Paper presented at 28th International Symposium on Remote Sensing of Environment, 27 - 31 March, 2000, Cape Town, South Africa.

Tropical algal bloom monitoring by sea truth

Soo Chin Liew[(a)], I-I Lin[(a)], Hock Lim[(a)], Leong Keong Kwoh[(a)], Michael Holmes[(b,c)], Serena Teo[(c)], Siong Teck Koh[(d)] and Karina Gin[(d)]

[(a)]Centre for Remote Imaging, Sensing and Processing, [(b)]Department of Biological Sciences, [(c)]Tropical Marine Science Institute, and [(d)]Department of Civil Engineering
National University of Singapore, Kent Ridge, Singapore 119260
email: liew_soo_chin@nus.edu.sg

Abstract - In-situ spectral reflectance of sea waters were acquired using a hand-held spectroradiometer during a series of sea-truth water sampling campaigns carried out in the Johore Strait, Singapore from Dec 1996 to Dec 1998. One field trip has also been carried out in Manila Bay, Philippines during an episode of harmful algal bloom in September 1998. The reflectance spectra were collected together with coincidental measurements of water quality parameters, such as the total suspended solid (TSS) and the chlorophyl-a (Chl-a) loadings. Phytoplankton cell counts and species identification were performed. Results of spectral analysis using the singular value decomposition technique show that, it is possible to distinguish different phytoplankton bloom types using the reflectance spectra.

INTRODUCTION

In the ocean, phytoplantons (or algae) constitute the base of the marine food web. Phytoplanton concentration is correlated to the ocean primary production. The identification and monitoring of phytoplankton concentration are often considered as a viable means to locate new fishing grounds. However, certain types of algae blooms are not beneficial. The terms 'Harmful Algal Bloom' (HAB) or 'Red Tides' are often used to describe algal blooms which cause negative impacts to humans[1, 2]. Algal blooms may cause harm by shading other aquatic life. When bloom collapses, the microbial respiration on the dead and decaying cells can lead to reduced oxygen concentrations that can kill fish and other aquatic organisms due to lack of oxygen. In situation whereby a bloom is dominated by toxic algal species, toxins can be accumulated in the food chain and eventually be consumed by humans to cause paralytic or diarrhetic shellfish poisoning. HABs have caused severe damage to fishing industry and resulted in human casualties.

It is important to monitor occurrences of algal blooms due to their strong social, economic and health impacts. Satellite remote sensing measurement of ocean colour provides a tool complementary to in-situ sea-truth measurements for red tide monitoring, due to its sypnotic coverage, frequent revisit capability and relatively low cost. As the individual phytoplankton pigments are characterised by their unique light absorbance features, detection of specific optical features can discriminate individual pigments[3, 4]. This property allows detection and identification of algal blooms by ocean colour remote sensing technique.

Many factors contribute to the difficulty in monitoring algal blooms in coastal waters. Thousands of algal bloom species exist and algae blooms are usually transient phenomena. In addition, algae blooms co-exist with other constituents in the water body, majority of which are sediments and dissolved organic matter (yellow substance)[4, 5, 6]. The presence of these other constituents may obscure the optical signatures of algal blooms. Due to the complexity of the problem, it is crucial to have large amount of *in situ* sea-truth data to help in the interpretation, calibration and validation of remote sensing data.

In this work, in-situ spectral reflectance data acquired using a hand-held spectrometer during a two-year sea-truth sampling programme[7], mainly in Singapore coastal waters, are analysed. During the two-year campaign, spectral reflectance signatures of seven classes of algal blooms have been collected, including one class collected from the Manila Bay during the HAB episode in September 1997. The preliminary results in the classification of the reflectance spectra using the singular value decomposition (SVD) technique indicate that it is possible to discriminate the different classes of algal blooms from their respective reflectance spectra. The analysis of the spectra provides a basis for classification of the bloom types from satellite ocean colour and hyperspectral reflectance data.

METHODS

The sea-truth water sampling campaigns were carried out from Dec 1996 to Dec 1998. Reflectance spectra were acquired using a portable GER 1500 spectroradiometer. The water quality parameters measued were, among other things, the total suspended solid (TSS), chlorophyll-a (Chl-a), dissolved organic matter (DOM), total phosphate, total nitrogen and plankton cell count.

An algorithm based on the singular value decomposition (SVD) technique[8] was tested for classification of algal bloom types from reflectance data. In this algorithm, for each algal bloom class-i, we seek a key vector $V_i(\lambda)$ such that dot product of $V_i(\lambda)$ with a reflectance spectrum $R_j(\lambda)$

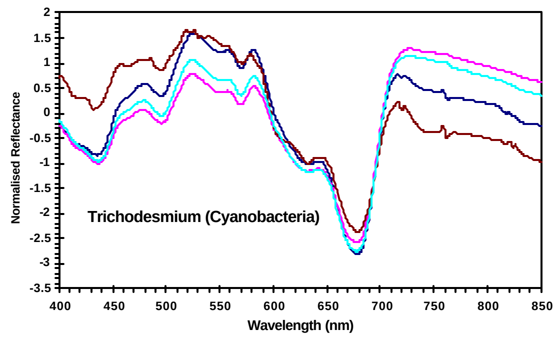

Fig. 1: Representative reflectance spectra of Trichodesmium (cyanobacteria) algal blooms.

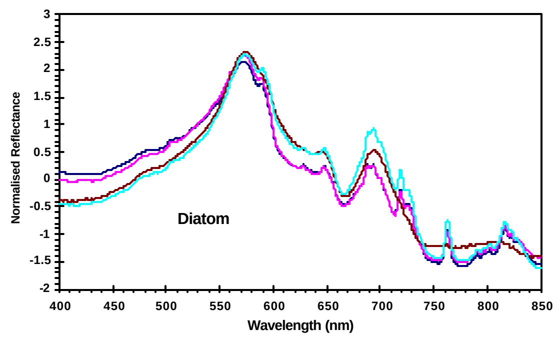

Fig. 2 Representative reflectance spectra of chain-forming diatom algal blooms.

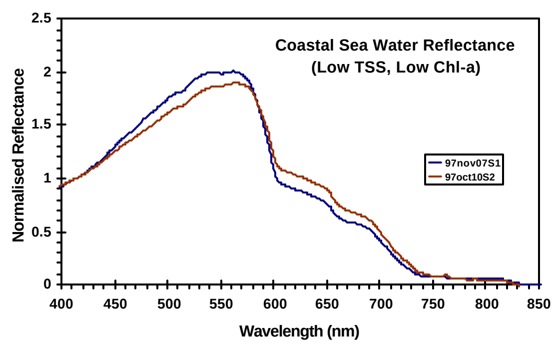

Fig. 3: Representative reflectance spectra of clear reference sea water (low Chl-1, low TSS).

measured for a given algal bloom class-j is one if $j = i$, and zero if $j \neq i$. Using a training set of spectra of known classes, the key vector for each class can be obtained using the singular value decomposition technique. After the key vectors have been determined, they are applied to each of the unknown spectra $R(\lambda)$ to be classified, by forming the dot-product:

$$w_i = \sum_{\lambda} R(\lambda) V_i(\lambda) \quad (1)$$

The dot product w_i is the score value of the reflectance spectrum with respect to class-i. If the unknown spectrum belongs to class-i, then the score value w_i should be a value close to one, otherwise, the value is close to zero.

RESULTS

From the collected reflectance spectra, it is found that different bloom classes are characterised by different spectra shapes. For example, reflectance spectra from Trichodesmium and chain forming diatom classes are shown in Fig. 1 and Fig. 2 respectively. The representative spectra of clear sea water (low chlorophyll-a and total suspended solid content) are also shown in Fig. 3 for comparison.

Trichodesmium is a species of cyanobacteria (blue-green algae). It is commonly found in the region of south east Asia and Australia. Although not a toxic phytoplankton species, it has been reported to cause death of fishes in Thailand, Indonesia, and Malaysia. The reflectance spectra of Trichodesmium bloom shown here waere acquired during a bloom occurring on 30th-31st July 1997 at the off the coast at the eastern part of Singapore. The bloom was characterised by orange-brown patches with typical dimension 0.5m by 5m.The Trichodesnium count was estimated to be 210,000 cells/l. In the spectra of Trichodesmium shown in Fig. 1, the chlorophyll absorption bands at 443 nm and 660 nm can be clearly seen. Another clear trough is found around 490nm corresponding to the pigment absorption.

Chain forming diatom blooms are the most common type of phytoplankton bloom which occurred in the Johor Strait, Singapore. It can be seen that the spectral shape of chain forming diatom bloom (Fig. 2) is very different from those of Trichodesmium (Fig. 1) and clear water (Fig. 3) spectra. Besides the 560nm peak of case II sea water, there is another peak found at around 690nm region. The absorption at 670 nm is clearly visible, but unlike the Trichodesmium spectra, there are no distinct peaks and troughs in other bands.

Results of spectral analysis for algal bloom types classification using various combinations of reflectance difference and reflectance ratio at several wavelength bands have been reported previously[7]. Use of different band combinations results in discrimination of different algal bloom types. Among the nine classes (seven algal bloom classes, two clear water classes), seven classes could be unambiguously separated.

In this paper, the preliminary results of using the singular value decomposition technique in classification of the reflectance spectra are reported. This technique makes use of the information contains in all the available wavelength channels, instead of selecting a small subset of the channels for analysis. Some representative results of classification using this technique is illustrated in Fig. 4. In each panel of Fig. 4, the score values w_i (evaluated using Equation 1) of all the reflectance spectra for all the nine algal bloom classes with respect to a given class-i are plotted.

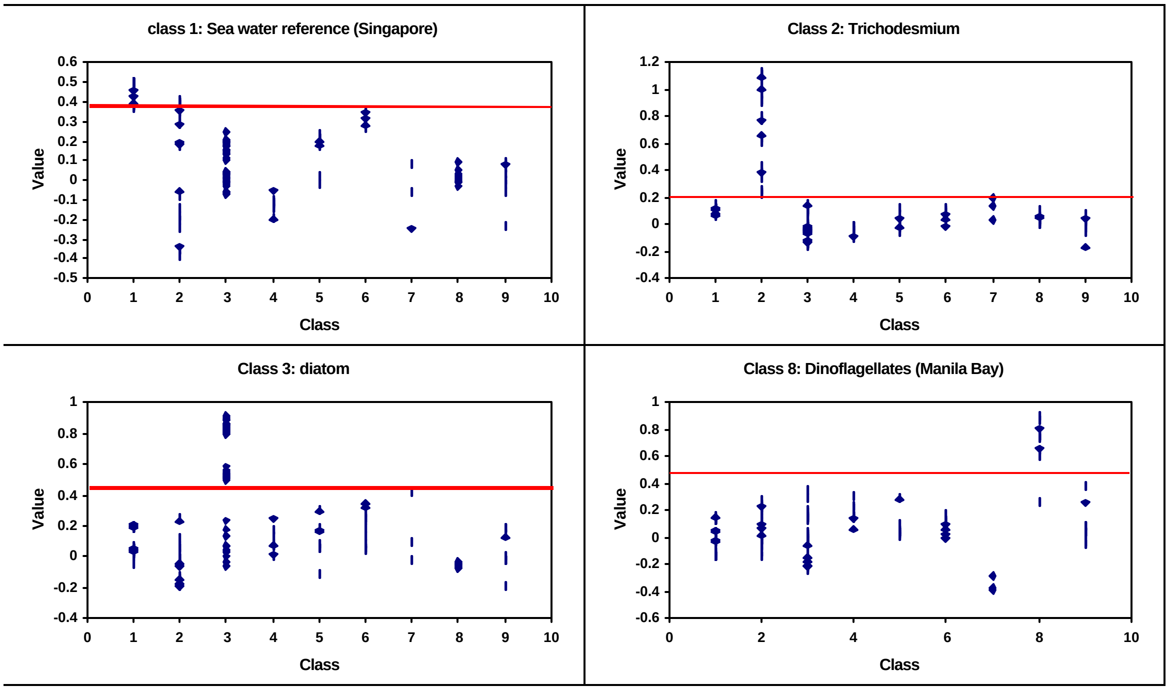

Fig. 4: Results of spectral analysis of the algal bloom spectra using the SVD technique. The nine classes are: 1. Reference sea water (Singapore), 2: Trichodesmium, 3: Diatoms, 4: Mixed diatom and dianoflagellate (high dinoflagellate count), 5: Mixed diatom and dianoflagellate (low dinoflagellate count), 6: Cochlodinium (Dianoflagellate), 7: Armoured Dianoflagellate, 8: Ceratium and Pyrodinium Bahamense (Manila Bay samples), 9: Reference sea water (Manila Bay).

For example, in the top left panel of Fig. 4, the score values of all spectra are evaluated with respect to the key vector for Singapore reference sea water (class-1). By using a threshold value of 0.39, almost all samples from the reference sea water (Singapore) class are correctly classified, while all other spectra except two from class-2 (Trichodesmium) are correctly classified as not belonging to class-1. The top right panel of Fig. 4 shows that all samples are correctly classified with respect to class-2 (Trichodesmium) if a threshold of 0.2 is used. In the bottom left panel, 31 out of a total of 40 spectra from class-3 (Diatom) can be correctly sepecated from the rest. The 9 misclassified spectra were all acquired on the same date, from the same site. On re-examination of the spectra, the shapes of these spectra were found to be visually different from the other spectra. The bottom right panel shows that all except one of the spectra from class-8 (Ceratium and Pyrodinium Bahamense from Manila Bay) are correctly classified. Two other classes (class-7 and class-9, results not shown) are also correctly classified. In summary, six classes (4 algal bloom classes and two reference sea water classes) out of nine can be identified with a reasonably good accuracy. The other three classes show a greater degree of confusion. However, all the seven algal bloom classes can be discriminated from the two reference sea water classes.

DISCUSSIONS AND CONCLUSIONS

Seven types of algal blooms have been observed and studied during the two-year sea-truth campaign. Six of them were observed in Singapore water, while the other one was observed during a field trip to the Manila Bay in September 1997. These algal bloom classes are characterised by different spectral signatures. The peaks and troughs observed in the spectra are related to different phytoplankton properties, e.g., chlorophyll-a absorption, and pigment absorption. A classification algorithm based on the singular value decomposition technique has been tested on the reflectance spectra. Six out of nine classes (including two reference sea water classes) can be identified with good accuracy. All the seven algal bloom classes can be discriminated from the two reference sea water classes. The result suggests the feasibility of detecting and identifying algal bloom types by their reflectance spectra.

The data used in this study belong to the class of hyperspectral data, with spectral radiance measured in 512 wavelength channels continuously from 350 to 1050 nm. Currently, there is no satellite-borne sensors capable of acquiring this type of hyperspectral data though several air-borne hyperspectral imagers are available. Currently, the SeaWiFS sensor on board the SeaStar satellite (launched

October 1997) is the only available satellite-borne ocean colour sensor. It has six bands in the visible region and two in the near-infrared region. Each band has 20 nm bandwidth. The other recent sensor was the OCTS onboard the Japan's ADEOS satellite launched in August 1996. ADEOS ceased operation in June 1997 when the ADEOS satellite stops its operation. It was the first second generation ocean color sensor after the 10 years gap since NASA's CZCS. Future planned ocean colour sensors include the NASA's MODIS, NASDA's ADEOS2-GLI and ESA's ENVISAT-MERIS. Satellites with truly hyperspectral sensors are forthcoming in the near future (e.g. the Hyperion sensor on the planned NASA's EO-1 mission). These future sensors have more wavelength bands with narrower bandwidths. Studies are currently being done to evaluate these ocean colour sensors for their capabilities in retrieval of water quality parameters in coastal waters and algal bloom type classification, using data simulated from the in-situ hyperspectral reflectance data. Further research is in progress to develop various techniques in utilising the spectral information for detection and identification of algal bloom types.

ACKNOWLEDGEMENT

This study was partially supported by the National Space Development Agency of Japan (NASDA) through the joint NASDA-ESCAP project entitled "National capacity building for sustainable environment and natural resources management through research and studies on the uses of ADEOS data". The authors wish to thank Prof. Rhodora Azanza of the Marine Science Institue, University of Philippines, for her assistance during the field trip to Manila Bay.

REFERENCES

1. R. A. Corrales, and E.D. Gomez, *in* Toxic Marine Phytoplankton, pp.453-458, Elsevier, 1990.

2. K. Richardson, K. Harmful or Exceptional Phytoplankton Blooms in the Marine ecosystem. Adv. Mar. Biol. 31, 301-385, 1997.

3. S. Sathyendranath, F. E. Hoge, T. Platt, and R. N. Swift, Detection of phytoplankton pigments from ocean color: improved algorithms, Appl. Opt. 33, 1081-1089, 1994.

4. S. Tassan, Local algorithms using SeaWiFS data for the retrieval of phytoplankton, pigments, suspended sediment, and yellow substance in coastal waters, Appl. Opt. 33, 2369-2378, 1994.

5. S. Sathyendranath, L. Prieur, and A. Morel, A three component model of ocean color and its application to remote sensing of phytoplanton pigments in coastal waters. Int. J. Remote Sens. 10, 1373-1394, 1989.

6. R. Doerffer and J. Fischer, Concentrations of chlorophyll, suspended matter, and gelbstoff in case II waters derived from satellite coastal zone color scanner data with inverse modeling methods, J. Geophys. Res. 99, 7457-7466, 1994.

7. I-I Lin, V. Khoo, M. Holmes, S. Teo, S. T. Koh, and K. Gin, Tropical algal bloom monitoring by sea truth, spectral and simulated satellite data. Proc. 1999 Int. Geosci. Rem. Sens. Symp. Vol. 2, 931-933, 1999.

8. S. Danaher and E. Omongain, Singular value decomposition in multispectral radiometry, Int. J. Remote Sens. 13, 1771-1777, 1992.