Met Office
Hadley Centre

The Carbon Cycle as a Grand Challenge

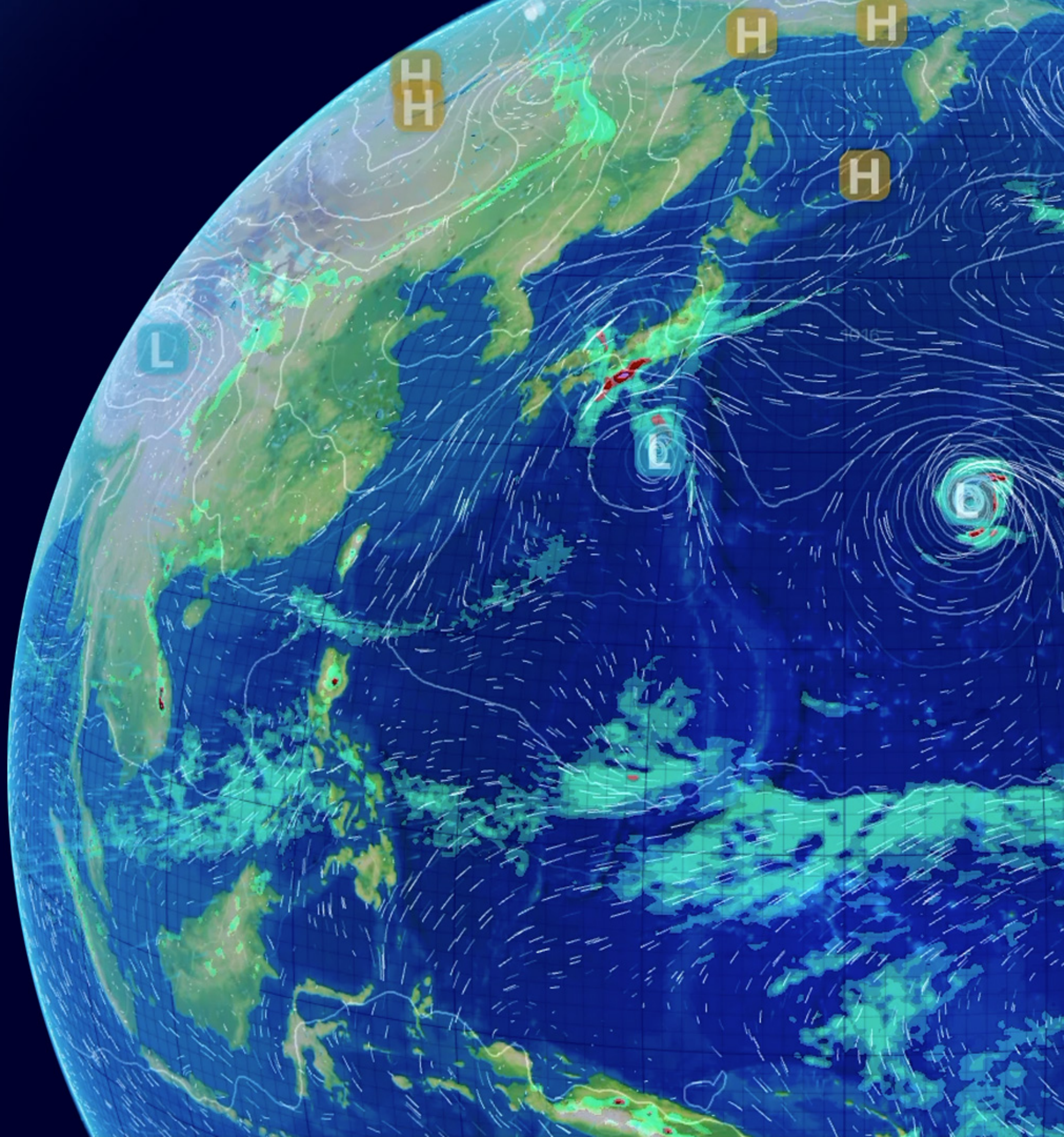
Chris Jones

Research fellow, Met Office Hadley Centre

Aspen Global Change Institute

Forest Dynamics in the Anthropocene, AGCI Workshop.

13 April 2021



Met Office Hadley Centre

Overview

- Why is the carbon cycle a Grand Challenge?
  - "Why do we care?"
- How do carbon sinks help us set/achieve climate targets?
  - "natural" carbon sinks & the remaining carbon budget
- How can we use carbon sinks to mitigate climate change?
  - "managed" carbon sinks & land-based mitigation
  - "nature based solutions" / "natural climate solutions"
  - how do carbon sinks respond to reducing CO2?
- Where are the uncertainties and research priorities?

opinion & comment

COMMENTARY:

Climate research must sharpen its view

Jochem Marotzke, Christian Jakob, Sandrine Bony, Paul A. Dirmeyer, Paul A. O'Gorman, Ed Hawkins, Sarah Perkins-Kirkpatrick, Corinne Le Quéré, Sophie Nowicki, Katsia Paulavets, Sonia I. Seneviratne, Bjorn Stevens and Matthias Tuma

Human activity is changing Earth's climate. Now that this has been acknowledged and accepted in international negotiations, climate research needs to define its next frontiers.

Marotzke et al., 2017

The carbon cycle as a Grand Challenge

"Climate research must sharpen its view"

- Human activity is changing Earth's climate. … this has been acknowledged and accepted in international negotiations …
- <we need to> … cast the challenges ahead into a few simple yet powerful guiding questions:
  - first, where does the carbon go?

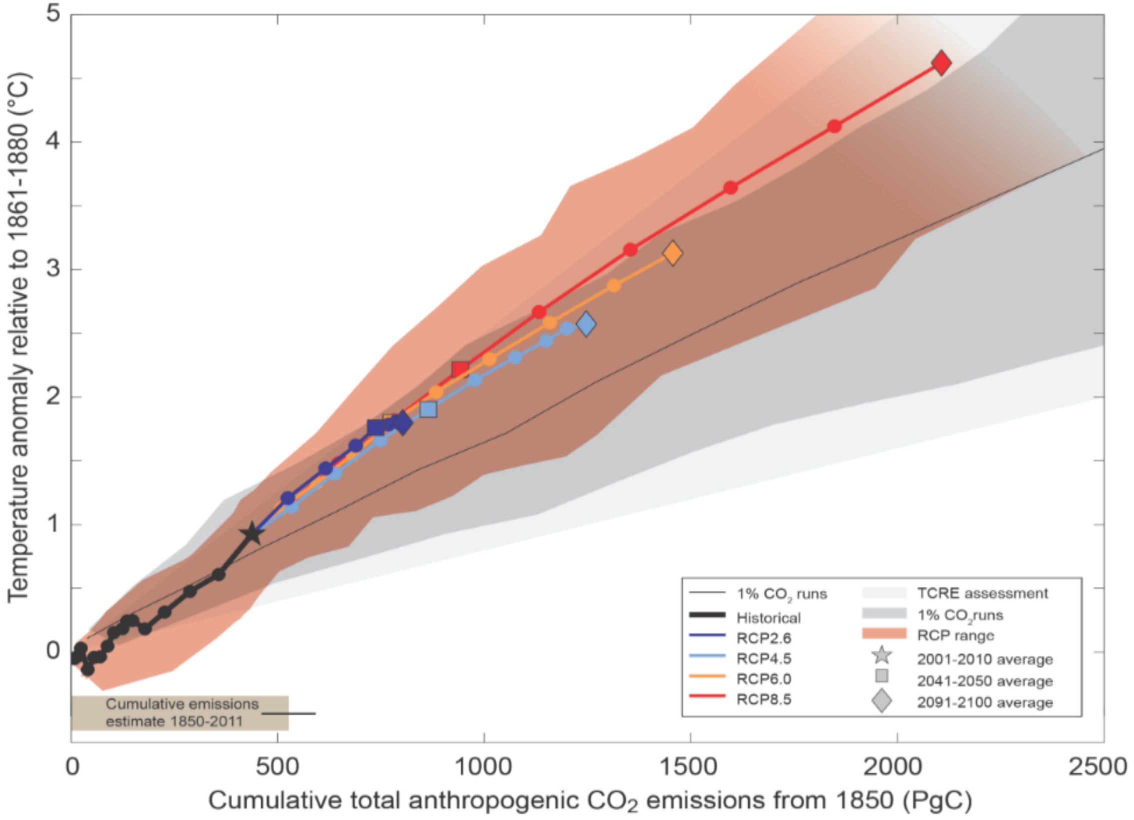
- **WCRP Grand Challenge on Carbon Feedbacks in the Climate System**

- What … processes … control land and ocean carbon sinks?
- Can … climate-carbon feedbacks amplify climate changes …?
- How will … land and ocean carbon reservoirs respond to … changes?

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

Total CO_2 emissions are strongly linked to total warming

- A key message from last IPCC report (AR5: 2013/14)
- Long-term warming is linearly related to total emissions of CO_2.
  - For a given warming target, higher emissions now imply lower emissions later.



IPCC WG1, AR5, 2013

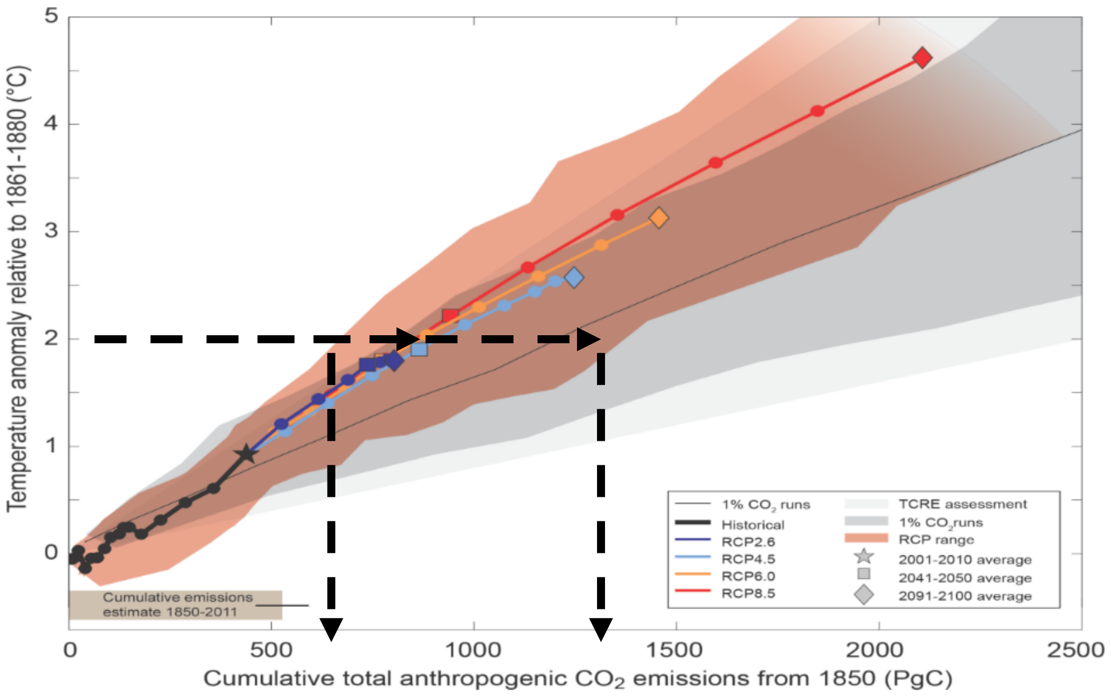
- Allows us to quantify exactly what we must do to meet targets
- Carbon "budget" we can spend
- Quantifying this drew together ***ALL*** of climate science into a single straight line!

TCRE: Transient Climate Response to cumulative carbon Emissions

Total CO_2 emissions are strongly linked to total warming

BUT: substantial uncertainty in this relationship…

- “2 degree” budget ranges from 1000 to 2000 GtCO2
- (plus or minus a few hundred)
- perhaps



IPCC WG1, AR5, 2013

Additional Warming since 2006–2015 [°C]*(1)	Approximate Warming since 1850–1900 [°C]*(1)	Remaining Carbon Budget (Excluding Additional Earth System Feedbacks*(5)) [$GtCO_2$ from 1.1.2018]*(2)			Key Uncertainties and Variations*(4)					
		Percentiles of TCRE *(3)			Earth System Feedbacks *(5)	Non-CO_2 scenario variation *(6)	Non-CO_2 forcing and response uncertainty	TCRE distribution uncertainty *(7)	Historical temperature uncertainty *(1)	Recent emissions uncertainty *(8)
		33rd	50th	67th	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]
0.3		290	160	80	Budgets on the left are reduced by about –100 on centennial time scales	±250	–400 to +200	+100 to +200	±250	±20
0.4		530	350	230						
0.5		770	530	380						
0.53	~1.5°C	840	580	420						
0.6		1010	710	530						
0.63		1080	770	570						
0.7		1240	900	680						
0.78		1440	1040	800						
0.8		1480	1080	830						
0.9		1720	1260	980						
1		1960	1450	1130						
1.03	~2°C	2030	1500	1170						
1.1		2200	1630	1280						
1.13		2270	1690	1320						
1.2		2440	1820	1430						

IPCC SR15, 2018

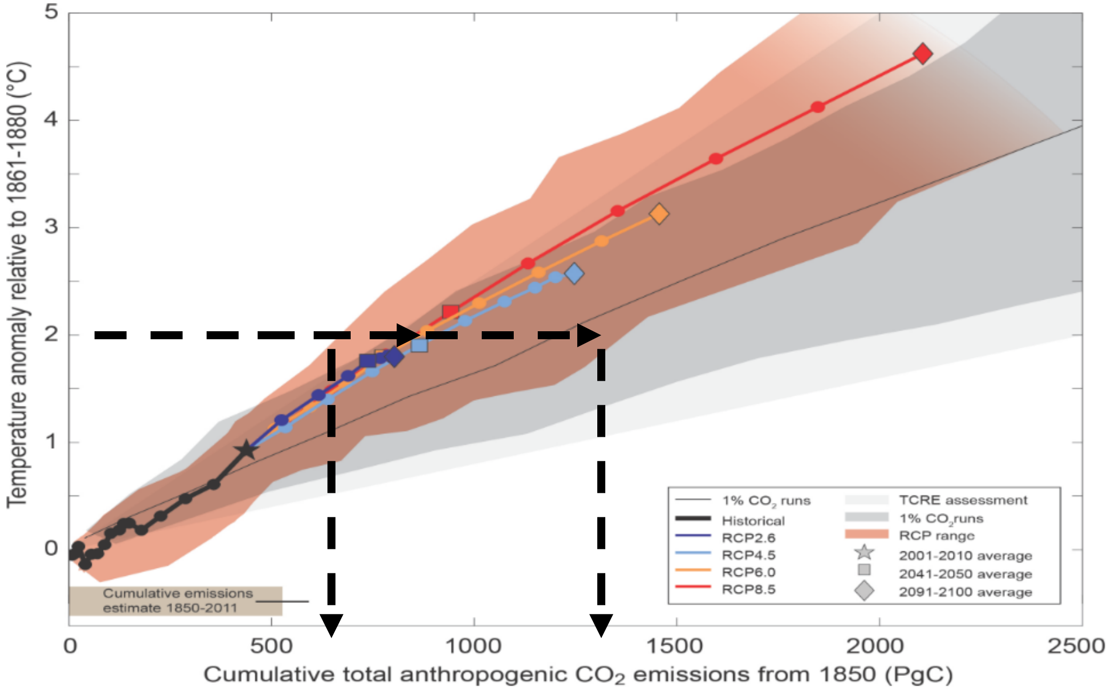
Why we care #1:
carbon cycle controls much of the uncertainty in remaining budget

TCRE = TCR * AF

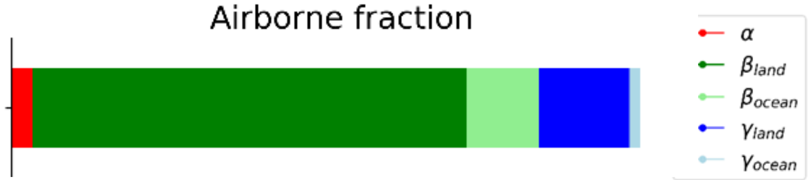
Climate sensitivity – clouds and stuff

<u>Airborne fraction</u> (a.k.a. where does the carbon go?)

- Circa 50% historically
- Very scenario-dependent in future
- Large uncertainty
- Largely determined by land biosphere response to CO2 (so-called “beta” in carbon cycle feedback)



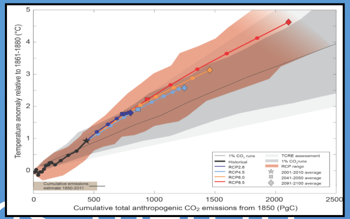
IPCC WG1, AR5, 2013



Jones & Friedlingstein, 2020, ERL

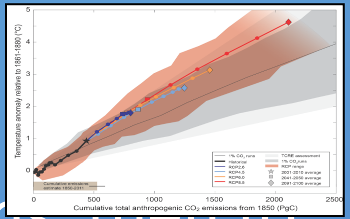
Why we care #2:

If warming linked to emissions, then to stop warming we must stop emissions…



Why we care #2:

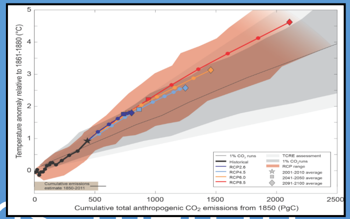
If warming linked to emissions, then to stop warming we must stop emissions…



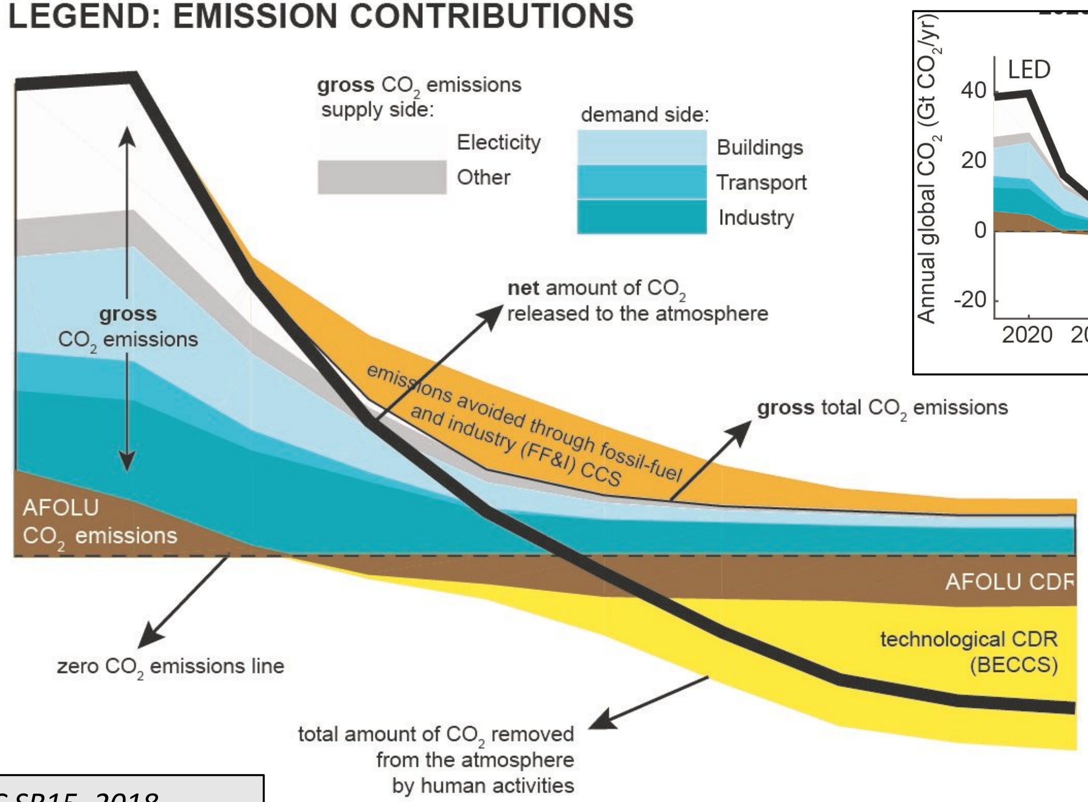
- Reduced emissions not enough
- We must reach net-zero (CO2)
- If we overshoot, need net-negative

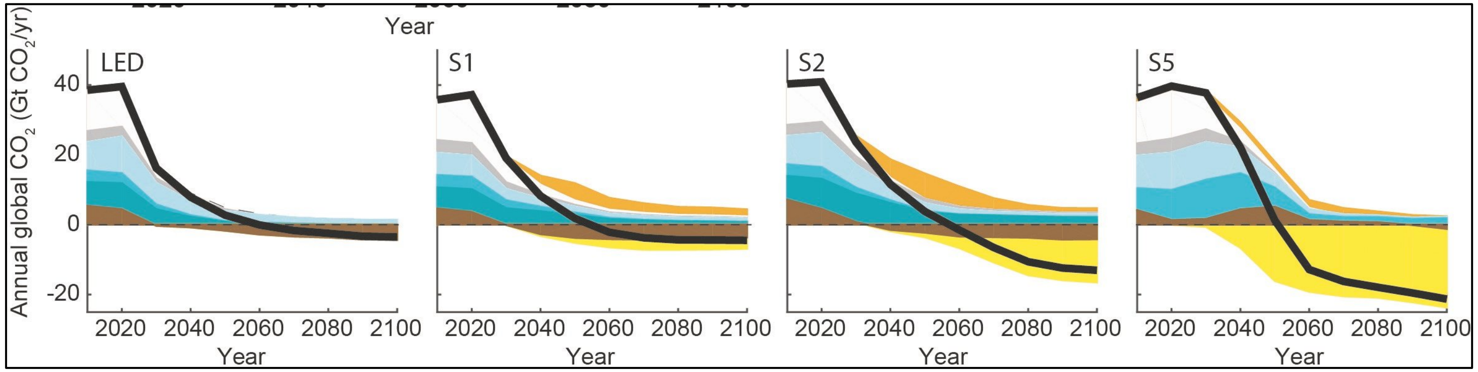
Why we care #2:

If warming linked to emissions, then to stop warming we must stop emissions…



- Reduced emissions not enough
- We must reach net-zero (CO2)
- If we overshoot, need net-negative





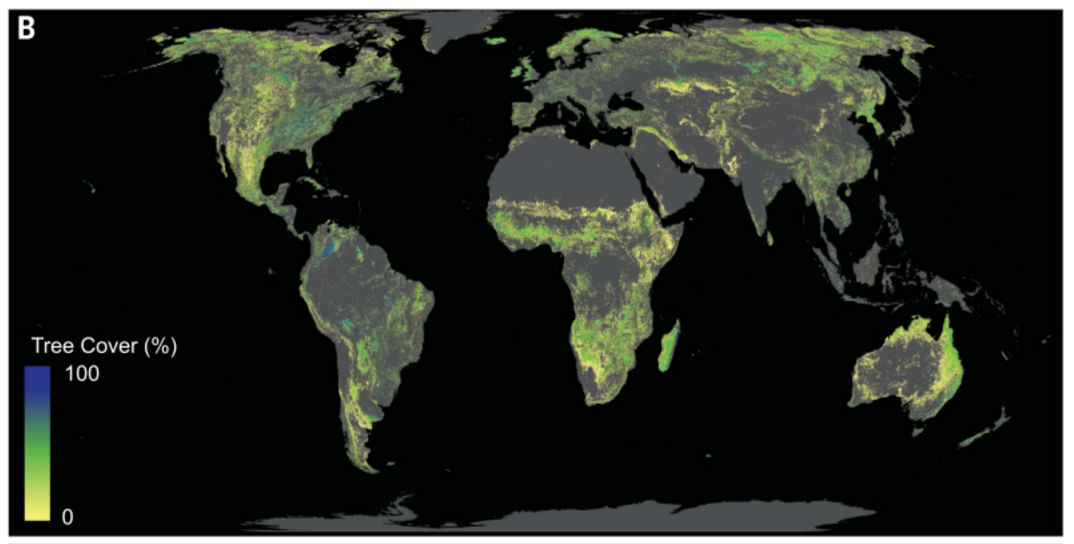
- To reach net zero – CDR required to offset hard-to-abate emissions
- If we exceed in near-term, need global net-negative in long term
- “natural” (AFOLU) CDR vs technological CDR
  - “Natural climate solutions”

IPCC SR15, 2018

RESTORATION ECOLOGY

The global tree restoration potential

Jean-Francois Bastin[1*], Yelena Finegold[2], Claude Garcia[3,4], Danilo Mollicone[2], Marcelo Rezende[2], Devin Routh[1], Constantin M. Zohner[1], Thomas W. Crowther[1]



- 1 billion hectares of trees?
- 200 PgC uptake?

https://science.sciencemag.org/content/365/6448/76

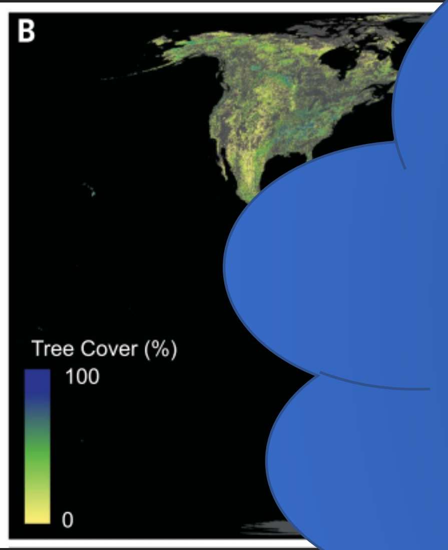
'Fake trees' could fight climate change

Forests of "fake trees" should be planted across the country to reduce the impact of climate change, according to a study.

RESTORATION ECOLOGY

The global tree restoration potential

Jean-Francois Bastin[1*], Yelena Finegold[2], Claude Garcia[3,4], Danilo Mollico...
Marcelo Rezende[2], Devin Routh[1], Constantin M. Zohner[1], Thomas W...



- 1 billion hectares of tr...
- 200 PgC uptake?

https://science.sciencemag.org/content/365/6448/76

Some sort of land-based mitigation is required to achieve net-zero and/or net-negative emissions

- What is the capacity?
- How quickly can these act?
- How will carbon sinks respond to decreasing CO2?

...ate change

...ntry to reduce the impact of

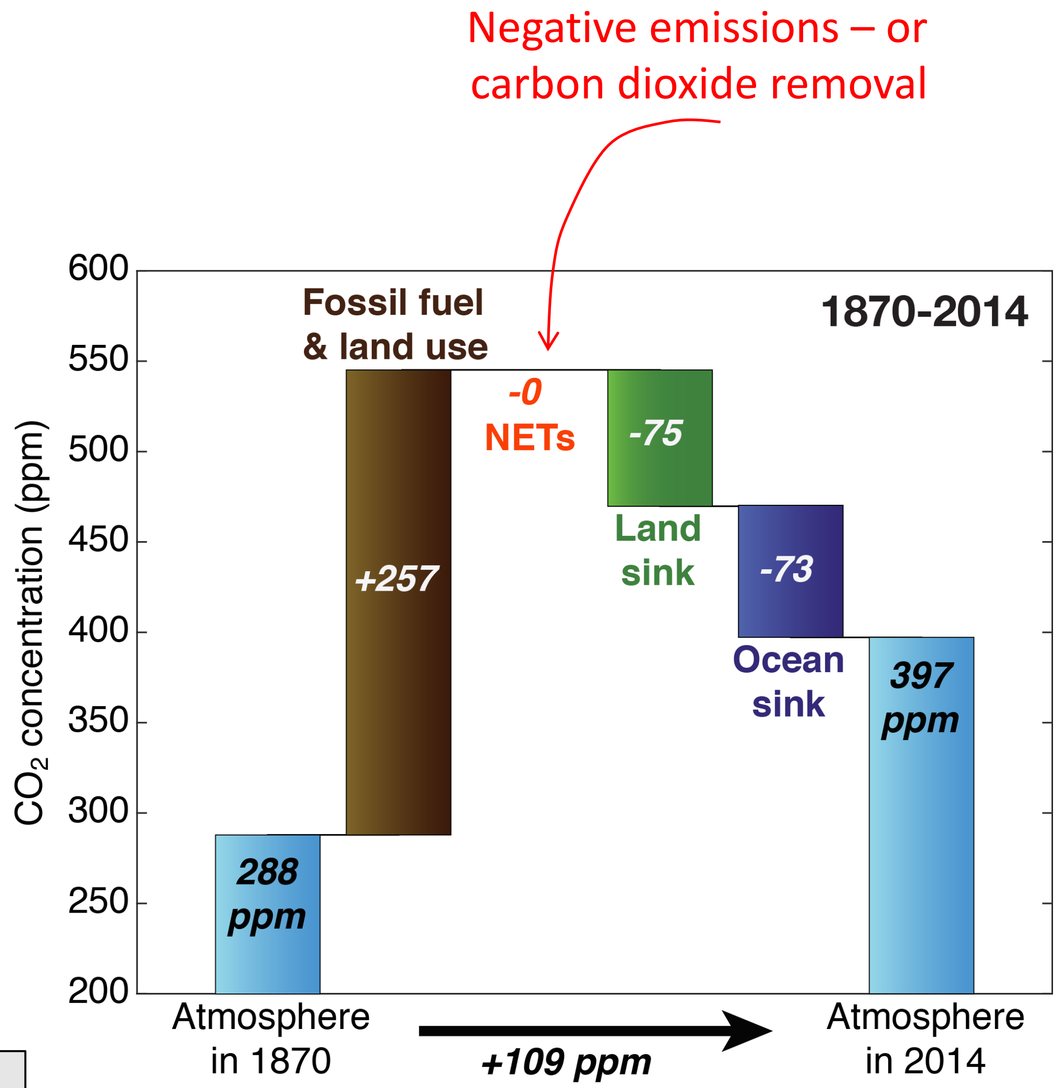
Why we care #3:

carbon sinks respond to CO_2 removal

What we care about – stabilising climate – depends on the balance of natural and anthropogenic sources and sinks

These are interconnected…

Historical carbon cycle was easy(ish)



We put some in...

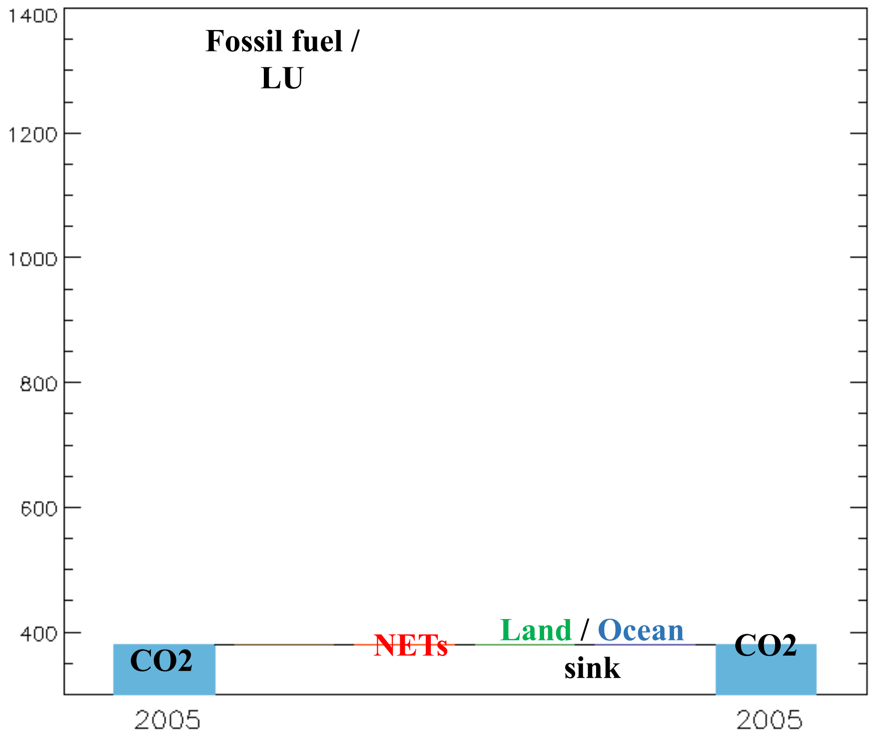
...nature took some out

- in approx constant fraction

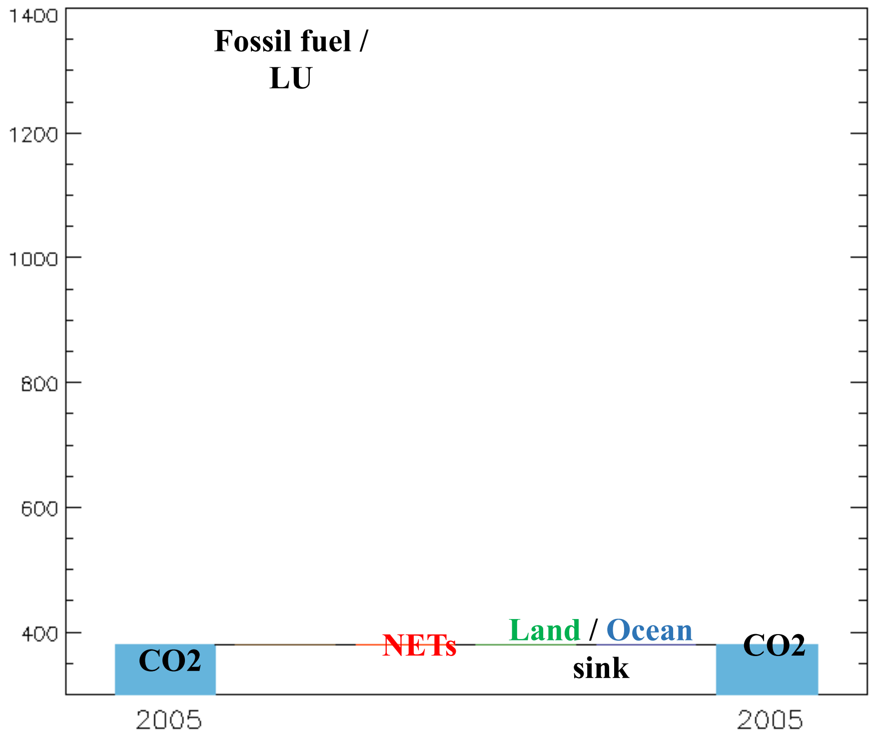
Here we use CMIP5 simulations to show how the balance of inputs and removals depends on scenario and changes dynamically over coming decades/centuries

Jones et al., ERL, 2016

RCP8.5 (high emissions)

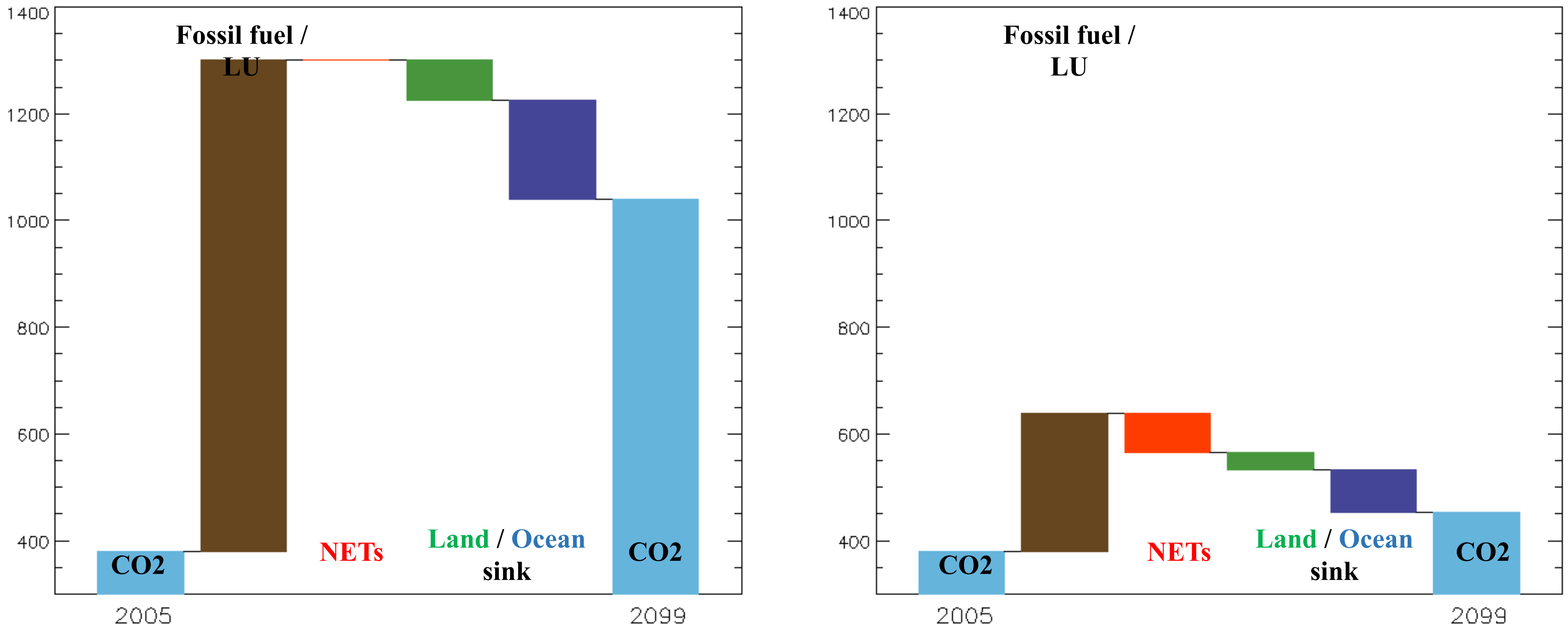


RCP2.6 (strong mitigation scenario)



Jones et al., ERL, 2016

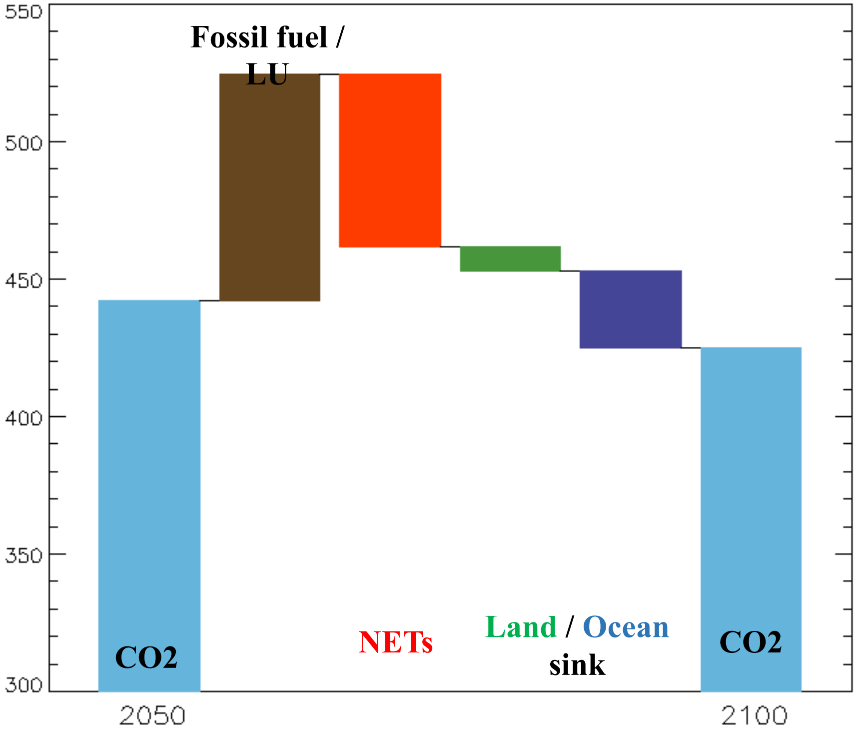
RCP8.5 (high emissions) | **RCP2.6 (strong mitigation scenario)**



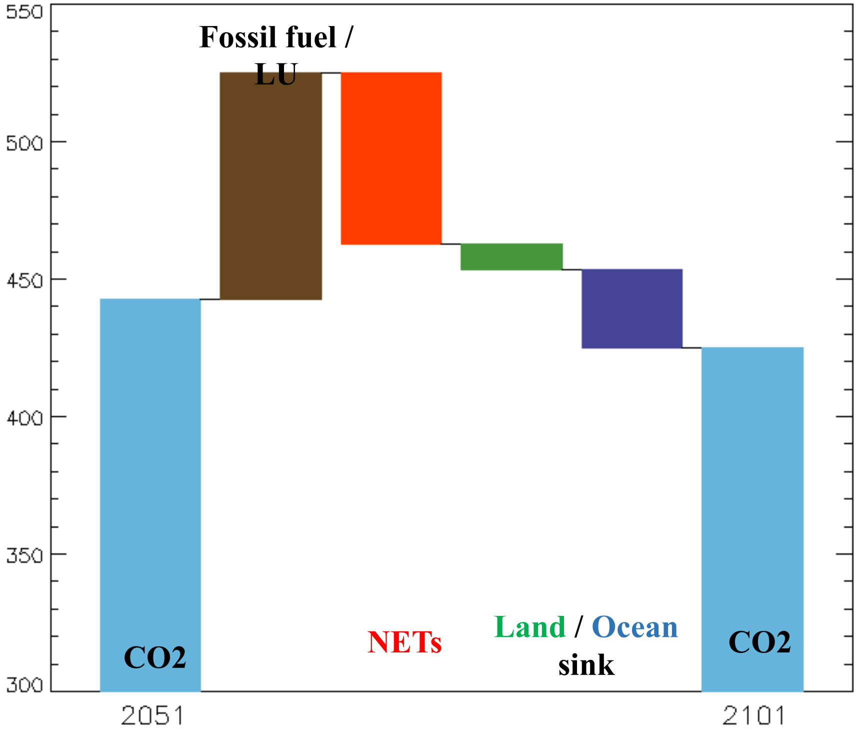
- So RCP2.6 relative to 8.5:
  - Lower fossil fuel emissions
  - More NETs
  - Perhaps not widely appreciated – much smaller land/ocean sinks (in absolute terms, but they're bigger fraction of the emissions)

Jones et al., ERL, 2016

RCP2.6 second half of 21st century

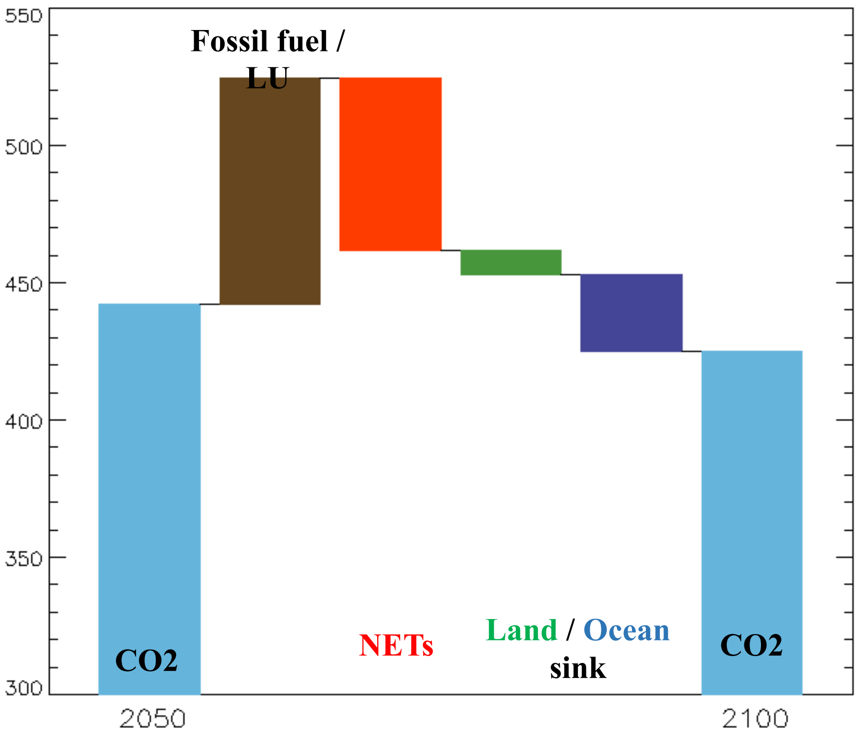


RCP2.6 50-year moving window

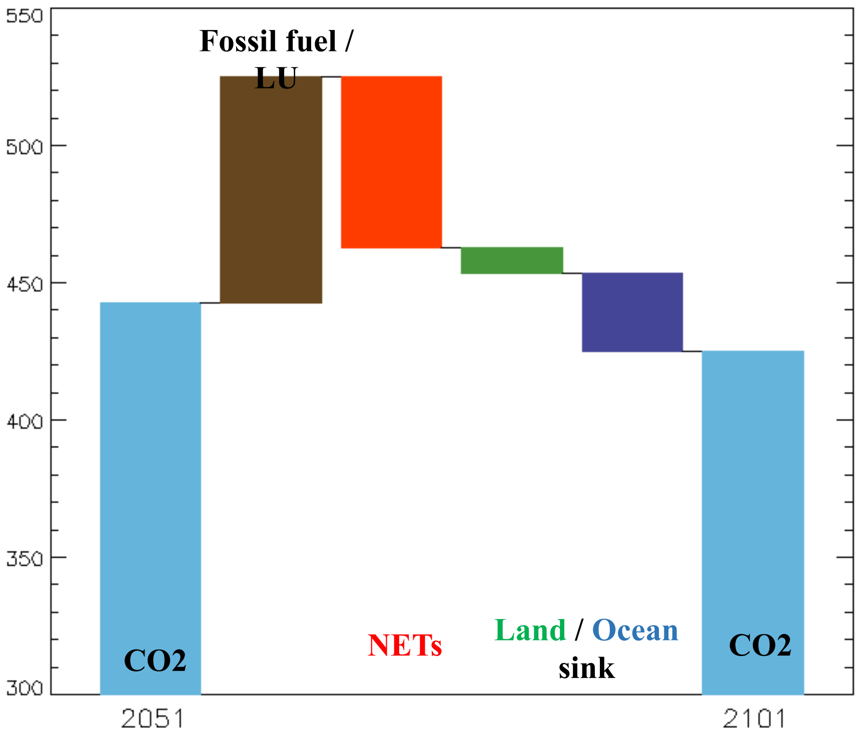


Jones et al., ERL, 2016

RCP2.6
second half of 21st century

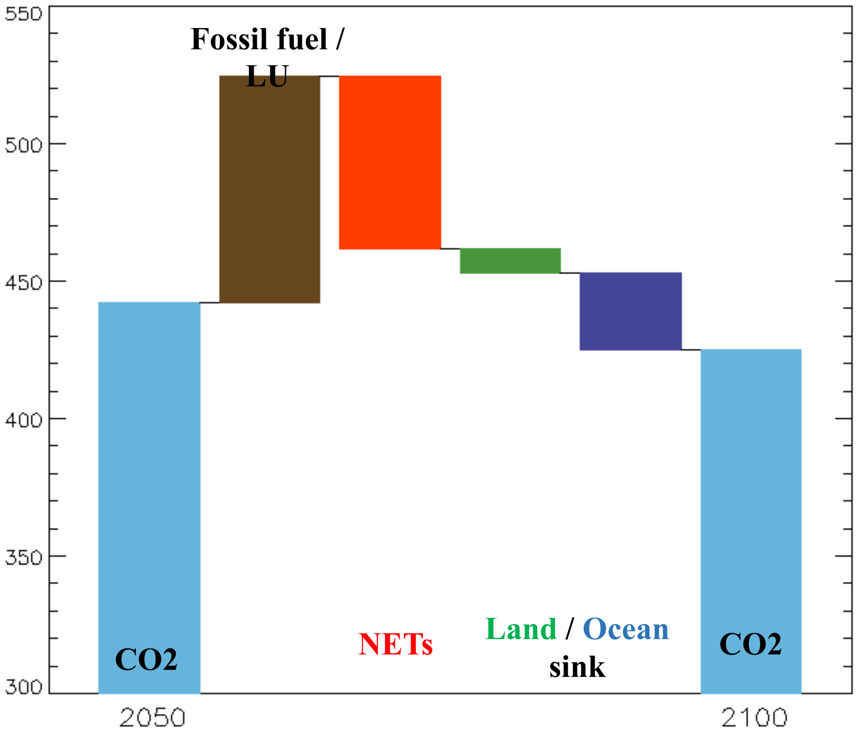


RCP2.6
50-year moving window



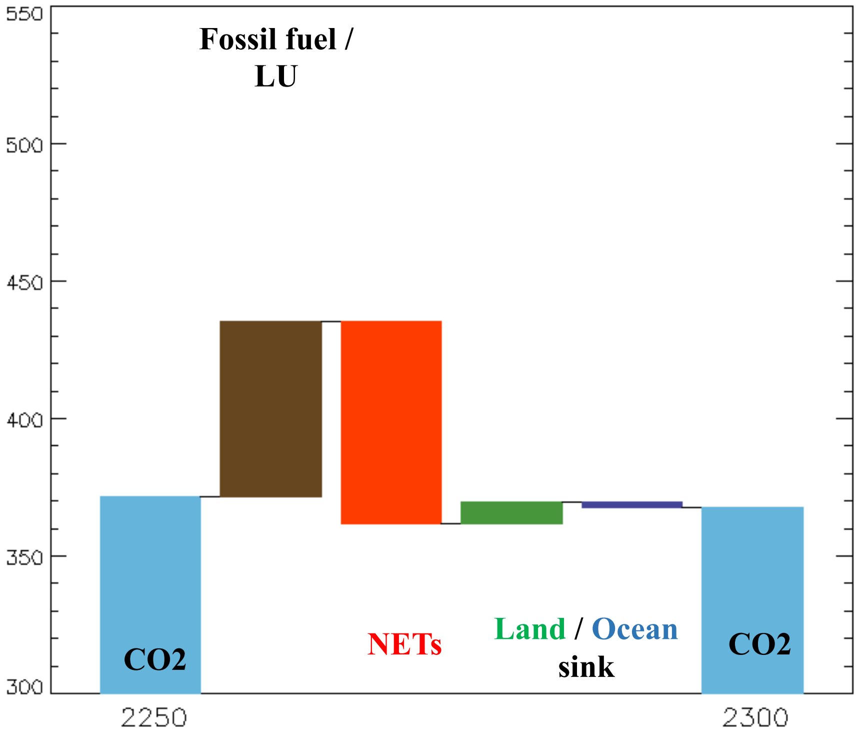
Jones et al., ERL, 2016

RCP2.6 second half of 21st century



- Human input: positive
- Natural input: negative
- CO_2 decreases ***because of*** natural sinks

RCP2.6 second half of 23rd century



- Human input: negative
- Natural input: positive
- CO_2 decreases ***despite*** natural sources

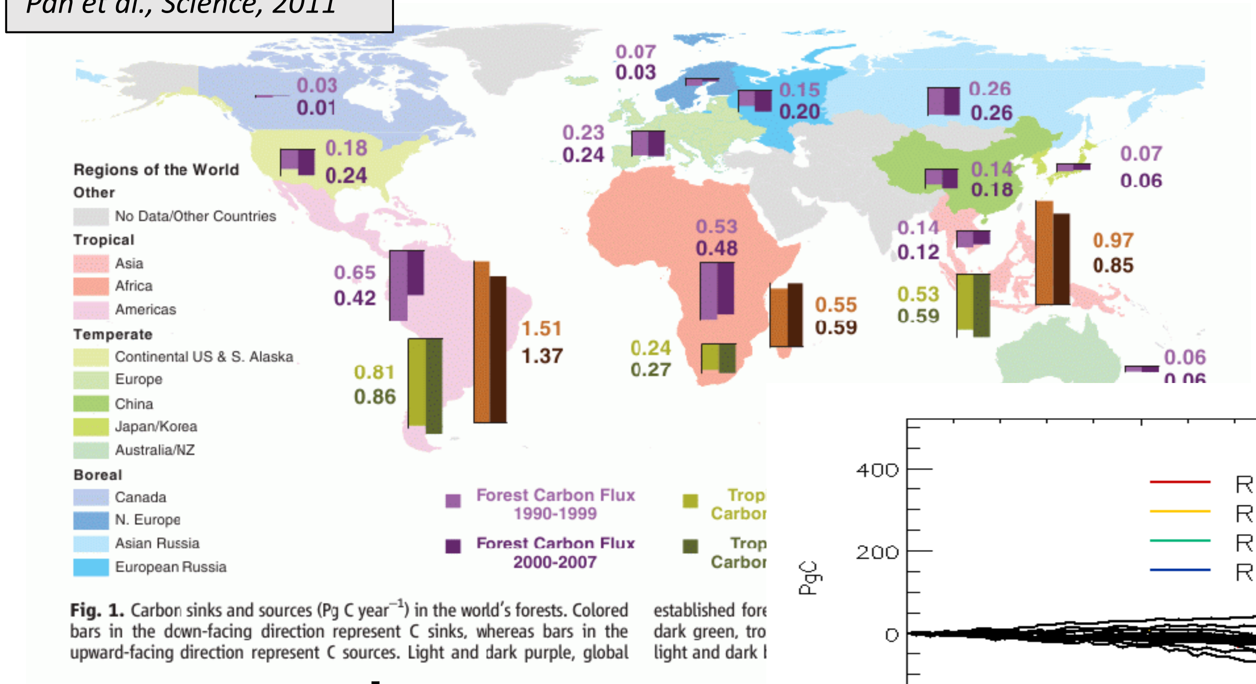
Jones et al., ERL, 2016

Modelling priorities:

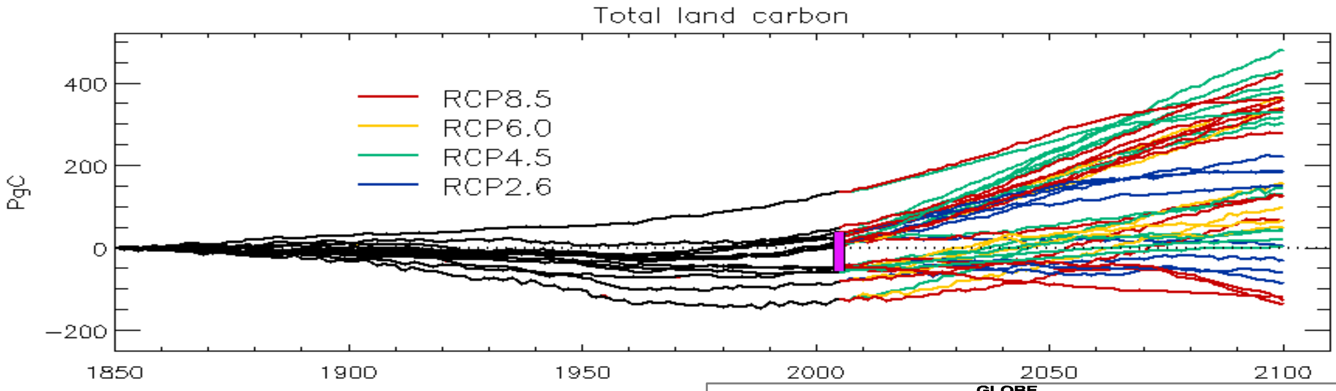
a word on fluxes vs stores

Are we actually making progress in the modelling?
Where do we need development and evaluation effort?

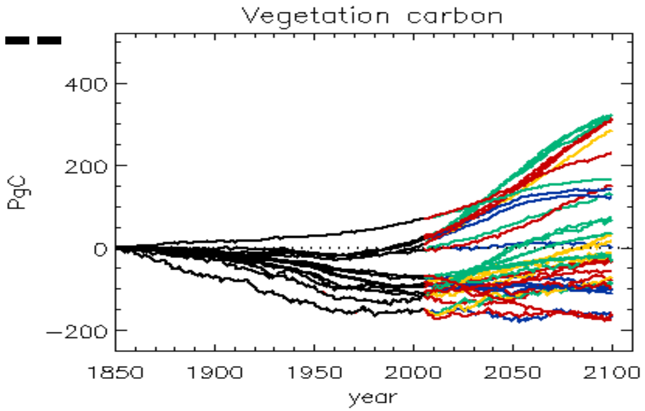
Pan et al., Science, 2011



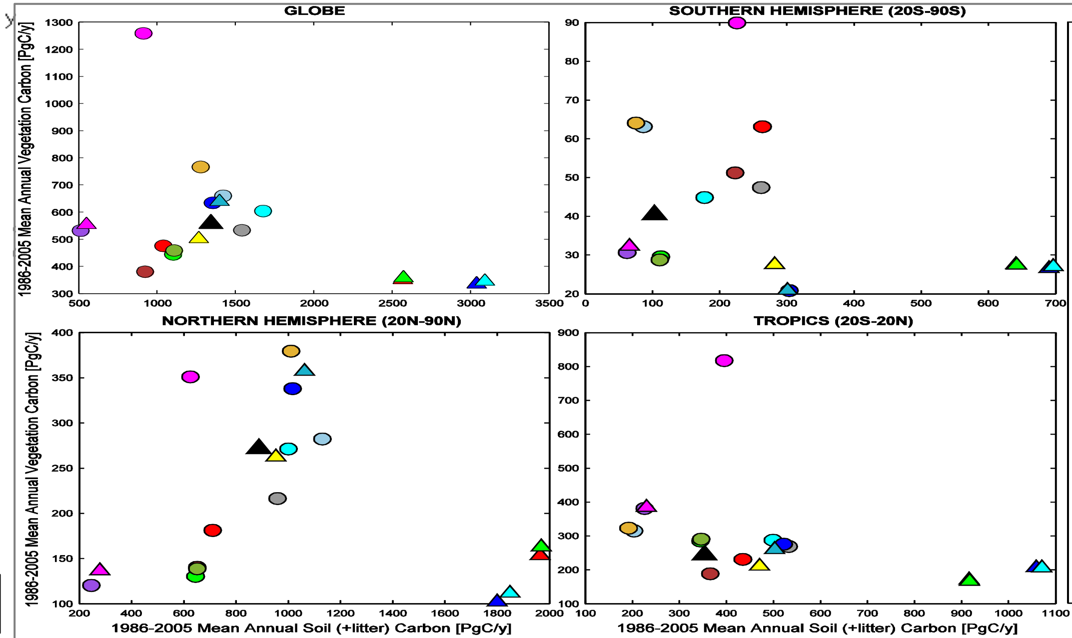
What we'd like…



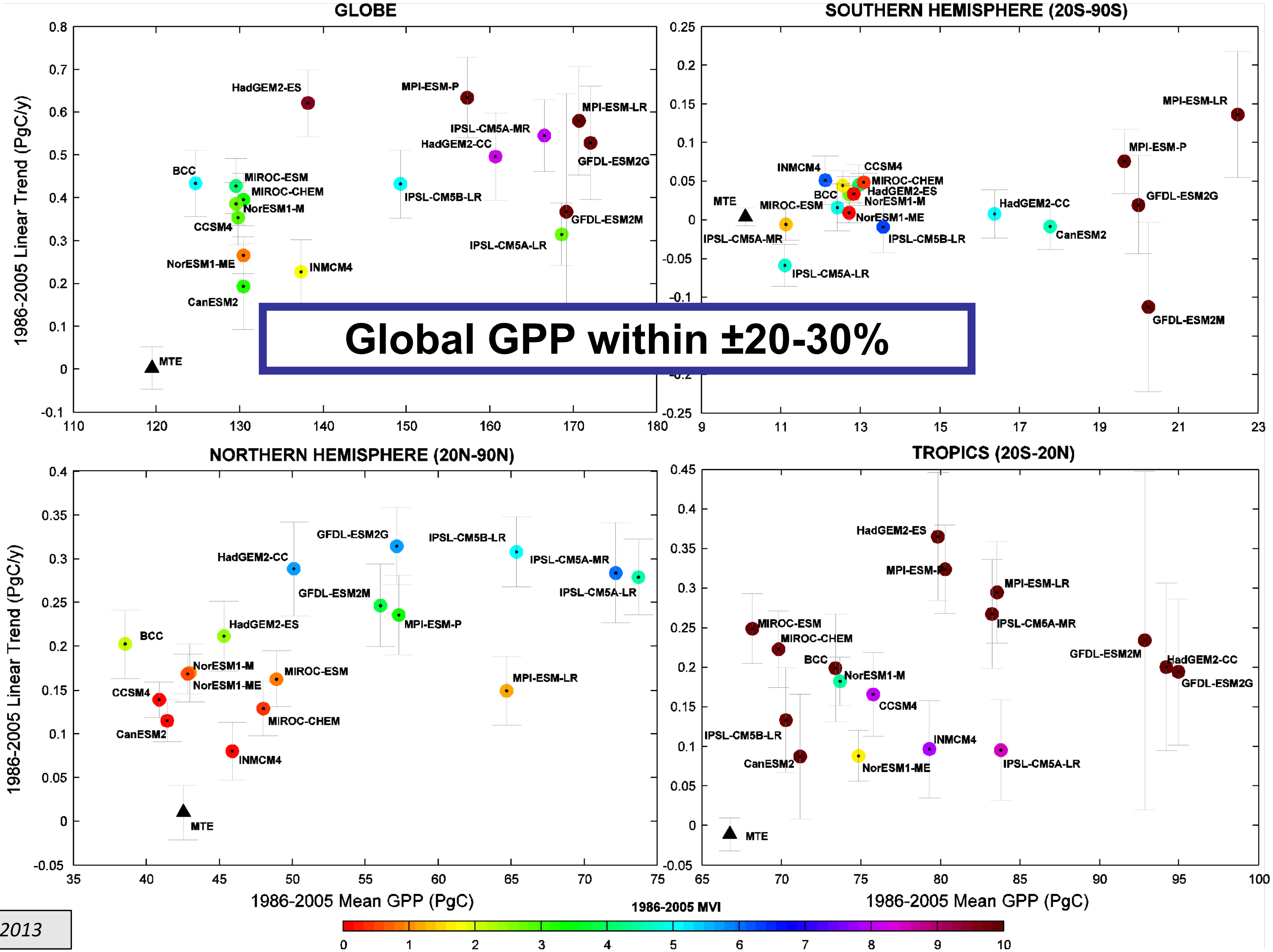
… what we've got



Jones et al., J. Clim., 2013

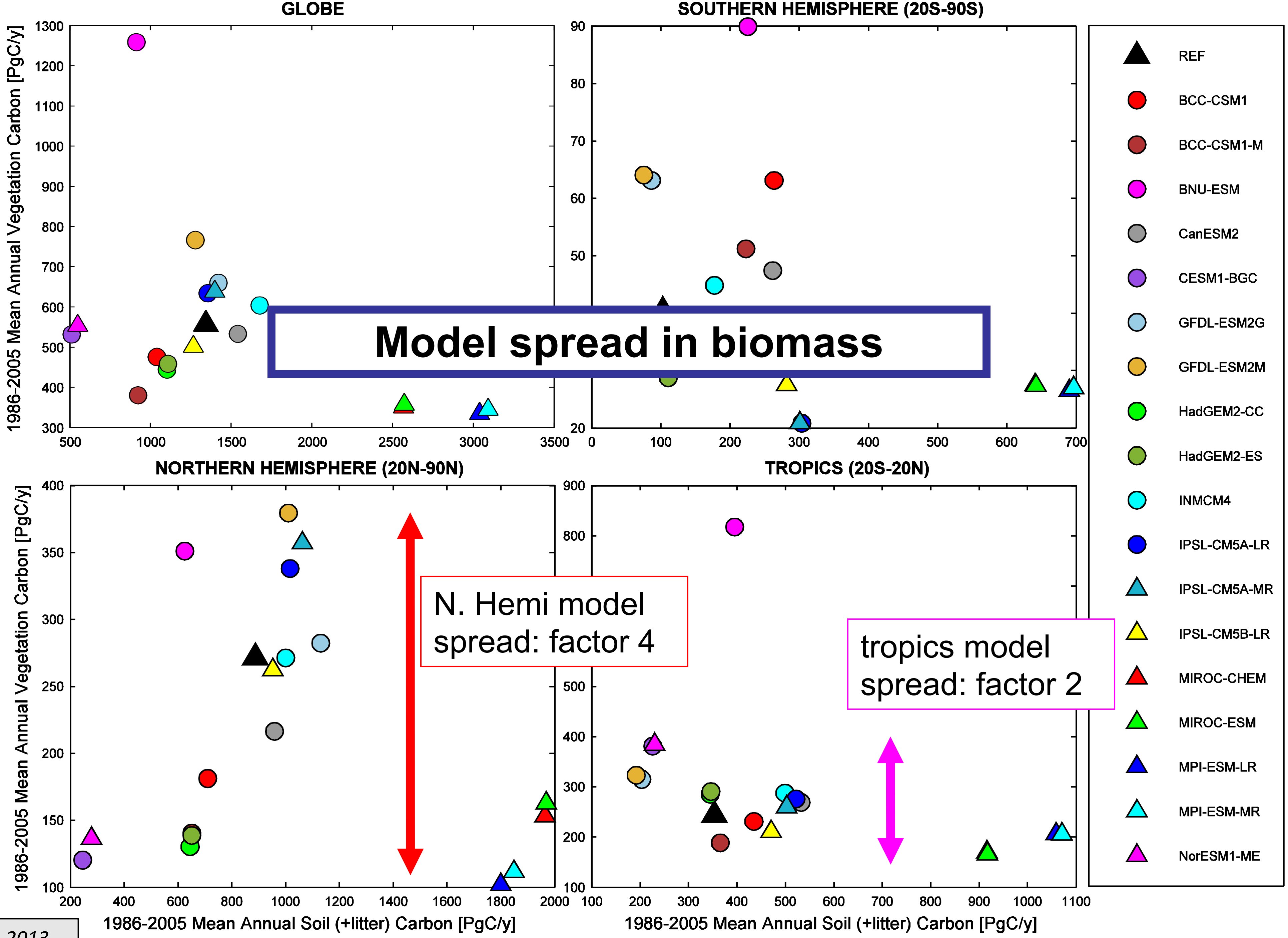


Anav et al., J. Clim., 2013



Global GPP within ±20-30%

Anav et al., J. Clim., 2013



Anav et al., J. Clim., 2013

Modelling priorities:

a word on fluxes vs stores

- Model evaluation must move beyond fluxes (flux towers are great, but not the whole story…)
- Residence time, carbon stores are what we care about
- “change in store” ≠ “integrated flux”?
    - different mindset

Met Office Hadley Centre

Concluding comments

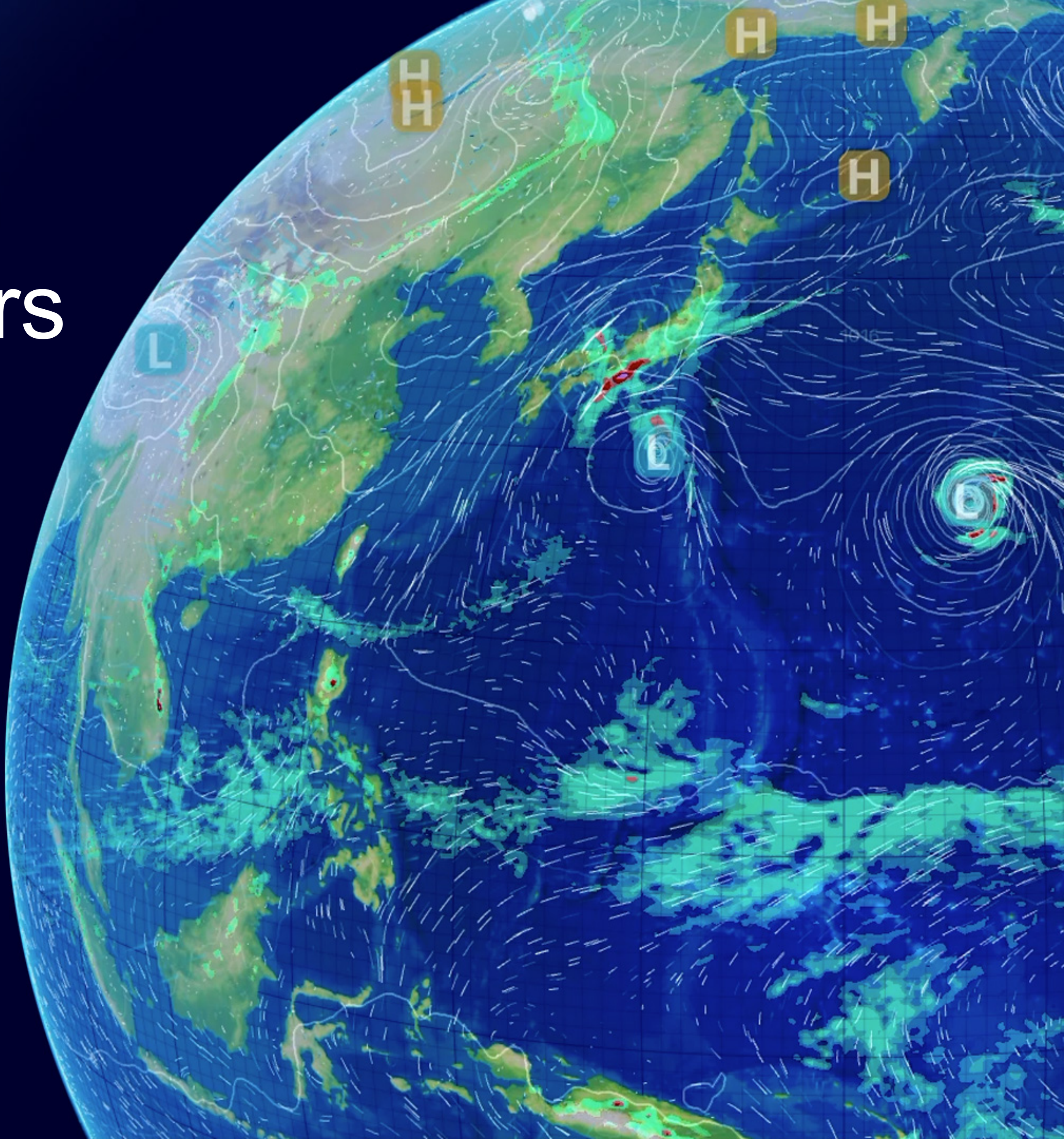
- The Carbon cycle is a Grand Challenge:

1. "Where does the carbon go?"
    - controlling question which determines carbon budgets
2. Natural climate solutions will rely on land-based mitigation
    - a crucial part of carbon dioxide removal
    - required for reaching net-zero
3. natural and anthropogenic sources and sinks interact
    - Need to *quantitatively* understand their dynamics and interplay
    - This requires Earth System Models

- Modelling needs care beyond fluxes
    - We care about the stores
    - … and how they respond to environmental changes

Met Office
Hadley Centre

Questions and Answers



references

- Anav et al., 2013, J. Clim, https://journals.ametsoc.org/view/journals/clim/26/18/jcli-d-12-00417.1.xml
- Bastin et al., 2019, Science, https://science.sciencemag.org/content/365/6448/76
- Jones et al., 2013, J. Clim, https://journals.ametsoc.org/view/journals/clim/26/13/jcli-d-12-00554.1.xml
- Jones et al., 2016, ERL, https://iopscience.iop.org/article/10.1088/1748-9326/11/9/095012
- Jones & Friedlingstein, 2020, ERL, https://iopscience.iop.org/article/10.1088/1748-9326/ab858a
- Marotzke et al., 2017, Nature Climate Change, https://www.nature.com/articles/nclimate3206
- Pan et al., 2011, Science, https://science.sciencemag.org/content/333/6045/988

- IPCC, AR5, WG1, SPM: http://www.climatechange2013.org/report/full-report/
- IPCC SR15, Ch.2: https://www.ipcc.ch/sr15/chapter/chapter-2/