OCEANOGRAPHIC EVENTS AT NORTHERN BORNEO AND THEIR RELATIONSHIP TO HARMFUL ALGAL BLOOMS

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ABSTRACT

The west coast of Northern Borneo is strongly influenced by Asian monsoon. Present research using the satellite ocean color (OC) remote sensing has identified some interesting oceanographic phenomena in this area that could be related to the harmful algal blooms (HAB). Occurrence of seasonal upwelling event was noticed off the northern tip of Borneo Island that could be related to the northeast monsoon wind. Harmful algal blooms by *Pyrodinium bahamense var. compressum* occurred since 1976. Subsequently, during December 2003, there was a report of new HAB by *Cochlodinium polykrikoides* in Northern Borneo. Analysis of OC images revealed that the *Cochlodinium* bloom had very high chlorophyll a signal and strong absorption characteristics. Results showed that the Baram River plume and upwelling at Northern Borneo were the source of nutrient for the *Cochlodinium* bloom in the offshore region. Ocean color images of 2004 showed that the bloom from Northern Borneo had crossed the Balabac Straits, reaching Palawan Island in Philippine. Due to the possibility of transboundary HAB problem, we propose a regional HAB monitoring network for an effective HAB management.

KEY WORDS: Borneo, upwelling, river plume, ocean color, harmful algal bloom

1. INTRODUCTION

1.1 Northern Borneo

Borneo Island located at the Southeast Asian region which is the third largest island in the world. It is the land to the world's second largest rainforest. Borneo Island is administratively divided by Malaysia, Brunei and Indonesia. It is strongly influence by the Asian monsoon, namely northeast monsoon (November – February) and southwest monsoon (May – August). During northeast monsoon (southwest monsoon), the northeasteries causes the surface current to move into southwest direction (northeast direction). However, the coastal oceanography condition is unclear for Northern Borneo as there are very limited oceanographic studies in this area.

1.2 Harmful Algal Bloom at Borneo

Occurrence of harmful algal bloom (HAB) or red tide at Northern Borneo started since 1976. The HAB event is caused by *Phyrodinium bahamense var. compressum*, which could cause Paralytic Shellfish Poisonings (PSP). The most serious PSP outbreak occurred in 1976 that resulted in 202 PSP cases and 7 deaths (Puyong et al., 1999). In early 2005, one PSP fatality case was reported in Sabah, Malaysia. The *Phyrodinium* blooms that occur two times per year are coincided with the onset of monsoon wind (Usup et al., 1989). Azanza and Taylor (2001) found that the *Phyrodinium* bloom could be related to El-Nino event.

During late 2003, another dinoflagellate blooms, caused by *Cochlodinium polykrikoides*, was noticed off Northern Borneo. In Japan and Korea, bloom of *Cochlodinium* has caused severe damage to fisheries during summer and fall. Studies in eastern Asia found that the optimum conditions for *Cochlodinium* bloom to be of salinity 32-34 psu, temperature 25-28^{o}C, and good sunlight (NOWPAP CEARAC, 2006), which are very similar to the oceanographic conditions in Borneo. However, the study on *Cochlodinium polykrikoides* in Southeast Asia has just started and not much information was available for this species. The *Cochlodinium* bloom was suspected to be originated from water ballasting activities, however, latest DNA analysis showed the species bloom in Northern Borneo is independent from the species in Korean or Japanese waters (Mitsunori Iwataki, personal communication).

1.3 HAB Monitoring Using Ocean Color Remote Sensing

Harmful algal bloom monitoring program at Northern Borneo have been initiated by the fisheries authorities in Brunei and Sabah. Routine sampling at selected location are carried out to identify the *Phyrodinium* cell quantities and measure the level of toxin. If the HAB event and high toxic level is identified, the fisheries authorities will issue the red tide warning. In Brunei, the Department of fisheries will activate the National Red Tide Action Plan. However, the in-situ sampling method are very resource consuming, and unable to provide synoptic view of the HAB event. This study is aimed to examine the potential of

satellite remote sensing in assisting the red tide monitoring program.

The effort of HAB monitoring using MODIS Aqua satellite for Northern Borneo started since early 2004. It is working on the voluntary basis. Daily MODIS Aqua images are processed and distributed to local authorities in Sabah, Sarawak and Brunei. Besides, the product will also been uploaded to the "Ocean Color Satellite Observation of Borneo Red Tide" website (http://sg.geocities.com/myredtide/Index.htm). The reports from this satellite monitoring effort have been used as additional information for the HAB monitoring program.

2. MATERIALS AND METHODS

Daily Level 2 MODIS Aqua chlorophyll a (chl-a), sea surface temperature (SST) and normalized water leaving radiance at 551 nm (nLw 551) images were downloaded from Ocean Color Web (data available at http://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sen=am). The imageries are processed by using SEADAS software (Software available at http://oceancolor.gsfc.nasa.gov/seadas/). Later, they are distributed to local authorities in Northern Borneo, and uploaded to the website.

Due to the chl-a over-estimation problem by the MODIS algorithm in turbid waters, the nLw 551 image is used to identify the turbid water areas, especially near the Baram River mouth. Besides, MODIS 250m true color RGB image are being processed using HDFLook software (Software available at http://www-loa.univ-lille1.fr/Hdflook/hdflook_gb.html) for the additional reference to the Level 2 MODIS Ocean Products.

3. RESULTS AND DISCUSSIONS

3.1 Seasonal Upwelling off Northern Borneo

Our results showed that there was a seasonal upwelling phenomenon at the northern tip of Borneo Island, which could be possibly caused by the alongshore northeast monsoon wind. Cooler upwelling water (about 25.5^{o}C) from the northern tip that extended toward the west is associated with higher surface chl-a (figure 1 top and bottom). The nutrient supply from the upwelling water is expected to be the main source that supporting the bloom of phytoplankton. We speculate that this upwelling event is related to the offshore phytoplankton bloom and the continuing occurrence of HAB along northwestern Borneo during northeast monsoon. Higher nLw 551 was observed within the cooler upwelling water that could indicate the high density of phytoplankton cells (figure 2 middle).

In February 2005, we noticed that the upwelling was more intensified than other years. Isoguchi et al. (2005) revealed that wind jet formation off Northern Borneo will lead to offshore cooling and chl-a bloom during the subsequent El-Nino years. The strong upwelling in early 2005 could be attributed to the wind jet. However, detail study is needed to identify the upwelling mechanism at the Northern Borneo during northeast monsoon.

3.2 Baram River Plume

The changing direction of Baram River plume is an interesting phenomenon in Northern Borneo. It shows the interaction between the wind and the surface current along west coast of Borneo. With the along shore wind blowing towards the southwest (northeast) direction during northeast (southwest) monsoon, the river plume is drifted towards the same direction. However, the prominent direction of the coastal current during different monsoon might change under certain circumstances.

During early January 2005, the Baram river plume was observed drifted towards northwest direction (figure 2). One week later, high chl-a extended from the Baram River plume moved toward northeast direction when the changing of coastal current occurred. The extension of this high chl-a water was found to be more than 200 km on 9-16 January 2005. The nutrient supply from river plume could sustain the long spreading of the high chl-a patches. The high chl-a patches found to be intensified when it met with the high chl-a upwelling water off shore on 17-24 January 2005. The high chl-a patches further spread into the Spratly Island region.

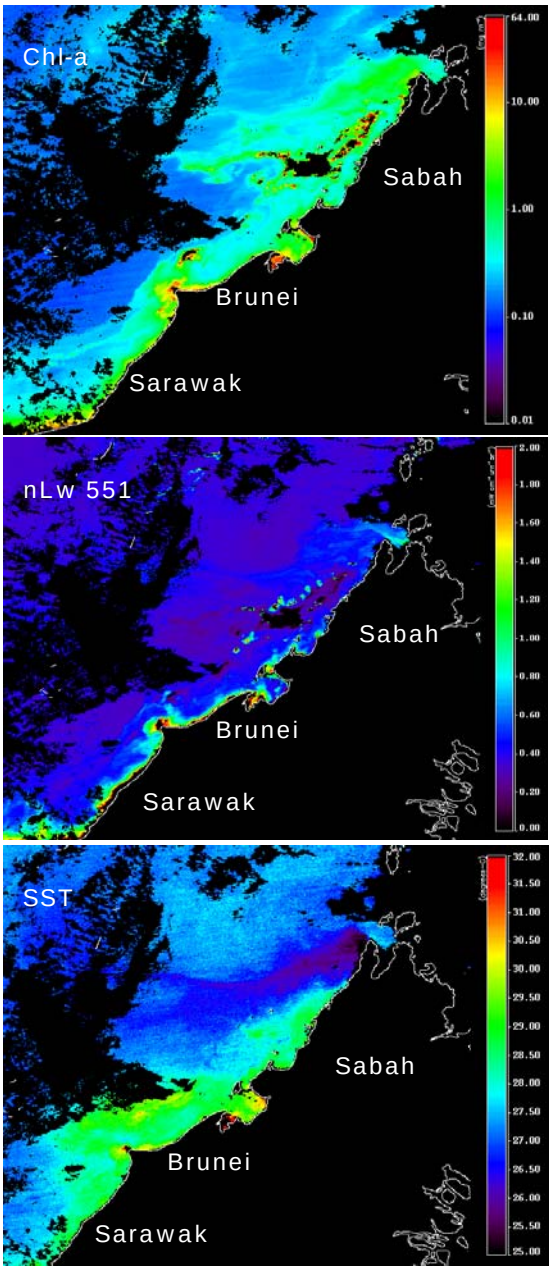


Figure 1. Daily MODIS Aqua chl-a (top), nLw 551 (middle) and SST (below) on 14 February 2005.

The mechanism of the reverse direction of Baram River plume needs more examination. We suspect that it could be related to the weakening of northeast monsoon winds or the anti-cyclonic circulation between the Borneo and Vietnam. With the continuing nutrient supply from the Northern Borneo upwelling water, the high chl-a patches from Baram River plume can maintain at the off shore region for a long period.

The extension of off shore high chl-a patches from Baram River plume had only been observed since 2004 that coincided with the new *Cochlodinium* bloom. We suspect that these phytoplankton blooms could be caused by *Cochlodinium polykrikoides*. Unfortunately, due to the limited observing stations that located along the coastal water, there was no available scientific evidence of HAB or decolourization report at the high chl-a patches off shore. Unofficial report from Sarawak, Malaysia, shows that there was red tide at 25 nm off the coast of Miri during March 2004. We speculate that the high chl-a patches off shore could be HAB.

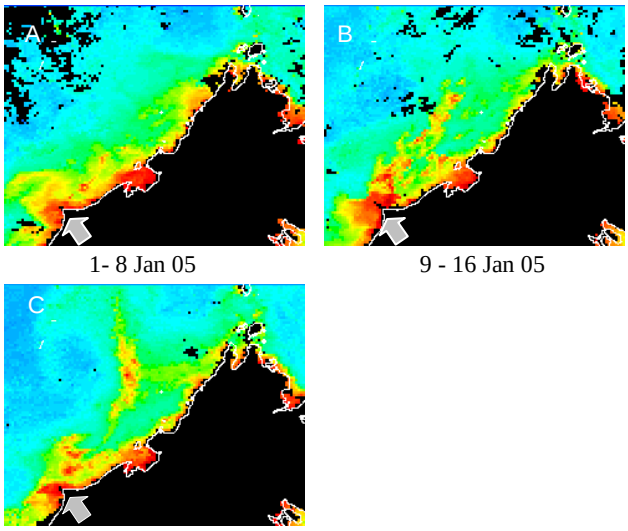


Figure 2. 8 days composite of MODIS Aqua chl-a images show changes of Baram River plume direction during 1 - 24 January 2005. Baram River mouth is pointed by grey arrow.

3.3 Strong Absorption of HAB

MODIS Aqua chl-a images showed high chl-a concentration for Baram River plume, Brunei bay, as well as potential red tide area (figure 3A). However, high chl-a area in ocean color images sometimes are not representing the actual chl-a concentration in the coastal areas, especially in Brunei Bay and Baram River plume, attribute to the influence of suspended sediment and/or yellow substances. The chl-a concentration at these areas is expected to be over-estimated.

By using the normalized water leaving radiance (nLw) data, especially nLw 551, we can examine the possibility of chl-a over-estimation in turbid water. When the non-organic suspended material is high, the nLw spectral will show peak reflectance at nLw 531 or 551 as the Baram River plume and Brunei Bay spectral pattern shown in figure 3B. The clear off shore water has high reflectance at lower wavelength at nLw 412 and 443, and low at nLw 551 (figure 3B). Light spectral of potential red tide area has very low nLw 551 as the off shore water, however, there are strong absorption at shorter wavelength (nLw 412-531) (figure 3B).

We noticed that some of the high chl-a areas below the cool upwelling water in the standard daily MODIS Aqua L2 image were masked due to very low nLw (figure 2). By examining the chl-a in surrounding masked areas, we found that the chl-a was about 30 mg m^{-3} which could possibly be the red tide areas (figure 3A). Further analysis at these offshore high chl-a patches showed very low nLw 551 (figure 3B). These off shore high chl-a waters could possibly been discoloured. Analysis on MODIS 250m RGB image also showed darker color at these strong nLw 551 absorption areas after applying enhancement on the image (not shown). More study is needed in order to determine the optical characteristics of HAB in Northern Borneo.

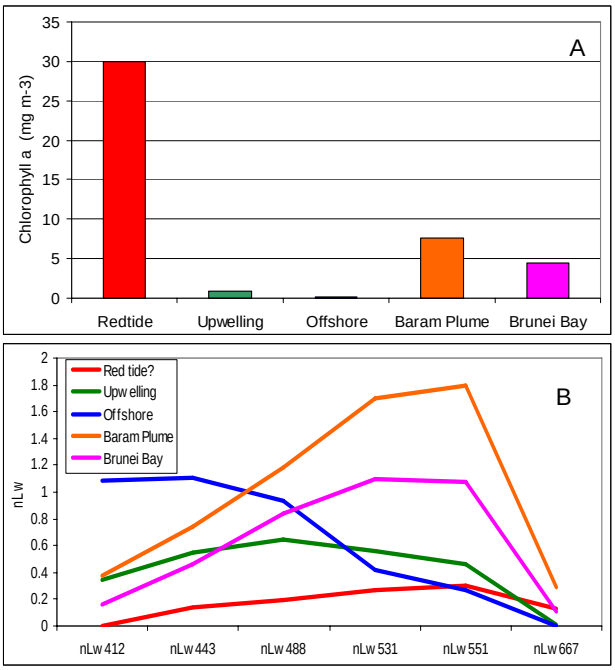
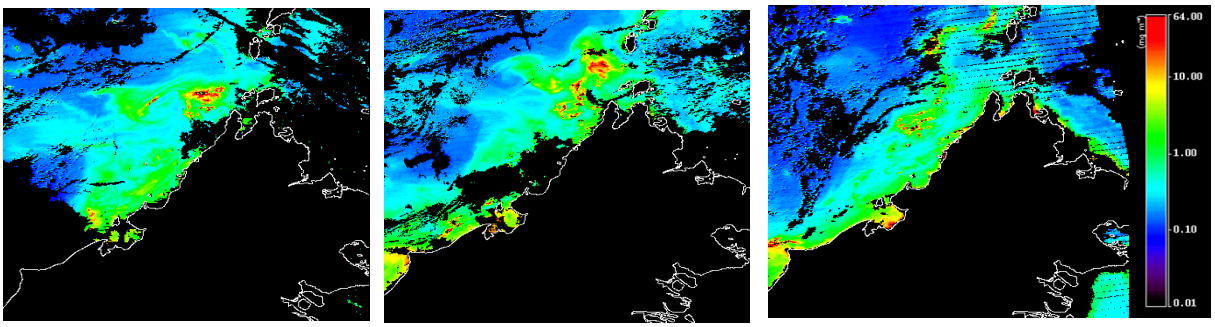


Figure 3. MODIS Aqua chl-a (A) and nLw spectral (B) for upwelling region, off shore water, Baram River plume, Brunei Bay and potential red tide area.

3.4 Transboundary HAB

Previously, the HAB event in Northern Borneo was believed to spread by the current from Sabah, Malaysia to Brunei during northeast monsoon. Through the continuous satellite monitoring, we discovered that it could actually spread into northeast direction towards Philippine. In mid of February 2004, a large patch of high chl-a was observed off the upwelling area at Northern Borneo (figure 4). The patches moved northward towards the Balabac Straits a few days later. After a week (21 February 2004), the high chl-a patches reached Palawan Island at Southern Philippine.

Field monitoring at Palawan confirmed the occurrence of *Cochlodinium* HAB in the boundary between Palawan and Sabah in January 2005 (Azanza and Baula, 2005). Some fishermen in Palawan witnessed a red discoloration off the Quezon water with dense floating algae. The *Cochlodinium* HAB had caused fish kill in Palawan Island in 2005. The bloom was believed to be originated from Malaysian waters following the circulation pattern during northeast monsoon (Azanza and Baula, 2005).



13 Feb 04 16 Feb 04 21 Feb 04

Figure 4. Transboundary harmful algal bloom.

4. CONCLUSION

The HAB monitoring using satellite ocean color remote sensing at Northern Borneo showed some interesting findings that could be related to the HAB events. However, more oceanographic studies is needed in order to understand the mechanism oceanographic event on the HAB. Due to the possibility of transboundary HAB event at Northern Borneo, we recommended for a regional joint monitoring effort. Besides, we suggest that the offshore oil and gas platform off Northern Borneo to be incorporated in the red tide monitoring program for the monitoring of offshore red tide. By the combination of remote sensing and the in-situ observations at both coastal and offshore areas, it will help to establish an effective HAB monitoring and early warning system.

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