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SEAWIFS OBSERVATION OF CHLOROPHYLL DISTRIBUTION IN REGIONAL SEAS

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ABSTRACT: The Centre for Remote Imaging, Sensing and Processing (CRISP) has been receiving SeaWiFS data since September 1999. To date, we have acquired more than 1200 passes covering regional seas in and around Southeast Asea. The data are processed into Level 1 and Level 2 format using the SeaDAS software provided by NASA and georectified using the software developed at CRISP. Cloud free multi-day composite maps of the chlorophyll-a concentration distribution at 1 km resolution are generated for regional seas. Short-term changes in chlorophyll concentration may indicate the occurrence of phenomena like red tides and pollution which have significant environmental and economic effects. In this context, we discuss the abrupt and abnormal changes of the pattern of chlorophyll concentration observed in Kimanis Bay, Sabah as well as Daya Bay, near Hong Kong during reported red tide periods. The behaviors of normalized water leaving radiances in the suspected region are also discussed. In the reported red tide areas, the chlorophyll-a concentrations and normalized water leaving radiances during reported tide periods are considerably different from other days. Thus, the change of chlorophyll-a concentration and spectrum of the normalized water leaving radiance may be used as indications of red tide.

1. INTRODUCTION

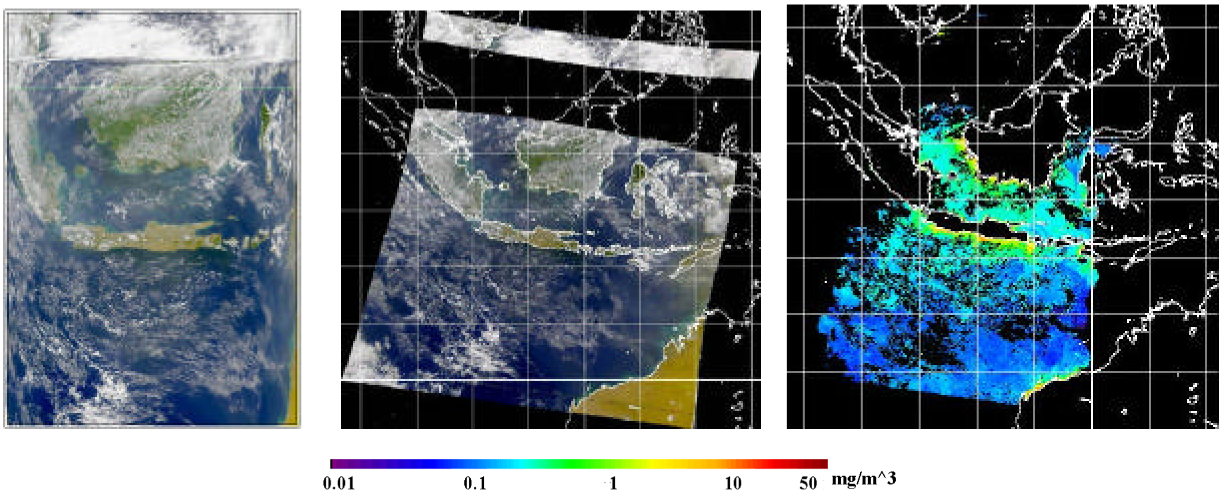
The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) is a sensor on board the SeaStar (Orbview 2) satellite which was launched in 1997. SeaWiFS has 8 bands ranging from the visible light to the near infrared (Band 1: 412 nm; Band 2: 443 nm; Band 3: 490 nm; Band 4: 510 nm; Band 5: 555 nm; Band 6: 670 nm; Band 7: 765 nm; Band 8: 865 nm). The spatial resolution is about 1.1 km at nadir viewing. SeaWiFS is designed for ocean color measurement.The ocean color reveals information on the presence and concentration of phytoplankton, sediments, and dissolved organic matters of the ocean. Thus, SeaWiFS can be used to monitor and manage the marine environment.

The Centre for Remote Imaging, Sensing and Processing (CRISP) has been receiving SeaWiFS data since September 1999. To date, we have acquired more than 1200 passes covering the seas in Southeast Asia, the South China Sea and part of the Indian Ocean (The quicklook of SeaWiFS images acquired by CRISP can be found at http://www.crisp.nus.edu.sg). With this dataset, the spatial and temporal distribution of chlorophyll-a in regional seas can be studied.

2. SEAWIFS DATA PROCESSING

The High Resolution Picture Transmission (HRPT) station for the reception of SeaWiFS data at CRISP is established in 1999 under a research agreement with NASA. A 14-day embargo period is imposed on the received SeaWiFS data. Using the SeaDAS (version 4) software provided by NASA, the acquired data are processed into Level 1 and Level 2 formats. Generation of level 2 data requires ancillary meteorological and ozone data.

Chlorophyll-a (chl-a) concentration distribution is one of the standard Level 2 products of SeaWiFS. Chlorophyll-a is the primary photosynthetic pigment in phytoplankton. Chlorophyll-a absorbs relatively more blue and red light than green, and the spectrum of backscattered sunlight or color of the ocean water progressively shifts from deep blue to green as the concentration of phytoplankton increases (Yentsch, 1960). In SeaDAS version 4, chl-a concentration is derived from the OC4 ocean color algorithm (O'Reilly et al., 1998). OC-4 algorithm for chl-a concentration is a maximum band ratio (MBR) algorithm based on the values of Remote Sensing Reflectance (Rrs) at wavelengths of 443, 490, 510, 555 nm. The generated data are georectified and projected to a specified map projection using software developed at CRISP, based on the model of an ellipsoidal Earth (Patt et al., 1994). Figure 1 shows the first SeaWiFS image received by CRISP and the consequent products after georectification. An example of georectified monthly chl-a composite is shown in Figure 2.



(a) (b) (c)

Fig. 1: The first SeaWiFS image acquired by CRISP on September 1, 1999.

(a) The standard SeaWiFS Level 1A image using SeaDAS (color combination: Red: Band 6, Green: Band 5, Blue: Band 1)
(b) The georectified Level 1A image
(c) The georectified Level 2 (chlorophyll-a concentration) image

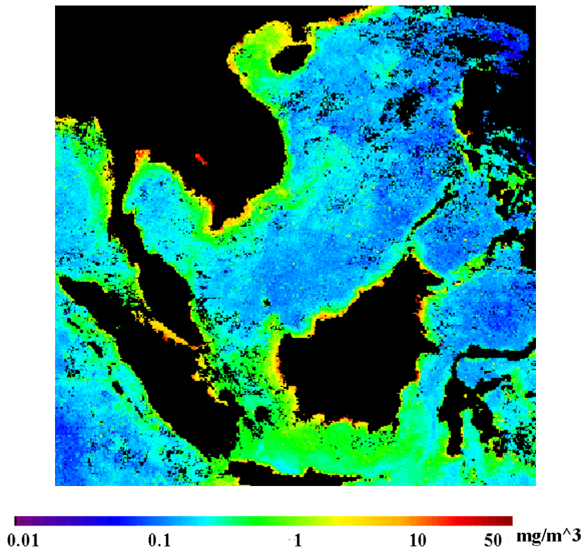


Fig. 2 Georectified monthly composite (September 2000) of chlorophyll-a concentration.

3. DATA ANALYSIS

The processed level 1 and level 2 data are used to study the spatial and temporal distribution of chlorophyll-a concentration in regional seas. The accuracy of water-leaving radiances measured by SeaWiFS is within 5%, and chl-a derived from the data is within 35% for case I waters (McClain et al, 1995). However, for turbid coastal case II waters, the use of the standard algorithm may give inaccurate results, primarily due to increased scattering by suspended matter and/or increased absorption by dissolved organic matter. Nevertheless, OC4-generated chlorophyll-a data still provide us with a useful indication about the situation of regional seas.

Generally speaking, coastal regions tend to have high concentration of chl-a than the open seas. For example, in Singapore waters, the usual chlorophyll-a concentration is about 10 mg/m^3, while in the middle of the South China Sea, the concentration is as low as 0.01 mg/m^3. However, some areas far from the coast also have high chlorophyll concentrations. This may be due to strong currents moving the high chlorophyll waters away from the coastal areas; monsoon winds which significantly affect the chlorophyll distribution; or upwelling which brings cool, nutrient-rich water from the ocean depths to the surface allowing phytoplankton to grow (Abbott et al., 1995). Short-term changes in chlorophyll concentration may indicate the occurrence of phenomena like algal blooms (usually called red tides) and pollution which have significant environmental and economic effect.

When a red tide occurs, algal productivity will increase significantly, resulting in a higher than normal chl-a concentration. Thus abnormal increase of chlorophyll-a concentration observed by SeaWiFS may be an indication of red tide. However, sea-truth measurements are needed for verification.

3.1 Red tide in Kimanis Bay, Sabah, Malaysia (Early December, 1999)

A red Tide phenomenon in the coastal waters near Brunei was first recorded in 1976. Since then the coastal waters there has experienced sporadic blooms (source: Fisheries Department, Brunei). In early December 1999, it is reported that red tide occurred at an area including Kimanis Bay (http://library.kcc.hawaii.edu/praise/news/eh72.html). Figure 3 shows the time sequence maps of chl-a concentration of Kimanis Bay, near Brunei, in November and December, 1999 derived from SeaWiFS data acquired by CRISP. The time series of the average chl-a concentration in the red rectangle area of Figure 3 is shown in Figure 4.

The Dec 2 image shows a peak of high concentration in Kimanis Bay (see the red rectangle in the image) compared with its previous (Nov 24, 27, 29) and the next (Dec 10, 30) scenes in November and December (Figure 4), which confirms the report. Note that there is also a high chl-a concentration in Kimanis Bay on Nov 23, but there was no report of red tide on that day. The cause of these occurrences may be the pollutants brought by the monsoon driven currents. During the Northeast monsoon season, the south going regional current dominates the tidal currents along the west coast of Sabah and Brunei. This has tremendous importance for the transport of pollutants emanating from the rivers north of the Klias Peninsula and is the major contributing factor to the occurrence of Red Tide in Kimanis Bay (Report of Danish Hydraulic Institute, 2001).

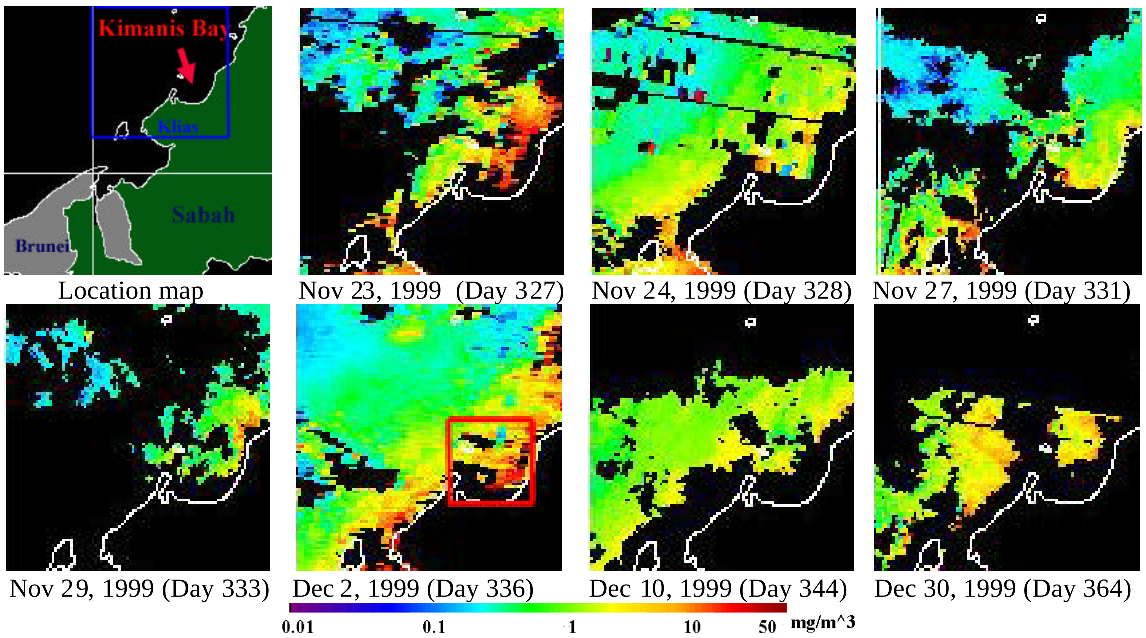


Figure 3. Time sequence chl-a concentration maps of Kimanis Bay, near Brunei, in November and December, 1999 acquired and processed by CRISP. (Image size: Location map: 200×200 km^2, Blue rectangle (zoom-in area): 100×100 km^2)

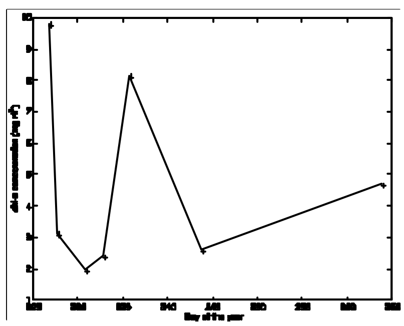


Fig. 4 Time series of average chl-a concentration in the area indicated by the red rectangle in Fig. 3, Kimanis Bay, Nov-Dec 1999.

A location in the red rectangle (Figure 3, Dec 2, 1999) was chosen as a study point and the spectra of normalized water leaving radiance (nwl) at 6 bands (412, 443, 490, 510, 555 and 670 nm) were plotted for each day (Figure 5). The location we choose is a representative point that it is not near the coast (more than 10 km away from the coastline) and each day this point has a chlorophyll-a concentration which is near the average value of the concentration in the red rectangle (Figure 3, Dec 2, 1999 (Day 336)).

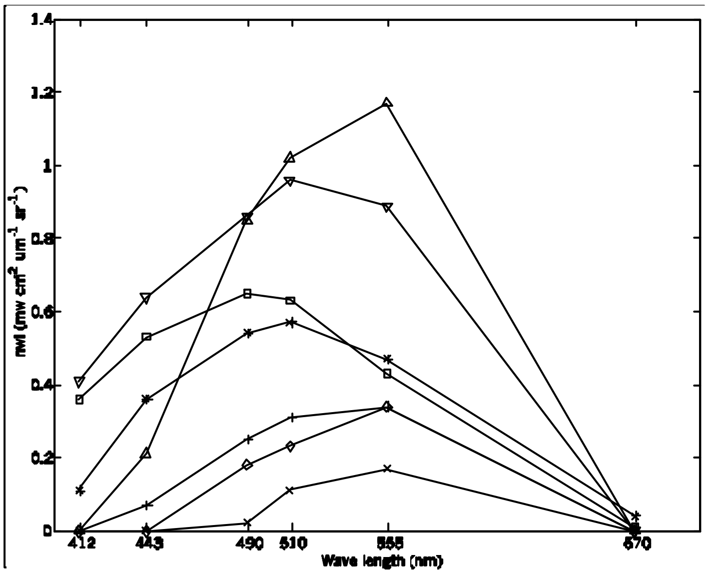


Fig. 5 Curves of normalized water leaving radiance at the study point.
Dates and chl-a concentrations: '×': Day 327, 11.52 mg/m^3; '+': Day 328, 3.27 mg/m^3; '✳': Day 331, 1.39 mg/m^3; Day 333, 0.85 mg/m^3, '◇': Day 336, 9.27 mg/m^3; '▽': Day 344, 1.92 mg/m^3; '△': Day 364, 3.73 mg/m^3; '□'.

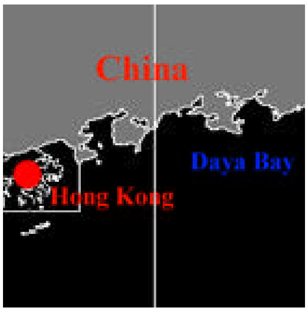
The spectrum at the study point is influenced by the combination of many factors such as chl-a concentration, suspended substance and dissolved organic matter. Figure 5 shows that, in general, in Kimanis Bay, the higher the chl-a concentration, the lower the normalized water leaving radiance, but with 2 exceptions (Days 344 and 364). The exceptions here may be due to varying sea conditions. The data from day 327 to day 336 show that when chl-a concentration increases, the color of the ocean becomes darker. It is also observed that when chl-a concentration is high, the peak of the curve moves from Band 510 to Band 555. The curves reveal that when a suspected red tide occurs, the color of the seawater becomes darker and more greenish due to absorption by chlorophyll.

3.2 Red tide in Daya Bay, China (August 8-19, 2000)

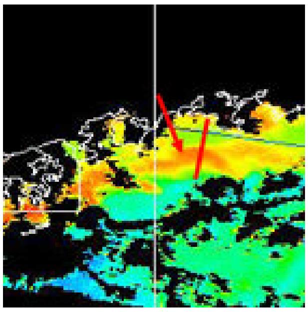
In August 2000, a case of red tide was reported to occur in Daya Bay, about 70 km east of Hong Kong. It was reported that the red tide area took on a yellowish-grey color during that period. The HAB area covered 20 km^2. The causative species are *Scrippsiella trochoidea* and *Peridinium quinquecorne* and the density is 1.2×10^6 cells/l (China HAB webpages, 2001). Hong Kong is near the edge of CRISP's reception circle and we only have a limited number of cloud-free images covering Daya Bay. We managed to find two reasonably good scenes in our archive for comparison (Figure 6): one during a confirmed red tide period (August 8, 2000) and the other one during low chl-a period (May 7, 2001).

In the Aug 8, 2000 image (Figure 6b), the concentration of chl-a in a location indicated by an arrow (in Figure 6b) is much higher than its surroundings and its usual value. The concentration of chl-a along a transect (red line in Figure 6b) is about 5-10 times higher for most points on the line during the red tide period (see Figure 7). The high chl-a concentration occurred in the reported red tide area. The SeaWiFS station in Hong Kong University of Science and Technology also received and processed the SeaWiFS images acquired during the red tide period. Images showing the time series of the red tide could be found at their website (CCAR, 2001).

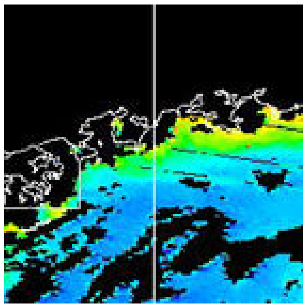
Figure 8 shows the spectrum of the normalized water leaving radiance at the point along the transect in Figure 6b with the highest chl-a concentration (pixel 25, chl-a = 11.4 mg/m^3). For comparison, we also plot the curve of normalized water leaving radiance at the corresponding point in the low chl-a image (Figure 6c).



(a) Location map of Daya Bay



(b) August 8, 2000 (high chl-a concentration in a red tide period indicated by the red arrow). The curve of chl-a concentration along the red line will be shown in Figure 7.



(c) May 7, 2001 (low chl-a concentration)

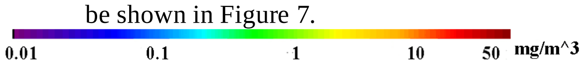


Fig. 6 Comparison of chlorophyll-a concentration between a normal period and a red tide period. Image size: 200×200 km^2.

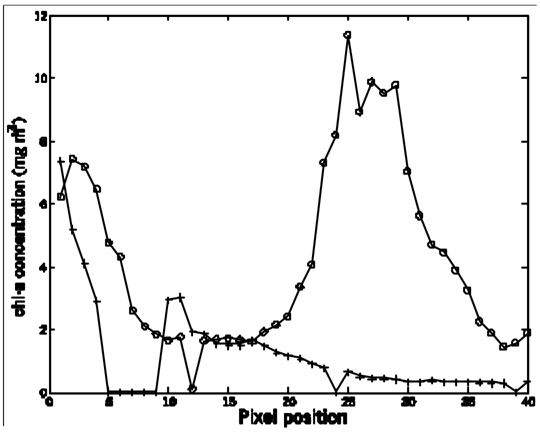


Fig. 7 Comparison of chl-a in Fig. 6b and 6c along a transect through the red tide area (red line in Fig. 6b, downward direction). ‘o’ and ‘+’ indicate the chl-a values in Fig. 6b and 6c , respectively. Sudden drops of chl-a concentrations in both curves are caused by drop lines in the SeaWiFS images or by cloud cover. In the interval between pixel 20 and pixel 40, the chl-a values of ‘o’ are much higher than the values of ‘+’, indicating the possible occurrence of a red tide.

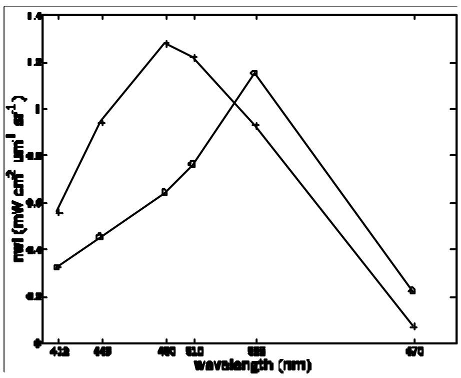


Fig. 8 Comparison of normalized water leaving radiance (nwl) in Fig. 6(b) and 6(c) at the point where chl-a concentration is highest along the red line on Aug. 8, 2000. ‘**o**’ indicate the values of nwl on Aug 8, 2000 (high chl-a). ‘+’ indicate the values on May 7, 2001 (low chl-a).

In Figure 8, it is seen that the peak of the curve shifts to the longer wavelength during red tide. The peak shifts from 490 nm (blue) during low chl-a period to 555 nm (green) when red tide occurs. This agrees with the observed shift in the color of ocean water from deep blue to green as the concentration of phytoplankton increase (Yentsch, 1960). The chlorophyll absorption around 440 nm is prominent during red tide, causing the radiance at shorter wavelengths to decrease.

4. CONCLUSIONS

Using SeaWiFS data acquired and processed at CRISP, we analysis the pattern of chlorophyll concentration and the curves of normalized water leaving radiance observed in Kimanis Bay, Sabah as well as Daya Bay, near Hong Kong during reported red tide periods. Time series of Kimanis Bay data show that the higher the chl-a concentration, the lower the normalized water leaving radiance, which may be explained by increased absorption by chlorophyll. In Daya Bay, the concentration of chl-a during the red tide period is 5 to 10 times higher than usual and the peak of the normalized water leaving radiance curve shifts from blue to green. Thus, the change of chlorophyll-a concentration and spectrum of the normalized water leaving radiance may be used as indications of red tide.

It is widely reported that chlorophyll patterns track sea surface temperature (SST) patterns in seas in various parts of the world. SeaWiFS does not have thermal bands to provide SST products. Simultaneous chl-a and SST data cannot be obtained. Now, CRISP has been receiving MODIS data as well. The simultaneous chlorophyll-a concentration and SST data provided by MODIS will provide useful information for analyzing the correlation between SST, chl-a and red tide incidence.

ACKNOWLEDGEMENT

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