Eddy covariance measurements of the forest floor CO_2 exchange in two contrasting forest stands in boreal Sweden

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1. Introduction

Boreal forests cover a large portion of land surface area in the northern hemisphere and greatly affect the global carbon (C) cycle and climate. Since these forests exchange carbon dioxide (CO_2) with the atmosphere in different vertical layers, many different CO_2 sources and sinks exist within the complex forest stand. The forest floor (soil and understory vegetation) may act as an important component of the C budget in a forest stand, however its contribution may vary from negligible to determining the inter-annual variability of ecosystem C balance. To date, there are only a limited number of studies that have directly quantified the CO_2 fluxes over a forest floor using the eddy covariance (EC) method. This is primarily due to challenges and potential violation of underlying assumptions when applying this method in the trunk space where turbulence characteristics are complicated, intermittent, and not in accordance with universal theories. In this study, we used two identical EC flux systems at two contrasting boreal forests (sparse pine stand vs. a dense mixed pine-spruce stand) in Sweden to measure the forest floor CO_2 exchange with the goal to improve our understanding of the role of the forest floor in the ecosystem-scale C budget in the boreal forest region.

2. Site description

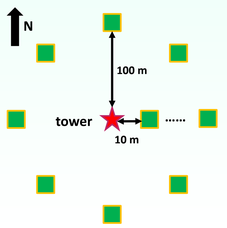
Svartberget (SVB)

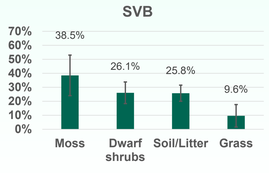
- 64° 15′ N, 19° 46′ E
- Mixed spruce, pine
- Dense canopy (LAI = 3.3)
- Till (>90%), shallow soils
- Dwarf shrubs (Bilberry, lingonberry), mosses
- Sloping terrain

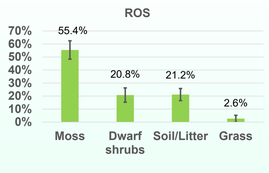
Rosinedal (ROS)

- 64° 9′ N, 19° 47′ E
- Pine forest
- Sparse canopy (LAI = 2.7)
- Sandy soil
- Dwarf shrubs (Bilberry, lingonberry), mosses
- Flat (~100 m radius; landscape scale slope)

3. Understory vegetation inventory

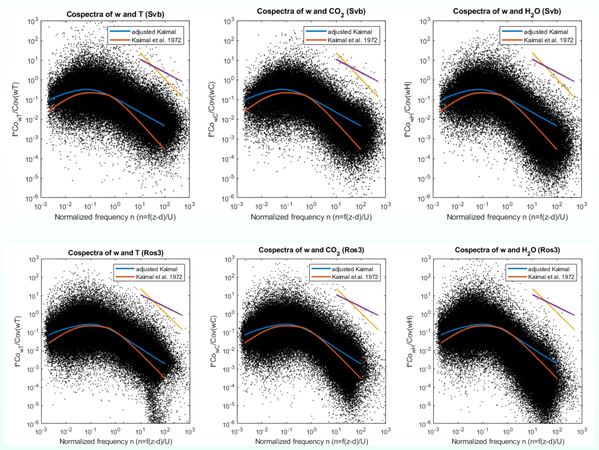






4. Empirical turbulence cospectral curves in the trunk space

- ***Data measured under well-mixed conditions in the trunk space without noise contamination are selected to fit the cospectral curves***
  1) *Well-mixed conditions: standard deviation of vertical wind speed (Launiainen et al. 2005)*
     - *$0.15 < \sigma_w < 0.3$ m/s for SVB*
     - *$0.2 < \sigma_w < 0.35$ m/s for ROS*
  2) *Noise-free: slope of inertial subrange (n>1) greater than 0 for SVB and ROS (Falk et al. 2005)*



Kaimal et al. 1972 equation

$$\frac{f C_{wT}(f)}{\overline{w'T'}} = \frac{a \cdot n}{(1 + b \cdot n)^c}$$

f: natural frequency (1/30min, 10Hz)
n: normalized frequency, *n=f(z-d)/u*
C_{wT}: cospectrum density of the flux
abc: fitted model parameters

Understanding the figures

- 9% and 11% of data (black dots) are selected for fitting the cospectral curves at SVB and ROS, respectively.
- Trunk-space cospectral curves (blue lines) are only fitted for the sensible heat fluxes.
- Above-canopy ideal cospectral curve is shown as the red lines.
- Purple lines have a slope of -4/3.
- Yellow lines depict a slope of -2/3.

5. Below canopy eddy covariance data processing

Raw data	• 20 Hz wind components and CO_2 mixing ratio
Eddypro	• 30 min CO_2 fluxes without spectral correction
Correction	• Spectral correction for trunk-space turbulence characteristics • CO_2 storage term between the measurement height and ground
QA/QC	• Undeveloped turbulence, non-steady state, advection, spikes, instrument failure, noise contamination, plausible limits
Gap-filling	• Marginal distribution sampling (below-canopy T_{air}, PAR, VPD)
Partitioning	• Nighttime-based T_{air} relationship using 15-days moving window

6. Net forest floor exchange of CO_2 (NFFE) at SVB and ROS

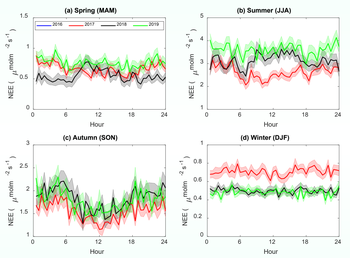


Figure a: NFFE diurnal patterns during the four seasons of 2017-2019 at SVB.

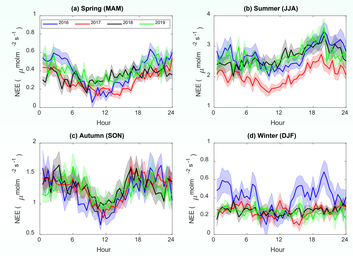


Figure b: NFFE diurnal patterns during the four seasons of 2016-2019 at ROS.

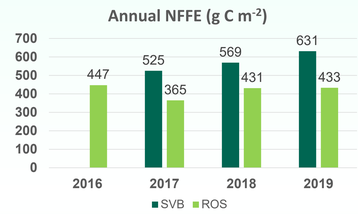


Figure c: Annual NFFE at SVB and ROS from 2016 to 2019.

Table 1: Annual C budgets of forest floor and forest ecosystem at SVB

SVB	NFFE	NEE	G_{FF}	GPP	R_{FF}	R_{eco}
2017	525	-167	-54	-806	579	639
2018	569	-186	-23	-920	592	734
2019	631	-211	-48	-910	679	699
Average	575	-188	-42	-879	617	691

Table 2: Annual C budgets of forest floor and forest ecosystem at ROS

ROS	NFFE	NEE	G_{FF}	GPP	R_{FF}	R_{eco}
2016	447	-342	-72	-1092	519	749
2017	365	-220	-54	-889	419	668
2018	431	-214	-21	-894	452	679
2019	433	-221	-16	-883	449	661
Average	419	-249	-41	-940	460	689

Tables 1&2: Unit is in g C m^{-2}.

7. Conclusions

- Our empirical below-canopy cospectral models show that more low- and high-frequency signals occurred in the forest trunk space than for the ideal above-canopy cospectral model.
- The difference between below- and above-canopy cospectra is more pronounced in the dense pine-spruce forest (SVB) compared to the open pine stand (ROS).
- Results revealed that the forest floor of the two contrasting forest stands acted as a net CO_2 source with a mean annual NFFE of 575 and 419 g C m^{-2} yr^{-1} for SVB and ROS, respectively.
- Forest floor accounts for ~5% of ecosystem GPP at both sites and 90% and 67% of ecosystem respiration at SVB and ROS, respectively.

References

- Launiainen, S. et al., 2005. Eddy covariance measurements of CO2 and sensible and latent heat fluxes during a full year in a boreal pine forest trunk-space. Boreal Environ. Res., 10(6): 569-588.
- Falk, M., et al., 2005. Is soil respiration a major contributor to the carbon budget within a Pacific Northwest old-growth forest? Agric. For. Meteorol., 135(1): 269-283.

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