Tropical Pacific Quasi-Decadal Variability Suppressed by Submesoscale Eddies

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Introduction

- ✓ Tropical Pacific quasi-decadal (TPQD) climate variability is characterized by quasi-decadal sea surface temperature (SST) variations in the central Pacific (CP).
- ✓ This low-frequency climate variability is suggested to influence extreme regional weather and substantially impact global climate patterns and associated socio-economy through teleconnections.
- ✓ Previous studies mostly attributed the TPQD climate variability to basin-scale air-sea coupling processes.
- ➢ However, the role of sub-basin-scale processes in modulating the TPQD climate variability is still unclear.

Modelling TPQD in high-resolution

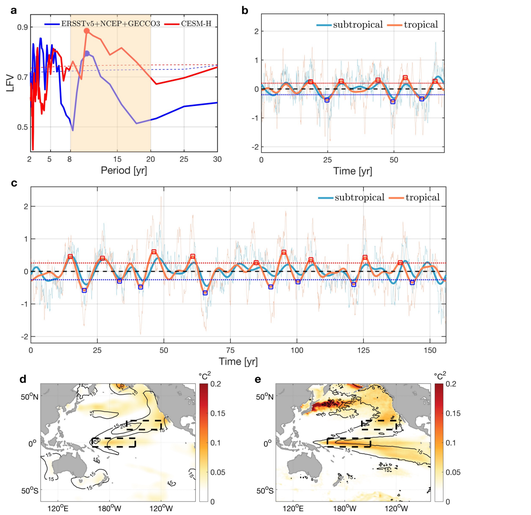


Fig. 1. (a) Local fraction variance (LFV) spectrum for the combined tropical Pacific sea surface temperature (SST), sea level pressure (SLP) and sea surface height (SSH) of observations (blue line) and the CESM (red line). (b) The observational time evolutions of Niño4 index (tropical SST indices; thin orange) and subtropical SST indices (thin cyan). (c) Same as (b) but for the CESM. Spatial distribution of the SST anomalies variance and corresponding variance in (d) observations and (e) the CESM on the quasi-decadal timescale.

The TPQD amplitude = *Niño4 index*

Submesoscale eddies inhibit TPQD growth

- **Submesoscale eddy vertical heat transport:** $Q_{eddy,v}^{subm}=\rho_0 c_p w'' T''$
- **Negative correlation between $Q_{eddy,v}^{subm}$ and TPQD:**

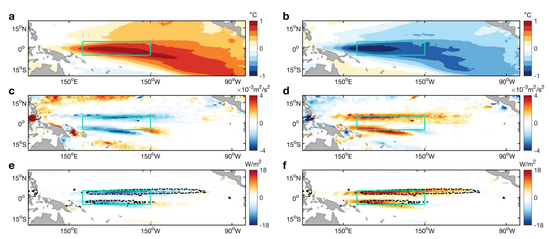


Fig. 2. Composite averages of SSTA at the peak positive TPQD events (a) and negative TPQD events (b); (c,d) same as (a,b) but for submesoscale eddy kinetic energy anomaly; (e,f) same as (a,b) but for $Q_{eddy,v}^{subm}$ anomaly at 50 m. The green box in (a-f) denotes the Niño4 region.

Impact of on $Q_{eddy,v}^{subm}$ on TPQD compared with other processes:

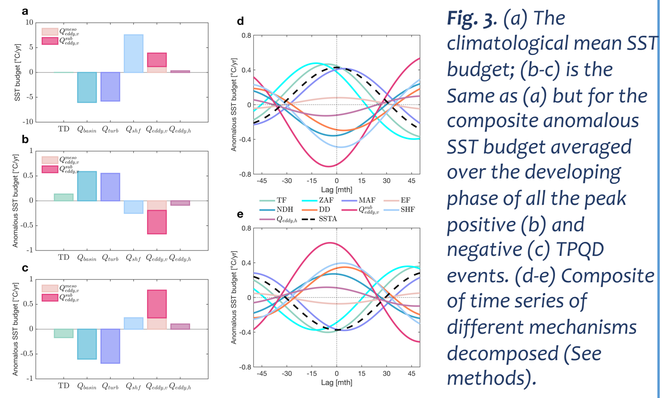
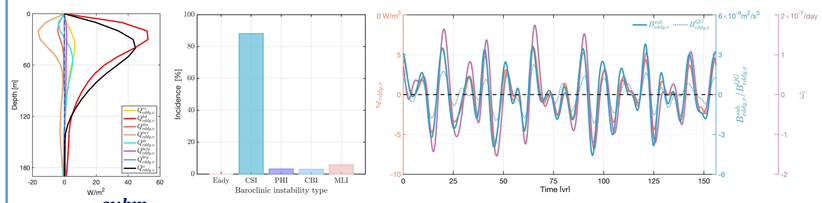


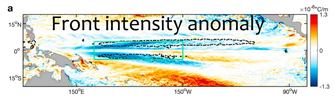
Fig. 3. (a) The climatological mean SST budget; (b-c) is the Same as (a) but for the composite anomalous SST budget averaged over the developing phase of all the peak positive (b) and negative (c) TPQD events. (d-e) Composite of time series of different mechanisms decomposed (See methods).

Precipitation and frontal intensity govern impact of submesoscale eddies



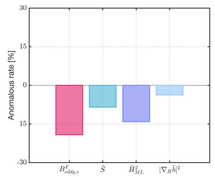
- ➢ $Q_{eddy,v}^{subm}$ **is attributed to kinematic deformation including baroclinic instability and frontogenesis;** *McWilliams. (2016)*
- ➢ **Baroclinic instability is dominated by Charney surface mode (CSI);**
- ➢ **Frontogenesis can be scaled by** $\widetilde{S}\widetilde{H}_{ML}^2\left|\nabla_H\tilde{b}\right|^2/f^2$ *(See methods).*

Positive events (baroclinic instability):

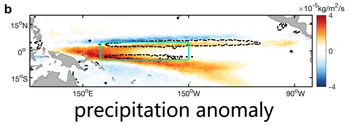


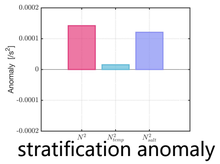
SST increase
↓
weakened cold tongue
↓
weakened SST gradient
↓
weakened baroclinic instability
↓
weakened $Q_{eddy,v}^{subm}$
↓
damp the SST

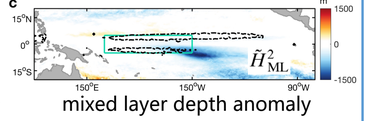
Positive events (frontogenesis):



Mixed layer depth dominates the quasi-decadal anomaly of frontogenesis.







rainfall increase ⟶ intensified N^2 ⟶ shallowing MLD
⟶ weakened frontogenesis ⟶ weakened $Q_{eddy,v}^{subm}$ ⟶ damp the SST

Methods

Decomposition of the heat budget analysis:

$$\left\langle\int_{-h}^{0}\rho_0 C_p\frac{\overline{\partial T}}{\partial t}dz\right\rangle=-\left\langle\int_{-h}^{0}\rho_0 C_p\nabla\cdot\left(\overline{\mathbf{u}}\,\overline{T}\right)dz\right\rangle-\left\langle\int_{-h}^{0}\rho_0 C_p\nabla_h\cdot\left(\overline{\mathbf{u}_h'T'}\right)dz\right\rangle+\left\langle\rho_0 C_p\overline{w'T'}\right\rangle|_{z=-h}$$

$$\mathrm{TD}\qquad\langle Q_{basin}\rangle\qquad\langle Q_{eddy,h}\rangle\qquad\langle Q_{eddy,v}\rangle$$
$$+\langle Q_{shf}\rangle+\langle Q_{turb}\rangle+\langle Q_{hmix}\rangle$$

Symbols: $\tilde{S}$ *indicates the background strain rate,* $\widetilde{H}_{ML}^2$ indicates the square of mixed layer depth, $\left|\nabla_H\tilde{b}\right|^2$ *indicates the square of background buoyancy gradient and f is the Coriolis parameter.*

Implication for TPQD modelling

- **The TPQD amplitude becomes smaller as the model resolution becomes finer.**

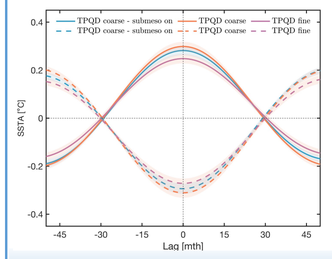


Fig. 4. Composites of Niño4 SSTA evolution at the peak positive TPQD and negative TPQD events in the fine-resolution (purple), coarse-resolution (orange), and coarse-resolution with submesoscale parameterization (cyan) CGCMs in CMIP6.

Conclusions

- ✓ Equatorial submesoscale eddies inhibit the growth of the TPQD variability by inducing an anomalous downward vertical heat flux from the surface to the subsurface ocean during the positive TPQD events and an anomalous upward vertical heat flux during the negative TPQD events.
- ✓ The quasi-decadal variability of the vertical heat flux of sub-mesoscale eddies is attributed to baroclinic instability and frontogenesis, which arise from the mean-state variations associated with the quasi-decadal variability of the cold-tongue thermal front and thermohaline stratification, respectively.

Key references

McWilliams (2016). Submesoscale currents in the ocean. *Proc. R. Soc. A.*, **472**, 20160117.

Wang et al (2022). El Niño/Southern Oscillation inhibited by submesoscale ocean eddies. *Nat. Geosci.*, **15**, 112–117.