Postprint of CO2 Flux Observational Study in the Koxkar Glacierized Area, Southern Tianshan Mountains

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Abstract

During the development and formation of glacier meltwater runoff, extensive hydrochemical weathering occurs, particularly the hydrolysis of K/Na feldspar and carbonate minerals, which may consume H+ in water bodies, promote the dissolution of atmospheric CO2 into water to form bicarbonate, and influence regional carbon cycling. From July 21, 2015 to July 18, 2017, a relatively flat and open debris-covered area of the Koxkar Glacier in the Western Tianshan Mountains was selected for CO2 flux monitoring using the eddy covariance method. The results indicated that the atmospheric CO2 flux ranged between -17.99 and 3.59 g•m-2d-1, with an average of -2.58 g•m-2d-1, demonstrating that the study area is a significant carbon sink. Net CO2 exchange in the glacier system is primarily dominated by atmospheric CO2 flux, but exhibits significant diurnal variation. During daytime, ice and snow ablation causes atmospheric CO2 to deposit into meltwater, promoting regional hydrochemical weathering, while at night, reduced solar radiation weakens or even halts ice and snow ablation, suppressing regional CO2 deposition, and even the formation of regelation ice can cause the release of CO2 dissolved in liquid water. Net CO2 exchange in the glacier system shows a significant negative correlation with air temperature, i.e., as temperature increases, atmospheric CO2 deposition increases. When precipitation is less than 8.8 mm, the exchange does not vary significantly with precipitation, whereas when precipitation exceeds 8.8 mm, CO2 deposition decreases with increasing precipitation. The rate of change of net CO2 exchange in the glacier system with daily runoff follows the order: snowmelt period > snow accumulation period > early glacier ablation period > late glacier ablation period > peak glacier ablation period, implying that when snowmelt is present, the system' s CO2 exchange varies more substantially with daily runoff. This may be due to the damping effect of snow itself or the underdeveloped hydrological channels during the snow period, causing snowmelt water to converge

more slowly than glacier ice meltwater, providing sufficient time for chemical reactions of soluble substances and enhancing CO2 deposition.

Full Text

Preamble

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Abstract: The hydrolysis of Na, K, Ca feldspar and carbonate in surface runoff consumes H , which causes atmospheric CO to sink. In glacier areas, the CO flux at the gas-liquid interface is usually analyzed using the hydrochemical mass balance method. In recent years, eddy covariance systems have been used to analyze energy balance, CO flux, and moisture flux in complex terrain. In this study, CO flux was monitored by eddy covariance system in the Koxkar Glacier of the Western Tianshan, Xinjiang, China from 2015 to 2017. Results showed that CO fluxes ranged from -17.99 to 3.59 g · m 2 · d 1 with an average of -2.58 g · m 2 · d 1. The CO flux values were negative in January (-0.21 g · m 2 · d 1), indicating that atmospheric CO sinks in the glacier area because of dissolved CO in water when water-rock interaction occurs during precipitation/snow and ice melting. Further analysis suggested that the net glacier exchange (NGE) of CO decreased as daily temperature increased, with a significant negative correlation between NGE and daily temperature. For precipitation, almost no effect on NGE was found when precipitation was less than 8.8 mm. However, daily NGE decreased exponentially with increasing precipitation when precipitation exceeded 8.8 mm. The effect of precipitation on CO absorption was mainly reflected in two aspects: (1) the CO sink at the gas-liquid interface slowed down due to weakened chemical erosion from reduced ice melting, which was caused by continuous heavy rain reducing temperature; and (2) the CO sink at the gas-liquid interface decreased due to increasing dissolved CO in the atmosphere from increasing precipitation. Finally, there were significant linear relationships between NGE and runoff, though the slopes varied during different periods due to changes in hydrochemical reaction type caused by changes in effective ablation area, and changes in hydrochemical reaction time effected by hydrological channels below the ice.

Keywords: CO flux; eddy covariance; runoff; Koxkar Glacier

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1 Introduction

1.1 Study Area

The Koxkar Glacier (41°43 N, 80°09 E) is located on the southern slope of the Tianshan Mountains in Xinjiang, China. The glacier has an elevation range of 4550–4700 m, covers an area of 82.89 km^2, and extends 19.0 km in length. The debris-covered area spans 30.6 km^2, accounting for 83% of the total glacier surface, with an average debris thickness of 2 m at 3700 m elevation. The region has a temperate continental climate, with precipitation concentrated in summer. Annual precipitation ranges from 0.9×10 to 1.2×10 m^3 · a ^{1}, of which 94.5% is derived from glacier meltwater.

1.2 Methods

CO flux was measured using an eddy covariance system installed on the glacier surface (3212 m) from July 21, 2015 to July 18, 2017. The system consisted of a CSAT3 sonic anemometer (Campbell Scientific Inc., USA) and a Li-7500 open-path infrared gas analyzer (IRGA) for CO /H O. A CR1000 data logger recorded data at 10 Hz frequency, with 30-minute averaged values stored on a 16 GB CF card. Quality control procedures included coordinate rotation, WPL correction, and storage term correction. The footprint analysis indicated that 75.24% of the flux originated from within ±0.2 mg · m ^{2} · s ^{1} of the measurement point.

A friction velocity threshold of 0.8 m · s ^{1} (daytime) and 0.6 m · s ^{1} (nighttime) was applied for data quality control. When wind speeds fell below these thresholds, CO flux measurements were affected by local respiration and excluded from analysis. The data processing followed standard protocols for complex terrain measurements.

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2 Results

2.1 Diurnal and Seasonal Variations of NGE

The net glacier exchange (NGE) showed distinct diurnal patterns, with peak CO absorption occurring at 16:00 (-0.13 mg · m ^{2} · s ^{1}). Seasonal variations revealed that summer months (June–August) accounted for 74.50% of annual CO absorption, while winter months (December–February) contributed only 24.38%. The NGE during spring (March–May) and autumn (September–November) showed intermediate values of 10.56% and 8.05% respectively.

2.2 Environmental Controls

Temperature: A significant negative correlation existed between NGE and daily temperature ($p < 0.01$). As temperature increased, CO absorption decreased, likely due to reduced solubility and altered chemical weathering rates.

Precipitation: Precipitation showed a threshold effect at 8.8 mm. Below this value, precipitation had minimal impact on NGE. Above 8.8 mm, NGE decreased exponentially with increasing precipitation. This dual effect occurred because: (1) continuous heavy rain lowered temperature, reducing ice melt and weakening chemical erosion; and (2) increased precipitation enhanced atmospheric CO dissolution, decreasing the gas-liquid interface sink.

Runoff: Significant linear relationships were observed between NGE and runoff, though the relationship slopes varied across seasons. These variations were attributed to changes in effective ablation area and hydrochemical reaction times in subglacial channels.

3 Discussion

3.1 Data Quality and Footprint Analysis

The data quality control procedures ensured robust measurements in harsh glacier environments. The footprint model indicated that 75% of the measured flux originated from within a limited fetch distance, validating the representativeness of the point measurements for the debris-covered glacier surface.

3.2 Hydrochemical Processes

The primary mechanism for CO absorption was carbonate dissolution:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$$

Additionally, silicate weathering contributed to CO consumption:

$$CaAl_2Si_2O_8 + 2CO_2 + 2H_2O \rightarrow Ca^{2+} + 2HCO_3^- + H_2Al_2Si_2O_8$$

These reactions were enhanced during melt periods when fresh mineral surfaces were exposed and water availability increased.

4 Conclusions

1. The Koxkar Glacier acted as a net CO sink with an average flux of -2.58 g · m^{2} · d^{1} during the observation period, with fluxes ranging from -17.99 to 3.59 g · m^{2} · d^{1}.
2. NGE showed significant negative correlation with daily temperature, decreasing as temperature increased. Seasonal patterns revealed highest absorption in summer (74.50%) and lowest in winter (24.38%).

3. Precipitation exhibited a threshold effect at 8.8 mm. Below this threshold, precipitation had minimal impact; above it, NGE decreased exponentially due to reduced chemical erosion from temperature depression and increased atmospheric CO dissolution.
4. Strong linear relationships existed between NGE and runoff, with seasonal variations in slope reflecting changes in effective ablation area and subglacial hydrological channel processes.

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