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Influence of precipitation on CO_2 soil emission in pine forests of the Central Siberia boreal zone

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Abstract. Boreal forests in Siberia cover more than 70% of the area of this region. Due to climate change these ecosystems represent a very sensitive and significant source of carbon. In the forests, the total ecosystem respiration tends to be dominated by the soil respiration, which accounts for approximately 70% of this large flux. Global models predict that the soil respiration will increase more than the total net primary productivity in response to climate warming and increasing precipitation. In consequence, the terrestrial carbon sink is expected to decline. However, for the Siberian boreal forest there is still a gap in understanding of the future response of soil emission to drought or overprecipitation conditions. In our study we estimate how various moisture conditions could change soil emission in the boreal zone. From field observation data we find optimal soil moisture conditions. The highest dependence between the soil temperature and soil emission rates has been obtained under the optimal soil moisture conditions.

1. Introduction

Boreal forests cover about 11% of the earth's land surface, being the largest terrestrial biome. These forests play a significant role in the global carbon cycle and are particularly sensitive to future climate warming [1]. The soils of the boreal region contain huge reserves of carbon accumulated over hundreds of years. Thus, the way boreal soils react to the current climate change [2] is likely to have a significant impact on the sustainability of forest ecosystems and the future concentration of CO_2 in the atmosphere.

On the seasonal scale, CO_2 fluxes from the soil strongly correlate with changes in the soil temperature when water is not a limiting factor [3]. A strong inhibition of the flow rates was observed with a low water content in the soil [4, 5], which is mainly due to a decrease in decomposition due to reduced microbial activity. However, the increased water content in the soil remains the subject of debate. The dependence of the CO_2 flux on humidity will often be specific, depending on the geographic location of a territory. In addition, the seasonal dependence of soil CO_2 emissions on the water content in soil is still poorly understood, since changes in the soil temperature and water content often correlate with each other, and the independent influence of each variable is difficult to detect or interpret [6].

The main goal of this work is to consider the reaction of soil CO_2 emission to a differentiated amount of precipitation for two seasons in the pine forests of Central Siberia, which are fundamentally different in terms of the moistening conditions.

2. Materials and methods

2.1 Study area

The investigations were carried out in the Turukhansk district of Krasnoyarsk region (60 ° N, 90 ° E). The main factor of the plant community distribution in this area is the groundwater table. The climate of the region is sharply continental. The sum of temperatures above 10 ° C is 800-1200 ° C. The average annual air temperature is minus 3.7 ° C. The amplitude of fluctuations of the mean monthly temperatures is 41.9 ° C. The average annual relative humidity of the air is 76%. The amount of precipitation is 590 mm per year [7].

2.2 Experiment sites

The study sites were located in lichen pine forests which represent not only a basis of the region's forest resources, but also have a low recovery rate after the action of various types of external factors and disturbances. Experimental work on introducing a differentiated amount of precipitation was carried out during the growing seasons (June-September) in 2015 and 2016. Four precipitation levels were chosen according to the amount of precipitation: 0%, 25%, 50%, and 100% (field conditions) of the field amount of precipitation after each rain event. The addition of a differentiated amount of precipitation was performed next morning. The experiment construction consisted of wooden boxes with a hinged roof 3 * 1 m2 in size, covered with polyethylene on top and on the longer sides. The height of the structure above the soil surface was about 20 cm. In each box, 3 plastic measuring collars were installed. The ground cover – lichen (Cladonia stellaris (Opiz) Pouzar et Vezda, Cl. arbuscula (Wallr) Flot.) – remained for the whole time of the experiment.

2.3 Measurements and data analysis

On each sample plot, plastic rings with a diameter of 20 cm were installed before the start of the experiment - in the spring of 2015. The soil CO2 efflux was measured by using an automated system unit based on an infrared gas analyzer LI 8100A (Li-cor Biogeosciences Inc., USA) with a survey chamber (8100-103) eight hours after the addition of water. The soil temperature was measured with a Soil Temperature Probe Type E thermocouple (Omega, USA). The soil moisture measurements were carried out at a depth of 5 cm from the soil surface using a Theta Probe Model ML2 (Delta T Devices Ltd., UK). A detailed measurement procedure was described in our earlier paper [8].

For analysis and processing of the observation data, licensed software LI8100_win-4.0.0 was used. In addition, a number of programs were used for statistical processing and data analysis: Microsoft Excel 2010, SigmaPlot 11.0, Statistica. The coefficient Q10 was determined from the van't Hoff equation [9] by the following formula:

$$Q_{10} = \left(\frac{R_2}{R_1}\right)^{\left(\frac{10}{T_2 - T_1}\right)} \quad (1)$$

where T_1 and T_2 are the soil temperatures, R_1 and R_2 are the respiration rates of the soil CO_2 emission at T_1 and T_2. The temperature coefficient was calculated for the soil temperatures on average from 5 to 21 °C in 2015, from 8 to 20 °C in 2016 for sites with different precipitation levels.

3 Results

3.1 Meteorological parameters and soil emission

The seasons of the experiment were obviously different in the meteorological conditions (Figure 1). When compared with the average long-term values (1966-2016) for the amount of precipitation (Figure 1b), in 2015, almost throughout the season, the rainfall was exceeded twice, except for the beginning of the season. The next season, on the contrary, demonstrates the opposite conditions of moistening, when the sum of precipitation at the beginning and at the end of the season was 3 times lower than the average long-term values.

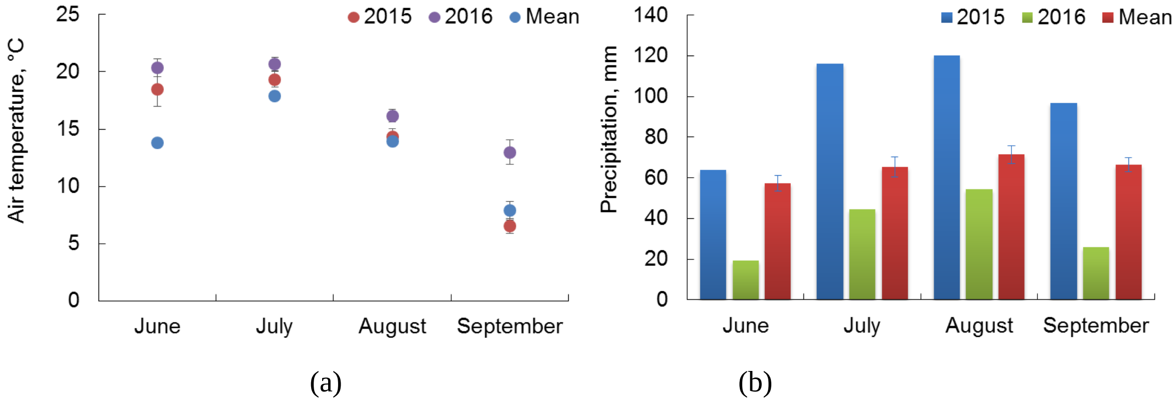

Figure 1. Meteorological conditions of growing season in comparison with average (Mean) values from the Bor meteorological station (data source – www.meteo.ru): (a) air temperature; (b) amount of precipitation. The data are average monthly values with standard errors.

As for the temperature conditions, there is no significant difference in the values for the two years of the experiment (Figure 1a). However, for a number of parameters (characteristics), one can identify some differences. At the beginning of the season (June), for two measurement seasons the air temperature exceeds the mean long-term values (1936-2016). The next difference exists only for 2016, it is the excess of the mean annual values at the end of the season by 1.6 times (by 5.1 ° C) at the end of the season (September).

The meteorological conditions of the season were reflected by the soil CO_2 efflux. Based on the magnitude of the fluxes, a maximum was observed in 2015 (Figure 2a), with wet conditions almost throughout the season. Maximum rates of the soil CO_2 emissions were inherent in the site without any precipitation during the season. The site with 25% of the precipitation amount is characterized by the mean flux rates. Such results were due to inhibition of the CO_2 fluxes by a significant amount of water. For the second season (Figure 2b) of the experiment, significantly different results were obtained. It was quite difficult to identify a site with maximum soil emission. However, due to the comparatively small measurement error, the site with 100% precipitation amount is characterized by the greatest soil CO_2 emissions during the season.

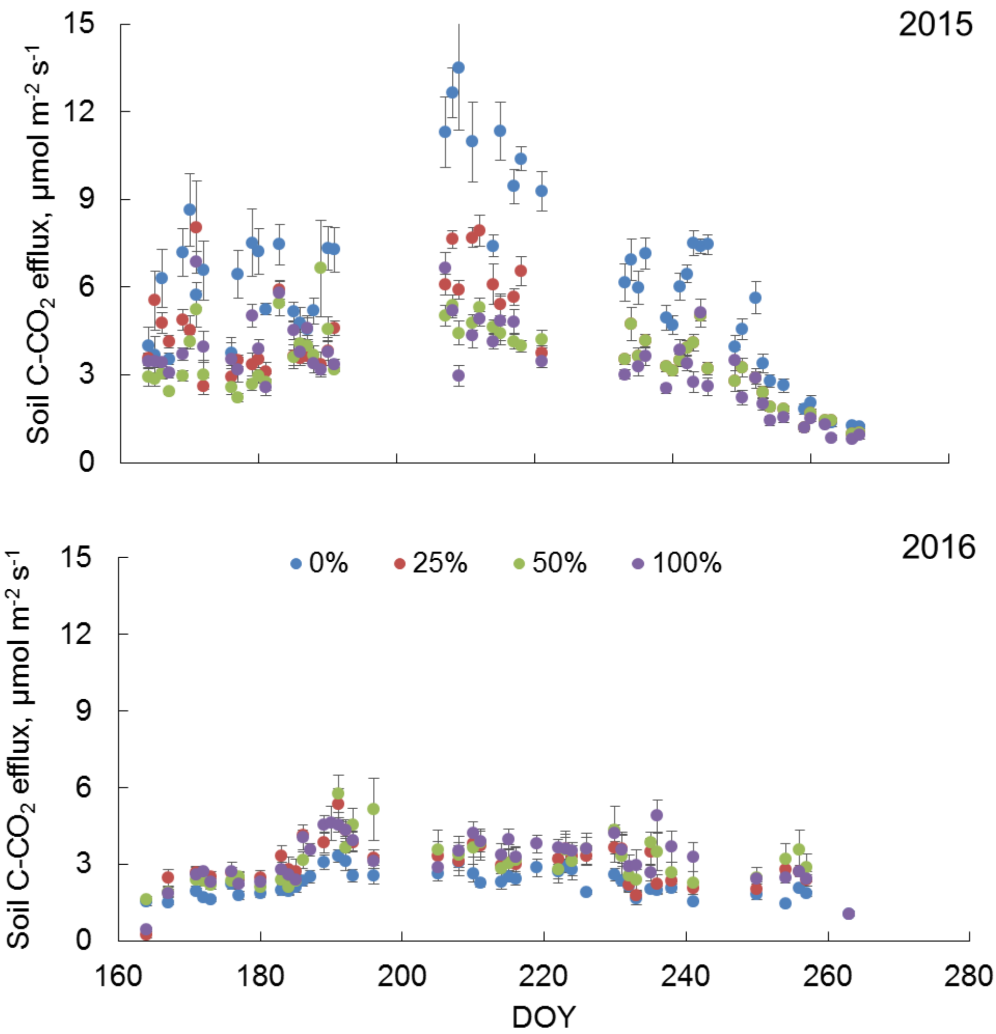

Figure 2. Seasonal dynamics of soil CO_2 emission for four precipitation levels for two seasons: (a) 2015, (b) 2016. The data present daily average values with standard errors.

In general, the season of 2016 was distinguished by arid conditions accompanied by high temperatures at the beginning and at the end of the season. Minimum rates of the soil CO_2 emissions were observed on the site without precipitation (Table 1).

Table 1. Mean seasonal data of soil emission and precipitation conditions.

	2015				2016			
Precipitation level	0%	25%	50%	100%	0%	25%	50%	100%
Mean seasonal flux (µmol C-CO_2 m^{-2} s^{-1})	6.1 ±0.6	4 ±0.3	3.4 ±0.3	3.4 ±0.3	2.2 ±0.2	3.1 ±0.4	3.1 ±0.5	3.3 ±0.3
Σ precipitation addition (mm)	0	89.5	179	357.9	0	48.6	97.2	194.3
Mean seasonal	10.1	25.5	25.4	21.5	13.5	17.8	24.9	21

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soil moisture (%)	±0.3	±0.9	±0.8	±0.6	±1.2	±0.9	±1.1	±0.6

The presented mean seasonal data underline two main points for both seasons: 1) the precipitation conditions can explain the soil emission rates only partly; 2) the natural field moisture conditions for the dry and wet seasons are similar.

3.2 Relations with soil conditions

The dependence of the CO_2 fluxes on the meteorological parameters of the soils for the two seasons also differed significantly. It was found that in 2015 for the most part of the season there was a high exponential dependence between the temperature rising and the emission rate (Figure 3). In 2016 during the season there were a few big rain events and including colder temperatures gave a small relation for the sites with higher (50 and 100%) precipitation levels.

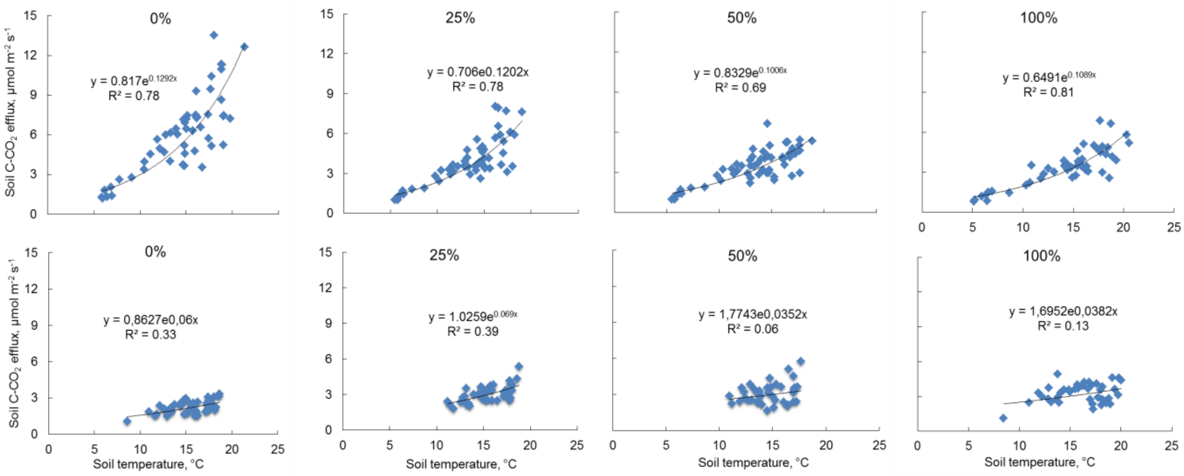

Figure 3. Relationship between soil temperature and soil CO_2 emission for different precipitation levels for two seasons.

At further consideration, the following dependence was found: the greater the number of days with soil moisture from 20 to 22%, the stronger the dependence.

3.3 Q_{10} coefficient

To check the differences in the temperature dependence, we calculated the Q_{10} coefficient (Figure 4). It shows that in a more humid year (2015) in treatments less than 100% (field conditions) the Q_{10} coefficient was significantly higher than in the dry season of 2016. In the dry year the Q_{10} coefficient did not change for all different water treatments (0, 25, and 50% of the precipitation amount). For both seasons for the 100% precipitation site (field conditions) Q_{10} was equal for two comparable seasons due to the precipitation conditions.

In the more humid season the Q_{10} coefficient for two groups (0 and 25% of the precipitation amount) is higher because of a high temperature dependence and the largest number of days with optimal moisture conditions: 20-22% SWC (Figure 3).

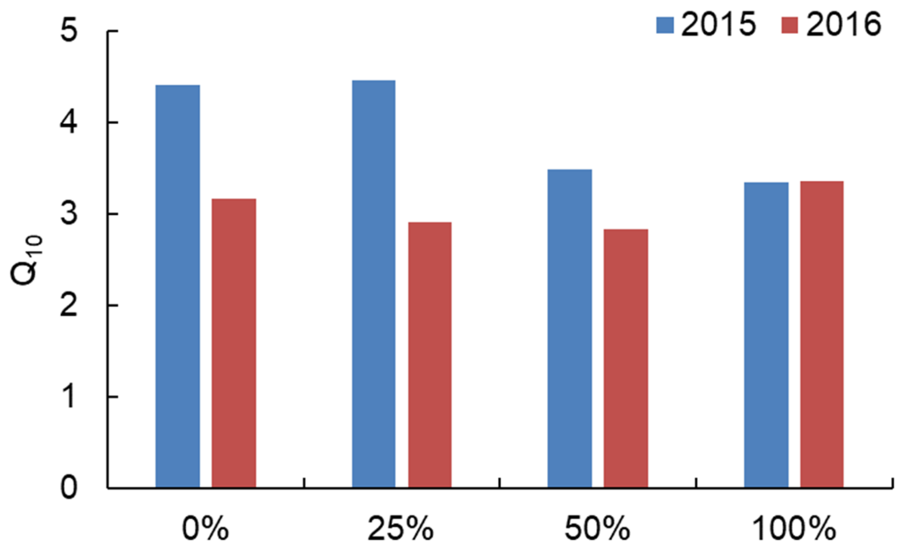

Figure 4. Q_{10} coefficient for four precipitation levels: 0, 25, 50, and 100% of the field conditions (rain event) for two seasons.

This suggests that the soil field conditions can adapt to different amounts of the precipitation input during the season and modify the soil emission rates: in the dry season by the decreasing the soil emission, and in the wet season, max soil emission in optimal water conditions.

4. Conclusions

A peculiarity of the pine forests of Central Siberia is their high sensitivity to the moistening of the territory during the growing season. The studied seasons demonstrated a diametrically opposite reaction of soil CO_2 emissions to various amounts of precipitation. A change in their amount may inhibit (at significant amounts) or intensify (at optimal moistening conditions) the rate of CO_2 fluxes from the soil.

The meteorological characteristics of the soil during the season may participate differently in the formation of soil CO_2 emissions. In the course of the experiment, optimum humidification conditions were determined under which the CO_2 flux was the highest for the soil temperature and the soil CO_2 emission rates, i.e. there was no restriction on this factor.

Acknowledgements

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