PRODUCT AND SERVICE PORTFOLIO

EOMORES

Inland and coastal water quality monitoring and forecasting services

UNIQUE WATER QUALITY MONITORING SOLUTIONS

Lakes, reservoirs and coastal water bodies are essential components of the hydrological and biogeochemical water cycles, and influence many aspects of ecology, economy, and human welfare. Inland and coastal waters provide numerous ecosystem services for recreation, drinking water, cooling water for industry, transport and fishing. Knowledge about the state of inland and coastal water bodies is therefore of great importance, for public authorities, citizens and business alike.

Monitoring the water quality of lakes and coastal waters is compulsory under a number of environmental policies, such as the Water Framework Directive (WFD)[1] and the Bathing Water Directive.[2] Consequently, Member States are to regularly monitor and report on a set of parameters.

Traditionally, water monitoring involves field work for sample collection and **laboratory work for testing**; in which samples are collected manually from selected areas of interest within the water body. The amount of labour makes the method both **costly and time-consuming**. Moreover, due to the limited reachability of sampling locations and to a sparse sampling frequency, the approach oftentimes fails to capture the complexity of dynamics (both spatial and temporal) within the examined water bodies.

EOMORES is a set of services designed to ensure the comprehensive monitoring of water quality parameters in either coastal or inland water bodies, including and complementary to in situ measurements. While using satellite data to measure or derive water quality parameters has been common practice over the past years, **EOMORES is the first service to seamlessly integrate cutting-edge, optical in situ instruments with free and open satellite data and sophisticated numerical models.** The result is a set of **user-tailored services able not only to report, but also to forecast** changes in water quality, and provide corresponding alerts.

This Product and Service Portfolio aims to showcase the benefits that EOMORES can provide to potential users interested in monitoring the quality of inland and coastal water bodies.

[1] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

[2] Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC

TABLE OF CONTENTS

WHAT DO WE MONITOR?

ALGAE

Bloom and scum monitoring and forecasting

PLANTS

Macrophyte depth, spread, distribution

HEALT IMPACTS

Risk maps, potentially toxic blooms, plumes

ECOSYSTEM ASSESSMENT

Biodiversity indicators, submerged habitat

SPATIAL PLANNING

Bathing sites, dredging

POLICY & WATER RESOURSE MANAGEMENT

WFD classes, monitoring, strategy

EVENT MONITORING

Plumes, construction, source identification

SITE CHARACTERISATION

Historical cloud, topology

The following parameters are measured or derived by EOMORES:

- Chorophyll-A (Chl-A)
- Total Suspended Matter (TSM)
- Turbidity
- Transparency
- Coloured Dissolved Organic Matter (CDOM)
- Water Surface Temperature (WST)

ALGAE

EOMORES uses Earth Observation and automated in situ data to provide a frequently-updated overview of the start, duration and distribution of algae and cyanobacteria blooms. Subsequently, forecasting models use these data to anticipate their evolution, helping users to plan mitigation actions.

What is the problem?

Due to human impact and climate change, water quality is on the decline resulting in, amongst other things, excessive algae growth and increased concentrations of cyanobacteria.

How does EOMORES address it?

The EOMORES services provide highly accurate and timely geospatial information as a result of combining satellite mapping, high-frequency in situ measurements and forecasting models of chlorophyll a (chl-a) and phycocyanin concentrations, and algal blooms.

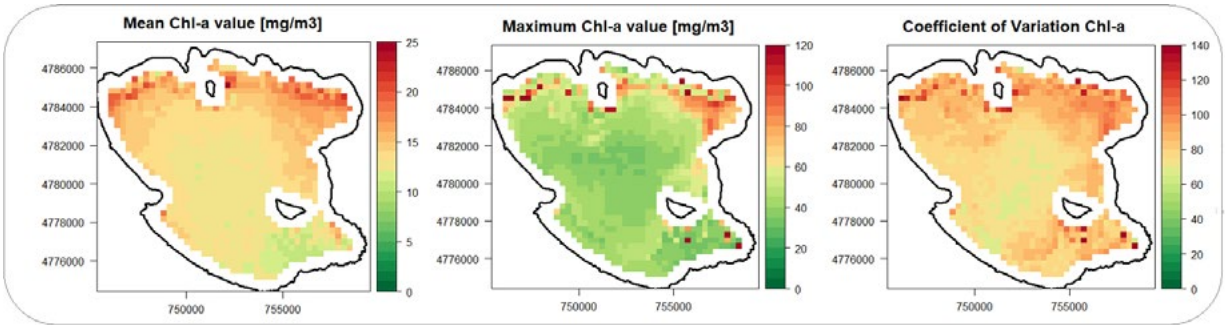
Showcased products:

- Chl-a concentration maps
- Semi-continuous water quality measurements
- Harmful algal bloom forecasts

Critical phenomena, such as algal blooms, can be identified and tracked over time. This information can then be used by local authorities to, for instance, plan sampling activities or issue advisory notices regarding swimming areas.

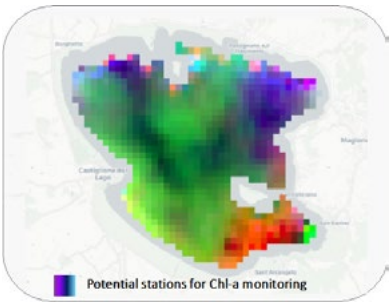
EOMORES in action: Identifying locations sensitive to phytoplankton dynamics in order to optimise chl-a sampling in Lake Trasimeno (Italy)

EOMORES combines chl-a maps to pinpoint the most appropriate locations for sampling, taking into consideration the specific geography and particularities of the water body. An example of such maps, based on satellite observations of one of Italy's biggest lakes during 2017, is presented in the figure below. The data in the first three maps show rather homogenous patterns of chl-a, with somewhat higher values in the north and lower in the south-east.



From left to right, the first three maps reflect the mean, maximum and coefficient variation (i.e. standard deviation divided by mean) of chl-a. Combining these maps results in a synthetic representation (in purple), which shows the areas most sensitive to phytoplankton dynamics.

The combined map constitutes a synthetic representation (right) which can be valuable when developing a sampling plan, such that stations are located in areas which are more sensitive to phytoplankton dynamics. The areas in purple are those which should be targeted by in situ monitoring. In the orange/red areas to the south-east, variation is due to suspended particulate matter, whereas in the green areas, variation occurs due to changes in all water quality parameters. Overall these two areas are less sensitive to chl-a variation.



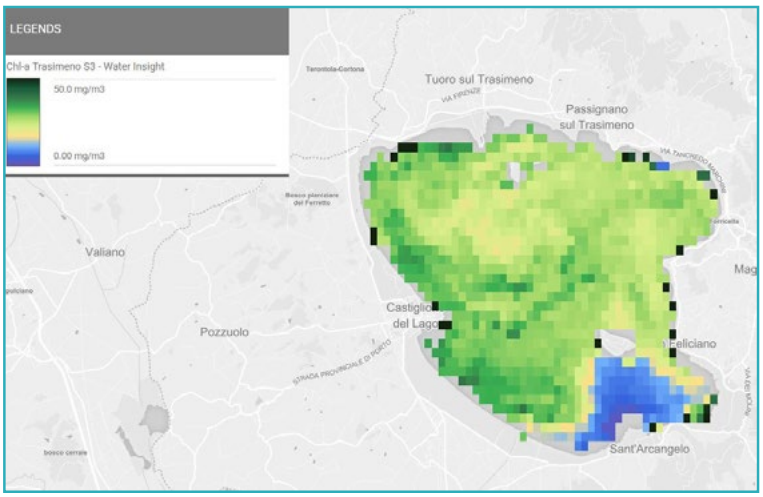
CHL-A CONCENTRATION MAPS

Target user
Environmental protection agencies, local municipalities

Application
Water quality assessment

Chl-a concentration is the main indicator of water quality under the Water Framework Directive. Satellite imagery helps track spatial variability, investigate changes in water quality and address gaps inherent to in situ measurements.

An example product is presented on the previous page.



Chl-a concentration map of Lake Trasimeno, Italy

Demonstration area
Lake Trasimeno, Italy

Applicable range

- Chl-a < 5- > 120 mg m^{-3}

Accuracy

- R^2 = 0.86, MAE = 7.10, RMSE = 15%, b = 8.73, a = 0.92

Limitations

- Not available during cloud cover
- Only the upper mixed layer is measured

Resolution(s)

- 10-20m (Sentinel-2)
- ~ 300 m (Sentinel-3)
- Point measurement (WISPstation)

Maximum frequency

- Every 15 minutes (WISPstation, harbour)
- Every ½-2 days (Sentinel-3)
- Every 3-5 days (Sentinel-2)

The above data sources are used in combination.

Delivery methods & service options

- Available via FTP or web viewer in all standard GIS file formats (e.g. GeoTiff, NetCDF)

SEMI-CONTINUOUS WATER QUALITY MEASUREMENTS

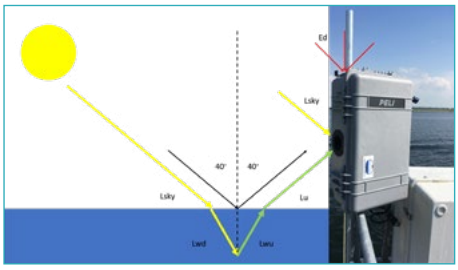
Target user
Water management authorities, tourism industry, aquaculture industry, engineering companies, drinking water companies

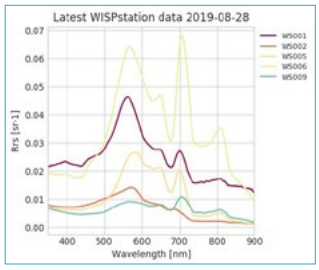
Application
Continuous water quality monitoring

Demonstration area
Lakes and coastal areas

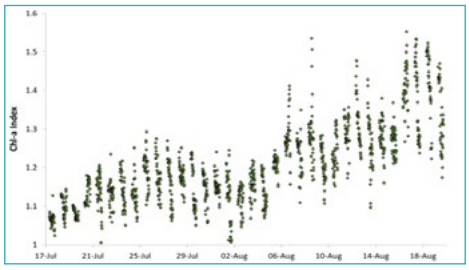
Many lakes and coastal areas are favoured locations for recreation, or commercial activities such as aquaculture. Potentially harmful cyanobacteria blooms can occur at these locations. Automated, in situ monitoring can warn water managers or aquaculture farmers when measures against blooms (e.g. turning on mixers) are required to save the fish or shellfish harvest. Similarly, the public can be warned of unsafe bathing waters.

Semi-continuous monitoring data can also be used to gain insights into the functioning of an ecosystem, track the daily cycle of scum appearance and disappearance, and serve as input into algal forecasting models.





Optical expert results



Chlorophyll time series

Applicable range
- Chl-a 0-120 mg m^{-3}
- SPM 0-100 g m^{-3}
- PC 5-100 mg m^{-3}
- SD 0.1-20 m

Accuracy
- MAE ~ 20 for SPM and chl-a

Accuracy is lake and parameter specific. The accuracy of EOMORES datasets is comparable to the one achieved by traditional methods.

Limitations
- No measurements possible in areas with bottom visibility
- No measurements during rain

Only surface measurements.

Resolution(s)
- Point measurement (WISPstation)

Maximum frequency
- Every 3 minutes (WISPstation)

Delivery methods & service options
- API (application programming interface)

Automatic coupling to your in-house GIS or data system possible.

HARMFUL ALGAL BLOOM FORECASTS

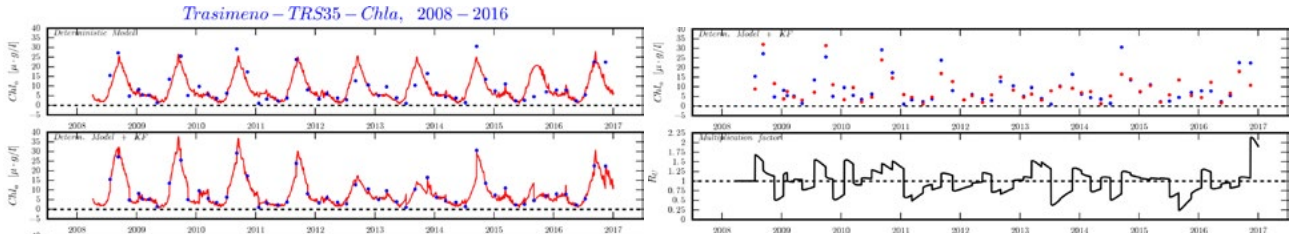
Demonstration area
Lake Trasimeno, Italy

Target user
Water management authorities, tourism industry

Application
Forecast of algae blooms over time

Worldwide, bathing waters are subject to harmful algal blooms that produce toxins and therefore pose a threat to recreationists. Predicting these blooms may help water managers to take the appropriate measures in time to take mitigating actions and thus keep bathing water locations open to the public. EOMORES offers a forecasting model called the AlgaeRadar, which has been demonstrated in Lake Trasimeno, as the example below showcases.

The top image shows the forecasts of algal blooms when the model is fed meteorological data only (weather forecasts). The lower panel shows the results after 'Kalman filtering': a process in which daily in situ chlorophyll a measurements are used to 'adjust' the model.



Model in red, in situ observations in blue.

Applicable range
- Only chl-a, no limitations

Accuracy
- Depends on weather forecasts and frequency of in situ measurements
- Lake-specific: in situ measurements are needed as input. Meteo data are retrieved from met offices.

Limitations
- No spatial information; forecast is for a specific point
- The sudden appearance of scums is not currently predicted

Resolution(s)
- Point forecast

Maximum frequency
- 15 minutes - daily (model)

Delivery methods & service options
- Reports
- Information delivery through Delft-FEWS

ECOSYSTEM ASSESSMENT

EOMORES uses Earth Observation and optical in situ data to monitor water quality parameters, relevant to ecosystem assessment. The products can be delivered as maps and time series for inland, transitional or coastal waters in order to allow visualisation of the spatial and temporal changes in the ecosystem.

What is the problem?

Ecosystem assessment can be a challenge when the data available are limited in time and/or space, as they tend to be in the case of routine, sample-based monitoring. Furthermore, a lack of historical data on water bodies makes it difficult to understand changes in the ecosystem.

How does EOMORES address it?

The EOMORES services are built on dense spatial and temporal series of data. They are particularly suitable for capturing the seasonal changes in phytoplankton or the timings of algal blooms: phenomena which are otherwise difficult to track when relying solely on in situ monitoring. The specific products are tailored to the user's needs, and can provide synoptic coverage, including information for remote areas, at different spatial scales. Both near-real time assessments and retrospective analysis are available.

Showcased products:

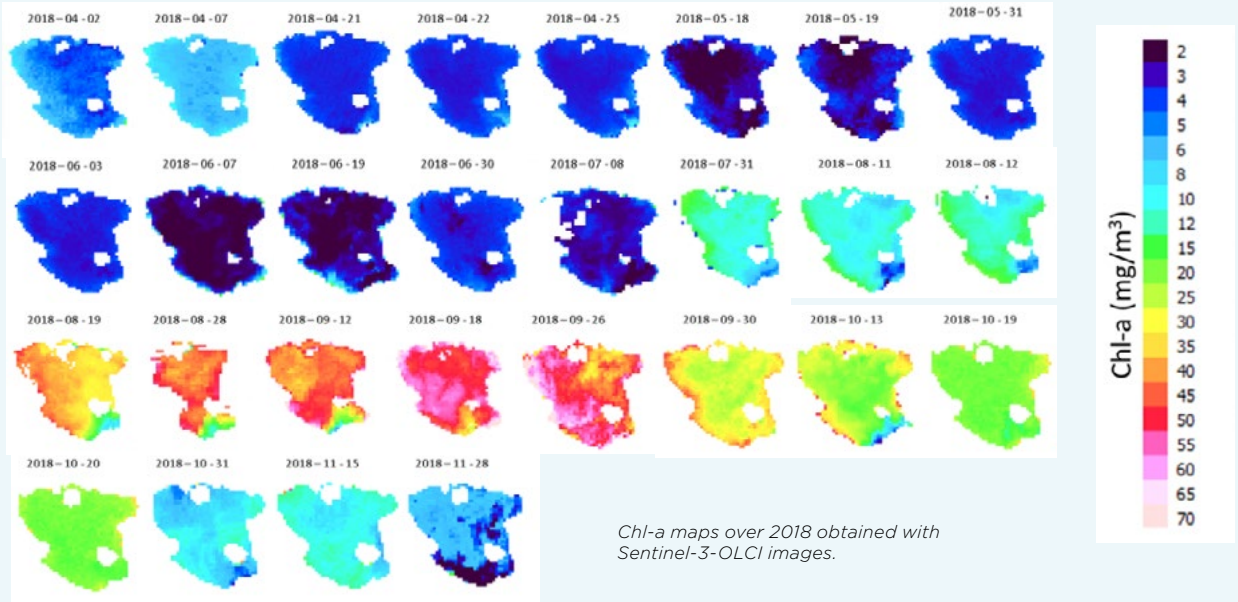
- Global lake water quality information
- Water quality time series
- Indicators supporting WFD and MSFD
- WFD assessment for coastal and lake water bodies
- Public EO-based information

Specifically, the EOMORES services address the following activities:

- Monitoring of algal blooms and their timings;
- Monitoring of the presence and extent of blue-green algae;
- Sediment plume identification or changes in suspended matter;
- Monitoring of land-derived inputs of dissolved organic matter in lakes.

EOMORES in action: Algal blooms in Lake Trasimeno

The products were provided to the regional water authority (ARPA Umbria), which supports the management of Lake Trasimeno and the associated WFD reporting. The aim was to improve the current monitoring of water quality, in terms of both spatial coverage and temporal frequency.



Chl-a maps over 2018 obtained with Sentinel-3-OLCI images.

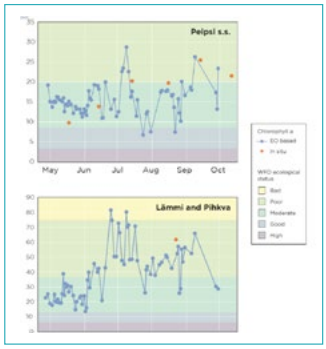
WATER QUALITY MAPS WITH WATER FRAMEWORK DIRECTIVE CLASSES

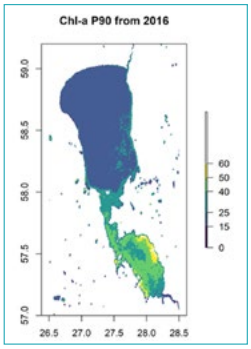
Target user
Water management authorities, tourism industry, aquaculture industry

Application
Monitoring water quality in large and cross-border water bodies

Demonstration area
Lake Peipsi, Estonia and Russia

Lake Peipsi is a shallow lake with a high spatial diversity, which makes it particularly suitable for monitoring using Earth Observation. The lake straddles the border between the EU and Russia and whilst the water quality must be reported in accordance with the Water Framework Directive, not all of the lake can be monitored in the same way. Satellite data easily enables an overview of the whole lake.





Applicable range
- Chl-a 5-150 mg m^{-3}
- TBM 0.1 – 50 g m^{-3}
- SD 0.2-15 m

Accuracy
- For chl-a and TBM, the accuracy increases with decreasing concentrations
- For SD RMSE 0.79m

Limitations
- Not available under cloud cover or during rain
- Uncertainties are higher along the coast
- Only surface measurements are available

Resolution(s)
- 10-20m (Sentinel-2)
- 30 m (Landsat 8)
- 300 m (Sentinel-3)

Maximum frequency
- Every ½-2 days (Sentinel-3)
- Every 3-5 days (Sentinel-2)

The above data sources are used in combination.

Delivery methods & service options
- Available via FTP or web viewer in all standard GIS file formats (e.g. GeoTiff, NetCDF)
- Automatic coupling to your in-house GIS or data system is possible

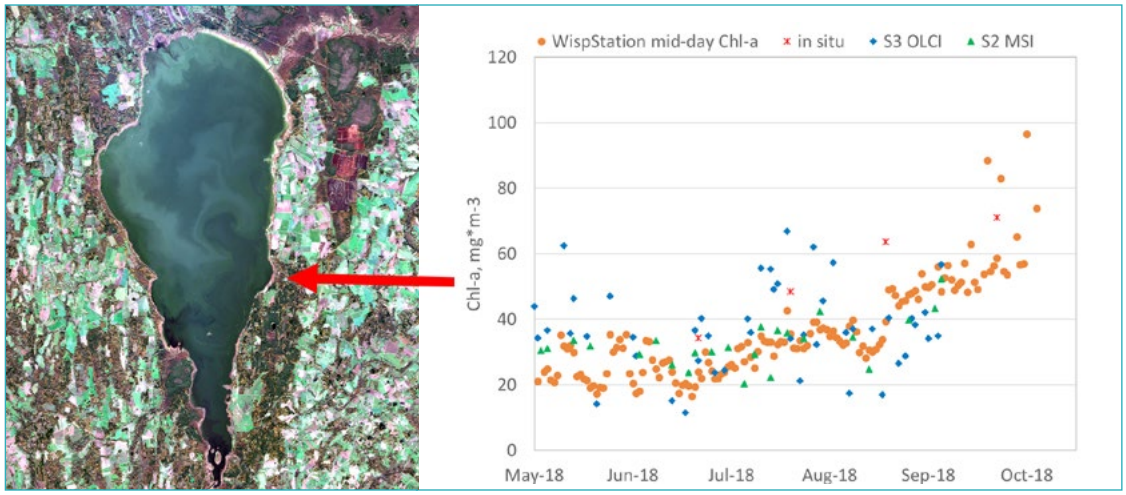
TIME SERIES OF EO-DERIVED WATER QUALITY PARAMETERS AND TRADITIONAL MONITORING

Target user
Water management authorities, tourism industry, aquaculture industry

Application
Automatic monitoring of algal blooms

Demonstration area
Lake Võrtsjärv, Estonia

The combination of satellite and in situ data enables the automatic monitoring of algal blooms with good temporal and spatial data coverage. As shown below, the time series of chlorophyll concentrations and Secchi depths derived from Earth Observation (Sentinel-2 MSI and Sentinel-3 OLCI) in Lake Võrtsjärv correspond well with the traditional in situ sample results and are integrated with the optical in situ data from the WISPstation.



Applicable range
- Chl-a 5-150 mg m^{-3}
- TBM 0.1 – 50 g m^{-3}
- SD 0.2-15 m

Accuracy
- For chl-a and TBM, the accuracy increases with decreasing concentrations
- For SD RMSE 0.79m

Limitations
- Not available under cloud cover or during rain
- Uncertainties are higher along the coast
- Only surface measurements are available

Resolution(s)
- 10-20m (Sentinel-2),
- ~ 300 m (Sentinel-3)
- Point measurement (WISPstation)

Maximum frequency
- Every ½-2 days (Sentinel-3)
- Every 3-5 days (Sentinel-2)
- Every 3 minutes (WISPstation)

The above data sources are used in combination.

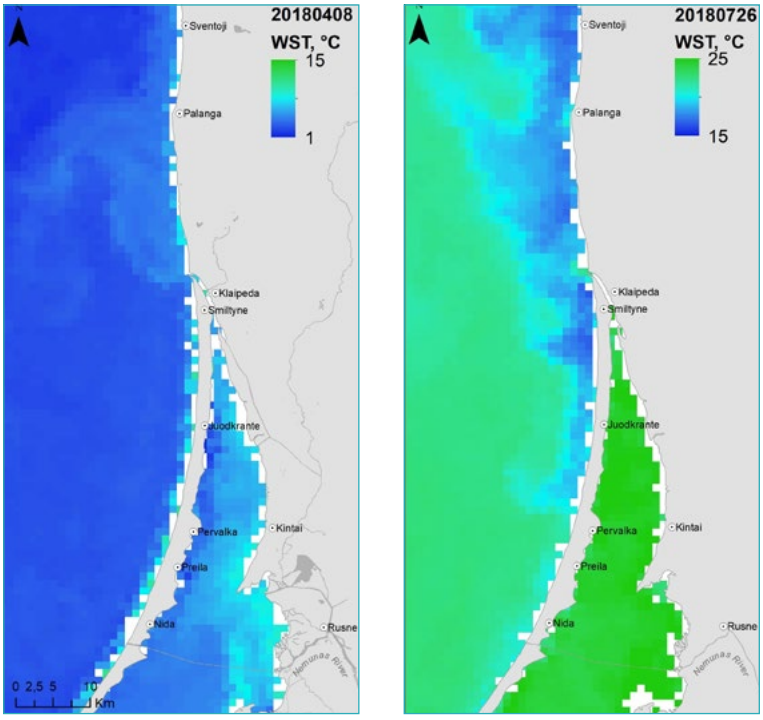
Delivery methods & service options
- Available via FTP or web viewer in all standard GIS file formats (e.g. GeoTiff, NetCDF)
- Automatic coupling to in-house GIS or data systems is possible

WATER SURFACE TEMPERATURE

Target user
Environmental protection agencies, local municipalities

Application
Water surface temperature mapping in coastal and transitional waters

Water Surface Temperature (WST) is permanently measured at monitoring stations and can be monitored by satellites such as MODIS Aqua/Terra and Sentinel-3. Sentinel-3's SLSTR1 instrument provides a spatial overview of WST variability in spring or summer. It also allows the monitoring of upwelling events in coastal areas, during which WST may drop by approximately 10 °C.



SE Baltic Sea temperature (08 April and 26 July 2018)

Demonstration area
Curonian Lagoon and Lithuanian coastal waters

Applicable range
- WST < 5 - >30 °C

Accuracy
- R^2 = 0.96, RMSD = 1.28

Limitations
- Not available in case of cloud cover
- Only surface measurements are available

Resolution(s)
- ~ 1 km (Sentinel-3 SLSTR)
- 100 m (Landsat temperature)
- 1 km (MODIS/Aqua, MODIS/Terra)

Maximum frequency
- Daily (WST)
- Every 16 days (Landsat 8)

The above data sources are used in combination.

Delivery methods & service options
- Available via FTP in GeoTiff format

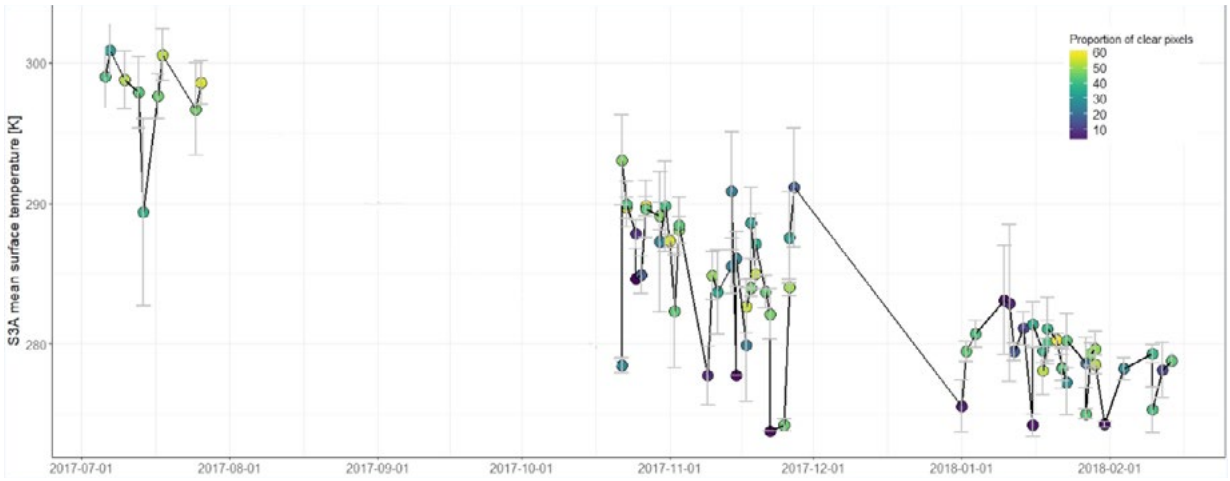
LAKE SURFACE WATER TEMPERATURE

Target user
Environmental protection agencies

Application
Monitoring Lake Surface Water Temperature (LSWT)

This product is comprised of a time trend analysis of surface temperature with average, standard deviation and percentage of pixel usable in the image with a quality control on usable pixels from standard products.

Demonstration area
Lake Iseo, Italy



Applicable range
- Kelvin degree 275-320

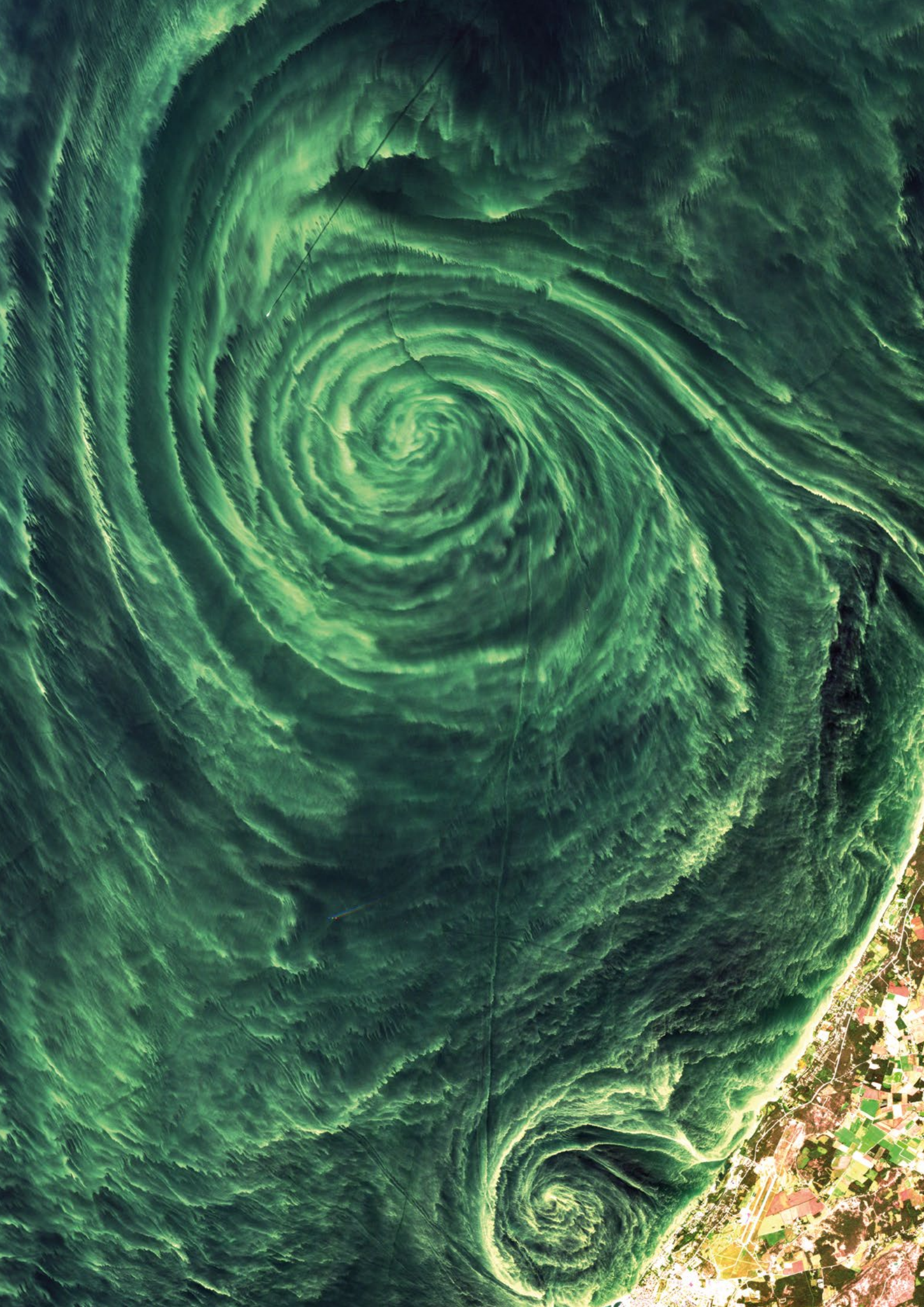
Accuracy
- rRMSE = 5%

Limitations
- Not available during cloud cover
- Not suitable for monitoring fine-scale phenomena

Resolution(s)
- 1 km (Sentinel-3/SLSTR)

Maximum frequency
- Every ½-2 days (Sentinel-3)

Delivery methods & service options
- Available via FTP or web viewer in csv format



POLICY & WATER RESOURCE MANAGEMENT

Policy-makers and water resource managers need periodic, if not constant, monitoring of water quality parameters. This need arises from the obligations pending on EU Member States to assess water quality and report on results periodically, as mandated by the Water Framework Directive. Thanks to the use of Earth Observation, the EOMORES services prove particularly suitable for monitoring changes that may occur in water quality, including the timing of algal blooms. The services can offer a more reliable and potentially cheaper data collection method.

What is the problem?

The Water Framework Directive prescribes routine monitoring of inland, transitional, coastal and groundwaters. At the same time, small scale or remote inland waters can often be difficult for experts to access, making it expensive and time-consuming to carry out in situ monitoring campaigns on a regular basis.

How does EOMORES address it?

The EOMORES services can potentially provide solutions for water resource management and policy through products such as high-resolution time series and maps based on Earth observation data. These products can fill the gaps generated by routine monitoring and provide detailed spatial insights, including on remote and otherwise inaccessible water bodies. Moreover, the EOMORES products capture season-driven changes in phytoplankton and harmful algae bloom timelines which might easily be missed with traditional monitoring techniques.

Showcased products:

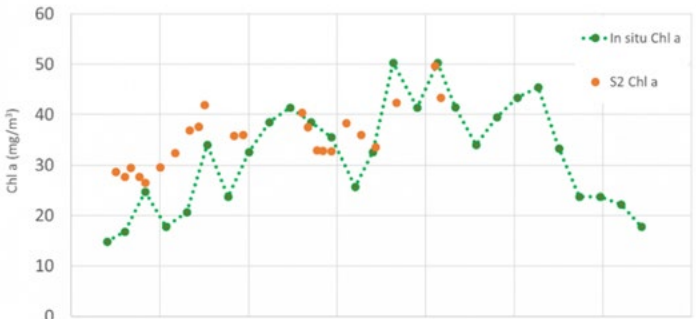
- Global lake water quality information
- Water quality time series
- Indicators supporting WFD and MSFD
- WFD assessment for coastal and lake water bodies
- Public EO-based information

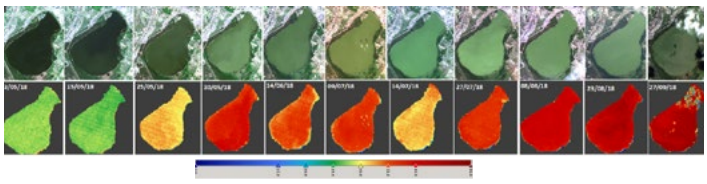
EOMORES services provide:

- Automated retrieval of e.g. WFD ecological status for phytoplankton biomass and transparency;
- EO historical and near-real time maps of water quality parameters (surface temperature, total suspended matter, chlorophyll a - proxy for phytoplankton biomass);
- Quantification of phytoplankton biomass;
- Identification of algal bloom presence and timeframes;
- Spatial data, also for remote and inaccessible water bodies;
- Near-real time water quality monitoring of drinking water reservoirs.

EOMORES in action: Monitoring phytoplankton in a drinking water reservoir (Lake Ülemiste, Estonia)

Lake Ülemiste is a natural shallow lake with spontaneously-occurring cyanobacterial blooms. A water treatment plant located on the lake's North-East coast provides for about 90% of the overall drinking water supply of the city of Tallinn.





The graph (above) shows chl-a values computed from Sentinel-2 MSI Level-1C data, alongside in situ measurements of chl-a in Lake Ülemiste. The Earth Observation data provided by Sentinel-2 for the monitoring of the lake's phytoplankton (below) adds complementary information regarding overall seasonal and spatial dynamics.

1. Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy

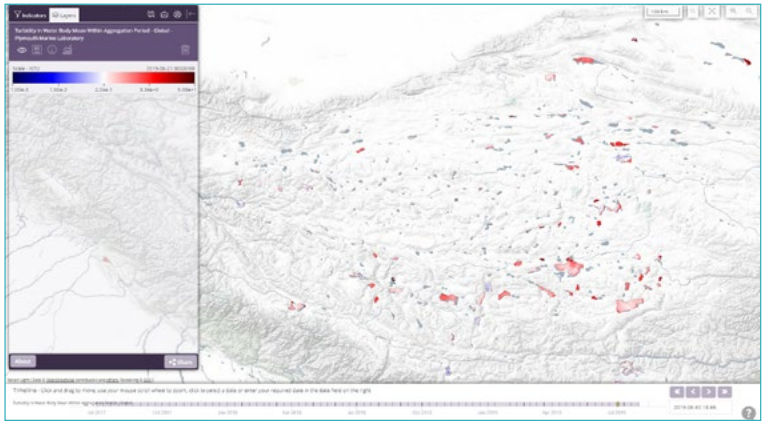
GLOBAL LAKE WATER QUALITY INFORMATION

Target user
Water management authorities, aquaculture industry

Application
Analysis of trends in water quality in global lakes

Demonstration area
Global lakes

Baselines and trends in water quality can be extracted from long time-series produced from suitable satellite sensors and a data processing chain which adapts to change (both seasonal and interannual) in the optical properties of each water body.



Turbidity shown for lakes on the Tibetan Plateau for the observation period 1-10 July 2019

Applicable range

- Chl-a 0-1000 mg m^{-3}
- Turbidity 0-50 NTU

Accuracy

- Per-pixel uncertainty estimates

The method provided dynamically selects and blends the results from the most applicable algorithms, depending on optical water type. Therefore, the application scope of the product is global.

Limitations

- Not available during cloud cover
- Observations are representative of the visible surface layer, assuming this is fully mixed
- The minimum lake area is 1km^2

Resolution(s)

- 30-100m (Sentinel-2)
- 300 m (Sentinel-3)
- Point measurement (WISPstation)

Maximum frequency

- Every ½-2 days (Sentinel-3)
- Every 3-5 days (Sentinel-2)

Time periods covered

2002-2012 and 2016-present

Delivery methods & service options

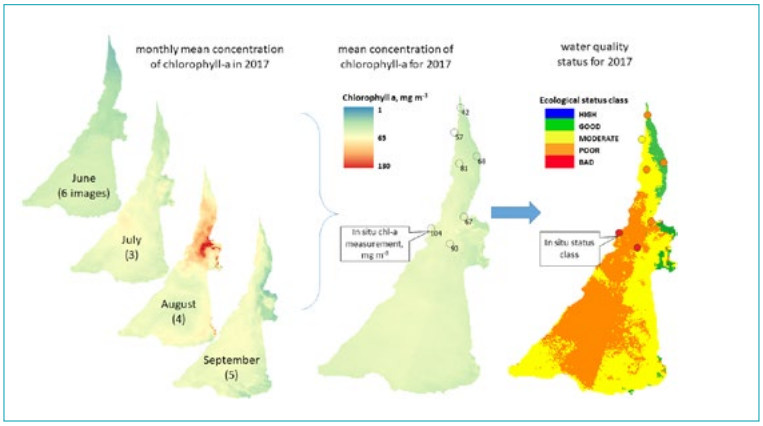
Available via FTP (netCDF) or web viewer

WATER QUALITY TIME SERIES

Target user
Environmental protection agencies

Application
Water quality monitoring, WFD reporting

During the summer months, the Curonian Lagoon is prone to algal blooms with high concentrations of cyanobacteria, which have the potential to produce toxins. Water quality parameters are permanently measured at monitoring stations. By combining measurements at monitoring stations with measurements from WISPstation, the monitoring of water quality parameters such as chlorophyll a, cyanobacteria and algal bloom is improved on a temporal basis. The central processing platform, WISPcloud, also performs automatic quality screening and stores the data safely.



Ecological status maps created by aggregating monthly mean chl-a concentration maps based on Sentinel-2 (10 m) and Sentinel-3 (300 m) images, alongside chl-a in situ monitoring results.

Demonstration area
Curonian Lagoon

Applicable range

- Chl-a <5-200 mg m^{-3}
- Classification according to WFD requirements

Accuracy

- For chl-a: R^2 = 0.86, MAE = 7.10, RMSE = 9.70, b = 8.73, a = 0.92
- Classification according to WFD requirements

Limitations

- Not available during cloud cover

Resolution(s)

- Point measurement (WISPstation)
- 10-20m (Sentinel-2)
- ~ 300 m (Sentinel-3)

Maximum frequency

- Circa 15 minutes (WISPstation)
- Every ½-2 days (Sentinel-3)
- Every 3-5 days (Sentinel-2)

The above data sources are used in combination.

Delivery methods & service options

- Available via FTP or web viewer in all standard GIS file formats (e.g. GeoTiff, NetCDF)
- API (application programming interface)

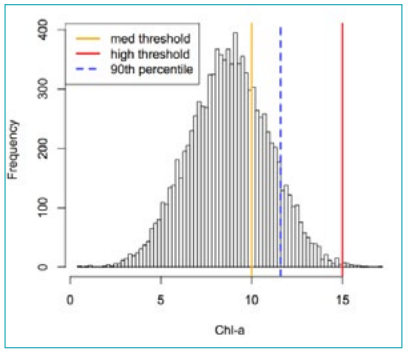
INDICATORS SUPPORTING WFD AND MSFD

Demonstration area
Coastal and inland waters of UK and Ireland

Target user
Environmental protection agencies

Application
Observations in support of the objectives of the Water Framework Directive (WFD) and Marine Strategy Framework Directive

Eutrophication monitoring based on the concentration of chlorophyll a is an important parameter in the Marine Strategy Framework Directive and Water Framework Directive. Especially because of the large spatial scale of coastal seas and the large number of smaller inland water bodies, Earth Observation is a valuable tool to increase the density of observations. Indicators of phytoplankton biomass (based on chlorophyll a, WFD indicator QE1-1) can be determined from satellite observations, and could offer a better cost-benefit ratio compared to the number of site visits otherwise required to observe episodic phytoplankton blooms. Similarly, transparency or turbidity can be determined even from high-spatial resolution sensors to fulfil the monitoring of WFD indicator QE3-1.



Per-pixel 90th percentile of chlorophyll a over defined timespan compared to thresholds, as an example for MSFD reporting support.

90th percentile map of coastal and inland water turbidity in 2019 for UK and Irish waters. The percentile map shows which areas are likely to exhibit a given turbidity level. The information is useful in establishing monitoring sites (dynamic versus stable) or e.g. aquaculture site selection.

Applicable range

- chl 0-1000 mg m^{-3}
- Turbidity 0-100 NTU

Resolution(s)

- 60-100m (Sentinel-2)
- 300 m (Sentinel-3)

Accuracy

Depending on the chosen product and in situ validation data available, per-pixel uncertainty estimates are provided.

Maximum frequency

Daily, weekly, monthly or other aggregation periods are possible. The examples shown are for annual aggregation providing 90th percentile products.

Limitations

- Not available during cloud cover
- No measurements are possible if the bottom of the water body is visible

Delivery methods & service options

Available via FTP, data service or web viewer in standard GIS file formats

WFD ASSESSMENT FOR COASTAL AND LAKE WATER BODIES

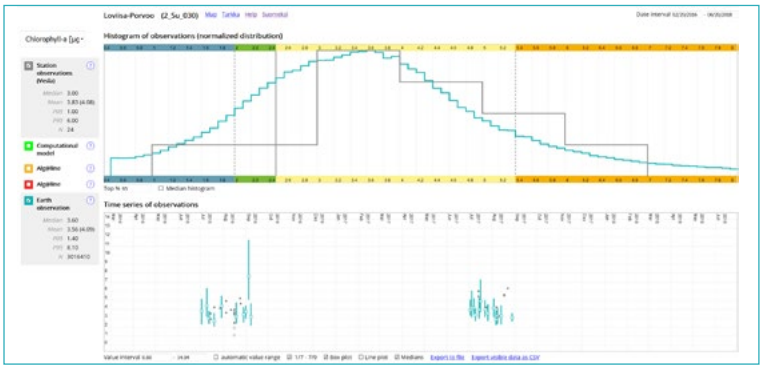
Target user
Environmental protection agencies

Application
Automatic support for ecological status assessment for the Water Framework Directive

Demonstration area
Coastal areas and lakes in Finland

For countries with numerous lakes, traditional water quality sampling for the Water Framework Directive is a laborious and costly operation. Earth Observation data, with its extensive spatial coverage and high frequency, increases the confidence of statistical information used in WFD assessments.

The STATUS service provides both periodically-aggregated statistics, time series and histograms of the distribution of Earth Observation and station sampling datasets over the water bodies. It currently covers information from over 2000 WFD water bodies in Finland (87% of the total area). STATUS is directly linked to the national water body information system used by the authorities for WFD status assessment.



A STATUS water body page, which shows statistics, distributions and time series of observations by all available data sources within the area (station sampling, EO and Alg@line Ferrybox observations). The colours above and below the histogram show the WFD class boundary limits.

The main interface of STATUS, in which users can select the area to examine.

Applicable range
- Product-dependent
- chl 0.5-140 µg l^{-1}
- Turbidity 0.5-150 FNU
- SD 0.5 - 10 m
- CDOM 0.5-35 m^{-1} (400 nm)

Resolution(s)
- 60 m (Sentinel-2)
- 60 m (Landsat 8)
- 300 m (Sentinel-3)

Accuracy
Product-dependent; described in the service

The accuracy is lake- and parameter specific, and is comparable to that of traditional water samples

- Chl-a : R = 0.7 (r2 = 0.49), RMSE = 5.4 µg l-1, MAE = 3.75 µg l-1, MAPE = 41.8%
- Turbidity: r2 = 0.78, RMSE = 2.6 FNU (93.8%), MAE = 1.05 FNU, MAPE = 37.95%
- SD: r2 = 0.65, RMSE = 1.09 m (51.27%), MAE = 0.82 m, MAPE = 38.81%

Maximum frequency
(at latitudes close to Finland)
- Every ½-1 days (Sentinel-3)
- Every 2-3 days (Sentinel-2)
- Every 8 days (Landsat 8)

The above data sources are used in combination.

Delivery methods & service options
STATUS is a web-based service that is currently accessible to environmental authorities in Finland. STATUS is used jointly with the web application TARKKA.

PUBLIC EO-BASED INFORMATION

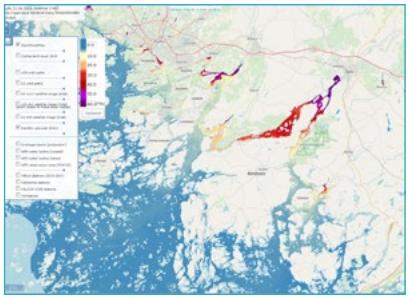
Target user
Environmental protection agencies, general public

Application
Public information on water quality and water temperature alongside satellite imagery

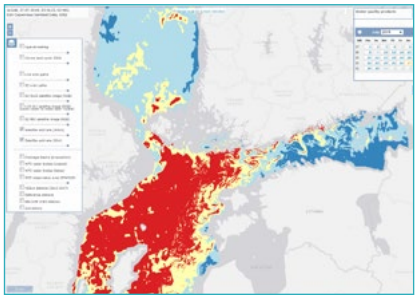
Demonstration area
Coastal areas and lakes in Finland

Earth Observation-based information is made available for national daily monitoring and reporting purposes as well as for the general public.

Maps and data services are accessible through: www.syke.fi/TARKKA/en. The information is updated daily and is utilised for several purposes, including environmental monitoring and public information.



Daily information on water turbidity based on Sentinel-2 and Landsat 8.



Daily cyanobacteria bloom observations from the Baltic Sea based on OLCI, Sentinel-2, Landsat 8 satellite data.

Applicable range

- Product-dependent;
- Chl-a 0.5-100 ug /l
- Turbidity 0.5-150 FNU
- SD 0.5 - 15 m
- CDOM 0-5 m^{-1}
- WST 0-30 C
- Surface accumulations of algae blooms (classified to bloom severity classes 1-4)

Accuracy

- Product-dependent; described on the service portal

Limitations

- Not available in case of cloud cover
- No measurements are possible in areas with bottom visibility
- Only surface measurements are available
- Minimum area: 60 m diameter

Resolution(s)

- 10-20m (RGB Sentinel-2)
- 30 m (RGB, Landsat 8)
- 60m algae bloom, turbidity, Secchi depth (Sentinel-2 & Landsat 8)
- ~ 300 m (Sentinel-3)
- 1 km (water surface temperature)

Maximum frequency (at latitudes close to Finland)

- Daily
- Every ½-1 days (Sentinel-3)
- Every 2-3 days (Sentinel-2)
- Every 8 days (Landsat 8)

The above data sources are used in combination.

EVENT MONITORING

A range of events can have an impact on water bodies and their environment, sometimes with negative consequences. Surface runoff can cause high turbidity in otherwise clear lakes with repercussions for flora and fauna; large harmful algae blooms can kill fish and aquatic birds and threaten recreational activities whilst oil spills are well-known for their impact on aquatic life. Each of these examples underlines the need to accurately monitor events and track their evolution.

What is the problem?

In the case of unexpected events, the task of understanding their cause or source can be rendered difficult or impossible due to a lack of early-stage in situ data. This may prevent experts from taking proper preparatory measures, or from taking measures to prevent similar events from happening in the future.

Showcased products:

- Water turbidity maps

How does EOMORES address it?

EOMORES makes two types of event monitoring options available:

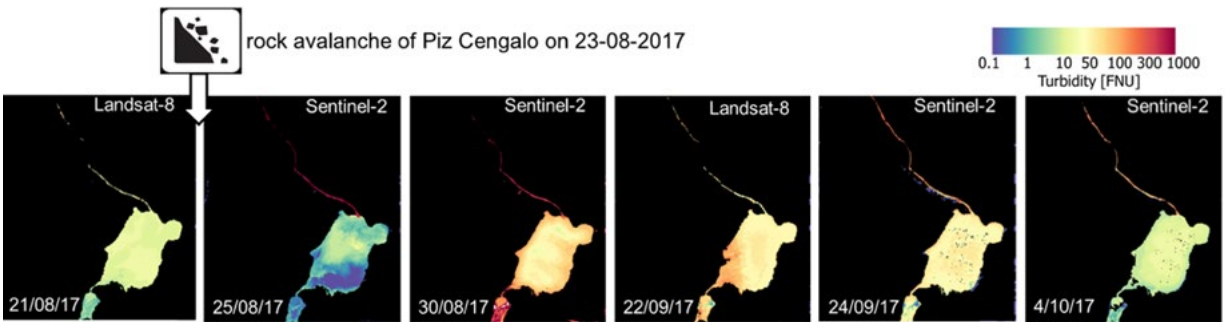
- Early warning services: certain high-impact events happen frequently, yet irregularly, and being able to prevent or limit potential damage from these types of events is highly beneficial. The EOMORES services combine satellite data, continuous in situ data and numerical modelling in order to provide compatible solutions in the form of early warning systems.
- Analysis in retrospect: suitable for situations in which no samples were collected during the occurrence of an event, or when the samples collected do not extend to the affected area. Satellite data is captured on a continuous basis, which means that data can be retrieved and processed retrospectively, allowing for an in-depth analysis of past events.

Mera River two months after the event. The turbidity is visible.

EOMORES in action: Rock avalanche in Piz Cengalo and consequent turbidity in Mera River and Lake Mezzola (Italy)

In August 2017, a few million square meters of rock collapsed and slid down Piz Cengalo in Switzerland. The debris flowed downstream into the Mera River and into a reservoir in Italy. To safeguard inhabitants from potential flooding in the event of new landslides, the reservoir was totally emptied, and all suspended sediments discharged into the Mera River. The sediment finally flowed into Lake Mezzola. This event has partially altered the lake's ecology and affected the aquatic vegetation of the following season (2018) in this Natura 2000 site.

Satellite data were used to support field investigations assessing the flow of suspended solids between August and November 2017. The sequence of satellite products clearly shows the spatial distribution of suspend solids transported from the Mera River into Lake Mezzola.



Sequence of satellite products showing the spatial distribution of suspended solids transported into Lake Mezzola from the Mera River following the rock avalanche on Piz Cengalo. The aquatic vegetation (in green) was visibly altered after the event of August 2017.

WATER TURBIDITY MAPS

Target user
Environmental protection agencies

Application
Monitoring during or after natural hazard events

This product serves to assess the impact of natural hazards such as avalanches on aquatic vegetation, or macrophytes.

An example product is presented under “EOMORES in action” on the previous page.

Demonstration area
Lake Mezzola, Italy

Applicable range
- Turbidity 0-1000 FNU

Accuracy
- rRMSE = 15%

Limitations
- Not available in case of cloud cover
- No measurements are possible in areas with bottom visibility
- Natural hazard monitoring might require increasing the revisit time (e.g. 1-2 days)

Resolution(s)
- 10-20m (Sentinel-2)
- 30 m (Landsat 8)

Maximum frequency
- Every 3-5 days (Sentinel-2)
- Every 16 days (Landsat 8)

The above data sources are used in combination.

Delivery methods & service options
- Available via FTP or web viewer in all standard GIS file formats (e.g. GeoTiff, NetCDF)

HEALTH IMPACTS

EOMORES provides timely and even early warning information about (potential) harmful algae blooms. Point-based in situ data is available in real time, and spatial data is usually delivered within the same day. Thanks to these early warnings, EOMORES services can make bathing waters a much safer place for the public.

What is the problem?

Within the current legal framework, the one parameter determining whether bathing water classifies as "excellent", "good" or "insufficient (poor)" is microbial pollution[1]. However, harmful algal blooms (HABs) and excessive algae growth can be a much greater concern in coastal areas and inland waters, as their presence can lead to the loss of prestige of recreational areas, as well as posing a threat to human health.

Showcased products:

- Chl-a concentration maps
- Bathing water quality maps
- Algal scum forecasts

How does EOMORES address it?

Based on forecasts of increasing cyanobacterial biomass, public authorities can take timely measures to reduce risks to human health.

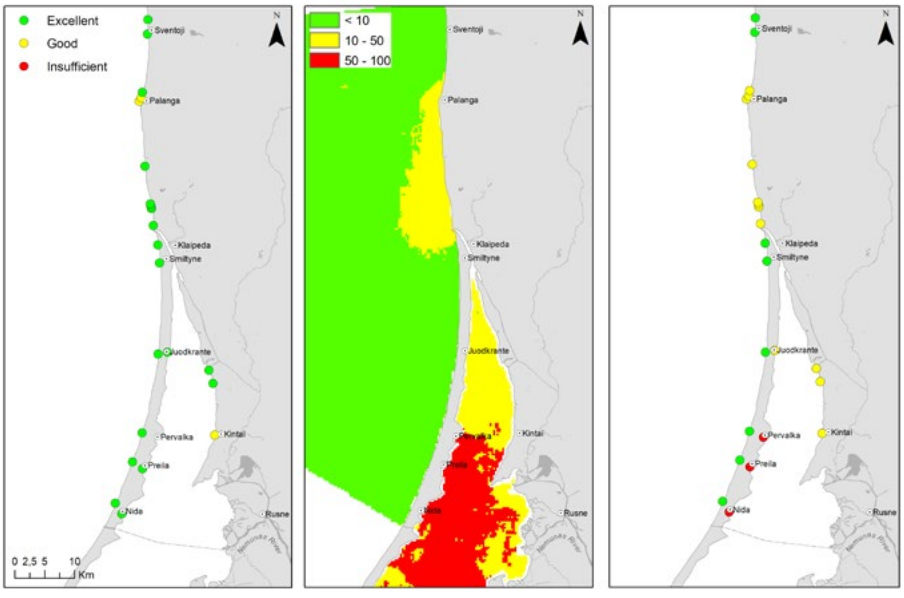
1) Satellite data provides spatial insight into the status of water bodies.

2) Algal forecasting models (i.e. the "AlgaeRadar") predict increases in cyanobacterial biomass and the location and predicted timing of scum appearance (via the 3D modelling of EWACS).

3) Automated in situ spectrometers (i.e. the WISPstation – see pages 8 and 11) act as a health warning tool by detecting an increase in cyanobacterial biomass.

EOMORES in action: Tracing harmful algal blooms (HABs) in the Curonian Lagoon

Frequent, harmful algae blooms occur in the south-eastern coast of the Baltic Sea. The coast is connected to the Curonian Lagoon via the narrow Klaipeda Strait, which provides the only connection to the Baltic Sea. Polluted freshwater from the Curonian Lagoon often flows out through the Klaipeda Strait into the coastal region, dramatically affecting the water quality there. The Curonian Lagoon is known for cyanobacteria hyperblooms during summer, which carry a high risk of potential toxicity.



Bathing water classification of Lithuanian beaches in 2017, based on (a) based on public monitoring data (E. coli and intestinal enterococci, Kataržytė et al., 2018); (b) satellite remote sensing-based chl-a concentration (classification as per WHO, 2003) and (c) based on both microbial parameter and chl-a concentration.

1. Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC

BATHING WATER QUALITY MAPS

Target user
Environmental protection agencies, water managers, tourism industry, aquaculture industry

Application
Mapping of cyanobacterial potential harmful bloom in terms of chl-a concentration, which impact on tourism, fish health and ecosystem functioning

Demonstration area
Curonian Lagoon and Lithuanian coastal waters

Cyanobacteria blooms, which can produce toxins, are increasing in magnitude and frequency. This has a large influence on e.g. recreation and human health. The World Health organization (WHO, 2003) provides the threshold values of chl-a for the indication of low risk, moderate risk, and high risk to human health.

The mapping of bathing water quality and cyanobacteria surface accumulations can be performed using optical satellite imagery and, if available, in combination with in situ microbiological pollution data.
An example product is presented under “EOMORES in action” on p 35.

Applicable range
- Chl-a from 5 to more than 100 mg m^{-3}
- Presence of surface accumulations

Accuracy
- For chl-a: R^2 = 0.86, MAE = 7.10, RMSE = 9.70, b = 8.73, a = 0.92
- Classification according to WHO (2003) requirements
- Presence/absence

Limitations
- Not available using optical data in case of cloud cover
- Only surface measurements are available
- The information about cyanobacteria surface accumulations provided as qualitative (presence/absence) maps

Resolution(s)
- 10-20m (Sentinel-2)
- 30 m (Landsat 8)
- ~ 300 m (Sentinel-3, MERIS/Envisat)
- ~ 2 m (VHR)
- ~ 0.5 m (other VHR)
- Point measurement (WISPstation)

Maximum frequency
- Every 15 minutes (WISPstation)
- Every ½-2 days (Sentinel-3)
- Every 3-5 days (Sentinel-2)
- Every 16 days (Landsat 8)

The above data sources are used in combination.

Delivery methods & service options
- Available via FTP or web viewer in all standard GIS file formats (e.g. GeoTiff, NetCDF)

ALGAL SCUM FORECASTS

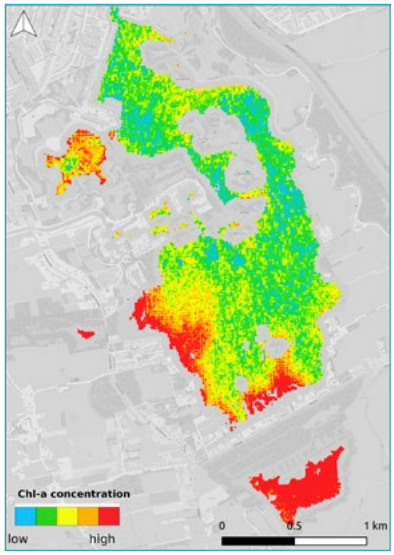
Target user

Water management authorities, tourism industry, aquaculture industry, drinking water companies

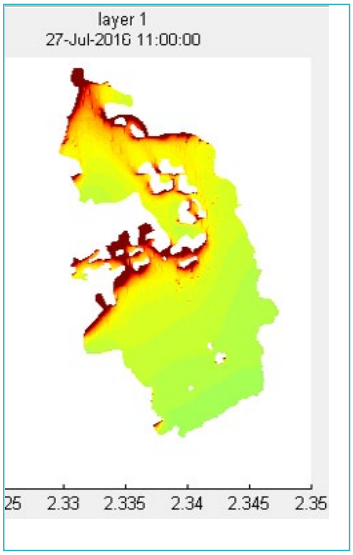
Application

Modelling and forecasting of cyanobacteria (scums) at bathing water locations

Forecasts of floating cyanobacterial scums allow preventive measures (such as flushing and/or aeration) to be implemented more efficiently. Models can also be used to run numerous scenarios, enabling a better understanding of the ecosystem and greater effectiveness of potential interventions.



Chlorophyll a distribution over lake Paterswoldsemeer, for one day in June 2016. One of the two in situ monitoring locations, as well as the bathing water, are located on the south-eastern shore.



Prediction of algal scums by the Delft3D-based model EWACS for a certain day and time in Lake Paterswoldsemeer.

Demonstration area

Lake Paterswoldsemeer, the Netherlands

Applicable range

- Chl-a 5-2000 mg m^{-3}

Accuracy

Dependent on weather forecasts and on frequency and spatial distribution of in situ chl-a measurements

Limitations

- The product is dependent on the accuracy of weather forecasts
- The product is dependent on the frequency of data input and the number of measured locations
- The product does not contain an algae growth model

Resolution(s)

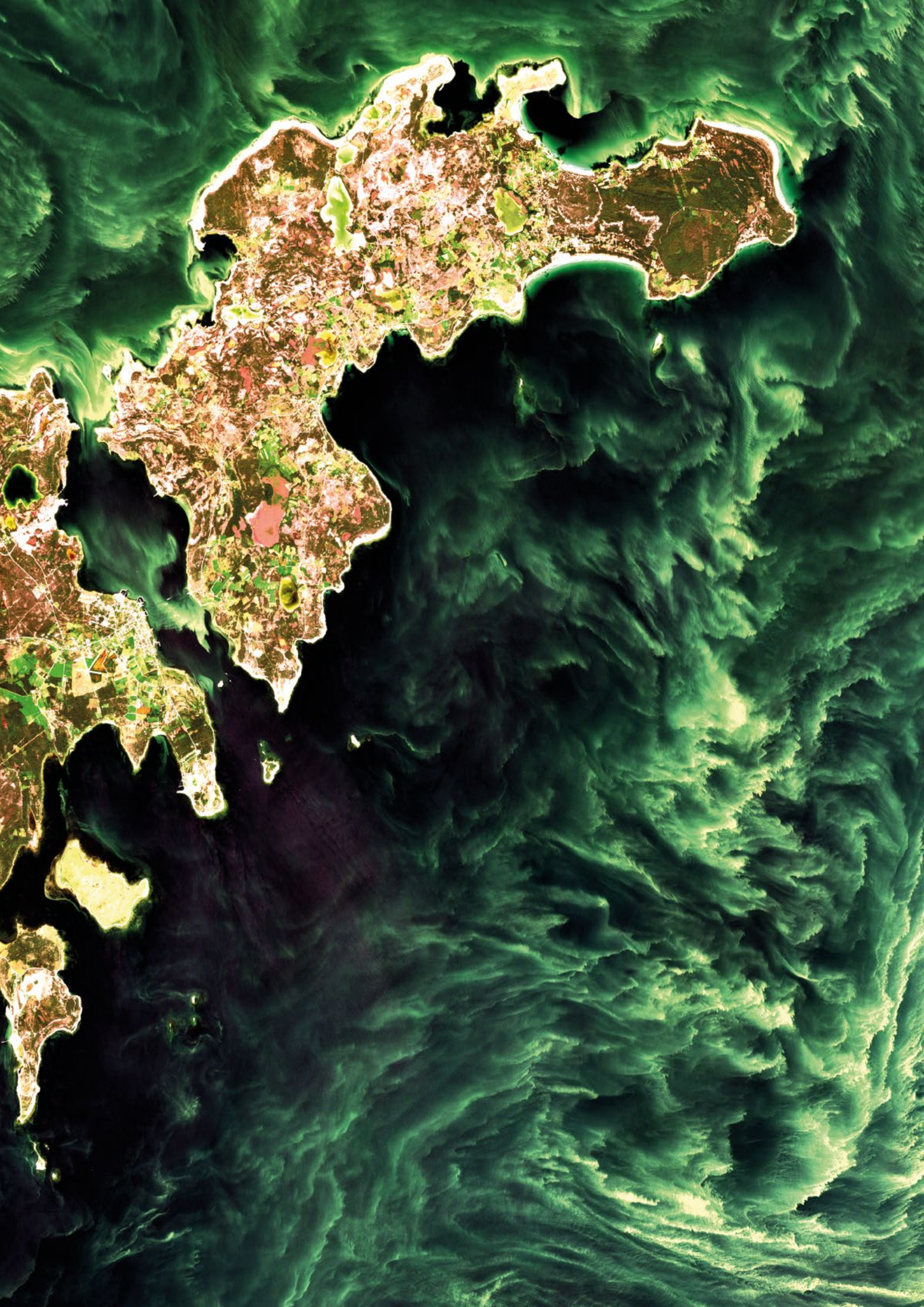
- Model resolutions depend on size of lake but can go as low as 10x10 m

Maximum frequency

each hour

Delivery methods & service options

- Bulletin
- Visualisation and analyses possible through the Delft-FEWS platform



PLANTS

The shallow coastal areas of lakes are often inhabited by a variety of aquatic plants, known as "macrophytes". The rooted macrophytes comprise many different species and constitute an extremely valuable component of the aquatic ecosystem being an important long-term indicator of water and sediment quality. This is why their monitoring is often prescribed by law (e.g. for EU Member States by the Water Framework Directive and by Natura 2000[1]). When compared to in situ measurements, products based on Earth Observation are better suited to tackle such needs, as they can cover large and remote areas with remarkable frequency.

What is the problem?

- Ecological researchers often need to carry out environmental assessments at temporal and spatial scales which can be difficult to achieve using in situ-only sampling methods.
- Monitoring and reporting on the status of aquatic vegetation is an obligation of each EU Member State. Field sampling, however, may be time-consuming and costly when it comes to assessing large or remote areas.

Showcased products:

- Aquatic vegetation maps

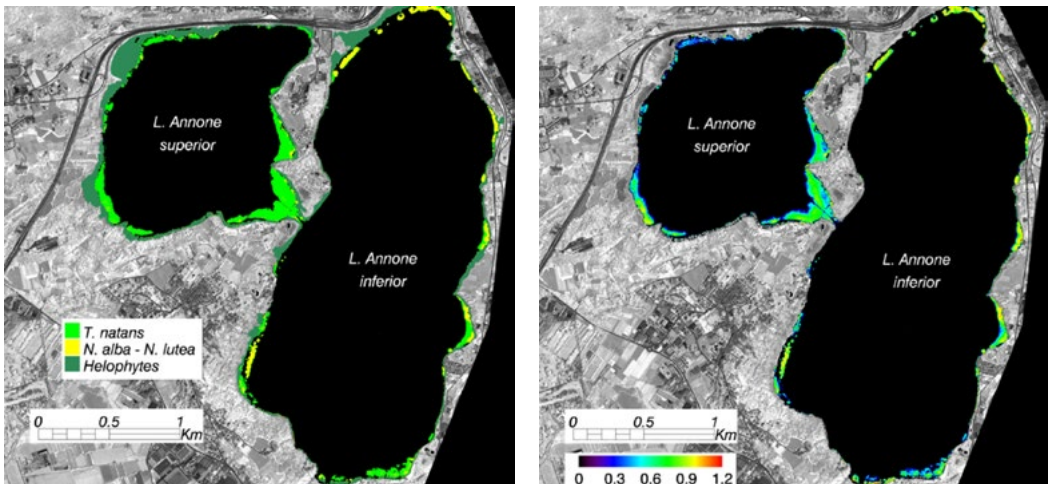
How does EOMORES address it?

There are several options available for aquatic vegetation monitoring:

- **Mapping the presence of macrophytes,** both historically and in near-real-time: the synoptic assessment of submerged and emerged communities of aquatic plants, and their variations, as provided by EOMORES, can be used both for Water Framework Directive reporting and for performing ecological studies.
- **Assessing plant health:** analysing the way in which sunlight interacts with plants in different portions of the electromagnetic spectrum, EOMORES can provide information on biochemical and structural water quality parameters.
- Satellite data, acquired in multi-spectral bands, can be used to **observe any variations of the leaf area index (LAI),** a proxy of plant health (the higher the better) over time and space.

EOMORES in action: Mapping macrophytes in perialpine lakes

The perialpine lakes in Northern Italy are characterised by the presence of large quantities of aquatic vegetation. Both helophytes (mainly Phragmites australis) and floating hydrophytes are present. These local species are an important element of the freshwater ecosystem, fulfilling multiple functions, such as carbon sequestration, habitat provision and nutrient uptake.



High-resolution spatial imagery from WorldView-2 acquired on 17 June 2018 was used to map macrophyte types (on the left) and Leaf Area Index (on the right) in Lake Annone, a peri-alpine lake in the Italian region of Lombardia.

1. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora

AQUATIC VEGETATION MAPS

Target user
Environmental protection agencies

Application
Monitoring of fragile ecosystems

Mapping the extent and type of aquatic vegetation is important to users because of the role macrophytes play in ecosystem functioning. EOMORES products can, for instance, be used to assess if and where management action is necessary to contain the excessive growth of certain species. An example product is presented under “EOMORES in action” on the previous page.

Demonstration area
Lake Annone, Italy

Applicable range
- Emergent macrophytes

Accuracy
- rRMSE = 10%

Limitations
- Not available in case of cloud cover
- The possibilities to map submerged vegetation depend on the water depth and transparency

Resolution(s)
- 10-20m (Sentinel-2)
- 5 m (VHR)

Maximum frequency
- Every season

Delivery methods & service options
- Available via FTP or web viewer in all standard GIS file formats (e.g. GeoTiff, NetCDF)

SITE CHARACTERISATION

EOMORES analyses historical and current data to assess the characteristics of water bodies, such as susceptibility to algal blooms and river discharge. The aim of the service is to enhance monitoring practices through, for example, better knowledge of meteorological conditions (e.g. typical cloud cover) and episodic water quality events.

What is the problem?

Long-term monitoring of ecosystem health indicators is non-existent for the vast majority of the world's more than 100 million water bodies. Even when regular sampling is carried out, the daily and seasonal variation is not always taken into consideration. Conclusions are often drawn based on an insufficient number of samples.

Remote sensing via satellite represents an opportunity to integrate a limited set of ecosystem health indicators into long-term observation records. A thorough characterisation of individual water bodies and coastal regions would lay the basis for developing more effective and standardised monitoring practices. Episodic events, easy to be missed out by traditional sampling, could thereby be anticipated and monitored.

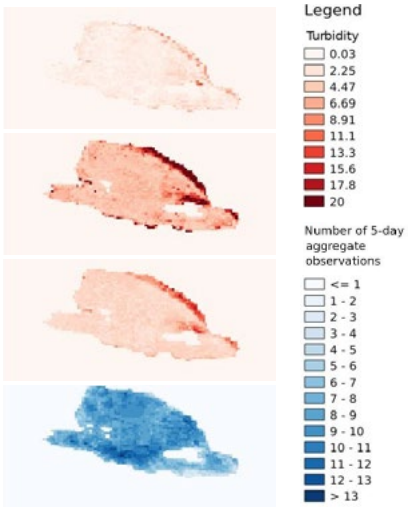
Showcased products:

- Suspended Particulate Matter maps
- Phytoplankton biomass (chl-a), Turbidity

How does EOMORES address it?

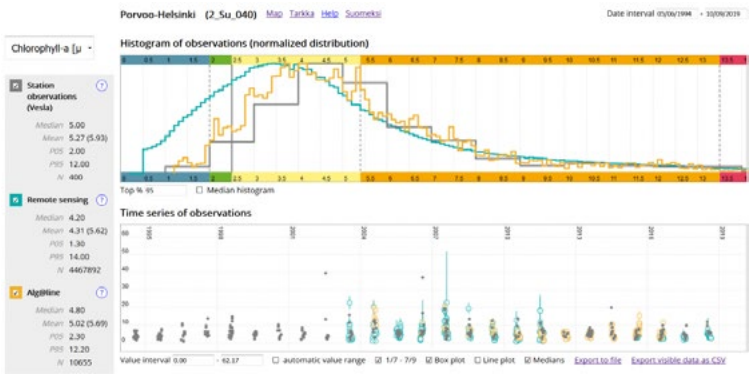
- EOMORES can provide analysis of archived and current Earth observation data to provide water quality products and statistics aggregated by year, season or by day. These data can be used to inform conventional monitoring practises (e.g. the selection of sampling sites) and reduce uncertainties in water quality estimates arising from sparse sampling strategies.
- EOMORES provides regional or water-body specific charts and maps tailored to the user's needs, illustrating the effects of episodic events on water quality.
- EOMORES also offers a service for collection of in situ measurements. These are essential for satellite data validation and product calibration, in order to ensure continuous observations under cloud cover (in accessible regions).

EOMORES in action: characterisation of turbidity (Loch Leven, UK, 2018)



The images from top to bottom show 10%, 50% and 90% of turbidity, respectively. The lowermost image shows the number of 5-day aggregated observations.

EOMORES in action: Aggregated data for reporting as per the Water Framework Directive (near Porvoo, Finland, 2018)



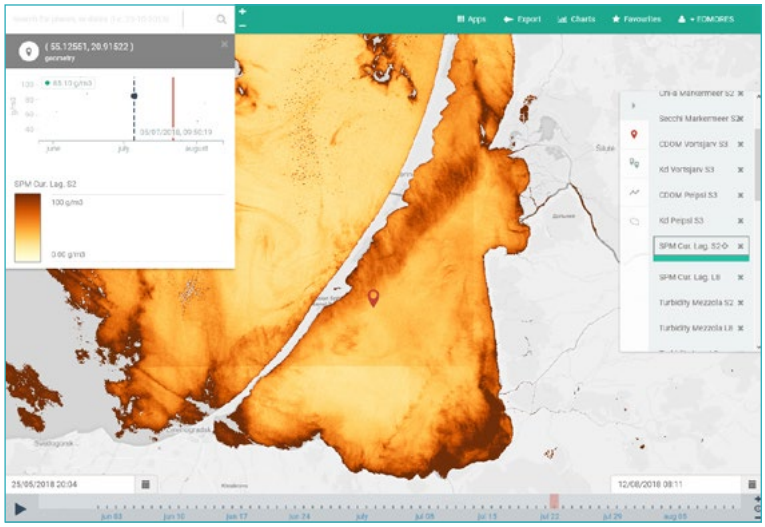
The image shows aggregated water quality information for WFD reporting. The graph includes water samples from stationary in situ instruments (grey), remote sensing data (cyan) and FerryBox measurements (orange). (Ferryboxes are instrument packages carried on "ships of opportunity", which collect data automatically as water flows through them during the ship's voyage). The histogram of the observations (top) refers to the entire time period defined in the time series diagram (bottom). Summary statistics for each dataset are shown in the tables on the left.

SUSPENDED PARTICULATE MATTER MAPS

Target user
Environmental protection agencies, local municipalities

Application
Water quality assessment

Suspended Particulate Matter (SPM) is one of the parameters included in national monitoring programs as an indicator of industrial (e.g. dredging of harbours and dumping) and natural (e.g. riverine loads, resuspension) pressure on water quality. Satellite imagery helps authorities understand and track the spatial variability of SPM, assess natural and anthropogenic pressure and investigate changes in water quality.



Time series of SPM in the Curonian Lagoon maps derived from Sentinel-2 data, presented in a user-friendly portal

Demonstration area
Curonian Lagoon

Applicable range

- SPM 0-100 g m^{-3}

Accuracy

- R^2 = 0.73, b = 5.02, a = 0.80

Limitations

- Not available in case of cloud cover
- Only upper mixed layer measurements are available

Resolution(s)

- 10-20m (Sentinel-2)
- 30 m (Landsat 8)
- 300 m (Sentinel-3)
- Point measurement (WISPstation)

Maximum frequency

- Every 15 minutes (WISPstation, harbour)
- Every 3-5 days (Sentinel-2)
- Every 16 days (Landsat 8)

The above data sources are used in combination.

Delivery methods & service options

- Available via FTP or web viewer in all standard GIS file formats (e.g. GeoTiff, NetCDF)

PHYTOPLANKTON BIOMASS (CHL-A), TURBIDITY

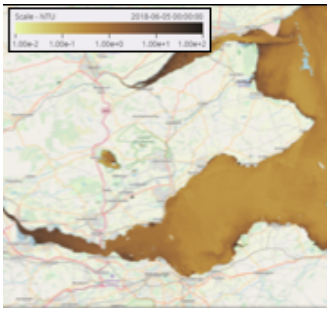
Target user
Water management authorities, aquaculture industry, tourism industry

Application
Analysis of water quality, particularly in under-sampled water bodies

Demonstration area
Coastal and inland waters of UK and Ireland

For large and remote areas, Earth Observation can provide water quality data with a much higher frequency than traditional sampling, followed by laboratory analysis. Novel satellite sensors also allow observation at higher resolutions than existing ocean-colour sensors.

Chlorophyll a (Sentinel-3)



Turbidity (Sentinel-2)

Applicable range
- Chl-a 0-1000 mg m^{-3}
- Turbidity 0 -1000 NTU
- SPM 0-1000 g m^{-3}

Accuracy
- Under investigation, using observations from the LIMNADES database
- Accuracy generally improves with increasing turbidity

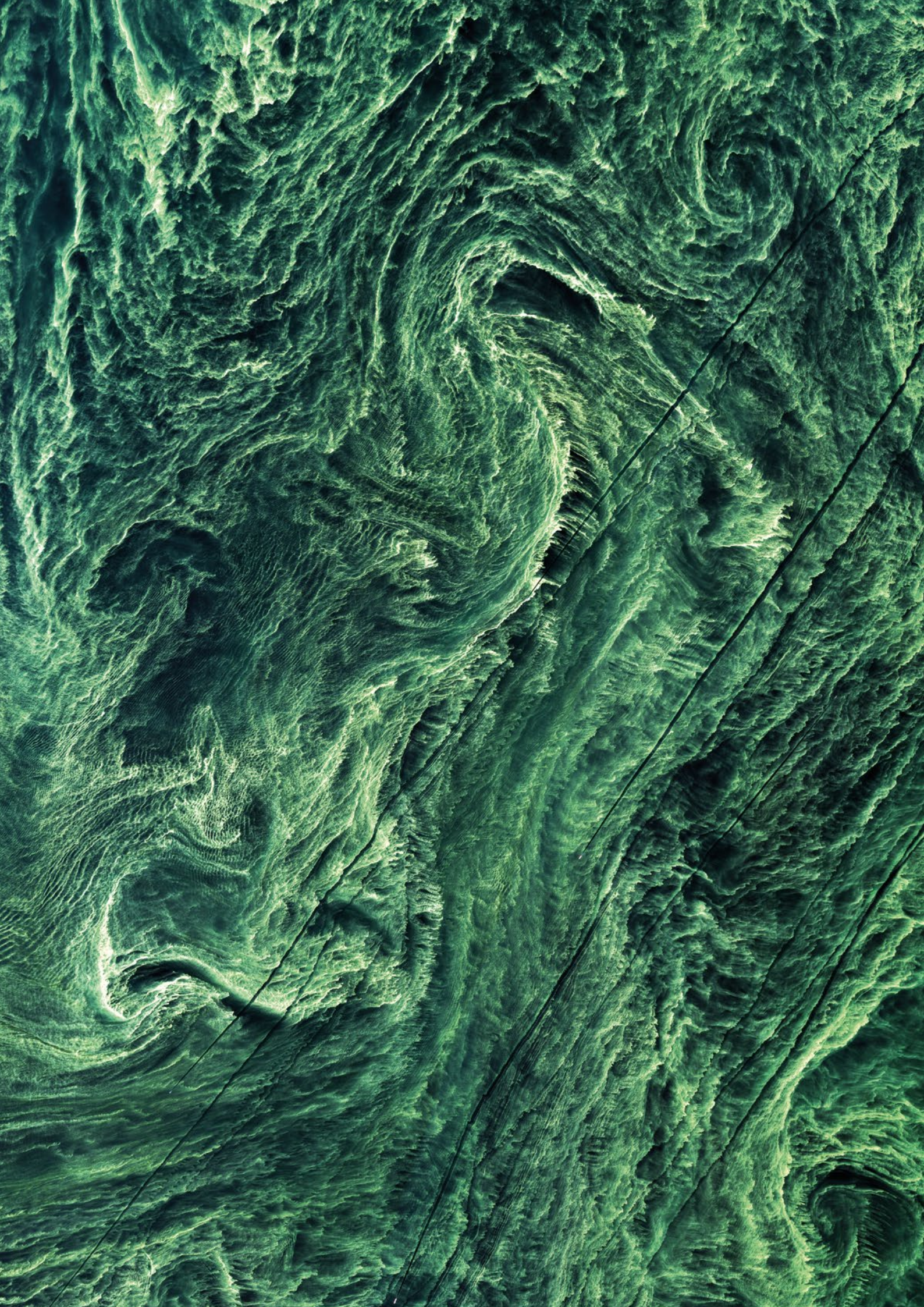
The method provided dynamically selects and blends the results generated by the most applicable algorithms for the specific optical water type. Therefore, the application scope of the product is global.

Limitations
- Not available in case of cloud cover or during rain
- No measurements possible in areas with bottom visibility
- Observations are representative of the visible surface layer, assuming this is fully mixed
- Minimum area: 100-500 m diameter

Resolution(s)
- 30-100m (Sentinel-2, Landsat 8)
- 300 m (Sentinel-3)
- Point measurement (WISPstation)

Maximum frequency
- Every 15 minutes (WISPstation)
- Every ½-2 days (Sentinel-3)
- Every 3-5 days (Sentinel-2)

Delivery methods & service options
- Available via an online portal



SPATIAL PLANNING

The EOMORES services provide insight on water quality for a number of spatial planning purposes. Two relevant cases are considered below:

1) determining the most representative locations for in situ sampling in order to identify the most suitable spots for bathing;
2) monitoring dredging events and properly assessing their consequences.

Showcased products:

- Monitoring the effects of construction work

MONITORING BATHING WATER LOCATIONS

What is the problem?

The spatial distribution of algae and cyanobacteria blooms can vary significantly. However, standard in situ samples are generally taken either in the middle of the lake or next to platforms or jetties although that such locations may not be as representative of the entire water body. Bathing locations tend to be situated on shores with sandy beaches or close to cities or access roads, often facing south for maximum sun exposure. From a public health perspective, however, bathing locations should not be situated in areas where cyanobacterial scums occur frequently, since such scums may contain high concentrations of toxins.

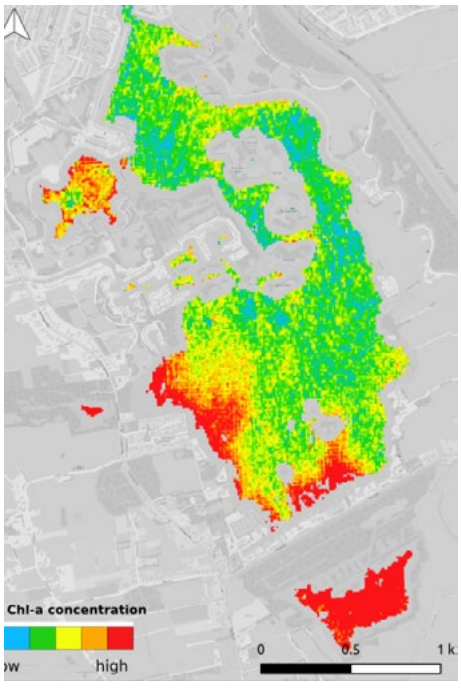
How does EOMORES address it?

Satellite-based maps, incorporating long time series of data (multi-annual), indicate the average spatial distribution of parameters such as chlorophyll and cyanobacterial pigment over specific areas. Patterns of distribution are determined through combined hydrodynamic-water quality models.

Such long-term spatial information can be used to determine which locations are the most representative of the water body as a whole in order to optimise in situ sampling and identify the safest zones for potential bathing areas.

EOMORES in action: Monitoring Chlorophyll a distribution over Lake Paterswoldsemeer (the Netherlands)

Chlorophyll a distribution over Lake Paterswoldsemeer, on a day in June 2016. One of the two in situ monitoring locations, as well as the bathing area, are located along the south-eastern shore.



DREDGING

What is the problem?

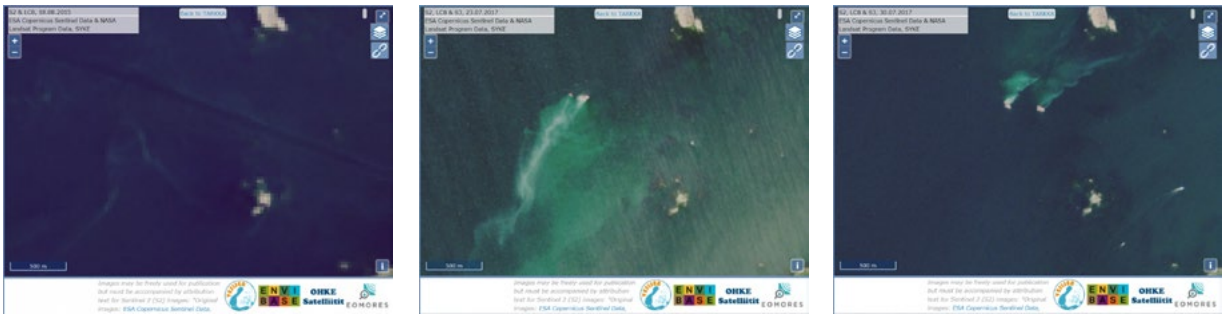
Dredging impacts the environment by increasing water turbidity in two ways: as a direct result of excavating material from lakes and from the seabed, and transporting it to the surface for storage; or as an effect of material overflow during transportation. The released sediments, spread out by currents, increase water turbidity over large areas. Depending on the sediment quality, dredging events can have various negative effects on the environment: from affecting light penetration and nutrient conditions in the aquatic ecosystem, to releasing harmful substances present on the water floor.

How does EOMORES address it?

Increased turbidity caused by dredging is often visible in optical satellite images. This allows the monitoring of the exact direction and length of the plume. EOMORES provides overview maps of water turbidity from before and after the dredging, which are based on satellite images and high-frequency in situ monitoring.

EOMORES forecasting models can estimate the evolution of plumes resulting from dredging activities, taking into account the specificities of the analysed water system. This information can be useful in anticipating where and when the most critical impacts from dredging on the environment are to be expected, and are hence relevant for environmental assessments or for planning in situ sampling following dredging events.

Example of the thematic service (provide visuals and/or testimonial quotes)



A dredging event identified by SYKE's Tarkka service (which is powered by EOMORES). Increased water turbidity caused by dredging in the Finnish coastal area, near the city of Rauma, is clearly visible in Sentinel-2 images. Before the dredging (left), the waters appear darker on the satellite images. The event clearly affects the water turbidity, as demonstrated by the change in colour. The sediments dislodged in the process are spread by the water currents, first to the south-west (middle) and a few days later, to the North-East (right).

MONITORING THE EFFECTS OF CONSTRUCTION WORK

Target user
Engineering companies, dredging companies, regulatory agencies

Application
Monitoring the effect of construction work (dredging, building) on water quality parameters and on surface water temperature

Demonstration area
Lakes Ijsselmeer and Markermeer, the Netherlands

An artificial island and swamp area are being built in Lake Markermeer (Markerwadden) with the aim of dampening waves, improving the underwater light field, and, ultimately, improving the ecological status of the lake. Satellite data can be used to monitor the effects of dredging and construction work, particularly as concerns the associated increase in suspended materials and their distribution over time. EO data proves equally efficient in monitoring the effects of construction works with regard to turbidity and phytoplankton blooms.

SPM (left) and Secchi disk depth (right) at the MarkerWadden islands in the EOMORES portal. Middle: MarkerWadden islands in a true colour images (Sentinel-2).

Applicable range
- Chl-a 0-100 mg m^{-3}
- SPM 0-100 g m^{-3}
- SD 0.1-20 m
- SST: all possible SSTs of water

Accuracy
- For the EO water quality data, MAE ~20
- Accuracy is lake- and parameter-specific

Limitations
- Not available during cloud cover
- No measurements are possible in areas with bottom visibility
- Only surface measurements are available
- Maximum turbidity: SD = 0.5 m

Resolution(s)
- 10-20m (Sentinel-2)
- 300 m (Sentinel-3)

Maximum frequency
- Every ½-2 days (Sentinel-3)
- Every 3-5 days (Sentinel-2)

A combination of the above can be used, leading to a frequency that is the sum of these.

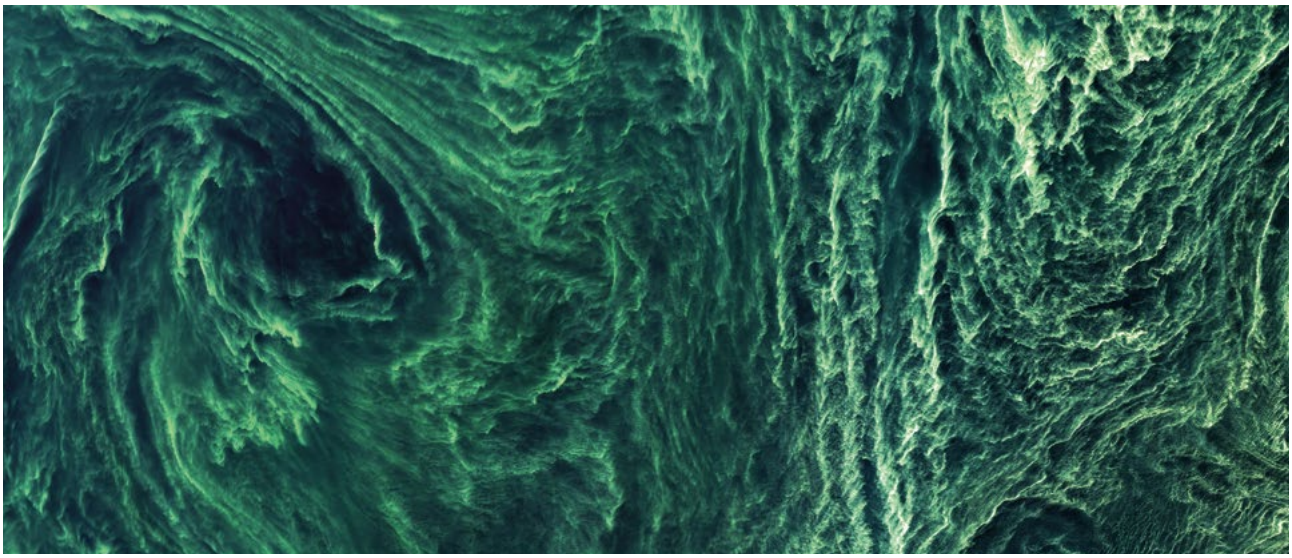
Delivery methods & service options
- Available via FTP or web viewer in all standard GIS file formats (e.g. GeoTiff, NetCDF)
- Automatic coupling to in-house GIS or data systems is possible

HOW DO WE MONITOR WATER QUALITY

We work closely with each interested user in order to assess their specific needs and address them comprehensively. What this means is that each customer is offered the appropriate combination of Earth Observation data, in situ and modelling products and services, designed to be most suitable for their specific region, requirements and use case.

The table below compares satellite and in situ monitoring, modelling and traditional manual sampling.

	 MONITORING WATER QUALITY VIA SATELLITE	 HIGH-FREQUENCY MONITORING WITH OPTICAL INSTRUMENTS	 MODELLING, FORECASTS, WARNINGS AND ALERTS	 MANUAL IN SITU WATER QUALITY SAMPLING
COVERAGE Scope of observation capability	 Resolution up to 0.5 m *(for plans)* or 10 m *(for the standard products)*	 Point measurement	 3D model	 Point measurement
FREQUENCY How often data is collected	 1-5 days	 15 minutes	 3-5 days in the future	 Months
DELIVERY Time before data is available	 Less than 24 h	 Near-real-time	 Up to 24 h	 Weeks



EARTH OBSERVATION

Earth Observation (EO) refers to the gathering of information about planet Earth's physical, chemical and biological systems by using remote sensing technologies, particularly satellites. Earth Observation is used to monitor and assess the status of, and changes in, the natural and the built environment.

Earth Observation technologies used for monitoring land and the open ocean have gradually matured in recent decades, and can be used to obtain information about water quality of more complex subjects, including coastal zones and inland waters.

Advancements in satellite instruments and their accuracy are particularly noteworthy. The ability of modern satellite instruments to capture information from a larger number of spectral bands allows a wider variety of substances to be distinguished, including chlorophyll a, suspended matter, dissolved organic matter, cyanobacterial pigment. The higher spatial resolution allows the monitoring of increasingly smaller water bodies. Earth Observation of water bodies has been the domain of academic research, although examples of operational services producing relatively small quantities of data are available.

Satellite data are captured regularly and can provide unique spatial coverage over large areas. Historical datasets can often also be accessed. Processing can be automated in such a way that water quality information can be produced 3 to 24 hours after the over-pass of the satellite.

The European Union's Copernicus programme has placed at the disposal of citizens, researchers and businesses a new generation of satellites, the Sentinels. These satellites are flown into orbit in pairs to provide frequent monitoring capabilities, largely without observation gaps.

The reliable long-term availability of data from the Copernicus programme paves the way for integrating Earth Observation into the operational management and reporting of aquatic ecosystems.

OPTICAL IN SITU MEASUREMENTS

Optical in situ measurements using hand-held or mounted sensors can be a highly effective complement to sample-based measurements, and may even replace them, in certain cases. Fixed-position sensors, in particular, are almost completely autonomous and capture data very frequently (every 15 minutes), providing a fine-grained view of temporal fluctuations.

Naturally, only certain water quality parameters can be monitored in this way (i.e. those that change the optical properties of the water body):

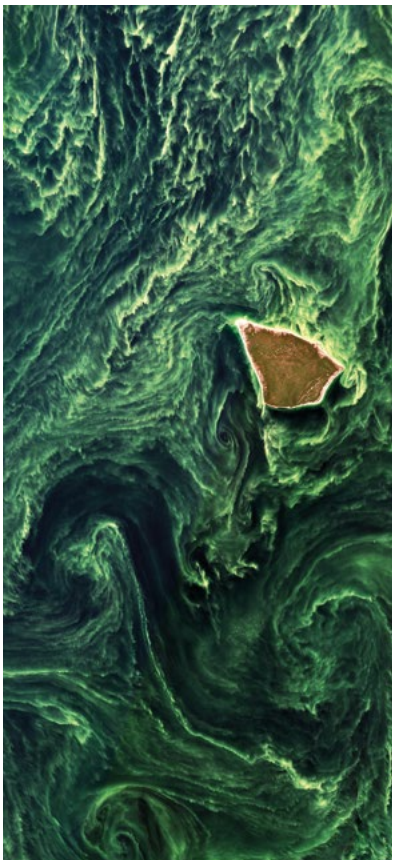
- Chlorophyll, which serves as a proxy measurement for algal biomass;
- Phycocyanin, which serves as a proxy measurement for cyanobacterial biomass;
- Suspended sediments (Total Suspended Matter, or TSM, also referred to as SPM);
- The coloured fraction of organic matter (CDOM);
- Transparency, which can be expressed as Secchi disk depth (SD) or as the diffuse attenuation coefficient (Kd);
- Colour.

Laboratory work is required for a full analysis of the water's chemical composition.

The instrument EOMORES offers for acquiring optical in situ data is known as WISP (Water Insight Spectrometer). There are two types of WISP: the fixed-position WISPstation and the handheld WISP-3. Both operate using the same physical principles: three spectrometers measure incoming light; two face upwards and collect downwelling radiance and irradiance, and the third faces downwards towards the water to collect upwelling radiance. Combining these signals, the WISP and the central processing platform (known as WISPweb) can derive the water quality parameters mentioned above, as well as Coloured Dissolved Organic Matter (CDOM) and water transparency.

The WISPstation is an optical instrument (spectrometer) designed to be mounted on a buoy, jetty or other infrastructure near or within the water body. It takes continuous, automatic measurements of surface water reflectance at a specific point, and has an additional set of spectrometers to compensate for the movement of the sun. The instrument sends its measurements to WISPweb at regular, pre-set intervals and ensures a flow of standardised information. The measurements are unaffected by cloud cover, but occasional maintenance and cleaning may be required.

The WISP-3 is a hand-held version of the WISPstation. Thanks to its speed, portability and flexibility, the WISP-3 is the ideal tool for water management authorities who need to make day-to-day decisions about safe drinking and swimming waters, ecological status and environmental protection. A high level of automation makes the WISP-3 a very user-friendly water quality scanner.

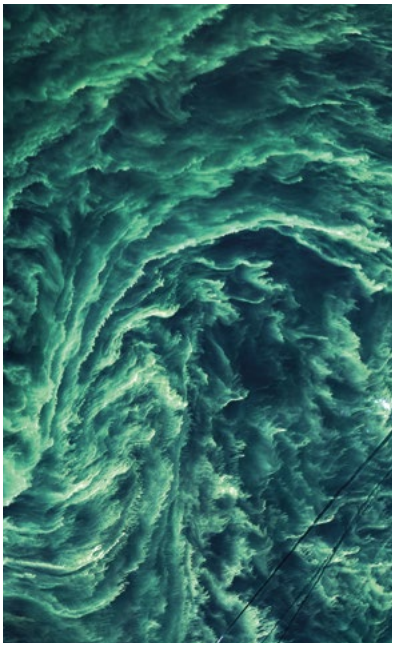


ECOLOGICAL MODELLING

Harmful algal blooms and surface scums represent a major problem faced by many beaches and recreational lakes worldwide. The ability to automatically forecast the timing and location of a harmful algal bloom and/or surface scum several days in advance allows water managers to make better decisions to potentially prevent scum from reaching the recreational areas, and issue more accurate public health announcements regarding potential health risks. Models can also be used for analysing data in retrospect, and to simulate the effects of proposed actions or measures (e.g. construction of new jetty, change in input flow volume, etc.).

Amongst the ecological models deployed by EOMORES is the Delft3D Algal forecasting model.

The Delft3D algal forecasting model, part of the Delft3D modelling suite, is used to forecast cyanobacterial scums and blooms. It usually consists of a hydrodynamic model to simulate the water motion (Delft3D-FLOW) and a water quality model (Delft3D-WAQ-BLOOM) to simulate the appearance, disappearance, movement and buoyancy of scums. Optionally, a fuzzy logic model (the "EcoFuzz" model within the Delft3D-WAQ process library) which simulates the potential for scum appearance and disappearance can be applied.



INTEGRATE AND CUSTOMISE: INDICATORS & HIGH-LEVEL PRODUCTS

The above components can be deployed in different combinations and tailored to your needs. Innovative, higher-level products and indicators can be custom-designed based on inter-disciplinary knowledge through the integration of multiple data sources. These products will be delivered in formats which fit seamlessly into your data management and information systems.

Higher-level products include, for example, EO-based maps of chlorophyll a and water transparency turned into WFD ecological status maps, model forecasts of cyanobacterial scum based on near-real time high-frequency in situ optical observations of cyanobacterial phycocyanin. These products can be integrated, for instance, into an operational monitoring and forecasting service concept (system) of cyanobacteria for bathing waters, or into a reporting service for the WFD-based on aggregated lake-wide indicators of the ecological status.

The three showcase concepts are:

A) Operational monitoring and forecasting of water quality, for day-to-day management;

B) Water Framework Directive and national reporting tools;

C) Compilation of time-series data for specific ecological analysis (e.g. source identification).

While these concepts might apply to a large range of users, the final products and purposes, and therefore the services, could be very diverse. Contact us to learn more on how EOMORES can help you tackle specific needs related to the monitoring of inland and coastal water quality.

ABBREVIATIONS

API	Application Programming Interface
CDOM	Coloured Dissolved Organic Matter
CHL-a	Chlorophyll *a* (proxy of algal biomass)
EO	Earth Observation
FNU	Formazin Nephelometric Unit
FTP	File Transfer Protocol
GIS	Geographic Information System
HAB	Harmful Algal Bloom
LAI	Leaf Area Index
LSWT	Lake Surface Water Temperature
MAE	Mean Absolute Error
MAPE	Mean Absolute Percent Error
MSFD	Marine Strategy Framework Directive
MSI	Multispectral Instrument
NTU	Nephelometric Turbidity Unit
OLCI	Ocean and Land Colour Instrument
R^2	Coefficient of Determination
RMSD	Root-Mean-Square-Deviation
RMSE	Root-Mean-Square-Error
SD	Standard Deviation
SLSTR	Sea and Land Surface Temperature Radiometer
SPM	Suspended Particulate Matter
SST	Sea Surface Temperature
TBM	Total Phytoplankton Biomass
TSM	Total Suspended Matter
VHR	Very High Resolution
WFD	Water Framework Directive
WHO	World Health Organization
WST	WST Water Surface Temperature

The products in this Portfolio were developed under the EU-funded EOMORES project and are available on a commercial basis through the participating service providers.

If you wish to learn more, or order the products, please visit our website: **eomores.eu**

Image credits: Cover: Karavasta lagoon, Albania. Captured by Sentinel - 2B on the 15 March 2017. Contains modified Copernicus Sentinel data (2017). Processed by ESA, CC BY-SA 3.0 IGO; Page 6: Algal bloom. Captured by Sentinel – 2 2LA on the 28 August 2019. contains modified Copernicus Sentinel data (2019); Pages 16, 28, 34, 39-41: Algal bloom. Captured by Sentinel – 2B on the 25 July 2019. contains modified Copernicus Sentinel data (2019).

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