
Denali National Park, National Park Service, Alaska, U.S

Constraining *shoulder season* carbon fluxes in the Arctic-Boreal region using satellite observations

Abhishek Chatterjee

Jet Propulsion Laboratory, California Institute of Technology
abhishek.chatterjee@jpl.nasa.gov

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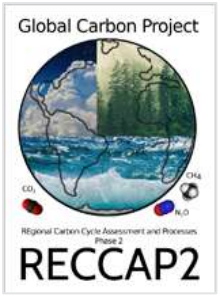
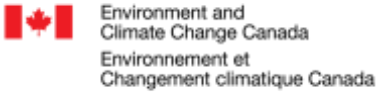
Acknowledgements



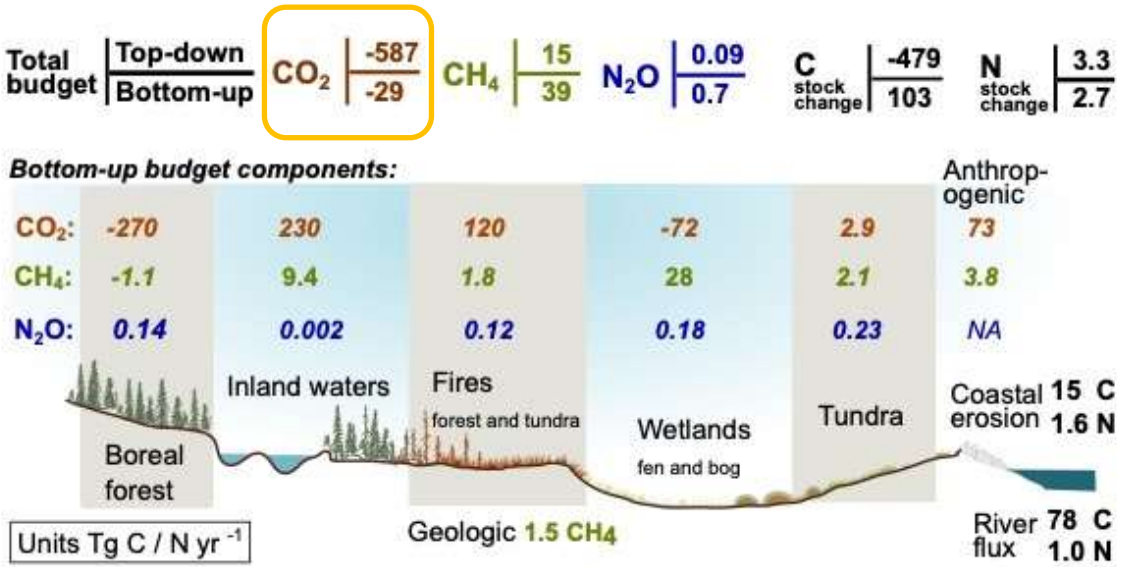
Sourish Basu, Joseph Mendonca, Hannakaisa Lindqvist, Logan Berner, Brendan Byrne, Antti Mikkonen, Ray Nassar, Chris O'Dell, Annett Bartsch, Luana Basso, Mathias Göckede, Scott Goetz, Peter Griffith, Daniel Hayes, Elizabeth Hoy, Gustaf Hugelius, Nima Madani, Julia Marshall, Charles Miller, Lesley Ott, Martijn Pallandt, Nicholas Parazoo, Jeralyn Poe, Benjamin Poulter, William Simpson, Debra Wunch, among others



A region with a highly uncertain C budget... and an uncertain future

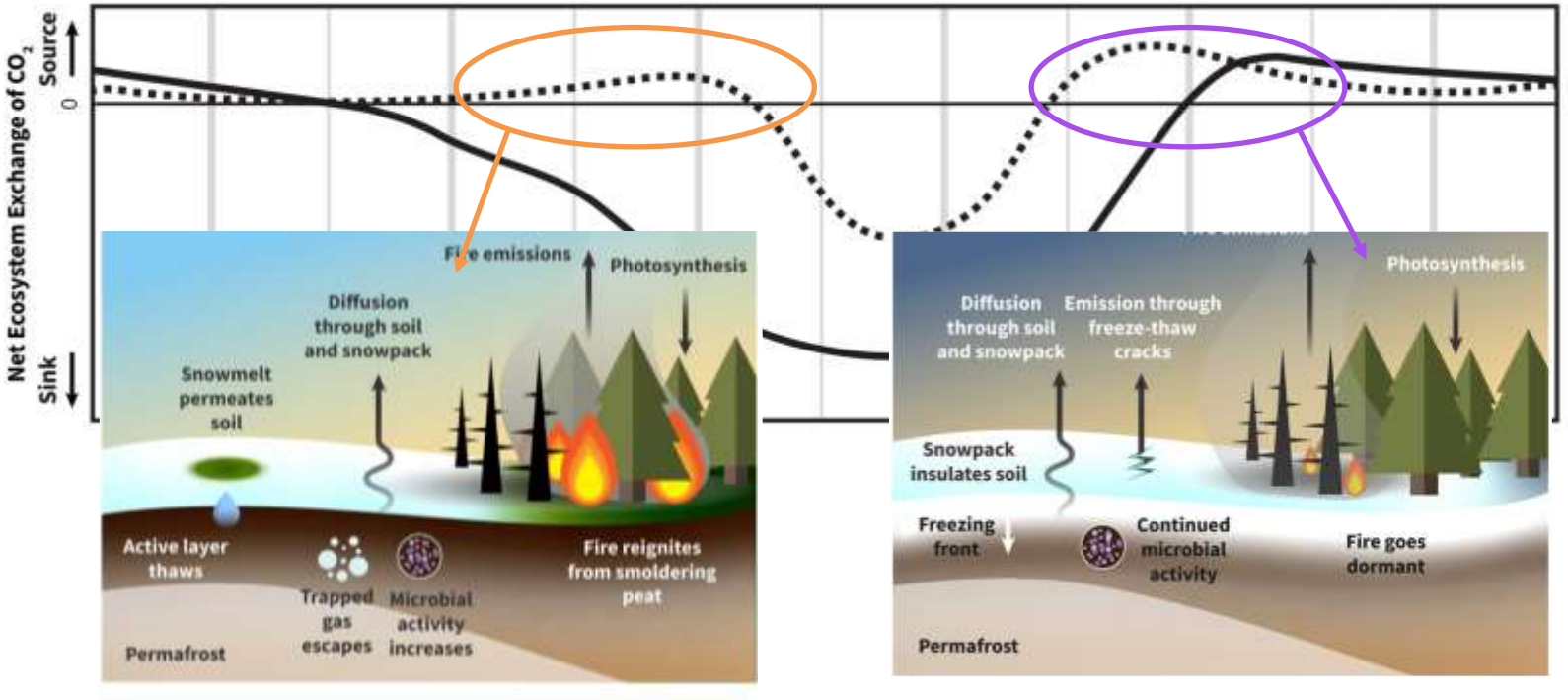
RECCAP-2 Permafrost

Ramage et al. [2024], Treat et al. [2024], Hugelius et al. [2024], Virkkala et al. [2025]



- Weak annual CO_2 sink and stable source of CH_4 and N_2O during the period 2000-2020
- **Bottom-up and top-down methods estimates on the sign, but cannot reconcile the huge difference in magnitudes**

Shoulder season carbon fluxes in the Arctic-Boreal

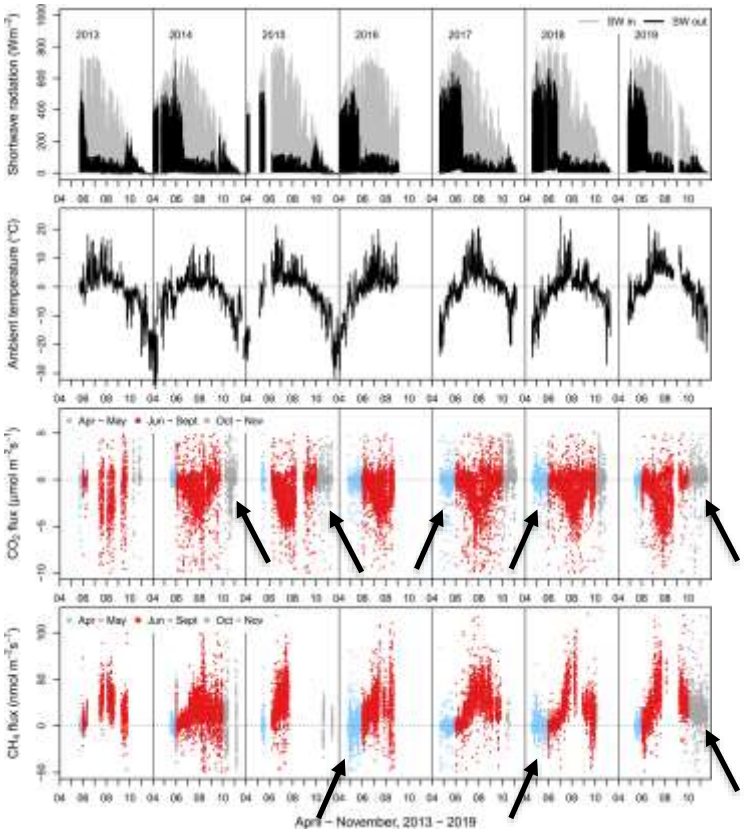


Credit: K. Arndt (WCRC)

These fluxes are significant, dynamic & underestimated!

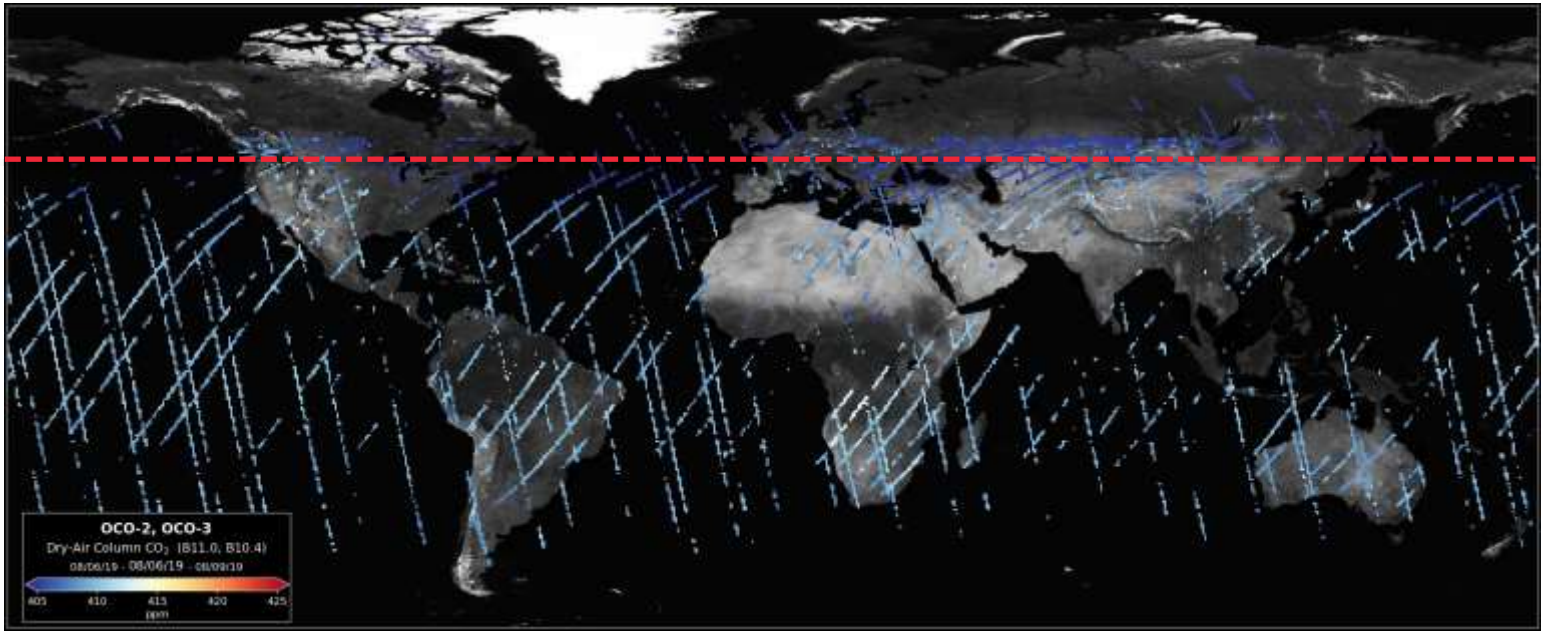
NGEE-Arctic Barrow (US-NGB) eddy flux site

Dengel et al. [2021]



- spring thaw and fall senescence CO_2 and CH_4 pulses play an important role in the seasonal cycle and annual budget
- we have observed these strong pulses from *in situ* networks, including airborne campaigns but these obs. are sparse
- models struggle to capture processes underlying these shoulder season fluxes

Our current gen. CO_2, CH_4 satellites are limited by the need for sunlit conditions

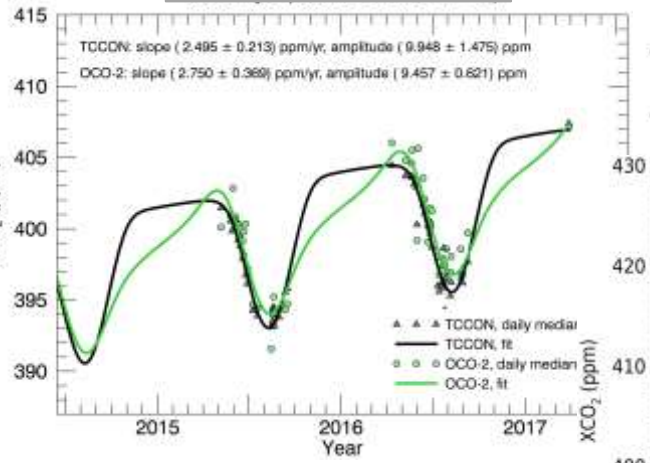


- ✓ GOSAT – since 2009
- ✓ OCO-2 – since 2014
- ✓ TROPOMI – since 2018

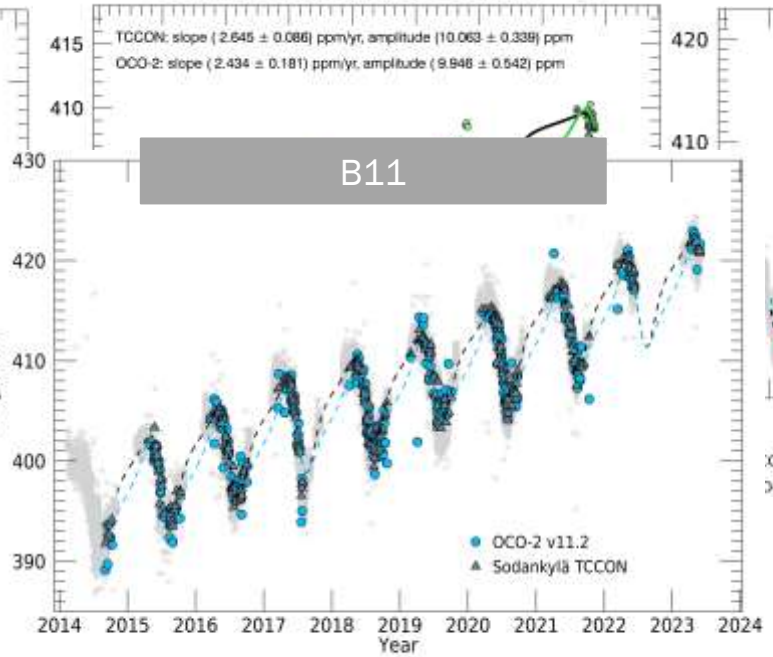
- ✓ robust constraint on the growing season
- ❑ limited constraint during the shoulder seasons
- • zero constraints between December – February

Good news though is that our retrieval algorithms continue to mature and improve

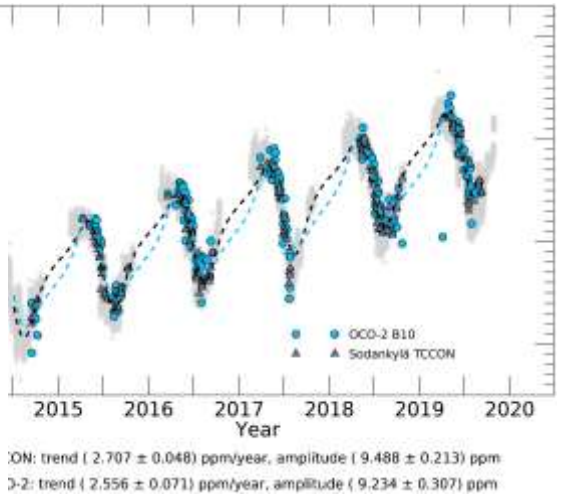
B8



B9



B10



B11

TCCON: trend (2.51 ± 0.02) ppm/year, amplitude (9.57 ± 0.15) ppm
OCO-2: trend (2.49 ± 0.04) ppm/year, amplitude (9.24 ± 0.23) ppm

abhishek.chatterjee@jpl.nasa.gov

Credit: H. Lindqvist (FMI)

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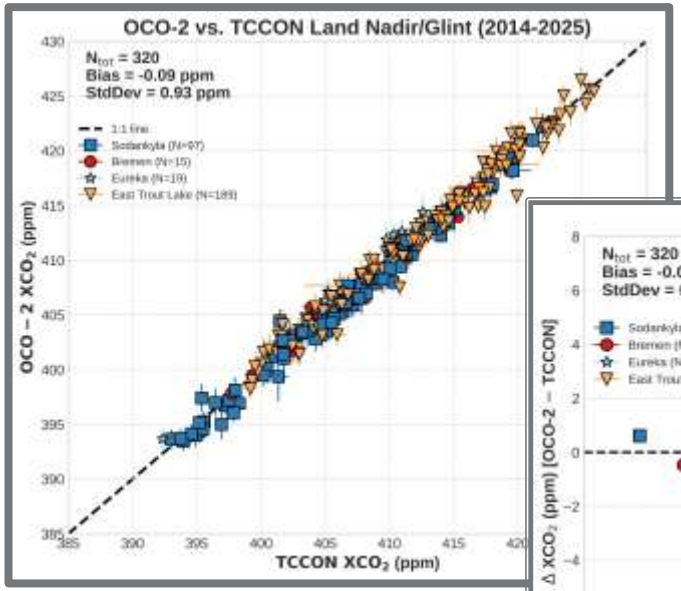

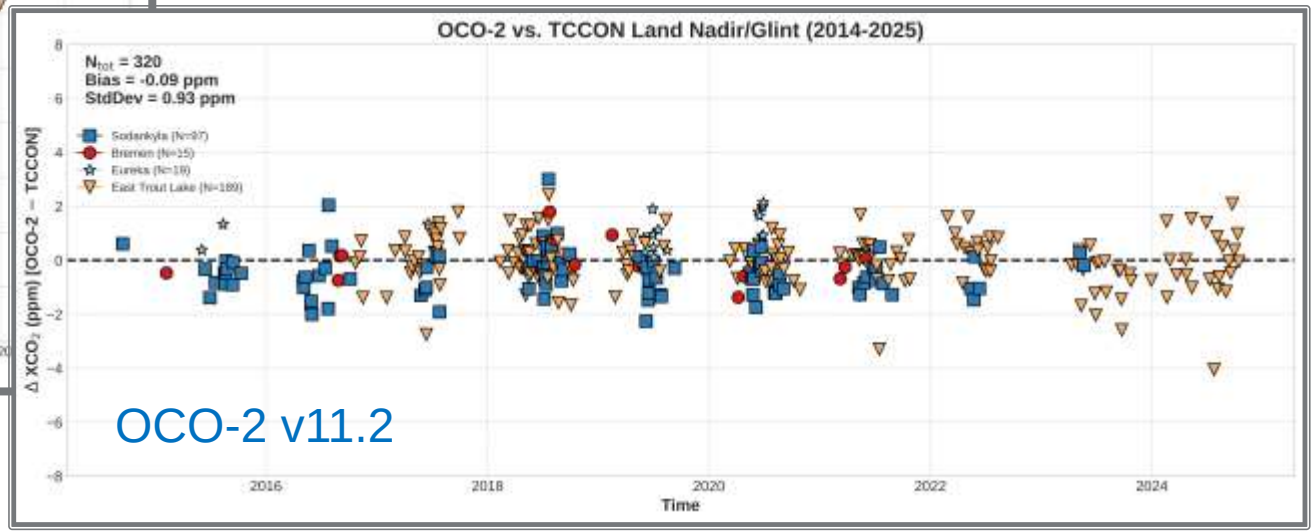

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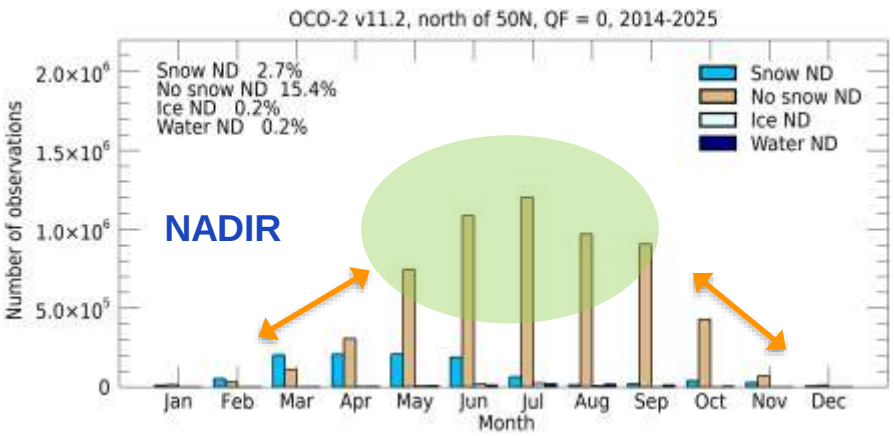
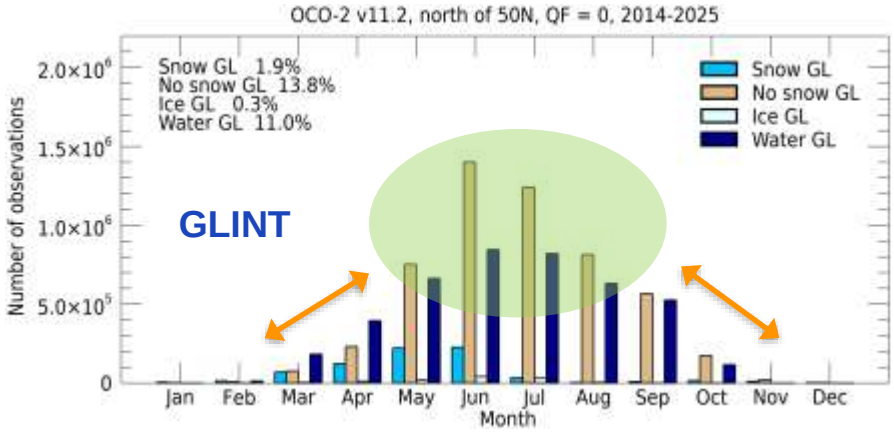
Credit: M. Kiel (JPL)

What we lack is “enough” good-quality soundings during shoulder seasons

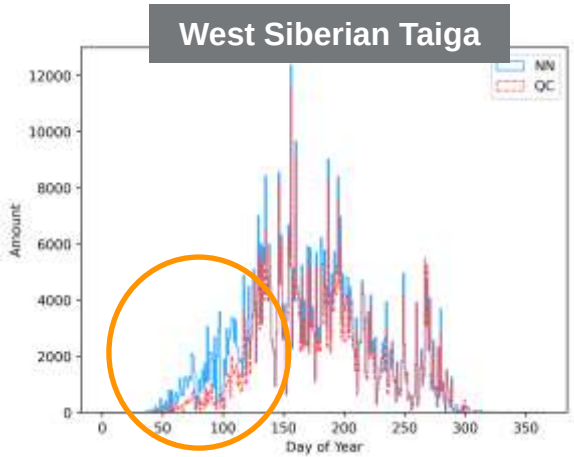


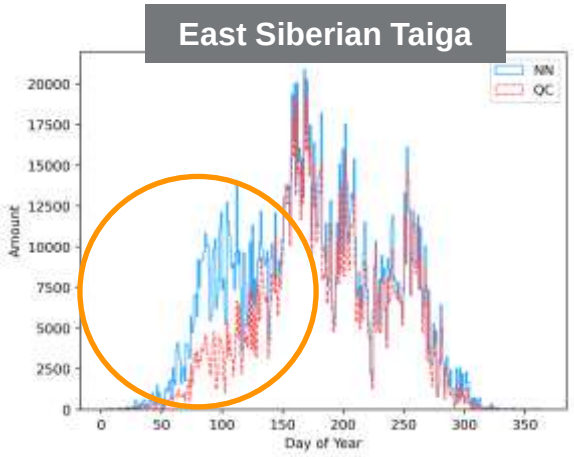


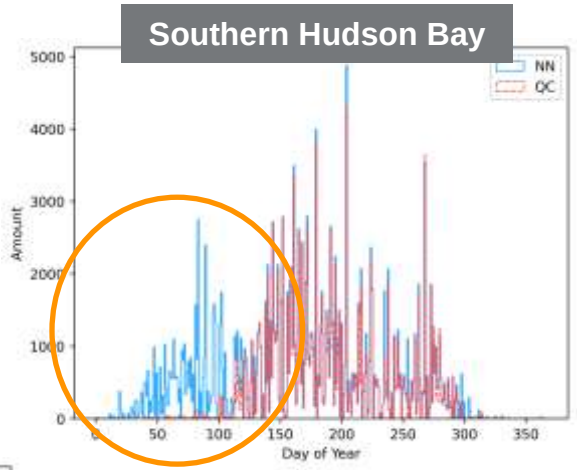
How do we extract more soundings during *shoulder seasons*?

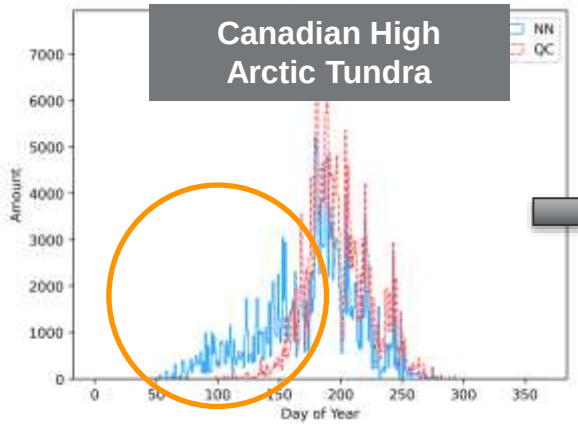
i.e., avoid screening out measurements recorded over snow-covered scenes

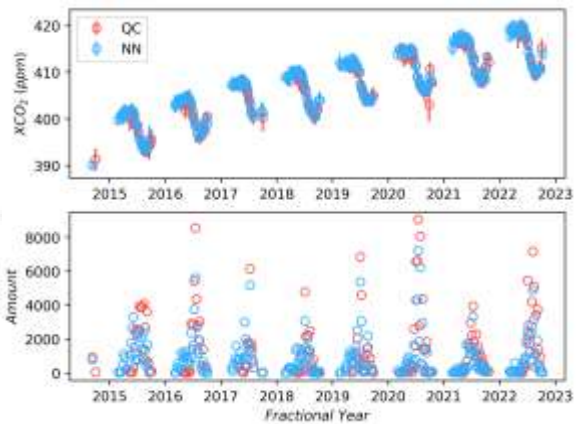
Implementing a neural network-based filtering technique











J. Mendonca et al.
(in preparation)

Mendonca et al. [2021], AMT

Do these “additional” obs. impact CO_2 flux estimates?

TM5-4DVAR Setup

2015–2022 (8-yr run)

Global 3°×2° with a **Nested 1°×1° b/w** 50°–75° latitude

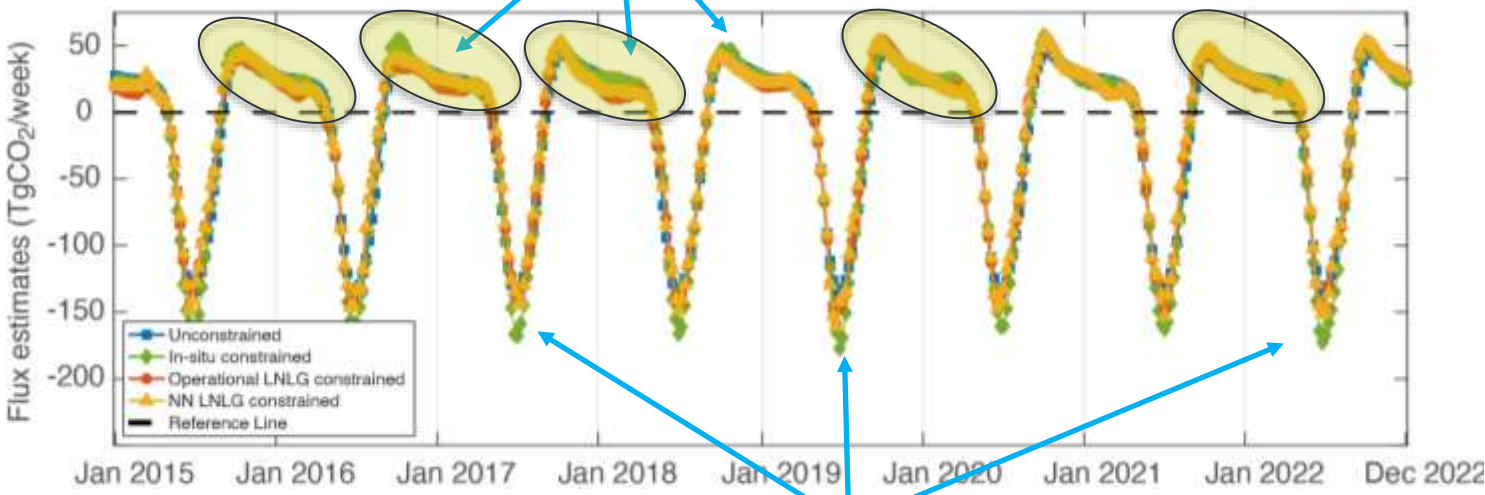
Weekly estimates

Ensemble of prior flux estimates

Total 9 experiments

pan-Arctic, 2015–2022

differences in non-growing season fluxes



differences in magnitude of growing season uptake

Do these “additional” obs. impact CO_2 flux estimates?

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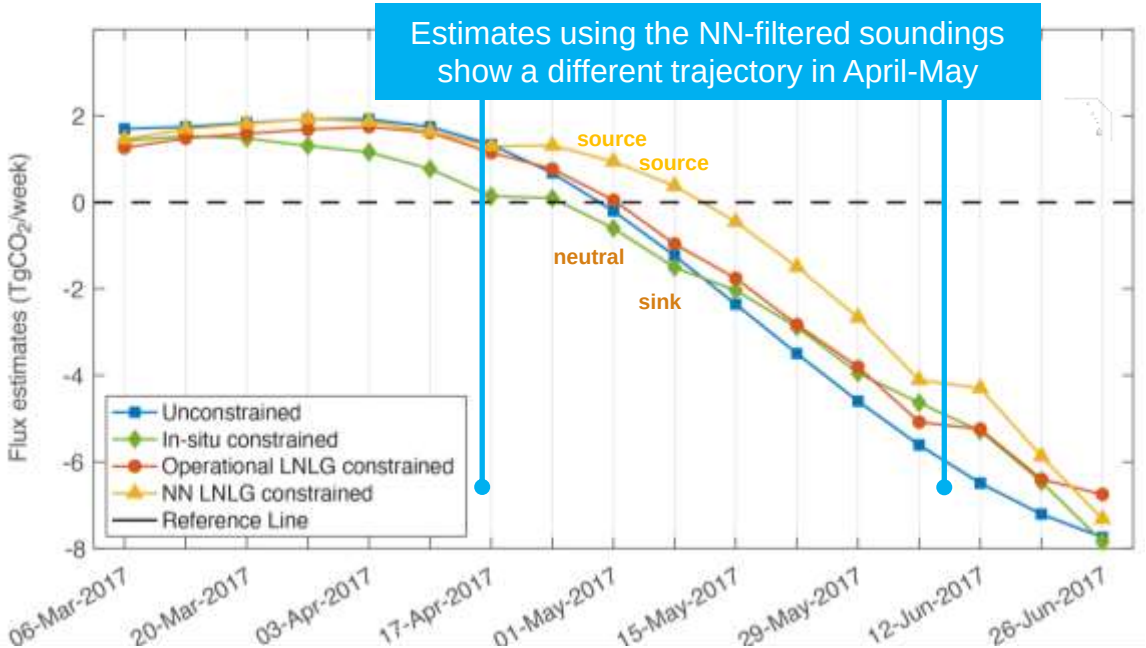
Weekly estimates

Ensemble of prior flux estimates

Total 9 experiments

Southern Hudson Bay, Spring Thaw 2017



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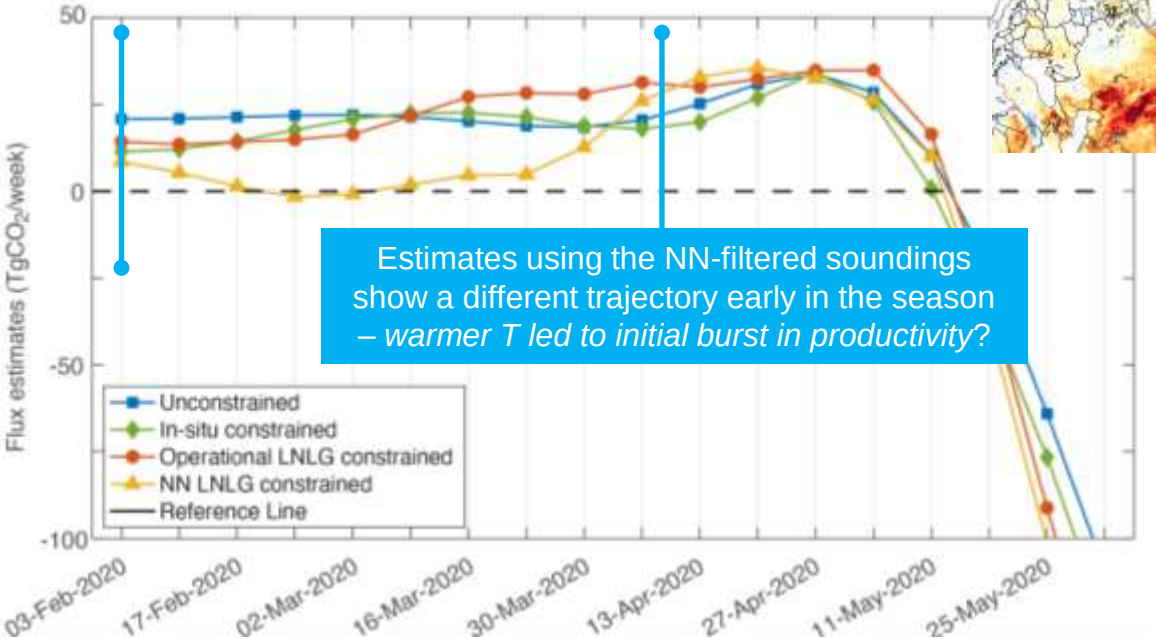
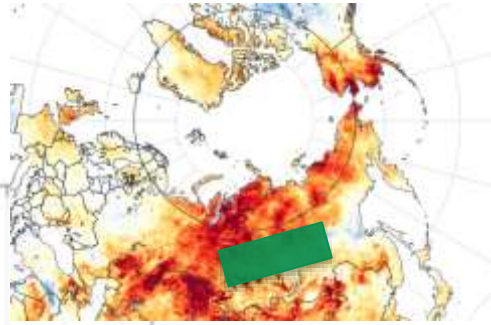
Total 9 experiments

Siberia, Jan. – Apr. 2020 Heatwave



Estimates using the NN-filtered soundings show a different trajectory early in the season *– warmer T led to initial burst in productivity*?



T anomalies, Spring 2020

Do our flux estimates *really* improve?

TM5-4DVAR Setup

2015–2022 (8-yr run)

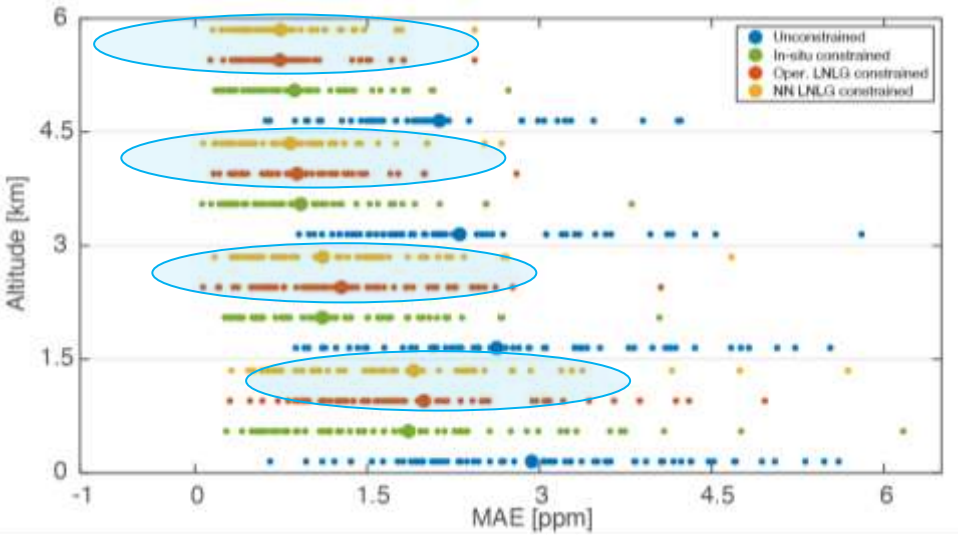
Global 3°×2° with a **Nested 1°×1° b/w** 50°–75° latitude

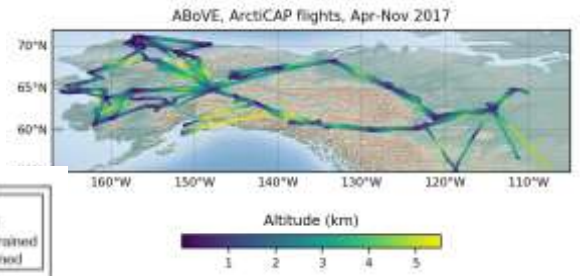
Weekly estimates

Ensemble of prior flux estimates

Total 9 experiments

NASA Arctic-CAP flights, 27 Apr. – 4 May 2017





- More ***robust*** validation analysis is underway, including searching for other independent datasets, evaluation against model and EC-upscaled flux estimates

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Additional efforts & activities to improve CO_2, CH_4 retrievals in the ABR

- Augmenting high-latitude validation network (CHARS TCCON site, Cambridge Bay, Northwest Territories; cal-val supersite at the FMI Arctic Space Center in Sodankylä – see poster #4.15)
- Development of a new retrieval algorithm for processing soundings collected over snow & ice surfaces → international collaboration across various teams (NASA/CSU → OCO2, FMI/ESA → CO2M, ECCC/CSA → AOM)

➢ Length of the satellite data record is growing (GOSAT → 15+ years, OCO-2 → 10+ years, TROPOMI → 5+ years) ☞ *invaluable for understanding how the ABR fluxes [growing season, shoulder season] are evolving*

Summary

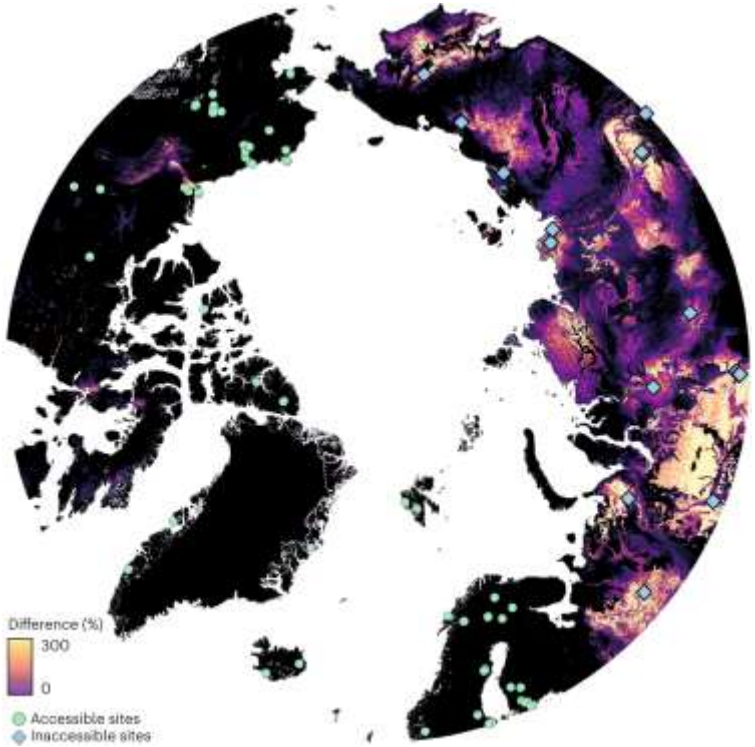
The ABR is changing rapidly, changes are happening now and will continue

- Space-based vantage point provides an opportunity to track these changes & improve understanding of the complex interactions that underlie C cycle dynamics in this region
- Satellite observations of CO_2 and CH_4 have already demonstrated that they can –
  - track C cycle response to extreme events (e.g., heatwaves and abrupt thaw)
  - provide insights into large-scale processes not well captured by process-based models (e.g., soil respiration during fall)
  - improve monitoring over remote regions of the Arctic (e.g., permafrost peatlands, the Arctic Ocean)
- Continued investments in improving the CO_2, CH_4 retrievals benefits both the quality and the quantity of observations [spatial coverage and Feb. – Nov. seasonal coverage] across the ABR

... and right now, these satellite observations are more important than ever!

- The loss of access to Russian territory, seas, and air space has significantly impacted the pan-Arctic science enterprise
- It is unclear when this geopolitical issue will be resolved
- Satellite observations help overcome these physical access constraints

Schuur et al. [2024]



Regions of environmental space described by the Arctic carbon monitoring network that are affected by loss of Russian science collaborations.

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QUESTIONS?

abhishek.chatterjee@jpl.nasa.gov

Photo Credit: Sandra Angers-Blondin & Isla Myers-Smith (UBC)