ADVANCES IN COMBINING OPTICAL CITIZEN OBSERVATIONS ON WATER QUALITY WITH SATELLITE OBSERVATIONS AS PART OF AN ENVIRONMENTAL MONITORING SYSTEM

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1. INTRODUCTION

Earth observation technology for environmental monitoring using satellite or airborne data is developed in Finnish Environment Institute (SYKE) in order to meet very profound information requirements: Finland is rather large and sparsely populated country, and for example large portion of the over 187 000 lakes are situated in least densely populated areas. Sparse population implies long distances from locations of specific environmental monitoring interest to nearest laboratory in which laboratory tests can be conducted on the water samples and extensive mileage for professional measurement technicians and experts with dedicated equipment. However, neither satellite data nor combined hydrological/ecological models alone can replace in situ observations for certain monitored parameters. Thus, recently increasing research efforts have been allocated for joint use of different sources of data. In this context, possible contributions from non-professional observers with more or less training, with or without measurement equipment to quantify the observations is of interest. Key “measurement equipment” widely available for use is a modern smartphone, mobile communication device with digital imaging and location capabilities. For water quality, optical properties of water derivable from these images are a logical comparison to optical properties estimated from satellite optical data. In addition to digital imagery, volunteer observers can be organized to report their other observations in standardized manner using web services or mobile applications, thus providing useful data of the environment.

2. CITIZEN OBSERVATIONS IN FINNISH WATER ENVIRONMENT MONITORING

Awareness of citizens on environmental issues and the state of surface inland waters and the Baltic Sea is high in Finland. Citizens report local and regional environmental authorities, and the Finnish Environment Institute (SYKE) on algal phenomena (e.g. algal mass occurrences) and other “interesting” or concerning observations and findings related to surface waters particularly during the holiday season in summer, when they spend more time next to lakes and the Baltic Sea in their summer cottages and/or when bathing or sailing. Regional environment centres (Centres for Economic Development, Transport and the Environment) and SYKE analyse generally for free the abundant algal bloom samples to identify the bloom or phenomenon forming taxa. This information is also transferred to Harmful Algal Bloom data base of SYKE [4 ]. SYKE invites and encourages citizens to make observations on cyanobacterial bloom situation and surface water temperature in lakes and the Baltic Sea during summer, and e.g. the occurrence of medusae, fluorescing dinoflagellates (e.g. Alexandrium ostenfeldii), and the bladder wrack (Fucus vesiculosus) in the Baltic Sea, and during winter the ice phenology in lakes [1, 4]. Also, voluntarily based observing of litter on the shores of the Finnish Baltic Sea is to be launched which will also serve the monitoring of Marine Strategy Directive of EU. These observations can be done using the mobile phone application Levävahti or using the web-service Järviwiki/Meriwiki provided by SYKE [1, 4]. All citizens observations are shown on-line in the
Järviwiki/Meriwiki available for all, where results are also stored and presented as maps. At present, environmental authorities use certain observations made by citizens as supporting additional data in the assessment of status of surface waters (e.g. algal bloom occurrence, frequency and intensity in lakes [4, 5]), but in future the purpose is to increase the usability of citizen observations with improved quality control, training, instructions and simple tools to make and report observations.

3. OPTICAL OBSERVATIONS AS COMBINED TO EO DATA

The joint use of citizen observations and high resolution satellite images was piloted in Lake Lohjanjärvi and surrounding lakes in southern Finland as part of the Karjaanjoki LIFE project (INNOWA, LIFE00 ENV/FIN/000668). Lake Lohjanjärvi (center coordinates: 60.5° N – 24.0° E) is a meso-eutrophic lake with an area of 89 km². In 2000–2001, 80 volunteers were trained for measuring Secchi disk transparency. The volunteers were local stakeholders from the different shoreline areas of the lakes, and they were advised to make their observations on three Landsat ETM+ (path 189, row 18) overpass days in 2002 in case of cloudless conditions. The coefficients of the empirical interpretation algorithm (based on a ratio of channel 1 and channel 2 of ETM+) was trained with citizen observations. On May 20th in 2002, when the range of citizen Secchi observations was 0.6 – 4.0 m (Fig. 1), the $R^2$ of the algorithm was 0.96. This day specific algorithm was applied to all the pixels of the ETM+ (Fig. 1). This study demonstrate how the combined use of citizen observations and satellite images makes possible to get spatially accurate estimate of water quality in a lake area with diverse lake types, not possible to map effectively by discrete sampling alone.

![Secchi transparency of Lake Lohjanjärvi and surrounding lakes on 20th May 2002 based on citizen observations at 19 stations (on left) and LANDSAT ETM+-image (on right). The citizen observations were used to algorithm training of the ETM+ image.](image)

4. SECCHI3000 TECHNOLOGY AND IQWTR MEASUREMENT DEVICE

In 2006, the original idea of Secchi3000 technology was invented by Timo Pyhälahti during EO & modeling ground truth gathering field work in spring, after watching brownish melting water from snow to flow over a white piece of ice: In case there is a known target device with fixed positions of reference black/white/grey/color panels submerged in water, the apparent color of panels varies due to different distances through water in the line of sight to them. In combination with known measurement geometry these color differences, as captured by a digital camera to numeric value in RGB (red-green-blue) domain, can be mathematically modeled to provide estimates of water optical properties and further to environmental monitoring variables such as Secchi depth or water turbidity. Naturally there is plenty of possible configurations of such devices: With iterations and technical tests in SYKE and HUT (currently part of Aalto University in Finland), a simple transparent container with two white-gray-black panels...
was selected as a prototype of an inexpensive measurement device. This one type of realization of Secchi3000 technology was then extensively tested with a set of similar prototypes and a mobile phone application system with VTT. The original development was then taken up by Water Insight / BlueLeg Monitor in order to turn the prototype systems into commercially available systems: Both hardware and software parts needed thorough redesign for practical parts, and now they are developed under iQwtr brand name.

5. RECENT RESULTS

5.1. Algal Bloom Monitoring in Finland by Citizens and Experts 2011-2013

Algal mass occurrences are one of the most distinguishing effects of eutrophication in lakes and the coastal waters of the Baltic Sea. Algal bloom occurrence in water bodies varies greatly in terms of both space and time, even during short periods, which makes reliable monitoring of blooms difficult. Remote sensing of algal mass occurrences by satellites can provide high temporal and spatial resolution bloom information of sea areas (e.g. [4]). Monitoring of small water bodies by satellite remote sensing requires images with a good spatial resolution (< 30 m). At present, such images are not operationally available on a daily basis. One possible way to increase both temporal and spatial coverage of surface bloom visual observations in a larger number of lakes and the coastal regions of the Baltic Sea is to include citizens as observers.

Kotovirta et al. [3] studied how reliable information citizens can provide for surface algal monitoring. They compared citizen observations against trained, expert algae observers that perform weekly algae monitoring in 320 pre-determined locations in Finland. Their results suggest that citizens can provide useful data for surface algal monitoring.

5.2. Secchi3000 technology development

After original ideas in 2006, Secchi3000 technology has been developed within various projects, and several designs were attempted. Finally, a compact container prototype design was further tested in field conditions using prototype devices.

5.2.1. VTT & SYKE Secchi3000 prototype tests

Toivanen et al. [2] used a Secchi3000 prototype for water transparency and turbidity monitoring. The results show that overall the system performs well. Both Secchi depth and turbidity are estimated with excellent or good accuracy when the measurements are taken with care. Their approach included a participatory sensing application for mobile phones with which users take pictures of target areas inside a cheap and simple measurement device filled with water and send them with related metadata (e.g., location) to a central server. On the server, water turbidity and Secchi depth are automatically post-processed from the images using pattern recognition and computer vision approaches.

The mobile phone application the users can use to gather observations is called EnviObserver [5]. It is a tool for participatory sensing which utilizes people as sensors by enabling them to report environmental observations with a mobile phone. The current version of the Secchi3000 measurement device consists of a container and two measurement tags that are used in the analysis. The tags are located at different depths in order to derive water turbidity. After filling the container with water, the user takes a picture looking inside the container through a hole in the lid. GPS location and timestamp are automatically retrieved during the measurement. In addition to the picture, users can enter supplementary information, e.g., ID of the measurement site. Finally, the user sends the data collected to a central server for automatic water quality analysis. The water quality analysis consists of two separate algorithms. After receiving a picture, the first algorithm automatically detects the
locations of the tags in the picture and extracts pixel RGB values for the black, grey, and white areas of the two tags. The second algorithm carries out the actual water quality analysis based on the RGB values extracted by the tag recognition algorithm. After the automatic analysis, the result is sent back to the user and stored on a database. The prototype performance was tested extensively for turbidity in laboratory[3]. Accuracy was found to be sufficient for turbidities less than 7 FTU (Formazine Nephelometric Unit), but the overall performance did not yet meet the full criteria for official monitoring. However, 7 FTU is sufficient for most Finnish lakes, thus gathered data is applicable as supplementary information.

5.2.2. iQwtr device for water quality
Mass production of devices intended for citizen monitoring is required in order to achieve sufficiently inexpensive equipment. In addition, factors like ease of use or ease of distribution of devices and mobile application are important, and they too are easier to focus on in a commercial organization. The practical experiences achieved with the Secchi3000 prototype were used by Water Insight and BlueLeg Monitor, Dutch companies, to re-design the device into iQwtr. Development of the commercial iQwtr is on-going.

6. OUTLINE OF FUTURE ACTIVITIES
In 2015, in the frame of a new Finnish national project Envibase, citizen observation gathering technologies and methods are among the key areas of development. During the next three years, the use of voluntary observers and their contributed data is developed and streamlined into useful component of general environmental monitoring. In addition to iQwtr equipment and methods technical development, crowdsourcing methods in general should be developed: How to enlist new enthusiastic observers, how to motivate more observations and sustain good quality in order to fill the observation gaps? How to synchronize and combine the data from satellites and other sources with the input by citizen observers? The challenges are not only scientific and technical – a major task is to formulate the organization and network which actually procures required equipment and trains the new observers in a sustainable way.

7. REFERENCES