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Title: Evaluating the Impact of Ocean Eddies in the Global Marine Carbon Cycle

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Evaluating the Impact of Ocean Eddies in the Global Marine Carbon Cycle

(w17_OceanEddies)

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Introduction

The ocean plays a crucial role in the Earth's carbon cycle due to its ability to exchange carbon dioxide (CO_2) with the atmosphere, and subsequently store it for long periods of time. Part of this sequestration is due to a mechanism known as the Biological Pump, a process where phytoplankton and autotrophic bacteria convert dissolved CO_2 to organic matter via photosynthesis, much of which ends up sinking and can remain in the deep ocean for hundreds or thousands of years. If the strength of the Biological Pump changes due the human-induced increase in atmospheric CO_2, it will affect the rate of global warming. Earth System Models (ESMs) are now including ocean biogeochemical processes in order to quantify changes in the global carbon cycle under climate change scenarios by embedding a model that represents ocean chemistry and the dynamics of marine ecosystems within an ocean circulation framework. Due to the increased computational cost of including marine biogeochemistry (BGC), they are typically run with relatively low complexity and coarse horizontal grid resolution. Our project utilizes Institutional Computing power to undertake an ESM simulation using a moderate complexity BGC model (35 constituents) and an increased grid resolution that allows the formation of turbulent mesoscale eddies (30 to 200 km in size) in the ocean. Comparing with low resolution runs will allow us to assess whether standard ESMs are biased in their representation of the carbon cycle due to parameterized effects of sub-grid scale physics.

Progress

The ESM we are using is the newly developed Energy Exascale Earth System Model (E3SM, formerly known as ACME). While this model has the advantage of improved accuracy and new capabilities compared to our previous model (CESM), it has also experienced development hurdles. During the initial spin up phase of our simulation, a significant bug was discovered in the ocean model that resulted in unacceptably poor representation of crucial high latitude circulation features. The issue has been fixed, but we are not as far along as we had hoped at this point in time. We have redone the spin up phase of the circulation and have completed 7 years of simulation (out of the proposed 65 years) of the base simulation.

Although only 7 years have run with full biogeochemistry, we are seeing some of the kinds of features that we had hoped for when proposing this work. Figure 1a shows the surface concentration of chlorophyll contained in the cells of the smallest class of photosynthetic phytoplankton from November of year 7 (Southern Hemisphere Spring). The abundance of this phytoplankton in the eddies west of South Africa is a clear example of a feature that isn't captured by low resolution simulations. Associated with this bloom of phytoplankton is a reduction of nutrients, such as nitrate (NO_3, not shown). Since these eddies move toward South American coast, they are delivering a relative deficit of nutrients across the South Atlantic in a way that is not possible in a lower resolution model. The transfer of CO_2 between the ocean and atmosphere (Figure 1b) shows that the ecodynamics in these eddies can actually change the sign of the flux compared to the surrounding water (from ocean release to uptake). Assessing whether the cumulative effect of eddy transports and dynamics modifies the carbon cycle in the model has yet to be determined, but is the primary goal of this work.

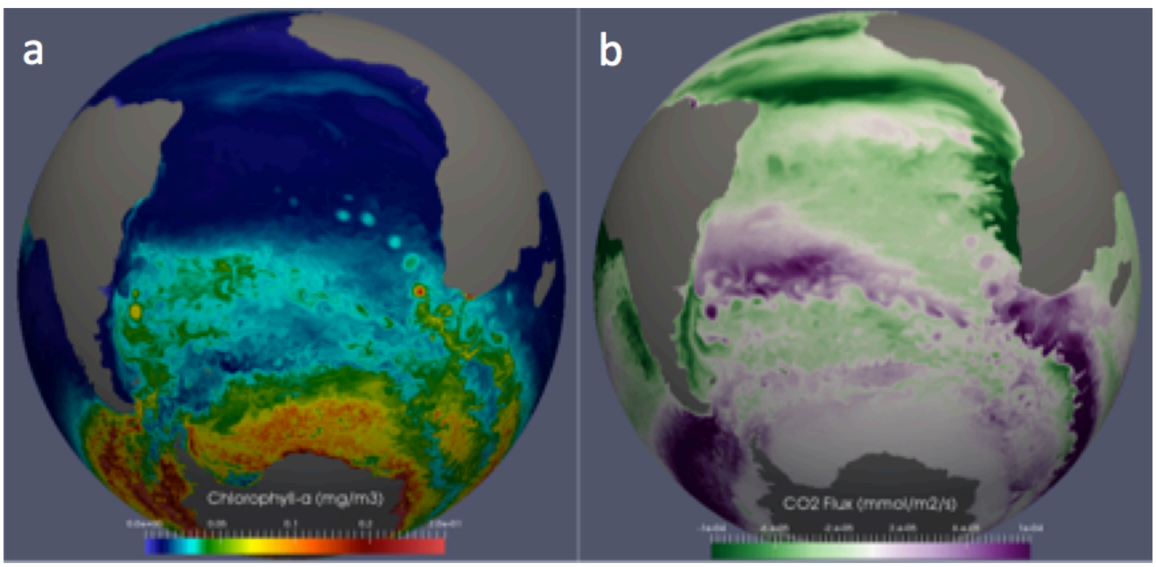

Figure 1. a) Surface chlorophyll-a concentration of small phytoplankton (mg/m^3) from November of year 7 of the simulation. b) Flux of CO_2 between the ocean and atmosphere (mmol/m^2/sec). Green colors denote outgassing from the ocean; purple denotes uptake by the ocean.

Financial Impacts

This simulation is being performed under the auspices of the DOE's Energy Exascale Earth System Model (E3SM) project, which provides 100% of Mathew Maltrud's salary and half of Shanlin Wang's salary, which has a $5.9 M/year LANL budget ($20 M over the entire DOE complex

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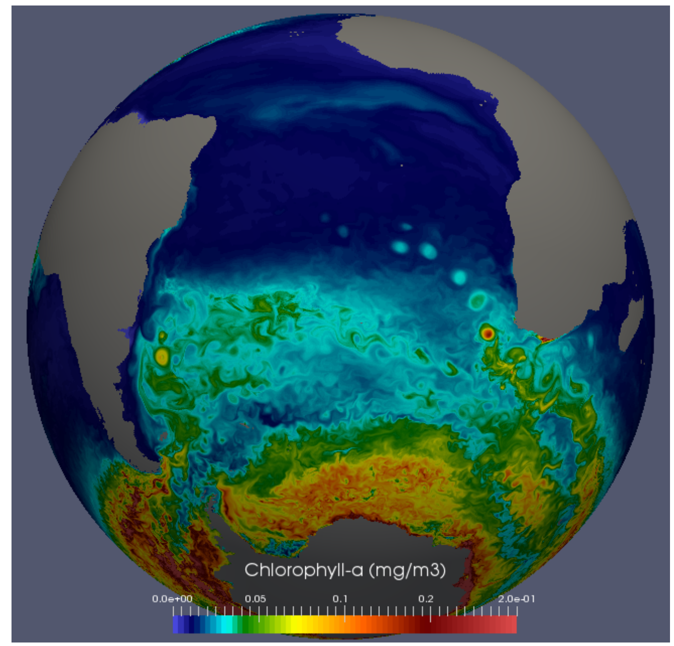
- The ocean plays a crucial role in determining the concentration of carbon dioxide (CO_2) in the atmosphere
- Photosynthetic phytoplankton convert CO_2 to organic C which then gets sequestered in the deep ocean (due to mortality, detrital matter, etc) for hundreds or thousands of years (the "Biological Pump")
- Earth System Models (ESMs) include marine ecology to simulate the carbon cycle in order to assess the possible future trajectories of atmospheric CO_2 and the associated changes in global climate
- We are performing simulations to help quantify the effect of model resolution on the characteristics of the Biological Pump and the marine carbon cycle



Ocean surface chlorophyll-a concentration (mg/m^3) due to small phytoplankton in November (Southern Hemisphere Spring). High values in the eddies west of South Africa are only possible in high resolution simulations.