On the Influence of Warm Pool SST Variability and Wind Stress Forcing on ENSO in SODA

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1. Introduction & Previous Study

- In observation, climate shift in the late 1970s : significant change in ocean temperature in the Pacific as well as atmospheric winds (Graham 1994, Guilderson and Schrag 1998, Wang and An 2000, Wu and Xie 2003).
- Details of the variability in the wind stress projection coefficient onto the oceanic baroclinic modes in the tropical Pacific with the ENSO decadal variability before and after the late 1970s (Moon et al. 2004).
- Formation of the western Pacific warm pool is fundamentally driven by ocean dynamics, but atmospheric processes also play an important role (Ramathan and Collis 1991; Waliser and Graham 1993; Ramanathan et al. 1995; Schneider et al. 1996; Clement et al. 2005).
- Moon et al. (2004) showed the enhanced role of the higher-order baroclinic mode (due to change of the ocean thermal structure) after the 1980s, which induced longer period and stronger intensity of ENSO.
- Wang (2008) pointed out that the atmosphere-ocean change is associated with Indo-Pacific warm pool (IPWP): The intensity of the deep convection is very sensitive to the SST change over the warm pool region and the interannual variability of SST over the western Pacific warm pool has a positive feedback on the ESNO cycle.
- Atmospheric trade winds are weakened in the central and eastern tropical Pacific (Wu and Xie 2003, Vecchi et al. 2006).
- Previous studies mainly focused on the effect of wind-stress forcing on the period and intensity of ENSO, and reported that equatorial western Pacific warm pool is strongly related to ENSO modulation.
- They found out that the change in western Pacific warm pool and wind-stress may lead to a variation in ENSO, however, they failed to explain the causes of this change and the underlying mechanism. To describe the dynamics and mechanism in detail, finding the source of the changes in wind is an important issue.

The underlying dynamics and source of the changes
in the **relationship between western Pacific warm pool variation and wind-stress forcing**

2. Data and Methodology

2. 1 Data

- SODA version 2.0.2 (based on Modular Ocean Model version 2 (MOM2) of GFDL
- Resolution : 0.5°x0.5° / 40 levels (with 10-m spacing near the surface)
- Variables : monthly ocean temperature, salinity, wind stress which is derived from SODA version 2.0.2. The constraint algorithm is based on optimal interpolation data assimilation. Assimilated data include temperature and salinity profiles from the World Ocean Atlas 2001
- Period: the 48-yr period from January 1958 to November 2005.

* *Carton et al. (2000) and Carton and Giese (2008) for a detailed description of the SODA system.*

- Hadley SST
- The SODA system is useful to examine the oceanic variables in the subsurface layers and shows the characteristic changes of mean state in the ocean before and after the mid 1970s (Moon et al. 2004; Dewitte et al. 2009). Therefore, it is appropriate to conduct the vertical modal decomposition using the temperature and salinity data in the SODA system. Since the focus of the paper is on the change in variability from before and after the late 70s, the analyzed period is 1958-1997.

2. 2 Methodology

- Horizontal scale >> vertical scale in ocean: The variables represented motion of the ocean can be expressed as the summation of the normal mode.
- According to Cane(1984)'s suggestion, the ocean variables are expressed as vertical mode as follows. The barotropic mode (n=0) was excepted.

$$[u(x,y,z,t), v(x,y,z,t), \rho^{-1}, P(x,y,z,t)] = \sum_{n=1}^{\infty}[u_n(x,y,t), v_n(x,y,t), gh_n(x,y,t)]A_n(z)$$

- u, v: zonal and meridional currents, P, h_n: pressure field and sea level height
- P_n : the value of the wind stress projecting on the n^{th} baroclinic mode
- → depends on the vertical structure functions
- Defined as in Lighthill (1969),

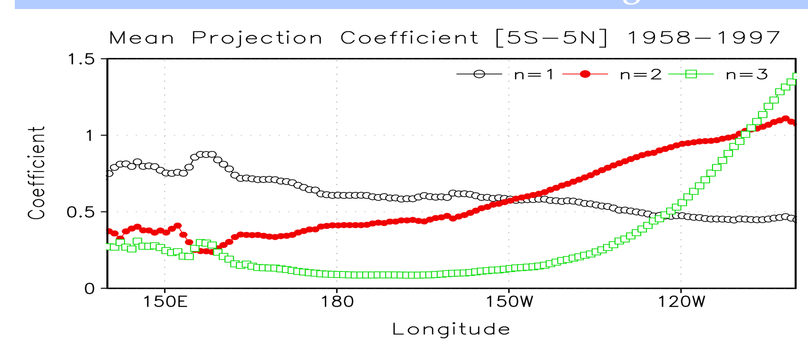
$$P_n = \frac{\int_{-H_{mix}}^{0} A_n(z)dz}{\int_{-H}^{0} A_n^2(z)dz} \qquad P_n = \frac{150}{\int_{-H}^{0} A_n^2(z)dz} \quad (n=1,2,3)$$

- H_{mix}: mixed layer depth, H: depth of ocean bottom
- Gravest vertical modes do not vary much within the mixed layer and using a normalization coefficient of 150 (corresponding to the mean thermocline depth in the central equatorial Pacific),
- $A_n(z)$:the vertical structure function which is derives from the vertical decomposition of the temperature and salinity profiles

3. Results

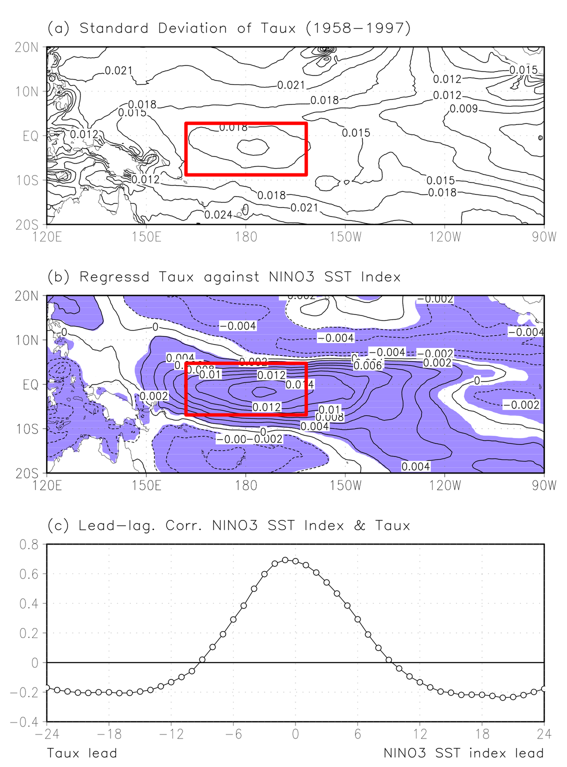
3. 1. Wind Stress Forcing Change

Longitudinal Distribution of Pn



- ✓ Western Pacific : 1^{st} mode > 2^{nd} and 3^{rd} mode
- ✓ Eastern Pacific : 1^{st} mode < 2^{nd} and 3^{rd} mode
- → Higher order mode has large variation in the eastern Pacific

Variation of Surface Momentum Forcing

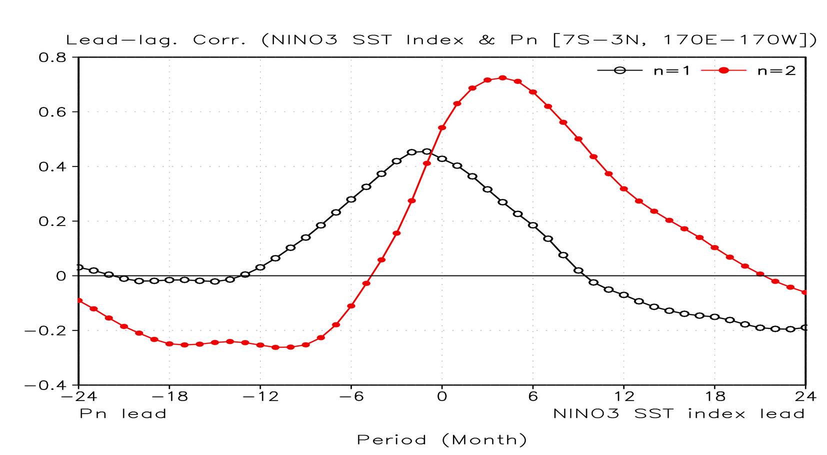


(a) Standard deviation of zonal wind stress: maximum standard deviation is located in the central Pacific.

(b) regressed zonal wind stress against the NINO3 SST index during the period of 1958-1997 (shaded areas are significant at 95% confidence level) : maximum regressed value – central Pacific (similar result in (a))

(c) Lead-lagged correlation coefficient between the zonal wind stress anomalies over the central equatorial Pacific and the NINO3 SST index : simultaneous correlation coefficient : 0.68

Lead-lag Correlation between NINO3 & Pn



P1 is ahead the Nino3 SST index at the 1-2 months lagged time
Share of the wind stress forcing projecting onto
- P1 : preliminary forces ENSO on a developing phase
- P2 : behind ENSO, response on the growing and decaying phase

Relationships between Each Mode

Coefficient	P2	P3
P1	0.04	-0.06
P2	•	0.91

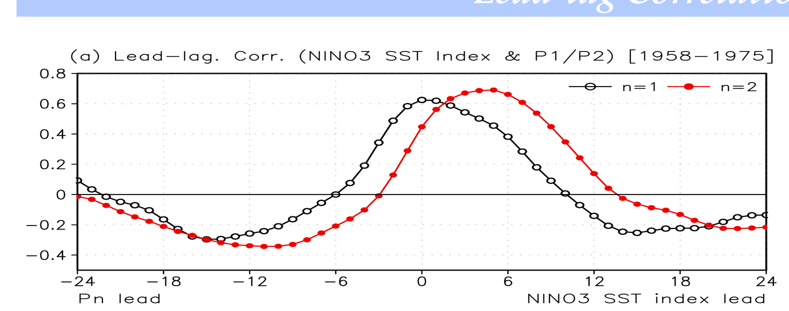
P2/P3 : highly correlation with each other
Surface zonal wind stress forcing projecting onto the gravest and high-order mode.

Coefficient	P2		P3	
	1958-1975	1980-1997	1958-1975	1980-1997
P1	0.53**	-0.37*	0.36**	-0.33*
P2	•	•	0.85**	0.94**

- Reversal relationship before and after the late 1970s (P1/P2, P1/P3)
- Relationship between P2/P3 is not changed.

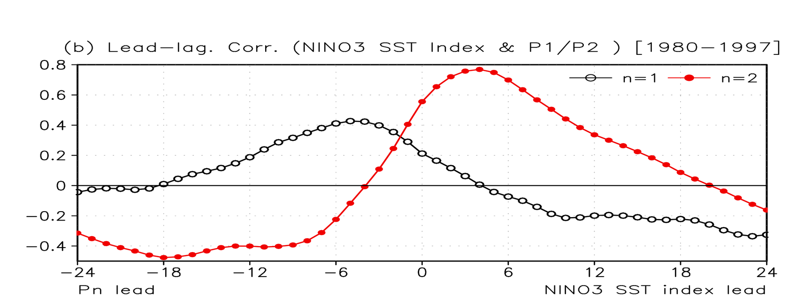
*** Significance at 95% confidence level*
** Significance at 90% confidence level*

Lead-lag Correlation between NINO3 & Pn



(a) 1958-1975
- P1: slightly behind NINO3 index
- P2: behind NINO3 index with 4-5 months

→ ENSO variability leads the wind stress projecting on the second oceanic baroclinic mode over the central equatorial Pacific

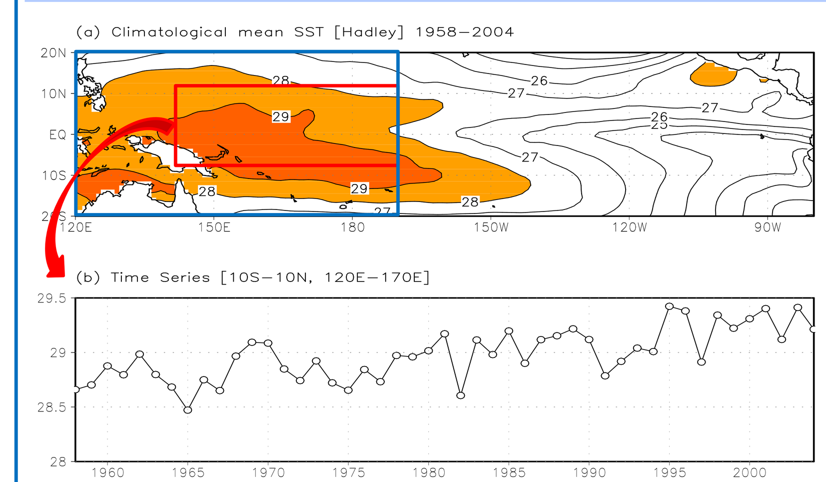


(b) 1980-1997
- P1: leads NINO3 index with 4-5 months
- P2: behind NINO3 index with 4-5 months

→ wind stress projecting onto the second oceanic baroclinic mode responses to ENSO on the growing and decaying phase

3. 2. Warm Pool Variability

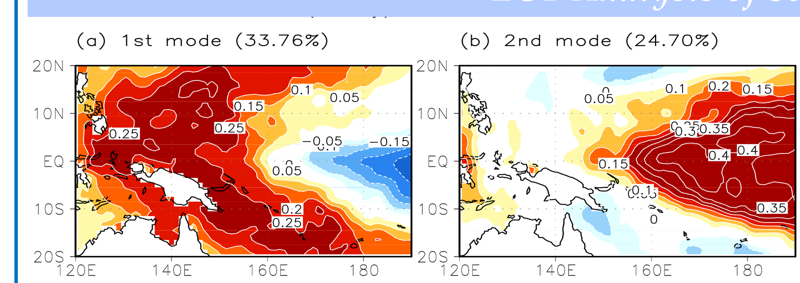
Climatological Mean SST (958-2004) & Mean SST over the warm pool region

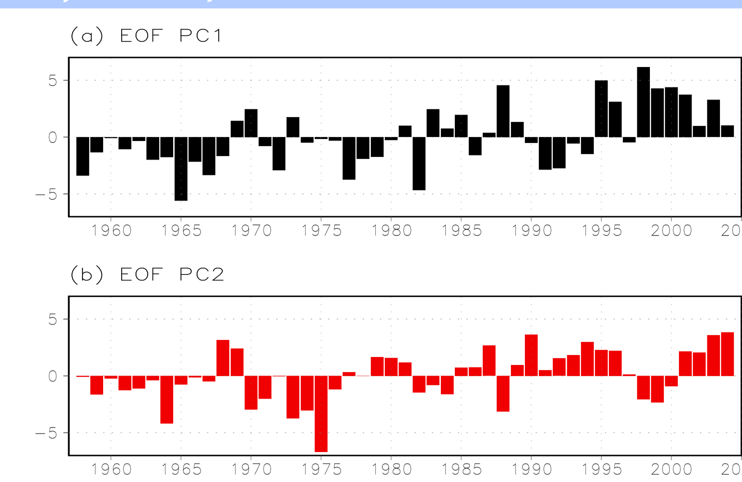


(a) Warm pool region: where the sea surface temperature exceed 28C in the western Pacific

(b) warm pool encompassed most of the western tropical Pacific and extends further into the southwestern tropical Pacific, maximum SST: 150-180E.
interannual variations are also evident. Warm pool temperatures have gradually increased over the past five decades.

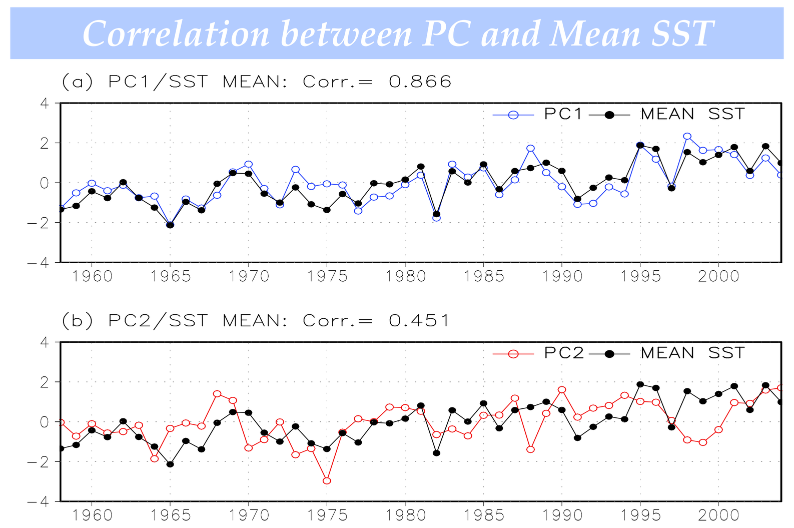
EOF Analysis of Sea Surface Temperature



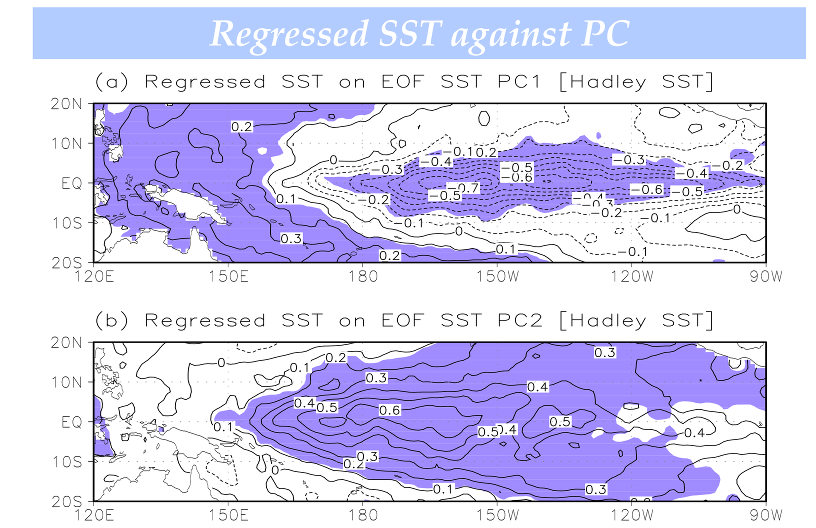


Opposite sign in the western and eastern Pacific
EOF1: La Nina-like pattern
EOF2: basin-wide –> maximum SST in NINO4 region (central Pacific El Nino)

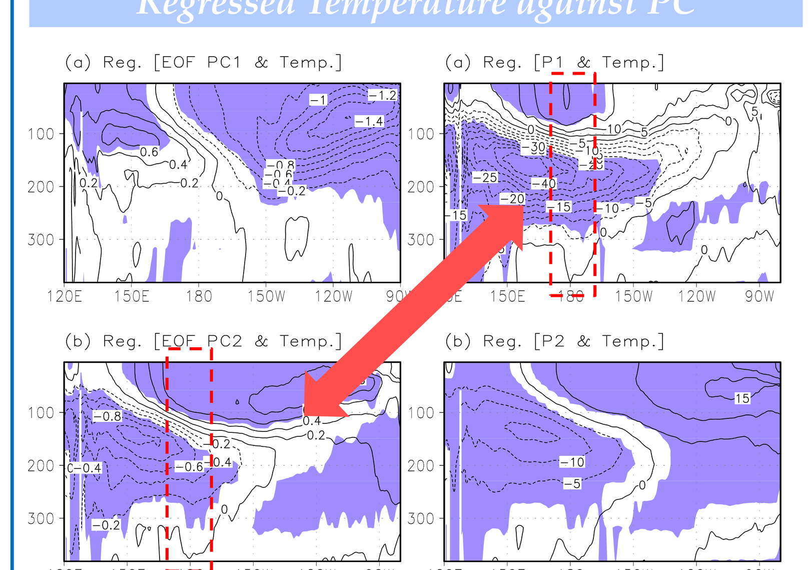
Correlation between PC and Mean SST



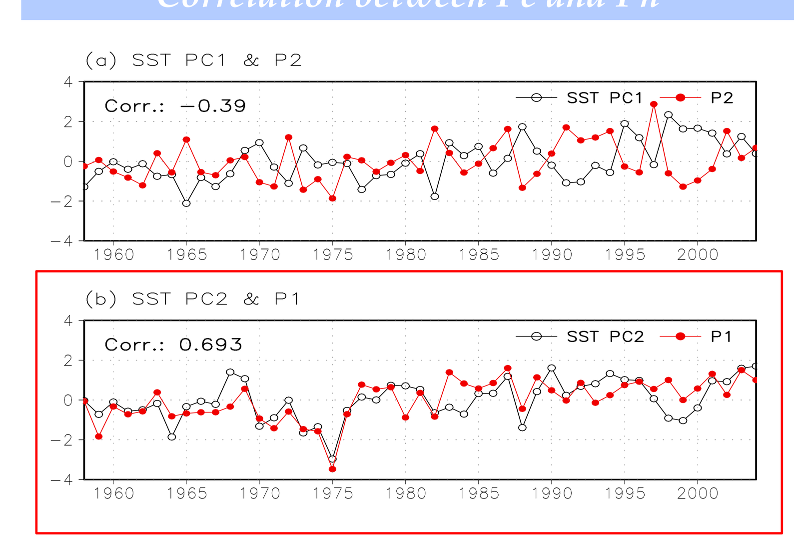
Regressed SST against PC



Regressed Temperature against PC



Correlation between Pc and Pn



4. Summary

- ❖ P1: abrupt increase after the mid 1970s
  P2: starting a little bit earlier than the mid 1970s
  → It may lead the climate shift of tropical Pacific around the mid 1970s
- ❖ Wind stress forcing in central Pacific is associated with ENSO.
- ❖ EOF SST (over the warm pool region, [120-190E, 20S-20N])
  EOF1: La Nina-like pattern
  EOF2: basin-wide –> maximum SST in NINO4 region (central Pacific El Nino)
- ❖ Wind stress forcing (mean projection coefficient) in western Pacific
  P1 ←→ SST PC2 (warm pool region) : 0.69 → NINO4 region (central Pacific El Nino