WCRP
World Climate Research Programme

Carbon Feedbacks in the Climate System
Report from the Kick-off Workshop

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Carbon Feedbacks in the Climate System Kick-off Workshop.
21 - 22 November 2016, Hamburg, Germany.

Introduction and background

The WCRP Grand Challenge on Carbon Feedbacks in the Climate System (GC-Carbon)[1] aims to enhance the understanding on how biogeochemical cycles and feedbacks control CO_2 concentrations and impact the climate system. The Grand Challenge will be addressed through community-led research initiatives focusing on the following guiding questions:

- *What are the drivers of land and ocean carbon sinks?*
- *What is the potential for amplification of climate change over the 21st century via climate-carbon cycle feedbacks?*
- *How do greenhouse gas fluxes from highly vulnerable carbon reservoirs respond to changing climate (including climate extremes and abrupt changes)?*

The overall effort to address these three guiding questions will focus on specific advances in our understanding of biogeochemical processes that will lead to significant improvement in climate projections, with substantial progress expected in the next 5-10 years. This effort is divided into four research areas, addressing the three guiding questions and expected to progress in parallel. These **four research areas** are: process understanding on land; process understanding in the ocean; learning from the existing record; and towards improving projections.

Outcomes of the kick-off workshop

GC-Carbon was launched via a kick-off workshop held in Hamburg on the 21st and 22nd of November 2016. The objective of this workshop was to strengthen the links between the guiding questions and research initiatives as well as to emphasize major gaps and to sharpen the priorities and plans of the program as a whole. The workshop had 40 participants, covering a wide range of expertise such as plant physiology, marine biology, atmospheric inversions, land and ocean biogeochemistry, paleo-climate, Earth system modelling, etc. The workshop was initiated with a brief introduction on the WCRP Grand Challenges (David Carlson), a presentation of GC-Carbon (Tatiana Ilyina and Pierre Friedlingstein), followed by two inspirational talks (Niki Gruber and Chris Jones) aimed to initiate discussions on the key gaps in knowledge and how to move forward. The rest of the workshop was organised around four rotating breakout groups, each focusing on one of the four research areas listed above. Breakout group outcomes were presented at the end of the meeting and are summarised here.

1. Process understanding on land

Chairs: Ivan Janssens and Ying-Ping Wang

Two key research areas have been identified.

(i) CO_2 Fertilisation. Can we better quantify the strength of the CO_2 fertilisation on land and how it is controlled by nutrients? The magnitude of CO_2 fertilisation was the largest source of uncertainty in carbon cycle feedbacks across the Coupled Model Intercomparison Project Phase 5 (CMIP5) Earth System Models (ESMs). The wide spread of responses was partly due to a couple of ESMs which included a land nitrogen cycle, and estimated much lower response than “carbon-only ESMs”. It is unclear at this stage whether this very low response is realistic. Changes in governing processes, such as carbon allocation, C:N stoichiometry, litter quality and microbial

[1] https://www.wcrp-climate.org/grand-challenges/gc-carbon-feedbacks

activity, ecosystem plasticity and acclimation are poorly represented in ESMs or constrained by observations.

(ii) Carbon turnover rate. Can we better constrain estimate of vegetation and soil carbon turnover rate and how it is affected by environmental conditions? Analysis of CMIP5 ESMs revealed a large spread in land ecosystem carbon reservoirs (both biomass and soil), partly due to large range of carbon turnover time in these reservoirs, highlighting the poor evaluation of the carbon dynamic in ecosystems. The atmospheric ^{14}C signal and its invasion in terrestrial ecosystems, combined with soil ^{14}C data, has the potential to help constrain ecosystem turnover time and the mean age of soil carbon. There is also a need to reconcile large discrepancies in estimates of carbon turnover rates based on mass-balance assumptions with those based on soil 14C.

2. Process understanding in the ocean

Chairs: Laurent Bopp, Nikki Lovenduski

With respect to the ocean carbon sink, the workshop participants identified a few urgent research gaps that are key for improved process understanding and where rapid progress can be achieved. These questions fall into three broad categories:

(i) Ocean physics and variability: First, what is the role of ocean stratification on carbon uptake? While the importance of ocean circulation, in particular the vertical mixing in controlling the physical carbon pump has been recognized for decades, characterization of these processes is still a challenge and a major source of discrepancies in projections of the ocean carbon sink. This problem needs to be revisited and assessed in the context of progress in model development and availability of new observational data. Second, what is the role of extreme events, including storms, heat waves, deep convection and upwelling events, on carbon uptake? It is now possible to study these questions using models with high spatial resolution and high frequency observational estimates (i.e. those from gliders). Third, how does decadal predictability affect the evolution of the carbon sink? Understanding decadal variability, teleconnections, sources of predictability, and carbon/heat uptake relationships is crucial for verification and attribution of variations in air-sea CO_2 fluxes.

(ii) Biological pump: Processes governing ocean biology are largely simplified in global biogeochemical models. Most modern ocean models focus on lower trophic levels and include only simplistic representation of sinking and remineralization processes and so the biological pump remains poorly quantified. First, it is poorly known how the export flux of carbon responds to changes in temperature and composition of exported material. Second, participants called for a map of remineralization length scale derived from observations – and an analysis of temporal sensitivity to potential drivers.

(iii) Interfaces, i.e. air-sea, coastal-open ocean, sea ice: First, can we estimate land-to-ocean carbon fluxes, their mean state, variability and changes (chemical form and lability)? Second, there is poor understanding of the role of water fluxes from sea-ice, continental ice on carbon uptake, the impact on stratification, convection, carbon chemistry, and biology. This topic can be addressed jointly with the Core Project ‘Climate and Cryosphere’.

3. Learning from the existing record

Chairs: Ashley Ballantyne, Peter Landschützer

On the ocean side, observational products based on observational networks like the Surface Ocean CO_2 Atlas (SOCAT, ARGO), provide comprehensive temporal and spatial distributions of air-sea fluxes of CO_2. There are uncertainties related to understanding variability of these fluxes both in those observational products and in models.

In terms of land processes and observational products, the breakout group focused on existing observations relevant to the key processes identified earlier (CO_2 fertilisation and carbon turnover rate). Global synthesis of ^{14}C measurements in soil, vegetation and atmosphere would be needed in order to support ESM evaluation. Likewise, synthesis of Free-Air Carbon dioxide Enrichment (FACE) experiments and compilation of available data is needed to facilitate evaluation of land model sensitivity to atmospheric CO_2 increases. It was also proposed to analyse satellite products (with increasing longer time coverage) looking for evidence of fertilisation effects.

4. Towards improved projections

Chairs: Peter Cox, Thomas Frölicher

One area of potential rapid improvement was identified and consists of extending the climate-carbon feedback framework (β,γ). Potential improvements include recognising different timescales (especially for the ocean), reducing the scenario dependence of the framework (especially, investigating pathways with overshoot and negative emissions), going beyond global temperature as measure of feedback, including the water cycle, developing regional frameworks, etc. One objective of the extension of the climate carbon feedback framework is to incorporate the transient climate response to cumulative carbon emissions (5TCRE) in this new framework. Emergent constraints (from paleo or contemporary observations) may help us to constraint better the components of the climate-carbon feedback framework (β,γ, TCRE).

The potential for exploring near-term (annual to decadal) predictability of the carbon cycle was discussed across several breakout groups. The current decadal prediction effort is focused on the predictability of the physical climate system, not the carbon cycle. The time dependence of surface carbon fluxes is very uncertain and there is a strong interest to understand the different modes of variability of the carbon cycle. This is definitely true for hindcasting, in order to understand the recent past variability of the carbon cycle, but potentially also for near term predictions, in order to better anticipate the near term variations of the ocean and land carbon sinks and the evolution of atmospheric CO_2 in response to CO_2 emissions. We note that as our understanding of predictability of the carbon cycle is still in its infancy, there was no agreement amongst participants whether predictions of CO_2 on annual to decadal timescales should be high on the agenda of GC-Carbon. Predictability of the carbon cycle can be addressed jointly with the Grand Challenge on ‘Near-Term Climate Prediction’.

Proposed actions

For 2017/2018, GC-Carbon identified several scientific areas where rapid progress could be anticipated:

1. Feedback framework: A workshop is proposed to develop an extended climate-carbon cycle feedback framework. This workshop would bring together mathematicians, experts in climate feedbacks, the carbon cycle and Earth System feedbacks.

2. Ocean physics and biogeochemistry: A workshop has been proposed on the ocean boundary layer and its impact on the carbon cycle focusing on mixing parameterizations in models, variation in stratification from data and projected trends with climate change. This workshop would bring together experts in ocean physics and biogeochemistry.

3. Ecosystems turnover time: A focused workshop is proposed in order to provide robust observation-based estimates of vegetation and soil carbon fluxes, pools and turn-over times and to design a ^{14}C global modelling framework for evaluation of land carbon dynamics. This workshop would bring together a few experts in atmospheric and soil carbon isotopes, ecosystem biogeochemists, and ESM modellers. In addition, there will be a particular focus on permafrost carbon reservoirs, in partnership with the Grand Challenge on the Cryosphere.

4. CO_2 fertilisation over land: A workshop has been proposed on Coupled Model Intercomparison Project Phase 6 (CMIP6) model evaluation against observations and proxies for CO_2 fertilisation, including the design of specific FACE site level benchmarking of land surface components of ESMs. The workshop would bring together FACE experimentalists, plant physiologists, remote sensing and atmospheric CO_2 experts, and ESM modellers.

5. Oceanic export production: A workshop has been proposed that would focus on the response of the export flux of carbon to temperature (Q_{10}) and on the stoichiometric ratio of the exported material (C:N:P). Such a workshop on model parameterizations would comprise experimentalists, process modellers and earth system modellers.

6. Decadal prediction: It is proposed to have an initial brain storming meeting between the Grand Challenge on Carbon Feedbacks in the Climate System and the Grand Challenge on Near-Term Climate Prediction to explore the potential scientific and societal interest in near term predictions of the carbon cycle.

Depending on resources and the availability of the GC-Carbon community to organise workshops, the proposal would be that activity (1) take place in 2017. We propose that activity (6) is organized as a small expert meeting between the two Grand Challenges in 2017. Potentially activity (3), being likewise a smaller scale meeting, and activity (2) could also take place in 2017 or early 2018. Activities (4) and (5) are proposed to follow in 2018-2019.

Annex 1: List of participants

1. Arneth, Almut	Karlsruhe Institute of Technology, Germany
2. Aumont, Olivier	IRD, France
3. Ballantyne, Ashley	University of Montana, USA
4. Bopp, Laurent	CNRS, LSCE-IPSL, France
5. Brasseur, Guy	Max-Planck-Institute for Meteorology, Germany,
6. Brovkin, Victor	Max-Planck-Institute for Meteorology, Germany
7. Carlson, Dave	WCRP, Switzerland
8. Ciais, Philippe	LSCE, France
9. Claussen, Martin	Max-Planck-Institute for Meteorology, Germany
10. Cox, Peter	University of Exeter, UK
11. Friedlingstein, Pierre	University of Exeter, UK
12. Frölicher, Thomas	ETH, Switzerland
13. Gruber, Nicolas	ETH, Switzerland
14. Henson, Stephanie	NOC, UK
15. Houweling, Sander	SRON - The Netherlands
16. Hugelius, Gustaf	University of Stockholm, Sweden
17. Ilyina, Tatiana	Max-Planck-Institute for Meteorology, Germany
18. Janssens, Ivan	University of Antwerp, Belgium
19. Jones, Chris	MetOffice, UK
20. Joos, Fortunat	University of Bern, Switzerland
21. Kaminski, Thomas	The Inversion Lab, Germany
22. Landschützer, Peter	Max-Planck-Institute for Meteorology, Germany
23. Langendijk, Gaby	WCRP, Switzerland
24. Li, Hongmei	Max-Planck-Institute for Meteorology, Germany
25. Lovenduski, Nicole	University of Colorado, USA
26. Luo, Yiqi	University of Oklahoma, USA
27. Monteiro, Pedro	CSIR, South Africa
28. Mossinger, Juliane C.	Nature, UK
29. Pan, Yude	USDA, USA
30. Piao, Shilong	Peking University, China
31. Pongratz, Julia	Max-Planck-Institute for Meteorology, Germany
32. Prentice, Colin	Imperial College, UK
33. Regnier, Pierre	University of Brussels, Belgium
34. Reick, Christian	Max-Planck-Institute for Meteorology, Germany
35. Rödenbeck, Christian	Max-Planck-Institute for Biogeochemistry, Germany
36. Rodgers, Keith	University of Princeton, USA
37. Schwinger, Jörg	University of Bergen, Norway
38. Takano, Yohei	Max-Planck-Institute for Meteorology, Germany
39. Wang, Yingping	CSIRO, Australia
40. Zaehle, Sönke	Max-Planck-Institute for Biogeochemistry, Germany

Annex 2: Agenda

Agenda of the Kick Off Meeting of the WCRP Grand Science Challenge 'Carbon feedbacks in the climate system"

Mon 21 Nov 2016

9:00 Welcome/Logistics/Organization (Tatiana)
9:10 WCRP Grand Challenges (David Carlson)
9:30 CG-Carbon Introduction (Pierre and Tatiana)

10:00 *Coffee break*

10:30 Inspirational talk #1 (Ocean) Niki Gruber (TBC)
11:10 Inspirational talk #2 (Land) Chris Jones (TBD)
11:50 Open discussion

12:30 *Lunch*

14:00 Parallel break-out sessions:
(R1) Process understanding on land (Wang, Janssens)
(R2) Process understanding in the ocean (Bopp, Lovenduski)

15:30 *Coffee Break*

16:00 continuation of break-out sessions (R1 and R2)

18:00 *Dinner*

Tues 22 Nov 2016

9:00 Parallel break-out sessions:
(R3) Learning from the existing record (Landschutzer, Ciais)
(R4) Towards improved projections (Cox, Frolicher)

10:30 *Coffee Break*

11:00 continuation of break-out sessions (R3 and R4)

12:00 *Lunch*

14:00 R1 synthesis / discussion
14:30 R2 synthesis / discussion

15:00 *Coffee Break*

15:20 R3 synthesis / discussion
15:50 R4 synthesis / discussion
16:20 Future planning / way forward

18:00 *Dinner*

Annex 3: Acronyms and other abbreviations

ARGO	Array for Real-time Geostrophic Oceanography
CMIP	Coupled Model Intercomparison Project
ESM	Earth System Model
FACE	Free Air CO_2 Enrichment
GC	Grand Challenge
GC-Carbon	WCRP Grand Challenge on Carbon Feedbacks in the Climate System
ICSU	International Council for Science
IOC	Intergovernmental Oceanographic Commission
JSC	Joint Scientific Committee
SOCAT	Surface Ocean CO_2 Atlas
TCRE	Transient Climate Response to Emissions
WCRP	World Climate Research Programme
WMO	World Meteorological Organization

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