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The CMEMS GlobColour *Chlorophyll-a* Product Based on Satellite Observation

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Abstract. This work concerns the chlorophyll products based on Satellite Observation and disseminated in the frame of the Copernicus Marine Environmental Monitoring Service (CMEMS).

This work highlights the main advantages provided by the Copernicus Globcolour processor which is used to serve the CMEMS with a long time series from 1997 to present with level 3 & 4 products at Global level (4 km of spatial resolution) and for the Atlantic level 4 product (1 km).

It discusses the different ways to merge data coming from different sensors and it is shown that the GlobColour processor approach provide a better flexibility. At present, it is the only one CMEMS processor able to ingest the OLCI-S3A in the merged product (OLCI-S3A data are ingested in the operational CMEMS products since the April 2018 release).

Behind the merging, the flagging strategy to go from level 2 provided by spatial agencies to the level 3 CMEMS products is also discussed. A better spatial coverage is demonstrated, including the coastal area which is of particular interest for many users involved in the EU Water Framework and Marine Strategy Framework Directive.

1 Introduction

The Copernicus Marine Environmental Service (CMEMS) provides regular and systematic reference information on the physical state and on marine ecosystems for the global ocean and the European regional seas (temperature, currents, salinity, sea surface height, sea ice, marine optical properties, etc.).

This capacity encompasses satellite and *in situ* observation-derived products, the description of the current situation (analysis), the prediction of the situation a few days ahead (forecast), and the provision of consistent retrospective data records for recent years (re-analysis).

The Ocean Thematic Assembly Centre (OCTAC) is part of CMEMS and is dedicated to the provision of Ocean Colour (OC) products derived from Satellite Observation (Le Traon et al., 2015). The OCTAC provides Global and Regional (Arctic, Atlantic, Baltic, Black Sea and Mediterranean) products from 1997 to present.

For Global products, the Copernicus GlobColour processor is used operationally since 2009 to serve CMEMS and its precursors (a series of EU research projects called MyOcean).

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The GlobColour processor has been initially developed in the frame of the GlobColour project started in 2005 as an ESA Data User Element (DUE) project to provide a continuous data set of merged L3 Ocean Colour products. Since the beginning of the project the Copernicus-GlobColour has been continuously serving more than 600 users worldwide. In 2014, a major reprocessing widely extended to a new set of products was performed thanks to financial support from the European Union Framework Program 7 under grant n°282723 (OSS2015) and French FEDER grant n°8 562 - 40 567 (MCGS). This effort has been continued especially in the frame of CMEMS to serve (among others) the chlorophyll Ocean Colour core product.

To retrieve chlorophyll from reflectances (RRS) observed by the satellite, many algorithms have been published (e.g., Muller Karger et al., 1990, Aiken et al., 1995, Morel 1997, O'Reilly et al., 1998, 2000). In CMEMS, the GlobColour *Chlorophyll-a* product relies on a combination of different algorithms:

- For oligotrophic water, the CI approach (Hu, 2012) is used. Among others, this approach has been adopted by the NASA OceanColour project and by the CCI/C3S project.
- For complex water, another major contribution is the OC5 algorithm (Gohin et al., 2002) to improve the classical approach OC3, OC4 especially for end users who should manage complex water along the coastal zone. For global daily interpolated products (Saulquin et al., 2018) of CMEMS since 2005, the OC5 approach has been used.

The continuity of the 3 algorithms (to avoid artefact when water type change) was initially obtained using a water classification approach (Saulquin al., 2018). Beginning of 2018, it has been changed to adopt the same approach as NASA. When the *Chlorophyll-a* concentration is in the range 0.15 and 0.2 mg.m^{-3}, a linear interpolation of OC5 and CI is used. The continuity between OCx (OC3 & OC4) and OC5 is guaranteed by the construction of the OC5 tables.

However, as the daily *Chlorophyll-a* estimated from a specific sensor do not cover the world ocean (Maritorena et al., 2010). Use efficient merging and flagging enable the improvement of the spatial coverage.

The work presented here highlights the conceptual advantage of the CMEMS Copernicus GlobColour processor concerning flagging and merging of sensors. Results are described and illustrated with comparison to other initiatives in the following sections.

2 Methods

1.1 Merging approach

The CMEMS *Chlorophyll-a* products rely at present on the following sensors: SeaWiFs (1997-2010), MERIS (2002-2012), MODIS-Aqua (2002-present), VIIRS-NPP (2012-present) and OLCI-S3A (2016-present). In the coming months it is planned to also use VIIRS-NOAA20/JPPS (2017-present) and OLCI-S3B (2018-present).

It means that the long time series from 1997 to present relies on different sensors, observing the Earth at different spectral bands (and different bandwidth), with different acquisition time (so different atmospheric and sun conditions), and with

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different spatial resolutions from about 300 meters to 1km at nadir (greater on the swath border). Main characteristics of the sensors/bands used for CMEMS are summarized in Table 1. VIIRS-NOOA20 and OLCI-S3B will be ingested in the operational products during 2019.

It should be noted that the global *Chlorophyll-a* product is at present provided at a 4km spatial resolution, but the objective in the coming years is to provide, at least along the coast, a 300 meter of resolution.

Sensors observed the Earth along a heliosynchronous orbit. It should be noted that one sensor is not able to provide the full Earth coverage for a given day (Maritorena et al., 2010, **Figure 1**). VIIRS is able to provide a larger swath than the other sensors but the coverage is still incomplete because impacted by sun glint.

When more than one sensor is available for the same period it is of interest to take benefit of the complementarity and redundancy of sensors. For instance depending of sensing time, morning haze can impact one sensor or another (Toole et al., 2000). The redundancy can also be a way to improve the quantification of the products uncertainty (Antoine et al., 2008).

To compute a multi-sensor *Chlorophyll-a* product, mainly two merging approaches exist:

A first approach is based on band shifting and bias correction. This approach provides merged RRS for the standard SeaWiFS wavelengths (412, 443, 490, 510, 555 and 670 nm). Merged RRS are then used by regional (at 1km) CMEMS processors and by the C3S/CCI to derive the regional long time series of *Chlorophyll-a* and the global CCI *Chlorophyll-a* CMEMS products. The blended *Chlorophyll-a* algorithm used in the CCI Product user guide v3.1 (hereafter denoted v3.1) attempts to weight the outputs of the best performing algorithms (from OCI [OC4+CI], OC3 and OC5) based on the water types in presence. This approach is theoretically very attractive since from merged RRS a common algorithm can be then deployed to retrieve *Chlorophyll-a* or other variables.

Conversely, in a second approach, the *Chlorophyll-a* can be computed in an initialisation step for each sensor using specific characteristics of the considered sensor (spectral band, resolution), and then the mono-sensor *Chlorophyll-a* as products are resampled and merged.

2.2 Flagging approach

Inputs of the Copernicus GlobColour processor are the level 2 provided by the space agencies. To derive the *Chlorophyll-a* map, the input level 2 reflectance (RRS) and input flags are used (level 2 provides flags/indicators about the quality of the reflectance at pixel basis). For instance a pixel can be impacted by a sun glint effect. In such case reflectance are available, but it is recommended by agencies to not use in the processing. Each space agency published a flagging strategy which has been designed to guaranty a good quality so usually adopted by users. The drawback is that for complex water (especially along coastal area), the data are usually flagged resulting in level 3 products with a limited/inappropriate coverage for end user.

One specificity of the OC5 algorithm (Gohin et al., 2002) and used by the GlobColour processor, is to use its own strategy to flag the data (the algorithm was initially designed for coastal monitoring). The flagging relies partially on the official flags (i.e., issued by agencies), and other criteria intrinsically linked to the retrieval of *Chlorophyll-a*. It means that experimental threshold about ratio of bands have been adjusted for each sensor to remove pixels contaminated by atmospheric condition. The ratio approach is able to preserve pixels that will have been considered not usable by the space agency as individual wavelength.

3 Results and Discussion

3.1 The RRS merging approach

The CCI approach is based on a common set of wavelengths selected for all sensors (some can be artificially obtained by interpolation/shifting). In an initialisation step, these RRS are resampled and merged on a common grid and then used as inputs of the *Chlorophyll-a* algorithm. This approach is very sensitive to the quality of the sensor RRS used as input and the quality of the SeaWIFS RRS (used as reference) for the bias correction. The results about the consistency of the long-time series provided in the CCI Product user guide (**Figure 2**) for the last release v3.1 and more especially at a regional scale (**Figure 3** for the Arctic) demonstrate strong limitations (see jump in 2002) linked to the quality of input RRS which can create artificial trends. During the first period until 2002, only SeaWiFS is available, then in 2012 there is the end of the MERIS contribution and the starting of VIIRS. It is known that both MODIS and VIIRS instrument have had major calibration issues starting this date.

At the end of year 2017, NASA has significantly improved the issues linked to the NOAA/NASA sensors. This new NASA processing (called R2018.1) do not yet benefit to the full CCI series (only for the recent CCI extension until June 2018). However, it should be noted that the R2018 still suffering of issues which will impact the future reprocessing. **Figure 4** and **Figure 5** illustrate issues especially for VIIRS sensor wavelength at 443 and 488. Indeed, VIIRS RRS443 and RRS488 increase regularly since 2012 while MODIS is more stable. The intercomparison of the resulting GSM *Chlorophyll-a* computed for each sensor clearly shows an issue with VIIRS. (**Figure 5**b). It is predictable that such trend will affect the approach based on merged wavelength bands, especially because the swath of VIIRS has a better coverage.

Another major difficulty for merging RRS for the different sensors is that the observed bias varies according to the region considered, and the season and has been previously shown with artificial trends along the years. This is especially true for the band 670 used by the CI-index (**Figure 6**). It should be noted that the CI algorithm contribution has a major effect since the CI algorithm concerns the clear water which represent about 70% to 80%, if we use a threshold of 0.15 to 0.20 $mg.m^{-3}$ to identify this class of water.

3.2 The *Chlorophyll-a* merging approach

The *Chlorophyll-a* is computed from the RRS of each sensor, and then the *Chlorophyll-a* is merged. This approach is the one used by the GlobColour processor for the CMEMS products. It should face the same difficulties about the quality of input RRS as the previous approach. However the sensor approach (instead starting from merged RRS) have crucial advantages compared to the previous one:

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First, the introduction of a new sensor is facilitated because validation can be handled independently from the others. If a bias of the *Chlorophyll-a* is observed it can be used to adjust the sensor with the others. As a consequence, the OLCI-S3A is successfully used in the merged *Chlorophyll-a* GlobColour chain but not yet in the other initiatives (CCI or CMEMS regional product).

Also, the algorithm is applied to the level 2 pixels before resampling and reprojection in the level 3 grid. This is of particular interest to handle high resolution to avoid mixing of pixel contaminated by coastal effect. This is also of major interest to be able to flag the data as explained in the next section.

Then, the algorithm is not limited to the usage of a limited set of RRS. For instance, for OLCI, the new bands could be used to better characterize the fluorescence than with usual one.

3.2 The flagging approach

The flagging approach of the OC5 algorithm allows the identification of pixel contaminated by atmospheric condition with a threshold of band ratio.

The OC5 strategy improves significantly the coverage of the product especially for NASA sensors. In the frame of CMEMS we have measured that at sensor level, the coverage is improved with the following factors: VIIRS-NPP x3.2, MODIS-a x2.6, MERIS x1.6, SeaWIFS x2, OLCI-S3A x1.3, see illustration on Fig. 7-9. For MERIS and OLCI-S3A the improvement is more limited, but it is planned to revisit the flagging strategy, especially for MERIS when the 4th reprocessing will be available (announced in 2019).

However, in some particular case, the CCI coverage could be better than the GlobColour one (e.g. Fig. 10), but CCI approach is affected by an important noise, potentially due to cloud contamination. This noise might be due to level 2 input. Indeed, while GlobColour is using the level 2 from agencies, CCI starts from level 1, apply POLYMER algorithm to MERIS and MODIS plus a specific flagging.

3 Conclusion

This work presents different way to merge sensors and flagging strategies.

The present findings demonstrate the importance of the way to merge the data of the different sensors and the flagging strategy to compute the level 3 *Chlorophyll-a* products.

Results of the approach are illustrated at http://hermes.acri.fr/index.php?class=animation

The available videos are based on 20 years of observations. Images used as input are the level 4 CMEMS products (without extra processing) based on the *Chlorophyll-a* merging approach discussed here.

The usage of CI algorithm (which impact more than 70% of the total surface water) better performs when applies at sensor level.

The RRS merging approach is a very attractive solution. However the issues linked to the instrument and difficulties of calibration shows that is challenging to be successful with this approach.

On the opposite, the *Chlorophyll-a* merging approach offer important advantages:

This approach is more flexible to ingest new sensors. At present the GlobColour processor is the only one ingested OLCI-S3A in the merged product since beginning 2018 and ingestion of VIIRS-NOOA20 (JPSS) and OLCI-S3B will occur at the beginning of 2019.

To satisfy the user community, which require a product with the better spatial resolution (300 meters), the *Chlorophyll-a* merging approach is also required. Algorithm should be applied on the level 2 track grid to limit the mixing of the pixels and support an efficient strategy. The *Chlorophyll-a* merging approach is also the way to use new algorithm using the new OLCI bands which cannot be interpolated for other sensors.

It should be noted that with the usage of 300 meters of resolution the merging data observed at different time will increase the probability to merge oceanic structure that have changed between the 2 observations. A RRS merging approach will lead to high uncertainty about the *Chlorophyll-a* retrieval. In such case, depending of the user need, it is probably better to keep one observation.

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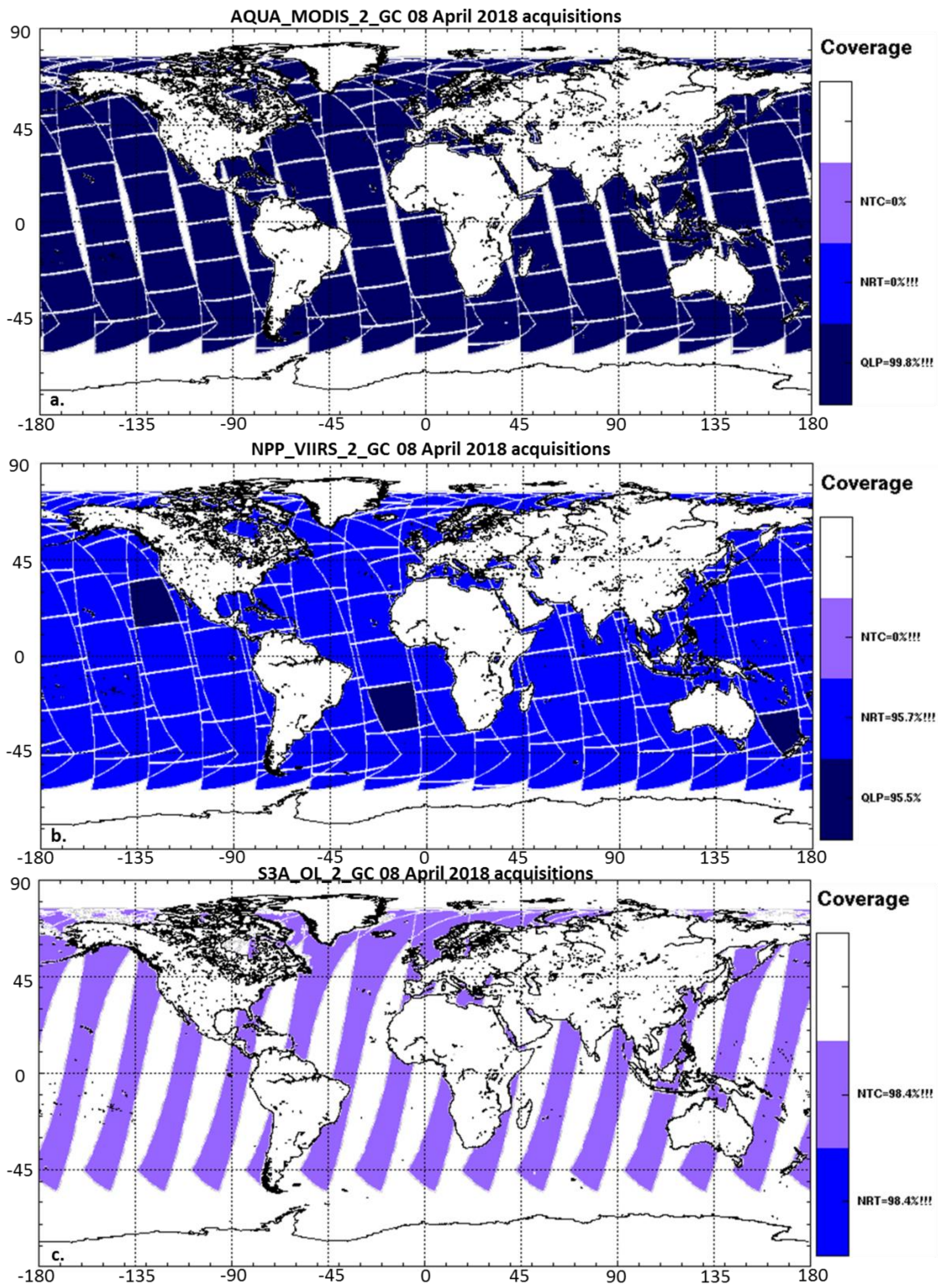

Figure 1: Swath of the different sensors used at present by CMEMS for a) MODIS-Aqua, b) VIIRS-NPP and c) OLCI-S3A. In practice the effective swath coverage is reduced mainly due to clouds or sun glint effects.

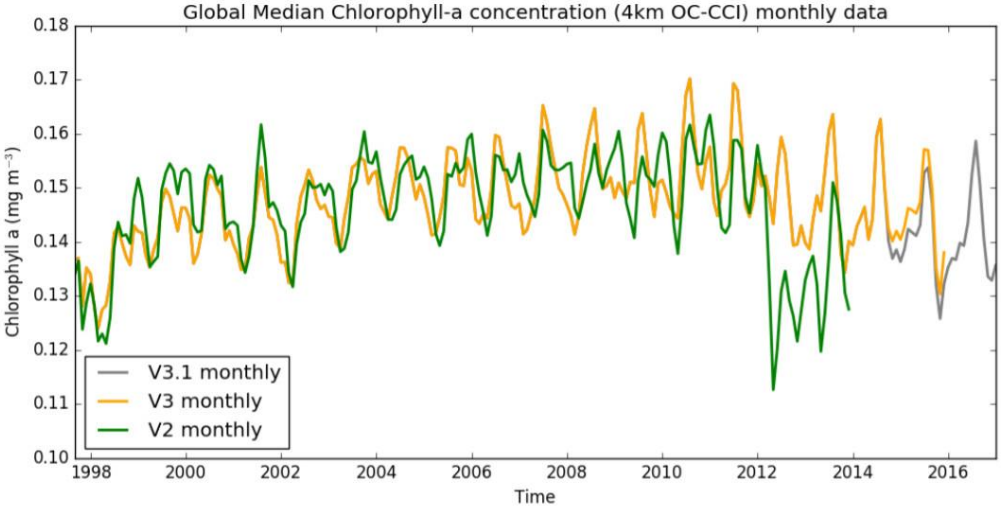

Figure 2: Comparison of the Global Median *Chlorophyll-a* concentration thought time for v2.0, v3.0 and v3.1 using the monthly composite as input. Source: Product User Guide, release 3.1.0, 24th of April 2017, http://www.esa-oceancolour-cci.org/index.php?q=webfm_send/684.

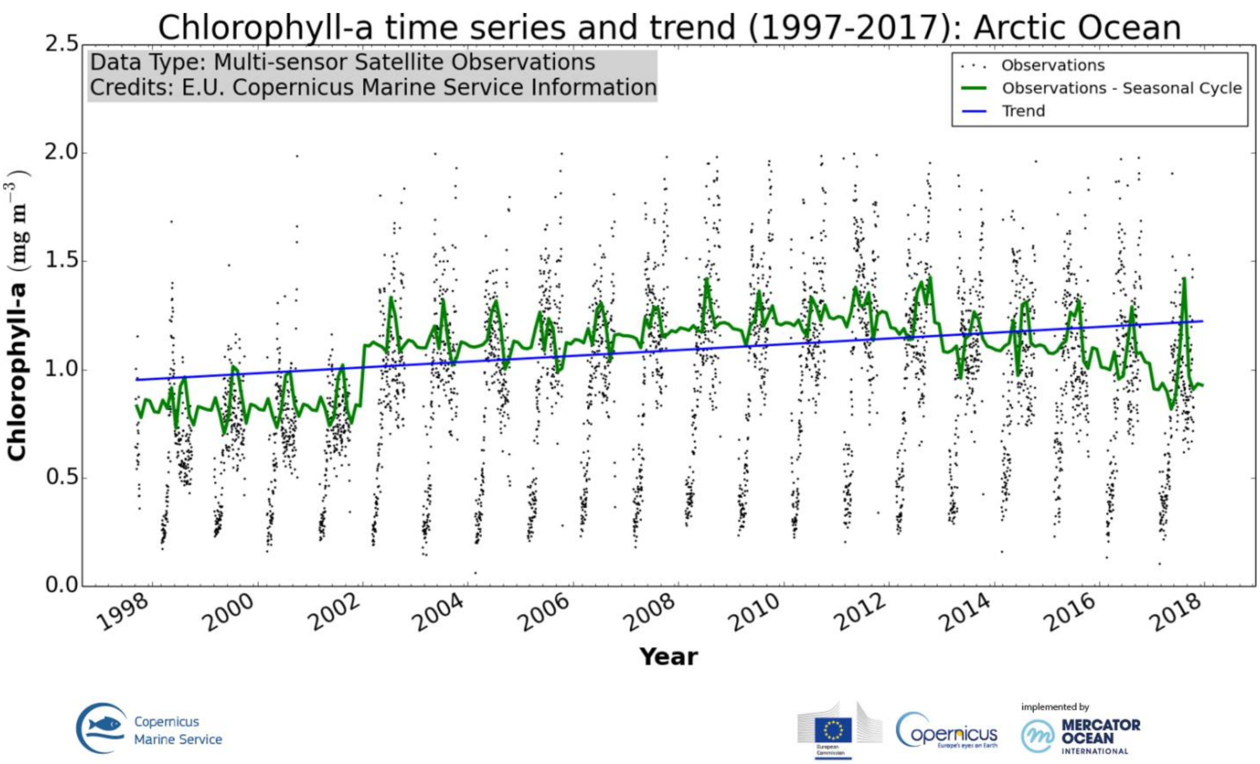

Figure 3 : Arctic time series and trend (1997-2017) from CCI product. The time series are derived from the regional *Chlorophyll-a* reprocessed (REP) products as distributed by CMEMS which, in turn, results from the application of

the regional *Chlorophyll-a* algorithms over remote sensing reflectances (RRS) provided by the ESA Ocean Colour Climate Change Initiative (ESA OC-CCI). Daily regional mean values are calculated by performing the average (weighted by pixel area) over the region of interest. A fixed annual cycle is extracted from the original signal, using the Census-I method as described in Vantrepotte et al. (2009). The deseasonalised time series is derived by subtracting the seasonal cycle from the original time series, and then fitted to a linear regression to, finally, obtain the linear trend. Source: CMEMS QUID.

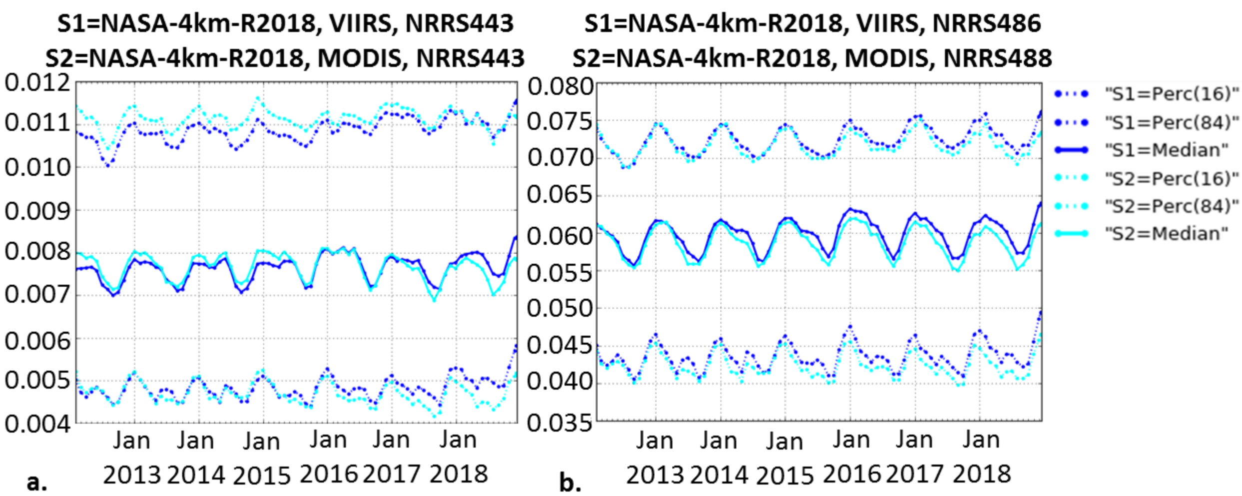

Figure 4: Time series from January 2012 to the 14 December 2018 of monthly median and percentile 16 and 84 of Global MODIS and VIIRS NASA R2018: a) NRRS443 for both VIIRS and MODIS, and b) NRRS486 and NRRS488, for VIIRS and MODIS, respectively. On both panel, the full line is for the median and dashed ones are for percentile. Source: this result is extracted of the monitoring regularly done by the OCTAC and reported on http:octac.acri.fr.

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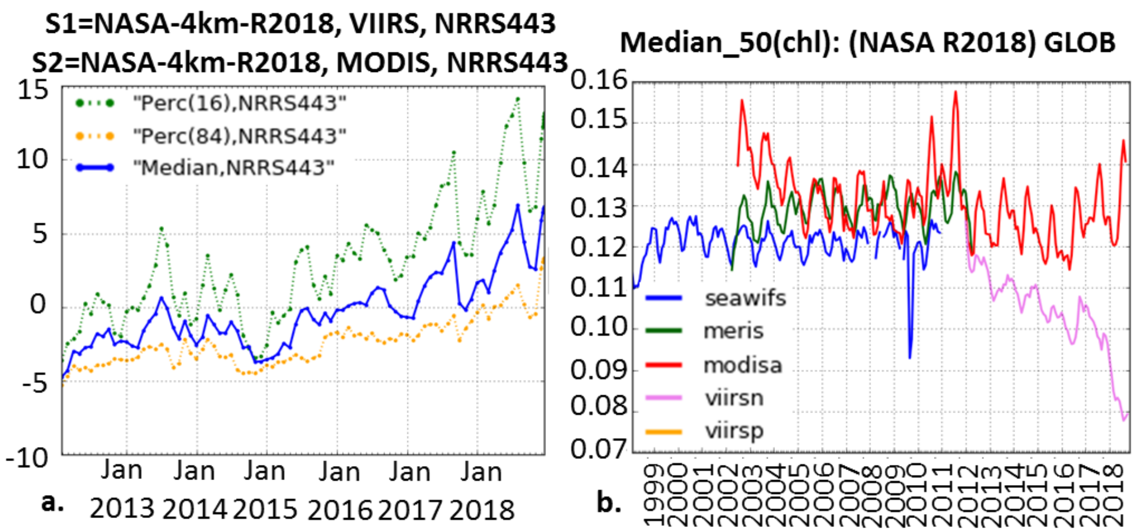

Figure 5: a) relative difference at 443 of VIIRS and MODIS, b) *Chlorophyll-a* concentration based on the GSM algorithm (median computed for each sensor, based on the GSM monthly NASA R2018 global products at 4km). VIIRS suffers of an important trend since it has been launched. Source: these plots are part of the monitoring regularly done by the OCTAC and reported on http:octca.acri.fr.

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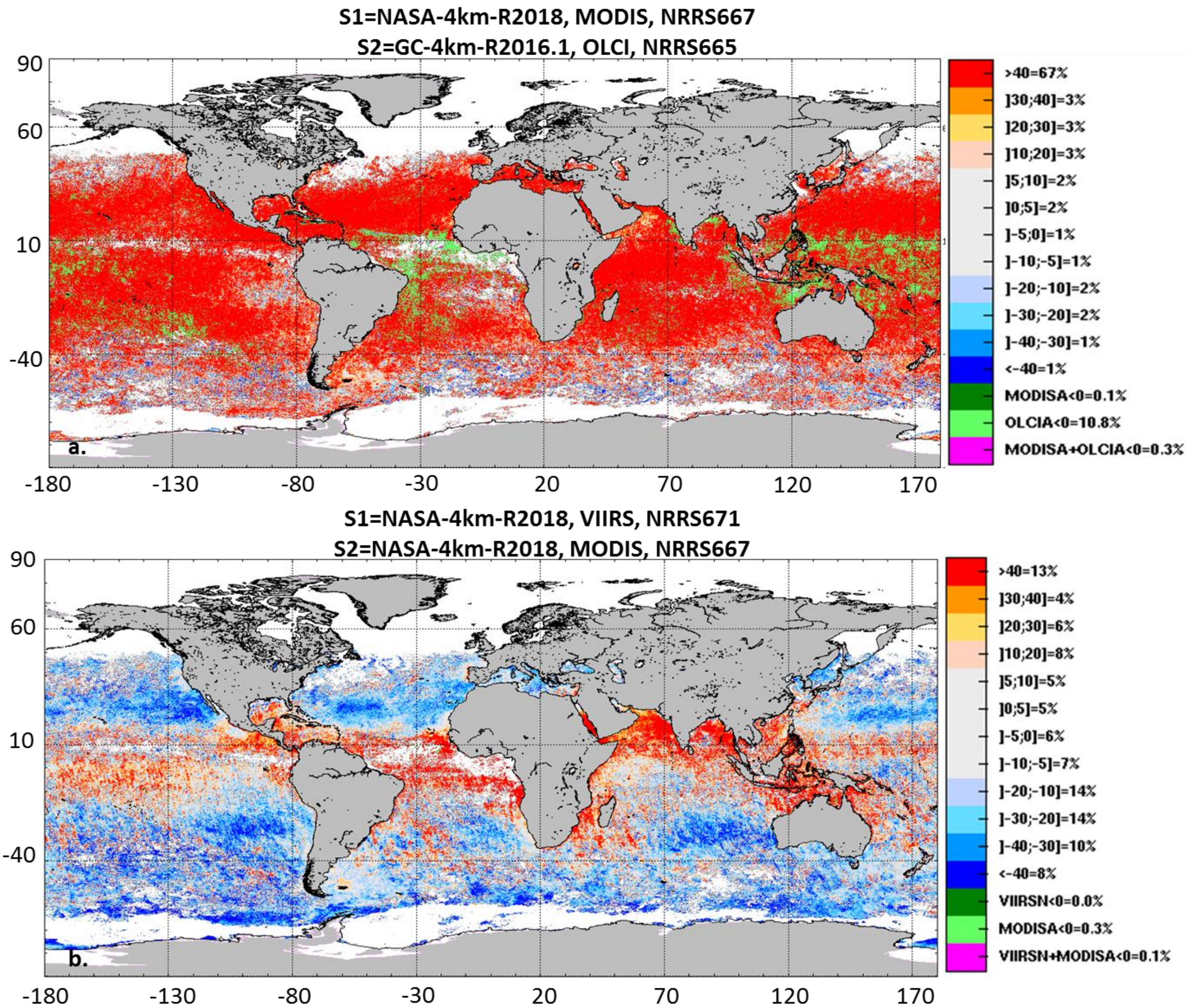

Figure 6: Relative difference between sensors [(S1-S2)/S2] of monthly NRRS (2018-11-11/2018-12-10), for a) MODIS-NRRS667 and OLCI-NRRS665 and b) VIIRS-NRRS671 and MODIS-NRRS667. Source: these plots are part of the monitoring regularly done by the OCTAC and reported on http:octac.acri.fr.

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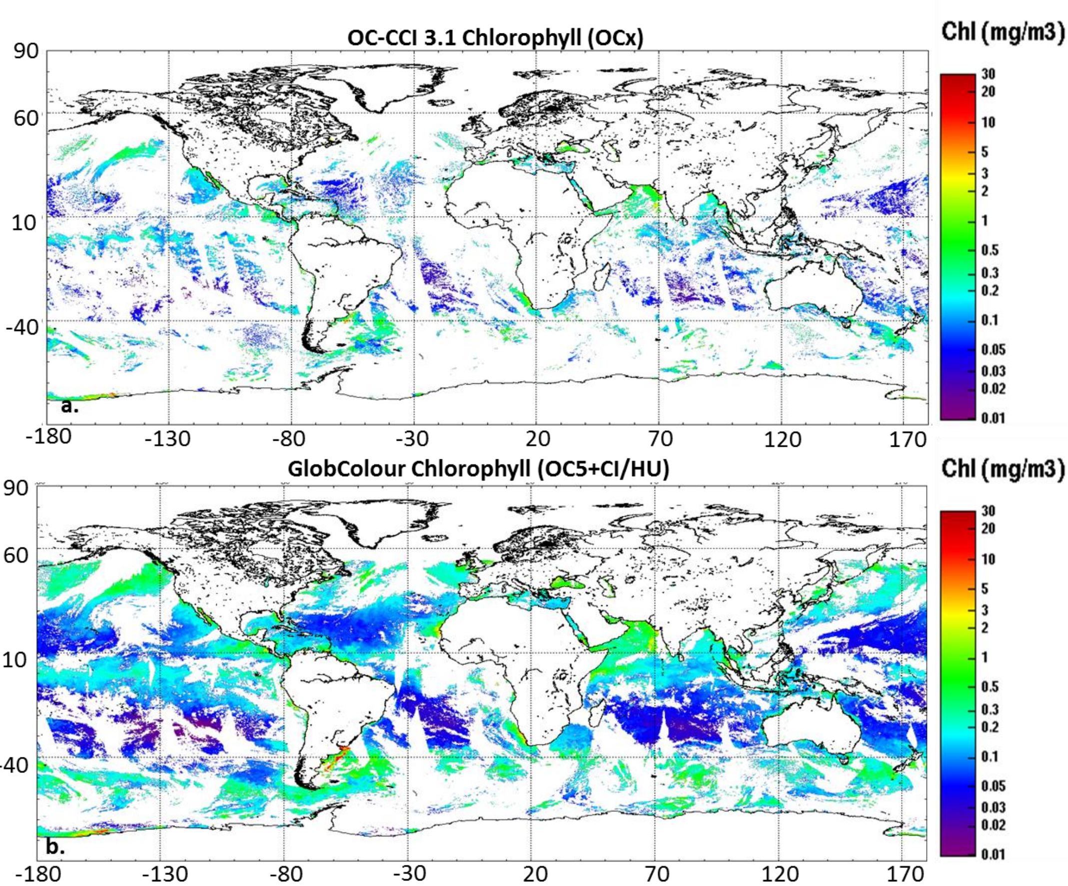

Figure 7: ***Chlorophyll-a*** **concentration (15 Dec 2017), a) CCI level 3 product and b) GlobColour product. The combination of the usage of OLCI and the flagging strategy permits to improve considerably the coverage without artefact. At this date both products benefits of the last NASA R2018 processing.**

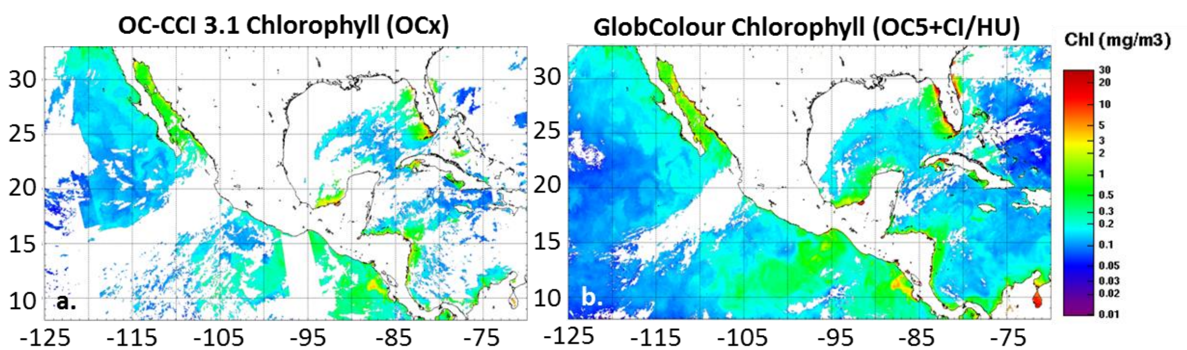

Figure 8: ***Chlorophyll-a*** **concentration (15 Dec 2017): a) CCI level 3 product, b) GlobColour product.**

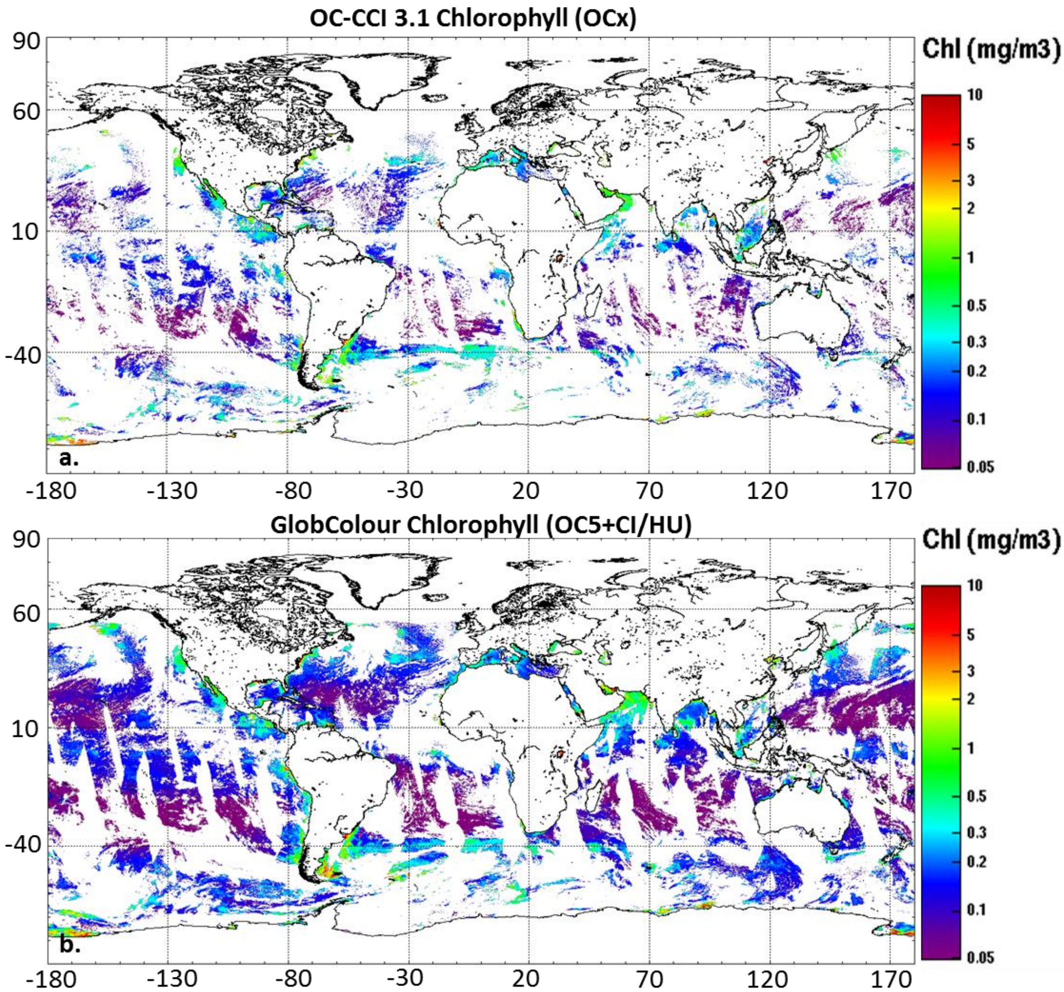

Figure 9: ***Chlorophyll-a*** **concentration (1 Jan 2012), a) CI level3 product and b) GlobColour product. The flagging strategy permits to improve considerably the coverage without artefact in most of the regions.**

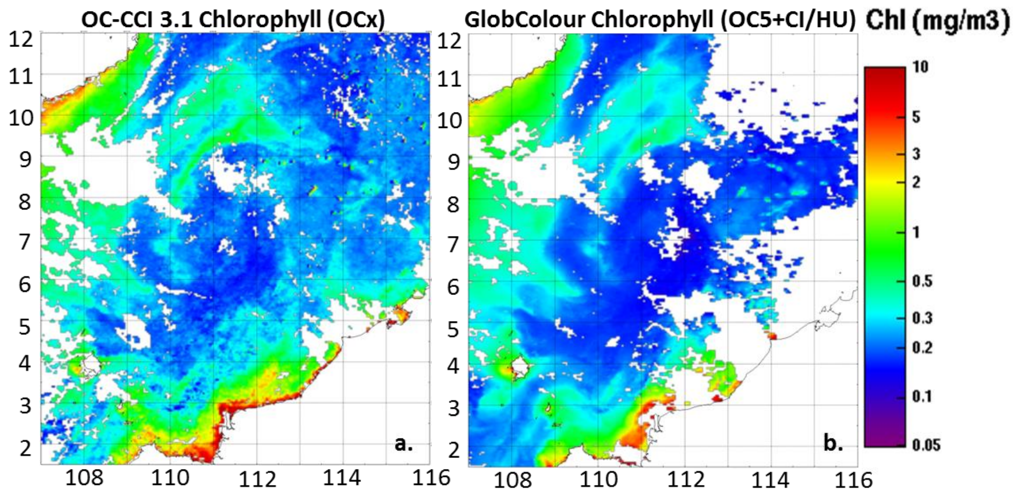

Figure 10: ***Chlorophyll-a*** **concentration (1 Jan 2012), a) CCI level3 product, b) GlobColour product. The flagging strategy of the CCI product leads here on an important noise, potentially originate from a cloud contamination.**

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Table 1: Main characteristics of sensors/bands used for CMEMS.

Sensor	RRS Wavelengths (nm)	Spatial Resolution At Nadir km	Swath width km	Equate crossing time	Period
SeaWiFS	412,443,490,510,555,670	1 & 4	1502	12:20	1997-2010
MERIS	413,443,490,510,560,620,665, 681,709	1 & 0.3	1150	10:00	2002-2012
MODIS-Aqua	412,443,469,488,531,547,555, 645,667,678	1	2330	13:30	2002-present
VIIRS-NPP	410,443,486,551,671	1	3040	10:30	2012-present
OLCI S3A	400,412,442,490,510,560,620, 665,674,681,709	0.3	1270	10:00	2016-present
VIIRS-JPPS1/NOAA20	410,443,486,551,671	1	3040	9:50	2017-present
OLCI S3B	400,412,442,490,510,560,620, 665,674,681,709	0.3	1270	10:00	2018-present