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Phytoplankton-Light Feedback and Climate Change : Polar Surprises ?

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INTRODUCTION

• **Phytoplankton** biomass can modulate **irradiance** penetration impacting **ocean physics** and establishing a **biophysical feedback**.

• Empirical estimates based on climate models (Sarmiento *et. al.*, 2004) suggest that **climate change** will impact the geographical distribution of surface phytoplankton biomass (SPB) that would **increase** in the **sea-ice covered oceans**.

• How will climate change alter this biophysical feedback if SPB changes in the **polar oceans** ? And how will **sea-ice cover (SIC)** will respond to that perturbation ?

METHODS

We use a global Ocean-Sea-Ice GCM **ORCA-LIM** (Timmermann *et al.*, 2005), that computes the physical ocean variables, coupled to the **Dynamic Green Ocean Model** (Le Quéré *et al.*, 2005) that computes [Chl], the key variable of this study. We run two simulations from 2005 to 2061 where we implement an atmospheric forcing (see description below) accounting for climate change. We apply this forcing to two versions of our model :

[1] Blue Ocean (BO) : In this version **we do not implement** the phytoplankton-light feedback. Irradiance at depth (I_z) is computed following the Paulson & Simpson 1977 parametrization where penetration depth scales of light (ξ) are set to the case of clear **oligotrophic waters** as follows :

$$I_z = I_o*[R*e^{-z/\xi 1}+(1-R)*e^{-z/\xi 2}]$$

where $\xi_1 = 0.35$ m, $\xi_2 = 23$ m, R=58, I_o is surface irradiance, and z is depth.

[2] Green Ocean (GO) : In this version **we implement** the phytoplankton-light feedback using the Morel 1988 parametrization where the **light penetration depth scale is inversely correlated to [Chl]** :

$$\xi = 1/k = 1/\{k_{sw} + a*[Chl]^b\}$$

where **k** is the light attenuation coefficient (lac), ksw is the lac of seawater and a and b are empirical coefficients. We use two averaged bands, red (ξ_r) and blue/green (ξ_b) splitting the visible part of the light in two parts and rearranging the previous equations as follows :

$$I_z = \{[I_o*R*e^{-z/\xi 1}]+[\gamma*e^{-z/\xi r}]+[(\gamma*e^{-z/\xi b}]\}$$
$$\gamma = (I_o/2)*(1-R)$$

RESULTS

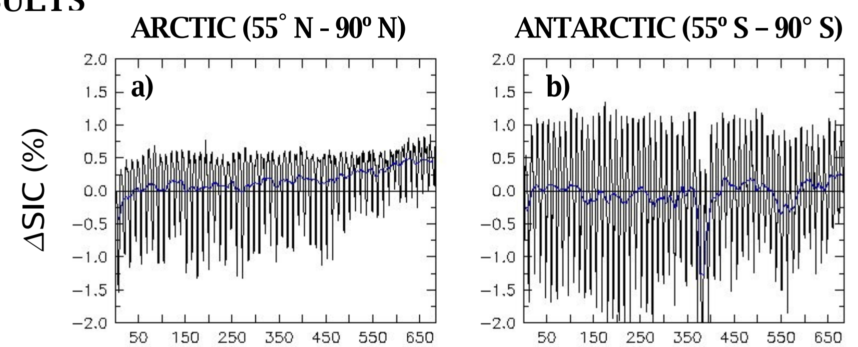
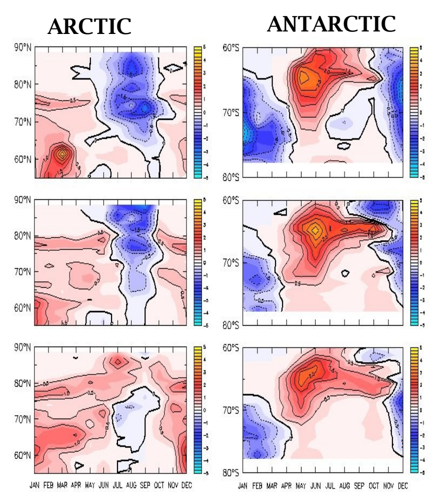


Fig. 1. Time-series of ΔSIC (GO minus BO) from 2005 to 2061. Model output are zonally (full length) and meridionally (55 to 90) averaged. Black thin line shows monthly difference and blue thick line shows 12-month running mean.



[1] The biophysical feedback produces an **amplification of SIC** in present climate conditions with **extra-melting in summer** (blue shades) and **extra-formation in winter** (red shades) (Manizza *et al.*, 2005; not shown here).

[2] While climate change progresses SIC reduces because of ocean warming. **Arctic Ocean Warming is faster than that in the Antarctic** (faster ocean heat uptake) and so SIC reduction is too. In the Arctic the faster reduction in SIC in summer generates **a progressive imbalance in SIC amplification** with evident dominance of winter effect (Fig 2, left panels).

[3] In the **Antarctic Ocean**, although climate change forcing progresses, the biophysical feedback **maintains the same mode operation** shown for present ocean climate (Fig. 2, right panels). with an amplification which remains active in both seasons.

[4] In the Arctic Ocean the imbalance in the amplification of SIC follows a clear trend (Fig.1a) that seems **to counteract the progressive SIC reduction** driven by climate change applied to both versions of of the model.

Fig. 2. Time-latitude plot of ΔSIC for (top) 2020, (middle) 2040, and (bottom) 2061 . Output are zonally averaged.

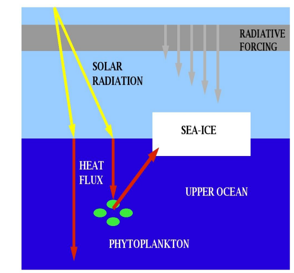
MODEL FORCING

Climate change forcing ψ(CC) is calculated from the climate anomaly form the output of the IPSL climate model and we apply a 30-year running mean $\psi(IPSL_{30RM})$ that is added to the re-analyzed NCEP atmospheric forcing for present climate ψ(NCEP) as follows :

$$\psi(CC) = \psi(NCEP) + \psi(IPSL_{30RM})$$

We obtain a simulated forcing form 2005 to 2061. The output of the IPSL climate model refers to emissions scenario A2 according to IPCC. We impose this forcing to our Ocean-Sea-Ice GCM apply in both simulations (*BO* and *GO*).

PROCESS



Biophysical Feedback & Climate Change

HIGHLIGHTS

[1] This study shows that **phytoplankton** can be considered another **physical player** of the Climate System.

[2] This **biophysical feedback** might add further **non-linearity** to the response of Earth"s Climate to anthropogenic forcing.

[3] SIC melting due to climate change overtakes the potential meting effect due to the increase in SPB in the polar oceans (not shown here).

FUTURE DIRECTIONS

[1] When the Antarctic Ocean will be showing the **same imbalance** shown in this study by the Arctic Ocean if climate change progresses at the same rate ?

[2] How important could be the **feedback to the atmosphere** of this biophysical on the radiative forcing via **planetary albedo ?**

To answer these questions simulations with the **MIT Earth System Model** are planned to explore new potential **biogeophysical feedbacks** between the Earth System and marine biota.