Development of an Eddy-Permitting Carbon Cycle Model using Southern Ocean State Estimate

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What are the role of eddies?

The goal of this study is to better understand the role of ocean eddies in controlling biological productivity and carbon fluxes in the Southern Ocean. We hypothesize that they play primary roles in the regional ecosystem, biogeochemistry and carbon uptake through processes such as:

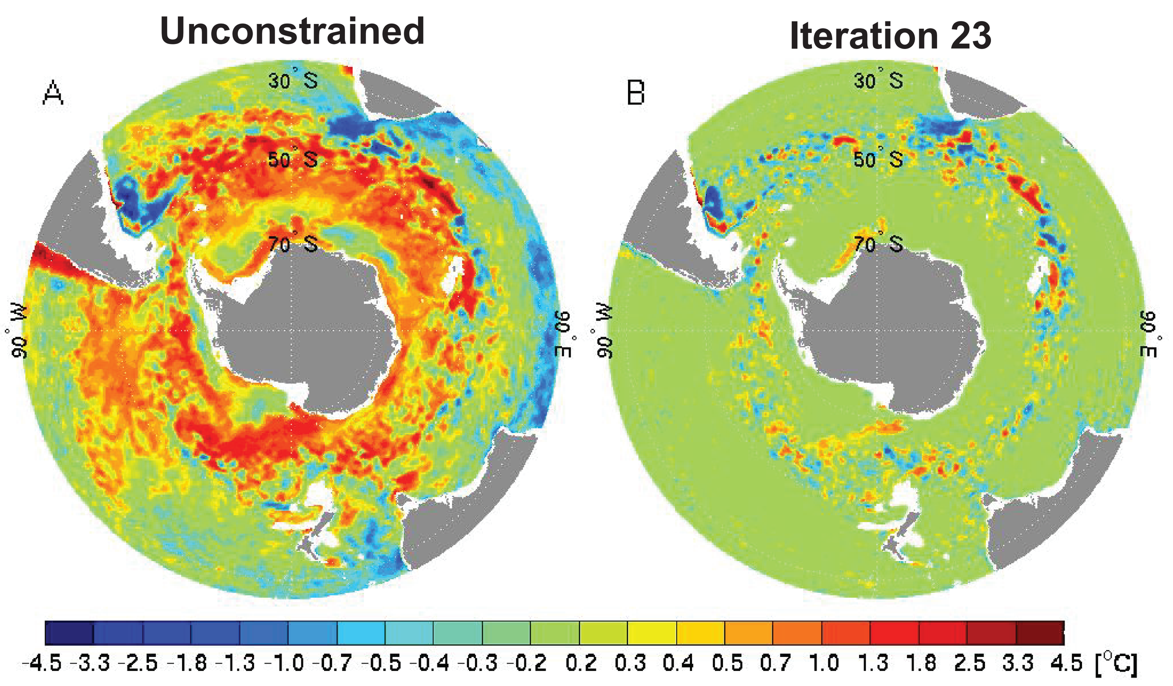
- **Intermittent upwelling**
- **Cross-frontal stirring**
- **Eddy-induced, large-scale advection**

Ocean eddies are not resolved in coarse resolution GCMs and have been crudely parameterized. Thus, we aim to produce realistic representation of ocean eddies by developing **a high resolution ocean carbon cycle model constrained by the suite of satellite and in-situ observations.** The results can lead to improved representaions of ocean carbon cycle at the scales of ocean fronts and eddies, reducing uncertainties in the estimates of regional ocean productivity and carbon uptake.

Southern Ocean State Estimate

Using adjoint method, an eddy-permitting ocean GCM (MITgcm) is iteratively fitted to the suite of satellite and in-situ observations. In collaboration with M. Mazloff, C. Wunsch and P. Heimbach of MIT, we employ physical ocean circulation fields determined by the Southern Ocean State Estimate (SOSE) of the Estimation of the Circulation and Climate of the Ocean (ECCO) project (For detailed information on ECCO activities, visit http://www.ecco-group.org)

Model-data misfit for SST



Model-data SST differences are first calculated against infrared and microwave SST data separately, and then averaged to produce the above figures.

Control variables (initial condition, prescribed atmospheric state, and open northern boundary at 24.7S) **are systematically adjusted to minimize the cost function.**

Model resolution and parameterizations
1/6 degree lat-lon grid and 42 vertical layers, KPP mixing scheme, bulk formula, thermodynamic sea ice model

Observational constraints used in SOSE:

Satellite altimeter (Topex/Poseidon, Jason, European Remote-Sensing, GFO)
Satellite geoid (GRACE: Gravity Recovery and Climate Experiment)
Satellite SST (NCEP/Reynolds and Remote Sensing System dataset that are derived from AVHRR and AMSR-E/TMI respectively)
In-situ T and S (ARGO float profiler, ship-based CTD and XBT, SEaOS dataset) The number of in-situ measurements exceeds 2 million data points.
Climatological T and S for deep ocean (World Ocean Atlas)
Satellite sea ice cover (NSIDC dataset which is derived from SSM/I)

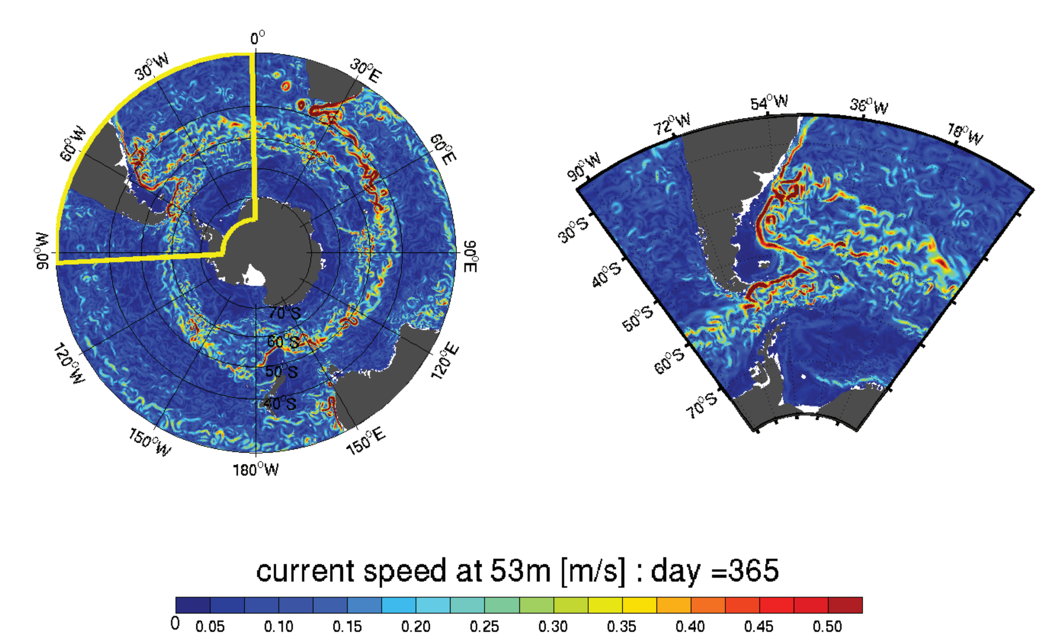
Model development

Two types of ocean carbon cycle models are embeded in the offline tracer transport scheme driven by the SOSE circulation including:

- **OCMIP : simplified biogeochemistry**
- **MITeco : Intermediate complexity ecosystem model**

OCMIP is computationally efficient including only 5 tracers (DIC, Alk, DIP, DOP and O_2). MITeco includes phosphate, iron and silica as limiting nutrients, two phytoplankton functional groups, a zooplankton class and detritus pools (Dutkiewicz et al. 2005).

At this initial stage, we evaluate the model by executing **regional simulations near Drake Passage**



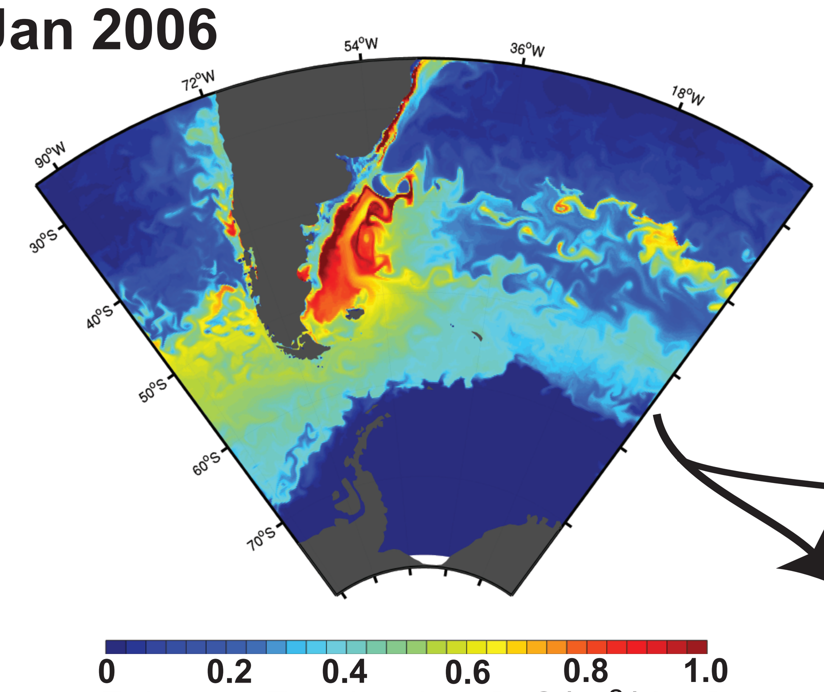
Computationally efficient (using 1/4 of model domain) suitable for test cases and sensitivity experiments

Open boundary conditions at the western, eastern and northern edges are interpolated from the global, corase resolution version of the model.

Both OCMIP and MITeco models are spun up for about 10 years.

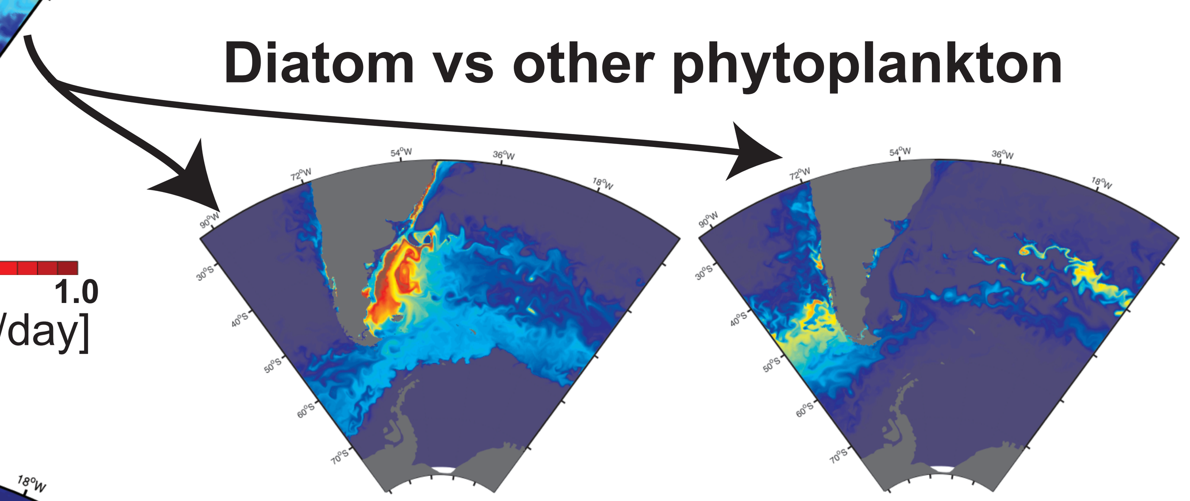
Ocean productivity

Jan 2006

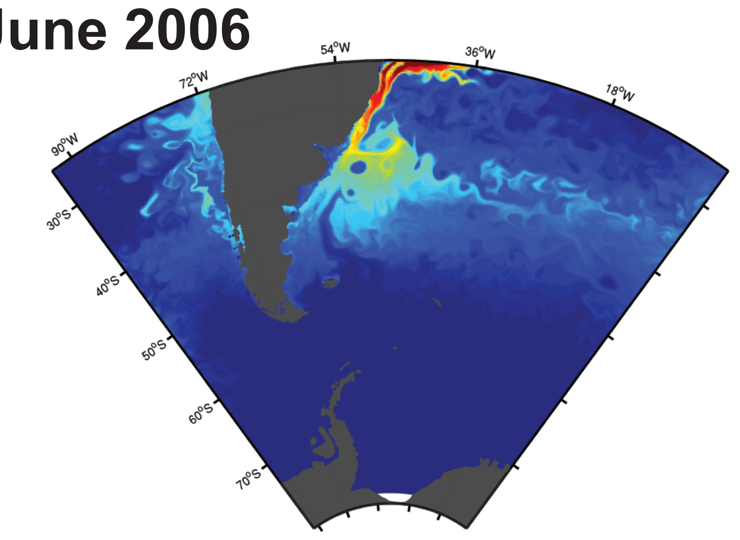


Primary production is explicitly calculated in MITeco as the growth rate of phytoplankton, which reflects the complex interplay between availability of light and nutrients, mixed layer depth, competition between different functional groups and grazing by zooplankton.

Diatom vs other phytoplankton



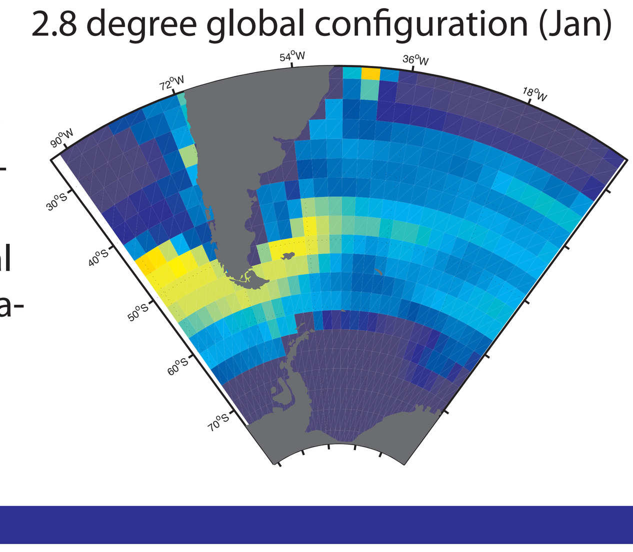
June 2006



Simulated productivity exhibits strong seasonal cycle and variability associated with sea ice, western boundary current, ocean fronts and eddies.

Sensitivity to model resolution

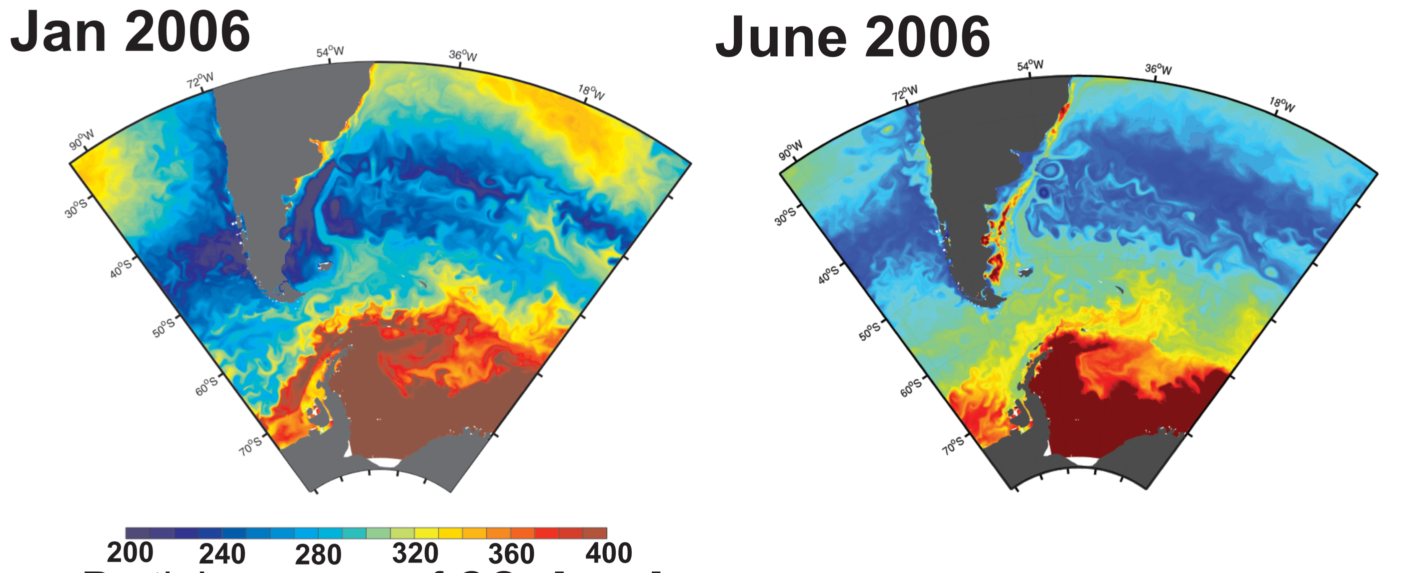
2.8 degree global configuration (Jan)



Using identical model parameters, coarse resolution model lacks strong productivity near the western boundary and at the frontal regions, leading to a qualitatively different pattern of productivity.

Surface ocean pCO_2

Natural carbon cycle
During the initial spin-up, atmospheric pCO_2 is set to 278 ppm in order to determine the background, natural component of surface ocean pCO_2. Ongoing calculations include the comtemporary carbon cycle simulations with the effect of rising atmospheric CO_2.



Competition between solubility and biological pump
During summer seasons, strong biological uptake tends to deplete surface ocean pCO_2 while surface heating tends to increase pCO_2. Inhibition of air-sea gas exchange due to sea ice cover keeps high pCO_2 under the ice-covered regions.

Mesoscale pCO_2 variability
Due to relatively slow gas exchange of CO_2 (~1 yr timescale), physical ocean transport and biological sources and sinks of carbon can significantly influence surface pCO_2 variability.

Future plans

While this project is at an initial stage, the early results are encouraging. SOSE is evolving and the model-data misfit continues to go down for physical fields. Ongoing and future developments include:

- **Physical model improvements**
  - Improving sea ice model
  - QuikSCAT winds
  - Continuing adjoint optimization
- **Comtemporary simulation** with historical atmospheric CO_2
- **Expanding the model domain**
  - Including the entire Southern Ocean
- **Detailed model evaluation and analysis**
  - Comparison against satellite and in-situ ocean productivity and CO_2 measurements

References and acknowledgements

Dutkiewicz, S.W., P. Parekh and M.J. Follows (2005) *Interactions of the iron and phosphorus cycles: A modelling study.* Global Biogeochem. Cycles. 19, GB1021, doi:10.1029/2004GB002342

Mazloff M. (2006), *Production and Analysis of a Southern Ocean State Estimate*, M.S. thesis, Department of Earth Atmospheric and Planetery Sciences, MIT.

Wunsch C. and P. Heimbach (2007), *Practical global ocean state estimation.* Physica D, 230(1-2), pp. 197-208, doi:10.1016/j.physd.2006.09.040.

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