REMOTE SENSING OF WATER QUALITY PARAMETERS AND CYANOBACTERIAL ALGAL BLOOMS USING MULTI-SPECTRAL MERIS AND LANDSAT, AND IN SITU HYPERSPECTRAL RADIOMETRIC DATA, IN ZEEKOEVLEI LAKE, CAPE TOWN, SOUTH AFRICA

Matthews Mark (mark.matthews@uct.ac.za), Bernard Stewart, Winter Kevin*

University of Cape Town

1. INTRODUCTION

Eutrophication, defined as the enhancement of biological production in water resources as a result of increased concentrations of nutrients, is a major problem in lakes in developing countries around the world and in South Africa because of the adverse impacts it has on water quality [1, 2]. One of the worst consequences of eutrophication is dominance by cyanobacterial species of algae which may be toxic, or so-called Harmful Algal Blooms (HABs). Cyanobacterial toxins, or cyanotoxins, pose a serious threat to humans, animals and lake ecosystems [3]. *Microcysitis aeruginosa*, a single celled cyanophyte producing *microcystin* toxin, is widespread in South Africa and has been found responsible for numerous animal deaths [4, 5]. Therefore, it is crucial, from a management point of view, that sufficient information is available in order to monitor the occurrence and distribution of eutrophication and HABs [6]. Remote sensing affords the opportunity to monitor for these events with large spatial coverage and high frequencies not afforded by traditional monitoring methods. The Medium Resolution Imaging Spectrometer (MERIS) [7] and Landsat 7 ETM+ [8] sensors have been used successfully for monitoring eutrophication and HABs in freshwater lakes. Detailed spectra provided by i*n situ* hyperspectral measurements of the up-welling water-leaving radiation are useful for describing relationships between the light field and water constituents. This pilot study combines multi-spectral MERIS and Landsat 7 ETM+ data with *in situ* hyperspectral and limnological measurements to map chlorophyll *a* and other water quality parameters in Zeekoevlei Lake. The study is intended to contribute towards developing methods which will, in future, be used for operational monitoring of freshwater lakes in southern Africa using remote sensing.

2. SITE DESCRIPTION

Zeekoevlei, literally translated from Afrikaans as "Hippo Lake", is a small (2.56Ha) hypertrophic lake situated on the Cape Flats, Cape Town, South Africa, displaying near-permanent dense algal blooms dominated by the cyanobacteria *Microcystis Aeruginosa* [9]. The lake has very high levels of primary production with very high concentrations of chlorophyll *a* (mean=240mg.m^{-3}) and suspended matter. The phytoplankton assemblage displays no fewer than 5 species capable of producing cyanotoxins and in 1995, a female bull terrier dog was killed by cyanotoxin *nodularin* [10]. Thus Zeekoevlei's near-permanent hypertrophic cyanobacteria-dominated condition presents an ideal site to test remote sensing technologies for monitoring eutrophication and HABs in small freshwater lakes.

3. METHODS

Fieldwork conducted during April 2008 took measurements of Zeekoevlei's up-welling light field using a Satlantic hyperspectral radiometer buoy (HyperTSRB) simultaneous to MERIS acquisitions and limnological measurements. Limnological measurements of chlorophyll *a* (Chl *a*), Total Suspended Solids (TSS), Secchi Disk depth (SD) and absorption by Coloured Dissolved Organic Matter (*a*CDOM) were made at four points around the lake using standard methods. The relationships between the TSRB measurements of the up-welling light field and water quality parameters were tested using correlation analysis based on a review of the relevant literature. MERIS images acquired simultaneous with limnological measurements were corrected for atmospheric effects using a radiative transfer code and Dark Object Subtraction (DOS) techniques [11]. The efficacy of the atmospheric corrections was evaluated by comparing the results with the *in situ* TSRB measurements. Water constituent retrieval by the MERIS Case 2 waters and the Eutrophic Lakes Processor algorithms were tested by comparing them to *in situ* measurements. Empirical algorithms for limnological parameters were derived using linear and non-linear regression analysis and used to produce water quality maps from MERIS. A map was made from a Landsat 7 ETM+ scene collected on May 2nd 2008 using an empirical algorithm derived by simulating the Landsat bands using TSRB data.

4. RESULTS

The correlations between limnological water quality parameters and HyperTSRB measured reflectance was good with $r^2 = 0.856$ for Chl *a*, $r^2 = 0.874$ for TSS and $r^2 = 0.684$ for SD depth ($N = 16$, $p < 0.05$). The atmospherically corrected MERIS L 1 water-leaving reflectance produced close matches with those measured *in situ* with the TSRB. The MERIS L2 P and Eutrophic Lakes Processor products produces inaccurate estimates of the water constituents because of errors associated with atmospheric corrections and parameterization of the algorithms. Empirical algorithms using top-of-atmosphere MERIS data mapped Chl *a* with $r^2 = 0.965$ and a RMSE of 12.7mg.m^{-3}, TSS with $r^2 = 0.760$ and a RMSE of 5.8mg.ℓ^{-1}, SD depth with $r^2 = 0.801$ and a RMSE = 2.3cm and a_{CDOM} with $r^2 = 0.751$ and a RMSE = 13%

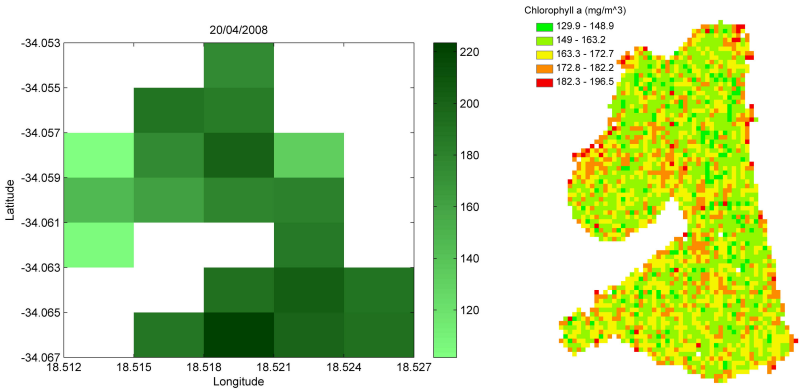

Fig. 1. Chlorophyll *a* (units = mg.m^{-3}) maps for Zeekoevlei from MERIS for 20th April 2008 (left hand side) and Landsat 7 ETM+ for May 2nd 2008 (right hand side).

(N = 9, $p < 0.05$) (see figure 1). Algorithms using simulated Landsat 7 ETM+ bands produced correlations for Chl *a* of $r^2 = 0.826$, the logarithm of TSS of $r^2 = 0.840$, SD depth of $r^2 = 0.727$ and the logarithm of a_{CDOM} of $r^2 = 0.569$ (N = 16, $p < 0.05$). The accuracy of estimating the mean spatial water quality parameters was improved by combining remotely sensed estimates with *in situ* measurements over *in situ* measurements alone (observed error of up to 30%).

5. DISCUSSION AND CONCLUSIONS

The results show that water quality parameters, including Chl *a*, can be accurately predicted from the water-leaving reflectance using empirical methods with *in situ* hyperspectral, multi-spectral MERIS and simulated Landsat 7 ETM+ data. Combining *in situ* measurements with remote sensing leads to more accurate mean spatial water quality parameter estimates for Zeekoevlei. Water quality maps for Zeekoevlei provide vital information to lake managers concerning trophic status and the distribution of HABs and similar techniques may in future be applied to other small inland lakes for monitoring hyper-eutrophication and cyanobacterial dominance.

6. REFERENCES

[1] V. H. Smith, S. B. Joye and R. W. Howarth, "Eutrophication of freshwater and marine ecosystems," *Limnol. Oceanogr.,* vol. 51, pp. 351-355, JAN. 2006.

[2] R. D. Walmsley, "Project report : Phase 1 : development of a strategy to control eutrophication in South Africa," Department of Water Affairs and Forestry, Pretoria, 2003.

[3] G. A. Codd, "Cyanobacterial toxins, the perception of water quality, and the prioritisation of eutrophication control," *Ecol. Eng.,* vol. 16, pp. 51-60, OCT. 2000.

[4] W. E. Scott, "Occurrence and significance of toxic cyanobacteria in southern Africa," *Water Science and Technology,* vol. 23, pp. 175-180, 1991.

[5] P. J. Oberholster, A. M. Botha and T. E. Cloete, "An overview of toxic freshwater cyanobacteria in South Africa with special reference to risk, impact and detection by molecular marker tools," *Biokemistri,* vol. 17, pp. 57-71, 2005.

[6] H. B. Glasgow, J. M. Burkholder, R. E. Reed, A. J. Lewitus and J. E. Kleinman, "Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies," *J. Exp. Mar. Biol. Ecol.,* vol. 300, pp. 409-448, MAR 31. 2004.

[7] C. Giardino, G. Candiani and E. Zilioli, "Detecting chlorophyll-a in Lake Guarda using TOA MERIS radiances," *Photogramm. Eng. Remote Sensing,* vol. 71, pp. 1045-1051, 2005.

[8] R. K. Vincent, X. M. Qin, R. M. L. McKay, J. Miner, K. Czajkowski, J. Savino and T. Bridgeman, "Phycocyanin detection from LANDSAT TM data for mapping cyanobacterial blooms in Lake Erie," *Remote Sens. Environ.,* vol. 89, pp. 381-392, FEB 15. 2004.

[9] W. R. Harding, "Phytoplankton primary production in a shallow, well-mixed, hypertrophic South African lake," *Hydrobiologia,* vol. 344, pp. 87-102, JAN 31. 1997.

[10] W. R. Harding, N. Rowe, J. C. WEssels, K. A. Beattie and G. A. Codd, "Suspected toxicosis of a dog attributed to the cyanobacterial (blue-green algal) hepatotoxin nodularin in South Africa," *Journal of the South African Vertinary Association,* vol. 66, pp. 256-259, 1995.

[11] P. S. Chavez, "Image-based atmospheric corrections - revisited and improved," *PE & RS,* vol. 62, pp. 1025-1036, 1996.