Modeling Arctic seafloor biogeochemistry in E3SM for InteRFACE

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Introduction

- **Why** include seafloor (benthic) biogeochemistry in Earth System Models?
  - How benthos BGC is integral to the *coastal/shelf carbon cycle*
  - How benthos BGC is integral to the *Arctic food web*

Elements of a 1D benthos biogeochemical model

- *Mixing* and *transport*
- *Reactive* (Biogeochemical) component

Prototype (Matlab) testcase – the *Arkona Basin* of the Baltic Sea

Current and future efforts – *MPAS-O*

Coastal Carbon Pools

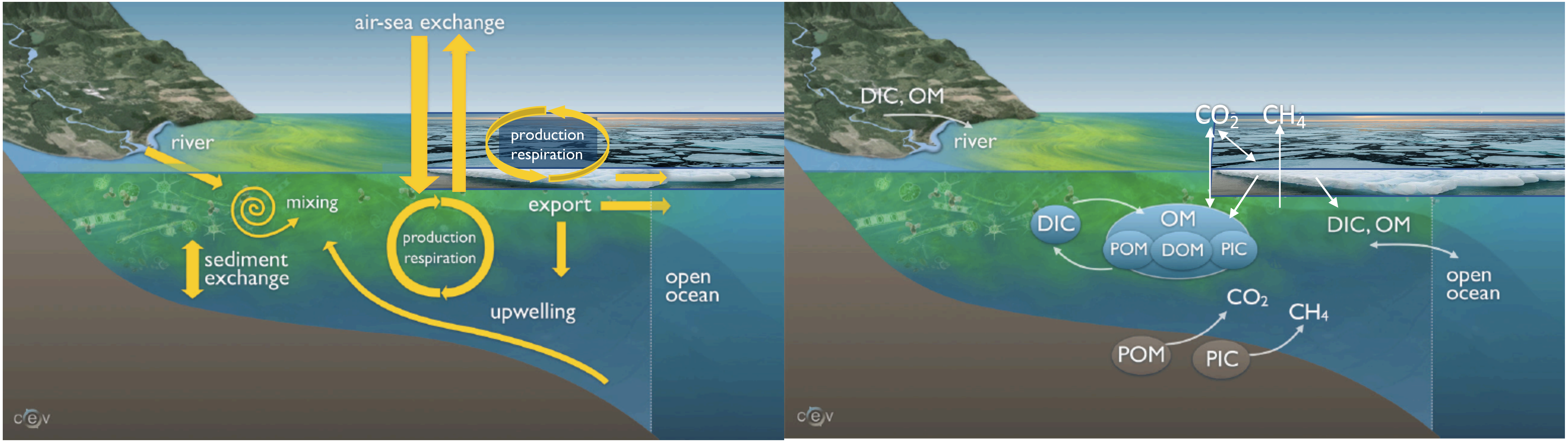


Figure 16.2. Major Coastal Carbon Pools and Fluxes. (a) Carbon in various forms (e.g., CO_2, carbon dioxide; CH_4, methane) is transferred among different pools and exchanged across interfaces between land, air, and ocean in coastal regions. **(b)** Carbon forms include dissolved inorganic carbon (DIC), organic matter (OM), particulate organic matter (POM), dissolved organic matter (DOM), and particulate inorganic matter (PIC). [Figure sources: Simone Alin, National Oceanic and Atmospheric Administration; Hunter Hadaway, University of Washington Center for Environmental Visualization; and Katja Fennel, Dalhousie University.]

Chapter 16: Coastal ocean and continental shelves: In Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report (2018)

Arctic Food Web

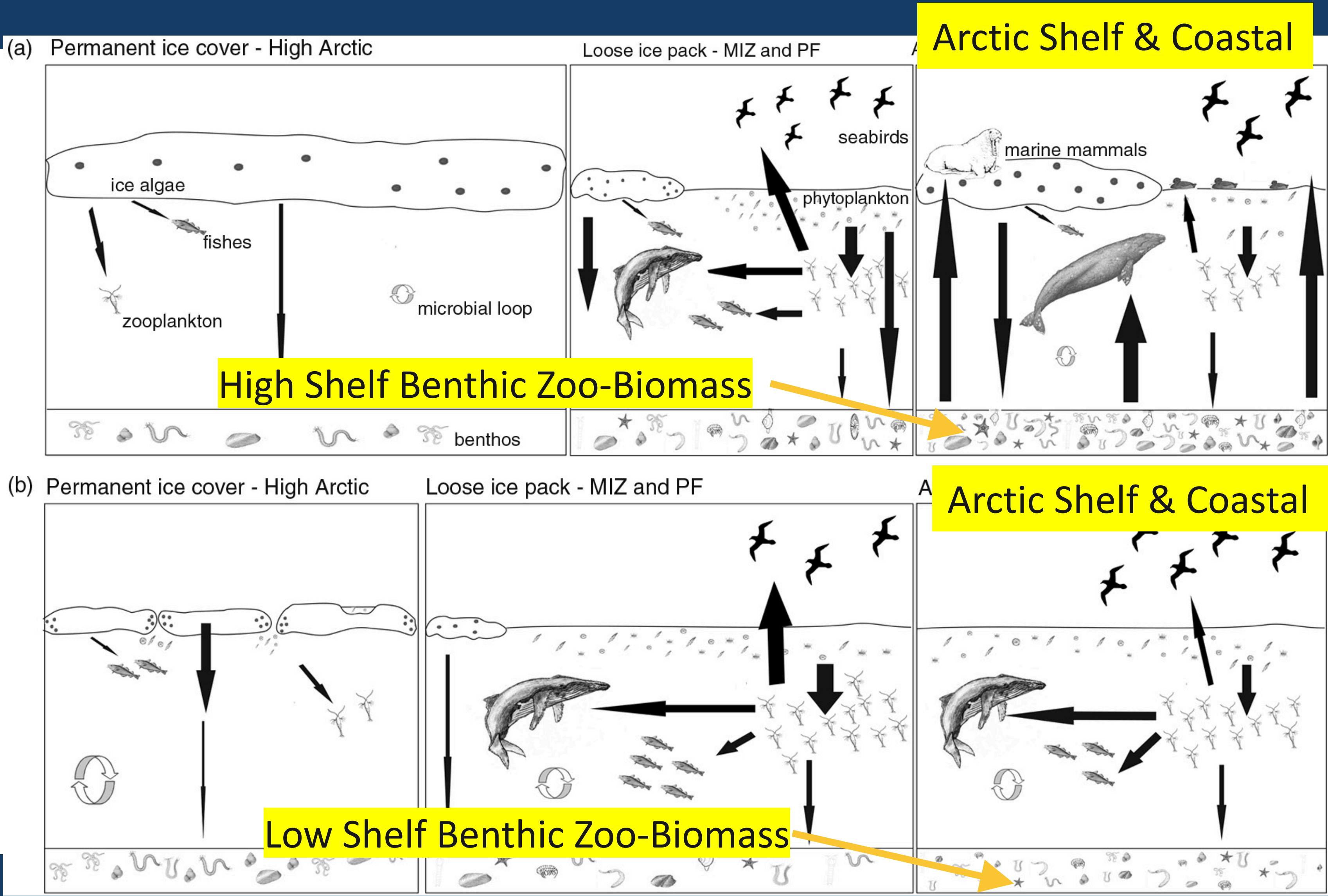
Arctic Food Web Scenarios

(a) Present Day:

Ice and ocean primary producers support a rich benthic biomass particularly in the shelf and coastal Arctic influenced by land processes.

(b) Future Estimate:

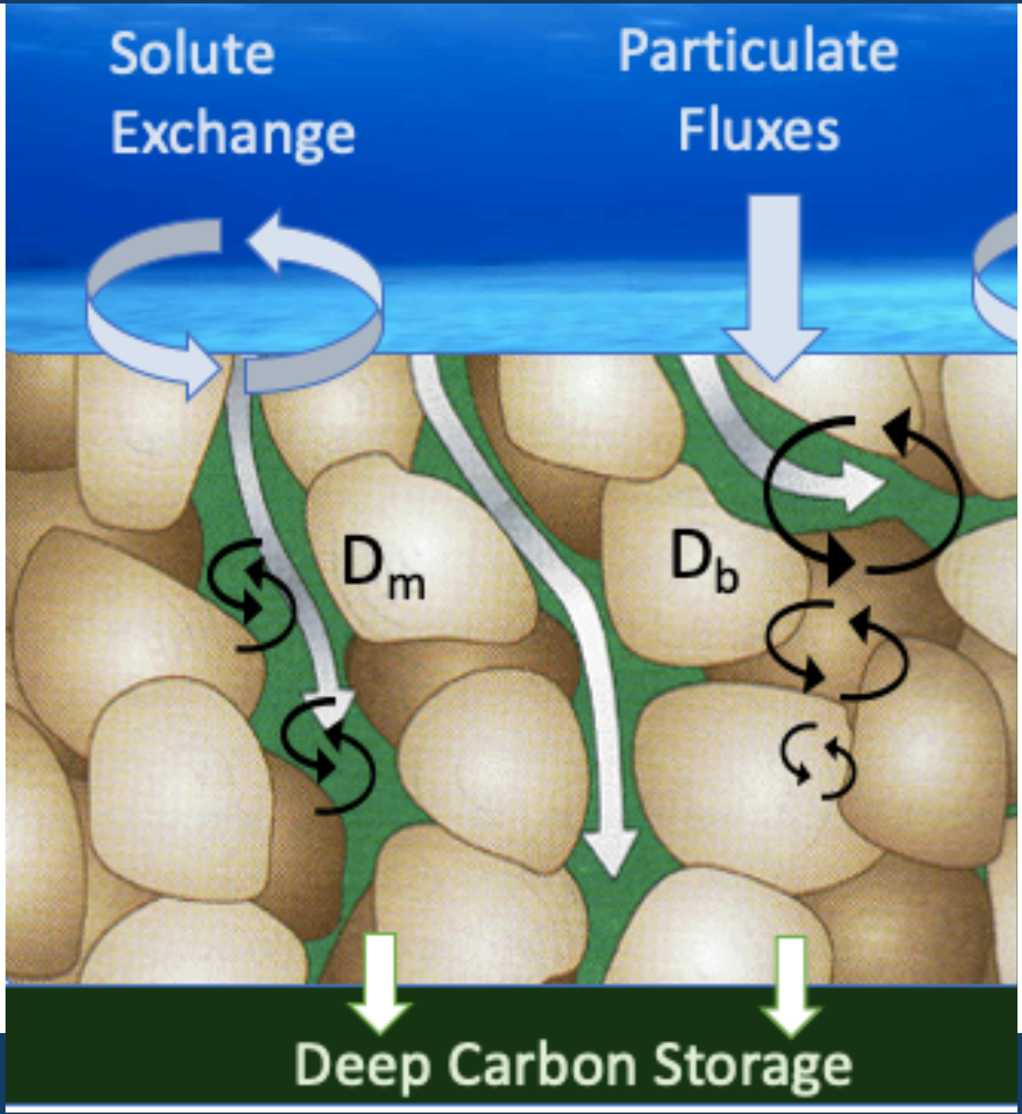
Loss of sea ice, changes in stratification reduce primary production fluxes to the benthos at the expense of many apex predators.



Will changes in coastal processes alter this scenario?

Ocean Benthos Diagenetic Model: Mixing and Transport

Active Sediment Layer



Ocean bottom (benthos) submodule consists of:

- ~30 cm active layer (30-300 grid levels)
- 35 solid and solute biogeochemical tracers
- Sinking **particulate fluxes** =
- sedimentation + *precipitation*
- Diffusive exchanges of solutes with ocean bottom waters

Interior mixing:

- D_m = molecular diffusion (corrected by tortuosity) of *solutes*
- D_b = Biodiffusion of *solids* and *solutes*

*Missing *V_i = Bio-Irrigation of solids and solutes**

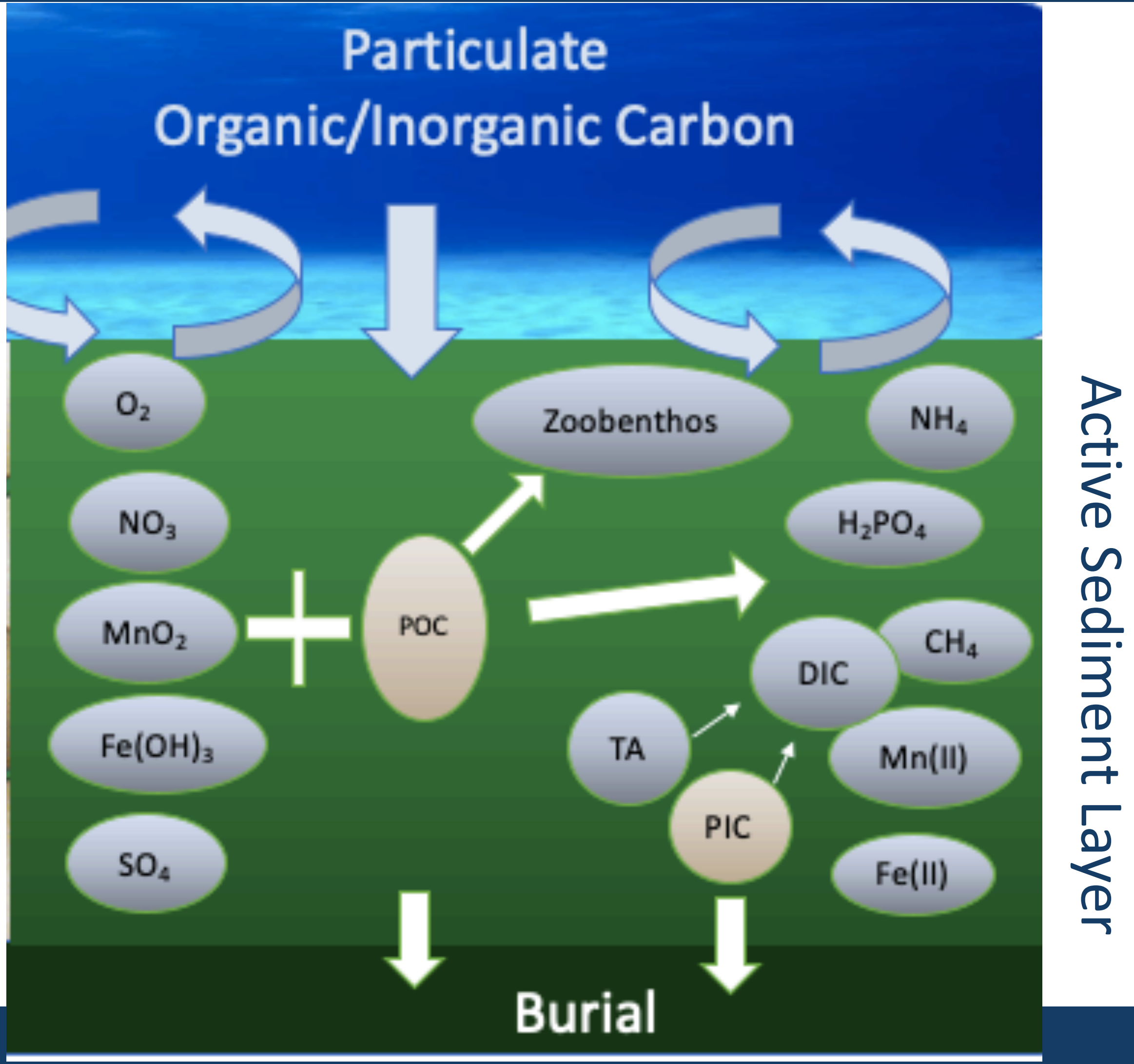
Ocean Benthos Diagenetic Model: Reactive Processes

Organic matter decomposition fuels the reactive transformations in the sediments

Microbiologically mediated, but microbial biomass is not explicit in the kinetics.

Rather kinetics follow the preferred oxidants: O_2, NO_3, MnO_2, $Fe(OH)_3$, and SO_4

Lastly, when oxidants are depleted, POM decomposes through methanogenesis (CH_4).

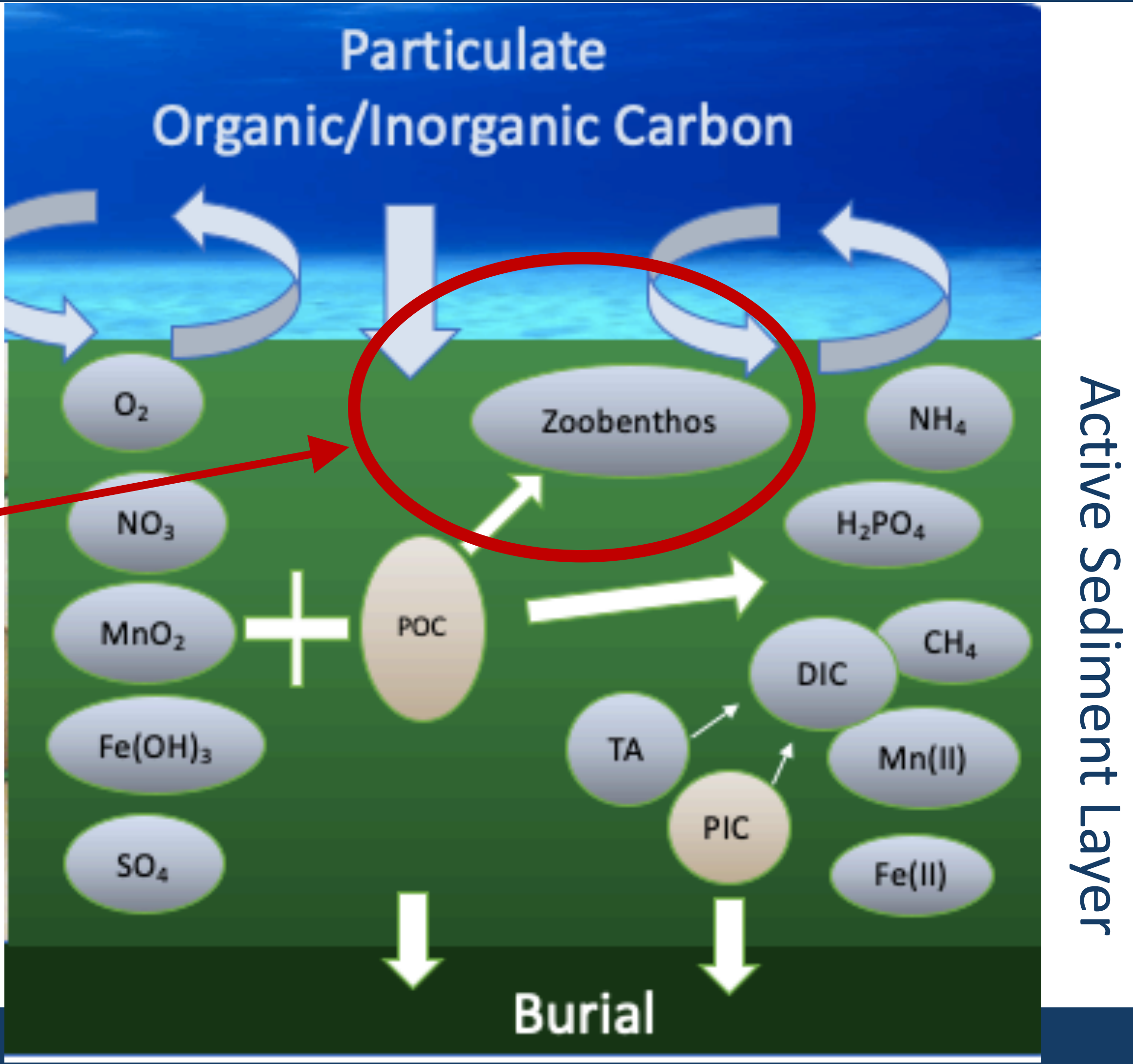


Ocean Benthos Diagenetic Model: Reactive Processes

Particulate inorganic carbon dissociation
Calcite, aragonite and 15% mg-calcite

Also included but not depicted are 19 secondary reactions

Still to do:
- Meio/macro –fauna biomass model (InteRFACE, food security implications)
- macroalgae (E3SM)



Arkona Basin, Baltic Sea Test Case in Progress

1D Prototype Model (Matlab)

Start with the benthos model of Reed et al. 2011 (not using his * bottom water model *)

add carbonate chemistry of Krumins et al. 2013

Borrowed heavily from MPAS-SI BGC, but many differences

Arkona Basin

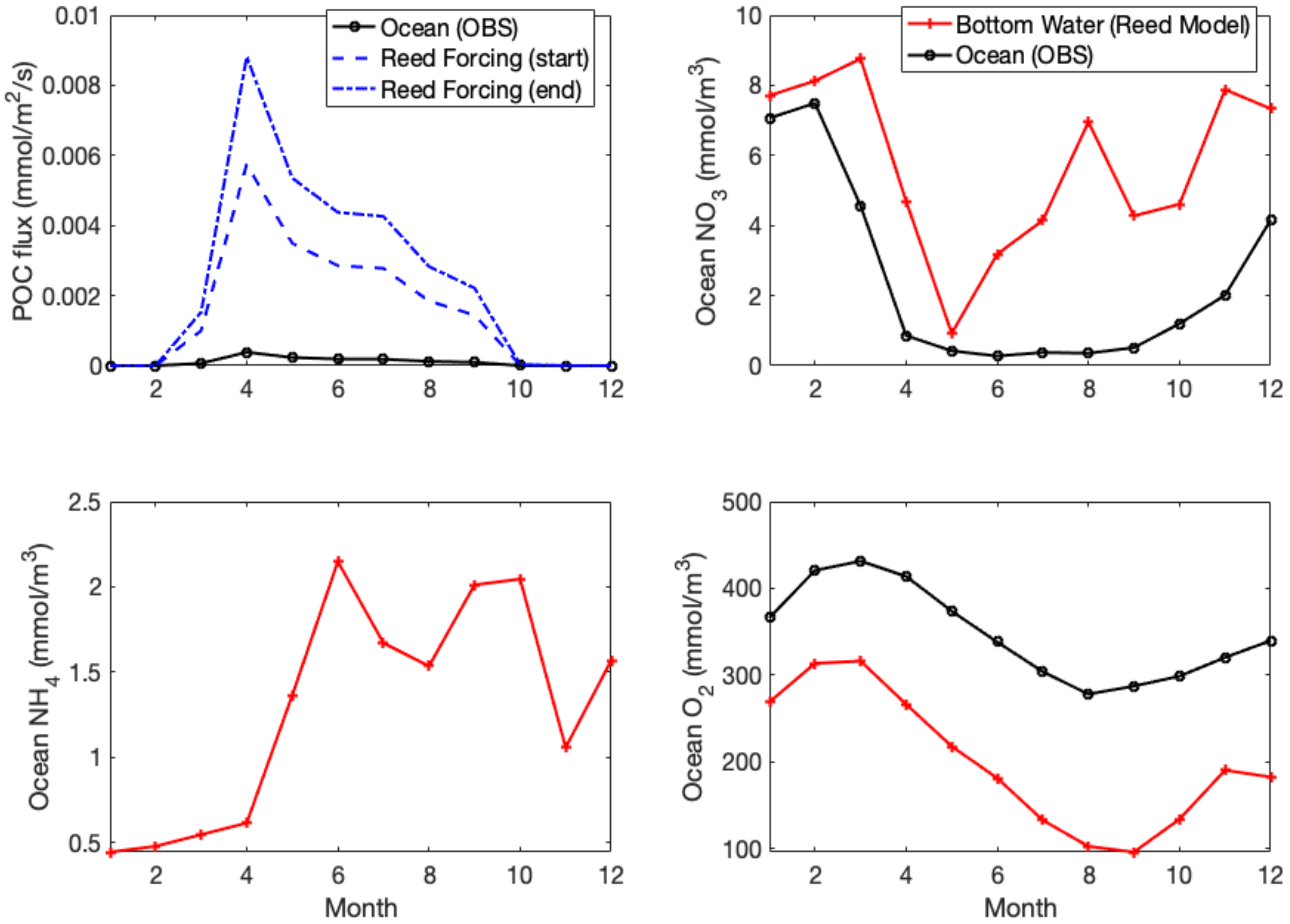
not in the Arctic, but data rich -> Sediment and pore water data + Ocean data. Mort et al. (2010)

Region of increasing hypoxia

Typical depths ~ 50 m

No apparent bio-irrigation

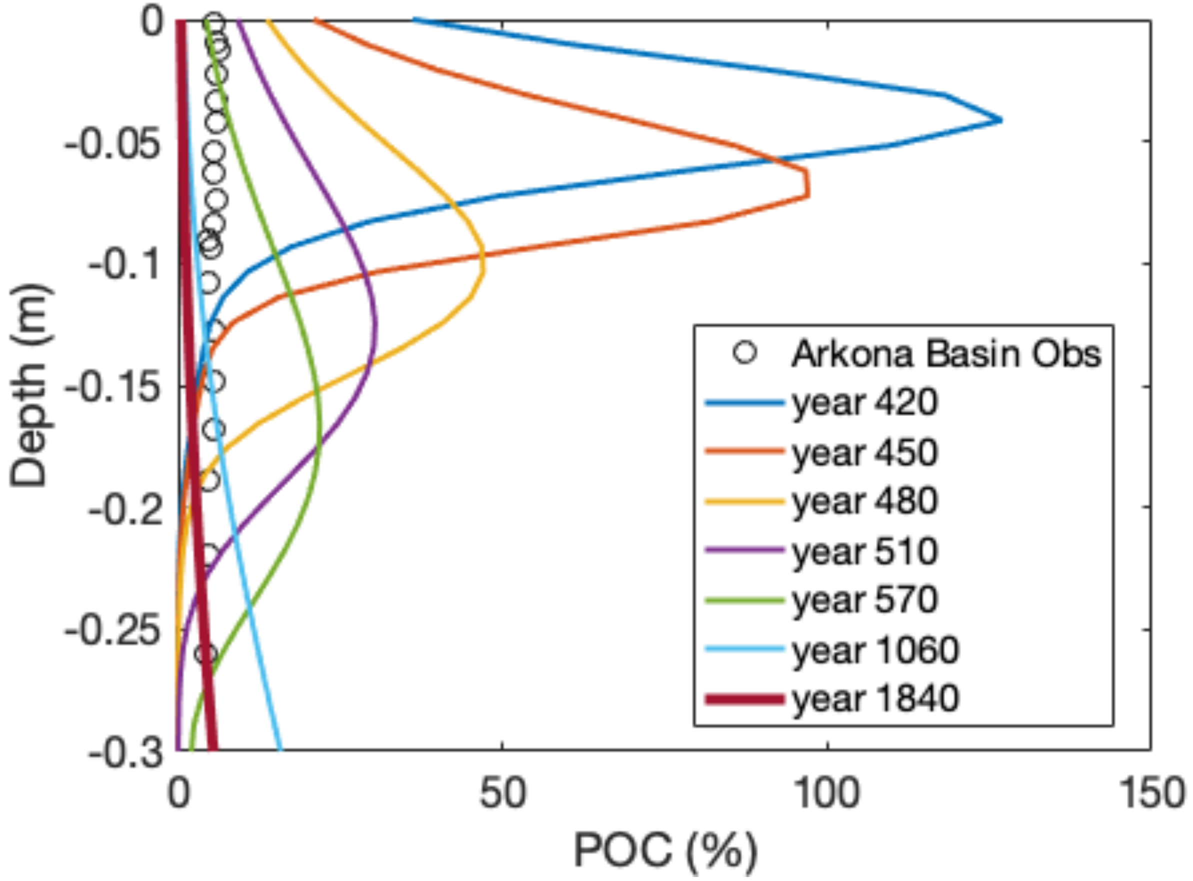
Forcing Ocean Source/Bottom Waters

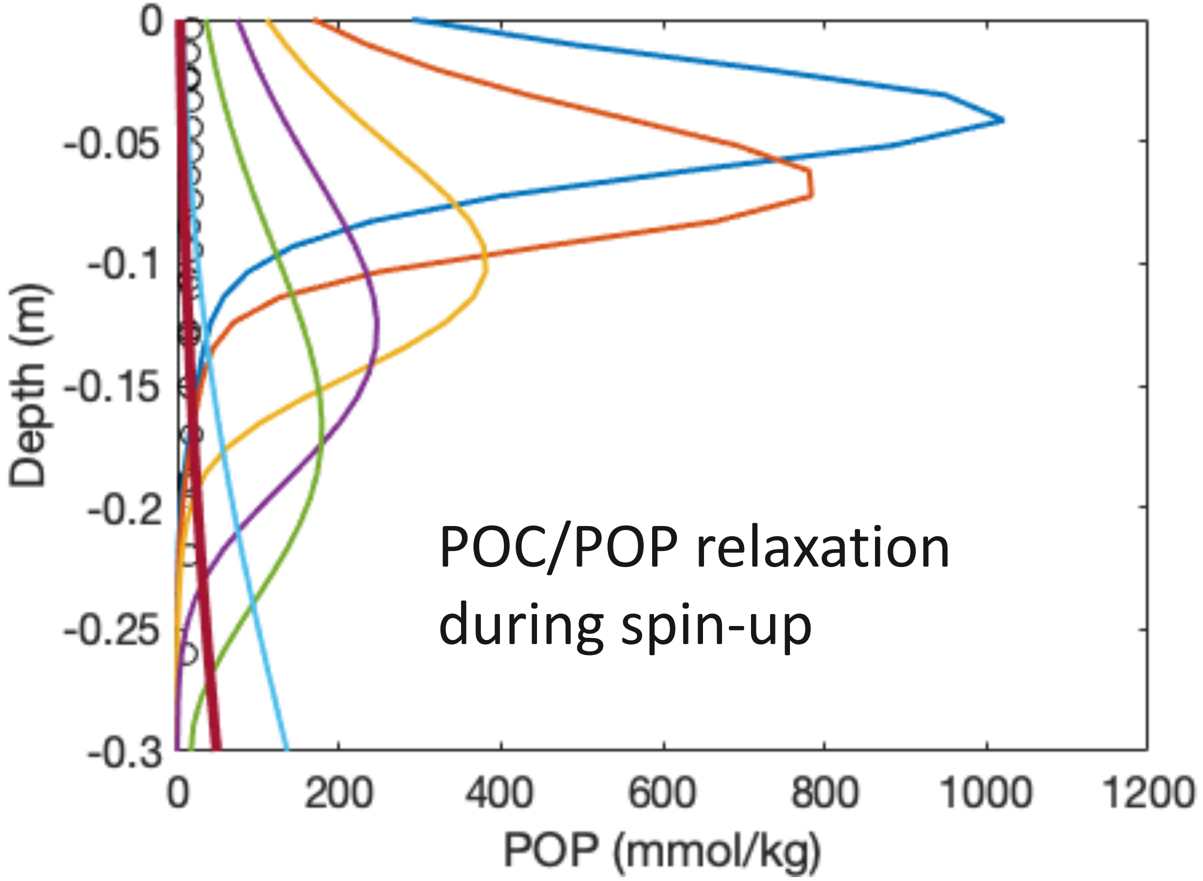


Key differences between our testcase & Reed et al 2011

- Reed et al. model the "bottom waters". I use his equilibrium values in the spin-up.
- Reed uses Enhanced POC fluxes for (at least) the last 80 years (blue lines). I use the ocean (OBS)
- Reed varies the POC/PON/POP ratios of the forcing and uses different POC:PON:POP ratios
- Reed computes the $Fe(OH)_3$ precipitation flux from his bottom water equation . I guess a value and keep it fixed. The MnO_2 precip is a tuning parameter.
- Reed uses "enhanced" POP remineralization. But how much???
- Reed uses 300 grid points, I use 30 **

Model Spin-up: Particulate Organic Matter

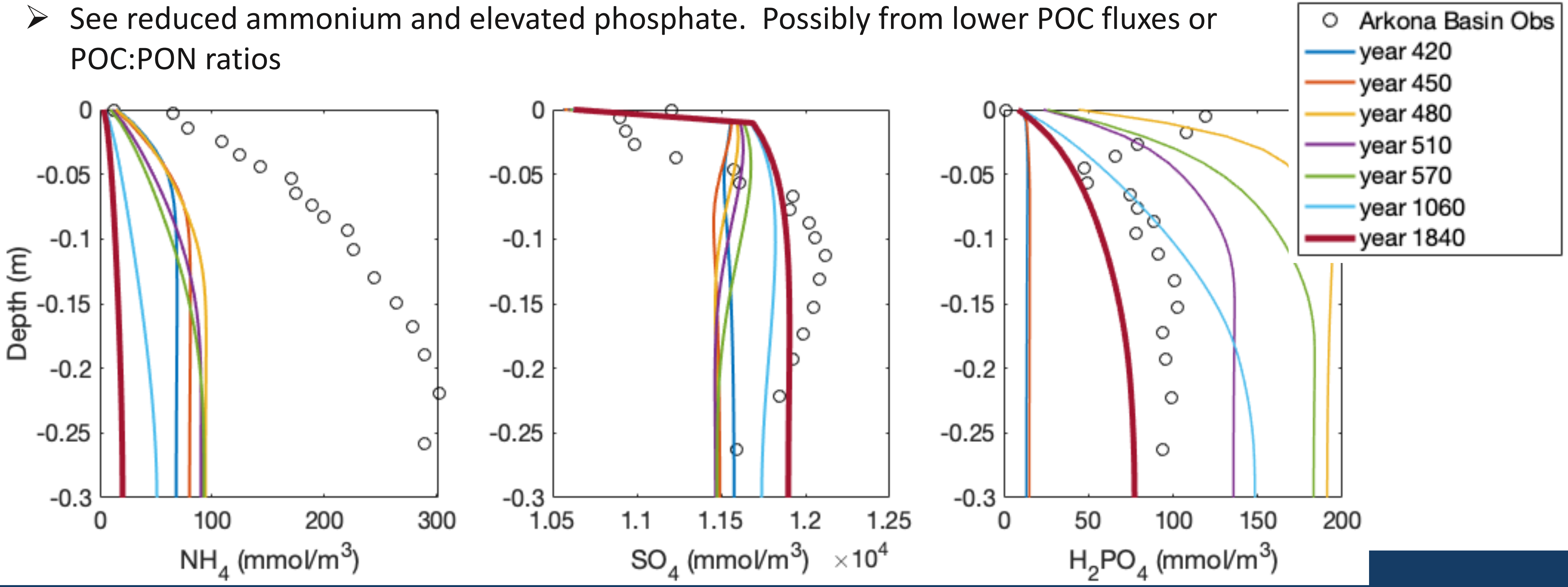




POC/POP relaxation during spin-up

After 1800 years of spin-up…

- Much faster equilibration of the solutes.
- SO_4 is strongly determined by the ocean concentration.
- See reduced ammonium and elevated phosphate. Possibly from lower POC fluxes or POC:PON ratios



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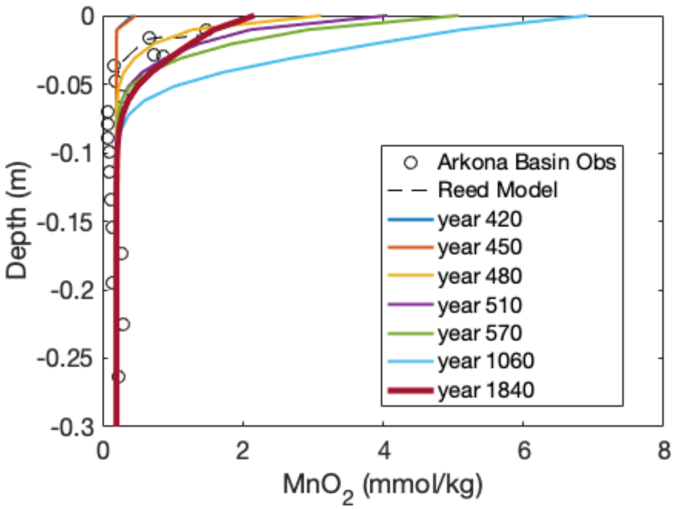
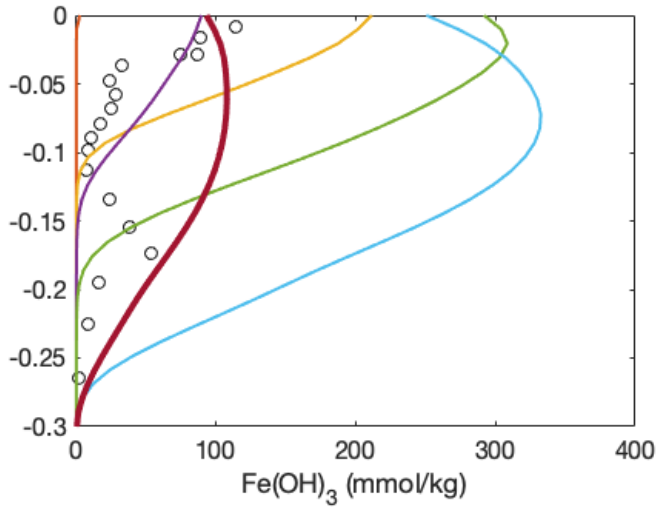
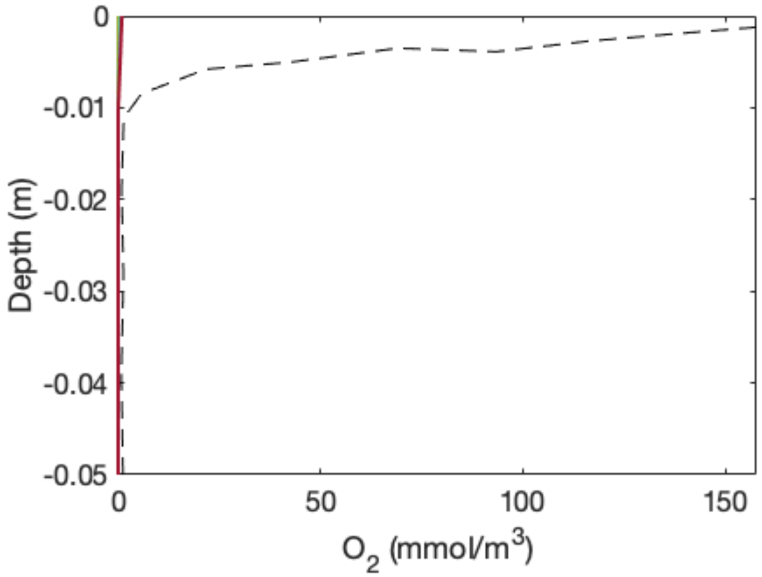
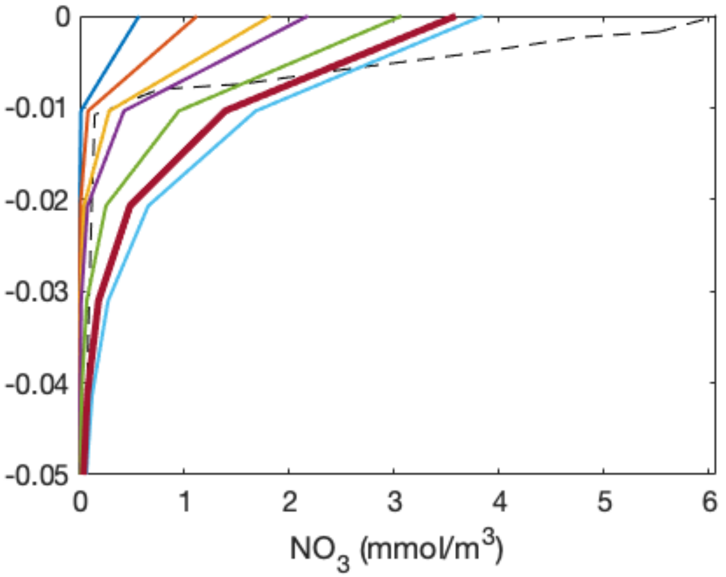




- MnO₂ and Fe(OH)₃ precipitation fluxes are tuned.
- A constant value for MnO2 works fairly well.
- Fe(OH)3 is more sensitive.

- Very high O_2 demand and reduced surface values in our model compared with Reed et al. 2011.
- Nitrate is better but our coarse resolution is evident





The Benthic Submodule in MPAS-O

- Ported the code to Fortran.
- Includes 11 test cases
- Working on verifying the port against 1D prototype version, thinking about spin-up.

Things that will change in a production version:

- Currently active for all MPAS-O grid cells, prefer coastal/shelf zone only
- Sediment fluxes and ocean bottom concentrations from BEC model but no feedbacks.
    - Currently no temperature dependence in reaction terms
    - Sediment density is a function of ocean depth based on observations.
    - Sediment fluxes are also function of ocean depth; Middelburg et al. (1997).
    - Eventually sediment flux needs to come from rivers/coast/ocean (ICOM).
    - Still need to add biology: meiofauna and macroalgae