Global Lakes Sentinel Services

Grant number 313256

Final report, April 2016

WI, SYKE, EOMAP, VU/VUmc, CNR, BC, TO, BG

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Consortium

No	Name	Short Name
1	WATER INSIGHT BV	WI
2	SUOMEN YMPARISTOKESKUS	SYKE
3	EOMAP GmbH & Co.KG	EOMAP
4	STICHTING VU-VUMC	VU/VUmc
5	BROCKMANN CONSULT GMBH	BC
6	CONSIGLIO NAZIONALE DELLE RICERCHE	CNR
7	TARTU OBSERVATORY	TO
8	BROCKMANN GEOMATICS SWEDEN AB	BG

Executive summary

Monitoring of water quality of inland waters is important for daily life, for drinking water, transport, recreation, agriculture (including drinking water for cattle and or irrigation) and for ecology. Water samples provide detailed information, but are limited in time and space. Earth Observation (EO) can provide a great spatial overview, which is very useful for example for ecologists and water mangers. The high spatial resolution of Sentinel-2 (S2) and the high overpass frequency of Sentinel-3 (S3) will provide unprecedented monitoring capabilities for inland waters. GLaSS developed examples of Sentinel services, to show a larger public what can be done with this new source of EO data.

A core system to ingest and pre-process Sentinel data on a list of selected lakes world-wide was set up. It was filled with Landsat-8 (L8), and is currently also ingesting S2 data. Also, a large database of in situ reflectance data, match-up satellite data (MERIS and L8) and HYDROLIGHT simulated S2, S3-OLCI and L8 data was created. The database includes data of lakes with a large range of optical properties (from clear and blue to green and brown and from highly reflecting to highly absorbing), and was used for testing algorithms. It appeared that most of the atmospheric correction algorithms or water quality algorithms were not suitable for all lakes or sensors. Reasons may be the large range of optical variation or its physical implementation, however, although the algorithms have variable performance between lakes, they have often a very good performance on the series of spectra per lake. This could mean that the inter-lake variability of SIOPs is much larger than the intra-lake variability of SIOPs. This provides good perspectives for remote sensing of lake water quality using S2 and S3. Once a tuning of these algorithms with lake-specific SIOPs has been done, EO data can be used operationally.

To facilitate the pre-selection of atmospheric correction and water quality retrieval algorithms for a lake with unknown optical properties, a pre-classification tool (OWT-GLaSS) was further developed. This tool selects the water type of the class that best matches the remotely sensed spectrum. Also, tools were developed to easily access and handle the data. The automatic Region of Interest and time series generation tool (ROIStats) allows aggregating valid lake pixels for time series production and extracting basic statistics for Regions Of Interest (ROIs) provided by the user. The Prediction tool allows the user to select specific pixels (e.g. lake, land, cloud), to train a model and apply the model to select similar pixels from other imagery.

During the course of the project, in situ campaigns were carried out in lakes in Finland, Estonia, Sweden, the Netherlands and Italy. The measurements were used to further characterise the optics of these lakes, and to validate L8 and S2 during their overpasses. Also, an interesting comparison was made between EO-based chlorophyll concentrations and (dissolved) nutrients that were calculated with the HYPE models. MERIS-Chl-a was in good agreement with the annual fluctuations in nutrients (DIP) from S-HYPE, both within and between years, for many sub-basins in Lake Vänern. For E-HYPE, there was generally a shift in the phases.

Based on a combination of a socio-economic analysis and optical classification, use case lakes were selected globally. The listed lakes were studied in detail with EO and in situ data, using the GLaSS tools and the adjusted algorithms.
For the use case *eutrophic lakes*, four algorithms were chosen to describe Chl-a content and cyanobacteria presence. Time series showed the effect of e.g. meteorological conditions and differences in chlorophyll distribution over the lakes in different years.
For the use case *deep clear lakes*, the focus was on long-term time series of EO data. A statistical approach showed that, although in some of the deep clear lakes there is indeed an indication that eutrophication takes place (Lakes Maggiore and Constance), there are also

lakes where the overall chlorophyll concentration decreases (Lakes Garda and Tanganyika). The use case on **shallow lakes with high suspended matter** concentrations showed the added value of high resolution data such as S2. It shows small-scale swirls in Lake Markermeer, it demonstrates a method to indicate which glacial lakes will potentially cause dangerous runoff events (based on the colour of lakes in the Himalaya) and it follows the restoration project in Lake Böyük Şor (Azerbaijan).

The **highly absorbing lakes** use case tests a new algorithm, SIOCS, on Nordic lakes. Although the results are very good for the simulated data, the in situ reflectance data still leads to less good retrievals. The other part of the study contains a theoretical analysis on the limits of changes in chlorophyll concentrations that can be detected with EO data based on the sensor noise characteristics.

In an additional use case, a method is developed to automatically locate **mine tailing ponds**, using L8 data. These ponds usually contain highly toxic liquids and their locations are not always well known. Incidents occurring every year show the need for locating and monitoring them globally.

In the last use case, the possibility to use **EO data for Water Framework Directive (WFD) reporting** is demonstrated. Although the WFD is EU-wide, the approach per country with regard to EO data is very different. A comparison to the US Clean Water Act was performed. Examples of histograms and time series and the derived classes were presented to potential users, who were very interested.

Altogether, the use cases demonstrate what can be done with the new Sentinel and other EO data with regard to monitoring, trend analysis and classification such as for the Water Framework Directive. Based on the use cases, training material was developed for students in e.g. ecology, environmental sciences, water management or GIS, to learn how to work with EO data on lakes. This material is made available via several sources, such as ESA LearnEO! and the GEO EO Capacity Building portal.
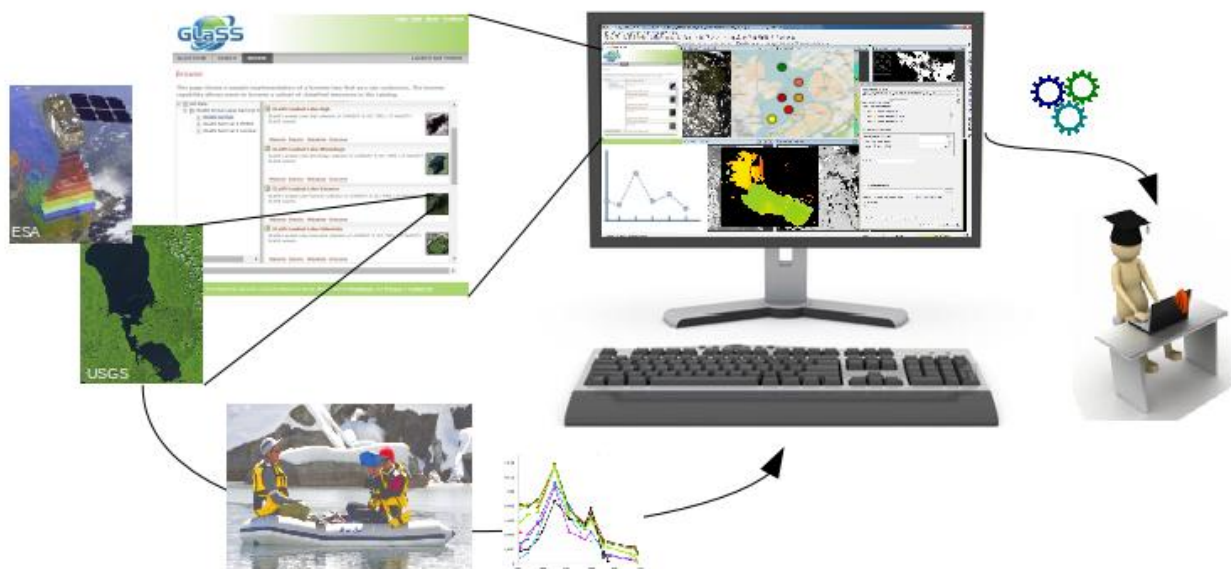

Figure 1, Overview of GLaSS

Table of contents

1 Project context and main objectives

GLaSS paved the way for water quality monitoring of lakes and reservoirs using the upcoming Sentinel-2 (S2) and Sentinel-3 (S3) satellites. Lakes and reservoirs provide essential ecosystem services, but are subject to significant pressure from agriculture, economical development, and climate change. Monitoring changes in the environmental status of lakes is important in water resource management and EU environmental policy instruments. Optical remote sensing techniques provide the means to deliver water quality information at the required spatiotemporal scales. The ESA Sentinel satellite constellations will provide unprecedented observation capabilities for inland waters. In particular, the high revisit frequency of Sentinel-3 and high spatial resolution of Sentinel-2 can be exploited. Large volumes of data have to be ingested, archived, processed and distributed to make full use of this information. New methods for data mining and aggregation need to be developed to turn these platforms into valuable resources for water quality management. It was the goal of GLaSS to develop a prototype infrastructure to ingest and process S2/S3 observations for inland waters, to make them accessible the partners and derived products to a large audience. Based on global lakes use cases, GLaSS aimed to show the potential of S2 and S3 in user-friendly ways.

Specific objectives were:
- Ingesting large quantities of satellite observations and processing the data into higher level products
- Developing data-mining and other tools to work with the data
- Adaptation of water quality algorithms to S2/S3-OLCI data
- Validation of the Earth Observation (EO) based results
- Providing global lakes use cases to demonstrate the possibilities of the Sentinel constellation to a large audience of potential users of this data
- Creation of training material to allow a larger audience to use the data

Global case studies were supposed to demonstrate the applicability of the GlaSS system to different lake types with different management issues:
- Shallow eutrophic lakes with potentially toxic phytoplankton
- Deep clear lakes suffering from increasing eutrophication
- Shallow turbid lakes with high sediment resuspension
- Small lakes with high coloured dissolved organic matter concentrations
- Mine tailing ponds with potentially highly toxic substances
- Reporting for the Water Framework Directive based on GLaSS products

At the end of project, the following achievements were expected:
- Sentinel2/ 3 data formats are integrated into user accessible tools
- Test datasets of S2 and S3-OLCI are available to user community
- S2 and S3-OLCI processing tools for atmospheric correction, feature extraction, time series analysis, etc. are tested and validated
- Updated algorithms for inland water analysis (chlorophyll-a, suspended matter, coloured dissolved organic matter, phycocyanin) are tested and validated for use with S2 and S3
- Educational materials are available from case studies

With these achievements, the GLaSS team aimed to create tools, data and representative results for a global community of next generation satellite remote sensing users.

2 Main science & technology results and foreground

2.1 Core system with interfaces

The GLaSS core-system was created to allow easy access and pre-processing of S2 and S3-OLCI data for the GLaSS team, without having to download large bulks of data by each partner. The core-system also functions as a first test-step towards operational Sentinel-services for a broader audience. Because of the delay of the launch of these instruments, Landsat-8 (L8) and MERIS data were used as a proxy for S2 and S3-OLCI data in the case studies, and the core-team served as the main data source for L8 data during the project. From November 2015 onwards also S2 images were ingested and processed into lakes subsets.

The GLaSS core-system handles the data flow from the central data hubs of the providers (ESA, USGS) through online retrieval, spatial sub-setting over the areas containing the lakes of interest, to the online archive. It performs the pre-processing and provides the subsets of lakes for the partners. Two principles of production are supported: data driven ('standard production') and on-demand production.

The processing chain in the GLaSS core system for each scene comprises:
- Ingesting of the images per lakes (scenes are already ordered by lakes, i.e. in subdirectories for each lake)
- Sub-setting from the complete Landsat 8 scene to the respective lake bounding box, including consistency check of the input product (i.e. completeness of the .tar.gz file)
- Sub-setting of the Sentinel-2 tiles to the respective lake bounding box, separated in the respective UTM zones.
- Formatting including quick look generation and metadata extraction.
- Archiving of the lake subsets and quick looks in the online archive accessible by the partner systems
- Catalogue registration in the GLaSS core system catalogue for data discovery by the partners
- Different interfaces for interactive and machine to machine data distribution (HTTP, openDAP, FTP)

The core-systems' catalogue allows an easy search for and download of the data. The GLaSS catalogue is based on the open-source ESRI GeoPortal software. This software comes with a web-based user interface that was customized for GLaSS. The data are organized in granules (images) and collections (a series of granules) and they are characterized by sensor and lake/region of interest. Metadata is an important element for catalogue, data search, information about collections and single granules. The metadata is retrieved during the data handling and processing within the Core System and provided to the user via xml and easy readable table format. With the implementation of machine-to-machine interfaces (CSW and WPS) the communication between the partners' subsystems and the GLaSS core system can also be fully automated.
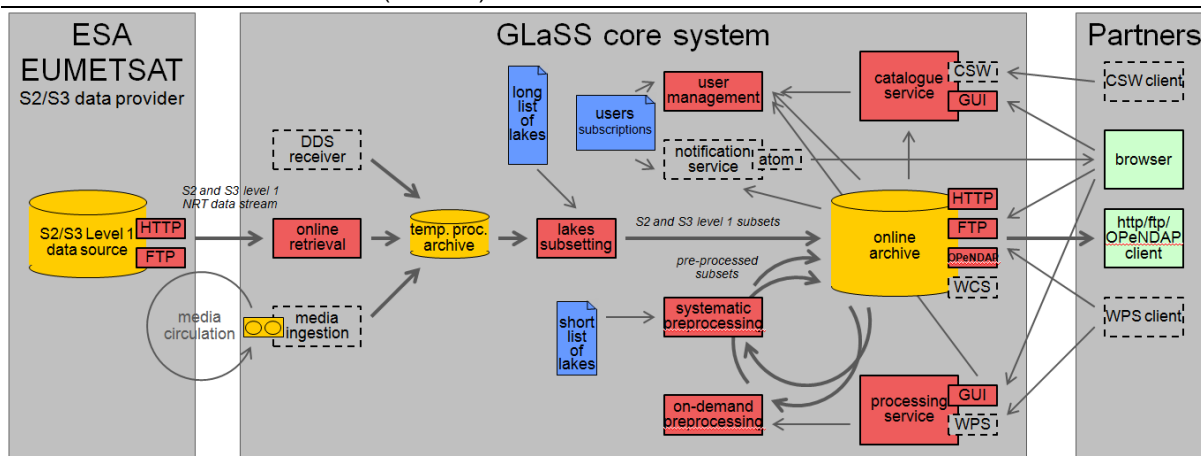
Figure 2, Setup of the core-system

While setup and testing of the core-system was based on L8, as already mentioned, S2 images are ingested and processed into lakes subsets since November 2015. The GLaSS core-system will be active for the GLaSS partners for one more year with all lakes and the two sensors available. The system will be up to two years open to the public with two sample lakes to obtain information on interest for continuation.

Figure 3, Screenshot of the core system

The core system is accessible via this page.

2.2 Simulated test data set

To be able to adjust and test atmospheric correction algorithms and in-water component retrieval algorithms to the new sensors, a test dataset with simulated S2 and S3-OLCI data was created for lakes with a large range in optical properties.

Simulated data were based on three different sources:
- MERIS and Landsat 5, 7 and 8 images from lakes in different countries (Finland, Sweden, Estonia, Netherlands, and Italy). To simulate S2 and S3-OLCI data from these images, a special spectral re-sampling tool was developed. The results were grid-data of top-of-atmosphere reflectances.
- Airborne data (AISA sensor) from Finland and Italy. The results were high resolution data without atmospheric correction.
- In situ spectra from a large number of lakes, with very different optical properties. These data were re-sampled on S2 and S3-OLCI bands: the results were single reflectance spectra on water level.
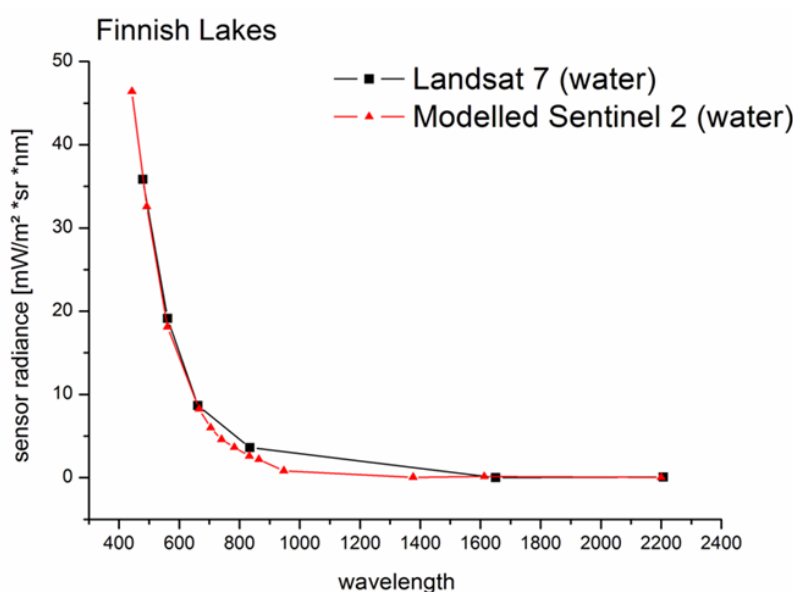
Figure 4, Modelled Sentinel-2 signal, based on a Landsat 7 signal

Also after the GLaSS work on algorithms, the data will continue to be valuable to the partners for updated and testing of their algorithms. The data is also available on request, the related deliverable report showing the details can be downloaded here.

2.3 Atmospheric correction algorithms

Harmonised atmospheric correction (AC) method(s) would be of a great value to process satellite data for global lakes. Therefore GLaSS analysed existing algorithms with regard to: characteristics/functionality and performance on a large range of lakes. The investigated algorithms were: C2R, FUB, CoastColour (CC), MIP, C-Wombat-C, 6S, Scape-M, ATCOR, MEGS and FLAASH. Also, many of these algorithms were adjusted to process data of S2 and S3-OLCI of Landsat 8.

The overview of the characteristics/functionality of the different ACs includes information for example about access, required parameters and possible tuning options for future sensors. Based on this information, weightings were specified by every partner to indicate the level of importance of topics like "Access and license" or "Validation outcome". In a subsequent step, the partners assessed for the different methods were classified on which level they meet the

proposed topics, from unsuitable to very feasible. For the initial requirement on a harmonized AC processor that is applicable for a wide range of high resolution sensors and a possible adaptation to S2 and S3, currently MIP, C-Wombat, 6S, Atcor and Flaash are feasible. Further adaptation of different methods to the new sensors are foreseen but not covered within GLaSS.
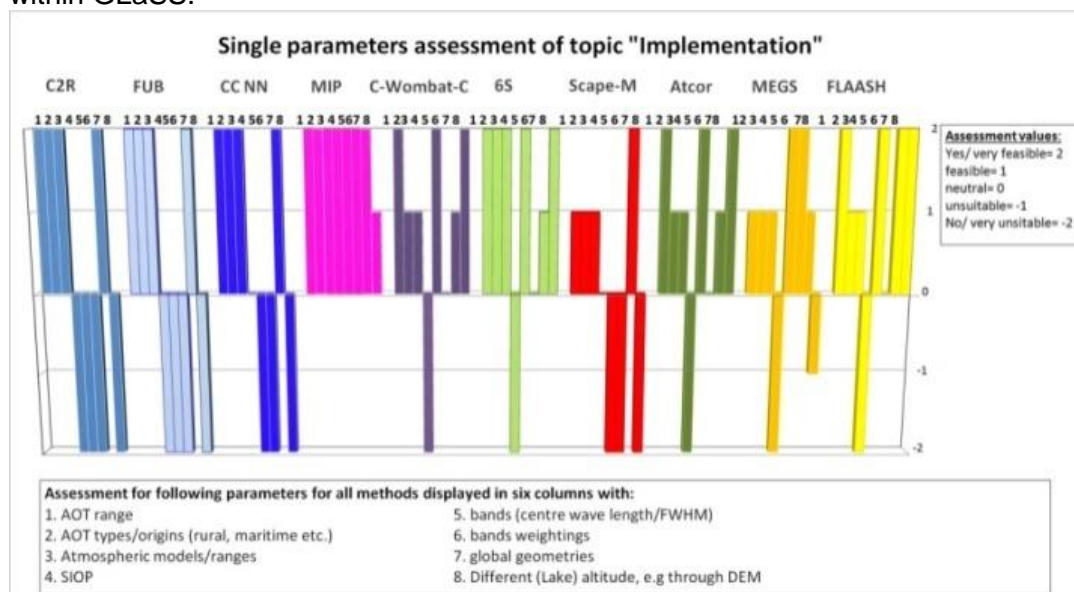
Figure 5, Example from the characteristics of AC methods that were compared: the parameters in "Implementation"

In parallel, the selected AC methods were tested, based on match up data sets (MERIS L2 data and Landsat 5/7 versus in situ reflectance data) from lakes with very different optical properties. The AC corrected satellite data was compared quantitatively (Chi-square: the lower the number the better the performance) as well as for spectra shape differences (spectral angle) with the in situ data. In total, 20 different scenes/ dates and 57 stations, located in Lake Vänern, Lake Maggiore, Lake Garda, Lake Peipsi, Lake Vesijärvi, Lake Päijänne, Lake Pyhäjärvi, Lake Lammin Pääjärvi and Marker- and Ijsselmeer have been investigated. There was a large difference of applicability between methods and lake types and sensors, and qualitative performance and spectral shape.
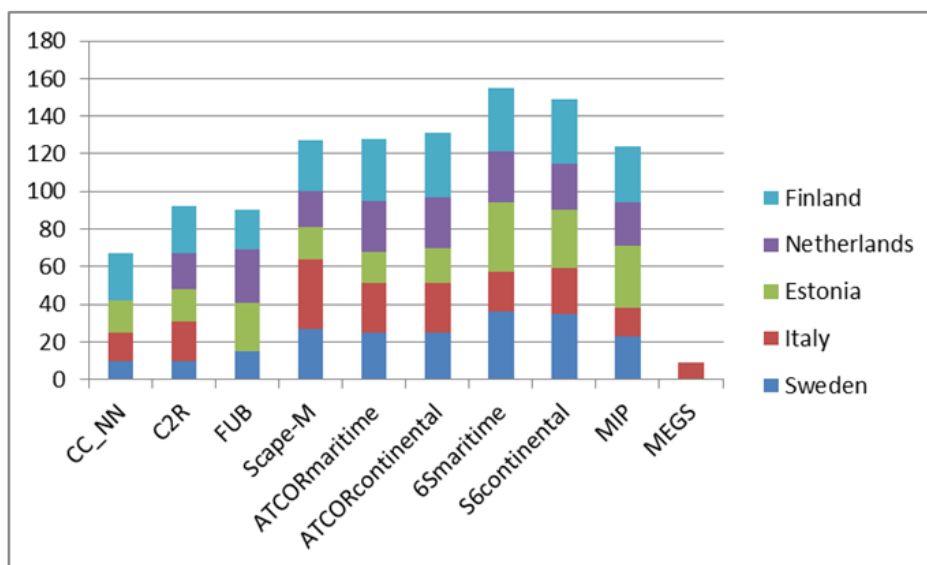
Figure 6, Chi-square for the different regions and methods

Clearly, a 'one-fits-all' method was not available, but the results were used in the GLaSS use cases to select suitable algorithms, and will help GLaSS partners and other remote sensing specialists in future to select an AC method that suits their (technical) needs and the lake under investigation. MIP, C-Wombat, 6S, Atcor and Flaash can be applied to S2 already, while for CC the method is currently being adjusted to S2 and S3-OLCI. The related deliverable report for the assessment of the atmospheric corrections can be downloaded here.

2.4 In situ component retrieval algorithms

Like for atmospheric correction, it would be of a great value to know on forehand which algorithm could be used to process satellite data for a lake somewhere in the world. Because of the differences in specific optical properties, it is expected that either lake type-specific algorithms or tuneable algorithms will fit this need. To create an overview of suitable lake-water algorithms, GLaSS analysed the performance of six algorithms to retrieve concentrations from a range of lakes with very different optical properties. Seven algorithms were adjusted - as much as possible - to S2 and S3-OLCI.

Six algorithms (RadMod5, BOMBER, BOREAL SIOCS, WISP, WASI and a set of band ratios) were tested on combinations of in-situ reflectance spectra and known concentrations. The in situ reflectance spectra were aggregated to MERIS, S2 MSI,S3-OLCI and L8 OLI bands. Most algorithms applied were capable to retrieve Chl-a, TSM and a_{CDOM}. For Secchi transparency two empirical band ratio algorithms were used. The comparison of algorithms was done against in situ data from rather clear lakes in Italy (Garda, Maggiore), shallow and eutrophic large lakes (Peipsi and Võrtsjärv) in Estonia, set of highly absorbing lakes (several small Finnish lakes and Lake Vänern in Sweden), four small water bodies with different optical properties in the Netherlands, and a hyper-trophic lake in China (Taihu).

While the algorithms have variable performance between lakes, they have often a very good performance on the series of spectra per lake. This could mean that the inter-lake variability of SIOPs is much larger than the intra-lake variability of SIOPs. This provides good perspectives for remote sensing of lake water quality using S2 and S3-OLCI. Once a tuning of these algorithms with lake-specific SIOPs has been done for a specific lake (type), EO data can be used operationally.

The algorithms were also technically prepared for the uptake of S2 and S3-OLCI imagery (adjustments to the band settings, tuning, and – as far as possible at the moment – the file format). Also, two algorithms that retrieve concentrations from top of atmosphere (TOA) data were adjusted to new sensors: MIP to S2 and C2R to L8.
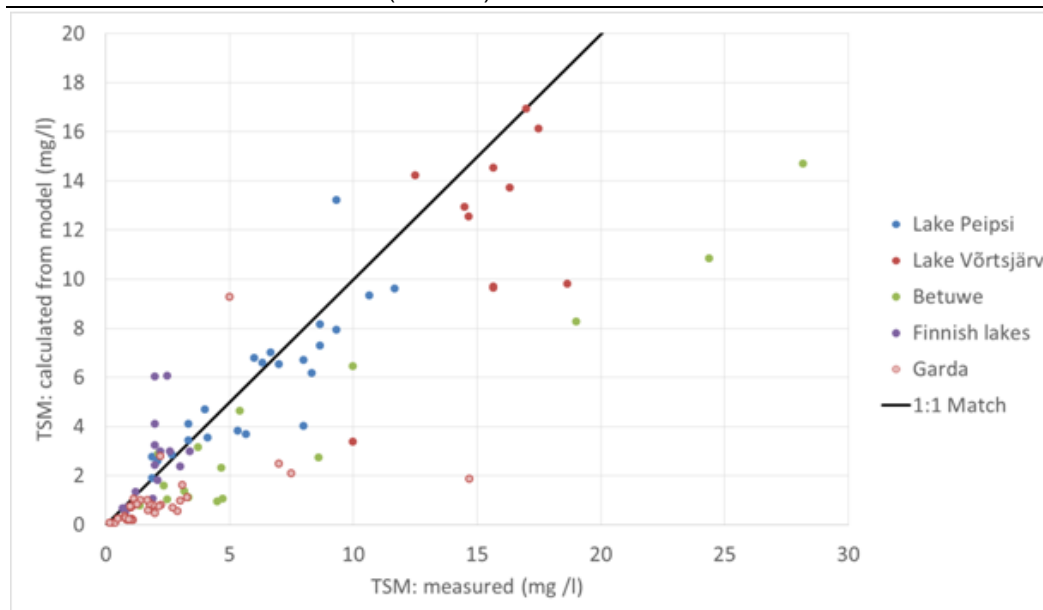
Figure 7, One of the scatter plots, showing the performance the BOMBER algorithm TSM results on S2 MSI aggregated reflectances from different regions

The preparation of algorithms to new sensors and the test results are important results for GLaSS, the remote sensing community and downstream users. The related deliverable report can be downloaded here.

2.5 Optical water type (OWT) classification tool

The development of an optical pre-classification algorithm to derive main water-types was considered necessary because inversion algorithms often have a limited range of applicability, while optical properties of lakes can vary over (much larger) ranges. An optical water type (OWT) tool can help to select a proper in-water retrieval algorithm or tuning. After creation and testing, the OWT tool appeared to be also very useful to check the suitability of the applied atmospheric correction method.

GLaSS opted for a spectrum-based classification, because satellite sensors collect such apparent optical properties (AOPs) for all (global) lakes. The developments within GLaSS were performed based on the existing tool developed by T. Moore (Moore et al., Remote Sensing of Environment, 2014), which was originally developed for ocean and coastal waters. Within GLaSS, lake specific optical water types where generated and added as option to the tool. Spectral clustering was applied to the GLaSS dataset of spectral data (Rrs, measured in situ), including lakes with very distinct optical properties. Three sets of clusters lead to the best coverage of the training set: one with five classes, one with six classes, and after normalisation of the training set, a set with six (normalised) classes. A spectral clustering method and the three selected sets of classes were implemented in the BEAM software as OWT-GLaSS. The tool can be applied to atmospherically corrected satellite data (at the moment: MERIS), and generates maps the water type of the class spectrum that matches the remotely sensed spectrum best. Based on this class, a suitable (tuning of) in-water component retrieval algorithm can be selected. During the testing, the tool appeared to be very sensitive to atmospheric correction errors. Therefore, it can also be used to check the atmospheric correction: if the algorithm does not find a good solution, if the resulting class is unexpected, or if there are unexpected spatial patterns along the coastlines, the atmospheric correction and/or adjacency effect correction should probably be adjusted.
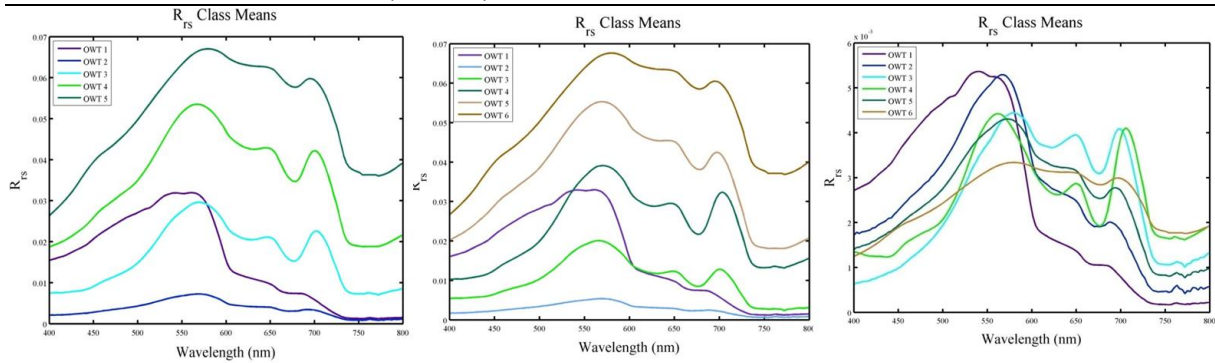
Figure 8, Thee classifications of the GLaSS OWT tool (left: 5 classes, mid: 6 classes, right: 6 classes normalised)

The OWT tool is available for the remote sensing community as plug-in of the BEAM software, and will become available in the SNAP software as well. Training material for working with this tool is available as part of the GLaSS training material. The related deliverable report can be downloaded here.

2.6 Region of Interest statistics tool

Because of the expected large volumes of data that will be produced by S2 and S3, a tool for automatic extraction and averaging of valid lake pixels for time series production within a region of interest (ROI) has been developed. The output of the new tool - called ROIStats - provides times series of spatial-temporal statistics in different aggregation levels, which can serve requirements for example for the Water Framework Directive.

ROIStats runs with a python script, and is an improvement of the functionality of the existing StatisticsOp in BEAM. The script is used to loop StatisticsOp over several input days, periods or seasons. ROIStats computes a number of basic statistics, e.g. minimum, maximum, average, sigma, median, percentiles and number of pixels, for the considered data products and pre-defined regions. In the same manner as StatisticsOp, ROIStats generates output in the widely used and very general CSV-format, using tab stops as separators or as ESRI shape file (.shp).
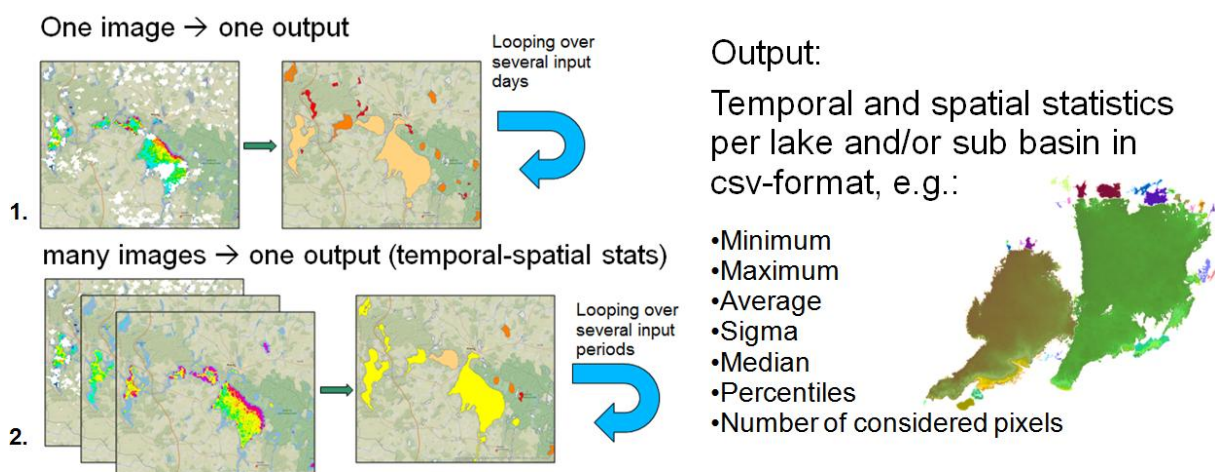

Figure 9, Principle and output of the ROIStats tool

ROIStats is available to GLaSS partners and is of great value for downstream service provision based on large data volumes. The related deliverable report can be downloaded here.

2.7 Prediction tool

The prediction tool allows users of EO data to train their own version of a scene classification tool. The GLaSS prediction tool focuses in the current first version on supervises learning and modelling. It is implemented as plugin in BEAM.

The training data consist of a set of training examples (pixels, ROIs, etc.). In supervised learning, each example is a pair consisting of an input object and a desired output value (label). A supervised learning algorithm analyzes the training data and produces an inferred function ("Train model"), which can be used for mapping new examples ("Apply to images"). These two steps are implemented as two separate tools. The algorithm allows to determine the class labels for pixels not in the training data set. This requires the learning algorithm to generalize from the training data to unseen situations in a "reasonable" way.

The three main steps of using the Prediction Tool are:

1. Select and label pixels groups. Training data are organized via masks. There is a variety of methods already offered by BEAM to create or derive masks from images. The current version of the tool, allows for the selection of the input bands from the opened product and its masks while the transfer of masks to other products is still limited.
2. Train model. The current version of the tool includes the Maximum Likelihood Supervised Classification, but the tool is set up in a way to also allow other models to be implemented.
3. Apply to Images. This is the actual classification step.

The Prediction Tool creates various outputs: the first type is the model itself, which can be can be saved for later use. The second type of output is the image, which is the result of the application of the model.
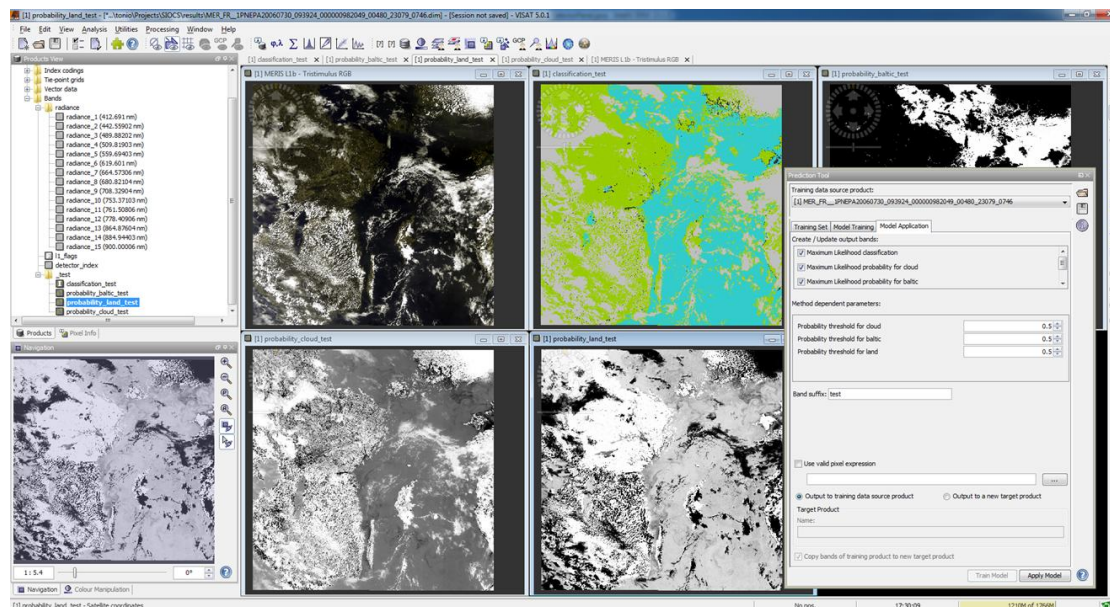
Figure 10, Screenshot of BEAM software while working with the predictor tool

The prediction tool is available for the remote sensing community to allow users to easily train their own models. It is available as plug-in of the BEAM software, and will become available in the SNAP software as well. Training material for working with this tool is available as part of the GLaSS training material. The related deliverable report can be downloaded here.

2.8 Field campaigns and in situ protocols

GLaSS carried out many field campaigns to increase the amount of (optical) (validation) data of lakes. Access to large datasets of in situ data is extremely important for remote sensing of water quality, as it serves both the tuning as validation of algorithms, and is required both for atmospheric correction as well as for water quality retrieval algorithms. Whenever possible, GLaSS campaigns were planned with an expected satellite overpass (Landsat 8), to allow the comparison of satellite and in situ data. The gathered data consisted of three main categories: apparent optical properties (in situ reflectance data, which can be used as reference for atmospheric correction, as well as input for water component retrieval algorithms), inherent optical properties (absorption and scattering characteristics, which can be used for training of algorithms), and concentration data (which is used as reference or validation).

Field campaigns and in situ data
Field campaigns in 2013 were organised in:
- Estonia (8-12 July, 13, 14 July, 29 July). During one of these campaigns, over Lake Peipsi, also airborne hyperspectral data with the HYSPEC sensor were achieved.
- Italy (5-7 March, 3-4 July, Lake Garda)

Field campaigns in 2014 were organised in:
- Italy (10 June, 5-7 March, 30 September, Lake Garda; 14 May, Lake Maggiore)
- Estonia (17-18 July, Lakes Peipsi and L. Võrtsjärv)
- Nepal (15-20 October, several Himalayan glacial lakes)

Field campaigns in 2015 were organised in:
- Estonia (May 28-29, Lakes Võrtsjärv and Peipsi together with the Estonian Marine Institute, Taiwan Center for Space and Remote Sensing Research (CSRSR, National Central University (NCU))
- the Netherlands (18 June, Lake Markermeer – together with Rijkswaterstaat),
- Italy (17, 22 and 30 July, Lake Maggiore; and 10 April, 12 May, 15,17, 27, 31 July, 6 August, Lake Garda),
- Finland (20 August, Lakes Pääjärvi, Ormajärvi and Keravanjärvi)
- Sweden, (30 July, Lake Vänern). This was a large campaign with the complete GLaSS consortium together with GLoboLakes. The first day (30.08.2015) activities were aiming for Landsat 8 validation (L8 overpass). Also one Sentinel-2 image was acquired during the field campaign. During the second day (31.08.2015) radiometry inter-comparison was performed. Involved radiometers were TRiOS Ramses, Satlantic HyperSas, WISP, ASD FieldSpec. A third target was to capture variability of optical properties. In addition, a flow-through system including an AC-9 instrument was used to collect more than 25 000 optical measurements.

Figure 11, One of the boats departing for the field campaign in Lake Vänern

The in situ data gathered during the field campaigns was used within GLaSS for several purposes: algorithm tuning, validation and in the use cases. The importance of the GLaSS data is that it includes in situ optical data from a large variety of lakes, ranging from clear to turbid (TSM), to eutrophic (Chl) and highly absorbing (CDOM). All partners agreed that in situ data collected during the GLaSS project are or will be uploaded later to the database LIMNADES, to make them available to a larger audience (LIMNADES access is available to all other LIMNADES contributors). In addition, the data acquired during the project will be available for the partners also after the project for further usage. They will be acknowledged as GLaSS foreground data, accordingly.

Optical in situ protocols for inland waters
During the GLaSS campaigns, it became clear that researchers use different instrumentation and protocols for in situ data retrieval. The main reason for this differences in protocols is that the only existing protocols for optical measurements of water quality are for open ocean (e.g. NASA's Ocean Optics protocols), and are often not suitable for lakes. Also, the applicability differs per lake type. There is a clear need for updated protocols for lakes. GLaSS therefore started to document the differences between the 'standard' NASA Ocean Optics protocols and the protocols for lakes that are used by the partners. Where applicable, the document also includes the reasons why the NASA protocols do not apply for lakes. Examples of this are that some lakes are too turbid to filter the required amount, surrounding land (mountains) prevent certain sky measurements to be taken under the required angle and equipment being too expensive for the often small inland water research groups. Also, inland water groups tend to follow the national monitoring guidelines, which differ per country.

Figure 12, Radiometric comparison with three WISP-3's, the AERONET-OC station Palgrunden in the background

The protocol document can serve as a starting point to create harmonised protocols for situ optical measurements and can be downloaded here.

2.9 Validation of reflectance data

To prove the applicability for the updated (atmospheric correction and in-water component retrieval) algorithms, a large validation exercise was carried out, mainly based on the results of the GLaSS field campaigns. The results of the validation activities serve the credibility of the global lakes use cases and EO data for water quality in general. The validation consists of two parts: comparisons of atmospherically corrected satellite data versus in situ reflectance data, and validation of retrieval of in-water constituents.

Due to the delay of the launch of S2 and S3, the focus of the atmospheric correction validation exercise was on Landsat 7 and 8, WorldView 2, and to a smaller extent archived MERIS data. However, preliminary results with S2 could just be included. Before the validation satellite data was pre-analyzed to assess the suitability of the satellite product and unsuitable scenes were left out. Satellite derived reflectances were processed with 6S, MIP, C2R and USGS algorithms, also, forcing the atmospheric correction based on one field measurement was applied. For the component retrieval, MIP, BOMBER and the WISP algorithm were validated, but not for all lakes. In Sweden, a large inter-calibration campaign was carried out together with the GloboLakes group Lake Vänern, for which the analysis is still ongoing.

To summarise, the results of the comparisons show that:
- the results differ greatly between the lakes (e.g. an algorithm performing well on one type of lake, but failing for another) because optically active substances concentrations vary much
- individual manually adapted methods can provide better results than the three automated methods (MIP, C2R, USGS).
- there is in general rather good agreement between different in situ reflectance instruments, however, in some cases WISP measurements show lower reflectance (Rrs) values than ASD and RAMSES

- for the corrected satellite data, it is important to check fore issues related to haze/cirrus which limits the use of data, even when the data is not flagged
- for component-retrieval, the physically based retrieval methods like BOMBER and MIP can be used over wide range of water types in order to adequately retrieve water quality parameters and both these algorithms show similar behaviour, although regionally tuned algorithms tend to perform better for each particular case where it was developed or tuned for

It can be considered whether the validation exercises should be supplemented by much measurements of optically active substances (turbidity, CDOM, Chl-a) jointly with optical closure calculations as showed for cases of Finnish lakes. This would support the evaluation of a higher number and much more varying water types. For the validation of water constituents, it might be also helpful to increase the number of match-ups through using standard water quality measurements (e.g. from national monitoring) in a wider range of water bodies. Together with provided uncertainty specifications for in situ measurements this can start to develop the consistency of independent EO based water quality monitoring approaches.
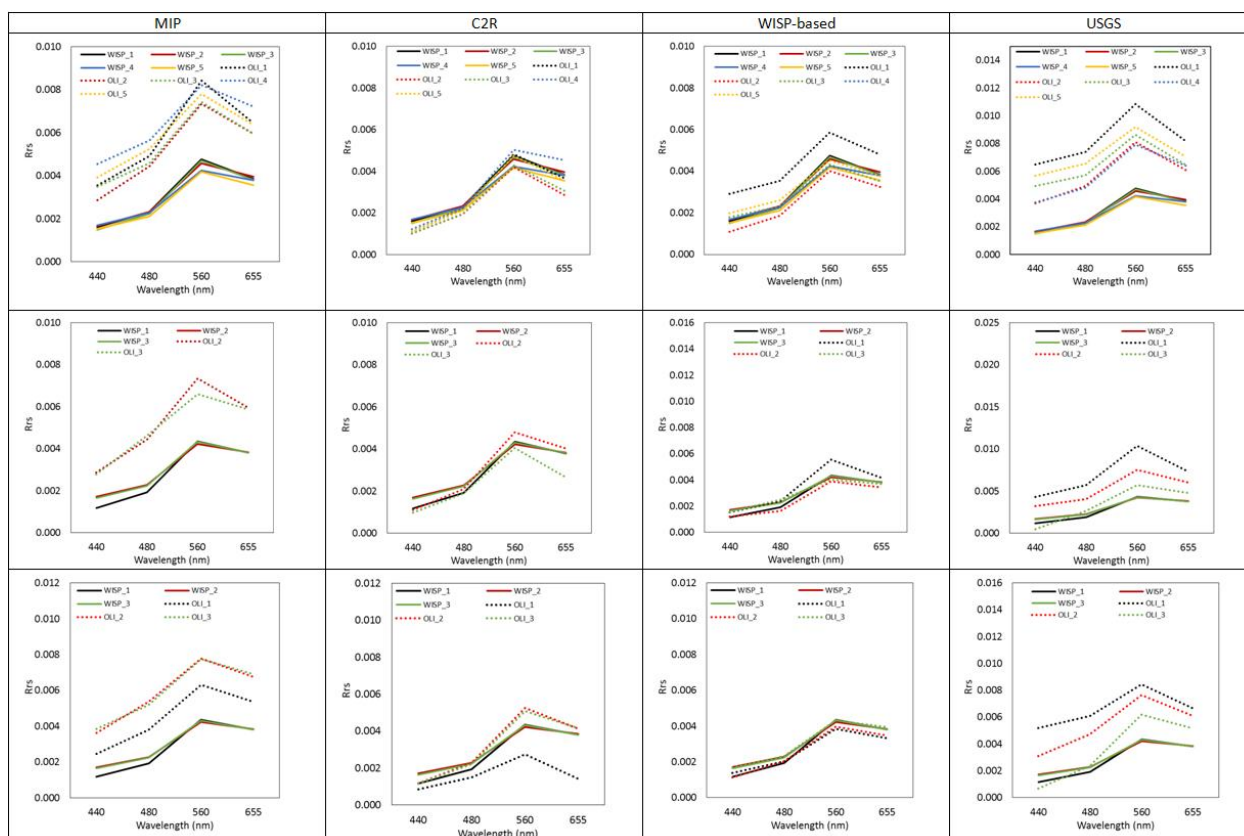
Figure 13, Comparison of Landsat 8 data, corrected with different processing methods (MIP, C2R, forcing the atmospheric correction based on the in situ data, and the USGS method) and in situ reflectance data for many stations in a small lake in the Netherlands. (Straight lines are in situ, dashed corrected L8 data, colours for different stations)

These kinds of validation exercises are very useful in context of (further) developing remote sensing algorithms. Often the lack of proper in situ measurements is hindering the detection of causes for uncertainties following from algorithm design and calibration. The validation results are important for GLaSS, the remote sensing community and for downstream users. The related deliverable report can be downloaded here. From the campaign in Lake Vänern the results are still being analysed: scientific publication(s) based on these analysis are planned.

2.10 HYPE model validation

Combination of data from different sources (EO, in situ, models) will lead to the most comprehensive insight in processes related to water quality in lakes. Therefore, GLaSS also compared EO-based results with HYPE model outputs.

The Pan-European hydrological model (E-HYPE) is an open source application of the HYPE model for the entire European continent where hydrological flows and nutrient processes are estimated for smaller sub-basins within a catchment area. Presently, data is available for about 35 500 basins in Europe. S-HYPE is a customized model, which has been parameterized and applied to Sweden. The model provides daily simulations of discharge and monthly concentrations of nitrogen and phosphorous for about 37 000 basins in Sweden. Compared to E-HYPE, S-HYPE is a more sophisticated model, as national databases and map layers of higher detail have been used to parameterize this model. GLaSS compared E-HYPE output with MERIS Chl-a data for Lake Peipsi, Lake Garda and Lake Constance, and S-HYPE data for all basins in Lake Vänern.

With respect to S-HYPE, there was an agreement between the three investigated data sets (MERIS-Chl-a, S-HYPE-DIP (Dissolved Inorganic Phosphorus) and in situ Chl-a) with respect to the internal order of the sub-basins, i.e. the modelled levels of nutrients in S-HYPE corresponded to higher levels of Chl-a measured by MERIS-FUB and in situ. In addition, MERIS-Chl-a was in good agreement with the annual fluctuations in nutrients (DIP), both within and between years, for many sub-basins in Lake Vänern. The smooth and regular seasonal appearance of the modelled time series might be an underestimation of the natural variability in each sub-basin, but the greater variability in MERIS-Chl-a time series should also be related to the number of images per month and if there is a bias towards certain time periods or if data is evenly spread over the month.

With respect to E-HYPE, there was a visible similarity between the time series of E-HYPE lake basin outflow nutrient values and MERIS Chl-a products for all three lakes investigated but there was generally a shift in the phases. SMHI suggested that there should be a correspondence more similar to the Swedish comparisons using S-HYPE, indicating that the model limitations may be causing discrepancies.
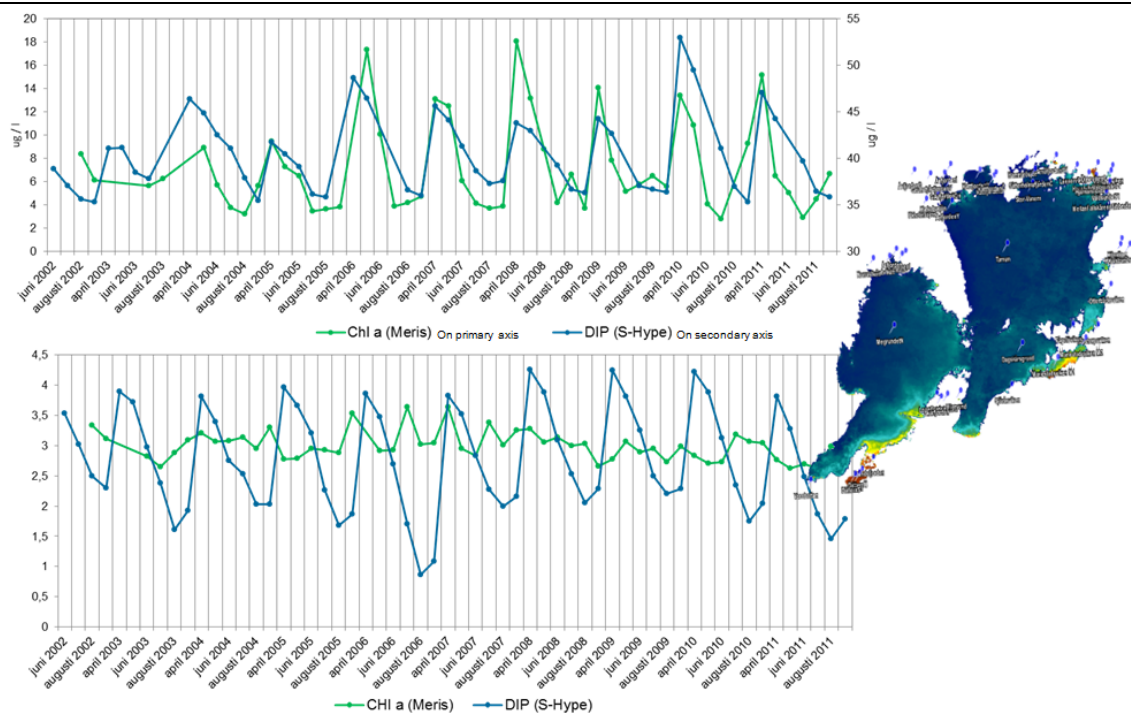
Figure 14, S-HYPE results for a bay in Lake Vänern

Further work to integrate EO-based results and the HYPE models would be interesting: EO data could feed into the model, and the model could gap-fill EO time series for cloudy days. The related deliverable report can be downloaded here.

2.11 Global use cases

To select interesting global use cases to be studied in more detail, a "long list" of lakes was created. Lakes were placed on the list because of their specific bio-physical, optical or ecological properties, their socio-economic concerns or importance. Literature, lakes databases and personal information from GLaSS partners were used to generate the list and find the bio-physical, optical, ecological and socio-economic information of each lake.

The lakes were grouped according to GLaSS 'use cases' and it was analysed if there were relations between optics or biophysical lake types (shallow etc.), and hazards for and benefits from this lake. The use cases are:
- Use case 1: Shallow lakes with high eutrophication
- Use case 2: Deep, clear lakes with increasing eutrophication
- Use case 3: Shallow lakes with low transparency due to sediment resuspension
- Use case 4: Highly absorbing lakes

The results show that the use cases reflected bio-physical lake types through the descriptors of lake ecosystems (morphometry, hydrodynamics, and trophic state), its environment (hydrology and land use in the watershed, ecoregions, geology), use (ecosystem services), and optics. Trophic thresholds may vary with morphometry or ecosystem-specific limitations to primary productivity, whereas the optics are determined by the variability in optical properties of the lake. Ecosystem services are for example the use of lakes as sources of drinking water and fish, sites for recreation, waterways or places for dumping wastes. Multiple use of lakes multiplies the pressure on the ecosystems that may lead to regime shifts, degradation of water quality and loss of some or most of the ecosystem services. Climate change occurring on top of all other anthropogenic pressures may worsen the ecological status of lake ecosystems, which stresses the need for monitoring.
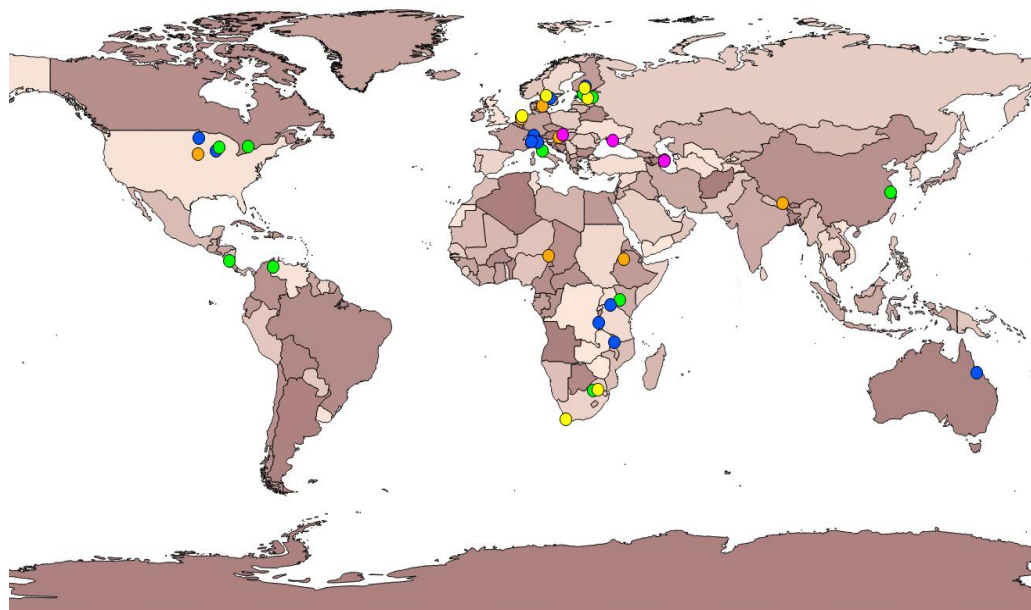
Figure 15, Overview of global distribution of lakes in the socio-economic analysis, per lake type (blue is deep clear, green is shallow eutrophic, orange is with high sediment load, yellow is highly absorbing, pink is mine tailing and other distinct coloured lakes)

A subset of the lakes on this list were studied in detail with satellite and in situ data, using the GLaSS tools and the adjusted algorithms in the GLaSS use cases. The socio-economic analysis on the global use cases can be downloaded here.

2.12 Eutrophic lakes use case

Shallow lakes are vulnerable to eutrophication. Cyanobacteria blooms can excrete toxins, and therefore hamper several ecosystem services (drinking water provision, recreation etc). In this use case many eutrophic lakes were studied in detail by applying algorithms that specifically focus on retrieval of Chl-a and cyanobacteria.

Four algorithms were applied to MERIS data for most of the selected lakes: Maximum Peak Height (MPH), Fluorescence Line Height (FLH), Maximum Chlorophyll Index (MCI) algorithms and CoastColour processing (CC). For two small lakes, tests with band-ratios on L8 data were performed. Validation of the algorithms was performed, and seasonal variation and year-to-year differences were analysed. Processing according to the Diversity-II project was used to create L3 images for yearly and monthly analyses of mean Chl-a (via MPH) for those lakes that were analysed with MERIS data.

To summarise the results:
- MCI, FLH and MPH algorithms gave similar results in all lakes, whereas FLH gave a slightly higher correlation with in situ measured Chl-a compared to MCI and MPH results.
- Good correlations between EO and in situ data were found, except for Lake Tuusulanjärvi probably due to its narrow shape (leading to higher adjacency effect) and its high concentration of CDOM.
- Seasonal variation of Chl-a was well captured with FLH (Lake Tuusulanjärvi, Lake Ülemiste), MCI (Lake Peipsi) and CoastColour (Lake Müggelsee) algorithms, giving additional information about summer period, but often missing events in September and October especially in northern countries due to frequent cloud cover.
- Yearly averages show for example that Chl-a concentrations were higher in Lake Trasimeno during years with lower water level and higher temperatures.

- The effect of meteorological conditions was visible from daily images of Lake Peipsi: cyanobacterial blooms diminished in surface layers after storm events.
- In all investigated lakes, the cyanobacterial biomass tends to increase towards autumn, with peaks in August and September.
- Comparison with in situ data showed for example that for Lake Trasimeno MERIS products clearly distinguished years and seasons with higher blooms (*Cylindrospermopsis* sp). Also very good agreement between in situ and satellite derived presence of cyanobacteria was found for Lake Müggelsee.
- The L8 band-ratio provided a proper seasonal pattern for Lake Paterswoldsemeer, but not for the clearer lower reflecting Lake Westeinderplassen. Correlation between Chl-a and TSM could play a role here.

It is expected that for the lakes that were analysed with MERIS, similar results will be obtained with the new Sentinel 3 OLCI instrument, while for the lakes that were analysed with L8, the results are expected to improve greatly with the data from Sentinel 2, because of the additional spectral bands in the red and near infrared wavelengths typically used to assess Chl-a concentration in productive waters.
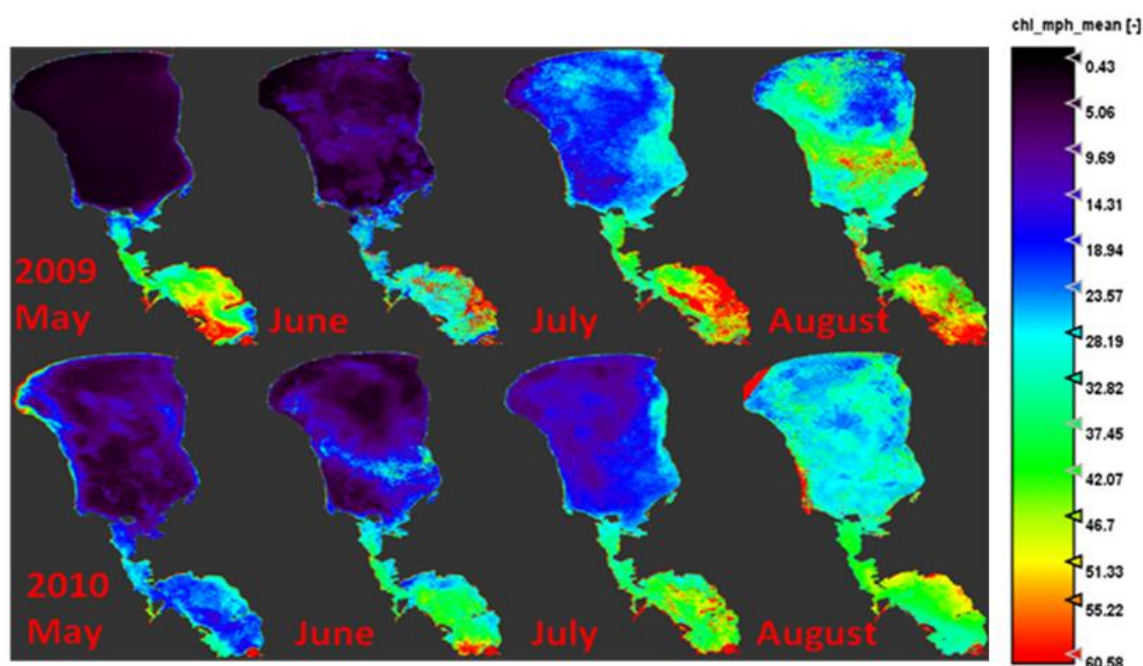
Figure 16, show the differences in average Chl-a distribution in Lake Peipsi in the summer months of two years (this analysis was carried out using data from the DiversityII project).

The eutrophic lakes use case clearly demonstrates to a larger audience of potential users (water managers, ecologists) what can be done with EO data to monitor phytoplankton blooms, including those of potentially toxic cyanobacteria. The related deliverable report can be downloaded here.

2.13 Deep clear lakes use case

Because of their size and therefore water volume, eutrophication of deep clear lakes might happen slowly and unnoticed. At the same time, deep clear lakes generally provide a large range of ecosystem services (e.g., fishing, irrigation, recreation and drinking water) and represent a valuable socio-economic resource for the region in which they are placed. Long-term time series of EO data are a very good step forward, also because the size of the lakes and the often trans-boundary conditions make in situ monitoring more difficult than for

smaller lakes.

In this use case seven deep clear lakes were selected: four of those are situated in Europe (Garda, Maggiore, Constance and Vättern), one in North America (Michigan) and two in Africa (Malawi and Tanganyika). For these lakes, the trophic status was evaluated based on 10-years time series of MERIS Chl-a. These parameters were obtained according to a suite of validated algorithms. To extract the parameters from these products (a total of 5216 images were used), a number of ROIs located in pelagic waters as well as some few other stations defined depending on the lakes morphology, on the presence of both river tributary permanent sampling stations were selected in each lake. Statistical analysis tools were applied to these observations to evaluate both trends (Kendall test) and phytoplankton abundance (depending on the frequency of occurrences per year/ROI).

Generally, the tropic status of deep clear lakes is almost stable. A slightly increasing trophic status trend was seen for Maggiore and Constance, a slight decreasing trophic status trend for Garda and Tanganyika and absolutely stable conditions for Vättern and Malawi. In Lake Michigan the situation was different per bay. The phenology showed for each lake the years with higher values of Chl-a. Potential causes for the observed (slight) changes are a combination of meteo-climatic conditions (e.g., windy and cool winter that facilitates the water column circulation) and anthropogenic impacts (e.g., under-dimensioned water treatment plants).
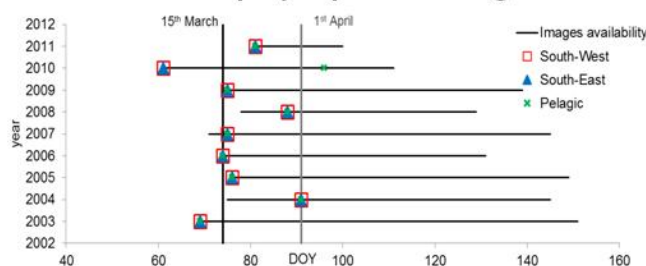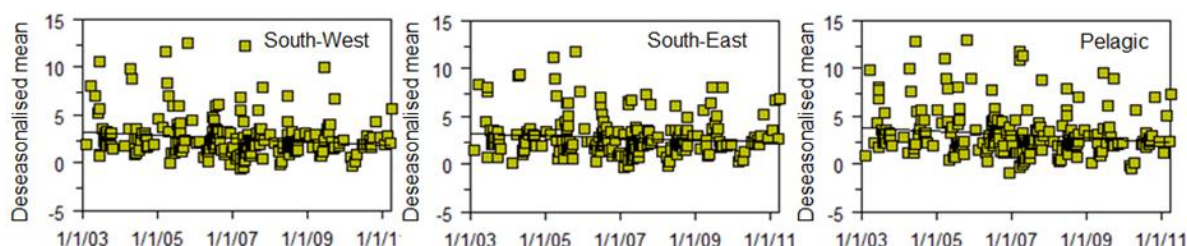
Figure 17, Results of the long-term time series of MERIS data on Lake Garda: onset of the phytoplankton bloom, mean concentrations for the three main regions and the statistical Kendall test results showing a decrease in Chl-a.

The deep clear lakes use case clearly demonstrates to a larger audience of potential users (ecologists, policy makers) how EO data can be used to generate long-term time series and insights on lakes, especially large trans-boundary ones. The related deliverable report can be downloaded here.

2.14 Use case on lakes with high suspended matter concentrations

The socio-economic analysis showed that many shallow lakes with high sediment concentrations are under (environmental) pressure, and those in highly populated areas are often undergoing restoration measures. A special group of lakes with high sediment concentrations are glacial lakes, for which glacial runoff causes high sediment concentration. Due to climate change, increasing glacial melting can cause the (natural) dams of these lakes to break, causing dangerous Glacial Lakes Outburst Flood (GLOF) events. Two shallow turbid lakes that are undergoing restoration measures (Lakes Markermeer in the Netherlands and Lake Böyük Şor in Azerbaijan) and Nepalese glacial lakes are selected to study in detail the possibilities of high resolution EO data.

Markermeer is a classic example of a lake dominated by resuspension of sediments due to wind-waves. To increase its ecological diversity, a restoration project is planned, during which tidal-flat like islands will be created ('Markerwadden'). For Lake Markermeer the focus was to obtain methods to analyse water quality changes based on L8 data, to prepare the monitoring of the Markerwadden project with S2. Good relation is seen in time series of in situ and EO-based results; however, there were not enough match-ups for direct validation of data that was obtained on the same day. Some example maps show the potential of high resolution monitoring for this lake. More detailed results expected from the higher resolution of S2, and especially the higher overpass frequency of S2 will have a large added value for better validation and for monitoring e.g. phytoplankton blooms.

Lake Böyük Şor used to be one of the worlds' most polluted lakes. Since 2014 it is undergoing a large restoration project to remove oil. GLaSS monitored the results of the restoration project using L8 data. The lake was cleaned; dams and sludge depots were built while the Olympic stadium for the European Games (2015) was constructed on the lake's shores. The coordinator of the restoration project, engineering company Witteveen+Bos, shared in situ data and knowledge. GLaSS tuned its algorithms based on this in situ data and then mapped 'oil potential' and turbidity (as a result of dredging). Generally, the patterns agreed with what was to be expected from the activities that were known to happen in the field: the effects of dredging, dam construction and resuspension due to wind-waves could be followed. However, the oil slicks at the surface hampered atmospheric correction and turbidity retrieval the presence of highly absorbing oil slicks becomes unreliable. It is expected that the higher spatial resolution of S2 will allow the detection of individual floating layers of oil. Also, a fully suitable atmospheric correction method that does not rely on either known atmospheric properties or assumptions about the water content, could improve the results. Finally, more spectral bands could probably improve the oil and turbidity algorithms, as the information in these additional bands could help to discriminate surfacing oil, high concentrations of sludge and land in the NIR.
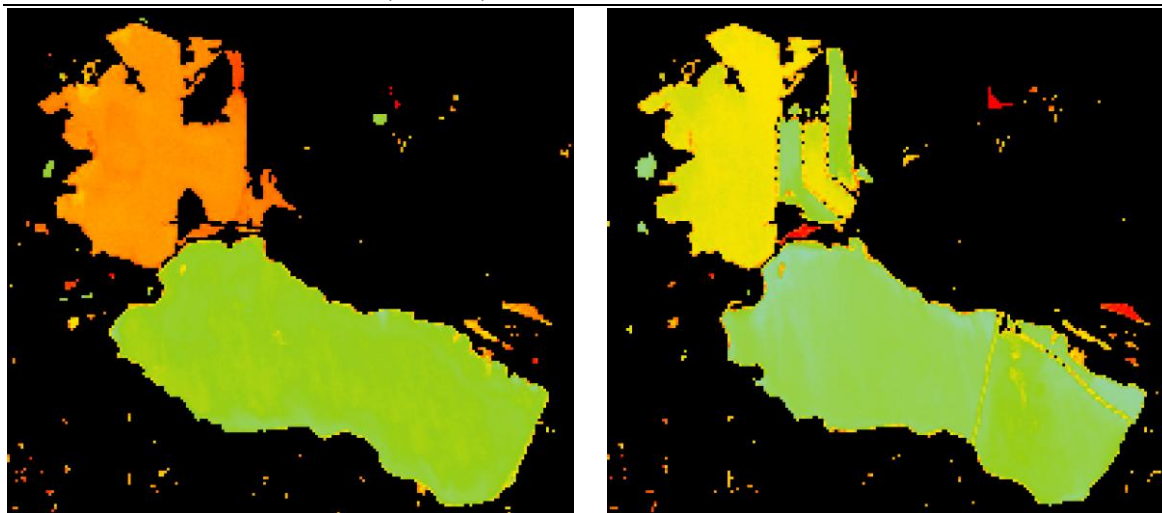
Figure 18. Lake Böyük Şor with the results of the oil-potential algorithm (blue is low, red is high) in July 2013 (left) and July 2014 (right)

Himalayan lakes are high altitude glacial lakes situated on the highest massif of the world. People living this extreme and isolated region depend on glacier lakes for their needs (e.g. drinking, agriculture), while GLOF events can also have destructive consequences for downstream villages. The correlation between the speed of glacial melting and suspended solid concentrations allows the use of EO data as one of the tools to derive indicators to predict GLOF (glacial lake outburst flood) events. During a field campaign in October 2014, the apparent optical properties and transparency of water for a set of 5 Nepalese lakes with different colour/transparency characteristics were measured. Three water colour classes were defined. The observation of field radiometric data allowed the subdivision of three water color classes (Blue, Turquoise and Grey) with increasing sediment content and the consequent classification of 119 lake water colour at regional scale (Landsat-8 OLI, 29-10-2014). In the snow and ice covered landscape an adjacency correction of image radiometry of both Landsat and GeoEye images was also very important.

The remote area of the Himalayan lakes makes EO a valuable tool for monitoring water quality in such poorly accessible areas. Together with the analysis of glaciers dynamics, water colour investigation of glacial lakes could help in understanding the climate change phenomena conditioning our planet in the last decades. In particular, high altitude ecosystems may provide useful knowledge about the first global warming effects, since they are ecologically simple, with low human impacts. Lakes subject to risk of GLOF can be also detected. Then, by considering the improved spatial resolution of S2 we assume that the number of lakes that can be mapped will be even larger, allowing to also make a quick scan of lakes that are vulnerable for GLOF events and update these regularly.
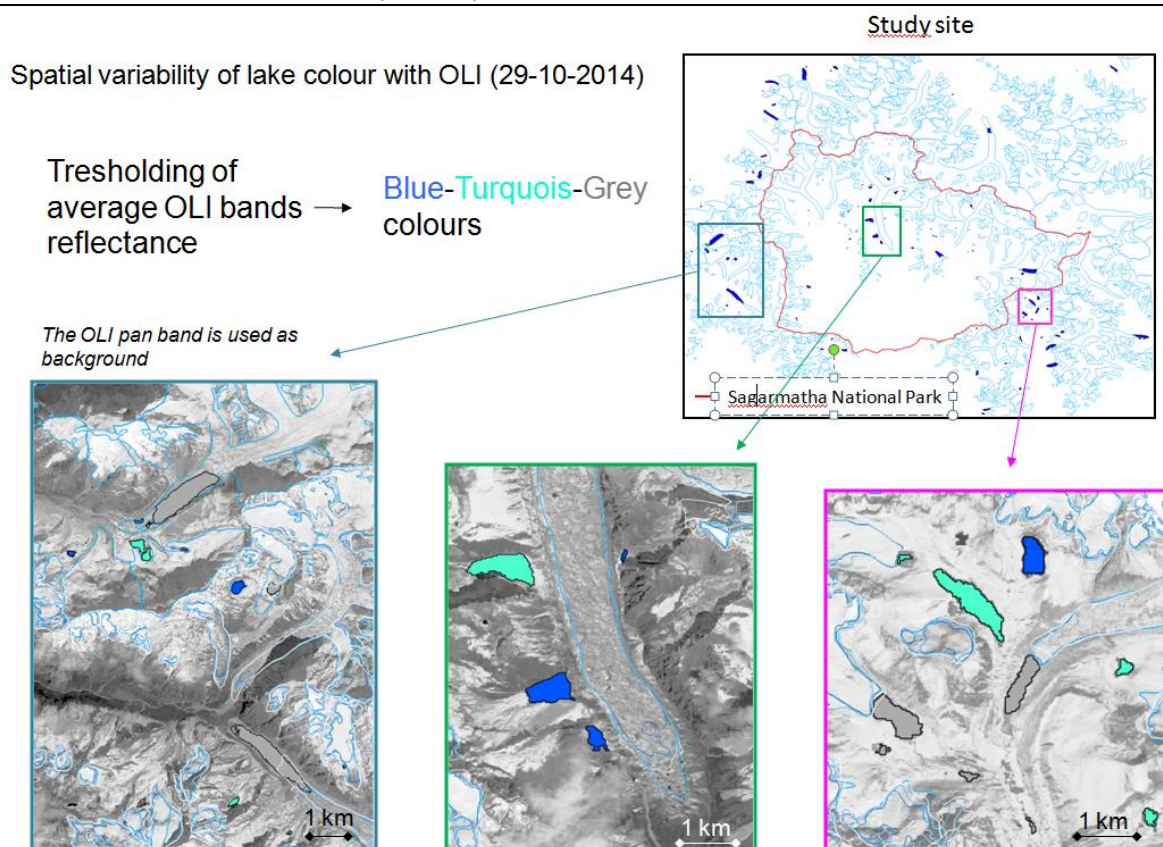
Figure 19 Lakes in the study area in the Himalaya, classified as blue, turquoise or grey based on Landsat data

Based on EO data, three very different lake cases were studied (Lake Markermeer, Lake Böyük Şor and Himalayan lakes). These can serve as showcases for the use of high-resolution EO data to potential users such as engineering companies and local governments that are involved in restoration projects. The study in the Himalayan lakes has an important social benefit for the population in the area, helping local governments to locate potential dangerous lakes and take preventive measures in time. For all three case studies, it is expected that S2 will improve the (already quite good) results, because of better spatial resolution, band settings and revisit time. Synergies with Landsat 8 are also foreseen. The related deliverable report can be downloaded here.

2.15 Use case on highly absorbing lakes

Highly absorbing lakes are difficult to monitor with optical EO and in situ instruments, because of the low reflectivity of the dark water, which can reach the lower limits of the sensitivity of the sensors (especially of the high resolution sensors with relatively low signal-to-noise ratios). To get a better grip on the possibilities and the limits of (close range) remote sensing in such lakes, several small studies were carried out, focusing on: algorithm testing and improvements, relating the satellite instrument sensitivity to a theoretical limit of component retrieval, and in situ instrument characterisation.

With regard to algorithms, first an updated version of Sensor-Independent Ocean Colour Processor (SIOCS) was tested with measured and simulated in situ reflectances. The results were very good ($R^2 > 0.99$ for estimation of Chl-a, TSM and a_{CDOM}) with simulated data. With measured data the errors were larger. The effect of absorption by CDOM is visible because those stations tend to show up as separate group in the scatter plots.
The FUB processor was tested in large humic lakes in Sweden. The a_{CDOM} training range of

FUB was 0-1 m^{-1} and the test data exceeded the range by including a_{CDOM}(443 nm) values up to 6.7 m^{-1}. Despite this, FUB was able to estimate Chl-a with R^2 of 0.64 to 0.82 depending of which data/which months were used in the analysis. However, the resulting concentrations from the processor had to be divided by a factor of approximately three in order to correspond to in situ levels. Also, there were problems with saturation of high (>100 µg/l) Chl-a values.

Landsat-8 data was used to estimate the concentrations of Chl-a, TSM and a_{CDOM} in small, very high CDOM lakes in Estonia (a_{CDOM}(442) between 13 and 30 m^{-1}). The R^2 for all parameters was <0.5 and due to the low number of data points (N = 5) and time-gap between the overpass and sampling clear conclusions could not be drawn.
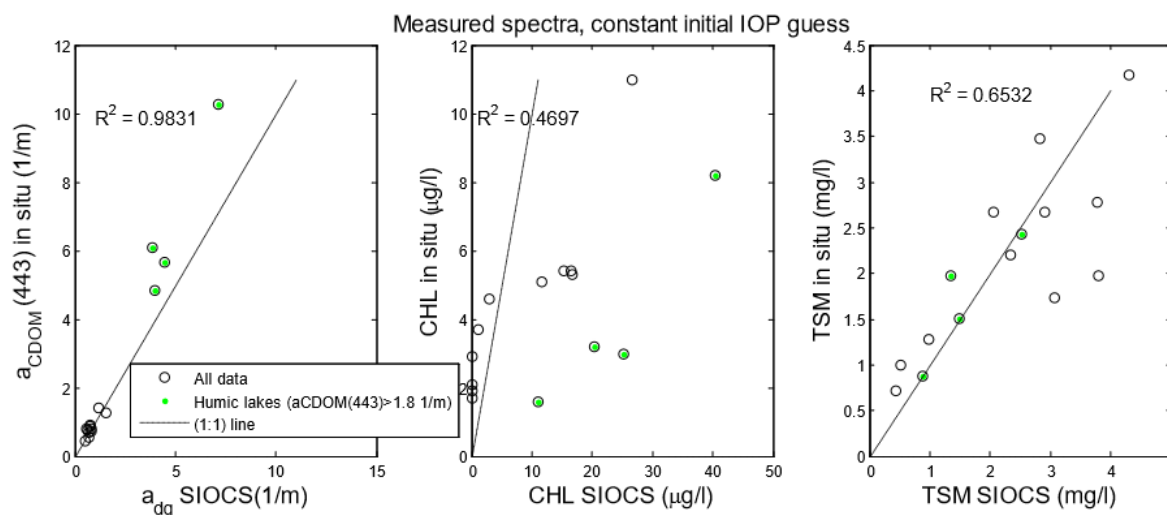
Figure 20, SIOCS results for CDOM, Chl-a and TSM compared to in situ data

The objective of a second part of the study was to analyze how the noise characteristics of the sensor affect the estimation of Chl-a in high CDOM waters. A method that estimates measurement uncertainty based on the noise characteristics of MERIS, the required signal to noise ratio, number of pixels (in case spatial aggregation is used), and the concentrations (Chl-a, TSM and a_{CDOM}) was developed. The results indicated that the noise characteristics of MERIS are sufficient for estimating the water quality in a majority of Finnish lakes (in roughly 4000 cases of 4390 the uncertainty is less than 5 µg/l with SNR requirement of 5 and when spatial aggregation is used).
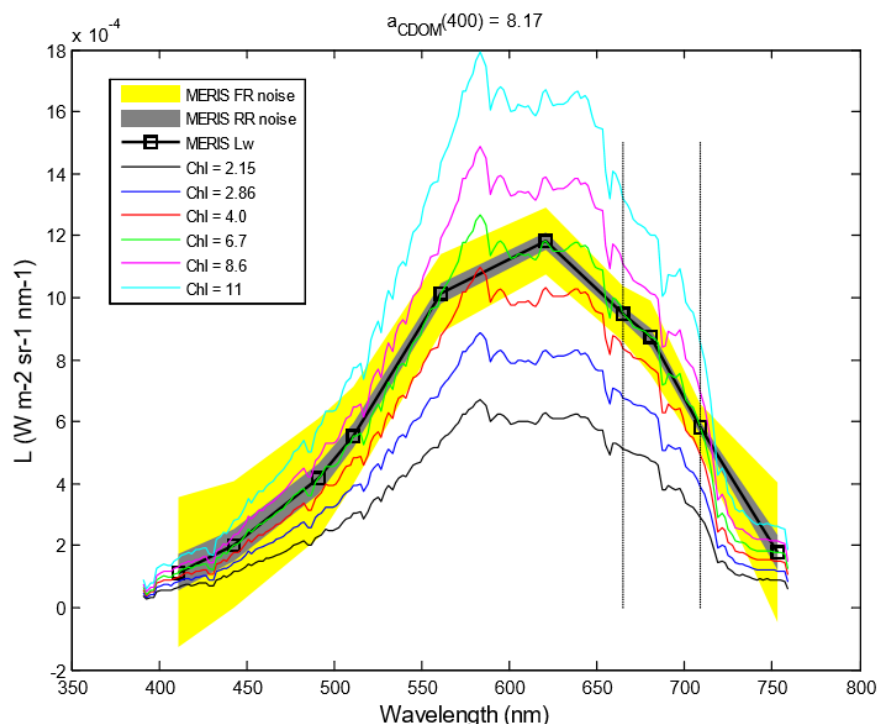
Figure 21, Simulated reflectance spectra with increasing Chl-a concentrations, MERIS Full Resolution and Reduced Resolution spectrum with noise and with vertical lines the area that is used to derived Chl from a reflectance spectrum

In the last part of the study it was analyzed what effect the change of the WISP-3 hand held spectrometer from 3° FOV (field-of-view) to 8° FOV has on the signal-to-noise ratio and the estimation accuracy of the instrument. The larger FOV improved the strength of the signal. However, it also introduced a higher noise in the blue region. In addition, different methods to remove the reflected sky radiance from the upwelling radiance were tested. The similarity spectrum approach and the finger print approach seemed to be promising, but still require more testing.

The highly absorbing lakes use case clearly demonstrates to a larger audience of remote sensing specialists and potential users (ecologists, policy makers) what the possibilities and the limits of EO data and optical in situ measurements are to retrieve water quality parameters in lakes with high organic matter content. The related deliverable report can be downloaded here.

2.16 Use case on mine tailing ponds

Mine tailing ponds often contain highly toxic liquids, and their locations are not always well known. Yearly incidents show the need for locating and monitoring them globally. GLaSS developed the basis for a method to locate mine tailing ponds based on EO data.

Because of the size of the ponds, the method was based on Landsat 8 data. First the data was converted to top-of-atmosphere reflectance. Mine-tailing ponds often contain high concentrations of suspended toxic solids and therefore show up as bright in the visible range and (relatively) dark in the near-infrared due to water absorption. Because the standard cloud and land flags appeared to be not suitable, an alternative water-mask was used. Locating "bright waters" appeared to work well with a combination of this water-mask and the flag for 66%-100% certainty snow/ice provided by USGS (which also scans for pixels that are bright in the visible range and relatively dark in the NIR). To be able to use the snow/ice flag for this

purpose, only images from the summer period were used. Additionally, a few band algorithms were implemented to fine tune the selection. The final hot spots are used to tag the water bodies that are expected to be mine tailing ponds. The developed algorithm seems to work for the test areas in Finland and Mongolia, but showing misclassifications in Azerbaijan. The method can probably be improved with S2: more spectral bands could help to identify specific contents of the ponds, and a higher resolution can help to locate more ponds. Also the method itself probably be improved, by developing a better 'bright water' criterion.

Figure 22, Mines located in an area in Mongolia, using Landsat 8 TOA reflectances data

This automated method to locate mine tailing can be used to locate abandoned and forgotten, but potentially dangerous ponds, to allow monitoring and prevent dam-breaking events with severe environmental, social and economic impact. The related deliverable report can be downloaded here.

2.17 Use case on the use of EO data for WFD reporting.

How EO-based products can be applied to various types of lakes was demonstrated in the other use cases. For all these lakes, reporting requirements exist in Europe, mainly under the Water Framework Directive (WFD). In this use case, examples were created to show water managers also these possibilities.

Although the WFD is an EU-wide framework, it leaves the practical details open for the member states. As a result, there are large differences in the reporting and monitoring approaches, also with regard to the use of EO data. While in some countries EO data is used as part of the monitoring (e.g. Finland, Sweden), other countries do not use it, because EO data is not yet included in the standard methods (Germany, Italy), or even do not allow it yet, because the parameters that can be derived from EO data are not included as such in the reporting requirements (e.g. Estonia, the Netherlands).

It is expected that examples and experience from e.g. Finland and Sweden can help to the government and water managers of other EU countries to adopt EO-based methods as well. Therefore, a set of example plots (histograms and time series) was created from the countries of all GLaSS partners. A comparison between the EU WFD and US CWA has been performed and some of the algorithms were applied to US lakes results are discussed with

EPA. This work will be continued after the end of GLaSS.
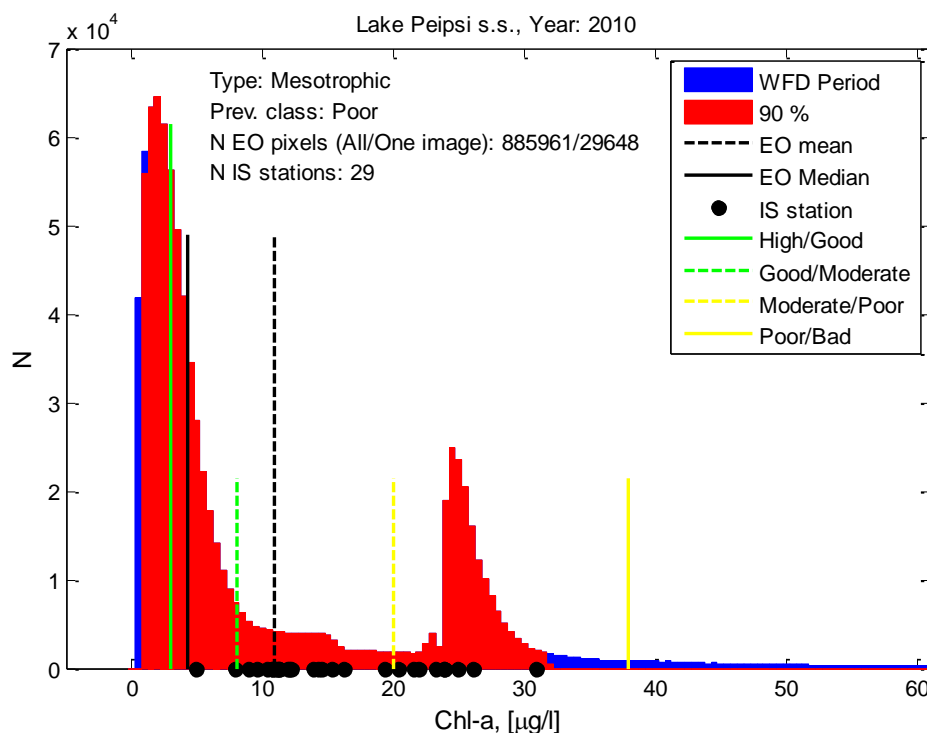
Figure 23, Example histogram for WFD reporting, for Lake Peipsi. The plot shows all data points over the reporting period (summer) for 2010, for both satellite data (each pixel) and in situ data, and in vertical lines the boundaries of the WFD classes.

The set of sample data was already shown to potential users of different counties, who responded very positive and with useful feedback. The samples will continue to serve as part of the portfolio of downstream service providers to approach potential users. The deliverable report with the examples can be downloaded here.

2.18 Training material

The GLaSS training materials provide training materials for a new generation of remote sensing experts, ecologists, environmental technicians and GIS experts to work with S2 and S3-OLCI data for water quality monitoring. The lessons are based on the global use cases.

The target group of the GLaSS lesson series is MSc/PhD level (without remote sensing experience, e.g. ecologists), BSc level (with remote sensing experience).
Each lesson consists of:
- Introductory text (.pdf). These texts describe the aim of the use case / lesson, information on the lakes that will be studied, the research questions, background on the environmental conditions of the lakes and on the methods that will be applied, all including proper references.
- Exercises (.pdf and e.g sample scripts).
- Data (.zip). The satellite data (in the right processing level), the in situ data and other data (e.g. shapefiles, meteo data etc) are to be included in the exercise.
- Answers and explanations (.pdf).

The table below shows a summary of the lessons.

#	Subject	Research question	Overall aim	Learning objectives
1	EO Data handling	What are the specifications of Sentinel 2, 3 and other high-resolution sensors regarding temporal, spatial, spectral characteristics and access mechanisms. Which tools are freely available for processing and analysis?	Learning the specifications of Sentinel 2, 3 and Landsat, how to access them and which tools are available for extracting water quality products from those sensors.	• Knowing about the specifications of Sentinel 2, 3 and Landsat in terms of spatial, temporal and spectral resolution and data formats • Being able to access the data, open it and prepare further analysing activities
2	Tools for GLaSS data analysis		Tools for statistical analysis of EO data: optical water types, image classification approaches, and semi-automatic pixel selection	• Familiarize EO data users with some of the tools available in BEAM/SNAP for data classification and statistical analysis on lakes
3	Eutrophic lakes	What is the spatial distribution of water quality parameters over Lake Peipsi?	Learn how to use satellite data to retrieve chlorophyll concentrations, as a proxy for eutrophication.	• Open an optical satellite image and perform some visual analysis on spatial variability • Apply an atmospheric correction method • Validate the results with in situ data (spectral+concentrations)
4	Deep clear lakes - Lake Tanganyika	Is Lake Tanganyika subject to eutrophication?	Analyse trends in the trophic level evolution in Lake Tanganyika. Teaching students on how to assess the trophic status tendency in a big deep clear lake based on processing of long term time series of MERIS data.	• Visualisation of MERIS-derived products • Spatial analysis • Definition of region of interests (ROI) on image data • Application of BEAM tools on time series of Chl-a products for long-time series analysis • Use of Kendall test to statistically assess if there is a monotonic upward or downward trend in Chl-a data
5	Phytoplankton phenology in deep clear lakes	Does the offset of phytoplankton blooms in Lake Constance change?	The aim of this lesson is to investigate the phenology response of Lake Constance in terms of onset of phytoplankton bloom and spatial distribution.	• Visualisation of MERIS-derived products • Investigation of phytoplankton abundance (in terms of Chl-a concentration) during the year in different sub-basins • Definition of region of interests (ROI) on image data based on different tools • Finding the timing of phytoplankton growth onset basic on statistics applied to time-series Chl-a data
6	Shallow	What is the effect of	Learn how to use satellite data	• Use the NIR to analyse the

	turbid lakes	wind on resuspension in Lake Markermeer?	to visualise the effect of wind waves and other global Lakes Sentinel Services disturbances in shallow turbid lakes. Find out about the added value of high resolution data.	effect of wind on resuspension and other disturbances in Lake Markermeer • Find out about the added value of high resolution data
7	Shallow lakes with high resuspension	Himalayan lakes could cause glacial outburst floods?	Classification of lakes in Himalayan region through remote sensing products and techniques, on the basis of their own colour, to distinguish among lakes, those fed by glacier.	• Lakes identification and surface extension assessment through remote sensing techniques, classifying image surfaces trough new GLaSS Prediction Tool • Assessment of lakes type through remote sensing colour • Masks generation for change detection • Classifying image surfaces trough new GLaSS Prediction Tool for the evaluation of new grey lakes on glacier tongues
8	Lakes with a high concentration of humic substances	What are the limits of remote sensing of water?	Get an overview of the issues that determine the limits of remote sensing of water.	• Find out about the effects of absorption • Find out about mixed pixels and adjacency effects • Learn about sensitivity
9	Mine tailing ponds	Where are potentially harmful mine tailing ponds located?	Where are potentially harmful mine tailing ponds located?	• Selecting the best suitable satellite data and processing level for your purpose • Setting up a logic approach • Using masks
10	Water Framework Directive	How remote sensing could support Water Framework Directive implementation in lakes?	To demonstrate how of remote sensing can support the implementation of the WFD. Teaching students on how to assess water quality status according to the limits set by the WFD in Sweden.	• To be informed about the WFD • Visualisation of MERIS-derived product • Checking differences in southern Sweden lakes based on WFD limit • Analysing differences among the Lake Vänern sub-basins depending on WFD regulation • Checking water quality status of Lake Vänern during time
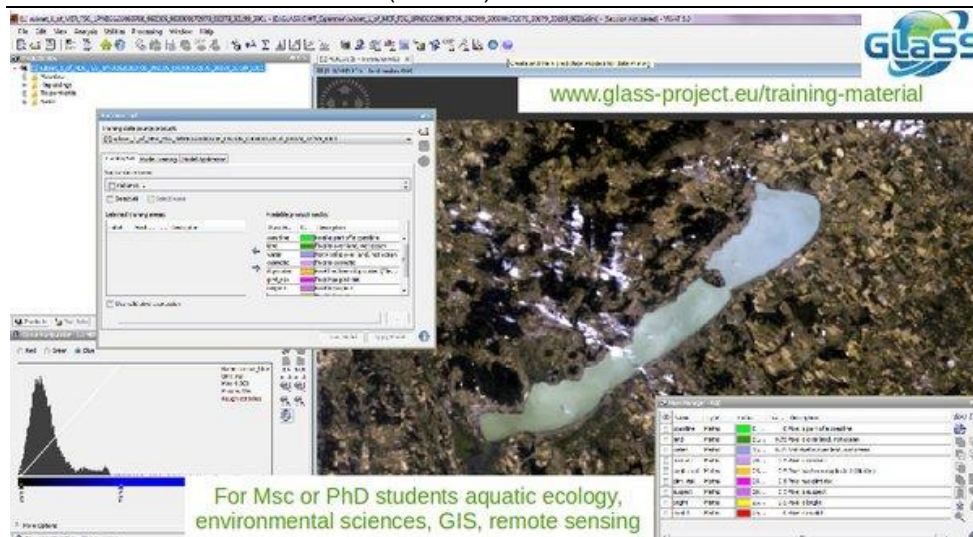
Figure 24, Screenshot from the training material, working on Lake Balaton with the BEAM software

The lesson outline is available online here and contains the permalinks to the training material (lessons and data packages). Several institutes that are involved in training and web-portals for capacity building have shown interest in the material. Some institutes indicate that they will probably use it in their classes, while the material is (in the process to become) hosted at four sites next to the GLaSS homepage.

3 Impact and main dissemination activities

3.1 Socio-economic impact and wider societal implications

GLaSS has:

- created the tools, tested and prepared the methods for downstream service providers to serve, for example water managers with EO based water quality services

- prepared worldwide examples on lakes use cases, to show a larger audience (e.g. water managers, advisors, students) what are the possibilities of the new Sentinel-2 and Sentinel-3 satellites

- generated on-line training material for students ((BSc), MSc, PhD level) or professionals. It is especially important for capacity building in developing countries that the material is freely available on-line

- made almost all of its tools, data, reports and material publicly available for further usage beyond the lifetime of the project.

The results of GLaSS:

- assist downstream service providers to set up viable operational water quality services based on EO data, using the GLaSS tools, adjusted algorithms and increased knowledge of a large range of lakes;

- allow water managers to choose validated methods for their monitoring, taking advantage of the high frequency, spatial overview and accuracy of EO data to improve their understanding of water systems, and assist them in the management of these;

- help to improve water quality, ecological status and the provision of ecosystem services such as clean drinking water, as well as the UN sustainable development goal for water by increasing the knowledge on water systems in lakes with improved monitoring possibilities;

- contribute to the larger framework of scientific knowledge on water quality remote sensing and especially the Copernicus program;

- provide training materials for a new generation of remote sensing experts, ecologists, environmental technicians and GIS experts to work with S2 and S3-OLCI data for water quality monitoring.

3.2 Main dissemination activities

A project website (www.glass-project.eu, and connected info@glass-project.eu email address) have been set up. An initial flyer and policy brief were created and spread via the web and at conferences and meetings.

During the project, the GLaSS partners have been in contact with the user communities via GEO, ESA S2 and S3 groups, limnologists/aquatic ecologists, related EO lakes projects and potential (commercial) users. The oral and poster presentations, flyers and other activities related to these activities are listed in the annex of this report.

The main media used to distribute results were newsletters and Twitter (both providing links to the downloadable reports where possible).

Four newsletters were sent during the course of the project. They were well-read:

- [Newsletter #1](). 6 June 2014: sent to 193 contacts. Unique "Open Rate": 48.76%. Unique "Click-Through Rate": 10.74%. The first newsletter was sent in batches, the percentages based on the largest batch.

- [Newsletter #2](). 23 December 2014: sent to 193 contacts: Unique "Open Rate": 39.38% "Click-Through Rate": 13.47%

- [Newsletter #3](). 30 June 2015: sent to 217 contacts, Unique "Open Rate": 44.81%, Unique "Click-Through Rate": 17.45%

- [Newsletter #4](). 7 December 2015: sent to 216 contacts, Unique "Open Rate": 38.6%, Unique "Click-Through Rate": 11.16%

- [Newsletter #5](). 5 April 2016: sent to 215 contacts, Unique "Open Rate": 41.7%, Unique "Click-Trough Rate": 8.8%.

During the project, GLaSS has maintained an active Twitter account. At the moment of finalising of this report (15 April 2016), the account **@GLaSS_Project**:

- Has produced 235 tweets (including re-tweets)
- Has 182 followers (following 135)
- Got 120 times re-tweeted (or GLaSS results (re-)tweeted) by others
- Got 67 likes by others

Within the followers are very relevant other community accounts, such as @NEREUSaisbl (Network of European Regions Using Space Technologies), @SIL_limnology (The International Society of Limnology), @GLEONetwork (Global Lake Ecological Observatory Network) and @Can_Limnology (Official twitter feed for the Society of Canadian Limnologists), as well as related projects, such as @NETLAKE (NETLAKE EU COST) or @globolakes (NERC GloboLakes).

3.3 Exploitation results

3.3.1 GLaSS core system and tools

The GLaSS core system was created to allow easy access and pre-processing for the GLaSS team to S2 and S3-OLCI data, without having to download large bulks of data. The tools were developed to simplify the use and further processing of the downloaded data.

The GLaSS core-system handles the data flow from the central data hubs of the providers (ESA, USGS) through online retrieval, spatial sub-setting over the areas containing the lakes of interest, to the online archive. It provides the subsets of lakes for the partners.

Three new tools for data mining and classification have been developed or further developed within GLaSS:
1. An optical pre-classification algorithm (OWT-GLaSS) that can distinguish the main optical water types and facilitate selection of water quality algorithms.
2. A prediction tool focusing on supervised learning and modeling.
3. A dedicated tool, ROIStats (Region Of Interest Statistics) for the extraction of temporal-spatial statistics from long time series of archived EO products. In the framework of GLaSS, a typical Region of Interest (ROI) - for which the statistics are generated - was a lake or sub regions of a lake. The inputs can be further temporally aggregated so that daily, weekly, monthly, seasonal statistics can be retrieved for the different regions.

The first two tools (OWT-GLaSS and the prediction tool) will be publicly available in the BEAM 5 software, and transferred into SNAP in the near future. This will make these tools available to the very large user group like scientists and downstream service providers of EO data. The Sentinel Application Platform (SNAP) is one of the tools that is available to work with Sentinel data and that will be further improved and updated in the near future. Because the launches of S2 and S3 were delayed, and the core system and tools were set up based on Landsat 8 imagery as a proxy for Sentinel 2 MSI and MERIS as a proxy of Sentinel-3 OLCI, the system and tools are currently being updated, to work with the new data within the next few months.

The ROIStats tool is not made available to the public: the main reason is that it does not comply with the standard qualities of a BEAM tool, coming in the form of the Python script that calls a GPT command tool. However, GLaSS partners will continue using the tool internally and to provide time series to their (downstream) users.

3.3.2 GLaSS methods and validation

The GLaSS reports on atmospheric correction development and in-water retrieval algorithms are important for the remote sensing community, to serve as a starting point for further scientific development, and as information source for downstream service providers. The reports are available as public deliverable reports, and were also presented at the joint GLaSS-GloboLakes workshop. Overlap between the two projects will allow GloboLakes to (also) build on the GLaSS results.

The (public) deliverable report on in situ validation is expected to be of value of researchers in the field, by providing them a large overview of comparisons between in situ radiometric readings and atmospherically corrected satellite imagery, where most published studies only focus on one or two lakes.

Some of the in situ validation work (the campaign in Sweden, 2015) is on its way to (a) joint scientific publication(s) with the GloboLakes community.

The (public) deliverable report on validation of the HYPE model leads to new insights in the working of the model and is the start of a very good co-operation between GLaSS partner BG and SMHI (HYPE developers). Even some improvements have been incorporated in the model based on the GLaSS results, providing the HYPE community with better models.

3.3.3 Data

Availability of high quality data is a requirement for algorithms training, calibration and validation. Therefore, it is important for scientific work as well as for downstream service providers to have large sets of data available. The GLaSS data is of a great interest because it covers a large range of lakes with very distinct optical properties and with broad concentrations ranges.

The simulated dataset is described in a public available report and can be made available from the involved partners on request.

The in situ data gathered during GLaSS are submitted (or in the process of being submitted) to the GLoboLakes LIMNADES database for optical water quality parameters of lakes. The latest information is that LIMNADES gathered data from about 1500 lakes, including 4000 stations with radiometric data. This database will be an important data source for optical scientists in the future. It is accessible for all contributors.

3.3.4 GLaSS global use cases reports

The GLaSS global use cases will help a larger audience (water managers, ecologists) to find out about the possibilities of the new Copernicus data. The results are described in deliverable reports. The reports are made available via the GLaSS website and via Research data. The links to the reports were provided in a GLaSS newsletter and tweeted via the

project twitter account. The WFD report was also placed in a dedicated LinkedIn groups.

The use case reports are an excellent way to show users the lake research and exploitation possibilities. Some GLaSS partners have already showed the examples from the WFD use case to their users, as a starting point for service setup. Also scientifically the use case reports are important: the results have been (and will be) presented at dedicated conferences and a few cases will be described in scientific publications.

3.3.5 GLaSS training material

The GLaSS training materials will help a new generation of remote sensing experts, ecologists, environmental technicians and GIS experts to work with S2 and S3-OLCI data for water quality monitoring.

The lesson packages are made available via the GLaSS project website. However, as the website might not have a permanent character, the 'permalinks' to the host location (WI server) are provided in the training material outline document, so that students in the future can always download the complete lessons series.

The link to the training material was also tweeted, where it was re-tweeted by the account NASA_Landsat, with 29 000 followers. The following 16 re-tweets and a similar number of likes of this indicate a large potential audience.

GLaSS partners who are involved in training of students or professionals will also use the material in their own courses and workshops.

The training material is made available via the GLaSS project website, and several platforms:
- LearnEO! (www.learn-eo.org) (in process of being submitted)
- GEO water quality portal (www.geo-water-quality.org)
- GEO EO capacity building website (www.geocab.org)
- EO Education and training (https://earth.esa.int/web/guest/eo-education-and-training

3.3.6 New projects

Three project proposals have been written based on GLaSS results and co-operation.

4 Roadmap

4.1 Algorithms

4.1.1. GLaSS results

The GLaSS deliverable reports on atmospheric correction harmonisation (D3.2), adapted water quality algorithms (D3.4), and validation (D4.2) together provide the reader an overview of the current status of algorithms for inland water remote sensing. There is not a straight-forward one-size-fits-all solution, such as an algorithm or a combination of methods that works best for all inland waters, or even specific water types. However, the reports will allow the reader to select the solution that is best for his or her situation and needs. Selection criteria depend on:

- EO sensor characteristics: some algorithms work better for one sensor than for another;
- the water type: some algorithms work better for clear water, others for more turbid, or absorbing waters;
- the data you have available: some algorithms that allow tuning with local aerosol properties or specific optical properties of water tend to work well, but require those data to be available;
- the spectral bands you are interested in: some atmospheric correction algorithms work well for some bands, but less well for other bands,
- the quality criterion you are using: some atmospheric correction algorithms produce good spectral shapes for the water leaving reflectance, but without the right intensity, wheareas for other algorithms it is the other way around. It depends on further processing steps if shape or intensity is the most important);
- the water constituents you are interested in (some algorithms work mostly for certain constituents);
- practical issues such as required software or licences.

In general, for each water body studied in GLaSS, both a suitable atmospheric correction and a suitable in-water component retrieval algorithm could be selected, or an algorithm that does a combination of these. Sometimes the results could be improved with local tuning (D3.4), while other algorithms are more generic and require less local tuning.

4.1.2. Next steps for S3 and S2 processing

The GLaSS results are promising for inland water remote sensing: although a direct global applicable method cannot be given (yet), the results show that water quality parameters can be estimated in many lakes after selecting a suitable (combination of) algorithm(s) (and local tuning or parameterisation). These results, including outlooks for S2 and S3-OLCI, are well demonstrated within the global lakes use cases.

It is expected that all the algorithm results that apply to MERIS will also apply to S3-OLCI. This means that only minor technical adjustments on the algorithms need to be implemented (such as adjustments to the file format) and tested when S3-OLCI data becomes available. During GLaSS, all involved algorithms have been made more flexible to file formats and band settings, which makes this step relatively easy. GLaSS has used Landsat-8 as a proxy for S2 to study water parameter retrievals. The expectation is that for S2 the results will be better than for L8 because it has more spectral bands. The status of the algorithm readiness is dissimilar: during the project, some of the algorithms have been applied to and tuned for simulated S2 data, while others still need re-tuning. However, as for S3-OLCI, the technical adjustments were prepared in the project. A few algorithms are already applied to real S2 data in the last months of the project.

4.1.3 Future of algorithms

For the community it would be good to have access to a selection of operational global applicable atmospheric correction algorithms that deliver water leaving reflectance data that are precise enough to use for water remote sensing. Such algorithms should be able to account for topographical altitude and adjacency effects. The variety of atmospheres and aerosols over inland waters is probably much bigger than seen over coastal waters, so an extended library of these properties will be required for algorithm parameterisation and/or training. Specific flagging for bottom visibility and floating materials might help to improve the quality of operational processing. E.g. D5.5 on highly absorbing lakes shows how precise the results even in highly absorbing lakes could be, when the results would just depend on the sensor sensitivity. However, further research on global atmospheric correction algorithms that can be applied to global lakes is currently not funded. Parallel to GLaSS, other projects (GloboLakes, INFORM, DiversityII) have been dealing with the same issues to harmonise algorithms for inland waters, in relatively small work packages. The distribution of tests over several projects makes the results scattered. Global methods were assumed to be ready and the starting point for further developments, however, this is not the case for inland waters that are too dark for land-based methods and contain too much suspended matter to be processed with ocean-based methods. Also, there is a lack of in-situ data for the purpose of calibration and validation (match ups with satellite data remain rare).

With regard to water-component retrieval, the inland water quality community balances between two alternatives. One way is a single globally applicable water-component retrieval algorithm, while another part of the community considers this impossible due to the large diversity of lakes and inherent optical properties, and advices to work towards tuning of water-component retrieval algorithms with local or suitable specific optical properties (which might be automated within the algorithm). The solution might be a combination of these.

Currently, inland waters are included in the land-component of Copernicus, which makes their status even more peculiar. To enhance developments, it is important that ESA/EUMETSAT and Copernicus recognise the special status of inland waters and pay attention to the needs of this community.

4.2. In situ data

4.2.1 GLaSS results

GLaSS has made a start to document in situ protocols for optical measurements in inland waters. Currently, different protocols are used, making the results difficult to compare. The main reason for this is that the only existing protocols for optical measurements of water quality are for open ocean (e.g. NASA Ocean Optics protocols) and they have not been adapted for lakes. GLaSS therefore started to record the differences between protocols for lakes and for ocean. This document was presented to GEO. All in situ data collected during GLaSS have been or will be submitted to the optical in situ database LIMNADES (set up by GloboLakes).

4.2.2 Recommendations on validation data

When Earth Observation will more and more turn into operational services, validation, especially of inland and coastal waters (those water with the highest monitoring needs) will be required by users. Standardised protocols and large test databases of in situ data on inland water (including a large range of water types) will therefore be very important for algorithm development and validation. GLaSS' recommendations to Copernicus, ESA and/or GEO are therefore to support further harmonisation of protocols for optical in situ measurements, and to support the continuation of the LIMNADES database or similar databases for optical inland water data. In addition, to back up and fund the collection of harmonised, well documented suitable data, over large ranges of conditions.

4.3 Downstream EO inland water services

4.3.1 GLaSS results

In six use cases GLaSS showed the current possibilities of EO for inland water quality in a social context (D5.1). Tracing potentially toxic cyanobacteria blooms (D5.2), following long-term changes in ecological status (D5.3), monitoring the effect of glacial runoff and the effects of restoration projects (D5.4), application of EO data to the most difficult types of lakes (D5.5), locating potentially dangerous mine tailing ponds (D5.6) and the use of EO data to fulfil monitoring requirements, such as those for the Water Framework Directive (D5.7) are covered. The results of the use cases come with training materials to guide new professionals in the field in how to use the data and tools.

4.3.2 Requirements

Operational downstream services require consistent EO data provision, which is on its way of being fulfilled by S2 and S3, suitable algorithms and validation (see previous sections) and interested users. By providing six use cases, GLaSS has generated showcases to attract potential users of downstream services. The GLaSS use cases serve here as an initial product portfolio, for a range of user types to learn about the possibilities and to formulate their service requirements.

A large boost towards the global uptake of EO-based water quality monitoring could be created by the UN sustainable development goals. Goal #6 requires sustainable water management, including the protection of inland waters such as lakes. These goals imply the needs for consistent, automated, cost-effective and global applicable monitoring services, which can be fulfilled by EO data.

4.3.3 Operational downstream services

To ensure a growing and sustainable development of downstream EO based products and services, adequate business models need to be developed and assured. The European Association of Remote Sensing Companies (EARSC) formulates potential downstream services as creating a platform "bringing together many services, allowing users' access to many diverse data types and means to convert them into sustainable services" (EARSC position paper, February 2016). From a business point of view it is important that free Copernicus core services do not interfere with these commercial downstream targets.

Sensors that are already planned to be launched after S2 and S3 will lead to further improved EO based water quality monitoring capabilities. Higher spectral coverage leads to new products and enhanced accuracy, finer spatial resolution enables small water body monitoring, and increased temporal coverage (in synergy with other sensors/platforms) opens new market potentials (D7.5). These new developments will need adjustment of algorithms, in situ validation data and good expertise to provide high quality data and ensure reliable products.

Attachment Use and dissemination of foregrounds

A1: List of all publications relating to the foreground of the project

- Alikas, K., Kangro, K. Randoja, R. Philipson, P., Asuküll, E., Pisek, J., Reinart, A., 2015. Satellite based products for monitoring optically complex inland waters in support of EU Water Framework Directive. International Journal of Remote Sensing, 36(17), 4446 - 4468.
- Alikas, Krista; Kratzer, Susanne; Reinart, Anu; Kauer, Tuuli; Paavel, Birgot., 2015. Robust remote sensing algorithms to derive the diffuse attenuation coefficient for lakes and coastal waters. Limnology and Oceanography: Methods, 13, 402 - 415.
- Broszeit, A. (2015): Assessing long-term inland water quality using satellite imagery: A feasibility and validation study of different lake types. Master thesis Julius-Maximilian University Würzburg
- Di Nicolantonio W., Cazzaniga I., Cacciari A., Bresciani M., Giardino C., 2015. Synergy of multi-spectral and multi-sensors satellite observations to evaluate desert aerosol transport and impact of dust deposition on inland waters: study case of Lake Garda. Journal of Applied Remote Sensing 095980-1 Vol. 9..
- Giardino, C., Bresciani, M.,Stroppiana, D., Oggioni, A., Morabito, G. (2014). Optical remote sensing of lakes: an overview on Lake Maggiore. Journal of Limnology 73(s1): 201-214. DOI: 10.4081/jlimnol.2014.817
- Giardino, C., Bresciani, M., Cazzaniga, I., Schenk, K., Rieger, P., Braga, F., Matta, E., Brando, V.E., 2014. Evaluation of Multi-Resolution Satellite Sensors for Assessing Water Quality and Bottom Depth of Lake Garda. Sensors 14, 24116-24131; Doi:10.3390/s141224116
- Lenstra W.K., Hahn-Woernle L., Matta E., Bresciani M., Giardino C., Salmaso N., Musanti M., Fila G., Uittenbogaard R., Genseberger M., van der Woerd H.J. & Dijkstra H.A., 2014. Diurnal variation of turbulence-related quantities in Lake Garda, Advances in Oceanography and Limnology, 5:2, 184-203, DOI: 10.1080/19475721.2014.971870.
- Matta E., Bresciani M., Giardino C., Boggero A., Use of satellite and in-situ reflectance data for lake water color characterization in the Everest Himalayan Region. Submitted in July 2015 to 'Mountain research and Development'.

Popular science:
- Alikas, K., Kangro, K., Randoja, R., Asuküll, E., Reinart, A. 2014. Satelliidi-info kasutamise võimalused veekogude seisundi määramiseks Eesti suurtes järvedes. Anne Aan, Kirke Narusk (Toim.). Kaugseire Eestis 2014 (59 - 68).Keskkonnaagentuur (In Estonian) (Popular science article)

A2: List of all dissemination activities

Presentations and other – 1st year

- Webinar (28/06/2013). WI. GLaSS Global Lakes Sentinel Services. On line for Group on Earth Observation (GEO). Audience: 25
- Flyers (02/07/2013). BC. GLaSS Global Lakes Sentinel Services. Budapest, Hungary (SEFS conference). Audience: 300
- Poster (10/09/2013). WI. GLaSS getting ready to use Sentinel 2 and 3 for inland water monitoring. Edinburgh (Living Planet Symposium). Audience: 2000
- Oral presentation (10/09/2013). TO. Monitoring optically complex inland waters in the context of EU WFD by means of satellite derived products. Edinburgh (Living Planet Symposium). Audience: 100
- Poster (12/09/2013). WI. Sentinel 3 Validation in Inland Waters (GlaSS-S3VAL). Edinburgh (Living Planet Symposium). Audience: 2000

- Poster (07/11/2013). CNR. Un progetto per lo sviluppo di strumenti innovativi per il monitoraggio dei laghi da dati Sentinel-2 e Sentinel-3. Firenze, Italy (17th CONFERENZA NAZIONALE ASITA). Audience: 100
- Oral presentation (28/11/2013). WI. GLaSS S3Val. Frascati (Sentinel-3 Validation Team meeting). Audience: 80
- Oral presentation (14/01/2014). WI. GLaSS - Global Lakes Sentinel Services. Stirling (Globolakes meeting). Audience: 30
- Flyers (16/01/2014). EOMAP. GLaSS Global Lakes Sentinel Services. Geneva, Swiss (GEO-X Exhibition). Audience: 1000
- Oral presentation (23/01/2014). CNR. GLaSS Global Lakes Sentinel Services. Mol, Belgium (Kick off meeting project INFORM). Audience: 700.

Presentations and other – 2nd year:
- Oral presentation (21-22/05/2014). WI. GLaSS - Global Lakes Sentinel Services. Sentinel-2 for science meeting. Frascati, Italy.
- Oral presentation (03/09/2014). TO. Robust remote sensing algorithms to derive diffuse attenuation coefficient for optically complex waters. World Lakes Conference. Perugia, Italy. Audience: 30
- Oral presentation (03/09/2014). WI. Monitoring the spatial temporal dynamics of water quality in lake Malawi from space. World Lakes Conference. Perugia, Italy. Audience: 30
- Oral presentation (03/09/2014). WI. Floating layer detection with remote sensing. World Lakes Conference. Perugia, Italy. Audience: 30
- Poster (03/09/2014). WI. GLaSS - Global Lakes Sentinel Services. World Lakes Conference. Perugia, Italy. Audience: 300.
- Poster (11-17/10/2014). TO. Mapping cyanobacterial development in shallow lake Peipsi (Estonia/Russia) by Maximum Chlorophyll Index (MCI). Antalya, Turkey. Audience: 250.
- Poster. (25-31/10/2014). TO. The relationship between the phytoplankton absorption coefficient and chlorophyll-a concentration for remote sensing application of Estonian large lakes. Ocean Optics XXII Conference, Portland, US. Audience: 100
- Oral presentation (29-30/10/2014). TO. What can fine resolution satellites provide for small coloured lakes? Finnish remote sensing days, Helsinki, Finland. Audience: 25
- Oral presentation (04/12/2014). WI. Latest results of GLaSS. Sentinel-3 Validation Team meeting (S3VT). Darmstad, Germany. Audience: 30
- Oral presentation (13/02/2015). VU/Vumc. Mentioned GLaSS work. NIOZ workshop and science day on water, atmosphere, remote sensing and participatory science. Texel, the Netherlands. Audience: 9.
- Oral presentation (21-22/05/2014). SYKE. Sentinel-2 MSI in the Monitoring of Lakes and Coastal Waters in Finland: Spectral and Spatial Resolution Considerations. Sentinel-2 for science meeting. Frascati, Italy. Audience: 40.
- Poster (2-5/06/2015). TO. Validation of hyperspectral airborne data on lake Peipsi. Sentinel-3 for Science Workshop, Venice, Italy. Audience: 40

Oral presentations at the joint GLaSS-WaterS meeting (Tartu, 3 April 2014, audience: 25, scientists):
- National experience in monitoring of lakes by remote sensing (Claudia Giardino)
- Monitoring of Swedish lakes by remote sensing (Petra Philipson)
- PAN-European inland water quality service (Karin Schenk)
- GLaSS Atmospheric correction tests (A Hommersom)
- HYPE model (Petra Philipson)
- Water quality algorithms adaptation to S2 and S3 (Krista Alikas)
- Optical pre-classification (Marieke Eleveld)

Presentations and other – 3rd year

GLaSS has several presentations at the Sentinel-3 for Science Workshop (in Venice, Italy, from 02 – 05 June 2015) for a large (over 200 participants) international audience. The presentations included three posters and one oral presentation:

- Proceedings of GLaSS: GLobal Lakes Sentinel Services, Peters, Steef. Water Insight, Netherlands (poster)
- Global Lakes Sentinel Services: Monitoring water quality trends in deep, clear lakes to detect causes and effects of changes in trophic status Poser, Kathrin (1); Peters, Steef (1); Hommersom, Annelies (1); Giardino, Claudia (2); Bresciani, Mariano (2); Cazzaniga, Ilaria (2); Schenk, Karin (3); Heege, Thomas (3); Philipson, Petra (4); Ruescas, Ana (5); Böttcher, Martin (5); Stelzer, Kerstin (5) 1: Water Insight, Netherlands; 2: CNR-IREA, Italy; 3: EOMAP, Germany; 4: Brockmann Geomatics, Sweden; 5: Brockmann Consult, Germany (poster)
- Performance Assessment of Water Insight SpectroPhotometer with Three Channels (WISP-3) against the Standard of Ocean Optics Protocols, Semhar Ghezehegn(1), Ilmar Ansko(2), Joel Kuusk(2) , Annelies Hommersom(1), Marnix Laanen(1), 1)Water Insight BV, P.O.Box 435,6700AK,Wageningen,The Netherlands, Email:semhar@waterinsight.nl (2)Tartu Observatory, EE-61602 Tartimaa, Estonia, Email: jazov@to.ee (poster)
- Global Lakes Sentinel Services: Water quality parameters retrieval in lakes using the MERIS and S3-OLCI band sets. Peters, Steef (1); Hommersom, Annelies (1); Alikas, Krista (2); Latt, Silver (2); Reinart, Anu (2); Giardino, Claudia (3); Bresciani, Mariano (3); Philipson, Petra (4); Ruescas, Ana (5); Stelzer, Kerstin (5); Schenk, Karin (6); Heege, Thomas (6); Gege, Peter (7); Koponen, Sampsa (8); Kallio, Karri (8); Zhang, Yunlin (9) 1: Water Insight BV, Netherlands, The; 2: Tartu Observatory, Estonia; 3: CNR, Italy; 4: Brockmann Geomatics, Sweden; 5: Brockmann Consult, Germany; 6: EOMAP, Germany; 7: DLR, Germany; 8: Syke, Finland; 9: Nanjing Institute of Geography and Limnology, P. R. China (oral)
- Investigation of Optical Properties over Large Estonian Inland Lake Using HySpex Images. Evelin Kangro, Tiit Kutser, Ele Vahtmäe, Tuuli Kauer (poster)

The following GLaSS results were presented in oral presentations during the workshop that was organised together with GLoboLakes (Stirling, UK, audience: ~40 scientists and a few potential users):

- GLaSS project overview (Steef Peters)
- In-water algorithms and atmospheric correction - overview of approach (K Schenk)
- GLaSS core system and tools (A Ruescas)
- Eutrophic lakes (E Kangro)
- Deep clear lakes (C Giardino)
- Lakes with high sediment due to resuspension (A Hommersom, M Bresciani)
- Lakes with high absorption due to CDOM (S Koponen)
- Mine tailing ponds (A Hommersom)
- Earth observation for Water Framework Directive reporting (K. Kallio)
- GLaSS In situ protocols (E Kangro)
- Satellite validation results / fieldwork (Elar Asuküll)
- HYPE model validation: (P Philipson)

Other presentations in the third year:

- Oral presentation (10-14/08/2015). TO. Validation of MERIS standard and processed data. Development of the relationship between phytoplankton absorption coefficient and chlorophyll-a concentration for remote sensing applications for large Estonian lakes. Challenges for Earth system science in the Baltic Sea region: From measurements to models. Evelin Kangro, Krista Alikas, Kersti Kangro, Silja Põldma. Physicum of University of Tartu and Island of Vilsandi, Estonia. Audience: 50.
- European lakes: interface with the HYPE model. Petra Philipson, Brockmann

Geomatics. Presentation of analysis and results related to D4.3 at SMHI, Sweden. Oral presentation (25/08/2015). Audience: 8.

- Stima dei trend di stato trofico in laghi profondi da dati MERIS (2002-2012). Ilaria Cazzaniga, Claudia Giardino, Mariano Bresciani, Steef Peters. Poster Presentation at Italian Conference XIX° ASITA, 29 September 1 October 2015, Lecco (Italy). Audience: 50. Conference proceeding pp. 245-252.
- Shallow lakes with high eutrophication and potentially toxic algae. Evelin Kangro, Tartu Observatory. Presentation of results related to D5.2 at Remote Sensing Seminar in Tartu Observatory. Oral presentation (04/02/2016). Audience: 15.
- Poster (30/06/2015). Global Lakes Sentinel Services: Monitoring water quality trends in deep, clear lakes to detect causes and effects of changes in trophic status, Ocean Remote Sensing Synergy summer school, Telecom Bretagne, Brest, France, 30/06-04/07 2015. Audience: 40.

For the Living Planet symposium 2016 (9-13 May), the following posters are accepted:
- GLaSS: Monitoring restoration of shallow lakes with high resuspension (WI)
- GLaSS training material: earth observation for lakes water quality (WI)
- A new method to locate potential hazardous mine tailing ponds around the world (WI)
- GLaSS: Evaluation of trophic trends in deep clear lakes (CNR)
- Observations of water reflectance of glacial lakes in the Everest Himalayan Region from in situ and satellite data (CNR)
- GLaSS: Study of Shallow Lakes with High Eutrophication and Potentially Toxic Algae (TO)
- Algorithms, processing and access infrastructures for harmonized water quality and water body monitoring with Sentinel-2 and 3 (EOMAP)
- Development and testing of the Boreal Sensor-Independent Ocean Colour Processor (BOREAL-SIOCS) (SYKE, BC)