Monitoring water quality in Lake Atitlan, Guatemala using Earth Observations

Africa Flores[1,4], Sundar Christopher[2], Robert Griffin[2], Ashutosh Limaye[3,4], Daniel Irwin[3,4]

[1]Earth System Science Center, The University of Alabama in Huntsville; [2]Atmospheric Science Department, The University of Alabama in Huntsville; [3]NASA-Marshall Space Flight Center, [4]Regional Visualization and Monitoring System (SERVIR), Huntsville, AL, USA

Corresponding author: africa.flores@nsstc.uah.edu

1. Motivation

The deteriorating conditions of the water quality in Lake Atitlan threaten human and ecological health as well as the local and national economy. Lake Atitlan is the second most visited tourist site in Guatemala. Yet, the combination of poor development planning, lack of sewage treatment plants and over use of land for agriculture, is leading to the degradation of this lake. In addition, the lack of frequent and spatially continuous water quality measurements make unfeasible to reliably quantify the changes and evolution of the lake's water quality. Earth observations provide an opportunity to fill this gap. In fact, in 2009 when the first massive algal bloom, caused by cyanobacteria, affected this lake, multiple satellite sensors were used to monitor the extent of the algal bloom. Such satellite monitoring proved how useful Earth Observations could be to monitor water quality. However, no quantitative estimations of concentrations were feasible since there were not enough in situ observations to calibrate and validate an algorithm.

2. Problem Statement

This study examines the applicability of a hyperspectral satellite sensor to measure chlorophyll a (*Chl a*) concentration and evaluates which spectral bands would be more appropriate to detect the changes of *Chl a* concentration in Lake Atitlan. The aim is to develop an algorithm from which satellite-derived *Chl a* can be calculated.

3. Datasets

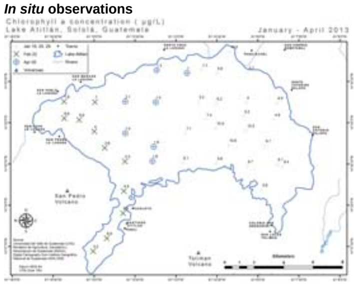
Satellite-derived reflectance from EO-1 Hyperion satellite images were used in combination with *in situ* measurements of chlorophyll concentrations.

Primary EO-1 Hyperion characteristics

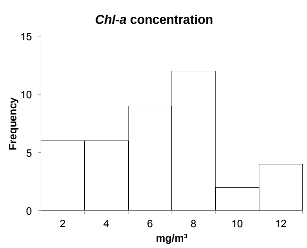
Characteristic	Hyperion
Spectral range	0.4 - 2.5 µm
Spectral resolution	10 nm
Swath width	7.6 km
Spatial resolution	30 m
Spectral coverage	Continuous
Number of bands	220

Example of EO-1 Hyperion satellite image

In situ observations



Location of *in situ* measurements of *Chl a* concentration for Lake Atitlan between Jan-Apr 2013



Histogram of the *in situ* measurements of *Chl a* concentration for Lake Atitlan between Jan-Apr 2013

4. Approach

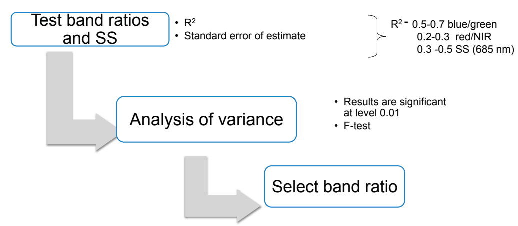
Surface reflectance was derived from the EO-1 Hyperion images by first deriving Top of the Atmosphere (TOA) reflectance and then removing the effect of the atmosphere. The Second simulation of the satellite signal in the solar spectrum-vector (6SV) was used to apply the atmospheric correction. Existing operational algorithms were tested, including the default blue to green ratio, red to NIR band ratio and the three band approach for spectral shape.

Reflectances used to estimate *Chl a* concentration from remote sensing measurements

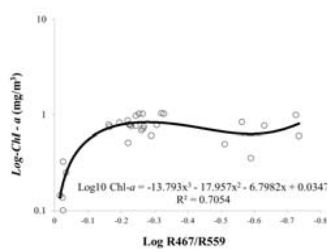
Technique	Notes	Reference
Blue/Green band ratios	Used for low *Chl a* concentration conditions (~<30 mg/m³)	O'Reilly 1998, Werdell & Bailey 2005
Red/NIR band ratios	Used in waters with extremely high levels of *Chl a* concentration (> 300 mg/m³)	Gitelson et al 2008
Spectral shape (3 band approach)	Based on the *Chl a* flourescence peak at 685 nm *Chl a* up to 30 mg/m³)	Gower et al 1999 and 2005

Algorithm development

Seventy five % (30 samples) of the in situ measurements were chosen randomly for algorithm development. The satellite-derived surface reflectance was fitted with their respective in situ measurement following criteria used by Le et al 2013, Bailey & Werdell, 2006, and Hu et al 2001.



Given the low *Chl a* concentrations evaluated, the blue and green band ratio provided the best results. Spectral bands positioned at 467nm and 559 nm provided the best results.



Plot of the band ratio algorithm with best performance. The remote sensing reflectance is the mean value from 3 by 3 pixel window that intersected the *in situ* measurement.

Algorithm evaluation

A cross-validation resampling technique was performed to generate a data set that will be used to assess the adequacy of the model. The leave-one-out method was used for this purpose (Chernik, 2012). The validation data set was conformed of 9 samples. The algorithm assessed in this thesis had a MRE error of about 33%, below the desired error set by NASA's Ocean Biology and Biogeochemistry Program (OBBP) of 35%.

5. Findings

Considering the conditions used for the algorithm development, such as relatively low *Chl a* concentrations (1- 10 mg/m³), the following results were obtained:

- ✓ EO-1 Hyperion spectral bands, in the blue and green part of the spectrum, showed significant sensitivity in resolving *Chl a* concentrations in Lake Atitlan
- ✓ The relative error of the of the final algorithm selected was slightly below the desired error set by NASA's OBBP
- ✓ The results of this research provide new tools to the Lake authorities (AMSCLAE, CONAP) and academia (UVG, Univ. of San Carlos) to monitor *Chl a*
- ➢ The final algorithm selected in this thesis assumes that the color of the water in Lake Atitlan is mainly driven by phytoplankton
- ‼ Given the low variability of the in situ samples used to develop the algorithm is expected that the relative error will increase if the same algorithm is applied in *Chl a* concentrations > 10 mg/m³
- ‼ New acquisitions of EO-1 Hyperion satellite images need to be tasked

6. Further Research

In order to have an operational system that estimates *Chl a* concentrations from Hyperion-derived surface reflectances, it will be necessary to apply atmospheric correction to the entire satellite image. As a next step it is envisioned to compile a methodology that performs a high quality atmospheric correction, based on 6SV, for the whole satellite image.

Additional analysis will be done with EO-ALI and Landsat ETM+ and OLI satellite images to test the performance of their broad bands in the blue and green part of the spectrum.

In addition, it is expected to expand the *in situ* datasets used for algorithm development to include more variability of *Chl a* concentration conditions. Since the current analysis did not include *in situ* samples from high *Chl a* concentration conditions, this aspect is of crucial interest.

This research also provided insight about the conditions under which extreme *Chl a* concentration events usually occurred. Algal bloom events have only been reported for the end of the rainy season, with such extreme events starting around October. A hypothesis is to test is how the changes in temperature and rainfall affect the thermal stratification of the lake, creating a turnover in which colder waters carrying cyanobacteria move to the surface level. At this point, high loads of nutrients provided by the runoff and high solar radiation are the triggers to start the cyanobacteria bloom.

ASTER satellite image captured on December 2009, portraying the algal bloom event that affected Lake Atitlan for over two months, with *Chl a* concentrations > 100 mg/m³. The following steps of this research will look forward to model extreme *Chl a* concentration by analyzing the effects of weather parameters, such as temperature, rainfall and solar radiation.

Acknowledgements

Thanks go to the Center of Lake Atitlan Studies (CEA) of Universidad del Valle, the Authority for Sustainable Management of the Lake Atitlan Basin and its Environment (AMSCLAE), NASA Goddard Space Flight Center for the acquisition of EO-1 Hyperion data, and to the additional support from NASA/USAID SERVIR program and the UAH Earth System Science program.

References

Chernick, M. R. (2012). Resampling methods. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery*, *2*(3), 255–262. doi: 10.1002/widm.1054

Gitelson A A, Dall'Olmo G, Moses W, Rundquist D C, Barrow T,Fisher T R, Gurlin D and Holz J (2008) A simple semi-analytical model for remote estimation of chlorophyll-a in turbid waters validation Remote Sens. Environ. 112 3582–93

Gower, J. F. R., Brown, L., & Borstad, G. A. (2004). Observation of chlorophyll fluorescence in west coast waters of Canada using the MODIS satellite sensor. *Canadian Journal of Remote Sensing*, *30*(1), 17–25. doi:10.5589/m03-048

Gower, J. F R., Doerffer, R., & Borstad, G. A. (1999). Interpretation of the 685 nm peak in water-leaving radiance spectra in terms of fluorescence, absorption and scattering, and its observation by MERIS. *International Journal of Remote Sensing*, *9*, 1771– 1786.

Werdell, P. J., & Bailey, S. W. (2005). An improved in-situ bio-optical data set for ocean color algorithm development and satellite data product validation. *Remote Sensing of Environment*, *98*(1), 122–140. doi:10.1016/j.rse.2005.07.001

O'Reilly, J. E., Maritorena, S., Mitchell, B. G., Siegel, D. a., Carder, K. L., Garver, S. a., ... McClain, C. (1998). Ocean color chlorophyll algorithms for SeaWiFS. *Journal of Geophysical Research*, *103*(C11), 24937. doi:10.1029/98JC02160

2014 Fall AGU Meeting. Session: GC53A. Climate and Environmental Data, Information, and Knowledge for Societal Decision Making in the U.S. and International/SERVIR Regions. San Francisco, California.