Accelerating rates of Arctic carbon cycling revealed by long-term atmospheric CO_2 measurements

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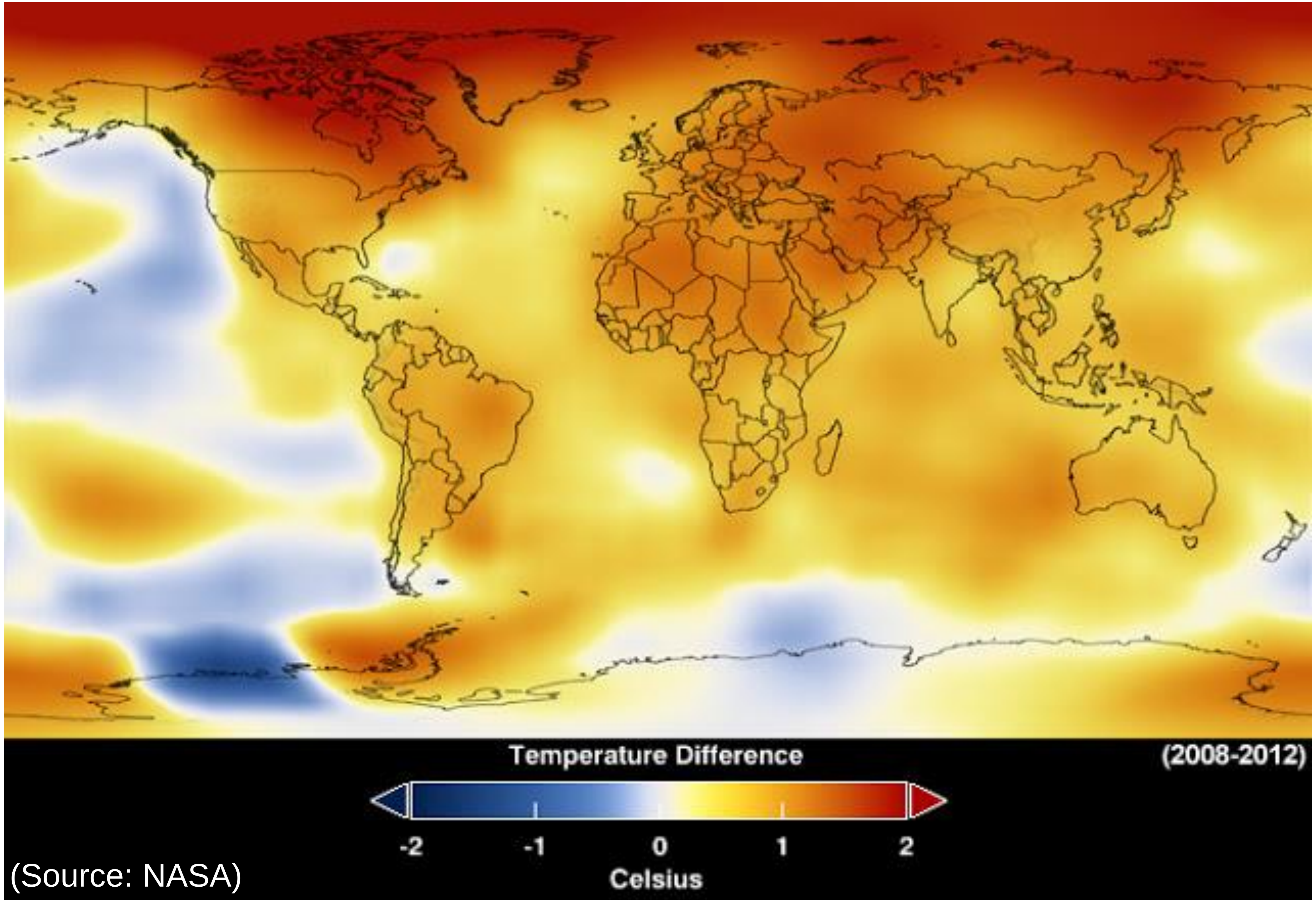
Figure source: NASA

APEC Climate Center, Pusan, 2018. 1. 31

Arctic warming



(Source: NASA)

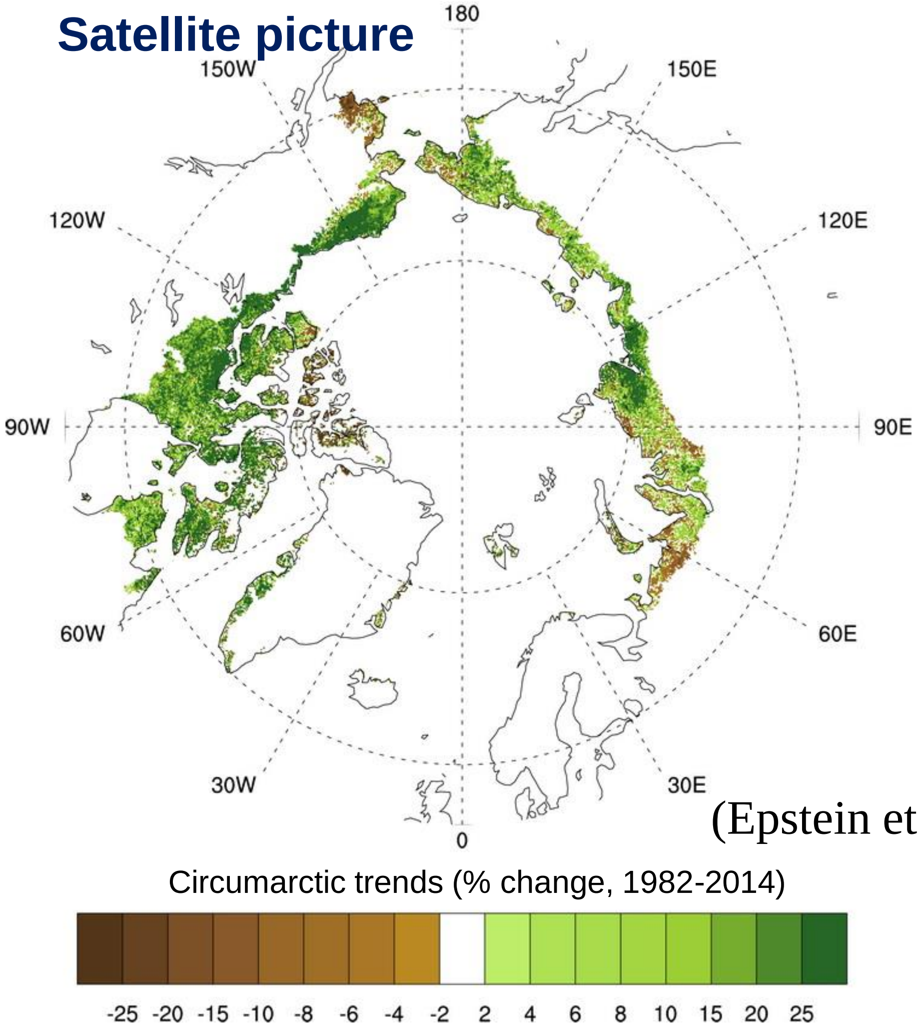
Shrubification

Camera picture

(Sturm et al., 2001)

"Shrub expansion over Alaskan arctic regions"

Satellite picture

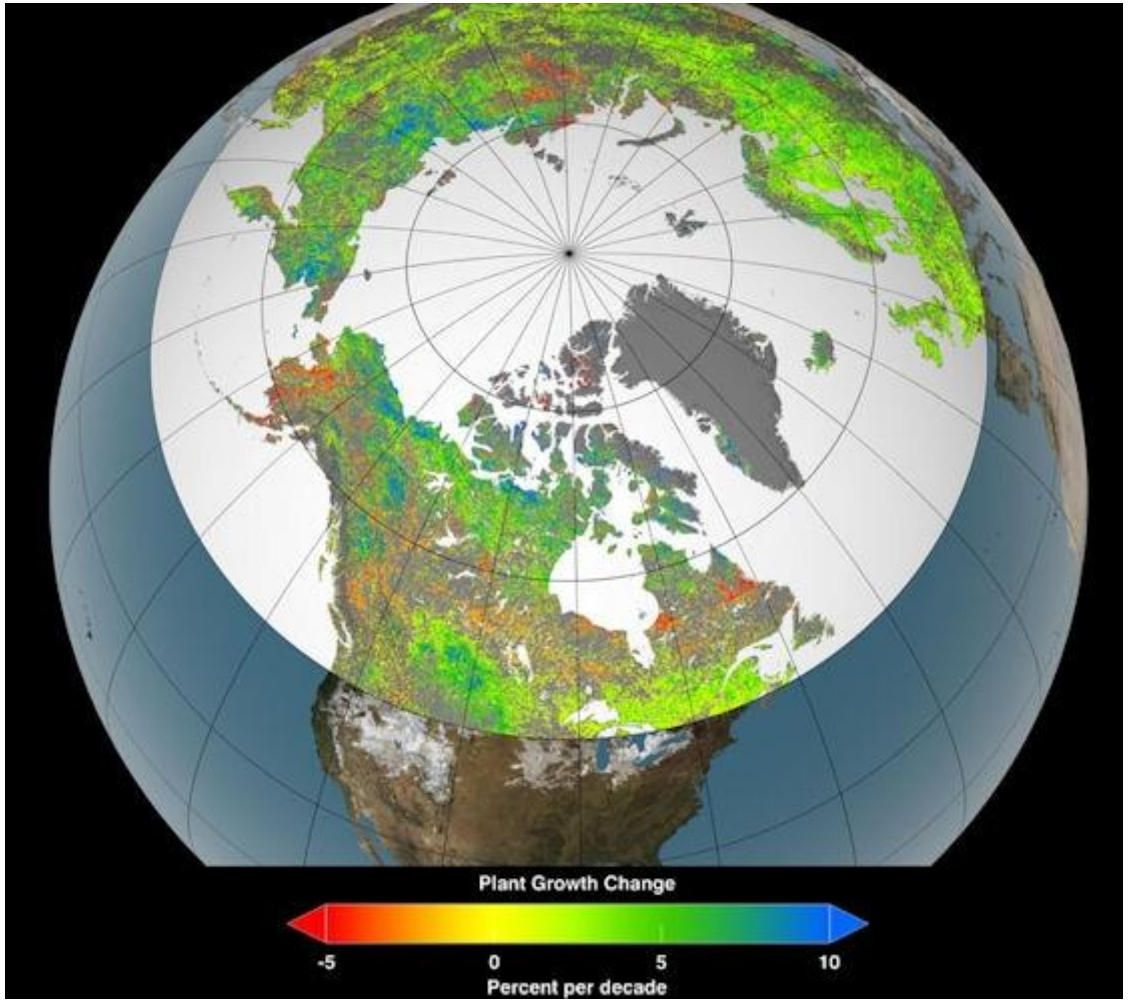


Circumarctic trends (% change, 1982-2014)

(Epstein et al., 2015)

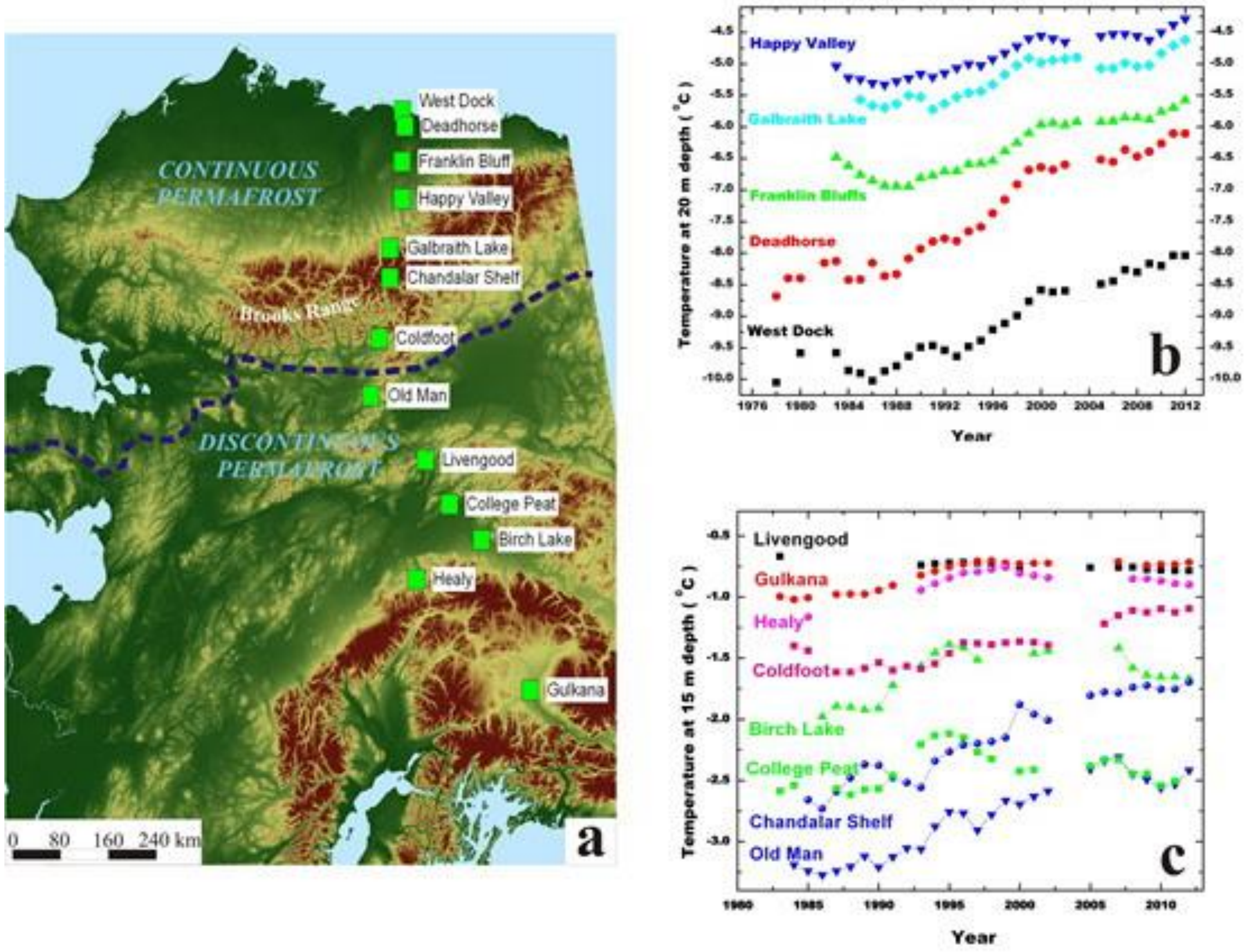
"Enhancing greenness in arctic tundra"

Greening



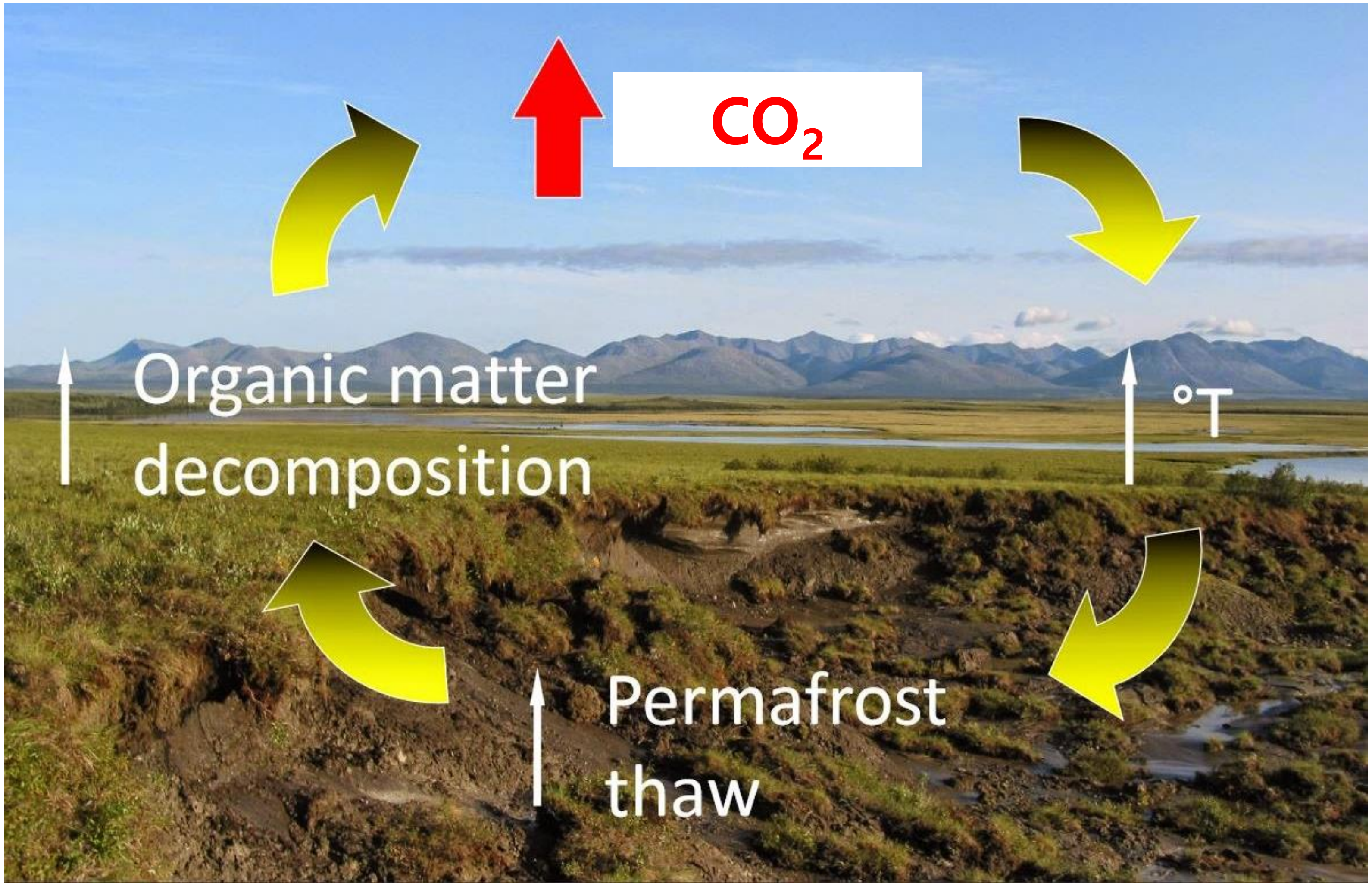
Xu et al., 2013
Nature Climate Change

Permafrost warming



[From V. Romanovsky, www.arctic.noaa.gov/report12]

Permafrost carbon feedback to warming



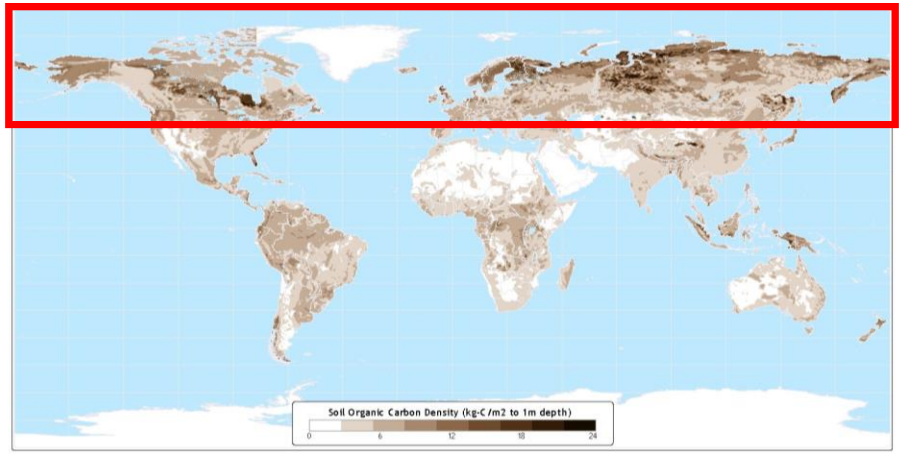
Permafrost

Permafrost is soil at or below the freezing point of water 0 °C for two or more years.

Permafrost distributions (24%)

International permafrost association (1998)

Soil carbon



IGBP-Global soil carbon data (1998)

Northern circumpolar permafrost soil carbon content equals approximately 1672 Pg. This is more than double the amount currently in the atmosphere.

Potential to change carbon cycle

Arctic warming

[Vegetation]

Increasing biomass productivity

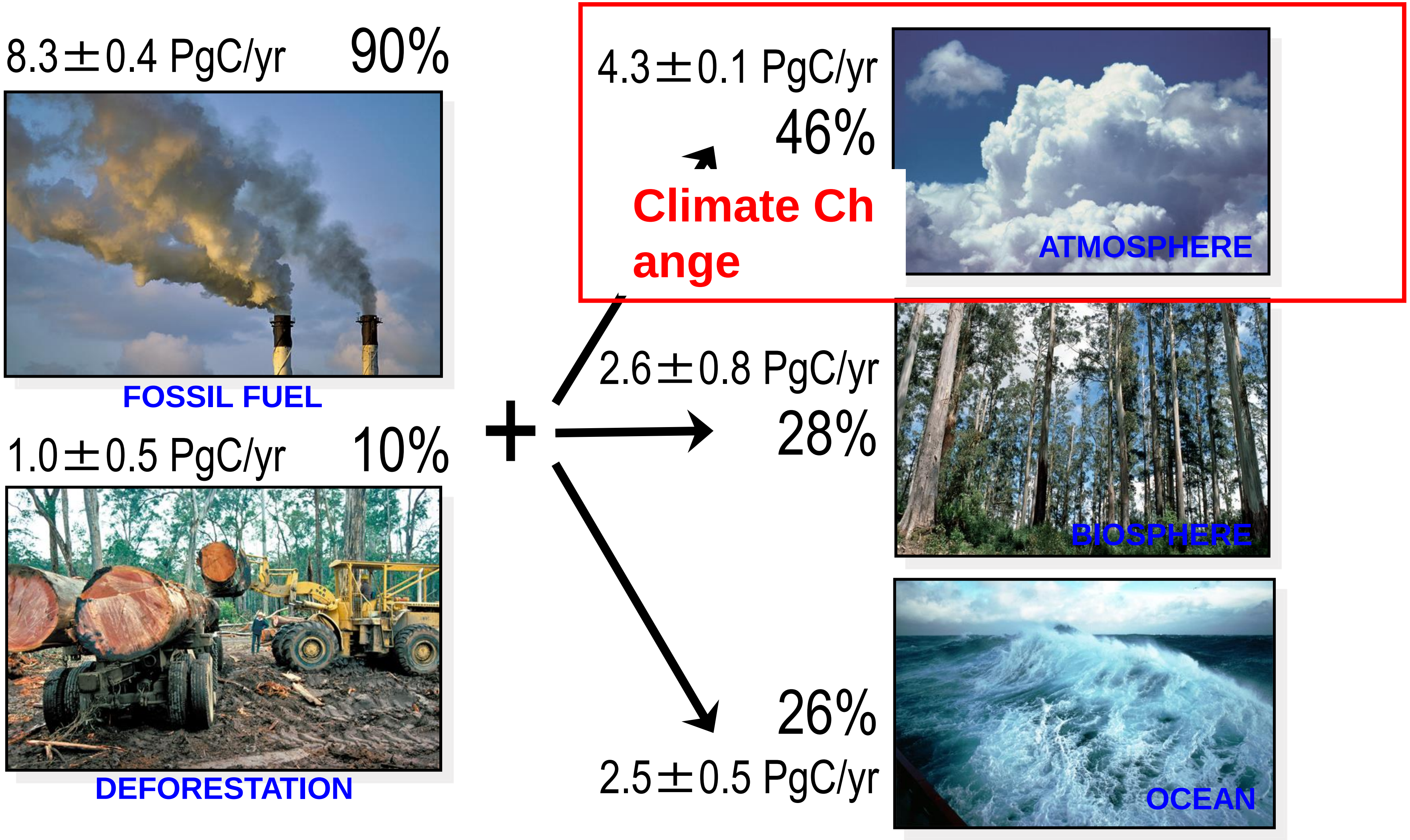
Potential of enhancing carbon uptake

[Soil]

Permafrost thawing

Potential of enhancing carbon release

Global Carbon Cycle



8.3±0.4 PgC/yr 90%

FOSSIL FUEL

1.0±0.5 PgC/yr 10%

DEFORESTATION

+

4.3±0.1 PgC/yr 46%

Climate Change

ATMOSPHERE

2.6±0.8 PgC/yr 28%

BIOSPHERE

26%

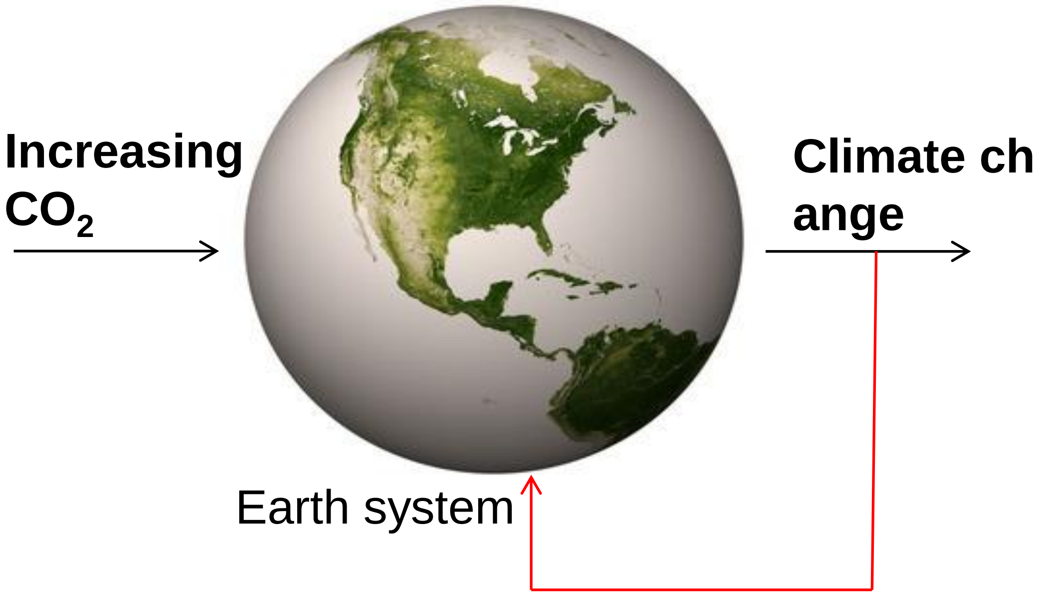
2.5±0.5 PgC/yr

OCEAN

Global budget (1994-2013)

Source: Le Quéré et al. 2014; Global Carbon Project 2014

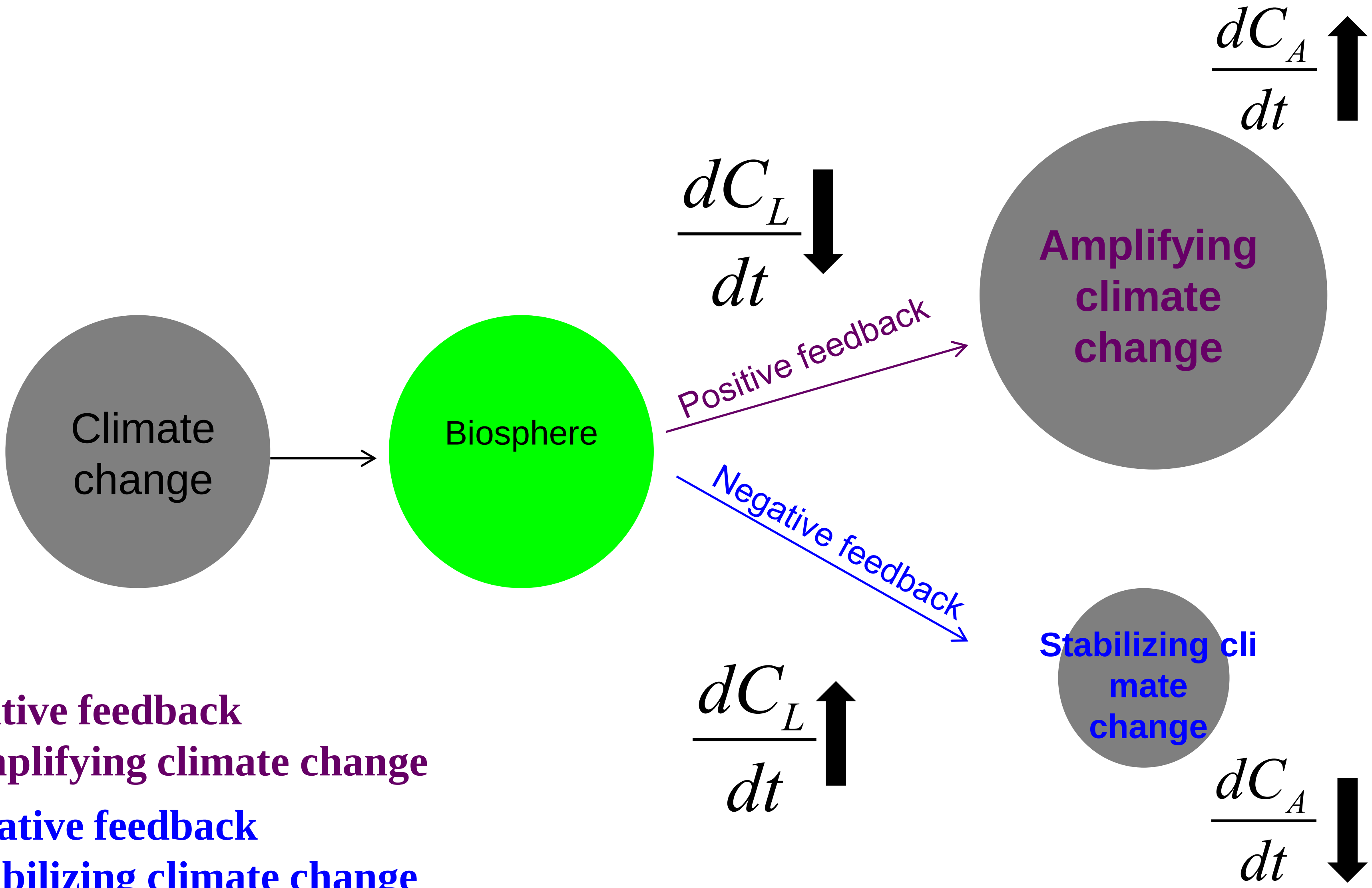
Carbon-Climate Feedback



Increase in **atmospheric CO_2** amount by human activity determine the magnitude of **climate change**.

Climate Change in turn change the **atmospheric CO_2** amount by affecting the carbon cycle in the Earth system.

Positive/Negative Feedback



Positive feedback
: amplifying climate change

Negative feedback
: stabilizing climate change

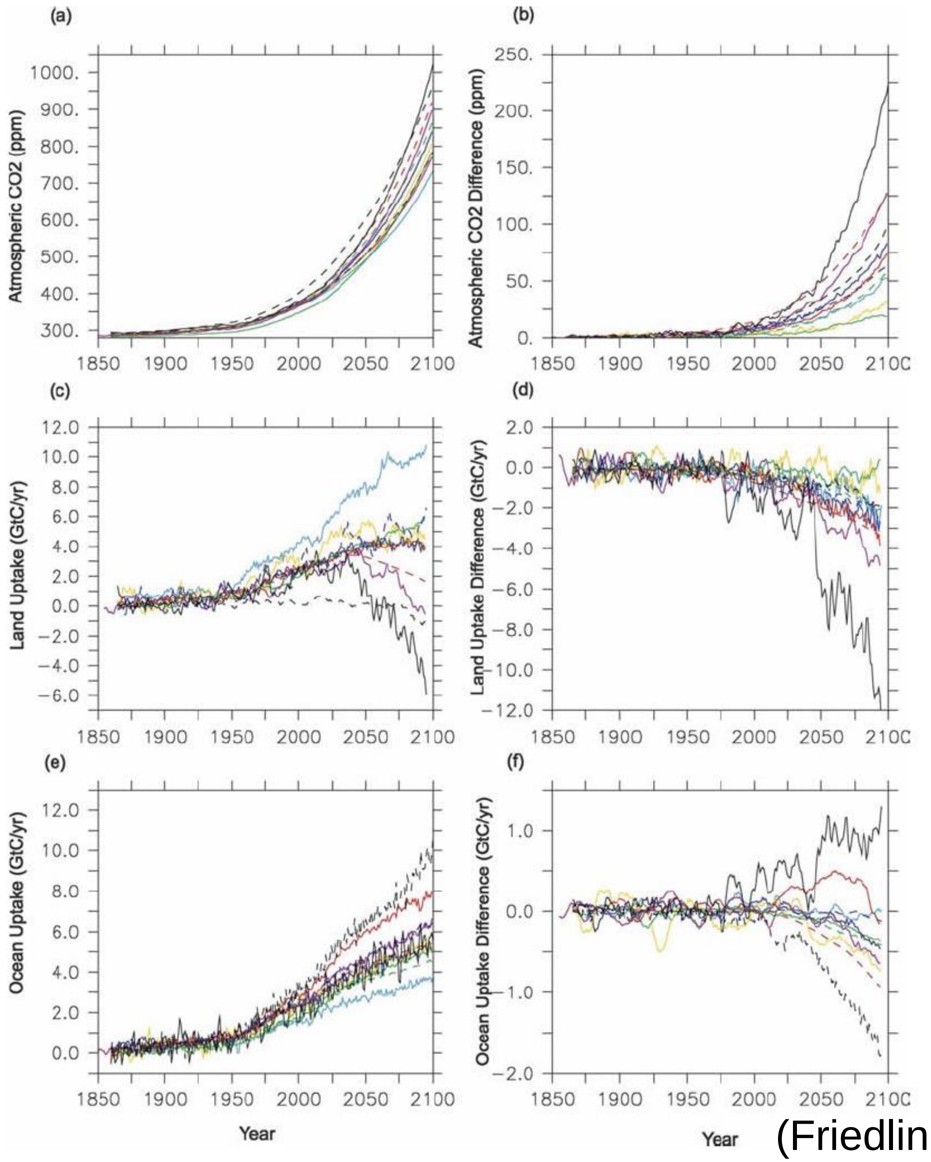
Uncertainty in future projections

Uncertainty in future climate projection

Uncertainty in atmospheric CO2 concentration

Uncertainty in terrestrial carbon uptake

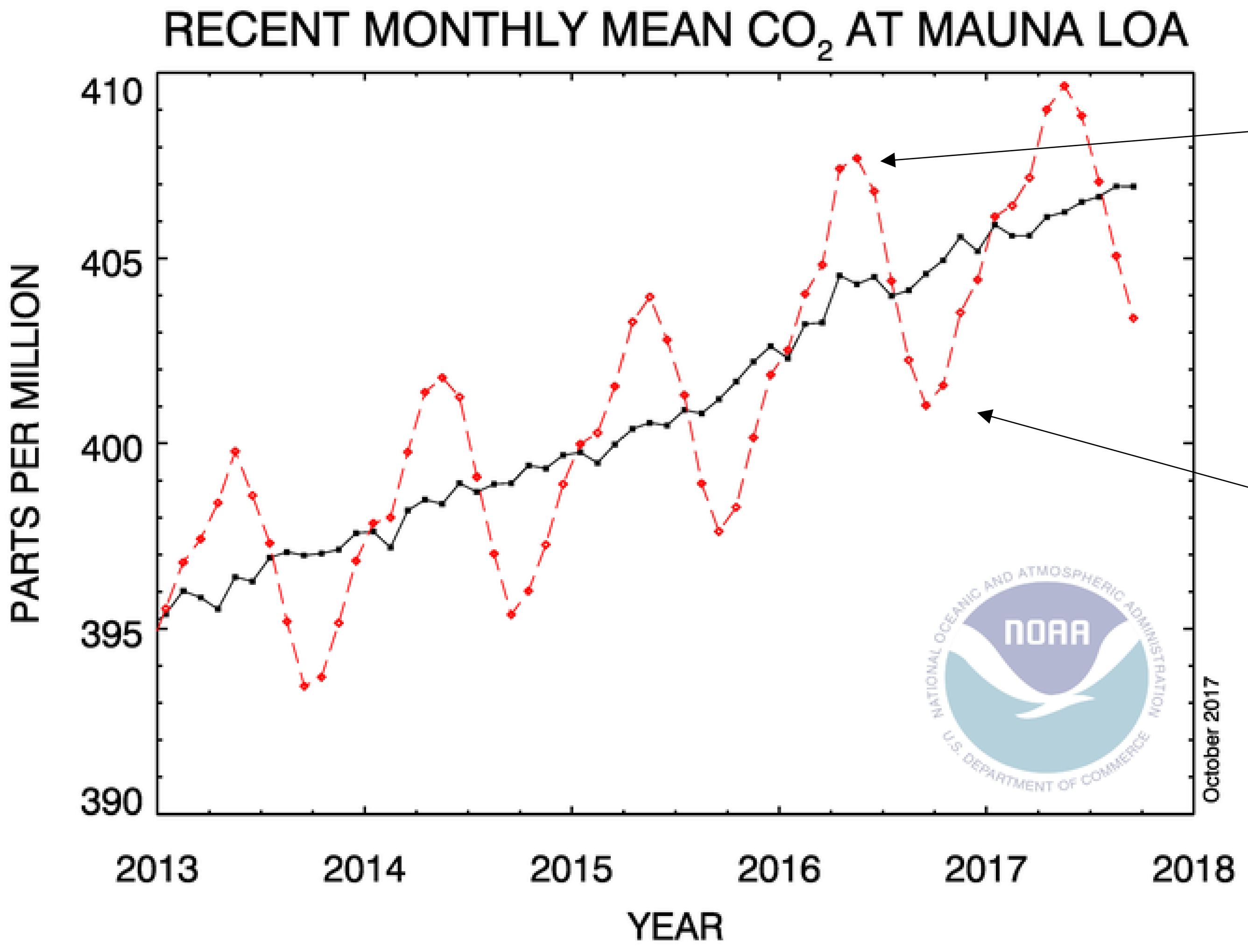
Uncertainty in vegetation dynamics



The uncertainty in future climate projection is mainly attributed to land surface problems.

(Friedlingsteing et al. 2006)

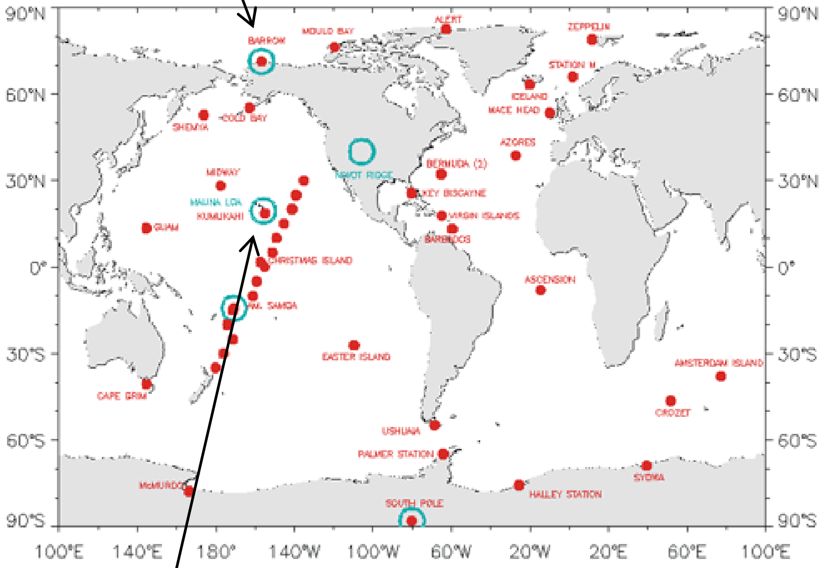
Atmospheric fingerprint



Ridge of seasonal cycle
: sign of land carbon release
: dormancy of ecosystem

Trough of seasonal cycle
: sign of land carbon uptake
: activation of ecosystem

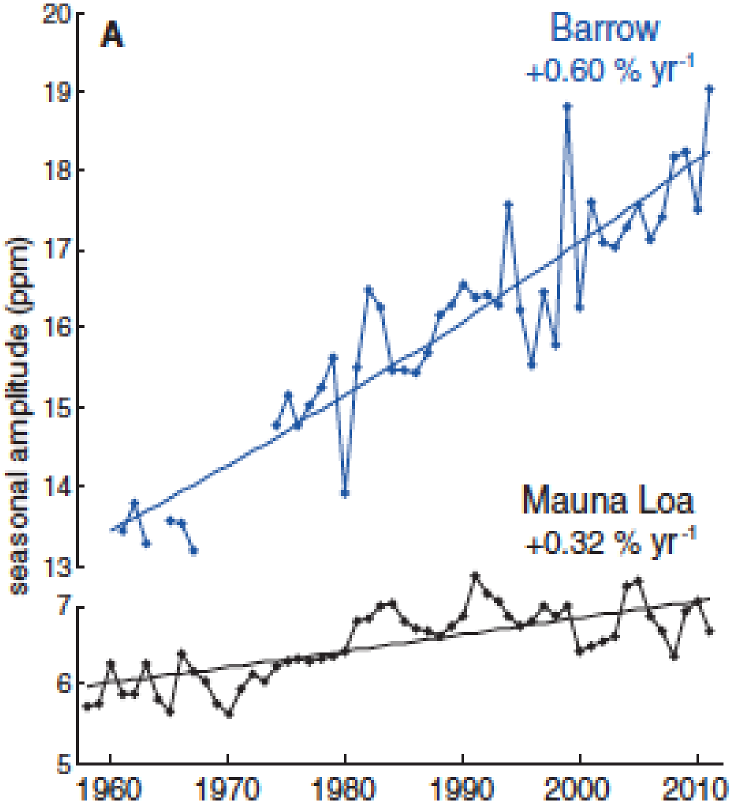
Enhancing CO_2 seasonal cycle



Barrow (71°N)

Mauna Loa (19°N)

Source: NOAA

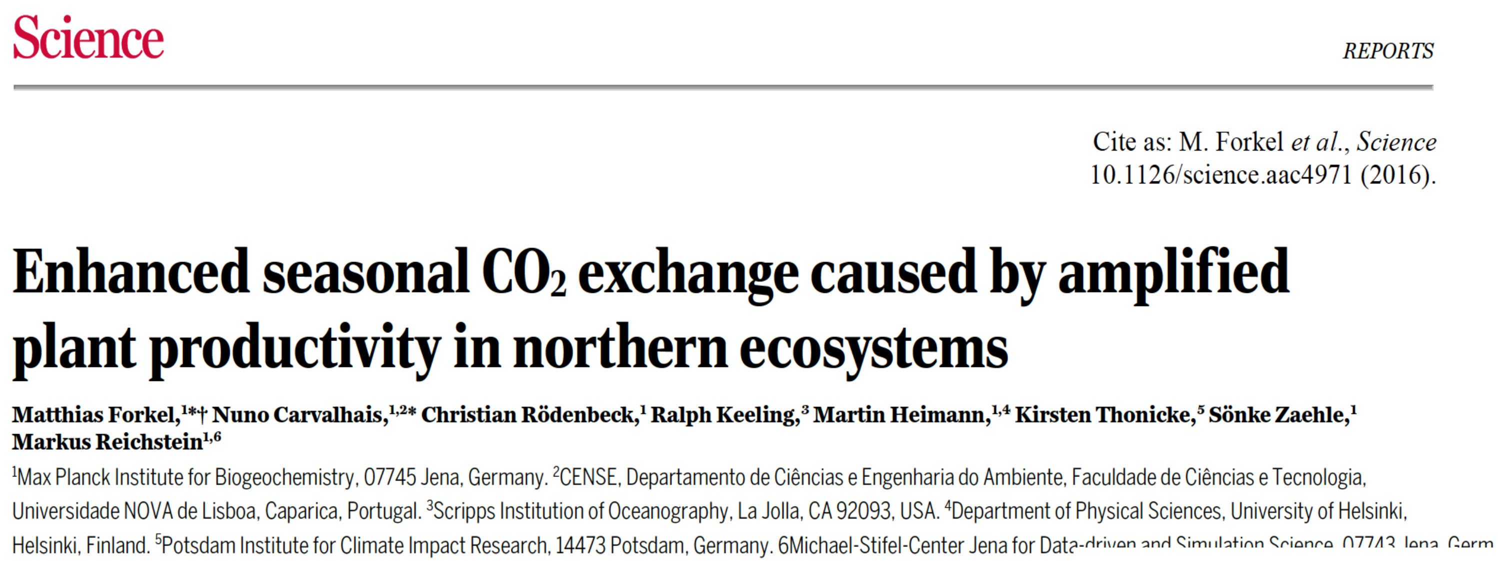


Graven et al., 2013

Science

Potential of significant ecosystem change in high latitudes

Vegetation vs Soil



Science

REPORTS

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Enhanced seasonal CO_2 exchange caused by amplified plant productivity in northern ecosystems

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Forkel et al. 2016
Science

REVIEW

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Climate change and the permafrost carbon feedback

E. A. G. Schuur[1,2], A. D. McGuire[3], C. Schädel[1,2], G. Grosse[4], J. W. Harden[5], D. J. Hayes[6], G. Hugelius[7], C. D. Koven[8], P. Kuhry[7], D. M. Lawrence[9], S. M. Natali[10], D. Olefeldt[11,12], V. E. Romanovsky[13,14], K. Schaefer[15], M. R. Turetsky[11], C. C. Treat[16] & J. E. Vonk[17]

Schuur et al. 2015
Nature

Vegetation vs Soil

1. **Greening: increase in carbon uptake (Forkel et al., 2016 Science)**

2. **Warming permafrost: increase in carbon release (Schuur et al., 2015 Nature)**

1 and 2 both can contribute to amplifying seasonal cycle of atmospheric CO_2 over high-latitudes

Our hypothesis

Especially in Arctic regions, with vast amounts of carbon stored in both the active layer and the underlying permafrost, an increase in soil carbon turnover due to increasing temperatures could transform the Arctic carbon balance to a permanent source.

"Arctic warming leads to simultaneous increases in carbon uptake and respiration, and hence a decrease in the mean carbon residence time within the Arctic ecosystem"

Placing observational constraints on Arctic carbon residence time is therefore key to understanding the evolution of Arctic carbon balance and disentangling changes in productivity and respiration.

Residence time

Residence time

The average length of time that material spends in a given pool. Residence time depends on the rate of outflow and on the size of the pool. Residence time is the mathematical inverse of turnover rate.

* 10 monkeys / (2 monkeys / hour) = 5 hours

Turnover rate

The fraction of material that leaves a pool in a specified time interval. Turnover rate is the mathematical inverse of residence time.

* (2 monkeys / hour) / 10 monkeys = 0.2 per hour

Challenge

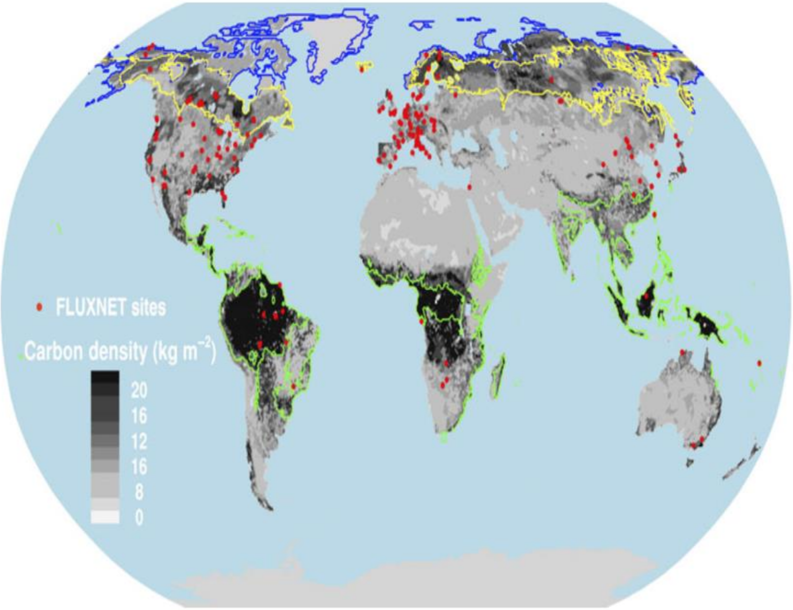


Fig. 1 Spatial distribution of terrestrial vegetation and soil carbon storage with the three 'tipping element' regions identified b
et al. (2008). The tipping elements coincide with regions of high storage and hence high potential for losses to influence atm
concentrations. Red points show the distribution of carbon flux observations, showing that this network, like the others assesse
study have sparse coverage in the tipping element regions. Data from Ruesch & Gibbs (2008) and FAO *et al.* (2009).

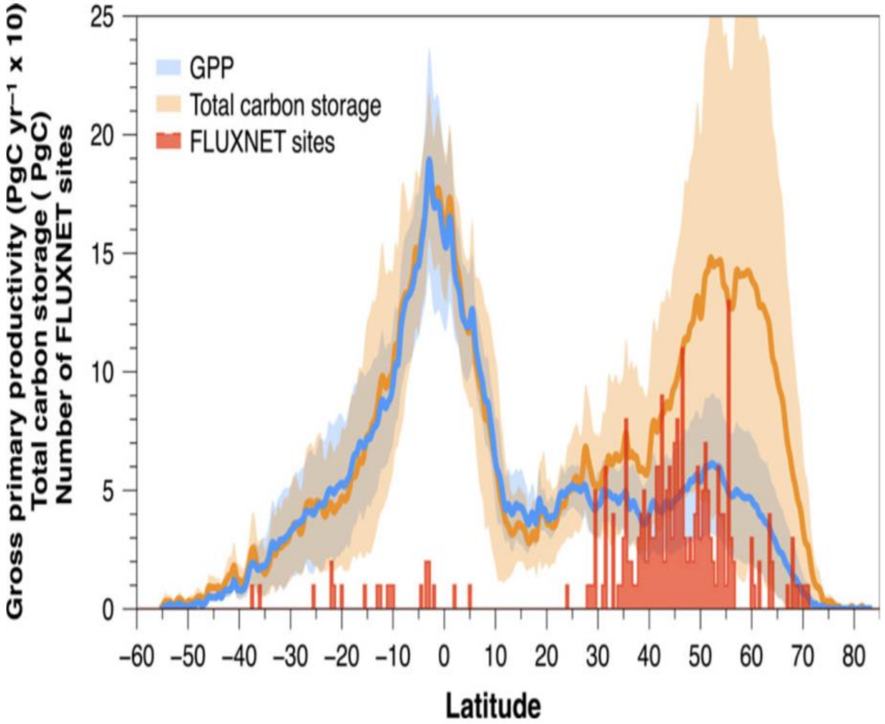


Fig. 3 The two 'poles' – tropical and arctic/boreal – of the terrestrial carbon cycle. The modeled distribution of GPP and total (soil plus vegetation) carbon storage. FLUXNET sampling spans the latitude range of global land, but sampling is sparse in regions with high flux (GPP) and storage.

Schimel et al., 2015

Seasonal limitation

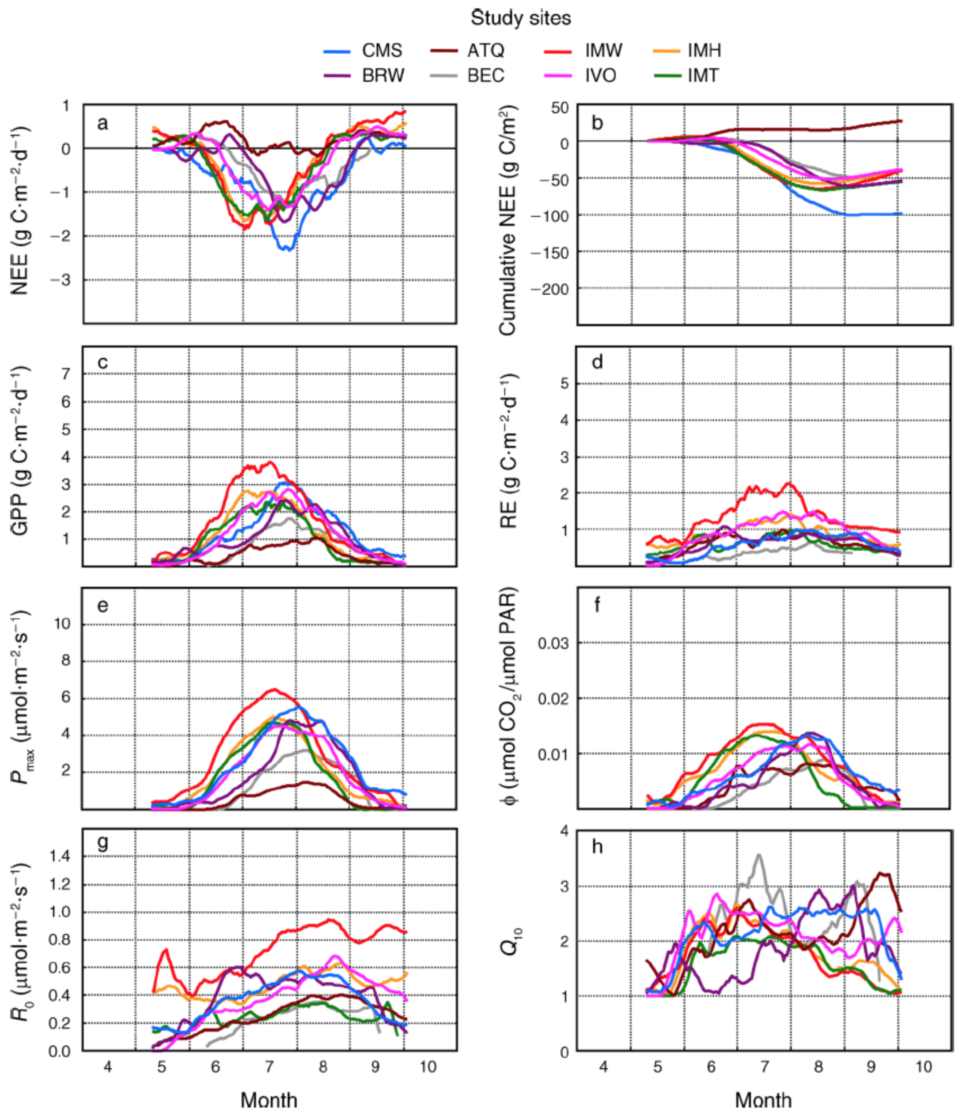


FIG. 2. Mean seasonality of (a) net ecosystem exchange (NEE), (b) cumulative NEE, (c) gross primary productivity (GPP), (d) ecosystem respiration (RE), (e) maximum photosynthetic rate (P_{max}), (f) initial slope for a non-rectangular hyperbola (ϕ), (g) RE at 0°C (R_0), and (h) temperature sensitivity coefficient of RE (Q_{10}) for the tundra ecosystems. Study sites are identified in *Methods: Study sites*. PAR stands for photosynthetically available radiation.

Ueyama et al., 2013

New method

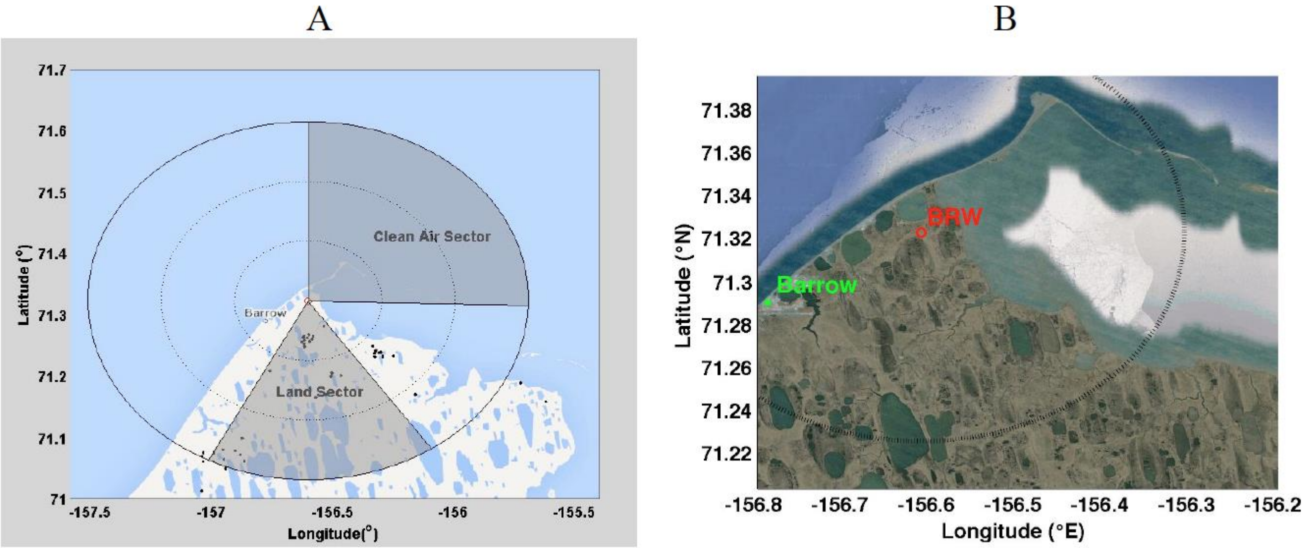


Figure S1. *Map of the NOAA Barrow CH_4 observation site (BRW). A) The "Clean Air Sector" is designated as the region where winds are coming from 0-90^0 and the "Land Sector" is the region where winds are coming from 150-210^0. Black dots indicate the location of oil and natural gas wells*

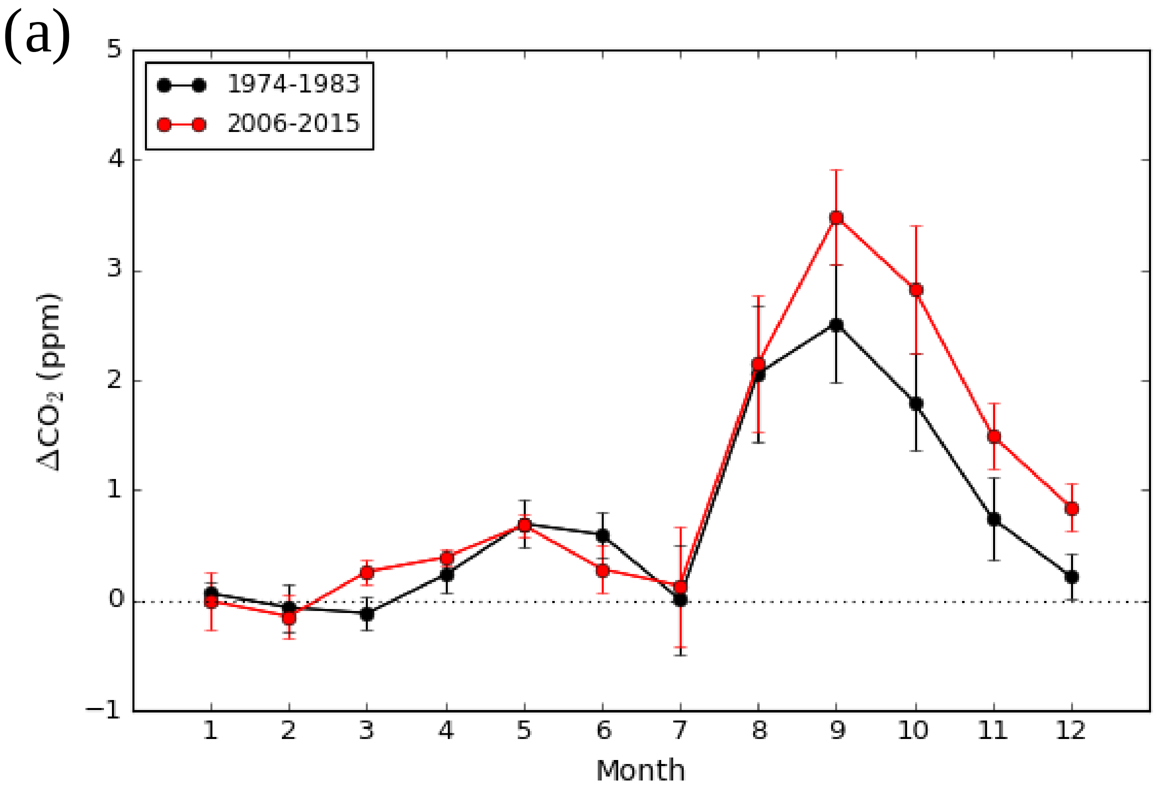
Sweeney et al., 2016
Commane et al., 2017

$$\Delta CO_2 = CO_2^{local} - CO_2^{background}$$

Monthly ΔCO_2 : a proxy for regional-scale (Alaska's North Slope that lies on the southern part of Barrow) carbon flux (i.e., carbon exchange between land and atmosphere).

Here, negative (positive) ΔCO_2 values denote regional carbon uptake (release) relative to background CO_2.

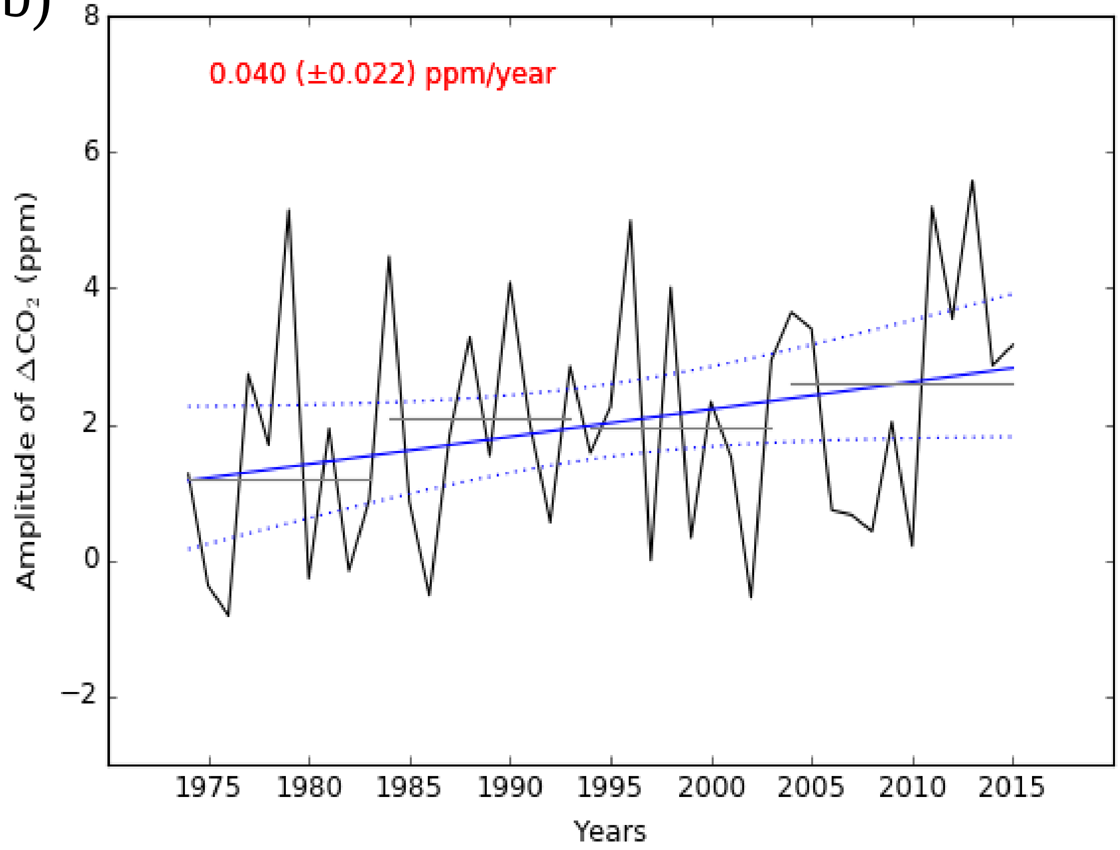
Seasonal cycle of ΔCO_2



Seasonal cycle has been changed in the recent decade (2006-2015) !!

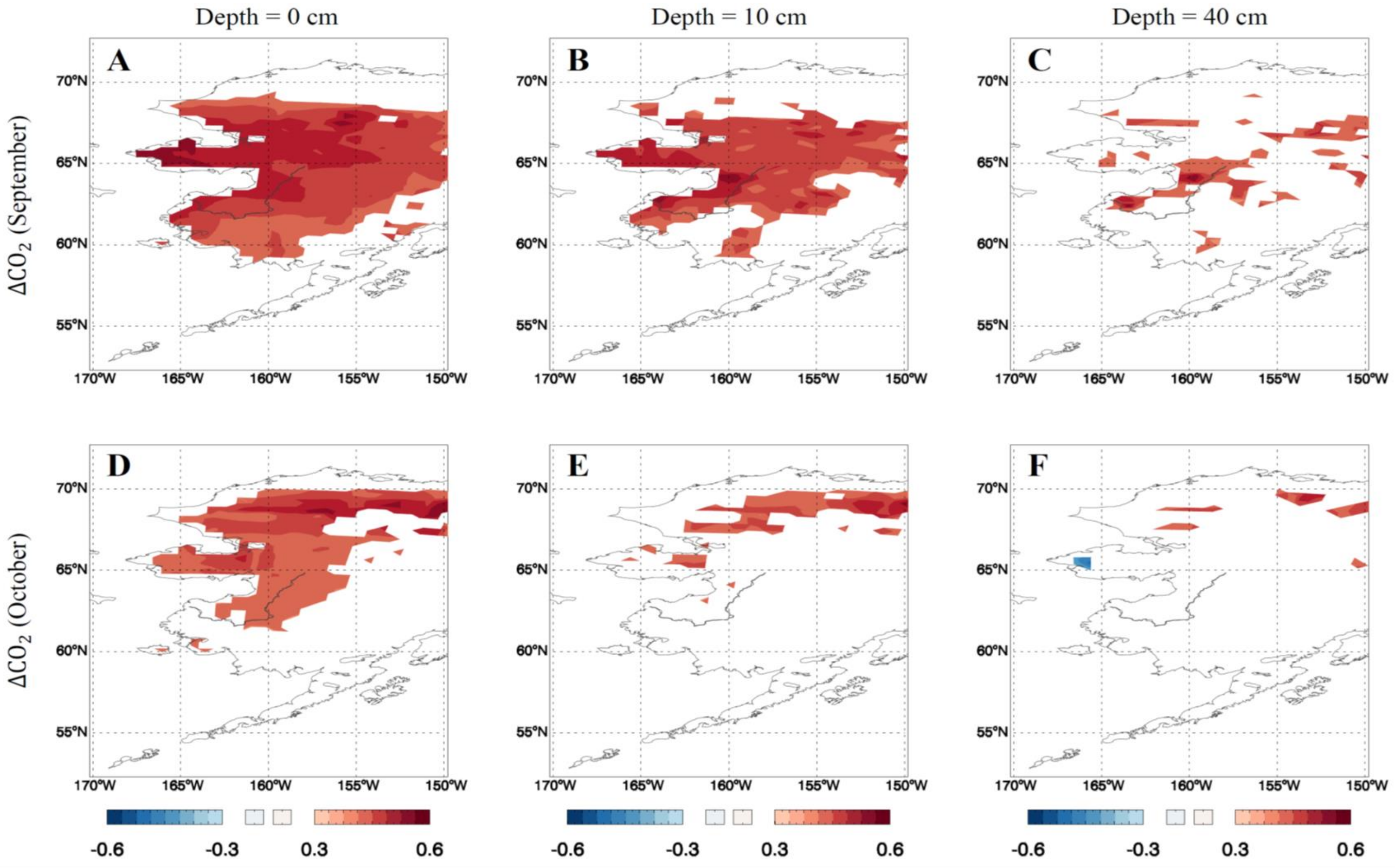
Changes in amplitude of ΔCO_2

(b)



This positive trend emerges from a decreasing early-summer (e.g., Jun) ΔCO_2 (-0.044 (+/-0.02) ppm/year, $p < 0.05$) combined with an increasing early cold season (e.g., Sep-Oct) ΔCO_2 (+0.042 (+/-0.02) ppm/year, $p < 0.05$) throughout the four-decade time period.

Autumn temperature



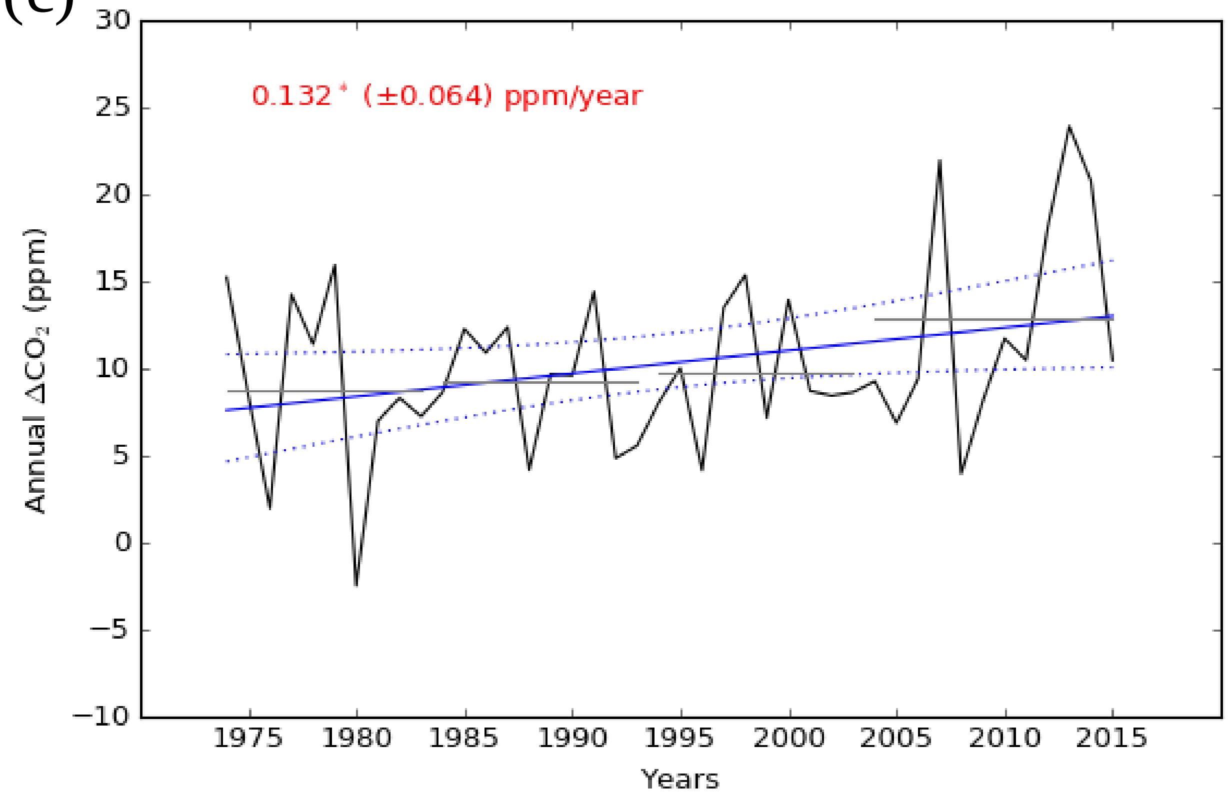
Our results suggest that increasing carbon uptake due to enhanced vegetation productivity is compensated by increasing carbon release linked to increased soil thawing, which could be linked to increasing autumn temperature.

Relationships between ΔCO_2 and soil temperature (0 – 40 cm). Correlation coefficients between detrended ΔCO_2 and detrended soil temperature for September and October, respectively.

Changes in annual ΔCO_2

Annual ΔCO_2 has been increased significantly in the last 40 years (+0.132 (+/-0.022) ppm/year, $p < 0.01$).

(c)



Carbon release linked to increased soil thawing outweighs increasing carbon uptake due to enhanced vegetation productivity.

Data-Model fusion

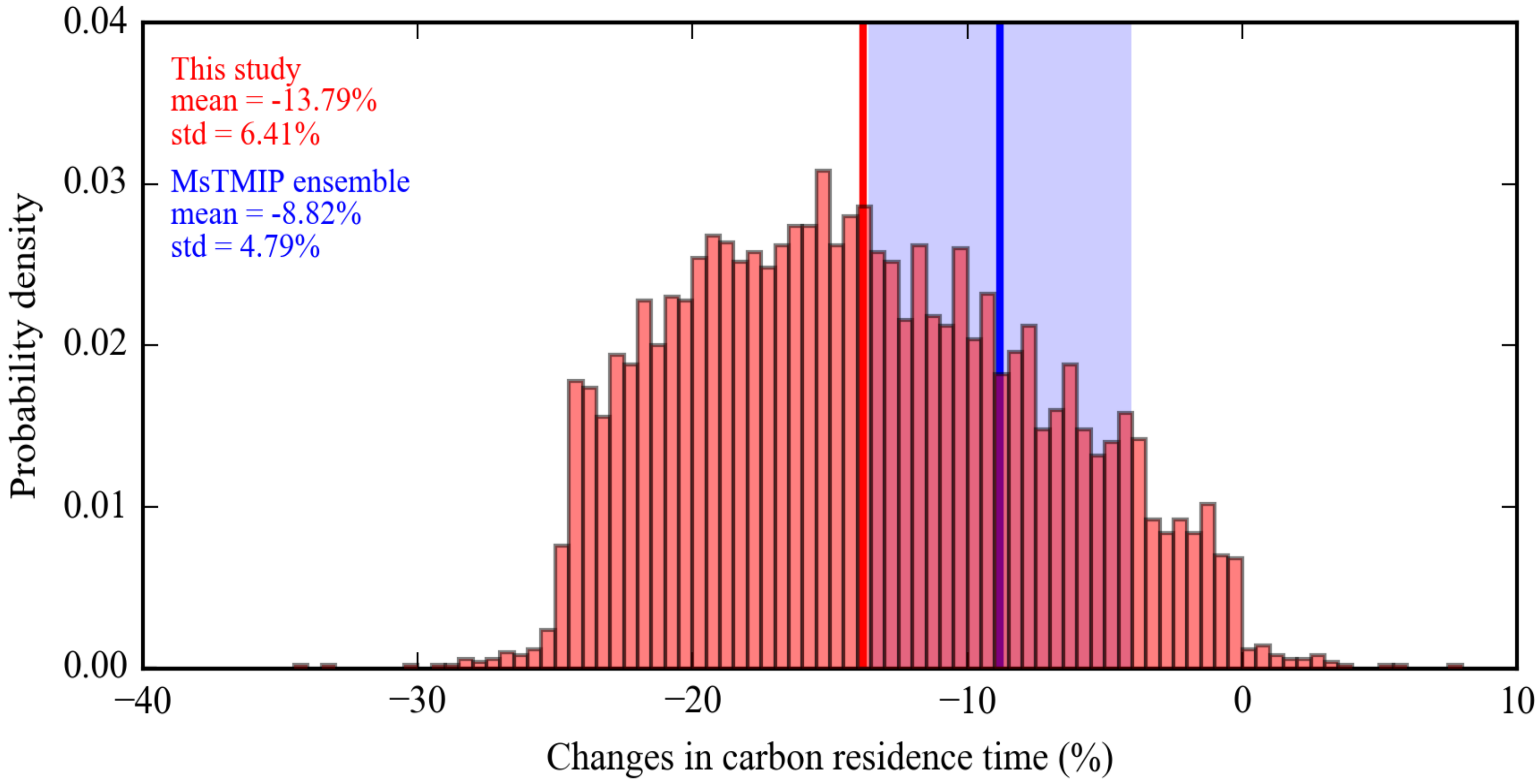
1. We retrieved the change in ecosystem carbon residence time by assimilating 1979-2015 ΔCO_2 into a single-pool ecosystem carbon balance model.

2. We used a Bayesian model-data fusion approach to optimize five model parameters relating to carbon uptake, initial ecosystem carbon stock, turnover rate and the temperature sensitivities of carbon uptake and respiration.

3. We used a Metropolis-Hastings Markov Chain Monte Carlo algorithm to sample 5,000 model parameters.

4. We evaluated the model results against a process-based terrestrial biosphere model ensemble, flux-tower based estimates of carbon uptake, and residence time retrievals.

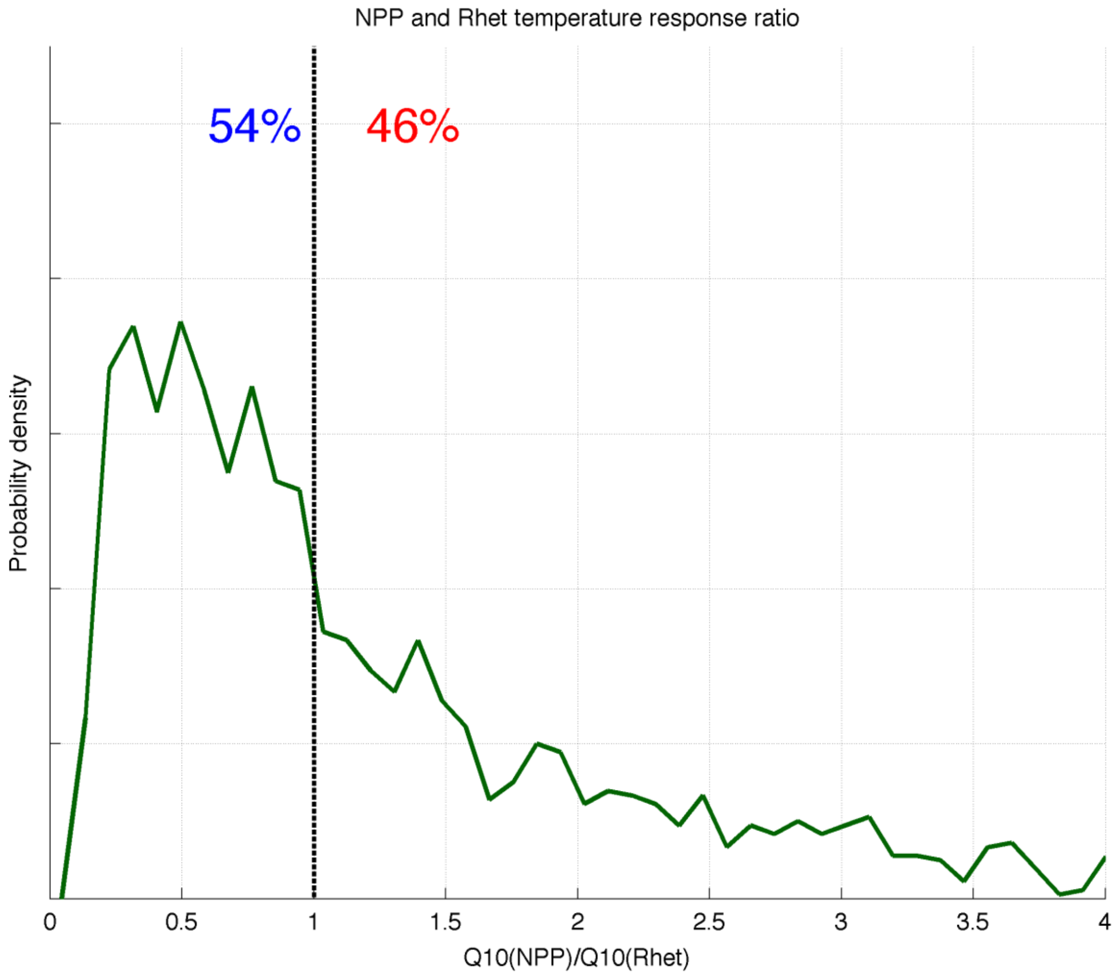
Changes in carbon residence time



Mean carbon residence time for 2004-2013 is 13.4% lower than for 1979-1988 !!!!!!

Retrieved changes in carbon residence time based on 1979-1988 and 2004-2013 10-yr periods.
Vertical red line indicates average of retrieved changes in carbon residence time. Blue line indicates mean (solid line) and range (shading) in the equivalent residence time change estimates from the MsTMIP model ensemble.

Soil respiration > Vegetation uptake



Q10(NPP)/Q10(Rhet) < 1
soil (heterotrophic) respiration is more temperature-sensitive than net carbon uptake

Q10(NPP)/Q10(Rhet) > 1
net carbon uptake is more temperature-sensitive than soil (heterotrophic) respiration

Our analysis also indicates a 54% probability that soil (heterotrophic) respiration is more temperature-sensitive than net carbon uptake; a higher heterotrophic respiration sensitivity to temperature implies net ecosystem carbon loss under elevated temperatures.

Summary

1. By separating CO_2 changes in the land sector from background variations in long-term measurements at Barrow, Alaska for the period of 1974-2015 (ΔCO_2), we find significant trends in long-term variations of ΔCO_2.

2. Increase in annual ΔCO_2 as well as enhancing seasonal amplitude of ΔCO_2. The results indicate not only increasing trends in seasonal uptake and respiration, but also significant change in the annual carbon balance.

3. Using data-model fusion, we find a 13.8 % decrease in mean carbon residence time (50% confidence range = 9 – 19 %) over the past four decades. (increased sensitivity of Arctic carbon cycling to climate change and variability)

4. Retrieved temperature dependence of respiration and carbon uptake suggest cold season Arctic carbon release will eventually exceed growing season carbon uptake.

Highlight

From Keeling et al. to Forkel et al.,
Enhancing carbon cycle amplitude indicates increasing growing season carbon uptake

From Belshe et al. to Schuur et al.,
Climatic warming (cold season) also increases the amount of carbon release from soil (this might be related to permafrost melting)

Form our study,
Considering both of carbon input and output at the same time, carbon residence time has been decreased.

"possible net ecosystem carbon loss in the future"

Acknowledgement

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Collaborator
NASA/JPL: David Schimel, Anthony Bloom, Nicholas Parazoo, Charles Miller
NOAA: Colm Sweeney
University of Zurich: Gabriela Schapeman
University of Notre Dame: David Medvigy

“Accelerating rates of Arctic carbon cycling revealed by long-term atmospheric CO_2 measurements, **Su-Jong Jeong**, A. Anthony Bloom, David Schimel, Colm Sweeney, Nicholas C. Parazoo, David Medvigy, Gabriela Schaepman-Strub, Charles E. Miller,
revised.”

SUSTech

Thank you !!