AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

Phytoplankton Dynamics in Subtropical Gyres: New Insights into Biomass and Physiology from 25 years of Satellite Observations

Seminario di Divisione CLIMAR – 29 maggio 2025 ore 10:00

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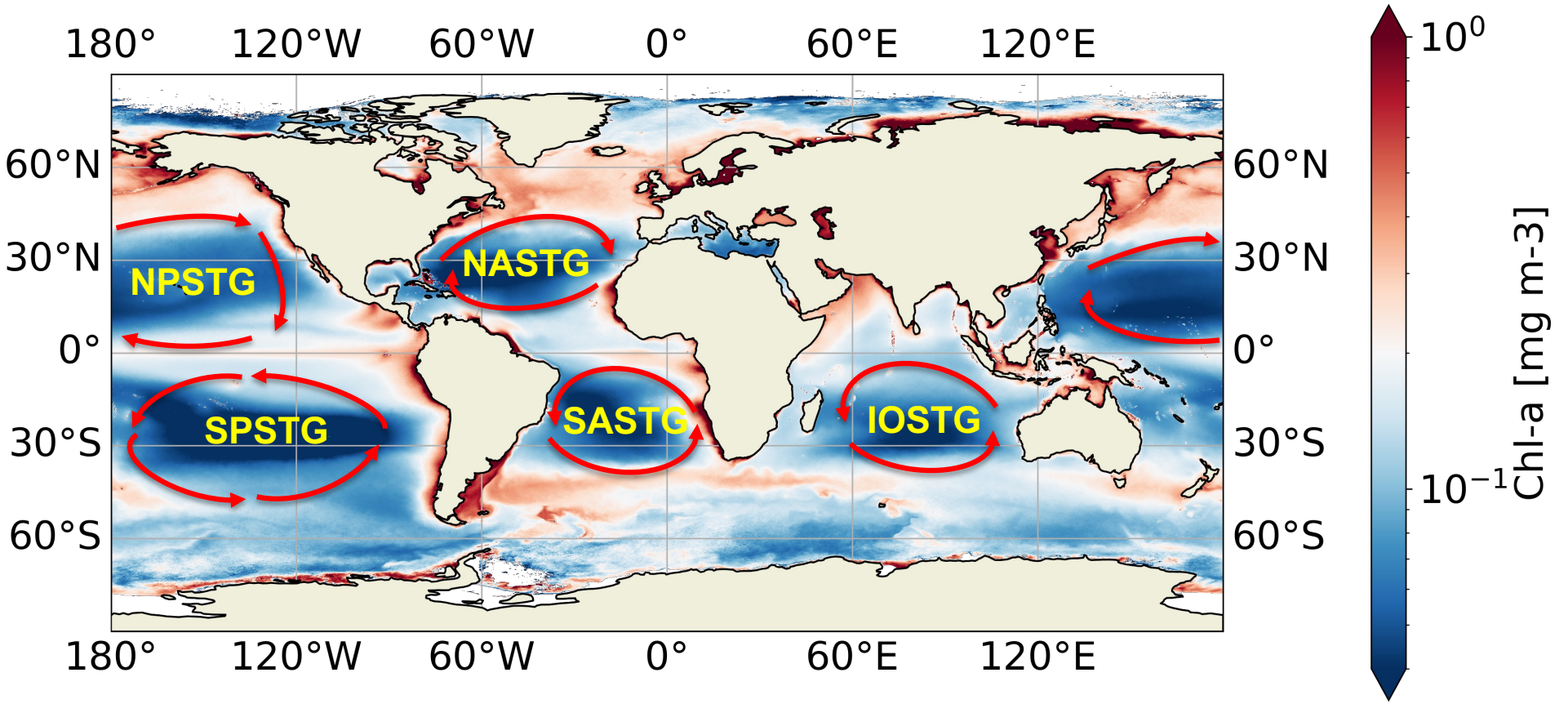
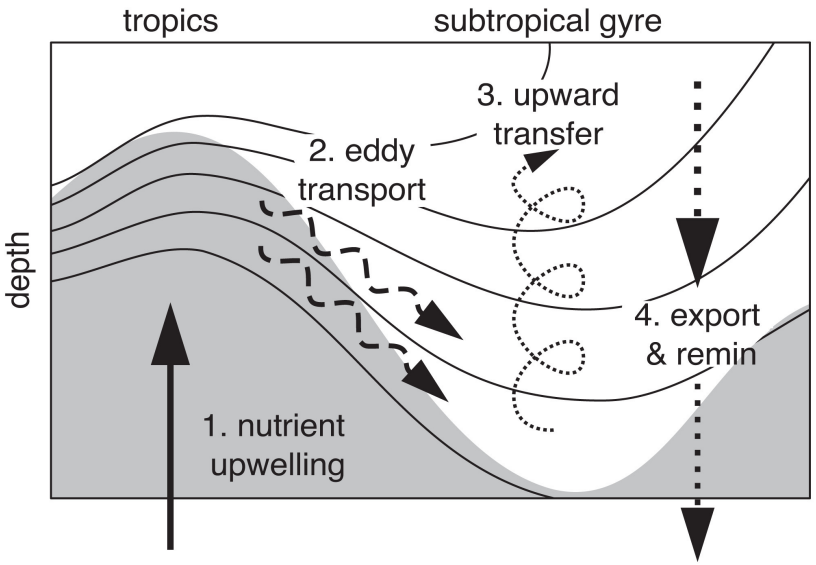
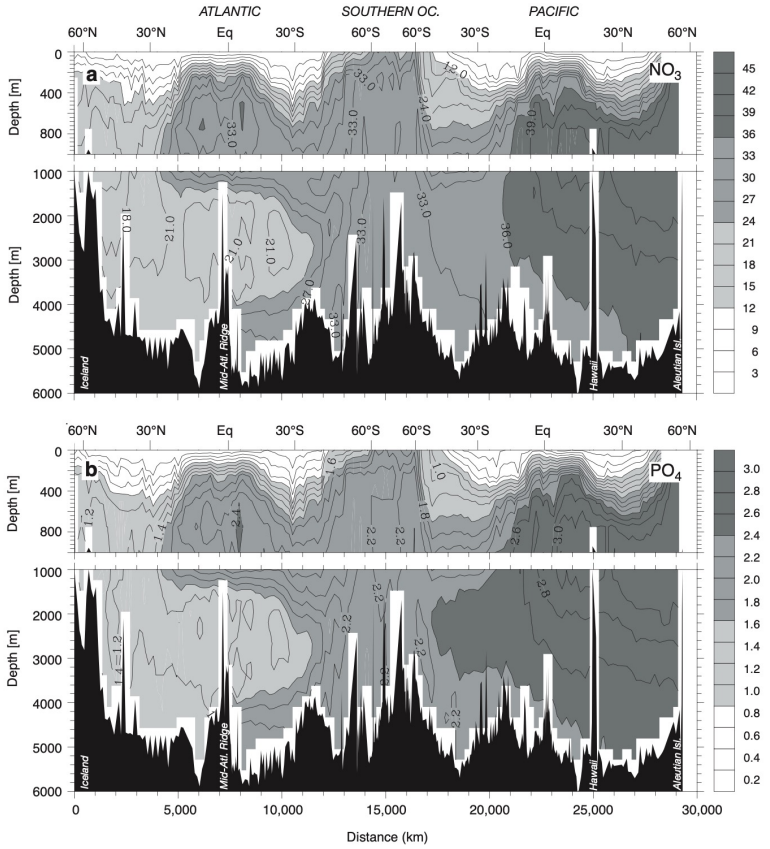
Background


180°
120°W
60°W
0°
60°E
120°E
60°N
30°N
0°
30°S
60°S
NPSTG
NASTG
SPSTG
SASTG
IOSTG
10^0
10^{-1}
Chl-a [mg m-3]

Background



Gupta et al., 2022, PNAS



Sarmiento & Gruber, 2006

Background

From **previous** satellite **studies**:

- Subtropical gyres are expanding (increasing oligotrophy – decreasing chlorophyll).
- **Desertification alert**: major concerns about its potential impact on the global climate were raised.

Gaps and limitations in previous studies:

- < 10-year analysis or focus on a single gyre (i.e., NASTG, NPSTG).
- **Chlorophyll-a** is used as a **proxy for phytoplankton biomass.**
- Photoacclimation physiological adaptation of phytoplankton is not accounted for (i.e., Chlorophyll-a is modulated by adaptation to nutrient, temperature and light conditions, and chlorophyll variations may or may not impact phytoplankton biomass; Behrenfeld et al., 2005).

Scientific questions

- How is desertification progressing in the five subtropical gyres?
    - Are they getting larger and becoming more oligotrophic?
- Does the previously observed chlorophyll decrease imply decreasing phytoplankton biomass?
- Which area is the most affected by desertification?

Methods

Data sets (1998 - 2022)

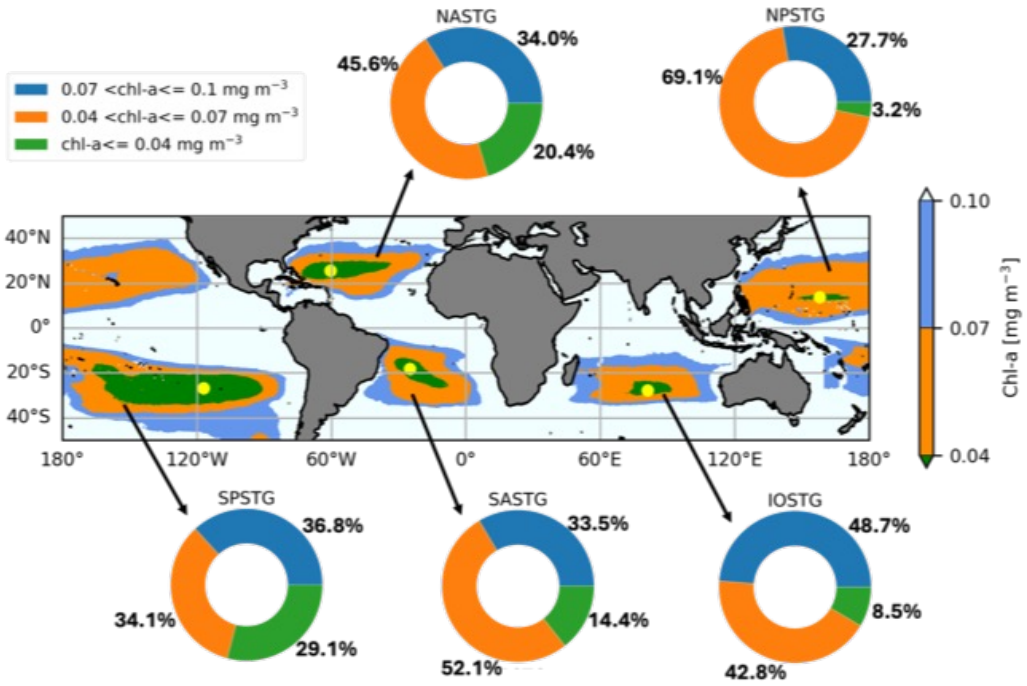
Variable	Temporal resolution	Spatial resolution	Observation type	Product Name	used to calculate
Chlorophyll-a (Chl)	daily	0.04°	Satellite	ESA-OC-CCI v6.0	area and C_{phy}
Backscattering coeff. at 443 nm (b_{bp})	daily	0.04°	Satellite	ESA-OC-CCI v6.0	C_{phy}
Sea Surface Temperature (SST)	daily	0.05°	Satellite	ESA-SST-CCI v2.1	C_{phy}
Attenuation coeff. at 490 nm (kd(490))	daily	0.04°	Satellite	ESA-OC-CCI v6.0	PAR_g
Mixed Layer Depth (MLD)	daily	0.25°	Reanalysis	GREP	PAR_g
Photosynthetically available radiation (PAR_{sat})	daily	0.05°	Satellite	GlobColour Project	PAR_g

Results

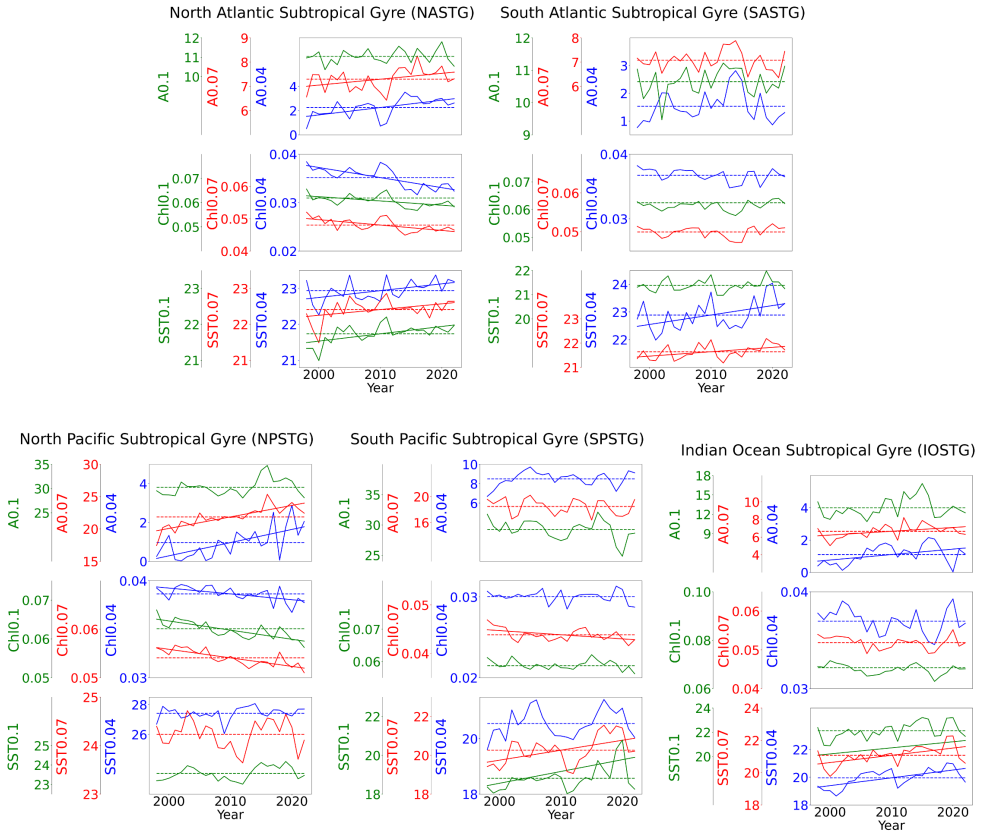
3 spatial scales:

- **gyre** (chl≤0.1 mg/m^3),
- **ultra-oligotrophic subregion** (chl ≤0.07 mg/m^3)
- **hyper-oligotrophic subregion** (chl ≤0.04 mg/m^3)

	NASTG	SASTG	NPSTG	SPSTG	IOSTG	Global scale
25-year averages						
$A_{0.1}$ (km^6)	11.0 (3.1%)	10.6 (2.9%)	30.2 (8.4%)	29.2 (8.1%)	13.0 (3.6%)	94.0 (26.1%)
$A_{0.07}$ (km^6)	7.3 (2.0%)	7.1 (2.0%)	21.9 (6.0%)	18.5 (5.1%)	6.7 (1.8%)	61.5 (16.9%)
$A_{0.04}$ (km^6)	2.3 (0.6%)	1.5 (0.4%)	1.0 (0.3%)	8.5 (2.3%)	1.1 (0.3%)	14.4 (3.9%)
$Chl_{0.1}$ (mg/m^3)	0.061	0.061	0.062	0.059	0.068	-



Results

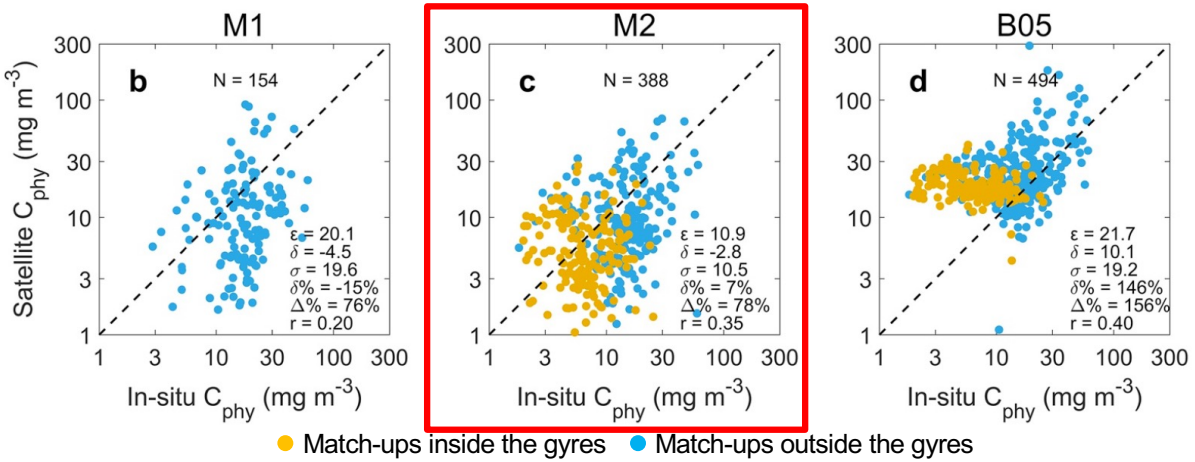


	NASTG	SASTG	NPSTG	SPSTG	IOSTG	Global scale
Linear variation rates (% yr^{-1})						
$A_{0.1}$	+0.07	+0.09	+0.27	-0.26	+0.37	+0.07
$A_{0.07}$	**+0.33**	-0.03	**+0.87**	-0.22	**+0.67**	**+0.32**
$A_{0.04}$	**+3.83**	+0.63	**+44.51**	+0.23	**+4.65**	**+1.54**
$Chl_{0.1}$	**-0.27**	+0.05	**-0.35**	-0.08	-0.12	**-0.16**
$Chl_{0.07}$	**-0.32**	+0.02	**-0.30**	**-0.18**	-0.11	**-0.18**
$Chl_{0.04}$	**-0.53**	-0.14	**-0.15**	-0.06	-0.13	**-0.21**
$SST_{0.1}$	**+0.09**	+0.03	+0.07	**+0.21**	**+0.20**	**+0.12**
$SST_{0.07}$	**+0.07**	**+0.08**	-0.006	**+0.24**	**+0.21**	**+0.11**
$SST_{0.04}$	**+0.08**	**+0.15**	+0.05	+0.07	**+0.28**	**+0.12**

$p<0.05$

Phytoplankton biomass calculation*

*Yang et al., 2024



$$Chl = \underbrace{13000\,(b_{bp} - b_{bNAP})}_{\text{Biomass } (C_{phy})}\ \underbrace{[\theta_{min} + (\theta_{max} - \theta_{min})\,exp^{-3PARg}}_{\text{Photoacclimation}}$$

→ Two unknowns (b_{bNAP} and θ_{min}), derived using non-linear least-squares regression.

b_{bp} = particulate backscattering coefficient

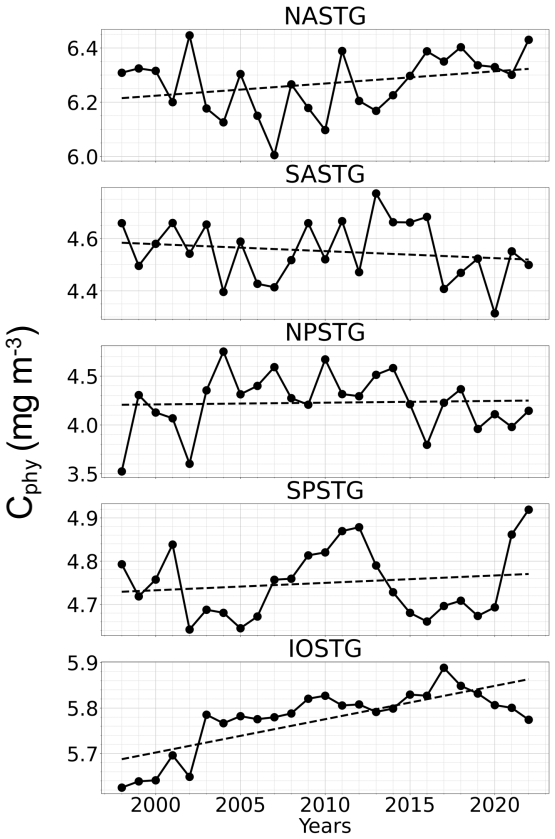
b_{bNAP} = non-algal particle fraction

θ_{min} = term accounting for nutrient limitation under saturated light conditions on Chl and C_{phy}

θ_{max} = term accounting for temperature effect on Chl and C_{phy}

PARg = median PAR value in the mixed layer

Results



	NASTG	SASTG	NPSTG	SPSTG	IOSTG	Global scale
Linear variation rates (% yr^{-1})						
$Chl_{0.04}$	**-0.53**	-0.14	**-0.15**	-0.06	-0.13	**-0.21**
$C_{phy0.04}$	+0.07	-0.06	+0.04	-0.17	**+0.12**	+0.01
$\theta_{0.04}$ (Chl/C_{phy})	**-0.70**	-0.08	-0.23	-0.09	**-0.25**	**-0.23**
$SST_{0.04}$	**+0.08**	**+0.15**	+0.05	+0.07	**+0.28**	**+0.12**
$MLD_{0.04}$	+0.11	+0.05	-0.26	-0.17	**-0.37**	-0.13
$PARg_{0.04}$	+0.002	**+0.08**	-0.002	+0.06	+0.03	+0.03

p<0.05

Results

Data correlation coefficients	$Chl_{0.04}$ vs. $SST_{0.04}$	$Chl_{0.04}$ vs. $MLD_{0.04}$	$Chl_{0.04}$ vs. $PARg_{0.04}$
NASTG	-0.36	-0.15	0.17
SASTG	0.13	0.07	-0.23
NPSTG	-0.27	0.15	0.02
SPSTG	0.24	-0.11	0.46
IOSTG	-0.26	-0.38	0.13

Data correlation coefficients	$C_{phy0.04}$ vs. $SST_{0.04}$	$C_{phy0.04}$ vs. $MLD_{0.04}$	$C_{phy0.04}$ vs. $PARg_{0.04}$
NASTG	0.51	-0.50	0.60
SASTG	-0.51	-0.17	-0.41
NPSTG	0.32	0.16	0.44
SPSTG	-0.79	0.26	-0.81
IOSTG	0.75	-0.07	0.16

Main conclusions

Q: Are the subtropical gyres getting larger and more oligotrophic?

A: Yes. The subtropical gyres are expanding and becoming more oligotrophic and warmer over time at the global scale.

Q: Does the chlorophyll decrease imply decreasing phytoplankton biomass?

A: No. The phytoplankton biomass is rather stable over time, suggesting that the physiological adaptation of the phytoplankton community to changing growing conditions may drive observed chlorophyll anomalies and trends.

Q: Which area is the most affected by desertification?

A: The most impacted area is the hyper-oligotrophic core of the NPSTG.

Emerging questions

- How does ocean warming alter the vertical distribution of phytoplankton chlorophyll and biomass?
- How do potential changes in the Deep Chlorophyll Maximum (DCM) and Deep Biomass Maximum (DBM) affect phytoplankton productivity?
- How do these changes impact the transfer efficiency of exported carbon to deeper ocean layers?

Grazie
per l'attenzione

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