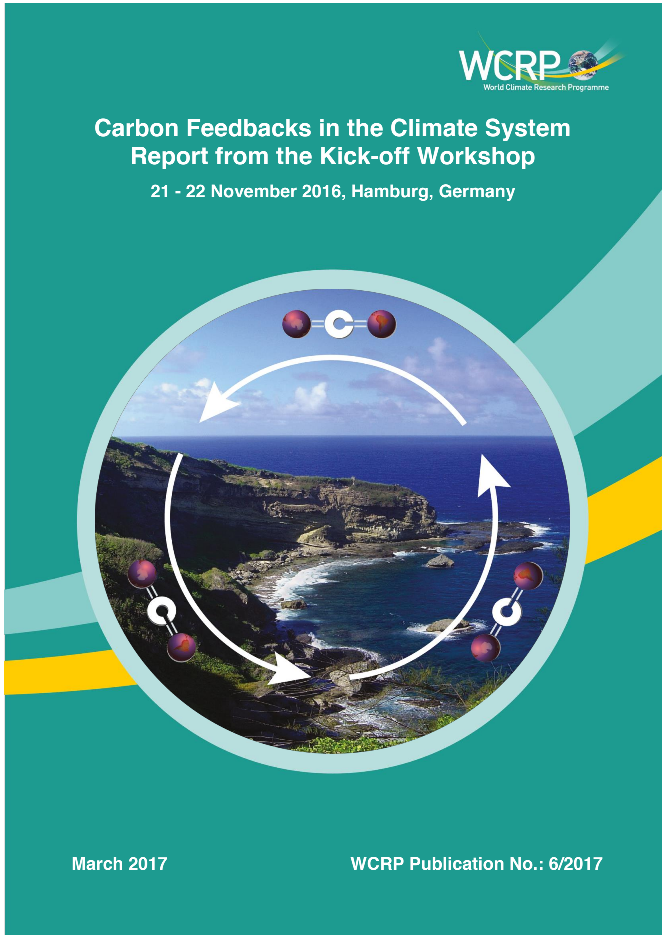
WCRP Grand Challenge

Carbon Feedbacks in the Climate System

coordinated by: **TATIANA ILYINA** Max Planck Institute for Meteorology **PIERRE FRIEDLINGSTEIN** University of Exeter

with contributions from: **G. Brasseur, V. Brovkin, P. Canadell, D. Carlson, P. Ciais, B. Collins, N. Gruber, N. Harris, M. Hegglin, G. Hugelius, C. Jones, C. LeQuéré, J. Marotzke, V. Ramaswamy, C. Sabine**

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

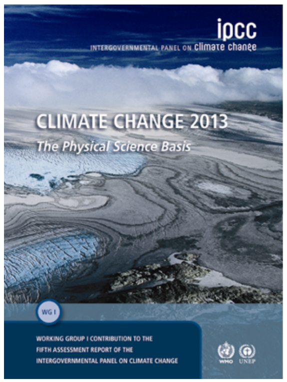
including organization of a brain storming meeting on predictions of the carbon cycle

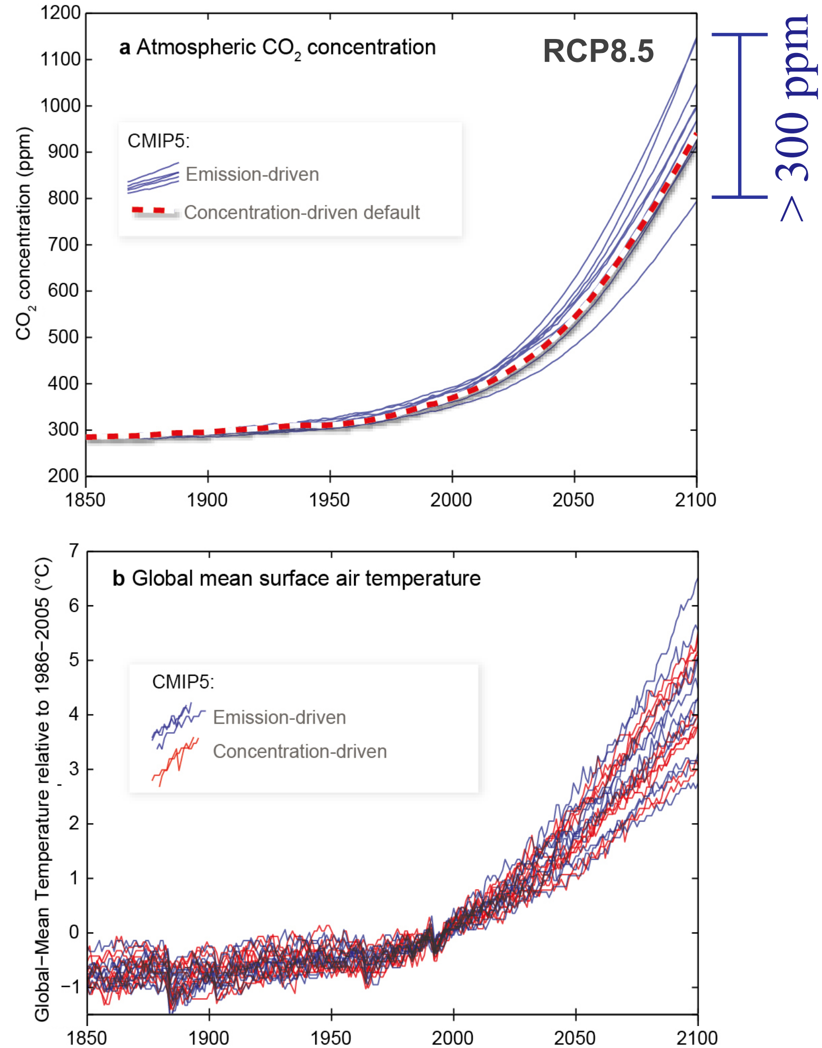
The Grand Challenge

to understand how biogeochemical cycles and feedbacks control CO_2 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

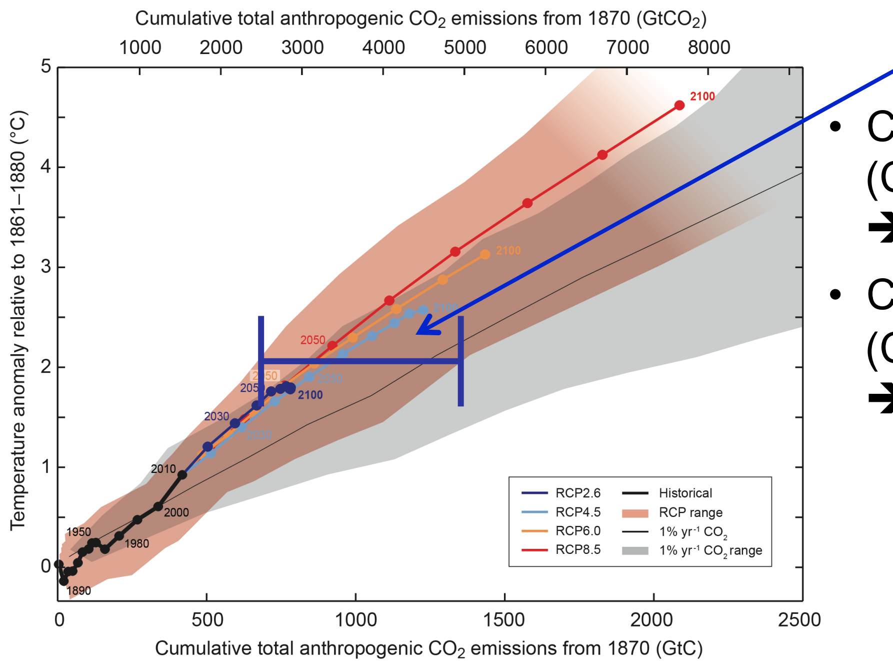
to understand how biogeochemical cycles and feedbacks control CO_2 concentrations and impact on the climate system

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 ➔ CO_2 concentration)
- Climate feedbacks (CO_2 concentrations ➔ 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 21st 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 *(questions 1, 2, 3)*

II. Process understanding in the ocean *(questions 1, 2, 3)*

III. Learning from the existing record *(question 1)*

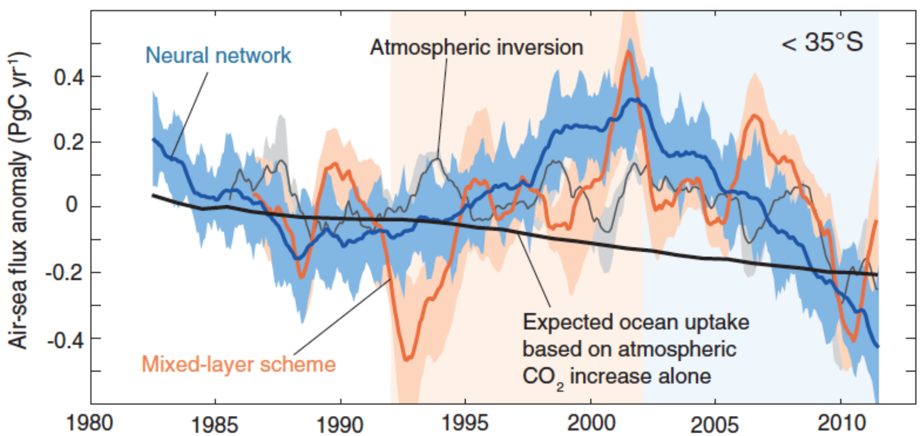
IV. Towards improved projections *(questions 2, 3)*

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*

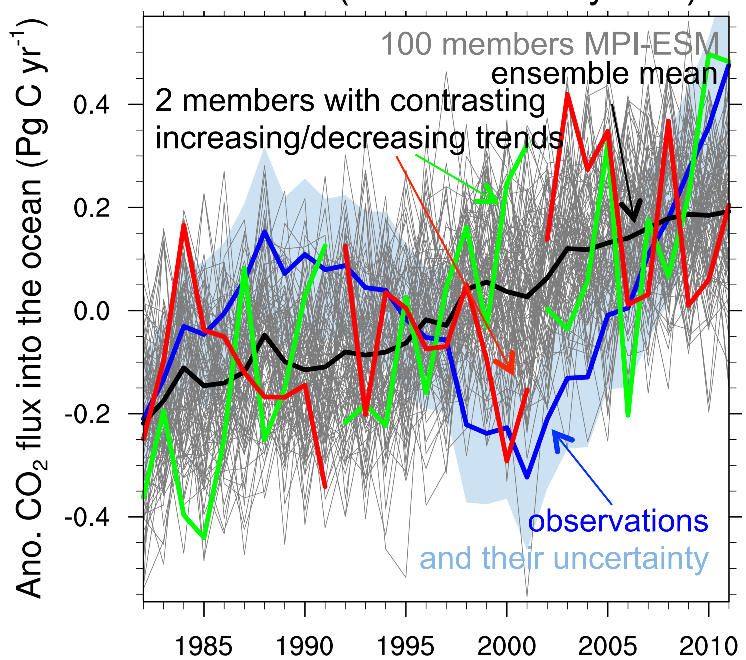
Southern Ocean is responsible for about half of the ocean carbon sink

Southern Ocean C-sink variations
Observations



Landschützer et al., Science, 2015

Southern Ocean C-sink variations
MPI-ESM (note reversed y-axis)



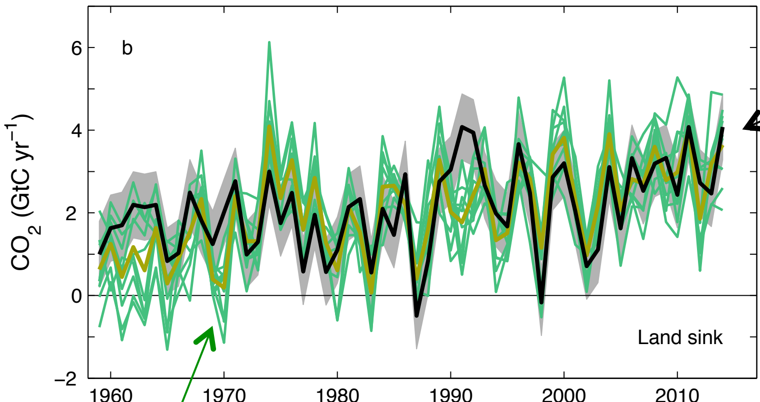
Hongmei Li in prep.

- 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

1. What are the drivers of land and ocean carbon sinks?

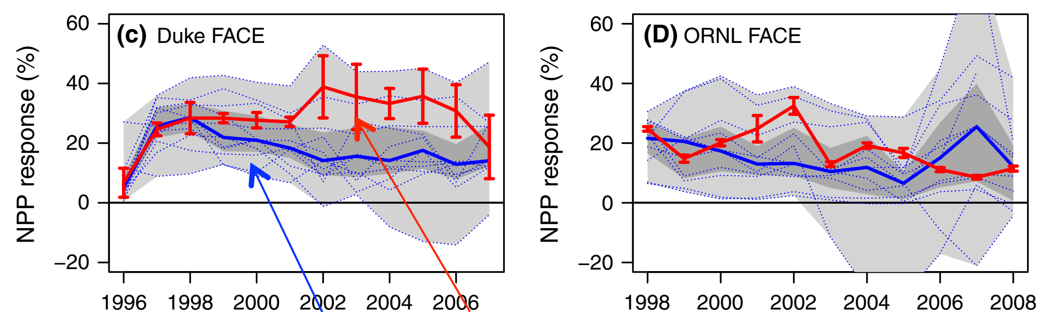
Land: *the main barriers relate to understanding of the actual processes driving the sinks*

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



LeQuéré et al., ESSD, 2015

But large uncertainty at the process level, e.g. plant response to CO_2 increase



Zaehle et al., New Phyt., 2014

Research Initiatives

I. Process understanding on land

- Quantification of the strength of the CO_2 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

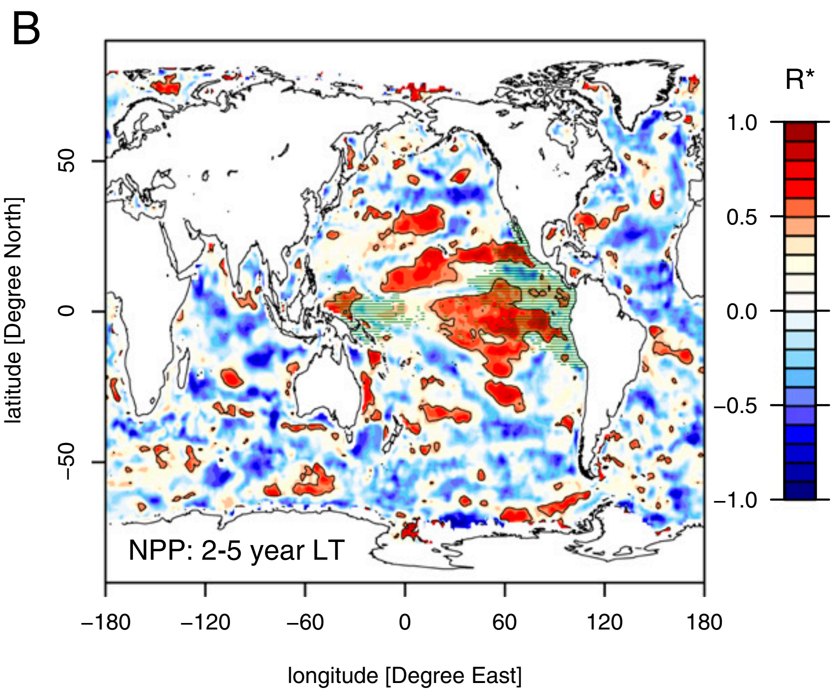
Future Earth projects

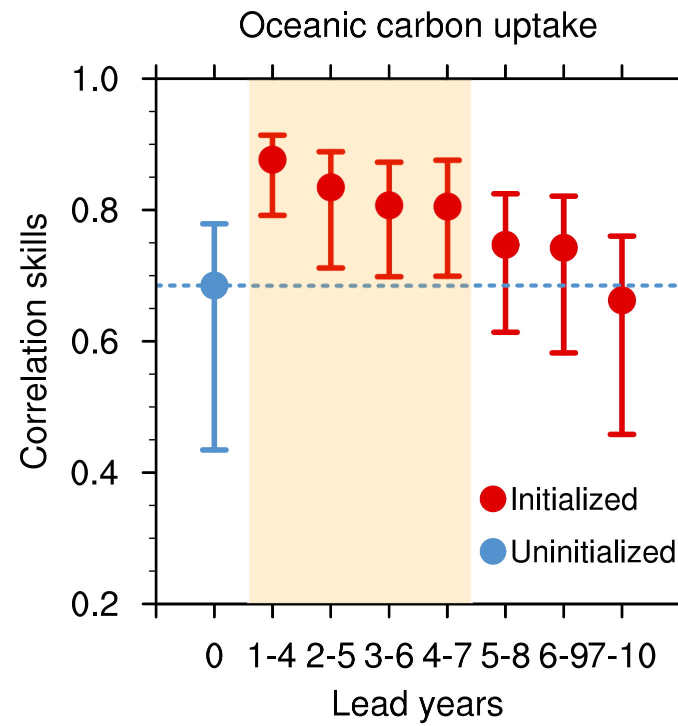
- GCP
- AIMES, SOLAS, ILEAPS, IMBER
- Knowledge Action Networks

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 CO_2 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?