Contributions of Upper Ocean Variability over the Western North Pacific to ENSO

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1. Introduction & Previous Study

- Western Pacific warm pool (140E-170W, 10S-10N) > annual mean SST, 28℃
- The SST in the warm-pool region has a simple thermodynamic energy balance between evaporative heat loss and radiative energy input [Newell *et al.*, 1978; Newell and Dopplick, 1979] with ocean dynamics mostly acting on the eastward expansion of warm SST through equatorial wave-induced zonal advection [Delcroix *et al.*, 2001].
- The warm-pool SST has been warming up over the last century (similar fashion to the global mean surface air temperature) [Sun, 2003; Wang and Mehta, 2008].
- An increase of warm-pool SST can change surface wind, which in turn change the ocean currents connecting the western tropical Pacific Ocean with the eastern tropical Pacific [Sun and Liu, 1996]; associated with the SST variability such as El Niño and Southern Oscillation (ENSO).
- Changes in the warm-pool SST could modify the atmosphere and ocean coupled system by changing both the zonal contrast of the SST between the eastern Pacific (NINO3 region) and the central Pacific (NINO4 region) and the vertical temperature structure.
- The zonal SST gradient across the equatorial Pacific influences ENSO through the zonal advective process [Picaut *et al.*, 1996], the vertical temperature structure is influential on the equatorial wave dynamics because it constrains the energy distributed by the oceanic vertical baroclinic mode.
- Recent studies based on coupled general circulation model (CGCM) analysis suggest that the change in the vertical contrast in the tropical Pacific under global warming, which is due to change in difference between the subsurface temperature and SST (cf. An *et al.* [2008]) or vertical mode changes (cf. Yeh *et al.* [2001]), is more influential on the ENSO modulation than change in the mean SST itself.

Changes in relationship between the oceanic stratification (related to ocean vertical baroclinic mode) in the warm-pool region and ENSO variablity

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 (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

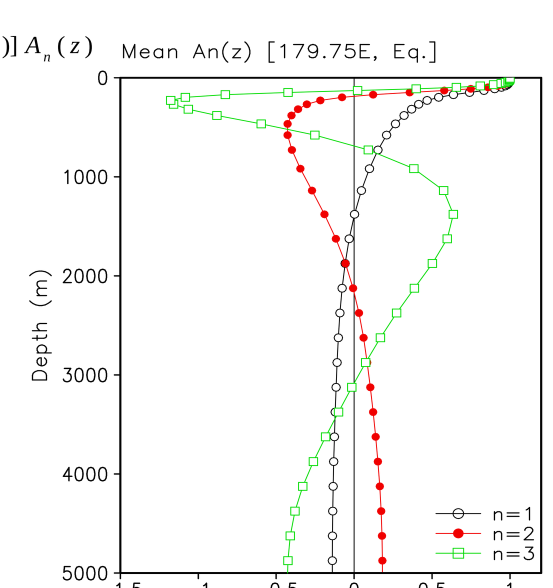
2. 2 Methodology

- 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),

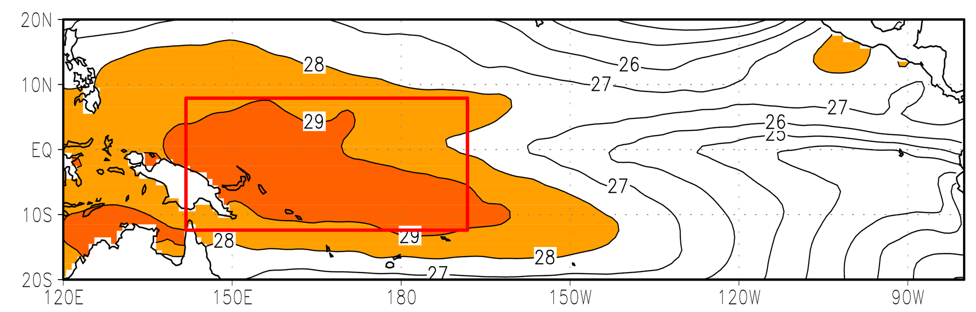
$$P_n = \frac{\int_{-H_{mix}}^{0} A_n(z)\,dz}{\int_{-H}^{0} A_n^2(z)\,dz} \qquad P_n = \frac{150}{\int_{-H}^{0} A_n^2(z)\,dz} \quad (n = 1, 2, 3)$$



- 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

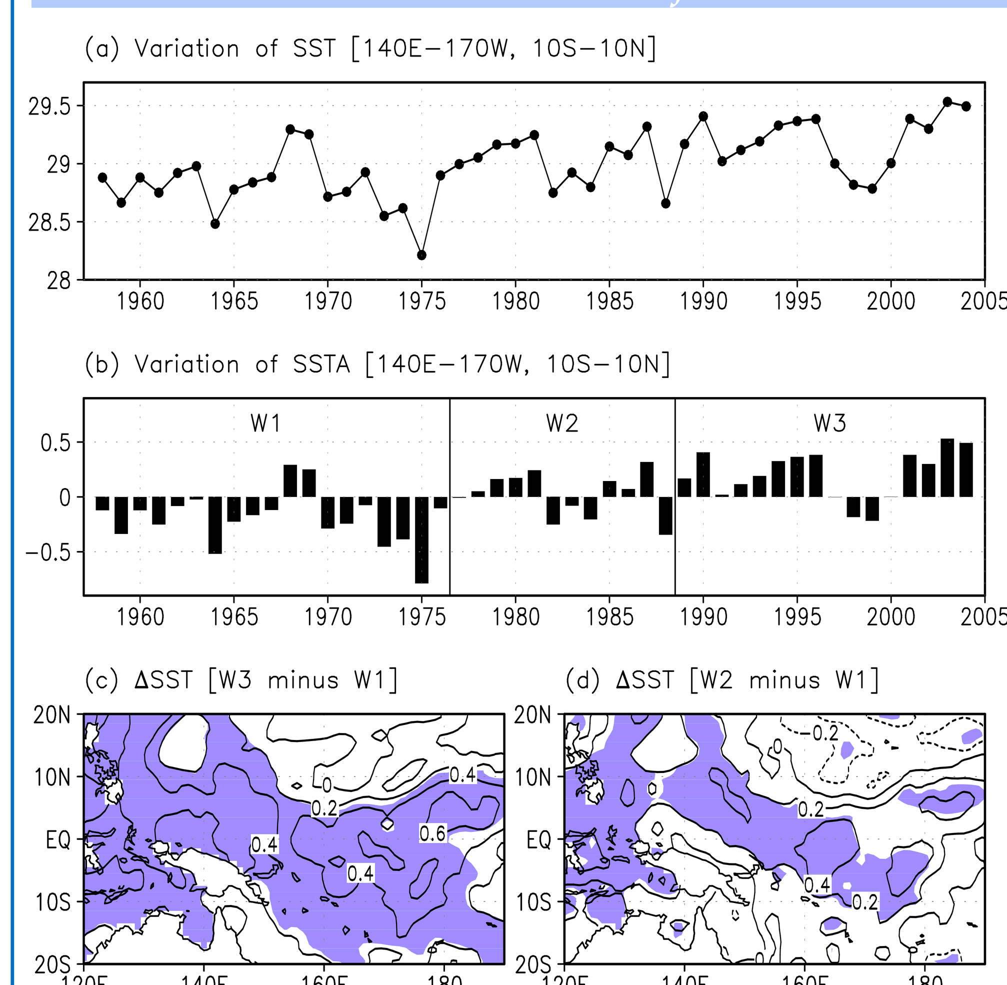
3. Results

Climatological Mean SST (1958-2004)



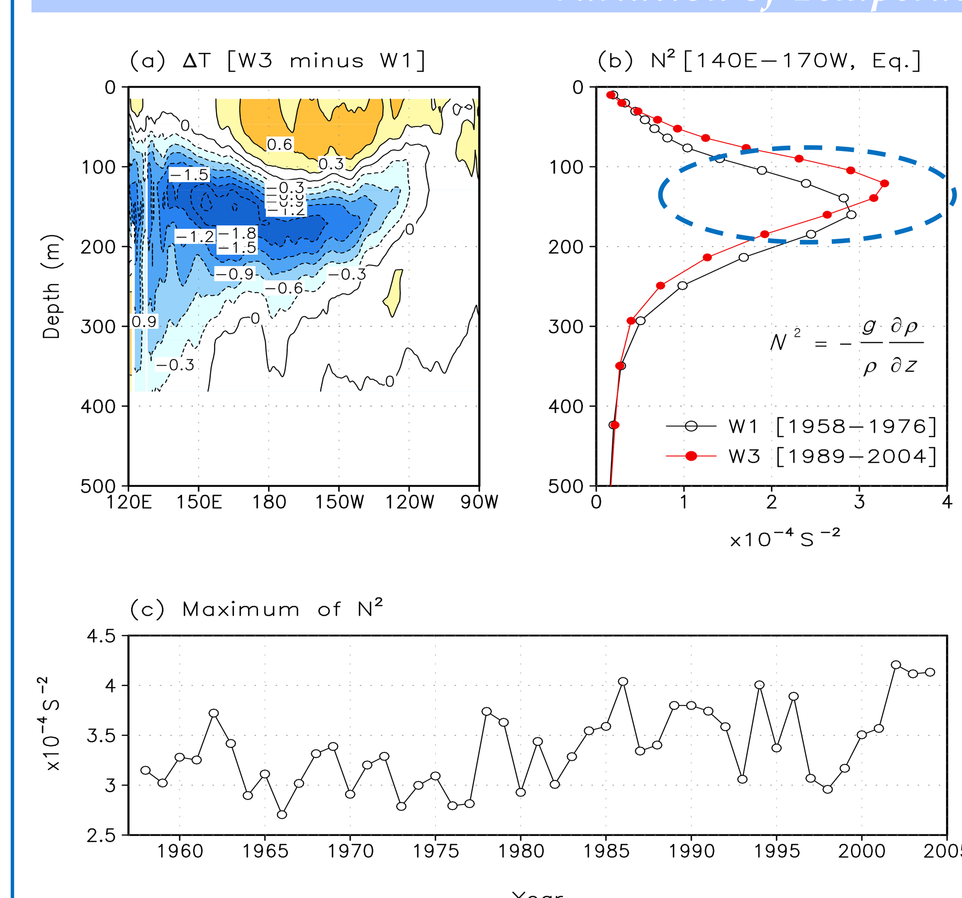
- Western Pacific warm pool (140E-170W, 10S-10N) > annual mean sea surface temperature, 28℃

Variation of SST & Mean SST Difference



- (a) the variation of HadISST [140E-170W, 10S-10N] during the winters (October-February) of 1958-2004. which constitutes the core of the warm-pool region where SSTs are usually above 28℃.
- (b) the variation of SST anomalies over the same time period and in the same region as Fig. 1a. → this variation of anomalies, will be referred to as the warm-pool index (WPI).
- (c) & (d) the difference of mean SST in the two periods [1989-2004]-[1958-76] & [1977-88]-[1958-76] - the change of warm-pool SST during [1989-2004]-[1958-76] is more evident compared to the [1977-1988]-[1958-1976].

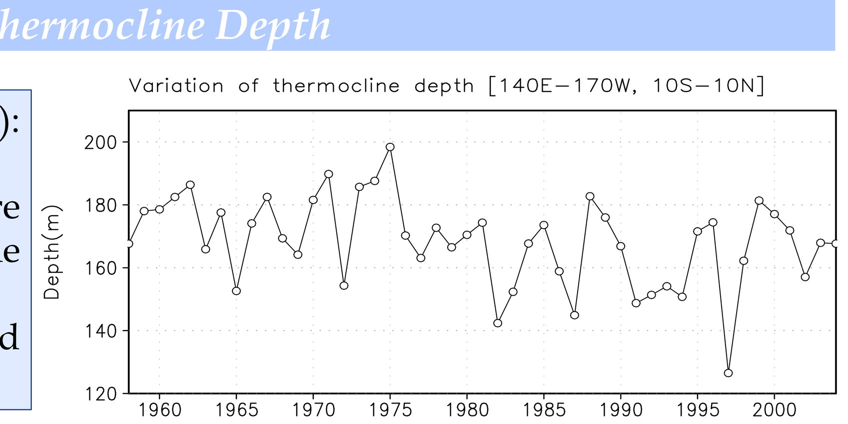
Variation of Temperature & N²



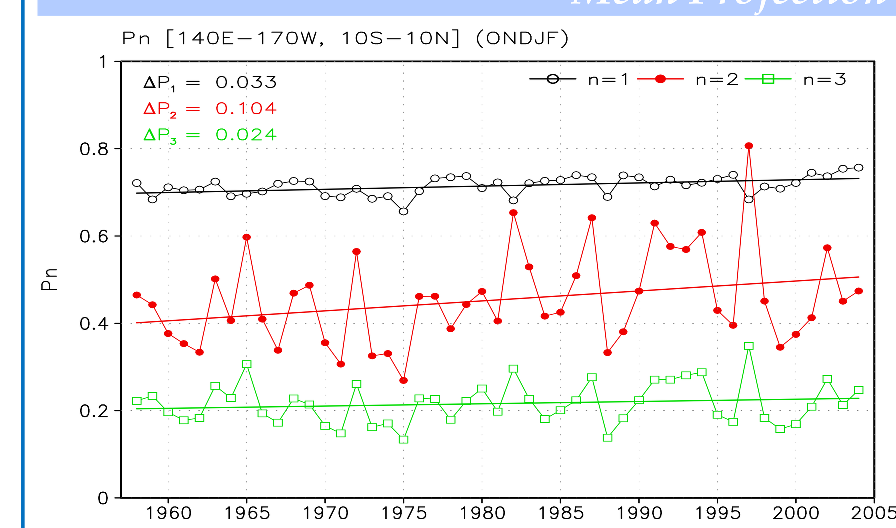
- (a) difference of vertical temperature between the mean over 1989-2004 and the mean over 1958-76.
- (b) Vertical profiles of the Brunt-Väisällä buoyancy frequency, $N^2(z)$, for the periods of 1958-76 and 1989-2004.
  - significantly greater during W3 period than W1 period
- (c) The time series of maximum value of the Brunt-Väisällä buoyancy frequency for the period 1958-2004
  - related to intensity
  - gradually increases over time
  - r (with WPI): 0.65
  - $N^2(z)$ & WPI: 0.72 (W3), 0.47(W1)

Variation of Thermocline Depth

- Thermocline depth (20°C isotherm depth): shallower from W1 period to the W3 period
- changes of stratification intensity: more closely associated with WPI than the variations of thermocline depth
- r (the time series of the maximum $N^2(z)$ and the thermocline depth variations): -0.19



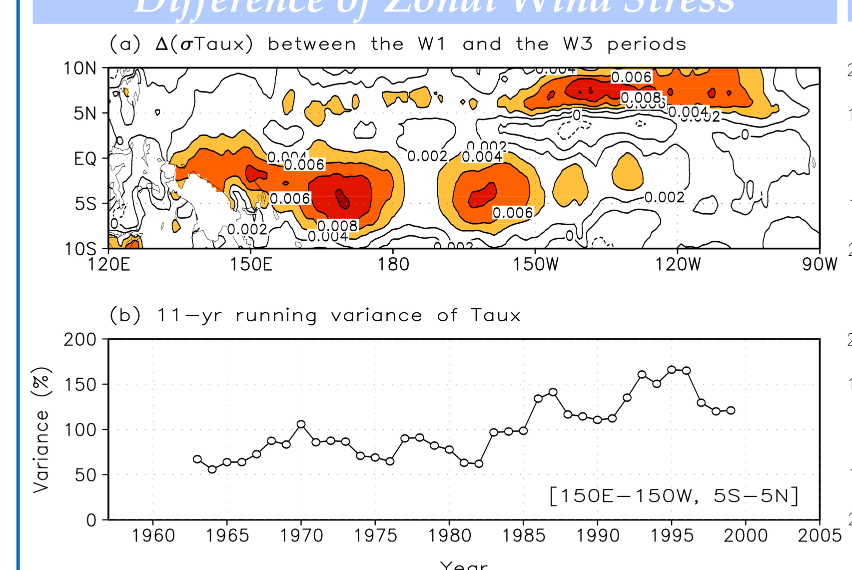
Mean Projection Coefficients



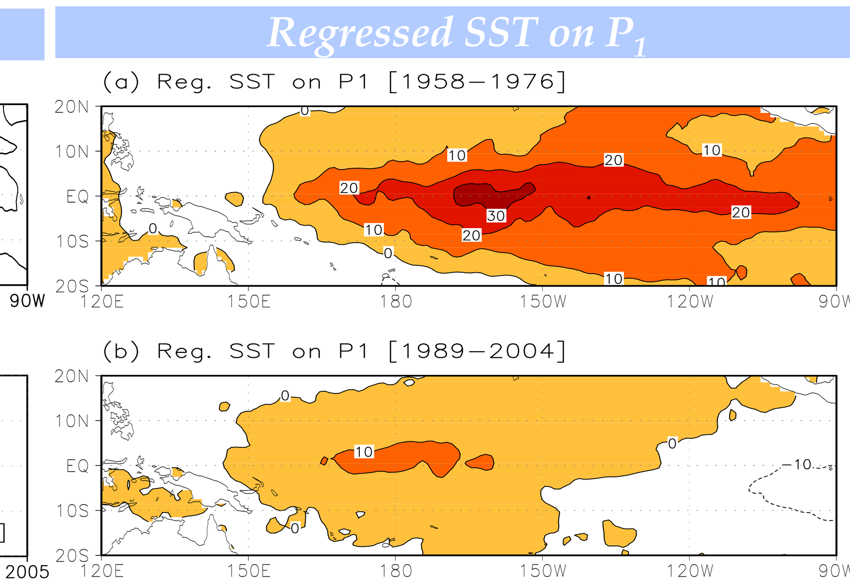
		P_1	P_2	P_3
WPI	1958-2004	0.73	0.38	0.33
	1989-2004	0.86	0.36	0.34
TDI	1958-2004	-0.15	-0.95	-0.90
	1989-2004	-0.26	-0.97	-0.89

- first three baroclinic modes (P_1, P_2 and P_3) [140°E-170°W, 10°S-10°N] for the period of 1958-2004.
- the largest projection coefficient in the warm-pool region is P_1, which suggests that wind stress forcing over the warm-pool primarily projects onto the first oceanic baroclinic mode compared to the second and third oceanic baroclinic mode.

Difference of Zonal Wind Stress

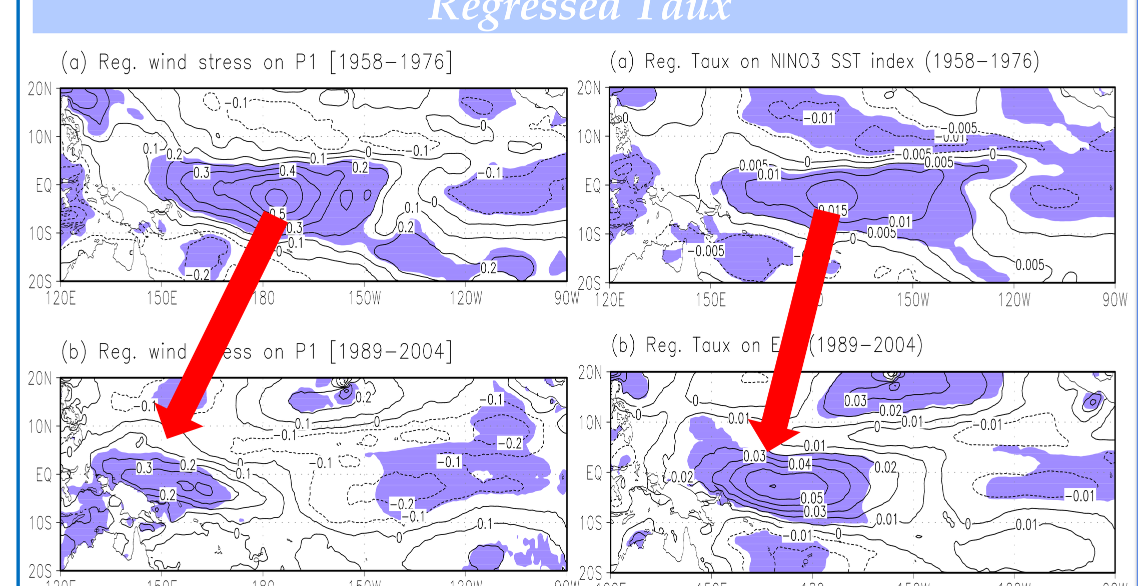


Regressed SST on P_1



- significantly enhanced Taux and SST from the W1 period to the W3 period
- significant change in the western and central tropical Pacific [150E-150W, 10S-10N] over the warm-pool region
- increase of warm-pool SST may influence the atmosphere

Regressed Taux



- W1 period: related to EP El Nino
- W3 period: sea-saw pattern, wind convergence around the date-line → convergence of surface current (Ekman currents) → maintain warm-pool edge
- positive zonal wind stress in WP: eastward movement of warm water in warm-pool
- negative zonal wind stress in EP: induces cooling in the EP by strengthen of trade winds

4. Summary

- Warming of warm-pool SST influences tropical Pacific SST variability through changes in oceanic baroclinic mode characteristics.
- Significant change : W1 period → W3 period
- W1 period: the anomalous SST in the eastern and central tropical Pacific
  W3 period: the anomalous SST with an east-west contrasting structure in the tropical Pacific
  ; Contribution to change the structure of total anomalous SST variability in which a center of maximum anomalous warm (cool) SST is shifted to the west in an El Niño (La Niña) event for the W3 period
  → changes in ocean stratification in the warm-pool region that are concomitant with increases in warm-pool SST may be responsible for changes in anomalous total SST variability because the momentum flux projecting onto the first oceanic baroclinic mode is changed from the W1 period to the W3 period.

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