Soil temperature response of soil respiration in Central Yakutia

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Introduction

Soil respiration is one of the most intense component flux in the global carbon cycle, equal to or little less than NPP estimated as 100-120 Gt year^{-1} [IPCC, 2001]. Thus it is predictable that even very small increase of soil respiration will cause considerable changes in annual carbon emission into the atmosphere. Increasing of annual averages of positive temperatures and amount of summer precipitation due to forecasted global climate changes will be reflected in hydrothermic regime of soils in cryolithozone (Oechel et al., 1993; Israel at al., 1999; Scott et al., 2000). D.S. Schimel et al. (1994) calculated that about 11 Gt of carbon (0.5% of total soil carbon) will be released per every 1K of temperature rise («The Century» model). It is also necessary to keep in mind such an important factor as high temperature sensitivity of soil respiration (Rustad et al., 2000; Stott et al., 2000).

Rise of average annual air temperature for the last 25-30 years in northern regions of Russia is estimated to be 0.2-2.3°C. Widely observed modern degradation of cryolithozone is connected with climate warming globally and with increased snow cover height in some regions. Forecasted air temperature rise in northern Russia may reach 3-5°C by 2050; change of precipitation regime to increase in summer amount is expected as well.

The aim of this study was estimation of soil respiration (F_{soil}) values against some environmental parameters. We tried to describe dependency of F_{soil} on soil temperature (T_{soil}) and moisture (η), to study temporal variability of F_{soil} and calculate seasonal cumulative soil CO_2 flux in some years differing in meteorological conditions.

Materials and methods

The study was conducted on the base of "Spasskaya Pad" forest station of IBPC SD RAS (Yakutsk, Russia). The study site is located at 62°15'N, 129°37'E, in 180-year-old cowberry Larch forest (Laricetum vacciniosum) growing on permafrost pale-solodic soil based on light old-alluvial sandy loam. The investigations were made using a full-automated soil respiration system (ASRS, Alterra, Netherlands) including CIRAS-SC IRGA (PP Systems, UK) measuring CO_2 samples taken every 1 hour by 4 auto-operated 32 cm diameter soil chambers with complementary soil temperature and moisture sensors penetrated into soil 5 to 10 cm deep.

The measurements were made in 2001 and 2004-2006. Meteorological conditions of these years are presented in Table 1.

Table 1

Precipitations and air temperature data, Yakutsk station

Year	Monthly average					Sum / Seasonal average
	May	Jun	Jul	Aug	Sep	
Rain, mm Many years average (for study period) = 158 mm						
2001	28	11	4	13	12	**68**
2004	15	22	30	42	19	**128**
2005	35	10	69	71	14	**199**
2006	11	13	27	151	54	**256**
Air temperature, °C Many years average (for study period) = 12.4°C						
2001	8.1	16.1	23	14.9	3.5	**13.12**
2004	6.2	13.7	18.8	13.8	6.9	**11.88**
2005	8.6	17.5	18.8	13.9	9.4	**13.64**
2006	7.5	17.3	18.7	15.9	7.0	**13.28**

The years studied were greatly different in hydrothermal regimes of the months with positive air temperatures (vegetative season). A period from May to September was chosen by us as the most important one for the assessment of soil CO_2 emission.

Each studied season was divided into two periods using the inflection point of T_{soil} and η on a seasonal curve as criteria for the separation, thus facilitating a better regression analysis. The 1st period (generally from mid May to mid July) appears to be a drying out one after it was watered by the previous autumn and current spring soil water, T_{soil} increasing at the same time. The 2nd period commonly starts from the end of July and continues until late August to early September; it is characterized by η increasing after late summer precipitation combined with maximum permafrost thawing concurrently with a slow decrease in T_{soil}.

Results and discussion

The study results showed that the extremes on diurnal F_{soil} curve are so connected with T_{soil} that they appear in 4-6 h after the extremes on diurnal T_{soil} curve, thus reflecting delayed movement of heat “wave” into the ground, i.e. its heat inertance. In other words, diurnal trend of F_{soil} magnitudes depends on T_{soil} with a lag of 4-6 h.

As seen from Table 2, correlation of F_{soil} values with changes in T_{soil} is minimal at mid-season and almost equals the coefficients of η. However, correlation coefficient of F_{soil} and T_{soil} at the beginning and close of the growing season is more than twice as high as at mid-season. The higher η, the lower correlation coefficient, and if η exceeds 16-20% then the coefficient changes its sign, i.e. correlation becomes negative. Such a situation, in our opinion, could be related to lower degree of soil aeration because of high moisture content in the ground that causes low respiratory activity of microorganisms and plant roots due to the lack of oxygen.

Table 2

Measured weekly average values and correlation coefficients (soil respiration vs. soil temperature [T_{soil}] and moisture [η])

Year	Parameter	Season		
		Beginning	Middle	End
2001	T_{soil}, °C	– / – *	11.33 / *-0.04*	6.05 / *0.76*
	η, kg·kg^{-1}	– / –	0.16 / *-0.05*	0.12 / *0.58*
2004	T_{soil}, °C	1.49 / *0.78*	11.90 / *0.32*	5.80 / *0.80*
	η, kg·kg^{-1}	0.22 / *0.08*	0.08 / *0.52*	0.09 / *0.78*
2005	T_{soil}, °C	3.47 / *0.77*	12.13 / *0.26*	6.52 / *0.68*
	η, kg·kg^{-1}	0.16 / *-0.11*	0.12 / *0.30*	0.20 / *0.01*
2006	T_{soil}, °C	5.53 / *0.71*	10.48 / *0.20*	7.14 / *0.52*
	η, kg·kg^{-1}	0.47 / *-0.58*	0.17 / *0.22*	0.65 / *-0.85*

* Numerator – average value;
denominator – correlation coefficient.

It is seen also that the higher mean T_{soil} for a decade, the lower F_{soil} correlation coefficient with temperature that seems to contradict Vant-Goff law. However this regularity, in our opinion, may be explained by the fact that at low η values not temperature but η itself becomes a limiting factor. It should be remembered as well that permafrost soils contain a lot of psychrophilic microorganisms that manifest their high activity exactly at low temperatures. In dry years, high amount of cellulose-fermenting microorganisms invokes soil CO_2 efflux comparable with that of humid years. But it should be noted that according to I.A.Mazilkin’s (1955, 1956) studies the content of cellulose-fermenting microorganisms in permafrost pale soils of Olekminsk region and Central Yakutia is low compared to the amount of microscopic fungi, particularly Trichoderma, Chaetomium and Lypomyces genus. We suppose that bigger part of F_{soil} is produced namely by these fungi. This question is getting a special concern in relation to the problem of separating F_{soil} components of permafrost soils of Yakutia and requires further studies.

Investigation of seasonal F_{soil} dynamics revealed that maximum magnitudes of CO_2 emission are observed from mid July to mid August (6.9-10.5 μmol CO_2 m^{-2} s^{-1}), when T_{soil} reaches its maximum values (10.5-15.4°C). Total seasonal F_{soil} course is reverse to seasonal trend of η and directly proportional to total trend of T_{soil} (Fig. 1).

As seen from Table 3, negative correlation between F_{soil} and η was observed at the first half of the season for all the years that indicated sufficient soil watering at season start. However, at the second period of dry years (2001 and 2004) there is positive correlation between CO_2 emission and η, while in humid years (2005 and 2006) the correlation remains negative. This testifies to continuing drying out of soil at the second period in dry years that cannot be stopped by sparse precipitation. Rain water evaporates from soil surface, thus not saturating the lower soil horizons by water. T_{soil} was the main factor affecting F_{soil} for all the years. In dry periods the effects of T_{soil} and η get equal that is proved by about the same correlation coefficients for the season.

Table 3

Seasonal correlation coefficients of soil respiration vs. soil temperature and moisture

Parameter	Season		Seasonal
	1st half	2nd half	
2001, extremely dry, warm			
Soil temperature	0.59	0.95	0.89
Soil moisture	-0.46	0.90	0.71
2004, dry, cold			
Soil temperature	0.92	0.73	0.65
Soil moisture	-0.76	0.63	-0.33
2005, moist, warm			
Soil temperature	0.91	0.94	0.90
Soil moisture	-0.83	-0.57	-0.16
2006, wet, warm			
Soil temperature	0.92	0.93	0.93
Soil moisture	-0.77	-0.90	-0.78

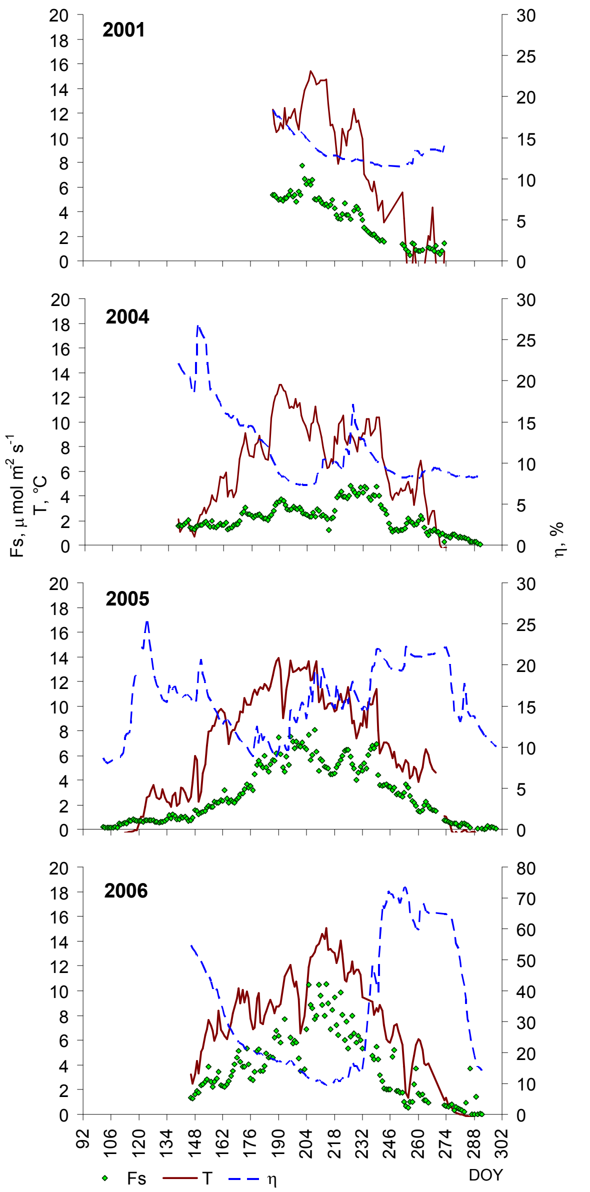

Fig. 1. Seasonal curves of soil respiration (Fs), soil temperature (T) and moisture (η).

Standardized regression coefficients for soil temperature and moisture (Table 4) showed that T_{soil} (regression coefficient 0.90) is a factor most impacting CO_2 emission by larch forest soils of Central Yakutia, while η factor's power is 3 times as less. T_{soil} has stronger effect at the first half and effect of η is reverse, though anyway is less than influence of T_{soil}. On average for the season the degree of T_{soil} influence was significantly (2-7 times) higher than the impact of η.

Most important result of soil CO_2 emission study is the cumulative sum (balance) of CO_2 for a specified time. Interannual variations of carbon dioxide efflux in the form of cumulative sum of CO_2 release by soil for the studied years are shown in Fig. 2.

Table 4

Standardized regression coefficients for soil temperature and moisture

Parameter	Season 1st half	Season 2nd half	Whole season
Soil temperature	0.89	0.74	0.90
Soil moisture	0.15	0.28	0.30

CO_2 flux magnitude was maximal in very warm and humid 2006, and reached 5.83 t C ha^{-1}. In 2001 and 2004 the maxima were 3.62 and 3.33 respectively. These two years were similar in the relative amplitude of hydroclimatic conditions, except that precipitation amount in 2001 was about twice as less as in 2004 but air temperature was higher in 2001. In warm and humid 2005 the magnitude of annual carbon emission made 4.91 t ha^{-1}. Thus, carbon release into the atmosphere in the form of CO_2 was on average by 65% higher in humid years compared to dry ones.

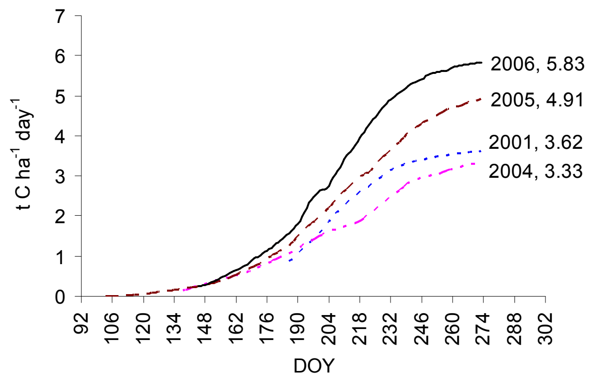

Fig. 2. Seasonal cumulative carbon flux from larch forest soils.

As seen from Table 5, most discharges of carbon into the atmosphere occurred in July-August, in dry and warm 2001 the maximum being in July, and in cool 2004 – in August.

Of particular interest is that the peak of F_{soil} intensity happens in July – the period of the highest photosynthetic activity of wild vegetation, both herb and wood-shrub (Maximov et al., 2005). Therefore, most bulk of emitted soil CO_2 is assimilated by plants in photosynthesis process. However, photosynthesis begin to cease after mid August and completely stops at the first decade of September, while CO_2 release from soil continues until freezing of the upper soil horizons at the end of September – beginning of October. On average, about 10% of annual CO_2 efflux from soil is accounted for September. This part of released carbon dioxide may be thrown into the atmosphere, being not utilized in photosynthesis. At the same time, mean assimilation of carbon by larch forests is about 7-8 t ha^{-1}. So, in the balance, almost all CO_2, released from soil for the season, is absorbed by plants. In the light of these statements, our earlier hypothesis postulating that the main bulk of CO_2 released by soil respiration at the end of summer – autumn partially remains unclaimed by local vegetation (Ivanov, Maximov, 1998) is still under the question.

Table 5

Monthly and seasonal carbon emission from larch forest soils

Year	May	June	July	Aug	Sep	Σ seasonal, t C · ha^{-1} ± st. dev.
2001	–	–	1.43 / 39.5	1.06 / 29.3	0.26 / 7.2	3.68±0.08*
2004	0.41 / 12.4	0.58 / 17.4	0.78 / 23.4	1.13 / 33.9	0.43 / 12.9	3.23±0.21
2005	0.33 / 6.71	0.77 / 15.7	1.56 / 31.8	1.53 / 31.2	0.72 / 14.7	4.82±0.12
2006	–	1.01 / 17.3	2.15 / 36.9	1.84 / 31.6	0.49 / 8.4	5.56±0.37**

Numerator – flux, t C ha^{-1}, denominator – percentage from seasonal cumulative sum.

* Including estimated May-June flux of 0.87 t C · ha^{-1} (24.1% of seasonal cumulative sum).

** Including estimated May flux of 0.34 t C · ha^{-1} (5.8% of seasonal cumulative sum).

In humid years the rate of physical-chemical processes (Q_{10}) in soil increases on average 6.5 times per every 10°C, while in dry years – 3 times (Table 6). High Q_{10} magnitudes in humid years indicate that at high values of η an increase in F_{soil} rate depends also on specific biochemical processes in living soil organisms. This question waits for further investigations.

Table 6

Soil temperature response (Q_{10}) and base respiration (b_0) coefficients of soil respiration

Year	Q_{10}	R_0	R^2
2001, extremely dry	3,48	1,05	0,84
2004, dry	2,62	1,19	0,61
2005, moist	6,13	0,69	0,79
2006, wet	6,92	0,72	0,86
4 years average	**4,79**	**0,91**	**0,78**

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