PHYTOplankton biomass and diversity Climate Change Initiative (PHYTO-CCI)

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Index

1 Introduction

1.1 Purpose of document

This User Requirement Document (URD) presents the results from the user consultation that was carried out by the PHYTOplankton biomass and diversity Climate Change Initiative (PHYTO-CCI). We reached out to a broad user group dealing with ocean colour data to understand their requirements, both technical and scientific, for phytoplankton biomass and diversity Essential Climate Variables (ECVs) following criteria formulated by the Global Climate Observing System (GCOS). The user consultation consisted of an online user requirements survey and three dedicated online workshops. All activities were carried out in collaboration with the Ocean Colour Climate Change Initiative (OC-CCI).

1.2 Structure

The URD describes the existing GCOS requirements for the ocean biosphere ECV, specifically those for phytoplankton carbon biomass and pigment diversity, as well as those for chlorophyll-a from the ocean colour ECV (for comparison) in Section 2. Relevant results from previous user consultations in OC-CCI are summarised in Section 3. The user requirements for PHYTO-CCI are provided in Section 4, in which the method and results from the user requirements survey and workshops are described. The conclusions are provided in Section 5 and references in Section 6. Appendix I contains the questions of the online user requirements survey and Appendix II contains a summary of comments made by participants during the user requirements workshops.

1.3 Related documents

Documents related to the PHYTO-CCI URD are the GCOS requirements (WMO, 2022), the OC-CCI user consultation documents (Sathyendranath 2011; and subsequent updates, see https://docs.pml.space/share/s/lg8js7hFSOaaZrtbtFGbmQ) and the PHYTO-CCI Product Specification Document (PSD).

1.4 Definitions

Throughout the document, GCOS and user requirements are discussed according to the following definitions:

- *Spatial resolution* (horizontal and vertical) is the area over which an observation is representative of and is expressed in m or km.
- *Temporal resolution* is the frequency of observations and is expressed in days, weeks or months.
- *Measurement uncertainty* characterises all errors (systematic and random) associated with the observations and is expressed as two standard deviations, unless otherwise stated.
- *Accuracy* is the measure of non-random, systematic error, or bias, that defines the offset between the measured value and the true value that constitutes the absolute international standard and is expressed as a percentage.
- *Precision* is a measure of reproducibility or repeatability of the observation without reference to an international standard, so that precision is a measure of the random and not the systematic error and is expressed as a percentage. Suitable averaging of the random error can improve the precision of the measurement, but does not establish the systematic error of the observation.
- *Stability* is the change in bias over time, expressed as percentage per decade, and is a term often invoked with respect to long-term records when no absolute standard is available to quantitatively establish the systematic error.
- *Timeliness* is the time expectation for accessibility and availability of data.

These requirements are assessed at three levels:

- *Threshold* – The minimum requirement to be met to ensure that data are useful. For each ECV product, a definition and units are provided together with the requirements.
- *Breakthrough* – An intermediate level between 'threshold' and 'goal' which, if achieved, would result in a significant improvement for the targeted application. The breakthrough value may also indicate the level at which specified uses within climate monitoring become possible. It may be appropriate to have different breakthrough values for different uses.
- *Goal* – An ideal requirement above which further improvements are not necessary.

2 GCOS requirements

In 2022, GCOS revised the ECV requirements for the ocean biosphere and specified that for phytoplankton both biomass and diversity now constitute ECV products (WMO, 2022). The Global Ocean Observing System (GOOS) also highlights the importance of phytoplankton biomass and diversity as Essential Ocean Variables (EOV) (Muller-Karger and Kudela, 2016). We use the definition for phytoplankton biomass and diversity as stated in the 2022 GCOS ECVs requirements document (WMO, 2022):

- *Phytoplankton biomass* is the weight of phytoplankton by volume (in mg m^{-3}); and
- *Phytoplankton diversity* is the concentration of pigment types and/or the number of species per unit sample (in unit surface area or unit volume).

GCOS requirements for ECVs are expressed in terms of five criteria, including the spatial resolution, temporal resolution, uncertainty, stability and timeliness at three different levels, e.g., at goal, breakthrough and threshold values (see Section 1.4 for definitions). While the first three criteria are identified for phytoplankton biomass and diversity, no requirements are provided on stability, which is the change in bias over time, and timeliness, which is the time it should take to make ECV data products accessible to the scientific community (Table 1). What is currently technically achievable for ocean-colour observations sets the background for the requirements that can be met for the satellite-based phytoplankton diversity and biomass ECV products. The required spatial and temporal resolution are currently met by ocean-colour satellite observations, from individual sensors as well as merged products such as those of OC-CCI, which provide data at a minimum of 300 m (OLCI) to 1 km (OC-CCI) horizontal resolution and daily temporal resolution. The vertical resolution required for phytoplankton diversity could be met at threshold values, but will be more difficult to achieve at higher values with ocean-colour observations typically only representing the surface ocean (up to one optical depth). Uncertainties for ocean-colour products such as chlorophyll-a, estimated from the bias as relative error, range between 2-16% for the available time series from OC-CCI between 1998-2023 (Sathyendranath 2024; Kulk *et al.* unpublished), but are below 5 % with the introduction of multiple ocean-colour sensors since 2002. This sets the stage for what we might expect in terms of uncertainty for other ocean-colour-derived ECV products, such as phytoplankton biomass and diversity, but uncertainty estimates are currently not routinely provided for most phytoplankton carbon and pigment algorithms. To date, validation efforts of satellite phytoplankton carbon products (Martínez-Vicente *et al.*, 2017) suggest higher uncertainties (e.g., >35 %), in part because phytoplankton carbon is difficult to quantify *in situ* and consequently the *in situ* data have high uncertainties. Yet, progress is being made within the ESA-funded 'Satellite-based observations of Carbon in the Ocean: Pools, Fluxes and Exchanges' (SCOPE) project to address the lack of pixel-by-pixel uncertainty and the relatively high uncertainty compared to the GCOS requirements.

Table 1. Summary of requirements for ECVs and associated products related to phytoplankton biomass and diversity according to GCOS (WMO, 2022). Requirements for the spatial and temporal resolution, timeliness (e.g., when data should be accessible), uncertainty and stability (e.g., change in bias over time) are provided at three levels of maturity: the ideal requirement above which no further improvements are needed (G – Goal), an intermediate level at which significant improvements are made (B – Breakthrough), and the minimum requirements to ensure usefulness of the data product (T – Threshold). The requirements for chlorophyll-a from the Ocean Colour ECV are provided for comparison. The values provided by GCOS for phytoplankton biomass and diversity are for in situ *observations, whereas the values for chlorophyll-a are provided for ocean-colour remote sensing observations. * Note that for phytoplankton diversity the values for the horizontal resolution provided in the table are for offshore waters and for nearshore waters the values are 0.1 km, 0.1 km and 1 km for G, B and T levels, respectively. † In the GCOS documentation the unit for the horizontal resolution is given as km, but logically this would be in m at goal level.*

	ECV	Plankton		Ocean Colour
	Product	Phytoplankton biomass	Phytoplankton diversity*	Chlorophyll-a
Requirement	Level	Values	Values	Values
Horizontal resolution	G B T	100 m † - 2000 km	100 m † 1 km 2000 km	4 km - 4 km
Vertical resolution	G B T	- - -	10 m nominal 10 m nominal Surface	- - -
Temporal resolution	G B T	Weekly-seasonal - 10 months	Weekly-monthly 3 months 12 months	1 day - 7 days
Required measurement uncertainty (2-sigma)	G B T	- - 5 %	- - 5 %	30 % - 30 %
Timeliness	G B T	- - -	- - -	- - -
Stability	G B T	- - -	- - -	3 % per decade - 3 % per decade

3 Historical user requirements

The OC-CCI has over a decade of experience in gathering and reviewing user requirements related to ocean-colour ECV products. Generally, the user community requires long-term, reliable, quality-controlled, stable products that are easy to access and can be used for climate studies (Sathyendranath, 2011). User consultations in OC-CCI identified that the expected accuracy (a measure of systematic error or bias) and precision (a measure of random errors) for chlorophyll-a, a measure of phytoplankton biomass, was more stringent than GOCS requirements at the time, with both Earth Observation (EO) scientists and ecosystem modellers requiring an accuracy and precision between 10-25 % (versus 30 % from GCOS) (Table 1). But user requirements for stability of the ECV, which is crucial for climate change studies, were lower for chlorophyll-a compared to GCOS requirements, i.e., 5 % change per decade for EO scientists and 10 % change per decade for ecosystem modellers versus 3 % change per decade according to GCOS. Importantly, almost all users (95-100 %) identified the need for ECV products with uncertainty estimates. Concerning the horizontal resolution, the requirements of ecosystem modellers were in line with GCOS requirements for chlorophyll-a (grid size of ~10 km or coarser), while EO scientists requested – ideally – 0.1-1 km products to be able to capture small-scale processes in coastal studies of climate change, but ~60 % of EO scientists found products with a 1-10 km spatial resolution acceptable as a minimum requirement. For the temporal resolution, a minimum of one week was identified by users to reduce limitations due to cloud cover and to meet requirements for data assimilation and studying seasonality in phytoplankton blooms. Importantly, various means of data access (FTP, HTTP, web browser, OPeNDAP, THREDDS) and formatting (Climate Forecast compliant netCDF, HDF and

CMIP formats) were identified by users with a request for user-friendly portals and toolboxes as well as user support.

What also became apparent from user consultations in OC-CCI, and in the ESA projects Pools of Carbon in the Ocean (POCO) and PAR for Primary Production (PPP), is that there was a general interest in additional products to chlorophyll-a and remote-sensing reflectances. Phytoplankton Functional Types (PFTs), a measure of phytoplankton diversity, was of interest to ~80 % of EO scientists and ~90 % of ecosystem modellers surveyed (Figure 1). At the time of the consultation (2010), satellite-based phytoplankton diversity products, based on algorithms that separate the ocean-colour signal among different phytoplankton types, were mainly experimental and often referred to separation by size class. Users from the EO and ecosystem modelling communities agreed on the importance of phytoplankton diversity products for ecosystem model validation and that, in this case, the spatial requirements could be relaxed. One modeller summarised the need for information on phytoplankton diversity as follows: "We desperately need data of PFTs to validate our state-of-the-art models, in particular since we do not yet know the complexity needed to address our biological and biogeochemical questions. Optimally, we would have phytoplankton-specific pigments from space, but I think this is beyond what this ESA mission [i.e., OC-CCI] can do for us. The consequences of not having any observationally-determined information on PFTs would be dire, we would not be able to validate our models." The user consultation from OC-CCI identified the minimum requirements for PFTs (Table 2) at threshold values, which are within the current GCOS requirements (Table 1), except for measurement uncertainty, for which the EO and ecosystem modelling user communities are more lenient.

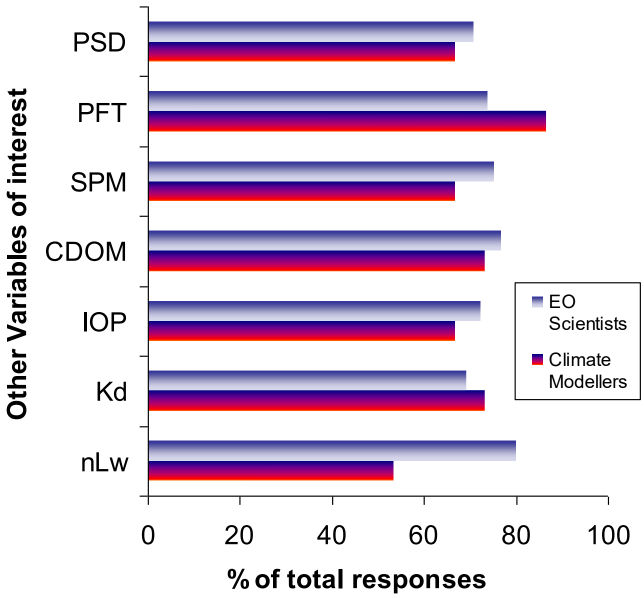

Figure 1. One of the outputs from the OC-CCI user consultation (Sathyendranath, 2011; and subsequent updates, see https://docs.pml.space/share/s/lg8js7hFSOaaZrtbtFGbmQ). Note in particular that in response to questions regarding other variables of interest not covered by OC-CCI, an overwhelming percentage of respondents (both Earth Observation (EO) scientists and climate modellers) identified phytoplankton functional types (PFTs) as of interest to them. There was also a high level of interest in particle size distribution (PSD). Note that OC-CCI now provides information on almost all the other user-identified variables, with the exception of PFT and PSD. Other abbreviations: Suspended Matter (SPM), Colour Dissolved Organic Matter (CDOM), Inherent Optical Properties (IOP), attenuation coefficient of light (Kd), normalised water-leaving radiances (nLw).

Table 2. Results from user consultations from OC-CCI during phase 1 (2010-2013) for chlorophyll-a (Chl-a) Phytoplankton Functional Types (PFTs). Requirements for the horizontal and temporal resolution, accuracy (systematic errors), precision (random errors) and stability (change in bias over time) are provided at three l maturity: the ideal requirement above which no further improvements are needed (G – Goal), an intermedia which significant improvements are made (B – Breakthrough), and the minimum requirements to ensure use the data product (T – Threshold). Information is taken from Sathyendranath (2011) and other user consultat undertaken by OC-CCI.

	Product	Chl-a			PFT	
	User community	EO scientists	Modellers	CMUG	EO scientists	M
Requirement	Level	Values	Values	Values	Values	
Horizontal resolution	G	0.1-1 km	0.1-1 km	-	-	
	B	0.1-1 km	1-10 km	4 km	-	
	T	1-10 km	1-10 km	-	1-10 km	1
Temporal resolution	G	1 day	1 day	-	-	
	B	7 days	7 days	1 d	-	
	T	1 month	1 month	-	7 d	
Accuracy	G	<10%	<10%	-	-	
	B	10-25%	10-25%	30%	-	
	T	10-25%	10-25%	-	10-25%	
Precision	G	<10%	<10%	-	-	
	B	10-25%	<10%	30%	-	
	T	10-25%	10-25%	-	10-25%	
Stability	G	1%	1%	-	-	
	B	1-2%	10%	-	-	
	T	5%	10%	-	2% per decade	

4 PHYTO-CCI user requirements

4.1 Target audience

It is important to consider which research and service communities should be targeted for the development of the phytoplankton carbon and diversity ECV products. Here we target the research community that uses ocean biosphere ECVs for climate research in the broadest sense, and in particular those communities that address the impact of climate variability and climate change on marine life from bacteria and phytoplankton all the way to the largest organisms in the ocean. Those communities that address inter-ECV interactions, such as those between sea surface temperature (SST) and phytoplankton, sea-ice and phytoplankton and/or aerosols and phytoplankton are of particularly importance. As the length of the time series of ocean-colour satellite observations grows – 28 years at the time of writing – the merit of the proposed ECV data as a stand-alone tool for climate research also becomes more important. We therefore target the community engaged in interpretation of time series data to understand the role of climate in observed variations, as well as the modelling community that assimilates data into their ecosystem models to improve model performance. Because of the central role of phytoplankton in the marine food web, the products could also be of use to those studying higher trophic levels and associated ecosystem services, such as aquaculture and fisheries. Another important group are providers of climate-quality data, such as Copernicus services, and national-level services, such as UK Earth Observation Climate Information Service (EOCIS).

4.2 User requirements survey

4.2.1 Method

A combined OC- and PHYTO-CCI user requirements survey was carried out online in September 2025, targeting the wider ocean-colour research and services communities as well as the Earth System and marine biogeochemical modelling communities (also see Section 4.1). The questions of the online survey were formulated based on previous surveys carried out under OC-CCI, for continuity in the assessment of user requirements for ocean-colour products, but with a specific focus on phytoplankton biomass and diversity. The survey was a mix of multiple choice and open questions, to poll specific user requirements according to GCOS standards and to gather insight into the reasons for specific user requirements. In addition, questions around data access and services were included to understand the experience of users in accessing ocean-colour products from CCI. Three different user groups were polled, i.e., Earth Observation (EO) scientists, modellers and other users, and depending on the user group, specific questions were posed (Figure 2). The questions of the online survey can be found in Appendix I. We note that the survey was comprehensive, and depending on the type of user (EO scientist, modeller, other user) it would take between 30-60 minutes to complete all questions. The OC- and PHYTO-CCI online user requirements survey was advertised on the CCI website, social media (personal accounts and PML's social media channels) and through newsletters of ESA and the International Ocean Colour Coordinating Group (IOCCG). Invitations to participate in the survey were also extended by email, through broader scientific networks, and specifically to the ESA-funded projects SCOPE, COOL, TIME, CAMP, PhytoDiverse and PlanktonSpace.

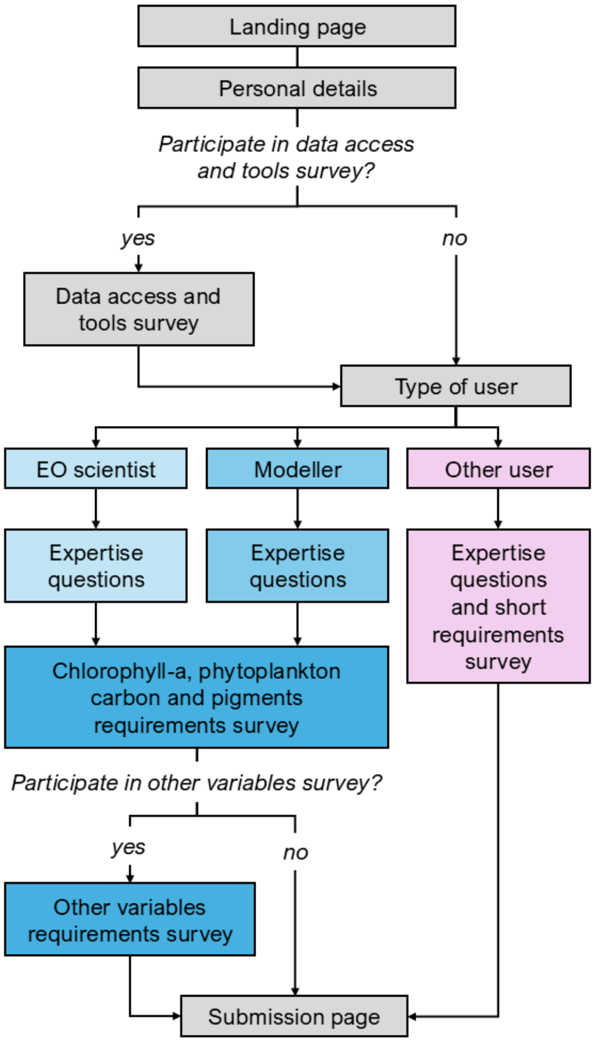

Figure 2. Overview of online user requirements survey, with different parts being completed depending on the expertise of participants and their willingness to participate in additional surveys related to data access and tools and other variables than the ocean biosphere ECV. The full list of questions used in the survey is available in Appendix I.

4.2.2 Results

The online user requirements survey was completed by 22 participants, who formed a diverse group from different geographic locations, scientific backgrounds and interests, and career stages (Figure 3). The group consisted of participants from four continents, with most participants (45 %) from Europe (Figure 3A), and was equally represented by participants from different career stages (Figure 3C) and gender (data not shown). The majority of participants had a background in EO or modelling (73 %), with the remaining participants indicating a different background (Figure 3B). The scientific interest of participants was diverse, and most participants indicated multiple scientific subjects, including topics related to phytoplankton ecology, diversity and production; water quality, fisheries and aquaculture; model development, assessment and data assimilation; and global and trend analyses (Figure 3D).

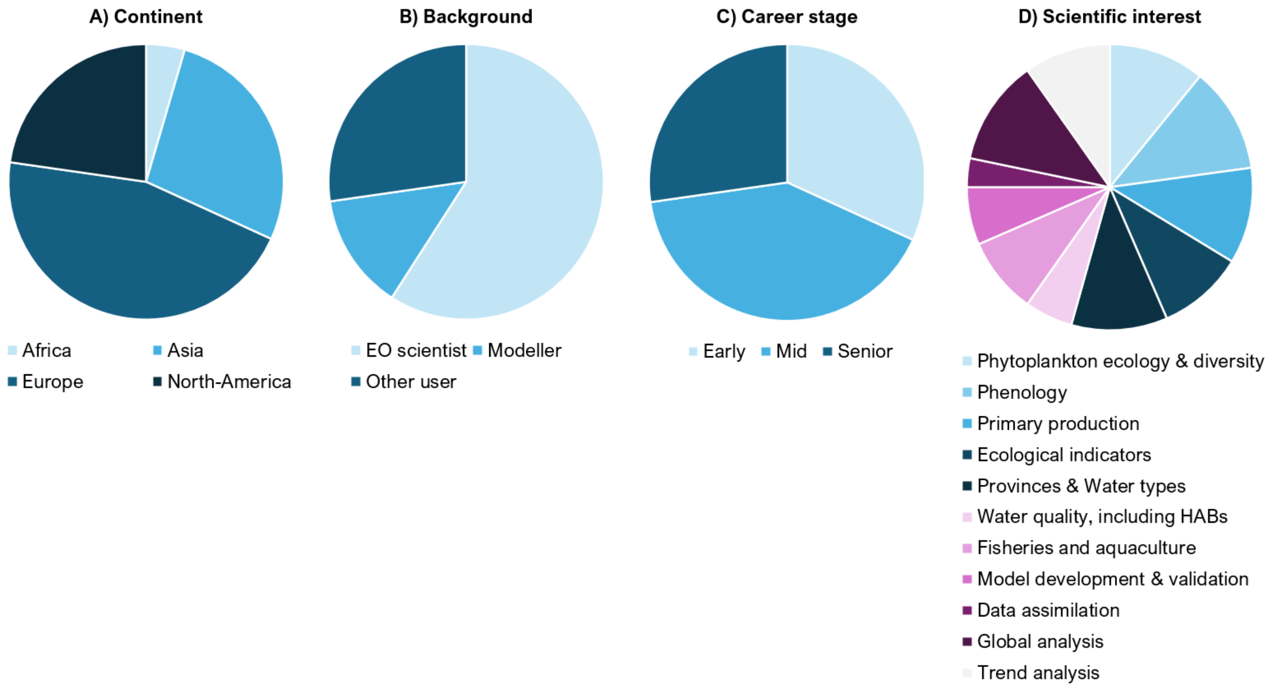

Figure 3. Details of participants of the online user consultation survey, with their geographic location (A), background (B), career stage (C) and scientific interest (D). A total of 22 participants completed the survey.

About three-quarters (73 %) of respondents indicated that they have used ocean-colour data before, specifically that of OC-CCI. Most of them use level-2 (53 %) and level-3 (35 %) data of OC-CCI, with a small group using level-1 and level-4 data (Figure 4A). Chlorophyll-a is most used by participants of the online user requirements survey, followed by the attenuation coefficient of light, remote sensing reflectances and inherent optical properties (Figure 4B). Many respondents also indicated that they use OC-CCI data to derive their own variables (Figure 4C). These variables included those related to phytoplankton biomass and diversity, i.e., chlorophyll-a, phytoplankton functional types and particle size distributions, and other ocean-colour-derived variables, including light attenuation coefficients at every wavelength (OC-CCI only provides this variable at 490 nm), optical water types, turbidity and primary production.

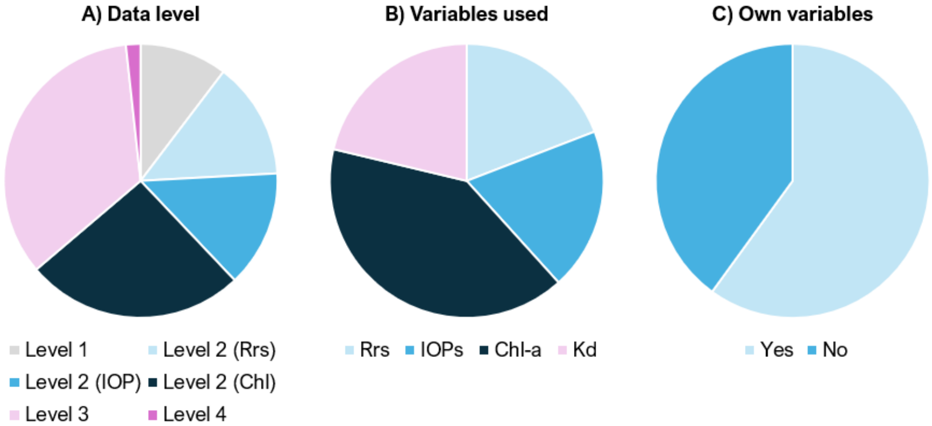

Figure 4. Use of ocean-colour data levels and variables from OC-CCI by respondents of the online user requirements survey. Abbreviations: Rrs – Remote sensing reflectance, IOP – Inherent Optical Properties, Chl-a – Chlorophyll-a, Kd – Attenuation coefficient of light.

The participants of the online user requirements survey who identified as EO scientist or modeller were presented with detailed questions about user requirements for phytoplankton biomass and diversity ECV products from ocean colour. For phytoplankton biomass, both chlorophyll-a and carbon were considered, and for phytoplankton diversity, pigments (other than chlorophyll-a) were considered. Following GCOS requirements and earlier user requirement surveys of OC-CCI, information was gathered on horizontal and temporal resolution, accuracy and precision (as measures of uncertainty) and stability at three different levels, i.e., threshold, breakthrough and goal (definitions can be found in Section 1.4).

Most respondents indicated that the horizontal resolution of ECV products of phytoplankton carbon biomass (Figure 5A) and pigment diversity (Figure 6A) should be between 1-10 km at threshold level and between 0.1-1 km at breakthrough and goal level, which is generally higher than GCOS requirements (Table 1). Temporal resolution of these products were 1 week at threshold and 1 day at breakthrough and goal levels (Figures 5B, 6B) and again more frequent than expected from GCOS requirements (Table 1). Respondents indicated that high spatial and temporal resolution is especially important in highly dynamic systems, such as coastal regions, and EO scientists generally agreed that monthly resolution would not be sufficient to study phytoplankton. Modellers had less stringent requirements on spatial resolution, with coarser products considered to be sufficient for data assimilation and model validation, but had different views on the temporal resolution, with some indicating monthly data as sufficient and others requiring daily data. The uncertainty in phytoplankton carbon biomass and pigment diversity, as indicated by the accuracy and precision, was expected to be >50 % at threshold level, between 25-50 % at breakthrough level and at 10-25 % at goal level (Figures 5C, 5D, 6C, 6D). These levels of uncertainty are less stringent than GCOS requirements (i.e., 5 %; see Table 1), but in line with what might be expected for EO data. Users indicated that the required uncertainty of ocean colour ECVs depends on the application, with those studying phenology and fisheries requiring lower uncertainties than those studying large-scale ecosystem processes. The required stability for phytoplankton carbon biomass and pigment diversity was 5 % at threshold level, between 2-5 % at breakthrough level and 1 % at goal level (Figures 5E, 6E), for which GCOS has not identified any requirements (Table 1). Users indicated that 5 % stability in the data would be sufficient for their current research, but they would prefer higher stability in the future for climate applications as change can be small in the ocean biosphere and ocean colour ECV variables.

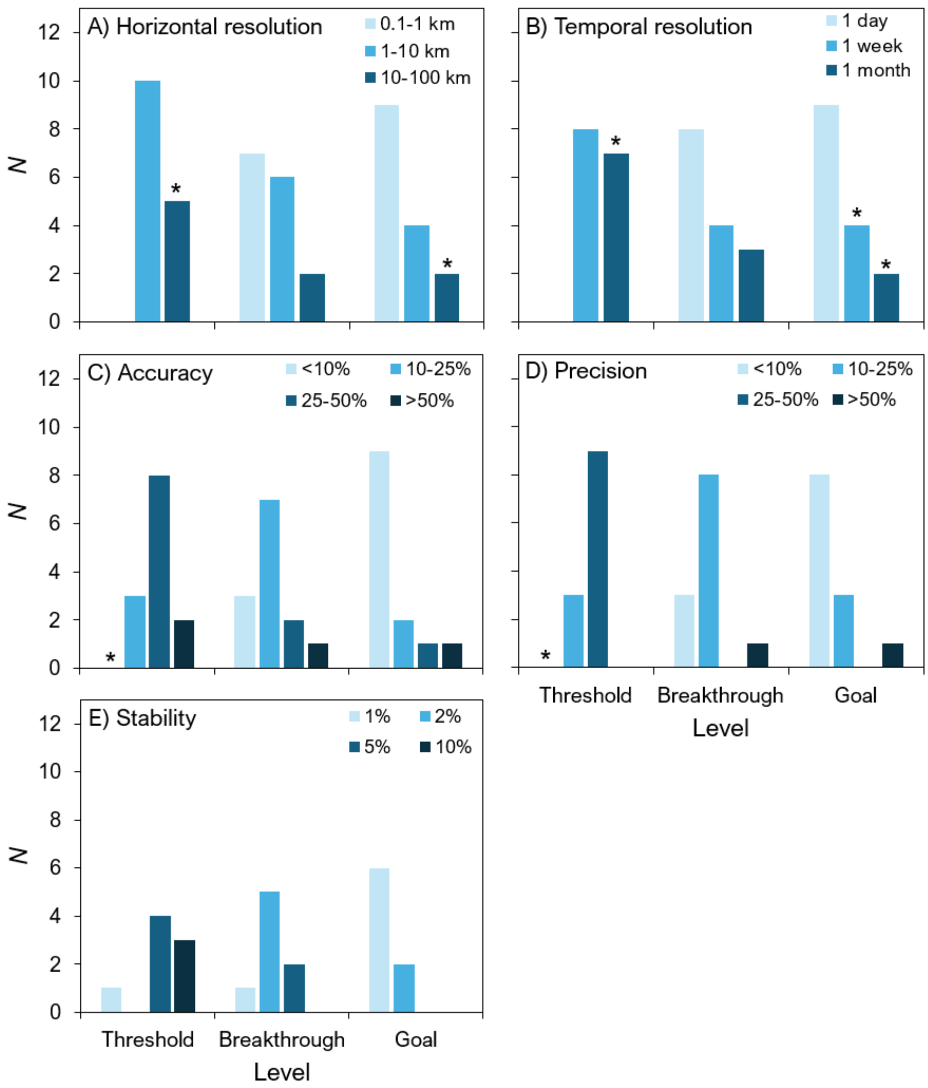

Figure 5. User requirements for phytoplankton carbon biomass as identified by the EO scientist and modeller user groups in the online user requirements survey. Users identified their preferred horizontal (A) and temporal (B) resolution of phytoplankton carbon data, the required accuracy (C) and precision (D) that the data should meet, and the stability (E) within the time series at threshold, breakthrough and goal levels. The asterisk marks the requirements according to GCOS (also see Table 1). Abbreviations: N – number of respondents.

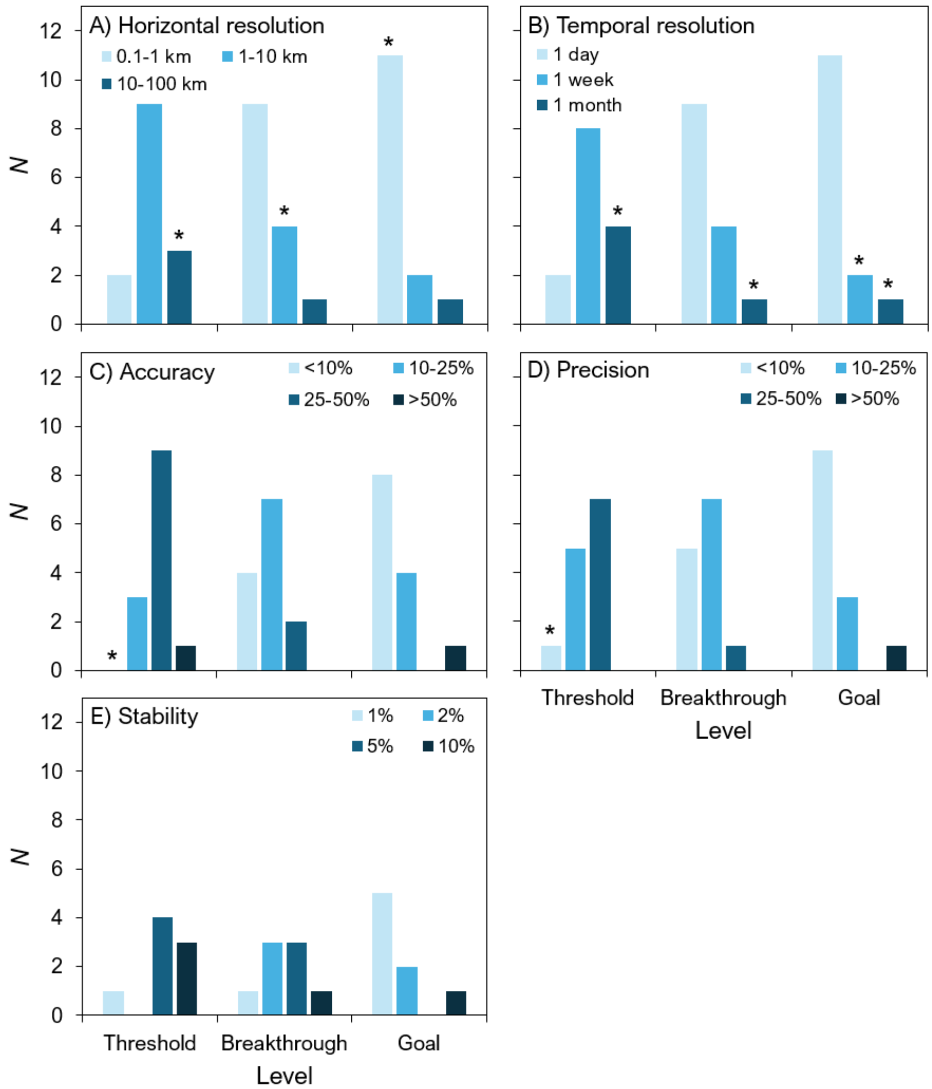

Figure 5. User requirements for phytoplankton pigment diversity as identified by the EO scientist and modeller user groups in the online user requirements survey. Users identified their preferred horizontal (A) and temporal (B) resolution of phytoplankton pigment (other than chlorophyll-a) data, the required accuracy (C) and precision (D) that the data should meet, and the stability (E) within the time series at threshold, breakthrough and goal levels. The asterisk marks the requirements according to GCOS (also see Table 1). Abbreviations: N – number of respondents.

The EO scientist and modeller user groups identified similar requirements for chlorophyll-a, another measure of phytoplankton biomass, with a horizontal resolution of 1-10 km at threshold level and of 0.1-1 km at breakthrough and goal levels (Figure 7A) and a temporal resolution of 1 week at threshold level and of 1 day at breakthrough and goal levels (Figure 7B). The temporal requirements were more frequent than GCOS requirements at goal level, indicating that users preferred higher resolution data. They indicated similar justifications of these values compared with the ocean biosphere ECV products, with high spatial resolution needed to address phytoplankton ecosystems in dynamic regions. User requirements for uncertainty in chlorophyll-a were between 10-50 % at threshold level, similar to GCOS requirements (i.e., 30 %; Table 1), but were more stringent at breakthrough and goal levels at <10 % (Figures 7C, 7D). Expectations on the stability of the data products ranged from 5 % to 1 % at threshold to goal levels, respectively, and were more stringent compared to GCOS requirements at goal level (Figure 7E, Table 1). Again, the justification of these requirements was similar to those of phytoplankton carbon biomass and pigment diversity, with the required uncertainty and stability of data products depending on the scientific application.

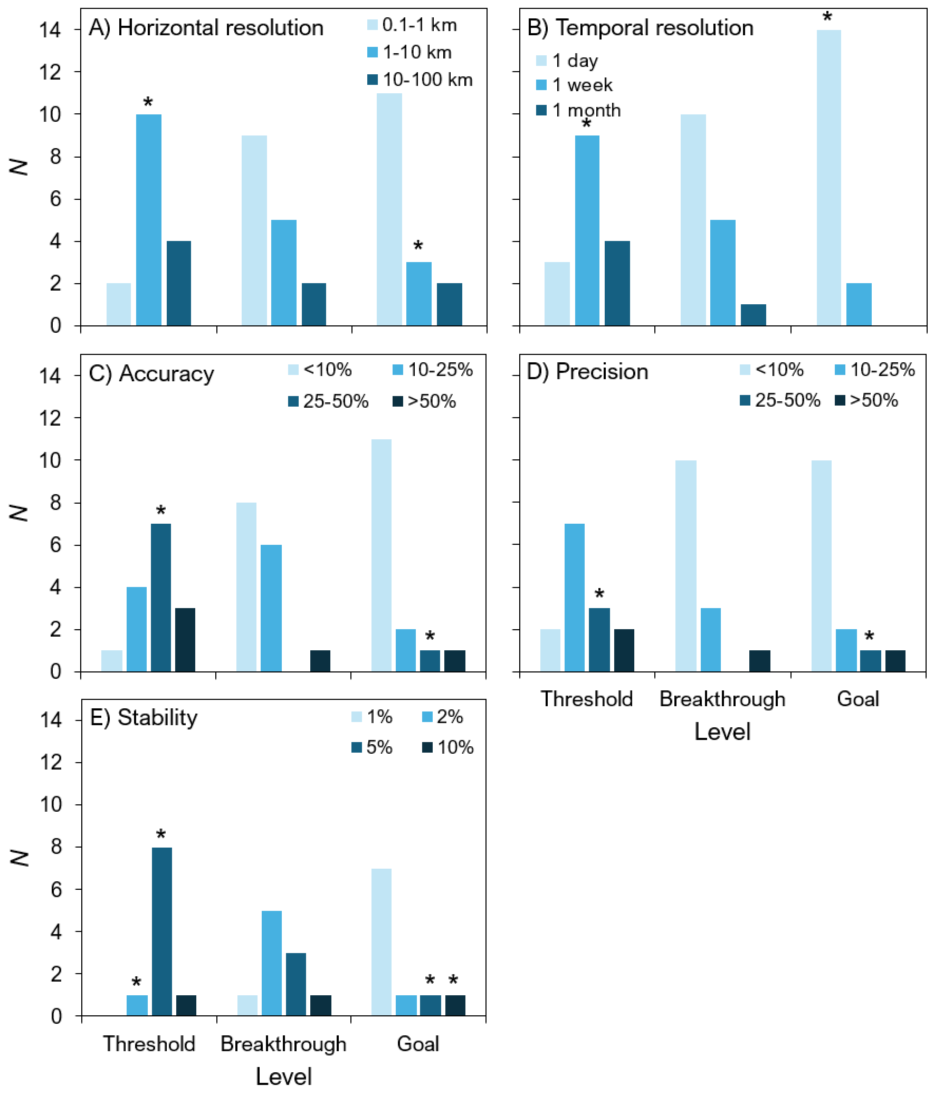

Figure 6. User requirements for chlorophyll-a as identified by the EO scientist and modeller user groups in the online user requirements survey. Users identified their preferred horizontal (A) and temporal (B) resolution of chlorophyll-a data, the required accuracy (C) and precision (D) that the data should meet, and the stability (E) within the time series at threshold, breakthrough and goal levels. The asterisk marks the requirements according to GCOS (also see Table 1). Abbreviations: N – number of respondents.

The EO scientist and modeller user groups were also asked about the importance of error characterisation for phytoplankton biomass and diversity ECV products from ocean-colour observations. The majority of users indicated that uncertainty estimates were important, with EO scientists assigning more importance to error characterisation than modellers (Figure 7).

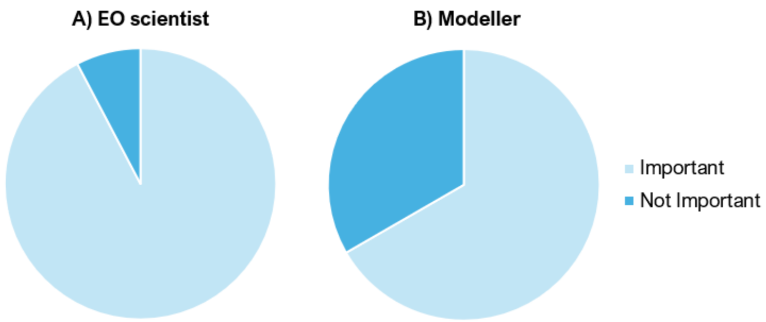

Figure 7. Importance of error characterisation for phytoplankton biomass and diversity ECV products from ocean-colour observations as polled among EO scientists (A) and modellers (B).

Sixteen respondents indicated that they were interested in other variables derived from ocean-colour observations, which included ECV products that are already provided by OC-CCI, i.e., remote sensing reflectances, inherent optical properties and the attenuation coefficient of light, but also include other variables, such as different phytoplankton diversity indicators, different components of the ocean carbon cycle and photosynthetically active radiation (Figure 8). Ten respondents filled out further questions related to user requirements of these other variables of interest at threshold level. Focusing here on those products that are not yet available through CCI, most users indicated similar requirements to chlorophyll-a for these additional variables with a horizontal resolution at 1-10 km and a temporal resolution of 1 week at threshold level (Table 3). Users indicated less stringent requirements for uncertainty for most of the additional ocean-colour variables compared with chlorophyll-a and stability was expected to be 5 % across all products, except for phytoplankton functional types (i.e., 2 %; Table 3).

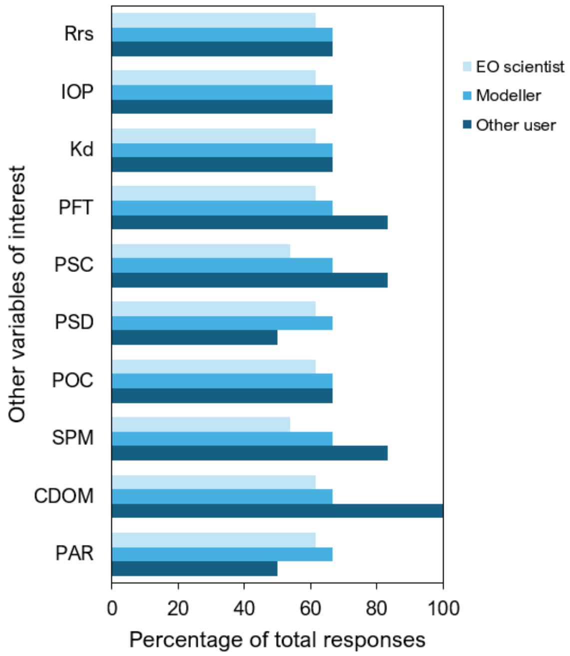

Figure 8. Other ocean colour variables of interest to respondents of the online user requirements survey, of which remote sensing reflectances (Rrs), inherent optical properties (IOP) and the light attenuation coefficient (Kd) are already provided through OC-CCI. Abbreviations: PFT – Phytoplankton Functional Types, PSC – Phytoplankton Size Classes, PSD – Particle Size Distribution, POC – Particulate Organic Carbon, SPM – Suspended Particulate Matter, CDOM – Coloured Dissolved Organic Matter, and PAR – Photosynthetically Active Radiation.

Table 3. User requirements for additional ECV products from ocean-colour observations (that are not part of OC-CCI) at threshold level according to the EO scientist and modeller user groups. Threshold values for chlorophyll-a, phytoplankton carbon and phytoplankton pigments (other than chlorophyll-s) are provided as reference. Abbreviations: Chl-a – Chlorophyll-a, PC – Phytoplankton Carbon, PFT – Phytoplankton Functional Types, PSC – Phytoplankton Size Classes, PSD – Particle Size Distribution, POC – Particulate Organic Carbon, SPM – Suspended Particulate Matter, CDOM – Coloured Dissolved Organic Matter, and PAR – Photosynthetically Active Radiation.

Variable	Requirement				
	Horizontal resolution	**Temporal resolution**	**Accuracy**	**Precision**	**Stability**
Chl-a	1-10 km	1 week	25-50 %	10-25 %	5 % per decade
PC	1-10 km	1 week	25-50 %	>50 %	5 % per decade
Pigments	1-10 km	1 week	25-50 %	>50 %	5 % per decade
PFT	1-10 km	1 week	>50 %	>50 %	2 % per decade
PSC	1-10 km	1 week	>50 %	25-50 %	5 % per decade
PSD	1-10 km	1 week	>50 %	10-50 %	5 % per decade
POC	1-10 km	1 week	>50 %	>50 %	5 % per decade
SPM	1-10 km	1 week	>50 %	10-50 %	5 % per decade
CDOM	1-10 km	1 week	25-50 %	>50 %	5 % per decade
PAR	1-10 km	1 week-1 month	>50 %	10-50 %	5 % per decade

In addition to specific requirements related to resolution, uncertainty and stability, users were also able to provide feedback on data access and services based on their experiences with OC-CCI. Most respondents who currently use OC-CCI data, indicated that they use multiple data formats, with NetCDF (65 %) and GeoTIFF (26 %) files being the most popular (Figure 9A). Users also typically access data through multiple platforms, including a web browser (33 %), ftp server (29 %) and cloud services (19 %) (Figure 9B), and commonly use the PML OC-CCI (38 %), Copernicus Climate Change Service (32 %) and ESA CCI (24 %) data portals (Figure 9C).

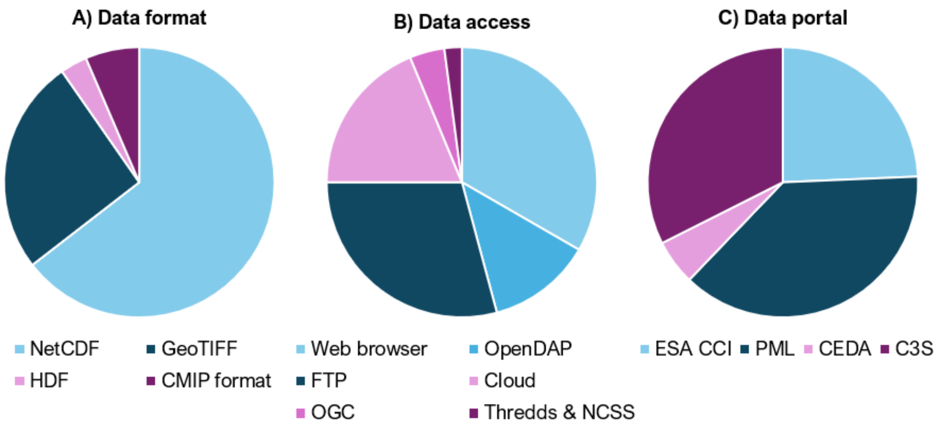

Figure 9. Data level, format and access, as polled among participants of the online user requirements survey, based on their experiences with OC-CCI and other ocean-colour data. Abbreviations: NetCDF – Network Common Data Form, HDF – Hierarchical Data Format, GeoTIFF – Georeferenced Tagged Image File Format, CMIP – Coupled Model Intercomparison Project, FTP – File Transfer Protocol, OGC – Open Geospatial Consortium, OpenDAP – Open-source Project for a Network Data Access Protocol, NCSS – NetCDF Subset Service, ESA – European Space Agency, CCI – Climate Change Initiative, PML – Plymouth Marine Laboratory, CEDA – Centre for Environmental Data Analysis, C3S – Copernicus Climate Change Service.

Respondents also make use of multiple third party tools to analyse ocean-colour data, including tools that allow for data handling, such as reading, subsetting, compositing and regridding, as well as data processing, analysing and visualisation tools (Figure 10A). Further third party tools are used for the generation of match-ups and trend analysis (Figure 10A). Respondents specified various third party tools that they currently use, including Python packages (xarray, numpy, pandas, cartopy, matplotlib, scipy), R libraries (terra, rgdal, raster), Sentinels Application Platform (SNAP), SeaWiFS Data Analysis System (SeaDAS) and Environmental Research Division Data Access Program (ERDDAP). Most respondents indicated that they would like these tools to be provided within OC- and PHYTO-CCI (Figure 10B). Respondents indicated that access to large data volumes is an obstacle, and tools that allow for subsetting, compositing and regridding would help with this. Most users (95 %) also indicated that such tools should be developed under an open-source license and should be provided with source-code, preferably in Python (i.e., 86 % respondents use this programming language).

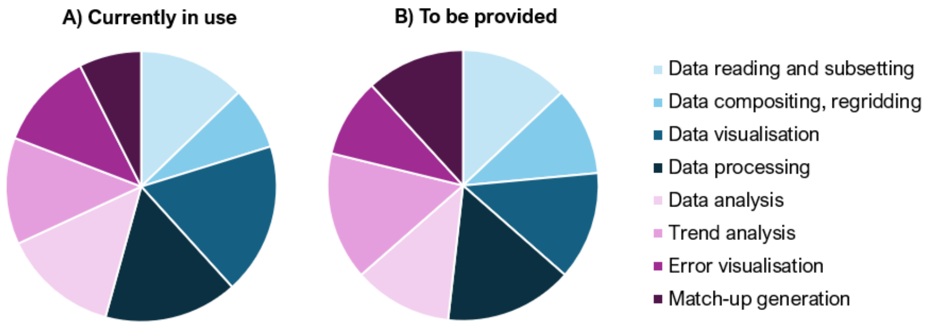

Figure 10. Third party tools currently used by participants of the online user requirements survey (A) and tools that they would like to be provided by OC- and PHYTO-CCI (B).

4.3 User consultation workshops

4.3.1 Method

The online user consultation workshops were organised in October 2025. Invitations were send directly to the scientific advisory board of PHYTO-CCI and key scientists in the field of ocean-colour remote sensing and biogeochemical modelling. Additional invitations were send to participants of the online survey, who indicated in the survey they would be interested in participating in an online user consultation workshop to further discuss their requirements for ocean-colour data. A total of 39 invitations were send.

Three 90-minutes online workshops were organised, with a maximum of 6 participants in each workshop to allow small group and interactive discussions. Each workshop consisted of two parts. The first part of each workshop included an introduction to ocean biosphere ECVs and presentations from the participants on their use of ocean-colour data products and their general feedback, followed by a discussion. For this part, each participant was asked to prepare 1-2 slides ahead of the workshop to address the following topics and seed questions:

1) *Current use of data*
   If you use OC-CCI and ocean-colour-derived phytoplankton data, what do you use it for? Can you give an example of your research? Why are ocean-colour data essential to your work? Is there any specific feedback you would like to give?

2) *Limitation to data use*
   Do you experience any limitations in the use of OC-CCI and ocean-colour-derived phytoplankton data? This could be technical (e.g., data access, data availability, etc.) or scientific (e.g., certain variables not being available, data does not meet requirements, etc.).

3) *Data and service improvements*
   How can we improve OC- and PHYTO-CCI products/services? For example, if products were generated with a higher spatial resolution, would you use them? Are there any additional ocean-colour variables that you would need (e.g., phytoplankton functional types, size classes, etc.)?

In the second part of each workshop, the results of the online survey were presented and further discussed with the workshop participants, following GCOS terminology. We used the following seed questions to initiate the discussion, which were shared with the participants ahead of the workshop:

- What are the most important requirements for your work (e.g., resolution, accuracy, stability, etc.)? And what would be the minimum level for these? Do you think the requirements emerging from the online questionnaire reflect realistic/useful requirements now/in the future?
- What are the ideal requirements for your work? What research questions would you be able to answer if these ideal requirements were met?

Each workshop was recorded for internal reporting purposes only.

4.3.2 Results

The user consultation workshops were attended by 14 participants in total. Half of the participants were from Europe, with the others from Africa, Asia, and North- and South-America (Figure 11A). The participants were from diverse scientific backgrounds and career stages, with EO and mid-career scientists forming the largest groups (Figures 11B, 11C). Just over half of participants also completed the online user requirements survey, either before or after they signed up for the workshops (Figure 11D). All participants were engaged during the workshop, and provided feedback by either presenting slides on their research and requirements, or discussing these topics without visual aids. The results of the user requirements workshops are summarised below, and detailed comments from participants are provided in Appendix II.

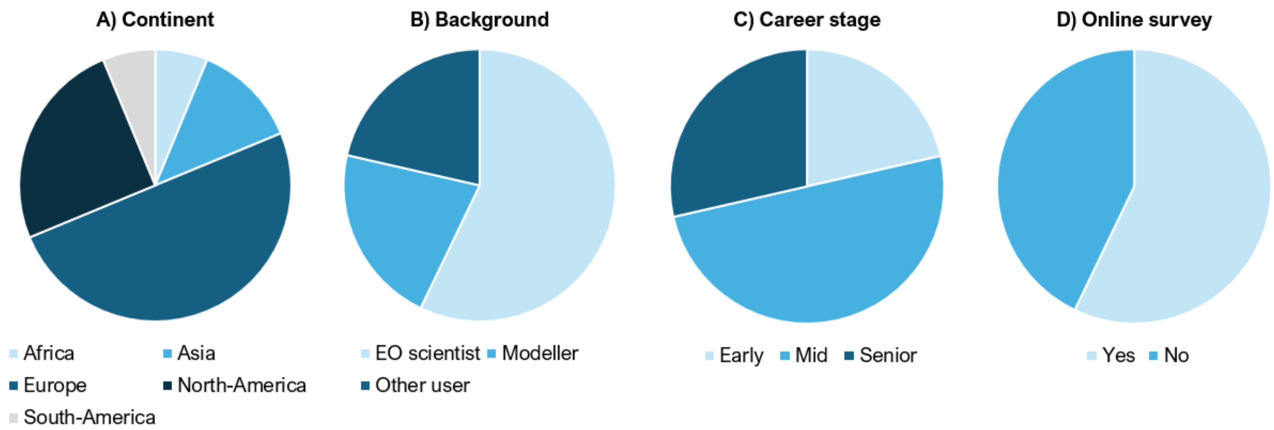

Figure 11. Details of the workshop participants, with their geographic location per continent (A), their scientific background (B) and their career stage (C), and whether they completed the online user requirements survey (D).

In general, the workshop participants were positive about the ocean-colour data that is currently available from OC-CCI. The length of the time series and the availability of global datasets were specifically mentioned as positives. The workshop participants use ocean-colour data for a variety of applications, similar to those indicated in the online user requirements survey (Figure 3D), including phytoplankton phenology, phytoplankton diversity, primary production, water quality, fisheries and aquaculture, model validation, data assimilation and time series and trend analysis. Several participants indicated that they derive their own phytoplankton biomass and diversity variables from OC-CCI data, including chlorophyll-a, phytoplankton carbon, phytoplankton functional types, phytoplankton size classes and particle size distributions.

About half of the workshop participants use ocean-colour data in coastal environments and indicated that OC-CCI data is not always suitable in these highly dynamic environments, but it was also mentioned that ocean-colour data from single sensors, such as MODIS, do not necessarily perform better. Examples were given for chlorophyll-a, which can be underestimated in high biomass coastal environments along the Brazil coast and the Islandic Basin. It was also raised that merged products, such as those from OC-CCI, sometimes result in discrepancies in the times series in coastal regions. Workshop participants are to some extent aware that data is flagged and uncertainties are available to assess the suitability of the OC-CCI data for coastal applications, but this information does not seem to be commonly used among the user community.

Around a third of workshop participants were interest in additional wavebands in OC-CCI data, this included bands in the near infrared. The main reason for this request was related to the development of regional algorithms for chlorophyll-a in coastal environments, but also for the development of phytoplankton pigment and other diversity variables. One participant noted that their algorithm for phytoplankton diversity was based on the specific wavebands currently available for OC-CCI version 6, and any changes to these wavebands would results in a significant amount of work to adjust their algorithm. They specifically requested multiple single wavebands to be available around a central waveband, or the capability to shift wavebands themselves.

During the workshops, users also indicated several additional ocean-colour-derived variables of interest, most notably phytoplankton diversity variables and photosynthetically active radiation, which is essential in the estimation of primary production from satellite observations. Workshop participants indicated that ideally these variables would all come from CCI, for consistency between products. For phytoplankton diversity variables, all modellers agreed that it would be useful to have the same classification of phytoplankton groups between ocean-colour data and ecosystem models. Depending on the ecosystem model used, the groups of interest could for example be diatoms and nanophytoplankton, while ocean-colour data typically provides phytoplankton size classes (pico-, nano- and microphytoplankton) or phytoplankton functional types (i.e., diatoms, etc.). Uniformity is an important requirement for modellers to be able to use ocean-colour data effectively. One modeller mentioned that phytoplankton carbon is the ultimate variable needed, and more specifically across phytoplankton functional types, to truly understand the role of phytoplankton in carbon and nutrient cycles.

When specific requirements of the ocean-colour data products were discussed, many workshop participants indicated that they expect higher spatial and temporal resolution than previous user consultations revealed. Although many were appreciative of the 1-km, daily data that is already available through OC-CCI, there was also a need for higher resolution data, especially from EO scientists working in coastal regions. Modellers were satisfied with the current spatial and temporal resolutions available, and indicated that model grids are generally much coarser. There was also an interest in near-real time data, especially for applications for marine services, such as harmful algal bloom warnings, but workshop participants acknowledged that CCI is not necessarily intended for this purpose. Others indicated that a quarterly update of the times series is sufficient for their climate related research. Other requirements that were seen as important included accuracy and stability, with one modeller indicating that accuracy was most important (i.e., more important than spatial and temporal resolution) and one EO scientist indicating that a high stability of the time series is essential when addressing trends.

It also emerged from the workshops that access to data and documentation is not always straightforward for users. Although many users were able to find OC-CCI data, many were confused about the potential differences between data from different sources, if any. Some users also indicated that there are issues around downloading the full times series of OC-CCI data and the required storage capacity needed for this, especially at higher spatial and temporal resolutions. Some users indicated that cloud services would be preferred, and that these should accommodate analysis over large geographic regions (i.e., large rendering capacity). One user advocated for FTP servers as they find this the easiest way to download data. In general, it seemed that workshop participants were not familiar with OC-CCI documentation, where to find documentation and what documentation is available. Some participants familiar with the product user guide mentioned that the documentation should be simplified or summarised, while other participants indicated that they would like more technical information, for example on the atmospheric correction used.

4.4 Summary of user requirements

Following the results from the user requirements survey and workshops, the user requirements for PHYTO-CCI are summarised in Table 4 according to GCOS criteria, with accuracy and precision representing measurement uncertainty. The requirements for phytoplankton carbon biomass and pigment diversity derived from ocean-colour observations are similar to those expected for chlorophyll-a, with the exception that the accuracy and precision is allowed to be higher for the ocean biosphere ECV products.

Table 4. Summary of requirements for Essential Climate Variables (ECVs) and associated products related to phytoplankton biomass and diversity according to the online user consultation survey. Requirements for the spatial and temporal resolution, uncertainty (accuracy and precision) and stability (e.g., change in bias over time) are provided at three levels of maturity: the ideal requirement above which no further improvements are needed (G – Goal), an intermediate level at which significant improvements are made (B – Breakthrough), and the minimum requirements to ensure usefulness of the data product (T – Threshold).

	ECV	Plankton		Ocean Colour
	Product	Phytoplankton carbon	Phytoplankton pigments	Chlorophyll-a
Requirement	Level	Values	Values	Values
Horizontal resolution	G B T	0.1-1 km 0.1-1 km 1-10 km	0.1-1 km 0.1-1 km 1-10 km	0.1-1 km 0.1-1 km 1-10 km
Temporal resolution	G B T	1 day 1 day 1 week	1 day 1 day 1 week	1 day 1 day 1 week
Accuracy	G B T	<10 % 10-25 % 25-50 %	<10 % 10-25 % 25-50 %	<10 % <10 % 25-50 %
Precision	G B T	<10 % 10-25 % >50 %	<10 % 10-25 % >50 %	<10 % <10 % 10-25 %
Stability	G B T	1 % per decade 2 % per decade 5 % per decade	1 % per decade 2-5 % per decade 5 % per decade	1 % per decade 2 % per decade 5 % per decade

5 Conclusions

It became clear from the user consultation that ocean-colour variables related to phytoplankton biomass and diversity are of interest to the user community, for EO scientists as well as modellers and other users. Some users already generate these variables from ocean-colour data (whether from merged or single sensor datasets), but a general appreciation of the quality of the CCI products and the length of the time series was shared among users. The user requirements for PHYTO-CCI are summarised in Table 4. In comparison to previous user consultations within OC-CCI, user requirements have changed primarily in the temporal resolution required, with users now looking for more frequent data (i.e., 1 week instead of 1 month at threshold level). This seems to be mainly driven by the interest among users to use ocean-colour data in more dynamic marine systems, such as coastal regions. While users indicated overwhelmingly that error characterisation is important, the uncertainty estimates provided in OC-CCI do not seem to be commonly used by users to assess the quality of the data for the intended application. It is noted that the visibility of the documentation associated with ocean colour CCI data could be improved to support users with understanding data processing, versioning and quality.

6 References

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Sathyendranath, S., 2011. User requirements document. Ref: D1.1 Issue 1.10. Technical Report ESA/ESRIN.

Sathyendranath (2024) OC-CCI Climate Assessment Report (Unpublished)

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Appendix I – Questions included in user requirements survey

Ocean Colour User Requirements Questionnaire for the Ocean Colour Climate Change Initiative (OC-CCI) and the PHYTOPlankton biomass and diversity Climate Change Initiative (PHYTO-CCI)

The OC-CCI & PHYTO-CCI projects - supported by the European Space Agency- are conducting a user survey to understand user requirements linked to the continued development of the OC-CCI dataset and generation of the PHYTO-CCI dataset that will build upon the OC-CCI dataset. The data collected will be used to improve the datasets and summarised (anonymously) within related user requirements deliverables.

This survey builds on a previous one sent around 15 years ago, and expanded to include questions on phytoplankton carbon and pigment retrieval.

1-Please allocate between 30 minutes and 1 hour for this questionnaire, if you intend to answer all questions
2- It is OK to leave blank fields in the majority of questions, but it is essential to go to the last page and press SUBMIT to complete the survey.
3- Survey open until the 30-September-2025

GDPR statement summary
By submitting this questionnaire, you explicitly consent PML collecting and processing your personal data for the purposes outlined in our privacy notice. Your responses will be used to refine the characteristics of the satellite products in OC-CCI and PHYTO-CCI to help us construct more user oriented datasets.Your data will be stored securely for 5 years and will only be accessed by PML and Pixalytics Ltd. You have the right to withdraw your consent at any time by emailing Victor Martinez (vmv@pml.ac.uk), and we will delete your data in line with our policy. For more information on how we protect your data, please read our full privacy notice https://pml.ac.uk/privacy-policy/ .

Sign in to Google to save your progress. Learn more

* Indicates required question

Personal Information

Full name (Name Surname) *

Your answer

Email Address *

Your answer

Are you happy that your responses are attributed to you? *

- ◯ Yes
- ◯ No

Country *

Your answer

Institution *

Your answer

Department

Your answer

Would you be interested in any of the following?
(select as appropriate)

- ☐ Participating in an online user consultation workshop to discuss user requirements in more detail (organised on 6 October 2025 14:30-16:00 BST and/or 7 October 2025 6:00-7:30 BST)?
- ☐ Being sent the user requirements document that will be based on the survey.
- ☐ Receiving test OC-CCI & PHYTO-CCI data to try out for your application; the test data are expected to be available in early 2013.
- ☐ Be contacted in the future with updates about the project.

Next　Page 1 of 34　Clear form

Satellite data distribution and tools

If you select YES below, you will have the opportunity to let us know your preferences for accessing ocean colour derived CCI datasets, currently and in future versions.

Are you interested on providing feedback on current and future access and tools to Ocean Colour CCI products? *

- ◯ Yes
- ◯ No

Back　Next　Page 2 of 34　Clear form

Data Distribution, including current use of the OC-CCI dataset

What data would you prefer? (Select as many as relevant)

- ☐ Level 1 Geophysical Measurements (e.g. Top of the atmosphere radiance)
- ☐ Level 2 Datasets (derived products such as remote sensing reflectance original space view)
- ☐ Level 2 Datasets (derived products such as IOP original space view)
- ☐ Level 2 Datasets (derived products such as Chl-a original space view)
- ☐ Level 3 (e.g. daily, monthly means gridded)
- ☐ Other:

What data format would you prefer? (Please select as many as relevant)

- ☐ CF Compliant NetCDF
- ☐ HDF
- ☐ GeoTIFF
- ☐ CMIP format
- ☐ Other:

What is your preferred means of access to the data? (Please select as many as relevant)

- ☐ FTP
- ☐ Web Browser, i.e. manual download
- ☐ OpenDAP
- ☐ Open Geospatial Consortium (OGC) standards (e.g., WMS, WCS)
- ☐ Cloud services
- ☐ Other:

If you are a current OC-CCI user, how are you currently accessing the Ocean Colour CCI (OC-CCI) dataset? (Please select as many as relevant)

- ☐ PML oceancolour portal (https://www.oceancolour.org/portal/)
- ☐ CEDA (https://catalogue.ceda.ac.uk/uuid/de8aeb4f1bec4348a1e475691ea651d4/)
- ☐ Copernicus Climate Change Service (https://cds.climate.copernicus.eu/datasets/satellite-ocean-colour?tab=overview)
- ☐ ESA Climate Change Initiative Open Data Portal (https://climate.esa.int/en/data/#/dashboard)
- ☐ Other:

If you are a current OC-CCI user, which products are you currently using? (Please select as many as relevant)

- [ ] Remote-sensing reflectance
- [ ] Chlorophyll-a
- [ ] Inherent optical properties
- [ ] Diffuse attenuation coefficient

If you are a current OC-CCI user, do you calculate your own biogeochemical products derived from the remote-sensing reflectance, and if so why and which algorithm?

Your answer

If you are a current OC-CCI user, is there any specific feedback you'd like to provide on your usage and how the access/format could be improved?

Your answer

Back Next Page 3 of 34 Clear form

Tools and Services

This section is designed to tell us what tools and services you require in order to make full use of the datasets

What tools provided by third parties do you currently make use of? (select as many as are relevant)

- [ ] Data reading and subsetting
- [ ] Flexibility to extract data on different grids
- [ ] Data composition
- [ ] Generation of matchup datasets
- [ ] Data visualisation tools
- [ ] Data processing tools such as spatial and temporal averaging
- [ ] Data analysis tools such as generation of statistics, graphs
- [ ] Trend analysis
- [ ] Tools for visualisation/evaluation of uncertainties and other data quality information
- [ ] Other:

Which specific third party tools do you use?

Your answer

What capabilities/features of these tools do you find particularly useful?

Your answer

Back Next Page 4 of 34 Clear form

Tools and Services

What tools provided by third parties would you like this project to provide? (select as many as are relevant)

- [ ] Data reading and subsetting
- [ ] Flexibility to extract data on different grids
- [ ] Data composition
- [ ] Generation of matchup datasets
- [ ] Data visualisation tools
- [ ] Data processing tools such as spatial and temporal averaging
- [ ] Data analysis tools such as generation of statistics, graphs
- [ ] Trend analysis
- [ ] Tools for visualisation/evaluation of uncertainties and other data quality information
- [ ] Other:

Which specific third party tools would you want?

Your answer

What additional capabilities/features of these tools would you find particularly useful?

Your answer

Back Next Page 5 of 34 Clear form

Tools and Services

Would you prefer using free tools that are developed under an open-source license and that comes with source-code?

- ( ) Yes
- ( ) No

Are you aware of the open source ESA SNAP Toolbox (https://step.esa.int/main/toolboxes/snap/)? (select as many as are relevant)

- [ ] Yes, I'm already using it
- [ ] Yes, I'm planning to use it
- [ ] Yes, but I don't use it anymore
- [ ] Yes, but I don't want to use it
- [ ] No

Would you find it beneficial if all or some of these tools and services would be realised in the SNAP toolbox? (select as many as are relevant)

- ( ) Yes
- ( ) No
- ( ) I do not mind

Would you like to incorporate analysis, visualisation and processing in your own software programmes by using a dedicated library which this project would provide? If so, for which programming languages should the project provide such an application programming interface (API)? (select as many as are relevant)

- [ ] C
- [ ] C++
- [ ] Java
- [ ] Python
- [ ] IDL
- [ ] MATLAB
- [ ] Other:

Back Next Page 6 of 34 Clear form

Type of user

Please tell us whether you are a climate modeller or an EO scientist to enable us to tailor our questionnaire to you.

Type of user *

- ( ) Climate Modeller
- ( ) Earth Observation Scientist
- ( ) Other User

Back Next Page 7 of 34 Clear form

Other user of climate quality ocean colour products

There are three different levels of requirements, threshold, breakthrough, and goal, and these are all explained below.

Threshold Requirements
Minimum requirement to ensure that the data is useful.

Breakthrough Requirements
An intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The "breakthrough" level may be considered as an optimum, from a cost benefit point of view when planning or designing observing systems (or models).

Goal Requirements
An ideal requirement above which further improvement is not necessary.

Scientific subject(s) of interest (select as many as are relevant) *

- ☐ Phytoplankton ecology
- ☐ Phytoplankton diversity
- ☐ Phenology
- ☐ Primary production
- ☐ Fisheries and aquaculture
- ☐ Water quality
- ☐ Other:

Are you using remote sensing ocean colour observations in your research? *

- ◯ Yes, I am currently using these data
- ◯ Yes, I have used these data in the past
- ◯ No

What is the horizontal resolution in phytoplankton biomass and diversity data that your application requires?
The area over which one value of the variable is representative of.

	0.1 - 1	1 - 10	10 - 100
Threshold (minimum) (in km)	◯	◯	◯
Breakthrough (preferred) (in km)	◯	◯	◯
Goal (ideal) (in km)	◯	◯	◯

What is the temporal resolution in phytoplankton biomass and diversity data that your application requires?
The temporal frequency at which the measurements are required.

	1 day	1 week	1 month
Threshold (minimum)	◯	◯	◯
Breakthrough (preferred)	◯	◯	◯
Goal (ideal)	◯	◯	◯

What is the accuracy in phytoplankton biomass and diversity data that your application requires?
The measure of the non-random, systematic error, or bias, that defines the offset between the measured value and the true value that constitutes the SI absolute standard.

	< 10	10 - 25	25 - 50	> 50
Threshold (minimum) (relative, %)	◯	◯	◯	◯
Breakthrough (preferred) (relative, %)	◯	◯	◯	◯
Goal (ideal) (relative, %)	◯	◯	◯	◯

What is the precision in phytoplankton biomass and diversity data that your application requires?
Precision is a measure of reproducibility or repeatability of the observation without reference to an international standard so that precision is a measure of the random and not the systematic error. Suitable averaging of the random error can improve the precision of the measurement but does not establish the systematic error of the observation.

	< 10	10 - 25	25 - 50	> 50
Threshold (minimum) (relative, %)	◯	◯	◯	◯
Breakthrough (preferred) (relative, %)	◯	◯	◯	◯
Goal (ideal) (relative, %)	◯	◯	◯	◯

What is the long-term stability (over 10 years) in phytoplankton biomass and diversity data that your application requires?
Stability is a term often invoked with respect to long-term records when no absolute standard is available to quantitatively establish the systematic error - the bias defining the time-dependent (or instrument-dependent) difference between the observed quantity and the true.

	1	2	5	10
Threshold (minimum) (relative, %)	◯	◯	◯	◯
Breakthrough (preferred) (relative, %)	◯	◯	◯	◯
Goal (ideal) (relative, %)	◯	◯	◯	◯

What other ocean colour products would you be interested in to study climate change? (select as many as are relevant) *

- ☐ Remote sensing reflectance (Rrs)
- ☐ Phytoplankton Functional Types (PFT)
- ☐ Phytoplankton Size Classes (PSC)
- ☐ Particle Size Distribution (PSD)
- ☐ Inherent Optical Properties (IOP)
- ☐ Coloured Dissolved Organic Matter (CDOM)
- ☐ Suspended Particulate Matter (SPM)
- ☐ Particulate Organic Carbon (POC)
- ☐ Diffuse attenuation coefficient (Kd)
- ☐ Photosynthetically Active Radiation (PAR)
- ☐ Other:

Back Next Page 8 of 34 Clear form

Requirements: Introduction

In the following pages you will be asked to provide a series of requirements for:

- Chlorophyll-a concentration,
- Phytoplankton carbon concentration, and
- Phytoplankton pigments (other than Chlorophyll-a) concentration.

There are three different levels of requirements, threshold, breakthrough and goal; and these are all explained below.

Threshold Requirements
Minimum requirement to ensure that the data is useful

Goal Requirements
An ideal requirement above which further improvement is not necessary.

Back Next Page 9 of 34 Clear form

Spatial and Temporal Resolution - Chlorophyll-a

What is the horizontal resolution in Chlorophyll-a data that your application requires?
The area over which one value of the variable is representative of.

	0.1 - 1	1 - 10	10 - 100
Threshold (minimum) (in km)	○	○	○
Breakthrough (preferred) (in km)	○	○	○
Goal (ideal) (in km)	○	○	○

Please justify yourchoice of threshold horizontal resolution and provide consequence of not meeting it.(Chl-a)

Your answer

What is the temporal resolution in chlorophyll data that your application requires?
The temporal frequency at which the measurements are required.

	1 day	1 week	1 month
Threshold (minimum)	○	○	○
Breakthrough (preferred)	○	○	○
Goal (ideal)	○	○	○

Please justify your choice of threshold of temporal resolution and provide consequence of not meeting it. (Chla)

Your answer

Back Next Page 10 of 34 Clear form

Spatial and Temporal Resolution - Phytoplankton pigments (other than Chlorophyll-a)

What is the horizontal resolution in phytoplankton pigments data that your application requires?
The area over which one value of the variable is representative of.

	0.1 - 1	1 - 10	10 - 100
Threshold (minimum) (in km)	○	○	○
Breakthrough (preferred) (in km)	○	○	○
Goal (ideal) (in km)	○	○	○

Please justify your choice of threshold horizontal resolution and provide consequence of not meeting it (Phytoplankton pigments).

Your answer

What is the temporal resolution in phytoplankton pigments data that your application requires?
The temporal frequency at which the measurements are required.

	1 day	1 week	1 month
Threshold (minimum)	○	○	○
Breakthrough (preferred)	○	○	○
Goal (ideal)	○	○	○

Please justify your choice of threshold temporal resolution and provide consequence of not meeting it. (Phytoplankton pigments)

Your answer

Back Next Page 11 of 34 Clear form

Spatial and Temporal Resolution - Phytoplankton Carbon

What is the horizontal resolution in Phytoplankton Carbon (PC) data that your application requires?
The area over which one value of the variable is representative of.

	0.1 - 1	1 - 10	10 - 100
Threshold (minimum) (in km)	○	○	○
Breakthrough (preferred) (in km)	○	○	○
Goal (ideal) (in km)	○	○	○

Please justify your choice of threshold horizontal resolution and provide consequence of not meeting it (PC).

Your answer

What is the temporal resolution in Phytoplankton Carbon data that your application requires?
The temporal frequency at which the measurements are required.

	1 day	1 week	1 month
Threshold (minimum)	○	○	○
Breakthrough (preferred)	○	○	○
Goal (ideal)	○	○	○

Please justify your choice of threshold temporal resolution and provide consequence of not meeting it. (PC)

Your answer

Back Next Page 12 of 34 Clear form

Accuracy and Precision - Chlorophyll-a

What is the accuracy in Chlorophyll-a (Chl-a) data that your application requires?
The measure of the non-random, systematic error, or bias, that defines the offset between the measured value and the true value that constitutes the SI absolute standard.

	< 10	10 - 25	25 - 50	> 50
Threshold (minimum) (relative, %)	○	○	○	○
Breakthrough (preferred) (relative, %)	○	○	○	○
Goal (ideal) (relative, %)	○	○	○	○

Please justify your choice of threshold accuracy and provide consequence of not meeting it (Chl-a).

Your answer

What is the precision in Chlorophyll-a data that your application requires?

Precision is a measure of reproducibility or repeatability of the observation without reference to an international standard so that precision is a measure of the random and not the systematic error. Suitable averaging of the random error can improve the precision of the measurement but does not establish the systematic error of the observation.

	< 10	10 - 25	25 - 50	> 50
Threshold (minimum) (relative, %)	○	○	○	○
Breakthrough (preferred) (relative, %)	○	○	○	○
Goal (ideal) (relative, %)	○	○	○	○

Please justify your choice of threshold precision and provide consequence of not meeting it (Chl-a).

Your answer

Back Next Page 13 of 34 Clear form

Accuracy and Precision - Phytoplankton pigments concentrations (other than Chlorophyll-a)

Please provide an overall indication not for a specific pigment.

What is the accuracy in pigments (other than Chlorophyll-a) data that your application requires?

The measure of the non-random, systematic error, or bias, that defines the offset between the measured value and the true value that constitutes the SI absolute standard.

	< 10	10 - 25	25 - 50	> 50
Threshold (minimum) (relative, %)	○	○	○	○
Breakthrough (preferred) (relative, %)	○	○	○	○
Goal (ideal) (relative, %)	○	○	○	○

Please justify your choice of threshold accuracy and provide consequence of not meeting it (Phytoplankton pigments).

Your answer

What is the precision in phytoplankton pigment (other than Chlorophyll-a) data that your application requires?

Precision is a measure of reproducibility or repeatability of the observation without reference to an international standard so that precision is a measure of the random and not the systematic error. Suitable averaging of the random error can improve the precision of the measurement but does not establish the systematic error of the observation.

	< 10	10 - 25	25 - 50	> 50
Threshold (minimum) (relative, %)	○	○	○	○
Breakthrough (preferred) (relative, %)	○	○	○	○
Goal (ideal) (relative, %)	○	○	○	○

Please justify your choice of threshold precision and provide consequence of not meeting it (Phytoplankton pigments).

Your answer

Back Next Page 14 of 34 Clear form

Accuracy and Precision - Phytoplankton Carbon

Please provide an overall indication.

What is the accuracy in Phytoplankton Carbon (PC) data that your application requires?

The measure of the non-random, systematic error, or bias, that defines the offset between the measured value and the true value that constitutes the SI absolute standard.

	< 10	10 - 25	25 - 50	> 50
Threshold (minimum) (relative, %)	○	○	○	○
Breakthrough (preferred) (relative, %)	○	○	○	○
Goal (ideal) (relative, %)	○	○	○	○

Please justify your choice of threshold accuracy and provide consequence of not meeting it (PC).

Your answer

What is the precision in Phytoplankton Carbon data that your application requires?

Precision is a measure of reproducibility or repeatability of the observation without reference to an international standard so that precision is a measure of the random and not the systematic error. Suitable averaging of the random error can improve the precision of the measurement but does not establish the systematic error of the observation.

	< 10	10 - 25	25 - 50	> 50
Threshold (minimum) (relative, %)	○	○	○	○
Breakthrough (preferred) (relative, %)	○	○	○	○
Goal (ideal) (relative, %)	○	○	○	○

Please justify choice of threshold precision and provide consequence of not meeting it (PC).

Your answer

Back Next Page 15 of 34 Clear form

Stability - Chlorophyll-a

What is the long-term stability (over 10 years) in Chlorophyll-a (Chl-a) data that your application requires?

Stability is a term often invoked with respect to long-term records when no absolute standard is available to quantitatively establish the systematic error - the bias defining the time-dependent (or instrument-dependent) difference between the observed quantity and the true value.

	1	2	5	10
Threshold (minimum) (relative, %)	○	○	○	○
Breakthrough (preferred) (relative, %)	○	○	○	○
Goal (ideal) (relative, %)	○	○	○	○

Please justify choice of threshold stability and provide consequence of not meeting it. (Chl-a)

Your answer

Back Next Page 16 of 34 Clear form

Stability - Phytoplankton pigments other than Chlorophyll-a

What is the long-term stability (over 10 years) in Phytoplankton pigments (other than Chlorophyll-a) data that your application requires?

Stability is a term often invoked with respect to long-term records when no absolute standard is available to quantitatively establish the systematic error - the bias defining the time-dependent (or instrument-dependent) difference between the observed quantity and the true.

	1	2	5	10
Threshold (minimum) (relative, %)	◯	◯	◯	◯
Breakthrough (preferred) (relative, %)	◯	◯	◯	◯
Goal (ideal) (relative, %)	◯	◯	◯	◯

Please justify your choice of threshold stability and provide consequence of not meeting it. (Phytoplankton pigments)

Your answer

Back Next Page 17 of 34 Clear form

Stability - Phytoplankton Carbon

What is the long-term stability (over 10 years) in Phytoplankton Carbon (PC) data that your application requires?

Stability is a term often invoked with respect to long-term records when no absolute standard is available to quantitatively establish the systematic error - the bias defining the time-dependent (or instrument-dependent) difference between the observed quantity and the true value.

	1	2	5	10
Threshold (minimum) (relative, %)	◯	◯	◯	◯
Breakthrough (preferred) (relative, %)	◯	◯	◯	◯
Goal (ideal) (relative, %)	◯	◯	◯	◯

Please justify your choice of threshold stability and provide consequence of not meeting it. (PC)

Your answer

Back Next Page 18 of 34 Clear form

Climate Modeller

Scientific Area(s) of interest
(select as appropriate)

- ☐ Global-scale models
- ☐ Regional models
- ☐ Model Development
- ☐ Model Validation/Skill assessment
- ☐ Model Initialisation
- ☐ Definition of boundary conditions
- ☐ Data assimilation
- ☐ Other:

How important is it for you to have error estimates for ocean-colour products? *

- ◯ Important
- ◯ Not Important

What units do you use in your model to quantify phytoplankton concentration?
(Select as appropriate)

- ☐ Chlorophyll-a
- ☐ Carbon
- ☐ Nitrogen
- ☐ Other:

Does your model allow a variable relationship between Chlorophyll-a and Phytoplankton Carbon or Nitrogen?

- ◯ Yes
- ◯ No

Back Next Page 19 of 34 Clear form

Other ocean colour products

Are you interested in providing feedback on addtional ocean colour products related to climate? *

- ◯ Yes
- ◯ No

Back Next Page 20 of 34 Clear form

Other Ocean Colour Products

On the following pages you will be given the chance to provide feedback on other possible ocean colour products for the study of climate change.

Please only complete the pages for the products you are interested in, and select the relevant threshold requirements.

Back Next Page 21 of 34 Clear form

Remote sensing reflectance (Rrs) - Threshold (minimum) requirements

Please only complete the questions for the products you are interested in, and select the relevant threshold requirements. Answers can be left blank on this page.

Are the minimum requirements for Rrs the same as for the Chlorophyll-a product? *

- Yes
- No, see my answers below

Horizontal resolution (Rrs)
in km

- 0.1 - 1
- 1 - 10
- 10 - 100

Temporal Resolution (Rrs)

- 1 day
- 1 week
- 1 month

Accuracy (Rrs)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Precision (Rrs)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Stability (Rrs)
relative, %

- 1
- 2
- 5
- 10

Error estimate important? (Rrs)

- Yes
- No

Please provide justification for your choice(s) to the questions on this page. Why do you need Remote sensing reflectance (Rrs) values? What would be the consequence of not having them?

Your answer

Phytoplankton Functional Types (PFT) - Threshold (minimum) requirements

Please only complete the questions for the products you are interested in, and select the relevant threshold requirements. Answers can be left blank on this page.

Are the minimum requirements for Phytoplankton Functional Types (PFT) the same as for the Chlorophyll-a product? *

- Yes
- No, see my answers below

Horizontal resolution (PFT)
in km

- 0.1 - 1
- 1 - 10
- 10 - 100

Temporal Resolution (PFT)

- 1 day
- 1 week
- 1 month

Accuracy (PFT)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Precision (PFT)
relative, %

- < 10
- 10 - 25
- 25 - 50
- .50

Stability (PFT)
relative, %

- 1
- 2
- 5
- 10

Error estimate important? (PFT)

- Yes
- No

Please provide justification for your choice(s) to the questions on this page. Please state why you need Phytoplankton Functional Types (PFT). What would be the consequence of not having this product?

Your answer

Phytoplankton Size Classes (PSC) - Threshold (minimum) requirements

Please only complete the questions for the products you are interested in, and select the relevant threshold requirements. Answers can be left blank on this page.

Are the minimum requirements for Phytoplankton Size Classes (PSC) the same as for the Chlorophyll-a product? *

- ◯ Yes
- ◯ No, see my answers below

Horizontal resolution (PSC)
in km

- ◯ 0.1 - 1
- ◯ 1 - 10
- ◯ 10 - 100

Temporal Resolution (PSC)

- ◯ 1 day
- ◯ 1 week
- ◯ 1 month

Accuracy (PSC)
relative, %

- ◯ < 10
- ◯ 10 - 25
- ◯ 25 - 50
- ◯ > 50

Precision (PSC)
relative, %

- ◯ < 10
- ◯ 10 - 25
- ◯ 25 - 50
- ◯ .50

Stability (PSC)
relative, %

- ◯ 1
- ◯ 2
- ◯ 5
- ◯ 10

Error estimate important? (PSC)

- ◯ Yes
- ◯ No

Please provide justification for your choice(s) to the questions on this page. Please state why you need Phytoplankton Size Classes (PSC). What would be the consequence of not having this product?

Your answer

Back Next

Clear form

Particle Size Distribution - Threshold (minimum) requirements

Please only complete the questions for the products you are interested in, and select the relevant threshold requirements. Answers can be left blank on this page.

Are the minimum requirements for Particle Size Distribution (PSD) the same as for the Chlorophyll-a product? *

- ◯ Yes
- ◯ No, see my answers below

Horizontal resolution (PSD)
in km

- ◯ 0.1 - 1
- ◯ 1 - 10
- ◯ 10 - 100

Temporal Resolution (PSD)

- ◯ 1 day
- ◯ 1 week
- ◯ 1 month

Accuracy (PSD)
relative, %

- ◯ < 10
- ◯ 10 - 25
- ◯ 25 - 50
- ◯ > 50

Precision (PSD)
relative, %

- ◯ < 10
- ◯ 10 - 25
- ◯ 25 - 50
- ◯ > 50

Stability (PSD)
relative, %

- ◯ 1
- ◯ 2
- ◯ 5
- ◯ 10

Error estimate important? (PSD)

- ◯ Yes
- ◯ No

Please provide justification for your choice(s) to the questions on this page. Please state why you need particle size distribution (PSD). What would be the consequence of not having this product?

Your answer

Back Next

Clear form

Inherent Optical Properties (IOP)- Threshold (minimum) requirements

Please only complete the questions for the products you are interested in, and select the relevant threshold requirements. Answers can be left blank in this page.

Are the minimum requirements for Inherent Optical Properties (IOP) the same as for the Chlorophyll-a product? *

- Yes
- No, see my answers below

Horizontal resolution (IOP)
in km

- 0.1 - 1
- 1 - 10
- 10 - 100

Temporal Resolution (IOP)

- 1 day
- 1 week
- 1 month

Accuracy (IOP)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Precision (IOP)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Stability (IOP)
relative, %

- 1
- 2
- 5
- 10

Error estimate important? (IOP)

- Yes
- No

Please provide justification for your choice(s) to the questions on this page. Please state why you need Inherent Optical Properties (IOP). What would be the consequence of not having this product?

Your answer

Back Next Page 26 of 34 Clear form

Diffuse attenuation coefficient (Kd) - Threshold (minimum) requirements

Please only complete the questions for the products you are interested in, and select the relevant threshold requirements. Answers can be left blank on this page.

Are the minimum requirements for diffuse attenuation coefficient (Kd) the same as for the Chlorophyll-a product? *

- Yes
- No, see my answers below

Horizontal resolution (Kd)
in km

- 0.1 - 1
- 1 - 10
- 10 - 100

Temporal Resolution (Kd)

- 1 day
- 1 week
- 1 month

Accuracy (Kd)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Precision (Kd)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Stability (Kd)
relative, %

- 1
- 2
- 5
- 10

Error estimate important? (Kd)

- Yes
- No

Please provide justification for your choice(s) to the questions on this page. Please state why you need the diffuse attenuation coefficient (Kd). What would be the consequence of not having this product?

Your answer

Back Next Page 27 of 34 Clear form

Photosynthetically Active Radiation (PAR) - Threshold (minimum) requirements

Please only complete the questions for the products you are interested in, and select the relevant threshold requirements. Answers can be left blank on this page.

Are the minimum requirements for Photosynthetically Active Radiation (PAR) the same as for the Chlorophyll-a product? *

- Yes
- No, see my answers below

Horizontal resolution (PAR)
in km

- 0.1 - 1
- 1 - 10
- 10 - 100

Temporal Resolution (PAR)

- 1 day
- 1 week
- 1 month

Accuracy (PAR)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Precision (PAR)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Stability (PAR)
relative, %

- 1
- 2
- 5
- 10

Error estimate important? (PAR)

- Yes
- No

Please provide justification for your choice(s) to the questions on this page. Please state why you need Phothosynthetically Active Radiation (PAR). What would be the consequence of not having this product?

Your answer

Back Next Clear form

Coloured Dissolved Organic Matter (CDOM) - Threshold (minimum) requirements

Please only complete the questions for the products you are interested in, and select the relevant threshold requirements. Answers can be left blank on this page.

Are the minimum requirements for Coloured Dissolved Organic Matter (CDOM) the same as for the Chlorophyll-a product? *

- Yes
- No, see my answers below

Horizontal resolution (CDOM)
in km

- 0.1 - 1
- 1 - 10
- 10 - 100

Temporal Resolution (CDOM)

- 1 day
- 1 week
- 1 month

Accuracy (CDOM)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Precision (CDOM)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Stability (CDOM)
relative, %

- 1
- 2
- 5
- 10

Error estimate important? (CDOM)

- Yes
- No

Please provide justification for your choice(s) to the questions on this page. Please state why you need Coloured Dissolved Organic Matter (CDOM). What would be the consequence of not having this product?

Your answer

Back Next Clear form

Particulate organic carbon (POC) - Threshold (minimum) requirements

Please only complete the questions for the products you are interested in, and select the relevant threshold requirements. Answers can be left blank on this page.

Are the minimum requirements for Particulate Organic Carbon (POC) the same as for the Chlorophyll-a product? *

- Yes
- No, see my answers below

Horizontal resolution (POC)
in km

- 0.1 - 1
- 1 - 10
- 10 - 100

Temporal Resolution (POC)

- 1 day
- 1 week
- 1 month

Accuracy (POC)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Precision (POC)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Stability (POC)
relative, %

- 1
- 2
- 5
- 10

Error estimate important? (POC)

- Yes
- No

Please provide justification for your choice(s) to the questions on this page. Please state why you need Particulate Organic Carbon (POC). What would be the consequence of not having this product?

Your answer

Suspended Particulate Matter (SPM) - Threshold (minimum) requirements

Please only complete the questions for the products you are interested in, and select the relevant threshold requirements. Answers can be left blank on this page.

Are the minimum requirements for Suspended Particulate Matter (SPM) the same as for the Chlorophyll-a product? *

- Yes
- No, see my answers below

Horizontal resolution (SPM)
in km

- 0.1 - 1
- 1 - 10
- 10 - 100

Temporal Resolution (SPM)

- 1 day
- 1 week
- 1 month

Accuracy (SPM)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Precision (SPM)
relative, %

- < 10
- 10 - 25
- 25 - 50
- > 50

Stability (SPM)
relative, %

- 1
- 2
- 5
- 10

Error estimate important? (SPM)

- Yes
- No

Please provide justification for your choice(s) to the questions on this page. Please state why you need Suspended Particulate Matter (SPM). What would be the consequence of not having this product?

Your answer

Other products, please specify - Threshold (minimum) requirements

Please specify any additional ocean colour products you are interested in, and select the relevant threshold requirements. Answers can be left blank on this page.

Other ocean colour products

Please type in a short name of any other product from ocean colour that would be of interest

Your answer

Are the minimum requirements for other additional product the same as for the Chlorophyll-a product? *

- ○ Yes
- ○ No, see my answers below

Horizontal resolution (Other product)

in km

- ○ 0.1 - 1
- ○ 1 - 10
- ○ 10 - 100

Temporal Resolution (Other product)

- ○ 1 day
- ○ 1 week
- ○ 1 month

Accuracy (Other product)

relative, %

- ○ < 10
- ○ 10 - 25
- ○ 25 - 50
- ○ > 50

Precision (Other product)

relative, %

- ○ < 10
- ○ 10 - 25
- ○ 25 - 50
- ○ > 50

Stability (Other product)

relative, %

- ○ 1
- ○ 2
- ○ 5
- ○ 10

Error estimate important? (Other product)

- ○ Yes
- ○ No

Please justify your choice of this other ocean colour product and provide the consequence of not having it.

Your answer

Back Next Page 32 of 34 Clear form

EO Scientist

Scientific Area(s) of interest

(Please select as many as are relevant)

- ☐ Global-scale analysis
- ☐ Primary production studies
- ☐ Phenology
- ☐ Ecological provinces
- ☐ Fisheries variability
- ☐ Trend Analysis
- ☐ Ecological indicators
- ☐ Other:

How important is it for you to have error estimates for ocean-colour products? *

- ○ Important
- ○ Not important

Back Next Page 33 of 34 Clear form

Thank You -

Thank you for your input. If you have anything else you would like to add please use the box below. Please use the "Submit" button below to submit and record your answers.

Final Notes

Your answer

Back Submit Page 34 of 34 Clear form

Appendix II – Comments from participants of the user requirements workshops

Comments from participants of the user requirements workshops are summarised in Table 5.

Table 5. Summary of comments provided by participants of the OC- and PHYTO-CCI user requirements workshops. Comments are taken from slides provided by the participants and summarised according to discussions held during the workshops.

#	Examples of current OC-CCI data use	Limitations of ocean colour CCI data	Desired improvements to ocean colour CCI
1	- Data assimilation and model validation - Globally and for the north-west European Shelf - Improve estimates of air-sea CO_2 flux		- Daily resolution for data assimilation - Could make use of phytoplankton functional types, provided that they match model phytoplankton types (i.e., diatoms and non-diatoms in MEDUSA for global applications and diatoms, dinoflagellates and/or pico-, nano-, and microphytoplankton in ERSEM for north-west European Shelf) - Likely to explore assimilation of other variables, including carbon, inherent optical properties, suspended particulate matter, etc., in the future - Could make use of along-track data
2	- Resource mapping for commercially important fisheries - Climate change in marine fisheries in India - Fluctuations in fish stocks variability to changes in environmental conditions and phytoplankton seasonal cycle - Migration patterns of tunas in regional seas in India - Coral reef ecosystem-monitoring and assessment - Identification of potential mariculture sites - Vulnerability assessment of all maritime coastal states - Geospatial assessment for coastal ecosystems such as mangroves - Identification of harmful algal blooms - Dynamics of waterborne diseases in aquatic ecosystems		- Phytoplankton diversity variables would be useful - Higher spatial and temporal resolution data would be helpful for fisheries and aquaculture applications
3	- Global phytoplankton bloom phenology - Global net primary production	- Cloud computing hard limit of 500 Mb, meant the need to download all data needed to local systems to perform analyses - Reliance on other services for required variables, for example there is no PAR data available from CCI and GlobColour products were used with unknown impact on analyses	- Increase in cloud computing limit - Higher spatial and temporal resolution data for match-ups with BGC-Argo floats - Size class information across all inherent optical properties would be useful do derive size-specific net primary production

4	- Chlorophyll-a and phytoplankton carbon are used for validation of ocean biogeochemical model used within EC-Earth Earth System Model - Phytoplankton carbon is used for data assimilation - Model tuning (using information from the above two points)	- Fragmented data sources and no centralized documentation hub: Ocean-colour data products come from multiple sources (OC-CCI, CMEMS, ESA catalogue, etc.) and it can be difficult to navigate between them or understand how they relate. There is no single, centralised location where users can find up-to-date, clear, and consistent documentation about all available products. - Lack of clear versioning information: When new versions of products are released, it is not always clear what has changed or how it might affect scientific results or long-term consistency. - Semantic misalignment between communities: Differences in terminology between EO and modelling communities can cause confusion. For example, a “measurement” in the modelling community may refer to observed quantities, whereas in EO it might include model-derived products from satellite retrievals.	- Additional ocean-colour variables are needed, including phytoplankton functional types that are aligned with groups in ecosystem models (e.g., diatoms, nanophytoplankton). - Vertically-resolved phytoplankton carbon profiles - All possible biogeochemical variables!
5	- Analysis of trends in chl-a in coastal regions.	- OC-CCI are useful products, but sometimes provide the right answer for the wrong reason. Two examples: 1) Use of OC-CCI chl-a product in the Gulf of California, there are inconsistencies in the time series due to MERIS going offline; 2) Use of OC-CCI chl-a product in the Antarctic Peninsula, where OC-CCI performs better than single-sensor products, but the atmospheric correction by polymer does not correctly deal with adjacency effects of ice cover (instead it is dealt with as sun glint).	- Care should be taken in analysing time series by ocean colour researchers, there might be inconsistencies in coastal regions. - Making sure that the atmospheric correction does the right job, i.e., correct for adjacency effects correctly.
6	- Phytoplankton community composition in equatorial Atlantic and Amazon river outflow.	- Questions around how well chl-a algorithm works in river plumes, for example the Amazon river outflow. - How is phytoplankton diversity estimated by satellites, and is there an *in situ* equivalent, for example phytoplankton functional types are not the same as pigments measured in the field (used for validation).	- Need for high spatial and temporal resolution as studying dynamic marine systems. - Extent of ‘coastal regions’ can be far, more than the typical 200-km offshore, for example river outflow can extend further, and therefor optical water classes might be a better way to identify complex waters (as done in OC-CCI). - Documentation could be provided in the data portal, instead of on a different website.
7	- Using OC-CCI ocean colour products to model spectrally resolved primary productivity. - Ocean colour data provides large-scale distribution for primary production models, enabling seasonal and spatial coverage beyond ship-based observations.	- OC-CCI underestimates high chlorophyll during bloom conditions (lower than *in situ*). - PAR not available in OC-CCI, currently obtained from NASA MODIS/VIIRS or computed using irradiance models.	- Accurate chlorophyll algorithms for bloom conditions: Incorporate Rrs at NIR bands (e.g., 748 nm) to better capture high-Chl regimes. - Include PAR as a standard OC-CCI product, this would support primary production modelling.

8	- OC-CCI products are global marine ecosystem/biogeochemical-relevant satellite products, and one of the primary goals is long-term trend analysis. - Therefore, the bias-corrected merged, global Rrs that OC-CCI provides is essential. Otherwise, algorithm would have to be adapted separately to each sensor’s data, resulting in more effort, shorter separate time series, and difficulty comparing them. - Importantly, consistency in input Rrs wavelengths across the entire dataset is essential. Otherwise it would be harder or even not feasible to apply the IOP algorithm currently needed as intermediate step towards PSD and derived products.	- Multiple ways to download and/or subset data should be maintained. FTP still works best for me, and eliminating it would pose challenges. - Providing explicitly lat/lon for each pixel, for both projections, is useful. What is your exact algorithm for re-projecting sinusoidal to geographic? Making that public/available to users? - It would be good to have an even more robust/detailed technical documentation and examples of how bias versus uncertainty are estimated and their exact meaning, and how to use each separately or combined to estimate error. - See on next slide my comment on common wavebands and band-shifting capabilities	- It is essential to put the entire dataset on a common set of wavelengths for Rrs, as is already the case for OC-CCI. - The waveband shifting algorithm is important and its details should be documented. - This is going to become relevant in somewhat different way with PACE, but it would be very useful to have a standardised way (consistent with how you do it, and accessible to users in the cloud or as code) to shift wavelengths of input Rrs as needed for the application of various algorithms, including legacy one, i.e., I would like to be able to regenerate the entire Rrs dataset to a different set of central wavelengths, realising this comes with limitations/assumptions. - This is often a huge limitation for using Rrs in a given set of wavelengths. - As a related sub-point, band-averaging to achieve that. - More than one IOP algorithm, e.g., apply Loisel and Stramski (2000) as well. - Document how the OC-CCI Rrs is estimated and normalised (e.g., for sun in the zenith, what sky and wind are assumed, what band-averaging is applied?), which will make it much easier to compare to theoretically derived or field-measured Rrs. - Potentially allow user to compute derived products in the cloud using their own algorithms, so they do not have to download the Rrs.
9	- Uses particle tracking model to understand carbon and nutrient cycles. Forcing datasets used in the model are from OC-CCI (chl-a) and level-4 products (primary production). Model is constrained by level-4 products, including export production.		- Would use phytoplankton functional types, pico-, nano-, microphytoplankton. - Phytoplankton diversity indicators from ocean colour need to be the same as those in ecosystem models. - Ideally I would use carbon content of phytoplankton functional types, this would be a game changes in understanding ocean nutrient and carbon cycles.
10	- Uses ocean colour data to estimate phytoplankton functional types, size classes and pigment concentrations using machine learning methods. - Long-term monitoring is important.	- Coastal waters are complex and challenging in terms of optics, there is a long way to go to produce good quality ocean colour products globally for these regions.	- Band ratio algorithms (chl-a) achieve an accuracy of around 35 % in coastal regions, and improving this is most important.
11	- Using OC-CCI Rrs and derived chlorophyll-a as core inputs to estimate phytoplankton functional types (PFTs) and pigment composition.	- Difficulty in coastal and optically complex waters (e.g., Baltic, Black Seas)	- Higher spatial (≤1 km) and temporal resolution products, e.g., several operational sensors (Sentinel-3 OLCI) already provide higher-resolution data.

	- Integration of *in situ* HPLC pigment datasets with regionalised empirical and SOM-based algorithms to improve representation of PFTs in optically complex waters (e.g., Baltic Sea, Black Sea). - Example study in the Baltic Sea: Combined OC-CCI Rrs and Chl-a–derived data with *in situ* HPLC pigment observations to reconstruct PFTs and community composition patterns at basin scale. - Provides consistent long-term, basin-scale observations essential for tracking phytoplankton community shifts, climate trends, and ecosystem responses. - Enables model calibration in regions with strong seasonal and biogeochemical variability. - OC-CCI data are reliable and well-calibrated, offering valuable time series continuity. - Inclusion of uncertainty metrics and improved match-up tools (e.g., pixel-level time averaging) would enhance validation workflows.	- Coarse spatial resolution (4 km) limits applicability for small-scale processes and coastal validation. - Data latency and occasional gaps in time series hinder near-real-time applications.	- Enhanced regionalization, .e.g., optical model tuning for complex waters. - Service enhancements could include simplified access via APIs and cloud-based visualisation tools and improved uncertainty quantification and validation match-up interfaces.
12	- "Validation" exercises – comparisons with other products and *in situ* data: OC-CCI has shown improved performance compared to other standard ocean colour products for intermediate Chl-a ranges, but biases for very low and high biomass ranges. - Retrieval of other ocean colour products (e.g., SPM, PSCs) - Time-series analysis - Evaluation of Biogeochemical Models and future data assimilation	- Lack of 'near real time' data. - Limited spectral resolution (e.g., to be able to derive SPM and PFTs). - Higher uncertainty for coastal waters.	- More complete documentation of the data processing, algorithms (parameterisation and blending) and different versions as well as validation exercises. - Guarantee consistency along all data records. - Near real time data latency. - Better coverage with gap-free level-4 products. - Spectral resolution, i.e., more bands within the current range and > 665-670 nm (e.g., OLCI) - Improved Rrs, OWT and Chl-a retrievals for coastal waters with appropriate approaches. - Additional products: SPM, POC, PSC and/or PFTs - Higher spatial resolution for coastal waters (e.g., High-Resolution Ocean Colour as from CMEMS).
13	- Near real time ocean colour data for harmful algal bloom monitoring and other marine services - Spatial resolution of 4-km is sufficient for global applications. - CCI data availability is good, products on CMEMS are useful.	- For coastal applications, higher resolution (at least 1-km or higher) is needed.	- SPM product would be appreciated for marine services related to water quality in coastal waters. - Interested in phytoplankton variables that could inform fisheries. - Inclusion of near-infrared bands to estimate chl-a in coastal regions. - Would be interested in a level-4 gap-filled product.
14	- Uses ocean colour data to study marine systems around Azores, including marine services, such as fisheries, aquaculture and harmful algal bloom monitoring. .	- Higher resolution data is needed to address dynamic processes in study area, such as mesoscale eddies and submesoscale filaments.	- A minimum of 1-3 km resolution is required to adequately resolve (sub)mesoscale features and avoid underestimating primary productivity hotspots.

	- Uses OC-CCI data, but marine services also depend on detecting near-real-time Chl-a anomalies. Daily or sub-daily data improves forecasting and reduces socioeconomic risk.		- <1 km resolution is ideal to detect nearshore chl-a anomalies that can affect ecosystem health and human activities. - Water column conditions drive rapid phytoplankton responses to nutrient pulses at scales of days rather than weeks, so high temporal resolution is also needed. - Also interested in particulate inorganic and organic carbon estimates (at 1-km resolution).