Using a Flux Footprint Model and Airborne LiDAR to Characterize Vegetation Structure and Topography Frequently Sampled by Eddy Covariance: Implications for MODIS GPP and Scaling

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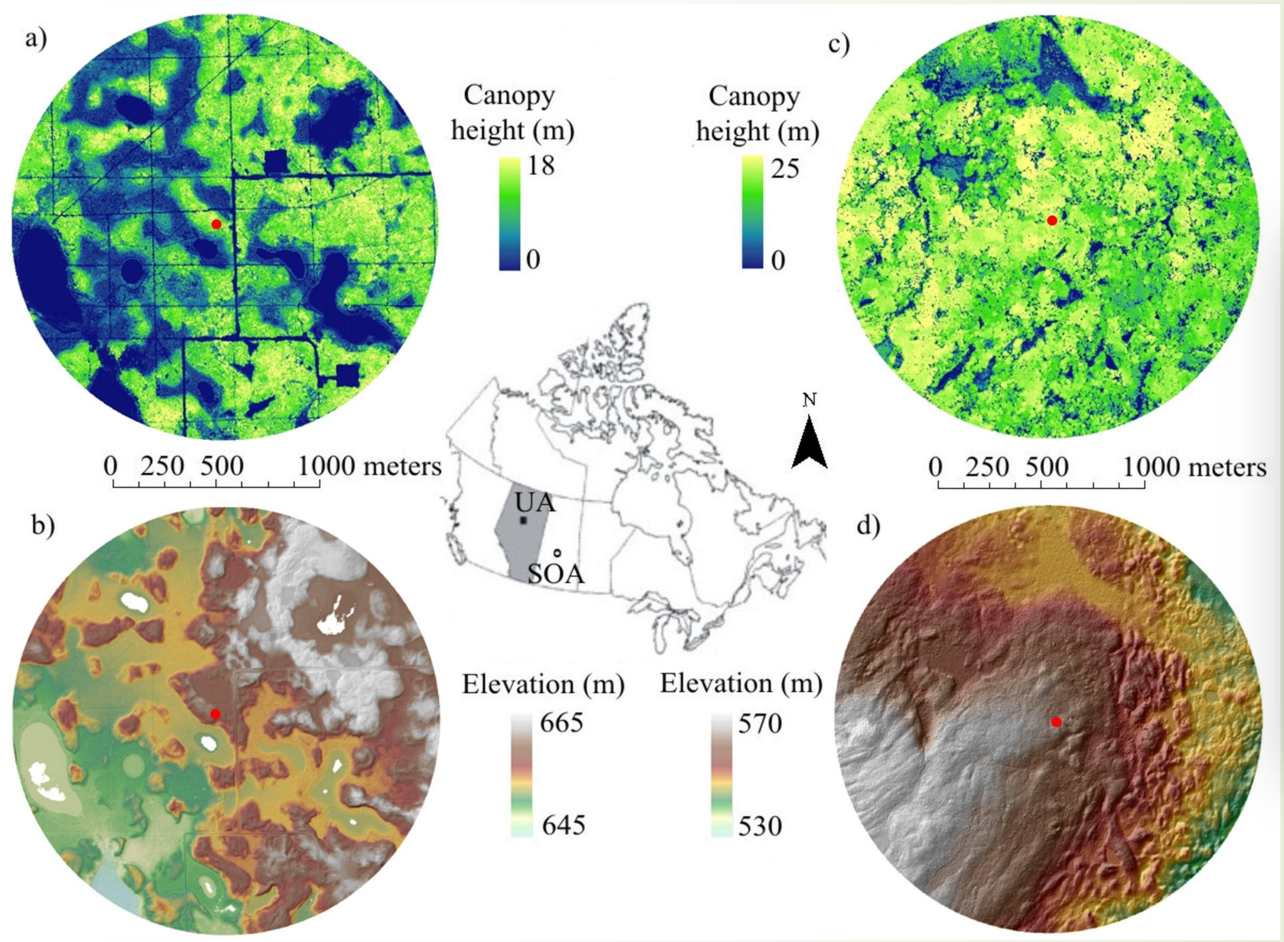
Exchanges of CO_2 transported to eddy covariance instrumentation, often assumed to be representative of site average characteristics and site heterogeneity, may not be well quantified. Heterogeneity could influence CO_2 exchanges if scalar fluxes from prevailing wind directions sample these parts more than others. **This could have implications for site representation, model evaluation, and remote sensing product validation.**

Combining footprint analysis with high resolution remote sensing data (e.g. LiDAR, Hyperspectral, etc.) provides a powerful tool for characterizing areas most frequently sampled by eddy covariance instrumentation.

In this study, we use a 3D classification methodology to characterize vegetation structural and topographic attributes most frequently sampled by eddy covariance within two contrasting mature boreal aspen stands. Characteristics most frequently sampled were used to classify the larger region for evaluation of the MODIS GPP product.

Heterogeneous Upland Aspen, Alberta
Homogeneous Southern Old Aspen, Saskatchewan



Location of Southern Old Aspen (SOA) and Upland Aspen (UA) sites. a), b) canopy height at UA and SOA within 1 km radius of eddy covariance (red square). c), d) elevation at UA and SOA.

Examined half-hourly GEP from eddy covariance (10:00 to 16:30 local time) from June 10-July28, 2006 and 2008 at UA and SOA for comparison with MODIS GPP.

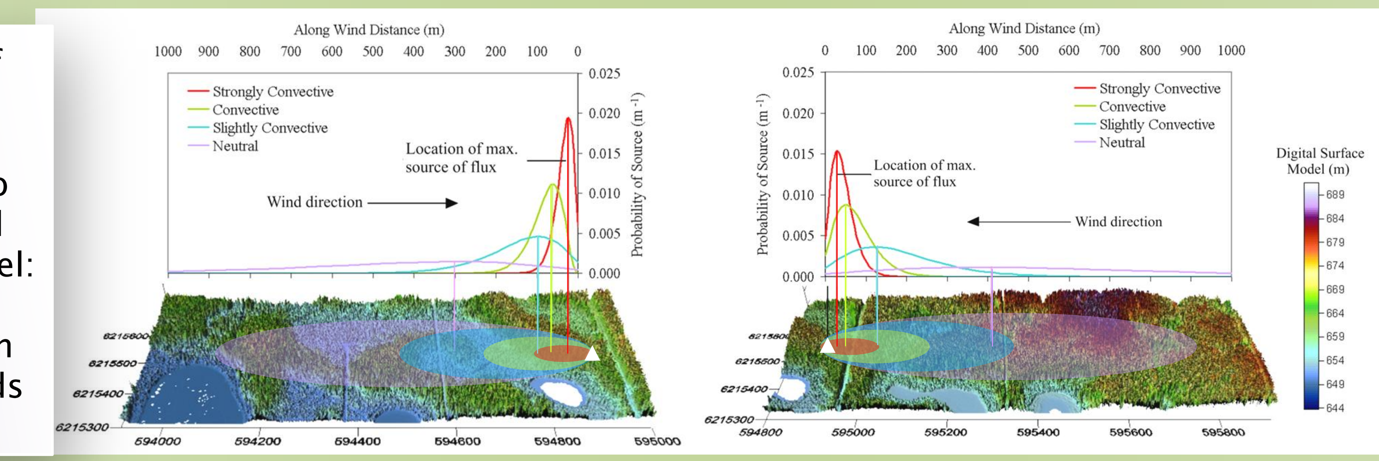
Objectives

1. Quantify parts of the ecosystem that are most frequently sampled by eddy covariance instrumentation.
2. Use structural and topographic attributes within footprint source/sink areas to classify site representation within and beyond the 1 km radius of the eddy covariance.
3. Compare GEP estimates from eddy covariance with MODIS GPP and assign confidence limits to MODIS pixels (both temporally and spatially).

Methods

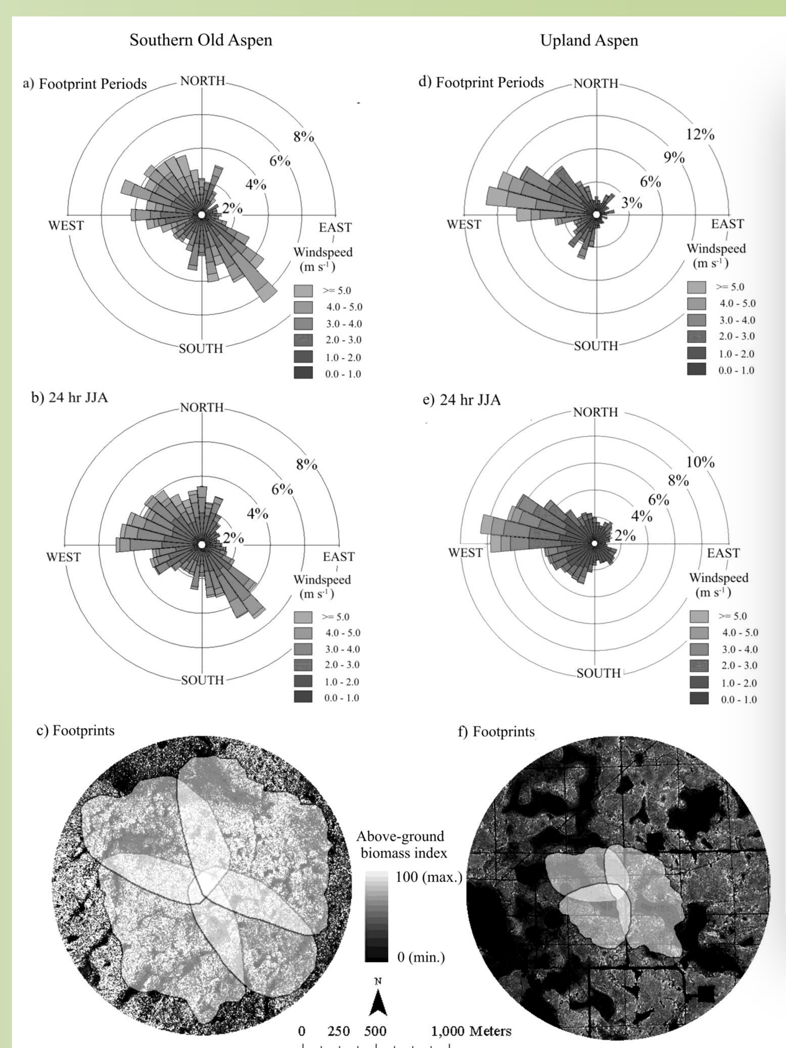
1. Footprint parameterization of Kljun *et al.* (2004) used to extract LiDAR data layers (canopy height, effective LAI, elevation, uplands and lowlands) from within half-hourly footprint source/sink areas.

Schematic of along-wind footprints overlaid onto LiDAR digital surface model: sampling of upland aspen and peatlands at UA.



2. Based on unique footprint 'signatures' of vegetation structural and topographic attributes, attribute ranges were used in a classification of heterogeneity within MODIS pixels.

Results
Frequency of Scalar Contributions, Characteristics



Frequency of prevailing wind directions represented by wind roses during a), d) footprint periods (time of study (10:00-16:30)); b), e) over 24 hours; and c), f) represented by cumulative footprint area (grouped by frequency) and overlaid onto a 'biomass index' (canopy height x effective LAI (LAIe)) LiDAR map.

SOA: Footprints from NW have, on average, taller trees (7%), greater LAIe (30%), denser understory (5%), fewer low-lying areas (topographic depressions) than from SE.

UA: Footprints from NW have, on average, shorter than average canopy heights (-11%), lower LAIe (-17%) and a greater proportion of topographic depressions than than other scalar directions (due to peatlands).

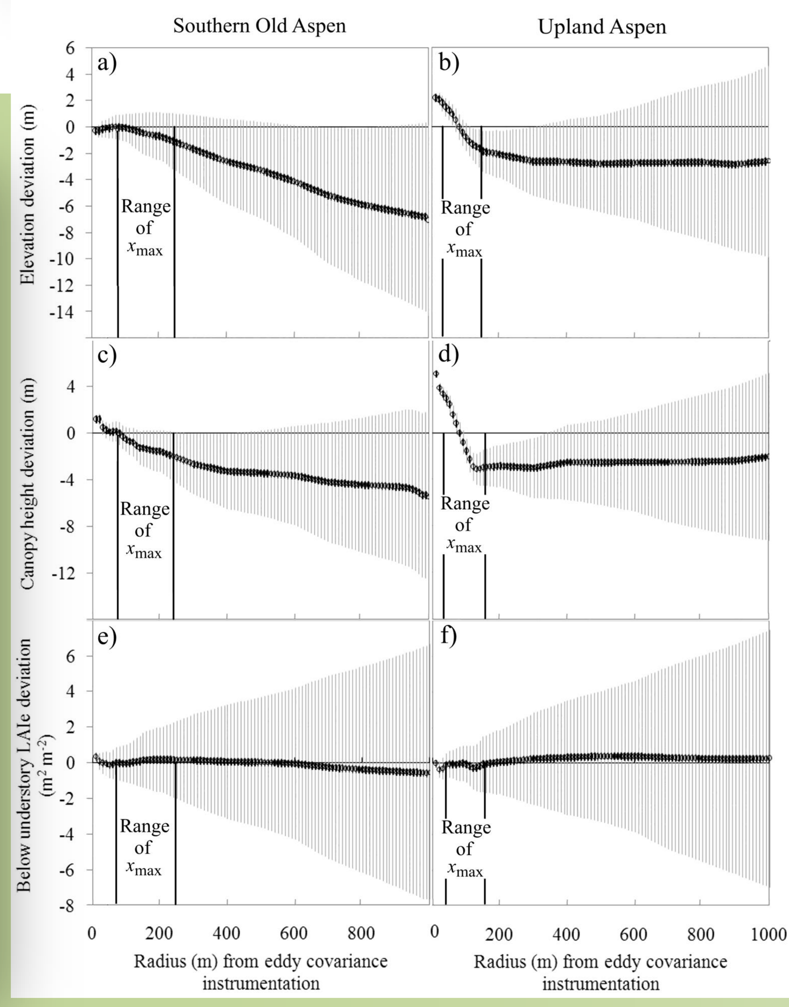
Deviation of vegetation structural and topographic characteristics from average footprint x_{max} (±1σ, ranges) at 10 m radius increments (concentric rings) from eddy covariance instrumentation. Range of x_{max} shows area of highest probability of sampling by eddy covariance.

Negative elevation differences → both sites located on uplands.

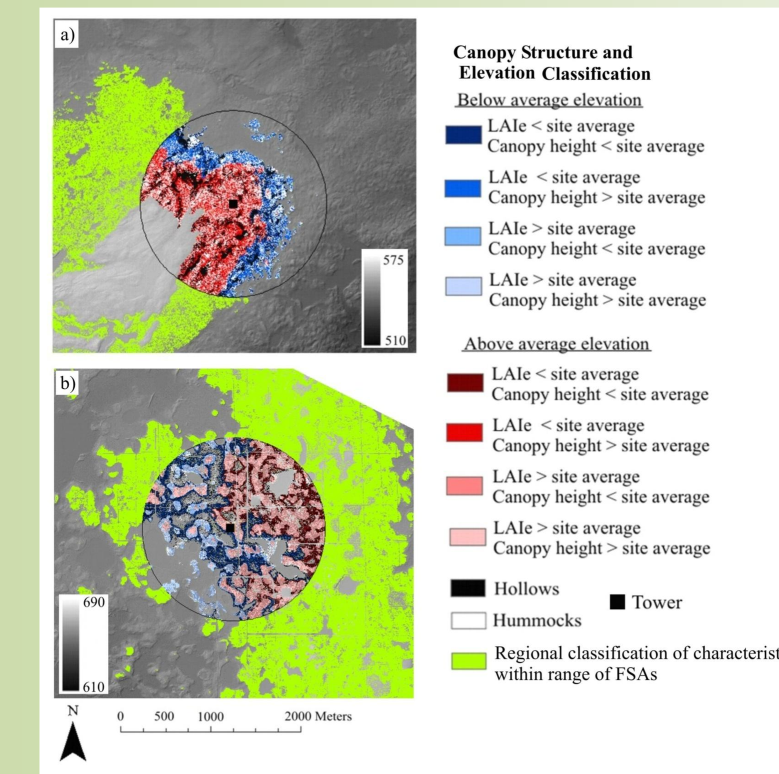
Canopy heights are greatest near tower but decrease with distance due to local bogs (SOA) and peatlands (UA) within ~200 m at both sites.

Range of LAIe does not vary greatly (due to averaging within rings).

Results have implications for near neutral stability.



Results
Classification of Footprint Signatures, Site Representation



Classification of vegetation structure and topography at a) SOA, b) UA within 1 km radius of tower based on footprints from prevailing wind directions (frequently sampled areas (FSAs)).

1 km radius of eddy covariance: **56% (SOA) and 69% (UA) were representative of vegetation structural and topographic attributes found within footprints** from prevailing wind directions.

4 km x 4 km area : **~21% (SOA) and 47% (UA) were representative of vegetation structural and topographic characteristics found within footprints** from prevailing wind directions.

Representation of Eddy Covariance Sampling: MODIS Pixels

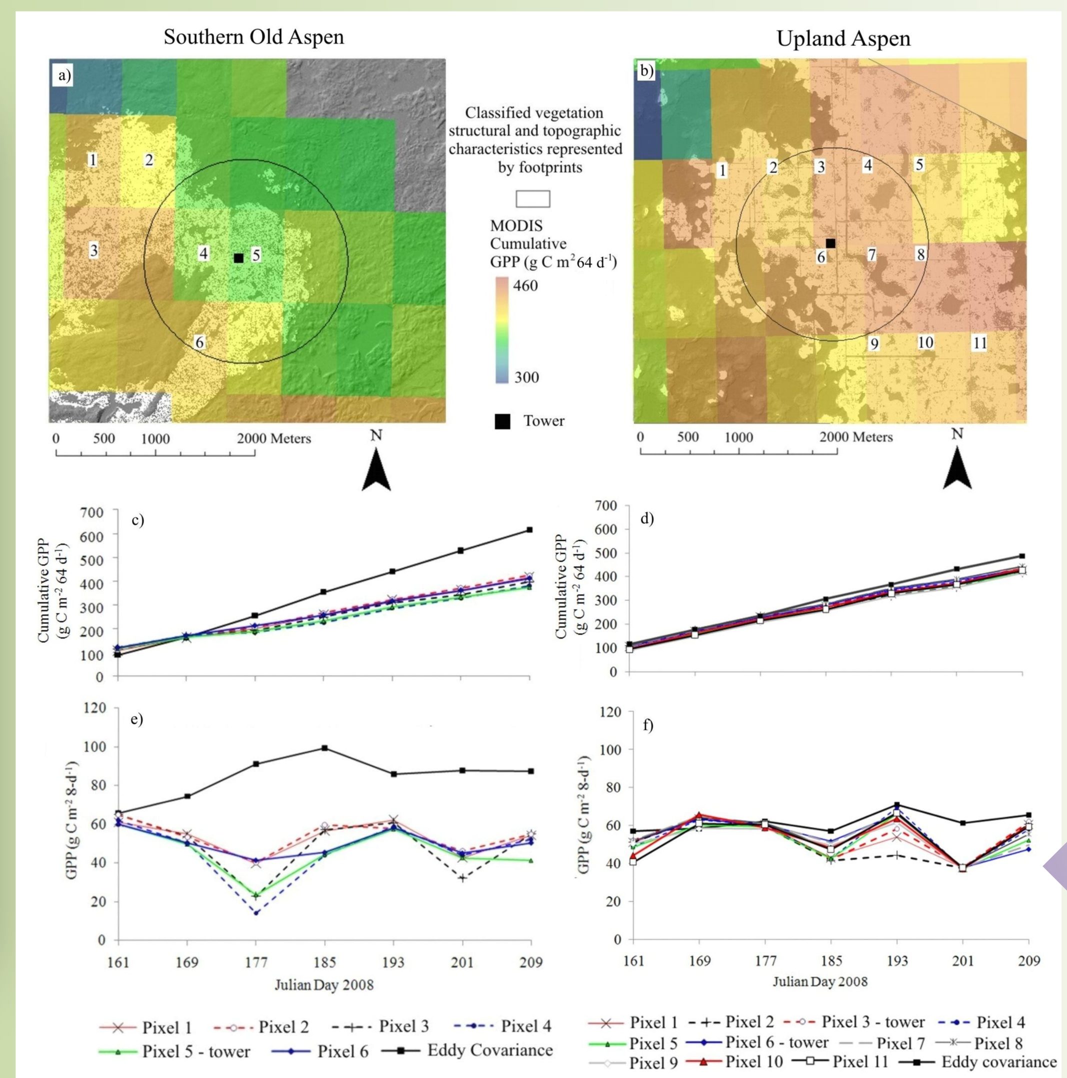


Table 1: Comparison between eddy covariance GPP and typically-used MODIS pixel comparison methods + results of using LiDAR to classify within pixel heterogeneity based on footprint analysis.

MODIS GPP Methods	Comparison Statistic	Southern Old Aspen	Upland Aspen
MODIS tower pixel GPP	r^2	0.81	0.69
	Slope	0.53	0.85
	RMSE	37.13	8.87
Average GPP of 3 x 3 MODIS pixels	r^2	0.71	0.69
	Slope	0.53	0.84
	RMSE	38.14	10.16
Average GPP of footprint-classified MODIS pixels	r^2	0.83	0.76
	Slope	0.55	0.83
	RMSE	37.12	8.47

MODIS cumulative GPP (opaque pixels) overlaid onto classified LiDAR data at a) SOA, b) UA. Numbered pixels have > 50% area coverage of 3D vegetation/topographic attribute ranges.

8-day cumulative GPP estimates from MODIS and eddy covariance at c) SOA and d) UA.

Time-series of 8-day cumulative GPP from MODIS and eddy covariance at e) SOA, and f) UA.

Take Home Message:

1. Marriage of plot measurements with eddy covariance data and low resolution satellite data products is difficult given differing spatial and temporal scales.
2. Airborne LiDAR data and footprint analysis can be used to link between scales.
3. In this study, use of a footprint model and LiDAR data improved comparisons between MODIS GPP and eddy covariance-estimated GPP when pixels were selected based on structural and topographic similarity to source/sink areas as opposed to selecting pixels that are proximal to the tower.
4. Implications include: assessment of spatial variability of vegetation/topography on NEE; identifying landscape features that are frequently sampled; classifying spatial heterogeneity; scaling.

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