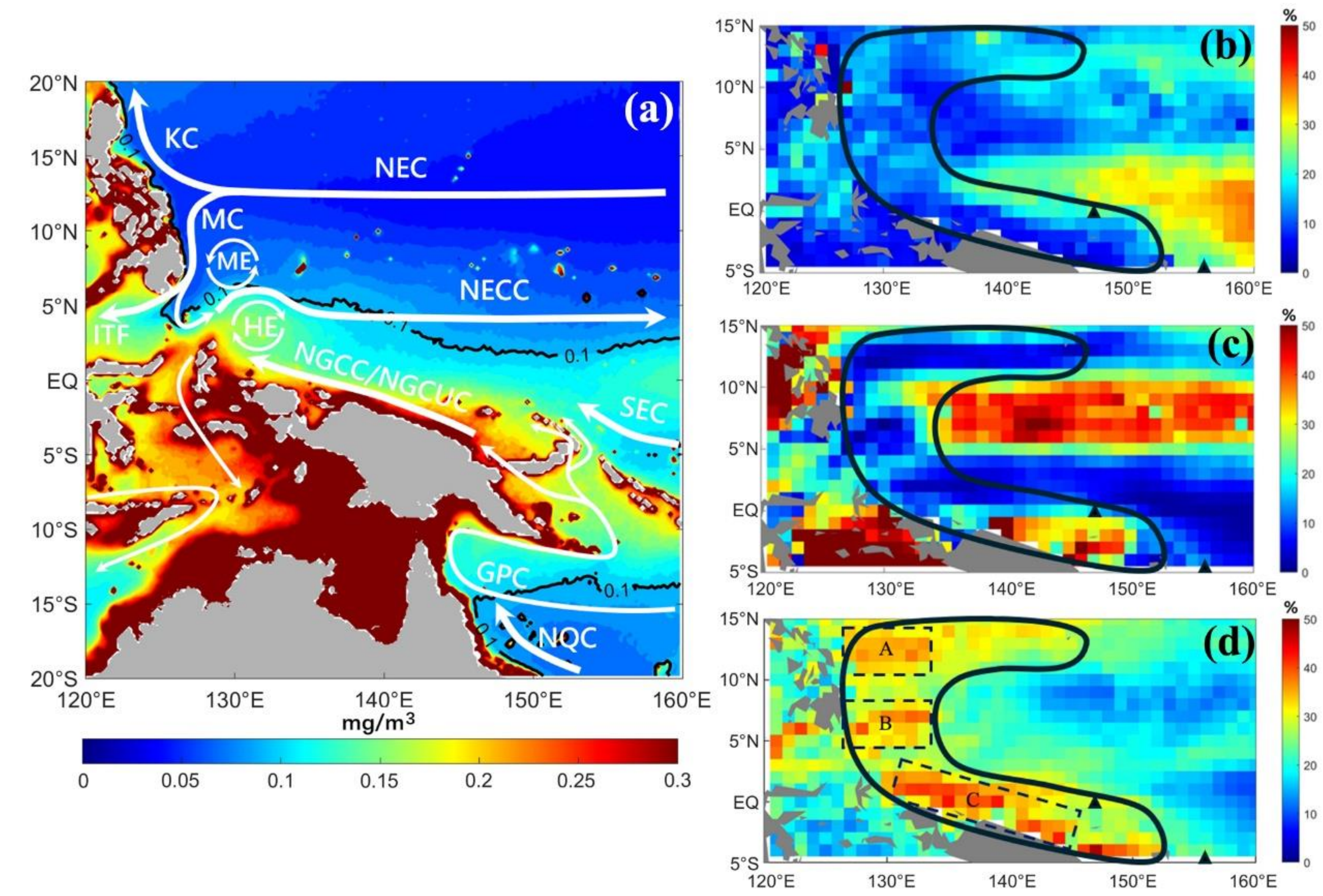
Dynamics of Significant Intraseasonal variability of surface Chlorophyll-a concentration in the far Western Tropical Pacific

Hui Zhou[1,2,3], Xueqi Liu[1], Shuo Wang[1], Lei He[4], Xingru Feng[1,2,3] ,Fan Wang[1,2,3]

[1] Institute of Oceanology, Chinese Academy of Sciences, Qingdao, China; [2]University of Chinese Academy of Sciences, Beijing, China.
[3]Laoshan Laboratory, Qingdao, China; [4]Sun Yat-sen University , Guangzhou, China

1. Introduction

The far Western Tropical Pacific(WYP) serves as a critical chokepoint in the global ocean conveyor belt and a dynamic crossroads where water masses from both hemispheres and the Pacific and Indian Oceans converge. Surface Chlorophyll-a(SChl) concentration, a proxy for phytoplankton biomass, functions as a key indicator of photosynthetic activity in the ocean and reflects the foundational role of phytoplankton in the marine food web. Among the existing studies on the variability of SChl in the far WTP, considerable attention has been directed towards the interannual variability. However, based on satellite-derived SChl data, we reveal that surface chlorophyll-a concentration in the far WTP is predominantly governed by intraseasonal variability (ISV). This study proposes that enhanced intraseasonal turbulent mixing and horizontal advection, primarily driven by the Madden-Julian Oscillation (MJO), significantly influence SChl concentrations.



(a) Schematic of ocean circulation in the western tropical Pacific, with surface chlorophyll-a concentration (mg/m^3) shown by color shading. The black line indicates the 0.1 mg/m^3 contour, defining oligotrophic waters. Percentage of the surface chlorophyll-a variance explained by (b) interannual (500-2500 day), (c) seasonal, and (d) intraseasonal (20-150 day) signals during 1999.01-2022.12. Within areas of high intraseasonal activity, as defined by the current system, three regions (boxed) are highlighted: A, the North Equatorial Current Bifurcation region; B, the nascent North Equatorial Countercurrent region; and C, the New Guinea Coastal Current/Undercurrent region.

2. Methods

Following Sverdrup defined the critical depth, we estimate the critical depth using the equation: $CD = \sum E_0 /(3.78Kd_{PAR})$

To assess causal relationships, we implement the Liang-Kleeman information flow framework, which characterizes information transfer between two entities in a dynamical system based on their covariance structure. The information flow from variable X_2 to X_1 ($T_{2\to1}$) is as follows:

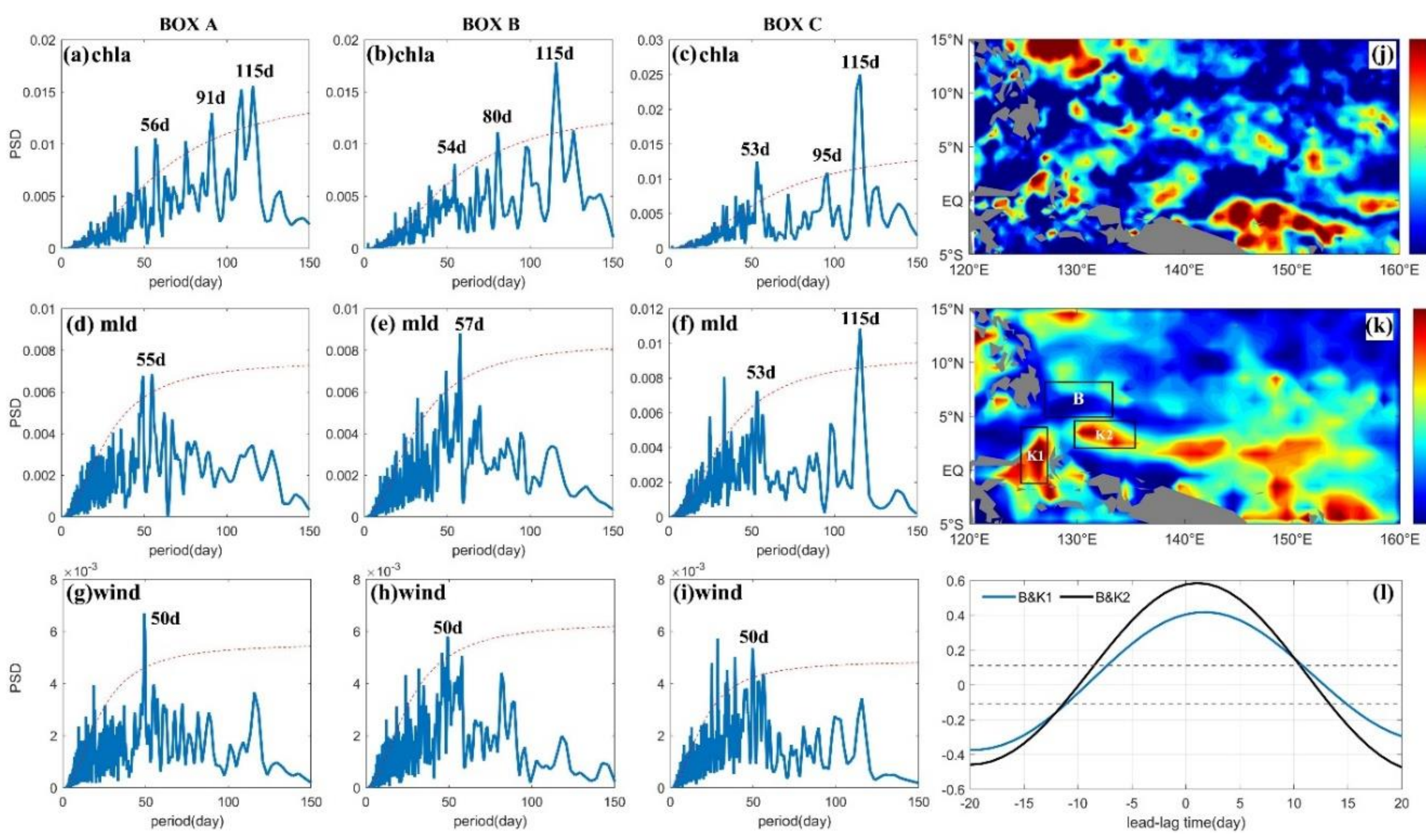
$$T_{2\to1} = \frac{c_{11}c_{12}c_{2,d1} - c_{12}^2 c_{1,d1}}{c_{11}^2 c_{22} - c_{11}c_{12}^2}$$

3. Significant Intraseasonal Variability in SChl

SChl power spectral analysis reveals significant peaks around 53-56 days, 80-90 days, and 115 days across all three boxes. **The 53-56 day period aligns with the MJO, positing it as a primary driver of ISV.** This is supported by persistent 55-day peaks in wind speed spectra, suggesting MJO's influence on both MLD and SChl ISV.

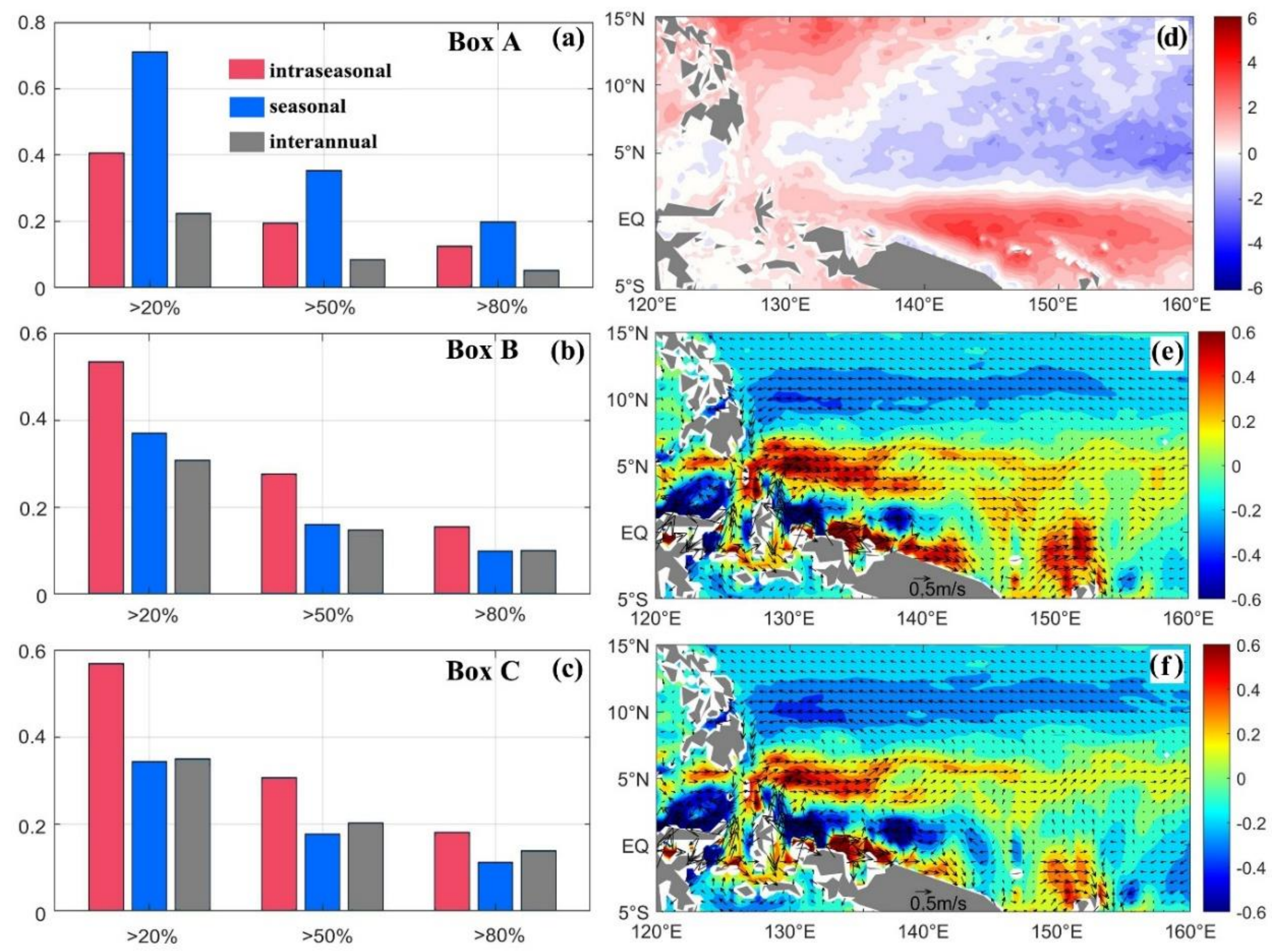
In Box A, the MJO significantly drives SChl ISV, with an information flow of 0.26 nats/month, further strengthened by intraseasonal wind speed and its direct vertical mixing. **Box C also shows the MJO as the cause of significant ISV**, with wind speed causality reaching 0.7-0.8 nats/month along New Guinea's eastern coast. Conversely, **Box B's SChl ISV is indirectly modulated by the MJO**, with the northern Maluku Channel and NGCC/NGCUC regions acting as key advective conduits.

***Correspondence to:**
Hui Zhou (zhouhui@qdio.ac.cn) & Fan Wang (Fwang@qdio.ac.cn)



Power spectrum of surface chlorophyll-a concentration (a-c), the mixed layer depth (d-f), and wind speed (g-i) for the NEC bifurcation region (Box A; left column), the nascent NECC region (Box B; middle column), and the NGCC/NGCUC region (Box C; right column) during 1999.01-2022.12. The causality (information flow in nats/month) from (j) the time series of MJO to the intraseasonal (30-60 day band passed) surface chlorophyll-a concentration anomalies in the far western tropical Pacific. (k) Similar to (j) but from intraseasonal wind speed anomalies to SChl anomalies. (l) Lead-lag correlations between surface Chl-a concentration anomalies averaged in Box K1 and Box B (blue line), Box K2 and Box B (black line).

4. Dynamics



Left column: The ratio of contribution exceeding 20%, 50% and 80% in the amplitude of all deepening events of mixed layer depth during 1999.01-2022.12 by intraseasonal (red), seasonal (blue), and interannual (gray) component for (a) Box A, (b)Box B, and (c) Box C, respectively. Right column: Composite of mixed layer depth anomalies during positive (active) MJO phase (d). Composite of OSCAR surface current during (e) positive and (f) negative phase of MJO. The contours represent zonal velocity

The MJO is the primary driver of significant SChl ISV, operating through two complementary pathways: **modulating mixed layer depth (MLD) and boosting high-nutrient water advection**. Specifically, the MJO drives SChl fluctuations by enhancing wind-induced vertical mixing and entrainment during its active phase, and by increasing the advection of nutrient-rich waters via anomalous currents during its negative phase.

5. Summary & Conclusion

This study identifies ISV as the dominant mode regulating SChl fluctuations in the far WTP, where it explains over 30% of the total SChl variance, highlighting its paramount importance in shaping regional biogeochemical cycles and ecosystem dynamics. **This variability is primarily induced by the MJO, which drives surface chlorophyll-a changes through both wind-induced vertical mixing and enhanced horizontal advection of nutrient-rich waters.** These findings highlight that incorporating the MJO is essential for improving the predictive skill of marine ecosystem models, which is vital for better understanding of biogeochemical cycles and ecosystem evolution within the ecologically and economically important Coral Triangle.