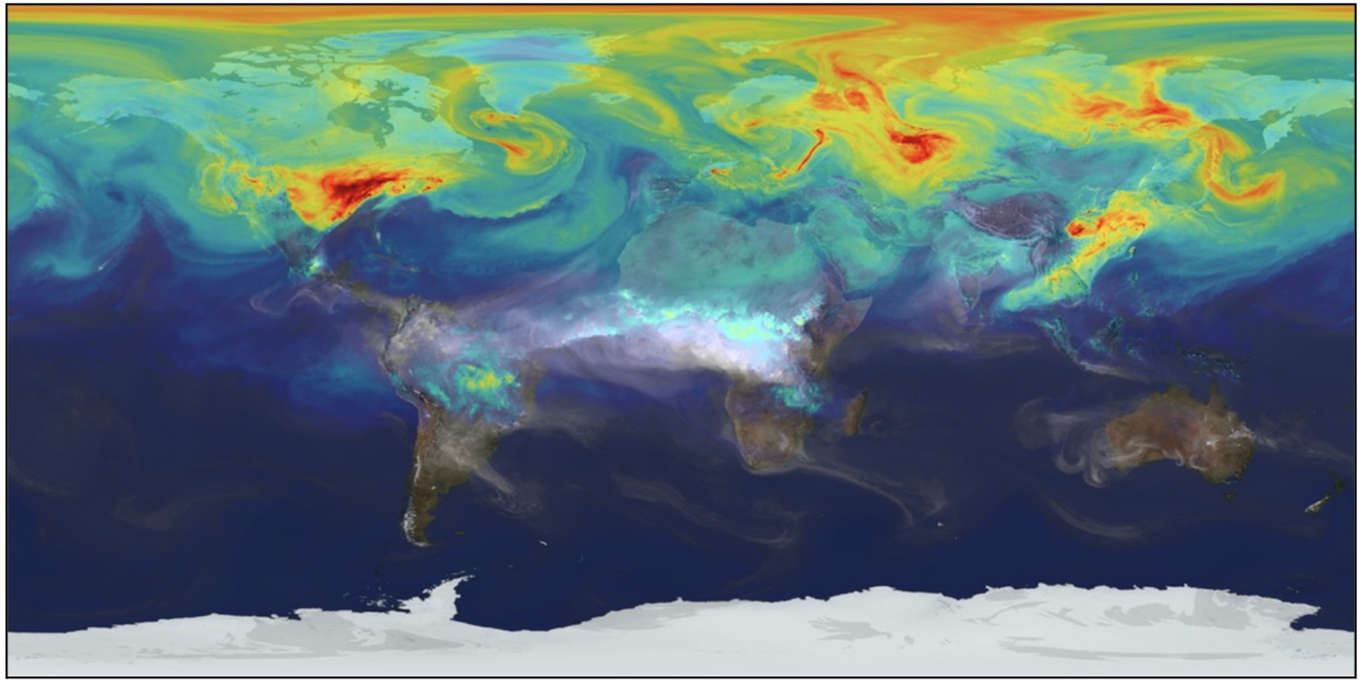

Estimating Fluxes in the Carbon Cycle

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BBC (http://www.bbc.com/news/science-environment-35073297)

The Paris Agreement

- Keep global temperatures "well below" 2.0C (3.6F) above pre-industrial times and "endeavour to limit" them even more, to 1.5C
- Limit the amount of greenhouse gases emitted by human activity to the same levels that trees, soil and oceans can absorb naturally, beginning at some point between 2050 and 2100
- Review each country's contribution to cutting emissions every five years so they scale up to the challenge
- Rich countries help poorer nations by providing "climate finance" to adapt to climate change and switch to renewable energy

United Nations
Climate Change

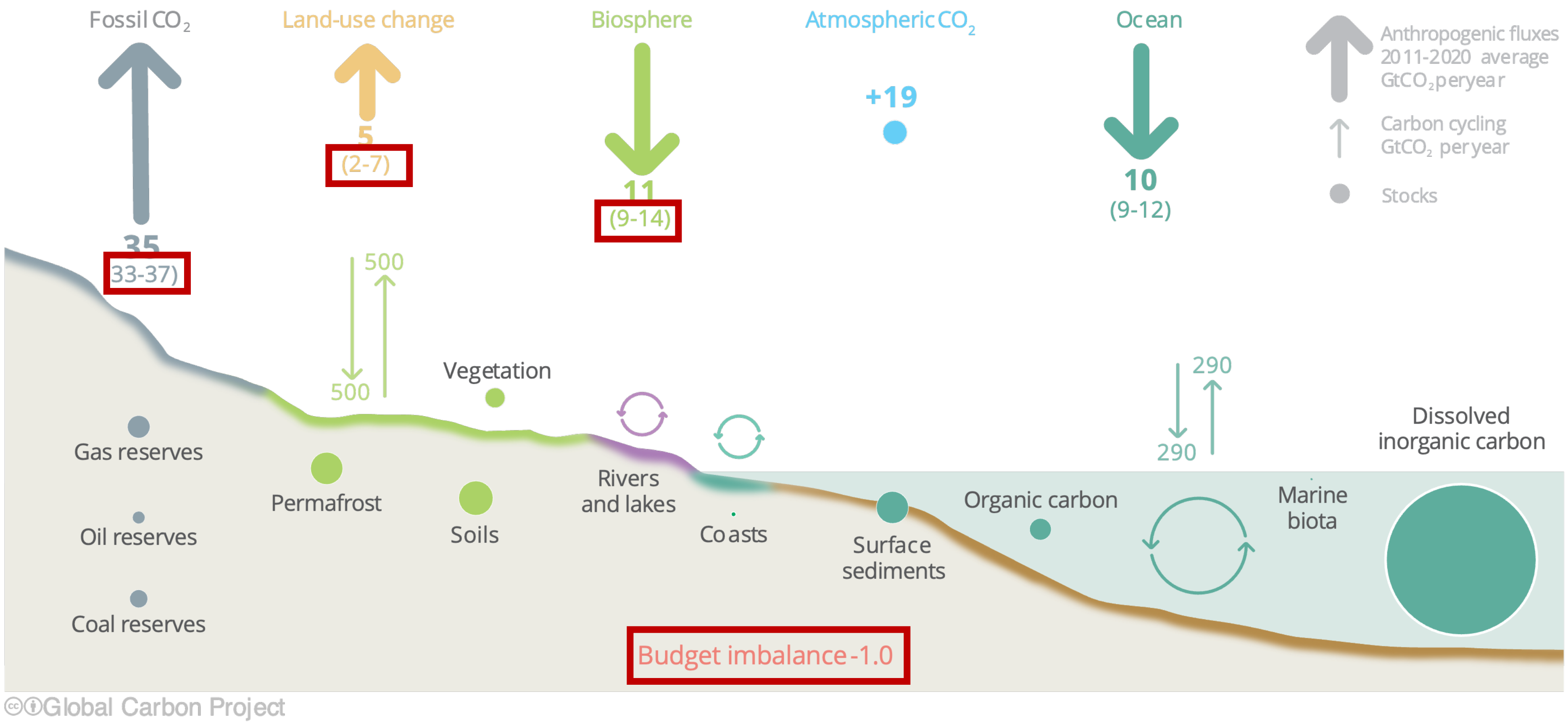
Graven (*Physics Today* 2016)

Global carbon budget since 1870

	Reservoir size in 1870 (Pg)
Atmospheric CO_2	610
Plants and soils	2500
Oceanic carbon	38 000
Geologic carbon	75 000 000

Anthropogenic perturbation of the global carbon cycle

Perturbation of the global carbon cycle caused by anthropogenic activities, global annual average for the decade 2012–2021 ($GtCO_2$/yr)

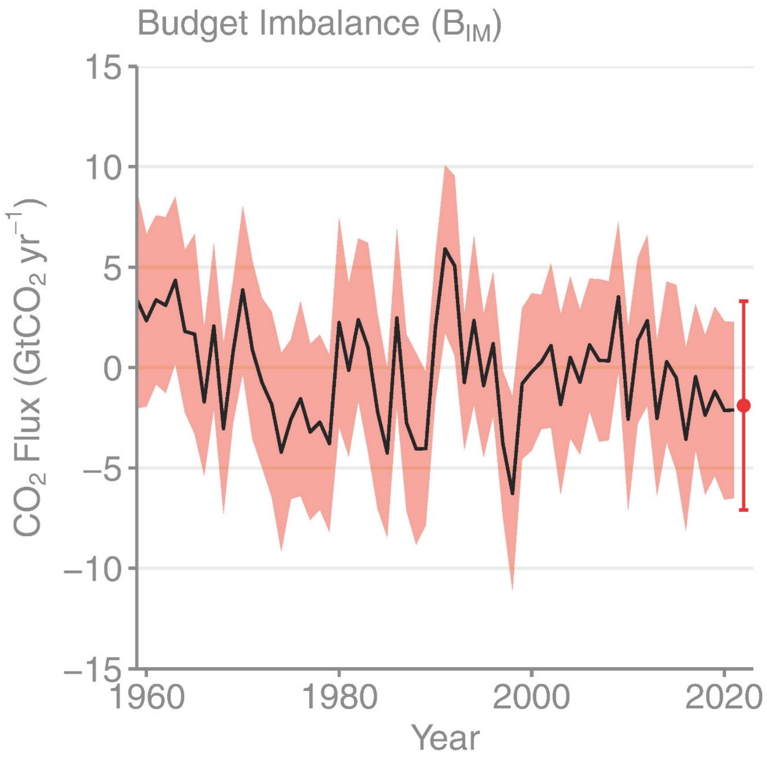


The budget imbalance is the difference between the estimated emissions and sinks.

Source: NOAA-ESRL; Friedlingstein et al 2022; Canadell et al 2021 (IPCC AR6 WG1 Chapter 5); Global Carbon Project 2022

Remaining carbon budget imbalance

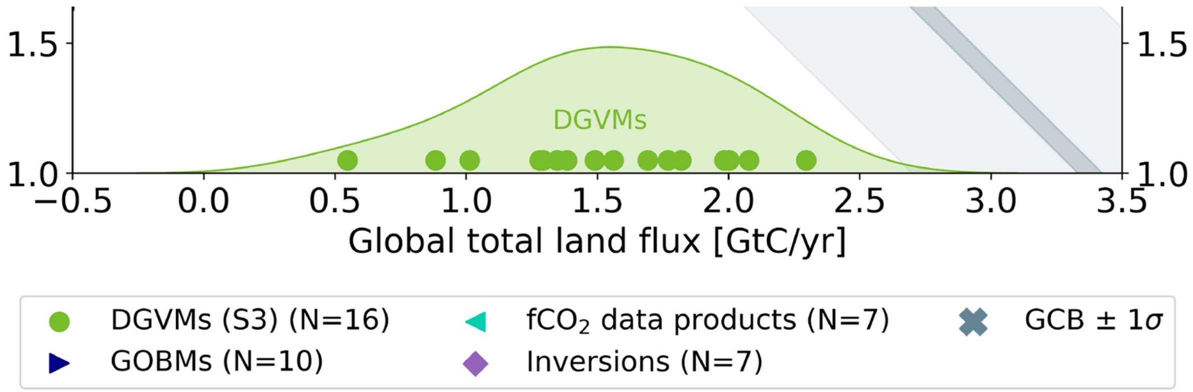
Large and unexplained variability in the global carbon balance caused by uncertainty and understanding hinder independent verification of reported CO_2 emissions



positive values mean overestimated emissions and/or underestimated sinks

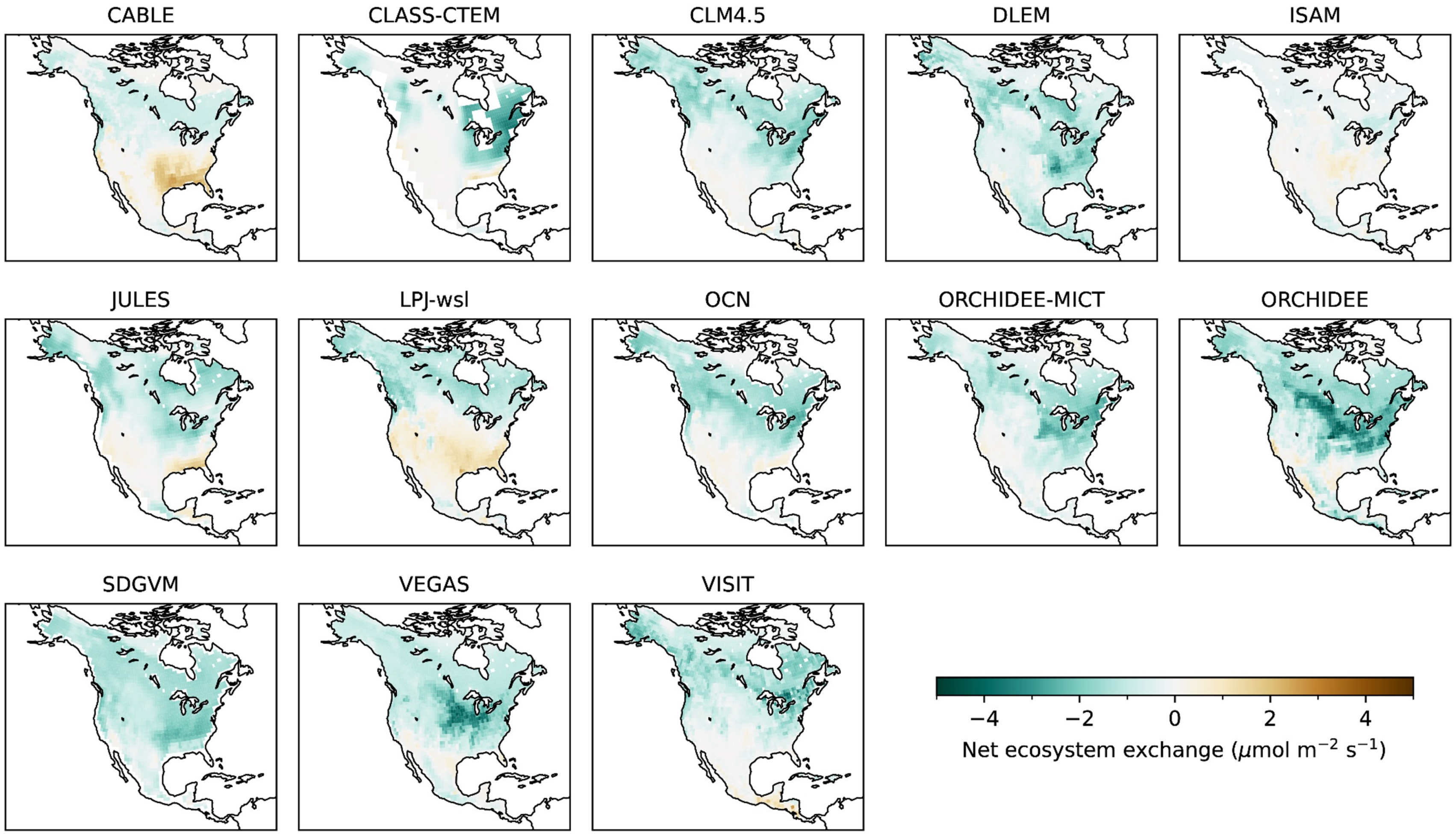
The budget imbalance is the carbon left after adding independent estimates for total emissions, minus the atmospheric growth rate and estimates for the land and ocean carbon sinks using models constrained by observations

Source: Friedlingstein et al 2022; Global Carbon Project 2022



Source: Friedlingstein et al 2022; Global Carbon Project 2022

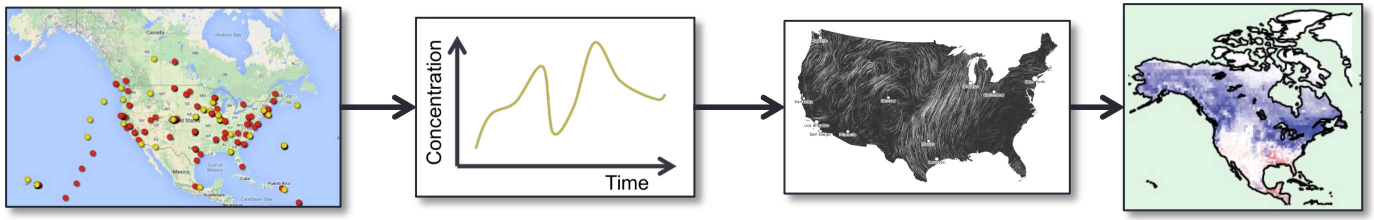
Summer patterns of net carbon uptake from DGVMs



Overall inverse problem

All vary in space and time

$$y = h(z) + \varepsilon_y + \varepsilon_h + \varepsilon_{rep} + \varepsilon_{agg}$$



y $h(.)$ z

Causation

Inference

The Paris Agreement

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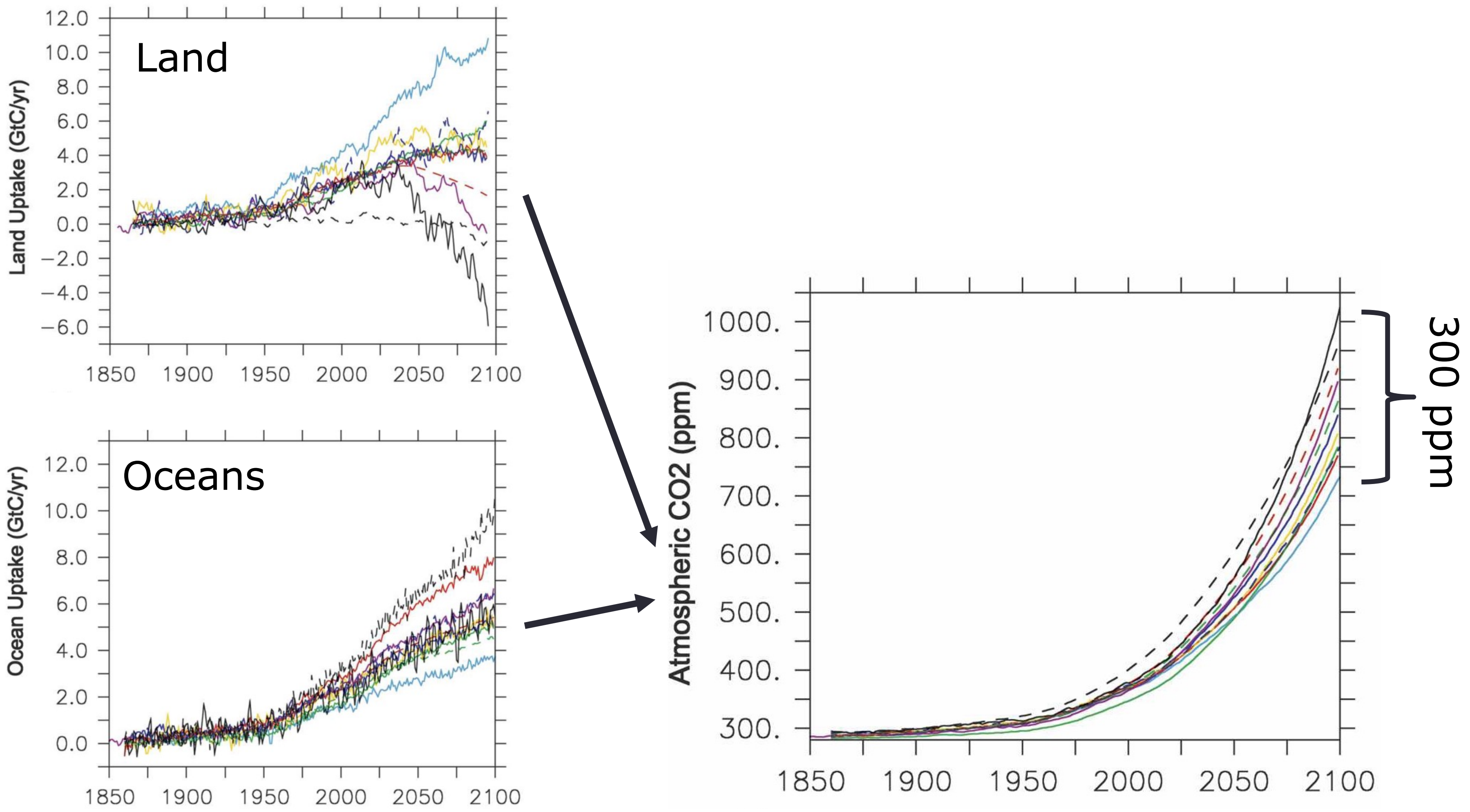
United Nations
Climate Change

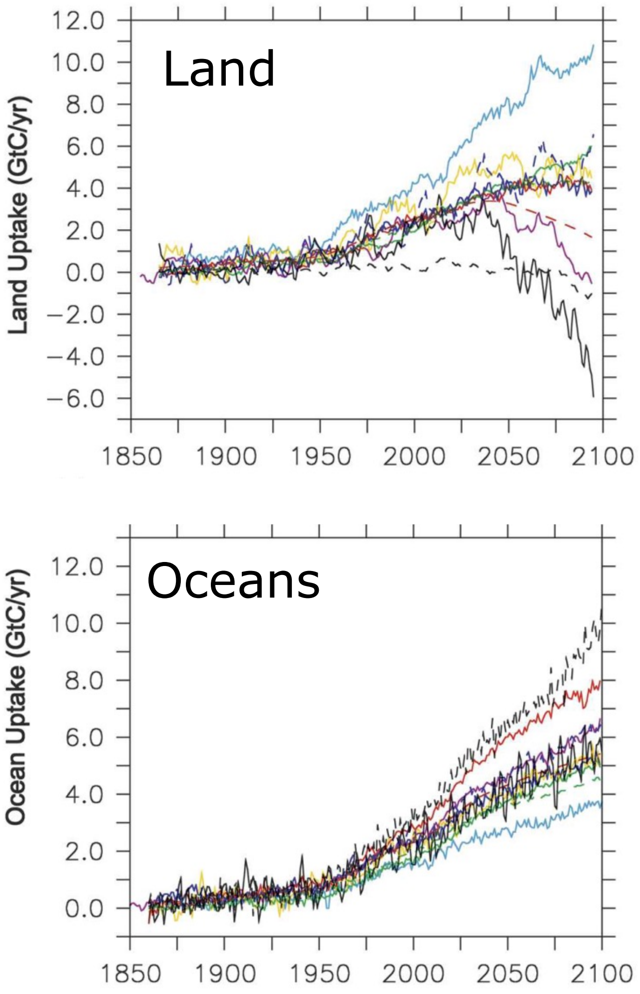
Friedlingstein et al. (J Climate, 2006, 2014)

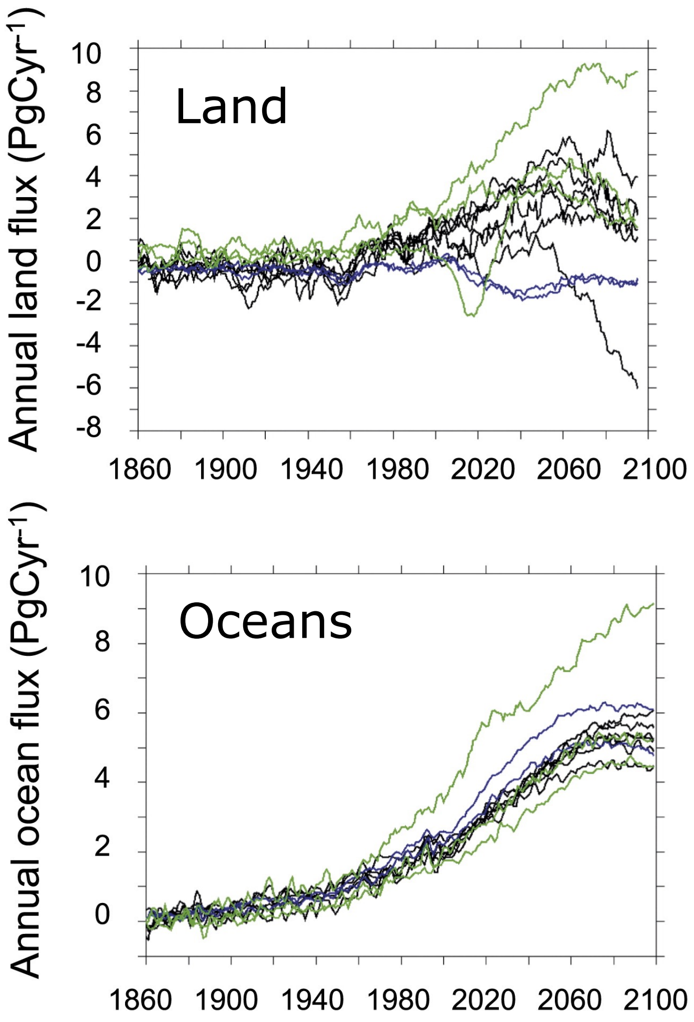
The future of natural carbon sinks



Projections from coupled carbon and climate simulations for several models

The future of natural carbon sinks



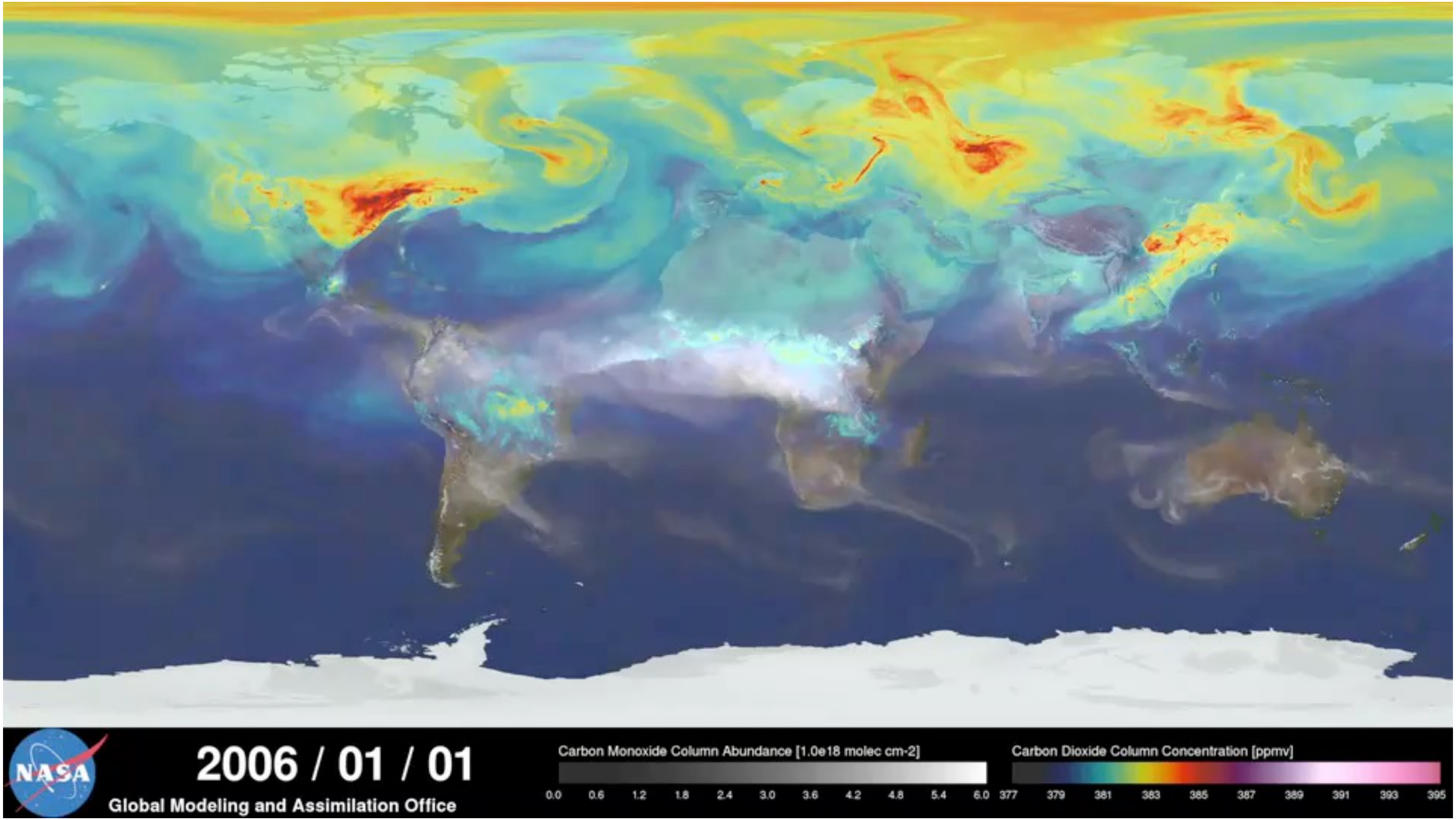


Projections from coupled carbon and climate simulations for several models

Challenges

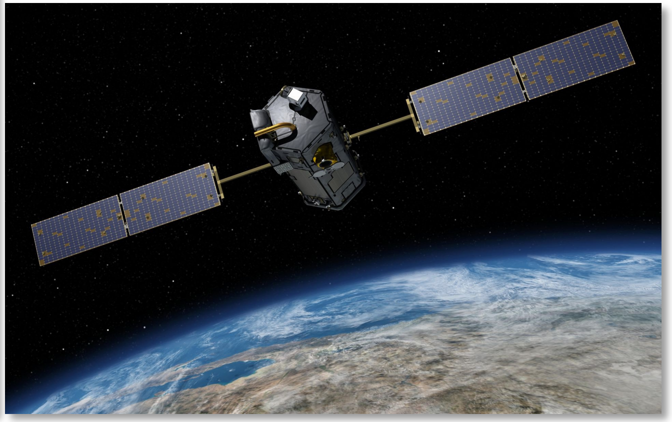
- Existing models cannot leverage quantity and diversity of available data. Models are limited in the types of observations that can be directly used, the spatiotemporal scales at which observations can be used to inform model structure and parameterization, and the ability to represent and track uncertainties.
- Fluxes cannot be observed directly at most scales. Essential variables needed to represent GHG fluxes and understand and distinguish the underlying drivers of change, cannot be directly observed at many scales.
- Increases in model complexity and resolution have outpaced ability to reconcile model simulations with observational constraints.

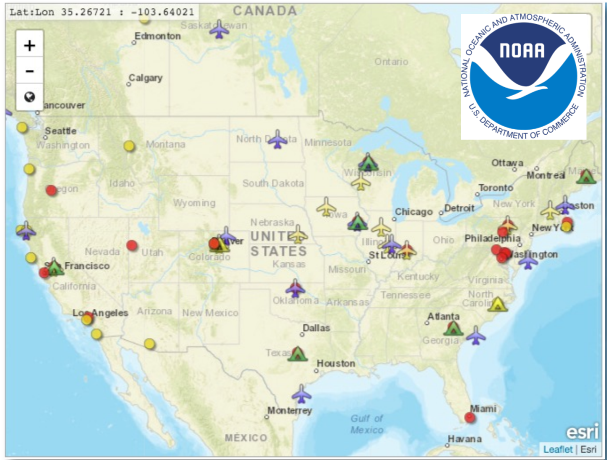
Source: NASA GMAO

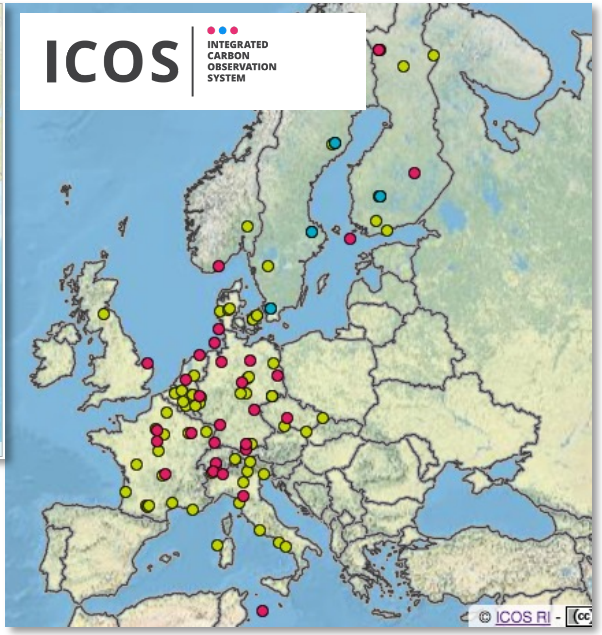


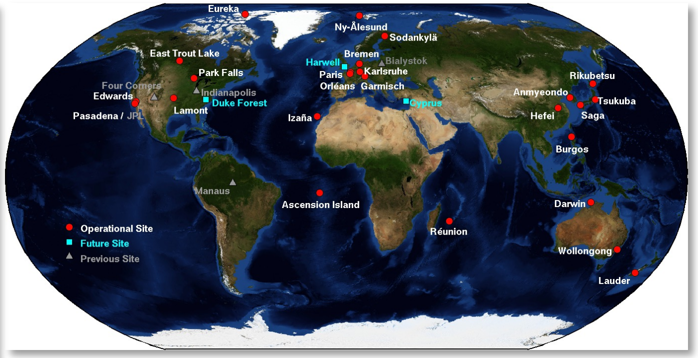
Atmospheric *concentration* observations

CARBON-I









OCO-2 ORBITING CARBON OBSERVATORY

GOSAT Greenhouse Gases Observing Satellite

GOSAT-2 PROJECT AT THE NATIONAL INSTITUTE FOR ENVIRONMENTAL STUDIES

OCO-3 ORBITING CARBON OBSERVATORY

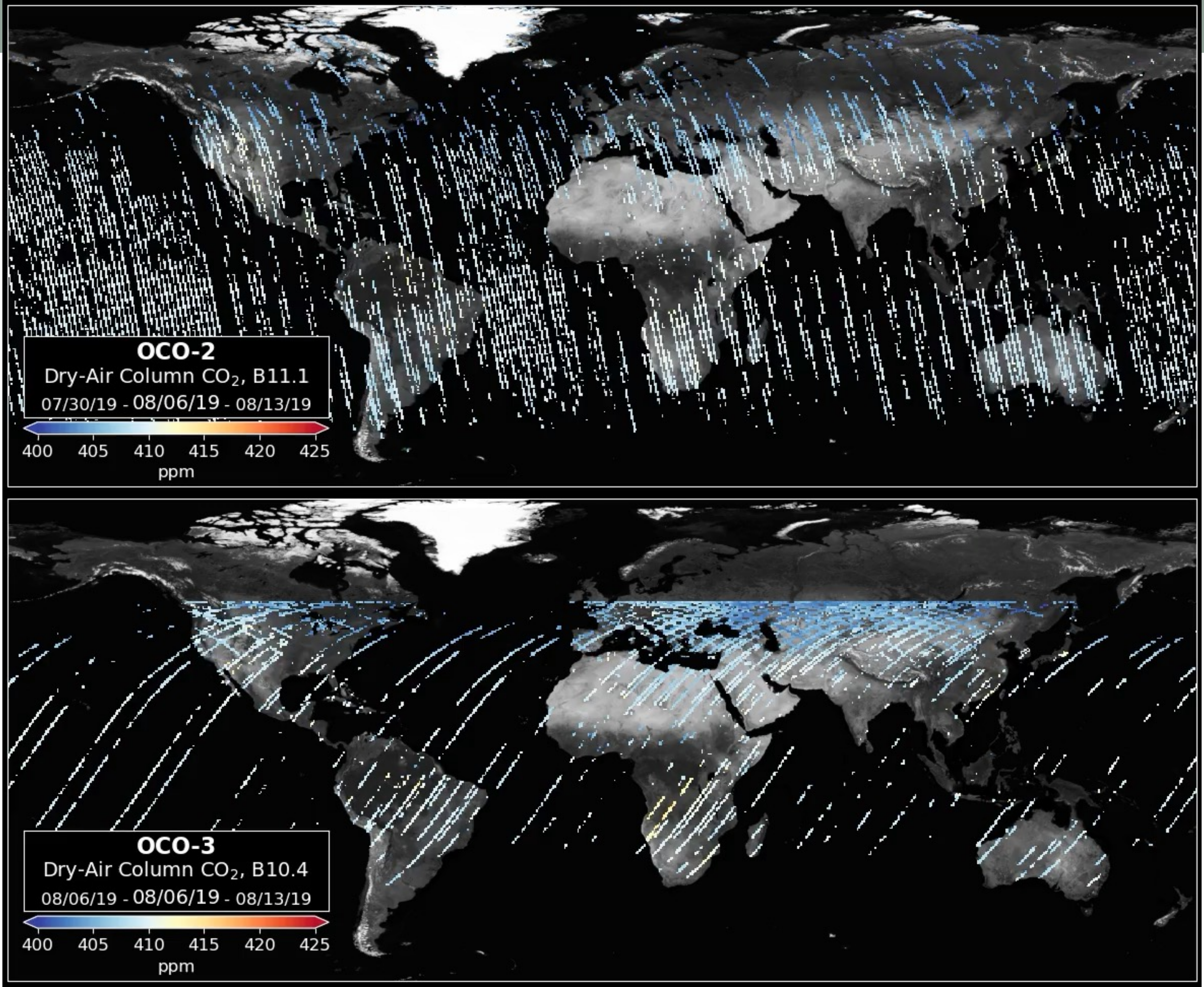
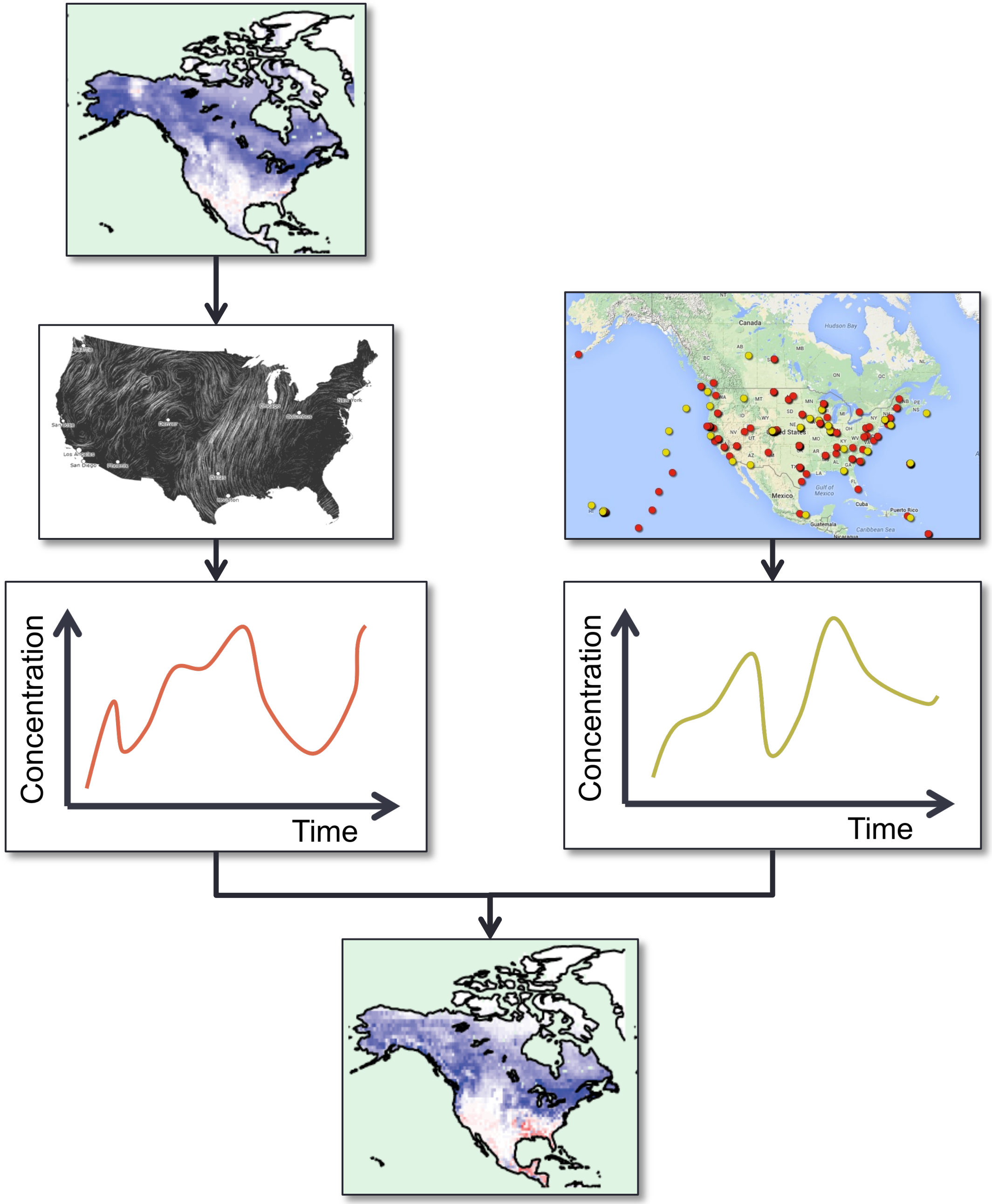
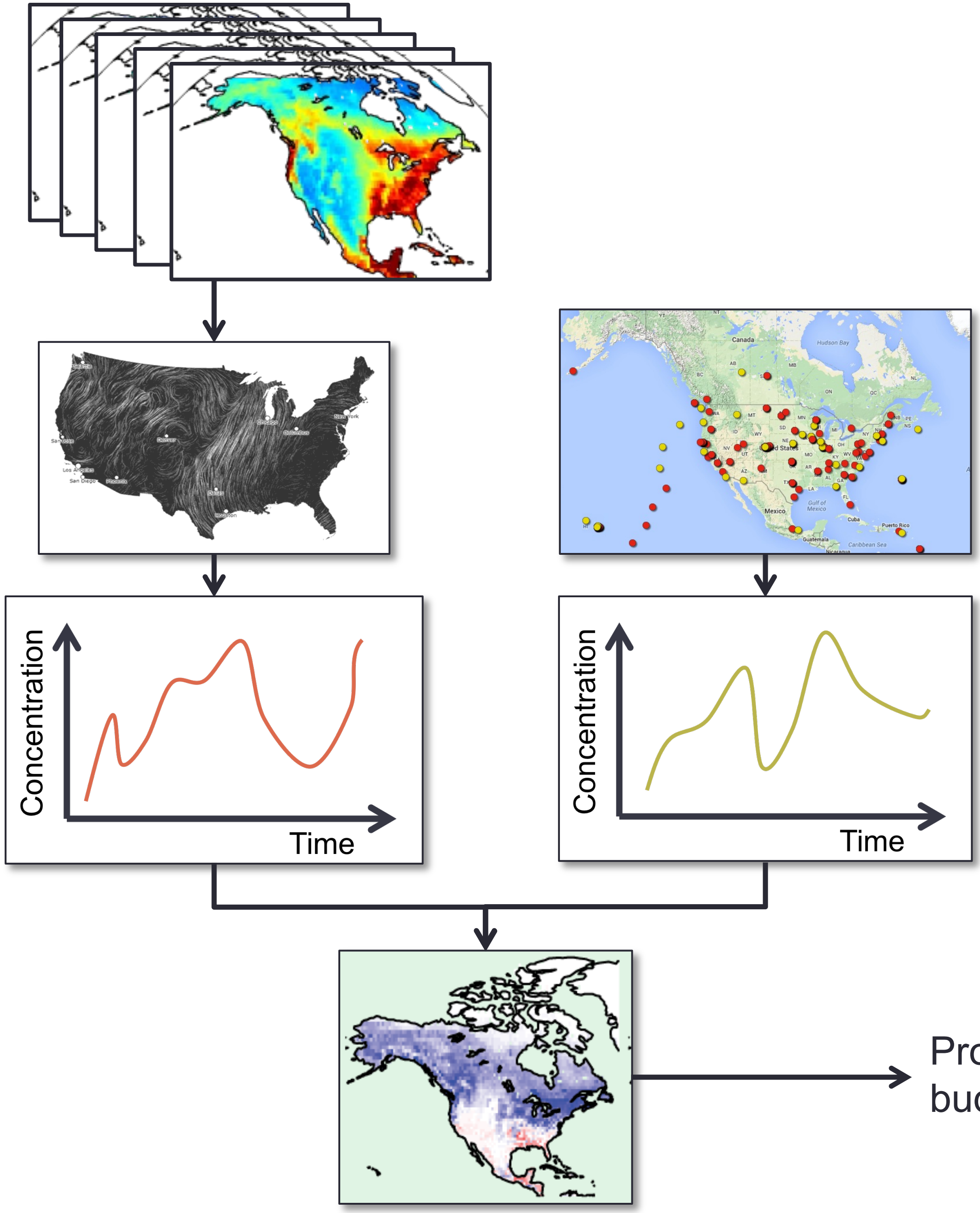
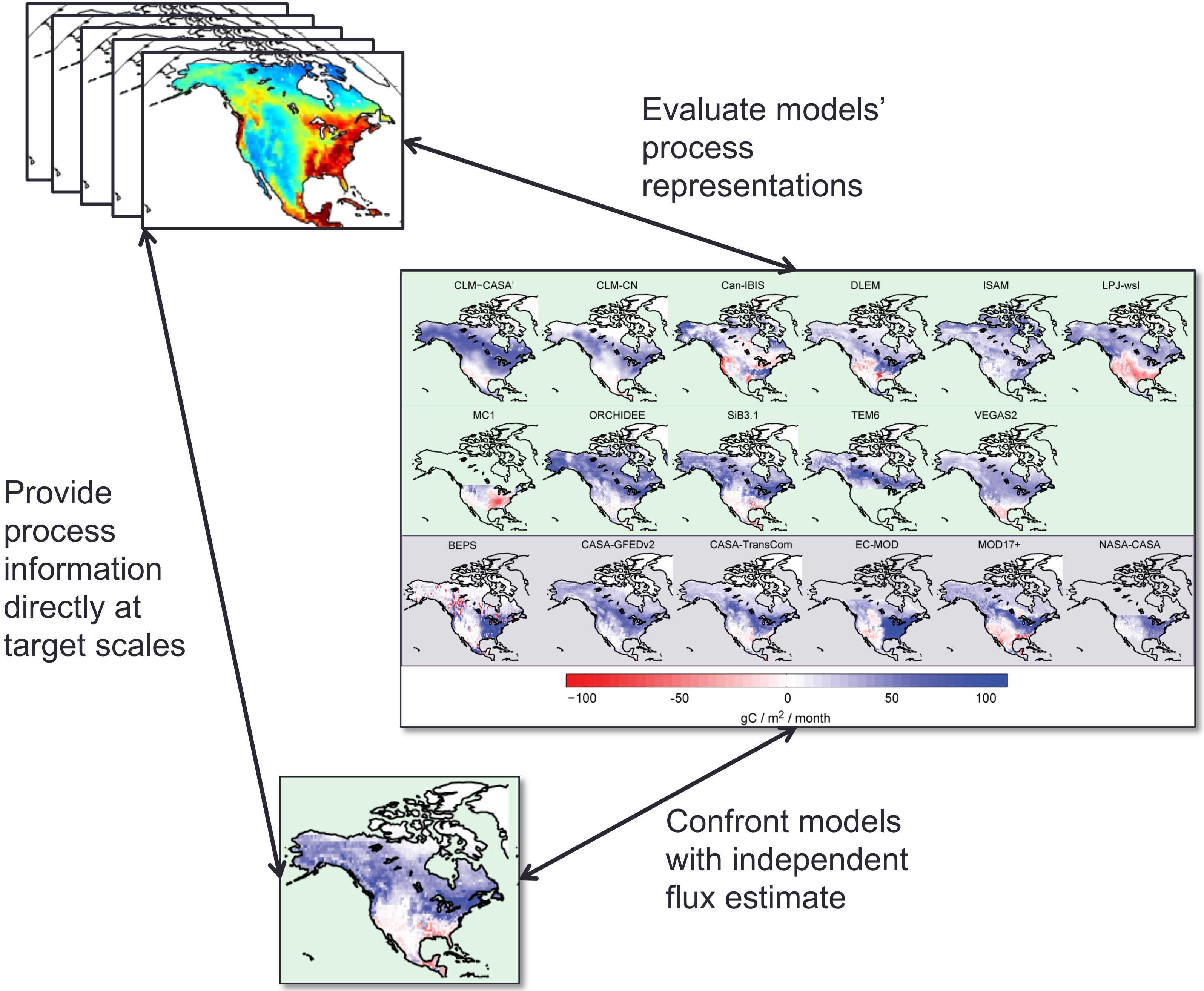

OCO-2
Dry-Air Column CO_2, B11.1
07/30/19 - 08/06/19 - 08/13/19
400 405 410 415 420 425
ppm
OCO-3
Dry-Air Column CO_2, B10.4
08/06/19 - 08/06/19 - 08/13/19
400 405 410 415 420 425
ppm

Image credit: NASA Earth Science Division


Concentration
Time
Concentration
Time



Provide data-driven budget estimates


Evaluate models' process representations
Provide process information directly at target scales
Confront models with independent flux estimate
CLM−CASA'
CLM-CN
Can-IBIS
DLEM
ISAM
LPJ-wsl
MC1
ORCHIDEE
SiB3.1
TEM6
VEGAS2
BEPS
CASA-GFEDv2
CASA-TransCom
EC-MOD
MOD17+
NASA-CASA
−100
-50
0
50
100
gC / m2 / month

Challenges

- Existing models cannot leverage quantity and diversity of available data. Models are limited in the types of observations that can be directly used, the spatiotemporal scales at which observations can be used to inform model structure and parameterization, and the ability to represent and track uncertainties.
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