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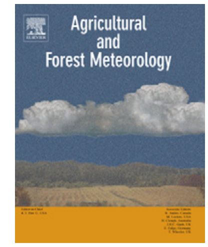

Spatial representativeness of tall tower eddy covariance measurements using remote sensing and footprint analysis

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ABSTRACT

We present a method for the estimation of the spatial representativeness of tall tower eddy covariance measurements monitoring a heterogeneous landscape. The approach attributes the measured signal to the different ecosystems surrounding the tall tower site. For the identification of the ecosystems, remotely sensed vegetation index time series are used. Using 250 m grid resolution defined by the available MODIS vegetation index data, we quantify the spatial distribution of winter and summer crops and we also provide an estimate on the fractional crop coverage for pixels with heterogeneous crop type. Using a state-of-the-art footprint model applicable in the mixed layer we calculate a footprint climatology for the 5-year period 2003–2007. With the synergy of the footprint analysis and the land cover classification scheme we quantify the representativeness of the eddy covariance measurement. It was found that the source region distribution is very similar from year to year. The biggest impact to the measurement originates generally within 1 km radius from the tower. 75–80% of the measured signal originates from agricultural areas, while the contribution of pastures is also relevant. Though there are important other land use types in the region (e.g. forests, settlements) their contribution to the measured signal is rather small (<5% for forested regions, <2% for urban areas). Inside the source area the relative importance and spatial distribution of summer and winter crops is variable among the years, which may influence the measured signal due to the different timing of the intensive carbon uptake period and harvest. The presented methodology is used to estimate summer and winter crop-specific carbon dioxide exchange time series. The crop-specific carbon dioxide fluxes are markedly different in each year, and exhibit strong covariation with the crop-specific NDVI time series. The results further suggest that the applied footprint model provides accurate footprint estimates.

1. Introduction

Within the framework of the FLUXNET network carbon dioxide, water vapour and energy exchanges between the biosphere and the atmosphere are measured on the ecosystem scale at more than 500 locations worldwide (Baldocchi et al., 2001; Baldocchi, 2008). The data are widely used, for example for the characterization of the environmental control

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on ecosystems (Falge et al., 2002; Law et al., 2002), for the determination of the carbon balance of ecosystems (Valentini et al., 2000; Nagy et al., 2007; Reichstein et al., 2007), for calibration of biogeochemical models (Hollinger and Richardson, 2005; Friend et al., 2007; Hidy et al., 2007; Wang et al., 2007), and for the evaluation of remotely sensed carbon cycle data (Running et al., 1999; Turner et al., 2006).

At the FLUXNET sites the so-called eddy covariance (EC) micrometeorological technique is used to derive fluxes (e.g., Aubinet et al., 2000; Baldocchi, 2003) with ancillary measurements for the interpretation of the data. The main element of a FLUXNET site is a tower usually a few tens of meters tall and equipped at least with an ultrasonic anemometer and an infrared gas analyzer (Aubinet et al., 2000). The equipment is typically mounted 3–30 m above the vegetation, where the latter is preferably homogeneous, and the terrain is more or less flat. Since the EC sensors measure the properties of the turbulent airflow and they are dislocated from the surface, it is not trivial to determine the origin of the measurement signal (Schmid, 1997). If the tower is surrounded by homogeneous vegetation, the signal can be attributed to the whole ecosystem. As in reality there are no ideal sites, spatial heterogeneity generally causes problems in data quality and data analysis. This problem can be addressed if the spatial representativeness of the measurements is known. Footprint models have been developed to determine the field of view (or source area) of EC measurements (Horst and Weil, 1992; Schmid, 1994, 1997, 2002; Rannik et al., 2000; Kljun et al., 2002, 2004; Göckede et al., 2004; Vesala et al., 2008), thus they provide information on the spatial representativeness of the data. For proper interpretation of the varying source areas land use maps and/or topographic maps are also needed.

Traditionally, footprint models were developed to be applicable in the surface layer (i.e. the lowest ~10% of the planetary boundary layer; Stull, 1988) over homogeneous land cover. There is a growing need in FLUXNET to derive footprint estimates over heterogeneous vegetation and even for cases where the EC system is outside the surface layer (Davis et al., 2003; Soegaard et al., 2003; Vesala et al., 2008). In order to acquire footprint climatologies, i.e. footprint estimates for long-term EC measurements, easy-to-use footprint models are needed (Vesala et al., 2008). To satisfy this need Kljun et al. (2004) presented a simple, easy-to-use parameterization based on a Lagrangian footprint model that can be applied outside the surface layer.

Reliable footprint climatologies together with a detailed land cover classification map can be used to fully characterize the spatial representativeness of heterogeneous landscapes and to explain the variability of the measured data. Reithmaier et al. (2006) presented an approach to use LANDSAT and ASTER satellite images for the characterization of German eddy covariance sites. They demonstrated the applicability of remotely sensed images for the description of the heterogeneous measurement sites. Reithmaier et al. (2006) used an analytical footprint model to locate the sampled region. Wang et al. (2006) performed a similar study to attribute the measured net ecosystem exchange (NEE) of CO_2 data to different land use elements and to see whether the aggregated NEE is a good measure for the landscape-wide NEE. They concluded that it is not possible to use single tower measurement data to infer the regional mean NEE since the footprint weighted land cover distribution may not be representative for the study region.

A tall tower eddy covariance site has been operated at Hegyhátsál, Western Hungary since 1997; the tower is surrounded by mixed, mostly agricultural vegetation (Haszpra et al., 2001, 2005). The aim of the present study is to provide an estimate of the spatial representativeness of the NEE measurements at 82 m height for multiple years. Remotely sensed vegetation index data is used to estimate the crop type distribution and the phenological cycle of crops in the region. As a new approach in the present context, crop types are estimated using an objective classification. Furthermore, we present a method to combine remotely sensed vegetation index signatures, a widely used land cover map and a state-of-the-art, mixed layer footprint model for the characterization of the source of the measured eddy covariance signal. The results are presented for a 5-year period (2003–2007) such that the interannual variability of the source area can be described. The presented methodology is also used to attribute the measured carbon dioxide exchange signal to specific crop types in the most frequently sampled source regions. The study demonstrates the applicability of cost efficient, medium resolution remotely sensed data to characterize the interannual variability of land cover.

2. Methods and data

2.1. Site and instrumentation

The tall tower based eddy covariance measurements used in this study are performed at 82 m height on a 117 m tall, free-standing TV/radio transmitter tower which is used for several greenhouse gas related monitoring and research projects (AEROCARB; CHIOTTO; CARBOEUROPE-IP; GEOMON, IMECC; cf. Haszpra, 1999; Barcza et al., 2003; Bakwin et al., 2004; Haszpra et al., 2005; Hidy et al., 2007). The tower, owned by Antenna Hungária Corporation, is located in a fairly flat region of western Hungary (46°57′21″N, 16°39′08″E, 248 m asl), in the vicinity of the small village Hegyhátsál.

The climate of the region is temperate continental. The long-term (1961–1990) mean annual temperature is 8.9 °C and the mean annual precipitation is 759 mm. The recent years covered by the NEE measurements (1997–present) were somewhat warmer and dryer than the long-term mean.

Measurements of the vertical flux of CO_2 and the energy balance components began in April 1997. The system consists of an ultrasonic anemometer (GILL Solent Research R3-50) and a fast response Li-Cor infrared CO_2/H_2O analyzer (LI-6262). Measurements are made at 4 Hz. Hourly fluxes of sensible heat, water vapour and carbon dioxide are calculated from the raw data. At tall tower based EC sites the storage term plays an essential role in the determination of the ecologically correct NEE (Yi et al., 2000; Davis et al., 2003; Haszpra et al., 2005). As it was pointed out by Yi et al. (2000) the contribution of storage increases with the measurement height. Consequently, the prerequisite of any tall tower related representativeness analysis is the adequate estimation of NEE that includes the accurately estimated storage term. The NEE data used in the