WCRP Grand Challenge

Carbon Feedbacks in the Climate System

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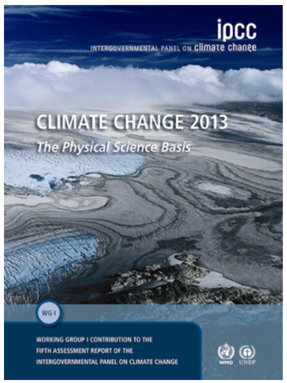
The Grand Challenge

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

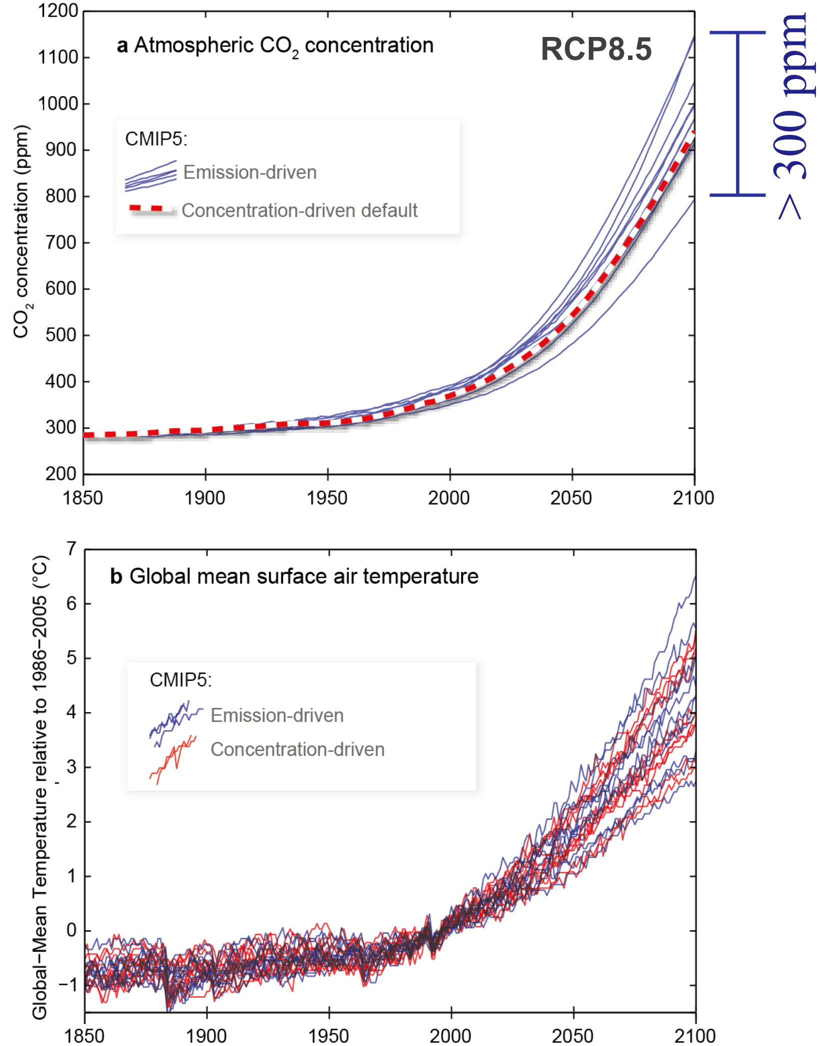


AR5 WG1 SPM:

"Based on ESMs, there is *high confidence* that the feedback between climate and the carbon cycle is positive in the 21st century."

CMIP5

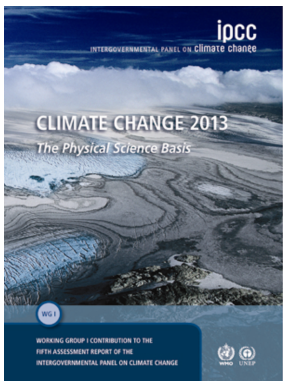
- >40 climate models (AOGCM)
- 10 ESMs (i.e. with BGC components)



The Grand Challenge *to understand how biogeochemical cycles and feedbacks control CO_2 concentrations and impact on the climate system*

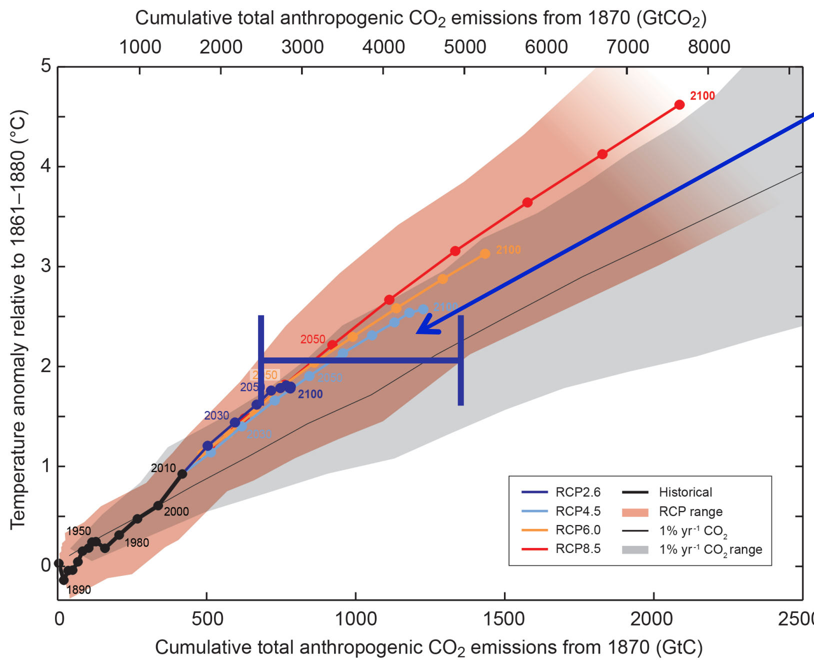
Large uncertainty in CO_2 emissions compatible with a given climate target.
Budget for the 2°C target is about 700GtC to 1300GtC.
Given 550 GtC emitted so far, that's **15 to 75 years of current emissions**.

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."

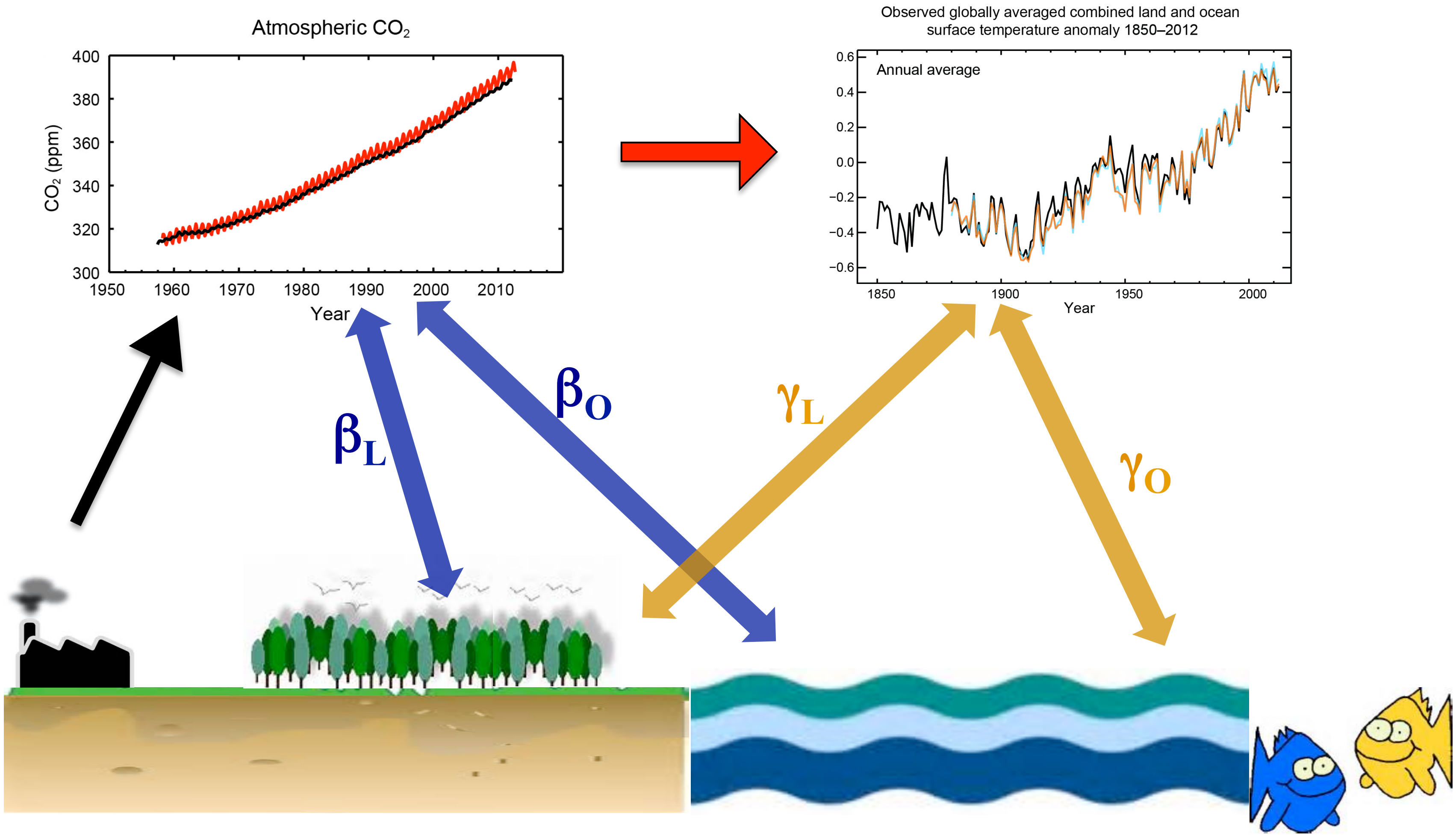


Uncertainty

- Carbon feedbacks (CO_2 emissions ➔ CO_2 concentration)
- Climate feedbacks (CO_2 concentrations ➔ climate response)

Carbon cycle feedbacks

- most feedbacks known (or suspected) for decades
- no or little direct observations
- basic or insufficient understanding of processes
- uncertain magnitude



β : concentration carbon cycle feedback – **Negative Feedback**

γ : climate carbon cycle feedback – **Positive Feedback**

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Guiding questions:

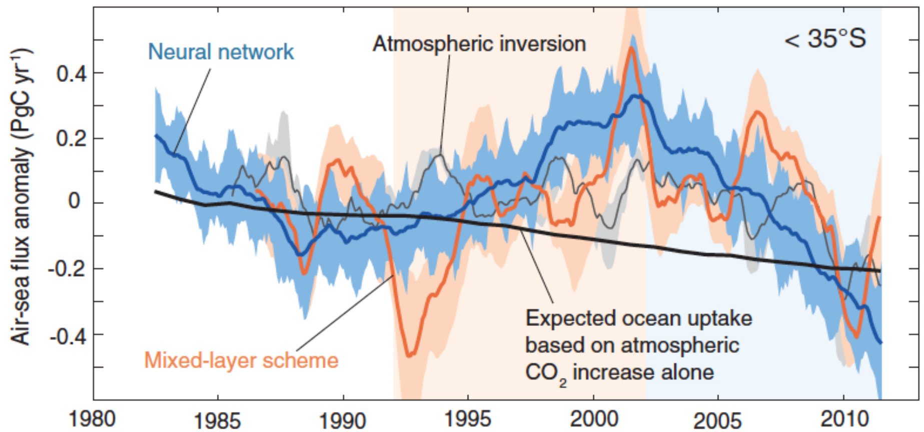
1. What are the drivers of land and ocean carbon sinks?
2. What is the potential for amplification of climate change over the 21^{st} century via climate-carbon cycle feedbacks?
3. How do greenhouse gases fluxes from highly vulnerable carbon reservoirs respond to changing climate (including climate extremes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

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*

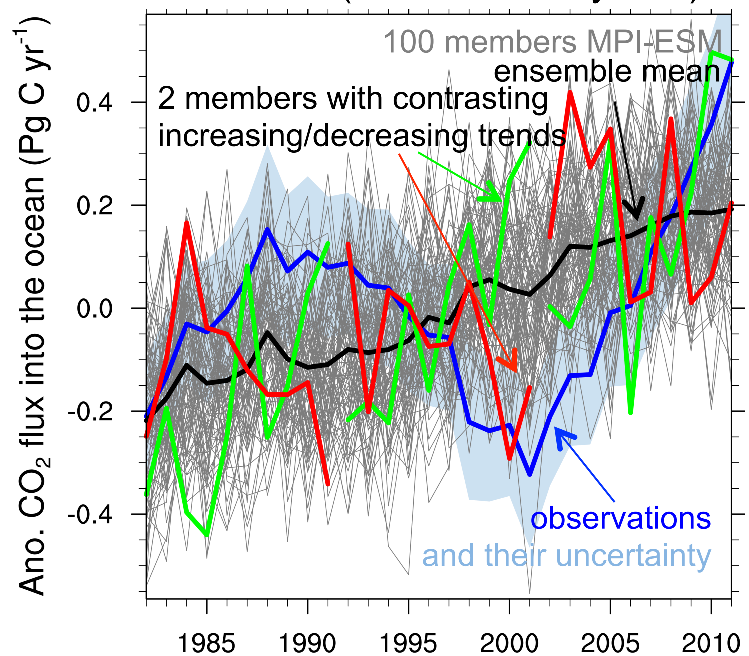
Southern Ocean is responsible for zbout half of the ocean carbon sink

Southern Ocean C-sink variations
Observations



Landschützer et al., Science, 2015

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

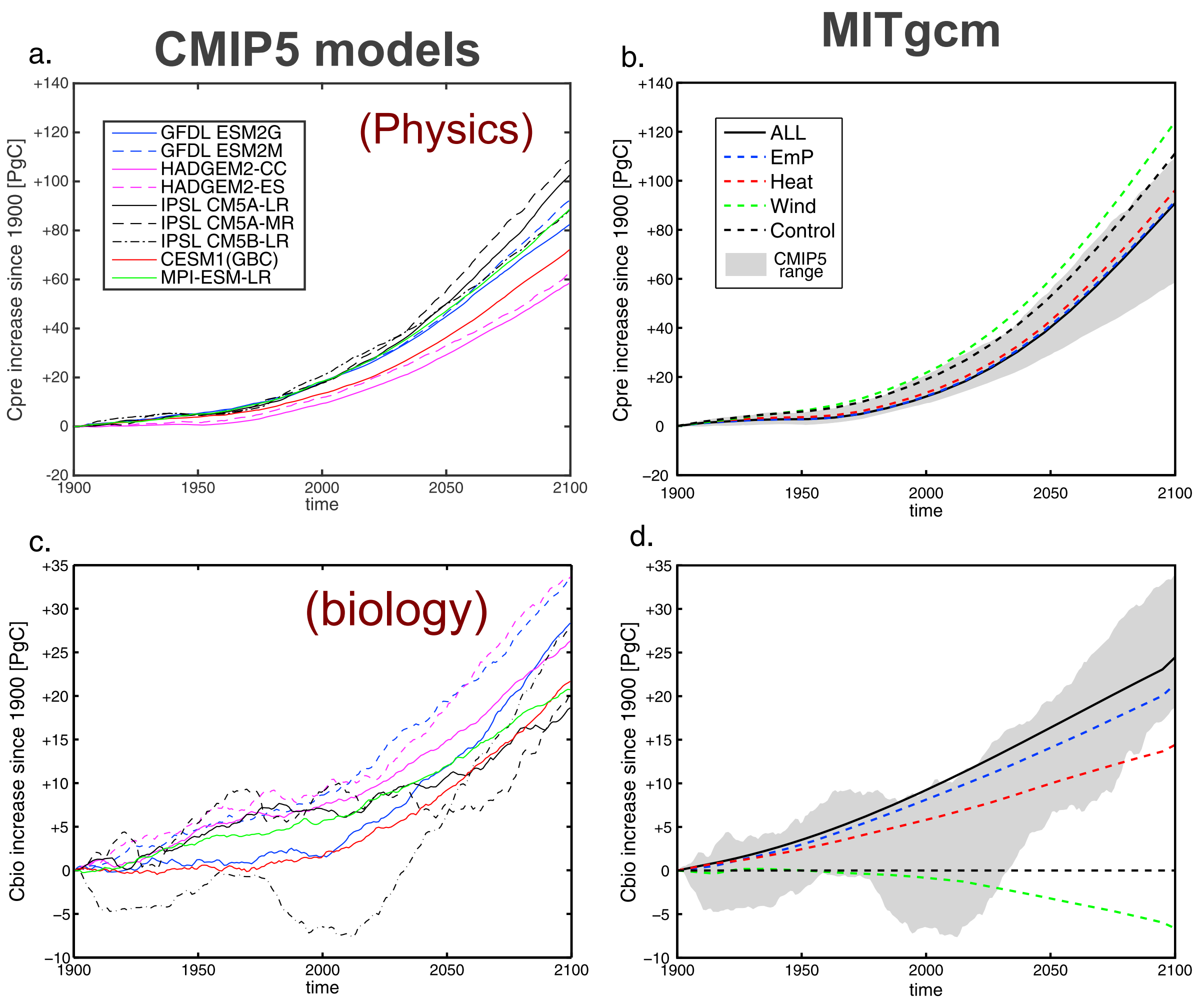


Hongmei Li in prep.

- 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?

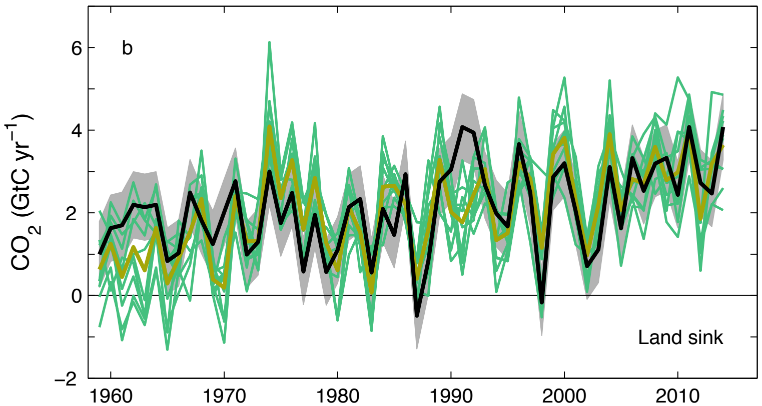


Ito et al., GRL, 2015

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

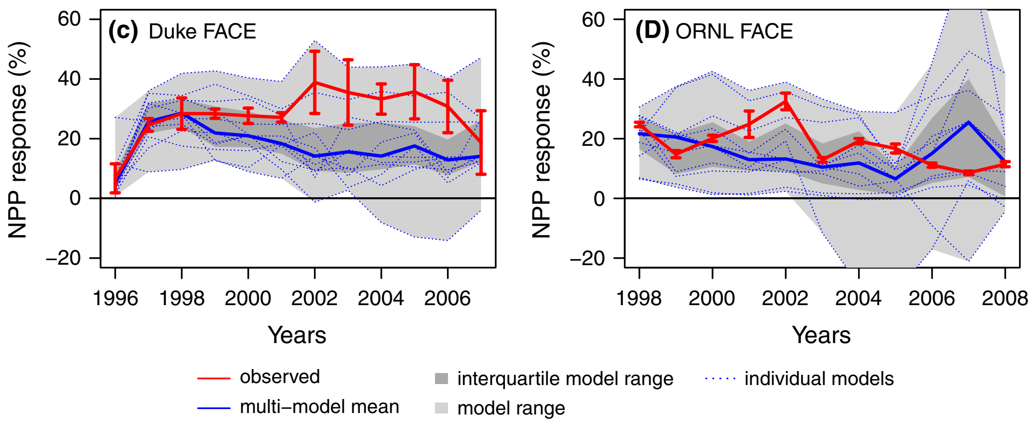
Land: *the main barriers relate to understanding of the actual processes driving the sinks*

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



LeQuéré et al., ESSDD, 2015

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

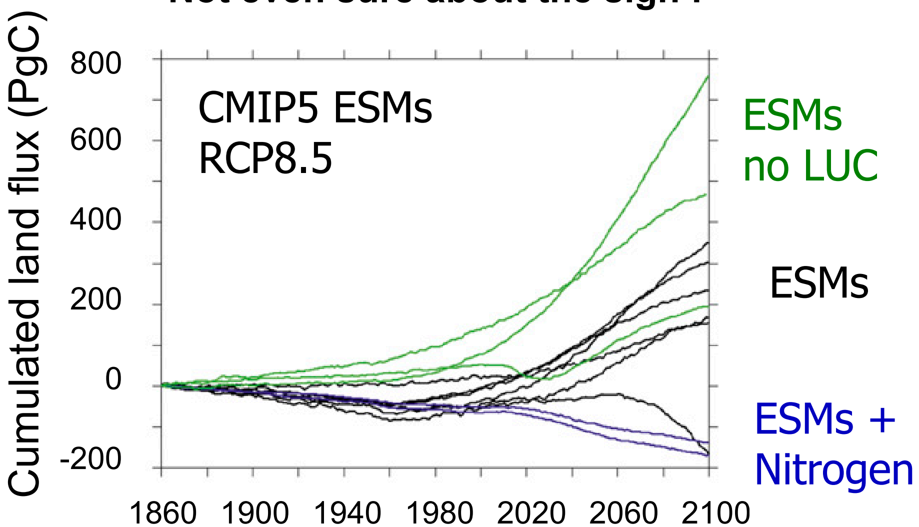


Zaehle et al., New Phyt., 2014

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

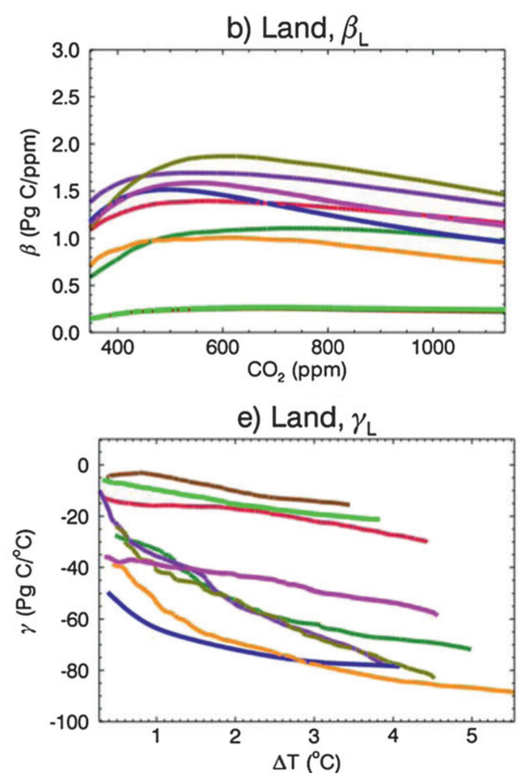
Land: How changes in climate, atmospheric composition, land use, and biogeochemical mechanisms will affect the land's capacity to sequester carbon?

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



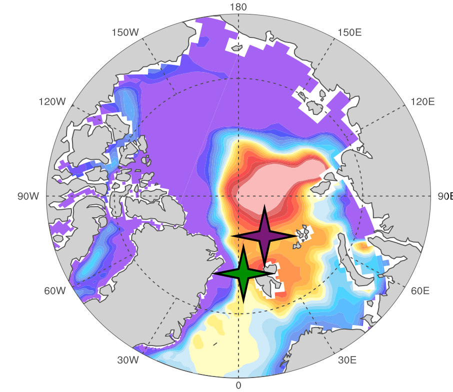
Friedlingstein et al., J. Clim, 2014

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



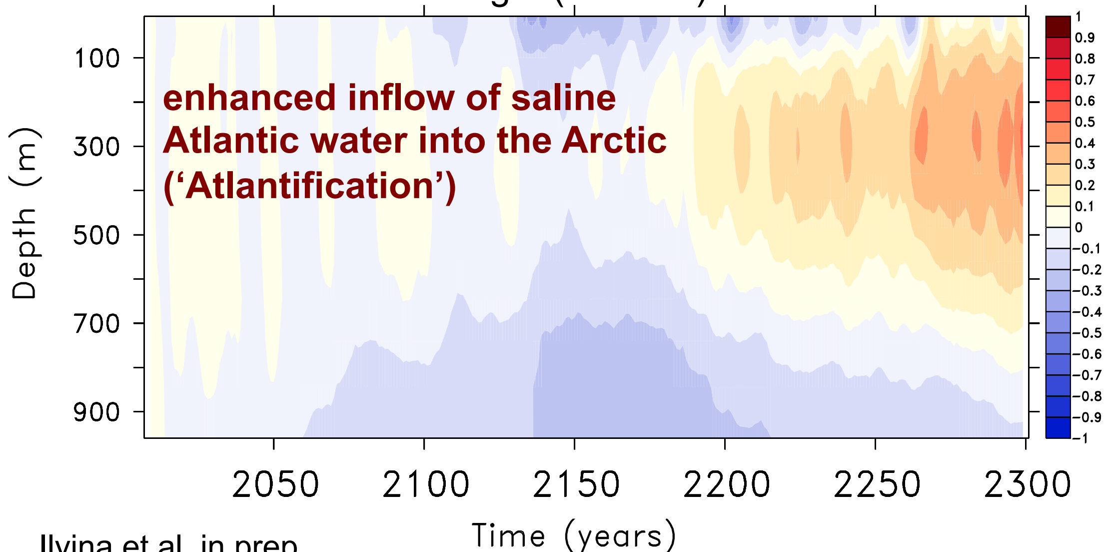
Arora et al., J. Clim, 2013

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



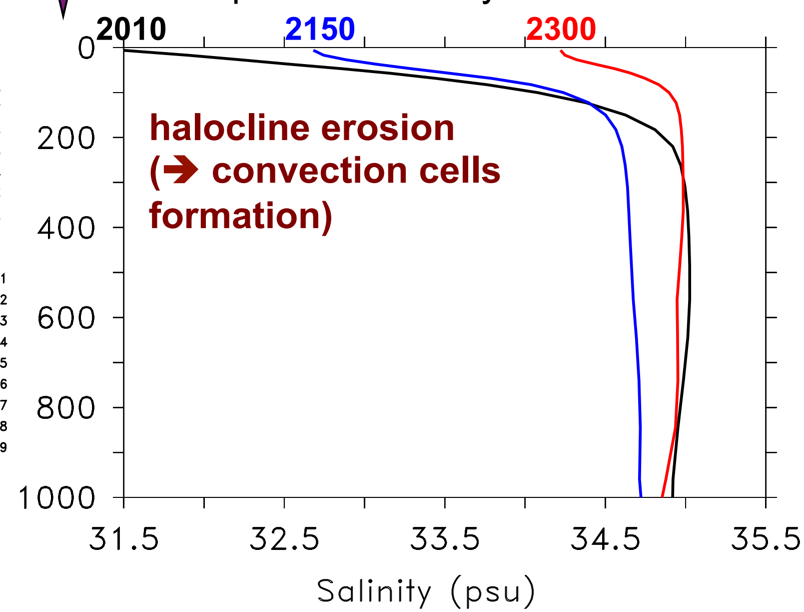
Ocean: changes in thermohaline circulation:
e.g. Arctic Ocean ‘Atlantification’ & halocline collapse
(potential for abrupt changes)

vertical profile of salinity anomaly in the Fram Straight (RCP8.5)



Ilyina et al. in prep.

vertical profile of salinity in:



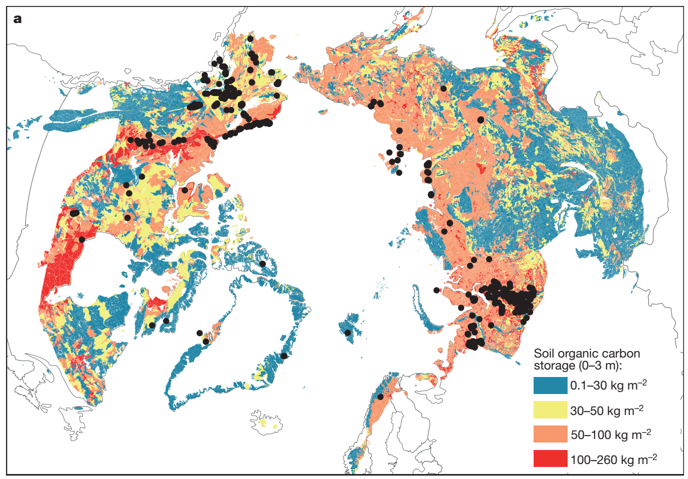
What are implications for carbon uptake and storage?

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

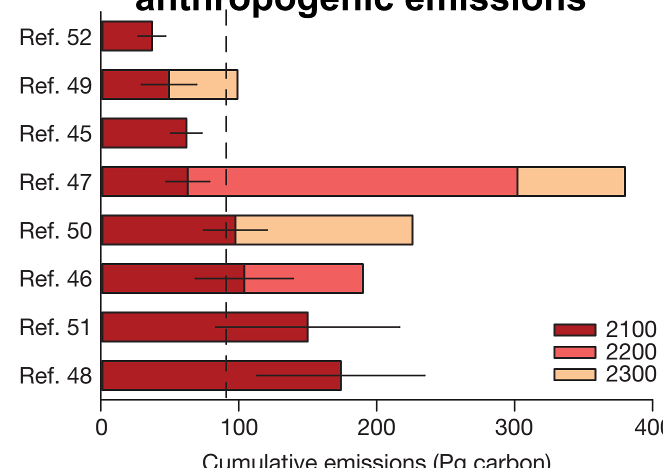
Land: Changes in Arctic soil temperature, or in tropical precipitation can lead to large, irreversible, carbon release from terrestrial ecosystems.

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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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; for historical attribution and future projections. Processes: photosynthesis, nitrogen cycle
- Quantification of gross carbon fluxes sensitivity to warming (and changes in hydrology); for future projections. Processes: vegetation dynamics, soil biogeochemistry
- Assessment of ecosystems vulnerability and risk of carbon loss; for future projections. Processes: vegetation dynamics, fire disturbance, frozen soil physics and biogeochemistry

II. Process understanding in the ocean

- Quantification of the strength of the Southern Ocean CO_2 uptake: the relative role of physical (i.e. eddies, convection, atmospheric dynamics) vs. biological processes (i.e. production, respiration)
- Assessment 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, models evaluation/benchmarking
- from paleorecord to satellite data
- new emerging constraints

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
"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

WCRP projects

- CLIVAR, SPARC

Future Earth projects

- GCP
- AIMES, SOLAS, ILEAPS

Other GCs

- GC-Cryosphere

Opportunities for WCRP

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 (and special reports) will “*very likely*” heavily rely on those simulations for assessment of climate projections, compatible emissions, TCR, TCRE, climate impact on land and marine ecosystems, irreversibility, etc
- Urgent need to have better understanding of key BGC processes and their feedbacks on the climate system.

1st Workshop

Haus Rissen, Hamburg
21-22 November 2016

- Grand Challenge kick-off
- About 40 participants
- Refine and update Research Initiatives
- Roadmap for research