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New low-cost automated system of closed chambers to measure greenhouse gas emissions from the tundra

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ABSTRACT

The northern high latitudes represent the world's largest soil carbon reservoir. Due to the rapid warming in the Arctic, permafrost thawing is expected to lead to increased emissions of greenhouse gases (GHG). Therefore, quantifying these emissions has become very important in order to determine the feedback impacts of GHG release from permafrost on the global climate. However, permafrost GHG emissions are difficult to quantify because direct measurements with conventional methods are generally expensive and time-consuming, resulting in short-spanned experiments and limited number of measurements. In order to take continuous measurements of GHG emissions over long periods of time, we developed and tested an affordable automated system of four closed chambers equipped with low-cost sensors and open-source microcontrollers. We measured carbon dioxide concentrations with a low-cost CO_2 sensor and compared it with an infrared gas analyzer (IRGA). Compared to the IRGA, the sensor overestimated fluxes by only 6%, making it a good alternative to conventional devices to measure CO_2 concentrations. The chambers were compared to a commercial chamber (SRC-1, PP Systems) and results showed a 15% discrepancy between the two types of chamber. However, more laboratory testing is necessary to confirm the exact cause of the discrepancy. This low-cost system shows high potential and represents a good alternative to existing methods and apparatuses to measure soil CO_2 emissions.

1. Introduction

Northern high latitudes hold approximately half of the earth's belowground organic carbon pool with a total estimated content of 1672 PgC (1 PgC = 10^{15} grams of carbon) (Tarnocai et al., 2009). This carbon, locked in permafrost (Field et al., 2007; McGuire et al., 2009), now threatens to be released into the atmosphere as the Arctic average temperature rises more rapidly than anywhere in the world (McBean et al., 2005). The release of carbon from the degradation of organic matter contained in permafrost could potentially participate to the greenhouse effect and significantly contribute to the global warming (Zhuang et al., 2006; Khvorostyanov et al., 2008; Koven et al., 2011; Schaefer et al., 2011; Burke et al., 2012; MacDougall et al., 2012; Schneider von Deimling et al., 2012). It has therefore become paramount to quantify carbon emissions from northern latitudes to predict future impacts of such emissions on Arctic ecosystems and the global climate.

Field measurements made with closed chamber[1] are one of the most widely used direct techniques to monitor small-scale carbon emissions (Davidson et al., 2002; Irvine and Law, 2002). Fluxes are determined by measuring the concentration increase of a given gas inside a chamber over a fixed period of time. However, closed-chamber measurements are both time-consuming and labor-intensive (Savage and Davidson, 2003; Lai et al., 2012). Indeed, this technique requires the continuous presence of an operator to place the chamber on the ground and note the concentration changes, limiting measurements to a single location since measurements cannot be taken at different locations simultaneously. In addition, field studies using manual measurements are gener-

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[1] Abbreviations: P_{con} = Control plot; P_{soil} = Plot without aboveground vegetation; P_{sat} = Plot in water-saturated conditions; P_{OTC} = Plot with an open-top chamber; AC = Automated chamber; AC_{con} = AC on P_{con}; AC_{soil} = AC on P_{soil}; AC_{sat} = AC on P_{sat}; AC_{OTC} = AC on P_{OTC}; ER = Ecosystem respiration; EGM-4 = Infrared gas analyzer EGM-4; SRC-1 = SRC-1 respiration chamber connected to the EGM-4; T_{soil} = Soil surface temperature; VWC = Soil surface volumetric water content.

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ally brief and datasets are discontinuous and short-spanned. As a consequence, data are recorded within a time period believed to be representative of the period studied, which can be misleading because respiration trends vary throughout the day and the entire growing season (Savage and Davidson, 2003).

Alternatively, automated systems of closed chambers can be used to make long-term continuous measurements (Goulden and Crill, 1997; King and Harrison, 2002). This allows to sample at a much higher temporal frequency. However, such systems are still not widely used because of the high costs involved and infrastructure constraints (Savage and Davidson, 2003). Commercial automated systems are usually prohibitively expensive, which often limits the total number of chambers that can be acquired. Non-commercial automated systems have also been developed to take continuous measurements at lower costs (Goulden and Crill, 1997; Irvine and Law, 2002; Liang et al., 2003; Edwards and Riggs, 2003; Savage and Davidson, 2003; Bäckstrand et al., 2008; Lai et al., 2012). All these systems use an infrared gas analyzer (IRGA) to measure CO_2 concentrations, the method of choice to conduct chamber-based soil respiration measurements (Davidson et al., 2002). However, IRGAs are costly and their use with automated systems using multiple chambers is complex and requires important infrastructures.

Our goal was to develop an automated system of closed chambers that uses low-cost sensors and microcontrollers to measure carbon dioxide (CO_2) emissions and to test whether or not this type of instrumentation is a viable alternative to conventional methods using an IRGA and commercial chambers. We aimed to develop a system that could work autonomously, operate multiple closed chambers simultaneously and that would not affect the integrity

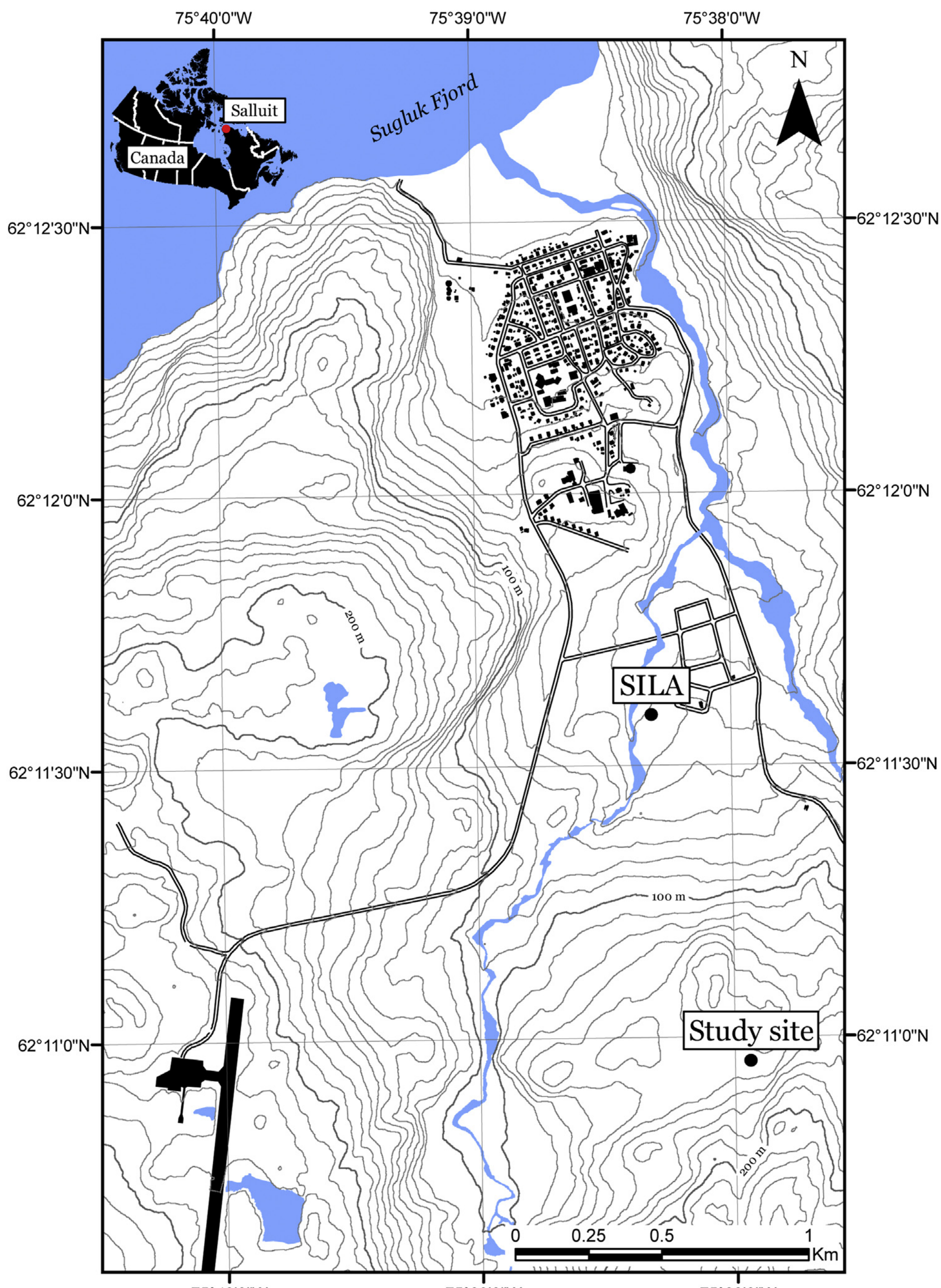

Fig. 1. Location of the study site in Salluit, Northern Québec. West of the study site is the Salluit airport and North is the SILA meteorological station.