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

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Author Comments in response to Referee #3

RC3: 'Comment on sp-2022-6', Sorin Constantin
As general comments, I would say that this study is well written, tackles an important subject and would definitely be of interest to a large audience. I have only minor suggestions that will hopefully help the authors to clarify some details, especially in the methodology section.

We thank very much the reviewer for the positive feedback and comments on this study. We have considered carefully the suggestions to improve the manuscript. 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.

Line 48: "Bracher et al., 2022" cannot be found in the final reference list. Either it's missing from there, or it should be 2020 instead of 2022 in the text.

Thanks for pointing out the missing reference (listed below). We have added it in the reference list.

Bracher, A., Brewin, R.J.W., Ciotti, A.M., Clementson, L.A., Hirata, T., Kostadinov, T., Mouw, C.B., & Organelli, E., (2022). Applications of satellite remote sensing technology to the analysis of phytoplankton community structure on large scales. In L.A. Clementson, R.S. Eriksen, & A. Willis (Eds.), Advances in Phytoplankton Ecology, pp. 217-244. Elsevier. doi: 10.1016/B978-0-12-822861-6.00015-7

L89: Why Table 2 and not Table 1, since it's the first one to be mentioned? Also, the CMEMS product mentioned here (OCEANCOLOUR_GLO_CHL_L4_REP_OBSERVATIONS_009_082) seems to be no longer available in the catalogue. I assume there were some changes and the new product containing these datasets is OCEANCOLOUR_GLO_BGC_L4_MY_009_104. Can you please verify?

We have now switched Table 1 and Table 2 to be in the right order.

We apologize for the unavailability of the data sets. In the last months there was an upgrade from CMEMS and the naming of many products was affected. Indeed, the new product is OCEANCOLOUR_GLO_BGC_L4_MY_009_104. We have updated Table 1 with the correct product name and links.

L123: "Time series analysis is done both, per-pixel […]" – not sure if the comma is needed here.

The comma was removed.

Section 3.1 – since you are showing scatterplots of monthly PFTs derived from SeaWiFS/MODIS/MERIS merged and MODIS/VIIRS merged Rrs data (figure 1), I think it might be useful (and more consistent, I would add) to show also such scatterplots between corrected MODIS/VIIRS and Sentinel 3A (as you mention in lines 133-134).

Thanks for the comment. This point was also raised by Reviewer 1. Due to length limit of such a report contribution, we did not include similar plots in the first manuscript. We have now added more information about the correction on the OLCI derived PFTs **(Lines 155-161)**: "The same is applied to the Sentinel 3A OLCI derived PFTs by comparing them to the corrected MODIS/VIIRS derived PFTs for the overlapped period April – December 2016, so that all PFT data from both MODIS/VIIRS and OLCI are now referenced to SeaWiFS/MODIS/MERIS derived PFTs. Though R^2 is slightly weaker (R^2 from 0.77 to 0.83) compared to that from the MODIS/VIIRS versus SeaWiFS/MODIS/MERIS derived PFTs (R^2 from 0.82 to 0.98), OLCI derived PFTs still showed overall good correlations to the corrected MODIS/VIIRS data with regression slopes between 0.83 and 1.03 despite that prokaryote Chla retrievals from OLCI data are in general higher."

Figure R2 shows scatterplots and regression relationships between the two products, however due to the paper length limit we decided not to include the figure in the revised manuscript.

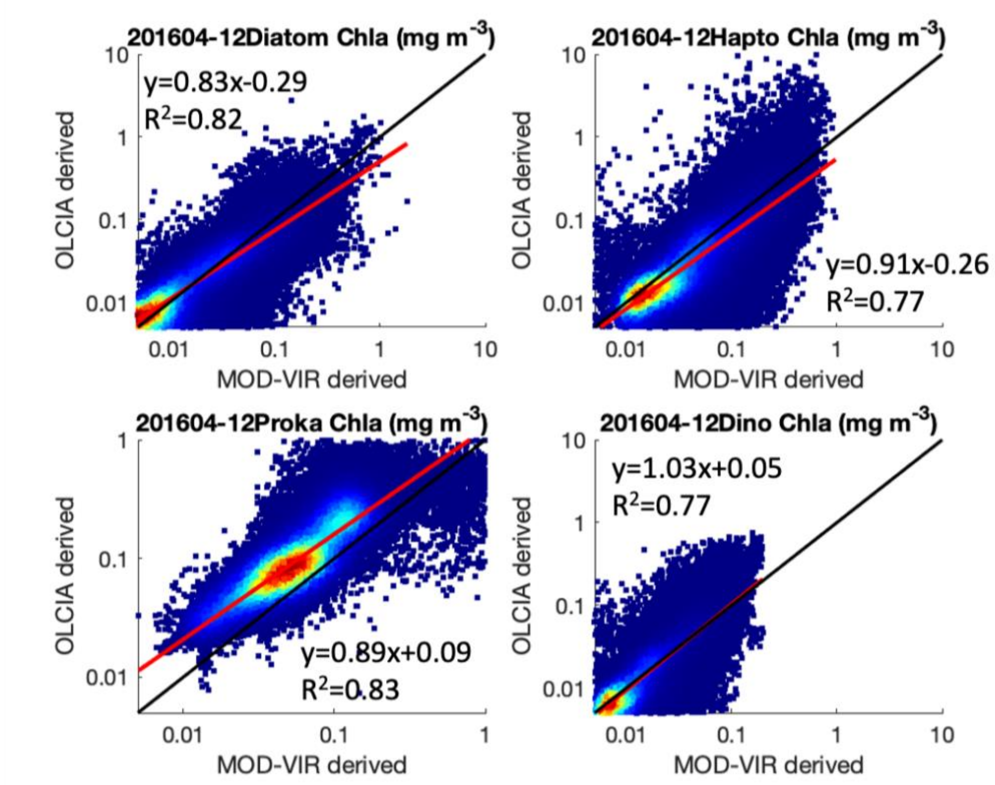

Figure R2: Scatterplots of monthly PFTs derived from OLCI Rrs and corrected MODIS/VIIRS merged Rrs data for the overlapping period April – December 2016. The 1:1 line is shown in black and the linear regression line (using type II regression with per-pixel uncertainty) in red. R^2, slopes and offsets determined in log-10 scale are also presented.

L137: I think it can be useful if you briefly explain what this "match-up criterion" is about. For more details readers can always go to the cited publication, but couple of words would make things clearer. Also, can you specify the time range for these match-ups (e.g. "match-ups corresponding to years 2015 and 2016")?

Brief sentences have been added to the text about the matchup extraction criterion (**Lines 126-129**): "For each in situ measurement a matchup of 3×3 pixels around the in situ location on the same day was extracted. Averaged data based on 3×3 pixels were computed following the matchup protocol as in Xi et al. (2020, 2021), including only matchups containing at least 50% of the valid pixels with a coefficient of variation (CV) of the valid pixel values lower than 0.15."

The time range of these matchups is from 2009 to 2019, which is the spanning period of our in situ data set described in **section 2.2** (**Lines 119-122**): "To evaluate the satellite PFT products, we use in situ HPLC pigment data from past expeditions between 2009 and 2019 covering the whole Atlantic polar to polar region (65°S to 80°N) which included nine expeditions from the North Atlantic to the Arctic Fram Strait (PS74, PSS76, PS78, PS80, PSS85, PS93, PSS99, PS106, PS107, PS121) and four expeditions in the trans-Atlantic Ocean (PS113, PS120, AMT28 and AMT29)."

L139-140: “Slope is always below one indicating that satellite retrievals show overestimation in low concentrations but underestimation in high concentrations.” - A slope below one does not, by itself, infer information on both under and overestimation. The value of the intercept is required, as well. So, it might be useful if you insert these values into current Table 1 or you show the distribution of points as scatterplots. Also, it is not completely clear if the slopes are computed taking into consideration the in situ derived PFT as a function of satellite PFT and not vice-versa. I assume the first option is true, but is not completely clear.

During the “under-review” stage we have obtained more in situ PFT data for the validation also with a more thorough matchup extraction, therefore, we have been able to extend the matchup data set and update the statistics in Table 2. The new validation is much more reliable and statistics has become overall better. We have added Figure R2 in this response document to show the scatterplots between the inter-sensor corrected satellite PFTs versus the in situ PFT data. This figure is not included in the revised manuscript as Table 2 summarizes adequately the statistics. It is also indicated in the caption of Table 2 that the statistical parameters are computed based on satellite derived PFT Chla (after inter-mission correction) as a function of in situ PFT Chla using least square fit.

The discussion regarding the validation statistics has also been updated in Section 3.1 and the Discussion (Section 4).

Section 3.1 Lines 162-168: “Validation was carried out by comparing the collocated satellite PFTs with the in situ PFTs using the extracted matchup data. Statistical results of the validation in Table 2 show in general acceptable agreement between the in situ and satellite derived PFTs. Median percent differences (MDPD) are consistent with the median satellite PFT uncertainties (relative error in %) estimated through Monte Carlo simulation and error propagation in Xi et al. (2021), and for dinoflagellates, notably lower. Higher MDPD is found for prokaryotes due to a systematic overestimation of the picophytoplankton in the retrieval algorithms for all the three sets of satellite OC sensors, however, no significant bias of satellite prokaryote products is detected between different sensors, therefore the overestimation should have minor influence on the time series data of prokaryotes.”

Section 4 Lines 279-287: “Validation using in situ data shows no significant biases of PFTs derived from different sensors, indicating that the inter-mission offset was effectively corrected. Chla of different PFTs are more upscaled retrievals compared to bulk satellite OC products such as total chlorophyll a, coloured dissolved organic matter (CDOM) and absorption properties. Especially, it is still challenging to retrieve accurately prokaryotic phytoplankton because in the open ocean these are dominating in the low Chla areas for which the satellite signals are weaker. Therefore, higher uncertainties exist in these products (e.g., Brewin et al. 2017; Losa et al. 2017; Xi et al. 2021) as compared to uncertainties for other PFTs (see Table 2). In summary, our statistical results of PFT validation are comparable to the evaluations of satellite PFT products derived from different approaches, according to the Quality Information Documents (QUID) that have been published on CMEMS (Garnesson et al., 2022; Pardo et al., 2022).”

Lines 530-535

Table 2: Statistical validation results of satellite derived PFT Chla (after inter-mission correction) as a function of in situ PFT Chla using least square fit in logarithmic scale. N: number of matchups; R: Pearson correlation coefficient; MDPD: median percent difference; RMSD: root-mean-square difference; definition equations of these terms were referred to Xi et al. 2020. Note that Slope, Intercept and R were calculated based on logarithmic scale. Median uncertainties calculated based on satellite per-pixel PFT uncertainty (equivalent to relative error in %) are also shown in the last column.

	N	Slope	Intercept	R	MDPD (%)	RMSD (mg m^{-3})	Median satellite PFT uncertainty (%)
Diatoms	192	0.71	-0.27	0.87	60.5	0.30	57.3
Haptophytes	191	0.95	-0.007	0.64	58.9	0.18	41.5
Prokaryotes	187	0.71	0.12	0.60	185	0.06	86.5
Dinoflagellates	144	1.07	0.04	0.81	59.1	0.07	74.3

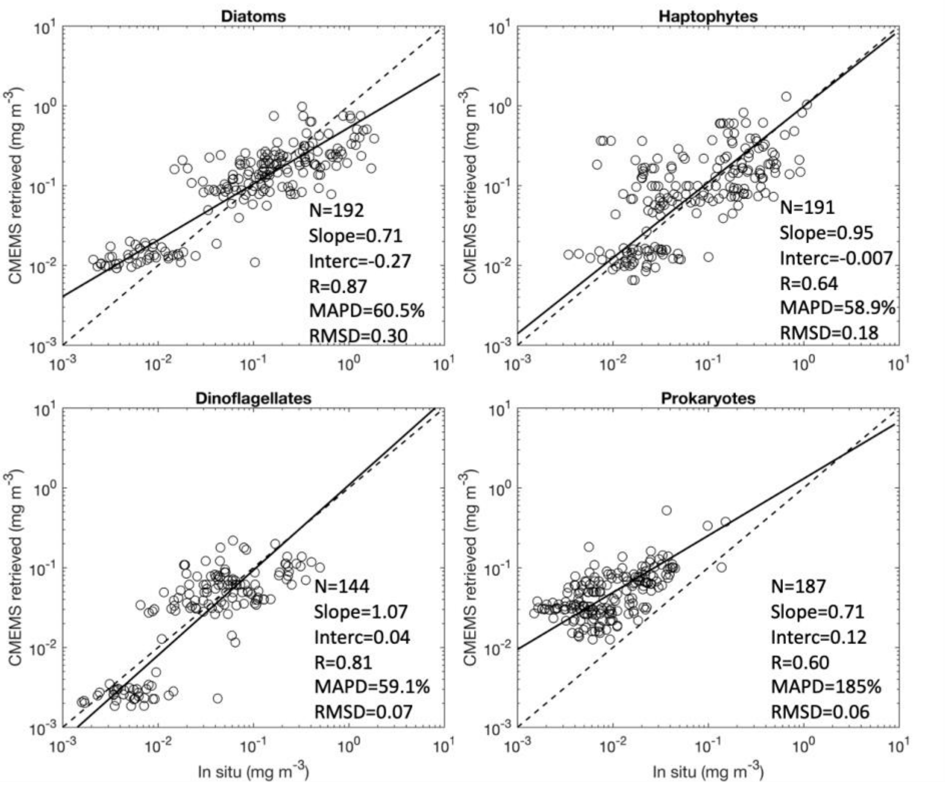

Figure R2: Scatterplots of the satellite derived PFT Chla after inter-mission correction versus in situ PFT Chla.

L143: "[…] are consistent with, the median satellite […]" – probably the comma is not required.

It was removed.

L180: "Per-pixel time series in Fig. 3c shows that significant increase is found only in the west coast of Africa (CNRY)" – shouldn't it be decrease?

We apologize for the typo. The reviewer was correct that it should be "...significant decrease is found…". We have modified it in the text.

L222: "Dinoflagellates show a stable state in 2021 among the four PFTs with only a very slight increase of Chla in the north Atlantic Ocean." - To what extent this observed stable state is due to the overall low Chla concentration of dinoflagellates? The PFT anomalies shown in figure 6 are given using mg m-3 as units. Would the same stable state be observed if the anomalies are shown as percentages, for example?

Thanks for the constructive comment. Indeed, the anomaly could be further normalized by the climatology to enhance the visibility of small absolute changes. Therefore we have redefined the anomaly **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)." Figure 6 has been modified with the maps of anomaly in percentage. This has altered some detailed patterns as small absolute changes especially in the gyres are now magnified, hence, Section 3.4 regarding the description of the anomaly has been updated correspondingly, and dinoflagellates still showed a relative stable state.

Accordingly, this was updated in **Section 3.4 Lines 249-260**: "Anomalies in percentage of the four PFTs in 2021 compared to the average state of the last two decades are shown in Fig. 6. Diatom anomaly presents changes mainly in high latitudes, gyres and some coastal regions (such as CNRY). The anomaly shows mostly lower diatom Chla in high latitudes except for NWCS and the southeastern part of NADR where diatom Chla is increased. Opposed to that, diatom Chla of 2021 in the gyres is generally higher (~ 30%) compared to the 20-year average state. Note that changes are shown in percentage instead of the absolute values to enhance the visibility of small absolute changes, which in the gyres can be very sensitive, as diatom Chla is extremely low there (< 0.01 mg m^{-3}). Haptophyte anomaly presents changes in similar regions with diatoms but reversely in high latitudes, especially in the Southern Ocean, where a more prominent increase and also larger coverage are observed. Increase of haptophytes in the area north of the equator in WTRA is more significant than diatoms. Different from diatoms and haptophytes, prokaryotes reveal a very slight decrease in 2021 mostly in low latitudes within 20°N-20°S, with higher prokaryote Chla in the west coast of Africa especially CNRY, whereas only mild increase (< 20%) is found in high latitudes. Dinoflagellates show the most stable state in 2021 among the four PFTs with only a slight increase of Chla in the north Atlantic Ocean above 40°N and a small decrease in CNRY."

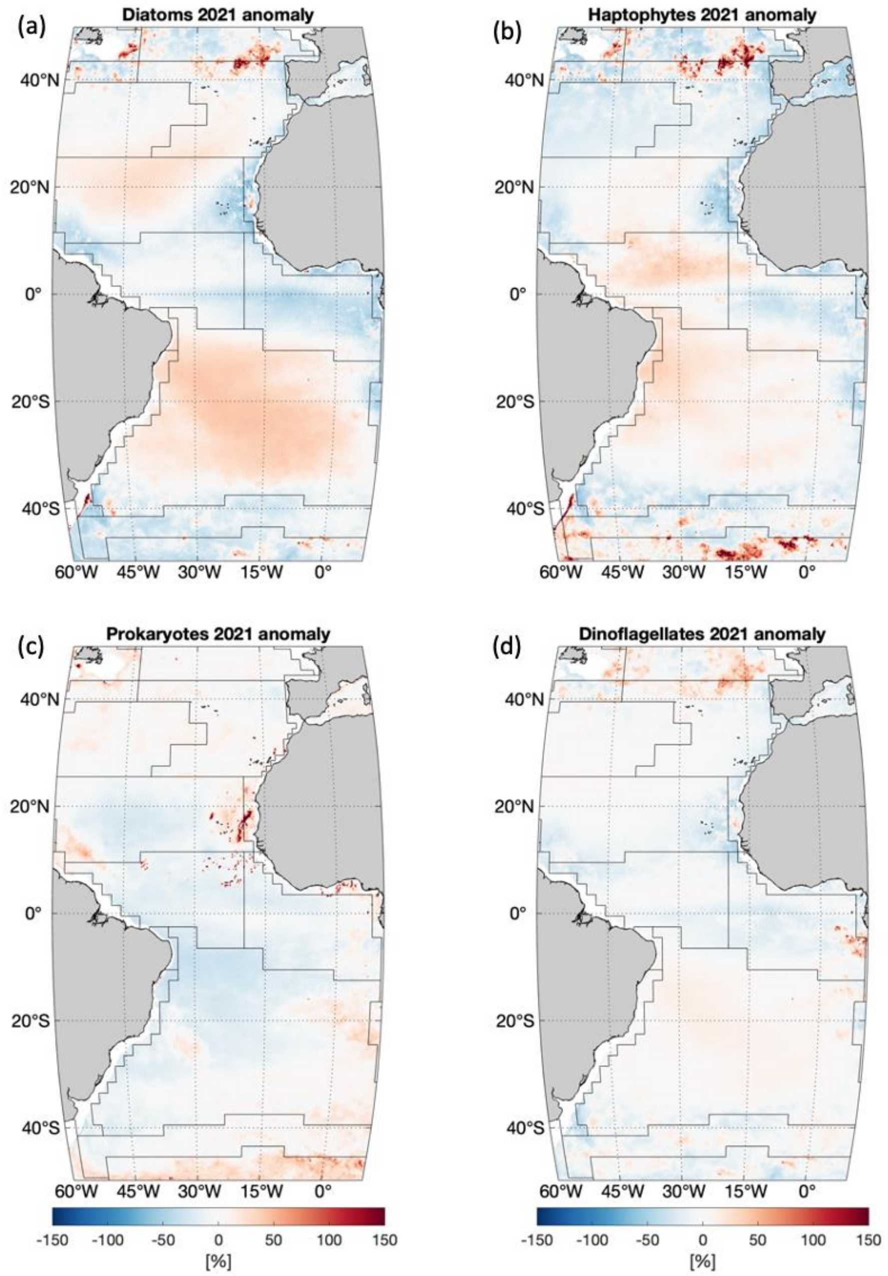

Figure 6: PFT anomaly in percentage [%] of 2021 compared to the 20-year mean for (a) diatoms, (b) haptophytes, (c) prokaryotes and (d) dinoflagellates. Anomaly in percentage is defined as (PFT_{2021} – climatology)/climatology*100. Black lines indicate boundaries of Longhurst provinces as in Fig. 4.

Fig. 3 c-f: did you try a different colour palette? One that would allow to spot even the smaller changes? Maybe you could try a version where the interval is set to [-3; 3] instead of [-5; 5]. Just an idea.

The color palette we used was with the white color in the middle to indicate zero change, however it could also cause the confusion as pointed out by another reviewer, that it is difficult to differentiate between the areas with significant small changes ($p<0.05$) and the areas with $p>0.05$. In response to both related comments from two reviewers, we have now used a different color palette in the revised manuscript.

It actually does not make much difference using a narrower interval such as [-3; 3] instead of [-5; 5] because the bigger changes (with the slope such as ~4 x10^{-5}) in coastal areas are an order of 2 higher in magnitude than those very small changes (such as ~3 x10^{-7} only) mainly in the mid- to low latitudes. We have slightly adjusted the interval for different PFTs with the updated color palette (Figure 3 c-f).

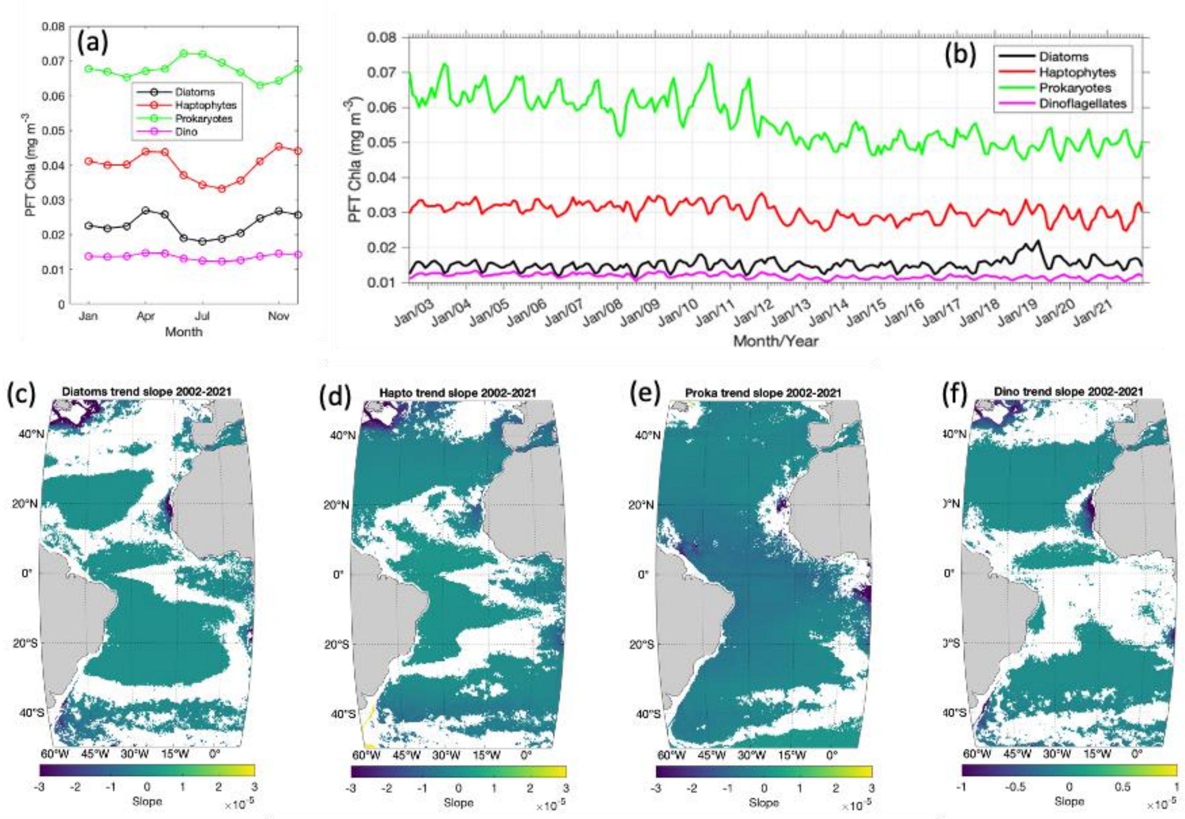

Figure 3: (a) Annual cycle of the four PFTs of diatoms, haptophytes, prokaryotes and dinoflagellates in the Atlantic Ocean (-50°S to 50°N, 60°W to 10°E), (b) 20-year time series from 2002 to 2021, and (c) per-pixel slope based on monthly Chla products of diatoms, (d) haptophytes, (e) prokaryotes and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

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