Linking phytoplankton ecology with ocean carbon: subpolar lessons from satellite data and CMIP5 models

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A. Introduction/Background

Marine phytoplankton photosynthesis is a critical part of the biological carbon pump, which transfers to depth part of the resulting organic carbon (C), leading to further oceanic CO_2 uptake at the surface and sub-surface ocean C sequestration. Seasonal and interannual physical variability alter nutrients, light, temperature, affecting ocean plankton and in turn air-sea CO_2 fluxes.

- ***We focus on biology in the highly seasonal subarctic Pacific (OSP) and subpolar North Atlantic (NABE) regions of high interest to the EXPORTS project.***

GOALS:

- ***Understand seasonal and interannual behavior of ocean phytoplankton ecology and links with air-sea CO_2 fluxes comparatively in SeaWIFS satellite data and CMIP5 (Coupled Model Intercomparison Project 5) models.***
- **Provide a background study for the NASA-sponsored EXPORTS field campaigns (Export Processes in the Ocean from Remote Sensing, oceanexports.org).**

B. Plankton Seasonality in Satellite Biomass products

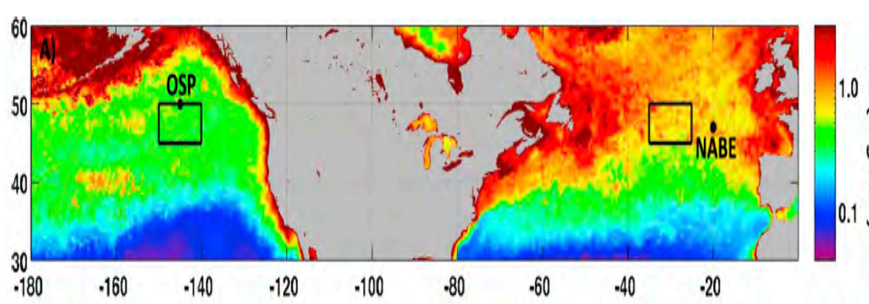


Figure 1: Spring/summer Chl Concentration. 2 black boxes show OSP and NABE. From Westberry et al. 2016

Subpolar North Atlantic (NABE)
Northeast Atlantic (NEA) at ~ 50N and 25W, in the vicinity of NABE (North Atlantic Bloom Experiment).

Tons of Iron; not an HNL region

Phytoplankton Light limited and macronutrient limited.

Subpolar North Pacific (OSP)

Ocean Station PAPA in the Subarctic Northeast Pacific (45-50N, 14-150W)

HNLC (high nutrient-low chlorophyll) Region

Fe and light limited phytoplankton growth.
Tons of macronutrients.

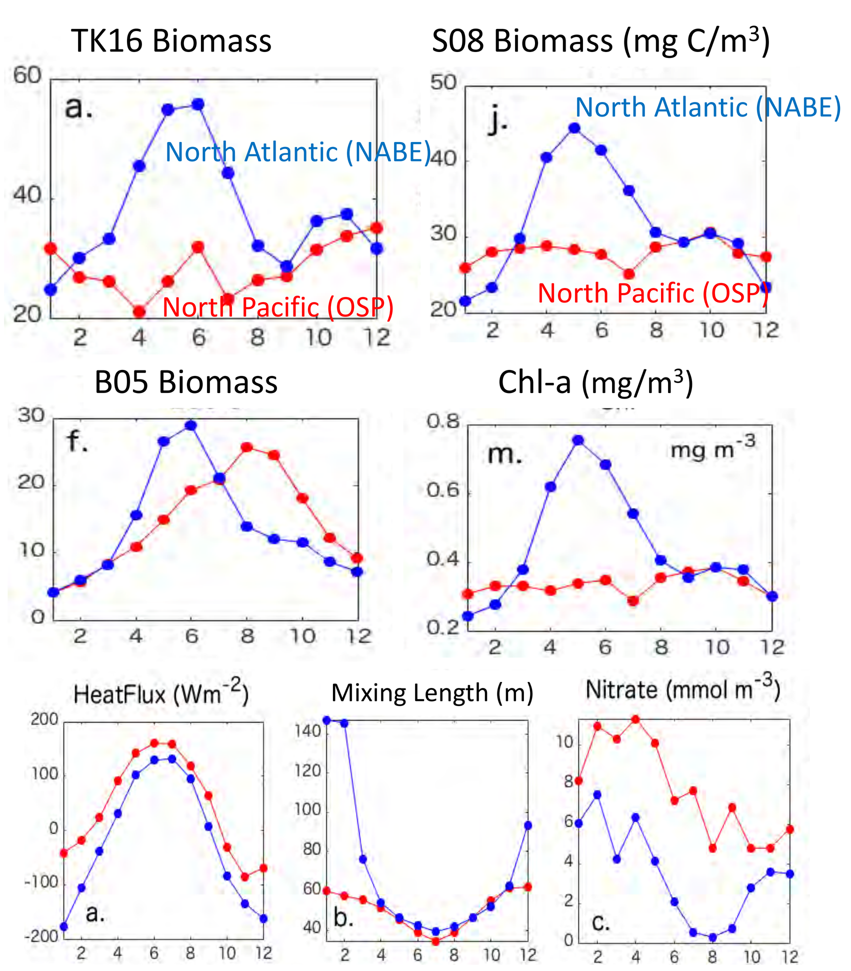


Figure 2: Seasonal Cycle of phytoplankton Biomass C (TK16, S08, B05 satellite products), Chl, heat flux, nitrate and active mixing length scale for the OSP (in red) and NABE (in blue) sites.

MAIN FINDINGS

Weaker seasonal cycle of Phytoplankton C and Chl in the subpolar North Pacific compared to the North Atlantic in the TK16, S08 products (but not B05)

WHY?

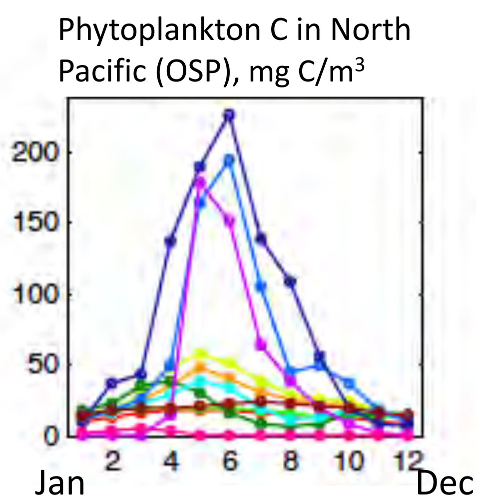
➢ *THEORY*

Different Spring bloom drivers at OSP and NABE

OSP: Grazers + Lack of Iron = keep phyto in check. Weak Spring bloom

NABE: As the ocean gains heat → ↑ stratification ↓ mixing → winter nutrients and plankton trapped closer to surface → ↑ light → strong spring bloom.

C. Compare subpolar OSP and NABE biology seasonality across CMIP5 models



We analyze Phytoplankton seasonality across CMIP5 models. Spread in plankton Biomass larger across CMIP5 models compared to satellite datasets Fig 2.

In agreement with satellite observations, we find that the more complex ecological models (Group 1, black circle in Fig 3) **show weaker Phytoplankton Biomass and Chl-a seasonal cycles and spring blooms in the N Pacific OSP relative to North Atlantic NABE. Why?**

Proposed Mechanisms:

Less deep (Iron/Nitrate) supply at OSP + less wintertime vertical mixing at OSP → *more surface Iron limitation in the North Pacific*

Larger (Zoo/Phyto) at OSP →

Tighter Zooplankton control on phytoplankton at NP

→ *Weaker seasonal cycle of Biomass and Chl at OSP.*

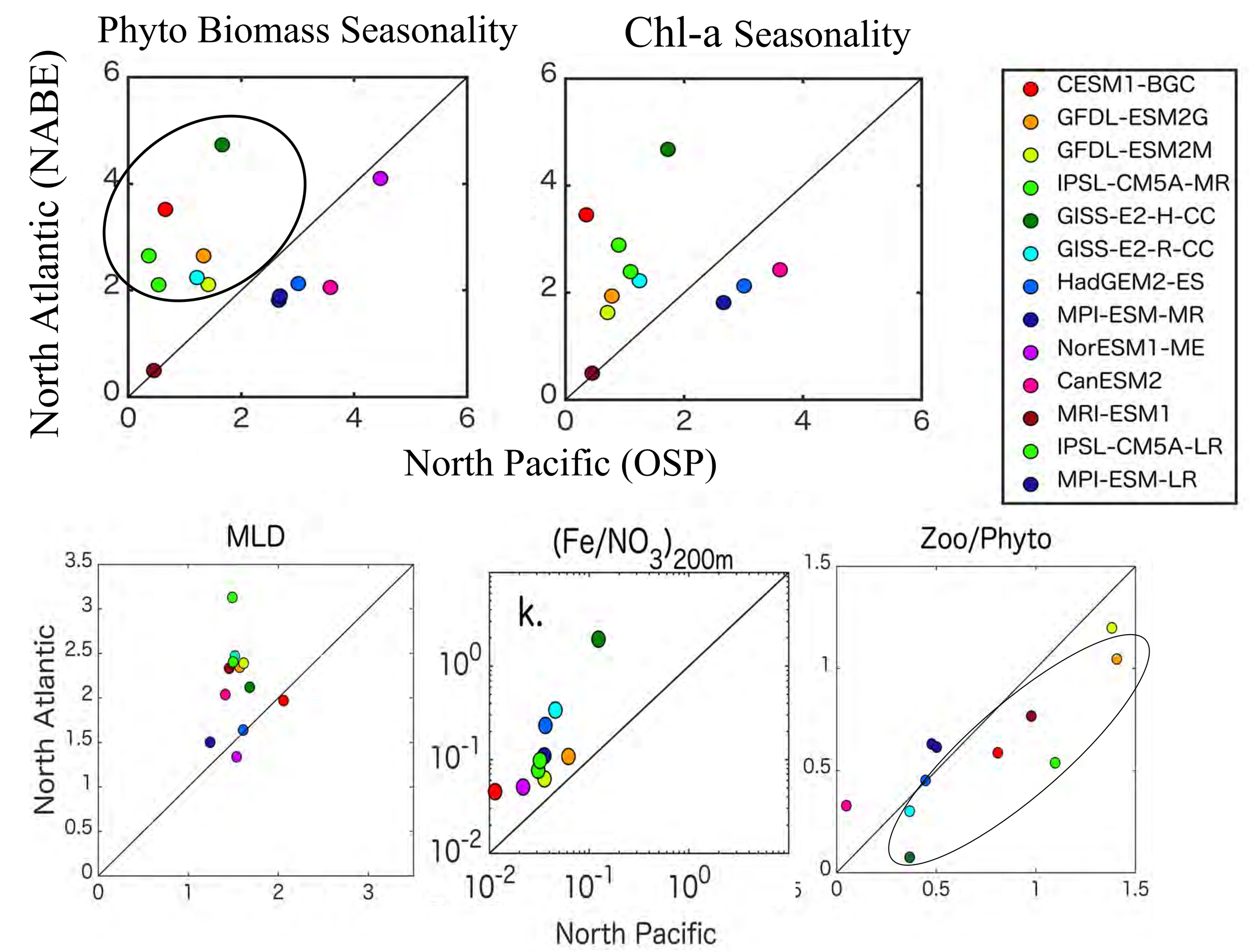


Figure 3. Comparing model variables in the North Atlantic (NABE) versus North Pacific (OSP). Variables are: Strength of seasonality (max-min/ave) in phytoplankton biomass (C), Chl-a, mixed layer depth. Annually averaged ratio of Iron to Nitrate at 200m, ratio of surface zooplankton to phyto biomass.

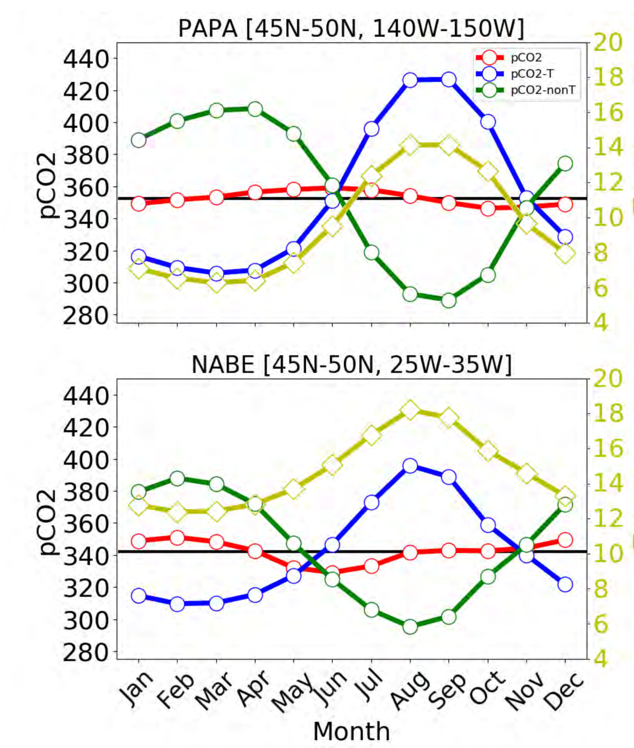
Datasets used: Sept 1997- Dec 2010	Details: Monthly resolution, 1997-2010 Spatial Resolution used: 1 degree
TK16 Phytoplankton biomass (C) B05 Phytoplankton biomass (C) Stramski 2008 Biomass (C) SeaWiFS chlorophyll (Chl) OAFLUX Heatflux surface ocean pCO_2	SeaWIFS biomass of Kostadinov et al. (2016) SeaWIFS biomass of Behrenfeld et al.2005 SeaWIFS biomass of Stramski et al. 2008 All Biomass expressed in Wm^{-2} (in ppm), SOCAT v3, statistical interpolation
CMIP5 Model Variables (13 models), historical runs, 1997-2010.	Phytoplankton Biomass, Nitrate, Chl, Iron, zooplankton, Mixed layer depth.

D. Seasonal cycle of surface pCO_2 – links with ocean biology

We define 2 components of surface pCO_2 from the annual mean values (Takahashi et al. '93, analysis inspired by Fay and McKinley '07):

$$pCO_2 - T = \overline{pCO_2} \times \exp[0.0423(SST - \overline{SST})]$$ Temperature-driven pCO_2

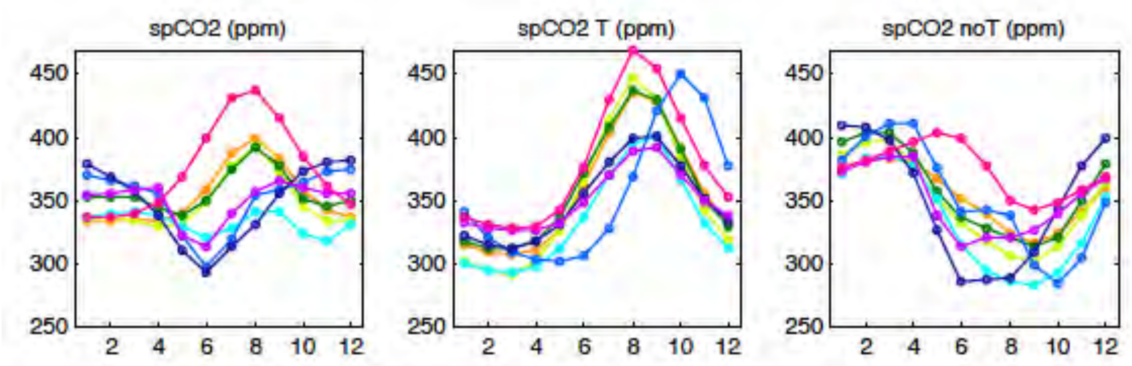
$$pCO_2 - nonT = pCO_2 \times \exp[0.0423(\overline{SST} - SST)].$$ Non temperature pCO_2 influenced by biology



Seasonal cycle of surface pCO_2 and its two components:

Fig 4 (left): Observed in the SOCAT data, at OSP and NABE.

Fig 5 (right): across CMIP5 models at OSP. The degree of seasonal compensation between the 2 components varies widely across models !

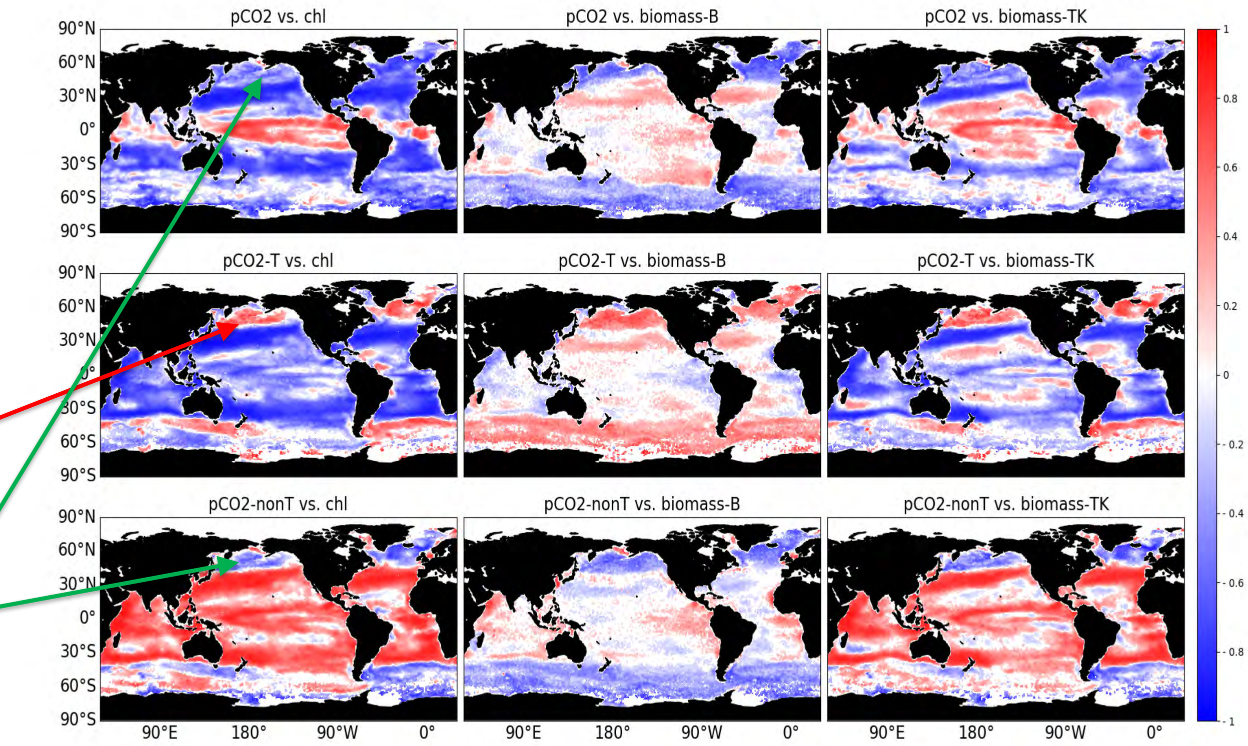


Can we understand surface pCO_2 based on Chl or biomass?

Fig. 6 below: Correlations between observed pCO_2, temperature and non-temp pCO_2 components and Chl (Column 1), Behrenfeld B05 biomass (Column 2), TK16 biomass (Column 3).

In subpolar regimes: **Total pCO_2 represents a close compensation between Temperature and non-Temperature driven components.** Ocean biology influences strongly pCO2-non-T.

Spring/summer or warmer years:
(a) Warmer ocean, lower solubility and more pCO_2–T in surface water (less CO_2 converted into HCO_3^-, CO_3^{2-}) → *positive (Chl, pCO_2-T) correlation.*
(b) Phytopl blooms; more productivity and Chl → more CO_2 uptake → less pCO_2 –nonT. → *Negative (Chl, pCO_2-nonT) correlation.*
This drives the total negative total pCO_2 – Chl correlations in the N Atl and N Pac.



SeaWIFS TK16 biomass more similar to Chl. B05 and TK16 products make different predictions about plankton-pCO_2 links.

E. Summary and Future Directions

- ➢ **Phytoplankton Spring bloom much weaker in the North Pacific (OSP) compared to North Atlantic (NABE)** in some satellite observations (TK16 and S08 biomass, Chl but not in B05 biomass), and in the complex (Group 1) CMIP5 climate models.
- ➢ **Theory: Less Iron supply and tighter zooplankton control on phytoplankton → weaker seasonal cycles of biomass at OSP compared to NABE.**
- ➢ **Subpolar regimes: Biology very important for setting surface pCO_2 and hence atmospheric pCO_2 fluxes.**

NEXT STEPS :

- Ongoing comparative analysis of Phytoplankton size group dynamics at OSP and NABE, in satellite data and CMIP5.
- Compare iron limitation in CMIP5 models and real data at OSP/NABE. CMIP5 models –not enough Fe limitation?

What iron data do people recommend I use ?

Working Question: Can we use the strength of the seasonal cycle of phytoplankton biomass/phytoplankton groups/NPP/export seasonal cycle to predict surface pCO_2?

Plan: Use novel satellite biomass datasets and CMIP5/CMIP6 models for this.

References

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