WCRP Grand Challenge
Carbon Feedbacks in the Climate System

coordinated by:

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KO workshop in November 2017

- 40 participants covering a wide range of expertise, i.e. plant physiology, marine biology, atmospheric inversions, land and ocean biogeochemistry, paleo-climate, Earth system modelling, etc.
- plan of action including organization of a brain storming meeting on predictions of the carbon cycle
The Grand Challenge to understand how biogeochemical cycles and feedbacks control CO₂ concentrations and impact on the climate system

Uncertainty in carbon cycle projections (>300 ppm) is comparable to differences across socio-economic scenarios.

IPCC AR5

AR5 WG1 SPM:
“Based on ESMs, there is high confidence that the feedback between climate and the carbon cycle is positive in the 21st century.”

CMIP5
• >40 climate models (AOGCM)
• 10 ESMs (i.e. with BGC components)
The Grand Challenge to understand how biogeochemical cycles and feedbacks control CO$_2$ concentrations and impact on the climate system

Large uncertainty in CO$_2$ emissions compatible with a given climate target. Budget for the 2°C target is about 700GtC to 1300GtC. Given 550 GtC emitted so far, that’s 15 to 75 years of current emissions.

IPCC AR5

AR5 WG1 SPM:
“Cumulative total emissions of CO$_2$ and global mean surface temperature response are approximately linearly related. Any given level of warming is associated with a range of cumulative CO$_2$ emissions.”

Uncertainty
- Carbon feedbacks (CO$_2$ emissions $\rightarrow$ CO$_2$ concentration)
- Climate feedbacks (CO$_2$ concentrations $\rightarrow$ climate response)
The Grand Challenge

to understand how biogeochemical cycles and feedbacks control CO$_2$ concentrations and impact on the climate system

Guiding questions:
1. What are the drivers of land and ocean carbon sinks?
2. What is the potential for amplification of climate change over the 21$^{st}$ century via climate-carbon cycle feedbacks?
3. How do greenhouse gases fluxes from highly vulnerable carbon reservoirs respond to changing climate (including climate extremes and abrupt changes)?

Research initiatives:
I. Process understanding on land \textit{(questions 1, 2, 3)}
II. Process understanding in the ocean \textit{(questions 1, 2, 3)}
III. Learning from the existing record \textit{(question 1)}
IV. Towards improved projections \textit{(questions 2, 3)}
1. What are the drivers of land and ocean carbon sinks?

Ocean: key mechanisms are identified, but with large uncertainties regarding their strength, regional and multi-year variability

Southern Ocean is responsible for about half of the ocean carbon sink

- large spread in both observational and modeled estimates of the ocean carbon sink
- poor understanding of origins of variability
- unclear relative contribution of physical vs. biological processes

Southern Ocean C-sink variations

Observations

Landschützer et al., Science, 2015

Southern Ocean C-sink variations

MPI-ESM (note reversed y-axis)

Hongmei Li in prep.
1. What are the drivers of land and ocean carbon sinks?

**Land:** the main barriers relate to understanding of the actual processes driving the sinks

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Fair global agreement between land carbon models and estimate from global carbon budget

![Graph showing CO₂ emissions and land sink](Image)

**Land carbon models**
LeQuéré et al., ESSD, 2015

GCP budget residual

But large uncertainty at the process level, e.g. plant response to CO₂ increase

![Graph showing NPP response](Image)

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Zaehle et al., New Phyt., 2014
Research Initiatives

I. Process understanding on land
   • Quantification of the strength of the CO₂ fertilization, photosynthesis and limitations from nitrogen cycle
   • Quantification of gross carbon fluxes sensitivity to warming and variability (and changes in hydrology)
   • Understanding of ecosystems vulnerability and risk of carbon loss

II. Process understanding in the ocean
   • Quantification of the strength of the Southern Ocean CO₂ uptake
   • The relative role of physical vs. biological processes in determining the ocean carbon sink
   • Understanding the origins of variability (from seasonal to decadal) of the ocean carbon sink
   • Relationship between anthropogenic carbon and heat uptake
Opportunities for rapid progress of this Grand Challenge

ESMs are becoming “standard” tools for the climate community

• CMIP6 will have more than 20 ESMs (CMIP5 had 10 ESMs)

• C4MIP is among the most popular CMIP6 endorsed MIP (along with ScenarioMIP and OMIP)

• IPCC AR6 will “very likely” heavily rely on those simulations for assessment of climate projections, compatible emissions, TCRE, climate impact on land and marine ecosystems, irreversibility, etc

• Advances in observational techniques (e.g. argo floats, satellite data, improved paleo reconstructions)

• Urgent need to have better understanding of key BGC processes and their feedbacks on the climate system.
Opportunities for rapid progress of this Grand Challenge
“Why now?”

**CMIP6**
- **C4MIP**
  - 1% runs: feedback analysis
  - E-driven scenarios: climate change amplification
- **Deck**
  - Historical: evaluation
  - 1% runs: feedback analysis
- **ScenarioMIP**
  - C-driven scenarios: C-cycle vulnerability to future climate
- **OMIP, LS3MIP, DCPP**
  - process understanding and evaluation

**Observational networks**
- SOCAT and GLODAP
- Argo floats
- New satellite data (e.g. CO$_2$)
- Flux measurement networks
- process oriented obs.

**WCRP projects**
- CLIVAR, SPARC

**Future Earth projects**
- GCP
- AIMES, SOLAS, ILEAPS, IMBER
- Knowledge Action Networks

**Other GCs**
- GC-Cryosphere
- GC-Decadal?
Towards decadal predictions of the carbon cycle

Roland Séférian et al., PNAS 2014

Predictive skill of the tropical Pacific NPP of up to 3 years

Hongmei Li et al., Nature Com. 2016

Potential predictive skill of the North Atlantic CO₂ uptake of up to 4-7 years
Potential for GC-carbon/GC-predictions interactions

• Paris Agreement and Global Stocktake: Where will we be in 2030?
• Carbon cycle has pronounced interannual (mainly land) to decadal (mainly ocean) variability. Is the variability of the carbon cycle predictable?
• How well can we reproduce past variability (hindcast) of the coupled climate and carbon cycle system?
• Can we predict climate and carbon cycle in the next couple of years/decades?
• Given national INDCs, what is the likely/range carbon sinks, atmospheric CO2 increase and climate response to be expected by 2030, when accounting for natural variability?
• Do we have CMIP6 simulations that can help addressing these questions?