Marine/sea ice BGC in E3SM

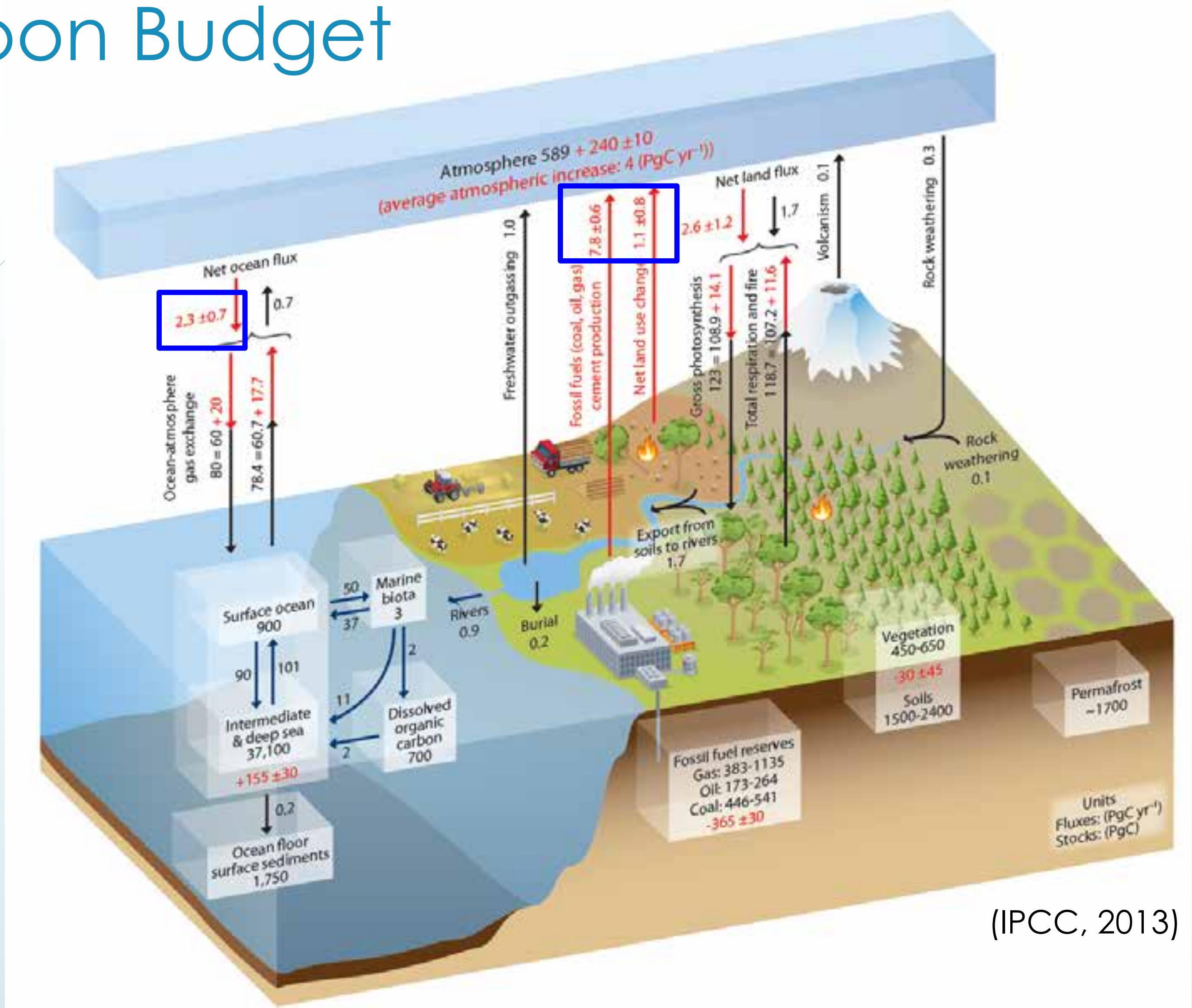
Shanlin Wang, Mathew Maltrud, Nicole Jeffery, Jonathan Wolfe

Ocean/sea ice BGC Team

Los Alamos National Laboratory

June 14, 2018

Global Carbon Budget

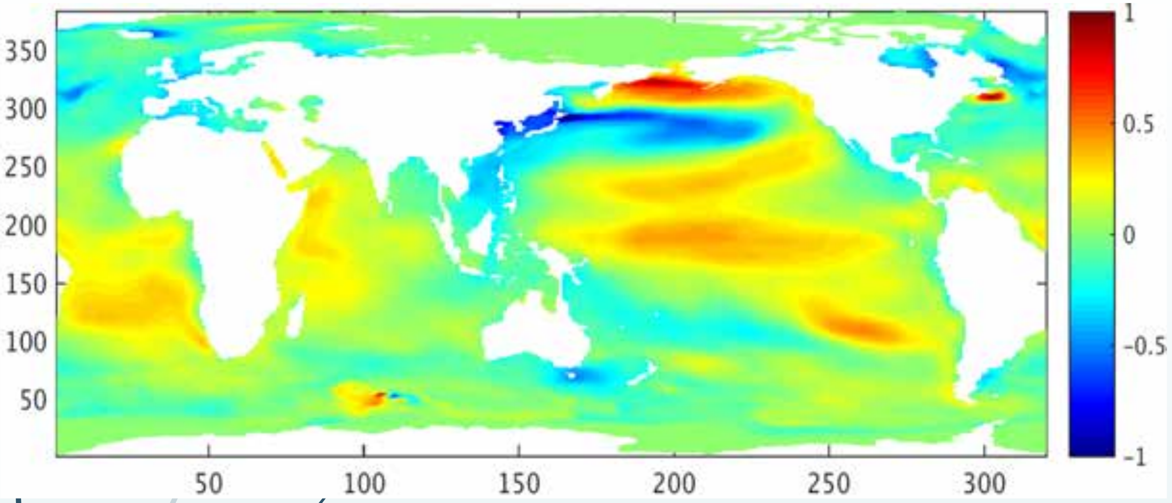


(IPCC, 2013)

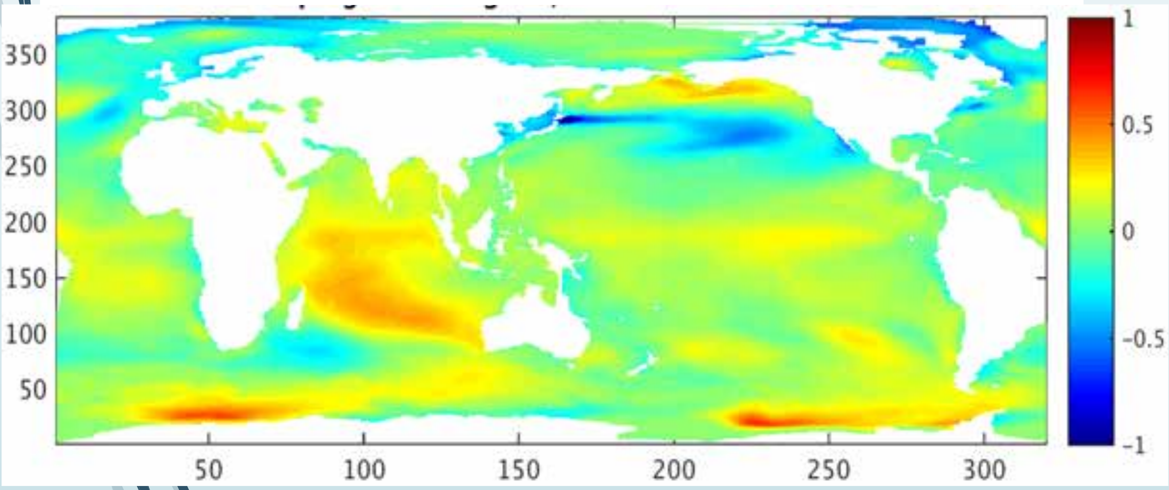
- The oceans take up 20% to 35% of anthropogenic CO_2 (Khatiwala et al., 2009; Sabine et al., 2004).
- The oceans play key roles in the global carbon cycle.

Impacts of chlorophyll

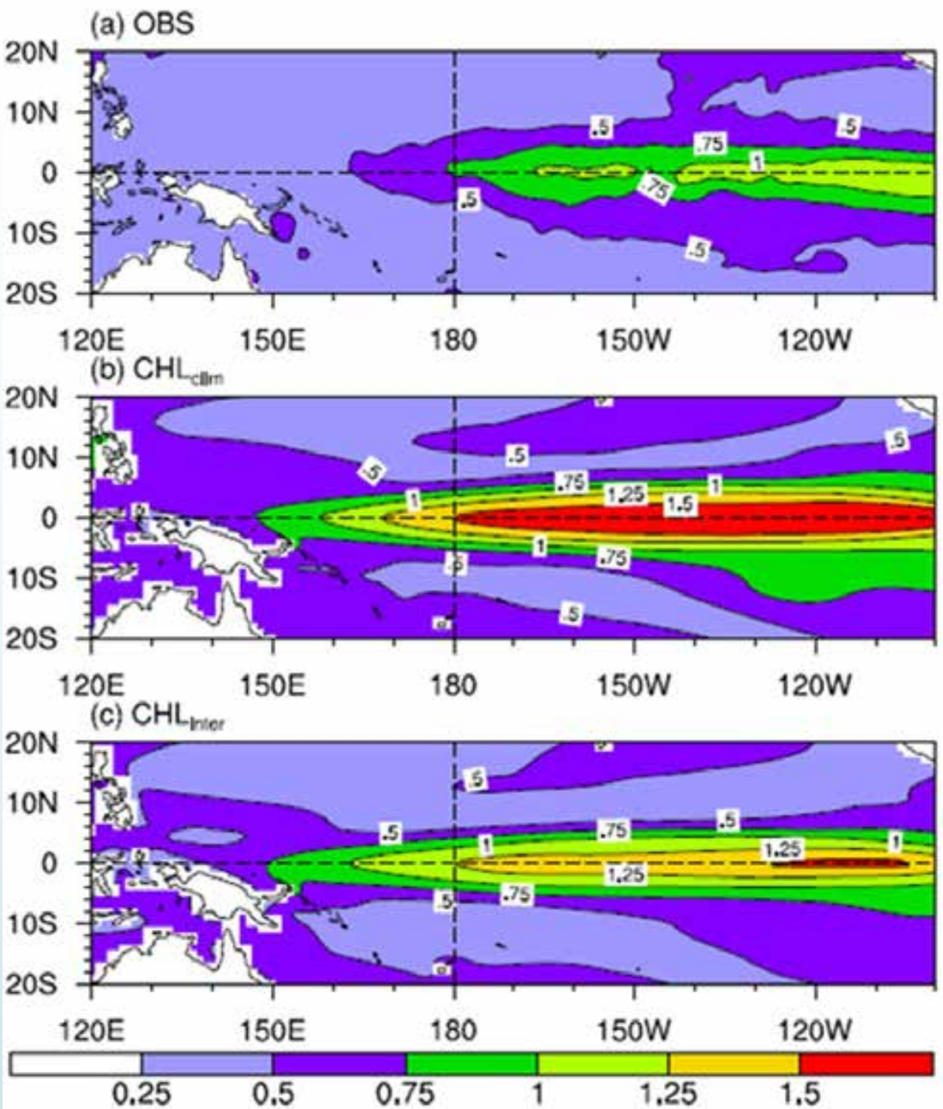
Diff SST (present day), prog Chl – clim. Chl



Diff SST (2100, RCP 8.5), prog Chl – clim. Chl

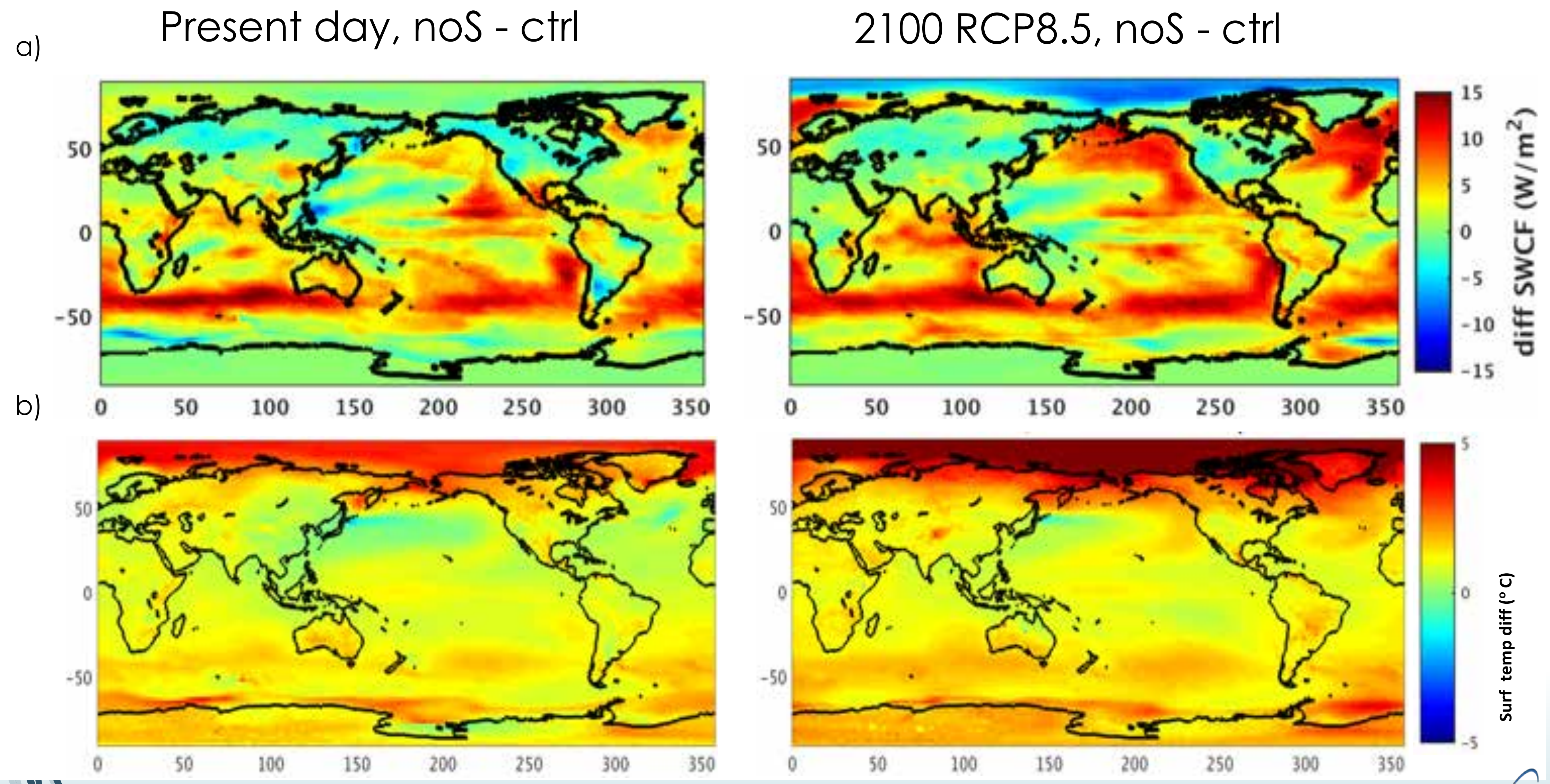


Standard deviation of the SST anomalies



(Kang et al., 2015, An improved ENSO simulation by representing chlorophyll-induced climate feedback

Impacts of marine biogenic aerosols (DMS)



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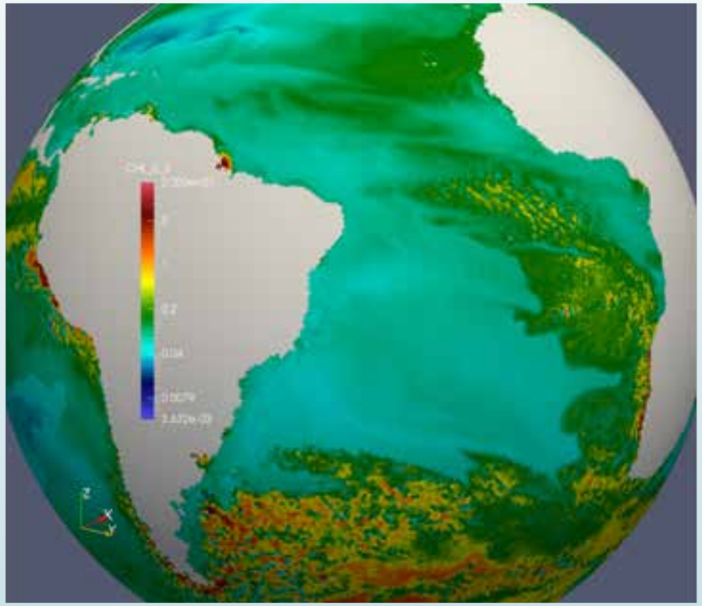
Required for E3SM v1 BGC Science Goal

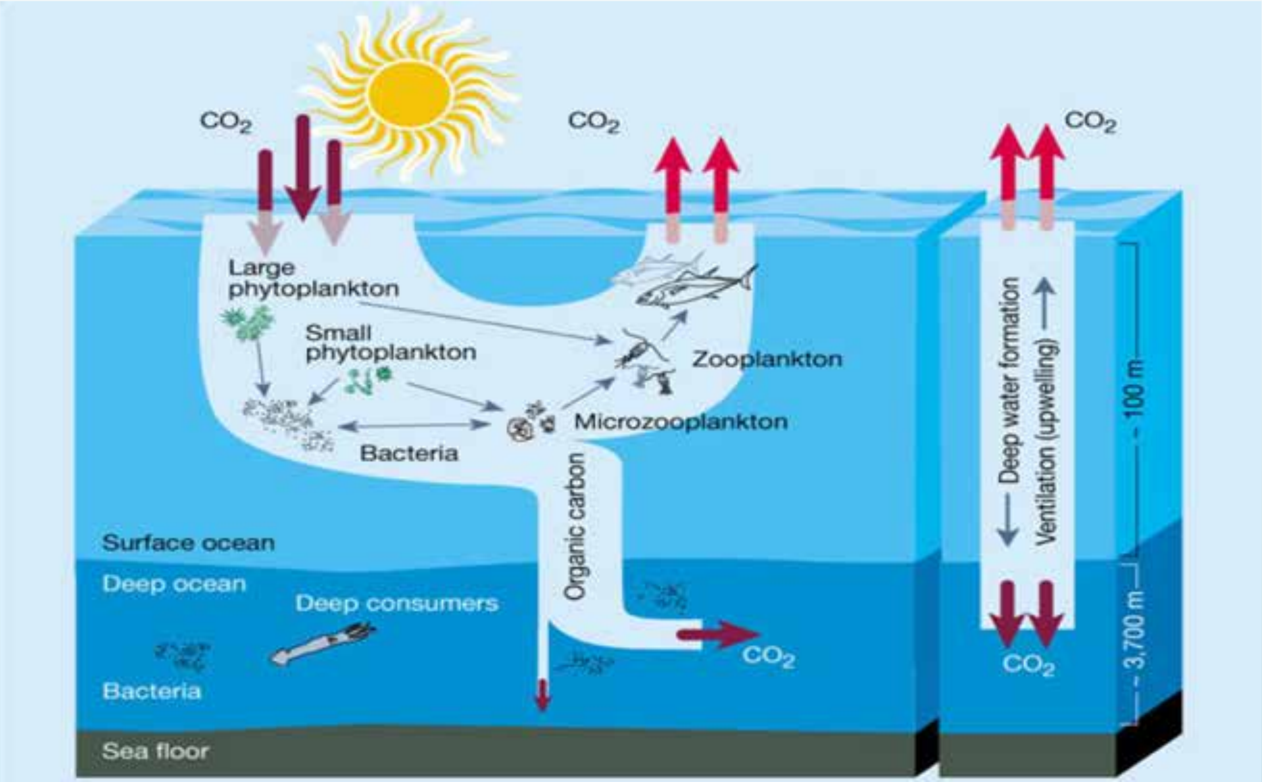
- Feedback analysis needs land and marine BGC
- Multiple CO_2 tracers allow isolation of carbon cycle processes
- Includes sea ice BGC (Jeffery, Wang, Elliott, Hunke)
  - Leverages porous flow capability of MPAS-CICE
  - Unique component of ESMs with this complexity



Marine surface chlorophyll (mg/m^3) simulation on the MPAS global, variable resolution, unstructured mesh.

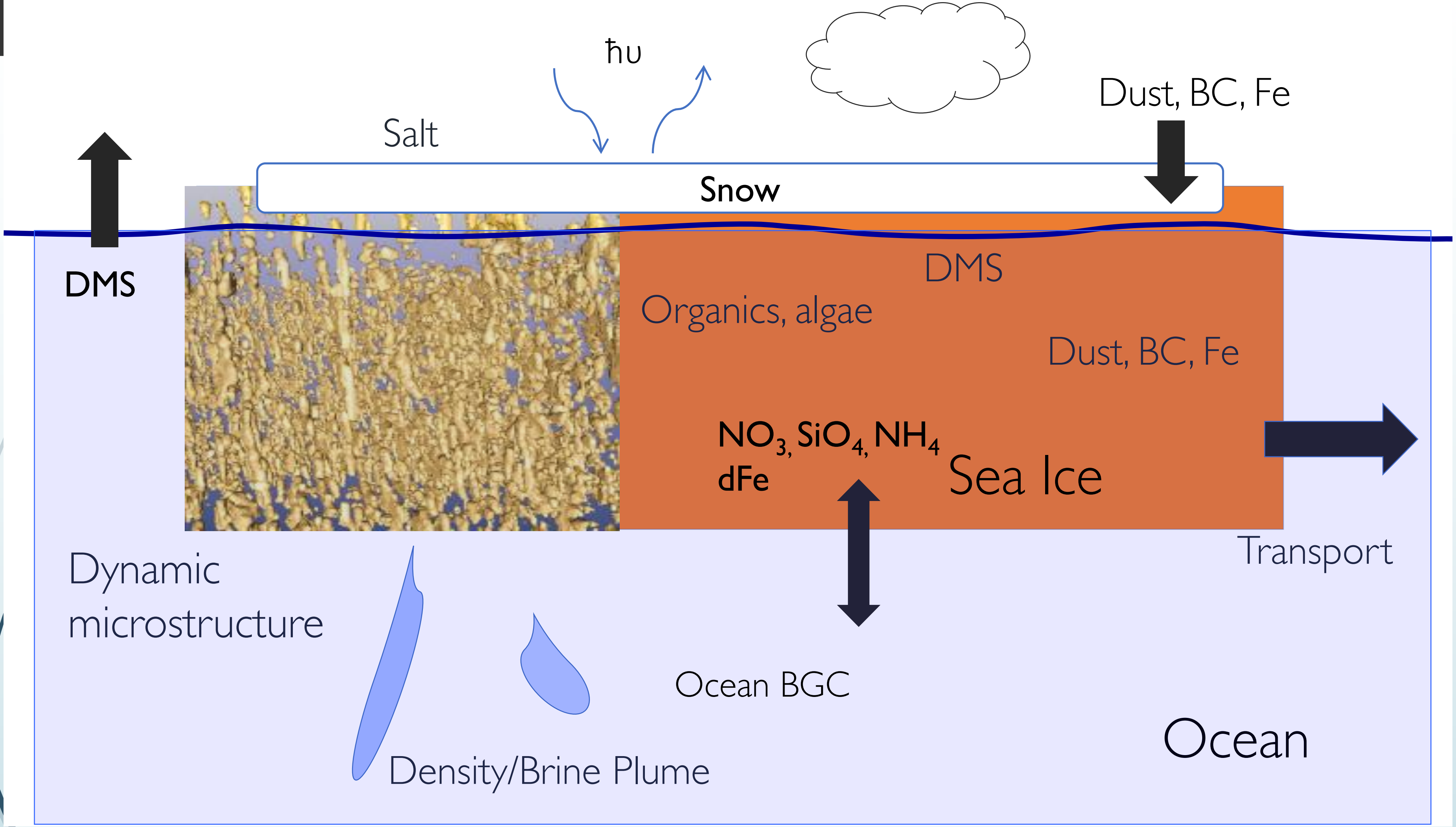
E3SM Ocean Biogeochemistry Intro

- Import Biogeochemical Elemental Cycling (BEC) into MPAS-O
- Characteristics
  - 5 phytoplankton functional groups (pico, diatoms, diazatrophs, Phaeocystis, implicit coccolithophores)
  - 1 zooplankton group
  - Tracegas and macro-molecules (Lipids, proteins, polysaccharides)

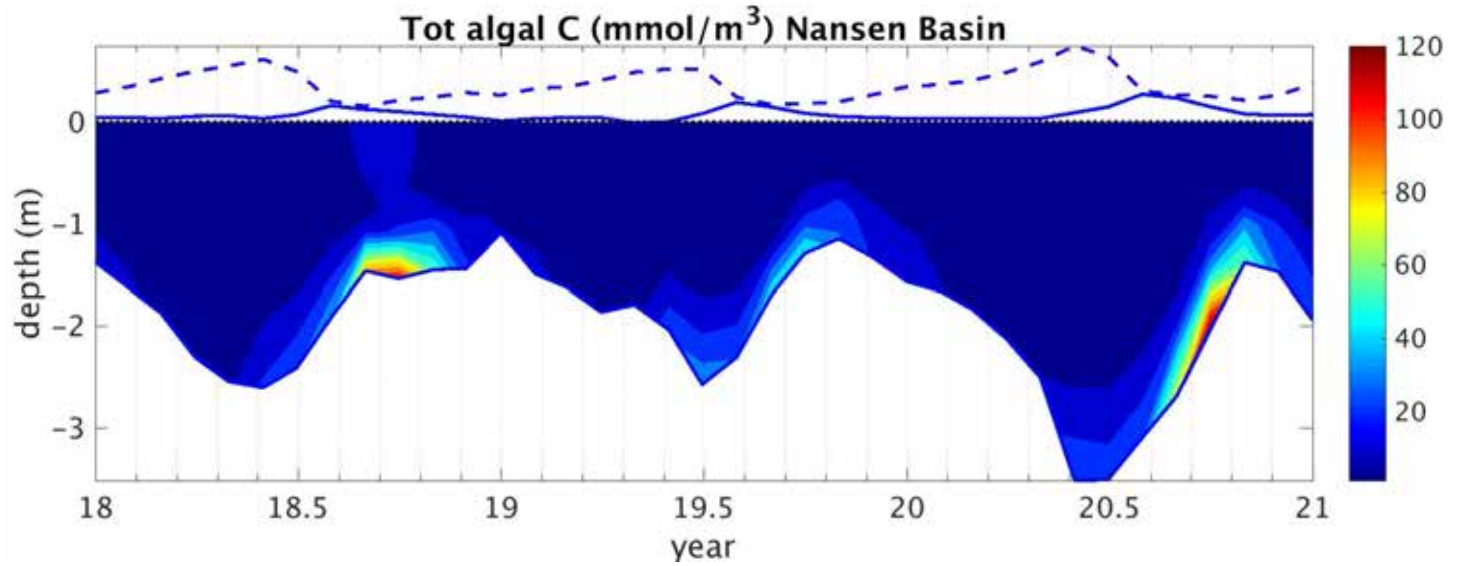


(Chisholm, 2000)

Global Sea Ice Biogeochemistry (zbgc) Intro

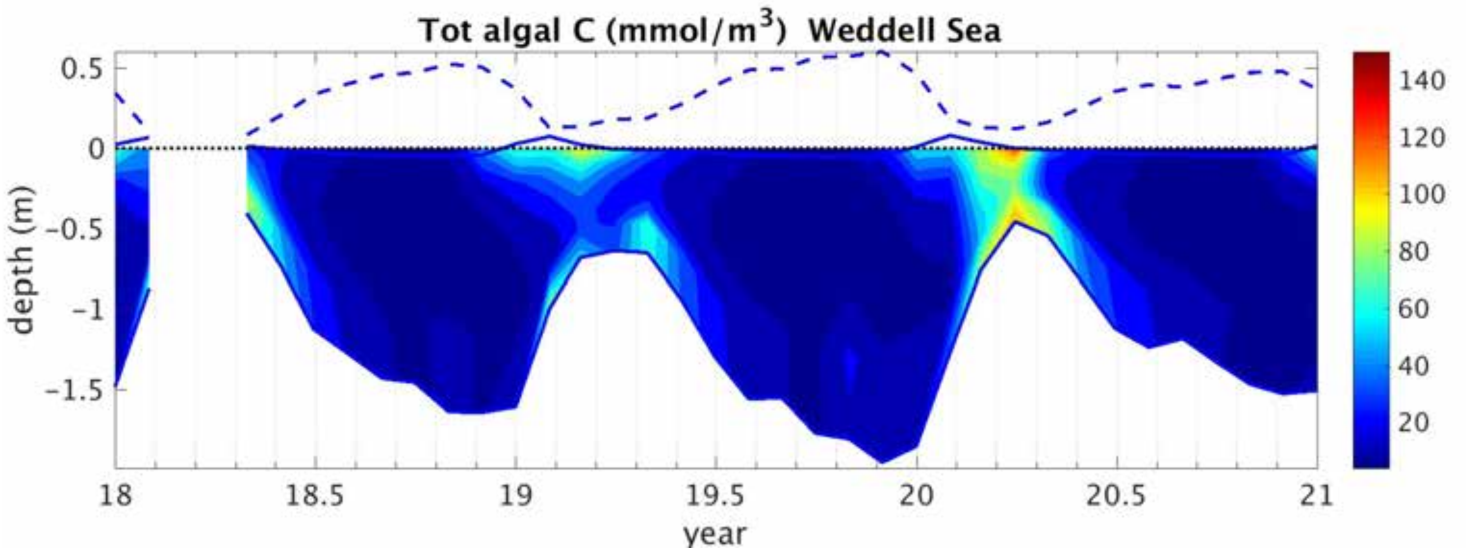


Ice BGC Profiles: Qualitative Agreement



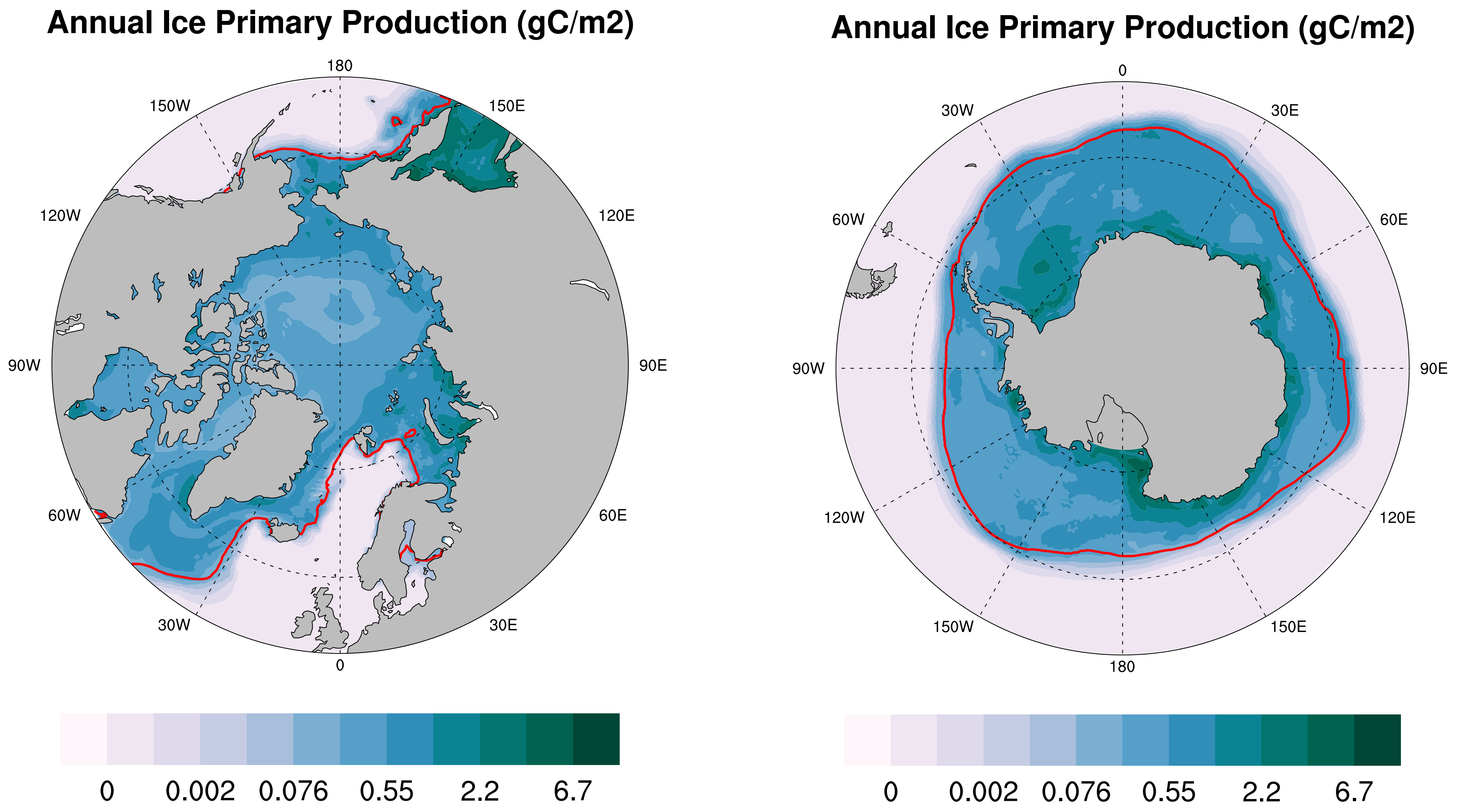
Arctic

1. Obs ***bottom*** layer chla peaks
2. ***Micro-scale*** processes – brine dynamics control nutrient supply at the ice ocean interface



Southern Ocean

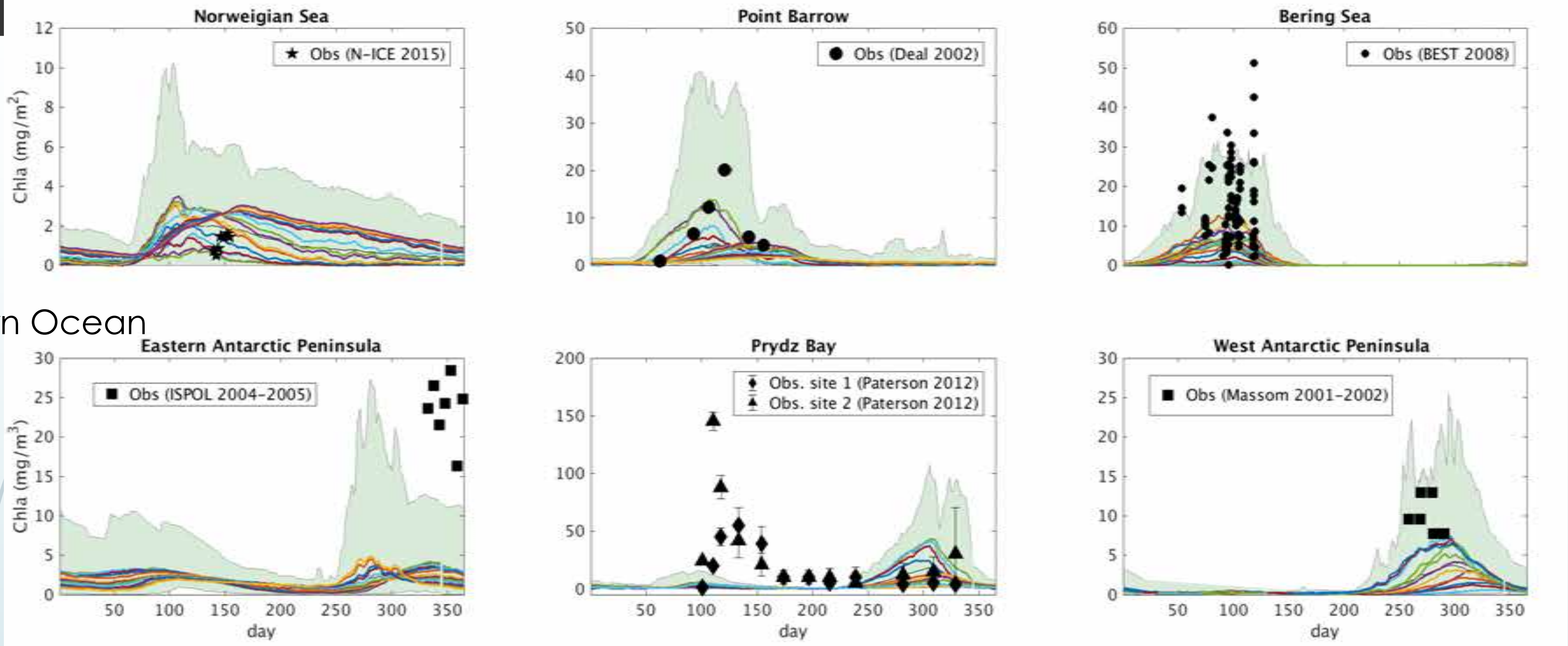
1. Obs ***surface*** chla peaks
2. ***Macro-scale*** processes -- heavy snow and flooding enrich the upper ice



Contours of total annual sea ice carbon production from year 60 of E3SM fully coupled BGC simulation. The red line is the mean 15% sea ice contour for the year.

Annual cycle of sea ice chlorophyll in E3SM

Arctic

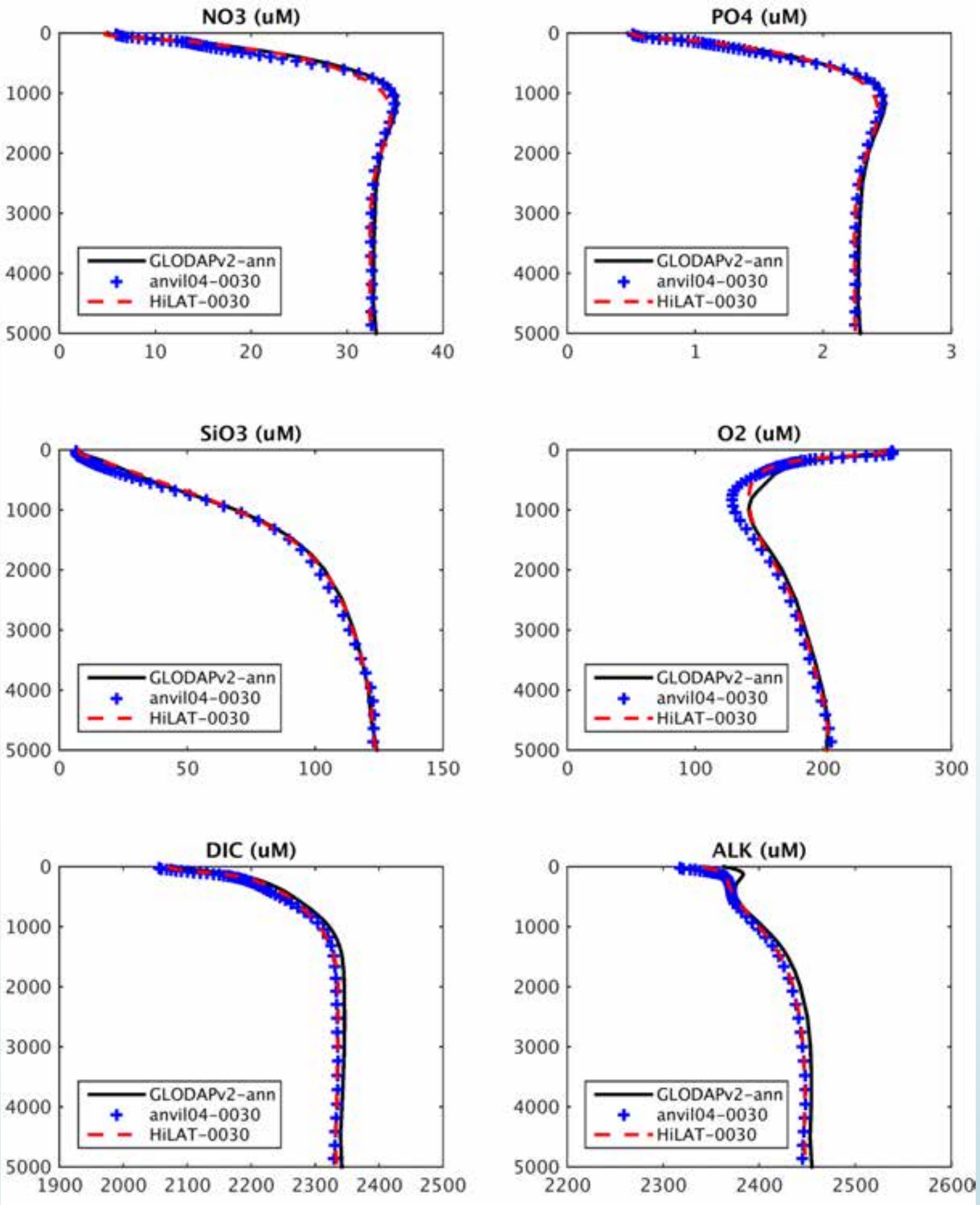


Southern Ocean

Sea ice chlorophyll concentrations from 15 years of fully-coupled spin-up compared with in situ measurements. Colored lines are annual daily averages for a given grid point clustered within 2° of the mean field location. The green shaded region indicates the maximal range of simulated values.

Ocean Nutrient and DIC

- Comparable nutrient distributions
- Further tuning is needed for E3SM ocean BGC



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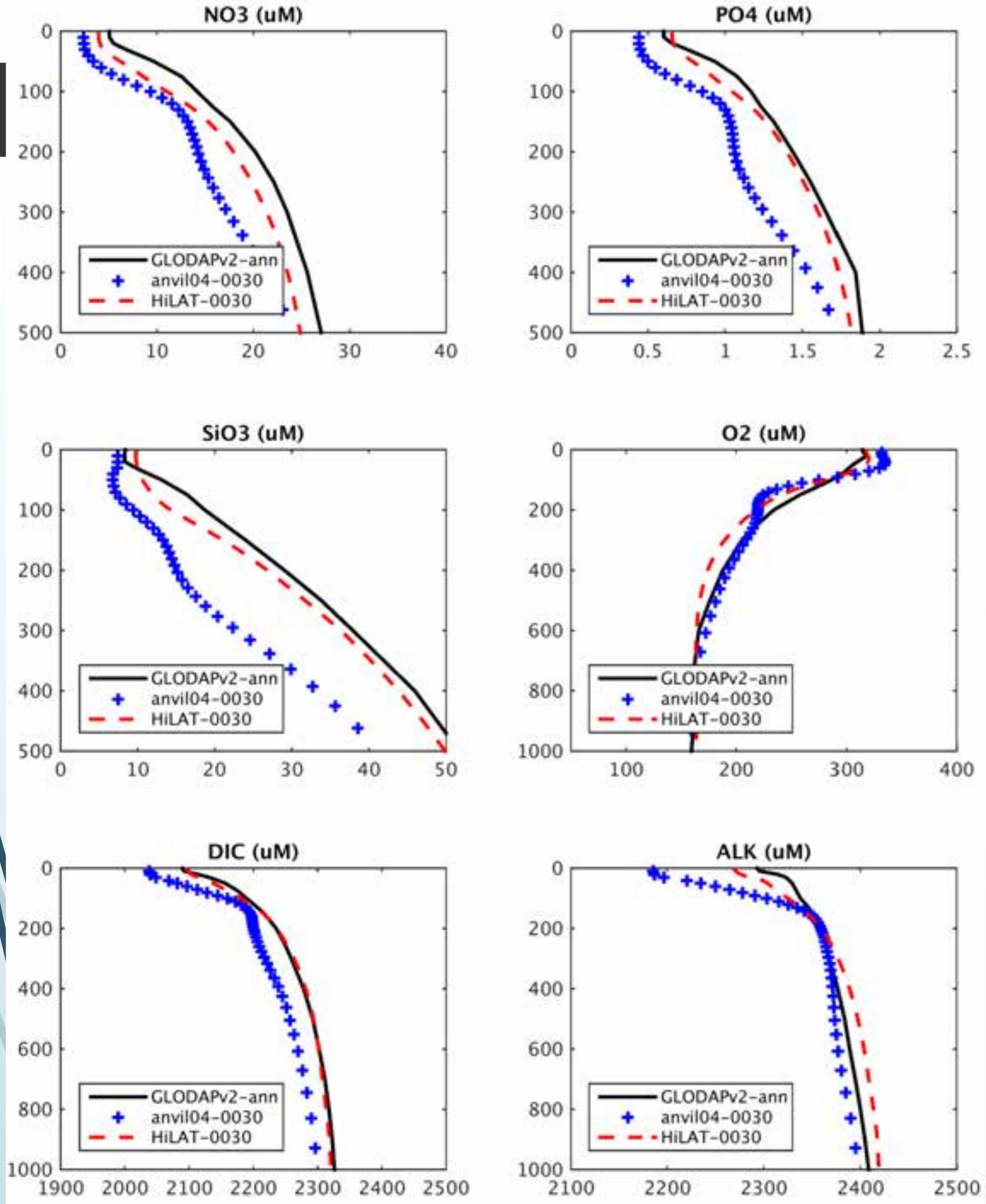
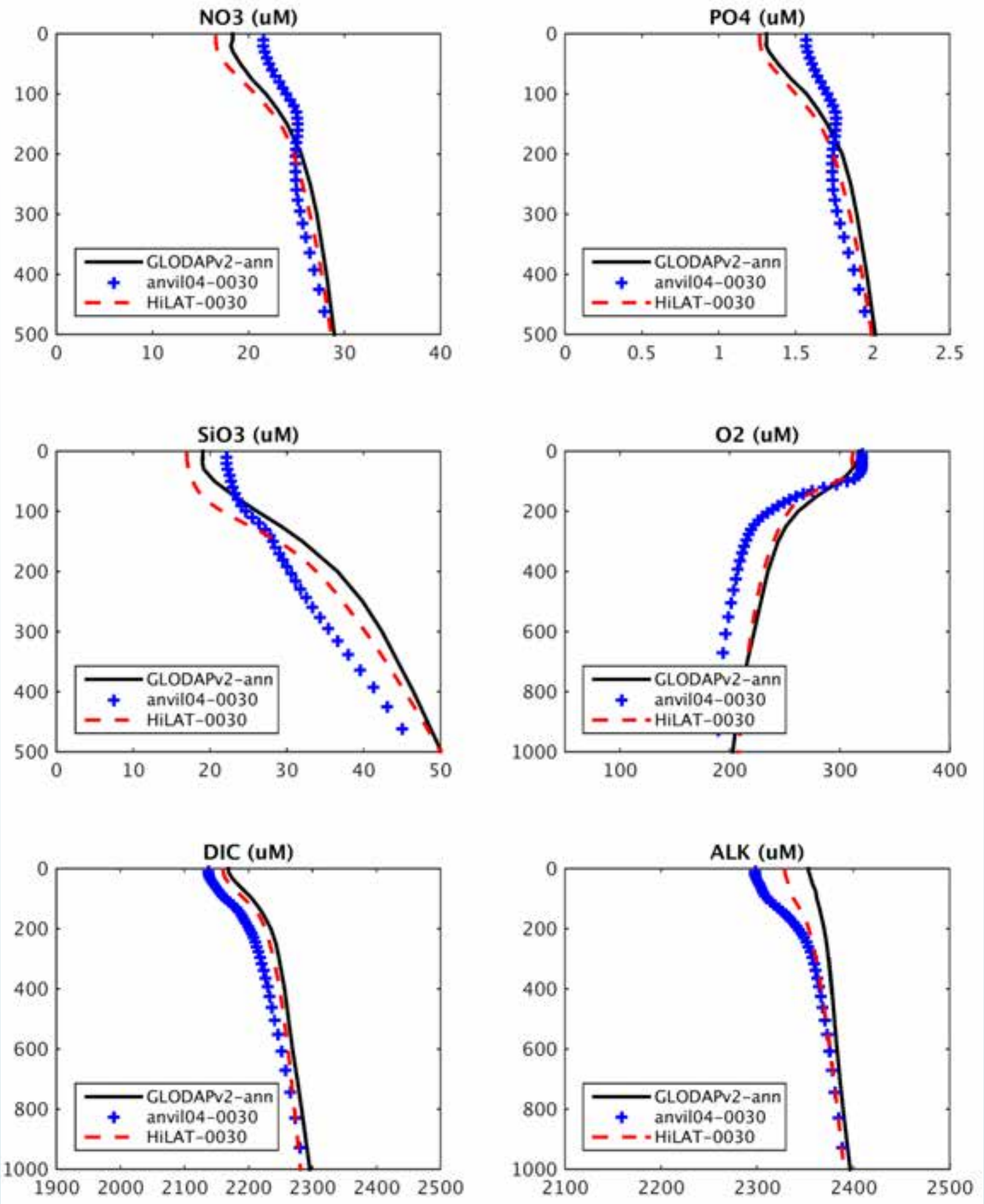
> 40°


NO3 (uM)
PO4 (uM)
SiO3 (uM)
O2 (uM)
DIC (uM)
ALK (uM)
GLODAPv2-ann
anvil04-0030
HiLAT-0030

< - 40°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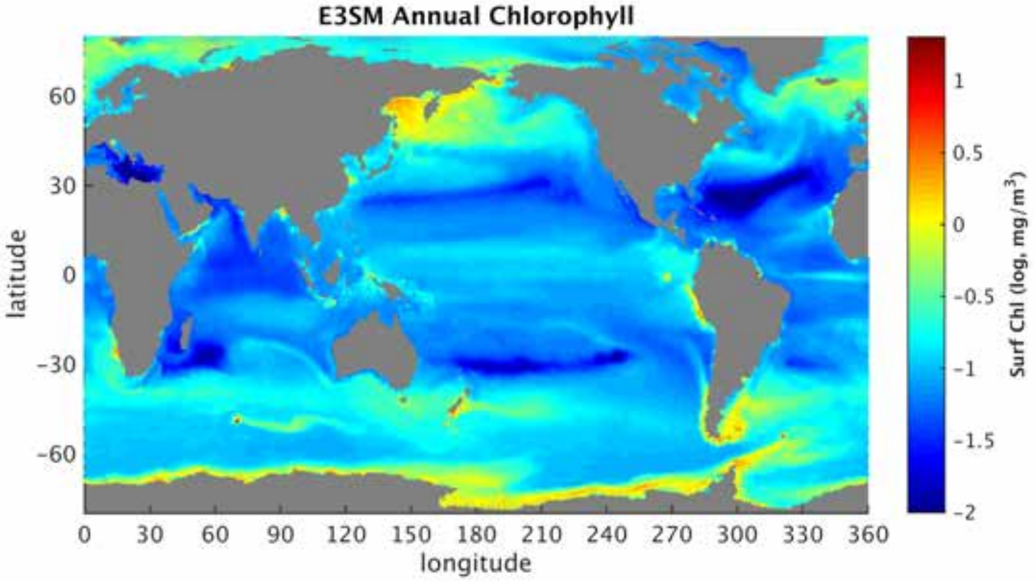
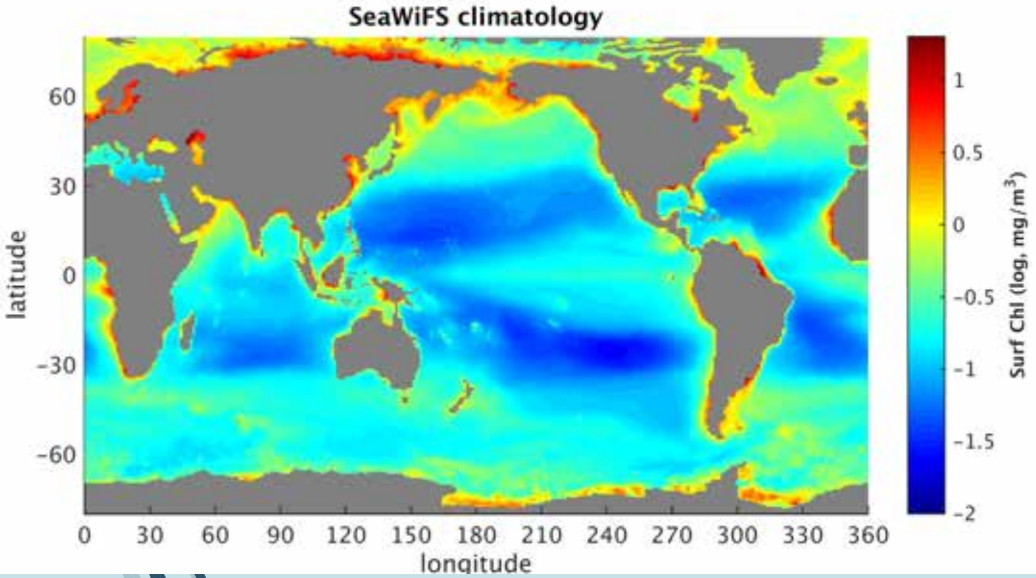
GLODAPv2-ann
anvil04-0030
HiLAT-0030

Annual mean chlorophyll (mg/m³)



E3SM



Satellite

- E3SM (yr 25 -30) and Satellite climatology show similar patterns
- Too little coastal production:
  - Resolution too coarse to represent coastal zone
  - BGC was tuned based on global open oceans
  - Missing processes to resolve coastal BGC

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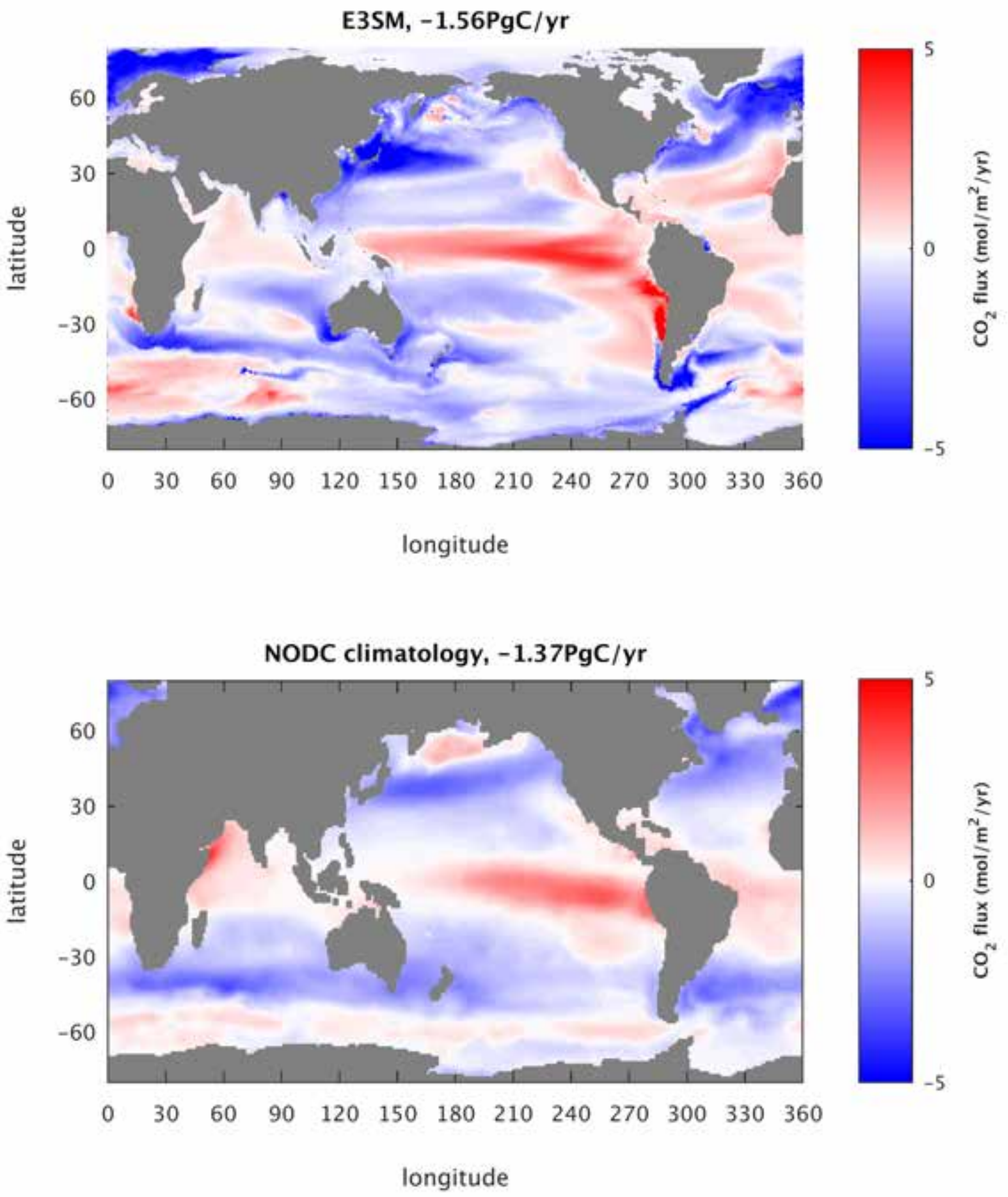
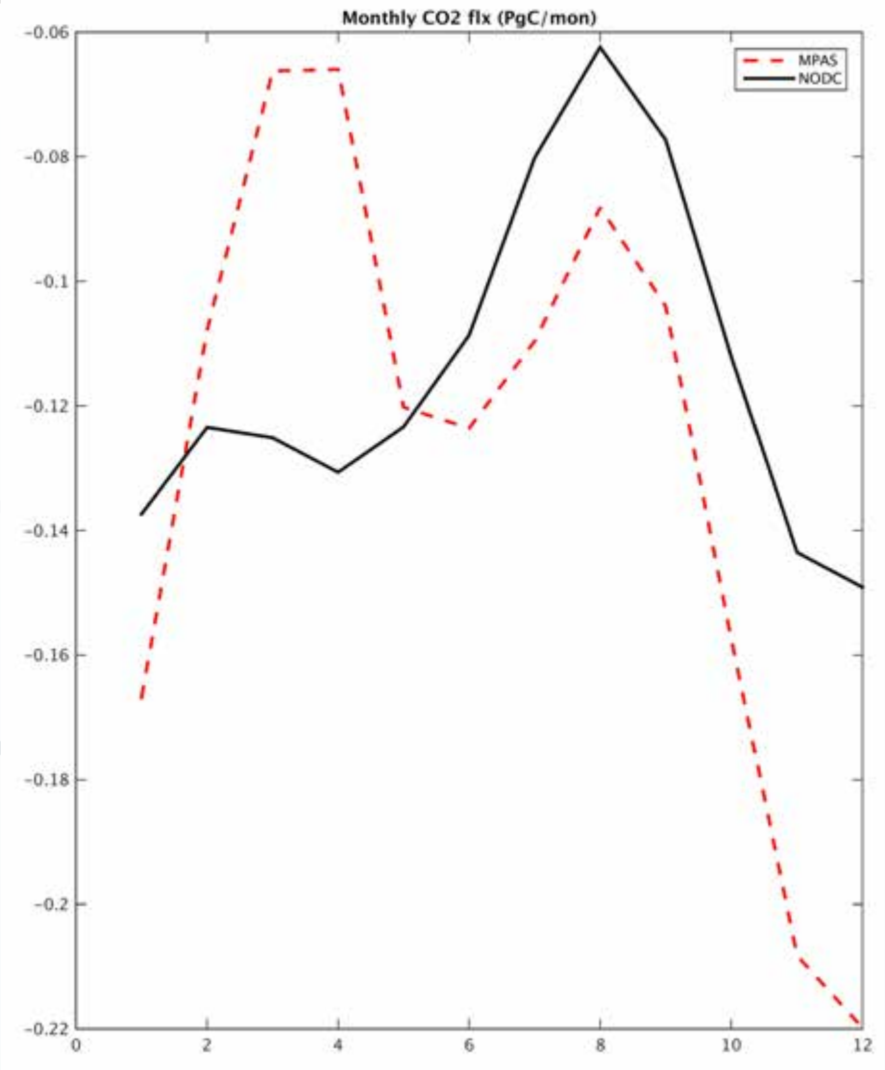
Ocean-Atmosphere CO_2 Flux (mol C/m²/yr)



- E3SM (yr 25 -30) and observation-based estimates show similar patterns
- Regional biases

Ocean-Atmosphere CO_2 (CONT.)



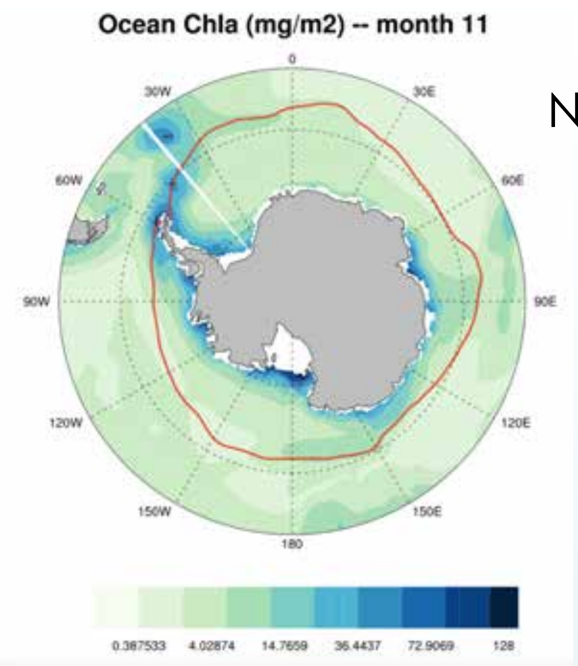
- Simulated preindustrial air-sea CO_2 flux is ~ - 0.6 PgC/yr (a weak sink), but it should be a weak source
- Seasonal variations of air-sea CO_2 fluxes are different
  - Biases in physical states, e.g. SST
  - Biases in biological uptake
- Currently, there is no feedback from ocean BGC to climate

What's next?

- Scientific questions:
  - What are the impacts of different energy and land use futures on the ocean carbon cycle?
  - How the ocean carbon cycle and biological activities will feedback to the coupled system?
  - How might coastal marine ecosystems respond to changing terrestrial and atmospheric inputs?

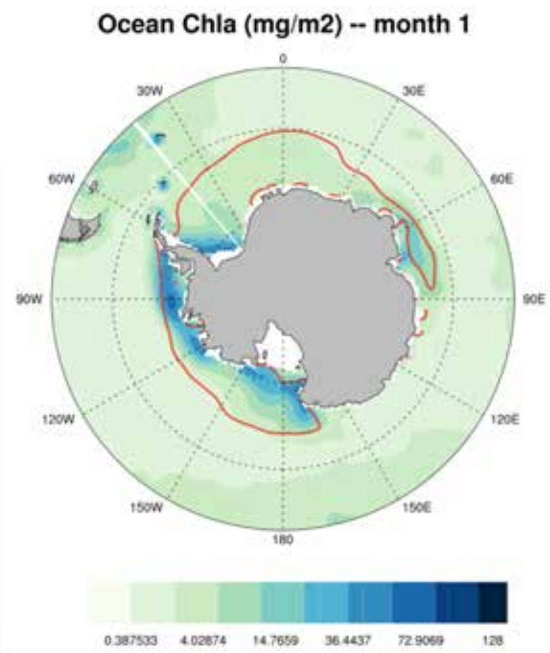
What is the impact of ice bgc on estimates of polar chlorophyll? (results from E3SM-HiLAT)

Ocean
Surface Chla



Nov.

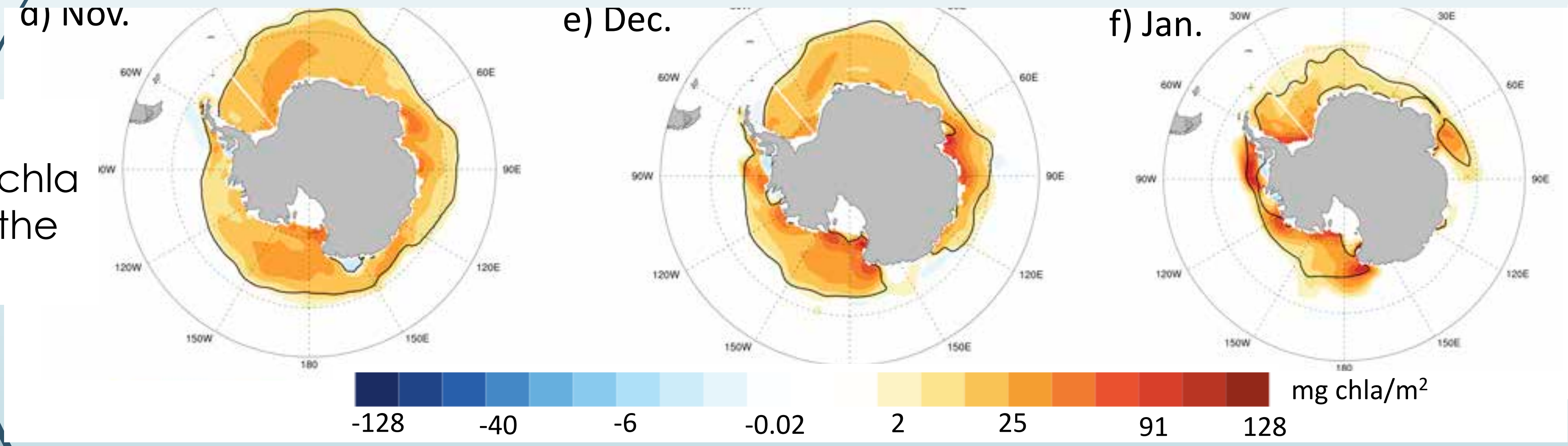
128 mg/m^2



Jan.

128 mg/m^2

Difference (surface ice+ocean chla with sea ice bgc – surface chla without sea ice bgc)



November:
Additional chla is mostly in the sea ice.

January:
Additional chla in the ocean due to sea ice melt release of dissolved Iron.

E3SM is in an optimal position to go beyond quantification of an ice bgc "chla" impact to…

1. Model CO_2 exchange directly between the atmosphere-ice and ice-ocean systems

(port existing DIC biochemical interactions to MPAS-seaice)

2. Activate snow-on-ice biochemistry to address the direct impacts of biogeochemistry on ice albedo and trace gas production from atmospheric chemical sources

(Enable direct atmosphere-ice fluxes of trace gases, nitrates, and testing of the snow domain)

3. Improve carbon sequestration estimates by allowing for deep penetrative mixing of ice to ocean biogeochemical fluxes

(Extend/port the ocean brine plume model for salinity to include ice-brine biochemical variables).

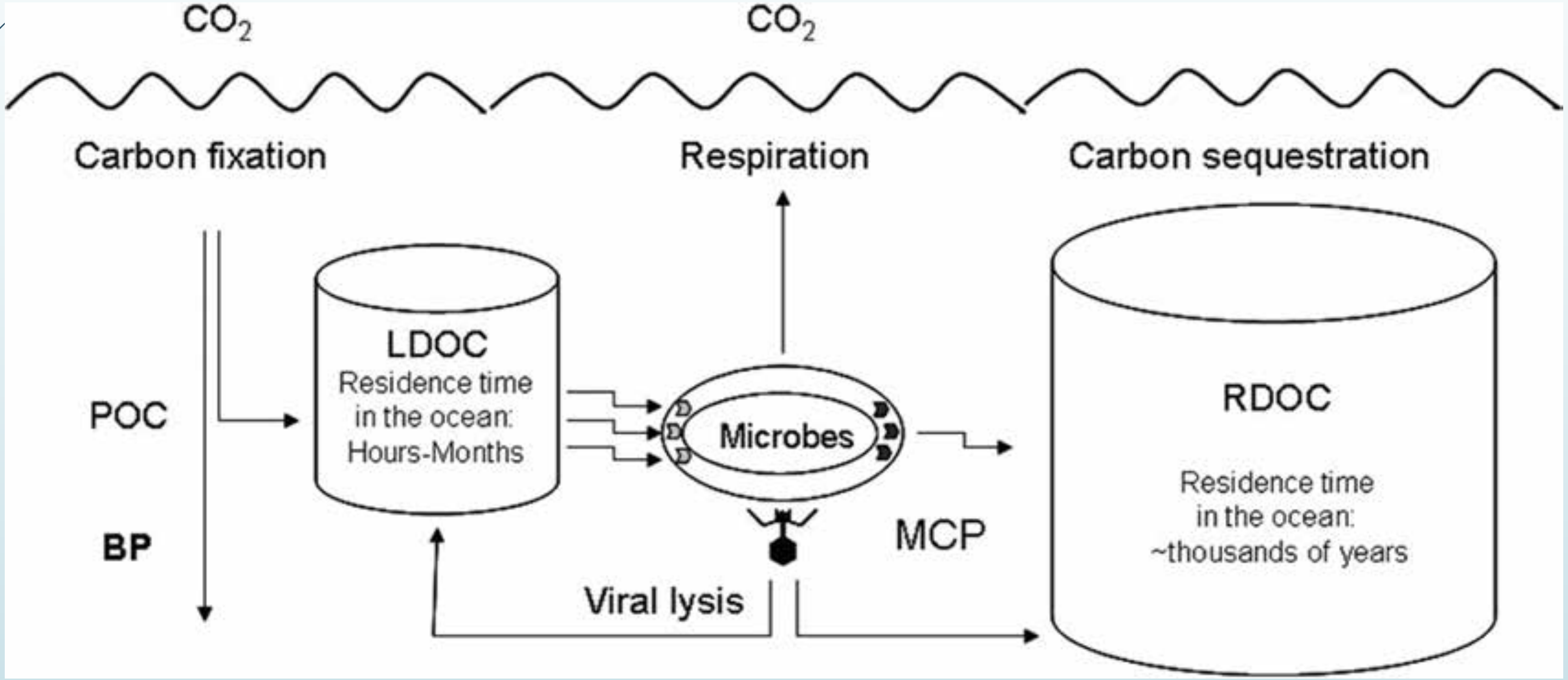
What's needed?

Short-term plan

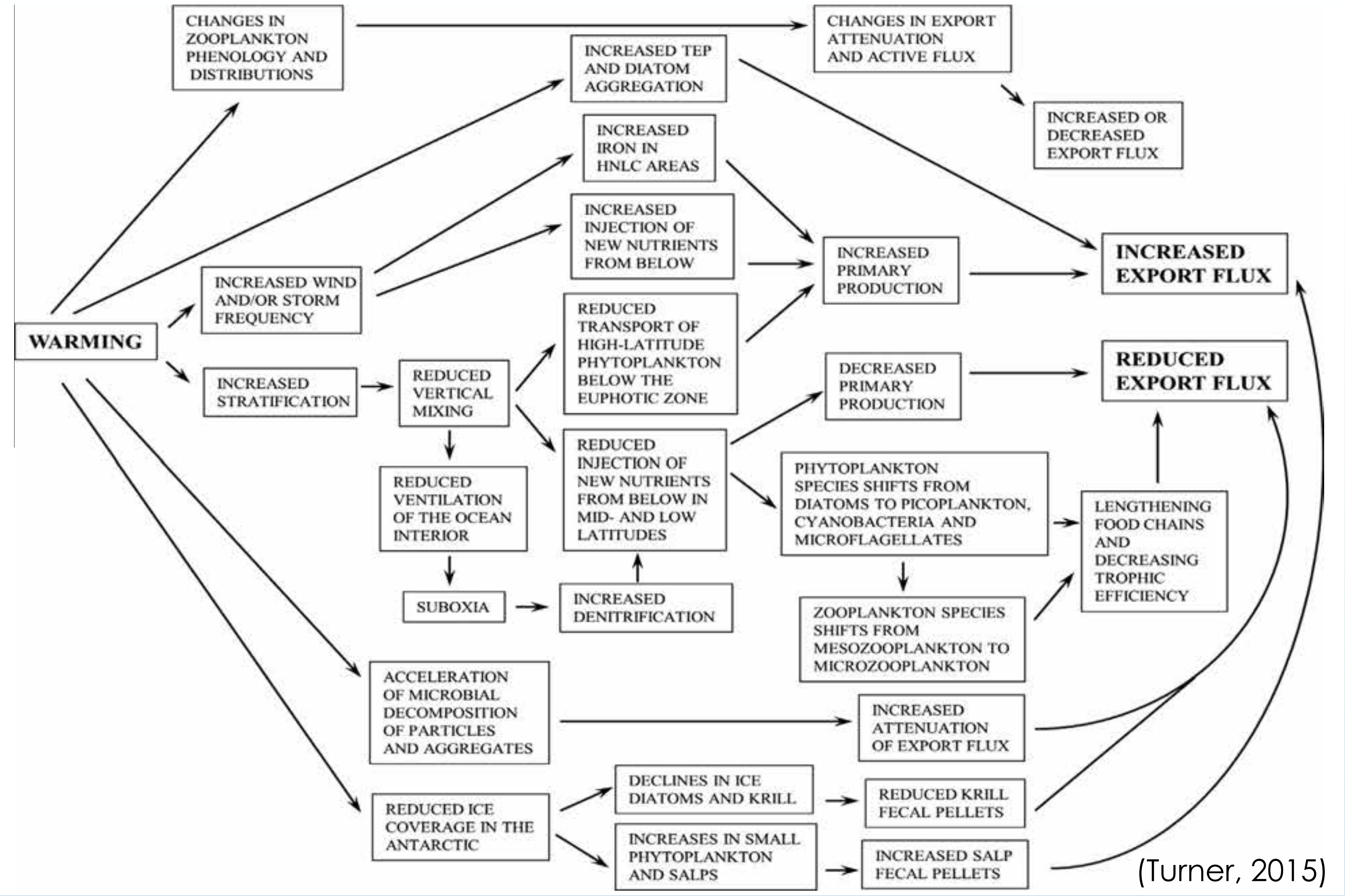
- Scale-aware parameterization to improve regional refined BGC simulations, especially for the coastal zone
- Supercycling of biogeochemistry time stepping to reduce the computational cost
- Implement two-way coupling between atmosphere and ocean, and land and ocean to diagnose impacts of anthropogenic activities on ocean BGC and its feedback

What's needed?

- Improve the representation of organic matter cycling
  - Explicit microbial processes
  - Incorporate model developments by university collaborators



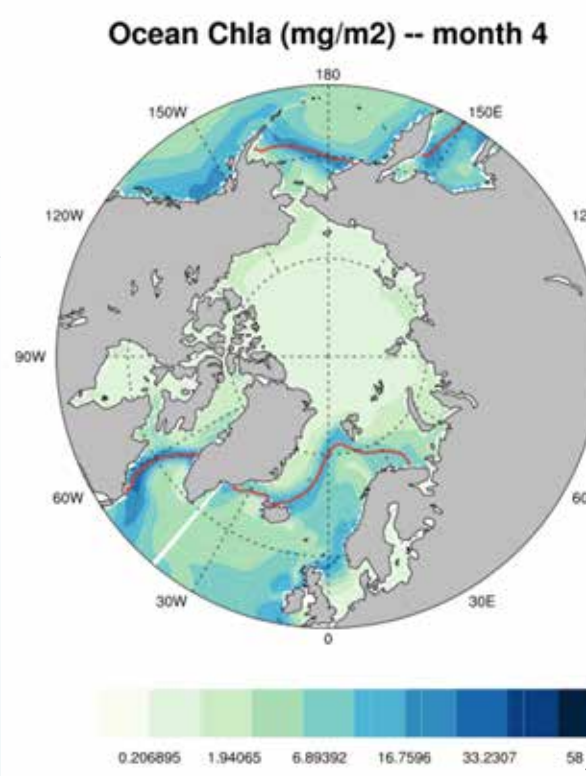
Improve the representation of export fluxes



(Turner, 2015)

Thank You!

Ocean Surface Chla



April

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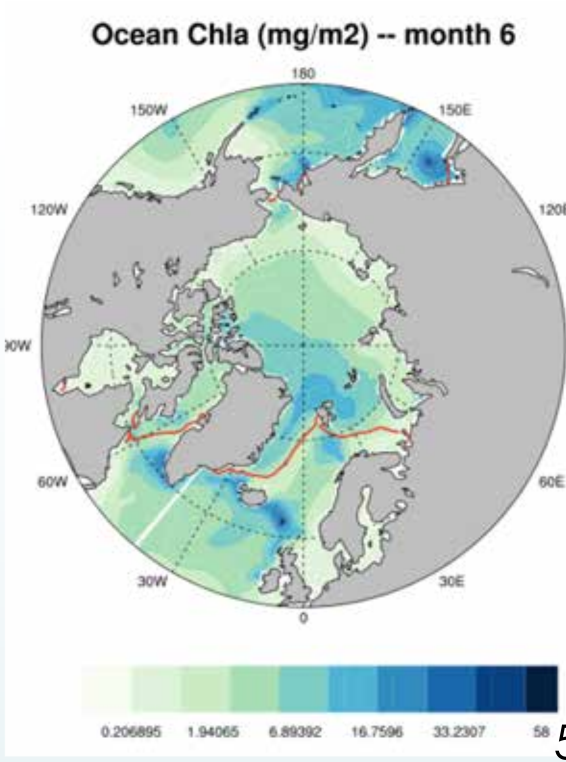

June

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Difference (polar chla with sea ice bgc – polar chla without)