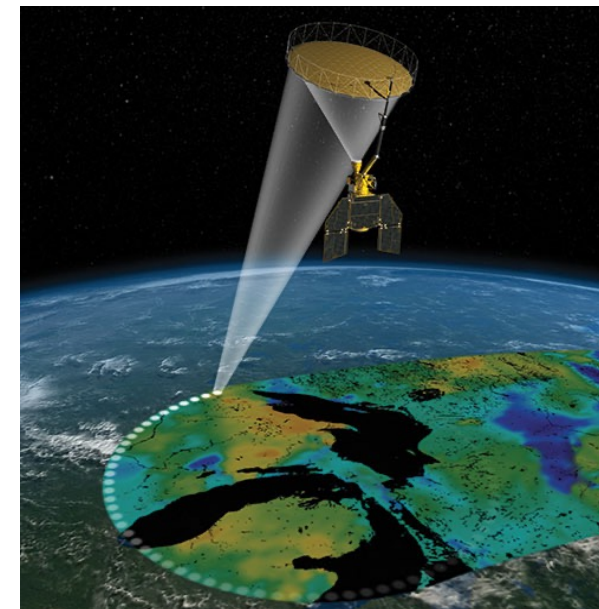


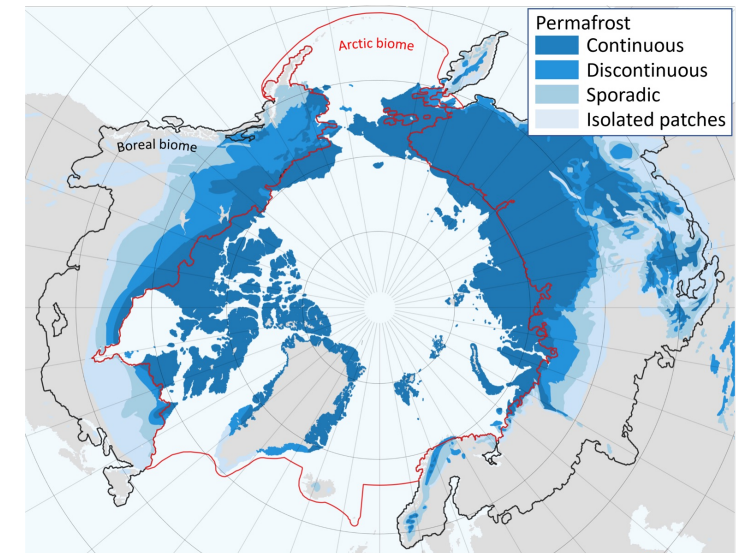
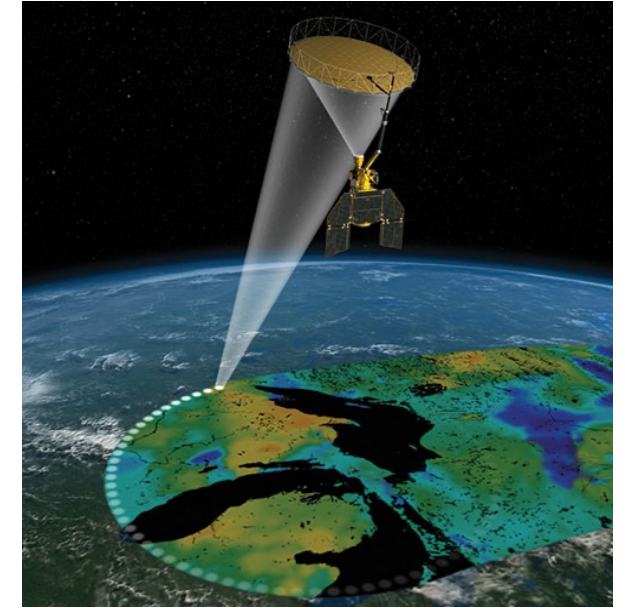
10 km Resolution L-Band Radiometry Workshop, Pasadena, USA, 10-12 October 2023

Carbon fluxes in northern regions and linkage with
Freeze/Thaw monitoring and beyond

Alexandre Roy, Université du Québec à Trois-Rivières

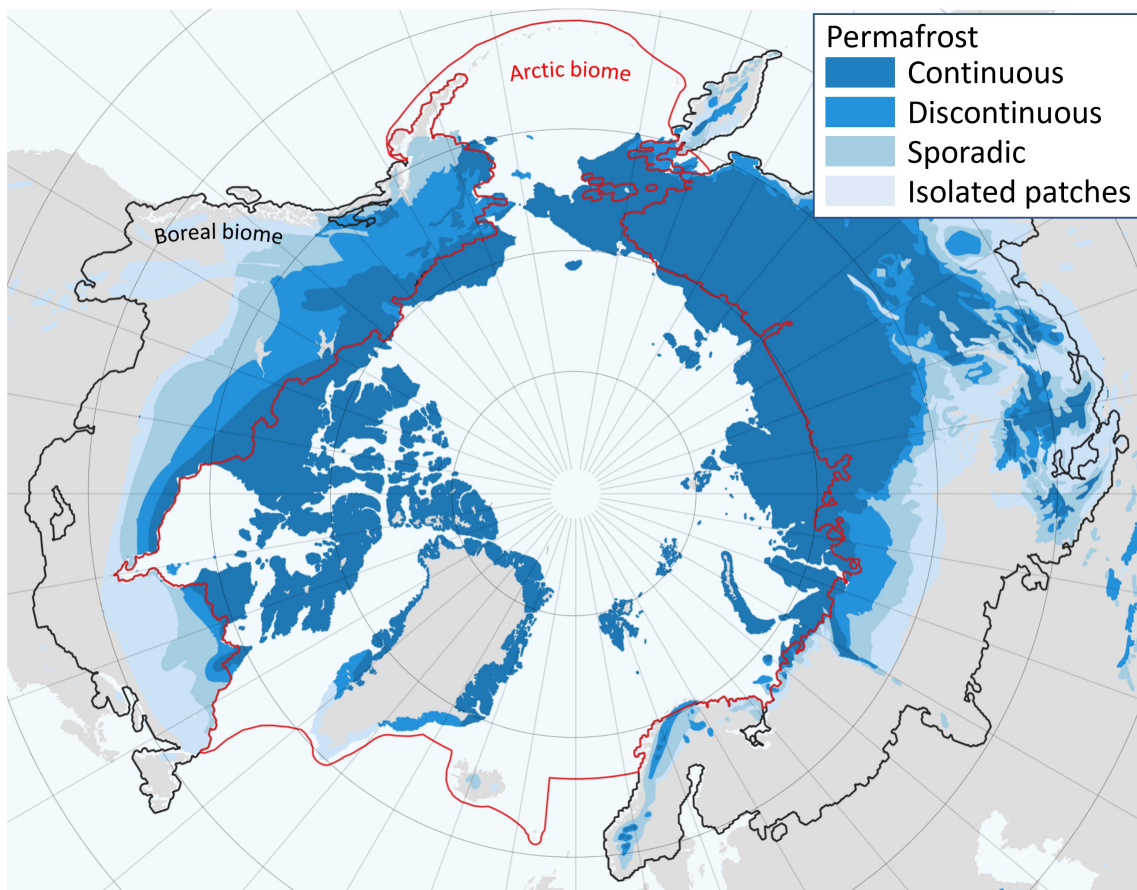


- Importance of northern region's carbon cycle in the climate system
- L-band radiometry and carbon cycle processes
 - Summer (soil moisture)
 - Shoulder-seasons (Freeze/thaw)
 - Winter (soil temperature)
- 10-km L-band radiometry



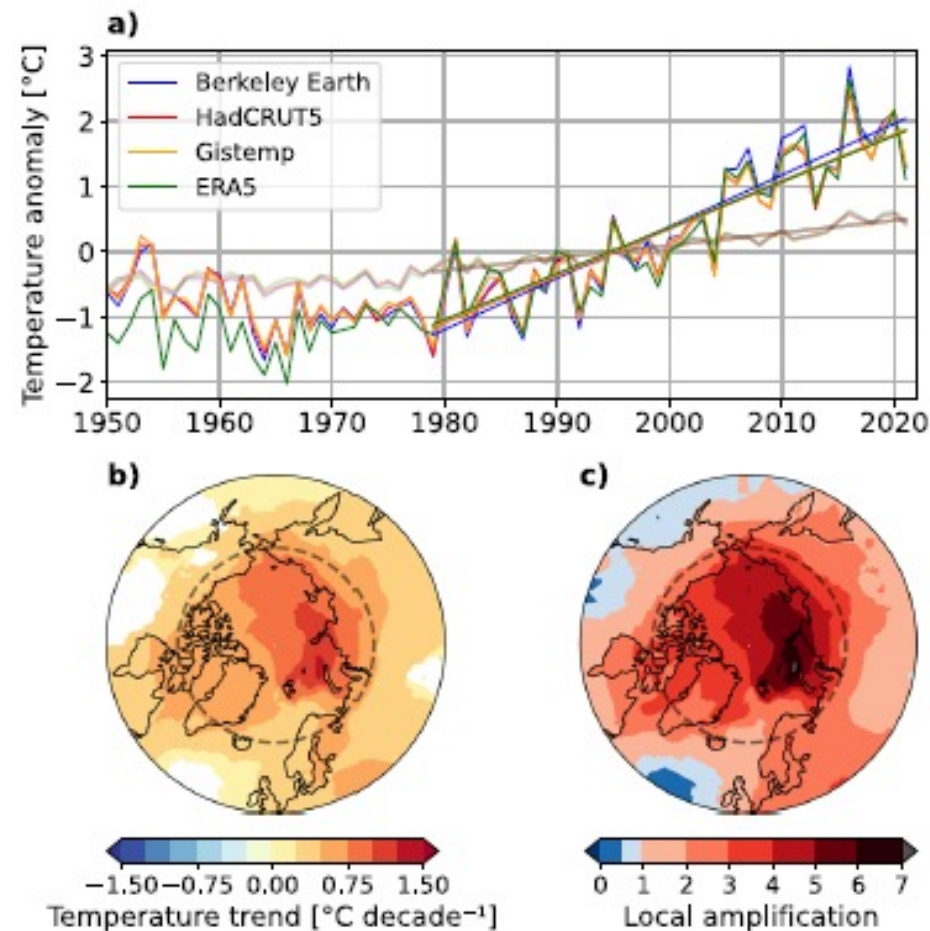
Northern regions: Boreal Forest and Arctic regions

- Presence or not of permafrost
- Processes are different



communications earth & environment

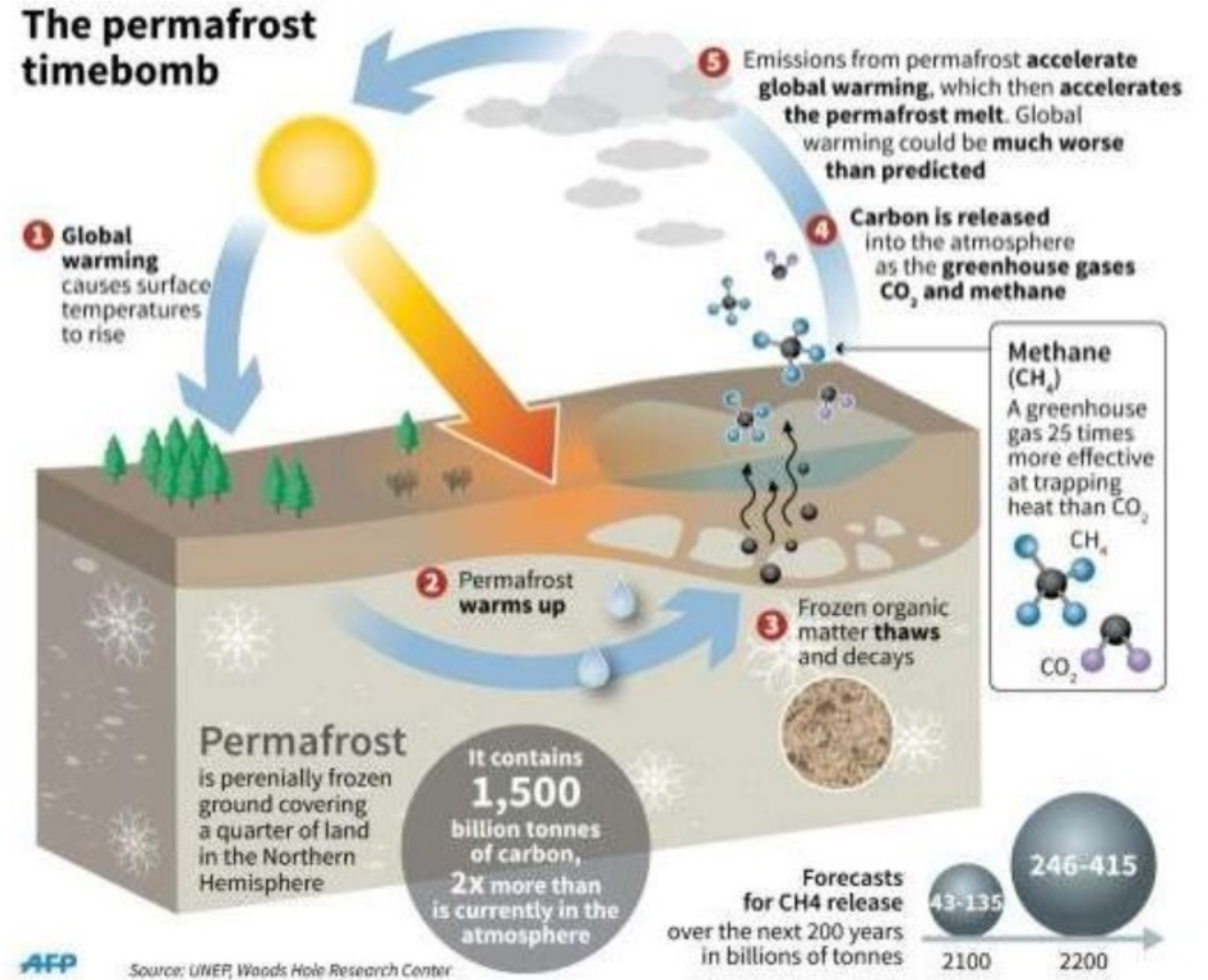
ARTICLE
<https://doi.org/10.1038/s43247-022-00498-3> OPEN
 The Arctic has warmed nearly four times faster than the globe since 1979
 Mika Rantanen^{1,2*}, Alexey Yu. Karpechko¹, Antti Lipponen², Kalle Nordling^{1,3}, Otto Hyvärinen¹, Kimmo Ruosteenoja¹, Timo Vihma¹ & Ari Laaksonen^{1,4}



The permafrost bomb...

But... still need to understand and quantify the release of carbon stored in the permafrost to the atmosphere (CO₂ and CH₄).

Not taken in account in climate prediction models.



And the boreal forest...

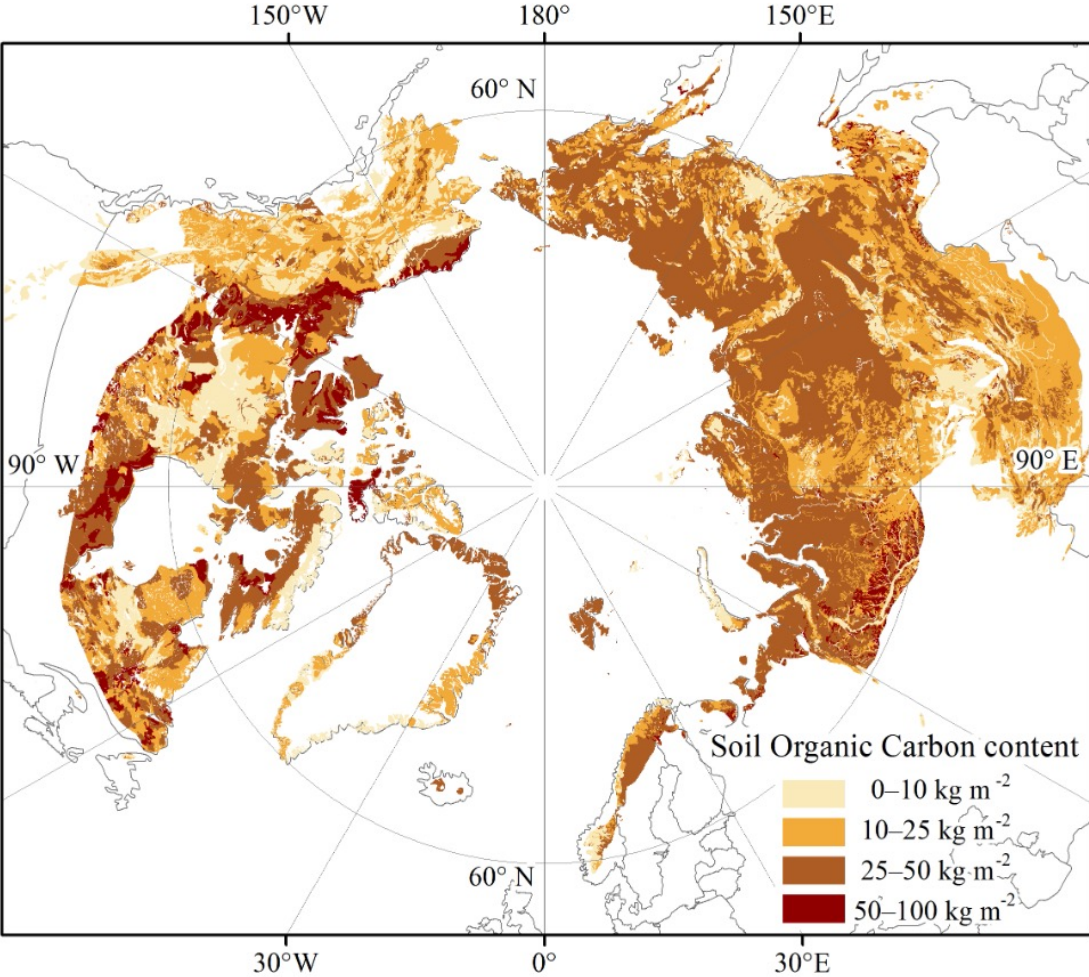
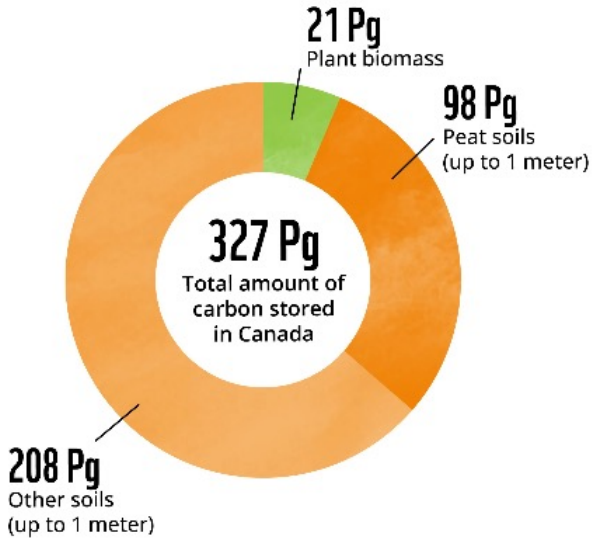
Even in non-permafrost zone important amounts of carbon is stored in soils

Table 2.2. Comparison of Carbon Storage in Boreal, Temperate, and Tropical Forests

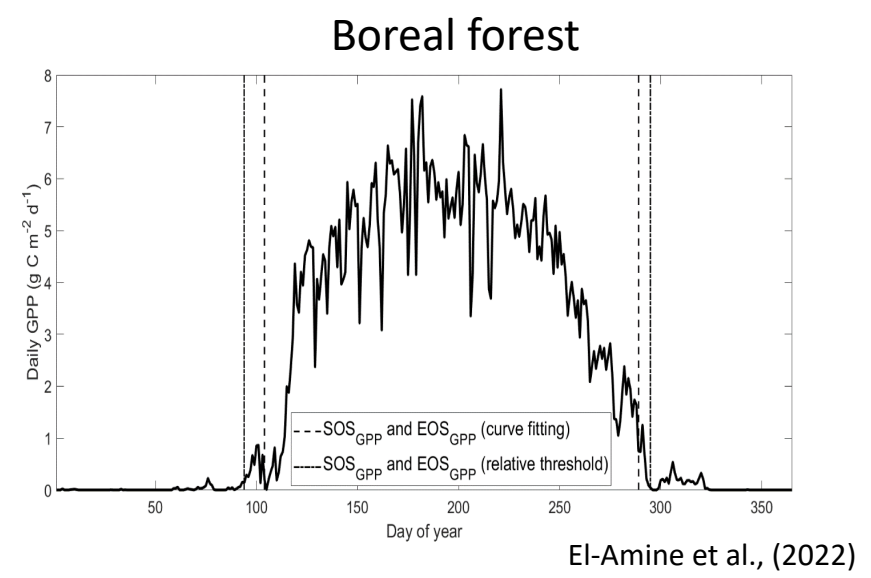
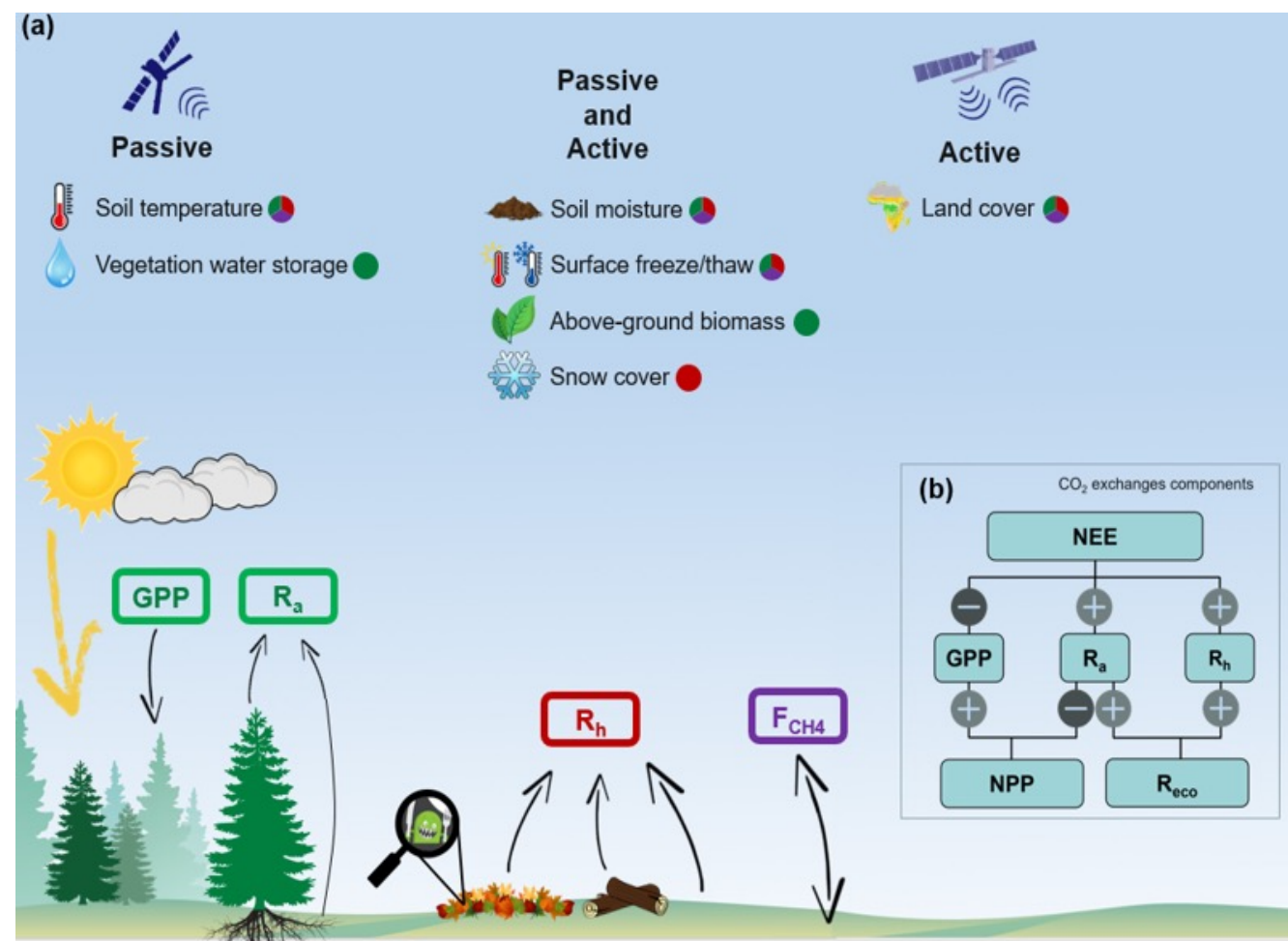
Biome	Area (× 10 ⁶ ha)	Soil carbon (Pg)	Plant biomass carbon (Pg)	Total carbon (Pg)
Boreal forest ^a	1,509	625	78	703
Tropical forest ^b	1,756	216	159	375
Temperate forest ^c	1,040	100	21	121

Kasischke, (2000)

Source: Sothe et al. 2022



Hugelius (2013)



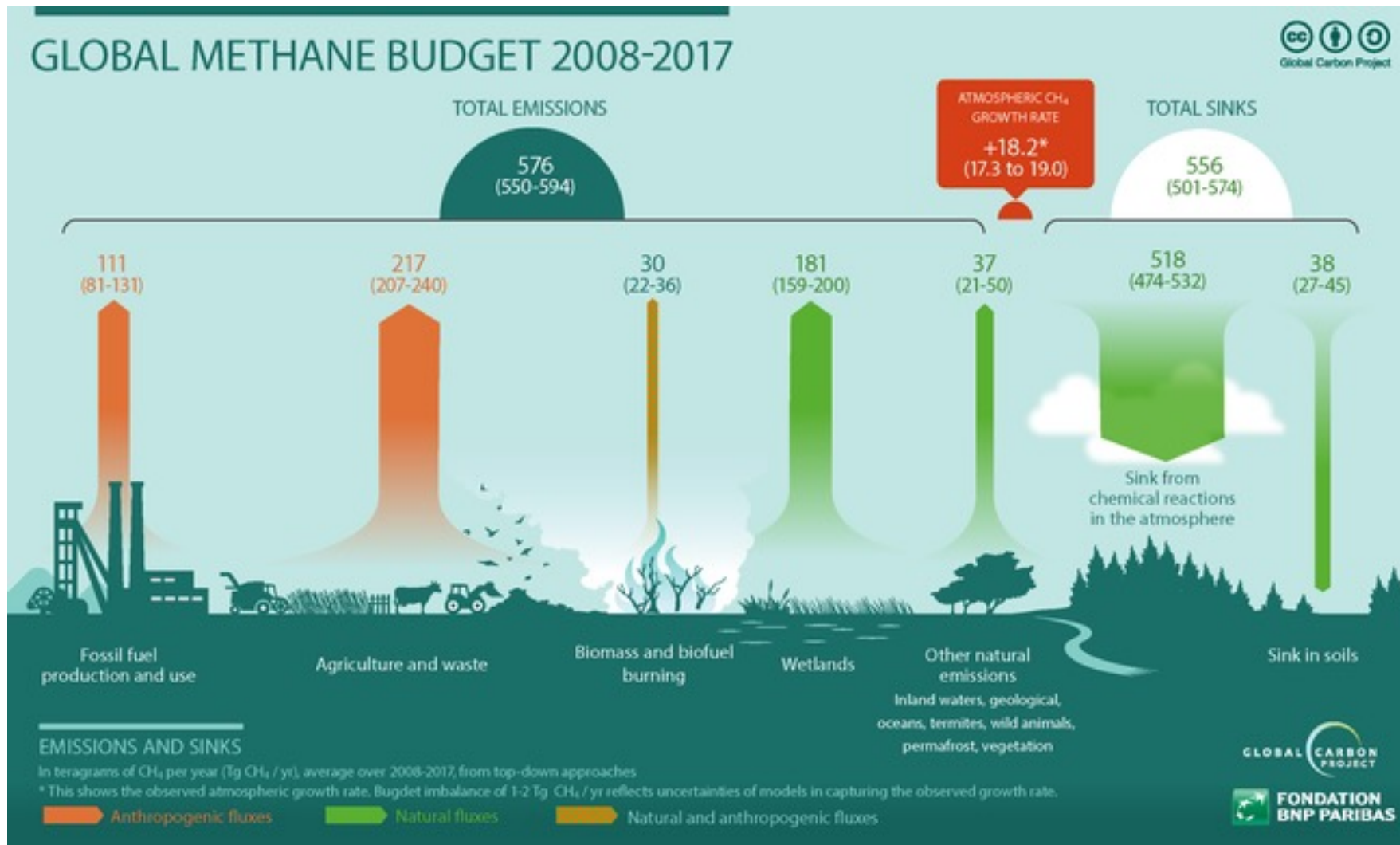
$$NEP = -NEE = GPP - R_{eco}$$

In northern regions, we can define 3 regimes :

- Summer : $NEP = GPP - R_{eco} [f(T, \text{water})]$
- Shoulder season : Freeze/thaw cycle
- Winter : $GPP = 0$ and R_{eco} ?

Figure 4: a) Carbon dioxide and methane fluxes between the land surface and the atmosphere including gross primary production (GPP), heterotrophic respiration (R_h), autotrophic respiration (R_a), and net methane fluxes (F_{CH4}) (units: gC m⁻² yr⁻¹). The fluxes are color-coded (green: GPP and R_a; red: R_h; purple: F_{CH4}) to match which relevant key variables important for CO₂ and CH₄ fluxes and deriveable with microwave remote sensing, and b) relationships of net primary productivity and net ecosystem productivity, and their component fluxes. (Mavrovic et al., 2023)

- Methanotropic organisms
- f(T, water)
- Methanogenesis organisms
- Anaerobic (wetland)



CO₂ fluxes is balanced by the positive impact of temperature on GPP and the negative impact on soil moisture

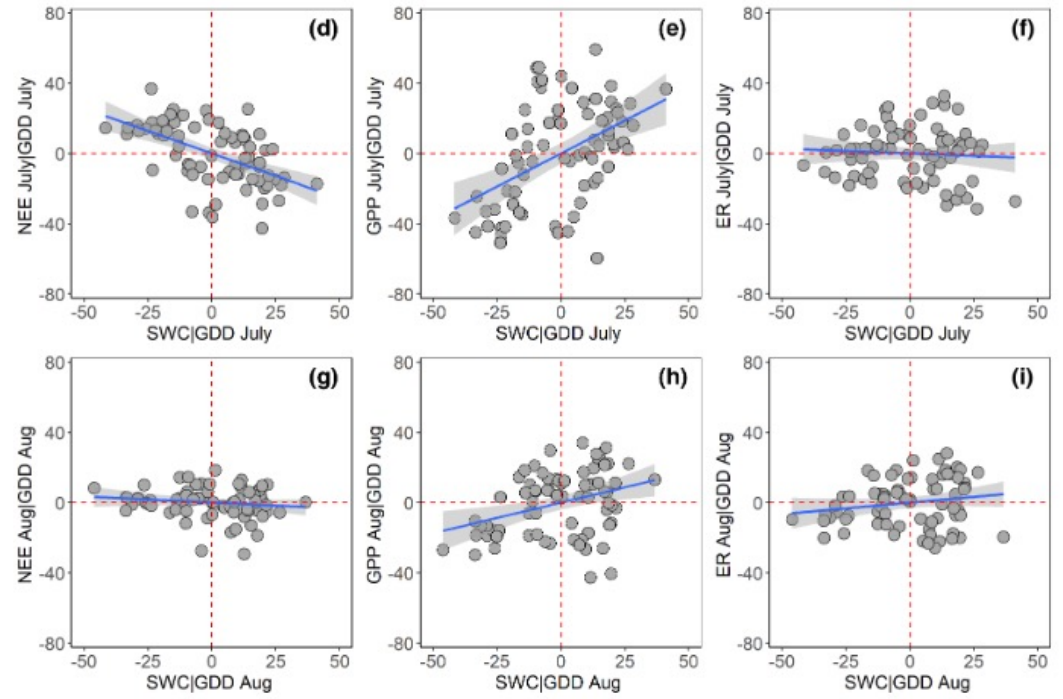


RESEARCH ARTICLE | [Open Access](#) |

Pan-Arctic soil moisture control on tundra carbon sequestration and plant productivity

Donatella Zona ✉, Peter M. Lafleur, Koen Hufkens, Beniamino Gioli, Barbara Bailey, George Burba, Eugénie S. Euskirchen, Jennifer D. Watts, Kyle A. Arndt, Mary Farina, John S. Kimball, Martin Heimann, Mathias Göckede, Martijn Pallandt, Torben R. Christensen, Mikhail Mastepanov, Efrén López-Blanco, Albertus J. Dolman, Roisin Commane, Charles E. Miller, Josh Hashemi, Lars Kutzbach, David Holl, Julia Boike, Christian Wille, Torsten Sachs, Aram Kalhori, Elyn R. Humphreys, Oliver Sonnentag, Gesa Meyer, Gabriel H. Gosselin, Philip Marsh, Walter C. Oechel ... [See fewer authors](#) ^

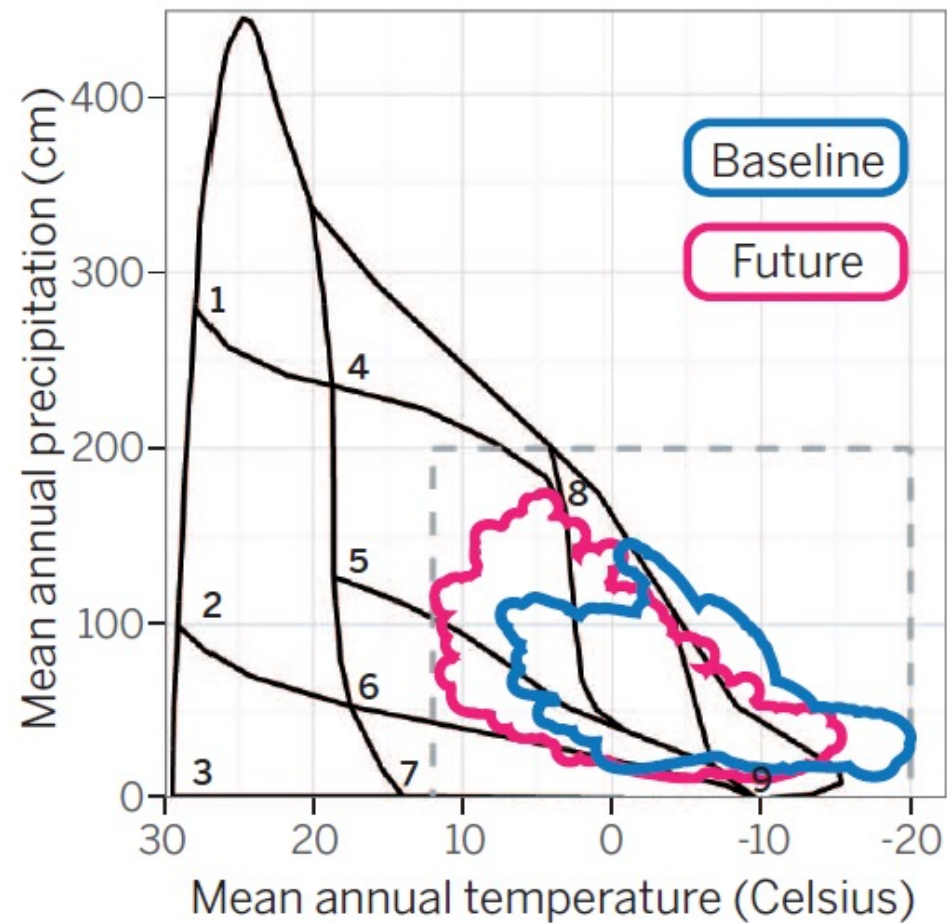
First published: 10 November 2022 | <https://doi.org/10.1111/gcb.16487> | Citations: 3



Zona et al., 2022

CO₂ fluxes is balanced by the positive impact of temperature on GPP and the negative impact on soil moisture...

A Climate space of terrestrial biomes



- 1. Tropical rain forest
- 2. Tropical seasonal forest/savanna
- 3. Subtropical desert
- 4. Temperate rain forest
- 5. Temperate seasonal forest
- 6. Woodland/shrubland
- 7. Temperate grassland/desert
- 8. Taiga
- 9. Tundra

Gauthier et al., 2015

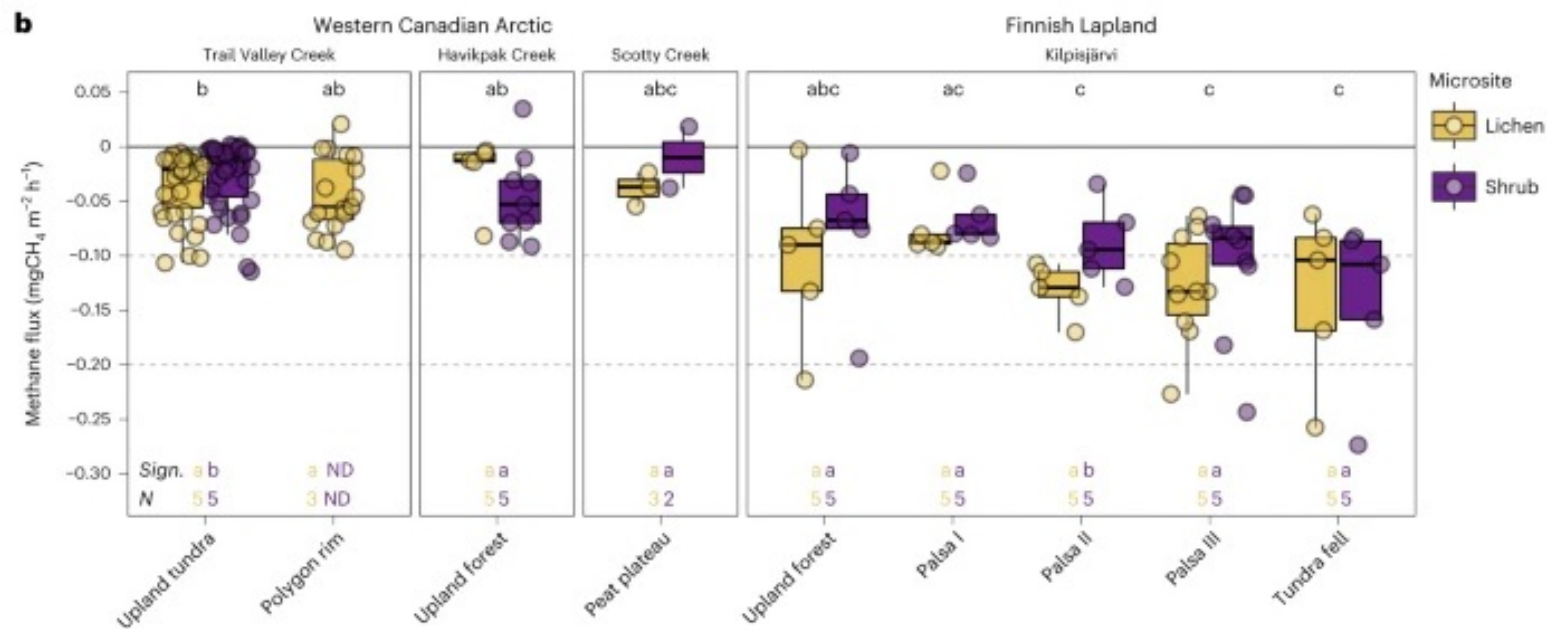
- Boreal Forest
- General drying of the North American boreal forest
 - Drought-induced mortality has been reported in several boreal regions and is predicted to increase regionally
 - We're not talking about the impact of fire on carbon budget...

Arctic soil methane sink increases with drier conditions and higher ecosystem respiration

[Carolina Voigt](#) , [Anna-Maria Virkkala](#), [Gabriel Hould Gosselin](#), [Kathryn A. Bennett](#), [T. Andrew Black](#), [Matteo Detto](#), [Charles Chevrier-Dion](#), [Georg Guggenberger](#), [Wasi Hashmi](#), [Lukas Kohl](#), [Dan Kou](#), [Charlotte Marquis](#), [Philip Marsh](#), [Majja E. Marushchak](#), [Zoran Nestic](#), [Hannu Nykänen](#), [Tajja Saarela](#), [Leopold Sauheitl](#), [Branden Walker](#), [Niels Weiss](#), [Evan J. Wilcox](#) & [Oliver Sonnentag](#)

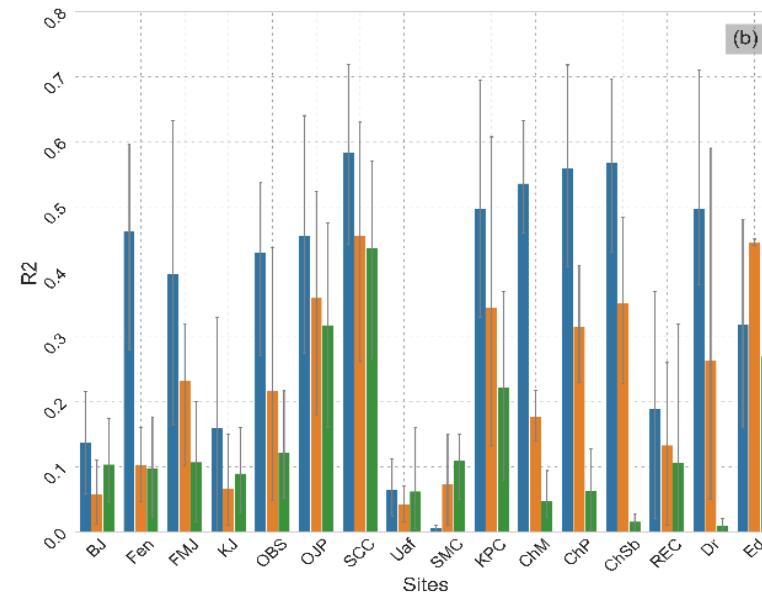
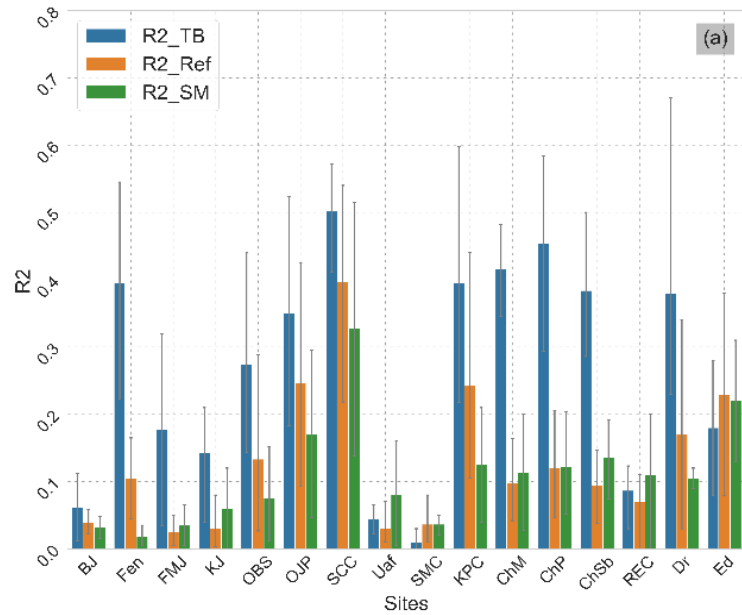
Nature Climate Change **13**, 1095–1104 (2023) | [Cite this article](#)

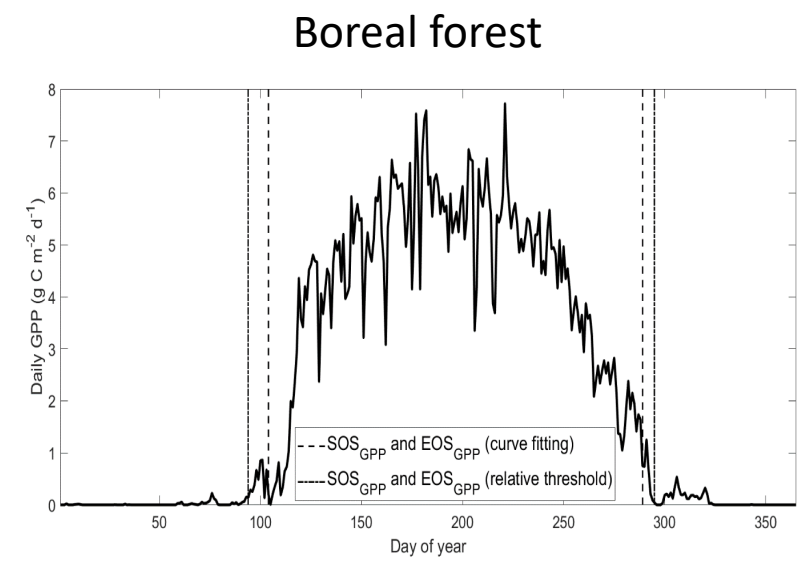
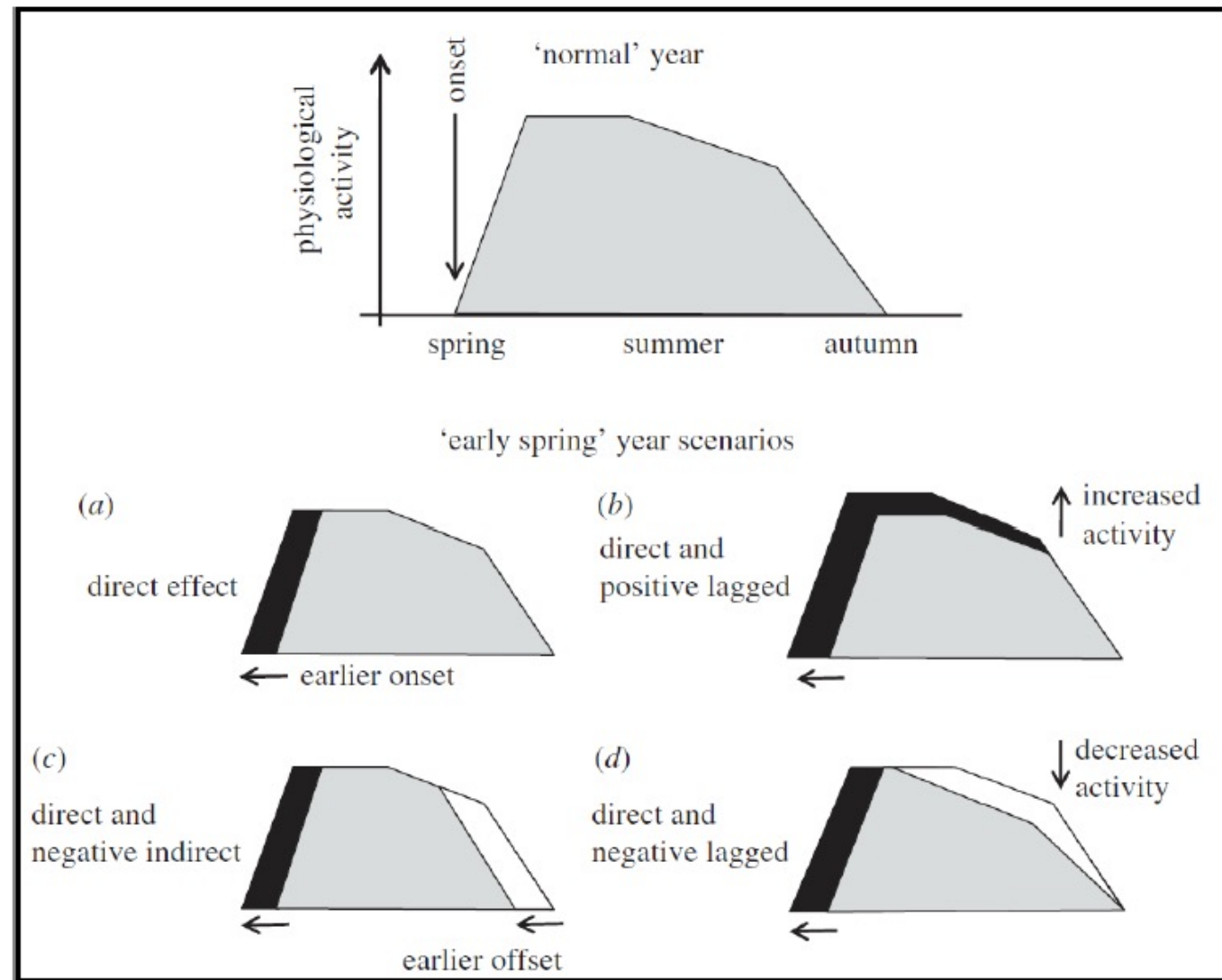
3984 Accesses | 135 Altmetric | [Metrics](#)



CO₂ fluxes in Northern regions : Summer

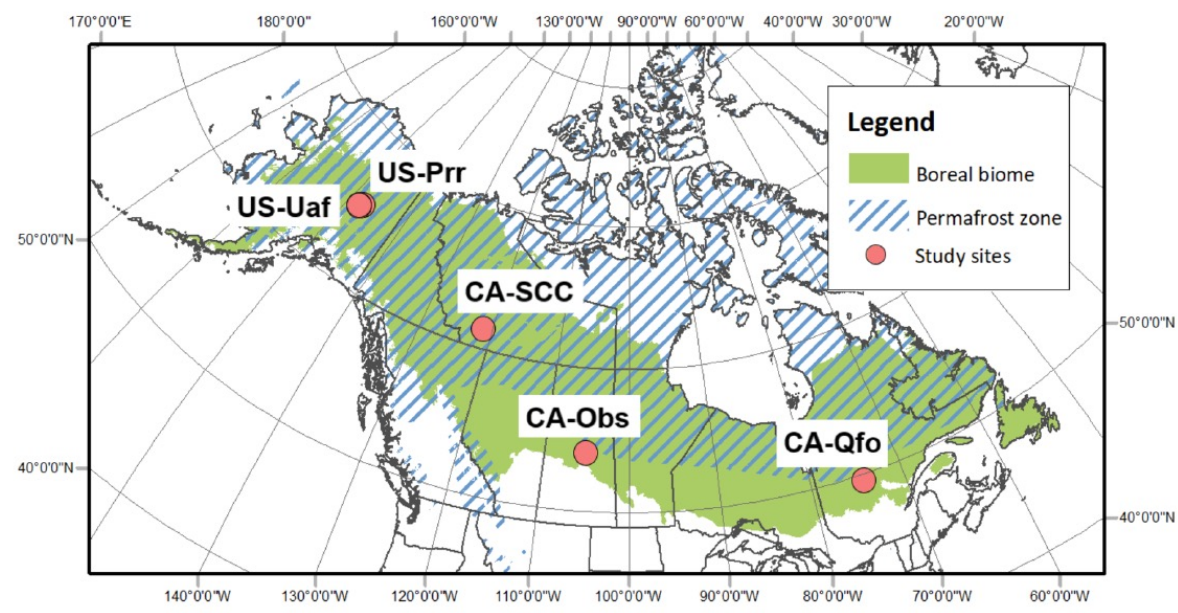
- We highlight the complexity of the (SMOS and SMAP) SM inversion in these regions
- Important to identify factors affecting the signal
 - Lakes
 - Vegetation attenuation
 - Moss/lichen vs surface roughness



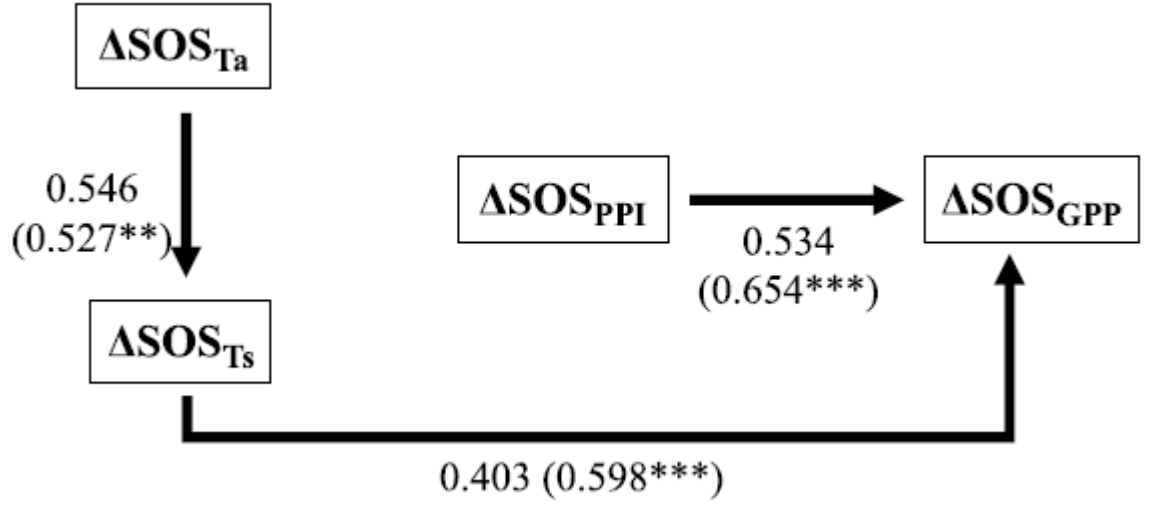


Structural Equation Modeling (40 site-years)

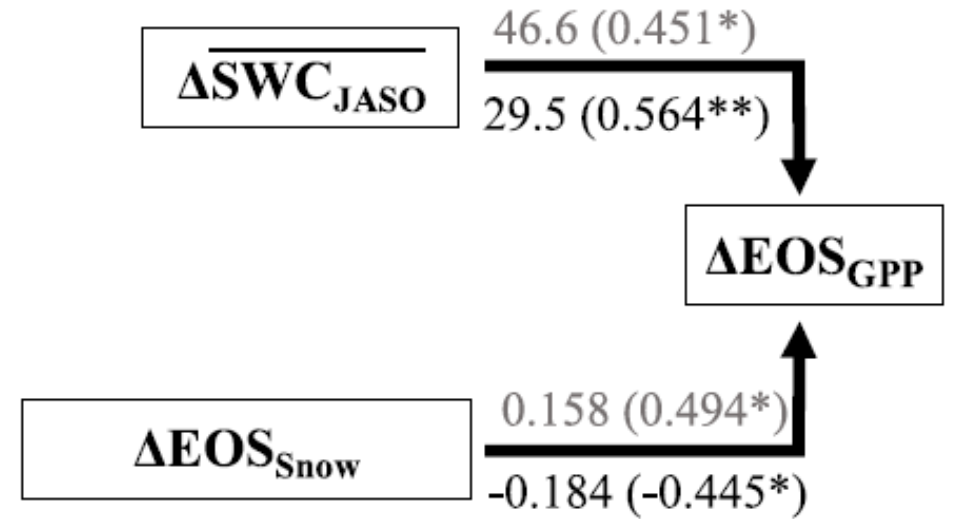
- Start of season (SOS), driven by air/soil temperature (Ta, Ts)
- End of season (EOS), driven by soil water content (SWC)



Start of the season



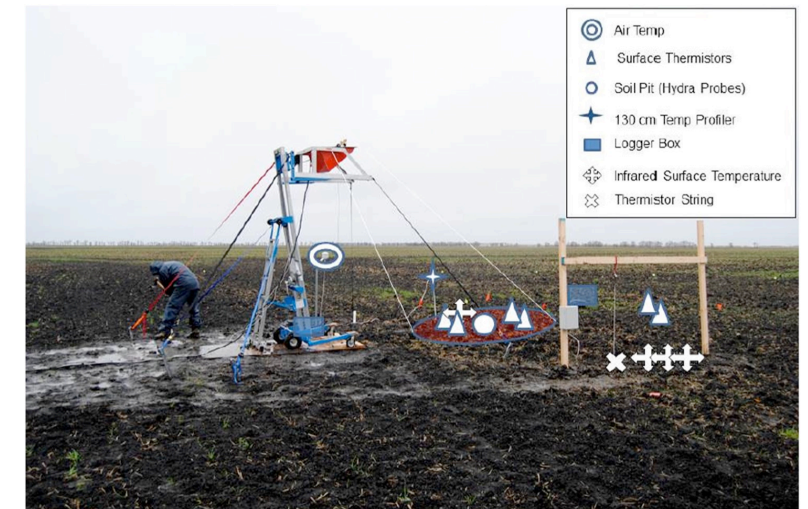
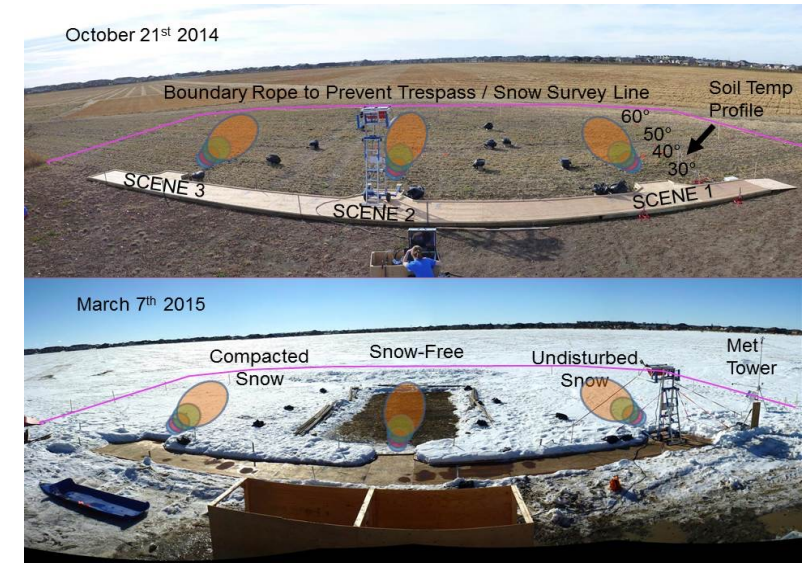
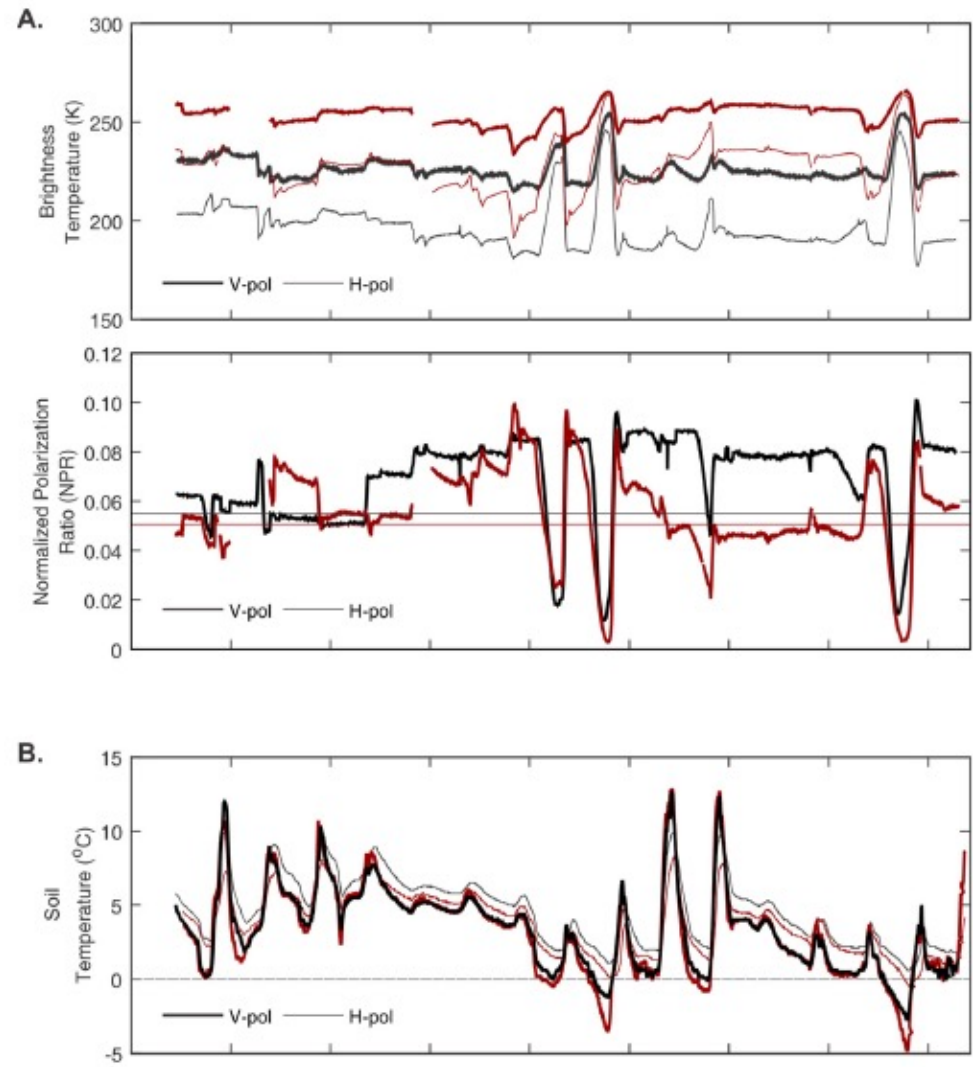
End of season



Ground-based radiometer
 experiment in agricultural field
 for freeze/thaw monitoring

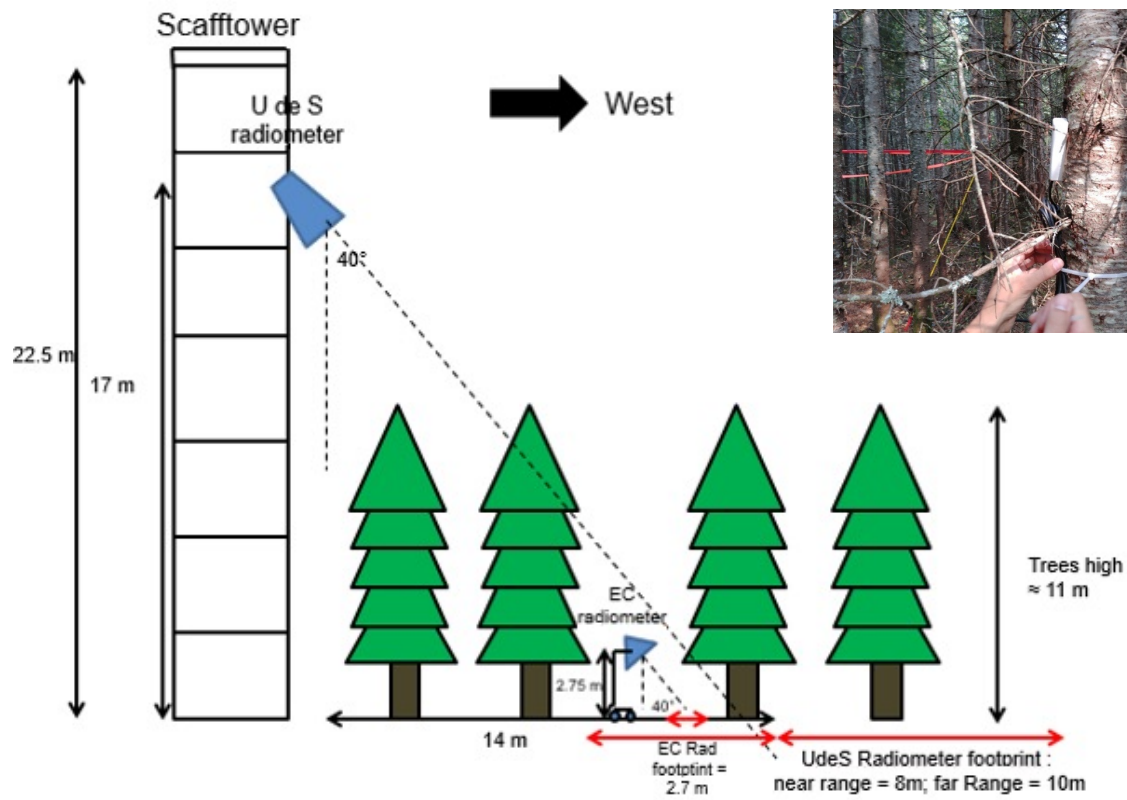
Saskatchewan 2014-2015 +
 SLAPVex2015

- Strong freeze/Thaw signal
- Freeze/thaw signal come from the first 1cm of soil
- Wet snow as a strong signal

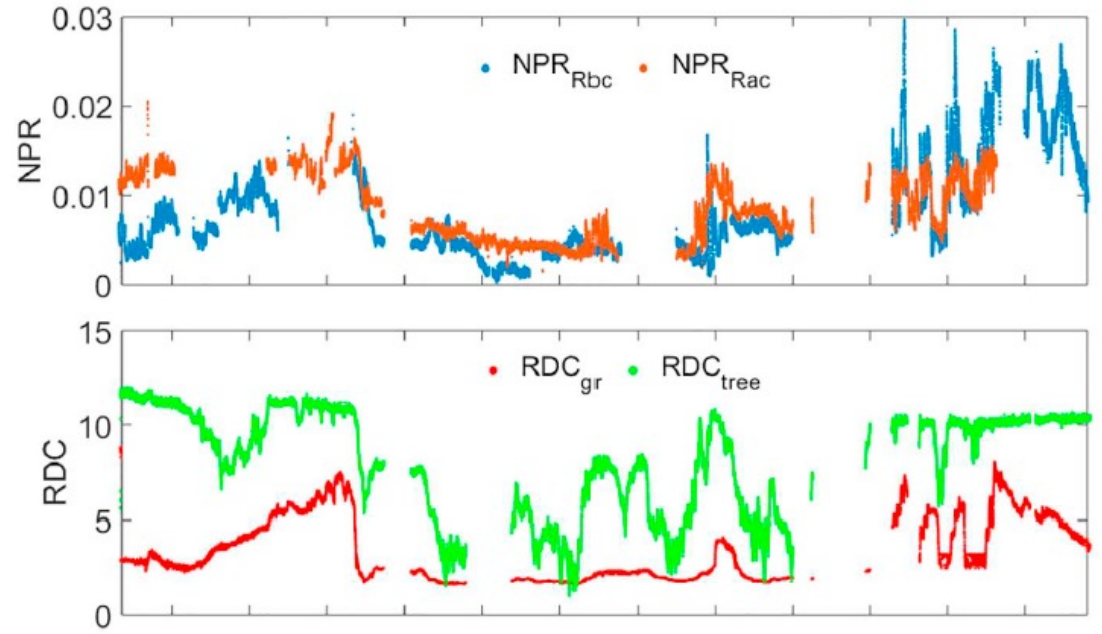


What's the link between L-Band FT signal and growing season?

Southern Old Black Spruce,
 Saskatchewan, 2017

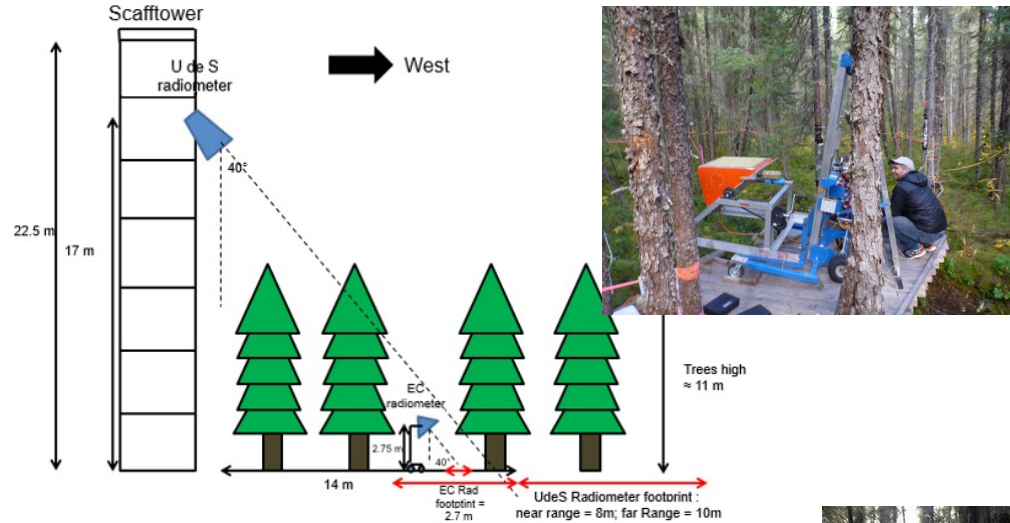


Dielectric sensors in tree



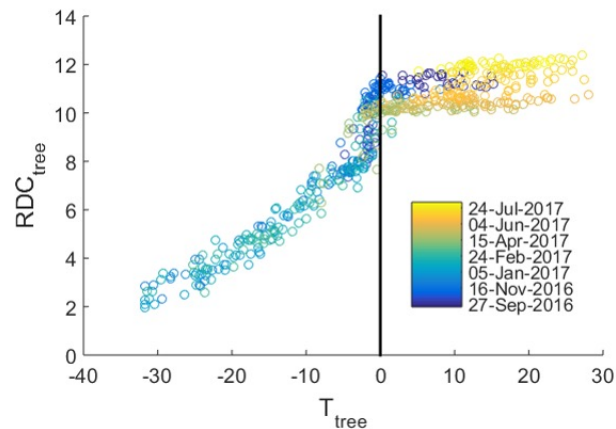
- Fall : Freeze = Frozen soil (RDC_{soil})
- Spring: thaw = liquid water in trees/snow /soil (RDC_{tree})

What's the link between L-Band FT signal and growing season?

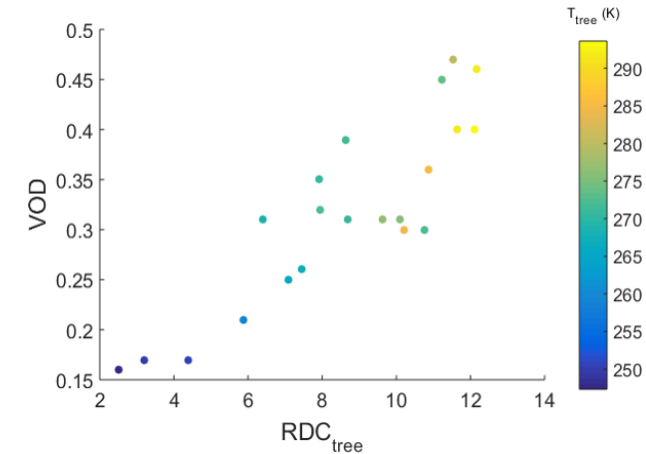
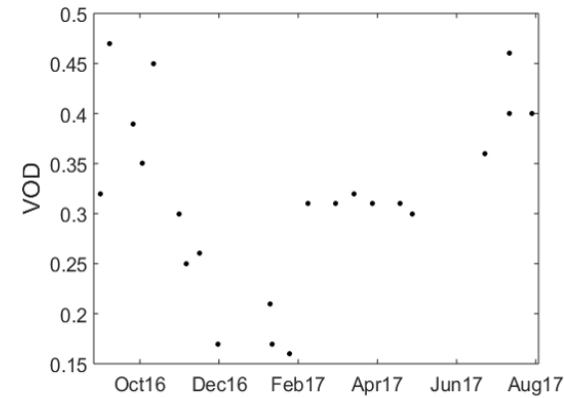


- Decrease of stem dielectric with temperature when the trees freeze
- Strong relationship between tree dielectric and VOD

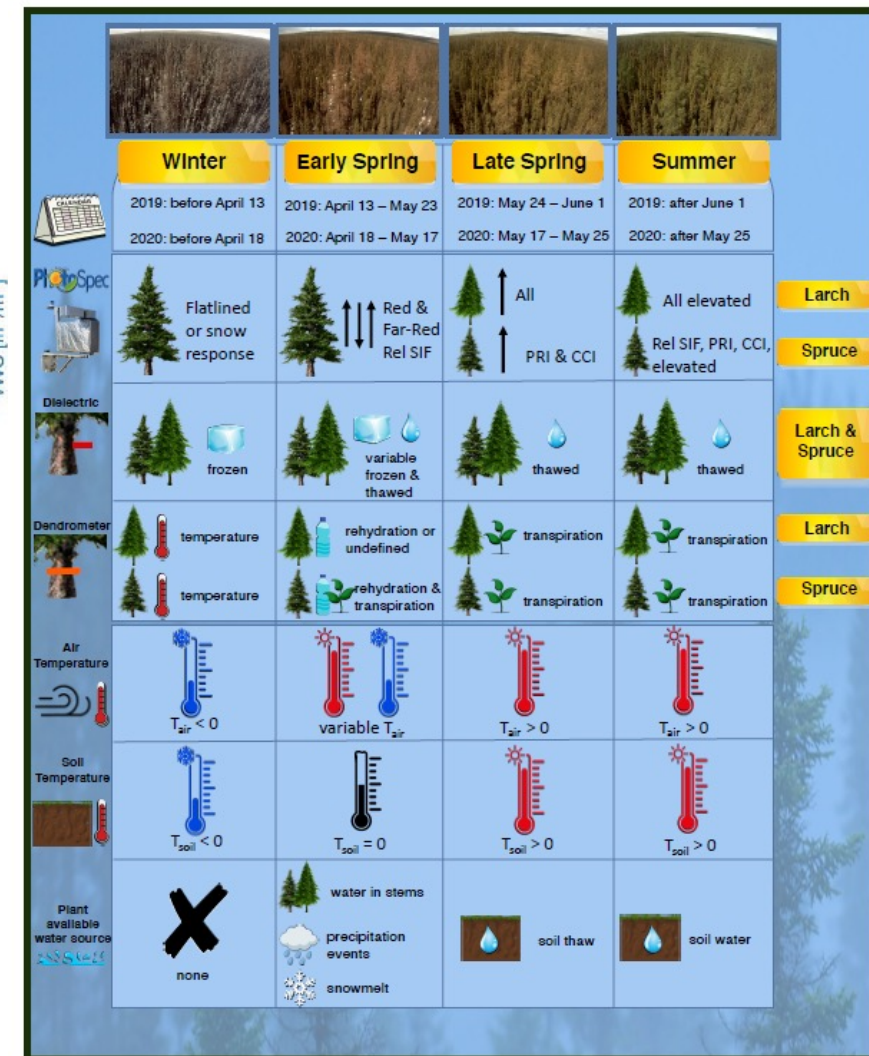
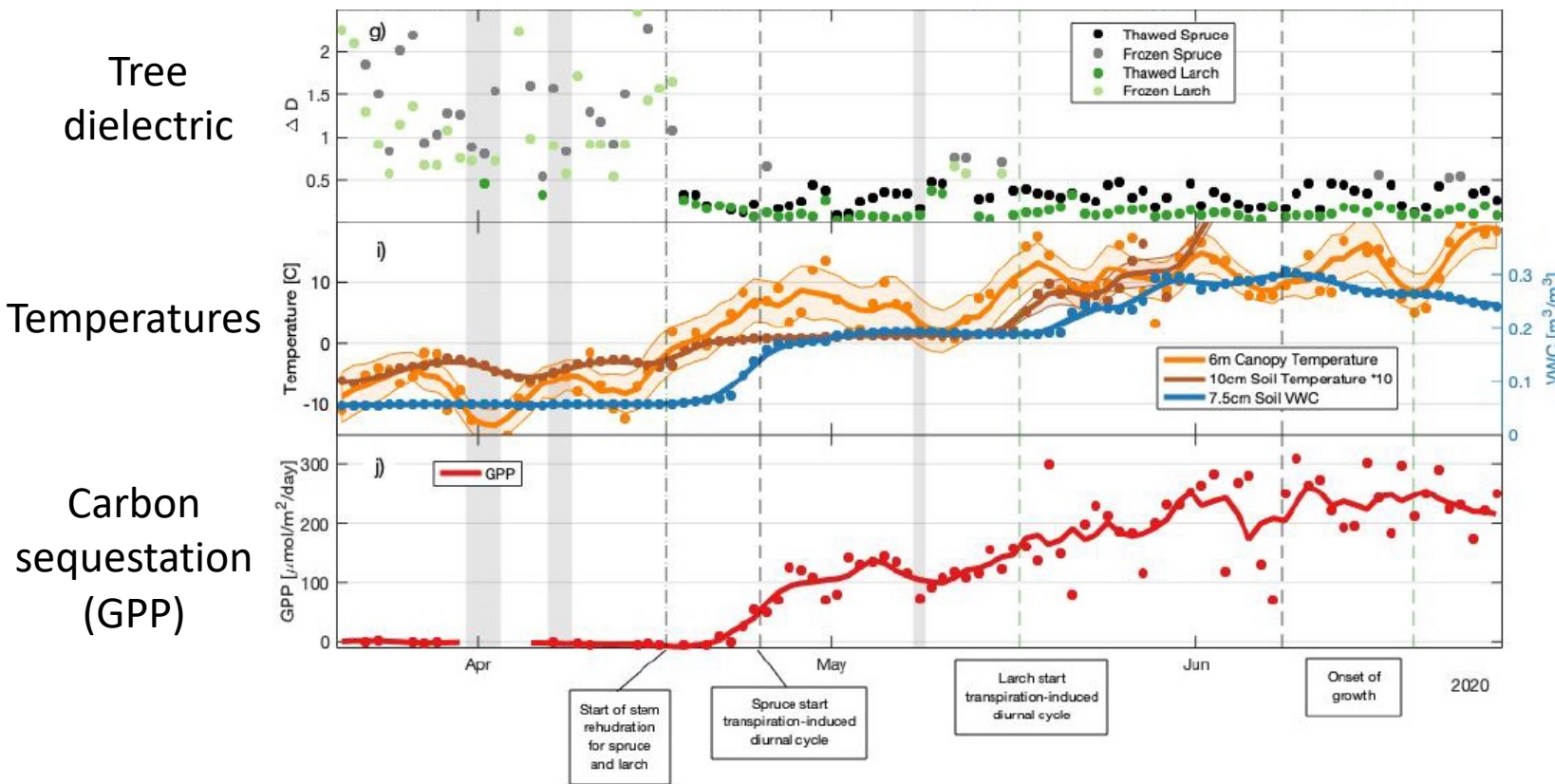
Dielectric probes in trees



Relationship between VOD and tree dielectric (RDC)

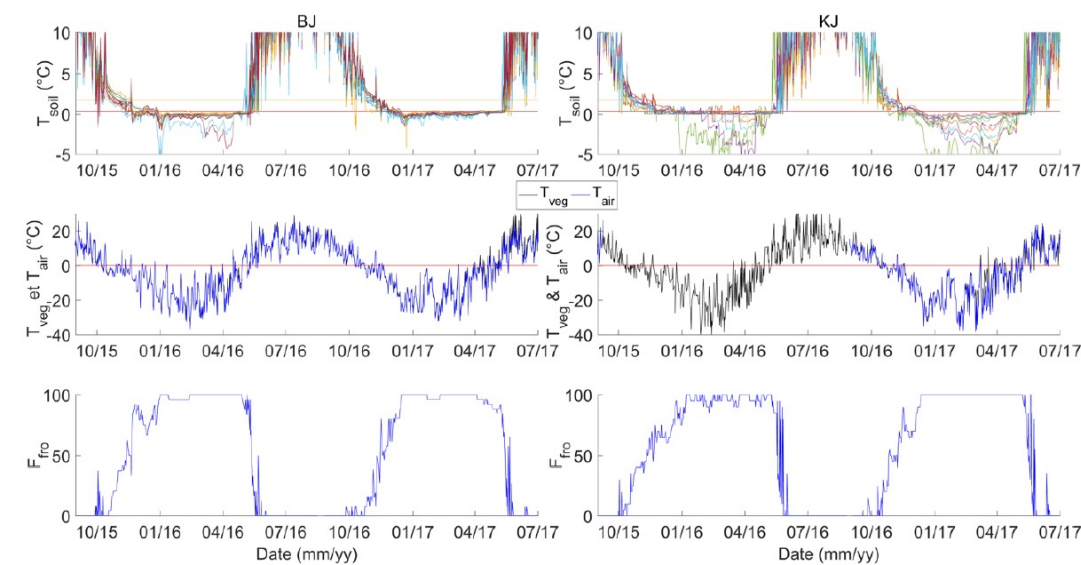
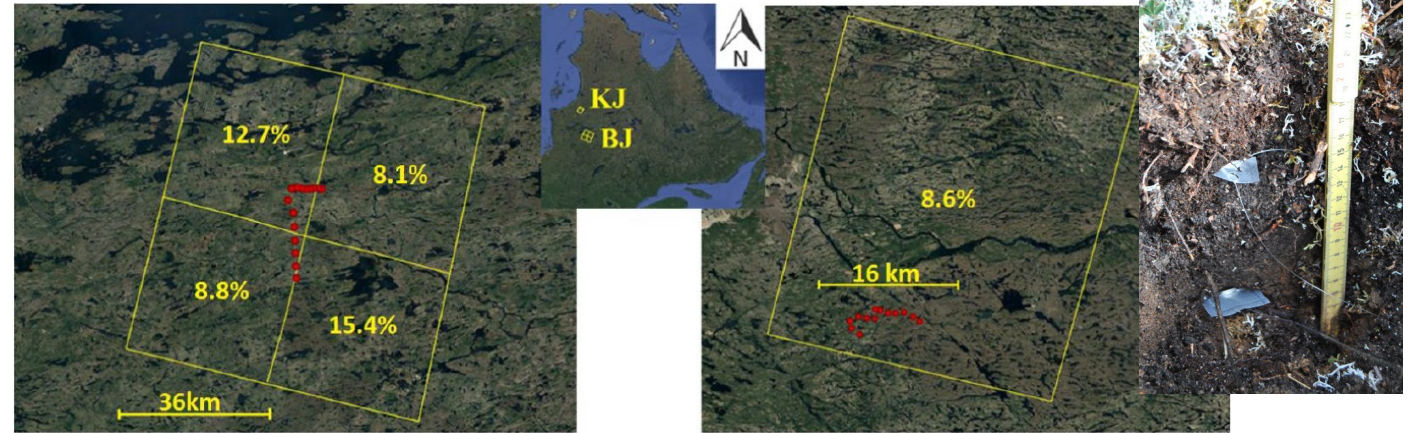


What's the link between L-Band FT signal and growing season?

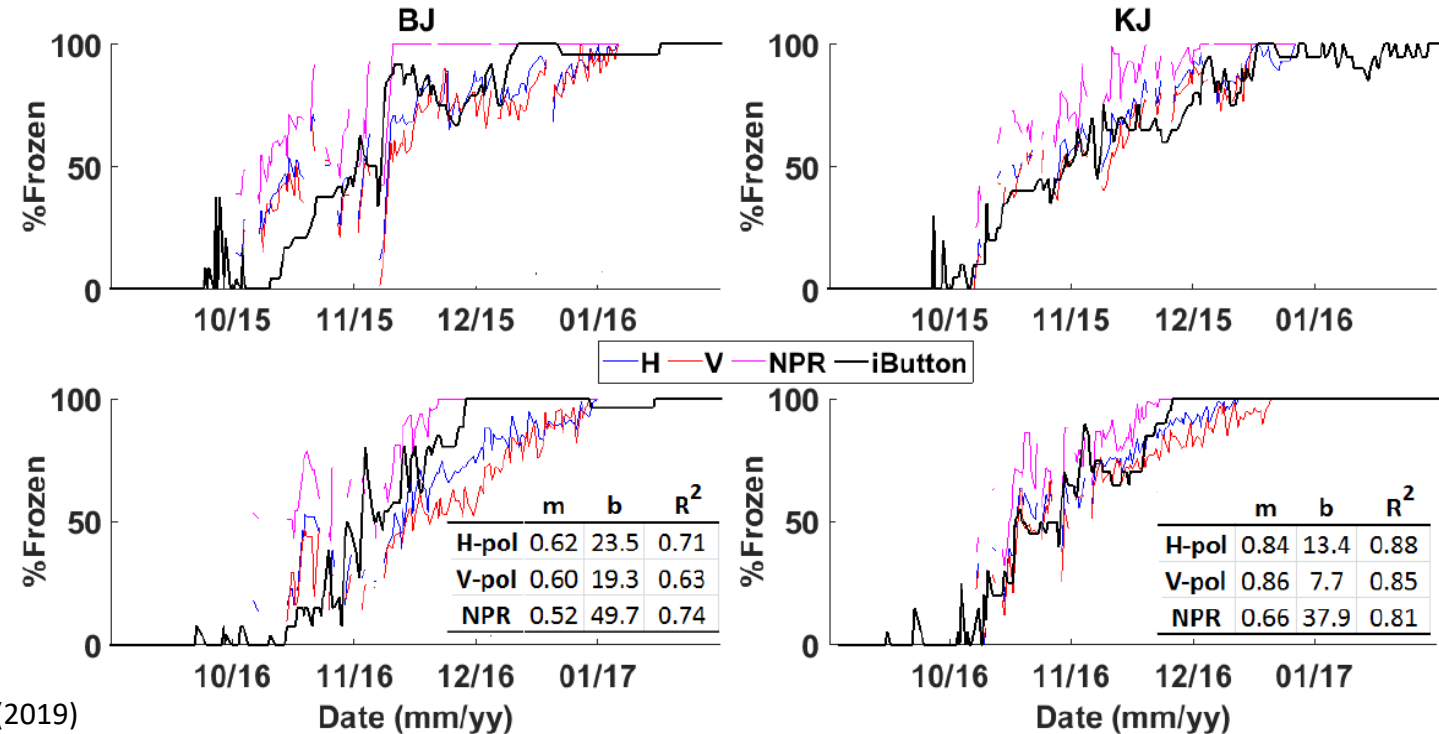


In spring, satellite is sensitive to the presence of liquid water → closely related to GPP onset in spring

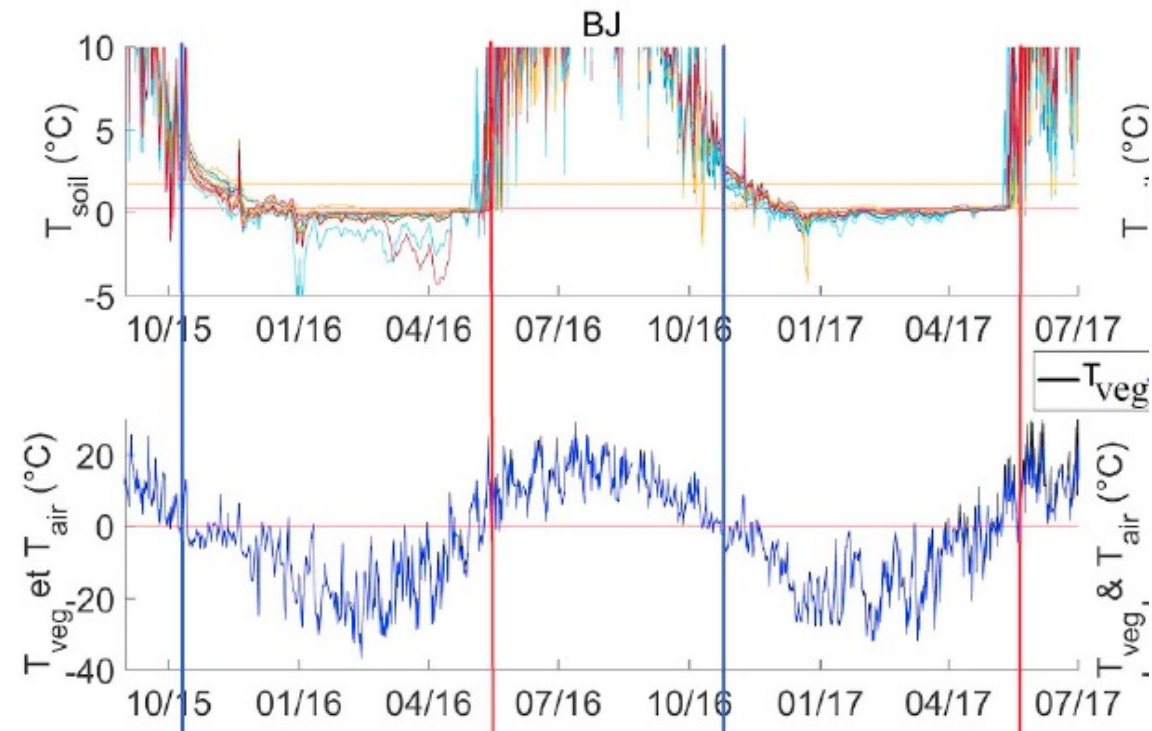
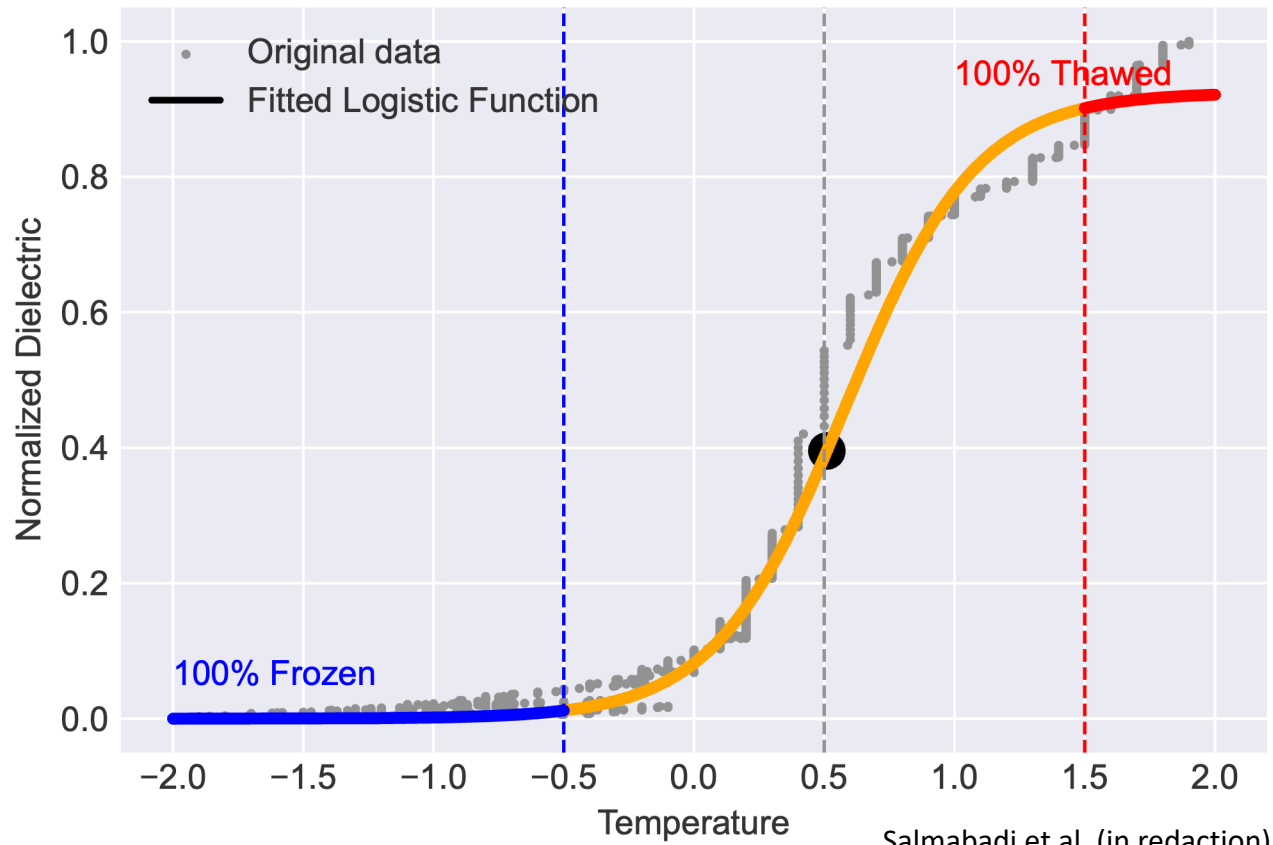
- Soil temperature remains at 0°C (zero curtain)
- Strong spatial variability in soil freezing
- Development of an algorithm to calculate the % of frozen soil (R² of 0.63 and 0.88)

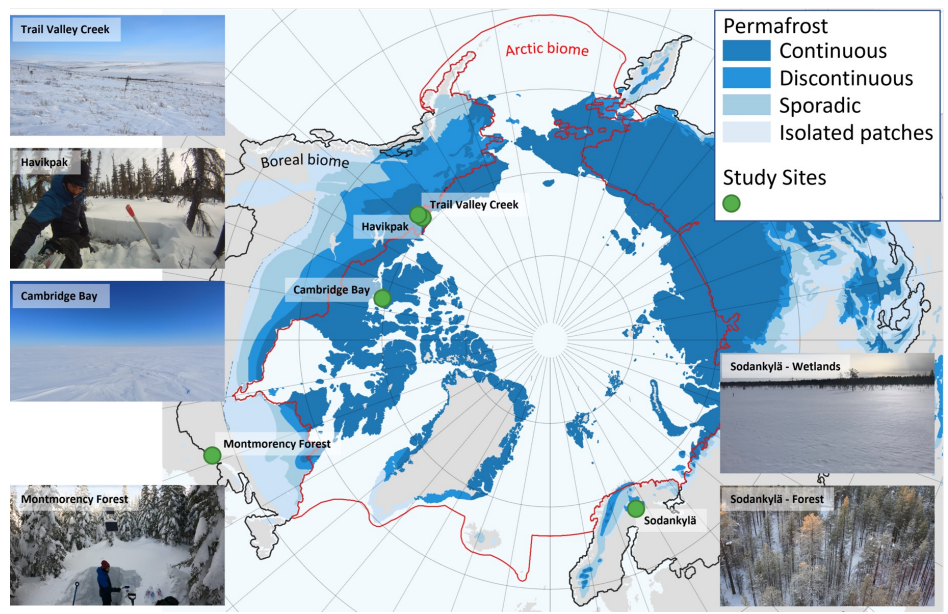


Prince et al. (2019)



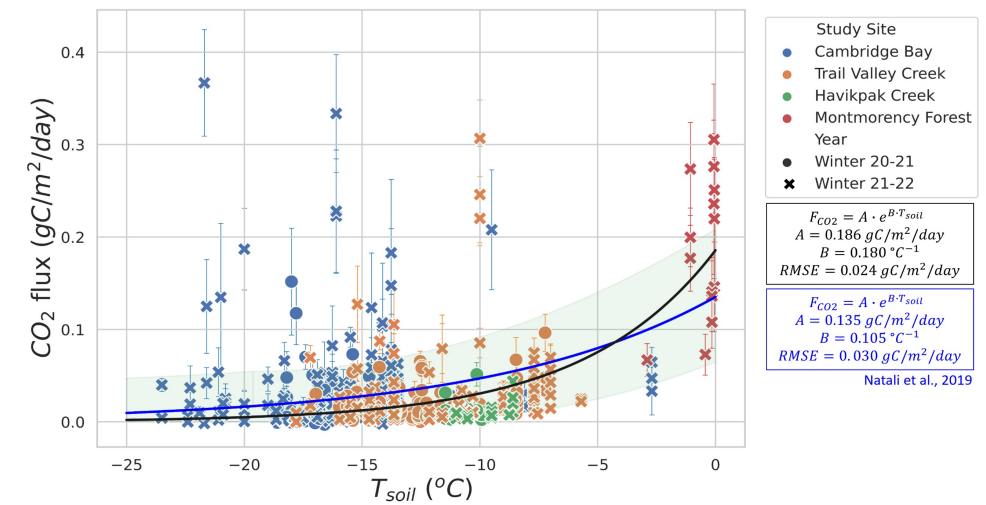
The zero-curtain effect



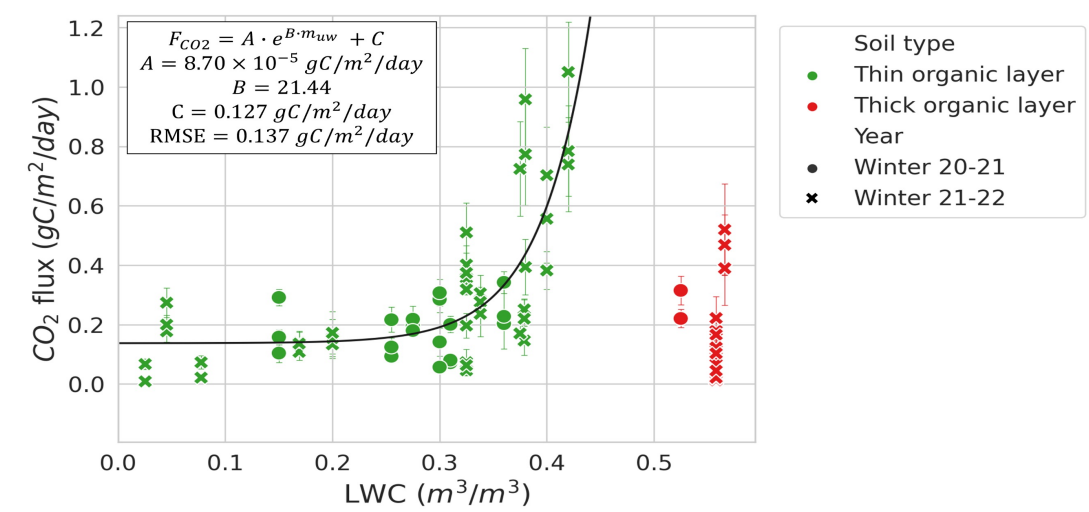
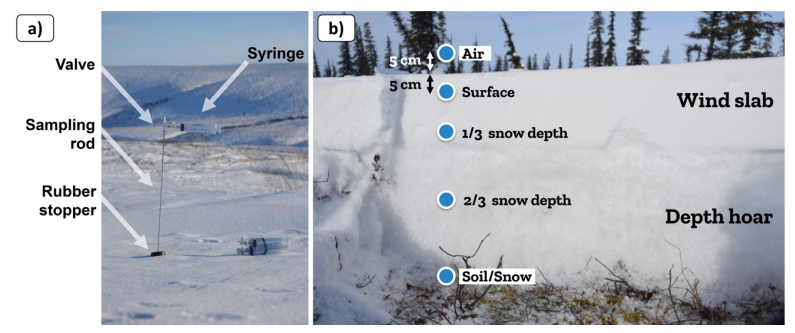


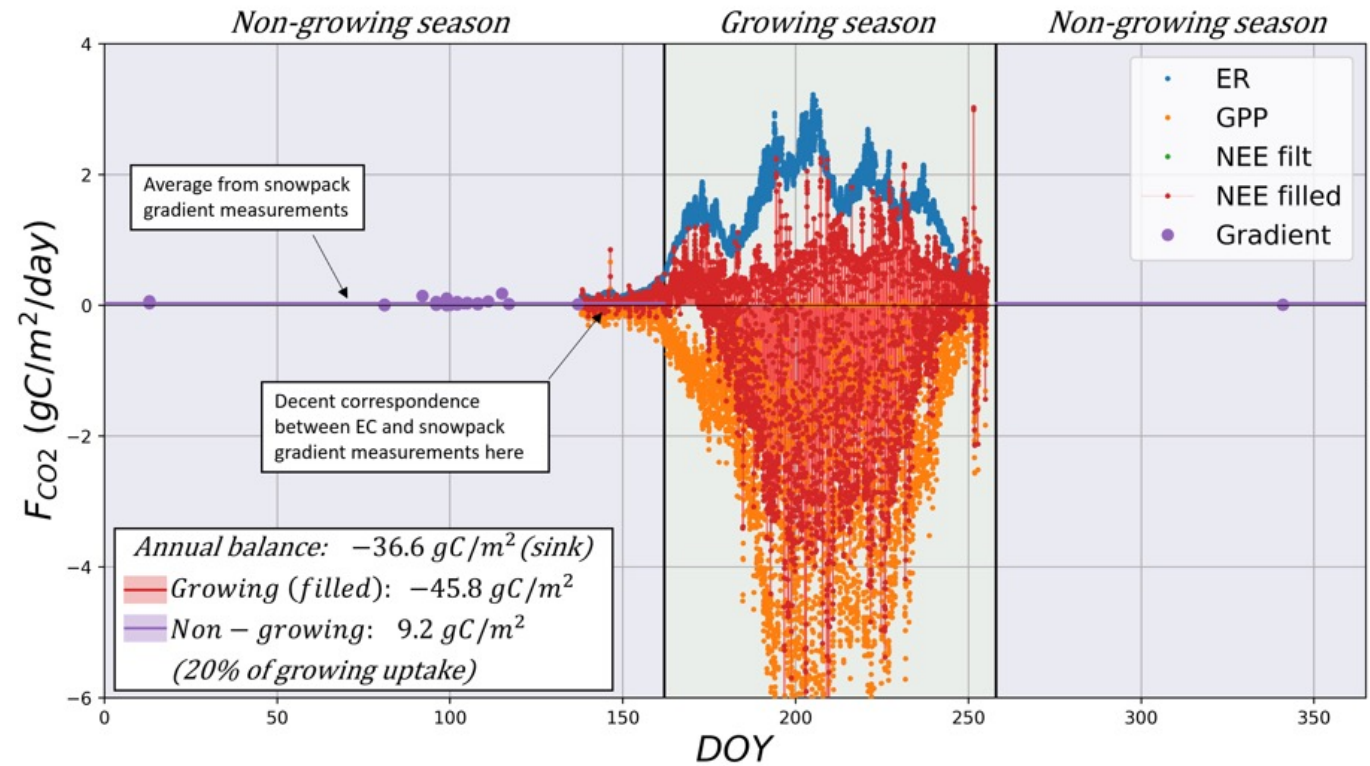
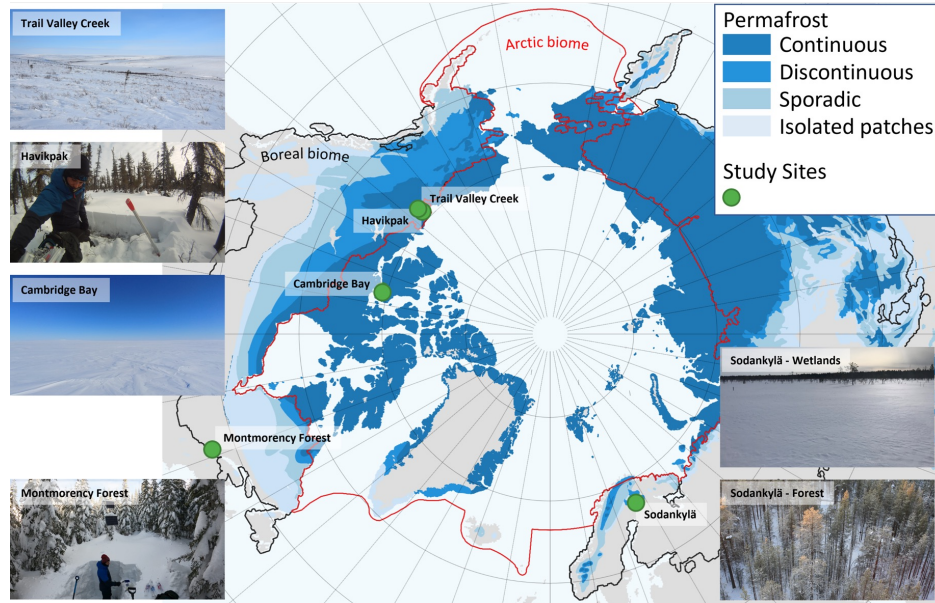
Environmental controls of winter season CO₂ flux

- When $T_{soil} < 0^{\circ}C$, then T_{soil} is the main control.
- When soil LWC $> 0 m^3/m^3$, then soil LWC is the main control.
- Exponential relationship with T_{soil} and soil LWC.

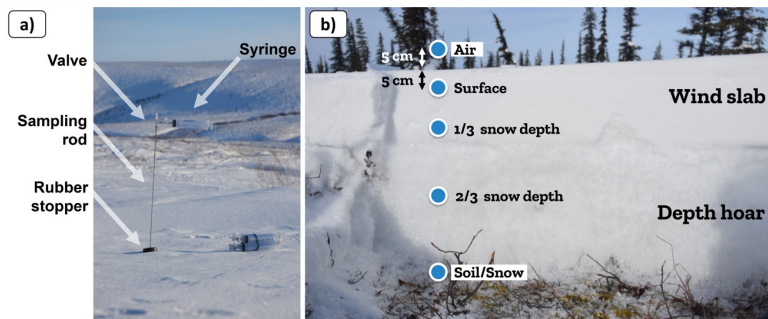


Snowpack diffusion gradient method

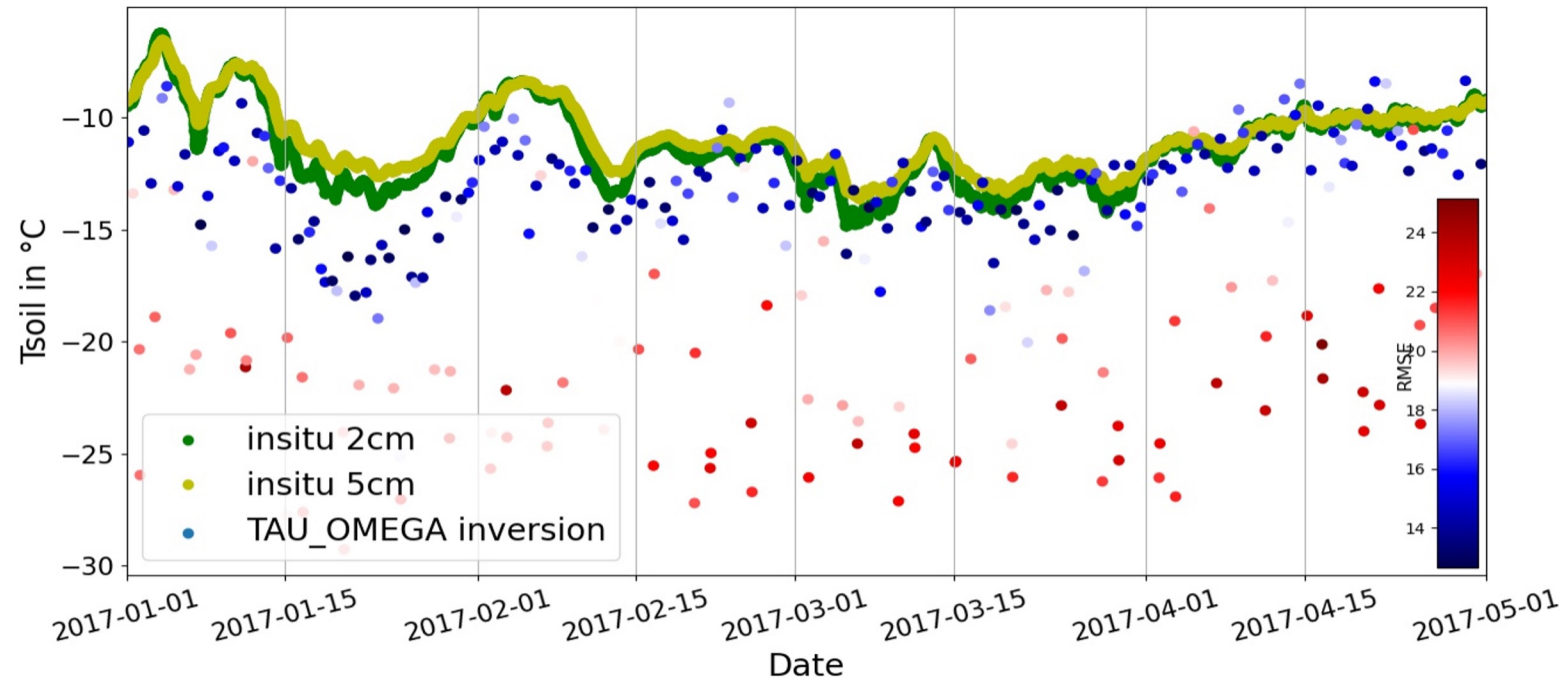




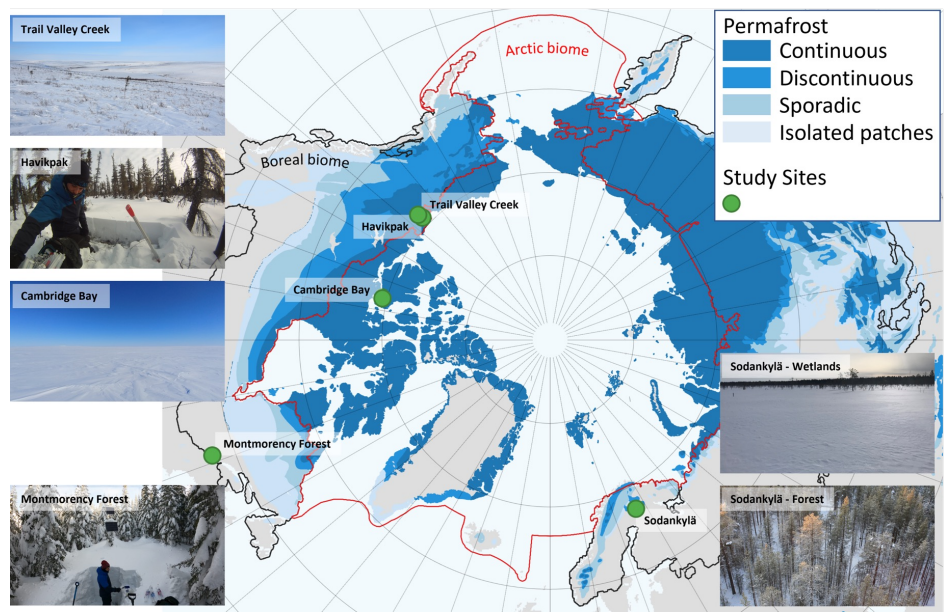
Snowpack diffusion gradient method



Retrievals of soil temperature in the Arctic permafrost area under the snow pack



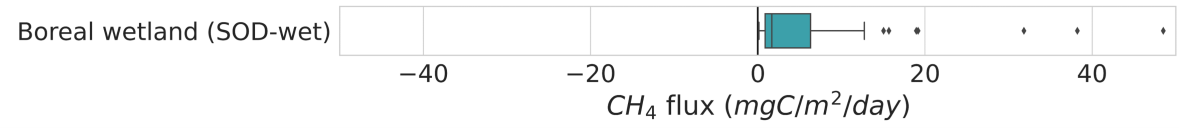
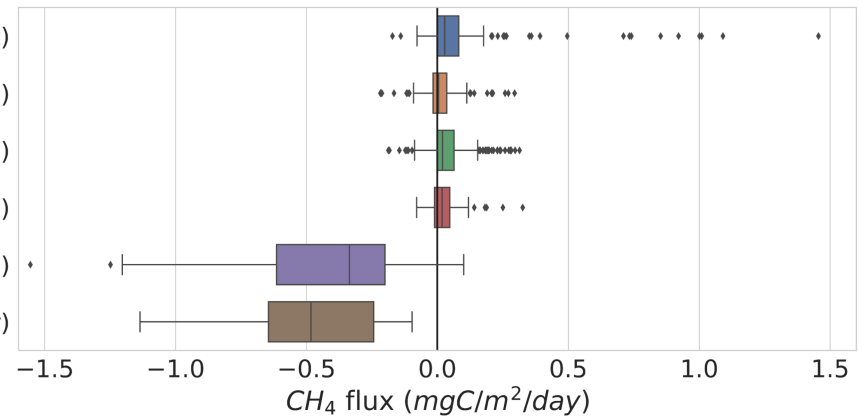
Method:
SMOS L3TB data
Fixed "frozen" soil dielectric
Inversion on Tsoil



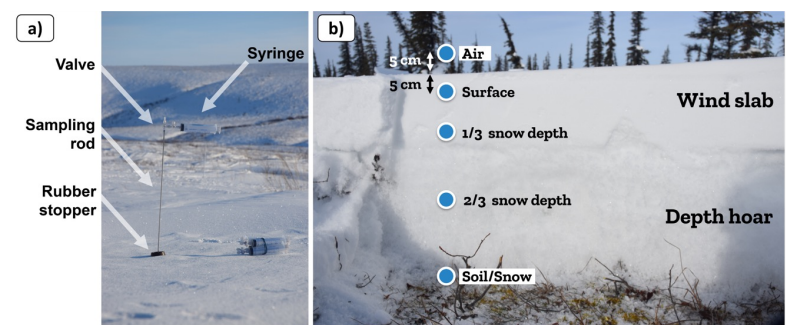
Environmental controls of winter season CH₄ flux

- Boreal forests soils act as a sink, wetlands act as a source.
- Site-specific linear relationship with soil LWC in boreal forest soils.
- Hotspots in arctic tundra wetlands.

- Prostrate tundra shrub - Wetland (CB-wet)
- Prostrate tundra shrub - Mesic (CB-mes)
- Erect tundra shrub (TVC)
- Open-crown coniferous boreal forest (HPC)
- Closed-crown coniferous boreal forest (MM)
- Closed-crown coniferous boreal forest (SOD-for)

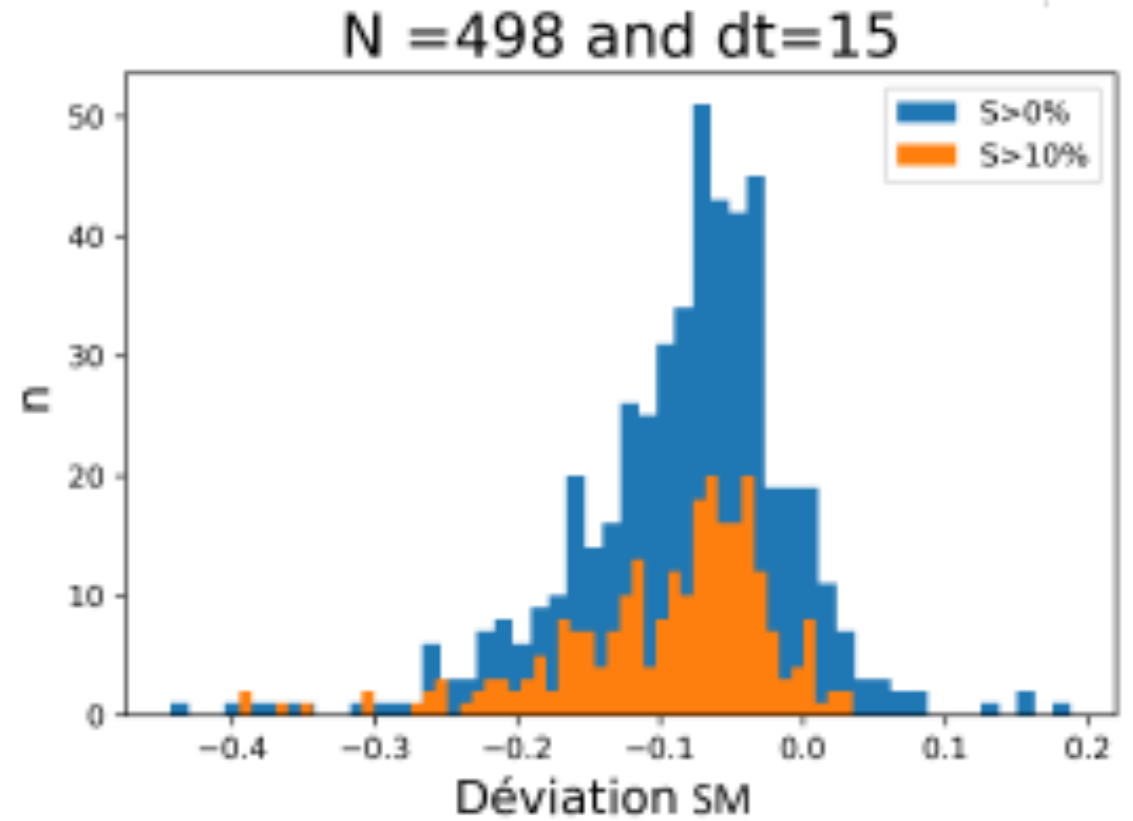


Snowpack diffusion gradient method

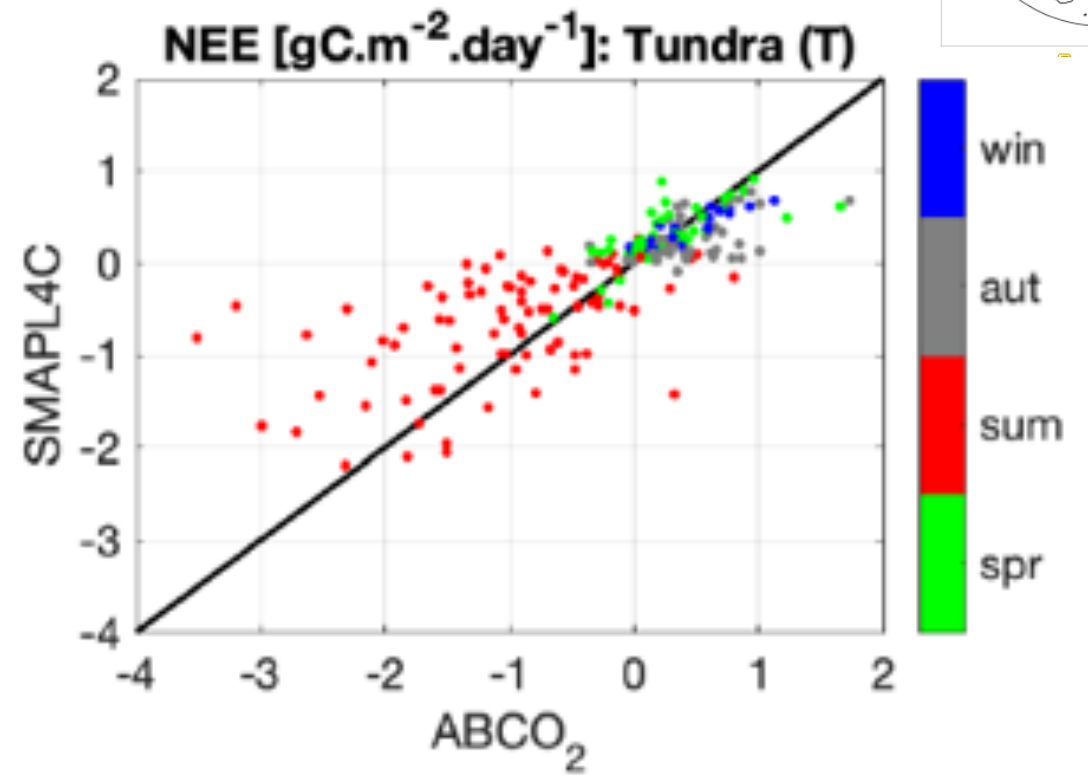
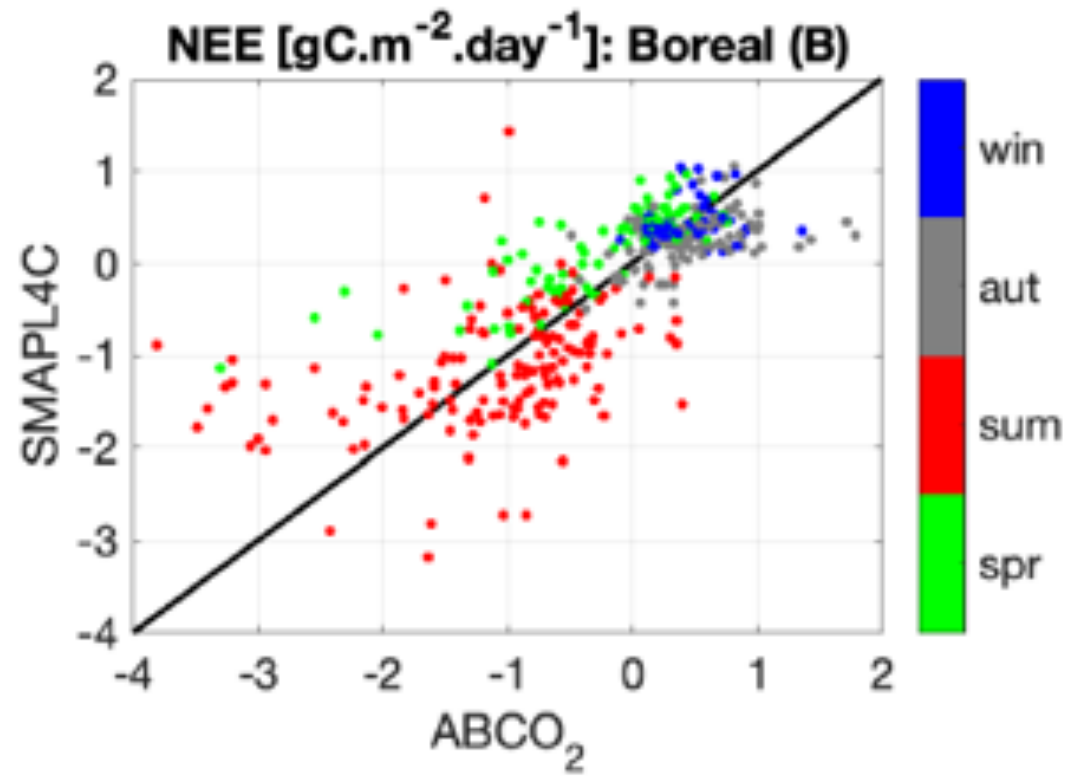
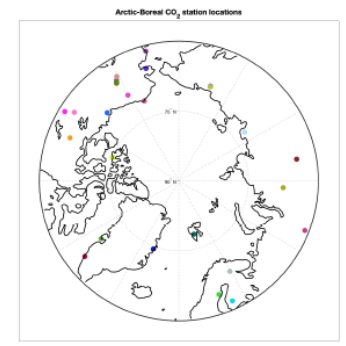


2023 Canada forest fire : 290 mégatonnes of carbon emitted to the atmosphere

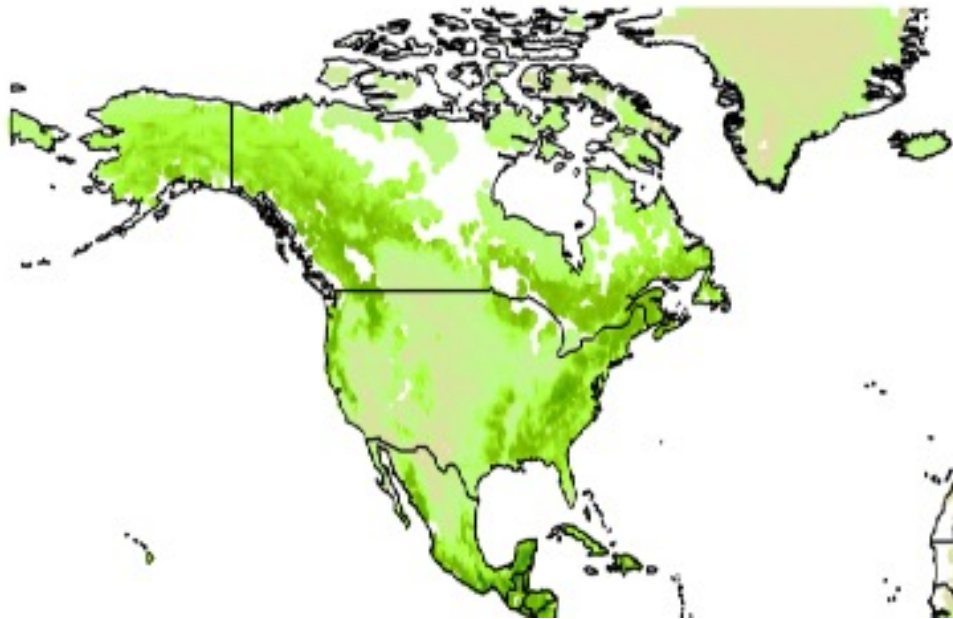
Northwest Territories : fires emitted 277x more carbon than citizens



The SMAPL4C product is very encouraging in northern regions
 (comparison with monthly ABCO₂ dataset)

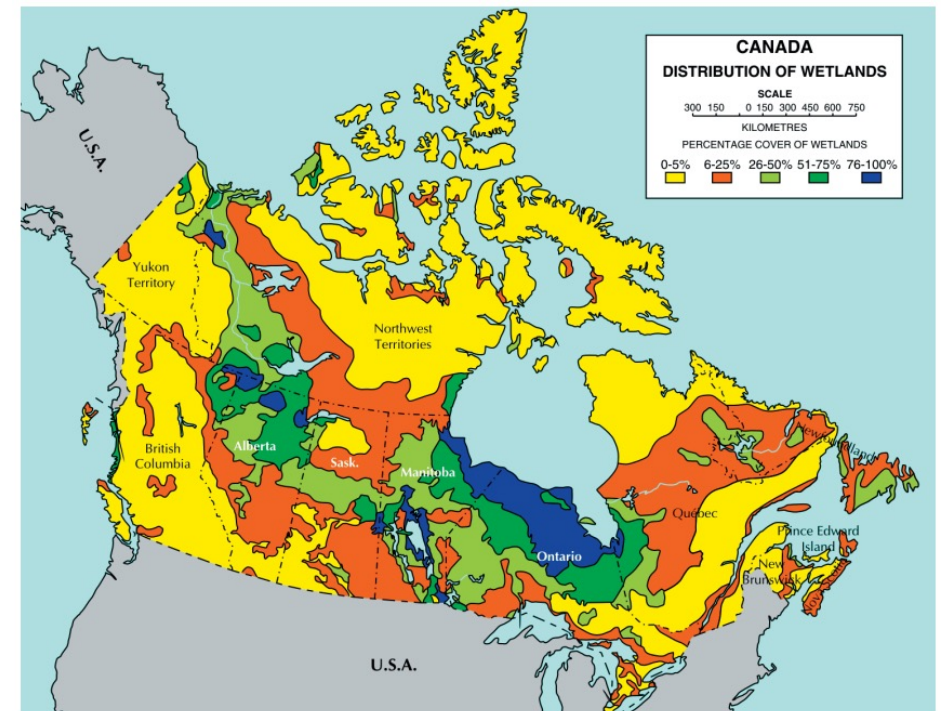


Strong spatial heterogeneity in Canadian Boreal forest :
 water bodies



Mialon et al. (2021)

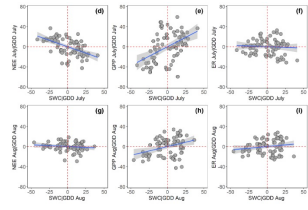
wetlands



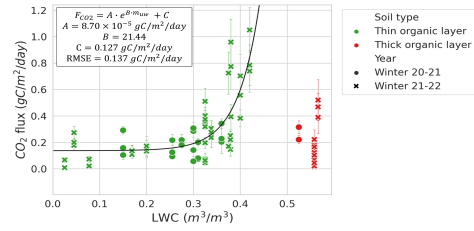
- Northern regions might play an important role in the climate system (high uncertainties)

- Carbon fluxes in Northern regions

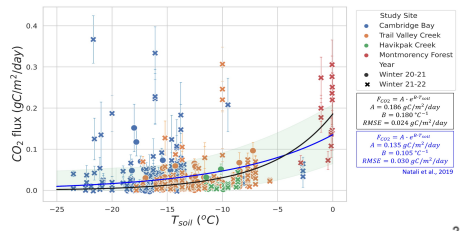
- Summer [f (T, water)]



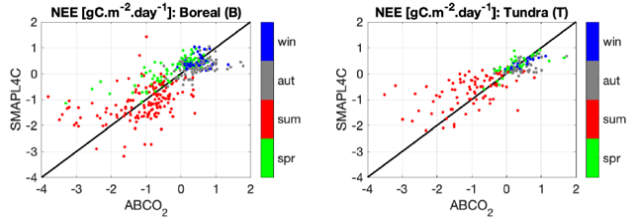
- Shoulder season : Freeze/thaw and beyond (zero-curtain)



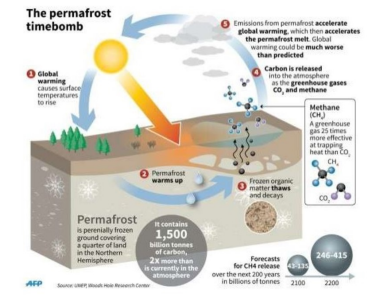
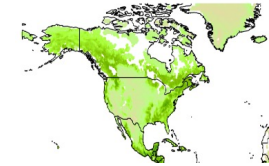
- Winter : soil temperature



- L-Band radiometry can provide valuable information



- 10 km L-Band radiometry to solve the spatial heterogeneity (still to be proven)



Thanks for your attention

