PERMAFROST CARBON EMISSIONS IN THE POLAR NIGHT

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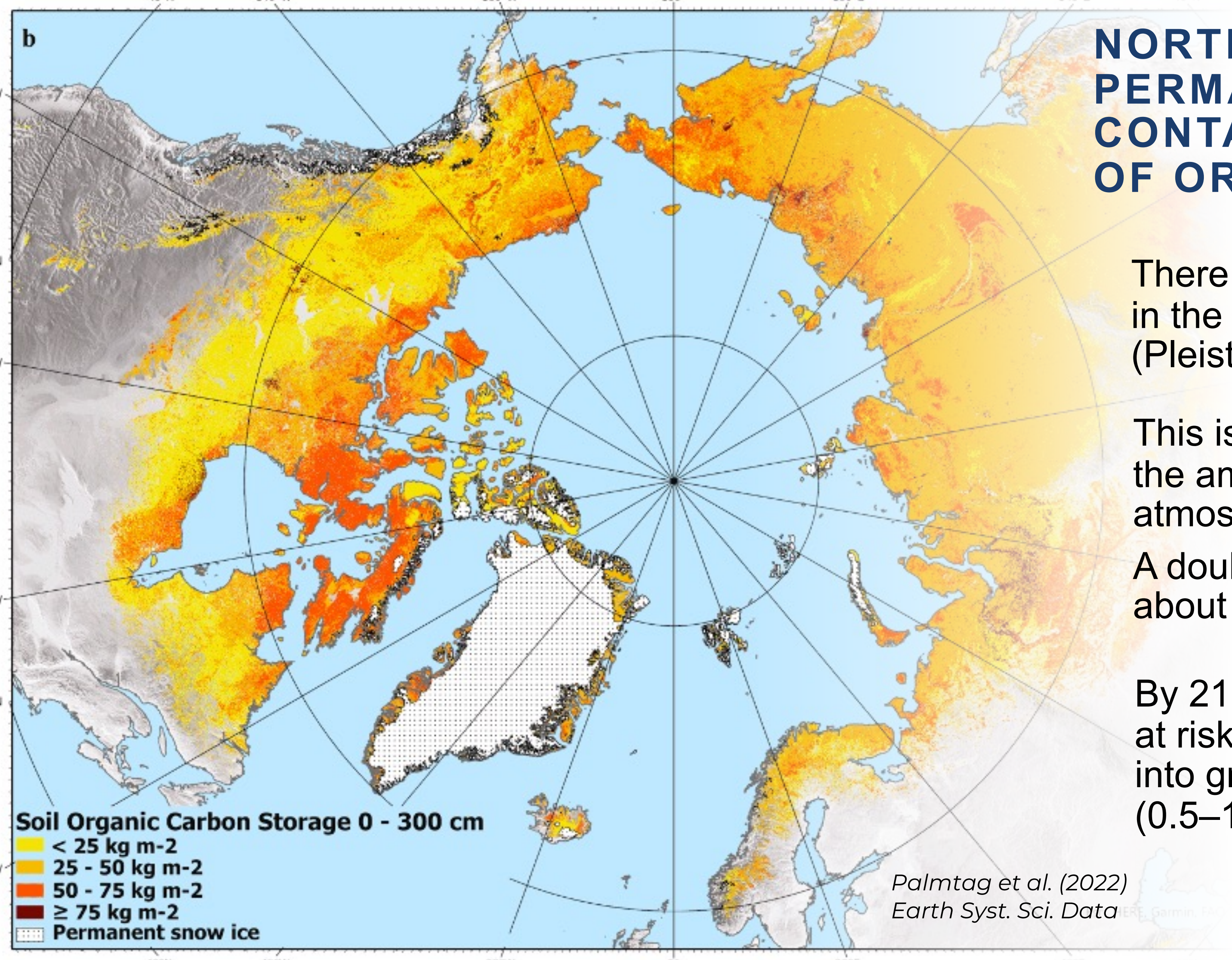


Palmtag et al. (2022)
Earth Syst. Sci. Data

NORTHERN CIRCUMPOLAR PERMAFROST SOILS CONTAIN VAST AMOUNTS OF ORGANIC CARBON

There are about 1000 Pg C (55 Pg N) in the top 3 m, much of it legacy (Pleistocene-age) carbon.

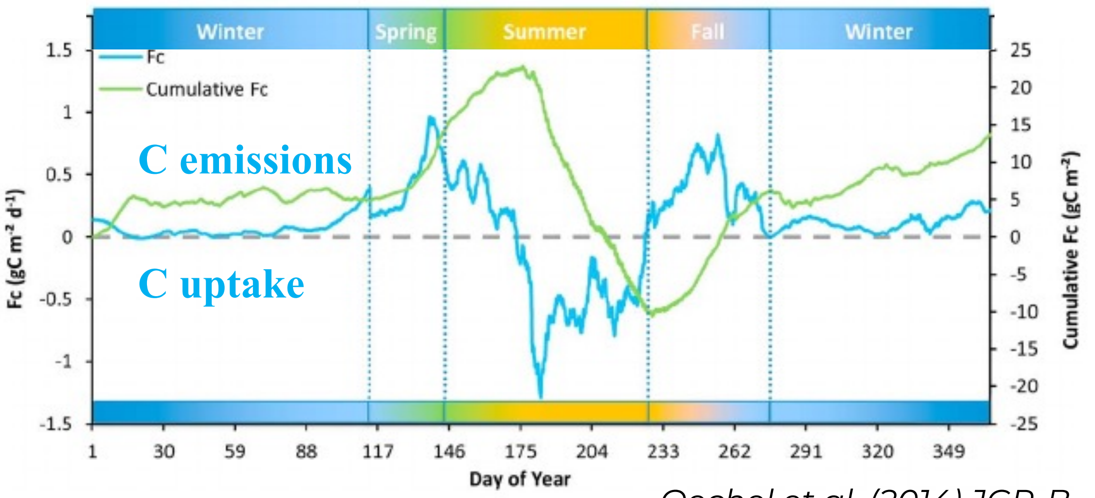
This is roughly equivalent to the amount of C in the atmosphere: 3200 Pg CO_2

A doubling CO_2 leads to about 3°C of warming.

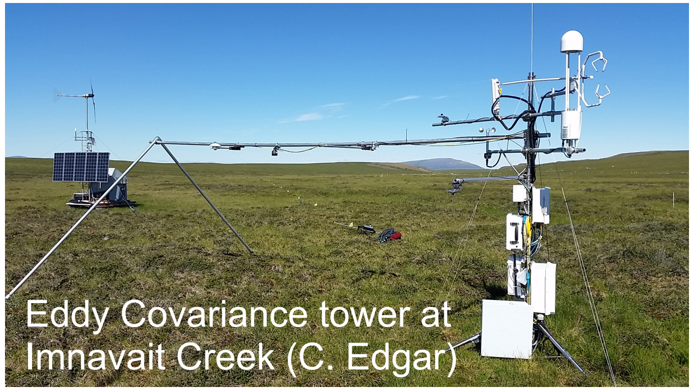
By 2100, 100–240 Pg C are at risk of being converted into greenhouse gases (0.5–1°C).

Schuur et al. (2015) Nature CC

ADVANCES IN MEASURING CO_2 FLUXES YEAR-ROUND SHOW THAT RISING WINTER EMISSIONS ARE TURNING THE ARCTIC INTO A C SOURCE



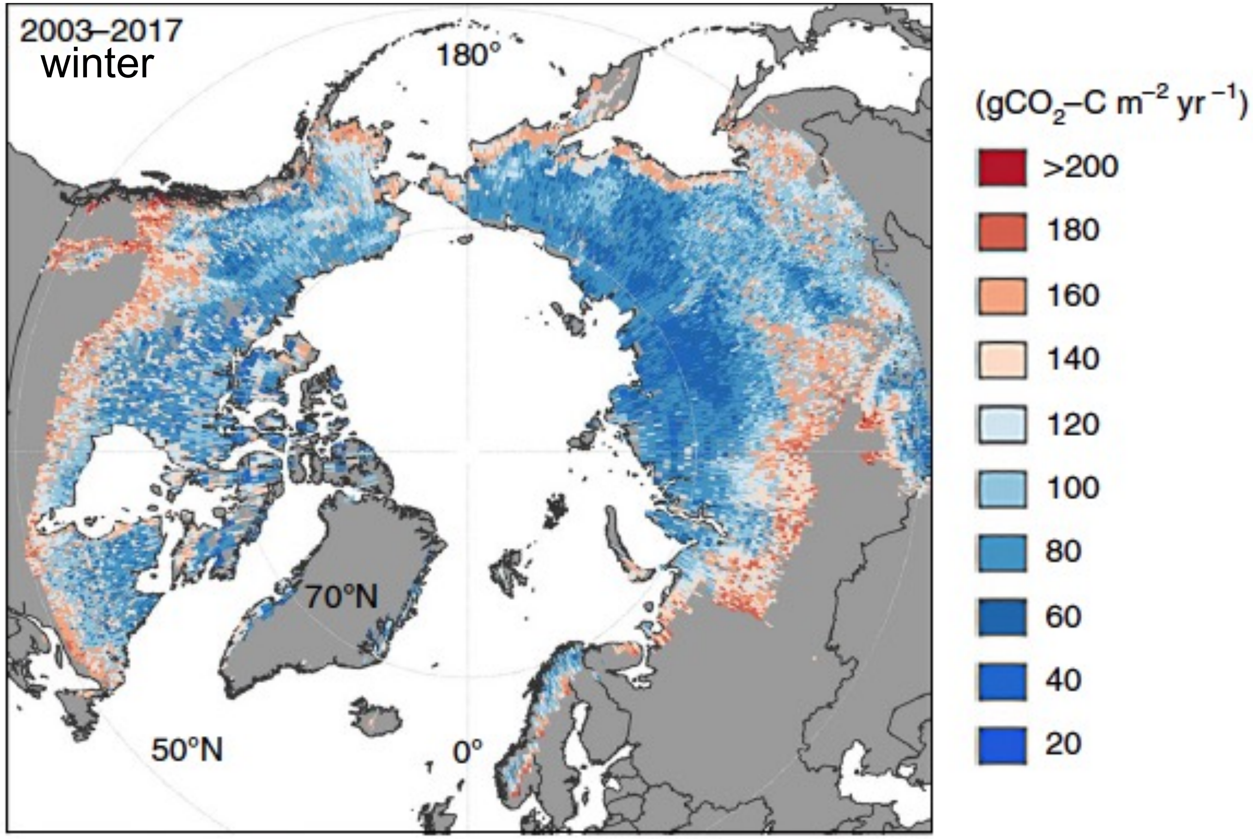
Oechel et al. (2014) JGR-B



Eddy Covariance tower at Imnavait Creek (C. Edgar)

Soil respiration station with forced diffusion chamber (J. Watts)

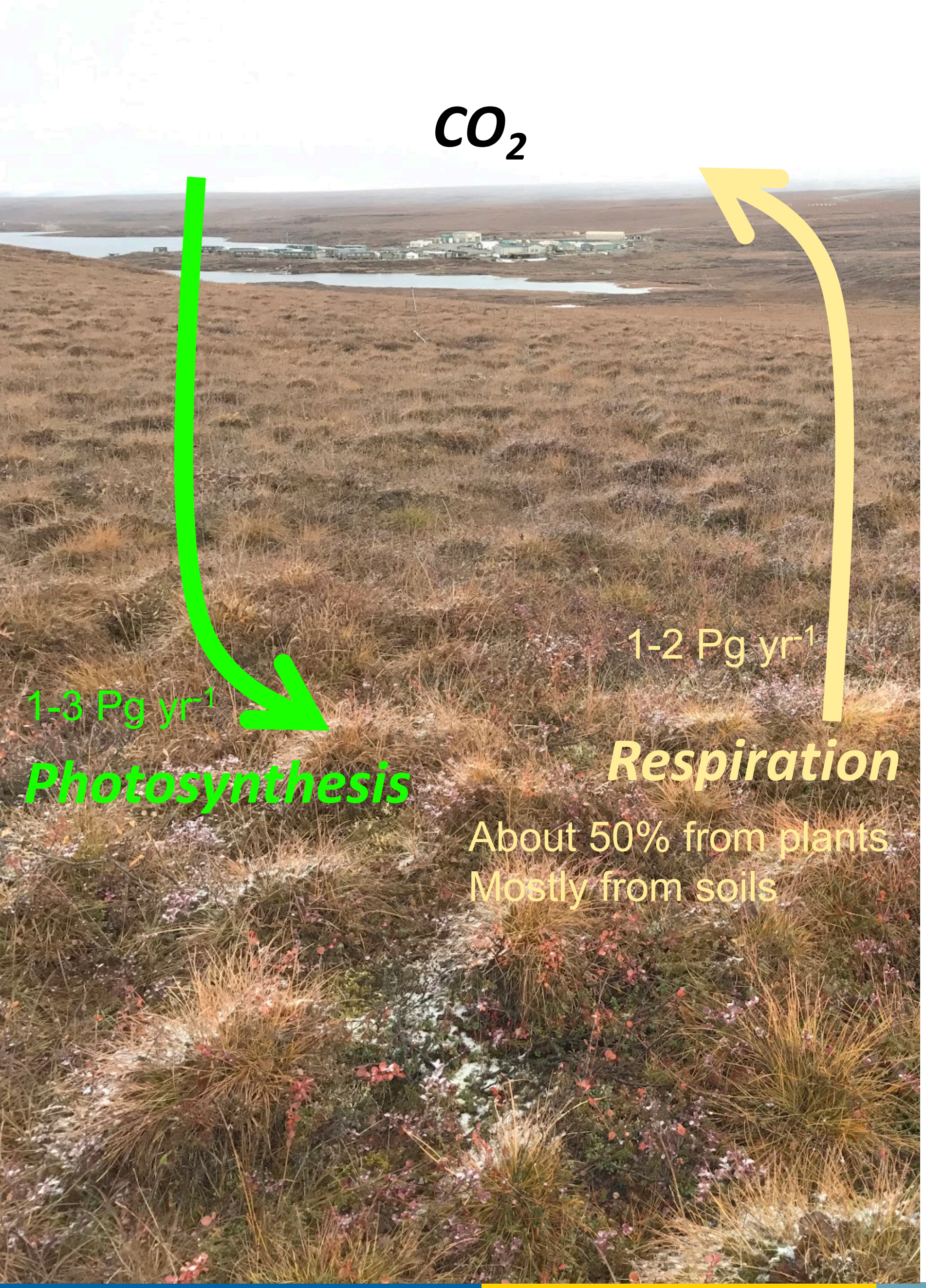
1.7 Pg C yr^{-1} are emitted as CO_2 from the permafrost region during the cold season, exceeding growing season uptake *Natali et al. (2019) Nature CC*



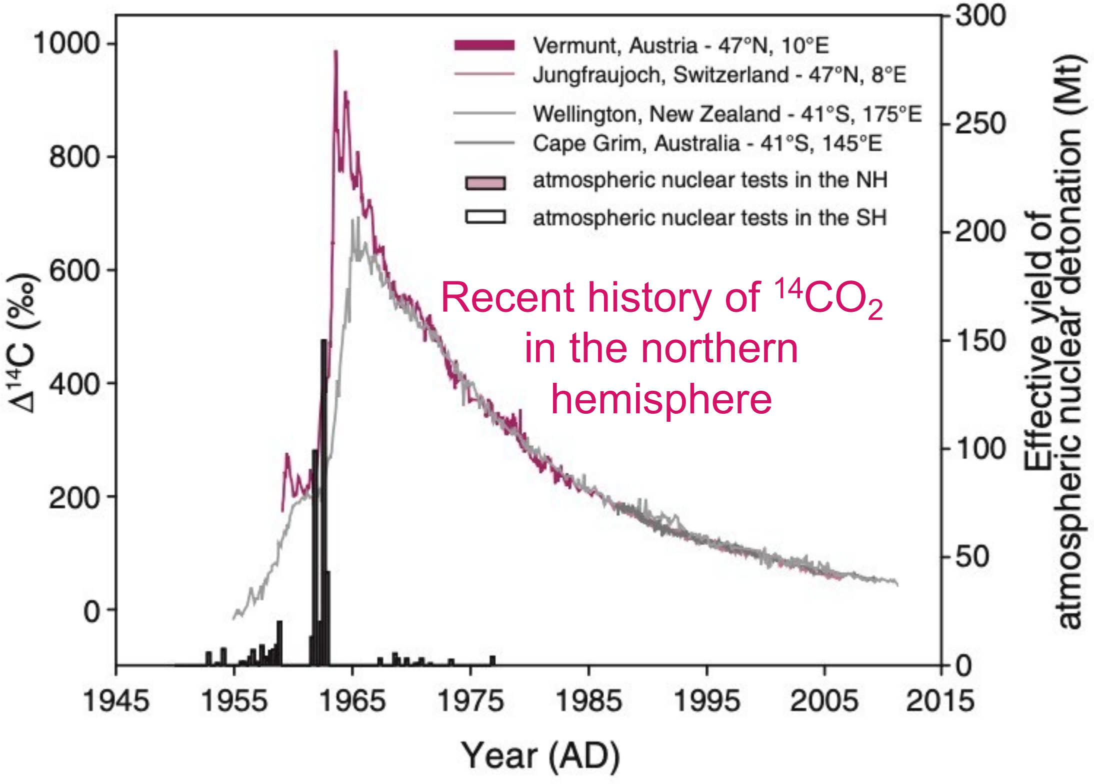
WHAT ARE THE SOURCES OF MICROBIAL CO_2 EMISSIONS DURING THE POLAR NIGHT?

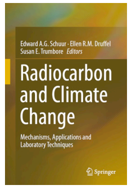
How large are contributions from legacy carbon in thawing permafrost?

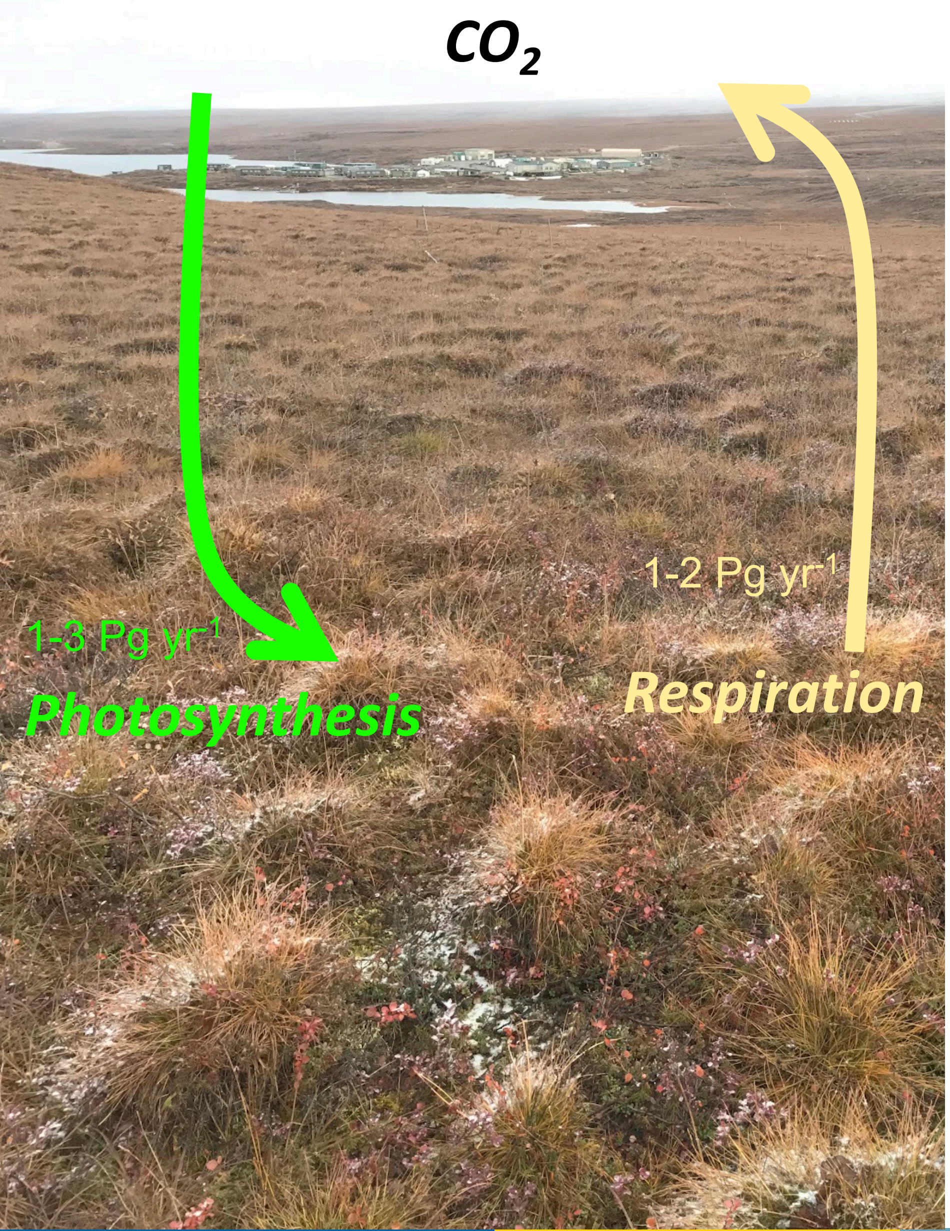
WE CAN DIFFERENTIATE RESPIRATION SOURCES WITH RADIOCARBON (^{14}C)



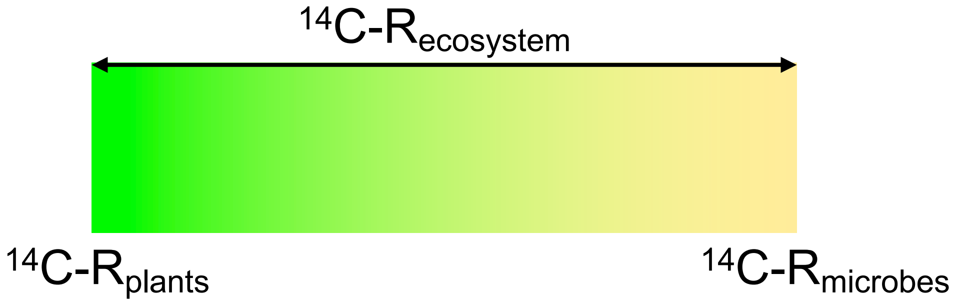
Plants respire CO_2 that was recently fixed from the atmosphere.
We know the history of atmospheric $^{14}CO_2$ and thus of plant respiration.

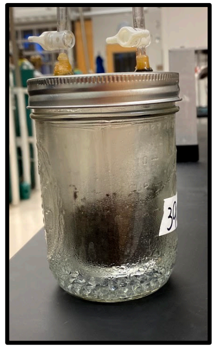






QUANTIFYING PLANT VS. MICROBIAL CONTRIBUTIONS TO RESPIRATION



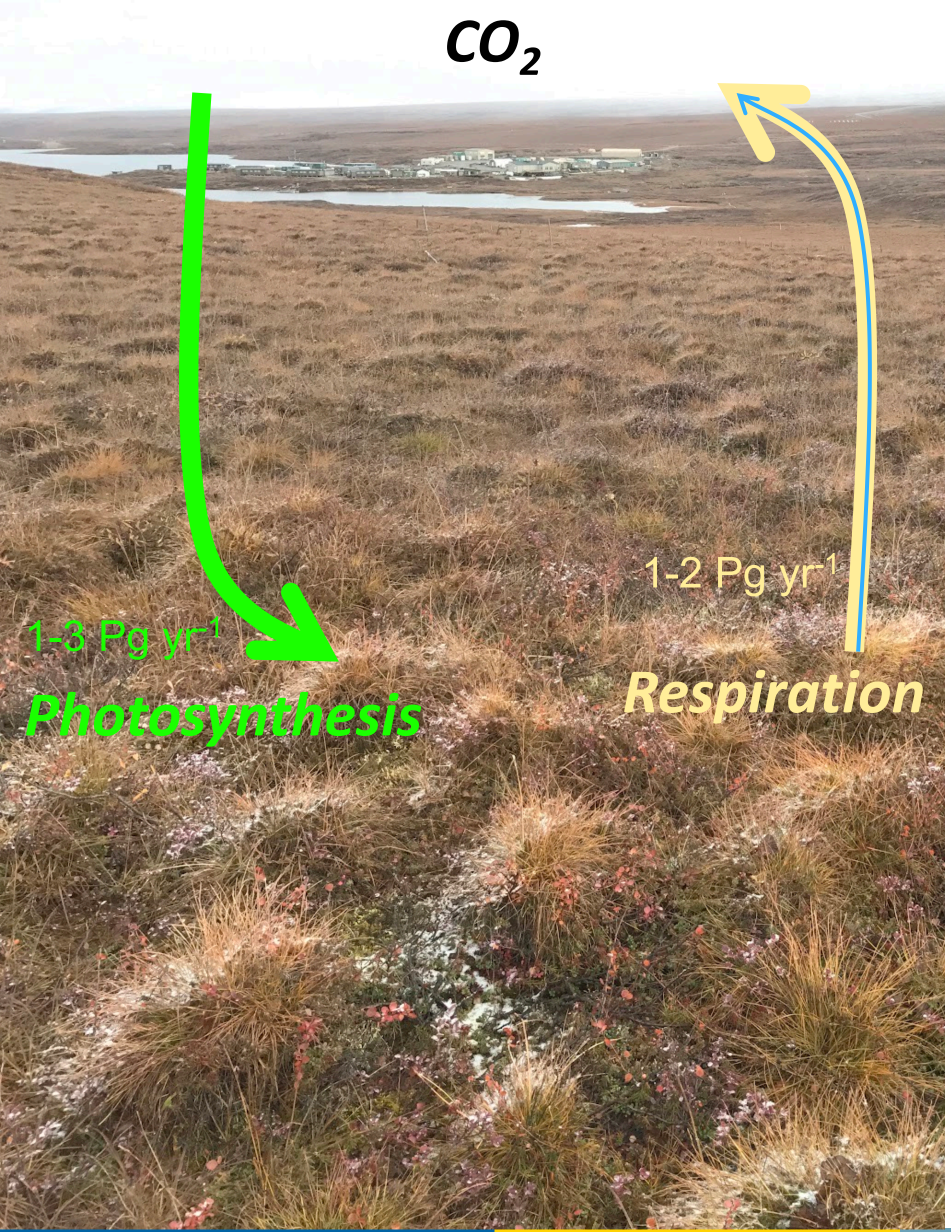


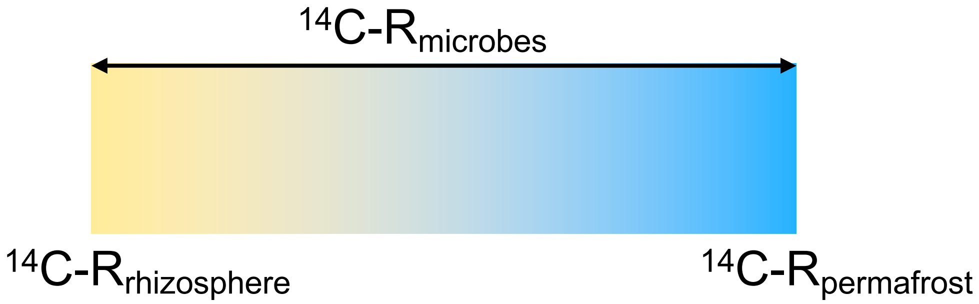
$$R_{ecosystem} = R_{plants} + R_{microbes}$$

measured — known — estimated from incubations

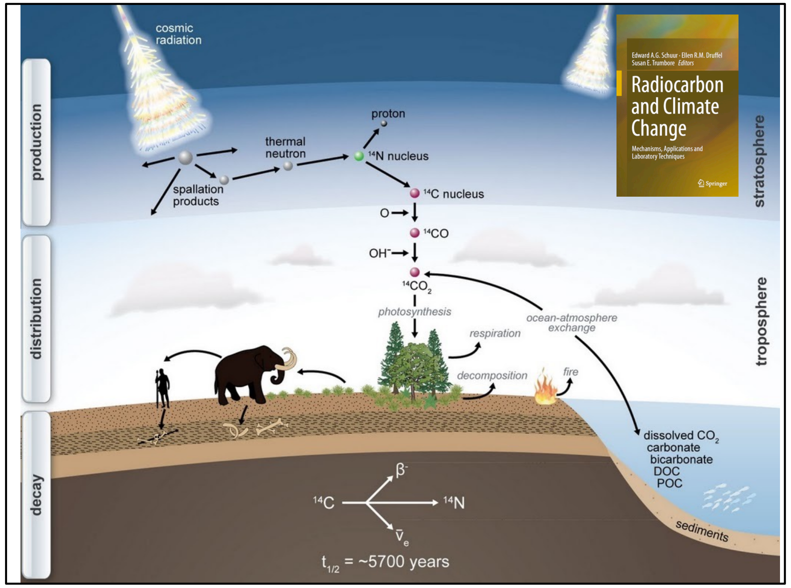
$$^{14}C\text{-}R_{ecosystem} = f_{plants} \times {}^{14}C\text{-}R_{plants} + f_{microbes} \times {}^{14}C\text{-}R_{microbes}$$

PERMAFROST CONTRIBUTIONS TO MICROBIAL RESPIRATION





Permafrost carbon is depleted in ^{14}C due to radioactive decay.



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Analysis of $^{14}CO_2$, accumulated in chambers

a) by pumping through molecular sieve or

b) in evacuated canisters via a flow-restricting capillary,

combined with soil incubations and/or bulk soil analyses, **has transformed our understanding of carbon cycling in terrestrial ecosystems.**

ECOLOGICAL APPLICATIONS
ECOLOGICAL SOCIETY OF AMERICA

Article | Full Access

AGE OF SOIL ORGANIC MATTER AND SOIL RESPIRATION: RADIOCARBON CONSTRAINTS ON BELOWGROUND C DYNAMICS

Susan Trumbore

Biogeochemistry **51:** 33–69, 2000.
© 2000 *Kluwer Academic Publishers. Printed in the Netherlands.*

Soil carbon cycling in a temperate forest: radiocarbon-based estimates of residence time sequestration rates and partitioning of fluxes

JULIA B. GAUDINSKI[1], SUSAN E. TRUMBORE[1], ERIC A. DAVIDSON[2] & SHUHUI ZHENG[1]
[1]*Department of Earth System Science, University of California at Irvine, Irvine CA;* [2]*Woods Hole Research Center, Woods Hole MA*

Received 27 December 1999; accepted 4 January 2000

Experimental warming and drying increase older carbon contributions to soil respiration in lowland tropical forests

Karis J. McFarlane, Daniela F. Cusack, Lee H. Dietterich, Alexandra L. Hedgpeth, Kari M. Finstad & Andrew T. Nottingham

Nature Communications **15**, Article number: 7084 (2024) | Cite this article

Global Change Biology

Full Access

Changing sources of soil respiration with time since fire in a boreal forest

CLAUDIA I. CZIMCZIK, SUSAN E. TRUMBORE, MARIAH S. CARBONE, GREGORY C. WINSTON

First published: 01 March 2006 | https://doi.org/10.1111/j.1365-2486.2006.01107.x | Citations: 9

Global Change Biology

Full Access

Partitioning sources of soil respiration in boreal black spruce forest using radiocarbon

Edward A.G. Schuur, Susan E. Trumbore

First published: 28 November 2005 | https://doi.org/10.1111/j.1365-2486.2005.01066.x | Citations: 140

High Arctic wetting reduces permafrost carbon feedbacks to climate warming

M. Lupascu, J. M. Welker, U. Seibt, K. Maseyk, X. Xu & C. I. Czimczik

Nature Climate Change **4**, 51–55 (2014) | Cite this article

Schuur, E. A., Hicks Pries, C., Mauritz, M., Pegoraro, E., Rodenhizer, H., See, C., & Ebert, C. (2023). Ecosystem and soil respiration radiocarbon detects old carbon release as a fingerprint of warming and permafrost destabilization with climate change. *Philosophical Transactions of the Royal Society A*, *381*(2261), 20220201.

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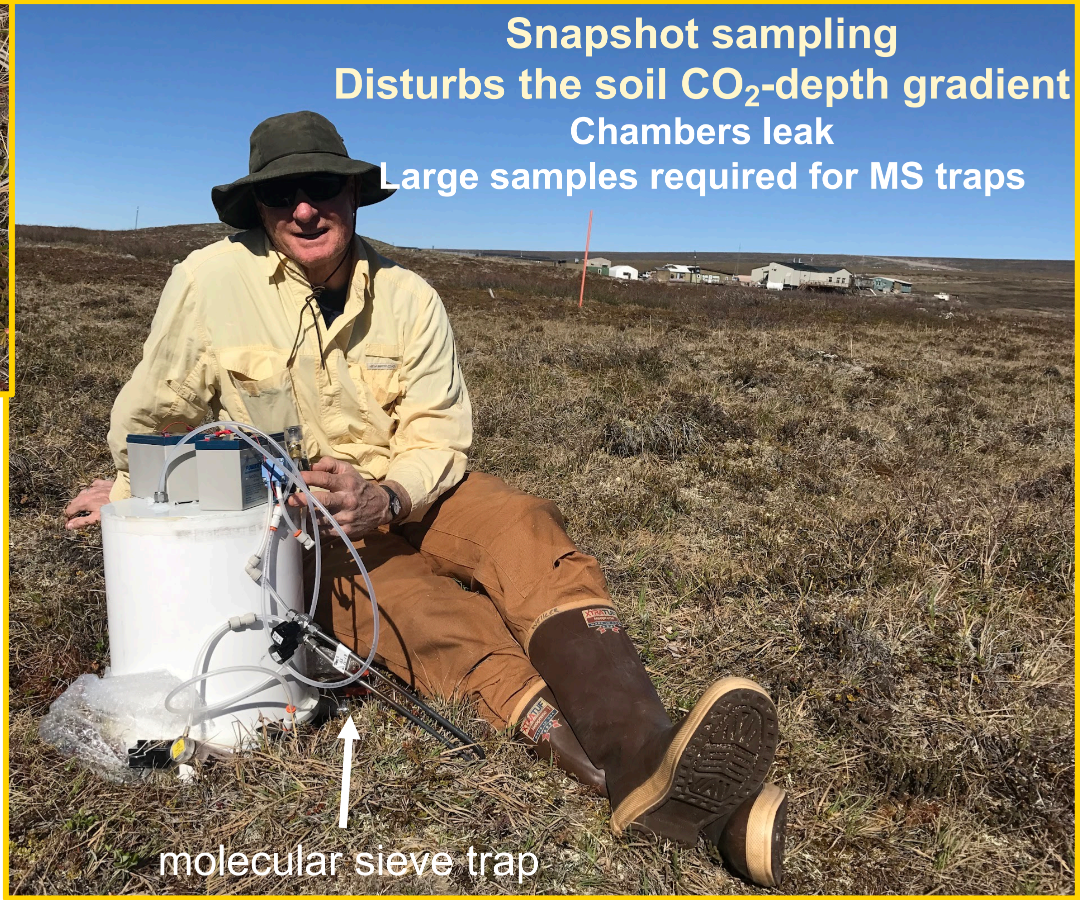
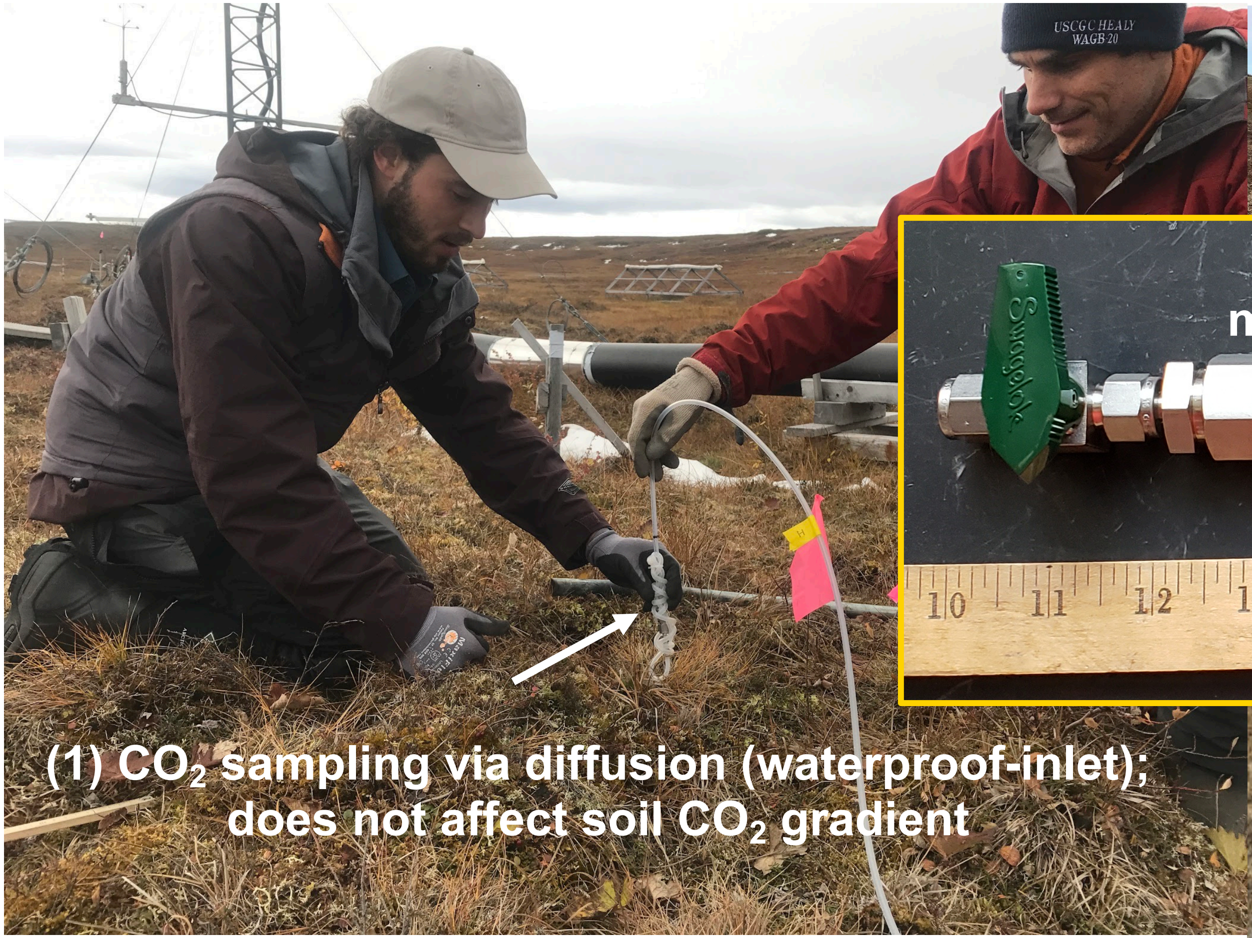
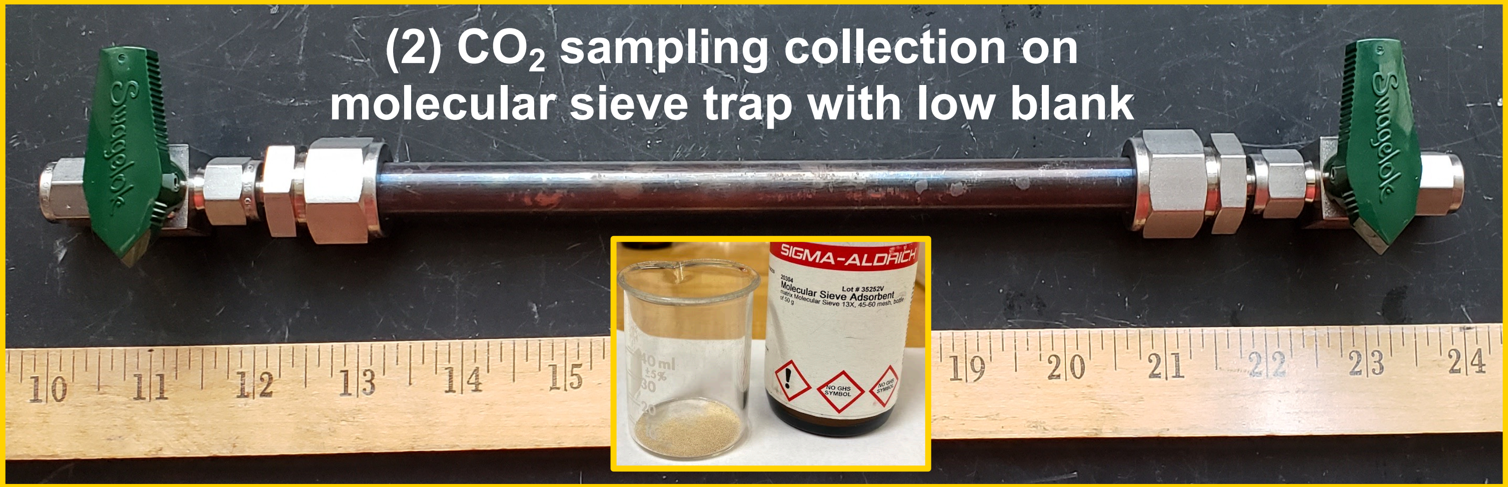
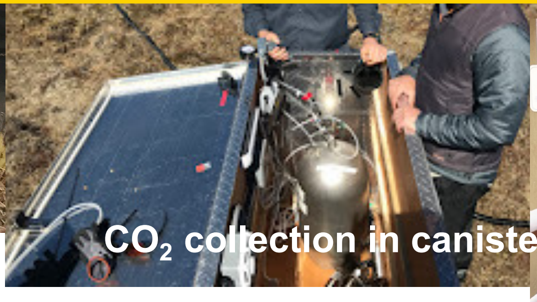
CHALLENGE: CAPTURING ARCTIC SOIL $^{14}CO_2$ YEAR-ROUND



SOLUTION: CONSTRUCTION OF RUGGED PASSIVE $^{14}CO_2$ SAMPLER







- In moist acidic tussock tundra,
  the most common land cover type in N Alaska (63,000 km^2).
- Alongside soil [CO_2], temperature, and moisture.



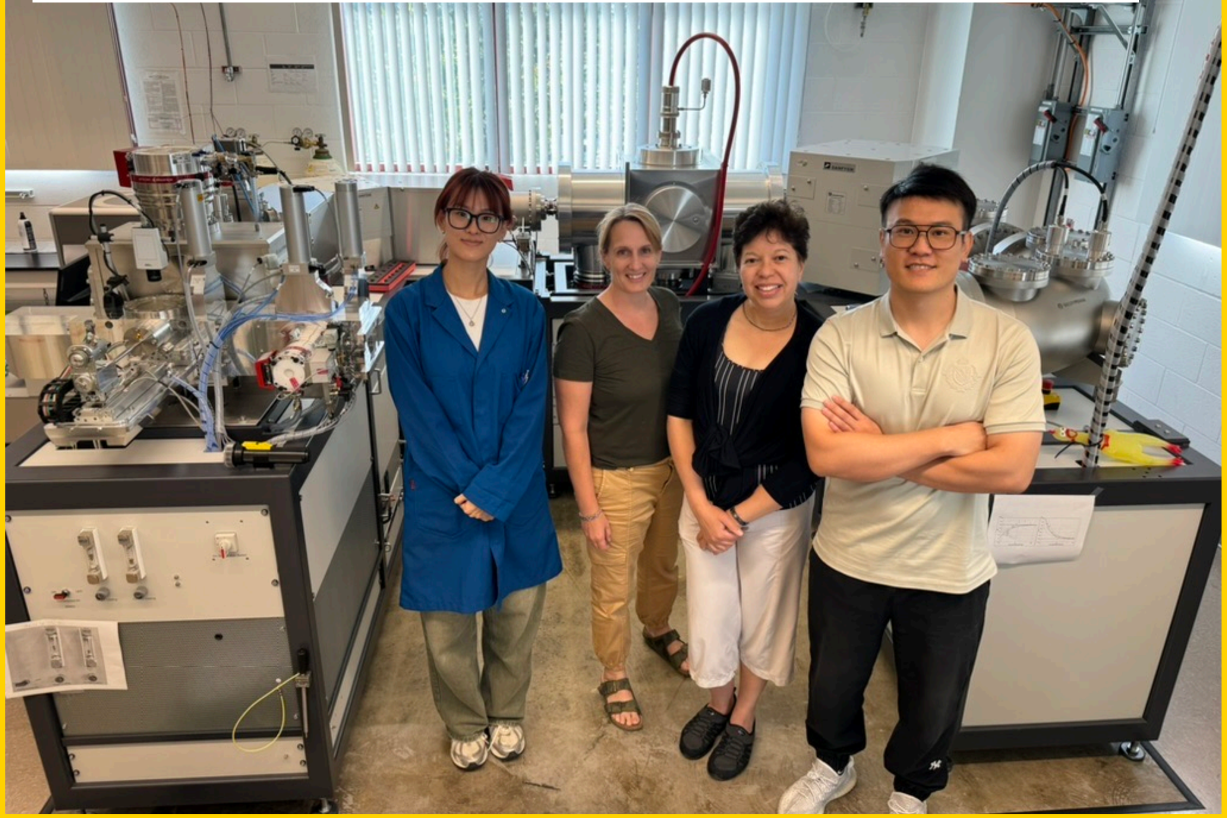
$^{14}CO_2$ COLLECTION DURING THE POLAR NIGHT

$^{14}CO_2$ ANALYSIS AT THE KCCAMS FACILITY AT UC IRVINE

Developed new heater for flow-through CO_2-extraction and cleaning of molecular sieve

Pedron et al. (2021) Radiocarbon

New Mini Carbon Dating System



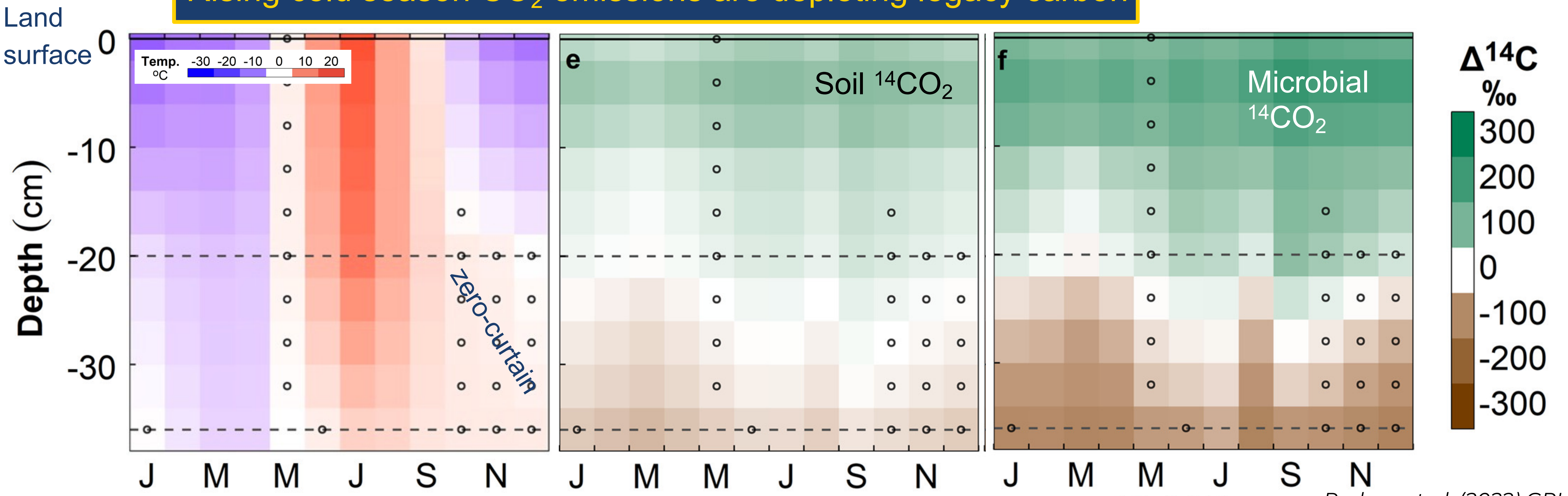
NSF-MRI 2117634

MONTHLY-INTEGRATED SOIL TEMPERATURE AND $^{14}CO_2$

Moist acidic Tussock Tundra (06/2017-08/2019)

- Emissions from older carbon pools at depth are highest in late summer (August) but masked by root respiration and microbial decomposition of ^{14}C-enriched organic matter near the surface
- Surface soils remain unfrozen and a CO_2 source throughout the fall
- Soil (microbial CO_2) becomes older as the season progresses

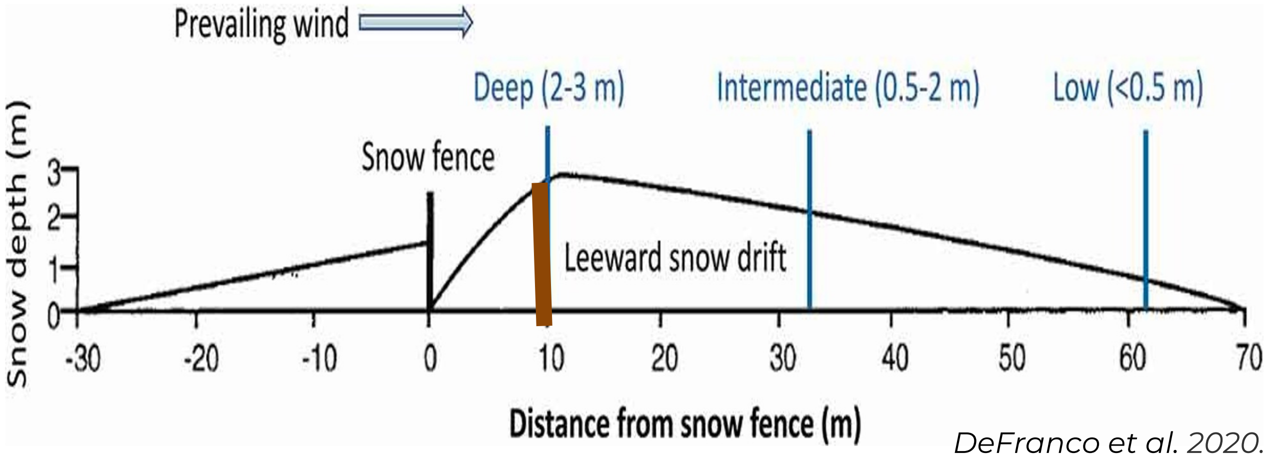
Rising cold season CO_2 emissions are depleting legacy carbon



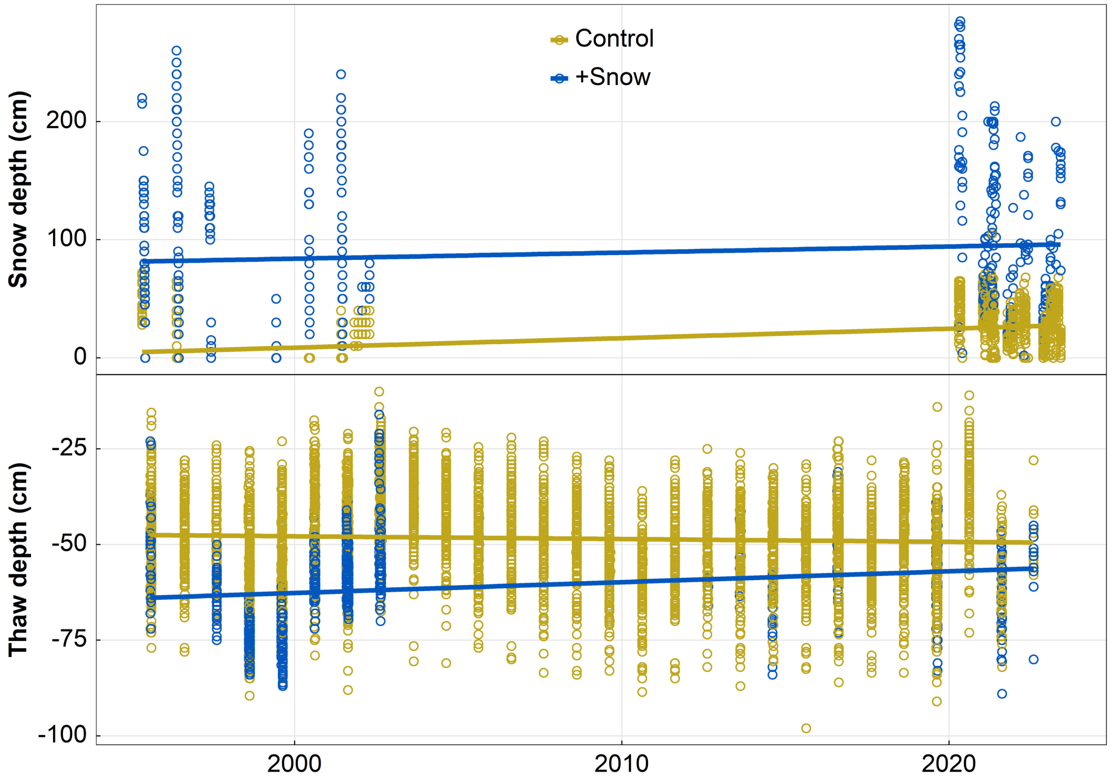
Pedron et al. (2022) GRL

HOW WILL AN EXPECTED INCREASE IN SNOW IMPACT PERMAFROST C EMISSIONS?

25-YEARS OF ITEX SNOW MANIPULATION EXPERIMENT AT TOOLIK: AN OPPORTUNITY TO UNDERSTAND THE NEW ARCTIC

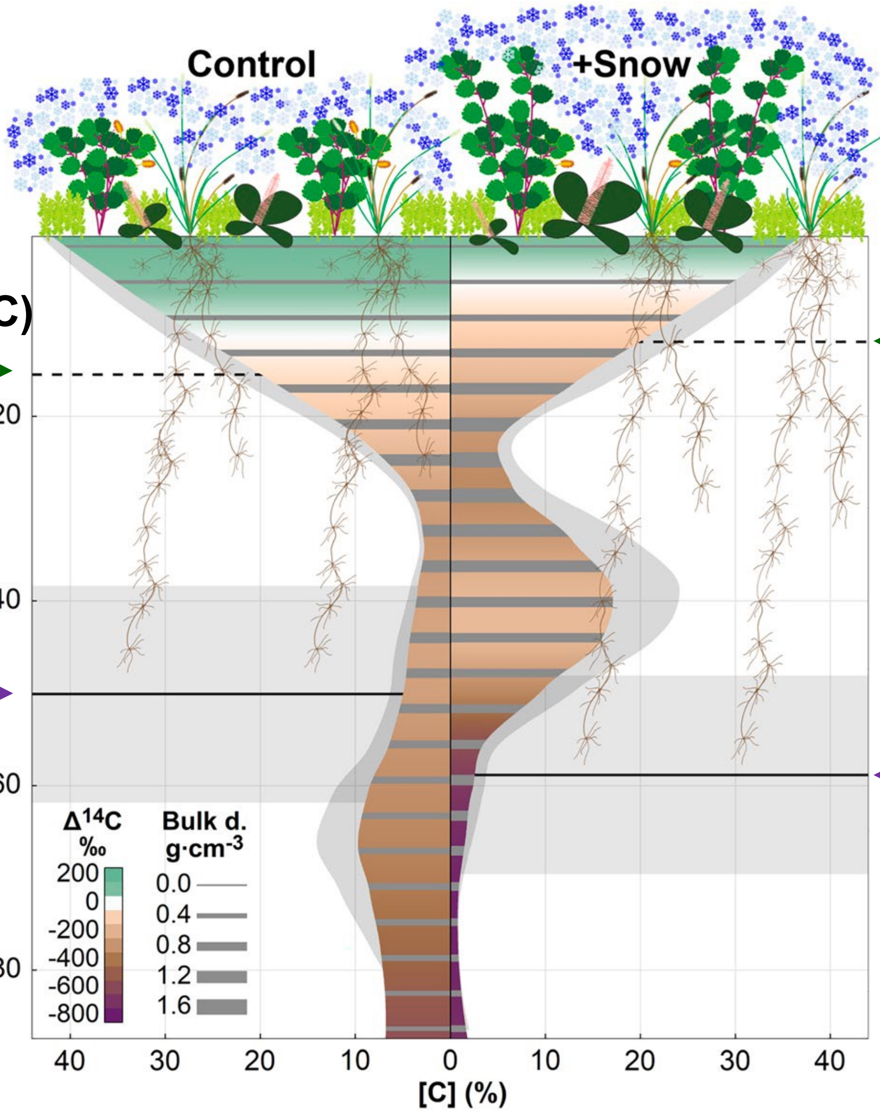


DeFranco et al. 2020. AAAR



Jespersen/Pedron et al. 2023. AGU Advances

SOIL PROPERTIES AFTER 25-YEARS OF ITEX SNOW MANIPULATION IN MOIST ACIDIC TUNDRA



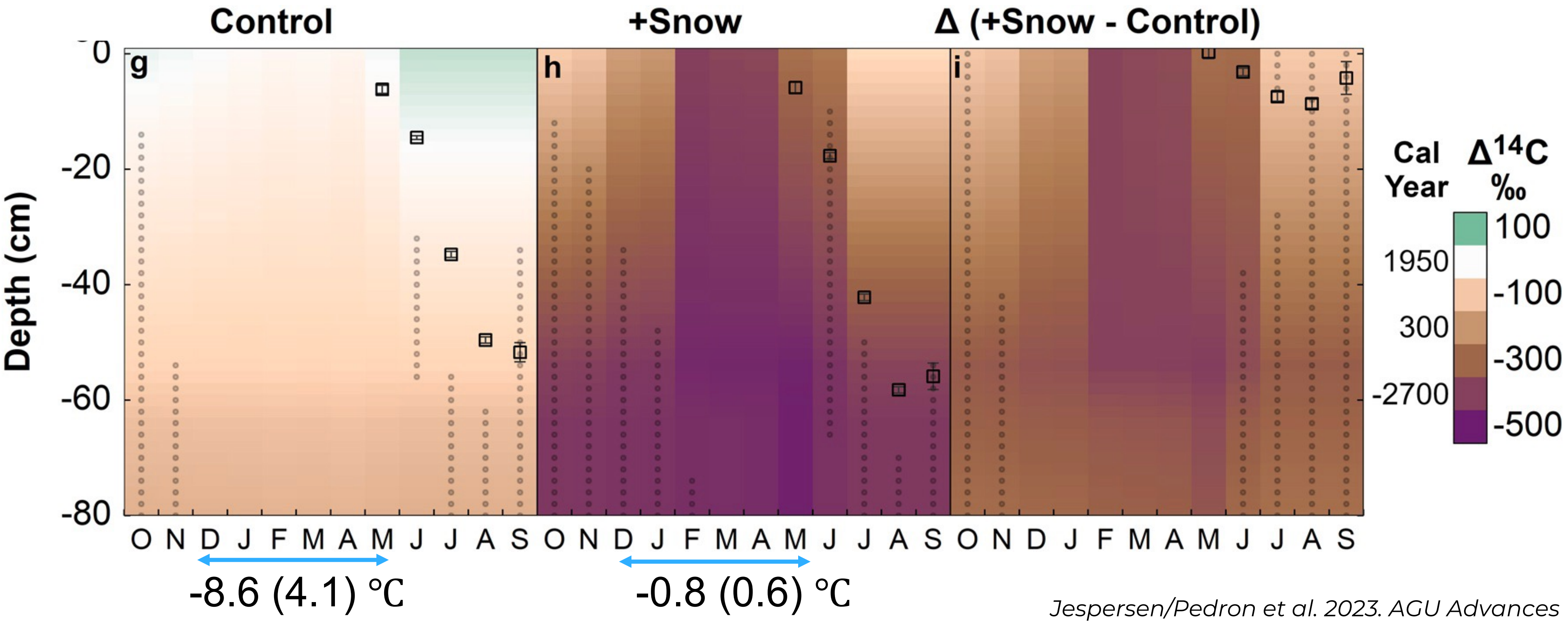
An inventory of bulk soil properties reveals **4x more carbon and nitrogen in the active layer**; mostly legacy C from permafrost due to compaction/subsidence/fresh inputs (from shrubs)

Jespersen/Pedron et al. 2023. AGU Advances

MORE SNOW ACCELERATES LEGACY CARBON LOSSES

Under deeper snow, soils remain unfrozen and winter CO_2 losses are 3-times higher (270 vs. 90 g C m-2, Oct-May) and depleting legacy carbon pools.

Legacy C emissions contribute to CO_2 emissions year-round.



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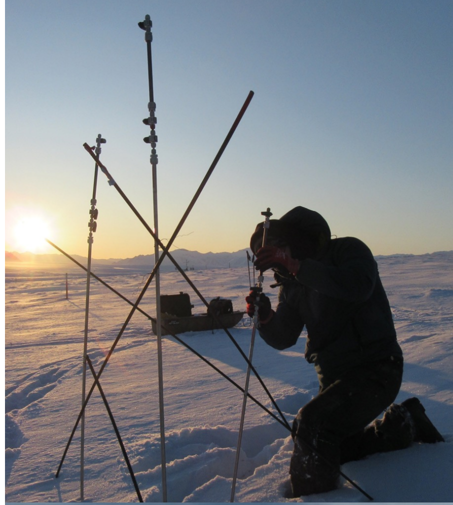

SUMMARY

We can measure monthly-integrated, depth-resolved $^{14}CO_2$ in permafrost soil year-round

Rising cold season CO_2 emissions are depleting legacy carbon

More snow will greatly accelerate permafrost C losses

Estimates of active layer deepening based on thaw depth monitoring underestimate permafrost C & N mobilization in ice-rich soils

SUMMARY

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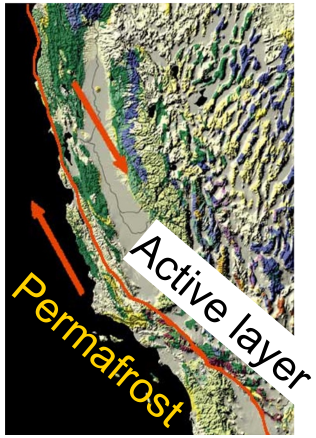
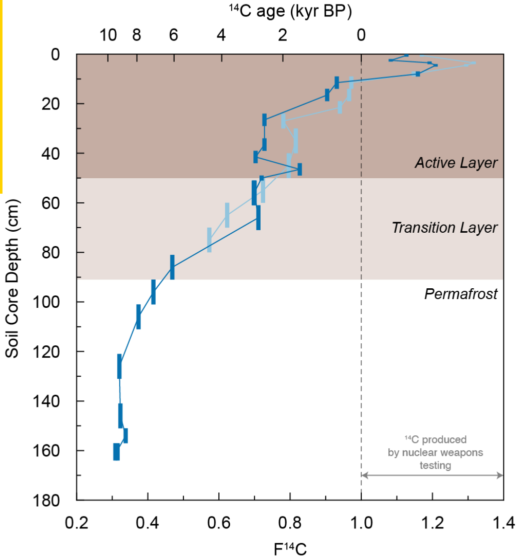
REMAINING QUESTIONS

How can we integrate year-round $^{14}CO_2$ with CO_2 flux estimates to quantify legacy C losses from the Arctic?

Are we digging deep enough to forecast emissions?





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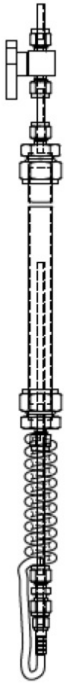
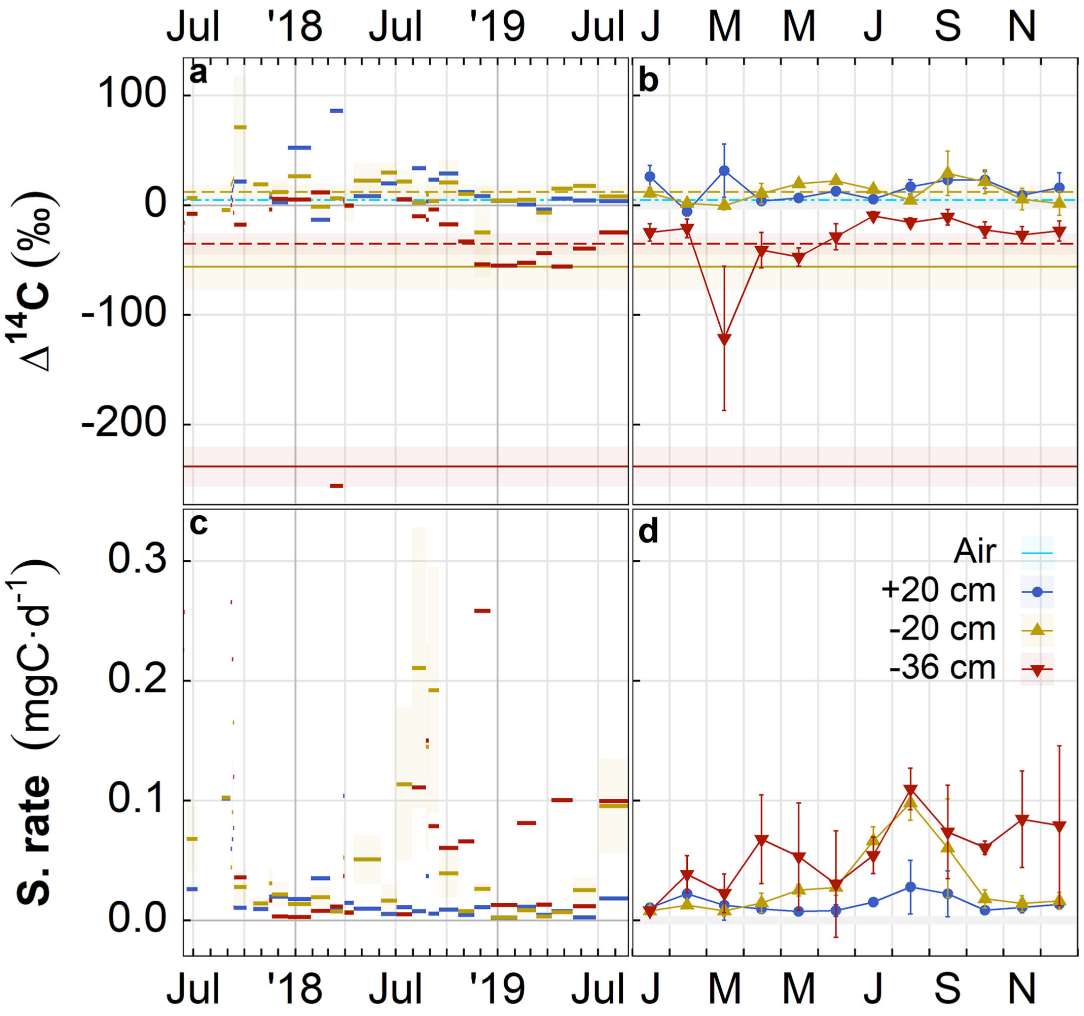
This work was supported by:

- Toolik Field Station 🧡
- ITEX and CALM network
- UCI's W.M. Keck Carbon Cycle Accelerator Mass Spectrometry (KCCAMS) facility & C. McCormick
- X. Xu, J. Lehman, S. Holden, Y. Liu, M. Tayo, Y. Khazindar, B. Martinez, T. Nguyen (UCI)

RAW $^{14}CO_2$ FROM MOIST ACID TUSSOCK TUNDRA YEAR-ROUND





- June 2017 to August 2019, over 3 days to 1.5 months
- Corrected for leakage via blank and mixing with air via $[CO_2]$
- Combined into 1-year of monthly data

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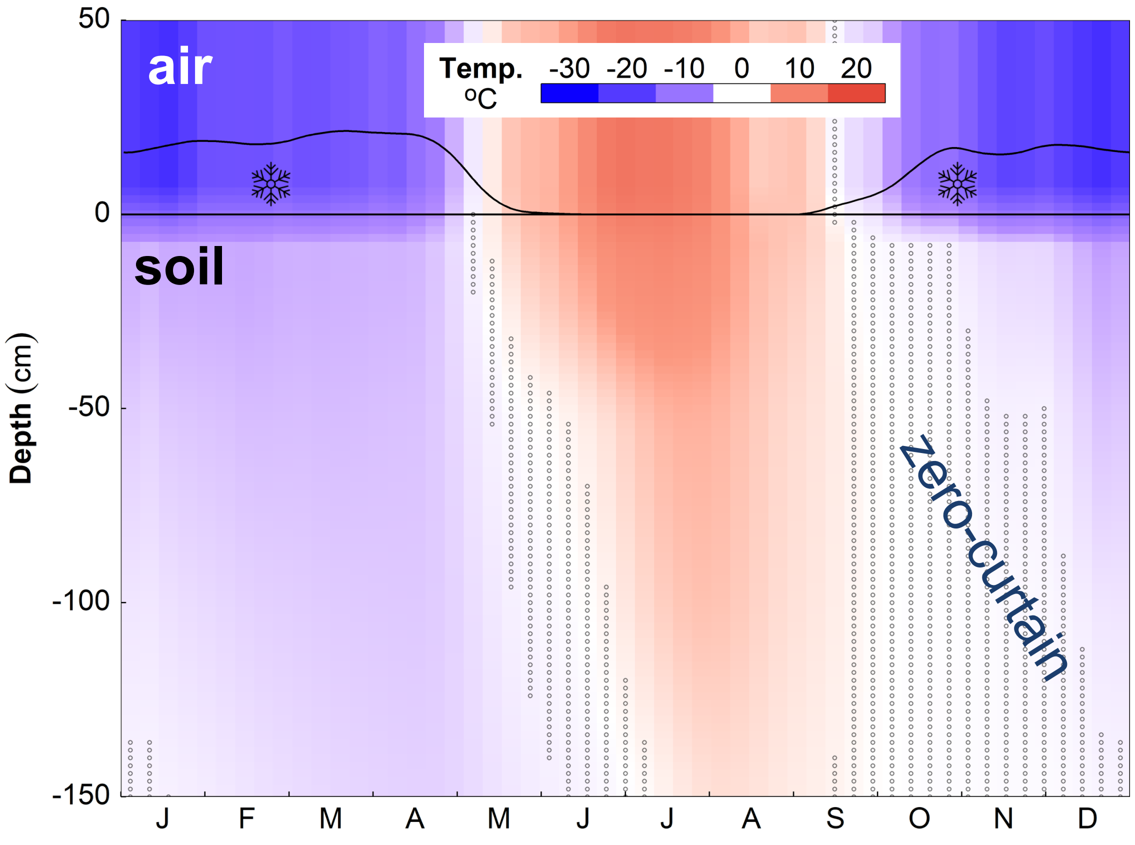
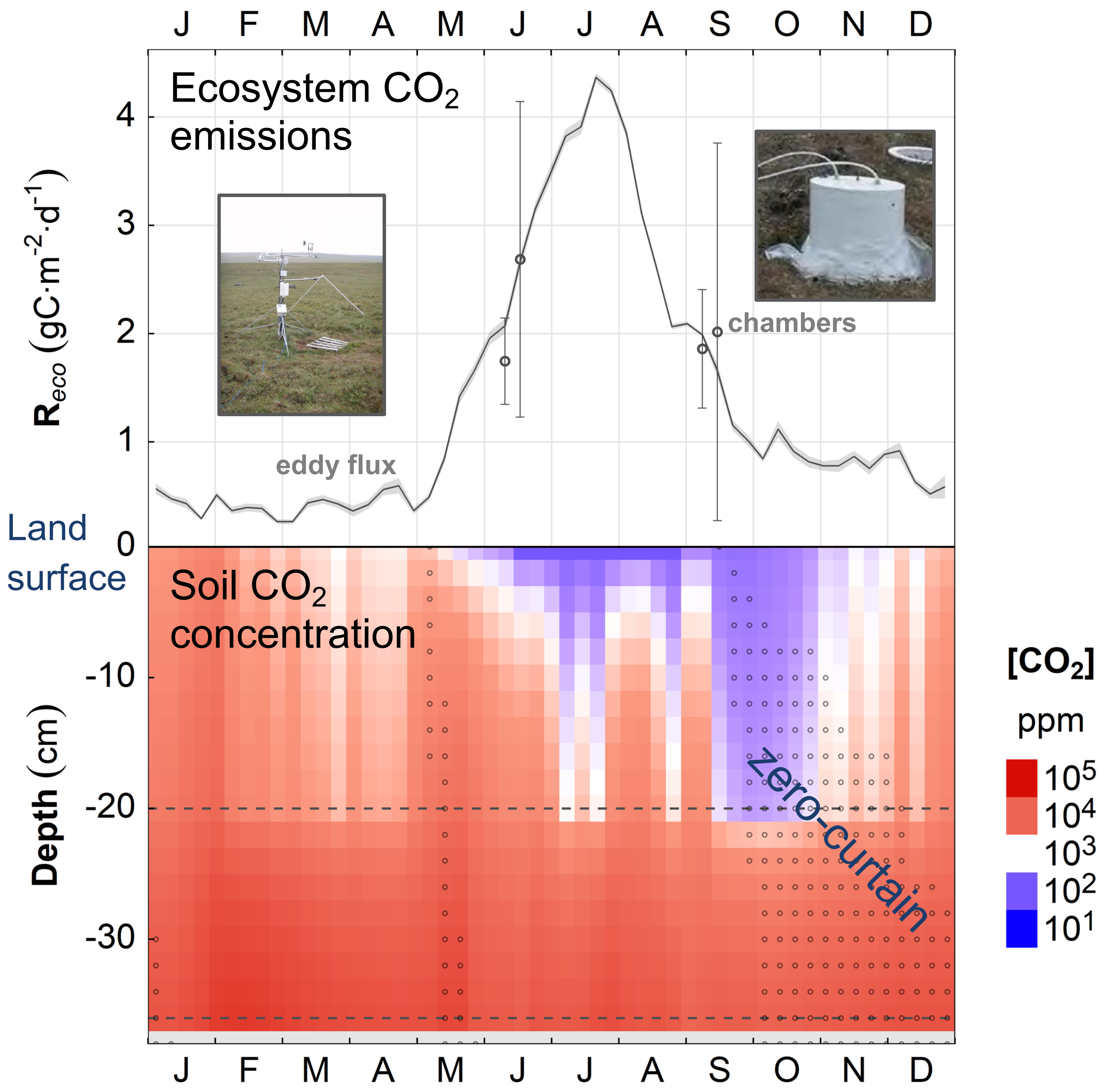
ANNUAL TIME SERIES

Moist acidic Tussock Tundra
06/2017-08/2019, 2-week-integrated

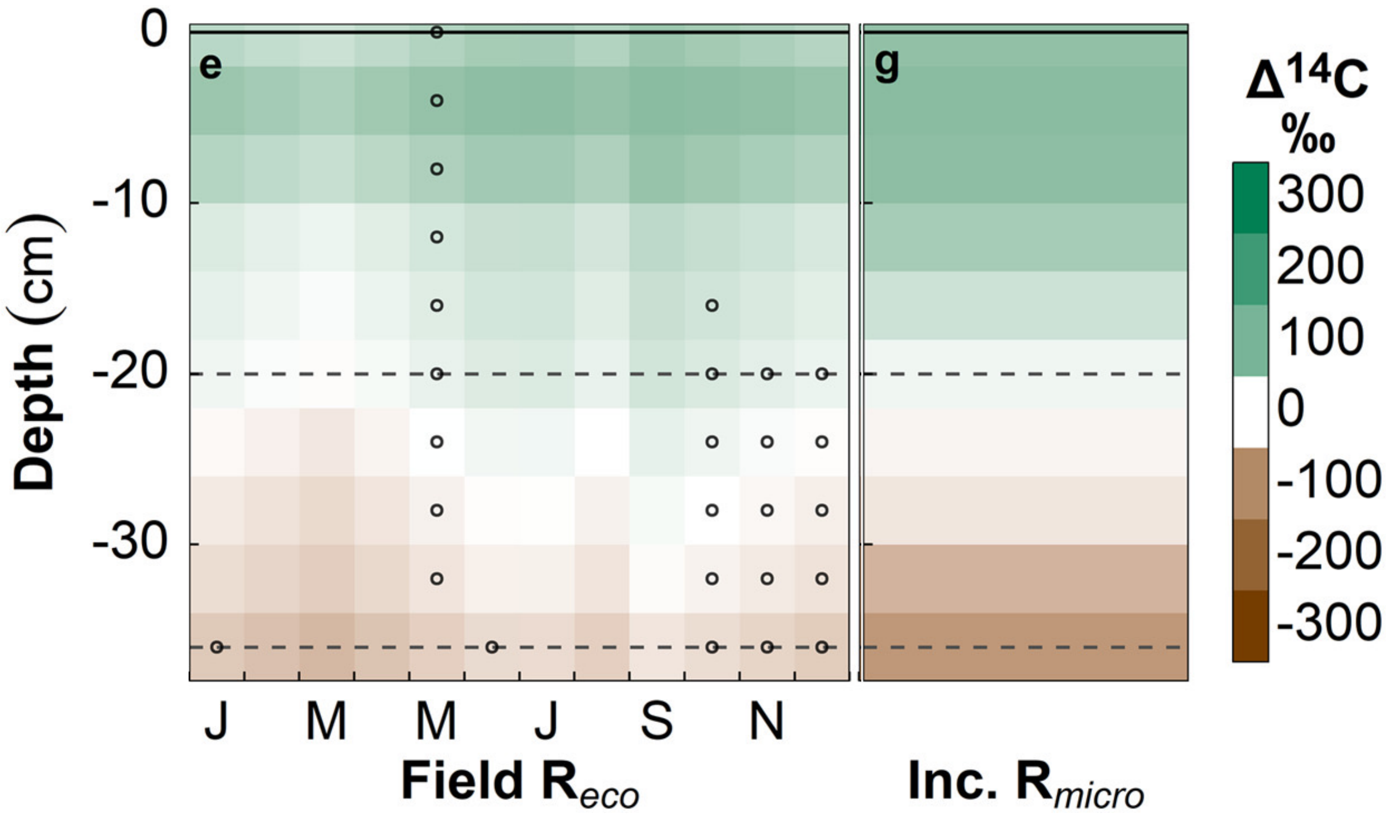
- Surface soils remain unfrozen (zero-curtain) and a CO_2 source throughout the fall period

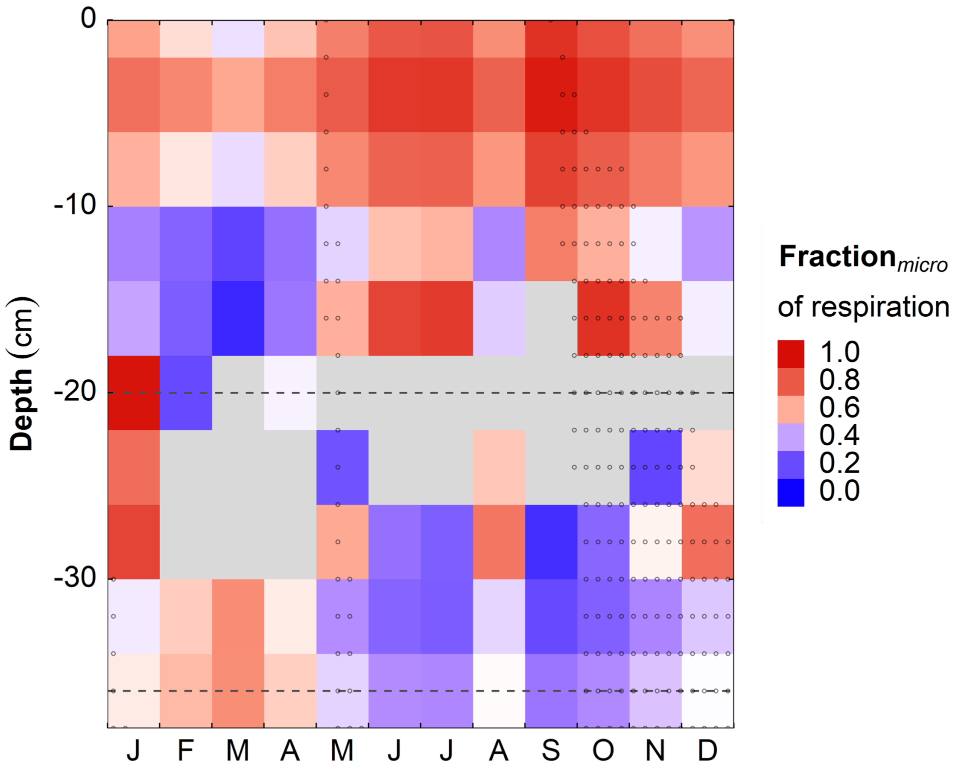




ESTIMATING MICROBIAL CO_2 PRODUCTION with static $^{14}CO_2$ from laboratory incubations

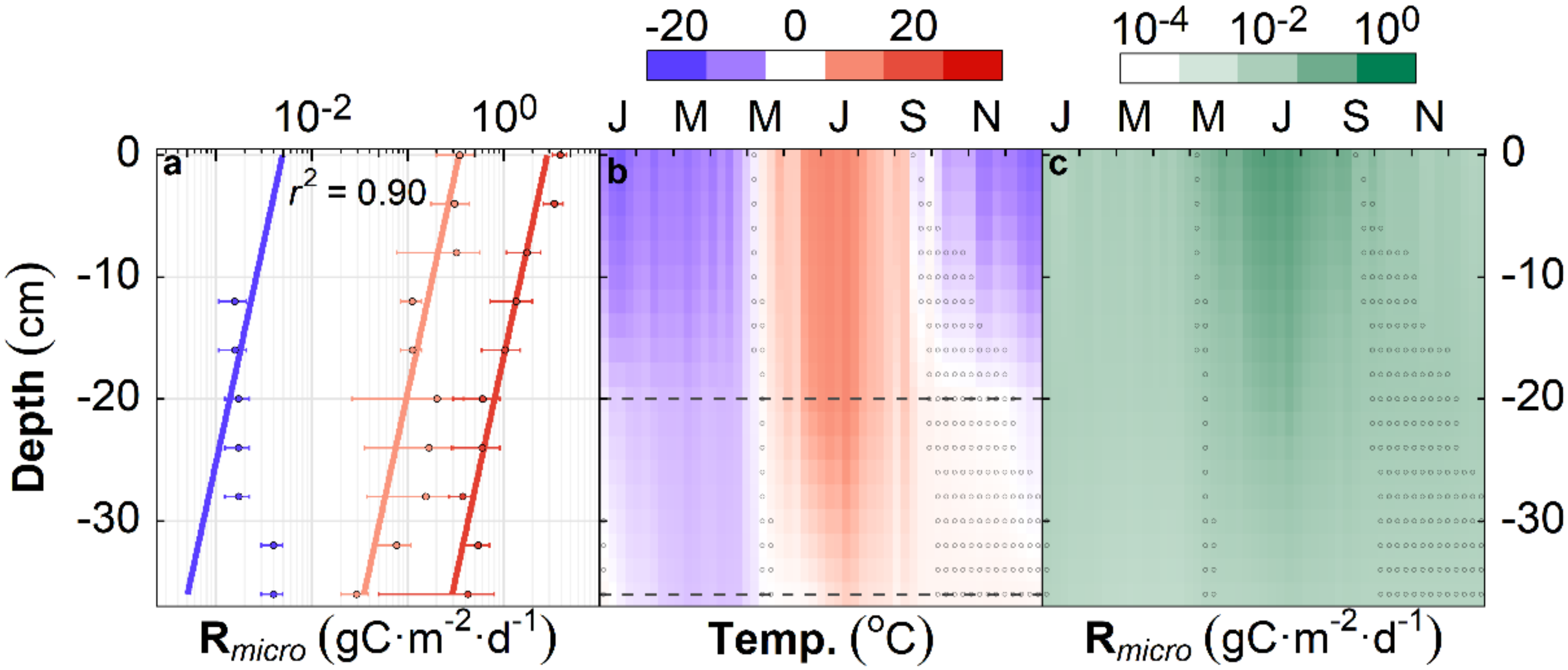
$$^{14}C\text{-}R_{eco} = f_{plant}\ ^{14}C\text{-}R_{plant} + f_{microbes}\ ^{14}C\text{-}R_{microbes}$$





Pedron et al. (2022) GRL

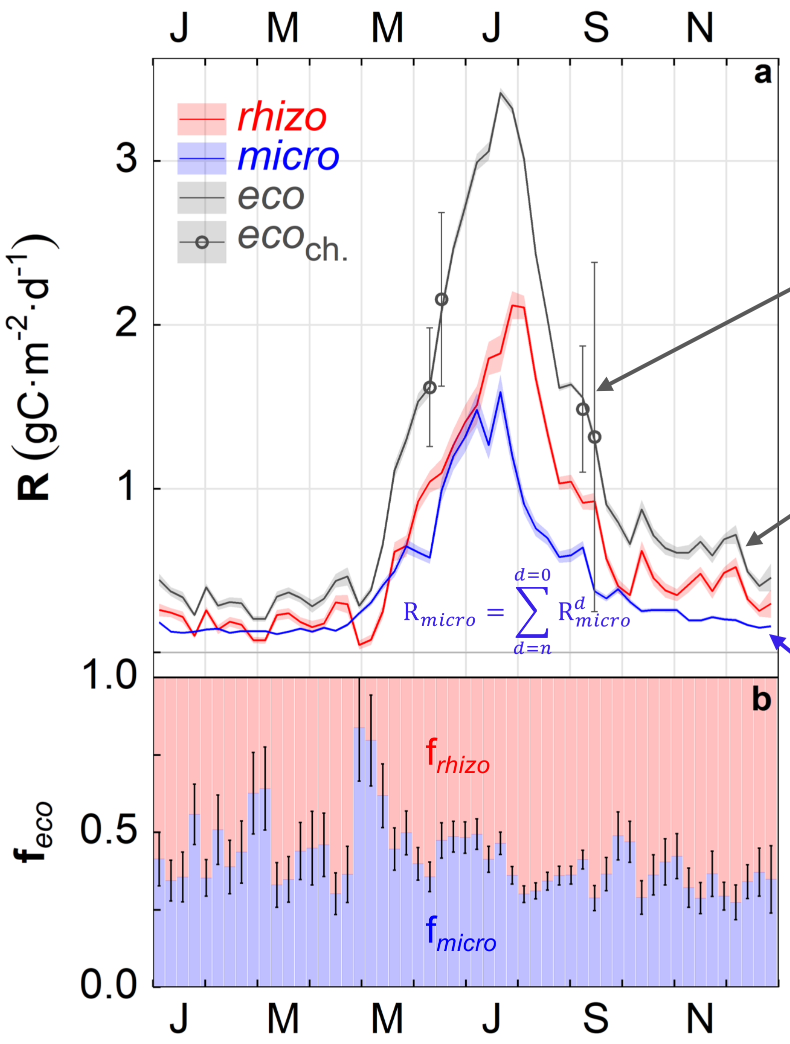
ESTIMATING MICROBIAL $^{14}CO_2$ PRODUCTION with temperature-dependent CO_2 fluxes from incubations

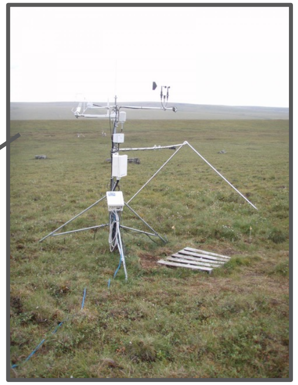


$$\mathbf{R}_{micro} = \boldsymbol{a} * \mathbf{exp}(\boldsymbol{b} * \mathbf{Temperature} + \boldsymbol{c} * \mathbf{Depth})$$

Pedron et al. (2022) GRL

MICROBIAL CONTRIBUTIONS TO SURFACE EMISSIONS





- Microbial emissions (like ecosystem emissions) follow a temperature-dependent seasonal dynamic, with a maximum in July
- Microbial contributions range from 35 to 60%
- Winter microbial emissions account for 18% ±6% (mean ± se) of annual ecosystem CO_2 emissions

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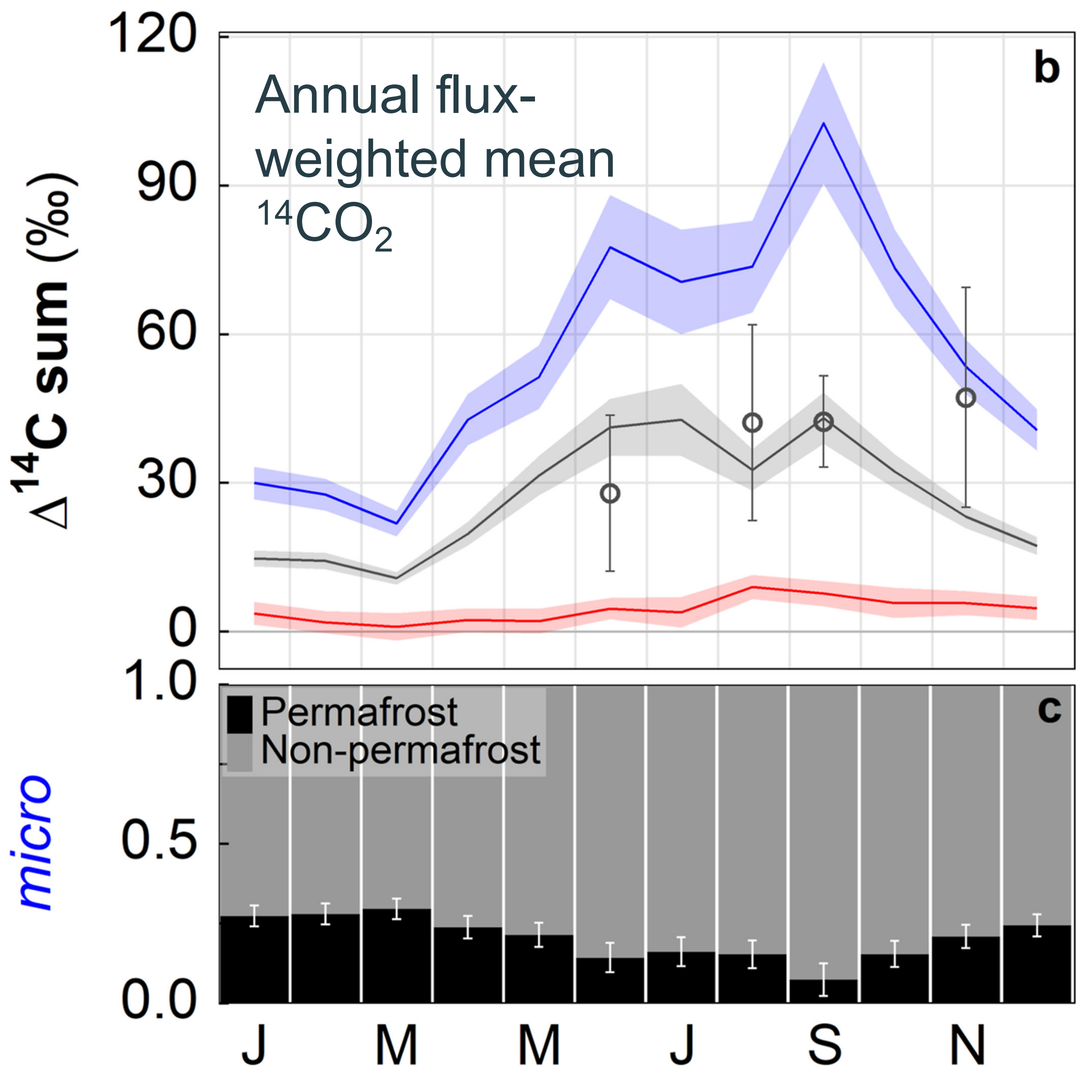
PERMAFROST CONTRIBUTIONS TO SURFACE EMISSIONS



- 22% ±2% of microbial emissions in winter are derived from permafrost

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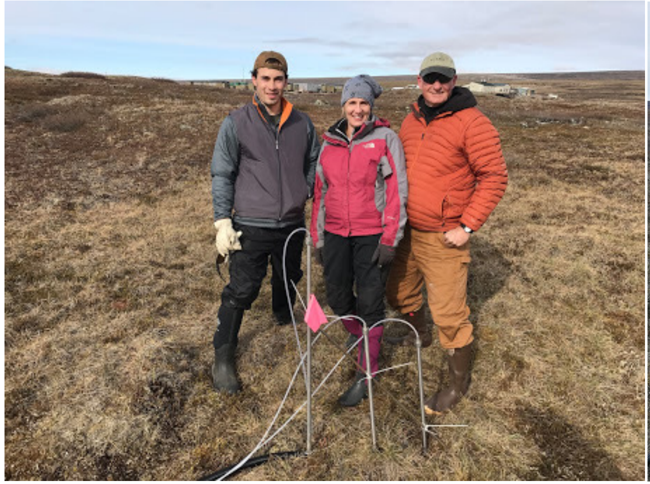
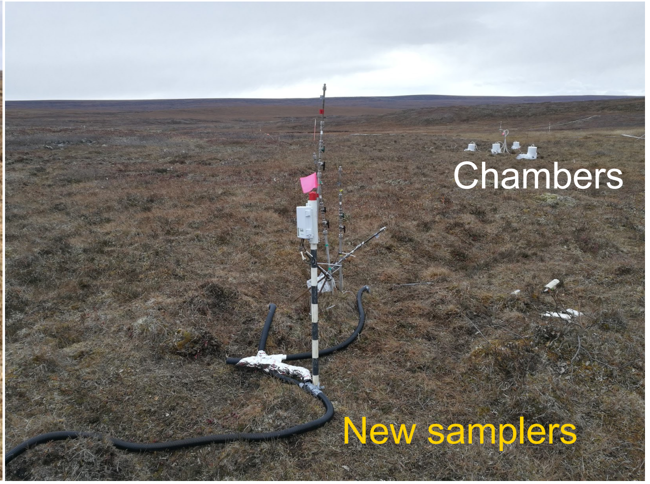
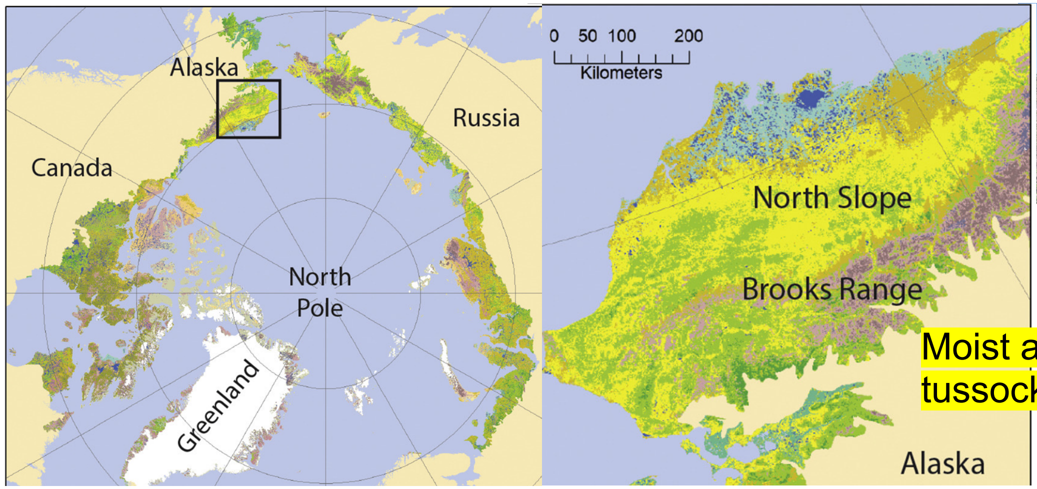
YEAR-ROUND SOIL $^{14}CO_2$ COLLECTION

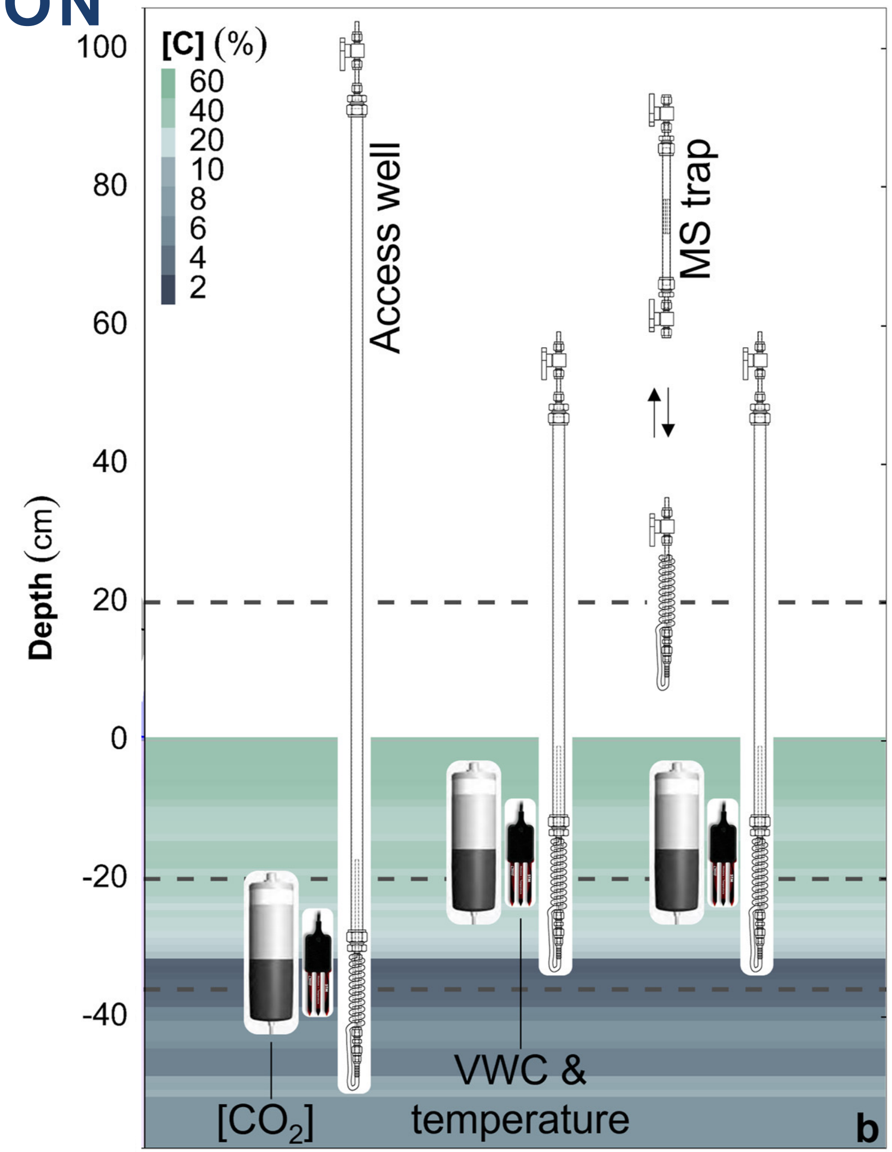






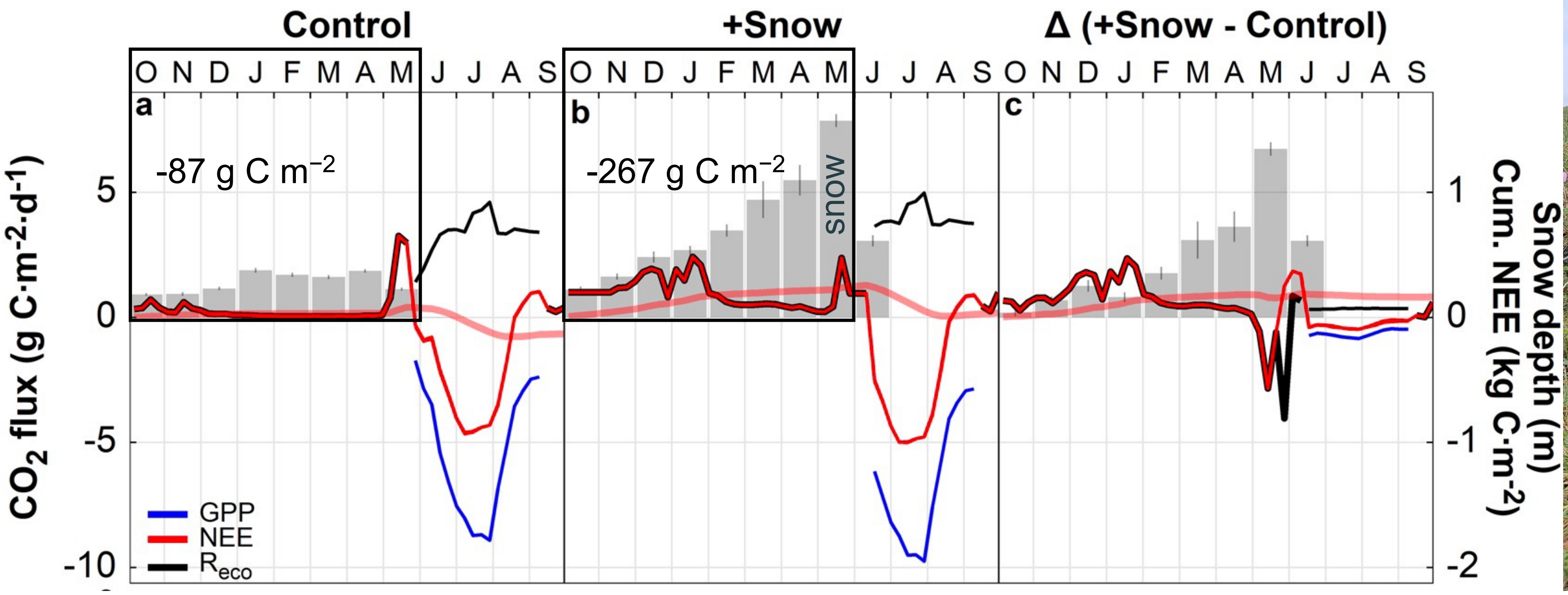
Eriophorum vaginatum
Photo: MK Raynolds

Raynolds et al. (2019) Rem. Sens. Env.



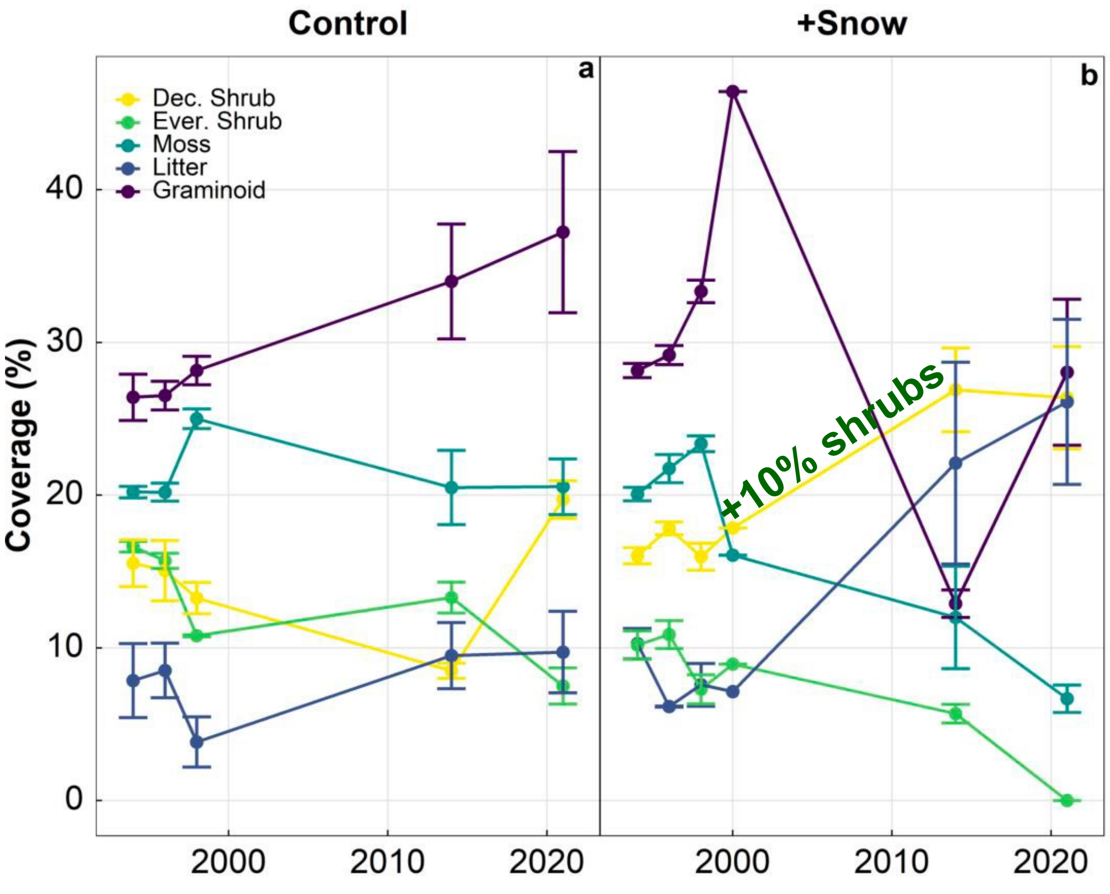
Pedron et al. (2021) Radiocarbon, Pedron et al. (2022) GRL

+SNOW INCREASES WINTER CO_2 LOSSES 3-TIMES



Jespersen/Pedron et al. 2023. AGU Advances

+SNOW TRANSFORMS TUSSOCK TUNDRA INTO A SHRUBLAND



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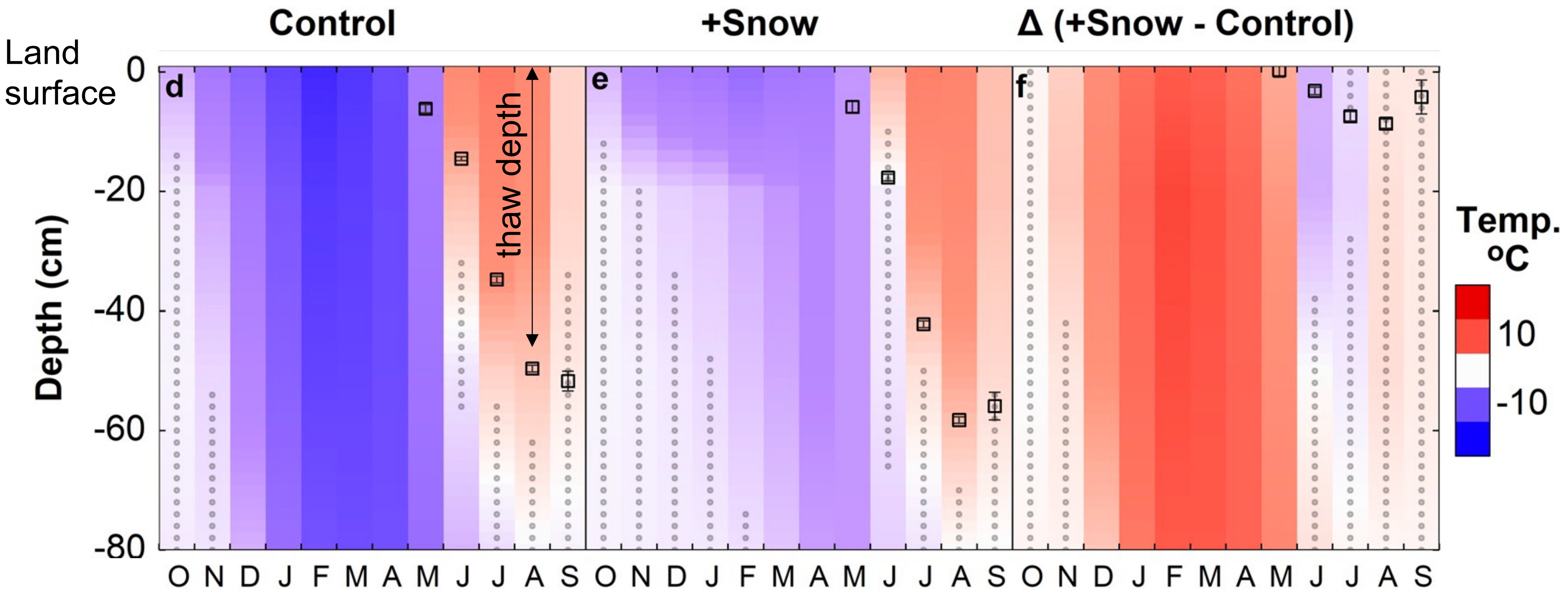
- >10% greater shrub cover
- Taller canopy
- More carbon uptake
  - 45% greater GPP ($P<0.05$)
  - 6–13% greater carbon sequestration during the growing season

Weeks (2021)	NEE ($g\ C\ m^{-2}$)	
	Control	+Snow
25-38	-203 (4)	-229 (4)
22-38	-217 (4)	NA

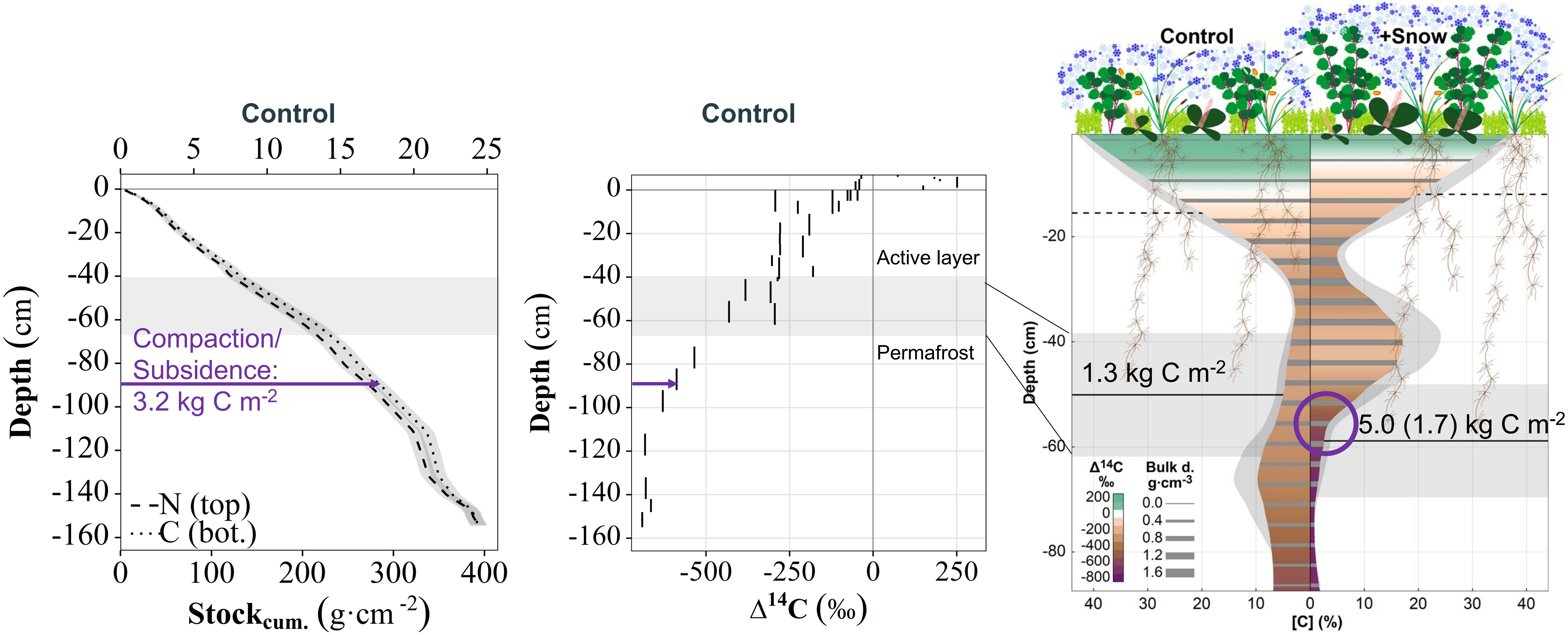
+SNOW INCREASES THAW DEPTH BY 20%



Based on 2019-2021 soil temperature (105T-L, Campbell Scientific, USA) sensors at 20, 50, and 80 cm depth (n=2-3/treatment).

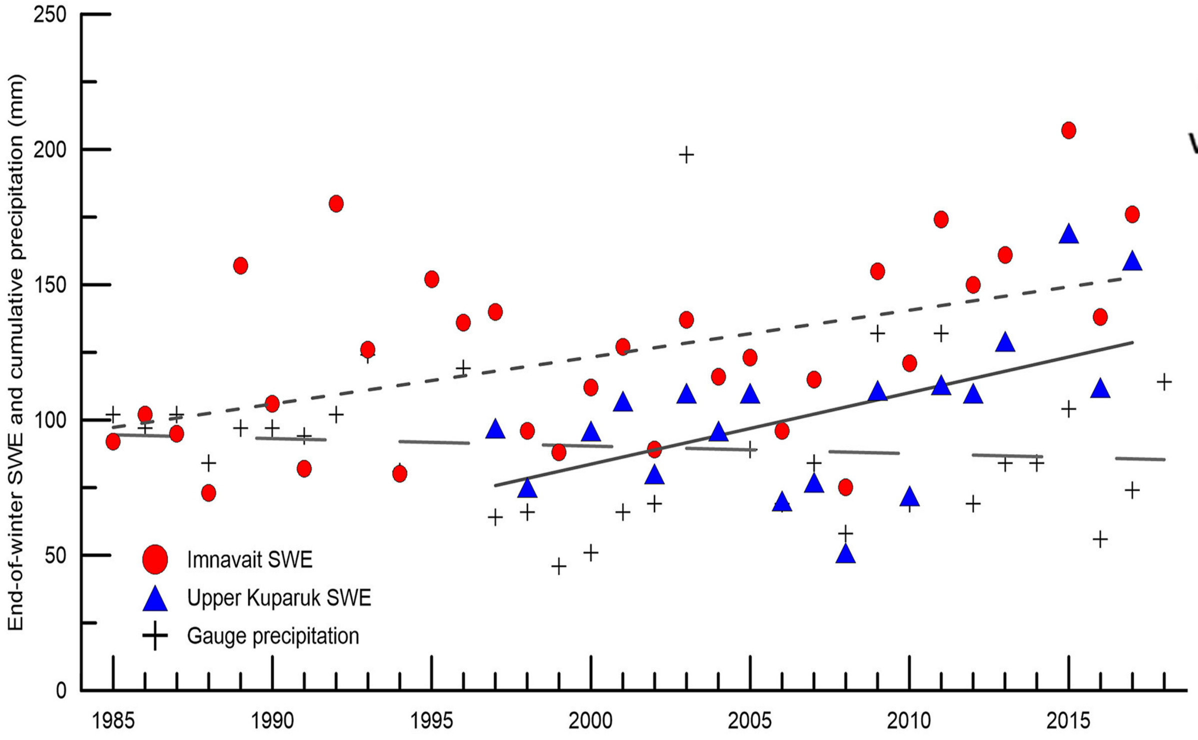
Jespersen/Pedron et al. 2023. AGU Advances

+SNOW EXPOSES LEGACY CARBON TO DECOMPOSITION

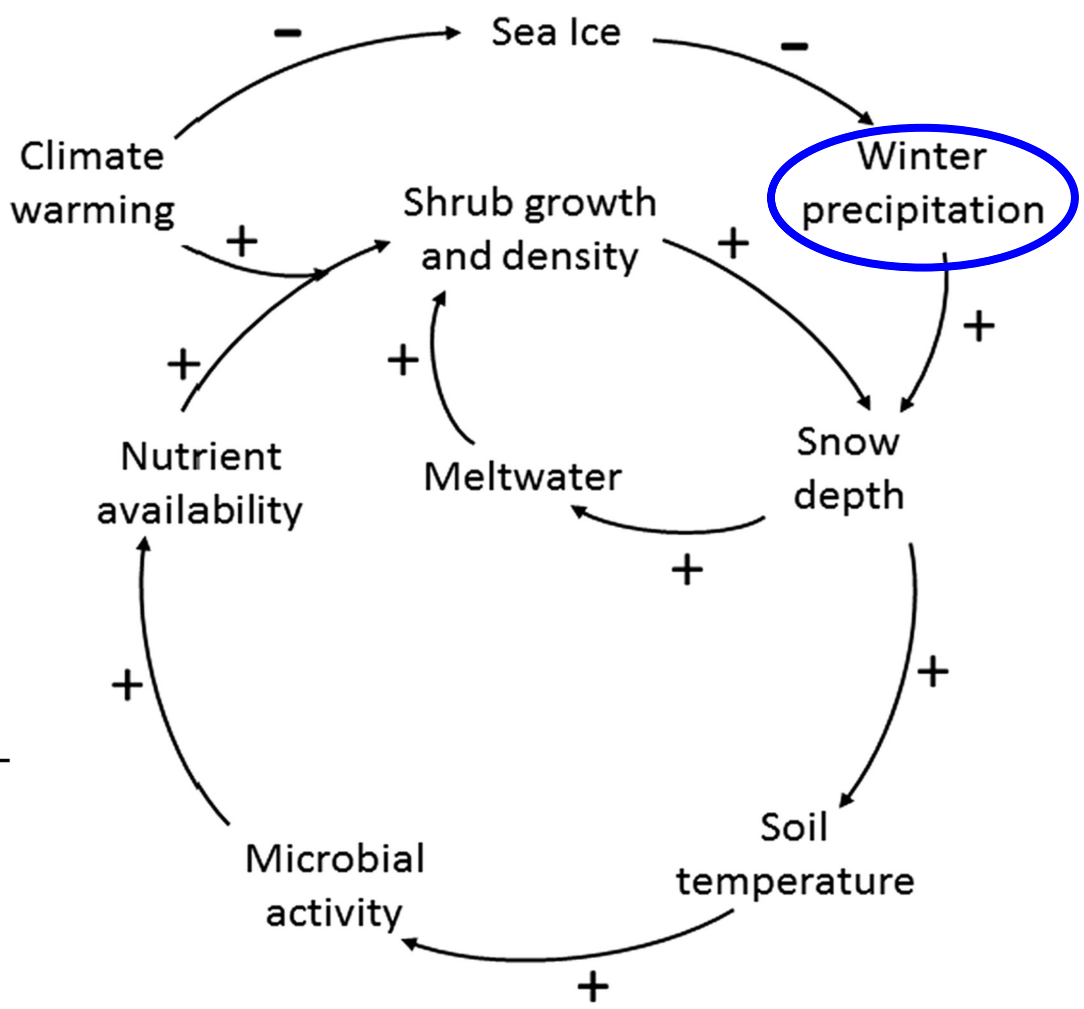


Jespersen/Pedron et al. 2023. AGU Advances

CHANGING WINTER CONDITIONS ARE TRANSFORMING THE TUNDRA



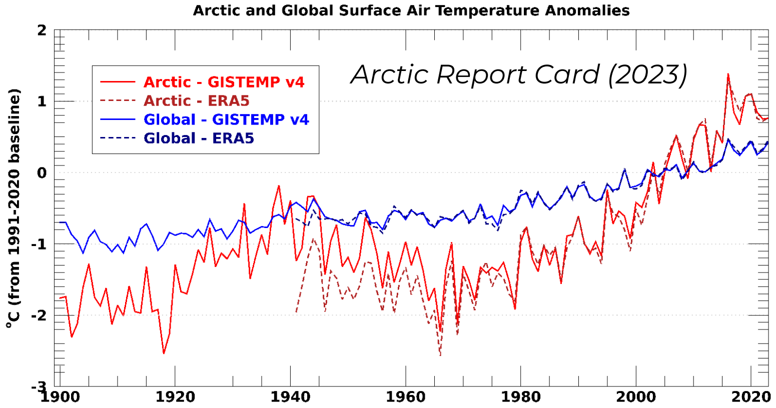
Stuefer et al. 2020. Water RR

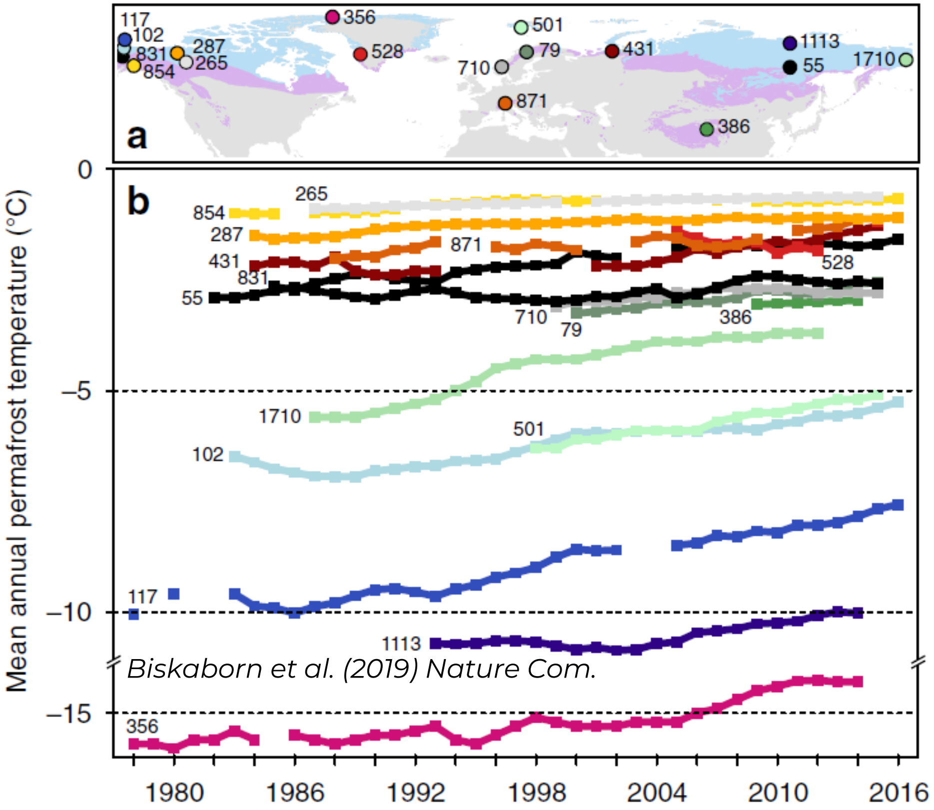


Jespersen et al. 2018. Oecologia

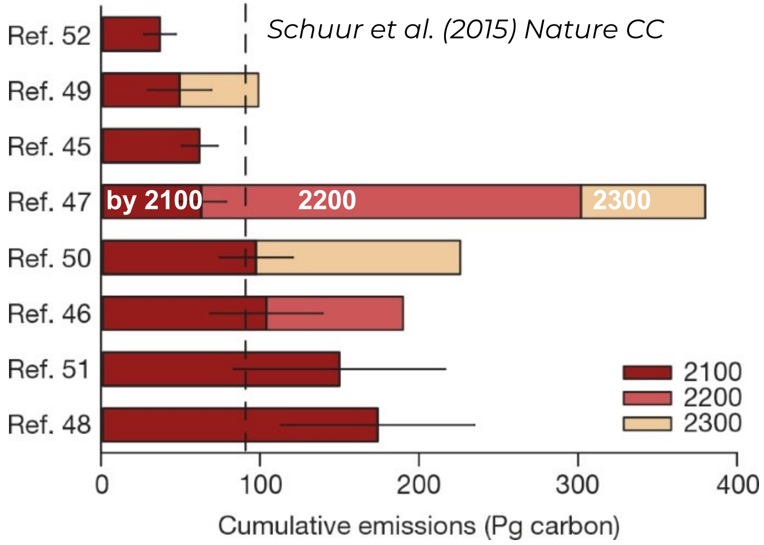
PERMAFROST CARBON @RISK

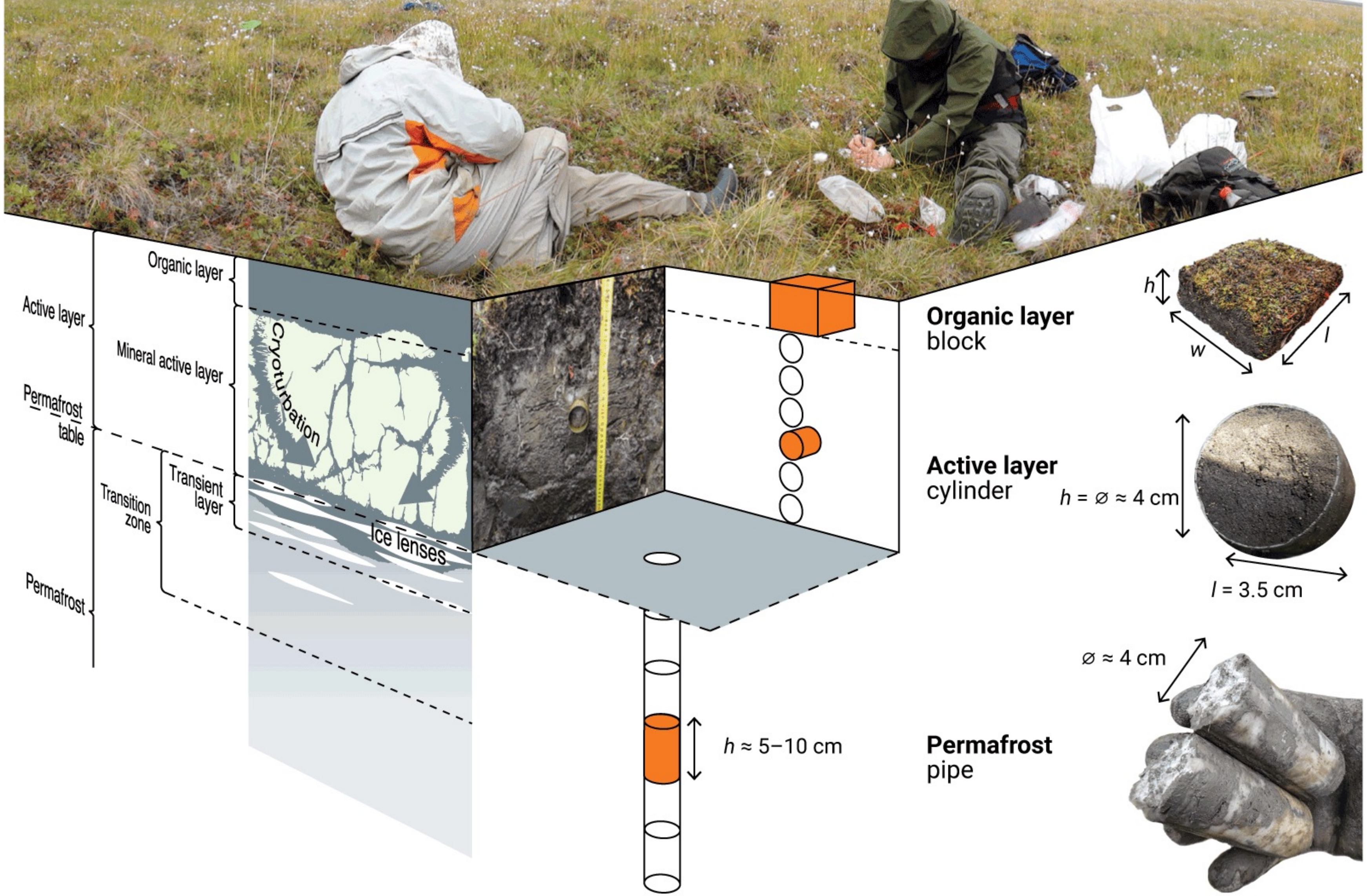
- Permafrost is thawing
  +0.3±0.1°C (2007-2016),
  25-75% may be lost
- Permafrost carbon emissions may be substantial
  Up to 240 Gt C by 2100,
  more in the next centuries
- Current emissions?
  Medium Evidence/Low Agreement
- CH_4 vs. CO_2?
  0.01–0.06 Gt CH4 yr^{-1}
  ≈ 40–70% of radiative forcing
- Plants (shrubs)?
  Medium Evidence/Low Agreement





Cumulative Permafrost C Emissions





Palmtag et al. (2022)
Earth Syst. Sci. Data

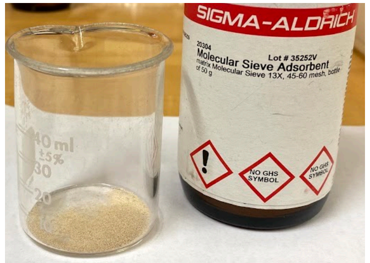
PASSIVE SOIL $^{14}CO_2$ SAMPLER

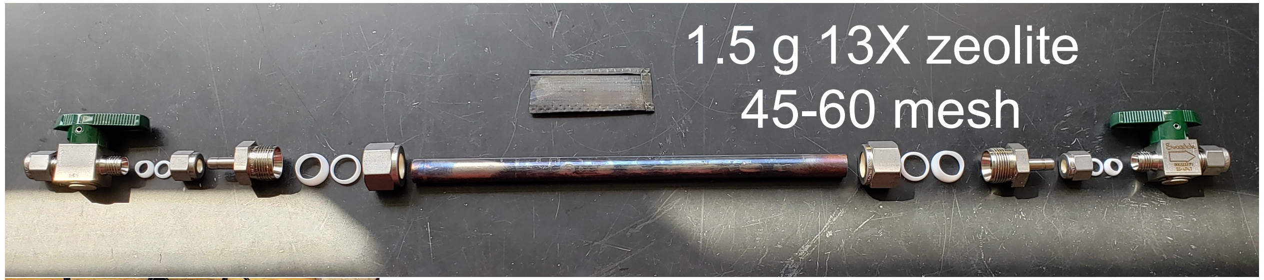
Permanent gas inlet

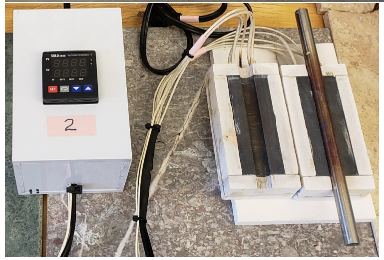
Diffusive (no pump!), Pt-cured silicone & stainless-steel tubing with sump

Exchangeable CO_2 trap

Molecular sieve







Pedron et al. (2021) Radiocarbon