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Treatment and assessment of the CO_2-exchange at a complex forest site in Thuringia, Germany

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ABSTRACT

Eddy covariance measurements were carried out at the Wetzstein site in Thuringia, Germany since December 2001. Soon after the start of the measurements night-time fluxes well above average CO_2-fluxes measured in temperate forest ecosystems were detected which could not be explained by biological processes but were valid with respect to standard quality criteria. The Wetzstein site is part of the CarboEurope-IP flux-network and the CO_2-exchange of this spruce forest is of general ecological interest as the site is typical for central European spruce forest ecosystems at mountainous elevation. Additional investigations were made in order to identify the causes for the large difference between the flux balance and the inventory based NEP. Specific weather patterns and micrometeorological situations were identified during which a decoupling of the flows above and below the canopy leads to additional CO_2-effluxes at the tower site which are not part of the net ecosystem exchange (NEE) at night. Rejecting data from these periods and gap-filling thereafter results in yearly sums of NEE, GPP and TER which are in better agreement with the biometric measurements at the tower site and comparable to other spruce forest sites. In this process ecosystem respiration was determined not only from extrapolation of night-time data but also from flux partitioning based on day-time data using the hyperbolic light response function. It can be shown that flux measurements at this complex site need to be treated in a modified procedure compared to what is generally performed, namely extrapolating ecosystem respiration from night-time data. Using multiple data sources and applying a careful filtering of the data, confidence in the estimates of the carbon balance components increased.

1. Introduction

The exchange of carbon dioxide between ecosystems and the atmosphere is an important component of the global carbon cycle, with forests contributing to about 50% to the net amount of carbon fixed in terrestrial vegetation (Grace, 2005). The growth rates of forests are known to be increasing (Nemani et al., 2003; Schulze, 2006). Thus ecological research is interested in continuous monitoring of the carbon exchange of forests to identify carbon budgets and their trends worldwide (Baldocchi et al., 2001). The eddy covariance technique is the most established tool for deriving the long-term balance of net ecosystem exchange of CO_2 (NEE) since the seminal dataset at Harvard Forest in the early 1990s (Wofsy et al., 1993). With the eddy flux approach source areas ranging between a hundred meters and several kilometers are sampled in situ and without any disturbance so that interrelations between CO_2-exchange and climatic factors can be elucidated (Baldocchi, 2003). But the accuracy of this method is only true over flat, homogenous surfaces as certain assumptions have to be made (Kaimal and Finnigan, 1994). However, forest ecosystems are often located in hilly and patchy regions where these assumptions cannot be met. This is the case for the Wetzstein site in Thuringia, Germany which has a complex topography with the measuring tower on the top of a crest (Fig. 1). Quality tests such as presented by Foken and Wichura (1996) can help to identify situations when environmental conditions do not fulfil the requirements needed for fully developed turbulence.

Usually it has been reported that nocturnal carbon efflux is underestimated by the eddy covariance technique during calm and stable nights even if including the change in storage of CO_2 below the flux sensors (Goulden et al., 1996; Aubinet et al., 2000; Miller et al., 2004) which has to be added to the turbulent fluxes if

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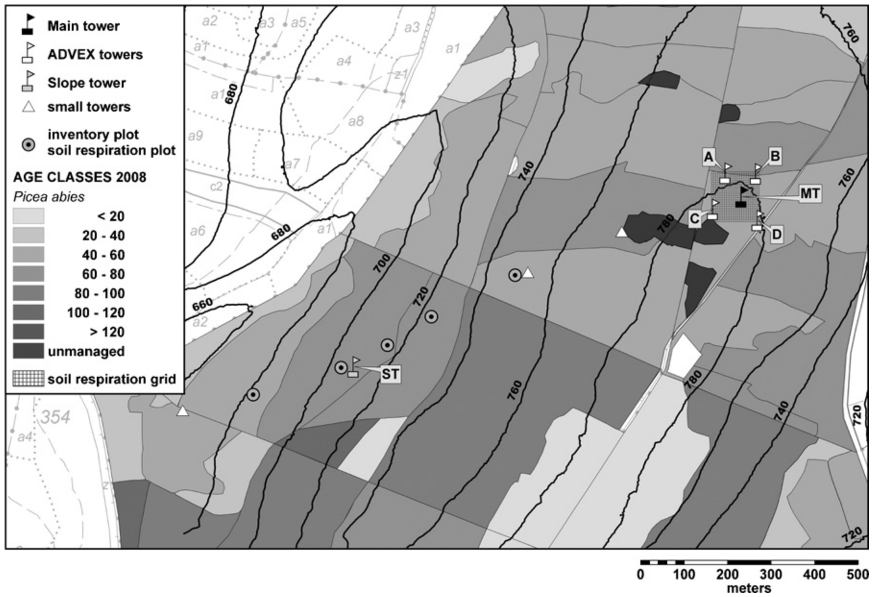

Fig. 1. Topographic map of the Wetzstein area with age classes of the spruce forest (distinguished by grey scale), tower positions (main tower: MT, slope tower: ST, ADVEX towers: A, B, D and C, small towers: triangles), and area of intensive soil respiration measurements. Thick lines represent the topography, thin and dotted lines represent borders of forestry sections (marked with a1, a2, . . .).

measuring above tall vegetation because of insufficient vertical mixing in the canopy space. At the Wetzstein site night-time fluxes of CO_2 showed a very anomalous behaviour with half-hourly values up to about 20 μmol m^{-2} s^{-1} or higher often lasting several hours during nights, as reported by Anthoni et al. (2004), albeit having applied restrictive quality tests (Foken and Wichura, 1996). Nocturnal NEE does not level off if plotted against the friction velocity u^*. A similar behaviour of night-time fluxes had also been reported by Van Gorsel et al. (2007) for a temperate *Eucalyptus* forest in southeast Australia. The apparent flux balance is close to zero for this young Eucalypt forest stand which shows maximum rates of growth. Venting anomalies with extreme CO_2-fluxes were also reported by Cook et al. (2004) with even higher CO_2-fluxes of up to 80 μmol m^{-2} s^{-1} indicating transport of pooled CO_2 to their flux measuring system.

Zeri (2008) investigated the occurrence of high nocturnal fluxes of CO_2 at this site and found that they were associated with south-west winds (the main wind direction at the site), neutral stratification and high values of u^*, as shown in Fig. 2. Additionally, the analysis of wind directions measured at the main tower at the hillcrest and at the slope tower revealed that the above- and below-canopy flows were not always coupled. For the hillcrest, the coupling of wind direction above and below the canopy for different classes of friction velocity (u^*) and stratification regime ($\zeta = (z - d)/L$, with z: measuring height, d: displacement height, L: Obukhov-length) revealed the existence of wind shear below the canopy. The decoupling was observed for south-west winds when u^* was higher than approximately 0.5 ms^{-1} and the surface layer was neutrally stratified, the same conditions associated with the unusually high nocturnal fluxes. The sub-canopy wind directions (1.5 m) varied between 200° and 300° when the wind direction at 30 m was approximately 240° (Zeri et al., 2010). The wind shear was most probably caused by the sub-canopy flow following the easiest way downhill, given that the tower is located near the edge of the plateau. Wind shear was also observed at the slope tower for south-west winds, as the sub-canopy flow follows the slope.

With the establishment of several additional measurements in the surrounding of the main flux tower and an extensive 3D-advection experiment (Feigenwinter et al., 2008) we tried to detect possible influences of advective contributions to the fluxes which might explain the unusual fluxes measured by the eddy covariance technique at the Wetzstein site. Results of the experiment performed at the Wetzstein site are discussed in detail in Zeri et al. (2010), Aubinet et al. (2010) and Feigenwinter et al. (2008). Main findings of the advection experiment were that measured advective fluxes cannot be directly used to determine NEE on a half-hourly basis because of their large scatter. On average vertical as well as horizontal advection values were low even though specific wind sectors and micrometeorological conditions could be pointed out where advective fluxes reached considerable values (Feigenwinter et al., 2008). These conditions occur usually for cross-ridge wind directions at the site, which however are comparably rare (about 11%).

The difficulty to apply advective fluxes for the determination of NEE leads to the question whether it is possible to ascertain reliable estimates of annual carbon exchange rates despite the complexity of a site, and if derived procedures may be applicable to other sites situated in complex terrain.

2. Materials and methods

2.1. Site description

The research site Wetzstein is located in Thuringia, a state of the Federal Republic of Germany, near the village Lehesten on a plateau in a mountain range (50°27′N, 11°27′E, 785 m a.s.l.). The ridge is oriented approximately to north-northeast with steep slopes to the ESE and WNW. The main tree species at the site is an even aged Norway spruce (*Picea abies*) plantation, about 22 m tall with a stand age of ~50 years (Fig. 1). Ground vegetation is very sparse with patches of moss. Leaf area index determined with an LAI-2000 system (LiCor Inc., Lincoln, USA) as the average of 20 fixed measurement points in the main wind direction is about 7 m^2 m^{-2} (corrected for clumping of needles according to LAI-2000 manual).

Eddy covariance measurements together with the acquisition of basic meteorological parameters started in December 2001. Due to