WCRP Grand Challenge

Carbon Feedbacks in the Climate System

coordinated by:

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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.

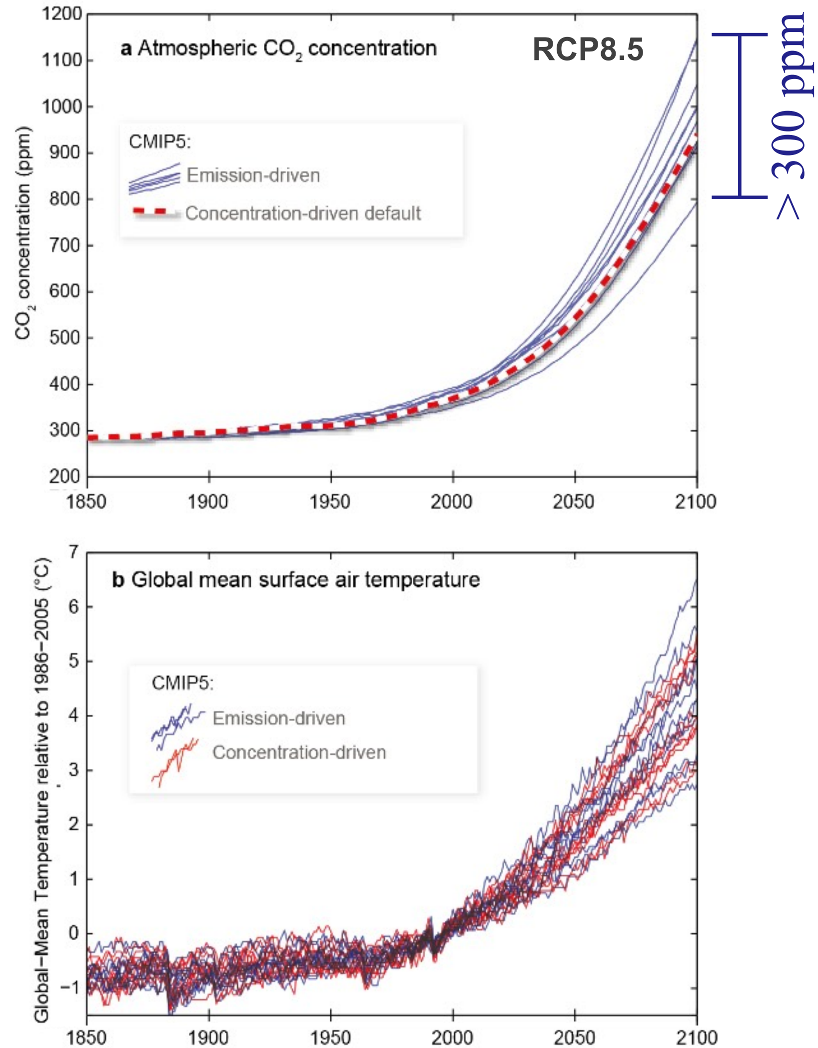
IPCC AR5

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)



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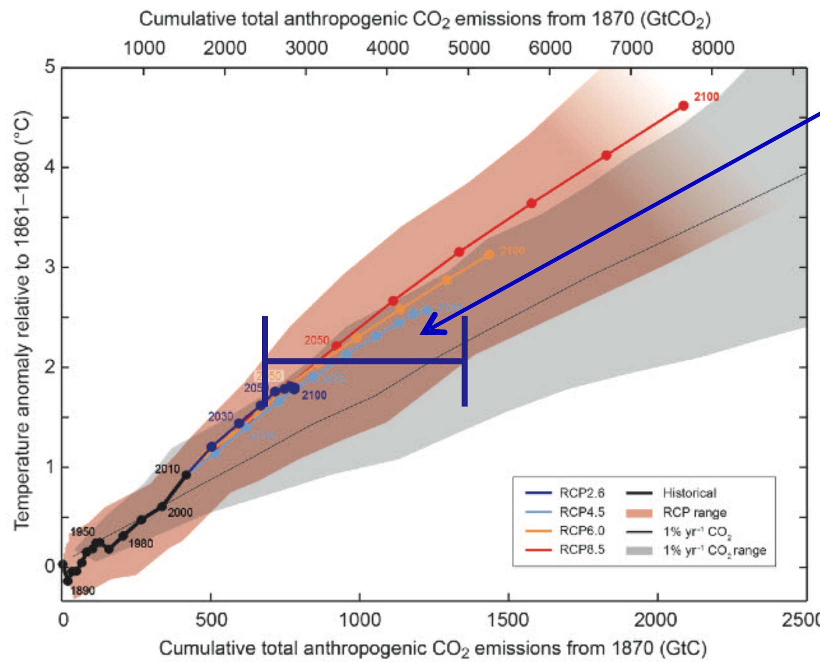
Large uncertainty in CO_2 emissions compatible with a given climate target.
Budget for the 2°C target is about 700GtC to 1300GtC.
Given 550 GtC emitted so far, that's **15 to 75 years of current emissions**.

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)

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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)?

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*

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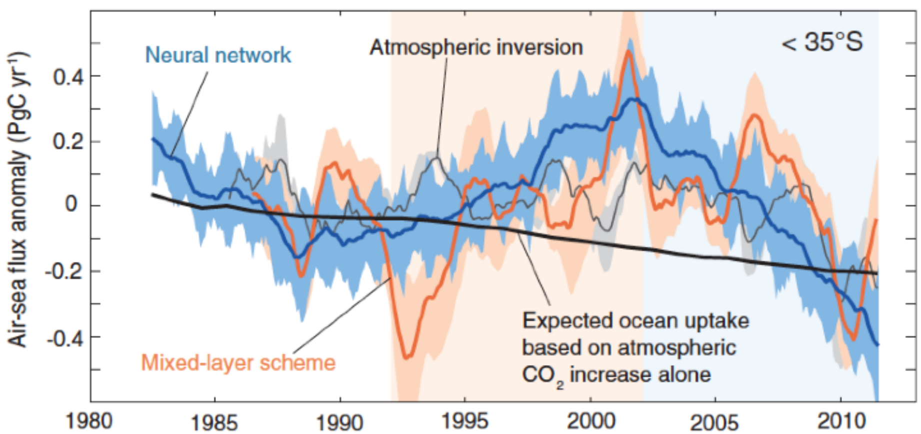
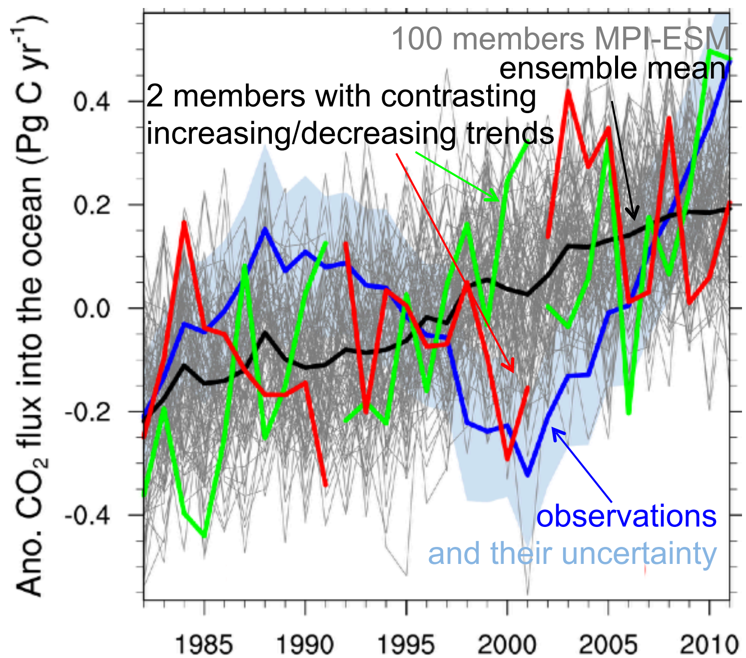
Southern Ocean is responsible for about half of the ocean carbon sink

Southern Ocean C-sink variations
Observations



Landschützer et al., Science, 2015

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



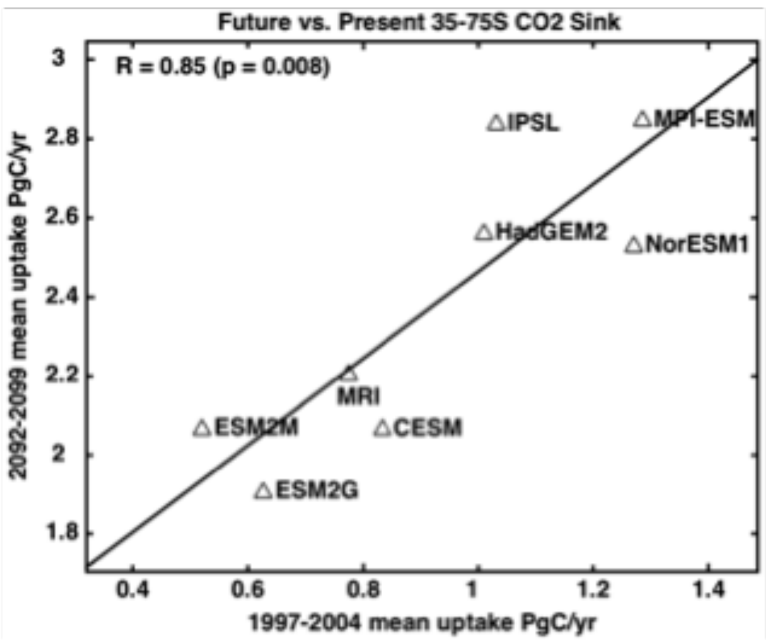
Hongmei Li in prep.

- 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

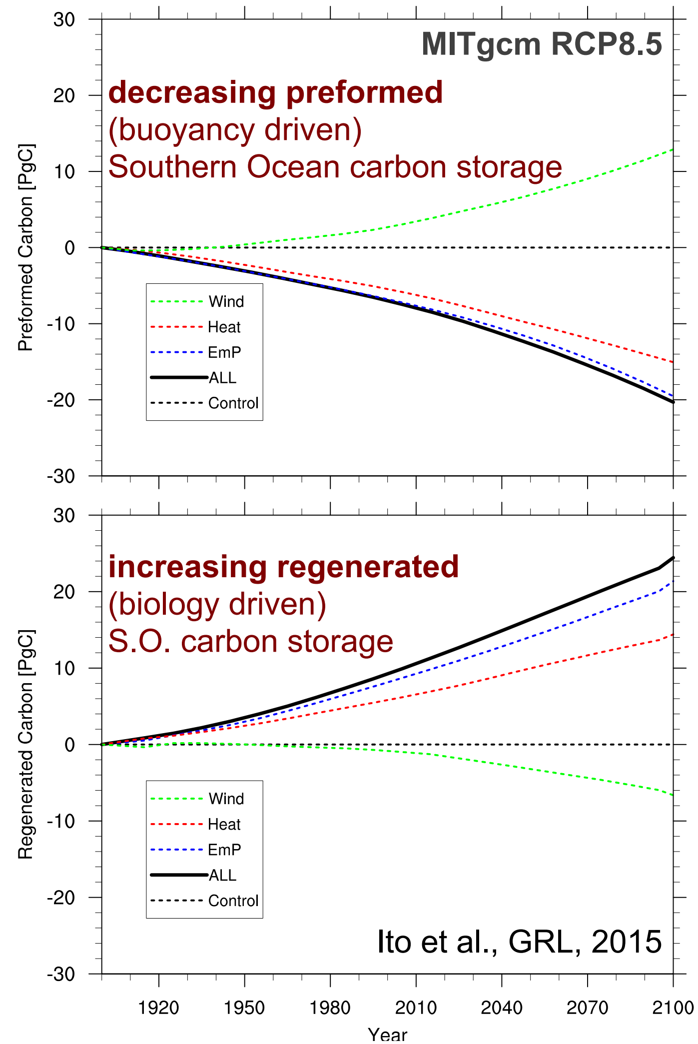
2. What is the potential for amplification of climate change over the 21st century via climate-carbon cycle feedbacks?

Ocean: How changes in climate, ocean circulation, and biogeochemical mechanisms will affect the ocean's capacity to sequester carbon?

ESMs with overestimated seasonal C-uptake project larger future C-uptake in the South. Ocean



Nevison et al, GRL, 2016

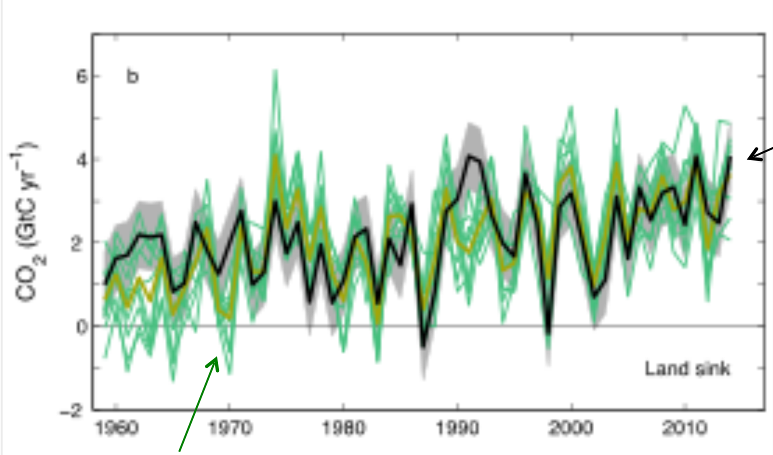


Ito et al., GRL, 2015

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

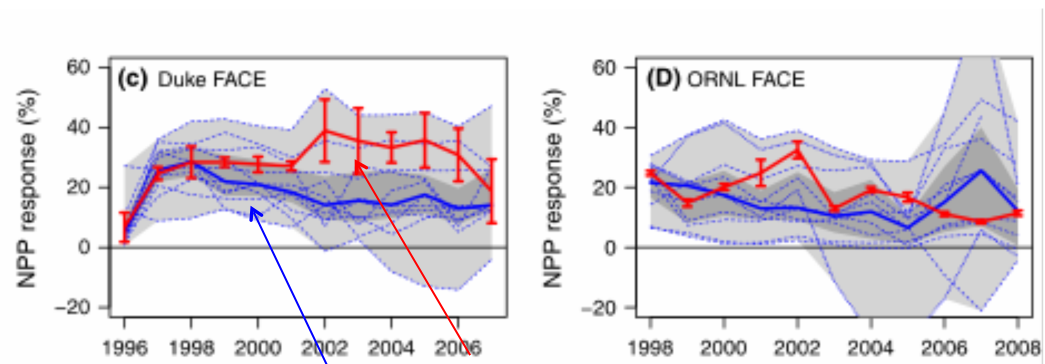


GCP budget residual

Land carbon models

LeQuéré et al., ESSD, 2015

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



Observations

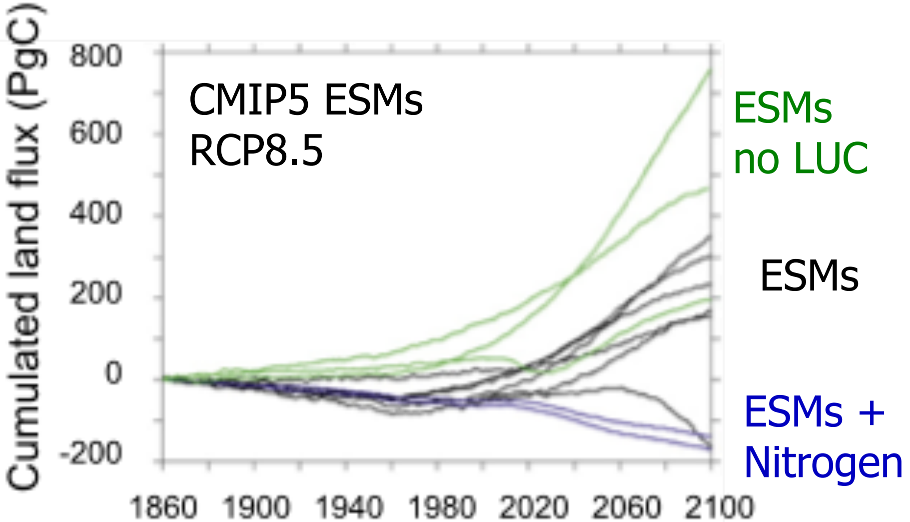
Models

Zaehle et al., New Phyt., 2014

2. What is the potential for amplification of climate change over the 21st century via climate-carbon cycle feedbacks?

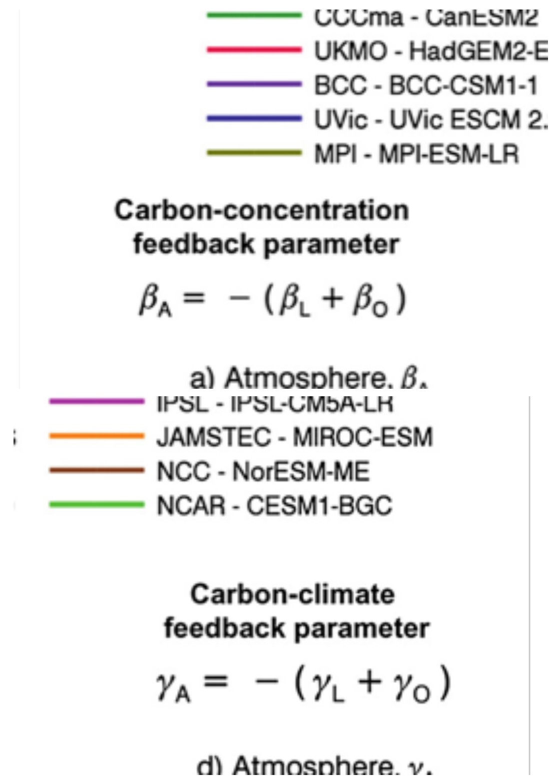
Land: How changes in climate, atmospheric composition, land use will affect the land's capacity to sequester carbon?

Future land sink in RCP scenario very uncertain. Not even sure about the sign !



Friedlingstein et al., J. Clim, 2014

Large uncertainty on land carbon response to CO_2 (β) and climate (γ)



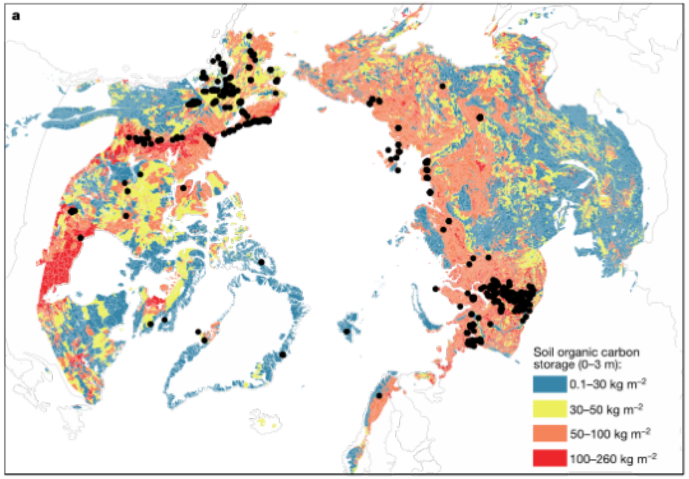
Arora et al., J. Clim, 2013

3. How do greenhouse gases fluxes from highly vulnerable carbon reservoirs respond to changing climate?

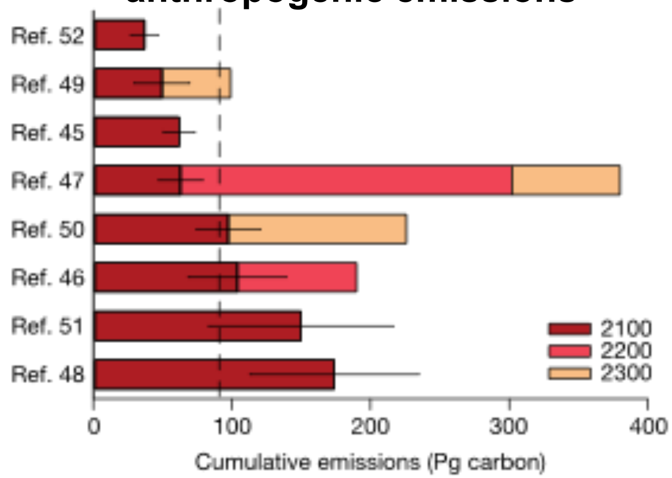
Land: Changes in Arctic soil temperature, or in tropical precipitation can lead to large, irreversible, carbon release from terrestrial ecosystems.

IPCC AR5

AR5 WG1 SPM:
"The release of CO_2 or CH_4 to the atmosphere from thawing permafrost carbon stocks over the 21st century is assessed to be in the range of 50 to 250 GtC for RCP8.5 (*low confidence*). "



Cumulative carbon emissions from Permafrost. Up to 10% of anthropogenic emissions



Schuur et al., Nature, 2015

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Guiding questions:

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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)*

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

Research Initiatives

III. Learning from the existing record

- observational frameworks, model evaluation/benchmarking
- new emerging constraints
- from paleorecord to satellite data

IV. Towards improved projections

- improved feedback framework (water cycle, regional focus)
- improved Earth System models
- ESM re-analysis (physics and biogeochemistry)

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?

Objectives of the workshop

1. update the white paper
   - Hopefully not a complete rewrite, but a clearer identification of overarching questions and Research Initiatives
   - Identify 1-2 well defined **Research Questions (RQs)** per Research Initiative
   - These need to be ambitious AND achievable

2. concrete plan of action
   - How can we tackle these RQs? What is currently limiting progress? How can we alleviate this?
   - How can the GC-Carbon help?
   - Identify RQs leaders, propose RQ specific activities?

3. Review/perspective paper summarizing this Grand Challenge

   Similar to Bony et al, NatGeo 2015 ?

nature geoscience

PERSPECTIVE

PUBLISHED ONLINE: 31 MARCH 2015 | DOI: 10.1038/NGEO2398

Clouds, circulation and climate sensitivity

Sandrine Bony[1*], Bjorn Stevens[2], Dargan M. W. Frierson[3], Christian Jakob[4], Masa Kageyama[5], Robert Pincus[6,7], Theodore G. Shepherd[8], Steven C. Sherwood[9], A. Pier Siebesma[10], Adam H. Sobel[11], Masahiro Watanabe[12] and Mark J. Webb[13]

Fundamental puzzles of climate science remain unsolved because of our limited understanding of how clouds, circulation and climate interact. One example is our inability to provide robust assessments of future global and regional climate changes. However, ongoing advances in our capacity to observe, simulate and conceptualize the climate system now make it possible to fill gaps in our knowledge. We argue that progress can be accelerated by focusing research on a handful of important scientific questions that have become tractable as a result of recent advances. We propose four such questions below; they involve understanding the role of cloud feedbacks and convective organization in climate, and the factors that control the position, the strength and the variability of the tropical rain belts and the extratropical storm tracks.

Clouds stimulate the human spirit. Although they have been recognized for centuries as harbingers of weather, only in recent decades have scientists begun to appreciate the role of clouds in determining the general circulation of the atmosphere and its susceptibility to change.

Forming mostly in the updrafts of the turbulent and chaotic airflow, clouds embody the complex and multiscale organization of the atmosphere into dynamical entities, or storms. These entities mediate the radiative transfer of energy, distribute precipitation and are often associated with extreme winds. It has long been recognized that the water and heat transfer that clouds mediate plays a fundamental role in tropical circulations, and there is increasing evidence that they also influence extratropical circulations[1]. Globally, the impact of clouds on Earth's radiation budget — and hence surface temperatures — also depends critically on how clouds interact with one another and with larger-scale circulations[2]. Far from being passive tracers of a turbulent atmosphere, clouds thus embody processes that can actively control circulation and climate (Box 1).

For practical reasons, early endeavours to understand climate deployed a 'divide and conquer' strategy in which efforts to understand clouds and convective processes developed separately from efforts to understand larger-scale circulations. Over time, a gap developed between the subdisciplines. But technological progress and conceptual advances have tremendously increased our capacity to observe and simulate the climate system, such that it is now possible to study more readily how small-scale convective processes — that is, clouds — couple to large-scale circulations (Box 2). Much as a new accelerator allows physicists to explore the implication of the interactions among forces acting over different length scales, these new capabilities are transforming how atmospheric scientists think about the interplay of clouds and climate. This offers a great opportunity not only to close the gap between scientific communities, but also to answer some of the most pressing questions about the fate of our planet.

Urgent need for accelerated progress

Climate is changing at an unprecedented pace[3]. Government and private decision-makers involved in planning and risk assessments urgently need information about how rapidly temperatures will rise, how rainfall patterns will change and to what extent the frequency of extreme weather will increase. Climate scientists have built a successful research framework for detecting and attributing some global aspects of climate change, such as the basic trends in globally averaged temperatures and sea level. This success is reflected in the growing level of confidence in understanding of such changes[3]. This framework is much less effective, however, when it comes to quantifying critical aspects of climate change such as the climate sensitivity or regional changes. On these aspects, observational datasets are limited, natural variability obscures the anthropogenic signal, and climate models produce uncertain projections[4,5]. This leads to low confidence in their assessment[3].

A deeper understanding of how clouds and aerosols affect the planetary energy budget is needed if we are to increase our confidence in these fundamental aspects of climate change[6,7]. But given the strong dependence of regional climate patterns and extremes on the large-scale circulation, it is equally important to understand better how clouds and convection affect atmospheric dynamics and its change as the troposphere becomes warmer and wetter, the stratosphere colder and the cryosphere smaller[4,8] (Box 1). Our degree of understanding of the interplay between clouds, circulation and climate sensitivity thus demarcates the frontier of our ability to anticipate climate changes.

Numerical models have always played an important role in climate change studies and assessments. But robust conclusions require more

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How can the GC-Carbon help

- “Support” research activities that contribute to the GC-Carbon
- Provide an international scientific framework
- Stimulate research for new generation
- (Co-) organise workshops, working groups, …
- Promote research outcomes

Measure of progress

How do we measure progress in the GC-Carbon?

Going back to Research Questions

- Improved understanding of key processes
- Reduced uncertainty across models (and for the right reason)
- Better quantification from observations (including emergent constraints)
- …

Overarching Questions

- Better understanding of carbon sinks dynamic?
- Reduced uncertainty in future projections?

Plan of the workshop

Break out groups:

I. Process understanding on land *(Ying-Ping, Ivan)*

II. Process understanding in the ocean *(Niki, Laurent)*

III. Learning from the existing record *(Philippe, Peter L.)*

IV. Towards improved projections *(Peter C., Thomas)*

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
11:10	Inspirational talk #2 (Land) Chris Jones
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)
12:30	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