Using a nested flux tower approach and footprint modelling over a heterogeneous boreal forest-peatland landscape with discontinuous permafrost

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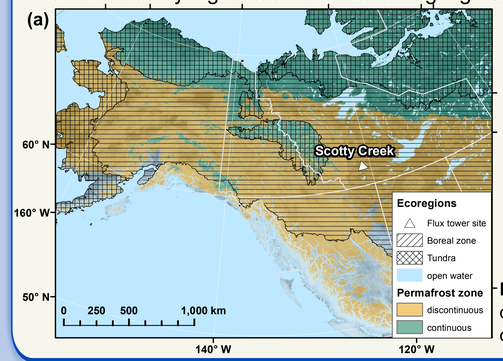
Scotty Creek watershed - a boreal forest-peatland landscape

The Scotty Creek watershed (61°18' N, 121°18'W) is located in the Taiga Plains ecoregions within the discontinuous permafrost zone. Mean annual air temperature is -2.8 °C and mean annual precipitation is 388 mm of which about 50 % falls as snow. Forested peat plateaus are underlain by permafrost and are dominated by black spruce with a mean canopy height of 7-8 m. The ground cover is mainly lichen and mosses. Permafrost-free bogs are treeless and dominated by *Sphagnum* mosses and low-stature shrubs. These peatlands are characterised by high water levels ensuring high surface soil moisture conditions.



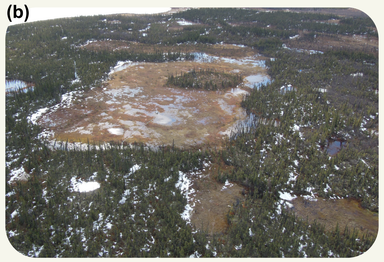
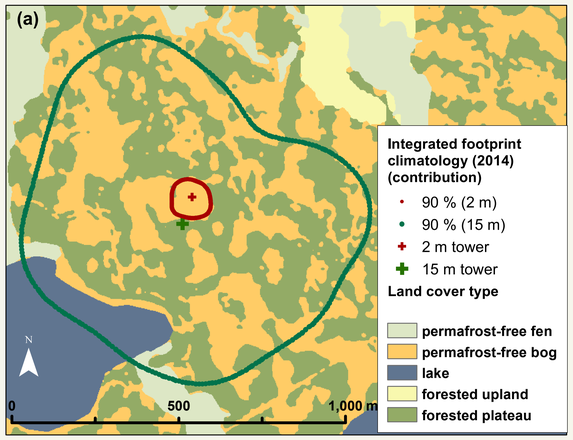


Fig. 1: **(a)** Permafrost distribution and ecoregions of North America (data from [1] & [2]) and location of the study site. **(b)** Aerial picture pf the study site.

The nested flux tower approach - How to deal with spatial heterogeneity?

Direct eddy covariance measurements of boreal forest fluxes are not feasible in such a heterogeneous landscape due to small forest patch sizes. A 15-m flux tower measures fluxes of CO_2, CH_4, and energy with varying footprint contributions from forests, permafrost-free bogs, and a lake. Low canopies of permafrost-free bogs allow a reduced measurement height resulting in small flux footprints, mainly lying within the bog boundaries. Relative contributions from land cover types within the flux source areas were derived from a 2-D footprint model (based on [3]) coupled to high resolution LIDAR data and a land cover classification map ([4]). A combination of a CSAT3A & EC150 (Campbell Scientific) and a LI-7700 (LI-COR Biosciences) was used at both towers.

Research question: How can we best resolve the spatial variability of fluxes of CO_2, CH_4, and energy and its drivers across a landscape affected by permafrost degradation?



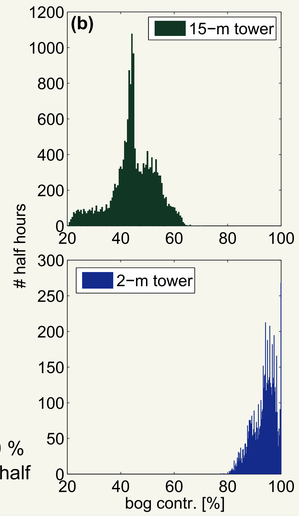


Fig. 2: (a) Land cover types in the vicinity of the flux towers and 90 % footprint extents. **(b)** Contribution of permafrost-free bogs to half hourly fluxes at the 15-m tower and at the nested 2-m tower.

Scaling of energy fluxes: from the ecosystem to the landscape

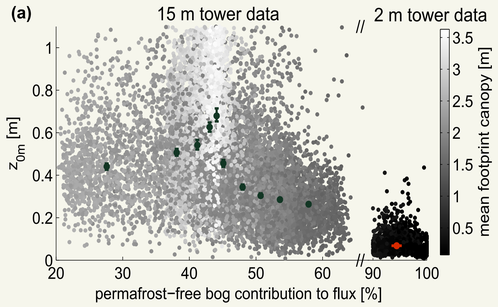
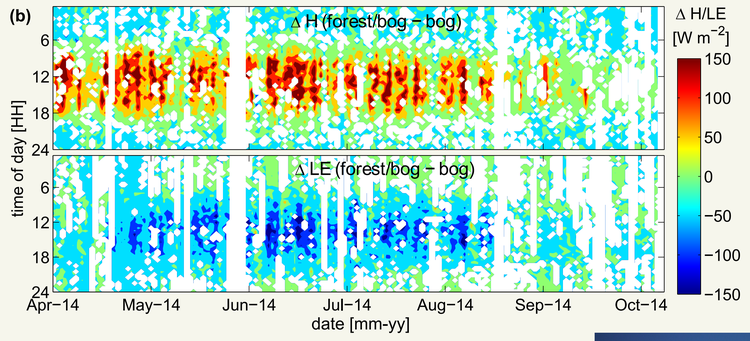
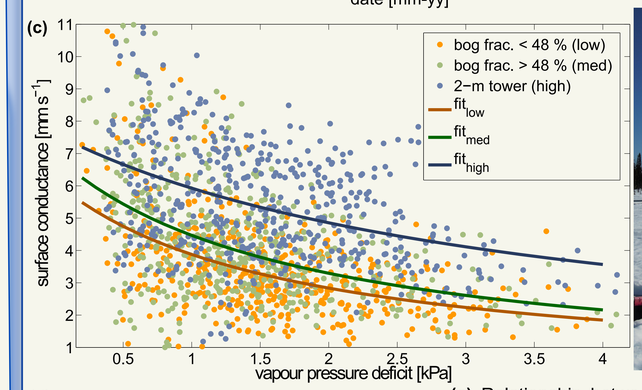
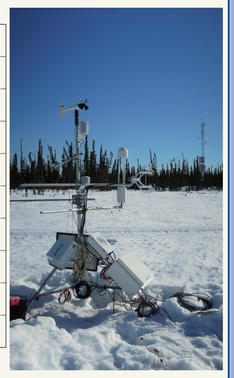
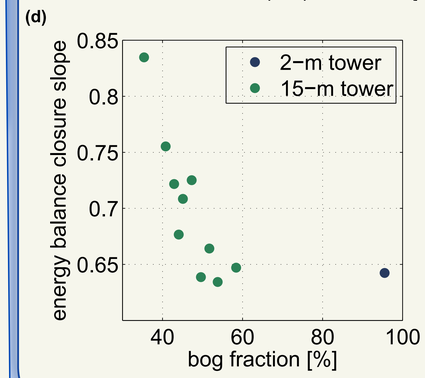


Fig. 3: (a) The influence of increased permafrost-free bog coverage on the momentum roughness length (z_{0m}). z_{0m} was iteratively derived using a Monin-Obukhov similarity framework. **(b)** Differences in sensible (H) & latent heat (LE) fluxes over a mix of forests & bogs (landscape) and over a single bog.









(c) Relationship between surface conductance (g_s) and vapour pressure deficit (*VPD*) for footprints with varying permafrost-free bog contribution. Surface conductance was derived using a simple bulk surface model. The data was fitted to vapour pressure deficit using the following formula:

$$g_s = \frac{g_{s,max}}{1+b_d\ VPD}$$

where $g_{c,\ max}$ are best fit parameter.

(d) Slopes of turbulent energy (H + LE) against available energy (net radiation - soil heat flux - heat storage in the air) for binned data according to footprint contributions at the 15-m tower. Available energy for the 15-m tower was calculated as weighted average using footprint contributions as weights.

Locating sources of CH_4 emissions: the role of degrading permafrost

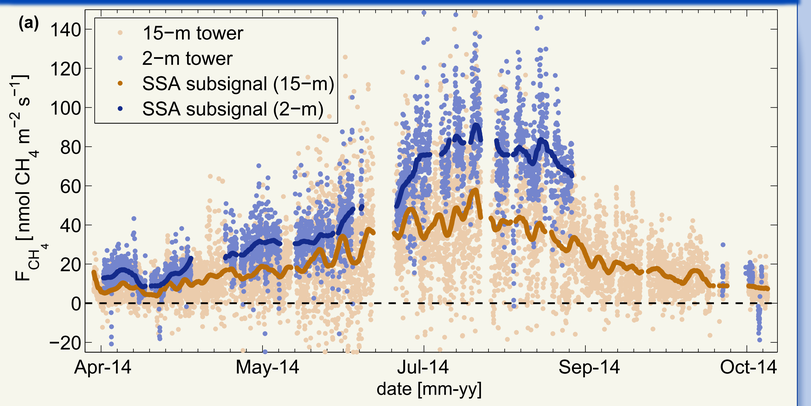
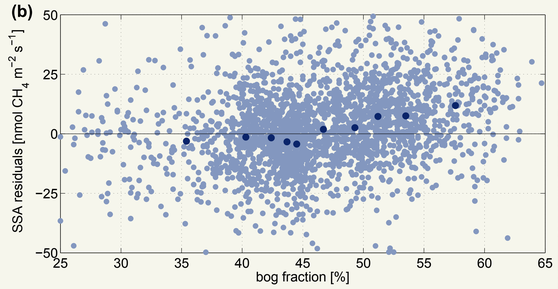
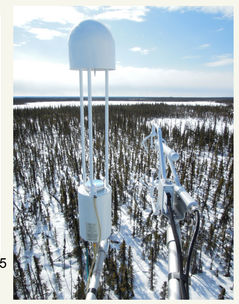


Fig. 4: (a) Growing season landscape (15-m tower) and permafrost-free bog (2-m tower) methane fluxes (F_{CH_4}) at the Scotty Creek watershed. The 30 min time series was decomposed into a slow (~2 days) and a fast component using singular spectrum analysis (SSA). (b) Relationship between residuals of the SSA decomposition of the landscape methand flux time series and contribution of permafrost-free bogs to the 30 min flux estimate. Only half hours with high quality flux data, less than 10 % contribution of the lake, and air temperatures above 15 C are shown.





Conclusions

- Eddy covariance flux measurements over **spatially heterogeneous** terrain contain both **temporal** and **spatial information**

- A **footprint modelling** approach allows the extraction of some of the spatial information, but might be limited by a **constrained** range of **footprint composition**

- A **nested tower** approach **extends** this range and enables detailled analyses of a **specific land cover type** within the landscape

- Nested tower data can be used to **cross-validate** footprint modelling results

- This approach works best if the **spatial variability** of the turbulent fluxes is **large**

References

[1] D. Olson et al., *BioSci.* 51, 933-938 (2001). [2] S. Gruber, *Cryos.* 6, 221-233 (2012).
[3] N. Kljun et al., *Bound.-Layer Meteor.* 112, 503-523 (2004). [4] L. Chasmer et al., *RSE* 143, 73-84 (2014)

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