El Nino and Southern Oscillation (ENSO) and Low frequency Ocean variability

Sang-Wook Yeh
Hanyang University

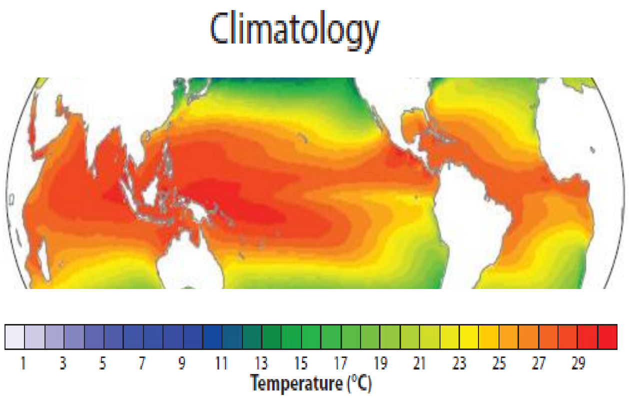
http://video.nationalgeographic.com/video/player/environment/environment-natural-disasters/landslides-and-more/el-nino.html

• ENSO (El Nino and Southern Oscillation)

-One of the most significant couplings between the ocean and atmosphere on an interannual timescale occurs in the tropical Pacific.

• Ocean-atmosphere coupled system I

Ocean



- Water vapor
- Deep convection
- Condensation & freezing

Heating

Atmospheric temperature & circulation

Ocean circulation

- Surface momentum
- Heat fluxes

Atmosphere

• Ocean-atmosphere coupled system II

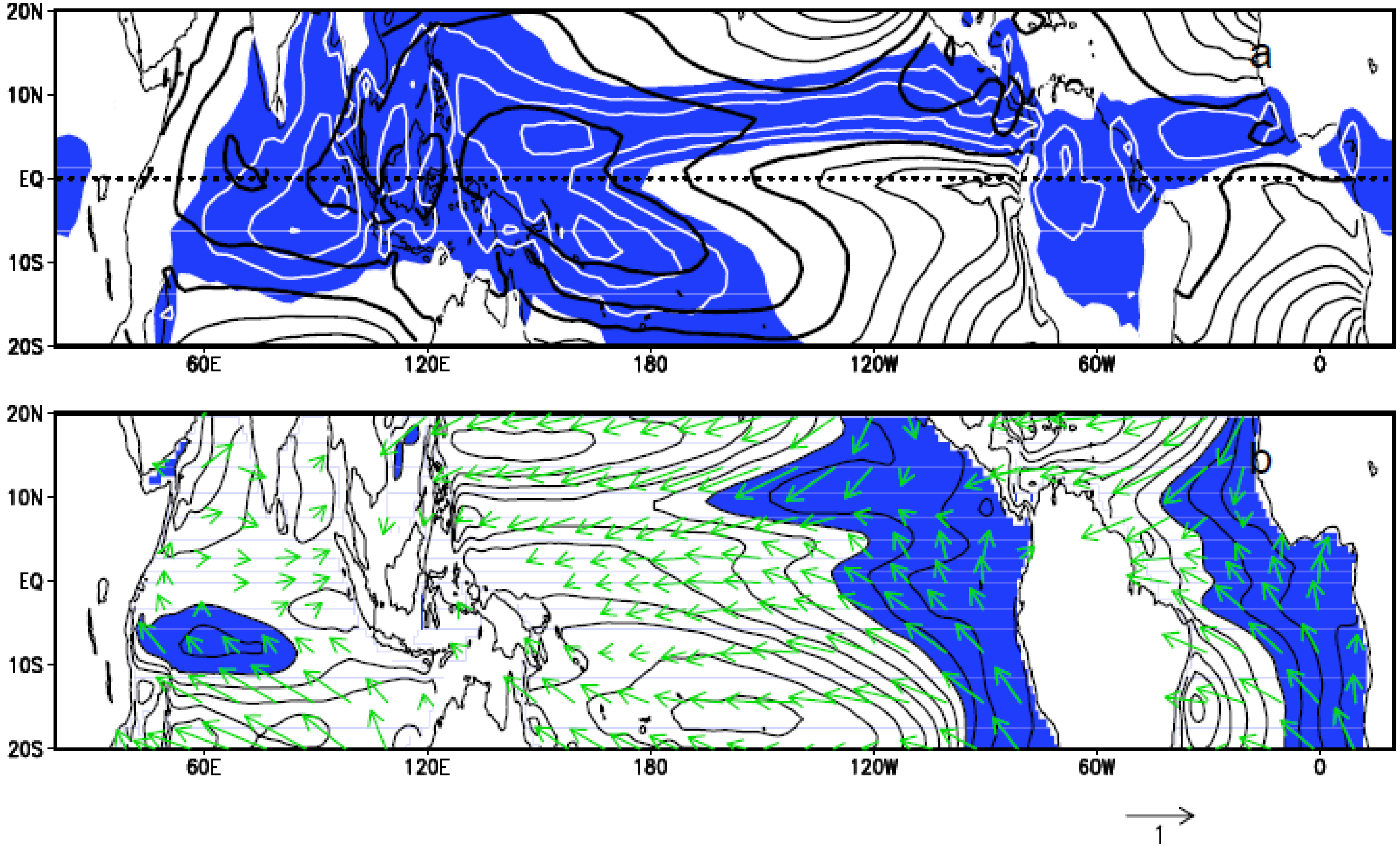
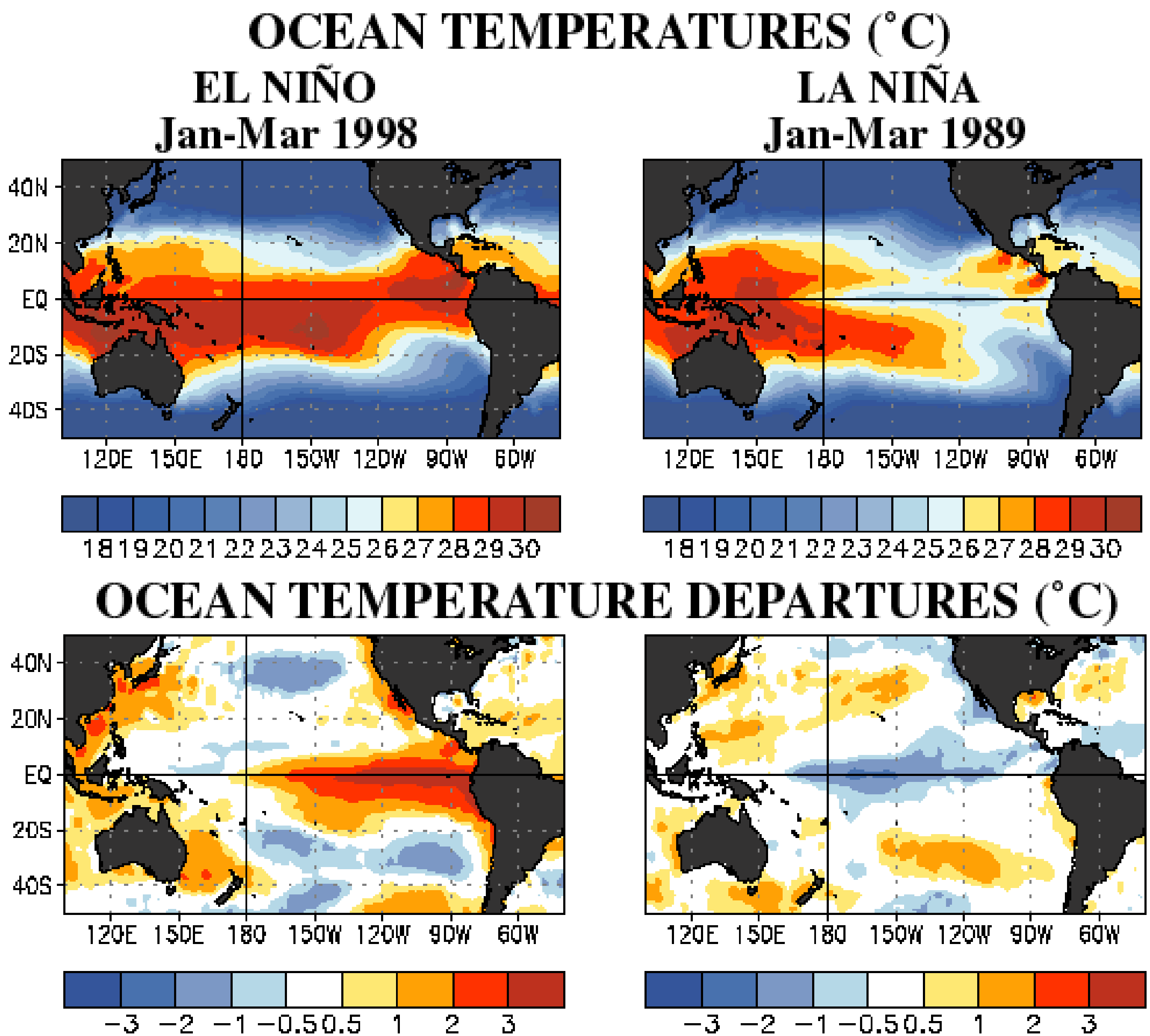
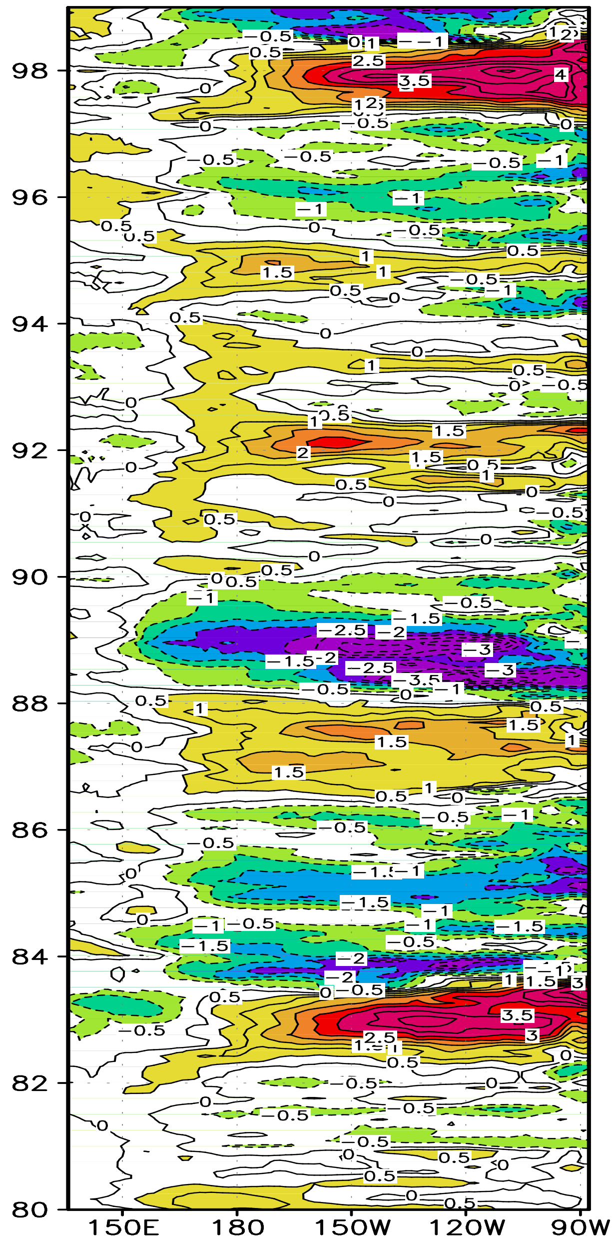


Figure 1. Annual-mean climatology: (a) SST (black contours at 1°C intervals; contours of SST greater than 27°C thickened) and precipitation (white contours at 2 mm/day; shade > 4 mm/day); (b) surface wind stress vectors (Nm^{-2}) and the 20°C isotherm depth (contours at 20 m intervals; shade < 100 m).

• ENSO (El Nino and Southern Oscillation)



• ENSO (El Nino and Southern Oscillation)



•ENSO Mechanism •

• ENSO (El Nino and Southern Oscillation)

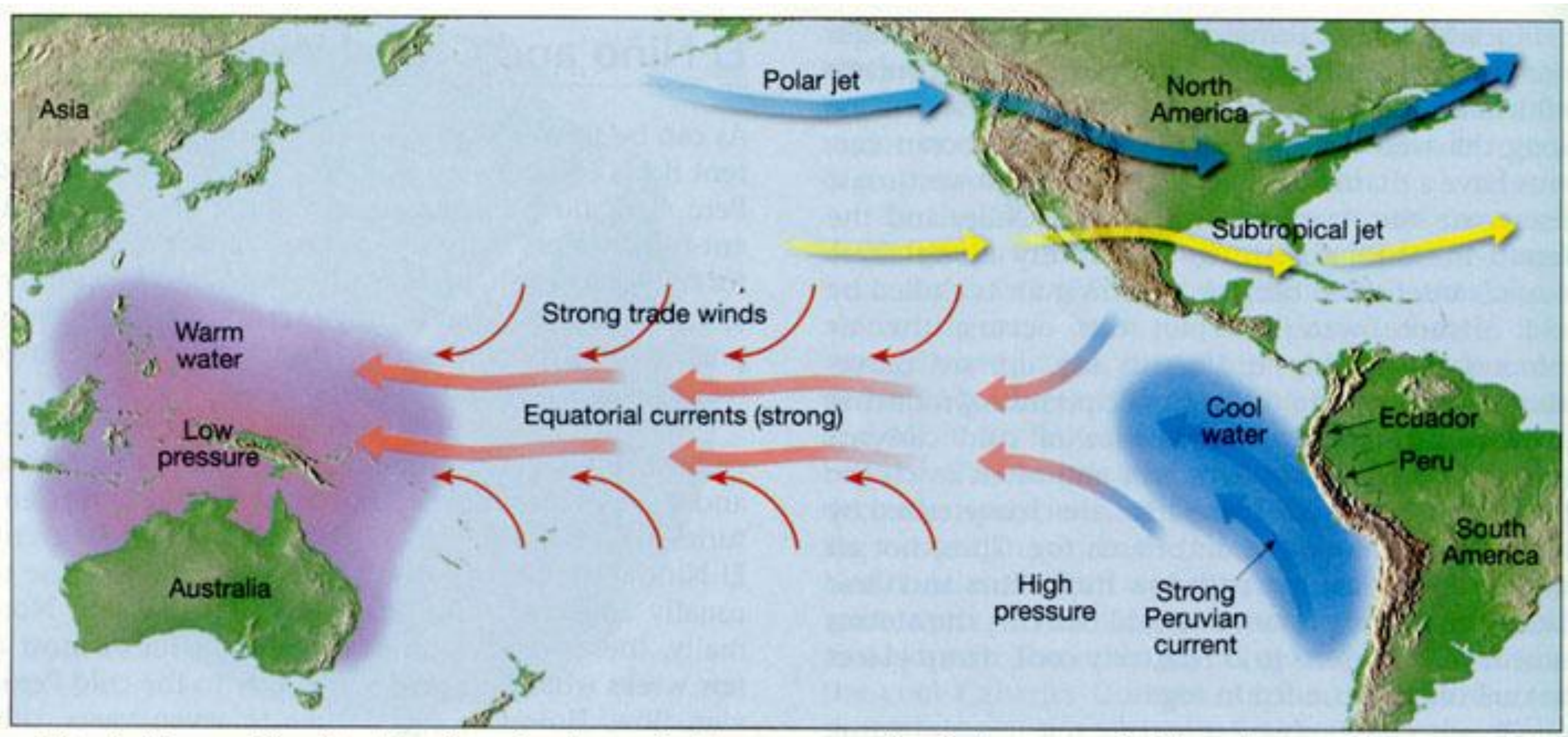


Fig.6 Normally, the trade winds and strong equatorial currents flow toward the west. At the same time, an intense Peruvian current causes upwelling of cold water along the west coast of South America.

• ENSO (El Nino and Southern Oscillation)

Walker circulation

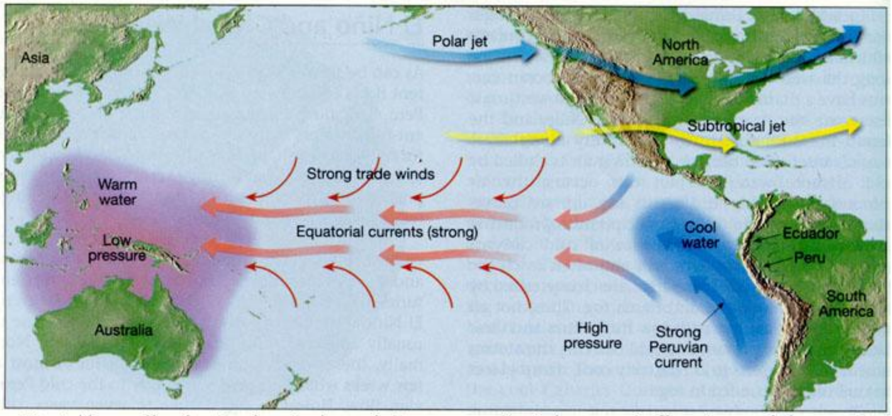
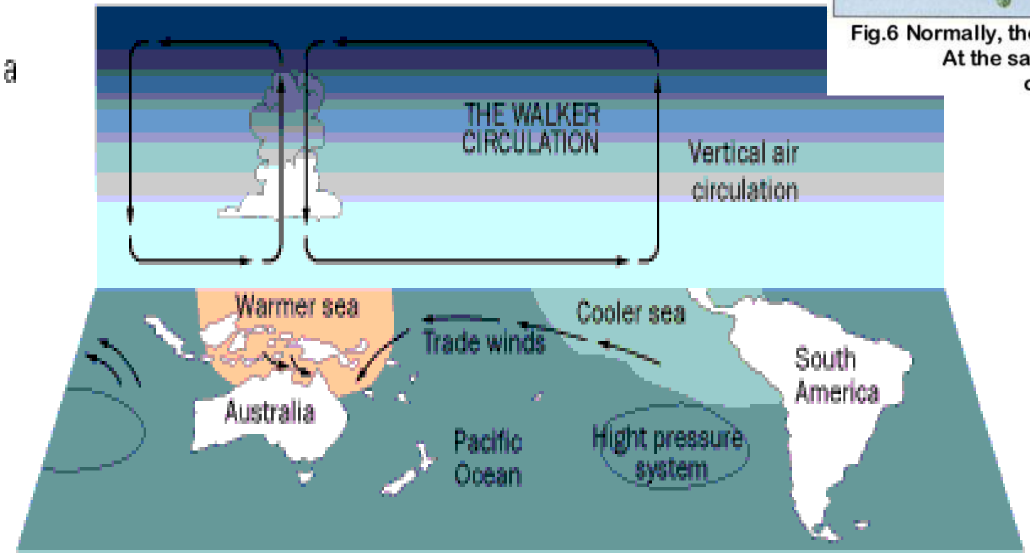


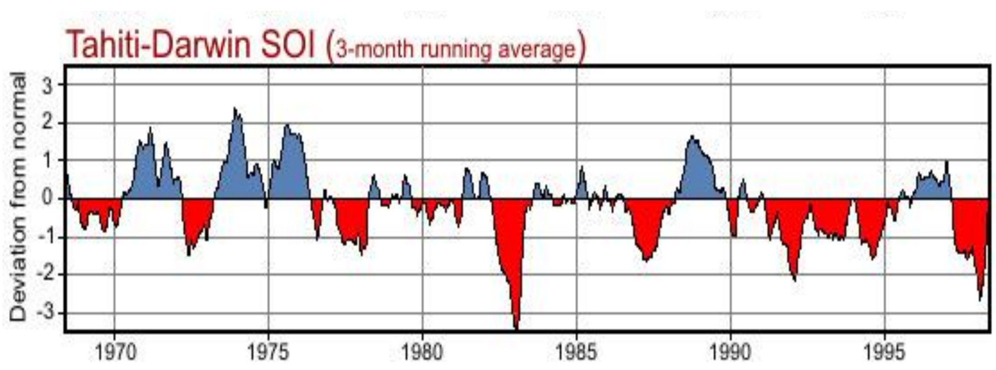
Fig.6 Normally, the trade winds and strong equatorial currents flow toward the west. At the same time, an intense Peruvian current causes upwelling of cold water along the west coast of South America.

a



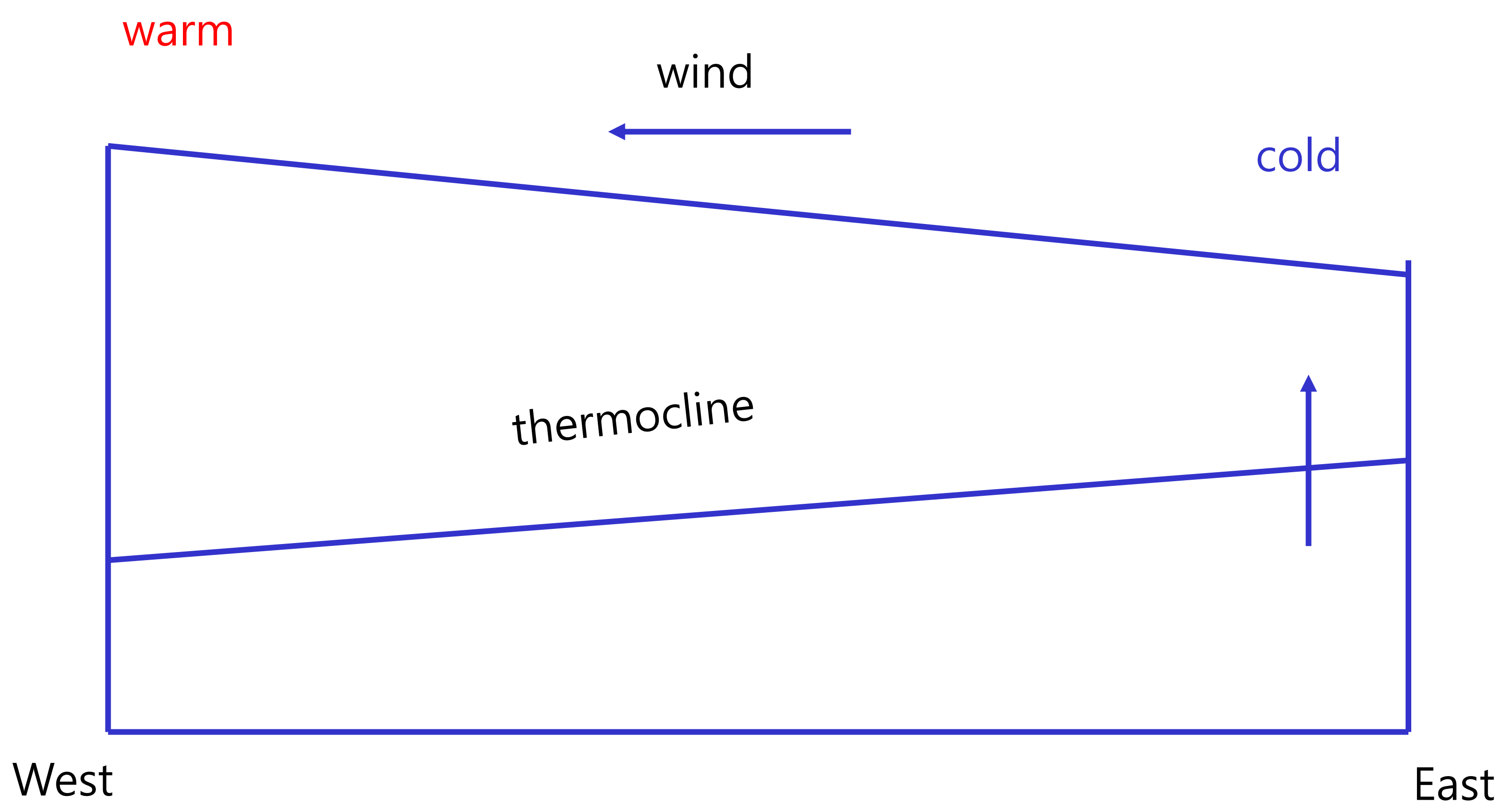
• ENSO (El Nino and Southern Oscillation)

Southern Oscillation



• ENSO (El Nino and Southern Oscillation)

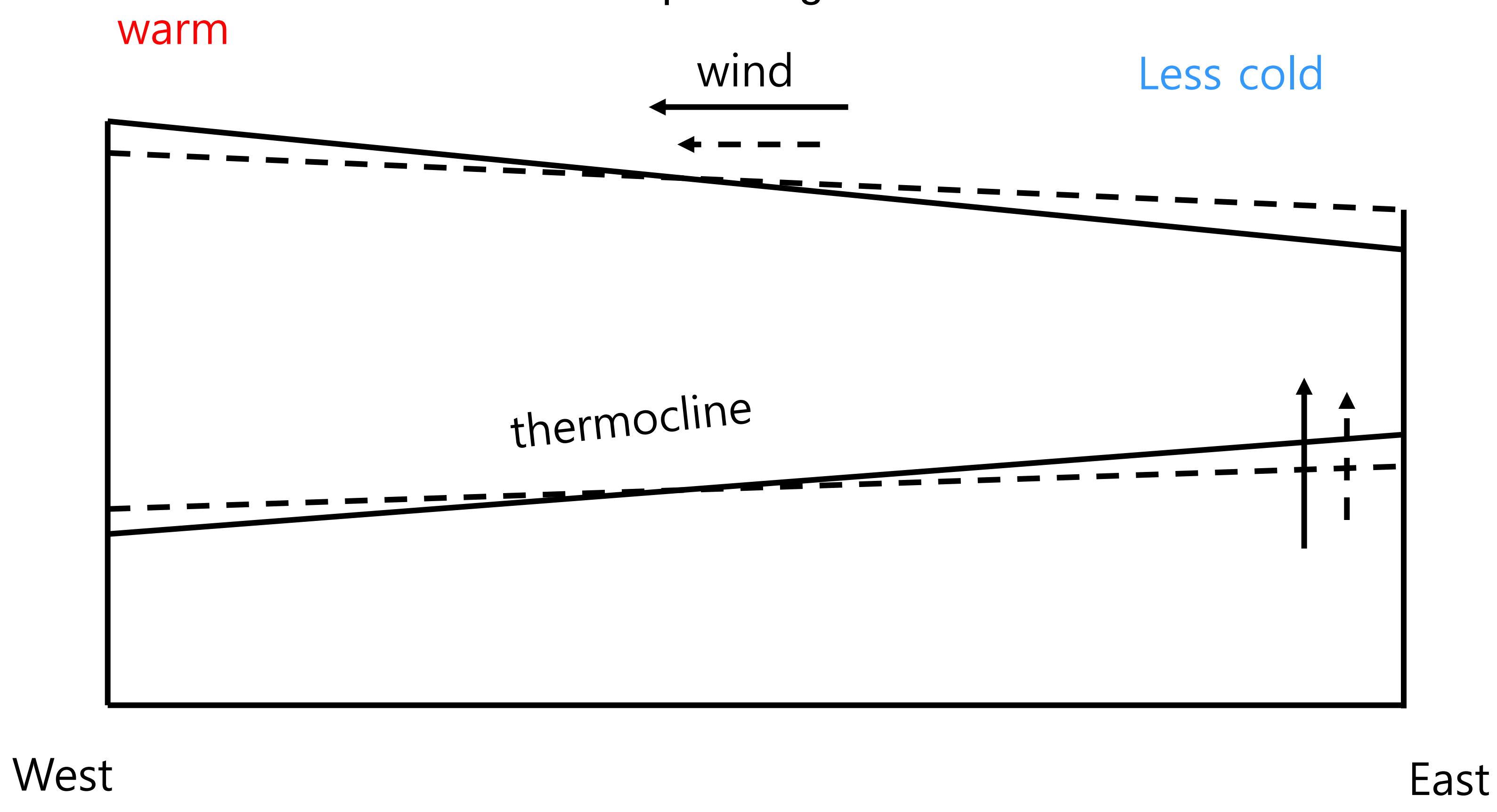
Wind α (warm minus cold)



• ENSO (El Nino and Southern Oscillation)

If the wind gets a little bit weaker .....

Δ wind -> Δ upwelling -> Δ SST

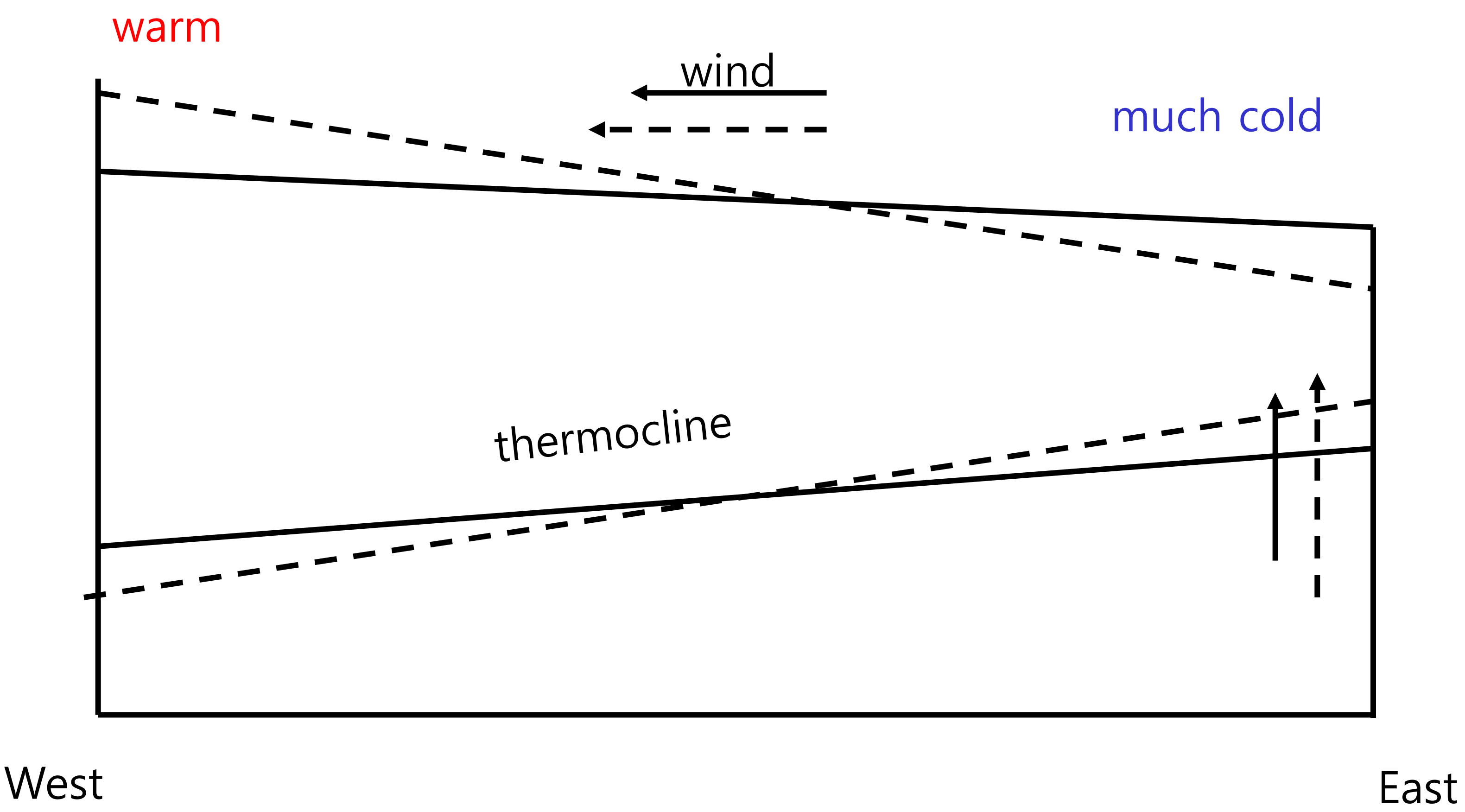


Wind α (warm minus Less cold) -> Even weaker wind

• ENSO (El Nino and Southern Oscillation)

If the wind gets a little bit stronger .....

Δ wind -> Δ upwelling -> Δ SST



Wind α (warm minus much cold) -> Even stronger wind

• ENSO (El Nino and Southern Oscillation)

El Niño

SST gradient E-W
weaker

Thermocline depth
at the east, etc
deeper

Tradewinds
weal

The Bjerknes Feedback

Normal, La Niña

SST gradient E-W
stronger

Thermocline depth
at the east, etc
shallower

Tradewinds
stronger

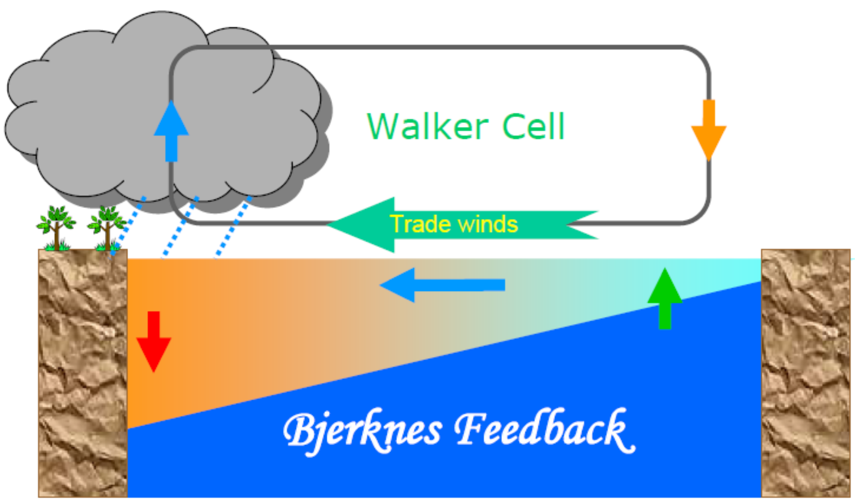
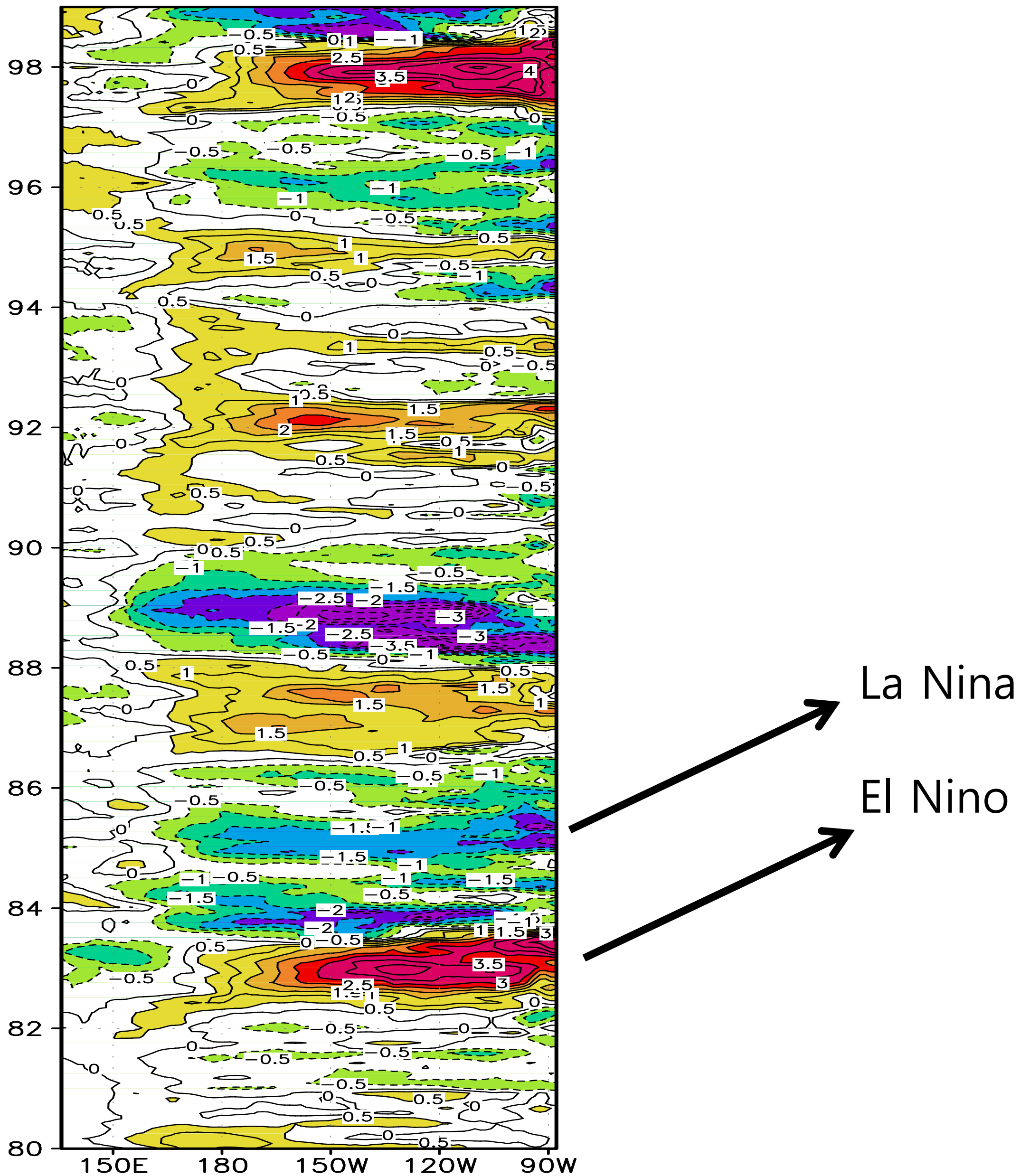


Figure 3. Schematic for Bjerknes feedback.

• ENSO (El Nino and Southern Oscillation)



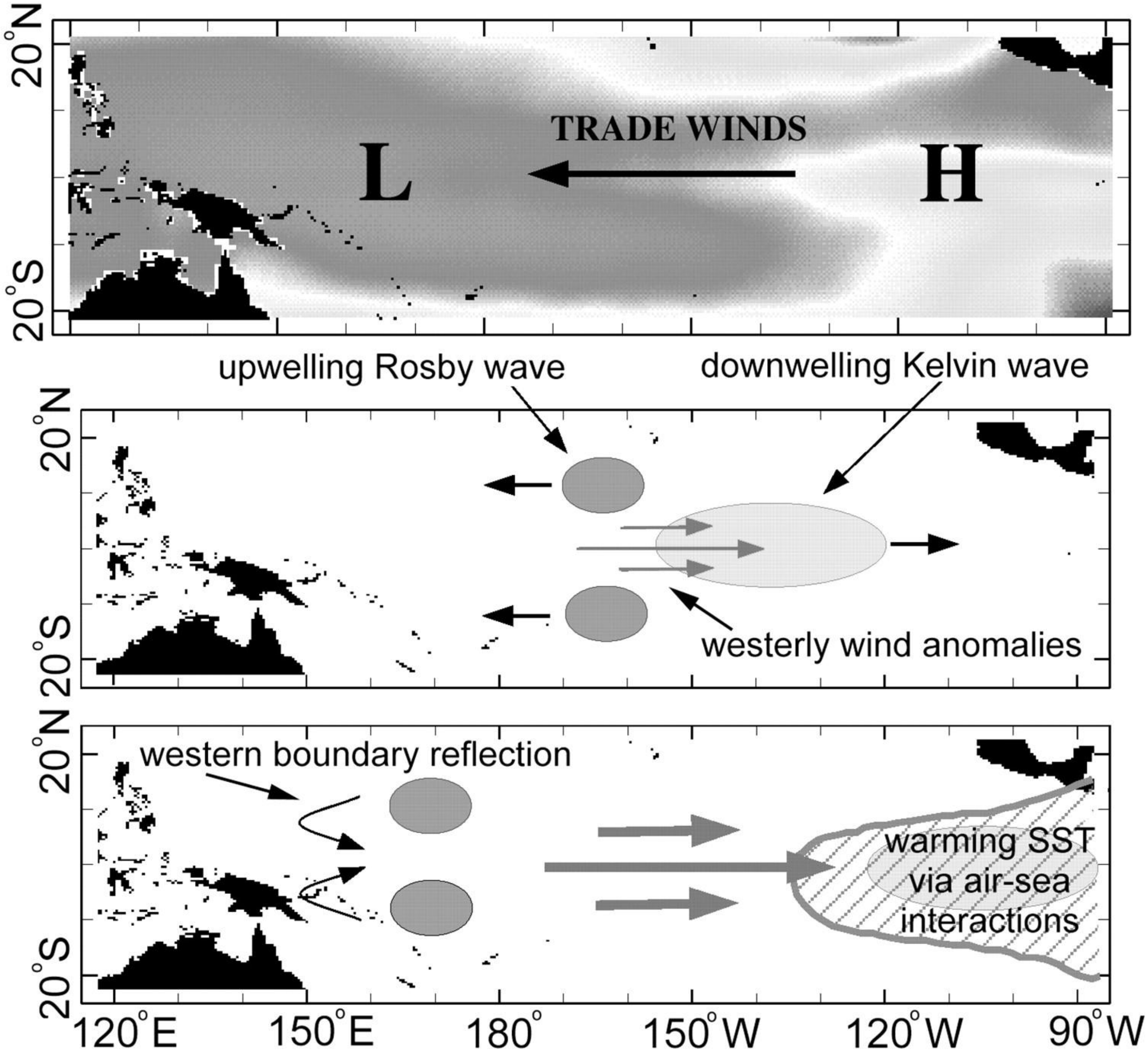
• ENSO (El Nino and Southern Oscillation)

Delayed Oscillator Theory

$$\frac{dT_E}{dt} = aT_E - bT_E(t - \delta)$$

Suarez and Schopf (1988) Battisti and Hirst (1989)

• ENSO (El Nino and Southern Oscillation)



• ENSO (El Nino and Southern Oscillation)

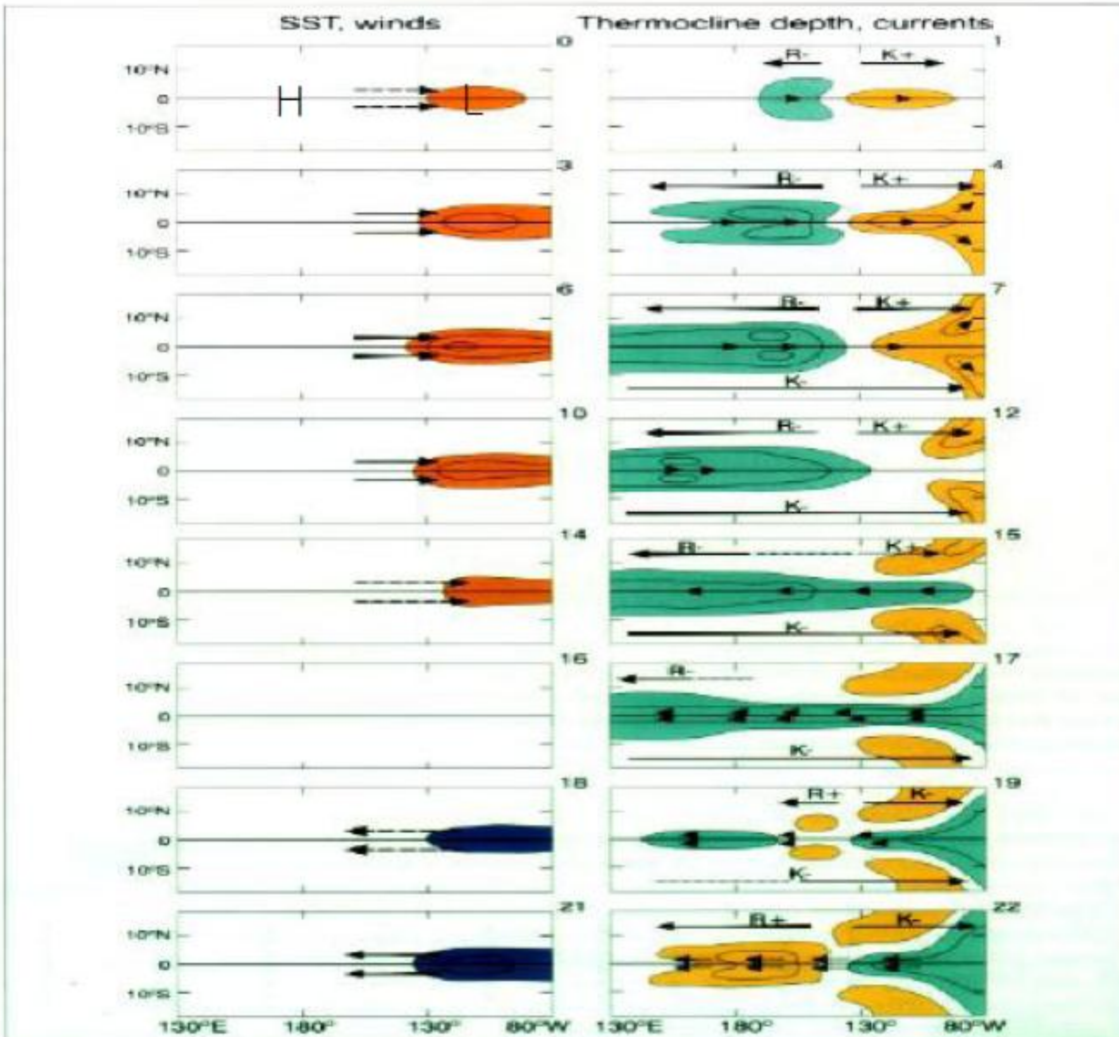


Figure 25: Schematic 'delayed action oscillator' behaviour of a coupled ocean–atmosphere model over the Pacific basin in response to the introduction of a westerly wind anomaly across the CEP. In the left-hand panels, arrows indicate wind anomalies (thickness indicates relative strength) and shadings indicate SST anomalies (positive in red and negative in blue). In the right-hand panels, thin dashed and solid arrows are ocean current anomalies and thicker arrows labelled K+ and K−, R+ and

•ENSO Impact •

• ENSO (El Nino and Southern Oscillation)

• Teleconnection

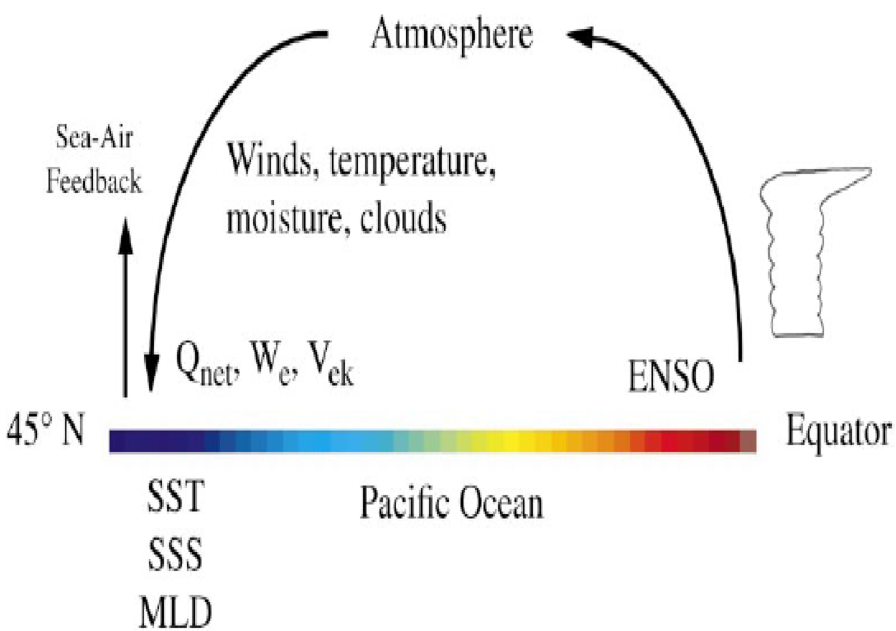


FIG. 1. Schematic of the "atmospheric bridge" between the tropical and North Pacific Oceans. The bridge concept also applies to the Atlantic, Indian, and South Pacific Oceans. The bridge occurs through changes in the Hadley and Walker cells, Rossby waves, and interactions between the quasi-stationary flow and storm tracks (see Trenberth et al. 1998). The Q_{net} is the net surface heat flux; w_e the entrainment rate into the mixed layer from below, which is primarily driven by surface fluxes; SST the sea surface temperature; SSS the sea surface salinity; and MLD the mixed layer depth.

Alexander et al. (2002)

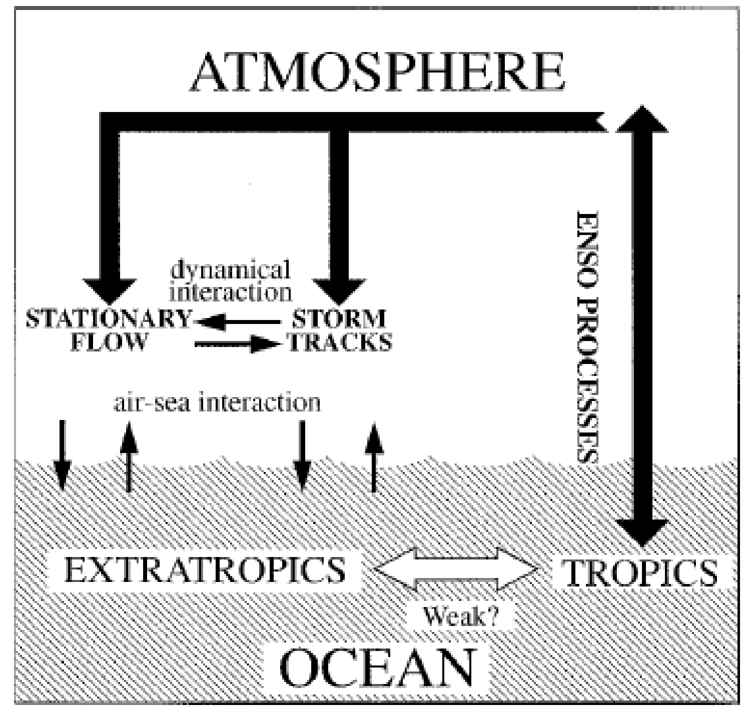


FIG. 7. Schematic diagram depicting the role of the atmospheric bridge in linking SST variations in the tropical and extratropical oceans.

Lau (1996)

• ENSO (El Nino and Southern Oscillation)

• Teleconnection

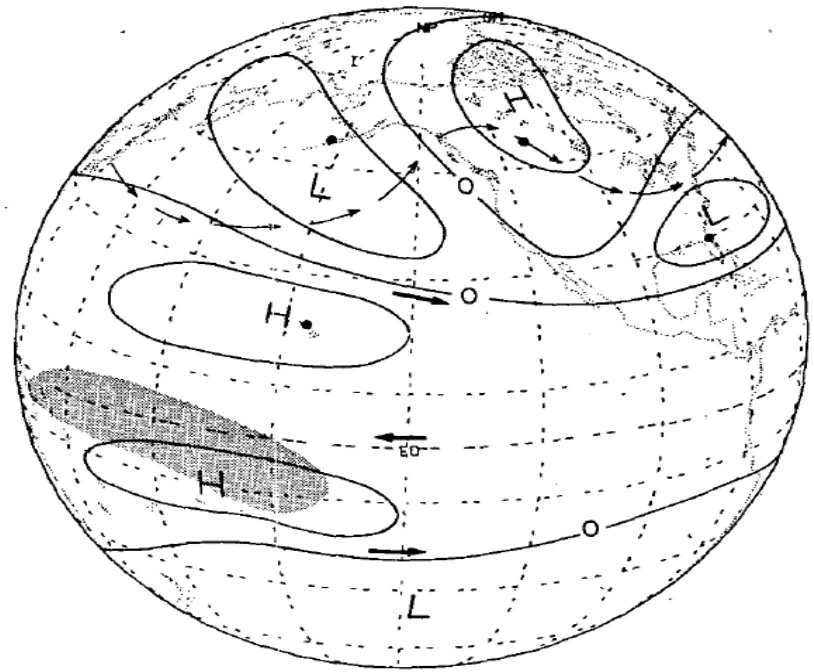
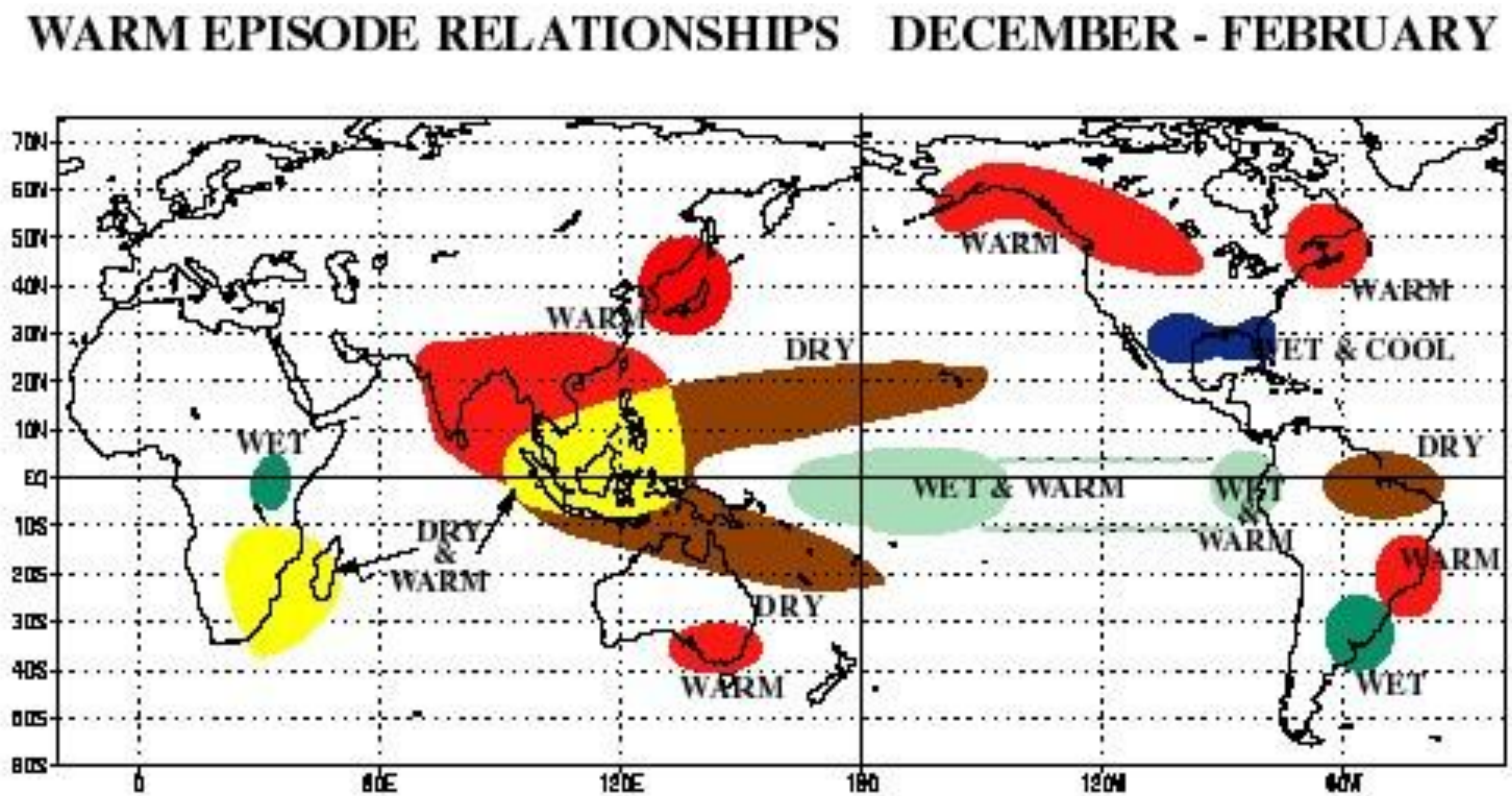


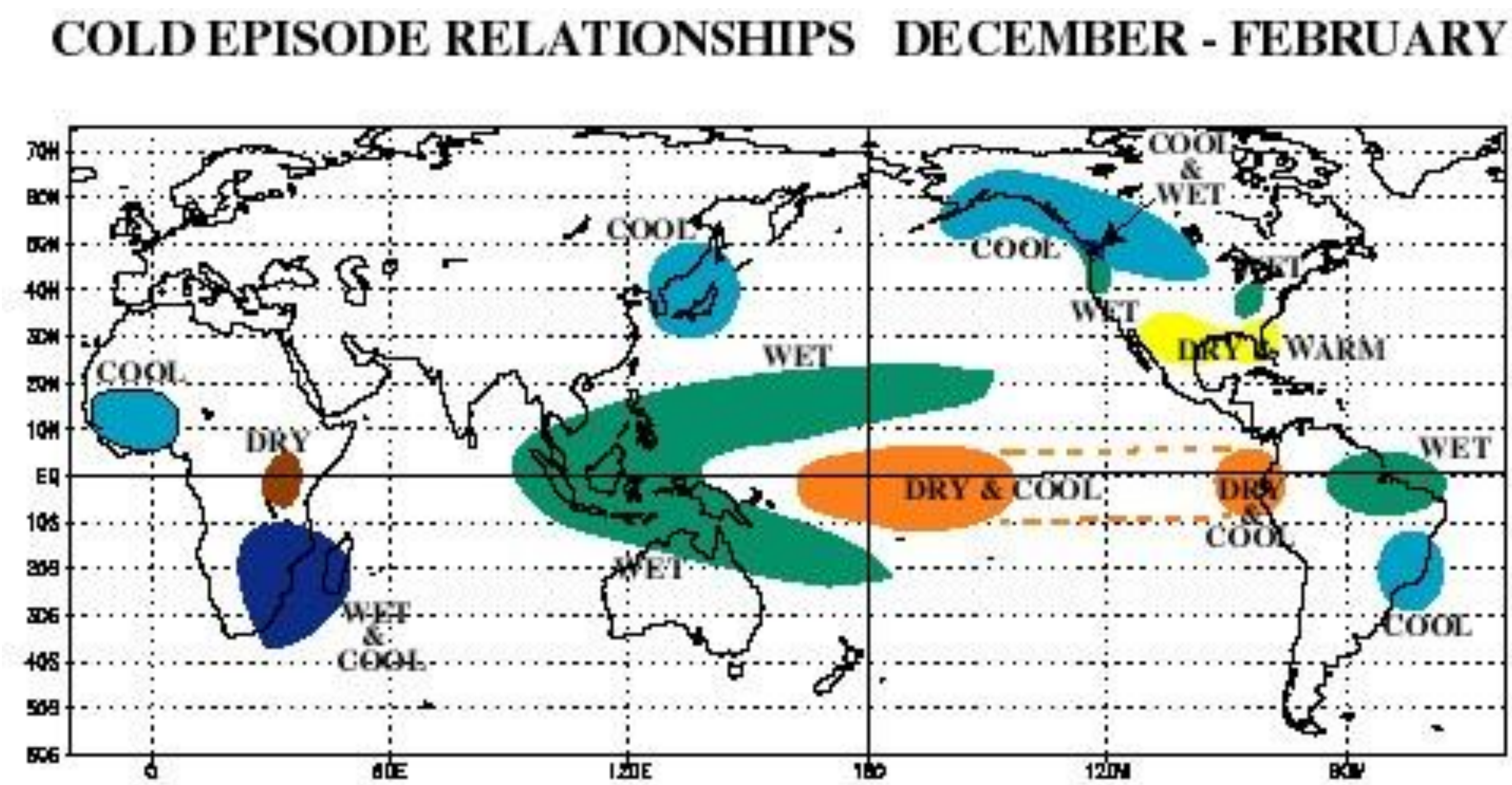
FIG. 11. Schematic illustration of the hypothesized global pattern of middle and upper tropospheric geopotential height anomalies (solid lines) during a Northern Hemisphere winter which falls within an episode of warm sea surface temperatures in the equatorial Pacific. The arrows in darker type reflect the strengthening of the subtropical jets in both hemispheres along with stronger easterlies near the equator during warm episodes. The arrows in lighter type depict a mid-tropospheric streamline as distorted by the anomaly pattern, with pronounced "troughing" over the central Pacific and "ridging" over western Canada. Shading indicates regions of enhanced cirriform cloudiness and rainfall. For further details see Section 7. The locations of the stations used in Table 4 are indicated by dots.

Horel and Wallace (1986)

• ENSO (El Nino and Southern Oscillation)



• ENSO (El Nino and Southern Oscillation)



• ENSO (El Nino and Southern Oscillation)

A brief look at research throughout the organization

El Niño and La Niña: More than mirror images

The El Niño-Southern Oscillation causes extreme weather, including floods and droughts, in many regions of the world. South American fishermen gave El Niño its name (Spanish for "The Boy") in reference to the Christ child, because the periodic warming of Pacific waters off Peru and Ecuador is usually noticed around Christmas. (Image ©UCAR.)

October 6, 2010 | El Niño and La Niña are counterparts in the El Niño-Southern Oscillation (ENSO), a cyclic warming and cooling of the eastern and central Pacific Ocean that exerts a major influence on global weather patterns. These children of the tropics are not mirror images, however, but display significant differences in spatial structure and seasonal evolution. A new study led by NCAR visiting scientist Yuko Okumura examines the asymmetry of their durations. The findings have important implications for the prediction of ENSO and its global influences.

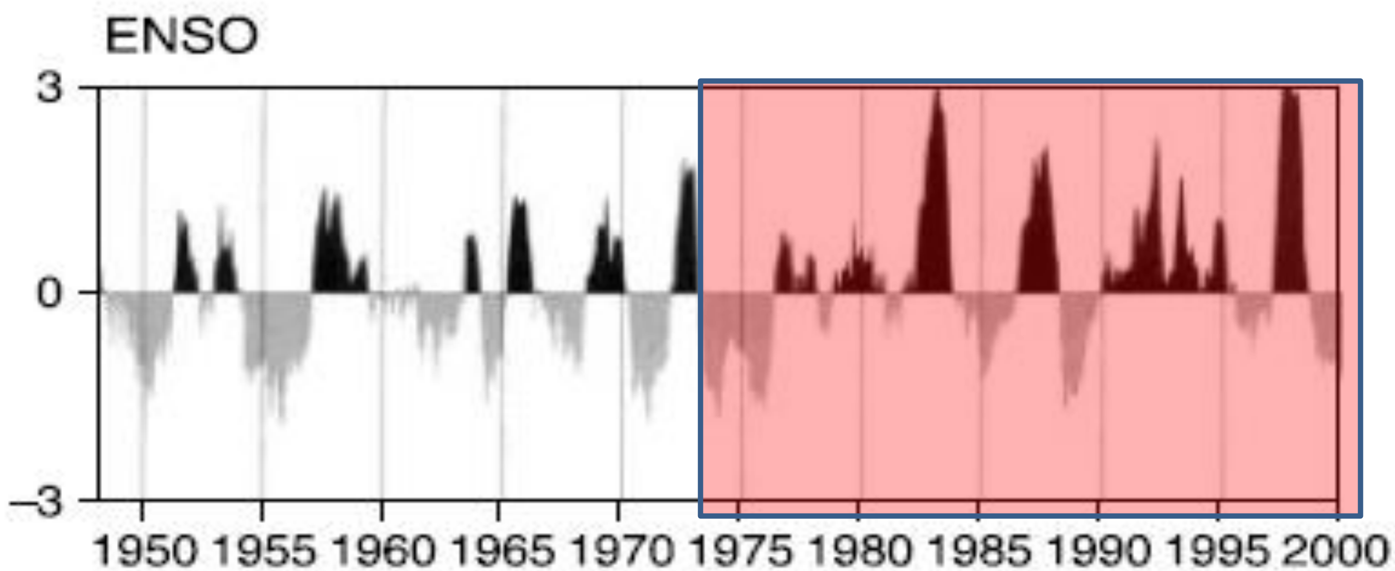
Okumura and her co-author analyzed two datasets of monthly sea surface temperatures spanning different periods: 1900–2008 and 1982–2008. They found a robust asymmetry between El Niño and La Niña throughout the record, especially during strong ENSO events. Both phases typically begin in late spring or summer. Most El Niños terminate rapidly after peaking in December or January, but many La Niñas persist through the following spring and summer and re-intensify in winter, some even lasting through a third year.

The researchers also looked at how ocean-atmosphere anomalies evolve in association with the asymmetric durations of El Niño and La Niña, identifying a pronounced asymmetry in the surface wind anomalies that develop in late fall over the far western Pacific. La Niña drives strong easterly winds over much of the western Pacific during its developing and mature phases. El Niño exhibits a similar structure with a reversed sign, except that a month prior to its mature phase, the westerly winds begin to weaken in the far western Pacific due to the effects of warming sea surface temperatures in the Indian Ocean.

The influence of the Indian Ocean can be felt more strongly in the western Pacific during El Niño compared to La Niña because of the more eastward location of atmospheric deep convection anomalies in the Pacific.

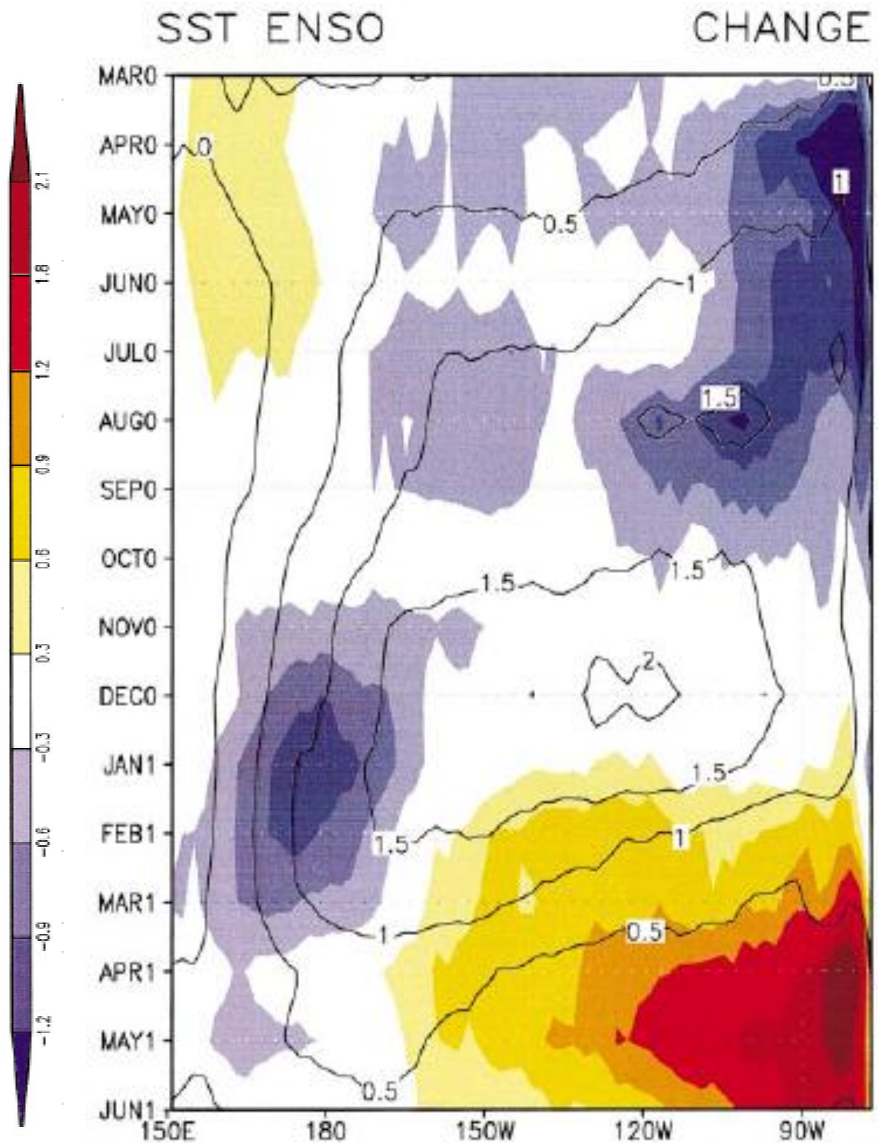
- ENSO low-frequency Variability
-

• ENSO (El Nino and Southern Oscillation)



Diaz et al. (2001)

• ENSO (El Nino and Southern Oscillation)



Diaz et al. (2001)

Plate 6. Hovmuller diagrams illustrating the change in the composite life cycle of SST and rainfall anomalies along the equatorial Pacific during 1948–1999. In the left panel, contours illustrate the composite El Niño SST (°C) anomaly based on pre-1976 events, whereas the shading illustrates the difference in El Niño SST composites for events occurring after versus before 1976. In the right panel, the contours illustrate the change in El Niño rainfall anomaly composites (mm/day) for events occurring after versus before 1976, as derived from climate simulations. The shading repeats the SST change of the left panel

• ENSO (El Nino and Southern Oscillation)

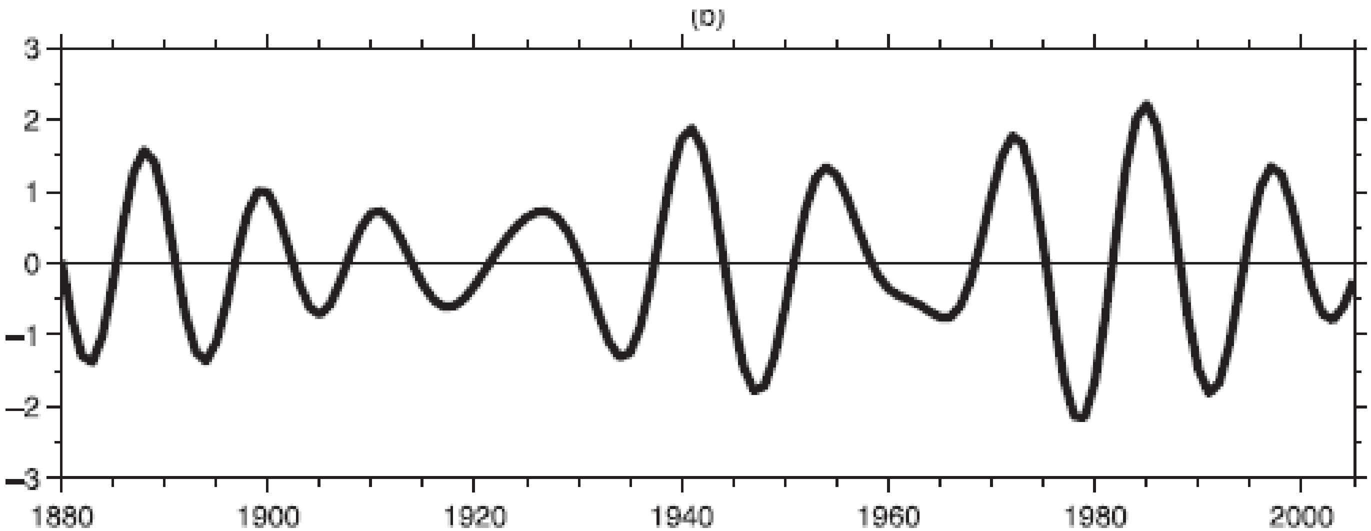


FIG. 1. (a) Time series of extended boreal winter (October–March) Niño-3.4 SST anomaly index (thin line), decadal amplitude (square root of ENVF; thick solid line), and its mirror (thick dashed line). (b): Standardized 10–20-yr bandpass-filtered ENVF.

Sun and Yu (2009)

• ENSO (El Nino and Southern Oscillation)

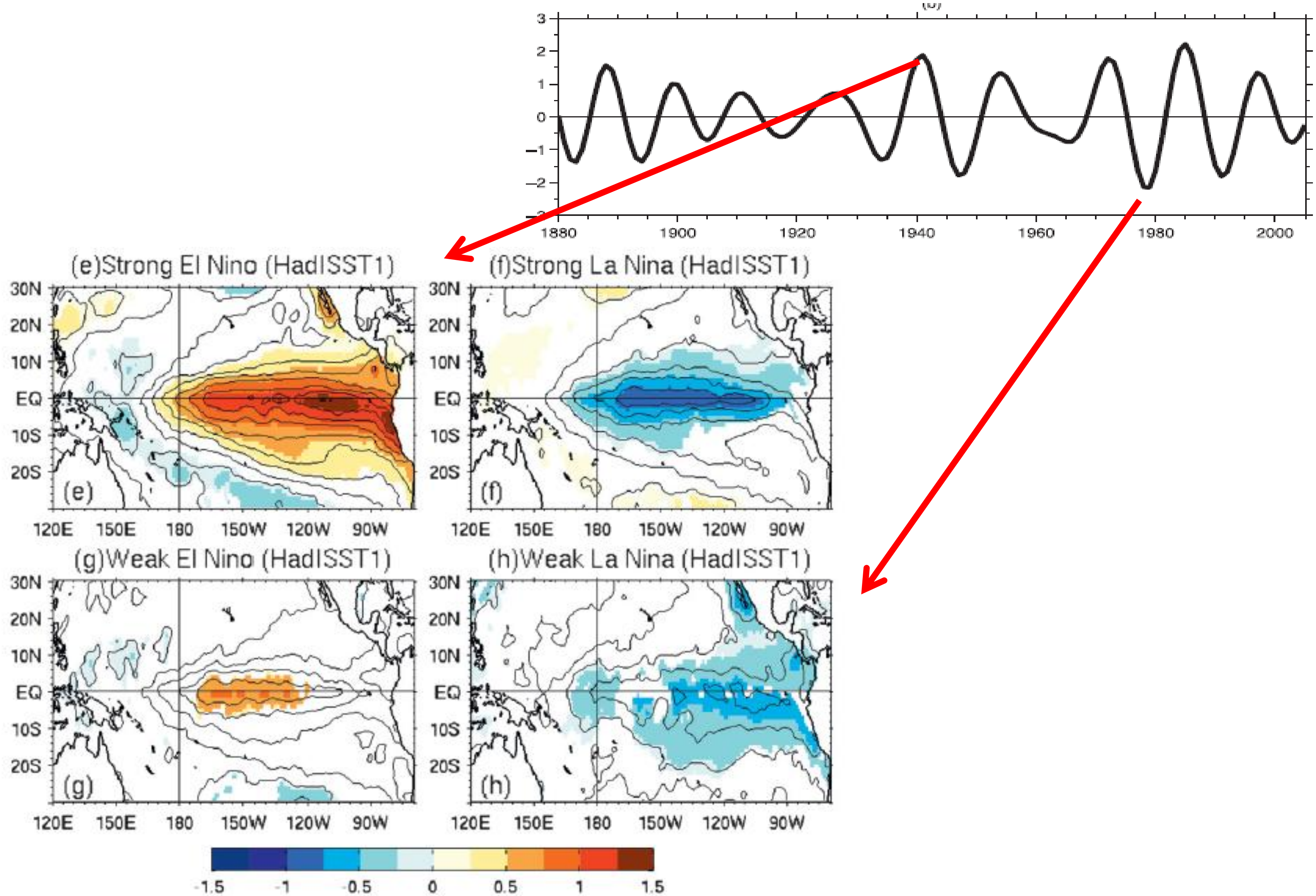
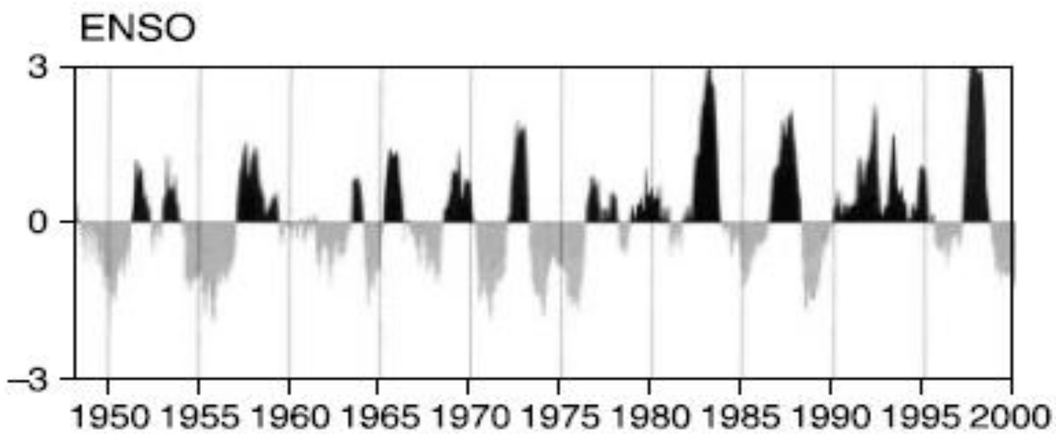


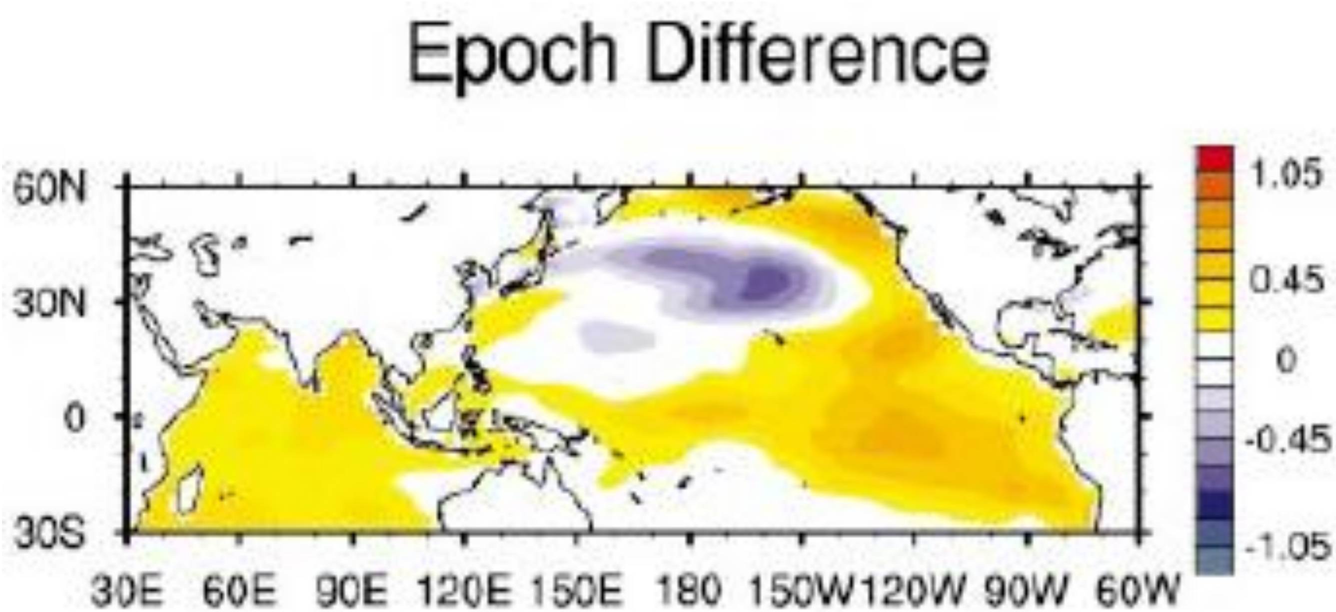
FIG. 3. Composite extended winter SST anomalies (ERSST.v2) for (a) El Niño and (b) La Niña events for the enhanced ENSO intensity periods. (c),(d) Same as (a) and (b) but for the weakened ENSO intensity periods. Contour interval (CI) is 0.2°C, and shading indicates 95% SL using a *t* test. (e)–(h) As in (a)–(d), but for HadISST1.

• ENSO (El Nino and Southern Oscillation)



- Tropical Mean state change
- Atmospheric forcing structural change
- Stochastic forcing
- Influence of mid-latitude forcing

• ENSO (El Nino and Southern Oscillation)



1977-97 minus 1947-76

Deser et al. (2004)

• ENSO (El Nino and Southern Oscillation)

5134 JOURNAL OF CLIMATE—SPECIAL SECTION VOLUME 19

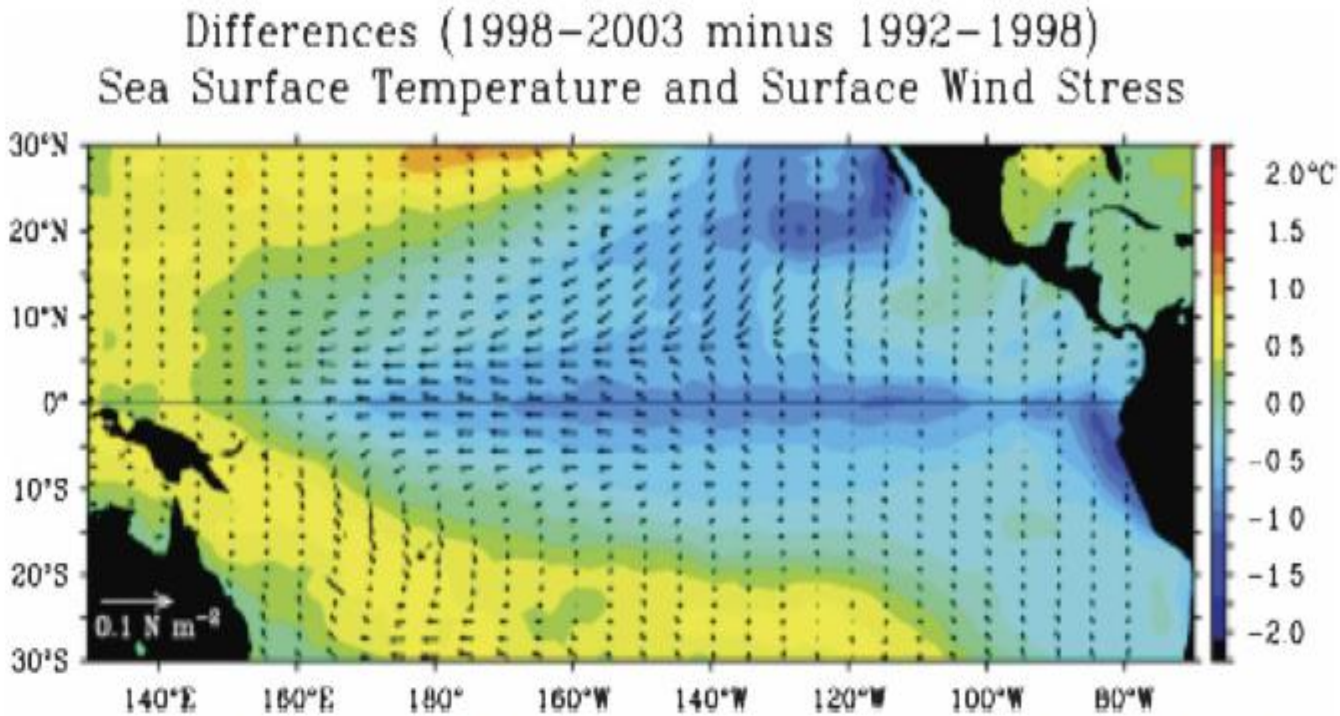
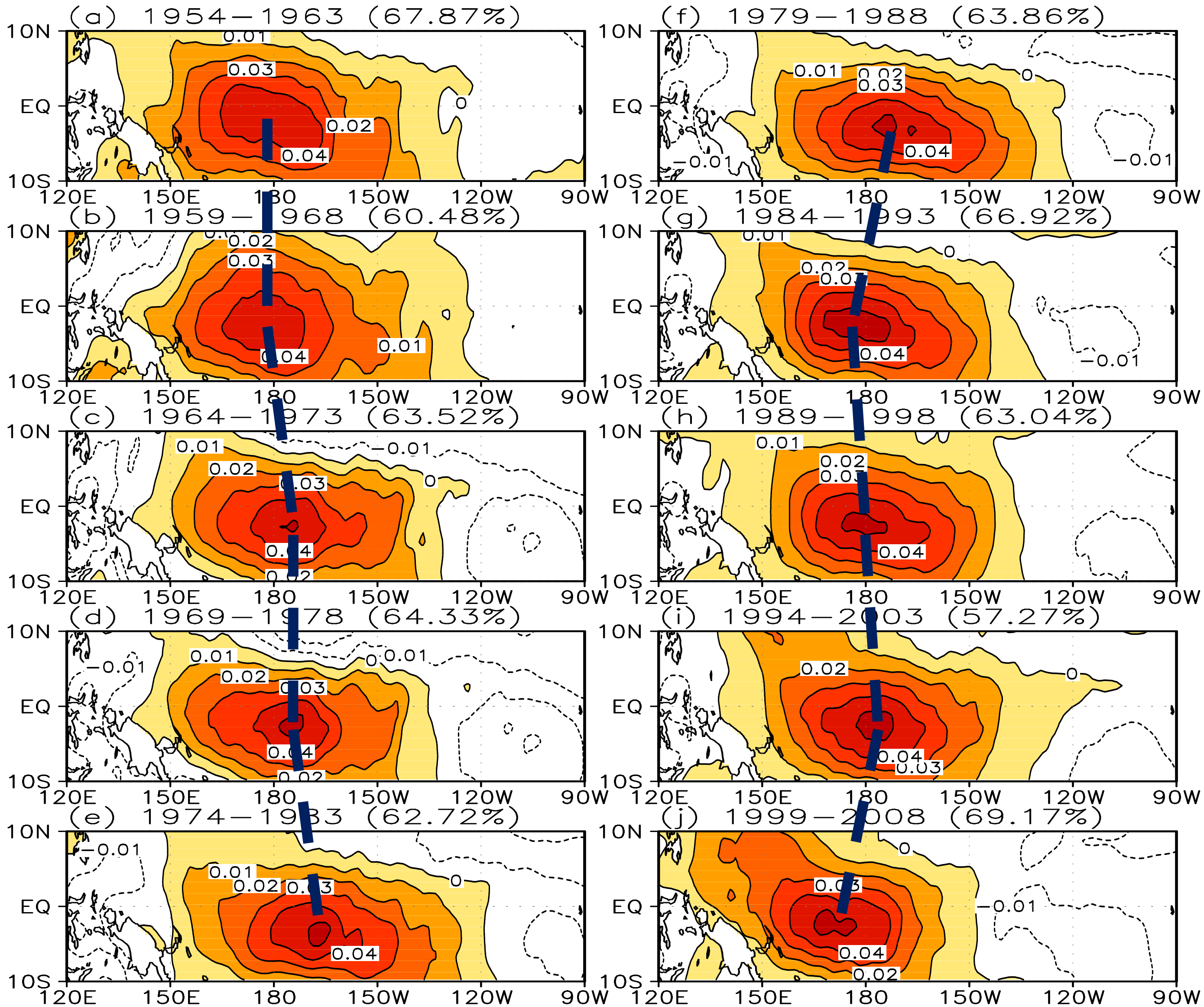


FIG. 5. Decadal differences in SST and winds in the tropical Pacific. (From McPhaden and Zhang 2004.)

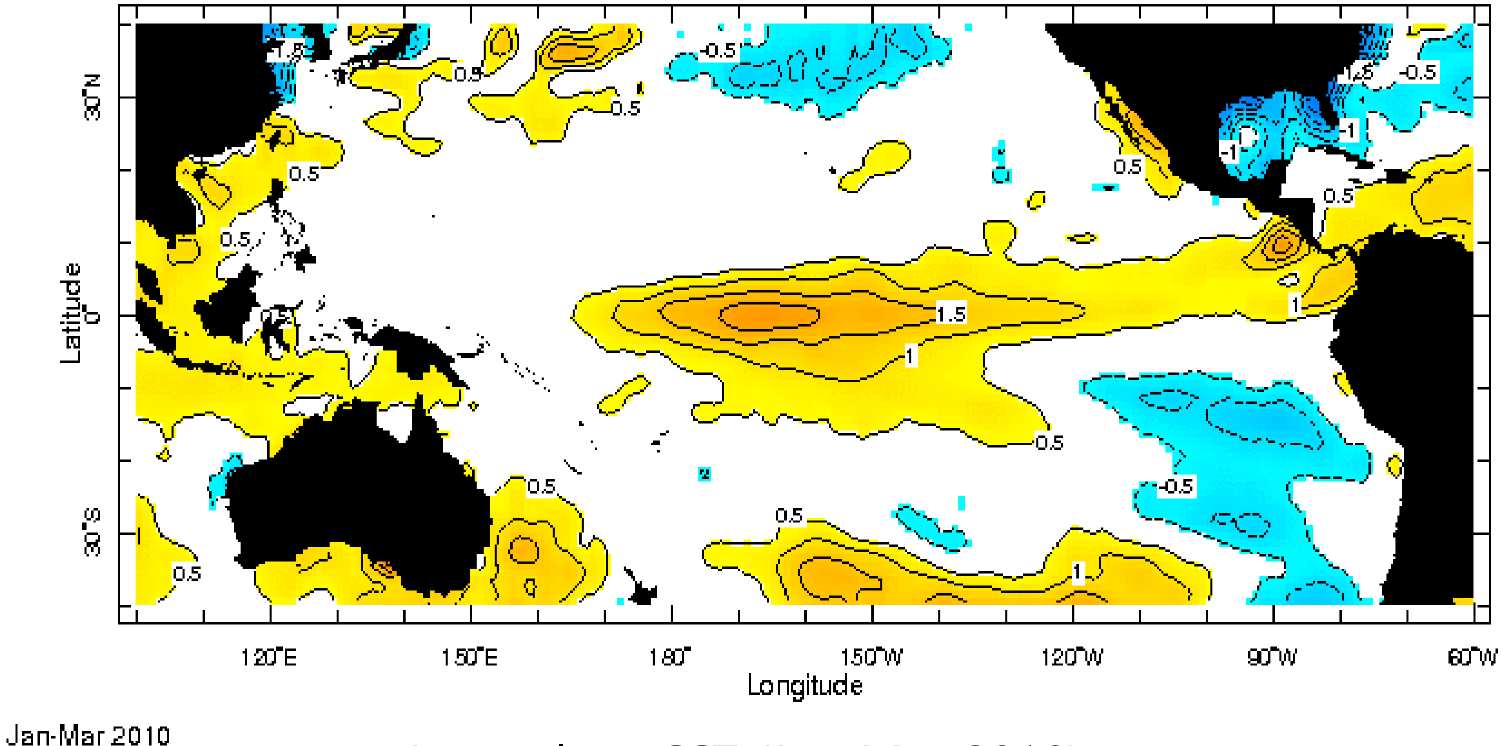
Chang et al. (2006)

• ENSO (El Nino and Southern Oscillation)



• ENSO (El Nino and Southern Oscillation)

:2009/10 El Nino

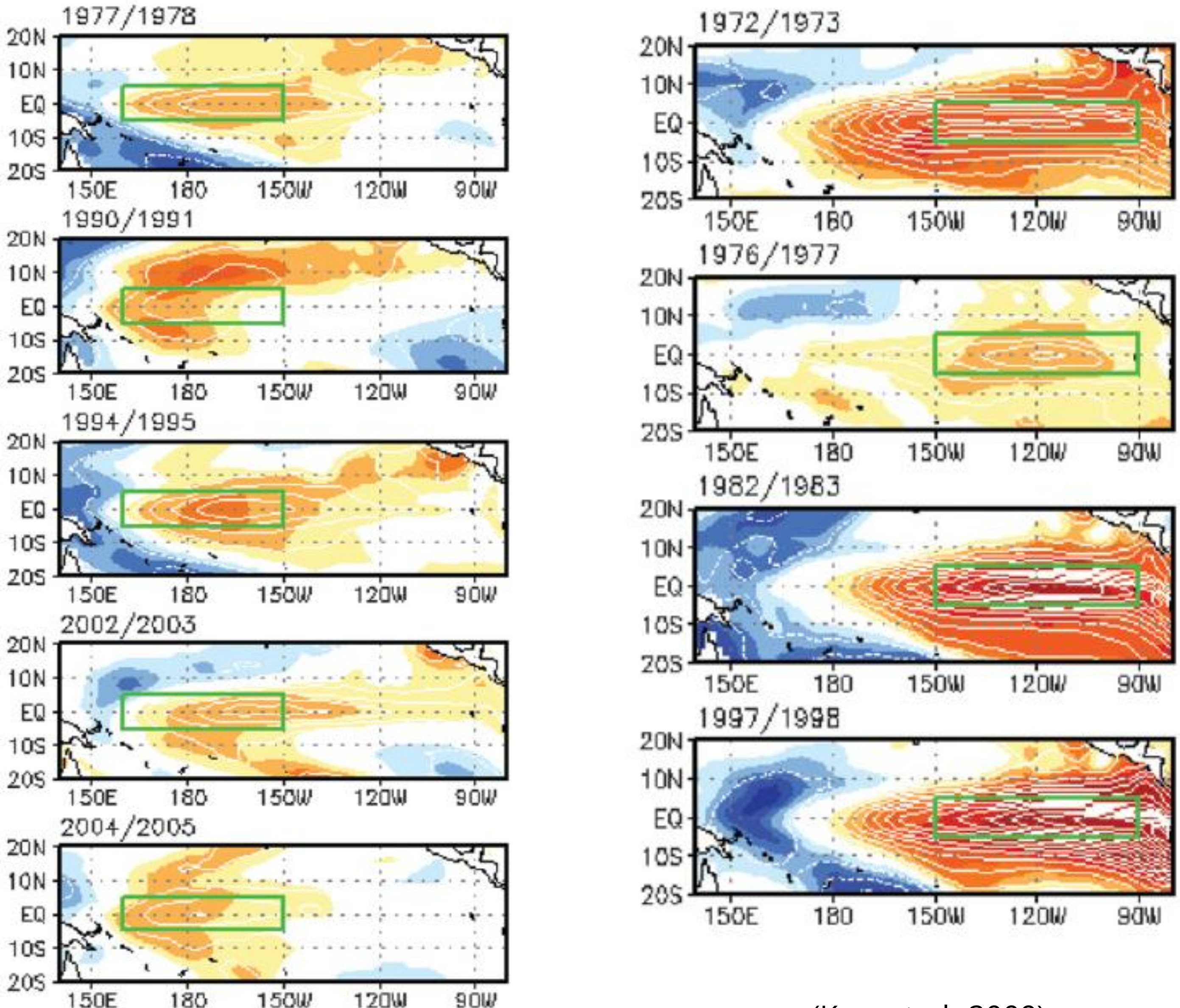


Anomalous SST (Jan-Mar 2010)

Base period: 1971-2000
Data source: NCEP, EMC

• ENSO (El Nino and Southern Oscillation)

:A different flavor of El Nino



(Kug et al. 2009)

• ENSO (El Nino and Southern Oscillation)

Supp. Table 1 The EP-El Niño and CP-El Niño years using the raw SST and detrended SST for each decade from 1854, respectively.

	Raw SST		Detrended SST	
	EP-El Niño years	CP-El Niño years	EP-El Niño years	CP-El Niño years
1850s				
1860s				
1870s	1876, 1877		1876, 1877	
1880s	1888		1888	
1890s	1896, 1899		1896, 1899	
1990s	1902,1904,1905		1902,1904,1905	
1910s	1911,1913,1914		1911,1913,1914,1918	
1920s	1925		1925	
1930s	1930, 1939		1930, 1939	
1940s	1940,1941		1940,1941	
1950s	1951,1957		1951,1957	
1960s	1963,1965,1969	1968	1963,1965,1969	1968
1970s	1972,1976,1979	1977	1972,1976,1979	1977
1980s	1982,1986,1987		1982,1986,1987	
1990s	1991,1997	1990,1992,1994	1991,1997	1990, 1994
2000s	2002,2003,2006	2001,2004	2003,2006	2001,2002,2004

: EP El Nino: Conventional El Nino

: CP El Nino:
A different flavor of El Nino

December-January-February (DJF)

NINO4 SST index > 0.5°C or

NINO3 SST index > 0.5°C

Central Pacific El Nino: CP-El Nino:

NINO4 SST index > NINO3 SST index

Eastern Pacific El Nino: EP-El Nino:

NINO3 SST index > NINO4 SST index

• ENSO (El Nino and Southern Oscillation)

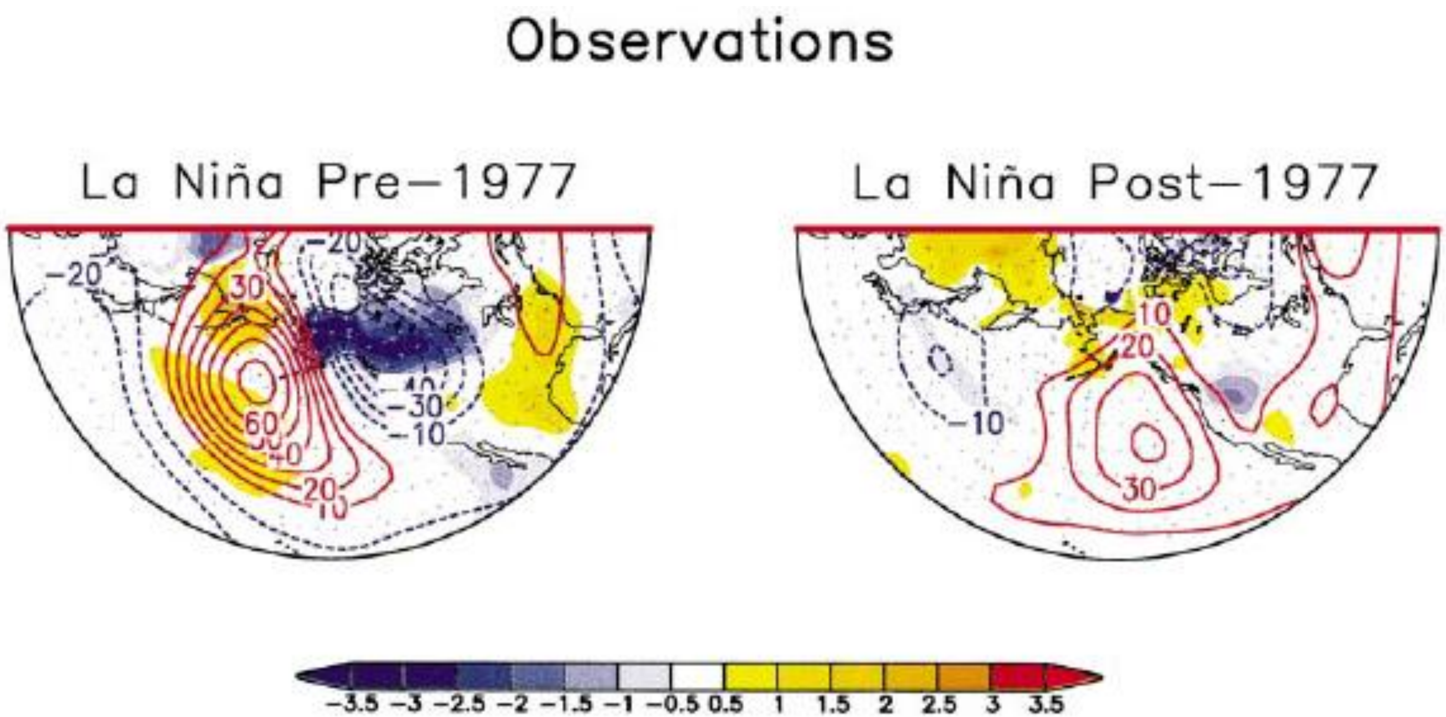
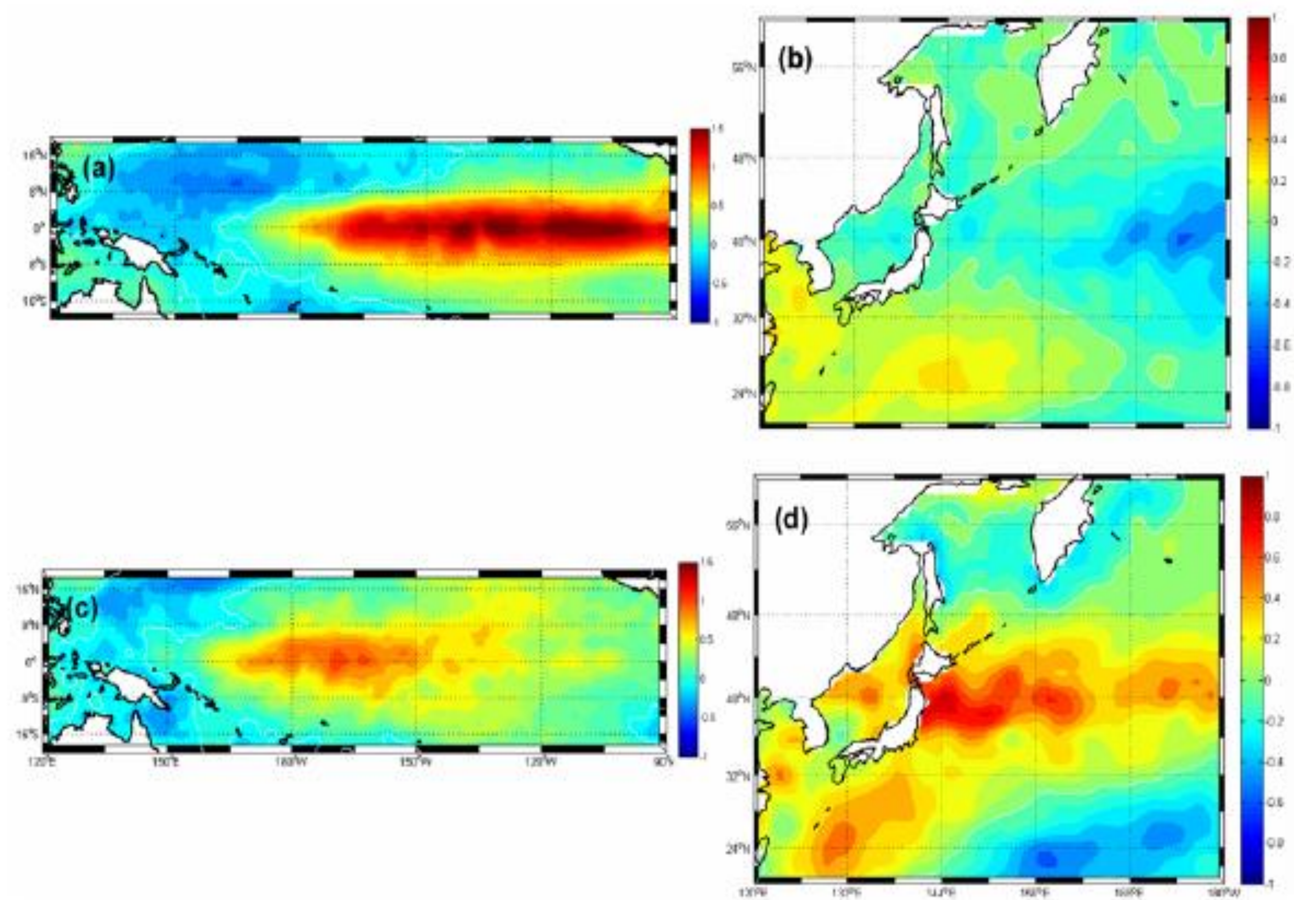


Plate 7. Composite DJF anomalies of 500-hPa height anomalies (contours) and surface temperature anomalies (shading) for La Niña events occurring before 1977 during the warm/positive phase of the PDO (left panels), and for La Niña events occurring after 1976 during the cold/negative phase of the PDO (right panel). Top panels are derived from observation, and bottom panels are derived from the nine-member ensemble of MRF9 climate simulations that have been forced with tropical Pacific SST anomalies only. Anomalies have been calculated relative to the 1950–1994 climatologies for the observations and the GCM, respectively

• ENSO (El Nino and Southern Oscillation)



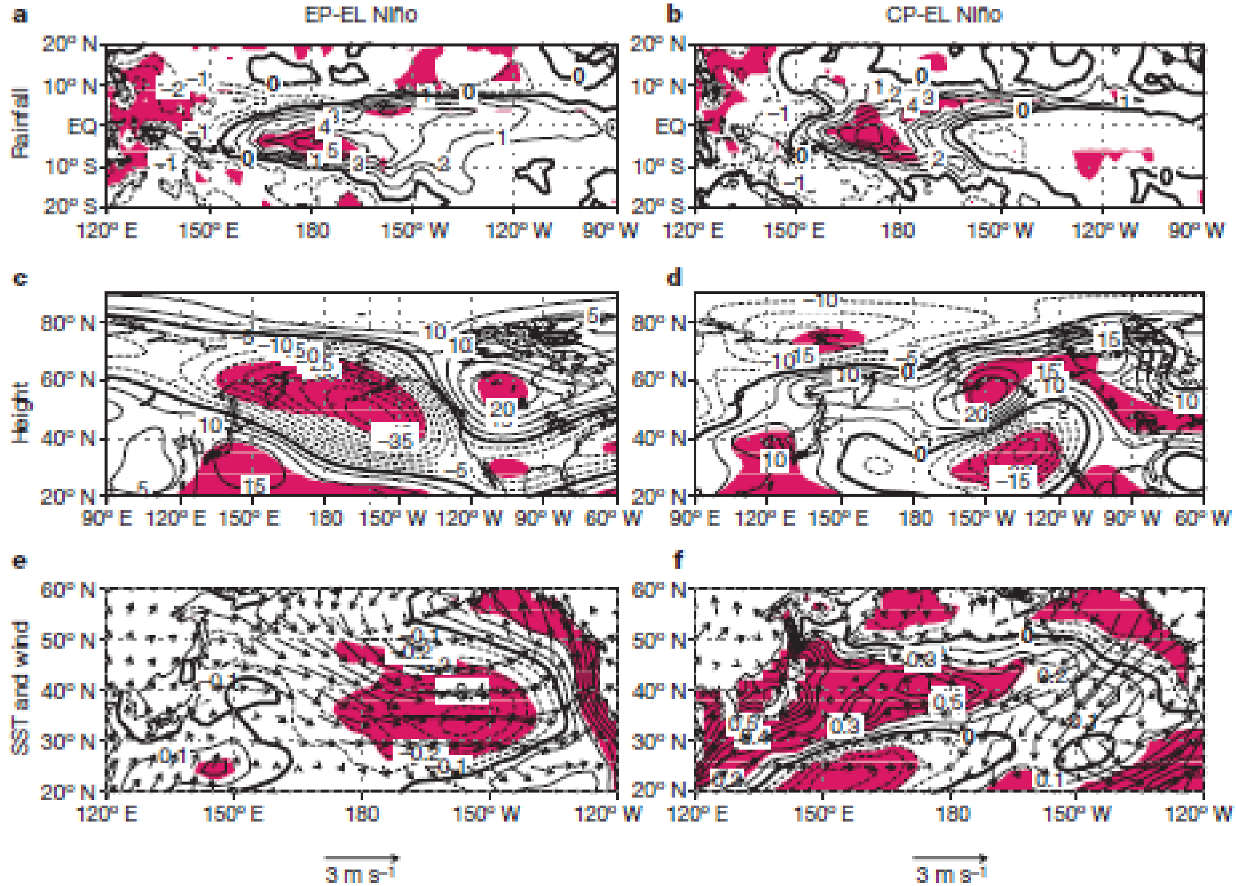


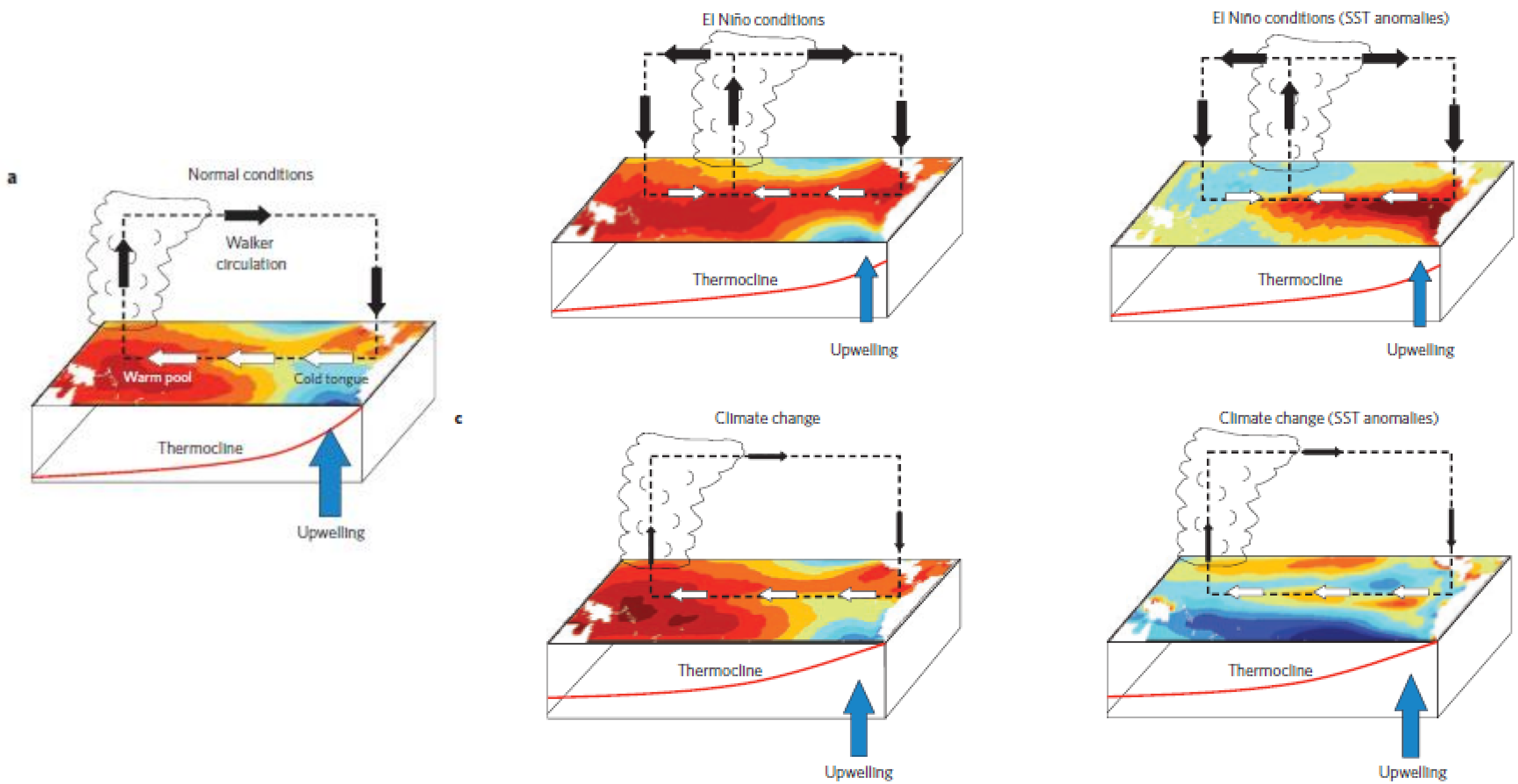
Figure 2 | Deviations for the two characteristics of El Niño from their climatology. **a**, **b**, The deviation of mean rainfall for the EP-El Niño (**a**) and the CP-El Niño (**b**). The contour interval is 1 mm per day. **c**, **d**, Mean geopotential height at 500 hPa. The contour interval is 5 m. **e**, **f**, Mean winds at 925 hPa (arrows, see scale arrow below) and mean SST (line). The solid (dotted) line denotes positive (negative) deviations from the mean. The contour interval is 0.1 °C. Shading in all panels indicates the region exceeding 95% significance based on a *t*-test and the zero line is denoted by the thick line. The climatology periods are 1979–2006 (for rainfall), 1950–2006 (for geopotential height and winds) and 1854–2006 (for SST), respectively.

•ENSO and global warming •

nature geoscience
REVIEW ARTICLE
PUBLISHED ONLINE: XX JUNE 2010 | DOI: 10.1038/NGEO868

The impact of global warming on the tropical Pacific Ocean and El Niño

Prepared on behalf of the CLIVAR Pacific Panel



Science

AAAS

Twentieth-Century Sea Surface Temperature Trends

Mark A. Cane, *et al.*

Science **275**, 957 (1997);
DOI: 10.1126/science.275.5302.957

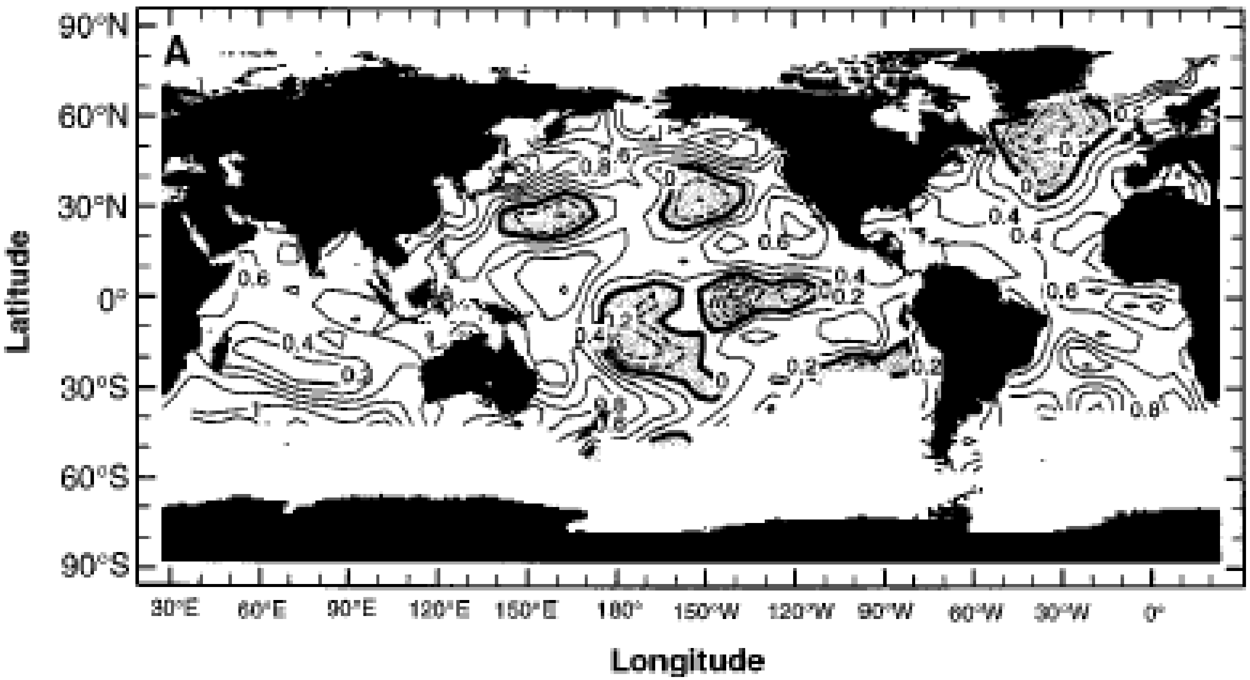
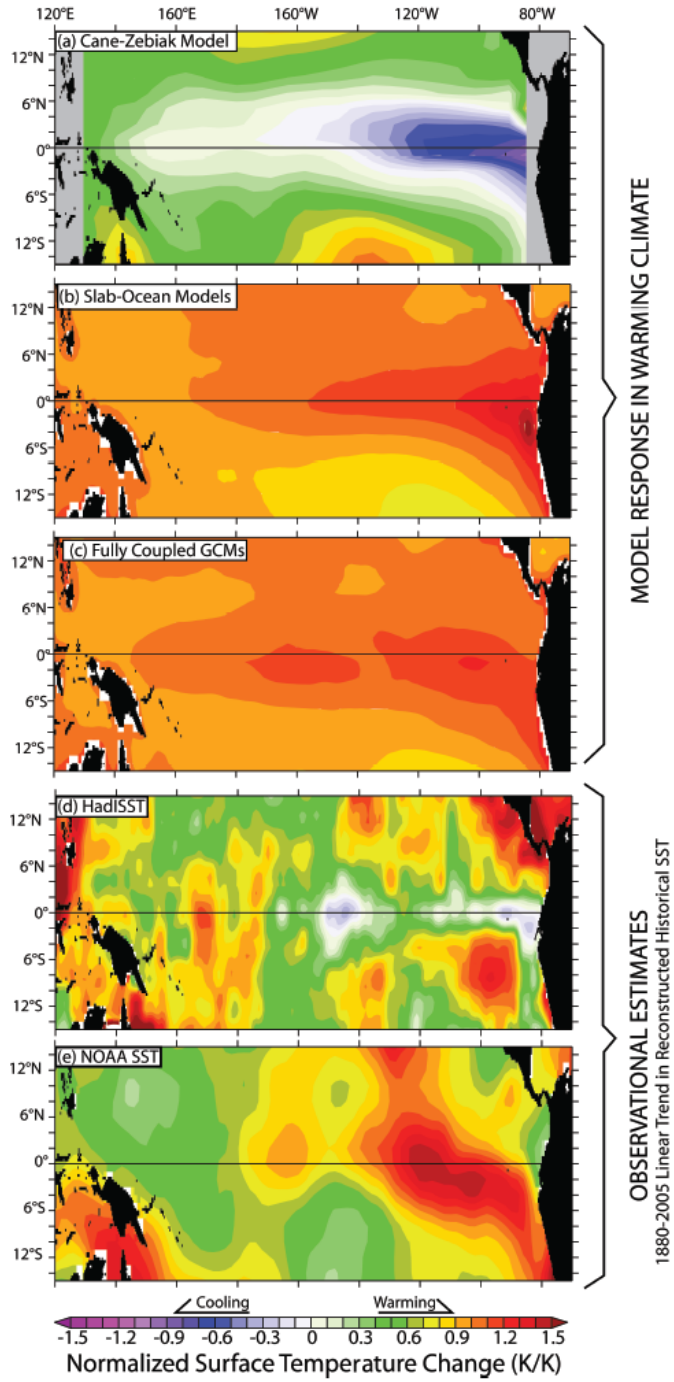


Fig. 3. (**A**) The trend in monthly mean SST anomalies for 1900 to 1991 in degrees Celsius per century. The SST fields are from an optimal smoother analysis (*21*). (**B**) As in (A), except that the influence of the large number of ENSO warm events at the end of the record was screened out before the trend was calculated. This was done by removing the ENSO mode, defined as the leading empirical orthogonal function of the variability in the 2- to 7-year band. The projection of this pattern onto the data was subtracted from the record, and the trend in the remainder was computed.



120°E
160°E
160°W
120°W
80°W
12°N
6°N
0°
6°S
12°S
(a) Cane-Zebiak Model
(b) Slab-Ocean Models
(c) Fully Coupled GCMs
(d) HadISST
(e) NOAA SST
MODEL RESPONSE IN WARMING CLIMATE
OBSERVATIONAL ESTIMATES
1880-2005 Linear Trend in Reconstructed Historical SST
Cooling
Warming
-1.5 -1.2 -0.9 -0.6 -0.3 0 0.3 0.6 0.9 1.2 1.5
Normalized Surface Temperature Change (K/K)

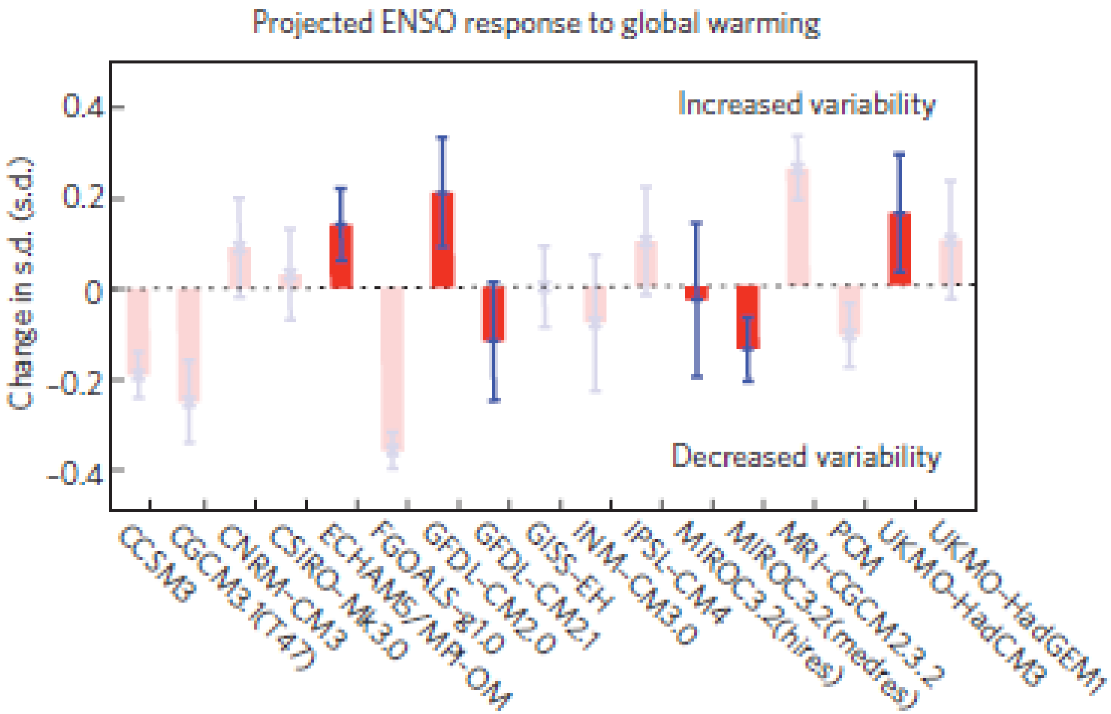


Figure 3 | Changes in the amplitude of ENSO variability from the CMIP3 models[8,9]. The measure is derived from the interannual standard deviation (s.d.) of a mean sea-level-pressure index, which is related to the strength of the Southern Oscillation variations. Positive changes indicate a strengthening of ENSO, and negative changes indicate a weakening. Statistical significance is assessed by the size of the blue bars, and the bars indicated in bold colours are from those CMIP3 CGCMs that are judged to have the best simulation of present-day ENSO characteristics and feedbacks.

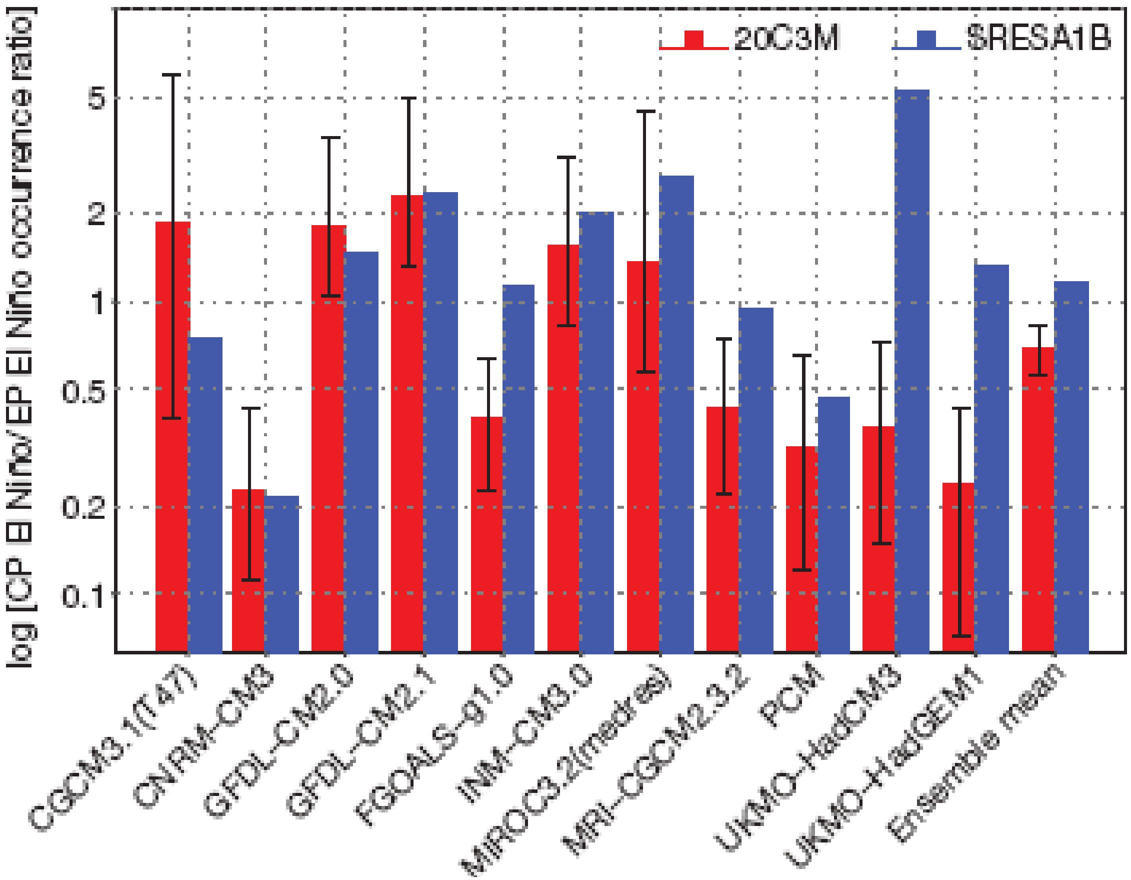
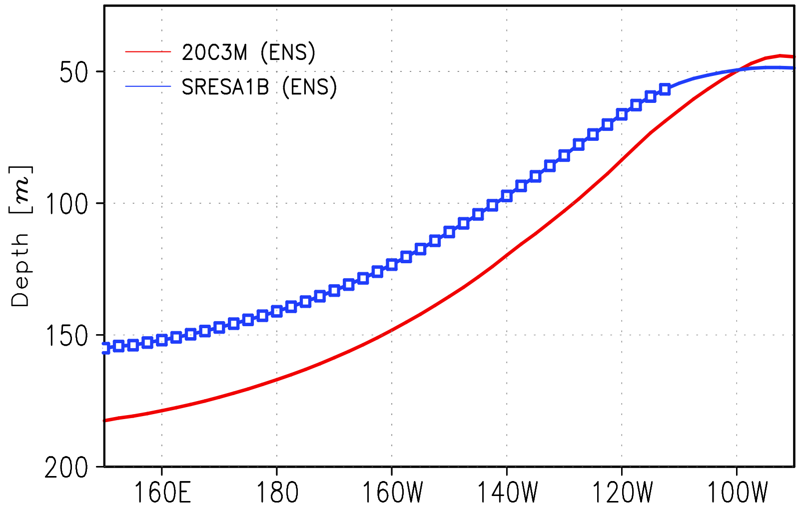


Figure 3 | The CP-El Niño/EP-El Niño occurrence ratio. Red bars, the 20C3M run; blue bars, the SRESA1B run. The vertical error bars denote the upper and lower limits associated with an increase and decrease of the CP-El Niño/EP-El Niño occurrence ratio at the 95% confidence level in the 20C3M run, respectively, based on a bootstrap method. Therefore, there is a significant increase (decrease) of the ratio of the CP-El Niño to the EP-El Niño from the 20C3M run to the SRESA1B run when the blue bar is above (below) the upper (lower) limit of the vertical segment. The *y*-axis scale is a common logarithmic scale.

20C3M: 20th century climate change simulation

SRESA1B: The climate change run following the SRESA1B scenario

- Mechanism



Zonal advective feedback process

Thermocline feedback process

$$\frac{\partial T'}{\partial t} \approx -u'\frac{\partial \overline{T}}{\partial x} - \overline{\omega}\frac{\partial T'}{\partial z}$$

- Thermocline depth flattening ~ reduces upwelling ~ reduce thermocline feedback process

- Vertical displacement of thermocline depth in the central Pacific

•ENSO and Warm pool •

Increase of warm pool SST

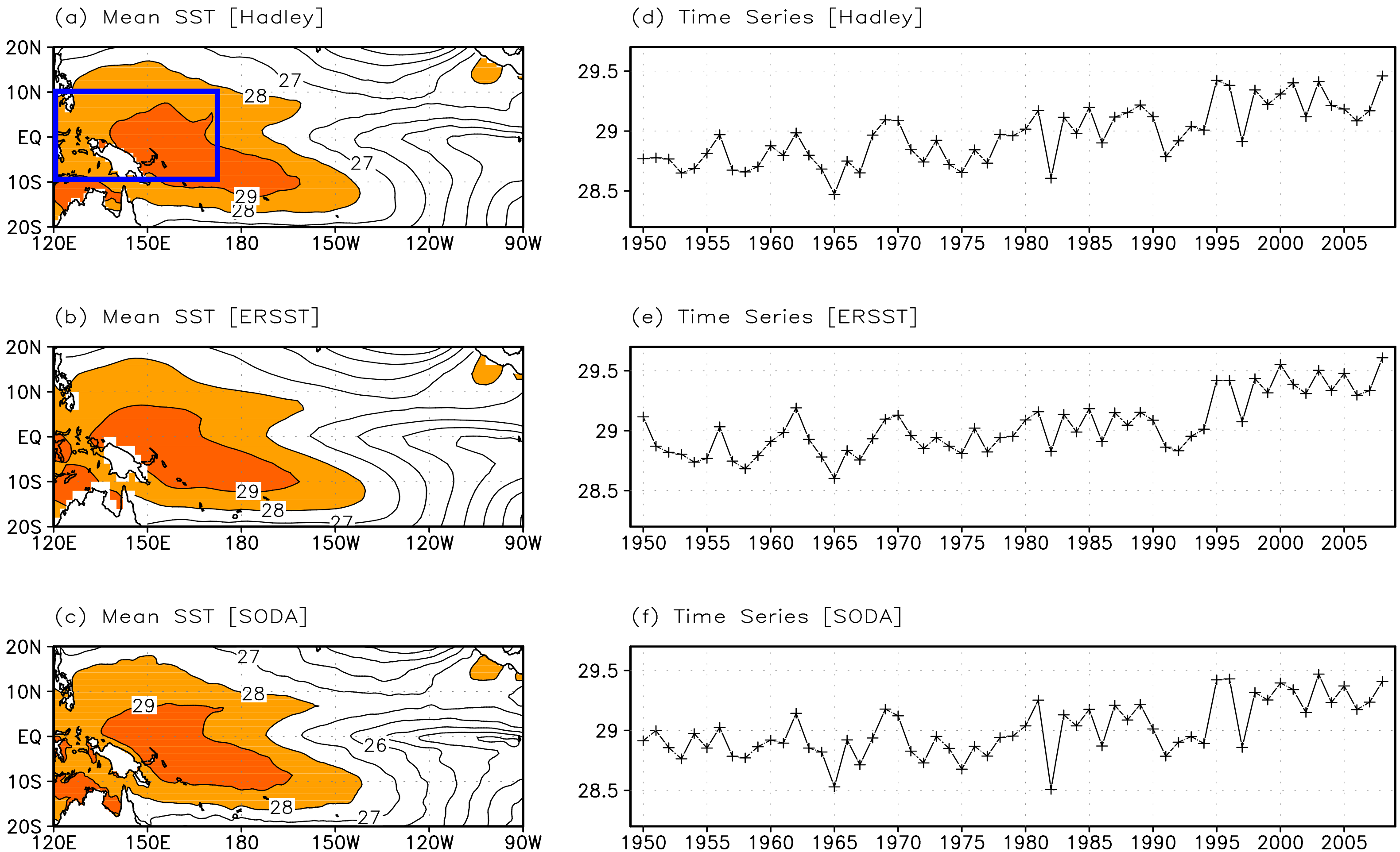
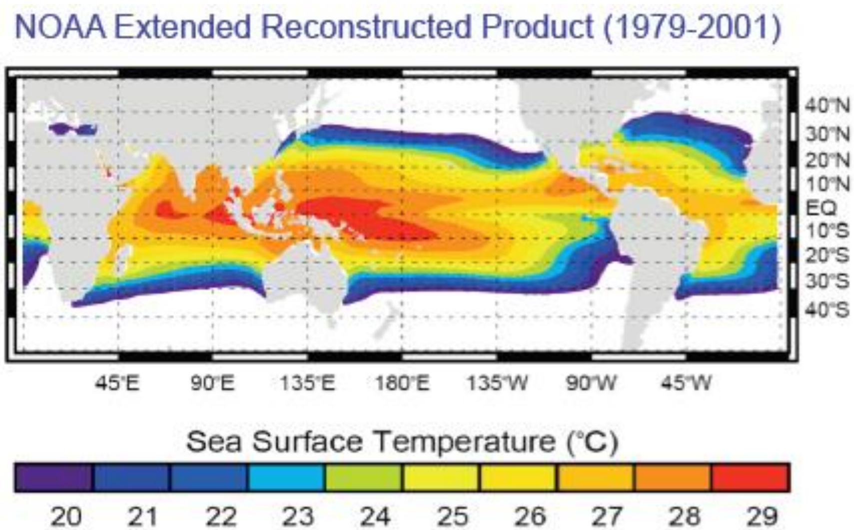


Figure 1. The climatological winter (Oct.-Feb.) mean SST in the tropical Pacific of (a) Hadley SST, (b) ERSST, (c) SODA, the time series of warm pool SST averaged in the region [120E-170E, 10S-10N] of (d) Hadley SST, (e) ERSST, and (f) SODA for the period of 1950-2008.



Warm pool corresponds to the area of the ocean where SSTs>28C

Warm pool defines the location and magnitude of the "boiler box" of the heat engine of the earth (e.g., Pierrehumber 1995).

Local impact

- Deep convection
- Tropical cyclogenesis region

Remote impact

- Modulation of Hadley and Walker cells
- Modulation of Monsoon circulation
- Modulation of ENSO and related teleconnections

Impact of warm pool

• Increase of warm pool SST is able to change the ocean current connecting the western tropical Pacific and the eastern tropical Pacific Ocean by changing surface winds

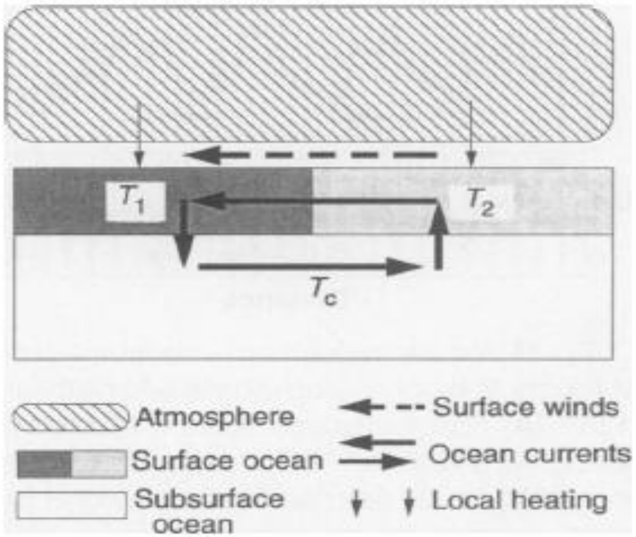


Fig. 1. A schematic diagram for the coupled model. The east-west surface current is the frictional flow driven by the east-west surface winds, and the return flow may be largely considered as the equatorial undercurrent. The east-west surface winds also drive a meridional cell that connects the equatorial subsurface ocean to the extratropical ocean (*11*).

(Sun and Liu, 1996)

Impact of warm pool

- Changes in the warm pool SST on the low frequency timescales may determine the tropical Pacific mean state toward "El Nino-like" or "La Nina-like".

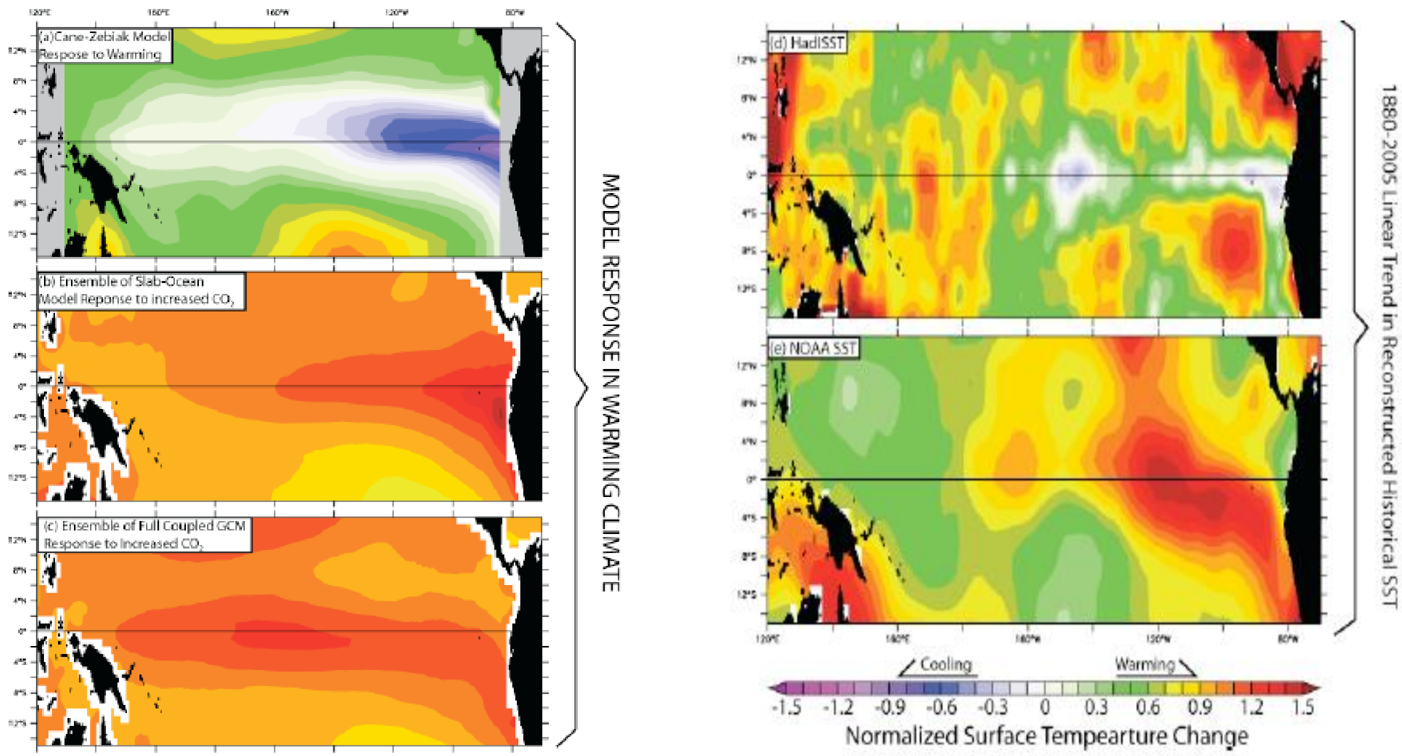
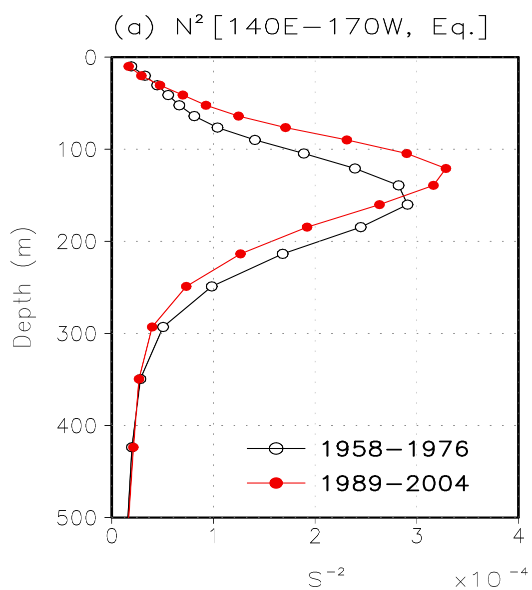


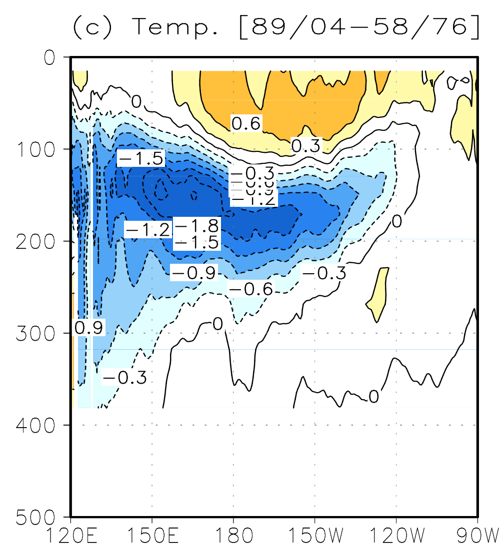
Figure 1

(Vecchi et al. 2009)

Impact of warm pool

- Increase of warm pool SST may change stratification in the warm pool region, which influence the momentum flux projecting into the ocean, resulting in changes in the oceanic baroclinic variability.



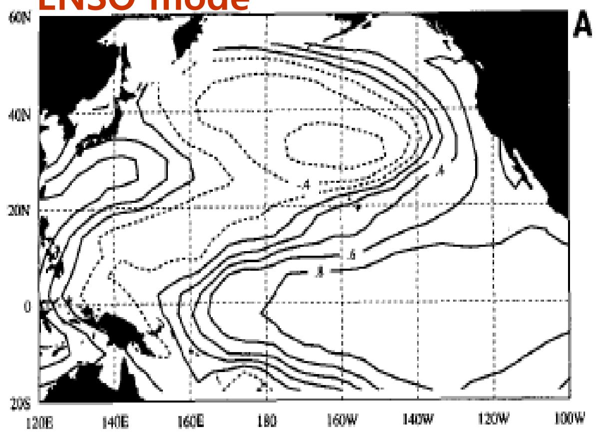


NOTES AND CORRESPONDENCE

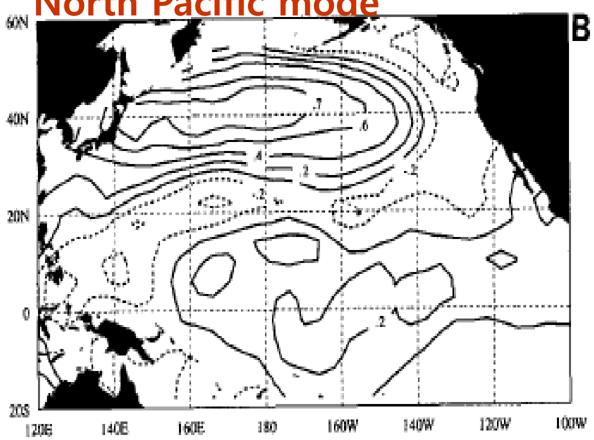
On the Relationship between Tropical and North Pacific Sea Surface Temperature Variations

Deser and Blackmon (1995, Journal of Climate)

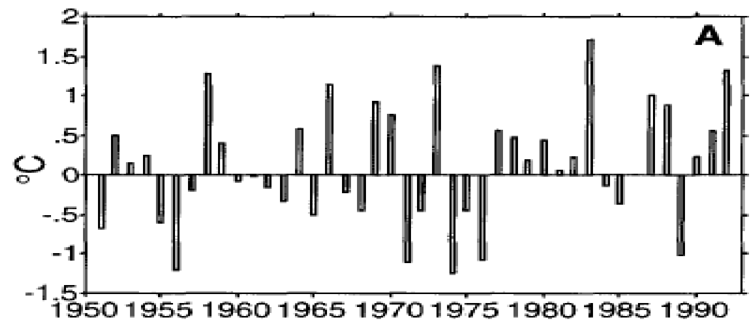
ENSO mode

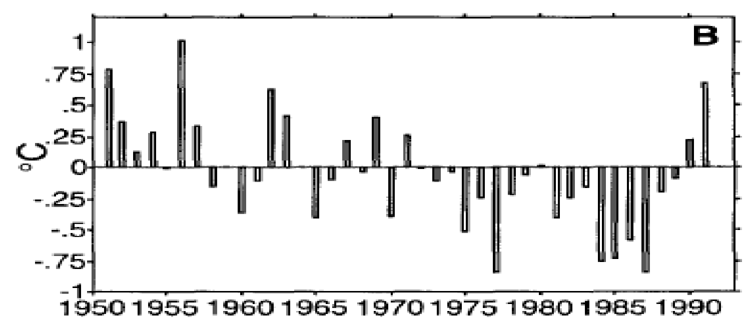


North Pacific mode



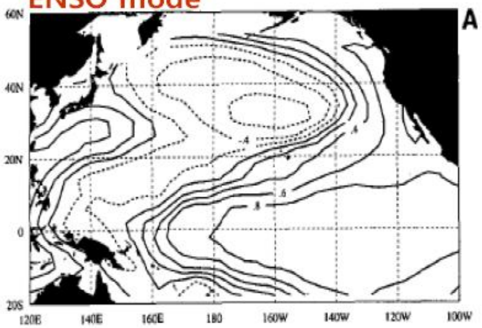
- 1950/51-1991/92, Winter (Nov.-Mar.)
- COADS data

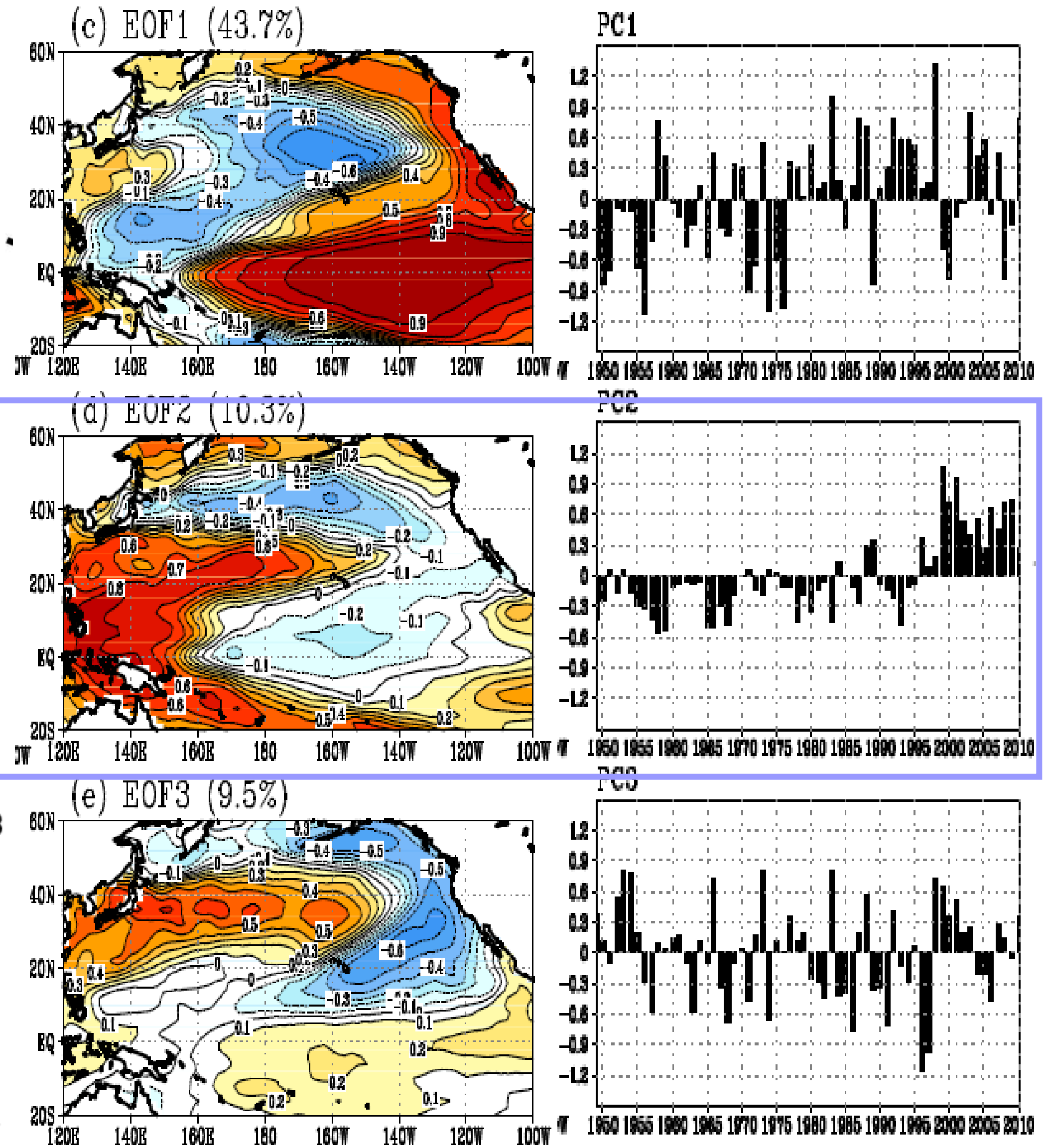




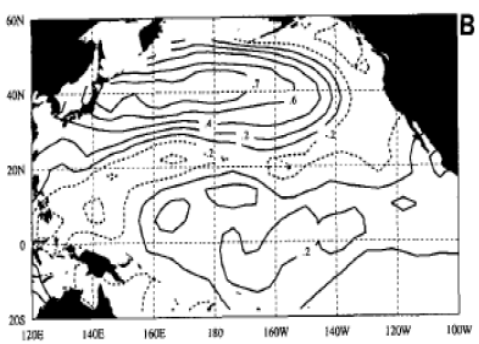
- 1949/50-2009/10, Winter (Nov.-Mar), ERSST

ENSO mode



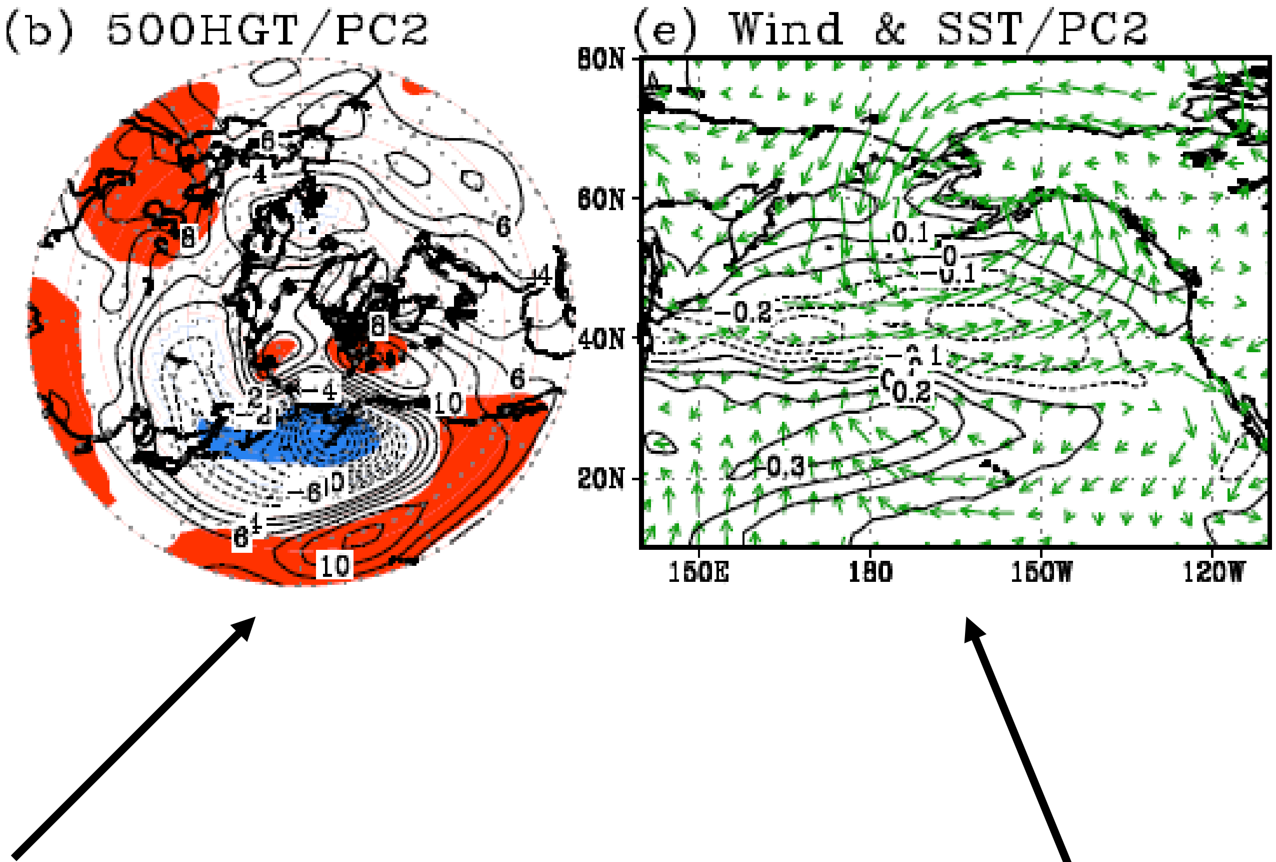


ENSO mode



North Pacific mode

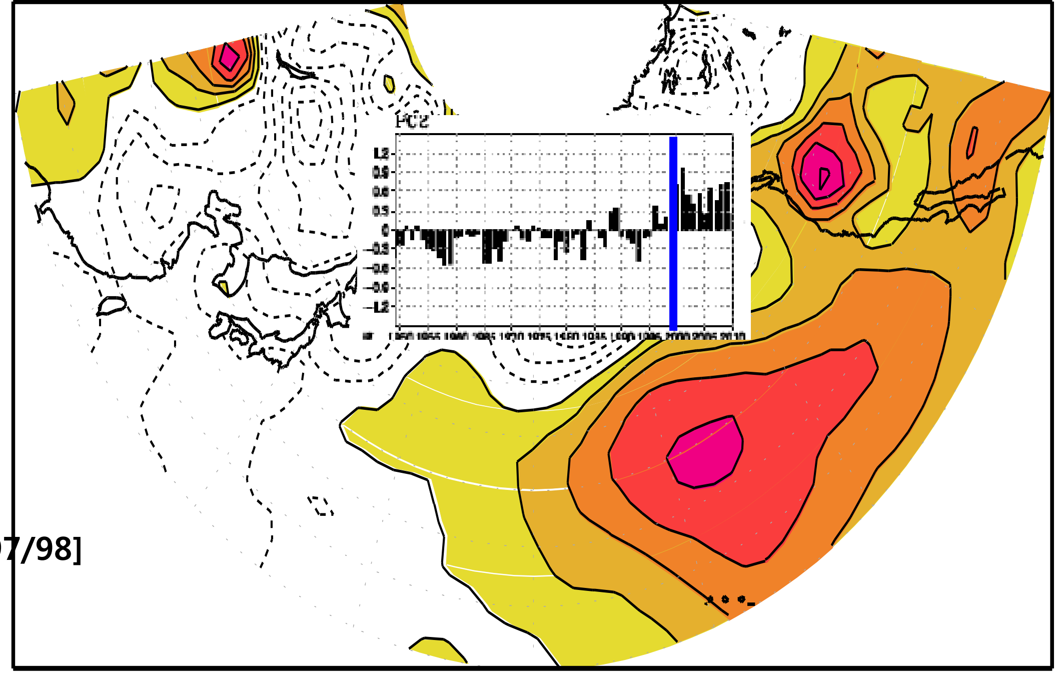
North Pacific mode



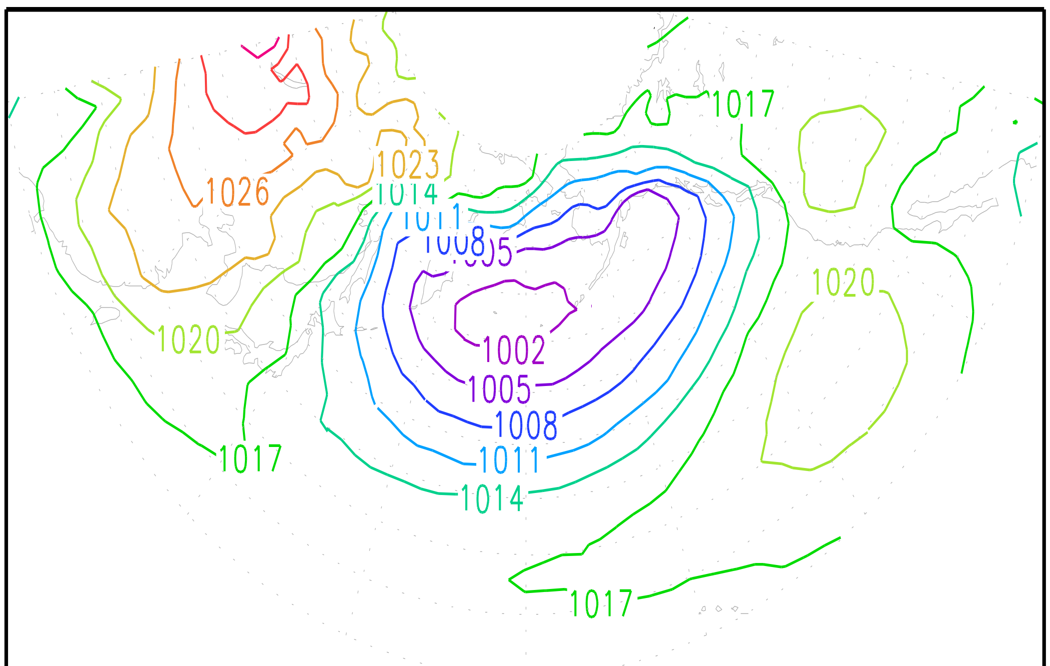
North Pacific Oscillation(NPO)-like atmospheric circulation

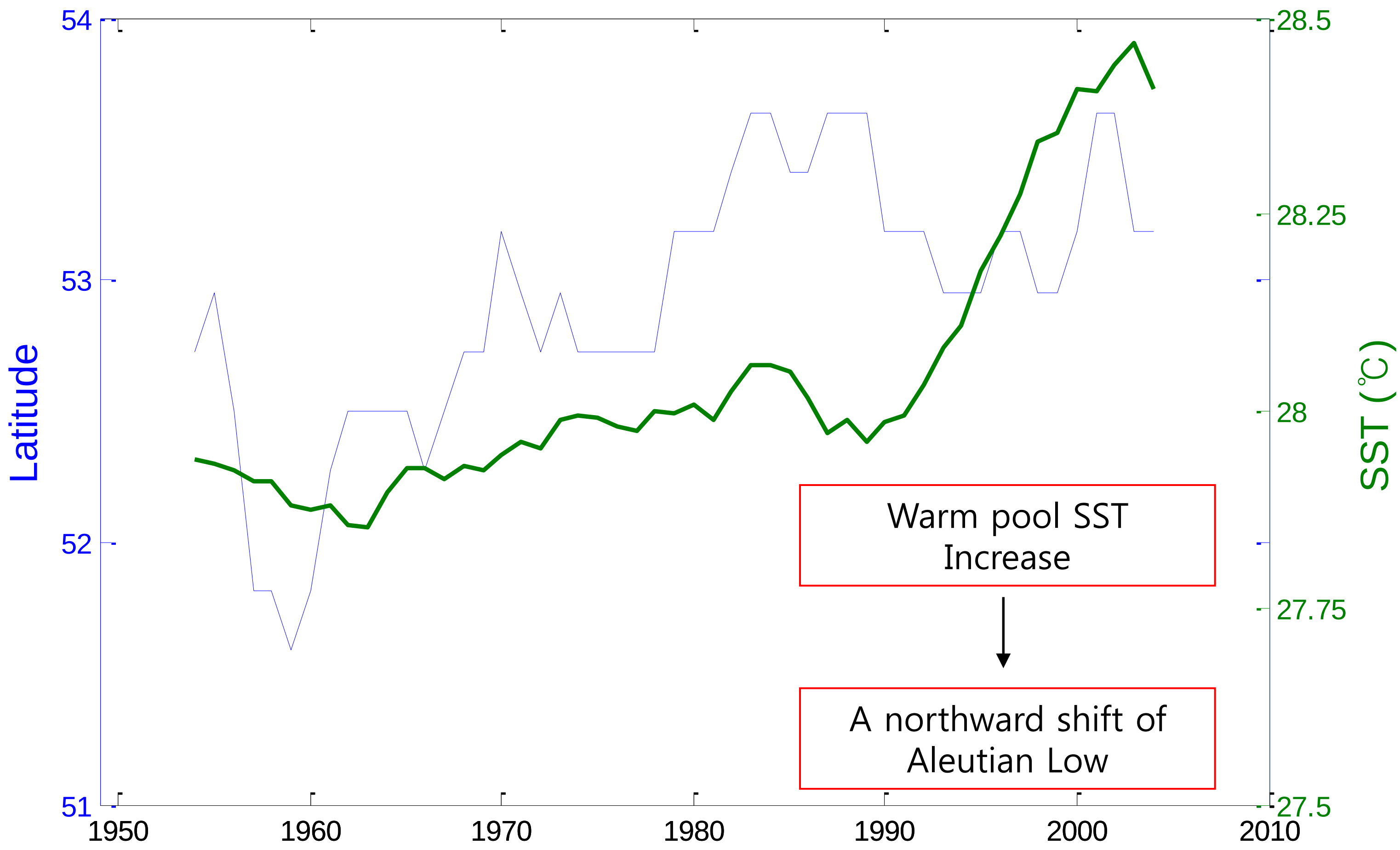
North Pacific Gyre Oscillation-like SST anomalies

M SLP Difference
/99-2009/10 minus 1949/50-1997/98]



NCEP Climatological SLP





Latitude
SST (℃)
54
53
52
51
28.5
28.25
28
27.75
27.5
1950
1960
1970
1980
1990
2000
2010
Warm pool SST Increase
A northward shift of Aleutian Low

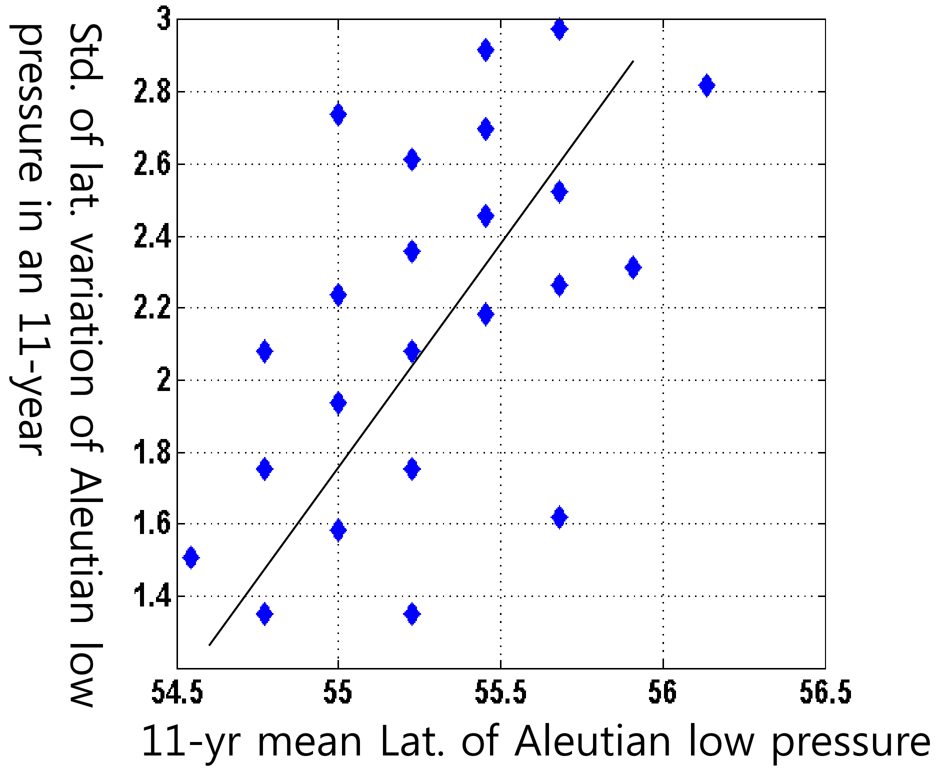
A northward shift of Aleutian Low

↓

An enhanced meridional variability of Aleutian Low

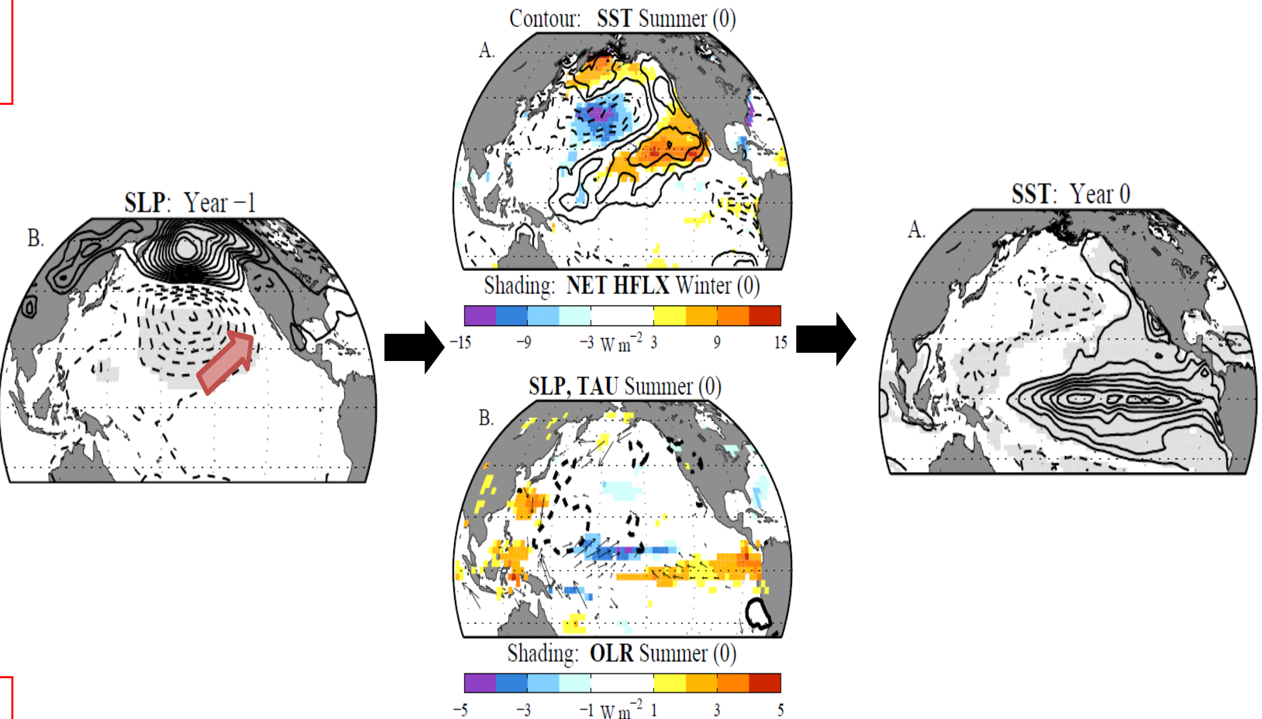
↓

Modification of NPO variability



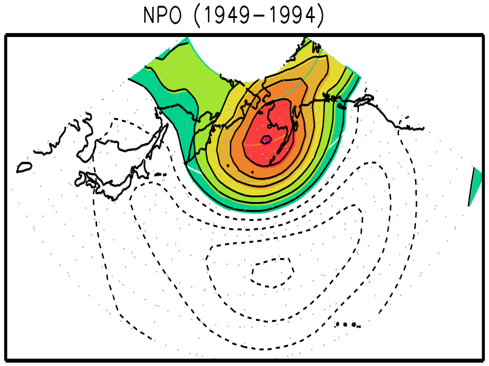
Modification of NPO variability

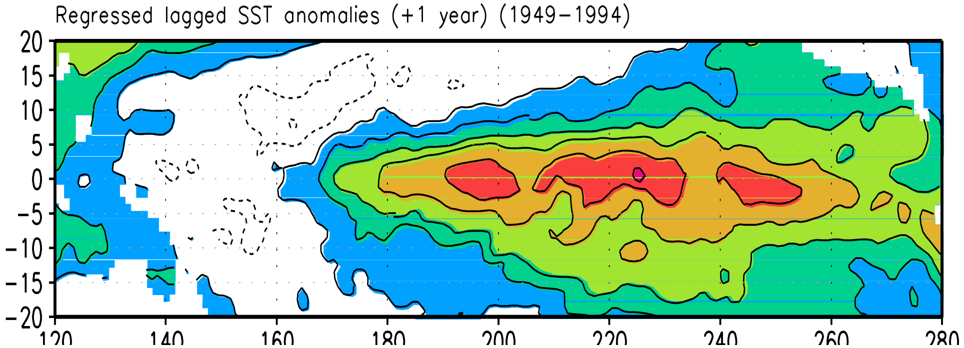
Modification of ENSO characteristics



Seasonal Footprint Mechanism
(Vimont et al. 2002)

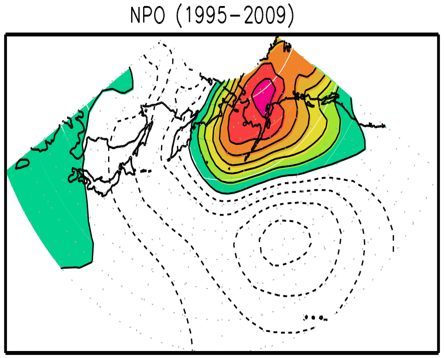
NPO structure (1949-1994)

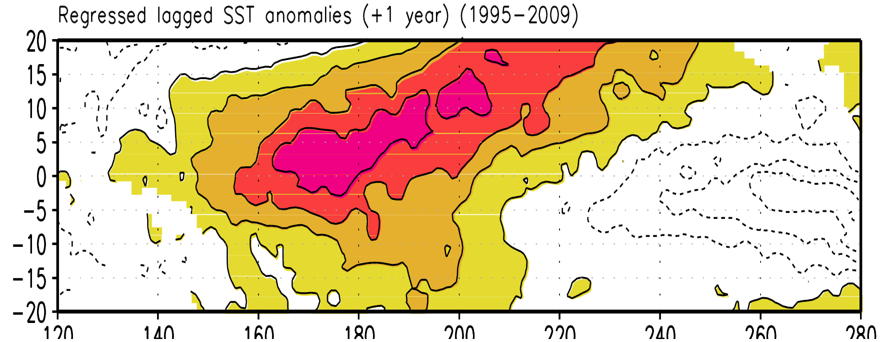




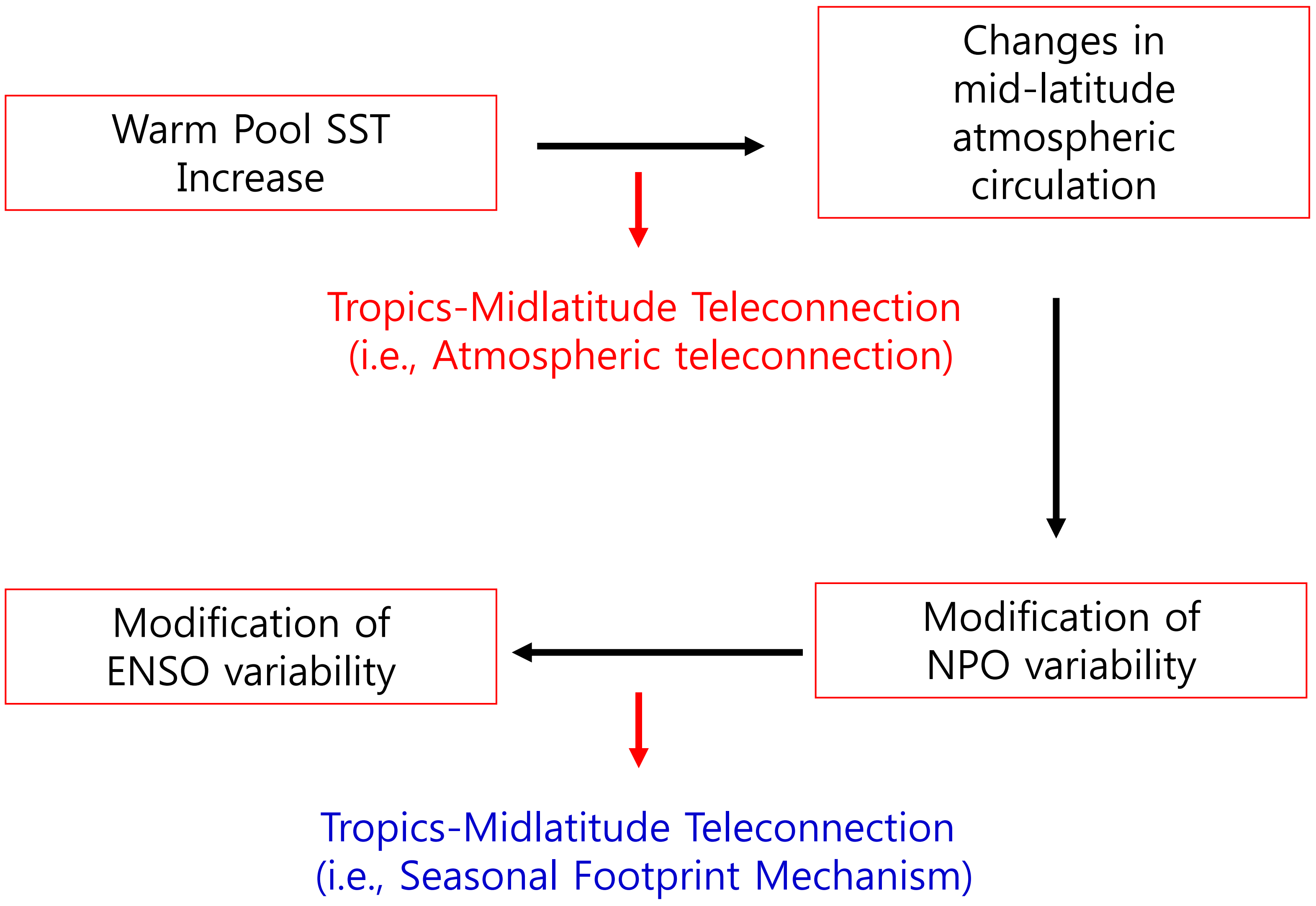
+1 year lagged regressed SST anomalies with NPO PC (1949-1994)

NPO structure (1995-2009)





+1 year lagged regressed SST anomalies with NPO PC (1995-2009)


Warm Pool SST Increase
Changes in mid-latitude atmospheric circulation
Tropics-Midlatitude Teleconnection
(i.e., Atmospheric teleconnection)
Modification of NPO variability
Modification of ENSO variability
Tropics-Midlatitude Teleconnection
(i.e., Seasonal Footprint Mechanism)

Thank you for your attention

• ENSO (El Nino and Southern Oscillation)