Chlorophyll and Black Carbon: Light Absorption in Arctic Sea Ice

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Abstract:

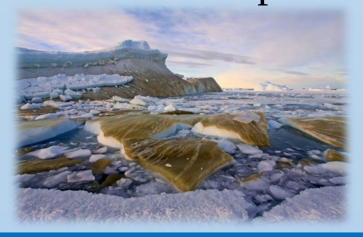
The extent of Arctic sea ice has been declining steadily. Two main factors are the deposition of black carbon (BC) on the snow and ice pack, and the growth of ice algae in the brine channels in vertical layers of ice. We present simulations for the contemporary period showing that the optical depth contributed by the chlorophyll in Arctic ice algal is comparable to BC during the Boreal Spring. The bottom ice layer in the Bering Sea and Sea of Okhotsk shows the greatest absorption where the chlorophyll pigment concentration is estimated to be 300 - 1000 mg m^{-3} whereas ice interior in regions north of 75° N and across the Canadian Archipelago has chlorophyll concentration of less than 0.1 μg m^{-3}. Intermediate level light reduction is observed in the freeboard and infiltration layers. The amount of light penetrates through the ice pack changes as a function of varying ice pack thickness, where the ice algae act as a crucial absorber. Assuming a continuous increase in relative chlorophyll activity and attenuation in the future, as the ice thins, a shift in relative contributions of the two absorber types is expected to occur. The contribution of BC to light absorption in the Arctic may decline as environmental restrictions are enforced.

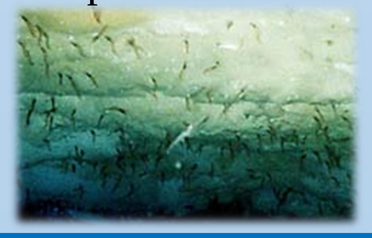
Introduction:

The understanding of the Arctic Biological System and its components is important as it makes a great impact on the global climate. Impurities over the Arctic is considered to have major impact to its environment as it has a potential to lower the surface albedo by changing the surface reflectivity strike due to the transformation of the sea ice to the open water. Although the decrease of the sea ice extent is a major driving force of the positive albedo feedback, the models that represent current global climate are unable to output results that are consistent with actual rates of the sea-ice disappearance.

In order to come up with an outcome that represents current rates accurately, models need to include additional contributions to the melting dynamics. Radiation absorption by BC on Arctic sea ice along the absorption by the chlorophyll are two hypothetical contributors in declining ice coverage. Further, the trajectory of aerosol particles and bio-geochemistry of Polar Regions have to be taken into account to improve Earth system models.

This work prepares us to study more traditional issues such as chlorophyll warming of the pack periphery (Lengainge et al. 2009) and chemical effects of the flow of organics from ice internal communities (Krembs et al. 2011). Modeling of these regional situations can both complement experimental work and help guide future observations.





Method:

A numerical model of a layered ice system was developed to simulate light absorption contribution by the substances of interest – sedimentation of black carbon from the atmosphere onto Arctic snow and ice, as well as chlorophyll-a within the four vertical layers of Arctic sea ice.

Estimation of the light absorption by black carbon distributed from the lower continents to the Arctic Ocean and other high latitude waters/ice relies on BC concentration distributions and deposition fields generated during the base case (IMPRV) experiment described in Qian et al. [2014] using the Community Atmospheric Model (CAM5) [Wang et al. 2013; Qian et al. 2014]. Chlorophyll concentration for algal calculations were obtained by converting bottom-ice algae nitrogen concentrations from Los Alamos Sea Ice Model (CICE) [Hunke et al., 2010], and also by constructing estimates of primary production in other layers through ocean nutrient uptake.

Results:

Figure 1: Spatial distribution of Black Carbon (BC) deposited on snow-ice (during spring season - MAM) absorbs significantly in parts of the Arctic

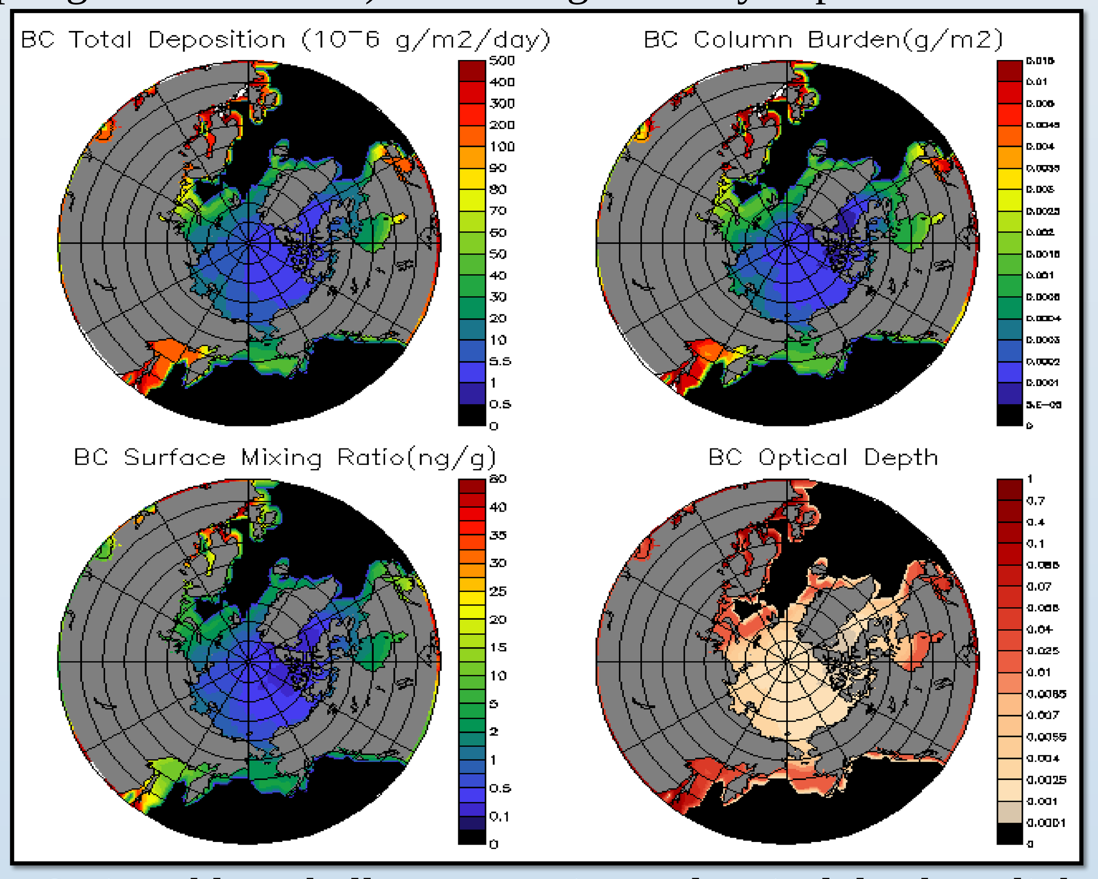


Figure 2a: Spring chlorophyll concentration and optical depth, as light passes through the Infiltration (Inf) layer of Arctic Sea Ice

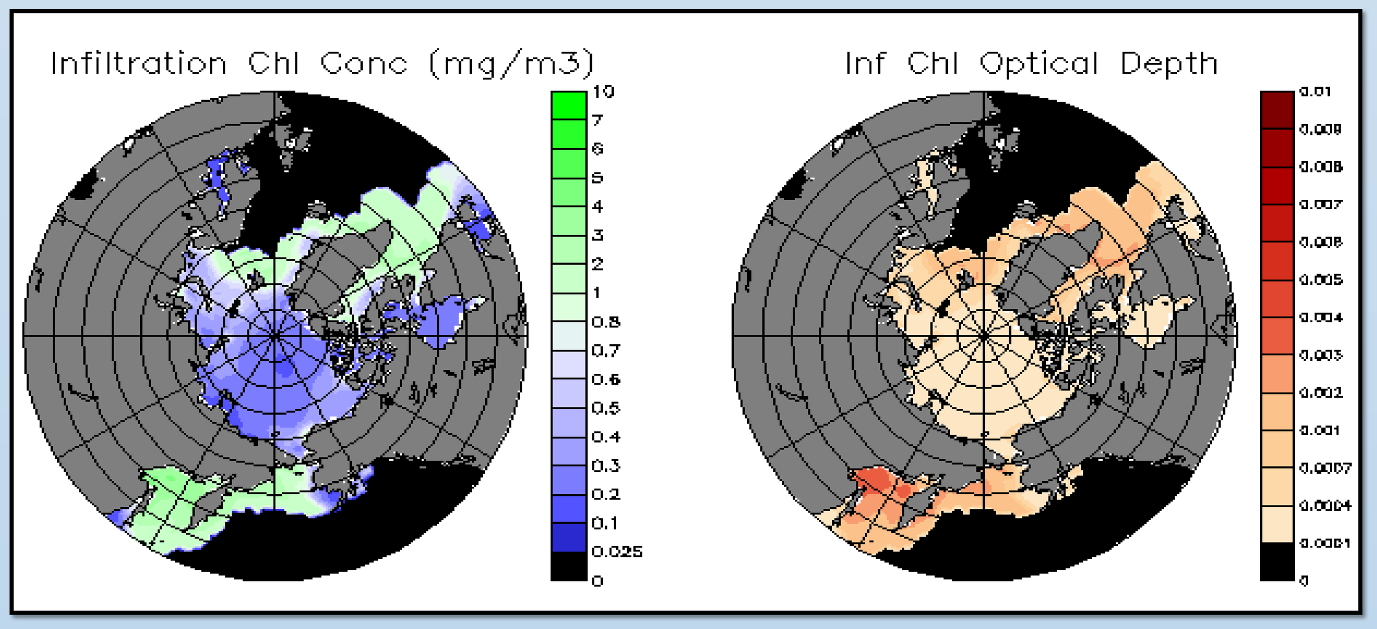


Figure 2b: Spring chlorophyll concentration and optical depth, as light passes through the freeboard (Frbd) layer of Arctic Sea Ice.

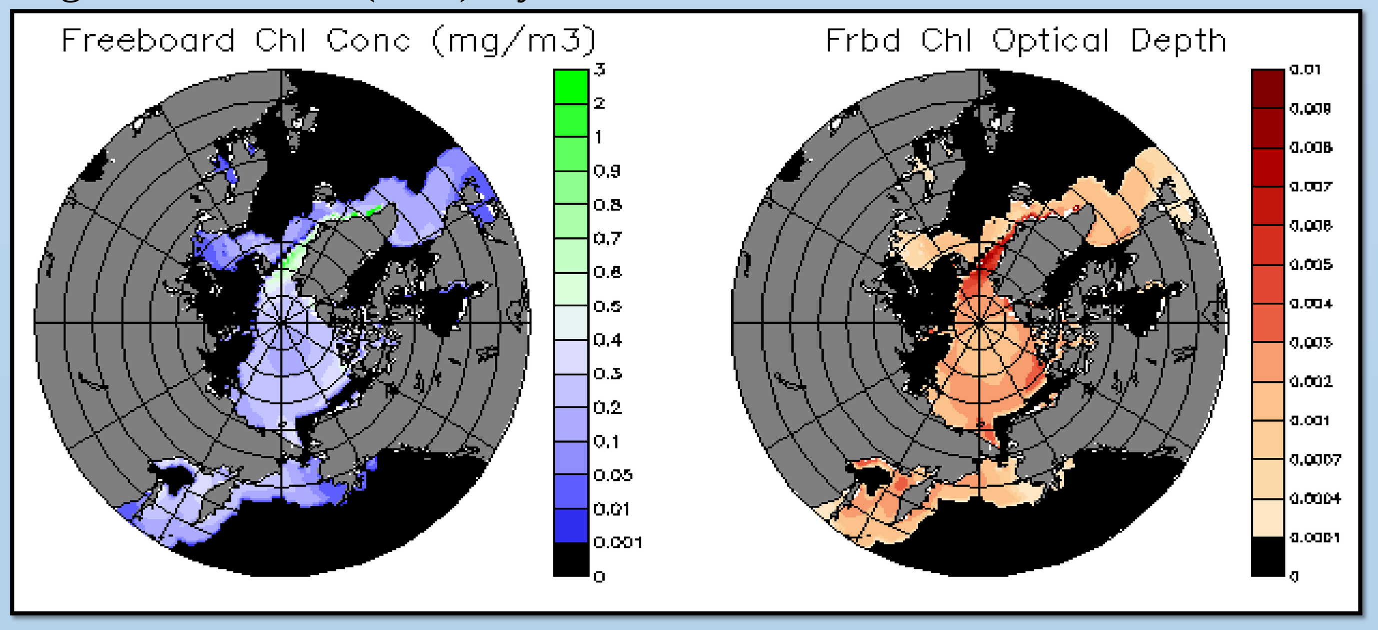
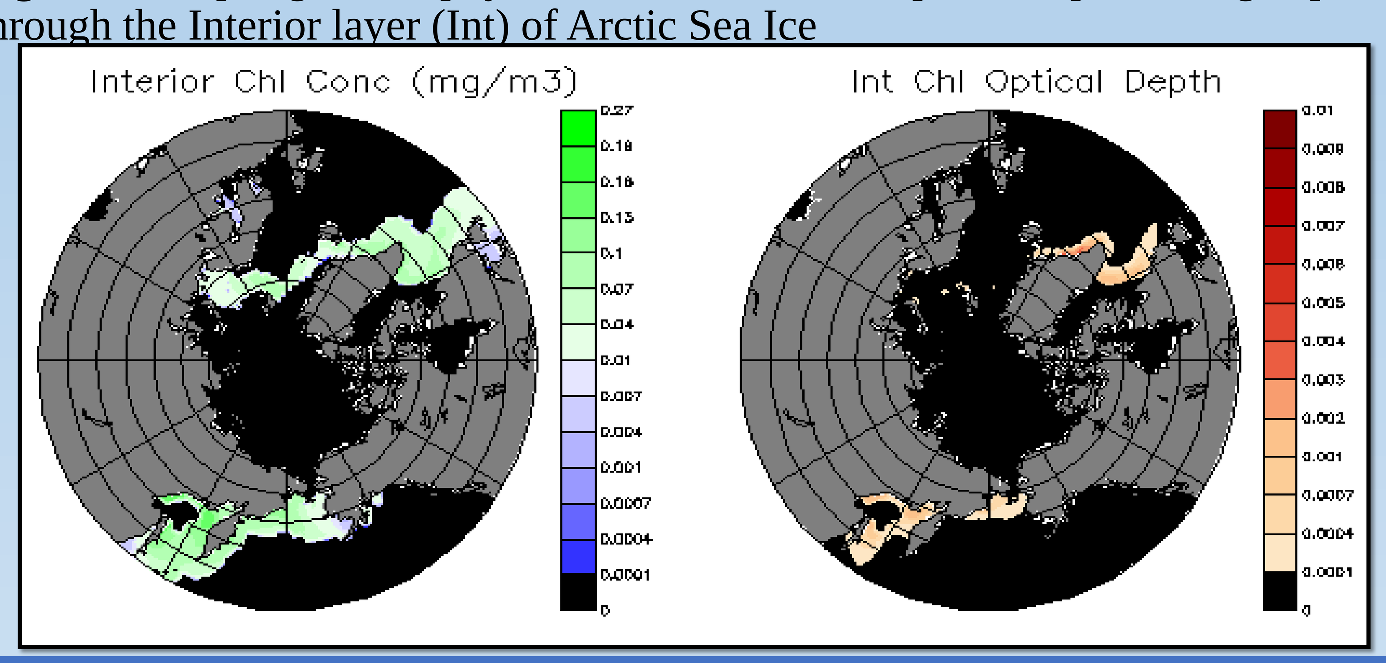


Figure 2c: Spring chlorophyll concentration and optical depth, as light passes through the Interior layer (Int) of Arctic Sea Ice



Results continued:

Figure 2d: Spring chlorophyll concentration and optical depth, as light passes through the bottom (Bot) layer of Arctic Sea Ice

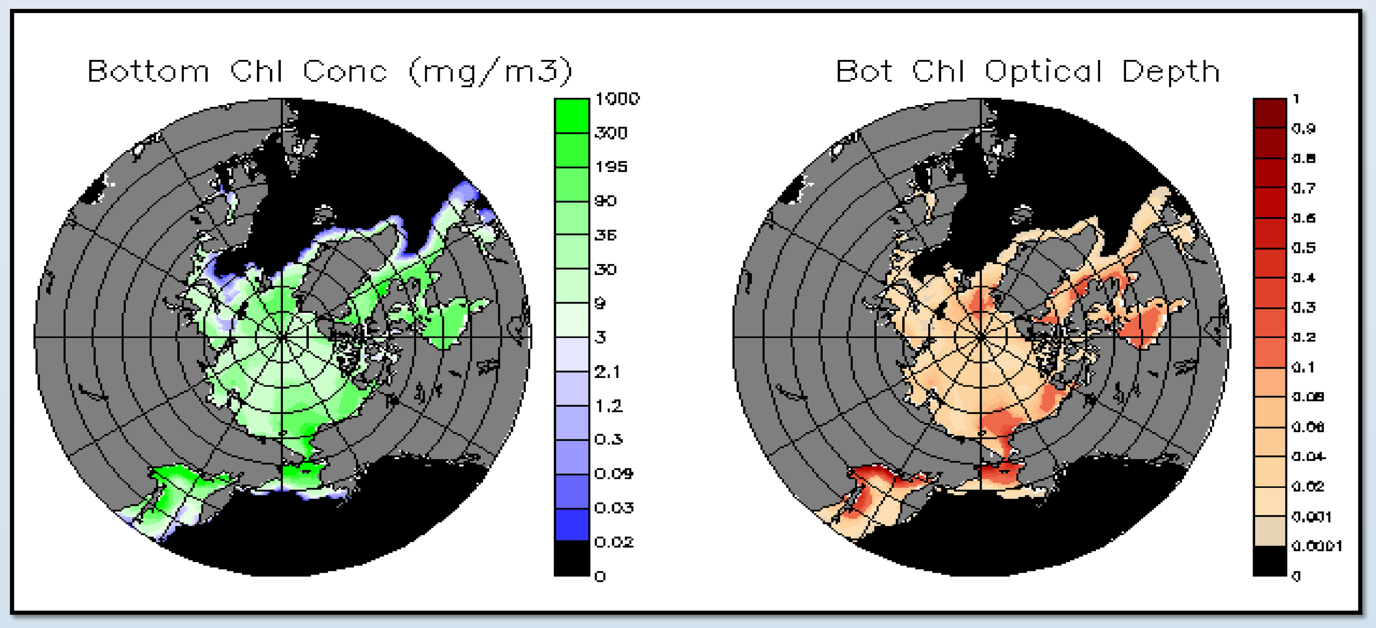
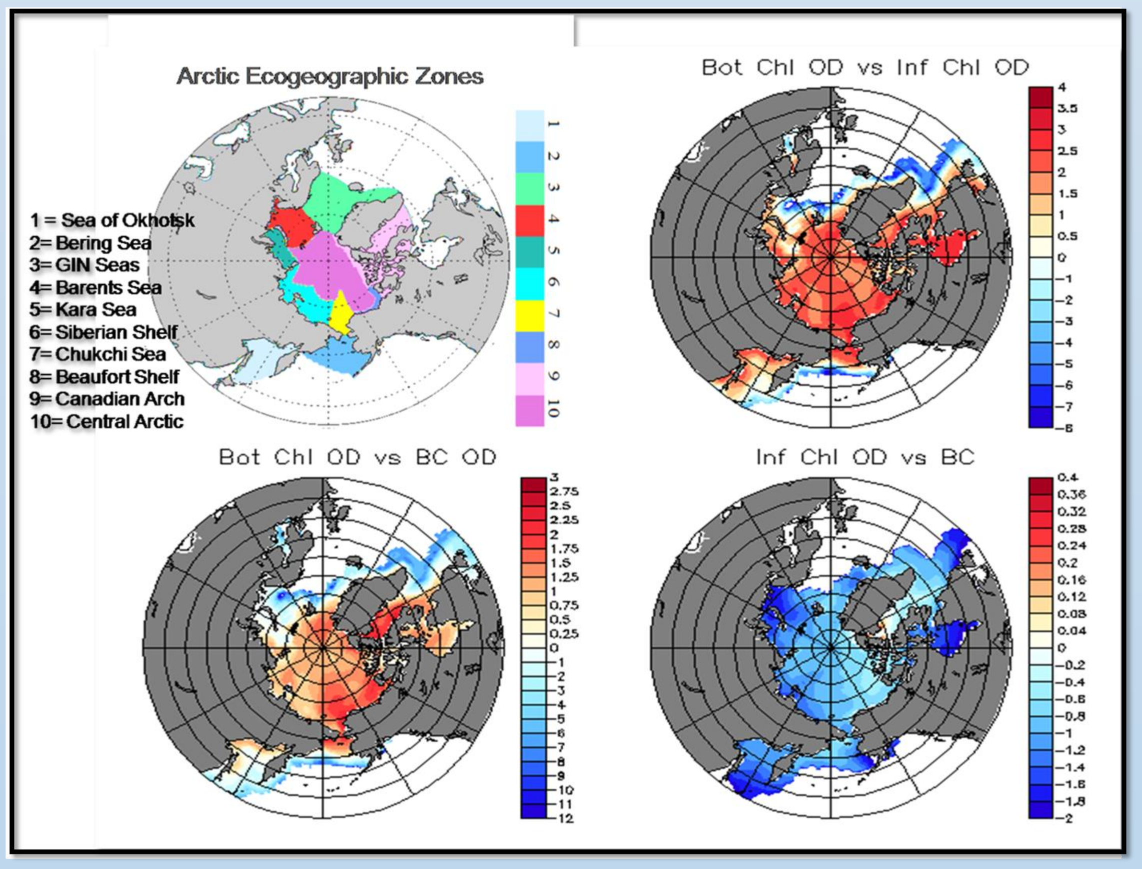


Figure 3: Eco-zones then examples for Arctic Sea ice optical depths, ratioed in permutation to the corresponding values for black carbon and chlorophyll, given as base10 logarithms. Bot = Bottom Layer, Inf = Infiltration Layer, BC = Black Carbon and Chl = Chlorophyll



Discussion and Conclusions:

We hypothesize, the divergence in the real rate of diminishing extent of the Arctic Sea Ice, could be minimize by accounting for the degree of contribution of chlorophyll.

In the boreal spring, light absorption by chlorophyll present in Arctic sea ice may be significant when compared to the contribution of anthropogenic BC. For other seasons, when the light and nutrient regimes are more limited, black carbon deposited on snow may be relatively more responsible for light absorption. As Arctic ice coverage becomes more tenuous in coming decades, it seems possible that chlorophyll will be a major driving force in the light absorption and the energy budget of the polar cap.

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