Using MODIS medium-resolution bands to monitor harmful algal blooms

Mati Kahru[*a], B. Greg Mitchell[a], Anibal Diaz[b]
[a]Scripps Institution of Oceanography, University of California, San Diego, CA 92093-0218, USA;
[b]GeoMap Digital S.A.C., Miraflores-Lima, Peru

ABSTRACT

MODIS medium-resolution (250- and 500-m) bands were successfully used to detect and map the distribution of a harmful phytoplankton bloom (HAB) in the Paracas Bay, Peru, that caused economic losses estimated at about $28.5 million. A Red-Green-Blue combination of bands 1, 4 and 3 was used to visually distinguish the HAB while the turbidity index, a semi-quantitative measure of the amount of particulate material in the near-surface water, was used to estimate the intensity of the HAB. The turbidity index was inversely correlated with oxygen concentration in the bay. Temporary anoxia caused by the HAB was probably the main mechanism causing fish kills. The 250-m resolution provided by MODIS bands 1 and 2 is essential to detect localized HABs in coastal areas. While turbidity is not specific to algal blooms, it is a quantitative estimate of the intensity of the bloom once the existence of the bloom is detected by the RGB images.

Keywords: MODIS, HAB, harmful algal bloom, Paracas, turbidity, oxygen deficiency

1. INTRODUCTION

Harmful algal blooms (HABs) are a growing problem in many parts of the World. Because of the transient and often unpredictable nature of HABs, their detection and monitoring is technically challenging. Depending on the scale of the bloom, different methods can be used.[1,2] Satellite remote sensing has been successfully used to map large-scale surface blooms [3,4] but has been difficult to use operationally because of the delays in data access. Multi-spectral MODIS data from the NASA Terra and Aqua satellites is now available at full resolution, at no cost and in almost real time. However, most HABs occur in coastal zones and have scales that are too small for the typical 1 km pixel size of ocean color sensors. Moreover, standard products from ocean color sensors either do not work at all or are highly inaccurate in coastal zones in typical HAB conditions. In this paper we describe the use of the medium-resolution (250- and 500-m) MODIS bands using empirical algorithms. We recognize that even the 250 m pixel size is too large for many blooms but it is still an important improvement compared to the typical 1 km data. We successfully applied our empirical methods in monitoring of a devastating bloom in the Paracas Bay, Peru.[5] We recognize that HABs have very different characteristics and that our methods will not work for all HABs. However, due to the rapid accessibility and relatively simple processing on a low-cost personal computer, we believe that our methods are an efficient way to monitor bays and other coastal areas where harmful algal blooms and/or water masses with increased turbidity present an

Remote Sensing of the Coastal Oceanic Environment, edited by Robert J. Frouin, Marcel Babin, Shubha Sathyendranath,
Proc. of SPIE Vol. 5885 (SPIE, Bellingham, WA, 2005) · 0277-786X/05/$15 · doi: 10.1117/12.615625

environmental problem.

2. DATA and METHODS

The medium-resolution (250- and 500-m) MODIS bands were designed for land applications, and their sensitivities are lower than those of the dedicated 1-km ocean bands. Recent work has shown that these bands have sufficient sensitivity to be useful in various aquatic applications such as detection and mapping of turbid plumes, oil slicks, and water quality in productive estuaries. [6,7] Quantitative use of the medium-resolution MODIS bands in ocean applications is hampered by the inadequate sensor calibration, highly problematic atmospheric correction, and bio-optical inversion procedures. [8] Considering these problems, we took an empirical approach and did not try to estimate the water-leaving radiance that is the traditional input to bio-optical models. Instead, a simplified atmospheric correction algorithm by Jacques Descloitres of the MODIS Rapid Response Project (http://rapidfire.sci.gsfc.nasa.gov) was used. This algorithm uses top-of-the-atmosphere level-1B radiance data to calculate a first approximation to surface reflectance by removing the gross effects of the Sun and sensor geometry, molecular path reflectance, and absorption by O2, O3, and H2O.

The corrected reflectance data of the MODIS bands 1 (620-670 nm), 2 (841-876 nm), 3 (459-479 nm), and 4 (545-565 nm) were then used to create two image products for detecting and mapping the algal bloom. First, true-color (red-green-blue) images using, respectively, bands 1, 4, and 3 showed a color signature (turquoise blue) that clearly identified the distribution of the bloom.[5]

Second, as a semi-quantitative measure of the amount of particulate material in the near-surface water, the turbidity index was calculated by subtracting band-2 reflectance from band-1 reflectance. Reflectance at longer wavelengths is known to be influenced mostly by scattering in the atmosphere because of the larger water absorption and the subtraction removes most of the residual atmospheric component due to aerosols. While turbidity is not specific to algal blooms, it is a quantitative estimate of the intensity of the bloom once the existence of the bloom is detected by the true-color images. Using in situ measurements of the total suspended mass (TSM) in the water the reflectance data can be converted to TSM using empirical regressions. Various modules of the Microsoft Windows-based software WIM Automation Module (http://www.wimsoft.com) were used throughout this study to process MODIS imagery.

3. HARMFUL ALGAL BLOOMS IN PARACAS BAY, PERU

Paracas Bay, off the central coast of Peru, is an important fishing area which is in close proximity to fishing industries in the port of Pisco. Around 130 fishing vessels are based in Pisco, and eight fisheries-related factories are located there. Fishing, fish meal manufacturing, and fish and shellfish farming are the region's most important economic activities. These activities are often disrupted by harmful algal blooms that can kill fish and shellfish both by producing toxins and causing anoxia (oxygen depletion) as a result of respiration and decay of the biomass. Mostly because of HABs the share of Pisco in total Peruvian anchovy landings decreased from 8.4% (5.165 million tons) in 2003 to 1.7% in 2004. Between 2-4 April 2004, Pisco fish landings were between 10.6 and 11.4 thousand tons per day. After the episode of massive fish deaths in the bay the port was closed in order to reduce the amount of effluents of the fish meal factories. The economic losses due to port closure were estimated at about $27.5 million in lost revenue.

Another sector devastated by the algal bloom was local aquaculture, which reported losses estimated at $1 million.

A study of a similar HAB in year 2000 concluded that the organic matter from fishery effluents, together with the harmful algal bloom, generated a synergistic effect that caused the mass mortality of benthic species.[9]

4. RESULTS

Visual observations of brownish-red discoloration of the water in the bay were made on 26-29 March 2004. This was probably the beginning of the algal bloom. The Peruvian Marine Research Institute (IMARPE) registered a red tide (algal bloom) in the Paracas area starting on 2 April 2004. The bloom was dominated by the dinoflagellate *Gymnodinium sanguineum*, with other dinoflagellate and diatom species present in high numbers (Lourdes Carbajo, Pisco Coastal Laboratory, IMARPE, personal communication, 2004). Concentrations of up to 3200 cells/mL were reported just before the massive death of phytoplankton between 9-11 April 2004. The toxicity of *G. sanguineum* is not well established, but the species is associated with fish and shellfish kills around the world.[10]

For a 25-day period from 30 March to 24 April 2004, including the bloom, 20 cloud-free Terra and Aqua images of the Paracas Bay, including 3 days with both Terra and Aqua images in the same day, were obtained. Some of these images are shown in Figure 1. The turbidity times series shows well the development of the HAB through its full cycle.

The rise and fall of the bloom was measured by the mean MODIS-detected mean turbidity in the bay that correlated well with visual observations. The bloom resulted in the accumulation of phytoplankton biomass that subsequently sunk to the bottom of the bay and caused oxygen depletion. The water turbidity index calculated from the 250-m MODIS data was inversely correlated with oxygen concentration measured in situ in the water column.[5] Because of strong and variable water exchange between the bay and the surrounding ocean areas, the oxygen concentrations were quite variable. During the short period of 11-14 April 2004 that coincided with the peak of the dinoflagellate bloom, oxygen concentration in the bay dropped below the "alert" level. Oxygen concentration was close to 0 on 12 April 2004, fish kills were reported that day. Previous reports of fish kills were on 2 April 2004 when oxygen concentration was still relatively high.

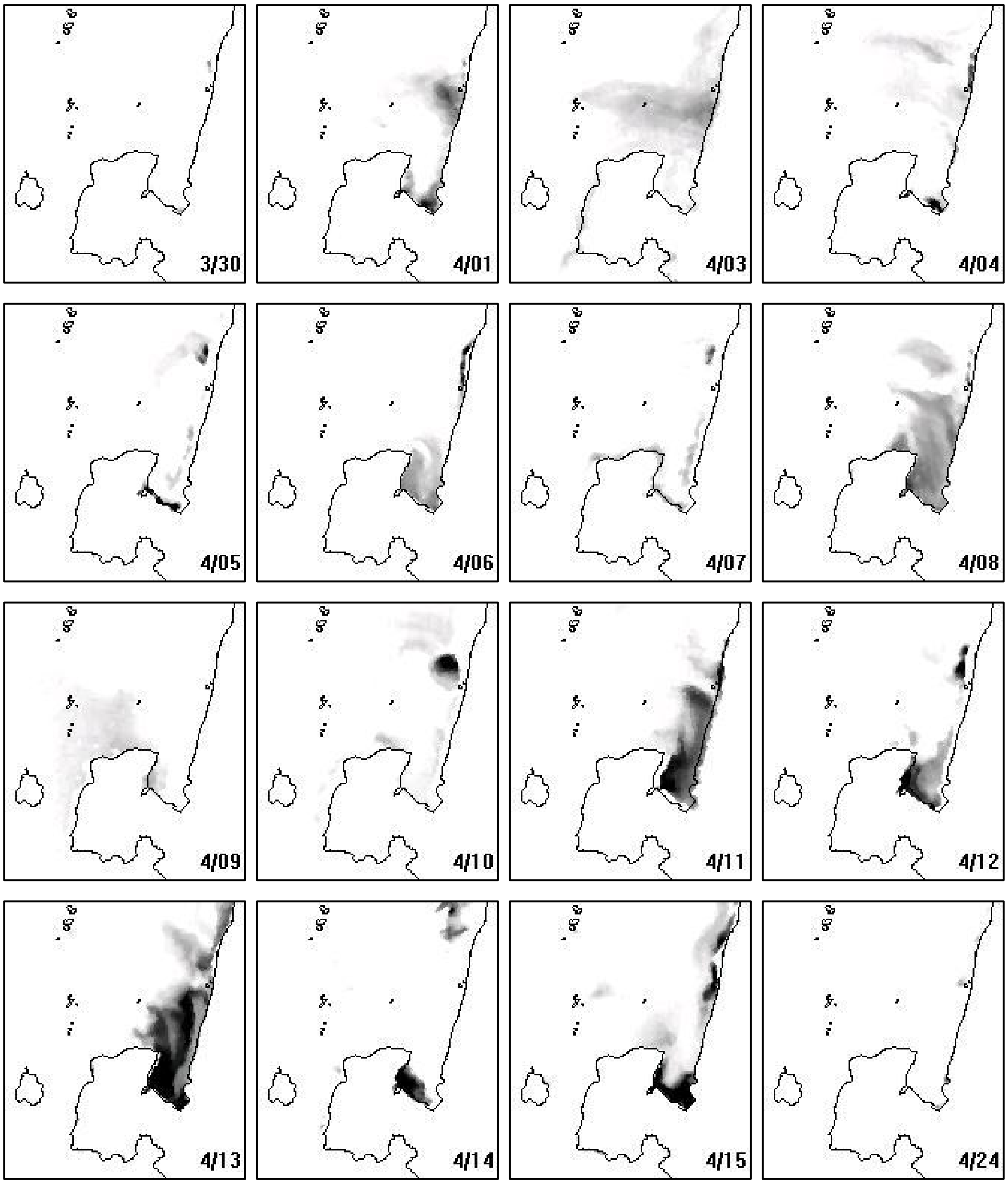

Fig. 1. Time series of turbidity images from Terra and Aqua showing the full cycle of the HAB.

4. CONCLUSIONS

Global MODIS data are available for downloading shortly after the satellite overpass at http://daac.gsfc.nasa.gov/MODIS/data_access.shtml. Although the volume of the data files is quite large, with improved network speeds this will be less of an issue even in remote locations. With simple processing on a low-cost personal computer, it is possible to cost-effectively monitor bays and other coastal areas where harmful algal blooms and/or water masses with increased turbidity present an environmental problem. Clouds are the main obstacle in using visible remote sensing imagery. As an average, we obtained 0.8 cloud-free scenes of the study area per day using both Terra and Aqua passes. The frequency of cloud-free imagery in other areas and other time periods may be lower. Government agencies as well as local fishing, oil, and gas companies have shown interest in the satellite data for the monitoring of the Paracas Bay. Currently, the true-color images like those that can show the existence of the HAB are being distributed commercially by a local company in Peru.

The procedures for monitoring of the HAB in a local area can be summarized as following.

1. Select and download MODIS Terra and Aqua passes for the selected area and time period.
2. Create enhanced true-color images of the study area mapped to a standard projection.
3. Create turbidity images of the study area mapped to the standard projection.
4. Visually inspect the true-color images for signs of a HAB. If HAB is detected then the turbidity image gives an estimate of its intensity.

ACKNOWLEDGEMENTS

The authors acknowledge Pluspetrol Peru Corporation for in situ monitoring data. MODIS data were made available by the NASA Goddard Earth Sciences Distributed Active Archive Center. M. Kahru and B. G. Mitchell were supported by NASA Ocean Biogeochemistry and ECOHAB programs (grant NNG04GA60G).

REFERENCES

1. M. Kahru and Ch.W. Brown (Eds). Monitoring algal blooms: New techniques for detecting large-scale environmental change. Springer Verlag, Berlin-Heidelberg-New York, 178 pp. (1997).
2. M. Babin J.J. Cullen, C.S. Roesler, P.L. Donaghay, G.J. Doucette, M. Kahru, M.R. Lewis, C.A. Scholin, M.E. Sieracki, H.M. Sosik. New approaches and technologies for observing harmful algal blooms. The Oceanography Journal, Vol. 18, N2, 210-227 (2005).
3. M. Kahru, U. Horstmann, O. Rud, Satellite detection of increased cyanobacteria blooms in the Baltic Sea: Natural fluctuation or ecosystem change? Ambio, 23 (8): 469-472 (1994).

4. M. Kahru, Using satellites to monitor large-scale environmental change: A case study of cyanobacteria blooms in the Baltic Sea. In: Monitoring algal blooms: New techniques for detecting large-scale environmental change. M. Kahru and Ch. W. Brown (Eds.). 43-61 (1997).
5. M. Kahru, B.G. Mitchell, A. Diaz, M. Miura. MODIS Detects a Devastating Algal Bloom in Paracas Bay, Peru. EOS, Trans. AGU, Vol. 85, N 45, p. 465-472 (2004).
6. C. Hu, F. Muller-Karger, C. J. Taylor, D. Myhre, B. Murch, A.L. Odriozola, and G. Godoy, MODIS detects oil spills in Lake Maracaibo, Venezuela, Eos Trans. AGU, 84 (33), 313 (2003).
7. R. R. Li, Y. J. Kaufman, B.-C. Gao, and C. O. Davis, Remote sensing of suspended sediments and shallow coastal waters, IEEE Trans. Geosci. Remote Sens., 41, 559-566 (2003).
8. C. Hu, Z. Chen, T. Clayton, P. Swarnzenski, J. Brock, and F. Muller-Karger, Assessment of estuarine water-quality indicators using MODIS medium-resolution bands: Initial results from Tampa Bay, Florida, Remote Sens. Environ. 93, 3, 423-441 (2004).
9. R. Cabello, J. Tam, and M. E. Jacinto, Procesos naturales y antropogenicos asociados al evento de mortalidad de conchas de abanico ocurrido e la Bahia de Paracas (Pisco, Peru) en junio del 2000, Rev. Peru. Biol., 9, 94-110 (2002).
10. M. A. Faust, R. A. Gulledge, Identifying harmful marine dinoflagellates, Smithson. Contrib. U. S. Natl. Herb., 42, 1-144 (2002).

*mkahru@ucsd.edu; phone 1 858 534 8947; fax 1 858 534 2997