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TAKING THE PULSE OF OUR PLANET FROM SPACE

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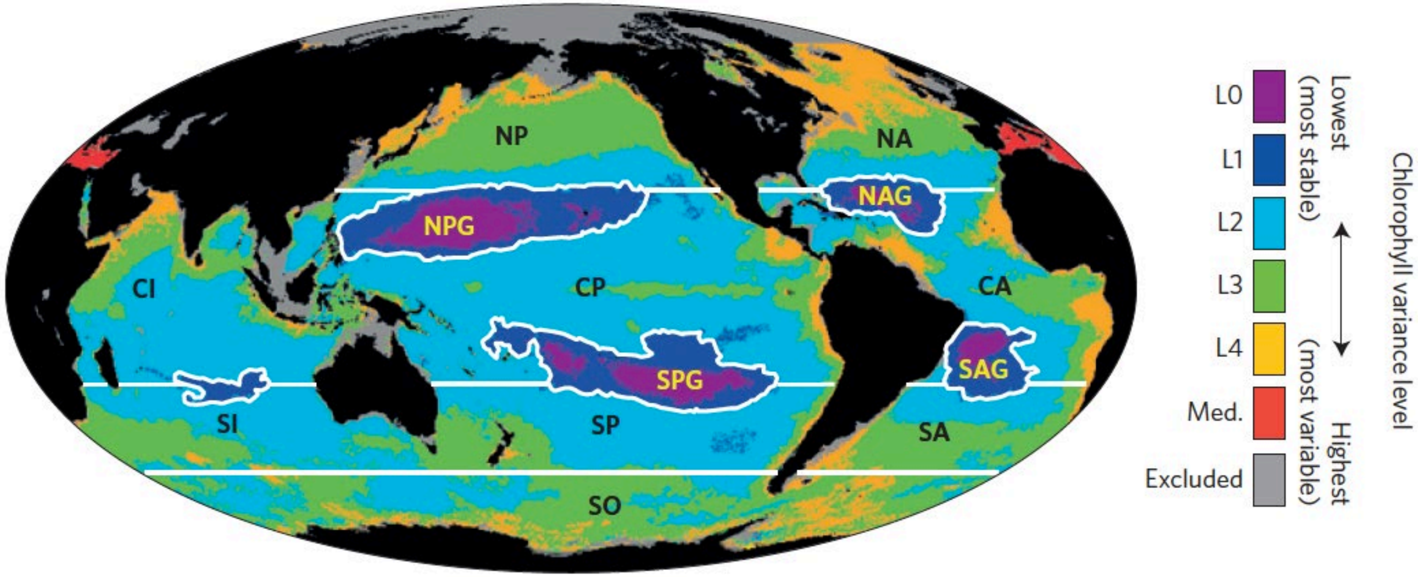
Ultra-oligotrophic regime shift of the North Atlantic Subtropical Gyre as revealed by long-term of satellite observations

Leonelli, F. E., Bellacicco, M, Pitarch, J., Organelli, E., Buongiorno Nardelli, B., de Toma, V., Cammarota, C., Marullo, S. and Santoleri, R.

25/05/2022

why it is important to study the subtropical gyres?



(Behrenfeld et al., 2015)

- **Occupy ~40%** of the surface of the Earth.
- Characterized by **oligotrophic conditions** (weak supply of nutrients, low phytoplankton biomass → often expressed in satellite chlorophyll-a concentration (CHL) ≤ 0.1 mg m^{-3}).
- They significantly contribute to the **global carbon export production** because of their **immense ecosystem size** (Dave et al., 2015).

Ocean deserts are increasing due to ocean warming

esa

GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L03606, doi:10.1029/2004GL021808, 2005

Recent trends in global ocean chlorophyll

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Received 21 October 2004; rev

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Deep-Sea Research II 51 (2004) 281–301

Subtropical gyre variability observed by ocean-colo

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Received 14 August 2002; received in revised form 21 April 2003; accepted 6 August 2003

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L03618, doi:10.1029/2007GL031745, 2008

Ocean's least productive waters are expanding

Jeffrey J. Polovina,[1] Evan A. Howell,[1] and Melanie Abecassis[2]

Received 20 August 2007; revised 3 December 2007; accepted 16 January 2008; published 14 February 2008.

GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L18609, doi:10.1029/2009GL039883, 2009

Are ocean deserts getting larger?

Andrew J. Irwin[1] and Matthew J. Oliver[2]

Received 1 July 2009; revised 14 August 2009; accepted 19 August 2009; published 26 September 2009.

[1] The spatial and temporal dynamics of ocean biomes and their provincial subdivisions are affected by the dynamics of Earth's climate system, but the effect of climate change on the distribution and variability of ocean biomes and provinces is largely unknown. A time-series analysis from multiple satellite platforms shows that the lowest productivity provinces have been growing over the last decade and that the growth rates of these provinces increase as they get larger, and decrease as they get smaller. The most oligotrophic provinces of the ocean grow by reducing the size of the slightly less oligotrophic provinces. As a consequence, while the ocean's most extreme deserts are increasing at an accelerating rate, some oligotrophic areas are simultaneously shrinking. The aggregate area of the oligotrophic provinces oscillated in phase with the Pacific Decadal Oscillation Index from 1998–2007.

Citation: Irwin, A. J., and M. J. Oliver (2009), Are ocean deserts getting larger?, *Geophys. Res. Lett.*, *36*, L18609, doi:10.1029/2009GL039883.

algorithm using ocean color and sea surface temperature can be used to identify discrete province classes in the ocean [*Moore et al.*, 2002; *Oliver et al.*, 2004; *Oliver and Irwin*, 2008] with similar geographic characteristics to the provinces of *Longhurst* [1998]. The time-independent province classification largely corresponds to the phenological classifications because ocean color (OC) and sea surface temperature (SST) have a high degree of temporal auto-correlation [*Mahadevan and Campbell*, 2004] and at a basic level, we use a satellite index of light and temperature to classify provinces. We define dynamic provinces by applying an objective, time-independent algorithm to a 10 year time-series of Sea-viewing Wide Field-of-view Sensor/Advanced Very High Resolution Radiometer (SeaWiFS/AVHRR) data and a 5 year time-series of Moderate Resolution Imaging Spectroradiometer (MODIS/Aqua) data. We then analyze the area of the oligotrophic provinces across the gyres, to test for decadal-scale changes in the lowest productivity areas of the ocean.

Ocean deserts are increasing due to ocean warming

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...nt trends in global ocean chlorophyll

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...waters are expanding

The fastest expansion of oligotrophic waters worldwide was observed within the area of the North Atlantic Subtropical Gyres with an enlargement of around 56% between 1998 and 2006

assess recent trends. Gl... 4.1% ($P < 0.05$). Most c... regions, defined as both... of 10.4% was obser... increase were the Pa... eastern Pacific, sout... Although the global... change, 4 of the 5... showed declines in... the North Atlanti... significant increas... one season. These... in the biology of... N. W. Casey, and... ocean chlorophyll

Subtropical gyre variability observed by ocean-colo...

Charles R. McClain[a,*], Sergio R. Signorini[b], James R. Christ...

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Abstract

The subtropical gyres of the world are extensive, coherent regions that occupy about 40% of the surface of th... Once thought to be homogeneous and static habitats, there is increasing evidence that mid-latitude gyres... substantial physical and biological variability on a variety of time scales. While biological productivity within... oligotrophic regions may be relatively small, their immense size makes their total contribution significant. Gl... distributions of dynamic height derived from satellite altimeter data, and chlorophyll concentration derived fr... satellite ocean-color data, show that the dynamic center of the gyres, the region of maximum dynamic height where the pycnocline is deepest, does not coincide with the region of minimum chlorophyll concentration. The physical and biological processes by which this distribution of ocean properties is maintained, and the spatial and temporal scales of variability associated with these processes, are analyzed using global surface chlorophyll-a concentrations, sea-surface

to 4.3%/... higher surface ... water. It is ... chlorophyll areas in these oceans com... from 1... chlorophyll areas in these oceans by about 15.0% from ... by 6.6 million km^2 or by about 15.0% ... shows a more rap... 2006. In both hemispheres, evidence shows during the ... expansion of the low surface chlorophyll waters ... smallest winter. The North Atlantic, which has the ... both annually oligotrophic gyre is expanding most rapidly, ... at 8.5%/yr. at 4.3%/yr and seasonally, in the first quarter ... subtropical Mean sea surface temperature in each of these 4 ... The expansion of gyres also increased over the 9-year period. ... with globa... the low chlorophyll waters is consistent ... stratificatio... warming scenarios based on increased vertical ... we obser... in the mid-latitudes, but the rates of expansion ... predictio... already greatly exceed recent model ... and M. Abec... **Citation:** Polovina, J. J., E. A. Howell, ... waters are expanding, Geo... (2008), Ocean's least productive ... Res. Lett., 35, L03618, doi:10.1029/2007GL031745.

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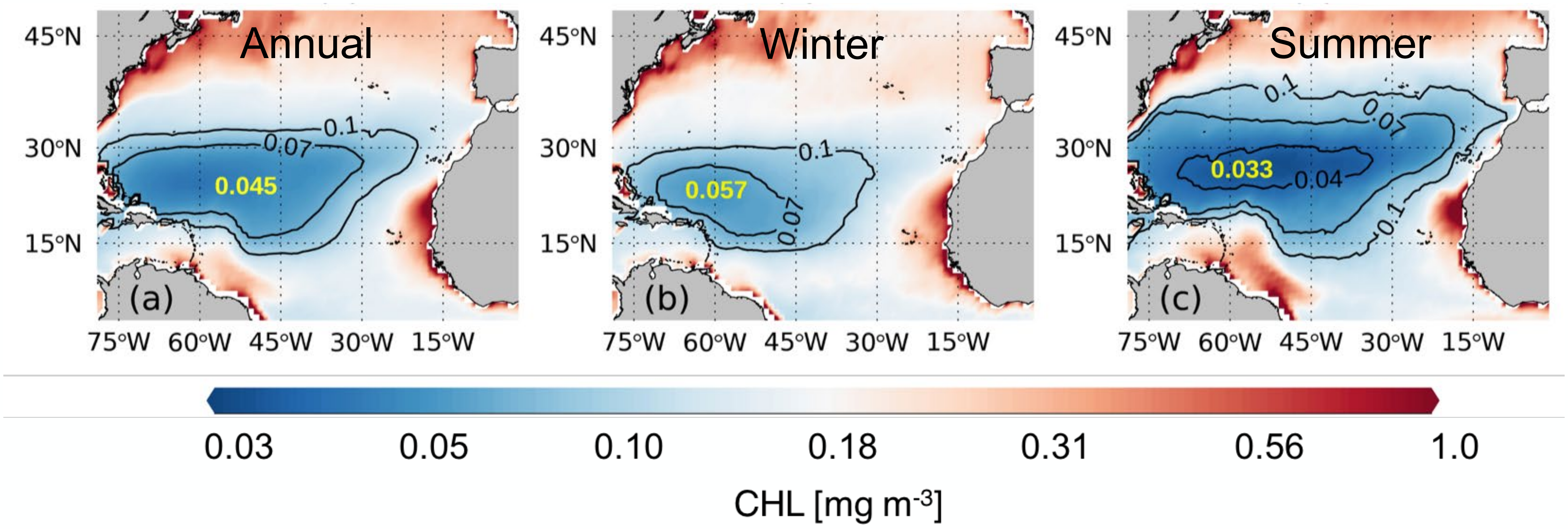
The North Atlantic Subtropical Gyre (NASTG)



Leonelli et al., (under review)

Critical points:

1. Satellite CHL alone cannot always give a reliable estimation of phytoplankton concentration in the subtropical gyres, being strongly influenced by physiological processes (i.e., photoacclimation; Behrenfeld et al., 2005).

2. Detection of long-term changes would require time series covering a period of at least 30 years, allowing with such length of observations to have a robust identification of typical values to refer to (WMO, 2017).

Most previous studies based on the use of satellite CHL time-series with a reduced length had critical caveats for reliable climate change interpretations (Dutkiewicz et al., 2019)

Are oligotrophic waters really expanding?

Dataset

ESA climate office

Home > ESA & Climate > ESA Climate Change Initiative

- **ESA Climate Change Initiative (CCI) monthly dataset at 25 km resolution from 1998 to 2018**

Monthly CHL → CCI 4.2 dataset at 4 km resolution.

Monthly optical backscattering coefficient (b_{bp}; 443nm; in m^{-1}) → computed from daily CCI Rrs 4.2 dataset at 4 km (Pitarch et al., 2020).

Monthly Secchi disk depth (z_{SD} in m^{-1}) → computed from daily CCI Rrs 4.2 dataset at 4 km resolution (Lee et al., 2015; Pitarch et al., 2020).

Monthly SST CCI dataset at 25 km resolution computed from daily CCI SST dataset at 4 km resolution.

- **Monthly MLD dataset at 25 km resolution from 1998 to 2018:**

Copernicus Europe's eyes on Earth

Copernicus Marine Service

Mixed Layer Depth (MLD; in m) data were extracted from the ARMOR3D Level 3 reprocessed dataset disseminated by the Copernicus Marine Service.

Dataset

esa

ESA climate office

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Monthly m
(Pitarch

All the dataset were re-mapped at 100 km resolution

Monthly Secchi disk depth (z_{SD} in m^{-1}) → computed from daily CCI Rrs 4.2 dataset at 4 km resolution (Lee et al., 2015; Pitarch et al., 2020).

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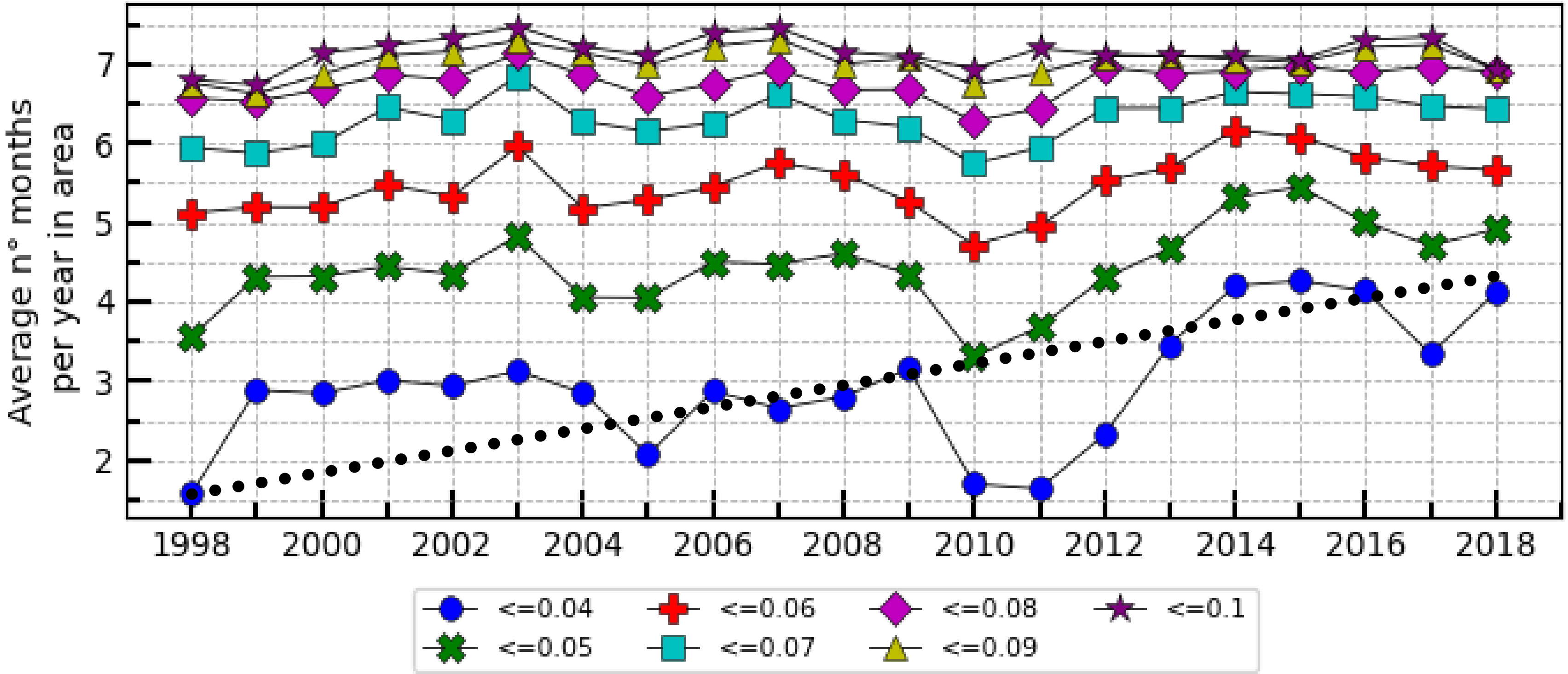
Threshold selection is critical



- CHL ≤ 0.1 mg m^{-3} **+2.64% (0.13% *per* year)**
- CHL ≤ 0.07 mg m^{-3} **+7.58% (0.48% *per* year)**
- CHL ≤ 0.04 mg m^{-3} **+53.76% (8.08% *per* year)**

Area [km^2] with CHL ≤ 0.04 mg m^{-3} **+96.34%** (21.63% *per* year)

Leonelli et al., (under review)

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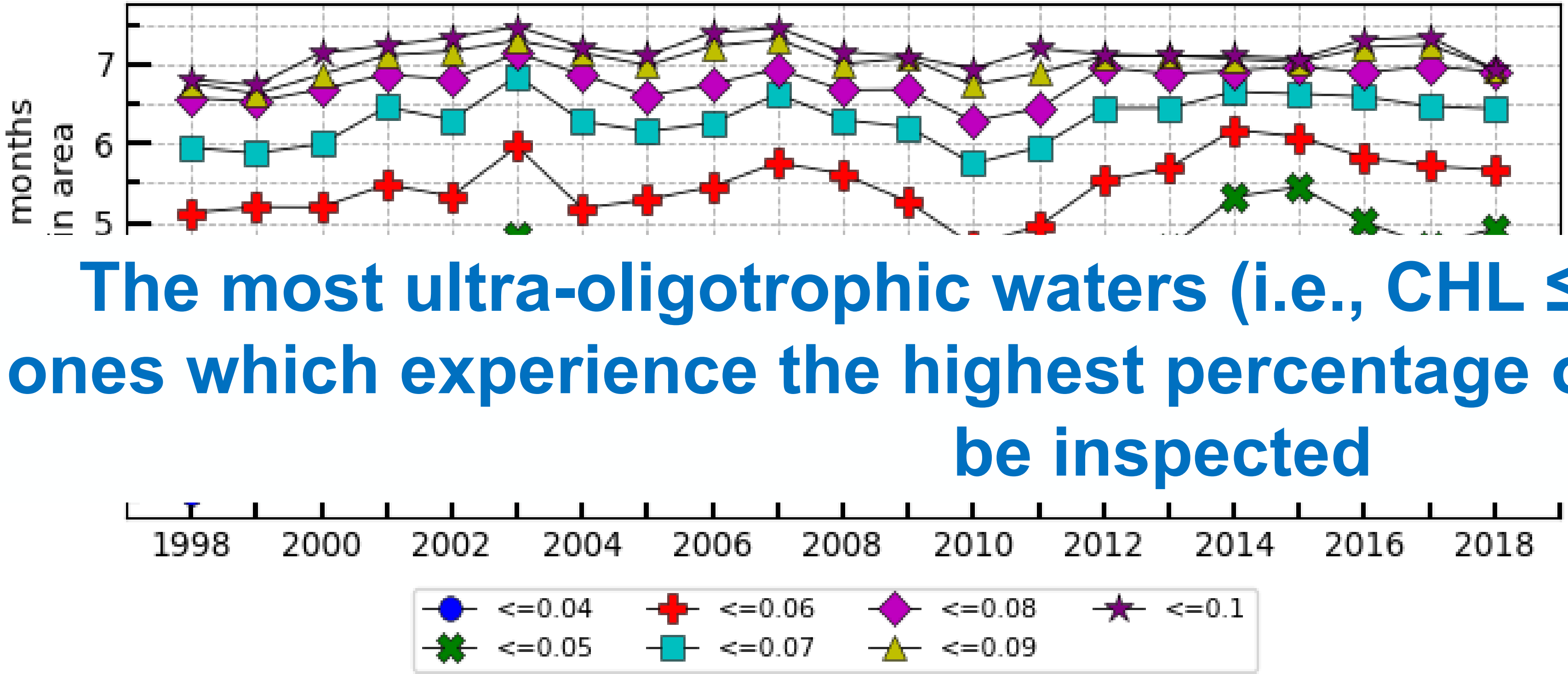


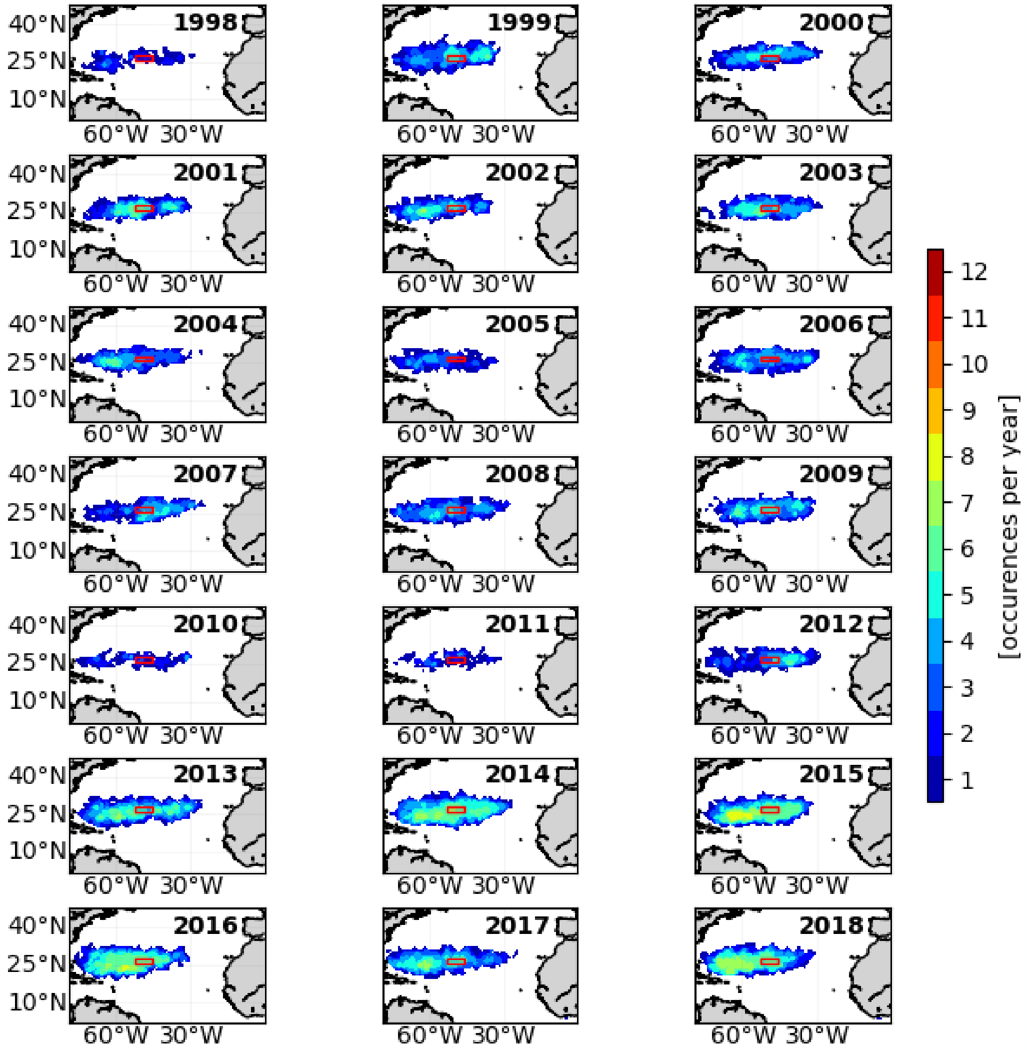
- CHL ≤ 0.1 mg m^{-3} **+2.64% (0.13% *per* year)**
- CHL ≤ 0.07 mg m^{-3} **+7.58%**

The most ultra-oligotrophic waters (i.e., CHL ≤ 0.04 mg m^{-3}) are the ones which experience the highest percentage of changes and need to be inspected

Area [km^2] with CHL ≤ 0.04 mg m^{-3} **+96.34%** (21.63% *per* year)

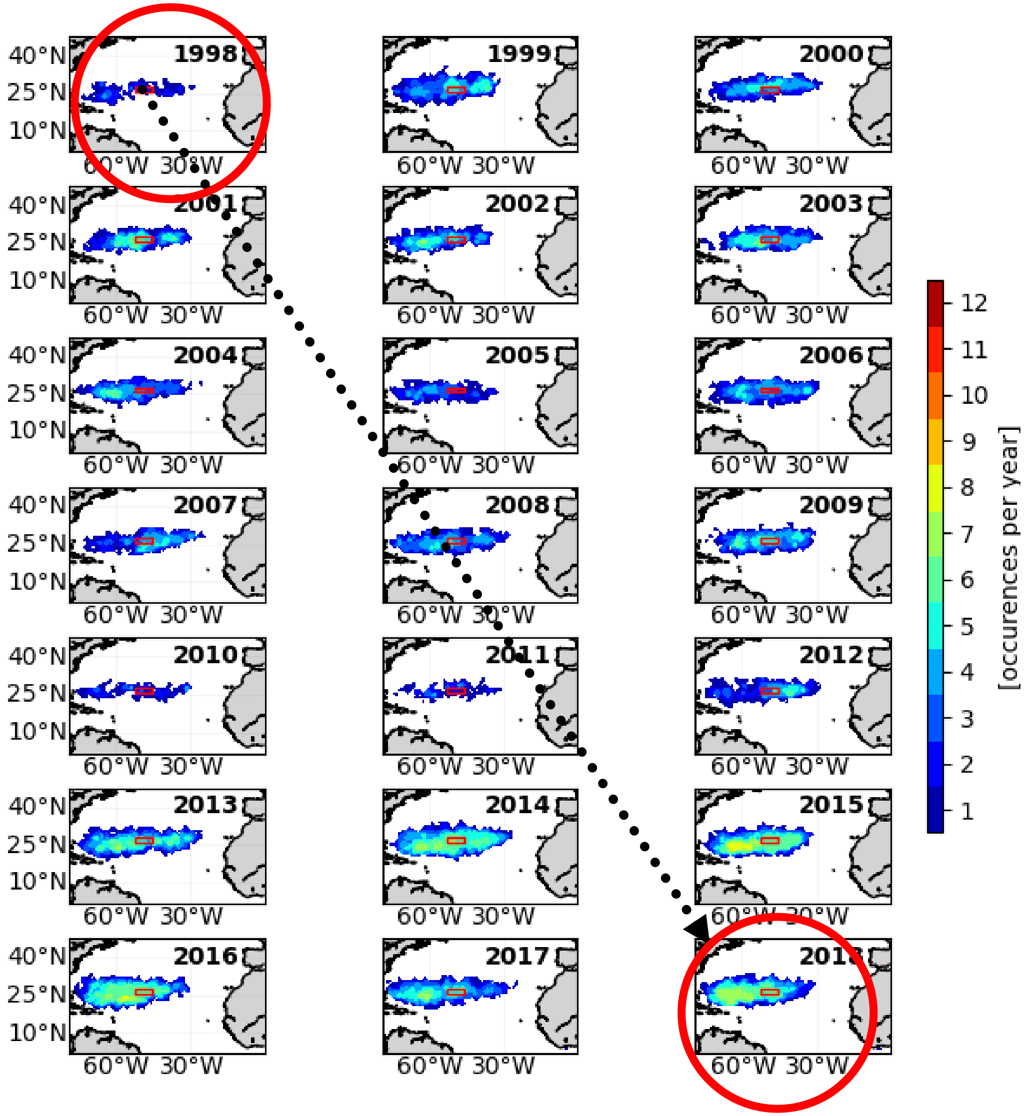
Leonelli et al., (under review)

Spatial expansion



Leonelli et al., (under review)

Spatial expansion



- Spatially, waters with CHL less than 0.04 mg m^{-3} are mostly in the core of the gyre.
- From 1999 to 2018, the occurrences of such conditions became more frequent with an average of four to five monthly observations *per* year, reaching in some areas peaks of 7-8 months *per* year.

Leonelli et al., (under review)

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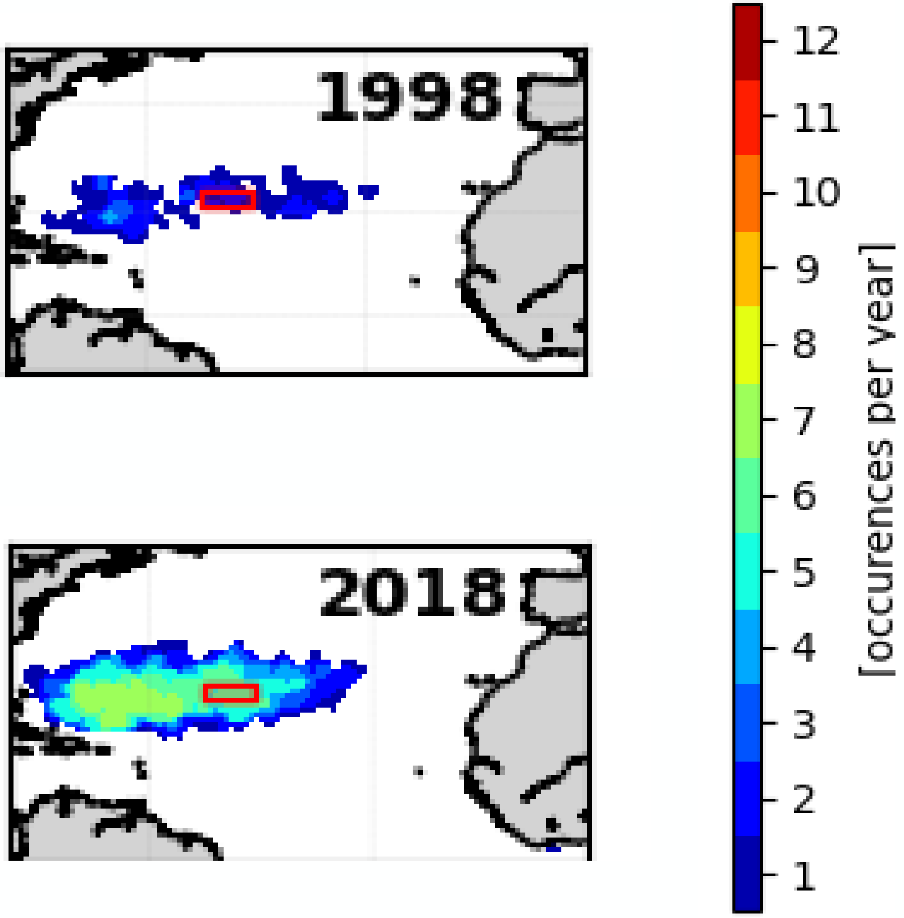

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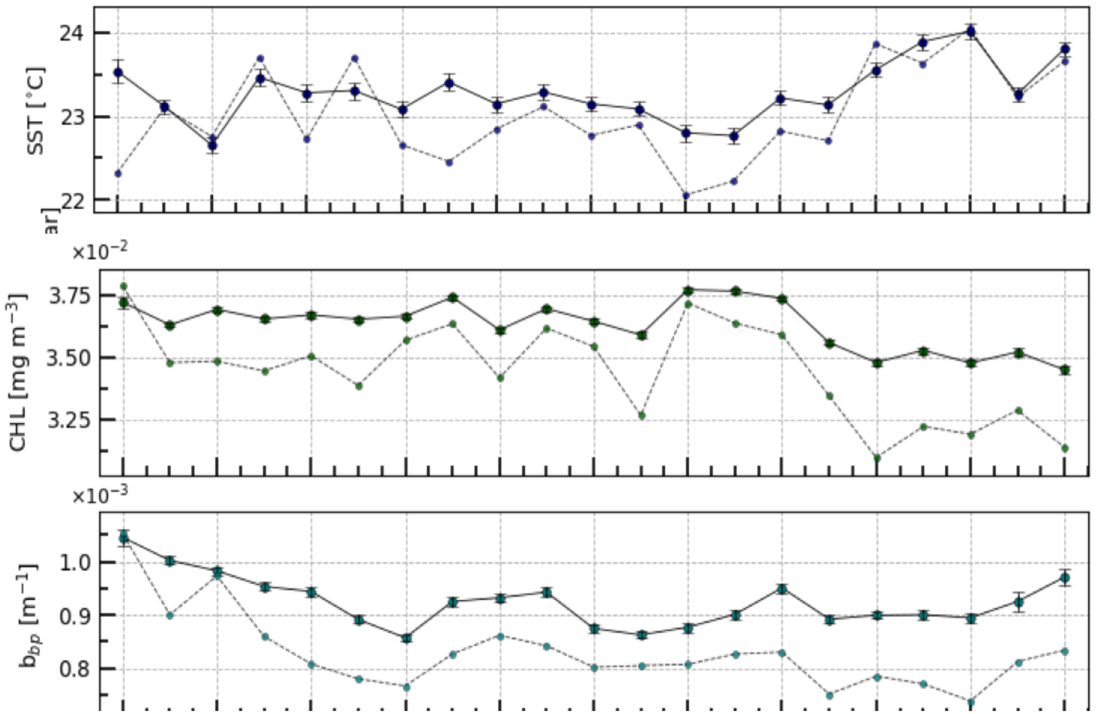
The ultra-oligotrophic regime that initially appeared as an infrequent condition by the end of the time series it occurs for half of the year on average and covers a wider area in the core of the NASTG

Leonelli et al., (under review)

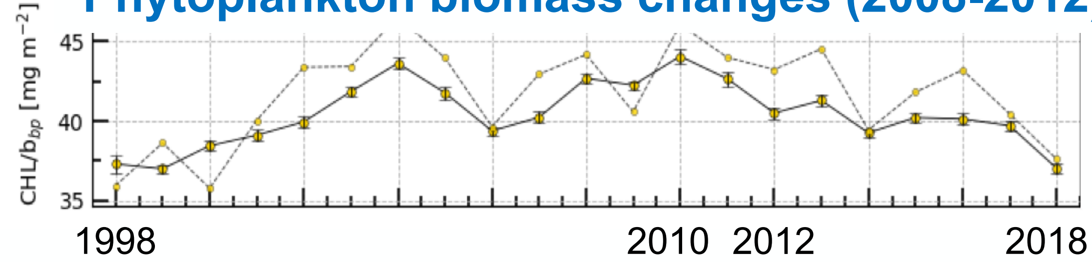
Temporal variations

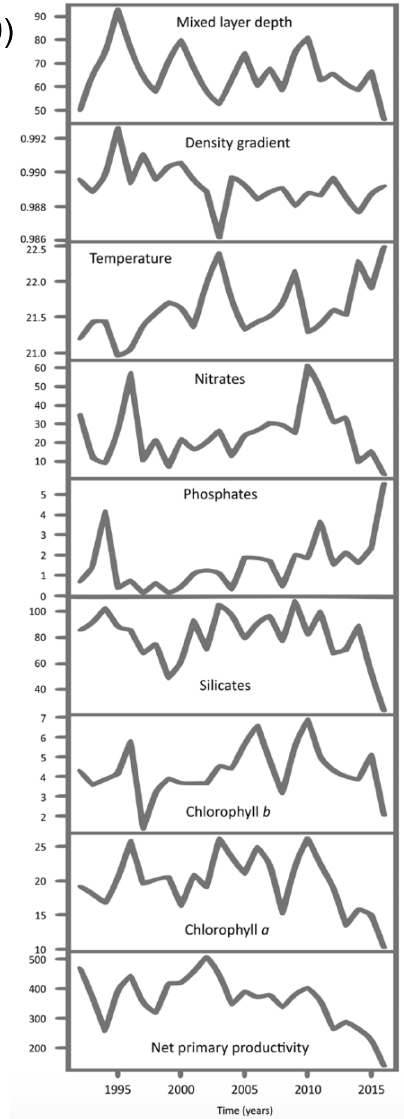
SST increasing around 0.8°C

D'Alelio et al. (2020)



Phytoplankton biomass changes (2008-2012)





Physiology and biomass changes (1998-2010)

Physiology dominance (2012-2018)

Leonelli et al., (under review)

Take home messages

- Previously-published articles used **CHL thresholds of 0.07/0.1 mg m^{-3}** to define the oligotrophic regime but since these limits do characterize the NASTG in all months, they **do not allow observing the expansion of the oligotrophic condition in the area**, hence motivating to focus and analyze the most oligotrophic waters characterized by CHL ≤ 0.04 mg m^{-3}.

- In the last 21 years, the ultra-oligotrophic waters (**CHL ≤ 0.04 mg m^{-3}**) **shows** a non-linear change pattern, though overall **expanding in space and increasing in frequency** accounting for an **area growth** of around **96.34% and** an increase of average **monthly occurrences** per year of **53.76%** in correspondence of a marked increase of SST and a deepening of the MLD.

What's next?

- **Understand** how **ocean warming impacts** the **ocean biology** of the NASTG along the **4D of the ocean**, thus coupling biogeochemical and physical variables (e.g. combination of long-term satellite data and multi-years autonomous platforms observations such as Biogeochemical-Argo floats).

- **Quantify** and **characterize** the impact of the **ultra-oligotrophic waters expansion** on the **biological carbon pump** (e.g. carbon exports) in the NASTG over the last decades.

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Thanks!

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