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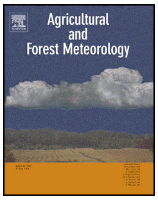

Soil contribution to carbon budget of Russian forests

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ABSTRACT

The flux of CO_2 from the soil to the atmosphere–soil respiration (R_S), is one of the least known components of the terrestrial carbon cycle. R_S depends on many factors and varies substantially in time and space. High uncertainty of R_S flux valuation leads to a wide range of reported carbon budget estimates for Russian forests. We developed a modeling system for assessing soil carbon stock and heterotrophic soil respiration based on a possible maximum of relevant input indicators. The most comprehensive databases of R_S in situ measurements focused on Northern Eurasia (780 records for the region) has been used. A statistical model for assessing R_S of Russian forests and its separation in autotrophic and heterotrophic parts were elaborated based on in situ measurements, climate parameters, soil and land cover datasets. The spatial resolution of the model is 1 km^2. Russian forest soil accumulated 144.5 Pg C (or 17.6 kg C m^{-2}) in 1 m depth, including 8.3 Pg C (or 1.0 kg C m^{-2}) in the labile topsoil organic layer. The total heterotrophic soil respiration (R_H) flux for the Russian forest is estimated at 1.7 Pg C yr^{-1} (206 g C m^{-2} yr^{-1}) that comprises 65% of Net Primary Production (NPP) and together with NPP is one of two major components of the net ecosystem carbon balance comprising on average 546 Tg C yr^{-1} (66 g C m^{-2} yr^{-1}) for 2007–2009. Interannual variability or R_H in 1996–2005 was estimated at 4.1% for forests of the whole country and typically from 5 to 11% for large individual regions with an average linear trend +0.2% per year. The uncertainty of annual average of R_H was estimated at 8% (confidential interval 0.9).

1. Introduction

Forests play an important role in the carbon (C) cycle and carbon sequestration at both regional and global scales. They represent the largest terrestrial ecosystem containing about 1150 Pg of organic carbon in live biomass, plant detritus and soil organic matter (Dixon et al., 1994). Whether forest is a source or sink of carbon to the atmosphere largely depends on the ratio between photosynthetic immobilization and respiratory release of CO_2 and on various disturbances (Malhi et al., 1999).

Soil is recognized as the largest terrestrial carbon reservoir in the global carbon cycle (Janzen, 2005). Depending on soil type, tree species and the impacts of disturbances, soil can contribute up to 96% of the total carbon stock in forest ecosystems (Rumpel and Kögel-Knabner, 2011; Mukhortova, 2012). Soil can accumulate or release carbon depending on climatic conditions, disturbance type and level, soil characteristics, and vegetation type. Each soil type has its own carbon carrying capacity—an equilibrium carbon content that depends on the soil properties, vegetation type and hydrothermal conditions (Guo and Gifford, 2002). This equilibrium C content is the outcome of a balance between input and output fluxes to the pool of soil C (Fearnside and Barbosa, 1998; Guo and Gifford, 2002). The main source of organic matter input into the soil is vegetation and the amount of this input depends on ecosystems' productivity. The output flux includes mineralization of organic matter, losses due to disturbances and leaching of dissolved organic carbon from the ecosystem (Guo and Gifford, 2002).

The mineralization efflux of CO_2 from the soil surface (soil respiration—R_S) is a key component of the carbon cycle of terrestrial ecosystems, which can contribute 50–95% of total ecosystem respiration (e.g. Xu and Qi, 2001). R_S is the sum of such processes as autotrophic root respiration (R_A) and plant residues decomposition (respiration of heterotrophic organisms). It can vary significantly across both time and space according to changes in vegetation and soil properties (e.g. Rochette et al., 1991; Stoyan et al., 2000; Xu and Qi, 2001; Raich et al., 2002; Hibbard et al., 2005). However, on short time scales, variation in soil CO_2 flux is mainly driven by soil temperature and moisture (e.g. Raich and Schlesinger, 1992; Peng

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and Thomas, 2006). The CO_2 emission from soil increases exponentially with increasing temperature when any other factors and resources are not limiting (Lloyd and Taylor, 1994) that often is modelled through Q_{10} coefficient. However, many studies report large variability of Q_{10} for the same sites during the growth season, e.g. from 1.98 to 5.00 for sod-poszolic soils and from 1.72 to 6.20 for gray forest soils (Kurganova, 2010), that may generate uncontrolled biases in the results. The relationship between intensity of soil CO_2 flux and soil moisture can be described by an upward convex curve (Peng et al., 2008).

Russian forest is a significant element of the global carbon budget (Pan et al., 2011), and hence they can play an important role in climate change mitigation. They comprise about 23% of the entire world's forest area. Forest land and forested area (closed forests) cover 51.6% and 45.3% of the total land area of the country respectively (Onuchin et al., 2009). These forest areas contain 21% of the world's growing stock, and 13% of the live forest biomass of the globe (FAO, 2009). They keep about 43 Pg C in terrestrial vegetation including 35 Pg C in live biomass (Shvidenko et al., 2007, 2009).

Current science on climate change has been coming to understanding of need of a terrestrial ecosystems full and verified carbon account (FCA). Uncertainty of the FCA is crucially driven by uncertainty of R_S and particularly its heterotrophic part (Shvidenko et al., 2010a,b). The major objective of this study is assessing the soil contribution to the current carbon budget of Russian forests aiming at uncertainty's level that would not exceed some certain levels acceptable for policy makers. The latter still remains a topic of discussions. Some studies indicate a presumptive level of ±20–25% (CI 0.9) for net ecosystem carbon budget at the continental scale (Nilsson et al., 2007). It means that uncertainty of R_h should not exceed this threshold. While a wide range of climatic conditions, diversity of landscapes and forest ecosystems and other drivers over the vast territory of Russian forests results in a large temporal and spatial variety of soil respiration, this study attempted to understand whether the FCA of forest ecosystems is achievable under proper organization of the information background and consistent application of systems (holistic) analysis. The paper also includes some results on forest soil carbon stock that have been earlier published in an aggregated form (Schepaschenko et al., 2013) taking into account relevance of consideration of links between the amount of carbon and heterotrophic respiration.

2. Materials and methods

2.1. Assessment of soil carbon pool

The soil organic carbon (SOC) pool was calculated separately for the topsoil organic O horizon (FAO, 2006) and for 1 m of soil below. The soil map of the Russian Federation at a scale of 1:2.5 million and a reference soil profiles' database (modified by authors from Stolbovoi and McCallum, 2002) were used to calculate the SOC pool for typical soil profiles and their distribution over the country. A database of soil carbon measurements (1068 records) was collected from published papers. It was used for accounting of zonal/regional specificity of SOC storage, vegetation type and land-use impact via a special system of correction coefficients.

The method of assessment of the SOC pool is described in detail in Schepaschenko et al. (2013).

2.2. Soil respiration database

We collected the majority of studies on R_S measurements in situ that were reported in peer-reviewed scientific literature and organized the reported results into a database. A substantial part of the data was picked up from the global database by Bond-Lamberty and Thomson (2010) that accounted for 3379 records from 818 studies. We have taken from this database only the records for the extra-tropical northern hemisphere where annual R_S flux or mean seasonal rate of R_S were reported or root contribution to the total carbon flux from soil was presented. Data from another 291 sources were collected by us on the same basis especially focusing on Russia. We aim to contribute this data to global database by Bond-Lamberty and Thomson.

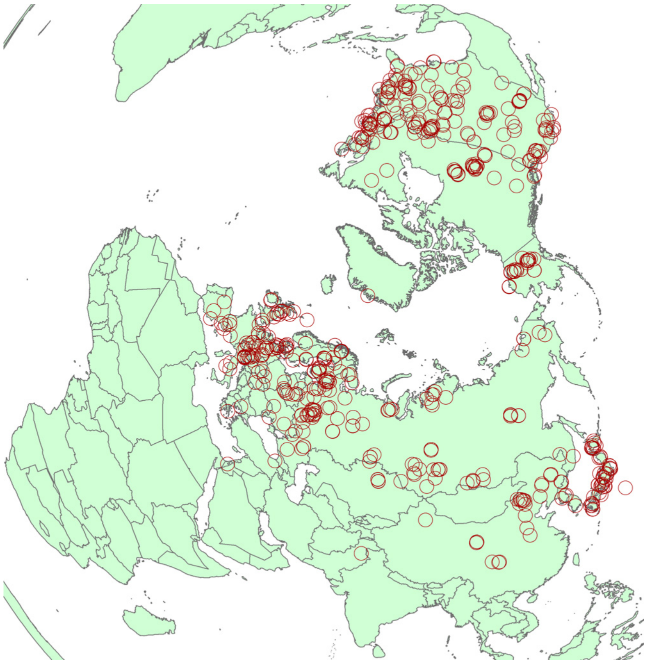

Fig. 1. Locations of collected database observations of the northern hemisphere.

In total, about 810 studies were used and 2254 records on R_S fluxes in arctic, boreal and temperate biomes were collected, spanning the measurement years 1961–2008. The regions represented are following: Northern America—1055 records, Europe—833 and Asia—366 (Fig. 1). Data from temperate ecosystems dominate the database ($n = 1287$), and the boreal zone is represented by 735 records. Most of the data came from forests ($n = 1532$), while grasslands ($n = 243$) and arable ($n = 131$) land are less represented.

The magnitude of annual R_S flux varied from 1 to 5180 g C m^{-2} yr^{-1} for all ecosystems and the majority of records varied between 100 and 1000 g C m^{-2} yr^{-1}.

Besides R_S measured value, the database contains information on climatic zone, vegetation class, soil group and 15 climatic characteristics (Table 1) for the year of measurements.

Climate data (temperature and precipitation) for the period 1974–2008 were obtained from FOODSEC (http://mars.jrc.ec.europa.eu/mars/About-us/FOODSEC/Data-Distribution). FOODSEC receives daily, 10-days and monthly outputs of the ECMWF (European Centre for Medium-Range Weather Forecast) global circulation model and provides the data aggregated for 10-day periods. The original global data are at 0.25° resolution. The data are provided by the ERA40 historical reanalysis time series project at 0.5° resolution.

Table 2 contains a list of climatic parameters we calculated for each year between 1974 and 2008 based on FOODSEC reanalysis.

The climate grids were then overlaid with the plot locations and the climate information was extracted for each plot and placed in the database for the year of measurement. For the measurements made before 1974 or without clear date (all together around 10%) we had to apply multiyear average climatic parameters.