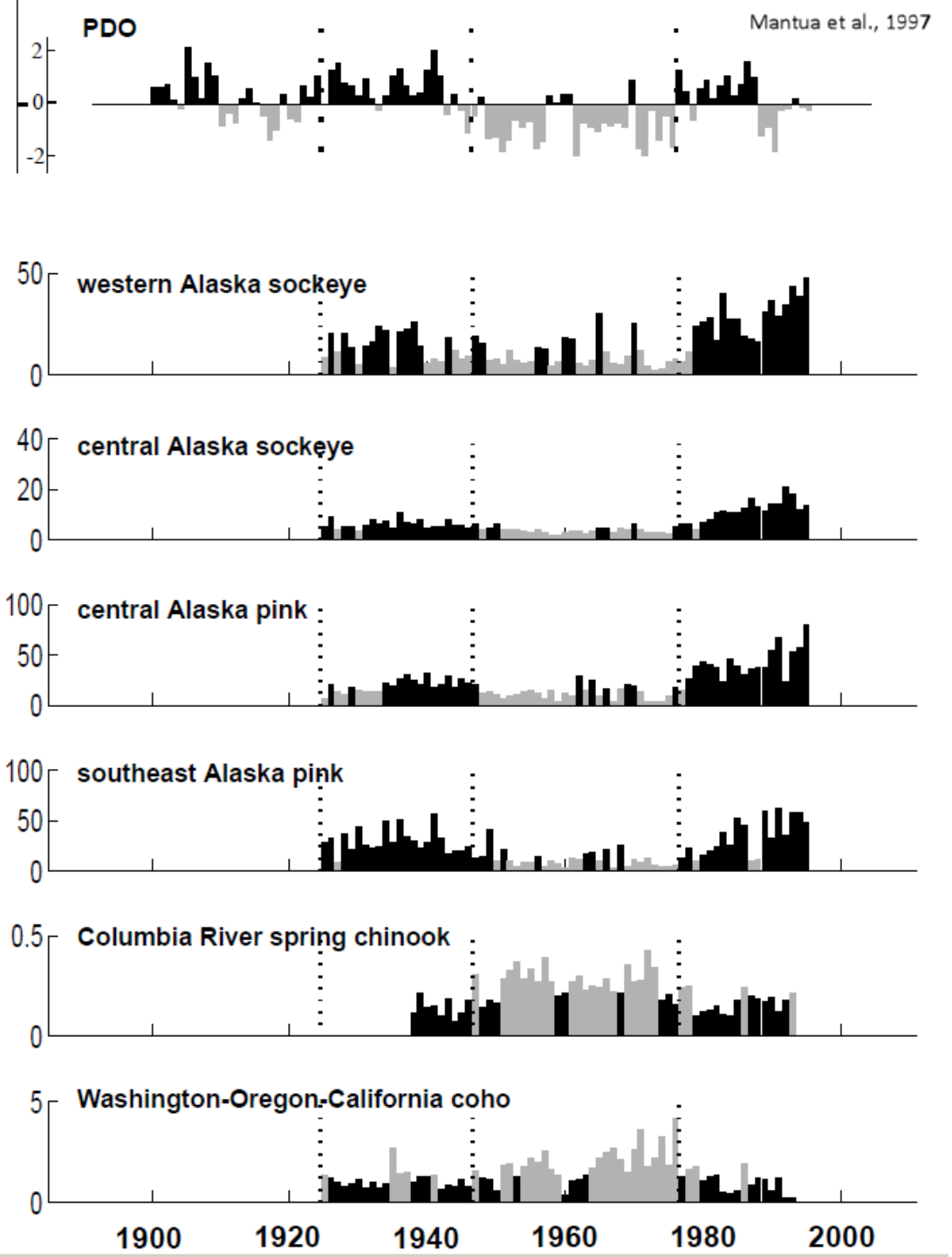
1995 Yearbook (Pacific Fishing 1995)

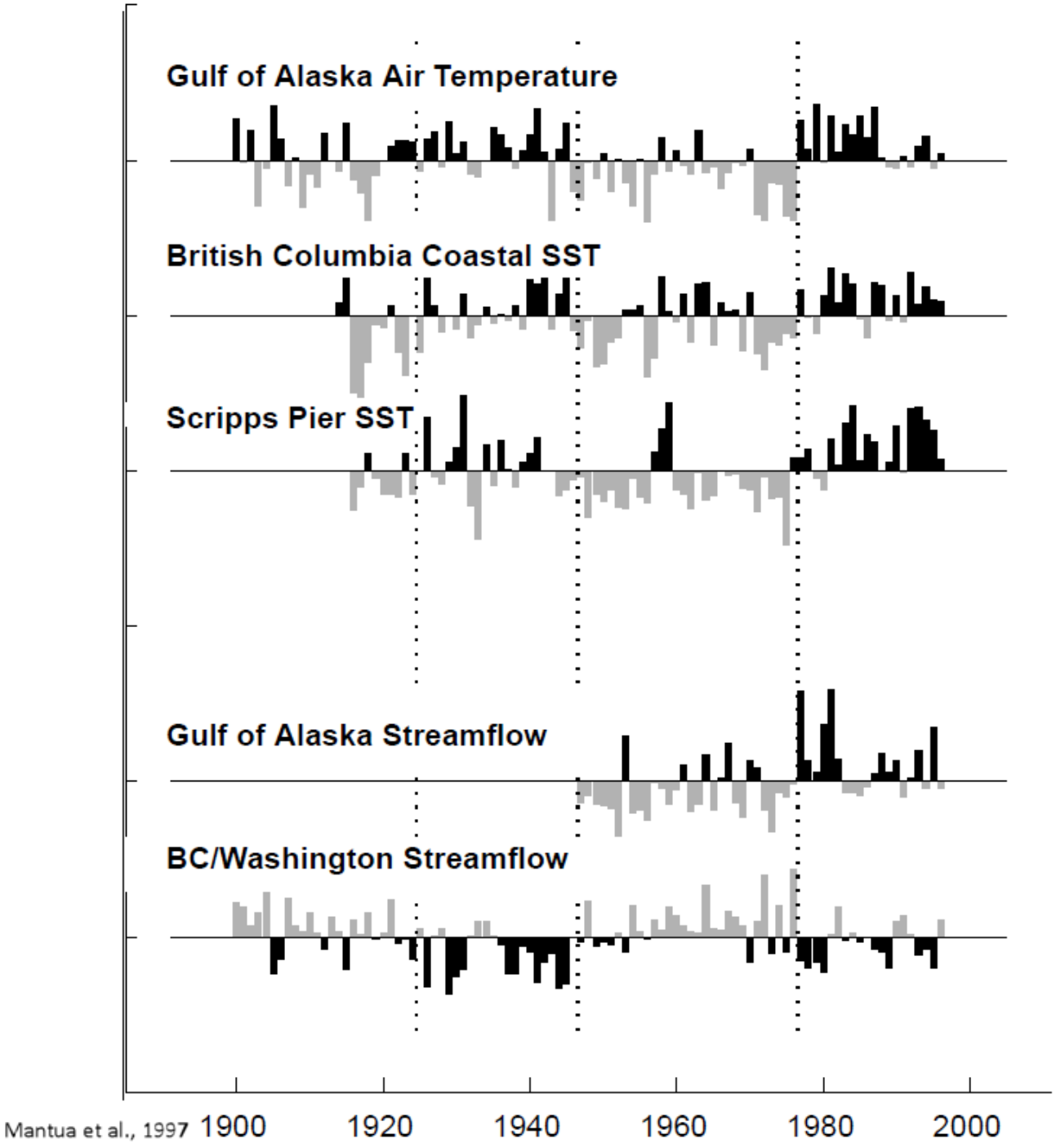
"Alaska set a new record for its salmon harvest in 1994, breaking the record sett he year before."

"Columbia [Washington and Oregon] spring chinook fishery shut down; west coast troll coho fishing banned."

Text from Mantua et al., 1997

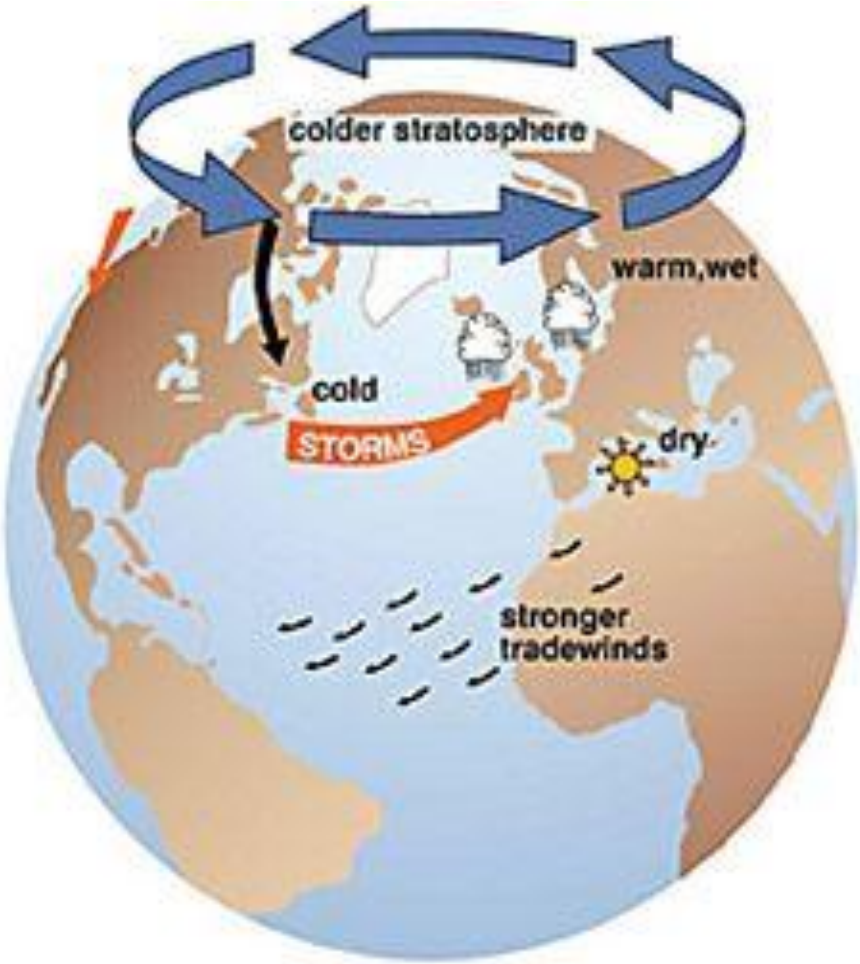


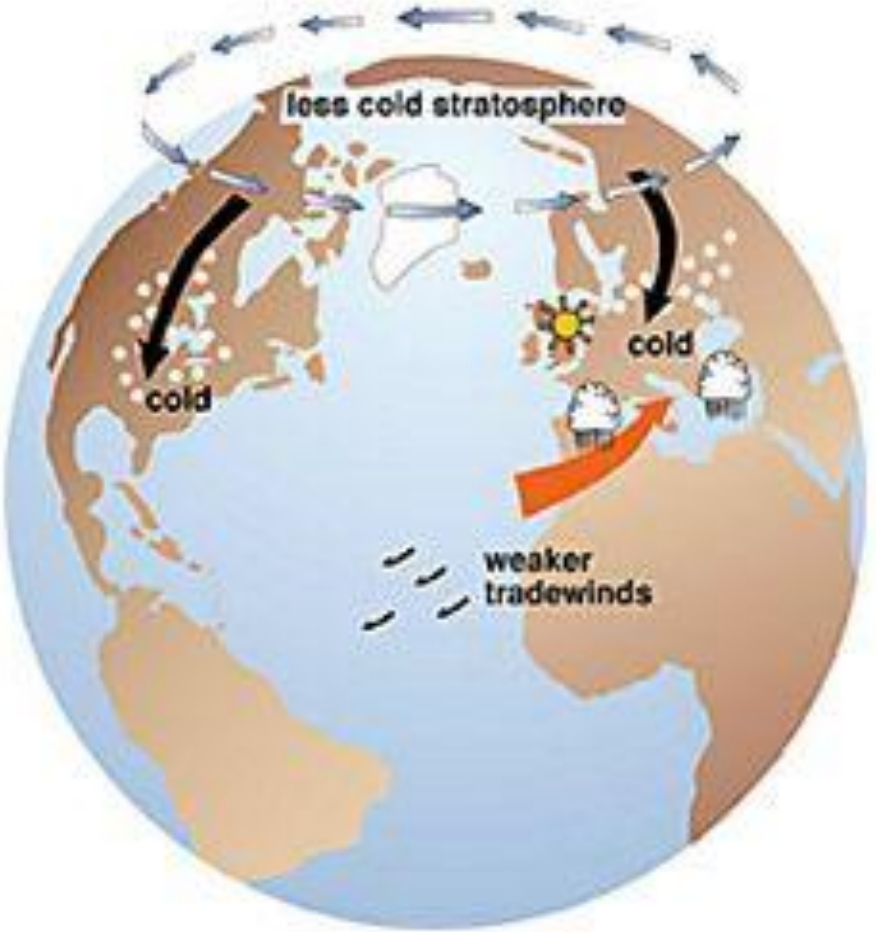

PDO
Mantua et al., 1997
2
0
-2
western Alaska sockeye
50
0
central Alaska sockeye
40
20
0
central Alaska pink
100
50
0
southeast Alaska pink
100
50
0
Columbia River spring chinook
0.5
0
Washington-Oregon-California coho
5
0
1900
1920
1940
1960
1980
2000



Mantua et al., 1997

Arctic Oscillation



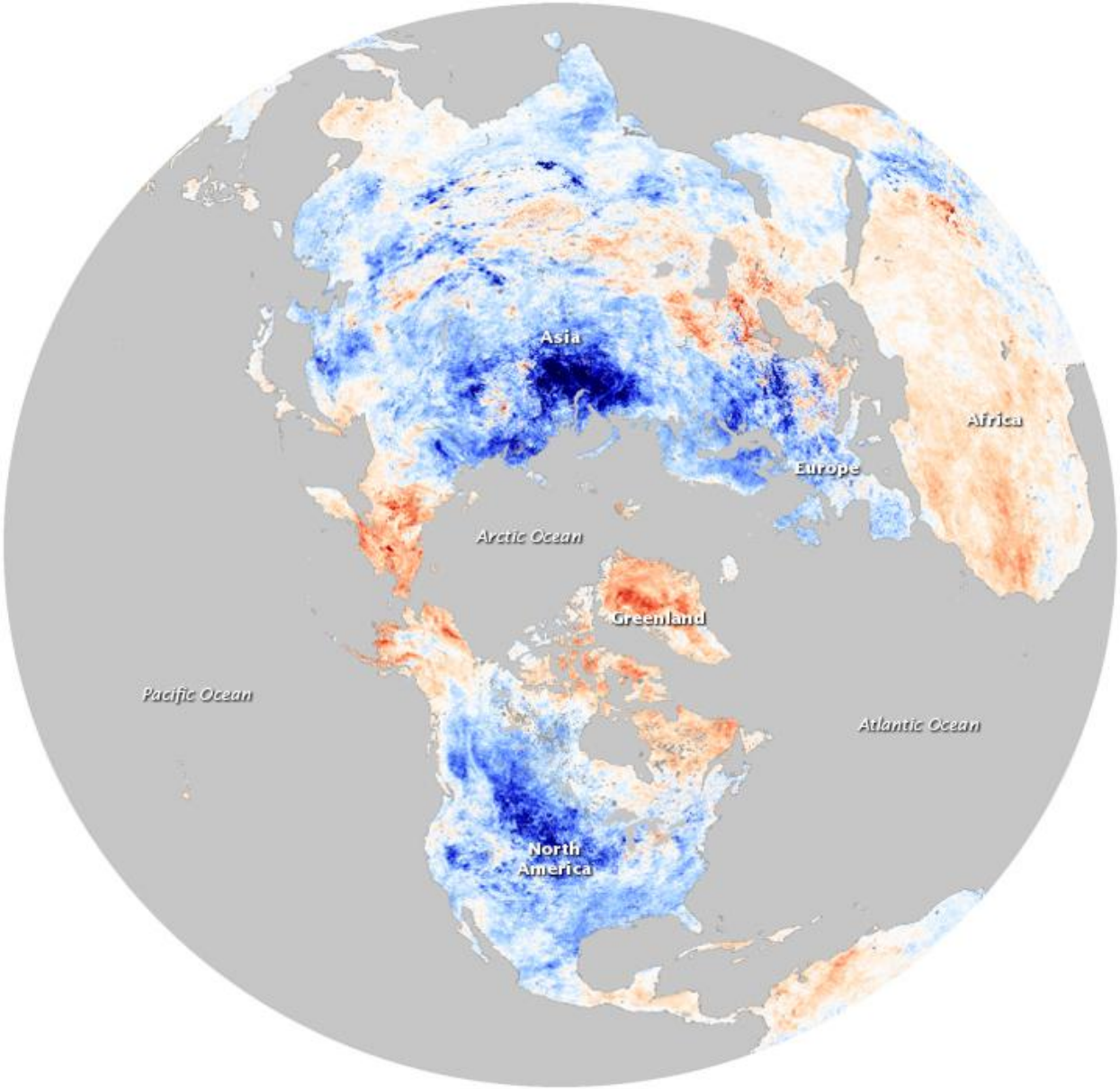


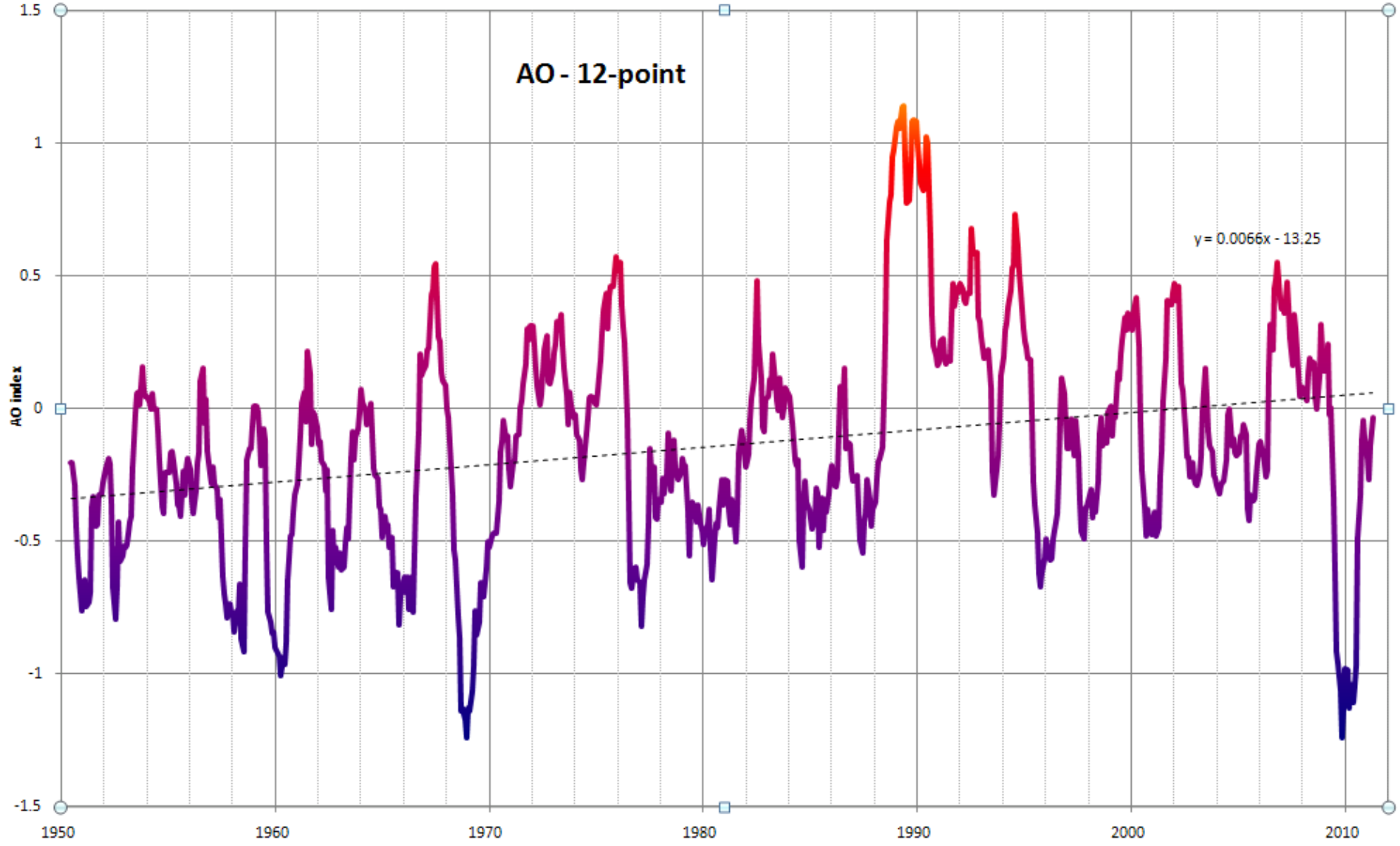
The Arctic Oscillation is a climate pattern that influences winter weather in the Northern Hemisphere. It is defined by the pressure difference between air at mid-latitudes (around 45 degrees North, about the latitude of Montreal, Canada or Bordeaux, France) and air over the Arctic. A low-pressure air mass usually dominates the Arctic, and while higher pressure air sits over the mid-latitudes.

This pressure difference generates winds that confine extremely cold air to the Arctic.

Sometimes, the pressure systems weaken, decreasing the pressure difference between the Arctic and mid-latitudes and allowing chilly Arctic air to slide south while warmer air creeps north.

Temperature anomalies during a strong negative AO period (2010)




AO - 12-point
y = 0.0066x - 13.25
AO index
1.5
1
0.5
0
-0.5
-1
-1.5
1950
1960
1970
1980
1990
2000
2010