Phytoplankton Growth Beneath Arctic Sea Ice: A Model Intercomparison Study

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Marine phytoplankton have a strong effect on both the physical and the biogeochemical properties of the Arctic Ocean. In high-latitude environments such as the Arctic, phytoplankton growth is strongly constrained by light availability (Arrigo et al. 2012; Clement Kinney et al. 2023). Because light penetration into the upper ocean is attenuated by snow and sea ice cover, it was generally believed that phytoplankton growth was limited to areas of open water, with little to no growth under the sea ice, until observations indicated unexpected, potentially large production under sea ice (Arrigo et al. 2012). Observations of phytoplankton under sea ice are rare due to the difficulty involved in accessing their pelagic habitat at the time when peak growth is expected (June-July in the Arctic). Shipboard expeditions have often occurred later in the summer season when ice is more navigable (e.g. Aug-Sep, which is after the under sea ice phytoplankton peak). Bottom-moored sensors in the upper water column are at risk of being destroyed by mobile sea ice and are rarely deployed, however ice-tethered profilers have suggested production under the ice as early as February (Hill et al. 2022). Satellite sensors are unable to return data beneath sea ice because of its reflectivity, however, some useful information can still be gained. For example, Payne et al. (2024) found evidence that under ice blooms likely occurred over nearly 40% of the observable seasonally ice-free Arctic Ocean, while marginal ice zone blooms covered 60% in any given year. Despite the difficulty in collecting in situ observations, some datasets detailing the growth and/or abundance of phytoplankton under sea ice exist throughout the Arctic environment. Ardyna et al. (2020; see their Table 1) provide a list of 33 relevant datasets beginning in 1957, with the majority of data collected in the Canadian High Arctic.

The goal of this model intercomparison (MIP) is to utilize multiple regional and global climate models to intercompare historical values of under sea ice phytoplankton biomass and primary production. At present, few studies exist from the modeling community on this topic, however we believe that biophysical modeling studies can shed light on this potentially very important source of carbon production in the Arctic (Jin et al. 2016; Clement Kinney et al. 2020). Modeling groups that have agreed to participate in the present study include: the Community Earth System Model version 2 (CESM2), the Canadian Ocean ecosystem and sea-ice biogeochemistry model (NAA-Canoe-CSIB), the Energy Exascale Earth System Model (E3SM), the Estimating the Circulation and Climate of the Ocean model (ECCO-Darwin), the Center for Climate System Research Ocean Component Model and the Arctic and North Pacific Ecosystem Model for Understanding Regional Oceanography with carbonate chemistry routine (COCO & Arctic NEMURO-C), the Geophysical Fluid Dynamics Laboratory (GFDL) global ocean with the Carbon, Ocean Biogeochemistry and Lower Tropics model (MOM6-COBALT), and the Regional Arctic System Model (RASM). Our MIP plans to evaluate variables from the models including: nitrate, silicate, chl-*a*, water column and, where possible, ice associated primary production, photosynthetically available radiation (PAR), and sea ice concentration. Validation with available datasets that include these variables will be part of this work, although we recognize that the observations will be extremely limited in space and time. Another objective of this work is to evaluate temporal trends in both the under sea ice and the open water chl-*a* and primary production. The project will use historical runs from 1958 to present (over 6 decades of output), which includes a period of an evolving sea ice cover with a dramatic loss of Arctic sea ice in recent decades.

A related question is whether the changing sea ice or other environmental variables has led to a change in the community composition of under sea ice phytoplankton. Although each of the participating models have variable representations of different phytoplankton functional groups, the project will aim to address this question with the available model and observational resources at hand. Perhaps we can provide information on the balance of large diatoms and smaller flagellates and whether the abundances of these groups have changed over time.

The overarching goal of this work is to reduce the uncertainty in estimates of the biomass and growth of under sea ice phytoplankton in the Arctic using a suite of models and their associated outputs, and compile the results in a peer-reviewed open-access paper. In addition, the project will provide information on possible temporal trends in these variables with respect to a changing sea ice cover that is known to have a strong impact on the biogeochemistry of this high latitude environment.

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