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CIRCULATION FEATURES IN THE GULF OF THAILAND INFERRED FROM SeaWiFS DATA

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ABSTRACT Ocean color data was applied to study circulation features in the Gulf of Thailand. Sea-Viewing Wide Field-of-view Sensor (SeaWiFS) level 1A HRPT data covering the area of the Gulf of Thailand spanning from September 1999 to February 2001 were processed to images of chlorophyll_a concentration according to standard OC4 algorithm. Although hampered by high frequency of cloud cover over the region, it was found that there were four main areas where water exhibited high chlorophyll_a concentration namely; the Inner Gulf which four major rivers drained, along the eastern sea board of Thailand where sometimes distinct fronts occurred, Samui island and the surroundings where high chlorophyll_a concentration were observed all year round and southern tip of Cape Camau where plume extending from the mouth of the Mekong river too persisted all year. Some interesting features included tongues of high chlorophyll_a coastal water extending from the eastern sea board. Interaction of general circulation with the coastline and topography could generate such features.

INTRODUCTION

The Gulf of Thailand is situated between latitudes 6 and 14 ^{o}N and longitudes 99 and 105 ^{o}E. It is a shallow semi-enclosed embayment opening to the South China Sea. The Gulf has significant influence on socio-economic of four littoral countries namely Malaysia, Thailand, Cambodia and Vietnam. Yet our knowledge of its circulation is still incomplete. Wattayakorn *et al*., 1998 using temperature, salinity and current data from moorings located along Thailand's coast argued that the main forcing is the influence of the South China Sea. During the southwest monsoon, high-salinity water from the South China Sea entered the Gulf along the Malaysian coast generated an anticyclonic gyre and left the Gulf along the Vietnam coast. In the northeast monsoon, low-salinity Mekong River entered the Gulf along the Vietnam coast produced a cyclonic gyre and left the Gulf along the Malaysian coast. Stansfield and Garrett, 1997 using hydrographic data from NAGA expedition in 1959-1960 to balance the salt and heat budget in the Gulf suggested that the Mekong River plume might enter the Gulf in the northeast monsoon via Vietnam coastal current. Yanagi and Takao,1998 used observed temperature, salinity and sea surface wind from NAGA expeditions in 1959-1960 to force the numerical model. It was found that there were two gyres in the Gulf , anticyclonic in the upper part and cyclonic in the lower part in both season. Buranapratheprat, 1997 developed a numerical model which showed a cyclonic gyre in both season. In addition anticyclonic eddies were found at Samui island as well as a flow separation to the east in June to August.

As direct measurement of current patterns is very scarce covering only limited temporal and spatial ranges, ocean color observation from satellite offers another mean for us to study circulation in the Gulf continuously with better spatial resolution. Optical water properties are influenced largely by dissolved and particulate constituents in seawater. By treating the plankton and suspended sediment as a passive tracer, dynamical features such as fronts, eddies and residual flow patterns can be revealed in ocean color images. This paper is intended to investigate whether ocean color observation can supply additional information about circulation in the Gulf of Thailand.

METHODOLOGY

Sea-viewing Wide Field-of-view Sensor (SeaWiFS) level 1A HRPT data covering the area of the Gulf of Thailand spanning from September 1999 to February 2001 were obtained from NASA GSFC DAAC. Of nearly 400 scenes under the period of consideration, only one-fourth of those with cloud-free condition are processed to images of chlorophyll_a concentration according to Ocean Chlorophyll 4 (OC4) algorithm (O'Reilly *et al*. 2000) using SeaDAS, the SeaWiFS Data Analysis System.

Coefficients for OC4 version 4 (Maximum Band Ratio, 4th Order Polynomial)

$$a = [0.366,-3.067,1.930,0.649,-1.532] \quad (1)$$

$$\text{Chl a (ug/l)} = 10.0\text{^}(a(0) + a(1)*R + a(2)*R\text{^}2 + a(3)*R\text{^}3 + a(4)*R\text{^}4) \quad (2)$$

$$R = ALOG_{10}((Rrs443/Rrs555) > (Rrs490/Rrs555) > (Rrs510/Rrs555)) \quad (3)$$

Where the argument of the logarithm is a shorthand representation for the maximum of the three values.

RESULTS

Although hampered by high frequency of cloud cover over the region, it was found that there were four main areas where water exhibited high chlorophyll_a concentration namely; the Inner Gulf which four major rivers drained, along the eastern sea board of Thailand where sometimes distinct fronts occurred, Samui island and the surroundings where high chlorophyll_a concentration were observed all year round and southern tip of Cape Camau where plume extending from the mouth of the Mekong river too persisted all year.

Some circulation features associated with each area included tongues of high chlorophyll_a coastal water extending westward from the eastern sea board which were observed twice in February 2000 (not shown) and in November 2000 (Figure 1), each episode lasted for couples of days.

Plume from the Mekong River persisted all year round extending normally 100 kilometers from the southernmost tip of Cape Camau and could be traced along the Cambodian coast (Figure 2). Very pronounce episode occurred twice on January 2000 and February 2001 when the plume traveled far down along the mouth of the Gulf nearly reach the Malaysian Peninsular.

From these features, general circulation in the Gulf could be inferred that there seemed to be two gyres, upper part and lower part with a separation around Samui island instead of one big gyre. The upper gyre alternate between monsoon season, being cyclonic in the northeast monsoon and anticyclonic in the southwest monsoon. Inflow along the Malaysian Peninsular occurred in both monsoon seasons.

DISCUSSION

Although OC4 algorithm used maximum band ratio of the three band ratios to account for wider ranges of chlorophyll_a concentration in the ocean, it is still widely recognized as suitable for Case 1 water where phytoplankton are the prime constituent responsible for variations of optical properties of sea water. Certain parts of the Gulf of Thailand especially in the proximity of river mouths and shallow coastal zones belong to Case 2 water in which other substances such as suspended sediment and color dissolved organic matter may significantly contribute to the signal detected by the sensor. Thus the estimation of absolute value of chlorophyll_a concentration in the Gulf is likely inexact. However if we restrict our interest to variation of chlorophyll_a concentration, features emerging from those images could provide important clues on circulation pattern in the Gulf.

Tongues of high chlorophyll_a coastal water extending westward from the eastern sea board could arise from cyclonic gyre in the northeast monsoon season when encountered with the coast created turbulence. In case there was a river runoff from coastal area drained into this zone, such turbulence could entrain chlorophyll-rich or suspended matter-rich water further west from the coast and vice versa in the southwest monsoon season.

These findings agreed with previous study indicating that sediments accumulated in the two area namely the central part of the upper gulf and around Samui island were rich in particulate contents (Chareonpanich and Seurungreong, 1999). Stansfield and Garret 1997 argued that the Mekong run-off might enter the Gulf either as a coastal jet around Cape Camau or horizontal eddies. From ocean color images plume extending from the mouth of the Mekong were clearly seen all year.

However satellite observation restricted us to only surface manifestation of processes. As Snidvongs *et al*., 1995 pointed out that the chlorophyll maximum located at or below the pycnocline with up to 10 times higher concentration of that at sea surface. This could render our application of ocean color to study circulation in the Gulf apart from high frequency of cloud cover over the area. Integration of different observation platforms as well as different techniques such as numerical modeling are required in order to get four-dimensional perspective of circulation in the Gulf.

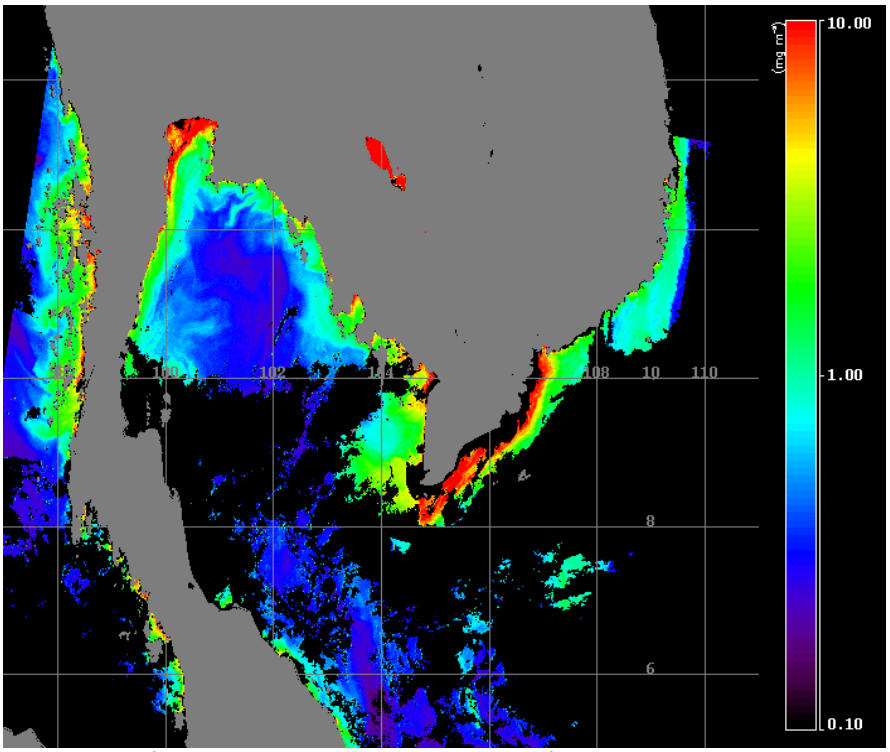

Figure 1: Image of chlorophyll_a concentration derived from SeaWiFS on 5 November 2000.
Note tongues of chlorophyll_a rich coastal water extending from the eastern sea board of Thailand.

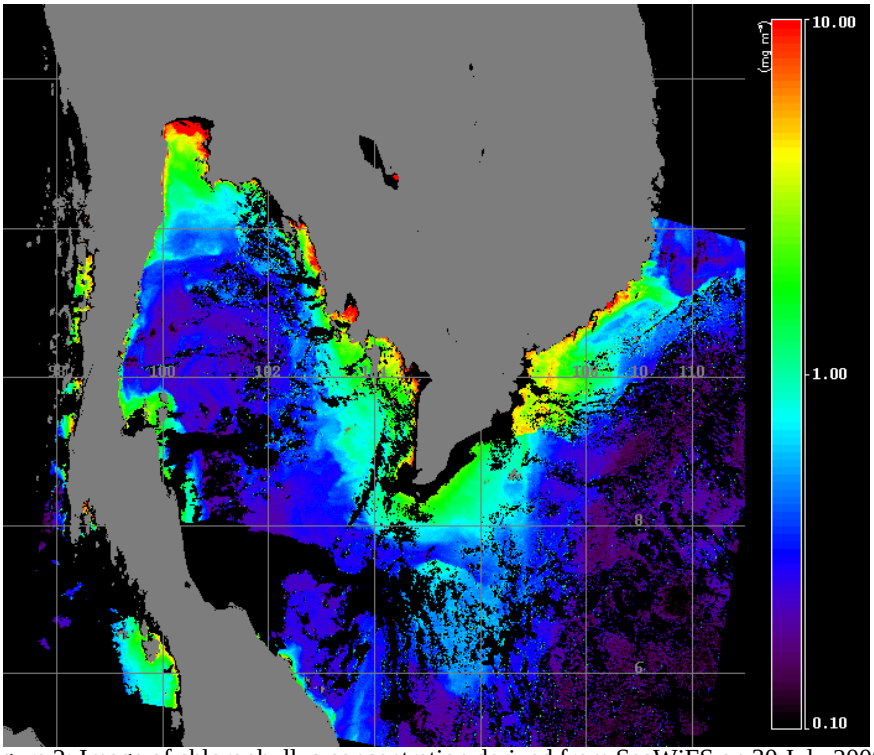

Figure 2: Image of chlorophyll_a concentration derived from SeaWiFS on 30 July 2000.
Note the extent of the Mekong river plume.

CONCLUSION

Ocean color data from SeaWiFS covering the area of the Gulf of Thailand from September 1999 to February 2001 were processed to images of chlorophyll_a concentration. There were four areas where water exhibited high chlorophyll_a concentration namely, the Inner gulf, the eastern sea board of Thailand, Samui island and Cape Camau. Interesting features including tongues of coastal water. Interaction of general circulation with the coastline and topography could generat such features. The images also showed the influence of the Mekong river to the Gulf of Thailand.

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