2018 OCB WORKSHOP

DATA ASSIMILATIVE ECOSYSTEM MODELING OF BACTERIAL DYNAMICS AND UPPER-OCEAN CARBON CYCLING IN THE COASTAL WEST ANTARCTIC PENINSULA

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INTRODUCTION

The West Antarctic Peninsula (WAP) is a climatically sensitive region where periods of warming have caused significant changes in marine ecosystem and biogeochemical processes over the past decades.

The Palmer Long-Term Ecological Research (LTER) program has spanned over 25 years of observations (1991-2018) of key biogeochemical variables to understand how ecosystem functions have responded to the variability of climate and physical forcing in the WAP.

Modeling can benefit from Palmer LTER's rich observations, but ecosystem models specific to simulating Palmer region had been lacking.

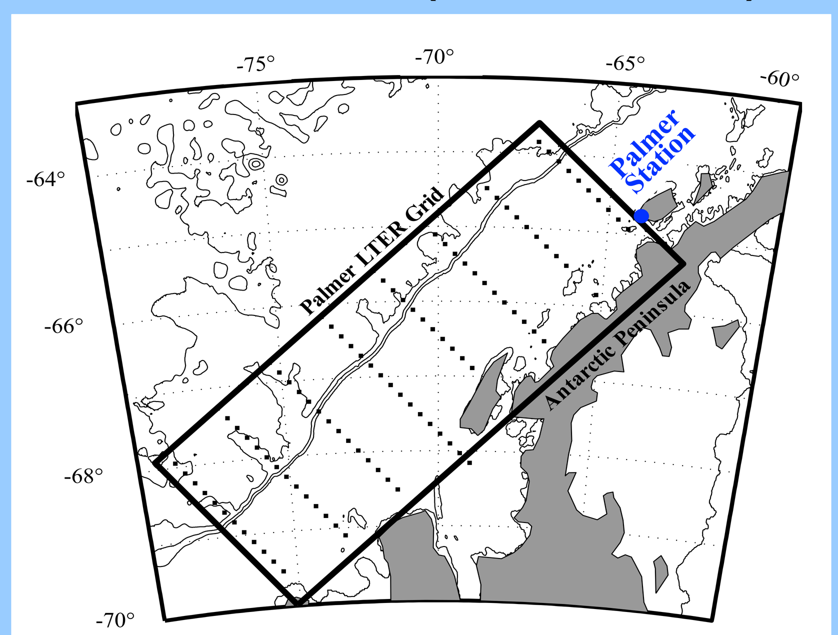
Here, we developed **a marine ecosystem model** that provides built-in capabilities for assimilating physical forcing data and optimizing biological model parameters based on **a variational adjoint scheme**.

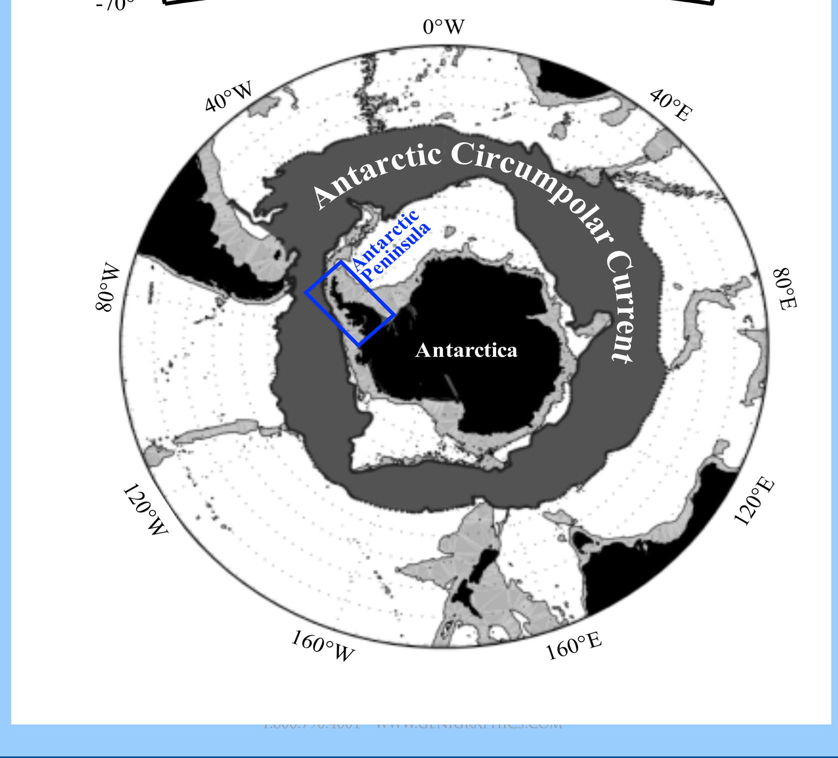
Assimilating Palmer LTER observational ecosystem variables, we simulate the flexible stoichiometric **C, N, and P stocks and flows of the WAP food-web components**.

With our model we explore how marine heterotrophic bacterial processes and upper-ocean cycling change in response to **increasing temperatures** to understand the ecosystem responses to climate change in the coastal WAP.

STUDY SITE

Palmer Station (64.8°S, 64.1°W)





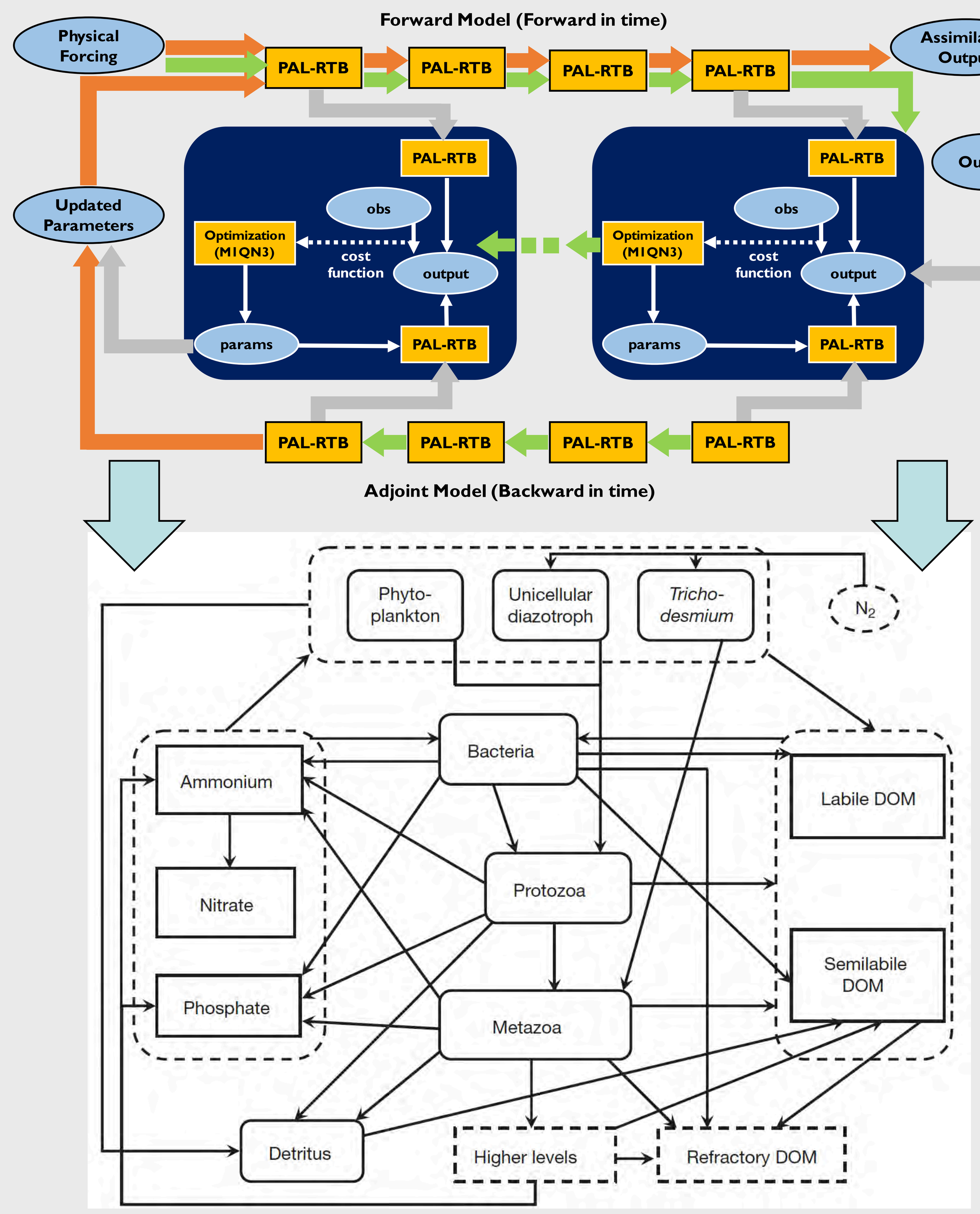
MODEL DESCRIPTION

1-D Ecosystem model. The model was built from existing regional test-beds (Friedrichs *et al.* 2006, Luo *et al.* 2010) with a newly added sea ice scheme (Long *et al.* 2015). The model is forced by MLD (CTD), PAR (NCEP reanalysis), sea ice (satellite), water temperature (CTD), vertical eddy diffusivity and velocity (CTD). The model simulates flows and stocks of flexible stoichiometric C, N, and P through each state variable (phytoplankton, bacteria, nutrients, zooplankton, DOM, and detritus) at **7 depths (2.5-60 m)** for **Austral growing seasons (September - March)** in the field seasons **2003-2004 (moderate ice year), 2005-2006 (high ice year),** and **2009-2010 (low ice year).**

Data assimilation. The model is equipped with a parameter optimization tool based on **a variational adjoint scheme** (Lawson *et al.* 1995). Total 10 Palmer LTER variables are assimilated to optimize the model output toward observation.

- Starting with an initial guess for the model parameter set, the model is run forward in time to obtain a value of the **cost function** (*i.e.* model-observation misfit).
- **The adjoint of the model** built from the Tangent linear and Adjoint Model Compiler is then run backward in time, computing **the gradients of the cost function** with respect to the model control parameters.
- The calculated gradients of the cost function are transferred to a limited memory quasi-Newton optimization software (M1QN3) where **the optimal step size and direction** are computed to minimize the cost function. This procedure gives new values of the model control parameters, forming the optimized model parameter set each cycle.
- The entire process is repeated in an iterative manner until **a convergence criterion** for data assimilation is met.

Model Structure

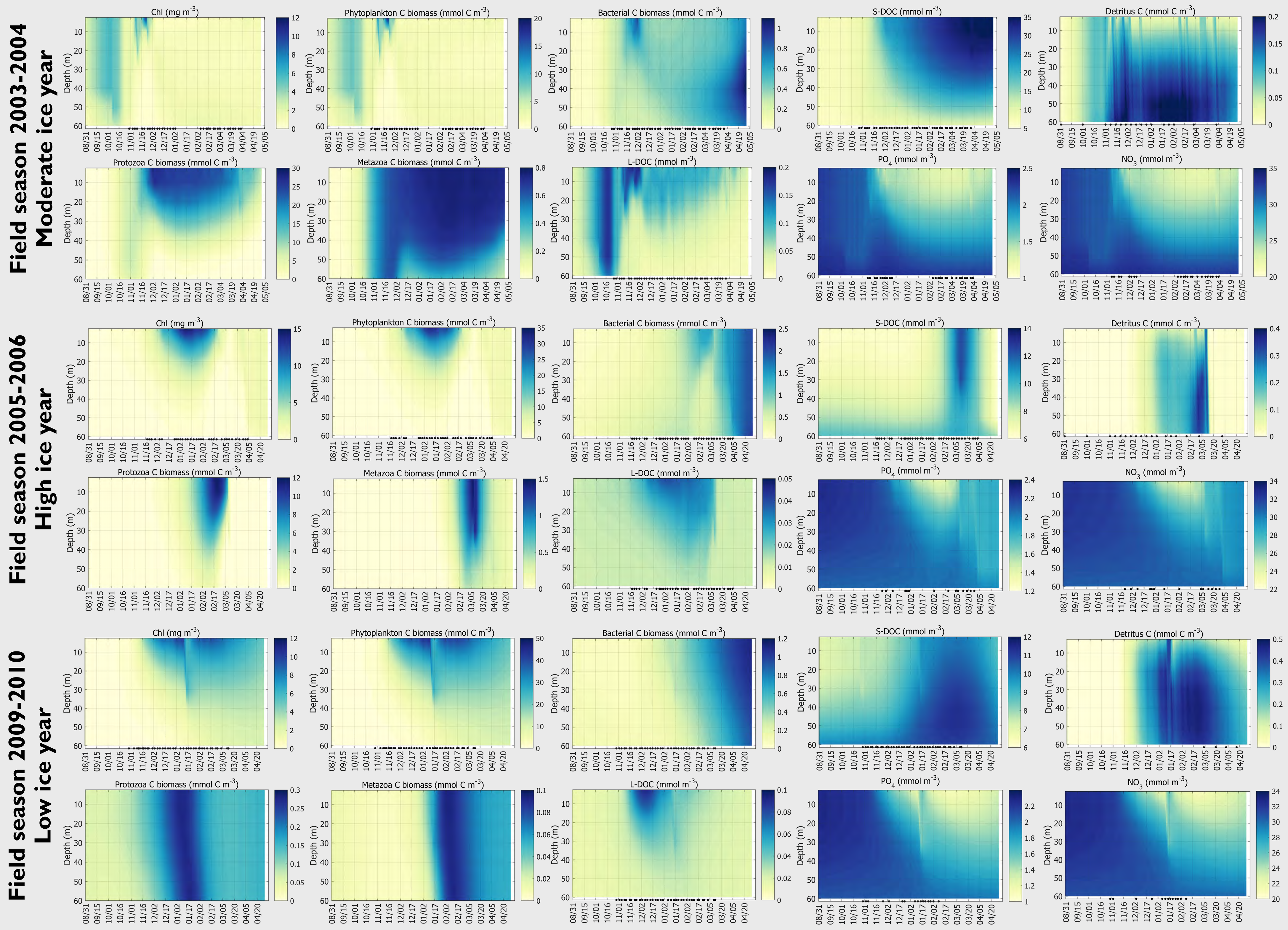


EXPERIMENTAL DESIGN

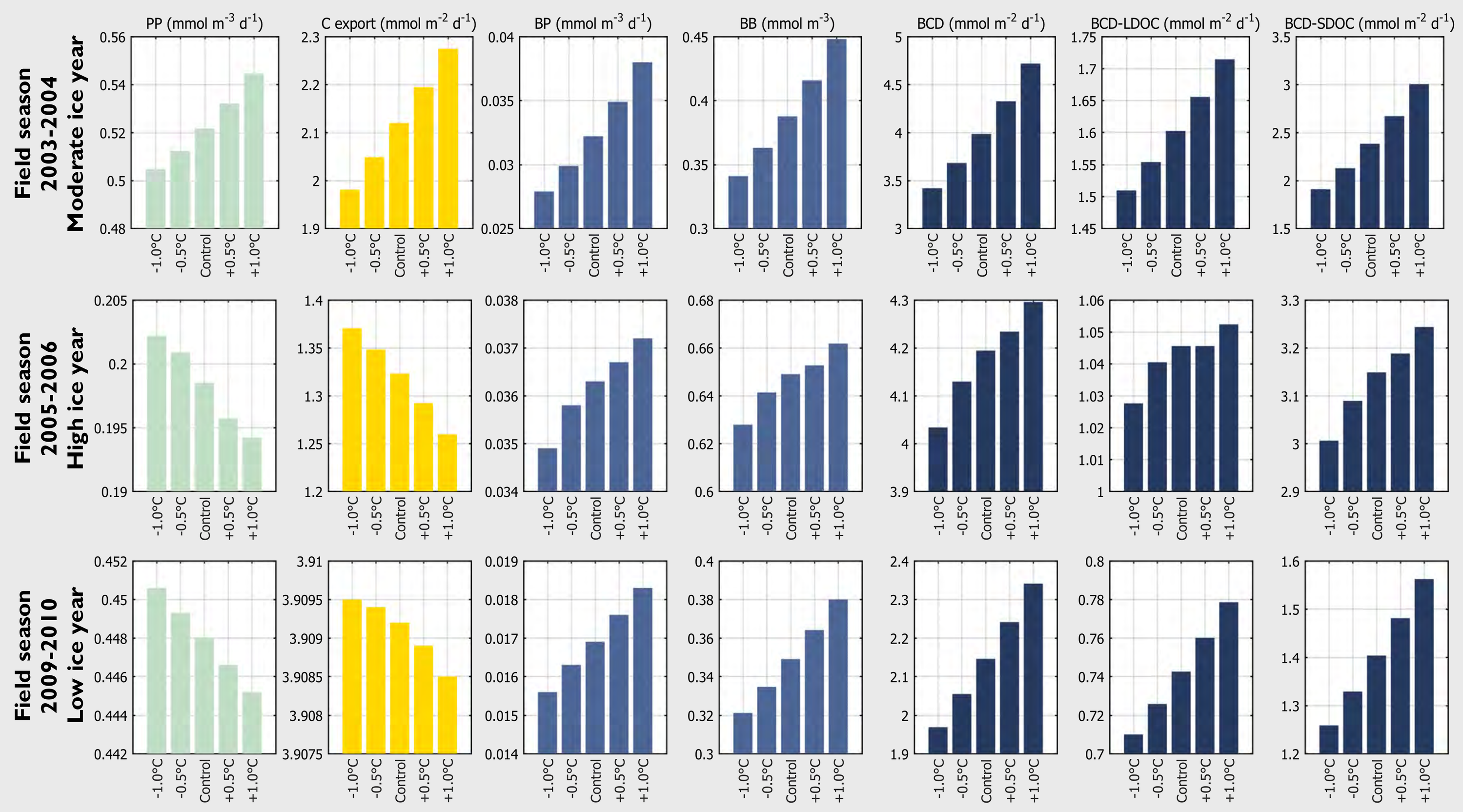
- The model is run for each field season using different initial guesses of the model parameters (*i.e.* **control runs**).
- With the optimized parameter sets for each field season, the model is rerun with **varying temperature forcing** fields.

RESULTS

Model-observation misfit. After data assimilation the cost functions successfully decreased by 73, 51, and 60% for the field season 2003-2004, 2005-2006, and 2009-2010, respectively. Out of total 59 biological model control parameters, 14, 12, and 8 parameters were optimized for each field season.



Modeled ecosystem dynamics. Depending on the degree of sea ice extent in each field season, there are different patterns of phytoplankton blooms, bacterial-phytoplankton coupling, and bacterial grazing by microzooplankton. Labile DOC (L-DOC) is largely produced by phytoplankton processes and supports bacterial blooms immediately after the phytoplankton blooms. Semi-labile (S-DOC) tends to increase in the later growing seasons, supporting late spring-summer bacterial blooms.



Bacterial responses to increasing temperatures. There are inconsistent responses of primary production (PP) and carbon export to increasing temperatures. In contrast, bacterial production (BP), biomass (BB), and bacterial carbon demand (BCD) always increase with temperatures. The rate of an increase in BCD supported by S-DOC is always higher than that supported by L-DOC.

DISCUSSION

- Our results suggest that temperature plays a significant role in shaping bacterial dynamics in the coastal WAP: The higher temperature the more active bacterial processes ("temperature limitation" on bacterial growth).
- The role of S-DOC in supporting bacterial growth is increasingly important under warming (*e.g.* changing L-DOC production by phytoplankton, increasing S-DOC from retreating glaciers).

FUTURE WORK

More sophisticated treatment of bacterial dynamics by implementing "trait-based approaches" and genomic framework in the model (Bowman *et al.* 2017).

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