Pol. J. Environ. Stud. Vol. 24, No. 2 (2015), 905-908
DOI: 10.15244/pjoes/23878

Short Communication

Negative Soil Respiration Fluxes in Unneglectable Arid Regions

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Received: 22 January 2014
Accepted: 28 March 2014

Abstract

This study examines the hypothesis that soil respiration fluxes are always positive, neglecting negative fluxes in arid regions that characterize more than 30% of Earth's total land area. To cut down uncertainty, we focus on non-vegetated areas at a typical, large arid region (Central Asia). Soil respiration fluxes were reconciled as a direct sum of influxes (CO_2 fluxes entering soils) and effluxes (CO_2 fluxes released from soils). It was indicated that the annual average of effluxes was only 8% higher than that of influxes in 1979-2011. At typically alkaline sites (soil pH>9.5), extreme local annual average of soil respiration fluxes are negative. Therefore, negative soil respiration fluxes in arid regions are unneglectable. Although the soil respiration flux is useful as a measure of CO_2 effluxes from the soils and CO_2 influxes to the soils, its value as a measure of ecosystem processes is very much limited.

Keywords: soil respiration flux, influxes and effluxes, climate changes

Introduction

Soils provide the second largest CO_2 fluxes (effluxes) from terrestrial ecosystems to the atmosphere [1, 2] and have significant implications to the global carbon balance [3-5]. Conventionally, these fluxes are comprised of two biological components controlled by distinct processes, namely the autotrophic respiration of plant root and the decomposition of soil organic carbon (SOC) by fauna and microbes (heterotrophic respiration), during which soil CO_2 is released [6-8]. Not surprisingly, soil respiration fluxes were always thought to be positive and significantly contributed to the increasing atmospheric CO_2 [9, 10]. However, recent studies in some arid and semiarid ecosystems demonstrated that soil respiration flux in special arid regions can be temporally negative, in which CO_2 flux entered rather than was released from the ground [11, 12]. The negative fluxes cannot be attributed to the biological processes. To rationalize these negative fluxes, some non-biological processes, such as pH-mediated CO_2 dissolution and diffusion in soils and the surface adhesion of CO_2 onto the soil minerals, were suggested, contributing the third dominant soil respiration flux in arid regions [13-16]. Despite of all these studies, however, the significance of soil CO_2 influx in the total soil respiration flux remains undetermined and the magnitude of negative soil respiration flux in arid regions is still a matter of controversy [17-19]. Arid regions characterize more than 30% of the Earth's total land surface and are still increasing due to the global trend toward increasing desertification [16, 20]. To cut down uncertainties in the global/regional carbon balance and in the prediction of future feedbacks in the coupled carbon-climate system, it is crucial to determine whether negative soil respiration flux in arid regions are worthy of being

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taken into account [14, 19]. Hence we reconciled the soil respiration fluxes as a direct sum of CO_2 influxes and effluxes and significance of negative soil respiration flux in arid regions was evaluated according to a comparison of annual intensities of influxes and effluxes at a typical, large arid region (Central Asia) in the past three decades (1979-2011).

Materials and Methods

Analyses in this study were based on the output data of an incorporated model for soil respiration flux (F_c) in arid land [21]. The input data of the incorporated model (including the surface air temperature, T_a), soil volumetric water content (θ_s) at 5 cm depth were collected from the Xinjiang and Central Asia Scientific Data Sharing Platform, where we got access of the data of T_a, θ_s, and annual precipitation (AP) for Central Asia (only considering the area with elevation <1500 m) in 1979-2011.

Temporal and spatial variations of pH are very important for the estimation of soil CO_2 flux. But there are no reliable and prepared data of temporal and spatial variations in pH at Central Asia in 1979-2011. To reduce uncertainty, a constant pH value (8.5) was applied, hypothetically representing the mean pH value at the large region in the past three decades.

A temperature-dependent Q_{10} model (the derivative of the exponential chemical reaction-temperature equation originally developed by Van't Hoff) has been widely performed around the world to estimate the temperature sensitivity of soil respiration fluxes (i.e., F_c) and predict the future feedbacks of F_c to climate change [22-24]. However, for arid regions where negative soil respiration fluxes frequently occur [13], the Q_{10} model must be refomulated as an incorporative model [18, 21]:

$$\begin{cases} F_c = F_a + F_x \\ F_a = R_{10} Q_{10}^{(T-10)/10} \\ F_x = r_7 q_7^{pH-7} + \lambda T + \mu\theta_S + e \end{cases} \quad (1)$$

...where the database of F_c was divided into two sub-datasets of soil organic respiration (F_a) and soil inorganic respiration (F_x); λ=0.0059, μ=0.0003, r_7=3.0191, q_7=0.7562, e= –2.5081, R_{10}=0.3625, and Q_{10}=1.5.

These parameters are hypothetically applicable worldwide in this study, and so the model has global implications. To calculate F_e and F_i, similar to Chen et al. [18], two half components of F_x, F_{x+}, and F_{x-}, termed as efflux and influx in F_x, respectively, were defined as:

$$F_{x+} = (F_x + |F_x|)/2 \quad F_{x-} = (F_x - |F_x|)/2 \quad (2)$$

...and hence F_c was reconciled as a direct sum of soil CO_2 effluxes (F_e) and influxes (F_i), which were respectively formulated as:

$$F_e = F_a + F_{x+} \quad F_i = F_{x-} \quad (3)$$

To determine the contributions of F_e and F_i in F_c, an index E/I was naturally defined as:

$$E/I = F_e / |F_i| = -F_e / F_i \quad (4)$$

This calculated E/I at the given pH (8.5). In order to further consider the variations of (the temporal and spatial average of F_c ($\mu mol \cdot m^{-2} \cdot s^{-1}$) with pH, the results were evaluated as well to investigate the dynamics of soil CO_2 fluxes at the local extremes of pH (8.1-8.5; see [18, 21]). This generated the contours of the annual soil respiration at the Central Asia annual) in the past three decades (coordinated to the year and soil pH).

Results and Discussions

Annual soil CO_2 effluxes were only 8% higher than soil CO_2 influxes at non-vegetated soil sites at Central Asia in the last three decades (referring to the trend of E/I; Fig.1). Negative soil respiration fluxes in the typical, large arid regions are unneglectable and hence must be taken into account in the budget of F_c in arid and semiarid ecosystems. This is essentially significant to cut down uncertainties in the global C budget accounting and in predictions of future feedback in the coupled carbon-climate systems. From 1979 to 2011 there is a significant decrease in the annual total precipitation and a corresponding decrease in θ_s. But there are no significant fluctuations in T_a and E/I. The significance of negative CO_2 fluxes (E/I) was sensitive to temperature changes since T_a and E/I at Central Asia exhibited a similar pattern in the past three decades.

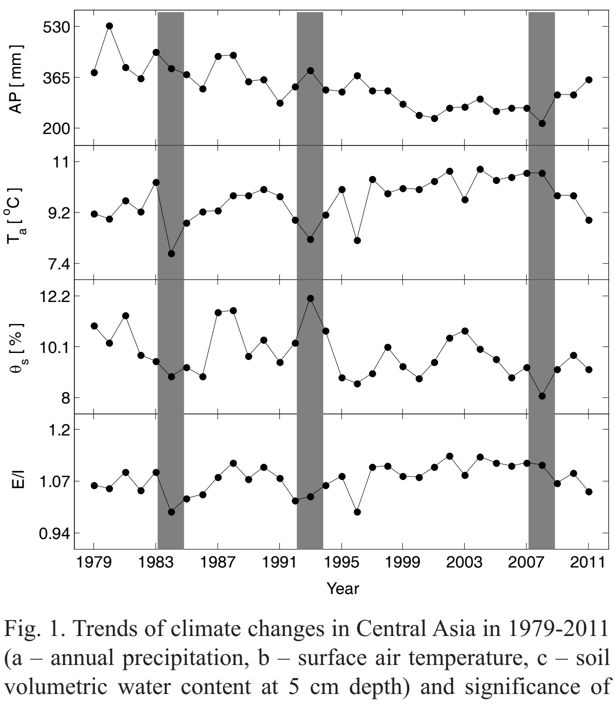

Fig. 1. Trends of climate changes in Central Asia in 1979-2011 (a – annual precipitation, b – surface air temperature, c – soil volumetric water content at 5 cm depth) and significance of negative CO_2 fluxes (d – evaluated by the index E/I) in Central Asia 1979-2011.

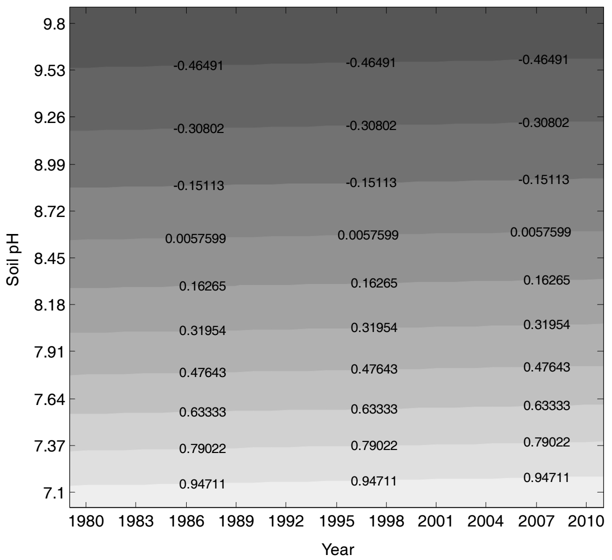

Fig. 2. Contours of annual soil respiration (μmol·m^{-2}·s^{-1}) in Central Asia in the past three decades (coordinated to the year and soil pH).

Contours of annual soil respiration (μmol·m^{-2}·s^{-1}) in Central Asia in the past three decades (coordinated to the year and soil pH) implied that the significance of negative soil respiration fluxes are decreasing in the past decades (Fig. 2). Referring to Fig. 1, such a decrease is largely driven by regional warming. At soil sites with pH<8.1, the average annual soil respiration fluxes are positive. But at soil sites with pH>9.5, the annual soil respiration fluxes are negative, implying that the extreme local soil respiration fluxes are largely negative.

There is strong evidence suggesting that negative soil respiration fluxes exert potential influences on the dynamics of soil respiration fluxes in arid regions. Note that arid regions characterize more than 30% of the Earth's land surface, and are still increasing due to the regional/global trend towards increasing desertification, the negative soil respiration flux in arid regions are worthy of being taken into account in evaluating the regional and global carbon balance [14].

Significance of negative soil respiration flux also highlighted the difference between "the real soil respiration" (dominantly biological) and "the apparent soil respiration" (dominantly non-biological at local extremes). The interpretation of soil respiration fluxes as biological processes (including autotrophic and heterotrophic respiration) is only true for real soil respiration, but it was not true for the measured F_c, which could only represent "apparent soil respiration" [18]. Because of the complicated porous structure, a part of the CO_2 effluxes from the real soil respiration are delayed and subsequently released in a physical diffusion [21]. Especially after precipitation, the infiltration of water reduces the stored space for CO_2 in the soil and always aggravates the CO_2 release in F_c (the so-called Birch effect), which can be largely attributed to non-biological processes [13]. Negative soil respiration fluxes are important for understanding the carbon cycle in arid and semiarid ecosystems [16]. The whole story of the little-known non-biological CO_2 absorption by soils and its overall importance on the regional and global carbon balance are worthy of further exploration [15].

Conclusion

Although F_c is useful as a measure of CO_2 fluxes from the soils, its value as a measure of ecosystem processes is very much limited. Since negative CO_2 fluxes observed with both chambers and the open- or close-path eddy systems were still included in the nocturnal data of ecosystem respiration, it should not be excluded from the data of soil respiration flux in arid and semiarid ecosystems. The Q_{10} model applied to these ecosystems must be replaced with a developed form to adopt negative fluxes.

Acknowledgements

This research was financially supported by the International S&T Cooperation Program of China (2010DFA92720-13). The authors thank the anonymous referees for their careful reading, detailed comments, and many constructive suggestions which greatly improved our presentation.

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