The effect of mixed layer deepening and sea ice on spatial variability in phytoplankton bloom dynamics in the Southern Ocean

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ABSTRACT

We explore spatial variability in phytoplankton bloom phenology, magnitude and dynamics across the entire Southern Ocean using high-temporal resolution output from the Community Earth System Model (CESM). The simulation utilizes a recently improved treatment of photosynthesis under sea ice. Population specific net biomass accumulation and cell growth growth rates are studied to characterize regional controlling mechanisms on bloom dynamics. Early results suggest a possible poleward transition from dominance of trophic interactions to growth conditions (i.e. nutrient and light availability). Spatial variability in the relevant physical processes (sea ice, mixed layer depth, etc.) appears to play a critical role in mediating this transition.

Methods and Metrics

We analyze daily-mean output from a global, 1-degree spatial resolution, 30 year Community Earth Systems Model simulation using an improved quantification of photosynthesis under sea ice[1].

Following Behrenfeld et al. (2013)[3] depth integrated diatom Chl (ΣChl) and carbon (Σc_{phyto}) inventories where calculated as the product of the surface concentration and the greater of the mixed layer depth or euphotic depth, estimated empirically following Morel (1986)[2]

Population specific net biomass accumulation rate 'r' is defined as the difference between phytoplankton specific cell division rate, *'u'*, and the loss rate, 'l', composed primarily of mortality from grazing

$$r = u - l \qquad \text{Eq. 1}$$

'r' is approximated following Behrenfeld et al (2013)[3] using the time rate of change in population specific phytoplankton biomass concentration and depth integrated biomass inventory as follows,

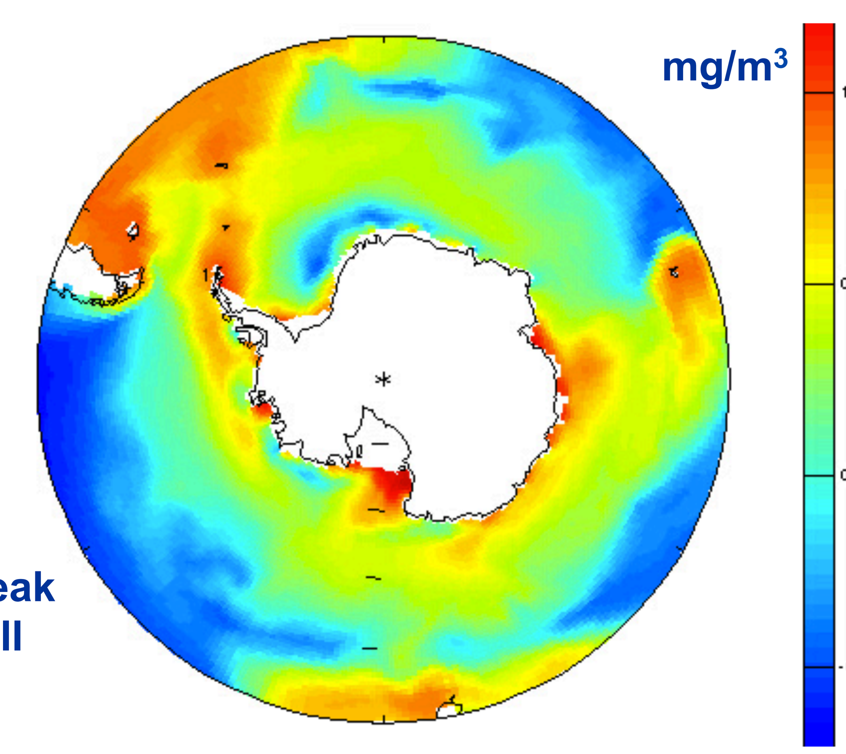
$$r = \ln\left(\sum C_{phyto-1} / \sum C_{phyto-0}\right)/\Delta t$$ Mixed layer deepening and greater than euphotic depth

$$r = \ln\left([C_{phyto-1}] / [C_{phyto-0}]\right)/\Delta t$$ Mixed layer shoaling or less than euphotic depth

Phytoplankton specific cell division rates, 'u' were found by dividing the water column integrated daily net primary production (Diatom C Fixation Rate (mmol/m^2/d)) by the, depth integrated Phytoplankton Carbon inventory, Σc_{phyto}

Results

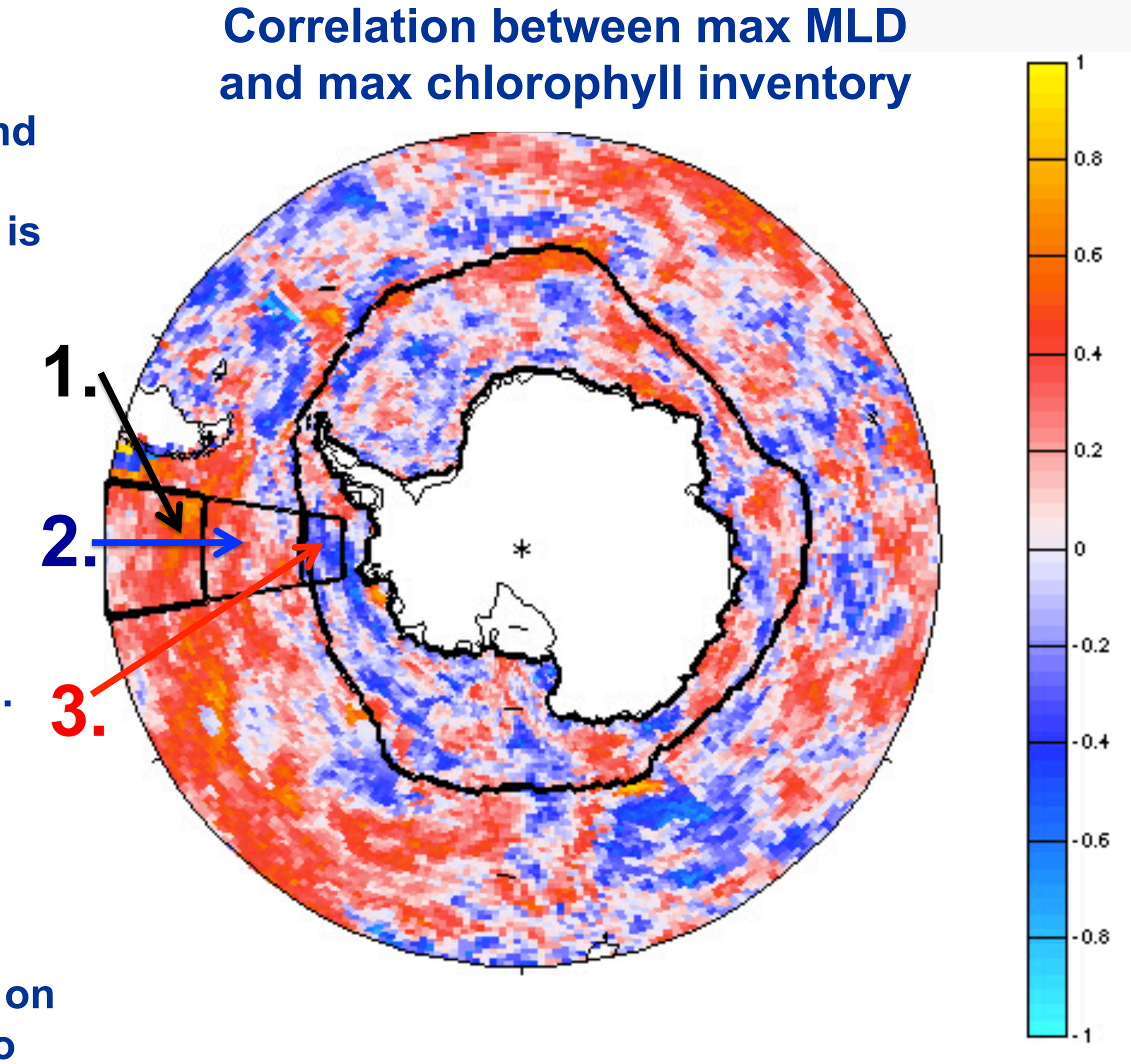
Figure 1. Log Mean peak annual surface chlorophyll across the southern ocean. Note the significant increase in bloom magnitude moving pole ward and along coastal regions at lower latitudes



Log mean annual peak surface chlorophyll

Correlation between max MLD and max chlorophyll inventory

Figure 2. The inter annual correlation between the maximum mixed layer depth and maximum Σc_{phyto}. The annual mean 30% ice fraction contour is included, along with outlined regional bins:
1 (55S - 45S, 100W-80W)
2 bin (65S -55S, 100W-80W)
3 (70S -65S, 100W-80W)



Deeper mixed layers lower phytoplankton concentrations working to decouple plankton from predation by zooplankton. This may lead to positive net biomass accumulation in the vertical integral and a strong positive correlation. Weak or negative correlation could suggest a greater dependence on growth conditions improving to trigger bloom initiation.

In Figure 2 stronger positive correlations are more prevalent at lower latitudes and become much rarer once sea-ice begins to appear (black contour).

Regional Hovmoller Diagrams

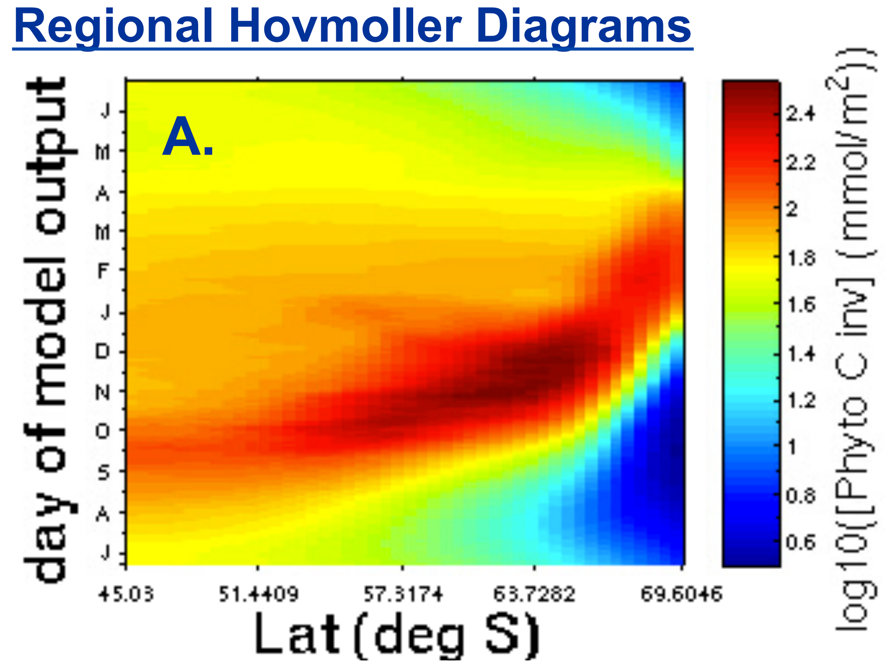
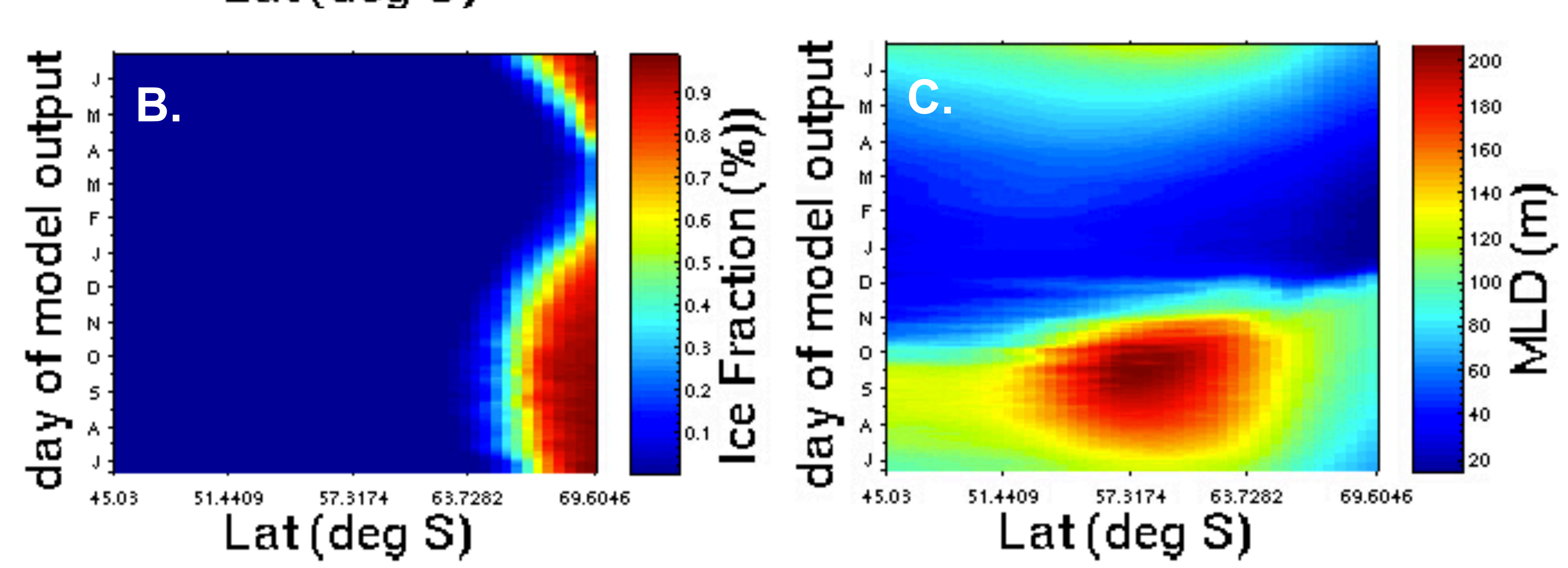


Figure 3. Longitudinally averaged (100W-80W) climatologies plotted for log phytoplankton biomass inventory (Σc_{phyto}) (A), ice fraction (B), and mixed layer depth (C). A large, sustained spring bloom (Sept.-Dec.) is spatially and temporally coherent with prolonged, deep winter mixed layers (Aug.- Nov.). Bloom initiation is delayed and peak intensified in seasonal sea-ice covered regions.



References

1. Long, M. C., K. Lindsay, M. M. Holland, and N. Norton, 2015: Modeling photosynthesis in partially ice covered waters. *Global Biogeochem. Cycles*, **submitted**.
2. Morel, A., and J. F. Berthon (1989), Surface pigments, algal biomass profiles, and potential production of the euphotic layer: Relationships reinvestigated in view of remote-sensing applications, Limnol. Oceanogr., 34(8), 1545–1562.
3. Behrenfeld, M.J., S.C. Doney, I. Lima, E.S. Boss, and D.A. Siegel (2013) Annual cycles of ecological disturbance and recovery underlying the subarctic Atlantic spring plankton bloom, *Global Biogeochem. Cycles*, 27, 526-540, doi:10.1002/gbc.20050

Regional Shift in bloom dynamics

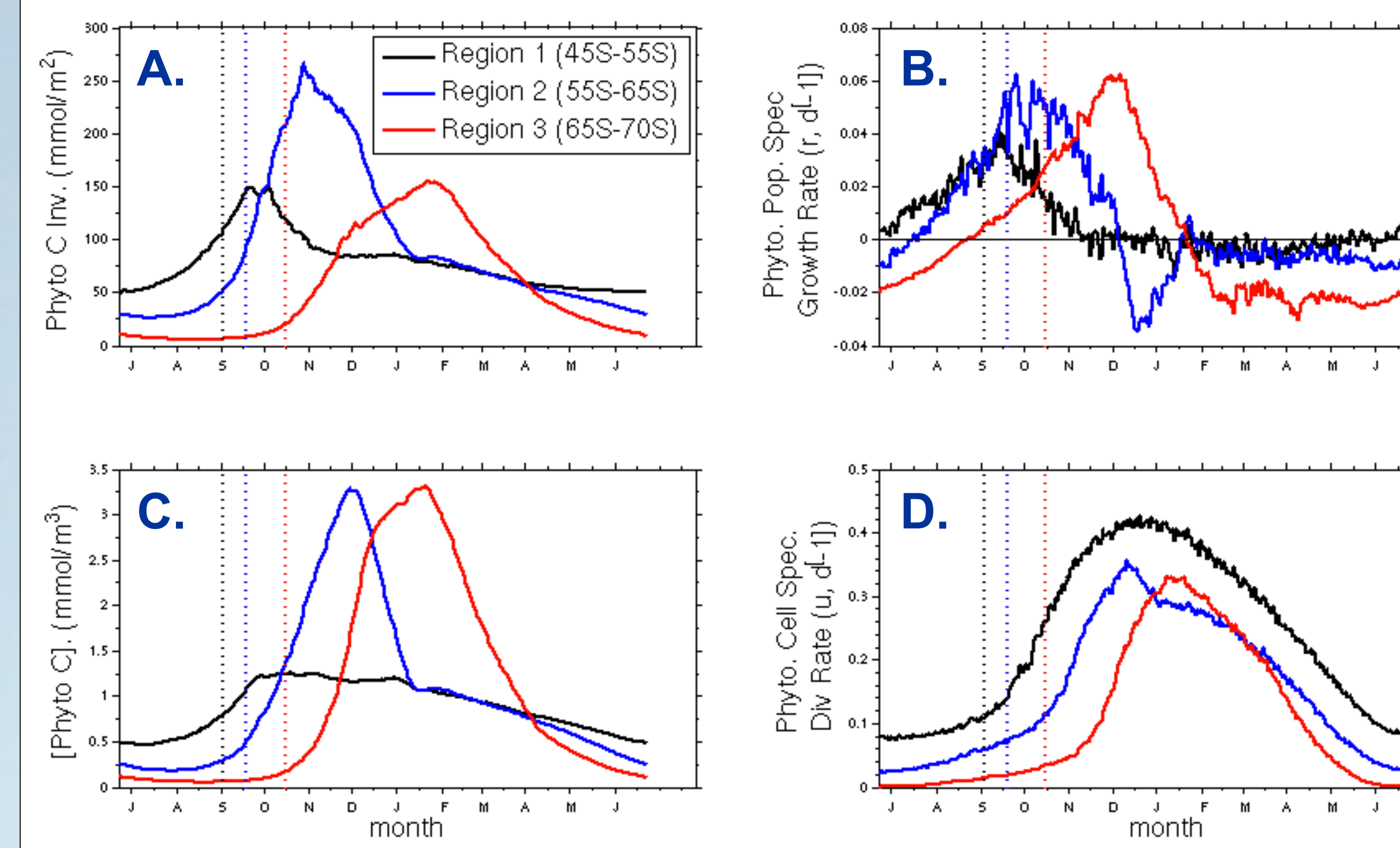


Figure 4. Regionally averaged (100W-80W) climatologies of phytoplankton biomass inventories (A) and concentrations (C) plotted alongside specific rates of net biomass accumulation 'r' and growth 'u'. The highest latitude bin (70S-65S) is plotted in red, the middle bin (65S-55S) in blue and lowest bin (55S-45S) in black. Date of mean maximum mixed layer depth is marked by a dashed line of the according color.

Region 1: Bloom initiation (date when r>0) (Fig. 4B) occurs in early May, while growth rates are still in steep decline (Fig. 4D), potentially indicative of a stronger top-down control on bloom initiation.

Region 2: Correlation between max ΣCphyto and MLD weakens (Fig. 2), and initiation occurs when growth conditions are beginning to improve, albeit still low (Fig. 4B, 4D)

Region 3 (sea-ice regime): Biomass accumulation and growth rates are inline, and peak growth rates are more removed from the peak mixed layer than at lower latitudes. Also inventory declines while concentrations increase.

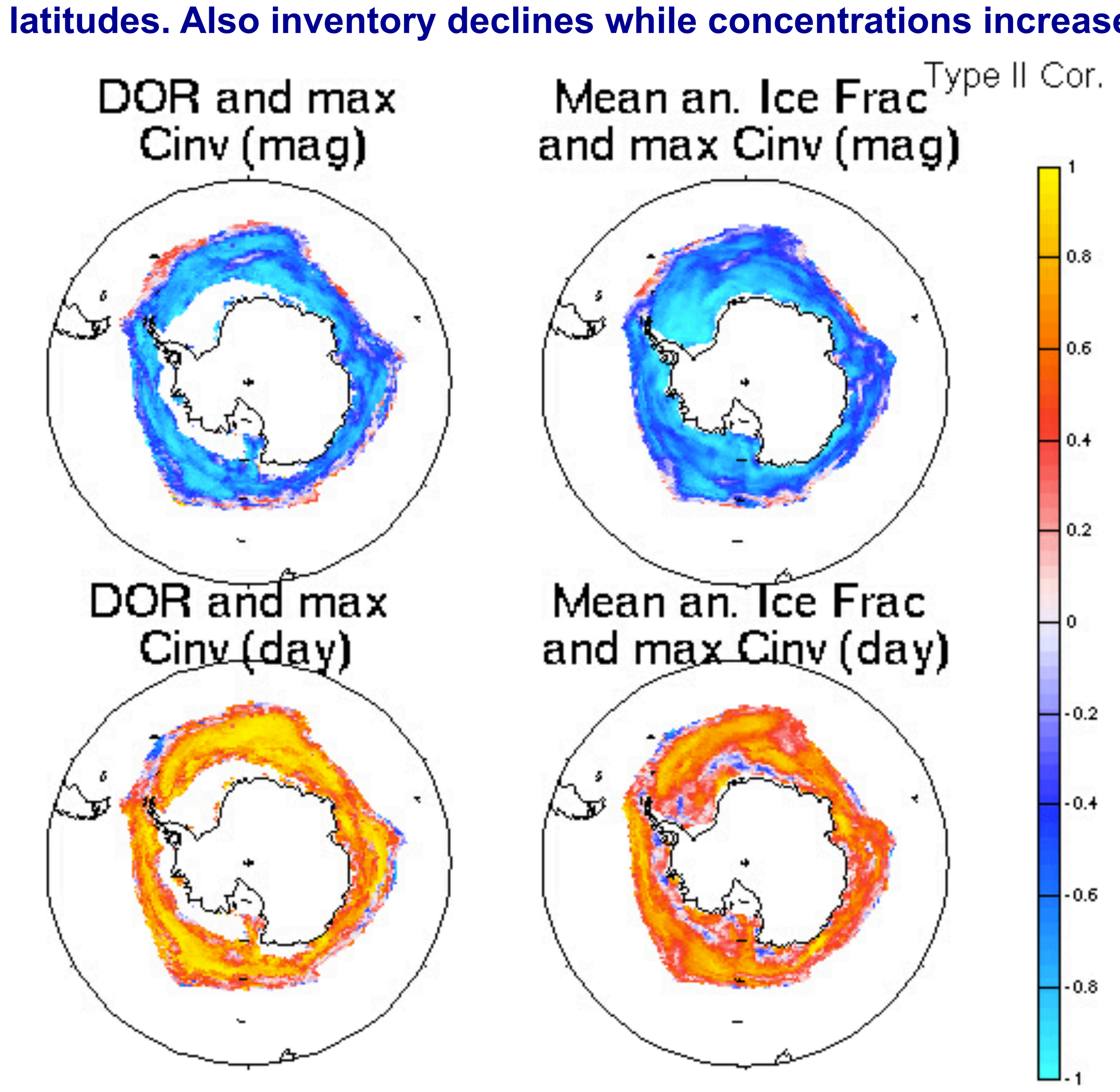


Figure 5. Interannual correlation between mean annual sea-ice fraction, day of sea-ice retreat, magnitude and date of peak phytoplankton biomass inventory. More sea-ice and a longer ice season (implied by a later day of retreat) create a severe bottom-up constraint, dominant over any dilution effects, limiting maximum bloom size. Date of bloom maximum is tied closely (positive correlation) to sea-ice phenology and ice fraction.