Two-decade satellite monitoring of surface phytoplankton functional types in the Atlantic Ocean

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Author Comments in response to Referee #2

Review of "Two-decade satellite monitoring of surface phytoplankton functional types in the Atlantic Ocean"

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General comments

Using long-time series of satellite-derived PFT products, Xi et al. investigate the two-decade trends, climatology, phenology, and anomaly of PFT in the whole Atlantic Ocean and its different biogeochemical provinces. Firstly, based on their previous studies (Xi et al., 2020, 2021), the authors obtain PFT Chla products (mainly four phytoplankton groups) using three different sets of ocean color data, covering from 2002 to 2021. Through the independent validation and the inter-comparison of among three sets of ocean color data within overlapping time periods, they then identify the systematic differences caused by different data sources, set up the SeaWiFS/MODIS/MERIS-derived products as reference, and correct the other two PFT datasets, to generate a consistent long-time series PFT products over the last two decades. Finally, the trends and variations of PFTs in the Atlantic Ocean and its biogeochemical provinces are analyzed.

In general, the manuscript is well written and logically organized, with clear purposes and conclusions. The findings of this work provide a preliminary distribution and variation of four PFTs in the Atlantic Ocean, and potential contribution of understanding how these phytoplankton groups respond to climate changes. However, there are some issues to be addressed before it can be considered for publication. Please see below for some major and specific comments.

We thank very much the reviewer for the constructive comments on this manuscript which we have carefully considered in our revision. We would also like to point out that this manuscript was submitted as a contribution to an upcoming Ocean State Report, for which specific requirements in paper length and number of tables/figures have to be followed. The current paper length is just at this limit; therefore, we extended/added the necessary discussion/information in the manuscript as concise as possible, but more details are provided in the individual responses below.

Major comments

1. In this study, when generating the consistent PFT products from different OC data sources, systematic differences among three sources are adjusted based on the relationships between Chla of PFTs derived from each OC data, as shown in section 2.1 and Figure 1. Since the Chla of PFTs are derived from Rrs, i.e., secondary products, why not consider correcting inter-mission bias of the Rrs first, then derive PFTs using the corrected Rrs? In this circumstance, for each of the other two OC datasets, only one correction with respect to Rrs is required, rather than four corrections for different phytoplankton groups. Have you compared the differences of PFT products between these two procedures?

   The reviewer's suggestion is very constructive and that would be a good idea when one could adjust the biases at the very beginning on the input data. However, that normally requires extensive data sets and thorough analyses to support the correction for each available band. In fact, the Rrs products (from merged sensors or OLCI) used for PFT estimation are provided in the frame of the EU funded GlobColour project, which aims for continuous data sets of merged L3 Ocean Colour products (https://www.globcolour.info/). One of the goals of GlobColour is merging outputs from different sensors that ensures data continuity, improves spatial and temporal coverage and reduces data noise. Systematic differences of Rrs from GlobColour have been already adjusted among different sensors after a series of in situ data validation, uncertainty assessment, and different merging approaches (Maritorena et al. 2010). We don't think we could do a better bias correction of the Rrs than the GlobColour team who has put much effort in achieving it. So far, OLCI Rrs data have not been merged to other sensors (e.g., MODIS and VIIRS) yet, but the two OLCI Rrs data sets from Sentinel 3A and 3B have been merged – however, current CMEMS PFT products are still based on S3A OLCI data only.

   There are actually a few reasons that cause the differences of PFTs from different periods: 1) the Rrs data with different bands (Table R1) are used for each period to involve as many bands as possible to improve the PFT estimation performance of the PFT approached based on EOF analysis; 2) PFT estimation models were assessed and finally established based on best algorithm performance separately for the three types of sensor (combinations), in which specific data sets (both in situ and satellite data) within the specific period have been used for model development (examples can be found in Xi et al. 2020 where both merged and OLCI Rrs were used); 3) Model input data for the three sets of sensor(s) are not only different in time, but also different in data size, and geolocations. Promisingly, despite these influencing factors the PFT retrievals from the three sets of data are still highly comparable both in magnitudes and spatial distribution pattern, we therefore would like to take the advantage to explore further the long term PFT observations.

Table R1: Wavebands of satellite sensor (combinations) involved in the PFT estimation approach.

Sensors involved	Center wavebands used in the EOF-PFT approach (nm)															
SeaWiFS/MODIS/MERIS merged[a]		412	443	490	510	531	547		555				670		678	
MODIS/VIIRS merged		412	443	490		531	547	551	555				670		678	
Sentinel 3A OLCI	400	412	443	490	510				555[b]	560	620	665		674		681

[a] SeaWiFS terminated in December 2010, therefore from Jan 2011 to April 2012 only MODIS/MERIS merged data were available.
[b] There is no band at 555 nm for OLCI itself, but the GlobColour Team provides also the 555 nm band through an inter-spectral conversion from 560 nm (details see ACRI-ST GlobColour Team et al., 2017)

2. As mentioned in the discussion, 20-year observation may not be enough for a robust trend analysis. I was wondering why PFT results derived from SeaWiFS between 1997 and 2002 are not included in this study? If they are included, the length could be extended to ~25 years.

   Indeed, if we could include the single SeaWiFS sensor it would be ~25 years observation. The PFT products were however derived based on satellite remote sensing reflectance (Rrs) data at **9 (for merged OC sensors) or 11 (for OLCI sensor) bands in the visible region (400-700 nm)** using the EOF-PFT approach developed in Xi et al. (2020) and a retuned version in Xi et al. (2021); Rrs from single SeaWiFS sensor contains only six bands which were not sufficient to get reliable PFT estimations through EOF trainings. It also the reasoning why for different sensor life times different band combinations were needed to be chosen for the EOF-PFT approach. Therefore, the SeaWiFS-only period (1997-2001) was not included.

3. Some parts of section Data and Method are lack of details, including: (1) the quality control of pigment data from Aiken et al. (2009); (2) diagnostic pigment analysis; (3) the correct functions among different OC data sources; (4) the sources/website of Longhurst's geographic classification system; (5) per-pixel uncertainties of PFT products derived from Rrs data; and (6) the calculation of the anomaly of PFTs for year 2021. Please consider including more details here, such as the description, equations, or detailed information from the references cited here (e.g., the number of equations/figures in previous works).

   We did not describe much in detail some of the points listed by the reviewer due to the strict length limit of such a paper contributed to the upcoming Copernicus Ocean State Report (OSR7) and also due to that the details could be found in the literature cited in the manuscript.

   The quality control procedure (point 1) of pigment data proposed Aiken et al. (2009, Section 2.3 therein) has been widely used by many other peers (Also in Xi et al. 2020, 2021 and reference provided in section 2.2). Therefore, details are not included. We have listed the procedure here in the response only (not in the manuscript): According to Aiken et al. (2009), only pigment data are considered if the following conditions are satisfied: "(a) The difference of TChla and AP (accessary pigments) concentration should be less than 30% of the TPig (total pigment) concentration. (b) Regression between TChla and AP should have a slope within the range 0.7–1.4 and must explain more than 90% of total variance (R^2>0.9). (c) The cruise data were accepted only if the number of samples passing the qualifying criteria were more than 85% of the total observations for a particular cruise". Point 2 regarding the diagnostic pigment analysis (DPA), has been also detailed in both Xi et al. (2020 and 2021) following different updates from previous studies listed in the manuscript (e.g., Vidussi et al., 2001; Brewin et al. 2015, etc.)

Point 3: The correction functions have been added to Figure 1.

Point 4: we have added the reference in the manuscript for the shapefile sources of the Longhurst provinces https://www.marineregions.org/sources.php#longhurst
Reference:
Flanders Marine Institute (2009). Longhurst Provinces. Available online at https://www.marineregions.org/. Consulted on 21 March 2022.

Point 5: A major part of the Xi et al. (2021) publication contributes to the methodology and detailed implementation of the per-pixel uncertainty assessment of PFTs to the satellite PFT products. We apologize for not including much information here in the manuscript due to the length limit. The uncertainty is used rather as hidden supporting information (in inter-mission PFT type II regressions as shown in Figure 1 and as median satellite PFT uncertainty in Table 2), therefore we did not extend it too much. To clarify it briefly in the manuscript, we have added a sentence in section 2.1 when describing the CMEMS PFT products (Lines 109-110): "Sections 2.3 and 3.3 in Xi et al (2021) may be referred to for a detailed description of the per-pixel uncertainty assessment of the PFT products."

Point 6: We briefly added the anomaly calculation in **section 2.3 (Lines 146-147)**: "Anomaly in percentage is determined by computing the relative difference between the PFT state of 2021 and the average state of the last two decades (i.e., climatology)." Also in the caption of updated Figure 6 the definition of anomaly used in this study has been described.

Specific comments

1. Line 89. Swich the order of Table 1 and Table 2. It seems that the Table 2 comes out firstly in the manuscript.

   Thanks for pointing it out. They have been switched.

2. Lines 142-144. This sentence is not clear. Please rewrite it.

   This sentence was rephrased (**Lines 164-165**): "Median percent differences (MDPD) are consistent with the median satellite PFT uncertainties (relative error in %) estimated through Monte Carlo simulation and error propagation analysis in Xi et al. (2021), and for dinoflagellates, notably lower."

3. Lines 174 and 251. A decline of prokaryotes from 2013 onwards are observed in the study. Is there any possibility that the decline is related to the removal of MERIS data

at this time? As argued in van Oostende et al. (2022), MERIS is able to observe more pixels near the coast and at high latitude, where Chla is higher. It may out of the scope of this study, but the coverage variability among different satellite missions should be taken into consideration in analyzing long-time series studies. van Oostende, M., Hieronymi, M., Krasemann, H., Baschek, B., & Röttgers, R. (2022). Correction of inter-mission inconsistencies in merged ocean colour satellite data. Frontiers in Remote Sensing, 3(July), 1–17. https://doi.org/10.3389/frsen.2022.882418

We have considered this possibility as well. However, we assume (added in **Section 4 Lines 308-314**), "the retreat of MERIS in 2012 should not influence very much on the prokaryote data set for the following reasoning: firstly, such a decline was not found in other PFTs; secondly, MERIS observed more pixels in the coast and high latitude, we however focus on the open ocean and have excluded the coastal regions with bathymetry <200 m, and this study covers the Atlantic Ocean between 50°N to 50°S. The main reason might be the relatively lower retrieval accuracy of prokaryotes compared to other PFTs as discussed above on the validation. Our previous work showed that all of the retrieval models for the three sets of sensor(s) have poorer performance for prokaryotic phytoplankton than for other PFT retrievals, this may cause weaker consistency of prokaryotes for the two decade period even after inter-mission correction."

We also strongly agree with the reviewer that it is worthwhile considering the coverage variability among different satellite missions when we look at the time series on the global scales and different waters, therefore we have added this statement in the discussion (**Section 4 Lines 314-316**): "Nevertheless, coverage variability among different satellite missions should be taken into consideration in analyzing long-time series studies as the ability of the sensors to observe certain waters may differ (van Oostende et al. 2022)."

4. Line 177. Slight increasing trend of haptophytes on the…

   Revised as suggested.

5. Figure 1. Since the SeaWiFS/MODIS/MERIS mission is used as the reference and the MODIS/VIIRS (or OLCI) is corrected to SeaWiFS/MODIS/MERIS, the x-axis should be MODIS/VIIRS and the y-axis should be SeaWiFS/MODIS/MERIS? Also, the equations should be changed accordingly.

   Thanks for the careful checking. Indeed MODIS/VIIRS is corrected to SeaWiFS/MODIS/MERIS, the calculations made in the manuscript are all correct. To avoid confusion, we have switched the x and y-axis and updated the equations as suggested in the revised Figure 1.

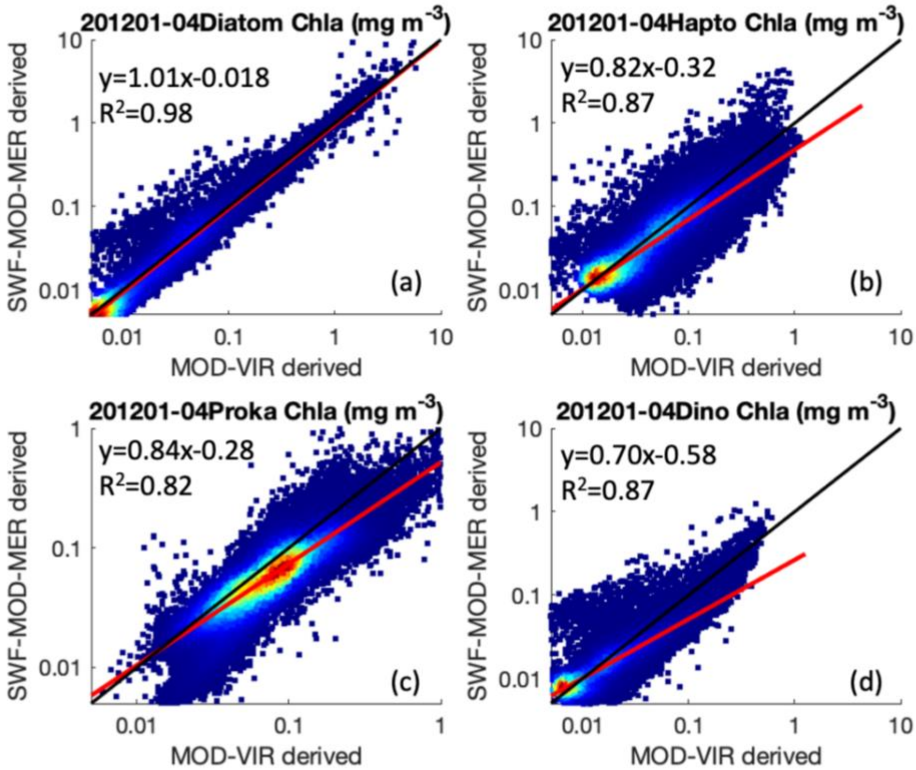

Figure 1: Scatterplots of monthly PFTs derived from SeaWiFS/MODIS/MERIS merged and MODIS/VIIRS merged Rrs data for the overlapping period January-April 2012. (a) diatoms, (b) haptophytes, (c) prokaryotes, and (d) dinoflagellates. The 1:1 line is shown in black and the linear regression line (using type II regression with per-pixel uncertainty) in red. R^2, slopes and offsets determined in log-10 scale are also presented.

6. Figure 3. Please change the colormap of the figures (c)-(f) here. It is not clear whether the white color in the figures represents the slope very close to 0 but significant ($p<0.05$) or the slope not significant ($p>0.05$).

   Thanks for the comment. The color palette we used was with the white color in the middle to indicate zero change, however the reviewer was right that it could cause the confusion that it is difficult to differentiate between the areas with significant small changes ($p<0.05$) and the areas with $p>0.05$. Another reviewer also suggested to use a different color palette. In response to the comments from both reviewers, we have now updated the maps also with a colorblind friendly colormap in the revised manuscript (Figure 3c-f).

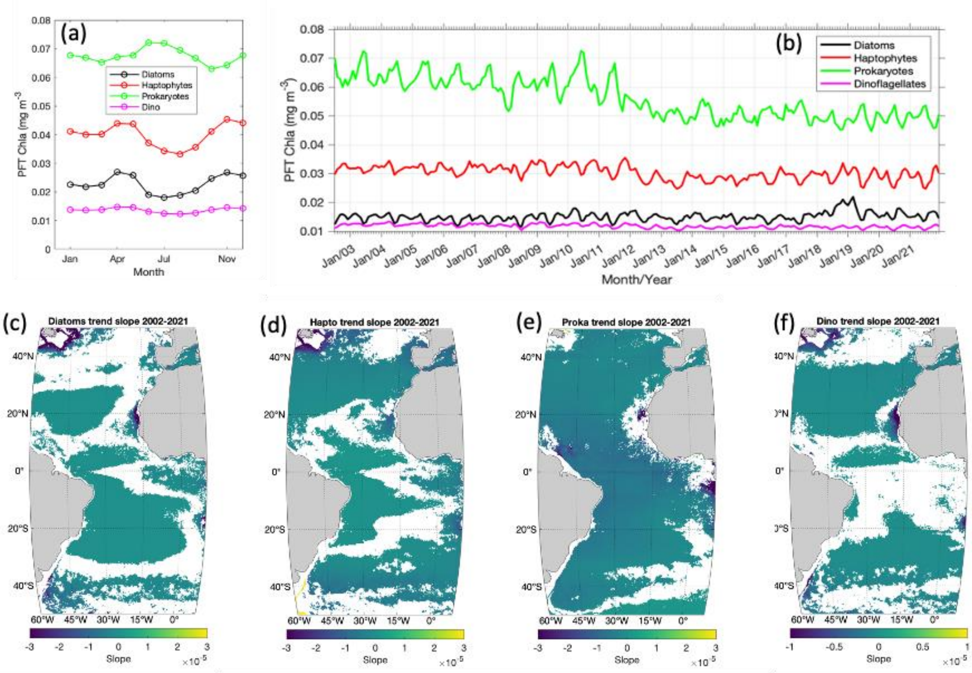

Figure 3: (a) Annual cycle of the four PFTs of diatoms, haptophytes, prokaryotes and dinoflagellates in the Atlantic Ocean (-50°S to 50°N, 60°W to 10°E), (b) 20-year time series from 2002 to 2021, and (c) per-pixel slope based on monthly Chla products of diatoms, (d) haptophytes, (e) prokaryotes and (f) dinoflagellates from 2002 to 2021 (where p<0.05 were shown, slope unit: Chla mg m^{-3} $month^{-1}$).

7. Figure 4. Consider changing the limits of y-axis for some provinces, such as the NATR, WTRA. Maybe it is worth adding the trend line in these time-series plots if there is a significant trend?

   Limits in y-axis for a few provinces were adjusted in Figure 4. Trendlines with slopes and correlation coefficients are also shown in the time series plots for provinces with significant trends (p<0.05). These trends in different provinces correspond well to the descriptions in the results.

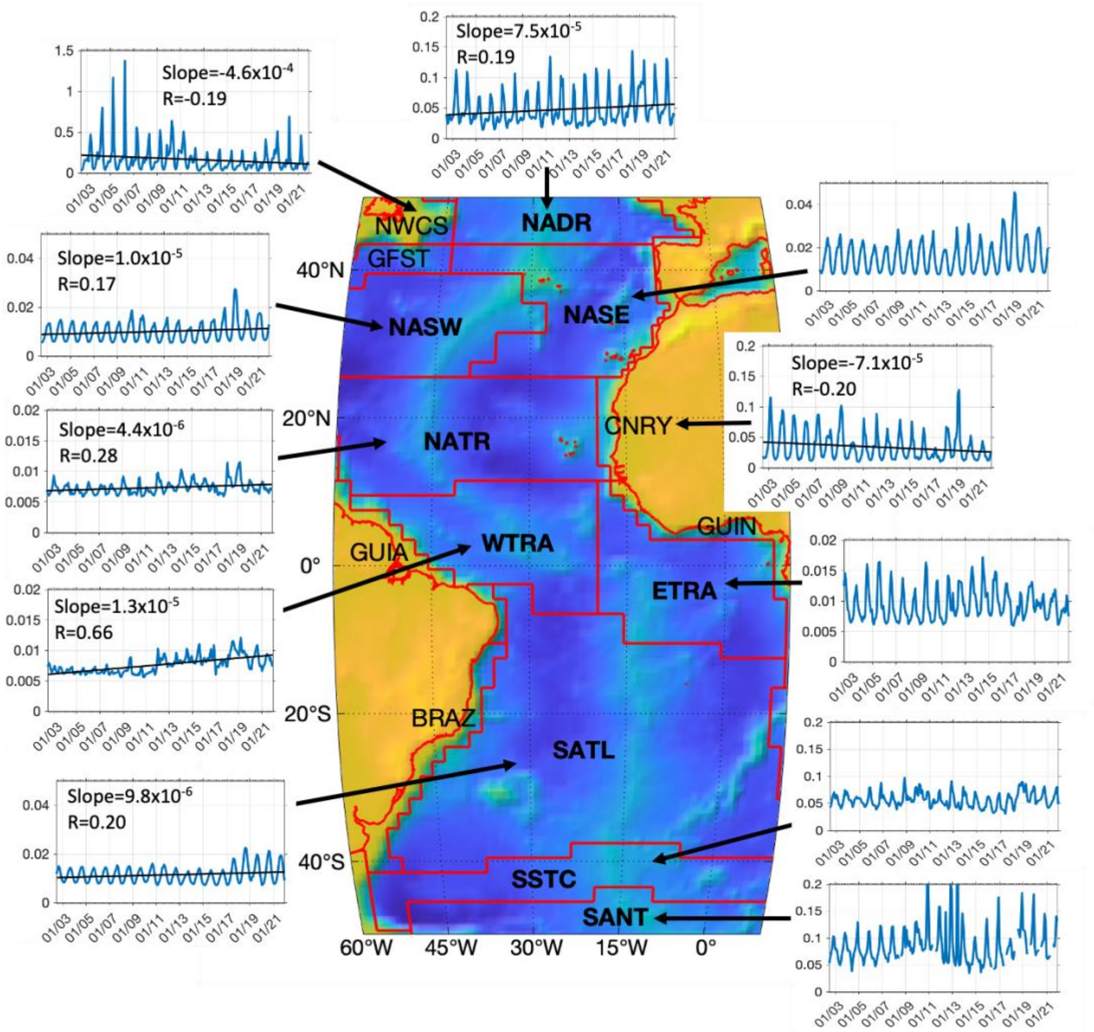

Figure 4: Time series of diatom Chla (unit: mg m^{-3}) in 11 Longhurst provinces in the Atlantic Ocean with bathymetric information based on ETOPO1 bathymetry (Amante & Eakins, 2009). Provinces according to Longhurst (2007) are: NADR for North Atlantic Drift Province, NWCS for Northwest Atlantic Shelves Province, NASW for North Atlantic Subtropical Gyral Province (West), NASE for North Atlantic Subtropical Gyral Province (East), NATR for North Atlantic Tropical Gyral Province, CNRY for Canary Current Coastal Province, WTRA for Western Tropical Atlantic Province, ETRA for Eastern Tropical Atlantic Province, SATL for South Atlantic Gyral Province, SSTC for South Subtropical Convergence Province, SANT for Subantarctic Water Ring Province, respectively. Trendlines with slopes (unit: Chla mg m^{-3} month^{-1}) and correlation coefficients are shown for provinces with significant trends ($p<0.05$).

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