Interannual Modulation of Kuroshio intensity in the East China Sea Over the Past Three Decades

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1. Introduction

- **It is known that Interannual variability of Kuroshio intensity is closely related to eddy activity along the Subtropical Counter Current (STCC).**
- **However, a strong positive correlation between the Kuroshio intensity and eddy kinetic energy (EKE) of the STCC has no longer sustain since the early 2000s.**
- **In this study, we will first show the significance of interannual variability of Kuroshio intensity in the East China sea. And then, we will demonstrate that the low-frequency planetary waves from the eastern pacific are another important modulator of the interannual variability of Kuroshio intensity over the past three decades, especially after the early 2000s.**

2. Data and Methods

Methods

- **Ensemble Empirical Mode Decomposition (EEMD) was used to investigate the modes of Kuroshio intensity.**
- **Also $1° \times 1°$ sparse ocean general circulation model (OGCM) was adopted to demonstrate the role of planetary waves compared to eddy activities on the Kuroshio intensity.**

Data

- **AVISO altimetry products, ECMWF surface wind UV component (1993~2020)**

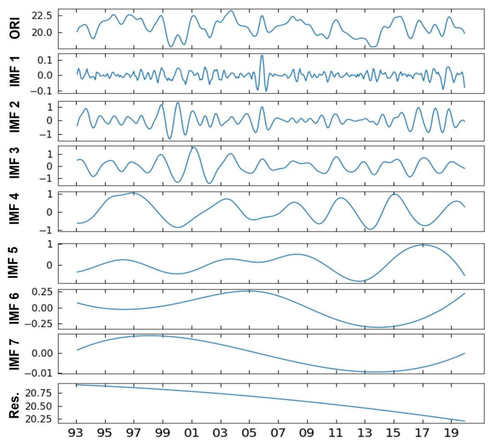

Figure 2 ▲. EEMD decompositions of one year low-pass filtered KVT. The original monthly data (top) are decomposed into seven IMFs and the resulting trends (bottom panels) by EEMD method.

3. The Kuroshio intensity in the East China Sea

- **Low-passed filtered Kuroshio intensity in the East China sea (Blue) and empirical Kuroshio volume transport index (black) (Yan and Sun 2015) showed a high correlation and distinct interannual variability.**
- **When the interannual Kuroshio intensity strengthened (weakened), SLAs of the East of Taiwan also showed positive (negative) anomalies (figure not shown).**
- **These results demonstrate the robust interannual variability of the Kuroshio intensity in the ECS, which may be associated with the propagation of SLAs, such as mesoscale eddy migration.**

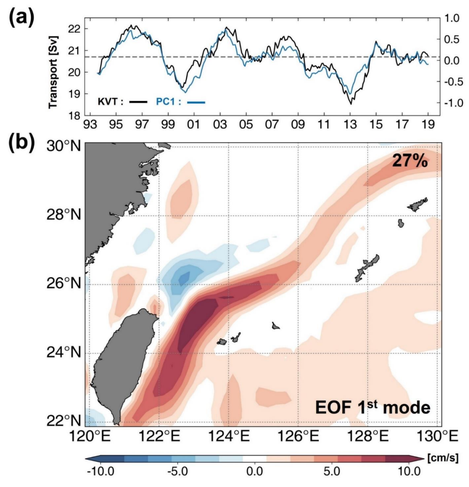

Figure 1▲. (a) Time series of the KVT (black) and principal component (PC) of first mode for satellite-based surface velocity (blue) over 1993–2020. Two-year moving average was applied to both KVT and PC time series. Grey dashed line indicates the average of the KVT (20.7Sv) over the period. (b) Spatial pattern of first-leading mode of geostrophic velocity in the ECS region.

4. Kuroshio intensity Associated with Mesoscale Eddy Activities

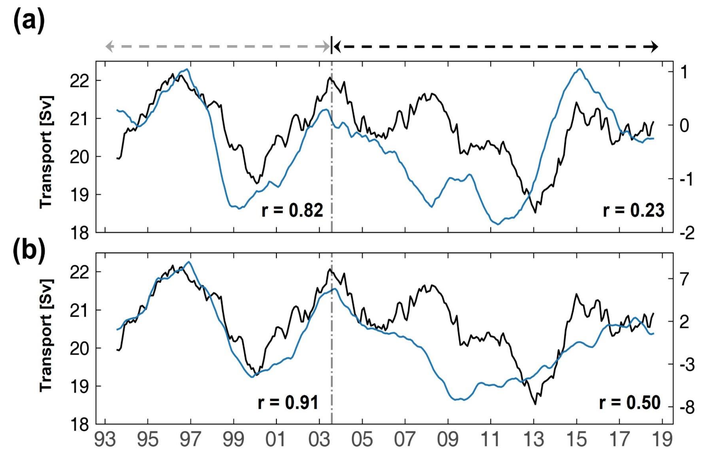

Figure 3 ◀. Comparison of the KVT east of Taiwan (black) time series with **(A)** PDO index (blue) and **(B)** EKE index (blue) averaged over the STCC region (10°–30°N, 125°–110°W) in the western North Pacific. The correlation coefficients are computed for two periods: before and after 2003 (vertical grey dashed lines).

- **The correlation between interannual Kuroshio intensity and PDO index and EKE index (Qiu and Chen 2011) has decreased markedly since 2003.**
- **The interannual Kuroshio intensity no more follows the PDO-related wind pattern, which brings enhancement of eddy activities.**

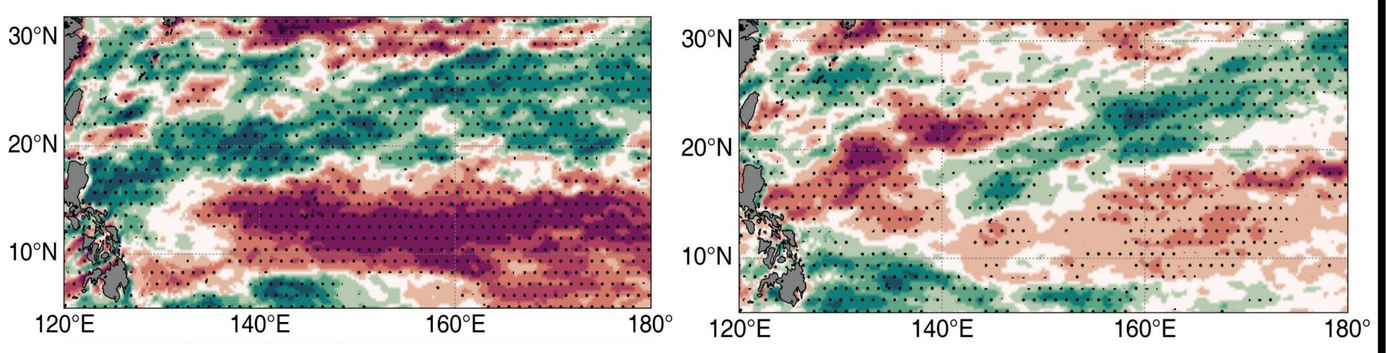

Figure 4 ▲. Correlation maps of wind stress curl (WSC) over the western North Pacific with the KVT east of Taiwan during the periods of **(A)** 1993–2003 and **(B)** 2004–2019. A two-year moving average was applied to the WSC data. Dotted areas denote the significance level above 99%.

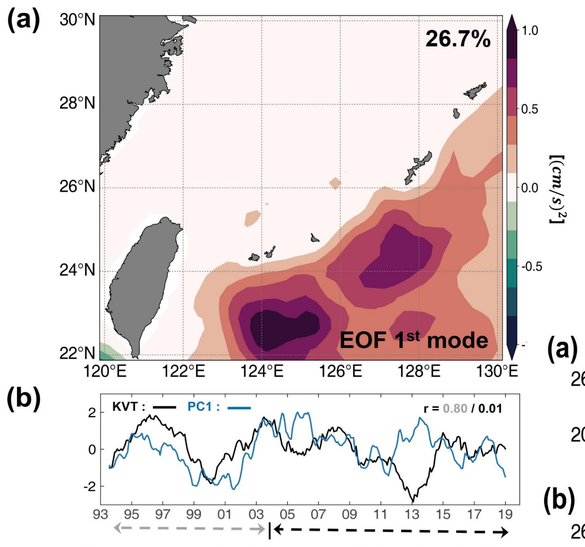

Figure 5▲. (A) Spatial pattern of the EOF. The first leading mode of the EKE in the east of Taiwan accounts for 26.7% of the total variance. **(B)** Time series of the KVT east of Taiwan (black) and the PC (blue) of the leading mode. Both time series were smoothed by a two-year moving average.

- **The mesoscale eddy activities associated with SLAs also showed decreases in the correlation with Kuroshio intensity.**
- **Before 2003, the EKE east of Taiwan was positively correlated with SLAs, showing a tilted band structure extending from east of Taiwan to about 140°E.**
- **However, the pattern disappeared during the period of 2004 to 2019.**

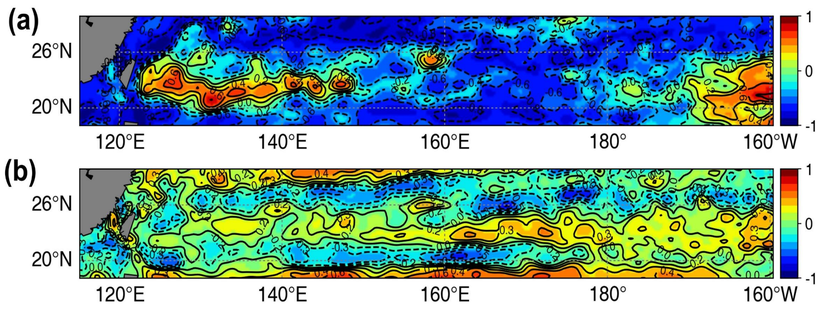

Figure 6 ▲. Correlation maps of SLAs with the EKE index during the periods of **(A)** 1993–2003 and **(B)** 2004–2019.

5. SLAs Propagating Westward From Central and eastern North Pacific

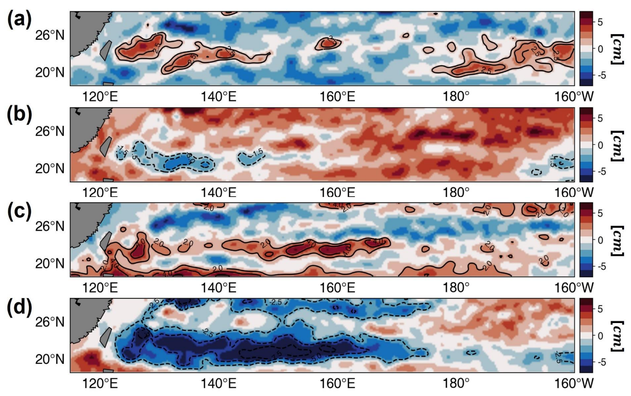

Figure 7▲. Composite maps of SLAs according to strong years of **(A)** 1995–1998 and **(C)** 1999–2002 and weak years of **(B)** 2006–2009 and **(D)** 2012–2014 on the KVT east of Taiwan.

- **Before 2003 ➔ Kuroshio intensity was affected by SLAs associated with eddy activity in the East of Taiwan.**
- **After 2003 ➔ Kuroshio intensity was affected by SLAs extending from the East coast of Taiwan to the eastern North pacific.**

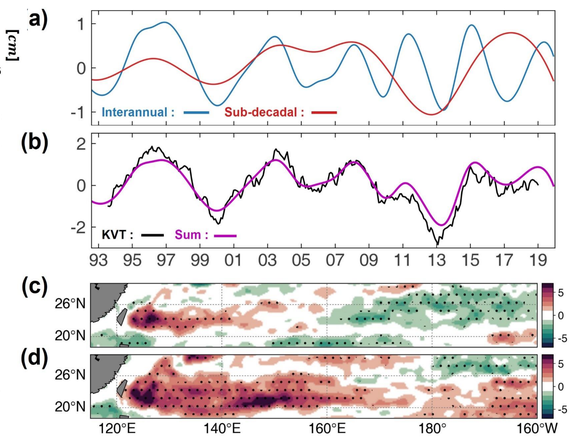

Figure 8 ▶. (A) Interannual (red) and sub-decadal (blue) modes of the KVT east of Taiwan extracted by EEMD method from 12-month low-passed filtered KVT time series. **(B)** Time series of the KVT east of Taiwan (black) and the sum of EEMD-determined two modes (purple) in **(A)**. Two time series are normalized by their standard deviation. Regression maps of SLAs against **(C)** the interannual and **(D)** sub-decadal mode over the period of 1993–2020. Dotted areas represent the significance level above 95%.

- **Interannual modulation of Kuroshio intensity is a combined effect of both interannual mode (eddy activity) and sub-decadal mode (planetary waves).**
- **The amplitude of the sub-decadal mode has enhanced since 2003; meanwhile, the interannual mode steadily variates during the past three decades.**
- **The change in the propagation of SLA may be favored by wind pattern change over the North Pacific since 1999 (Wu et. al 2019).**

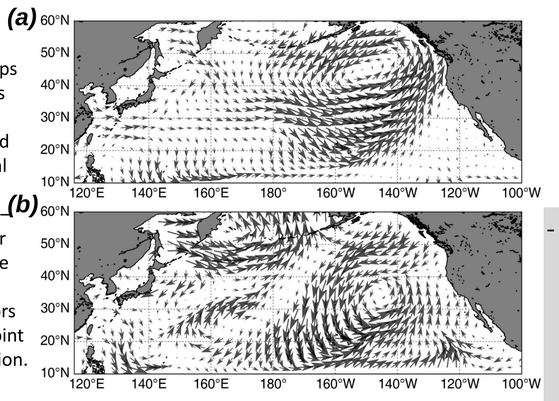

Figure 9 ▶. Regression maps of wind vectors against **(a)** the interannual and **(b)** sub-decadal mode over the period of 1993–2020. Two-year moving average was applied to the wind vectors of each grid point before regression.

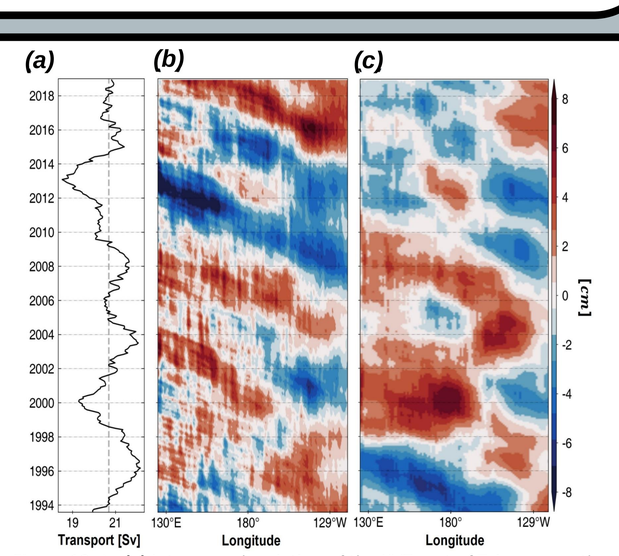

Figure 10 ▲. (a) Interannual variation of the KVT east of Taiwan over the period of 1994–2019. *Hovmöller* diagram of SLA of the **(b)** altimeters and **(C)** OGCM result along the latitude band of 21.5–24°N. Two-year moving average was applied to the data. Grey dashed line represents the mean value of the KVT east of Taiwan over the period.

- **If not eddy-resolved, the numerical model could not fully reproduce the intensity change in Kuroshio, especially before 2003. Contrarily, it represented well the propagation of linear waves from eastern north Pacific to ECS and following intensity change in the Kuroshio.**

6. Conclusion

- **The Strong positive correlation between the interannual Kuroshio intensity and eddy kinetic energy has decreased since the early 2000s.**
- **Kuroshio intensity can be determined by a combination of westward propagating mesoscale eddies from the STCC region and oceanic planetary waves from the east.**
- **EEMD analysis revealed that the eddy activities in the STCC region had fluctuated consistently over the past three decades, whereas the low-frequency mode has become stronger since the early 2000s.**
- **Consequently, prior to the early 2000s, the interannual variability of Kuroshio intensity was mainly affected by the formation and propagation of eddies from the STCC region. However, since then, low-frequency waves propagating westward across the Pacific basin have largely modulated the Kuroshio variability in the ECS, superposing the variability associated with eddies.**