Global Carbon Cycle – Climate Feedbacks

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Recent, On-Orbit + Near-Term JPL Earth Science Space Missions

- OCO-2/3 (Carbon fluxes)
- SMAP (Soil moisture)
- SWOT (Streamflow)
- AIRS (Temperature/water vapor profiles)
- MISR (Aerosols, surface BRDF)
- MAIA (Aerosols, urban, particulates)
- EMIT (Soil minerology, canopy nitrogen, lignin, snow albedo, wind erosion, CH_4 point sources)
- ECOSTRESS (Evapotranspiration)
- PREFIRE (Polar energy balance)
- NISAR (Forest biomass)
- Cloudsat/Calipso (Clouds and aerosols)

CC&E at JPL
~25 Core Staff in 3+ Groups

- Three main science focus areas:
  - Carbon-Climate Feedbacks (β and γ)
  - Human Infrastructure in the Earth System
  - Biodiversity, Functional Diversity and Ecosystem Function
- Geographic foci on high storage-high flux regions
  - Northern High Latitudes-Arctic Boreal Zone
  - Tropical Wet Forest and Semi-arid Systems
  - Southern ocean
- Methodologies
  - Remote sensing
  - Airborne science and field studies
  - Process modeling
  - Data assimilation, data science, data fusion

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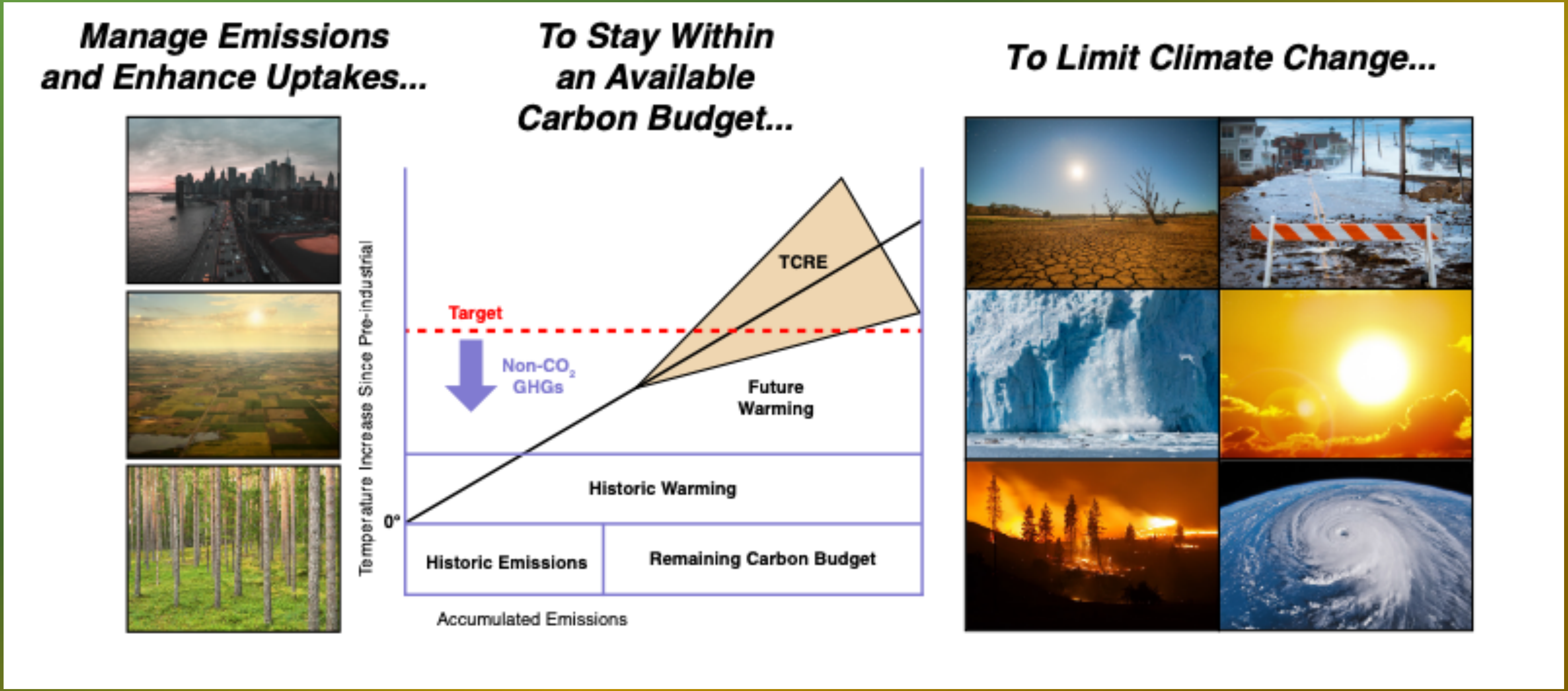
What is it that we're trying to do in managing the carbon cycle?



I started my career in soil carbon studies

Published September, 1987

DIVISION S-3—SOIL MICROBIOLOGY AND BIOCHEMISTRY

Analysis of Factors Controlling Soil Organic Matter Levels in Great Plains Grasslands[1]

W. J. PARTON, D. S. SCHIMEL, C. V. COLE, AND D. S. OJIMA[2]

DAYCENT and its land surface submodel: description and testing

William J. Parton [a,*], Melannie Hartman [a], Dennis Ojima [a], David Schimel [b]

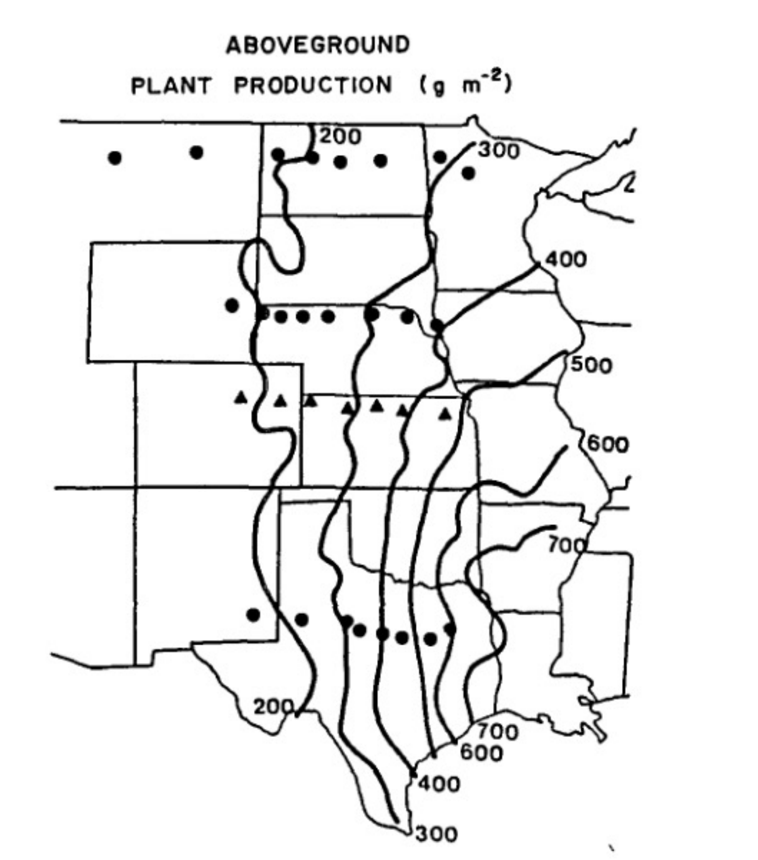
[a] *Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, USA*
[b] *Climate and Global Dynamics Division, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80303, USA*

Received 20 September 1997; accepted 9 February 1998

Global Biogeochemical Cycles®

Climatic, edaphic, and biotic controls over storage and turnover of carbon in soils

David S. Schimel, B. H. Braswell, Elisabeth A. Holland, Rebecca McKeown, D. S. Ojima, Thomas H. Painter, William J. Parton, Alan R. Townsend



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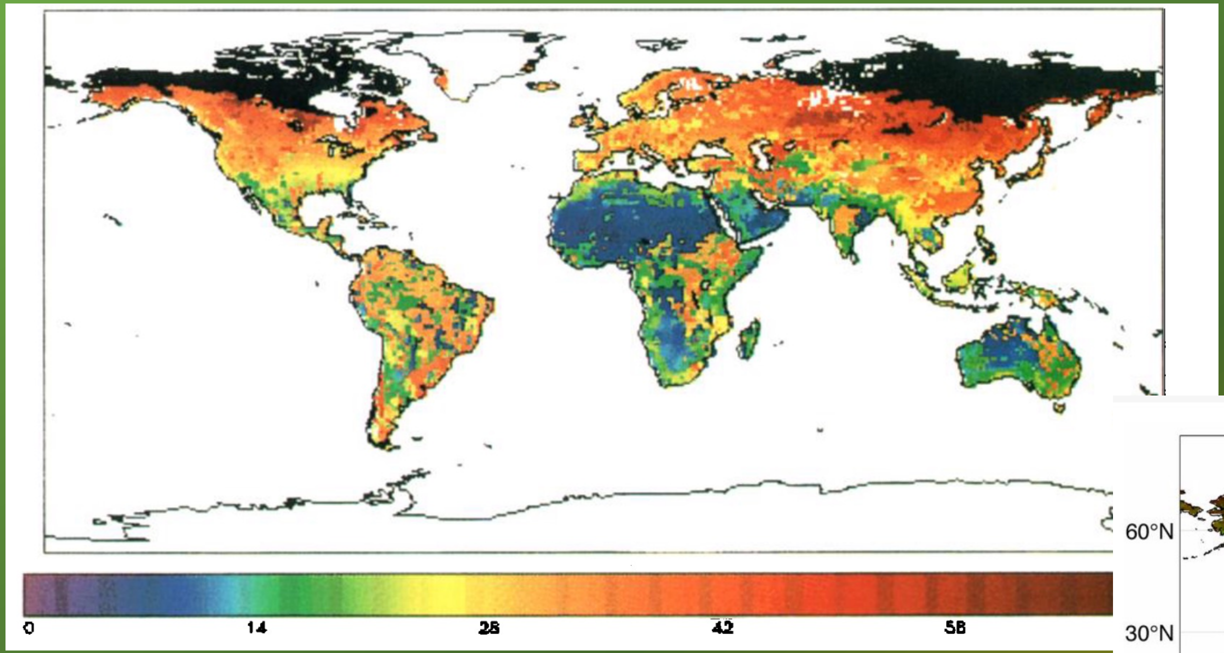
Soil Carbon: Global Perspective

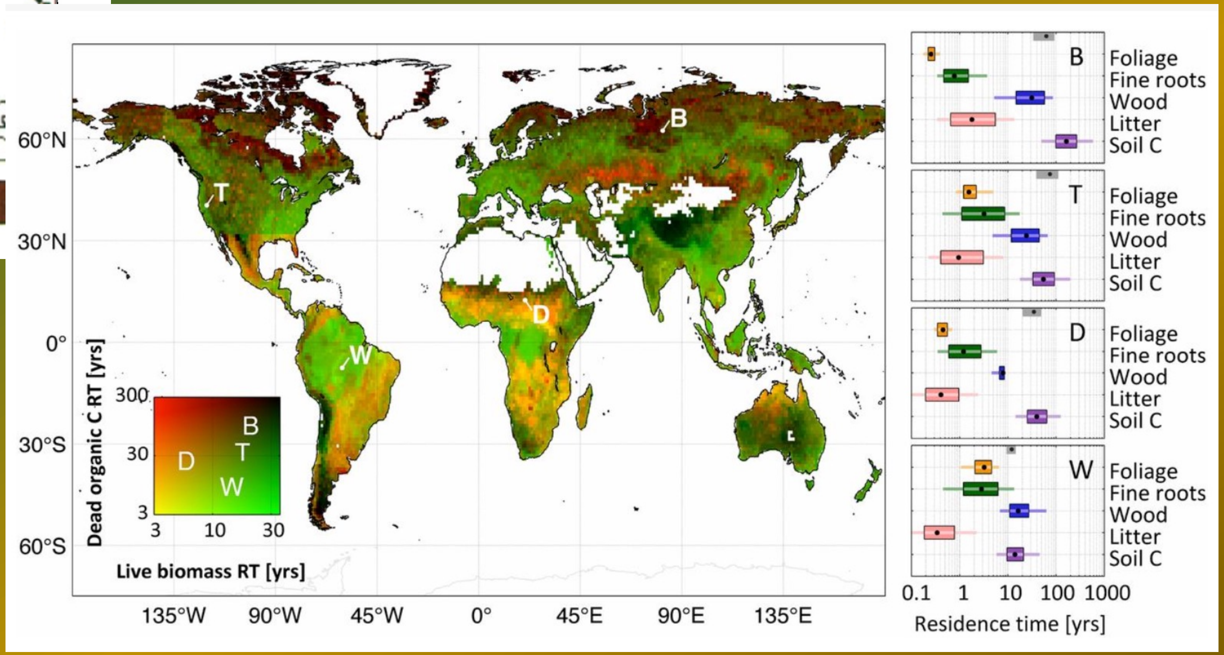
I was the global guy in the Century group



Modeled τ ca 1996

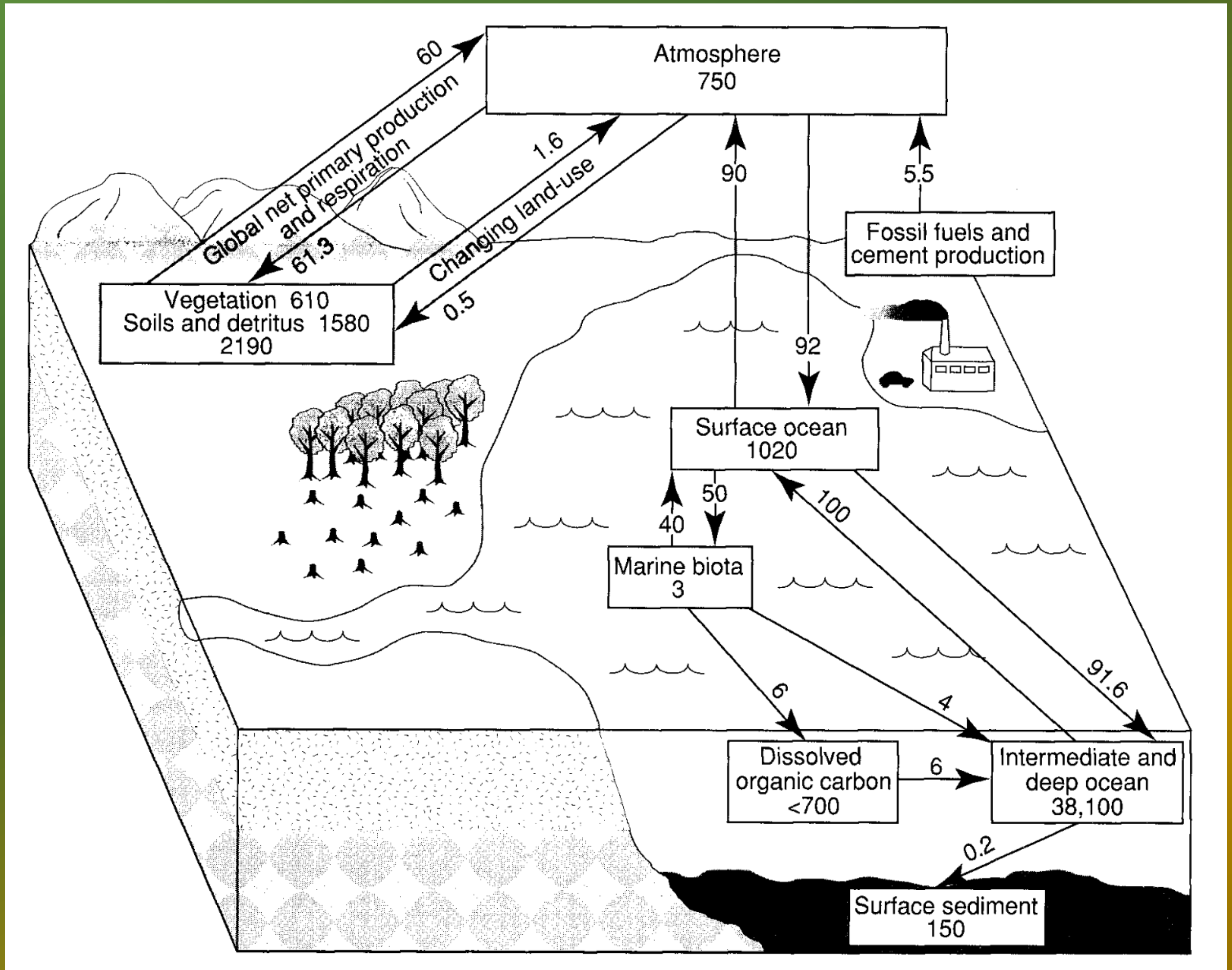
Schimel DS, Braswell BH, et al. Climatic, edaphic, and biotic controls over storage and turnover of carbon in soils. Global biogeochemical cycles. 1994 Sep;8(3):279-93.

Modeled τ ca 2020



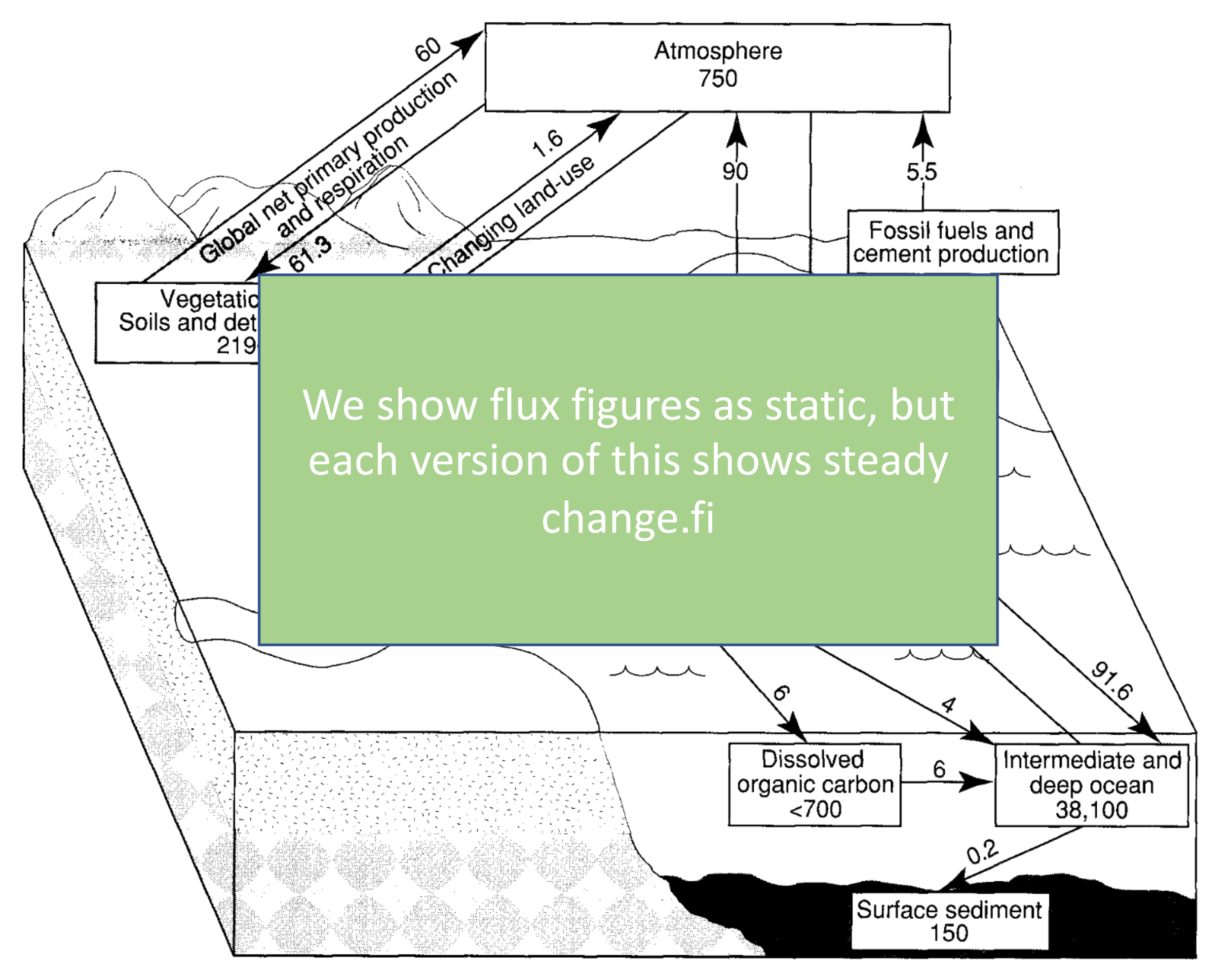
Bloom AA, Exbrayat Jfet al. The decadal state of the terrestrial carbon cycle: Global retrievals of terrestrial carbon allocation, pools, and residence times. PNAS. 2016 Feb 2;113(5):1285-90.

The Carbon Cycle (*ca* 1995)

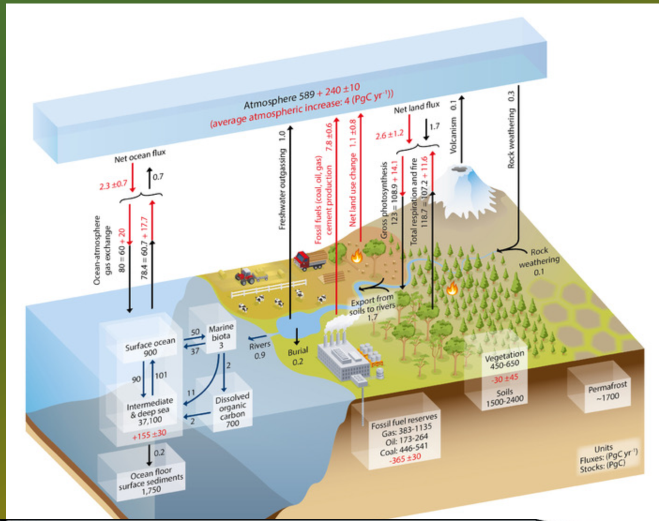


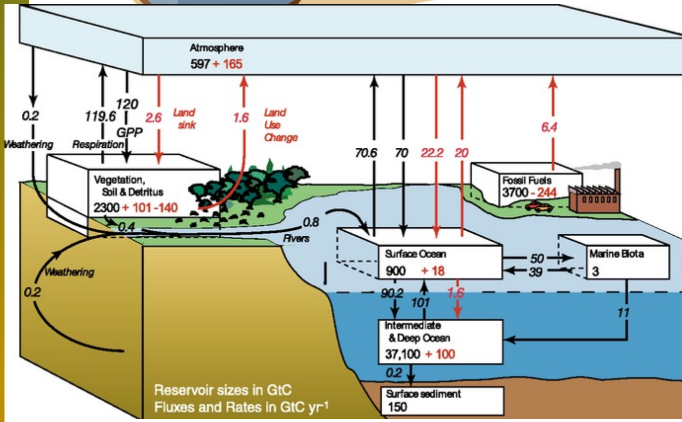
IPCC SAR

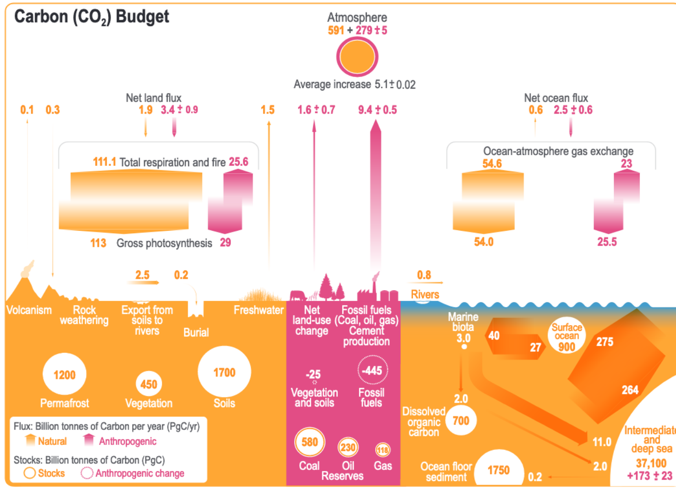
The Carbon Cycle (*ca* 1995)



We show flux figures as static, but each version of this shows steady change.fi

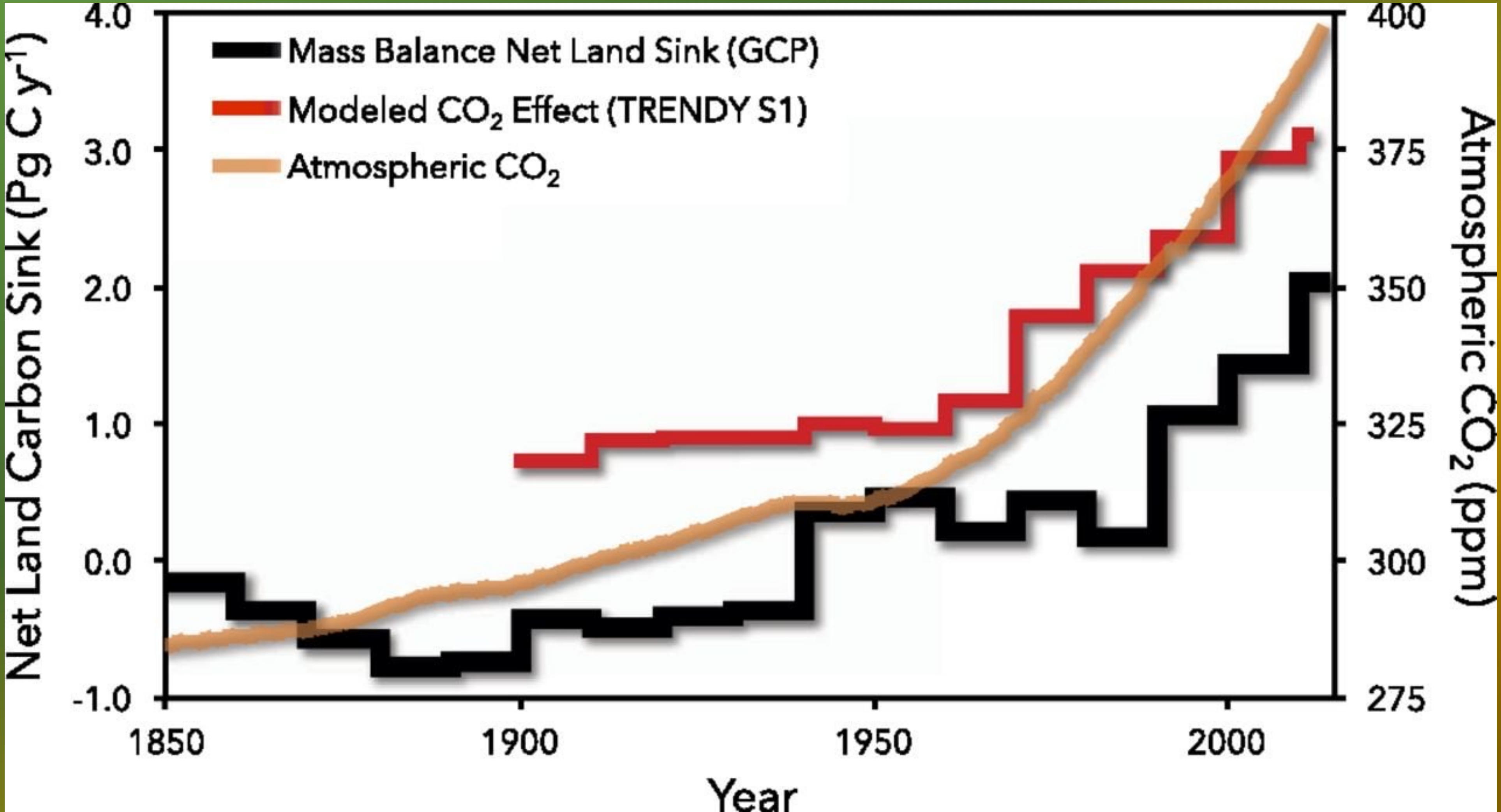






IPCC SAR

CO_2 fertilization: The land sink has increased in near-lock step with atmospheric CO_2



CO_2 as a driving force: good news and bad news

$$\frac{dC}{dt} = GPP \cdot r \cdot \tau.$$

The simple Thompson, Field equation (r = rate of increase for whatever reason, τ = residence time)

$$\frac{dC}{dt} = \frac{\beta \frac{dCa}{dt}}{Ca(t)} \cdot GPP(t-1) \cdot \tau.$$

The Taylor and Lloyd version, the famous β expression, showing the dependance of carbon storage on the the sensitivity of GPP to CO_2 and the residence time of that carbon, a sum of exponentials.

As the annual change in CO_2 slows and goes negative, GPP will remain high but carbon storage will go to zero on a time scale defined by τ

The global carbon budget, what, where and why?

Carbon Cycle Component	Flux 1960–1970 (Pg C year^{-1})	Flux 2012–2021 (Pg C year^{-1})	% Flux in Northern Hemisphere	% Flux in Tropics	% Flux in Southern Hemisphere
Fossil + Cement	3.0 ± 0.2	9.6 ± 0.5	80 (source)	16 (source)	03 (source)
Land Sink	1.3 ± 0.4	2.7 ± 0.5	80 (sink)	04 (sink)	15 (sink)
Land-use Change	1.5 ± 0.7	1.2 ± 0.7	22 (source)	72 (source)	05 (source)
Ocean Sink	1.1 ± 0.4	2.9 ± 0.4	44 (sink)	03 (source)	52 (sink)
Atmospheric Growth Rate	1.7 ± 0.1	5.2 ± 0.2	N/A	N/A	N/A
Airborne Fraction (Growth Rate / Total Emissions)	0.4 ± 0.7	0.48 ± 0.9	N/A	N/A	N/A
Imbalance	0.4	0.3	N/A	N/A	N/A

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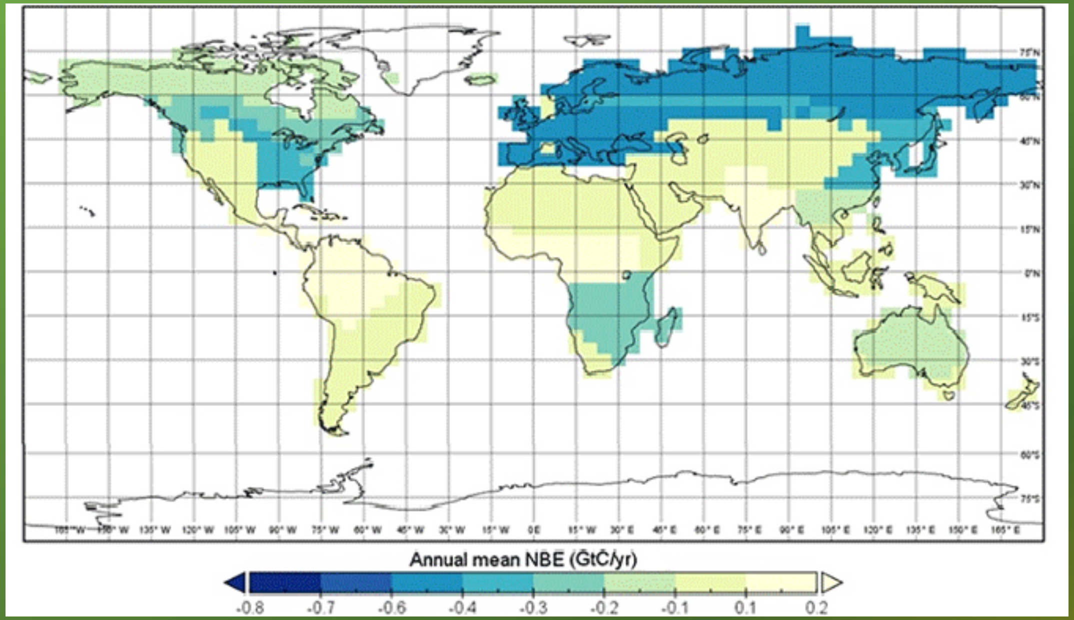
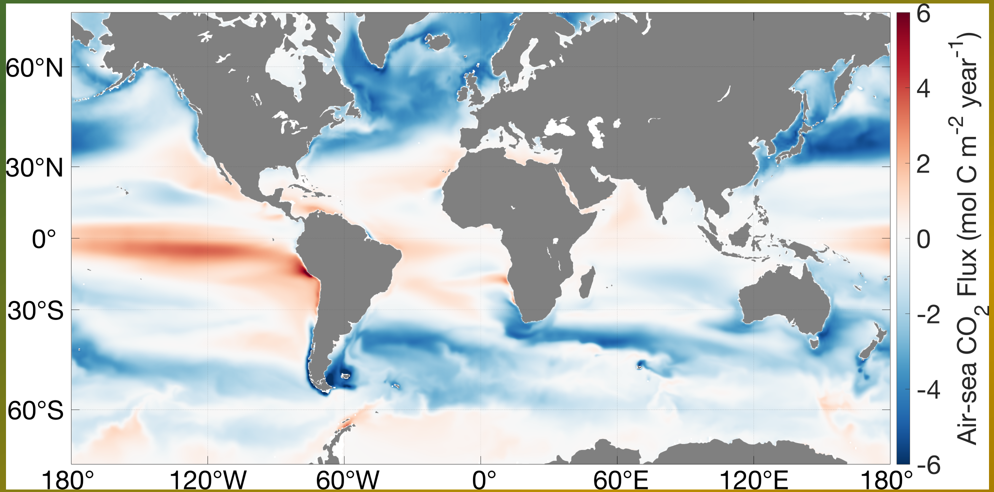
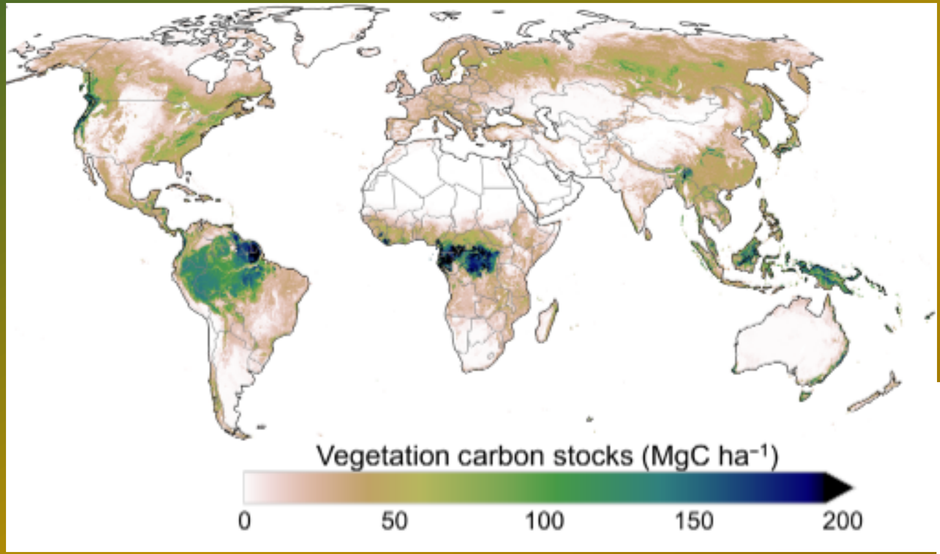
Satellite-Constrained Land and Ocean Estimates



Net Ecosystem Exchange



Air-Sea CO_2 Exchange



Vegetation Biomass

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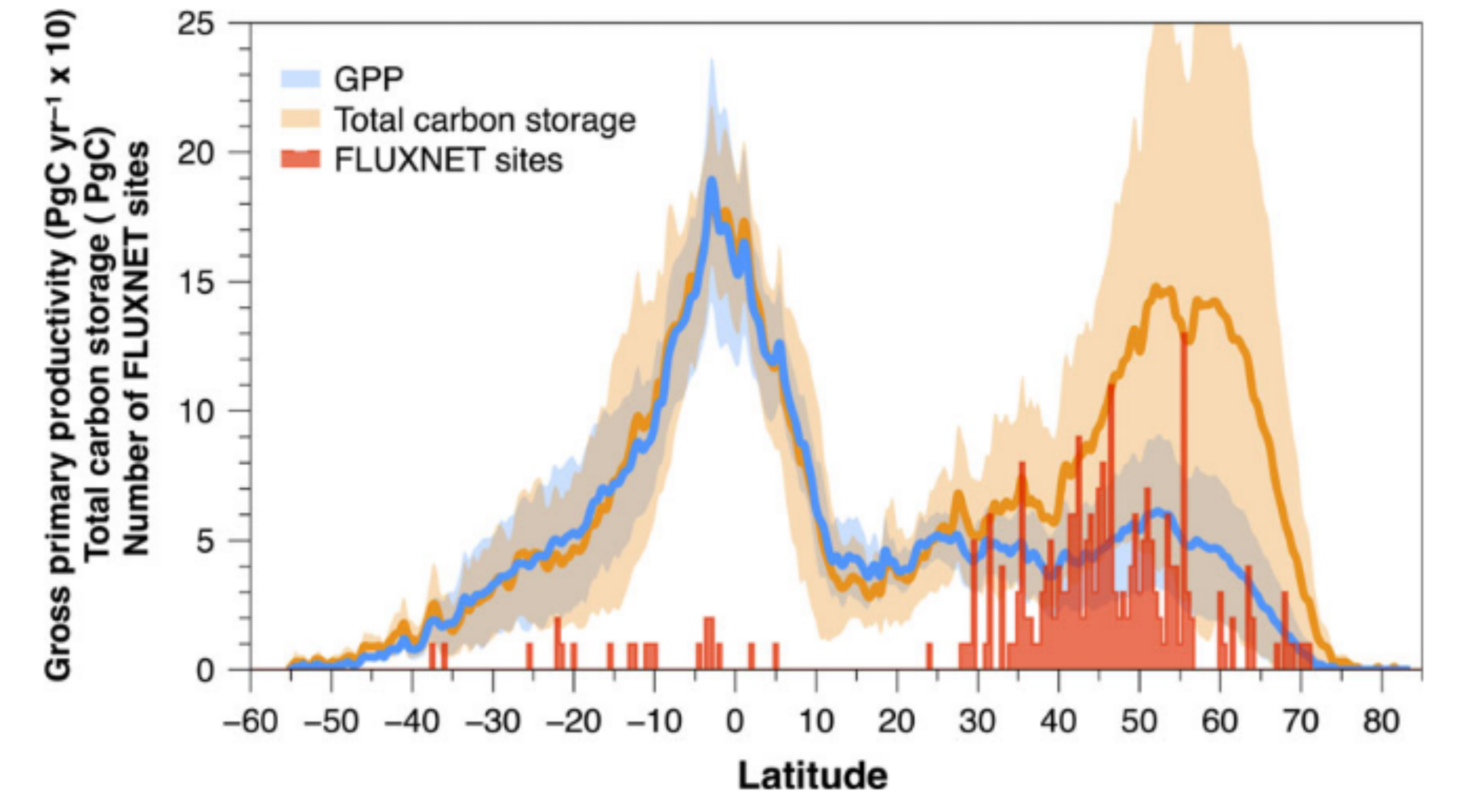
“Best” empirical, satellite informed estimate



Resolution in Time and Space

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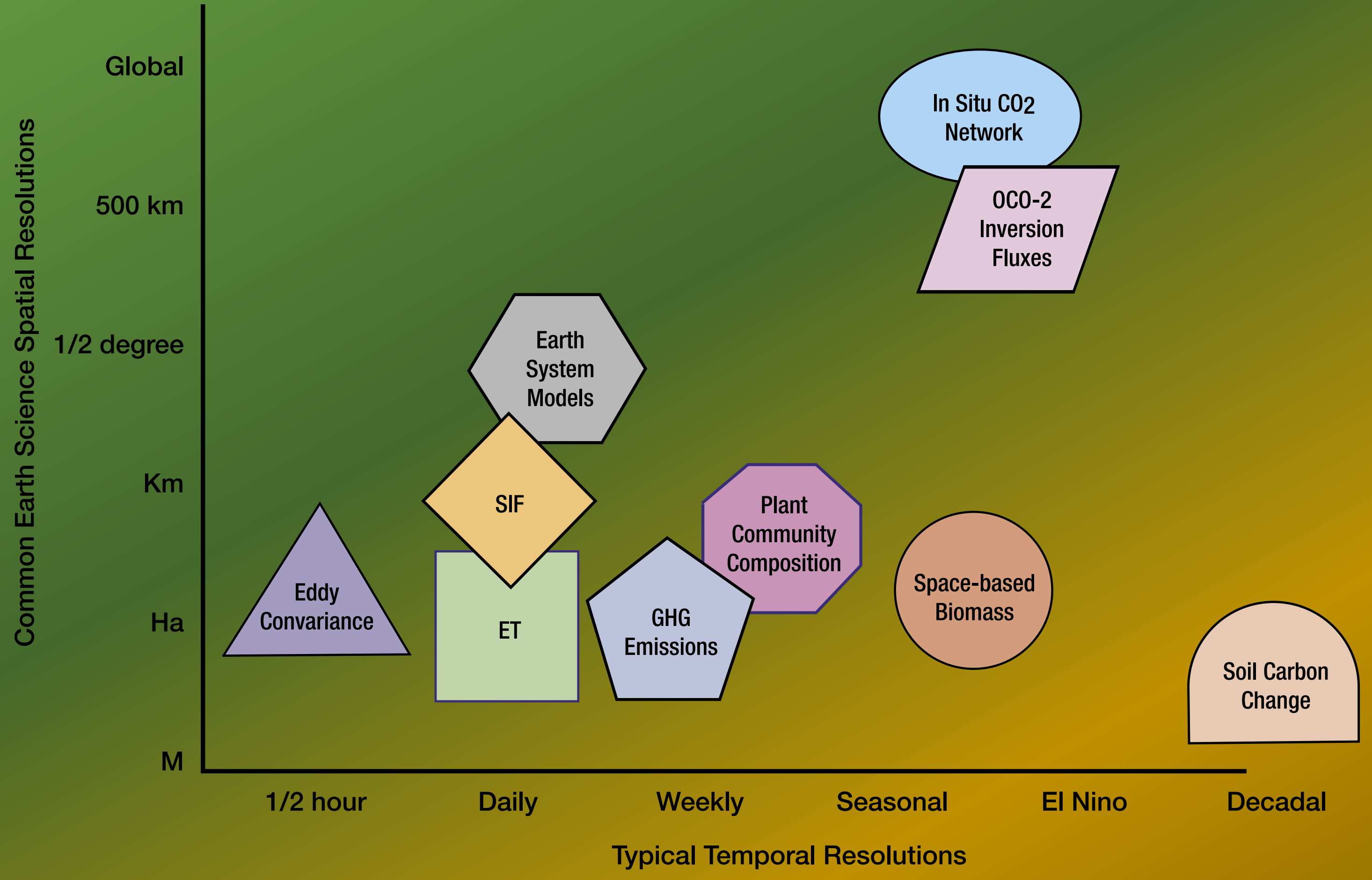

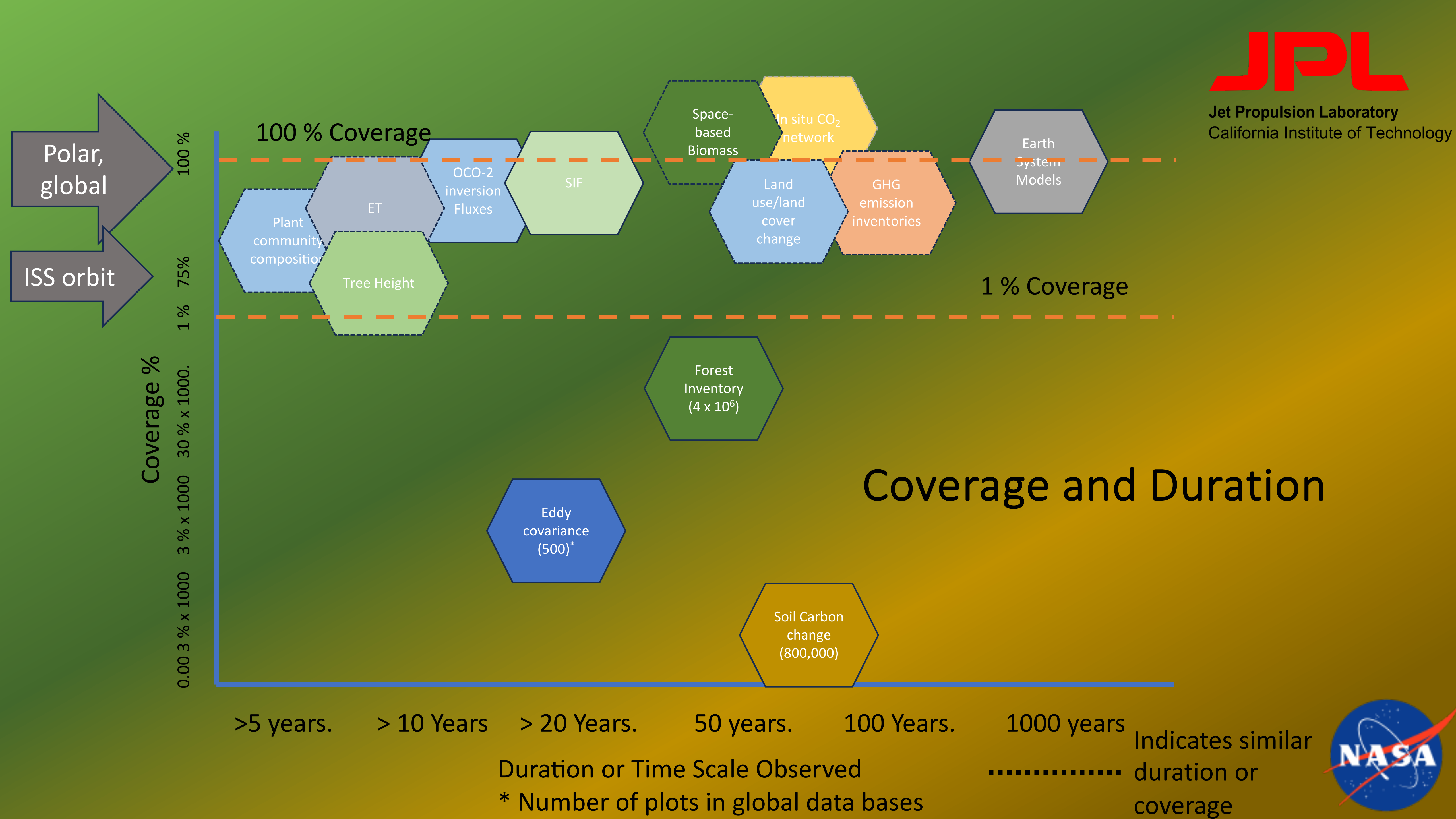
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Polar, global
ISS orbit
100 % Coverage
1 % Coverage
Coverage %
100 %
75%
1 %
30 % x 1000.
3 % x 1000
0.00 3 % x 1000
Plant community composition
ET
OCO-2 inversion Fluxes
SIF
Tree Height
Space-based Biomass
In situ CO_2 network
Land use/land cover change
GHG emission inventories
Earth System Models
Forest Inventory (4×10^6)
Eddy covariance (500)*
Soil Carbon change (800,000)
Coverage and Duration
>5 years.
> 10 Years
> 20 Years.
50 years.
100 Years.
1000 years
Duration or Time Scale Observed
* Number of plots in global data bases
Indicates similar duration or coverage
NASA

WHAT DO MODELS SAY (AND DO WE BELIEVE THEM)

- Models predict sustained uptake into very warm climate.
- Models predict sustained soil carbon storage even in very warm climates.
- Models predict that positive effects of increasing CO_2 remain larger than negative impacts of warmer, drier climates.
- In situ, airborne and satellite measurements are showing changes to arctic and tropical ecosystems similar to those predicted for the 2050s.
- In general, to the extent one can compare, model sensitivities seem inconsistent with the bulk of experimental and observational studies.

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Earth System Models Disagree and are probably just wrong!

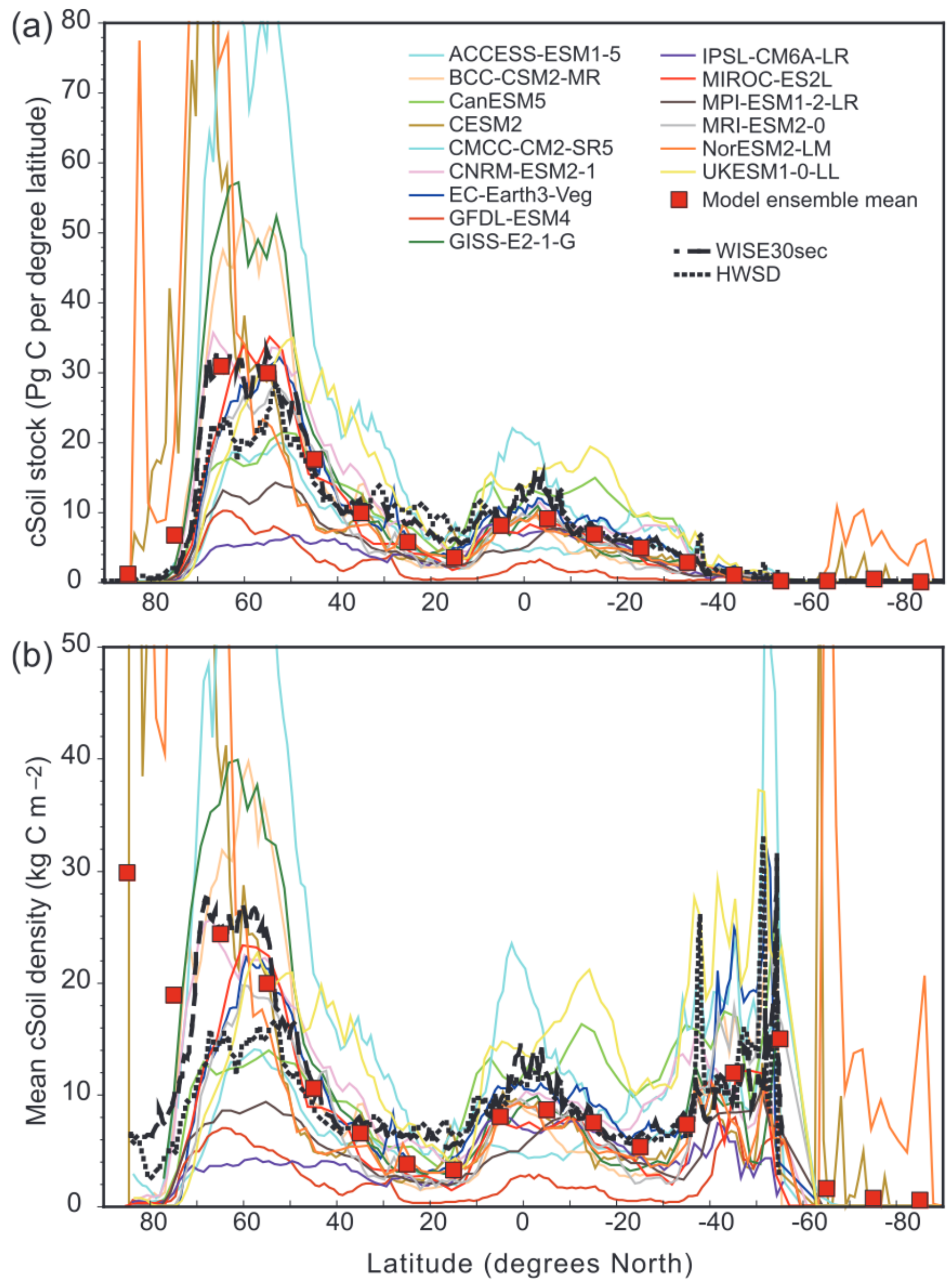

Figure 2. Latitudinal distributions of (a) carbon stocks in cSoil and (b) mean areal carbon density, simulated by CMIP6 ESMs in the 2000s. Distributions in the global soil datasets HWSD and WISE30sec (1 m soil depth) are included for comparison.

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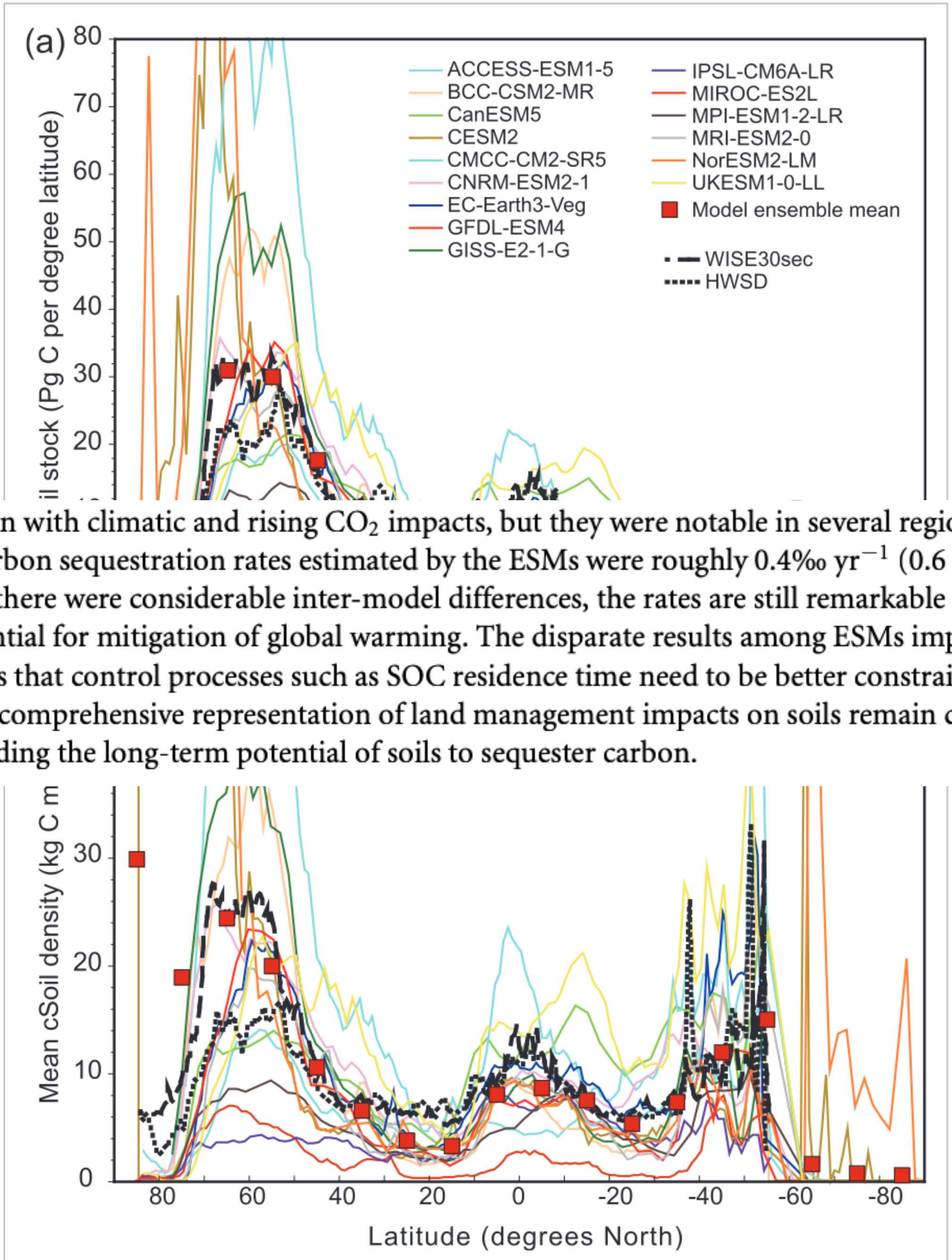

Figure 2. Latitudinal distributions of (a) carbon stocks in cSoil and (b) mean areal carbon density, simulated by CMIP6 ESMs in the 2000s. Distributions in the global soil datasets HWSD and WISE30sec (1 m soil depth) are included for comparison.

comparison with climatic and rising CO_2 impacts, but they were notable in several regions. Future net soil carbon sequestration rates estimated by the ESMs were roughly 0.4‰ yr^{-1} (0.6 Pg C yr^{-1}). Although there were considerable inter-model differences, the rates are still remarkable in terms of their potential for mitigation of global warming. The disparate results among ESMs imply that key parameters that control processes such as SOC residence time need to be better constrained and that more comprehensive representation of land management impacts on soils remain critical for understanding the long-term potential of soils to sequester carbon.

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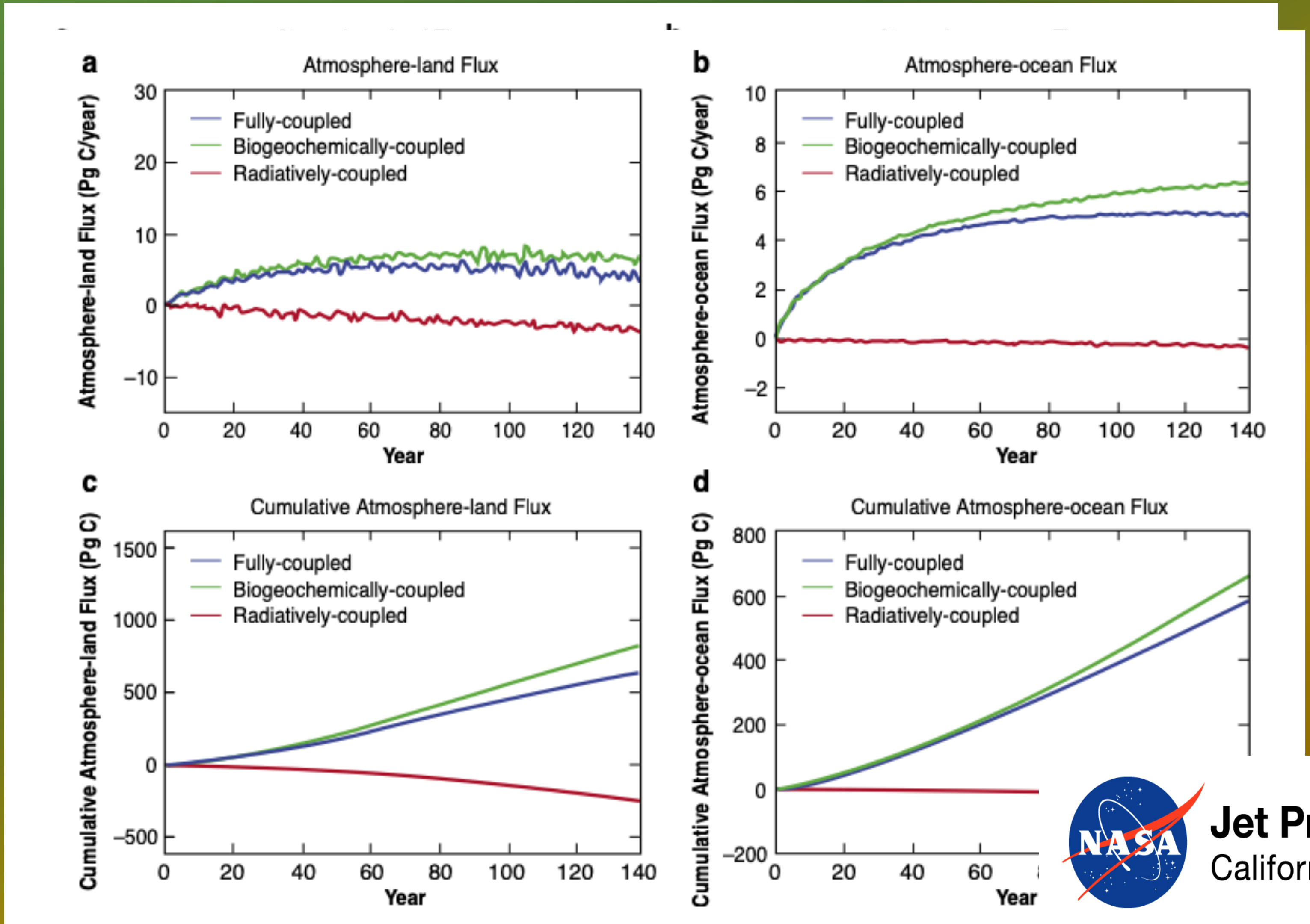
MODELS PREDICT SUSTAINED UPTAKE EVEN INTO VERY WARM CLIMATES



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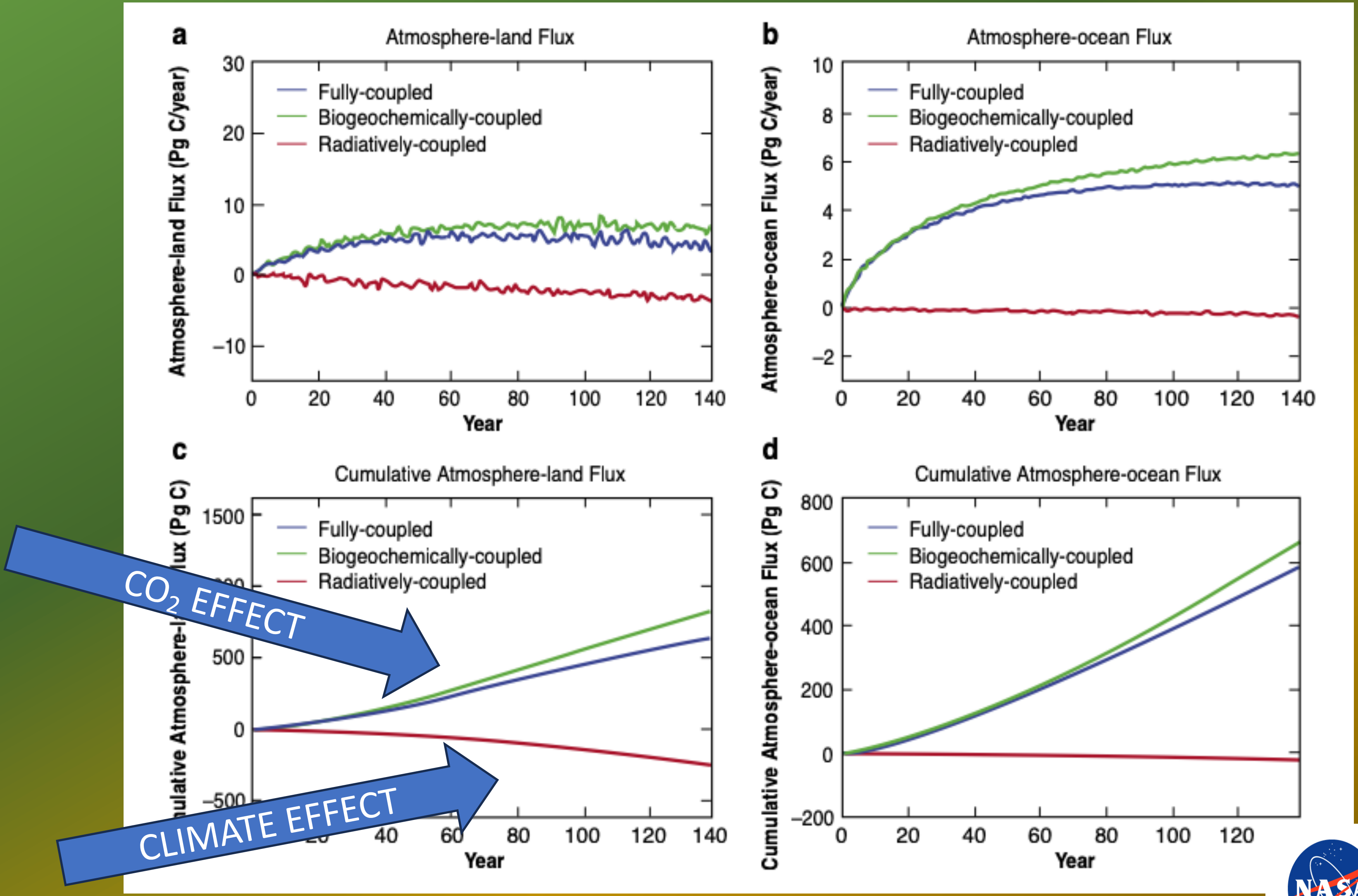
MODELS VERY LIKE OVERESTIMATE CO_2 EFFECTS AND UNDERESTIMATE CLIMATE SENSITIVITY



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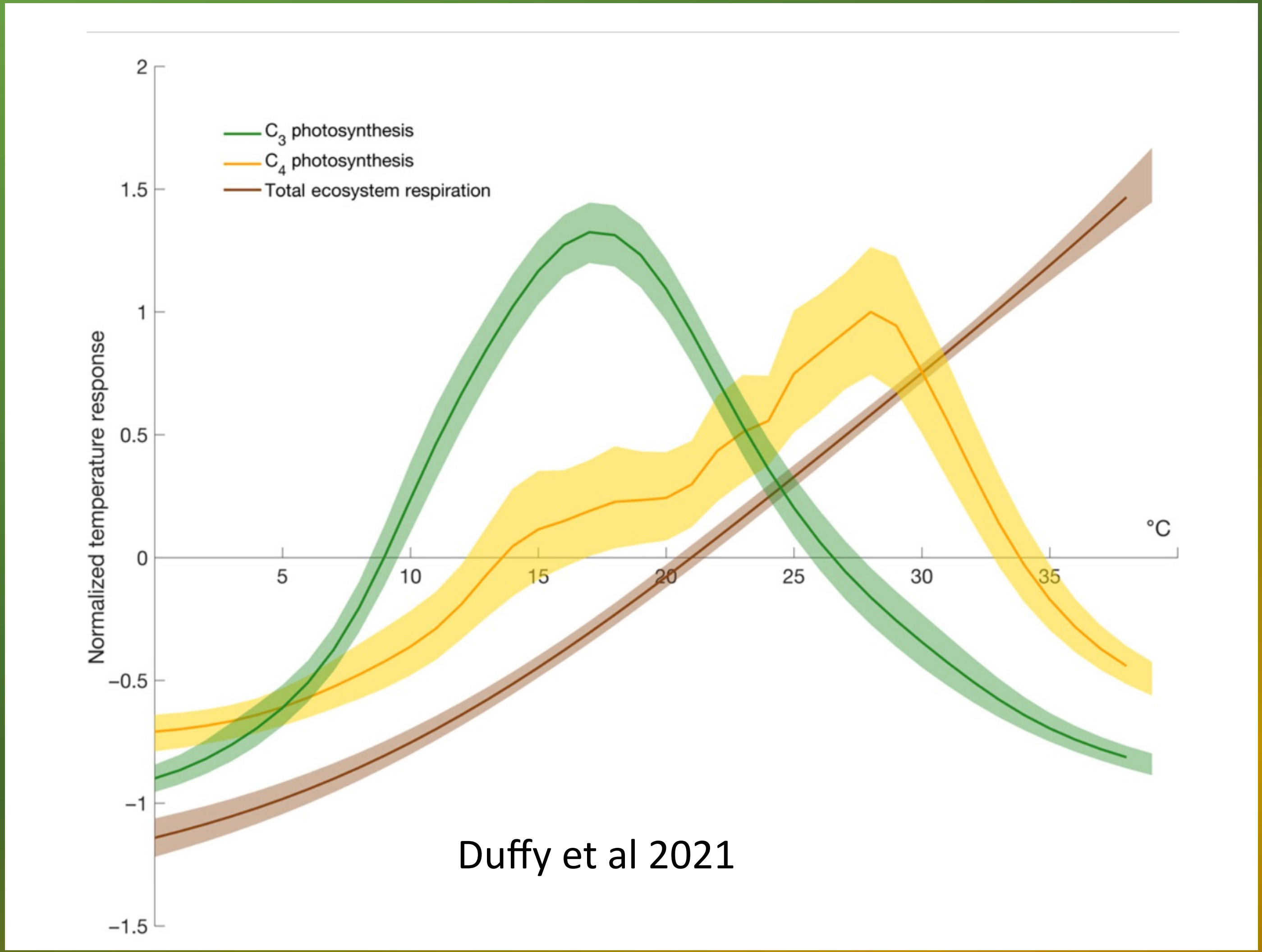
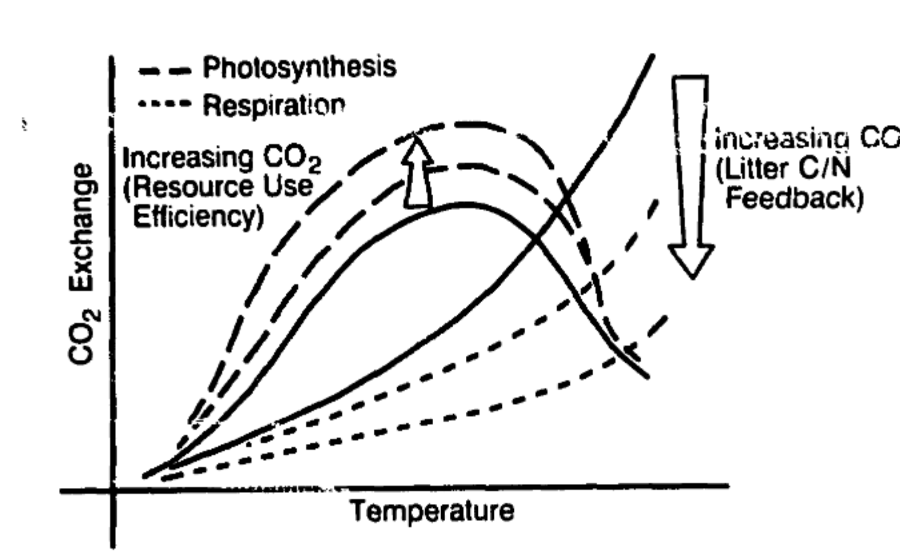
We may be close to temperature and drought stress tipping points



Duffy et al 2021



Sellers and Schimel 1993

Century Model Simulations

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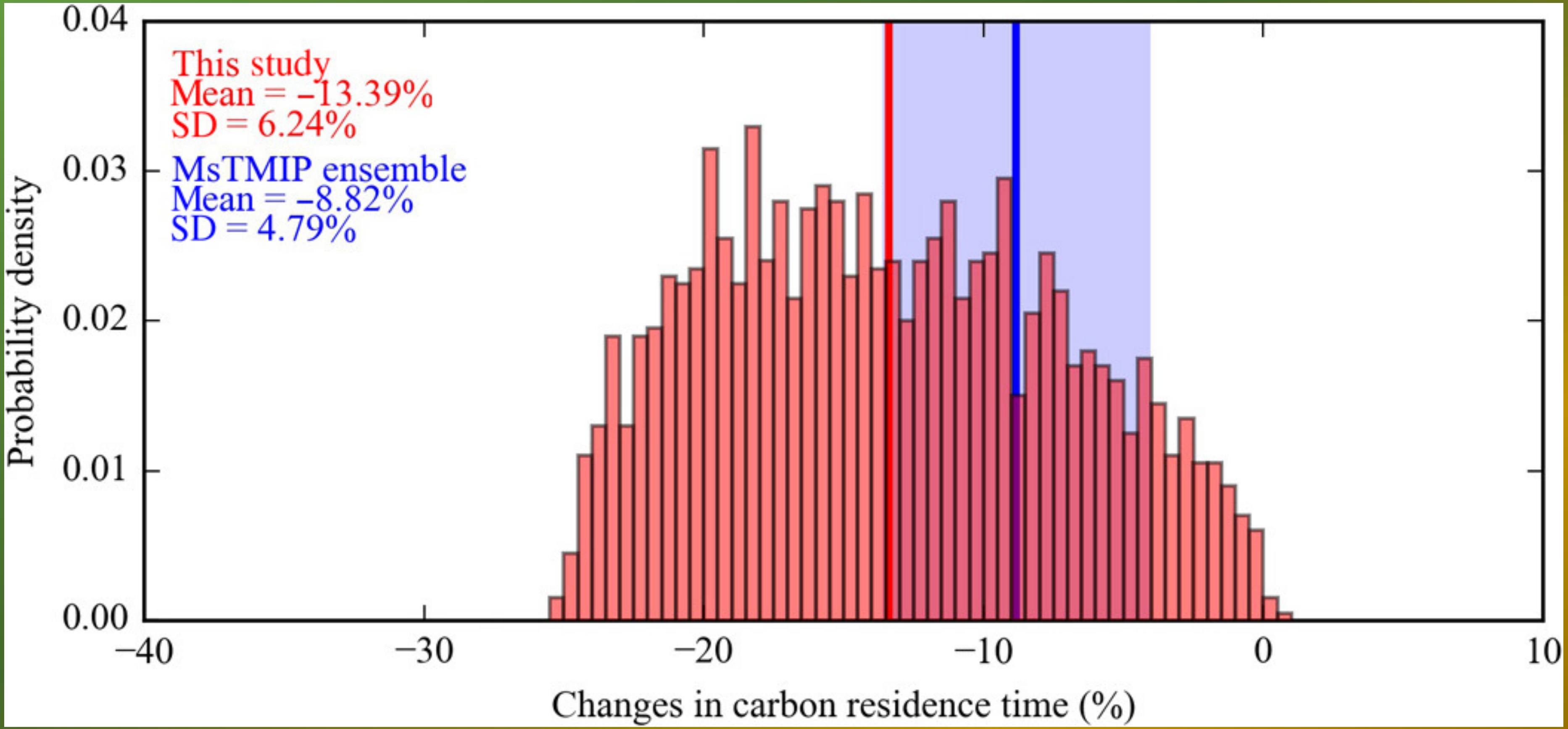
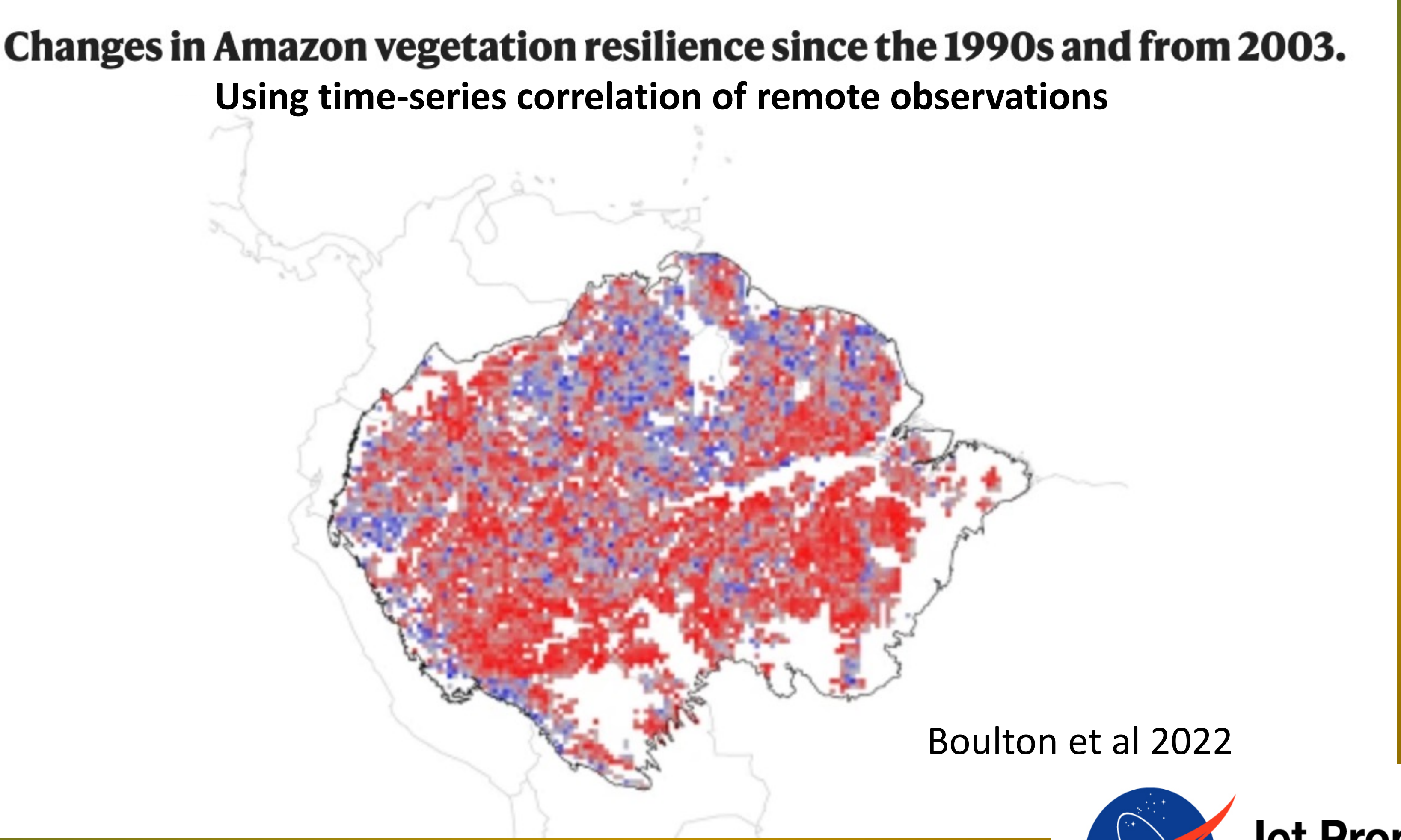
Arctic soil carbon residence Time (τ) constrained by assimilating the seasonal cycle of atmospheric CO_2



Jeong SJ, Bloom AA, Schimel D, et al. Accelerating rates of Arctic carbon cycling revealed by long-term atmospheric CO_2 measurements. Science advances. 2018 Jul 11;4(7):eaao1167.

Close to or crossing tipping points
Instability as thresholds are approached



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In a post-Paris world, the main driving force for sinks will slow and stop, while climate feedbacks (elevated respiration, drought impacts on GPP, wildfire) will continue.

Managing stocks to retain existing carbon storage, much less increasing carbon storage, will require active and creative management.

You can't manage what you can't measure (or model).

Tools to optimize soil management are critical!

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Summary

- Model projections of both the global carbon cycle and to inform managed sequestration are limited by insufficient data, incomplete process understanding and pressure to inform predictions.
- Critical data range widely in their coverage, duration, spatial and temporal scales, accuracy and precision.
- Sampling and bias in sampling is a bigger problem than we may realize.
- New and heritage observations taken together may be far more powerful than separately if only we knew how to fuse them.

Summary

- Model projections suggest sustained uptake, including increasing soil carbon into very warm and high CO_2 futures.
- Contemporary observations and experiments suggest models may be fundamentally optimistic.
- Stabilizing atmospheric CO_2 at post-Paris levels presents its own challenges—the driving force for uptake (β) will weaken and cease, while, based on the present day, climate effects (γ) will continue and strengthen.
- Increasing and stabilizing soil carbon storage in a hot, dry world will require our best efforts.

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