Investigating the Variability of Surface Chlorophyll-a in Association with Sea Surface Temperature and Surface Wind in the South China Sea

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The aim of study is to investigate the spatial and temporal variability of surface Chl-a in the entire South China Sea (SCS)
to understand the physical processes in the SCS through the correlation between Chl-a and the physical forcing (sea surface temperature (SST) and surface wind (SW))

South China Sea (Fig. 1)

- Connect to the East China Sea, the Sulu Sea, the Java Sea, the Indian Ocean, and the Pacific Ocean
- Major rivers flowing into the SCS: the Pearl, Red, and Mekong Rivers
- Located in the East Asian monsoon region: northeasterly from November-March; southwesterly from June-September (Fig. 3)
- Surface circulations: a basin-scale cyclone in winter; a southern anticyclone and a weak northern cyclone in summer

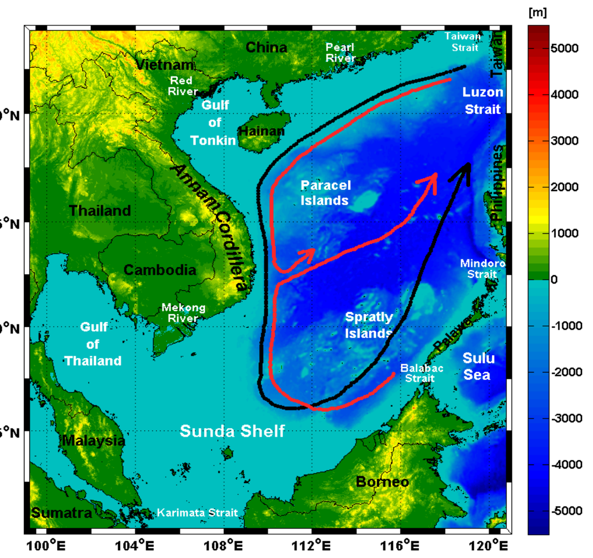

Fig. 1. *The South China Sea and its bathymetry (in m). The main surface circulation patterns: winter (black line) and summer (red line) .*

Data and Method

Data

- Ocean color data: gridded level-3, 8-day, 4-km MODISA Chl-a and SST (2003-2016)
- SW: gridded, daily, 25-km cross-calibrated multiplatform (CCMP) v2.0 (2003-2016)

Method

- To fill in missing data of the MODISA Chl-a and SST: Data INterpolating Empirical Orthogonal Functions (DINEOF, *Beckers and Rixen (2003); Alvera-Azcárate et al. (2005)*). DINEOF was used to successfully reconstruct the long-term (1989-2009) daily AVHRR SST, with a very high percentage (~ 88 %) of missing data, for the SCS (*Huynh et al. 2016*)

Modes of the Variability

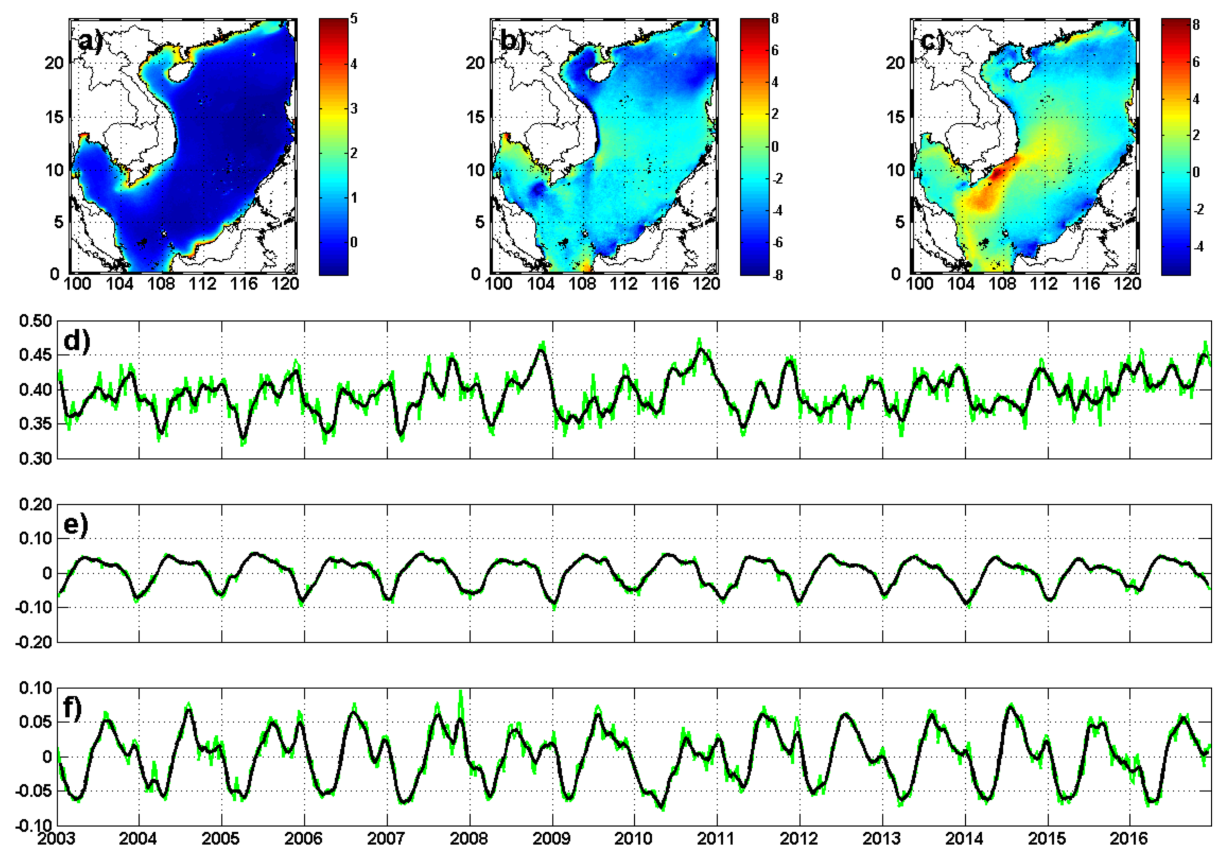

Fig. 5. *The first three Chl-a EOFs. (a)-(c) the first three spatial EOFs, respectively. (d)-(f) the first three temporal EOFs, respectively. Chl-a is on a based-10 logarithm scale; negative values represent decimals and positive values represent Chl-a greater than 1. The temporal EOFs are smoothed (black line)*

- **The Chl-a EOF1s** (77% of the total variance, Fig. 5a,d) show the variability of Chl-a in coastal areas, reaching peaks in June-August and November-December, with the highest in November-December, and troughs in March-May and October, with the lowest in March-May. There is not a correlation between this mode and the SST and SW EOFs (Figs. 6-7, respectively).
- **The Chl-a EOF2s** (9.49% of the total variance, Fig. 5b,e) present the seasonal variability of Chl-a in the SCS: increase in winter and decrease from spring to autumn. The highest variability occurs in the northern SCS, a narrow band along the center of Vietnam coast, the southern Gulf of Thailand, and small areas along the coast of Borneo and Palawan Islands. This mode has a correlation with the seasonal upwelling favorable SW (Fig. 6a,d).
- **The Chl-a EOF3s** (2.69% of the total variance, Fig. 5c,f) highlight the out-of-phase variability between the western and eastern SCS. There is a considerable correlation between the third Chl-a and SST (Fig. 7c,f) and SW (Fig. 6a,d) modes. This mode captures the upwelling phenomena in the SCS in winter and summer.

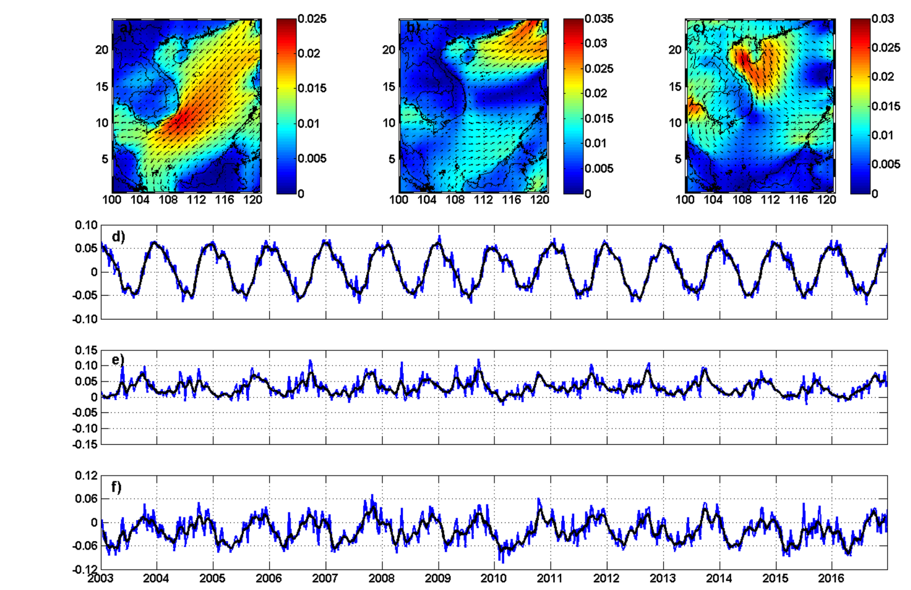

Fig. 6. *The first three SW EOFs. (a)-(c) are the first three spatial EOFs (unit m/s), respectively. (d)-(f) are the first three temporal EOFs, respectively. The temporal EOFs are smoothed (black line)*

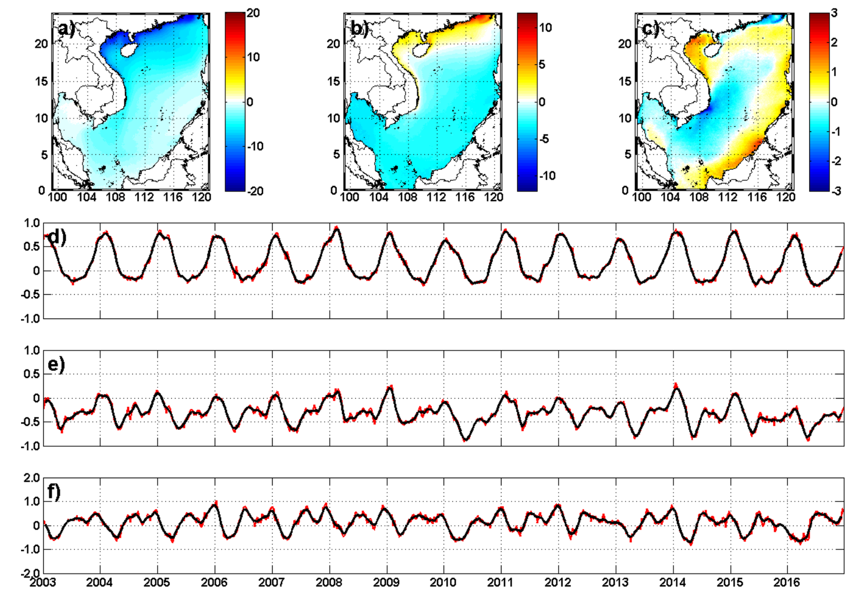

Fig. 7. *The first three SST EOFs. (a)-(c) are the first three spatial EOFs (unit °C), respectively. (d)-(f) are the first three temporal EOFs, respectively. The temporal EOFs are smoothed (black line)*

Monthly Climatology

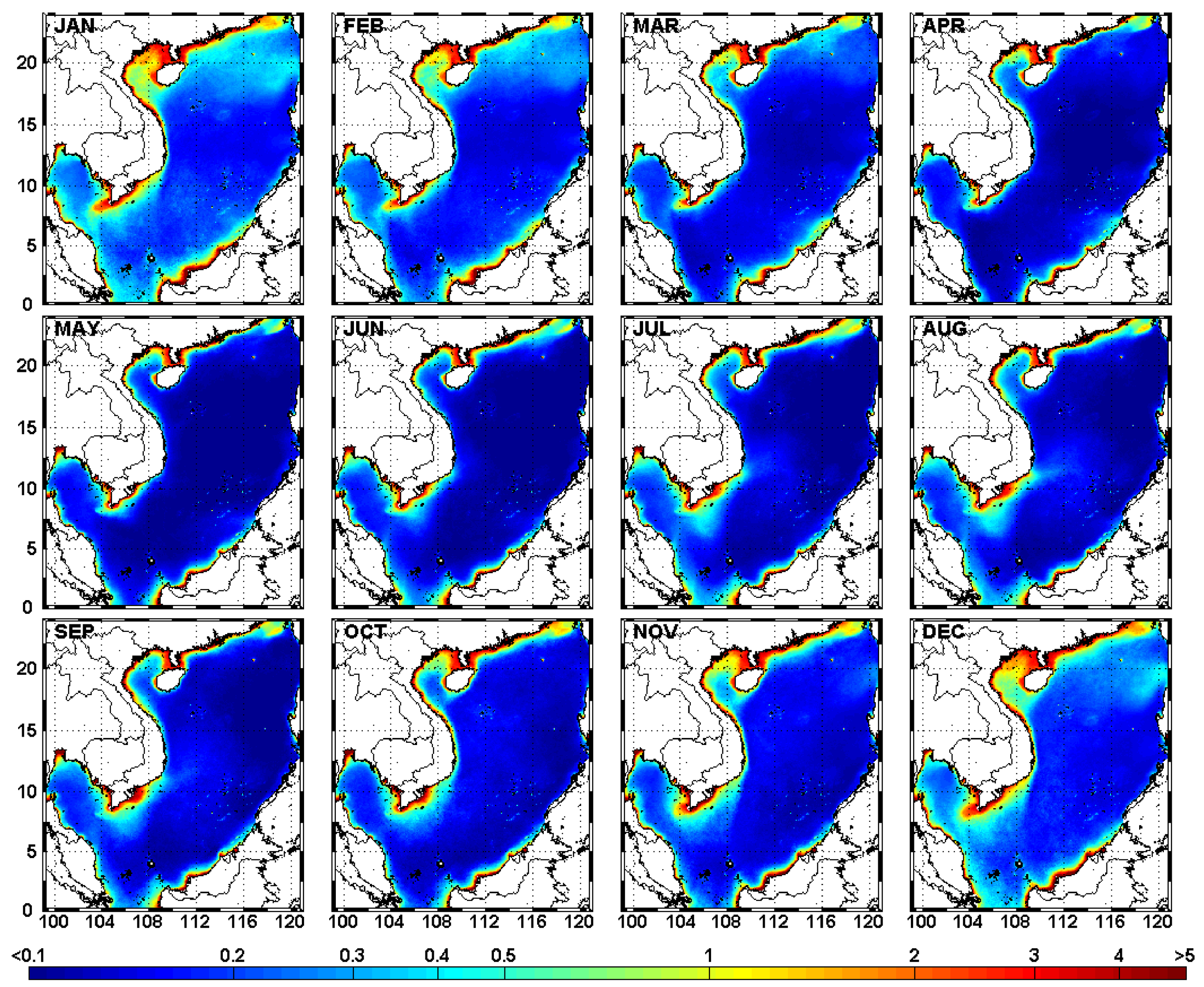

Fig. 2. *Monthly Chl-a climatology (unit mg/m³) computed from the 8-day DINEOF Chl-a (2003-2016)*

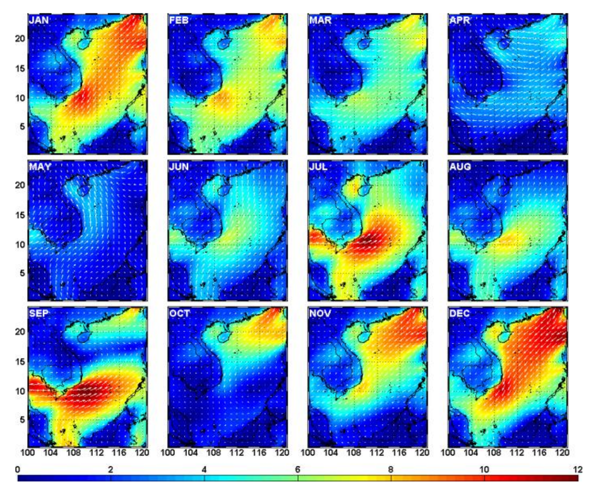

Fig. 3. *Monthly SW climatology computed from the 8-day CCMP SW (2003-2016). Note that the arrows in each plot are not scaled in speed, just show the direction of SW. Wind speed is represented by color (unit m/s)*

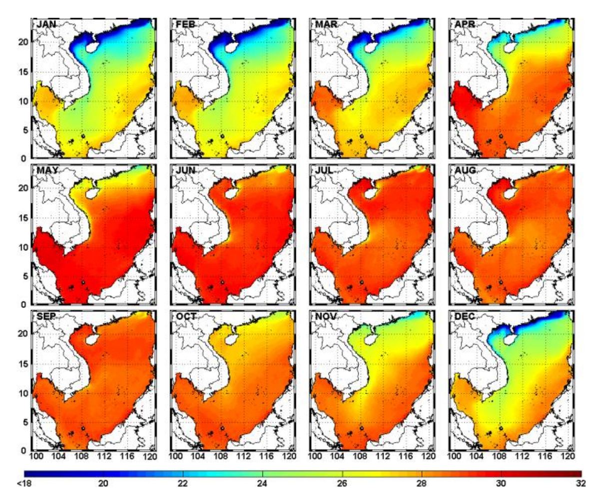

Fig. 4. *Monthly SST climatology (unit °C) computed from the 8-day DINEOF SST (2003-2016)*

- Chl-a is high along coastal regions (> 0.5 mg/m³), except for the coast of Palawan and Philippine Islands due to steep slopes without shelves; and low in deep basin (< 0.1 mg/m³).
- Chl-a in the entire SCS is highest in January.
- From December to February, a prominent feature is the high Chl-a (> 0.4 mg/m³) in the deep basin, off the northwestern Luzon Island, corresponding to the strong upwelling favorable wind (Fig. 3), although there is insignificant decrease in SST (Fig. 4).
- Chl-a in the entire SCS is lowest in May when SW reverses from northeasterly to southwesterly and SST is highest.
- In summer, Chl-a is high in the southeastern Vietnam coast, the Malaysia coast, the Hainan Island, and the Taiwan Strait, corresponding to low SST and upwelling favorable SW.
- The monthly climatology of SST, SW, and Chl-a (Figs. 2-4 JUL-SEP) clearly presents a stretch of cold water with high Chl-a under the wind forcing from the southeastern Vietnam coast to the open sea in summer.

Conclusions

- ***The variability of coastal Chl-a reaches maximum values in November-December and minimum values in April-May and does not have a clear seasonal cycle.***
- ***The variability of open-sea Chl-a has a seasonal cycle and a correlation with the seasonal upwelling favorable SW.***
- ***The seasonal upwelling occurs in the eastern SCS in winter and in the western SCS in summer. The intensity of upwelling in summer is stronger than that in winter.***

Main references

Alvera-Azcárate, A., Barth, A., Rixen, M., and Beckers, J.-M. (2005). Reconstruction of incomplete oceanographic data sets using empirical orthogonal functions: application to the Adriatic sea surface temperature. Ocean Modelling, 9(4):325-346

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Acknowledgements

8-day MODISA Chl-a and SST were obtained from OceanColor Web (https://oceancolor.gsfc.nasa.gov). CCMP Version-2.0 vector wind analyses are produced by Remote Sensing Systems (www.remss.com).