ENSO MODOKI (Pseudo-ENSO) AND ITS IMPACT ON THE WORLD CLIMATE

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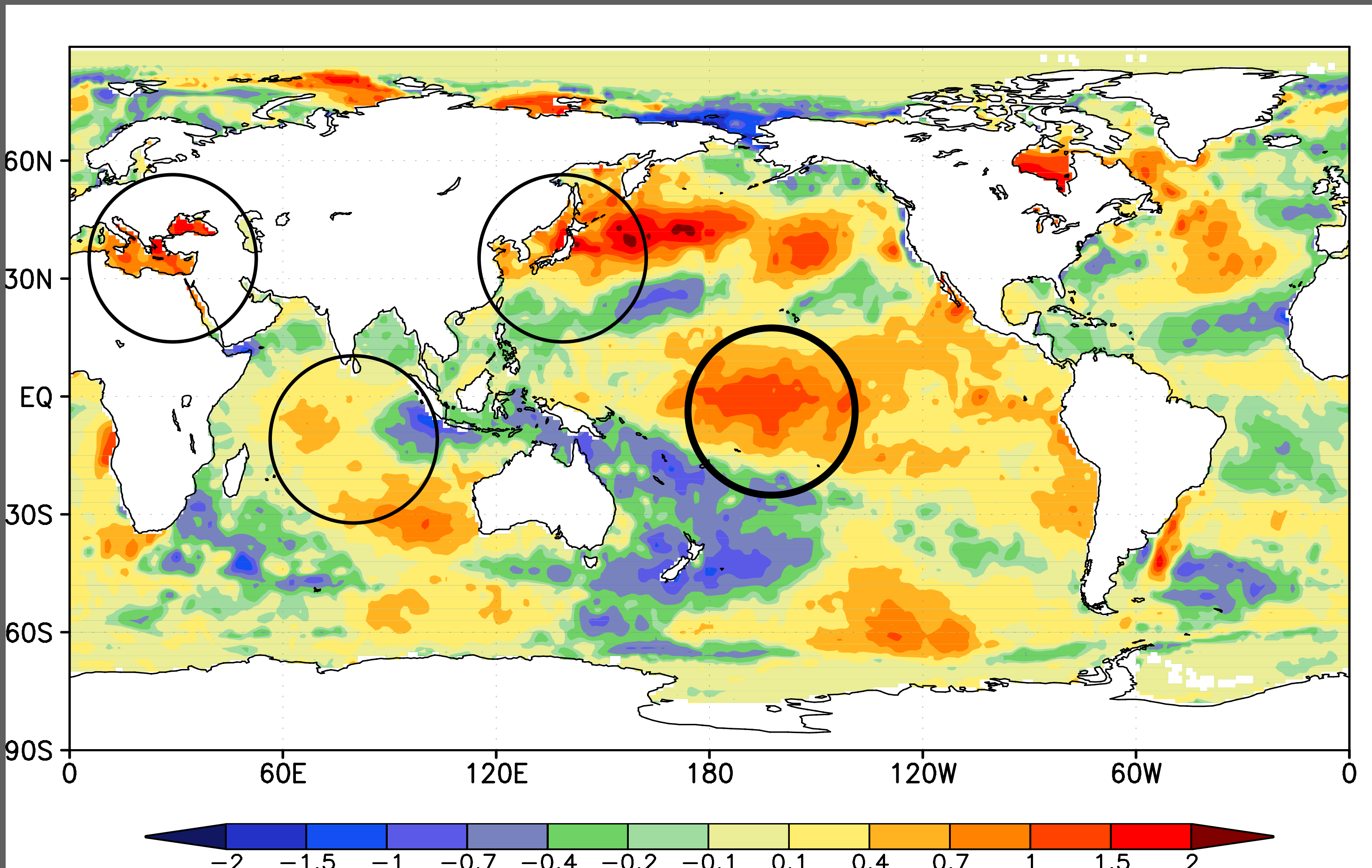
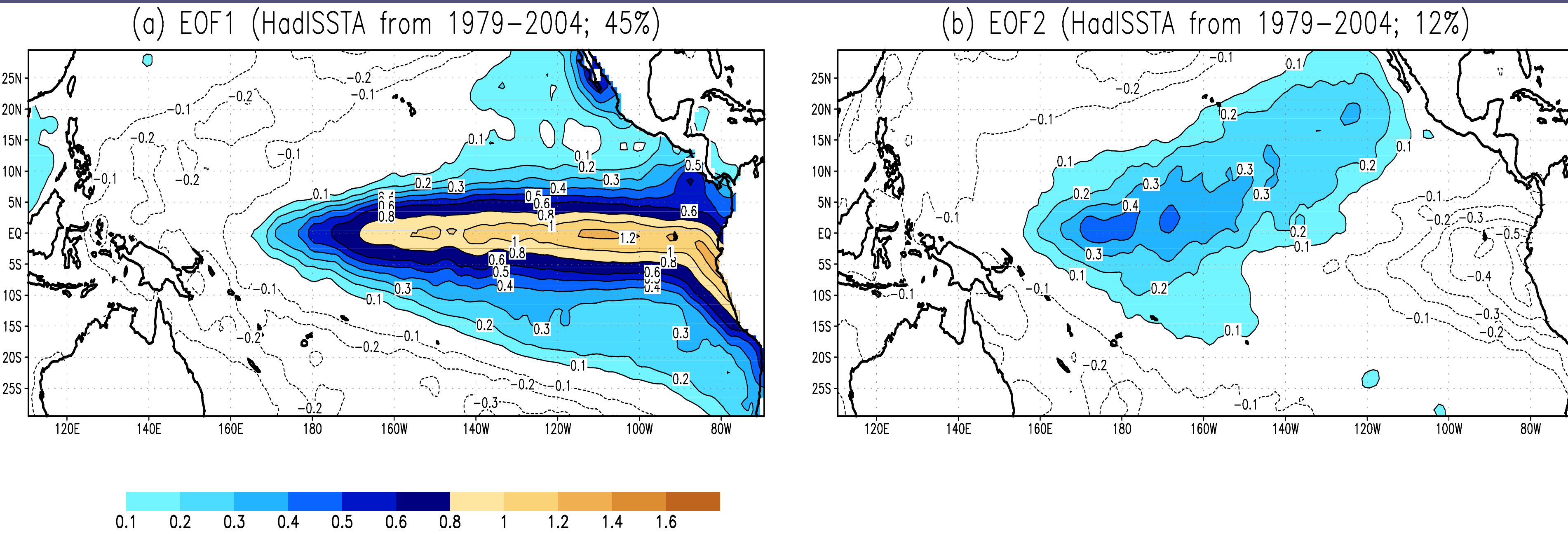
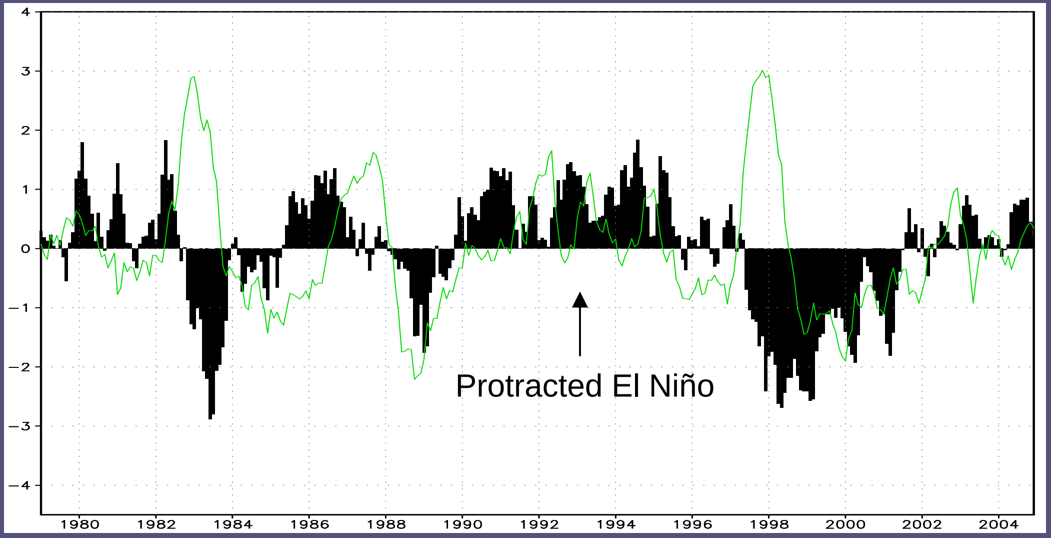
"Modoki" is an old Japanese word that means "similar but different".

Recent Interdecadal Change of SST



海面水温の変化の広域分布　{(1979年~2005年)-(1958年~1979年)}





Above: First two major EOF modes of tropical Pacific SSTA (1979-2005 Feb.) multiplied by respective standard deviations of the principal components; units in ºC.

Left: Normalized time series of PC1 (Green line) and PC2 (Bar graph).

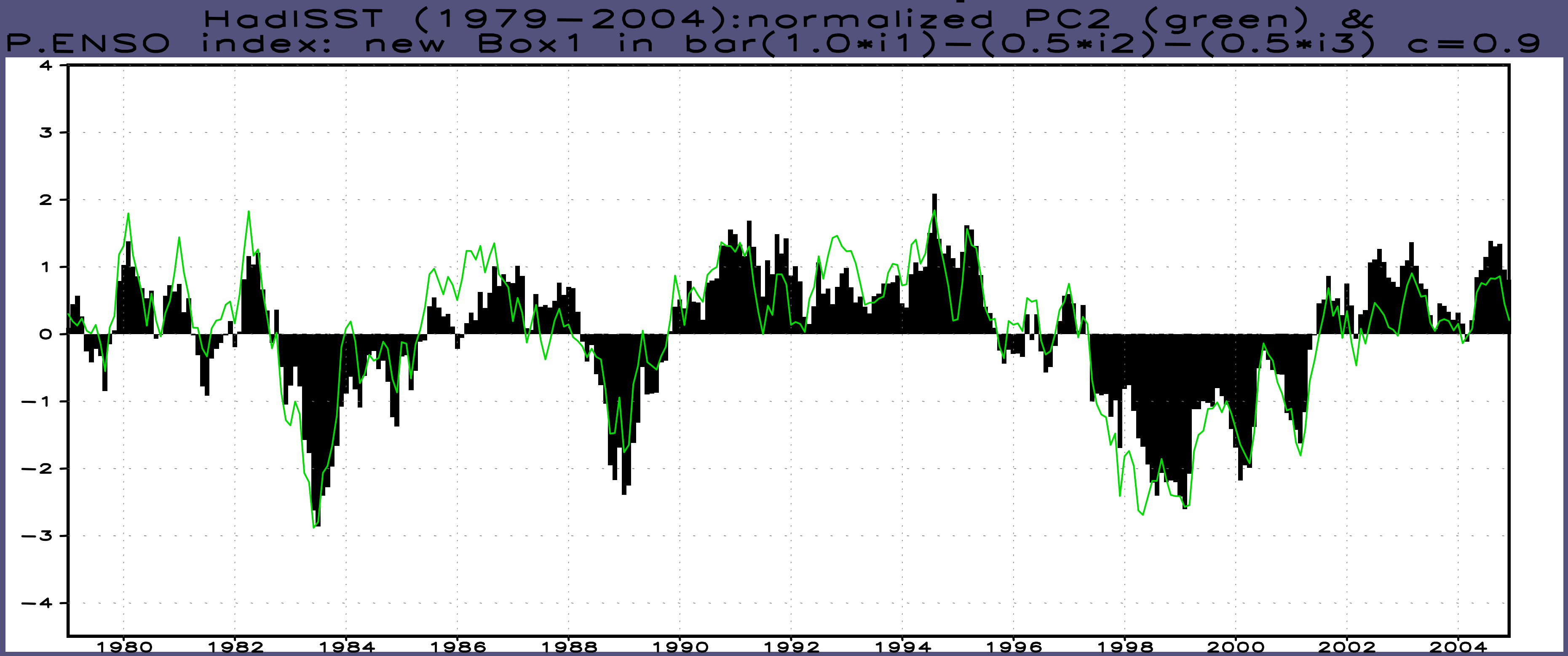
Introduction of El Niño Modoki Index

Suggested by the EOF2 pattern, we derive an El Niño Modoki index (EMI). Because of the unique tripole nature of the SSTA, the EMI SST index is introduced as follows:

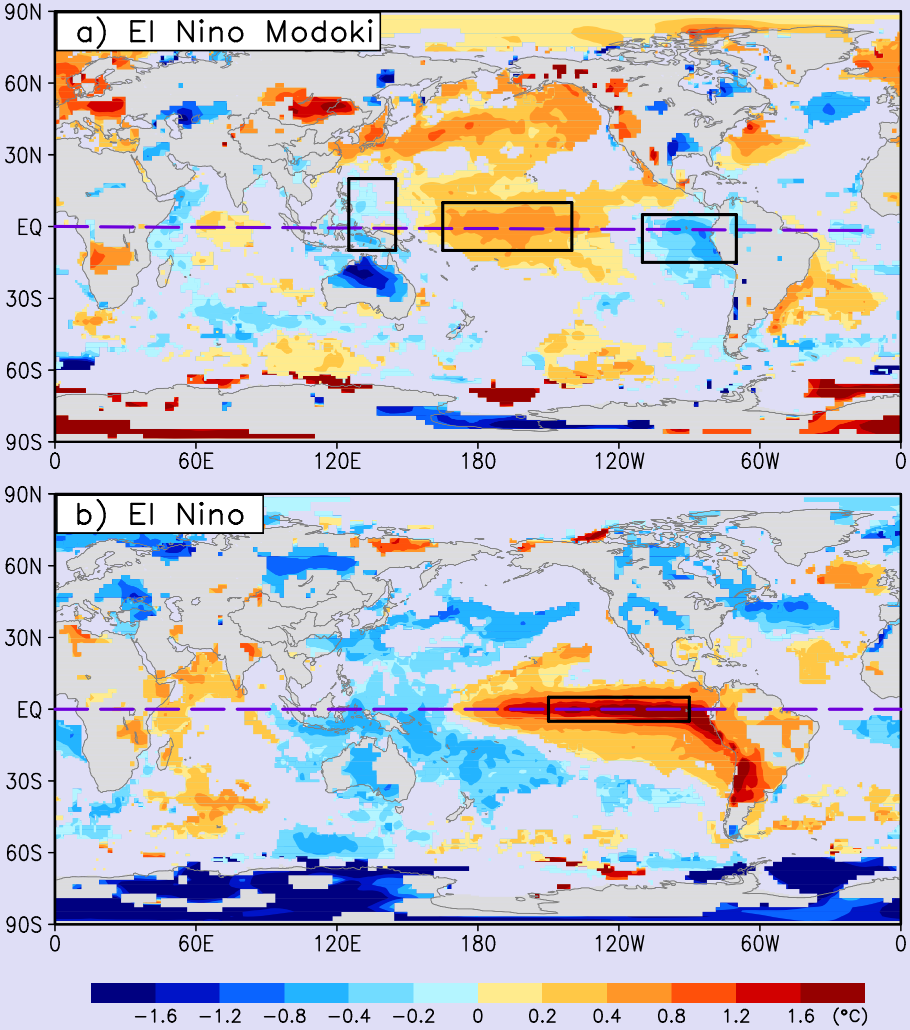
$$EMI = C - 0.5x(E + W)$$

where C, E, and W are the area-averaged SSTA over the central tropical Pacific (165° E - 140° W, 10° S - 10° N), eastern tropical Pacific (110° W - 70° W, 15° S - 5° N), and western tropical Pacific (125° E - 145° E,10° S - 20° N), respectively.

EMI thus defined captures PC2



Time series of normalized ENSO Modoki index (EMI; in black bar) and that of the PC2 (green line). The standard deviation of the EMI is 0.52ºC. The correlation with PC2 for the period 1979-2005Feb. is 0.92.



EMI = $[SSTA]_C - 0.5x\{[SSTA]_E + [SSTA]_W\}$

C=(165° E-140° W, 10° S-10° N)

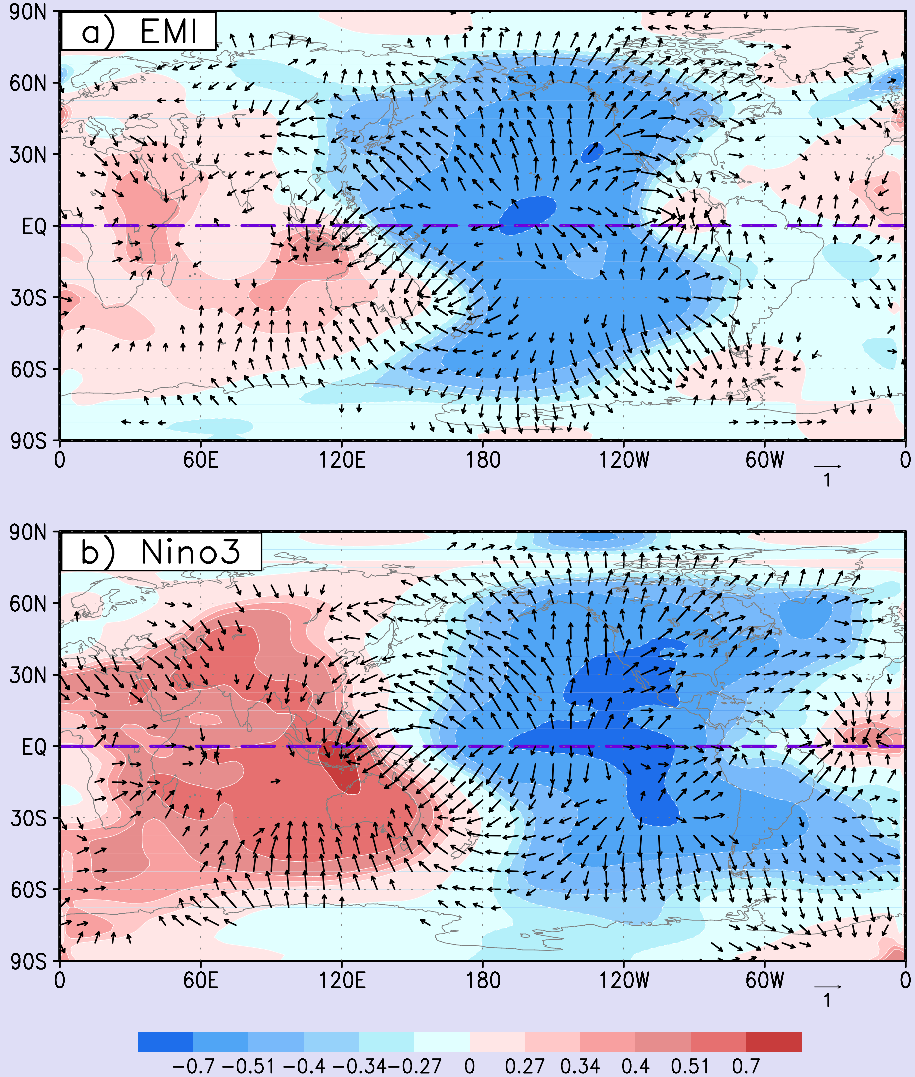
E=(110° -70° W, 15° S-5° N)

W=(125° -145° E, 10° S-20° N)

Nino3=[SSTA](150° -90° W, 5° S-5° N)

Composite SSTA over oceans and skin temperature anomalies over land (unit: ° C) for three largest events of El Niño Modoki based on EMI (1994, 2002, and 2004) and El Niño based on Niño3 index (1982, 1987, and 1997). Only the temperature anomalies significant at and above the 80% level are shown.

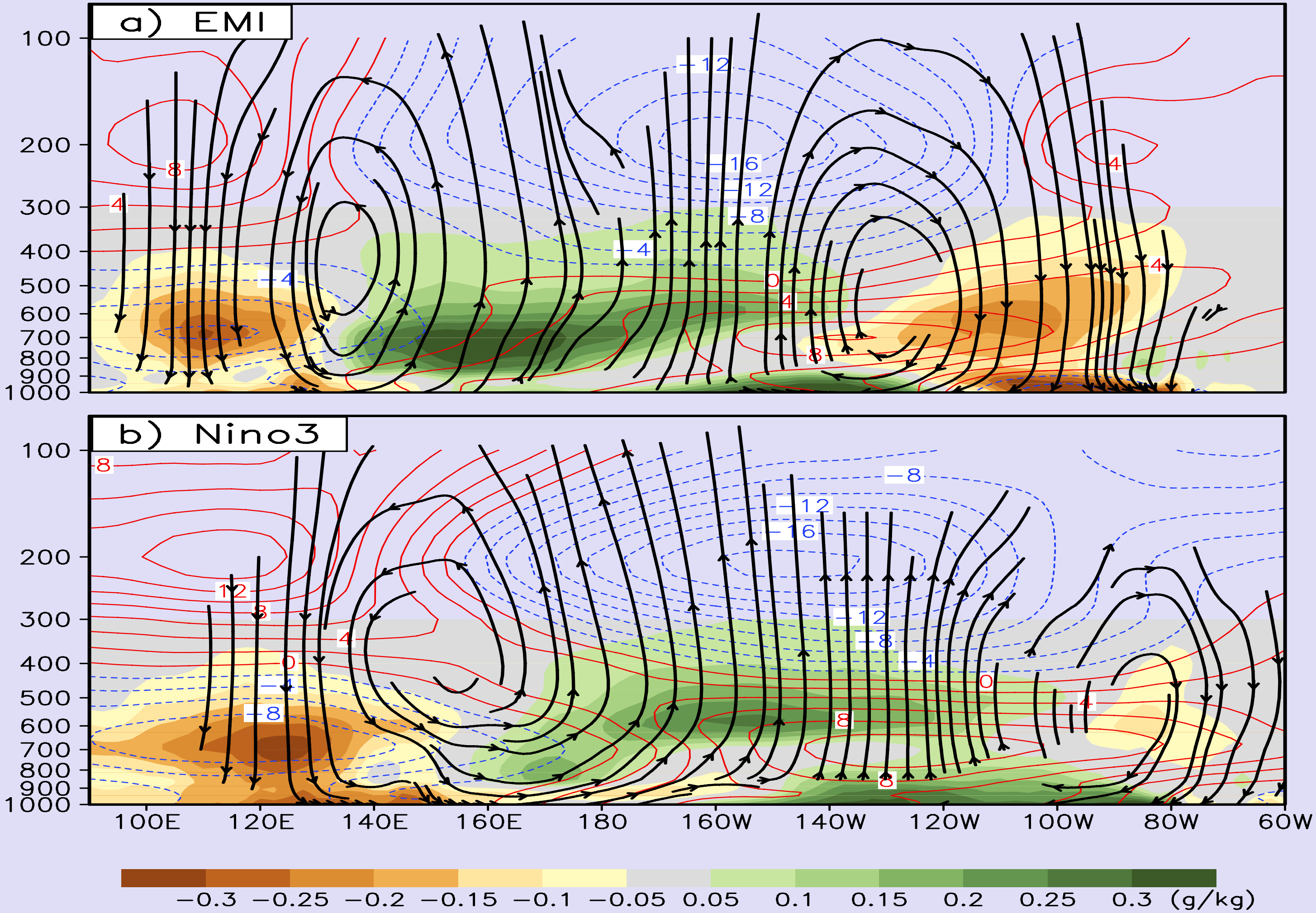
Differences in upper-level atmospheric circulation anomalies between El Niño Modoki and El Niño summers



EMI: **Tripole** pattern in the Indo-Pacific sector

Nino3: **Dipole** pattern in the Indo-Pacific sector

Partial correlation patterns of 200hPa divergent winds (arrows) and velocity potential anomalies (shaded) against a) EMI and b) Niño3 index.

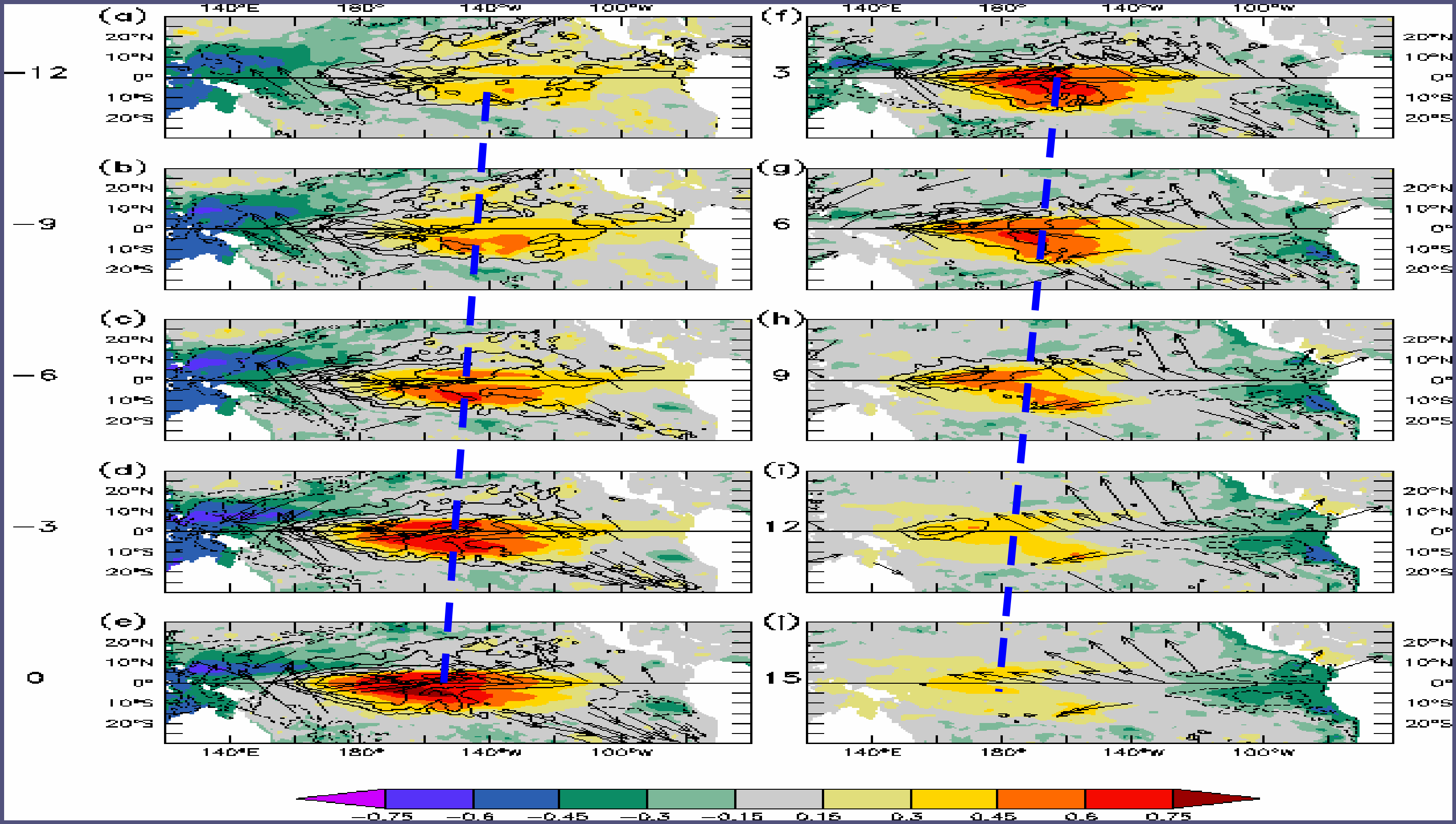


Anomalous Walker Circulations (10S -10N)

between 90E and 60W based on partial regression for EMI and Niño3.

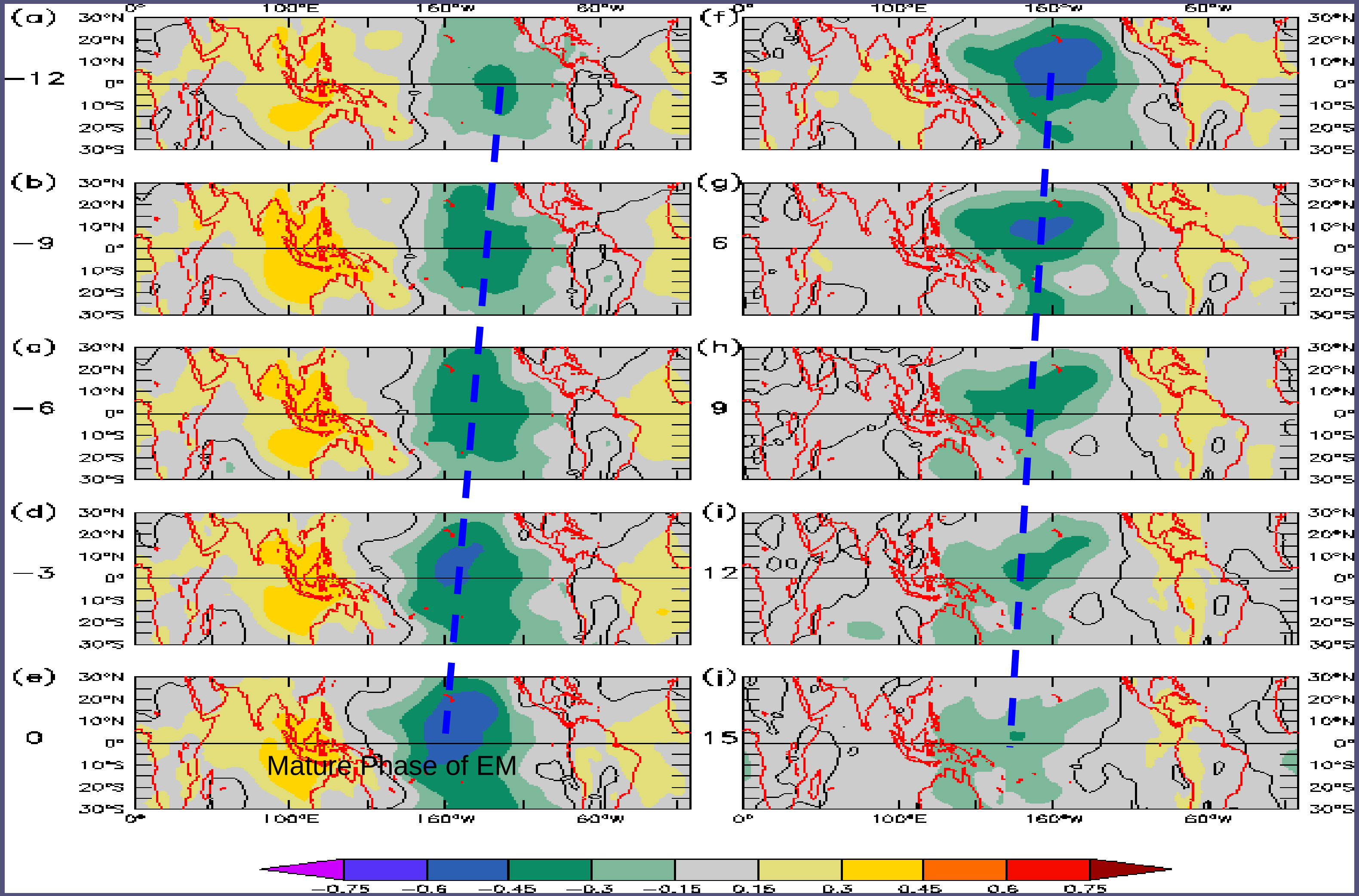
The regressed specific humidity is shaded. The contours are for regressed velocity potential (unit: 10^5 m^2s^{-1}).

Lead/lag correlations of EMI with SSH anomalies (shading) and ocean temperature anomalies at 10 meter depth (contours)

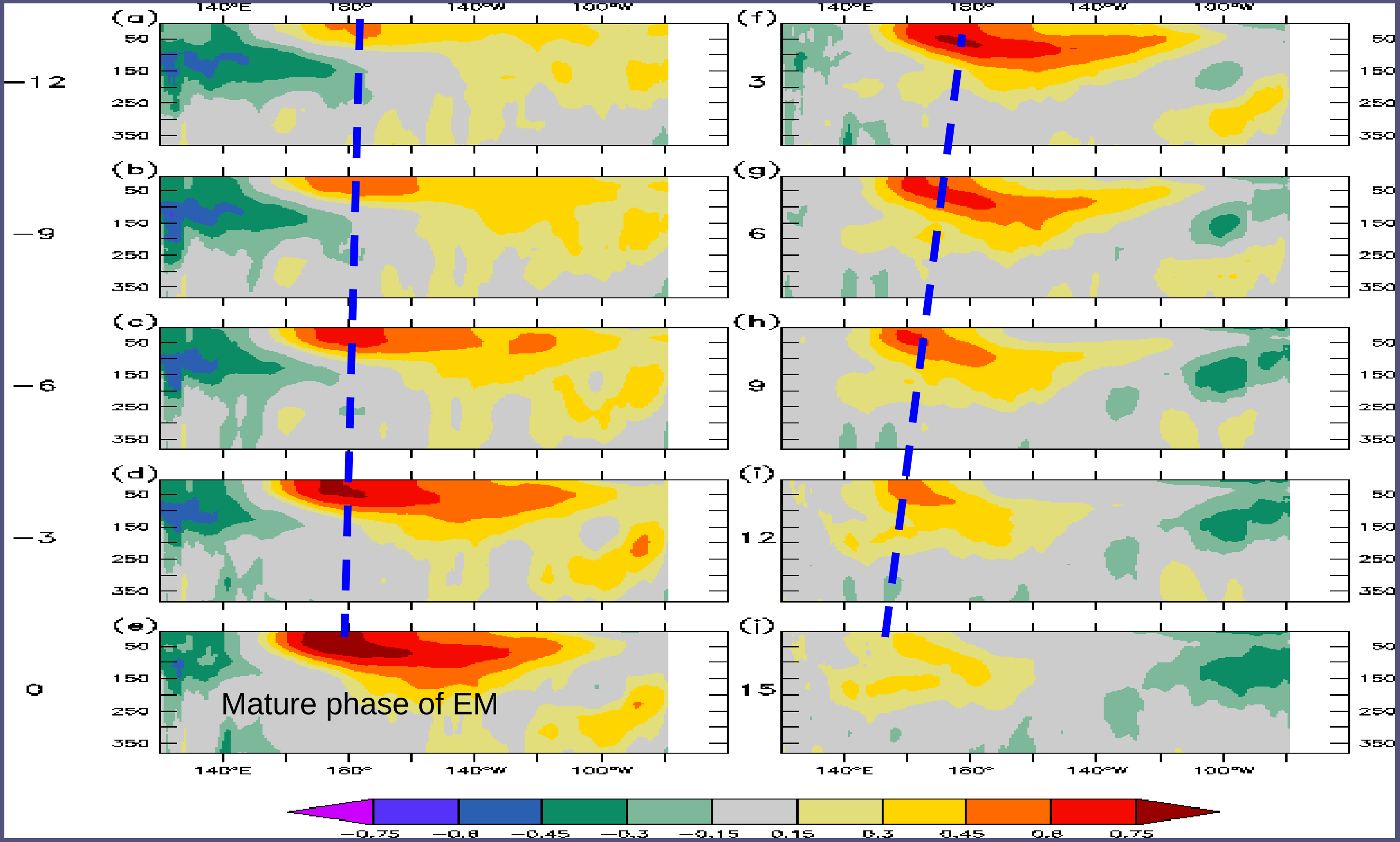


Positive (negative) correlation coefficients correspond to rise (fall) of sea level. Regressed winds with EMI are shown only if the correlation coefficient between EMI and respective wind components exceeds 0.15 (significant at 90% confidence level from a 2-tailed Student's t-test). Lead/lag values in months are shown on the left hand side of each plot.

Lead/lag correlations of EMI with SLPA

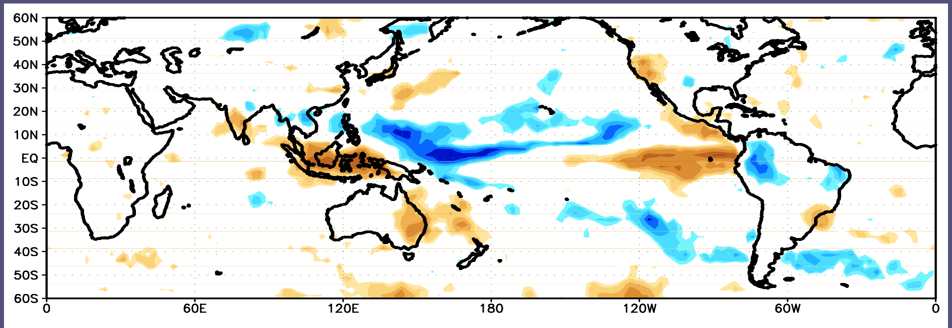


Lead/lag correlations of EMI with equatorial ocean temperature anomalies (averaged over 2ºS-4ºS.)

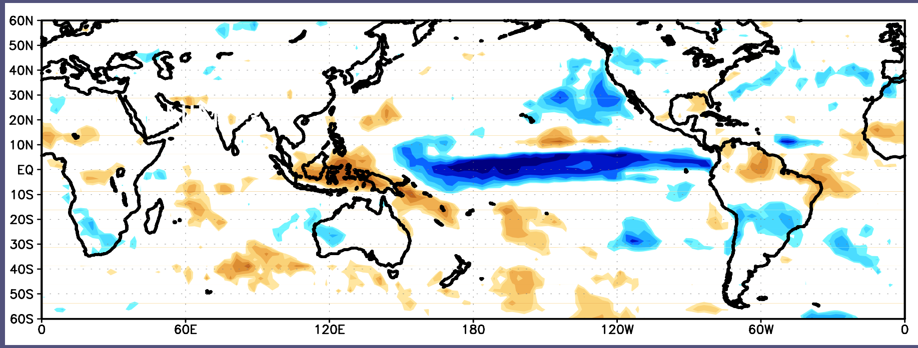


Lead/lag values in months are shown on the left hand side of each plot.

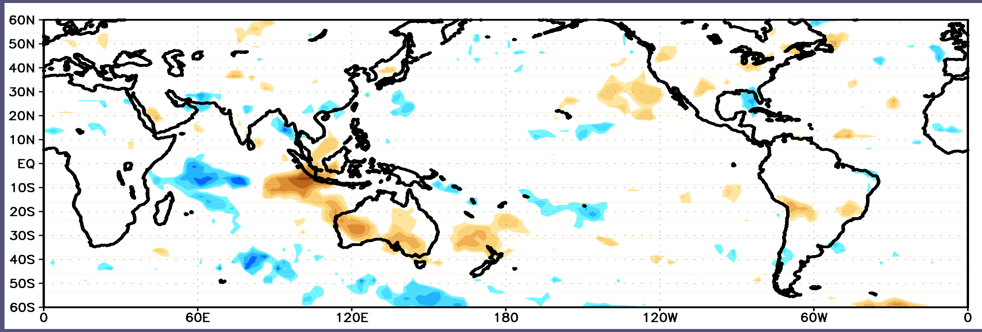
JJAS Partial Correlation of GPCP Rainfall



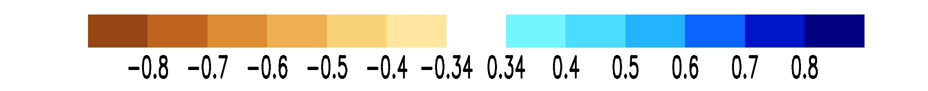
with EMI

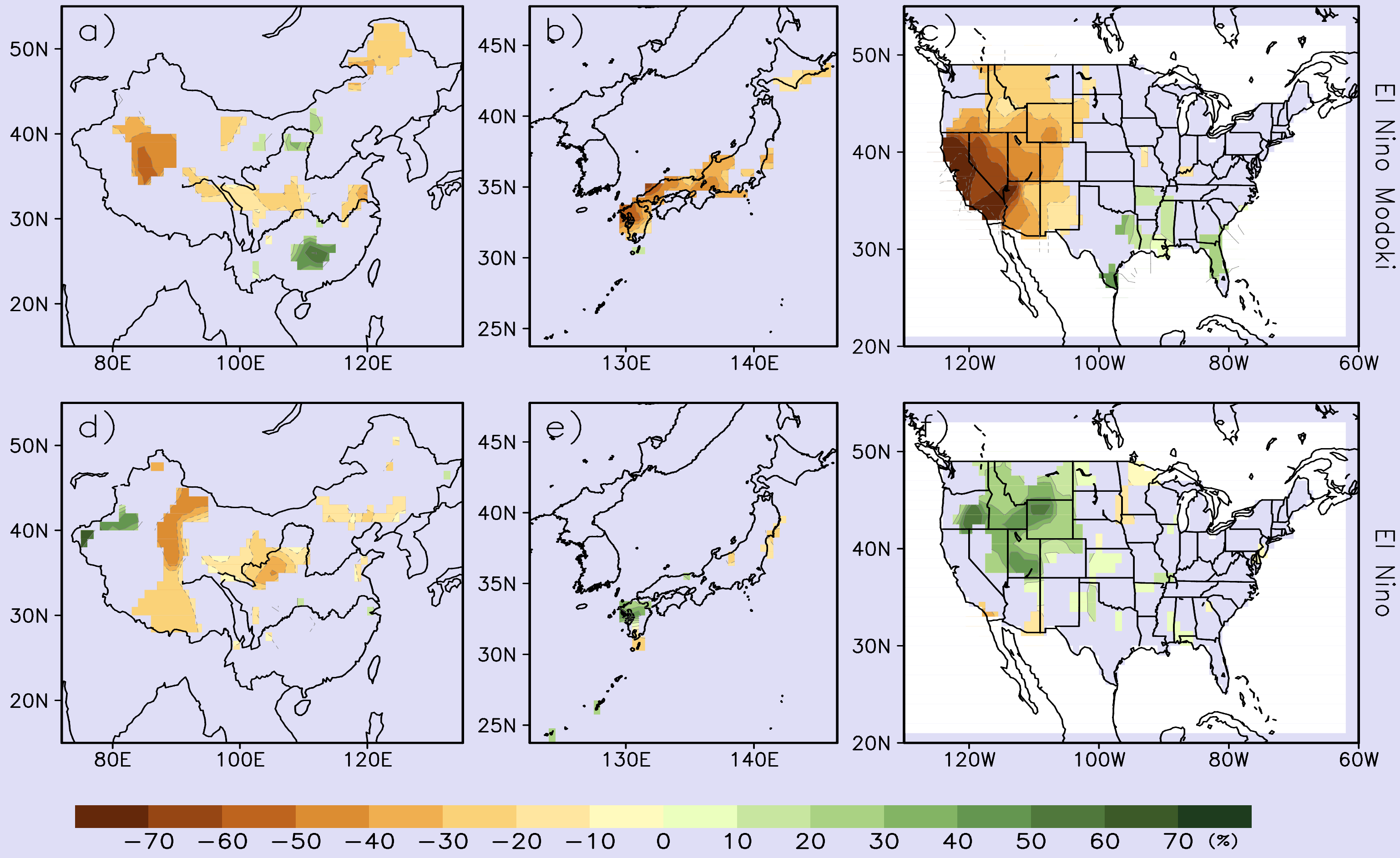


with NINO3



with IODMI

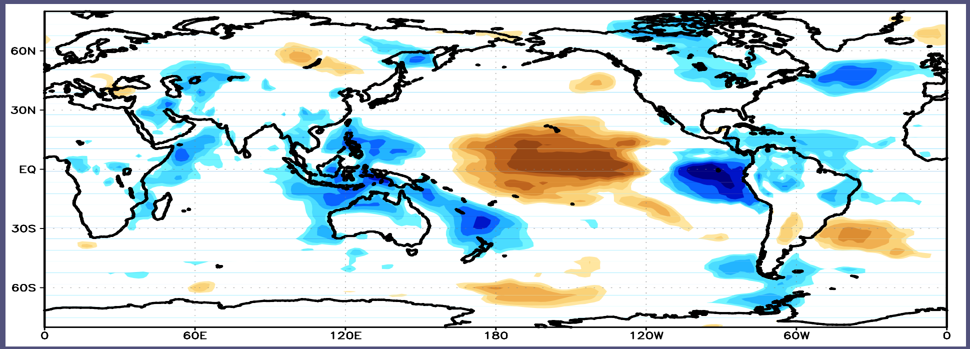




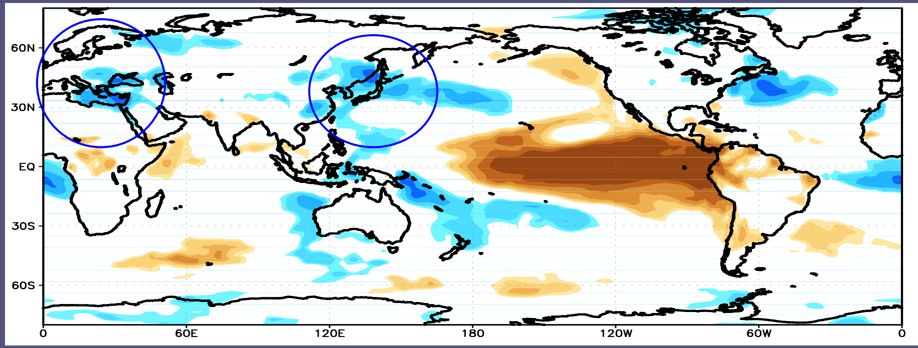
Composite JJA rainfall patterns (anomaly percent of normal: %)
for the three largest El Niño Modoki events (1994, 2002, and 2004)
and those for the three larges El Niño events (1982, 1987, and 1997).

The values with significant levels less than 80% are omitted.

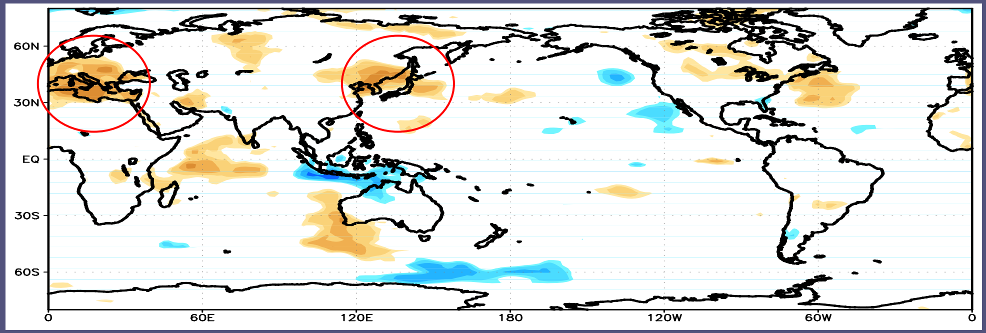
JJAS Partial Correlation of Air Temperature (2m height)



with EMI

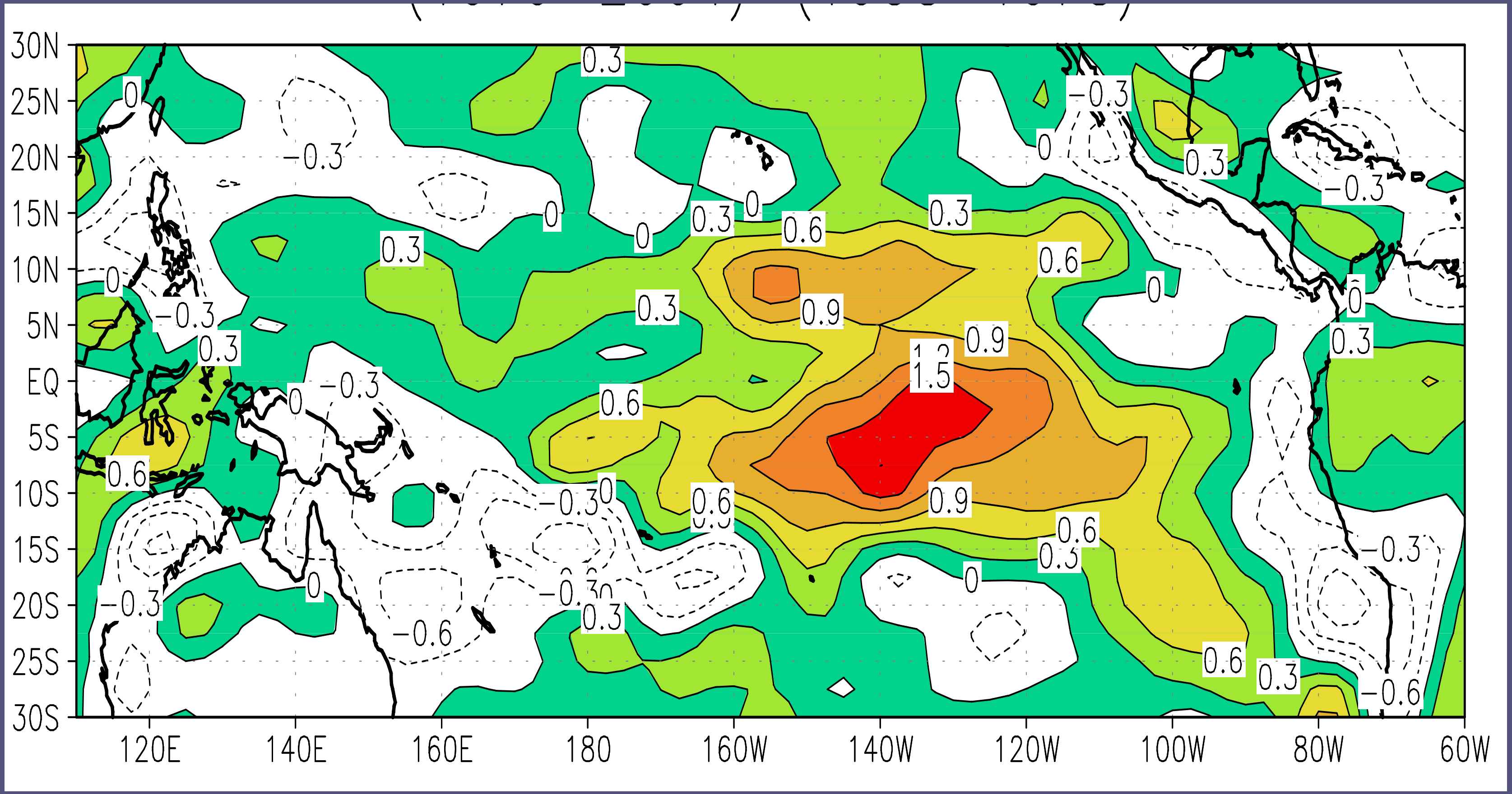


with NINO3

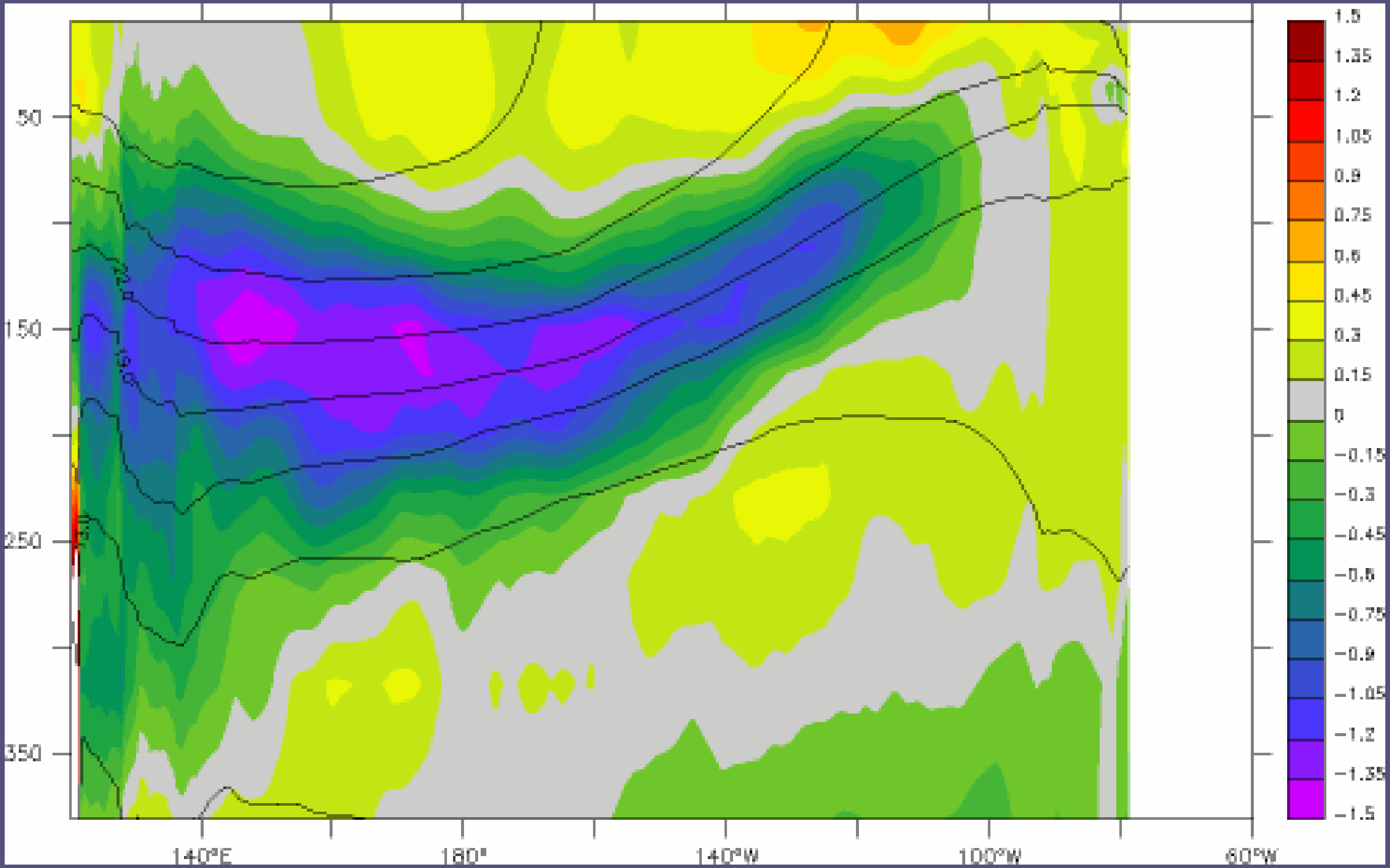


with IODMI

Long-term changes in annual mean zonal winds at 1000 hPa (m/s)



Differences of ocean temperature in two periods of 1958-78 and 1979-2004



Climatological ocean temperature is shown using black contours.

Summary

- ENSO Modoki is a unique coupled phenomenon in the tropical Pacific, which seems to be different from ENSO as seen from the different evolution and teleconnection characteristics.
- ENSO and ENSO Modoki may be two major modes in the coupled tropical Pacific system. The system chooses either one of them, depending on the background conditions.
- Because of recent weakening zonal gradient of the equatorial thermocline associated with the weakening trend of the easterlies, ENSO Modoki appears more frequently in recent decades.

＊ The NINO3.4 index is not proper to define El Niño phenomena, because it picks up the warming in either the eastern or central equatorial Pacific. Thus, the El Niño events defined by this index mixes up both the canonical El Niño events and El Niño Modoki events. The teleconnection patterns related to NINO3.4 index is a residual of those related to two different phenomena: El Niño Modoki and El Niño.

Simultaneous Correlations with PC2

NINO3 index	-0.09
NINO4 index	0.51
NINO1+2 index	-0.44
NINO3.4 index	0.19
IODMI	0.1
SDMI	0.15

Lead-Lag between EMI and El Niño Indices

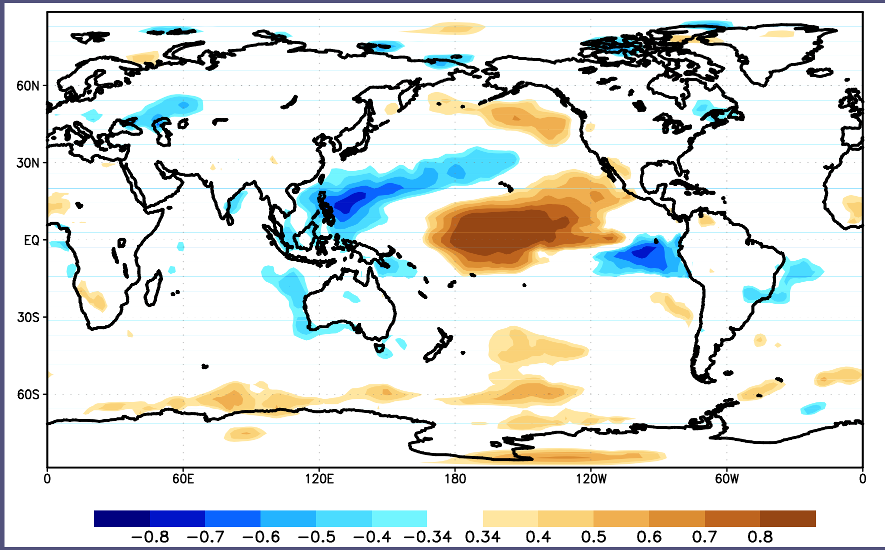
EMI between April and October leads Dec. NINO3 index with correlation larger than 0.45.

EMI leads NINO 3.4 index by 4 months with correlation of 0.49.

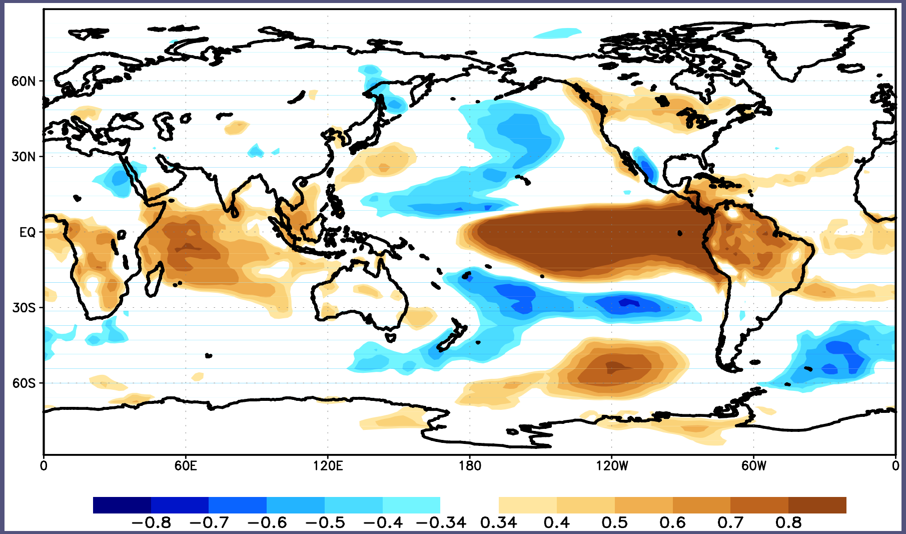
Aug. EMI lags behind Feb. NINO3 index with correlation of about 0.5.

All these indicate that, after 1978, about 30% of the total variance of either one of the El Niño Modoki and El Niño phenomena can be explained by the other with some lead or lag.

DJF Partial Correlation of Air Temperature (2m height)



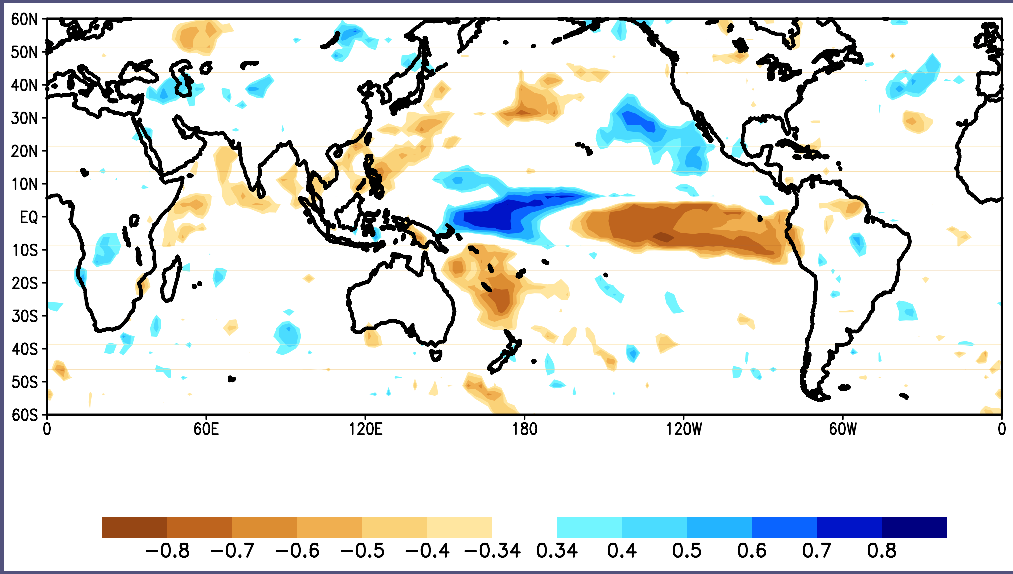
with EMI



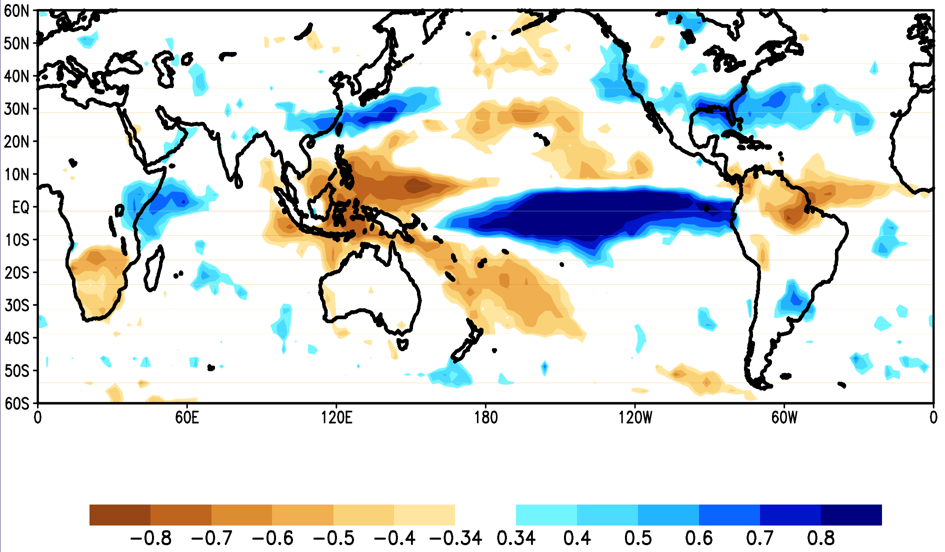
with NINO3

Shaded values are significant at 90% confidence level from a two tailed Student's t-test.

DJF Partial Correlation of GPCP Rainfall



with EMI



Shaded values are significant at 90% confidence level from a two tailed Student's t-test.

with NINO3

Composite Analysis

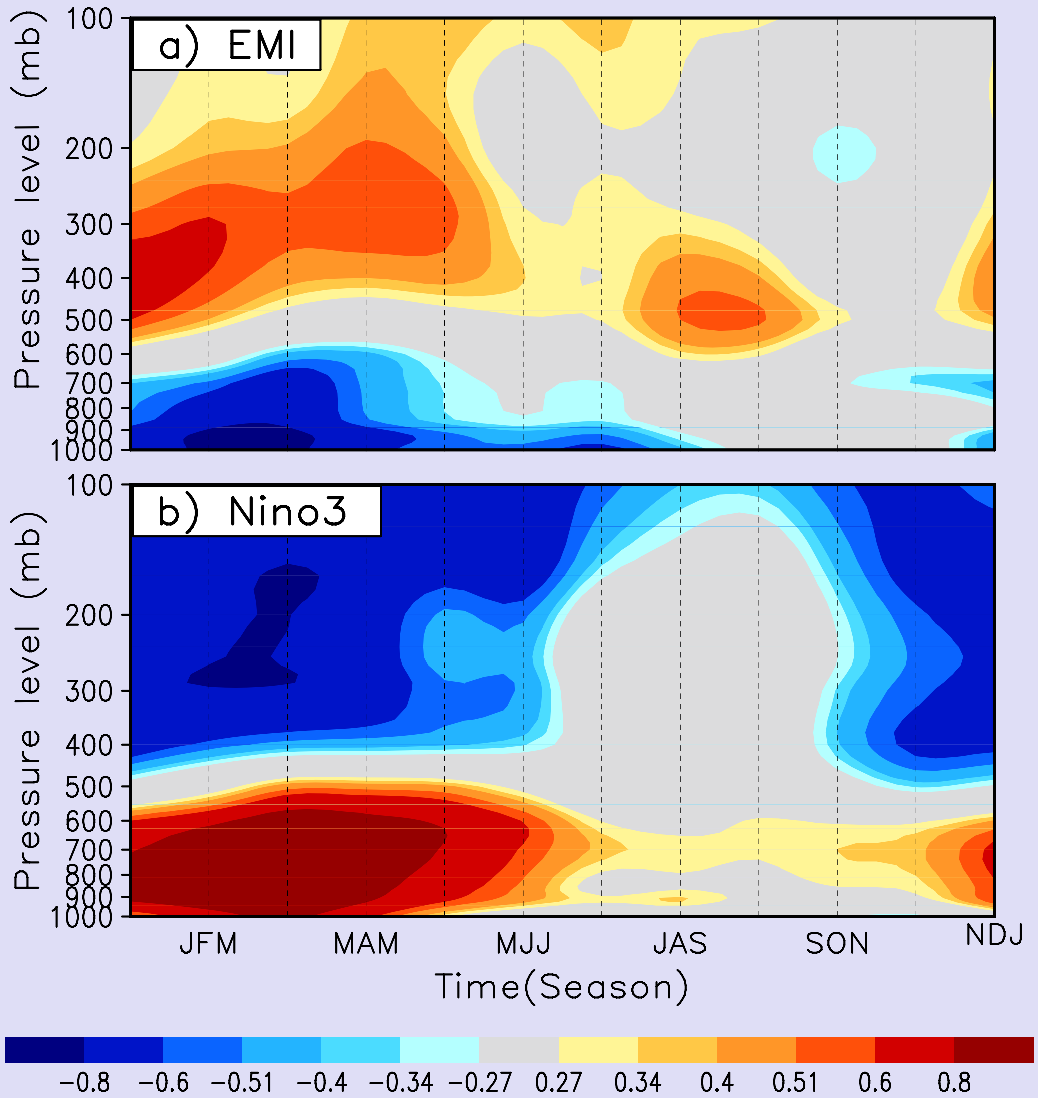
Based on the EMI, we identify seven strong El Niño Modoki events that lasted from boreal summer through boreal winter, peaking in one of these seasons (seasonal standard deviations for boreal summer and winter are 0.5ºC and 0.54ºC respectively).

They occurred in 1986, 1990, 1991, 1992, 1994, 2002, and 2004.

Additionally, we identified one strong El Niño Modoki during the boreal winter of 1979-80 that lasted through the summer of 1980, though its amplitude fell below the threshold of 0.7 σ by then.

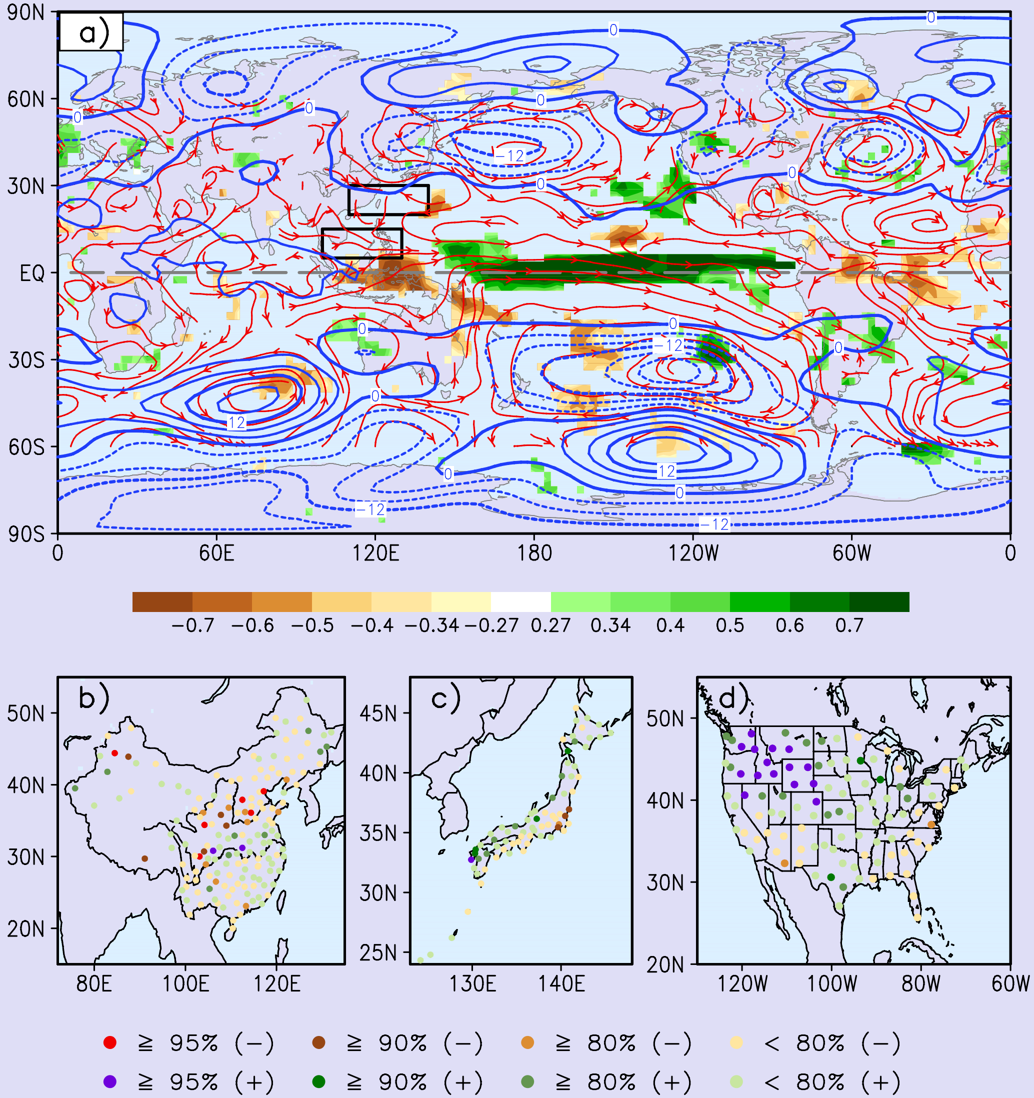
** A strong El Niño Modoki event is the case of which amplitude is equal to or greater than 0.7 σ, where σ is the seasonal standard deviation.*

Differences in zonal wind anomalies in the eastern tropical Pacific between El Niño Modoki and El Niño



Partial correlation between the zonal wind anomalies for 1000-100hPa during different seasons at 120W and a) EMI and b) Niño3 index.

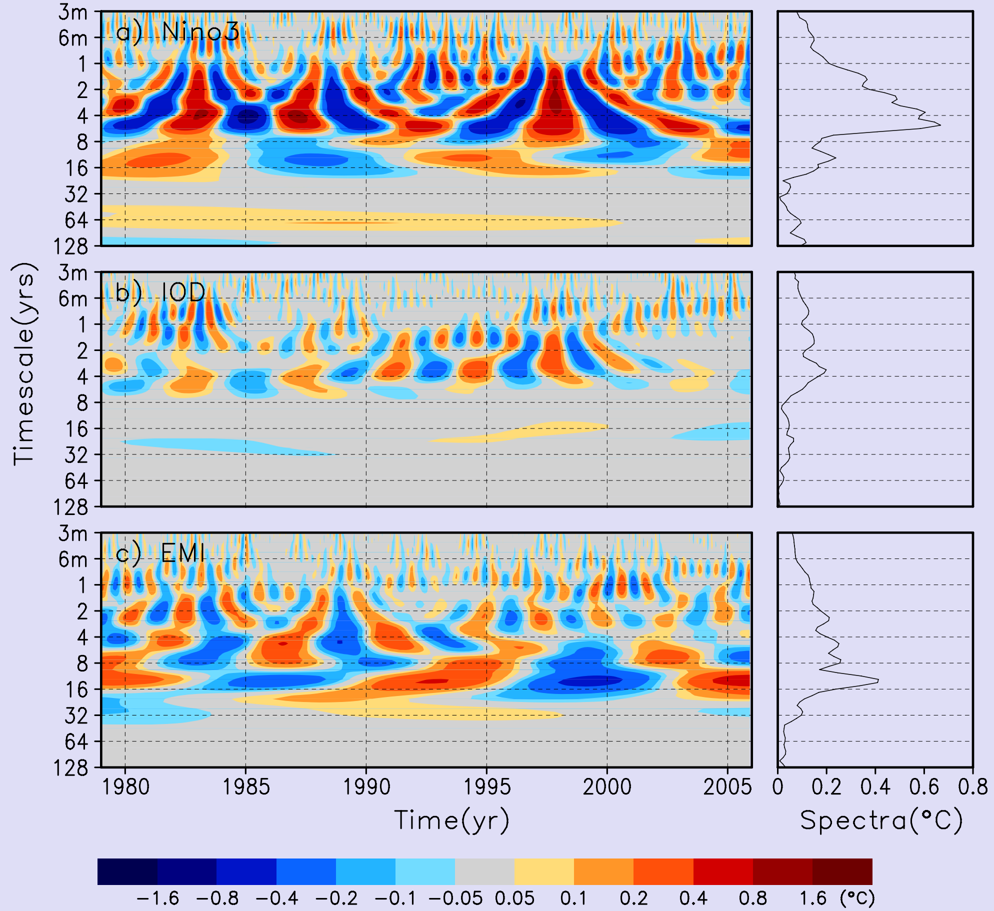
The abscissa is 3-month running season, and the ordinate is pressure level (hPa). The criteria at the 80%, 90%, 95%, and 99% significance levels are |0.27|, |0.34|, |0.4| and |0.51|, respectively.



El Niño

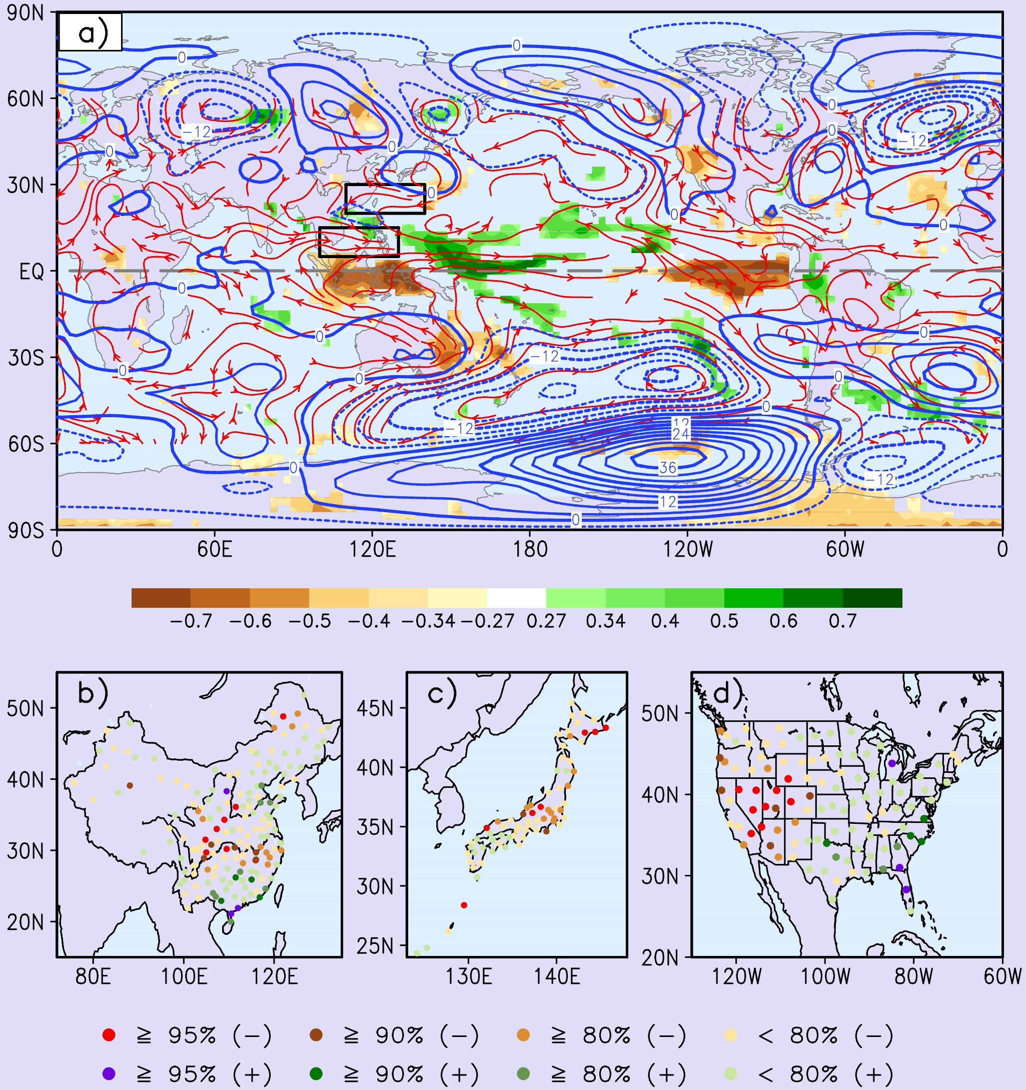
Both WNPSM and EASM are weak than normal.

China. Northern: dry; YRV: wet.
Japan. Japan Sea side: wet; Pacific Ocean side is dry
U. S. Most regions, esp. N. W.: wet; S. W. and S.E.: dry



Morlet wavelet real coefficients (left panels) and global wavelet spectra (right)

El Niño Modoki



WNPSH: 135E30N

WNPMI (Wang and Fan 1999):
$=U_{850S} - U_{850N}$

S: (5-15N, 100-130E)
N: (20-30N, 110-140E)

WNPMI(EASM) is strong(weak)

China. South coast - wet; YRV- dry.
Japan. Most of Japan- dry; Kyushu Shikoku wet due to Typhoon.
U. S. Most of West- dry; S.E.- wet due to hurricanes.

a) Partial regression patterns of 500hPa gph (blue contours; m), 850hPa horizontal wind (red streamlines) against EMI, and the partial correlation pattern of GPCP precipitation anomalies (green/brown shaded for positive/negative values; unit: mm d^{-1}. Significant level < 80% level neglected.) b), c) and d) are partial correlations of JJA EMI with JJA rainfall anomalies in China, Japan and the United States, respectively.

Datasets

(mainly for the period 1979-2005)

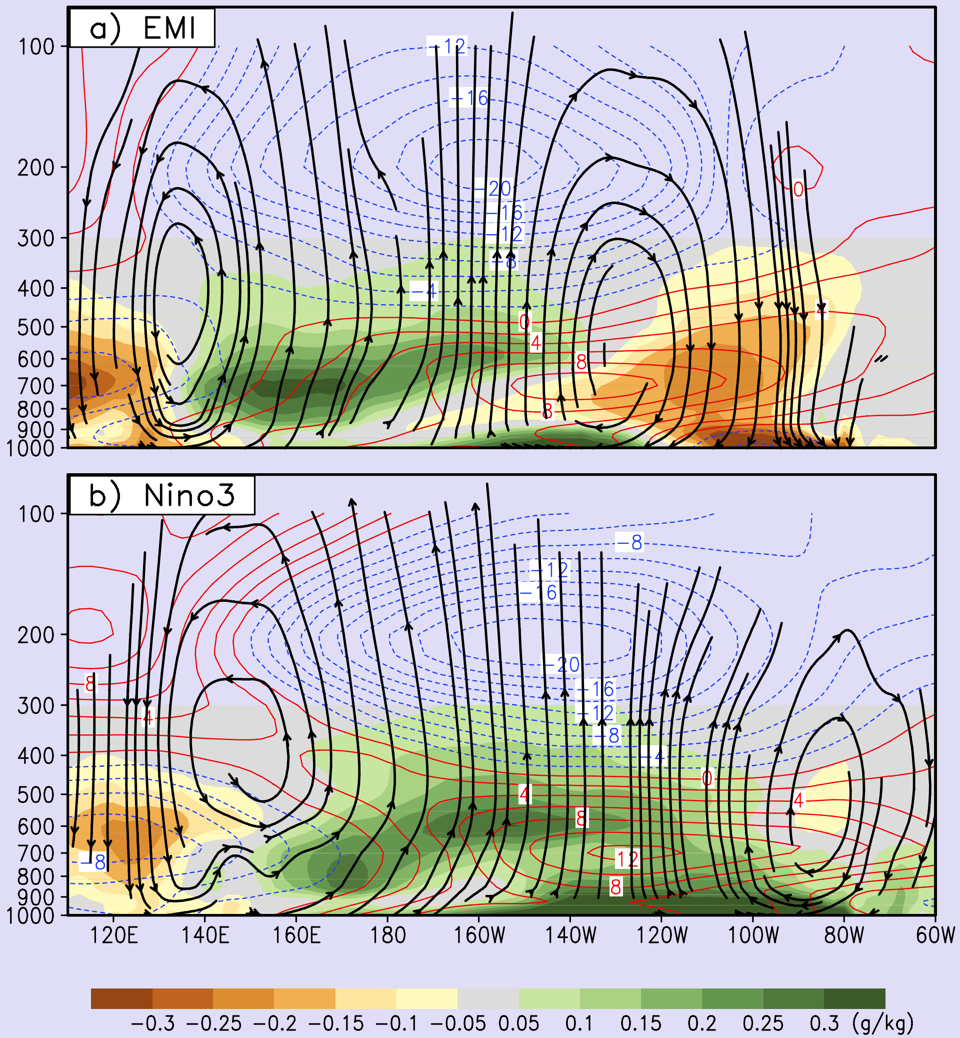
- HadISST (Rayner et al., 2003)

  Verification by OISST (Reynolds, 2002) from 1982
- GPCP Precipitation (Adler et al., 2003)

  Verification by CMAP precipitation (Xie and Arkim, 1996)
- NCEP/NCAR reanalysis (Kalnay et al., 1996)

  Verification by ERA40 (Simmons and Gibson, 2000)
- SODA (Carton et al., 2005; Carton and Giese, 2006).
- Also Levitus data, Aviso data, QUICKSCAT data etc.

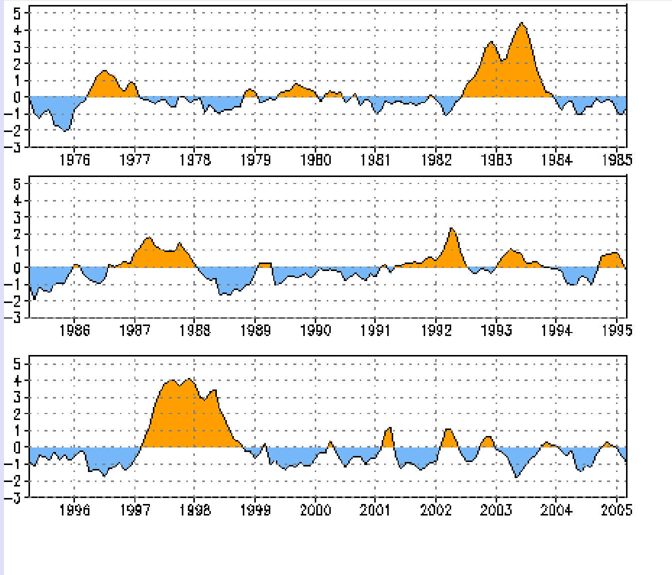
Differences in Walker Circulations between El Niño Modoki and El Niño summers



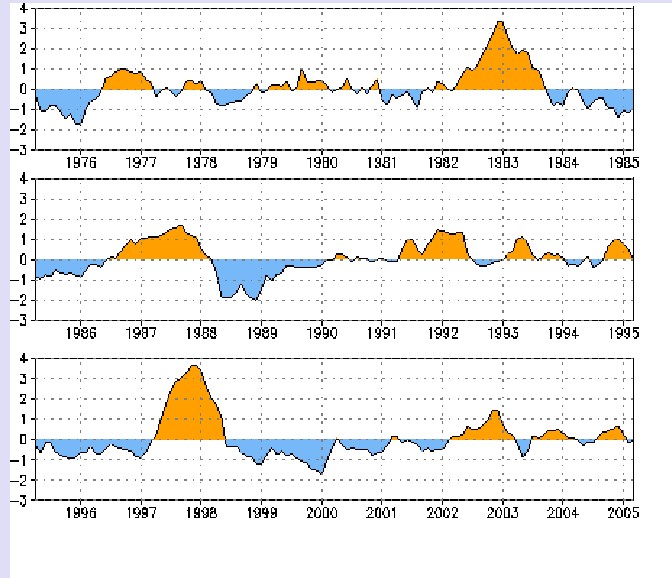
EMI: Clear double cells over the tropical Pacific. Joint ascent branches spans 135E-130W. West descent (110-135E) East descent (east 120W) enhance the dryness in PDZ.

Nino3: One and a half cells over The tropical Pacific. Eastern Part Is the wettest, without PDZ.

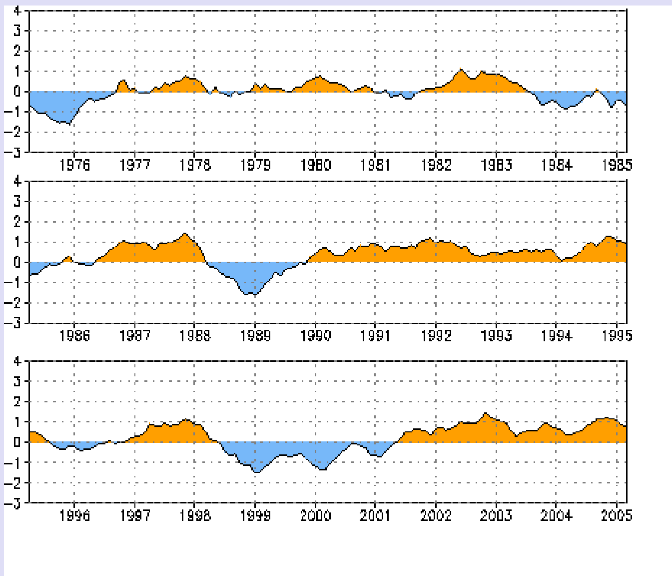
Nino1+2



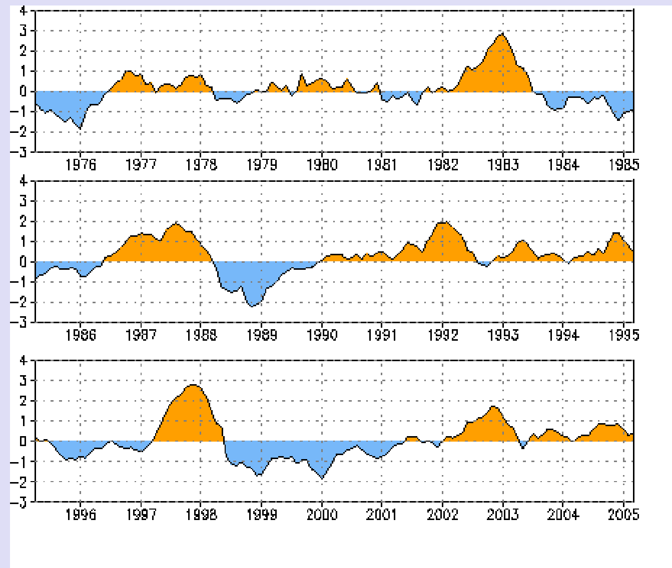
Nino3



Nino4



Nino3.4



CLIMATE PREDICTION CENTER/NCEP

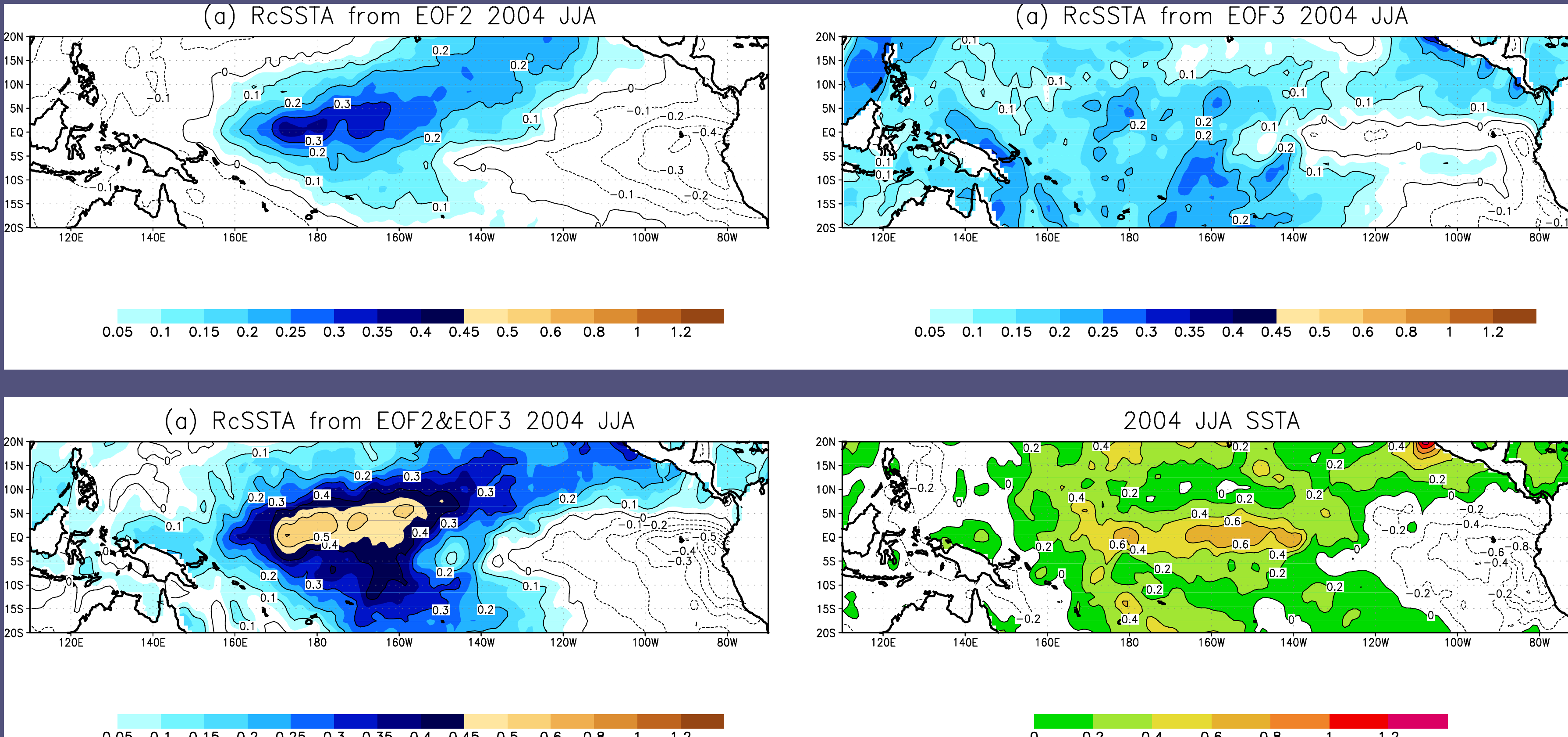
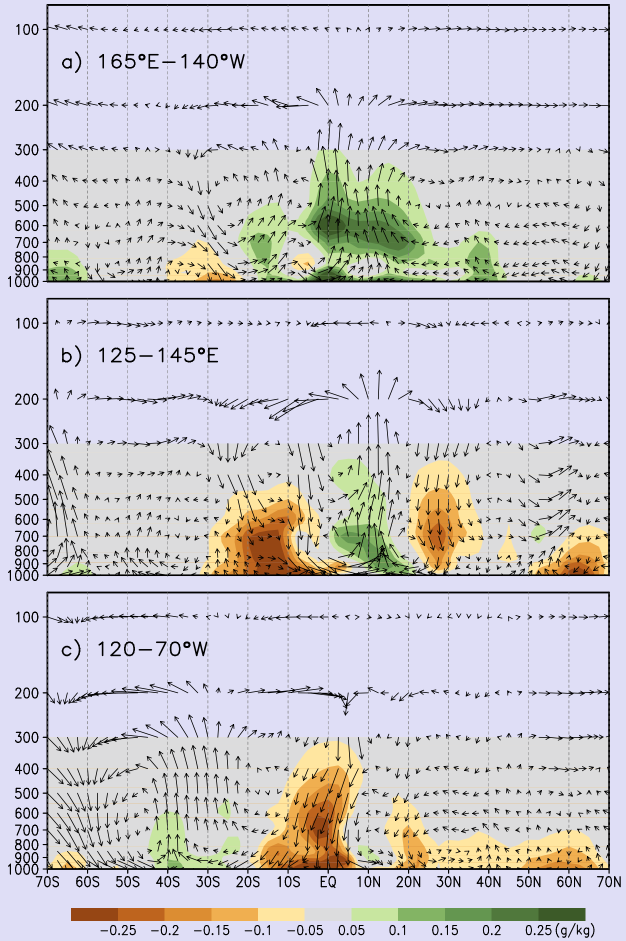


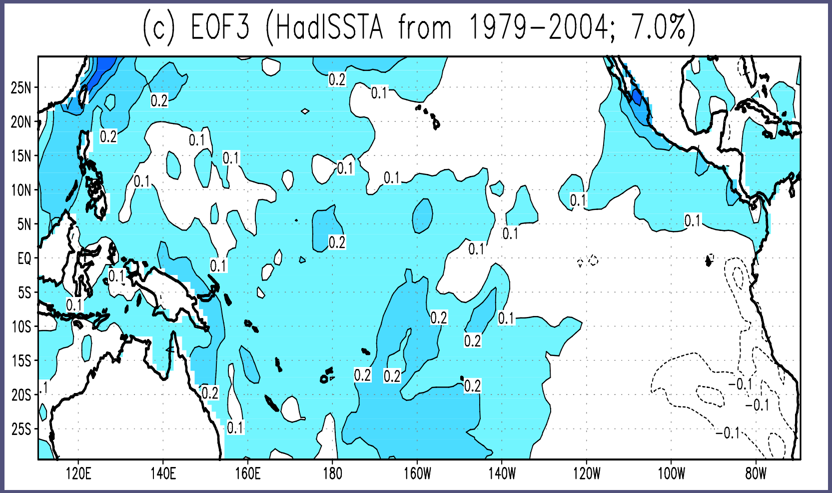
Figure: (a) contributions from EOF2 during JJA 2004 obtained by multiplying the EOF2 with seasonal average of PC2 for JJA 2004,
(b) same as in (a) but from EOF3, (c) combined contributions from EOF2 and EOF3 during JJA 2004,
(d) observed SSTA during JJA 2004

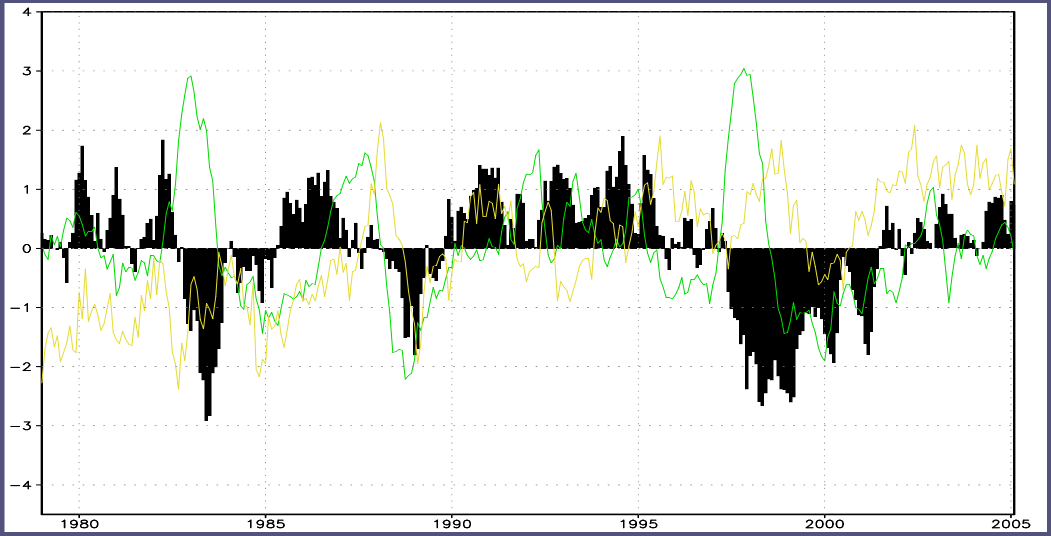
Three regional meridional circulations and related specific humidity

W: Wet ascent in 10-15N strong. Dry descent to both south and north.

E: Dry descent over Tropics. Extend to West US.

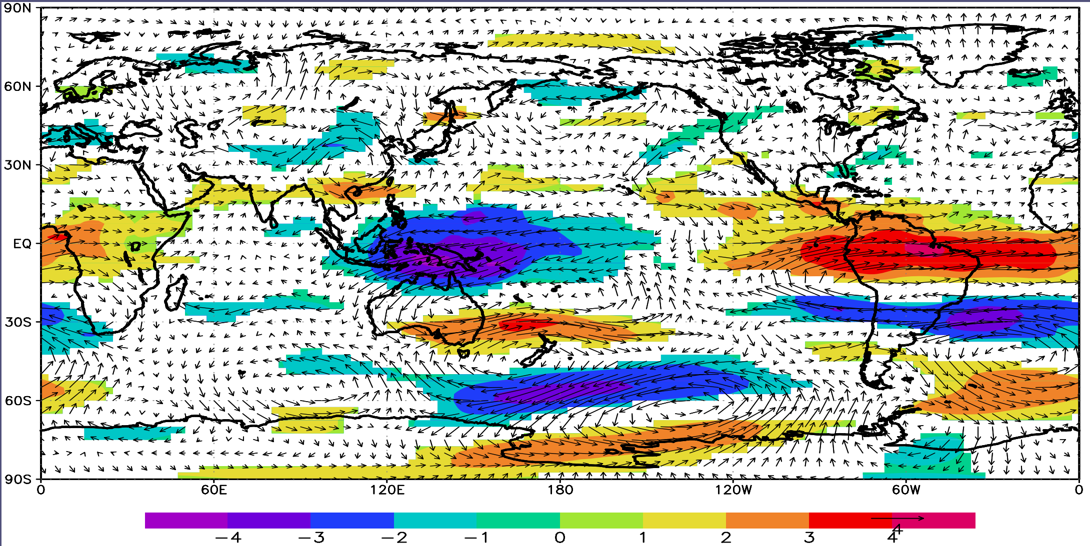




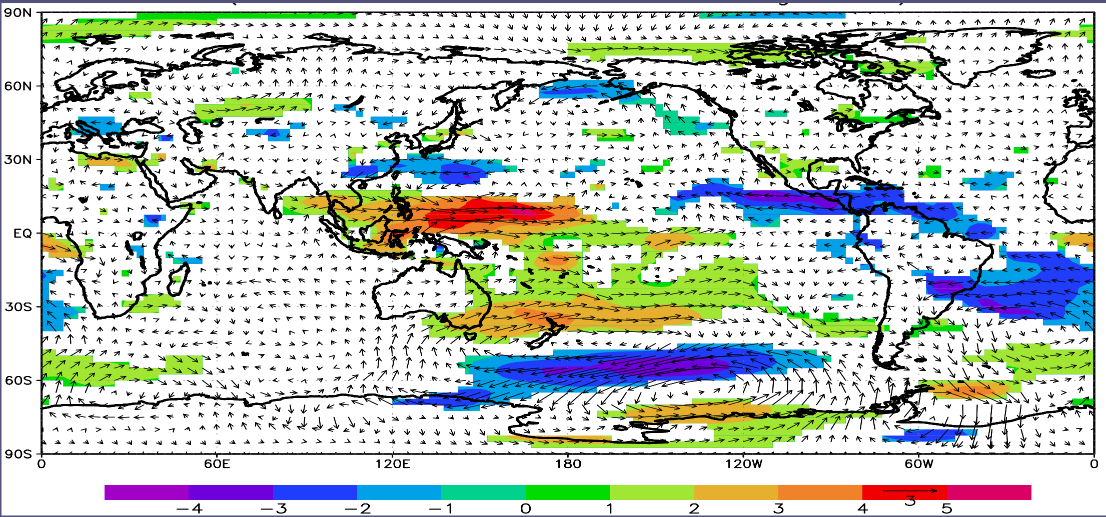


Top left contributions from EOF2 during JJA 2004 obtained by multiplying the EOF2 with seasonal average of PC2 for JJA 2004,
Top right : (b) same as in (a) but from EOF3.
Bottom: Pc1 (green0, PC2 (Bar), and PC3 (Yellow)

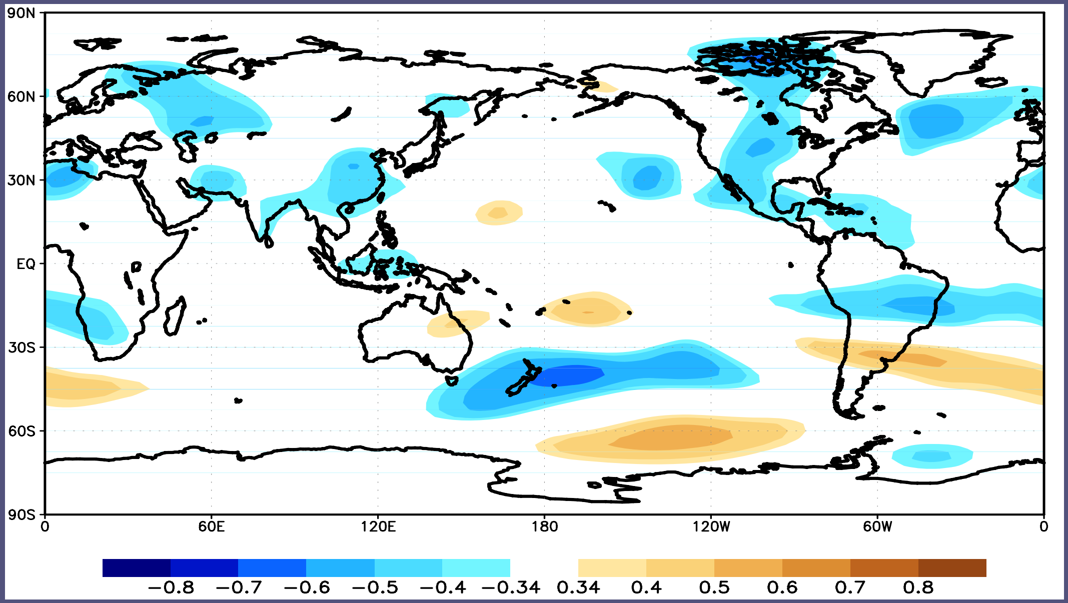
Composite JJAS anomalous winds obtained from seven strong El Niño Modoki events

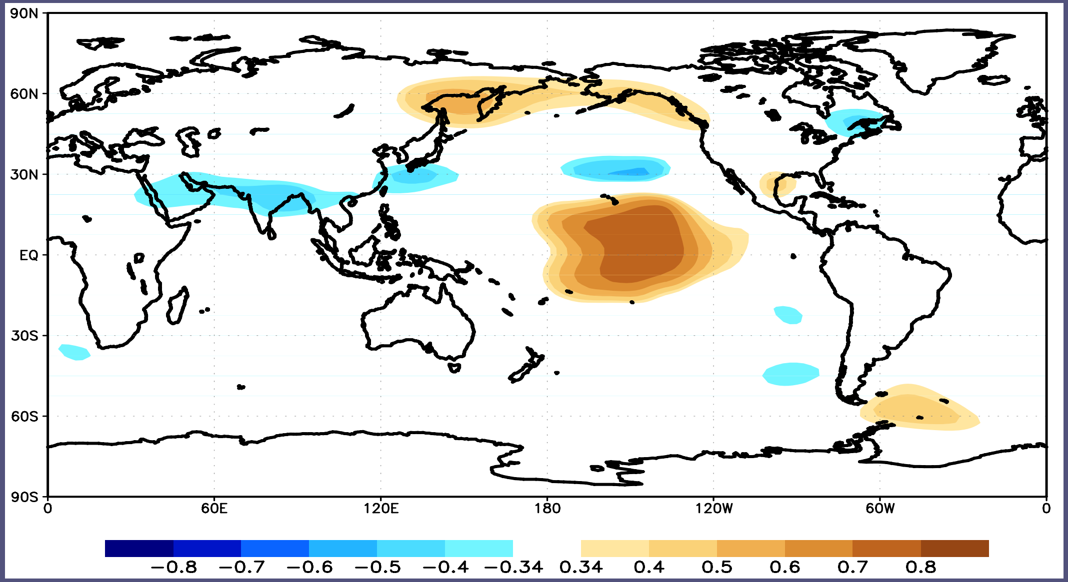


at 200 hPa

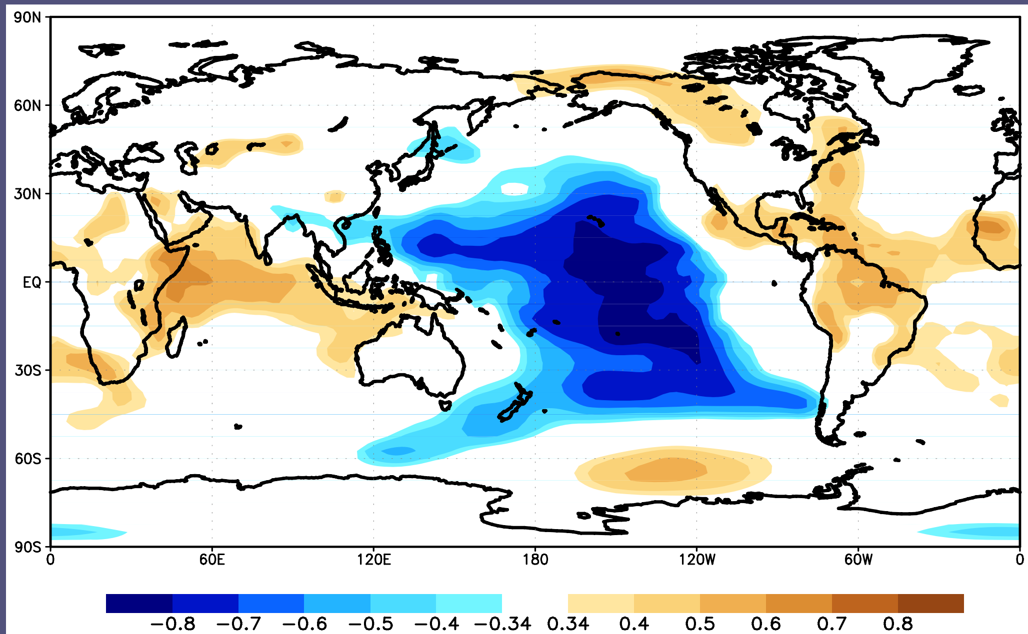


at 850 hPa

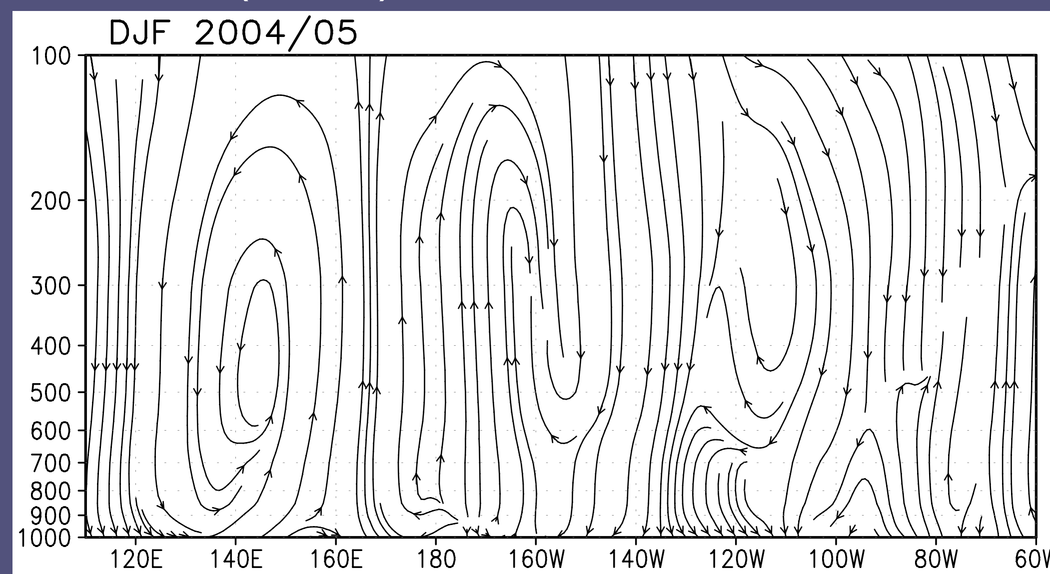




JJAS (1979-2004) partial correlations between 200 hPa geopotential anomalies and EMI (top) for JJAS (b) for DJF.
Shaded values are significant at 90% confidence level from a two tailed Student’s t-test.

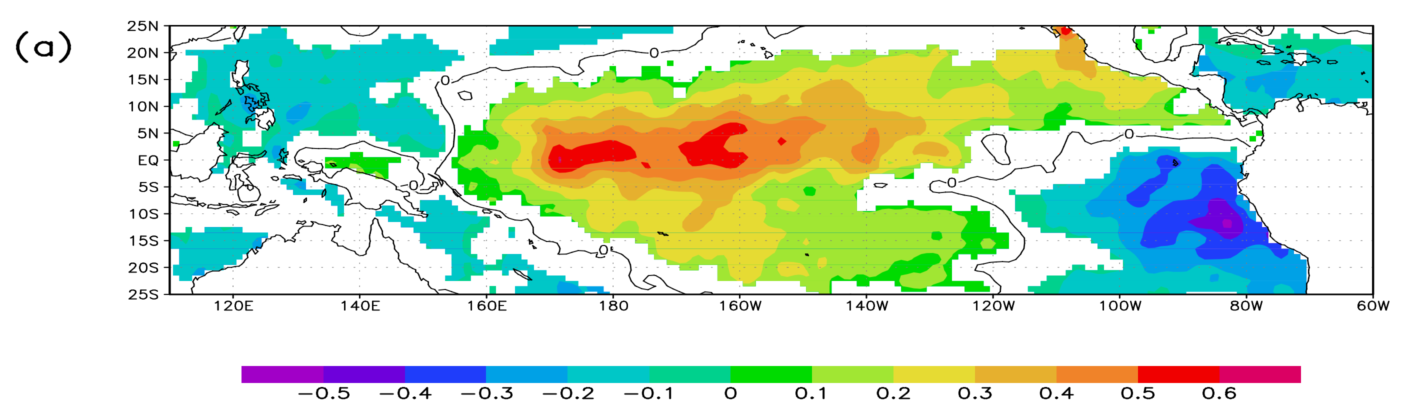


(Top): partial correlations between SLPA and EMI. (bottom): Walker circulation anoms, DJF 2004/05

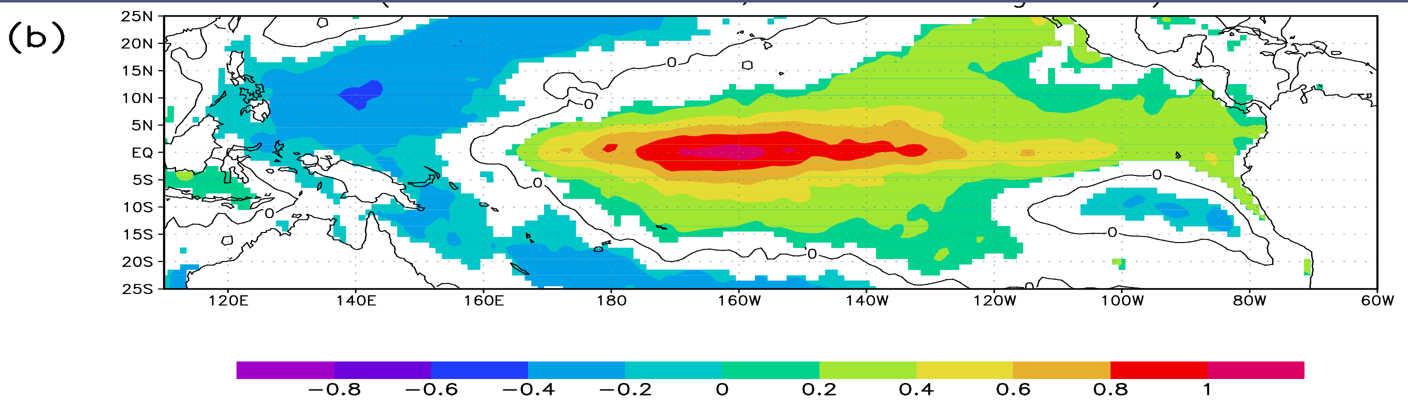


Composite SSTA in ºC

JJAS



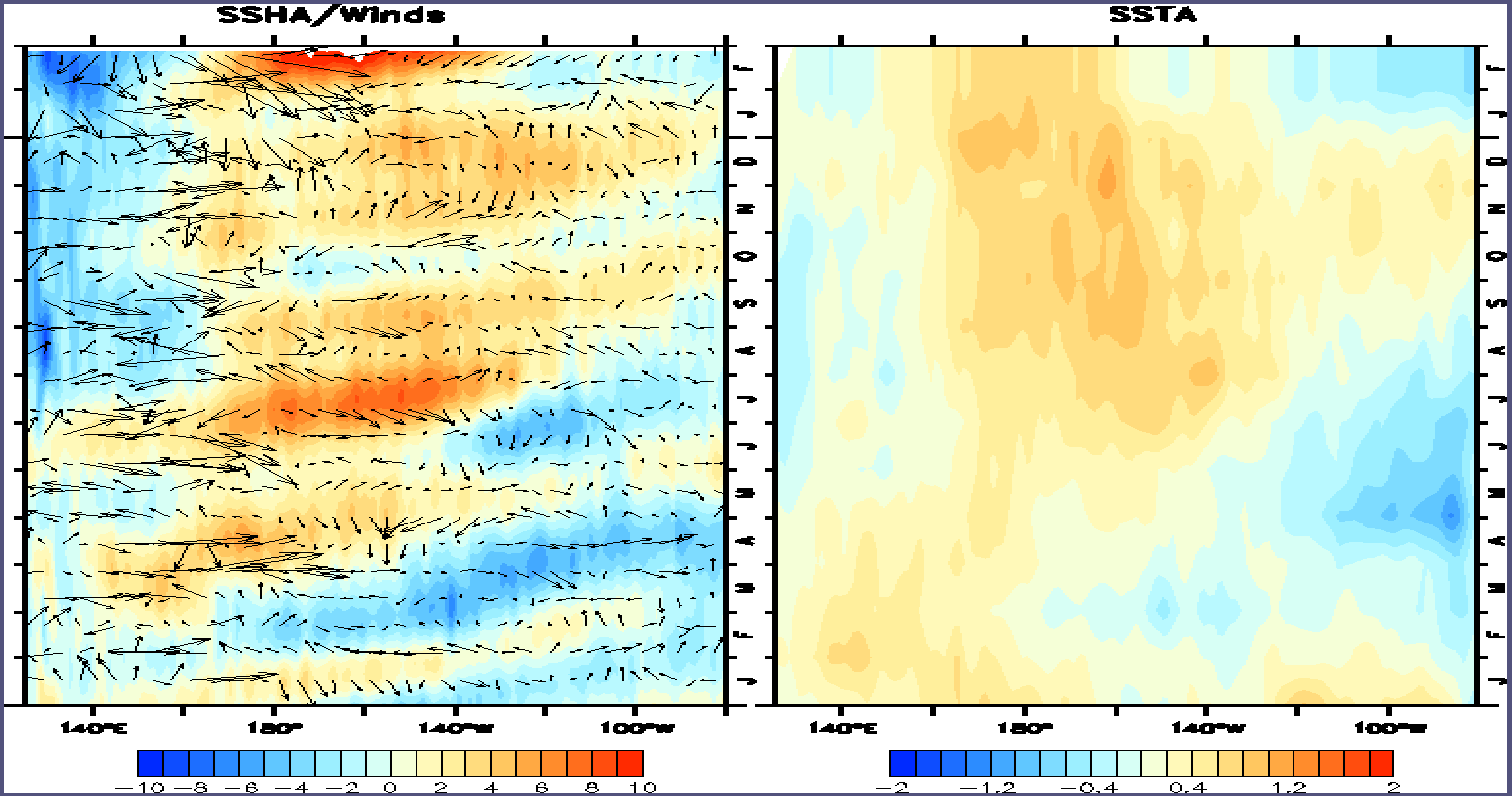
DJF



(a) 7 boreal summers, namely JJAS seasons of 1986,1990, 1991, 1992, 1994, 2002 and 2004.

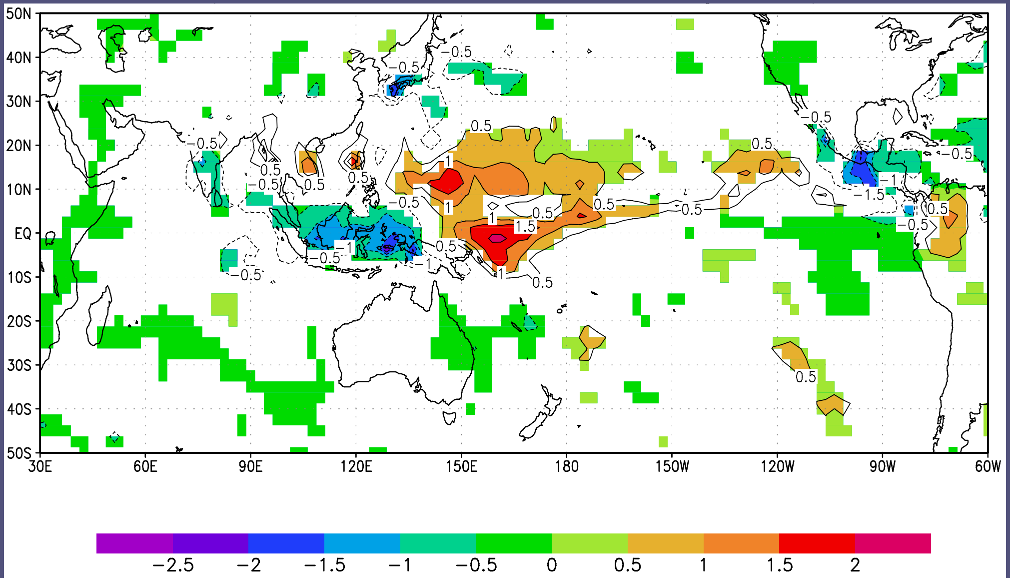
(b) 8 boreal winters, namely DJF seasons of 1979-80, 1986-87,1990-91, 1991-92, 1992-93, 1994-95, 2002-2003 and 2004-05.

Significant values above 95% confidence level from a two tailed Student's t-test are shaded.

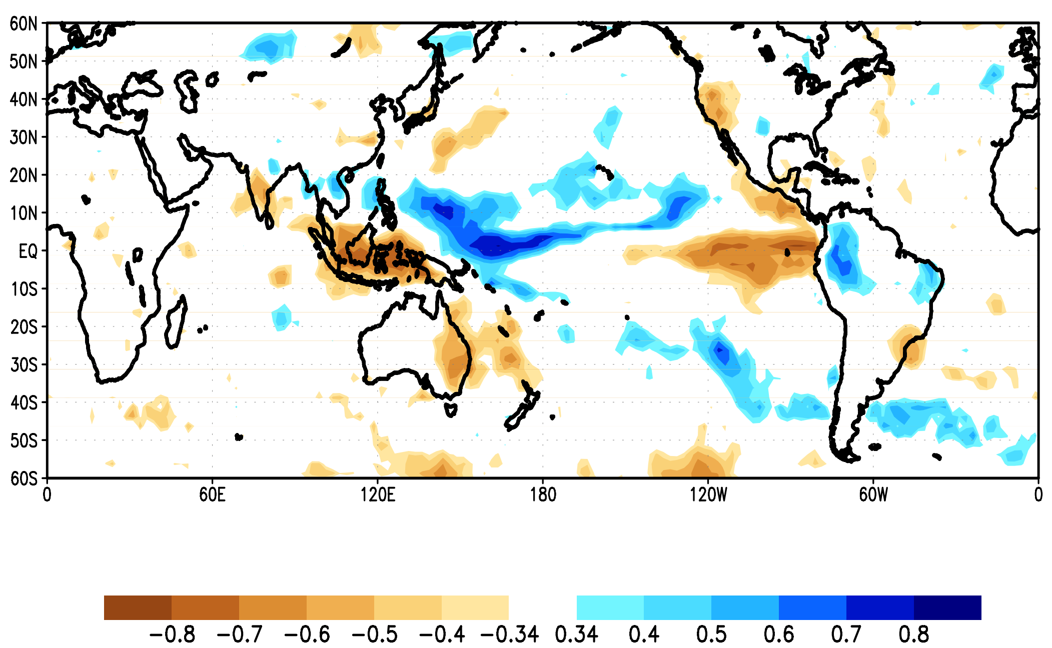


ENSO Modoki events are triggered in the tropical western Pacific.

Because of this importance of the western tropical Pacific, it is also worth noticing that the correlation of the western tropical Pacific SSTA with EMI is -0.51, much larger than the correlation of 0.25 with TNI.



(top) Composite JJAS GPCP rainfall anomalies (cm/month) during strong positive El Niño Modoki events averaged over seven boreal summers. **(below)**Partial Corr. of GPCP rainfall With EMI.



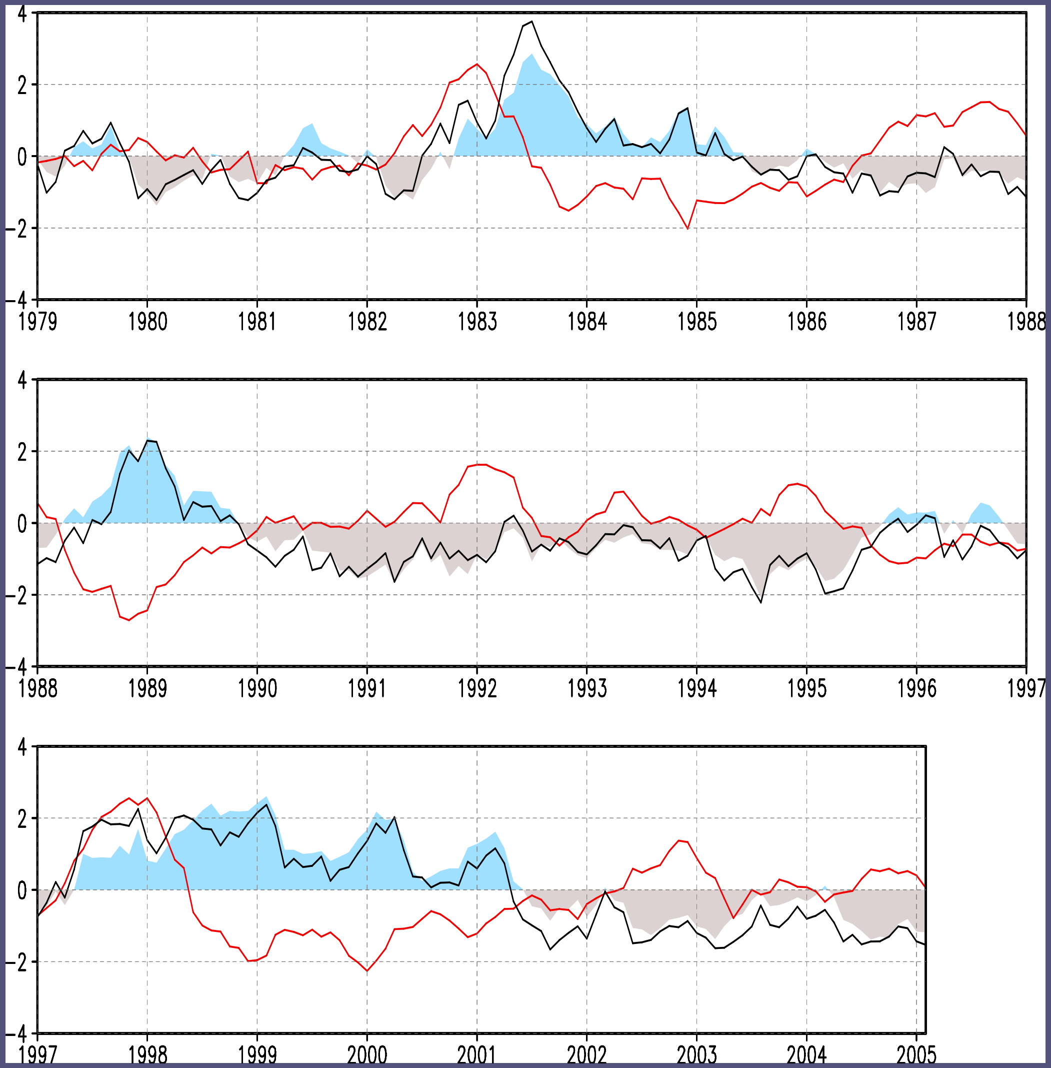
The correlations of the PC2 with NINO4 and NINO1+2 indices are 0.51 and -0.44 , respectively. Its correlations with SSTA in our equivalent boxes in the central and eastern tropical Pacific are 0.51 and -0.42. Therefore, both indices are similar.

The correlation of the PC2 with the western box B is -0.45. The western tropical Pacific SSTA is just as important as that of the eastern Pacific.

EMI vs. TNI

- Trenberth and Stepaniak (2001) introduced another index called trans-Nino index (TNI) as the difference between normalized SSTA between NINO4 and NINO1+2. TNI is correlated at 0.8 with the time series of SVD2 of SSTA and several atmospheric fields such as precipitation (Trenberth et al., 2002), and hence they accept TNI as an index to represent the SVD2 in the tropical Pacific; the correlation of the SVD2 time series with the tropical Pacific SSTA resembles that of our EOF2.

- The correlation between TNI and EMI is -0.87 for the study period. From this simple analysis, TNI appears to be almost the same as EMI. Nevertheless, we will show the advantage of EMI in the following.



The time series of normalized Nino3.4 (red line) index, and TNI (black line) as defined by Trenberth and Stepaniak (2001). Also shown is the time series of the *inverted* EMI (shaded). The sign of the EMI has been deliberately reversed in this figure to facilitate easy comparison of its evolution with the TNI.

TheEMI is better statistically as well as dynamically to represent the EOF2 pattern of tropical Pacific SSTA variability.

The relative correlations of EMI and TNI with PC2 are 0.93 and 0.88.

Because of their strong similarity and association with EOF2, both indices may be considered analogous in representation of the El Niño Modoki for many practical purposes, just as the NINO3 and NINO3.4 indices in case of El Niño events.

Relationship between ENSO and ENSO Modoki

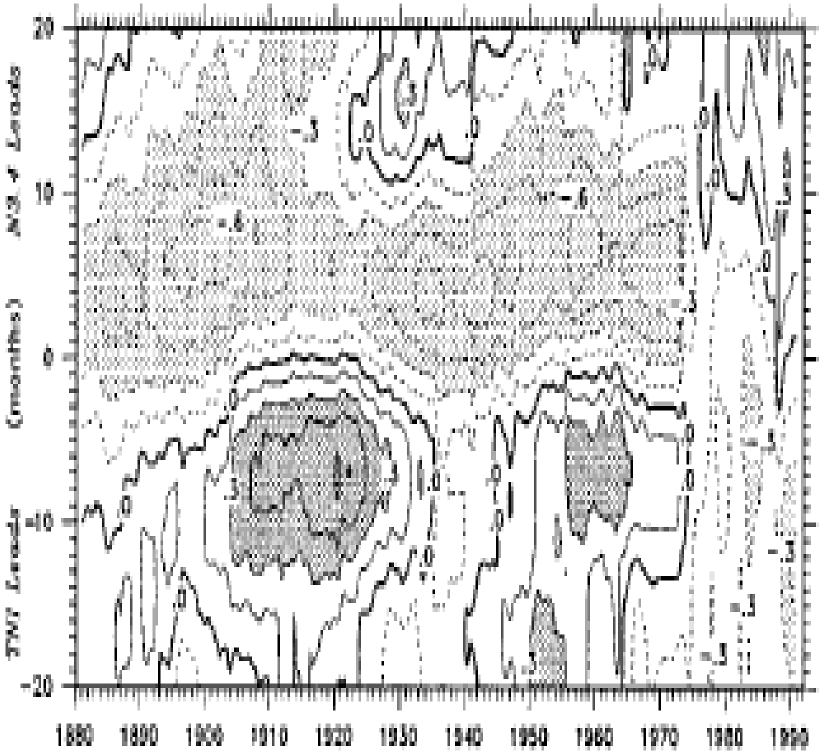
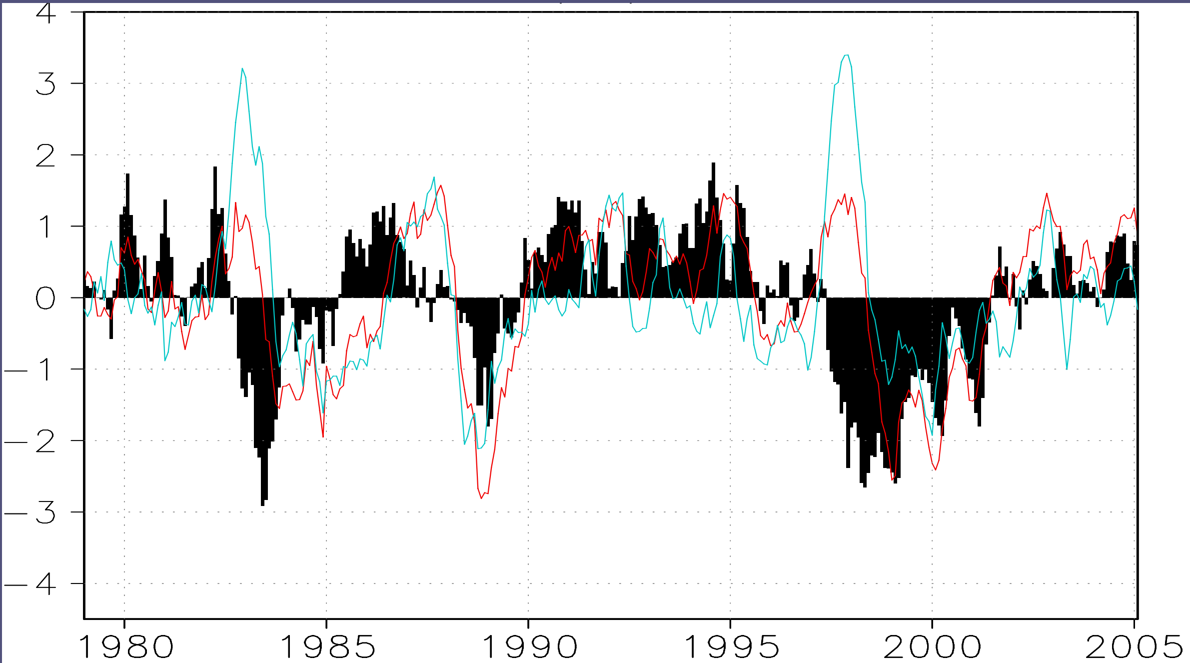


FIG. 2. Moving cross correlations of TNI with N3.4 as 241-month running means (about 20 yr). Negative lag means TNI leads, and positive lag means N3.4 leads. Values exceeding 0.3 in magnitude are shaded.

Trenberth and Stepaniak (2001) indicate that NINO3.4 and TNI are significantly correlated at different lags/leads, and hence they conclude that their SVD2 pattern is one phase of ENSO evolution.

However, they admit that the relationship has changed along with changes in ENSO characteristics after the climate regime shift in the middle 1970s (Nitta and Yamada, 1989). It is seen in their Fig. 2 that the lag/lead moving correlations have considerably weakened after 1976; these also changed their respective signs. Hence, their conjecture that the trans Nino pattern of SSTA is part of El Niño evolution is not always supported.

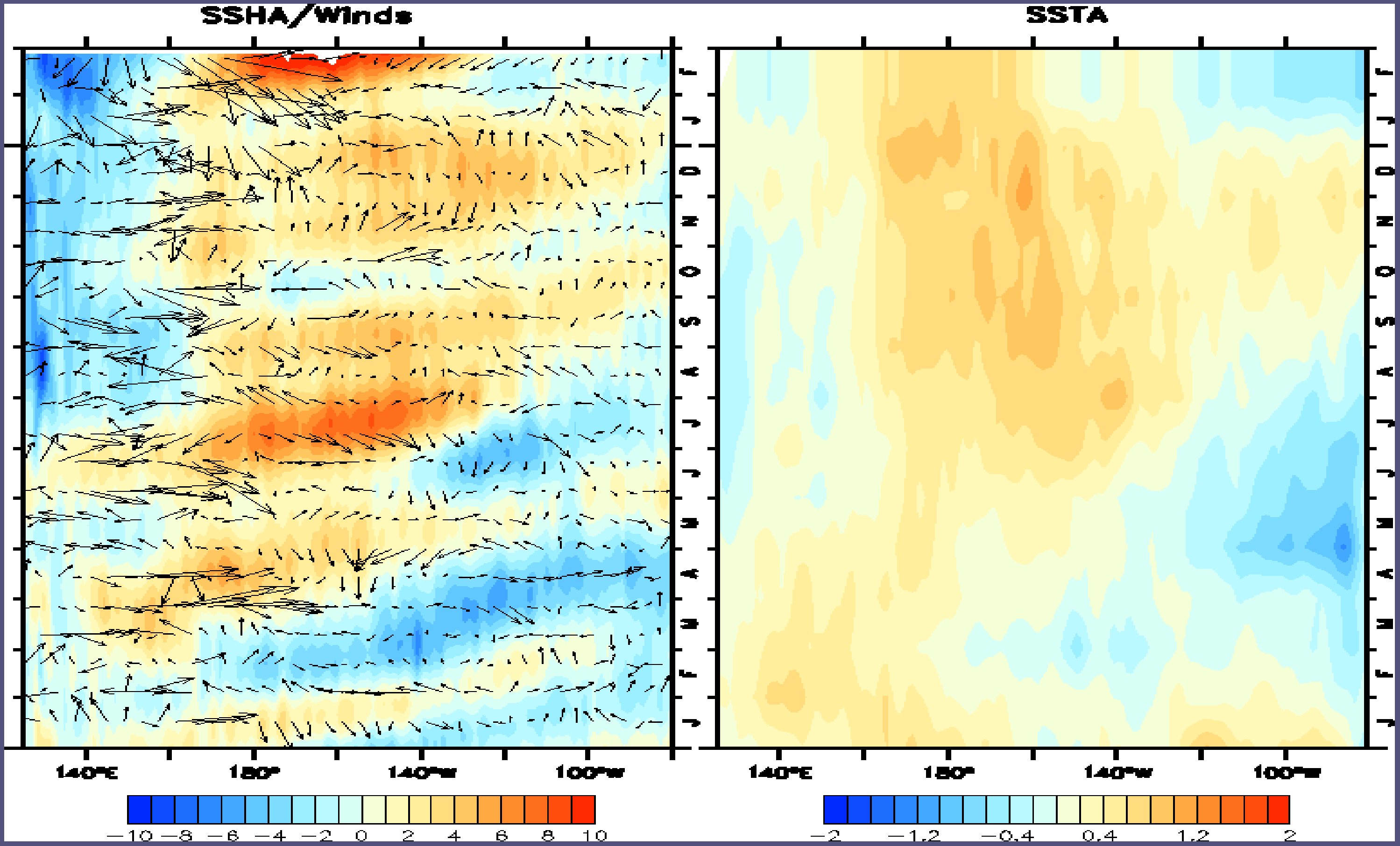


Normalized time series of the PC2 of the tropical Pacific SST variability (Bar), NINO3 SSTA (blue) and Nino4 indices (red).

If the hypothesis of Trenberth and Stepaniak (2001) applies, the El Niño Modoki conditions in summer of 2004 should have been followed (preceded) by an El Niño (a La Niña) after (before) 3-12 months; ***neither of these things happened, as indicated by the NINO3.4 index (or by the NINO3 index)***.

- In fact, out of the three major El Niño events after 1977, only the 1982-83 period fits the hypothesis stipulated by Trenberth and Stepaniak (2001).

- Even during 1997 when a strong El Niño event occurred, it was preceded by a very weak El Niño Modoki event. Importantly, it can also be seen that that the condition suggested by Trenberth and Stepaniak (2001) is not valid for the so-called protracted El Niño period of 1990-94.



Abnormal conditions during JJA in 2004: (a) SSTA in ºC (b) evolution of SSHA in cm (shaded) and wind anomalies (m.s-1; vectors), averaged between 2ºS-2ºN, and (c) evolution of SSTA averaged between 5ºS-5º N.
(Aviso SSHA, Quickscat winds, and HadiSSTA)

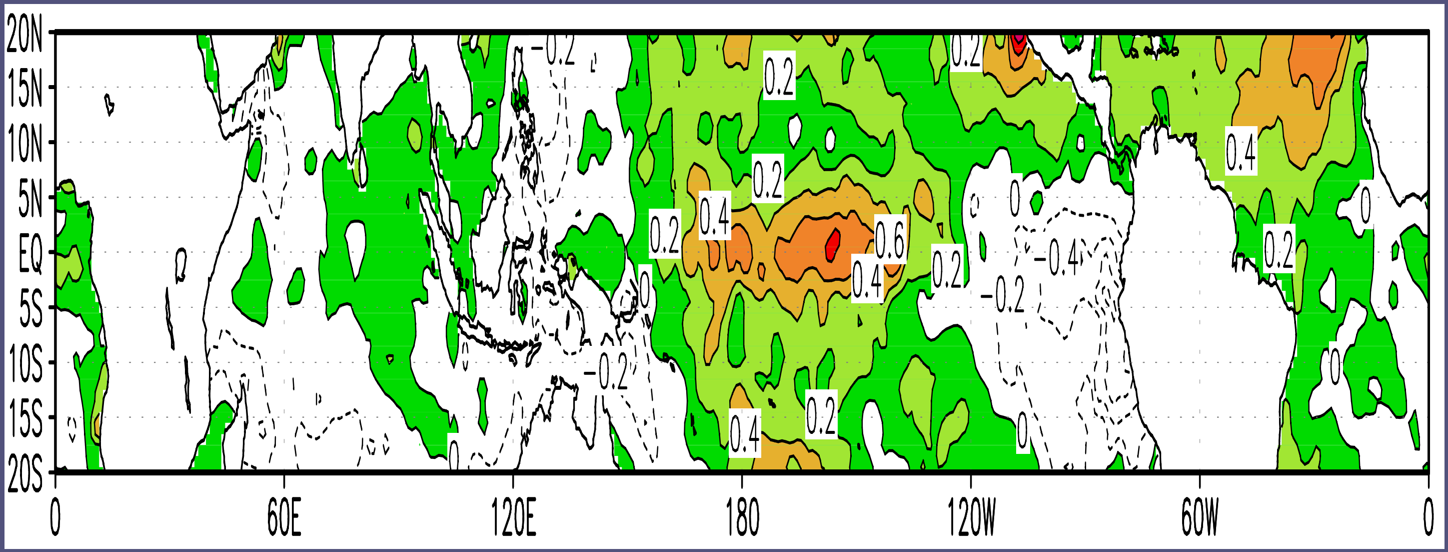
The Press

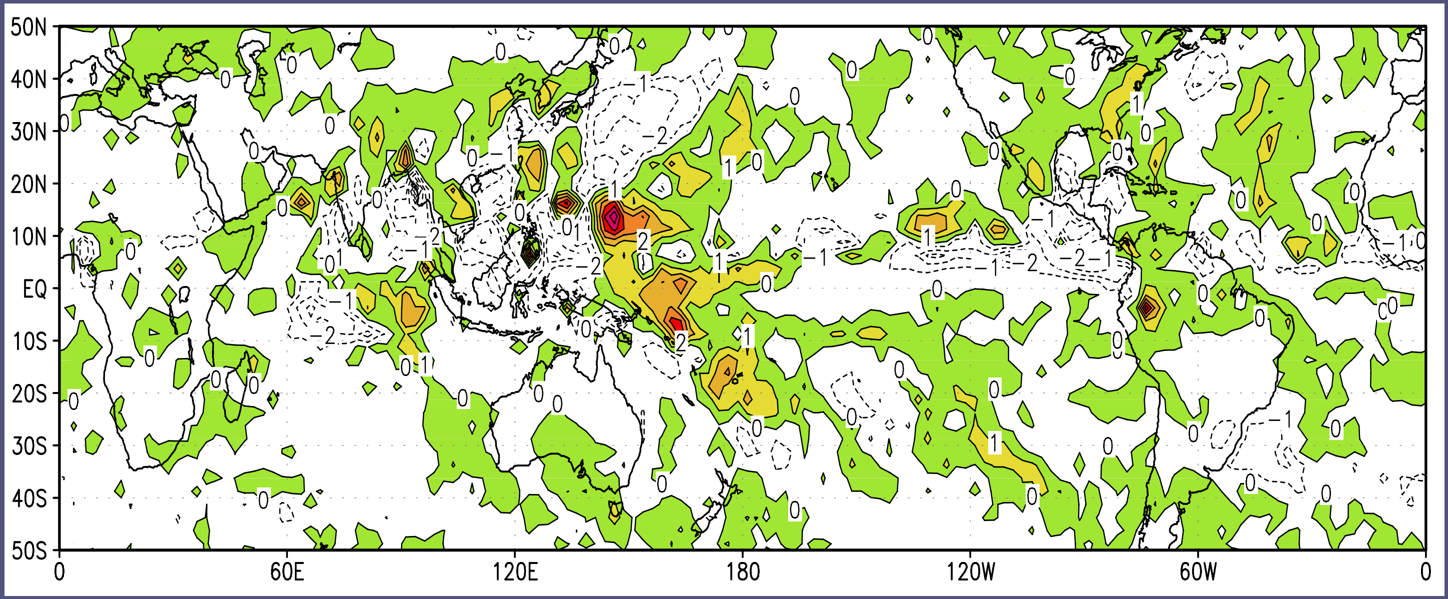
- A news also appeared in “Japan times” on July 24, 2004 under the heading “'Mock El Nino' culprit behind heat wave, floods: Professor”, which follows: “The heat wave and floods in various parts of Japan are being caused by an El Nino-like phenomenon in the central Pacific Ocean, a Japanese researcher said Friday. Toshio Yamagata, a professor at the University of Tokyo specializing in climate dynamics, said an increase in the sea surface temperature has activated convection currents and promoted a high-pressure ridge in the Pacific, bringing a hot summer to Japan ……..” For further details of this news, see http://www.japantimes.co.jp/cgi-bin/getarticle.pl5?nn20040724f3.htm
- Some other links to Japanese news items and related articles follow:

http://www.kyoto-np.co.jp/kp/special/ecology/eco/eco63.html

http://www.tbs.co.jp/morita/qa_nanmon/faq_040811-1.html

- It has been long said that each El Nino has its own face
- Recently introduced so-called “Date line El Niño” (NOAA definition /Larkin and Harrison, 2005 GRL) is only based on warming in NINO3.4 region *irrespective of warming/cooling in the eastern tropical Pacific*.





Top: Anomalous JJAS 2004 SST (ºC).
Bottom: Anomalous JJAS 2004 rainfall (cm/month)

- El Niño Modoki – a new tropical Pacific mode ?
- Not a part of El Niño evolution
- Involves ocean-atmosphere coupled processes – it is a coupled mode
- Teleconnection
- Decadal variability and its link with the change of the background state
- Summary

The reason for the lag/lead correlations

- The significant lead/lag correlations between the indices of ENSO and ENSO Modoki discussed earlier can be attributed to the fact that the tropical central Pacific is the common playground for both of these phenomena. Nevertheless, the magnitude of these correlations is relatively modest. This is because of the difference in the zonal extent of this playground for the coupled dynamics during these two phenomena. During El Niño events in years such as 1982-83 and 1997-98, the equatorial central Pacific warming propagates to the tropical eastern Pacific. However, during majority of the El Niño Modoki events, the propagation takes place only up to the equatorial central Pacific.

Concluding Remarks

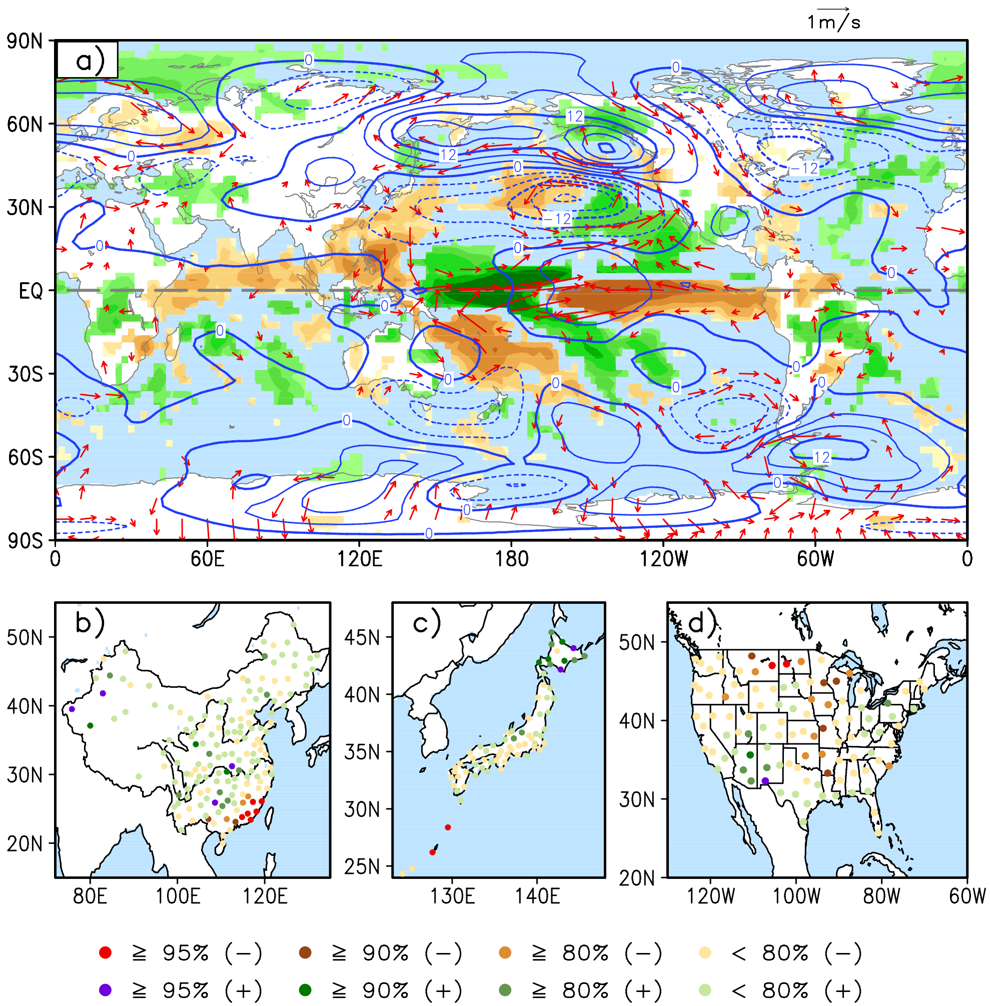
1. El Niño Modoki is a phenomenon in the tropical Pacific, has different spatial and temporal characteristics from those of canonical El Niño.

2. The extratropical response to the tropical SST distribution in El Niño Modoki, and the location where the largest moisture transport from the tropical Pacific to the subtropical and extratropical regions are very different from those during El Niño events.

3. The large decadal background provide background of persistent droughts in some region, such as the West of the United States in the beginning of the 21st century.

4. The Nino3.4 index is not proper to define El Niño phenomena, because it picks up the warming in either eastern or central equatorial Pacific. Thus, the El Niño events defined by this index mixes up both the canonical El Niño events and El Niño Modoki events. The teleconnection patterns related to Nino3.4 index is a residual of those related to two different phenomena: El Nino Modoki and El Nino.

Mid- and Low-level circulation and rainfall anomalies in El Niño Modoki winters



Tropics: The 500hPa high anomaly over central eastern Pacific . 850hPa westerly anomaly over W. Pacific. Strong PDZ in E. Pacific; the dry zones in the west & northwest displaced northward compared with Nino3.

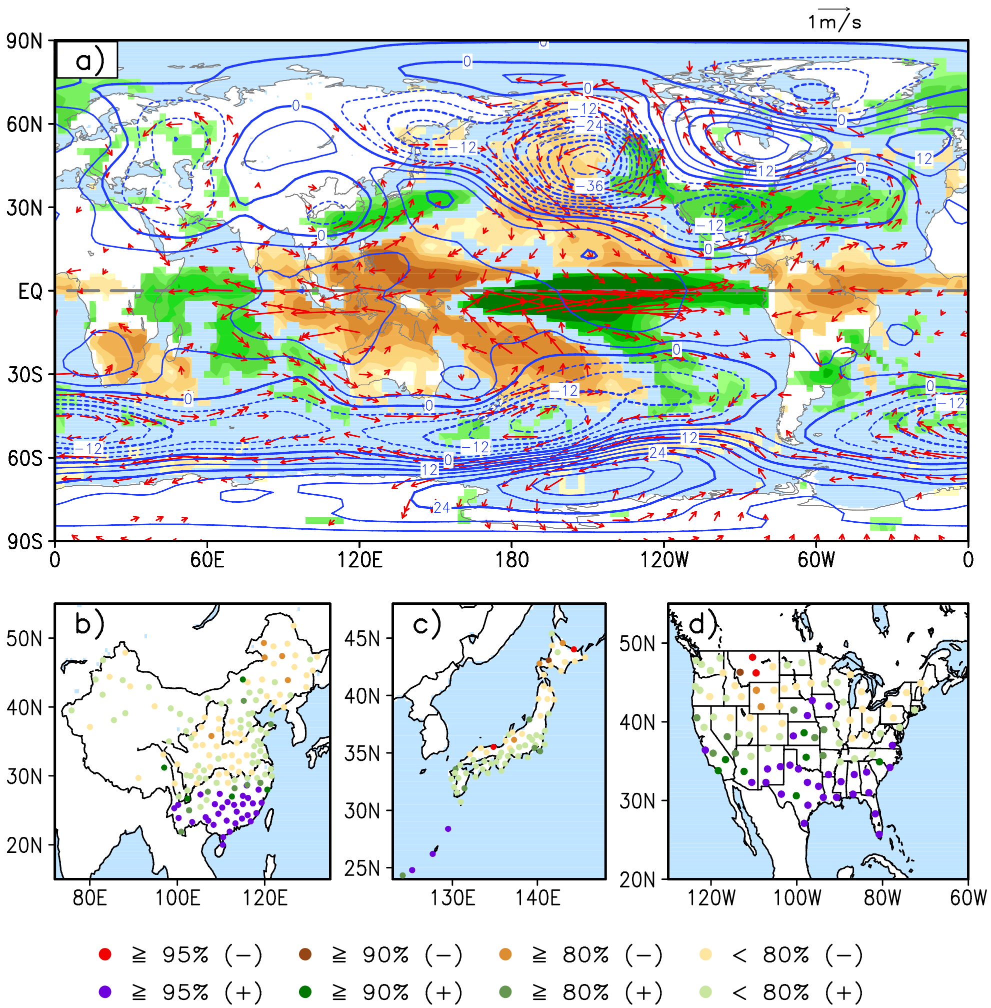
N.H.: A basin-wide low band in subtropical Pacific, a high band to its north, forming a blocking situation, especially in E. Pacific – a meridional wave train from the tropical high. Opposite to the Nino3 related patern.

China: Dry in southern coast;

Japan: Dry in Nansei Islands, extending to Kanto region. Wet from Kinki to Tohoku/Hokkaido.

U.S.: Dry in most states, especially in northern Great Plains. Wet in southwestern states.

Mid- and Low-level circulation and rainfall anomalies in El Niño winters



Tropics: two 500hPa high anomalies over central eastern Pacific and Indonesia. 850hPa easterly anomaly over Indonesia. No, PDZ in E. Pacific; broad dry zones in the west, east, northwest, southwest of the wet Equator.

N.H.: Aleutian Low very strong centered 150W45N. NW Pacific,high/low over south/north Japan. Two wet zones in Southeast Asia And southern N. America.

China: Wet in southern coast;

Japan: Wet in Nansei Islands, extending to Kanto region. Dry from Kinki to Tohoku/Hokkaido.

U.S.: Wet in most southern states. Dry in northern Rockies.

a) Partial regression patterns of 500hPa geopotential height (blue contours; m), 850hPa horizontal wind (arrows; m s-1) against Nino3, and the partial correlation pattern of GPCP precipitation rate anomalies (green/brown shaded for Positive/negative values; unit: mm d-1. Significance level < 80% neglected.) b), c) and d) are partial correlations of JJA EMI with JJA rainfall anomalies in China, Japan and the United States, respectively.