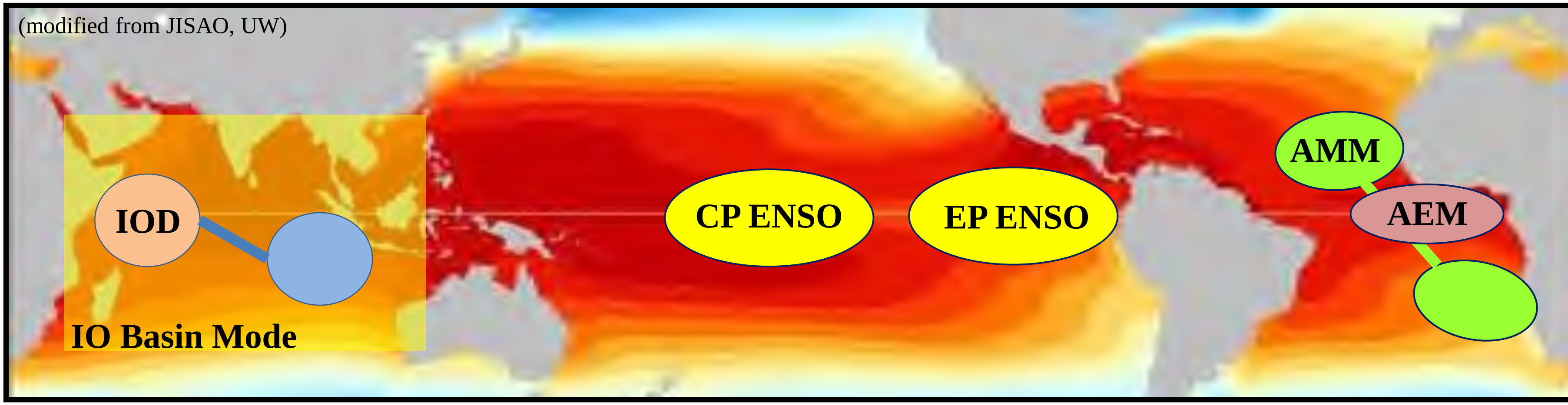
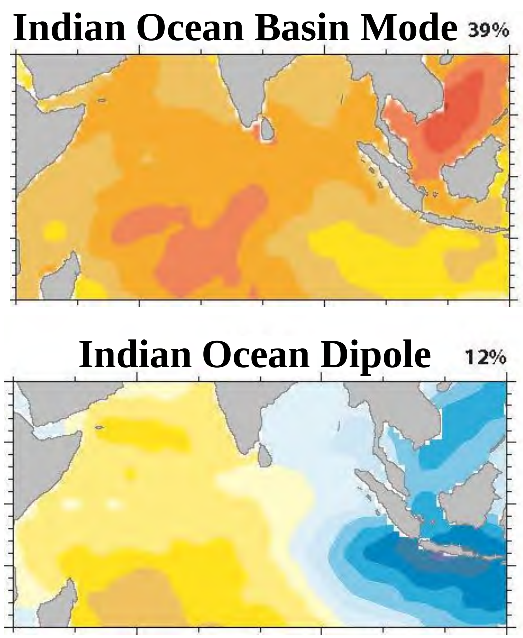
The increased Influence of Atlantic Ocean on Pacific Climate after Early 1990s

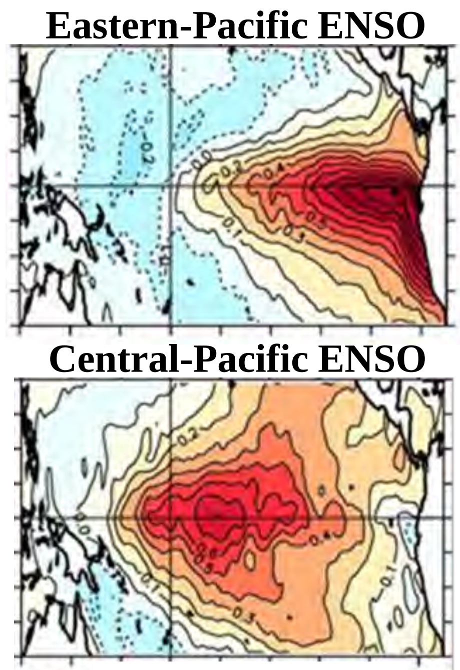
Jin-Yi Yu
Department of Earth System Science
University of California, Irvine

Inter-Basin Interactions in Tropics

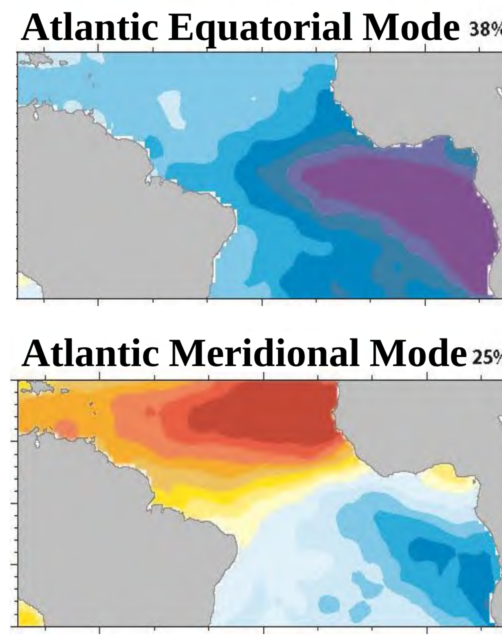




(from Deser et al. 2010)

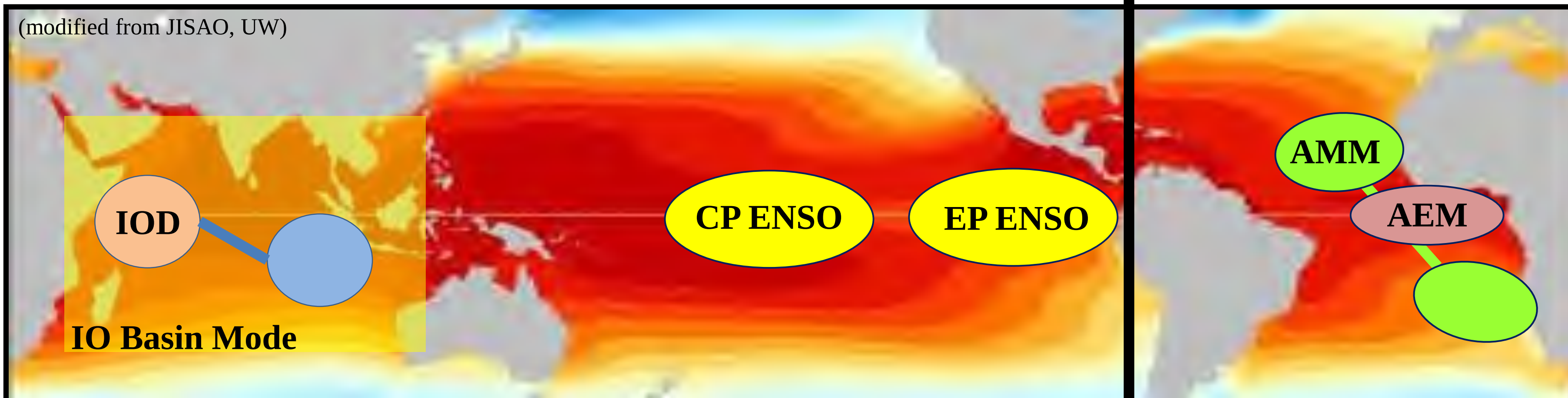


(from Yu and Paek 2016)

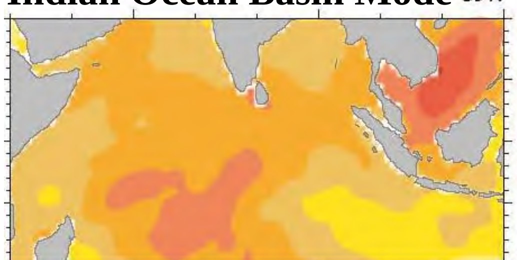


(from Deser et al. 2010)

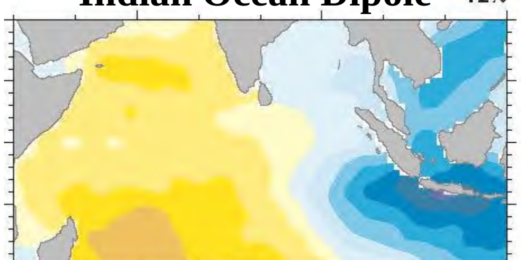
Pacific Ocean ↔ Indian Ocean



Indian Ocean Basin Mode 39%

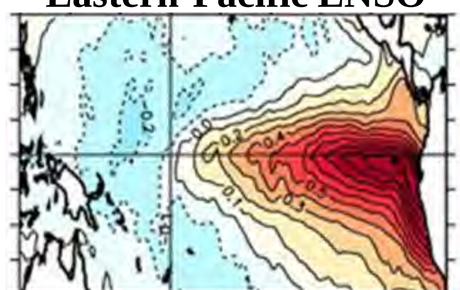


Indian Ocean Dipole 12%

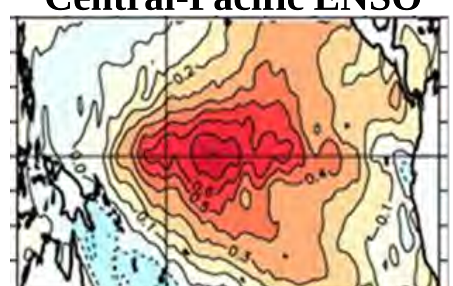


(from Deser et al. 2010)

Eastern-Pacific ENSO

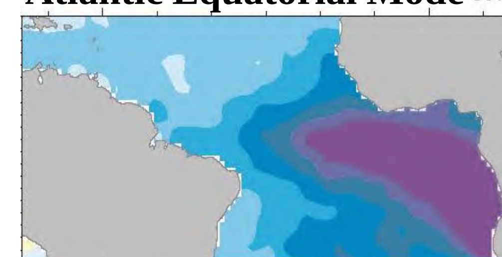


Central-Pacific ENSO

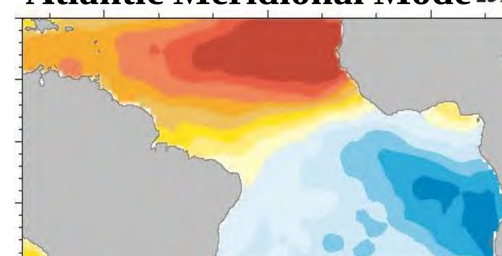


(from Yu and Paek 2016)

Atlantic Equatorial Mode 38%

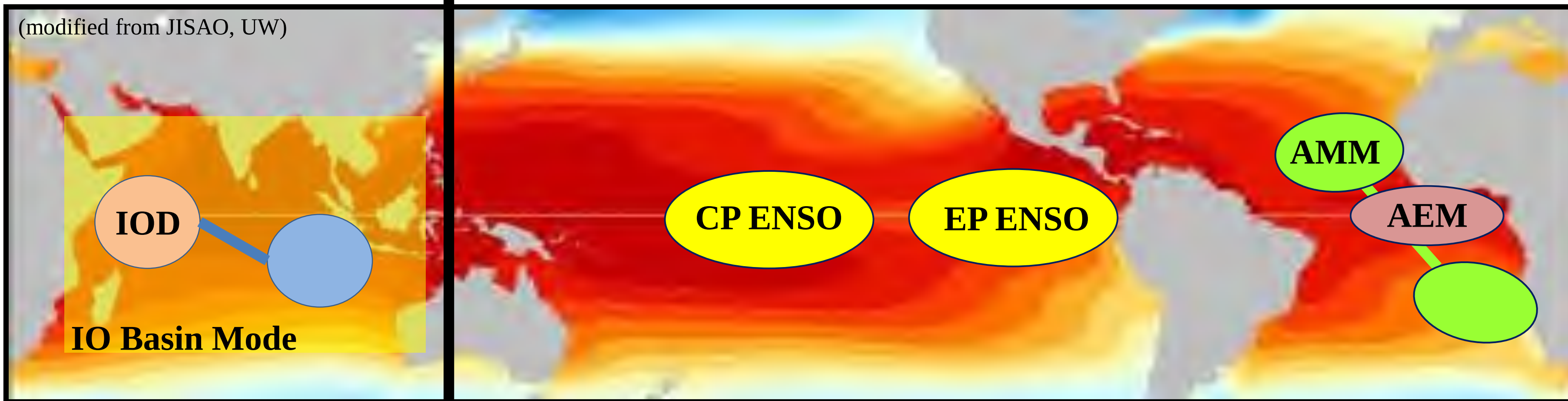


Atlantic Meridional Mode 25%

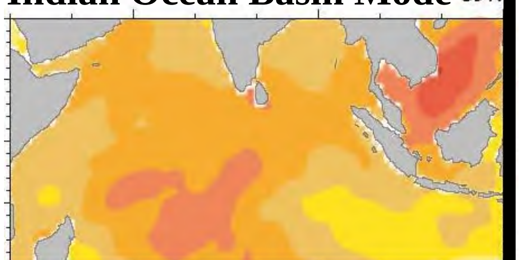


(from Deser et al. 2010)

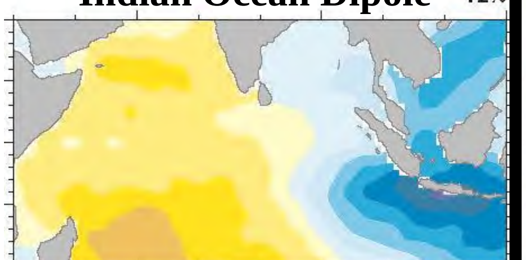
Pacific Ocean ←→ Atlantic Ocean



Indian Ocean Basin Mode 39%

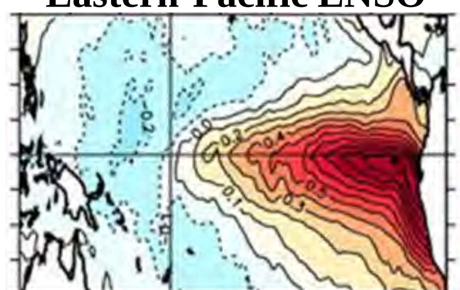


Indian Ocean Dipole 12%



(from Deser et al. 2010)

Eastern-Pacific ENSO



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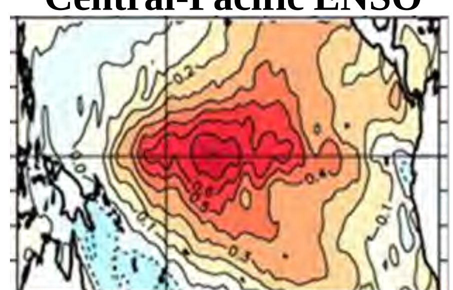

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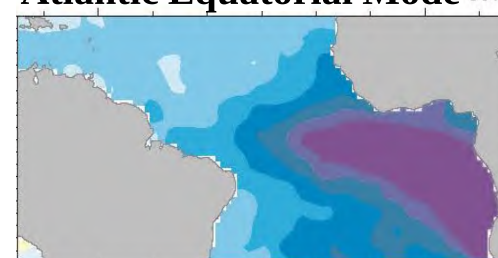
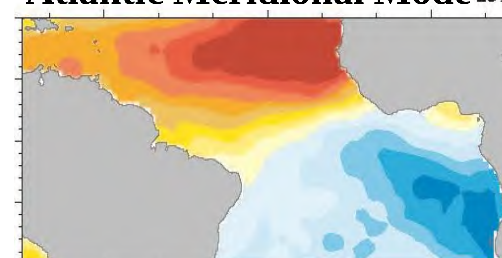


Atlantic Meridional Mode 25%

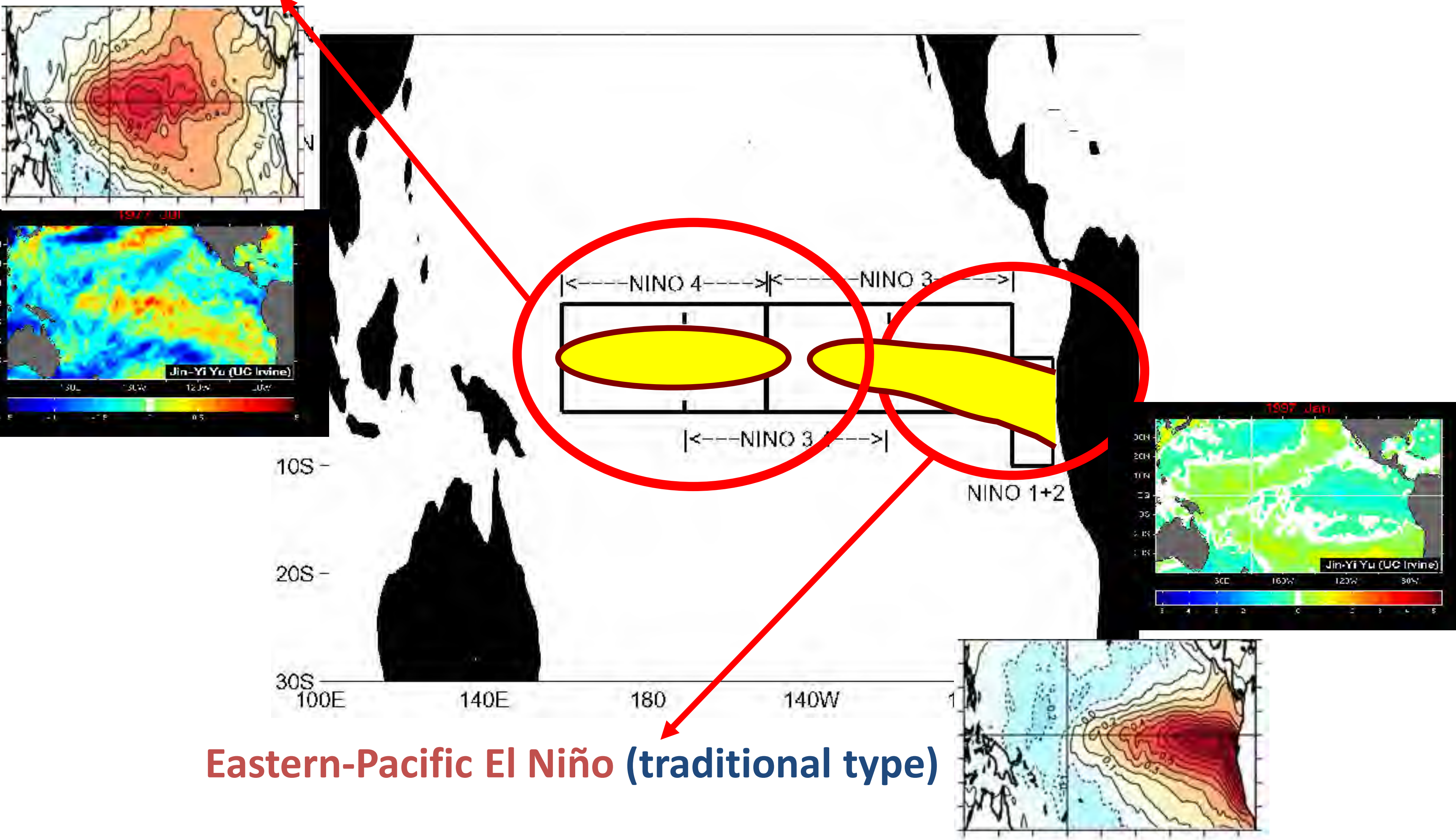


(from Deser et al. 2010)

Two Types of El Niño = ENSO Diversity

(Yu and Kao 2007; Kao and Yu 2009)

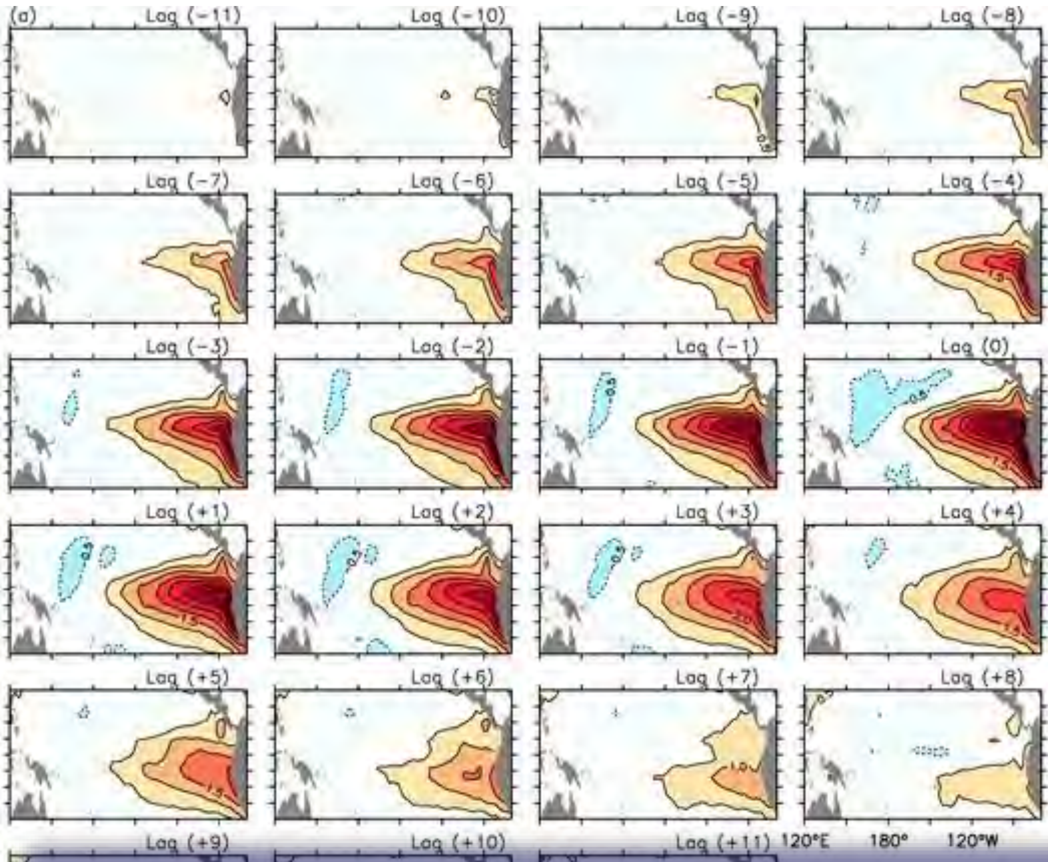
Central-Pacific El Niño (New Type)



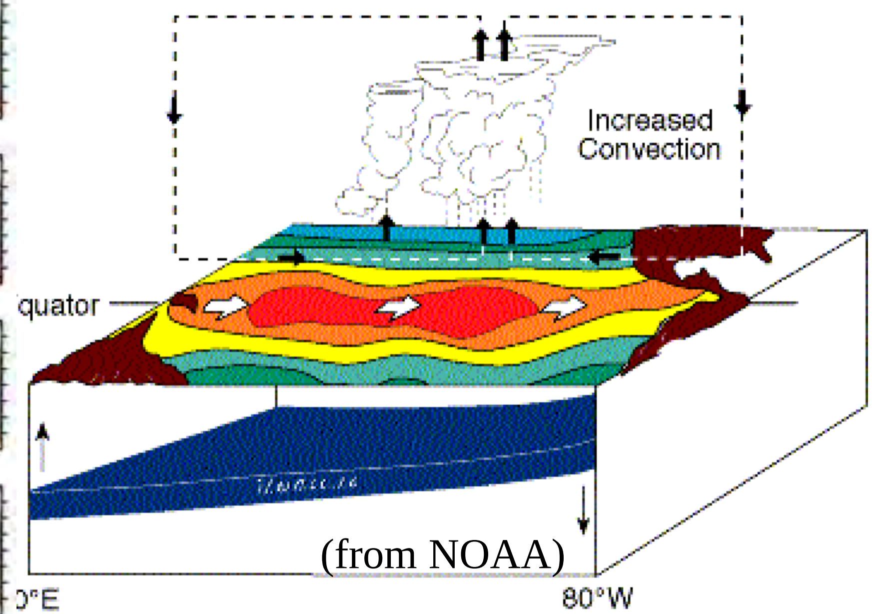
Eastern-Pacific El Niño (traditional type)

EP El Niño and Walker Circulation

Eastern Pacific El Niño

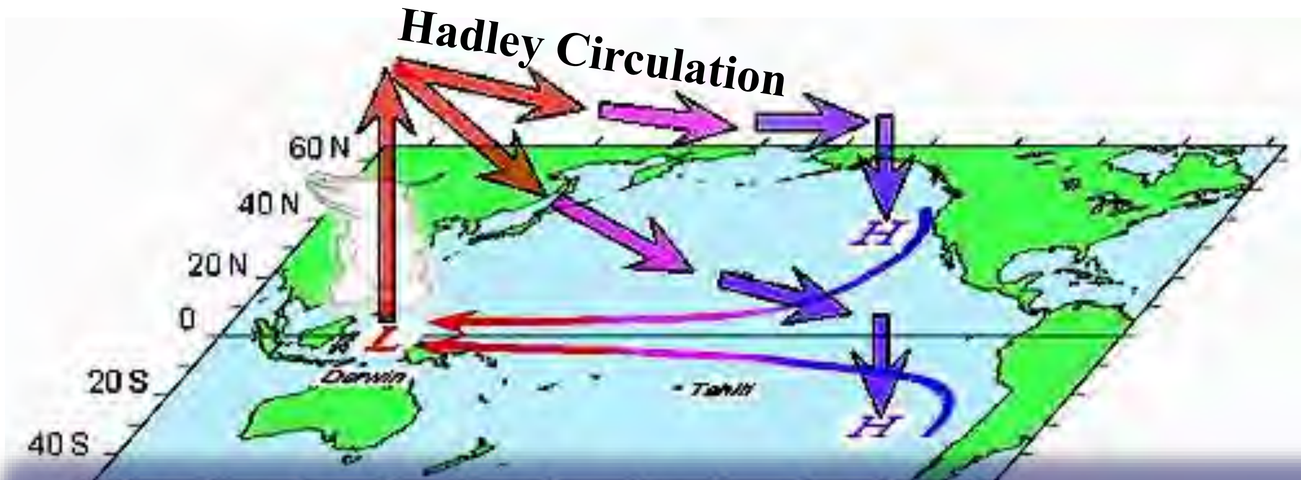


El Niño Condition

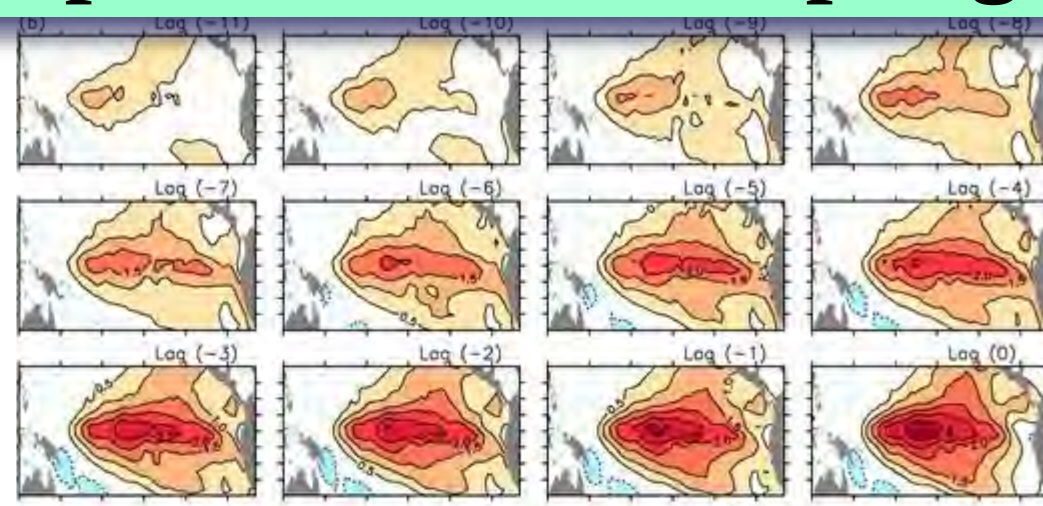


Tropical Atmosphere-Ocean Coupling

CP El Niño and Hadley Circulation

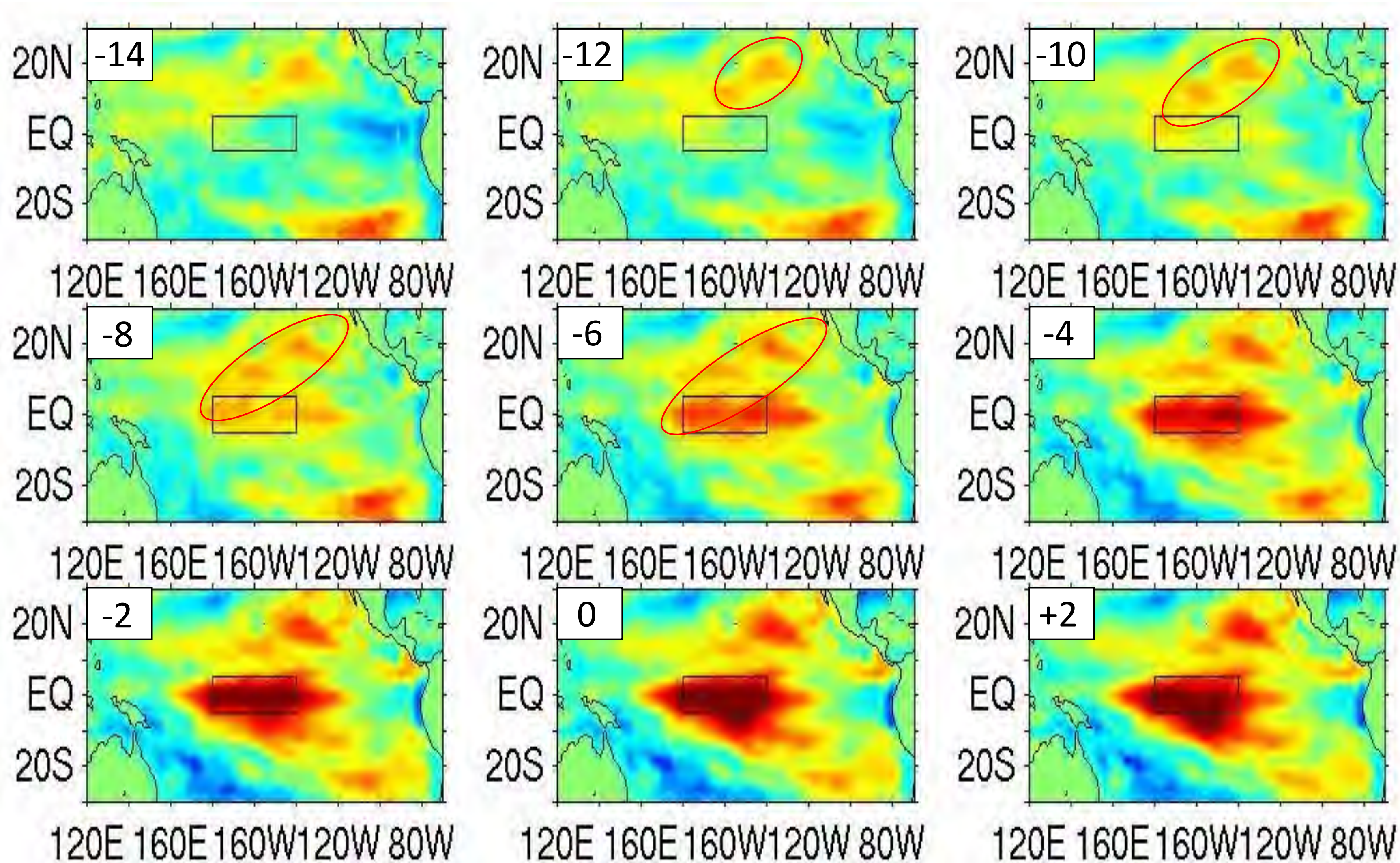


Subtropical Atmosphere-Ocean Coupling

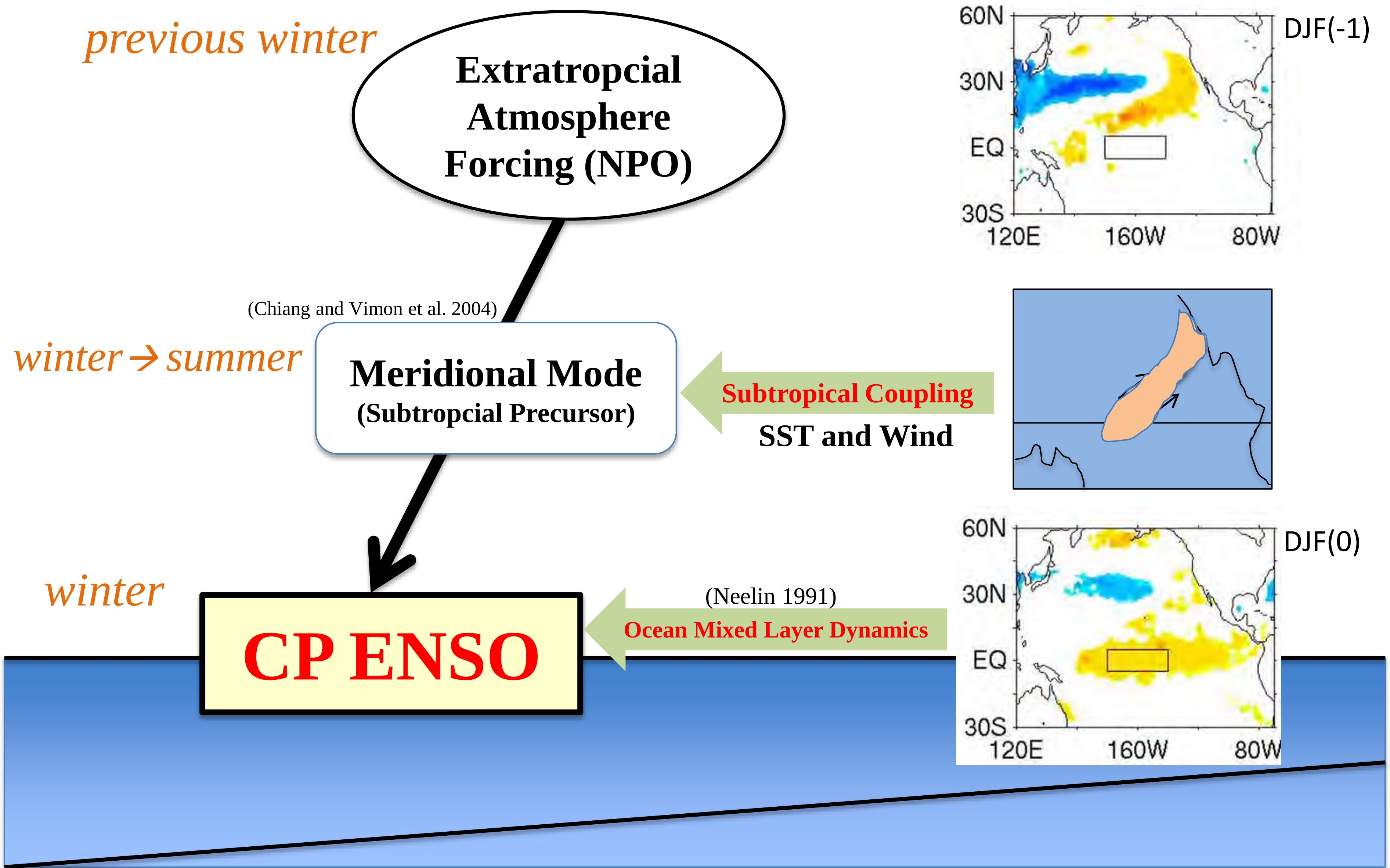


CP-El Niño SST Variations

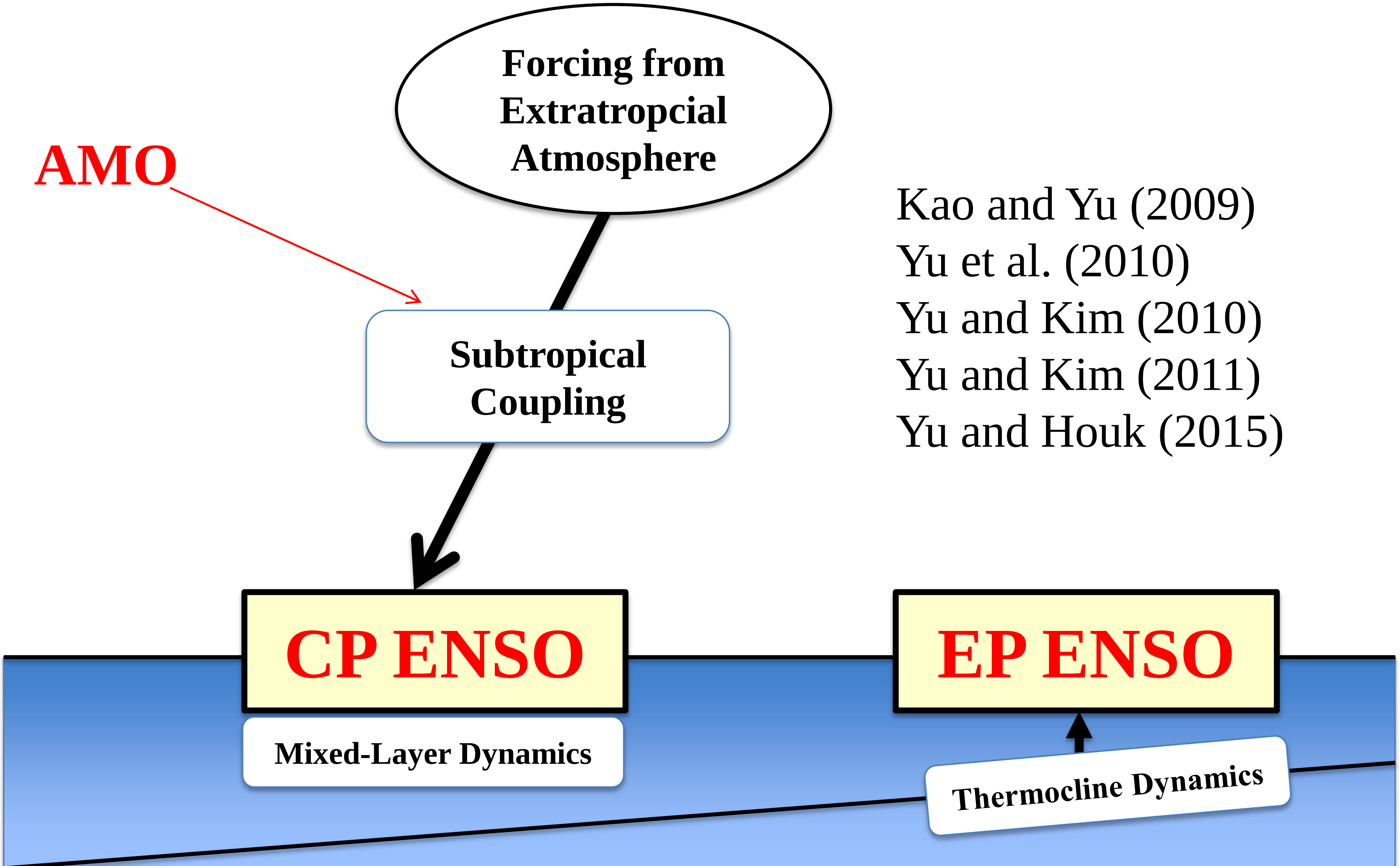
(Yu et al, 2010)



Subtropcial Precursor and CP ENSO

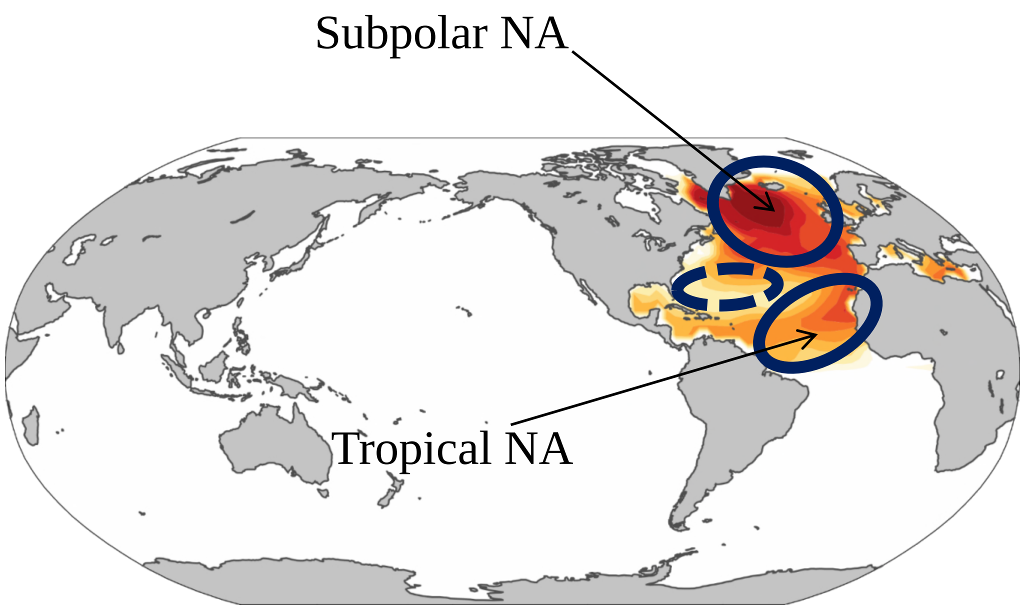


Generation Mechanisms for CP and EP ENSO

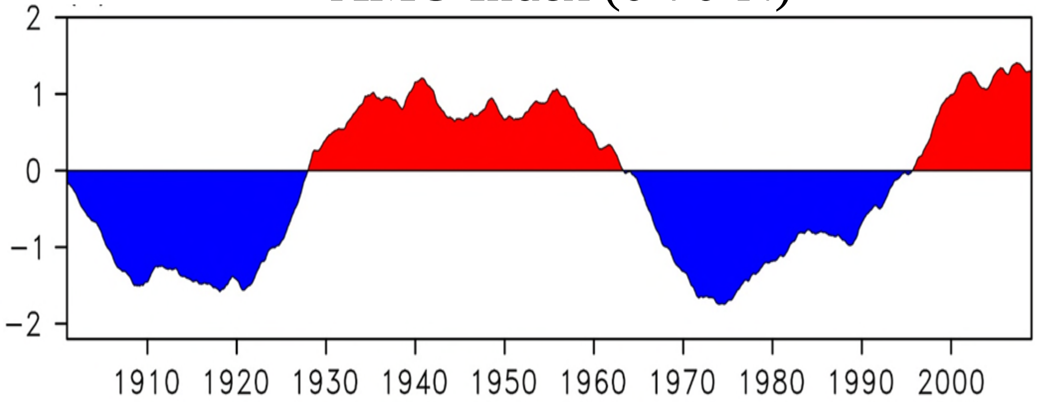


Kao and Yu (2009)
Yu et al. (2010)
Yu and Kim (2010)
Yu and Kim (2011)
Yu and Houk (2015)

Atlantic Multi-decadal Oscillation (AMO)



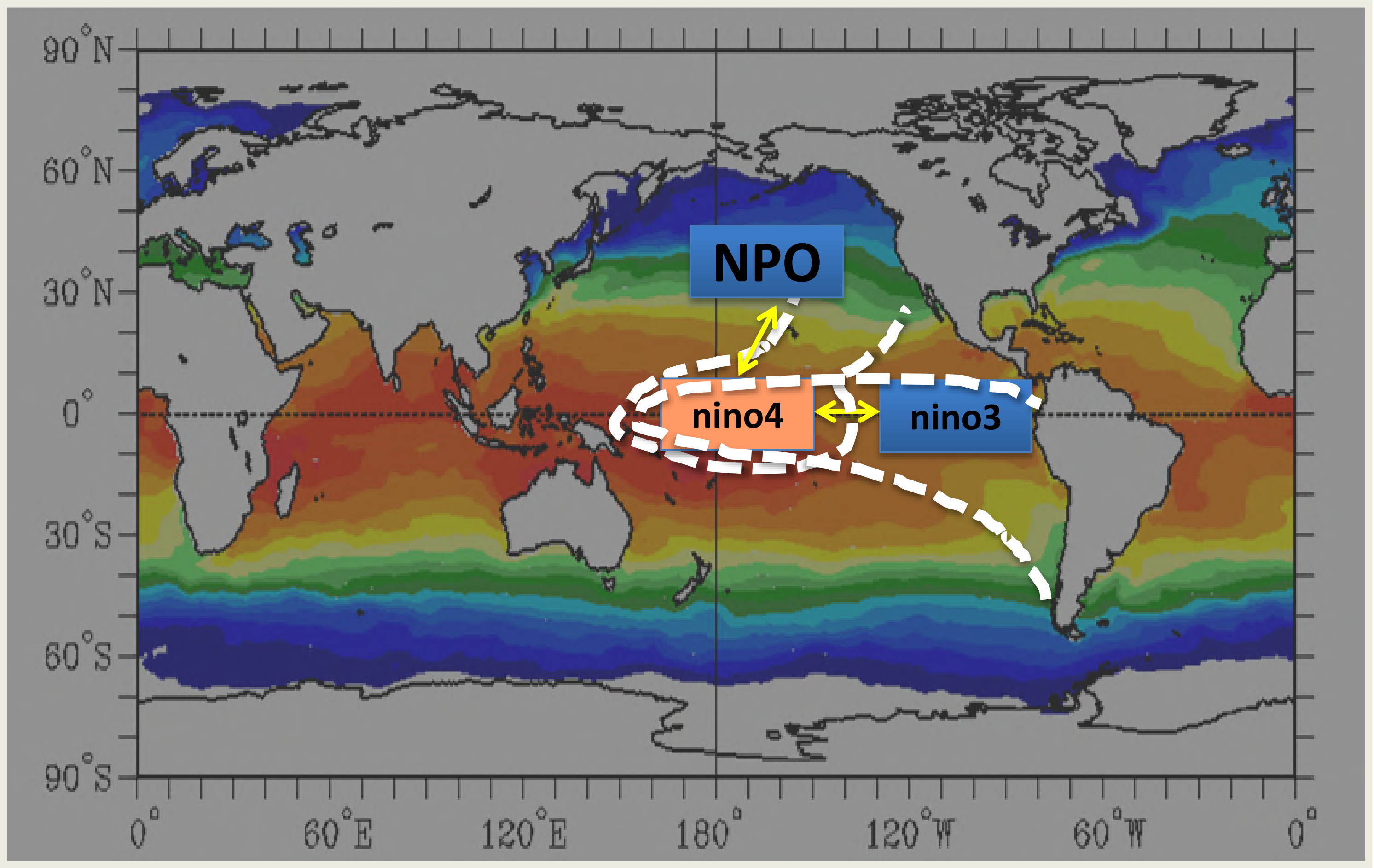
AMO Index (0-70ºN)



- The AMO is identified as a coherent pattern of variability in basin-wide North Atlantic SSTs with a period of 60-80 years.
- AMO has been suggested to be produced by the variation of the Atlantic Meridional Overturning Oscillation (AMOC) or stochastic forcing from the atmosphere.
- AMO can impact global climate through atmospheric waves, oceanic waves, and coupled oceanic–atmospheric propagation.

Determine the Year El Nino Changes Type

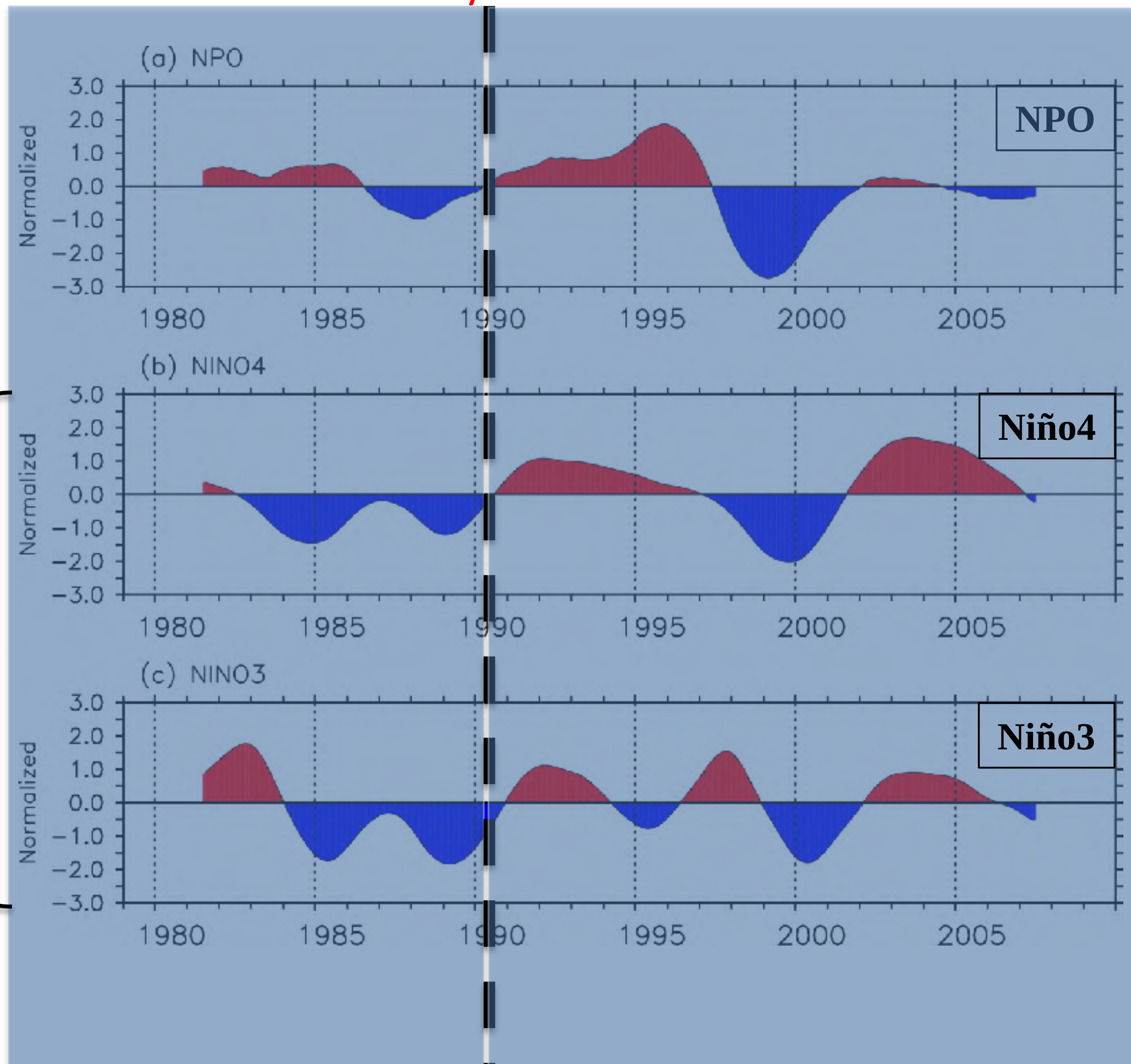
(Yu, Lu, and Kim 2012)



NPO Index and Niño Index

(Yu, Lu, and Kim 2012)

Early-1990s



Early-1990s

Before early-1990

Central T. Pacific SSTA is less related to extratropical atmosphere, but more related to eastern tropical Pacific.

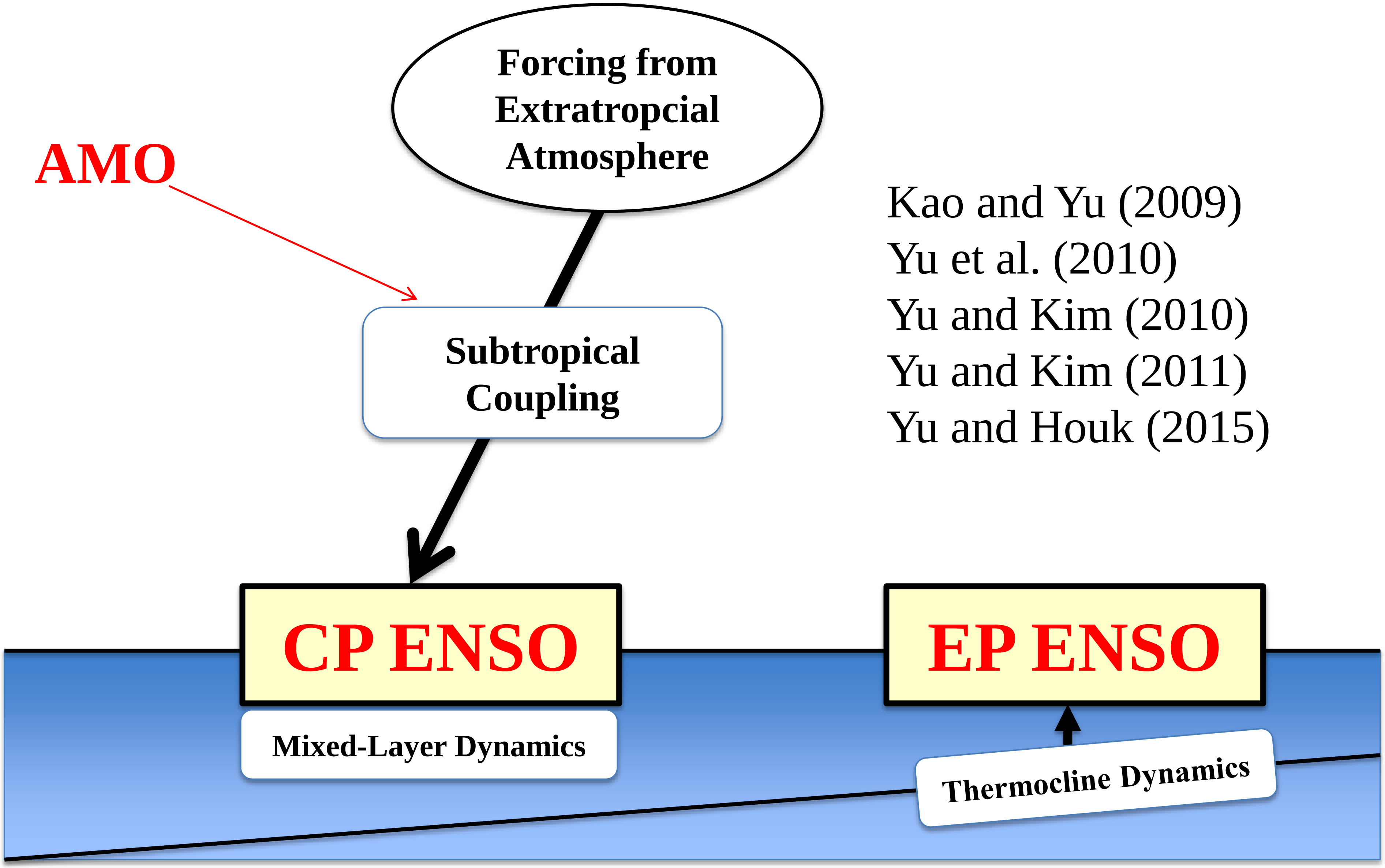
➔ EP ENSO

After early-1990

Central Pacific SSTA is closely related to Extratropical atmosphere (i.e. NPO), but less related to eastern tropical Pacific.

➔ CP ENSO

Generation Mechanisms for CP and EP ENSO

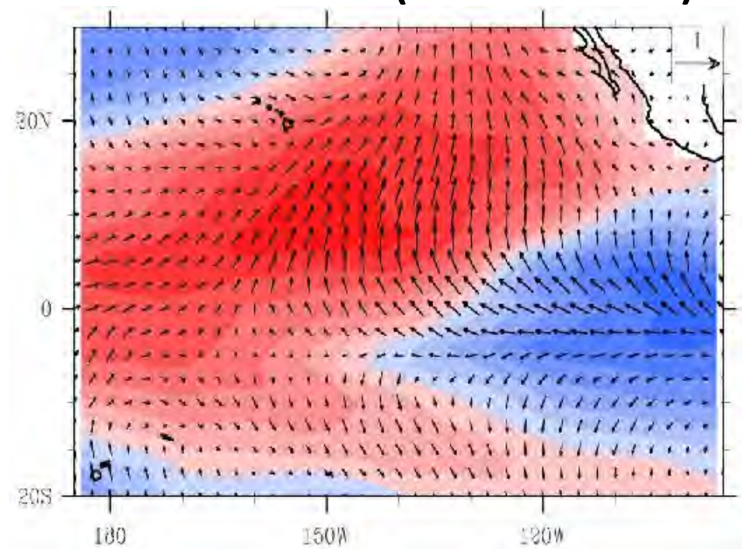


Kao and Yu (2009)
Yu et al. (2010)
Yu and Kim (2010)
Yu and Kim (2011)
Yu and Houk (2015)

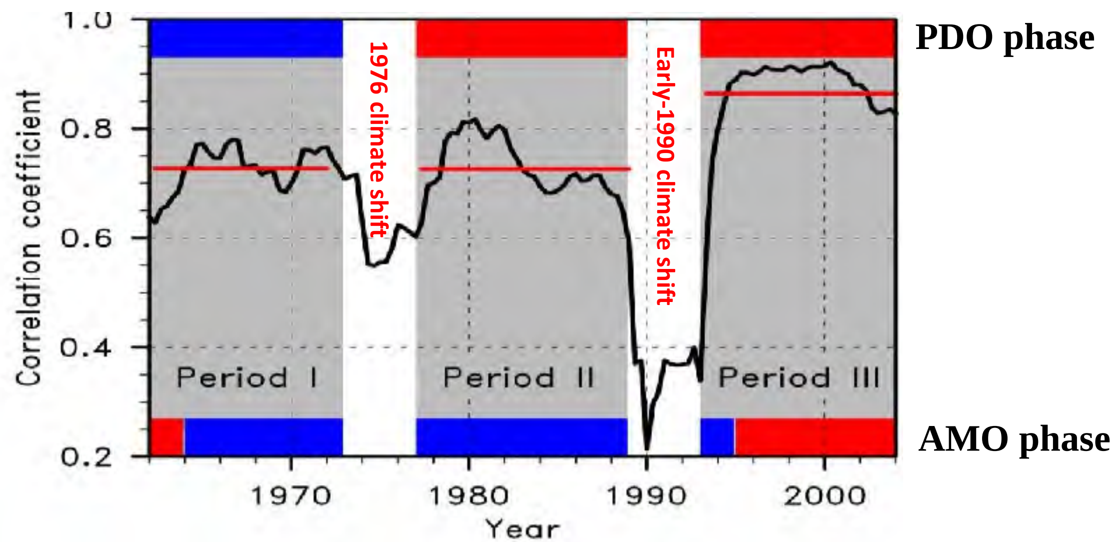
Slow Variations in Pacific Meridional Mode

(Yu et al. 2015)

PMM Structure (SST and Wind)



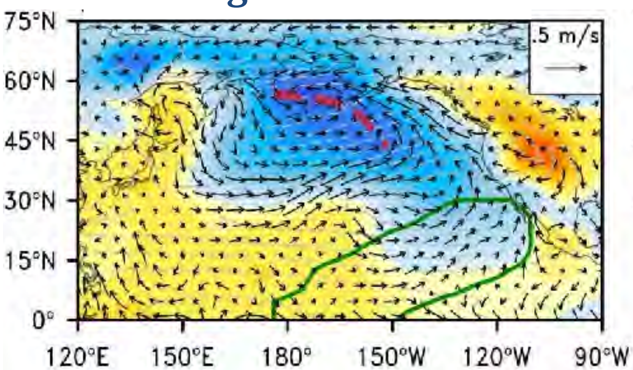
Correlation btw SST and Sfc Wind



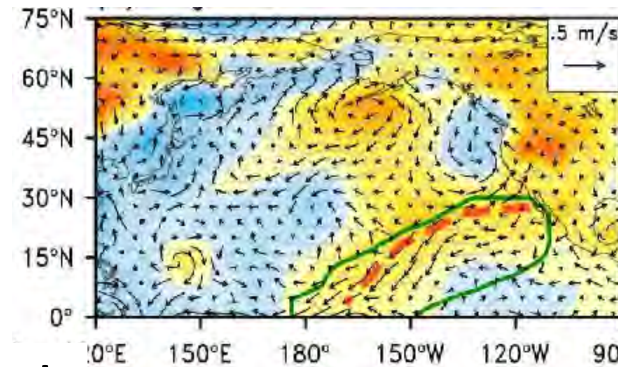
Pacific MM and PDO and AMO

(Yu et al, 2014)

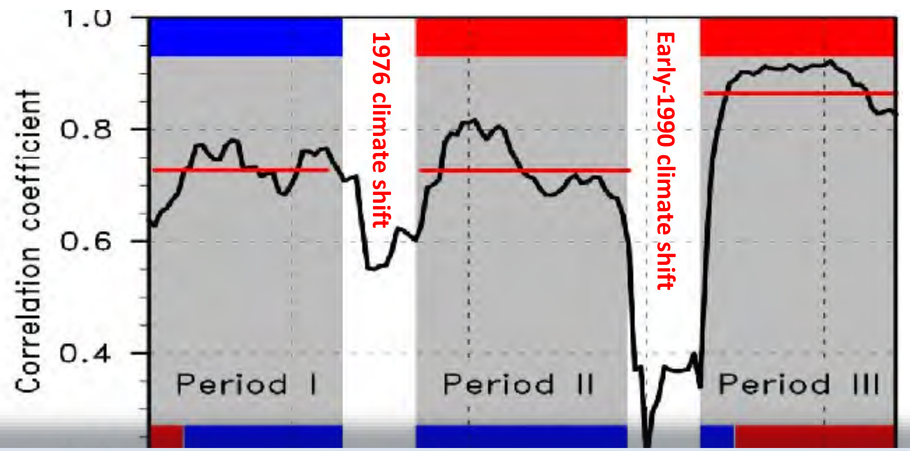
SLP regressed to PDO

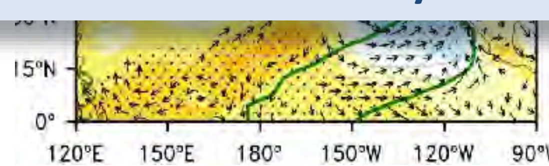


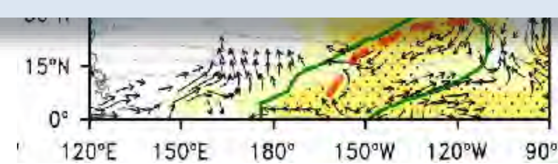
SLP regressed to AMO



Variation in MM Coupling Strength

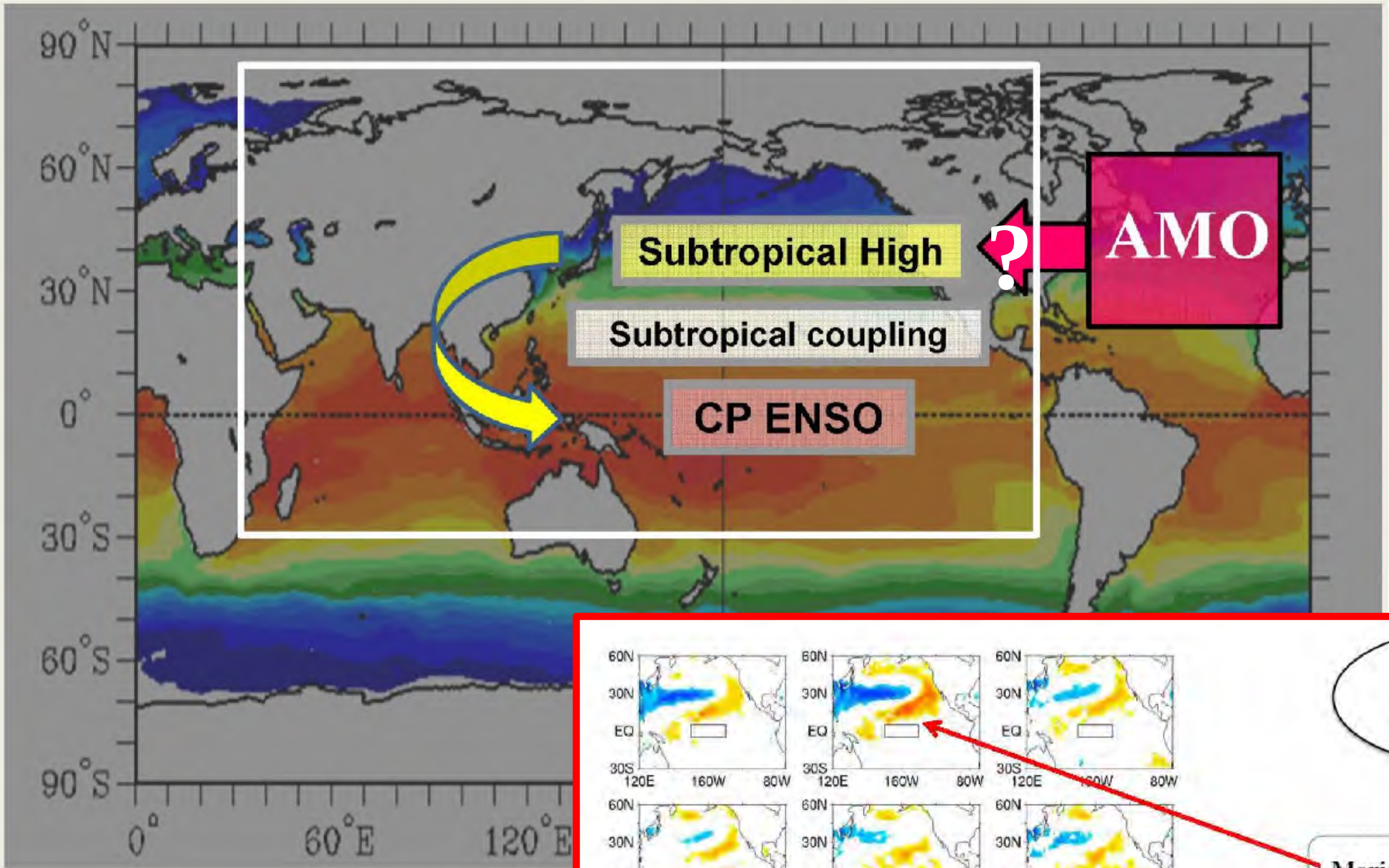


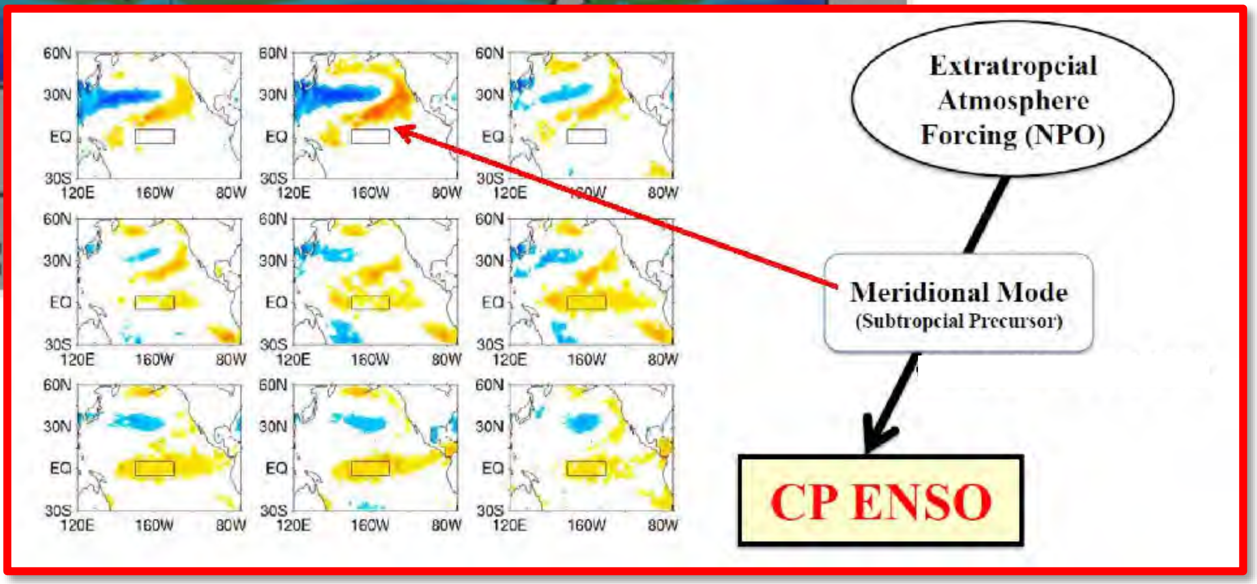




AMO increased the strength of subtropical Pacific High to enhance the subtropical Pacific coupling (i.e., the precursor mechanism), which then leaded to the increased occurrence of CP El Nino after the early-1990s climate shift.

Atlantic Multi-decadal Oscillation and CP El Niño

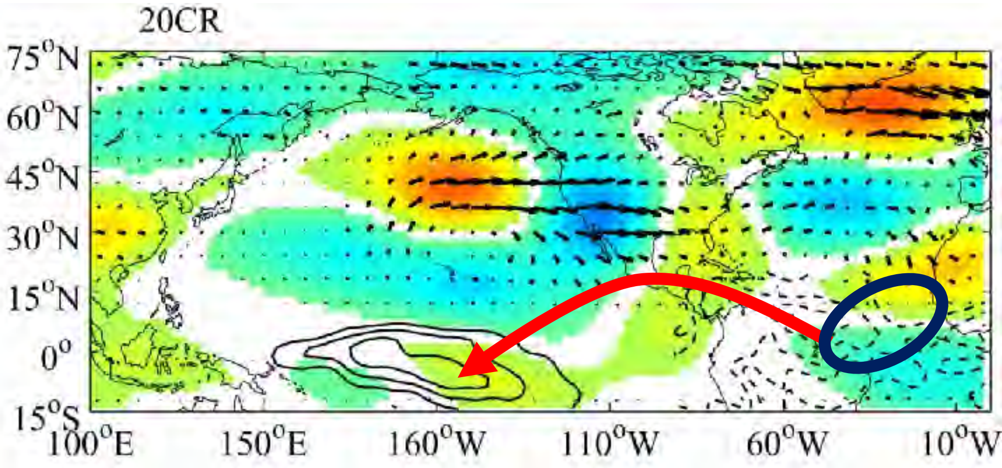


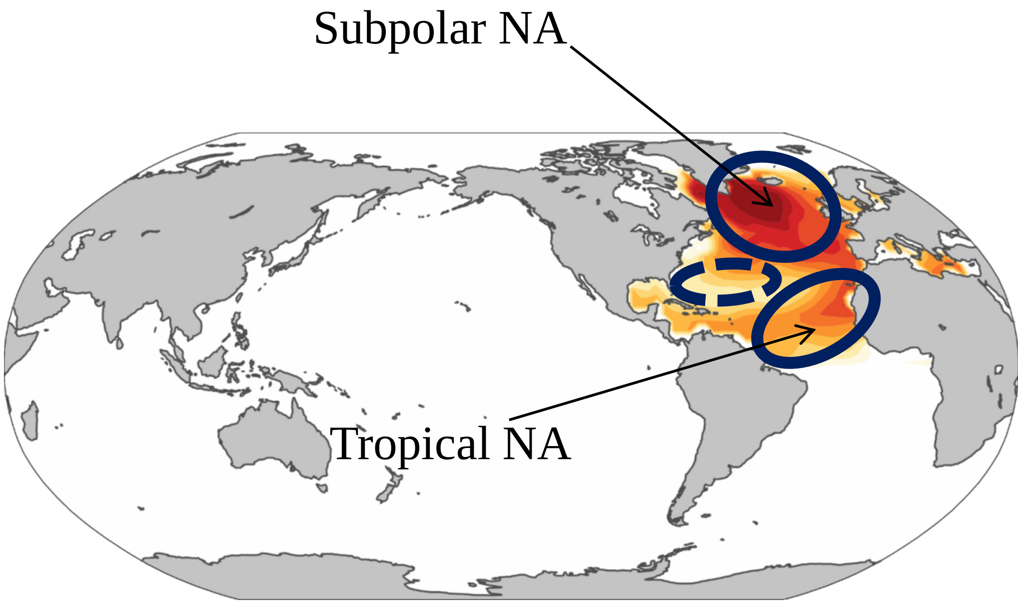


How did the AMO intensify the Pacific High?

(Lyu, Yu, and Paek 2016)

OLR (contour) and Barotropic Stream Function (color)





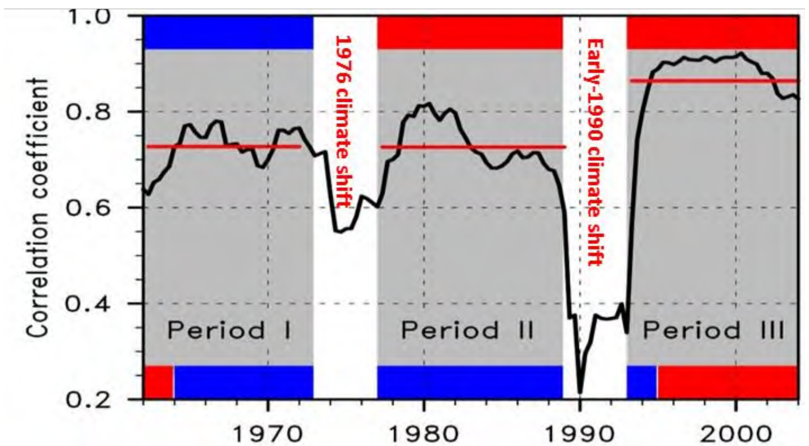
AMO SST Anomalies

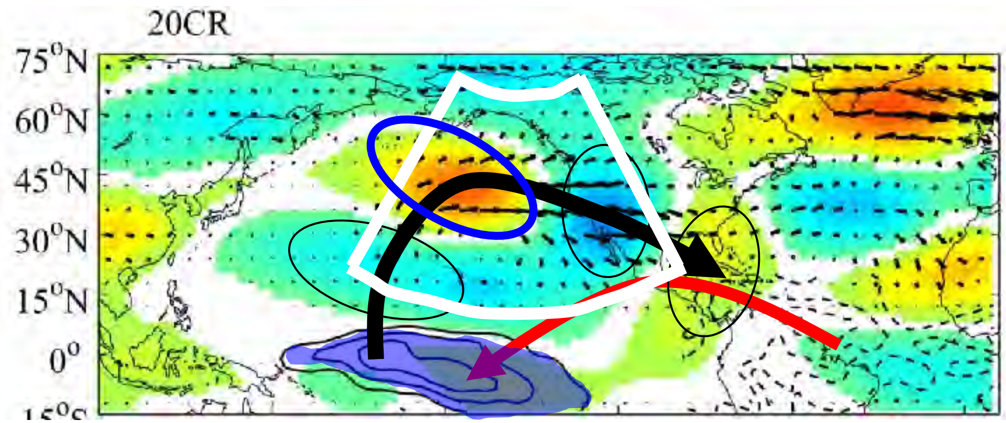
How did the AMO intensify the Pacific High?

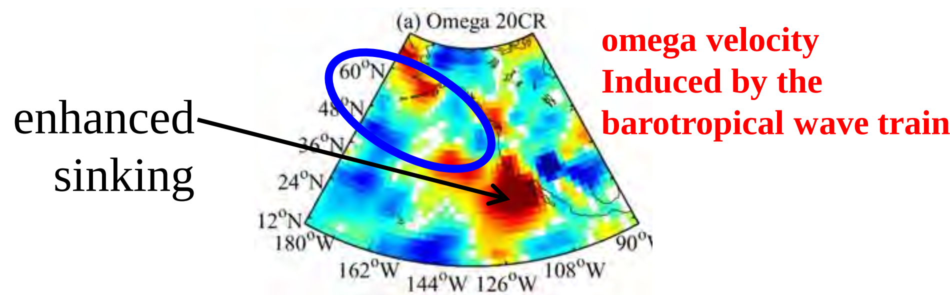
(Lyu, Yu, and Paek 2016)

OLR (contour) and Barotropic Stream Function (color)

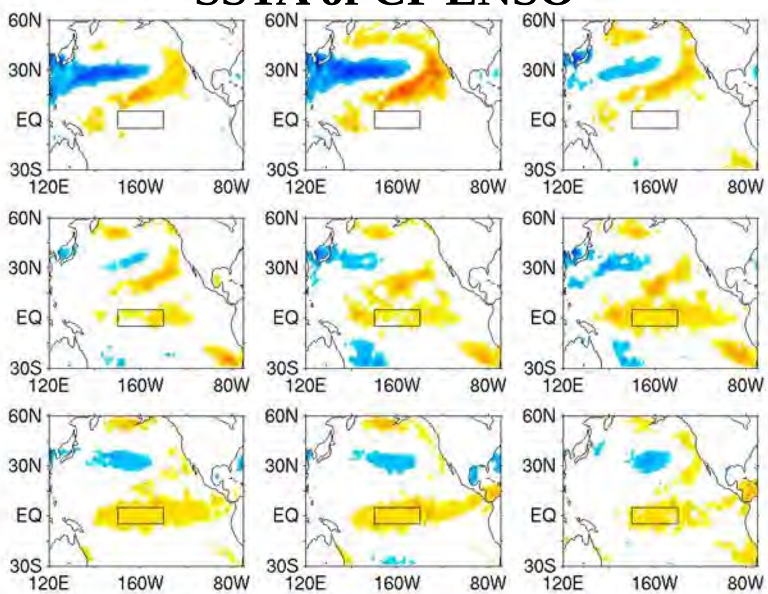
Correlation btw SST and Sfc Wind



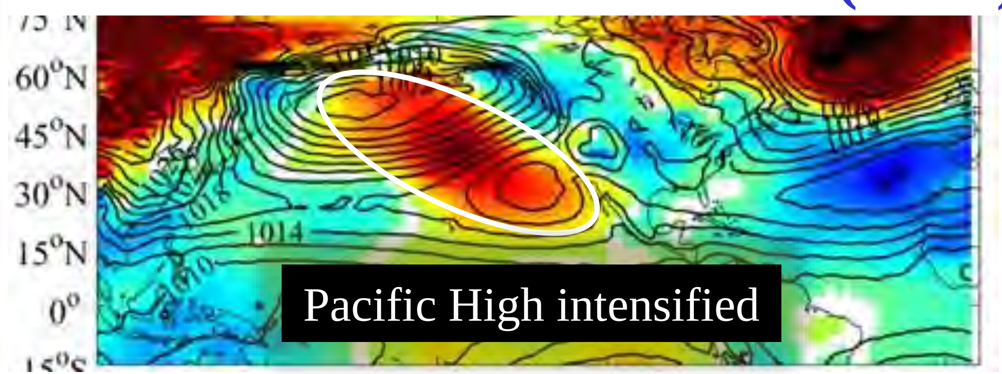




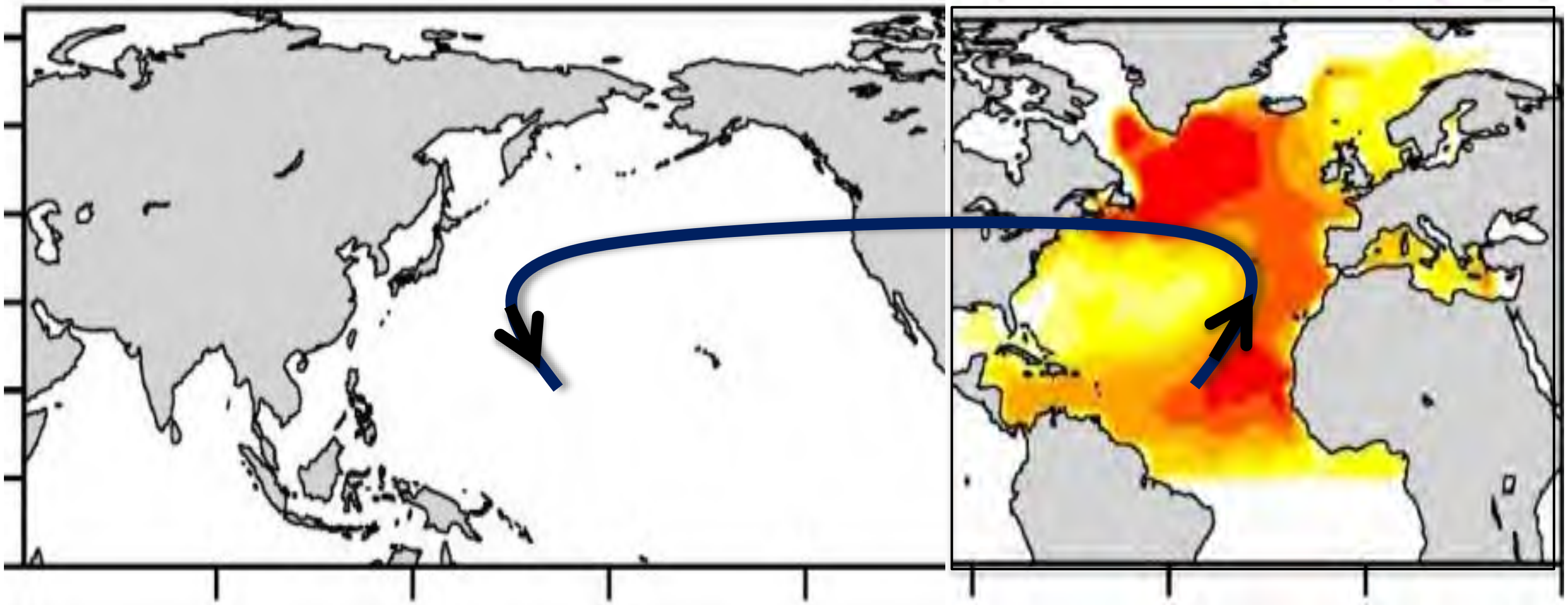
SSTA of CP ENSO



Sea Level Pressure Anomalies (color)

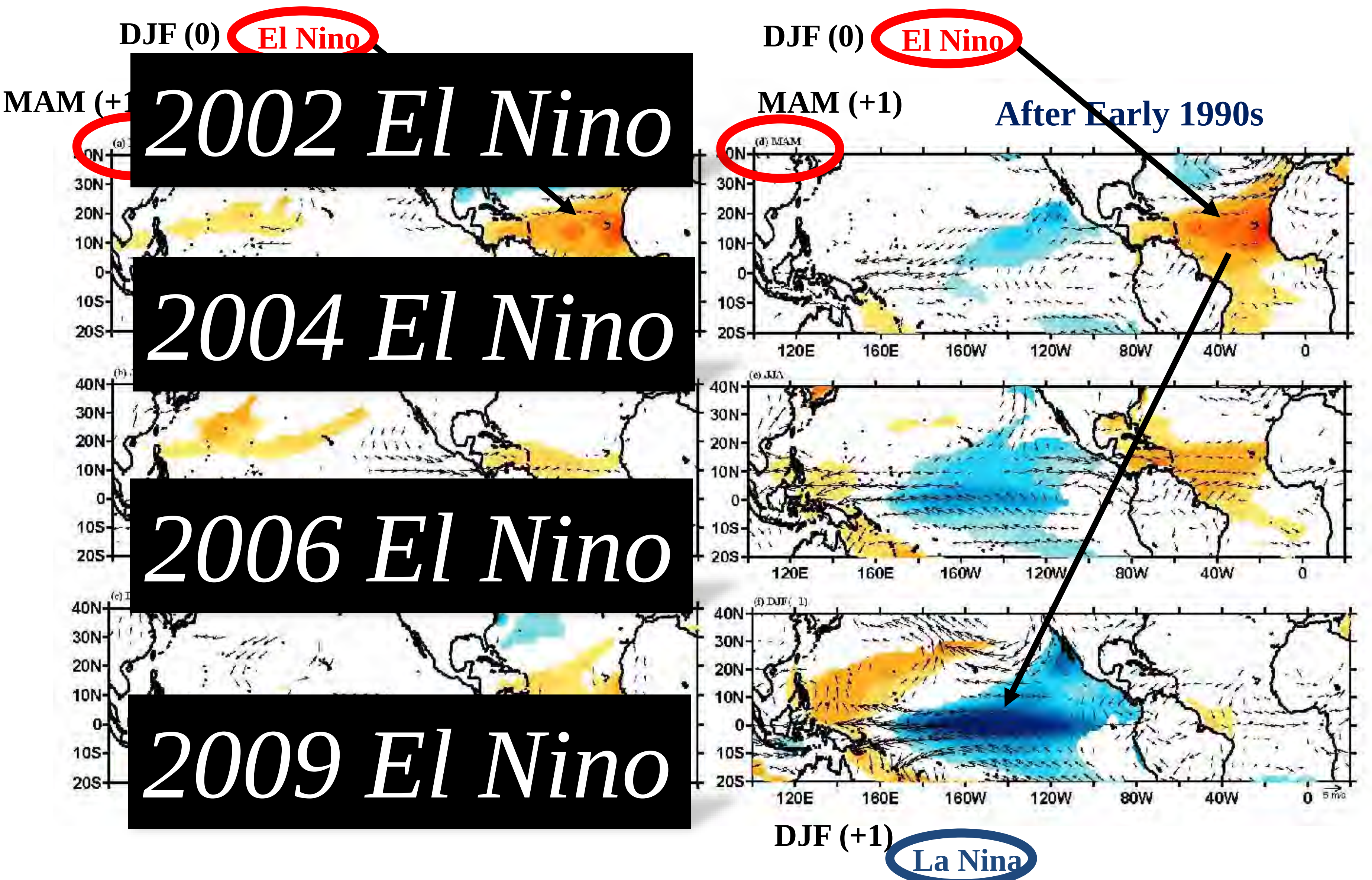


Warmer Atlantic ➔ Stronger Feedback to Pacific



El Nino Became more Biennial after Early 1990s

(Wang, Yu, and Paek 2016; under review)

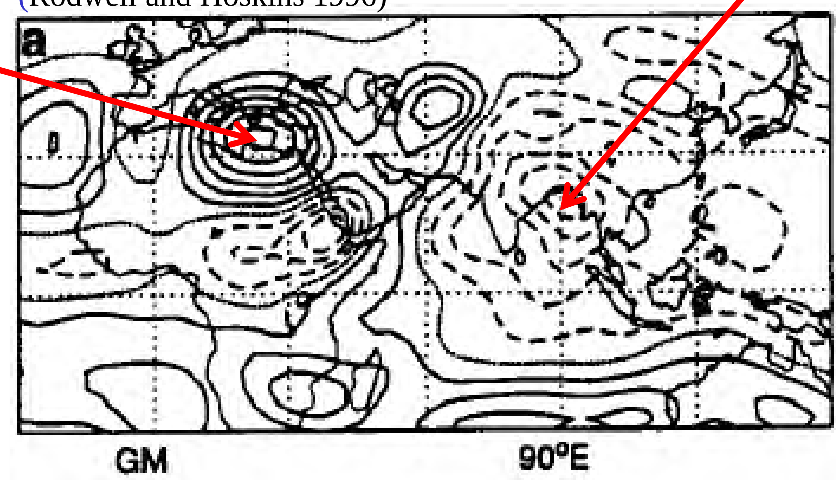


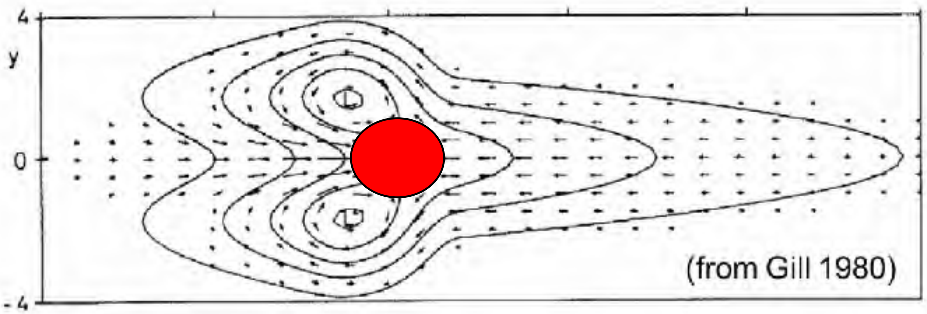
Gill Type Response to Tropical Heating

Desert/descending

Asian monsoon

(Rodwell and Hoskins 1996)





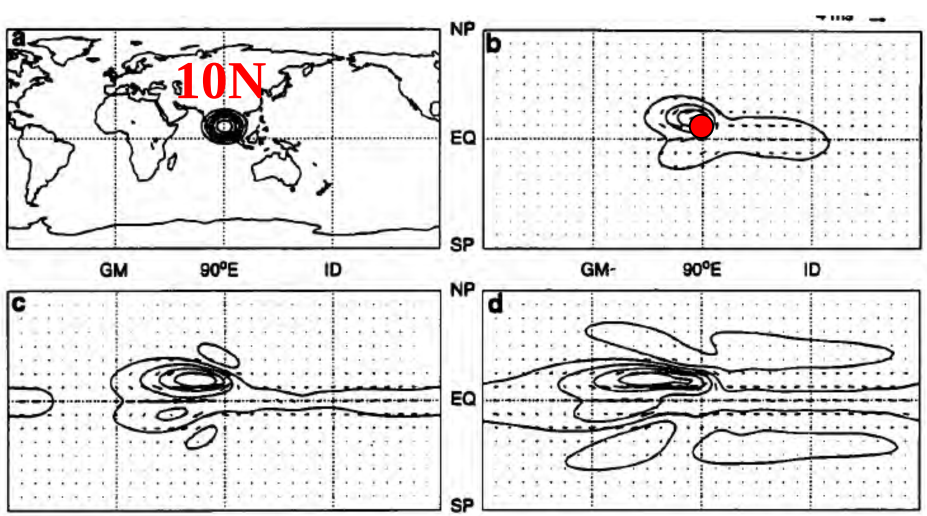


Figure 6. (a) Column-mean diabatic heating centred at 90°E, 10°N. The contour interval is 50 W m^{-2}; the zero contour is not shown. (b), (c) and (d) show the corresponding perturbation surface pressure and 887 hPa horizontal winds for an integration linearized about a resting basic-state at (b) day 3, (c) day 7 and (d) day 11. The contour interval is 1 hPa.

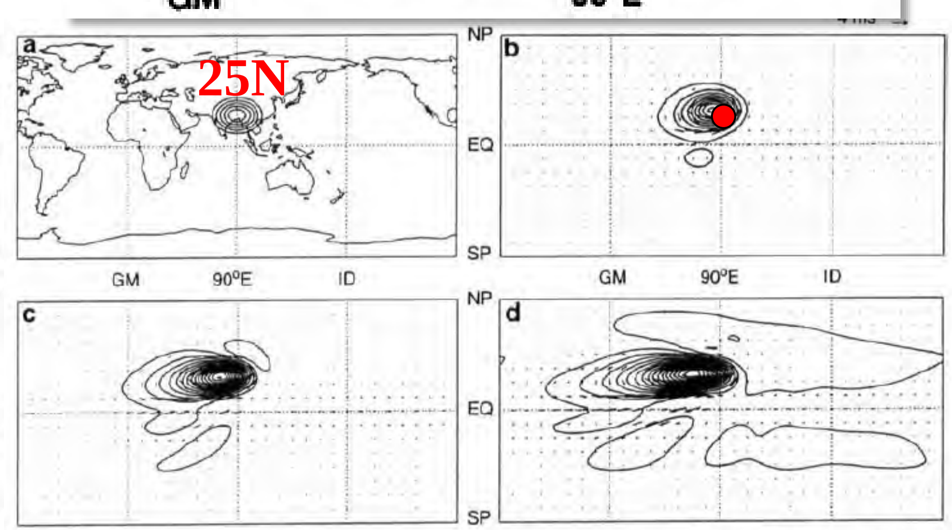
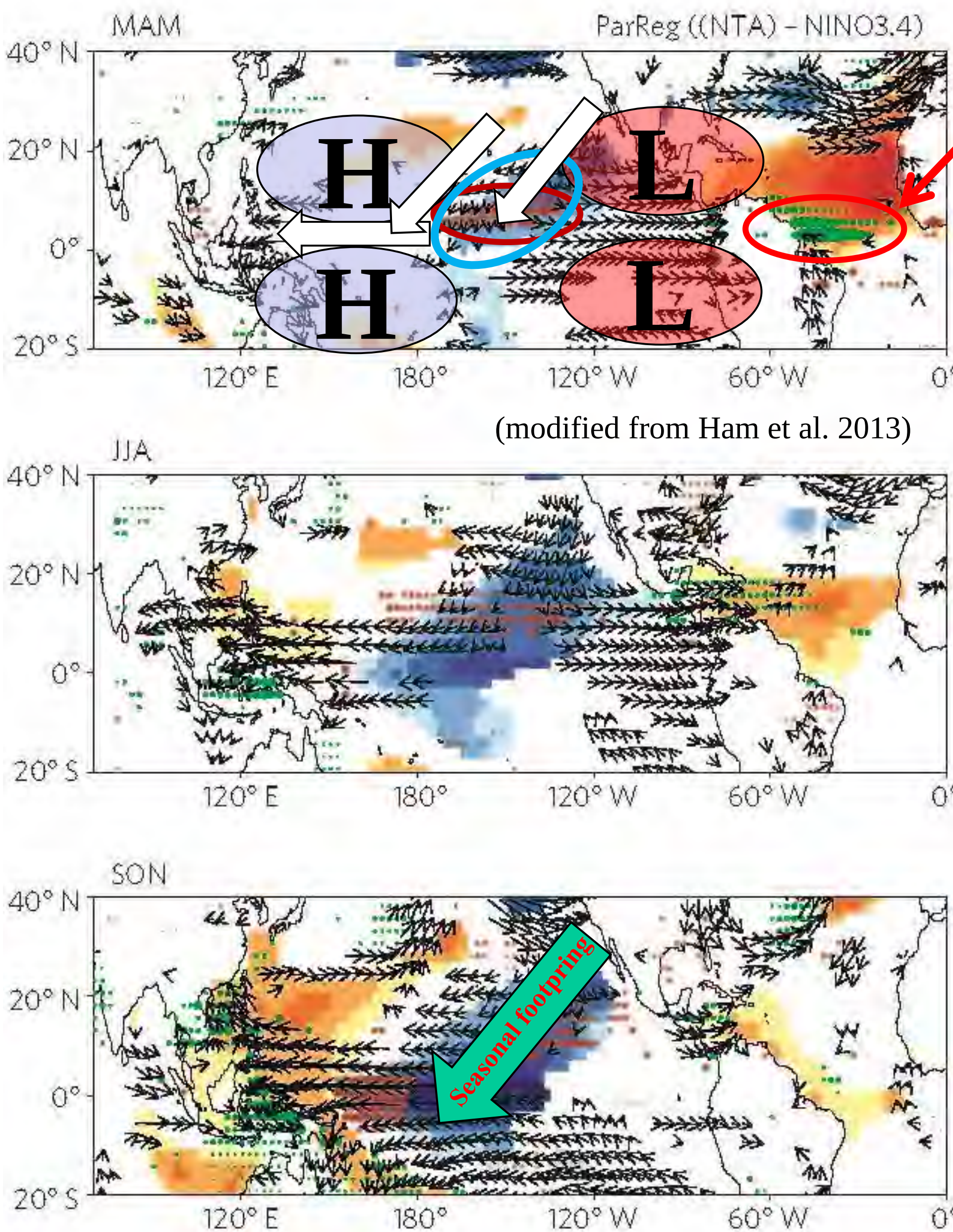


Figure 7. (a) Column-mean diabatic heating centred at 90°E, 25°N. The contour interval is 50 W m^{-2}; the zero contour is not shown. (b), (c) and (d) show the corresponding perturbation surface pressure and 887 hPa horizontal winds for an integration linearized about a resting basic-state at (b) day 3, (c) day 7 and (d) day 11. The contour interval is 1 hPa.

Gill-Type Response Mechanism

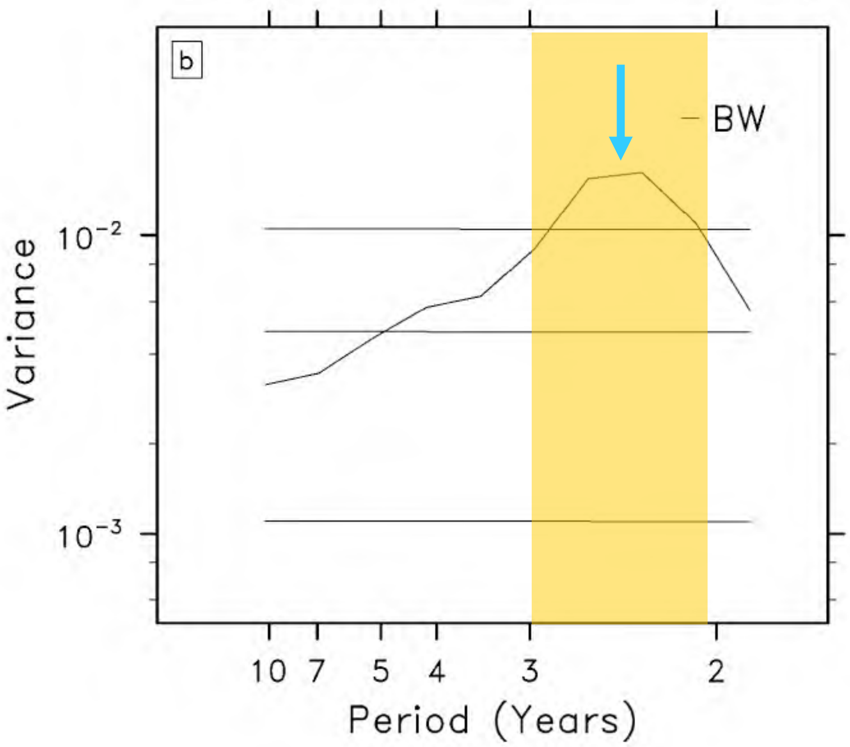


NTA warming in boreal spring

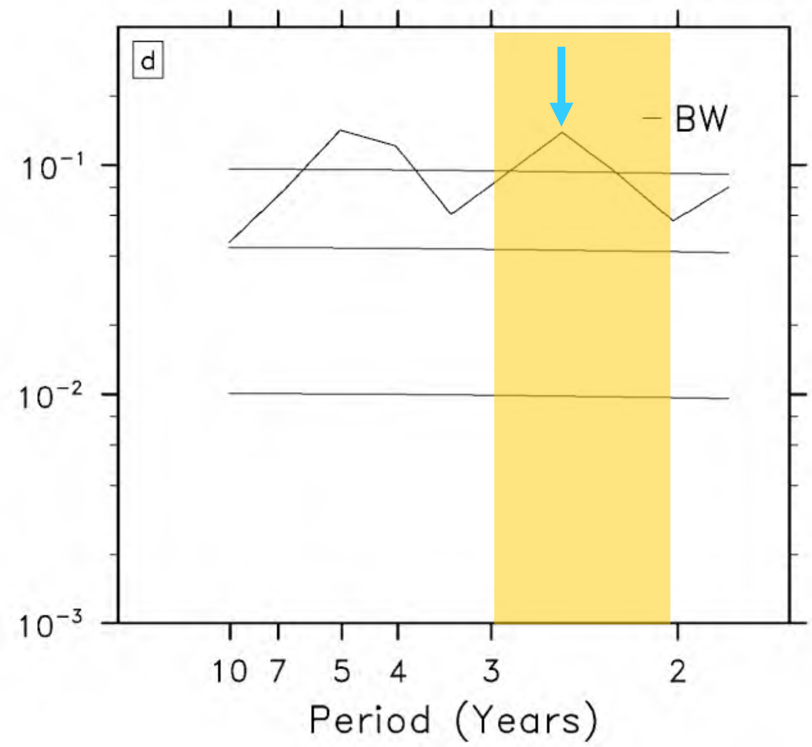
- ➔ Enhances Atlantic ITCZ convection
- ➔ Induces a low-level cyclonic atmospheric flow over the eastern Pacific (i.e., Gill type response)
- ➔ Produces a northerly flow on its west flank
- ➔ The northerly flow leads to surface cooling through the enhanced wind speed and cold/dry advection from higher latitudes
- ➔ Suppresses Pacific ITCZ convection
- ➔ Produces a low-level anticyclonic flow over the western Pacific during the following summer (i.e., Gill type response)
- ➔ This anticyclonic flow enhances the northerly flow at its eastern edge, which reinforces the negative precipitation anomaly.
- ➔ This coupling maintain and negative precipitation anomalies and generates easterly winds over the western equatorial Pacific
- ➔ The winds cool the equatorial Pacific
- ➔ May trigger a **Central-Pacific type of La Niña** event the following winter.

Power Spectra of Monsoon Rainfall Index

Indian Summer Monsoon



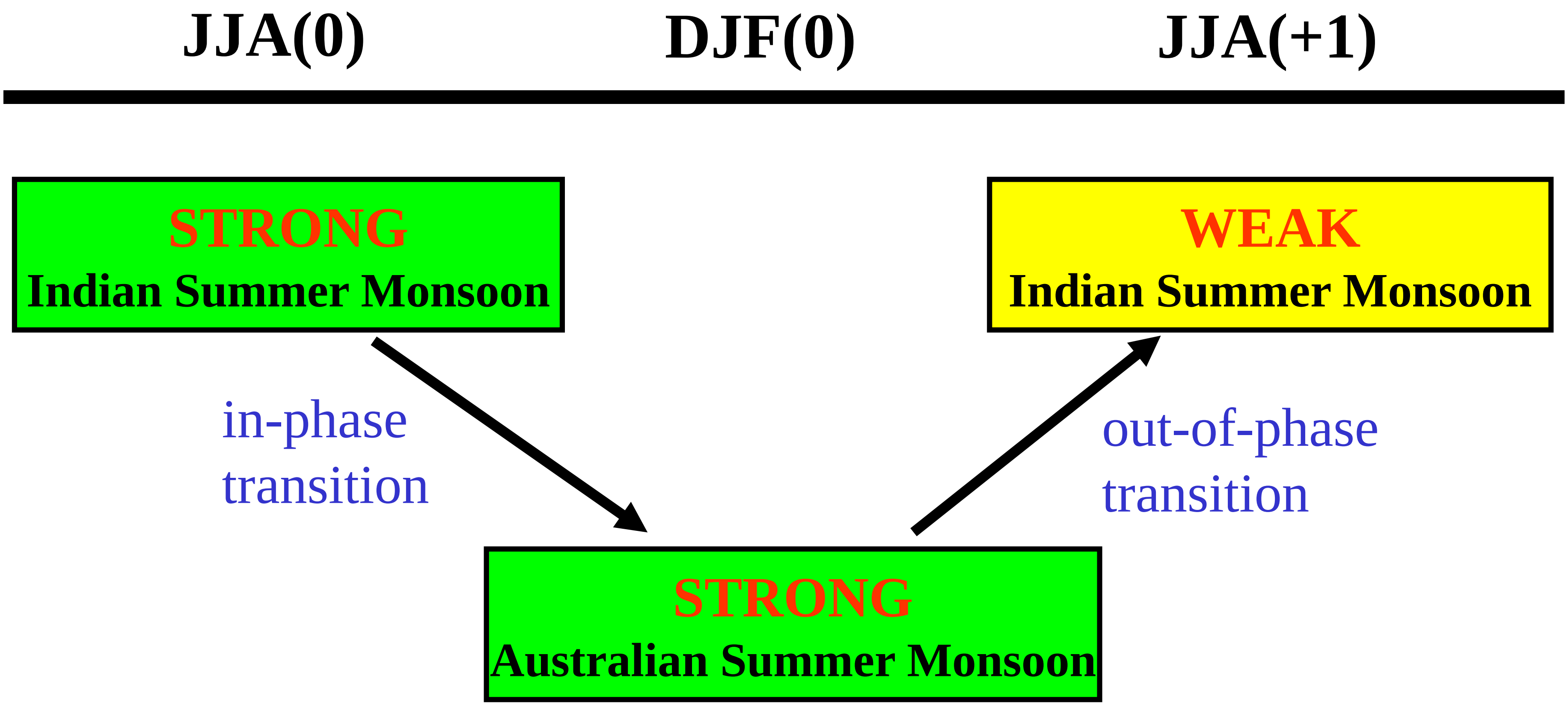
Australian Summer Monsoon



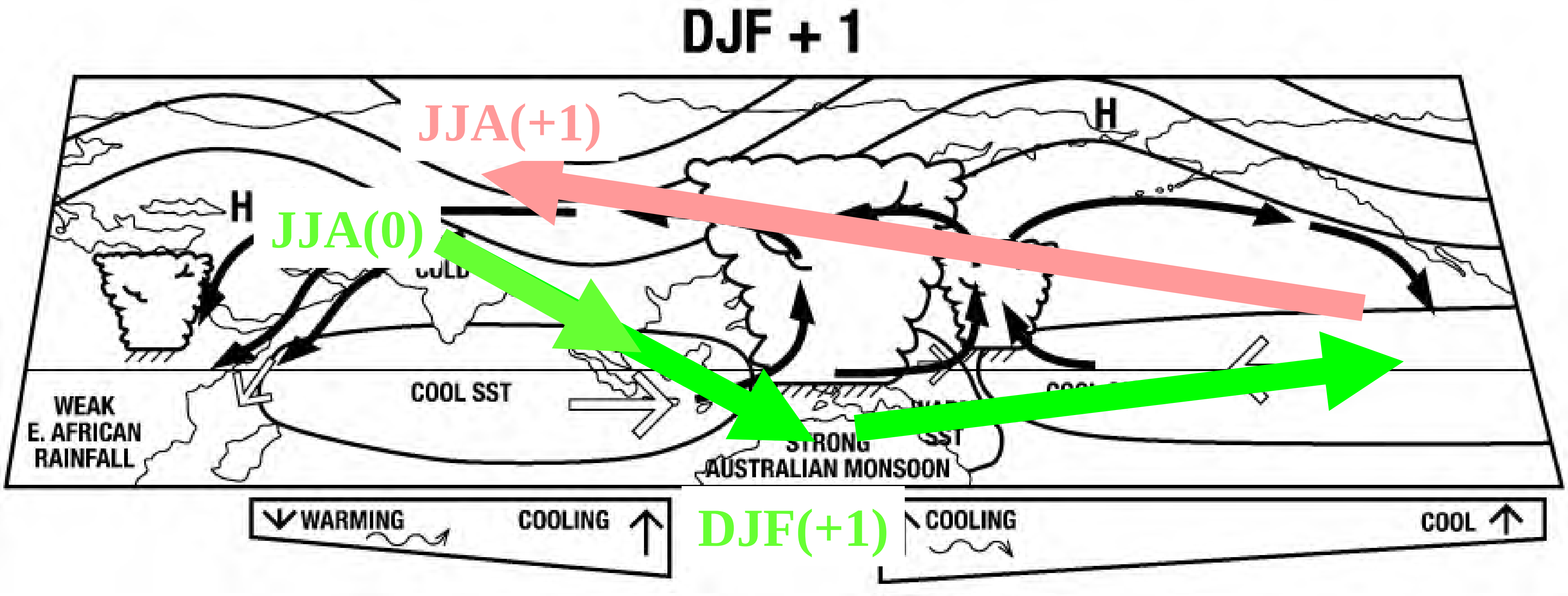
(modified from Meehl and Arblaster 2002)

Transition between Indian and Australian Monsoons

(during Tropospheric Biennial Oscillation)



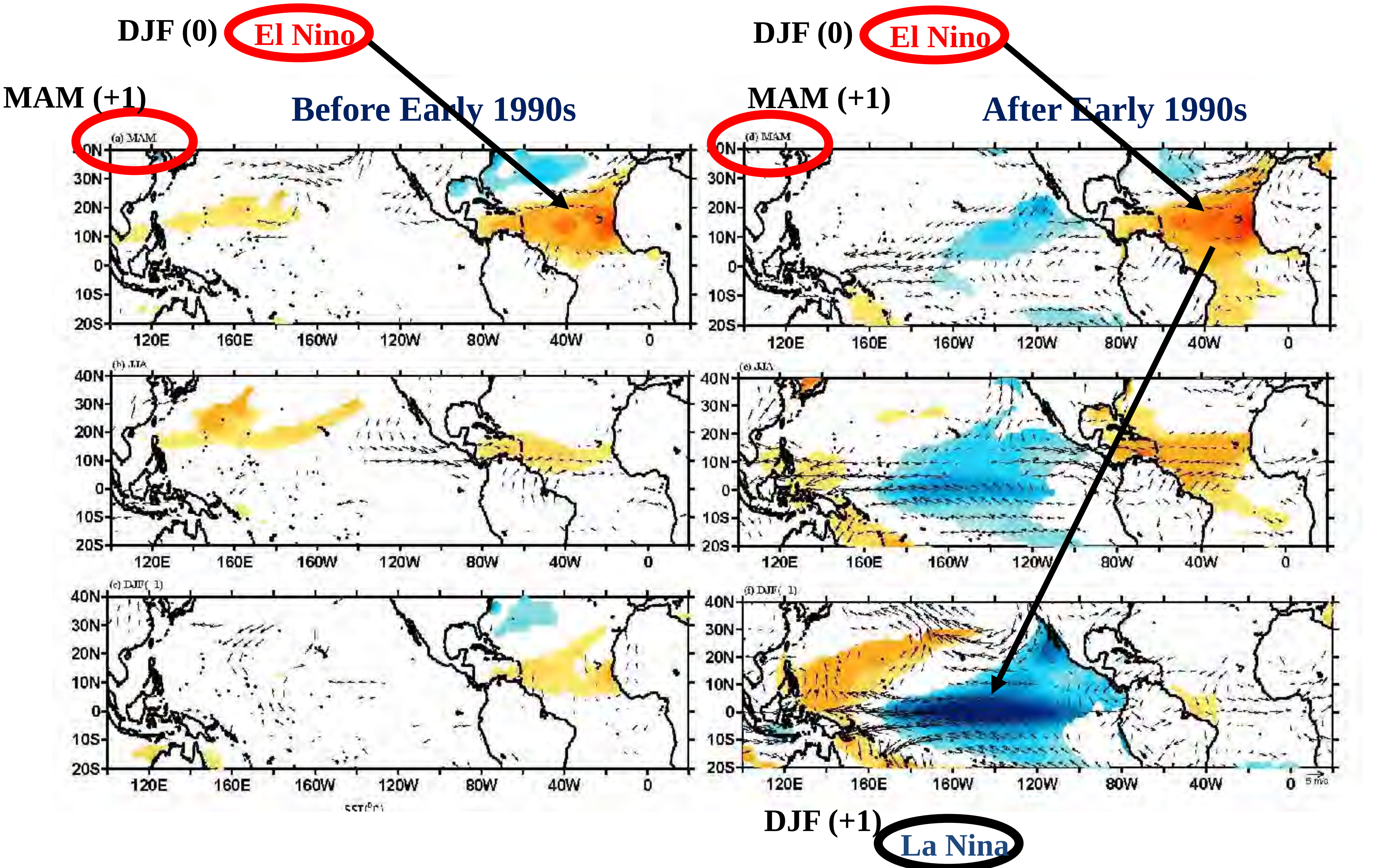
Tropospheric Biennial Oscillation (TBO)



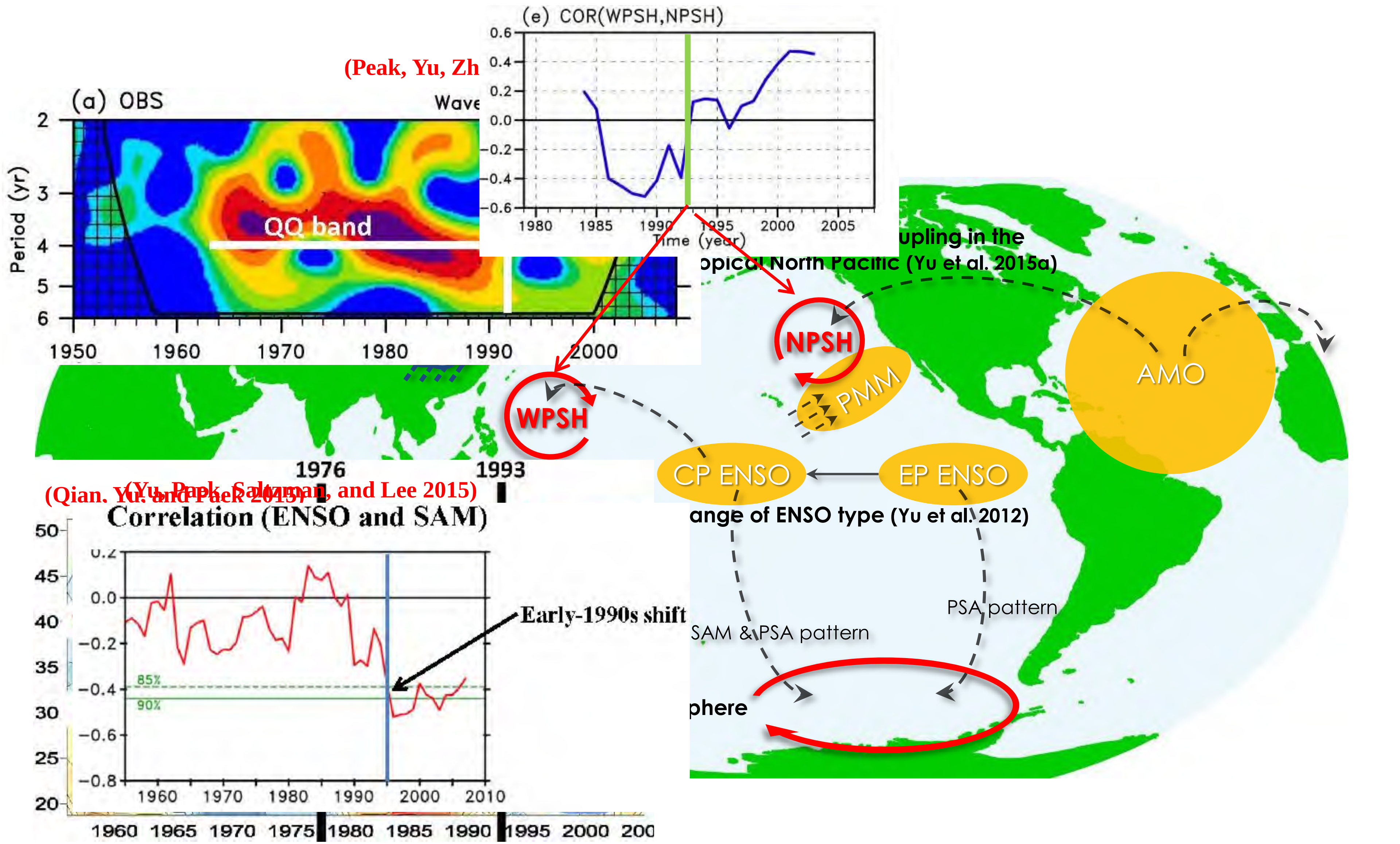
(From Meehl 2002)

El Nino Became more Biennial after Early 1990s

(Wang, Yu, and Paek 2016; under review)

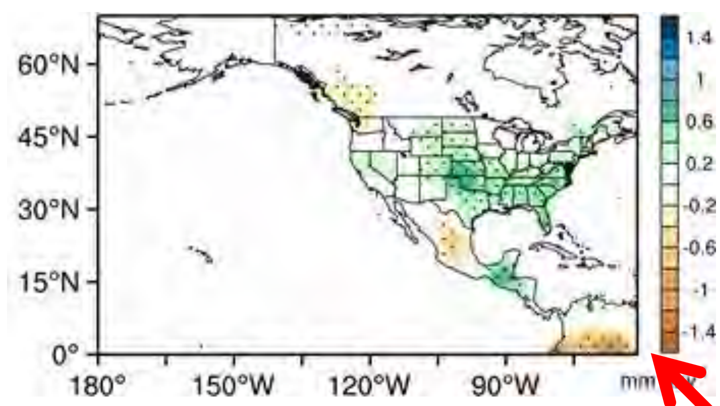


Evidence of the early-1990s climate shift in the Pacific

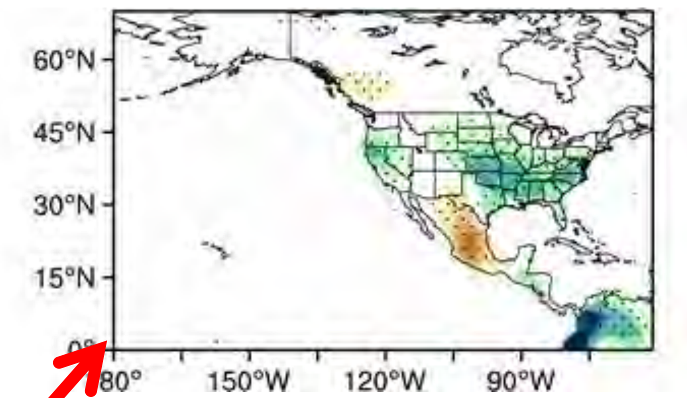


2015/16 vs 1997/98 El Nino / SSTA evolution

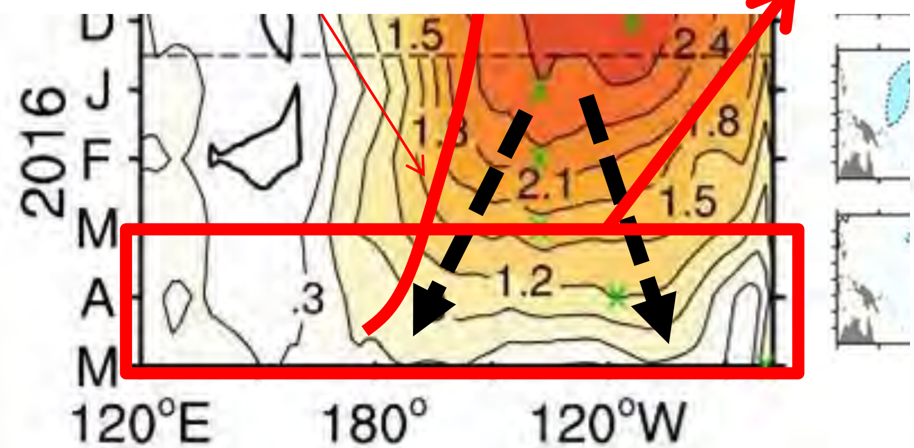
SST: 2015/16

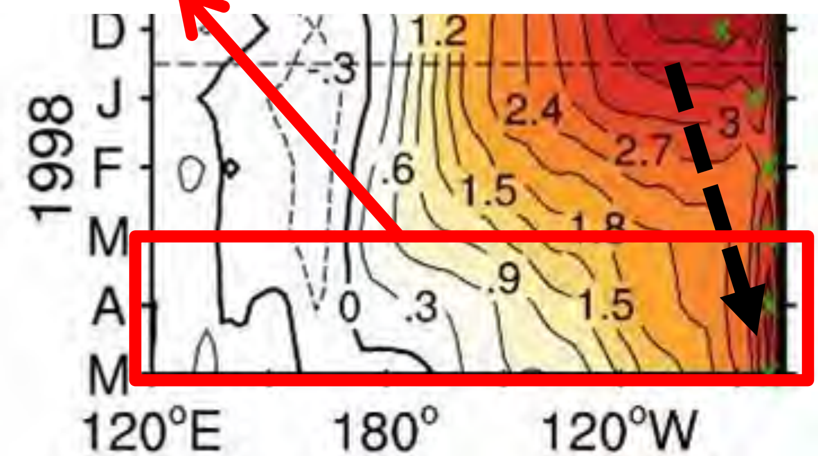


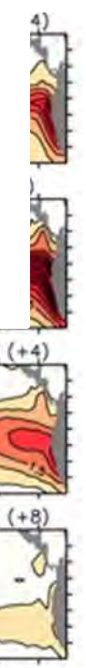
SST: 1997/98



CAM5
50-members
Ensemble Experiments

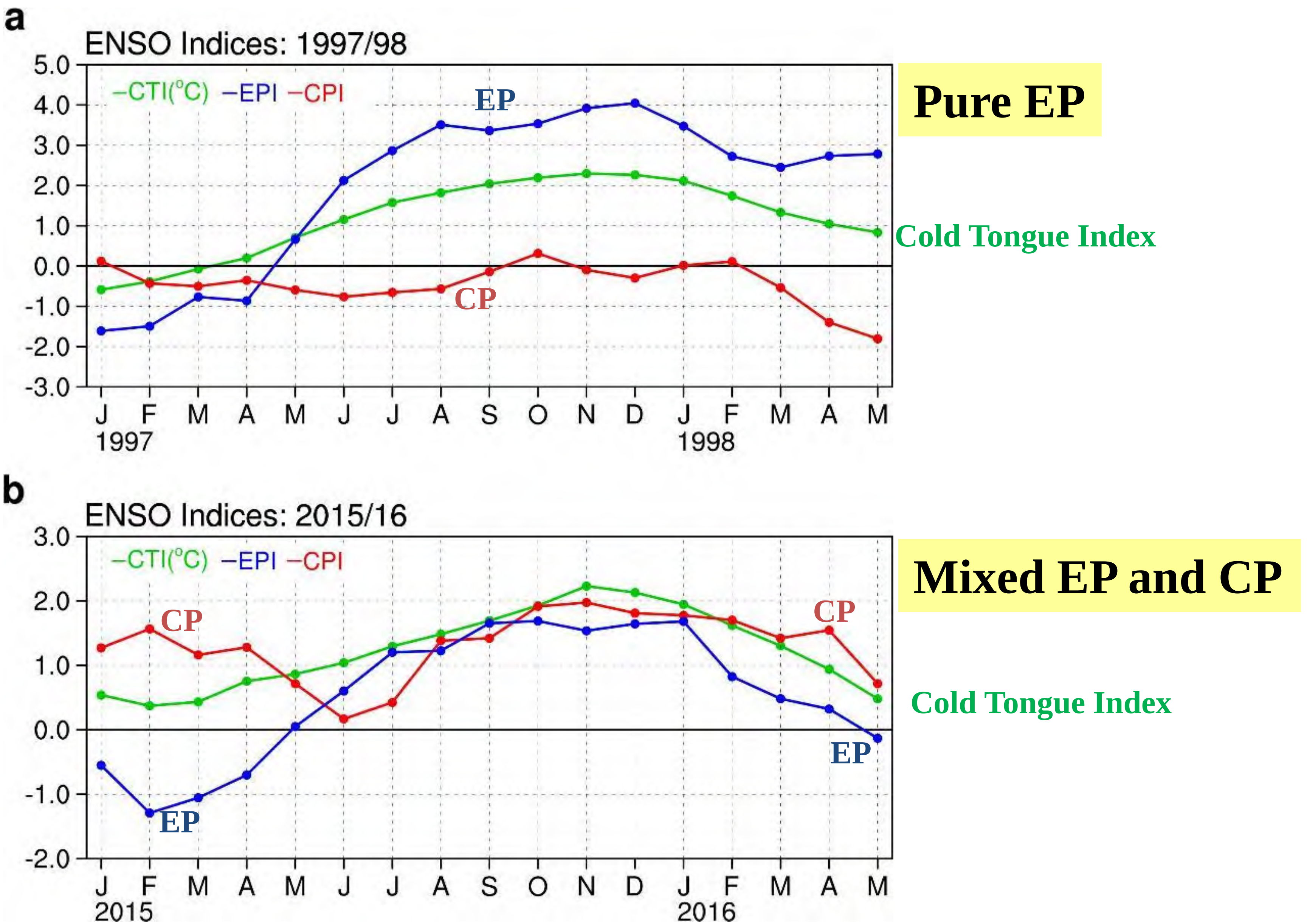






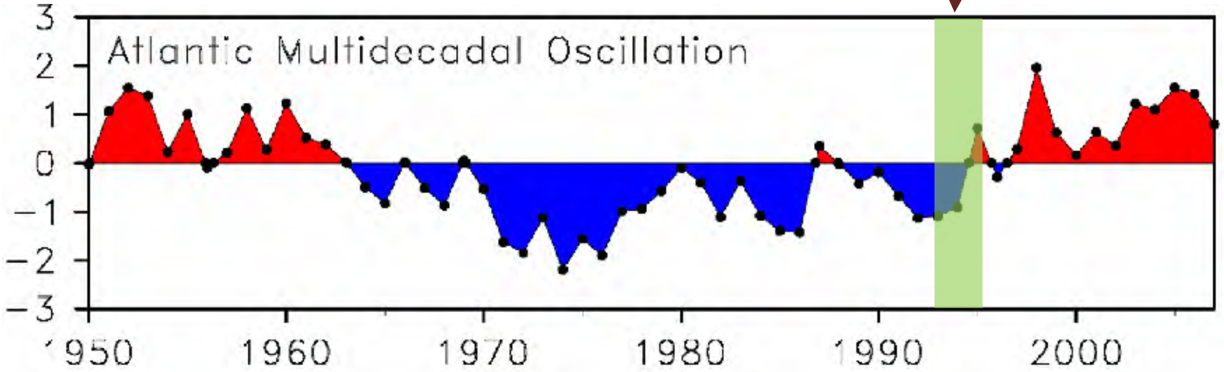
Why are the 2015/16 and 1997/98 El Nino Different?

(Paek, Yu, and Qian 2016; under review)



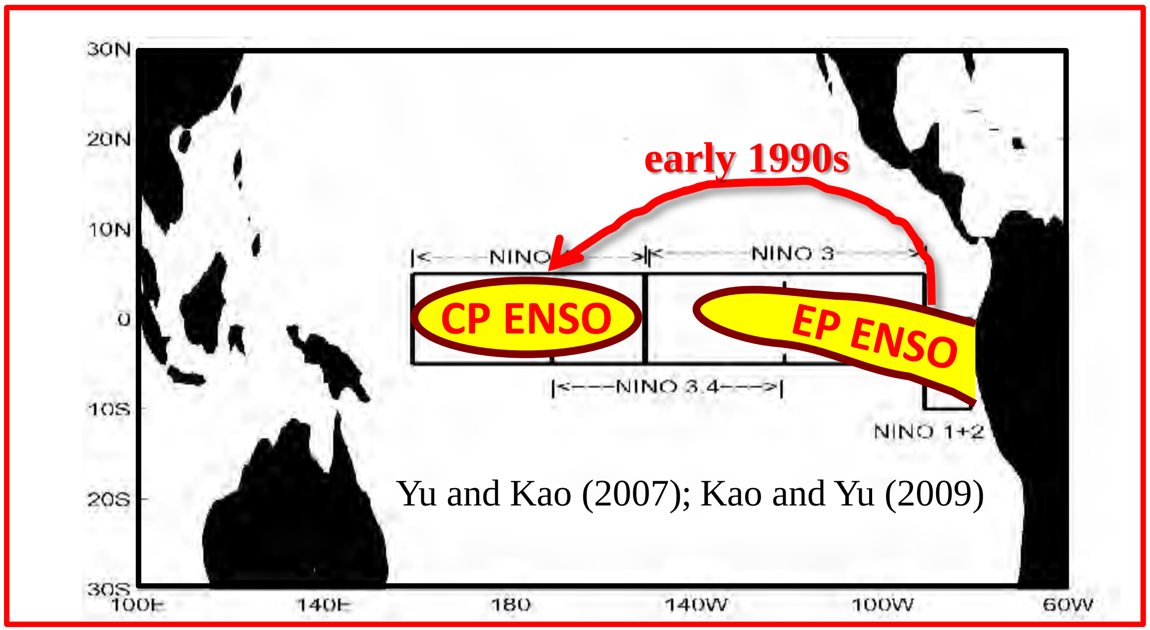
AMO and Early-1990s Climate Shift in Pacific

Early-1990s climate shift

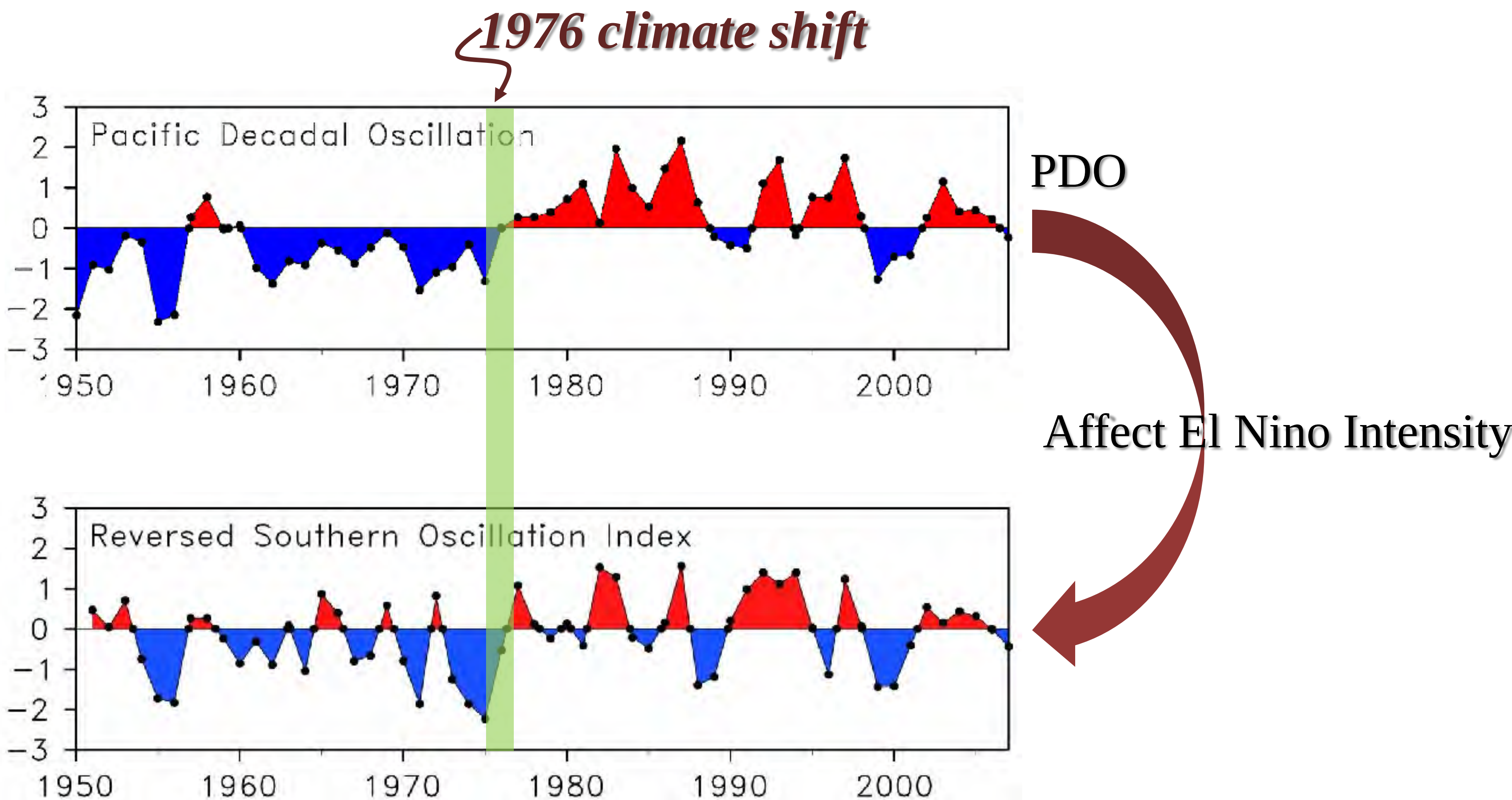


AMO

Affect El Nino Type



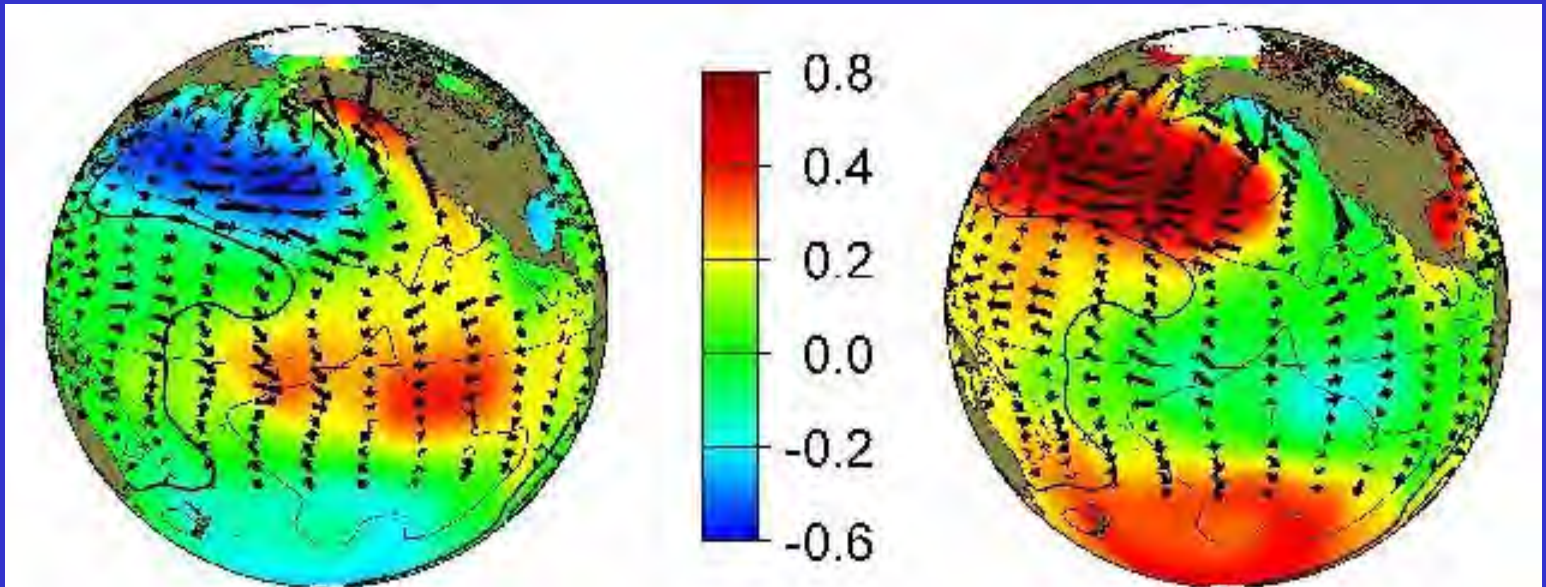
1976 Climate Shift and El Nino Intensity



- ENSO amplitude increased after the 1976 climate shift.
- ENSO periodicity also increased from 2-3 years to 4-5 years after the shift.

Pacific Decadal Oscillation

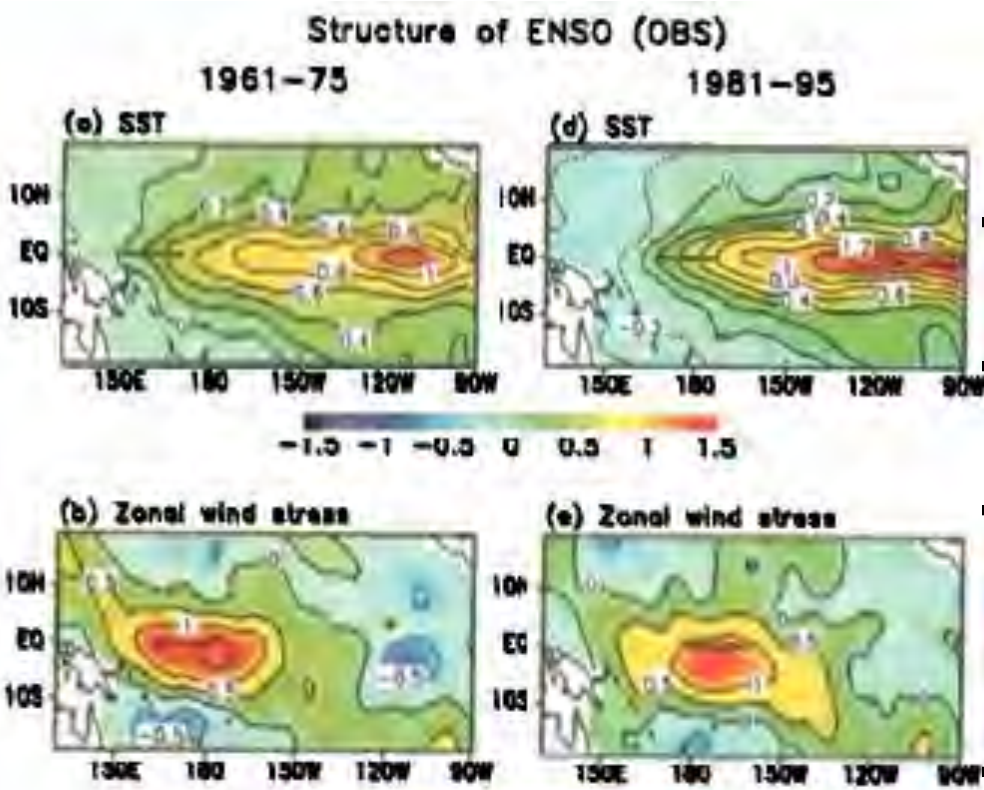
Positive PDO **Negative PDO**

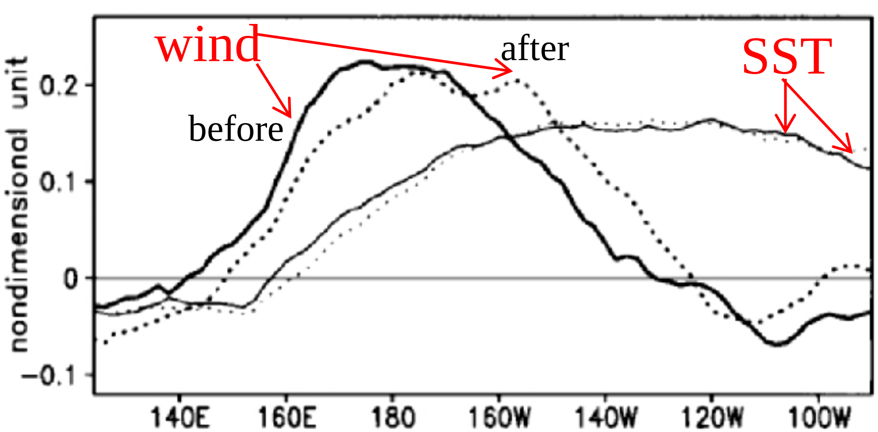


(from University of Washington)

- "Pacific Decadal Oscillation" (PDO) is a decadal-scale climate variability that describe an oscillation in northern Pacific sea surface temperatures (SSTs).
- PDO is found to link to the decadal variations of ENSO intensity.

ENSO Structures b/a 1976 Climate Shift





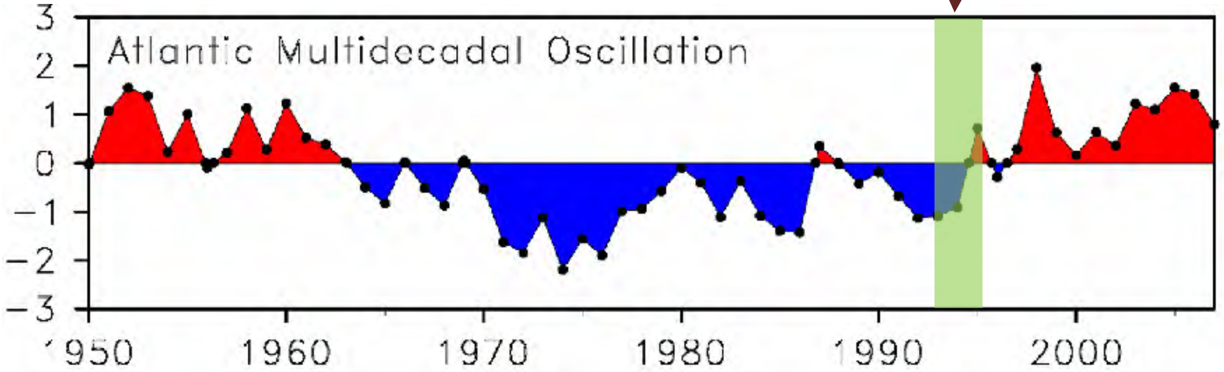
(from Wang and An 2001)

The 1976-77 climate shift (PDO+)

- ➔ a eastward shifted in the climatological trade winds
- ➔ caused ENSO wind anomalies to shift more eastward
- ➔ Lengthened the ENSO period by increasing the time required for Rossby waves to reflect from the western boundary
- ➔ Increased ENSO periodicity
- ➔ The increased delay gave the ENSO more time to grow from air-sea interactions
- ➔ **Strong and longer-period ENSO after the 1976-77 climate shift**

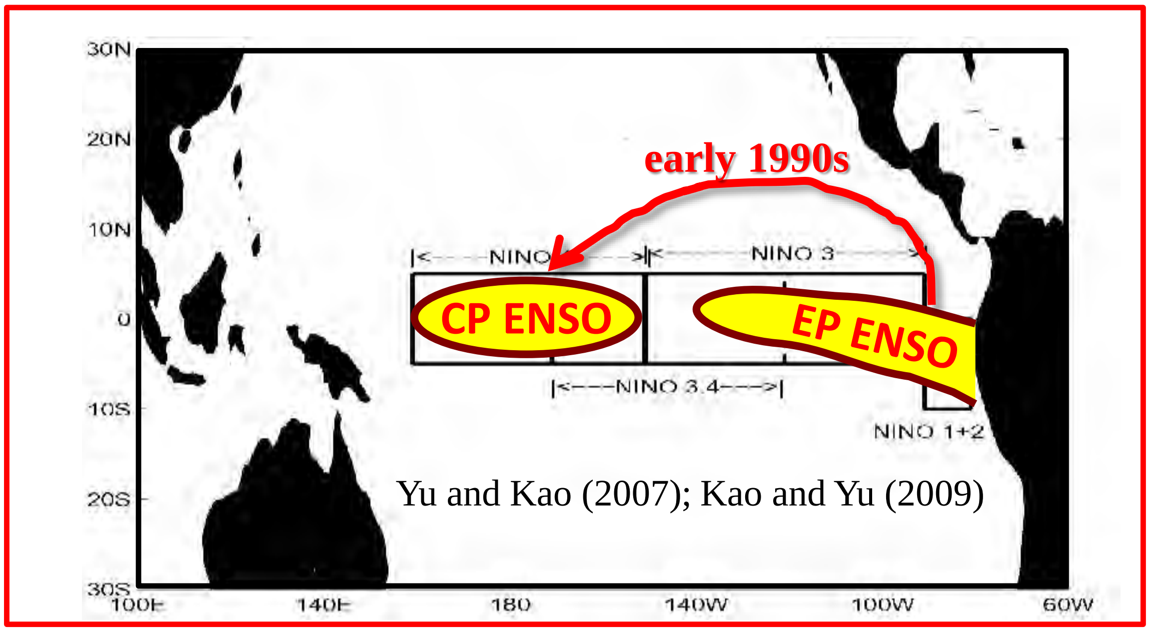
AMO and Early-1990s Climate Shift in Pacific

Early-1990s climate shift

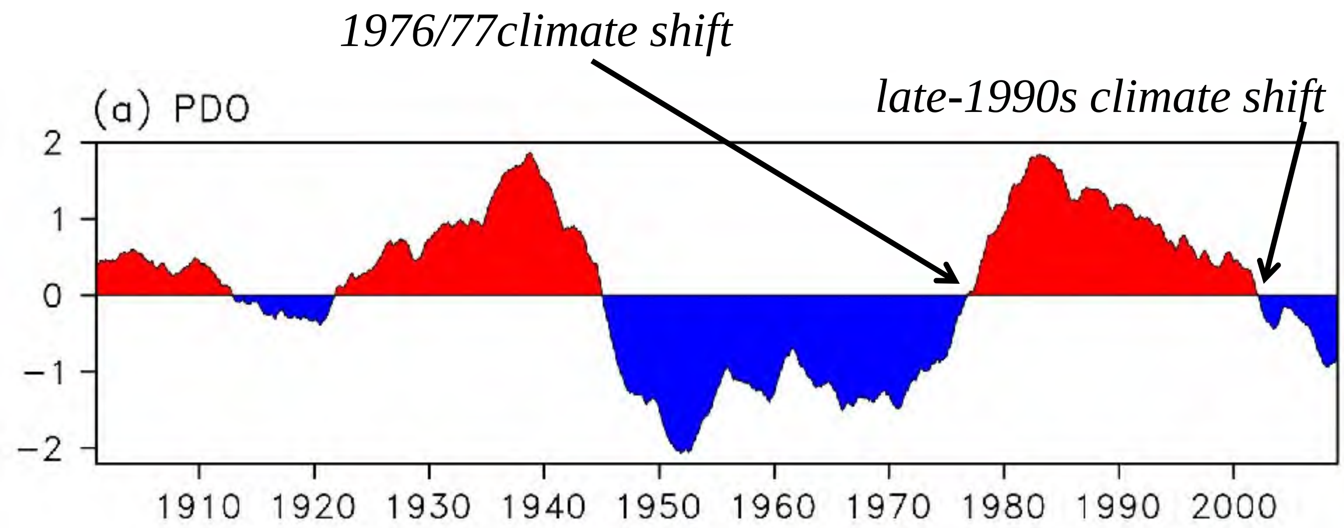


AMO

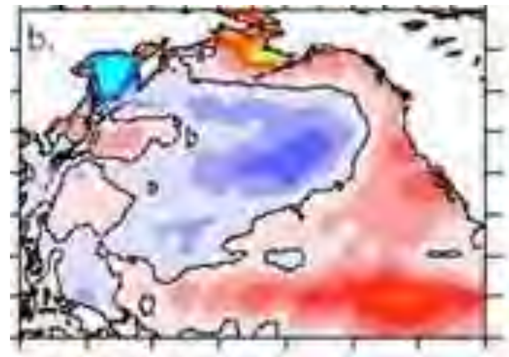
Affect El Nino Type



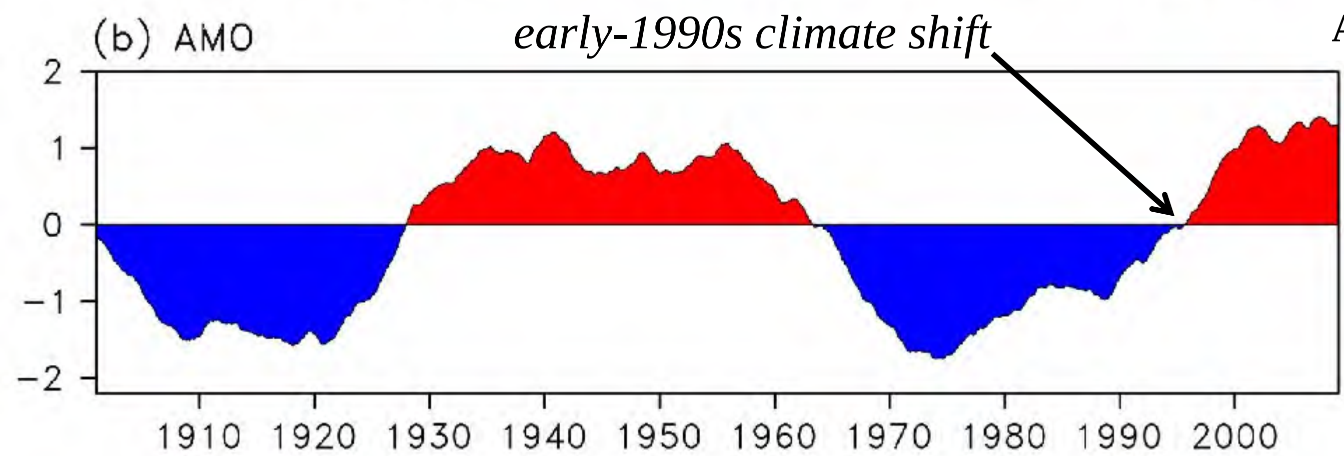
Two Major Modes of Natural Decadal Variability



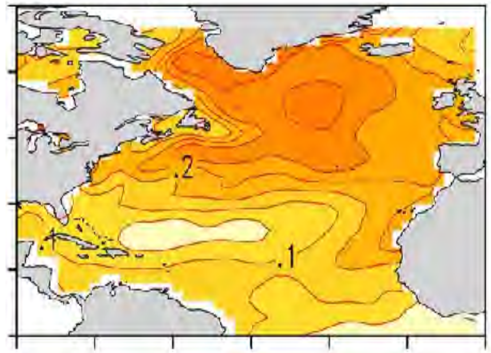
Pacific Decadal Oscillation



(from NOAA)

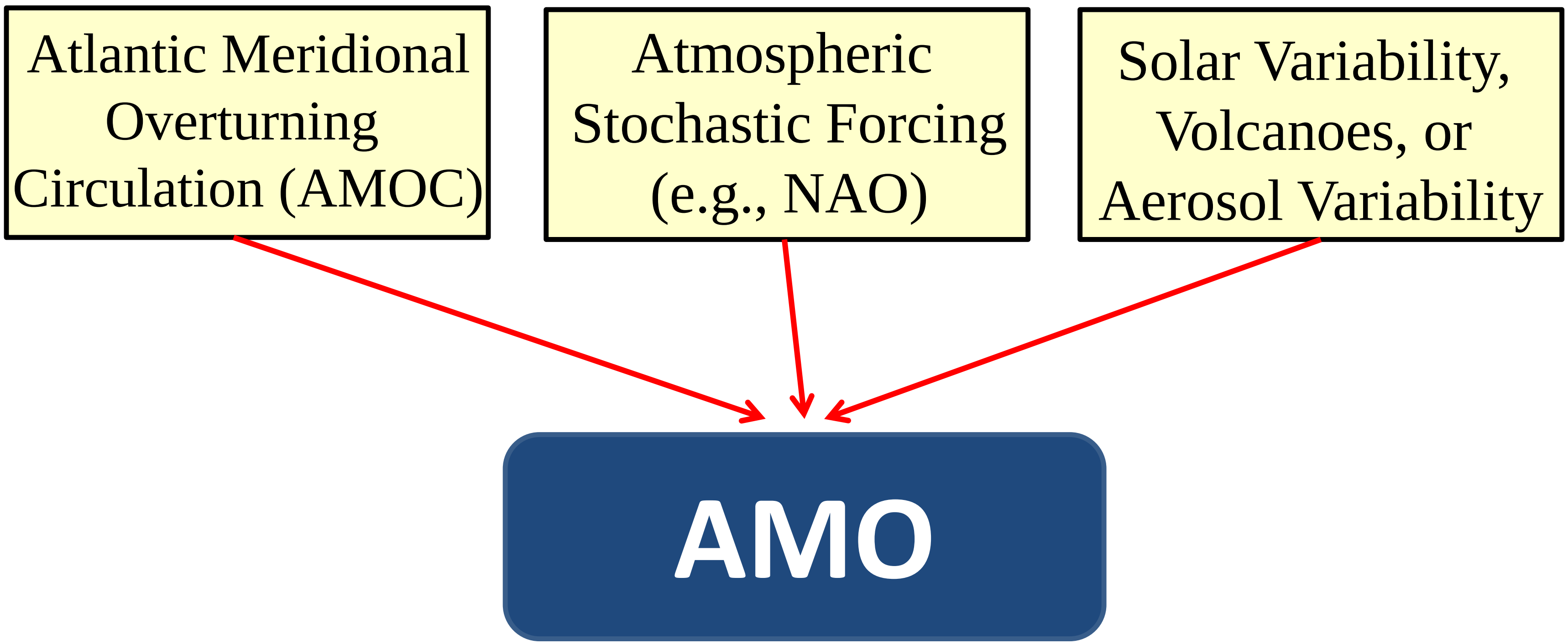


Atlantic Multi-decadal Oscillation



(from Yu et al. 2015)

Possible Generation Mechanisms for AMO



Hasselmann model of climate variability, where a system with a long memory (the ocean) integrates stochastic forcing, thereby transforming a white-noise signal into a red-noise one, thus explaining (without special assumptions) the ubiquitous red-noise signals seen in the climate.

- AMO is induced by the internal variability of the AMOC.

AMO Mechanism: AMOC Variation

The AMOC is characterized by net northward flow of warm water (red) in the upper 1,000 metres of the Atlantic Ocean and southward flow of cold deep water (blue).

A strengthened AMOC

➔ Produces a heat transport convergence in the North Atlantic Ocean

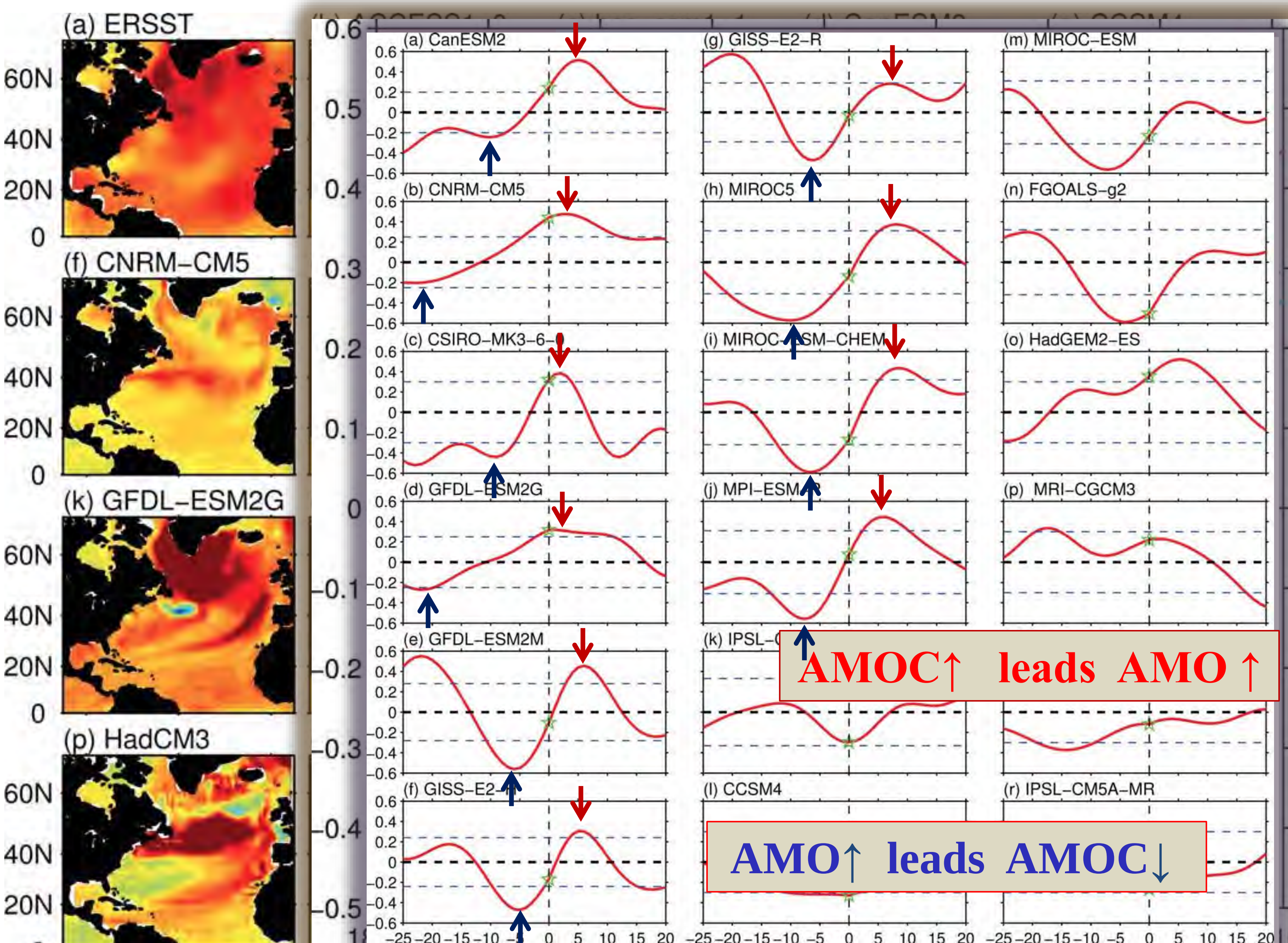
➔ Enters the warm phase of the AMO

➔ The AMO reduces the meridional density gradient over the North Atlantic Ocean

➔ Weakens the AMOC

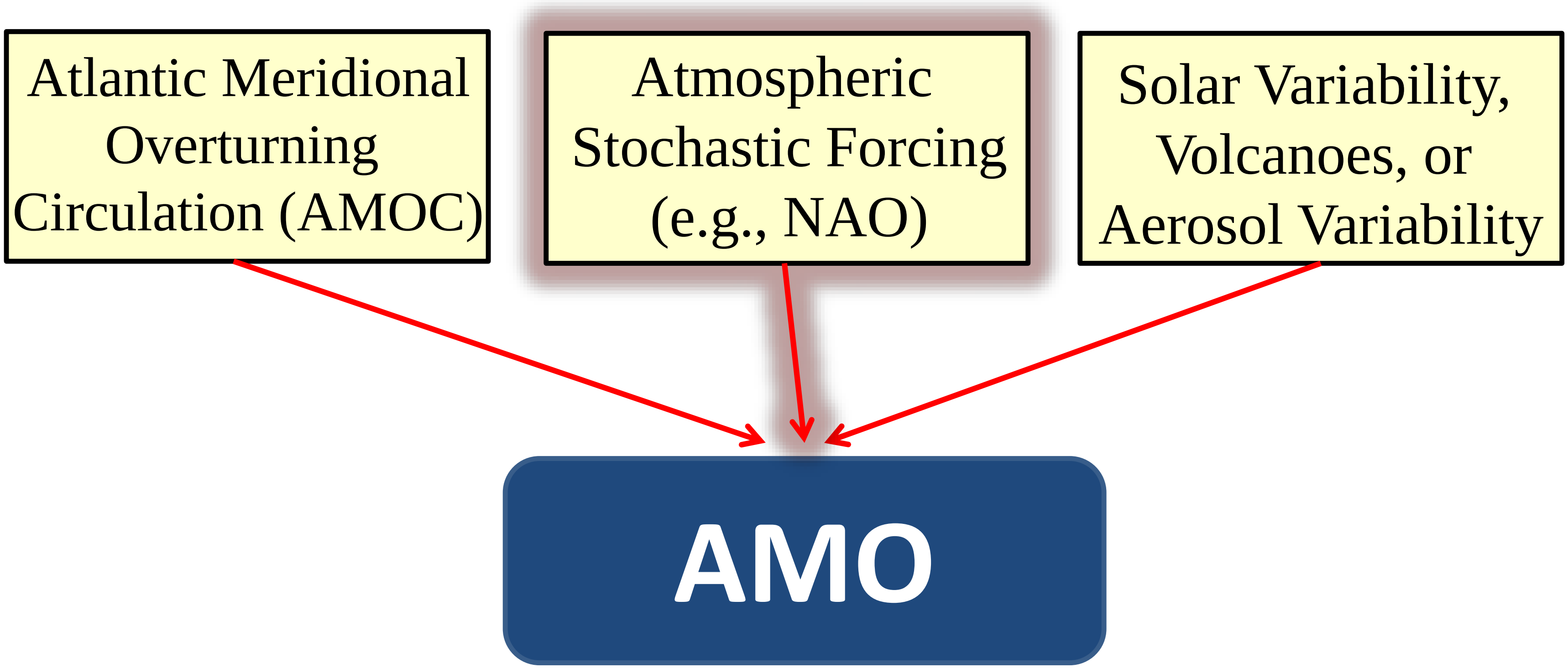
➔ **A weakened AMOC**

AMOC ➔ AMO / CMIP5 Historical Runs



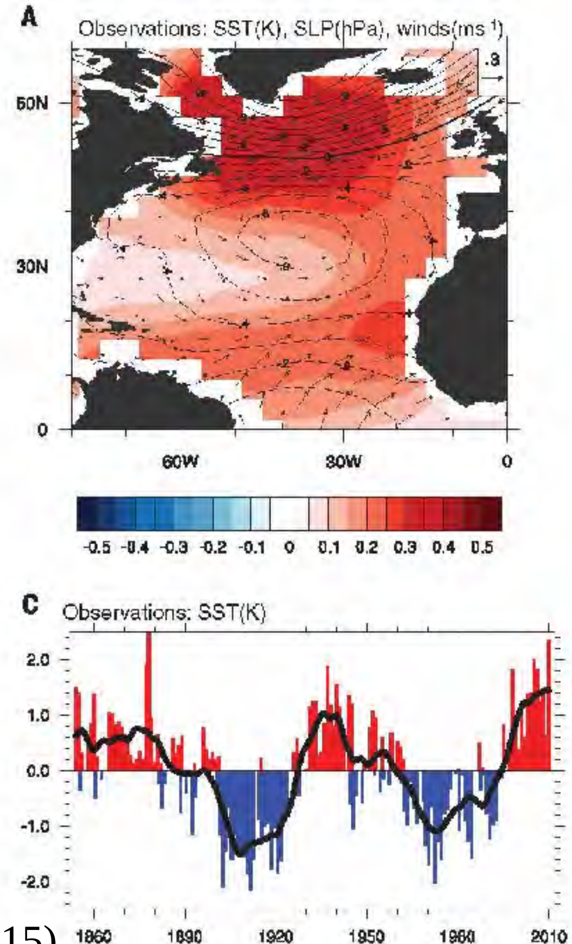
(modified from Zhang Liping and Wang Chunzai, 2013)

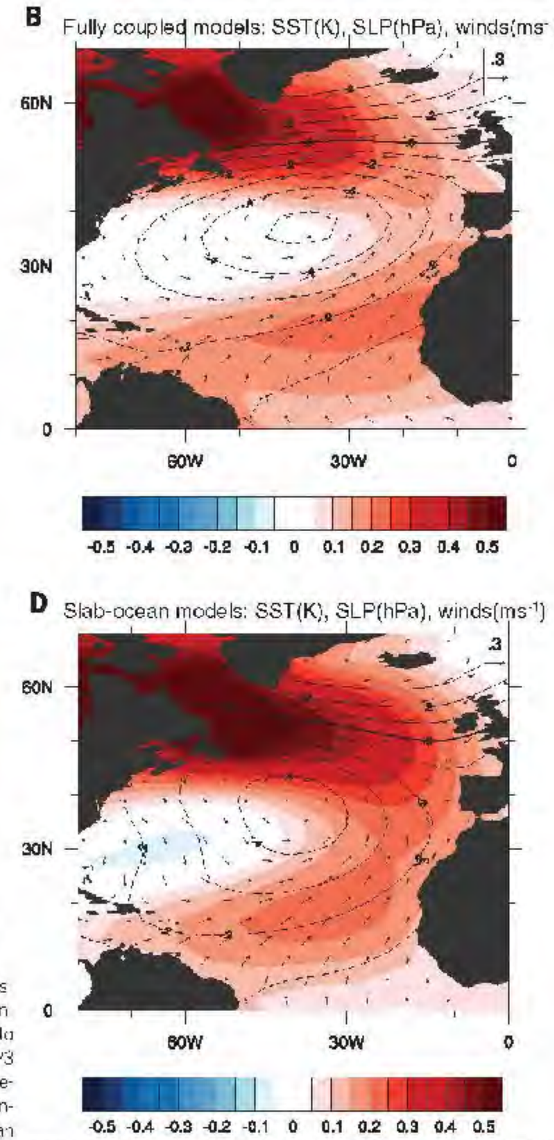
Possible Generation Mechanisms for AMO



Hasselmann model of climate variability, where a system with a long memory (the ocean) integrates stochastic forcing, thereby transforming a white-noise signal into a red-noise one, thus explaining (without special assumptions) the ubiquitous red-noise signals seen in the climate.

AMO Mechanism: Stochastic Forcing





(from Clement et al. 2015)

Fig. 1. Observations and model simulation of the AMO. (**A**, **B**, and **D**) Regression of SST (shaded), SLP (contours), and surface winds (vectors) on the standardized AMO index (0° to 60°N, 80°W to 0°). SLP contours range from −1.8 hPa to 1.8 hPa, with intervals of 0.1 hPa. (A) Observations. (B) Multimodel mean of CMIP3 preindustrial control fully coupled models. (D) Multimodel mean of CMIP3 preindustrial control slab-ocean models. Values are of K, hPa, and m s⁻¹ per unit of standard deviation of the AMO index. (**C**) Observations. Time series of annual mean anomalies of the standardized AMO index (colored bars) with a 10-year running average superimposed (black line). The observed SST is from ERSSTv3b, whereas surface winds and SLP are from the NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) reanalysis. All fields are detrended.

Summary

- There are evidence that the Pacific experiences a climate shift in the early 1990s, which has a close association with the phase change of the Atlantic Multi-decadal oscillation (AMO).
- The Atlantic began to play an active role in influencing the Pacific variability after early 1990s.
- Due to the stronger Atlantic influences, the ENSO changes to the CP type and became biennial after early 1990s.
- The early-1990s climate shift can also be identified in many other climate phenomena in the Pacific.