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# Partitioning of net ecosystem exchange using chamber measurements data from bare soil and vegetated sites

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ABSTRACT

A model of net ecosystem exchange (NEE) was suggested to study the influence of different environmental factors and to calculate daily and annual carbon budget. The model uses air temperature, incoming photosynthetically active radiation, vapor pressure deficit, and leaf area index as the explanatory factors for gross primary production, heterotrophic and autotrophic respiration. The model coefficients were calibrated using data collected by automated soil carbon dioxide ($CO_2$) flux system with clear long-term chamber at an urban grassland in Tomsk, Russia. Observation results obtained at two sites (bare soil and vegetated) allows to calculate the temperature sensitivity for soil and plant respiration. Revealed fast and slow responses of soil respiration to temperature contribute together to the pulsed behavior of heterotrophic respiration. The total annual NEE resulted in 163.5 g C m$^{-2}$. Growing plants accumulate 522.7 g C m$^{-2}$ in total, but the net annual release of $CO_2$ is higher (686.2 g C m$^{-2}$). The studied ecosystem is a source of carbon according to modelling and observation results. Results indicate that the suggested model is a promising tool for a better understanding of ecosystem biogeochemical processes.



## 1. Introduction

Terrestrial ecosystems are the source of uncertainty in our understanding of the global carbon cycle, which is strongly coupled with climatic change (Ciais et al., 2013). Interest in the estimation of the carbon fluxes in the terrestrial biosphere has resulted in the development of observation techniques and different modeling approaches integrating processes from the leaf-level to the whole ecosystem (Reichstein et al., 2005; Lee and Park, 2007; Bahn et al., 2008; Vesala et al., 2008; Gilmanov et al., 2013; Jia et al., 2014). Carbon dioxide fluxes can be readily measured by the eddy covariance method (Aubinet et al., 2012; Zanotelli et al., 2013; Baldocchi and Sturtevant, 2015) or with the chamber-based method (for short and small canopy) (Pumpanen et al., 2004, 2015; Jassal et al., 2012; Görres et al., 2016). These methods now serve as a basement for bottom-up estimates of continental carbon balance components.

Modeling approaches are useful to separate or partition the observed net ecosystem exchange (NEE) into gross primary production (GPP) and total ecosystem respiration (ER) components, since this provides better diagnostic about ecosystem processes and their regulating factors (Falge et al., 2002; Suleau et al., 2011; Runkle et al., 2013; Ciais et al., 2013; Jia et al., 2014; Baldocchi and Sturtevant, 2015). Partitioning of the NEE flux is needed to better understand interannual and spatial variability of carbon fluxes (Valentini et al., 2000; Xu and Baldocchi, 2004; Reichstein et al., 2005; Shi et al., 2012). Several approaches are popular for flux partitioning (Baldocchi and Sturtevant, 2015).

Photosynthetic response to light flux density have been studied for many plants (Pessarakli, 2005; Runkle et al., 2013; Jia et al., 2014; Baldocchi and Sturtevant, 2015). A rectangular hyperbolic saturation curve described by Thornley and Johnson (1990) is frequently applied in ecosystem analyses (Kandel et al., 2013; Runkle et al., 2013; Jia et al., 2014; Raivonen et al., 2015).

Ecosystem respiration consists mainly of above-ground vegetation, root and microbial respiration. Reliable methods for partitioning of ER into its components is necessary to estimate how ecosystem will respond to environmental perturbations (Golovatskaya and Dyukarev, 2009; Shi et al., 2012; Pumpanen et al., 2015). Understanding the response of ER to temperature change is important for predicting possible feedback between the global carbon cycle and climate system and improving carbon balance models. The determination of the respiration temperature sensitivity is extensively discussed (Reichstein et al., 2005; Golovatskaya and Dyukarev, 2012; Runkle et al., 2013; Jia et al., 2014; Baldocchi and Sturtevant, 2015). It was shown (Reichstein et al., 2005; Mahecha et al., 2010; Chen et al., 2011) that short-term and long-term ER temperature sensitivity values are different.

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The seasonal changes in the temperature sensitivity of respiration occurred due to the fluctuating microbial biomass (Janssens et al., 2003; Rodeghiero and Cescatti, 2005). Microbial biomass may vary considerably during the year, usually peaking in spring or summer.

Soil respiration (root and microbial respiration) is an important carbon flux between the terrestrial ecosystem and the atmosphere, and it plays a critical role in global carbon cycling (Kuzyakov, 2006; Comstedt et al., 2011). The trenching method was considered to be a simple and effective approach for soil respiration studies and it has been increasingly used (Jassal and Black, 2006; Bond-Lamberty et al., 2011; Comstedt et al., 2011; Díaz-Pinés et al., 2010). Debates about the accuracy and utility of trenched method are continued, but it is a labour-intensive commonly used method in soil respiration studies (Kuzyakov, 2006; Bond-Lamberty et al., 2011). It is criticized because of the large disturbance involved in trenching, uncertainties surrounding residual root decomposition (Comstedt et al., 2011), changes in the soil water status and microbial community (Díaz-Pinés et al., 2010), and potential changes in the soil $CO_2$ concentration gradient (Jassal and Black, 2006). A results obtained from the trenching experiments can overestimate the overall heterotrophic respiration (Comstedt et al., 2011).

Non-growing season $CO_2$ fluxes can be a very important part of the annual carbon balance, where the snow cover season is long (Wang et al., 2013). With the low temperatures and no living plants during the non- growing season $CO_2$ efflux mainly comes from heterotrophic respiration. The magnitude of the effluxes is considerably smaller under snowpack than that during the growing season (Shi et al., 2012; Wang et al., 2013; Pumpanen et al., 2015).

Only few studies have yet reported on the $CO_2$ fluxes at urban vegetated areas, and the available studies have focused on micrometeorological techniques or soil efflux only (Vesala et al., 2008; Kordowski and Kuttler, 2010; Decina et al., 2016). The role of urban grassland in the global carbon dioxide emissions is still remaining unclear.

The objective of this study was: (1) to develop a mathematical model for the estimation of $CO_2$ exchange fluxes for the urban grassland site, (2) to calibrate the model using $CO_2$ fluxes field observation data obtained using automatic transparent chamber and infra-red gas analyzer and (3) to estimate the carbon balance components and the total net ecosystem exchange for the urban grassland site.

## 2. Methods

### 2.1. Site description

The measurement site is located in the east part of Tomsk city (West Siberia, Russia) at the Lower Observation Point of Institute of Monitoring of Climatic and Ecological Systems of Siberian Branch of Russian Academy of Sciences (IMCES SB RAS). The Lower Observation Point (56° 28.5′ N, 82° 3.2′ E; 170 a.s.l.) is situated behind the main building of the Institute. This place is an area approximately 0.1 ha with sparsely distributed meteorological equipment. The observation site can be referred as an urban grassland ecosystem. The ground vegetation consists of *Taraxacum officinale* and *Poa pratensis*. The soil is an Alfisols with clay-enriched subsoil. The vegetation is usually mown twice a summer, but during the summer 2014 vegetation has not been disturbed on a distance of 5 m around the measurement site.

There is a humid continental climate at the observation site according to weather station Tomsk (WMO ID 29430). Annual average (1981–2010) temperature is 0.87 °C. Winters are severe and lengthy. Average temperature in January is between −21 °C and −13 °C. Average temperature in July is +18.7 °C. Total annual precipitation is 568 mm with maximum in July (75 mm). Snow cover lasts 181 days on average. Total annual sunshine duration is 2123 h. (http://www.pogodaiklimat.ru/climate/29430.htm, accessed 05.05.2016).

### 2.2. $CO_2$ fluxes measurements

An experimental setup equipment was operating from 14 April 2014–20 October 2014. LI-8100A (LI-COR Biosciences, USA) automated soil $CO_2$ flux system with clear long-term chamber (8100-104C model) was used for continuous soil efflux measurements. The LI-8100A utilizes a closed dynamic chamber accumulation method with an infrared $CO_2/H_2O$ analyzer to determine $CO_2$ concentrations (LI-COR Biosciences, 2010). The chamber was opened most of the time exposing the chamber interior to the ambient conditions. While measuring the chamber was closed intermittently for 2 min. Measurements were repeated every twenty minutes. Raw data were collected at the observation point, and flux rates were calculated using the LI-8100A software. $CO_2$ flux was estimated based on the change of $CO_2$ concentration within chamber from the exponential fit curve (LI-COR Biosciences, 2010). The LI-8100A device was factory calibrated and checked for zero drift before the experiment using $CO_2$-free nitrogen gas. Comparison of known mass-flow fluxes with the LI-8100A measurements shows that mean absolute error is 3% of the flux (Xu et al., 2015).

Two plastic basements with inner diameter of 20 cm were installed in both vegetated area and bare soil area. The LI-8100A automatic chamber was placed at two sites consequently 2–5 times in a month for few days. Vegetation at the observation point gradually developed from mid-April to July. Longest experiment with vegetated plot was performed from 1 to 15 September. Shortest experiment with bare soil was in mid-May. Total number of days with the experimental investigation of $CO_2$ fluxes in 2014 was 98.8. Totally eleven experiments were carried out during 65 days with vegetated site and eleven experiments during 33.4 days with the bare soil site.

The bare soil site (trenched soil site) was prepared six months before the experiment. Vegetation at the site was thoroughly cut in September 2013, large roots were extracted from the surface layer. There was no soil digging to keep the soil compaction and inner structure, so some amount of fine roots remained in the soil. During summer 2014 all small sprouts of new vegetation were pulled out from the bare soil site. The ground was kept free of any vegetation during the study period. The $CO_2$ flux measured at the bare soil site in the absence of vegetation represents the heterotrophic respiration flux (HR), which results from a litter and soil organic matter decomposition produced by soil micro-organisms. The total $CO_2$ flux measured at the vegetated site by transparent chamber is defined as the net ecosystem exchange between an ecosystem and the atmosphere (Suleau et al., 2011).

Winter time experiments were organised to estimate the total annual carbon balance. Non-growing season $CO_2$ effluxes were measured from October to April in 2010–2012 (see Supplement Table S2). $CO_2$ flux measurements from the snow surface was made using the manual opaque plastic chamber, and the chamber was closed during 30 min.

In this study NEE is negative when the value of GPP exceeds the ER value and there is a net removal of carbon dioxide from the atmosphere. NEE is positive when the ER value exceeds the GPP value and carbon dioxide is released from the ecosystem to the atmosphere. GPP and ER were defined as a positive flux.

### 2.3. Environmental conditions measurements

Environmental variables were measured using the Automated Meteorological Informational Measurement System (AMIMS)