Climate carbon feedback cycle uncertainty

Pierre Friedlingstein
University of Exeter, UK
Dave Schimel
Jet Propulsion Lab

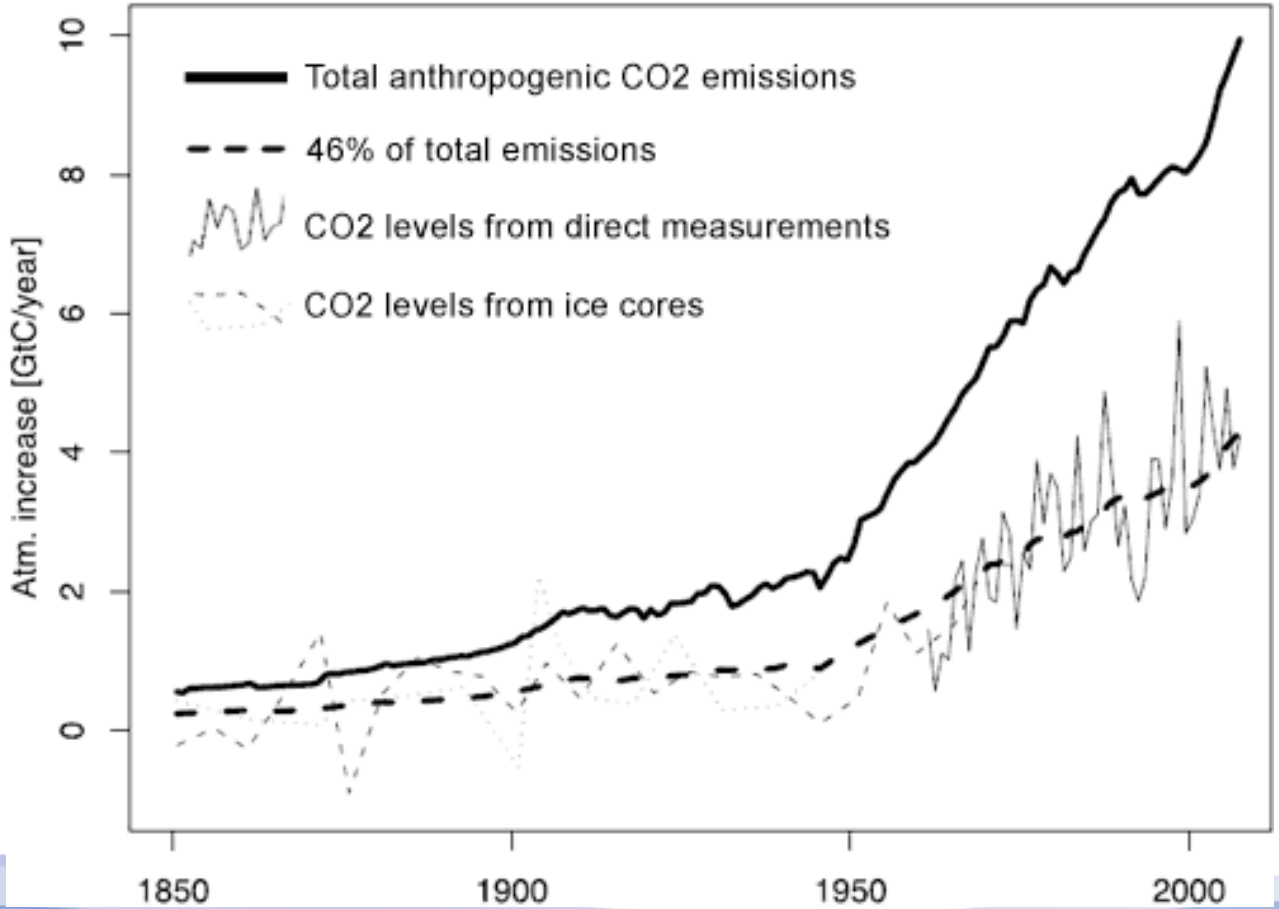
Carbon and climate

- ***The goal for this science area – the Carbon-Climate System - is to significantly improve our understanding of, and our ability to predict, the likely future trajectory of the atmospheric carbon fraction.***
- ***What we have: a sparse, exploratory framework.***
- ***What we need: a dense, robust and sustained system.***

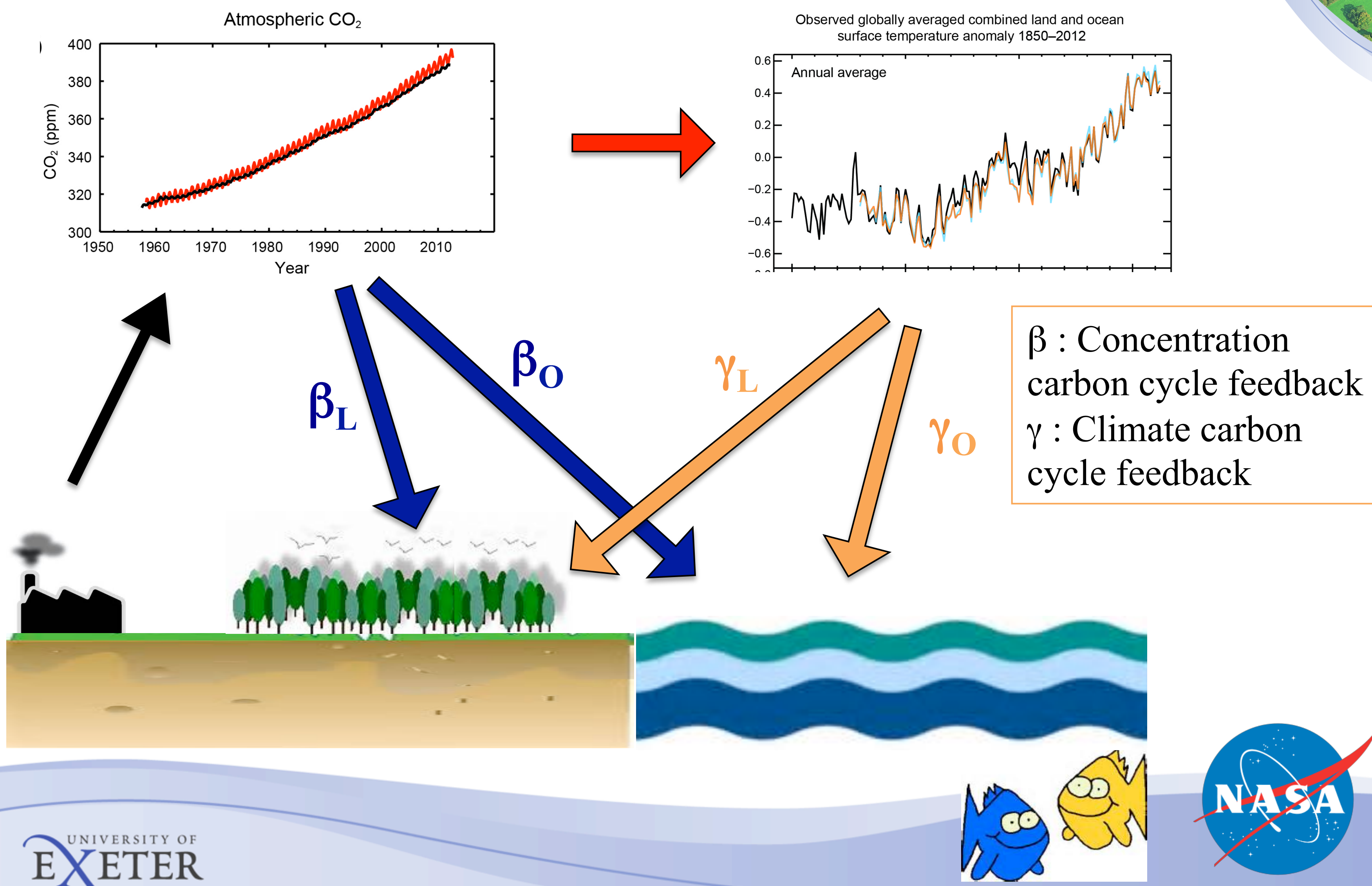
UNIVERSITY OF EXETER

NASA

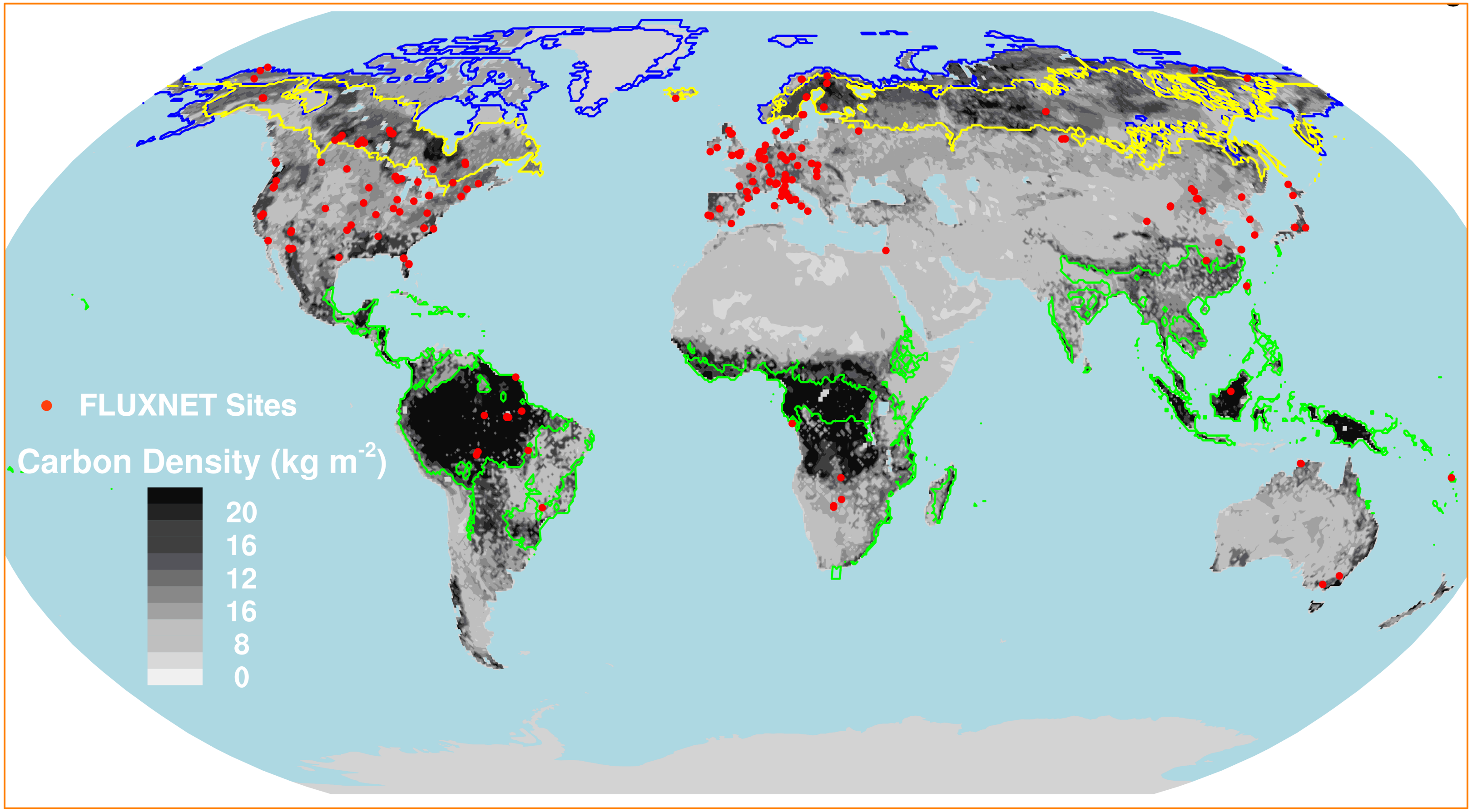
What is the carbon budget and where is the missing carbon going?



Carbon cycle feedbacks

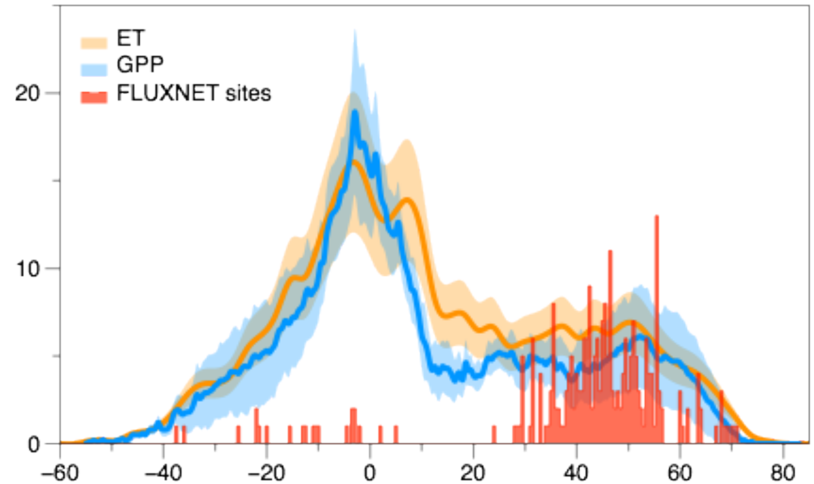


Our observing system is weakest where feedbacks are likely strongest

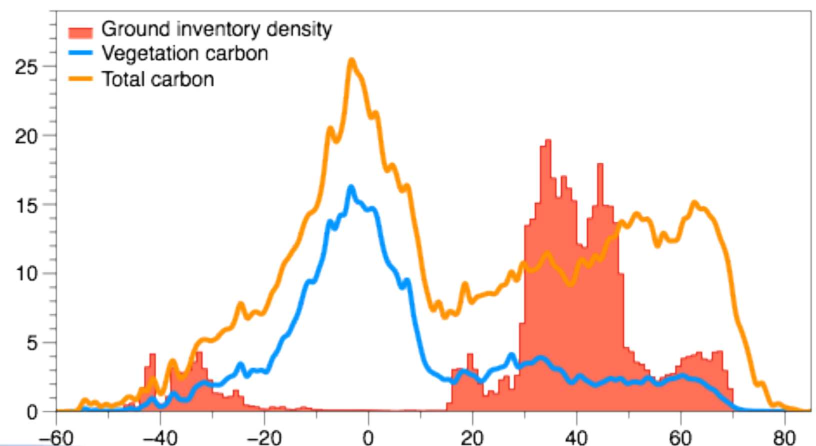


Remote sensing must focus on the critical regions

Stock and fluxes versus *in situ* observations

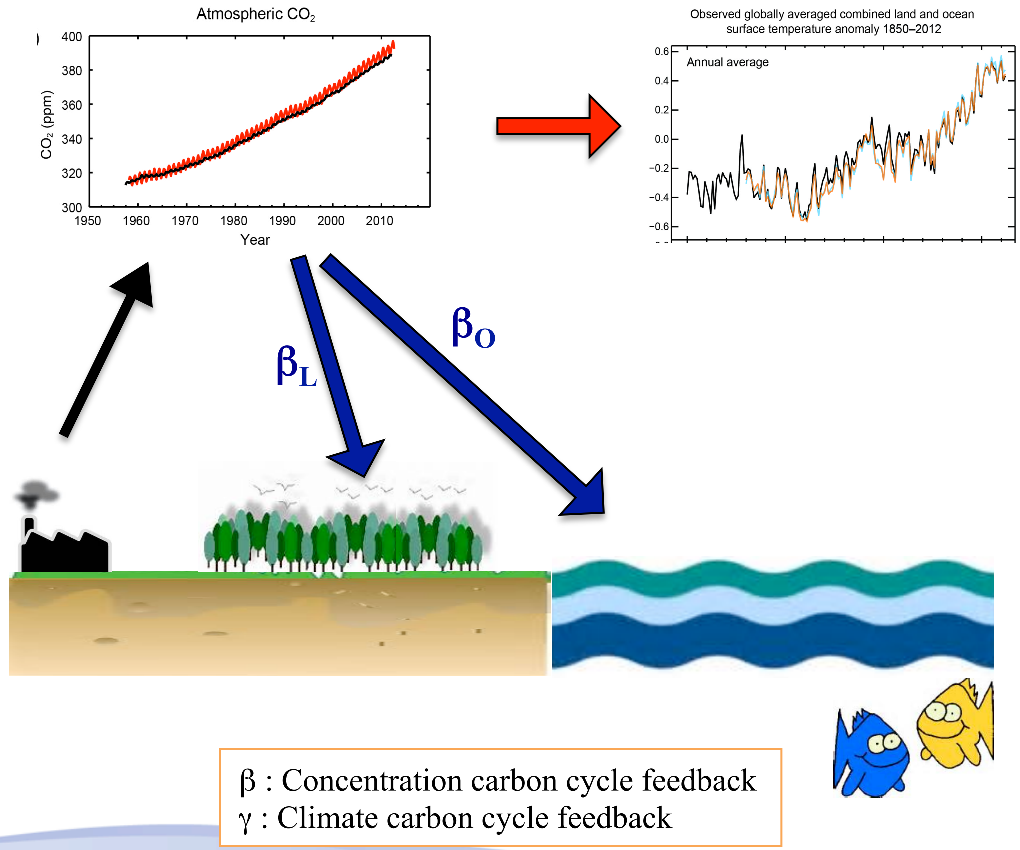


GPP and ET, compared to FLUXNET



Biomass and total carbon storage compared to forest inventory plots

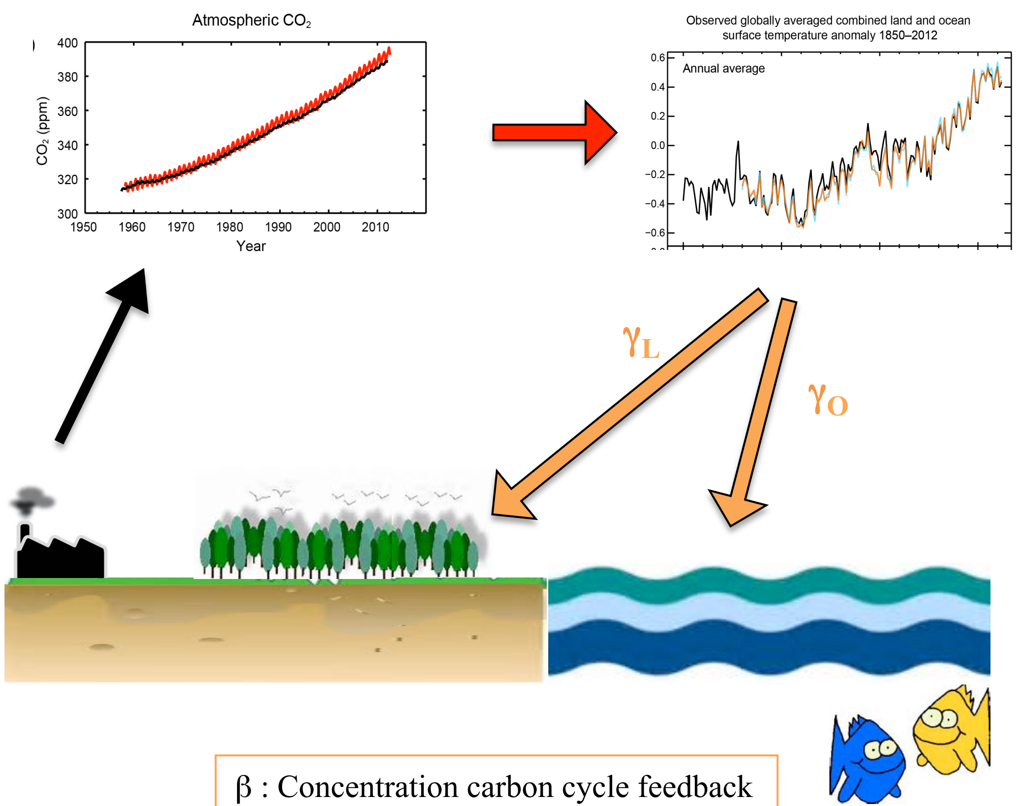
Carbon cycle feedbacks



Concentration carbon feedback

- Existence known for decades:
  - 60-70's for the ocean (Bolin, Oeschger, Siegenthaler,… ocean C box-diffusion models)
  - 80-90's for the land (Esser,Mooney, Melillo, Friedlingstein, … global land C models)
- Direct observations:
  - Ocean : YES(-ish)
  - Land: NO
- Processes understood
- Magnitude very uncertain (esp. land)

Carbon cycle feedbacks



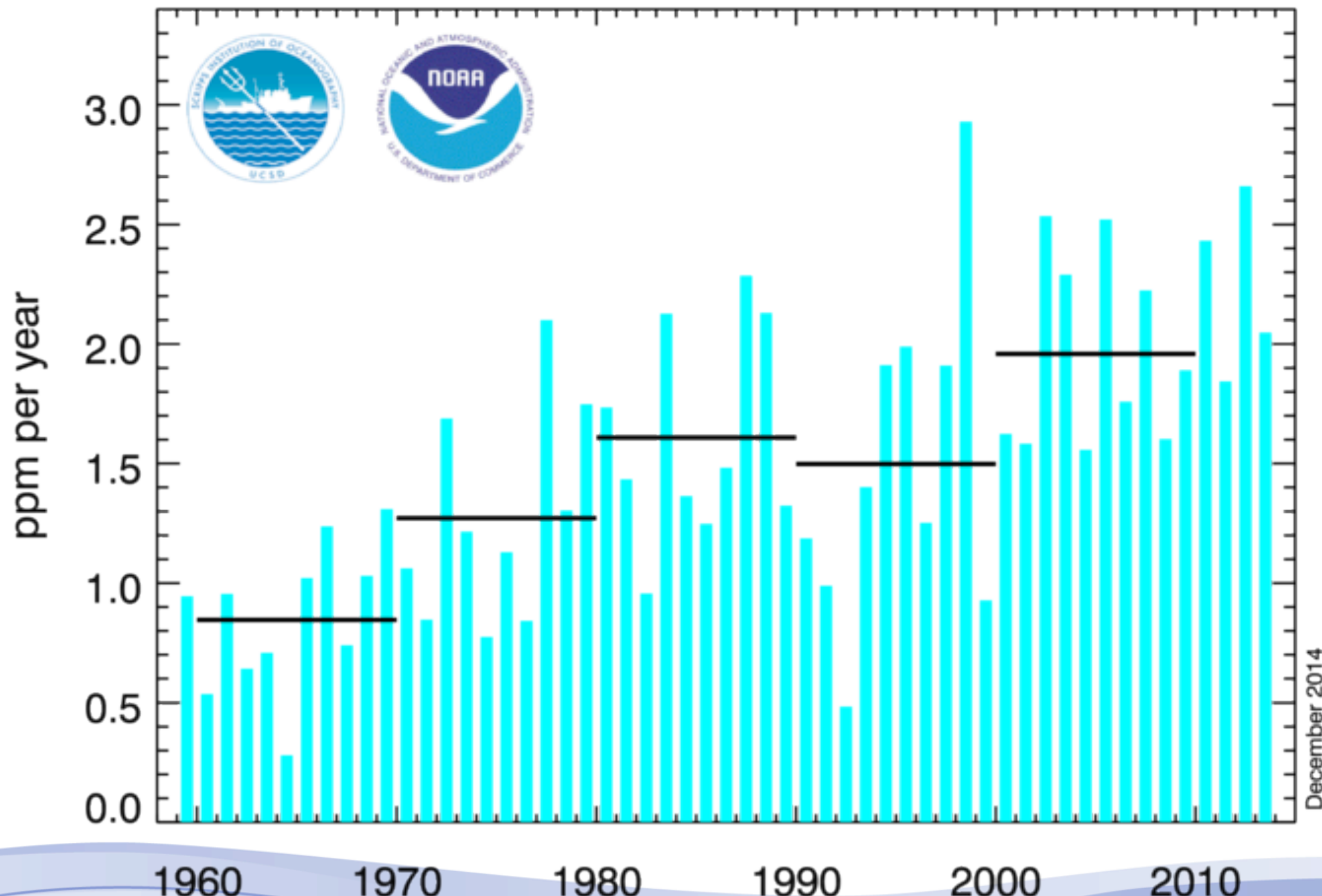
β : Concentration carbon cycle feedback
γ : Climate carbon cycle feedback

Climate carbon feedback

- Existence suspected for decades
  - Couple of early papers
  - Ice core data
- Rediscovered in the late 90s-2000's
- No direct observations
- Process understanding missing
- Magnitude very uncertain (esp. land)

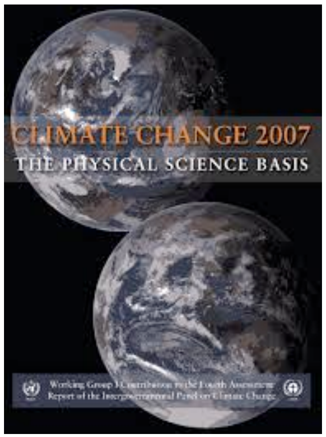
UNIVERSITY OF EXETER

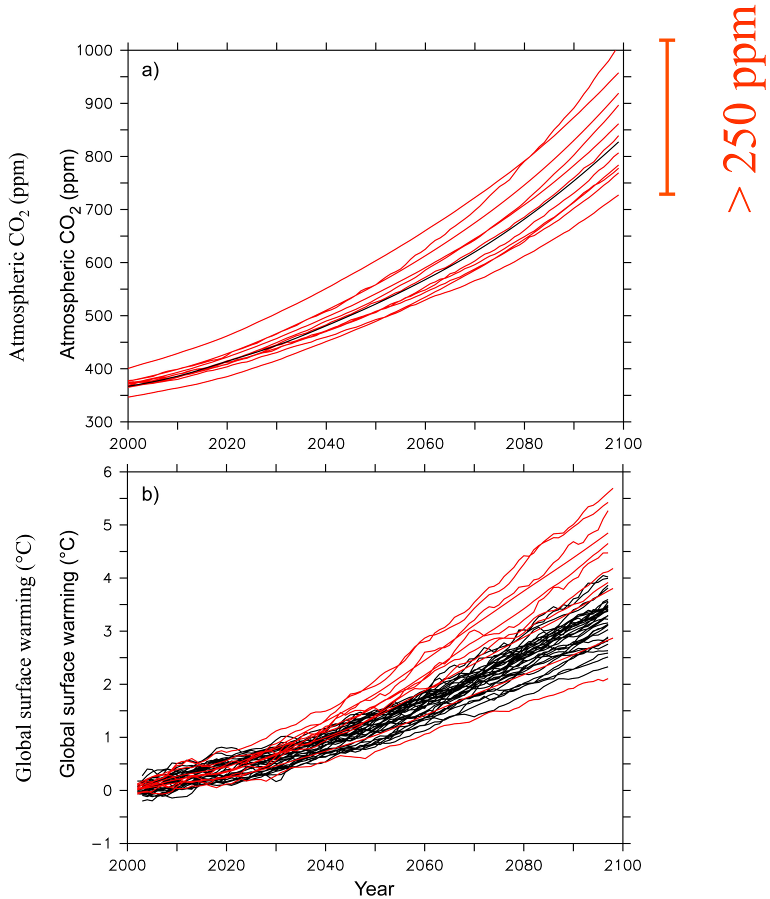
Climate -γ- effects from variability



Model uncertainty: at the time of IPCC AR4

IPCC AR4





CMIP3

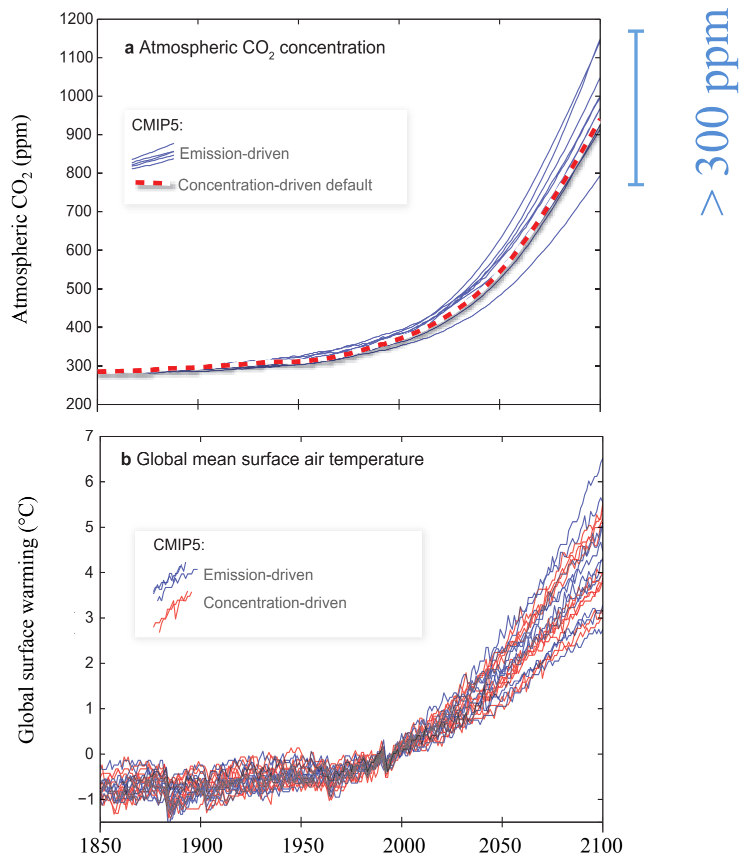
- More than 20 climate models (AOGCM)
- No ESMs
- 11 C^4MIP models, but not officially part of CMIP3

AR4 WG1 SPM: "Warming tends to reduce land and ocean uptake of atmospheric carbon dioxide, increasing the fraction of anthropogenic emissions that remains in the atmosphere."

IPCC, AR4, 2007

And in IPCC AR5

IPCC AR5



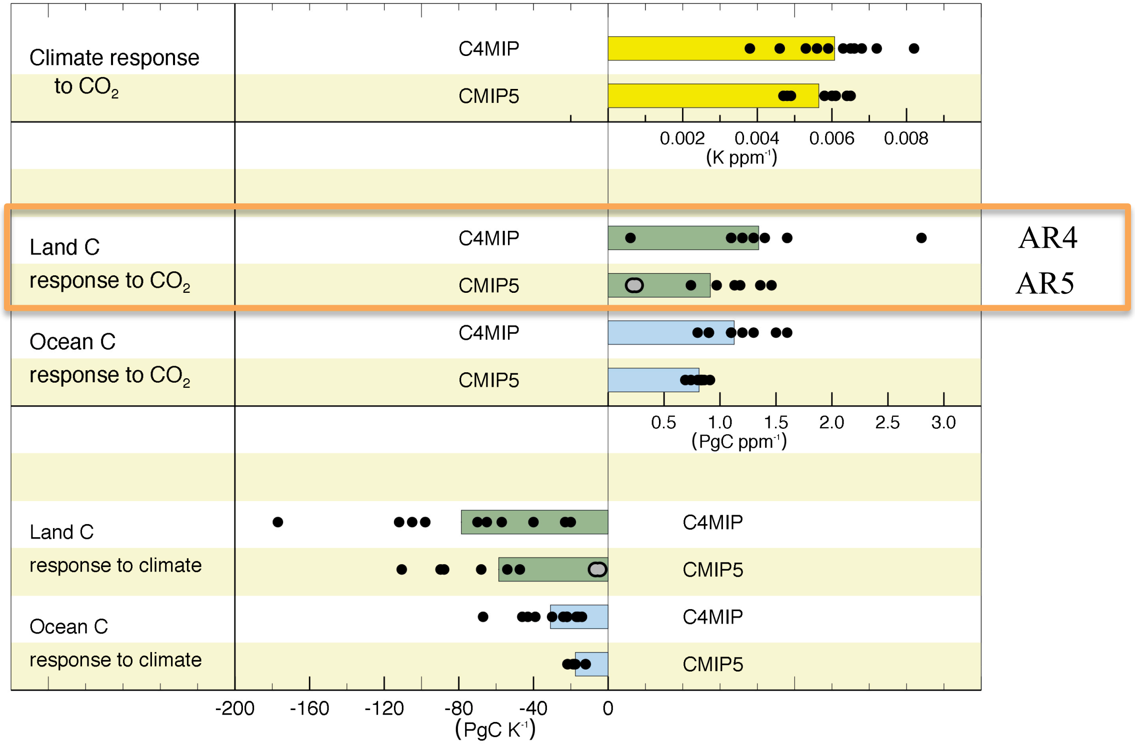
CMIP5

- More than 40 climate models (AOGCMs)
- 10 Earth System Models (ESMs)
- All part of CMIP5

AR5 WG1 SPM: “Based on Earth System Models, there is *high confidence* that the feedback between climate and the carbon cycle is positive in the 21st century; …”.

IPCC, AR5, 2013

However, uncertainty remains large

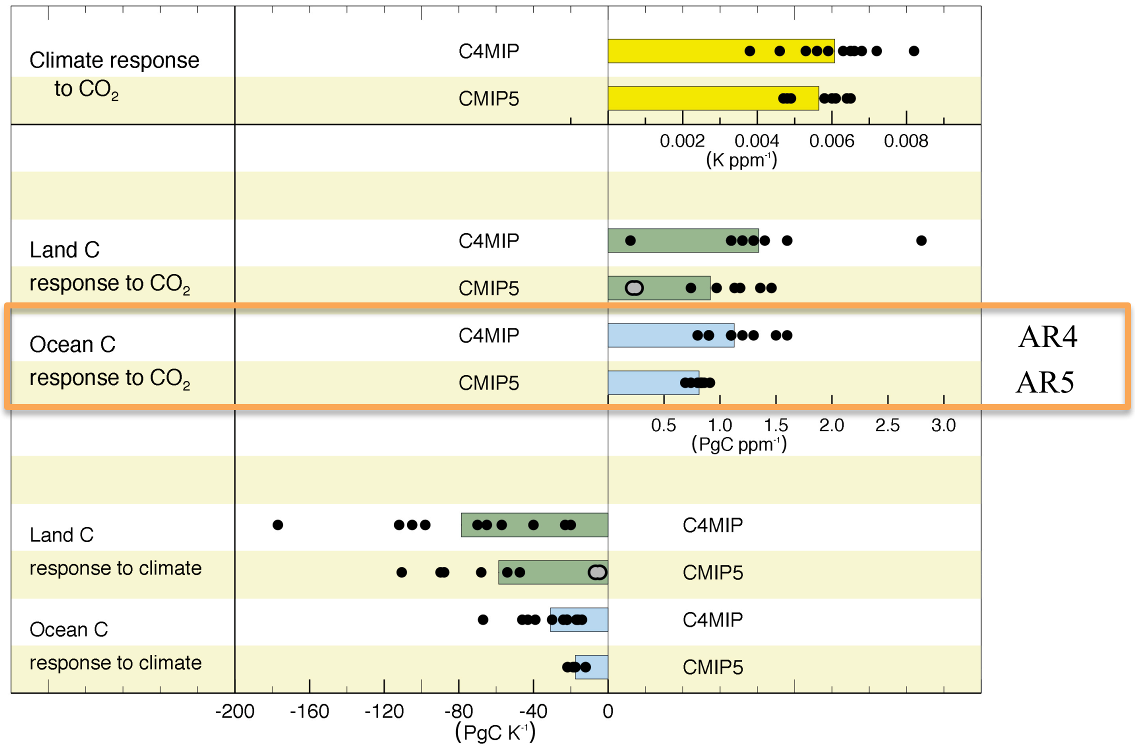


IPCC, AR5, 2013

β_L uncertainty

Moderate reduction (thanks to one model)

However, uncertainty remains large



IPCC, AR5, 2013

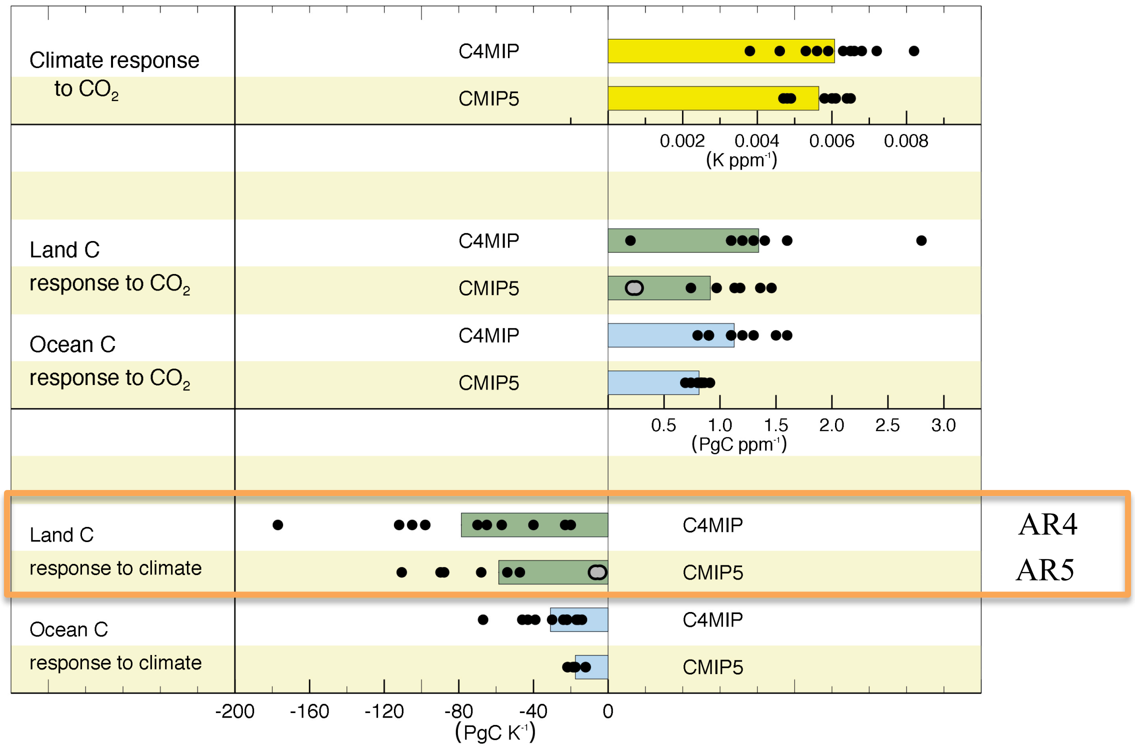
β_L uncertainty

Moderate reduction (thanks to one model)

β_O uncertainty

Large reduction

However, uncertainty remains large



IPCC, AR5, 2013

β_L uncertainty

Moderate reduction (thanks to one model)

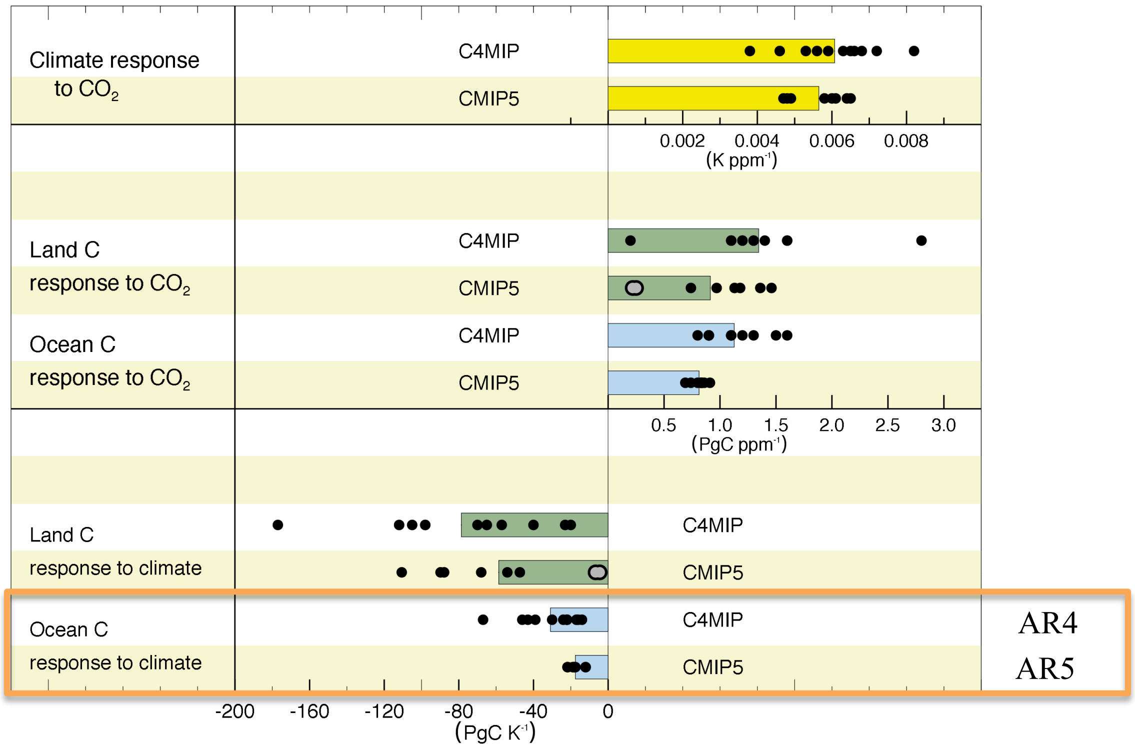
β_O uncertainty

Large reduction

γ_L uncertainty

Moderate reduction (thanks to one model)

However, uncertainty remains large



IPCC, AR5, 2013

β_L uncertainty

Moderate reduction (thanks to one model)

β_O uncertainty

Large reduction

γ_L uncertainty

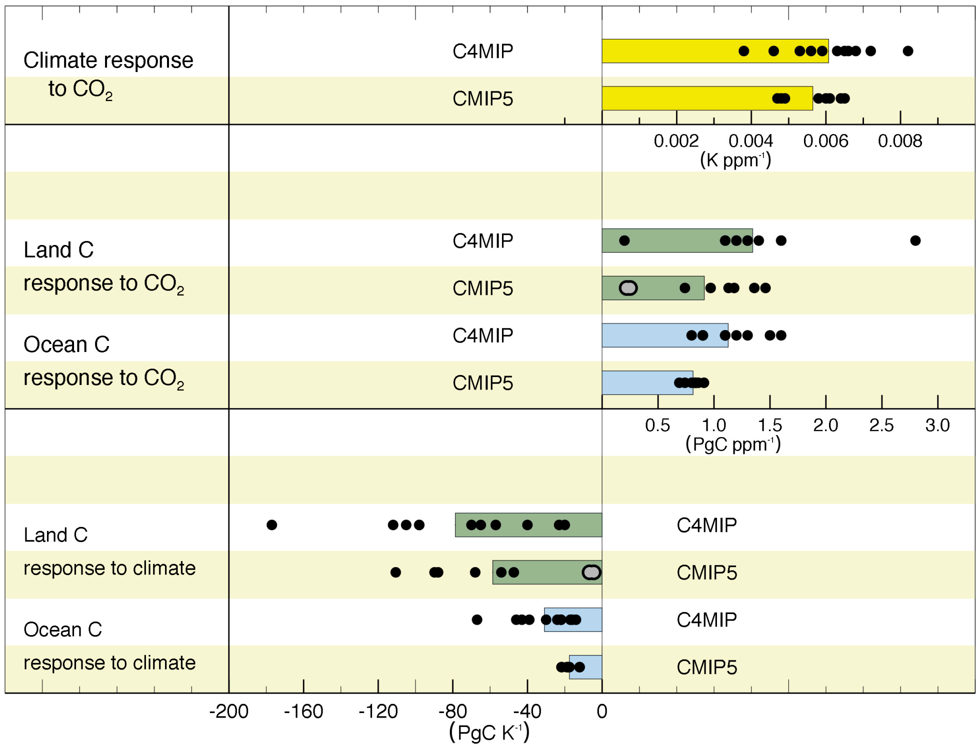
Moderate reduction (thanks to one model)

γ_O uncertainty

Large reduction

UNIVERSITY OF EXETER

However, uncertainty remains large



IPCC, AR5, 2013

Uncertainty in carbon cycle feedbacks is still quite large

Very modest improvements over the last 10-15 years

In particular for the land component, large uncertainty remains (factor of 10 !)

The ocean is in a much better shape…

UNIVERSITY OF EXETER

Observational constraints

1. There are **no** direct observations of climate carbon cycle feedbacks
2. Ice-core data can inform on the climate – [CO_2] relationship. Last millennium data gives a sensitivity of about 7ppm/K (Frank et al. 2010)
3. Emerging constraints are promising tool, [CO_2] inter-annual variability gives a constraints on the tropical land carbon sensitivity to climate (γ_L): about -50GtC/K (Cox et al., 2013, Wenzel et al., 2014)
4. None of the above is absolutely certain (quite a few assumptions along the way)
5. None of the above explains **what process** is actually responsible for the land climate-carbon cycle feedback
6. None of the above gives much information on the **spatial distribution** of the feedback: the ice-core data provides a global estimate (land plus ocean), the inter-annual variability-so far- provides a constraint on tropical land only.

UNIVERSITY OF EXETER

The observing system

- What we have: *a sparse, exploratory framework*[1].
- What we need: *a dense, robust, and sustained system*.
- What OCO-2 gives us: *a denser, more robust and potentially sustainable atmospheric observing system*.

(1: Ciais et al 2014).

Could current monitoring network help reducing uncertainty on land feedbacks?

Site level data (eg. fluxnet)

- Great for understanding physiological to ecosystem-level processes.
- Far from ideal for estimate of mean carbon sink, even less for change in sink strength (non trivial C-budget closure),
- Not representative of global land (non trivial upscaling): systematic undersampling of crtical regions

No hope of being use to constraint carbon cycle feedbacks

Could current monitoring network help reducing uncertainty on land feedbacks?

Atmospheric CO_2 (eg. NOAA/ESRL)

- Great to estimate of land/ocean carbon sink partitioning at the global to continental scale
- Great to understand link between climate variability and carbon cycle
- Spatial coverage is still very sparse, inducing large uncertainty on sinks estimate. Far from ideal for estimate of change in sink strength

No hope of being a strong constraint over carbon cycle feedbacks

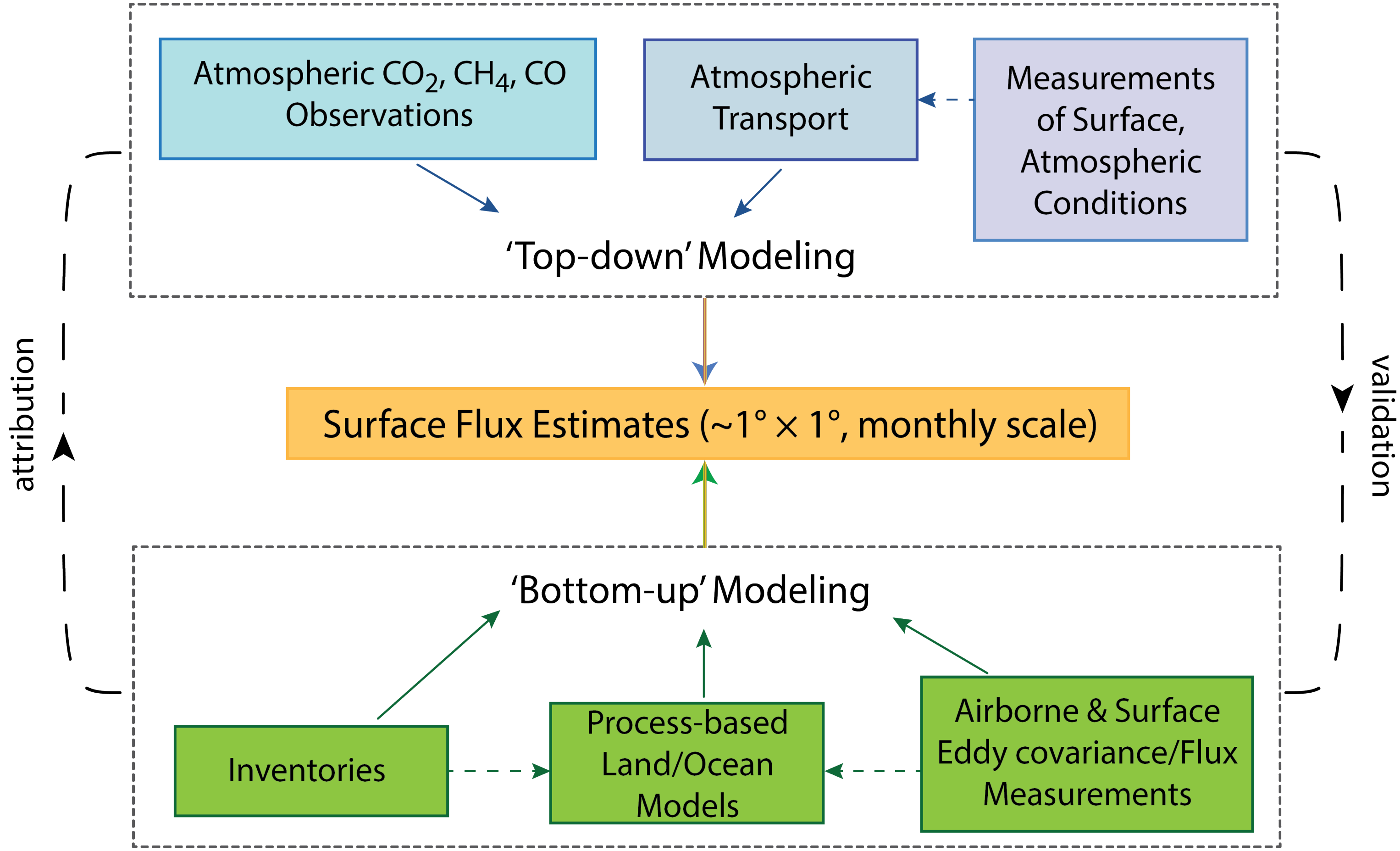
Way ahead …

CO_2 from space

- Potentially quite dense spatial and temporal coverage.
- Relatively long time-series (>10 years) required
- Need to run Earth System models, producing concentration fields,
- Use Detection & Attribution techniques to attribute changes in CO_2 growth rate to climate-carbon cycle feedbacks.

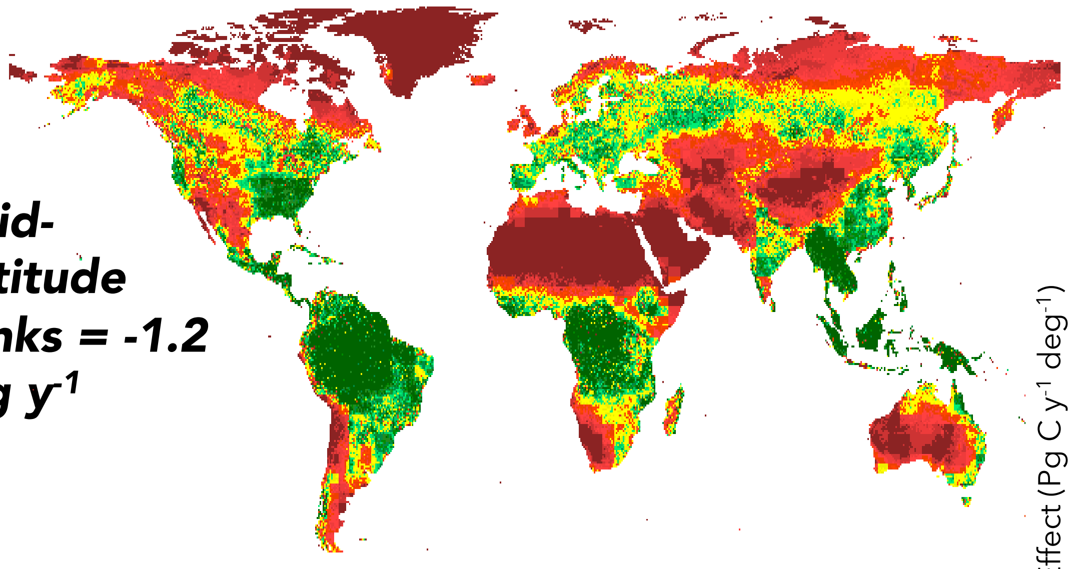
Clear potential to constrain carbon cycle feedback uncetainty

Way forward-schematic

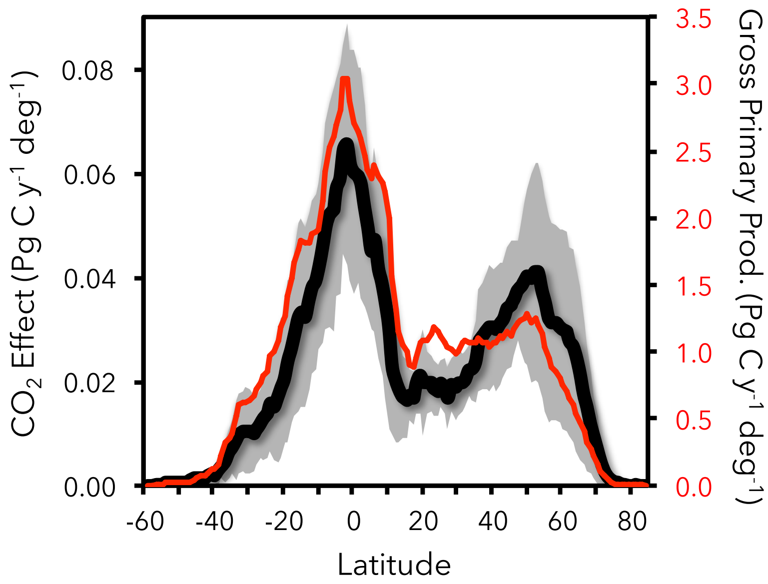


Land CO_2 effect - β_L

Mid-latitude sinks = -1.2 Pg y^{-1}



Tropical sinks = -3 Pg y^{-1}

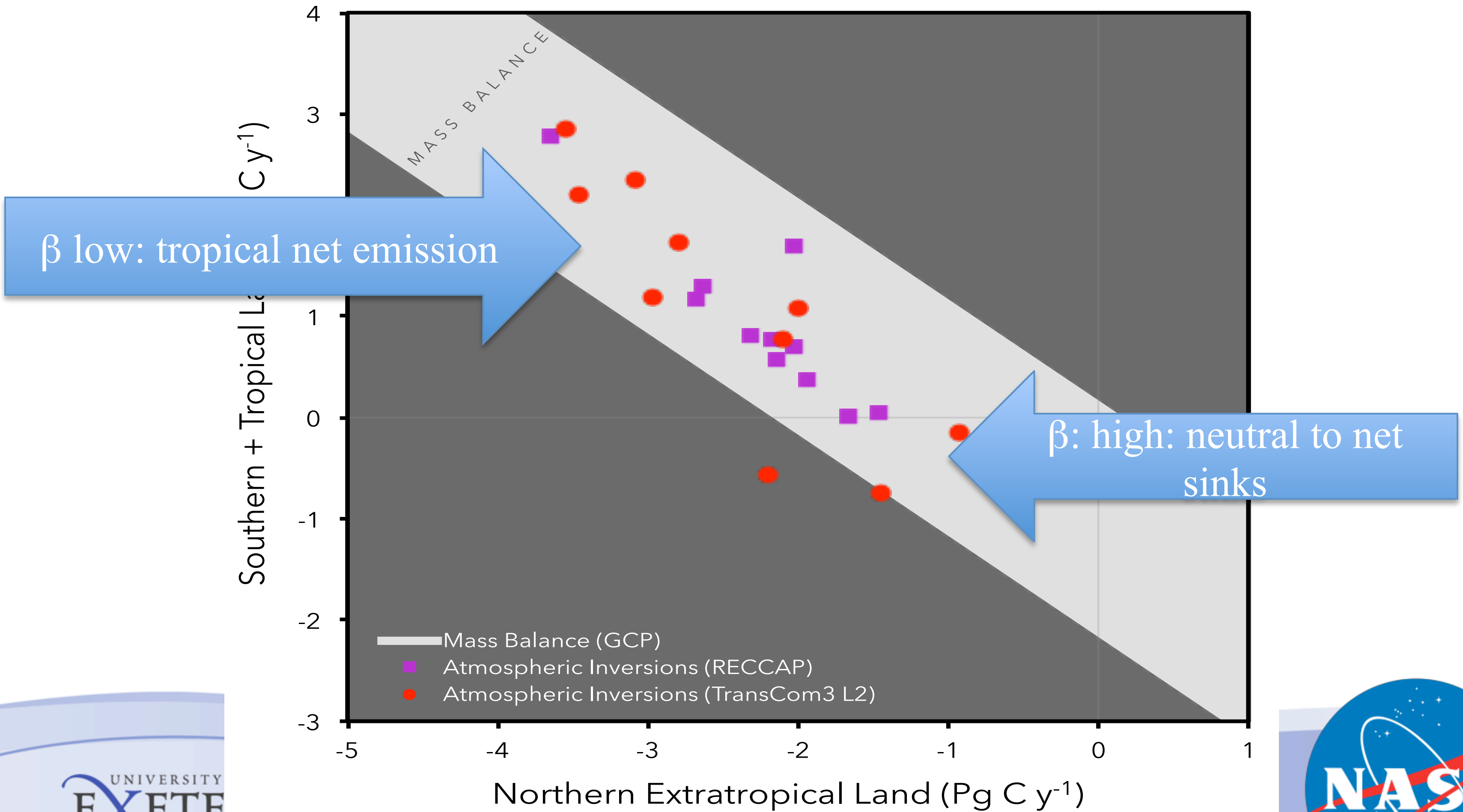


Modeled CO_2 effect
(Friedlingstein et al 1995)

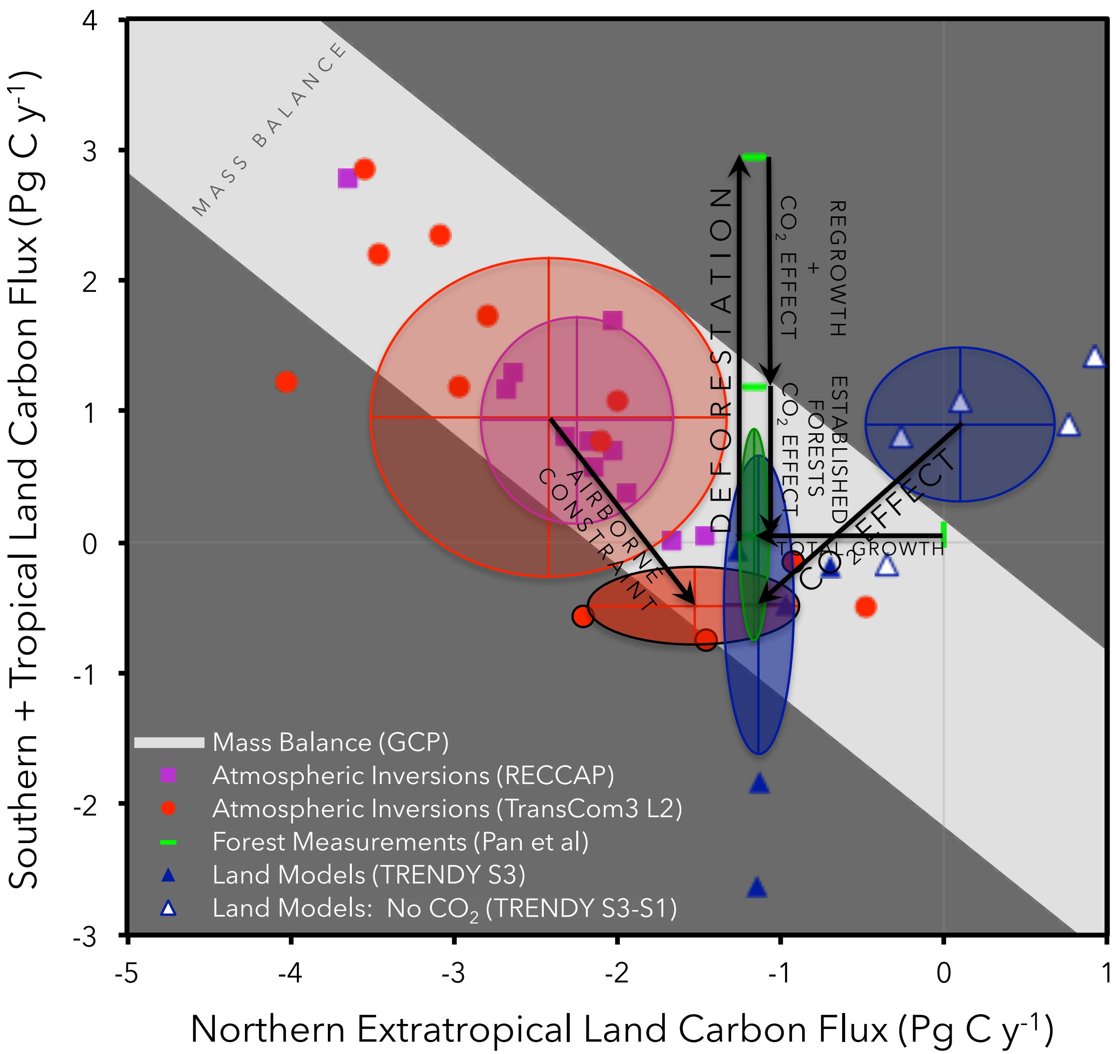
UNIVERSITY OF EXETER

NASA

Hypothesis testing for β



Combining data suggests and strong tropical uptake and a significant β

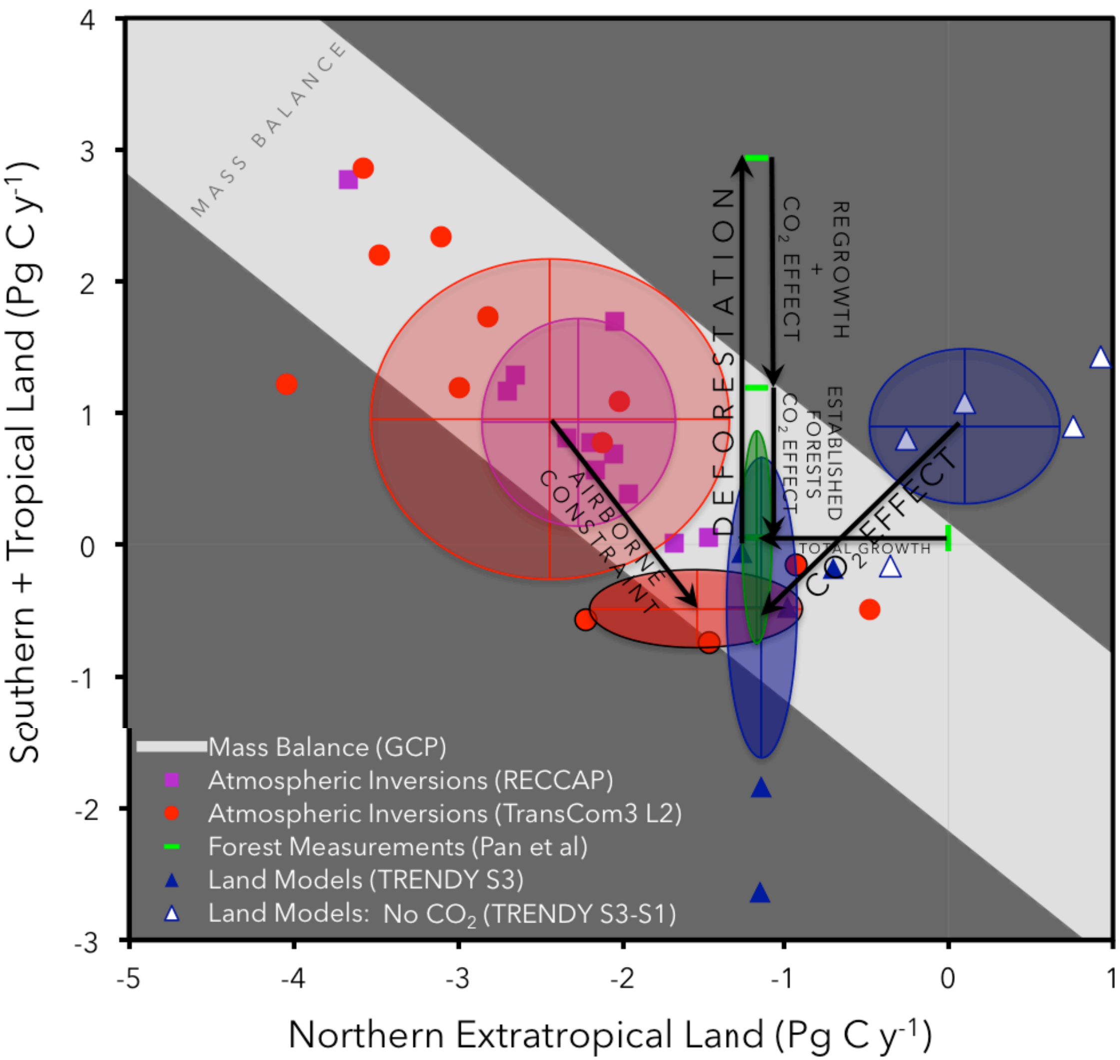


Can the remaining uncertainty be reduced by satellite data?

The top-down constraint is critical because the annual local signal of the CO_2 effect is 1/100 of average local NPP.

EXETER

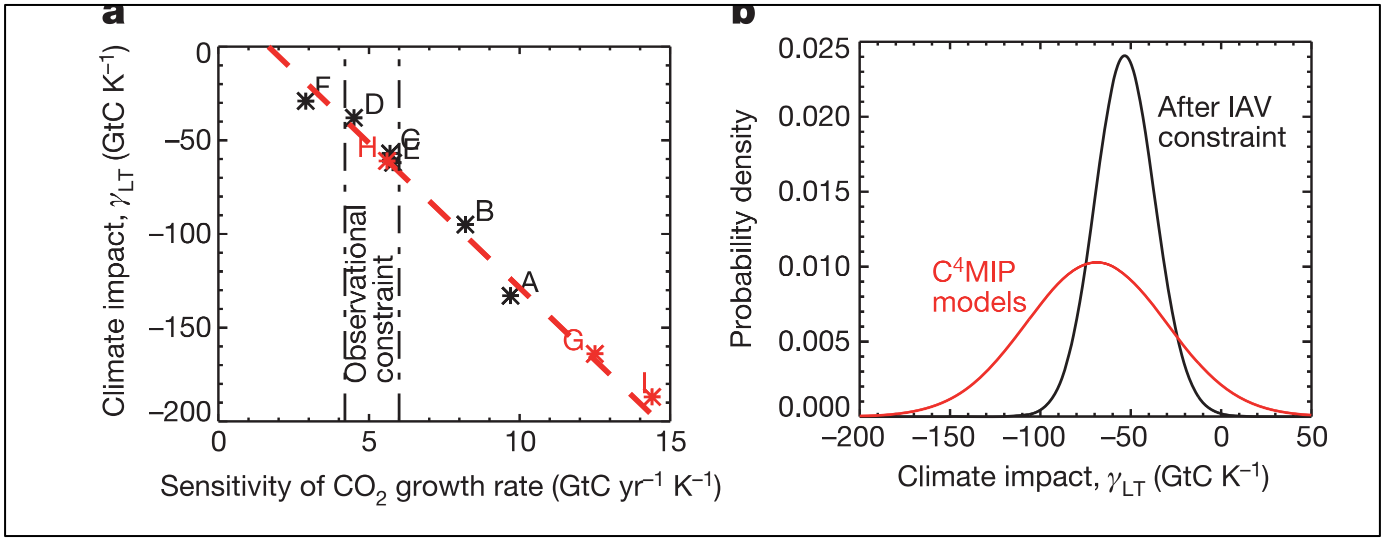
NASA



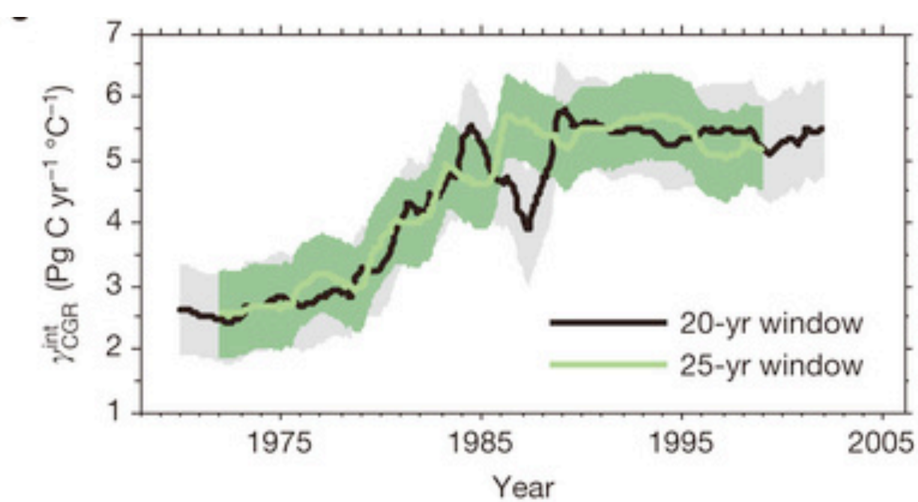
[redacted]

Schimel, D., Stephens, B.B., Fisher, J.B., in press. Effect of increasing CO_2 on the terrestrial carbon cycle. *Proceedings of the National Academy of Sciences, USA.*

Climate: estimates of carbon cycle sensitivity from tropical variability



Global growth rate anomalies and temperature provide a short term correlate and constrain on long term model sensitivity.



Estimated sensitivity changes over time

Regional carbon-climate sensitivity

Total flux tendency 2011-2010 for each region.

The sensitivity of total flux tendency to the temperature tendency