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Long-term tall tower carbon dioxide flux monitoring over an area of mixed vegetation

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Abstract

A methodology is described to determine the carbon budget of an extended region with mixed vegetation. The eddy covariance measuring system is operated at 82 m elevation on a tall radio/television transmitter tower above an area covered by agricultural fields and forest patches. The methodology ensuring the high quality of the calculated fluxes is described. Net ecosystem exchange (NEE) of CO_2 is determined as the sum of the eddy flux at 82 m and the rate of change of CO_2 storage below the measurement level. The gap filling technique used to patch the missing measurements is also presented. In contrast to several long-term NEE measurements low turbulent conditions does not seem to bias the annual sums of NEE at the site. Maximum daytime NEE reached -1.4 to -1.5 mg CO_2 m^{-2} s^{-1} (negative value indicates uptake) during the most active phase of the vegetation, while mean night-time respiration was around 0.1–0.3 mg CO_2 m^{-2} s^{-1}. During the dormant season typical net exchange was around 1 g C m^{-2} day^{-1}, while the vegetation adsorbed around 2–4 g C m^{-2} day^{-1} in the growing season. The overall dependence of the landscape-wide NEE on the environmental factors is described with non-linear regression functions. It is demonstrated that tall tower NEE measurements may provide repeatable, consistent estimates of the landscape-wide carbon exchange. The results may contribute to a better constraint on the ‘‘bottom-up’’ flux estimates. During the period of 1997–2004 (year 2000 is missing) the region mostly behaved as a weak net CO_2 sink on annual scale. Year-round NEE was in the range of -107 ± 48 and 69 ± 37 g C m^{-2} $year^{-1}$. Climate data are presented to explain the interannual variability of NEE, gross primary production (GPP) and total ecosystem respiration (R_{eco}).

Keywords: Eddy covariance; Footprint; CO_2 exchange; Agricultural landscape; NEE; Inter-annual variability; Regional scale

1. Introduction

Small-scale and long-term carbon dioxide flux studies have been established worldwide to investigate the carbon dioxide and energy exchange processes between the biosphere and the atmosphere. Currently,

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more than 200 measuring sites are registered worldwide in various ecological environments (e.g. FLUXNET (http://daac.ornl.gov/FLUXNET/); Valentini et al., 2000; Baldocchi et al., 2001a; Falge et al., 2002; Valentini, 2003) with several sites providing continuous carbon exchange data year by year. Most of the programs are performed over forests, grasslands or croplands with uniform vegetation, and provide information on a limited area of about 1–3 km^2 (Running et al., 1999). There is also a growing need to carry out measurements over intensive agricultural regions, since these areas are currently underrepresented (Running et al., 1999; Baldocchi et al., 2001a). Because of the limited representativeness of the small-scale flux studies, programs have been initiated to assess the carbon balance of larger regions (from regional to global scale; see Running et al., 1999, for a comprehensive overview; Davis et al., 2003; Soegaard et al., 2003), to better understand the global carbon cycle. Extrapolation and combination of the results obtained from the small-scale studies may be misleading. Regional scale airborne measurements cannot provide continuous information, which is necessary to monitor the processes that govern the carbon balance of the ecosystems. Tall tower measurements may partly resolve the spatial scale mismatch between the local scale measurements and the large-scale, remotely sensed data.

The first tall tower site for long-term large-scale biosphere/atmosphere CO_2 exchange monitoring was established in Wisconsin, U.S.A., in 1994 (Bakwin et al., 1998; Davis et al., 2003). The Hungarian tall tower based large-scale net ecosystem exchange (NEE) research project was initiated in the framework of a U.S.-Hungarian cooperation (National Oceanic and Atmospheric Administration [NOAA]-Hungarian Meteorological Service/Eötvös Loránd University, Budapest) in 1997 (Haszpra et al., 2001). The aim of the project was to monitor and evaluate the biosphere/atmosphere exchange of CO_2 of an ensemble of different natural and agricultural ecological systems, which can be considered typical for an extended region. The interpretation of the results obtained over this heterogeneous area was also a methodological challenge.

The paper gives the results of the multiannual CO_2 NEE measurements performed at the Hungarian tall tower site. We present the methodology for the determination of NEE from eddy covariance measurements carried out at 82 m elevation over the ground. A gap filling technique is also presented for filling the data gaps, which inevitably occur during long-term operations. The sign convention used in this study is that negative values indicate CO_2 (or carbon) removal from the atmosphere, while a positive value marks CO_2 (or carbon) loss from the ecosystem.

2. Site and instrumentation

The eddy covariance measurements are carried out at 82 m above the ground on a 117 m tall, free-standing TV/radio transmitter tower which is the base of several greenhouse gas related monitoring and research projects (AEROCARB (http://www.aerocarb.cnrs-gif.fr); CHIOTTO (http://www.chiotto.org); CARBOEUROPE-IP; NOAA (http://www.cmdl.noaa.gov/ccgg); Demény and Haszpra, 2002; Barcza et al., 2003). The tower, owned by Antenna Hungária Corp., is located in a fairly flat region of western Hungary (46°57′N, 16°39′E, 248 m asl), in the vicinity of a small village called Hegyhátsál.

The tower is surrounded by a regionally typical mixture of agricultural fields (mostly crops and fodder of annually changing types) and forest patches (60% arable land, 30% forest and woodland and 10% other [vineyard, settlements, etc.]). The soil type in the region is '*Lessivated brown forest soil*' (Alfisol, according to USDA system). The upper layer is generally 10–20 cm thick, and its organic matter content is 5–8%. Human habitations within 10 km of the tower are only small villages (100–400 inhabitants). There is no notable industrial activity in this dominantly agricultural region. Local roads have mostly low levels of traffic. In general, the monitoring station is located as far from direct anthropogenic pollution sources as it is possible in the densely populated, highly industrialized Central Europe, and it can be characterized as a rural background site.

Fig. 1 shows the estimated region of representativeness of the site on the land use map. The curves were derived from the so-called mini-FSAM model of Schmid (1994) taking into account the correction for the measurement height that is described in Schmid (1997). The source area was calculated for the summer of 2003, for daytime unstable conditions (Schmid's