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Scale interaction in the tropics.

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Scale interactions in the Tropics

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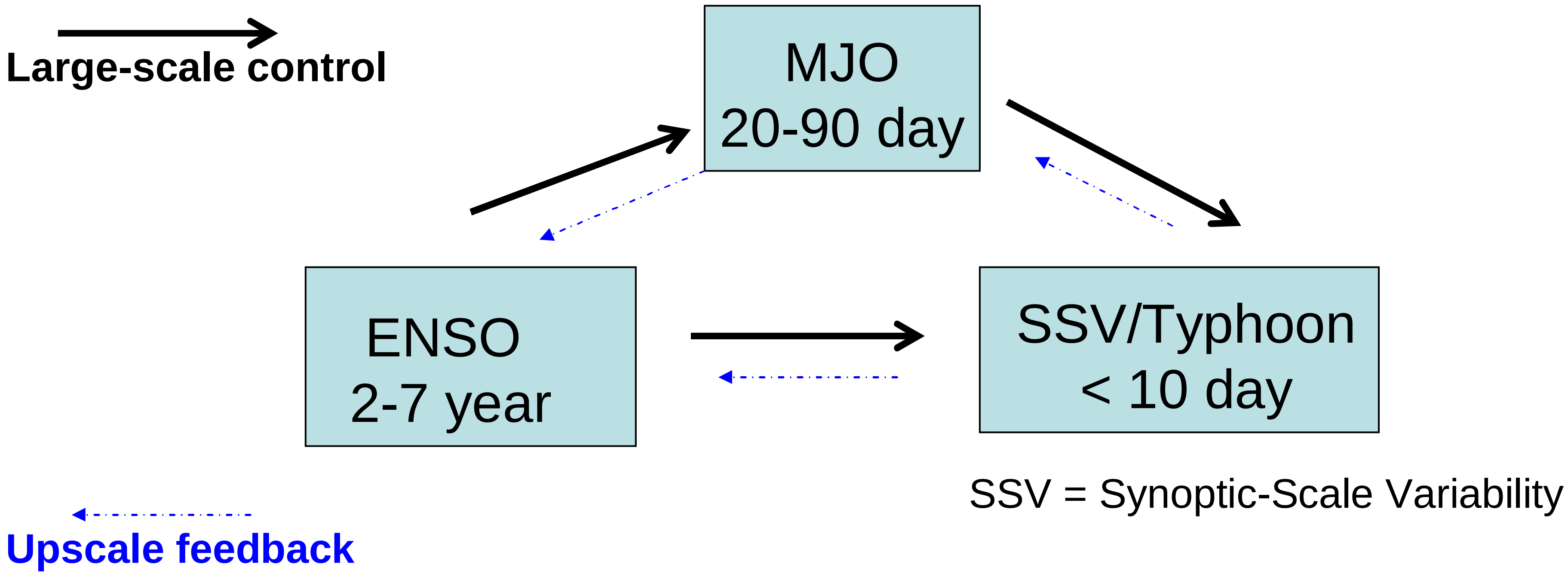
Acknowledgement: C. Zhou, X. Rong, R. Zhang, J. Su, J. Kug



1. Upscale feedback of SSV to ISO
2. Upscale feedback of MJO/SSV to ENSO

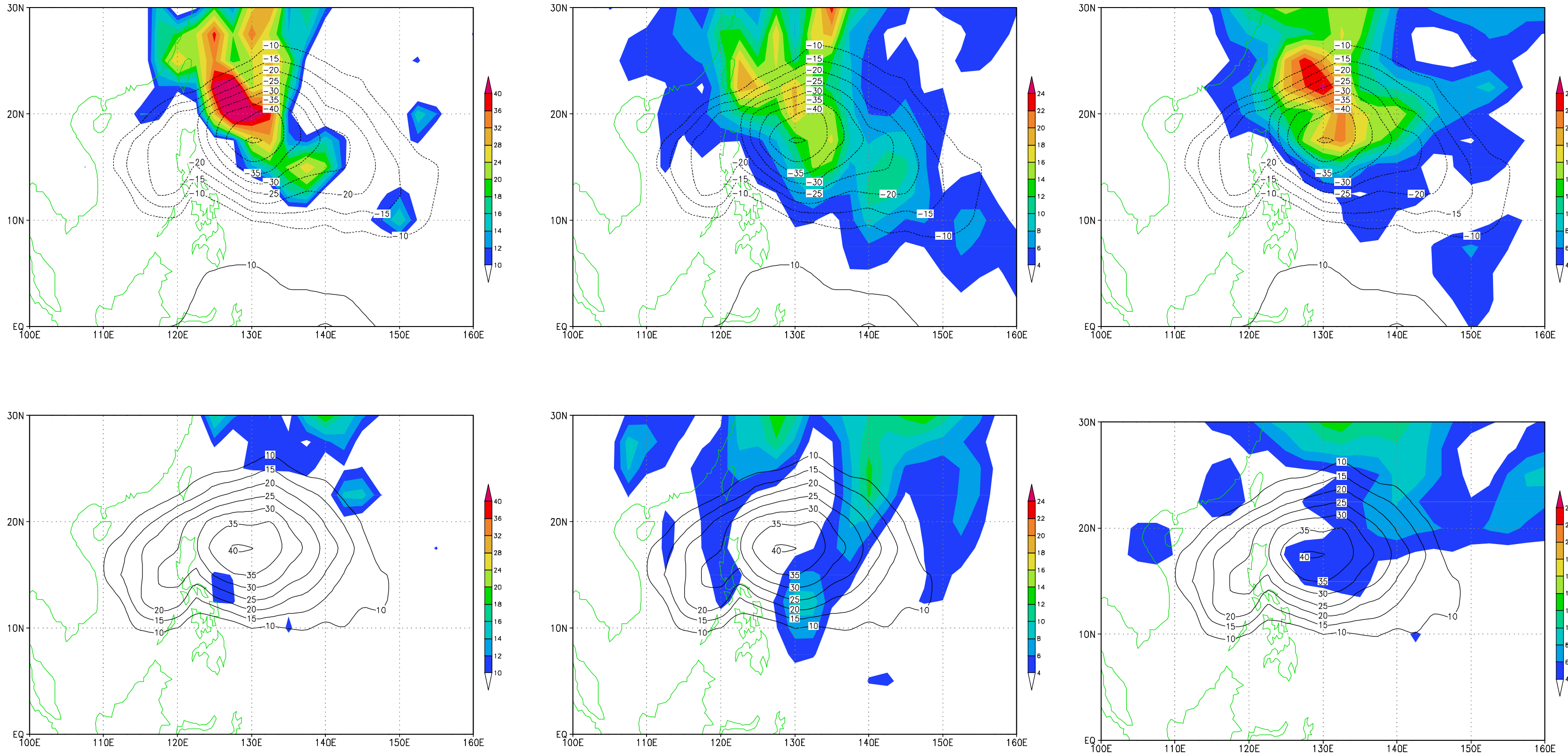
To understand how SSV feeds back to ISO, first we reveal *how SSV is modulated by ISO*.

Northwest Pacific (125E-135E,15N-20N)

ς'^2 v'^2 u'^2

wet

dry



ς', v', u' : synoptic scale (3–8d)

Contour: 20-90d OLR

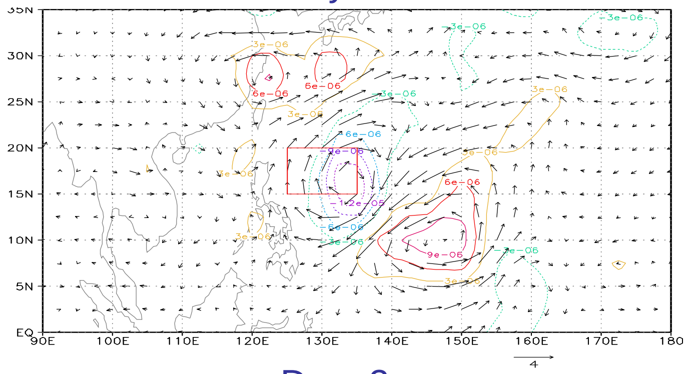
Color: 850mb ς'^2, v'^2, u'^2

Enhanced SSV during ISO wet phase

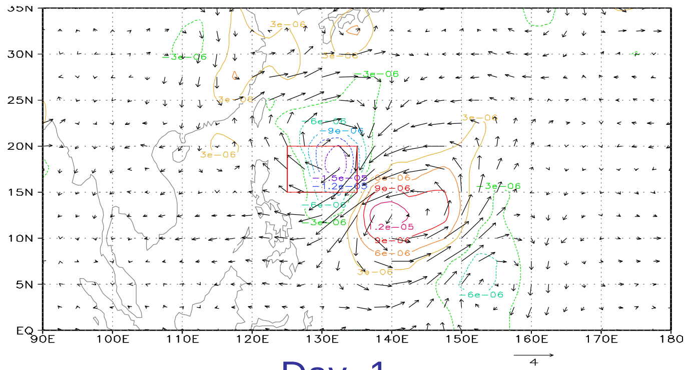
Suppressed SSV during ISO dry phase

Evolution of synoptic disturbances during ISO wet phase

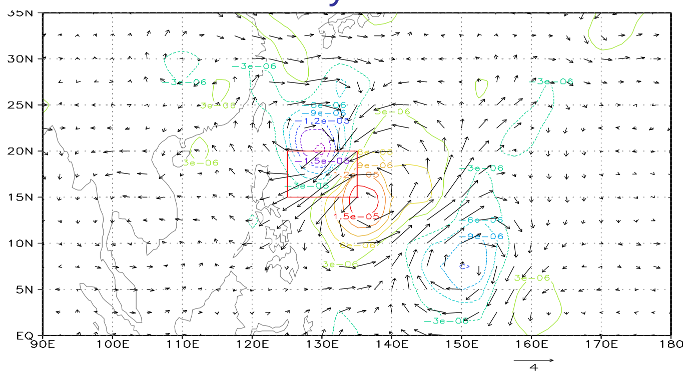
Day -3



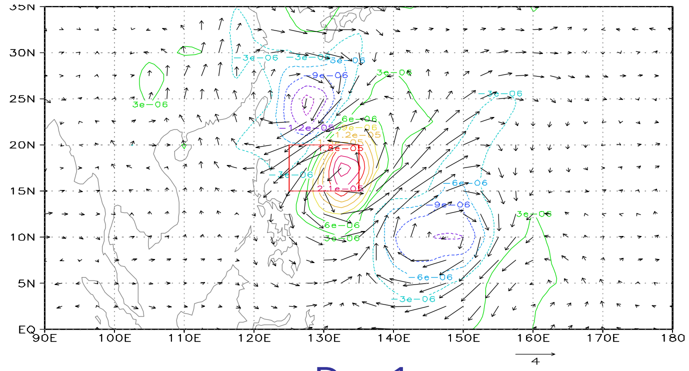
Day -2



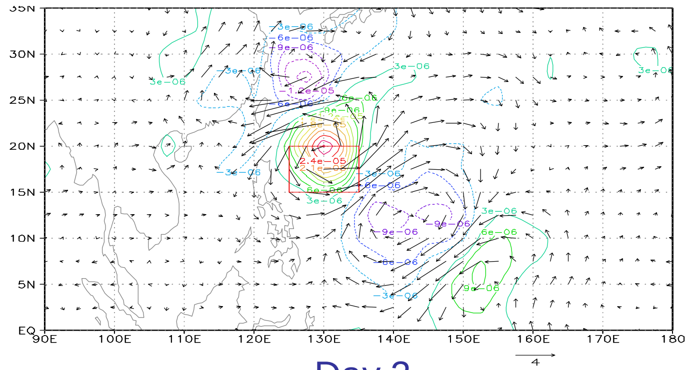
Day -1



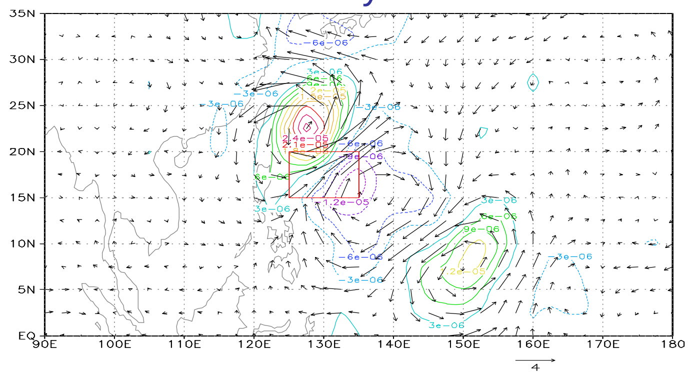
Day 0



Day 1



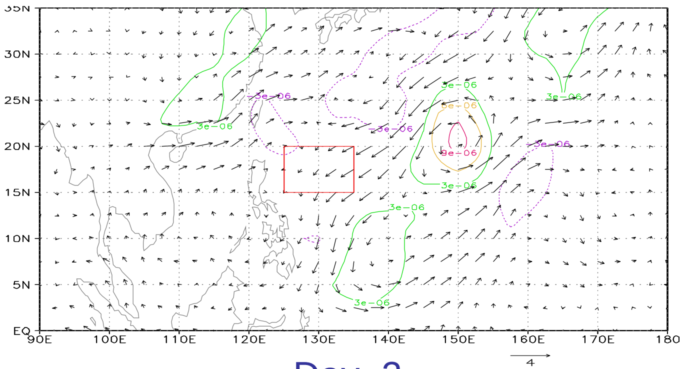
Day 2



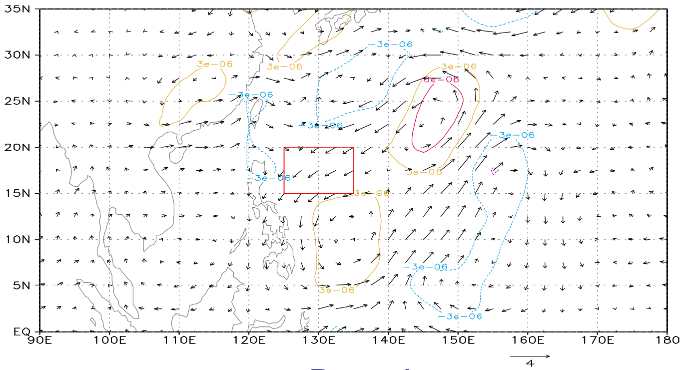
This synoptic wave train was revealed by Lau and Lau 1990 and Chang et al. 1996

Evolution of synoptic disturbances during ISO dry phase

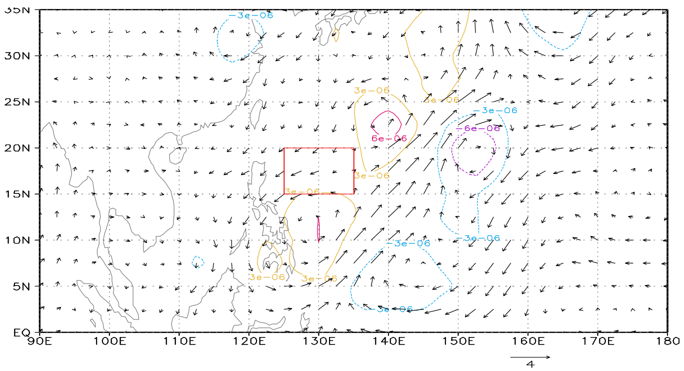
Day -3



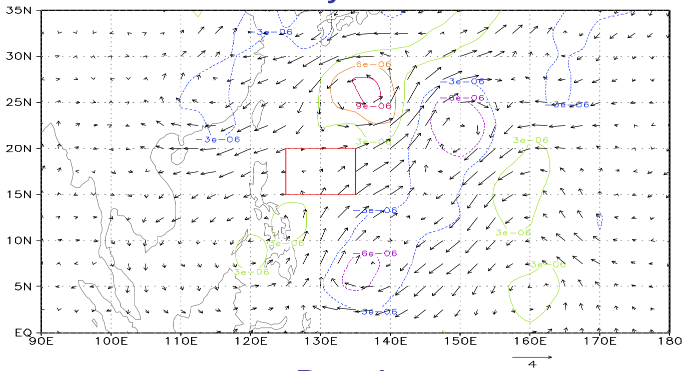
Day -2



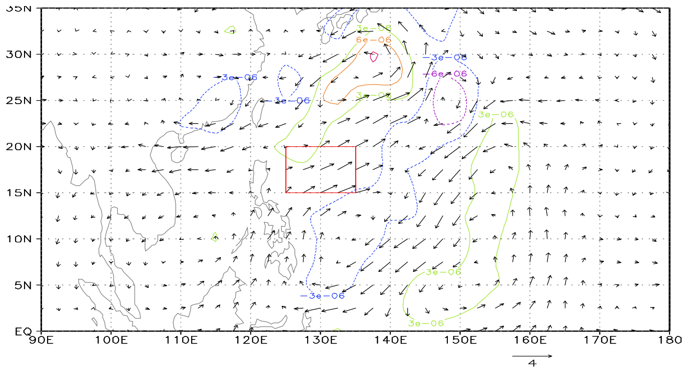
Day -1



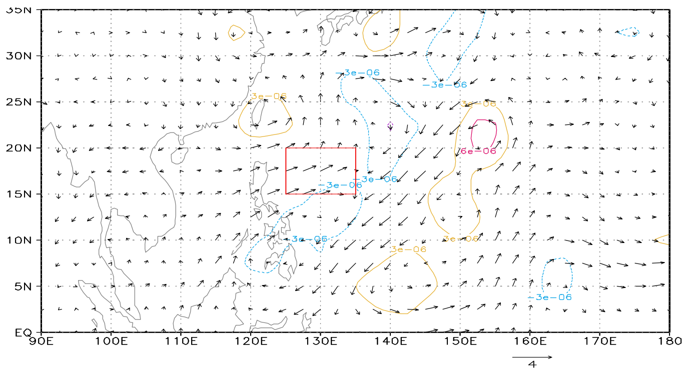
Day 0



Day 1



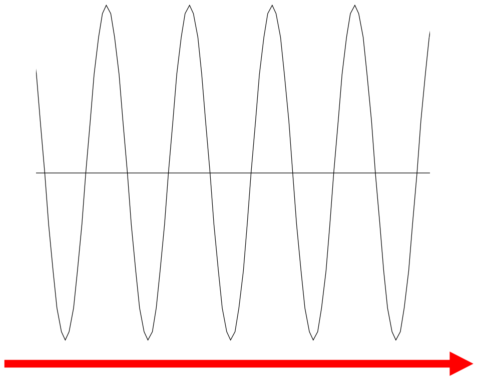
Day 2



ISO-phase-dependent SSV

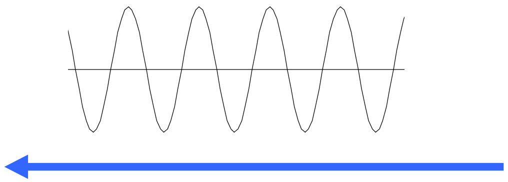
u', v' synoptic motion

$$\sum u' = \sum v' \approx 0$$



ISO westerly phase

(enhanced convective phase)



ISO easterly phase

(suppressed convective phase)

How does SSV feed back to ISO?

Hypothesis: SSV feeds back to ISO through nonlinear rectification of intraseasonal surface heat fluxes

$$\sum |\vec{v}| = \sum \sqrt{u'^2 + v'^2}$$ larger

$$\sum (Surface\ \ Latent\ \ Heat\ \ flux) \uparrow$$

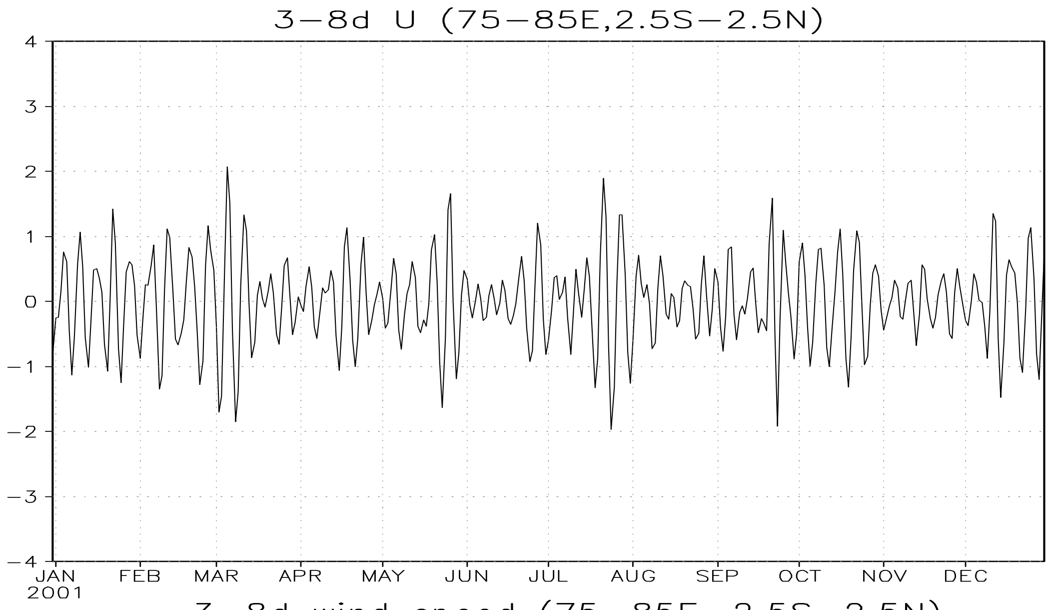
⟹ Pre-conditioning/moistening

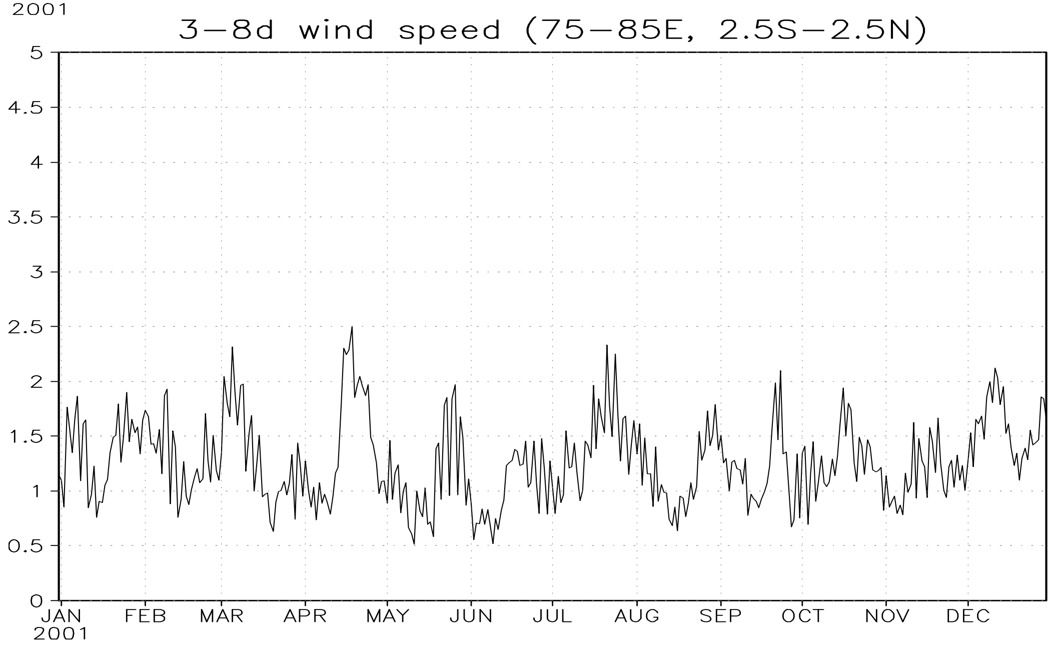
⟹ **+ feedback** to ISO

$$\sum |\vec{v}| = \sum \sqrt{u'^2 + v'^2}$$ smaller

$$\sum (Surface\ \ Latent\ \ Heat\ \ flux) \downarrow$$

3-8-day filtered QuikSCAT surface wind





Synoptic-scale u, v

➔ can project into intraseasonal wind speed

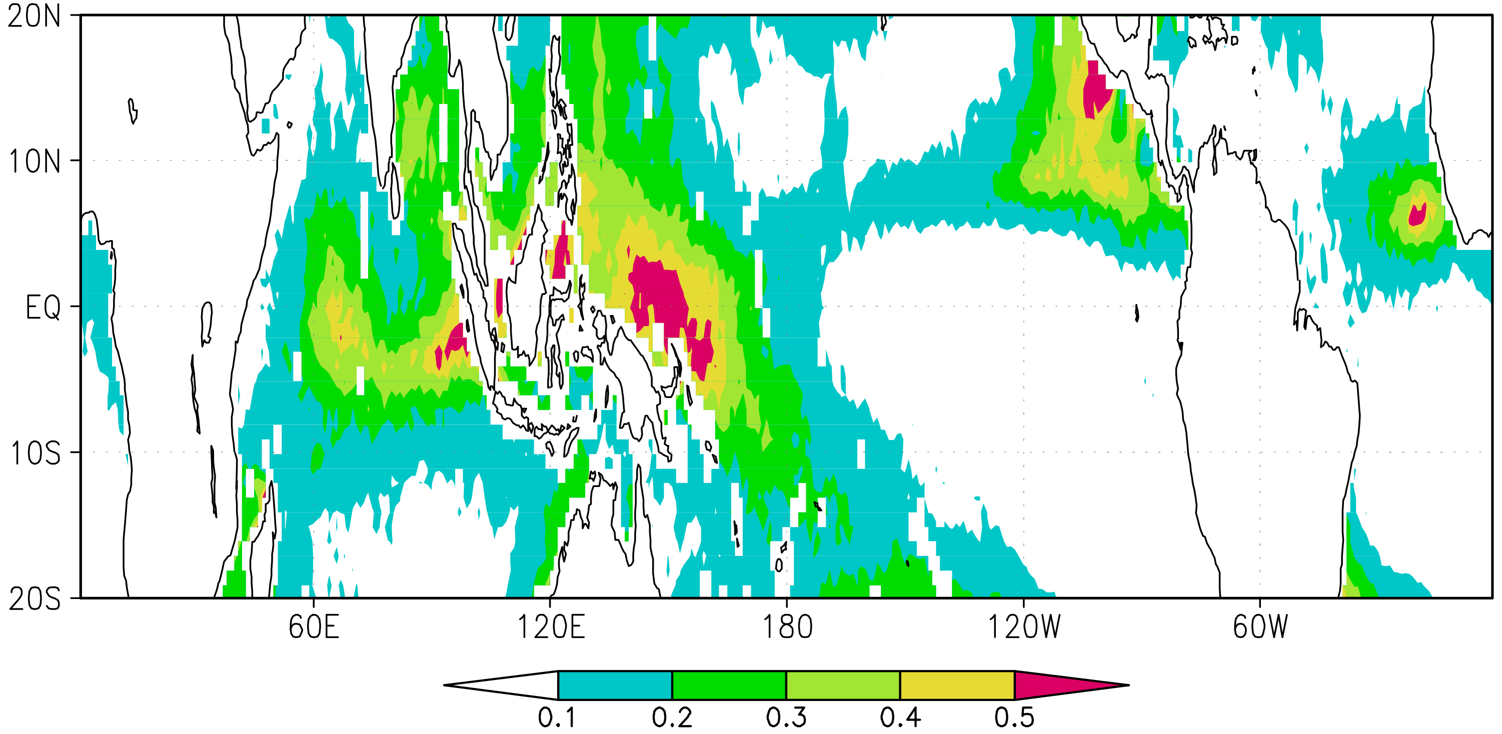
➔ may contribute to intraseasonal latent heat flux and thus impact ISO convection

$$LH = \rho L_c C_E \sqrt{u^2 + v^2}(q_s - q_a)$$

$$u = \overline{u} + \tilde{u} + u'; \; v = \overline{v} + \tilde{v} + v'; q = \overline{q} + \tilde{q} + q'$$

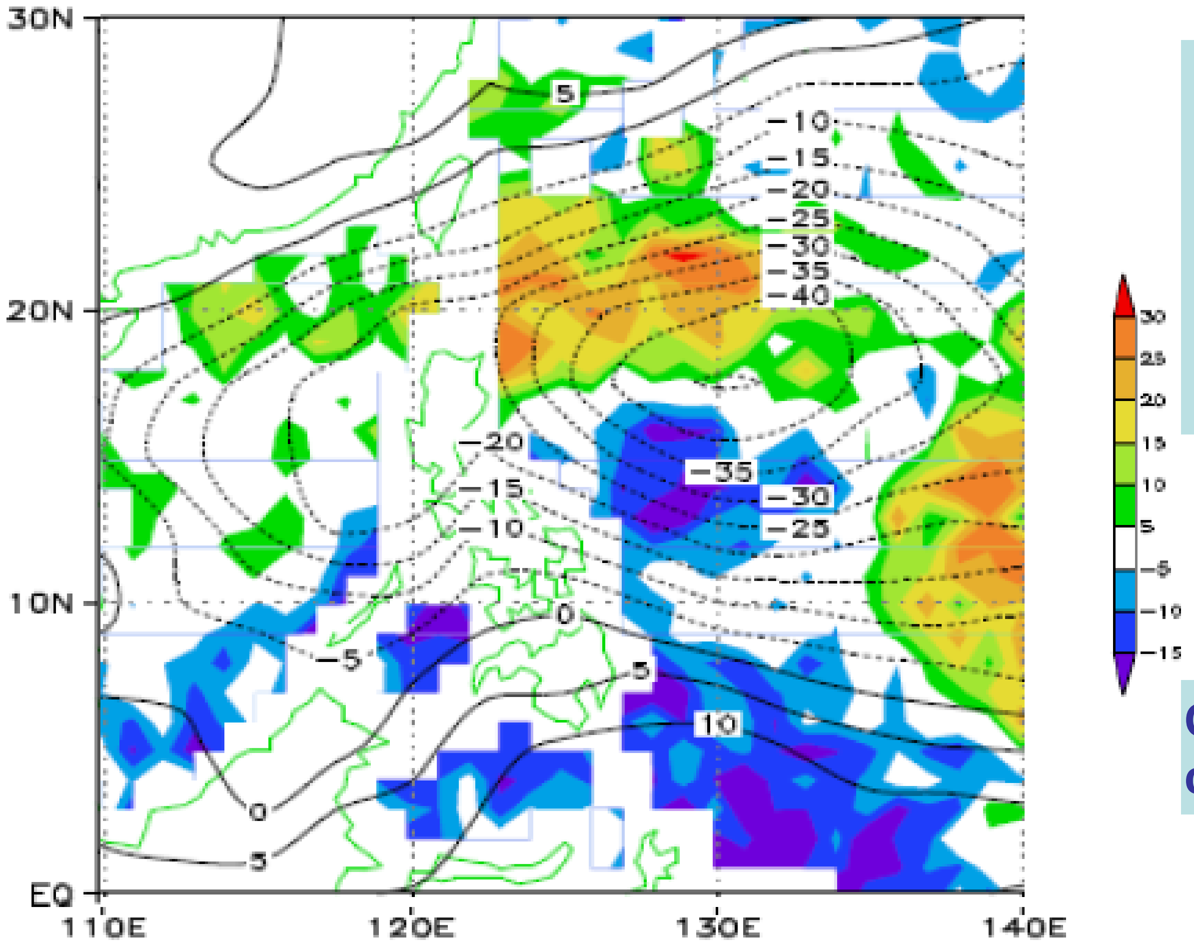
(¯) : climatological mean annual cycle; ('): synoptic (3-8d);

(~) : intraseasonal (20-90d)



$$\frac{\text{STD (20-90d LH, based on 3-8d + mean u,v,dq)}}{\text{STD (20-90d LH, based on total u,v,dq)}}$$

Phase relation between ISO convection (contour) and nonlinearly rectified (SSV-induced) intraseasonal latent heat flux (shaded)



Color: wet – dry composite of LH (3-8d + mean u,v,dq) field projected into the ISO (20-90d) timescale

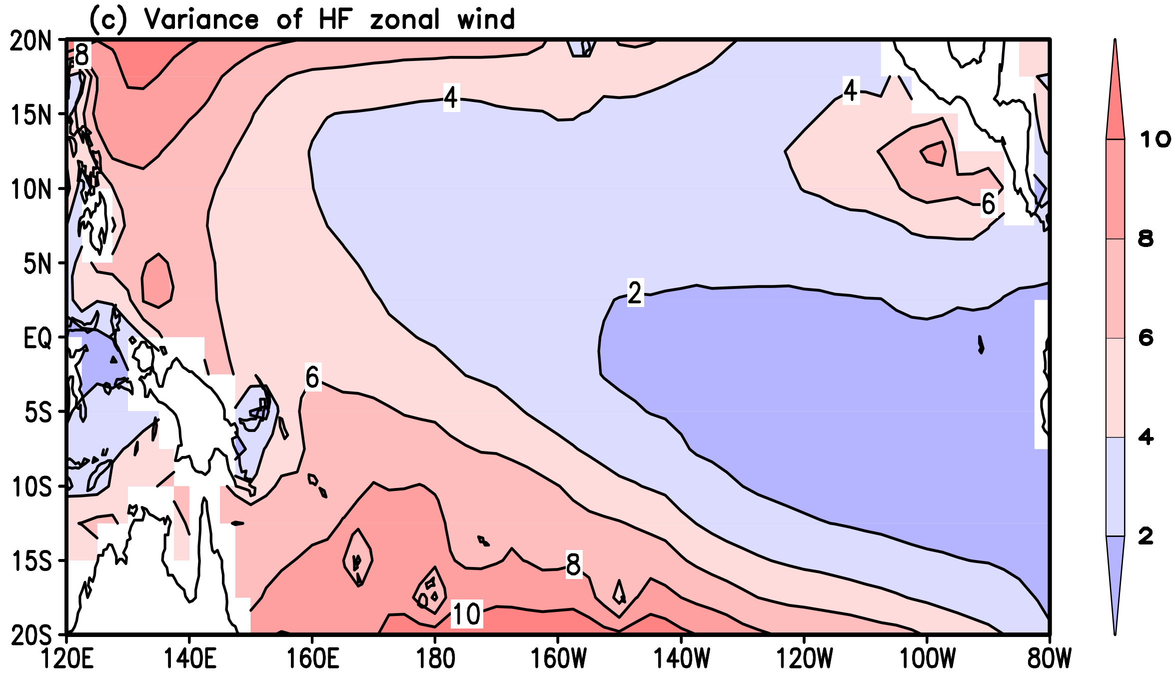
(It represents SSV-induced intraseasonal LHF)

Contour: 20-90d OLR wet-dry composite

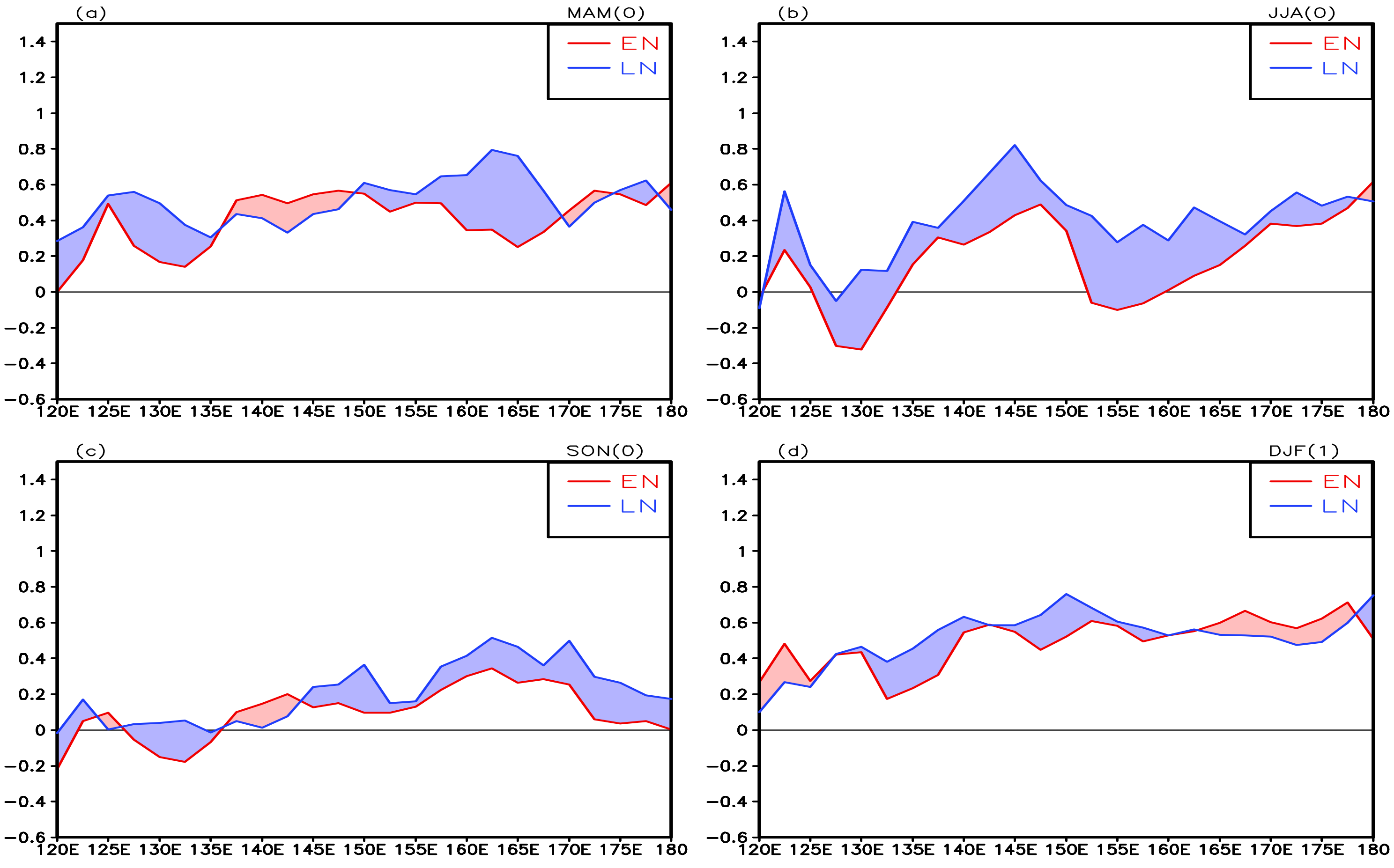
Implication: **SSV-induced nonlinearly rectified surface latent heat flux** may **1) enhance ISO** and **2) contribute to northwestward propagation of ISO** in WNP.

Impacts of High-Frequency (HF, 90 days or less) Wind Variabilities on Low-Frequency (LF, 2-7-yr) Wind Stress and SST Anomalies Associated with ENSO

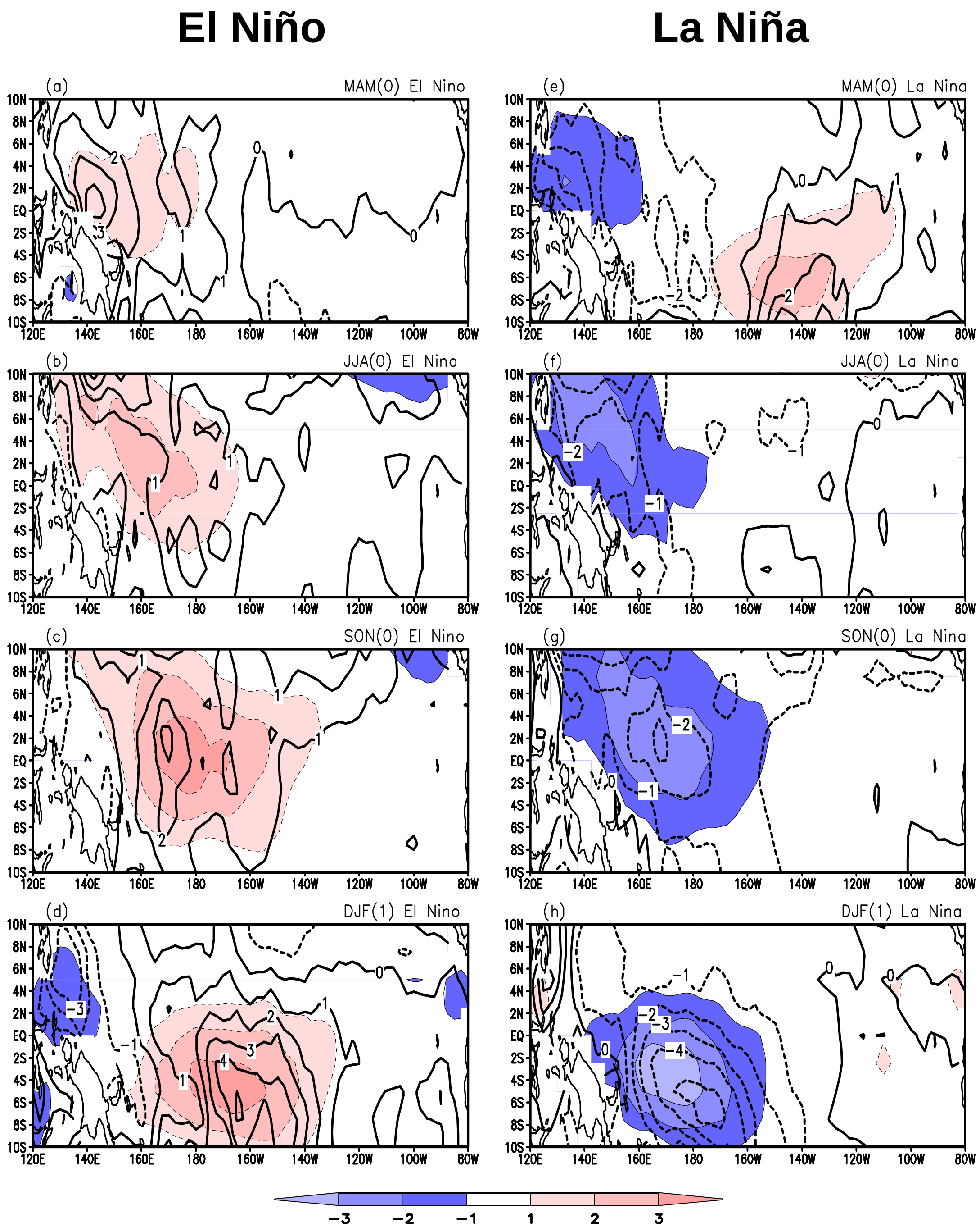
Characteristics of HF surface zonal wind in the tropics



Skewness of HF zonal winds during El Niño and La Niña



HF westerly wind events during El Nino onset and developing phases are not stronger than those during La Nina phases !

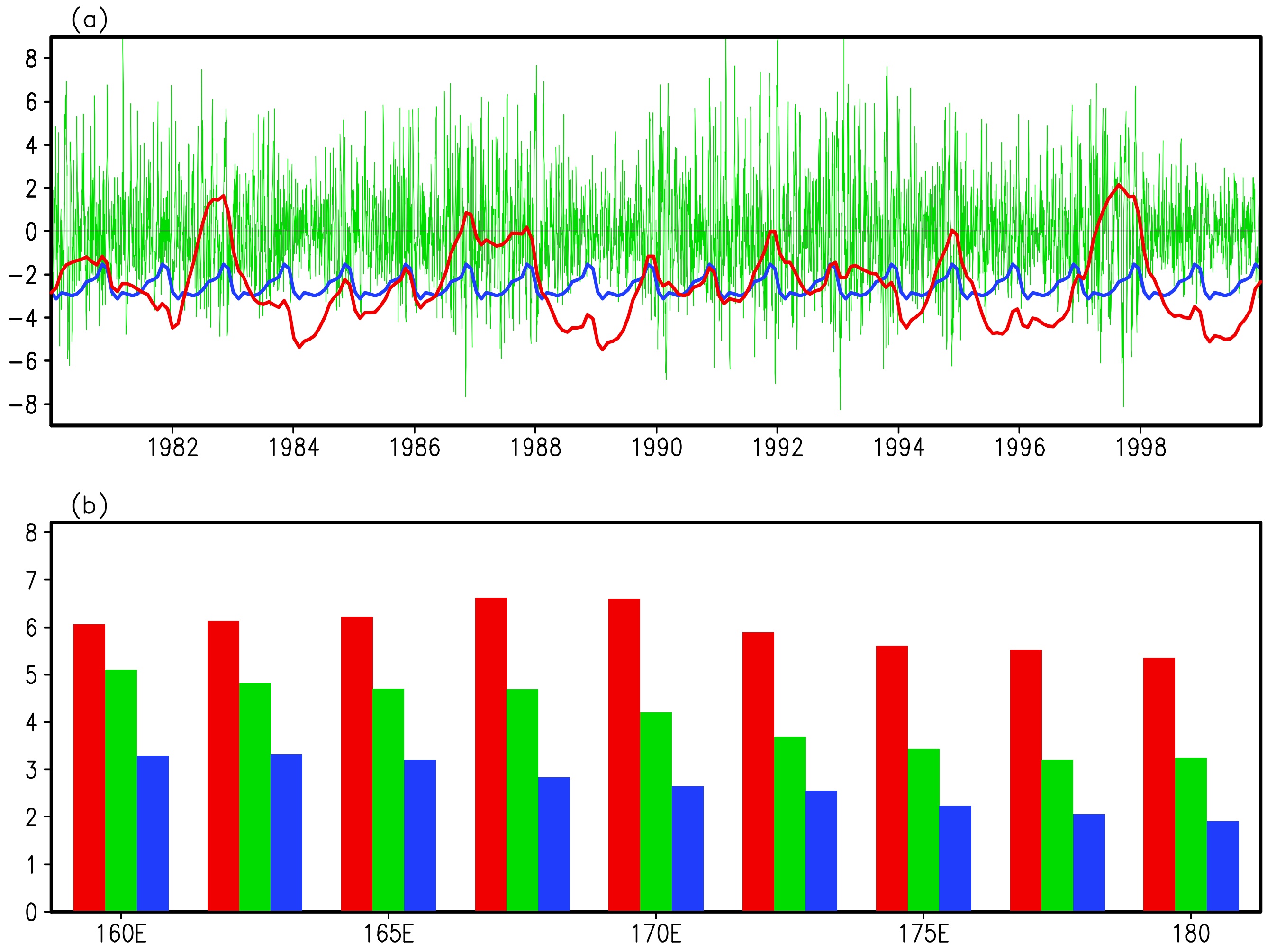


Contour: HF zonal wind variance

Shaded: LF zonal wind anomaly (units: m s-1)

However, HF wind variance is ENSO-phase dependent !

ENSO-phase dependent HF wind variability



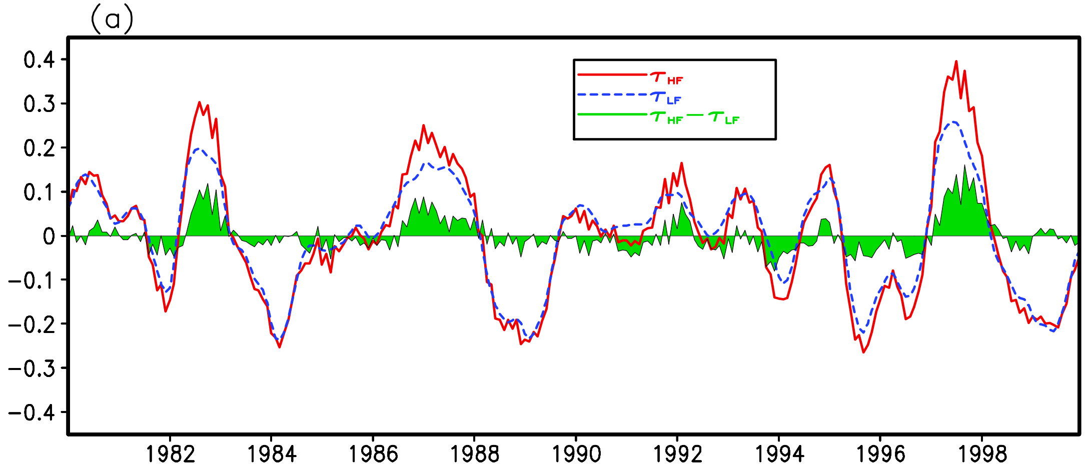
(a) Time series of **HF zonal wind (green line) at 170˚E, 0˚N** and the LF (red line) and the climatological mean (blue solid) zonal wind anomaly over 160˚E-180˚, 5˚S-5˚N.

(b) Variance of the HF zonal wind over 5˚S-5˚N in JJASON composed for El Niño (red bars), La Niña (blue bars) and normal (green bars) years.

How does the phase-dependent HF variability feed back to ENSO?

1: Enhance the amplitude of interannual wind stress anomaly

2: Modify the skewness of the wind stress anomaly



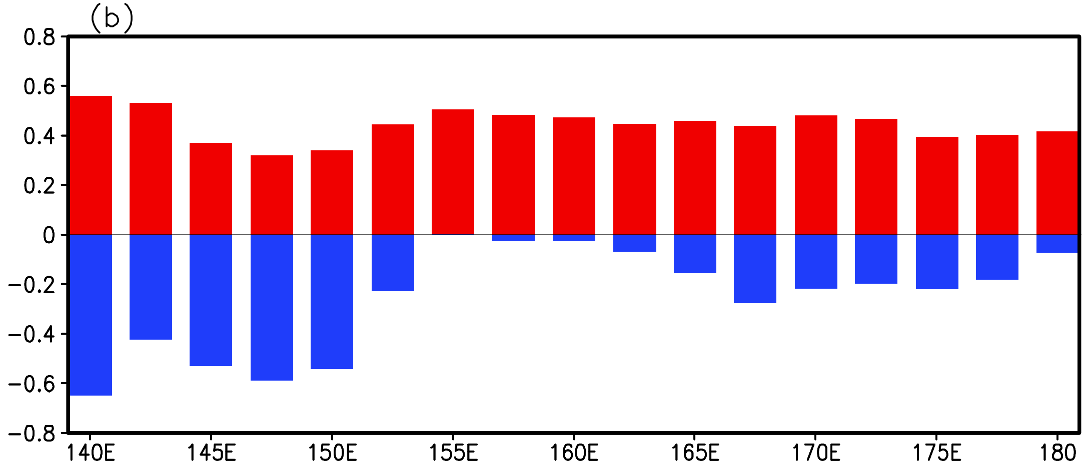
$$\tau = \rho C_D |V| u$$

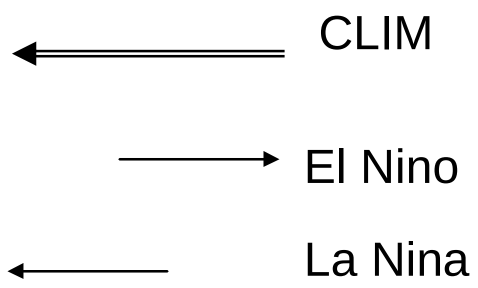
τ_{LF} *(pure effect of LF wind):*

$$u = u_c + u_l$$

τ_{HF} *(include effect of HF wind):*

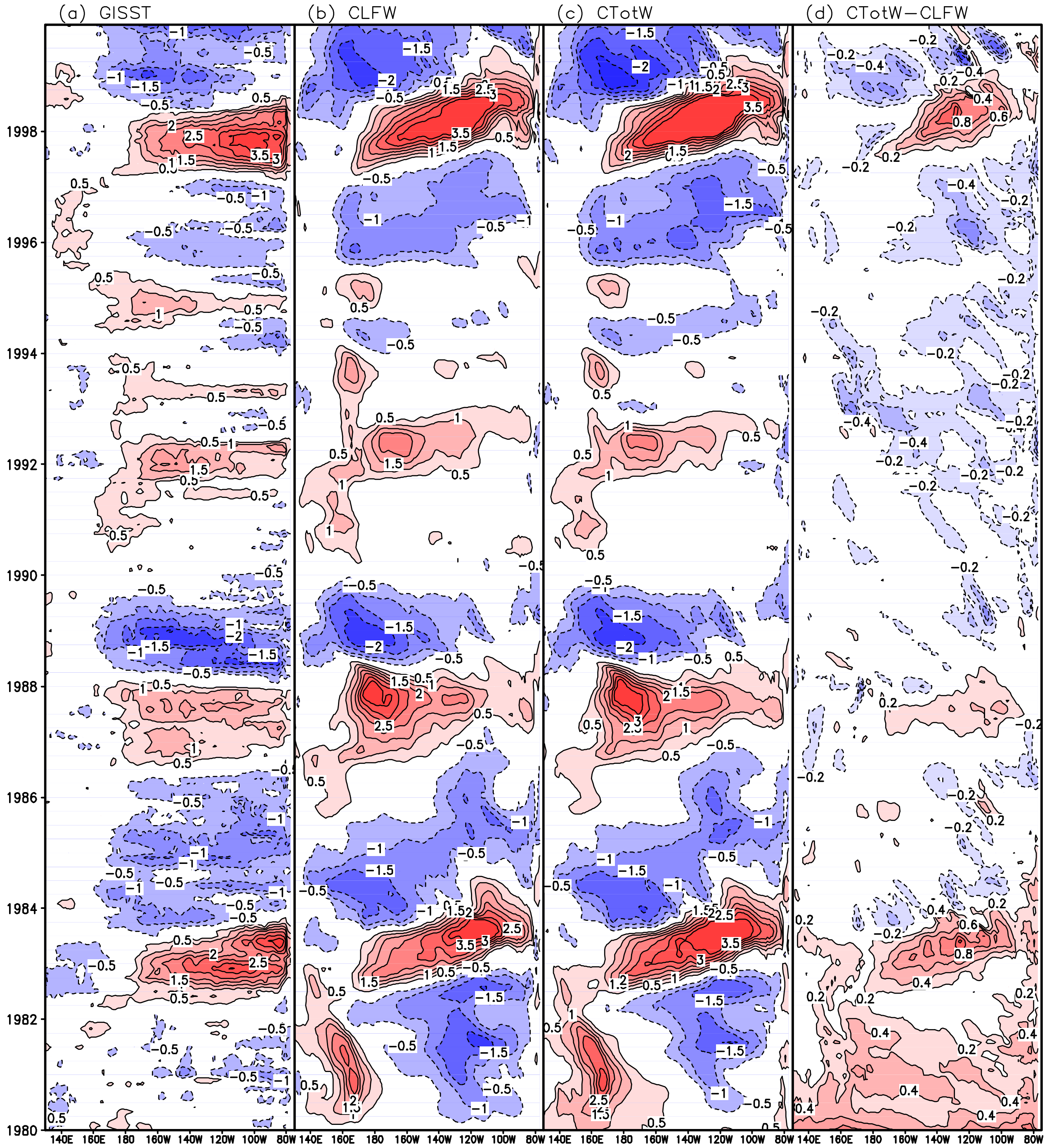
$$u = u_c + u_l + u_h$$





(a) Time series of zonal wind stress anomalies (Units: dyne/cm^2) averaged over **160˚E-180˚, 5˚S-5˚N**. Red and blue lines denote τ_{HF} and τ_{LF} respectively, and green shaded denotes the difference.

(b) Skewness of τ_{HF} (red bars) and τ_{LF} (blue bars) averaged over 5˚S-5˚N.



OGCM simulations

Time evolution of SSTA along the equator:

(a) GISST observation

(b) OGCM simulation with C+LF wind forcing

(c) OGCM simulation with C+LF+HF wind forcing

(d) Difference between (c) and (b)

Conclusion:

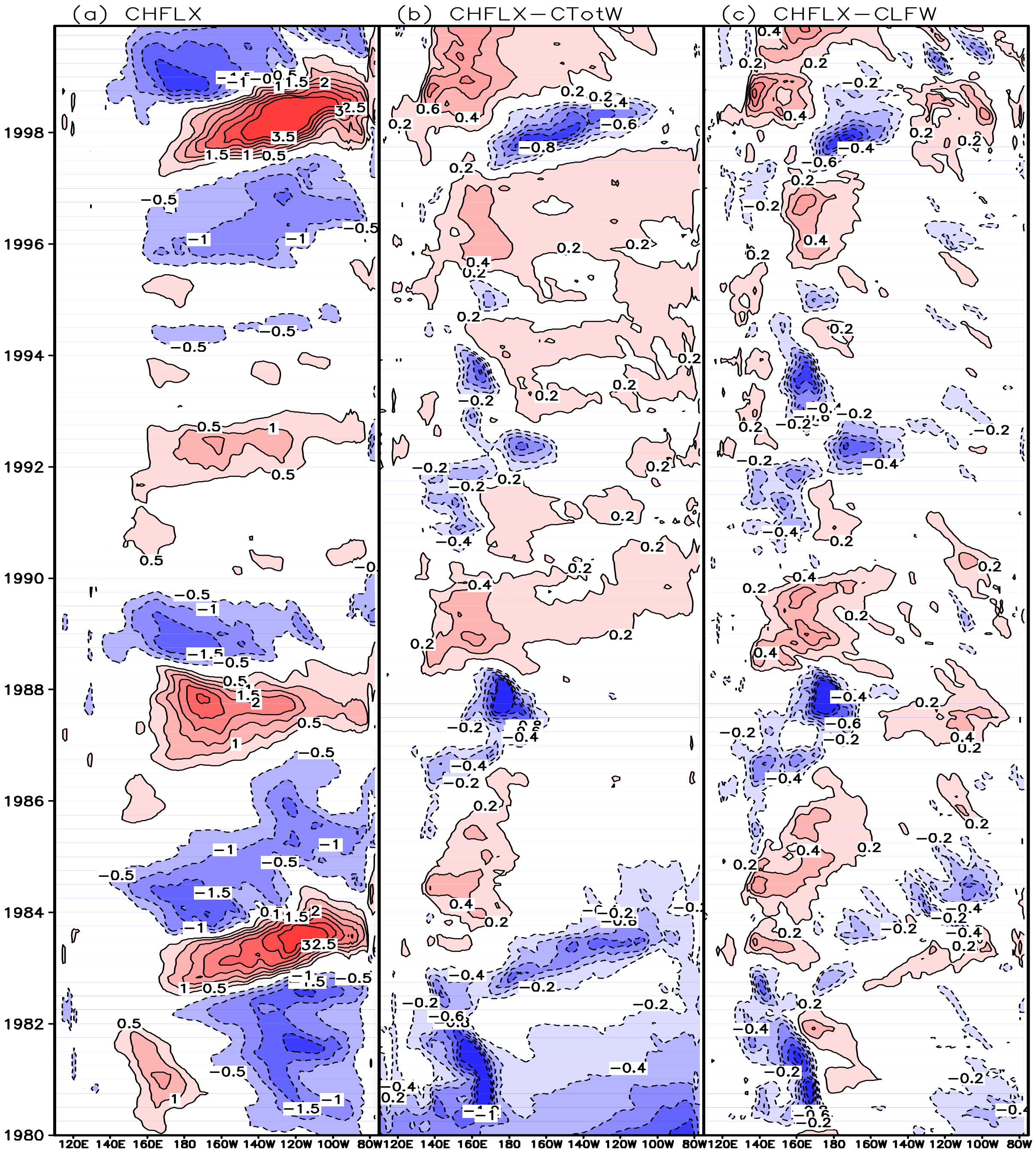
1. SSV significantly modulates intraseasonal surface latent heat flux. In particular in WNP, *the nonlinearly rectified latent heat flux tends to enhance ISO and contribute to its northwestward propagation* through the pre-conditioning of moisture.

2. HF wind induced nonlinearly rectified LF wind stress anomaly *forces a significant interannual SST anomaly* in the eastern equatorial Pacific.

3. Whereas the LF wind associated with ENSO leads to a negative zonal wind stress skewness in the western and central equatorial Pacific, *the ENSO-state dependent HF wind tends to reverse the negative skewness to a positive skewness.*

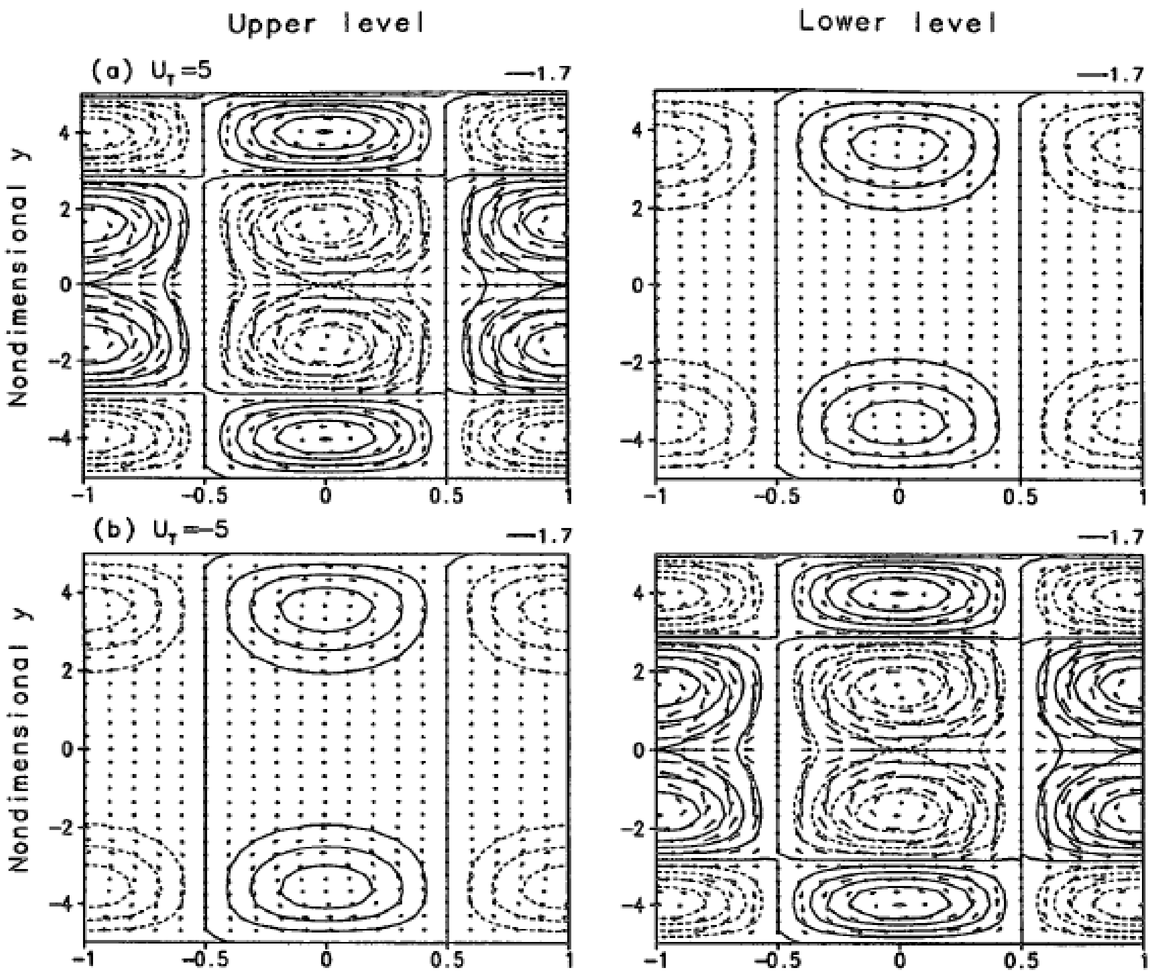
4. OGCM simulations reveals that HF wind forcing leads to *a stronger and more positively skewed interannual SST anomaly*.


Thanks
Diamond Head



(a) CHFLX
(b) CHFLX−CTotW
(c) CHFLX−CLFW
1998
1996
1994
1992
1990
1988
1986
1984
1982
1980
120E 140E 160E 180 160W 140W 120W 100W 80W

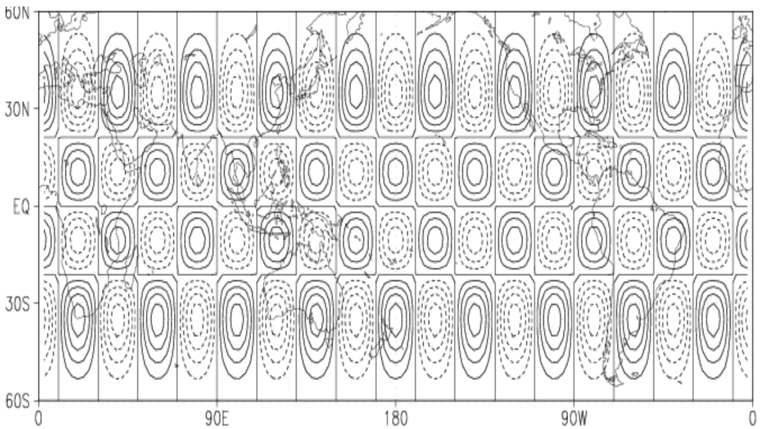
A mechanism for the enhanced synoptic disturbances during ISO wet phase: **vertical shear effect**

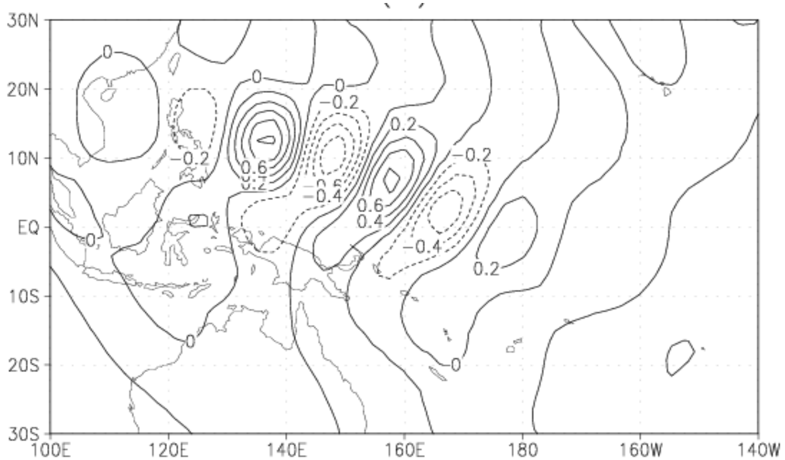


Wang and Xie 1996, JAS

An easterly shear leads the amplification of Rossby waves at lower levels, whereas a westerly shear favors the amplification of Rossby waves at upper levels.

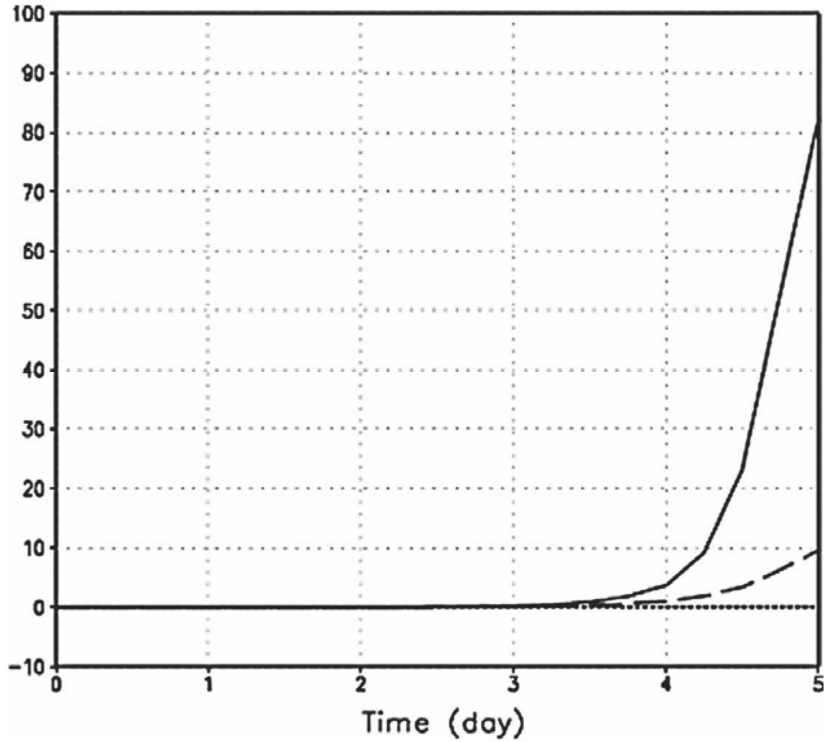
The **vertical shear effect (Cont.)**



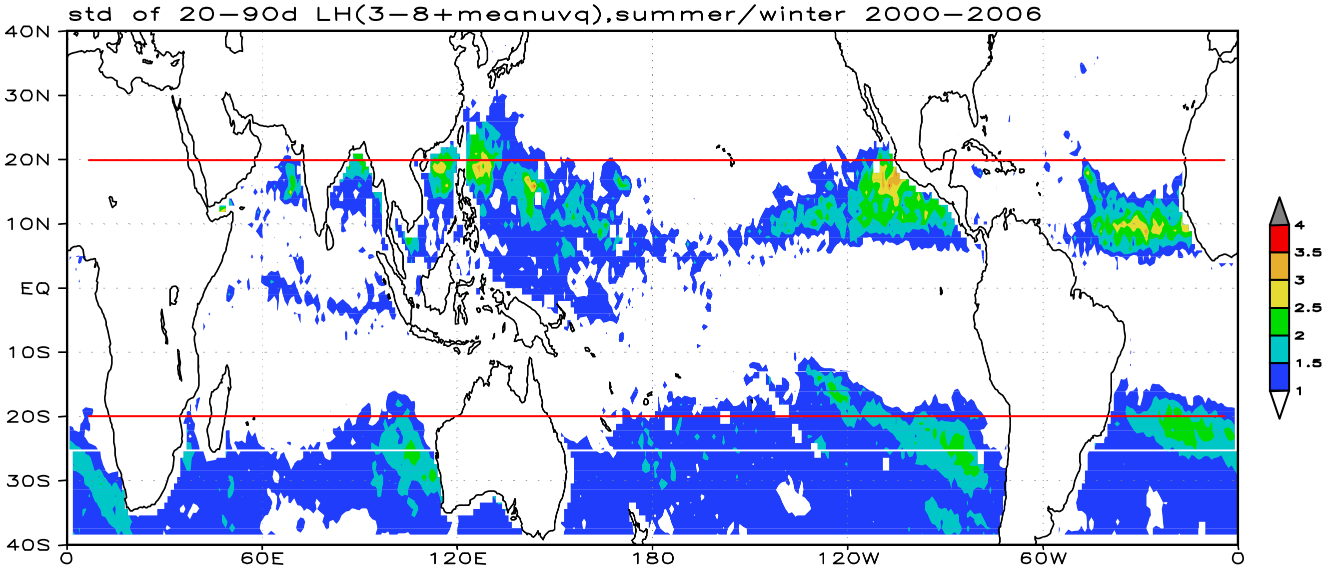


Left: Anomaly AGCM simulation with specified 3D summer (JJA) mean flows and SST and surface moisture condition

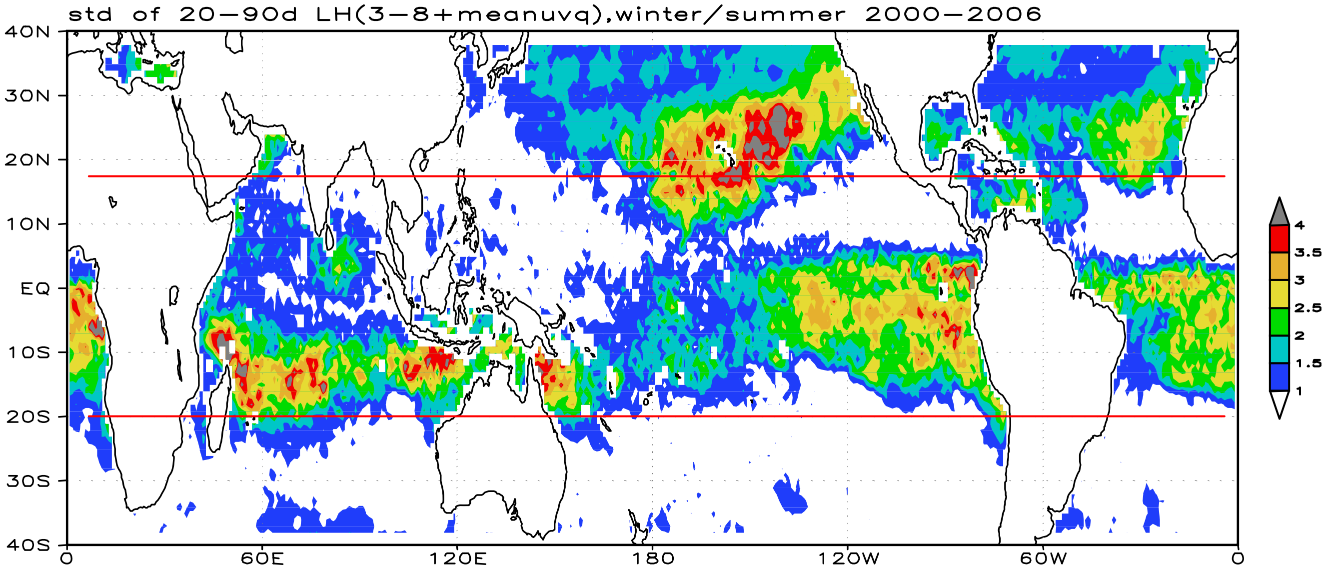
Li 2006, JAS



Right: Evolution of maximum perturbation kinetic energy under a constant easterly shear (solid line), westerly shear (dashed line), and zero shear (dotted line). JJA SST and surface moisture fields are specified.



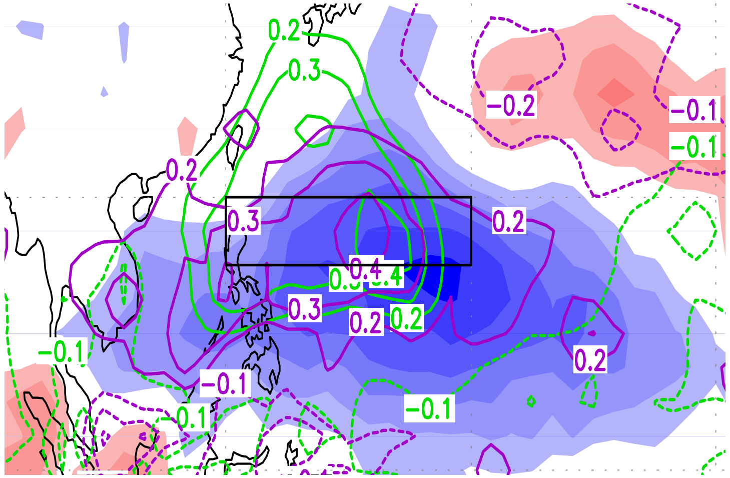
$$\frac{\text{STD(20-90d LH, summer)}}{\text{STD(20-90d LH, winter)}}$$



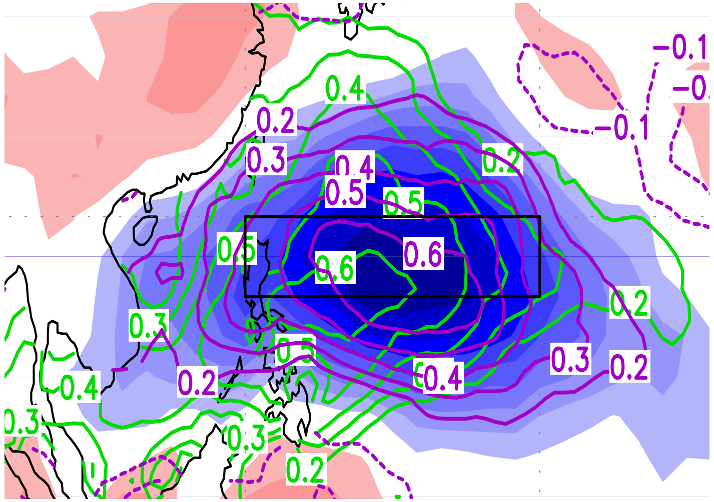
$$\frac{\text{STD(20-90d LH, winter)}}{\text{STD(20-90d LH, summer)}}$$

LH: based on 3-8d + mean u, v, dq

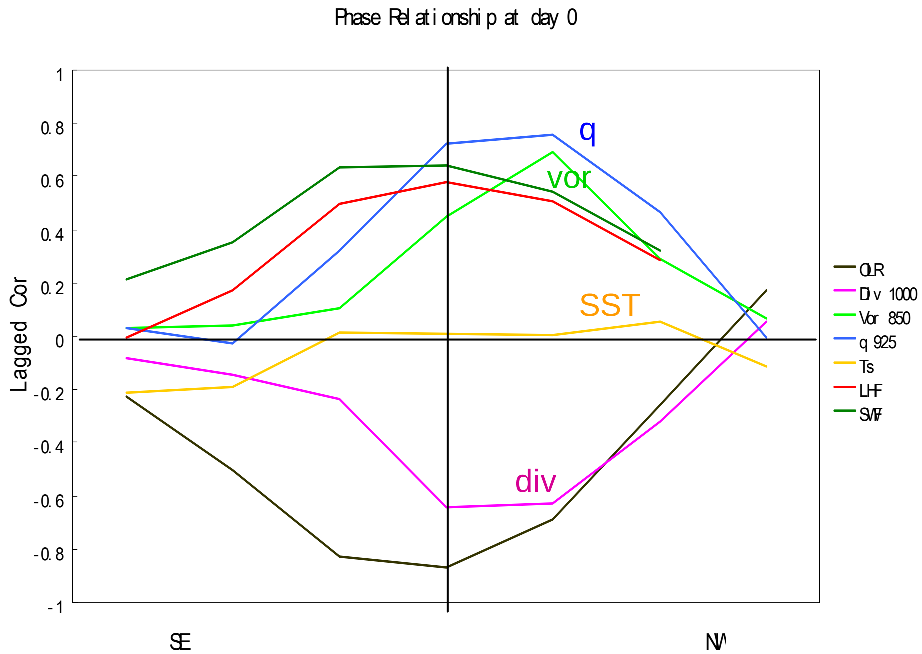
ISO OLR phase relation with SST, q, LHF, and SWR



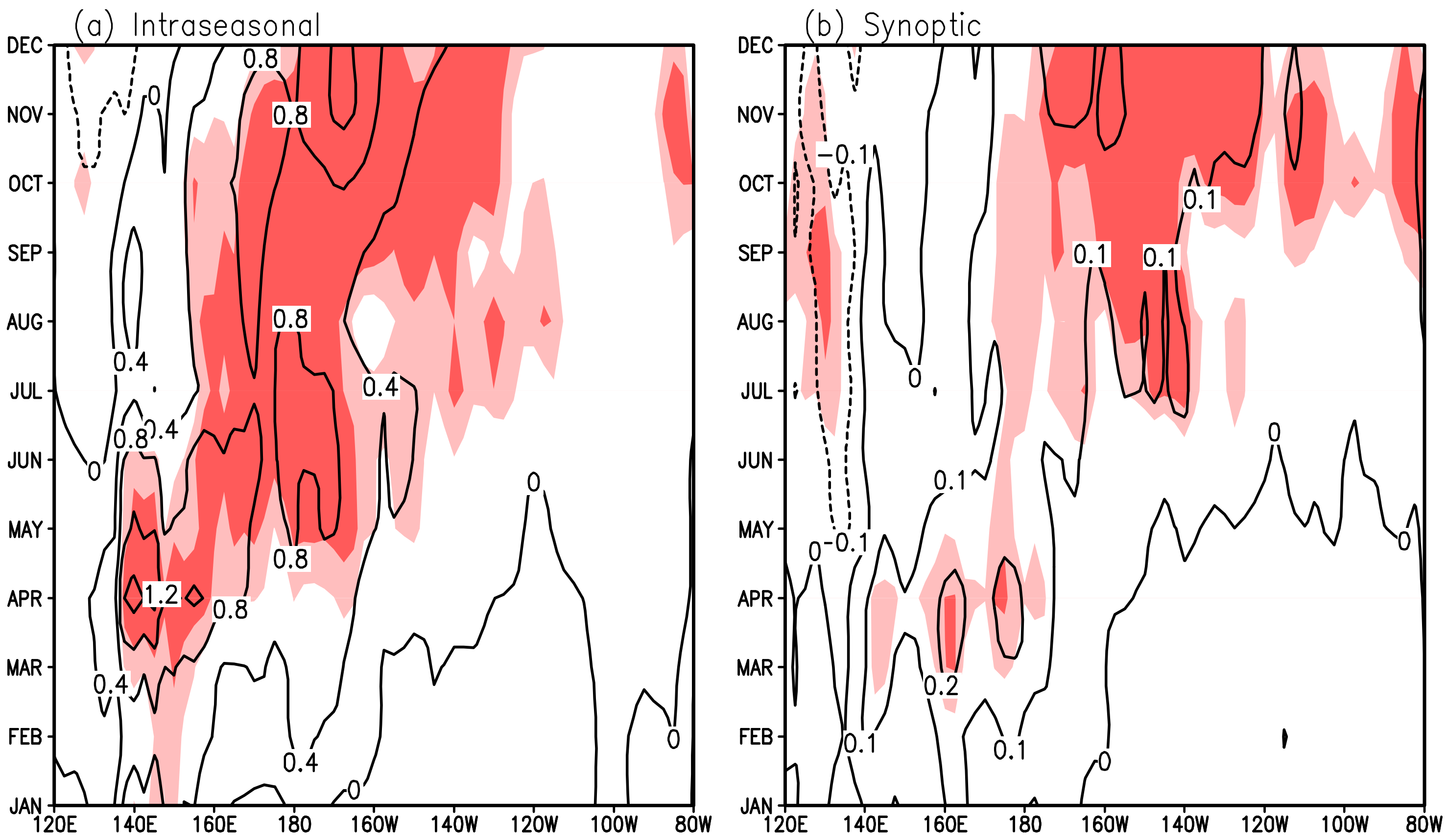
surface temperature (green), specific humidity (925hPa) (purple)



latent heat flux (green), shortwave radiation flux (purple)



HF variances: relative contribution of ISO and SSV



Lagged regression coefficients between the observed NDJ Nino3 index and the variance of (a) intraseasonal (20-90-day) and (b) synoptic (3-10-day) zonal winds along the equator (averaged over 5˚S-5˚N). Significant levels at 95% and 99% are shaded.

A Conceptual Model

$$\tau = \rho C_D |V| u \quad \text{where} \quad u = u_c + u_l + u_h$$

$$u_l = A \cdot \cos(2\pi t / T_1)$$

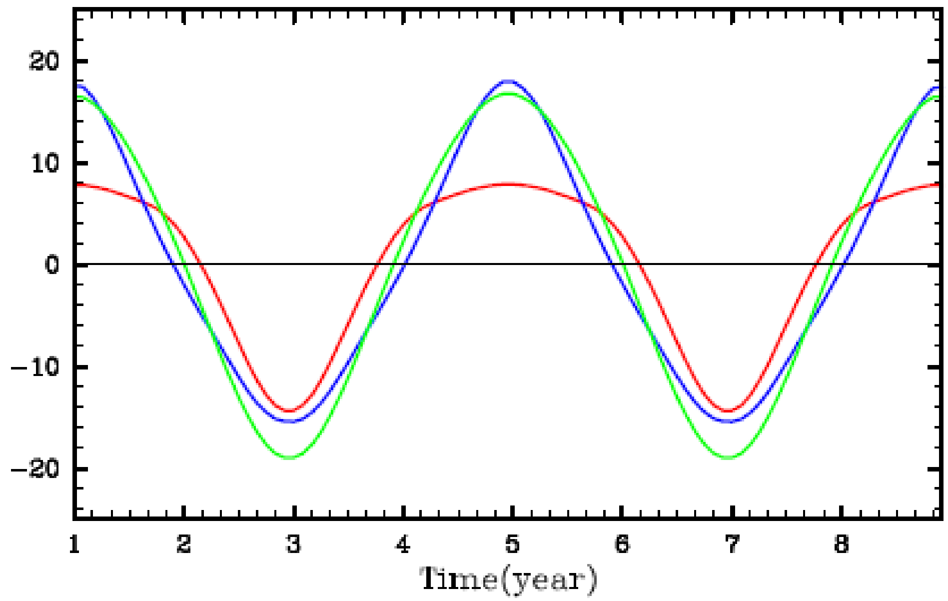
$$u_h = [B + C \cdot \cos(2\pi t / T_1)] \cdot \cos(2\pi t / T_2)$$

where t is time, u_c denotes the climatological mean, u_l represents the LF wind at a period of T_1=4 yr, and u_h is the HF wind at a period of T_2=10 days and with its amplitude being controlled by the phase of u_l.

Case A: u_c=-1.5m/s, A=3m/s, B=C=0. to illustrate the pure effect of the LF wind in the wind stress skewness.

Case B, u_c=-1.5m/s, A=3m/s, B=4, C=0. to examine how the HF random weather noise may impact the skewness.

Case C, u_c=-1.5m/s, A=3m/s, B=4, C=2. to examine the role of the ENSO-state-dependent HF wind variability.



Skewness:
red line: -0.66
green line: -0.15
blue line: 0.17

Time series of the wind stress anomalies calculated by the conceptual model for **case A (red line), case B (green line)** and **case C (blue line).**

Conceptual model:

$$u = u_c + u_l + u_h$$

$$u_l = A \cdot \cos(2\pi t / T_1)$$

$$u_h = [B + C \cdot \cos(2\pi t / T_1)] \cdot \cos(2\pi t / T_2)$$

u_c=-1.5 m/s

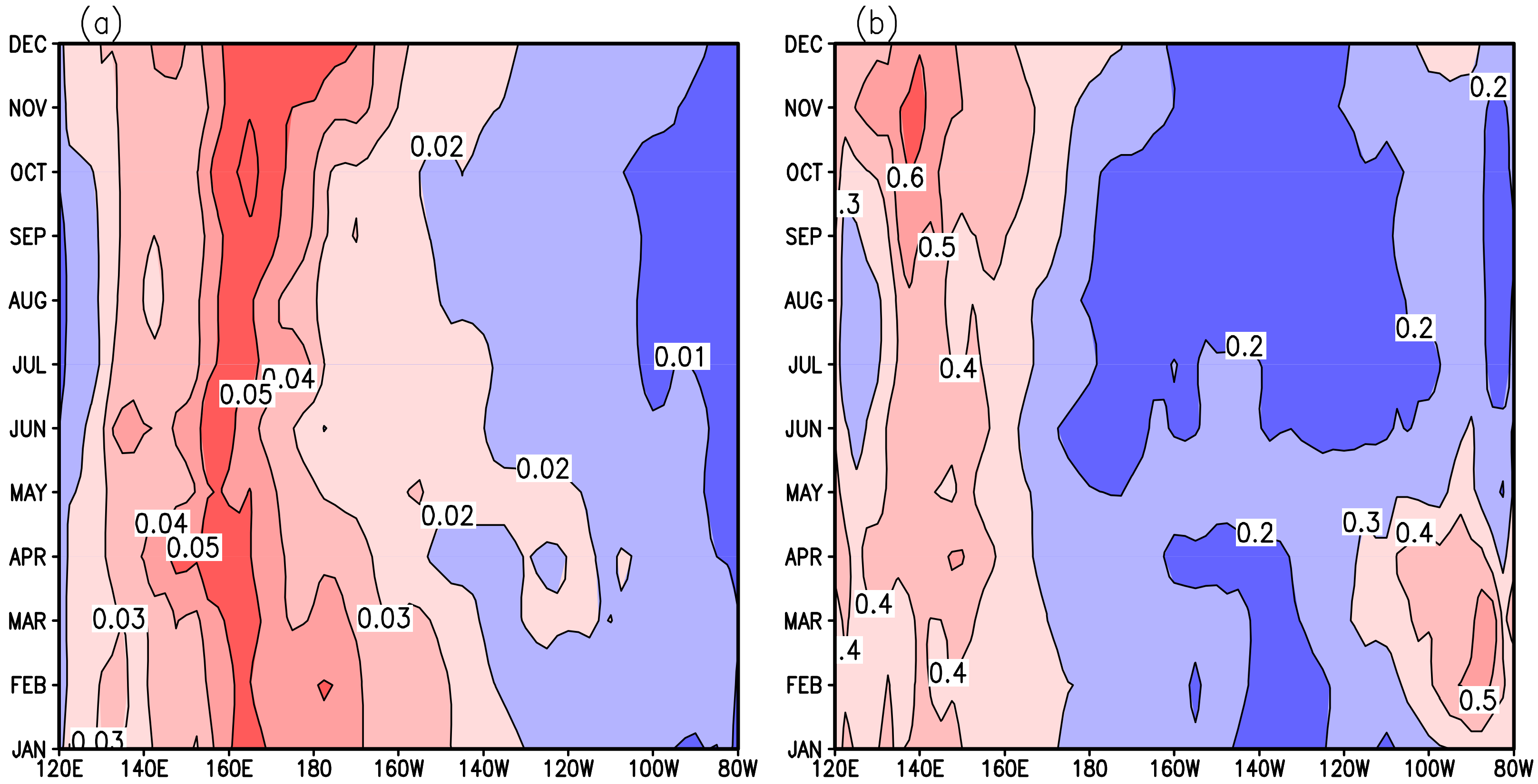
A=3m/s

B=4,C=2

T_1=4 yr (ENSO frequency)

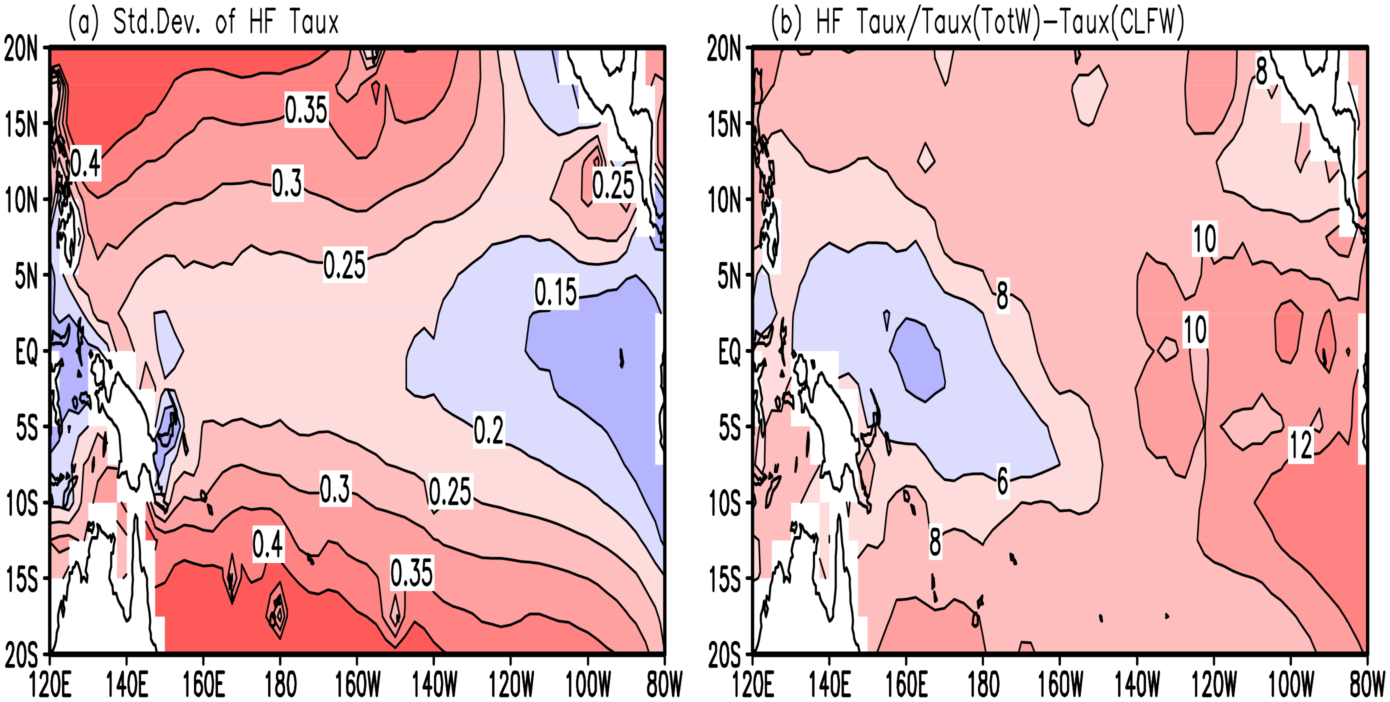
T_2=10 days (SSV frequency)

Nonlinear rectification of surface wind stress by HF winds



Left: Standard deviation of nonlinear rectified LF wind stress [Tau(C+LF+HF) – Tau(C+LF)] along 5S-5N

Right: Ratio of (a) to the standard deviation of total interannual wind stress [Tau(C+LF+HF)]

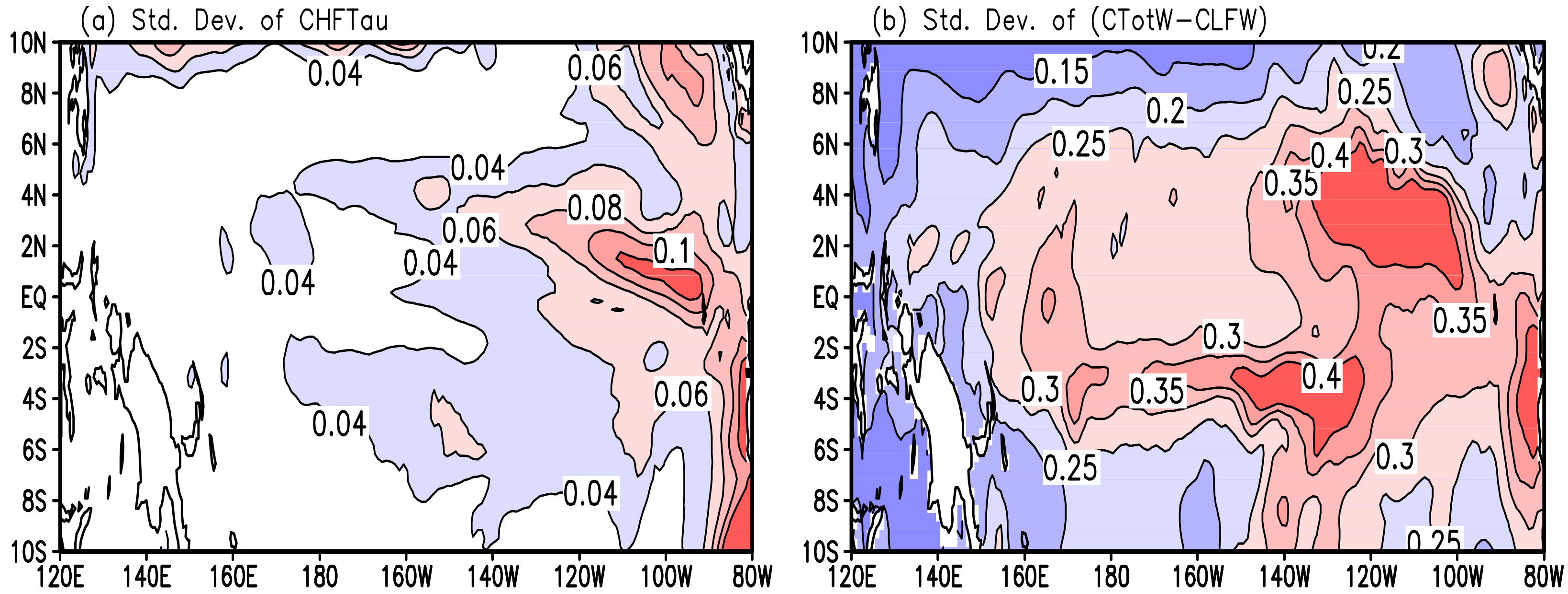


(a)Standard deviation of the HF (< 90 day) zonal wind stress (Units: dyne cm-2)

(b) the ratio of (a) to the standard deviation of nonlinear rectified LF wind stress [i.e., Tau (C+LF+HF) – Tau (C+LF)]

Process 2: HF atmospheric variability impacts LF ENSO SSTA through 1) internal nonlinear ocean processes and 2) nonlinear wind stress rectification.

MOM OGCM Simulated Interannual SST Variability

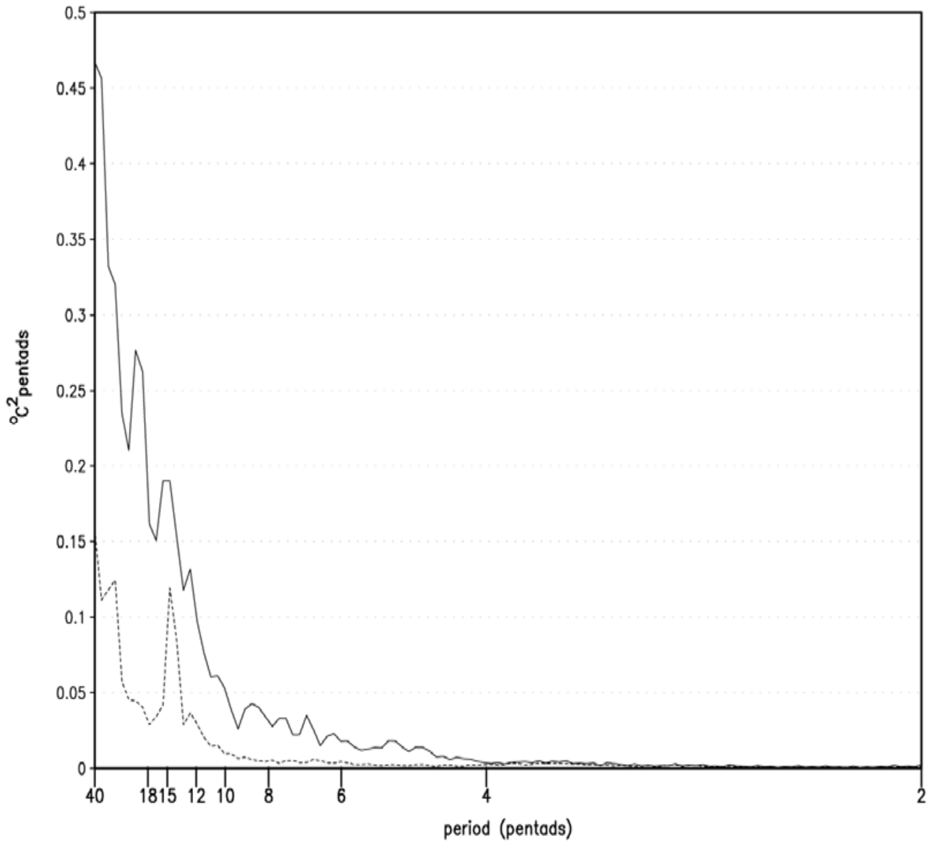


(a) Standard deviation of the OGCM simulated SSTA forced by HF (< 90 day) zonal wind stress (Units: dyne cm-2) only

(b) Ratio of (a) to the standard deviation of the SSTA forced by the nonlinear rectified LF wind stress [i.e., Tau (C+LF+HF) – Tau (C+LF)]

Process 2: SSV impacts ISO through induced intraseasonal SST variation (nonlinear oceanic process)

Below: power spectrum of the SST simulated by a 2.5-layer ocean model



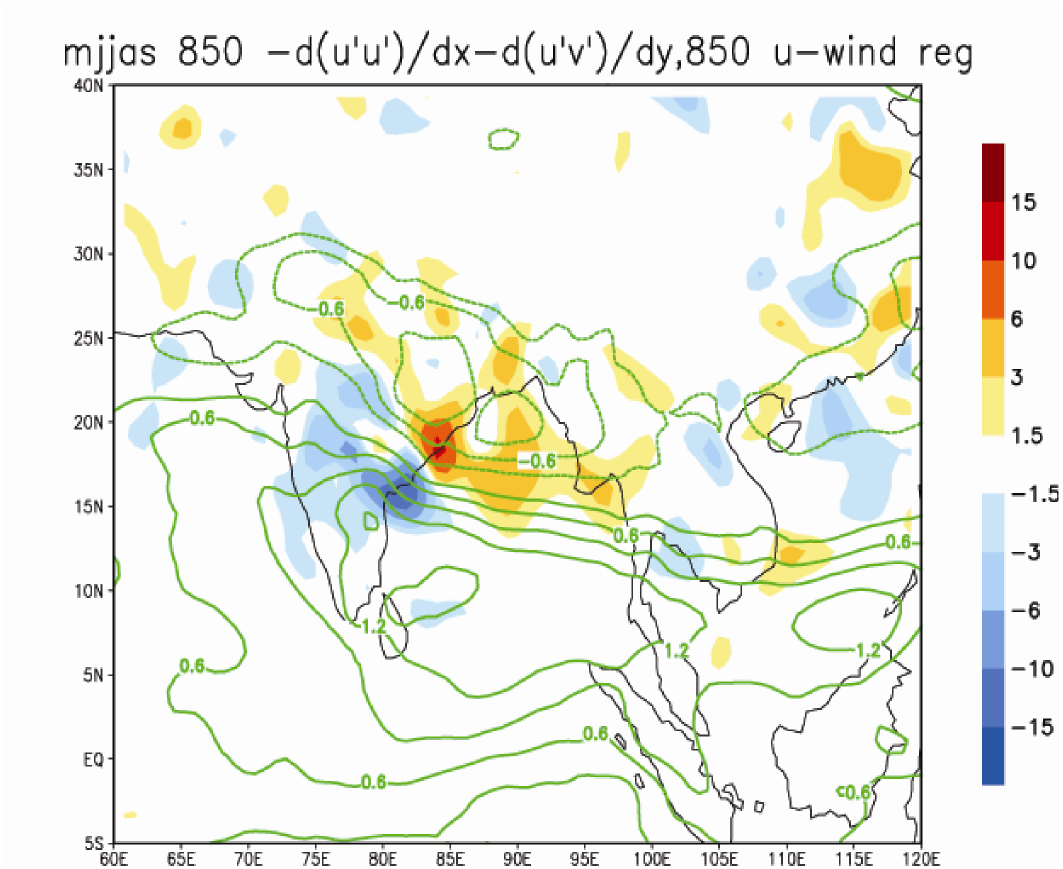
Tam and Li 2008

Solid line: forced by total wind and flux fields (SSV+ISO+climatology)

Dashed line: forced by climatology plus SSV wind and flux fields

Conclusion: 15-25% of the intraseasonal SST variance in the tropical Indian Ocean is attributed to the nonlinear rectification of the synoptic-scale variability.

Process 3: SSV feeds back to ISO through internal atmospheric dynamics



$$\frac{\partial \tilde{u}}{\partial t} \propto -\frac{\partial \langle u'u' \rangle}{\partial x} - \frac{\partial \langle u'v' \rangle}{\partial y}$$

Contour: ISO wet-dry composite of 850-hPa zonal wind

Shading: zonal wind tendency due to eddy momentum flux convergence (ISO wet-dry phase)