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Initial report on methane and carbon dioxide emission dynamics from sub-Antarctic freshwater ecosystems: A seasonal study of a lake and a reservoir

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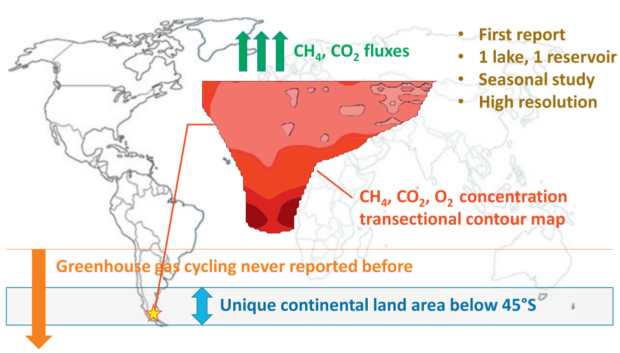
HIGHLIGHTS

- Greenhouse gas emissions from sub-Antarctic lakes have not yet been reported.
- A sub-Antarctic lake and a reservoir were seasonally characterized.
- CH_4 and CO_2 fluxes and concentrations were similar to those in northern lakes.
- In contrast, ebullition was never observed in these sub-Antarctic lakes.
- Lakes in this region likely contribute a marginal amount to global GHG emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

The sub-Antarctic Magellanic ecoregion is a part of the world where ecosystems have been understudied and where the CH_4 cycling and emissions in lakes has not ever been reported. To fill that knowledge gap, a lake and a reservoir located at 53°S were selected and studied during three campaigns equally distributed over one year. Among the parameters measured were CH_4 and CO_2 emissions, as well their dissolved concentrations in the water column, which were determined with high spatial resolution. No ebullition was observed and the CH_4 flux ranged from 0.0094 to 4.47 mmol m^{-2} d^{-1} while the CO_2 flux ranged from −22.95 to 35.68 mmol m^{-2} d^{-1}. Dissolved CH_4 concentrations varied over more than four orders of magnitude (0.025–128.75 μmol L^{-1}), and the dissolved carbon dioxide ranged from below the detection limit of our method (i.e., 0.15 μmol L^{-1}) to 379.09 μmol L^{-1}. The high spatial resolution of the methods used enabled the construction of bathymetric maps, surface contour maps of CH_4 and CO_2 fluxes, and transect contour maps of dissolved oxygen, temperature, and dissolved greenhouse gases. Overall, both lakes were net greenhouse gas producers and were not significantly different from temperate lakes located at a similar northern latitudes (53°N), except that ebullition was never observed in the studied sub-Antarctic lakes.

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1. Introduction

Although lakes and reservoirs only cover about 3.7% of the continental surface on Earth (Verpoorter et al., 2014), it has been estimated that they are responsible for about 16% of the total CH_4 emissions to the atmosphere (Bastviken et al., 2011; Saunois et al., 2016). CH_4 emissions from lakes and reservoirs are therefore a major component of the global biogeochemical carbon cycle. CH_4 production in freshwater ecosystems has been well described since the early 1960s (Koyama, 1963), while CH_4 emissions have been the subject of growing interest since the early 1980s (Harriss and Sebacher, 1981). Similarly, freshwater ecosystems are an important source of CO_2, emitting an estimated 1.4 Pg-C y^{-1} (Tranvik et al. 2009), of which lakes and reservoirs emit about 0.32 Pg-C y^{-1} (Raymond et al., 2013). However, despite a large number of reports on CH_4 and CO_2 cycling in freshwater ecosystems, little attention has been given to the southern hemisphere. For example, the syntheses by Bastviken et al. (2011) and Saunois et al. (2016) do not report CH_4 emissions from aquatic ecosystems further south than 24°S, and to the best of our knowledge, there are not reports on CO_2 emissions from these southern latitudes, either.

Southern Patagonia, or more precisely the sub-Antarctic Magellanic ecoregion (Rozzi et al., 2012), is a part of the world where ecosystems have been understudied (Rozzi et al., 2008) and from which the CH_4 cycling and emissions in lakes have never been reported. However, this region of 145,000 km^2 is of major importance for several reasons. First, it is a globally unique continental area located between 45 and 55°S, further south than the Cape of Good Hope (Africa, 35°S) and the Bass Strait (Australia, 39°S). Second, this region is one of the twenty-four most conserved areas of the world because of its preserved flora and fauna combined with low population density (72% of the area is protected; Mittermeier et al., 2003). Third, the area is characterized by the cleanest rainwater and streams in the world, mostly because rain originates over the southern Pacific, outside of air streams carrying industrial pollutants (Hedin et al., 1995).

Measuring CH_4 and CO_2 cycling and emissions in lakes from the sub-Antarctic Magellanic ecoregion is therefore of great importance, because it would fill a knowledge gap and better constrain global estimates of greenhouse gas emissions from aquatic ecosystems. Moreover, it may also serve as a baseline for conditions in temperate pristine environments with which to compare temperate lakes in Europe and North America.

In this context, the objective of the present work was to characterize CH_4 and CO_2 cycling and emissions with high spatial resolution for a lake and a reservoir in the sub-Antarctic Magellanic ecoregion in three seasonally characteristic months (i.e., for spring, summer, and winter). The CH_4 and CO_2 cycling and emissions were characterized through an extensive determination of fluxes and dissolved concentrations in the water column. To complement our understanding of CH_4 and CO_2 cycling, dissolved oxygen (DO) concentrations and several other physicochemical parameters were also measured. The various parameters of the studied lakes are discussed and compared with those of northern lakes.

2. Material and methods

2.1. Study sites and campaigns

Two sub-Antarctic lakes were selected. The first was Lake Hambre (LH; 53.6035°S, 70.9526°W; Fig. 1A and Fig. S1A), a natural lake with a round shape located 50 km south of Punta Arenas (53.16°S,70.92°W) and 60 m above sea level (ASL). This lake is in a protected area with limited access and operated by "Parque del Estrecho de Magallanes." The second was Lake Lynch (LL; 53.1757°S, 71.0076°W; Fig. 1B, C, and Fig. S1B), which is a natural lake that was modified in 1925 and 1940 with a constructed dam to increase its capacity. That reservoir is located 12 km west of Punta Arenas at 220 m ASL and within another protected area—"Reserva Nacional de Magallanes." There is no current anthropogenic use of the water in LH, while LL is a primary source of drinking water for Punta Arenas City, the water services of which are operated by "Aguas de Magallanes." The selection of these lakes was based on several criteria, specifically remoteness from anthropogenic activities, boat accessibility, communication ability, and the presence of natural sub-polar forests (the dominant ecosystem of the region) in the lake surroundings. Moreover, we selected relatively small lakes (Table 1) because small lakes are a common feature of the region as well as the major type of lake worldwide (Cael and Seekell, 2016). Small lakes are also more dynamic than large lakes (Cael and Seekell, 2016; Holgerson and Raymond, 2016), making them a good model for this first approach study.

Weather in the Punta Arenas region is cold, with an annual average temperature of 6.5 °C and a range in monthly average temperatures of 10 °C, with July and January being the coldest and hottest months at average temperatures of 1.8 and 11.0 °C, respectively (Butorovic, 2013). The region is characterized by heavy wind, with an average wind speed of 5.2 m s^{-1} and frequent gusts up to 30 m s^{-1} (Butorovic, 2013). No reliable data on the weather at LH is available, although it is assumed that the weather is similar to that at Punta Arenas because of their proximity. However, LL is at an elevation 160 m higher than that

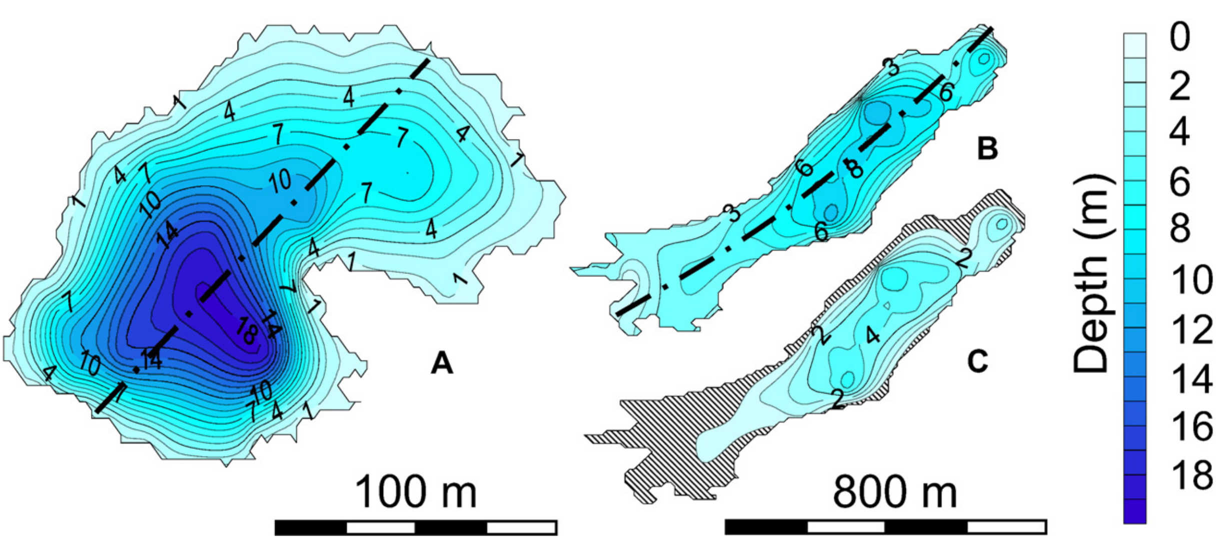

Fig. 1. Bathymetric maps of Lake Hambre, LH (A), and Lake Lynch, LL, during spring (B) and summer (C); discontinuous lines show the longitudinal transects used for transection mapping.