Joint CLIVAR / OCB Working Group on

Oceanic carbon uptake in the CMIP5 models

Co-Chairs: Annalisa Bracco, Curtis Deutsch and Taka Ito

June 30, 2015

Working group' members

- Annalisa Bracco, GaTech
- Curtis Deutsch, U. Washington
- Scott Doney, WHOI
- John Dunne, NOAA/GFDL
- Taka Ito, Gatech
- Marcus Jochum, NCAR
- Matt Long, NCAR
- Nicole Lovenduski, U. Colorado
- Galen McKinley, U. Wisconsin
- Ralph Milliff, Colorado Res. Associates
- Shang-Ping Xie, U. Hawaii/ IPRC

International Contributing Member

Jamie Palter, McGill University

Accomplishments

- July 29 – August 16, 2013 NCAR ASP Summer Colloquium on 'Carbon-climate connections in the Earth system' and Research Workshop on Key Uncertainties in the Global Carbon-Cycle: Perspectives Across Terrestrial and Ocean Ecosystems
- EOS article, Examining Uncertainties in Representations of the Carbon Cycle in Earth System Models, 2013
- BAMS article, NCAR's Summer Colloquium: Capacity building in Cross-disciplinary Research of Earth System Carbon-climate Connections, In Press
- Input to US CLIVAR Science Plan
- Input to CMIP6 planning
- Workshop held in San Francisco, December 2014 together with Southern Ocean WG
- Workshop report in final stages of preparation
- Special Issue of CLIVAR Variations and OCB newsletter (Spring 2015)

Summer Colloquium

- 25 graduate students (chosen between ~ 120 applicants) and 17 lecturers; 6 group projects

Workshop

- Research workshop co-sponsored by OCB, US-CLIVAR, and CCIWG via USDA. Designed to bring together terrestrial and ocean carbon cycle scientists; over 60 participants
- Objectives: explore key uncertainties in the ESM representation of the global carbon cycle and build a dialogue crossing disciplinary boundaries to address common challenges.
- Outcomes, recommendations and challenges summarized in EOS and BAMS articles
- Presentations organized around 5 topics:
  - global carbon cycle controls
  - mechanisms that regulate nutrient cycling and their impacts
  - remineralization pathways
  - the role of individuals in ecosystem dynamics
  - observational data that might constrain carbon cycle feedbacks

Recommendations

- Develop a trans-disciplinary initiative between terrestrial and ocean scientists studying **respiration pathways**

- More observational studies examining the mechanistic controls on **nutrient budgets**, and better synergy between modelers and experimentalists to constrain model formulations through targeted manipulation experiments

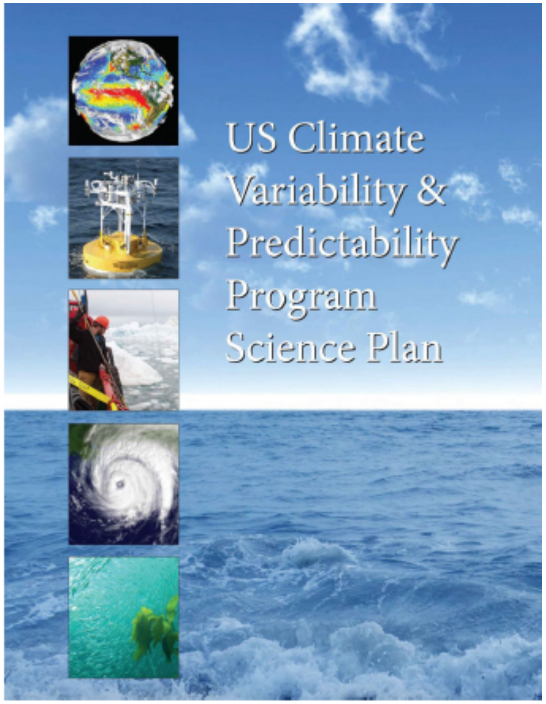
- Tighter collaboration between physiologists and modelers to account for **physiological traits**. Need to consider optimization of traits at both ecological and evolutionary time scales

- **Trophic coupling** uncertainties: In marine ecosystems, trophic coupling controls phytoplankton biomass and export. Models have rudimentary parameterizations and behave dramatically differently for subtle parameter changes → improved data constraints for grazing parameterizations through a targeted observational effort

- **Evaluation of ecosystem models** using suites of different physical settings to provide insight into the representation of ecological as well as physical processes
- Modeling frameworks that permit interoperability of subcomponents (i.e. **modularity** that permits swapping **process-level parameterizations**)

US CLIVAR Science Plan

Under Research Challenges, Section 5.4: Climate and marine carbon/biogeochemistry



- Definition, Significance
  - Marine ecosystem
  - Carbon cycling
- Dynamics
  - Marine ecosystem
  - Carbon cycling
  - Southern Ocean
- Future Research and needs
  - Multi-purpose and integrated ocean-observing networks
  - Continued innovation of oceanographic instrumentation
  - Integrated ecosystem process studies
  - Coupled physical/biogeochemical modeling

CMIP6 recommendations

Three proposed MIPs related to the ocean carbon cycle: C4MIP, OMIP and OCMIP.

- Ok to combine OMIP and OCMIP
- Investigating the ocean carbon cycle is a necessary investment: if the overall contribution of the ocean to the uptake of atmospheric CO_2 is ~ settled, large uncertainties remain on the mechanisms, their relative roles, and regional distribution of present carbon uptake and future weakening
- Passive tracers experiments will help attributing ocean carbon uptake and modeled patterns. OCMIP-like experiments are needed to successfully interpret C4MIP ➡
  Recommend to run CFCs and SF6 in OMIP experiments
  For the carbon / biogeochemistry component, the temporal constrains implicit in OMIP could be worked out using the preindustrial spin-up from the C4MIP control (but this issue remains open)

Workshop: Ocean's Carbon and heat uptake: Uncertainties and Metrics

- Held Dec 12-14, 2014 in San Francisco
- Joint between our and the Southern Ocean WG
- Synthesis of WG efforts to
  - develop metrics for evaluating biases in CMIP-5 simulations
  - estimate uncertainties in model projections of heat and carbon uptake
  - inform future observations, model development, and analysis strategies for addressing biases and uncertainties (including protocols of CMIP-6)

Report in progress

Workshop and report organized around 4 themes:

- Model Biases and Uncertainties in CMIP5 Models

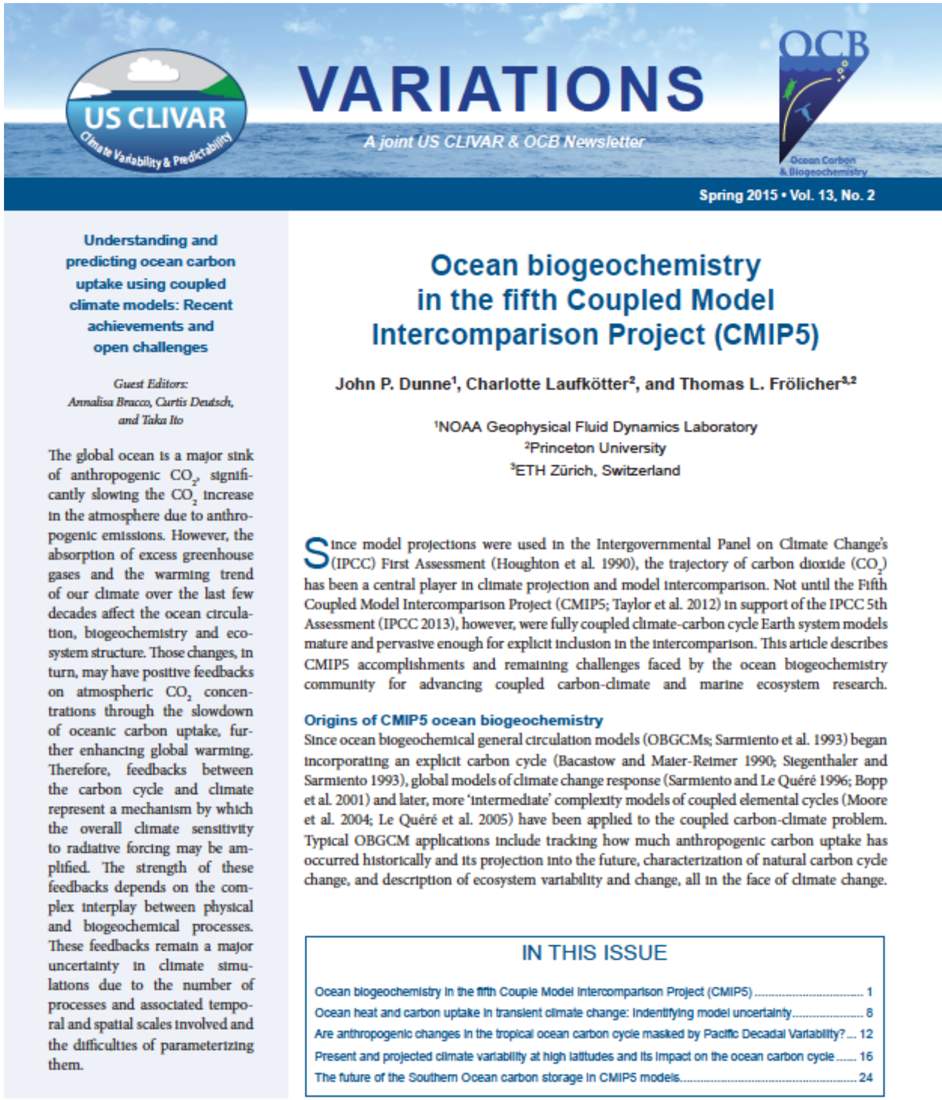
- Observational Gaps and Uncertainties

- Process Studies: Gaps, New Measurements, and Parameterizations

- Southern Ocean: Circulation and Carbon Cycle

US Clivar Variations/OCB newsletter

- Spring 2015
- 5 contributions + Introduction
- Based on workshop presentations and WG' members work over the past three years



VARIATIONS

A joint US CLIVAR & OCB Newsletter

Spring 2015 • Vol. 13, No. 2

Understanding and predicting ocean carbon uptake using coupled climate models: Recent achievements and open challenges

Guest Editors: Annalisa Bracco, Curtis Deutsch, and Taka Ito

The global ocean is a major sink of anthropogenic CO_2, significantly slowing the CO_2 increase in the atmosphere due to anthropogenic emissions. However, the absorption of excess greenhouse gases and the warming trend of our climate over the last few decades affect the ocean circulation, biogeochemistry and ecosystem structure. Those changes, in turn, may have positive feedbacks on atmospheric CO_2 concentrations through the slowdown of oceanic carbon uptake, further enhancing global warming. Therefore, feedbacks between the carbon cycle and climate represent a mechanism by which the overall climate sensitivity to radiative forcing may be amplified. The strength of these feedbacks depends on the complex interplay between physical and biogeochemical processes. These feedbacks remain a major uncertainty in climate simulations due to the number of processes and associated temporal and spatial scales involved and the difficulties of parameterizing them.

Ocean biogeochemistry in the fifth Coupled Model Intercomparison Project (CMIP5)

John P. Dunne[1], Charlotte Laufkötter[2], and Thomas L. Frölicher[3,2]

[1]NOAA Geophysical Fluid Dynamics Laboratory
[2]Princeton University
[3]ETH Zürich, Switzerland

Since model projections were used in the Intergovernmental Panel on Climate Change's (IPCC) First Assessment (Houghton et al. 1990), the trajectory of carbon dioxide (CO_2) has been a central player in climate projection and model intercomparison. Not until the Fifth Coupled Model Intercomparison Project (CMIP5; Taylor et al. 2012) in support of the IPCC 5th Assessment (IPCC 2013), however, were fully coupled climate-carbon cycle Earth system models mature and pervasive enough for explicit inclusion in the intercomparison. This article describes CMIP5 accomplishments and remaining challenges faced by the ocean biogeochemistry community for advancing coupled carbon-climate and marine ecosystem research.

Origins of CMIP5 ocean biogeochemistry

Since ocean biogeochemical general circulation models (OBGCMs; Sarmiento et al. 1993) began incorporating an explicit carbon cycle (Bacastow and Maier-Reimer 1990; Siegenthaler and Sarmiento 1993), global models of climate change response (Sarmiento and Le Quéré 1996; Bopp et al. 2001) and later, more 'intermediate' complexity models of coupled elemental cycles (Moore et al. 2004; Le Quéré et al. 2005) have been applied to the coupled carbon-climate problem. Typical OBGCM applications include tracking how much anthropogenic carbon uptake has occurred historically and its projection into the future, characterization of natural carbon cycle change, and description of ecosystem variability and change, all in the face of climate change.

IN THIS ISSUE

- Ocean biogeochemistry in the fifth Coupled Model Intercomparison Project (CMIP5) by John P. Dunne, Charlotte Laufkötter, and Thomas L. Frölicher

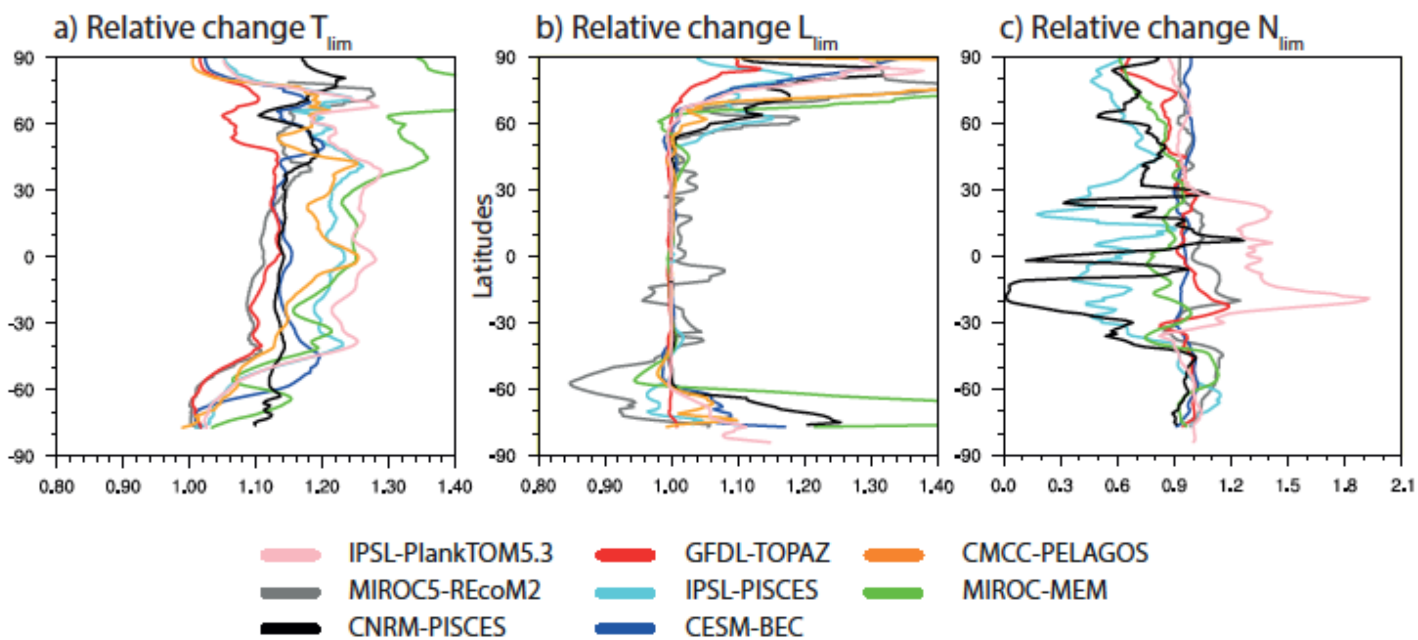


Figure 3: Zonal mean of the relative change in (a) temperature, (b) light, and (c) nutrient limitation factors for nine marine biogeochemistry models. Relative change is calculated as the 2081–2100 average divided by the 2012–2031 average. Based on Figure 6 of Laufkötter et al. (2015).

Little agreement in relation to processes that generate regional structure in projected changes among models

Challenge: full model documentation and parameter values

Recommendation: include an updated list of parameter values for participation in the MIP

Challenges: Multimember ensembles for detection and attribution, centennial - millennial scales; idealized sensitivity; assessment of potential for predictability; experimental biogeochemistry prediction; resolution.

Recommendations: Sensitivity of physiological responses to temperature, acidification, oxygen, macro- and micronutrient limitation; combined multi-stressor responses; consistent representation of aerosol, Fe, CH_4 and N cycles, and ecosystems across models.

Ocean heat and carbon uptake in transient climate change: Identifying model uncertainty by Anastasia Romanou and John Marshall

In CMIP5 models the Atlantic meridional overturning circulation (AMOC) controls transient ocean heat uptake through regulating deep ocean ventilation. Kostov et al. (2014) found that the AMOC depth sets the depth to which heat is sequestered, and hence the effective heat capacity of the ocean in transient climate change → the spread in heat uptake across CMIP5 models could be largely explained by differences in their AMOC properties.

CORE-like experiments can help attributing regional warming patterns.

Challenge: quantify contribution of the ocean component to uncertainties in climate change projections

Recommendation: Flux-Anomaly-Forced Model Intercomparison Project (FAFMIP) → run existing coupled control runs and add air-sea flux "overrides" - i.e., wind stress, evaporation-precipitation, heat fluxes – chosen to be representative of those induced by climate change.

Are anthropogenic changes in the tropical ocean carbon cycle masked by Pacific Decadal Variability? by Pedro N. DiNezio, Leticia Barbero, Matthew C. Long, Nikki Lovenduski, Clara Deser

Challenge: reconciling the nearly zero-trend in $\Delta p\mathrm{CO_2}$ in the tropical Pacific with the projections of a robust decrease in the CMIP5 models under increased greenhouse gases. Attribution issue

Recommendation: Long integrations or numerous ensemble members to disentangle internal variability and externally forced changes (in particular role of Pacific Decadal Variability, PDV, on tropical Pacific outgassing)

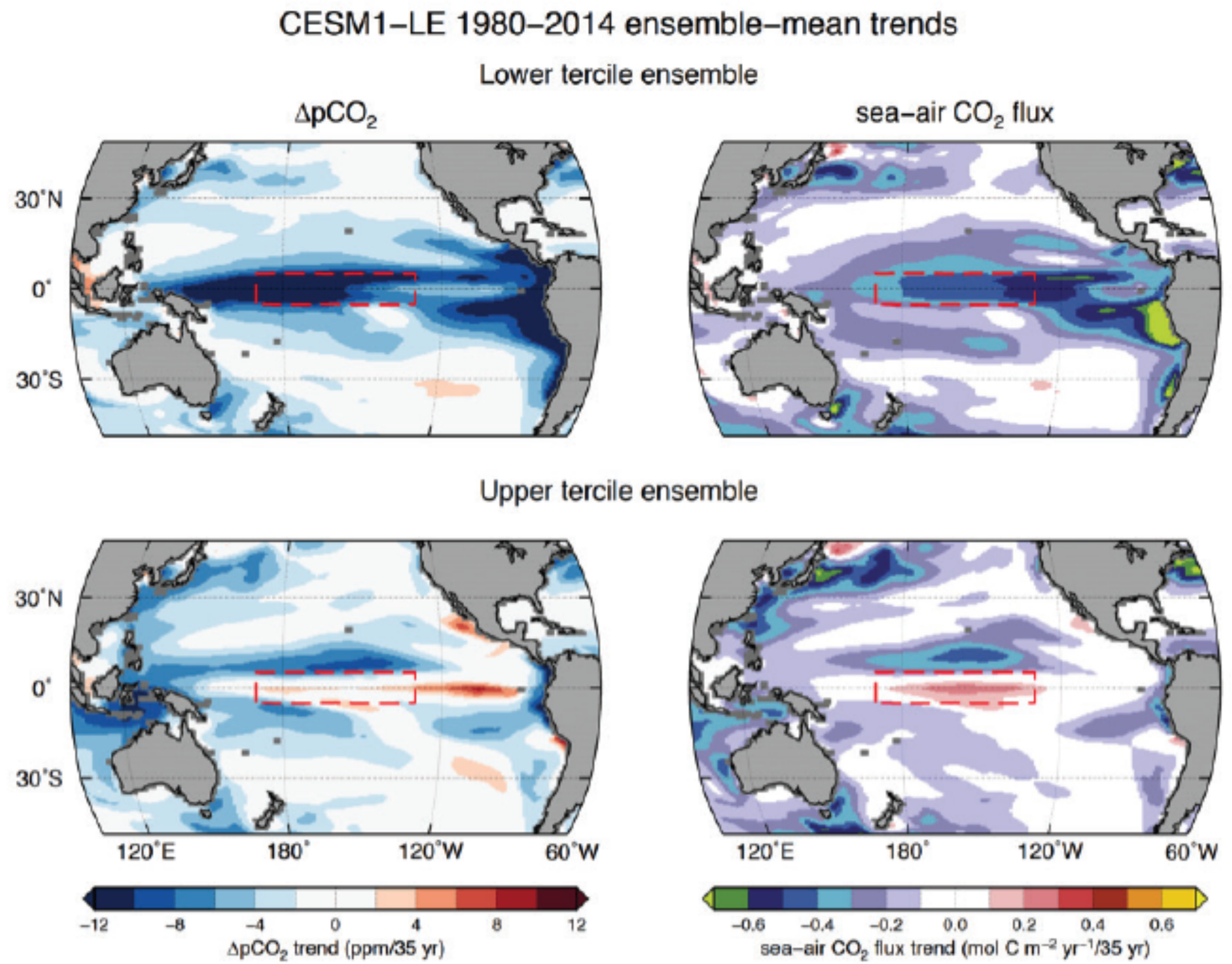


Figure 2: Trends (1980-2014) in ΔpCO_2 (left; ppm/35 yr) and sea-air CO_2 flux (right; mol C m^{-2} yr^{-1}/35 yr) simulated by the CESM1-LE, over grouped according to the lower and upper terciles of the pCO_2 trends over the Nino-3.4m region. The lower tercile ensemble (top) contains 9 simulations with the most negative Nino-3.4m ΔpCO_2 trends. The upper tercile ensemble (bottom) contains 9 simulations with negligible trends. The red box over the central equatorial Pacific indicates the Nino-3.4m region. Positive sea-air CO_2 flux indicates increased outgassing.

Present and projected climate variability at high latitudes and its impact on the ocean carbon cycle by Irina Marinov, Raffaele Bernardello, and Jaime B. Palter

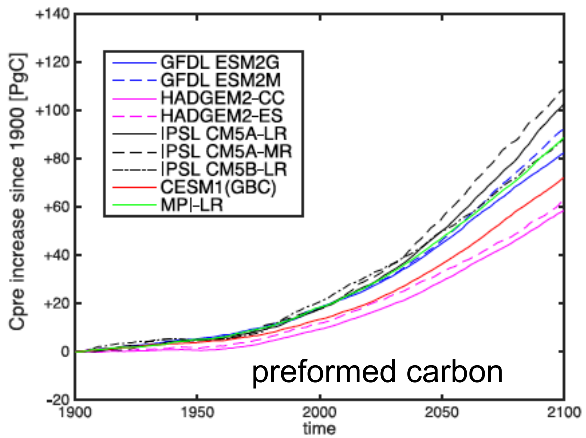
Understanding how the Southern Ocean and North Atlantic carbon uptake and storage will respond to a changing climate is a prerequisite for predicting future atmospheric CO_2 concentrations.

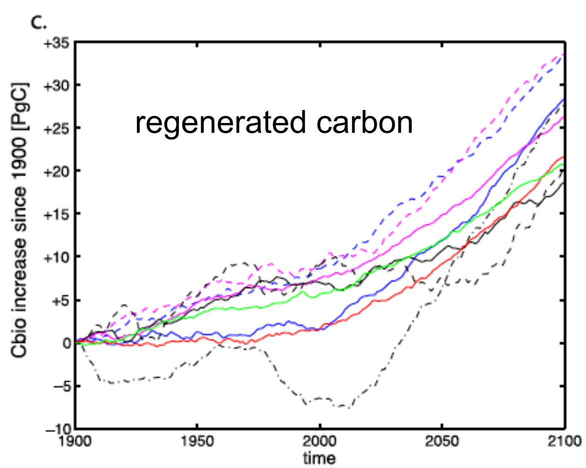
Challenges: representation of the export of deep water from continental shelves; Model biases in Labrador Sea convection resulting in unrealistic links between NAO and AMOC, biases in Weddell Sea convection that affect Southern Ocean decadal to centennial variability of heat and carbon uptake; largest inter-model spread for air-sea CO_2 fluxes and anthropogenic C inventories largest in the Southern Ocean

Recommendations: Long term, sustained observations of biogeochemical cycles at high latitudes; hierarchy of modeling approaches; development and testing of parameterizations to transport deep and bottom water from the shelves to the open ocean; comparison of climate responses across high- and low-resolution models

The future of the Southern Ocean carbon storage in CMIP5 models by Takamitsu Ito, Annalisa Bracco, Curtis Deutsch

According to CMIP5 models the ability of the Southern Ocean to store CO_2 will continue to increase during this century despite slowdown of total ocean uptake





Southern Ocean carbon inventory change (in PgC) since 1900

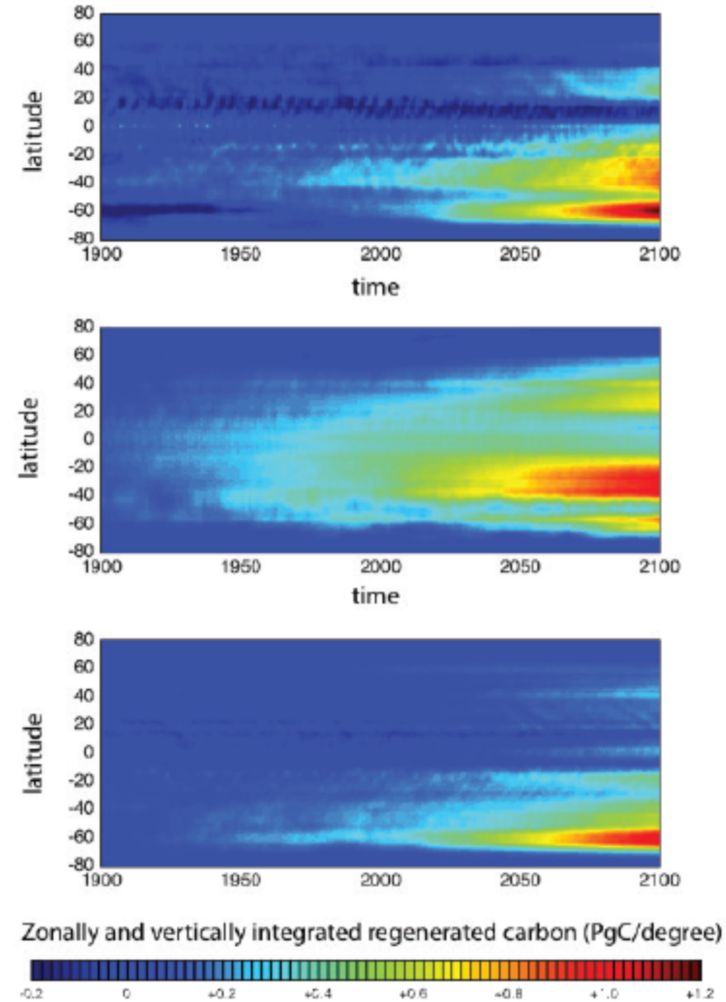


Figure 4: Zonally and vertically integrated annual mean regenerated carbon anomaly (PgC/degree) from 1900-2100 relative to 1860 in three of the models analyzed. Top: GFDL-ESM2M; Middle: IPSL-A-LR; Bottom: MPI-LR.

Challenges: quantify the relative contributions of physical and biological processes; estimate the degree of nonlinearity of the interactions between processes; understand regional expressions and their inter-model large differences

Recommendations: passive tracers such as CFCs and SF6 to constrain the roles of physical advection and mixing and differences across models; Hierarchy of models; Sensitivity experiments in which perturbations to physical or biological states are introduced in a controlled manner