Monitoring Harmful Algal Blooms in Singapore: Developing a HABs Observing System

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Abstract— **The increase in frequencies and the noxious effects of HABs in global coastal waters have led to enhanced interest in monitoring and detecting of such blooms. In December 2009, a toxic bloom hit Singapore waters along East Johor Strait causing massive fish kills and great economic losses. Interdisciplinary approach involving robotic network adaptation, multi-scale-sensing using autonomous vehicles and in-situ and real time multidisciplinary data acquisition using unmanned and wireless network was utilized to study and monitor HABs in Singapore waters. The present study managed to collect high spatial resolution data using ASV around station S2 located at Johor Strait. Distinct biological and physical patterns were observed from the data collected from the ASV. Low salinity was observed near the mouth of the reservoir, and the salinity increased with increasing distance from the reservoir mouth. In contrast, high phytoplankton biomass was observed near the reservoir mouth, while lower concentration was found further away from the mouth. This information could assist in defining bloom parameters and enhance our ability in determining and detecting pre-bloom condition. In addition, the ASV platform used in this study could assist in collecting high spatial resolution data set, which was not possible with point sampling. The information provided by the present study can assist in refining of bio-optical models for detecting and monitoring of HABs.**

Keywords-absorption, CDOM; harmful algal blooms; massive fish kills; optical properties; salinity; Singapore

I. Introduction

Harmful algal blooms (HABs) are increasing problems in coastal and estuarine environments particularly those caused by toxic dinoflagellates. Toxic bloom-forming species are a causative organism for shellfish poisoning and fish kills, and they can cause significant damage in coastal areas. Moreover, the magnitude and the duration of a bloom may also determine the degree of impact on a coastal ecosystem [1]. These detrimental events in coastal waters have led to enhanced interest in monitoring and detecting of such blooms.

In Southeast Asia, many regions are affected by regular HABs occurrence. In Singapore, there were several reports of massive death of marine life, probably caused by algal blooms. In December 2009, a toxic bloom hit Singapore waters along East Johor Strait causing massive fish kills and great economic losses [2]. Detecting and monitoring of algal blooms in these waters are essential to describe the trends of blooms, and thus providing a means for protecting commercial aquacultures and public health.

The specific causes of HABs are complex, and they vary between species and locations, and are not all well understood. The detection and monitoring of HABs in the tropical Southeast Asian regions is challenging due to regular eutrophication events and high levels of sediments in the water column. These characteristics make traditional optical and satellite detection methods unreliable. However, in recent years, technological developments of optical techniques have been shown to be a promising means of detecting HABs. Moreover, these methods need to be evaluated and optimized for use in the eutrophic coastal waters typically found around Asian coastal cities.

Johor Strait, Singapore is characterized by large terrestrial inputs resulting in significant eutrophication and high phytoplankton biomass. Multidisciplinary data and high spatial resolution data sets are essential to observe the oceanographic processes and dynamics of algal blooms in this area. In the present study, interdisciplinary approach was utilized to study and monitor HABs in Singapore waters. The focus of the present study was to develop mobile sensor networks for monitoring HAB events, formation and the biology of bloom-forming species in Singapore waters.

II. Materials and Methods

A. *Interdisciplinary Approach*

The present study used a tiered adaptive network for multi-scale sensing. Our approach involves robotic network adaptation, multi-scale-sensing using autonomous vehicles and in-situ and real time multidisciplinary data acquisition using unmanned and wireless network. The network consists of ships, fixed instruments, and autonomous vehicles (unmanned aerial vehicle (UAV), autonomous surface vehicle (ASV), autonomous underwater vehicle (AUV).

B. *Study Areas*

Sampling locations along Johor Strait Singapore (fig. 1 & 2) are selected based on some known HABs favourable pre-

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conditions and conditions. Conditions include areas with possible nutrient input from terrestrial sources, freshwater input and areas with minimum water movement.

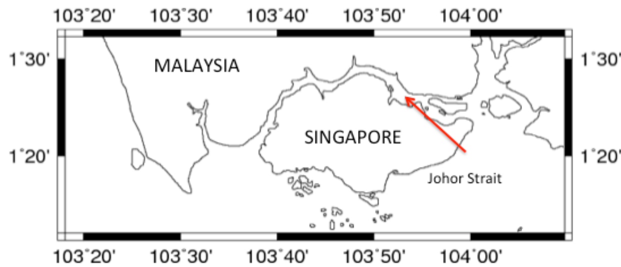

Figure 1. Map of Singapore.

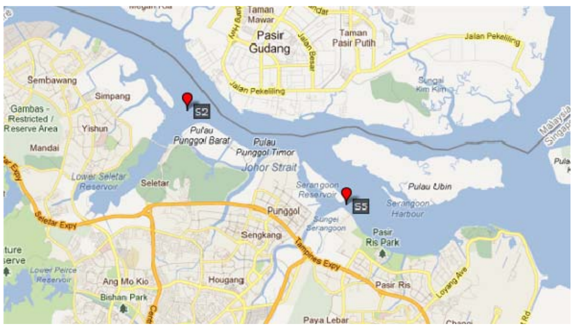

Figure 2. Sampling stations along Johor Strait, Singapore. (Map of Johor Strait Singapore, retrieved on Jan 8, 2012 from website www.gpsvisualizer.com)

C. Data Collection and Measurements

Tiered adaptive network for multi-scale sensing was used to measure environmental parameters. Areas around a targeted station or area was monitored using UAV. After confirmation by the UAV, path planning for ASV and AUV were done on ship. Then the ASVs and AUVs mounted with multiples sensors were deployed accordingly for data collections. Experimental trials were conducted every six months from Dec 2010 to Jan 2012. The following parameters; temperature, salinity, chlorophyll (chl)-*a* and dissolved oxygen were measured.

Time series measurements were conducted from Sept 2010 to Jan 2012 at station S2 to S5 along East Johor Strait, Singapore (Fig 2). Physical parameters were measure at site. Sea water samples for nutrients, pigments (chl-*a*) and colored dissolved organic matter (CDOM), were collected from the surface water a clean bucket.

D. Data Preparation and Analysis

Contour maps are created using ocean data view [3].

III. Results and Discussions

During the Jan 2012 experimental trial, we managed to successfully improve the path planning for ASV's mission as compared to the Jun 2011 trial (Fig 3). With the improved path planning and enhanced ASV's performance, we could collect high-resolution spatial distribution of environmental parameters and biological data such as phytoplankton biomass.

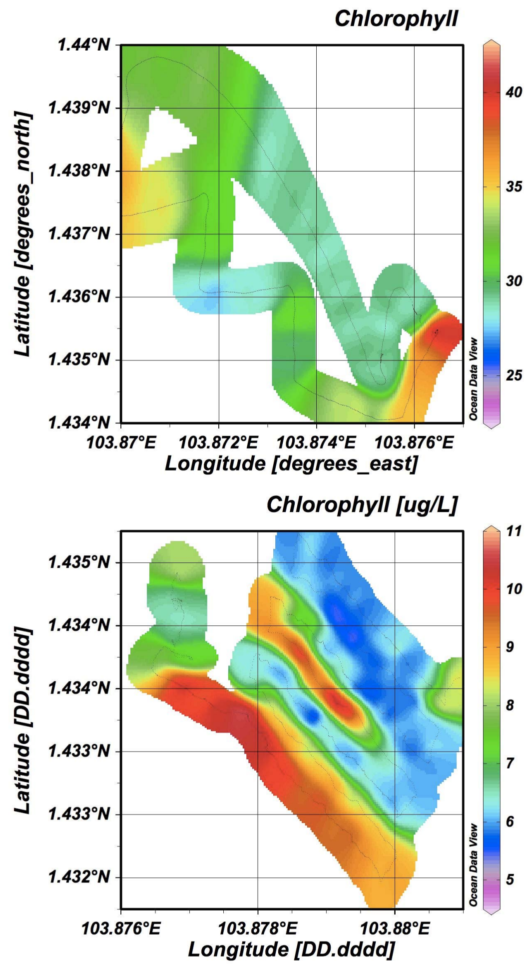

Figure 3. Sampling stations along Johor Strait, Singapore. (Map of Johor Strait Singapore, retrieved on Jan 8, 2012 from website www.gpsvisualizer.com)

During the Jan 2012 trial, on Jan 4, we observed that the salinity was lower at the outlet of the Seletar Reservoir (Fig. 2) compared to salinity measured further away from the reservoir outlet (Fig. 4). On the contrary, biomass as indicated by chl-*a* concentration showed a decreased in concentration with increasing distance from the reservoir's outlet (Fig. 4). A significant relationship between salinity and chl-*a* was found at S2 and other stations along the East Johor Strait (Fig. 5). Similar trend between salinity and chl-*a* was also observed from phytoplankton assemblage from other study areas [4-5]. This observation suggests that salinity might be an important factor regulating the phytoplankton biomass in Johor Strait, Singapore. The salinity level might also affect the phytoplankton communities, and thus, it should be considered when monitoring and detecting HABs in Singapore waters.

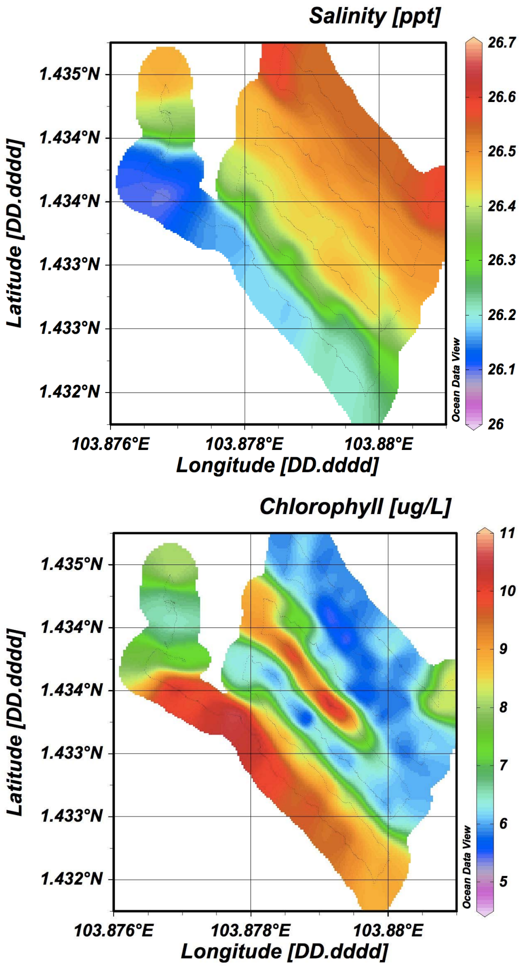

Figure 4. Spatial observation of salinity and chlorophyll-*a* at S2 along East Johor Strait Singapore.

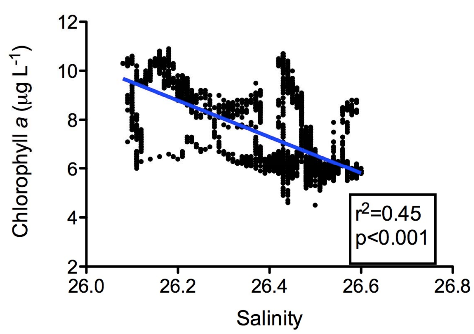

Figure 5. Relationship between salinity and chlorophyll-*a* at S2 along East Johor Strait Singapore.

On Jan 17th, the spatial data was collected nearer to the eastern side of Seletar Island and closer to the outlet of Seletar Reservoir when compared to Jan 4th. Towards the reservoir's outlet, increased in sea surface temperature (SST) and decreased in salinity were observed. As a result, high biomass concentration was found towards the reservoir (Fig. 6), similar to those results observed on Jan 4th.

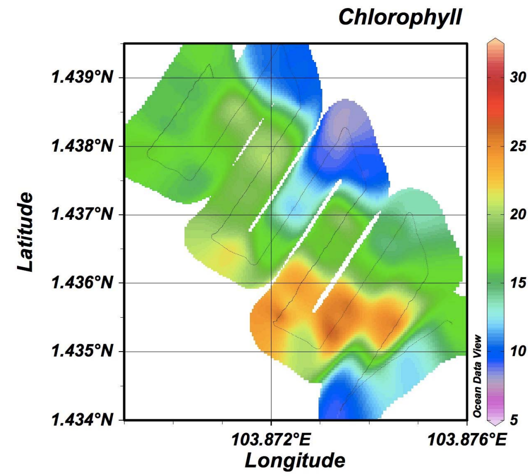

Figure 6. Spatial observation of chlorophyll-*a* at S2 observed on Jan 17th.

The hydrographic conditions of the strait are mainly affected by the northeast and southwest monsoons [6]. At a smaller scale, the semi-diurnal tides are the dominant factor controlling the hydrology of Johor Strait. Johor Strait receives inflow during flood tide from the far eastern side of the strait and vice versa.

On the 18 of Jan, we conducted measurements at different tide i.e. ebb tide vs. flood tide. During ebb tide, narrower range of variability in both environmental parameters and biological measurement were observed (Fig. 7). On the other hand, during flood tide, larger range of fluctuation in parameters was observed (Fig. 7). For example, the chl-*a* concentration was found to differ around two times between ebb and flood tide (Fig. 7). These observations showed that data collected by traditional method of point sampling at a station in an area could not be used to represent the data in an area. We need high-resolution spatial data in order to determine the range of variability of a parameter within a targeted area. We also showed that the timing of data collection is very important. For instance, the type of tide should be considered in area with tidal currents when collecting data.

Low salinity and high CDOM might be some of the conditions necessary for high phytoplankton biomass to develop in East Johor Strait. Although, such phenomenon along the Johor Strait was observed, more data and more works are necessary to confirm the pre-conditions of algal bloom especially toxic algal blooms in Singapore waters.

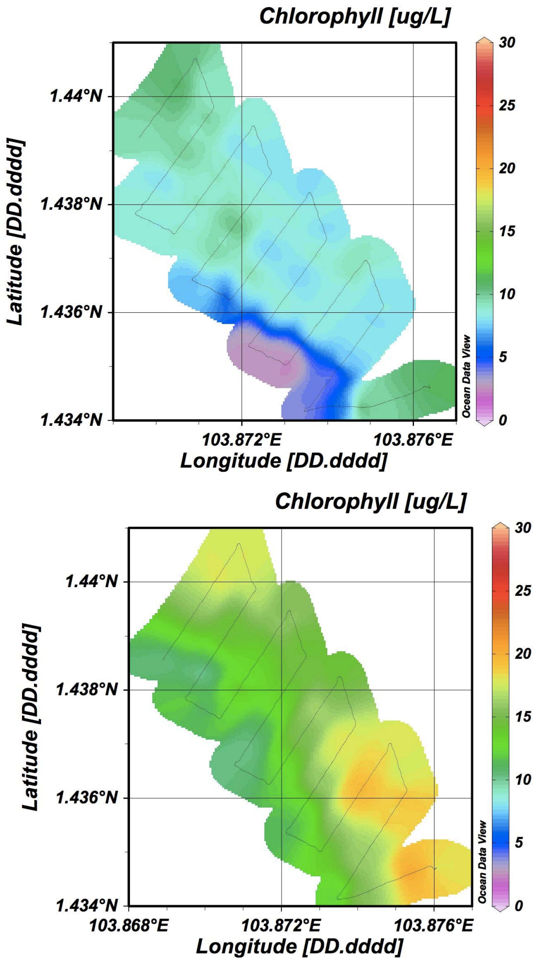

Figure 7. Spatial distribution of chlorophyll-*a* at S2 between ebb tide (top) and flood tide (flood).

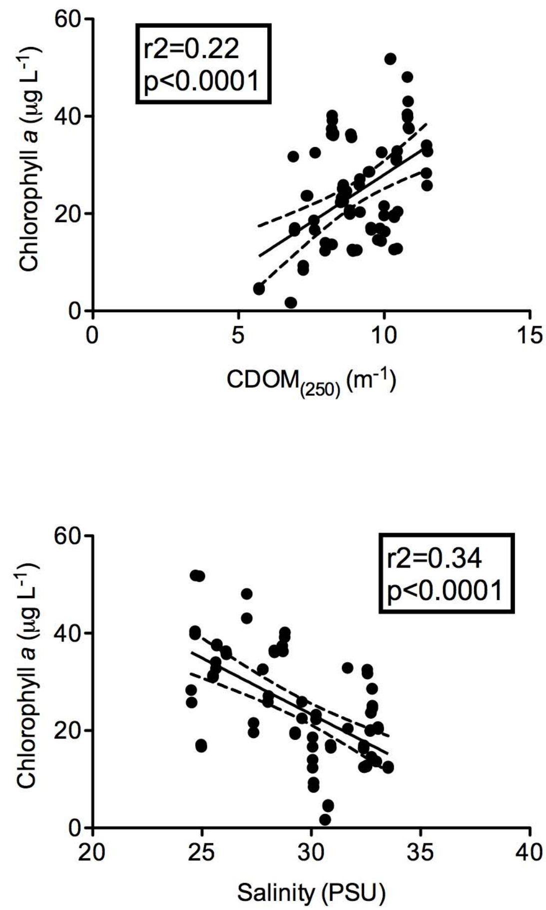

Figure 8. Relationship of between CDOM absorption and salinity and chlorophyll-a in East Johor Strait.

As for the time series experiments, during the sampling period, we found that the concentration of colored dissolved organic matter (CDOM) in the Johor Strait were very high in East Johor Strait as shown by the indicative index *CDOM*(250). CDOM is known as the main absorber of sunlight and a major factor determining the optical properties of coastal waters. CDOM can also serve as a source of nitrogen in marine waters. The CDOM concentration is high in general compared to other areas such as the Singapore strait. We also found significant relationships of between CDOM and chl-*a* and salinity along the East Johor Strait (Fig. 8). The quantity of CDOM showed a negative relationship with salinity (i.e. high concentrations were observed at low salinity). This phenomenon was consistent with the observation found in other studies [7]. This is because high CDOM is usually associated with low salinity and CDOM is normally originated from freshwater sources.

IV. CONCLUSION

Circulation patterns driven by tides play an important role in determining the distribution of phytoplankton biomass and other environmental parameters along Johor Strait.

Variability in the biomass along Johor Strait could be determined by environmental parameters such as salinity and CDOM.

East Johor Strait is a very unique region to study the dynamics bloom-forming species and their blooms. This region is extremely rich in organic matter as shown in the present study. The observed variability of environmental parameters in the present study suggested that the condition of this coastal system is subjected to multiple influences such as the input of terrestrial sources, atmospheric conditions, and tidal currents.

This coastal system is still not fully explored and in order to characterize the habitats, species and biological communities, living and non-living resources and their inter-relationships, significantly extensive knowledge is necessary. Characterization of these parameters in Johor Strait could assist in the identification of trends, and the estimation of short and long-term implications of such changes for the environment and society. Moreover, such information could assist in detecting and mitigating HABs. With more data, algorithm could be fine-tuned to provide a means to interpret field populations and enhance the capability for detecting harmful species. With evolving technologies and the accuracy of bio-optical instruments improving, the spatial and temporal characterizations of HAB dynamics could be possible.

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REFERENCES

[1] S.C.Y Leong, M. Maekawa, and S. Taguchi, “Carbon and nitrogen acquisition by the toxic dinoflagellate *Alexandrium tamarense* in response to different nitrogen sources and supply mode,” Harmful Algae, vol 9, pp. 48-58, 2010.

[2] C. Quek, and J. Lim, “Plankton bloom causes losses reaching hundreds of thousands of dollars,” Straits Times, 1 January 10, 2010. Web site: http://wildsingaporenews.blogspot.com/2010/01/200000-fish-in-farms-off-pasir-ris-dead.html.

[3] R. Schlitzer, Ocean Data View, 2012. http://odv.awi.de.

[4] K. Härnström, I. Karunasagar, A. Godhe, “Phytoplankton species assemblages and their relationship to hydrographic factorw-a study at the old port in Mangalore, coastal Arabian Sea,” Indian J. Mar. Sci., vol 28, pp. 224-234, 2009.

[5] A.M. Marcarelli, W.A. Wurtsbaugh, O. Griset, “Salinity controls phytoplnkton response to nutrient enrichment in the Great Salt Lake, Utah, USA,” Can. J. Aquat. Sci., vol 63, pp. 2236-2248, 2006.

[6] P. Tkalich, and P. Sundarambal, “Eutrophication modelling for Singapore waters,” Singapore Maritime Port J., pp. 122-136, 2003.

[7] B. Nieke, R. Reuter, R. Heuermann, H. Wang, M. Babin, and J.C. Therriault, “Light absorption and fluorescence properties of chromophoric dissolved organic matter (CDOM), in the St. Lawrence Estuary,” Cont. Shelf. Res., vol 17, pp. 235-252, 1997.