Using CO_2, CH_4 and land-surface observations to resolve the sign and magnitude of northern high latitude carbon-climate feedbacks

TE2021 – ABoVE Phase 3 project

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Environmental change impacts on NHL biosphere-atmosphere GHG fluxes

Changing climate -> Carbon-climate feedback

Net increase in atmospheric CO2 & CH4 flux?

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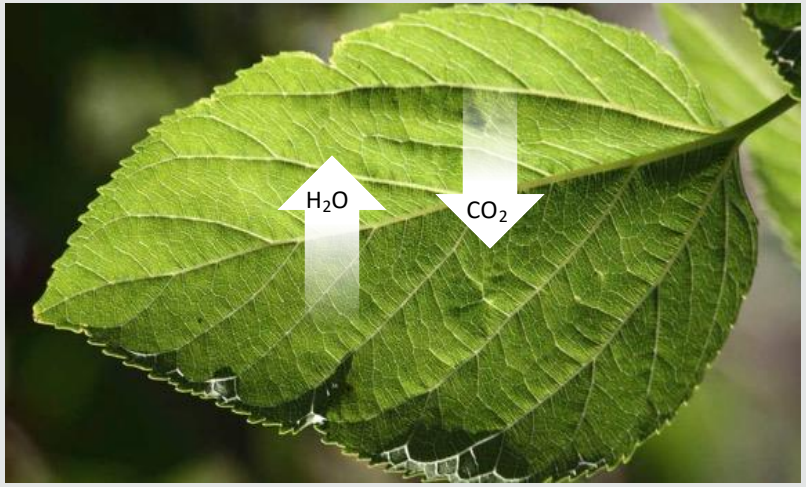
Net reductions in atmospheric CO2 & CH4 flux?

Responses to climate trends are regionally unique (Warming? Wetting? Snow cover changes? Other?)

Rising CO_2 -> Carbon-concentration feedback



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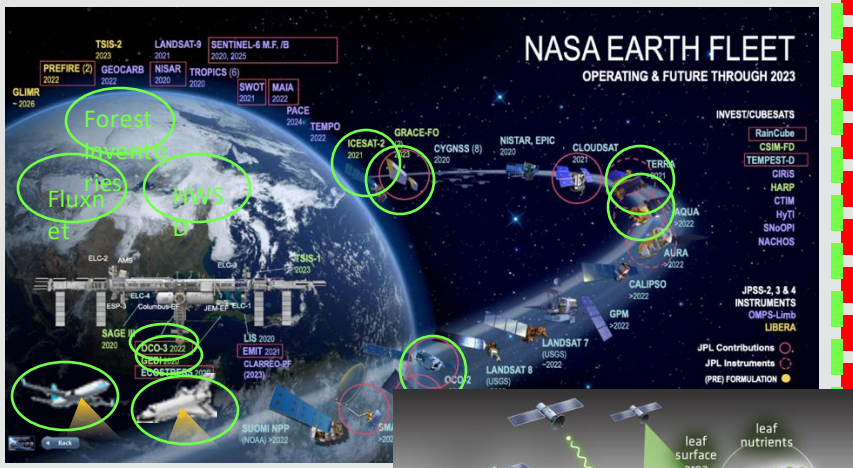
Net decrease in atmospheric CO2 burden…

Stomatal-level response to rising CO2, or "CO2 fertilization effect" enhanced ability to photosynthesize CO2 and/or to reduce water use.

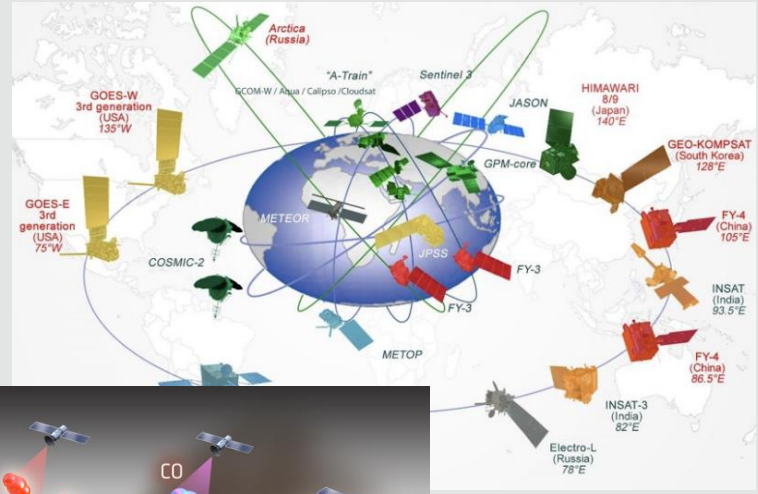
Multitude of land-atmosphere GHG responses to environmental forcing trends, net effect remains unknown

ABoVE domain CO_2 and CH_4 mediated feedback questions

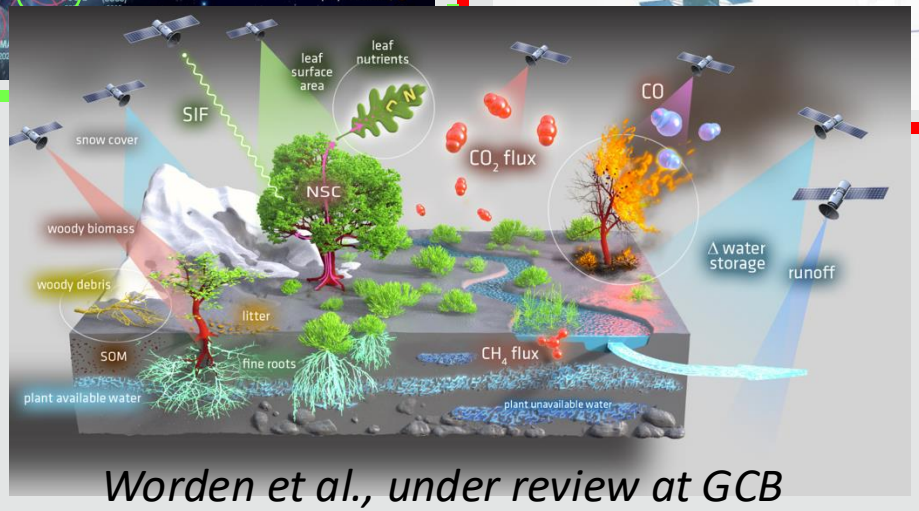
The CARDAMOM observing system



Constraints



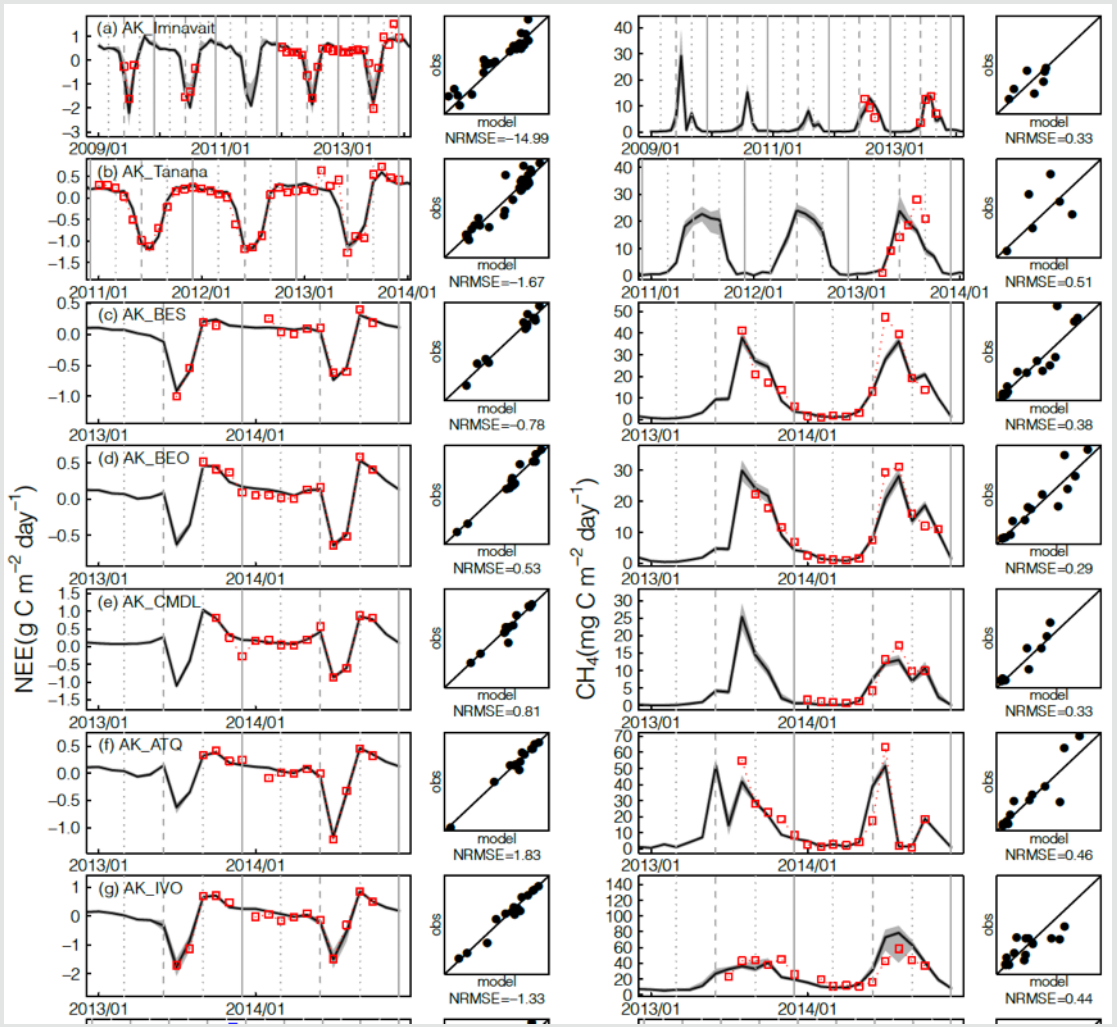
Forcing



Worden et al., under review at GCB

- ***Question 1:** How do ABoVE domain ecosystem CO_2 and CH_4 fluxes respond to multi-decadal climatic variability and trends?*
- ***Question 2:** Will the integrated ABoVE domain GHG (CH_4 + CO_2) flux responses to projected climate changes induce positive or negative carbon-climate feedbacks?*
- ***Question 3:** How does the integrated GHG (CH_4 + CO_2) flux response to climate, compare to the integrated GHG flux response to rising atmospheric CO2?*

Global warming potential of joint CH_4 and CO_2 climate sensitivities



Ma et al., 2023

Black = Optimized CARDAMOM fluxes

Red = Alaska eddy covariance datasets

(1) Combined effects of warming and wetting lead to opposing carbon-climate feedback responses across vegetation types.

(2) Knowledge of CH4 response to changes in temperature and precipitation key for resolving the sign and magnitude of the GWP-weighed GHG response of the biosphere

Global Biogeochemical Cycles

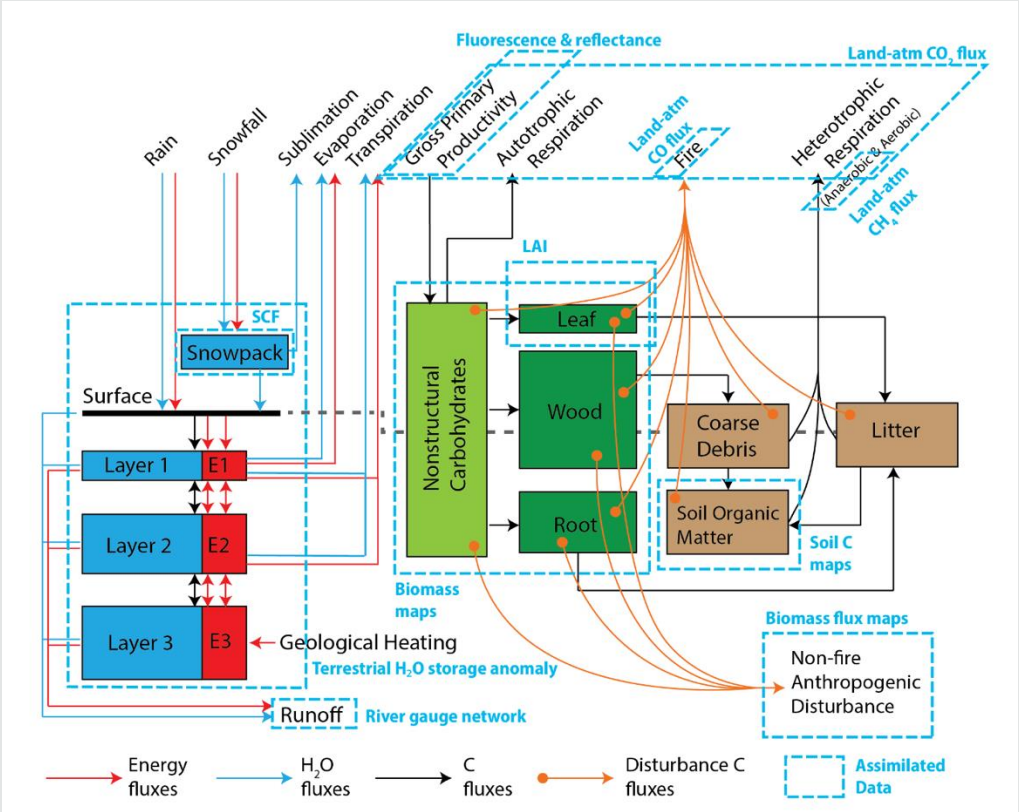
Research Article | Open Access

Resolving the Carbon-Climate Feedback Potential of Wetland CO_2 and CH_4 Fluxes in Alaska

Shuang Ma, A. Anthony Bloom, Jennifer D. Watts, Gregory R. Quetin, Zona Donatella, Eugénie S. Euskirchen, Alexander J. Norton, Yi Yin, Paul A. Levine ... See all authors

CARDAMOM global gridded run at 4x5 degrees, with disturbance fluxes

	Variable	Source/Description
Forcing data	**Atmospheric CO_2**, 2001-2021	NOAA ESRL
	Burned area, 2001-2021	GFEDv4, Randerson *et al.* (2018)
	Deforestation, 2001-2019	ISS GEDI, airborne LiDAR, etc, Xu *et al*. (2021)
	Meteorology, 2001-2021	ERA5 reanalysis
Constraining data	**GPP**, 2001-2019	FluxSat, Joiner *et al*. (2019)
	TWS, 2002-2021	GRACE/GRACE-FO, Wiese *et al*., 2016
	LAI, 2001-2016	Terra/Aqua MODIS, Myneni *et al*., 2015
	SCF, 2001-2021	Terra/Aqua MODIS, Hall *et al*., 2015
	Fire CO flux, 2010-2015	Terra MOPPIT, Jiang *et al.* (2016)
	CH_4 flux, 2010-2012	GOSAT, Ma *et al.* (2021)
	SOC, single value	HWSD, Hiederer and Köchy (2011)
	ABGB, 2001-2019	ISS GEDI, airborne LiDAR, etc, Xu *et al*. (2021)
	NBE, 2010-2021	OCO-2/3, Liu et al (2021)
	Runoff, 2001-2014	River gauge network, Ghiggi *et al*. (2019)



Bilir et al., *in review*

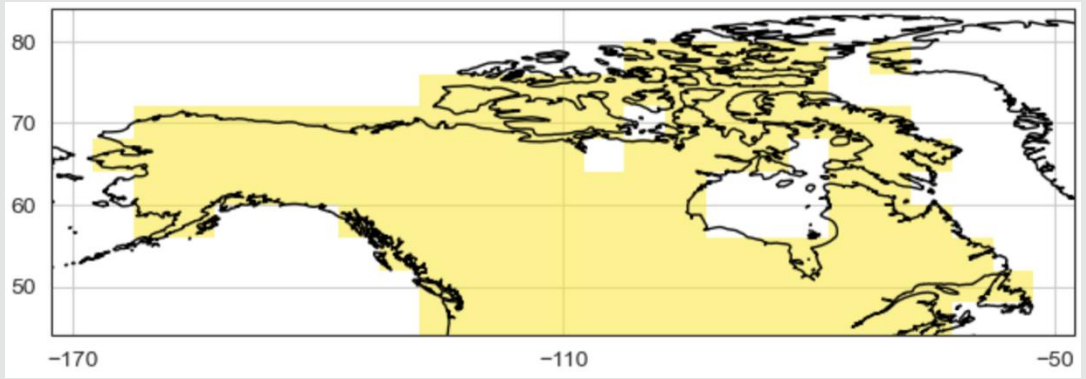
CO2 vs Climate sensitivity: attribution approach

Run name	Forcing Used
F0: Base case	Observed Climate, CO2, fire & deforestation
F1: Observed climate only	**2001 *detrended* climate**, with observed CO2, fire, deforestation maintained.
F2: Observed CO2 only	**2001-2021 *detrended* CO_2**, with observed climate, fire, deforestation maintained.
F3: Observed CO2 + Climate	**2001 *detrended* climate, 2001-2021 *detrended* CO_2**, with observed fire, deforestation maintained.

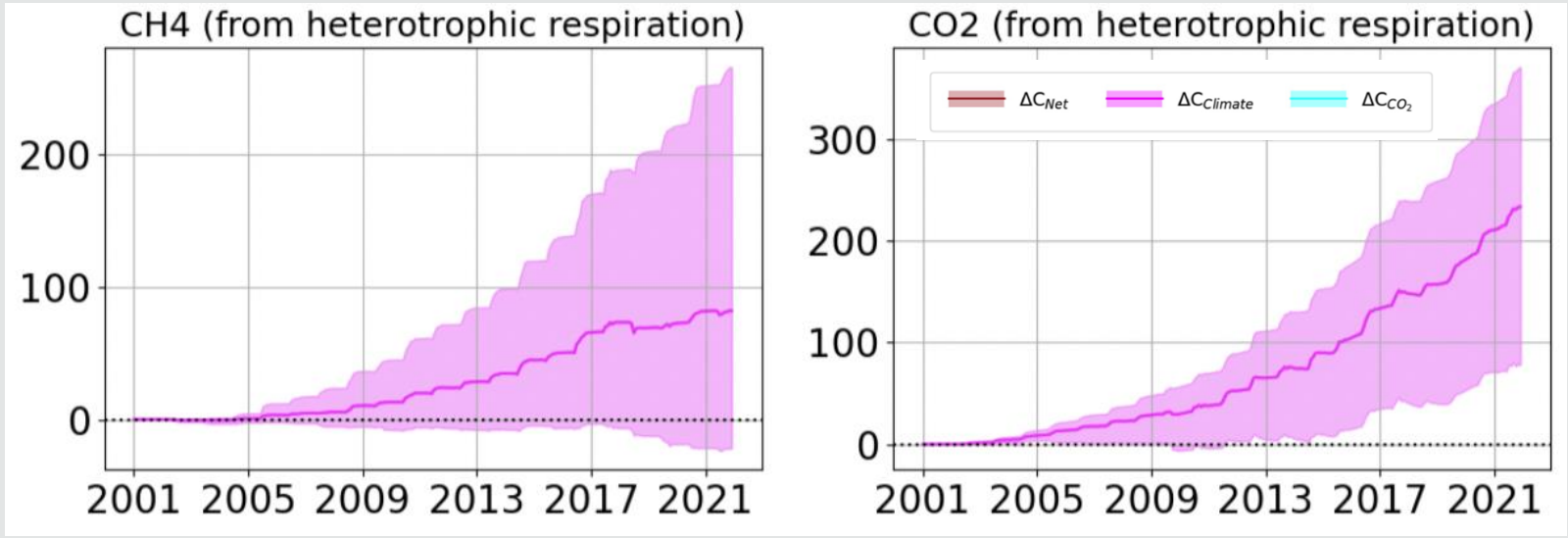
$$\Delta C_{Total} = \Delta C_{CO2} + \Delta C_{Climate} + \Delta C_{other}$$

ΔC_{CO2}: F2 – F0; $\Delta C_{Climate}$: F1 – F0; $C_{netCO2Climate}$: F3 – F0.

Heterotrophic respiration flux sensitivities: CO_2 & CH_4 climate sensitivities

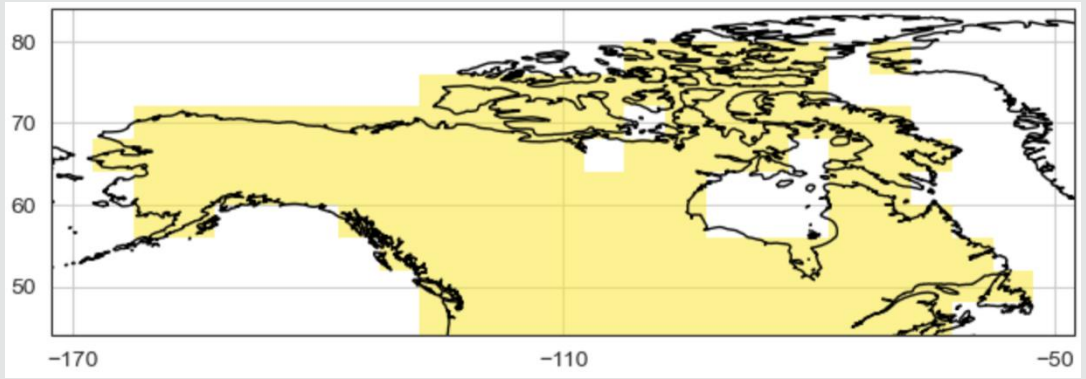


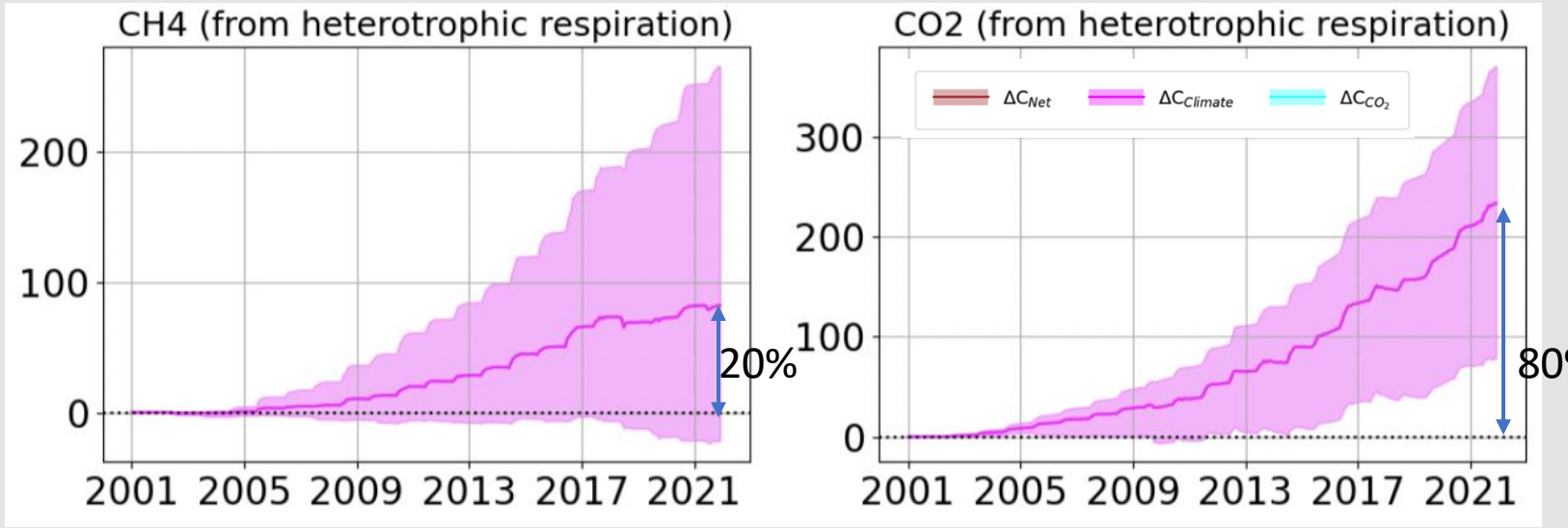
GHG flux response [$gCO_2eq_{(20yr)}$ m^{-2}]



25th-75th percentile

Heterotrophic respiration flux sensitivities: CO_2 & CH_4 climate sensitivities

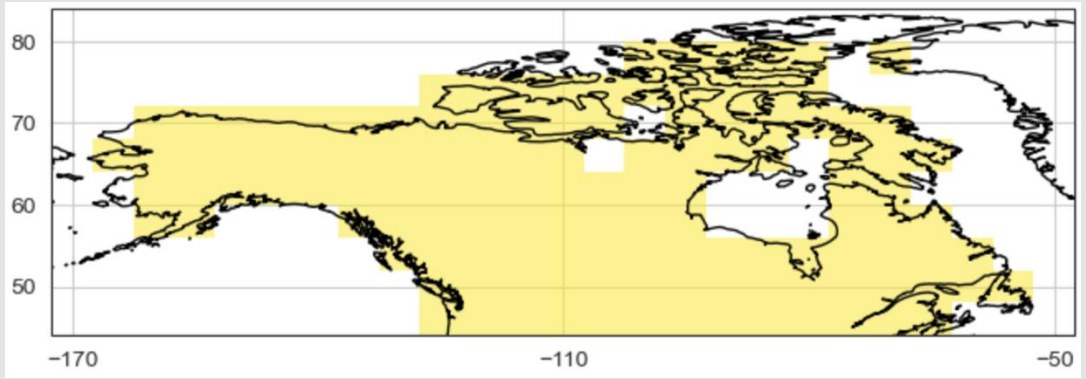




- ***Question 1:** How do ABoVE domain ecosystem CO2 and CH4 fluxes respond to multi-decadal climatic variability and trends?*

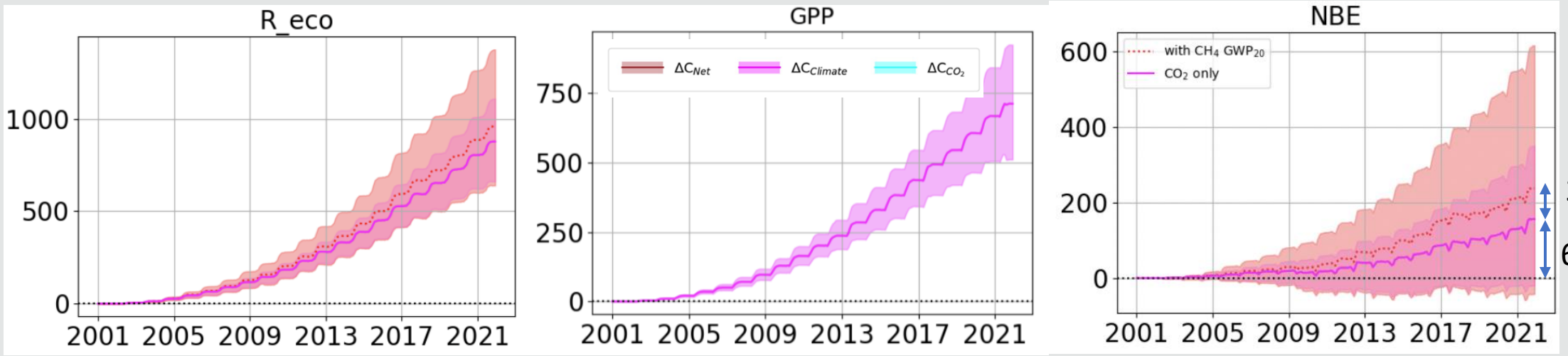
Result: CH4 accounts for 20% of GHG flux response to climate

Net land-atmosphere carbon flux: climate sensitivities



- ***Question 2: Will the integrated ABoVE domain GHG (CH_4 + CO_2) flux responses to projected climate changes induce positive or negative carbon-climate feedbacks?***

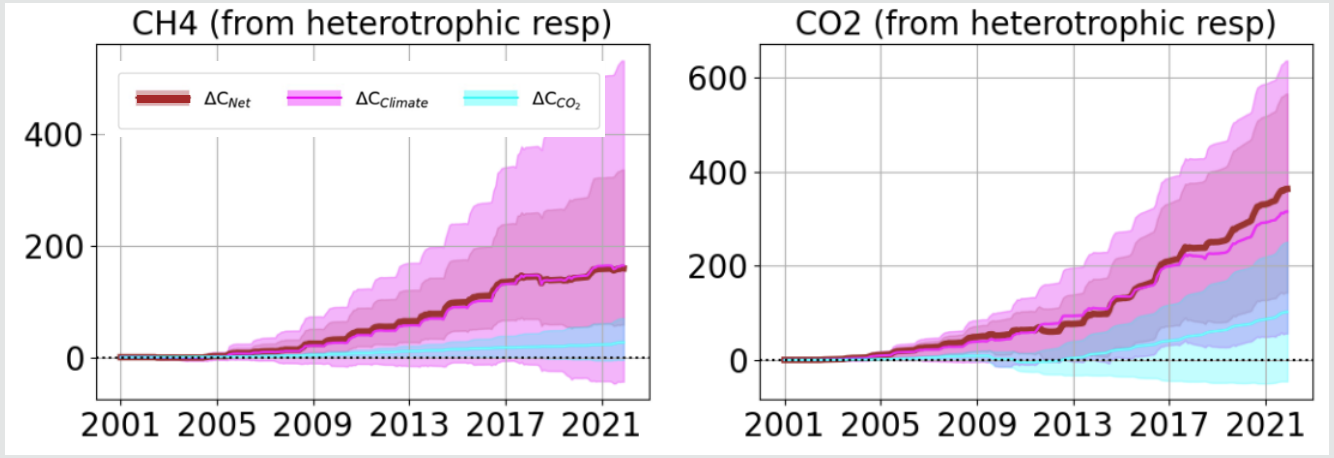
GHG flux response [$gCO_2eq_{(20yr)}$ m^{-2}]

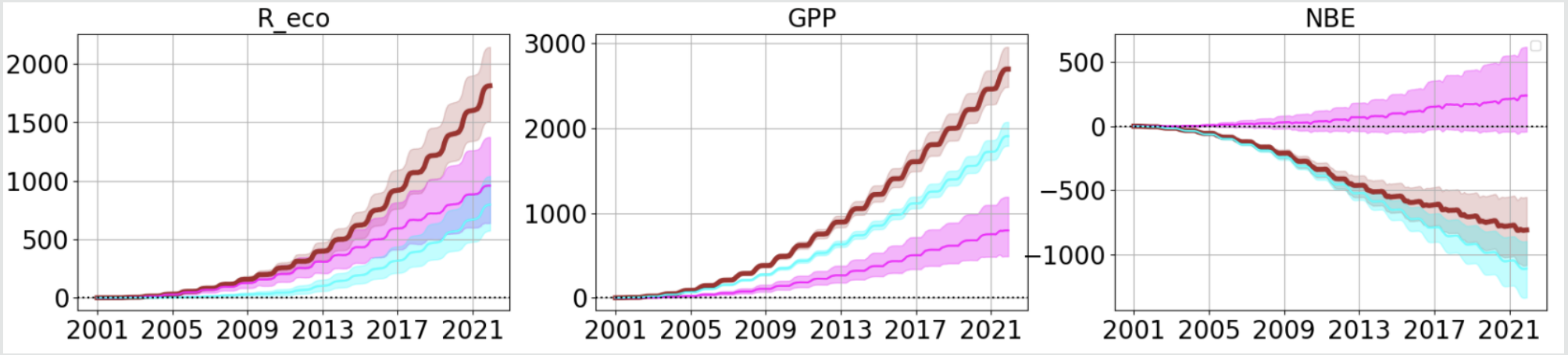


Result: positive climate-carbon feedback; CH4 accounts for ~1/3 of GWP

Net land-atmosphere carbon flux: climate and CO_2 sensitivities

- ***Question 3:* How does the integrated GHG (CH_4 + CO_2) flux response to climate, compare to the integrated GHG flux response to rising atmospheric CO2?**





GHG flux response [$gCO_2eq_{(20yr)}$ m^{-2}]

Result: negative feedback (CO2 fertilization dominance); CH4 reduces by 10%

Related poster

National Aeronautics and Space Administration

Using model-data fusion to resolve carbon-water-energy processes within the ABoVE domain

T. Eren Bilir[1], Shuang Ma[2], A. Anthony Bloom[1], Nicholas C. Parazoo[1], Junjie Liu[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, [2]University of California Los Angeles

1. Background & Motivation

As northern high latitudes warm faster than any other region on Earth, they are undergoing major functional shifts with uncertain consequences for global carbon, water, and energy cycling. Here, we show how satellite observations can be assimilated into a process-based terrestrial biosphere model (CARDAMOM, *fig. 1*) to provide a window into critical dynamical processes and interactions between the land biosphere's carbon, water and energy cycles.

2. Approach & Results

Data constraints (Gross Primary Productivity [GPP], Terrestrial Water Storage [TWS], Leaf Area Index [LAI], Snow-Covered Fraction [SCF], Above- and Below-ground Biomass [ABGB], Soil Organic Carbon [SOC], Fire CO emissions, wetland CH_4 emissions, Runoff, and Net Biosphere Exchange [NBE]) and **model drivers** (Meteorology, Deforestation, Burned Area, Atmospheric CO_2) inform CARDAMOM parameters.

Table 1: Datasets used

	Variable	Source/Description
Forcing data	**Atmospheric CO_2**, 2001-2021	NOAA ESRL
	Burned area, 2001-2021	GFEDv4, Randerson *et al.* (2018)
	Deforestation, 2001-2019	ISS GEDI, airborne LiDAR, etc, Xu *et al.* (2021)
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	NBE, 2010-2021	OCO-2/3, Liu et al (2021)
	Runoff, 2001-2014	River gauge network, Ghiggi *et al.* (2019)

CARDAMOM's simulations show:

- Methane (CH_4) flux sensitivities amount to 20% of the high-latitude positive feedback of soil respiration with climate change (*fig. 4*)
- CH_4 flux sensitivities cancel out 10% of the high-latitude negative feedback of the land sink with climate change (*fig. 4*)
- New energy and water balance processes and constraints improve representation of joint CO_2–CH_4 respiration fluxes, and additionally show promise for tracking permafrost thaw (*fig. 2*), streamflow temperatures (*fig. 3*), and riverine dissolved organic carbon export (*fig. 5*)

4. Future Work

- Incorporate glaciers for improved mass and energy flux attribution
- Further evaluate streamflow temperature and riverine DOC flux representations against existing data
- Add N cycle for explicit process linkages and attribution
- Produce datasets at finer resolution

Contact: teresa.e.bilir@jpl.nasa.gov

CARDAMOM at JPL

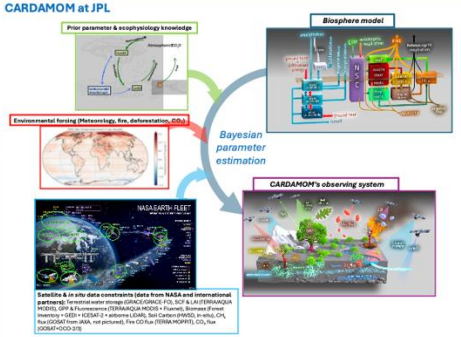


Figure 1: CARDAMOM (CARbon DAta MOdel fraMework) is a Bayesian model–data fusion platform that uses carbon, water, and energy cycling observations to inform estimates of the parameters governing pools and fluxes in a biosphere model.

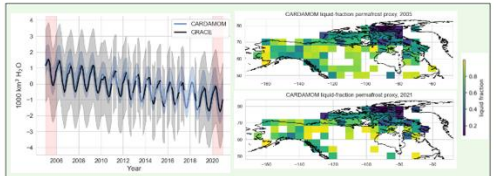
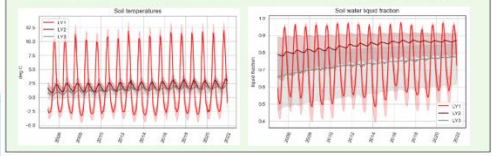


Figure 2: The GRACE satellite shows declines in water storage over high latitude North America. CARDAMOM reproduces this decline through increasing the liquid fraction in each of three soil layers, and exporting more liquid water via runoff and ET. These process linkages show the potential to diagnose permafrost thaw trends and the mechanistic environmental sensitivities of permafrost via joint constraints on water, carbon and energy cycling (*tab. 1*).



Jet Propulsion Laboratory
California Institute of Technology

This research was supported by NASA Earth Sciences grant **NNH21ZDA001N-TE**, "Using CO_2, CH_4 and land-surface observations to resolve the sign and magnitude of northern high latitude carbon-climate feedbacks"

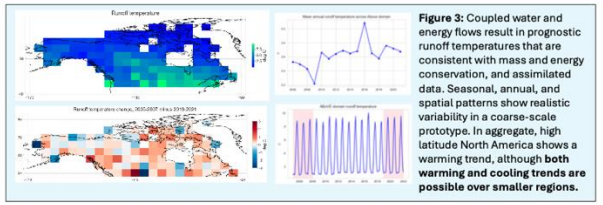


Figure 3: Coupled water and energy flows result in prognostic runoff temperatures that are consistent with mass and energy conservation, and assimilated data. Seasonal, annual, and spatial patterns show realistic variability in a coarse-scale prototype. In aggregate, high latitude North America shows a warming trend, although **both warming and cooling trends are possible over smaller regions.**

Figure 4 (right): CARDAMOM's mechanistic process representations and closed-budget biogeochemical cycles make it well-suited to counterfactual experiments. With new constraints on the seasonality of temperature and moisture states modulating aerobic and anaerobic microbial activity, we make a new estimate of carbon flux sensitivities to rising CO_2 and climate change over high-latitude North America using the following factorial approach:

Run name	Forcing Used
F0: Base case	Observed Climate, CO2, fire & deforestation
F1: Observed climate only	**2001 *detrended* climate**, with observed CO2, fire, deforestation maintained.
F2: Observed CO2 only	**2001-2021 *detrended* CO_2**, with observed climate, fire, deforestation maintained.
F3: Observed CO2 + Climate	**2001 *detrended* climate, 2001-2021 *detrended* CO_2**, with observed fire, deforestation maintained.

ΔC_{CO2}: F2 – F0; $\Delta C_{Climate}$: F1 – F0; $C_{netCO2Climate}$: F3 – F0.

$$\Delta C_{Total} = \Delta C_{CO2} + \Delta C_{Climate} + \Delta C_{other}$$

Both aerobic (CO_2, top panel) and anaerobic (CH_4, second panel) respiratory fluxes show positive feedbacks with both climate trends and CO_2 rise. **In terms of warming potential over 20 years (GWP_{20}), anaerobic (CH_4) respiratory fluxes amount to ~20% of the net heterotrophic respiration response.**

The response of net land-atmosphere CO_2 exchange is an enhanced land sink (bottom panel), because the positive response of GPP (4th panel) outweighs that of R_eco (3rd panel). **In terms of GWP_{20}, the CH_4 response cancels out ~10% of the enhanced land CO_2 sink.**

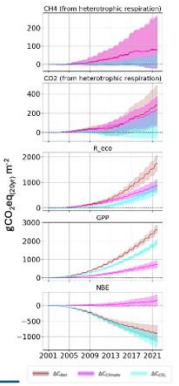
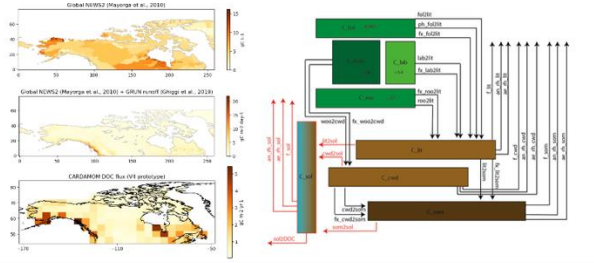


Figure 5: Carbon cycle constraints on respiration and energy cycle constraints on freeze-thaw inform production of soluble carbon states in CARDAMOM's soils. Water cycle constraints on timing and amount of runoff work with this new pool to generate riverine DOC fluxes that are mechanistically responsive to changing environmental conditions.



Summary & future efforts

- Joint CO_2 and CH_4 sensitivities have been jointly resolved in a gridded protype with improved water and energy balance.
- Across domain, GWP impact of CO_2 fertilization effect dominates over climate feedbacks
- Next steps: Continue model development: permafrost, streamflow temperature, river DOC fluxes (separate effort)
- Next steps: Continue with integration of ABoVE aircraft data
- Dataset: publish a 1x1 carbon water energy reanalysis product; anticipate publication on joint GHG flux responses

Program Stats

- Support: two postdocs (Shuang Ma, Eren Bilir), PI (Anthony Bloom)
- Engagement: multiple conference presentations from Shuang Ma and Anthony Bloom
- Products: 1 publication (Ma et al., 2023) and expected future paper (Bilir et al, in prep) along with dataset