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SPATIO-TEMPORAL VARIATIONS OF SEA SURFACE TEMPERATURE, SEA SURFACE WIND AND THE CHLOROPHYLL-A CONCENTRATION IN GULF OF TONKIN

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ABSTRACT

The temporal and spatial variability of sea surface temperature (SST), sea surface wind and the chlorophyll-a (chl-a) concentration in the Gulf of Tonkin is analyzed based on satellite data for one year 2002. The analysis results indicated that monthly and spatial variations of the chl-a are primarily associated with the monsoonal winds activity and sea surface temperature distributions. In general, the results show the average monthly Chl-a concentrations were high in most area of the Gulf under northeasterly monsoonal, with a belt of higher Chl-a concentrations along the coast during throughout year, which is consistent with the winter northeast monsoon. The offshore-ward phytoplankton blooming events with a high chl-a concentration (> 1.5 mg m^{-3}) patch extending southwestward from the northeast coast to most area of the gulf in the strong northeast wind months. The high chl-a concentration is found to be consistent with low SST spatial distribution in the northeastern gulf during winter monsoon season. In summer, chl-a concentrations were quite low in center part of the gulf, with a belt of higher chl-a concentrations along the coast. During summer, SST was high (28-31 ^{0}C) with higher values in the northern gulf, while northeast winter monsoon winds were stronger than southwest summer monsoon winds in this year.

Keywords: Chlorophyll-a concentration, sea surface temperature, sea surface wind, monsoon, Gulf of Tonkin.

1. INTRODUCTION

The Gulf of Tonkin is a semi-enclosed gulf located in the northwest Vietnam East Sea (VES). Monthly ocean and atmospheric variability in the Gulf of Tonkin are greatly affected by the Asian monsoon with strong northeast monsoon winds from September to April and weak southwesterly monsoonal winds from July to August. There are many rivers running into the Gulf of Tonkin. One of major rivers running into the gulf is the Red River. These rivers discharge into the Gulf with fresh water and nutrients, which in turn may significantly affect on water temperature, circulation, and phytoplankton growth, especially in coastal regions. The physical, chemical and biological processes over the ocean were known to be in closed relationship (Chaturvedi et al., 1998; Tang et al., 2004). Remote sensing is the most efficient way to monitor and study the marine environment. Chlorophyll-a concentration estimated by satellite ocean color imagery is an index of phytoplankton biomass. Sea-view Wide Field-of-view Sensor (SeaWiFS) ocean color images, and Advanced Very High Resolution Radiometer (AVHRR) data have been utilized for several studies on marine environment in the VES (Thien, 2018; Tang et al., 2002), but few studies have been carried out in the Gulf of Tonkin.

The monsoon wind regimes play an important role in hydrological features and the general circulation in the study area. However, characteristics of chlorophyll-a and its distribution associated with monsoon activity and SST distributions have remained unknown or poorly known for most of the gulf. In the present study, we investigate monthly averaged and spatial variations of Chlorophyll-a (Chl-a), sea surface wind, and sea surface temperature conditions in the Gulf of Tonkin during the whole year 2002 by examining satellite measurements.

2. STUDY AREA AND SATELLITE DATA, AND METHODS

2.1. Study area

The study region is the Gulf of Tonkin (area in Fig. 1, 106^0E – 110^0E, 17^0N – 22^0N). The average depth of Gulf of Tonkin is about 38.5m. This region experiences reversal monsoon with weak southwest monsoon in the summer and strong northeast monsoon in the winter.

2.2. Satellite-derived Chlorophyll-a

Sea viewing Wide Field-of View Scanner (SeaWiFS) derived Chlorophyll-a were processed using the Ocean Color 4-band algorithm (OC4) (O'Reilly et al., 2000; O'Reilly et al., 1998). Monthly averaged Chl-a concentrations with 3x3km spatial resolution were obtained and processed for the study region. Ocean Color and Temperature Scanner (OCTS) aboard Advanced Earth Observing Satellite observed the Chl-a concentration in the surface layer from October 1996 to June 1997 with quality similar to that of SeaWiFS (Kawamura et al., 1998). SeaWiFS-derived Chl-a concentrations are consistent with survey measurement in most area in the western VES, including coastal waters (Tang et al., 2004).

2.3. Satellite-derived surface vector winds

Sea surface vector winds have been measured from the microwave scatterometers [10]. We used 0.5-degree monthly mean wind fields obtained from the QuickBird satellite which was launched in June 1999. QuikScat is a radar device that transmits radar pulses down to the Earth's surface and then measures the power that is scattered back to the instrument. Wind speed and direction over the ocean surface are obtained from measurements of the QuikScat backscattered power (Wentz et al., 2001).

2.4. Satellite-derived sea surface temperature

National Oceanic and Atmospheric Administration (NOAA) satellites provide SST observations form Advanced Very High Resolution Radiometer (AVHRR) instruments. AVHRR images with 1.1 km spatial resolution at nadir were obtained from satellite (Hsu et al., 2000). The cloud free images were processed to obtain the multi-channel SST data (Kubota, 1994; Simpson et al., 1990). Then monthly SST data were obtained by arithmetically averaging all available scenes in each month on a pixel by pixel basis.

3. RERULTS

The climatological monthly variations and spatial distributions of Chl-a concentrations, surface winds and SST from January to December 2002 were analyzed and shown by some representative figures. In the Gulf of Tonkin the northeast monsoon of winter season in 2002 begins in September with an average velocity changing from 1 ms^{-1} in the south to 6 ms^{-1} in the north (not shown). The wind speed has increased and reached its peak in November (>8 ms^{-1}). The typical seasonal features of a strong northeast monsoon in January were shown in figure 3 with an average of 6.6 ms^{-1} in the northeast and 5.1 ms^{-1} in the south of the Gulf. The monthly spatial distributions of chl-a are generally higher along the coastal area and lower values off shore throughout the entire year. The distribution of chl-a had seasonal variations with higher values and larger area during the northeast monsoon.

During winter (January 2002), the Chl-a concentrations were entending in the entrire gulf with a belt of relatively high Chl-a concentrations (>1.5 mg m^{-3}) along the coast of the Gulf (Fig. 2) and strong northeast monsoon winds (> 6m/s) were observed on the northern side of the gulf above latitude 19N (Fig 3). This is coincided with that SST was low (<20.5^0C) in the northern part and increased gradually southward (>23.5^0C) (Fig.4).

These characteristics were found to be similar in February although the extended area of high Chl-a and the magnitudes of winds were smaller than in January (not shown). The northeast monsoon weakens from March and vanishes in April and May (not shown). The weaker south and southeast winds dominated almost entire the gulf and ranged from 2-4.5 m/s during April, May and

June (not shown). Because of blocking effects of Hainan Island, there is low wind in the northeast gulf during these two months. March, April, May and June are transition months, during which high chl-a concentrations found in coastal area with higher values in the north part of the gulf (not shown). This ch-a distribution coincided with the SST spatial variation with lower SST in the northeast of the gulf (not shown).

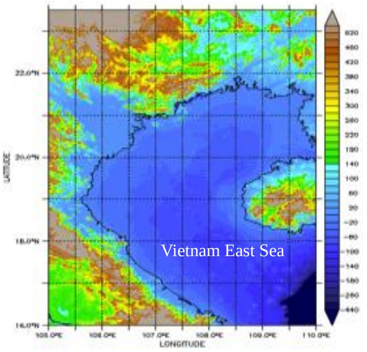

Figure 1. Bathymetry of the study area.

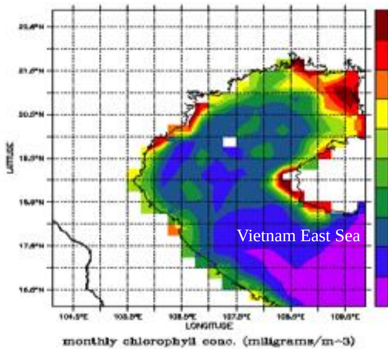

Figure 2. Monthly mean SeaWiFS Chl-a for January 2002.

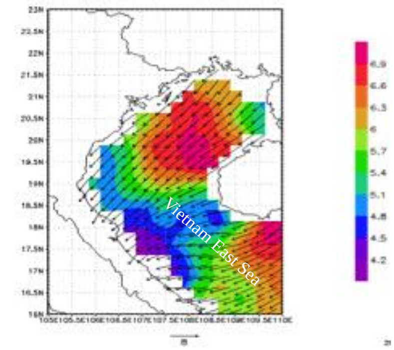

Figure 3. Monthly mean QuikScat surface vector winds for January 2002.

The first appearance of the southwest summer monsoon in 2002 is in July and ends in August. During summer (July 2002), chl-a concentrations were low (< 0.5 mg m^{-3}) in entrire center of gulf; high chl-a concentrations were limited to the coastal areas (Fig. 5). The prevailing winds in the gulf were very strong southwesterly winds with surface wind speed reached from 4-7m/s during this month (Fig. 6). SST may be influenced by sea surface heating in summer. Figure 7 shows relatively uniform temperature in the gulf. SST increased quickly and distributed evenly in the whole gulf in this season with highest SST (29-31 ^{o}C) in July. This characteristic is the same as found in August (not shown).

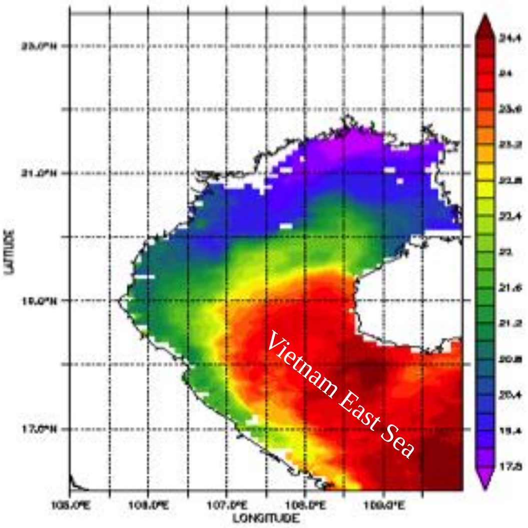

Figure 4. Monthly mean sea surface temperature for January 2002

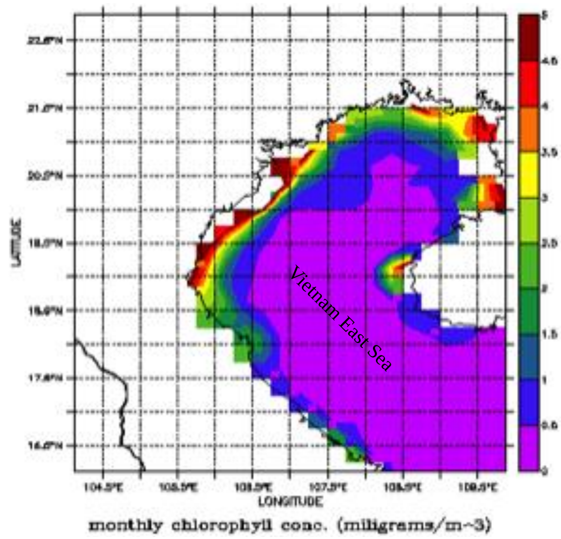

Figure 5. Monthly mean SeaWiFS Chl-a for July 2002

The northeast winter monsoon in 2002 begins in September. High wind area is observed mostly in the north of the gulf during the northeast monsoon. Chl-a concentrations, sea surface wind vector, and SST distributions from September to December were generally found to be similar to pattern in January (not shown). It is worth to note here that northeast monsoon was stronger than southwest monsoon during this year.

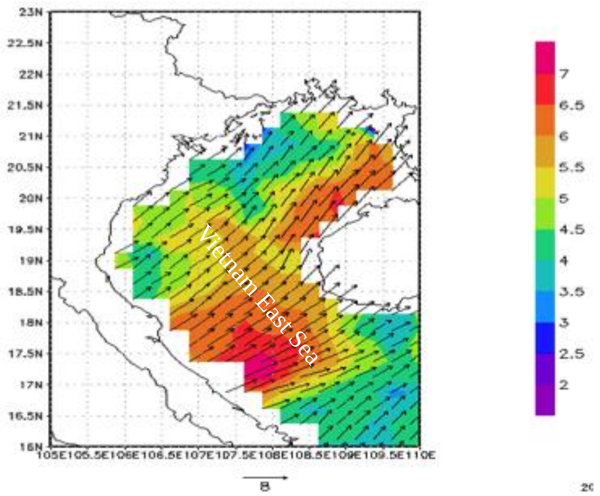

Figure 6. Monthly mean QuikScat surface vector winds for July 2002

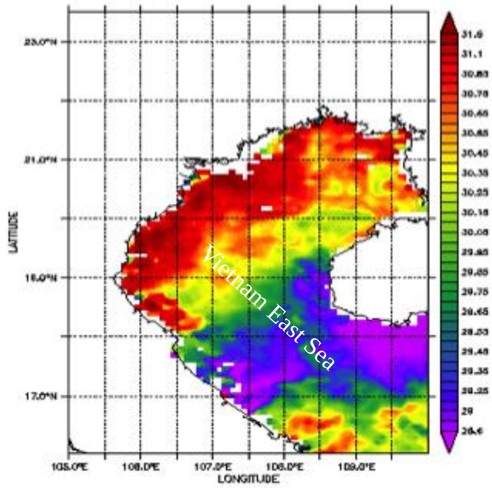

Figure 7. Monthly mean sea surface temperature for July 2002

4. CONCLUSION AND DISCUSSION

The Gulf of Tonkin has features receiving relatively high energy of solar radiation which in turn creates favorable conditions for the phytosyn-thesis of phytoplankton (An et al., 2000). The Gulf was also dominated by the Asian monsoon, which obviously illustrates the reversed wind direction in a year with northeast winds in the winter and southwest winds in the summer. The present study reveals a characteristic of seasonal distribution of chl-a in this region.

In general, in summer southwest monsoon, Chl-a concentration was low and uniform in the whole gulf. The phytoplankton blooms with high Chl-a concentration (>1.5 mg m^{-3}) appeared along the coast in southwest monsoon and decreased during transition months. This coincided with weak wind and relatively high uniform SST in the entire gulf for this season. These factors may limit upwelling of nutrients and phytoplankton growth. High chl-a concentrations along the Vietnam coastal area may be related to nutrients from beach towns and some rivers that discharge into the gulf. In contrast, during northeast monsoon the chl-a concentrations increase in the whole gulf, particularly in the northeast of the gulf. This spatial variation of chl-a is consistent with lower SST and stronger northeast winds in the northeast gulf. Water temperature and nutrients are two important factors associated with phytoplankton growth. In the gulf, some previous studies showed that solar radiation induced favorable water temperature is responsible for phytoplankton growth (An et al., 2000) and nutrients along the coastal area were discharged from rivers (Suchint et al., 2000) In addition, entrainment of nutrient-rich water by wind mixing may act to enhance phytoplankton blooms during monsoon in this gulf. The strong winds during northeast monsoon in the winter mix water to deeper depths and thus bring nutrients to the mixed layer induced high Chl-a. (Tang et al., 2003) indicated that phytoplankton blooms in the center of the gulf during northeast monsoon months was associated with water advection by Ekman drift, strong water vertical mixing and tidal mixing.

During the mature phase of El Nino, (Wang et al., 2006) showed a decrease in cloudiness and increase in the shortwave radiation in November over the gulf. Thus the strong winds during the northeast winter monsoon may mix water to deeper depths and consequently induct nutrients to the mixing layer resulting in high Chl-a in the clear sky period of year 2002.

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