MONITORING LONG TIME TRENDS IN LAKE CDOM USING LANDSAT IMAGE ARCHIVE

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1. INTRODUCTION

Lakes and reservoirs comprise a small portion of the Earth's total surface area, yet they are likely to play a substantial role both as regulators of future climate change, and as integrators of the present and past effects of climate change on terrestrial and aquatic ecosystems. Lentic ecosystems are the lowest point in the surrounding landscape and as such can provide information on how climate change alters not only aquatic ecosystems, but also the terrestrial ecosystems in the surrounding watershed. Alterations in seasonal temperature and precipitation patterns as well as climate control of carbon flux into and out of lakes may play a central role in both the ecology of aquatic and terrestrial communities and ecosystems, and in global biogeochemical cycles.

Recent estimates [1] show that the emissions of carbon from inland waters to the atmosphere are similar in magnitude to global terrestrial net ecosystem production, and that the rate of burial of organic carbon in inland water sediments exceeds organic carbon sequestration on the ocean floor. Downing et al. [2] even suggest that the rate of deposition of fixed organic carbon in lakes and reservoirs exceeds by up to four times that being deposited in the world's oceans. However, the coupled climate-carbon cycle models used by the Intergovernmental Panel of Climate Change [3] to predict future climate change scenarios ignore lakes completely [4]. The models treat lakes and rivers as inert “pipes” transporting carbon from terrestrial systems to oceans i.e. all the carbon produced on land is transported into oceans. Cole et al. [5] proposed so called “active pipe” hypothesis where the inland waters have significant active role in the carbon cycle. The present estimate of annual carbon fluxes [1] suggests that from 2.9 Pg carbon originated from land 0.9 Pg reaches oceans, 0.6 Pg is deposited in sediments of inland waters and 1.4 Pg is degassed from inland waters to atmosphere.

Changes in lake carbon content have also direct impact on human wellbeing besides affecting the global carbon cycle. Chlorination of water rich in DOC results in the formation of mutagenic chlorinated by products [6,7] and DOC has been shown to have hormone-like effects on vertebrates [9]. Climate scenarios with warming climate indicate probable increase in the amount of precipitation in northern latitudes and more dissolved organic carbon reaching lakes. Therefore, it is very important to map carbon content of lakes.

It has been shown [9, 10] that satellite remote sensing can be used to map lake CDOM concentration from space. In boreal lakes CDOM is closely correlated with DOC and CO_2 supersaturation in water [11]. Consequently, remote sensing could be a useful tool to monitor changes in lake carbon content. Landsat Thematic Mapper data is available since 1984. Although we have shown [8] that Landsat sensitivity is not sufficient to map lake CDOM content in dark brown lakes it is still tempting to try can the freely available Landsat archive be suitable for mapping.

2. SATELLITE IMAGERY AND IN SITU DATA

Swedish University of Natural Sciences has been monitoring lakes since the sixties. The monitoring data includes absorbance of filtered water at 420 nm that can be considered as a proxy of CDOM concentration in lakes. Surface sample data from this database was used to test suitability of Landsat imagery for monitoring changes in lake CDOM content. The used in situ data includes 19 sampling stations. Five of the stations were from Lake Mälaren (third largest lake in Sweden), two from Lake Vättern (second largest lake in Sweden) and 12 sampling stations were in different small lakes.

Landsat imagery of two sites – one in central Sweden and one in southern Sweden was downloaded from the now freely available Landsat archive. More or less cloud free imagery from the period between 1984 and 2008 were used. Landsat data was processed to a different degree. We used reflectance imagery that was produced by re-calculating raw digital number into the top of atmosphere radiance and then correcting the images with FLAASH atmospheric correction module in ENVI software package. Raw imagery was also used.

3. RESULTS AND DISCUSSION

The in situ data revealed that variations in CDOM concentration over the more than 40 year period may be quite different even if the lakes are in the same region. In the case of large gomorphologically sophisticated lake like Mälaren CDOM variations differ even on basin scale. For example in two basins the CDOM concentration has been relatively stable over the years with very modest increase over last 46 years. On the other hand there is about two-fold increase in CDOM in three other basins of the lake.

Landsat band 2 and band 3 ratio was used to describe concentration of CDOM in lakes under investigation. Like in case of publications [9, 10] the Landsat B2/B3 ratio decreased exponentially with decreasing CDOM concentration. However, scattering of the results is relatively high, especially in the case of brown lakes with high CDOM concentration. One of the reasons is time difference between the in situ sampling and image acquisition. In situ data that was collected within a month from the image acquisition was still used in the analysis. Usually the CDOM concentration in boreal lakes decreases from spring to autumn. However, heavy rain can cause rapid changes in CDOM concentration. There are also some exceptional cases where spatial distribution of CDOM may cause scattering in the relationship between B2/B3 ration and CDOM concentration. For example image data suggests that there are areas in Lake Mälaren where concentration of CDOM has remarkable variations due to riverine input of CDOM-rich water. Location of these areas varies rapidly in time. In such areas even small time differences between sampling and image acquisition may cause serious discrepancy between the results.

Although the above mentioned reasons may cause unsatisfactory correlation between the in situ and satellite data the main obstacle in using Landsat for water monitoring is sensitivity of the instrument. Landsat is a 8-bit instrument. It means that the whole range of energy measured by the sensor is divided into 256 energy levels. Our results indicate that the total variability in digital values measured over lakes does not exceed four digital numbers. Nichol and Vohora [12] have shown that there is systematic noise in Landsat data that decreases the number of useful digital values by one. If the total variability in blue band is 2 digital units and in red and green bands it reaches 3 then the total number of possible spectral shapes is very low compared to the whole range of optical properties of lakes. It means that the changes in optical properties (e.g. concentration of CDOM) have to be dramatic to change Landsat signal by one digital number. In most lakes the variation in CDOM concentration over the years or annually is too small to be detectable by such insensitive sensor like Landsat Thematic Mapper.

Like Kallio et al. [13] we found that there is practically no difference between the results whether to use raw Landsat data or atmospherically corrected imagery. It can be explained by the small number of detectable signal levels. For example if the total variability in the case water pixels in one Landsat band is just two or three then it does not matter much do we use integer digital values of the raw imagery or correct the same three values into reflectance.

Our results suggest that the suitability of Landsat archive for studying trends in lake water quality are fairly limited due to technical characteristics of the Thematic Mapper sensors. In our previous studies [9,10,14] we showed that the Advanced Land Imager (ALI) is suitable for mapping lake CDOM even in dark brown lakes. ALI is the predecessor of next generation Landsat sensor to be Launched in December 2012. Thus, from 2013 onwards there will be a sensor suitable for studying lake carbon content and the role of lakes in the global carbon cycle. However, it will take several more years before the new sensor's image archive will be long enough to study trends in lake carbon concentrations.

4. REFERENCES

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