Spatial and temporal variability of soil C-CO_2 emissions and its relation with soil temperature in King George Island, Maritime Antarctica

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Abstract
There are few studies on the effects of temperature on the spatial and temporal changes of soil C-CO_2 emissions in Antarctica. In this work, we present *in situ* measurements of C-CO2 and its relationship with temperature, using dynamic chambers. The results of immediate emission yielded mean values reaching 0.16 g of C-CO_2/m^2/h for the soil covered with the grass *Deschampsia antarctica*. The C-CO_2 loss relates to soil temperature through an exponential function with Q10 close to 2.1. The spatial variability analysis was conducted in a 60-points grid which had mosses and *Deschampsia antarctica* uniformly distributed. Our results suggest soil temperature as a controlling factor of soil C-CO_2 emission temporal variability, but not of its spatial variability, which seems to be more related to the distribution of the different vegetation types.

Key Words
Climate change, organic carbon, Cryosols.

Introduction

Under natural conditions, in regions where soils are not impacted by human actions, the loss of soil organic C depends almost exclusively on soil temperature and humidity variations. Therefore, the sensibility to soil temperature is affected by the numerous factors which are directly or indirectly related to temperature. This sensibility is commonly reported by the Q10 factor, which indicates the variation of emissions due to a temperature increase of 10 ^oC, and even more commonly by exponential models of the relationship between these variables (Fang and Moncrieff 2001). Despite all efforts, most of the soil studies in Antarctica dealing with soil C-CO_2 fluxes were based on incubation experiments, with controlled temperatures under laboratory conditions. *In situ* studies are extremely important in Antarctica, especially when conducted intensively in space and time, since it is the region with the highest temperature increases in the last decades (Turner *et al.* 2007). In the present work, we investigated the *in situ* temporal and spatial variations of soil C-CO_2 emissions in King George island, Maritime Antarctica, and its relationship with soil temperature variations during the austral summer of 2008 and 2009.

Methods

The studied site was selected based on previous soil studies (Simas *et al.* 2008) and is located at Keller Peninsula (UTM, zone 21E 427091 E and 3116260 N), presenting patches of moss carpets dominated by *Sannionia uncinata*; grass carpets with *Deschampsia antarctica* and bare soil. Total organic carbon content is 7.57 and 5.96 g/kg, for the 0-10 and 10-20 cm layers, respectively. A completely randomized experiment was carried out, with three replicates. The measurements were obtained from January to March 2009 using a portable LI-8100 analyzer (LiCor, EUA) coupled to a dynamic chamber. Soil temperature and humidity for the 0-10 cm layer were also measured. The spatial variability study of the soil C-CO_2 emission was conducted in March 13th of 2009, from 9:40 to 11:00 am. Measurements were carried out in a 3 x 1.5 meter, 60-points regular grid with minimum distance of 0.5 m between grid points. The grid was installed so that 30 of its points represented moss carpets and the other 30 patches of grass. A regression was performed using $FC\text{-}CO_2 = F0\ e^{BxSoilT}$, where F0 is the initial emission (at soilT=0) and B is the sensibility of the emission to soil temperature (/^oC). After linearization, the equation becomes Ln(FCO2) = A + B(SoilT), where A, the linear coefficient, is equal to Ln(F0). The spatial variability was analyzed using descriptive statistics and the adjustment of the semivariogram models to the soil C-CO_2 emission and temperature data.

Results

The mean soil C-CO_2 emission was 0.16 and 0.03 g of C- CO_2/m^2/h for sites with *Deschanpsia antarctica* and bare soil, respectively (Table 1). For the moss carpet, an intermediate value of 0.07 g of C- CO_2/m^2/h was obtained. All three values differ statistically ($p<0.05$) suggesting that C-CO_2 emissions were determined by the type of plant community. A significant exponential relationship ($p<0.05$) was verified between the C-CO_2 emission and temperature for all three studied situations, independently of soil water content. Sites with *Deschampsia antarctica* and those with mosses presented higher variation and an increase of 514 % and 174 % of the CO_2 emissions, respectively, when compared to the site with no vegetation, which reflects the effect of plant respiration on C-CO_2 emission. The highest value for the *Deschampsia antarctica* site when compared to mosses and the bare soil is partially explained by the fact that it possesses true root systems, which increase respiration.

Table 1. Descriptive statistics of the C-CO_2 ($g/m^2/h$) emissions for the studied soil covers.

Site	Mean	Standard deviation	Mean error	Min	Max
D*	0.16	0.05	0.01	0.07	0.25
M	0.07	0.03	0.01	0.04	0.12
B	0.03	0.01	0.00	0.01	0.04

D = *Deschampsia antarctica,* M = mosses and B = bare soil. N=22

The sensibility of soil C-CO_2 emissions to temperature variations is similar for all studied situations, as evidenced by similar rates of emission increase (Figure 1). Mathematically, this sensibility is expressed in terms of the angular coefficient of the relationship between Ln(FC-CO_2) and soil temperature (soilT), which is the B parameter of the regression.

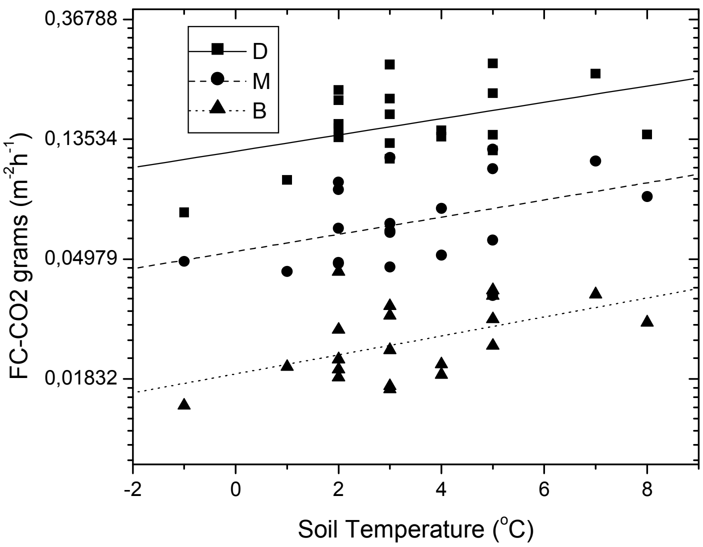

Figure 1. C-CO_2 emissions in function of soil temperature for the studied soil covers. D = *Deschampsia antarctica,* M = mosses and B = bare soil. N=22.

The B coefficients for all studied situations were statistically similar and a mean value of 0.073 /°C was calculated for B, which represents an increase of 7.3 % for soil C-CO_2 emission for each 1°C increase in soil temperature. The highest Q10 value was obtained for the bare soil (2.21), and the lowest for the area with *Deschampsia* Antarctica (1.98). However the Q10 values do not differ statistically. The exponential regression showed lower determination coefficients when compared to other Antarctic soils (Hopkins *et al.* 2006; Smith 2005). This might be due to the fact that our determinations were made *in situ* whereas most of the published studies were carried in the laboratory. Hopkins *et al.* (2006), in a laboratory experiment, report Q10 values ranging from 1.4 to 3.3 for different Antarctic soils submitted to temperature increases from -0.5 to 20°C. Smith (2005) verified for different soils from Maritime Antarctica that the emission rate increased exponentially with soil temperature for all water contents. In the present work, the sensibility of C-CO_2 emissions in relation to soil temperature refers to a soil condition with no water limitation as it refers to ice-free areas during the thawing period, for which the Q10 is close to 2 (Yuste *et al.* 2007). The increase of the C-CO_2 emissions due to temperature elevation indicates an increase of microbiological activity enhancing soil organic matter mineralization. The mean soil CO_2 emission and soil temperature based on the grid measurements were 0.24 g $CO_2/m^2/h$ and 4.94°C, respectively. The variation coefficient (CV) of soil C-CO_2 is higher than for soil temperature, which is in agreement with similar studies in which spatial distribution of

both properties was studied simultaneously (Konda *et al.* 2008; La Scala Jr. *et al.* 2000). According to the spatial variability criteria, the CV values found for CCO_2 emission and soil temperature can be considered high, since they are over 24% (Warrick and Nielsen 1980). Nevertheless, this value is in agreement with those found in other regions, under different vegetations (Konda *et al.* 2008; La Scala Jr. *et al.* 2000).
The models for soil C-CO_2 emission and soil temperature were spherical and Gaussian, respectively (Figure 3), with both adjustments presenting high determination coefficients (R^2>0.95).

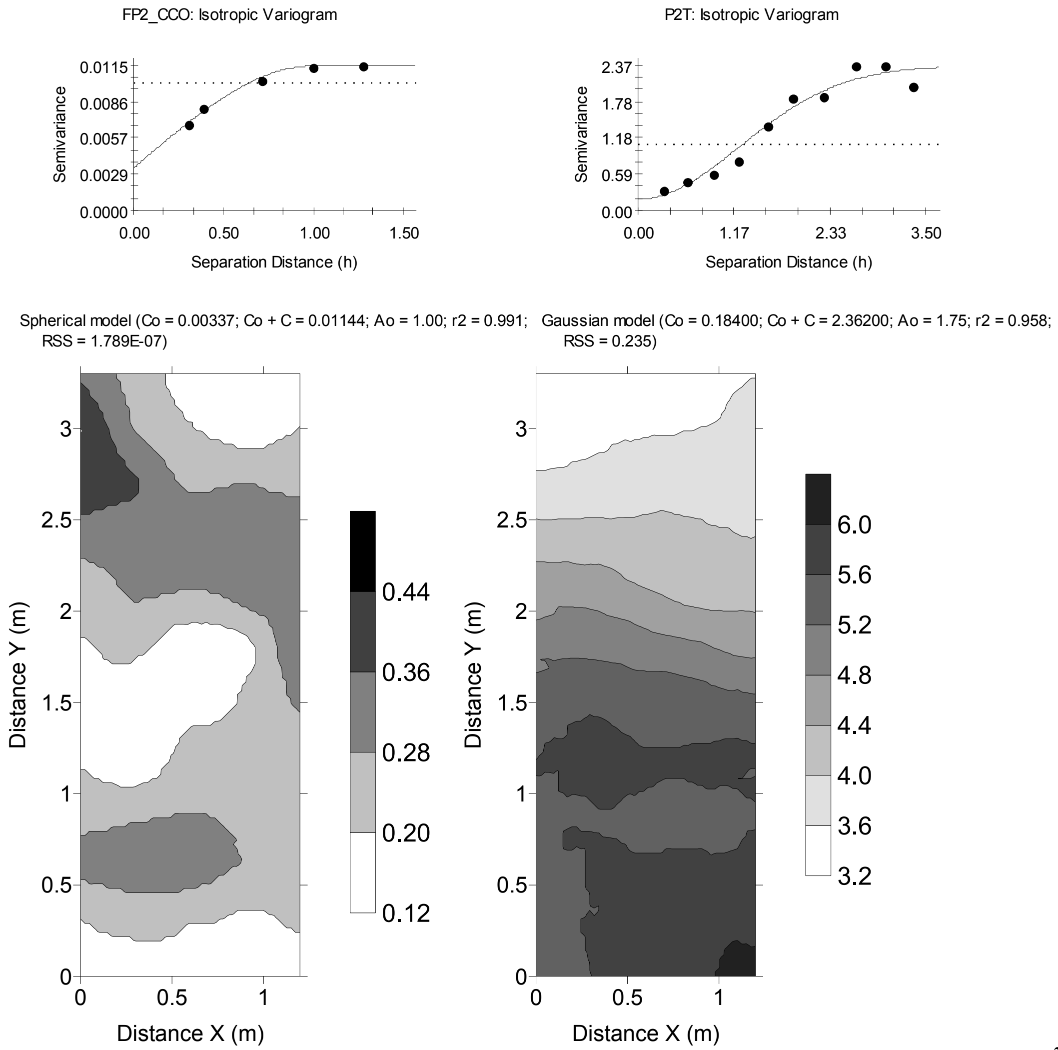

Figure 3. Semivariance as a function of distance and kriging maps of soil CO_2 emission (g/m^2/h) and soil temperature (^{o}C).

This is in agreement with similar works on soil CO_2 emission (Konda *et al.* 2008; La Scala *et al.* 2000).The scale dependence degree of the data (SDD) indicates moderate spatial dependence of the soil C-CO_2 emission (0.25 < SDD < 0.75) but strong spatial dependence for soil temperature (SDD < 0.25) (Cambardella *et al.* 1994). Moderate and weak SDD have been observed for soil C-CO_2 emission in different ecosystems (Konda *et al.* 2008; La Scala Jr. *et al.* 2000). Range values were 1.00 and 3.03 m, for C-CO_2 emission and soil temperature, respectively, indicating that soil temperature has little relation with soil C-CO_2 emission. In addition, no significant correlation is found when the 60 point measurements of C-CO_2 emission and soil temperature are linearly related. This evidences that the soil C-CO_2 emission variability model cannot be directly related to the spatial changes in soil temperature, especially under vegetated conditions.

The semivariograms and kriging maps of C-CO_2 emission and soil temperature are shown in Figure 2. Mean values for the 30 points with *Deschampsia antarctica* were higher than that obtained for the other 30 points with mosses. This feature is also observable in the C-CO_2 emission map, which indicates a higher emission at its upper part, where *Deschampsia antarctica* was located. When both maps are compared it is possible to see that the higher soil temperatures were registered usually at the portion under mosses rather than under *Deschampsia antarctica*. Nevertheless, as observed before, this does not seem to be a significant factor for

CO_2 emission, suggesting that the differences between emissions registered for both soil covers could come predominantly from roots respiration, instead of soil carbon decay only.

Conclusions

The highest mean C-CO_2 emission was registered for the site with *Deschanpsia antarctica*, in comparison to the moss carpet and the bare soil, indicating the effect of root systems in soil respiration. The relationship between soil C-CO_2 emission and soil temperature allowed the estimation of an increase of 7.6% for soil C-CO_2 emission for each 1°C increase in soil temperature. The spatial variability analysis suggests that the type of vegetation, rather than soil temperature, is controlling the spatial variability model since no relationship was observed with soil temperature, either by linear correlation or by comparing the spatial variability models and maps.

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