Carbon Dynamics WG Updates

Abhishek Chatterjee

Jet Propulsion Laboratory, California Institute of Technology

abhishek.chatterjee@jpl.nasa.gov

Contributions from - J. Abshire, D. Butman, B. Byrne, M. Farina, L. Kuai, N. Madani, T. Magney, C. Miller, S. Miller, D. Moore, B. Poulter, B. Rogers, L. Schiferl, W. Sun, K. Walter Anthony, Z. Zhang

Focus of Carbon Dynamics WG during Phase 1-2:

Excerpt from Goetz et al. ABoVE Phase 1 & 2 overview paper

(a) Linkages between changes in climate with changes in soil temperature, vegetation and the water cycle, in turn affects the carbon cycle - aboveground biomass, net primary productivity, heterotrophic respiration, and soil organic carbon production

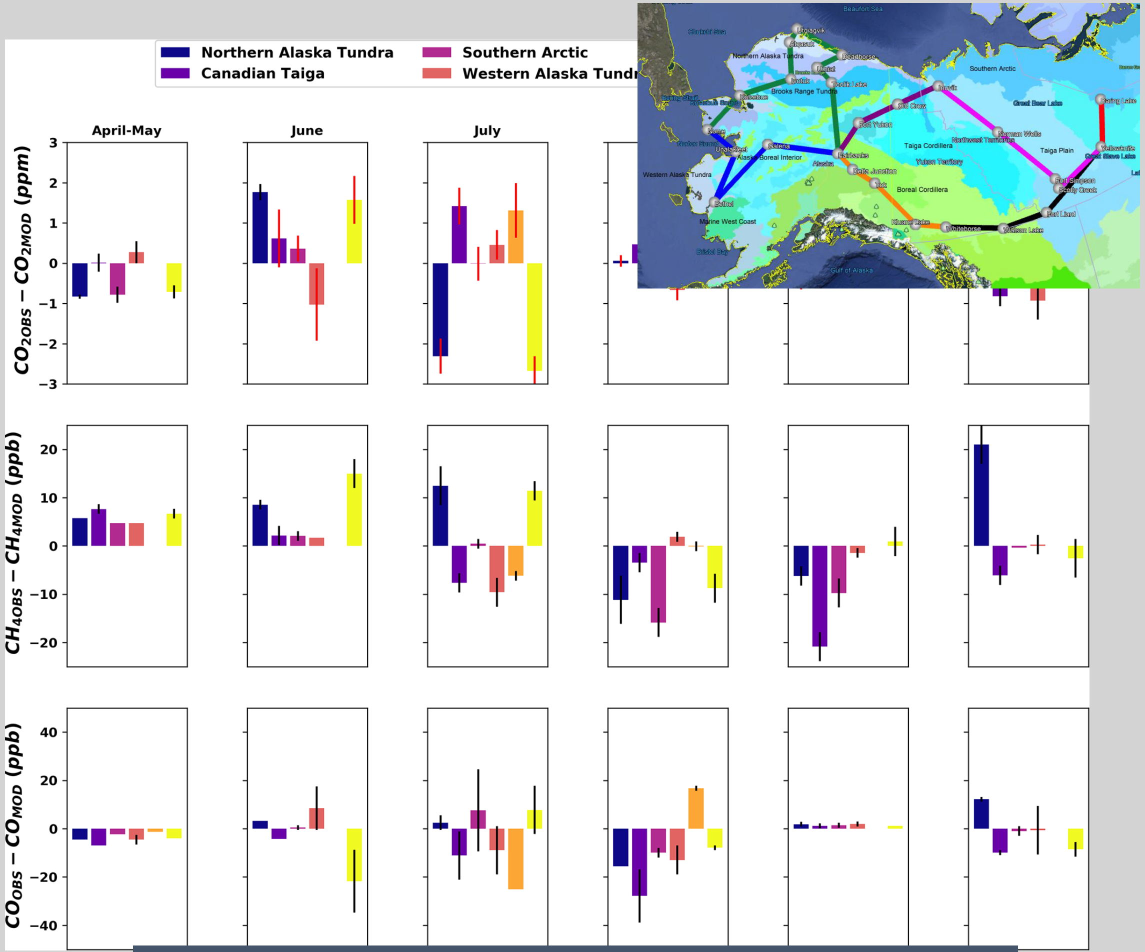
(b) Role of disturbances - increased drought stress and fire disturbance on ecosystem productivity, response and post-fire recovery

(c) Diagnosing and attributing methane fluxes from the plot level to regional scales, understanding heterogeneity of methane emissions in time and space

(d) Quantifying changes in the phenological and seasonal carbon cycle, in terms of both magnitude and amplitude, for e.g., summer carbon uptake being increasingly offset by soil carbon respiration during the fall and early cold seasons, increasing CO_2 amplitudes

Focus of Carbon Dynamics WG during Phase 1-2:

- A variety of carbon cycle activities continued to move forward, spanning observational, bottom-up and advances in top-down modeling …
- Observational side of things: while ground-based sensors, space-based data collection went on, we lacked relevant airborne data (since 2017 AAC) that could bridge the gap between surface measurements and satellite retrievals
- Modeling side of things:
  - Unique advances in modeling of methane fluxes, use of OCS and SIF, among others
  - Ad-hoc working group activity on carbon synthesis topics acted as a **precursor** to studies proposed in Phase 3



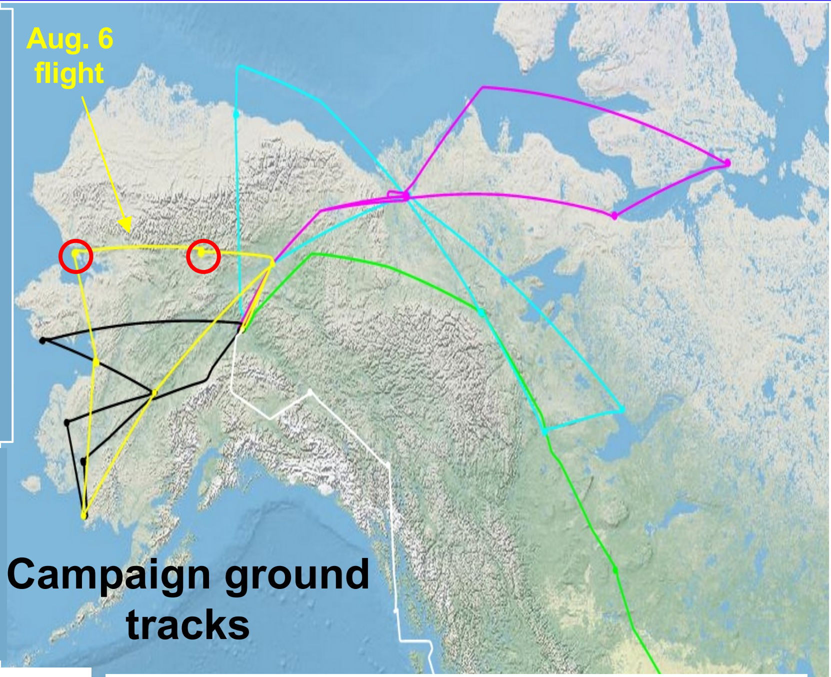
Sweeney, Chatterjee et al. 2021, Atmospheric Chemistry and Physics

Airborne Lidar Measurements of Atmospheric Column CO_2 Concentrations to Cloud Tops in the Arctic

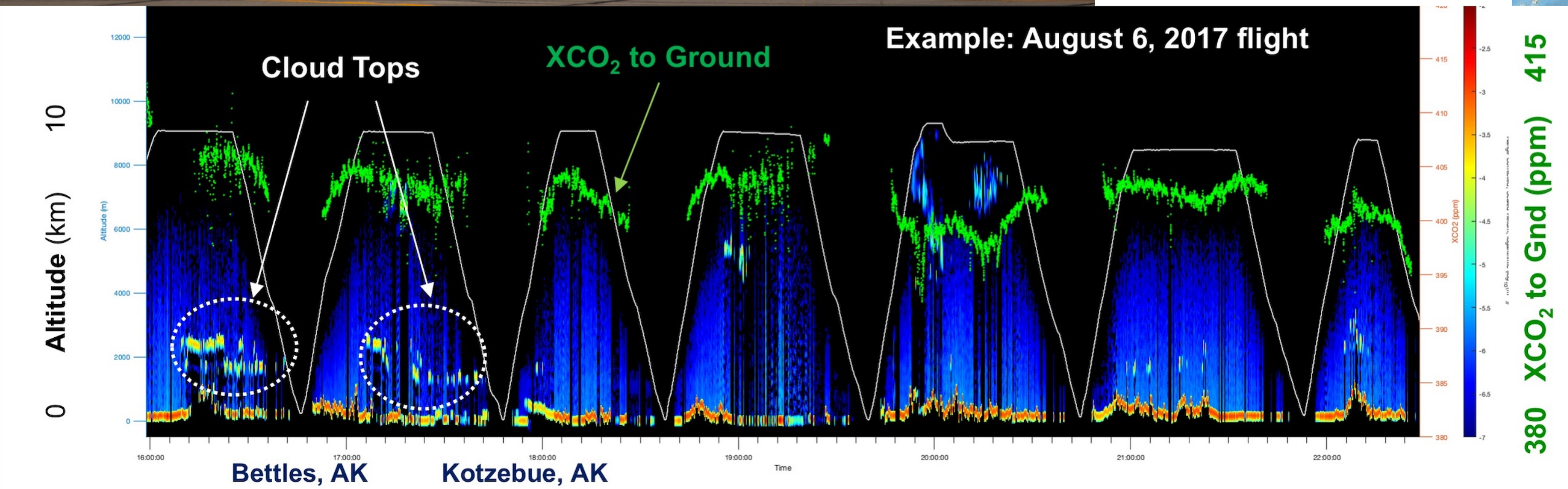
James B. Abshire, Jianping Mao, Xiaoli Sun, Paul T. Kolbeck, S. Randy Kawa

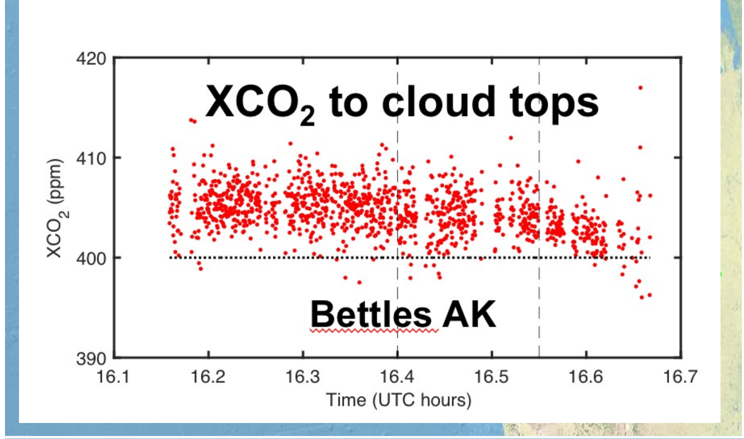
Campaign flown on NASA DC-8, with:
- Goddard CO_2 Sounder Lidar
- Goddard Picarro, *in situ*
- LaRC AVOCET & DLH, *in situ*

- 8 flights
- July 20- Aug 8, 2017
- 55 hours of airborne lidar measurements
- Comparison with *in-situ* at 47 spiral sites



- Lidar measurements of XCO_2 over long flight lines in Arctic for 1st time
- Lidar simultaneously measured height-resolved aerosol scattering profiles
- Measurements together enable XCO_2 retrievals to cloud tops



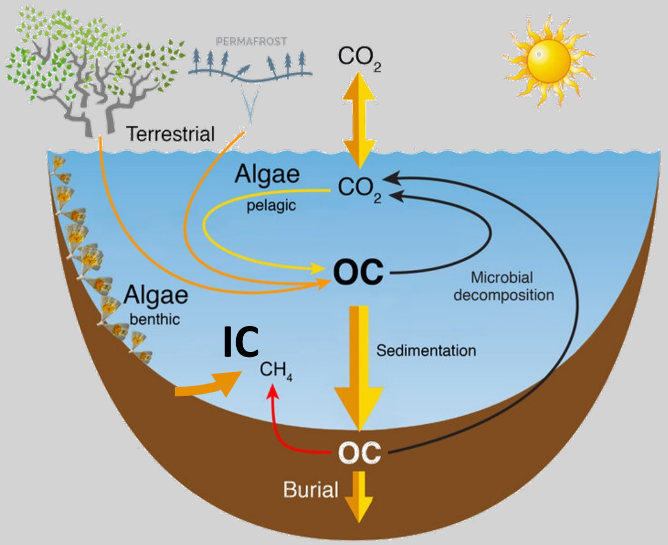


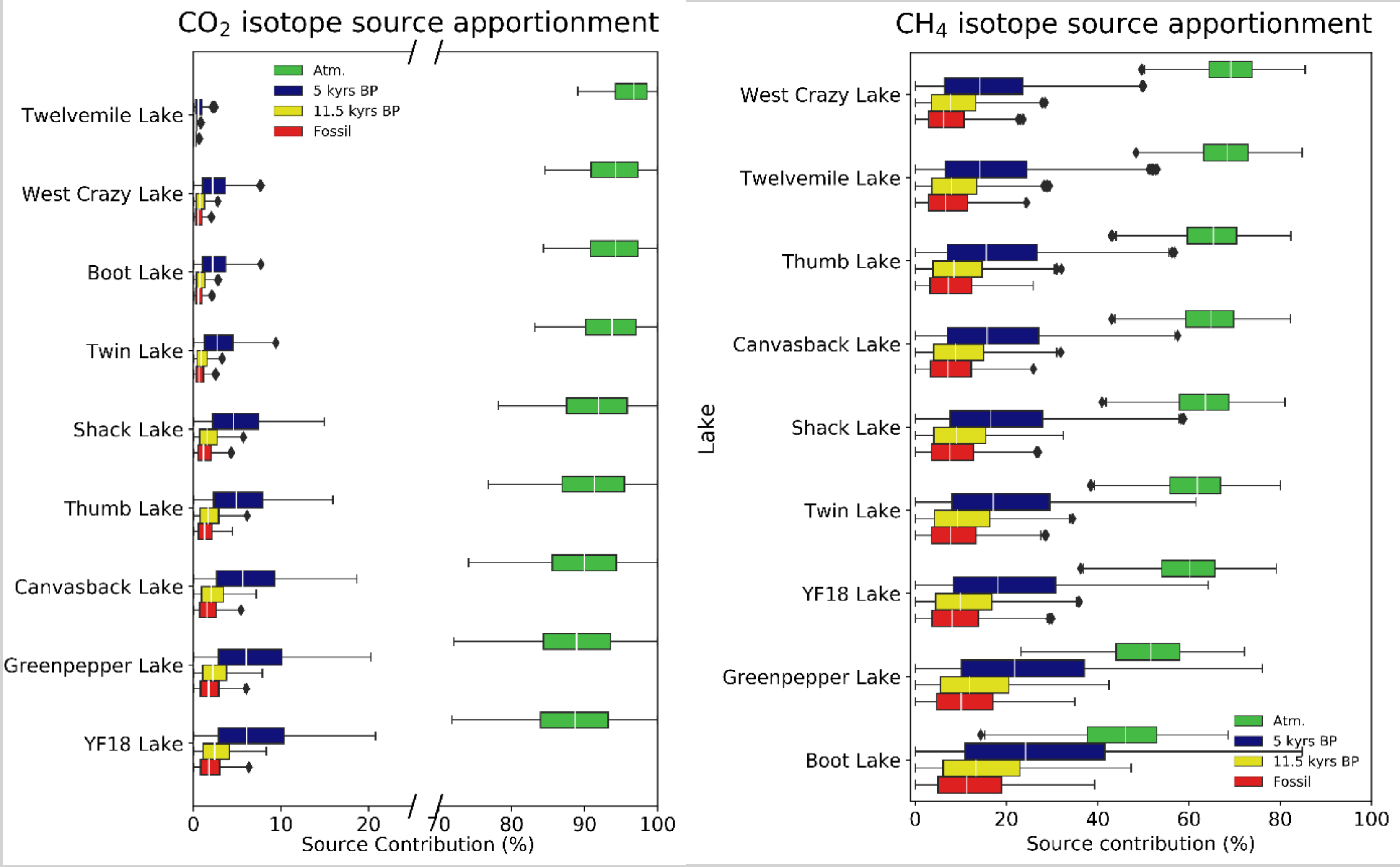
ABoVE projects and Data Access
Abshire (2017), Sun (2020)
Data Access via ORNL DAAC

Butman (TE 2018): Crossing the divide: Inundation drives hotspots of carbon flux

KEY FINDING: Yukon Flats Lake CO_2 and CH_4 Emissions show little influence from aged carbon sources.

- Stable and radioisotope mixing model



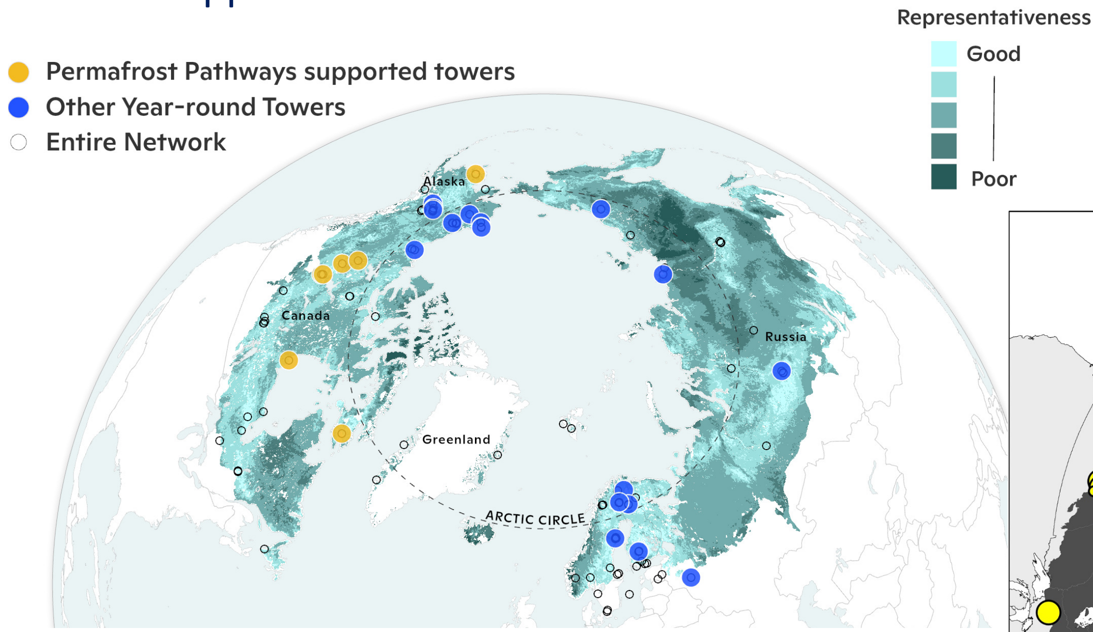


Garcia-Tigreros et al. final revision – L&O Letters 2023

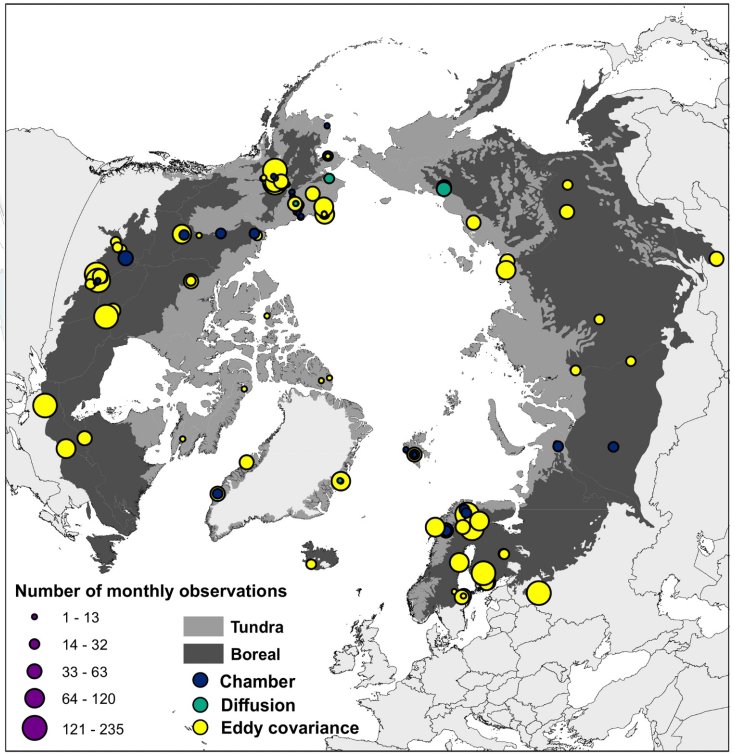
Updates from Rogers (CARBON 2014), Natali (GBMF 2019), & Rogers (2022)

CO_2 & CH_4 flux observations

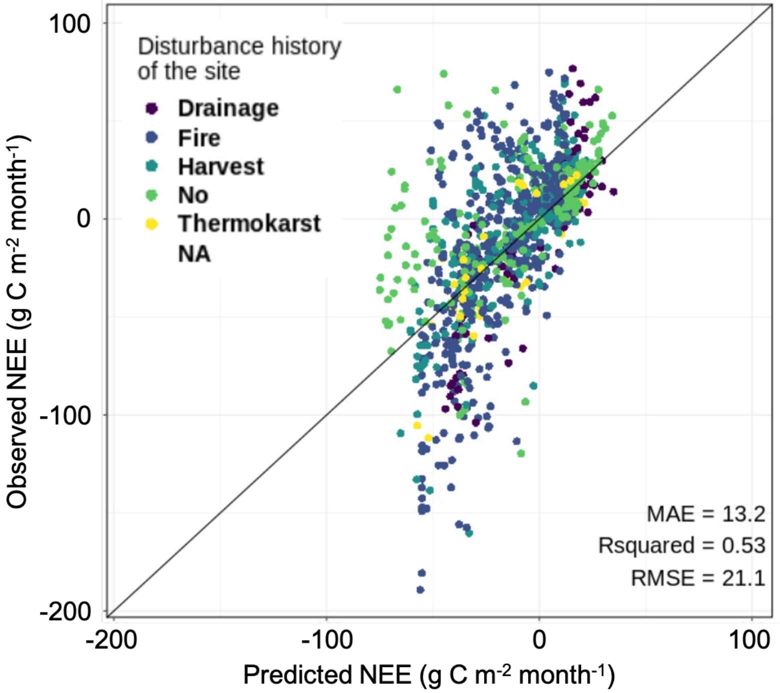
Support & installation of flux towers



Flux database compilation (ABCflux; Virkkala et al., 2022)



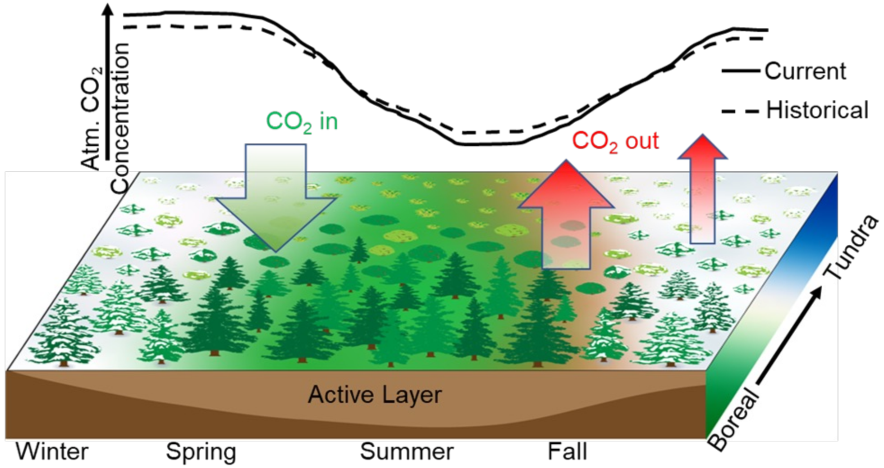
Statistical upscaling of fluxes (Virkkala et al., in prep.)



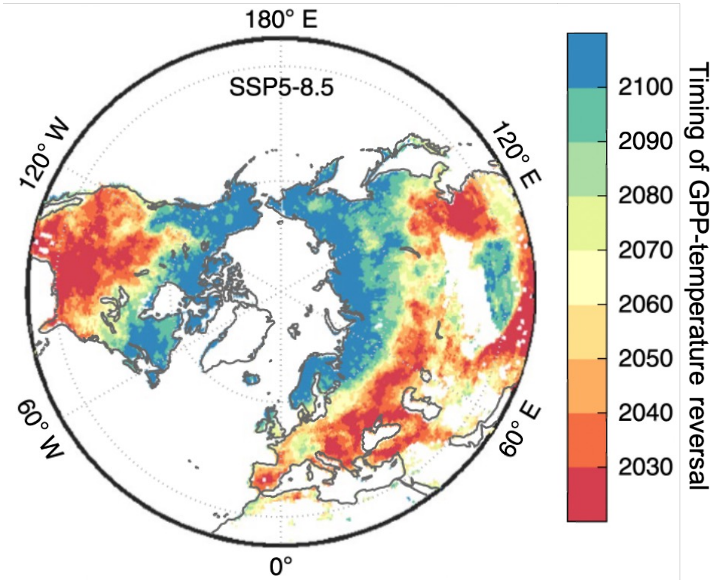
Updates from Rogers (CARBON 2014), Natali (GBMF 2019), & Rogers (2022)

Synthesis & publications

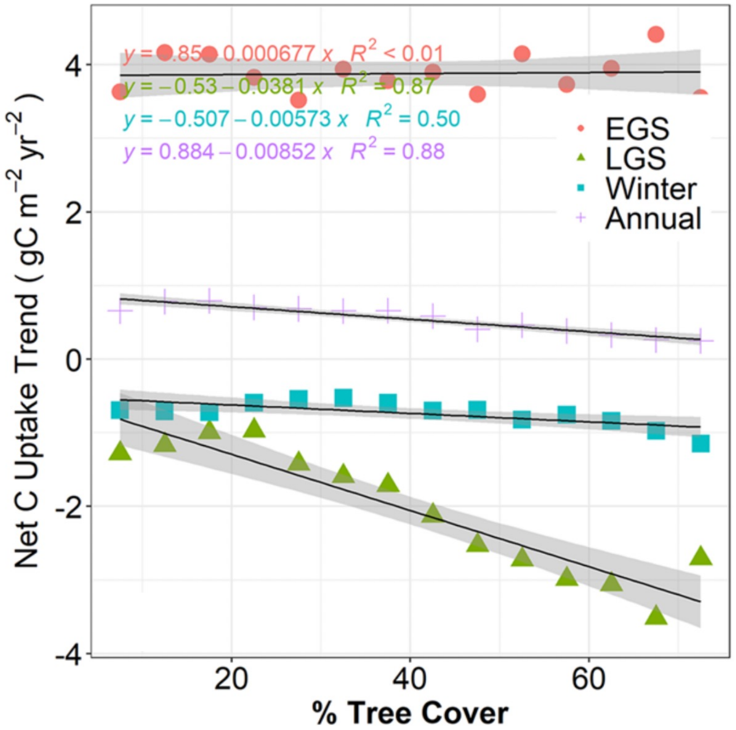
CO_2 amplitude synthesis (Liu et al., in prep.)



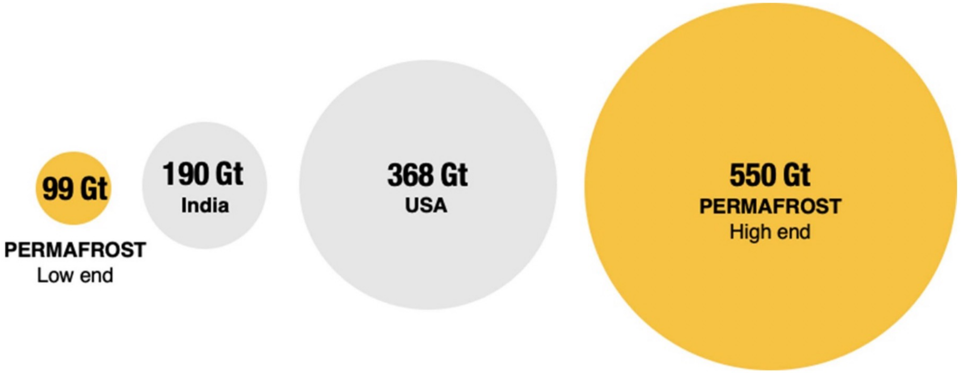
Future reversal of warming-enhanced productivity (Zhang et al., 2022)



Respiratory loss in late growing season determines CO_2 sink (Liu et al., 2022)



Incorporating permafrost into policy (Natali et al., 2022)

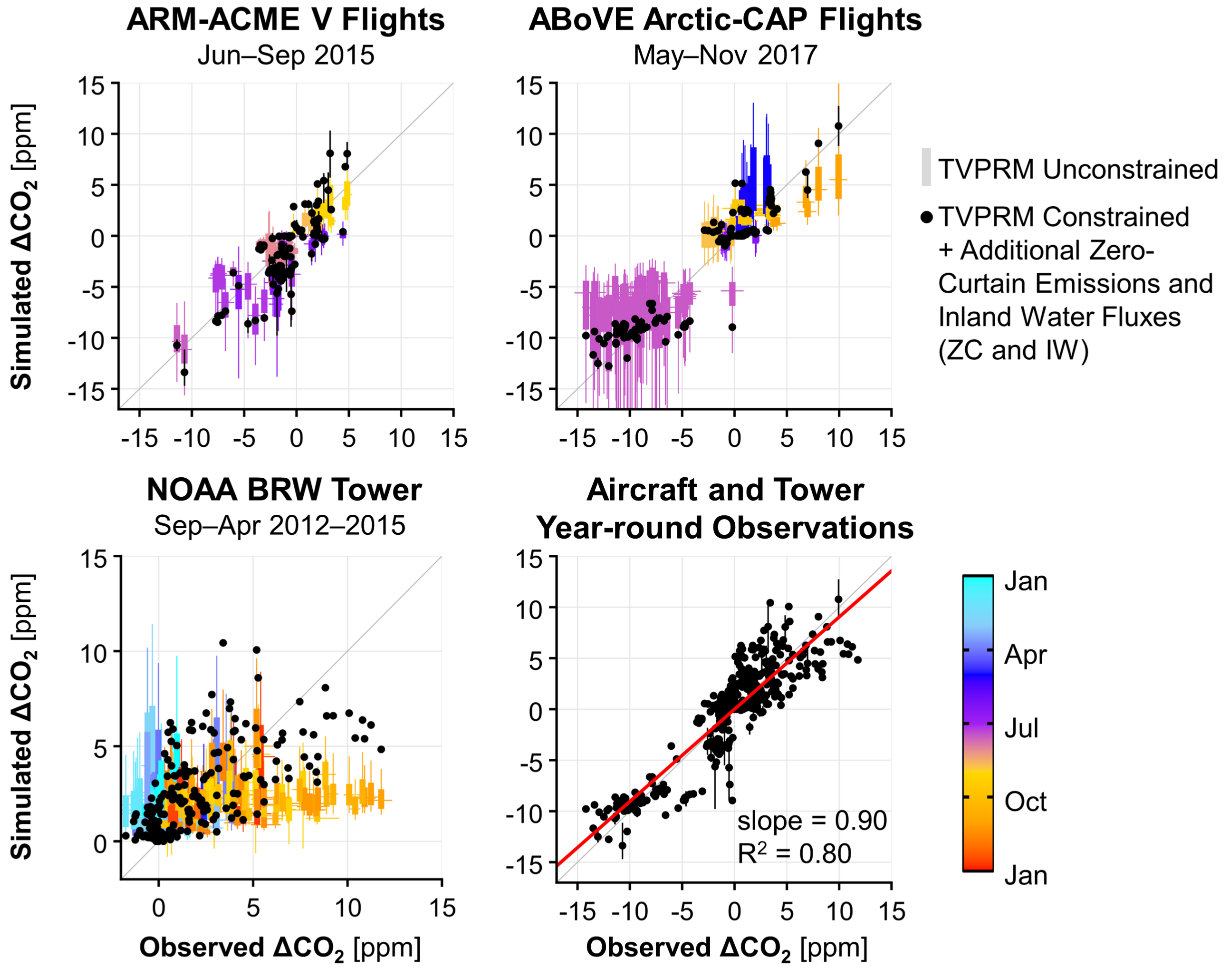


Using atmospheric observations to quantify annual biogenic carbon dioxide fluxes on the Alaska North Slope

Schiferl et al. (2022) Highlight article in *Biogeosciences*

- Atmospheric CO_2 concentration observations help evaluate several biogenic CO_2 flux models – both growing season net uptake and cold season respiration
- Additional zero-curtain CO_2 emissions not driven by soil temperature and CO_2 fluxes from inland water important for reproducing observations on the Alaska North Slope
- Recent quantifications of cold season emissions are likely overestimated for this region during Jan–Apr, enough to change the sign of the annual net CO_2 budget
- Constrained by the atmospheric observations, the Alaska North Slope net CO_2 flux ranges from –6 to 6 TgC for 2012–2017. In each year, the sign is determined by the magnitude of the net CO_2 flux in the growing season.

ABoVE and ABoVE-affiliated projects:
McKain (TE 2016), Munger (CARBON 2016), Anderson (NSF 2018), Natali (TE 2014), Watts (NIP 2017)



Explore the biogenic CO_2 flux model comparisons!

atmoscomp.ldeo.columbia.edu/tvprm

New publication: Carbon uptake in Eurasian boreal forests dominates the high-latitude net ecosystem carbon budget

Jennifer Watts, Mary Farina, John Kimball, Luke Schiferl, Zhihua Liu, Kyle Arndt, Donatella Zona, et al. *Global Change Biology* (2023)

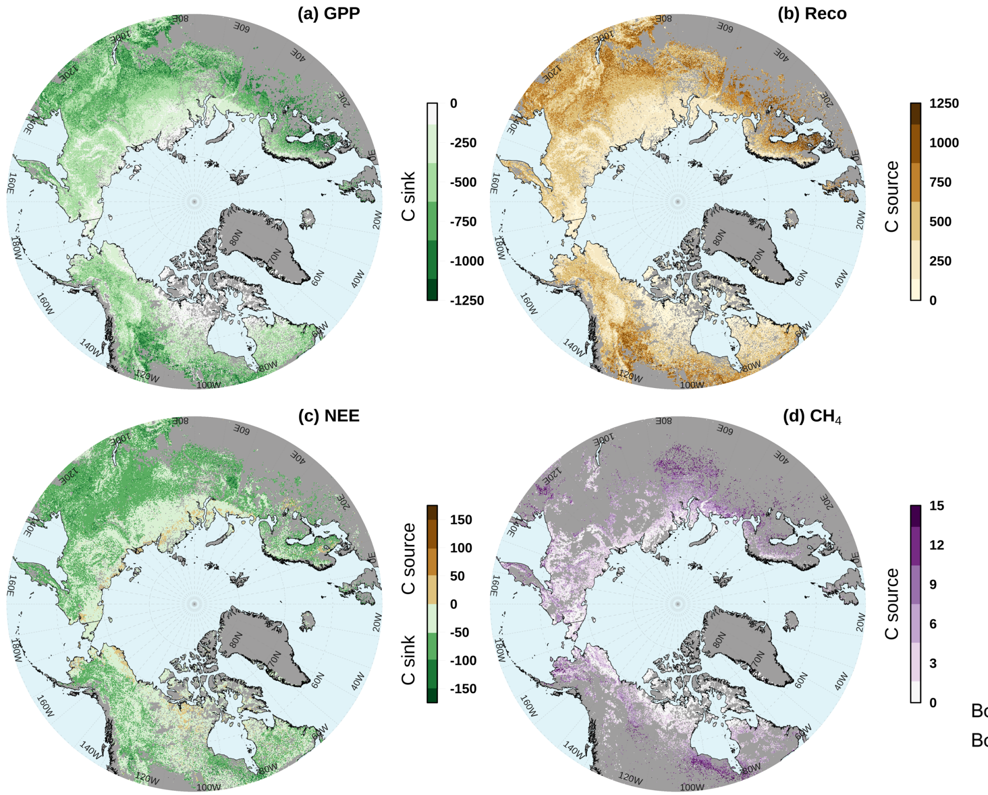


Figure 1. Annual GPP, R_{eco}, NEE, and CH_4 emissions ($gC\ m^{-2}\ yr^{-1}$) from a satellite data-driven hybrid process-model for northern ecosystems (Arctic Terrestrial Carbon Flux Model; TCFM-Arctic).

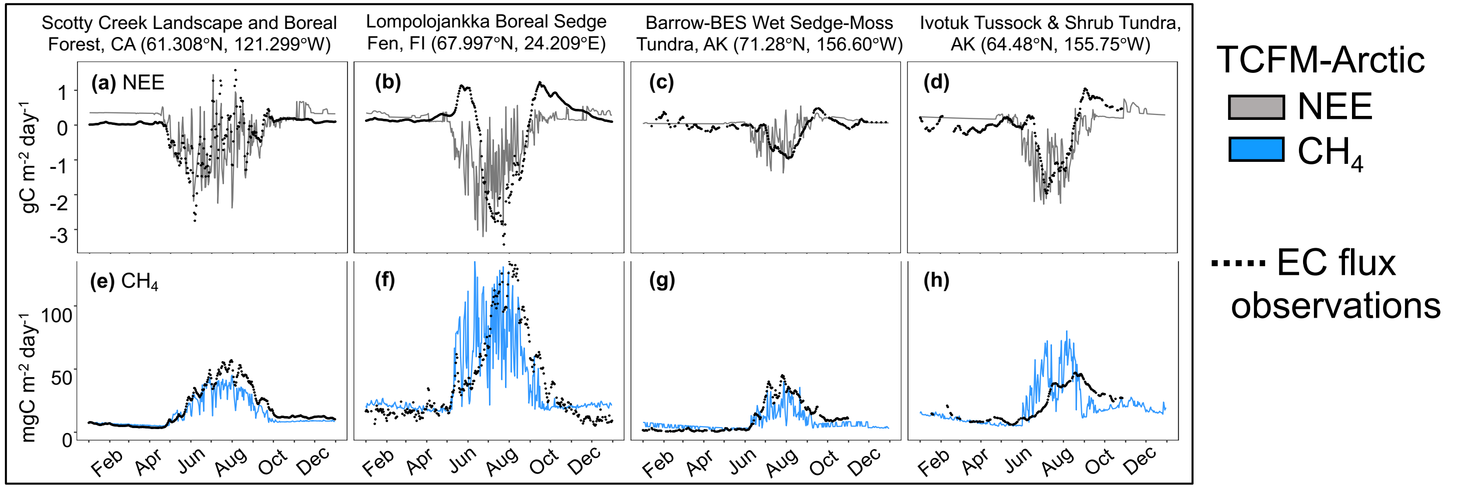


Figure 2. Agreement between TCFM-Arctic simulations of NEE and CH4 emissions with tower eddy covariance (EC) flux observations.

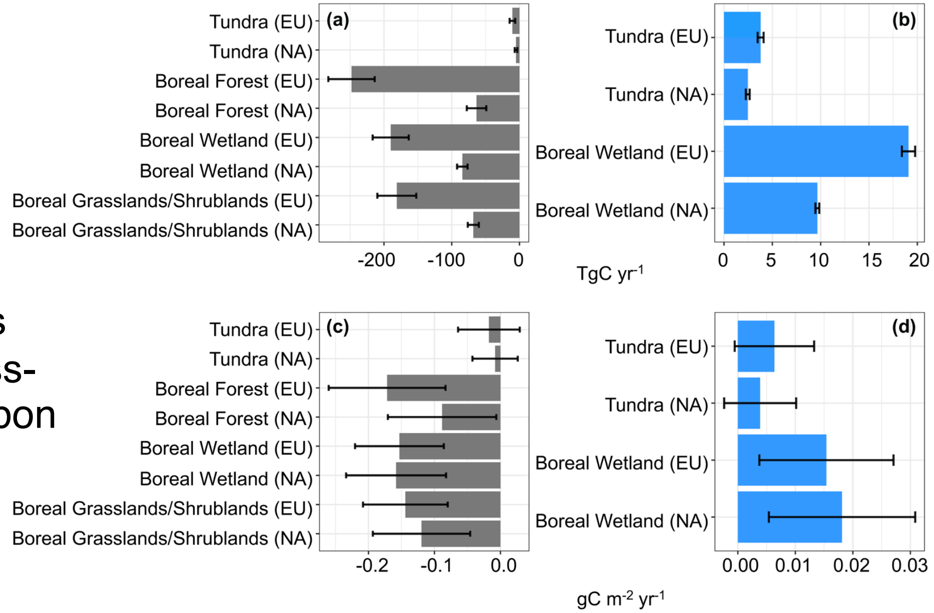
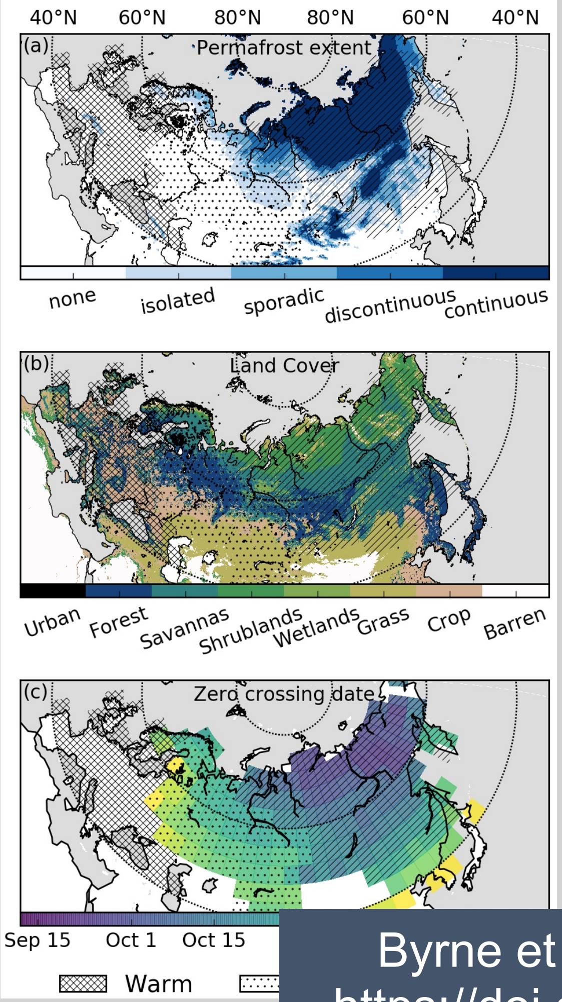
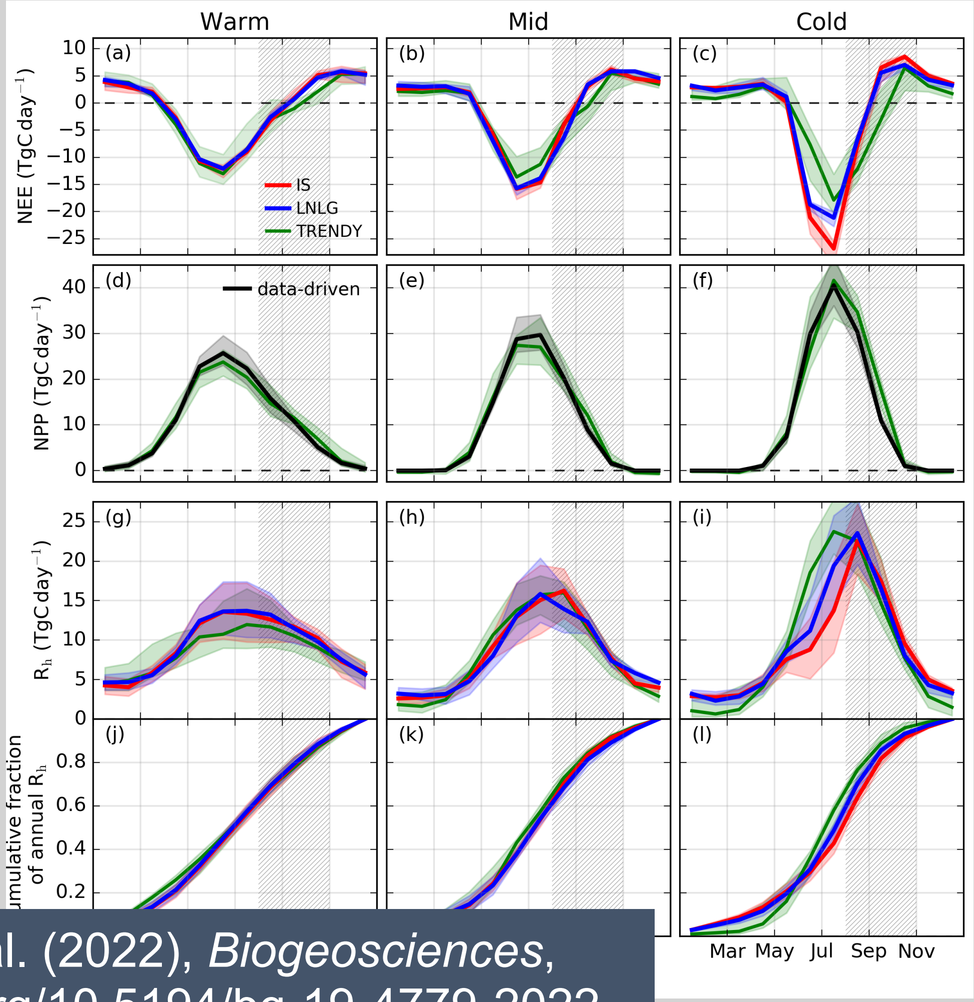


Figure 3. TCFM-Arctic annual NEE and CH_4 budgets. Eurasian boreal forests and wetlands contributed a large NEE sink of -438 and a CH_4 budget of 19 TgC yr^{-1}, contributing more than 51% of the Arctic-boreal NECB sink.

ABoVE ARCTIC BOREAL VULNERABILITY EXPERIMENT · Woodwell Climate Research Center · NTSG Numerical Terradynamic Simulation Group · MONTANA STATE UNIVERSITY

Quantifying pan-Arctic CO_2 flux seasonality using OCO-2 retrievals





Byrne et al. (2022), *Biogeosciences*, https://doi.org/10.5194/bg-19-4779-2022

ABOVE Project - Chatterjee (TE 2017)

- Site-level observations have shown pervasive cold season CO_2 release across Arctic and boreal ecosystems, impacting annual carbon budgets.
- Top-down NEE, based on OCO-2 observations, imply strong summer uptake followed by strong autumn release of CO_2 over the entire cold northeastern region of Eurasia.
- This seasonality implies less summer heterotrophic respiration (Rh) and greater autumn Rh than would be expected given an exponential relationship between respiration and surface temperature.

How is the performance of wetland methane models across time scales for the high latitudes?

Zhen Zhang[1,2], Sheel Bansal[3], Kuang-Yu Chang[4], Etienne Fluet-Chouinard[5], Kyle Delwiche[6], Mathias Goeckede[7], Adrian Gustafson[8], Sara Knox[9], Antti Leppänen[10], Licheng Liu[11], Jinxun Liu[12], Avni Malhotra[13], Tiina Markkanen[10], Gavin McNicol[14], Joe R. Melton[15], Paul A. Miller[8], Changhui Peng[16], Maarit Raivonen[10], William J. Riley[4], Oliver Sonnentag[17], Aalto Tuula[10], Rodrigo Vargas[18], Wenxin Zhang[8], Qing Zhu[4], Qiuan Zhu[19], Qianlai Zhuang[11], Lisamarie Windham-Myers[20], Robert B. Jackson[21], Benjamin Poulter[22]

Conclusions:

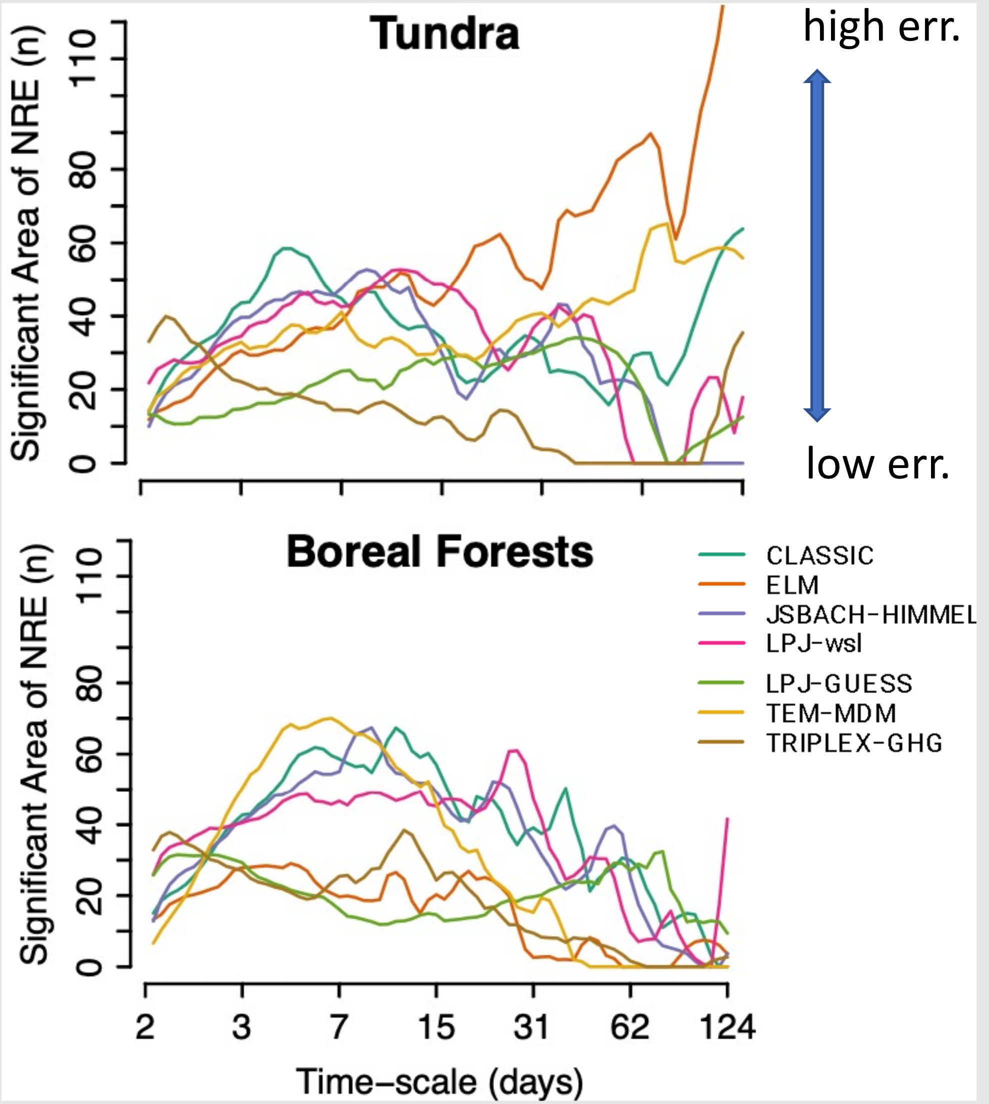
- Models have better performance at long time scales for Boreal and Wet Tundra sites than at short time scales (< 15 days).
- Biases at short time scales contribute to persistent systematic bias at long time scales.
- Models need to improve the representation of processes at short time scales

- Observations: eddy covariance CH_4 measurements from FLUXNET-CH4 covering boreal forest and wet tundra with a total number of 40 site-years

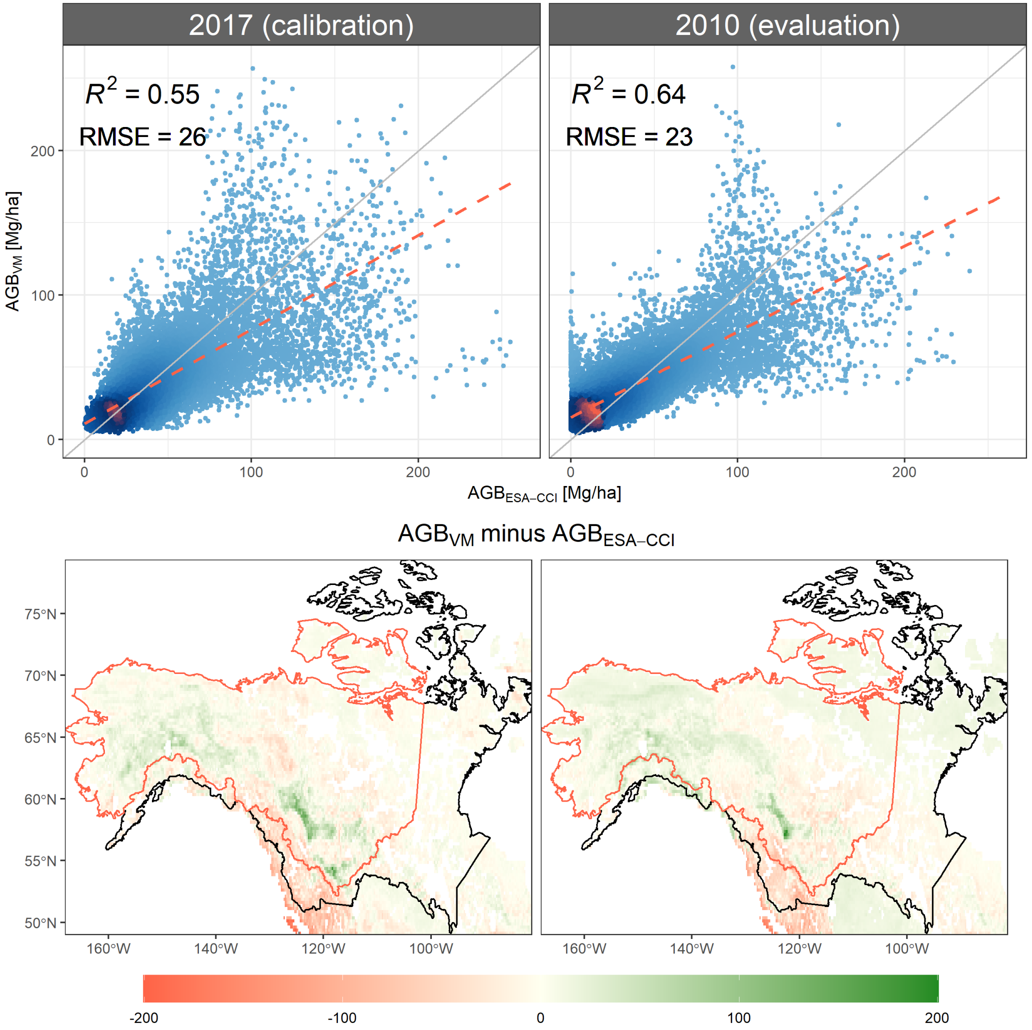
- Wetland Models: CLASSIC, ELM, JSBACH-HIMMELI; LPJ-wsl; LPJ-GUESS, TEM-MDM; TRIPLEX-GHG.

Zhang et al., JGRB, in review

Model Normalized Residual Error (NRE) along time scales



New microwave-based biomass product responsive to disturbance

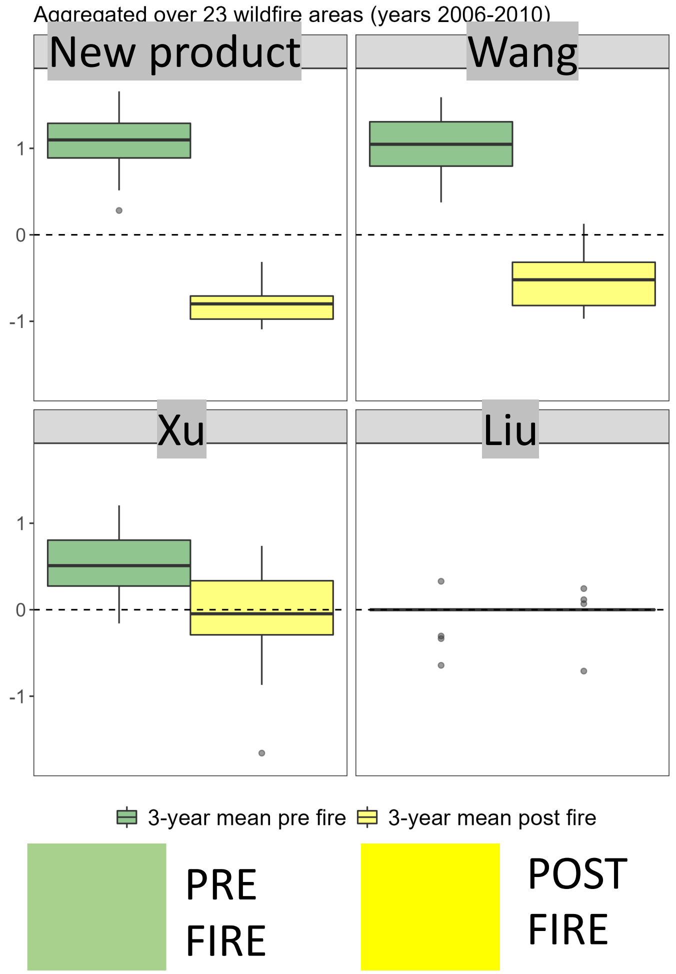


We developed a new biomass product that includes forest and non-forest area.

Pre/post fire **dynamics** are like Wang product but different absolution values

Based on VOD & VARI
Paper in prep.

Devine, Smith, Moore et al in prep

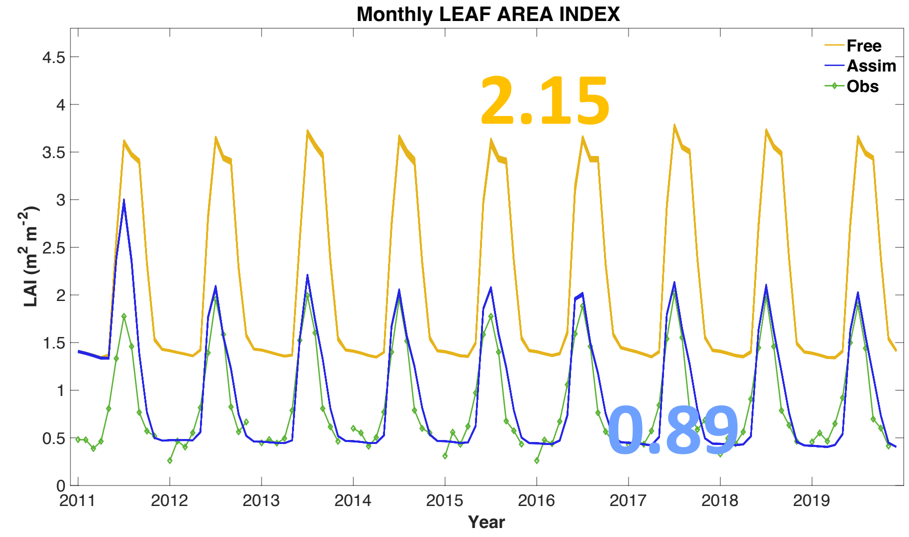


Moore (TE 2018), NASA Terrestrial Ecosystems Grant 80NSSC19M0103

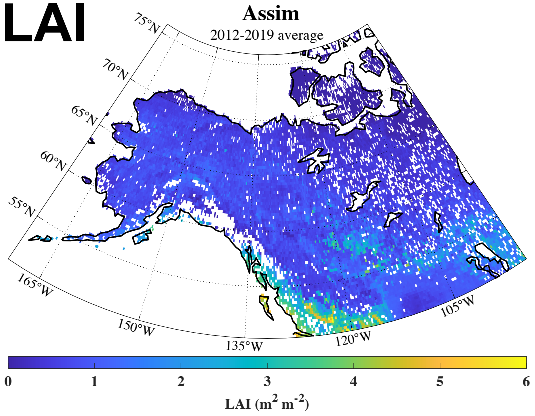
Assimilating biomass & LAI improves C-cycle estimates in CLM

Huo, Fox, Moore et al in prep

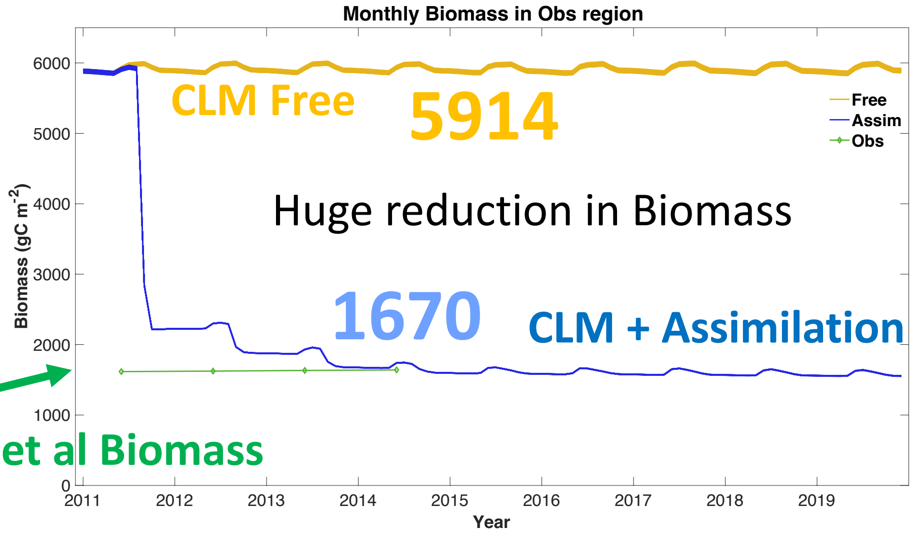
58.8%



LAI

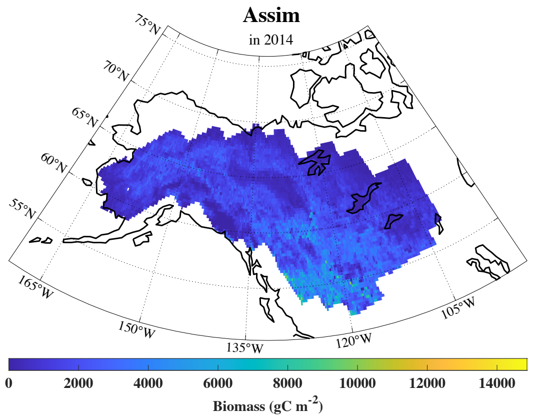


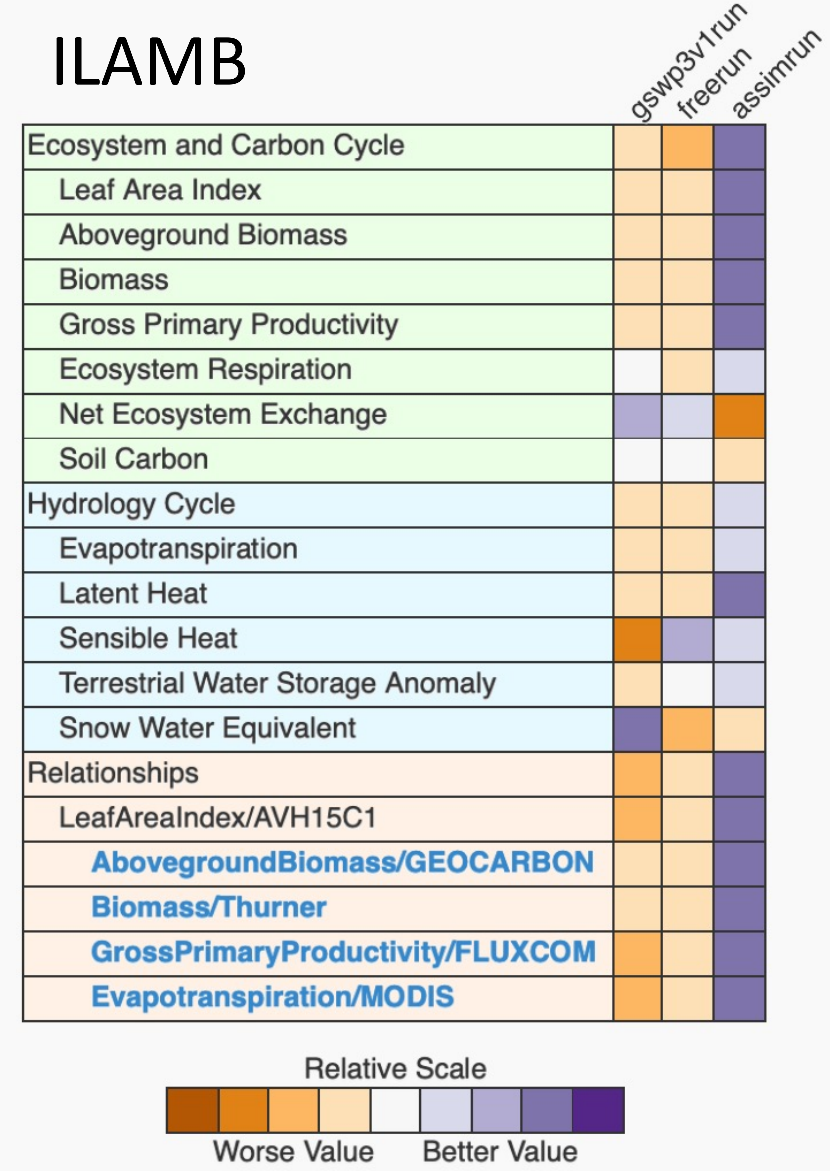
71.8%



Wang et al Biomass

Biomass





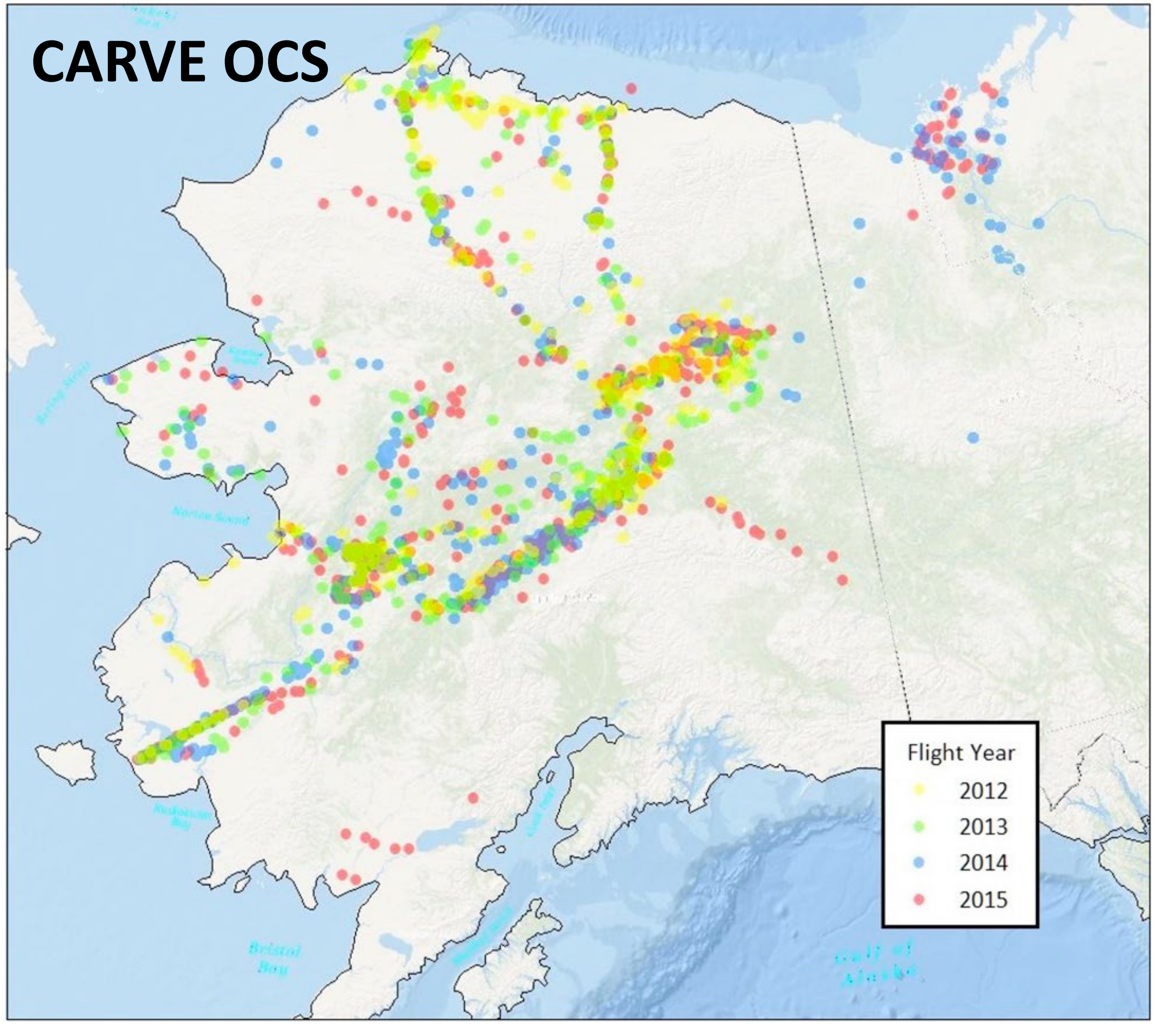
ABoVE ARCTIC - BOREAL VULNERABILITY EXPERIMENT

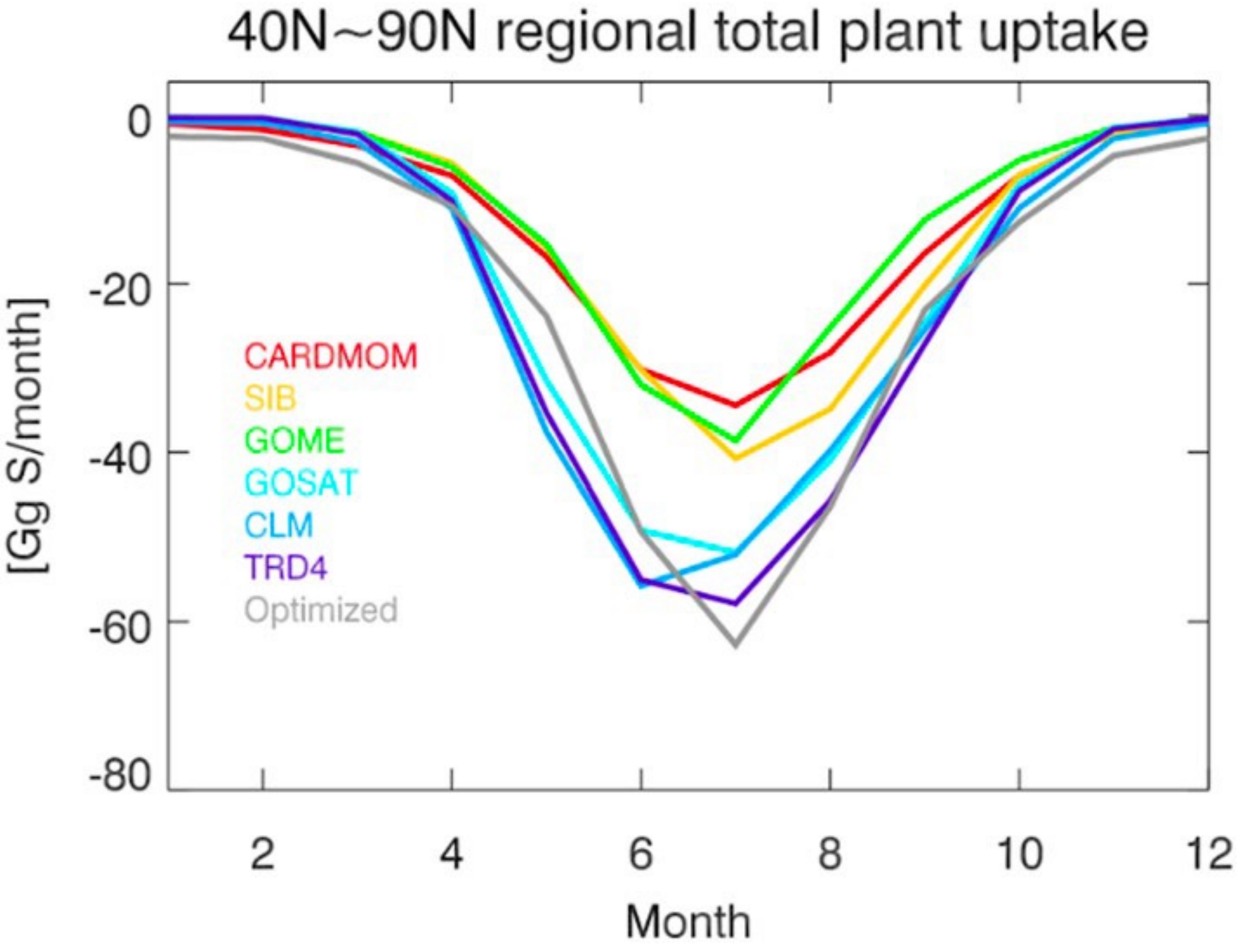
Moore (TE 2018), NASA Terrestrial Ecosystems Grant 80NSSC19M0103

THE UNIVERSITY OF ARIZONA

Airborne OCS Observations Suggest 25% More NHL GPP Than 6-Model Mean

L. Kuai, C. Miller





Kuai et al., Global Biogeochemical Cycles (2022)

Troy Magney

JGR Biogeosciences

RESEARCH ARTICLE
10.1029/2021JG006588

Key Points:

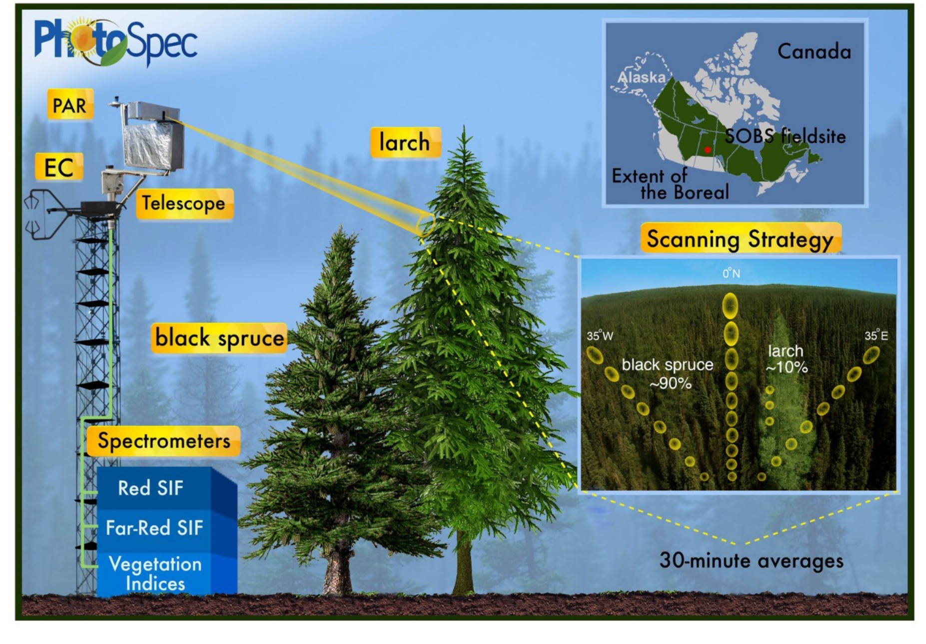
- Tower-based solar-induced chlorophyll fluorescence (SIF) closely tracks gross primary productivity (GPP) over two years in a mixed-species boreal forest
- Light saturation of photosynthesis drives non-linearity between SIF and GPP
- The SIF-GPP relationship is seasonally variant due to dynamics between LUE_F and LUE_P

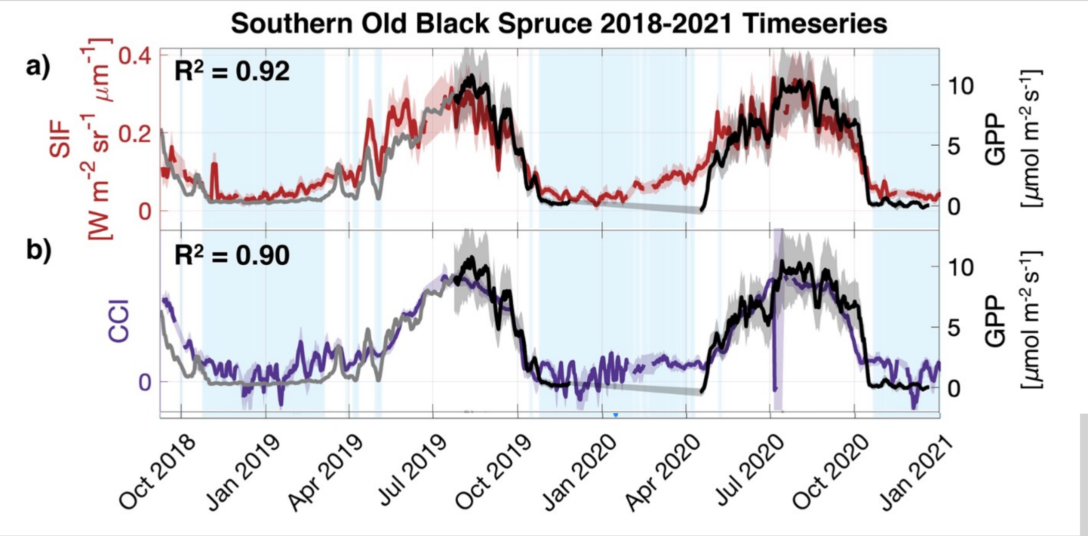
Diurnal and Seasonal Dynamics of Solar-Induced Chlorophyll Fluorescence, Vegetation Indices, and Gross Primary Productivity in the Boreal Forest

Zoe Pierrat[1], Troy Magney[2], Nicholas C. Parazoo[3,4], Katja Grossmann[5], David R. Bowling[6], Ulli Seibt[1], Bruce Johnson[7], Warren Helgason[7], Alan Barr[7], Jacob Bortnik[1], Alexander Norton[3], Andrew Maguire[3], Christian Frankenberg[4], and Jochen Stutz[1]

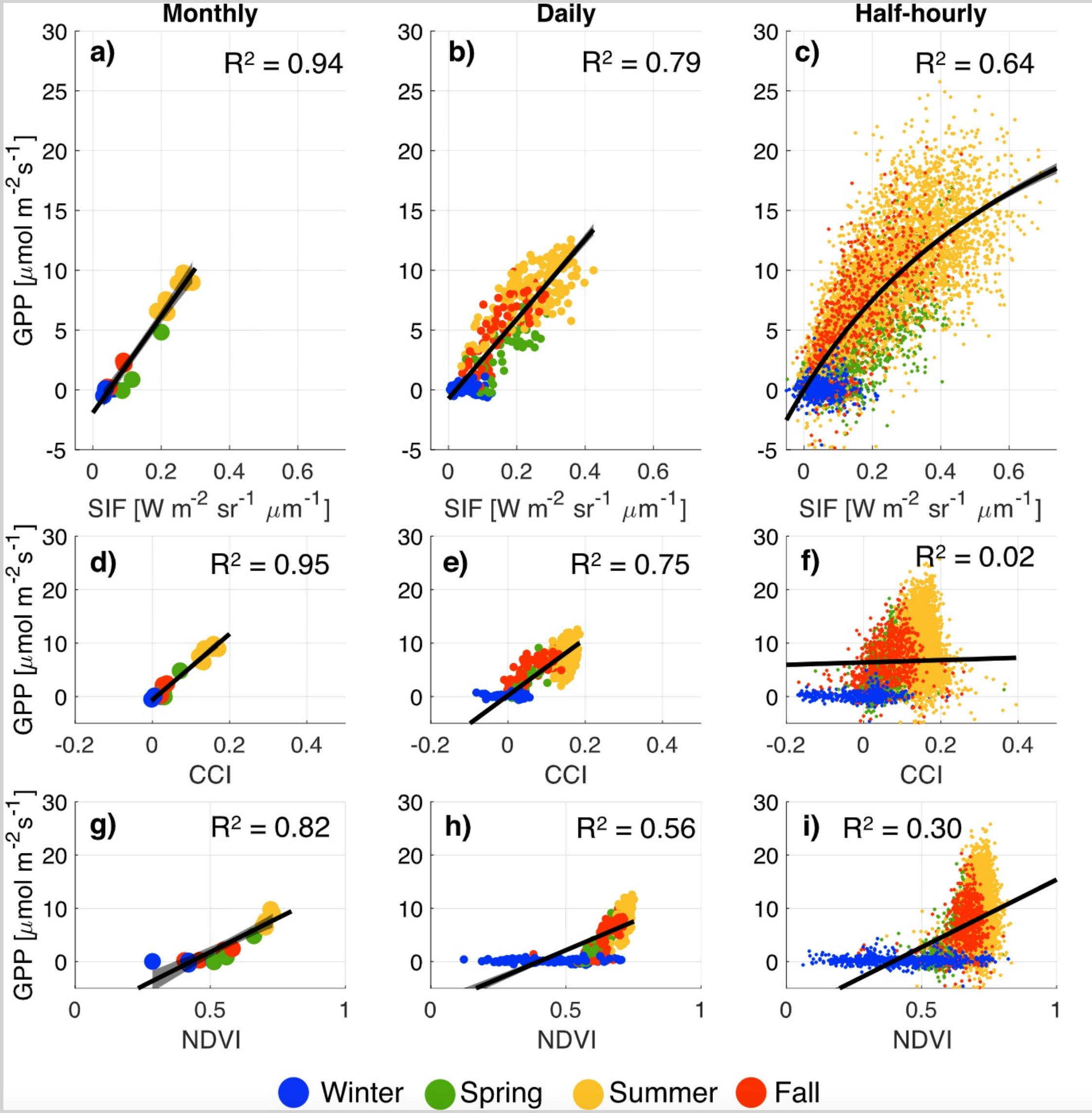
[1]University of California Los Angeles, Los Angeles, CA, USA, [2]University of California Davis, Davis, CA, USA, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [4]California Institute of Technology, Pasadena, CA, USA, [5]University of Heidelberg, Heidelberg, Germany, [6]University of Utah, Salt Lake City, UT, USA, [7]University of Saskatchewan, Saskatoon, SK, Canada

- Used high resolution tower spectral data to look at temporal dynamics of VIs and SIF at the Southern Old Black Spruce site in Saskatchewan





Troy Magney



- Relationships between NDVI, CCI and SIF at Monthly, Daily and Half-hourly time scales
- Observed non-linearity in SIF at the half-hourly time scale due to GPP saturation at high light
- The SIF:GPP relationship is non-linear at half-hourly intervals and the nature of the relationship changes on a monthly basis.
- CCI and NDVI show no relationship at the half-hourly time scale with improvements in temporal aggregration

Troy Magney

ENVIRONMENTAL RESEARCH
LETTERS

LETTER

CrossMark

OPEN ACCESS

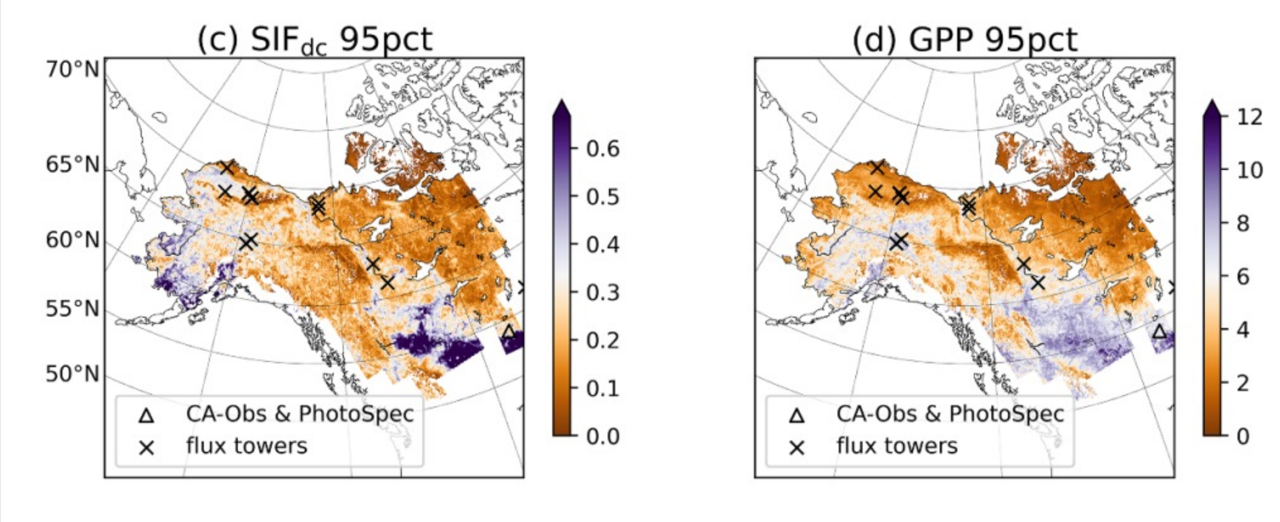
RECEIVED
15 July 2022

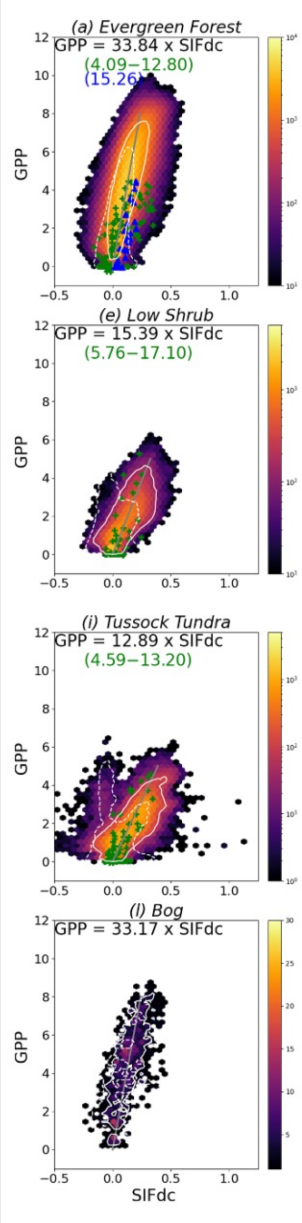
REVISED
16 October 2022

ACCEPTED FOR PUBLICATION

Evaluating photosynthetic activity across Arctic-Boreal land cover types using solar-induced fluorescence

Rui Cheng[1,13,*], Troy S Magney[2], Erica L Orcutt[2], Zoe Pierrat[8], Philipp Köhler[7], David R Bowling[3], M Syndonia Bret-Harte[4], Eugénie S Euskirchen[4], Martin Jung[5], Hideki Kobayashi[6], Adrian V Rocha[9], Oliver Sonnentag[10], Jochen Stutz[8], Sophia Walther[5], Donatella Zona[11] and Christian Frankenberg[1,12]





- **We report the regression slope, linear correlation coefficient, and the goodness of the fit of TROPOMI SIF-FLUXCOM GPP relationships for 15 Arctic-Boreal land cover types.**
- **We found several potential issues specific to the Arctic-Boreal region that should be considered:**
- (a) unrealistically high FluxCom GPP due to the presence of snow and water at the subpixel scale;
- (b) changing biomass distribution and SIF-GPP relationship along elevational gradients, and
- (c) limited perspective and misrepresentation of heterogeneous land cover across spatial resolutions.

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Climate Change is Enforcing Physiological Changes in Arctic Ecosystems

Nima Madani, Nima.madani@jpl.nasa.gov

Science or Technology Question:

Research Objective: Tracking phenological changes in pan-Arctic ecosystems in the last two decades.

Science goal: Understanding the response of ecosystems to changes in climate using satellite observations.

Data & Results:

- We leveraged solar induced chlorophyll fluorescence (SIF) to study changes in ecosystem phenology across the pan-Arctic domain from 2000-2020.
- We observed unique regional trends in responses of ecosystems to climate change affecting the timing of spring photosynthesis onset, magnitude of peak productivity during the growing season and fall senescence (Fig 1).
- Ecoregions, as a proxy for species and plant functional traits, were the single most important variable to explain the spatial and phenological heterogeneity in observed SIF trends.
- Early growing season onset trends across the vast majority of tends to decline at the end of the season for nearly half of the land area, including parts of North America but more significantly in central Siberia.

Significance:

- The observed changes in phenology highlight the role of biodiversity in regional climate sensitivity.
- The physiological changes would have profound impact on important ecosystem processes such as carbon uptake.

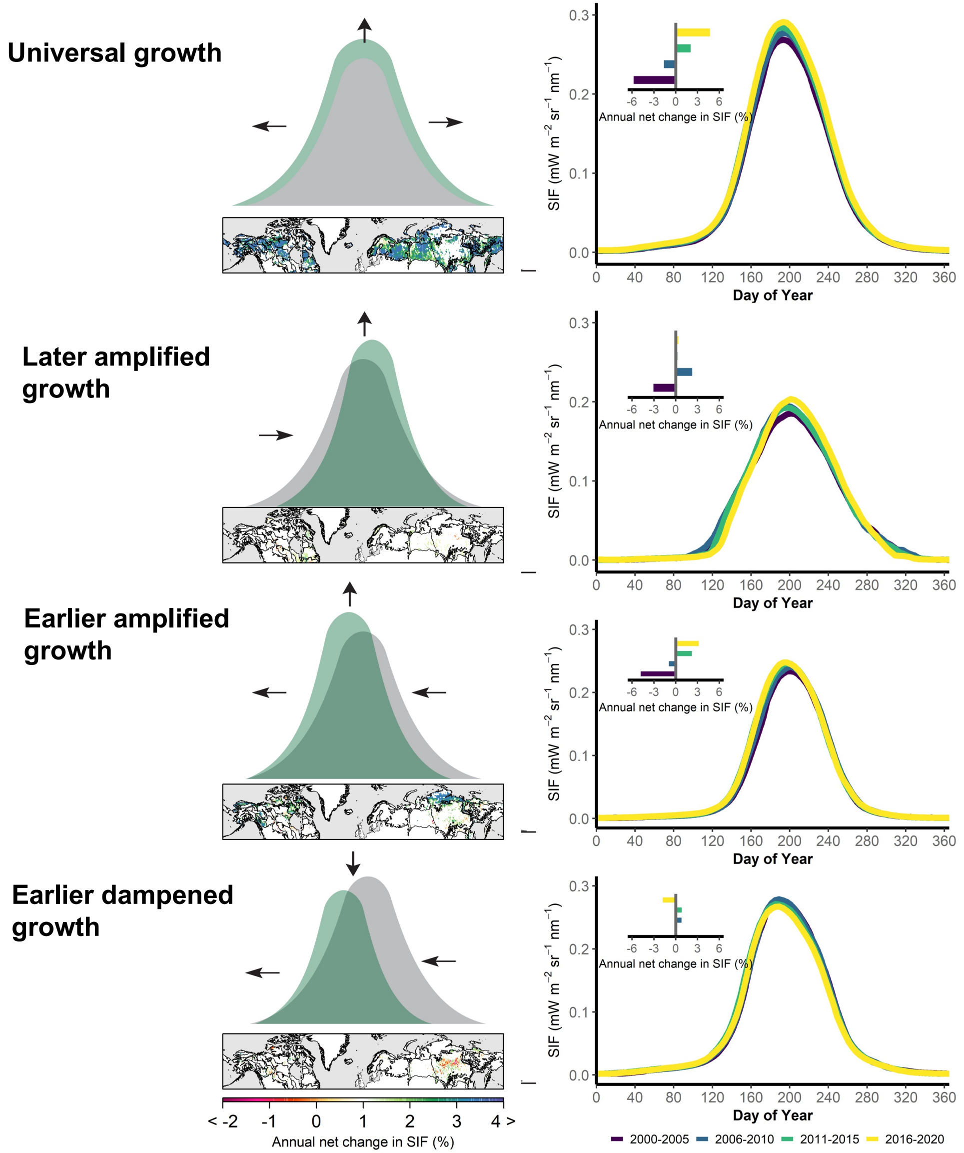
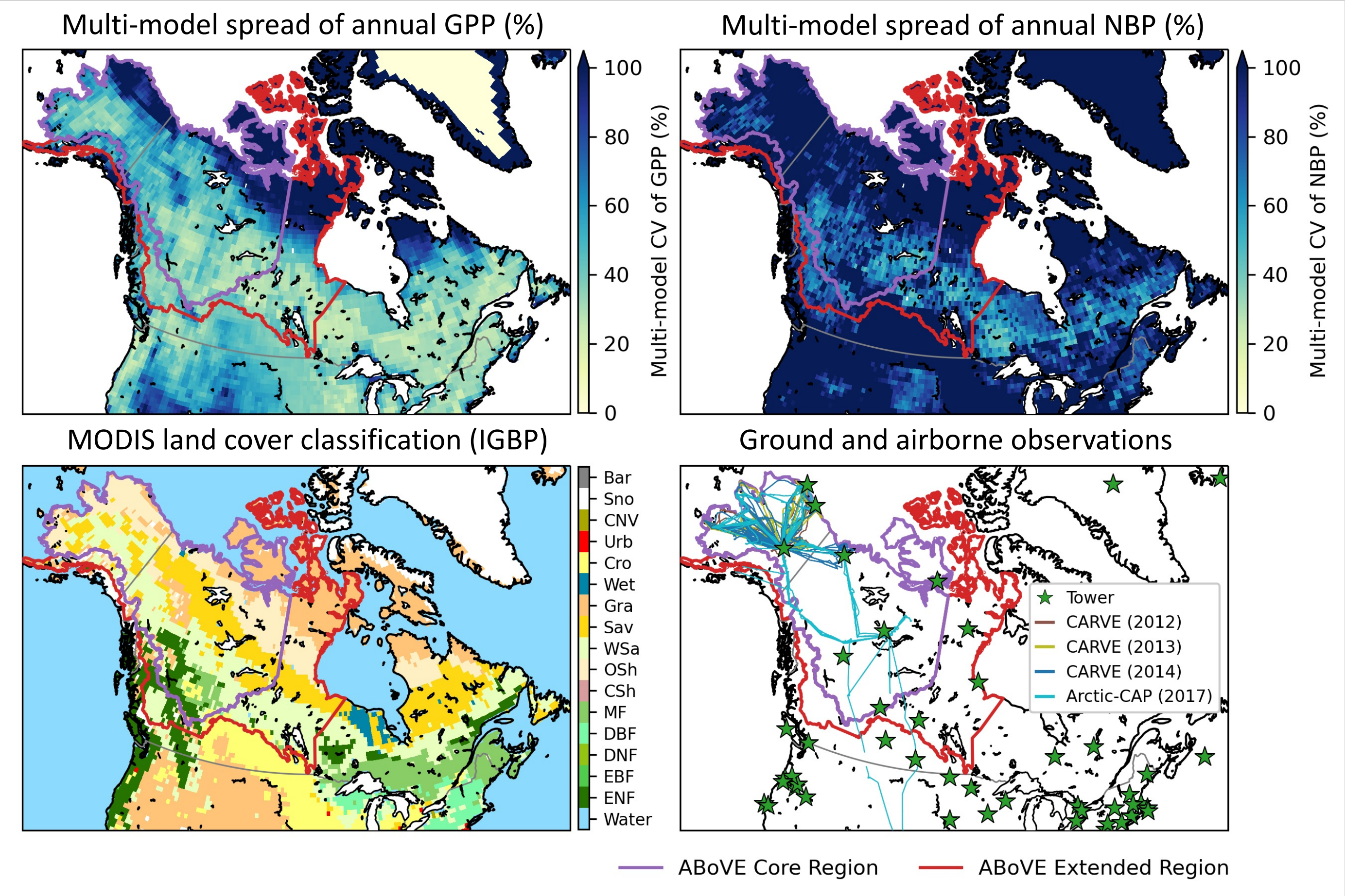


Fig 1. Changes in phenological patterns in pan-Arctic under four unique growth categories.

Quantifying climate sensitivities of photosynthesis and respiration in Arctic and boreal ecosystems from top-down observational constraints (Phase 3)



PI: Anna M. Michalak (Carnegie Institution)
Co-I/Science PI: Wu Sun (Carnegie Institution)
Co-I: Ben Bond-Lamberty (PNNL)
Collaborators: V. Balaji (Princeton), Joe Berry (Carnegie), Chip Miller (JPL), Elena Shevliakova (NOAA GFDL), and Mary Whelan (Rutgers)

Objectives

1. Assess functional responses of simulated GPP and ecosystem respiration to climate drivers
2. Use ABoVE observations to constrain the sensitivities of carbon fluxes to climate
3. Assess impact of improved sensitivity representation on historical and present-day flux estimates
4. Assess impact of improved sensitivity representation on projections of future carbon balance

CARNEGIE SCIENCE

Pacific Northwest NATIONAL LABORATORY

Project title: **A synthesis of variability in CO_2 and CH_4 fluxes from across the ABoVE domain**

Investigators: Scot Miller (Johns Hopkins)
Debbie Huntzinger (Northern Arizona)
Vineet Yadav (NASA JPL)

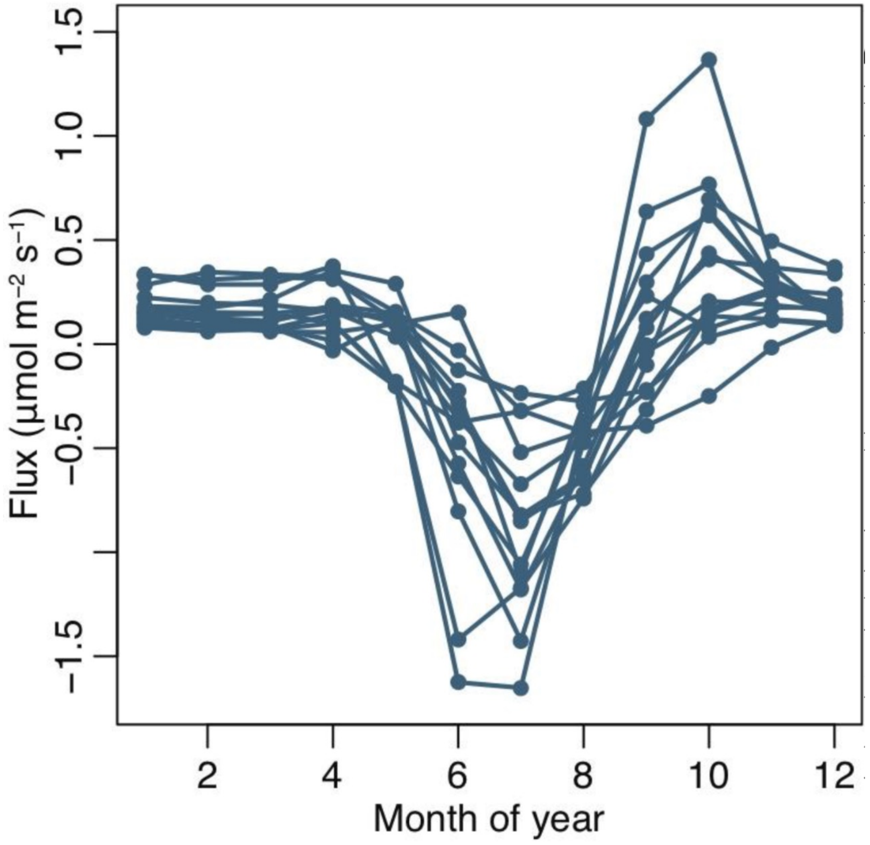
Key objectives:

1. Estimate the spatial and seasonal distribution of GHG fluxes across the ABoVE domain. Focus on fall and spring shoulder seasons.

2. Quantify IAV in CO_2 and CH_4 fluxes across the ABoVE domain.

3. Evaluate the magnitude, variability, and key environmental drivers of CO_2 and CH_4 fluxes across an ensemble of terrestrial biosphere models. Compare against inferences from atmospheric inverse modeling to identify avenues for reconciling the two.

Status updates: Project officially started late this fall. Currently recruiting PhD students to start work late this spring.



Caption: Mean net CO_2 fluxes by month (year 2018) estimated by the TRENDY biosphere models for global high latitudes (>60° N). Models yield very different estimates for the magnitude of fluxes and different seasonal cycles.

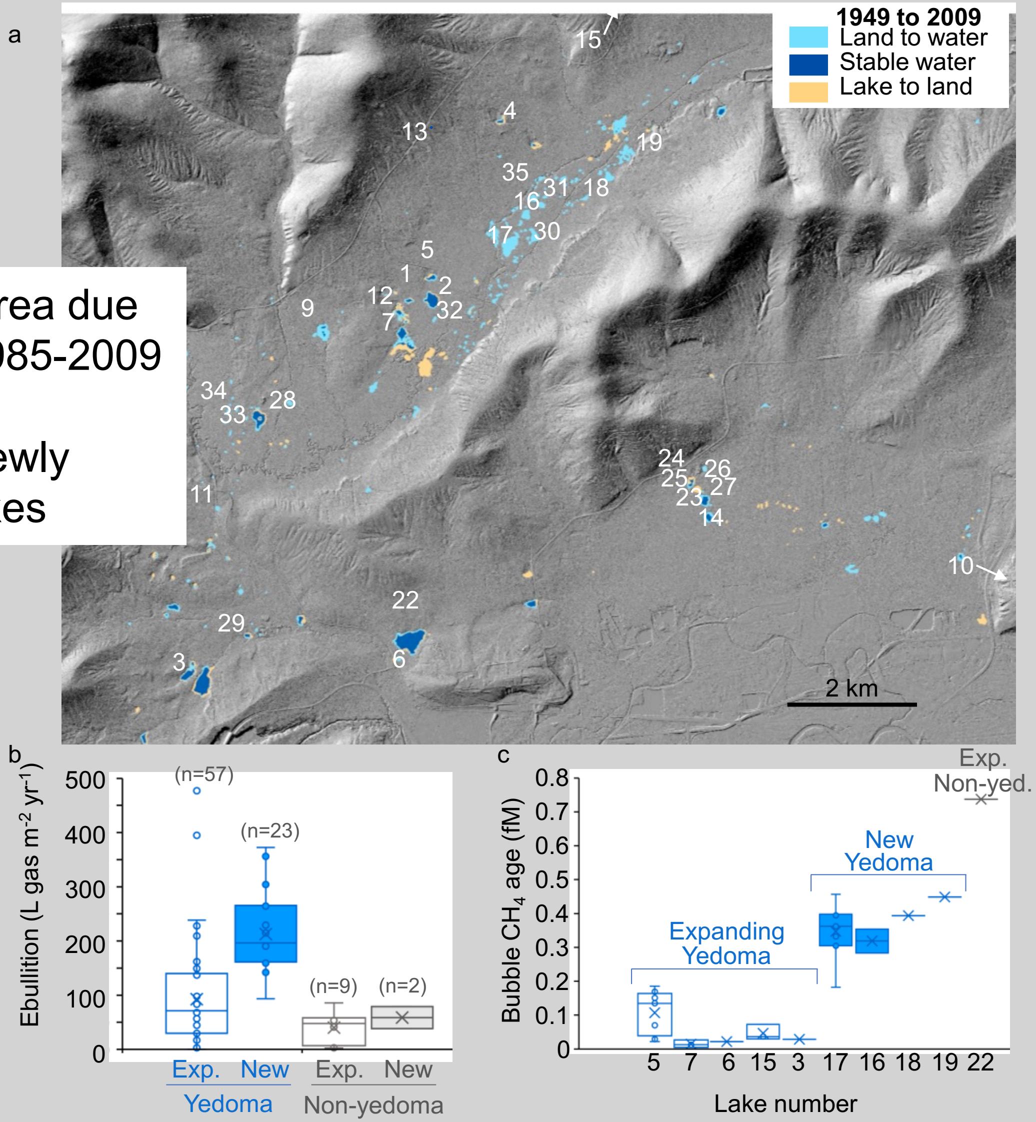
Enhanced Methane Emissions in Transitional Permafrost Environments: An ABoVE Phase 3 Synthesis Investigation

Katey Walter Anthony, University Alaska Fairbanks (Co-I),
Charles Miller (lead PI)

- Field work targets for 2023:
  - Big Trail Lake (near Fairbanks)
  - Minto Flats
  - NW Alaska (Baldwin Peninsula)
- Objectives
  - CH_4 seep mapping.
  - CH_4 fluxes relationship to geophysical measurements of abrupt thaw.
  - Geospatial relationships to AVIRIS-NG hotspots.
- See Walter Anthony et al. (2021) – ERL, Pellerin et al. (2022) – GCB, Sullivan et al. (2021) – PPP, Engram and Walter Anthony (in review) – RSE, Lotem et al. (in review) – Limnology and Oceanography

38% increase in lake area due to warming between 1985-2009

Methane hotspots in newly formed thermokarst lakes



Looking ahead..

- Phase II wrap-up (projects, data deliveries, synthesis activities) & transition to Phase III (current).
- Signing off as Chair of Carbon Dynamics and the ad-hoc Carbon Synthesis group.
- New co-chairs for the WG – Jon Wang (Univ. of Utah) and Jennifer Watts (WCRC)

QUESTIONS?

abhishek.chatterjee@jpl.nasa.gov

Incoming chairs - jon.wang@utah.edu, jwatts@woodwellclimate.org