GLaSS has paved the way for water quality monitoring of lakes and reservoirs using the new Sentinel-2 and Sentinel-3 satellites. A system to ingest and process Sentinel data was created, algorithm tests have been performed and several tools were developed to work with the data. Global lakes use cases demonstrate what can be done with the new Sentinel. Also, training material was created, to learn how to work with Earth Observation data on lakes.

Background
Monitoring of water quality of inland waters is important in every day 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 can be very useful for ecologists and water managers for instance. 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.

1 System and algorithms
A core system to ingest and process Sentinel data of global lakes was set up. A large database of in situ reflectance data, match-up satellite data (MERIS and Landsat 8) and S2 and S3 data simulated with HYDROLIGHT was created as well. The database, including data from lakes with a large range of optical properties (from clear and blue to green and brown and from highly reflecting to highly absorbing waters), was used for testing algorithms. It appeared that none of the atmospheric correction or water quality algorithms was suitable for all lakes, because of the large range optical variation.

2 Tools
To facilitate the pre-selection of an atmospheric correction and water quality retrieval algorithm for a lake with unknown optical properties, a pre-classification tool (OWT-GLaSS) was developed. This tool selects the water type of the class best matching 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 the aggregation valid lake pixels for time series production and extracts 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), train a model and let the model select similar pixels from other imagery.

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3 Validation
During the course of the project, in situ campaigns were carried out in lakes in Finland, Estonia, Sweden, the Netherlands and Italy, further characterising the optics of these lakes, and validating L8 and S2 during their overpasses. Also, an interesting comparison was made between EO-derived chlorophyll and (dissolved) nutrients from 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.

4 Global lakes use cases
Based on socioeconomic analysis and optical classification, global lakes use cases were selected. The listed lakes were studied in detail with satellite and in situ data, using the GLaSS tools and the adjusted algorithms.
For the eutrophic lakes, four algorithms were chosen to monitor Chl-a and cyanobacteria. Time series showed the effect of e.g. meteorological conditions and differences in chlorophyll distribution over the lakes in different years.
For the 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 (Garda and Tanganyika).
The use case on shallow lakes with high suspended matter concentrations used high resolution data. Resuspension effects due to wind and dredging are followed, and a method to indicate which glacial lakes will potentially cause dangerous runoff events, based on the colour of glacial lakes, was set up.
The highly absorbing lakes case tests a new algorithm, SIOCCS, on Nordic lakes. Also, a theoretical analysis was carried out on the limits of changes in chlorophyll concentrations that can be detected with EO data based on the sensor sensitivity.
Also, a method was 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. Leaks resulting in environmental damage have occurred every year recently, which shows the need for locating and monitoring them globally.
Finally, 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 satellite data is very different. Examples of histograms, time series and the derived classes were created for lakes in several countries.

Training material
The global lakes use cases demonstrated 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 available via platforms such as ESA LearnEO! and the GEO EO Capacity Building portal.