CYANOBACTERIA ASSESSMENT IN ITALIAN AND SWEDISH WATERS FROM SPACE

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Table of contents

Acknowledgements 2

Summary 4

1. Scientific rationale 5

2. Project's aims 5

3. Project's team 5

4. Research activities 6

4.1 Introduction 6

4.2 Ecological status of cyanobacteria 8
Cyanobacteria blooming in the study area 9

4.4 Remote sensing of cyanobacteria 10
State of art 11
Algorithms developing 14
Limnological analysis 18

5. Cooperation activities 23

5.1 Workshops 23
"Remote Sensing of Lakes" 23
"Remote Sensing of Cyanobacteria" 24

5.2 Joint campaigns 27
Lakes of Mantua 27
Lake Vänern 33

6. External expertise 42

7. Education 42

8. Divulgation 43

9. Conclusions 44

10. References 44

11. Acronyms and symbols 52

12. Annexes 54

Annex I. Synergic projects 54

Annex II. Workshop "Remote Sensing of Lakes" - List of participants 56
Italian Contribution 56

Annex III. Workshop "Remote Sensing of Cyanobacteria" 57
Leaflet 57
List of participants 58
Video of the oral session 58

Annex IV. AERONET-OC Pålgrunden station 59

13. List of digital files 60

Summary

During the first year of our bilateral cooperation in cyan-IS-was we have completed important measurements in the field and are currently analysing the results. We have also made some good progress regarding the satellite data processing. In particular improvements in the algorithms development for assessing cyanobacteria from space have been accomplished. It has been demonstrated that band-ratio-types algorithms are able to distinguish cyanobacteria from other algae. A bio-optical model has been also considered for the detection of cyanobacteria simultaneously to other water quality parameters but further *in situ* data are needed to calibrate the algorithms. For this, *in situ* data collected with new instrumentation purchased within cyan-IS-was framework represents a central task.

The project activities have been mainly focused on inland waters but the preliminary steps for research activities in marine waters and satellite image processing, scheduled for the next years, have been accomplished.

The cooperation activities allowed the Italian and Swedish teams to share both knowledge and instrumentation as documented by the organisations of two scientific workshops and of two joint campaigns carried out in the lakes of Mantua and in Lake Värnen, respectively.

Furthermore, the cyan-IS-was project activities included PhD and MSc student training for students both from Italy and Sweden. Moreover, the involvement of external experts allowed us to reach the project aims according to the project plan.

1. Scientific rationale

Eutrophication and cyanobacteria blooms present an increasing threat to the health of aquatic ecosystems and to humans who use these resources for multiple purposes (e.g. drinking, recreation, aquaculture). Cyanobacteria are the predominant harmful algal blooms (HABs) organisms, although other phytoplankton species (e.g. chrysophytes and dinophytes) might also contain or release toxins into the water when the algae die and decay. Recent findings show that global climate change and higher temperatures are expected to worsen the shift to turbid water and cyanobacteria-dominated conditions in waters (Johnk et al. 2008). HABs are now a more common and spatially more extended occurrence, but the management of such new problems by the local authorities is often quite complex, due to the lack of expertise with the early detection of blooms, and due to difficulties in an objective evaluation of field data. It is therefore a challenge to foresee the extent of the environmental damage and of the health risk caused. Measurements are generally performed at relatively few monitoring stations and not repeated frequently enough due to the high costs associated with field activities.

Remote sensing is a good complement for assessing such information and it is being used increasingly as a tool for monitoring these phenomena in inland and near-coastal waters (Matthews et al. 2010) as it provides a synoptic view of a whole lake, and other lakes nearby. As an integrated technique, remote sensing represents the opportunity to extend the standard point observations into the spatial domain, and can also provide continuous time-series of data. These time series permit monitoring and evaluation of changes in water quality that are the result of human and natural changes to the aquatic ecosystems.

2. Project's aims

The Cyan-IS-was project aims to develop algorithms for detecting cyanobacterial blooms from earth observation (EO) data. To achieve this result, expertise from EO research groups from Italy and Sweden are used. There is also a clear emphasis on bilateral cooperation between the Cyan-IS-was partners in terms of joint field-work and workshops. Furthermore, dissemination and educational activities are also another important component of the project mission.

3. Project's team

The project team is composed by researcher, post doc and PhD students as well as by of the field experts of the field.

Italian research unit

Name	**Institute**	**Main role**
Claudia Giardino	CNR-IREA, Milano	Italian PI
Anna Rampini	CNR-IREA, Milano	Project reviewer
Mariano Bresciani	CNR-IREA, Milano	EO and ecology
Simone Lella	CNR-IREA, Milano	EO and ICT
Monica Pepe	CNR-IREA, Milano	Fieldwork
Daniela Stroppiana	CNR-IREA, Milano	Fieldwork and EO
Giacomo De Carolis	CNR-IREA, Milano	Fieldwork
Paolo Villa	CNR-IREA, Milano	EO and ICT
Mauro Musanti	CNR-IREA, Milano	Fieldwork
Federica Braga	CNR-ISMAR, Venezia	EO and fieldwork
Marco Bartoli	University of Parma	Ecology

Swedish research unit

Name	**Institute**	**Main role**
Susanne Kratzer	Stockholm University	Swedish PI
Niklas Strömbeck	Strömbeck Consulting	Project manager, optics and ecology
Annelies Hommersom	Stockholm University	Bio-optics and fieldwork coordination
Therese Harvey	Stockholm University	Bio-optics and fieldwork activities
Jose Beltran	Stockholm University	EO and fieldwork
Gerald Moore	Bio-Optika, UK	Research engineer, modeller

4. Research activities

4.1 Introduction

Fresh and coastal waters are a precious source of life for all life forms on planet Earth. The impact on the environment of the human species has already caused profound changes on the balance, health status and the presence of all other species. Unfortunately, the trend of development of our society seems increasingly to continue the abuse of environmental resources. It is therefore of fundamental importance to know about the characteristics, adaptations and changes that occur in the dynamics of ecosystems. In particular, it is important the understanding of the relationship between the biotic and abiotic components, as a function of both direct human impacts on time at both global changes.

Nowadays, one of the main problems interesting lake and coastal waters is the eutrophication, seen as excessive development of phytoplankton component due to natural and/or human-driven factors. In particular, the excessive presence of organic nutrients in water and sediments, associated with increases in temperature and changes in water levels, creates the phenomena of algal blooms. Given the impact that can result in aquatic ecosystems one of most important phytoplankton blooms are those defined as harmful algal blooms (HABs), which include those species that may lead to the production of dangerous toxins (Falconer 2001). Generally, cyanobacteria (Jhonk et al. 2008), maybe also associated with chrysophyta and dinophyta (Hudnell et al. 2010), are the most common species causing HABs.

The frequency and extent of intense phytoplankton blooms has increased in inland and coastal waters around the world (Hallegraeff 2003; Sellner et al. 2003; Glibert et al. 2005a,b). Potentially harmful effects of the blooms (Edler et al. 1985; Horner et al. 1997; Landsberg 2002; Backer and McGillicuddy 2006) on human and animal health, drinking water quality and recreational use of water bodies have raised the awareness of the general public, environmental agencies and water authorities. Therefore, reliable monitoring of potentially harmful blooms is needed.

But there are still many gaps in knowledge about the distribution and proliferation of cyanobacteria. In particular, the role of environmental stress on their ability to dominate the nutrients is still unclear, as well as the degree of competition of cyanobacteria over other phytoplankton species. The limited knowledge about cyanobacteria growth and proliferation is also due to shortcomings for their classification (adopted by different institutions dedicated to their monitoring), for the different methods of counting, for the lack of standardization in sampling frequency and quantity. Furthermore, no comprehensive information on the seasonality of cyanobacteria and on their vertical distribution under natural conditions or during bloom is available.

Conventional monitoring networks, based on infrequent sampling at a few fixed monitoring stations are a basic methodology to try to understand the mechanisms and dynamics of aquatic ecosystems but they cannot provide the information required for evaluation as the blooms are very heterogeneous, both spatially and temporally (Liu et al. 2003; Nausch et al. 2008). The gap can be filled by remote sensing providing the spatial and temporal coverage needed (Fig. 1).

Figure 1 - MERIS captures blue-green algae blooms filling the Baltic Sea, which is roughly 1600 km long, 190 km wide and has a surface area of about 377 000 km^2 (ESA©).

The usefulness of airborne (Wrigley and Horne 1974) and satellite (Öström 1976) remote sensing in detecting phytoplankton blooms was demonstrated more than three decades ago. Several works have in particular focused on the satellite-inferred estimation of the concentration of phytoplankton (Baban 1993; Giardino et al. 2001; Gons et al. 2002; Strömbeck and Pierson 2002; Doerffer and Schiller 2007; Gitelson et al. 2007; Gower and King 2007; Bilgehan et al. 2009; Bresciani et al. 2009). In fact, changes in the concentration of chl-a are associated to changes in the amount of water leaving radiance in the photosynthetically active radiation region of the electromagnetic spectrum and these changes can be detected with optical remote sensors (Baban 1999).

4.2 Ecological status of cyanobacteria

Since 1970, in different parts of the world, a continuous increase in frequency of algal blooms, often with species producing toxins, has been documented because both the increasing attention of scientific community towards cyanobacteria-related studies and the increasing frequency of episodes of poisoning of animals, including man (Chorus and Bartram 1999). Massive blooms of cyanobacteria are known and reported in different lakes: Okarito (Walsby et al. 1987), Åland (Lindholm et al. 1989), St. George (McQueen and Lean 1987) and Orielton (Jones et al. 1994). In coastal areas the first blooms were observed in the Baltic Sea (Horstmann 1975), in the Curonian Lagoon in Lithuania and in the Patos Lagoon in Brazil (Younes et al. 1996).

In the last decade, blooms of cyanobacteria have become an entity of concern not only for those lakes whose morphological characteristics (e.g. reduced depth, high intake of organic loads) facilitate eutrophic and dystrophic conditions (e.g. Lake Trasimeno (Cingolani et al. 2007), Lake Chahou (Deng et al. 2007)) but also interest deep oligotrophic lakes such as the Italian subalpine lakes.

Overall, the HABs can reach very high concentrations such as in some eutrophic lakes in the Czech Republic where the bloom reached a biovolume greater than 100 mm^3/l (Znachor et al. 2006): Otherwise HABs can interest large area with extensions of 100000 km^2 in the Baltic Sea (Metsamaa et al. 2006). Meanwhile, toxins produced by cyanobacteria can be lethal to humans and animals (Codd et al. 2005).

The growth of cyanobacteria is related to defined conditions: water temperature between 10 and 30 °C, with optimal value of 25 °C (Robarts et al. 1987), no wind (maximum of 3-4 ms^{-1} in addition to which it is unlikely the formation of blooms and foam (Reynolds 1987)), pH between 7.5 and 9.0 (Shapiro 1990), high atmospheric pressure and lack of water turbulence. The rate of appearance of the bloom can be very rapid, up to two days under optimal conditions (Ressom et al. 1994), and involves a significant alteration of the physical and chemical characteristics of water. Foams as well as water discolour produce unpleasant odours causing problems to aquatic life (Deng et al. 2008). The blooms have varying rates of persistence (a few days to several weeks) and generate a potential hazard, due to bioaccumulation of toxic substances, that can persist for more than three months before sunlight and microfauna degrade them.

Cyanobacteria blooming in the study area

The presence of cyanobacteria in Italian lakes is known since the 50s (Bazzichelli and Abdelahad 1994), but intense blooms with related ecological and health problems are attributable to late 80s. According to the Italian Institute of Health the presence and development of toxic blooms of cyanobacteria have affected a total of over 50 lakes and reservoirs of the Country. The growth has been linked to the general increase in trophic status (Garibaldi et al. 2003; Garibaldi et al. 1997; Cordella and Salmaso 1992). The blooms of cyanobacteria are documented both in shallow eutrophic lakes, characterized by high loads of organic nutrients (e.g. Lake Trasimeno (Manti et al. 2005), Lake Albano (Bogialli et al. 2006)) and in deep Subalpine lakes whose waters are meso-oligotrophic (Morabito et al. 2001; Salmaso, 2006). Intense blooms have been reported in also in some reservoirs of Sicily and Sardinia (Naselli-Flores et al. 2007), whose importance is relevant since provide waters for various human activities.

According to our research activities now we focus the state of art of the first year of cyan-IS-was project on inland water which include three Italian lakes (Fig. 1), two of them belonging to the Subalpine lake district and the other to Central Italy and the largest lake in Sweden.

Lake Garda - First blooms of cyanobacteria in Lake Garda were documented over 15 years ago: In particular, in the eastern basin an extensive bloom of *Anabaena lemmermannii* associated with *Microcystis aeruginosa* (Salmaso and Cordella, 1994) was observed in October 1990. Later on single-specie blooms (*Anabaena lemmermannii*) were observed from 1991 to 1997 between July and August (Salmaso, 2005). The blooms have occurred in the form of thin layers and thin yellow-green stripes floating in a layer thickness of about 2 cm. The counts were of the order of 190000 cell/m in the first centimetre of waters and of 95000 cells/m in the 0-2 m. In the water column fro 0 to 20 m, the concentration of Anabaena have never exceeded 250 cells/m, even in occasion of strong blooms (Salmaso 2000). Since the end of the 90, *Anabaena* blooms have spread to all parts of the lake as a result of increased trophic conditions and of the changing of weather conditions (Salmaso et al. 2001). From 1993 to 2007, the temporal variation of biomass of phytoplankton showed an increase from 7 to over 20% (Salmaso et al. 2009) of the total component of cyanobacteria.

Lake Trasimeno - Until 1990 phytoplankton communities of Trasimeno were mainly dominated by cloroficee and diatoms and cyanobacteria (*Phormidium* spp. and *Oscillatoria tenuis*) were present in small quantities only. More recently the community tend to be populated by filamentous blue-green algae, especially during late-summer when the presence of *Cylindrospermopsis raciborskii* and of *Planktothrix agardhii*, through the thickness of lake surface has been documented (Cingolani, 2000). From August to September intense blooms of *Cylindrospermopsis raciborskii* in the whole water column was observed in 2004 and 2005. They were related to the presence of optimal conditions for their growth, such as prolonged high water temperature and sunlight (Cingolani et al. 2008).

Lake Maggiore - In latest years, cyanobacteria represent the dominant group with the greatest biodiversity observable in Lake Maggiore. The growth of cyanobacteria has focused mainly in summer. The *Snowella lacustris* was the most important species in terms of biovolume but in the last years an increasing trend of *Aphanizomenon flos-aquae* and

Planktothrix rubescens, Oscillatoriales/agardhii was observed at the expense of Chroococcales. Then, in 2005 and 2006, some extensive blooms of *Anabaena lemmermannii* were documented. The study of algal succession of the lake, through cluster analysis, showed that during late summer and autumn the most common species belong to S & C strategy, including picocianobatteri that, at very low irradiance (Caravati, 2003), have higher efficiency than nano and microfitoplancton.

Lake Vänern - According to the authorities, no cyanobacterial blooms occur in Lake Vänern. However, the presence of cyanobacteria is documented (Vänern, Årsskrift 2010) in the monitoring data from the summer of 2009, mainly *Aphanizomenon flosaquae v. klebahnii* and *Woronichinia naegeliana*. Moreover, the authors (Kratzer and Strömbeck) have at two different occasions in 2009 and 2011 observed streak-forming buoyant cyanobacteria on the open Lake Vänern.

4.4 Remote sensing of cyanobacteria

The first applications of remote sensing to the study of aquatic environments date back almost fifty years ago when satellites measurements of chlorophyll provided the basis for the first large-scale estimates of oceanic net primary production and determination of its close links with climate (Tatem et al. 2009). Then, with the advent of higher spatial resolution sensors in the '80, estimations of chl-a has been also possible in inland and coastal waters (Baban, 1993; Giardino et al. 2001; Gons et al. 2002; Strömbeck and Pierson 2002; Doerffer and Schiller, 2007; Gitelson et al. 2007; Gower and King, 2007; Bilgehan et al. 2009; Bresciani et al. 2009). More recently, with improving of spectral and radiometric resolutions the exploitation of satellite data to map cyanobacteria has been also documented. Cyanobacteria are photosynthetic pigments with (carotenoids, phycocyanins, alloficocianine, phycoerythrin) absorbing sunlight in different wavelengths. This capability makes them efficient and allows different species to coexist in the same habitat. In particular, phycobiliproteins absorb in a spectral range (500-650 nm) which is rarely used by other phytoplankton species. In addition, they are able to vary the phycocyanine/phycoerythrin ratio and to synthesize pigments best suited to absorb the light present in the environment where they live. Hunter et al. (2008) showed that the concentration of cyanobacterial cells in the phycocyanine is closely linked to their physiological state and can vary greatly depending on the presence of nitrogen. If there is a lot of the availability of this N, phycocyanine (which contains N) are synthesized in large quantities, while in periods of scarcity of N, it is destroyed to make the nitrogen available for algal growth. Moreover, the efficiency of absorption of this pigment is influenced by environmental conditions, availability of light and nutrients, competition between different phytoplankton species and season (Randolph et al. 2008).

Pigments such as phycoerythrin and phycocyanine with their characteristic absorption peaks (usually very different than the other groups of phytoplankton component) become hence detectable from satellite sensors. Cyanobacteria dominated by phycocyanine have a characteristic absorption peak around 650 nm (Gons et al. 1999), while cyanobacteria dominated by phycoerythrin have a reflection peak around 600 nm only. But the wide variation of specific photosynthetic pigments makes not easier the identification of cyanobacteria from space. For instance, some species (those that generate foams), in order to protect the cell from high levels of illumination, have photosynthetic pigments (e.g.

carotenoids) able to absorb wavelengths at low photosynthetic efficiency (Chorus, 2001), others (e.g. *Cylindrospermopsis raciborskii*) are instead not affected in their growth by the intensity light (Moore et al. 2005). Nevertheless, different studies showed the capability of remote sensing to detect the extent of intense bloom of cyanobacteria (Kutser et al. 2008; Gons et al. 2005). To the aim different types of satellite sensors have been used: AVHRR (Kahru et al. 1993), CZCS (Siegel et al. 1999), SeaWiFS (Joint and Groom, 2000) and hyperspectral (Kutser, 2004; Kutser et al. 2006; Metsamaa et al. 2006; Reinart and Kutser, 2006; Simis et al. 2007) Other studies showed the potentiality of airborne imaging spectrometry (Dekker et al. 1992) and SAR (Svejkovsky and Shandley, 2001). A dedicated paragraph on state of the art is following.

With respect to cyan-IS-was, spectral characteristics of waters with cyanobacteria blooms were collected with a series of in situ measurements in different Italian lakes. To the aim spectroradiometers, fluoro-probes and water sampling analysis were used both in case of algal bloom and in absence. Acquired data, combined with an already available data set, allowed us to assess the impact of cyanobacteria on apparent optical properties in the major Italian lakes: Garda, Maggiore, Mantua, Idro and Trasimeno. In order to verify the variability of AOP in the vertical distribution of cyanobacteria, a series of measurements at different depths were collected. Moreover, since cyanobacteria are characterized not only by a high seasonal variability but also by diurnal cycle of sunlight (Serizawa et al. 2008), in situ measurement during the day were also collected. These data allow to investigate the migration along the thermal gradients of water column as a response to sunlight stimulus that inhibit some species (Reynolds, 1984) or photo-activate the synthesis of gas vacuoles (Sigee, 2005) needed to migrate towards the top the water column.

A final remarks on which parameter should be used to describe the concentration of cyanobacteria by using remote sensing it is necessary. In other words: "which in situ parameter has to be used to develop algorithms?" Potentially there are in fact different correlations feasible: with the number of cells of cyanobacteria (e.g. Gons et al. 2002; Ruiz-Verdù et al. 2008; Alikas, 2010; Hunter et al. 2010), the biovolume (e.g. Reinart et al. 2006; Alikas, 2010; Hunter et al. 2010), the concentrations of pigments characteristic measured by fluorimetric techniques (e.g Svejkovsky and Shandley, 2001, Vincent et al. 2004; Seppala et al. 2007; Giardino et al. 2010), with HPLC measurements (Zimba and Gitelson, 2006) and also with cyanobacteria-related chl-a concentrations (e.g. Senay et al. 2001; Gons et al. 2005, 2008; Gitelson et al. 2007; Hunter et al. 2008, 2009, 2010; Metsamaa and Kutser, 2008; Randolph et al. 2008; Zhang et al. 2009; Bresciani et al. 2010; Matthews et al. 2010). For each of this different parameter cyan-IS-was aim to evaluate pro and constrains.

State of art

The review of about 30 papers (cf. "State_of_art_summary.xls" file) on remote sensing of cyanobacteria firstly highlighted the complexity of their estimation and monitoring through satellite data. In fact, if the extension of cyanobacteria blooms is relatively simple to map, the retrieval of concentration may be tricky especially at low concentrations for several reasons.

First of all, it is necessary to consider that inland waters (case-II), differently from ocean waters (case-I), are characterized by the presence of optically active substances, which influence, regardless of the concentration of phytoplankton, the optical properties of the water (Kutser 2004; Gons et al. 2008; Metsamaa and Kutser 2008). In particular, the coloured dissolved organic matter (CDOM), which mainly absorb in the blue-green spectrum limit the use of this range for the derivation of spectral parameters related to phytoplankton. Secondly, cyanobacteria have certain properties that make them difficult to sample, among them their ability to move and organize horizontally and vertically within the water column (Kutser 2004; Kutser et al. 2008). Hunter et al. (2008) found a pattern of daily vertical migration of cyanobacteria influenced by sunlight duration and wind: in the darkness the cells aggregated together near the water surface, and then migrate to deeper waters due to the production, through photosynthesis, of heavy polymers. Then, when the wind is reduced, the cells return to the surface because become lighter for the destruction of metabolic reserve polymers. This migratory behaviour, defined as “buoyancy”, makes difficult to estimate cyanobacteria since a certain concentration of cyanobacteria could generate different spectral signals depending on their spatial distribution into the water column. Kutser et al. (2008), by use of bio-optical models has shown how the vertical distribution of chlorophyll in the water column affects both the magnitude and the shape of AOP. It is therefore recommended to combine satellite radiance measurements to in situ data at various depths.

With respect to in situ data collection Seppala et al. (2007) suggested to use fluorescence of phycocyanine as a parameter indicative of the amount of cyanobacteria. However it should considered that there is a modification of the actual distribution of cyanobacteria caused by passage of the boat used for sampling (Kutser 2004). With respect of in situ data to be used for validation of satellite products, it is also useful to consider than routine water sampling could occur at depths (e.g. 5 m) not matching the depth sensed by satellite sensors (about 10-20 cm in occasion of massive blooms) (Kutser 2004). Moreover, the concentration of cyanobacteria can vary significantly even within the space of ten meters; variation that could not be detected by most satellite sensors due to their low spatial resolution (more than 30 m for SeaWiFS, MERIS, MODIS and Landsat).

Despite these complications, several authors have reported positive and encouraging results in an attempt to quantify cyanobacteria concentration and remote sensing is, in any case, the most advantageous method for the monitoring of their bloom. Gonse et al. (2005) demonstrated the efficiency of optical remote sensing including in situ measurements of reflectance to have the sea-truth and airborne measurements for partly solving the atmospheric influences and improve the spatial resolution of satellite data. Then, satellite sensor can provide data with higher temporal resolution and coverage at lower costs.

The literature review showed two main approaches to estimate the concentration of pigments in cyanobacteria: bio-optical (or analytical) modelling and empirical methods. Bio-optical modelling (Kutser 2004; Gons et al. 2005; Simis et al. 2005a,b; Kutser et al. 2008) relates the spectral reflectance of apparent optical properties to the concentrations of its components by means of specific IOPs (i.e. coefficients of absorption and backscattering). The empirical approach can be used when spectral characteristics of the parameters of interest are known. This knowledge is included in the statistical analysis by focusing on well-chosen spectral areas and appropriate wavebands used as correlates.

Quantitatively, the relationships developed to assess concentrations within empirical approaches are sensor-depending and only apply to the data from which they are derived.

Well-calibrated and validated physics-based approaches are instead applicable to every scene acquired over the selected targets (presuming constant SIOPs), giving the opportunity to assess water quality independently from ground measurements. However a deep knowledge of the inherent optical properties and appropriate atmospheric correction are needed to retrieve reliable concentrations (Kutser 2004; Gons et al. 2005; Matthews et al. 2010).

The use of empirical algorithms is instead more effortless and direct. The approach attempts to find the best mathematical equation that relates the reflectance recorded by satellite signal preferably corrected by atmospheric effect, with pigment concentrations measured in situ (Hunter et al. 2008, 2009; Gitelson et al. 2007; Alikas et al. 2010). The approximation algorithms are site specific and may very well represent the environment in which they were made but they are not able to be successfully applied in other contexts.

Whichever approach is chosen, the derivation of the concentration of cyanobacteria pigments make use of specific characteristics of spectral signature (reflectance) in different wavelengths that can be sensed by optical sensors. The spectral signature brings the contributions of backscattering and absorption of pure water and of all optically active substances suspended or dissolved in it (i.e. phytoplankton, suspended solids, dissolved organic matter). Although the signal is attributable to all components, it is possible to identify some specific characteristic of the spectral behaviour of some of them. For example in productive generates a reflectance peak around 700 nm. Gitelson et al. (2007) showed that this peak may shift depending on the content of chlorophyll while the amplitude of the peak is explained by phytoplankton for only 2%, suggesting the contribution of reflection in this region might be due to organic and inorganic suspended sediments also. The blue-green ratio, commonly used to estimate phytoplankton in case-I waters, is in fact inadequate in meso-eutrophic case-II waters (Zimba and Gitelson, 2006; Gitelson et al. 2007; Gons et al. 2008; Kutser et al. 2008; Gonse et al. 2008,) while several band combination (commonly two or three) have been tested by using red and near infrared wavelengths: 708/664 nm (Simis et al. 2005a; Gons et al. 2008; Giardino et al. 2010; Matthews et al. 2010); 705/672nm (Senay et al. 2001), 720/670 nm, 765/670 nm, 748/667 nm (Gitelson et al. 2007), peak between 695-710 nm and 680 nm (Kutser et al. 2008), a quadratic function of 710/670nm (Hunter et al. 2010). It should be noted that use of band-ratios as a great advantage because the estimates can be accurate even with errors in atmospheric correction or in sensor calibration (Matthews et al. 2010; Bresciani et al. 2011). The use of three bands are based on the identification of wavelengths with λ_1 is the region of maximum absorption by the pigment of interest (650 nm is the ideal location for chl-a (Zimba and Gitelson 2006)), λ_2 is a wavelength insensitive to the pigment to be detected, and λ3, which is minimally affected by the absorption of the pigment, takes into account the variability of the medium through which the radiation passes, (Zimba and Gitelson 2006). Base on this approach, to estimate chl-a concentration, Matthews et al. (2010) used 670, 710 and 740 nm, while Gitelson et al. (2007), used 665, 708 and 750nm and Zhang et al. (2009), 690, 703 and 759nm. In all cases the three-band model seems more robust than simple ratio and might be applied to a wider range of chlorophyll concentrations (e.g. from 4 to 449 mg/m^3 (Zhang et al. 2009)).

With respect to the estimates of cyanobacteria, most of the studies are still based on the estimation of chl-a, being assumed as a proxy of cyanobacteria, although forbid to differentiate the different phytoplankton species (e.g. cyanobacteria, diatoms) (Senay et al. 2001; Svejkovsky and Shandley 2001; Lee et al. 2004; Kutser 2004; Gons et al. 2005; Zimba and Gitelson 2006; Gitelson et al. 2007, 2008; Kutser et al. 2008; Metsamaa and Kutser 2008; Zhang et al. 2009; Alikas et al. 2010; Bresciani et al. 2010; Giardino et al. 2010; Matthewes et al. 2010). Therefore, some authors, have focused the algorithm development on phycocyanine (Jorgensen et al. 1988; Vincent et al. 2004; Gons et al. 2005; Simis et al. 2005a,b,; Kutser et al 2006; Reinart et al. 2006; Seppala et al. 2007; Randolph et al. 2008; Ruiz Verdú et al. 2008; Hunter et al. 2008, 2009, 2010), being the only pigment found in cyanobacteria. Phycocyanine have a characteristic absorption maximum at 620 nm and a reflection peak at 650 nm. However this behaviour becomes recognizable from spectral reflectance spectra only with a certain concentration of cyanobacteria, at least 10 mg/m^3, hence higher than what it is considered dangerous ($4mg/m^3$) for the Baltic Sea (Kutser et al. 2006, Reinard et al. 2006). The algorithms for the derivation of phycocyanine seems overestimating its concentration when the ratio of CPC/chl-a is quite low (less than 0.4 for Simis et al. (2005a) and Randolph et al. (2008)). Vincent et al. (2004) successfully tested two empirical algorithms for the derivation of phycocyanine by combining Landsat TM bands in Lake Erie. Despite the poor spectral resolution of TM, a robust relationship between in situ values and satellite-inferred measurements was found. Simis et al. (2005b) combined bio-optical modelling and band ratio 709/620nm, to derive the concentration of phycocyanine; an approach adopted by other authors also (Hunter et al. 2008, 2009). Hunter et al. (2010) showed a correlation between phycocyanine derived by this approach and both the number of cyanobacterial cells and their biovolume (also Randolph et al. 2008). Ruiz Verdú (2008) showed the performances of the algorithm in the range of PCP concentration from 50 to 200 mg/m^3.

Several types of sensors have been tested for mapping cyanobacteria bloom and most of the papers agree in considering the spectral resolution of MERIS the most congenial to identify peaks of cyanobacteria pigments. In fact, bands 6 and 7 support the detection of phycocyanine, while the bands 8 and 9 the chlorophyll-a. (Kutser et al. 2006). Kutser et al. (2006) also noted the inadequacy of other sensors: TM band 2 is too wide, while MODIS has no band in the spectral range of PCP although in case of intense blooms in an advanced stage of development it might be successfully used (Reinard et al. 2006). Gitelson et al. (2007) tested a two bands model for estimating chl-a concentration from MODIS and SeaWiFS, resulting in a RMSE of $11mg/m^3$. The three bands model applied to MERIS data provided a RMSE of 8 mg/m^3. Svejkovsky and Shandley (2001) found a relationship between AVHRR-NOAA and chl-a in clear coastal waters in California. Several airborne imaging spectrometry have been also evaluated: MIVIS (Bresciani et al. 2010), EPS-A (Gonsar et al. 2005), CASI-2 (Senay et al. 2001; Hunter et al. 2008, 2009, 2010). The new generation of satellite hyperspectral sensors, such as Hyperion were still not very experienced but the improved spectral resolution is powerful for detecting spectral features of different algal pigments (Kutser 2004).

Algorithms developing

The database of spectral signature of waters compiled thanks to past and recent fieldwork activities (Tab. 1) performed within the cyan-IS-was and other synergic projects (cf. Annex I) was used to develop algorithms for estimating cyanobacteria concentrations is resumed in

Fig. 2. It is composed by more than 300 spectra collected in lakes and coastal waters of Italy, Sweden, and Lithuania (sampled during a impressive cyanobacterial bloom).

Table 1 - Summary of sites visited in 2011 in order to collect in situ data for algorithm developing. The synergic project of cyan-IS-was are also indicated.

Month	Site	Synergic Project
May-June	Lake Garda	EuLakes
August	Lake Trasimeno	MELINOS
April	Lake Maggiore	MELINOS
July-August	Lakes of Mantua	HABLakes
July	Adriatic coastal zones	CLAM-PHYM
March	Tyrrhenian coastal zones	CLAM-PHYM

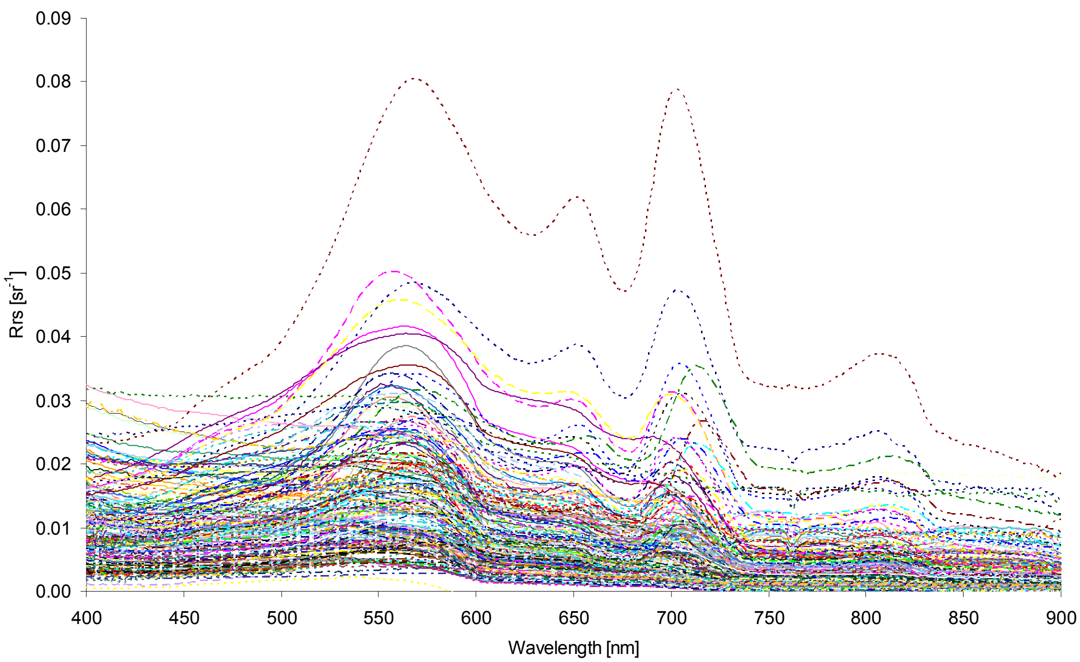

Figure 2 - Rrs data collected in various lakes and coastal waters ranging from oligotrophic to hypertrophic status.

Form the dataset the spectral signature of productive waters affected by cyanobacterial bloom were selected (Fig. 3) on the basis of their spectral shape and ancillary data (e.g. fluoro-probe measurement of algal pigments) in order to test empirical models.

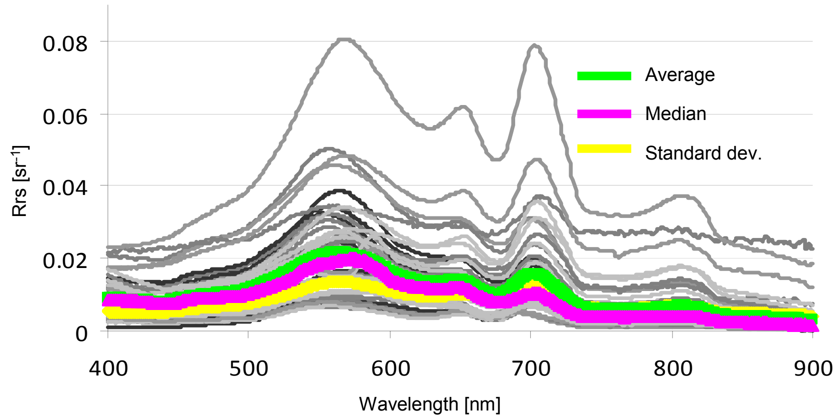

Figure 3 - Rrs data collected in waters affected by cyanobacterial blooms.

Rrs data providing information of cyanobacteria were used to build empirical algorithms for the detection of different algal pigments based both literature data (Gitelson et al. 2007; Kutser, 2004) and ad-hoc developing (Bresciani et al. 2011) (Fig. 4).

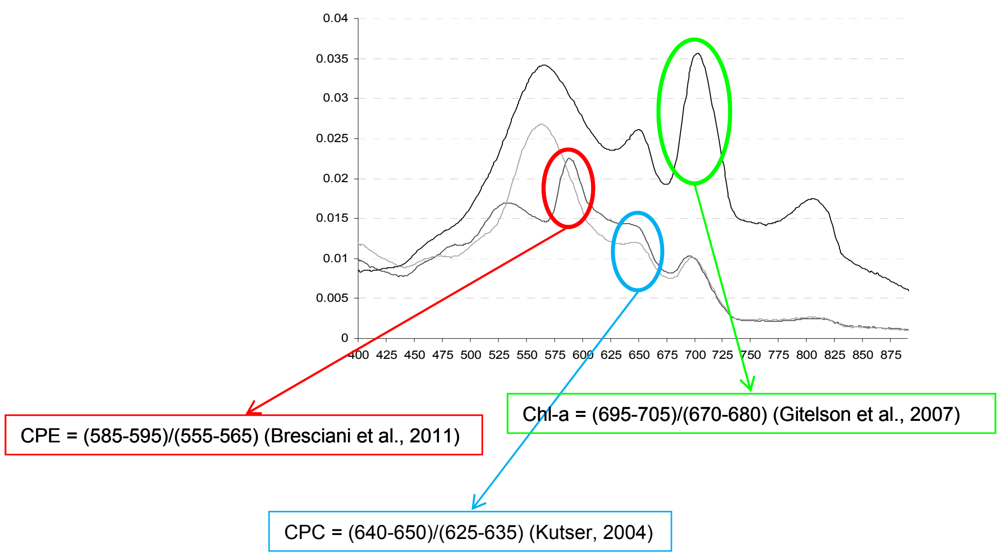

Figure 4 - Wavelengths used for develop empirical algorithms for detecting algal pigments from Rrs data

Empirical data (Fig. 5) allowed appreciating the variation of Rrs for different changing domains: the diurnal cycle of sunlight, the vertical depth and the locations of sampling. Of course this changing will be further investigated in the next phases of cyan-IS-was by using remote sensing data.

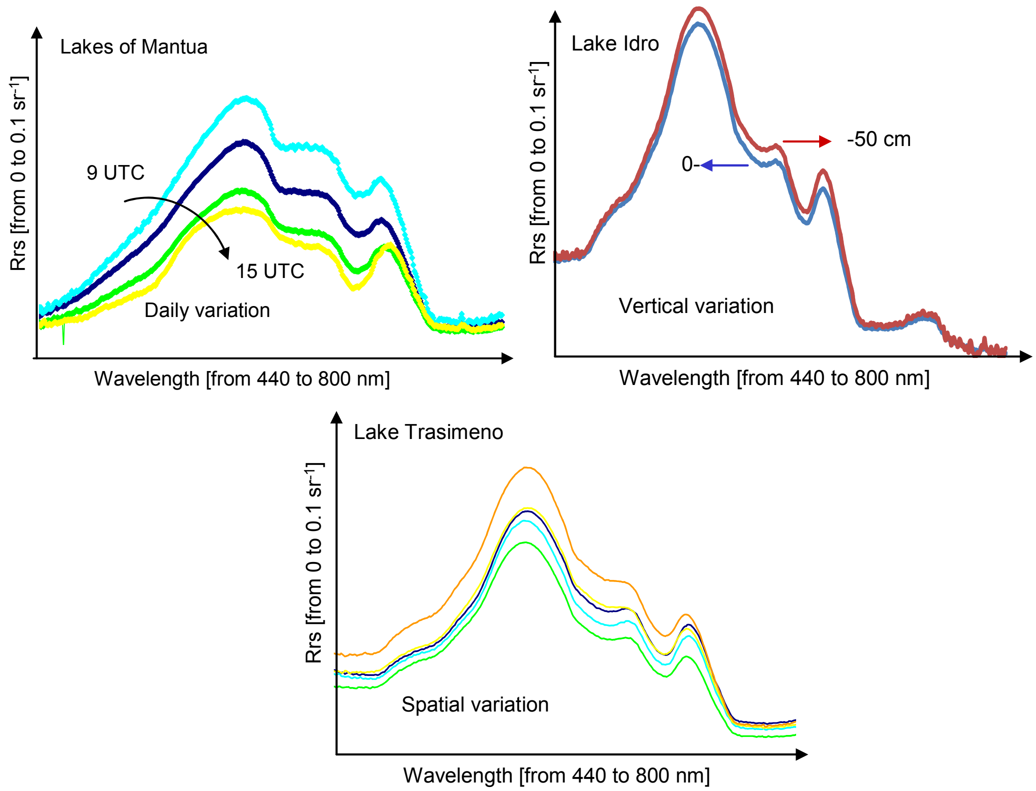

Figure 5 - In situ data showing the evidence of variation of Rrs data associated to different variable domains: diurnal cycle of sunlight, vertical depth and locations of sampling.

In situ data of absorption and backscattering coefficients were then used to perform a preliminary calibration of a three-component bio-optical model (Dekker et al. 2003; Giardino et al. 2007). Figure 6 shows a forward run of the bio-optical model for fixed concentration of water quality components (chl-a= 20 mg/m^3, TSM= 34 g/m^3 and CDOM= 0.6 m^{-1}) and concentrations of phycocyanine varying from 0 to 300 mg/m^3. Figure 7 shows a forward run of the bio-optical model for variable concentrations of water quality components and fixed concentrations of PCP = 70 mg/m^3.

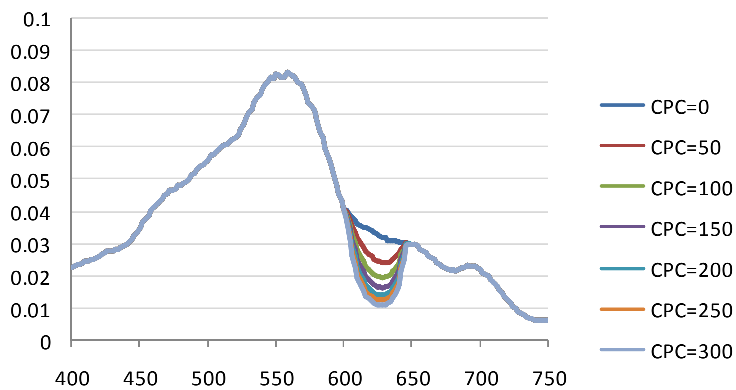

Figure 6 - Simulation of R(0-) for variable concentrations of CPC and fixed concentration of water quality components.

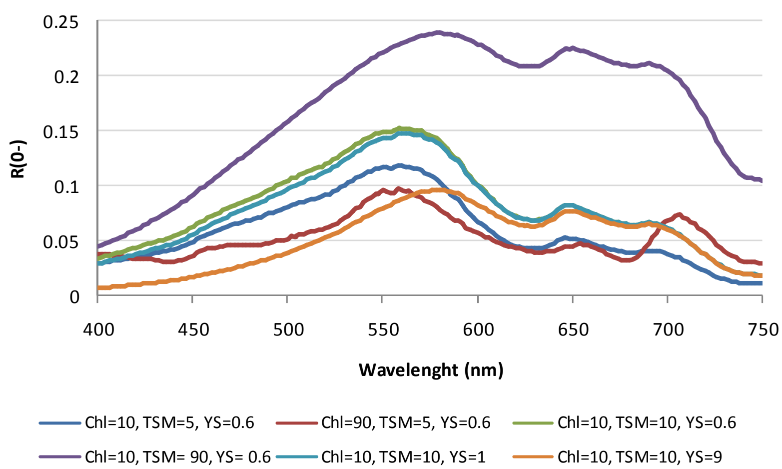

Figure 7 - Simulation of R(0-) for variable concentrations of water quality components and fixed concentrations of CPC.

Limnological analysis

Most of the authors estimate pigment concentrations using a common laboratory analysis procedure, slightly changing some parameters. Three common steps are performed: the first one is filtration through glass fiber filters (largely used Whatman 47 mm GF/F and less used GF/C (Gitelson et al. 2007, Hunter et al. 2008, Zhang et al. 2009)).

As Kutser (2004) highlights in its article, water sample during intense cyanobacteria bloom condition is really difficult and this operation can modify radiometric measures. The simple scraping of water surface with a bucket obviously destroys the bloom forming aggregates, diluting them in an unpredictable way which depends on the non-reproducible bucket handling (Bertoni 2011). The picture in figure 8 demonstrates how it could be difficult to sample water with conventional water sampler during intense blooms.

Recently, Bertoni (2011) proposed the use of a Surface Bloom Sampler (SUBS) to allow the correct cyanobacterial bloom sampling.

Figure 8 - Intense surface cyanobacteria bloom, which obstructs sampling operations

After filtration, the second step is pigments extraction. For chl-a extraction different chemical solutions, such as ethanol (96% by Alikas, 2010 and Seppala et al. 2007; 95% by Matthews et al. 2010; 90% Zhang et al. 2009 and Bresciani et al. 2011; 80% by Simis et al. 2005), methanol 90% (Catherine et al. 2008), or acetone 90% (Gitelson et al. 2007; Gons et al. 2008; Hunter et al. 2008, 2010; Matthews et al. 2010; Randolph et al. 2008; Vincent et al. 2004) are used. The last operation is the spectrophotometer or fluorometer analysis (Gons et al. 2008; Matthews et al. 2010; Randolph et al. 2008; Vincent et al. 2004).

Different studies highlighted the variance of the results using different extraction methodologies. Dowdy and Wearden (1983), Lindell et al. (1999) and Pepe et al. 2011, summarize the most important differences caused by the use of different extractors (Fig. 9). Lindell et al. (1999) also suggests using methanol solution in hypertrophic conditions.

Table 2. Results of T-test (Dowdy and Wearden, 1983), one-tail and two-tail, for paired comparisons between chlorophyll-a concentration data obtained with the ISO and Methanol methods, per month for lake Iseo.

Data Chlorophyll a	*10/3/98*	*27/4/98*	*4/6/98*	*18/6/98*	*23/7/98*	*10/11/98*
Mean conc.: ISO (µg/l)	7.7	2.2	1.7	1.6	2.6	3.5
Mean conc.: Methanol	12	1.3	2.3	1.7	1.7	7.4
Degrees of freedom	40	16	33	35	34	34
T Stat	8.51	-3.01	3.26	1.56	-9.08	10.49
P(T<=t) one-tail	8.06	0.004	0.001	0.064	6.59E-11	1.7E-12
t critical one-tail	1.68	1.75	1.69	1.69	1.69	1.69
P(T<=t) two-tail	1.61	0.008	0.003	0.129	1.32E-10	3.39E-12
t critical two-tail	2.02	2.12	2.03	2.03	2.03	2.03

Figure 9 - From Pepe et al. (2001), differences coming from the use of different chemical extractors for the retriavl of chl-a concentrations.

Enumeration of phytoplankton species have been performed proceeding according to Utermöhl's method (1958), which consists in phytoplankton Lugol's solution fixation, followed by inverted microscope count.

Field measures are completed, by different authors, with physical and chemical water parameters retrieval: Secchi disk transparency, salinity, temperature (°C), depth (Gitelson et al. 2007; Hunter et al. 2008; Bresciani et al. 2011), pH values (Randolph et al. 2008; Vincent et al. 2004). Hunter et al. (2008), studying vertical migration by *Microcystis aeruginosa*, collected a lot of nutrient parameters like Total Phosphorus, Soluble Reactive Phosphorus, Nitrite-nitrogen, nitrate-nitrogen, ammonium-nitrogen, Total Oxidized Nitrogen, Dissolved Inorganic Nitrogen, relating cyanobacteria behavior to nutrients presence and concentrations.

For estimation of phycocyanin concentration the methodology used has been the following: extraction into a 50 mmol L21 sodium phosphate buffer using probe sonication (1 min; 15-s bursts) and nine freeze-thaw cycles as described in Sarada et al. (1999). The extracts have been clarified by centrifugation and the C-PC concentration in the extracts has been quantified using the spectrophotometric equations of Bennett and Bogorad (1973).

Another methodology for the phytoplankton pigments and cyanobacteria estimation consists in the use of the fluorometer in situ. The instrument functioning is based on the analysis of the fluorescence spectrum generated by some accessory pigments, after their excitation with a known waveband input light. Chlorophyll concentration estimation, associated to every spectral (algal) group, is then obtained from the comparison between a reference model spectrum and the values obtained from in-situ measures.

Fluorimetric techniques can provide a good accuracy with high pigment concentrations (chl-a=20 µg l-1). This limit value depends on the specific spectrometer noise signal, the scattering signal produced by the water and by the inside dissolved matter, but even on the single phytoplanktonic cell morphology and, finally, on the compositional difference between the analyzed phytoplankton population and the one used for the calibration (Beutler, 1998).

Another useful method for the cyanobacteria pigments identification is based on the use of HPLC technique. For the cyanobacteria pigments analysis the Reversed phase-HPLC (Pfander et al. 1995; Jeffrey et al. 1999) is usually used.

Among the different cyanobacteria blooms evaluation techniques, an interesting and useful operation is the cell growing speed estimation and the cell dispersion observation from a potential nutrients source. Two experimental approaches are proposted in order to evaluate whether the availability and stoichiometry of nutrients can be an important factor as trigger of cyanobacteria blooms. The first method is based on the use of bioassays, that allow to evaluate where phytoplankton (and cyanobacteria in particular) have higher growth potentials. The second method is based on the incubation of intact sediment cores, that allow to measure the regeneration rates (and the stoichiometry) of N, Si and P.

Bioassay for phytoplankton growth

One of the key, open questions dealing with the development of phytoplancton or cyanobacterial blooms is about the origin and the trigger of the bloom. We thus thought about a bioassay that can be deploied in situ and give important informations about the growth potential of algal cells in a certain area, which is in turn dependent upon nutrient availability. Living organisms in fact can discriminate between really small differences in the concentrations of limiting nutrients and extract them from the water. The bioassays are made of small bags (250 ml) realized with transparent dialisis membrane (400 dalton) that is permeable to ions but not to planctonic organisms. Such bags are filled with water with a known amount of algae collected from the site of investigation and left suspended in the water column for 2-3 days.

After such incubation period the bags are recovered, the water inside is filtered and the phytoplankton quantified via standard colorimetric techniques. Basically, the minimum information that can be obtained is an increase in chlorophyll which can be translated into an increase in phytoplankton biomass. Such information can be inplemented adding the analysis of all the pigments before and after the in situ incubation or analyzing the elemental composition of grown algae in terms of C, N, Si and P content. Bioassays are easy to assemble and can be prepared for a number of stations for which other phisico-chemical informations are available. It is then possible to map a certain area (a lake for example) for the growth potential of algae. Such growth potential is generally sustained by favourable conditions as light availability, water temperature and dissolved nutrients.

We have realized 10 sets of bioassays like that shown in figure 10, which will be deployed in the Lago d'Idro, the first results show that the presence of cyanobacteria is partly related to the availability of nutrients and how, in the non-turbulent water, their presence and quantity of nutrients is influenced by the spatially.

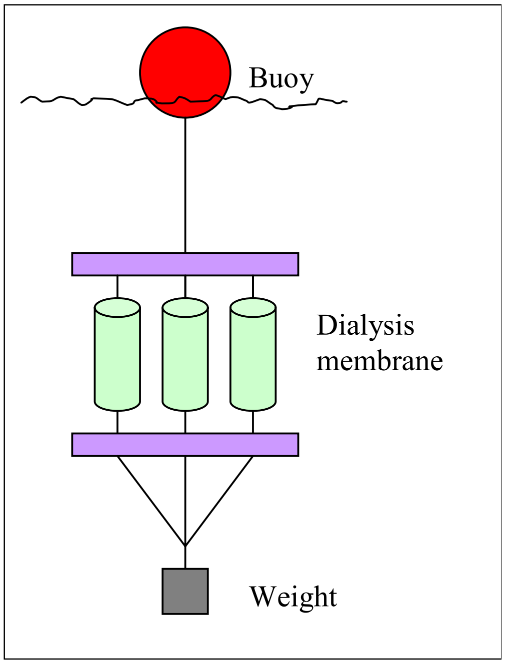

Figure 10 - Scheme of the experiment of bioassays for phytoplankton growth.

Incubation of intact sediment cores

In shallow basins surface sediments can be a site of accumulation and regeneration of nutrients and recycled N, P and Si can sustain elevated rates of primary production. One can hypothesize that blooms of cyanobacteria can be the consequence of the stoichiometry of regenerated nutrients, with unbalanced N:Si or N:P ratios. In order to verify such hypothesis we decided to incubate sediments collected from 3 sites where cyanobaterial blooms are generally occurring during summer months.

All experiments were done using the same material and the same incubation procedures: sediments were collected by hand or via a sediment corer in 8 cm i.d. plexiglas cores (height 30 cm). One collected the cores were transported submersed in in situ cooled water in the laboratory for overnight preincubation. The cores were preincubated within an aerated tank containing in situ water at environment temperature; the water inside the cores was stirred with magnetic stirrers (60 r.p.m.). The morning after, the cores were incubated in the dark for 3 to 5 hours. Subsamples of the overlying water were collected before and after the incubation. We analyzed dissolved oxygen, dissolved inorganic nitrogen, phosphorus and silica.

Cores (Fig. 11) were collected in the summer period of 2011 from 3 sites: Mantua lakes, Lake Trasimeno and Lake Idro (Italy). Preliminary results suggest that dark respiration is similar at all sites and varying between 2 and 4 mmol O2 m-2d-1. Such respiration rate is elevated and typical for eutrophic, organic rich sediments. Incubations revealed also that large amounts of ammonium and reactive silica were regenerated but that the fluxes of soluble reactive phosphorus were negligible. The latter result was surprising as we expected large P regeneration, but this was not the case. We also tried to incubate the cores under anoxic conditions but 5-10 hours of anoxia did not stimulate the release of P from sediments.

Even if such results are preliminary we can say that the unbalanced N:P ratio in regenerated nutrients is not an evident outcome at the 3 study sites and is probably not the cause of cyanobacterial blooms in these areas.

Figure 11 - Example of collected cores and measuring

5. Cooperation activities

To promote cooperation activities between Sweden and Italy two workshops and two joint campaigns have been organized during the project.

5.1 Workshops

Two workshops has been organized by cyan-IS-was partners, the first workshop in Oslo was on remote sensing of lakes in general, whereas the second workshop in Italy held on 19 July 2011 was dedicated to the detection of cyanobacteria and also included both seminars and a field campaign.

"Remote Sensing of Lakes"

The workshop "Remote Sensing of Lakes" was organized by the Nordic Network for Aquatic Remote Sensing (NordAquaRemS), coordinated by Susanne Kratzer who is also the PI of the Swedish team of cyan-IS-was. The workshop was held in Oslo February 16-17, 2011 at the Norwegian Space Centre in Oslo.

The aim of the workshop was to present and discuss the latest achievements related to remote sensing of lakes, with a specific focus on the Nordic countries. The topics of the presented work included research on satellite algorithm development (e.g. atmospheric correction, retrieval of water quality parameters etc) and validation, as well as application of remote sensing data for national and international lake monitoring programs. In connection to the workshop a BEAM training course was given by Brockmann Consult. The course focused on new functionalities of BEAM 4.8 and 4.9 (which are the layer manager and the GIS like functionality offered) and programming.

About 30 persons attended the workshop including cyan-IS-was partners, scientists from the NordAquaRemS team and Advisory Group, PhD/MSc students and young scientists from the Nordic and Baltic countries (cf. Annex II).

Claudia Giardino (coordinator of the Italian cyan-IS-was team) was invited speaker in this work-shop and gave the in augury talk about remote sensing of lakes with a clear focus on management approaches.

"Remote Sensing of Cyanobacteria"

The workshop "Remote Sensing of Cyanobacteria" (cf. Annex III), organized by CNR IREA was held on 19 July 2011 in Mantua and Garda lakes (Fig. 12). The workshop aims were: to collect data in eutrophic lakes affected by cyanobacterial blooms and to disseminate the cyan-IS-was project. For this second aim some presentations were held in a workshop with other research projects (Annex I) which are carried out in synergy with cyan-IS-was. These collaborative projects provide *in situ*, airborne and satellite data useful for reaching the cyan-IS-was objectives, moreover they represent a valuable frame to disseminate the cyan-IS-was results to a wider user community.

The workshop was attended by colleagues and PhD/MSc students of different research institutes and universities (cf. Annex III) for a total of 23 participants in total. Representatives from small private companies, i.e. Strömbeck Consulting, Luode Consulting Oy and Odermatt Earth Observation (OEO) collaborating with the cyan-IS-was project attended the workshop (Annex III).

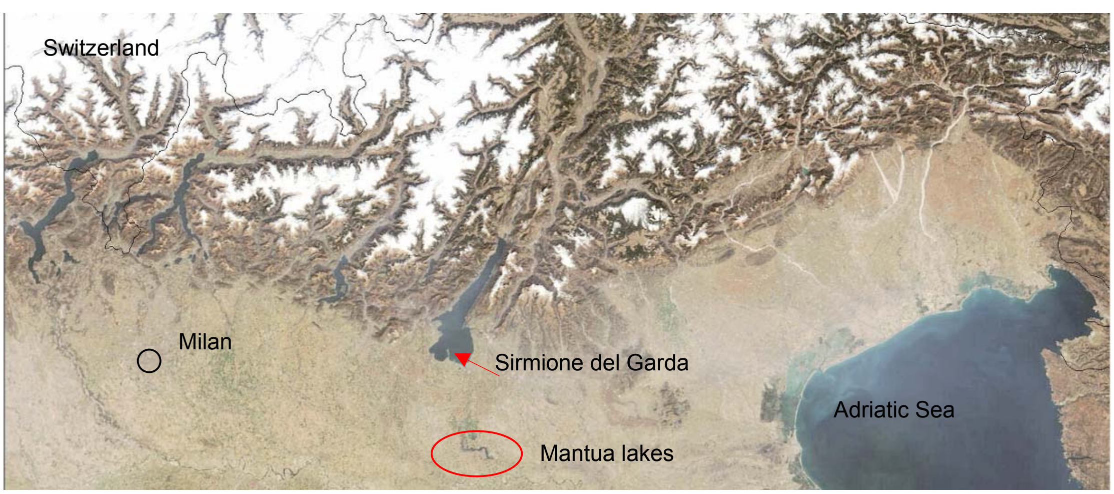

Figure 12 - Area of interest (in red) for the workshop "Remote sensing of cyanobacteria" from MERIS.

Mantua lakes, located in the Po plain valley and fed by the Mincio River, which is the emissary of Lake Garda, are characterised by eutrophic levels (chl-a up to 150 mg m^{-3}), high concentrations of cyanobacteria (CPC up to 50 mg m^{-3}), excess organic matter sedimentation and excess growth of macrophyte vegetation.

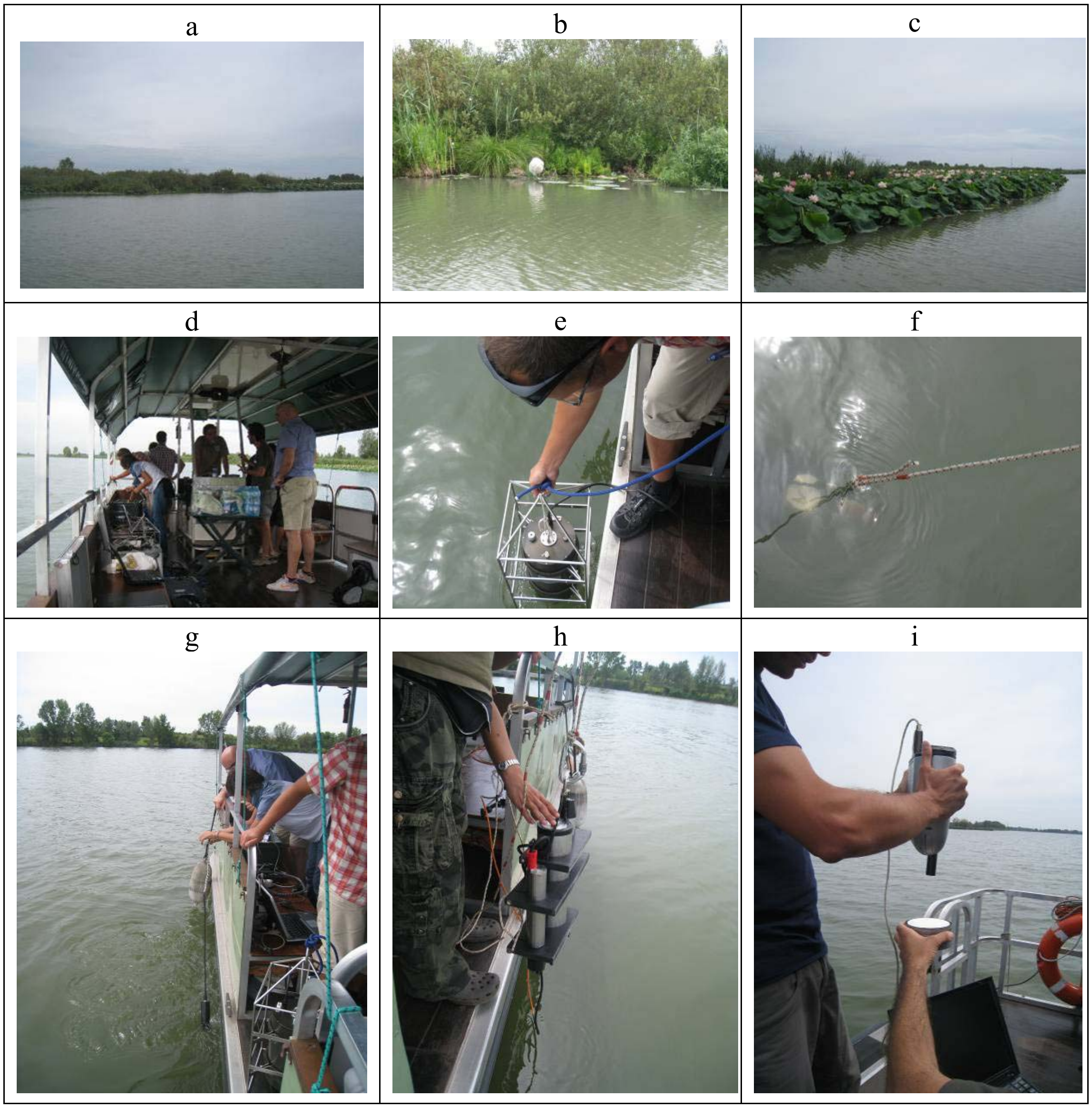

Figure 13 - Images of fieldwork activities in Mantua lakes. a: view of the lake; b: view of the lakes coast; c: islands of lotus flower (*Nelumbo nucifera*), covering a large part of the lakes from spring to autumn; d: set-up of instruments; e: Hydroscat-6; f: Secchi disk; g: Turner Design SCUFA; h: Trios Ramses; i: ASD Hand-held.

During the survey the following instruments have been used (between brackets the instruments holder):

- 3 submergible spectroradiometers: ASD FieldSpec Full-Resolution Pro (IREA), TriOS Ramses (ISMAR) and Licor-192SA Underwater Quantum PAR Sensor (IREA);
- 2 above-water spectroradiometers: ASD Hand-Held (University of Milano Bicocca) and Spectrascan PR650 (ISMAR);
- 2 fluorometric probes: Turner Designs SCUFA (IREA) and Turner Designs Cyclops-7 (IREA);
- 1 sensor for backscattering: HOBI labs Hydroscat-6 (ISMAR)

In addition to the above instrumentation water samples were collected for subsequent laboratory analysis at University of Parma. Two stations were visited during the campaign and at each station Secchi disk depth and bottom depth were also measured. Figure 13 shows some photos taken during the fieldwork.

The seminar series held at “Stazione Sperimentale Eugenio Ziloli”, the experimental station of IREA located in Sirmione del Garda, aimed to present the cyan-IS-was project, together with other synergic research projects (cf. Annex III), to colleagues and students interested in remote sensing of lakes. Figure 14 shows some photos taken during the seminar in Sirmione.

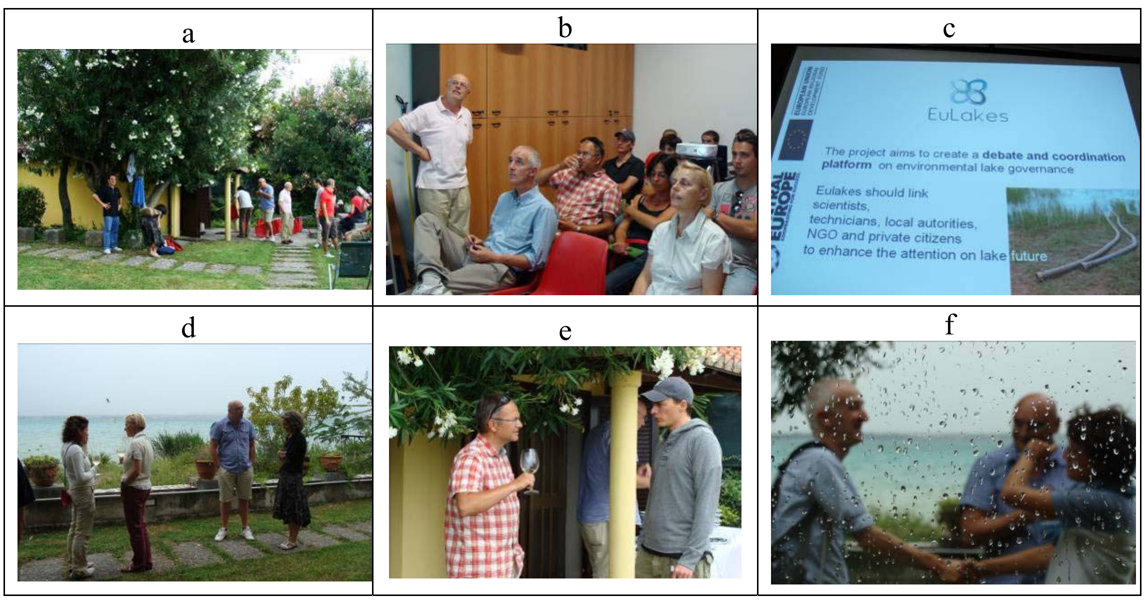

Figure 14 - Images at the Experimental Station Eugenio Zilioli in Sirmione. a: participants arriving at the Station; b: Brivio (head of IREA) gives the welcome to the Station; c: a slide of Eulakes project presented by its coordinator Gallinaro (Comunità del Garda); d: conversing after the presentations: from left, Braga (ISMAR) with Carrara (IREA) and De Carolis (IREA) with Bordogna (IDPA); e: Strömbeck (left) converses with Odermatt (OEO, right); f: farewells under the rain.

5.2 Joint campaigns

Two campaigns have been organized by cyan-IS-was partners in the respective countries. The first campaign was carried out on 19 July 2011 in the lakes of Mantua in occasion of the Workshop "Remote Sensing of Cyanobacteria". In particular, N. Strömbeck from Sweden was involved in the campaign for collecting and analyzing backscattering data. The second campaign was carried out on 3-4 August 2011 in Lake Vänern, the third largest lake in Europe. Personnel from CNR-IREA joint the Swedish team for colleting AOP and fluoroprobe data on algal pigments and CDOM.

Lakes of Mantua

The study area comprises a system of three shallow lakes located in the city of Mantua (northern Italy), respectively called: Upper, Middle and Lower Lake Mantua. With a total lake area of 6.32 km^2 and maximum depth of 3.6 m, the lakes are characterised by hypertrophic levels, anomalous growth of aquatic vegetations and problematic processes of organic matter sedimentation. The lakes are part of the Po River basin where 16 millions of inhabitants live and the anthropogenic pressure is the highest of Italy (agriculture 40%; industry 37%).

Figure 15 - Google Earth view of the study area and location of the two stations where the Italian joint campaign of cyan-IS-was was carried out on 19 July 2011.

As a part of the workshop "Remote Sensing of Cyanobacteria", the morning of 19 July 2011 a field camping was performed in the lakes of Mantua. The campaign was involving partner from Sweden in addition to colleagues from Switzerland, Milano and Parma who provided required skills and instruments. Besides the workshops aims (see before) the campaign allowed to collect both radiometric and limnological data, complementing previous data of the study area (Bresciani et al. 2009; Bresciani et al. 2010) would help to develop the algorithms for detecting cyanobacteria concentrations from radiometric data. The *in situ* data were collected in a station 1 (st1) in the Upper lake and in a second station (st2) close to Mincio River, the river feeding the lakes (Fig. 15).

The following parameters were measured:

- Water samples for subsequent analysis of chlorophyll-a, SPM, SPIM, SPOM, yellow substances and spectral absorption coefficients of particles, phytoplankton and non-algal-particles. Laboratory measurements are performed according to Strömbeck and Pierson (2001);
- Secchi disk and bottom depths;
- in vivo fluorescence measurements of phycocyanin pigments to estimate the cyanobacterial loads;
- extinction of light in the PAR and Kd at selected wavelengths λ and depths Z
- backscattering coefficients of particles;
- upwelling radiances, downwelling irradiances, sky radiances, Spectralon® reference radiance; i.e. all the radiometric quantities to compute a series of AOP (e.g. remote sensing reflectance above and below the air/water interface, Q-factor).

Table 2 summarises the parameters measured at the two stations: station 1 (st1) is richer in phytoplankton (Chl-a=15.1 mgm^{-3}) but with less turbid waters in comparison to station 2 (st2) where Secchi disk depth was 0.5 m and the SPM=21.5 gm^{-3}, hence about three times the concentration measured in st1 (SPM=8.8 gm^{-3}). This is quite in agreement with locations of sampling sites being st1 in lakes water while st2 in correspondence of the Mincio River inlet.

Table 2 - Average values (with standard deviations in brackets, when available) of *in situ* measurements.

Lat/Long (deg)	Secchi depth [m]	Bottom depth [m]	$a_{CDOM}(440)$ [m^{-1}], S_{CDOM} [-]	SPM [gm^{-3}]	Chl-a [mgm^{-3}]	Kd(490)$_{Z_{av}=1m}$ [m^{-1}]	Q-factor [sr]
st1: 45.161/10.755	1	3	0.37, 0.01	8.8 (±0.6)	15.1 (±4.2)	1.891	5.5
st2: 45.158/10.715	0.5	2	0.22, 0.01	21.5 (±0.7)	4.6 (±2.7)	3.166	6.8

With respect to chl-a estimation the influence of its retrieval by the use of different filters was tested. The filtrations have been done using different brands and filters typologies (Tab. 3) and correspondent chl-a concentrations from the same water sample have been compared (Tab. 4).

Table 3 Different filters typologies and their characteristics.

Brand	Grade	Basis weight (g/m^2)	Thickness (nm)	Retention (liquid) µm
Whatman	GF/C	53	0.26	1.2
Munktell	MG/C	52	0.26	1.2
Munktell	MG/F	75	0.45	0.7
Millipore	PVDF	n.a.	0.45	n.a.

Table 4 - Average chl-a values (mg/m3) from two Mantua Lakes stations (see Fig. 5) and correspondent standard deviations (in brackets) depending on different filters typologies used

	MG/C	MG/F	GF/C	PVDF
st.1	16.02 (0.46)	12.36 (0.42)	19.45 (0.67)	10.97 (0.59)
st.2	5.59 (0.18)	2.67 (0.37)	7.49 (0.22)	2.22 (0.16)

The following graphs shows the values of some AOP measured with different instruments. Figure 16 shows the dimensionless the reflectance factor computed as Lw/Lref from two ASD spectroradiometers. The agreement is acceptable by considering that in productive waters patchy structure of optical properties may interfere with intercalibration exercises. The ASD Hand-Held (HH) was slightly noisier than the ASD Full-Resolution (FR) but both instruments were able to distinguish the different behaviour between the stations. According to Table 1 the turbid waters of st2 are brighter than those measured in st1, that, however, reveal the typical peak around 700 nm due to phytoplankton fluorescence (more correctly: a trough at 664 nm due to phytoplankton absorption). This is also evident from figure 17, where remote sensing reflectance (Rrs) is computed with the SpectraScan (SS) spectroradiometer. This instrument was used following the SeaWiFS protocol (Fargion and Mueller, 2000) to have data comparable with the oceanographic data.

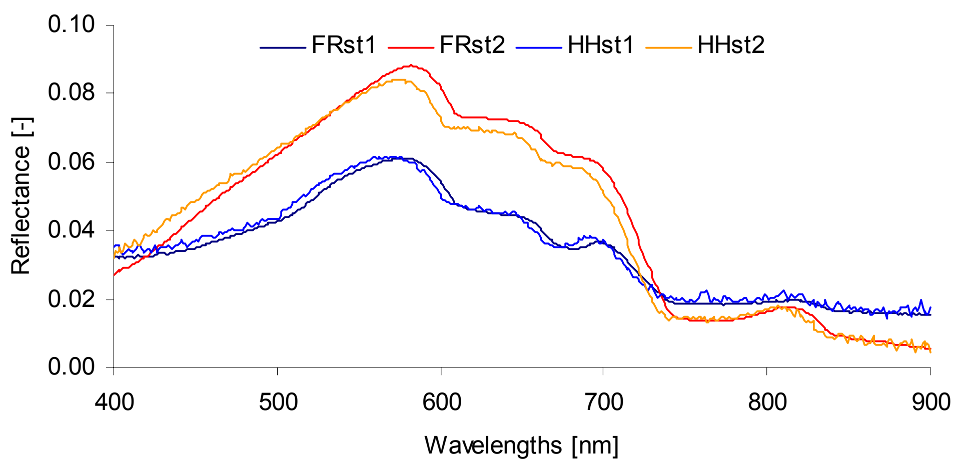

Figure 16 - Comparison of the two ASD instruments (Hand-Held, HH and Full-Resolution, FR) used to compute the reflectance factor of water in the two stations.

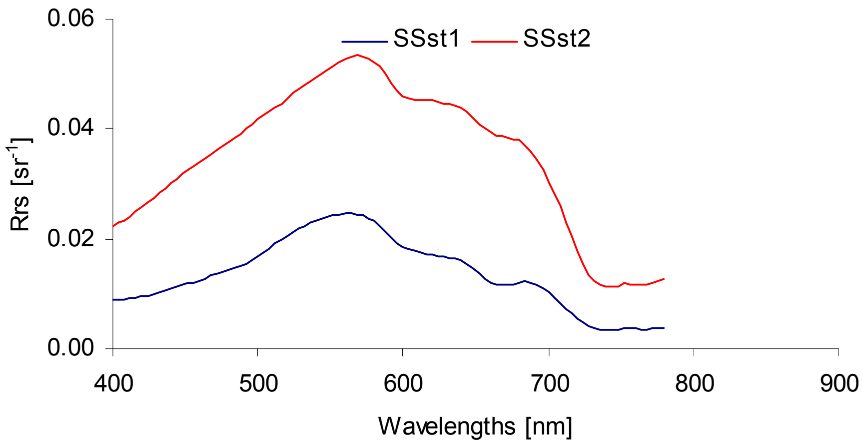

Figure 17 - Rrs data derived from SpectraScan by applying the SeaWiFS protocol.

The Rrs vales above (0+) and below (0-) the water surface were also computed with the submergible spectroradiometers Ramses (RAM) and the ASD FR from the ratio Lw/Ed (Fig. 18). The above water measurements confirm the agreement of the two devices; the differences among the values collected into the water are due to the displacement of the optics of the two sensors: at the same height in case of ASD FR; at about 20-cm of difference in case of Ramses.

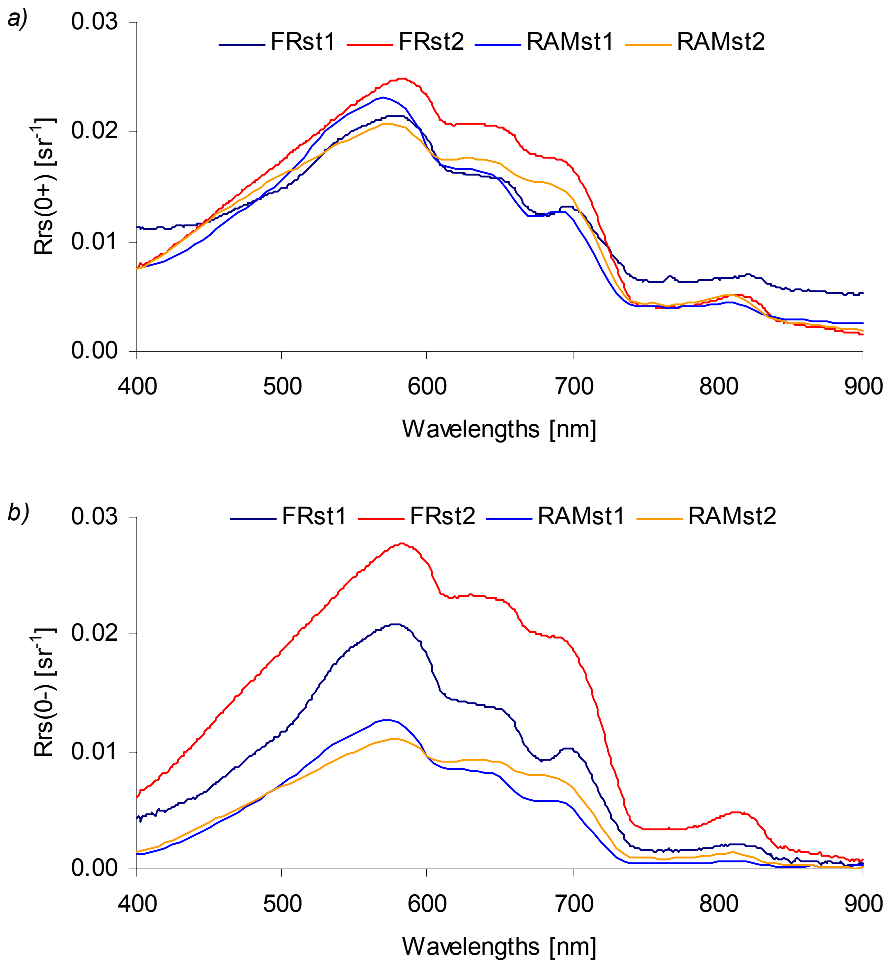

Figure 18 - Rrs data derived from ASD (FR) and Ramses (RAM) from Lw and Ed measurements above *a)* and below *b)* the water surface. The peak around 700 nm is due to chl-a, while the peak around 650 nm is due do PCP associated to cyanobacteria.

A further inter-comparison for Rrs(0+) was performed with the three instruments SpectraScan (cf. Fig. 3), ASD FR and Ramses (cf. Fig. 19). The exercise is applicable to st1 data only because the more homogenous patterns of their waters. The results are showed in figure 20. The match is reasonable even if some displacements in wavelengths positioning is arising.

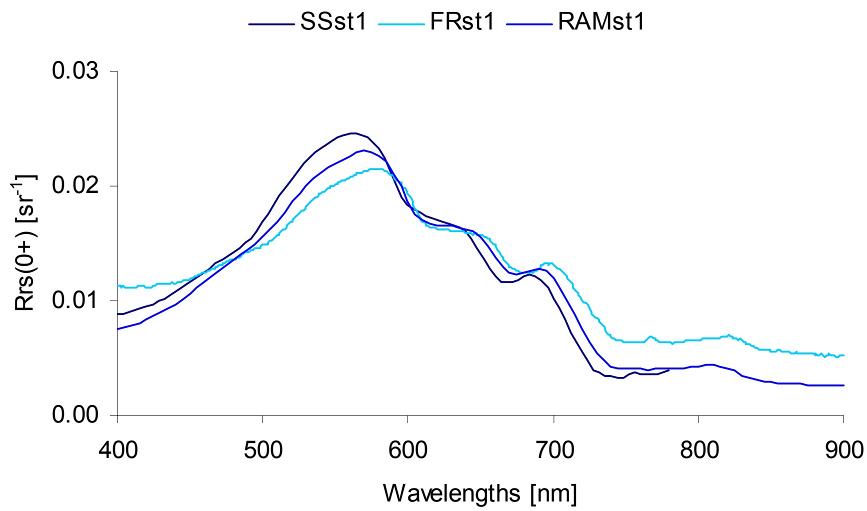

Figure 19 - Rrs data of station st1 derived with three different spectroradiometers.

Finally, figure 21 shows the behaviour of spectral K_d from 400 to 700 nm. According to Table 1 and the AOP graphs plotted above also K_d reveal a higher attenuation coefficient in st2, confirming high turbidity in these waters.

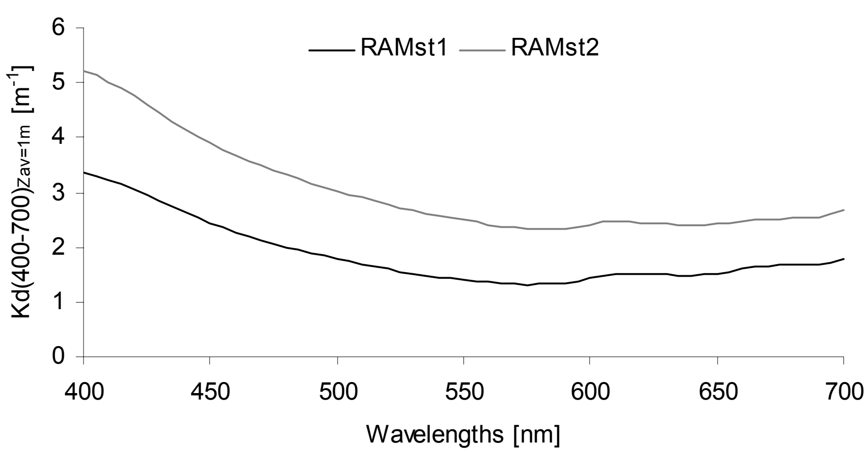

Figure 20 - Attenuation coefficient of downwelling irradiance in the first meter of water column in the two stations.

In addition to water quality (cf. Tab. 1) and AOP values (cf. Figs. 16-20), IOP data of the study area were collected. In particular, the absorption and the backscattering coefficients of particles also show large differences among the two stations with st1 more dominated by phytoplankton absorption (Fig. 21) and st2 more influenced by the backscattering of suspended sediments. The absorption spectra of particles ap(λ) retained on four different types of filters changing in pore sizes, were measured in the laboratory with spectrophotometer and the filter-pad technique (Tassan and Ferrari, 1995).

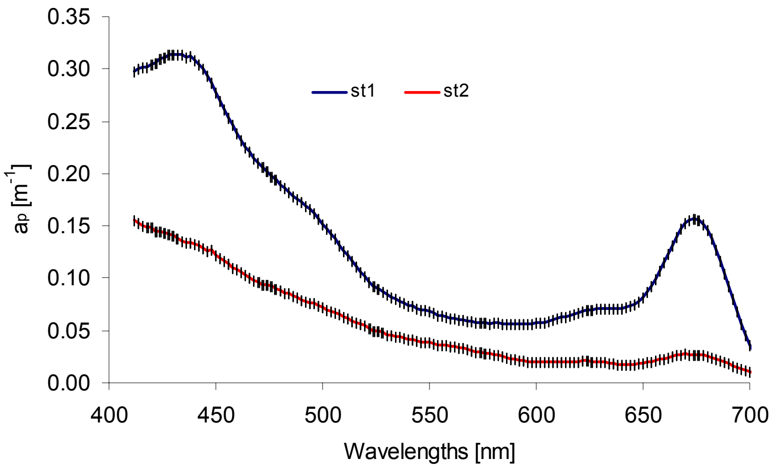

Figure 21 - Absorption coefficients of particles in the two stations. The plot shows the average values obtained by the measurements with the different filters (vertical bars indicate the standard deviation).

Lake Vänern

Lake Vänern is the largest lake of Sweden and Europe's third largest lake with an area of 6560 km^2. It has two open main basins with vast archipelagos with 22 000 islands in between. Medium depth is 27 m and the maximum depth is 106 m. The lake provides drinking water for 800 000 persons (9% of Sweden's inhabitants). Lake Vänern is an oligotrophic lake with relatively low phytoplankton biomass. The ecological status of the open areas is classified as good based, while a few more coastal and shallow areas have a lower classification regarding cyanobacteria. Typical Secchi Disk depth is 3-5 m with a greatest officially measured (since 1973) Secchi Disk measured in the summer of 2009 of 7.2 m (Vänern, Årsskrift 2010).

According to the authorities, no cyanobacterial blooms occur in Lake Vänern. However, the presence of cyanobacteria is documented (Vänern, Årsskrift 2010) in the monitoring data from the summer of 2009, mainly *Aphanizomenon flosaquae v. klebahnii* and *Woronichinia naegeliana*. Moreover, the authors (Kratzer and Strömbeck) have at two different occasions in 2009 and 2011 observed streak-forming buoyant cyanobacteria on the open Lake Vänern.

During a joint fieldwork organized by Stockholm University aiming at calibration/validation of MERIS data, a two-day joint campaign was performed during 3-4 August 2011 in Lake Vänern within the cyan-IS-was framework as well as the EU WaterS project (Fig. 22). The first day the survey was carried out in order to acquire *in situ* data for validating MERIS data.

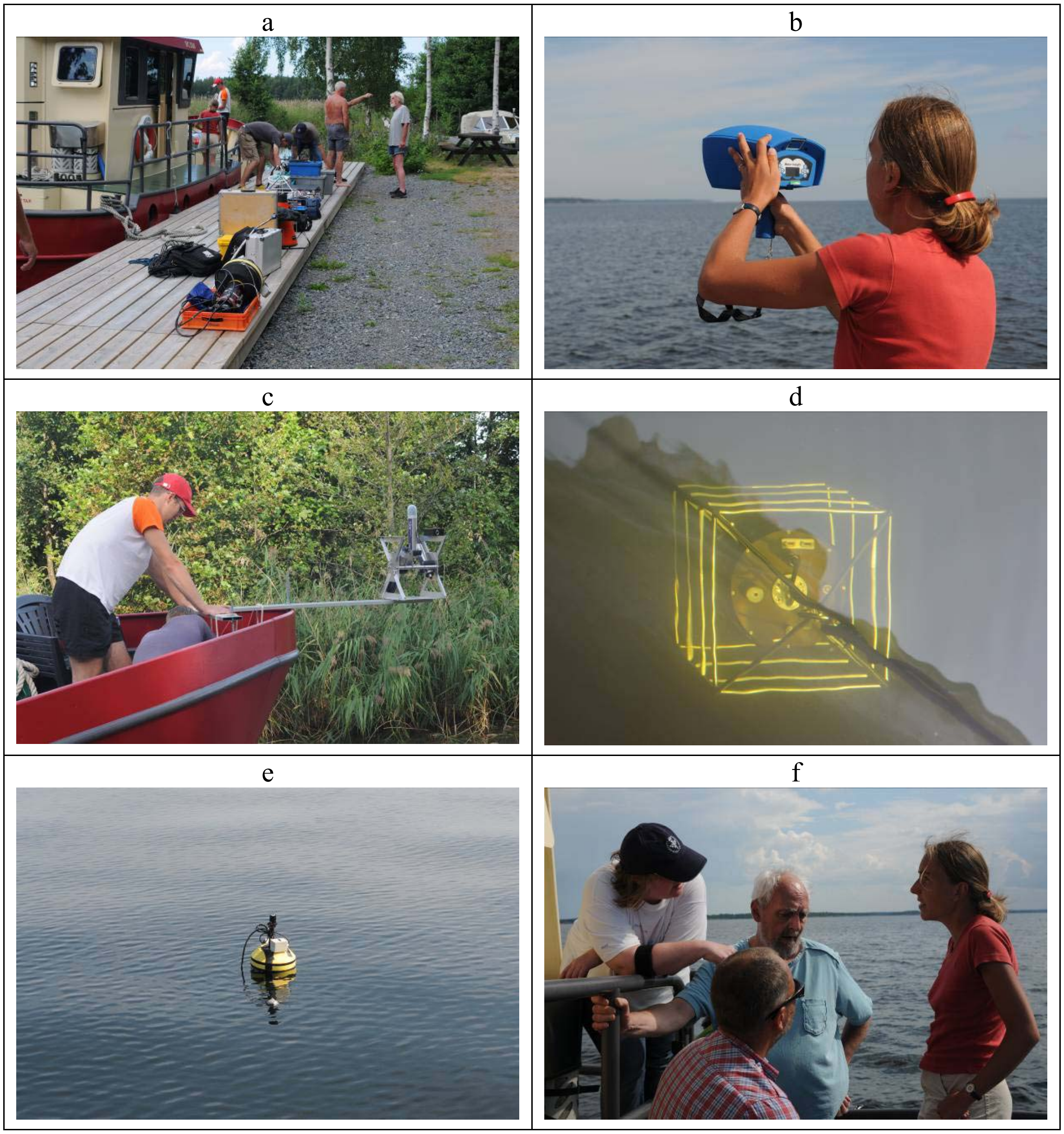

Figure 22 - Images of the joint camping in Lake Vänern. a: view of the instruments before the departure; b: Hommersom (Stockholm University and Water Insight) measuring Rrs with WISP; c: Ligi (Tartu Observatory, Estonia) setting up the Ramses spectroradiomters; d: deploying Hydroscat-6 along vertical profiles; e: radiance and irradiance measurements with the Satlantic radiometers; f: brainstorming: clockwise from left: Kratzer (Stockholm University), Moore, Hommersom and Strömbeck (Strömbeck Consulting, Luode Consulting Oy, Sweden).

Two stations (Fig. 23) were visited synchronously to the MERIS overpass between 11.45 and 13.25. The second day several stations were measured aiming the collection of AOPs, IOPs and concentrations in sites characterized by variable optical properties. Ten stations

(Fig. 23) were sampled from about 9.30 to 16. Figure 23 shows some pictures taken in the fieldwork.

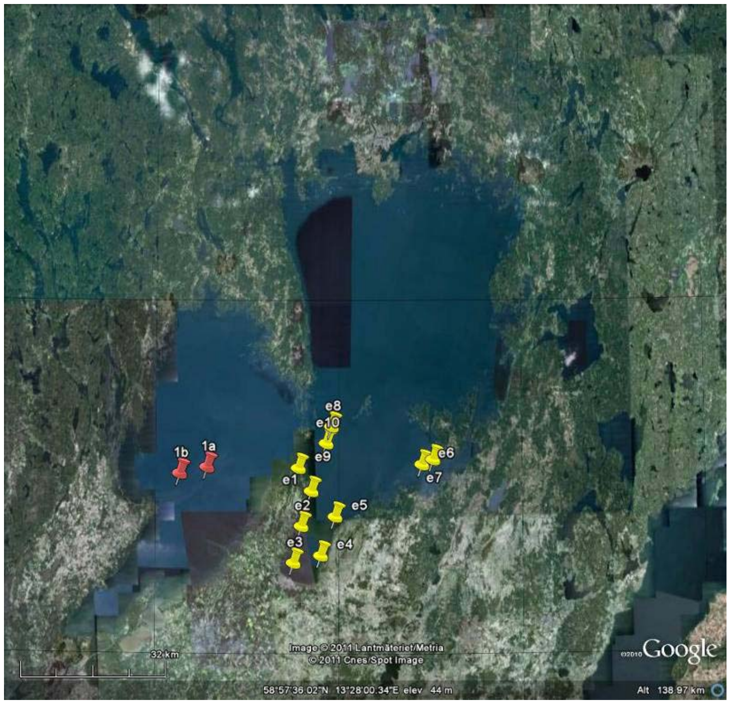

Figure 23 - Google Earth view of the study area and location of the two stations measured on 3 August and of the ten stations surveyed on 4 August.

The following graphs (Figs. 24 and 25) gives the depth profiles of Phycocyanin (CPC), chlorophyll-a (chl-a), Phycoerythrin (CPE), CDOM and temperature (T) as a function of depth for the two stations measured on 3 August. Figure 15 gives the correspondent R(0-) spectra and Figure 16 the turbidity (in NTU units) and temperature values measured with the Scufa sensor. The stations appear rather similar with respect to both water quality parameters and AOPs. In particular, few concentrations of both PCP and PCE pigments were measured in both sites. With respect to chl-a it is clear a peak of concentrations at about 5 m depth. Stockholm University hired a TriLux *in vivo* fluorometer from Chelsea Instruments (UK), and took simultaneous measurements with the Turner fluorometer. The data is still being analyzed for a comparison of the two multi-channel fluorometers.

Figure 26 shows the spectra measured at the same stations and figure 27 the turbidity and temperature values. It is quite evident that few differences in AOP characterise the calibration/validation MERIS stations.

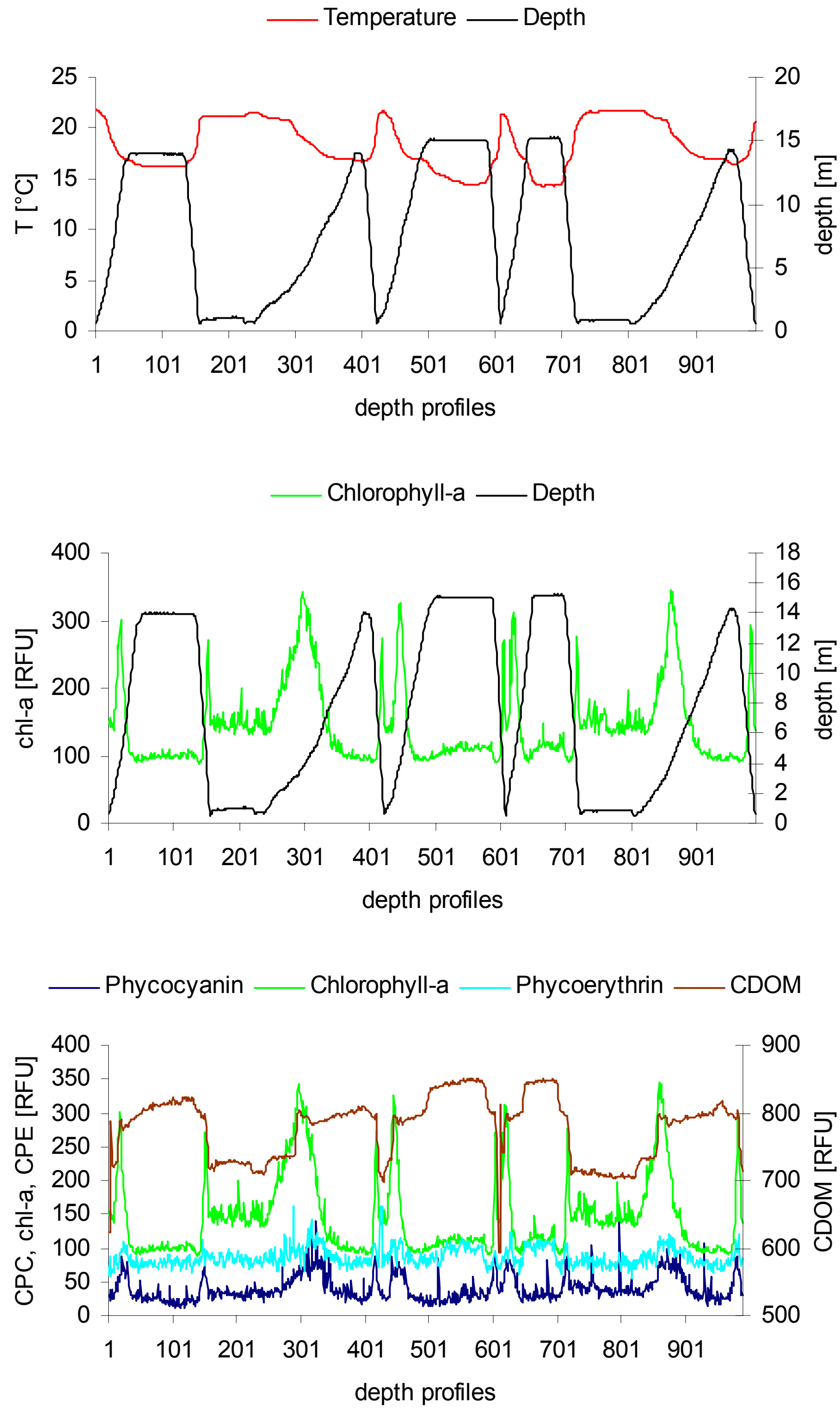

Figure 24 - Depth profiles of Phycocyanin (CPC), Chlorophyll-a (chl-a), Phycoerythrin (CPE), CDOM and temperature (T) in the station St1a measured on 3 August.

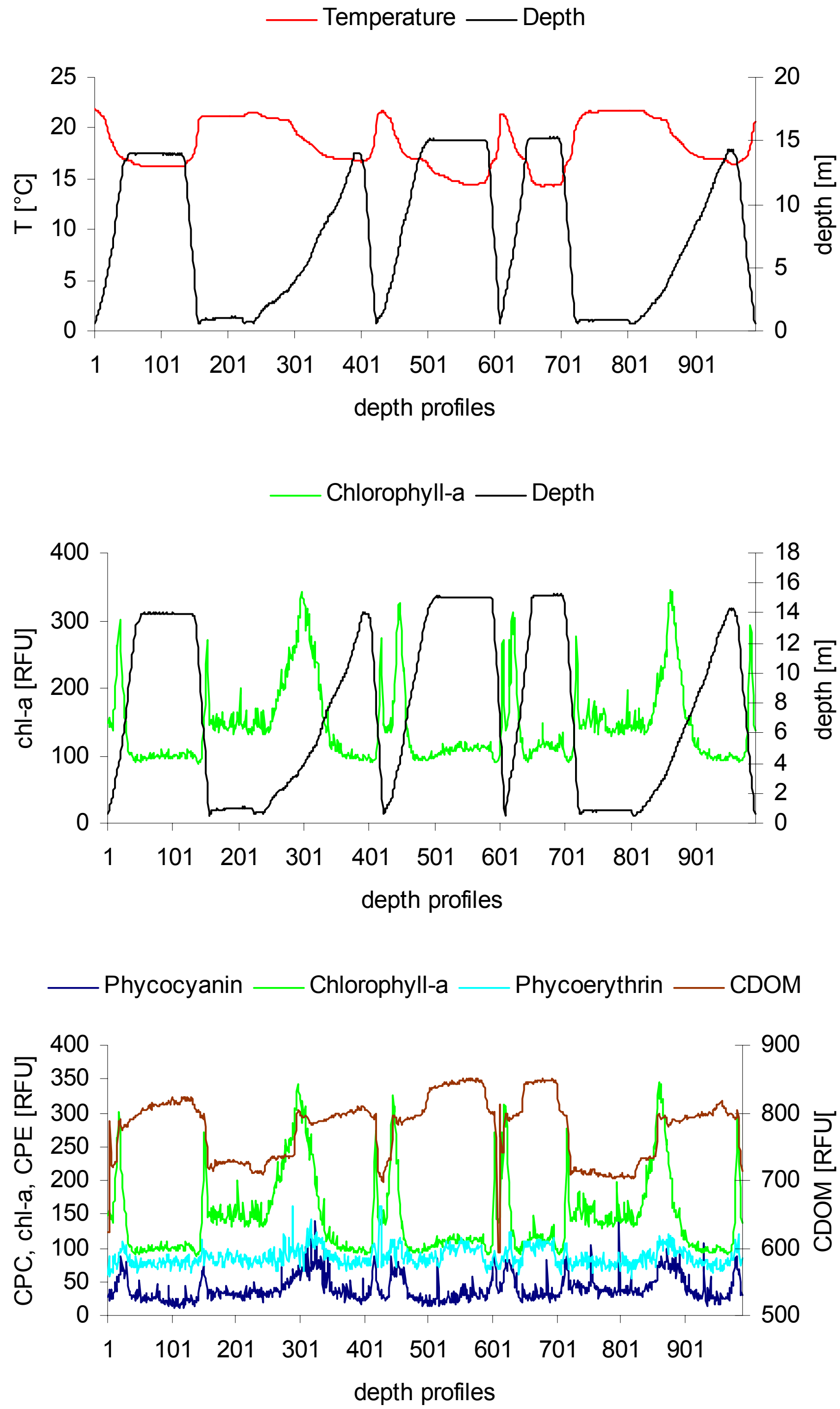

Figure 25 - Depth profiles of Phycocyanin (CPC), Chlorophyll-a (chl-a), Phycoerythrin (CPE), CDOM and temperature (T) in the station St1b measured on 3 August.

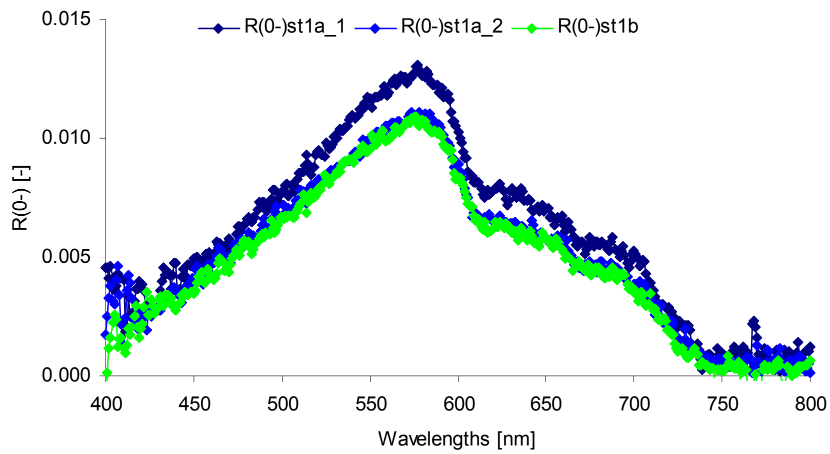

Figure 26 - R(0-) spectra derived from ASD data from underwater measurements of upwelling and downwelling irradiance in the two stations measured on 3 August. For the station st1a two sets of spectra were measured at different time (st1a_1 at 11.45, st1a_2 at 12.05; st1b was measured at 13.25).

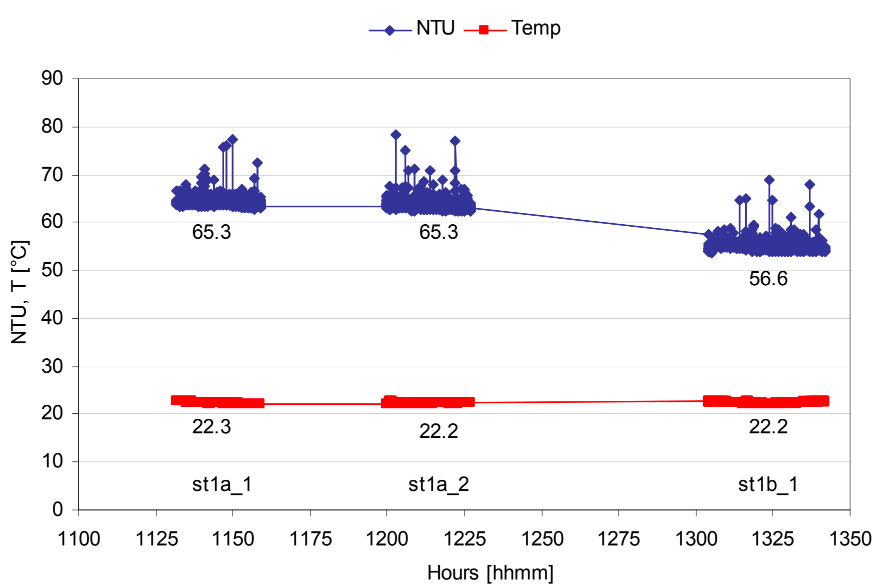

Figure 27 - Turbidity (in NTU units) and temperature values in the MERIS validation stations measured on 3 August 2001.

The stations measured on 4 August reveal more variable both phytoplankton pigments (Fig. 28), CDOM and turbidity (Fig. 29), temperature (Fig. 30) and water reflectance (Fig. 31). In particular, the station e3 shows the effect of the river entering in the lake as a source of both chl-a concentration, CDOM and turbidity. With respect to temperature, figure 30 shows the good agreement between the two sensors Scufa and Cylops-7 for water temperature measurements.

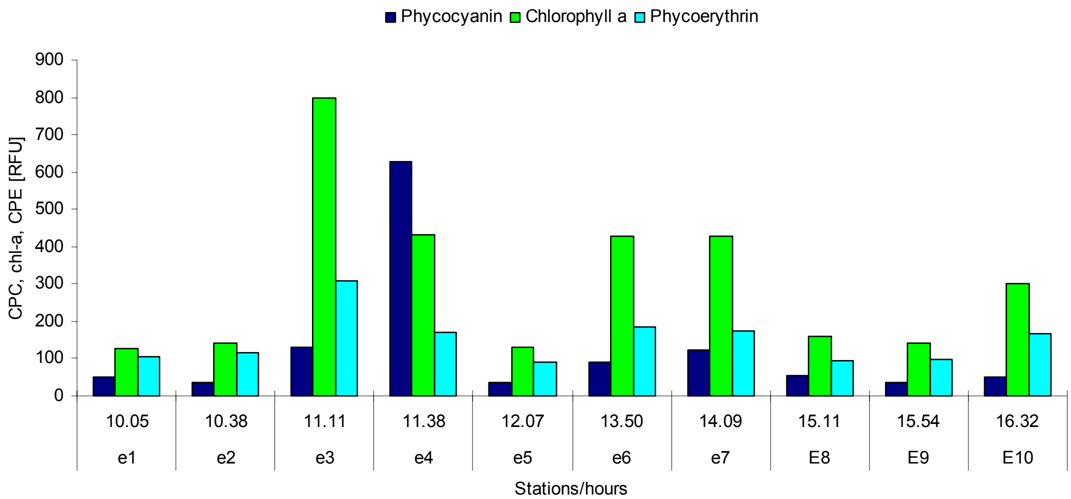

Figure 28 - Average values of Phycocyanin (CPC), Chlorophyll-a (chl-a) and Phycoerythrin (CPE) at the stations measured on 4 August. Data were collected at about 50-cm depth.

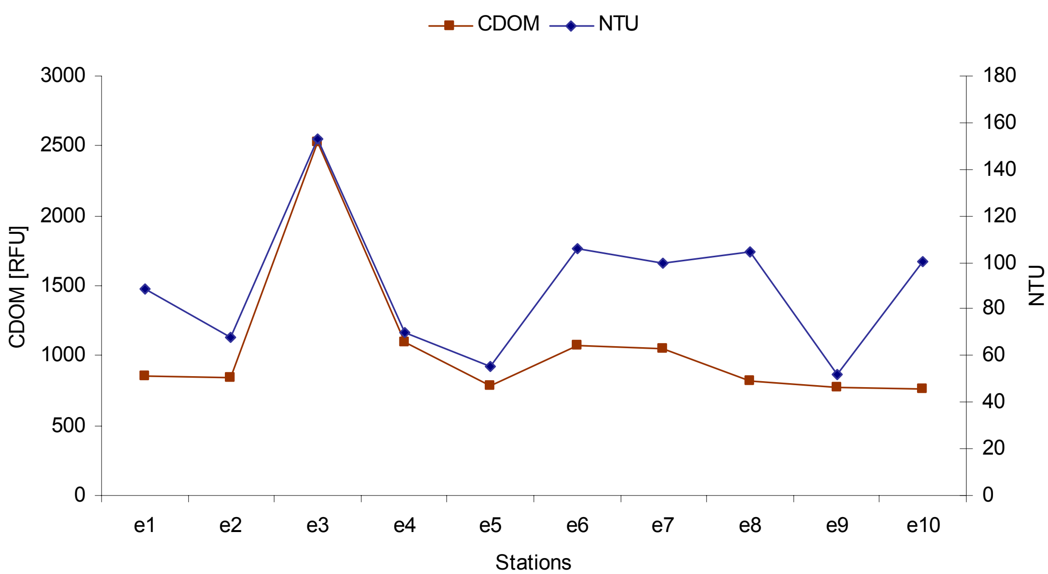

Figure 29 - Turbidity (in NTU units) and CDOM values for at the stations measured on 4 August 2001.

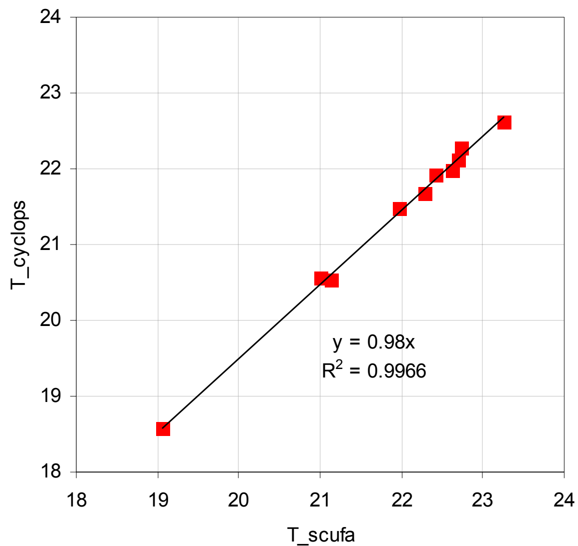

Figure 30 - Scatterplot between temperature values measured with Scufa and Cyclops sensors in the ten stations measured on 4 August.

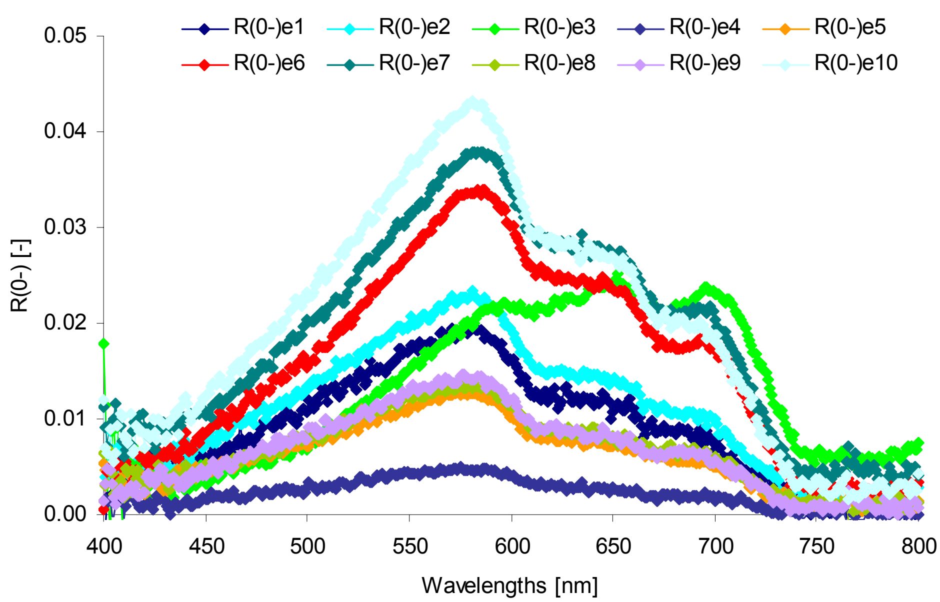

Figure 31 - R(0-) spectra derived from ASD data from underwater measurements of upwelling and downwelling irradiance in the ten stations measured on 4 August.

Table 4 reports the empirical values measured in situ of the Q-factor ((E(0-)/Lu(0-)) for the whole stations save station e4 because the changing conditions of cloud cover did not allow to get good data to compute the Q-factor. On average, the Q-factor are around 5.8 sr, a value that verifies the predictions of the radiative transfer model Hydrolight (Mobley, 1994), due to the empirical behaviour of its generation.

Table 5 - In situ measurements of Q factor in the Lake Vänern stations

	st1a_1	st1a_2	st1b	e1	e2	e3	e5	e6	e7	e8	e9	e10
average	5.4	5.6	4.9	5.8	6.1	5.8	5.0	5.5	6.6	6.1	6.4	6.1
St.Dev.	0.1	0.3	0.1	0.3	0.2	0.9	0.3	0.1	0.3	0.2	0.3	0.2

Intercomparison of radiometers

In our joint campaign we used four types of radiometers simultaneously for sea-truthing. The simultaneous measurements will be used for intercalibration. The four instruments were:

- The Tethered Attenuation Coefficient Chain Sensor (TACCS, Satlantic Inc. Canada) radiometer has 7 channels for upwelling radiance (Lu) at 50 cm depth and 3 channels for Ed above the surface, and a chain of Ed sensors at 2, 4, 6, 8 m deep. The TACCS is deployed at 10-20 m distance from the ship to avoid shadow. It was set to record for 2 minutes at a rate of 1 sample per second. With an AC9plus, depth profiles were taken. The TACCS and AC9 data are used together to derive the spectral reflectance (Kratzer et al. 2008).
- The TriOS radiometric measurement system (Tartu Observatory) consists of three TriOS- RAMSES hyperspectral radiometers (350-950 nm). The radiometers can be deployed above or below water. In this study an above water system was used: one irradiance sensor measuring Ed, and two radiance sensors with a FOV of 7°, measuring respectively the total radiance (Lt) at 40˚ from the nadir and the radiance from the sky (Lsky) at 40˚ from the zenith; measurements were taken at an azimuth of 135˚ with respect to sun. Recording period was set to 20 seconds for 2 minutes.
- The ASD FieldSpec is a hyperspectral instrument with a spectral range 350 to 2500 nm. It can be deployed above and below water; in this study an above water system was used. A measurement of Lu is directly followed by a measurement of Ld.
- The Water Insight SPectrometer with three radiometers (WISP-3) is a new close range optical hand-held radiometer. The instrument was designed for monitoring and research on water quality. It is easy to handle and deploy, also for non-expert users. The intercalibration is a test case for the WISP-3.

TACCS, TriOS, ASD FieldSpec, and WISP-3 radiometers were deployed simultaneously and reflectances derived from these measurements will be compared. We are planning to write a manuscript about this field intercomparison. The SeaPRISM, installed at Pålgrunden lighthouse (NASA Aeronet-OC station), was intended to be included in this intercomparison, but there appeared were dredging activities in that area during our measurements, so the SeaPRISM data cannot be included.

Stockholm University measured also CTD profiles and turbidity on their AC9plus set-up that can additionally used for instrument comparison. The AC9plus frame also has a volume scattering function meter, VSF-3 (WetLabs) that was used for comparative measurements with the Hydroscat-6.

Furthermore, we filtered water samples for CDOM, SPM, chlorophyll-a and filter-pad technique measurements in our field laboratory and measured turbidity with a bench fluorometer. The data from the field work are currently still being processed and the results of the intercomparison of the different instruments will be included in the report from 2012.

6. External expertise

Within the project some specific know-how was needed to reach cyan-IS-was goals. In particular, the following two expertises joined the project

- Erica Matta, degree in Environmental Sciences in 2007 at University of Milano Bicocca, collaborated in the project by participating in the fieldwork activities in Italy, and by compiling the state-of-the-art and by supporting the dissemination activities.
- OEO (Odermatt Erath Observation) performed the pre-elaboration of a set of MERIS satellite images in order to remove radiometric and atmospheric noise. These corrected products consist of image data in physical units suitable for the retrieval of optically active components and in particular cyanobacteria algal species. Experts from OEO also participated to dissemination activities as the “Remote Sensing of Cyanobacteria” workshop.
- The Swedish group was supported by Gerald Moore, one of Europe’s most experienced researchers in bio-optics. He supports the group in terms of electronic engineering, bio-optical modelling and programming as well as advice on remote sensing. His participation in the field-work in Vänern was funded by ESA and the Swedish National Space Board.

7. Education

Within the project young researchers and PhD/MSc students have been involved in order to give them experience in remote sensing data analysis and measurements of water quality to reach cyan-IS-was goals.

- Mariano Bresciani, PhD student in ecology at the University of Parma, performed part of his research activities about the characterisation of optical of cyanobacteria within the scientific frame of cyan-IS-was project.
- Simone Sciumbata, MSc student in Environmental Sciences at University of Milano Bicocca, performed part of his educational activities on in situ data handling of Mantua lakes within the scientific frame of cyan-IS-was project.

- Simone Lella, degree in Information and Communication Technology in 2009 and young researcher at CNR-IREA, performed part of his research activities on ICT services within the frame of cyan-IS-was project.
- Jose Beltran, PhD student at Stockholm University received training for sea-truthing and laboratory analysis during our campaign in Vänern.
- Martin Ligi and Ilmar Ansko from Tartu Observatory also participated in the field-campaign in Vänern, and in the intercomparison of radiometers. Martin Ligi is at the start of is PhD, and this exercise provided him with important field training.
- The work-shop on 'Remote Sensing of Lakes' had 10 participating PhD students from the Nordic Network for Aquatic Remote Sensing.

8. Divulgation

The cyan-IS-was project was presented in occasion of several events, including scientific symposium and workshop.

- F. Braga (CNR-ISMAR) promoted cyan-IS-was at the symposium "Convegno Mare Amico", 27-29 May, 2001, Sircausa, Italy
- C. Giardino (CNR-IREA) presented the cyan-IS-was project at the kick-off meeting of Clam-Phym at the Italian Space Agency, Rome, 14 April 2011.
- M. Bresciani (CNR-IREA) presented cyan-IS-was project at the working group of "Gruppo nazionale per la gestione del rischio cianobatteri in acque destinate al consume umano" at the Istituto Superiore di Sanità, Rome, 25-26 January 2011.
- M. Bresciani (CNR-IREA) presented cyan-IS-was project at the "Corso di accompagnamento al lavoro - Corso di laurea in Scienze e sicurezza chimico", University of Milan, 19 May 2011.
- M. Bresciani (CNR-IREA) presented "Analisi delle fioriture di cianobatteri nei laghi d'Idro e Trasimeno attraverso l'utilizzo delle tecniche di telerilevamento" at workshop "VIII incontro dei dottorandi in scienze ecologiche" at Scuola Superiore S. Chiara, Siena, 11-13 May 2011.
- The paper "Recognising harmful algal bloom based on remote sensing reflectance band ratio" by Bresciani et al. is accepted for publication in the Journal of Applied Remote Sensing (see the included digital file "Bresciani_etal_JARS.pdf").
- S. Kratzer promoted cyan-IS-was in her presentation about Nordic cooperation, and A. Hommersom presented first results of the Vänern campaign during the work-shop on Baltic Sea Remote Sensing during the "Baltic Sea Science Congress" in St. Petersburg on 24 August 2011.

9. Conclusions

On the basis that the Swedish partnership already received the approval of cyan-IS-was for the period 28-02-2011 and 31-12-2014 from the Swedish Research Council, we expect to continue the cooperation activities in the next years.

According to the proposal, next year we will focus on marine waters also and on cyanobacterial mapping by using satellite data. With respect to sea waters, the cyan-IS-was partners already discussed to focus on Adriatic Sea in Italy and on the Baltic Sea in Sweden.

We will work both on the analysis of satellite data and the in situ measurements. Sea and lake-truth data will be used for the evaluation of the satellite maps derived from ad-hoc developed algorithms and processors. We expect that these processors will work differently in different water bodies, dependant on the range of inherent optical properties.

On the basis of what has been achieved this year, intercomparison of radiometers, multi-channel fluorometer and backscatter instruments will also continue.

Of course, more concrete plans will be made once the Italian research group has received the approval of continuation of this bilateral collaboration.

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11. Acronyms and symbols

$a_{CDOM}(440)$: absorption coefficient due to CDOM at 440 nm
AOP: Apparent optical properties
ASD: Analytical Spectral Device Inc.
CDOM: Coloured dissolved organic matter (also known as yellow substances)
Chl-a: Chlorophyll-*a*
CNR: Consiglio Nazionale delle Ricerche (National Reserach Council of Italy)
CPC: Phycocyanin
CPE: Phycoerythrin
CTD: Conductivity, Temperature, Depth
Ed: downwelling solar irradiance
EO: Earth Observation
FOV: Field of View
FR: Full Resolution
HH: Hand-Held
HPLC: High-performance liquid chromatography
ICT: Information Communication Technology
IDPA: Istituto per la Dinamica dei Processi Ambientali
IOP: Inherent optical properties
IREA: Istituto per il Rilevamento Elettromagnetico dell'Ambiente
ISMAR: Istituto di Scienze Marine
$Kd(\lambda)_{Z_{av}}$: Coefficient of extinction of the downwelling irradiance at a certain wavelength λ and for an average depth *Zav*
Lref: radiance of reference Spectralon® panel
Lsky: radiance from the sky at 40˚ from the zenith
Lt: total radiance at 40˚ from the nadir
Lw: upwelling water radiance
MERIS: Medium-Resolution Imaging Spectrometer
MODIS: Moderate Resolution Imaging Spectroradiometer
MSc: Master of Science
NASA: National Aeronautics and Space Administration
OEO: Odermatt Earth Observation
R: Reflectance factor
RAM: Ramses

Rrs: Remote sensing reflectance
R(0-): irradiance reflectance below the surface
SD: Secchi disk
SPIM: Suspended particulate inorganic matter
SPM: Suspended particulate matter
SPOM: Suspended particulate organic matter
SS: SpectraScan
SU: Stockholm University
TACCS: Tethered Attenuation Coefficient Chain Sensor
WISP: Water Insight Spectrometer

12. Annexes

Annex I. Synergic projects

Logo	Name	Coordinator	Duration	Funding	Contribute to cyan-IS-was
CLAM-PHYM	Coasts and Lake Assessment and Monitoring by PRISMA HYperspectral Mission	Luigi Alberotanza, CNR-ISMAR	2011-14	Italian Space Agency	In situ data, hyperspectral satellite data (i.e. PRISMA)
EUFAR European Facility For Airborne Research HABLakes	Spectral characterization of Harmful Algal Blooms in Mantua Lakes (Italy)	Claudia Giardino, CNR-IREA	2011-12	EUFAR	Airborne imaging spectrometry (APEX)
EuLakes	European Lakes Under Environmental Stressors	Nicola Gallinaro, Lake Garda Community	2010-2014	EU Central Europe Programme	Limnological records, ecological features
MELINOS	Monitoring European Lakes by means of an Integrated Earth Observation System	Claudia Giardino, CNR-IREA	2003-on going	ESA cat-1 (AO553)	Satellite data (MERIS, Chris-Proba)
WaterS	Strategic partner-ship for improved basin-scale Water quality parameter retrieval from optical Signatures	Anu Reinart, Tartu Observatory	2010-2014	EU FP7 Marie Curie (IAPP)	Support for field-work in lake Vänern
norden NordForsk	Nordic Network for Aquatic Remote Sensing (NordAquaRem)	Susanne Kratzer, SU	2008-2011 and 2012-2014	NordForsk (Nordic Ministers)	Support of workshop on Remote Sensing of Lakes in Oslo

	Using MERIS full resolution data for improved monitoring of coastal areas in the Baltic Sea - from research to application	Susanne Kratzer, SU	2010-2011 possible continuation	Swedish National Space Board	Support for salaries of Susanne Kratzer's research group
	Technical Assistance for the validation of MERIS products in lake Vänern and coastal waters of the north-western Baltic Sea (Sweden)	Susanne Kratzer, SU	2008-2012	ESA ENVISAT	Support for field work and Niklas Strömbeck's salary

Project partners:

- CLAM-PHYM - CNR-ISMAR (coordinator), CNR-IREA, CNR-IIA (all from Italy)
- EuLakes - Lake Garda Community (coordinator), Italy; APPA Trento, Italy; E. Mach Foundation, Italy; CNR-IREA, Italy; Lake Balaton Development Coordination Agency, Hungary; University of Pannonia, Hungary; Austrian Institute of Technology, Austria; Austrian League of Nature Conservation Burgenland, Austria; Institute of Meteorology and Water Management, Poland.
- HABLakes - CNR-IREA (coordinator), University of Parma, University of Milano Bicocca (all from Italy)
- MELINOS - Several partners and users take part of the project depending by the study site; among them: CSIRO-Land and Water, Australia; CNR-ISE, Italy; Klaipeda University, Lithuania; CAS Beijing, PRC; ENAS Sardinia, Italy; ARPA Umbria, Italy; CRA Sirmione, Italy.
- WaterS: Tartu Observatory, Estonia (coordination) , Stockholm University, Systems Ecology, Sweden Finnish Environmental Institute, Finland, Brockmann Geomatics AB, Sweden, Water Insight, The Netherlands, Brockmann Consult, Environmental Informatics, Germany
- NordAquaRemS: Stockholm University (coordination), Helsinki University, Finland; Tartu Observatory, Estonia; Institute of Oceanology, Polish Academy of Sciences (IOPS), Poland; Norwegian Institute for Water Research (NIVA), Norway; National Environmental Research Institute (NERI), Denmark; University of Tartu, Estonia; Finnish Environment Institute (SYKE), Finland; Free University of Berlin (FUB), Germany; Brockmann Consult, Germany; Marine Research Institute in Iceland (MRI), Iceland; University of Oslo; University of Gdansk, Poland

Annex II. Workshop "Remote Sensing of Lakes" - List of participants

Name	Position/role	Institute
Are Folkestad	Workshop coordinator	NIVA, Norway
Susanne Kratzer	NordAquaRemS coordinator, CyanIs-Was PI	Stockholm University
Annelies Hommersom	post Doc, cyan-IS-was	Stockholm University
Therese Harvey	PhD student	Stockholm University
Jose M. Beltran-Abaunza	PhD student	Stockholm University
Petra Philipson	Invited lecturer (NordAquaRemS partner)	Vattenfall Power Consultant, Sweden
Claudia Giardino	Invited lecturer (cyan-IS-was PI)	CNR-IREA, Milano
Sampsa Koponen	Invited lecturer	SYKE, Finland
Anu Reinart	Researcher (NordAquaRemS partner)	Tartu Observatory, Estonia
Martin Ligi	PhD student	Tartu Observatory, Estonia
Tiit Kutser	Researcher (NordAquaRemS partner)	Estonian Marine Institute
Birgot Paavel	NordAquaRemS partner	Estonian Marine Institute
Tuuli Kauer	PhD student	Estonian Marine Institute
Carsten Brockmann	BEAM Training	Brockmann Consult, Germany
Kerstin Stelzer	BEAM Training	Brockmann Consult, Germany
Kai Sørensen	NordAquaRemS partner	NIVA, Norway
Erlend Kjeldsberg Hovland	PhD student	NTNU, Norway
Øyvind Kleiv	MSc student	University of Oslo
Eyvind Aas	NordAquaRemS	University of Oslo
Jakob Stamnes	Prof	University of Bergen
Hugo Parr		Barenstwatch/ MD, Norway
Tom Andersen		University of Oslo
Sigrid haande		NIVA, Norway
Thomas Rohrlack		NIVA, Norway
Briger Skjelbred		NIVA, Norway
Anne Lyche Solheim		NIVA, Norway
Markus Lindholm		NIVA, Norway

Italian Contribution

The presentation: "Remote sensing of lakes. Towards management relevant applications" from Claudia Giardino can be found in the "NordAquaRemS-CGiardino.ppt" file.

Annex III. Workshop "Remote Sensing of Cyanobacteria"

Leaflet

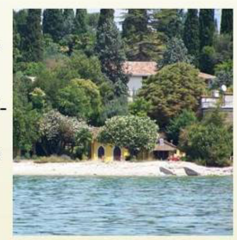
Workshop
"Remote Sensing of Cyanobacteria"

Mantua and Garda lakes, 19 July 2011

istituto per il rilevamento elettromagnetico dell'ambiente

Organised by CNR-IREA Milano in collaboration with University of Sweden, Strömbeck Consulting, Luode Consulting Oy, OEO Odermatt Earth Observation, CNR-ISMAR Venice, CNR-IIA Rome, University of Parma

Rationale - Eutrophication and cyanobacterial blooms present an increasing threat to the health of aquatic ecosystems and to humans who use these resources for multiple purposes (e.g. drinking, recreation, aquaculture). Remote sensing is being used increasingly as a tool for monitoring these phenomena in inland and near-coastal waters (Matthews et al., 2010).



Aims - A set of spectroradiometers (e.g. Ramses, ASD), fluorimetric probes and optical sensors (e.g. Hydroscat-6) will be operated simultaneously with water sampling in order to: *1*) perform inter-calibration exercises, *2*) collect data during cyanobacterial bloom and *3*) promote cooperation activities. The oral session aims to divulgate some research projects on remote sensing of lakes.

Program

8-10→Transfer from Milan to Mantua

10-13.30→**Fieldwork activities** in **Mantua lakes** (lunch box will be served on-board)

14-15.30→Transfer from Mantua to **E. Zilioli Research Station** in **Sirmione del Garda**

15.30-18.00→**Oral session**:

- Welcome to the Station (Brivio IREA)
- Introduction to Cyan-Is-Was Project (Giardino IREA)
- Summary of fieldwork activities in Mantua lakes (Strömbeck Consulting, Luode Consulting Oy.)
- Links with other projects:
  - Eufar - HABlakes (Bresciani IREA, Rossini Università Milano Bicocca)
  - Central Europe - EULAKES (Gallinaro Comunità del Garda)
  - ASI - CLAM-PHYM (Braga ISMAR, Cavalli IIA)
  - Life Plus - EnvEurope (Carrara IREA)
- Discussion and conclusions

18-21→**Outdoor dinner** at E. Zilioli Research Station and return to Milan

Research framework -** The workshop is part of **Cyan-Is-Was** a cooperation project between Italy and Sweden (2010-2011, MIUR) to detect cyanobacterial blooms in Italian and Swedish waters from earth observation technology **(Iniziativa svolta con il contributo del Ministero dell'Istruzione dell'Università e della Ricerca).

EuLakes · EUFAR European Facility For Airborne Research · ASI CLAM-PHYM · Centro Rilevamento Ambientale (CRA) Comune di Sirmione · CENTRAL EUROPE COOPERATING FOR SUCCESS. · EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Logistic: GEO Eventi & Servizi srl

List of participants

Name	Position/project frame	Institute
Pietro Alessandro Brivio	Head of IREA	IREA
Giacomo De Carolis	Researcher (CLAM-PHYM partner)	IREA
Paolo Villa	Post-doc researcher	IREA
Simone Lella	Young researcher	IREA
Paola Carrara	Researcher	IREA
Mariano Bresciani	PhD student for cyan-IS-was	IREA
Claudia Giardino	cyan-IS-was coordinator	IREA
Alba L'Astorina	Researcher	IREA
Alberto Crema	Young researcher	IREA
Giacinto Manfron	MSc student	IREA
Francesco Nutini	PhD student	IREA
Erica Matta	Young researcher for cyan-IS-was	IREA
Daniele Longhi	Post-doc researcher (cyan-IS-was partner)	University of Parma
Nicola Gallinaro	Eulakes coordinator	Comunità del Garda
Roberto Colombo	Researcher (HABlakes partner)	University of Milano Bicocca
Sergio Cogliati	Post-doc researcher (HABlakes partner)	University of Milano Bicocca
Micol Rossini	Post-doc researcher (HABlakes partner)	University of Milano Bicocca
Simone Sciumbata	MSc student	University of Milano Bicocca, IREA
Federica Braga	Researcher (cyan-IS-was partner)	CNR-ISMAR Venice
Gloria Bordogna	Researcher	CNR-IDPA Bergamo
Niklas Strömbeck	cyan-IS-was partner	Strömbeck Consulting, Luode Consulting Oy, Sweden
Daniel Odermatt	Collaborator of cyan-IS-was	OEO Zurich
Livia Kurer	Post-doc researcher	University of Zurich

Note: Filled forms of each participant are given in the "Work_cyan-IS-was_forms.pdf" file.

Video of the oral session

A brief video (cf. the file "Workshop_RScyano.wmv") summarizing some contributes presented at the oral session of the workshop is included as digital file.

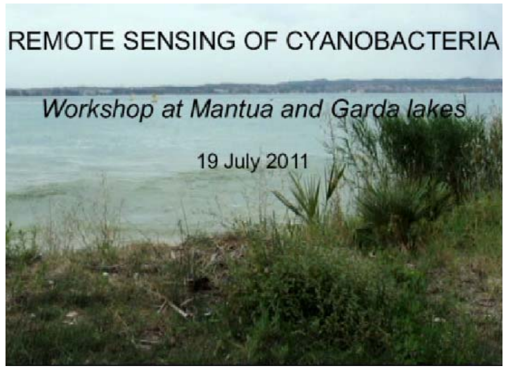


Figure 32 – View of the video made at the Workshop

Annex IV. AERONET-OC Pålgrunden station

Since the spring of 2008, an autonomous SeaPRISM station (SeaWiFS Photometer Revision for Incident Surface Measurements, Zibordi et al. 2004) has been deployed annually during the summer season at the Pålgrunden Lighthouse (Fig. 14) Tower in the center of Lake Vänern (position 58˚45.310 N and 13˚09.092 E). The station is a part of the AERONET-OC (Ocean Color, Zibordi et al. 2006) network and the Pålgrunden station is the seventh operational unit in the world, and the first working in a freshwater environment. SeaPRISM stations address several important issues of ocean color (i.e. optical satellite remote sensing of water quality). They provide estimations of path radiance for atmospheric corrections, sea truth radiometric measurements of water leaving radiance for validation and they can also be used for estimations of water quality directly on site. Data is transferred by satellite link, to a large extent automatically processed and freely available within short time on the AERONET home page.

The station is owned by Susanne Kratzer, Stockholm University, and managed by Niklas Strömbeck, Strömbeck Consulting with technical support by the Swedish Maritime Administration (2008) and the private company Ydergrens HB (2009-2011). Main funding has been provided by the Swedish National Space Board (No. 183/07: Validation of MERIS/MODIS Case 2 water products by use of autonomous SeaPRISM stations in the AERONET-OC network, Strömbeck) and ESA (Algorithm development and validation of MERIS data over optically complex waters, Kratzer).

On of the aims of this project, cyan-IS-was, is to fully explore the capabilities of the Pålgrunden SeaPRISM station for monitoring of cyanobacterial presence. Data collected in previous projects will be revised with special emphasis on cyanobacteria, resulting in a bio-optical model. The model in turn will be used in a reversed direction to access concentrations on chlorophyll a and cyanobacterial pigments in the water form the SeaPRISM measurements.

Figure 33 - The AERONET-OC Pålgrunden station located in center of Lake Vänern.

13. List of digital files

01. Cyan-IS-was_final-report.pdf: this document.
02. State_of_art_summary.xls: summary of the review of about 30 papers on remote sensing of cyanobacteria
03. Workshop_RScyano_forms.pdf: forms of people attending the workshop "Remote Sensing of Cyanobacteria", Mantua lakes and Sirmione del Garda, 19 July 2011.
04. Workshop_RScyano.wmv: video summarizing some contributes presented at the oral session of the workshop "Remote Sensing of Cyanobacteria".
05. NordAquaRemS-CGiardino.ppt: slides of the talk of C. Giardino at the workshop "Remote Sensing of Lakes", Oslo, 16-17 February 2011.
06. 06_Bresciani_etal_JARS2011_proof.pdf: proof of paper "Recognising harmful algal bloom based on remote sensing reflectance band ratio" by Bresciani et al. 2011, published in the Journal of Applied Remote Sensing (SPIE).