Greenhouse gas (GHG) emission in the permafrost regions of western Mongolia: case area in the Munkhkhairkhan mountain

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Abstract. Permafrost thaws accelerate the rates of carbon released by the soil into the atmosphere and cause significant positive climate-change feedback. We selected Munkhkhairkhan mountain as the study area. The main purpose of this study is to estimate GHG emissions and to calculate the emission factor (EF) at the study sites in Doloon Nuur and Shuurkhai in Munkhkhairkhan. This study is conducted in summer 2022 and carbon dioxide (CO_2) emissions were measured using the EGM-4 instrument. Soil samples were collected at depths of 0-5 cm, 5-10 cm, and 10-15 cm at the sites. We have determined the soil organic carbon content (SOC) at peat and nonpeat in both sites. According to the results, CO_2 fluxes ranged between 0.1 and 18.5 µmol/m-^{2} s-^{1} in the Doloon Nuur and Shuurkhai. Furthermore, EF at all sites on Munkhkhairkhan mountain (±standard error) was 112.3 g [CO_2] m^{-2} yr^{-1} (±18.2), 5.9 g [CH_4] m^{-2} yr^{-1} (±1.0). SOC content was 10.5% in 0-5 cm, 14.2% in 5-10 cm, and 11.4% in 10-15 cm at the study sites in Shuurkhai. The SOC content at the sites in Doloon Nuur ranges from 3.1% in 0-5 cm, 2.3% in 10-15 cm and 1.7% in 10-15 cm. This study is conducted with a year measurement; therefore, further research should extend the time period and can be used as a baseline study.

Keywords: Greenhouse gas, emission factor, organic carbon in the soil, permafrost

1 Introduction

In recent decades, the degradation of permafrost that accompany climate warming has been widely detected in mountain permafrost regions, as well as in high-latitude Arctic regions [1]. This degradation is evident from the deepening of the active layer thickness [2, 3], increases in ground temperature [4, 5], and formations of thermokarsts in the terrain [6]. A large amount of organic carbon from the soil is stored in mountain permafrost regions, and the carbon pools in these regions are very sensitive to increasing temperature [7, 8].

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Approximately 1,700 Pg of carbon is stored in permafrost soil, approximately twice the amount of carbon that is currently in the atmosphere [9]. This is the remnant of plants, animals, and microbes that have accumulated in permafrost soils over hundreds of thousands of years [10]. CO_2 and CH_4 will accelerate the global increase in temperature and have a positive effect on terrestrial ecosystems [11].

Most previous studies have investigated GHG emissions and their long-term trends in permafrost regions of the northern hemisphere [11-15]. In Mongolia, some research on greenhouse gas emissions has been carried out in recent years [16-18]. For example, Saruulzaya et al. (2021) investigated CO_2 and CH_4 concentrations in Mongolian permafrost regions between 2010 and 2020 using GOSAT satellite data. Their results showed that CO_2 increased by 2.24 ppm / year and 7.29 ppb / year during the study period. However, they calculated seasonal variations of CO_2 concentrations and showed different patterns in four permafrost zones: Continuous and discontinuous permafrost zones had lower near-surface CO_2 concentrations in summer and autumn, and sporadic and isolated permafrost zones had higher near-surface CO_2 concentrations in winter and spring. Sainbayar et al. (2022) studied seasonal fluctuations of CO_2 in the atmosphere in Mongolia. CO_2 concentration has seasonal fluctuations, while vegetation cover plays an important role in the emission and absorption of natural carbon, and is the main factor in seasonal fluctuations of terrestrial CO_2. Furthermore, Saruulzaya et al. (2022) calculated the emission factors CO_2 and CH_4 in wetlands, peatland, and cropland in Ulaanbaatar City and the Khurkh river valley in Khentii province of Mongolia. GHG emissions were determined to have higher values in peatlands than in wetland and croplands.

Much research has been done on climate change, glaciation, and permafrost changes in the Munkhkhairkhan glacier mountain [19-23]. Although this environmental gradient would be interesting for a comprehensive analysis of the factors that control CO_2 flux and SOC, EF has not been determined in the mountain so far. The main purpose of this study is to estimate the GHG emissions in the Doloon Nuur and Shuurkhai of Munkhkhairkhan Mountain.

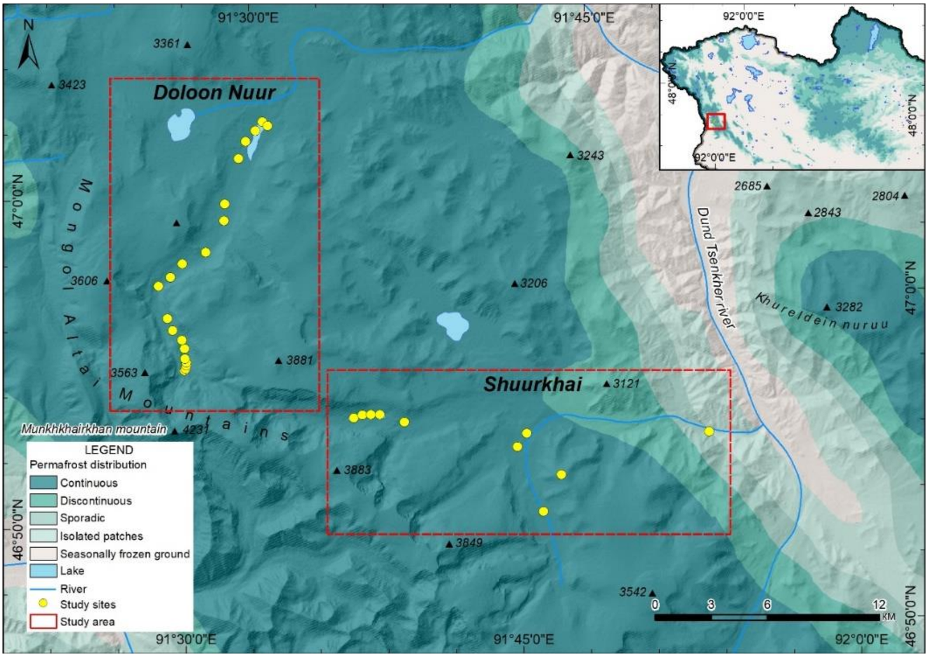

Fig.1. Location of the Munkhkhairkhan mountain and study sites in Doloon Nuur and Shuurkhai. (Jambaljav et al., 2016)

2 Study area

The Munkhkhairkhan mountain with a glacier is located in Khovd province in the western part of the Mongolian permafrost zone. The average air temperature in the coldest month of January fluctuates from 30 ° C to 34 ° C, and the average air temperature in July the warmest month ranges from +15 to +10°C. The mean annual total precipitation ranges between 300 and 400 mm [24]. Most of the study area is covered by alpine vegetation. In this study, we selected several sites in the Munkhkhairkhan glacier mountain that is located in sporadic, continuous permafrost zones (Fig.1).

3 Methods and Materials

3.1 Soil sample

According to fieldwork, soil samples were collected at 30 sites in Doloon Nuur and Shuurkhai in August 2022. A total of 10 sites are located in Shuurkhai and 20 sites in Doloon Nuur. There are peat soils more concentrated at sites in Shuurkhai, whereas nonpeat soils were in Doloon Nuur. We collected a total of 90 soil samples at sites with depths of 0-5 cm, 5-10 cm, and 10-15 cm, respectively. These soil samples were analyzed in the soil laboratory of the Institute of Geography and Geoecology of the Mongolian Academy of Sciences to determine the contents of SOC (percent volume, %).

3.2 CO_2 flux measurements

The EGM-4 (Environmental Gas Monitor for CO_2) instrument was used to measure the CO_2 concentration at 30 sites in Doloon Nuur and Shuurkhai in the Munkhkhairkhan mountain. Before starting the measurements, cuttings of plants were taken from the study area, roots were collected, and the chamber was tightly sealed. Connect the well-sealed chamber to the CO_2 analyzer.

The duration of the measurement of CO_2 concentration is 5 minutes and we have measured CO_2 at the study sites three times. Then we calculate the CO_2 fluxes using the following equation (Equation 1).

3.3 Emission factor (EF)

An EF is defined as the average emission rate of a given CO_2 for a given source relative to units of activity. We used the IPCC method [25] 'Equation (1)'.

$$EF = \frac{W}{A * t} \quad (1)$$

EF – Emission factor [g CO_2/CH_4 m^{-2} year-1], W – total weight of GHG [g CO_2/CH_4], A – area [m^2], t – period [years].

4 Results and Discussion

In this study, we have estimated CO_2 fluxes at the study sites in Doloon Nuur and Shuurkhai of the Munkhkhairkhan mountain in the continuous and sporadic permafrost zones. As shown in the results, CO_2 fluxes ranged between 0.1 and 18.5 µmol/m^{-2} s^{-1} in Doloon Nuur and Shuurkhai. The average flux of CO2 at all sites was 6.0 µmol/m^{-2} s^{-1} in Shuurkhai and Doloon Nuur (Fig.2a). Fig.2b shows that CO_2 fluxes depend on several environmental factors such as sunlight, vegetation cover, soil temperature, and humidity. The highest values of CO_2 fluxes were recorded between 12:00 pm and 3:00 pm, which was more related to temperature and the effects of sunlight (Fig.2b).

Based on the analysis of the soil samples, the SOC content was 10.5% in 0-5 cm, 14.2% in 5-10 cm and 11.4% in 10-15 cm at the study sites in Shuurkhai. However, the SOC contents at the Doloon Nuur sites range from 3.1% in 0-5 cm, 2.3% in 10-15 cm and 1.7% in 10-15 cm (Fig.2c). We found that the SOC at the study sites in Shuurkhai was higher than at the sites in Doloon Nuur. Fig.3 shows the relationships between CO_2 flux, SOC contents, photosynthetic active radiation (PAR), temperature, and assimilation rates in both Doloon Nuur and Shuurkhai. The relationship between CO_2 flux and SOC was weak in both Doloon Nuur and Shuurkhai (Fig.3a). However, the results of the relationship of CO_2 flux and temperature ($R^2 = 0.59$) were more significant in Shuurkhai than in Doloon Nuur (R^2 = 0.025) (Fig.3b). The regression coefficient of the relationship between CO_2 flux and PAR was more significant in Shuurkhai than in Doloon Nuur (Fig.3c). The relationship between CO_2 flux and assimilation rates is more significant at both sites (Fig.3d).

The EF is calculated at all the sites in Doloon Nuur and Shuurkhai of the Munkhkhairkhan mountain. EF at all sites in the Munkhkhairkhan mountain (±standard error) was 112.3 g [CO_2] m^{-2} yr^{-1} (±18.2), 5.9 g [CH_4] m^{-2} yr^{-1} (±1.0).

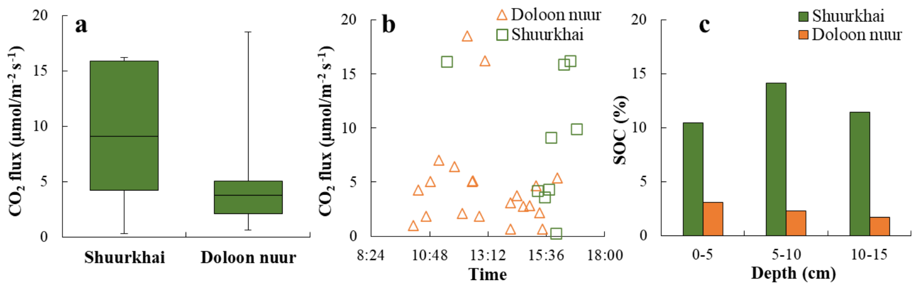

Fig.2. (a) CO_2 fluxes in the Doloon Nuur and Shuurkhai of the Munkhkhairkhan mountain; (b) CO_2 fluxes in different time periods; (c) SOC contents at different depths.

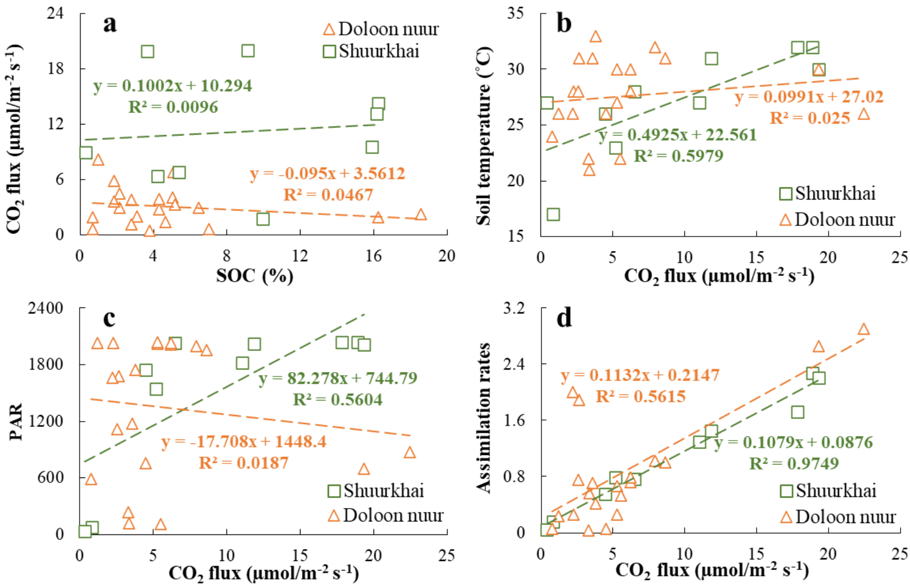

Fig.3. Relationship between CO_2 flux and SOC, soil temperature, PAR and assimilation rates.

Batkhishig et al., (2021) reported that soil organic content has decreased by 12.3% during the last 35 years. During this period, air temperature increased by 1.25 ° C, precipitation decreased by 5 mm, and livestock increased 2.6 times [26]. Organic content, which is the main indicator of pasture soil fertility, has been decreasing in recent years due to the increase in the number of livestock [26].

Additionally, several reports have indicated that permafrost degradation has been detected in Mongolia, and these changes probably have had significant impacts on surface energy balances, local hydrological cycles, ecosystem services, and environmental changes in recent decades [27-31]. For example, based on in situ measurement data from 69 well sites in this region, it was found that ecosystem-driven permafrost is degrading in warm regions of Mongolia [31]. Our results are attributed to their results. For example, the number of livestock in Doloon Nuur was higher than that in Shuurkhai, which may have influenced the changes in SOCC. Future studies are required to address the spatial and temporal changes in CO_2 and CH_4 in the Munkhkhairkhan mountain.

5 Conclusions

This study estimates the first baseline information on CO_2 fluxes at 30 sites in the Munkhkhairkhan mountain in the continuous and sporadic permafrost zones. At the study sites, we collected a total of 90 soil samples in August 2022 with depths of 0-5 cm, 5-10 cm, and 10-15 cm, respectively. We used the EGM-4 instrument to measure CO_2 concentration at the study sites in Doloon Nuur and Shuurkhai. Then, we calculate the CO_2 flux and EF in this study area. We found that the CO_2 fluxes had different values in both areas. While the SOC content at the study sites in Shuurkhai was higher than at the sites in Doloon Nuur. The SOC content was highest in the peat sites concentrated in Shuurkhai. The results of CO_2 fluxes depend on several environmental factors, such as soil temperature, PAR, assimilation rates, and SOC content. We have concluded that the SOC content is higher in Shuurkhai than in Doloon Nuur, which is related to herders’ camps and the number of livestock. This study was carried out with a year measurement, and with further research extending the time period, it can be used as a baseline study of the effects of climate change.

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