A thawing boreal peat landscape along the southern limit of permafrost presently is carbon neutral

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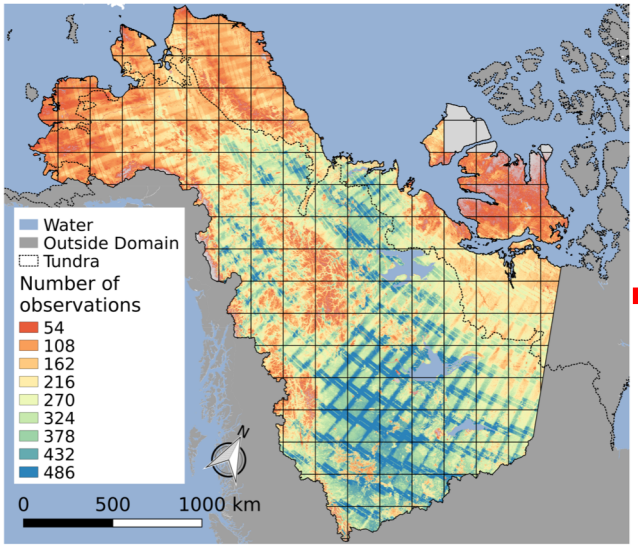
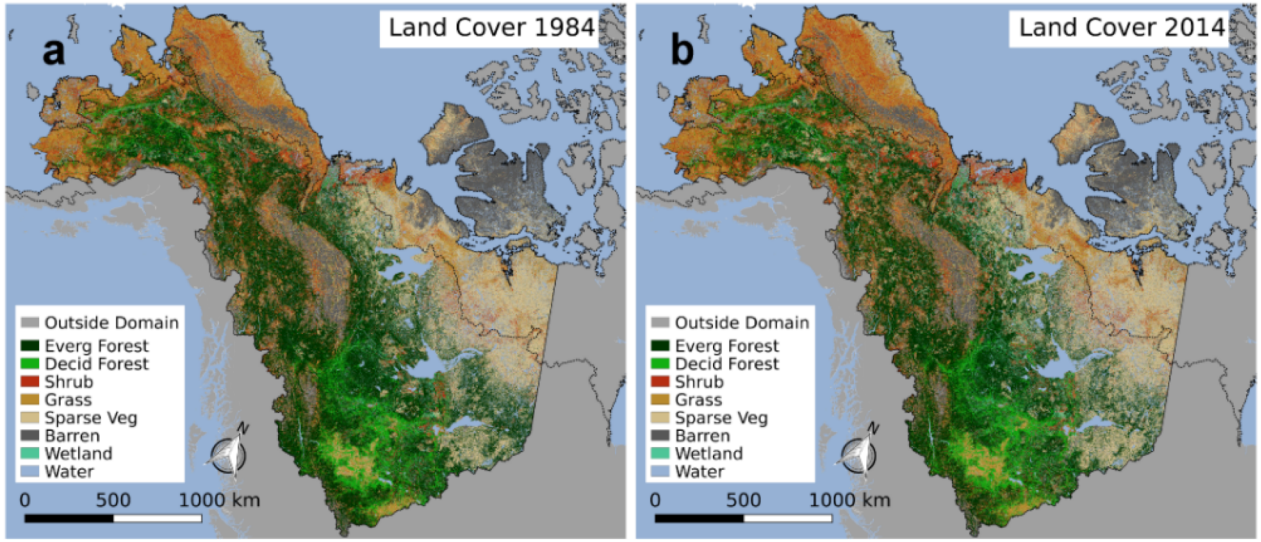
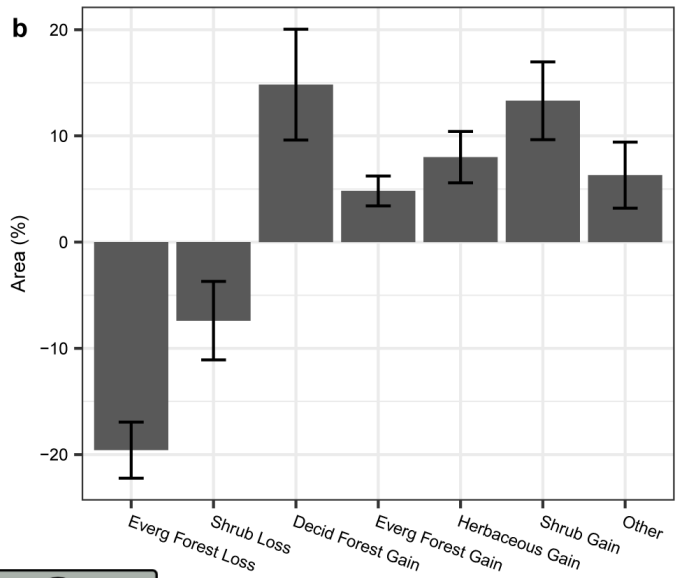
2 NW North America's Arctic-Boreal Region





Two major « modes » of land cover change across NW Canada (1984 – 2015):



- **Boreal biome**: simultaneous decrease/ increase in evergreen deciduous forest
- **Arctic biome**: expansion of of herbaceous vegetation and woody shrubs

(Wang et al., 2020, *Global Change Biology*)

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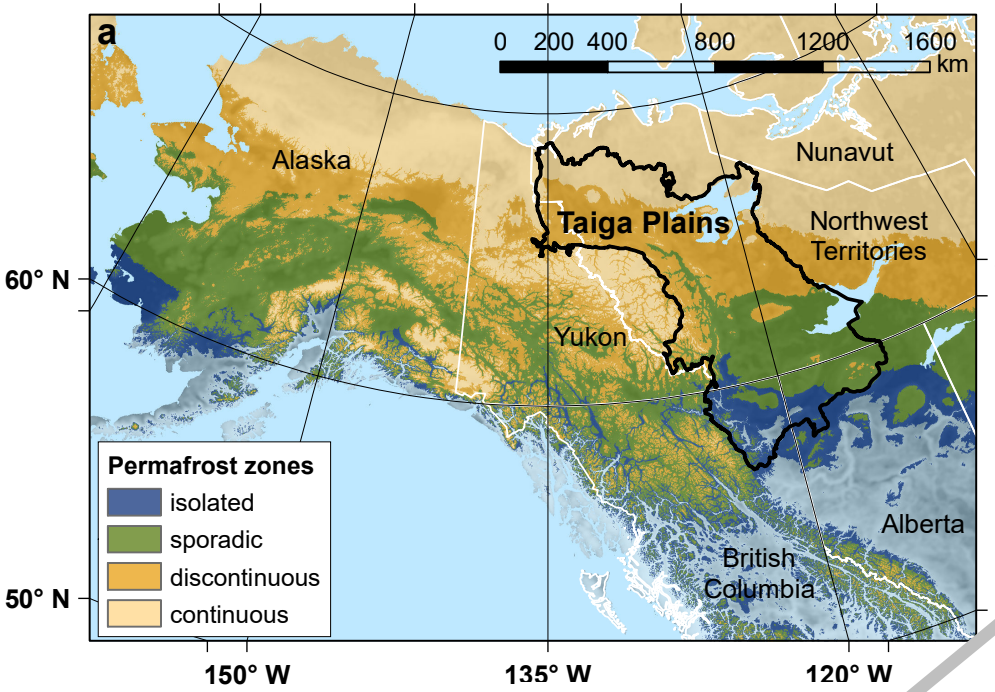
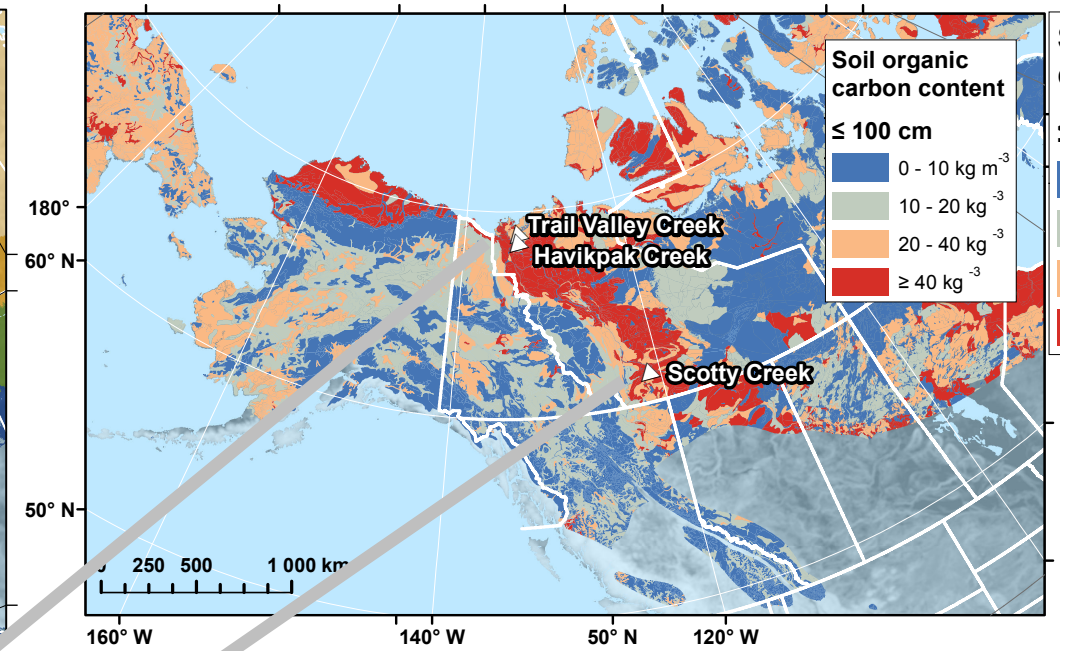
3 Taiga Plains ecozone: high soil organic C



(Gruber, 2012, *The Cryosphere*)



(Hugelius et al., 2013, *Earth System Science Data*)

e.g., Havikpak Creek/ Trail Valley Creek: boreal forest – (Arctic) tundra

e.g., Scotty Creek: boreal forest – wetlands

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4 Permafrost thaw

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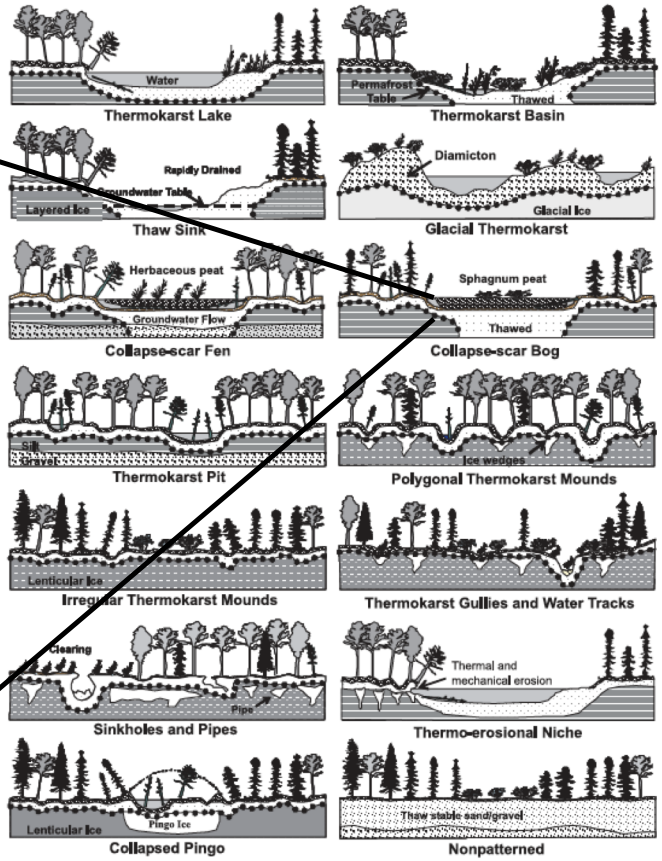
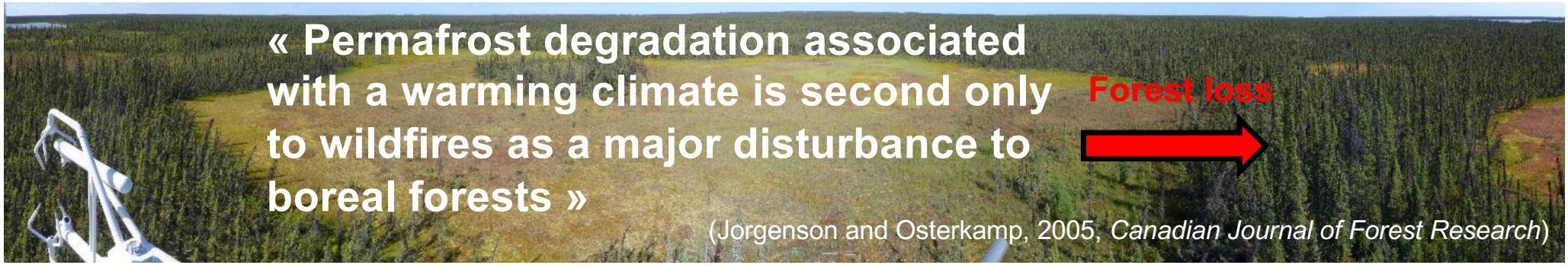
Thermokarst landforms along the southern limit of permafrost: Scotty Creek



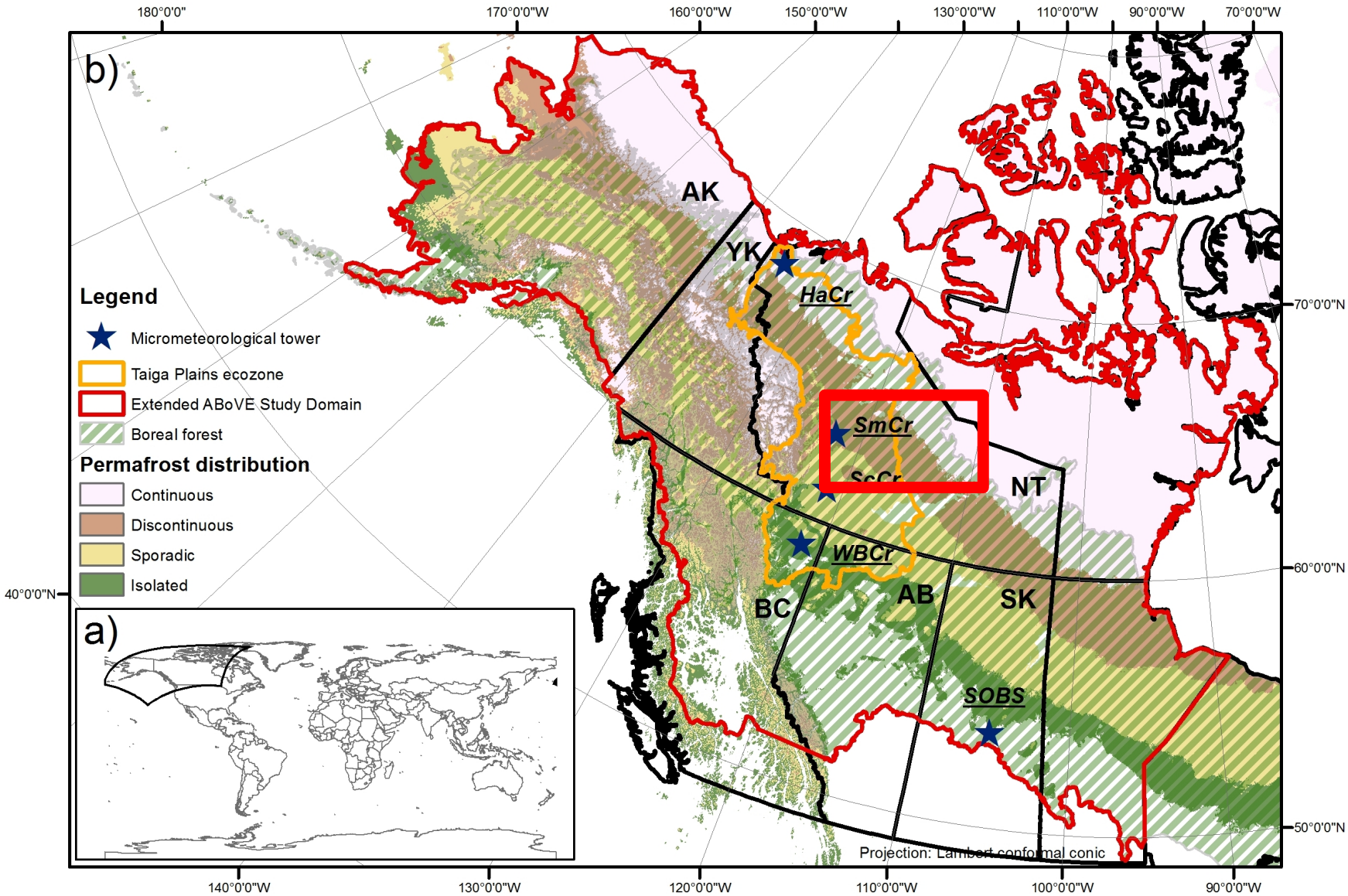


« Permafrost degradation associated with a warming climate is second only to wildfires as a major disturbance to boreal forests »

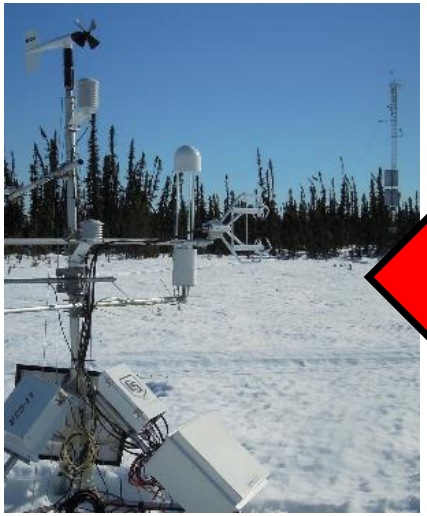
Forest loss

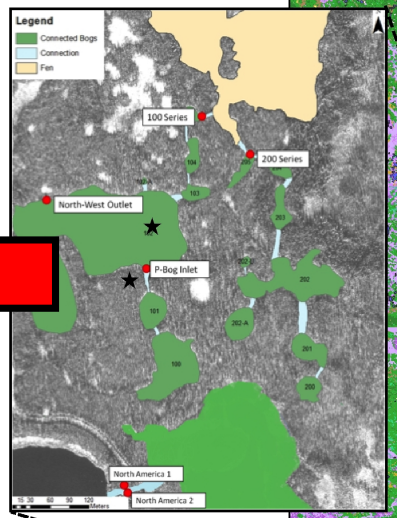
(Jorgenson and Osterkamp, 2005, *Canadian Journal of Forest Research*)

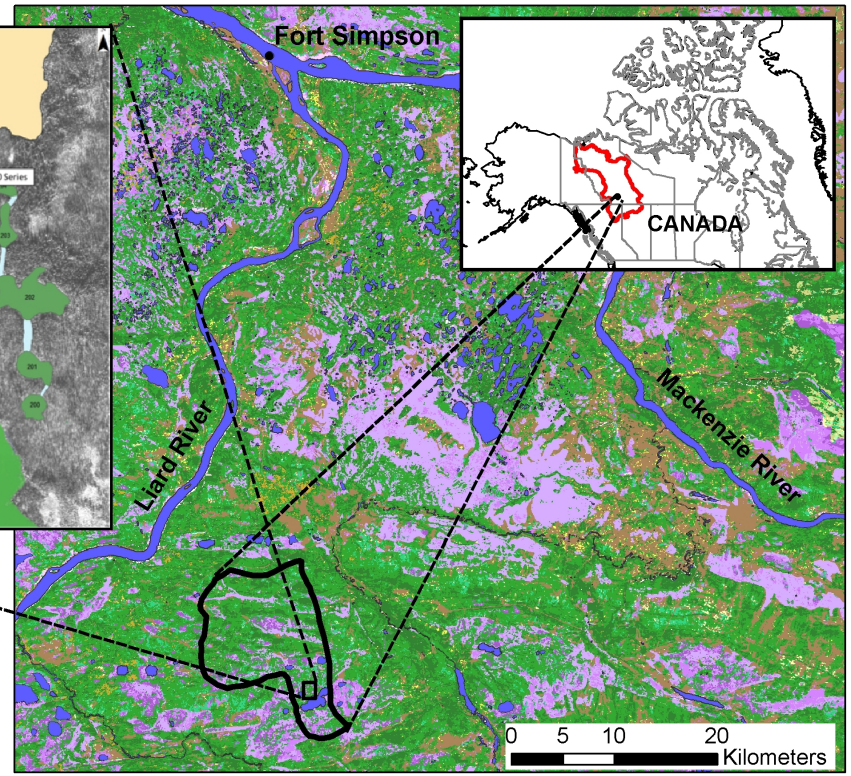
5 Taiga Plains ecozone: permafrost



6 Scotty Creek basin







NAD83 UTM Zone 10N; Natural Resources Canada - Centre for Topographic Information (2009)

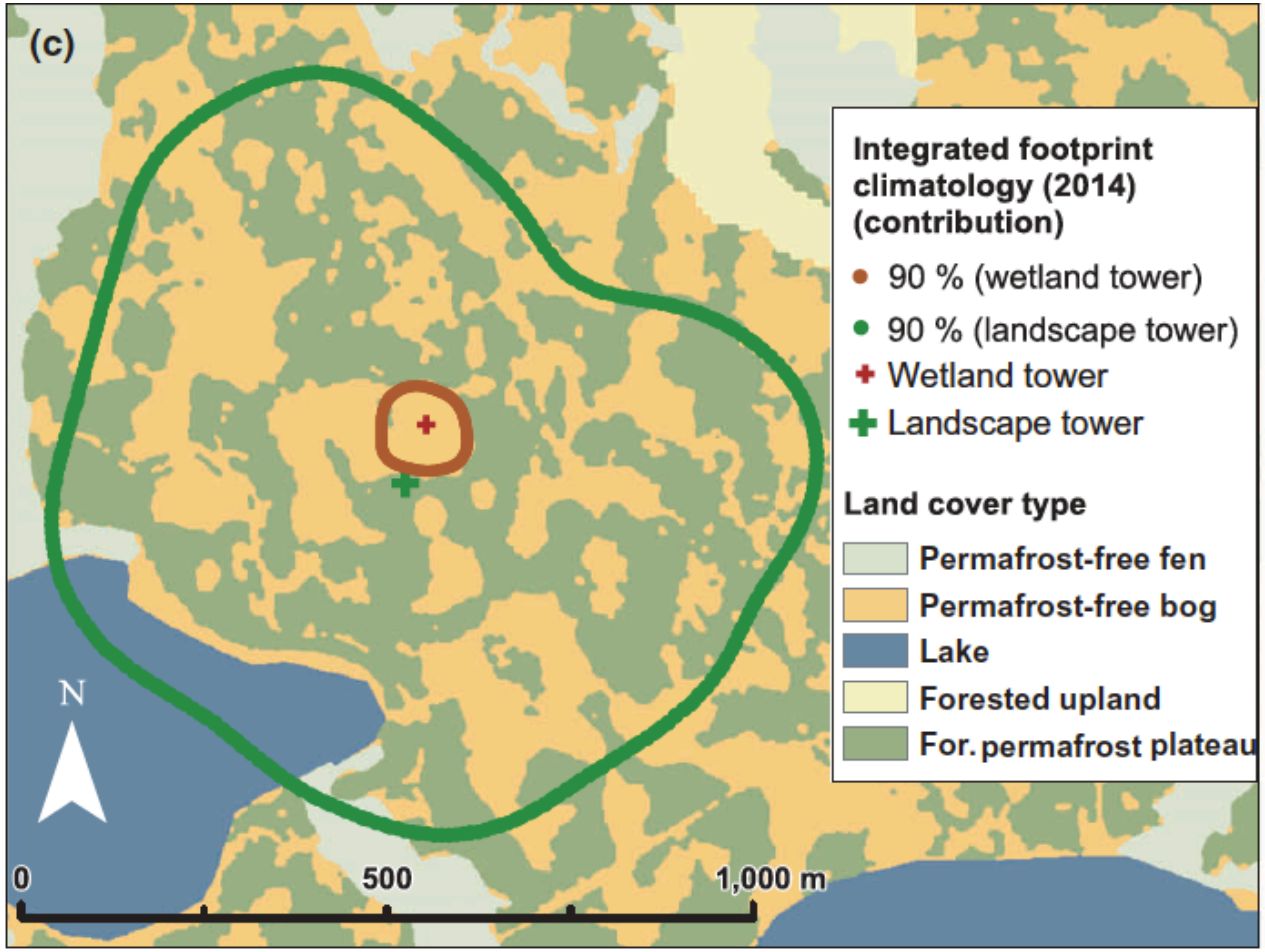
Nested eddy covariance systems (CO_2, CH_4, LE, H):

15 m (landscape-scale): boreal forest-wetland

1.9 m (ecosystem-scale): collapse-scar bog

Headwater portion of ca. 152 km^2-basin: forested peat plateaus with permafrost (38%), and permafrost-free wetlands (bogs [27%] & fens [26%]) and lakes (9%)

7 Nested eddy covariance systems



- Collapse-scar wetland (wetland footprint)
- Landscape (boreal forest-wetland footprint)

(Helbig et al., 2016a, *Global Change Biology*)

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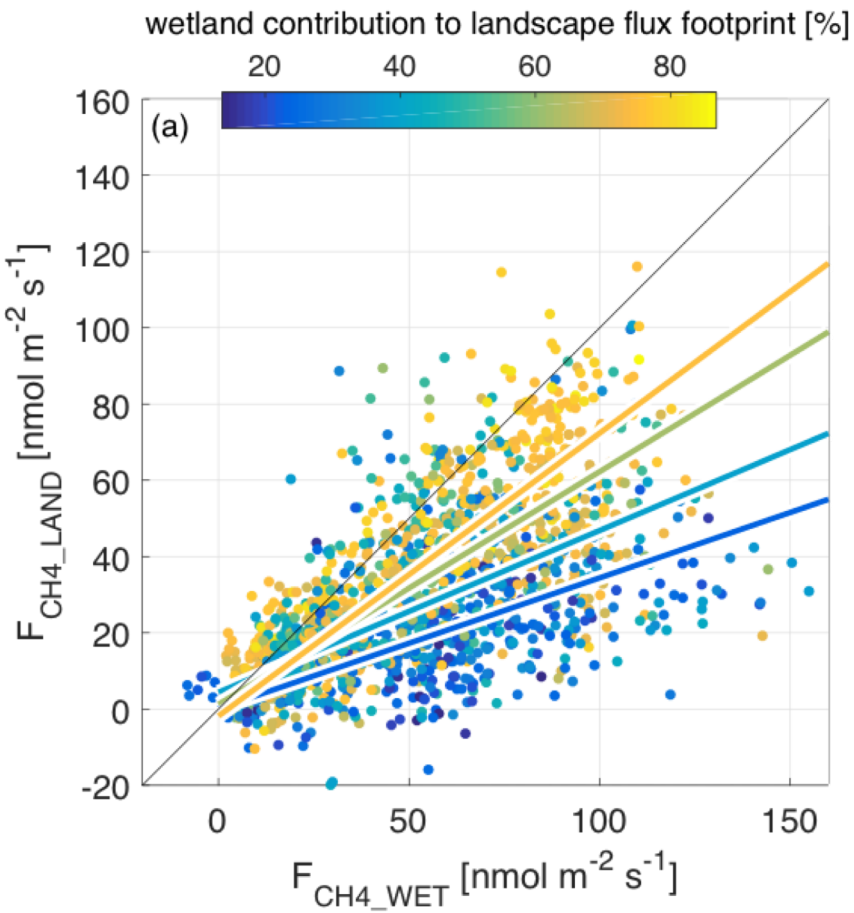
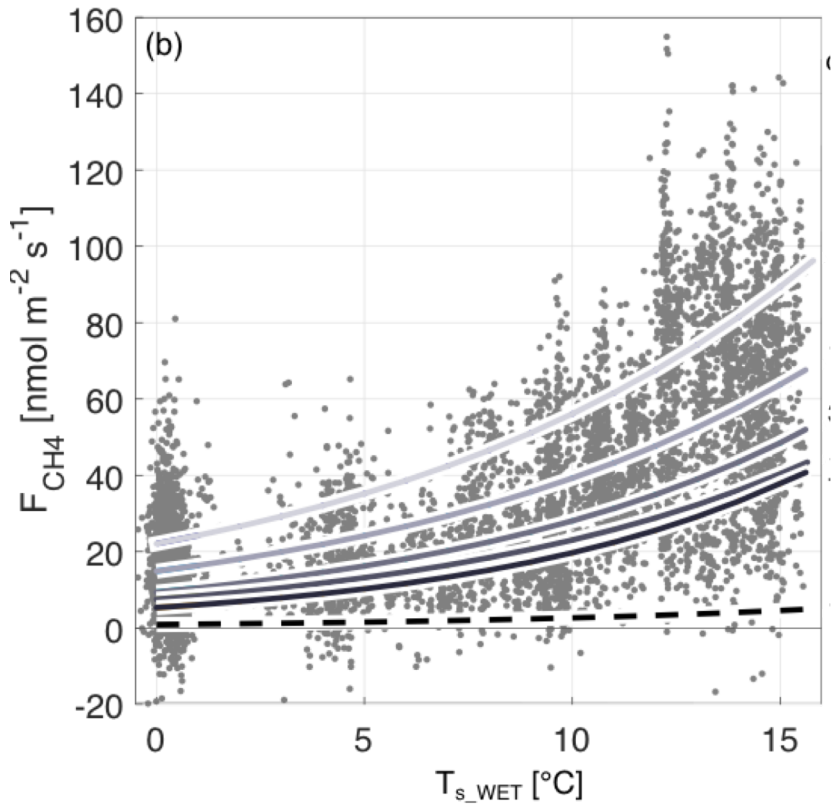
8 Thaw-induced change in methane emissions





- Net landscape methane fluxes (F_{CH4}) increase with permafrost-free wetland extent
- Temperature-sensitivity of F_{CH4} increases with wetland extent
- Higher/earlier peak F_{CH4} in years with warmer spring: 20-25% increase in growing season and annual $\sum F_{CH4}$

(Helbig et al., 2016b, *Global Change Biology*)

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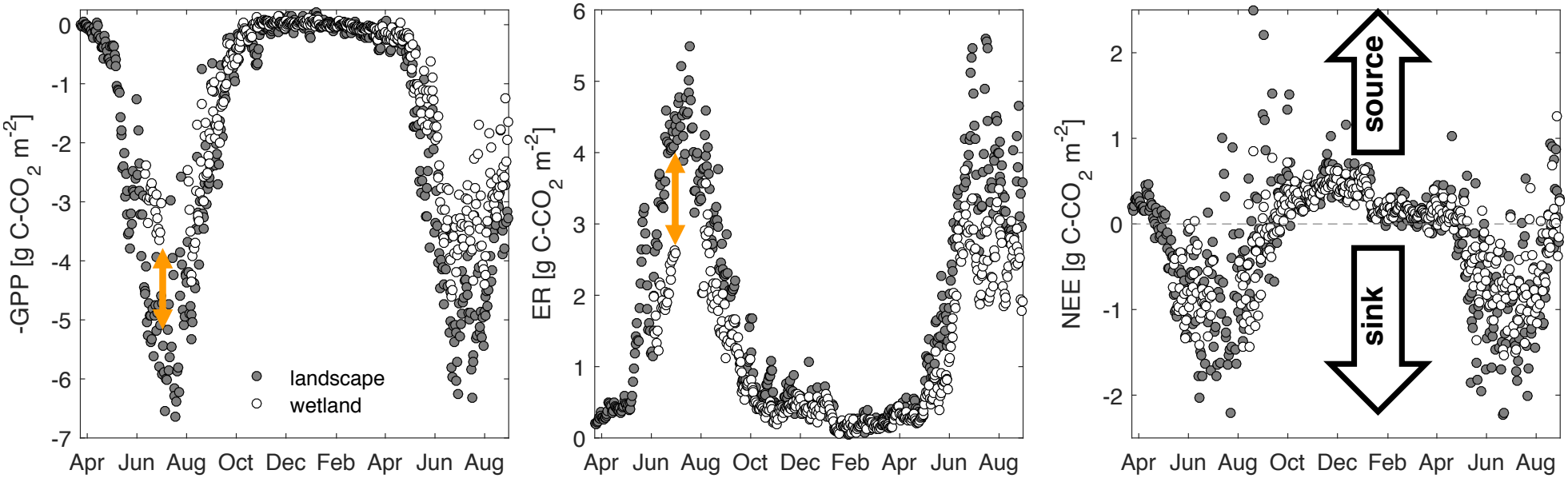
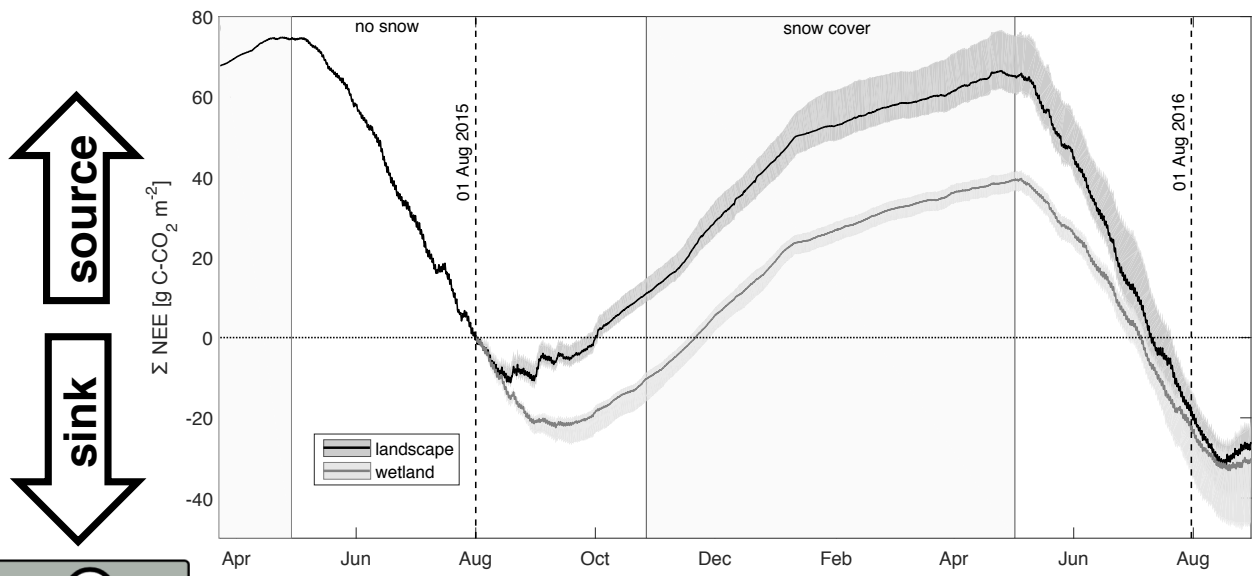
Net ecosystem CO_2 exchange (NEE)

-Gross primary productivity + Ecosystem respiration = Net ecosystem exchange





landscape NEE
≈
wetland NEE

(Helbig et al., 2017, *Global Change Biology*; Sonnentag et al., *in prep.*)

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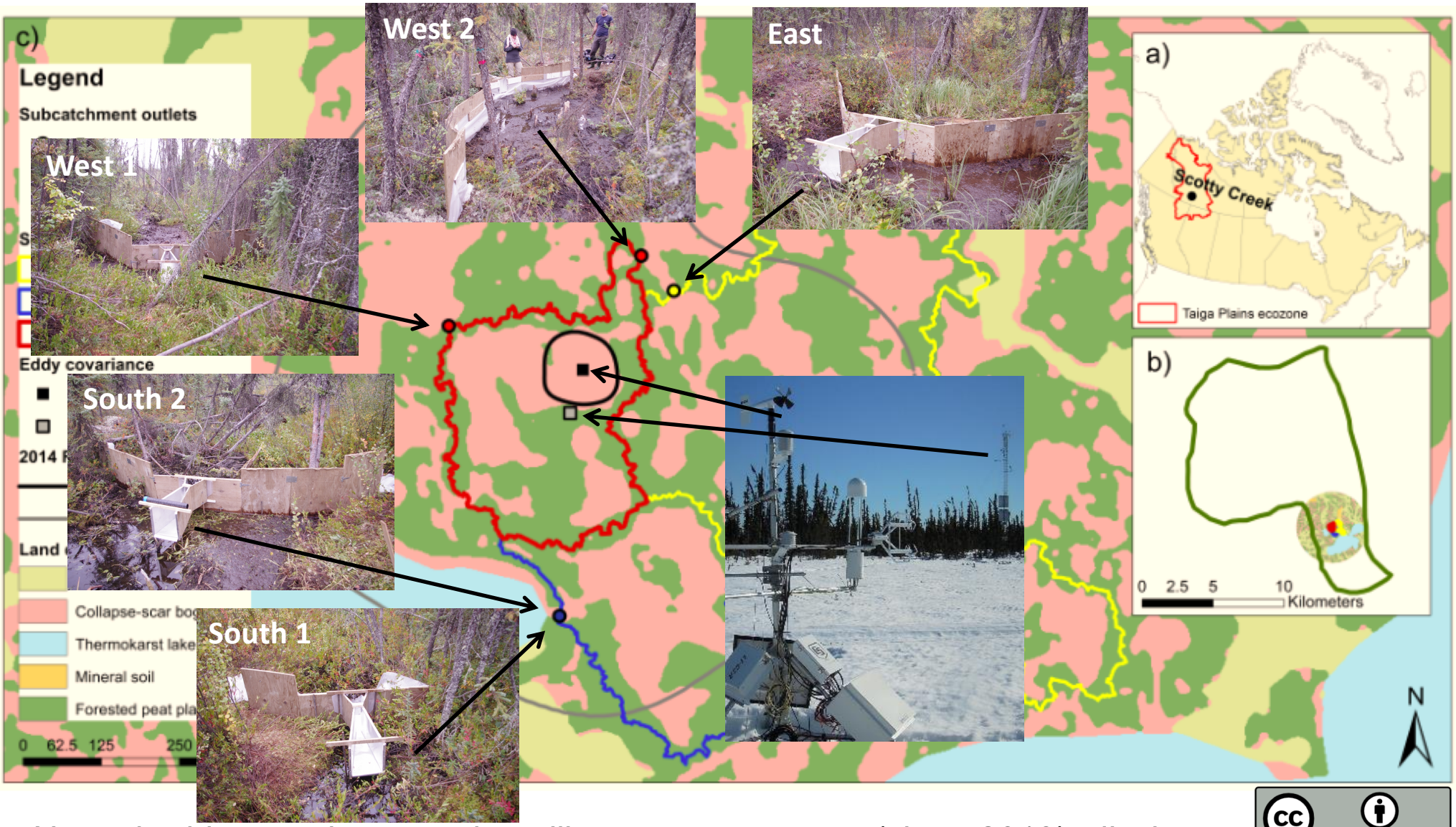
10 Runoff and water chemistry monitoring



Nested eddy covariance and ancillary measurements (since 2013), discharge (2014 – 2016) and water sampling (2015 & 2016) from three gauged catchments (0.1 – 0.3 km^2) draining the eddy covariance footprint.

(Sonnentag et al., *in prep.*)

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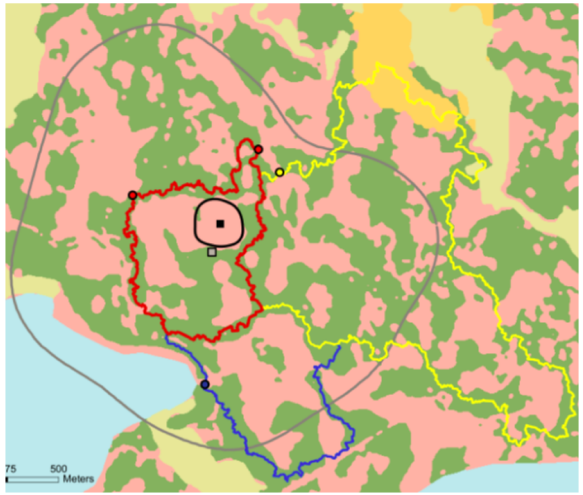
11 Catchment hydrology

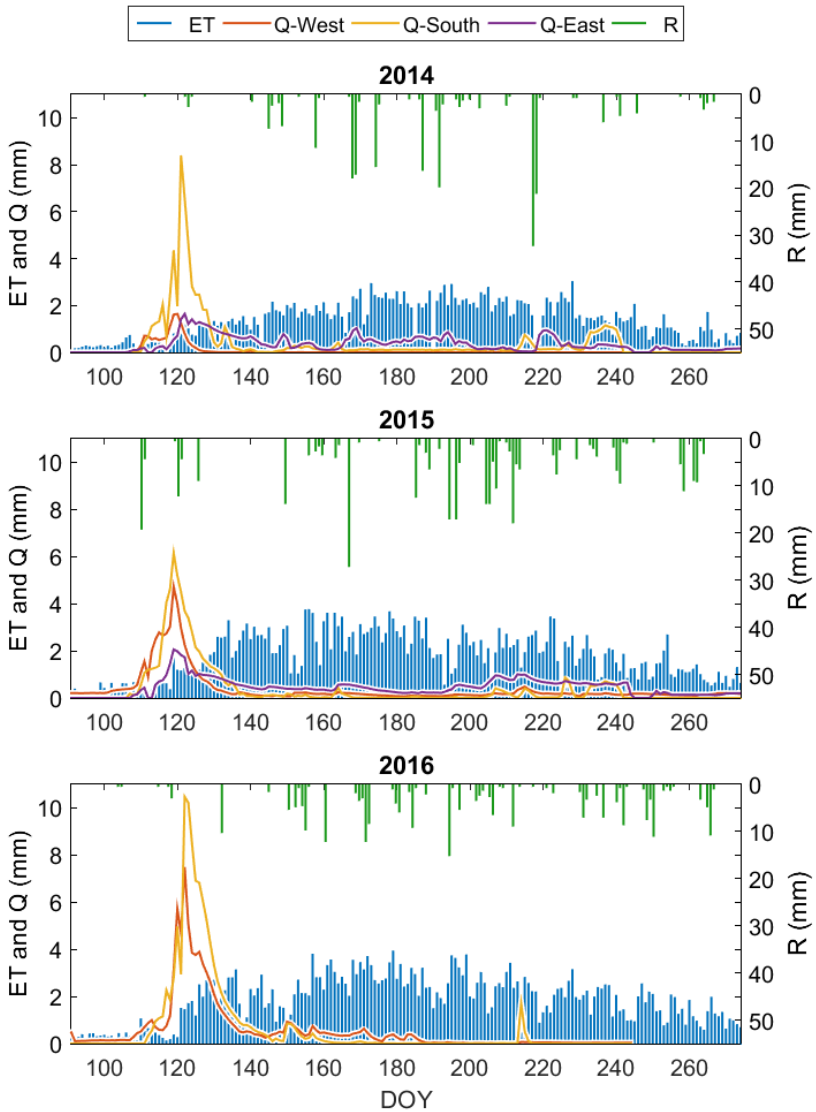


Wetland-to-forest ratio:

« East »: 0.84

« West »: 1.06

« South »: 1.24



Warmer, drier (cooler spring)

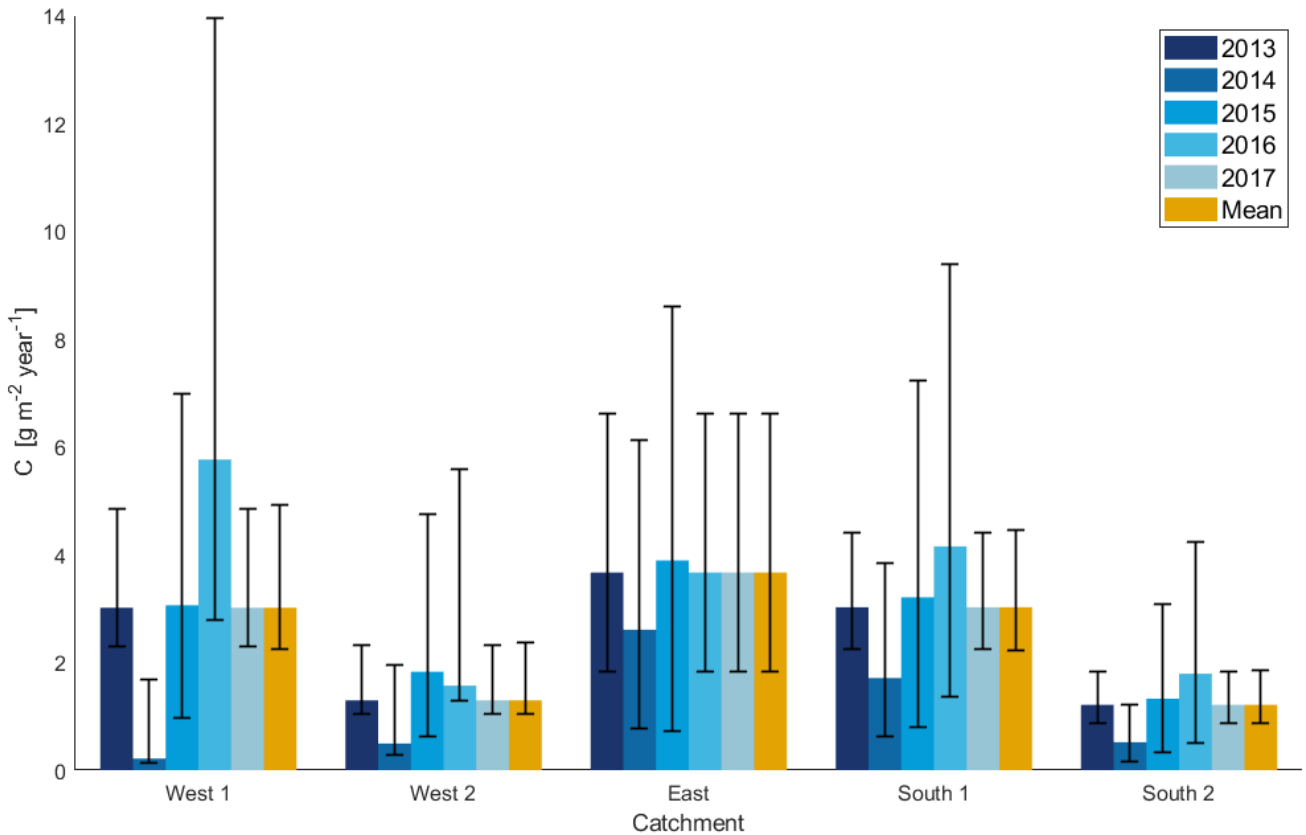
Warmer, wetter (warmer spring)

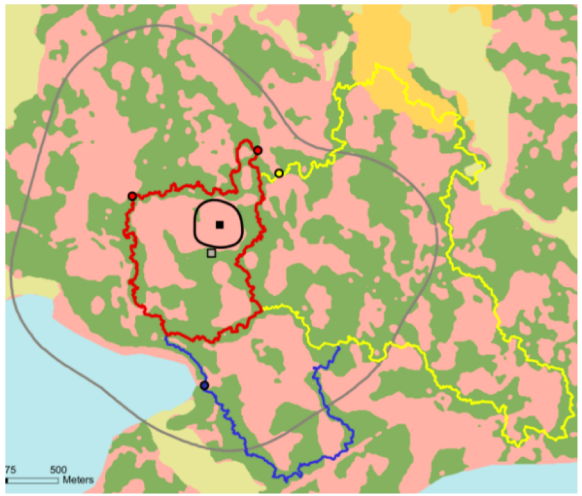
Warmer, drier (warmer spring)

Spring freshet dominates hydrograph (timing, Q); differences in growing season rainfall (R) timing, magnitude and intensity among years.

(Sonnentag et al., *in prep.*)

12 Dissolved carbon export ($\sum F_{DIC_DOC}$)





Wetland-to-forest ratio:

« East »: 0.84

« West »: 1.06

« South »: 1.24

During spring freshet:

- **Antecedent snow cover, thaw front depth and wetland moisture control $\sum F_{DC_ex}$**

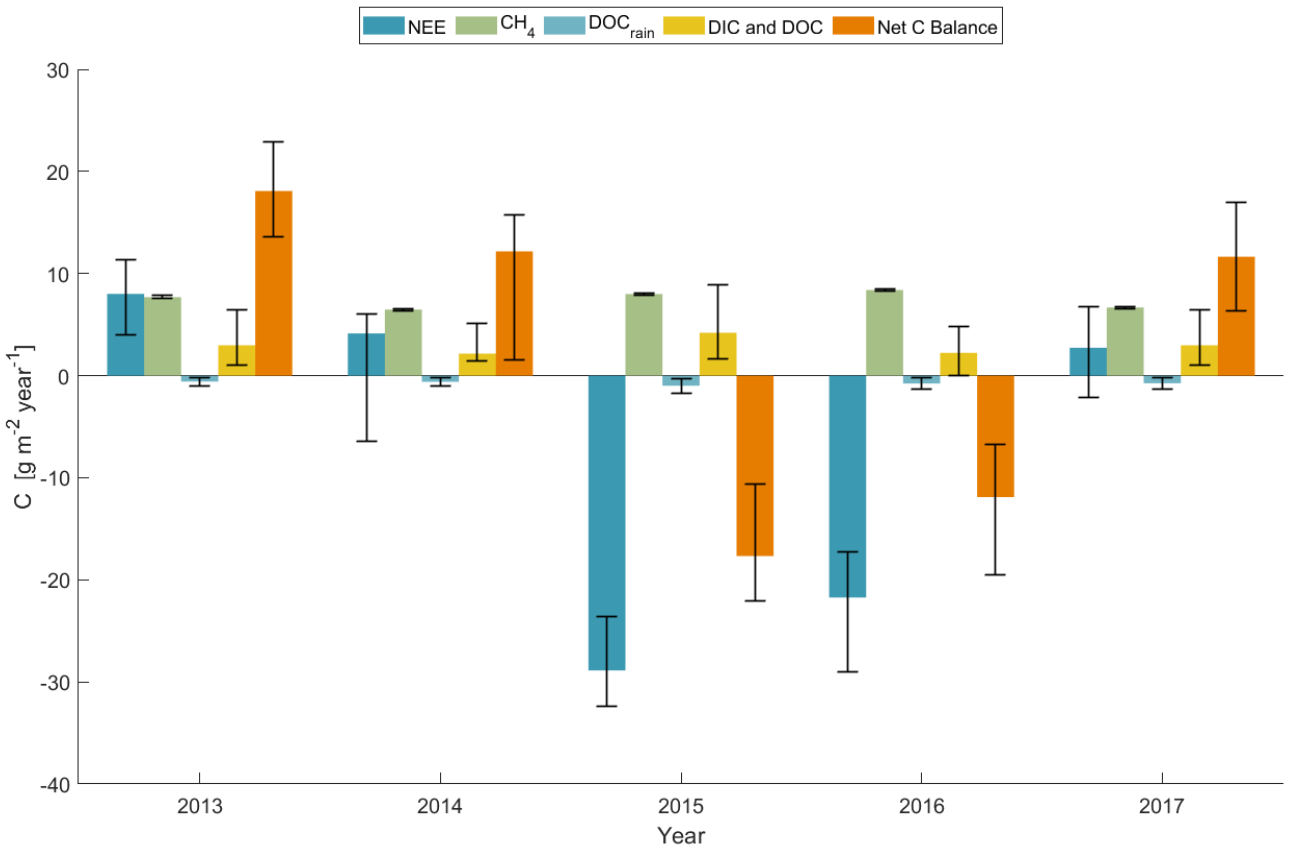
During summer:

- **Hydrological connectivity may control DOC supply to outlets**

(Sonnentag et al., *in prep.*)

13 Net ecosystem carbon balance (NECB)

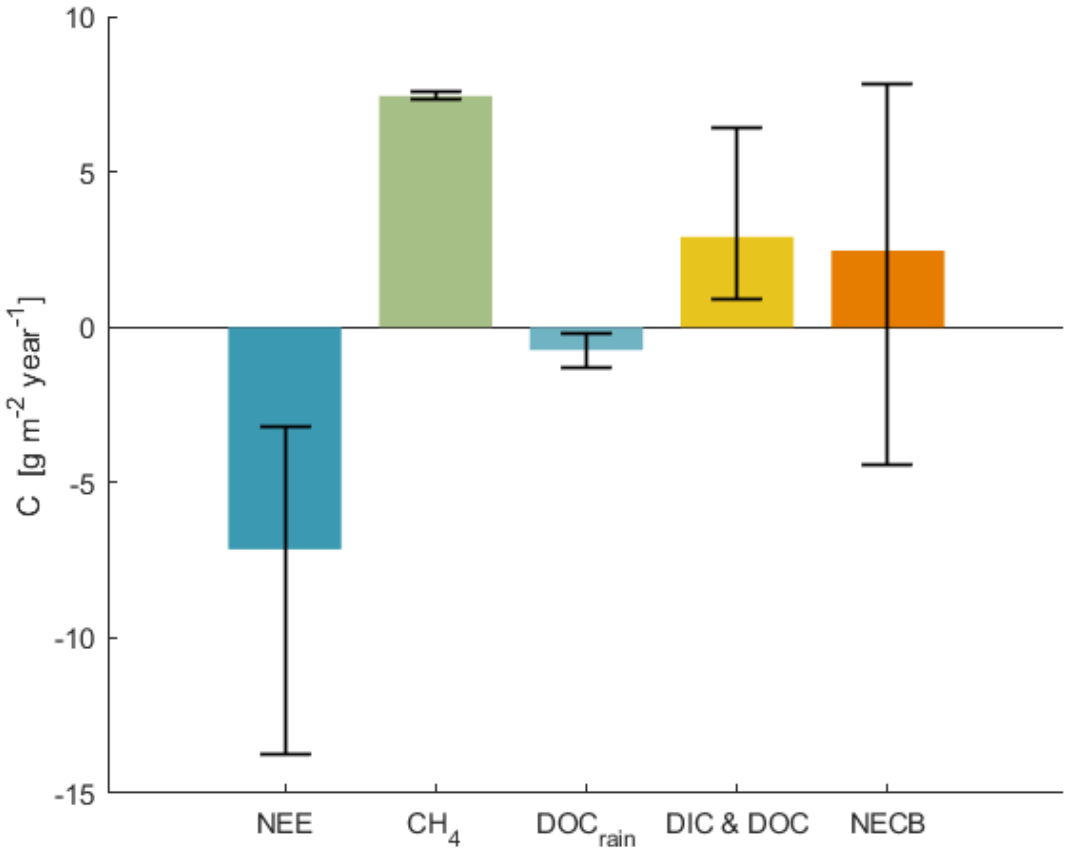
$$\mathbf{NECB} = \sum \mathbf{NEE} + \sum \mathbf{F_{DOC_rain}} - \sum \mathbf{F_{CH4}} - \sum \mathbf{F_{DIC_DOC}}$$



- Between-year differences in NECB are largely controlled by differences in net ecosystem CO_2 exchange (NEE) as controlled by weather.
- Wetter years have higher net CO_2 uptake (see Frolking, 1997) thus increased C-sink strength?

(Sonnentag et al., *in prep.*)

14 Five-year net ecosystem carbon balance



Boreal bog:

-21.5 ± 39.0 g C m^{-2} y^{-1} (six years)

Boreal fen:

-27.0 (2004) and -20.0 g C m^{-2} y^{-1} (2005)

Atlantic blanket bog:

-29.7 ± 30.6 g C m^{-2} y^{-1} (six years)

Ombrotrophic peatland:

-38.2 (2007) and -101.0 g C m^{-2} y^{-1} (2008)

Palsa mire:

-55.8 (2008) and -33.0 g C m^{-2} y^{-1} (2009)

Southern Hemisphere bog:

-176.3 ± 20.1 g C m^{-2} y^{-1} (four years)

A thawing boreal peat landscape along the southern limit of permafrost presently is carbon neutral.

(Goodrich et al., 2017, *Biogeosciences*; Koehler et al., 2011, *Global Change Biology*; Nilsson et al., 2008, *JGR-Biogeosciences*; Olefeldt et al., 2012, *Geophysical Research Letters*; Roulet et al., 2007, *Global Change Biology*; Sonnentag et al., *in prep.*)