

Dear Emmanuel Boss and anonymous Referees,

Please find below 4 documents:

1. The authors comments/responses (in blue) inserted in the review done by Emmanuel Boss.
2. The authors comments/responses (in blue) inserted in the review done by the anonymous Referee.
3. A new release of the article. This a major revision: the form has been changed and the assertions are better argued. Most of the figures have been also reviewed. The note <https://www.ocean-sci-discuss.net/os-2018-155/os-2018-155-RC2-supplement.pdf> has been also taken into account.
4. The same release of the article but with the word track changes.

Thank you for again for your useful comments.

Philippe Garnesson on behalf of co-authors.

1/ Answers (in blue) in the note (in black) of Emmanuel Boss

Emmanuel Boss (Referee) emmanuel.boss@maine.edu

Received and published: 12 February 2019

Reviewer: Emmanuel Boss, University of Maine

This paper describes the chlorophyll products based on Satellite Observation and disseminated in the frame of the Copernicus Marine Environmental Monitoring Service (CMEMS). Different strategies for merging remote sensing data are presented (e.g. merging radiance vs. merging the products) and the choice of using a merged product approach is justified.

While I see the benefit in publishing this paper, in its current form, it reads like a report to a funding agency rather than a scientific paper. In addition, this paper can benefit a lot from being read by a native English speaker (I am not).

The form of the paper has been reviewed.

For example, I would have expected that the comparison between products will also involve the statistics of distributions of values of chlorophyll (histograms) as done when such algorithms are published (both globally and regionally).

The objective of this article is to highlight two major topics (merging and flagging) and to justify the approach selected for the GlobColour CMEMS processor (there is no innovation proposed in terms of chlorophyll algorithm retrieval). We have modified title/abstract/conclusion to better explain our objective.

Statements are made in the conclusion sections that are not justified by results.

The conclusion has been fully reviewed.

Figures look like they were taken out of a report or a powerpoint presentation rather than high quality publication type figures (with cryptic titles, which is not the norm in papers, lines that don't show as in Fig. 4).

All figures have been revisited.

Some results are provided in an external private website (<http://hermes.acri.fr/index.php?class=animation>). If they are to be considered they should be in the public domain.

The Reference to the website has been removed (out of scope).

I am returning an annotated PDF with many detailed comments.

All these comments were fully pertinent and have been fixed: form, redundancy, statements justified (or removed).

Please also note the supplement to this comment: <https://www.ocean-sci-discuss.net/os-2018-155/os-2018-155-RC2-supplement.pdf>

Interactive comment on Ocean Sci. Discuss., <https://doi.org/10.5194/os-2018-155>, 2019.

2/ Answer (in blue) in the note (in black) of the anonymous Referee.

Anonymous Referee #1

Received and published: 24 January 2019

This article presents the new version of the GlobColour product delivered by ACRIST within the CMEMS. As this GlobColour Chlorophyll-a (Chl-a) product has a global coverage and provides retrievals in coastal waters this manuscript can be of interest for many current and future users of satellite-derived products.

Chl-a in this new GlobColour product is derived from two algorithms: the Color Index of NASA for clear waters ($\text{Chl-a} < 0.15 \text{ mg m}^{-3}$) and the OC5 algorithm of Ifremer for water where Chl-a is superior to 0.2 mg m^{-3} , including the coastal turbid waters. This is very similar to the strategy chosen by the Plymouth Marine Laboratory for the OC-CCI product, also provided at global scale. However a distinction is clearly made by the authors: the GlobColour processing chain provides a Level 3 Chl-a multi-sensor product obtained from mono-sensor Chl-a whilst the Level-3 Chl-a of OC-CCI is obtained from C1 OSD Interactive comment Printer-friendly version Discussion paper a prior merging of the remote-sensing reflectance of the different sensors on a common reference of spectral bands (SeaWiFS).

The OC-CCI approach is similar to that of the Mediterranean Product Unit of CMEMS described in Volpe et al. (Ocean science, accepted). Targeting directly Chl-a, the GlobColour processing can theoretically and practically be adapted more quickly to the modification of the products of any single sensor (following the reprocessing by the Agencies) whilst this task is more difficult to achieve through the complexity of the band switch and band correction operated in the OC-CCI approach. However as pointed out by Volpe et al., the band merging approach has the advantage of providing a homogeneous dataset of spectral reflectance from which can be derived, in full consistency for the long term, different environmental parameters, amongst them Chl-a but also light attenuation, K_d , Suspended Particulate Matter, . . .

Yes, we fully agree with Volpe, and “line 16, section 2.1”, it was indicated <<the approach is theoretically very attractive>> but the promising consistency supposed the input reflectances are consistent. We add a paragraph to discuss advantages and drawbacks underlined by Volpe in part 3.1 (p 4, lines 19-23).

The authors discuss different issues encountered in the near real-time and long term processing of Ocean Colour data and some interesting illustrations are provided on the effect of the drift of R_{rs} in flight and the successive reprocessings by the Agencies onto the OC-CCI product (Fig. 2 & 3) or onto the GSM/Nasa (Fig. 5.) product.

However these major operational constraints have also consequences on the GlobColour and these latters are not described Thorough descriptions of the quality and flaws of the GlobColour products over the period 1997-2018 are missing.

Because previous remark about Volpe, it is important to highlight that the input reflectances (merged or not merged) have issues with consistency. Clearly GlobColour is impacted in the same way as OC-CCI (and it was indicated line 30 of section 3.2). We have added the figure 7 and comments to be clearer on this point.

This could be due to the fact that this GlobColour product is new. In that case, would it not be better to change the title for something as “The new GlobColour product and the challenge of Ocean Colour processing at global scale?” The choices of the author in the article should be easier to understand.

The objective of this article is to highlight two major topics (merging and flagging) and to justify the approach selected for the GlobColour CMEMS processor. So, we agree the title should be more explicit. We have changed it with “The CMEMS GlobColour Chlorophyll-a Product Based on Satellite Observation: multi-sensor merging and flagging strategies.”

In conclusion of these general remarks, the paper should be re-organized. For instance, the first paragraph of the Result and Discussion, 3.1, deals only with the OC-CCI and GSM products!

GSM discussion and plots have been removed: it was just to illustrate the sensor drifts, but we agree it was confusing to introduce another algorithm.

Finally, in this text, the GlobColour product is assessed through its difference (more flexibility as for ingesting OLCI data) with other products but not through comparisons to in situ data; which is a main issue in OC applications, particularly in the coastal waters that are now clearly addressed by OC-CCI and GlobColour. This issue should, at minimum, appear in the discussion.

As CMEMS OC products aim at covering coastal waters, why not take advantage of the coastal monitoring networks for a better flexibility in modifying the processing chains after a reprocessing by the Agencies or the availability of a new sensor?

As said previously, the objective of this paper is to highlight strategies used by CMEMS GlobColour for merging and flagging. It will be of course pertinent to be able to justify strategy using an in situ assessment. However, from our point of view this is a utopic objective: number of in situ are too limited especially on coastal area, the quality of the in situ and the satellite observation are highly questionable (e.g. change of 10% of chlorophyll with NASA-R2018, drifts of sensors). Of course, for CMEMS we are providing a global assessment, but badly it cannot be used to justify merging or flagging approach.

Despite these comments, the manuscript is worth publishing. The illustrations are very informative and the main issues in the operational processing of OC data are pointed out. Specific remarks Introduction Line 11 the CCI/Sv3 is mentioned but not referenced.

It is now referenced at the first citation in the abstract.

That will be done later in the text. Line 19 The continuity between OCx (OC3 & OC4) and OC5 is guaranteed by the construction of the OC5 tables. What do you mean, OC3 and OC4 are used in the GlobColour product in complement to CI and OC5?

In fact, OC5 is using a lookup table based on the ratio used by OC3/OC4. This table is only adjusted for complex water. The text about this topic has been fully reviewed (section 2.1 lines 24-26)

2.2 Flagging approach This chapter is not clear. How is the OC5 LUT doing its own flagging? Not sure there is a control of the errors coming from the atmospheric correction or clouds by the ratios used in OC5. The

412 Rrs processed in OC5 can take into account a possible effect of the overcorrection of the atmospheric content but it could only be marginal in case of clouds, . . .

The level2 upstream products of agencies are provided with flags and some official recommendation to apply them. For instance, if one of the reflectance associated to a pixel is negative this is suspicious, and it can be better to not use this pixel, however in practice other reflectance can be valid. All these flags are based on threshold set up to have the “best” compromise between quality and coverage. However, sometimes the official flags are not working (e.g. specially to determine the frontier of clouds). OC5 flagging is based on the flags from agency and empirical test which permits to improve the coverage (e.g. the sun zenith angle (SZA) is set to 78° instead 70°). The example talking about “atmospheric conditions” was misleading and has been removed.

3.1 Results are those of OC-CCI (already mentioned). However this chapter deals with interesting issues in OC monitoring. In Figure 6, it would be better to show the 2 deviations with a same reference: MODIS Rrs 667. OLCI-MODIS and VIIRS-MODIS would appear with similar colours, demonstrating the variability of the atmospheric corrections between OLCI and VIIRS on one side and MODIS on the other.

It has been changed (figure 5)

Conclusion It is not really a conclusion. The conclusion (or the last lines of the discussion) should open a window on a possible improvement of the processing chains; I would have appreciated a larger view, a strategy for improving the quality of the products, an opening to validation and flexibility after the launch of a new sensor or after a major reprocessing by the Agencies.

The conclusion has been fully rewritten.

Technical corrections Page 1 (fixed or justified/removed in the new submission): Line 12: provides Line 24: the Ocean Colour Thematic Assembly Centre Page 2: Line 12; the CCI/S3v project is not defined Lines 16-19; the continuity of the 3 algorithms. CI , OC5 and ? Lines 20-21: the two sentences could be merged. Page 3: Lines 2 and 3. you already said (page 2 line 29) that VIIRS-NOAA20 and OLCIB data will be incorporated into the GlobColour chain. Line 5: meters Line 11: Do you mean "The redundancy can decrease the level of uncertainty"? The idea expressed Line 16: could you provide more information on the reference of the CCI product Line 27: use them Page6: Lines 1-2: “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.” This assertion is not really proven. Line 7; requires

The CMEMS GlobColour Chlorophyll-a Product Based on Satellite Observation: multi-sensor merging and flagging strategies.

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5 ²Laboratory example, city, postal code, country

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Abstract. This paper concerns the GlobColour merged chlorophyll-a products based on Satellite Observation (SeaWiFS, MERIS, MODIS, VIIRS and OLCI) and disseminated in the frame of the Copernicus Marine Environmental Monitoring Service (CMEMS).

10 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 at Global level (4 km of spatial resolution) and for the Atlantic level 4 product (1 km).

To compute the merged chlorophyll-a product, two major topics are discussed:

- The strategy for merging remote sensing data; for which two options are considered. On the one hand, a merged chlorophyll-a product computed from a prior merging of the remote-sensing reflectance of a set of sensors. On another hand, a merged chlorophyll-a product resulting from a combination of chlorophyll-a products computed for each sensor.
- The flagging strategy used to discard non-significant observation (e.g. clouds, high glint...)

These topics are illustrated by comparing the CMEMS GlobColour products provided by ACRI-ST (Garnesson et al., 2019) with the CCI/C3S project (Sathyendranath et al., 2018). While GlobColour is merging chlorophyll-a products with a specific flagging, the CCI approach is based on a prior reflectance merging before chlorophyll-a derivation and uses a more constraints flagging approach.

Although this work addresses these two topics, it does not pretend to provide a full comparison of the two datasets, which will require a better characterisation and additional inter-comparison with *in situ*.

25 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 for 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 dissemination 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 for the period spanning from 1997 to the 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).

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. This effort has been continued in the framework of CMEMS to derive (among others) the chlorophyll-a Ocean Colour core product.

Many algorithms have been published to retrieve chlorophyll-a from reflectances (RRS) observed by the satellite (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 (70% to 80% of ocean), the CI approach (Hu, 2012) is used,
- for mesotrophic water, the classical approach OCx (OC3, OC4, OC4Me depending the sensor),
- for complex water, another major contribution is the use of empirical OC5 algorithm (Gohin et al., 2002) which is of specific interest for end users who should manage complex water along the coastal zone.

The work presented here highlights the conceptual advantage of the CMEMS Copernicus GlobColour processor concerning flagging and merging of sensors. In the following sections, results are described and illustrated with comparison to the CCI/C3S products.

The comparison between GlobColour and CCI is especially relevant since the same chlorophyll-a algorithms (CI/HUE and OC5) are used by the two initiatives: it means the differences mainly come from the merging strategies and flagging scheme.

2 Methods

2.1 Merging approach

The CMEMS GlobColour merged chlorophyll-a product relies 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).

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 different spatial resolutions from about 300 meters to 1 km at nadir (larger 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 in 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 chlorophyll-a product at 300 meters of resolution.

All sensors used observe the Earth along a helio-synchronous orbit . One sensor is not able to provide the full Earth coverage for a given day (Maritorena et al., 2010, Figure 1). VIIRS provides a larger swath than the other sensors, but the coverage is incomplete because of 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).

To compute a multi-sensors chlorophyll-a product, mainly two merging approaches exist.

- A first approach (used by CCI) is based on merged Reflectance (RRS) computed in a prior step and then used to derive chlorophyll-a. Based on a band shifting and bias correction approach, merged RRS for the standard SeaWiFS wavelengths (412, 443, 490, 510, 555 and 670 nm) are provided. The blended chlorophyll-a algorithm used in the CCI v3.1 release attempts to weight the outputs of the best performing algorithms based on the water types in presence.
- Conversely, in a second approach (used by CMEMS GlobColour), the chlorophyll-a is 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 products are resampled and merged. The continuity of the different algorithms was initially obtained using a water classification approach (Saulquin al., 2018). Beginning of 2018, a new approach has been adopted:
 - o First, the continuity of algorithms used for mesotrophic and complex water are guaranteed by the OC5 lookup tables. The OC5 lookup table is initialized using the OC3 and OC4 coefficients from agencies and then empirically adjusted when the green band exceeds a threshold (see Gohin et al., 2002 for details).
 - o Then, the CI and OC5 continuity is based on 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. This provides continuity between the two algorithms.

2.2 Flagging approach

Inputs of the Copernicus GlobColour processor are the level 2 products 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 it in the processing. Each space agency publishes a flagging strategy which has been designed to guaranty the quality of its products. The drawback is that for complex water (especially along coastal area), the data are usually flagged, resulting in level 3 products with a limited coverage.

- 5 One specificity of the OC5 algorithm (Gohin et al., 2002) is to use its own strategy to flag data (the algorithm was initially designed for coastal monitoring). It is based on part of the official flags plus empirical thresholds that have been tuned for each sensor (e.g. the OC5 sun zenith angle (SZA) is set to 78° instead 70°).

The OC5 flagging is used by the GlobColour sensor approach but does not benefit to the CCI approach which uses a specific OC5 lookup table to be apply to the merged reflectance.

10

Concerning CCI/C3S the flagging strategy for release v3.1 depends of the sensor. When the reflectances are based on the level 2 provided by the agency (SeaWiFS and VIIRS-SNPP) the official flags from the agencies are applied. When the POLYMER algorithm (Steinmetz et al. 2011) is used for atmospheric correction (MERIS and MODIS) a generic pixel identification and classification algorithm called Idepix is used (part of BEAM software) instead the standard POLYMER

- 15 flagging (which is too permissive).

3 Results and Discussion

3.1 The reflectance merging approach

- The reflectance merging approach is used by the C3S/CCI to derive the global Chlorophyll-a CCI timeseries and by the regional CMEMS products. As pointed by Volpe et al. (2019) for the regional Mediterranean products, the band merging
20 approach has the advantage of providing a homogeneous dataset of spectral reflectance from which can be derived, in full consistency for the long term, different environmental parameters, among them chlorophyll-a product but also light attenuation, Kd, Suspended Particulate Matter and others.

- However, the consistency of the long-time series provided by CCI suffers from some limitations. The CCI Product user guide (Figure 2) intercompares the different release of the CCI time series. It shows that the V2 release was strongly
25 impacted when the MERIS sensor has stopped in April 2012 (see Table 1). The V3 release demonstrate a trend depending of the sensors used: It increases for the period 2002-2010 (based on the contribution of SeaWiFS, MODIS and MERIS) and decrease for the period 2012-2017 (based on MODIS and VIIRS-SNPP).

- At regional scale, the figure 3 for the Arctic (derived from the CCI-products, source CMEMS OMI QUID) also demonstrates strong limitations about the consistency of the time-series and trends that are derived. During the first period until 2002, only
30 SeaWiFS is available, then in 2012 there is the end of the MERIS contribution and the starting of VIIRS-SNPP with the same trends as above.

It is known that both MODIS and VIIRS instrument have major calibration issues starting at about 2012. VIIRS-SNPP degradation has been identified a few months after launch and MODIS designed for a lifetime of 7 years is now 17 years old. MODIS calibration has required regular modification to adjust the temporal trends (R2009.1, R2010.0 and especially R2012.0). At the end of year 2017, the NASA reprocessing (called R2018) has significantly improved these issues for VIIRS and especially the MODIS drift with a new procedure to regularly update the MODIS calibration (available about 3 months after acquisition).

It should be noted that this new NASA processing (called R2018.1) does not yet benefit to the full CCI series (only for the recent CCI v3.1 extension until June 2018) but a new CCI v4 release is scheduled for 2019.

It should be also underlined that the R2018 still suffering from issues which will continue to impact the future reprocessing, and 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 Figure 4 shows the relative difference at RRS443 of VIIRS and MODIS (in %) based on the monthly NASA R2018 global products at 4km. VIIRS suffers from a significant drift since its launch as illustrated with January evolution for years 2012, 2016, 2019. In January 2012, 90 % of MODIS at global level was higher than VIIRS-SNPP, while in January 2019 100% of VIIRS-SNPP pixels was higher than MODIS.

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 as previously shown with artificial trends along the years. The Figure 5 shows the inter-comparison of RRS at about 670nm between VIIRS-SNPP and OLCI-S3A compared to MODIS. It shows very important bias (e.g 82% of the pixels of OLCI exceeds a relative difference of 20%), and in the case of MODIS the equatorial zone has a different behaviour than high latitude.

Impact of such reflectance merging on chlorophyll-a is showed on the Figure 6. It shows for the year 2018, limitation to handle clear water (the color scale has been set to the range 0.01 to 0.2 mg/l): discontinuities between tracks of the sensor clearly appeared.

The previous illustrations aim at demonstrating the limits about the assumption of the consistency along the OC-CCI time series (and at daily basis Figure 6) but is clear that the GlobColour products are also impacted by the quality of input RRS upstream.

Figure 7 shows at monthly basis the median computed at global level for OC-CCI and GlobColour monthly products. The oscillations of the median along the time should be carefully interpreted: it is due to a change of the spatial coverage linked to the sensors used, not due to a chlorophyll-a concentration change. To make the two datasets inter-comparable, statistics at monthly basis are computed on common pixels. However, the spatial coverage varies when the sensors used are changed. For instance, until 2002 only SeaWiFS is contributing. It means, the gap at this date not corresponds to a change in the continuity of the time-series but a change of the pixels used to compute the median. It means potential trends should be only considered when same sensors are used (yellow sections on the plot shows the change of sensor combination). The higher values for CCI are probably linked to the NASA R2018 which is used by GlobColour but not yet by OC-CCI During this

R2018 reprocessing, the MOBY (in situ data) and SeaWiFS calibration were also improved with a resulting decrease in chlorophyll of order 10% for all sensors.

5

3.2 The chlorophyll-a merging approach

This approach is the one used by the GlobColour processor for the CMEMS products and is not proposed to solve the issues linked to the upstream data. However, the sensor approach (instead starting from merged RRS) have crucial advantages compared to the previous one:

- When a new sensor (or when a new reprocessing of this sensor) is available, limited efforts are required because the bias correction is limited to the chlorophyll field of the considered sensor. For the merge reflectance approach, the bias correction of 5 reflectance and interpolation to simulate the band 510 is required (this band is not available for VIIRS-SNPP, VIIRS-JPPS1 and MODIS (see Table 1)).
- For the CI-Hue algorithm, the GlobColour processor takes benefit of the efforts of the spatial agencies to adjust, for each sensor, the coefficients taking to take into account the high variability of the band 670 (see Figure 5).
- It should be noted that the chlorophyll-a algorithm is applied on the level 2 sensor grid while in the merging approach it is applied on the common grid required to merge the reflectance. The use of sensor level 2 grid guaranty that the algorithm is applied on reflectance with consistent time observations. On the opposite, when reflectance are re-projected on a common grid, it results in mixing pixels observed with an observation shift that can of raise 4 hours (see Table 1) in the case of MODIS and VIIRS-JPSS1). This consideration is not fully relevant in the case of the Global product with a spatial resolution of 4 km but will become more sensitive when product will be provided with 300 meters of resolution.

3.3 The flagging approach

Compared to the official agencies recommendations, the OC5 flagging strategy improves significantly the coverage of the product especially for NASA sensors. In the frame of CMEMS we have estimated 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

As a consequence, for the merged product, it has been measured that GlobColour chlorophyll-a product coverage is improved by a factor 2.8 compared to CCI. For the period 2002-2012 the increase in coverage is limited to a factor 1.5

(Figure 8 and Figure 9 shows the result of the flagging strategy when bot SeaWiFS, MODIS and MERIS are used).

The combination of the usage of the flagging strategy and OLCI permits to improve considerably the coverage without artefact (see Figure 10). At this date both products benefit of the last NASA R2018 processing.

Note that in certain cases, the CCI coverage could be better than the GlobColour one (e.g. Figure 11). However, in this example the CCI approach is affected by an important noise, potentially due to cloud contamination. This noise might be due to level 2 inputs. 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.

4 Conclusion

This work presents different ways to merge sensors and different flagging strategies to estimate the chlorophyll-a field at daily basis.

Compared to the chlorophyll-a merging approach, the major interest of the reflectance merging approach is to provide a homogeneous dataset of spectral reflectance useful to derive the chlorophyll-a product using a common algorithm. It should lead to a better consistency for the long time series. However as illustrated in the previous section, this assumption is not true since the homogeneity of the spectral reflectance is at present not obtained (spatial and temporal discontinuities exist).

It should be underlined that this limitation also exists with the sensor chlorophyll merging approach: in both approaches if a trend is observed along the time it should be carefully analysed.

The present findings illustrated in the previous sections highlight the advantage of a Chlorophyll-a per sensor merging approach compared to the reflectance merging approach:

- The sensor approach facilitates the ingestion of a new sensor or a new reprocessing. Consequently, the NASA R2018 and OLCI-S3A have been successfully introduced in April 2018 for the merged chlorophyll-a GlobColour chain but is not yet available in the other initiatives (CCI or CMEMS regional product). The addition of VIIRS-NOOA20 (JPSS) and OLCI-S3B in the merged GlobColour chlorophyll-a product will occur during 2019.
- It should be noted that the reflectance merging approach provides a limited set of six common spectral bands based on SeaWiFS sensors. For more recent sensors (i.e. Modis, VIIRS-SNPP and VIIRS-JPPS1) only 5 native reflectance are available (see Table 1): the band at 510 nm is obtained by interpolation. Other extra bands from MERIS or MODIS or OLCI which are not part of the 6 bands are not usable in the reflectance merging approach (because the spatial complementarity of the sensors cannot be used at daily level and for the full time series). For the chlorophyll merging approach, when extra bands are available (i.e. MERIS, MODIS and OLCI) they can be used to improve the algorithm in the future. This perspective is already investigated to retrieve PFT from OLCI (e.g. Xi, 2018).
- The sensor approach provides an improved daily spatial coverage when OC5 is apply on the sensor reflectance (not on merged reflectance). For the period spanning from 2012 to present the spatial coverage is improved with an important factor (about 2.8) compared to the CCI product. Both open ocean and coastal area are improved. It is required for many users involved in the EU Water Framework and Marine Strategy Framework Directive. To

satisfy the user coastal community, a better spatial resolution (300 meters) is also required. From this point of view the chlorophyll-a merging approach is also more promising (algorithm can be applied on the level 2 track grid to limit the mixing of the pixels).

A better spatial coverage is also a key point to guaranty the quality of the CMEMS GlobColour chlorophyll-a “cloud free” product (called daily L4 in the CMEMS catalogue) which is based on a spatial and temporal interpolation of daily level3level 3 product. A better daily coverage limits the risk of artefact due to interpolation.

Acknowledgement

10 We thanks Emmanuel Boss and another anonymous referee for their constructive comments which allow to improve the quality of this manuscript.

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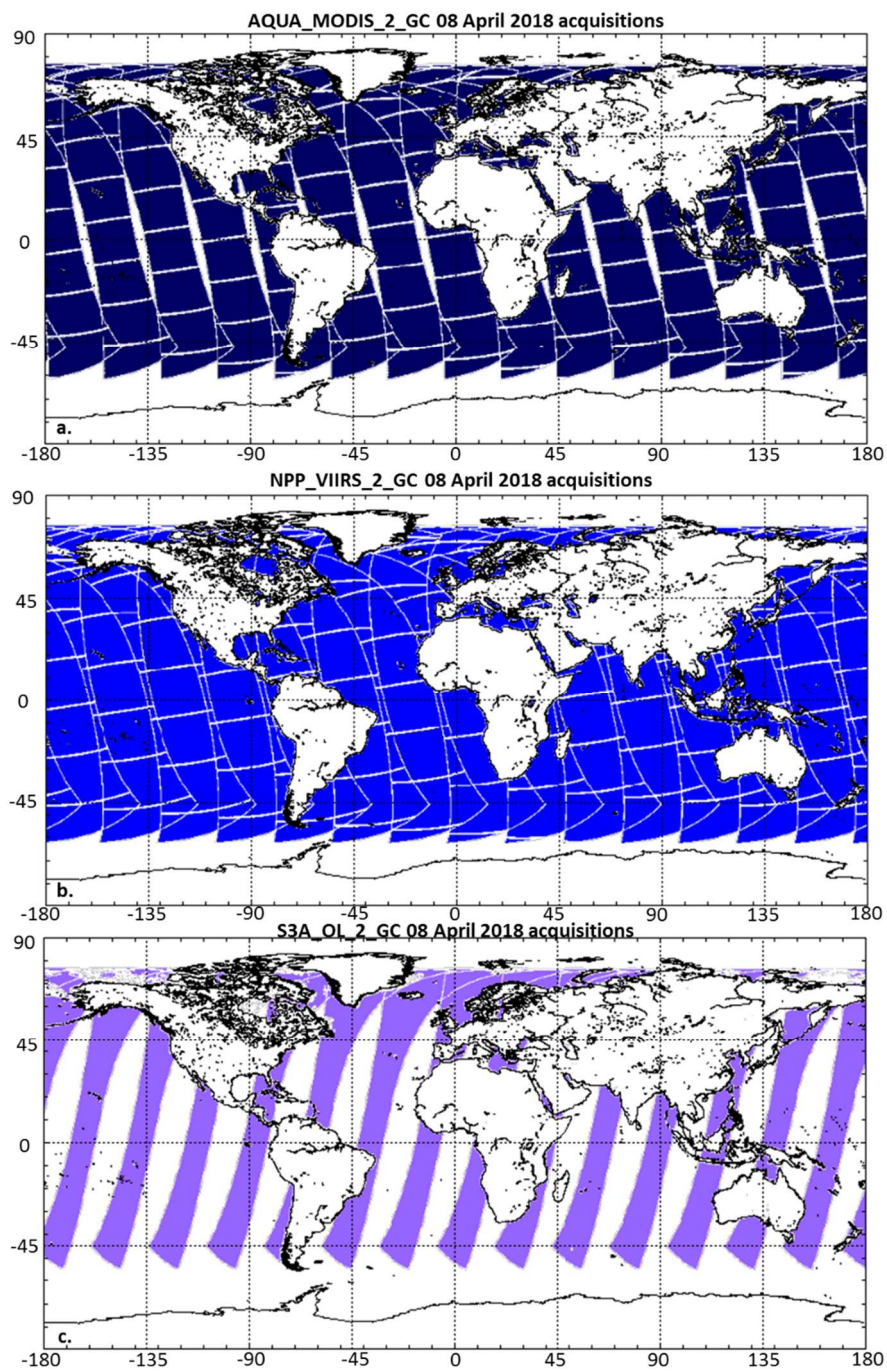


Figure 1: Swath of the different sensors used at present by CMEMS for a) MODIS-Aqua, b) VIIRS-NPP and c) OLCI-S3A. In practice the effective swath coverage is reduced mainly due to clouds or sun glint effects.

Source: <http://octac.acri.fr>.

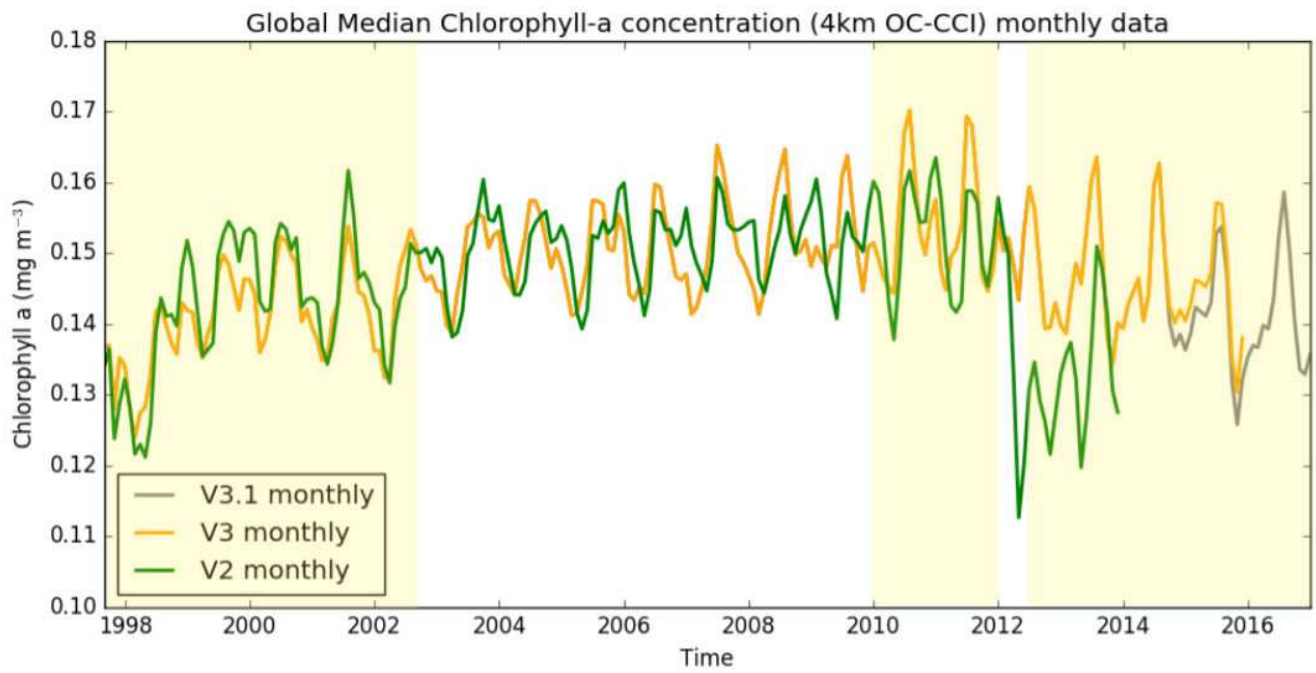


Figure 2: Comparison of the Global Median chlorophyll-a concentration as function of time for v2.0, v3.0 and v3.1 using the monthly composite as input. Source: CCI Product User Guide, release 3.1.0, 24th of April 2017.

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Yellow part shows change of sensor combinations (see Table 1)

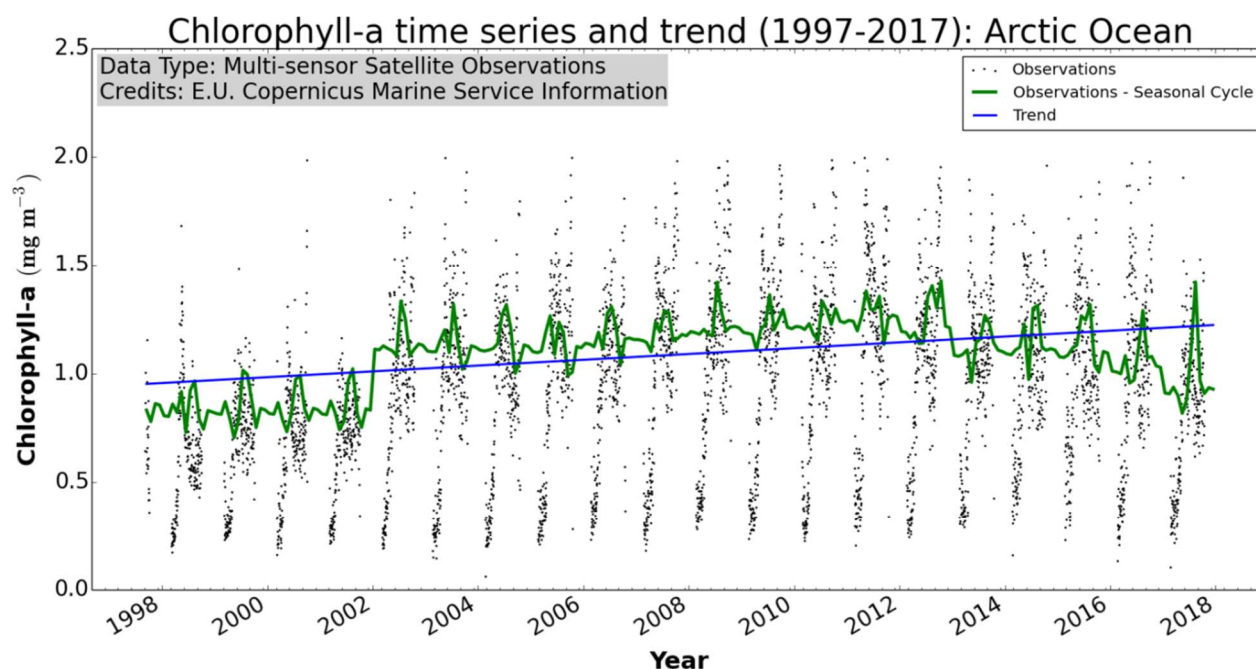


Figure 3 : Arctic time series and trend (1997-2017) from CCI product. The time series are derived from the regional chlorophyll-a reprocessed (REP) products as distributed by CMEMS which, in turn, results from the application of the regional chlorophyll-a algorithms with remote sensing reflectances (RRS) 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 obtain the linear trend. Source: CMEMS QUID.

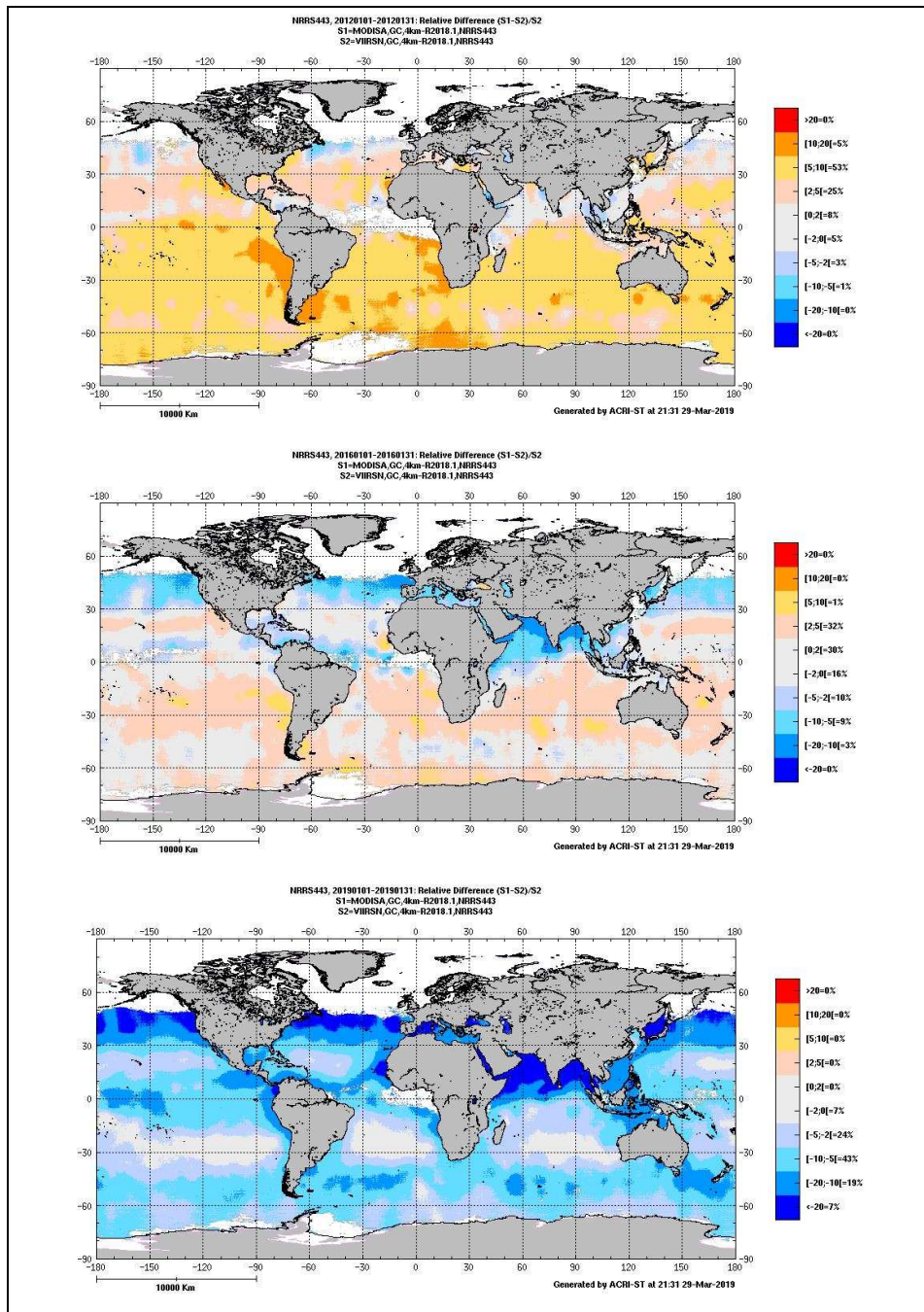


Figure 4: relative difference at RRS443 of VIIRS and MODIS (in %) based on the monthly NASA R2018 global products at 4km). VIIRS suffers from a significant trend since it has been launched as illustrated with January month evolution for years 2012, 2016, 2019.

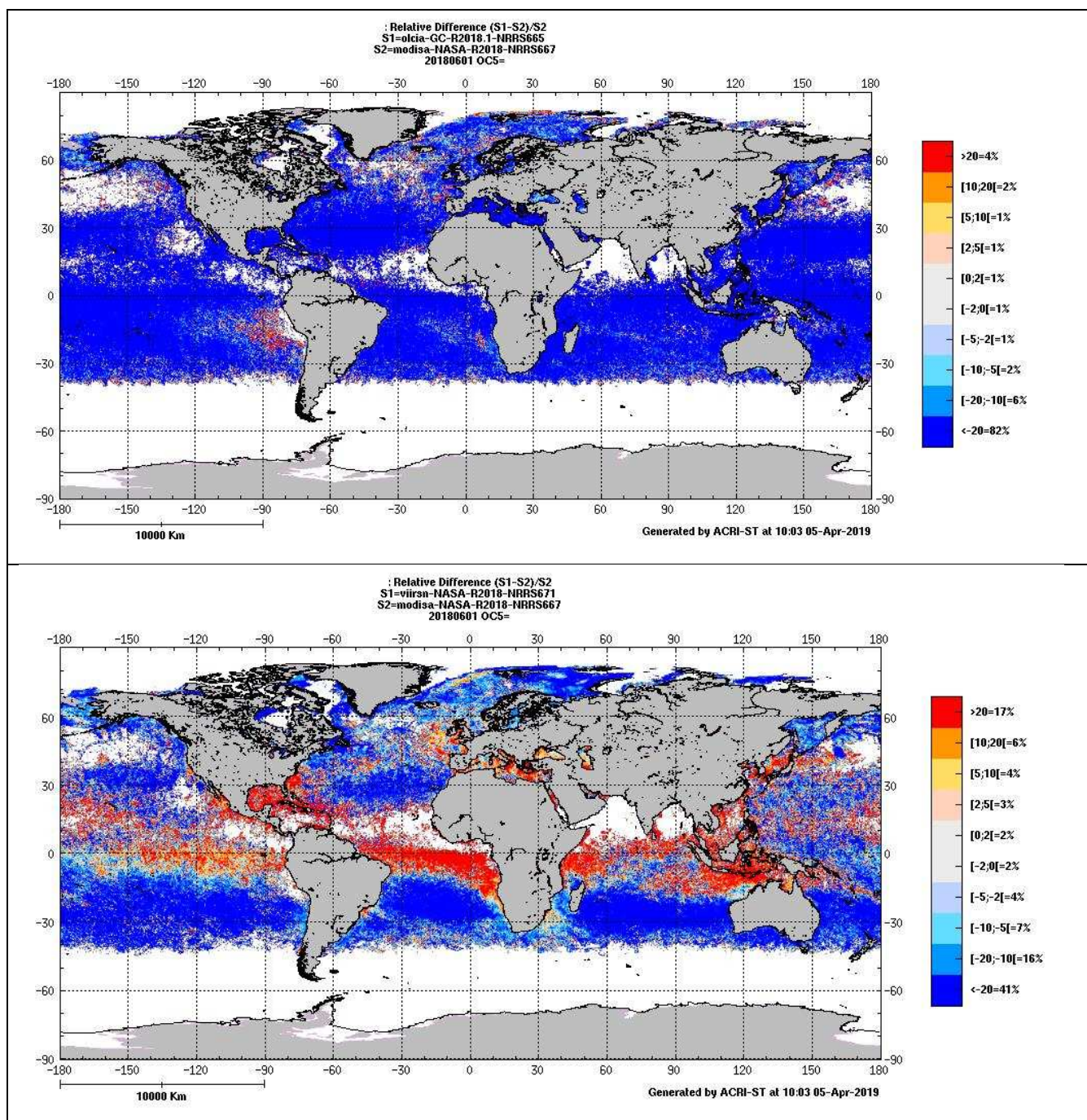


Figure 5: Relative difference between sensors [(S1-S2)/S2] of monthly NRRS (June 2018), for a) MODIS-NRRS667 and OLCI-NRRS665 and b) VIIRS-NRRS671 and MODIS-NRRS667. Source: these plots are part of the monitoring done by the OCTAC and reported on <http://octac.acri.fr>.

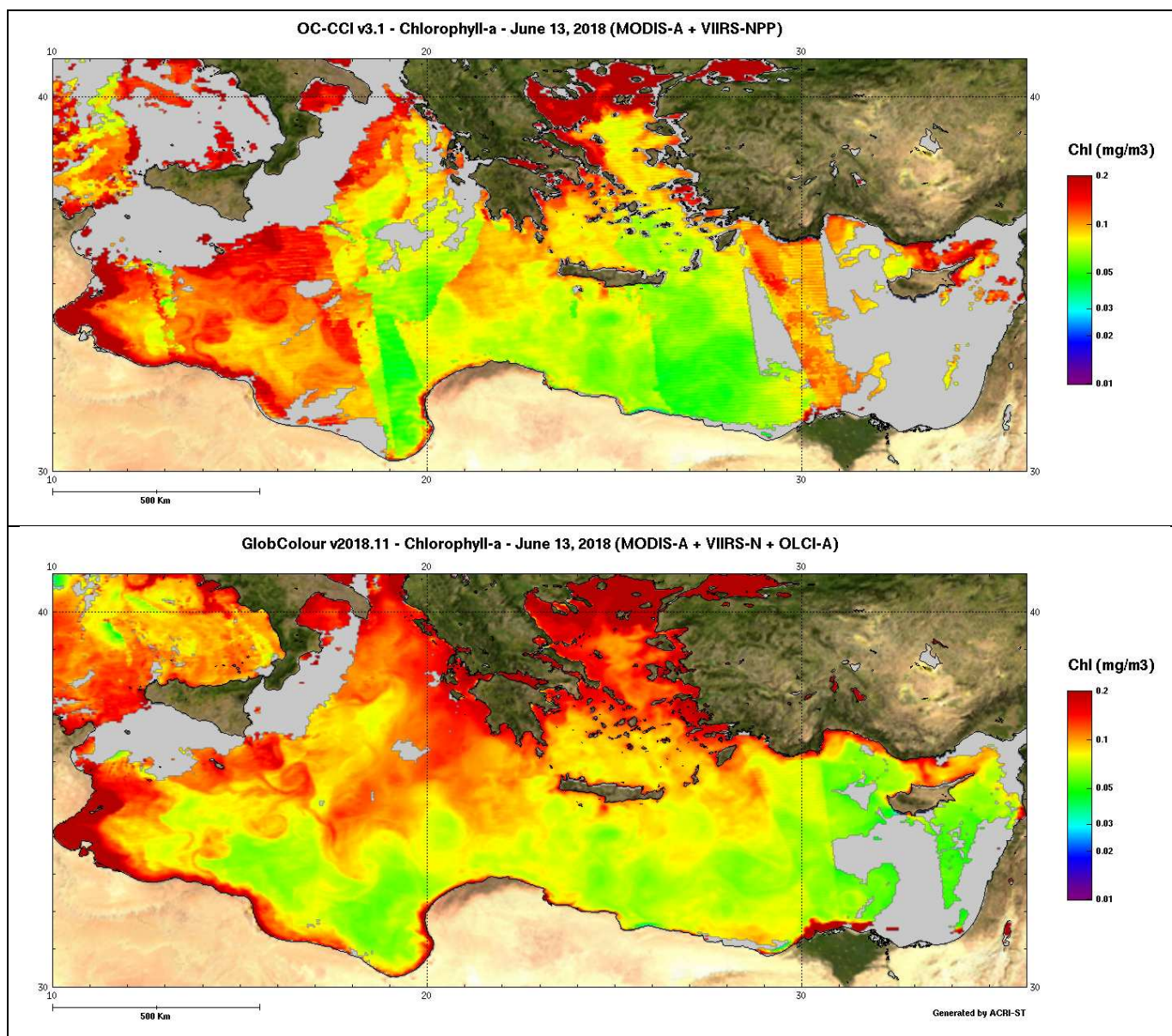


Figure 6: Inter-comparison of GlobColour product and OC-CCI during 2018 for Oligotrophic water (CI/HU algorithm). the color scale has been set to the range 0.01 to 0.2 mg/l: discontinuities between tracks of the sensor clearly appeared on the OC-CCI case at the top.

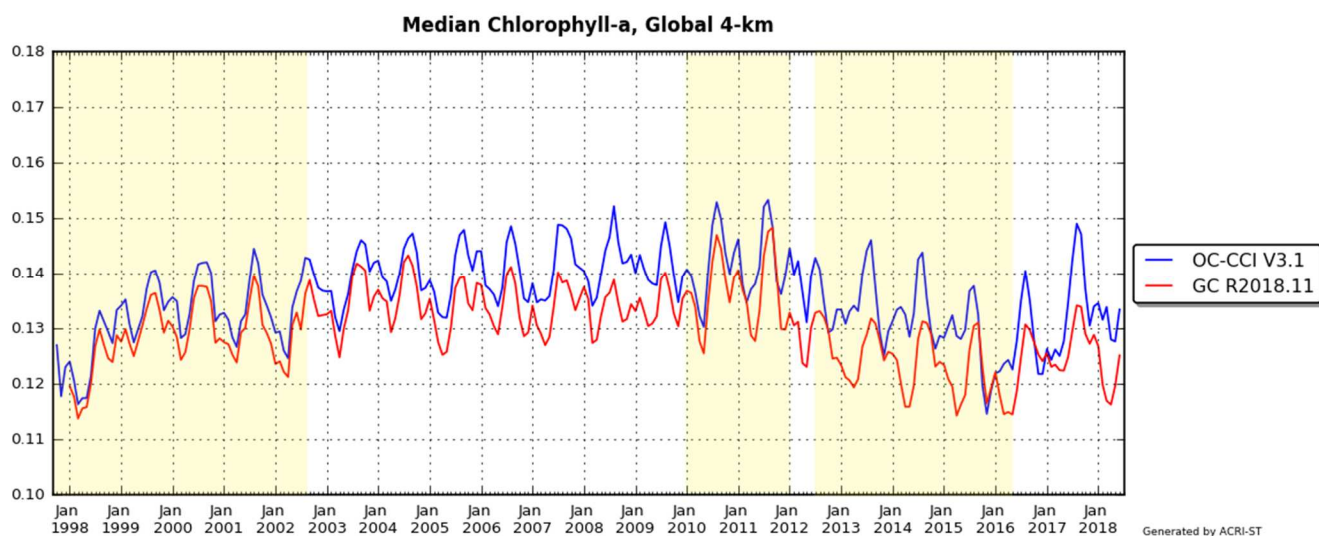


Figure 7: Comparison of the Global Median chlorophyll-a concentration as function of time for CCI v3.1 and GlobColour R2018.11. The discontinuities of the median along the time should be carefully interpreted: it is due to a change of the spatial coverage linked to the sensors used, not due to a chlorophyll-a concentration change. It means

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potential trends should be only considered when same sensors (see Table 1).

Yellow part shows change of sensor combinations (see Table 1)

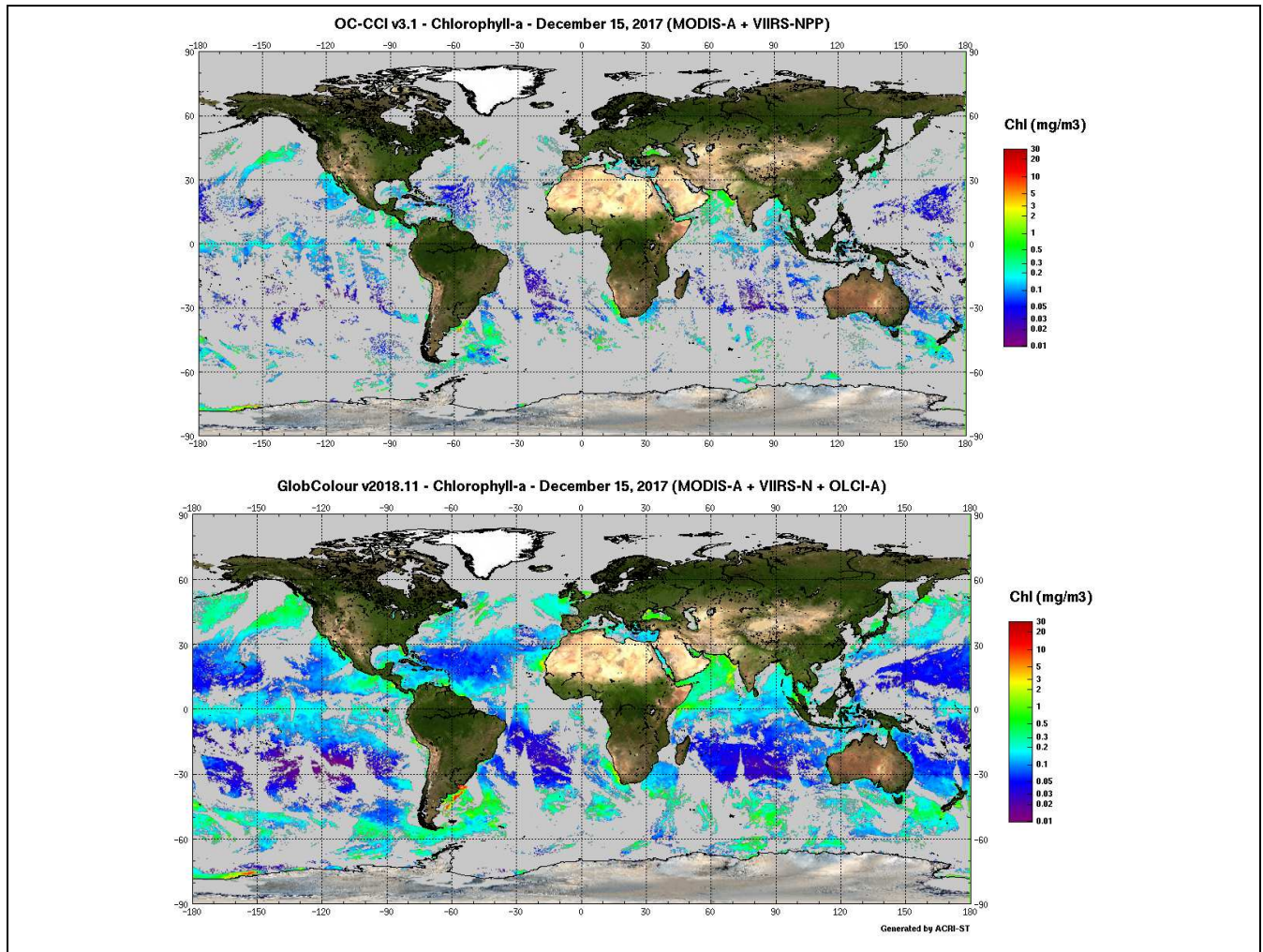


Figure 8: Chlorophyll-a concentration (15 Dec 2017), a) CCI level 3 product and b) GlobColour product.
The two initiatives are using MODIS-A, and VIIRS-SNPP at this date, in complement OLCI-S3A is also used by
GlobColour products

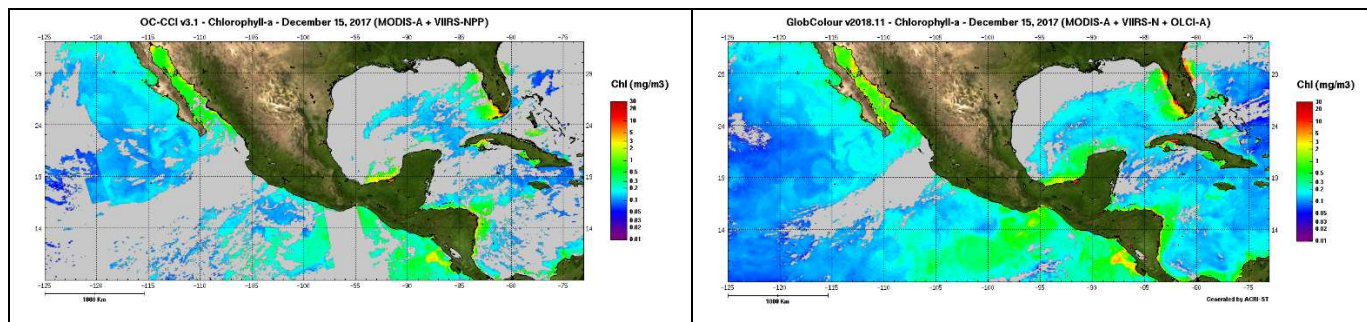


Figure 9: Chlorophyll-a concentration (15 Dec 2017): a) CCI level 3 product, b) GlobColour product.

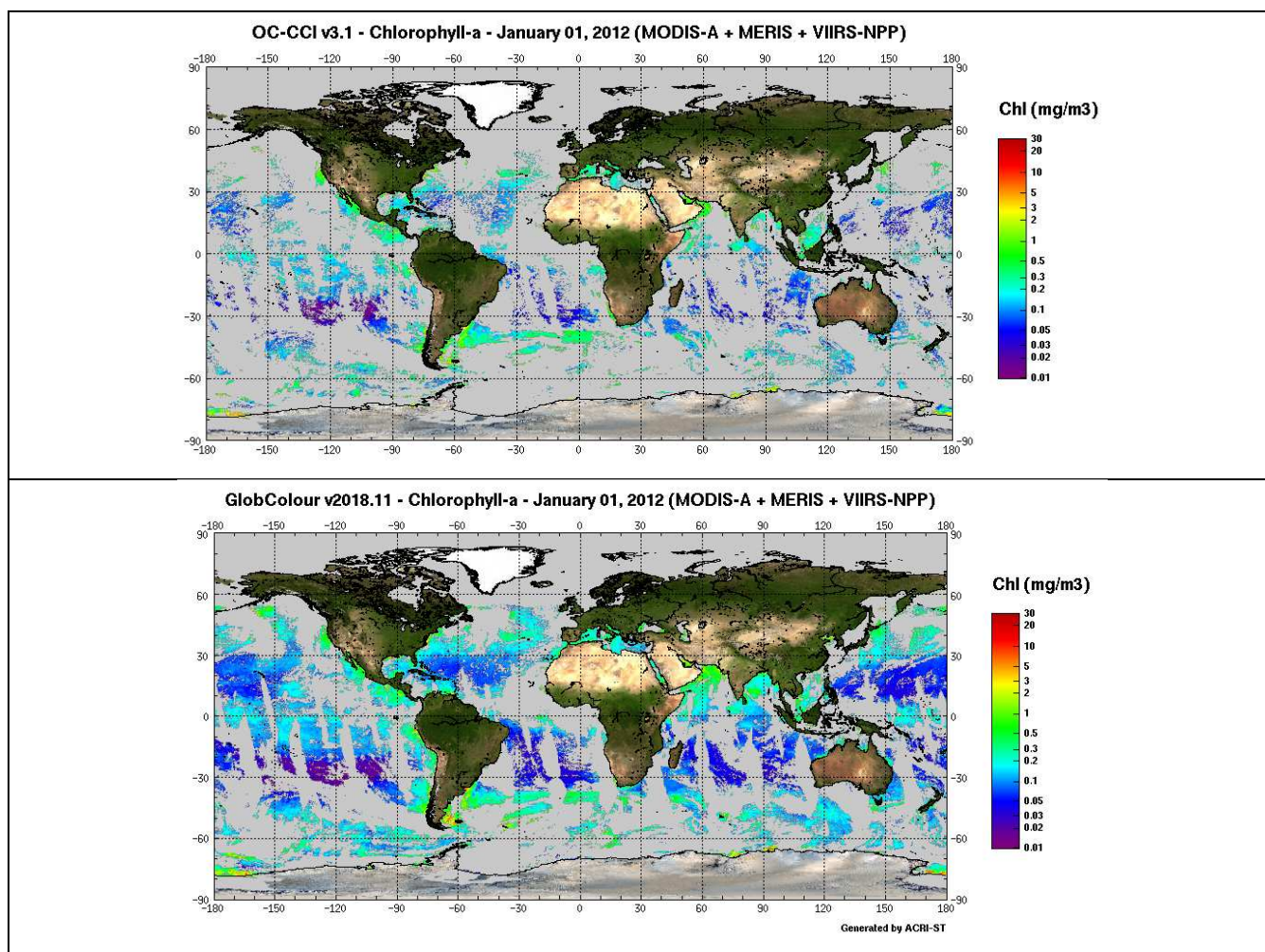
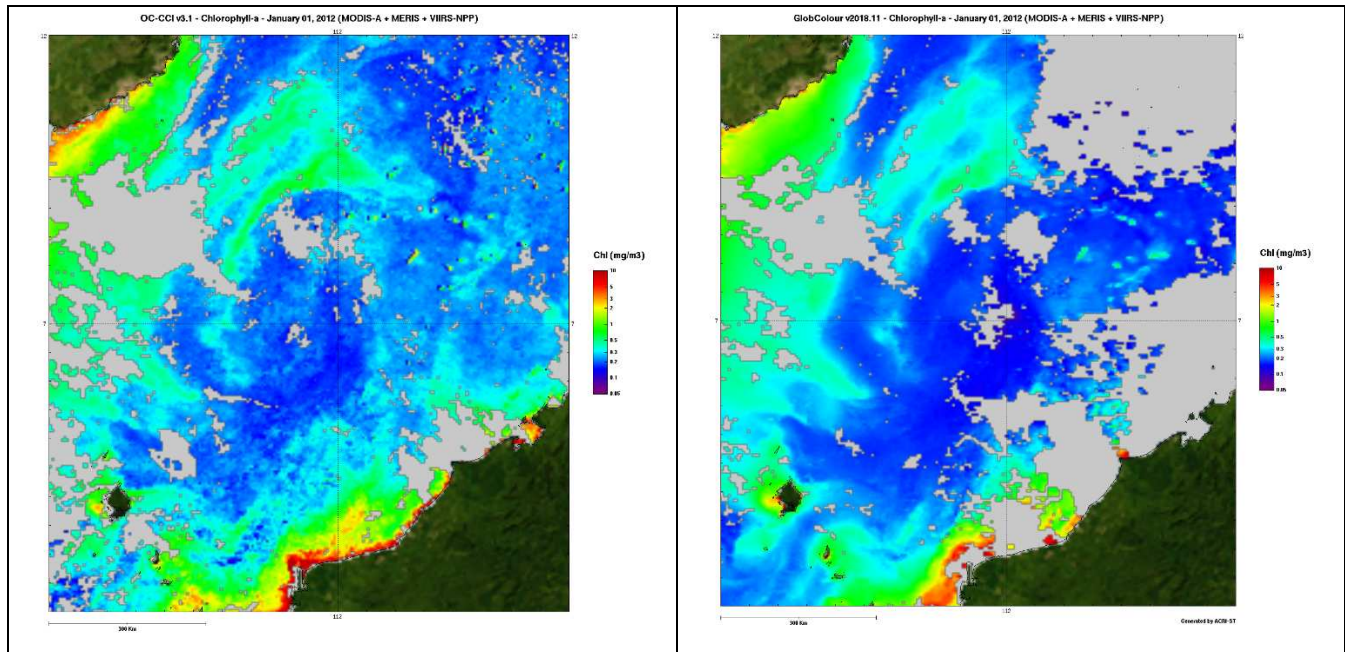


Figure 10: Chlorophyll-a concentration (1 Jan 2012), a) CI level3 product and b) GlobColour product.

The two initiatives are using MODIS-A, MERIS and VIIRS-SNPP at this date.



5 **Figure 11: Chlorophyll-a concentration (1 Jan 2012), a) CCI level3 product, b) GlobColour product.**

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	413,443,490,510,560,620,667,681,709	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	1.2 & 0.3	1270	10:00	2016-present
VIIRS-JPPS1/NOAA20	411,445,489,556,667	0.75	3040	9:50	Dec-2017-present
OLCI S3B	400,412,442,490,510,560,620,665,674,681,709	1.2 & 0.3	1270	10:00	2018-present

The CMEMS GlobColour Chlorophyll-a Product Based on Satellite Observation: multi-sensor merging and flagging strategies.

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Abstract. This ~~paperwork~~ concerns the GlobColour merged chlorophyll-a products based on Satellite Observation (SeaWiFS, MERIS, MODIS, VIIRS and OLCI) and disseminated in the frame of the Copernicus Marine Environmental Monitoring Service (CMEMS).

This work highlights the main advantages provided by the Copernicus GlobCeolour~~Globeolour~~ 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):

To compute the merged ~~sensor~~ chlorophyll-a product, two major topics are discussed:

- 15 • The strategy for merging remote sensing data; for which two options are considered. On ~~one side~~the one hand, a merged chlorophyll-a product computed from a prior merging of the remote-sensing reflectance of a set of sensors. On another ~~hand~~the other side, a merged chlorophyll-a product resulting from a combination of chlorophyll-a products computed for each sensor.

- The flagging strategy used to ~~discard~~ignore non-significant observation (e.g. clouds, high glint...)

- 20 These topics are illustrated by comparing the CMEMS GlobColour products provided by ACRI-ST (Garnesson et al., 2019) with the CCI/C3S project (Sathyendranath et al., 2018). While: ~~on one side~~ GlobColour is merging ~~sensor~~ cChlorophyll-a products with a specific flagging, ~~on the other side~~ the CCI approach is based on a prior reflectance merging before chlorophyll-a derivation and ~~using~~uses a more constraints flagging approach.

- 25 Although ~~t~~This work addresses these two topics, ~~it, but~~ does not pretend. The objective is ~~not~~ to provide a full comparison of the two ~~dataset~~initiatives, which will require a better characterisation ~~of the trends~~ and additional inter-comparison with *in situ*.

It discusses the different ways to merge data coming from different sensors and it shows. 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

5 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 for the European regional seas (temperature, currents, salinity, sea surface height, sea ice, marine optical al propertiess, 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
10 records for recent years (re-analysis).

The Ocean Thematic Assembly Centre (OCTAC) is part of CMEMS and is dedicated to the dissemination 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 for the period spanning from 1997 to the present. For Global products, the Copernicus GlobColour processor is used operationally since 2009 to serve CMEMS and its
15 precursors (a series of EU research projects called MyOcean).

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 framework of CMEMS to deriveserve (among others) the chlorophyll-a Ocean Colour core product.

20 European Union Framework Program 7 under grant n°282723 (OSS2015) and French FEDER grant n°8 562 40 567 (MCGS).

Many algorithms have been published ~~To~~ to retrieve chlorophyll-a 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 (70% to 80% of ocean), the CI approach (Hu, 2012) is used,
- for mesotrophic water, the classical approach OCx (OC3, OC4, OC4Me depending the sensor),
- for complex water, another major contribution is the use~~d~~ of empirical OC5 algorithm (Gohin et al., 2002) which is of
30 specific interest for end users who should manage complex water along the coastal zone.

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 et al., 2018). Beginning of 2018, it has been changed. The continuity between OCx (OC3 & OC4) and OC5 is guaranteed by the construction of the OC5 tables.

~~to adopt the same approach as NASA. When the chlorophyll 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 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. In the following sections, Results are described and illustrated with comparison to the CCI/C3S products~~other initiatives in the following sections.~~

The comparison between GlobColour and CCI is especially relevant since the same chlorophyll-a algorithms (CI/HUE and OC5) are used by the two initiatives: it means the differences mainly comes from the merging strategies and flagging scheme.

2 Methods

2.1 Merging approach

The CMEMS GlobColour merged chlorophyll-a products relies 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 wavelength-spectral bands (and different bandwidth), with different acquisition time (so different atmospheric and sun conditions), and with different spatial resolutions from about 300 meters to 1 km at nadir (larggreater on the swath border). Main characteristics of the sensors/bands used for CMEMS are summarized in Table 1. VIIRS-NOAA20 and OLCI-S3B will be ingested in the operational products sometime duringin 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 chlorophyll-a product at 300 meters of resolution.

All sensors used observed the Earth along with a helio-synchronous orbit. One sensor is not able to provide the full Earth coverage of the earth for a given day (Maritorena et al., 2010, Figure 1). VIIRS is able to provides a larger swath than the other sensors, but the coverage is incomplete because impacted by of 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 the uncertainty of the products (Antoine et al., 2008).

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

- A first approach (used by CCI) is based on merged Reflectance (RRS) computed in a prior step and then used to derive chlorophyll-a. Based on a band shifting and bias correction approach, merged RRS for the standard SeaWiFS wavelengths (412, 443, 490, 510, 555 and 670 nm) are provided. The blended chlorophyll-a algorithm used in the CCI v3.1 release attempts to weight the outputs of the best performing algorithms based on the water types in presence. 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 and the global CCI Chlorophyll CMEMS products. The blended chlorophyll 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 or other variables.

- Conversely, in a second approach (used by CMEMS GlobColour), the chlorophyll-a is 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 products are resampled and merged. The continuity of the different algorithms OCI [OC4+CI], OC3 and OC5 to avoid artefact when water type change was initially obtained using a water classification approach (Saulquin al., 2018), to avoid artefact when water type change. Beginning of 2018, a new approach has been adopted:

- First, the continuity of algorithms used for mesotrophic and complex water are guaranteed by the OC5 lookup tables. The OC5 lookup table is initialized using the OC3 and OC4 coefficients from agencies and then empirically adjusted when the green band exceeds a threshold (see Gohin et al., 2002 for details).
- Then, the CI and OC5 continuity is based on 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. This provides continuity between the two algorithms.

2.2 Flagging approach

- Inputs of the Copernicus GlobColour processor are the level 2 [products](#) provided by the space agencies. To derive the [chlorophyll-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 [instanceinstance](#), 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 [it](#) in the processing. Each space agency publishes [a](#) flagging strategy which has been designed to guaranty [the quality of its productsa 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 coveragefor 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). [It is based on part of the official flags plus empirical thresholds that have been tuned for each sensor \(e.g. the OC5 sun zenith angle \(SZA\) is set to 78° instead 70°\).](#) [The flagging relies partially on the official \(i.e. issued by agencies\) flags, and other criteria intrinsically linked to the retrieval of chlorophyll. It means that experimental threshold about ratio of bands have has 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.](#) The OC5 flagging is used by the GlobColour sensor approach but [does not benefit to the CCI approach which uses a specific OC5 lookup table to be apply to the merged reflectance](#).
- Concerning CCI/C3S the flagging strategy for release v3.1 depends of the sensor. When the reflectances are based on the level 2 provided by the agency (SeaWiFS and VIIRS-SNPP) the official flags from the agencies are applied. When the POLYMER algorithm (Steinmetz et al. 2011) is used for atmospheric correction (MERIS and MODIS) a generic pixel identification and classification algorithm called Idepix is used (part of BEAM software) instead the standard POLYMER flagging (which is too permissive).
- The flagging approach of the OC5 algorithm allows the identification of pixel contaminated by atmospheric condition with a threshold of band ratio.

3 Results and Discussion

3.1 The [reflectanceRRS](#) merging approach

- The reflectance merging approach is used by the C3S/CCI to derive the global Chlorophyll-a CCI timeseries and by the regional CMEMS products. As pointed by [Volpe et al. \(2019\)](#) for the regional Mediterranean products, the band merging

approach has the advantage of providing a homogeneous dataset of spectral reflectance from which can be derived, in full consistency for the long term, different environmental parameters, amongst them chlorophyll-a product but also light attenuation, Kd, Suspended Particulate Matter and others.

However, the consistency of the long-time series provided by CCI suffers from some limitations. The CCI Product user guide (Figure 2) intercompares the different release of the CCI time series. It shows that the V2 release was strongly impacted when the MERIS sensor has stopped in April 2012 (see Table 1). The V3 release demonstrate a trend depending of the sensors used: It increases ~~eing~~ for the period 2002-2010 (based on the contribution of SeaWiFS, MODIS and MERIS) and decrease for the period 2012-2017 (based on MODIS and VIIRS-SNPP).

~~for the last release v3.1 and more especially a~~ At a regional scale, ~~the~~ (figure 3 for the Arctic (derived from the CCI-products, source CMEMS OMI QUID)) ~~also demonstratedemonstrates~~ strong limitations about the consistency of the time-series and trends that are derived. (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-SNPP with the same trends as above.

It is known that both MODIS and VIIRS instrument have major calibration issues starting at about 2012. VIIRS-SNPP degradation has been identified a few months after launched and MODIS designed for a lifetime of 7 years is now 17 years old. MODIS calibration has required regular modification to adjust the temporal trends (R2009.1, R2010.0 and especially R2012.0). At the end of year 2017, the NASA reprocessing (called R2018) has significantly improved these issues for VIIRS and especially the MODIS drift with a new procedure to regularly update the MODIS calibration (available about 3 months after acquisition).

It should be noted that this new NASA processing (called R2018.1) ~~does~~ not yet benefit to the full CCI series (only for the recent CCI v3.1 extension until June 2018) but a new CCI v4 release is scheduled for 2019.

~~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 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~~ It should be also underlined ~~noted~~ that the R2018 still suffering ~~from~~ issues ~~ww~~hich will continue to impact the

future reprocessing. and 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 computed for each sensor clearly shows an issue with VIIRS. (Figure 5b). 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.~~

5 ~~The Figure 4 shows the relative difference at RRS443 of VIIRS and MODIS (in %) based on the monthly NASA R2018 global products at 4km. VIIRS suffers from a significant drift trend since it has been launched as illustrated with January month evolution for years 2012, 2016, 2019. In January 2012, 90 % of MODIS at global level was higher than VIIRS-SNPP, while in January 2019 100% of VIIRS-SNPP pixels was higher than MODIS.~~

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. The Figure 5 shows the inter-comparison of RRS at about 670nm between VIIRS-SNPP and OLCI-S3A compared to MODIS. It shows very important bias (e.g 82% of the pixels of OLCI exceeds a relative difference of 20%), and in the case of MODIS the equatorial zone has a different behaviour than high latitude.~~

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~~Impact of such reflectance merging on chlorophyll-a is showed on the Figure 6. It shows for the year 2018, limitation to handle clear water (the palette color scale has been set to the range 0.01 to 0.2 mg/l): discontinuities between tracks of the sensor clearly appeared.~~

~~The previous illustrations aim at demonstrating the limits about the assumption of the consistency along the OC-CCI time series (and at daily basis Figure 6) but is clear that the GlobColour products are also impacted by the quality of input RRS upstream.~~

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~~Figure 7 shows at monthly basis the median computed (at global level) for common pixels for OC-CCI and GlobColour monthly products. The discontinuities oscillations of the median along the time should be carefully interpreted: it is due to a change of the spatial coverage linked to the sensors used, not due to a chlorophyll-a concentration change. To make the two datasets inter-comparable, statistics at monthly basis are computed on common pixels. However, the spatial coverage varies when the sensors used are changed. For instance, until 2002 only SeaWiFS is contributing. It means, the gap at this date not corresponds to a change in the continuity of the time-series but a change of the pixels used to compute the median. It means potential trends should be only considered when same sensors are used (yellow sections on the plot shows the change of sensor combination). The higher values for CCI are probably linked to the NASA R2018 which is used by GlobColour but not yet by OC-CCI During this R2018 reprocessing, the MOBY (in situ data) and SeaWiFS calibration were also improved with a resulting decrease in chlorophyll of order 10% for all sensors.~~

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3.2 The ~~Chlorophyll~~chlorophyll-a merging approach

~~This approach is the one used by the GlobColour processor for the CMEMS products and is not proposed to solve the issues linked to the upstream data. It should face the same difficulties about the quality of input RRS as the previous approach.~~

5 ~~However~~However, the sensor approach (instead starting from merged RRS) have crucial advantages compared to the previous one:

- ~~When a new sensor (or when a new reprocessing of this sensor) is available,~~ is available, limited efforts are required because the bias correction is limited to the chlorophyll field of the considered sensor. For the merge reflectance approach, the bias correction of 5 reflectance and interpolation to simulate the band 510 is required (this band is not available for VIIRS-SNPP, VIIRS-JPPS1 and MODIS (see Table 1)).
- For the CI-Hue algorithm, the GlobColour processor takes benefit of the efforts of the spatial agencies to adjust, for each sensor, the coefficients taking to take into account the high variability of the band 670 (see Figure 5).
- It should be noted that the chlorophyll-a algorithm is applied on the level 2 sensor grid while in the merging approach it is applied on the common grid required to merge the reflectance. The use of sensor level 2 grid guaranty that the algorithm is applied on reflectance with consistent time observations. On the opposite, when reflectance are re-projected on a common grid, it results in mixing pixels observed with an observation shift that can of raise 4 hours (see Table 1) in the case of MODIS and VIIRS-JPSS1). This consideration is not ~~really relevant~~ ~~relevant~~ in the case of the Global product with a spatial resolution of 4 km but will become more sensitive w-sensible-when product will be provided with 300 meters of resolution.

20 ~~The chlorophyll is computed from the RRS of each sensor, and then the chlorophyll 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:~~

25 ~~First, the introduction of a new sensor is facilitated because validation can be handled independently from the others. If a bias of the chlorophyll 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 GlobColour chain but not yet in the other initiatives (CCI or CMEMS regional product).~~

30 ~~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.~~

3.32 The flagging approach

~~Compared to the official agencies recommendations, The flagging approach of the OC5 algorithm allows the identification of pixel contaminated by atmospheric condition with a threshold of band ratio.~~

The OC5 flagging strategy improves significantly the coverage of the product especially for NASA sensors. In the frame of CMEMS we have ~~estimated~~measured that at sensor level, the coverage is improved with the following factors: VIIRS-NPP x3.2, MODIS-a x2.6, MERIS x1.6, SeaWiFSSeaWiFS x2, OLCI-S3A x1.3, ~~see illustration on Fig. 7-9. 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. 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).~~

As a consequence, for the merged product, it has been measured that GlobColour chlorophyll-a product coverage is improved ~~by~~with a factor 2.8 compared to CCI. For the period 2002-2012 the increase in coverage is limited to a factor 1.5 (Figure 8 and Figure 9 shows the result of the flagging strategy when bot SeaWiFS, MODIS and MERIS are used).

The combination of the usage of the flagging strategy and OLCI permits to improve considerably the coverage without artefact (see Figure 10). At this date both products benefit of the last NASA R2018 processing.

~~Note However, that in certain cases, in some particular case,~~ the CCI coverage could be better than the GlobColour one (e.g. ~~Figure 11~~Fig. 10). However, in this example the CCI approach is affected by an important noise, potentially due to cloud contamination. This noise might be due to level 2 inputs. 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.

43 Conclusion

This work presents ~~discuss-on~~ different ways to merge sensors and different flagging strategies to estimate the chlorophyll-a field at daily basis.

Compared to the chlorophyll-a merging approach, the major interest of the reflectance merging approach is to provide a homogeneous dataset of spectral reflectance useful to derive the chlorophyll-a product using a common algorithm. It should lead to a better consistency for the long time series. However as illustrated in the previous section, this assumption is not true since the homogeneity of the spectral reflectance is at present not obtained (spatial and temporal discontinuities exist).

It should be underlined that this limitation also exists with the sensor chlorophyll merging approach: in both approaches if a trend is observed along the time it should be carefully analys~~interpret~~ed.

The present findings illustrated in the previous sections highlight~~demonstrate~~ the advantage of a Chlorophyll-a per sensor merging approach compared to the reflectance merging approach:

• The sensor approach facilitates the ingestion of a new sensor or a new reprocessing. Consequently, the NASA R2018 and OLCI-S3A have been successfully introduced in April 2018 for the merged chlorophyll-a GlobColour chain but is not yet available in the other initiatives (CCI or CMEMS regional product). The addition of VIIRS-NOOA20 (JPSS) and OLCI-S3B in the merged GlobColour chlorophyll-a product will occur during 2019.

• It should be noted that the reflectance merging approach provides a limited set of six common spectral bands based on SeaWiFS sensors. For more recent sensors (i.e. Modis, VIIRS-SNPP and VIIRS-JPPS1) only 5 native reflectance are available (see Table 1): the band at 510 nm is obtained by interpolation. Other extra bands from MERIS or MODIS or OLCI which are not part of the 6 bands are not usable in the reflectance merging approach (because the spatial complementarity of the sensors cannot be used at daily level and for the full time series). For the chlorophyll merging approach, when extra bands are available (i.e. MERIS, MODIS and OLCI) they can be used to improve the algorithm in the future. This perspective is already investigated to retrieve **phytoplankton species-PFT** from OLCI (e.g. Xi, 2018).

• The sensor approach provides an improved daily spatial coverage when OC5 is apply on the sensor reflectance (not on merged reflectance). For the period spanning from 2012 to present the spatial coverage is improved with an important factor (~~about 2.8-estimation~~) compared to the CCI product. Both open ocean and coastal area are improved. It is required for many users involved in the EU Water Framework and Marine Strategy Framework Directive. To satisfy the user coastal community, a better spatial resolution (300 meters) is also required. From this point of view the chlorophyll-a merging approach is also more promising (algorithm can be applied on the level 2 track grid to limit the mixing of the pixels).

A better spatial coverage is also a key point to guaranty the quality of the CMEMS GlobColour chlorophyll-a “cloud free” product (called daily L4 in the CMEMS catalogue) which is based on a spatial and temporal interpolation of daily level3level 3 product. A better daily coverage limits the risk of artefact due to interpolation.

~~For global daily interpolated products (Saulquin et al., 2018) of CMEMS since 2005, the OC5 approach has been used.~~

Acknowledgement

We thanks Emmanuel Boss and another anonymous referee for their constructive comments which allow to improve the quality of this manuscript.

~~importance of the way to merge the data of the different sensors and the flagging strategy to compute the level 3 chlorophyll 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 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 merging approach offer important advantages:

First, 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 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 merging approach is also the way to use new algorithm using the new OLCI bands which can not 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 retrieval. In such case, depending of the user need, it is probably better to keep one observation.

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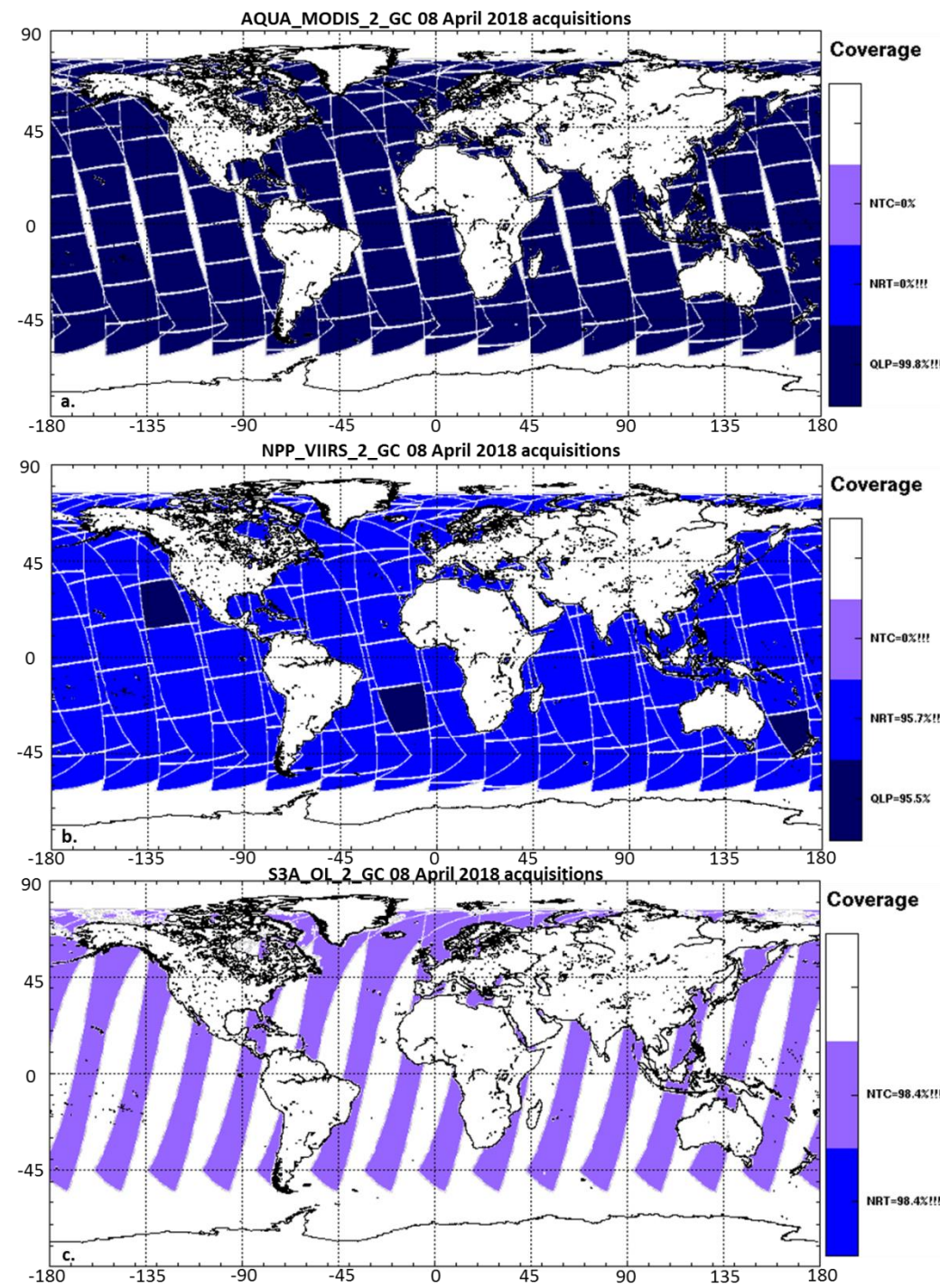
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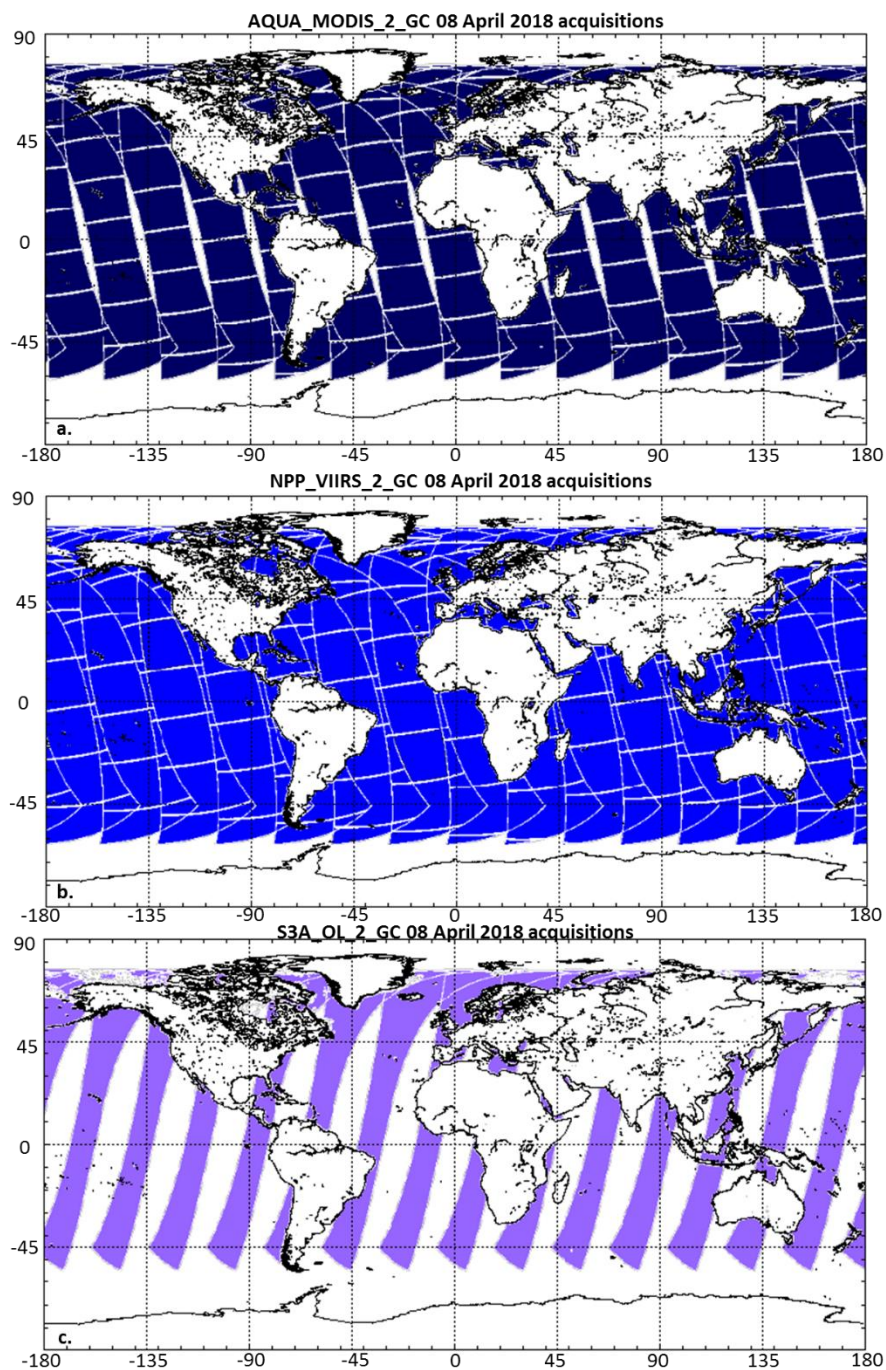


Figure 1: Swath of the different sensors used at present by CMEMS for a) MODIS-Aqua, b) VIIRS-NPP and c) OLCI-S3A. In practice the effective swath coverage is reduced mainly due to clouds or sun glint effects.

[Source: http://octac.acri.fr](http://octac.acri.fr)

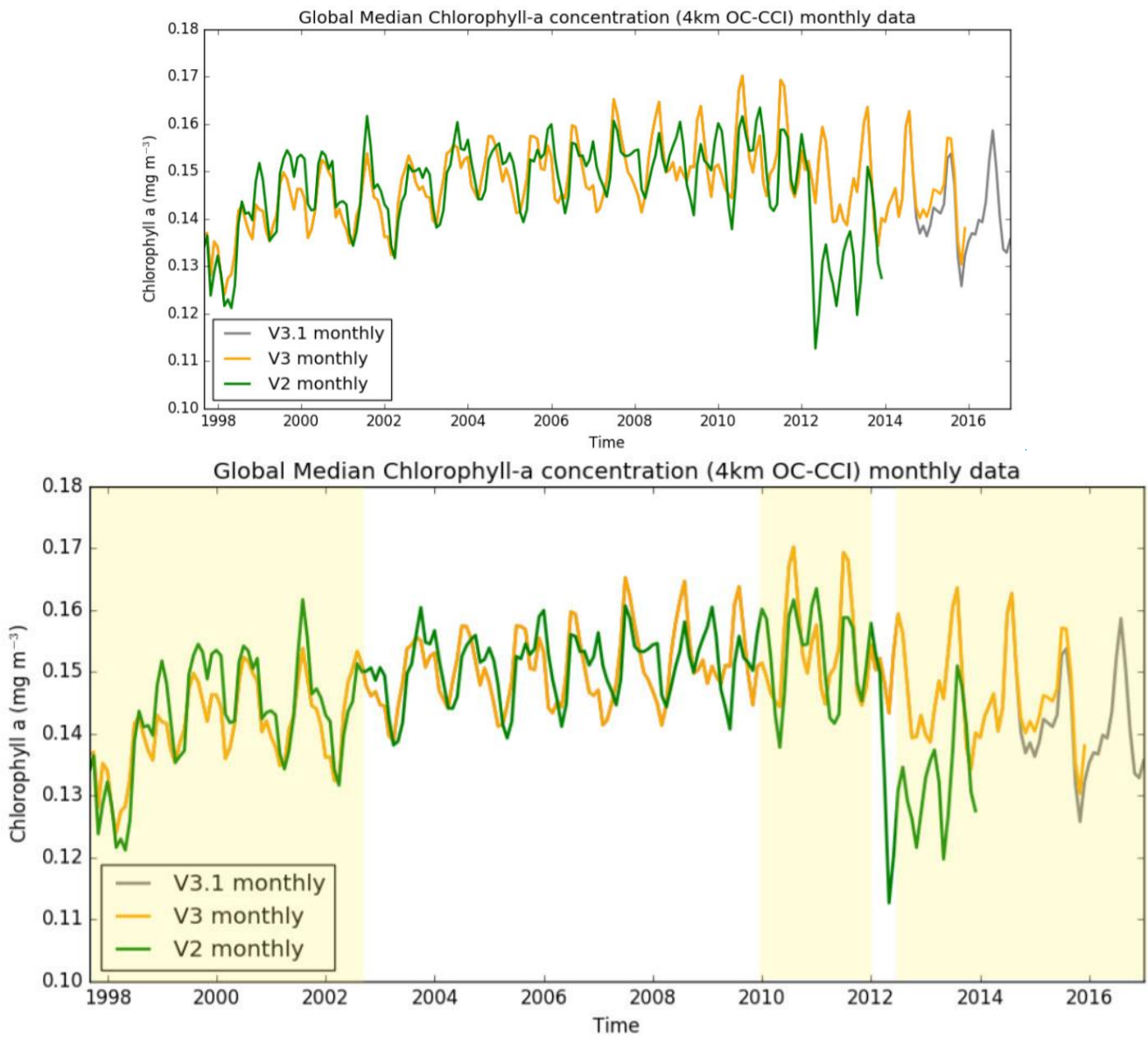


Figure 22: Comparison of the Global Median Chlorophyll-a concentration ~~thought as function of~~ as function of time for v2.0, v3.0 and v3.1 using the monthly composite as input. Source: [CCI Product User Guide](#), release 3.1.0, 24th of April 2017.

Yellow part shows change of sensor combinations (see Table 1).

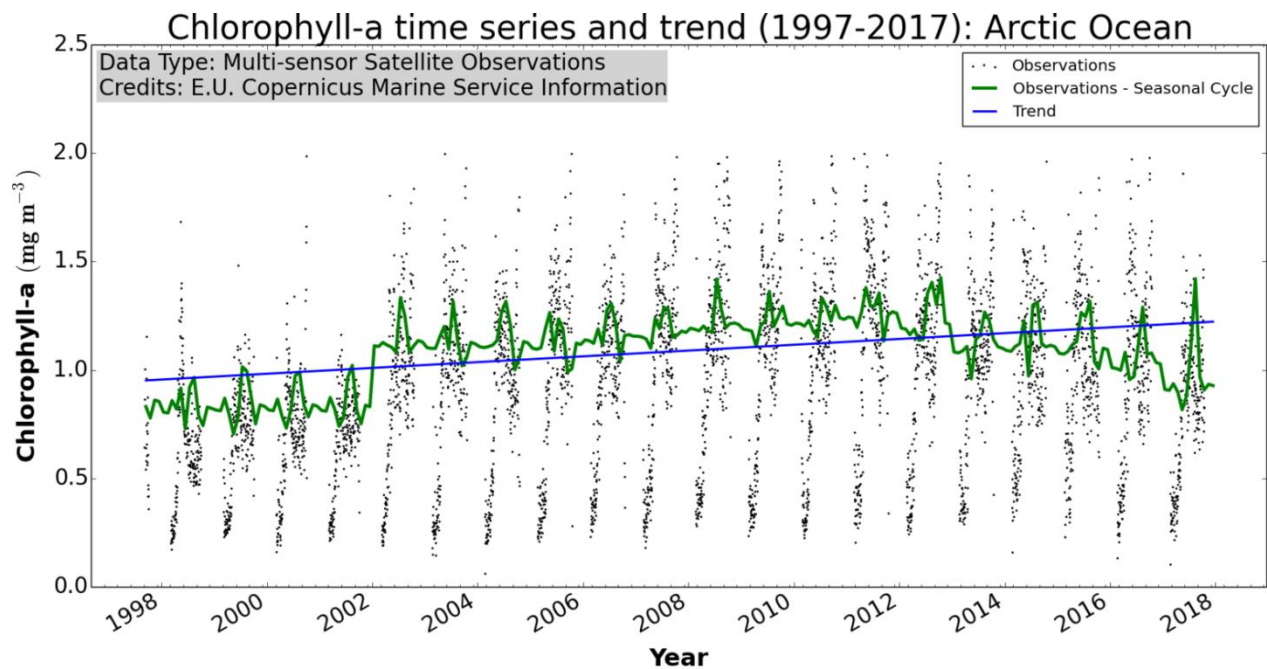


Figure 3 : Arctic time series and trend (1997-2017) from CCI product. The time series are derived from the regional chlorophyll reprocessed (REP) products as distributed by CMEMS which, in turn, results from the application of the regional chlorophyll algorithms over remote sensing reflectances (RRS) 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.

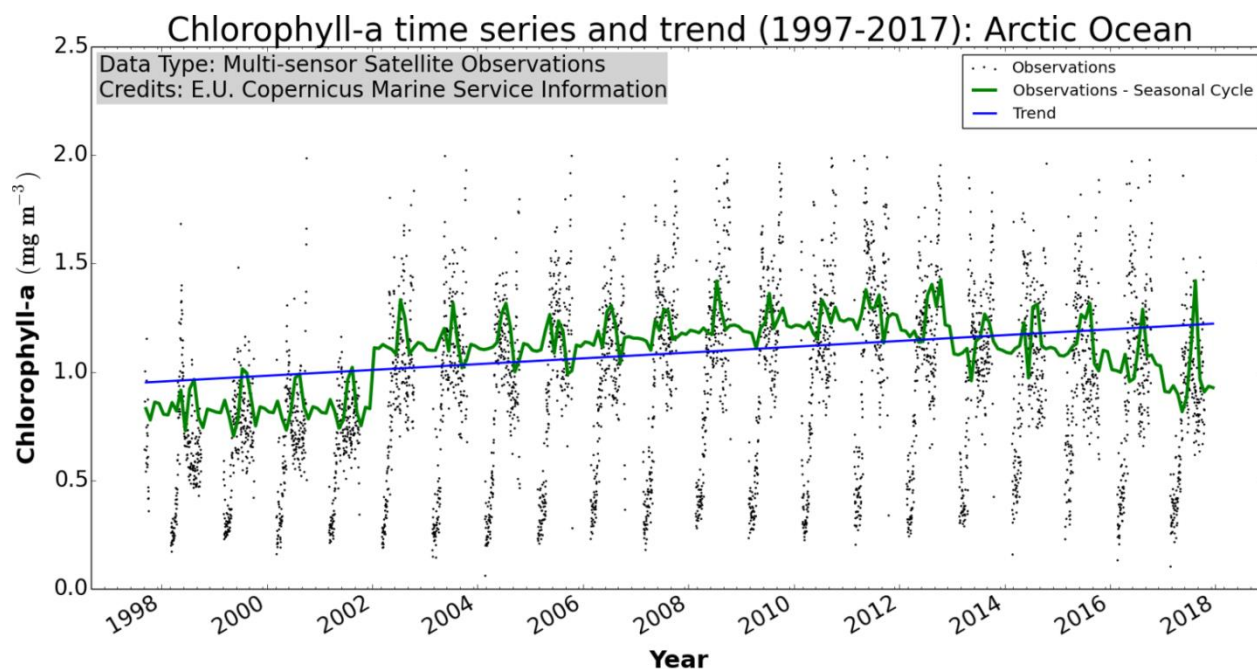


Figure 3 : Arctic time series and trend (1997-2017) from CCI product. The time series are derived from the regional chlorophyll-a reprocessed (REP) products as distributed by CMEMS which, in turn, results from the application of the regional chlorophyll-a algorithms with remote sensing reflectances (RRS) 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 obtain the linear trend. Source: CMEMS QUID.

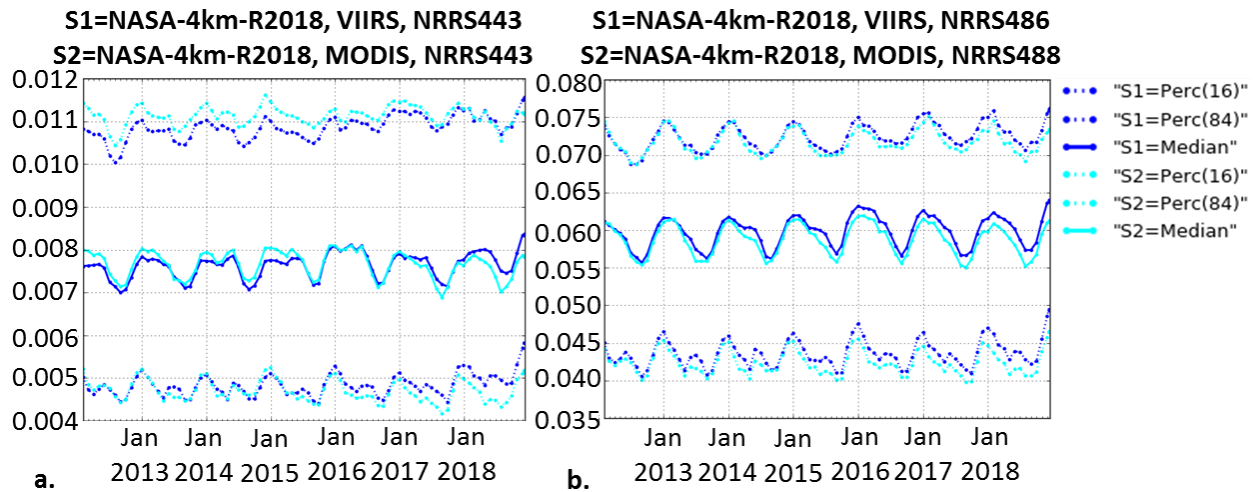


Figure 4: Time series from January 2012 to the 14 December 2018 of monthly median and percentile 16 and 84 of Global MODIS and VIIRS (NASA reprocessing R2018:); a) NRRS443 for both VIIRS and MODIS, and b) NRRS486 and NRRS488, for VIIRS and MODIS, respectively. On both panel, the full line is for the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

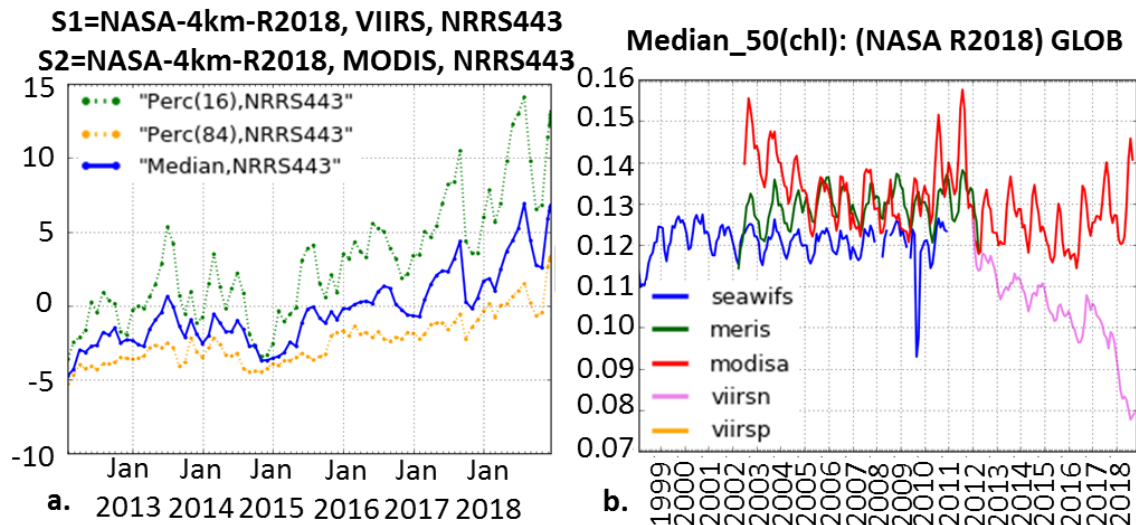


Figure 5: a) relative difference at 443 of VIIRS and MODIS, (in %), b) chlorophyll concentration (mg.m^{-3}) based on the GSM algorithm (median computed for each sensor, based on the GSM monthly NASA R2018 global products at

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>.

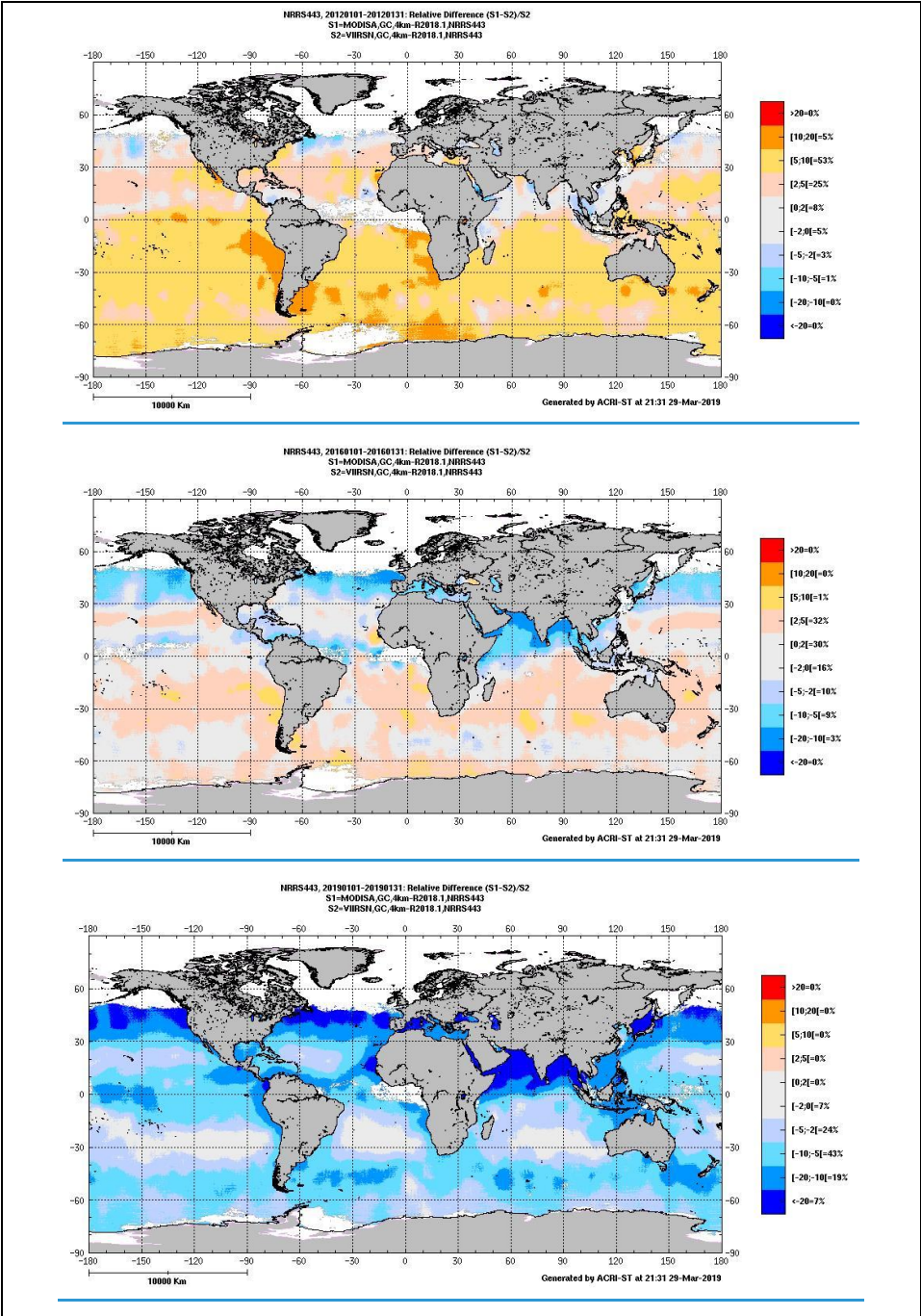
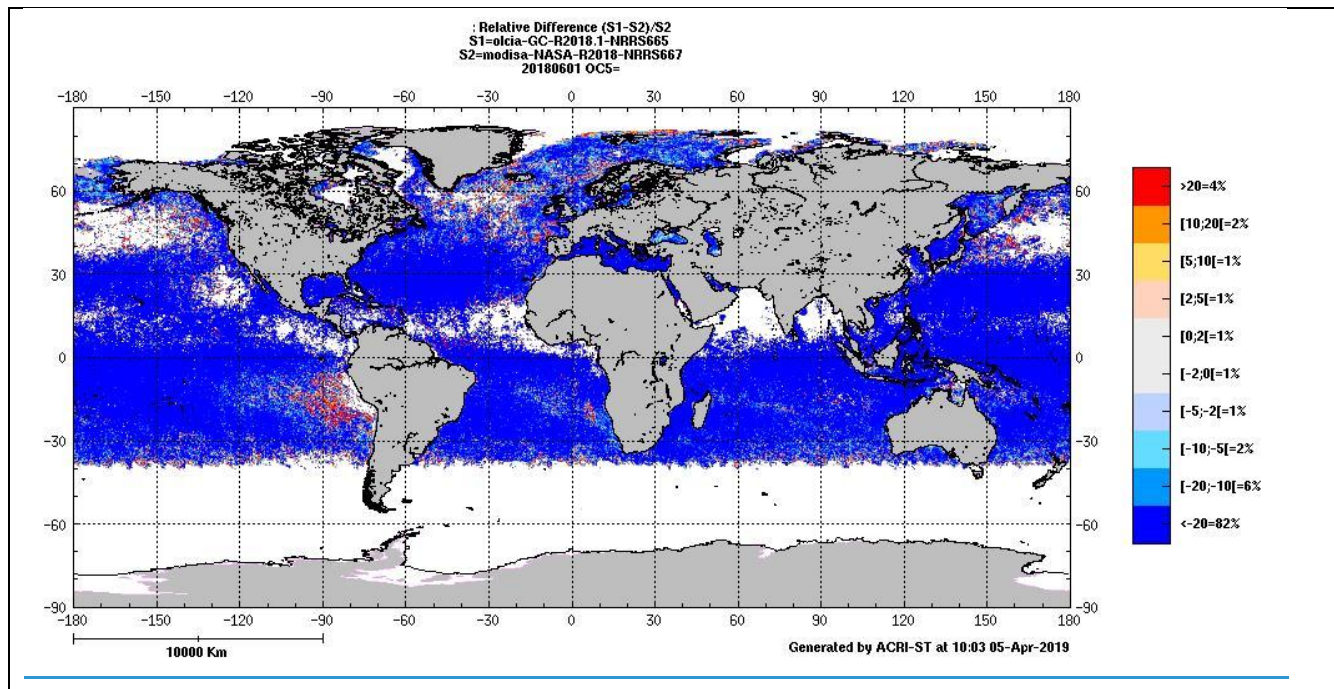
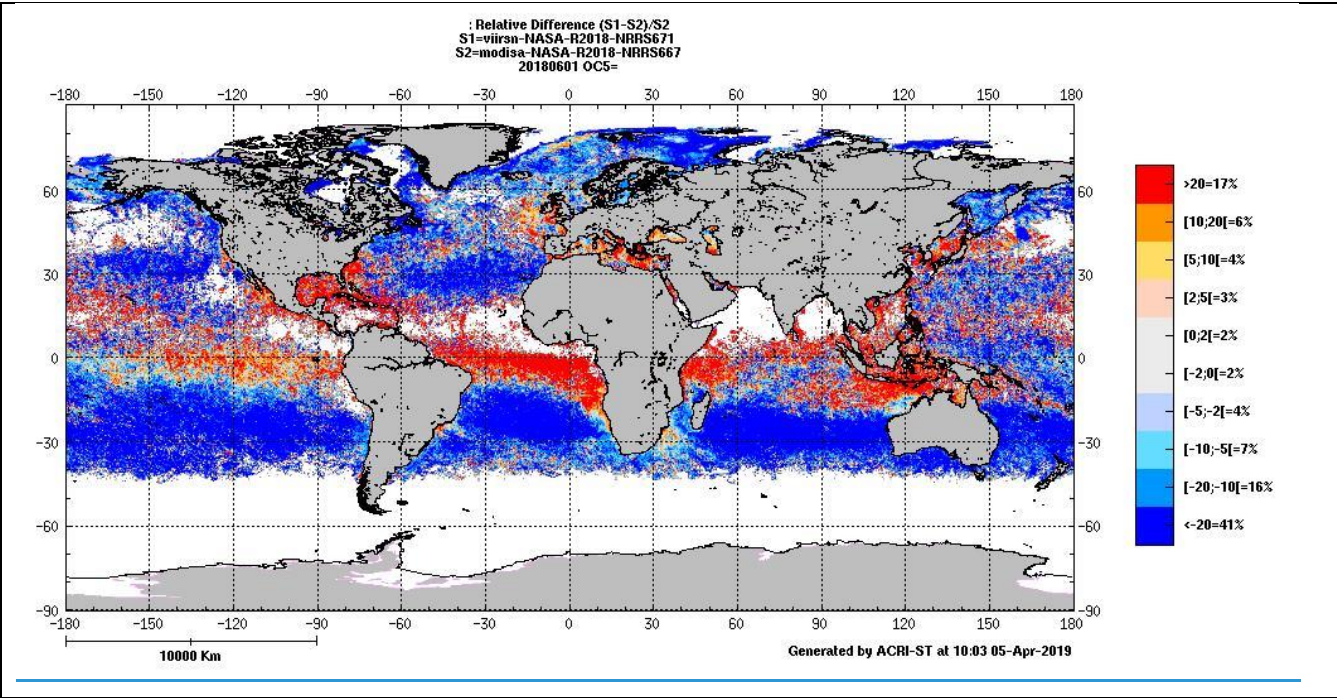


Figure 4: relative difference at RRS443 of VIIRS and MODIS (in %) based on the monthly NASA R2018 global products at 4km). VIIRS suffers from a significant trend since it has been launched as illustrated with January month evolution for years 2012, 2016, 2019.





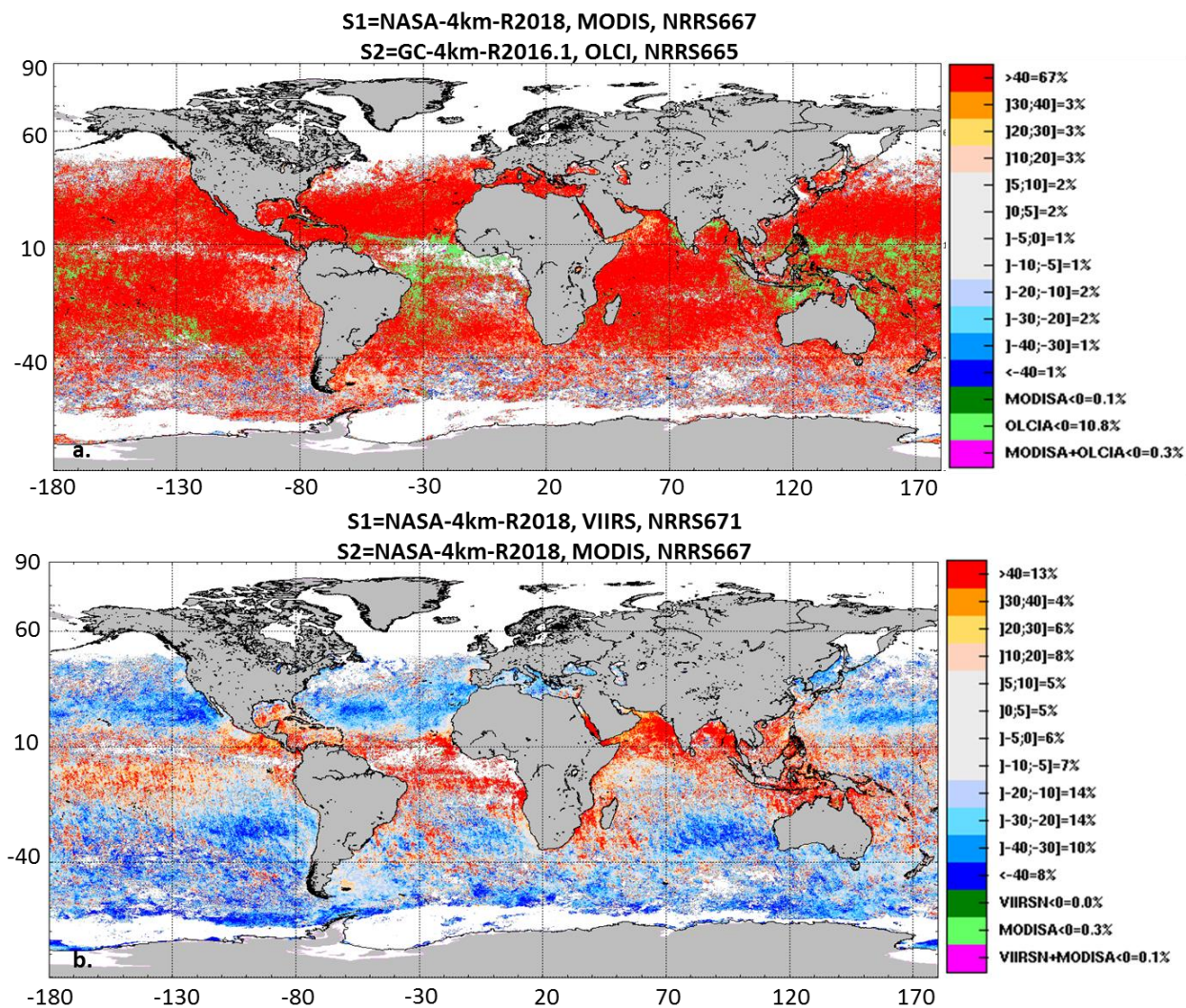


Figure 56: Relative difference between sensors $[(S1-S2)/S2]$ of monthly NRRS (June 2018 ~~11-11/2018-12-10~~), for a) MODIS-NRRS667 and OLCI-NRRS665 and b) VIIRS-NRRS671 and MODIS-NRRS667. Source: these plots are part of the monitoring regularly done by the OCTAC and reported on <http://octac.acri.fr>.

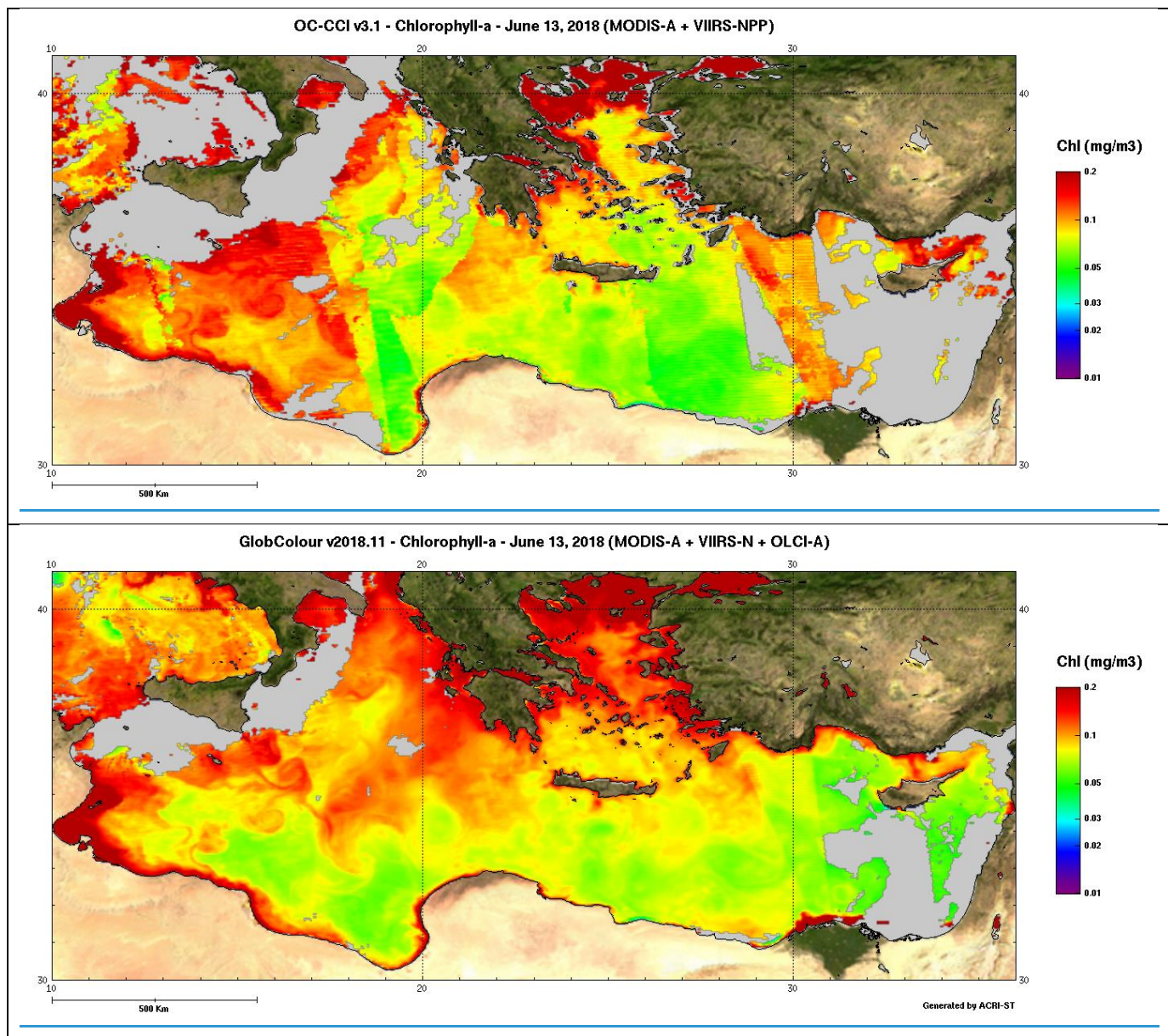


Figure 6: Inter-comparison of GlobColour product and OC-CCI during 2018 for Oligotrophic water (CI/HU algorithm). the color scale has been set to the range 0.01 to 0.2 mg/l: discontinuities between tracks of the sensor clearly appeared on the OC-CCI case at the top.

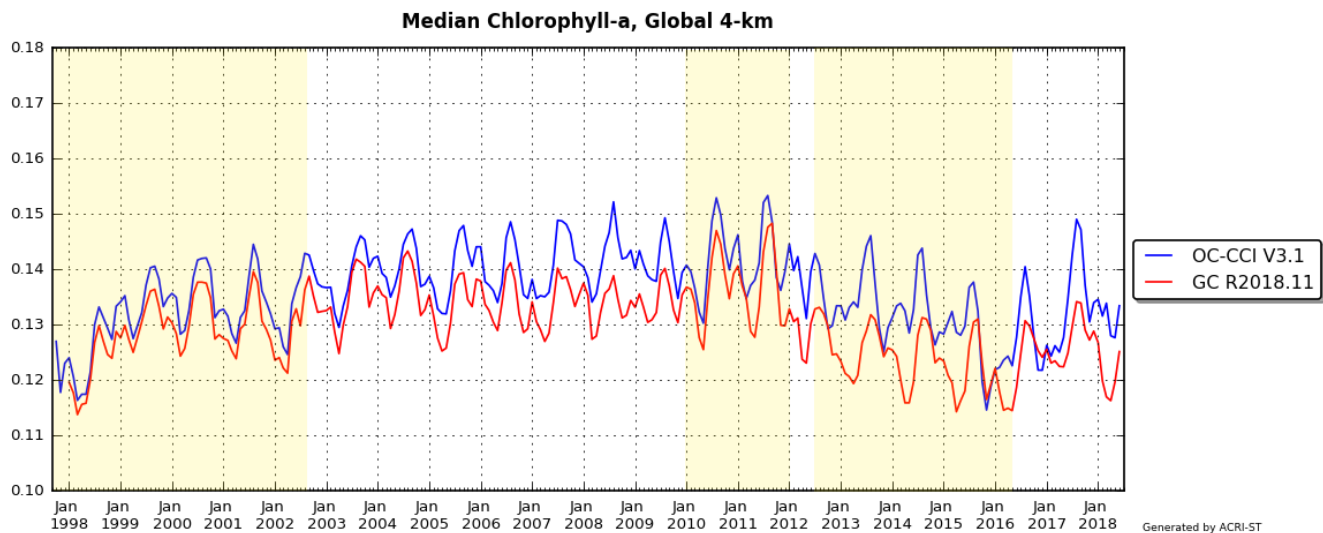
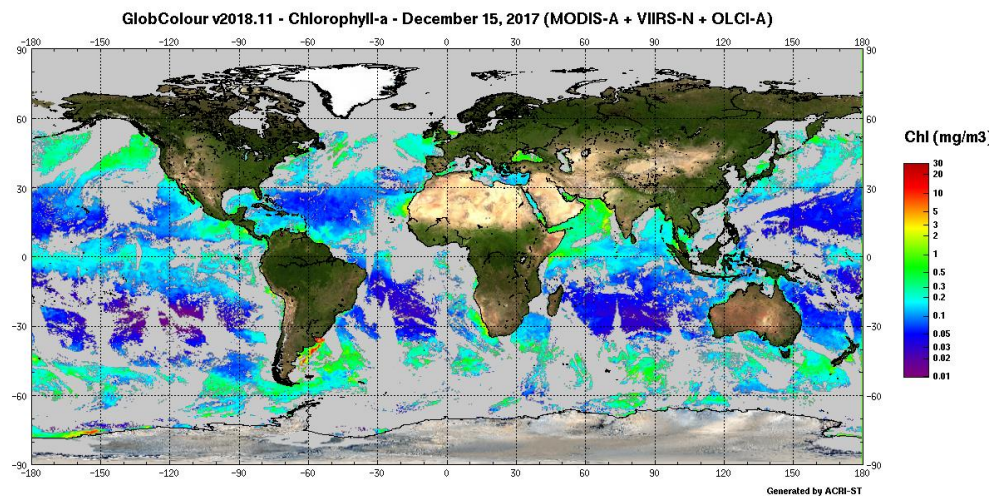
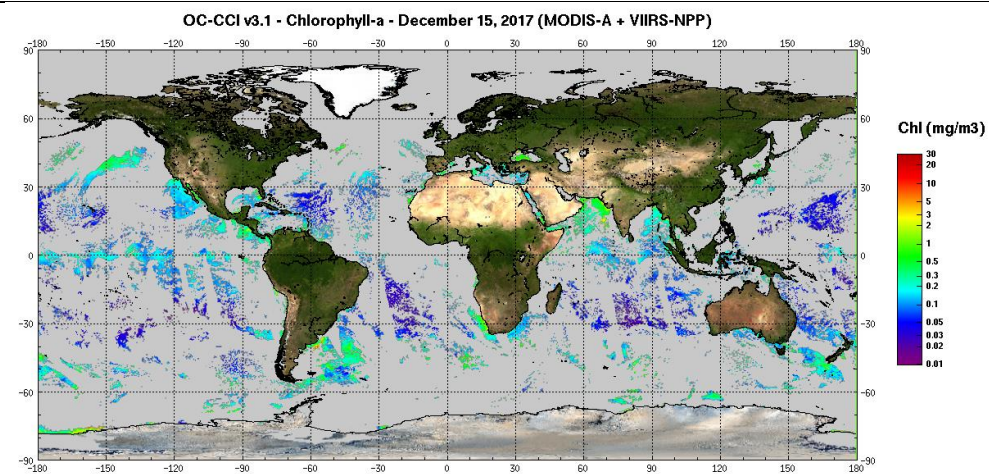


Figure 7: Comparison of the Global Median chlorophyll-a concentration as function of time for CCI v3.1 and GlobColour R2018.11. The discontinuities of the median along the time should be carefully interpreted: it is due to a change of the spatial coverage linked to the sensors used, not due to a chlorophyll-a concentration change. It means potential trends should be only considered when same sensors (see Table 1).

Yellow part shows change of sensor combinations (see Table 1)



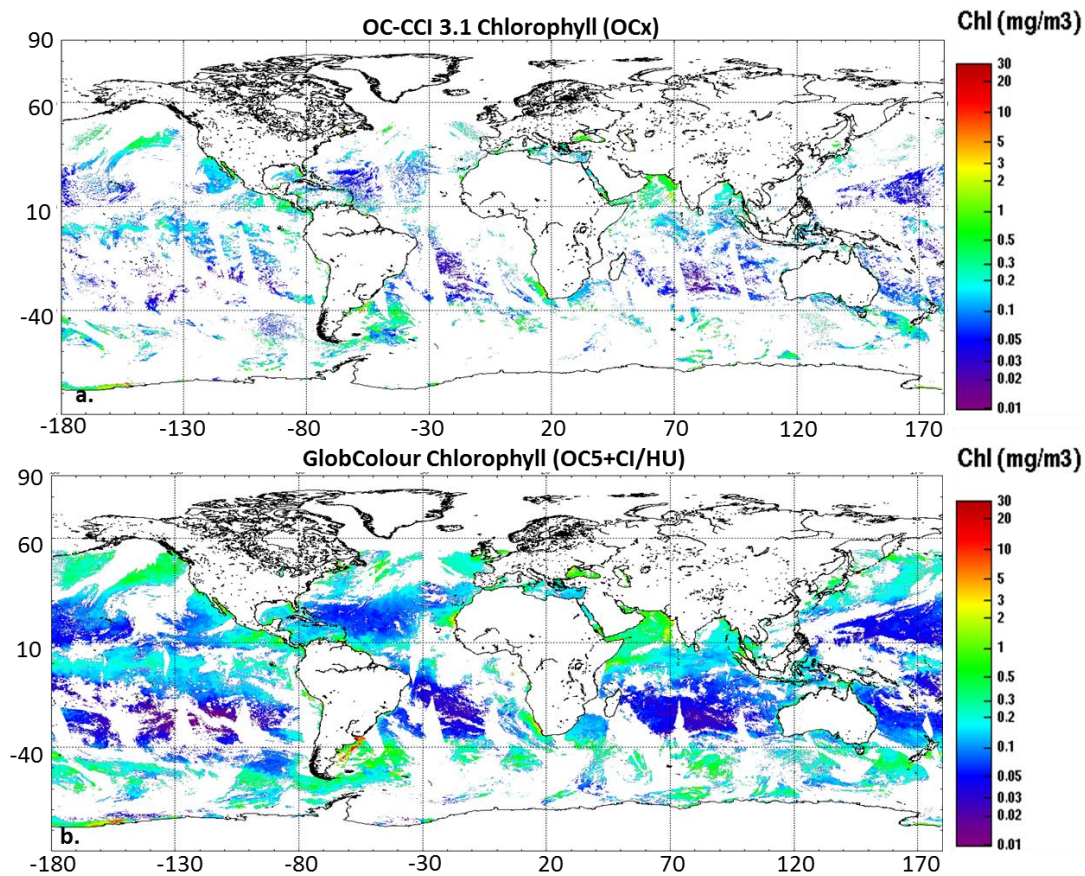


Figure 87: Chlorophyll-a concentration (15 Dec 2017), a) CCI level 3 product and b) GlobColour product. ~~The combination of the usage of OLCI and the flagging strategy permits to improve considerably the coverage without artefact. At this date both products benefits of the last NASA R2018 processing.~~

The two initiatives are using MODIS-A, and VIIRS-SNPP at this date, in complement OLCI-S3A is also used by GlobColour products

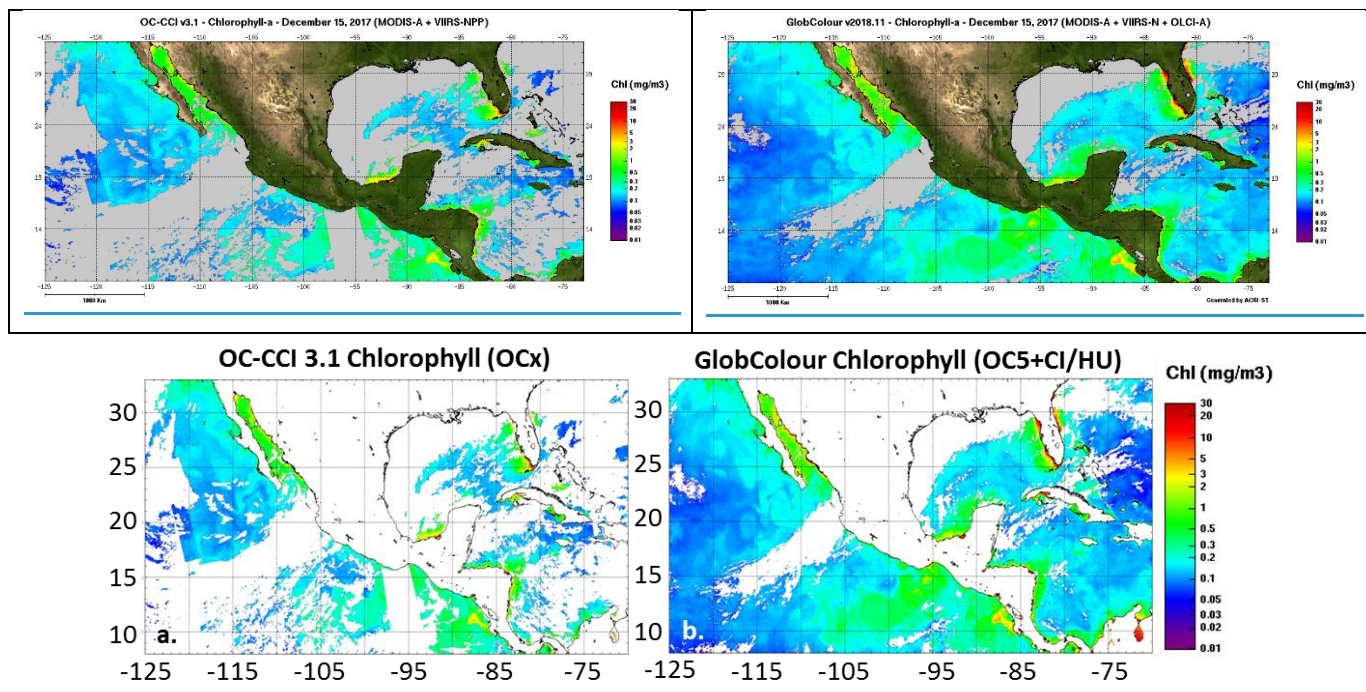
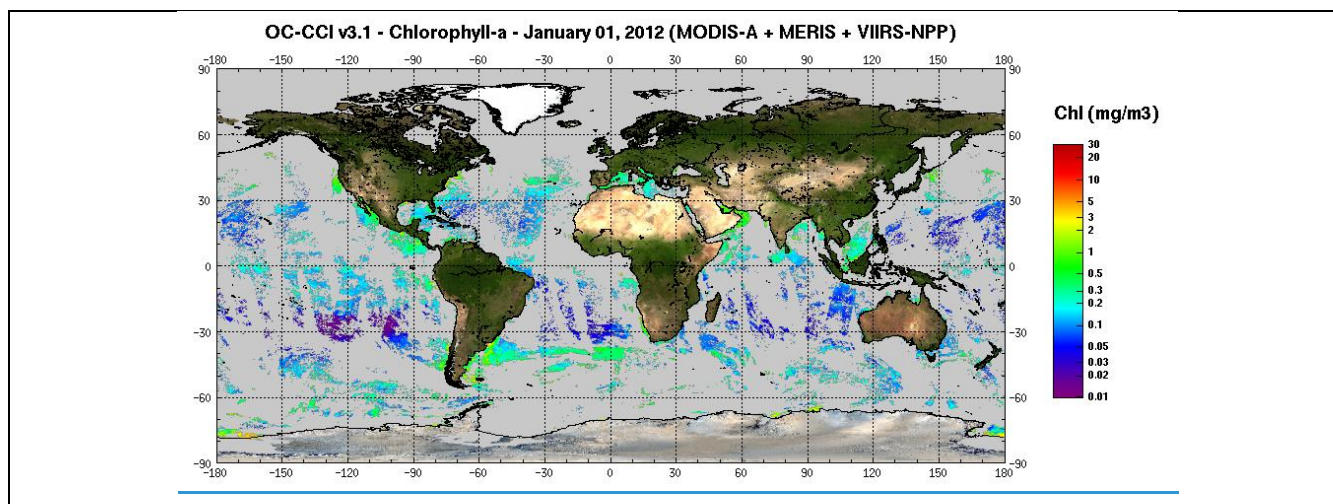


Figure 98: Chlorophyll-a concentration (15 Dec 2017): a) CCI level 3 product, b) GlobColour product.



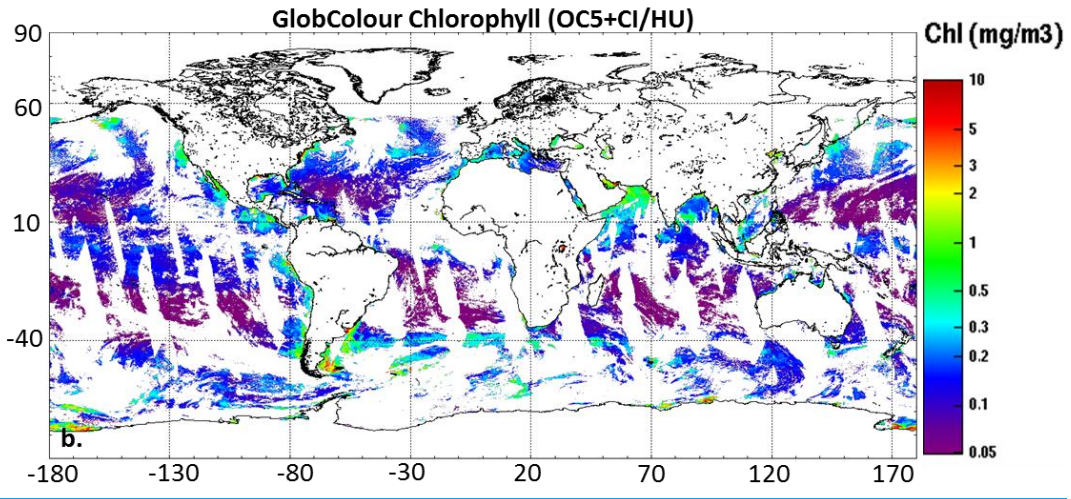
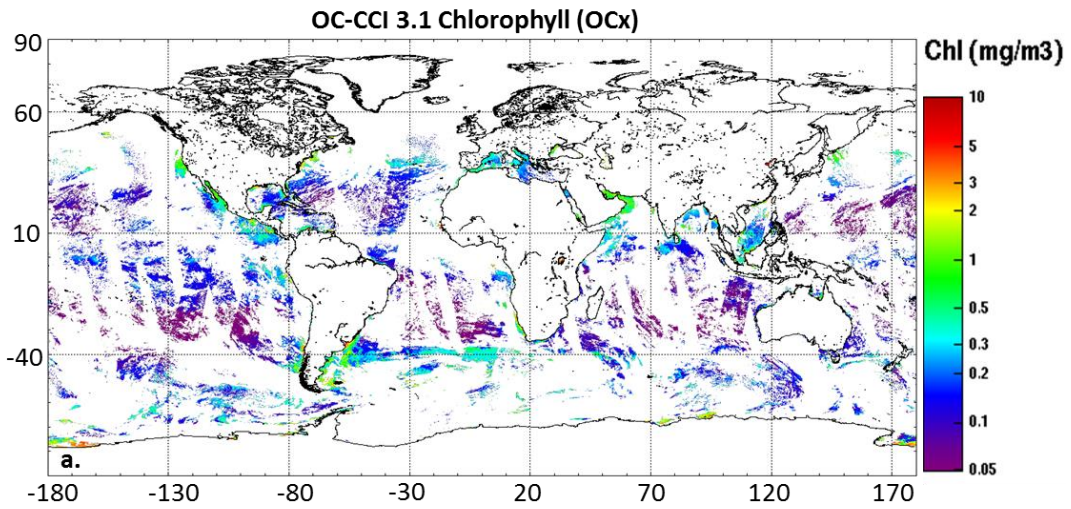
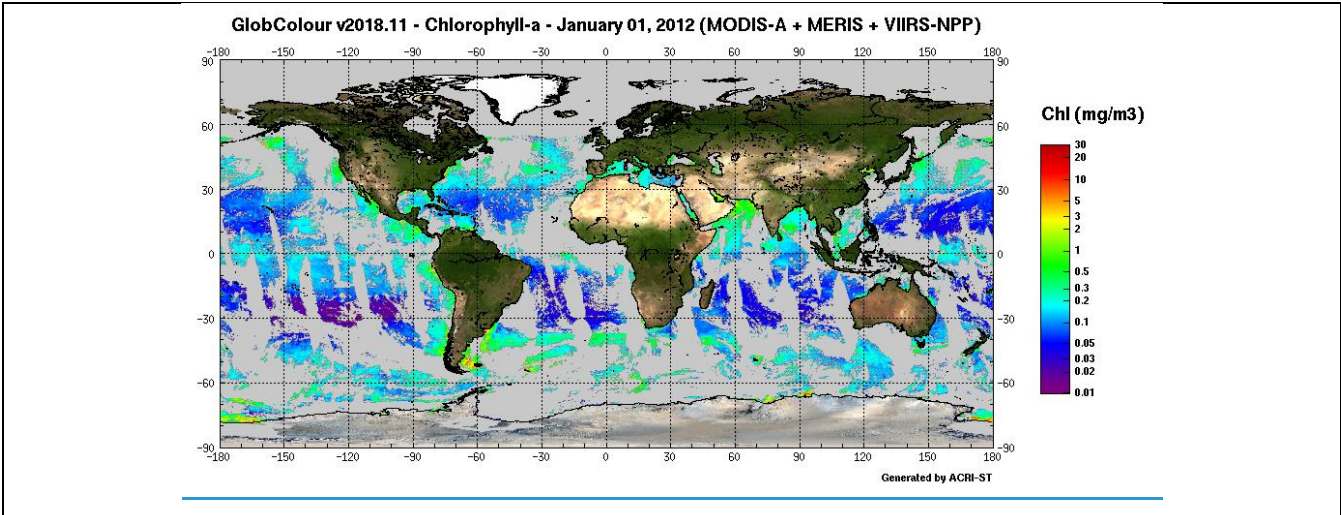


Figure 109: Chlorophyll-a concentration (1 Jan 2012), a) CI level3 product and b) GlobColour product. ~~The flagging strategy permits to improve considerably the coverage without artefact in most of the regions.~~
The two initiatives are using MODIS-A, MERIS and VIIRS-SNPP at this date.

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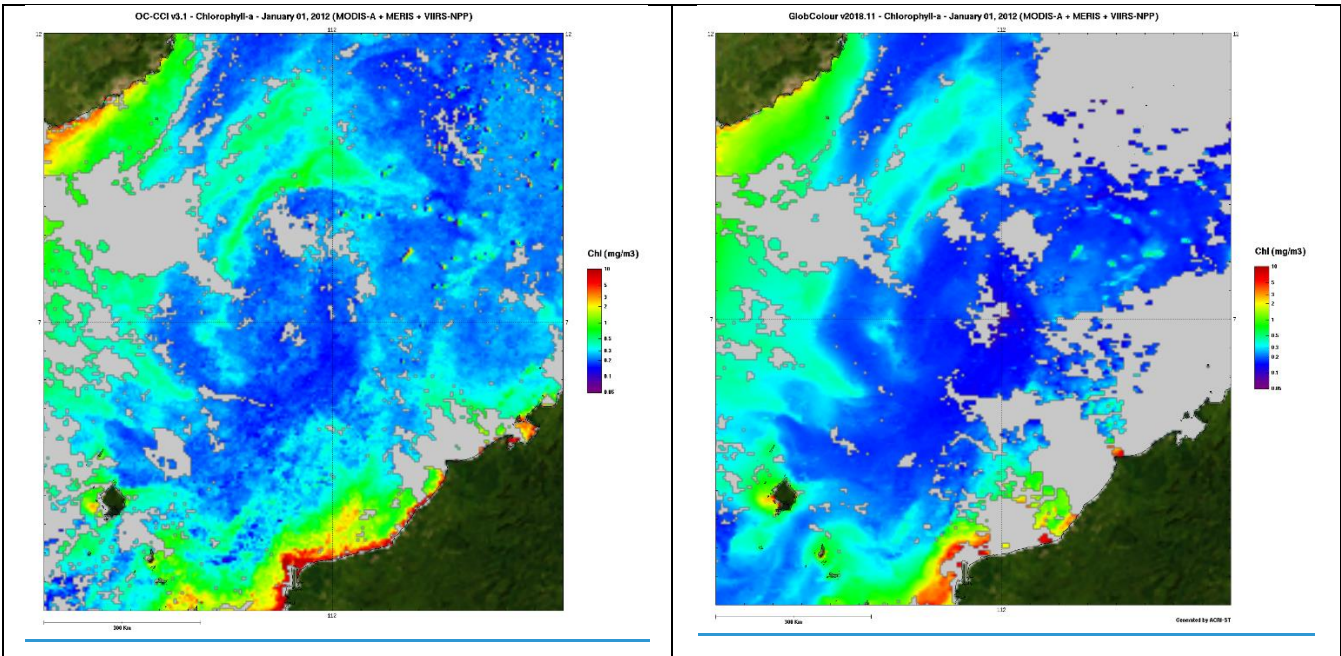
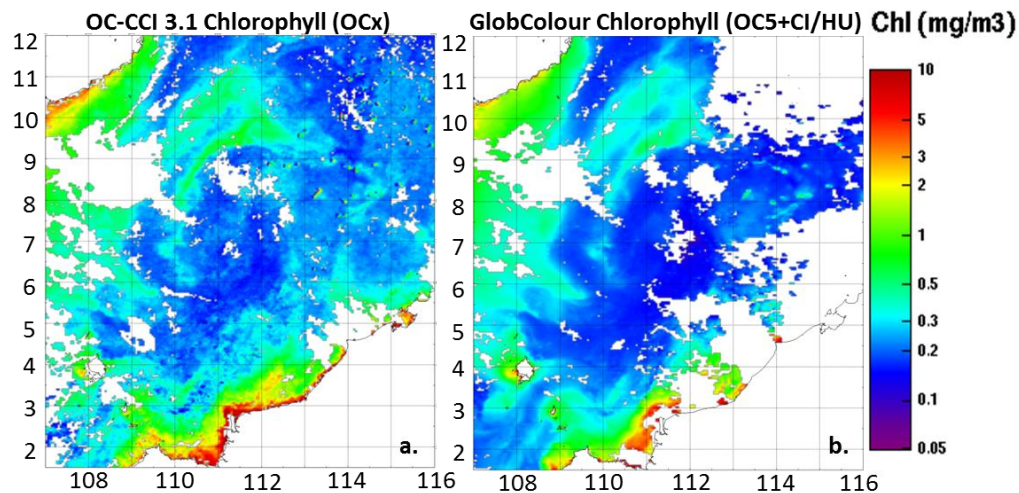


Figure 110: Chlorophyll-a concentration (1 Jan 2012), a) CCI level3 product, b) GlobColour product. ~~The flagging strategy of the CCI product leads here on an important noise, potentially originate from a cloud contamination.~~

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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 SeaWiFS	412,443,490,510,555,670	1 & 4	1502	12:20	1997-2010
MERIS	413,443,490,510,560,620,667,681,709	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,	1.2 & 0.3	1270	10:00	2016-present

	665,674,681,709				
VIIRS- JPPS1/NOAA20	4110,4453,4896,5564,66774	0.754	3040	9:50	Dec-2017- present
OLCI S3B	400,412,442,490,510,560,620, 665,674,681,709	1.2 & 0.3	1270	10:00	2018-present