June 9, 2010

Talk for the Freshwater Research Unit

June 10^{th} 2010

University of Cape Town

Abstract

Eutrophication and Harmful Algal blooms (HABs) are a common occurrence in southern African inland and near-coastal waters and are a threat to ecosystems, animals and even humans. Remote sensing may be used to rapidly assess these phenomena over large regions to effectively minimise risks and provide a wealth of information on ecosystem functioning. Preliminary results from Zeekoevlei lake show the efficiency of various approaches for deriving water quality information products from satellite sensors and highlight the high potential for a broader application to many southern African inland waters. The development of regionally applicable approaches through research will enable routine generation of water quality information products from remote sensing that would be of considerable value for scientists, authorities, managers, and the general public of South Africa.

Good morning ladies and gentlemen, and thank you for coming to my talk today entitled “Remote sensing of eutrophication and cyanobacterial algal blooms in South African inland waters: feasibility, perspectives and research overview”.

Eutrophication and cyanobacterial blooms

Eutrophication, or nutrient enrichment, has for the several decades been known to be one of the major factors responsible for the deterioration in quality of freshwaters in southern Africa, and is widespread in our lakes and rivers. Eutrophication is also responsible for the deterioration of freshwater quality globally. In the coming century eutrophication is expected to become more severe in developing countries due to a lack of measures to limit the amount of nutrients entering our waters from agriculture and domestic effluent (sewage). If that were not enough, climate changes occurring over the next century are also expected to exacerbate the shift to turbid, eutrophic conditions, especially in shallow lakes. Eutrophication therefore remains one of the greatest challenges facing limnologists and scientists in this century.

Eutrophication is associated with many negative impacts on lakes and streams. The most noticeable of these are greatly increased phytoplankton biomass, turbid water and decreased water transparency, anoxia leading to increased incidence of fish kills, and a loss of biodiversity. Arguably the worst consequence of eutrophication is an increased tendency of blue-green algae, also known as cyanobacteria, a toxin producing algae, to dominate the phytoplankton assemblage. This domination comes as a result of the competitive advantage afforded to cyanobacteria in nutrient rich conditions, for example the ability to grow at low light intensities, and the presence of gas vacuoles which enables them to regulate their movement in the water column.

The toxins produced by cyanobacteria are lethal to animals and human, the worst of which, saxitoxins, are more toxic than cobra venom. When blooms of cyanobacteria form with sufficient density as thick surface scums this may be ingested by drinking animals, or may come into contact with recreational users. For animals, such as cattle, sheep, or wildlife, this can be fatal: there are plentiful instances of poisonings recorded throughout South Africa since the middle of the last century. In humans, fatalities are less common. Fortunately, there are no known human fatalities recorded in South Africa: however, in Brazil in the early 90s, there were deaths of at least 50 people on two occasions following the release of toxins into the local water supply which was used by hemodialysis patients. Recreational contact with blooms may result in effects such as weakness, vomiting, heavy breathing, diarrhea and skin irritations. There are a few reported incidences in South Africa of these symptoms following recreational contact or drinking, however, many incidences are likely to be falsely diagnosed or unreported. Cyanotoxins in drinking water have also been linked to the occurrence of liver cancer in populations in the US and China. Cyanobacteria exist distributed throughout many water supply and recreational reservoirs in South Africa, often as the dominant species. It is reasonable to assume that these continue to constitute a threat to animals and humans who use these resources for drinking and recreation.

Remote sensing in inland waters

Remote sensing has the capacity to provide crucial information on the occurrence of eutrophication and cyanobacterial blooms in inland waters. This is mainly through the advantages of satellite remote sensing such as timely, consistent data acquisition, synoptic coverage, and cost effectiveness through large user groups. Satellite instruments measuring light in the visible spectrum give the most information on water. The spatial, spectral, temporal and radiometric resolution of the instrument determines its usefulness for water applications. Instruments ideally suited for inland waters should have high resolutions. However there is a trade-off between, for instance, spatial and temporal resolution owing to instrument design constraints. The optimal current sensor for inland monitoring is the European Space Agency's Medium Resolution Imaging Spectrometer, or MERIS. MERIS has 15 visible spectral bands, an overpass time of 2/3 days, a pixel size of 260 by 290 m, and a strong signal-to-noise ratio. Furthermore, MERIS is available free for research projects. MERIS was designed specifically for ocean colour and multiple applications. As will be discussed later, in comparison with terrestrial viewing instruments, MERIS is superior for water-related applications.

It is worth asking what it is possible to see in the water from a satellite. The answer is that only substances which have a visible impact on the colour of the water, or are 'optically active', can be seen from satellite. Inland and coastal waters are 'optically complex' meaning that there are three or more constituents which influence the colour of the water. In this way they differ from water found in the open ocean. Most simply these constituents are phytoplankton or algae, suspended minerals, and dissolved organic matter or yellow substances, although these can include bubbles, viruses and bacteria, oils etc and don't forget water itself. Each of these constituents has a unique optical signature which has a visible effect on the water-leaving reflectance. It is possible to solve for these constituents, using iterative procedures or radiative transfer models, if their effects on the absorption and scattering within the water are known, i.e. their Inherent Optical Properties (IOPs). These are so-called bio-optical inversion algorithms. These inversion algorithms are able to provide detailed information on the water constituents but require regional/local parameterization and training beforehand. The fact that the constituents may be covariant but more often vary independently from one another leads to complexity and potential ambiguity for algorithms.

Additional complexity is introduced into water remote sensing when accounting for the influence of the atmosphere on the signal: for example, for water targets, more than 90% of the signal at the top of the atmosphere is from the atmosphere. This means that only 10% of the signal is useful, the remainder for our purposes is 'noise'. Accurately removing the effects of the atmosphere is the single biggest challenge for water remote sensing. Errors in this procedure necessarily lead to large errors in algorithm estimates of water parameters, especially for 'inversion' type algorithms. The alternative is to use so-called top of atmosphere algorithms which use the signal at the top of the atmosphere rather than trying to correct the signal. This is achieved though using band ratios which effectively normalize for the atmosphere. As will be shown these are more than capable of providing course products such as eutrophication indices without the need for an atmospheric correction and are likely to be suitable for operational use in hypertrophic/eutrophic systems.

The most commonly detected parameters in inland waters are the concentration of phytoplankton pigments or Chl a, suspended matter (*tripton*), water transparency and the concentration of coloured dissolved organic matter, also called yellow substances. These may be detected using inversion algorithms or alternatively more simple ‘empirical’ procedures. Empirical algorithms relate concurrently collected limnological and remotely sensed data using statistical regression techniques to produce predictor algorithms. These solve for one parameter at a time, rather than solving for several parameters simultaneously as the inversion algorithms do. Advantages of the empirical approach are its ease of implementation, simplicity and its robustness. More specialized algorithms are able to detect major species changes in the phytoplankton assemblage through changes in particle size, or accessory pigmentation. For example, the accessory pigment *phycocyanin* is almost unique to cyanobacteria and can effectively be used to establish the presence of cyanobacteria dominated water. Water quality products available from remote sensing include transparency, primary production, differential biomass/phytoplankton community structure, turbidity/eutrophication indices, submerged vegetation, and bloom/plume dynamics.

Zeekoevlei Case Study

We will now look at a case study from Zeekoevlei using results obtained from my masters research carried out between 2007 and 2009. Zeekoevlei is notorious for its hypertrophic turbid cyanobacteria dominant conditions and is therefore an ideal site for testing and developing remote sensing of eutrophication and cyanobacteria. The cyanophyte *Microcystis aeruginosa*, a colony forming, toxin producing species, is permanently dominant and there are documented instances of at least one animal poisoning. The water quality appears to have worsened in terms of phytoplankton biomass and total P concentrations in the last 20 years, a trend that is likely to continue without immediate mitigation measures. Nevertheless, the lake is of high conservation and recreational importance being a local nature reserve part of the False Bay Ecology Park, the fifth most important wetland bird area in South Africa, and a vital link in the Cape Town biodiversity network.

The aim of the research was fourfold: to determine the suitability of various satellite instruments for monitoring in Zeekoevlei, to determine the primary water constituents affecting the water-leaving reflectance, to derive empirical algorithms and asses the performance of some standard inversion algorithms, and to produce maps for management purposes. The fieldwork involved the simultaneous collection of limnological, environmental and remote sensing data which included Chl a pigments, organic and inorganic suspended solids, absorption by yellow substances, Secchi Disk depth, in-water upwelling radiance, downwelling irradiance, atmospheric thickness, wind speed and direction etc. These were used to derive and test the algorithms using MERIS (and Landsat 7 ETM+) data acquired simultaneously.

The results show the main factor influencing the water leaving reflectance is strong absorption from the very high phytoplankton biomass, strong scattering from suspended minerals, and high absorption in the blue from detritus and yellow substances. This is characteristic of other hypertrophic cyanobacteria dominated systems. Empirical algorithms derived for the lake had very high correlation coefficients, albeit using a small data set. The strongest correlations were for TOA algorithms and Chl *a*. The inversion type algorithms failed to produce accurate or realistic water quality parameter estimates. Maps produced from the algorithms from MERIS effectively show the variability in spatial pattern and magnitude of the parameters. For example, the southern basin shows sustained higher concentrations of Chl *a* which is accounted for by its proximity to the adjacent WTW. Variability in the northern basin was explained by the physical climate, most importantly wind: higher wind was associated with increased suspended sediment and Chl *a* concentrations owing to re-suspension of sediments from the lake bottom. Not surprisingly, in this study MERIS was far better suited than Landsat for monitoring in Zeekoevlei. For example, only one Landsat scene was acquired and that after the study period, while 9 MERIS scenes were collected during the month long fieldwork. The Landsat bands were unsuited for the application of the empirical algorithms, while MERIS was ideal. Conversely the higher spatial resolution does not offer sufficient advantages to merit its use over MERIS whose few pixels satisfactorily displayed the range and distribution of the parameters.

Conclusion and broader applications and future research

The case study on Zeekoevlei shows that remote sensing can provide cost effective, synoptic and timely information on eutrophication and cyanobacterial blooms for small hypertrophic systems such as Zeekoevlei. There are a number of important outcomes from this study: remote sensing should be integrated into inland water quality monitoring initiatives, such as the National Eutrophication Monitoring Program (NEMP), in order to better determine the status and trends of environmental threats from eutrophication and cyanobacterial algal blooms. This is achievable in the immediate short-term initially using top of atmosphere empirical type algorithms for the detection of eutrophication. Application of the algorithms developed here is already providing preliminary information on the trophic status of other impoundments, such as the Vaal dam.

Research initiatives currently underway are in line with the needs identified from my Masters research, local CSIR research project Safe Water Earth Observation Systems (SWEOS), as well as international initiatives such as the GEO working group on inland and coastal remote sensing, and the TIGER Africa and Coastcolour ESA initiatives. The initial research objectives and aims are to:

1. Characterization of regional IOPs for use in inversion algorithms, including optical modeling of phytoplankton species. This will provide a full description of the influence constituents on the light field for use in Hydrolight radiative transfer model.
2. Development of regionally specific hyperspectral inversion algorithms for providing detailed water quality information products. This includes a large simulated dataset as well as sensitivity analyses.
3. Development of cyanobacteria specific algorithms based on *phycocyanin* detection or size.

The final aim is the development of integrated *in situ* and remote sensing systems through the deployment of bio-optical moorings allowing calibration and validation, and continuous surveillance of water quality. This should partially be achieved using multi-site multi-scale pilot projects will be undertaken under SWEOS at key sites across South Africa. This will lead to the development of demonstration operational inland water quality monitoring systems based on remote sensing that enables rapid response and early warning of environmental threats.