Long-term trends in the distribution of ocean chlorophyll

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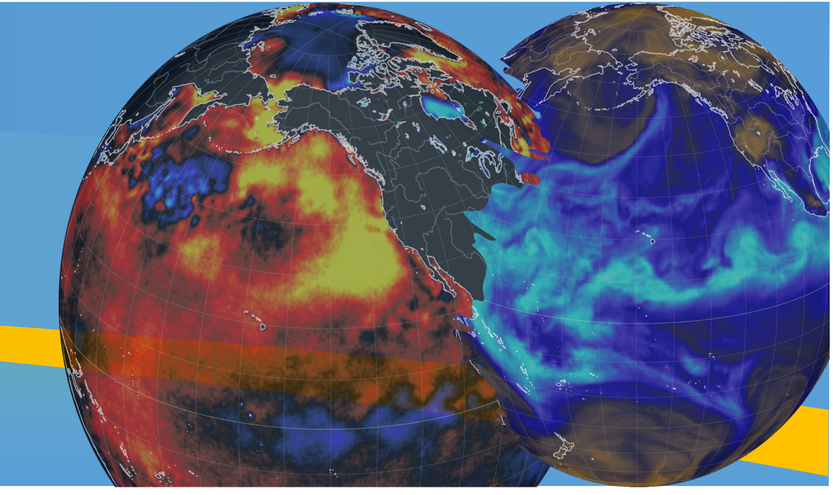


Introduction

Most studies focus on the impact of climate change on the mean state of phytoplankton and primary productivity, but little is known about whether and how climate change is impacting variance and extremes. In this study, we assess changes in chlorophyll-a concentration (CHL), which is an important proxy for primary production of marine ecosystems. Previous study suggests a decreasing variability in phytoplankton chlorophyll in both observational period and the model ensemble [1]. Our objective is to understand whether and how climate change impacts the whole distribution of variability in primary productivity. We utilize a series of statistical methods and reanalysis of CHL datasets to assess the variance and extremes of all distributions of CHL.

Data and Methods

Data

We use two chlorophyll-a (mg/m^3) data products spanning 1997 to 2022. The first one is derived from the ESA's Ocean Color Climate Change Initiative (OC-CCI) project [2]. The second dataset is derived from the GlobColour Project of Copernicus Marine Service (CMEMS) [3]. Both datasets are gridded at 4km spatial resolution and monthly temporal resolutions. They have been regridded from a 1/24◦ grid to a 1◦ grid by averaging within 1 degree boxes. Before fitting the quantile regression model, the monthly data is deseasonalized in both datasets.

Quantile Regression Model

Instead of modeling the mean response in the regression model, quantile regression (QR) models the response at a given quantile level [4]. We use a QR model to assess trends of CHL in various quantile levels.

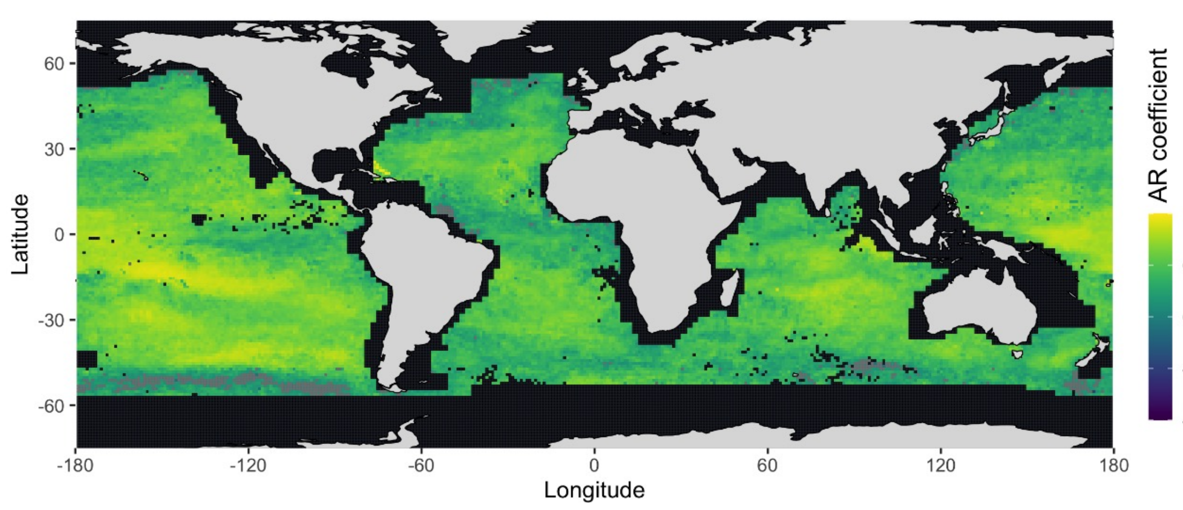


Figure 1. Using statistical test method verifying the first order of autocorrelation. The grey shadows are regions where trends are not significant at a 5% level.

Conclusion

- Long-term changes are detected in different aspects of the distribution of chlorophyll-a (not just the mean state).
- Oceanic chlorophyll-a extremes high are changing faster than chlorophyll-a mean at the global scale during 1997-2022.
- Different quantiles changing at different speed implies a change in variability of CHL.
- On a regional scale, chlorophyll-a extremes trends are predominant at high latitude (+), equatorial (-), and oligotrophic regions (-).
- Future work should focus on quantifying and comparing detection times in CHL distribution to develop the ability to formally detect the impact of climate change in marine ecosystems as soon as possible.

Results

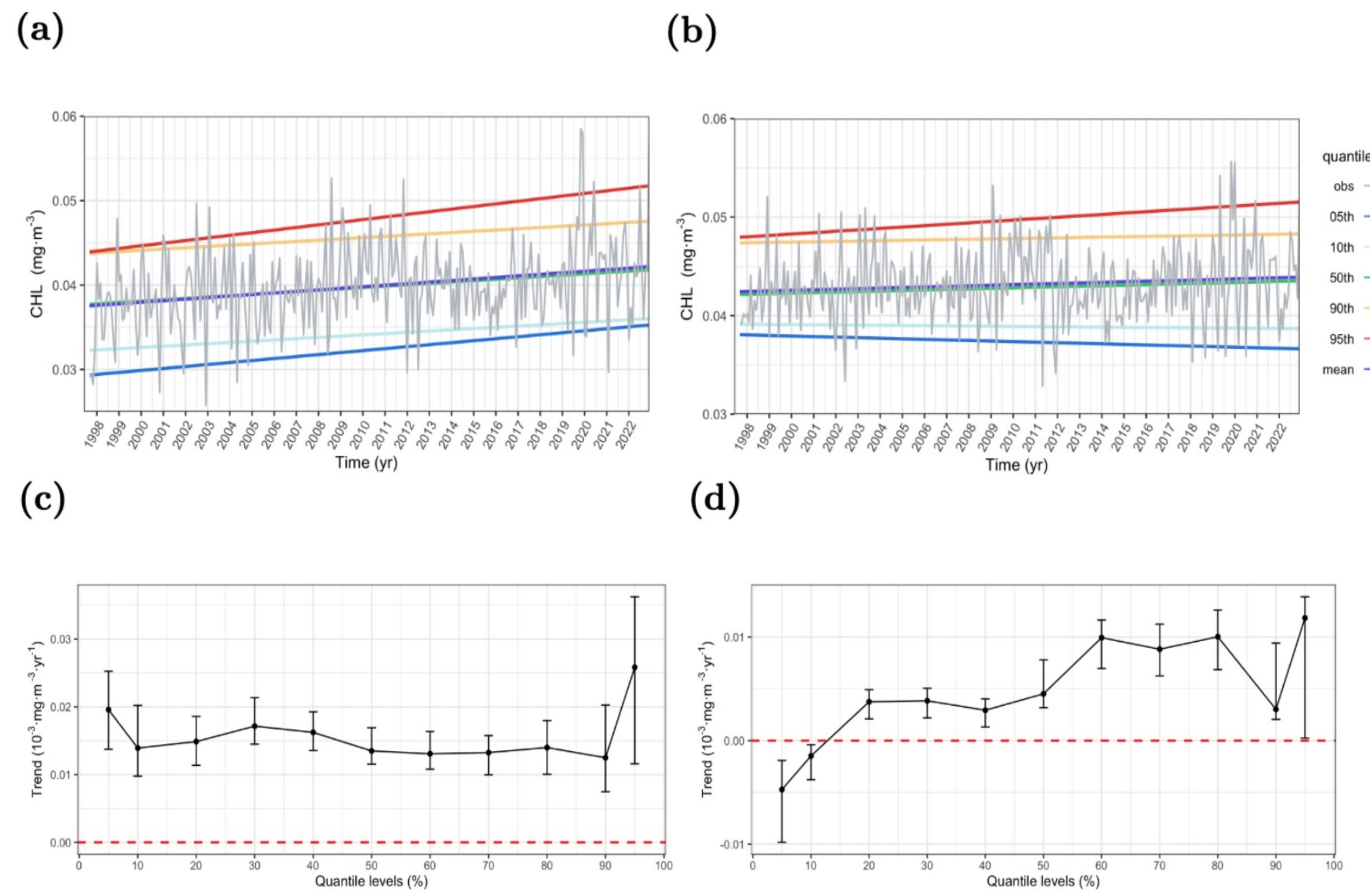


Figure 2. (left) Time series of monthly global mean CHL from 1997-2022 and CHL trends in different quantile levels from (a) OC-CCI data product and (b) CMEMS data product. Trends in different quantile levels (5%, 10%, 50%, 90%, and 95% levels) with 95% confidence intervals from (c) OC-CCI data product and (d) CMEMS data product. The magnitude of trends in the upper quantile of global CHL (95th) is larger than those in the middle and lower quantiles (<50th). Though the magnitude and uncertainty of global CHL trends differ by quantile level, these results are more consistent with an increasing variance.

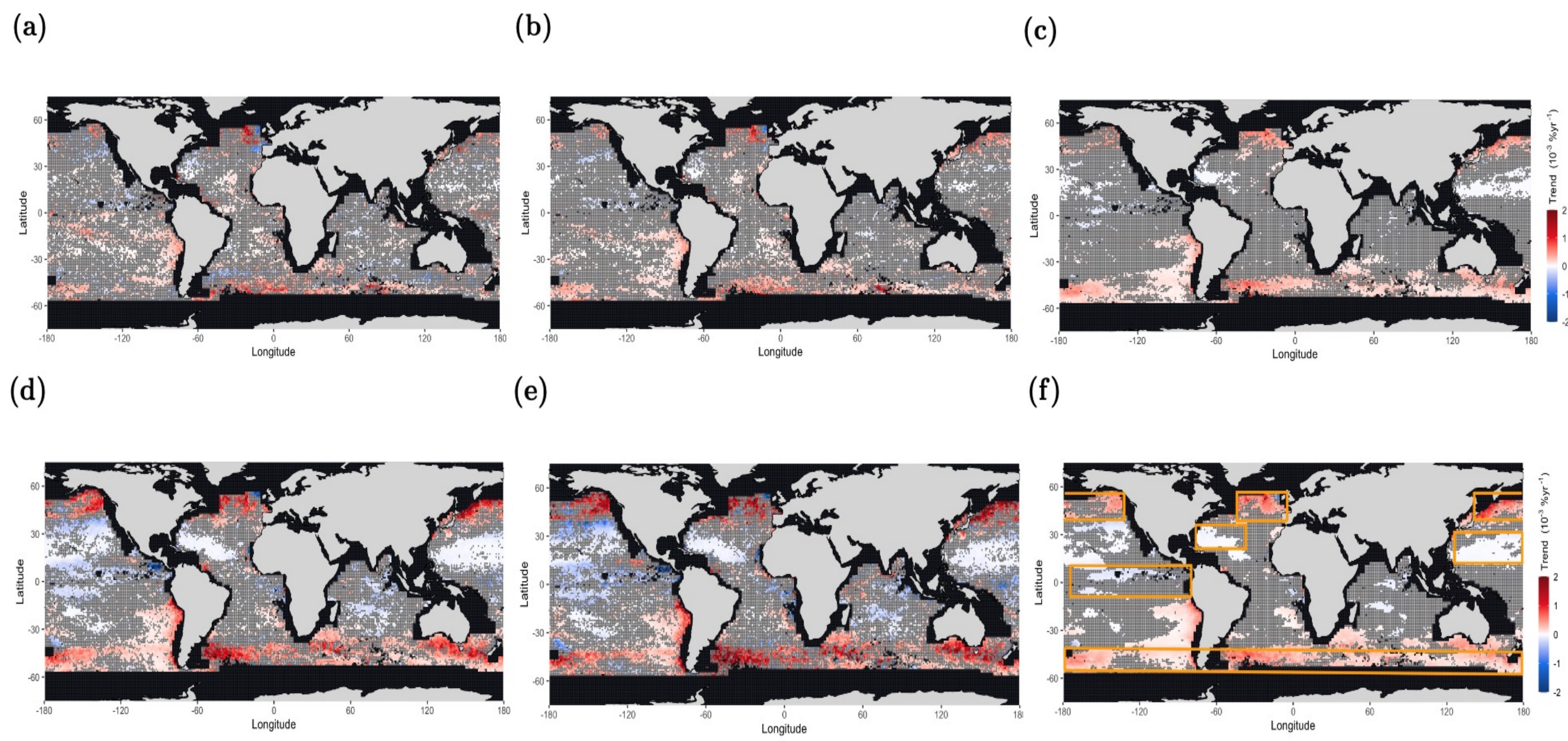


Figure 3. (top) Maps of CHL trends from OC-CCI data product during 1997-2022 in (a)5th, (b) 10th, (c) 50th, (d) 90th, (e) 95th quantile levels, and (f) in CHL mean, respectively. Trends in lower quantiles are more scattered (a and b), and patterns become more apparent in the median and larger quantiles (c, d, and e).

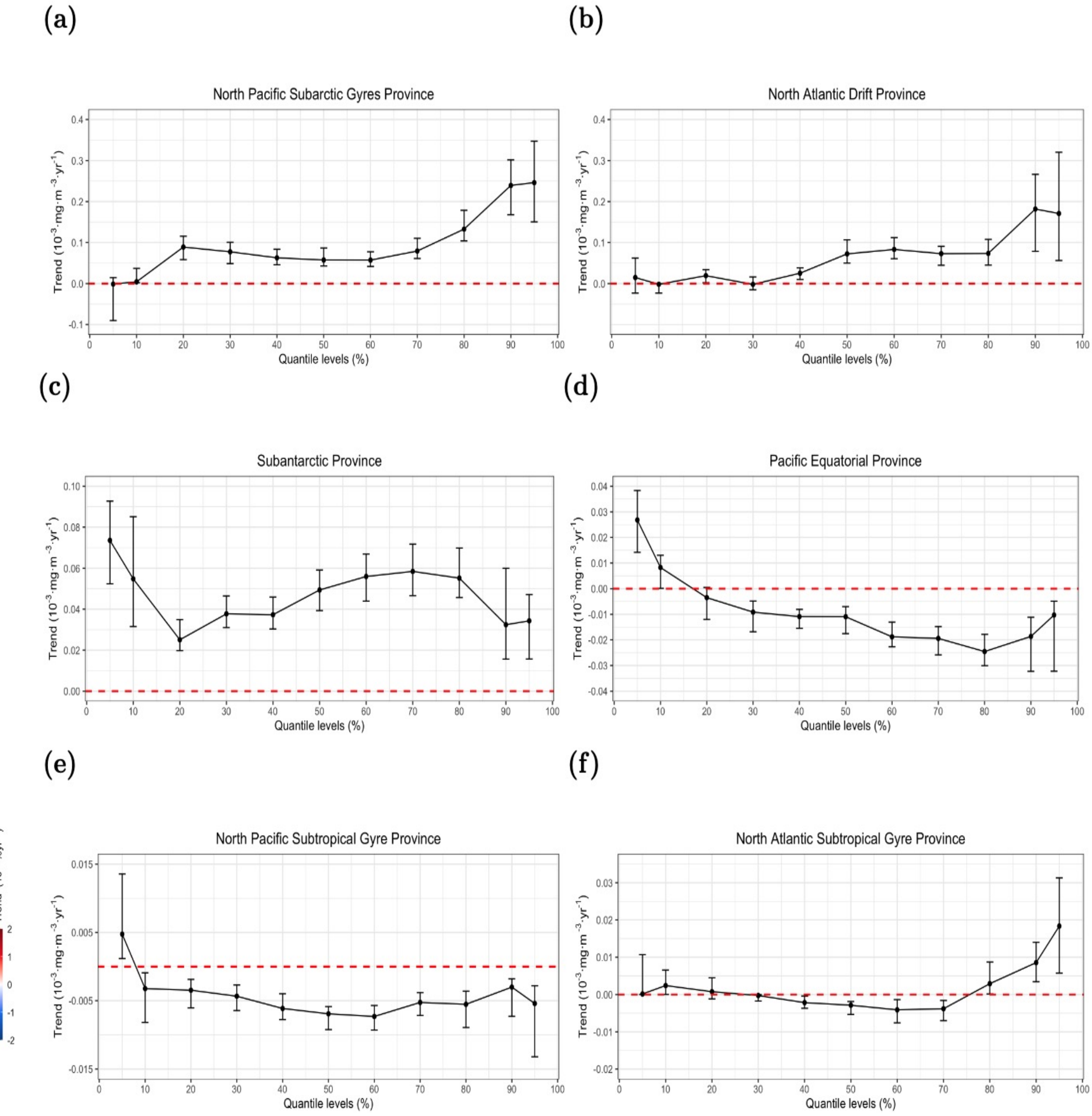
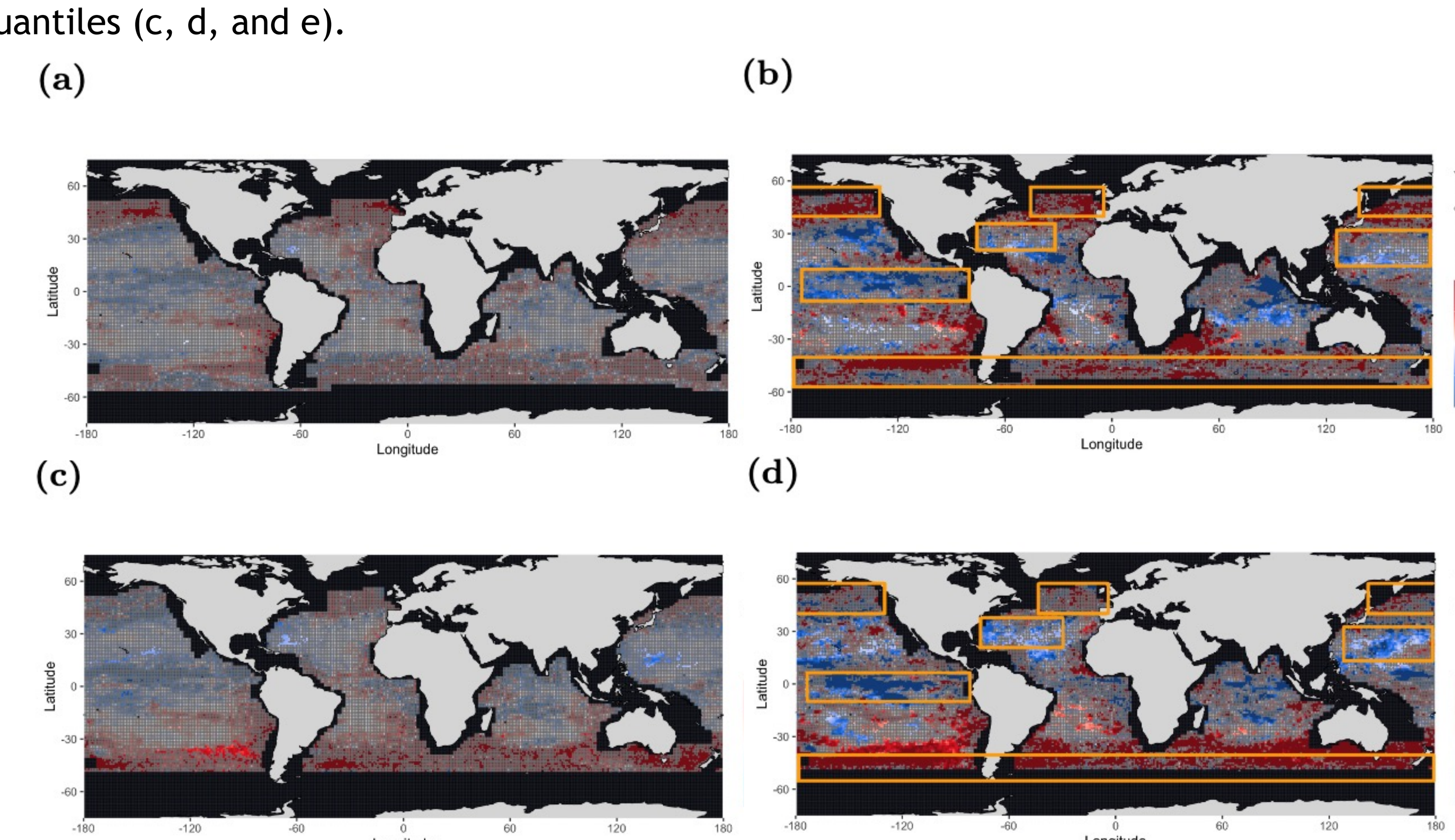


Figure 4. (top) Trends in different quantile levels estimated by quantile regression at regions, (a) North Pacific Subarctic Gyre Province, (b) North Atlantic Drift Province, (c)Subantarctic Province, (d) Pacific Equatorial Province, (e) North Pacific Subtropical Gyre Province, and (f) North Atlantic Subtropical Gyre Province from OC-CCI-data product. The 95% confidence intervals for each regression are represented by the vertical lines. The red horizontal dashed line is zero. In Figure 4a, 4b, and 4f, trends detected in different quantiles are consistent with an increasing variability over the observational record. Figure 4c, 4d, and 4e present consistent trends with an overall decrease in variability. Smaller uncertainty is associated with steady trends in the middle quantile levels, implying that the homogeneous character of CHL is distributed in North Atlantic oligotrophic gyre. Trend estimates obtained by the OLS model are closely parallel to those for the 50th percentile in all the regions.

Figure 5. (right) Maps of CHL trends from OC-CCI data products during 1997-2022 in (a) 50th and (b) 95th quantile level trends in December, January, and February (DJF) CHL means (c) 50th and (d) 95th quantile level trends in June, July, and August (JJA) CHL means. The orange boxes are regions of focus with trends significant in multiple quantiles. The overlapped stippling shows areas where the trends are not significant at a 5% level. Our findings suggest that trends in CHL extremes high are mainly associated with DJF instead of JJA, implying the long-term trends in the high latitude are closely related to the seasonal variance of climate variables.



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Acknowledgements

The OC-CCI chlorophyll-a data product can be found on the open portal of ESA's climate office: https://www.oceancolour.org/. The CMEMS chlorophyll-a data can be found on the GlobColour Project of Copernicus program: https://www.copernicus.eu/en/access-data.

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