Tropical Indian Ocean Impact on Regional and Global Climate

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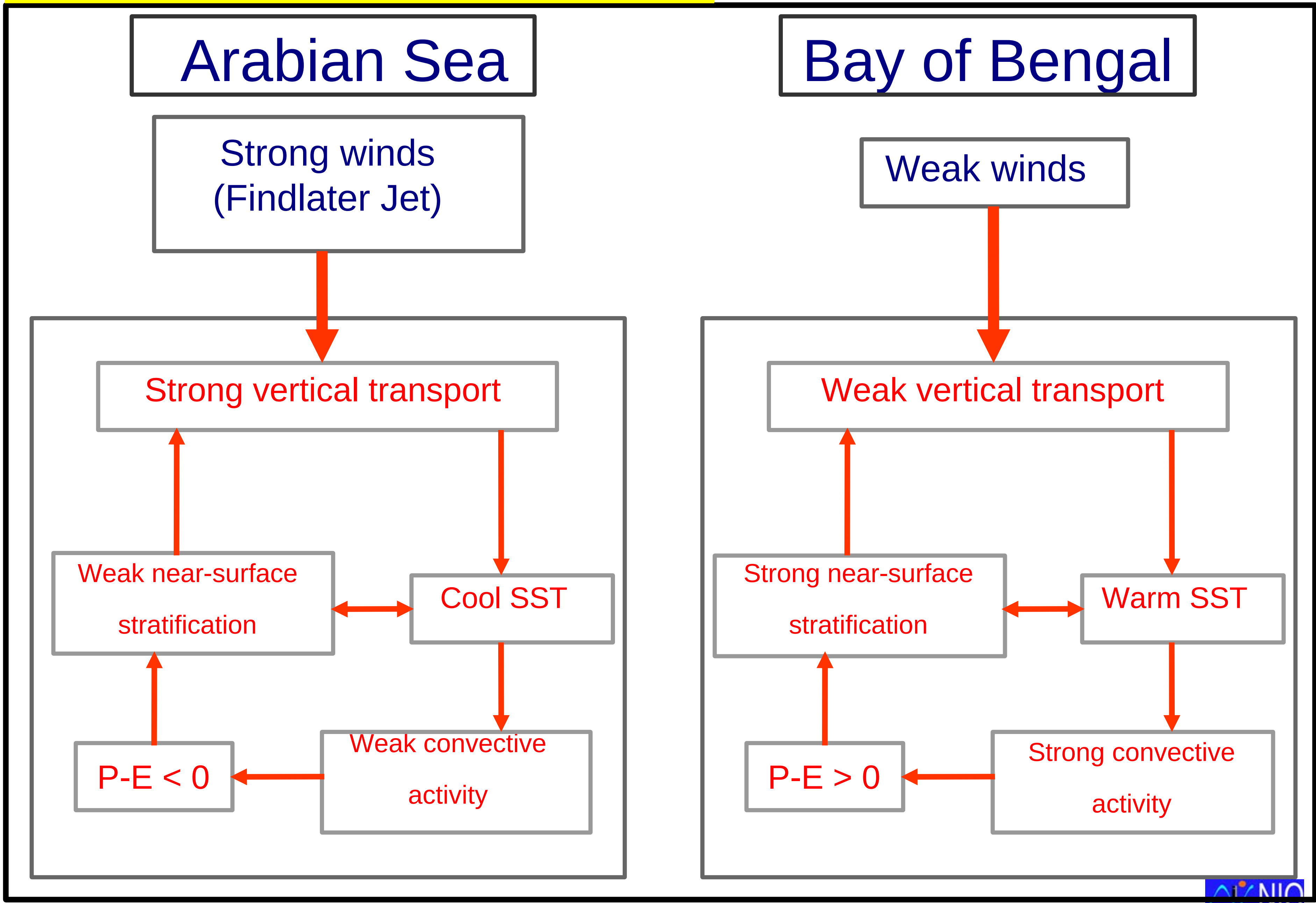
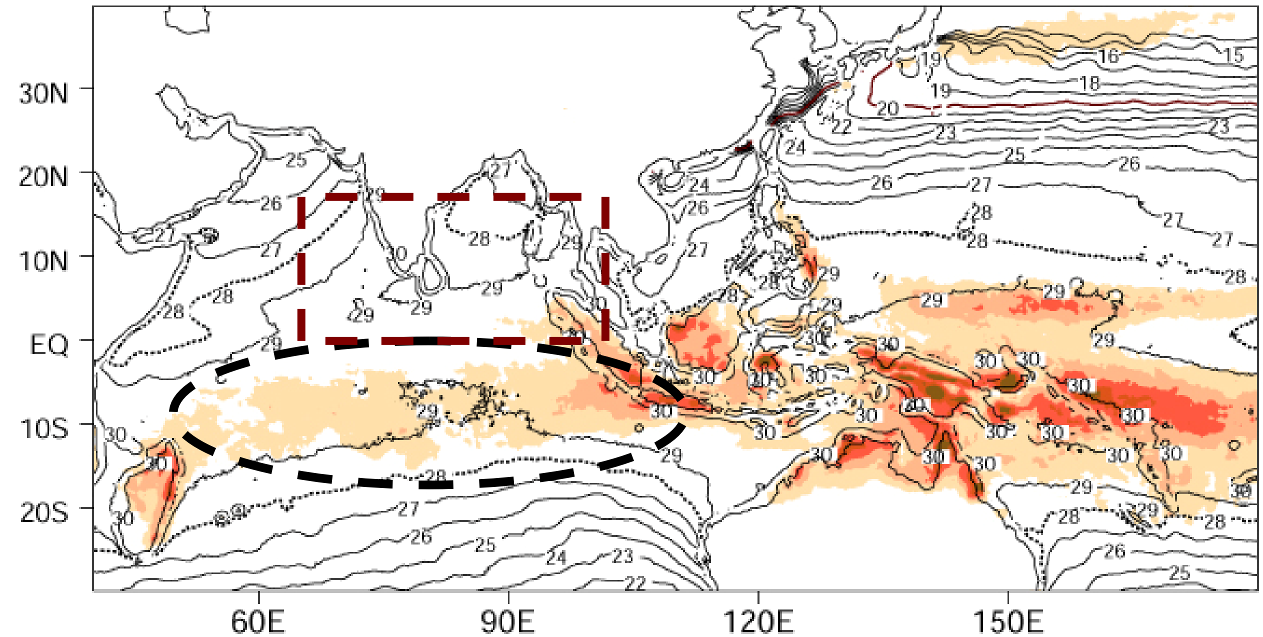
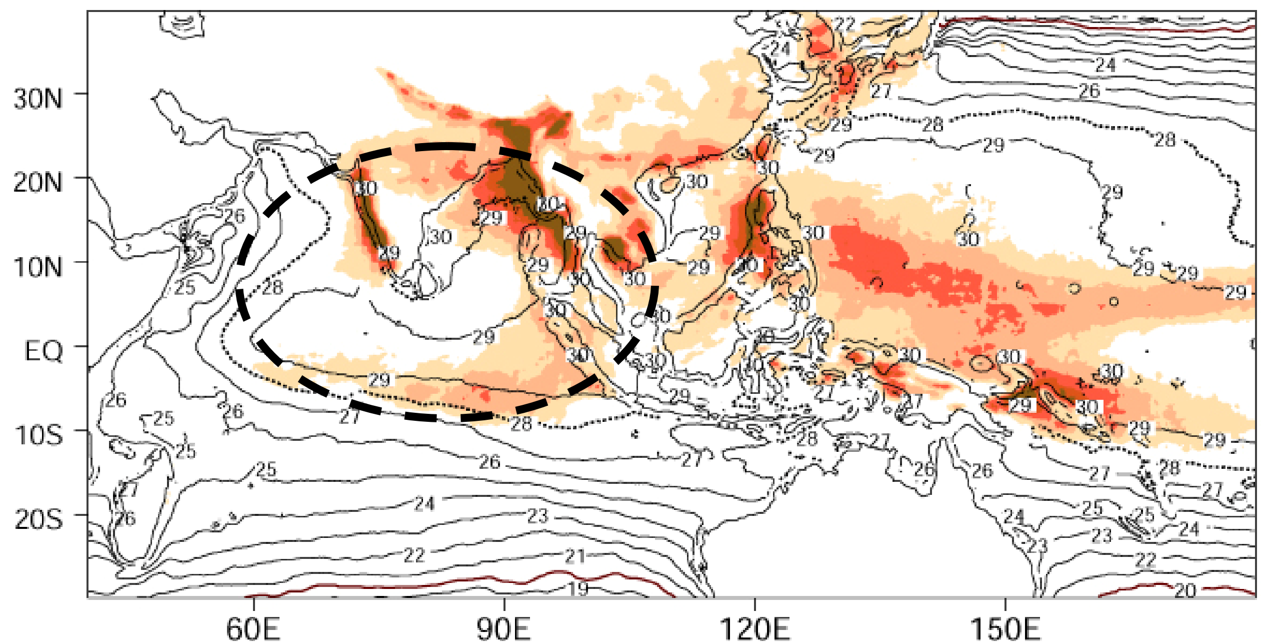
The monsoons: An oceanographer's view …

Shenoi et al (2002)



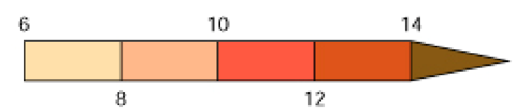


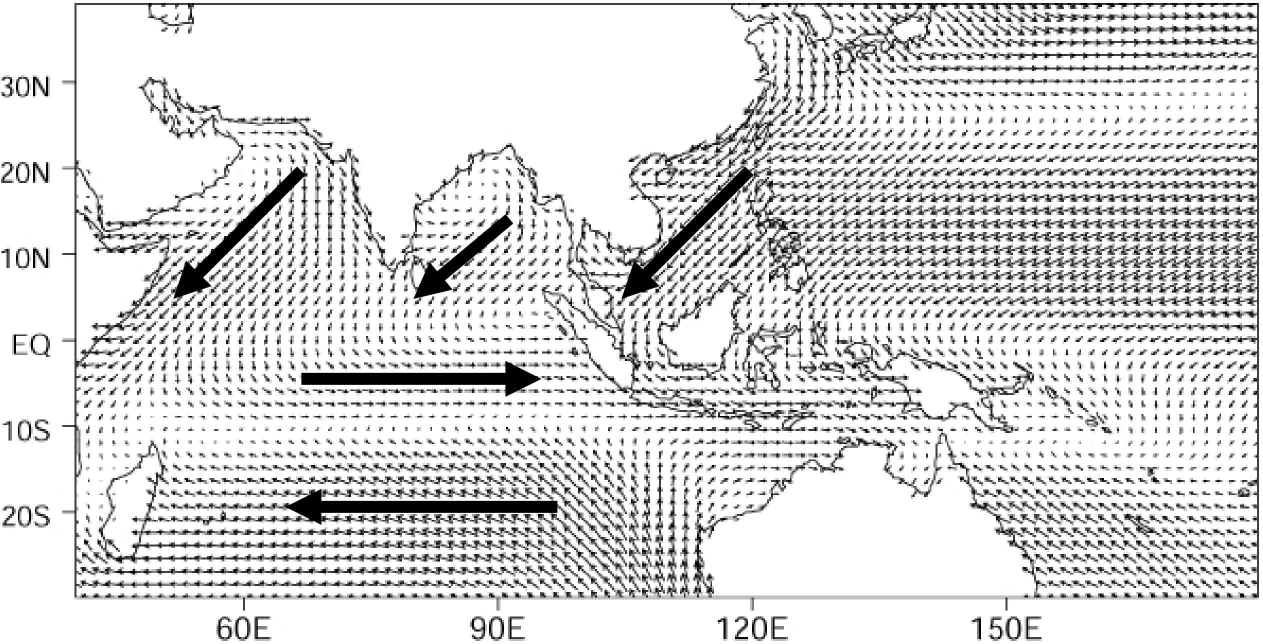
TRMM SST, Pr (DJF)



TRMM SST, Pr (JJA)

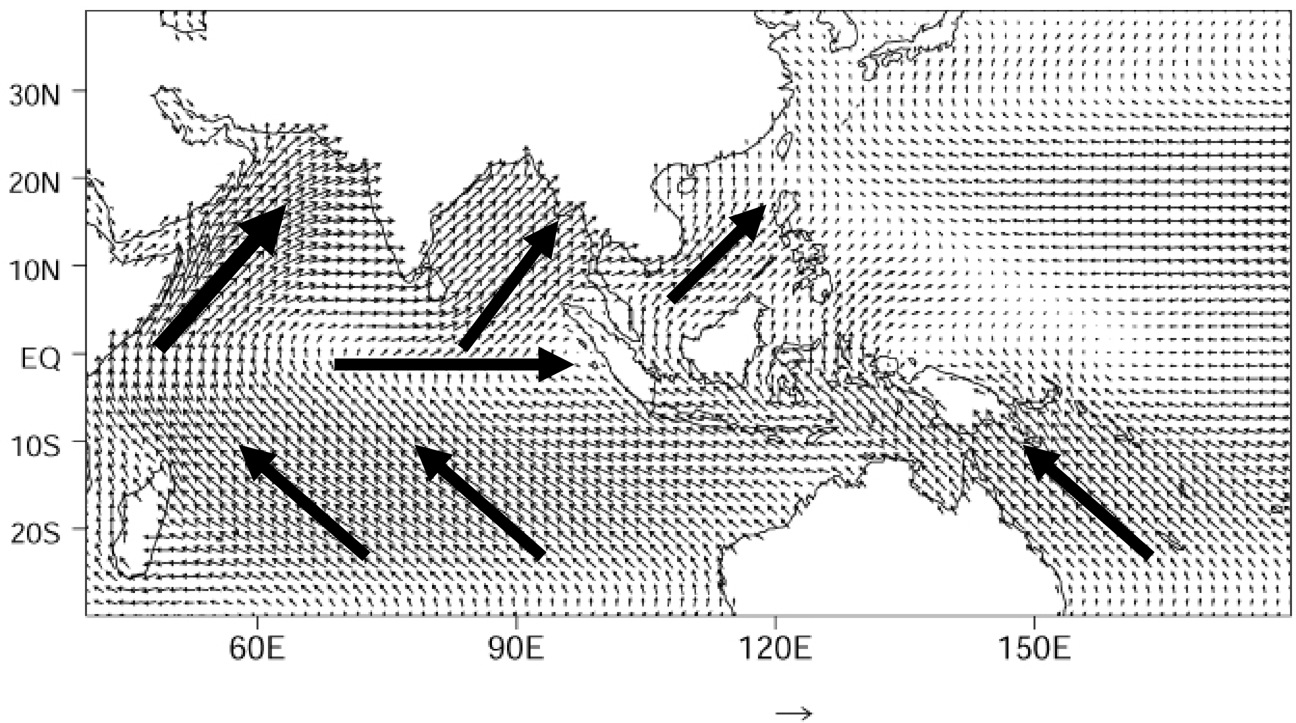
SST > 28^{o}C (necessary but not a sufficient condition)

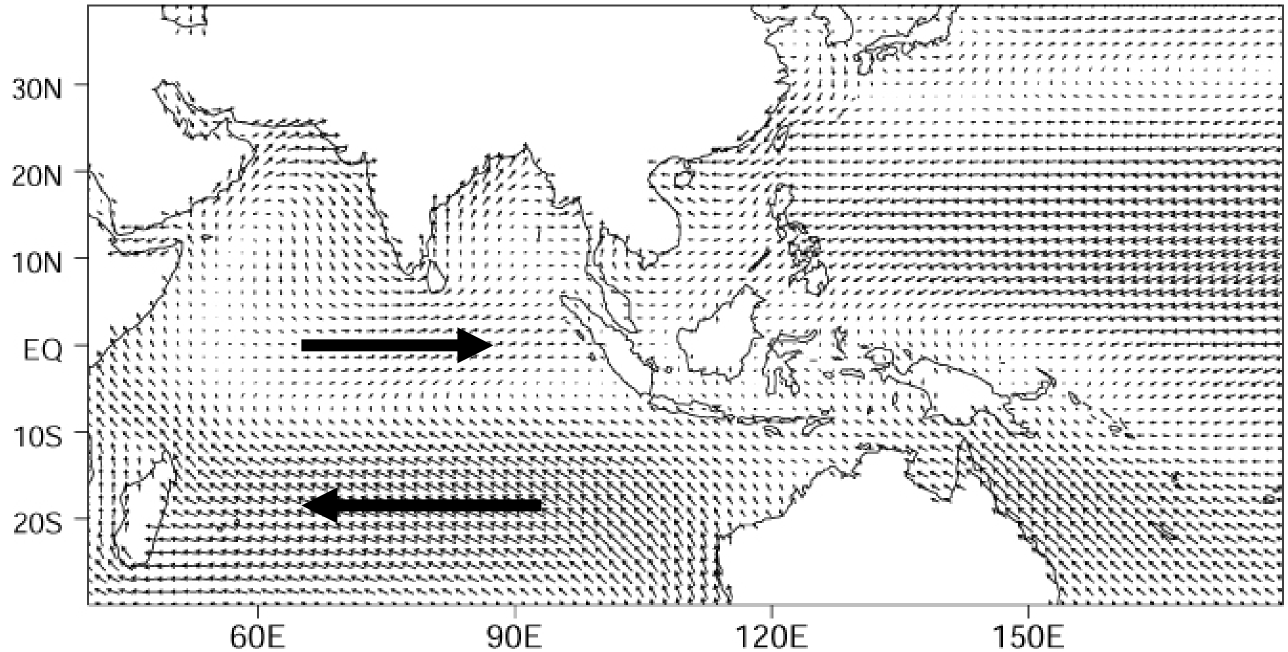




QSCAT winds (DJF)

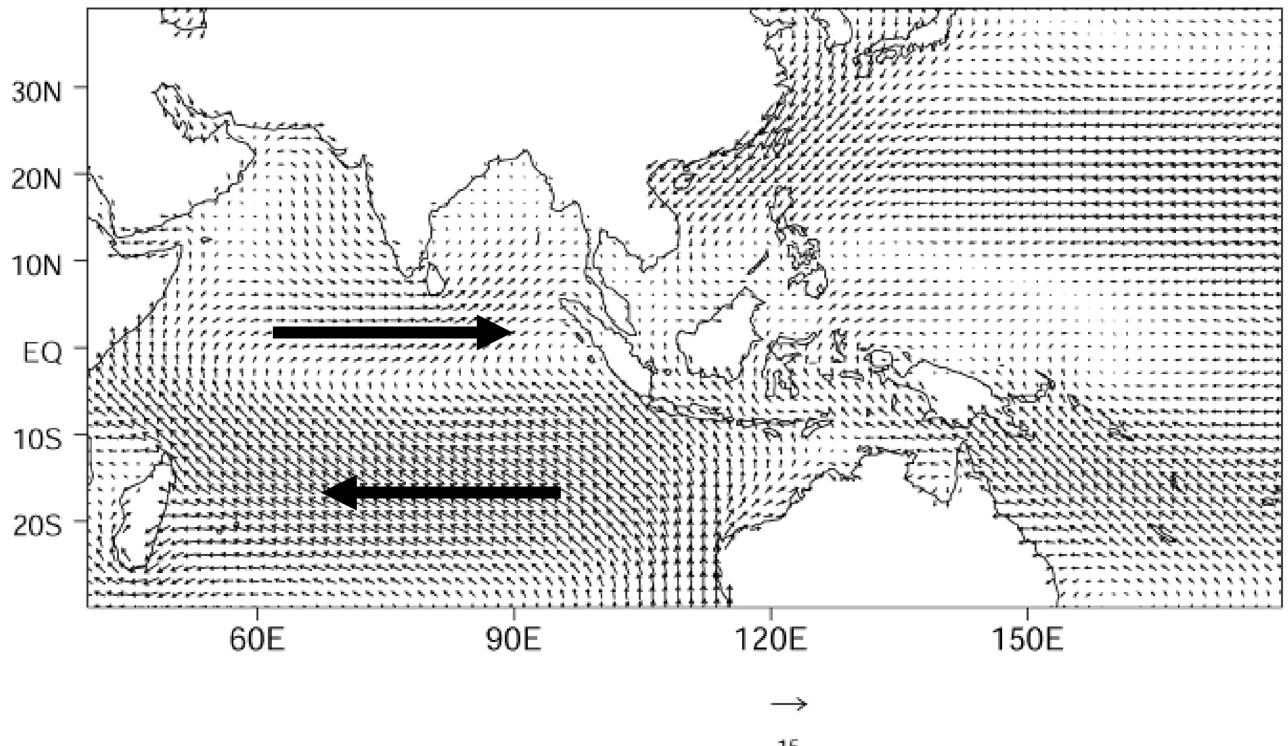
QSCAT winds (JJA)





QSCAT winds (MAM)

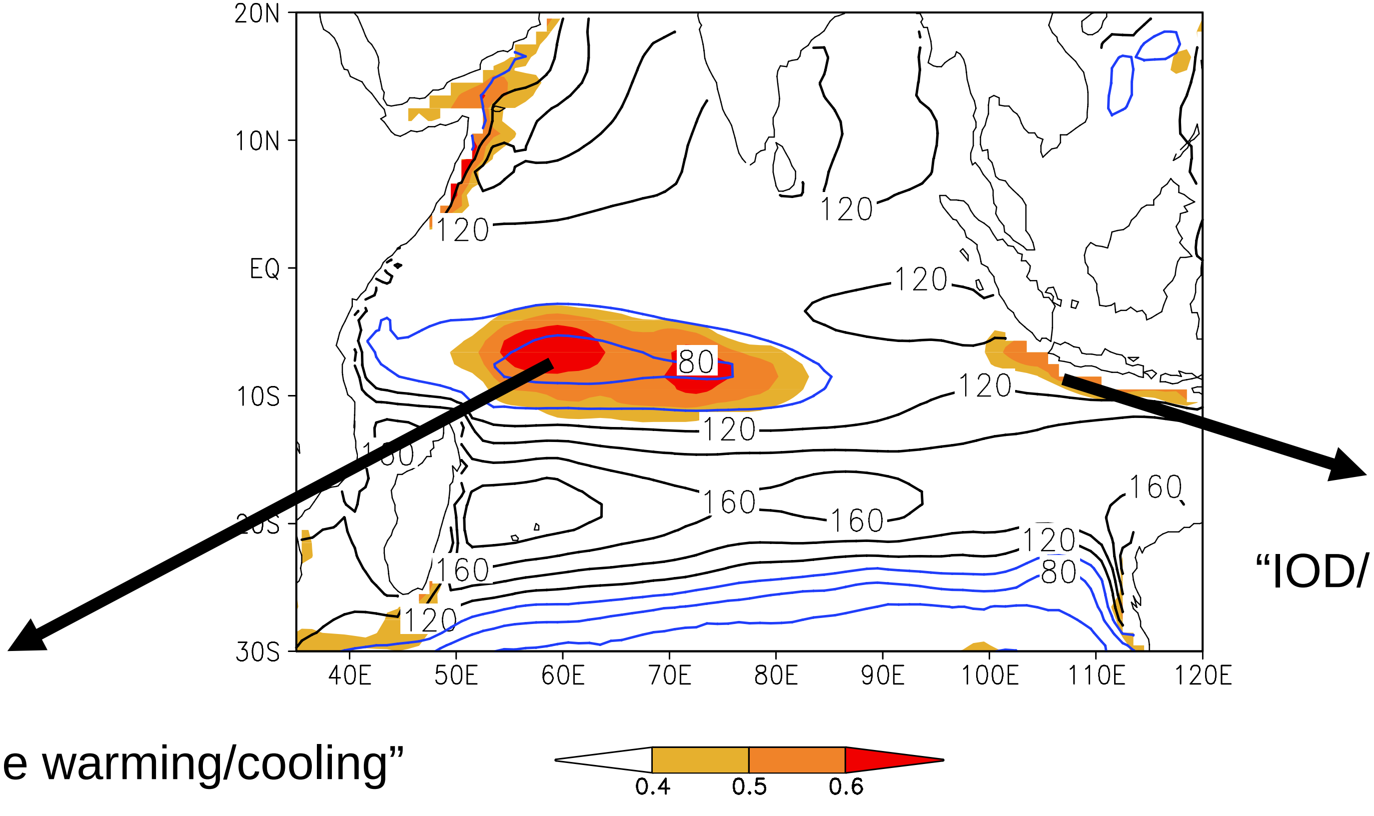
“Spring Wyrtki Jet”



QSCAT winds (SON)

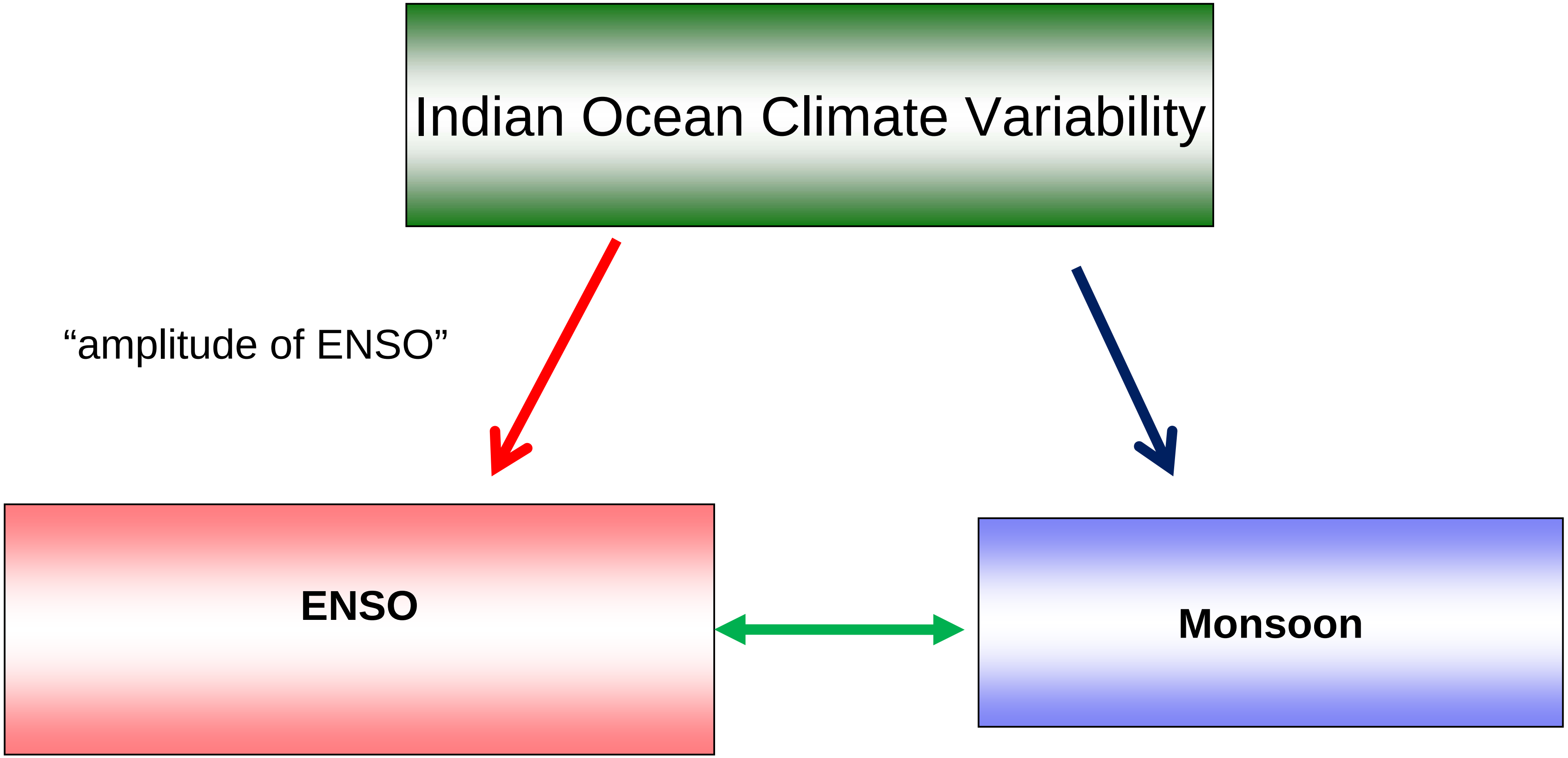
“Fall Wyrtki Jet”

Indian Ocean Climate Variability



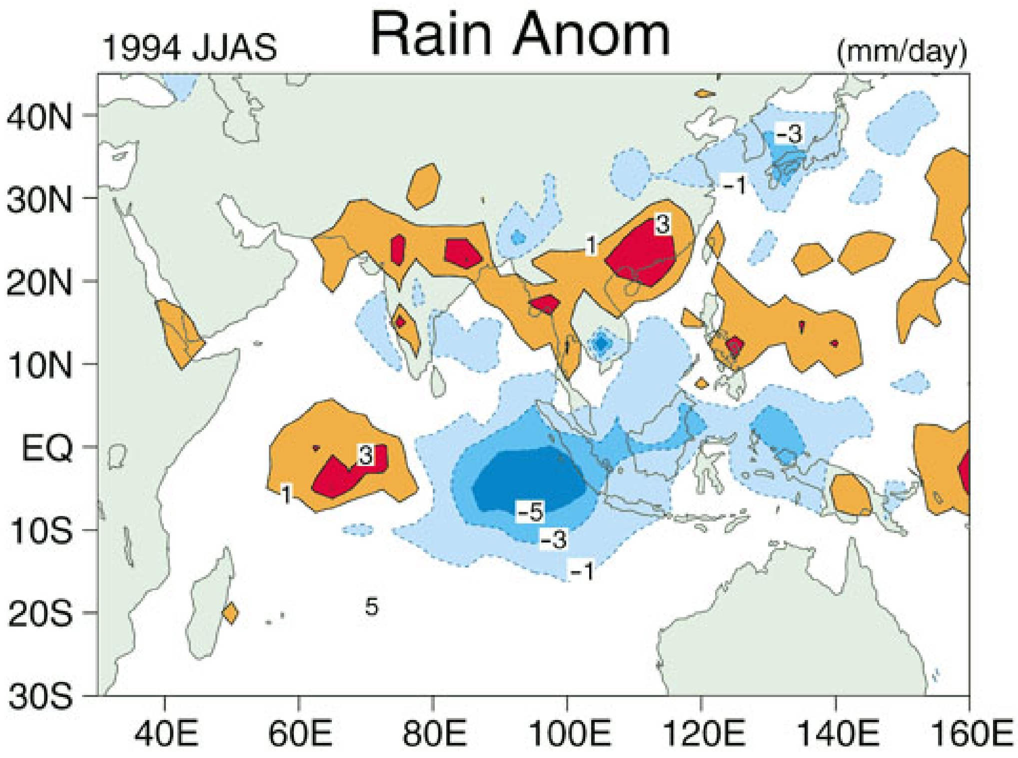
"IOD/IOZM"

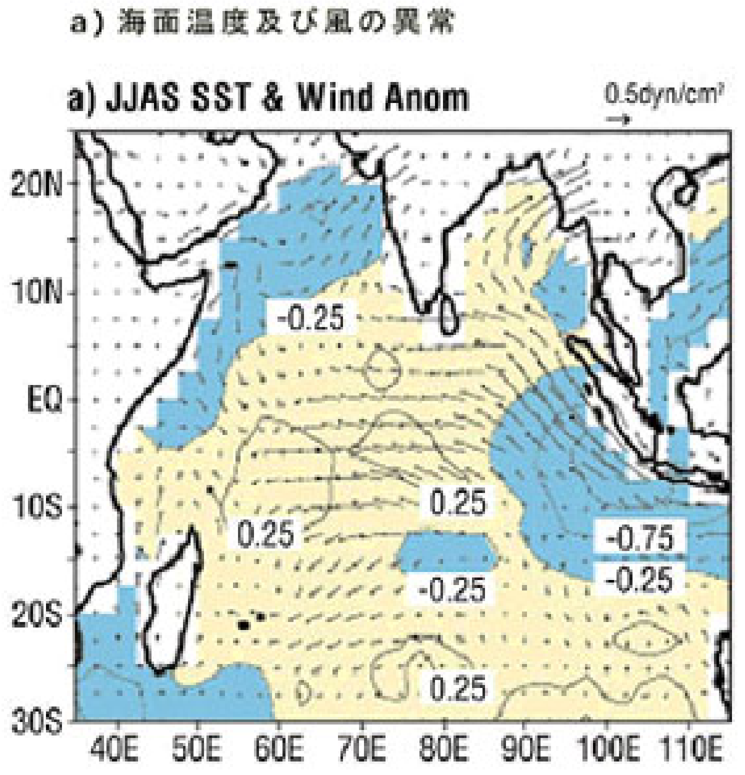
"basin-wide warming/cooling"



ENSO and Monsoon – Two dominant modes of tropical climate system

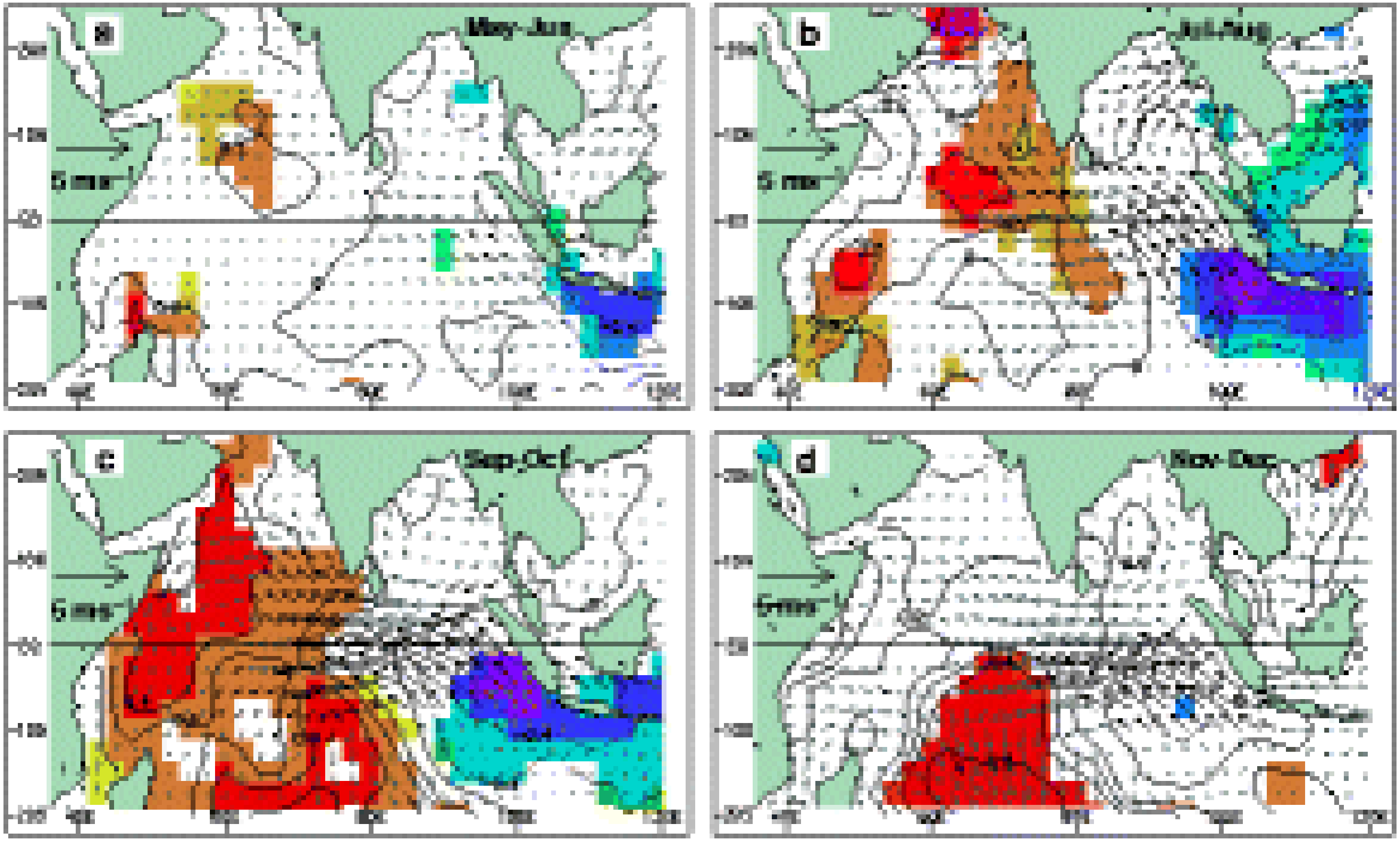
Indian Ocean Dipole/Zonal Mode



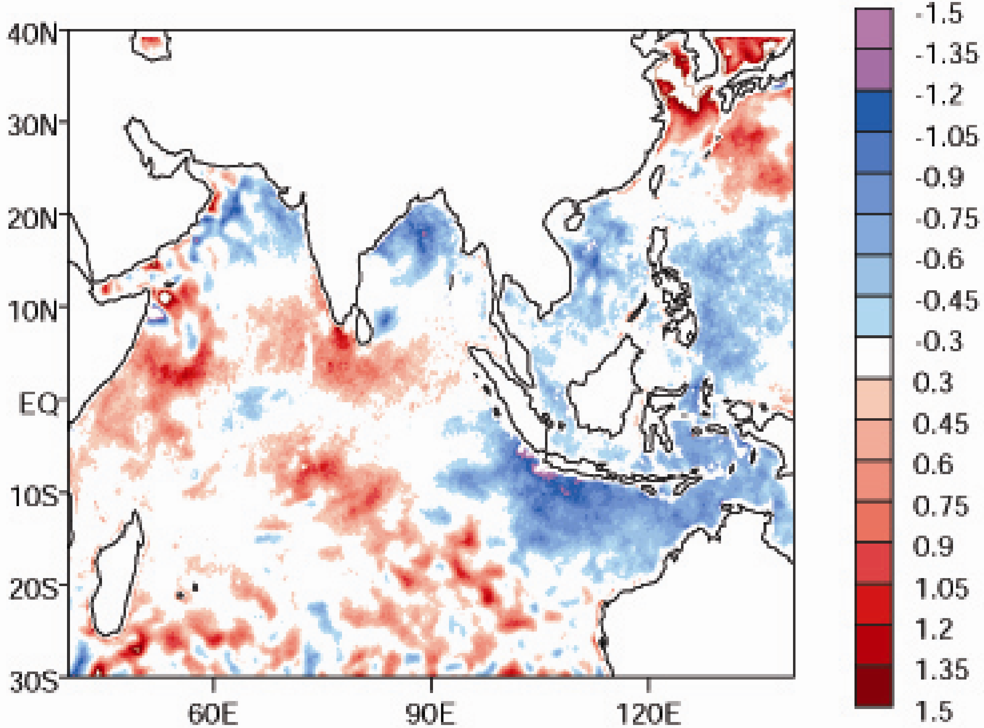


Strong IODZM events (1961; 1994; 1997; 2006)

SST and Surface Winds (Composite evolution of IOD/IOZM)



Saji et al. (1999); Webster et al. (1999); Murtugudde et al. (1998; 2000)

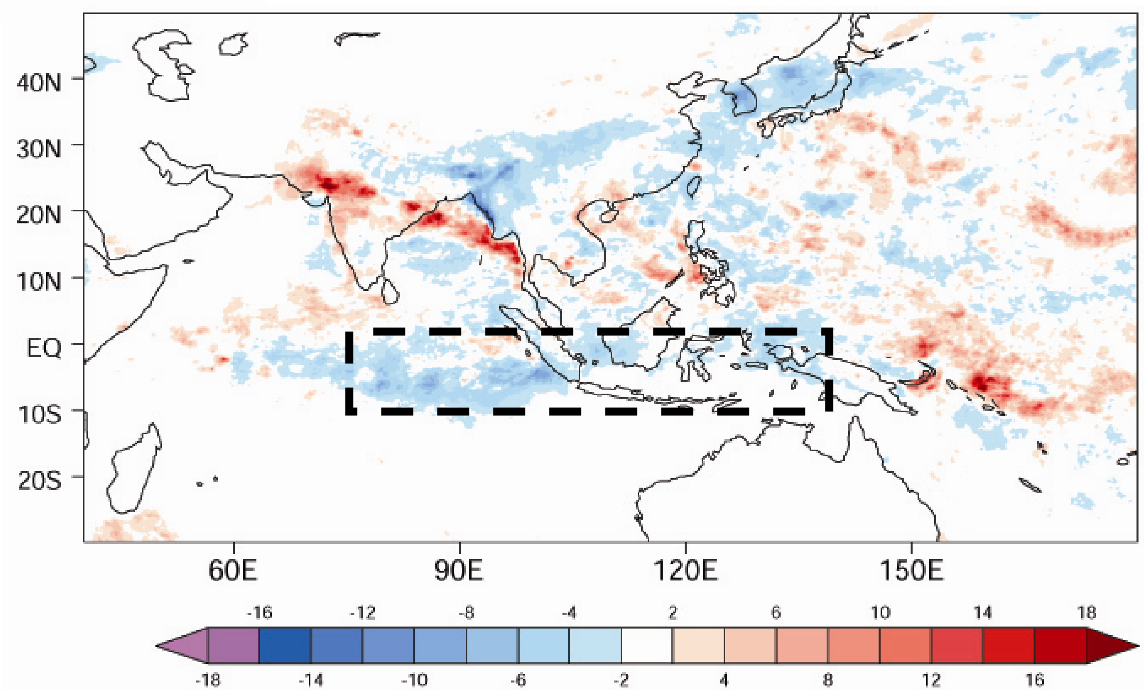


August 2006 TRMM_SST

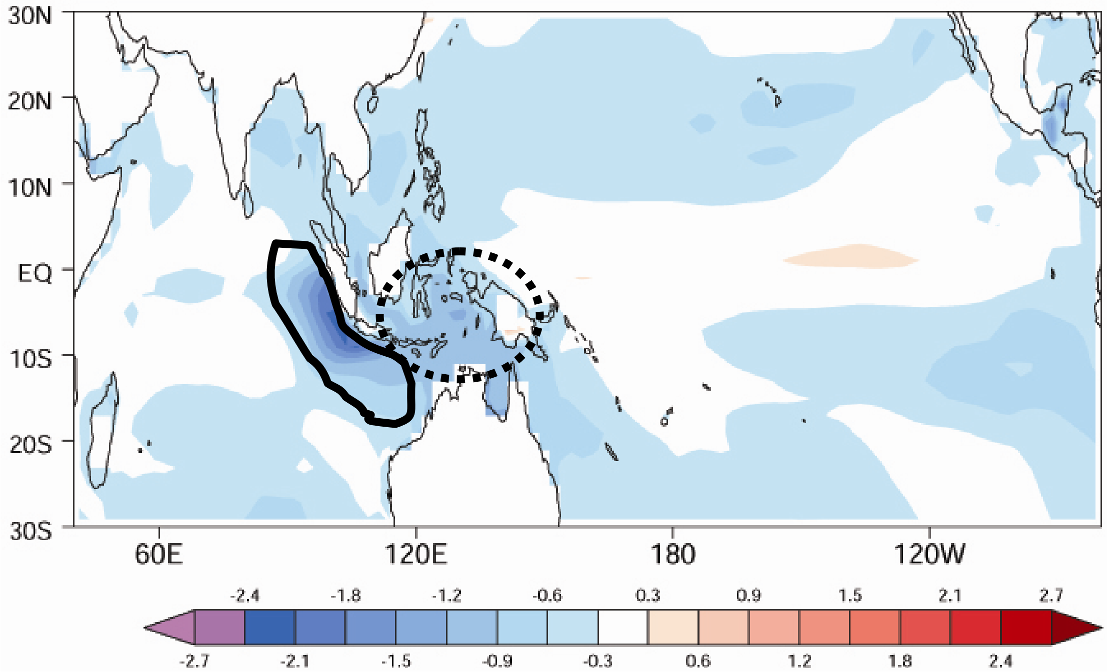
“SST-rainfall -ve CC along the trough”

“SST-rainfall +ve CC over the EIO-MC”

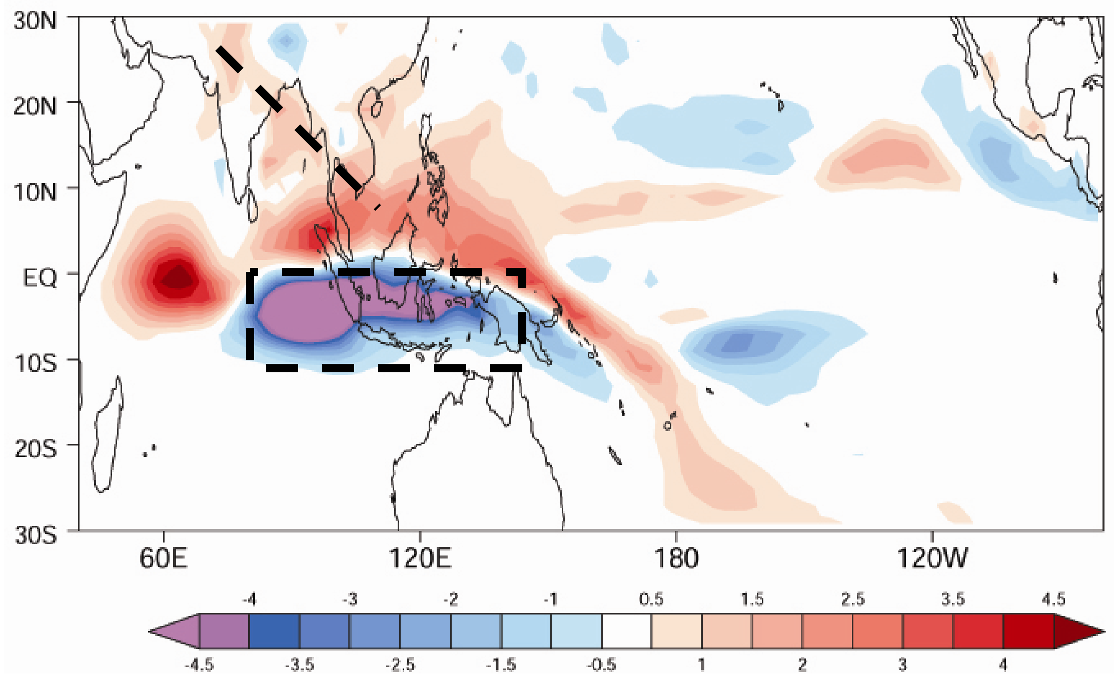
August 2006 TRMM_B43_rain



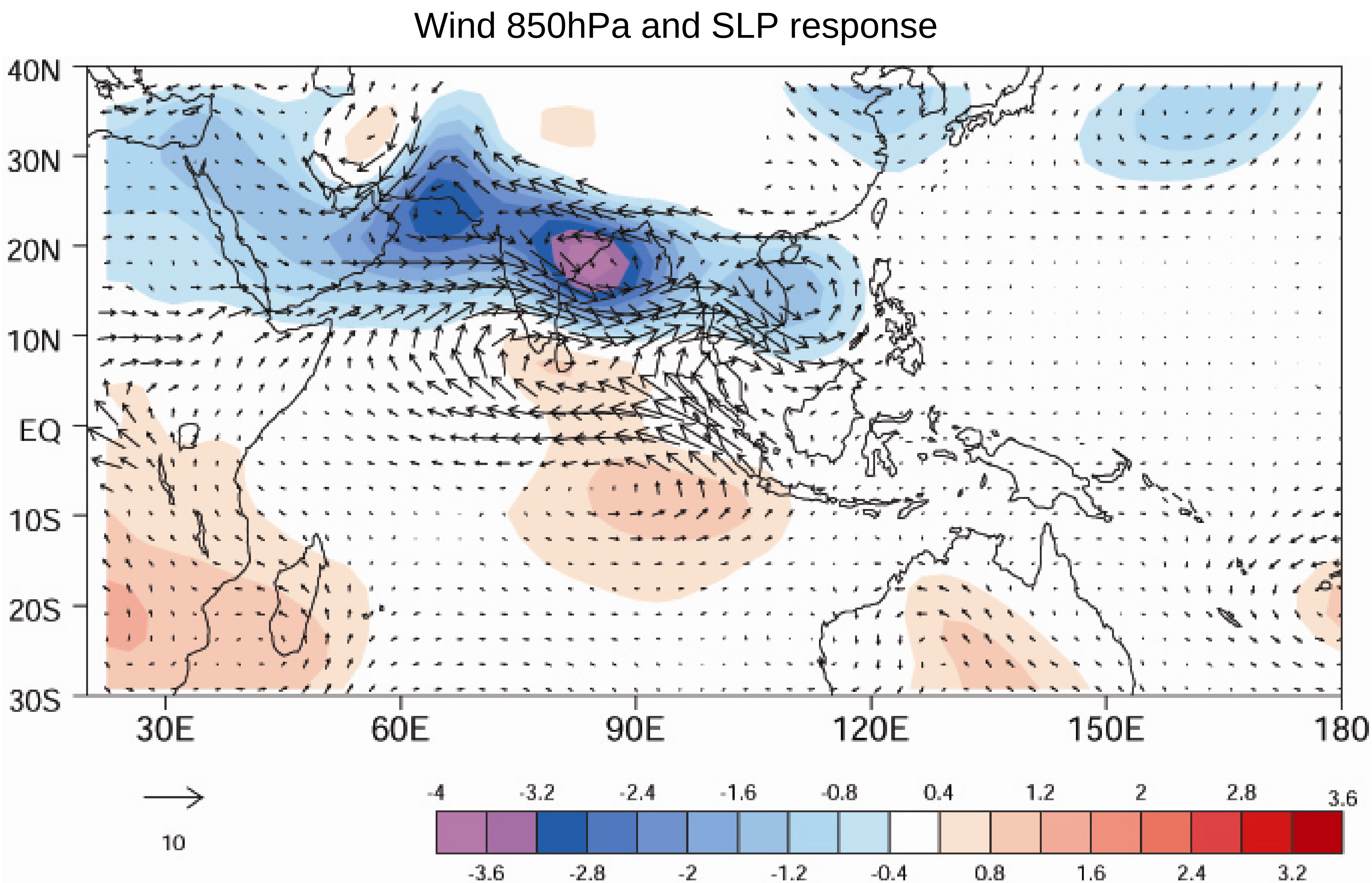
SST (July-Aug)



Precip. (July-Aug)



EIO SST Forcing



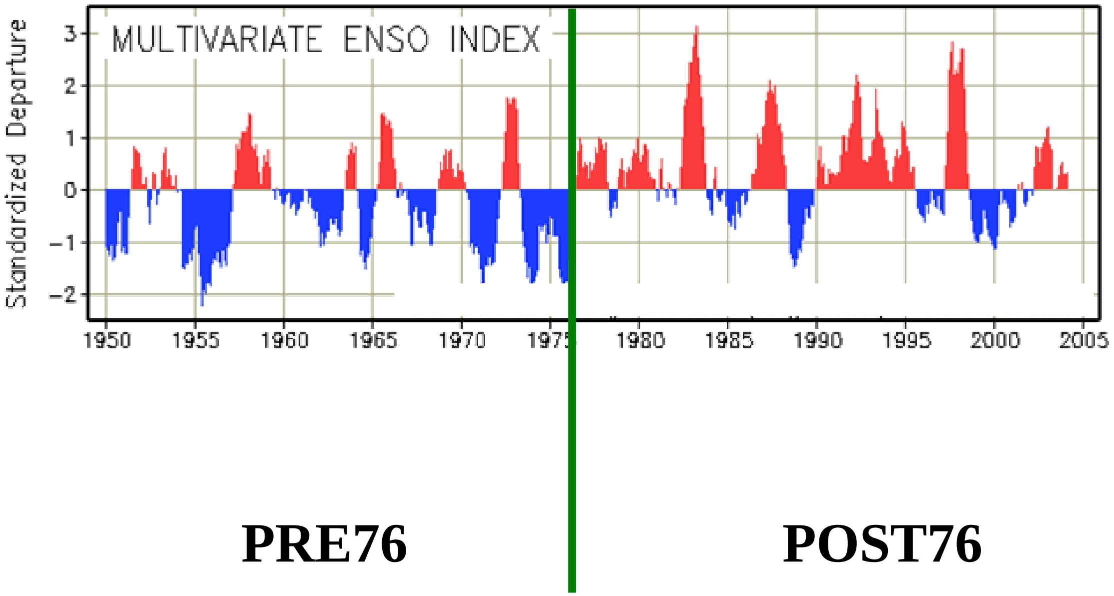
Moist Static Energy Budget

$$\hat{D}_T T' + \hat{D}_q q' + \left(M_1 \nabla \cdot \mathbf{v}_1\right)' = \left(g/p_T\right) F'_{rad} + \left(g/p_T\right) E' + \left(g/p_T\right) H'$$

(temp. adv. + moisture adv. + moist energy convergence = radiation + evap. + sensible)

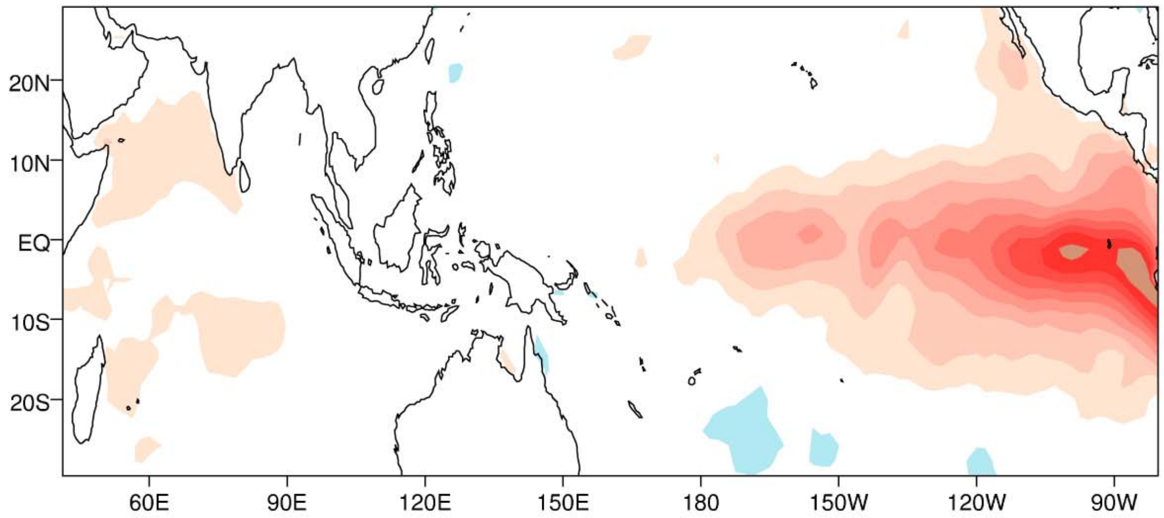
Annamalai (2008)

Indian Ocean on ENSO properties?

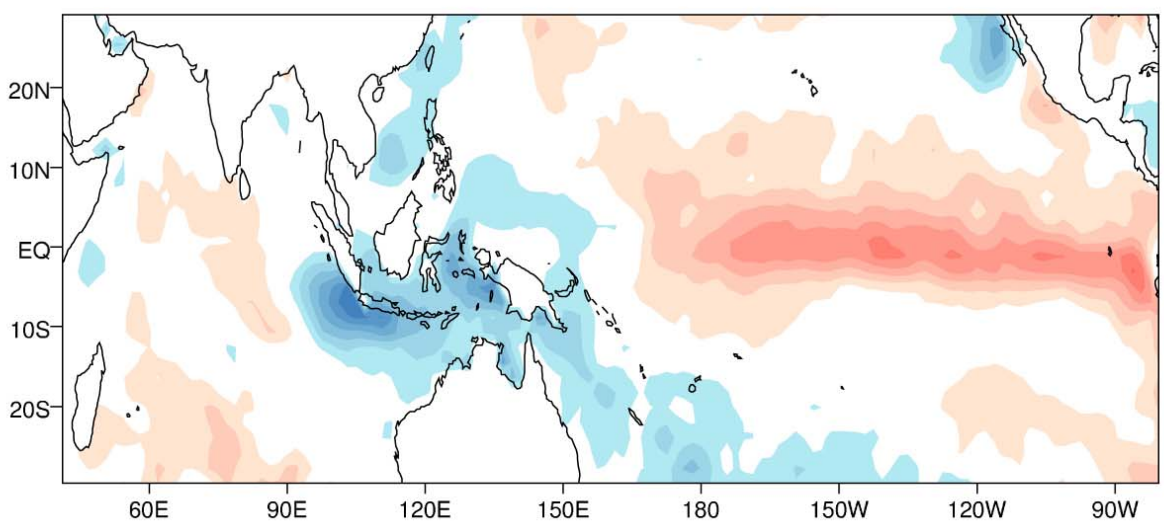


PRE76 **POST76**

PRE 76 July-August

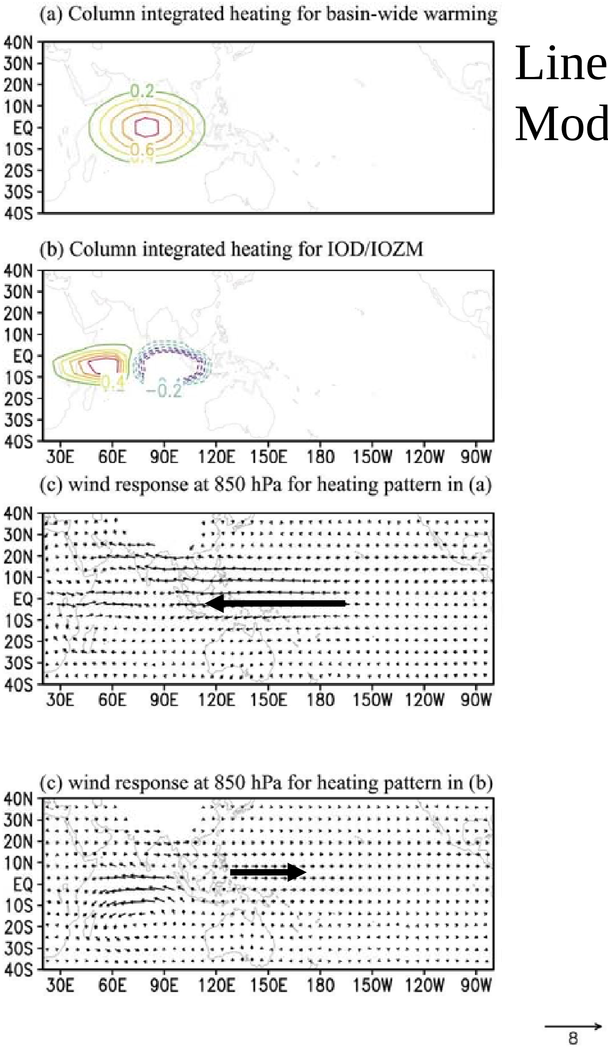


July-August **POST 76**



SST anomalies over the warm pool

Linear Atmospheric Model – **Watanabe**

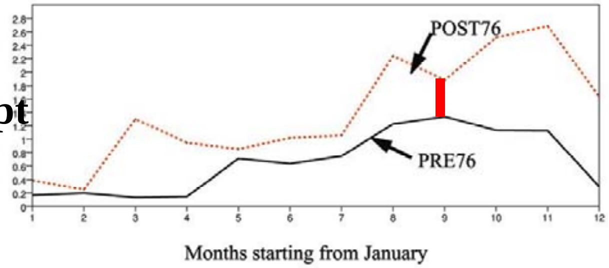


Weakens El Nino Induced Westerlies

Strengthens El Nino Forced Westerlies

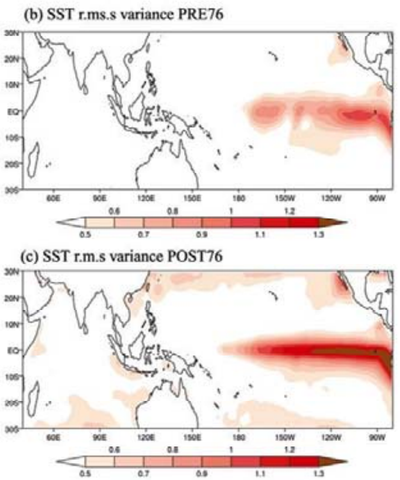
850 hPa winds – Eq. Central Pacfic

Intensifies in Sept
During POST76



Decreases in Nov.

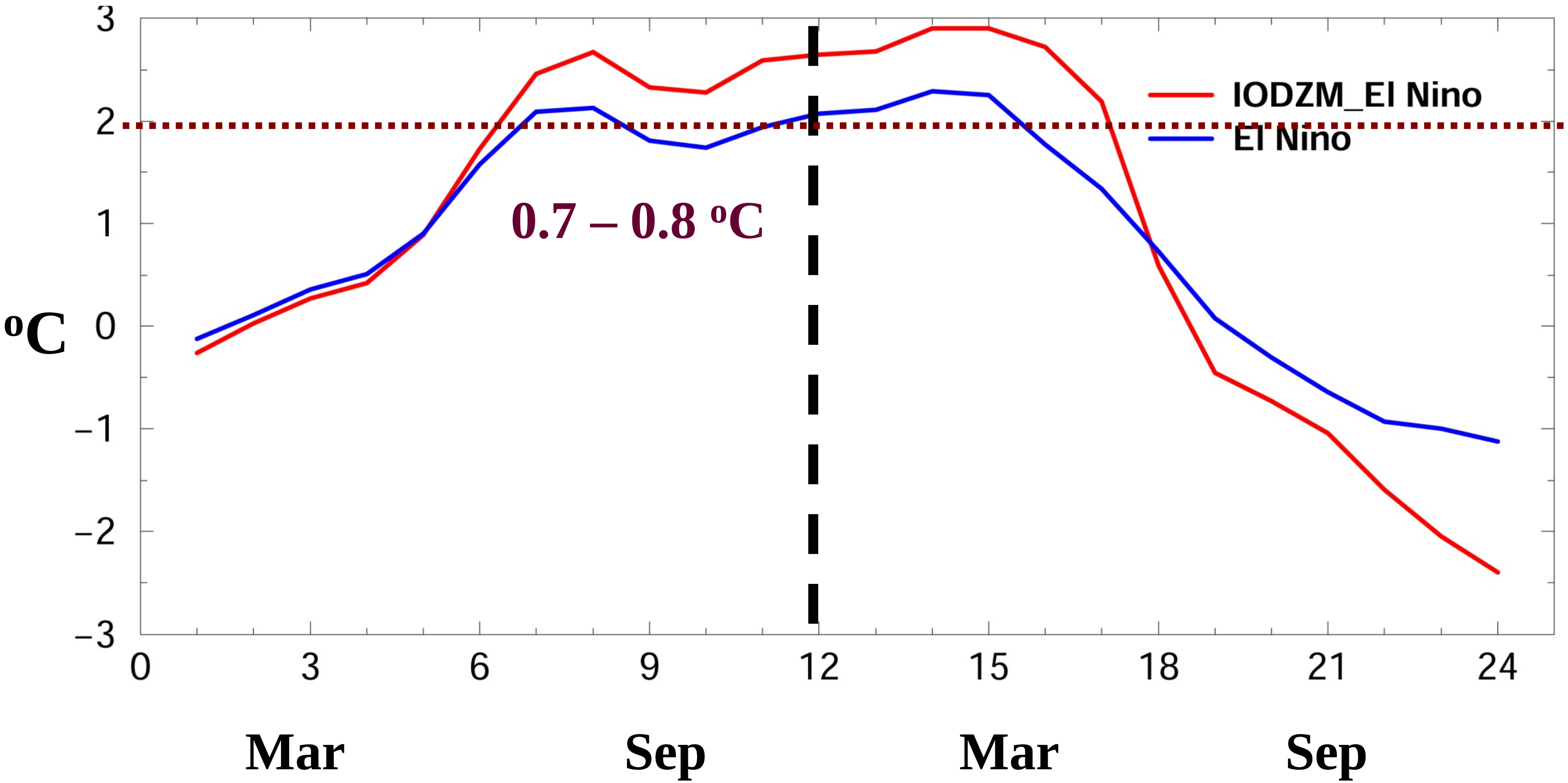
Decreases in Sept.



PRE76

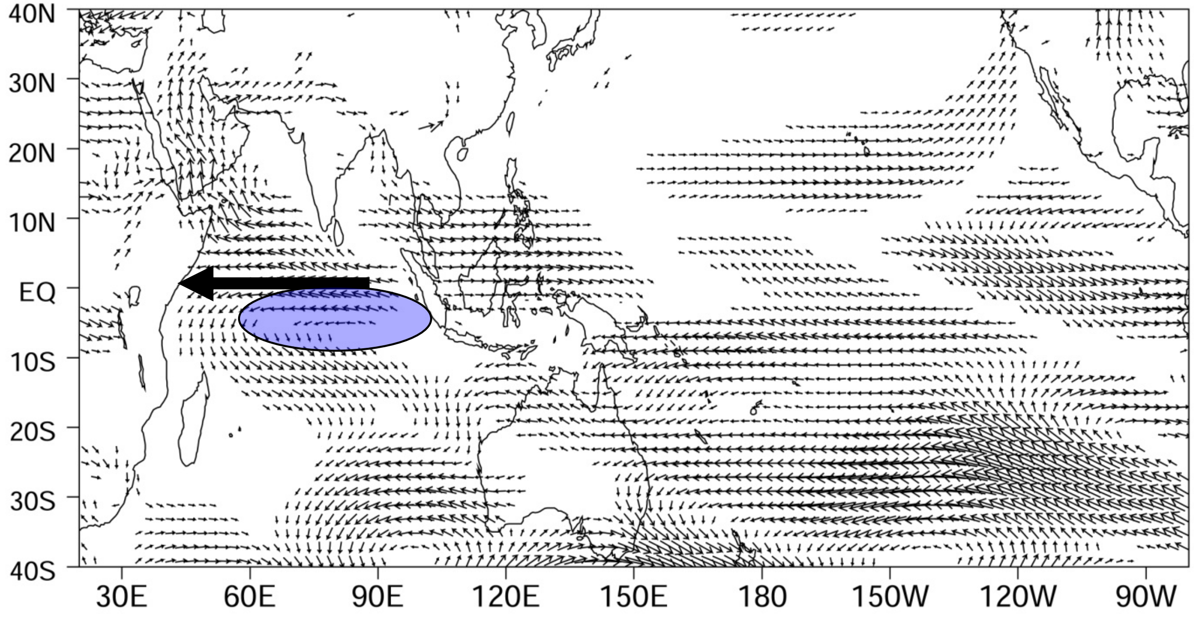
POST76

NINO3 SST anomalies

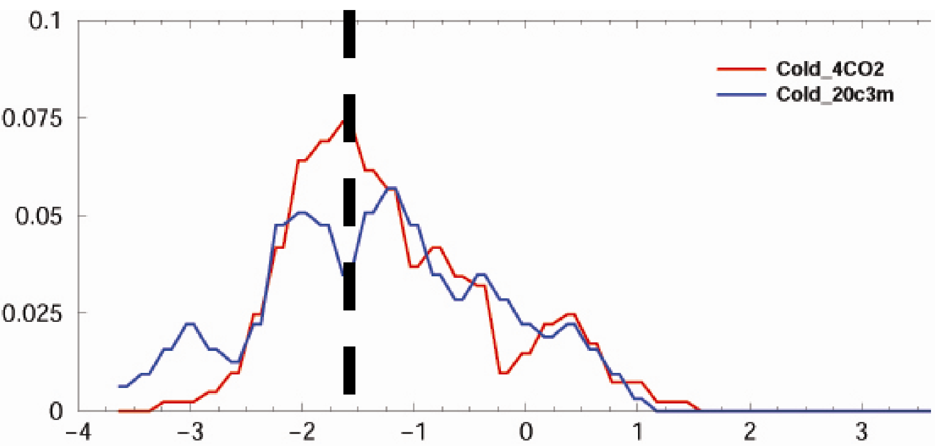


"boreal summer – first change – then, maintained"

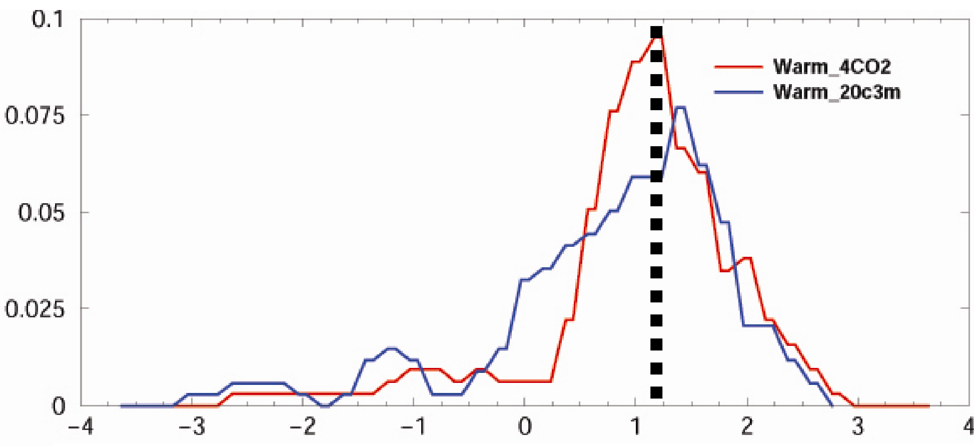
850hPa wind difference (4xCO_2 – 20c3m)



PDF of IODZM (+ve events)



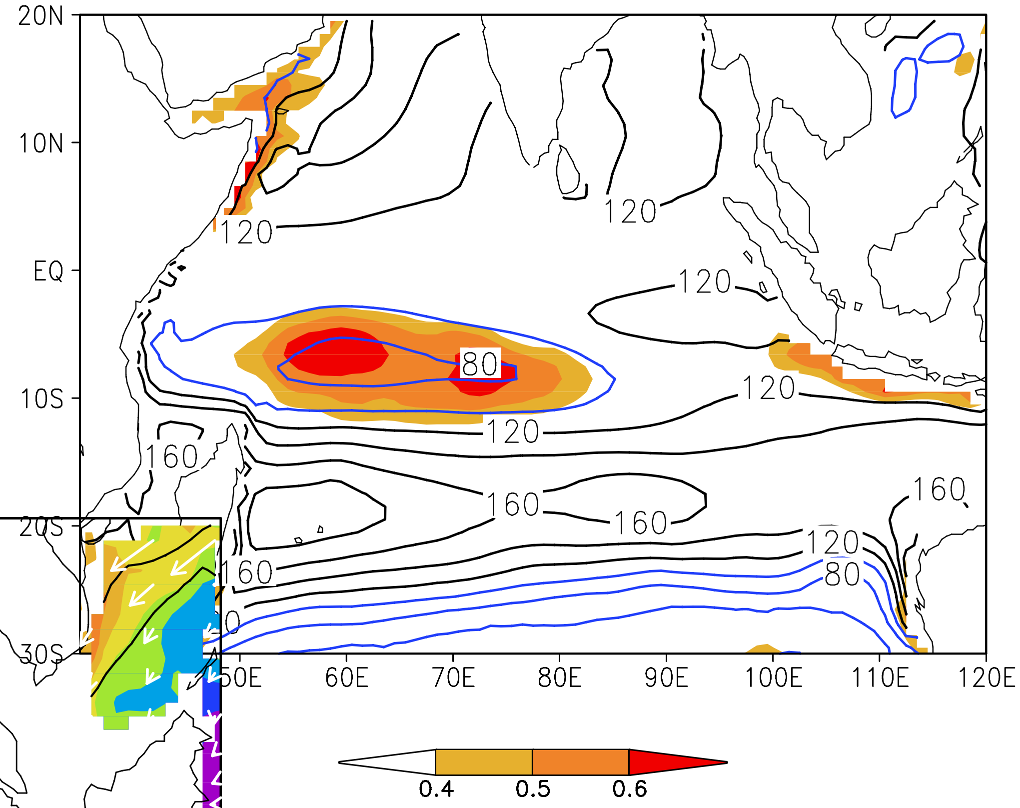
PDF of IODZM (-ve events)



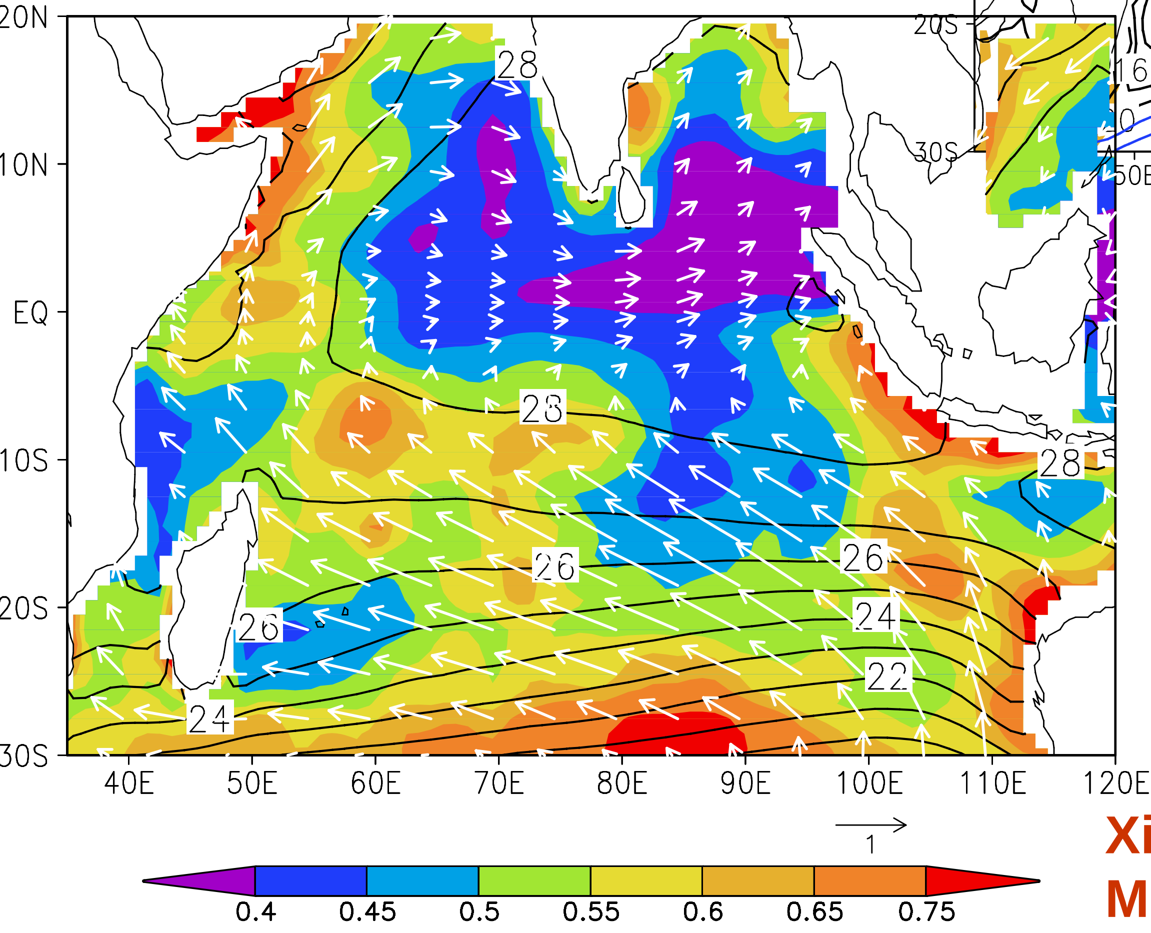
"possible increase in frequency of occurrences"

Thermocline Depth Z20

r(Z20,SST)

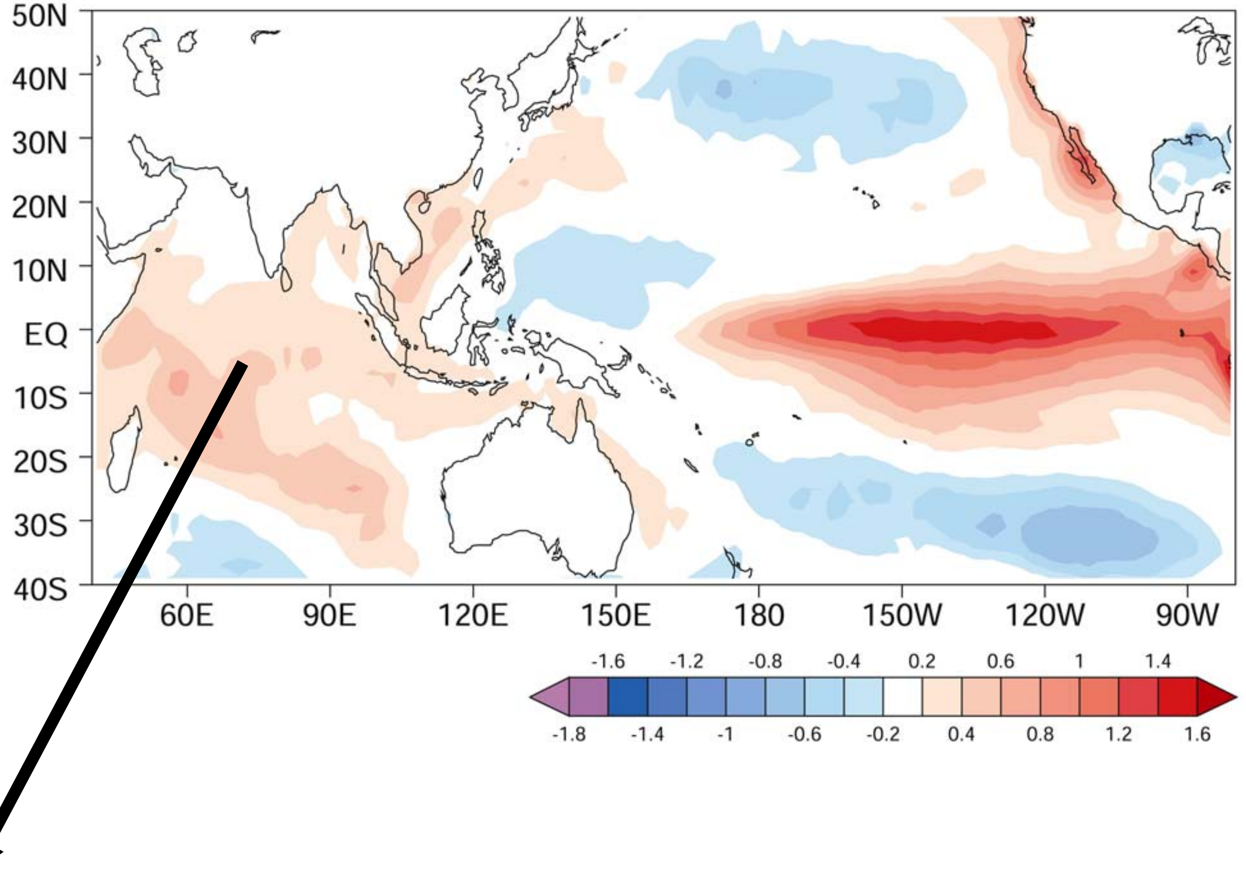


rms(SST) 1970-99

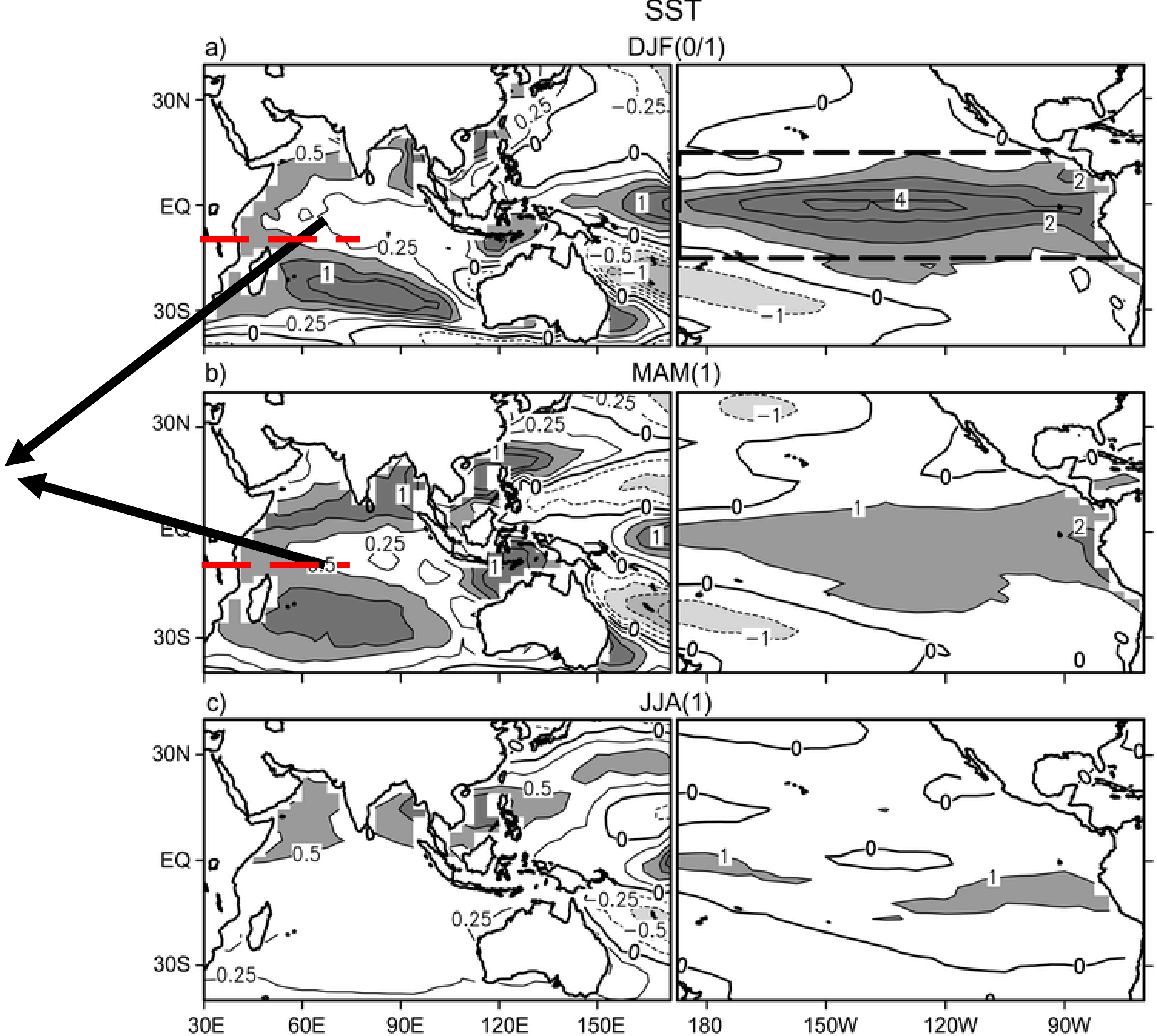


Xie, Annamalai, Schott, McCreary, (2002), J. Climate

SST anomalies (December – May)

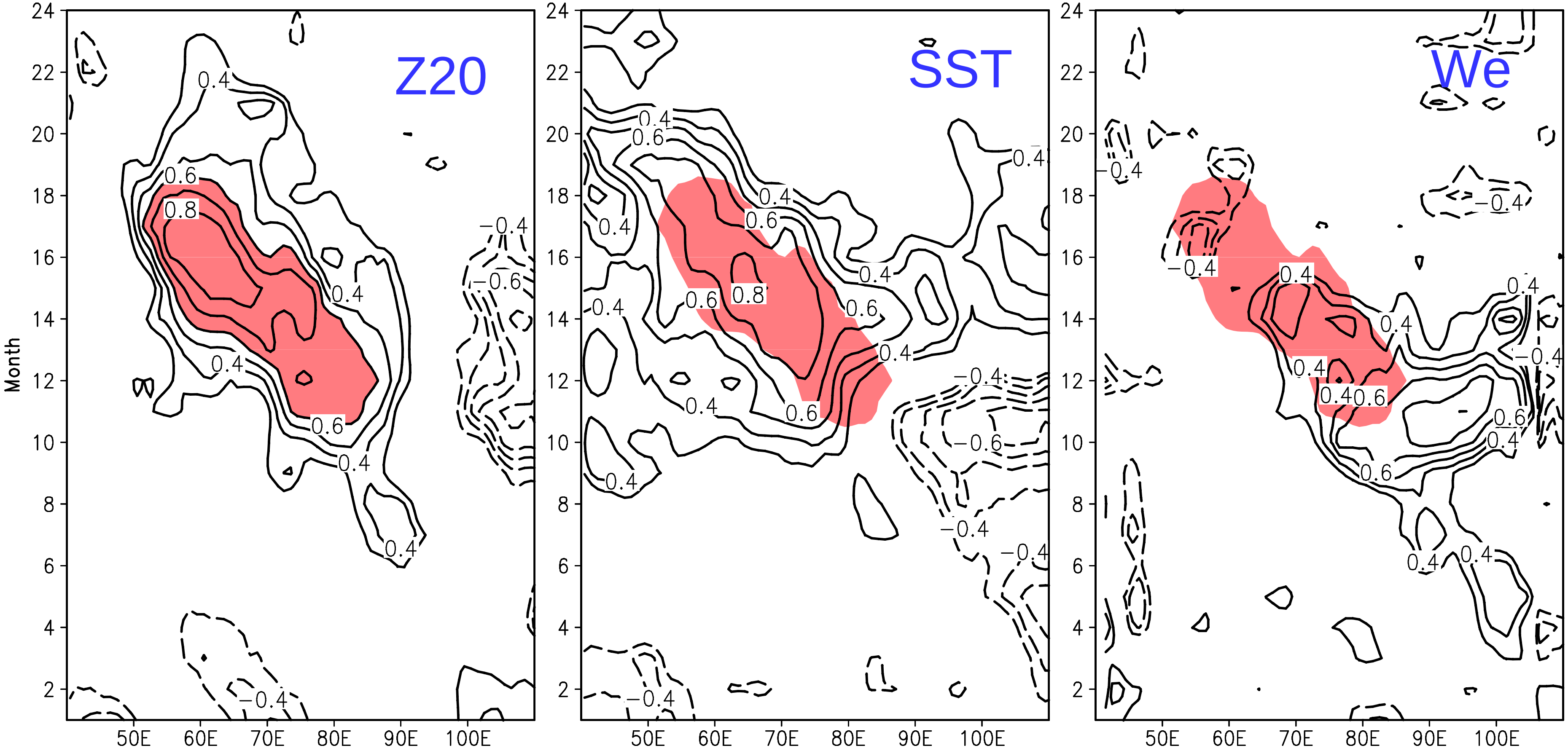


“basin-wide warming”



Lau et al (2005, JC)

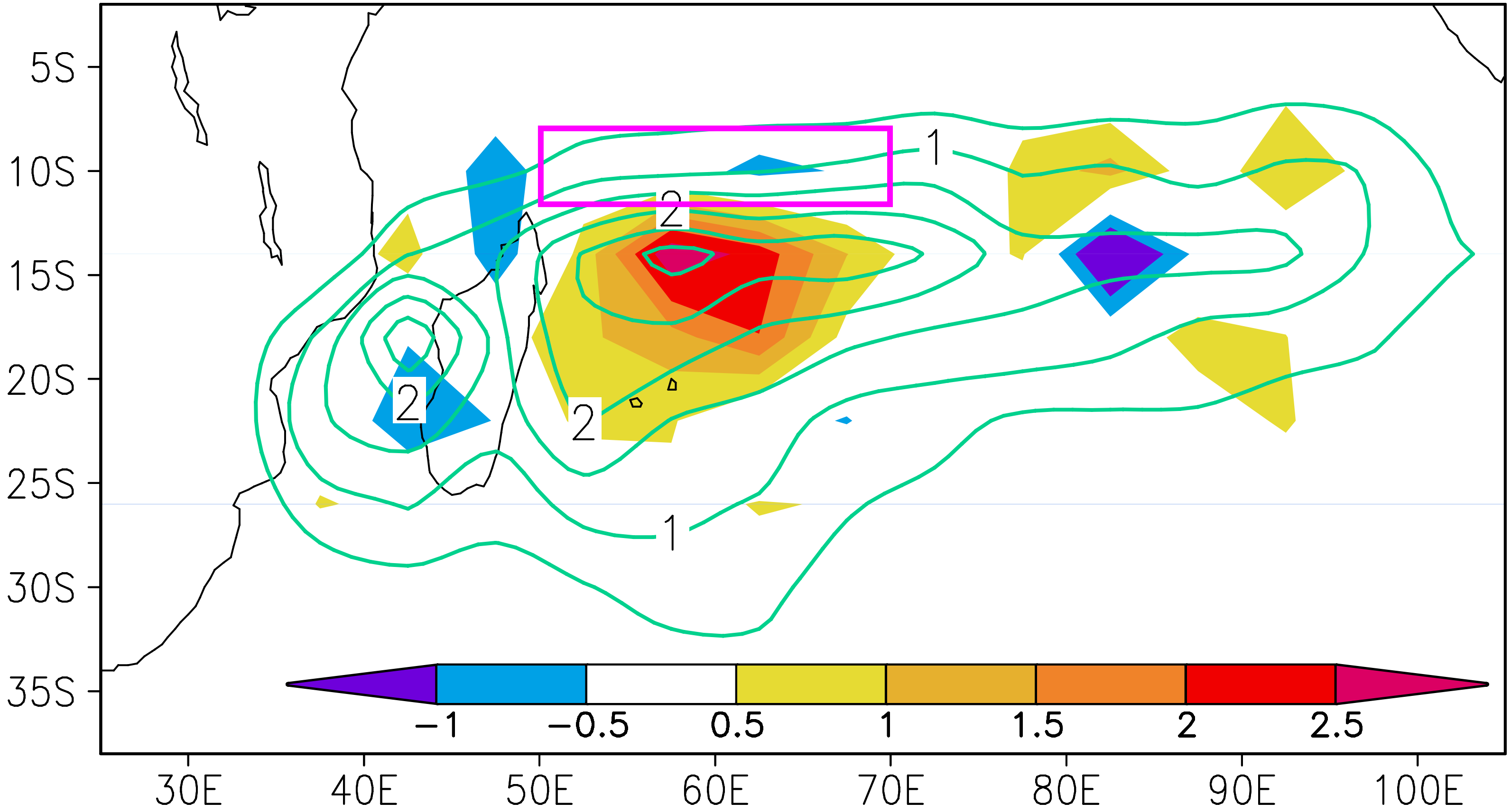
Correlation with ENSO (Averaged over 8-12^{o}S)



Shade: r_{Z20} >0.6

downward +ve

Tropical cyclone days for Dec-Apr



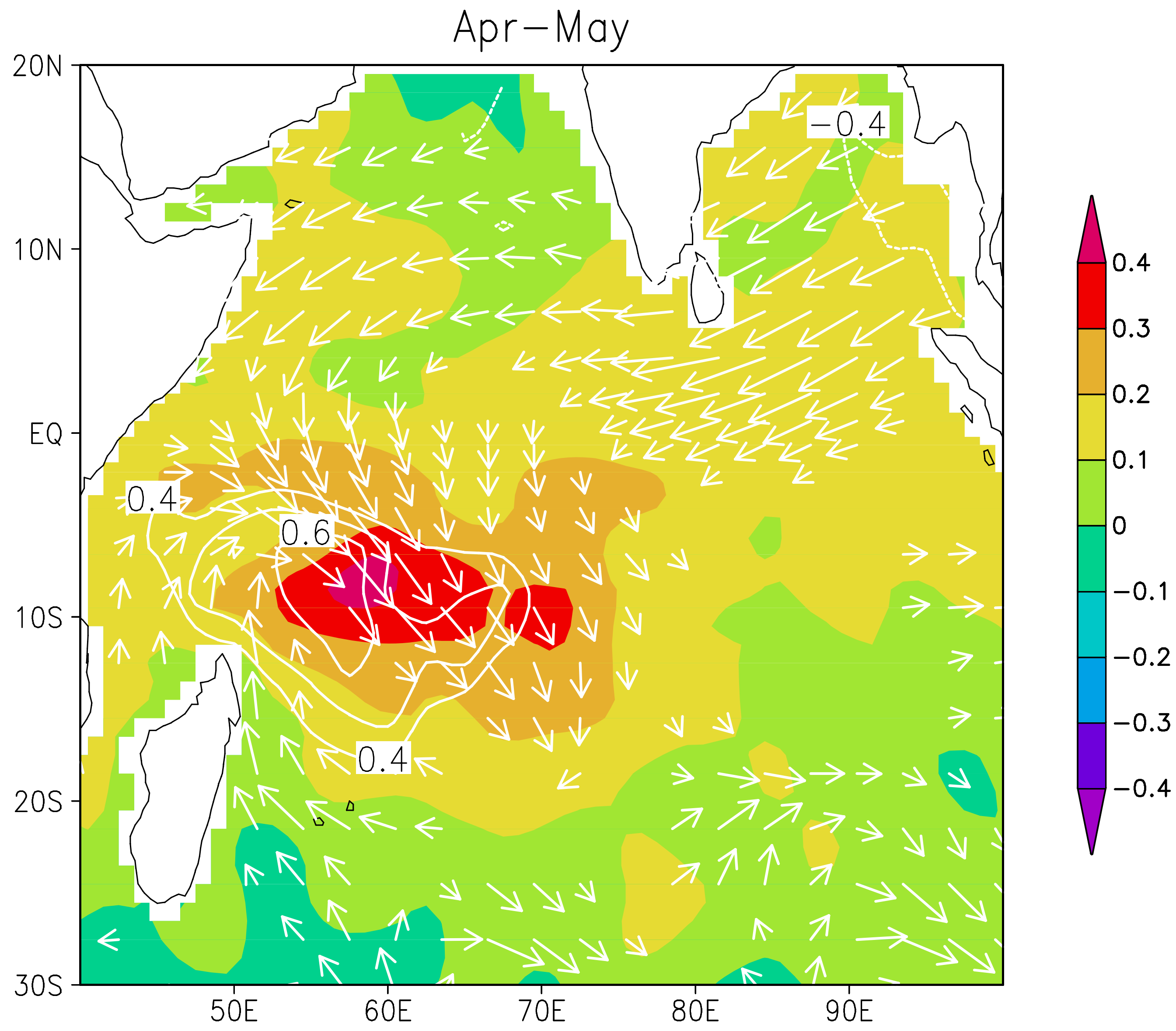
Xie, Annamalai, Schott, and McCreary (2002)

Coupled Rossby Wave

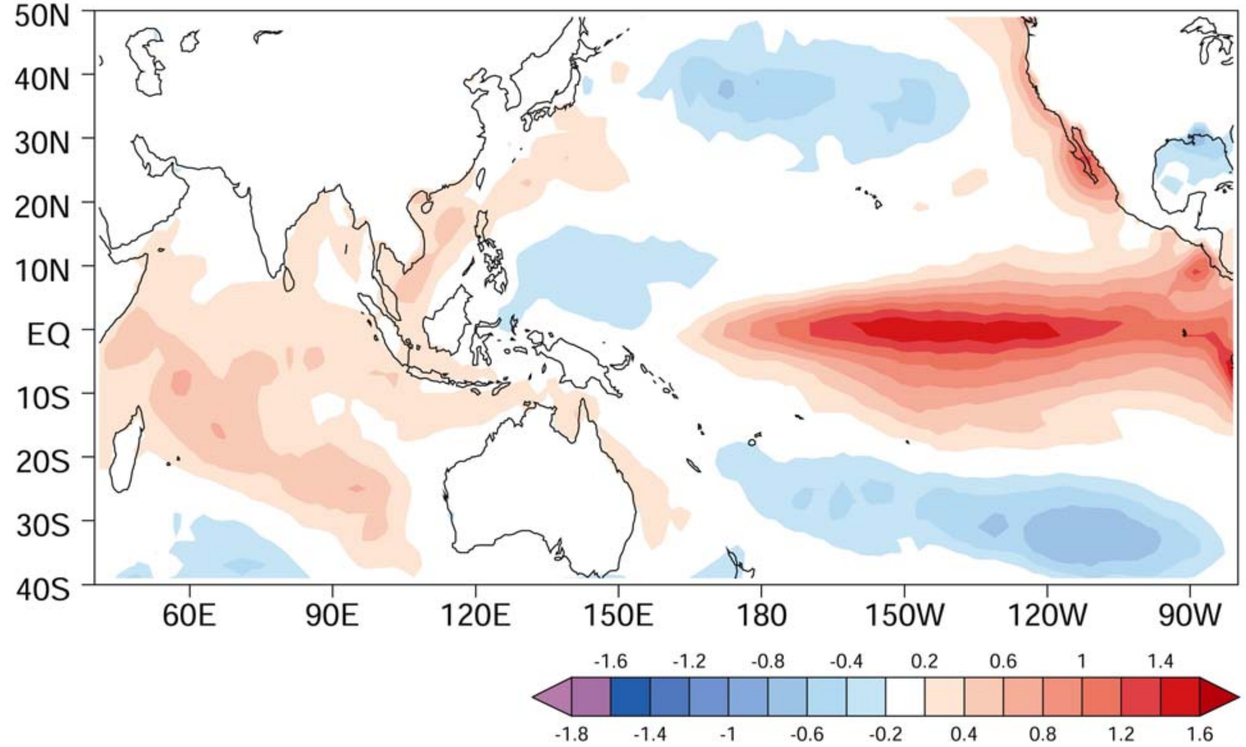
SST (color)

Wind stress (vector)

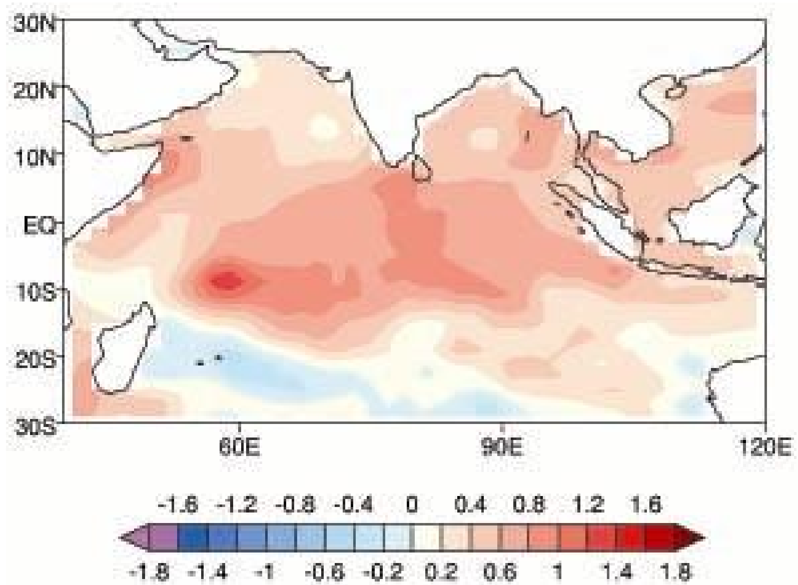
Precipitation (contour)



SST anomalies during El Nino (Dec – May)

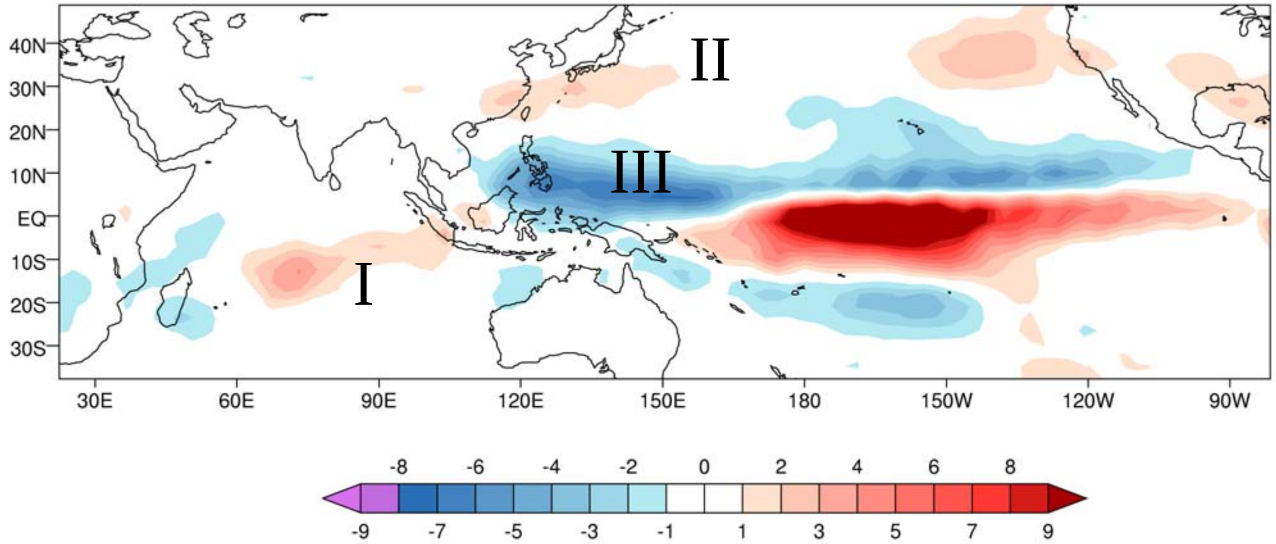


May

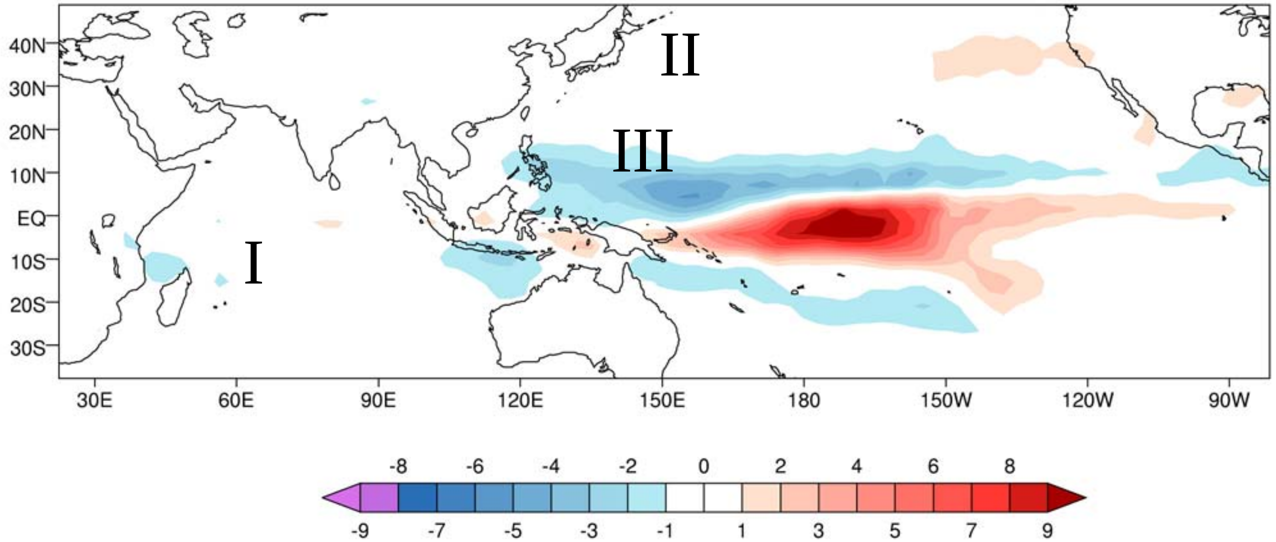


ENSO-induced regional SST anomalies "additional" source of predictability?

(a) Precip. anomalies (TIP run)



(a) Precip. anomalies (TPO run)

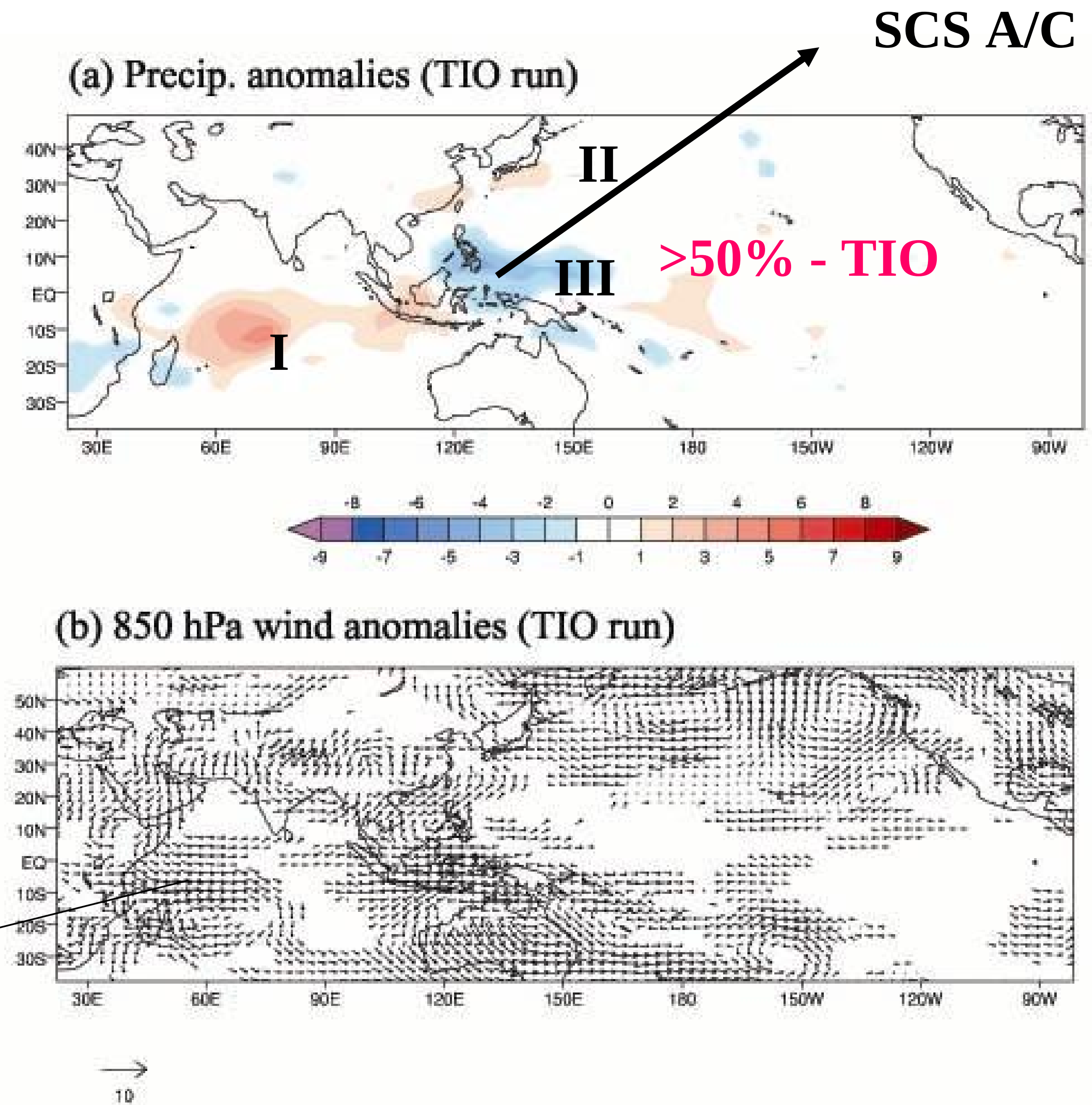


TPO precip. anomalies are weaker than in TIP EVERYWHERE

Effect on EAM

Wang et al. (2001, JC)

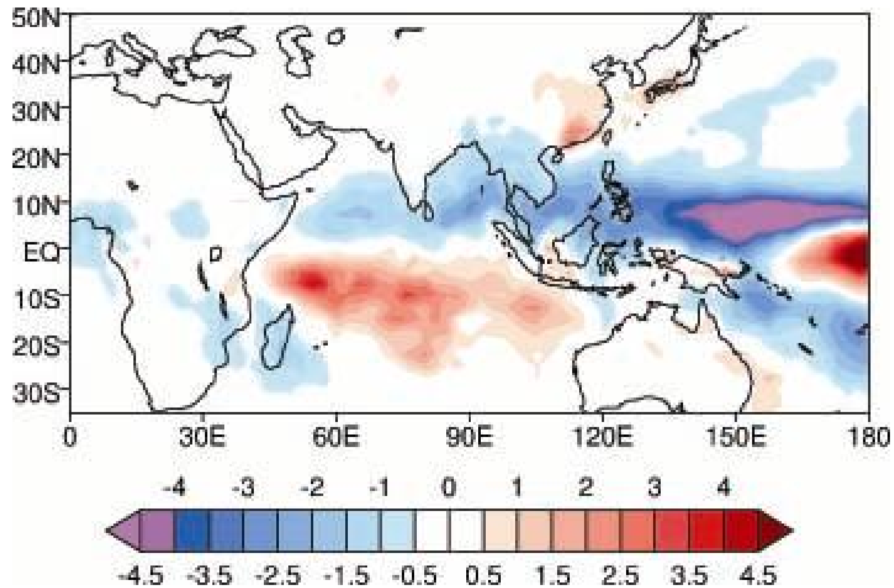
Lau et al. (2003, JC)



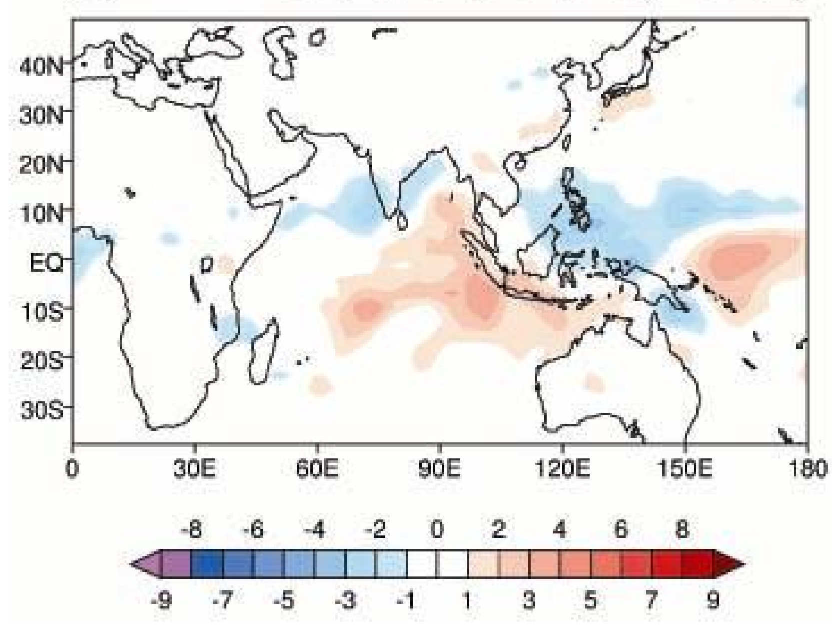
Rossby-wave response

Local SST anomalies determine in-situ precip. anomalies

MAM - Precipitation anomalies (Observation)



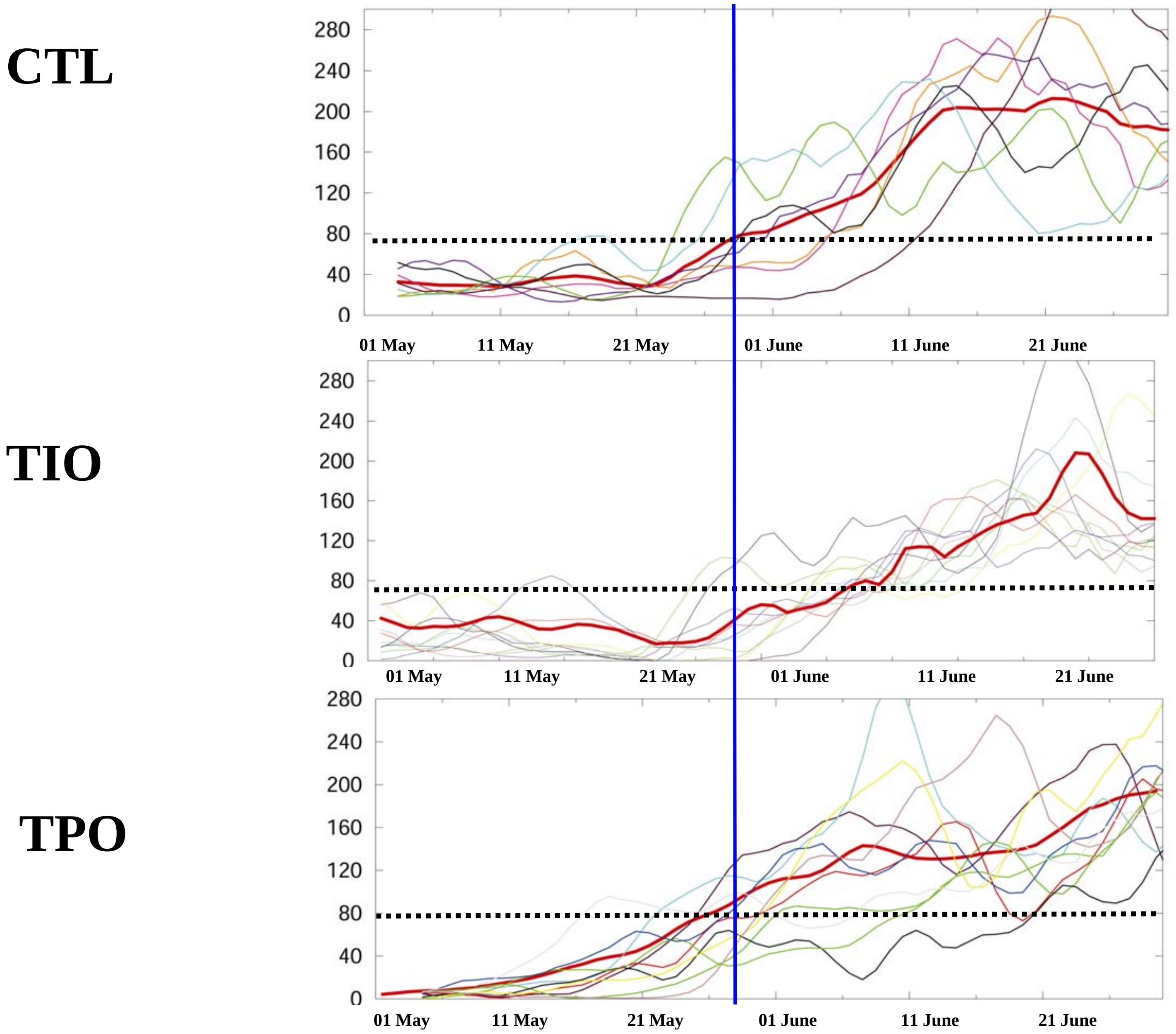
(b) MAM Precipitation anomalies (TIO run)



Hypothesis…………..

SST anomalies over the Indian Ocean cause interannual variability in the Onset of the ISM through affecting the timing of the northwestward movement of the equatorial convection

K.E. (50º-70ºE, 5º-12ºN)



Effect on EAM

Wang et al. (2001, JC)

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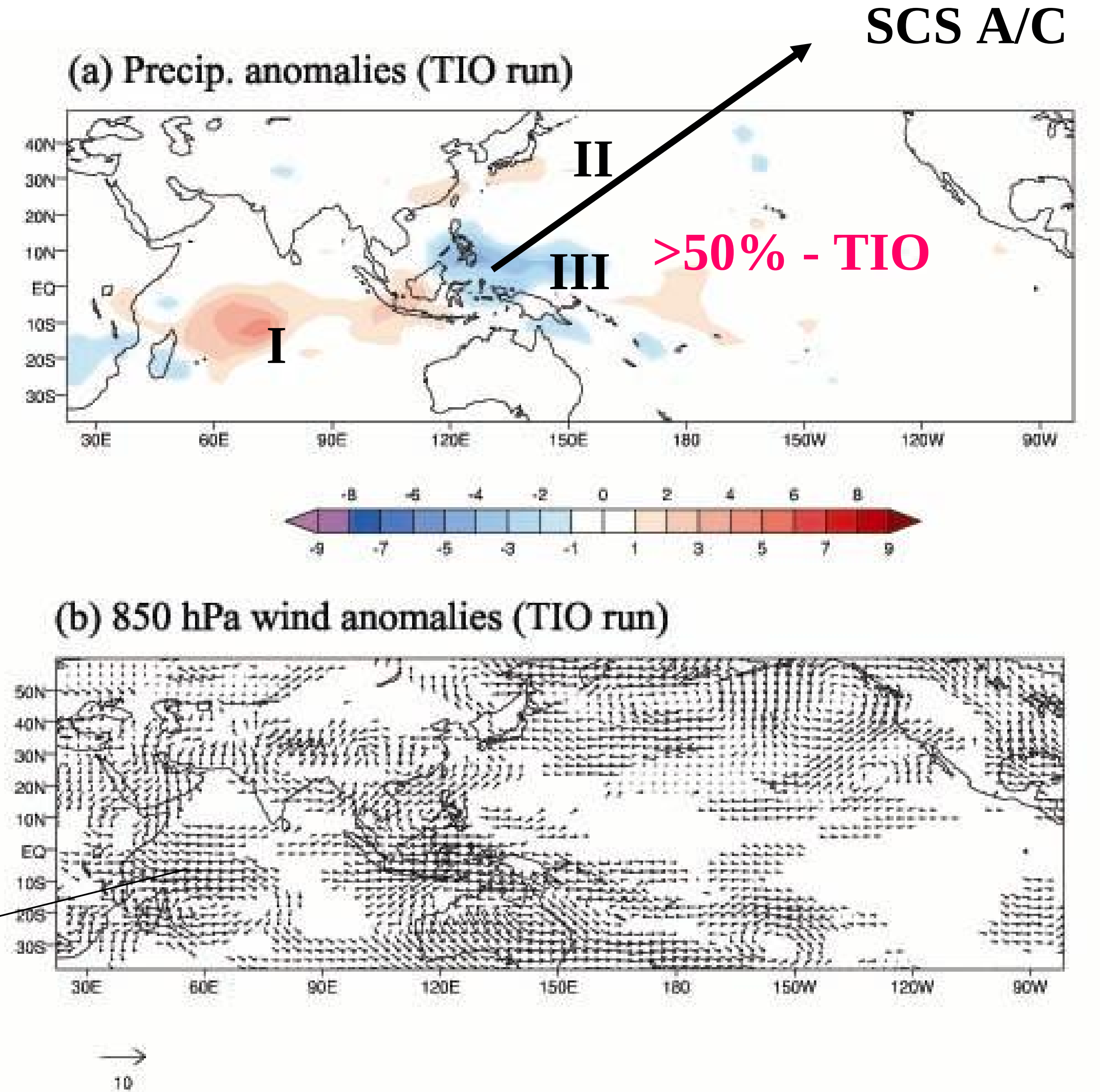
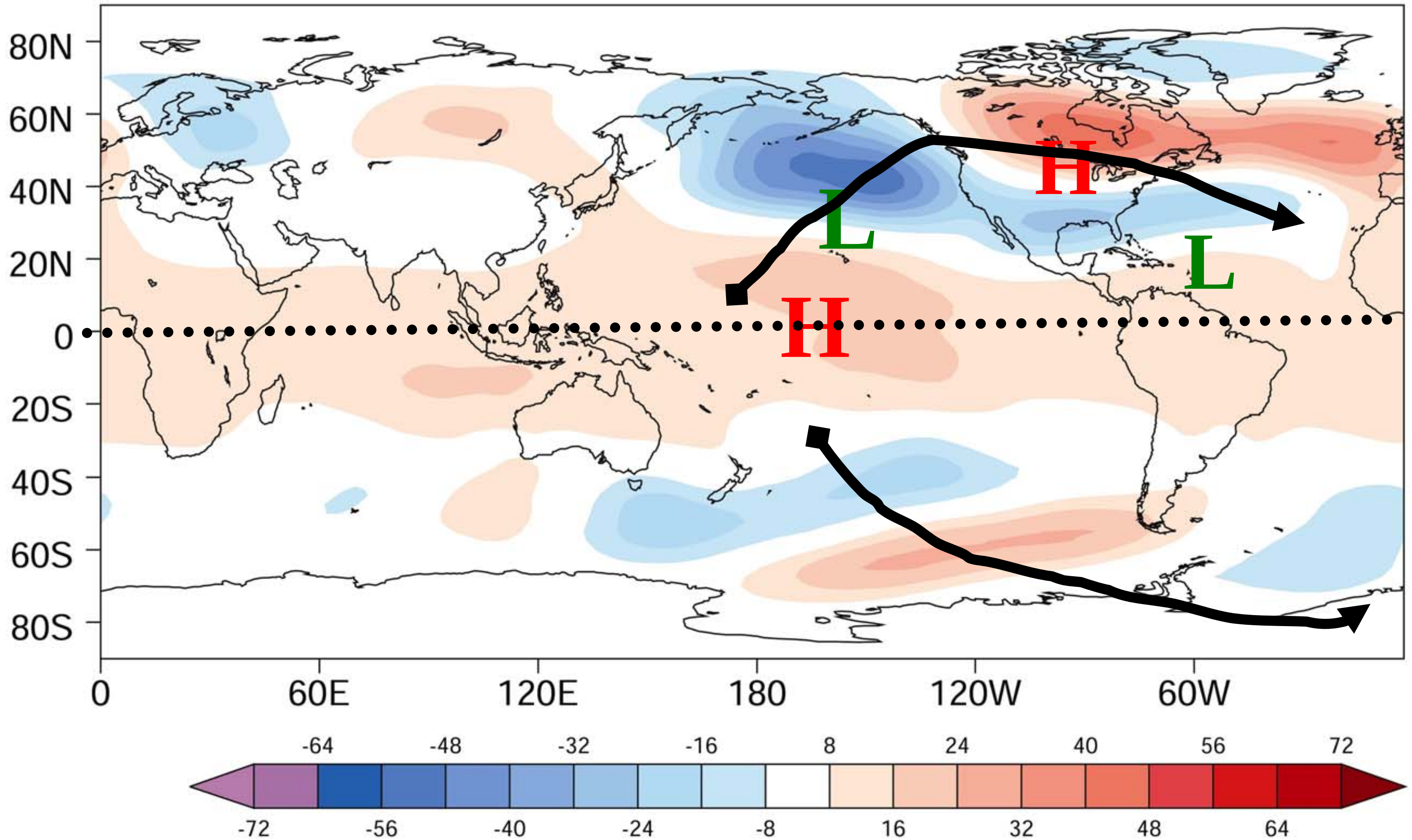


Rossby-wave response

Local SST anomalies determine in-situ precip. anomalies

JFM 500 hPa Height Anomalies – El Nino



Pacific – North American (PNA) pattern

Horel and Wallace (1981)

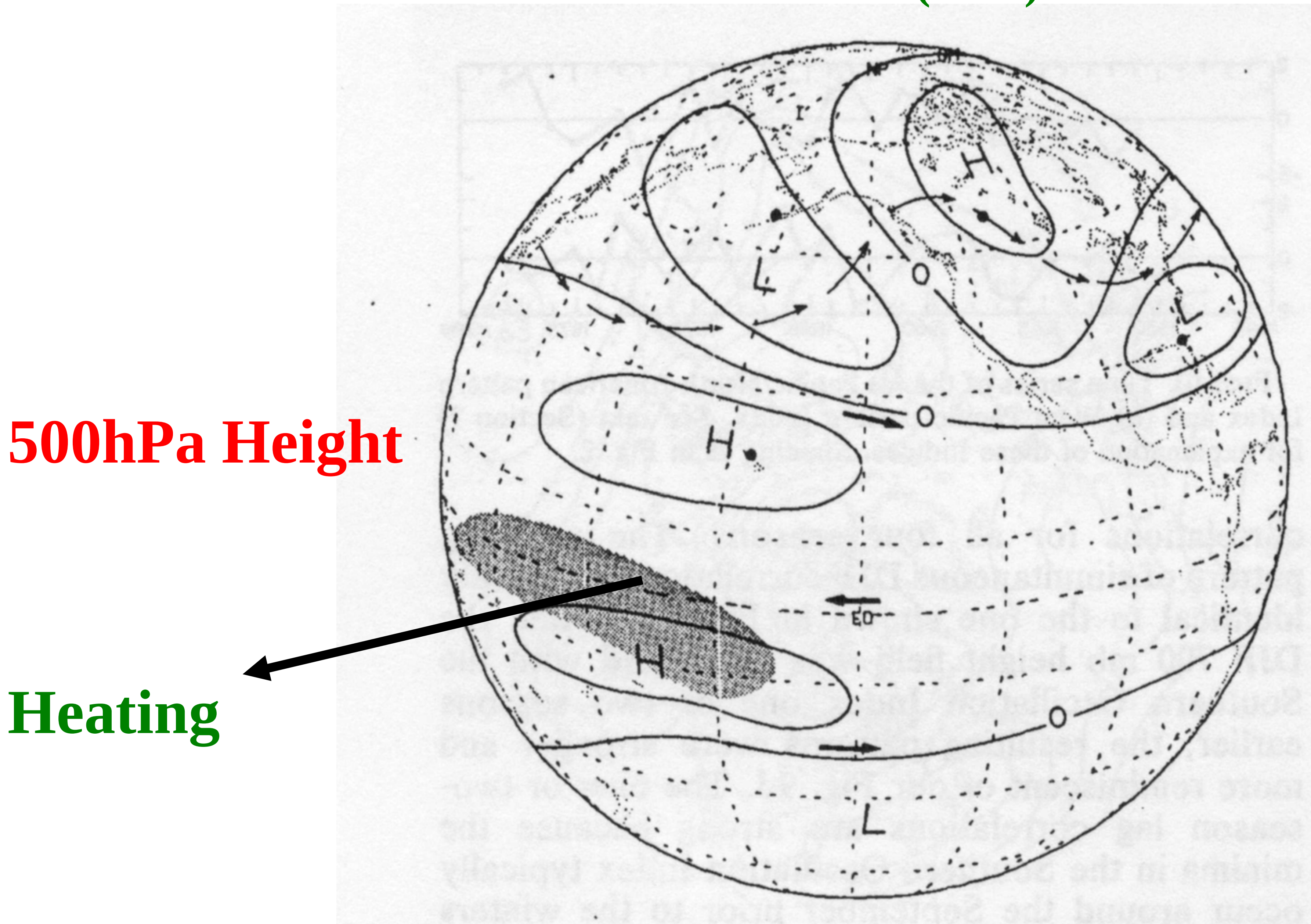


FIG. 11. Schematic illustration of the hypothesized global pat-

Hoskins and Karoly (1981)

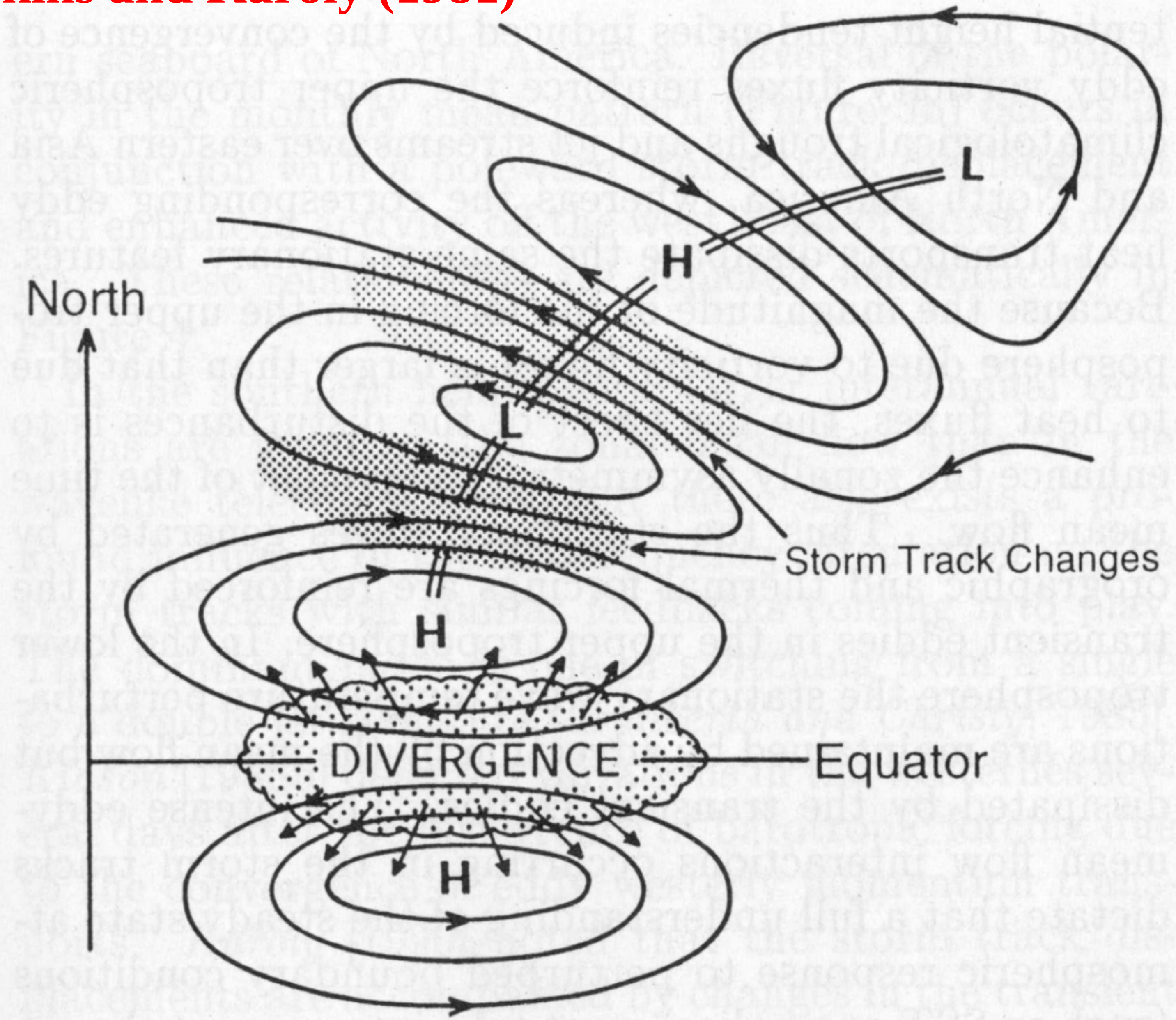
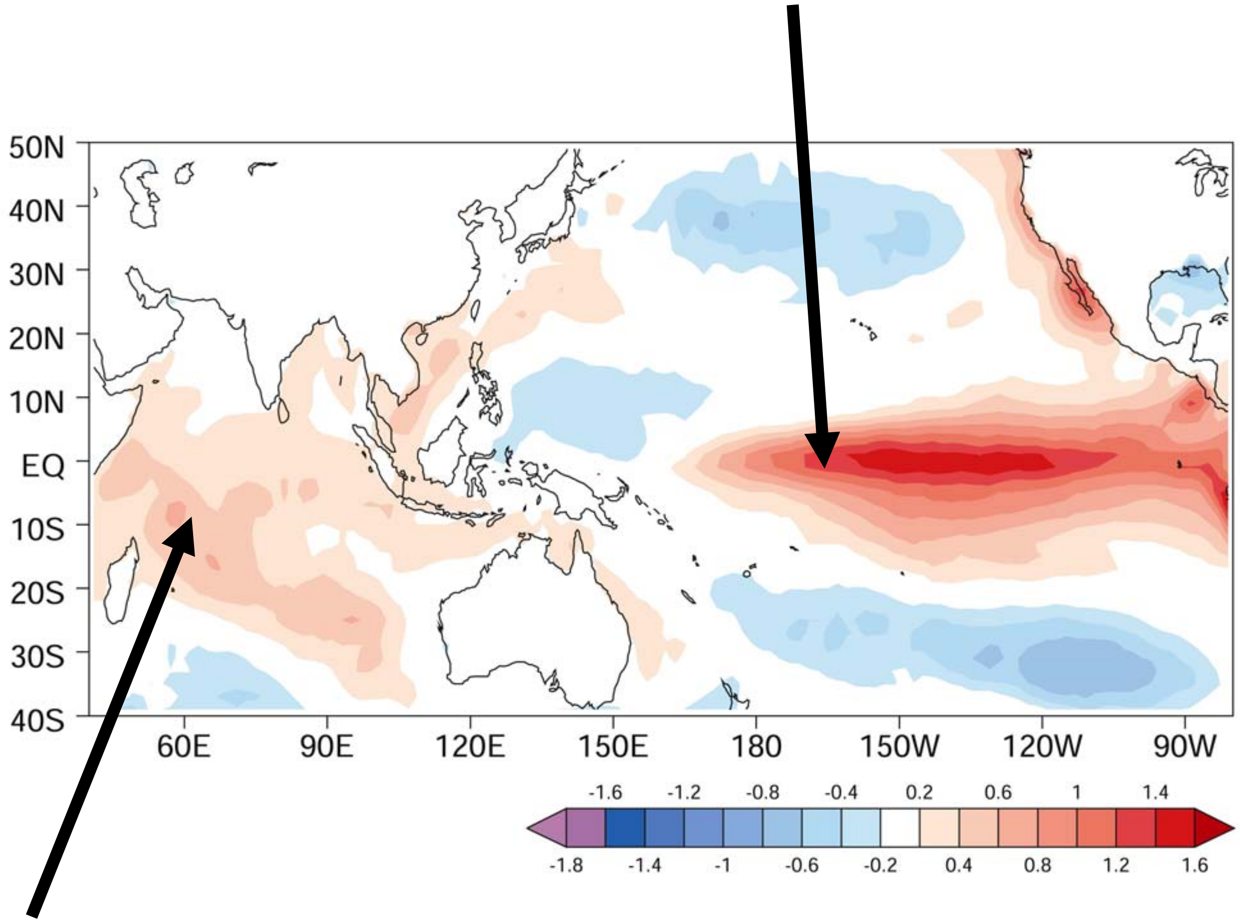


Figure 4. Schematic view of the dominant changes in

PNA Pattern

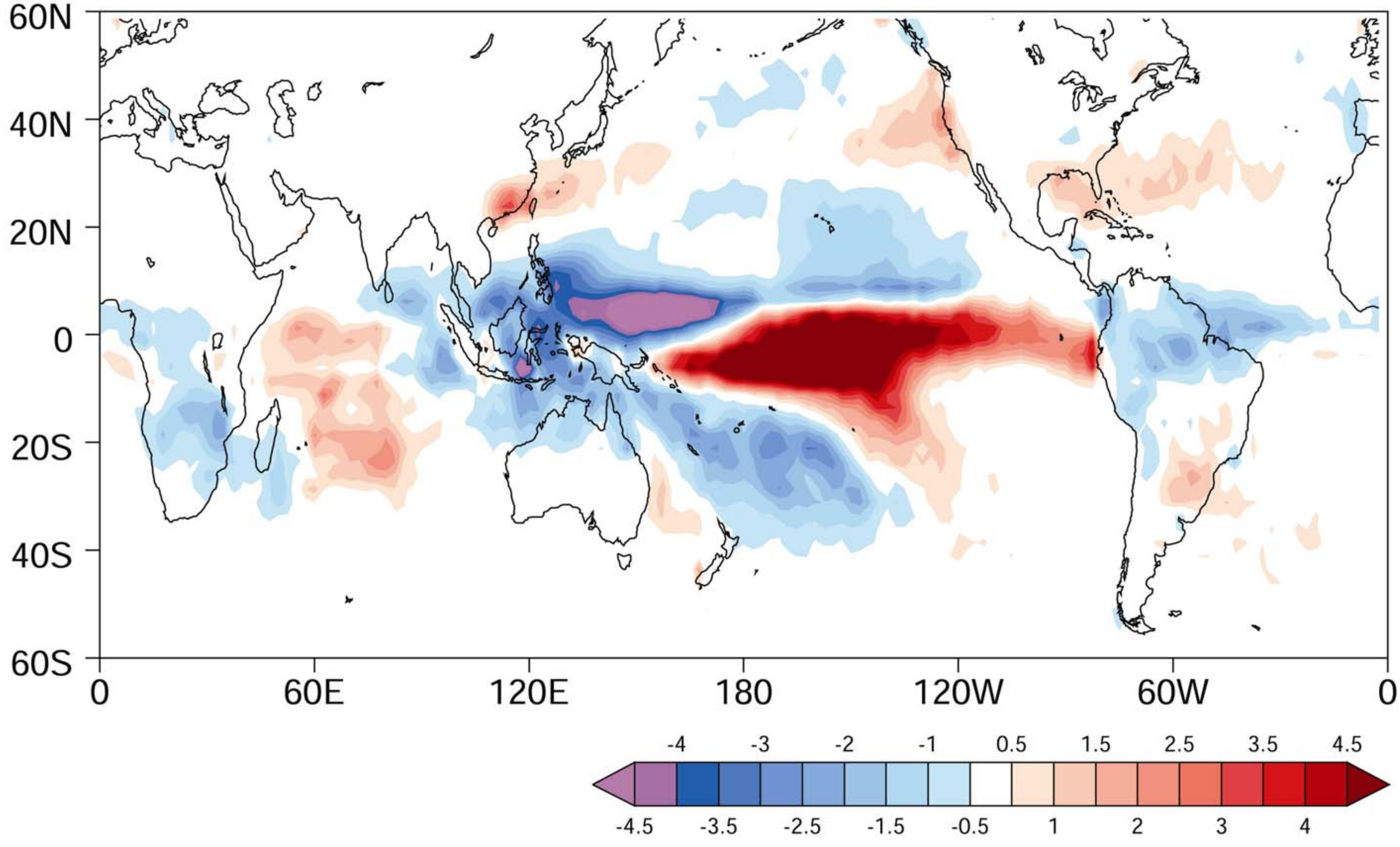


Trenberth et al (1998)

Do TIO SST anomalies have any impact on the NH circulation?

Arunkumar and Hoerling (1998, JGR)

Precipitation anomalies – JFM – El Nino years

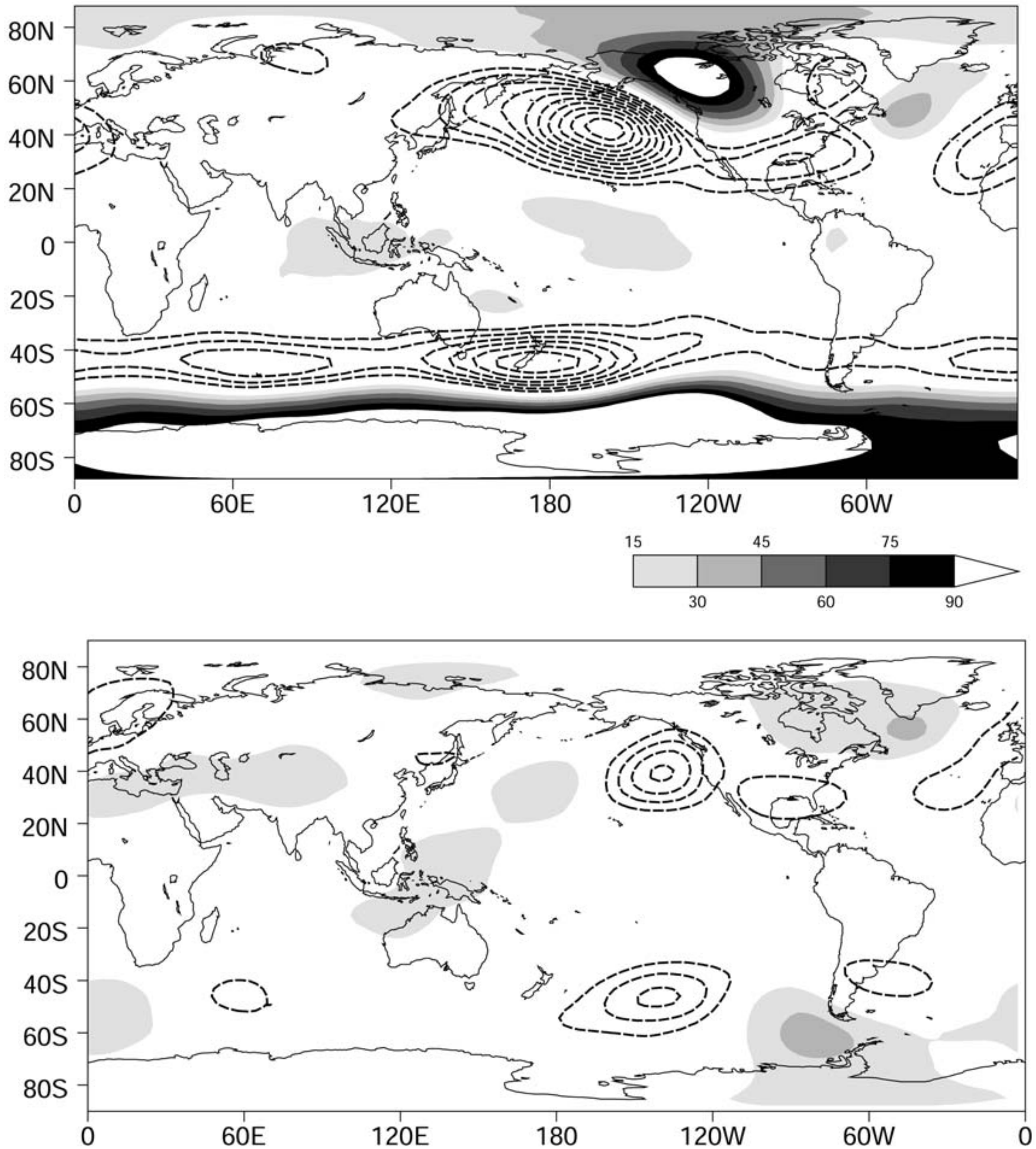


Annamalai, Okajima, and Watanabe (2007, J. Climate)

500hPa Height anomalies

RMSE – PNA

160^{o}E-40^{o}W, 20^{o}-70^{o}N

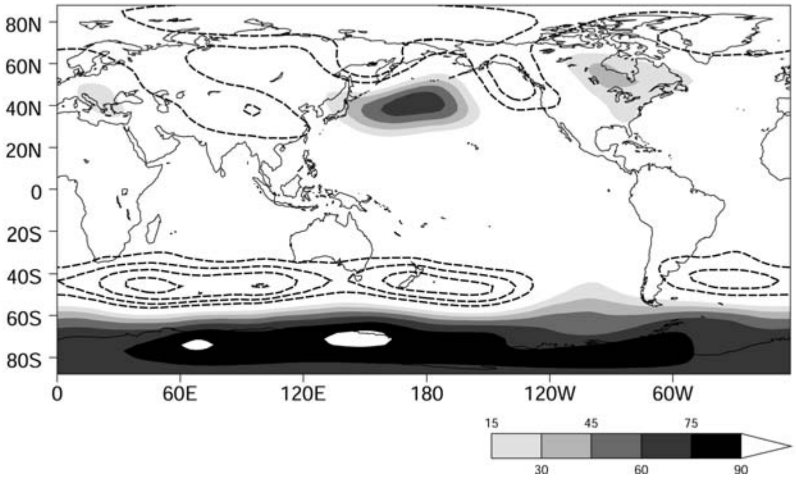


ECHAM5 – 42.0

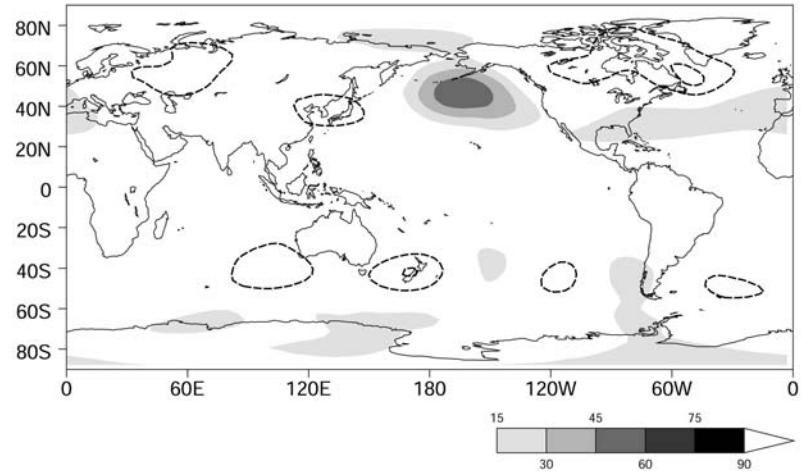
CCSR – 20.9

500hPa Height Anomalies - TIO

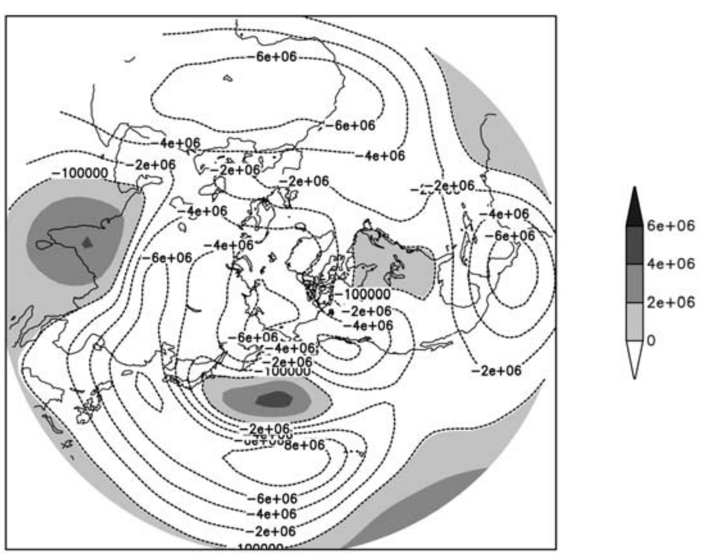
ECHAM5



CCSR



200-hPa stream function

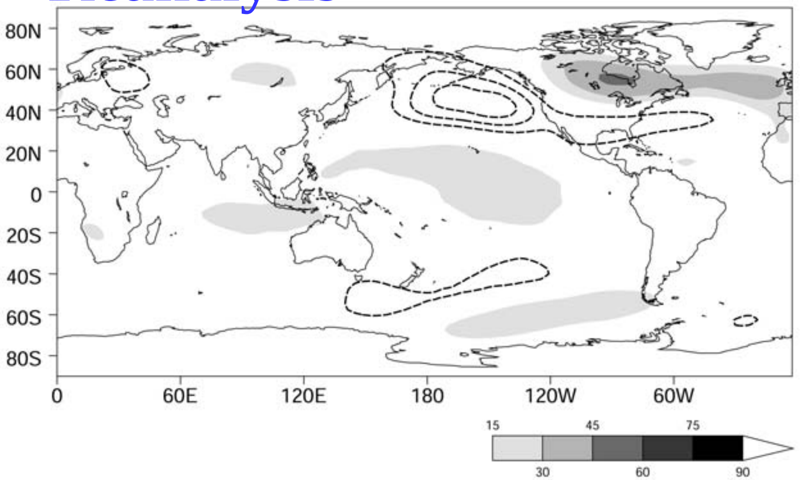


"oppose and destructively Interfere"

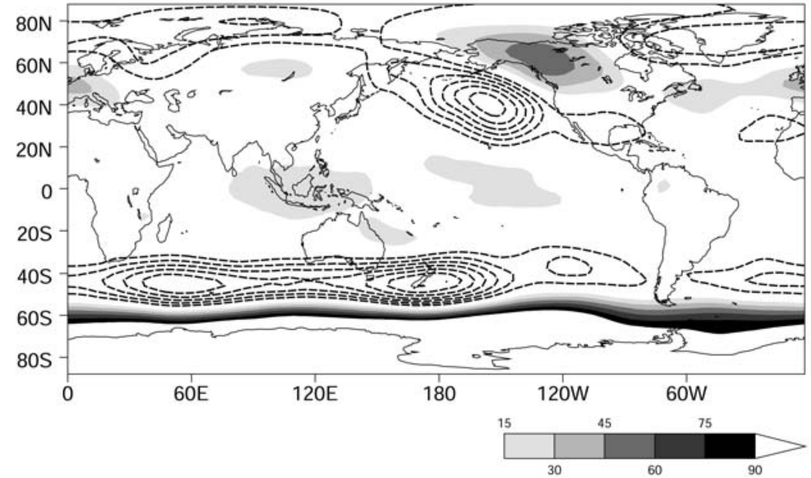
AGCM forced only with SWIO SST anomalies reproduces the above results

500hPa Height anomalies – TIP

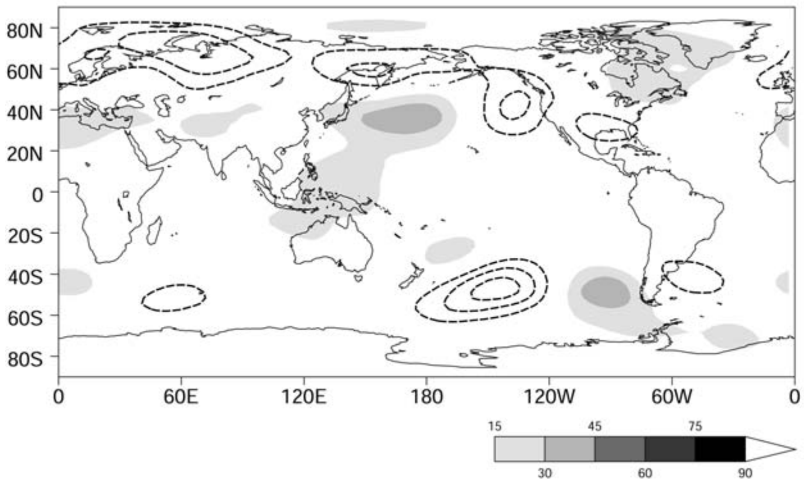
Reanalysis



ECHAM5



CCSR



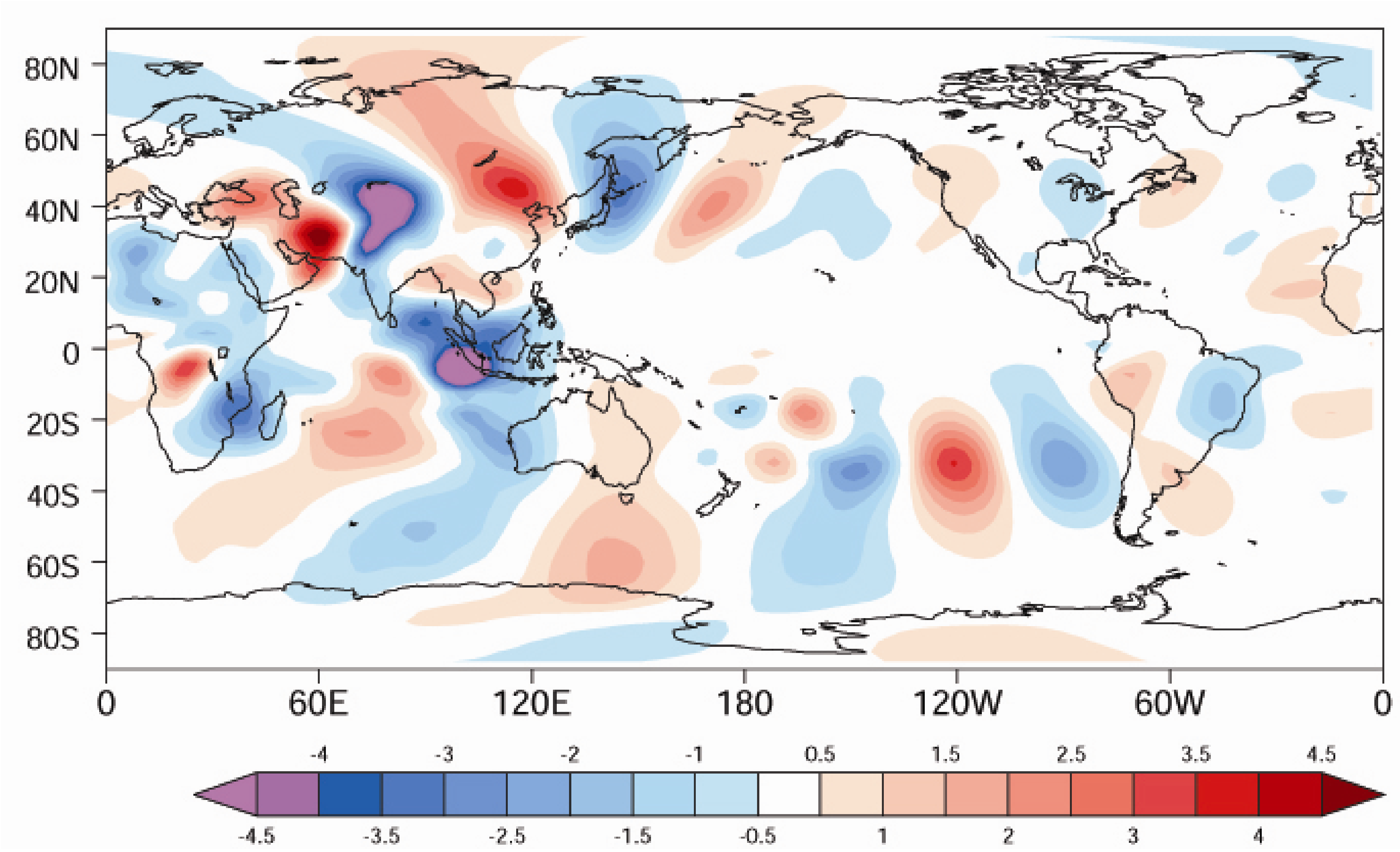
RMSE - PNA

ECHAM5 – 24.5 (42.0)

CCSR – 17.7 (20.9)

TPO

200hPa Meridional wind response to EIO SST forcing



“enhanced monsoon convection / anticyclone – enhances the westerly jet stream

Indian Ocean SST trend on NAO/PNA.......

- Hoerling et al. (2004). **Indian ocean** SST's force 50 year trend in North Atlantic "**NAO**"-like pattern. Science….

- Bargusli, J.J., and P.D. Sardeshmukh, 2002: Global atmospheric sensitivity to Tropical SST anomalies throughout the Indo-Pacific basin. *J. Climate*, **15,** 3427-3442

Summary.....

- Tropical Indian Ocean plays an **active role** in regional and global climate

- Tropical Indian and Pacific Oceans – **two-way** interactions (IPRC contribution)

References…

(i) Schott, F., and J. McCreary 2001: The monsoon circulation of the Indian Ocean, *Prog. Oceanogr.,* **51,** 1-123.

(ii) Schott, F., S.P. Xie., J. P. McCreary 2008: Indian Ocean circulation and climate variability. *Review of Geophysics*, (in press)

(iii) Annamalai, H., and R. Murtugudde, 2004: Role of the Indian Ocean in regional climate variability. Earth's Climate: The ocean-atmosphere interaction. *Geophysical Monograph series,* **147,** 213-246.

(iv) Yamagata, T., S.K. Behera, J.J. Luo, S. Massson, M.R. Jury, and S.A. Rao., 2004: Coupled ocean-atmosphere variability in the tropical Indian Ocean. Earth's Climate: The ocean-atmosphere interaction. *Geophysical Monograph series,* **147,** 189-212.