

Figure 1: Global maps of (top left) Chlorophyll-a concentration, (top right) Chlorophyll-a bias, (bottom left) RMSD and (bottom right) total number of observations for the merged monthly v2 products, June 2003. Produced by the Ocean Colour CCI Team, 2015.

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Ocean Colour Climate Change Initiative: Project Overview and status

The European Space Agency's Climate Change Initiative programme aims to realize the full potential of the long-term global Earth Observation archives that ESA, together with its Member states and partner nations, have established over the last thirty years, as a significant and timely contribution to the Essential Climate Variable (ECV) databases required by United Nations Framework Convention on Climate Change (UNFCCC).

The Ocean Colour CCI (OC-CCI) project focuses on water-leaving radiance in the visible domain, derived chlorophyll-a and additional products (inherent optical properties and diffuse attenuation coefficient) that utilise data from ESA's MERIS and NASA's SeaWiFS and MODIS-Aqua archives.

Activities include building a system based on requirements analysis, algorithm selection, data processing, product validation and error characterisation.

Phase 2, which started in February 2014, follows a cyclical update process of Review > Improve > Produce > Assess. The activities, as in Phase 1, include Requirements Management, Algorithm Development and Selection, System Evolution, Production and Product Assessment.

Feedback from the users is a key part of the cyclical process, with version 2.0 of the products having been released in April 2015. Future reprocessing versions will include new instruments, such as the NOAA/NASA Visible

Infrared Imaging Radiometer Suite (VIIRS) and EC/ESA Sentinel-3 OLCI, to ensure a long-term extension of the ECV products with a focus on reducing the uncertainties in Case 2 (primarily coastal) waters.

Previous research under OC-CCI (Racault et al. 2012) was included in the 5th Intergovernmental Panel on Climate Change Fifth Assessment Report (Hoegh-Guldberg et al. 2014), highlighting the strong seasonal variability of primary productivity high latitudes.



Why Ocean Colour?

The world's oceans are home to nearly half of the world's known species, and more than 30% of all our carbon dioxide emissions end up in the sea.

Carbon dioxide (CO₂) from the Earth's atmosphere reacts with seawater to form carbonic acid, which changes the ocean's seawater chemistry, and may have a devastating toll on aquatic life. This is often called ocean acidification, referring to the gradual decrease of pH.

Phytoplankton, aquatic photosynthetic microalgae, are the foundation of the marine food chain. Their role in carbon fixation potentially reduces human-induced carbon dioxide in the atmosphere, but can also increase ocean acidification.

Biogeochemical modeling has improved climate models, enabling the investigation of carbon-climate feedback, such as the strength of biogeochemical feedback and quantifying its importance in total carbon cycle responses. The geophysical impact of phytoplankton, which has been overlooked, reveals that future phytoplankton change influenced by greenhouse warming can amplify Arctic surface warming considerably (Park et al. 2015).

Biogeochemical reanalyses are key to reconstructing past conditions, understand-

ing and differentiating natural variability and climate trends, improving the biases in models and observations, and providing information for present and future monitoring programmes (Ford et al. 2012). Assimilating ocean colour data combines the advantages of models and observations, which can produce results that are potentially more accurate than either activity alone, and improves our understanding of marine ecosystems.

Ocean Colour CCI product performance

The Version 2 data has improved in performance compared to V1 with respect to the match-ups for both Chlorophyll-a (Chl-a) and remote-sensing reflectance (Rrs). Also, we are very close to meeting all the Global Climate Observing System (GCOS) requirements for product performance.

The GCOS requirements identify time series data of spectrally-resolved Rrs and Chl-a as a priority. However, since the three ocean colour sensors used in the project each had different sets of spectral bands, a reference sensor had to be selected and the remote-sensing reflectance wavebands of the other sensors shifted to that of the reference sensor (SeaWiFS); ensuring a merged product at the same wavelength throughout the time series (Mélin and Sclep 2015). This "band-shifting" was also essential to establish inter-sensor biases, which had to be corrected, to avoid spurious trends in time series data.

A major achievement for the project was devising a method to provide pixel-by-pixel error characterisation for the merged product. The uncertainties provided include the Root Mean Square Difference (RMSD) and bias, based on validation with in situ data. This was achieved through the use of optical classification of pixels, and optical-class based uncertainty characterisation. A number of optical-water-classes were defined by spectral reflectance values. Uncertainties were computed for each optical-water-class, for each product. The uncertainty for a product at any given pixel can then be estimated using the optical classification of the pixel and the class-spe-

cific product uncertainties.

A new integrated in situ database was set up from a number of available sources and matched with satellite data to help establish the uncertainty characteristics. The database also provides the basis for the validation exercises (Bewin et al. 2013 and Müller et al. 2015); in addition, a number of comparison exercises have been undertaken to evaluate the consistency of the data products.

Version 1 of the Ocean Colour CCI data set provided better coverage, error characterisation and bias correction

compared with previous datasets whilst meeting the GCOS requirements for temporal resolution and accuracy (Sathyendranath et al. Submitted).

Version 2 extends the time series to the end of 2013. It also optimises the uncertainty, improves consistency in many areas, incorporates an improved bias correction and MERIS cloud mask.

On-going feedback is encouraged from all users, please email: help@esa-oceancolour-cci.org. We gratefully acknowledge the ongoing support received from ESA, NASA and the community at large.

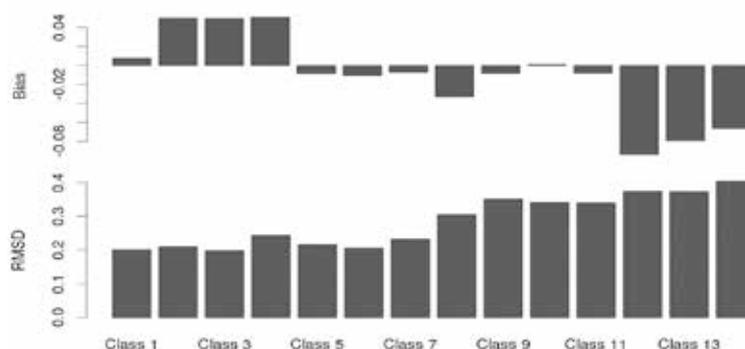


Figure 2: The bias is variable across the class numbers, with higher bias values for groups at the Case1 and Case 2 extremes. Whilst the uncertainty (RMSD) is generally increasing with class number i.e., progressing from Case 1 to Case 2 waters.



ocean colour
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Changes in the Red Sea

“One of the advantages of this new dataset is the improved spatial and seasonal coverage, particularly in the Gulf of Aden and the Red Sea where previously there had been nearly no coverage during the summer months” Prof. Ibrahim Hoteit at KAUST University.

Recent studies have shown a reasonable agreement between satellite-derived and in situ Chl-a in the Red Sea. However, regionally-tuned algorithms have not been available until now.

Making use of the limited in situ bio-optical data collected in the Red Sea, and the improved data coverage of CCI (more match-ups), a Red-Sea-tuned Chl-a algorithm was developed, specifically to cope

(<http://www.learn-eo.org/lessons/l11/>).

Future applications:

In contrast with general predictions for tropical oceans, it has been observed in the OC-CI data that the Red Sea phytoplankton have increased abruptly during recent warmer climate periods; a surprising observation that does not agree with findings reported in other tropical seas (Raitos et al. 2015). Initial results suggest that changes in Earth climate processes (Indian monsoons and ENSO teleconnections) have led to a warmer but more fertile Red Sea.

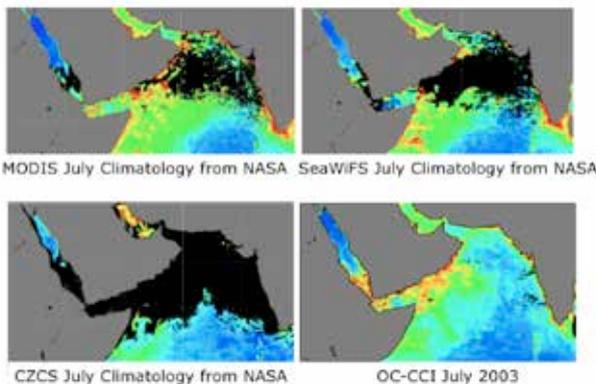


Figure 3: A comparison of the Red and Arabian Sea Chl-a between MODIS, SeaWiFS, CZCS and OC-CCI for July 2003. It is clear that the OC-CCI offers the best data coverage for this area.

with the unique properties of the Red Sea (Brewin et al. 2015).

The new dataset has revealed that the reef-bound coastal waters display equal or higher peak Chl-a concentrations and equal or longer duration of phytoplankton growth during the summer period [relative to the typical winter phytoplankton growth period in the Red Sea] (Racault et al. 2015); introduced by a prize-winning ESA LearnEO! Bilko lesson

However, the driving mechanisms behind this significant change in the Red Sea phytoplankton, and their impact on higher trophic levels, remain largely unknown. The OC-CCI product, which is the longest validated Red Sea biological dataset, will serve further to enhance understanding of the unexplored ecosystem in the Red Sea.

Assimilating data into models

OC-CCI products are characterized by a higher spatial coverage than other products, and a per-pixel quantification of errors. The benefits of these characteristics for shelf-sea reanalysis were explored by assimilating 5-day composites into a North West European region model.

Five-day OC-CCI composites were assimilated using a localized ensemble data assimilation system for ocean colour (Ciavatta et al. 2011).

Assimilation of OC-CCI Chl-a in April 2004 impacted the model simulation of carbon fluxes in May for the whole North West European shelf. In general, the model was over-estimating the observed Chl-a field in coastal areas, and so the assimilation re-initialized the model by decreasing Chl-a concentrations and phytoplankton biomass. This reduced the simulated coastal net primary production (shown example), which in turn led to a lower quantity of organic carbon sinking towards the bottom. The reduced production also decreased the phytoplankton uptake of carbon dioxide, and therefore the overall CO₂ uptake by the ocean decreased.

Importantly, the OC-CCI data covered the coastal areas extensively, as well as the open shelf, allowing the localized assimilation system to correct the model simulation at most of the model grid points. On a decadal time scale, 2002-2011, the average extent of the assimilable OC-CCI composites was 67% of the North West European shelf.

Research (Ciavatta et al. 2014) has also shown that assimilating the diffuse attenuation coefficient can outperform Chl-a, because it is a bulk optical property of marine ecosystems.

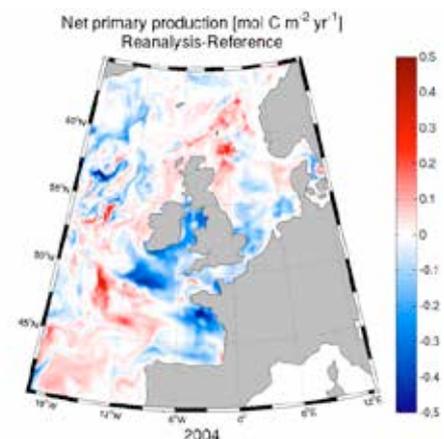


Figure 4: Impact of data assimilation on the North West European shelf-sea simulated carbon fluxes; shown as the differences in primary production with and without assimilation.



What's the future?

The future of the CCI datasets lie in their transition to operational services alongside continued development through research that focuses on reducing the causes of the highest uncertainty. Ocean colour derived products provide insights into the metabolic state of the oligotrophic ocean, which has remained controversial, despite its importance in ocean–climate interactions.

Serret et al. (2015), in *Nature Communications*, showed the existence of systematic differences in the metabolic state of the North (heterotrophic) and South (autotrophic) Atlantic oligotrophic gyres, resulting from differences in both photosynthesis and respiration i.e., the oligotrophic ocean is neither auto- nor heterotrophic, but functionally diverse. These results come from the Atlantic Meridional Transect (AMT) cruises that both supported, and were supported by CCI ocean colour data.

The open ocean (Case 1) ECV products, including remote-sensing reflectance and Chl-a, are suitable to be transferred to operational services by the end of Phase 2 and could be offered as operational services under Copernicus. Conversely the products in coastal waters (Case 2) and integrated Case 1/2 products need further research and development to reach the GCOS requirements. In addition, the incorporation of new sensors, to ensure a consistent (and ideally improving) quality of the products,

needs continued research as each sensor has its own characteristics.

CCI has also focused on a limited set of products, with derived products such as carbon being developed through newly started, parallel projects that will feed into and expand the number of products available to users.

Project Team

ESA's Technical Officer for the Ocean Colour CCI project, Dr Peter Regner, is working with an international team brought together under the scientific leadership of Dr Shubha Sathyendranath (PML, UK) who is supported by John Swinton (Telespazio VEGA, UK). The consortium comprises three

teams, with the EO Science Team focusing on algorithm definition and ECV production prototyping, the Climate Research Group providing independent peer-review analysis of the results and the System Engineering Team delivering analysis on the ECV data processing and future production aspects.

In addition the project benefits from many inputs from the broader community, who gave inputs during the user consultation, contributed in situ data, participated in the algorithm comparison exercises and continue to give valuable feedback.

Cited publications

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Sathyendranath, S et al. (Submitted). *Creating an ocean-colour time series for use in climate studies: the experience of the ocean-colour climate change initiative*.

Serret, P et al. (2015). *Both respiration and photosynthesis determine the scaling of plankton metabolism in the oligotrophic ocean*, <http://dx.doi.org/10.1038/ncomms79>

Overall this project (to date) has led to 33 publications, see <http://www.esa-ocean-colour-cci.org/?q=publications>

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