D5.3: Final Validation Report

WP5 – Validation

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Table of Contents

EOMORES
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EOMORES

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Table of Figures

EOMORES
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EOMORES

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EOMORES
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Table of Tables

EOMORES
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Abbreviations

Abbreviation	Meaning
a_{CDOM}	Absorption coefficient of CDOM (m^{-1})
CDOM	Coloured Dissolved Organic Matter
Chl-a	Chlorophyll-a concentration (µg/l or mg m^{-3})
DMS	Data Management System
EO	Earth Observation
K_d	Diffuse attenuation coefficient
L8	Landsat-8
LSWT /WST	Lake Surface Water Temperature / Water Surface Temperature
MAE	Mean Absolute Error
MSFD	Marine Strategy Framework Directive
MSI	Multispectral instrument of Sentinel-2
n	Sample size
OLCI	Ocean and Land Colour Instrument of Sentinel-3
PML	Plymouth Marine Laboratory
R^2	R-squared, Coefficient of Determination
RMSE	Root Mean Square Error
R_{rs}	Remote sensing reflectance
R_w	Normalised water-leaving reflectance
S1	Sentinel-1
S2	Sentinel-2
S3	Sentinel-3
SD	Secchi disk depth (m)
SYKE	Finnish Environmental Administration
TSM / SPM	Total Suspended Matter / Suspended Particulate Matter (mg/l)
WFD	Water Framework Directive
WI	Water Insight
WISP-3	Water Insight SPectrometer with 3 channels
WISPStation	Water Insight Spectrometer Station
WP	Work Package

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I. Abstract

The aim of the H2020 EOMORES project was to develop user-relevant and sustainable commercial downstream services for operational inland and coastal water quality monitoring and reporting. This service has now been developed based on a combination of satellite Earth Observation (EO), *in situ* and modelling components, with user feedback guiding product and service development throughout. Validation is a key part of the operational service development, in order to ensure the users can be confident in the service provided. Thus, this deliverable presents all validation results, using data collected during the three years of the EOMORES project (2017-2019) to validate the final service products (T5.1). Additionally, this deliverable evaluates the product fitness for purpose (T5.2) and the service functionalities and user satisfaction (T5.3).

Overall, the EOMORES service products indicated good performance according to the quantitative uncertainty metrics. EO product validation has been presented by region for each of the service products, including Chl-a, TSM, turbidity, Secchi depth, CDOM, LSWT and macrophyte coverage. From user assessment of the product fitness for purpose, most users received the products and found they were as expected and spatial patterns typically agreed with user expectations. Users highlighted that temporal frequency and spatial coverage was mostly sufficient and an improvement on their routine monitoring programmes. In general, the users were also (very) content with the quality of the service, with scores of 6+ out of 10 from all users for all criteria queried (Timely delivery, Format/interface, Ease of use, Operational capability). Some users are already implementing the EOMORES service for (bathing) water quality monitoring or to inform WFD and MSFD, while many more indicated they hope to use the EOMORES service in the future for a range of purposes. Overall, users were satisfied with the EOMROES service (7+ out of 10). These results indicate there are robust products included in the EOMORES service, and that users are typically satisfied with the service, highlighting the spatial coverage as a key improvement to current monitoring methods for inland and coastal waters.

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II. Introduction

The aim of the H2020 EOMORES project was to develop user-relevant and sustainable commercial downstream services for operational inland and coastal water quality monitoring and reporting. At this final stage of the project, the service has been developed based on a combination of satellite Earth Observation (EO), *in situ* and modelling components, with user feedback guiding product and service development throughout. In this way, EOMORES is in place to provide national, regional, local, public and private water managers with an operational service for efficient monitoring of water quality parameters and reporting according to requirements of the European Union (EU) Water Framework Directive (WFD), Marine Strategy Framework Directive (MSFD) and other (national) directives. These include parameters such as Chlorophyll-a (Chl-a), Total suspended matter (TSM; also referred to as Suspended Particulate Matter, SPM), Turbidity, Coloured dissolved organic matter (a_{CDOM}), Lake water surface temperature (LWST) and macrophytes.

A vital part of the operational service development, however, is to ensure the users can be confident in the service provided. The validation process can be defined as assessment of the reliability of the data products derived from a system output with independent means (Kleywegt, 2007). Thus, the validation process provides users assurance that the EOMORES products and service are robust and will be suitable for their needs. This was assessed quantitatively for EOMORES products according to the guidance outlined in D2.3 Validation Plan. Furthermore, user meetings and questionnaires were used to gain feedback on the service itself, including product fitness for purpose, service quality and utility, and overall user satisfaction with the EOMORES service.

An initial validation report was presented for EOMORES (D5.2 Initial Validation Report), which included results through May 2018 (the first 18 months of the project), and focused mainly on product validation results and progress with some initial user feedback on the products and service. This final validation report will cover all data collected during the three years of the EOMORES project (2017-2019) and use these data to validate the final service products (T5.1). Additionally, this deliverable will focus on the evaluation of the product fitness for purpose (T5.2) and validation of the service functionalities and user satisfaction (T5.3). The results of these assessments will be presented by region (Estonia, Lithuania, Italy, Finland, Netherlands, UK), and then by service product type.

II.1. Scope

The first objective of this deliverable is to present validation of the final EOMORES service line products, including evaluation of the accuracy of the three service components (EO products, *in situ* data and ecological models). This comprises the activities in T5.1 Product Accuracy Assessment, and includes all EOMORES validation results available to date (2017-2019).

Secondly, this deliverable aims to assess the product fitness for purpose (T5.2), which evaluates whether the information content of the EOMORES products fit the user's expectations and requirements.

Finally, this deliverable will validate and evaluate the service functionalities and assess the overall satisfaction of the end-users (T5.3). This is evaluated in terms of delivery timing, data quality and service reliability. We also evaluate whether the EOMORES service can be incorporated into the users' existing work-flow, as well as assess the added value of the service to the users.

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III. Summary of EOMORES sampling effort

A summary table of the EOMORES validation datasets are presented by region in Table 1. Over the period 2017-2019, more than 390 samples were collected for EOMORES, demonstrating the extensive validation effort conducted during this project. Additional, independent, water quality and reflectance observations were also collected by end-users, adding over 9700 observations available for validation. Furthermore, an additional 3026 WISP measurements were taken in 5 countries for validation of remote sensing reflectance (R_{rs}), and 5 WISPstations were installed for collection of continuous *in situ* R_{rs} and water quality parameters.

Table 1 – Summary of EOMORES validation data collected 2017-2019

Region	Lake	Survey Dates	Number of Samples/ Spectra (n)	List of Parameters collected
Estonia	Peipsi	May-October 2017-2019	57	Chl-a, TSM, CDOM, Rrs (TriOS)*
	Võrtsjärv	May-October 2017-2019	15	Chl-a, TSM, CDOM, Rrs (TriOS) *
	Small lakes	Once per vegetation period 2017-2019	20	Chl-a, TSM, CDOM, Rrs (TriOS) *
Lithuania	The Curonian Lagoon	May-October 2018-2019	74	Chl-a, TSM, CDOM, Secchi disk depth, Rrs (WISP-3)
Italy	Lake Trasimeno	March - September 2017; January – October 2018 and 2019	35 by EOMORES + 7 by user	Chl-a, TSM, CDOM, Rrs (Fieldspec ASD FR, SpectralEvolution SR-3500, WISP-3),
	Deep Subalpine Lakes (Garda, Como, Iseo, Mezzola)	March - September 2017; June – September 2018; May – October 2019	62 (+ 31 for macrophytes)	Chl-a, TSM, CDOM, LSWT, Macrophytes, Rrs (Fieldspec ASD FR, SpectralEvolution SR-3500, WISP-3)
Finland	Lake Vesijärvi	Sep 2017	5	Rrs (WISP-3), laboratory, automated stations, Chl a-, turbidity, secch depth
	Parainen (coastal site)	Aug 14, 2017	7	Rrs (WISP-3; ASD), laboratory, Chl a-, TSM, turbidity, CDOM, secchi depth
	Validation integrated to the national in situ data collection on lakes and coastal areas	2017 onwards	>100	Turbidity, chl-a, secchi depth, CDOM

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Region	Lake	Survey Dates	Number of Samples/ Spectra (n)	List of Parameters collected
Netherlands	Markermeer	23 May 2017 by EOMORES May-November 2018 by user	6 by EOMORES + 180 by user	EOMORES: SPM, CDOM, beam attenuation, SD, Rrs (WISP-3) User: Chl-a, SPM, SD, sometimes Rrs (WISP-3)
	Channels in area of user NZV	May-June 2018	30	Rrs (WISP-3), Chl (algae sensor)
UK	Loch Leven	May – October 2017 and 2018	38	Chl-a, TSM, CDOM, Rrs (TriOS, WISP)
	Loch Lomond	May – October 2017 and 2018	29	Chl-a, TSM, CDOM, Rrs (TriOS, WISP)
	SEPA (Scottish Lochs, UK)	January 2017 – November 2018	7,203	Chl-a, Suspended Solids (TSM), Rrs (WISP, 2017 only)
	Environment Agency (Lake District, UK)	January 2017 – September 2018	234	Chl-a, Transparency, Rrs (WISP, 2018 only)
	Ireland EPA (Ireland Lakes)	January - December 2017	2,150	Transparency

IV. EO Product Accuracy Assessment

All EO products were developed and tuned to each region or globally tuned using optical water types to ensure good performance in advance of implementation in the service. The EOMORES EO products include the following water quality parameters:

- Chlorophyll-a (Chl-a),
- Total suspended matter (TSM),
- Turbidity,
- Coloured dissolved organic matter (a_{CDOM}),
- Lake water surface temperature (LWST),
- Macrophytes.

These are all downstream products based on satellite sensors (Sentinel-3 OLCI, Sentinel-2 MSI, Landsat-8 OLI) and are implemented operationally in the respective EOMORES service line.

Satellite remote sensing reflectance ($R_{rs}(\lambda)$) was validated prior to product tuning and validation, ensuring that the reflectance is the result of accurate atmospheric correction procedures. These results were presented in the D5.2 Initial Validation Report and are not part of the final products validated here.

All EO products are assessed according to the D2.3 Validation Plan. In summary, the error metrics for validation of **quantitative** data are as follows:

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- Mean Absolute Error (MAE);
- Root Mean Squared Error (RMSE);
- Intercept and slope of a regression line;
- Scatterplot of EO data vs. *in situ* data (with a diagonal of perfect prediction line).

The statistical accuracy/uncertainty measures for validation of **qualitative** data are as follows:

- Area under the receiver operating characteristic (ROC) curve (AUC);
- Sensitivity, or True Positive Rate (TPR);
- Specificity, or True False Rate (TFR).

The below sections outline the validation efforts undertaken for each region, using scatterplots and error metrics to assess the performance of each EO product.

IV.1. Estonia

The validation data for Estonia (2017-2019) were collected on Lake Peipsi and Võrtsjärv between May and October, as well as once per vegetation period on small Estonian lakes. Peipsi and Võrtsjärv are large, shallow, eutrophic and well-mixed lakes. Peipsi is spatially and temporally very inhomogeneous and different water types can be observed: clearest and deepest water in the norther part, more turbid, brownish and phytoplankton rich waters in the southern part. Lake Võrtsjärv is a very turbid, well-mixed, eutrophic and non-stratified lake with high CDOM, phytoplankton and TSM. For both large lakes, cyanobacterial blooms may be present annually.

Reflectance measurements were collected for validation of atmospheric correction, as well as water quality parameters (Chl-a, TSM, CDOM). Only the data collected on the same day with satellite overpass was used to validate the products.

IV.1.1. Chl-a

The EOMORES Chl-a product for large Estonian lakes, via the WI processing chain covering period 2018-2019, worked reasonably well (Figure 1) for S3 data. However, we note that the validation dataset for Lake Peipsi consisted of two dates (15/05/2018 and 15/10/2018), representing more modest concentrations. EO methods did not register Chl-a concentrations below 10 mg/m^3 with Sentinel 3 and below 20 mg/m^3 with Sentinel 2. Chl-a in L. Peipsi was higher in southern part of the lake during the entire vegetation period (Figure 2).

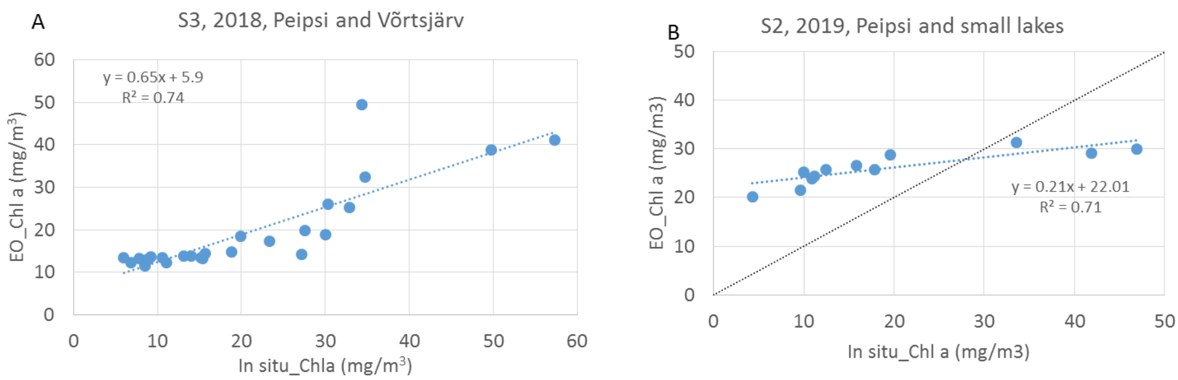

Figure 1 - Validation scatterplots for A) Chl a S3 EOMORES product from 2018, derived based on data from Peipsi and Võrtsjärv, and B) Chl a S2 EOMORES product, derived based on L. Peipsi and small lakes; indicating R2 and linear regression fit.

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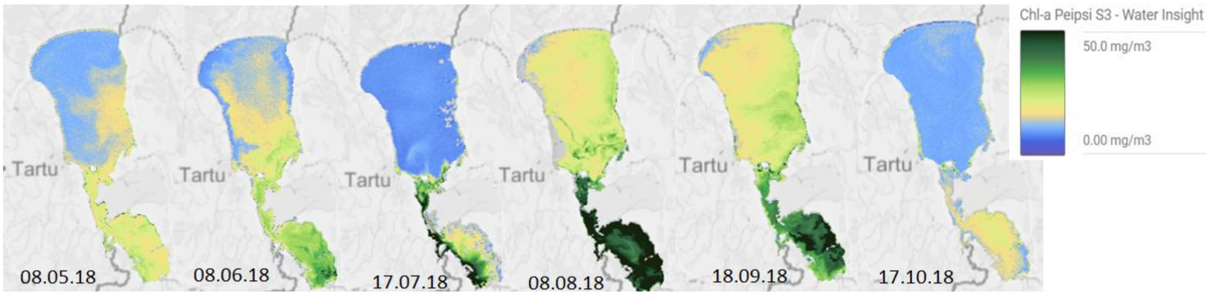

Figure 2 - Example map of Chl a S3 EOMORES product for seasonal and spatial dynamics during 2018

IV.1.2. CDOM

CDOM validation results appear to be more scattered (Figure 3). For Sentinel 2, less available data is present for the validation and underestimation of high *in situ* measured values by EO result in a lower correlation coefficient (Figure 3B). The CDOM concentration in L. Võrtsjärv is rather homogeneous (Figure 4).

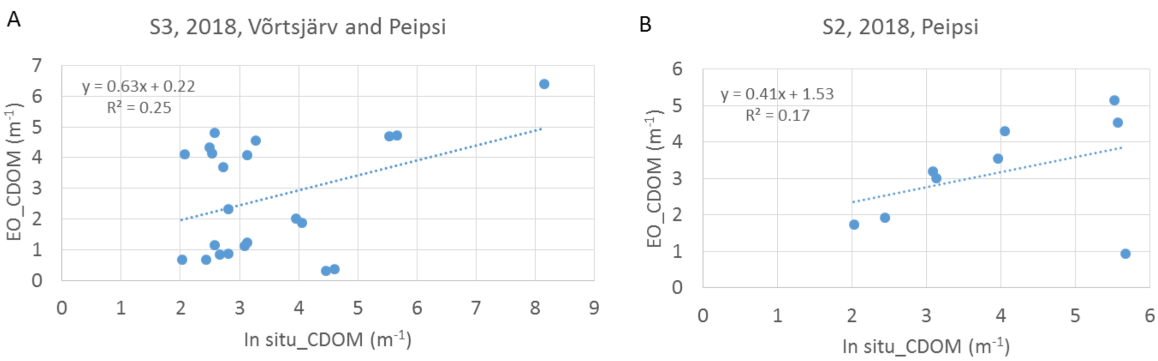

Figure 3 - Validation scatterplots for CDOM S3 EOMORES product (A), based on the data from L. Peipsi and Võrtsjärv, 2018 and CDOM S2 EOMORES product (B), based on the data from L. Peipsi, 2018; indicating R2 and linear regression fit

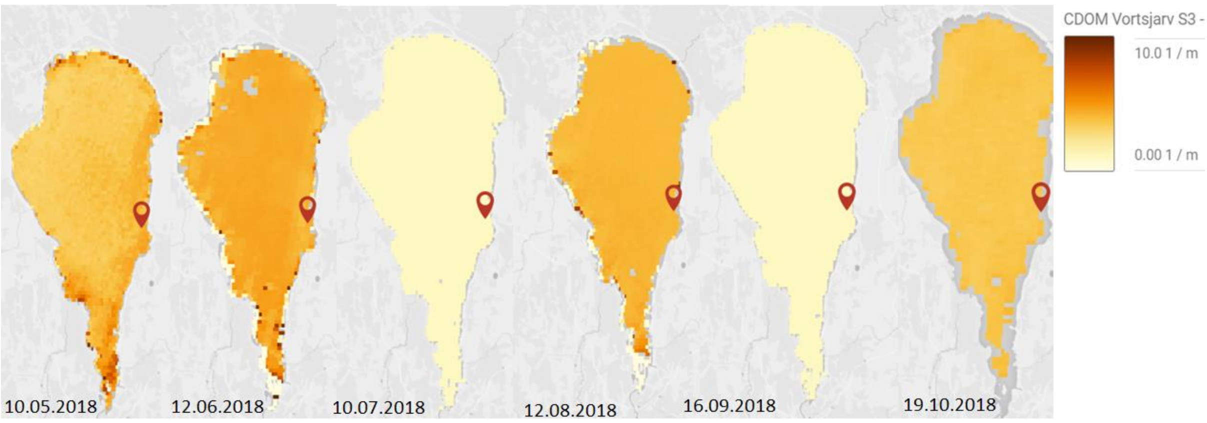

Figure 4 - Example map of CDOM S3 EOMORES product for seasonal and spatial dynamics during vegetation period of 2018. Marked is the WISP-station location.

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IV.1.3. Uncertainty Assessment

A summary of the uncertainty metrics for the Estonia regional products is provided in Table 2.

Table 2 – Uncertainty metrics for Estonia EOMORES EO products

Product	R^2	Slope	RMSE	MAE	n
Chl a S3	0.74	0.65	5.07	0.84	26
Chl a S2	0.71	0.21	1.74	0.45	12
CDOM S3	0.25	0.63	1.72	0.25	23
CDOM S2	0.17	0.41	1.21	0.43	9

IV.2. Lithuania

For the EOMORES operational service development, the main focus was given to the Curonian Lagoon – the largest European lagoons that is of great importance for the both Lithuanian users: Environmental Protection Agency and Nature Research Center. The Curonian Lagoon is a large, shallow water body (total area 1584 km^2, mean depth 3.8 m) located along the south-eastern coast of the Baltic Sea. Geographically the lagoon is positioned between the Republic of Lithuania and the Russian Federation. The main ecological problem is eutrophication due to pollution by nutrients with summer wide-spread cyanobacteria blooms. The products developed within the EOMORES operational service cover both countries, but validated part was only in the area of Lithuania.

For the Curonian Lagoon the satellite data production was aiming to map Chl-a concentration, Total Suspended Matter (TSM) and Water Surface Temperature (WST). In this report, the validation was performed for Chl-a and TSM in relation on the available *in situ* data set. EOMORES products have been validated with water quality measurements gathered *in situ* during both, dedicated field campaigns organised by KU and joint field campaigns organised by EOMORES user. Here, we note that the products validated were processed by KU rather than those from the WI service line.

IV.2.1. Chl-a

For 2018 and 2019 two different atmospheric correction approaches were used in order to produce the Chl-a product for the Curonian Lagoon: for 2019 Polymer was applied, for 2018 6SV code was used as indicated in Deliverable 3.3. The same band ratio algorithm was used to calculate the Chl-a concentration.

The better fit (R^2 = 0.95) between *in situ* measured and satellite derived Chl-a concentration was found after the application of Polymer, however, more than 50% of sampling sites were masked by the processor. Good agreement with *in situ* measured Chl-a was found also after application of 6SV code for atmospheric correction, however the processing can't be done in an operational mode, therefore since year 2019 Polymer was selected as an alternative way.

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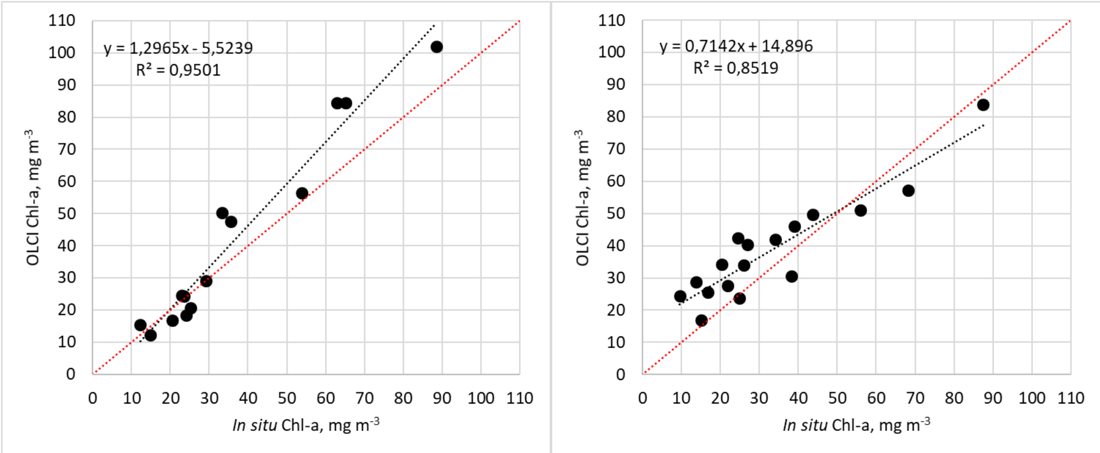

Figure 5 - Validation scatterplots for Chl-a EOMORES product for 2019 (left) and for 2018 (right), indicating R^2 and linear regression fit

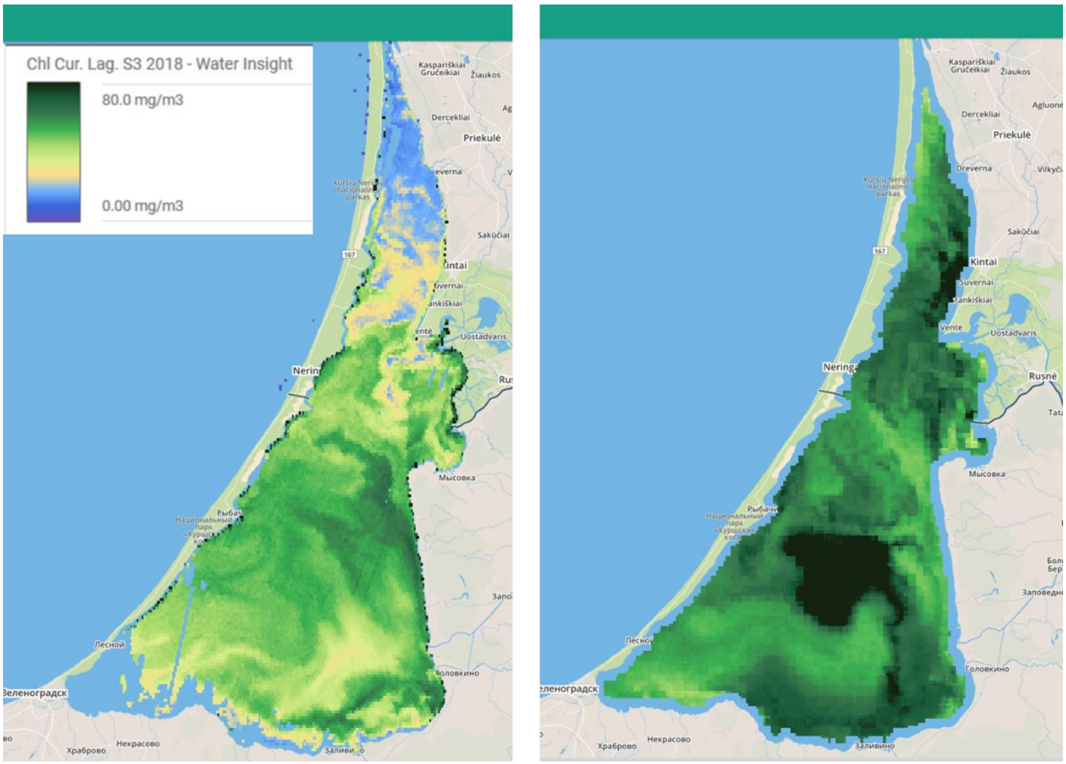

Figure 6 - Example map of Chl-a EOMORES product for 08.05.2019 (left) and 08.08.2018 (right).

IV.2.2. TSM

For the TSM retrieval ACOLITE was used for both Sentinel-2 and Landsat-8 remote sensing data. Figure 7 shows the results for the Curonian Lagoon for the four match ups obtained in 2019. TSM retrieved from Sentinel-2 data appears to be more scattered comparing with values retrieved from Landsat-8. The better fit was found between *in situ* measured TSM retrieved from Landsat-8 OLI with R^2=0.92, however the available dataset of *in situ* measurements was significantly smaller (n=13) in comparison with dataset available for the validation of Sentinel-2 data (n=35).

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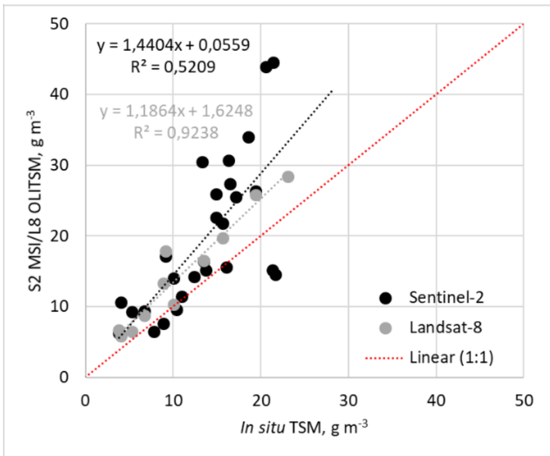

Figure 7 - Validation scatterplot(s) for TSM EOMORES product, indicating R2 and linear regression fit

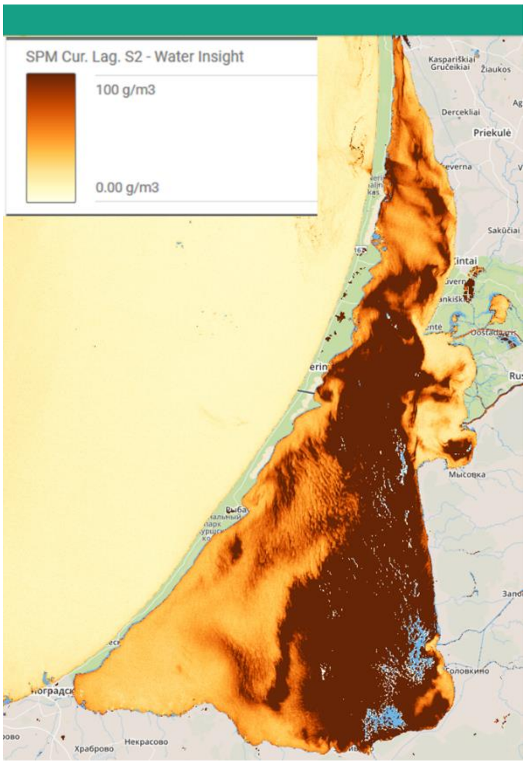

Figure 8 - Example map of TSM EOMORES product for 10.09.2018

IV.2.3. Uncertainty Assessment

A summary of the uncertainty metrics for Chl-a and TSM products for Lithuania is shown in Table 3.

Table 3 – Uncertainty metrics for Lithuania EOMORES EO products

Product	R^2	Slope	RMSE	MAE	n
Chl S3 2019	0.95	1.29	7.35	10.03	15 (28)
Chl S3 2018	0.85	1.44	7.26	9.69	27 (25)
TSM S2	0.52	1.44	7.26	9.69	27 (35)
TSM L8	0.92	1.19	3.65	4.34	11 (13)

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IV.3. Italy

The Italian lakes on which EOMORES is focusing on are Lake Trasimeno in central Italy and series of lakes, which are part of the Subalpine lake district in northern Italy. Located at different latitudinal ranges, they are characterised by highly differentiated trophic levels and morphological characteristics, while all are equally relevant sites for providing relevant water resources to the nearby regions.

In particular, with a surface of 128 km^2, Lake Trasimeno is the fourth largest Italian lake. It is a post-tectonic lake and it belongs to the Tevere river basin. It is a close lake, with un-stratified and very shallow waters. The lake shows from mesotrophic to eutrophic conditions, where principal critical parameters are phosphorous and chlorophyll-a. Water levels of Trasimeno are very variable depending on meteorological conditions but the current climatic evolution shows a significant reduction in water availability. The lacustrine ecosystem is an area of exceptional value for its wealth of flora and fauna. Tourism, agriculture and livestock breeding are the most important activities in the Trasimeno area. In cooperation with ARPA-U, the satellite data production for Trasimeno was aiming to map LSWT, chl-a and SPM (or turbidity) from data gathered by Sentinel-3, Sentinel-2 and Landsat-8.

The subalpine lake district, part of the Po river basin (the longest river in Italy), stores up to 80% of freshwater of the country. This region also represents an essential renewable resource for the surrounding environment, which is the most densely populated and industrialized of Italy. The most important lakes of the subalpine district are characterized by great depths and large volumes; they are oligomictic lakes, with summer stratification between June and October. The subalpine region also includes smaller basins (e.g. Mezzola), in terms of size and depths, having waters generally more turbid and productive than the deep large lakes. In agreement to ARPA-L, EOMORES has targeted three big lakes (Garda, Como and Iseo) as well as some small basins (Mezzola, Pusiano and Oggiono). For the largest and deepest lakes, the satellite data production was aiming to map LSWT, chl-a and SPM (or turbidity) from data gathered by Sentinel-3, Sentinel-2 and Landsat-8, while, for the smaller basins, the mapping was focused on water turbidity and aquatic vegetation from Sentinel-2 imagery.

As described in the following sections, the EO products of Italian lakes have been validated with coincident reference measurements gathered *in situ* with protocols described in D 2.3. Field data on water quality parameters include measurements obtained from water sampling. For each section scatterplots and related statistics are reported to show the fitting between satellite and fields data, while maps are shown as examples of the products accessible via the EOMORES geoportal developed by WI.

IV.3.1. Chl-a

The chl-a validation relies on match-ups with *in situ* data collected over three years. As plotted in Figure 9, field and satellite data of Lake Trasimeno shows a comparable range of variation from 0 to 50 mg/m^3, with a close match for both MSI and OLCI sensors, on board of Sentinel-2 and Sentinel-3, respectively. Figure 10 shows the validation for the three deep subalpine lakes, where data include both measurements collected the same day of satellite overpasses, as well as data having a mismatch up to ± 1-3 days. Even though the range of chl-a variation of 0-10 mg/m^3 is definitely lower than for Trasimeno, the degree of fit between satellite and field data is very good (R^2=0.83).

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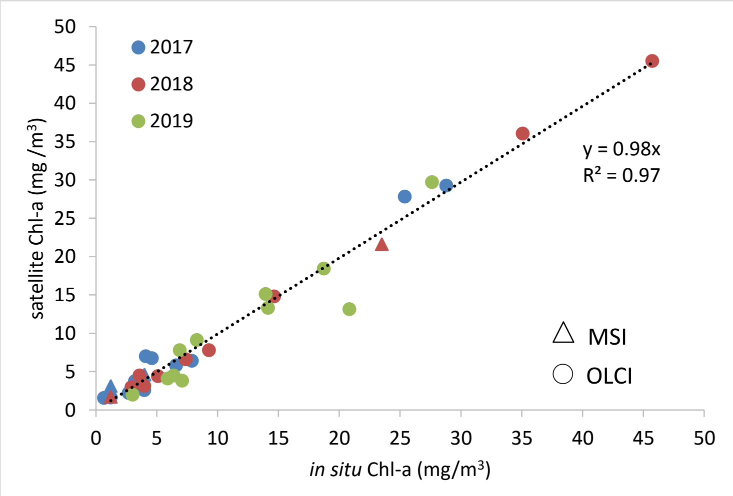

Figure 9 - Validation scatterplot for Trasimeno Chl-a EOMORES product, indicating R^2 and linear regression fit. The colors (blue, red, green) indicate the different years of the validation and symbols represent the different satellite sensors used. The match-up is related to synchronous acquisition between in situ *and satellite data.*

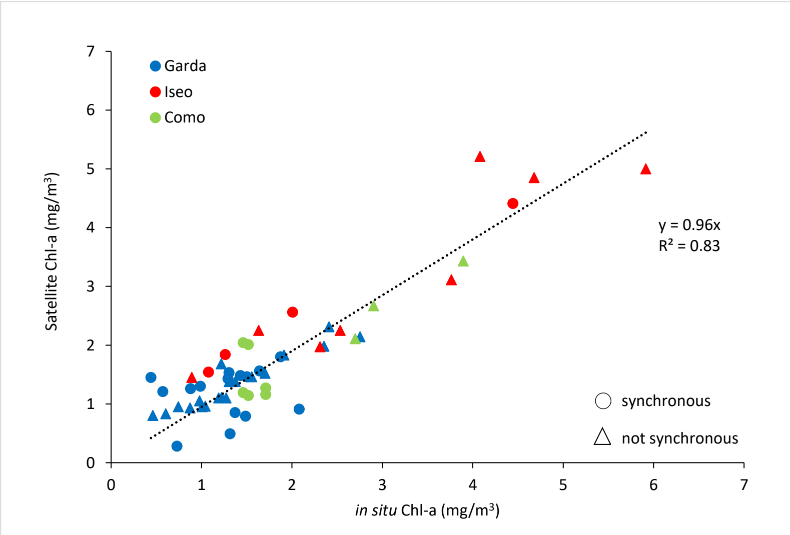

Figure 10 - Validation scatterplot for Subalpine lakes Chl-a EOMORES product, indicating R^2 and linear regression fit. The colors (blue, red, green) indicate the different lakes of the validation, the circle represents the match-up synchronous, while the triangle the match-up with ± 1-3 days (not synchronous) between in situ *and satellite data.*

Figure 14 and Figure 15, provide examples of Chl-a maps derived from Sentinel-3 OLCI for Trasimeno and Garda viewed from the EOMORES portal. The maps show how spatial patterns vary between the lakes, both in terms of concentrations and heterogeneity.

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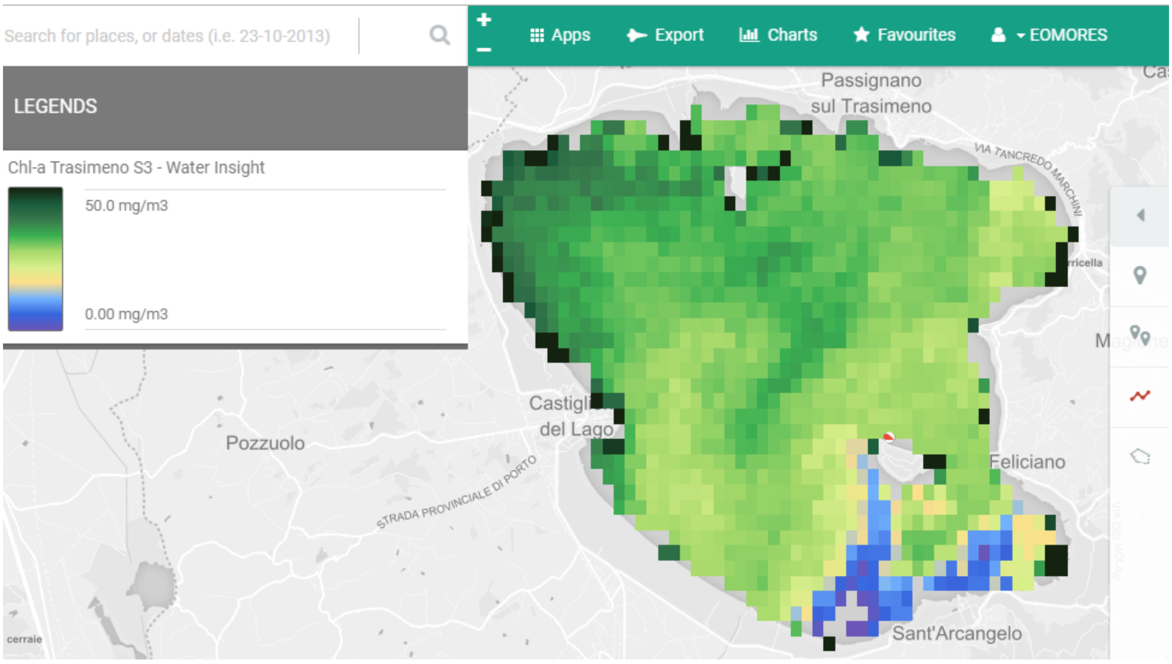

Figure 11 - Example map of Trasimeno Chl-a EOMORES product for 04.09.2019

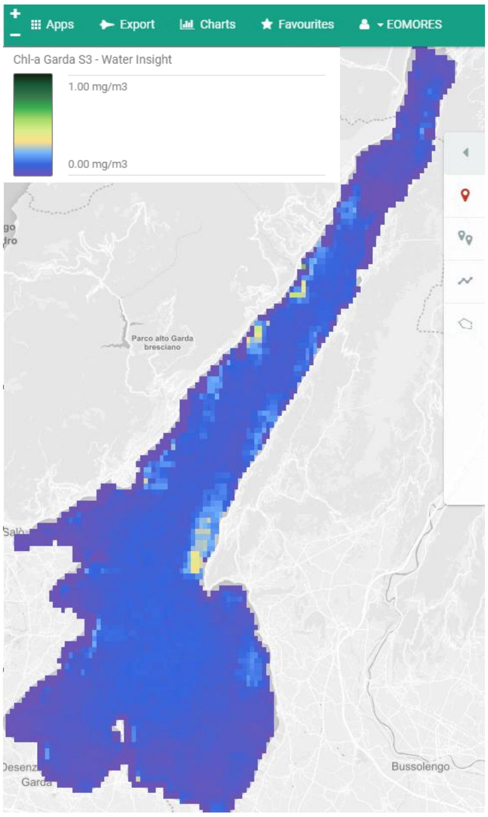

Figure 13 - Example map of Garda lake Chl-a EOMORES product for 28.07.2019

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IV.3.2. TSM/Turbidity

As in the previous section, scatterplot and maps are reported to show the results of EO data processing with respect to water turbidity or Total Suspended Matter, where *in situ* data are those obtained from water sampling. Figure 12 shows the results for Trasimeno for the four match-ups obtained in 2019. Figure 13 shows the results for the largest subalpine lakes by also including the match-up with ± 1-3 days between *in situ* and satellite data. In all cases, the degree of fitting is high, with best results for Trasimeno due to the larger range of variation (0-30 g/m^3, Figure 12) as compared to subalpine lakes (0-8 g/m^3, Figure 13).

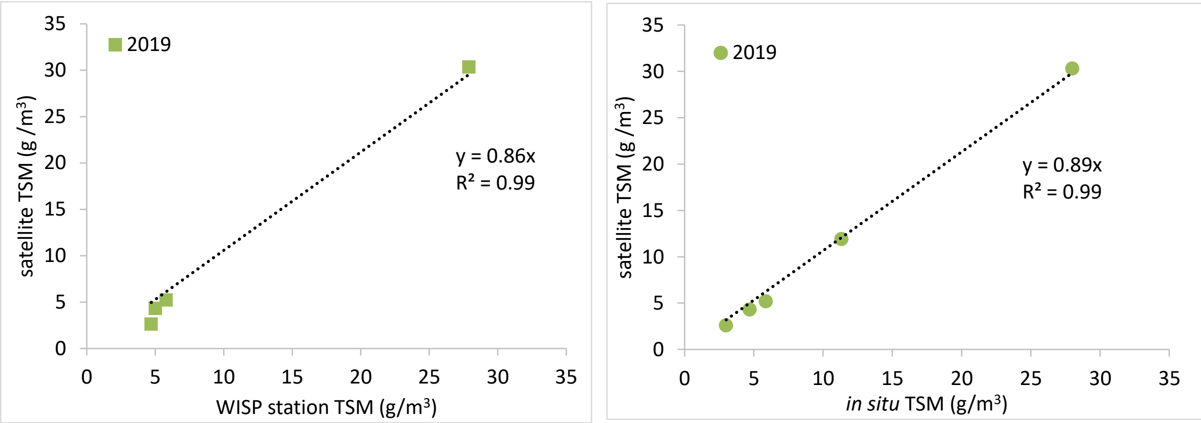

Figure 12 - Validation scatterplots for Trasimeno TSM EOMORES product, indicating R^2 and linear regression fit. Satellite versus WISP station data are reported on the left graph. Satellite versus in situ *data are reported on the right graph.*

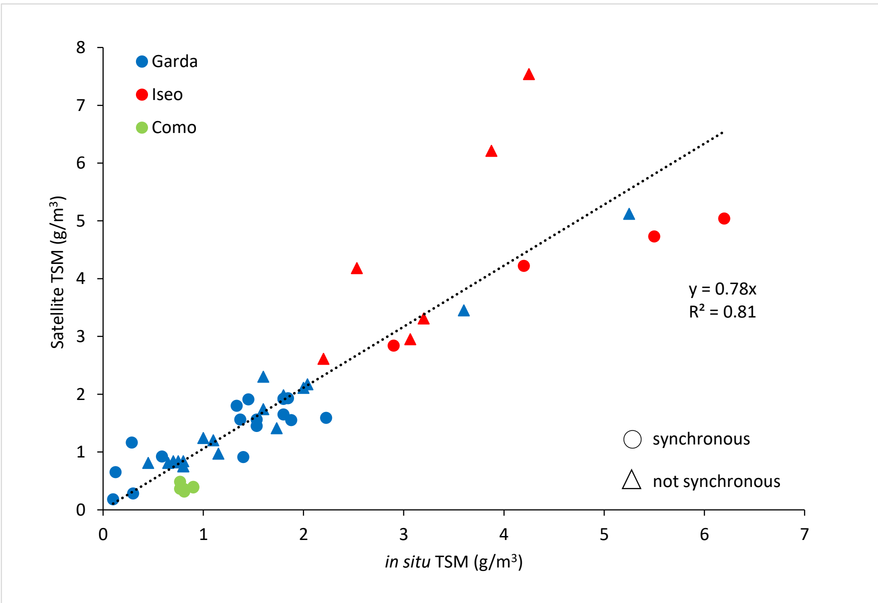

Figure 13 - Validation scatterplot for Subalpine lakes TSM EOMORES product, indicating R^2 and linear regression fit. The colors (blue, red, green) indicate the different lakes of the validation, the circle represents the match-up synchronous, while the triangle the match-up with ± 1-3 days (not synchronous) between in situ *and satellite data*

Figure 14 and Figure 15 depict the turbidity maps in FNU units for Lake Mezzola, one of the smaller lakes of the subalpine lake district studied in EOMORES and Lake Iseo. In particular, the EO-derived lake turbidity time-series in the Mezzola was produced after specific request from ARPA Lombardia, since the lake had suffered from the impacts of a massive landslide that took place upstream of the lake basin in summer 2017.

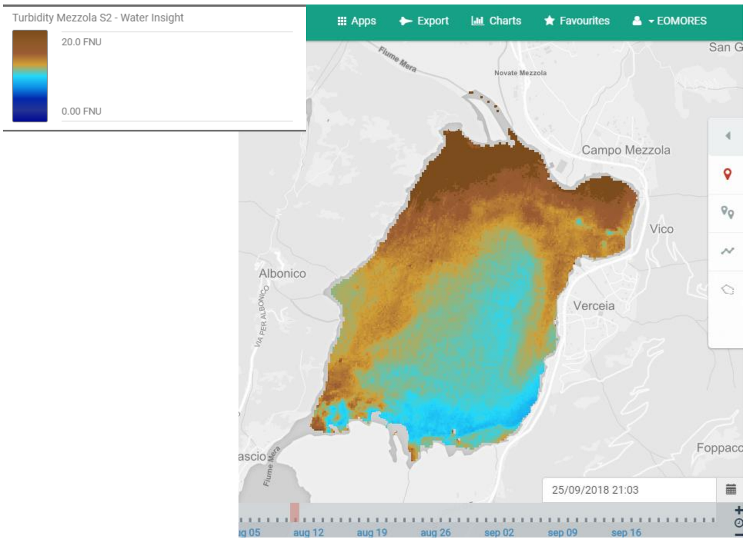

Figure 14 - Example map of Mezzola Turbidity EOMORES product for 10.08.2018.

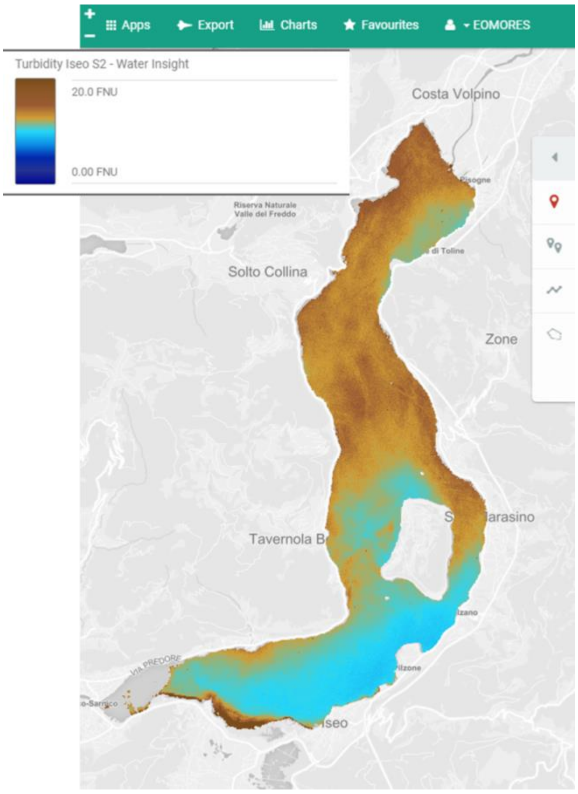

Figure 15 - Example map of Iseo lake turbidity EOMORES product for 02.09.2018

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IV.3.3. Lake Surface Water Temperature (LSWT)

Lake water surface temperature (LSWT) was mapped from imagery acquired by TIRS on Landsat-8 and SLSTR instrument onboard Sentinel-3. EO products were compared to field measurements of water temperature only for Lake Garda as only for this lake *in situ* data were available. A good degree of fitting was obtained (R^2=0.96) (Figure 16). An example of the LSWT from SLSTR is provided in Figure 17.

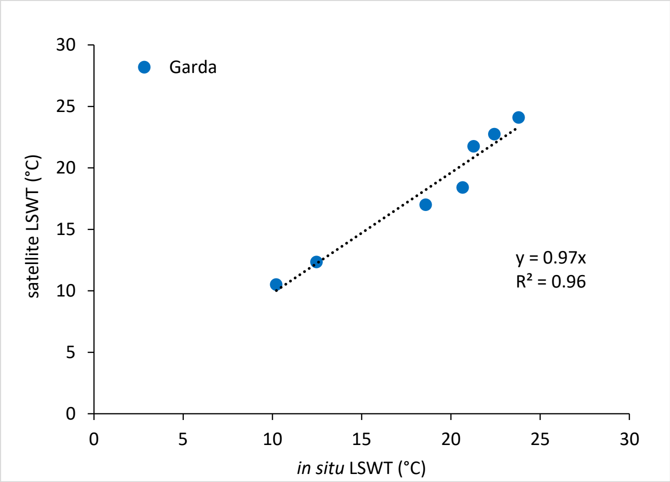

Figure 16 - Validation scatterplot for Garda Lake Surface Water Temperature (LSWT) EOMORES product, indicating R^2 and linear regression fit.

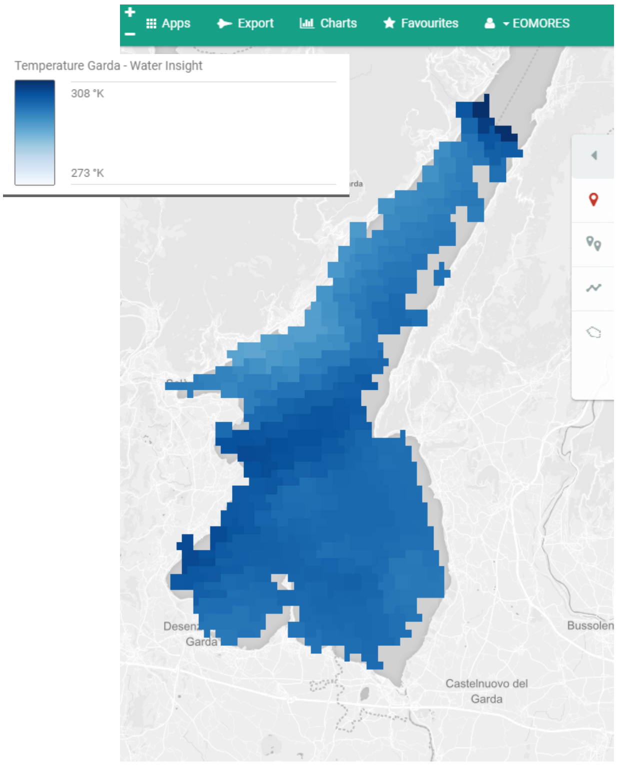

Figure 17 - Example map of Garda LSWT EOMORES product for 13.07.2018.

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IV.3.4. Macrophytes

For specific lakes and depending on the requests from EOMORES users, a map depicting the extent and fractional cover of aquatic vegetation was produced. The validation of this classified product was based on comparing satellite data with ground data describing the presence/absence of plants along with its density, in terms of biomass. Satellite and field observations were then compared by building a confusion matrix. Table 4 and Figure 18 show these results for the southern part of Lake Iseo, where gentle slopes and shallow depths enable the growth of submerged prairies of macrophytes.

Table 4 – Confusion matrix depicting the agreement of earth observations classified data with respect to in situ *surveys. RM = rooted macrophytes, BS = bare sediments.*

		In situ			
		RM	BS	Deep Water	Producer's Accuracy
Classified	RM	29	1	1	93.5%
	BS		7		100.0%
	Deep water		1	8	88.9%
	User's Accuracy	100.0%	77.8%	88.9%	93.6%

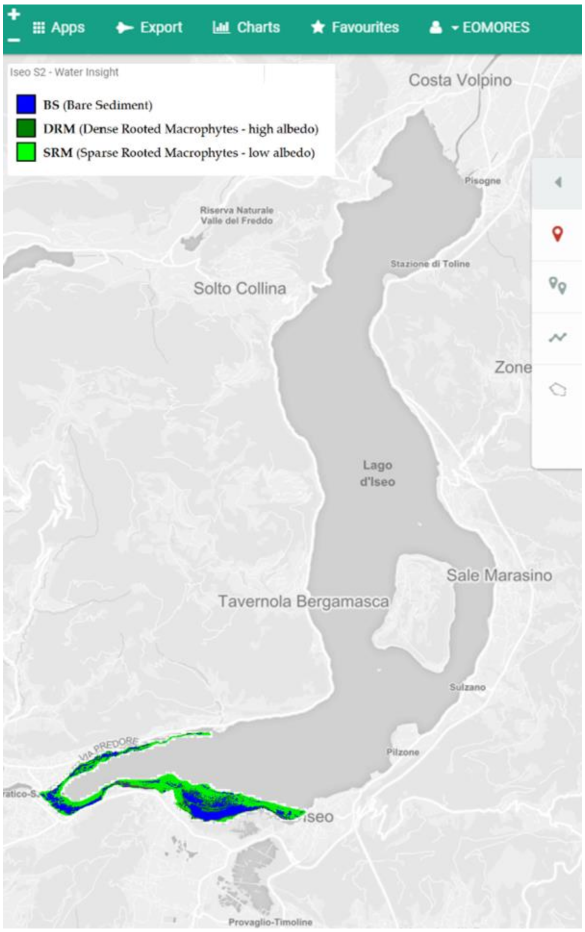

Figure 18 - Example map of Iseo macrophytes and bare sediments for the EOMORES product on 24.10.2017; for macrophytes two classes of fractional cover are reported.

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IV.3.5. Uncertainty Assessment

A summary of the uncertainty metrics for validation of the Italy EOMORES products is shown in Table 5.

Table 5 – Uncertainty metrics for Italy EOMORES EO products.

Product	R^2	Slope	RMSE	MAE	n
Chl-a Trasimeno	0.97	0.98	17.16	1.28	37
Chl-a Subalpine	0.83	0.96	25.08	0.33	55
TSM Trasimeno	0.99	0.89	10.68	0.87	5
TSM Subalpine	0.81	0.78	37.48	0.38	52
LSWT Subalpine	0.96	0.97	5.84	0.76	7

IV.4. Finland

The SYKE EO products for the EOMORES service are as follows:

- Chl-a as water body statistics (2016-2019) for ~2000 lakes and ~250 coastal water bodies
- Turbidity as water body statistics (2013-2019) for ~2000 lakes and ~250 coastal water bodies.
- CDOM [a_{CDOM}(400)]
- Secchi depth

The products were validated against monitoring station site sampling, in particular over reference stations. These stations are identified as representative locations with respect to sampling frequency, lake water type and distance from the nearby land objects.

IV.4.1. Chl-a

The validation results for the Finland Chl-a product are shown in Figure 19 for inland and coastal waters. An example Chl-a map is provided in Figure 20 from the SYKE service line portal.

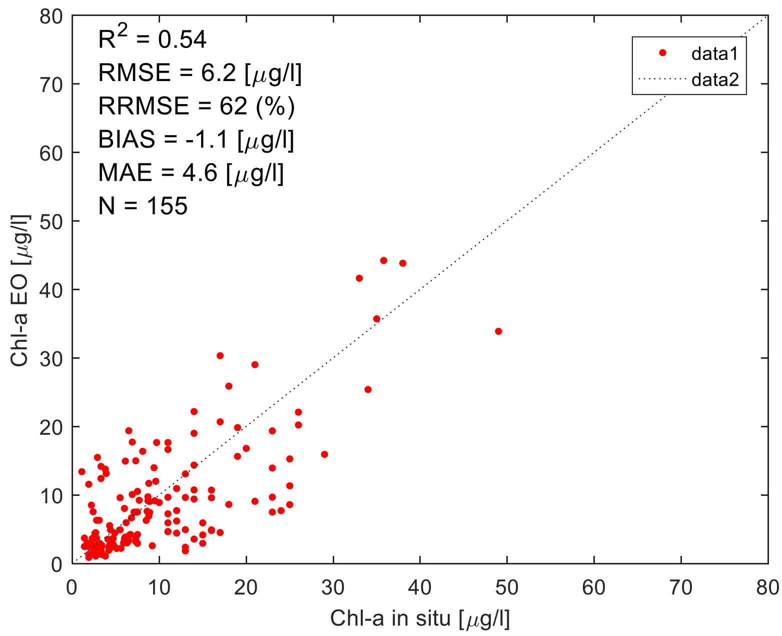

Figure 19 - Validation scatterplot(s) for chl-a EOMORES product, indicating R^2 and linear regression fit coastal and lakes stations included, years 2016-2019.

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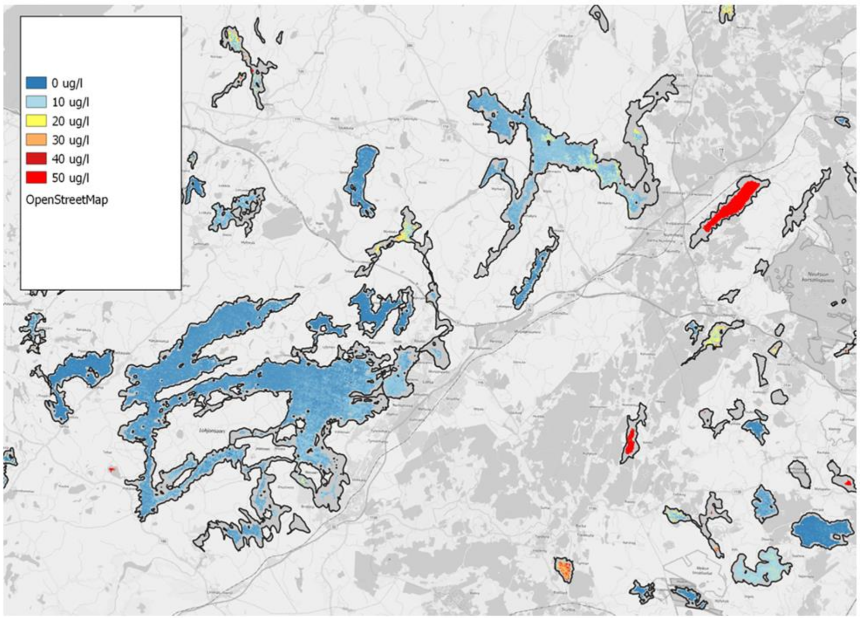

Figure 20 - Example map of chl-a EOMORES product over Southern Finland lakes district for summerly season 2017 (annual period accounted in WFD).

IV.4.2. Turbidity

The validation results for the Finland turbidity product are shown for coastal (Figure 21a) and coastal waters and lakes combined (Figure 21b). Example turbidity maps are provided in Figure 22 from the SYKE service line portal.

a) b)

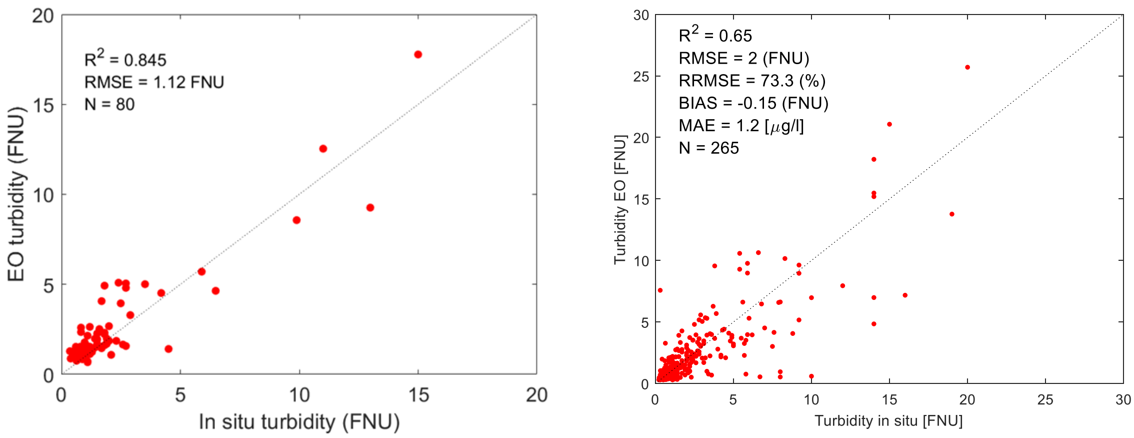

Figure 21 - Validation scatterplot(s) for turbidity EOMORES product, indicating R^2 and linear regression fit. a) coastal stations (2016-2017), b) coastal and lakes stations (2016-2019).

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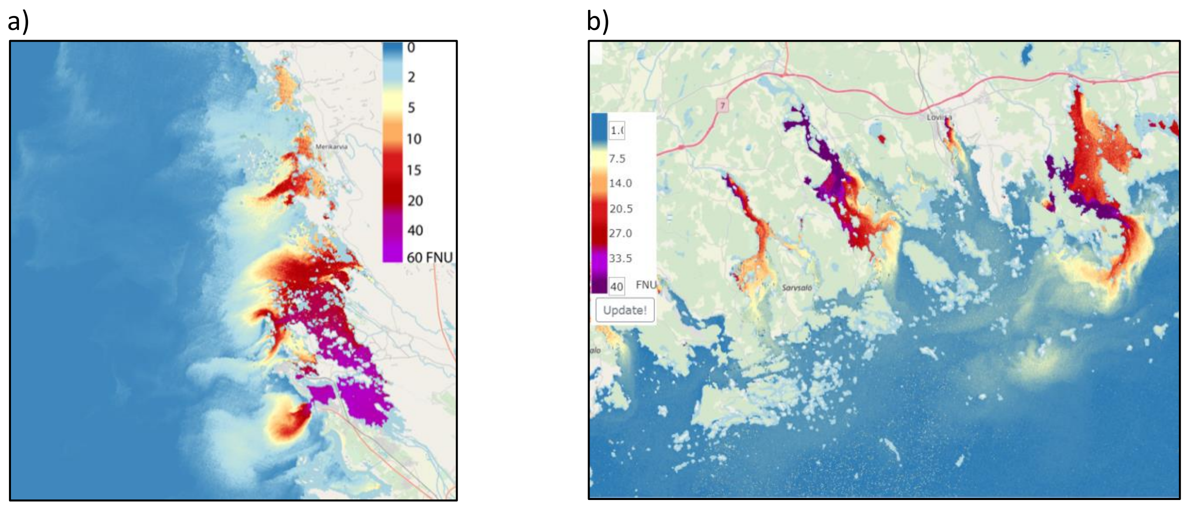

Figure 22 - Example map of turbidity EOMORES product for a) 14.4.2016 in west-coast of Finland and b) 20.4.2019 in the coastal Gulf of Finland. Riverine input to coastal waters is high during melting period.

IV.4.3. Coloured dissolved organic matter ($a_{CDOM}(400)$)

Validation of the CDOM absorption product for Finland is shown in Figure 23a. Additionally, results from a field campaign where samples were collected along a transect are shown in Figure 23b, indicating a good fit between the S2 MSI turbidity product (black) and CDOM from water samples (yellow). An example map from the SYKE service line portal is provided in Figure 24.

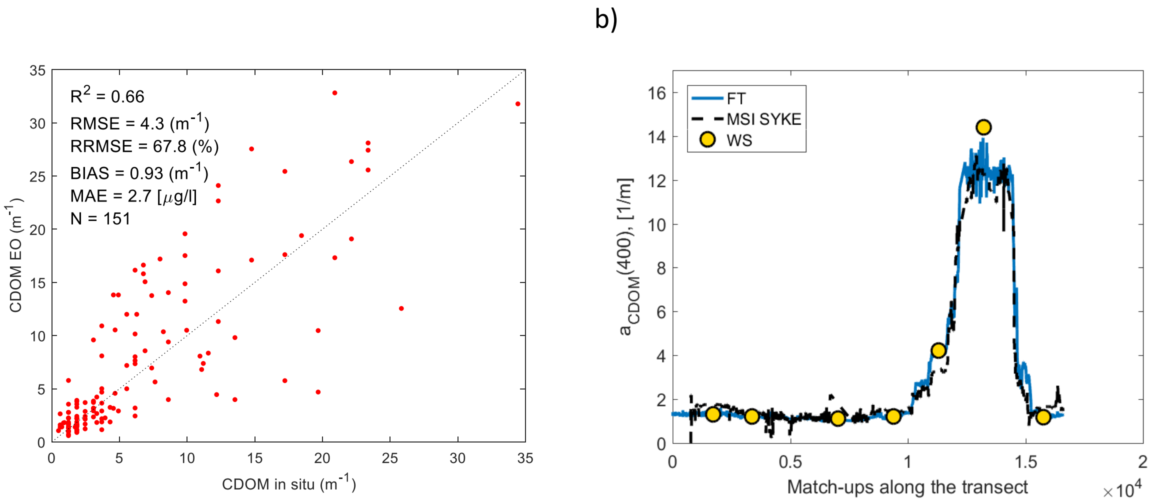

Figure 23 - Validation scatterplot(s) for a) $a_{CDOM}(400)$ EOMORES product, indicating R^2 and linear regression fit against aCDOM coarsely estimated from Pt water colour measurements over the stations (not actual a_{CDOM} measurements), and b) over a transect line (blue line) and water samples (yellow dots) during a coastal field campaign on 8.9.2016.

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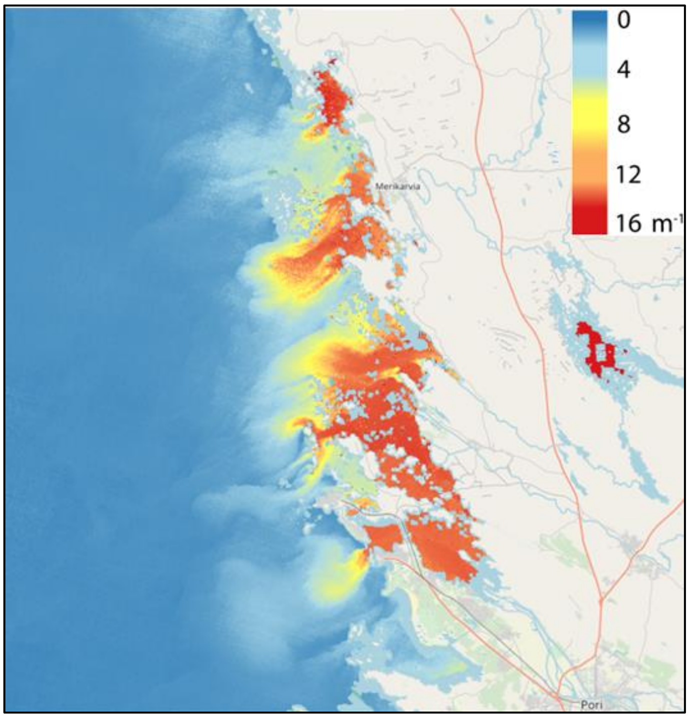

Figure 24 - Example map of Humic substances ($a_{CDOM}(400)$) EOMORES product for 14.4.2016 off the western coast of Finland.

IV.4.4. Secchi depth

The Secchi depth validation scatterplot for Finland is shown in Figure 25, indicating a good fit between satellite Secchi depth (from Landsat-8) and *in situ* Secchi depth (R^2=0.65). An example map of Secchi depth from the SYKE portal is shown in Figure 26.

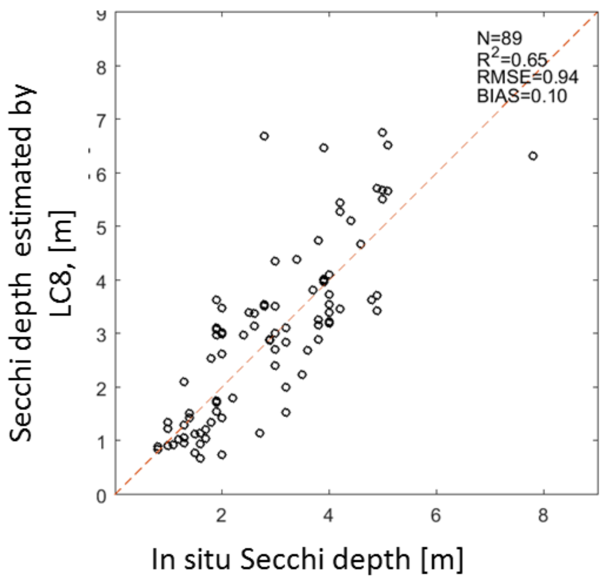

Figure 25 - Validation scatterplot(s) for Secchi depth EOMORES product, indicating R^2 and linear regression fit for coastal stations.

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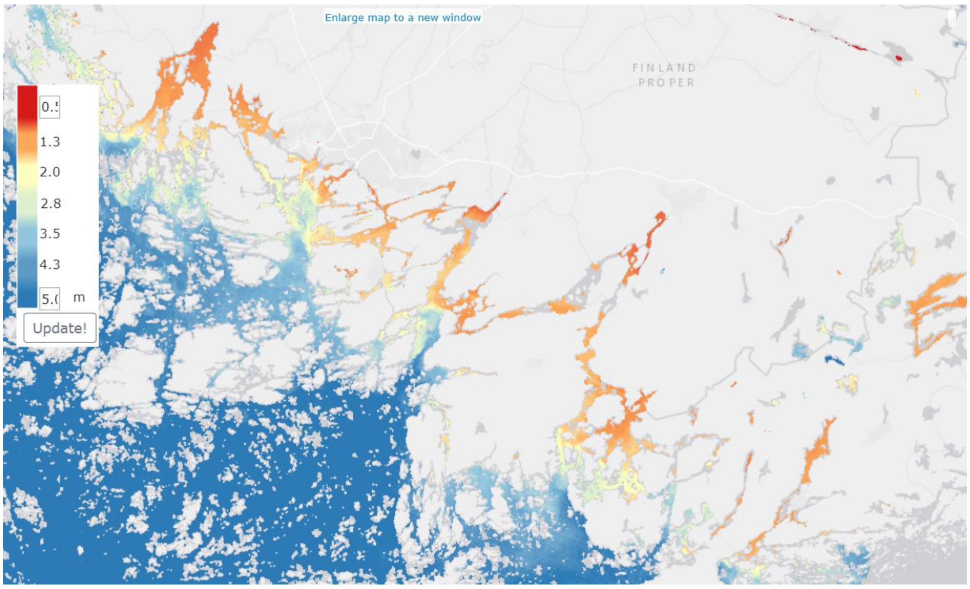

Figure 26 - Example map of Secchi depth EOMORES product for 9.5.2016.

IV.4.5. Surface algal bloom maps

Surface algal bloom EO maps cannot be validated using field sampling, as there are no observations other than coast guard flight announcements on surface blooms. However, some examples of the algal bloom product are shown below for the Northern Baltic Sea and Western Gulf of Finland (Figure 27).

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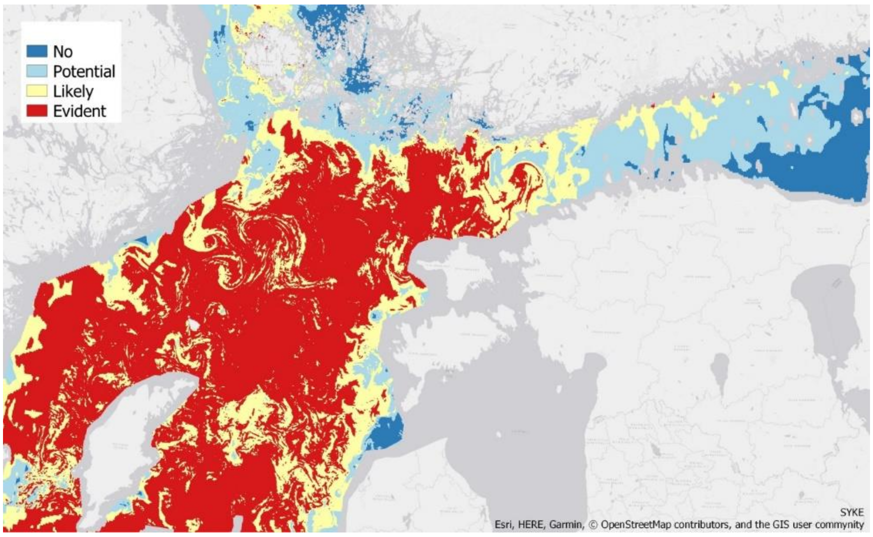
a)



b)

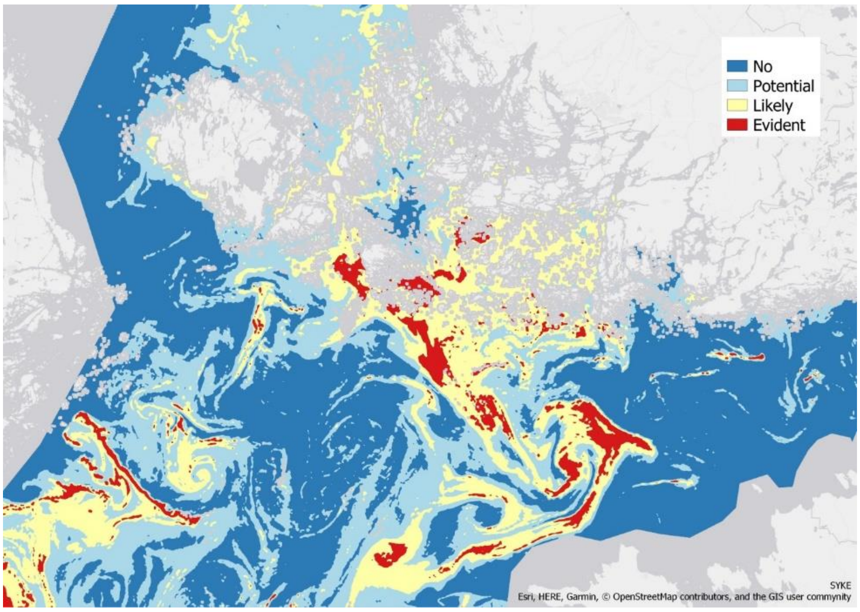


Figure 27 - Example map of surface algal bloom map EOMORES product for a) 25.7.2019 and b) 25.7.2018 for the area of Northern Baltic proper and Western Gulf of Finland.

IV.4.6. Uncertainty Assessment

A summary of the uncertainty metrics for the Finland EOMORES EO products is provided in Table 5. Results are presented for some parameters for coastal waters only, and for lakes and coastal waters combined.

Table 5 – Uncertainty metrics for Finland EOMORES EO products. Statistics are calculated by lakes and coastal water bodies (n> 1400) and by reference stations (n<500). CDOM is validated against field measurements from Pt water colour transformed to coarsely account for $a_{CDOM}(400)$.

Product	R^2	Slope	RMSE	MAE	n
Chl-a	0.55	0.72	6.2 µg l^{-1} (62 %)	5 µg l^{-1}	155

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Product	R^2	Slope	RMSE	MAE	n
Turbidity	0.65	0.8	2 FNU (73.3%)	1.2	265
Secchi depth, LC8	0.65	-	0.94	-	89
CDOM*	0.66	0.93	4.3 m^{-1} (67.8%)	2.7	151
Chl-a (Coastal and lakes)	0.49 (R = 0.7)	-	5.4 µg l^{-1} (60.2 %)	MAE = 3.75 µg l^{-1}	1484
Turbidity (coastal and lakes)	0.78	-	2.6 FNU (93.8%)	1.05 FNU	1595
Secchi depth (coastal and lakes)	0.65	-	1.09 m (51.27%)	0.82 m	1592

IV.5. Netherlands

For Lake Markermeer, *in situ* SPM, Chl-a and Secchi disk depth data of 2018 was provided by user NIOO-KNAW (NIOO). Also, for one day in August, optical measurements were taken with a WISP-3 instrument from WI.

Sentinel 2 and Sentinel 3 satellite data were used by to process into water quality maps of SPM, Chl-a and Secchi disk depth. This led to hundreds of maps, which were made available in the EOMORES portal. For the validation however, there were only a few days on which there were Sentinel satellite imagery as well as *in situ* data available. Instead, for algorithm testing, WISP-3 radiometric data can also be used to compare with *in situ* data. However, such a comparison simplifies the validation to validation of parameter retrieval algorithms, while for parameter retrievals from satellite validation also atmospheric correction is needed. The matching sets are the following: 27th June 2018 (*In situ* and WISP-3), 20th July 2018 (*In situ* and Sentinel-2), 21st August 2018 (*In situ*, Sentinel-2, Sentinel-3 and WISP-3), 25th September 2018 (*In situ*, Sentinel-2 and Sentinel-3), 14th November 2018 (*In situ* and Sentinel-2).

IV.5.1. SPM

The measurement data of SPM for which there are matching satellite and/or WISP-3 measurements with *in situ* measurements are mostly in the range between 10 and 15 mg/l. The few higher concentrations lead to outliers in the scatterplots (Figure 28, Figure 29), however, it is unclear if this is caused by a systematic error or a random error in the correlation, since there are too small data sets for the higher concentrations. Also, the expected error in the data of the two datasets is expected to be large compared to the difference between most of the measurements (Figure 30). R^2 and linear regression fit do not lead to proper values because of that.

A map (Figure 32) and a time series at a random point close to the MarkerWadden (Figure 31) shows that concentrations in the range of 10-15 mg/l occur frequently in the area in summer, but are not representative of the whole area nor for the whole year.

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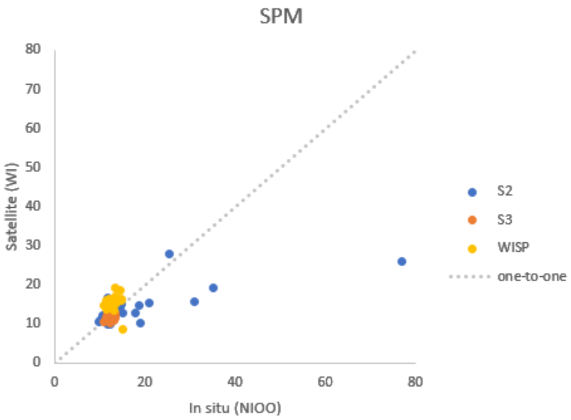

Figure 28 - Validation scatterplot for SPM

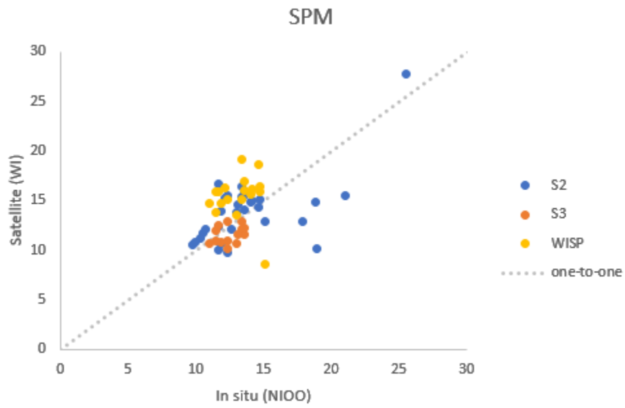

Figure 29 - Validation scatterplot for SPM zoomed in to the lower concentrations

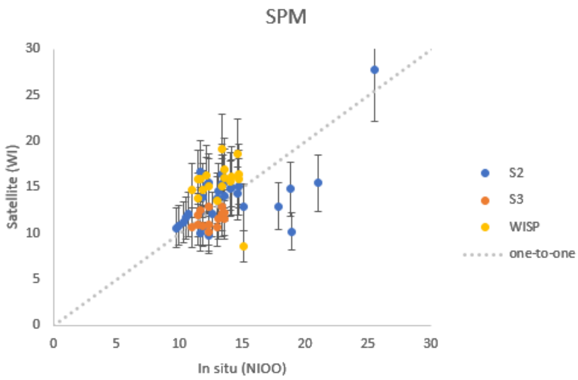

Figure 30 - Validation scatterplot for SPM zoomed in to the lower concentrations and with uncertainty bars of 20%

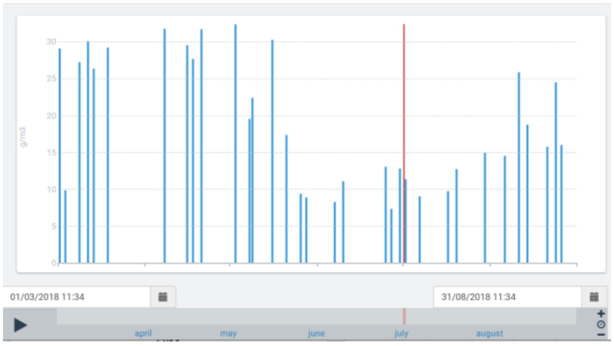

Figure 31 - SPM time series of concentrations derived from Sentinel-2 at a random point close to the MarkerWadden.

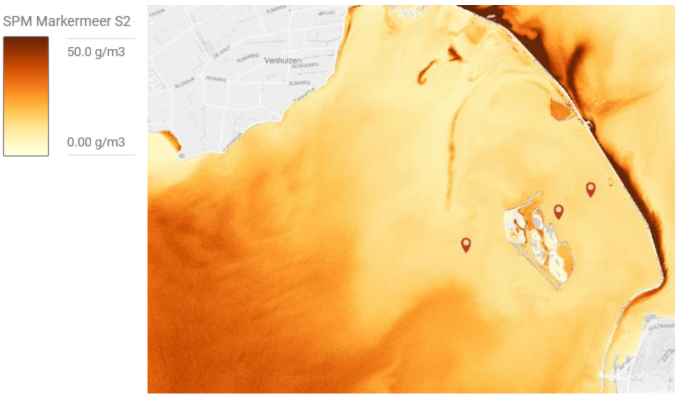

Figure 32 - Example map of SPM EOMORES product for 01.07.2018

IV.5.2. Chl-a

The chlorophyll algorithm which was used to derive Chl-a from the Sentinel satellites as well as with the WISP-3 is not calibrated for concentrations < 5 µg/l. If that range is ignored it appears that for the concentrations a similar issue occurs as for SPM: most matching sets of data are within small range, so that the expected error in the data of the two datasets is expected to be large compared to the difference between most of the measurements (Figure 33 and Figure 34). On the other hand, there are no outliers in the Chl-a scatterplots.

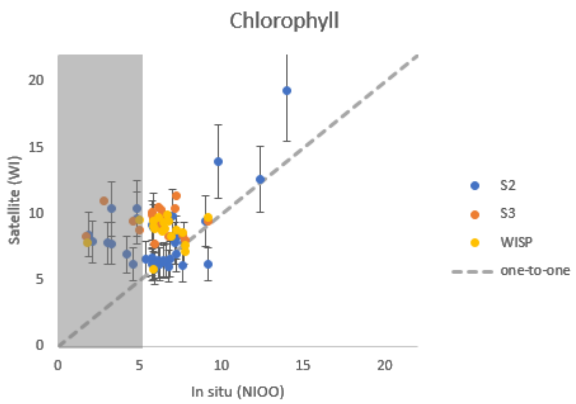

Figure 33 - Validation scatterplot for Chl-a, including 20% error bars. The concentration range for which the algorithm for WISP-3 and satellite data is known to be not applicable (< 5 µg/l) is greyed out.

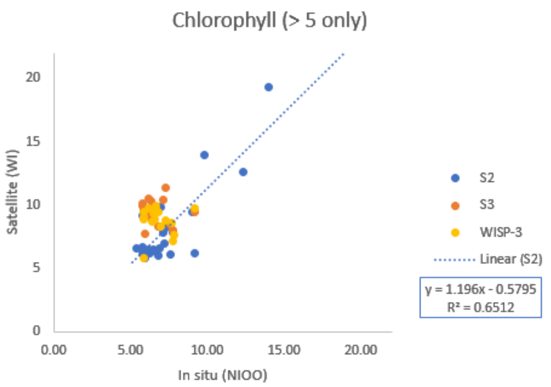

Figure 34 - Validation scatterplot for Chl-a from S2, S3 and WISP-3, for concentrations > 5 µg/l, indicating R2 and linear regression fit S2, for which the range is large enough to derive sensible statistics

A map (Figure 35) and time series of Chl-a from a random point close to the MarkerWadden (the same as used for SPM) derived from Sentinel-2 (Figure 36) show that in the area the concentration range of 5-10 µg/l is quite representative.

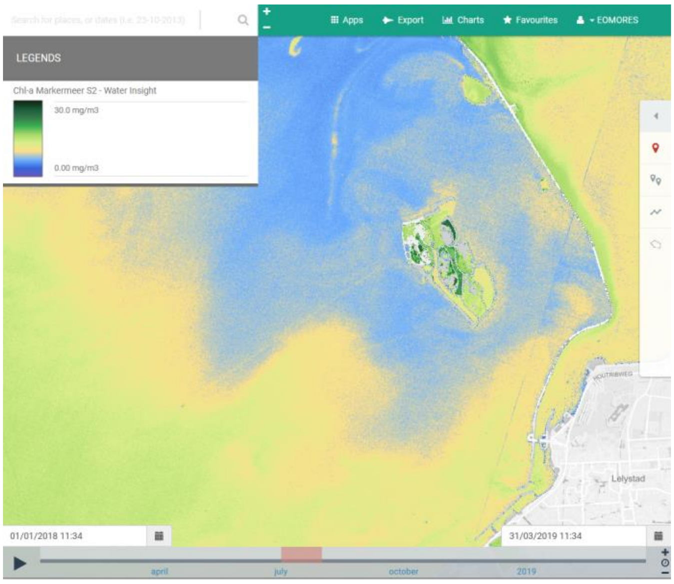

Figure 35 - Example map of Chl-a based on Sentinel-2 product for 01.07.2018

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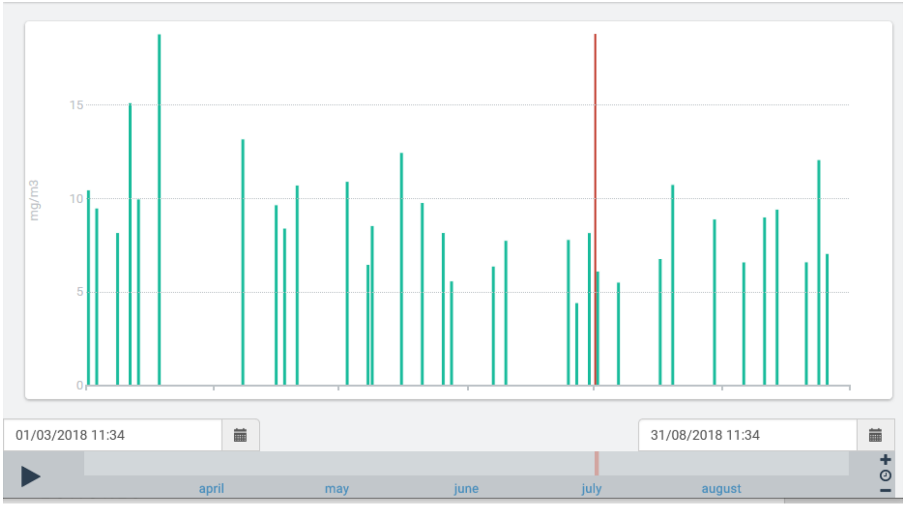

Figure 36 - Chl-a time series of concentrations derived from Sentinel-2 at a random point close to the MarkerWadden

IV.5.3. Secchi disk depth

The SD algorithms can easily be adjusted or tuned, since it is known that the correlation between the diffuse attenuation coefficient (K_d), which is the first parameter that is retrieved from EO and WISP-3 data, depends on properties of the available sediments and phytoplankton. For the WISP-3, the algorithm was tuned by adjusting the factor to retrieve SD from K_d, for the EO data this was not done yet.

If all matching data for SD is compared (Figure 37) the scatterplot seems rather noisy. However, if separate days are plotted (Figure 38, Figure 39, Figure 40) there seem to be two datasets. One part compares quite well, for the other part the Secchi disk depths are 1 ½ to 2 times larger than those observed *in situ*. Especially on August 21st, the data retrieved from WISP-3, Sentinel-2 and Sentinel-3 matches quite well and all seem to be about twice as high as the *in situ* observations (Figure 40).

The expectation is that the differences are related to sun and shadow in one of the two datasets. Since the *in situ* and satellite data are acquired on the same day, but not at the same moment, chances are that while for example a certain pixel in the satellite image was acquired during a bright sunny moment, the matching *in situ* Secchi disk depth could have been measured in the shadow, leading to a shallower Secchi disk depth.

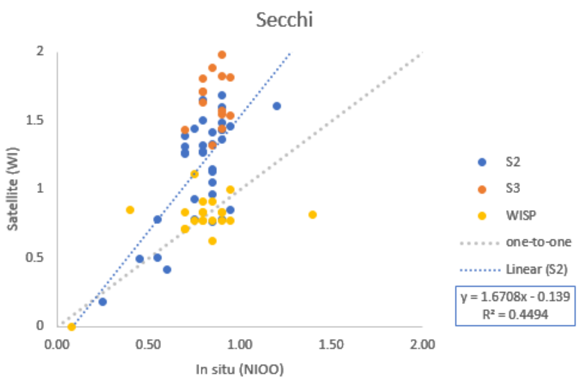

Figure 37 - Validation scatterplot for SD of all matching dataset indicating R2 and linear regression fit S2.

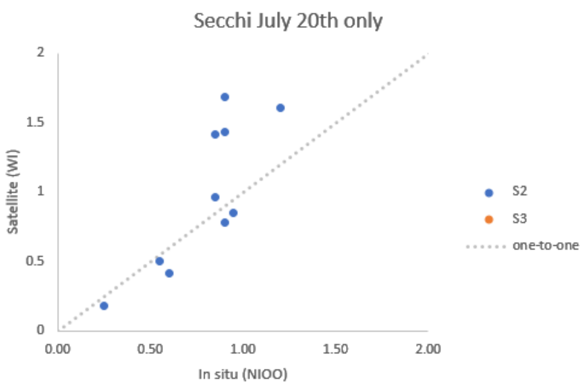

Figure 38 - Validation scatterplot for SD for July 20th only

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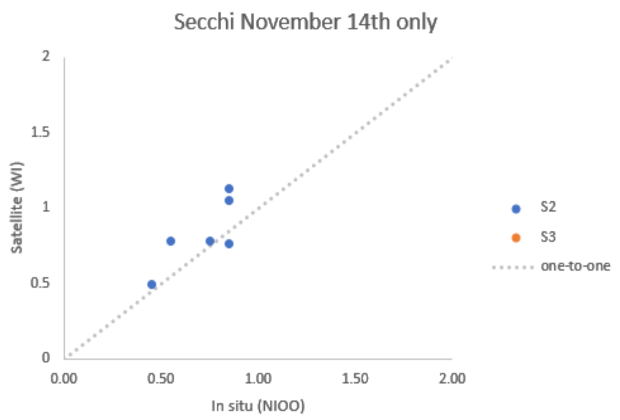

Figure 39 - Validation scatterplot for SD for November 14th only

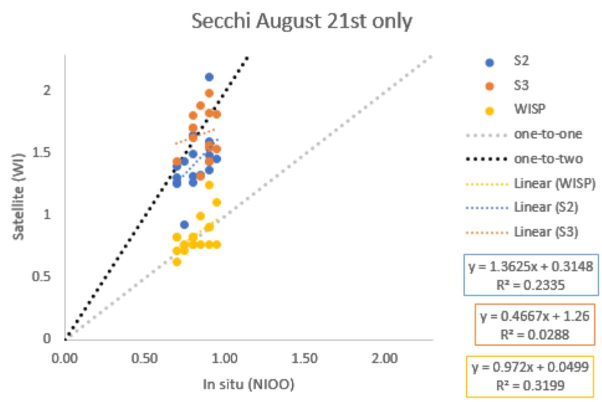

Figure 40 - Secchi disk scatterplot for August 21st only, indicating R2 and linear regression fit for all datasets

The SD maps for August 21[st] based on S2 and S3 are shown in Figure 41 and Figure 42 respectively.

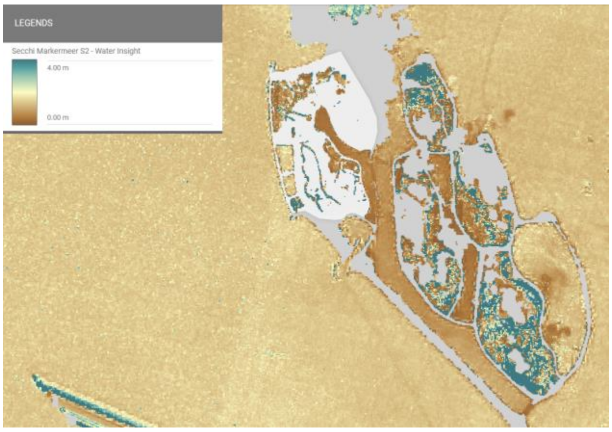

Figure 41 - Example map of SD based on S2 product for 21.08.2018

Figure 42 - Example map of SD based on S3 product for 21.08.2018

IV.5.4. Uncertainty Assessment

For Lake Markermeer, the matchups between *in situ* measurements and satellite acquisitions occurred in a small concentration range. Therefore, the expected error in the datasets is for several sets larger than the difference within the sets. The SPM range was only somewhat larger for the S2 versus *in situ* set. The few high concentrations points in the scatterplot are either outliers or the algorithm to retrieve SPM needs to be adjusted. For Chl-a, the algorithm seems suitable, but a larger concentration range would be helpful for a more robust validation. Tuning of the WISP-3 SD algorithm lead to a reasonable correlation. Figure 40 suggests that a similar tuning will also lead to good results from S2 and S3. Such a tuning is not applied yet because it would be better to have a larger matchup dataset to do so.

Table 6 – Uncertainty metrics for Netherlands EOMORES EO products

Product	R^2	Slope	RMSE	MAE	n
SPM (S2)	-	-	2.0	2.0	34
Chl (S2)	0.65	1.2	0.58	0.58	26
SD (S2, all days)	1.67	0.45	0.31	0.31	35

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IV.6. UK

Dedicated field campaigns were conducted opportunistically on Loch Leven (56.198641, -3.374202) and Loch Lomond (56.075124, -4.591543) to collect in situ data for validation of UK EOMORES products. Data were collected from 67 stations in both lochs, between May and October 2017-2018. During these campaigns, biogeochemical (chlorophyll-a (Chl-a), Total Suspended Matter (TSM)) samples were collected for water quality product validation, and radiometric (TriOS Ramses) data for validation of the satellite normalized water-leaving reflectance ($R_w(\lambda)$).

Additional datasets were acquired from UK and Ireland public users (SEPA, EA, EPA) resulting in Chl-a, TSM and transparency (Secchi depth) datasets for validation. Many of these samples were taken from the shore and are not ideally suitable for satellite validation. These samples were only used where they sufficiently increased the sample size. Further work is ongoing to investigate how we can use these in situ datasets for satellite validation.

All satellite reflectance data were processed using the *Calimnos* processing chain (PML) including atmospheric correction using Polymer. Both Sentinel-2 MSI and Sentinel-3 OLCI validation results are presented here for all algorithms tested, although blended algorithm results using an optical water type framework (Spyrakos et al. 2018) are applied in the EOMORES service.

IV.6.1. Chl-a

Sentinel-2 MSI

The Sentinel-2 MSI Chl-a algorithm tested included the Ocean Colour 2 (OC2; O'Reilly et al., 2000), Gons05 semi-analytical (Gons et al., 2005) and near infrared-red empirical models (Gitelson et al., 2011). Of these, the Chl-a product with the lowest RMSE, MAE and MAPE was the OC2 algorithm for the validation dataset. However, this algorithm is only suitable for clear waters and Chl-a below 10 mg m^{-3} above which it is likely to still correlate with Chl-a but no longer diagnostic of the pigment concentration. Since most of the in situ measurements are greater than 10 mg m^{-3} it is not advisable to tune this algorithm here in order to resolve the consistent underestimation of Chl-a (Figure 43). The fact that the NIR-red band ratio algorithms do not outperform the blue-green (OC2) ratio algorithm is indicative of issues in the atmospheric correction stage, distorting the shape of the retrieved reflectance spectrum.

An example S2 Chl-a product map from the PML EOMORES service is shown in Figure 44 for Loch Lomond and the Trossachs lakes.

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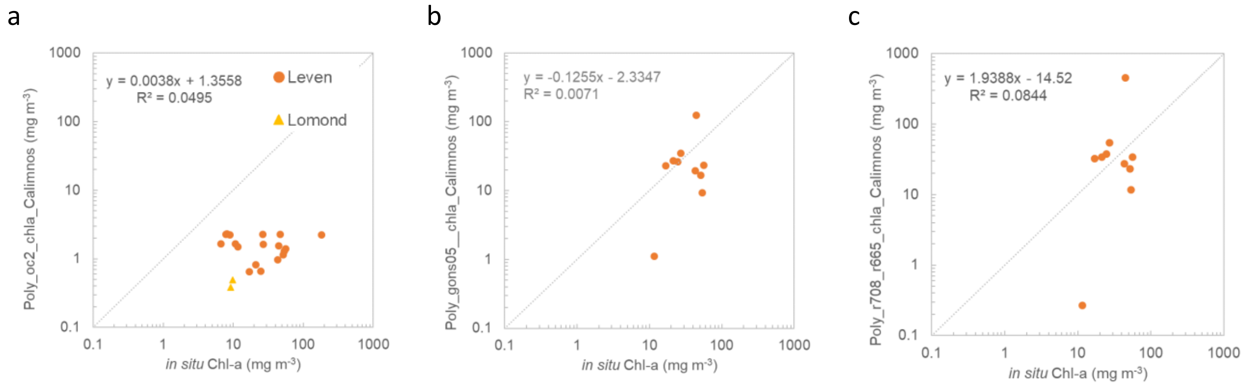

Figure 43 - Validation scatterplots for UK S2 Chl-a product, indicating R^2 and linear regression fit for a) OC2, b) Gons et al (2005) and c) NIR-red empirical algorithms.

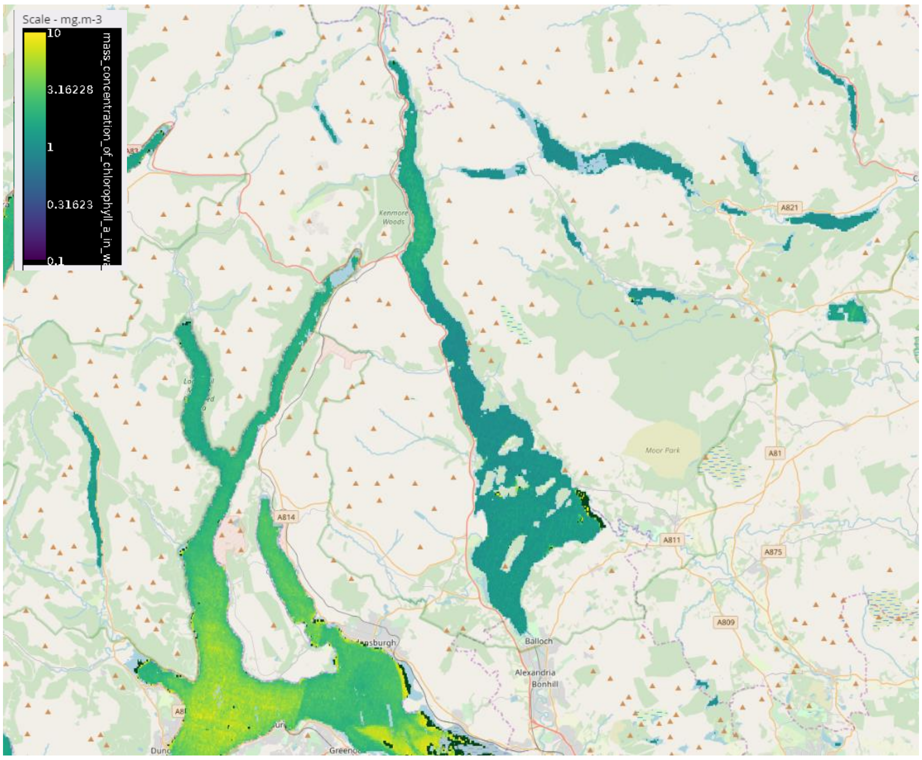

Figure 44 - Example map of S2 Chl-a product for Loch Lomond and the Trossachs lakes, UK on 25.06.2019 (OC2 algorithm)

Sentinel-3 OLCI

The Sentinel-3 OLCI Chl-a algorithms implemented in Calimnos were the OC2 (O'Reilly et al. 2000), two version of the Quasi-analytical Algorithm (QAA; Lee et al., 2002; Mishra et al., 2013), a near infrared-red empirical model (Gitelson et al., 2011) and the Gons et al. (2005) semi-analytical model. Results for validation using the USTIR dedicated field campaigns only are shown here, as these data were specifically collected for matchup with satellite data and use a consistent laboratory method for Chl-a analysis (HPLC) (Figure 45). Of the algorithms tested, the Gons semi-analytical model was the best performer, with the highest R^2 (0.417) and lowest RMSE (31.0 mg m^{-3}). However, we note that

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the OC2 Chl-a model also had relatively low errors (MAPE=95.8%, MAE=18.1 mg m^{-3}, RMSE=36.7 mg m^{-3}).

An example S3 Chl-a product map from the PML EOMORES service is shown in Figure 46 for Loch Leven.

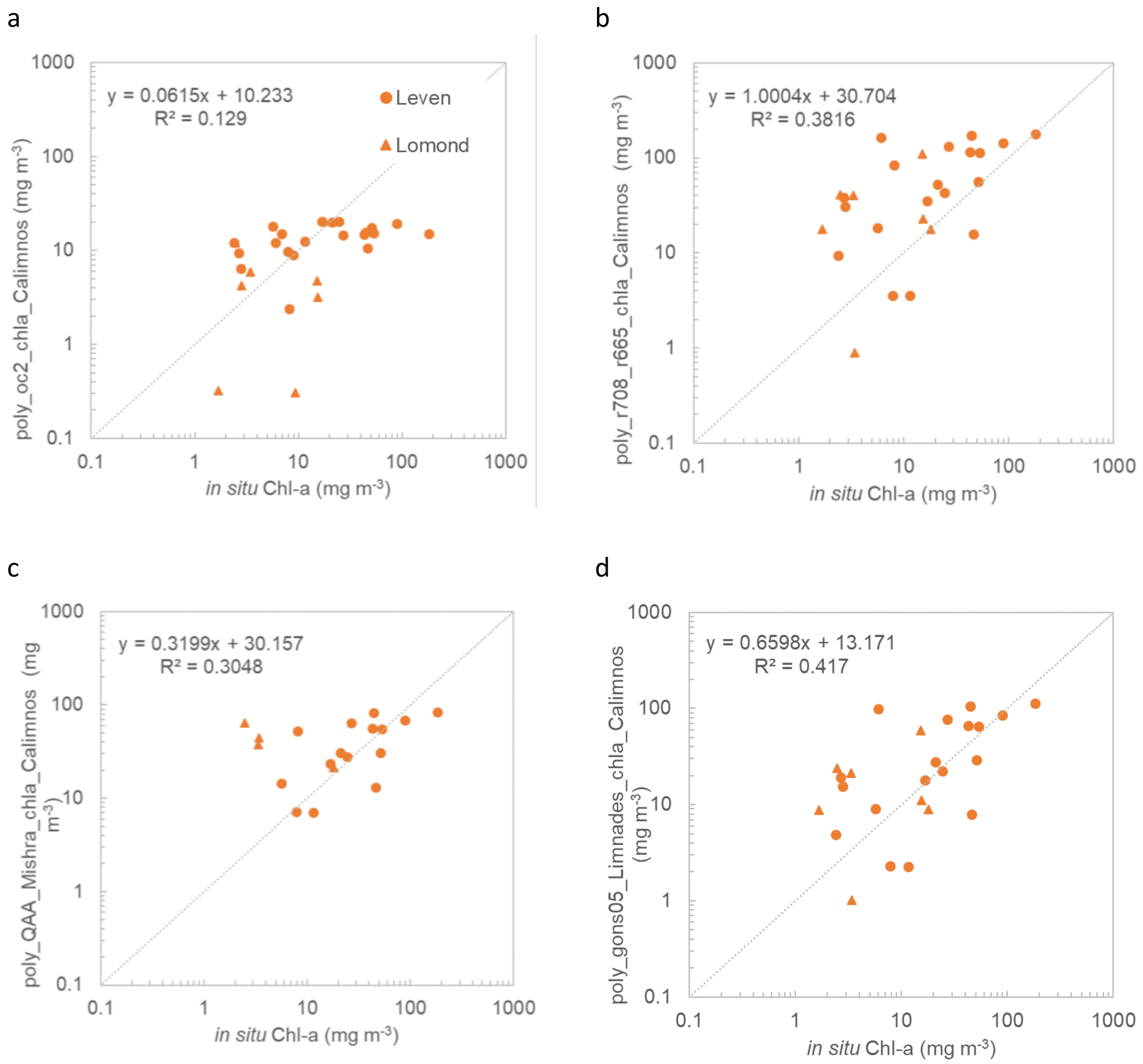

Figure 45 - Validation scatterplot(s) for UK S3 Chl-a products, indicating R^2 and linear regression fit for a) OC2, b) NIR-red empirical, c) QAA and d) Gons et al (2005) algorithms.

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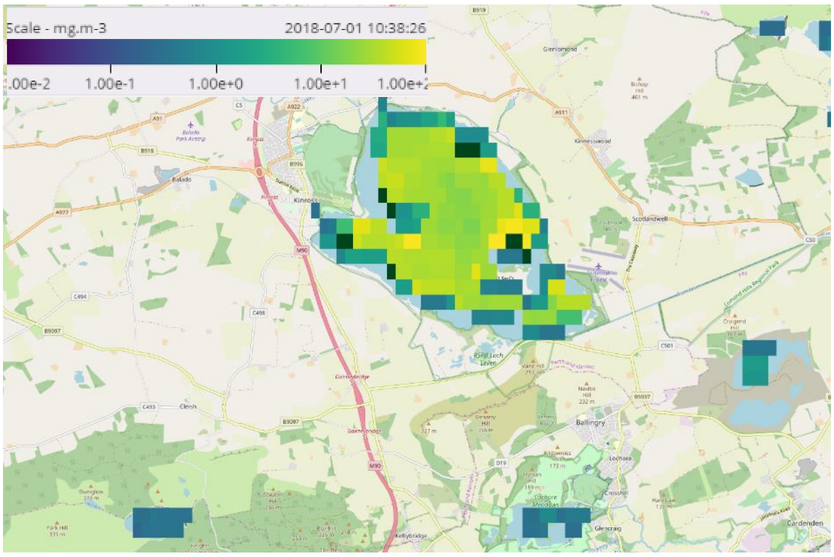


Figure 46 - Example map of S3 Chl-a EOMORES product for Loch Leven, UK on 01.07.2018 (blended Chl-a product from predominant optical water type)

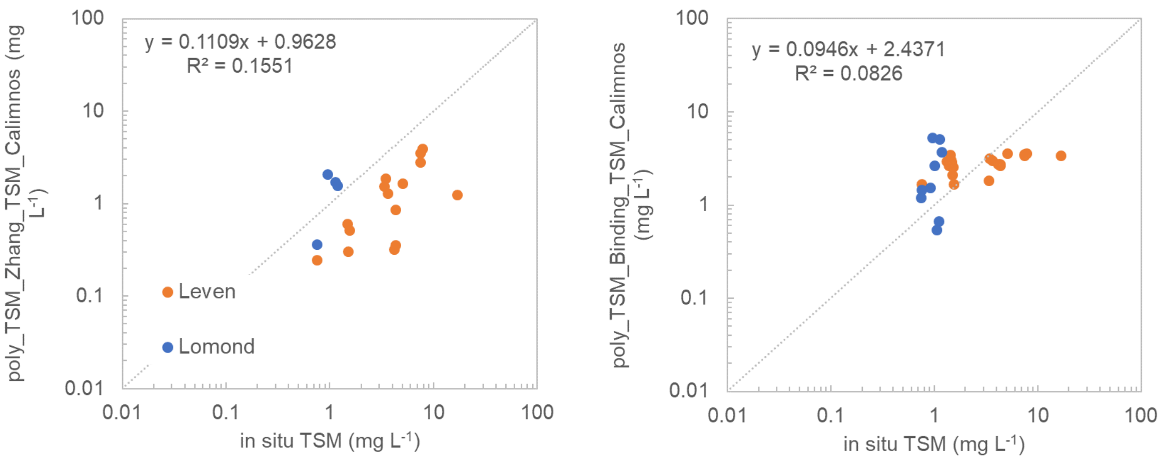
IV.6.2. TSM

Sentinel-3 OLCI

Several single-band or regional TSM algorithms were tested for Sentinel-3, including Vantrepotte et al (2011), Zhang et al (2014), Nechad et al (2010) and Binding et al (2010a,b). These were validated with the dedicated field campaign data from Loch Leven and Loch Lomond, as the SEPA suspended solids dataset were shore based samples and thus there were few matchups with Sentinel-3. The best performing algorithm was Binding et al (2010), with the lowest RMSE, MAE and Bias, however the best correlation between satellite and *in situ* TSM was found for the Zhang et al (2014) algorithm.

An example S3 blended turbidity product map from the PML EOMORES service is shown in Figure 48. S3 turbidity was derived from blending of the TSM algorithms.

a b



c d

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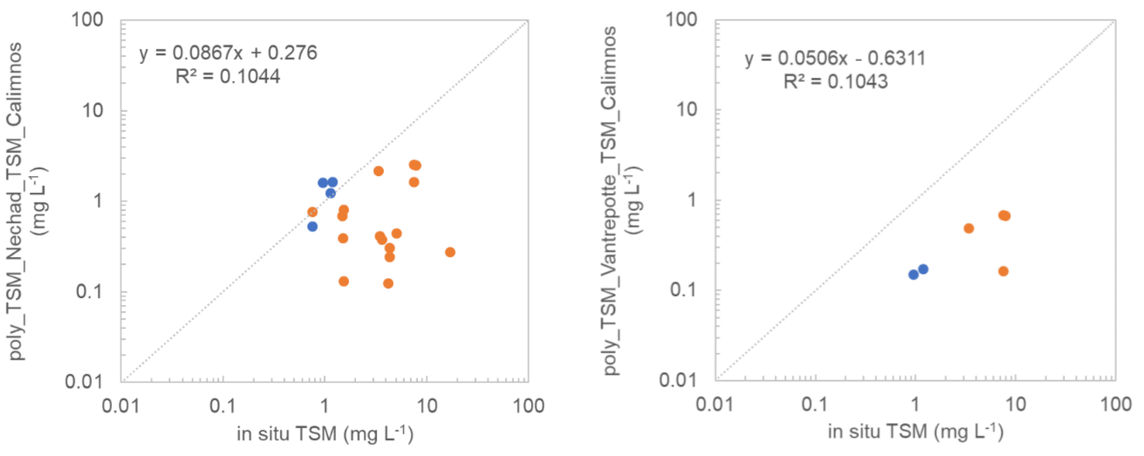

Figure 47 - Validation scatterplots for UK Sentinel-3 TSM product, indicating R^2 and linear regression fit for a) Zhang et al (2014), b) Binding et al (2010), c) Nechad et al (2010) and d) Vantrepotte et al (2011) algorithms.

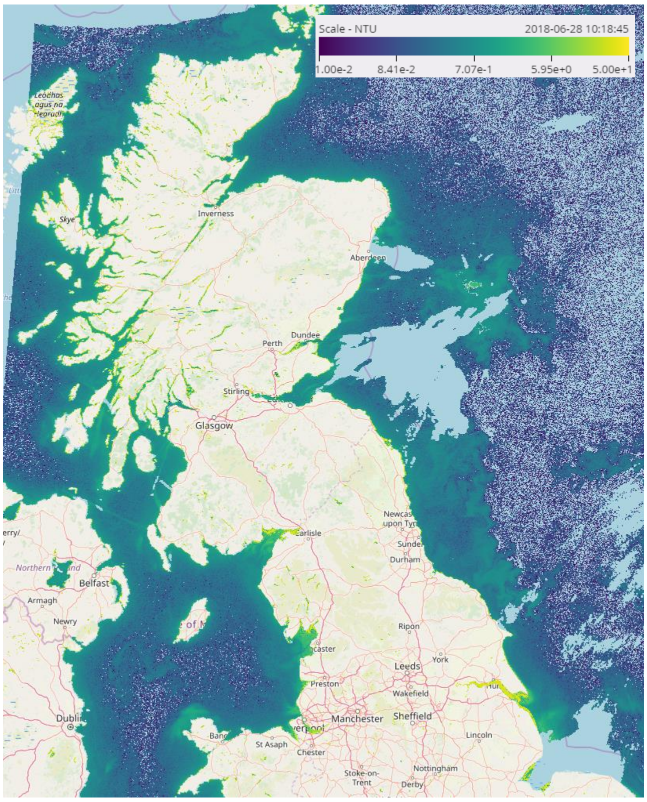

Figure 48 - Example map of EOMORES turbidity (blended from TSM algorithms) product for UK inland and coastal waters on 28.06.2018

IV.6.3. Turbidity

The UK turbidity products were validated using the TSM data from the dedicated field campaigns on Loch Leven and the SEPA monitoring TSM data for Scottish Lochs. Note, that there were no validation metrics presented for turbidity, as this product is only partially validated with TSM due to the lack of a sufficiently large in situ turbidity dataset. However, the coefficient of determination and linear regression are able to indicate goodness of fit for the turbidity products.

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Sentinel-2 MSI

The Nechad et al (2009) turbidity algorithm was implemented for S2 using the red and near infrared wavelengths (665, 705, 783 and 865 nm). Of these, the highest R^2 value was for the 705 nm band Nechad algorithm (R^2=0.495, USTIR + SEPA datasets).

An example S2 turbidity product map from the PML EOMORES service is shown in Figure 50 for Windermere, Esthwaite Water and Coniston Water (Lake District, UK).

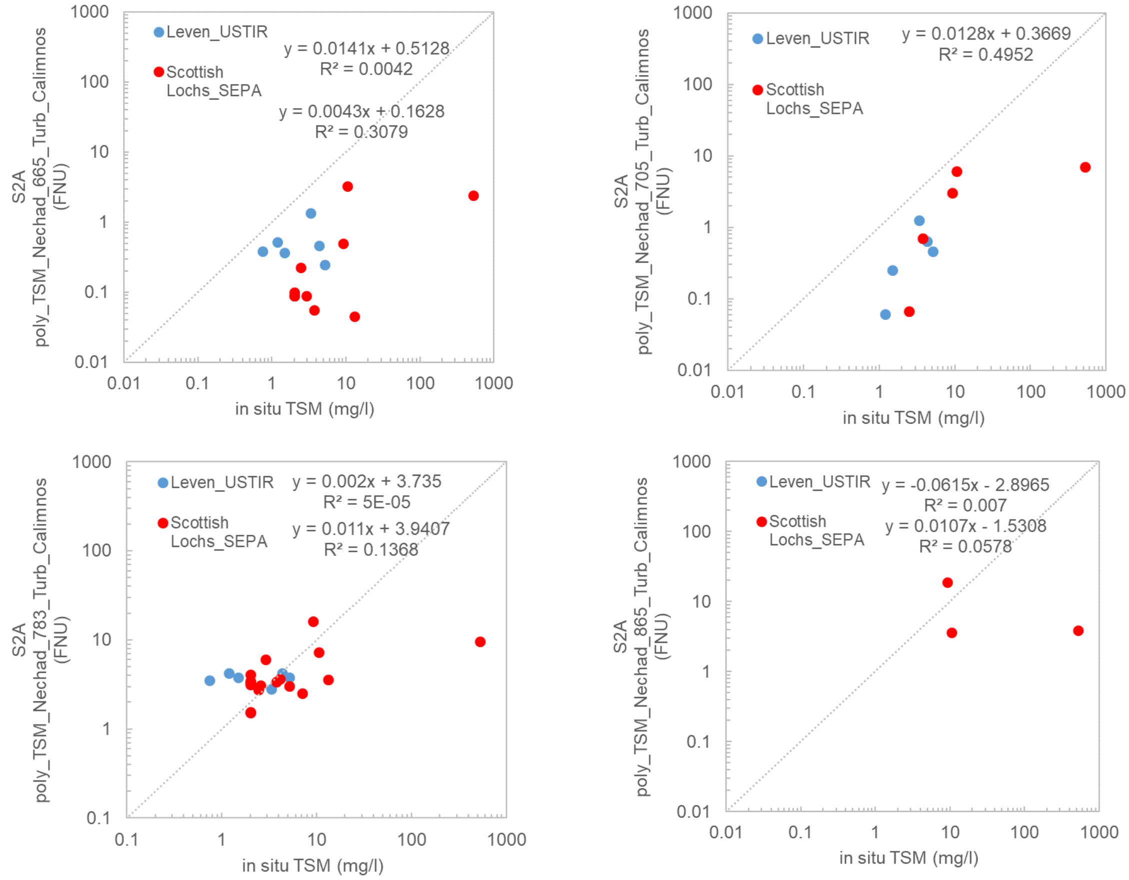

Figure 49 - Validation scatterplots for UK S2 EOMORES turbidity product, indicating R2 and linear regression fits for each dataset

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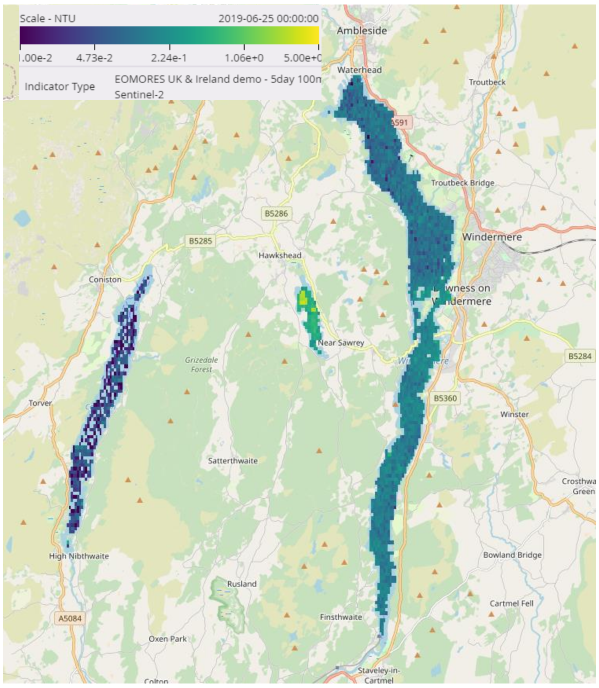

Figure 50 - Example map of EOMORES S2 turbidity product for the Lake District, UK on 25.06.2019

IV.6.4. Uncertainty Assessment

Overall, the UK EOMORES validation shows that individual algorithm performance is relatively poor (Table 7). This is partly due to challenging observation conditions (atmospheric conditions, lake morphology, many relatively clear and narrow lakes) and limited matchup availability and partly due to the spatio-temporal variability of the optically active components in the tested lakes. Work is ongoing to provide adequate alignment of high-resolution S2 MSI products with the ocean-colour sensor based (but coarser) S3 OLCI products. Figure 51 shows Sentinel-2 vs Sentinel-3 Chl-a for the three algorithms used and that further tuning of the Sentinel-2 algorithms is required. The main source of error in these products remains the atmospheric correction procedure, as can be seen from generally more accurate retrieval results using in situ radiometry, in the next section.

Table 7 – Uncertainty metrics for UK EOMORES EO products

Product	R^2	Slope	RMSE	MAE	n
S2 Chl-a (OC2)	0.05	0.0038	49.4	31.7	20
S3 Chl-a (Gons et al., 2005)	0.417	0.660	31.0	21.2	29
S3 TSM (Binding)	0.155	0.111	3.21	2.07	29
S2 Turbidity (Nechad)	0.495	0.0128	-	-	24

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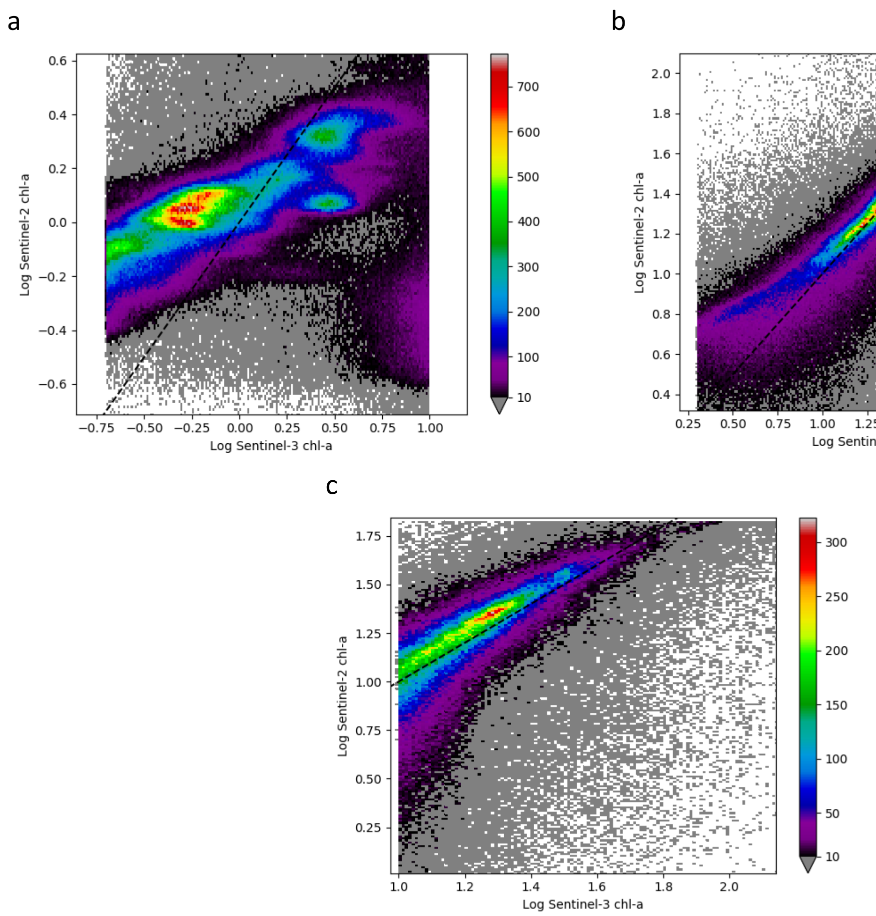

Figure 51 - Density plots of Sentinel-2 vs Sentinel-3 Chl-a derived from a set of global lakes. Images show OC2 (a), NIR-red (b) and Gons05 (c). Colour scale denotes the number of observations per-pixel.

V. *In situ* Product Accuracy Assessment

V.1. WISPstation

The EOMORES *in situ* instrument (WISPstation, Water Insight) was installed in Italy, Estonia, Lithuania (x 2) and the UK. The WISPstation collects high-frequency *in situ* measurements of remote sensing reflectance (R_{rs}) and water quality parameters are derived from the reflectance data. During the 2017-2019 period, match-up *in situ* reflectances and water quality (Chl-a and TSM) data were collected at each site to use for validation of the WISPstation, and these results are presented below.

V.1.1. Chl-a

Chl-a was derived from five different WISPstations of four regions, and compared with Chl-a acquired from simultaneous (for Italy an average over the hours of *in situ* sampling) *in situ* samples (Figure 52). The *in situ* data samples were processed with different methods, depending on institutes' or national standards. Extractions with done with acetone, ethanol and methanol, and methods were spectrophotometric and HPLC. Those differences in methods between countries could explain the slight differences in slope between the sets of the different countries.

Overall, there is a very good fit between in situ and WISPstation Chl-a, with an R^2 of 0.83 and a slope of 0.87.

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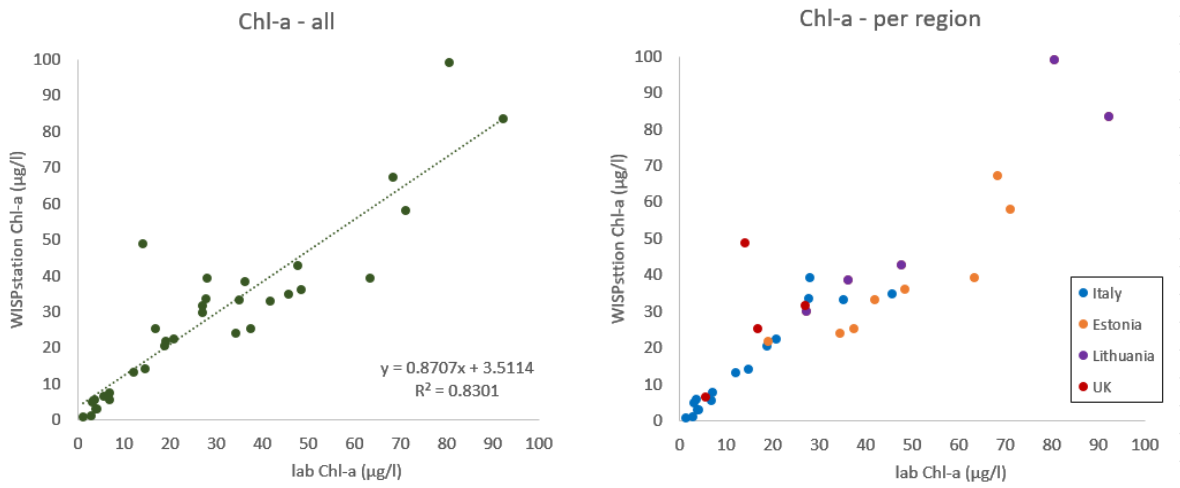

Figure 52 - Validation scatterplots for WISPstation Chl-a, indicating R^2 and linear regression fit

V.1.2. SPM

SPM was derived from five different WISPstations of four regions, and compared with SPM acquired from simultaneous *in situ* samples (Figure 53). All SPM samples were filtered and the concentrations were derived gravimetrically. In the UK the mean of three replicates was used.

Overall, there is a very good fit between in situ and WISPstation SPM, with an R^2 of 0.88 and a slope of 0.80. However, there is an offset of 3.4 mg/l, and the scatter seems to increase for the higher concentrations.

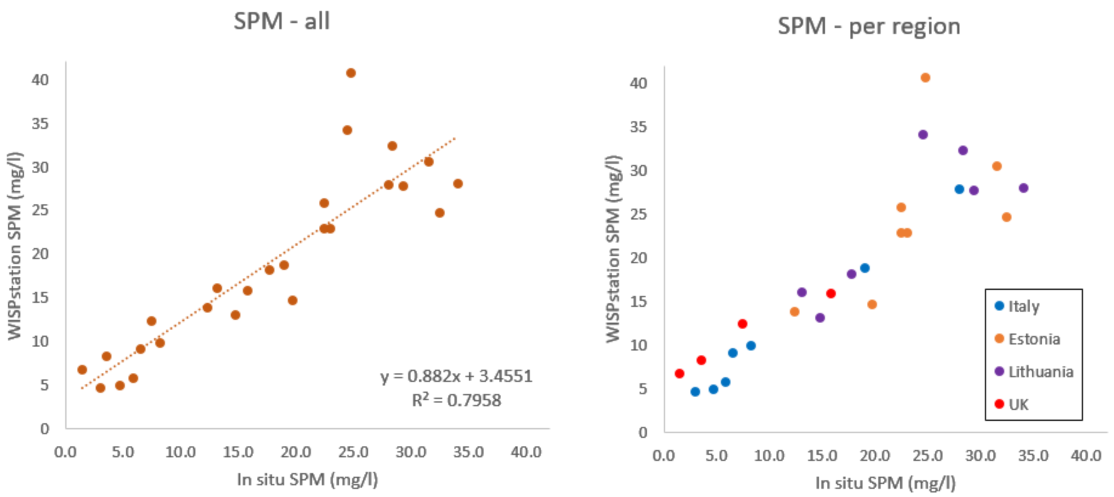

Figure 53 - Validation scatterplots for WISPstation TSM, indicating R^2 and linear regression fit

V.1.3. R_{rs}

The WISPstation measures the reflectance on the water surface. From these, it derives Chl-a and SPM (see previous paragraphs). Since some users might be interested in the reflectance itself, we provide examples of reflectance spectra for the different regions here (Figure 54).

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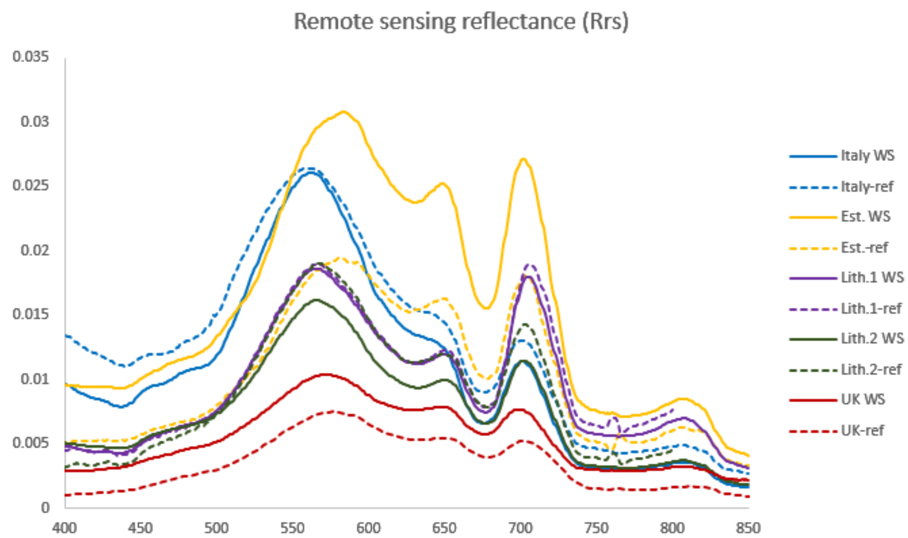

Figure 54 - Examples of matching Rrs spectra from the different regions. WS stands for WISPstation, -ref for the reference instrument (which is different per region). Est. = Estonia, Lith. = Lithuania. In Lithuania there are two WISPstation installed.

For clarity, the matchup reflectance sets for each region are also shown separately in the following figure (Figure 55). Note that the vertical axis scaling varies.

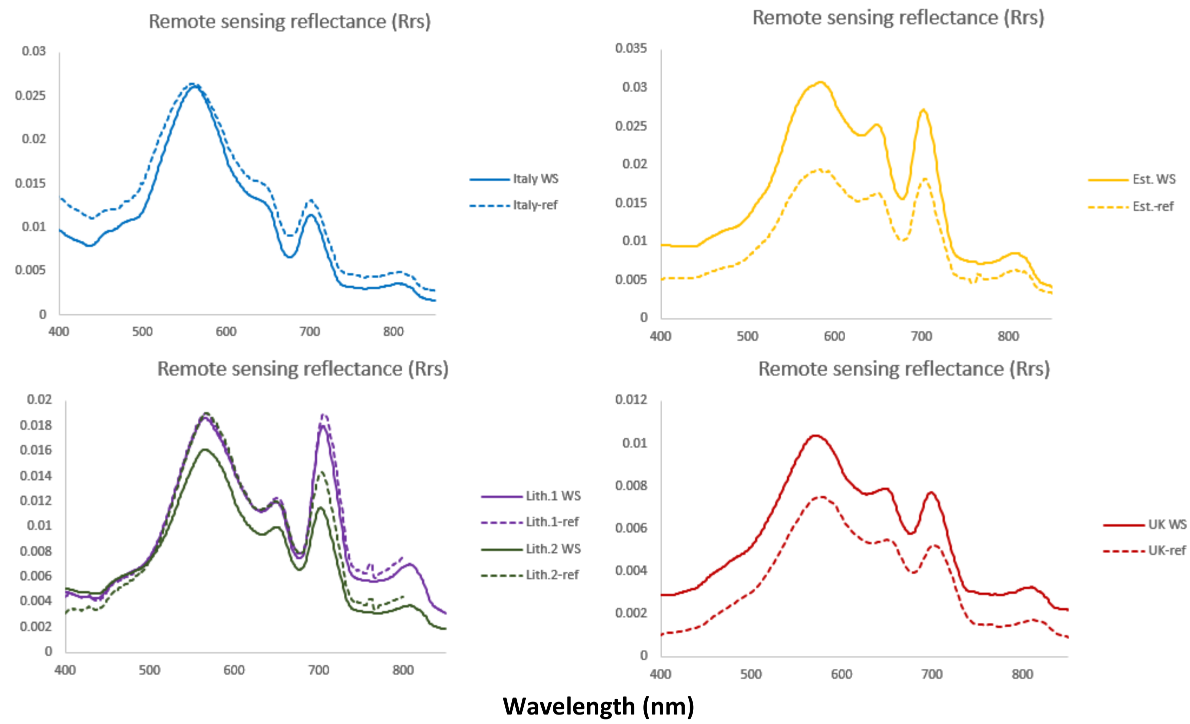

Figure 55 - Reflectance spectra of the different regions (y-axis units = sr^{-1}). WS stands for WISPstation, -ref for the reference instrument (which is different per region). Est. = Estonia, Lith. = Lithuania. In Lithuania there are two WISPstation installed. The reference instruments are: Italy: SpectralEvolution SR-3500, Lithuania: WISP-3 (with own calibration), Estonia: WISP-3, UK: TriOS Ramses

The reflectance spectra are very similar in Italy and for both WISPstations in Lithuania. The spectral shapes the WISPstation and reference sensors are very similar in Estonia and the UK, but for these locations there is (at least for the presented matches) an offset in the intensity of the reflectance. In both cases, the WISPstation R_{rs} is higher than the reference.

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V.1.4. Uncertainty Assessment

Table 8 provides the uncertainty metrics for Chl-a and SPM from the WISPstation as compared to *in situ* samples processed in laboratories in Italy, Estonia, Lithuania and the UK.

Table 8 – Uncertainty metrics for EOMORES in situ products from the WISP Station

Product	R^2	Slope	RMSE	MAE	n
Chl-a	0.83	0.87	3.37	3.37	33
SPM	0.88	0.80	1.39	1.39	26

VI. Modelling Product Accuracy Assessment

VI.1. Algae Radar

The Algae Radar model was presented in the Initial Validation Report (D5.2). Here, the performance results for 2018 are shown as a time series in Figure 56, indicating a good matchup between *in situ* (blue) and modelled (red line) Chl-a. Model performance results for the Paterswoldsemeer, Netherlands for 2010-2017 are presented in Table 9. Overall, 74% of the predictions matched with the observations (i.e. 100 correct predictions out of 136 total observations).

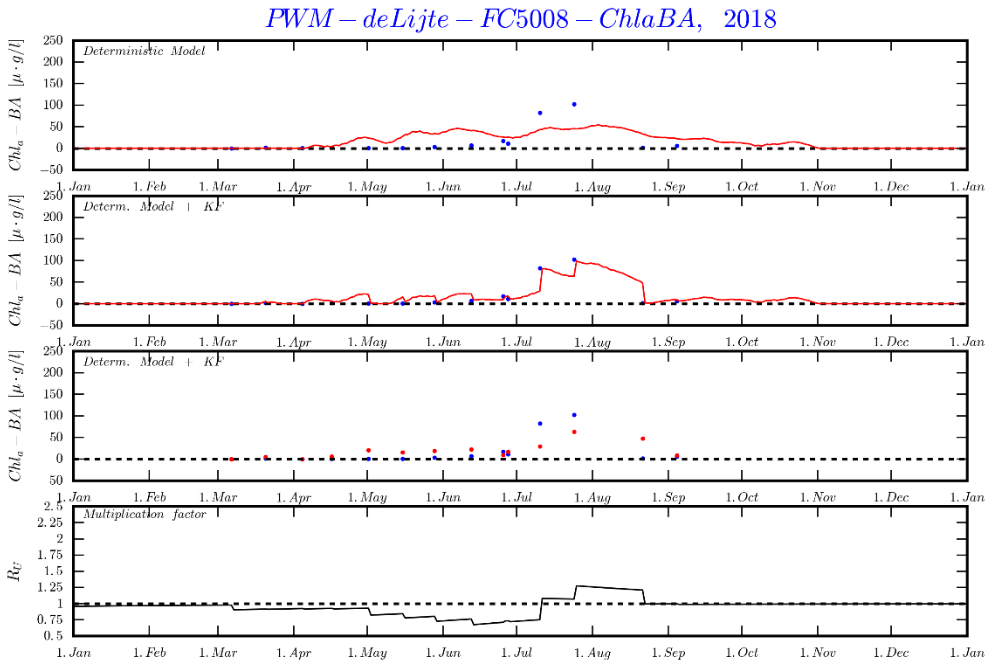

Figure 56 - Model time series plot with in situ data

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Table 9 - Model performance for the Paterswoldsemeer from 2010-2017. The Chl ranges are the bathing water indexes used in the Netherlands for cyanobacteria (based on chlorophyll-a). Numbers in bold indicate a match between model predictions and observations. In this case 74% of the predictions match with the observations.

		Observations (n=136)		
Predictions	Chl ranges ↓ →	0-12.5	12.5-75	>75
	0-12.5	**79**	4	0
	12.5-75	23	**21**	6
	>75	0	3	**0**

VII. Product fitness for purpose assessment

In addition to assessment of the products, we produced a questionnaire for all partners to use to during user meetings following delivery of the EOMORES products and service. Users were asked to evaluate the product fitness for purpose, including assessment and feedback on general completeness of products received or not received. Users were also queried on product quality/accuracy and fitness for purpose, which included whether the products showed the expected values or patterns, and whether the products are suitable for their purposes (in terms of acceptable uncertainty, metadata, temporal frequency and spatial coverage).

Responses were gauged on a scale of 0-10, where suitable, where a rating of 0 is 'Not at all', 5 is 'Somewhat' and 10 is 'Yes, Excellent'. The below sections summarise user feedback on product fitness for purpose for all EOMORES products. A list of the users interviewed and the questionnaire template can be found in the Annexes.

VII.1. General Completeness and Product quality/accuracy and fitness for purpose

Overall, most users received all products they expected (9 of 11 users), while some said there were outstanding products (2 users; Figure 57a). Of those users that did not receive all products, this was specifically related to the Secchi disc depth (transparency) and CDOM products in the Water Insight service line. However, shortly after these questionnaires were completed, these products were added to the EOMORES portal.

All but one user thought the products were presented as expected (10 of 11 users; Figure 57b). The user that answered "Other" clarified that the products were not yet ready for use by their organisation.

Users were also asked if the concentrations and patterns in the data were as they expected (Figure 57c). 7 of 11 users agreed the concentrations and patterns were as expected. However, 2 users thought they would have liked to see more presented on chlorophyll products rather than turbidity. 1 user thought the macrophyte product was not as expected, however the Algae Radar modelled product did fit their expectations. Lastly, 1 user responded "yes and no", the large degree of spatial variation was expected on the maps, however, the specific calibration range from *in situ* samples was too narrow for very accurate calibration.

Users were also queried on whether the product accuracies were presented (if required) and if so, whether these were acceptable for their use (Figure 57d). Most users (6 out of 11) agreed the product

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accuracies were acceptable for their use. 2 users stated that accuracy information was not required. A further 2 users stated that uncertainty information around the data is available but uncertainty around the capture of the "right" concentration is not, in order to ensure comparability between EO and *in situ* data. The final user was interested in accuracy estimation, but that these were not provided in the portal EO service; however, this user acknowledged that the EOMORES partner provided this user with product uncertainty metrics.

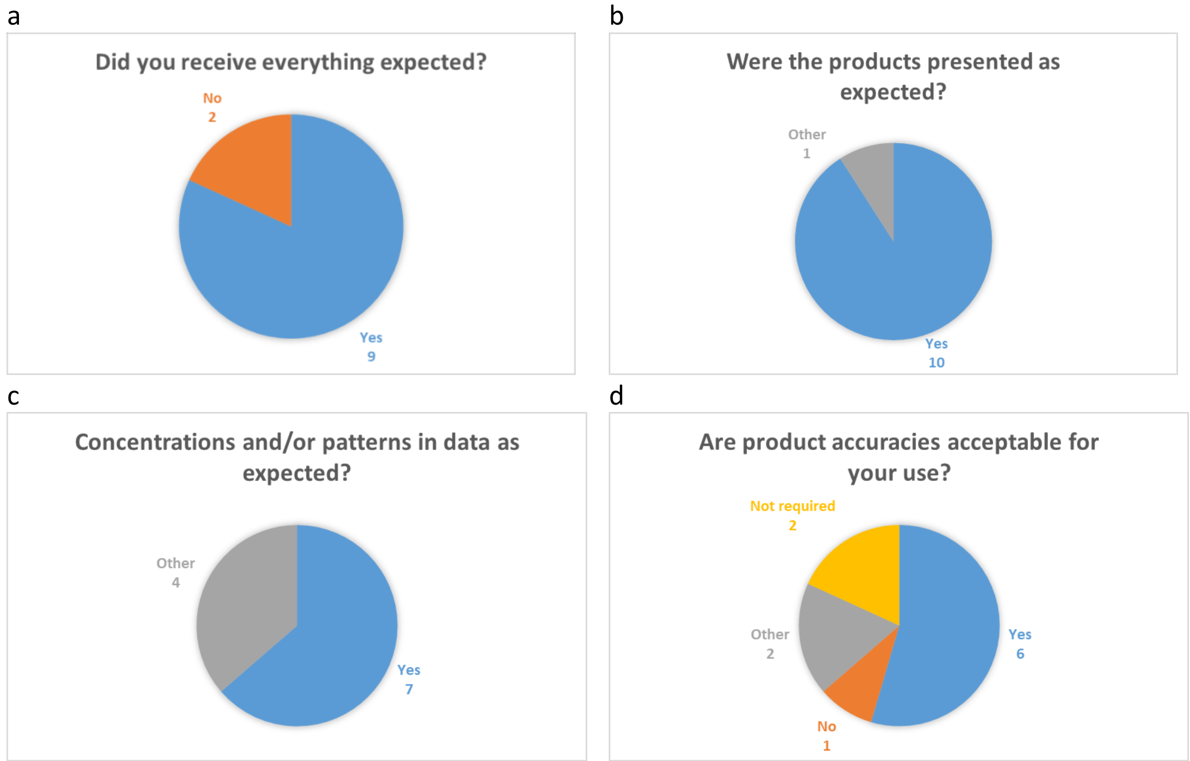

Figure 57 – EOMORES user feedback on general completeness and products.

Additionally, users were queried on the product metadata, specifically whether they found it was clearly available and accessible (Figure 58). 10 users responded with ratings of 5-10 out of 10, with most users (6 out of 11) providing a score of 8 or more. User suggestions for metadata included details on the algorithm used (particularly if they differ for timing and/or sites), and specifically for the SYKE EOMORES service line, metadata for histograms, time series and statistics for WFD water bodies, and combined uncertainty metrics could be useful. It was noted that the SYKE service line is presently reviewing the metadata system for EO products.

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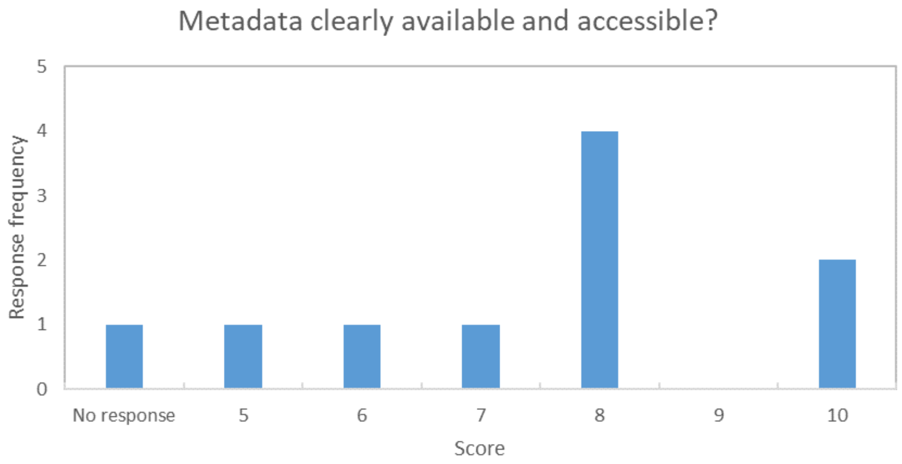

Figure 58 – User questionnaire results on Metadata

Questionnaire results indicated that most users presently undertake *in situ* routine monitoring programs only (7 out of 10 users; Figure 59a). 2 users did not respond, 1 user implements automated monitoring stations as well as *in situ* monitoring, and 1 user implements a combination of automated, *in situ* and EO methods. Most users have considered alternative monitoring methods (Figure 59b), including automated *in situ* sensors and EO, high frequency optical *in situ* measurements (EcoWatch) and underwater drones, cyanobacteria toxin monitoring and underwater drones, and data fusion approaches (including EO). This highlights that the current users are receptive to considering alternative monitoring approaches, including those services EOMORES can provide.

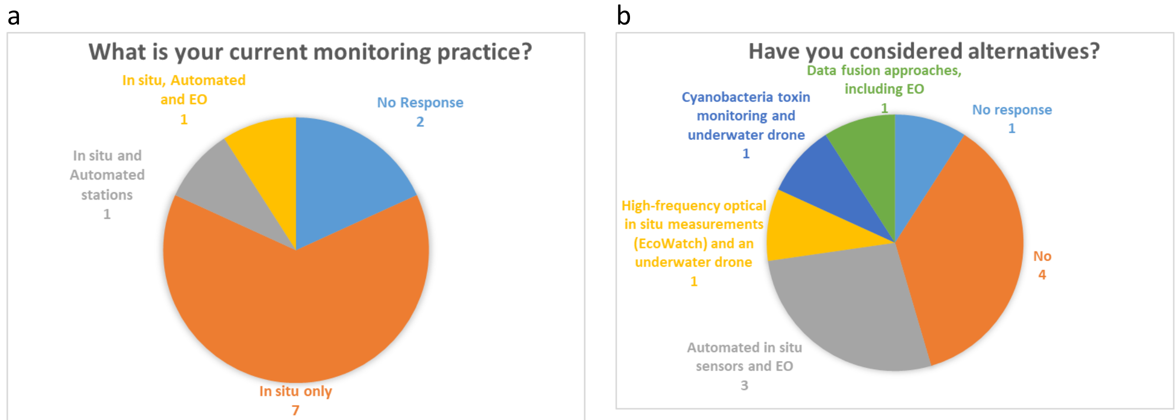

Figure 59 – User questionnaire results on current monitoring practice and alternative approaches considered

For the final assessment of product fitness for purpose, users were asked whether they found the EOMORES products to provide sufficient temporal frequency and spatial coverage (Figure 60). Of those users that provided a response, all users gave a score of 5-10 out of 10 for temporal frequency. We note the user who provided a score of 5 out of 10, stated this was due to the patchiness in satellite coverage due to cloud cover, and that this is likely to vary by region of interest. Nonetheless, 9 out of 11 users agreed the EOMORES products provided increased temporal frequency to their routine monitoring programmes (Figure 61a).

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Where users responded, they scored spatial coverage as 7-10 out of 10, indicating a high rate of satisfaction with the spatial coverage provided by EOMORES products. Furthermore, all users (11 out of 11) indicated the EOMORES products provided increased spatial coverage to their routine monitoring programmes. This indicates that spatial coverage is a key benefit of the EOMORES products.

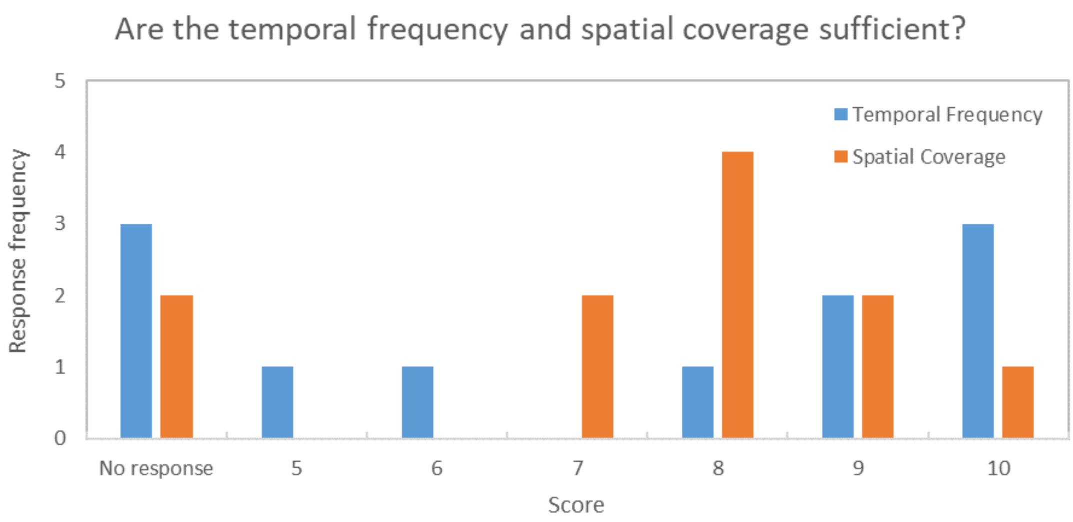

Figure 60 – User questionnaire results for temporal frequency and spatial coverage (score out of 10)

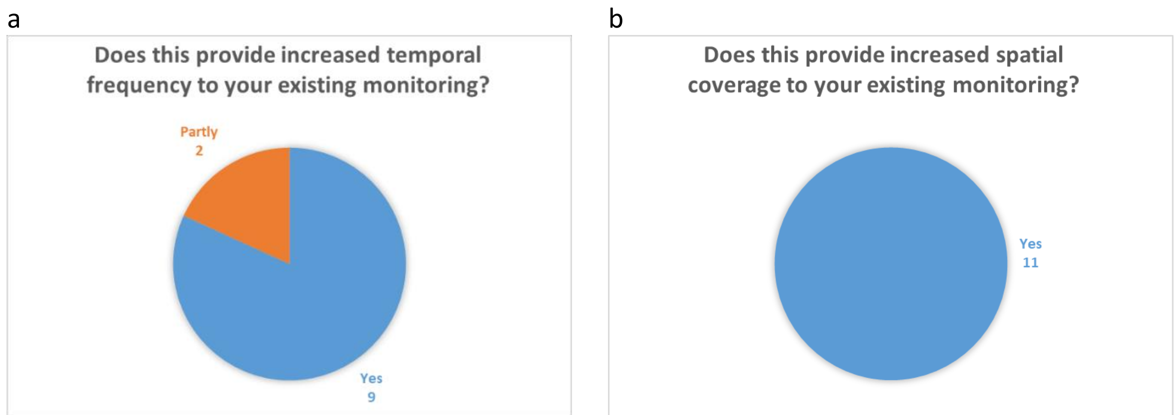

Figure 61 – User questionnaire results on whether the EOMORES products provide increased a) temporal frequency and b) spatial coverage as compared to their existing monitoring approach.

VIII. Service Quality and Utility Assessment

In addition to assessment of the products themselves and product fitness for purpose, EOMORES partners gathered user feedback on the service quality and utility, using the questionnaire as a guide. Users were asked to evaluate whether the service was provided in a timely manner and whether the data was in a useful format/interface. Additionally, users were asked whether the service was easy to access and use, if there were any missing features, and if the service overall capability met their needs and could be incorporated into their data management system. To assess service utility, we asked open ended questions to query how users have used or plan to use the EOMORES service, and if this

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could be useful for WFD reporting. Overall, users were queried on whether they felt the service was a reliable and useful source of data and if this could be integrated to suit their organisational needs. Finally, the willingness of users to pay was ascertained using the questionnaire to identify if users are interested in using the EOMORES service on a commercial basis.

Responses were gauged on a scale of 0-10, where suitable, where a rating of 0 is Not at all, 5 is Somewhat and 10 is Excellent. The below sections summarise user feedback on product fitness for purpose for all EOMORES services. A list of the users interviewed and the questionnaire template can be found in the Annexes.

VIII.1. Service Quality

Figure 62 shows the rating of the EO service with regard to timely delivery, data format and/or interface, the access to the service, the use of the service and the perceived operational capability. The histograms shows the frequency of each rating provided by 9 users. Seven of them were served by the WI portal. One was served with a model and one via the SYKE portal. The two users who were served by the PML portal did not fill out a rating.

Figure 62 - Service quality evaluation summary of WI EO services

In general, the users were (very) content with the quality of the service: all of them gave a score of 'Somewhat' (6) to very positive (10 – 'Excellent').

Reasons for the lower rates (6 or 7) were:

Timely delivery:

- The start of the operational processing phase in the project was delayed, and for one user the quality control was not done correctly so that it took more time to correct that.
- User would have preferred real time data in the project. Real time data was provided for most products, but this user received model data and Very High Resolution (VHR) satellite data (for which real time was not possible).

Format/interface:

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- High potential in using portal for a first basic analysis, but then further elaborations for specific cases, emergencies, etc.., should be generally conducted locally (with the support of the local EOMORES partner)
- Basically yes, the format is not a problem, but at the level of maybe it would have been easier for us to work with data from a Web Service that can be interfaced with our GIS platform.
- The users who did not provide a rate for the PML portal wrote as feedback: The portal provides examples of what is possible but the information is not in a format [user] can readily use at this stage in development. However, the portal enables visualisation of data from particular lakes in a useful manner.
- The user who received model and VHR data would have preferred those in a more user-friendly way: the model with a user interface and the VHR data with easier georeferencing.

Ease of use

- Same comment as first point for format/interface
- The layer insertion toolbar is not a practical tool; sometimes it remains a little difficult to perform even simple operations
- It takes time to get to be used especially in sub setting with time line.
- The users who did not provide a rate for the PML portal wrote as feedback: Hard to use and fully understand without being very familiar with terminology around EO data.

Operational capability:

- For one user the quality checks were not done properly before delivery. This has been improved now.
- The service is pretty good for preliminary visualizations, please see first bullet in format/interface for the main lacks for real "operational" use.

Additionally, there was a question for missing or new features. The responses to this were:

- Possibility to average data over time or space: e.g. spatial map of annual mean Chl a concentration to estimate the status necessary for EU WFD reporting.
- The portal lacks editing mode for controlling of colour pallet *(>> this can actually easily be done on request*)
- Ideally, statistical aggregation over distinct periods of time, indicators development
- The ability to import custom vector layers / monitoring points or additional layers into the portal
- Interested in further development of the data fusion products

We also asked if the user has a data management system (DMS), and if yes, if the EOMORES service could be incorporated in that system. The responses are shown in Figure 63. One user misunderstood the question, so this response was not taken into account. The two users who responded with 'yes but not directly' the new data should either be used as external support first (1), or it should be approved by standards (1).

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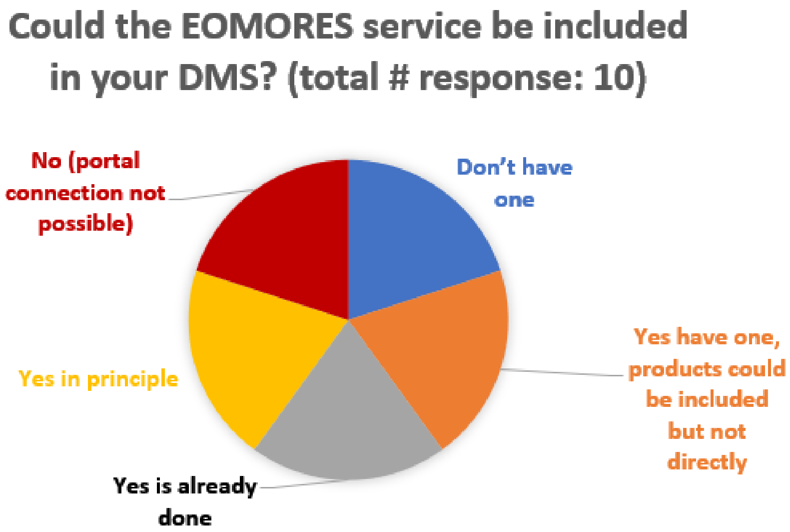

Figure 63 - Pie chart summarising the possibility to include the EOMORES service in the data management system of the user

VIII.2. Service Utility

Most users used the EOMORES services during the project lifetime (Figure 64), several users mentioned more than one purpose. A few users mentioned that they had just tested or validated the services, to check the quality or to see what would be possible with it.

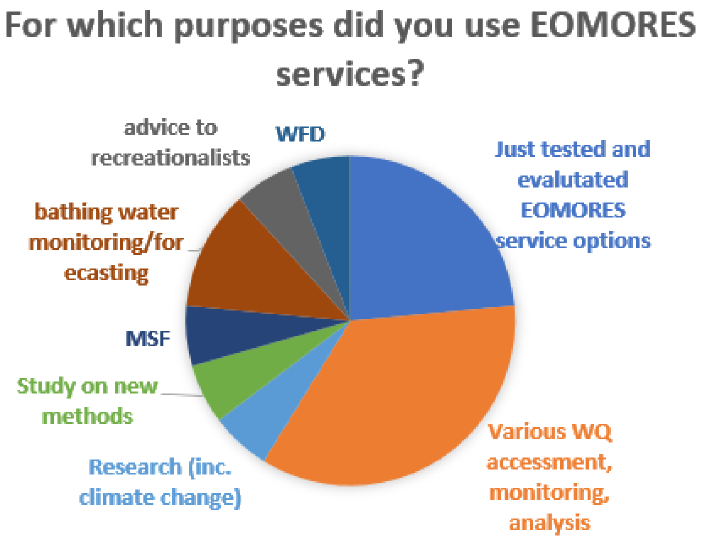

Figure 64 - Use of EOMORES services

We asked them also for with other purposes they are planning to use the service. Those are shown in Figure 65.

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Figure 65 – Planned (additional) use of EOMORES services

The following figures (Figure 66, Figure 67, Figure 68) are specifically about the use of EOMORES services for WFD reporting. Depending on their country, some users mention that Chl-a is the only parameter which currently fits with the WFD reporting, while in other countries the EOMORES techniques are not allowed within the (national) regulations and therefore respond 'no'. Two users find that the data not sufficiently well understood to use with confidence and does not conform to formats of current databases, data requirements or classification systems and therefore does not fit with the WFD reporting (Figure 66).

In contrast, the Finnish user mentions that EOMORES services have already been incorporated as a part of the national assessment system of the WFD in the latest assessment period.

All users except one user think that the methods *should* be allowed, some mention that more validation would be required or that this should only apply to specific parameters (Figure 67). The user who responded 'no' is a Dutch water manager who is responsible for very many small and narrow water bodies, which appeared to be smaller than the applicable range of the EOMORES EO-based water quality services.

Half of the users find that the EOMORES data is enough discriminative for WFD ecological classes. Some request other map types for this, note that required important parameters are missing for this, or that it cannot be according to the current prescribed methods. One user mentions that ecological status also requires taxonomic data to be incorporated (Figure 68).

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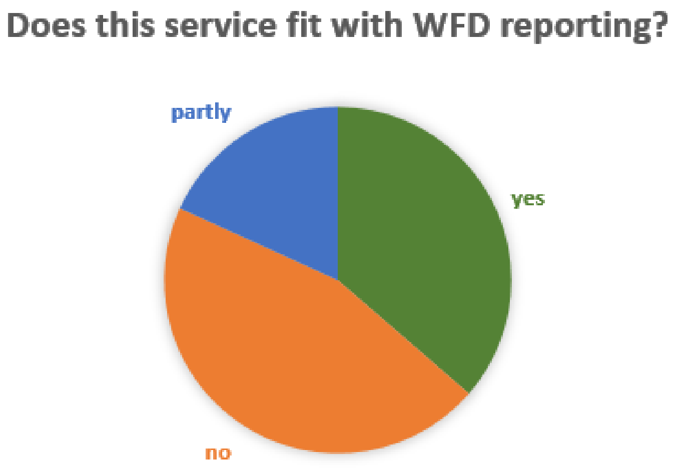

Figure 66 - EOMORES services fit with WFD

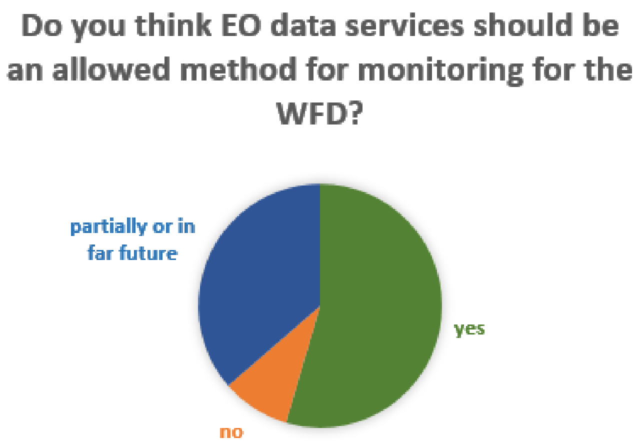

Figure 67 - EO data should be allowed for WFD

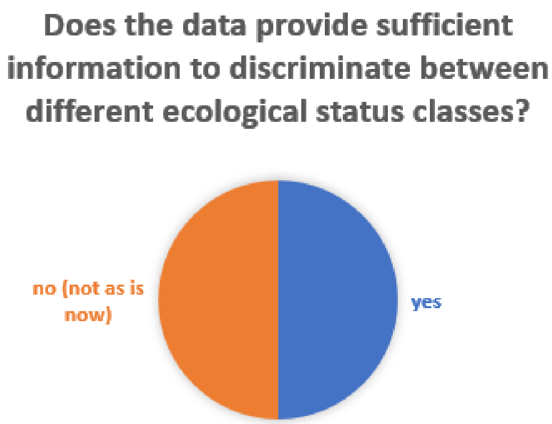

Figure 68 - Discrimination between ecological status classes of WFD

The majority of the users find the EOMORES services a reliable resource (Figure 69). Two users write 'unsure, uncertain about future availability' and one mentions that the service is as reliable as the available satellite data.

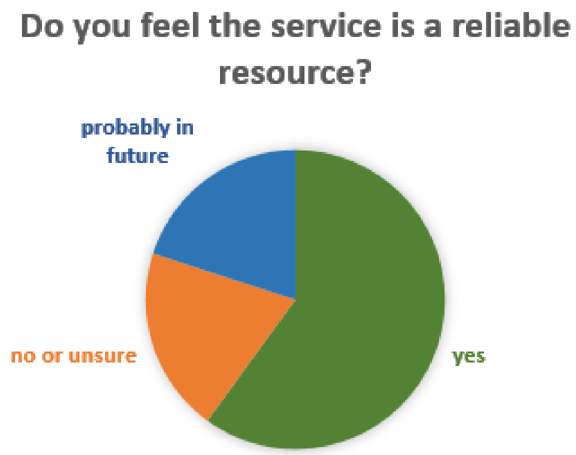

Figure 69 - Reliability of EOMORES services

With regard to integrating the data into the operational procedures of the users' organisations, often the response was not write a clear 'yes' or 'no'. Some write 'it can be done' [which we took as 'yes']

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but mention that it would require an approval by a governmental agency. Others respond the other way around with 'no' [no] 'because it would require an approval'. Therefore, the chart of Figure 70 should be read keeping this in mind.

Figure 70 - Integration of EOMORES services in operational procedures

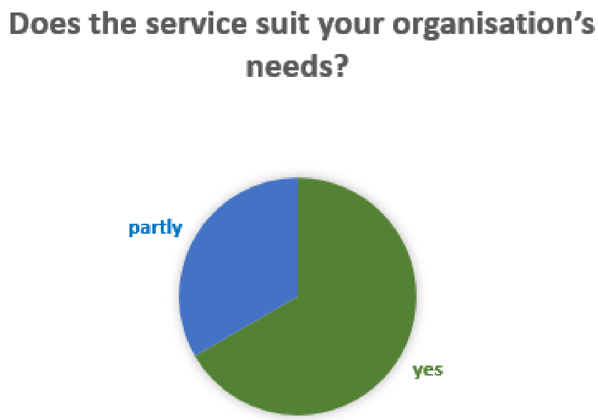

Figure 71 - EOMORES services suit the organisations' needs

Figure 71 shows that the services generally suit the users' needs. The mentioned improvements are about extending the services: "In terms of Chl a, it suits the organisation's needs. If any additional parameters will be incorporated, it could improve the service." and "Following long terms analysis, providing accuracy evaluations and comparison with field data, testing some indicator in order to compare different periods, etc."

VIII.3. Overall satisfaction

A rate for 'overall satisfaction' was filled out by 8 users. Figure 72 shows that the users are satisfied to very satisfied with the WI-EOMORES service. The two users from the UK and one from Finland did not rate the service. We note that the user who rated the service with a 7 wrote that there was 'too little time for testing the operational service within the project phase'. Most users refer to feedback provided with earlier questions.

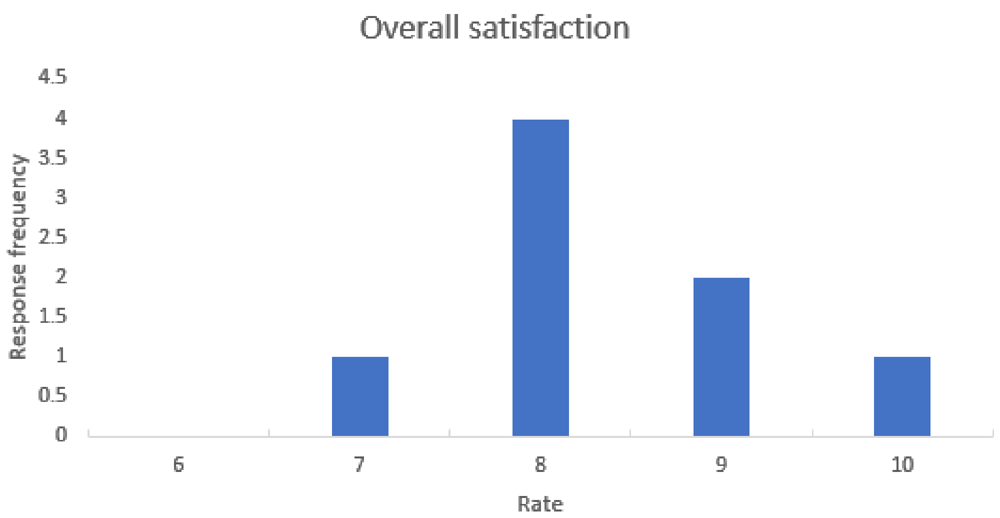

Figure 72 – Overall satisfaction of WI EO services

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IX. Summary & Conclusions

In order to develop a commercial service based on EO, *in situ* and modelled data products, it is vital to first validate all products to ensure they are robust and fit for purpose. Thus, the EOMORES service products have been quantitatively and qualitatively assessed, using the validation procedures outlined in D2.3 Validation Plan. The validation results are presented in this deliverable, by region and product, and for all EOMORES services.

Overall, the EOMORES service products indicated good performance according to the quantitative uncertainty metrics. EO product validation has been presented by region for each of the service products, including Chl-a, TSM, turbidity, Secchi depth, CDOM, LSWT and macrophyte coverage. The uncertainty metrics for each product were presented in Table 2-Table 7, indicating typically high determination coefficients and low uncertainty metrics. Example product maps for each were presented, taken from the respective EOMORES service line portals (WI, PML or SYKE). The WISPstation validation results were shown for the *in situ* component of the EOMORES service, indicating good agreement between WISPstation derived parameters and *in situ* Chl-a and SPM at all sites tested (R^2 >0.83, RMSE <3.4 mg m^{-3} or mg L^{-1}). Algae Radar modelling results also indicated good agreement between *in situ* and modelled Chl-a for the Paterswoldsemeer, Netherlands for 2010-2017, with 74% of predictions correct. These validation results can provide the EOMORES users and potential future users with confidence, and demonstrates robust commercial service products.

We have also here presented the results from the user assessment of the product fitness for purpose. The product assessment was conducted via user interviews using a questionnaire format. Most users received the products and found they were as expected. Spatial patterns typically agreed with user expectations, and most users agreed product accuracies were acceptable (or not required). Users typically found metadata to be available and accessible, however some users suggested they would like further information on algorithms used or combined uncertainty metrics to better evaluate product fitness. User questionnaires also highlighted that temporal frequency and spatial coverage was mostly sufficient and an improvement on their routine monitoring programmes.

Users also evaluated the service quality and utility via user interviews with the questionnaire. In general, the users were (very) content with the quality of the service, with scores of 6+ out of 10 from all users for all criteria queried (Timely delivery, Format/interface, Ease of use, Operational capability). Over half of the users indicated the EOMORES service could be (or in principle) integrated into their current data management system. In terms of service utility, some users simply tested the EOMORES service, while most users implemented the products from the service to inform WFD and MSFD, water quality monitoring and studies, research, bathing water quality, advice to recreationalists, and as a study on new methods. In future, more users hope to use the EOMORES service to inform WFD and MSFD assessment, as well as navigating, dredging and infrastructure, water quality monitoring and assessment, bathing water quality monitoring, research and education. Furthermore, while some users already employ the EOMORES service for the WFD, nearly all have indicated that EO should be incorporated in future for WFD monitoring and assessment. Overall, users were satisfied with the EOMROES service (7+ out of 10).

This deliverable presents assessment of the product accuracy as well as user feedback on product fitness for purpose and service quality and utility. These results indicate there are robust products included in the EOMORES service, and that users are typically satisfied with the service, highlighting the spatial coverage as a key improvement to current monitoring methods. The users have indicated

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a range of current and proposed uses for the service, to help them better monitor inland and coastal waters.

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X. References

Binding, C., Bowers, D.G., Mitchelson-Jacob, E.G. (2010a). An algorithm for the retrieval of suspended sediment concentrations in the Irish Sea from SeaWiFS ocean colour satellite imagery. *International Journal of Remote Sensing*, 24(19): 3790-3806.

Binding, C., Jerome, J.H., Bukata, R.P., Booty, W.G. (2010b). Suspended particulate matter in Lake Erie derived from MODIS aquatic colour imagery. *International Journal of Remote Sensing*, 31(19): 5239-5255.

Gitelson, A. A., Gao, B. C., Li, R. R., Berdnikov, S., & Saprygin, V. (2011). Estimation of chlorophyll-a concentration in productive turbid waters using a Hyperspectral Imager for the Coastal Ocean—the Azov Sea case study. *Environmental Research Letters*, 6(2), 024023.

Gons, H. J., Auer, M. T., & Effler, S. W. (2008). MERIS satellite chlorophyll mapping of oligotrophic and eutrophic waters in the Laurentian Great Lakes. *Remote Sensing of Environment*, 112(11): 4098-4106.

Gons, H. J., Rijkeboer, M., & Ruddick, K. G. (2005). Effect of a waveband shift on chlorophyll retrieval from MERIS imagery of inland and coastal waters. *Journal of Plankton Research*, 27(1): 125-127.

Kleywegt, G.J. (2007). Quality control and validation. In Macromolecular crystallography protocols (pp. 255-272). Humana Press.

Lee, Z. P., Carder, K. L., & Arnone, R. A. (2002). Deriving inherent optical properties from water color: A multi-band quasi-analytical algorithm for optically deep waters. *Applied Optics*, 41, 5755–5772.

Mishra, S., Mishra, D., Lee, Z. and Tucker, C.S. (2013). Quantifying cyanobacterial phycocyanin concentration in turbid productive waters: A quasi-analytical approach. *Remote Sensing of Environment*, 133: 141-151.

Nechad, B., Ruddick, K.G., Neukermans, G. (2009). Calibration and validation of a generic multisensor algorithm for mapping of turbidity in coastal waters. Proc. of SPIE 7473. Remote Sens. of the Ocean, Sea Ice, and Large Water Regions 2009 7473, 11.

Nechad, B., Ruddick, K. G., & Park, Y. (2010). Calibration and validation of a generic multisensor algorithm for mapping of total suspended matter in turbid waters. *Remote Sensing of Environment*, 114(4): 854-866.

Neil, C., Spyrakos, E., Hunter, P.D., Tyler, A.N. (2019). A global approach for chlorophyll-a retrieval across optically complex inland waters based on optical water types. *Remote Sensing of Environment*, 229: 159-178.

Spyrakos, E., et al. (2017). Optical types of inland and coastal waters. *Limnology and Oceanography*, 63(2): 846-870.

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Vantrepotte, V., Loisel, H., Mériaux, X., Jamet, C., Dessailly, D., Neukermans, G., Gensac, E., Gardel, A. (2011). Seasonal and inter-annual (1998–2010) variability of the suspended particulate matter as retrieved from satellite ocean color sensors over the French Guiana coastal waters. *Journal of Coastal Research*, SI, 0749-0208, 64.

Zhang Y., Shi K., Liu X., Zhou Y., Qin B. (2014). Lake Topography and Wind Waves Determining Seasonal-Spatial Dynamics of Total Suspended Matter in Turbid Lake Taihu, China: Assessment Using Long-Term High-Resolution MERIS Data. PLoS ONE 9(5): e98055.

XI. Annex 1 – List of users interviewed (2019)

The questionnaire (Annex II) was used as guideline to lead the one-to-one interviews that were carried out between EOMORES users and EOMORES partners during 2019. The following users were interviewed:

Table 10 – List of EOMORES users interviewed in 2019

User	Abbreviation
Water Authority Noorderzijlvest (NL)	NZV
Regional Agency for Environmental Protection, Regione Lombardia (IT)	ARPA-L
Centre for Limnology (EE)	CfL
Finnish Environment Institute (SYKE) (FIN)	SYKE
UK Environment Agency (UK)	UK-EA
Regional Agency for Environmental Protection, Regione Umbria (IT)	ARPA-U
Water Authority Hoogheemraadschap Hollands Noorderkwartier (NL)	HHNK
Netherlands Institute for Ecology (co-operation with user Natuurmonumenten) (NL)	Officially NIOO-KNAW, in this document NIOO
Marine Research Department, Environmental Protection Agency (LI)	EPA Lithuania
Nature Research Center, Laboratory of Algology and Microbial Ecology (LI)	NRC
Scottish Environment Protection Agency (UK)	SEPA

The abbreviations of the user organisations are used throughout the document.

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XII. Annex 2 – User Questionnaire Template (2019)

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The aim of this document

This document is a survey following the second year of EOMORES to evaluate primarily the product fitness for purpose and service quality and utility. This document should be used to lead the meeting with your user(s) as a checklist/questionnaire. The purpose is to collect input for:

- **D 2.6** Final user requirements document and validation plan
- Task **5.2**: Product fitness for purpose assessment
- Task **5.3**: Service quality and utility assessment
- **D 5.3** Final Validation Report
- **D 7.8** Updated Business plan
- **D 7.6** White paper

Make sure you have:

- Checked the SLD signed early 2018 (and for some 2017) with your user (if relevant/required).
- Delivered expected test products/services/validation information/images/reports.

Note: All user interviews should be completed by **Monday 30th September 2019** latest.

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Evaluation of the 2018 products and service

I. General completeness of the products and service

1. Did the user receive everything that was expected? If not, why not?

Specifically, according to the SLD, did you receive the following:

[EOMORES partners: add specific products for each user below]

Development products:

Product	Received? Y/N

Operational products:

Product	Received? Y/N

II. Product quality / accuracy

1. Are the products presented as expected? If not, how do they differ?

2. Are the concentrations and/or patterns in the data as expected? If not, how do they differ?

3. If this was agreed: Is the uncertainty shown for each product? Are the product accuracies acceptable for your use?

4. Are the product metadata clearly available and accessible? On a scale of 0-10, please provide a rating below.

0 Not at all	1	2	3	4	5 Somewhat	6	7	8	9	10 Yes, Excellent

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5. Do you require other information about the products that has not been provided (e.g. error metrics, algorithms used, etc)?

III. Fitness for purpose

1. Background on user monitoring approach:
    a. What is your current monitoring practice?

    b. What alternatives have you considered, if at all, to improve the monitoring process?

    c. If other alternatives were considered, why were they not adopted?

2. Regarding the EOMORES service:
    a. is the data temporal frequency sufficient? On a scale of 0-10, please provide a rating below.

0 Not at all	1	2	3	4	5 Somewhat	6	7	8	9	10 Yes, Excellent

    b. Does this provide increased data frequency from your existing monitoring? Y/N

    c. Is the data spatial coverage sufficient? On a scale of 0-10, please provide a rating below.

0 Not at all	1	2	3	4	5 Somewhat	6	7	8	9	10 Yes, Excellent

    d. Does this provide further spatial information than your existing monitoring? Y/N

IV. Service quality

3. Was the service provided in a timely manner? On a scale of 0-10, please provide a rating below.

0 Not at all	1	2	3	4	5 Somewhat	6	7	8	9	10 Yes, Excellent

If not excellent, when would you prefer data to be provided?

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4. Is the data provided in a useful format or interface? On a scale of 0-10, please provide a rating below.

0	1	2	3	4	5	6	7	8	9	10
Not at all					Somewhat Useful					Yes, Excellent

If not excellent, how would you prefer data to be provided?

2. Is the portal/service easy to access? On a scale of 0-10, please provide a rating below.

0	1	2	3	4	5	6	7	8	9	10
Not at all					Somewhat					Yes, Excellent

3. Is the portal service easy to use? On a scale of 0-10, please provide a rating below.

0	1	2	3	4	5	6	7	8	9	10
Not at all					Somewhat					Yes, Excellent

If not excellent, why not?

4. Are there any missing features you would like to see provided in the portal?

5. Overall, does the service operational capability meet your expectations? On a scale of 0-10, please provide a rating below.

0	1	2	3	4	5	6	7	8	9	10
Not at all					Somewhat					Yes, Excellent

If not, why not?

6. Do you have a data management system for storing water quality monitoring data?

   If so, could the EOMORES service be incorporated into this system? If not, why not?

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V. Service utility

1. For which purposes have you used the service?

2. For which (other) purposes do you plan to use the service?

3. How does this service fit with WFD reporting?

   If it does not fit, what is the reason for this?

   Do you think EO data services should be an allowed method for monitoring for the WFD?

4. Does the data provide sufficient information to discriminate between different ecological status classes?

5. Do you feel the service is a reliable resource? If not, why not?

6. Do you feel this service can/will be integrated into your operational procedures? If not, why not?

7. Does the service suit your organisation's needs? If not: how can the service be improved?

VI. Willingness to pay

8. Does EOMORES services provide cost-savings for your organization? If so, how much per year (€) (if known)?

9. Do you think this service provides more, new or additional information which will be worth buying as a commercial service? (assuming the price suits your organisation)

10. Aside from budgetary constraints, what would be necessary in order to convince your organisation's decision-makers to purchase EOMORES services (e.g. service quality / service scope / delivery mode / technical constraints)? Please describe any decisions that need to be taken within and outside your organization, any criteria the service should meet, relevant decision-making processes, etc.

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11. Please provide contact names of person(s) from your organization who would need to agree and confirm the use of EO-derived products for WFD monitoring and reporting at national and local level (contacts for White Paper):

12. Please provide the name and contact details of a person in your organisation who we can approach regarding purchase of the EOMORES services:

13. Would you be willing to use the EOMORES service on a commercial basis? If so, please see and answer the questions below, as relevant.

I'm am interested in continuing the following EOMORES services on a commercial basis:

Service (*EOMORES partners: please list the services you delivered)*	**1** **Not interested**	**2**	**3** **Maybe**	**4**	**5** **Very interested**

If not interested, please explain why:

14. Does your organization require a public tender for service contracts above a set amount? If so what amount(€)?

15. Is there is a threshold value for services at your organisation? If so, what is the amount (€)? Is this per year/month/other?

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16. If you are interested in using the EOMORES service on a commercial basis, please complete the below table on willingness to pay:

Willingness to Pay	If yes, willingness to pay per year (per line, so for the total # of water bodies and km^2 or coverage, per instrument, training or validation)										
Service	**Parameter**	**Interested?**	**# water bodies**	**Total ~ km^2**	**resolution (< 1 m, 10-60 m, ~ 300 m, ~ 1 km)**	**€ 5 000 - € 10 000**	**€ 10 000 - € 20 000**	**€ 20 000 - € 30 000**	**€ 30 000 - € 40 000**	**€ 40 000 - € 50 000**	**Other**
'Daily' EO Water quality data (daily referring to all the data that is available, e.g. for 10-60 m that is ~ 100 images a year, 300 m and 1 km about daily, however all data availability is dependent on cloud cover)	Chl	Yes/no									
	SPM	Yes/no									
	Kd	Yes/no									
	Cyanos	Yes/no									
	Surface Temp	Yes/no			1 km						
	Macrophyte mapping				< 1 m						
EO WFD classification (spatial class over a season for Chl and / or transparency)		Yes/no									
EO aggregates (e.g. monthly, seasonal) of any of the above)		Yes/no									
EWACS model (model resolution)		Yes/no									
AlgaeRadar model (point)		Yes/no									
WISPstation lease (price per instrument including data service)		Yes/no									
Validation of any of the above services by an independent scientific institute or laboratory (e.g. your EOMORES project partner)		Yes/no									
Training / workshops etc (per instance)		Yes/no									

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VII. Overall satisfaction

1. Overall, how satisfied are you with the EOMORES service? On a scale of 0-10, please provide a rating below.

0	1	2	3	4	5	6	7	8	9	10
Not at all					Somewhat					Yes, Excellent

Additional explanation/comments:

Additional Information

If you have any additional comments or questions about the EOMORES products or services, please provide us with further detail here.

User- or Service-Specific Information (Optional)

(EOMORES partners: please add any user-specific or service-specific questions here).

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XIII. Annex 3 – User Questionnaires (2019)

All completed user questionnaires are provided here.

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