A key role for DON remineralization in Arctic sea ice

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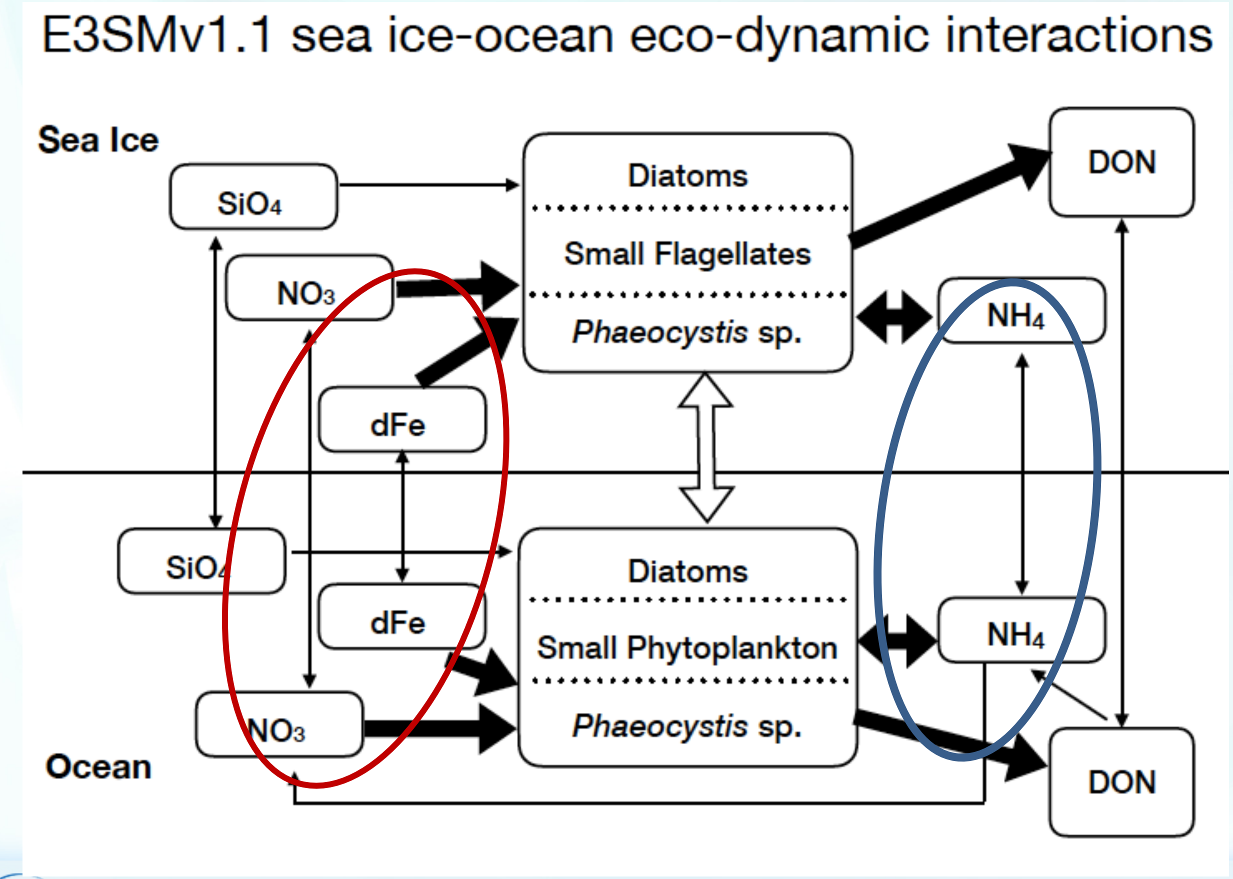
ESMD/E3SM PI Meeting, Oct 26-29, 2020

Introduction

- Sea ice (sympagic) algae provide a key source of primary carbon production in Arctic waters, particularly during winter and early spring.
- This primary production (PP) is tightly coupled with seafloor biogeochemical processes and may be integral to the survival of many polar species.
- In E3SMv1.1-CBGC, we confirmed that nitrate plays a key role in driving variability in Arctic sea ice PP (Jeffery et al. 2020).
- However model *biases in ocean surface nitrate* and *structural biases in the assumed sea ice nitrogen cycle* greatly limit our model's predictive capability…

Structural Biases in V1 Sea Ice BGC

- In version 1 of E3SM, we have two sources of nitrogen from the ocean – Nitrate (NO_3) and Ammonium (NH_4)

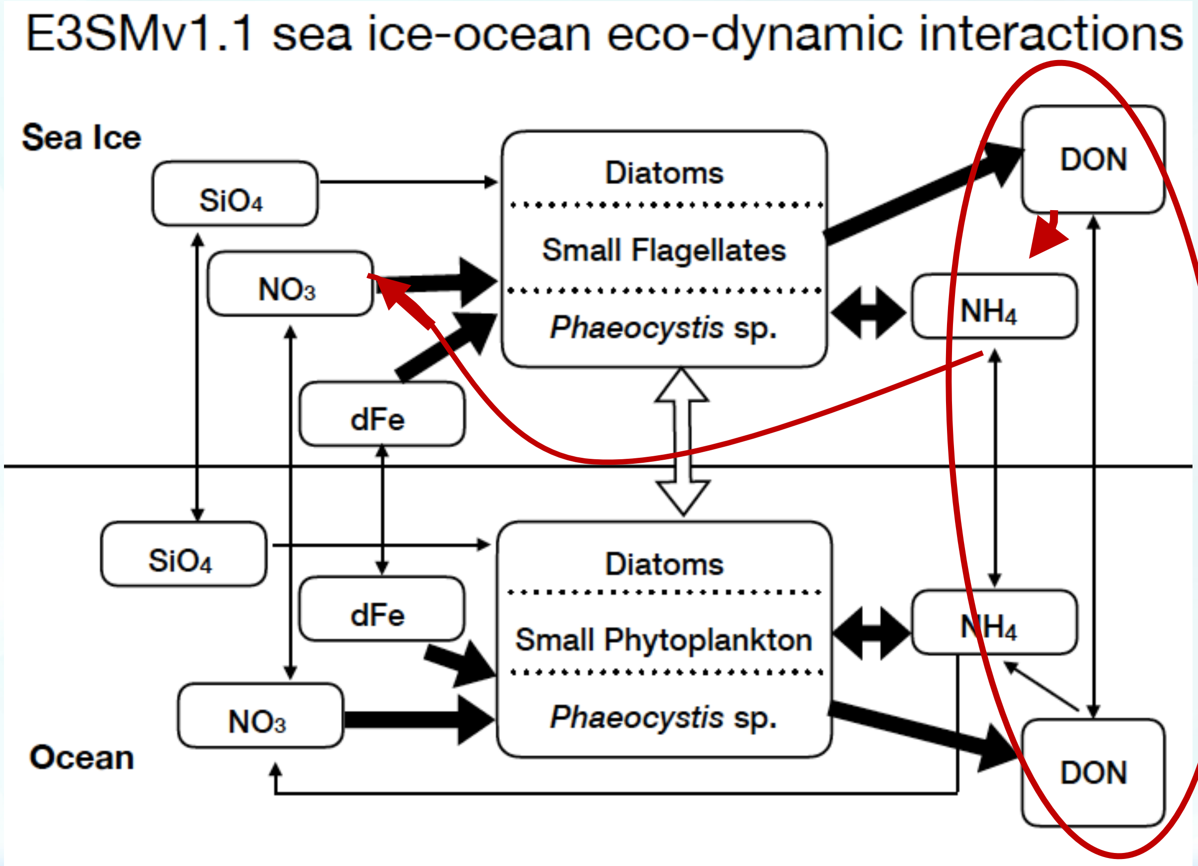


NO3 is a deep ocean source and generally more abundant than NH_4 in surface ocean waters though under-represented in v1 simulations.

NH4 is a remineralized source also produced in sea ice, less abundant in ocean surface waters

Our Approach

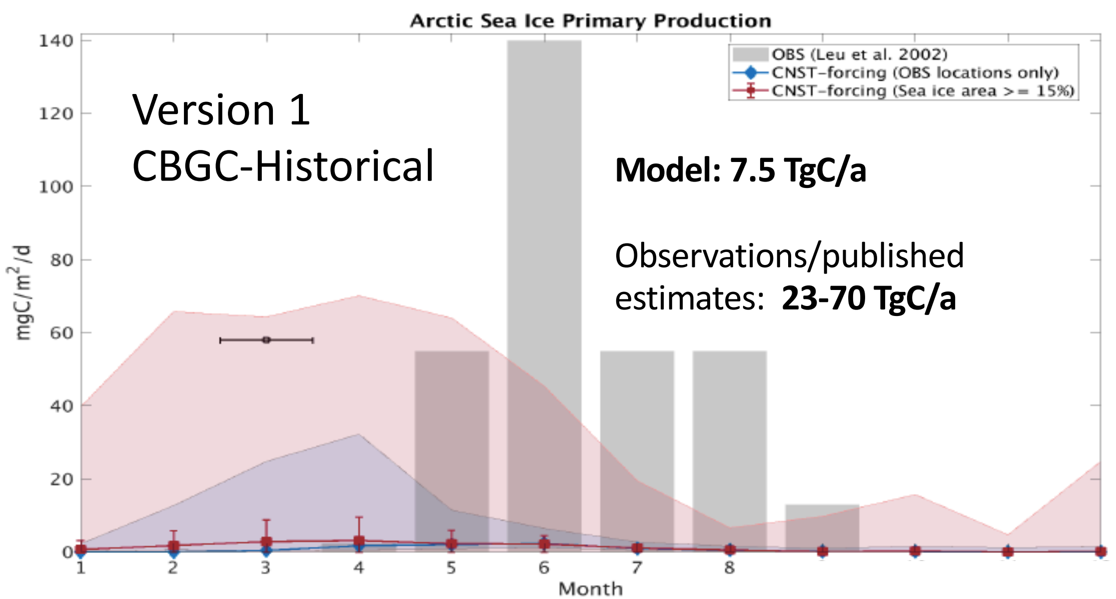
- In version 2 of E3SM, we have improved the sympagic nitrogen cycle by adding remineralization of dissolved organic nitrogen (DON) and nitrification of ammonium.

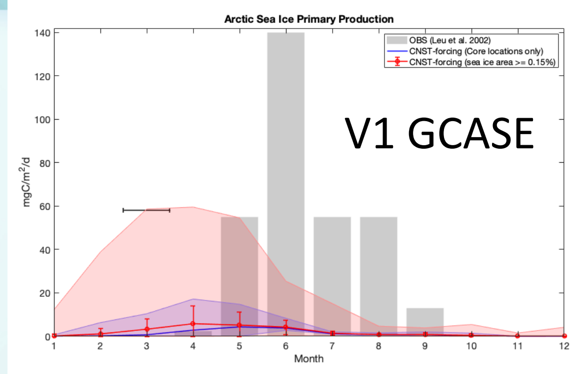


Unlike NO_3, DON adsorbs to ice crystals and so is accumulated in sea ice during fall/winter ice growth.

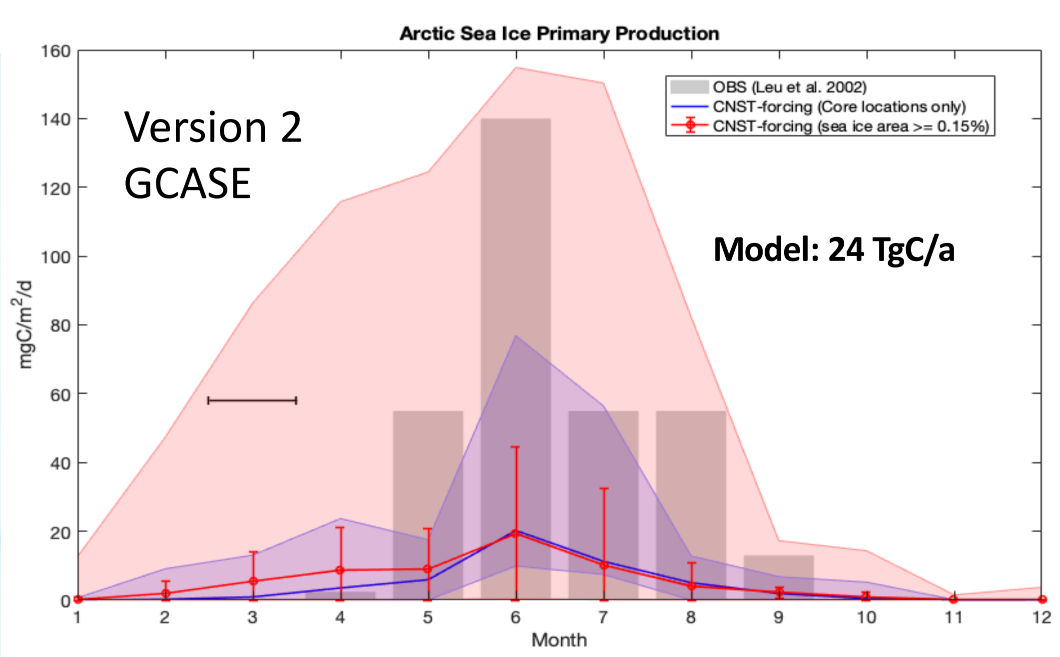
DON sympagic remineralization to NH_4 and NO_3 produces an N source for PP later in the season

The Impact on Arctic Sea Ice PP





Range in monthly means of the V1 CBGC-historical and GCASE runs shows a drastically underestimated PP peak, earlier in the season (April/May)

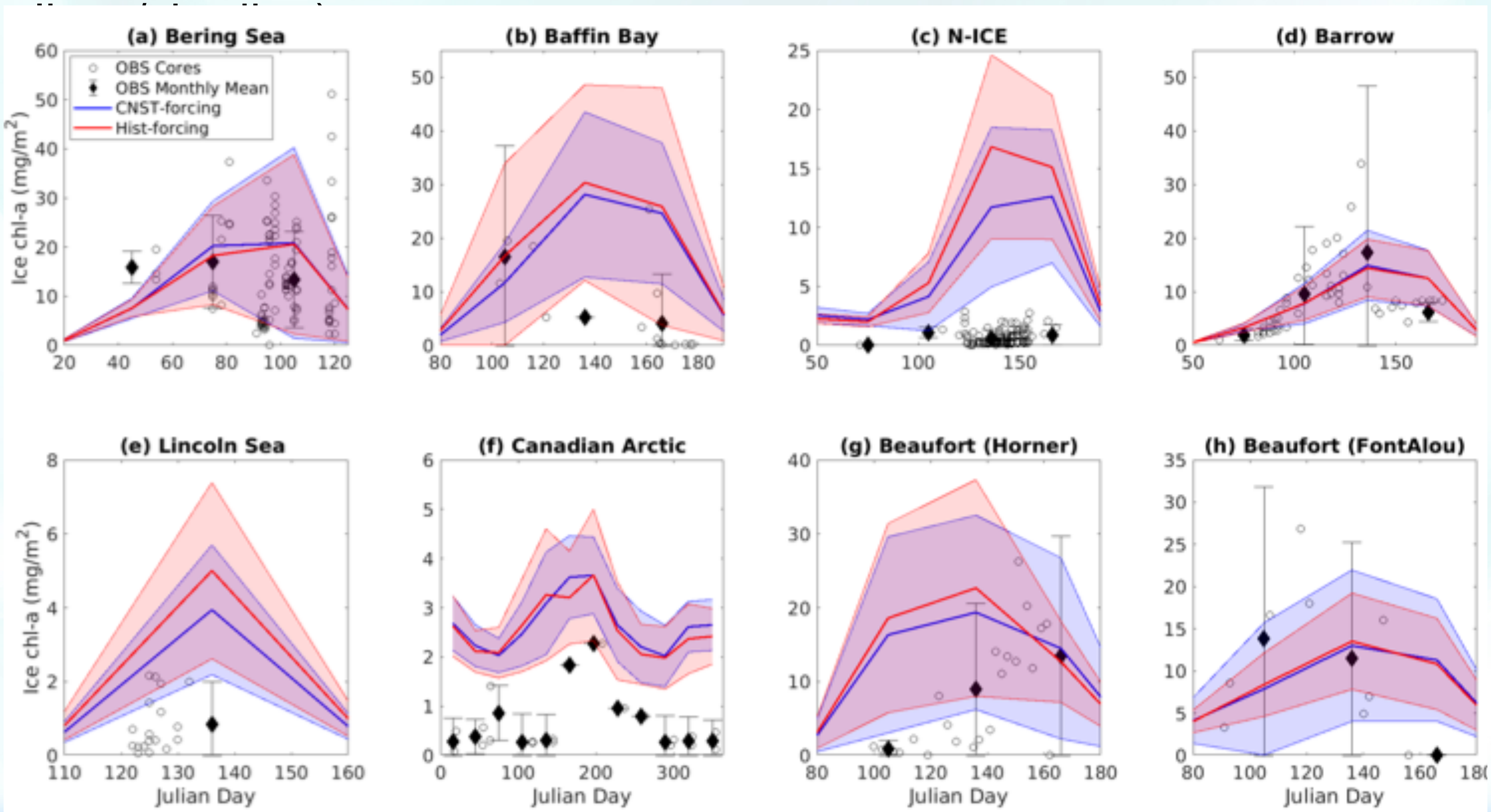


Years 10-13 of a Ocean-Ice (GCASE) simulation with V2 N cycling show improved timing (June) and magnitude of the PP peak.

E3SM Energy Exascale Earth System Model

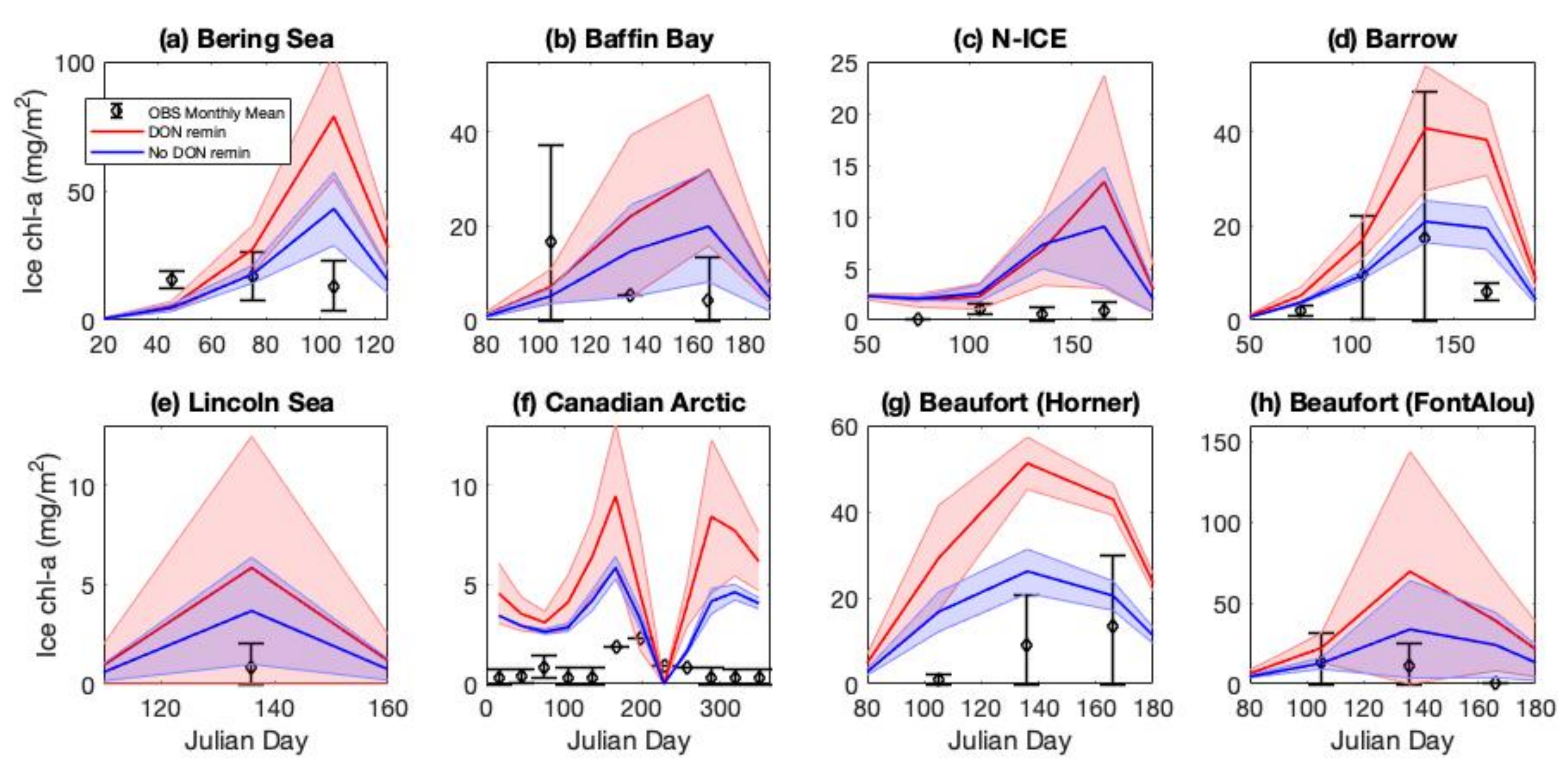
But, have we traded one problem for another?

- Version 1 Arctic chlorophyll estimates (all lines and shading) were broadly consistent with observations (symbols) even with low PP



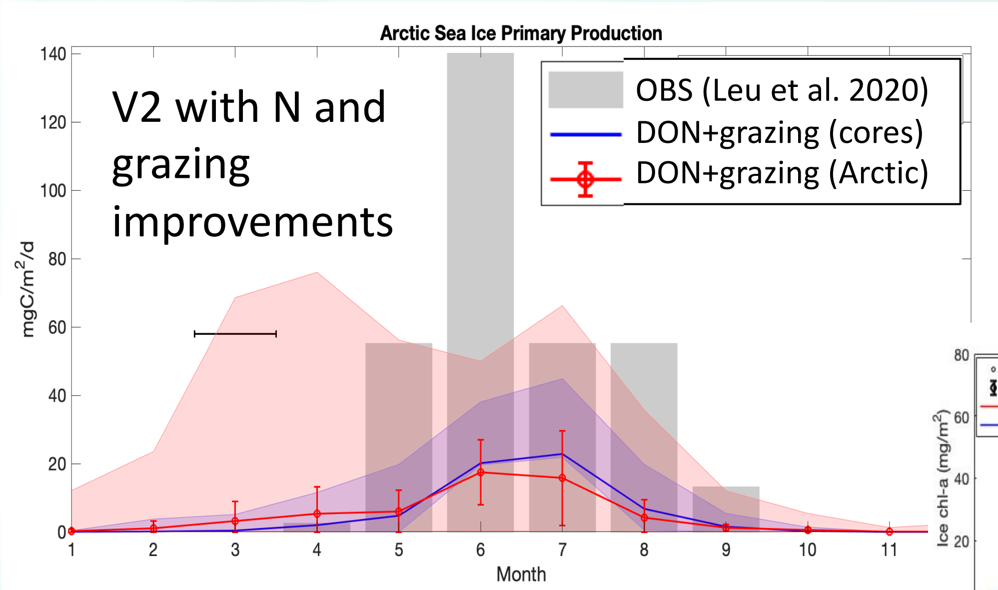
But, have we traded one problem for another?

- Improved nitrogen cycling in Version 2 alone enhances **PP** *and* **sea ice chlorophyll** concentrations (red lines) compared with Version 1 (blue lines) with a poorer fit to observations.

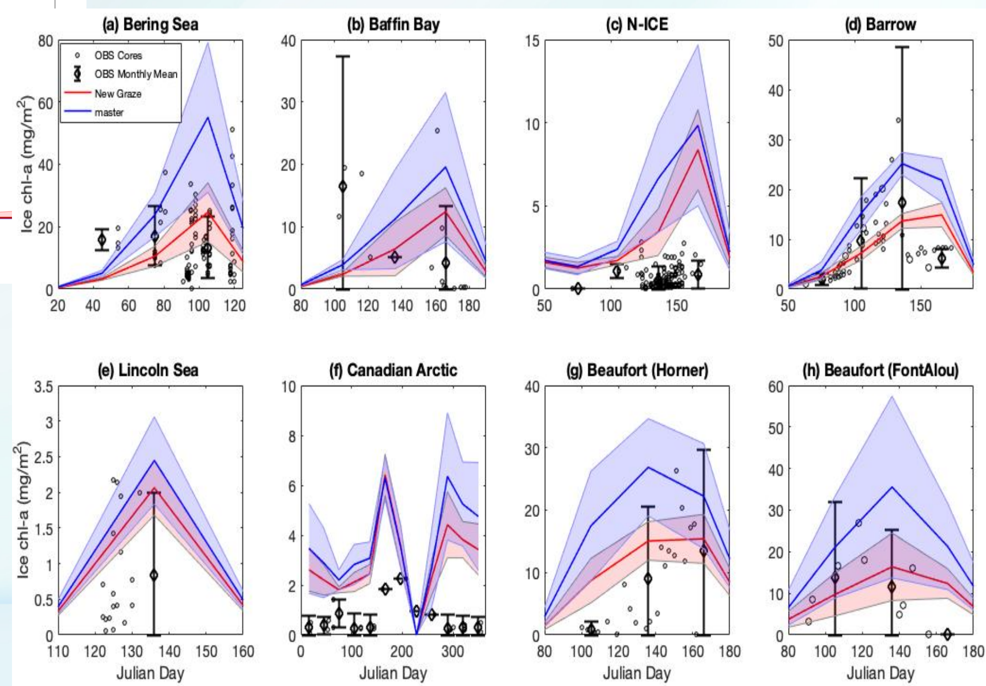


Improved ice algal grazing parametrization…

- Sea ice chlorophyll is a result of primary production (fluxes in) and grazing or other loss terms (fluxes out). By improving our grazing parameterization as well, we retain PP improvements without diminishing chl-a behavior



-- DON + grazing improvements
-- DON improvements



V2 sea ice model has a faster carbon turnover
Much more consistent with observations!

E3SM Energy Exascale Earth System Model

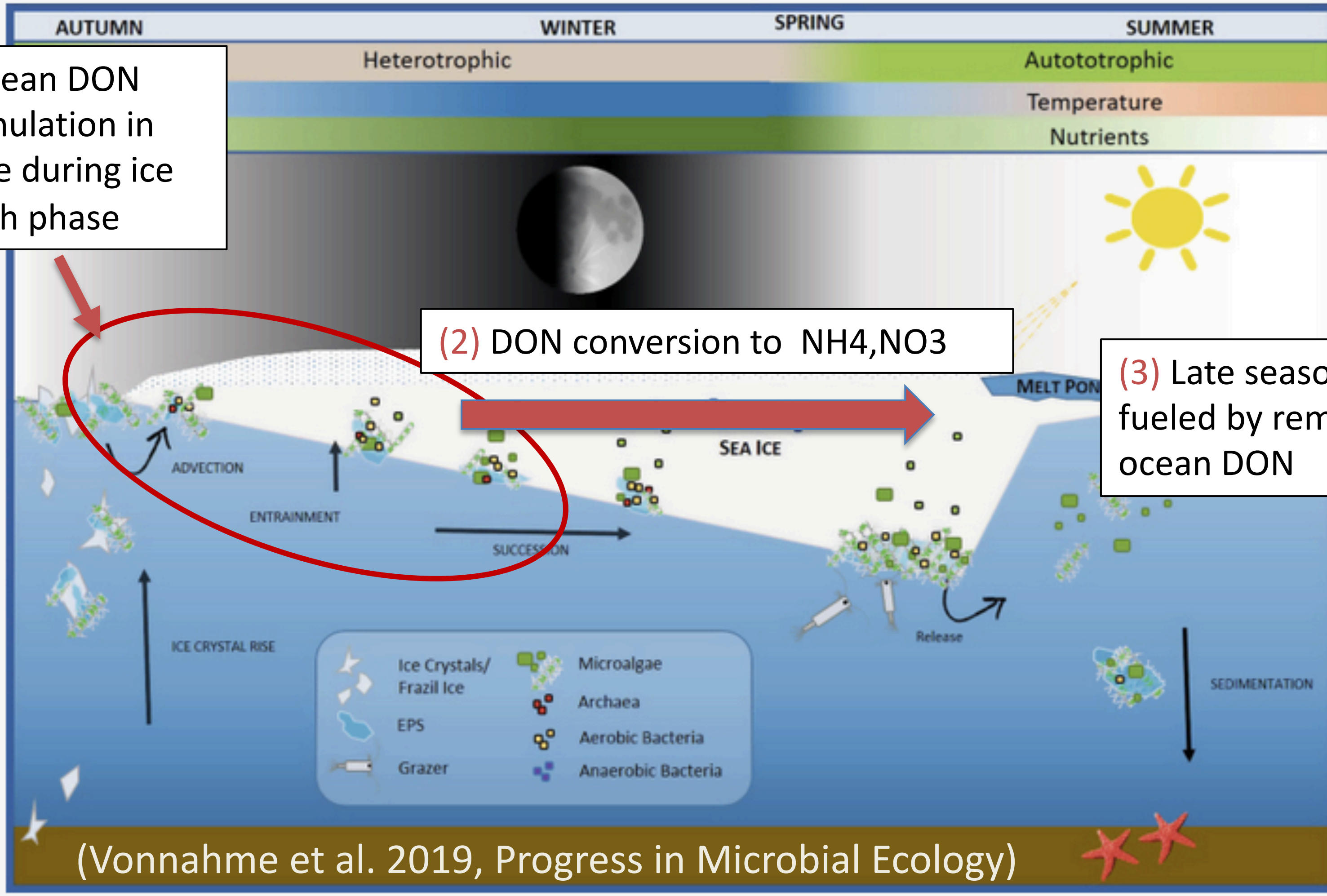
Conclusion 1:

Improved nitrogen cycling in E3SMv2 adds important mechanisms behind the seasonality of Arctic sea ice primary production

(1) Ocean DON accumulation in sea ice during ice growth phase

(2) DON conversion to NH4,NO3

(3) Late season PP fueled by remineralized ocean DON



(Vonnahme et al. 2019, Progress in Microbial Ecology)

Conclusion 2:

We are still under-estimating PP in the Arctic, likely because of ocean surface nutrient biases. Bottom-layer sea ice blooms (bottom ~3 cm of sea ice) are driven by gravity drainage fluxes of upper ocean nutrients (NO_3) throughout the season when light is available.