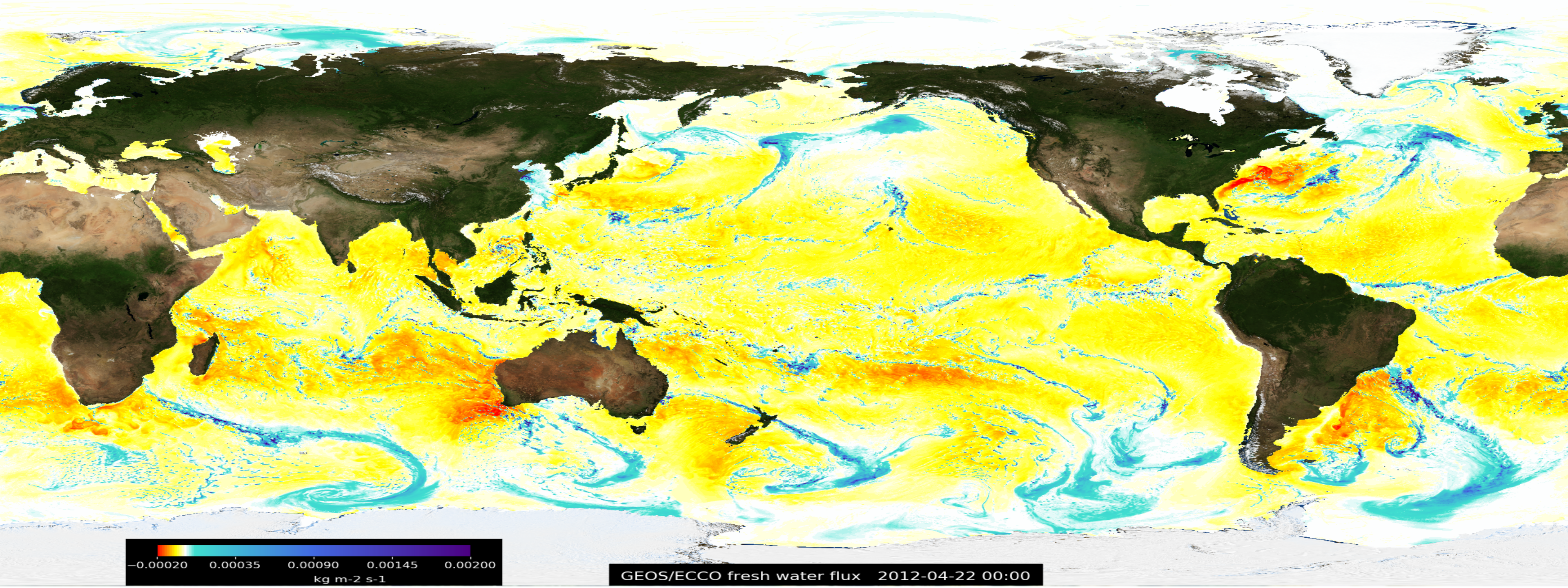

Virtual Research Presentation Conference

The Southern Ocean Carbon Cycle in 2050: Source or Sink of Anthropogenic Carbon?

PIs: Dimitris Menemenlis (329) and Andrew Thompson (Caltech)
JPL Co-Is: Sahra Kacimi (334); Kay Suselj, Hong Zhang, and Amy Braverman (C398)
Caltech Co-Is: Mar Flexas and Houman Owhadi (Caltech)
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Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Abstract

The Southern Ocean is the primary site where deep-ocean waters, the largest mobile reservoir in the climate system, interact directly with the atmosphere. Coupled ocean-atmosphere processes (Fig. 1) have been shown to cause the Southern Ocean's carbon uptake capacity to transition between a strong sink to a near-saturated state over periods as short as a decade. This initiative seeks to improve predictions of the Southern Ocean's capacity to remain a sink of atmospheric carbon dioxide in response to changes in atmospheric forcing and sea ice conditions over the next 30 years. We focus on specific capabilities, through which a combined campus and JPL effort can address unique components of the carbon cycle that have leading order impacts on Southern Ocean air-sea exchange: (1) the relatively unconstrained contribution of carbon exchange in the marginal ice zone and how it will change by 2050; (2) the potential for change in upper-ocean stratification in response to changing patterns of atmospheric winds, precipitation, sea ice, and planetary boundary layer turbulence; and (3) a quantitative assessment of how future remote sensing and in-situ observing systems might reduce uncertainty in decadal predictions of Southern Ocean carbon uptake.

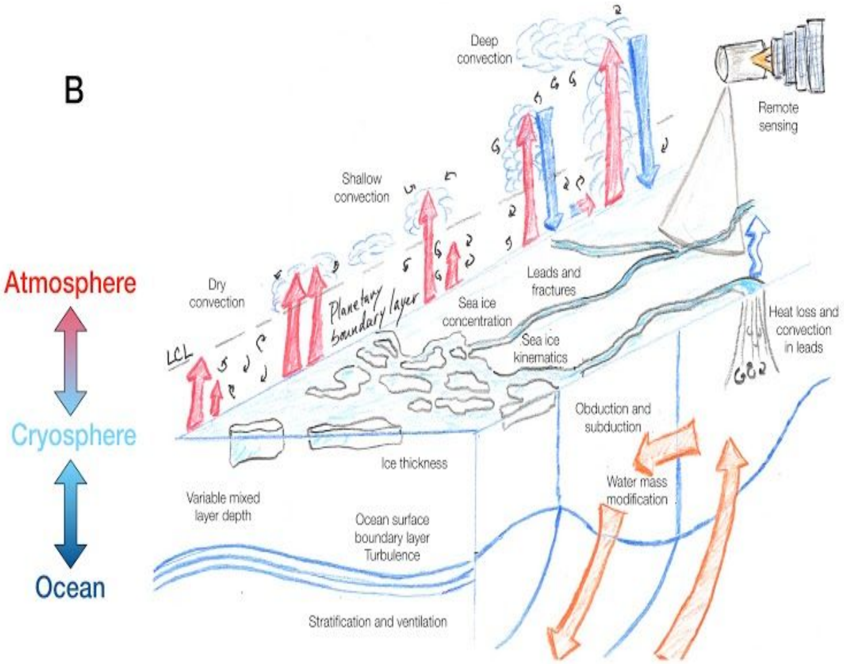

Figure 1: Schematic of key coupled processes explored by this initiative; emphasis is on the atmospheric planetary boundary layer, marginal ice zone, and ocean surface boundary layer.

Problem Description

The Southern Ocean is the only location in the Earth system where the largest reservoir of carbon, the deep ocean, is in direct contact with the atmosphere. But ocean carbon cycle models are currently unable to capture decadal-scale variability in Southern Ocean CO_2 fluxes (Fig. 2) . We aim for following advancements:

- Models consistently misrepresent observed changes in Southern Ocean sea-ice extent; JPL can provide unique Southern Ocean data products for model evaluation and parameter estimation.
- Southern Ocean clouds and atmosphere/ocean boundary layer parameterizations are poorly tested; campus and JPL will implement, evaluate, and adjust a new, state-of-the-art parameterization of atmospheric planetary boundary layer and clouds in the coupled ocean-atmosphere simulations.
- A key missing observational component for Southern-Ocean studies is direct, frequent, and pervasive observations of air-sea fluxes of momentum, freshwater, heat, and carbon. This initiative will provide additional science justification for the formulation and development of missions that can observe these fluxes.

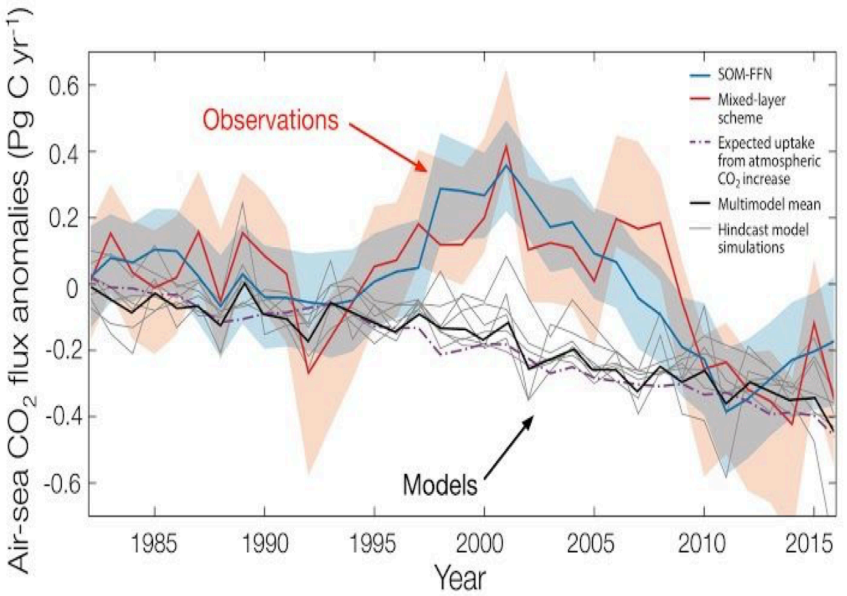

Figure 2: Multi-decadal Southern Ocean CO_2 flux anomalies from observations (colored curves) and hindcast models (black curves); adapted from Gruber et al. (2019). Models are unable to capture decadal variability in CO_2 fluxes, questioning their ability for decadal prediction.

Methodology

Early results from the Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) project indicate that fluxes south of the Polar Front, within the seasonal ice zone, could be a primary contributor to discrepancies between model and observational estimates of CO2 fluxes (Gray et al. 2018). JPL is currently the international leader on observational products informing ocean-ice coupling; this initiative will lead to valuable new data sets critical for assessing future predictions of changes in sea ice characteristics, and upper ocean stratification.

The modeling component of this initiative employs the Goddard Earth Observing System (GEOS) atmospheric model recently coupled to the Estimating the Circulation and Climate of the Ocean (ECCO) data-assimilating model (Strobach et al. 2020 and figure on title page). The GEOS/ECCO model has been enhanced by inclusion of JPL's Eddy-Diffusivity/Mass-Flux (EDMF) planetary boundary layer (PBL) and cloud parameterization (example results in Fig. 3).

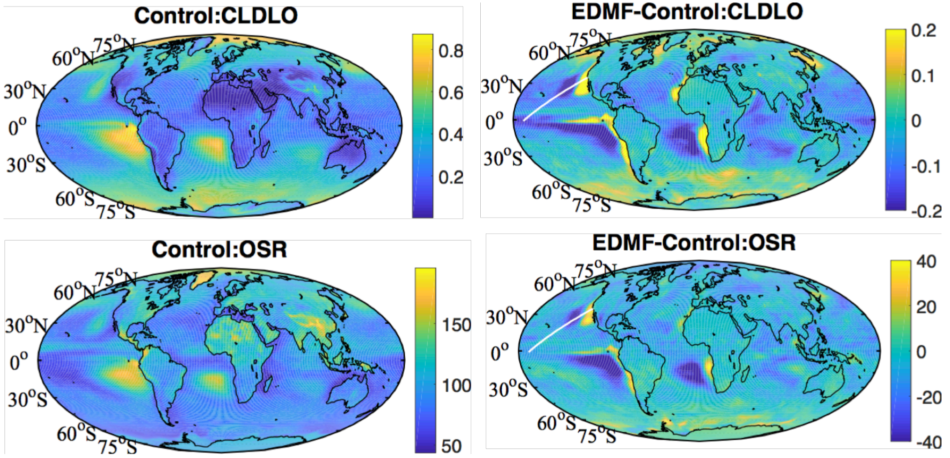

Figure 3: Impact of the Eddy-Diffusivity/Mass-Flux (EDMF) parameterization on coupled ocean-atmosphere simulations. The EDMF scheme has been implemented in the GESO/ECCO coupled model and is expected to lead to improved representation of atmospheric boundary layer dynamics.

Completed Milestones

- Extend Southern Ocean marginal ice zone sea surface height products using Cryosat-2 and IceSat-2 data (Armitage et al. 2018 and in preparation)
- Begin development of sea ice thickness product for the Southern Ocean (example results in Fig. 4)
- Include the EDMF parameterization scheme into the coupled GEOS/ECCO model (example results in Fig. 3)
- Development of uncertainty quantification framework (Owhadi 2017) and application to an idealized Southern Ocean meridional overturning model (Fig. 5)

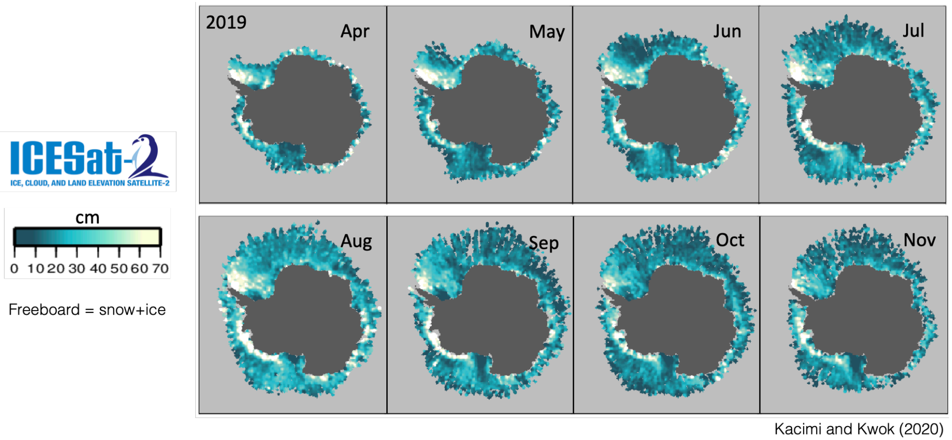

Figure 4: Estimates of Southern Ocean sea ice thickness and snow depth have been obtained using ICESat-2 and CryoSat-2 observations. These results are being used for evaluation and adjustment of the coupled GEOS/ECCO ocean-atmosphere model.

Year-2 Milestones

- Use high-resolution synthetic aperture radar (SAR) to develop ice kinematics products (strain, lead fractions, etc.)
- Complete and refine the sea ice thickness product (Fig. 4)
- Complete a suite of multi-decadal GEOS/ECCO sensitivity and use these to adjust empirical coupled model parameters to reduce model-data differences (Fig. 3)
- Evaluate atmospheric PBL, clouds, SSH, and sea ice in simulations vs data products
- Initiate perturbation experiments with various atmospheric CO2 using the newly-developed ECCO-Darwin ocean biogeochemistry model (Carroll et al. 2020)
- Develop framework for uncertainty quantification from model output.
- Assessment of uncertainties linked with EDMF parameterization.

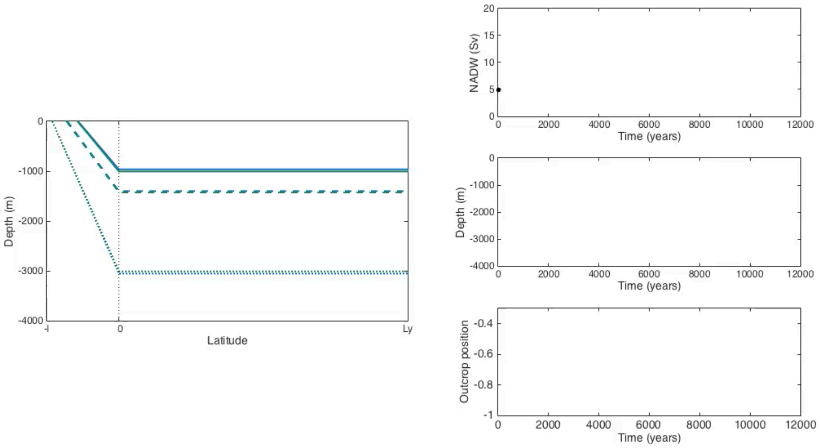

Figure 5: Simplified model of Southern Ocean meridional overturning circulation, which is being used for demonstrating the application of game theory to uncertainty quantification for climate variables.

Publications and References

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