Proposal: Joint CLIVAR / OCB Working Group
Oceanic carbon uptake in the CMIP5 models

1. Scientific Motivation and Relevance

The global ocean is a major sink of anthropogenic CO_2, significantly slowing the CO_2 increase in the atmosphere. The absorption of excess greenhouse gases and the warming trend of our climate over the last four decades, however, affect in multiple ways the ocean circulation, biogeochemistry and ecosystem structure (OCB objective). Those changes in the ocean, in turn, may feedback positively onto the atmospheric carbon dioxide concentrations through the slowdown the 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 (US CLIVAR objective). The strength of these feedbacks depends on the complex interplay between physical and biogeochemical processes regulating the sensitivity of ocean carbon uptake to climate perturbation. They remain a major uncertainty in climate simulations, due to the number of processes, time and spatial scales involved, and the difficulty to parameterize them.

The Coupled Model Intercomparison Project phase 5 (hereafter, CMIP5) provides coordinated sets of climate simulations using state-of-the-art global climate models with interactive carbon cycling component and represents a unique and time-sensitive opportunity to assess the strength of the climate-carbon cycle feedbacks in a multi-model context. Understanding differences among model predictions across multiple time scales and in different ocean basins offers the opportunity to refine the representation of such feedbacks and narrow their uncertainties in the current generation of Earth system models.

2. Objectives of the WG

The primary goal of this WG is to foster and promote collaboration between members of the US-CLIVAR and OCB communities and between modelers and theoreticians within each community, to advance our understanding of the processes responsible for the oceanic carbon uptake and their representation in climate models.

This objective will be pursued with a coordinated analysis of CMIP5 model experiments designed to improve our understanding of feedbacks between the marine carbon cycle and climate, focusing in particular on the relative role of ocean stratification in the mixed layer, mixing parameterization schemes, and atmospheric wind forcing in the oceanic carbon uptake.

The first generation of coupled carbon-climate models showed that the inclusion of an interactive carbon cycle increases the sensitivity of climate to a given emission rate, because both terrestrial and oceanic sinks become less effective over time (Friedlingstein et al., 2006). However there remains considerable uncertainty about the strength of the carbon-climate feedback in both models and observations. Studies of the oceanic carbon uptake in historical climate models has shown that a substantial fraction of the large model-model ranges in biogeochemical fields results from the propagation of known errors in model physics (Doney et al., 2004; Matsumoto et al., 2004). Improvements in this direction are - hopefully – achieved in the CMIP5 integrations. There still remain, however, considerable uncertainties about the physical mechanisms responsible for the carbon uptake, and their relative role in different regions (Orr et al., 2001), and at different time-scales.

We will specifically focus on the relative importance of ocean stratification and wind forcing in controlling the air-sea CO_2 fluxes, relevant for attributions and for quantifying uncertainties in future changes. An increase in ocean stratification can alter the rate of vertical exchange of dissolved inorganic carbon (hereafter DIC) and nutrients in the water column. The

response of the global oceanic carbon uptake may involve several compensating factors. For example, a slowdown of Atlantic Meridional Overturning Circulation (hereafter, AMOC) can significantly reduce the carbon uptake in the northern North Atlantic (Sarmiento et al, 1998); a reduced upwelling in the equatorial Pacific and the polar Southern Ocean may also reduce the outgassing of CO_2 in those regions (Lovenduski and Ito, 2009), which tends to compensate for the AMOC perturbation. Furthermore, wind-stress increase over the Southern Ocean can increase the rate of deep water upwelling there; however, the sensitivity of the upwelling may depend on the representation of sub-grid scale physics and ultimately on the eddy parameterization. An increase in the upwelling enhances both the outgassing of natural CO_2 and the uptake of anthropogenic CO_2, and the net effect is dominated by the natural component in the present climate (Lovenduski et al, 2008). Finally, climate change impacts on marine ecosystem, including deep-sea communities (Smith et al., 2009) can significantly alter the biological carbon uptake, and the ocean stratification and wind forcing profoundly impact the supply of nutrient to the surface euphotic layer.

To understand the differences among model predictions across multiple time scales and in different ocean basins, it is necessary to design and coordinate a common framework to analyze the model outputs. The WG will facilitate the validation of the CMIP5 integrations that include an explicit representation of the carbon cycle (see figure below, runs identified in green fonts).

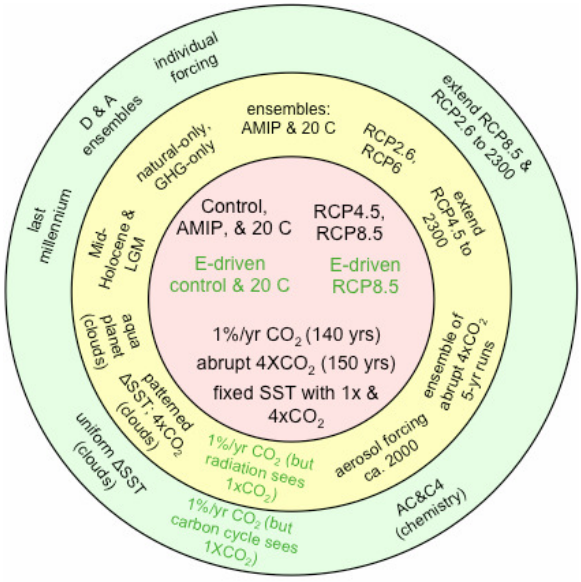

Figure 1: Schematic of CMIP5 experiments. Green font indicates simulations that will be performed by ocean-atmosphere coupled models with carbon cycle representation. E-driven stands for emission driven runs. The projection including the carbon cycle representation is consistent with a high emissions scenario (RCP8.5)

The Working Group will develop a list of physical and biogeochemical metric to guide the model-model and model-data comparison. To identify the feedback mechanisms and strengths, perturbation simulations using the same model will be investigated. There are control, 20th century simulations, a future simulation with the high scenario (RCP8.5) driven by emissions, and two carbon cycle feedback experiments. In the first, climate change is suppressed by not letting the radiation code "see" the increasing CO_2 concentration, so the carbon cycle responds only to the changing CO_2. In the second, the climate responds to CO_2 increases, but the carbon cycle module "sees" constant CO_2 concentrations. The comparison of the surface fluxes of

CO_2 from these two experiments with those from the corresponding "core" experiments in which the carbon cycle simultaneously responds to both climate and CO_2 concentration changes allows for investigating the model representation of the strength of carbon-climate feedback.

The working group will provide means of coordination and communication to enhance the outcomes of the model analysis and comparison. Progress towards the goal of attributing CO_2 air-sea fluxes will be achieved by tackling the following tasks:

1. Identification of common metrics of physical ocean/climate forcing (primarily wind strength, mixed-layer stratification, and ocean mixing); Comparison of those metrics in the various models and in the observations; Identification of geographical regions for the flux analysis (likely to be included: the Southern Ocean, the North Atlantic, the Tropical Pacific)
2. Coordinated model evaluation of the climatic influence on CO_2 uptake at different time scales (interannual/decadal variability vs longer term impacts up to centennial trends)

In the Southern Ocean, the analysis performed on the CMIP5 models will be shared and coordinated with the WG on "Heat and Carbon Uptake by the Southern Ocean" to understand coarse resolution limitations and to validate the CMIP5 performances against observations.

3. Activities, Products and Timeline

The WG will meet two times every year, with specific goals each time. Conference calls before each meeting will allow for exchanging information on the status of the model runs and of the analysis performed before each meeting, and for discussing the meeting agenda. Every six months a conference call will also be organized between the co-chairs of this WG (A. Bracco, C. Deutsch and T. Ito) and the co-chairs of the WG on "Heat and Carbon Uptake by the Southern Ocean" (I. Kamenkovich and J. Russell) to collaborate on the interpretation of model analysis in the Southern Ocean.
A web site will be created to share the outcome of the WG activities with the broader community. After each meeting the chairs of the working group will be responsible for compiling a report to be posted on the WG web site. We also hope to organize the 2013 ASP Colloquium at NCAR on "Carbon and Climate" to engage graduate and postgraduate students from both communities in the problems related to carbon – climate interactions, while training them in the use and interpretation of complex earth system model data.

Year 1 - 2012
- February 2012 – First Working Group Meeting following Ocean Sciences (1 day) and website creation – objective #1
- July 2012 – Second WG meeting preceding the OCB or the CLIVAR annual meetings (1 day). Finalization of methodologies for the model evaluation. Drafting of application package for ASP Summer Colloquium at NCAR (Deadline Sept. 15). Immediately after the meeting the WG members will start the coordinated analysis – objective #1; begin objective #2
- October 2012 Article for OBC and CLIVAR Newsletters summarizing the strategy chosen for the coordinated model evaluation and expectations.

Year 2 – 2013
- February or March 2013 – Third Working Group Meeting (1 day). Coordinated interpretation of the analysis performed. – objective #3
- June 2013 – Possibly ASP Summer Colloquium on "Carbon and Climate" (ASP Director is already aware of this initiative and open to CLIVAR involvement).
- November 2013 – Cross-Disciplinary OCB-CLIVAR Workshop (2 days; 30-50 people) – Objective # 3 and # 4; Submission of manuscript(s) in Global Biogeochemical Cycles and/or

Journal of Climate (at least one manuscript; possibly two focusing on aspects of major relevance to the two communities).
The final workshop will bring together the community working on ocean - carbon interactions. A session will be specifically devoted to frame the observational needs emerged from the coordinated model evaluation experiment and its theoretical interpretation. Representatives from the funding agencies will be invited.

4. Publications and Outreach
- CLIVAR and OCB Newsletter Article (Yr 1)
- Website, periodically updated by WG and linked to both US-CLIVAR and OCB websites (Yr 1 and 2)
- Possibly ASP Summer Colloquium in 2013 on 'Carbon and Climate' targeted to graduate and postgraduate students.
- Final Workshop in late fall 2013 and white paper describing source of uncertainties, recommending strategies to improve model representation, and addressing observational needs.
- At least one peer-review publication (possibly two) on Global Biogeochemical Cycles (and/or Journal of Climate) summarizing findings from model intercomparison effort.

5. Group Membership (includes 5 female scientists and 5 junior scientists)

The proposed membership of the working group is listed below. Working group members will be encouraged to include graduate and postgraduate students in all WG activities. We also plan to include few other researchers from outside the U.S. to ensure a representation of all modeling groups interested.

1. **Annalisa Bracco** (*Associate Professor, Georgia Inst. of Technology*) – Co-chair
Ocean modeling, mesoscale and submesoscale dynamics and coupling with the marine ecosystem, tropical dynamics, climate predictability, model uncertainties. Co-Chair PPAI-US CLIVAR Panel
2. **Curtis Deutsch** (*Assistant Profesor, UCLA)* – Co-chair
Interactions of biogeochemical cycles and climate system. Modeling connections between ocean biogeochemistry and climate from human to geological time scales. Carbon cycling and climate change. Member of OCB and PPAI-US CLIVAR panel.
3. **Taka Ito** (*Assistant Professor, Georgia Inst. of Technology)* – Co-Chair
Mathematical and numerical models of physical and biogeochemical processes in the oceans. OCB contributor

4**. Ken Caldeira** (*Senior Scientist and Professor, Carnegie Institution of Washington and Stanford University*) Carbon cycling, ocean carbon cycling, climate remediation, numerical modeling, Lead Author IPCC Special Report on CO2 Capture and Storage, Oceans Chapter (2005).
5. **Scott Doney** (*Senior Scientist, WHOI*) Ocean biogeochemistry, ocean acidification and the coupling with the global climate system using numerical models and satellite remote sensing. Chair, OCB scientific steering committee.
6. **John Dunne** (*Scientist, NOAA/GFDL*), lead developer of GFDL's ocean biogeochemical models.
6. **Stephanie Dutkewicz** (*Research Scientist, MIT*) Role of marine physical and biological environments in the climate system. OCB GBF-OOI Scientific Steering Committee
7. **Marcus Jochum** (*Scientist III, NCAR*) Pacific climate variability, climate modeling, ENSO and CO_2 linkages in the oceanic carbon cycle. CLIVAR Pacific Implementation panel

8. **Matthew Long** (*Postdoctoral Fellow, ASP, NCAR Climate Section Analysis*) Ocean Biogeochemistry, Physical-biological coupling, Hydrology.
9. **Nicole Lovenduski** (*Assistant Professor, Un. of Colorado at Boulder*) Marine carbon cycle; ocean climate variability and change; ocean modeling; OCB contributor
10. **Damon Matthews** (*Associate Professor, Concordia Un., Canada, Contributing participant*) Assessment of the role of the global carbon cycle in future climate change.
11. **Katsumi Matsumoto** (*Associate Professor, University of Minnesota*) Physical processes influencing ocean carbon uptake in coupled climate models.
12. **Ralph F. Milliff** (*Senior Research Scientist, Colorado Res. Associates Division*) Atmospheric surface forcing for ocean models, reanalysis products, ocean data assimilation, Bayesian models.
13. **Synte Peacock** (*Scientist III, NCAR*) Ocean biogeochemical modeling, Paleoclimate and paleoceanography.
14. **Rong Zhang** (*NOAA/GFDL, Oceanographer*) Ocean's role in climate change and global teleconnections of climate change; AMOC variability; climate modeling.
15. **Shang-Ping Xie** (*Professor, Un. Hawaii and IPRC*) Large-scale ocean-atmosphere interaction; general circulation, Pacific variability. Diagnostic and modeling studies. Former member US-CLIVAR; Lead Author, IPCC 5th Assessment Report

4. Budget

Funding is requested for the 3 working group meetings, two of which are combined with a scientific meeting (Ocean Sciences and the OCB or US CLIVAR summer summit) to limit travel expenses, for teleconferences, for developing a website and for the final Workshop.

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