Agricultural and Forest Meteorology 232 (2017) 23–34

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Apparent winter CO_2 uptake by a boreal forest due to decoupling

Georg Jocher[a,*], Mikaell Ottosson Löfvenius[a,b], Giuseppe De Simon[b], Thomas Hörnlund[b], Sune Linder[c], Tomas Lundmark[a], John Marshall[a], Mats B. Nilsson[a], Torgny Näsholm[a], Lasse Tarvainen[a], Mats Öquist[a], Matthias Peichl[a]

[a] Swedish University of Agricultural Sciences (SLU), Department of Forest Ecology and Management, SE-901 83 Umeå, Sweden
[b] SLU, Vindeln Experimental Forests, SE-922 91 Vindeln, Sweden
[c] SLU, Southern Swedish Forest Research Centre, PO Box 49, SE-230 53 Alnarp, Sweden

ARTICLE INFO

Article history:
Received 25 January 2016
Received in revised form 3 August 2016
Accepted 5 August 2016
Available online 10 August 2016

Keywords:
Advection
Coupling/decoupling
Eddy covariance
FLUXNET
Net ecosystem CO_2 exchange
Scots pine

ABSTRACT

Net uptake of carbon dioxide (CO_2) was observed during the winter when using the eddy covariance (EC) technique above a ~90-year-old Scots pine (*Pinus sylvestris* L.) stand in northern Sweden. This uptake occurred despite photosynthetic dormancy. This discrepancy led us to investigate the potential impact of decoupling of below- and above-canopy air mass flow and accompanying below-canopy horizontal advection on these measurements. We used the correlation of above- and below-canopy standard deviation of vertical wind speed (σ_w), derived from EC measurements above and below the canopy, as the main mixing criterion. We identified 0.33 m s^{-1} and 0.06 m s^{-1} as site-specific σ_w thresholds for above and below canopy, respectively, to reach the fully coupled state. Decoupling was observed in 45% of all cases during the measurement period (5.11.2014–25.2.2015). After filtering out decoupled periods the above-canopy mean winter NEE shifted from −0.52 μmol m^{-2} s^{-1} to a more reasonable positive value of 0.31 μmol m^{-2} s^{-1}. None of the above-canopy data filtering criteria we tested (i.e., friction velocity threshold; horizontal wind speed threshold; single-level σ_w threshold) ensured sufficient mixing. All missed critical periods that were detected only by the two-level filtering approach. Tower-surrounding topography induced a predominant below-canopy wind direction and consequent wind shear between above- and below-canopy air masses. These processes may foster decoupling and below-canopy removal of CO_2 rich air. To determine how broadly such a topographical influence might apply, we compared the topography surrounding our tower to that surrounding other forest flux sites worldwide. Medians of maximum elevation differences within 300 m and 1000 m around 110 FLUXNET forest EC towers were 24 m and 66 m, respectively, compared to 24 m and 114 m, respectively, at our site. Consequently, below-canopy flow may influence above-canopy NEE detections at many forested EC sites. Based on our findings we suggest below-canopy measurements as standard procedure at sites evaluating forest CO_2 budgets.

1. Introduction

Global warming, driven by the greenhouse gas concentrations in the atmosphere, affects the entire earth in manifold ways (e.g. IPCC, 2014). Forests play a crucial role in this context as they sequester carbon dioxide (CO_2) – a major greenhouse gas – all over the world. Consequently, confident predictions of both the future climate and forest carbon cycle require a thorough understanding and measurements of the processes determining the CO_2 sink strength of forest ecosystems.

The eddy covariance (EC) method has become the state-of-the-art method for quantifying the net ecosystem exchange (NEE) of CO_2 in various ecosystems all over the world. Around 40% of the 683 registered sites (as of April 2014) are classified as forest sites by FLUXNET, a worldwide network of EC flux measurement stations. The EC data are frequently used as the reference for compartmental fluxes of forest ecosystems and biometric measurements (e.g. Meyer et al., 2013; Peichl et al., 2010; Zha et al., 2007) or for validation of modeling approaches estimating gross primary production (GPP) and NEE (e.g. Beer et al., 2010; McCallum et al., 2013). Furthermore, EC data have been the basis for several high impact synthesis studies on global forest CO_2 sink strength (e.g. Beer et al., 2010; Fernández-Martínez et al., 2014; Keenan et al., 2013; Luyssaert et al., 2007; Mahecha et al., 2010; Schwalm et al., 2010). Misson et al. (2007) presented a synthesis study using EC data derived

* Corresponding author.
E-mail address: Georg.Jocher@slu.se (G. Jocher).

http://dx.doi.org/10.1016/j.agrformet.2016.08.002

above and below the canopy at ten EC forest sites located in different climate zones worldwide. They stressed the importance of understory measurements for the interpretation of above canopy derived data. However, the clear majority of synthesis studies are based on single-level EC data derived above the forest ecosystem(s) without explicit analysis of the coupling behavior between below- and above-canopy air masses.

In a forest, the below-canopy airflow can be influenced by the local topography and thereby cause horizontal exchange of the below-canopy air (e.g. Belcher et al., 2012). For instance, local wind might flow preferentially downslope or upslope due to pressure gradients created in clear and calm weather situations (e.g. Butler et al., 2015; Kutsch and Kolari, 2015). The horizontal below-canopy flow needs special considerations in terms of data interpretation (e.g. Aubinet et al., 2005; Feigenwinter et al., 2004; Staebler and Fitzjarrald, 2004), especially if the vertical exchange between air masses below and above canopy is inhibited. Under such conditions the results based on above-forest measurements do not sufficiently reflect the whole ecosystem CO_2 exchange. Consequently, when decoupling and below-canopy horizontal flow occur there is potential for a considerable overestimation of the above-canopy derived forest CO_2 sink strength as below-canopy respiratory fluxes might not be detected at the EC system above canopy (Goulden et al., 1996).

During the last decades several studies have addressed theoretical issues regarding the complex energy and CO_2 exchange behavior in forests and between forest and atmosphere (e.g. Baldocchi and Meyers, 1988; Belcher et al., 2008; Finnigan, 2000; Fröhlich and Schmid, 2006; Launiainen et al., 2007; Lee, 2000; Raupach and Thom, 1981). Furthermore, a number of case studies have been published dealing with canopy decoupling and its carbon budget consequences for different sites and forest types. Feigenwinter et al. (2010), for instance, interpreted the CO_2 exchange of an alpine spruce forest in terms of a persistent local slope wind system. Vickers et al. (2012), Oliveira et al. (2013) and Alekseychik et al. (2013) investigated nocturnal sub-canopy horizontal flow regimes and their impact on above canopy CO_2 exchange during the growing season at their pine forest sites in Oregon (USA), southern Brazil and southern Finland, respectively. Nonetheless, even if the topic is not new, decoupling is still not considered at many EC forest sites. Most rely on above-canopy based descriptions of the coupling behavior, which may introduce a bias in the stand-scale CO_2 exchange estimates.

Currently, the most common filtering procedure to ensure good coupling is to use a friction velocity threshold derived from above-canopy EC measurements. The friction velocity threshold depends on canopy roughness, which in turn depends on site-specific quantities such as stem density, leaf area index and the vertical distribution of canopy foliar and branch biomass in the stand (e.g. Foken, 2008; Poggi et al., 2004). Nevertheless, in certain cases it might not be possible to determine a friction velocity threshold (e.g. chapter 5 in Aubinet et al., 2012) or it might not be sufficient to use such a threshold (e.g. Speckman et al., 2015).

The behavior of coherent structures of the flux of interest in the vertical column from soil to above canopy can also be used as an indicator of mixing (e.g. Foken et al., 2012; Serafimovich et al., 2011; Thomas and Foken, 2007). This method requires several EC measurements below, inside and above canopy and is therefore not affordable for most EC sites.

Another above-canopy variable for investigating the canopy-atmosphere mixing behavior is the standard deviation of the vertical wind velocity (e.g. Acevedo et al., 2009; Launiainen et al., 2005). Moreover, the relation of this variable between below- and above-canopy measurements can describe the coupling behavior: if air masses below and above canopy are fully coupled then this relation is linear (Thomas et al., 2013). This quality check is, however, not commonly used as it requires an additional EC system below the canopy.

Eddy covariance data from our site situated in northern Sweden indicate occurrences of net CO_2 uptake during winter periods. These observations are highly questionable since continuous gas exchange measurements in boreal Scots pine stands have shown that there was no net CO_2 uptake during the winter months November to February (e.g. Kolari et al., 2007; Linder and Lohammar, 1981; Troeng and Linder, 1982). Thus, some measurement artifact is highly likely. The biasing influence of decoupling and accompanying horizontal below-canopy air flow on the above-canopy derived NEE values has been shown for several forest types and stand densities during summer, both for daytime and nighttime conditions (e.g. Alekseychik et al., 2013; Thomas et al., 2013). An analysis of decoupling events during wintertime is, to our knowledge, currently lacking. Even if forest floor respiration is normally at a low rate during winter, it still contributes significantly to the annual ecosystem carbon budget (e.g. Goulden et al., 1998; Haei and Laudon, 2015; Ilvesniemi et al., 2005; Lindroth et al., 1998; Öquist and Laudon, 2008; Winston et al., 1997). Hence, decoupling and accompanying horizontal below-canopy flow may have an impact on the apparent carbon budget even during wintertime.

In this study, we analyzed a winter period (5.11.2014–25.2.2015) of NEE measurements above a boreal Scots pine forest and assessed coupling/decoupling and horizontal below-canopy flow. We used EC measurements below and above the canopy, following the approach proposed by Thomas et al. (2013). The overall aim was to examine to what extent decoupling and below-canopy horizontal flow were responsible for the observed negative NEE during winter despite the complete lack of photosynthesis during most of this period.

The main study objectives were:

i) to quantify the frequency of decoupling during wintertime.
ii) to investigate the potential implications of decoupling and horizontal below-canopy flow on the above-canopy derived NEE.
iii) to explore the potential of several filtering approaches for addressing coupling/decoupling, using quantities derived from above-canopy EC measurements.
iv) to compare the topography surrounding our EC tower to others in the worldwide network of forest flux sites (FLUXNET) as a means for determining how common such biased NEE results might be.

2. Materials and methods

2.1. Site description and characteristics

This study was conducted during the winter period of 5.11.2014–25.2.2015 at Rosinedalsheden experimental forest which is a ~90-year-old Scots pine (*Pinus sylvestris* L.) stand near Vindeln in northern Sweden (64°10′N, 19°45′ E; 155 – 160 m above sea level). The overall experiment was initiated in 2006 to study the effect of nitrogen (N) availability on stand-scale carbon cycling and consists of stands with high and low N addition rates, respectively, and a non-fertilized reference stand. Each stand is equipped with an EC tower for measuring the turbulent exchange of momentum, sensible heat, latent heat, and CO_2. The current study was conducted at the stand with the high N addition rate, which has received 100 and 50 kg N ha^{-1} yr^{-1} since 2006 and 2012, respectively, applied over an area of 15 ha around the EC tower.

The mean annual temperature in this region is 1.8 °C and the mean annual precipitation is 614 mm (Laudon et al., 2013; 30-year averages between 1981 and 2013 at the Svartberget field station, ca. 8 km away from the study site; www.slu.se/en/