Strategic partnership for improved basin-scale water quality parameter retrieval from optical Signatures - WaterS.

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Abstract - As the inland and near-coastal waters are under the strongest anthropogenic impact there is need for a better way to monitor their ecological status. European network FP7 project WaterS focuses on creating conditions for strategic dynamic partnerships in the form of long-term cooperation between three research groups and three enterprises with unique complementary expertise and tools. The research objectives are:
1) Improve the interpretation of optical signals from remote sensing platforms for the optically complex Nordic waters through bio-optical modeling of characterized variability in optical properties.
2) Innovation in development of spectral instruments to perform state-of-the-art measurements optimized for aquatic environments.
3) Improved understanding of optically complex waters by means of classification and typification for mapping water bodies by optical signature.
4) Using EO capacities, water quality retrieval algorithms and GIS systems develop of novel product for lake water quality and ecological assessment.

Keywords: Coastal waters, Lakes, Satellite remote sensing, Close range remote sensing, Ecology, Services

1. INTRODUCTION

Sustainable use of water resources requires the coupling of surface waters assessment monitoring programs and decision making and management tools. The Water Framework Directive (WFD) is the major reference in Europe to guide efforts for attaining a sustainable aquatic environment in the years to come. Ultimately the monitoring programs are needed to know if WFD goals are met and to show that water quality is not deteriorating. For this, reliable and validated monitoring methods have to be put in place. Remote sensing of water quality has been proposed as an operational means to support the monitoring of parameters that are required by the WFD but unfortunately there is little overlap between the compounds that are on the WFD monitoring list (Nõges and Nõges 2006).

When deterioration of water quality is caused by optically active substances, the effect of these changes can be observed with optical remote sensing instruments. In general, the parameters that have been identified in literature as detectable by modern satellites are:

1) green algae pigments mainly Chlorophyll-a (Chl-a) as a proxy of phytoplankton biomass
2) Total Suspended Matter (TSM) which is placed in suspension by wind-wave stirring of shallow waters and is a tracer for inflowing pollutants
3) Colored dissolved organic matter (CDOM), relevant also for estimations of global carbon cycle
4) the diffused attenuation (K_d) as measure for the water transparency, closely linked to traditional Secchi disk transparency (Kratzer et al. 2003)
5) the cyanobacterial pigment phycocyanin (Simis et al. 2008)

The basis of EO water monitoring is the measurement and understanding of the spectrum/optical signature of water leaving light. The optical signature as received by a sensor in space is influenced by optical interactions in water (depending on optical properties of substances in water) and by optical interactions in the atmosphere (depending on the optical properties of components and particles suspended in air, which may also vary greatly by Zibordi et al. 2009). These interactions are well understood for simple situations like over oceanic waters and use of EO satellites for remote sensing of clear ocean waters (optical Case 1 waters) has become very successful in the last decades.

Physically, large lakes exhibit several similarities to seas and oceans in their thermal structure and circulation dynamics but their optical properties differ markedly. Concentrations of optically active substances in inland waters may exceed the concentrations found in oceanic waters by several orders of magnitude, and also exhibit great variation between geographically close lakes (Arst et. al. 2008) belonging into different optical class (Arst and Reinart 2008). In contrast, Baltic Sea waters are in many respects more similar to large lakes than to marine waters worldwide (Kratzer et al. 2007). The consequences of this variability on the solutions of optical models that derive information from observed spectra is largely unknown. As a result of this poor understanding of natural variability there has been a tendency to build locally valid models which fail in situations other than the calibration case.

For water quality estimations it is necessary to have the full operating system available, which starts from near-real time acquisition of satellite data, archiving and processing. The ground system includes in situ measurements and laboratory analyses for development, calibration, and validation of remote-sensing based water quality products, as well as appropriate instrument development and calibration (IOOCCG 2005).

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During processing two steps are needed: (1) correction procedure which can be used operationally to remove atmospheric effects, effects from neighboring pixels (adjacency effect) and bottom reflection from images, yielding a product defined as water leaving radiance; (2) algorithms that relate satellite derived water leaving radiance or reflectance to Apparent or Inherent Optical Properties (AOPs, IOPs).

To make step forward in this field the consortium of 6 partners was formed and cooperation program WaterS is presented as follows.

2. INTERANTIONAL EXPERINECE

The network focuses on creating strategic and dynamic partnerships for long-term cooperation between three excellent research groups with proven high competence and capacity in the field of remote sensing of optically complex waters from Tartu Observatory, TO (Estonia), Stockholm University, SU (Sweden), and the Finnish Environment Institute, SYKE (Finland), as well as three successful and quickly developing enterprises with unique complementary expertise and tools (Water Insight, WI The Netherlands; Brockmann Consult, BC Germany; Vattenfall Power Consult, now Brockmann Geomatics, Sweden) (Fig. 1). The partners have demonstrated enough overlap in the field of remote sensing of optically-complex waters to launch common research interests (Table 1).
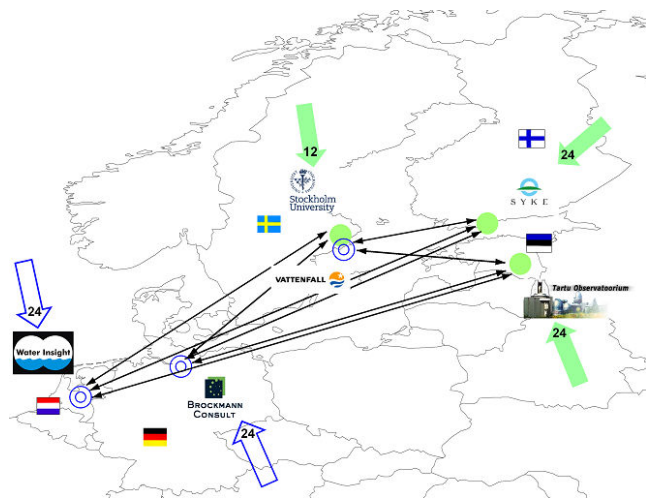

Fig. 1. WaterS Consortium Structure: 3 Academy and 3 Industry partners. Arrows indicate direction of secondments, bock arrows show recruitments and duration.

To facilitate the research program, partners provide significant infrastructural and human resources from their national and international networks. To foster interaction at human level, the WaterS transfer of knowledge program contains (Fig. 1) secondment of the staff members, recruitment of experienced researchers and organization of joint activities.

The WaterS consortium possess relevant experience from several EU and ESA funded research projects,: FP5 project SALMON summarized methodology for remote sensing of lakes; methods and protocols for Case 2 waters were updated in FP6 project

REVAMP (Tilstone et al. 2004). ESA GMES (Global Monitoring for Environment and Security) Service element three year project MarCoast provides integrated network of detection and monitoring technologies involved in water quality, oil spill and metereological information over European seas including the North sea and Baltic Sea. The aim of ESA GSE CoastWatch is to provide services to help better monitoring and assessment in the frame of environmental policy of the coastal zone. CoastColour is connecting users and researchers for new service development systems to fully exploit the potential of the MERIS instrument for remote sensing of the coastal zone.

Table 1. Partners competences in the key research areas

Competence area\Partner	TO	SU	SYKE	VF	WI	BC
Inovation in optical radiometry and instrumentation	x		x		x	
Bio-optical measurements for Sea-truthing, field and laboratory experiments	x	x	x			
Bio-optical modelling			x		x	
Natural Water Resource Management using Geo-information and EO data		x	x	x		
Baltic Sea and inland water monitoring and ecosystem modelling		x	x			x
Benthic habitat mapping in turbid waters			x	x	x	
Vegetation reflectance modelling and measurements	x			x		
Atmospheric aersol and other atmospheric effects	x			x		x
Automated operational processing chain and software development			x	x	x	x
Computational algorithms and technology for large datasets					x	x

3. APPLICARIONS FOR INLAND WATERS

For inland waters, not as many internationally coordinated activities have been initiated. Two new lake remote sensing data processors were released in July 2008 for the Envisat/MERIS instrument after the ESA project "Development of MERIS Lake Water Algorithms" (2007-2008). The bio-optical models used in the development were parameterized using in situ data from Finnish and Spanish lakes (Koponen et al. 2008). These modules are based on Case 2 regional (Doerffer and Schiller, 2007) and use the ICOL module (Santer et al. 2007) for adjacency effects. It has yet to be demonstrated that these improvements are sufficient to allow operational monitoring of water quality of inland waters.

An extremely complicating and poorly understood effect on water quality remote sensing is masking of color. One highly concentrated coloured component can suppress the retrieval possibilities for others. This is especially the case in lakes and coastal waters where CDOM is present and tends to mask phytoplancton absorption and suspended matter scattering in the blue to green wavelengths. Many problems coasted probably by CDOM have been reported:

1) The satellite observed water leaving radiance in the blue range is often quite different from spectral observations close to the surface (Soerensen et al., 2007).
2) Chl-a derived from semi-empirical algorithms (such as the widely used OC4v4 algorithm developed for SeaWiFS) may be seriously affected by not incorporating knowledge on (the variability of) CDOM absorption (Kutser et al. 2005, Peters et al. 2005).
3) Algorithms that derive Chl-a, TSM and CDOM simultaneously from the satellite observed spectrum suffer from the influence of errors in blue bands on the CDOM retrieval, thus affecting the balance between all three parameters. This also leads

often to errors in the Chl-a concentration (Hommerersom et al. 2009)

4)   CDOM in European coastal waters as derived from satellite spectral observations has been validated on only a few occasions always showing unacceptable results (Soerensen et al., 2007, Alikas and Reinart 2008).

4.   USER DRIVEN ALGORITHM DEVELOPMENT

Algorithms development for remote sensing evolved from bio-optical modelling, using anything from simple approximations of the radiative transfer to neural networks and analytical models such as Hydrolight (Doerffer and Schiller, 2007; Schroeder et al., 2007). Recently inversion algorithms for water quality parameter retrieval have been developed that are able (with varying success) to resolve IOPs directly: total absorption (a), backscattering (b_b), the attenuation coefficient (c), and the diffuse attenuation coefficient (K_d) as well as the apparent optical property (AOP) of Secchi disk transparency (SD) from remote sensing observations of water leaving radiance in Case 2 waters (Doerffer and Schiller, 2007, Van der Woerd and Pasterkamp, 2008, Smyth et al., 2006). This gives new challenges also for more sophisticated application over optically complex waters especially in lakes.

Lately the importance of lakes and reservoirs to reflect the influence of climate change in their catchments was brought to the attention of the global community (Williamson et al. 2009). As many of the large lakes have been studied seasonally for many years, they have often become valuable model objects for studying pressure–impact relationships in detail, that is needed as a basis for setting the WFD water quality class boundaries. In recent years, several large lakes have been included in European research projects. The EC project EUROLAKES aimed to develop an integrated water resource management strategy for a number of important deep European lakes and their catchments and contributed to the estimation of ecological criteria.

In the EC project ECOFRAME, which developed ecological quality and functioning of shallow lake ecosystems with respect to the needs of WFD included also representative of large lake (Estonian Lake Võrtsjärv). In the EC project CLIME, the impacts of climate on lakes in Europe were assessed and particular attention was paid to the water quality variables that are used as diagnostic elements in the WFD. This points out the continuous need for good quality, spatially and temporally frequent coherent data over large geographical regions, that only remote sensing in conjunction with network of contact measurements could provide.

5.   RESEARCH METHODOLOGY

The workplan of the WaterS is divided into seven work packages to ensure coherence between research & technology activities based on the transfer of knowledge program with synergy creation, dissemination plan and management (Fig. 2):

WP1: Management
WP2: Knowledge sharing for cooperative research & ground-based techniques for the observation of optically complex waters
WP3: Knowledge sharing for cooperative research & development in remote sensing techniques
WP4: Knowledge sharing for cooperative research & development in ecological mapping through optical signatures

WP5: Knowledge sharing for cooperative research & development in data management and processing
WP6: Creating a common knowledge base and synergy
WP7: Broad skills development and increasing consortium visibility

The following key research areas are touched upon in the research program:

•   Advanced bio-optical modeling based on radiative transfer theory which is crucial for processing optical signature from CDOM and TSM loaded waters.
•   Characterization of optical properties and its determining variation limits in three largest European and several smaller lakes and basins in Baltic Sea.
•   Optical radiometry and development of miniature spectroradimeters for water monitoring authorities.
•   Characterization of aerosol properties and climatology over the Baltic region, for further use in improved atmospheric correction models.
•   Studies on methods for mapping bottom and coastal vegetations by their specific optical signature.
•   Improved understanding of ecological status of lakes in Nordic region as example of the method that could be extended to operational service systems in other regions.
•   Combing new research based models, parameters and methods into open Software and database for further applications.
•   Extended use of satellite data in conjunction with close-range remote sensing and contact measurements for optically-complex waters.
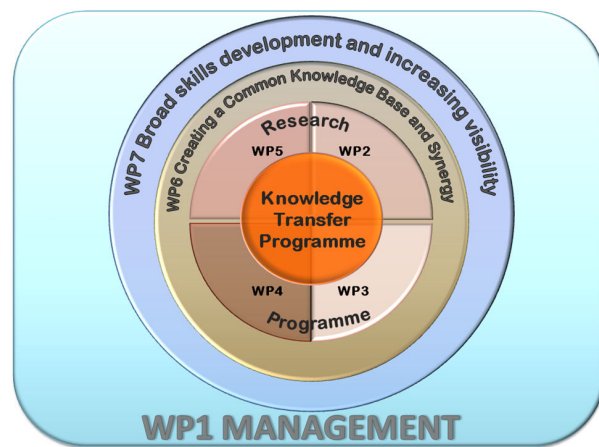

Fig. 2 Interaction of WaterS research methodology and knowledge transfer program.

6.   CONCLUSIONS

The impacts of the network includes significant progress beyond-the-state-of-the-art in many areas:

1. Innovation in close-range optical spectral measurements and automatized data storage and processing. A small spectral instrument which can be used in small and shallow water bodies will combine simultaneous spectro-radiometric measurements in 3 directions to measure the light that leaves the water (water-

leaving radiance). This type of measurement originates from lake and coastal waters research in the 1980s but in the last years, enormous progress has been made because of a need to validate high resolution satellite measurements. Ideally, this will also result in the merging of data streams from satellite and in situ observations in conjunction with other ranges remote sensing and integrate published algorithms for water quality parameter assessment into one instrument/information service. It is a primary aim to establish a data processing framework compliant with the INSPIRE initiative.

2. Original way to fill growing need for optical information coming from developers of aquatic ecological models. Especially accurate K_d estimates are required to drive primary production models. In the near future, the integration of ecological models and remote sensing may result in the potential to predict optical water quality (e.g. in terms of algal species and thus the IOPs). This will probably significantly improve the skill of remote sensing retrievals because in this way regional/local information about variability in optical properties can be used to parameterize the underlying optical model per pixel.

3. The conversion of proven space technology to monitoring water quality in relatively small inland water bodies. Elaborate a GIS based approach to assess water quality parameters for lakes in Northern Europe and development of novel product for lakes water quality assessment and mapping could be a precursor for a potential operational services globally.

4. Increase globally the understanding of factors included to the carbon cycle – estimation of CDOM concentrations is up to now so difficult by attempting to combine state-of-the-art measurements of IOPs and AOPs and robust analytical models to simulate realistic maximum observable CDOM stepsizes at the satellite.

5. Starting point to discover challenges of the follow up satellite missions for lake applications and for further international operational programs like GMES and GEOSS.

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