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A provisional method for assessing the impact on, and recovery of, Antarctic Desert Pavements from human-induced disturbances

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Abstract
A set of criteria were developed to quantify the relative stage of desert pavement recovery in the Ross Sea region of Antarctica. The innovative desert pavement classification system was formulated based around a number of distinguishing morphological features that change over time as the pavement re-establishes and stabilises. Features included clast characteristics, such as embeddedness, impressions and attributes to describe clast characteristics (e.g. ventifacted, pitted); surface colour contrast; degree of deflation; varnish; pavement crust coherence and thickness; nature of pavement armour (packing and % of surface armoured); presence of salt coatings on rock undersides, as well as general surface stability (e.g. evidence of subsidence, melt, recent disturbance, and concentrations of salt).

In year one (2008/2009 summer season) of a two year study the parameters were measured experimentally at five sites at Crater Hill and the vicinity of Scott Base, Ross Island. Sites had been disturbed by activities such as bulldozer scraping for road-fill and contouring for infrastructure at times ranging from one week to 50 years prior to assessment. The initial study sites were re-examined in 2009/2010 to test for repeatability and also the extent of visible recovery; and new sites were classified in the McMurdo Dry Valley region. Sites included previously disturbed sites at Marble Point, Lake Vanda in the Wright Valley, and Cape Roberts.

Pavement regeneration and rates of recovery have not previously been studied in the *polar* desert realm. The ability to predict the rate of recovery from disturbance on a range of surfaces assists with assessing the potential impacts of proposed activities in the Antarctic environment. Given knowledge of the site parent material, the application of the criteria showed it was possible to estimate the stage of desert pavement rehabilitation at each site. The system can also potentially be used to estimate the number of years since the desert pavement disturbance occurred.

Keywords
Antarctica, polar desert, desert pavement, human disturbance, recovery.

Introduction
Desert pavements are prominent features of hot arid and polar arid landscapes. Occurring worldwide, pavements are commonly found on gentle sloping sites where vegetation is minimal to non-existent and precipitation is scarce, such as areas in the southwestern U.S.A (McFadden *et al*. 1987) and the McMurdo Dry Valley region of the Antarctic continent. Pavements play an important role in the desert system, acting as protective armour to stabilize both the slope and the soil.

Mature, undisturbed Antarctic desert pavements are typically characterised by a layer of gravel, cobble, and boulder sized rock material; often platy, ventifacted, and coated with desert varnish. Clasts are embedded into a finer matrix; and their undersides are often coated in salts. The clasts are but are not usually strongly cemented to one another or the substrate beneath. Pavement surfaces in Antarctica are consequently easily disturbed by man and machinery, with human impacts commonly including foot traffic, tyre impressions, and bulldozer blade scrapes. Moreover, the prevailing cold desert conditions of the Antarctic continent result in naturally slow recovery rates (Campbell *et al*. 1993); consequently desert pavement at some sites has a low rehabilitative capability following disturbance.

Methods
During the 2008/2009 field season we investigated disturbed sites of varying age and causes of disturbance, within the Ross Island area. The classification system was developed on previously disturbed sites on Crater

Hill, Ross Island, Antarctica. Crater Hill provided an excellent case study for pavement rehabilitation studies as it had a chronological succession of disturbed and undisturbed surfaces where the timing of the disturbance is well constrained, from the most recently disturbed wind farm associated bulldozer scrape and cut/fill sites of November 2008, right back to sites disturbed during the inception of Scott Base and McMurdo Station in the late 1950s. Upon examining the sites around Crater Hill and the extent of visible recovery of the desert pavement, it became apparent that a number of observable criteria could be used to distinguish between the relative level of pavement rehabilitation of each surface, and a relative stage of desert pavement recovery could be assigned for each previously disturbed surface.

Morphological features identified as proxies for pavement recovery (Table 1) are outlined below.

Table 1. Provisional Desert Pavement Classification System.

Parameter		Classification Criteria	0 Highly Disturbed	1 Clearly Disturbed	2 Moderately Disturbed	3 Weakly Disturbed	4 Undisturbed
Surface Clasts	i	Embeddedness of surface clasts	none	few	some	most	all
	ii	Impressions of removed clasts	sharp/fresh	clear	distinct	faint	not visible
	iii	Degree of clast surface weathering (i.e ventifaction, pitting, polish)	unweathered	weakly weathered	moderately weathered	strongly weathered	very strongly weathered
	iv	% overturned clasts	> 75%	50-75%	20-50%	1-20%	0%
	v	CaCO3 on underside of clasts - "10 cobble" test	0-20%	20-40%	40-60%	60-80%	80-100%
	vi	Degree of development of CaCO3 coatings	not visible	weakly developed	moderately developed	strongly developed	very strongly developed
Pavement	vii	Armouring (1m2 test plot)	0-20%	20-40%	40-60%	60-80%	80-100%
	viii	Colour contrast (munsell unit difference)	very strong (>3)	strong (3)	moderate (2)	weak (1)	not visible (0)
Crust	ix	Crust integrity (strength/coherence)	structureless	weakly developed	moderately developed	well developed (semi-intact when disturbed)	strongly developed (separates cleanly when disturbed)
	x	Crust thickness	0 mm	<1 mm	1-3 mm	3-5 mm	>5 mm
Surface Stability	xi	Evidence of subsidence and melt-out	prominent	distinct	faint	indistinct	not visible
	xii	Accumulation of salt on cut surfaces	abundant	common	some	rare	not visible
	xiii	Patterned ground development	not visible	indistinct	faint	distinct	prominent

Some examples of parameters
Embeddedness – the proportion of the clast below the plane of the ground surface. In areas of mature undisturbed surfaces up to 85% of a cobble-sized clast can be embedded below the ground surface.

Impressions – indentations in the ground surface that result from removal or overturning of clasts during disturbance. Colluvial infilling is time dependant so impressions can persist for a long time in the Antarctic environment.

CaCO$_3$ coatings – carbonate accumulation and salts on the underside of clasts is a measure of pavement maturity and in-situ clasts can be used to determine the relative stage of pavement rehabilitation.

% overturned clasts – precariously 'perched' and overturned clasts on the ground surface are an obvious indication of recent disturbance. Unlike mature or rehabilitated surfaces, characterised by a smooth layer of adjacent flat-lying clasts, recently disturbed surfaces contain up-ended overlapping clasts.

Armouring – surface clast density increases with age and stage of rehabilitation; the % of armouring is comparatively lower on recently disturbed surfaces.

Criteria were assigned a severity/extent rating from zero to four, zero being highly disturbed, and four being undisturbed (Table 1). This severity rating system was devised in the field on sites with the timing and nature of the disturbance is well constrained. A relative % recovery for each parameter was then calculated, which is based on the deviation of that parameter – relative to a control or undisturbed equivalent surface. (Table 2). An overall Mean Recovery Index (MRI) could then be assigned to each pavement surface, expressed as pavement rehabilitation stage one through five (Table 3).

Table 2. Relative desert pavement recovery for the McMurdo to Willys Field Pipeline site (Site B), Crater Hill, Ross Island, Antarctica.

Criteria	Site B	Control	% Recovery
i	2	4	50
ii	3	4	75
iii	2	2	100
iv	3	4	75
v	2	4	50
vi	2	4	50
vii	2	4	50
viii	2	4	50
ix	0	1	0
x	0	1	0
xi	2	4	50
xii	2	4	50
xiii	2	2	100
Mean Recovery Index			50

Table 3. Mean Recovery Index (MRI).

MRI (%)	Rehabilitative stage	Description
0	1	newly disturbed
25	2	incipient pavement
50	3	intermediate recovery
75	4	advanced recovery
100	5	indistinguishable from undisturbed site

Provisional results

Case study: Crater Hill, Ross Island, Antarctica

In January 2009 during a detailed investigation of the Crater Hill wind farm site near Scott Base, Ross Island, it was observed that there were distinct differences in the physical integrity of the desert pavement surface at previously disturbed surfaces on Crater Hill, over small distances. Five sites were investigated, four on Crater Hill proper, and one lower on Crater Hill, underneath the fuel pipeline which runs between McMurdo Station and Willys Field. The known dates for disturbance to these individual units ranges from November 2008 to the early 1960s. It was recognised that these observed differences were temporal in origin (as there was little spatial variability in parent material), and inferred that these visible differences reflected various stages in the rate of recovery and desert pavement regeneration post-disturbance. Findings are summarised in Figure 1.
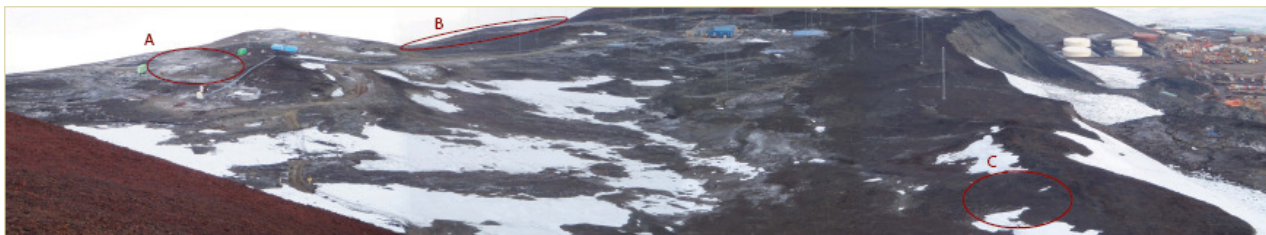
Site A = Recently disturbed turbine site, disturbed Nov 2008.
Clasts not embedded; do not show weathering; >75% overturned. Interlocking pavement armour is absent. Crust undeveloped. Distinct evidence of melt-out/subsidence; accumulation of salt on cut surfaces. Stage of desert pavement recovery: beginnings of the formation of an incipient desert pavement. MRI = 25%.

Site B = McMurdo to Willy Field Pipeline, disturbed c. 1992.
Some clasts are embedded; show some weathering; 1-20% overturned. Some accumulation of salt. Some recovery of patterned ground. Stage of desert pavement recovery: intermediate. MRI = 50%.

Control = Crater Hill far ridge site, undisturbed.
All clasts are embedded; some show weathering; 0% overturned. Very strongly developed $CaCO_3$ coatings. No evidence of melt-out/subsidence. Prominent patterned ground development. Stage of desert pavement recovery: Undisturbed pavement/control. MRI = 100%.

Figure 1. Mosaic of photos shows a panoramic view of Crater Hill study site. Sites A, B, and Control are highlighted.

Conclusion
This two year study revealed that a number of distinguishing morphological features change over time as the pavement re-establishes and stabilises. The parameters used on Ross Island and in the McMurdo Dry Valleys to distinguish between the relative level of pavement rehabilitation, and mean recovery indices were assigned to previously disturbed surfaces to depict their relative stage of desert pavement recovery. Understanding the site-to-site differences in rehabilitative capability is critical when planning activities in the Antarctic environment and will assist managers when dealing with potential impacts of such activities.

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Carbon sequestration dynamics and climate change in Subarctic and Low Arctic Organic Cryosols in Canada

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Abstract

Organic Cryosols began to develop in the Low Arctic and Subarctic of the Mackenzie Valley in northwestern Canada between approximately 5480 and 9460 yr BP. In the Low Arctic the long-term rate of organic carbon sequestration in these soils ranged from 1.0–55.0 gC/m^2/yr with approximately 1.0–2.1 gC/m^2/yr being sequestered in the surface soil layer (0–50 cm). In the Subarctic the long-term average rate of organic carbon sequestration in these soils ranged from 4.7–53.7 gC/m^2/yr with approximately 9.6–23.6 gC/m^2/yr being sequestered in the surface soil layer. High rates of organic carbon sequestration occurred in Low Arctic Organic Cryosols at approximately 7000–9000 yr BP and in Subarctic Organic Cryosols at 3000–6000 yr BP and 8000–9000 yr BP. It has been suggested that Subarctic Organic Cryosols could be severely affected by climate change, leading to severe thawing, increased decomposition and, ultimately, cessation of the carbon sequestration process. These soils would thus become a carbon source and could trigger very strong feedback mechanisms that might further increase climate warming.

Key Words

Organic soils, peatlands, radiocarbon dates, sampling, peat, climate warming

Introduction

Organic Cryosols (permafrost-affected organic soils) are common soils in Subarctic and Arctic Canada. These soils cover approximately 284 x10^3 km^2, which is about 23% of the entire area of organic soils in Canada, and contain approximately 35 Gt of organic carbon (Tarnocai 2000; 2006). They are associated with perennially frozen peatlands such as peat plateaus, polygonal peat plateaus and low-centre and high-centre lowland polygons (National Wetlands Working Group 1988). In this paper carbon dynamics are given for Organic Cryosols associated with high-centre lowland polygons in the Low Arctic and polygonal peat plateaus in the Subarctic of the Mackenzie Valley in the Northwest Territories of Canada.

Methods

Organic Cryosols were sampled in two ecological regions, the Low Arctic (site T5: 68° 57.387 N, 133° 50.123 W and site MD-1: 69° 09' N, 134° 17' W) and the Subarctic (Inuvik area – sites IN-BG-1 and IN-BG-3: 68° 19' 01"N, 133° 25' 57"W; Norman Wells area – sites NW-BG-8 and NW-BG-10: 65° 12' 48" N, 127° 00' 58" W). The locations of these sites are shown on Figure 1. Although a number of cores were collected from these areas, only the sites listed above were used for analysis in this paper. Sampling was carried out using a SIPRE corer that produced continuous peat cores (3.8 cm in diameter) (Figure 2) for the entire depth of the soil through the basal peat to the underlying mineral layer. These peat cores were used to describe the soil horizons on the basis of the botanical composition of the peat and samples were taken for chemical analysis, bulk density determination and radiocarbon dating.

Organic carbon concentrations were determined using a LECO CHN analyzer (Sheldrick 1984). Frozen weights of bulk density samples were measured in the field, samples were oven-dried at 50° C in the laboratory and moisture (ice) content and bulk densities were calculated (Sheldrick 1984). Radiocarbon dating was carried out by Beta Analytical Incorporated's radiocarbon laboratory using standard AMS dating analysis.

Carbon accumulation was calculated on the basis of intermittent radiocarbon dates, usually four to six dated depths between the soil surface and the basal peat. The soil organic content (SOCC kg/m^2) of each layer was calculated using the formula:

$$SOCC = C \times BD \times T \times (1 - CF) \tag{1}$$

where C is organic carbon (% weight), BD is bulk density (g/cm^3), T is soil layer thickness (cm), and CF is coarse fragments and/or ice content (% weight). The SOCC calculated for each layer was divided by the age of the layer to determine the average amount of carbon deposited annually.
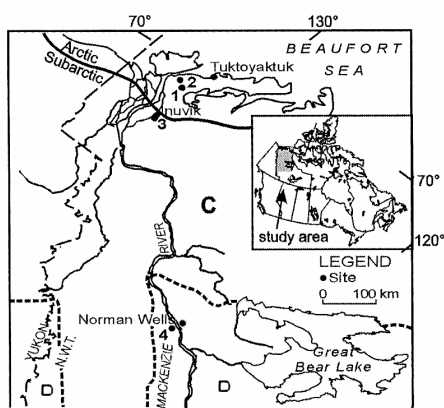
Figure 1. Map showing the sampling sites, the ecological provinces (Subarctic and Arctic) and the discontinuous (D) and continuous (C) permafrost zones.

Figure 2. Frozen soil core samples from the Norman Wells site. The right end of the upper core is the surface and the left end of the lower core is the mineral layer below the basal peat.

Results

Soil characteristics

The organic materials associated with these Organic Cryosols are dominantly moss peat with Sphagnum moss underlain by sedge or woody sedge peat in the peat profile. The active layer of soils (the surface layer that freezes and thaws annually) is between 30 and 50 cm deep. The underlying perennially-frozen layer has an ice content of 75–92%. These soils are very extremely acid to strongly acid (pH 3.7–5.5) and have organic carbon concentrations of 40–55%.

Age

The age of the basal peat represents the beginning of the development (peat deposition) of the Organic Cryosol. Radiocarbon dates for the basal peat of the six soils used in this study range from 5480 ± 50 yr BP to 9460 ± 50 yr BP (Table 1). These dates suggest that, for most of these soils, carbon deposition began shortly after the deglaciation of the Mackenzie Valley.

Table 1. Age of Organic Cryosols based on radiocarbon dates of the basal peat.

Site No.[a]	Peat core sites	Depth (cm)	Age of basal peat (yr BP)	Radiocarbon laboratory number	Sampling date
1	T5	95	7960 ± 80	Beta-240093	November 2007
2	MD-1	735	8850 ± 90	Beta-11565	July 1973
3	IN-BG-1	375	8130 ± 40	Beta-240911	September 2007
3	IN-BG-3	200	5480 ± 50	Beta-240095	September 2007
4	NW-BG-8	208	9460 ± 50	Beta-251736	May 2008
4	NW-BG-10	150	9310 ± 50	Beta-251737	May 2008

[a] Locations of these sites are shown in Figure 1 and the coordinates are given in the Methods section

Carbon accumulation

The means and ranges for carbon accumulations in these soils are given in Table 2. The average rates long-term carbon accumulation were 29.8 gC/m²/yr for Low Arctic soils and 21.8 gC/m²/yr for Subarctic soils (Table 2). It should be noted that the higher rates of carbon accumulation in Low Arctic peatlands are due, to some extent, to partial erosion of the surface peat, especially at site T5. As a result, the rates of carbon accumulation in these peatlands were based on the lower depths of the soils, where carbon sequestration had been higher. For example, the date for the 40 cm depth at site T5 was 7380 yr BP. The mean rates of carbon accumulation in the surface layers were 1.5 gC/m²/yr for Low Arctic Organic Cryosols and 17.8 gC/m²/yr for Subarctic Organic Cryosols (Table 2). For comparison, Britta et al. (2008) reported long-term carbon sequestration (accumulation) rates of 12.5–12.7 gC/m²/yr for Subarctic peat plateaus in west-central Canada and 3.7–5.2 gC/m²/yr for the surface layer.

Table 2. Carbon sequestration rates in various types of peatlands.

Site	Soil	Peatland type	No. of dated layers	Long-term carbon sequestration rates[a] (gC/m²/yr)		Carbon sequestration rates in the surface layer[b] (gC/m²/yr)	
				Mean	Range	Mean	Range
Low Arctic	OC[c]	HCLP[d]	7	29.8	1.0–55.0	1.5	1.0–2.1
Subarctic–Inuvik	OC[c]	PPP[e]	10	24.8	4.7–53.7	18.9	14.8–23.0
Subarctic–Norman Wells	OC[c]	PP[f]	11	18.9	6.1–50.0	16.6	9.6–23.6

[a]based on intermittent dates

[b]0–50 cm depth

[c]OC: Organic Cryosols (Canadian System of Soil Classification) and Histels (US Soil Taxonomy)

[d]HCLP: High-centre lowland polygon

[e]PPP : Polygonal peat plateau

[f]PP : Peat plateau

The rates of carbon accumulation were not uniform during the life of these soils (Table 2). The rate of carbon accumulation in Low Arctic Organic Cryosols was highest between 7000 and 9000 yr BP during the Hypsithermal Maximum (Figure 3). The rate of carbon sequestration in Subarctic Organic Cryosols (in both Inuvik and Norman Wells) also showed increased rates of carbon accumulation between 8000 and 9000 yr BP with a second maximum between 3000 and 6000 yr BP (Figure 3). This suggests that, on Low Arctic sites, carbon sequestration rates reached a maximum between 7000 and 9000 yr BP and then slowed down after this period, becoming very slow during the last several hundred years. The Subarctic sites, on the other hand, had two periods with higher rates of carbon sequestration (8000–9000 and 3000–6000 yr BP) and an intermediate period with a lower rate of sequestration (6000 to 8000 yr BP). These Subarctic sites, however, have still been sequestering carbon at a moderate rate (17.8 gC/m²/yr) during the past several hundred years (Figure 3).
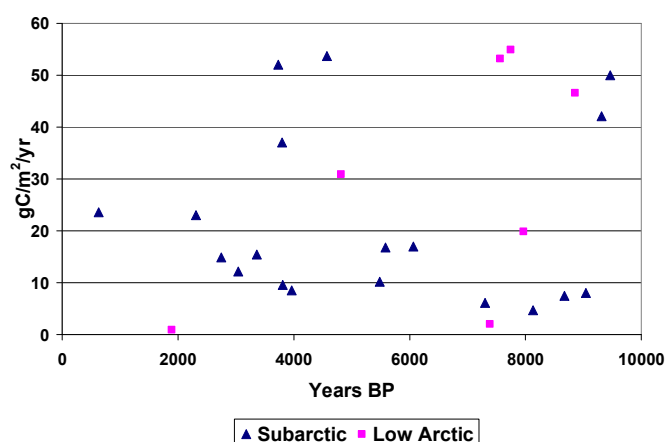

Figure 3. Rates of carbon accumulation in Low Arctic and Subarctic Organic Cryosols during the last 9500 years. Note that the highest rates of carbon accumulation occurred at 7000–9000 yr BP in the Low Arctic and at 8000–9000 and 3000–6000 yr BP in the Subarctic.

Conclusion

Organic Cryosols in the Subarctic and Low Arctic regions of the Mackenzie Valley have been accumulating carbon for the past 9000 years. During this period the rate of carbon sequestration varied widely because of changes in climate, hydrology, composition of peat materials and frequency of wildfires (indicated by the presence of ash layers and charcoal).

Although mean long-term carbon sequestration rates for Organic Cryosols in the two ecological regions are similar (Low Arctic: 29.8 gC/m²/yr; Subarctic: 21.8 gC/m²/yr), these values do not correspond to the current rate of carbon sequestration. The rapid rate of carbon sequestration in Low Arctic Organic Cryosols between 7000 and 9000 yr BP skewed the long-term average rate, giving the impression that these soils still sequester carbon at a high rate. However, the rate of carbon sequestration in the surface layer of these soils is very low (1.5 gC/m²/yr) because drying of the peat surface lead to erosion of the soil surface and wildfires. The

current rate of carbon sequestration in Subarctic Organic Cryosols is also lower than the long-term average rate, but these soils are still sequestering carbon at a moderate rate (17.8 gC/m^2/yr). Therefore, in order to obtain information on recent carbon accumulation in these areas, carbon sequestration rates for the surface layer should be used.

Global circulation models predict that the greatest increases in temperature will occur in the Arctic and Subarctic regions. Tarnocai (2006) indicated that 18% of the Organic Cryosols in the Arctic and 77% in the Subarctic could be severely to extremely-severely affected by climate change. Since climate warming has already begun to trigger severe thawing of ice-rich permafrost and increased decomposition of peat materials, these soils are in the process of becoming a carbon source and will eventually no longer sequester carbon. This double effect could trigger very strong feedback mechanisms that might further increase climate warming (Oechel *et al*. 1993).

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Controlling factors of soil nitrogen and carbon contents across the Tibetan Plateau: soil formation, permafrost, and soil moisture

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Abstract
The Tibetan Plateau is the largest high-altitude and low-latitude permafrost area of the world. We assume that permafrost dynamics are mainly controlled by topography, precipitation and temperature having a central impact on soil degradation, carbon sources and sinks. We investigated the main parameters (e.g. mean annual air (MAT) and soil temperature (MAST), mean annual precipitation (MAP), soil moisture (SM), soil chemistry and physics) influencing organic carbon (C_{org}), total nitrogen (N_t) and mineralised nitrogen (N_{min}) at 47 sites along a 1,200 km transect of the central-eastern Tibetan Plateau. This large-scale survey allows testing the hypothesis that diversity of pedogenesis is another major component for assessing C and N cycling. We demonstrate that SM is the dominant parameter explaining 64% of C_{org} and 60% of N variation. The extent of the effect of SM is determined by permafrost, aeolian sedimentation and pedogenesis. Thus, the explanatory power for C and N concentrations is significantly improved by adding $CaCO_3$ content ($P = 0.012$ for C_{org}; $P = 0.006$ for N_t) and soil texture ($P = 0.077$ for C_{org}; $P = 0.015$ for N_t) to the model. SM overrides soil temperature as the main driving parameter at landscape scale. Our study shows that degradation of permafrost and corresponding changes in soil hydrology combined with a shift from mature stages of pedogenesis to initial stages, have severe impact on soil C and N cycles.

Key Words
Soil formation, permafrost degradation, alpine grassland, C and N stocks, global warming

Introduction
The Tibetan Plateau represents a key area for environmental evolution of the earth at regional and global scales proving particularly sensitivity to global warming (Yao *et al*. 1995; Liu and Chen 2000). It is the largest high-altitude and low-latitude permafrost area of the world with 54.3% of its total surface affected by permafrost (Cheng 2005), characterised by strong diurnal patterns, high radiation on the surface as well as a distinct geothermal gradient (Wang and French 1994). Further, the proposed decay of the Tibetan permafrost (Böhner and Lehmkuhl 2005) will have a strong impact on soil hydrology, leading to severe changes in soil moisture–temperature regimes (Zhang *et al. 200*3). Thus, there is a direct link to soils, which are the basic resources life in terrestrial ecosystems depends on and of particular importance for the global C cycle (Schimel 1995; Sudgen *et al*. 2004). Global environmental change, largely caused by human activities, affects climate as well as soils, and consequently reassigns their role in ecosystem functioning (Vitousek *et al. 199*7; Chapin *et al*. 2000).
The main objective of our study was to investigate, on a landscape scale, the influence of pedogenesis on C and N stocks supplementary to the generally used ecological parameters like climate, temperature, moisture conditions, vegetation, topography, and hydrology. We hypothesize that diversity patterns of pedological features across a changing landscape are crucial to assess C and N dynamics more precisely (cf. Baumann *et al. 200*9).

Study sites and methods
During an expedition in summer 2006 (cooperation of Peking University, China and University of Tübingen, Germany) along a transect of about 1,200 km length and 200 km width in the central-eastern part of the Tibetan Plateau from Xining to Lhasa, botanical, ecological and pedological settings have been investigated at 47 sites. The transect was situated between 91 and 101°E latitude and 30 to 36°N longitude with an eastern section from Xining to Yushu and a western part from Golmud to Lhasa (Figure 1).
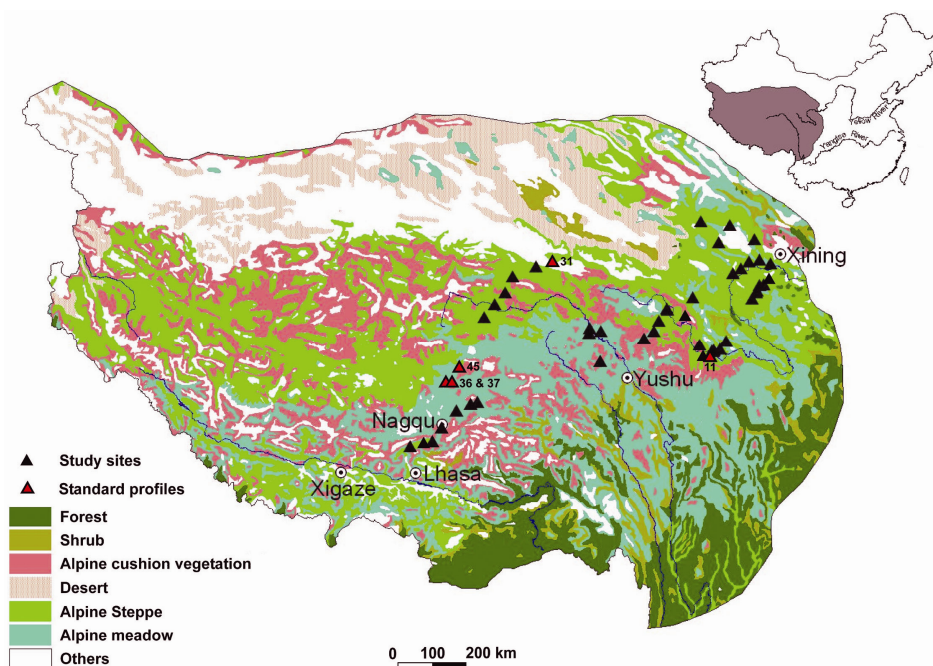
Figure 1. Vegetation map of the Tibetan Plateau, adapted from the Vegetation Map of China (Hou 1982), showing study sites and standard soil profiles representing the most important soil groups (Baumann *et al.* 2009).

Detailed field investigations included soil profile description according to FAO (2006). N_{min} was extracted on-site. At each site four schematic samples of each depth-increment (0–5, 5–10, and 10–20 cm) were mixed. Macroscopic root material and other organic compounds were removed. An aliquot of 10 g of homogenised soil was used for extraction with 50mL 1M KCl for 60 minutes immediately after sampling, stirred with a glass stirrer every 10 minutes, and then filtered into 100mL PE-vials. SM was determined directly in the field by TDR-probes (Delta-T Devices Ltd.) for all soil horizons as well as for the depth increments. Above- and below-ground biomass was investigated at a $1m^2$ sampling square at each site by clipping and digging out the roots. The same method was used to describe plant species composition. Soil temperature was measured with buried temperature data loggers (Hobo U12, Onset Computer Corporation, Pocasset, MA, USA) at an interval of 1 h starting in July 2006 for 1 year. Grain size analysis was done by combined pipette and sieving method. EC was determined in distilled H_2O, pH was measured in both 0.01M $CaCl_2$ and distilled H_2O potentiometrically. $CaCO_3$ was analyzed volumetrically. N_t and C_{org} were measured with heat combustion (VARIO EL III). C bound in $CaCO_3$ was subtracted from C_t quantified with CN analysis to get the proportion of C_{org}. KCl-extractions for N_{min} analysis were measured photometrically (CFA SAN Plus). Water content was determined gravimetrically by subtracting the coarse size fraction (>2mm). Climate data for each site was calculated based on linear models using latitude, longitude, and altitude as variables from 50-year averaged temperature and precipitation records (1951–2000) at 680 well-distributed climate stations across China (He *et al.* 2006). For statistics the results of the schematic sampling series was utilized (sample size n=141), split into the depth increments (0–5, 5–10, 10–20 cm). To examine dependencies, correlation, and regression analyses were conducted for SM, MAST, MAT, MAP, soil texture, $CaCO_3$ content, and pH. To address multi-colinearity, out of these predictors only variables with $R^2<0.5$ were used for regression analysis in the same model.

Results and Discussion

Pedogenesis
All investigated soil profiles were allocated to five main soil groups, covering most soil types of the Tibetan Plateau (Initially formed soils IS = 13, Regosols RG = 7, Cambisols CM = 11, Groundwater influenced GL = 4, Permafrost influenced PF = 12). These main soil groups represent different stages of maturity, from initial soil formation to long developed soils underlain by stable permafrost conditions. Soil development is often young and has been frequently disturbed over time. Therefore, relict, mostly humic horizons can be observed in some profiles, representing phases of stability. The most important factor controlling these processes is recent active aeolian sedimentation, diluting the topsoil's chemical composition or burying the developed

soils completely. This explains the strong trend to accumulate carbonates and bases often relocated to deeper horizons, recognizable by carbonate pseudo-mycelic structures. In the southern and eastern part, distinct weathering and enrichment of secondary Fe oxides in Bw horizons can be found disappearing to the north of the continuous permafrost zone. Strong gleyic or stagnic properties were evident towards the southern and eastern margin of the permafrost-affected area with increasing precipitation, although the permafrost table was deeper.

The main differences between sites are substantially related to the permafrost regime. Figure 2 shows profile 37 and 36 situated in the discontinuous permafrost zone south of Amduo (4900m ASL). The vegetation was dominated by *Kobresia tibetica* and *Carex spp.* community developing in a hummocky area. The distribution of the hummocks was inhomogeneous. Permafrost could be detected at this site in 190cm depth. At a distance of only 150m away (site 36, colluvic Regosol) no permafrost was evident to a depth of 240 cm with correspondingly different C and N contents as well as soil parameters.
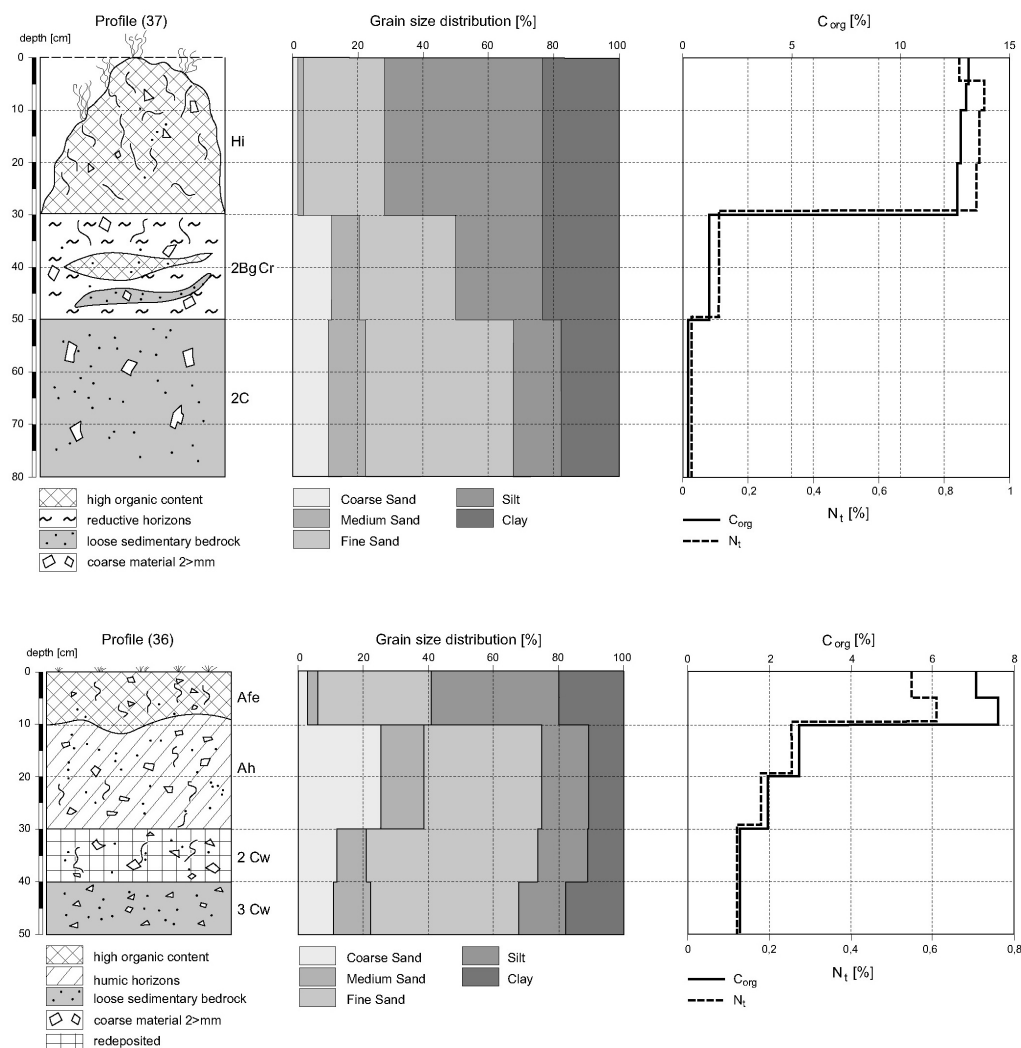

Figure 2. Sites 37 (Calcaric Gelic Histosol) and site 36 (Colluvic Regosol) (cf. Baumann *et al.* 2009).

C and N stocks: amount and distribution

Highly fluctuating C and N contents of topsoils were observed on small spatial scales, mainly controlled by relief position and in particular by related permafrost distribution in discontinuous permafrost areas (Figure 2). The mineralized fraction of N at the investigated sites can be found almost exclusively as NH_4^+, with the highest contents occurring at water saturated sites underlain by permafrost. Highest C and N contents occur in permafrost and groundwater influenced soils, whereas the lowest amounts appear in initially formed soils. There was a clear trend to higher C and N stocks with an advanced degree of maturity of soil development observable, with increasing soil acidity, decreasing carbonate content and grain size distribution showing more fine-rich textures.

C and N dynamics and General Linear Model (GLM)
Analyses of schematic soil samples show significant correlations for SM and C contents as well as for SM and N contents. Furthermore, significant, but relatively weak relationships are evident for MAP, whereas no significant correlations (P<0.01) were found concerning MAT and MAST. All three fractions of soil texture (sand, silt, and clay) also had significant relationships (P<0.01) with C and N contents, whereas only the sand fraction was negatively correlated. Both pH and $CaCO_3$ content had negative relationships to the dependent variables. Variables used as predictors for pedogenesis showed strong relationships within the independent parameter set. This was true for MAP and SM (R^2=0.42, P<0.001) as well as for pH and $CaCO_3$ (R^2=0.50, P<0.001). But also other parameters correlate, e.g. soil texture and soil moisture. The General Linear Model suggests SM as the most important parameter explaining 64% of C_{org} variation. Slightly lower values can be identified for N_t. Both C_{org} and N_t predictions can be significantly improved by adding $CaCO_3$ and sand contents to the model, explaining 65% and 64% of the variation. MAT as well as MAST has no influence on the model. Looking at the control parameters, SM explains 64%, MAP 20%, pH 38%, $CaCO_3$ 23%, and sand 29% for C_{org}. Concerning N_t, SM accounts for 60%, MAP 27%, pH 24%, $CaCO_3$ 26% and sand for 35% of the variation.

Conclusion
The soil development stage is an important predictor for C and N contents in soils on the Tibetan Plateau. This is emphasized by significant contributions of $CaCO_3$ and sand contents to the General Linear Model, which are used to describe pedogenesis. Our results imply that SM is the major controlling parameter of C and N stocks in high altitude grassland ecosystems influenced by permafrost, explaining 65% of C_{org} and 64% of N_t variations, respectively. As MAP and SM show only a moderate correlation compared with the very high relationship between MAT and MAST, it can be concluded that SM is closely linked to permafrost. Consequently, C and N stocks as well as ecosystem functioning are predominantly affected by permafrost, aeolian sedimentation and the stage of soil development. Permafrost and aeolian sedimentation triggered by permafrost degradation are also a function of relief position, parent material, human impact, and seasonal climatic fluctuations. Given a shift to drier and warmer climatic conditions, the Tibetan Plateau could change from a net C sink to a net source, implying significant C loss by respiration.

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Correlation between atmospheric physical factors and soil temperature of Keller Peninsula, King George Island, Antarctica

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Abstract
This study investigated what atmospheric physical factors (air temperature, precipitation, solar radiation, air moisture and wind) contribute to soil temperature in Keller Peninsula, King George Island, Antarctica. Temperature sensors were installed at three soil depths at two sites, near to the Antarctic Station Comandante Ferraz (Brazil). Data were collected every three hours during the period from March to December 2008 and were compared with atmospheric data from the meteorological station of the Instituto Nacional de Pesquisas Espaciais (INPE, Brazil). The air temperature was the factor that most influenced the soil temperature. Other factors such as precipitation and solar radiation had a significant contribution, however minor. The air humidity and wind affect respectively, the first 5 and 20 cm of soil. These results demonstrated the importance of monitoring the soil temperature as an indicator of climate change.

Key Words
Climate change, meteorology, cryosols, permafrost, active layer.

Introduction
The Maritime Antarctic region has the highest temperature and rainfall across the Antarctic continent which promotes primary production, soil genesis and biological activity in general. The increase in ice-free areas in the Antarctic, as a result of climate change, causes a series of local transformations that may affect the microclimate of the soil, causing greater melting of the permafrost and causing changes in the soil moisture (Francelino 2004). The study of soils in maritime Antarctica, considering the seasonal variation of the active layer and permafrost, is an efficient tool that highlights the effects of higher temperatures in the region, as the active layer and permafrost are both sensitive to climate change (Wu *et al.* 2005). In Antarctica, there is little information about the distribution, thickness, chemical, or physical properties of permafrost. This study was a comparison between the temperatures at different soil depths and atmospheric physical factors such as air temperature, humidity, precipitation, wind speed and solar radiation, in Keller Peninsula, located in King George Island, Antarctica Maritime.

Methods
Two sites were chosen (A and B) for monitoring the temperature of the soil, near to the Brazilian Antarctic Station Comandante Ferraz in the Keller peninsula (Figure 1). At each site three temperature sensors (Model 107 Temperature Probe) were installed at different soil depths and coupled to a storage device CR1000 data logger from Campbell Scientific. The system was programmed to perform reading of data every hour. Data on soil temperature, obtained from March to December 2008 were compared to data of precipitation (mm), air temperature (°C), relative humidity (%), solar radiation (W/m) and wind speed (m/s) in the same period, collected every 3 hours by the weather station of the National Institute for Space Research (INPE 2009), located next to EACF. For this comparison was calculated and tested - the 5% significance - the Pearson correlation coefficient (r) between the different variables, using the program STATISTICA 7.1 (StatSoft 2005). Data on soil temperature obtained by using the weather station at depths 0, 5, 10 and 20 cm, were used as a control. The data of radiation and moisture were processed to obtain a normal distribution, using the equation $\log(x +1)$.
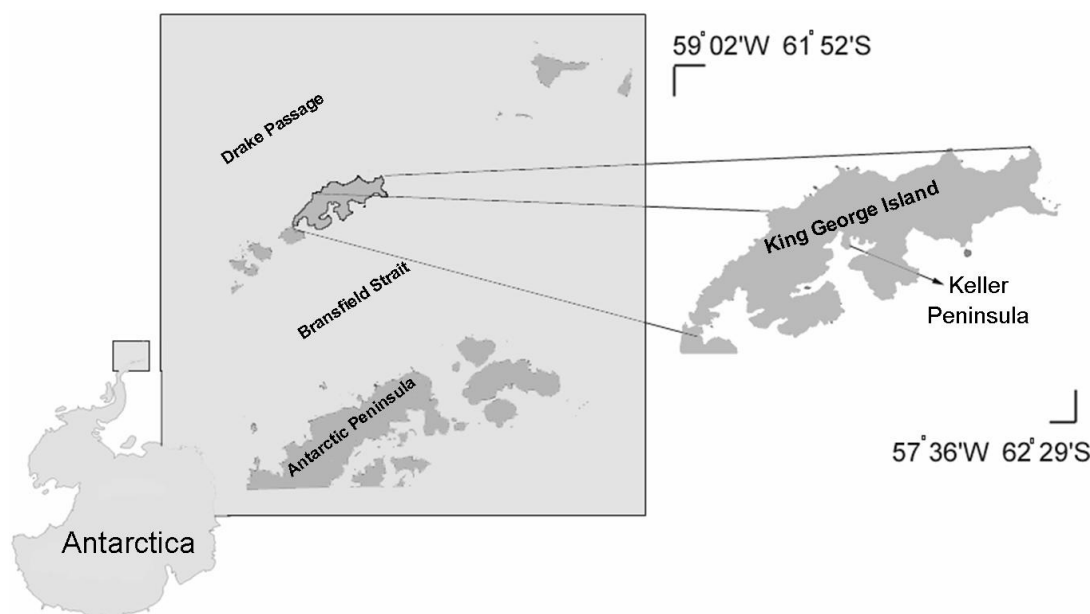
Figure 1. Location of Keller Peninsula in King George Island, Antarctica.

Results

There was a higher correlation between soil and air temperature than other factors studied (Table 1). However the correlation between soil and air temperature decreased with increasing the soil depth. This behavior was expected, (Francelino *et al.* 2004), since the air is in direct contact with the soil surface. Precipitation and solar radiation also contributed to soil temperature ($p <0.05$), but at a lower intensity. The contributions of precipitation and solar radiation also decreased in the deeper layers. Air moisture had a negative correlation with soil temperature, being significant in the sensors of the meteorological station of INPE, where the moisture influenced the temperature of the soil to a depth of 5 cm. The wind affected the temperature of the soil to a depth of 20 cm.

Table 1. Correlations between atmospheric physical factors and soil temperature in the Keller Peninsula, Maritime Antarctica.

Site	Coordenate (UTM) E	N	Soil depth (cm)	Air temp.	Wind	Precip.	Moisture	Radiation
A	427137	3115583	10	0,61*	0,05*	0,10*	-0,04	0,31*
			44	0,43*	0,01	0,07*	-0,02	0,20*
			99	0,27*	-0,01	0,04*	0,02	0,08*
B	427053	3115790	10	0,70*	0,07*	0,12*	-0,03	0,36*
			51	0,53*	0,02	0,09*	-0,04	0,29*
			92	0,42*	-0,01	0,08*	-0,02	0,22*
INPE	427272	3115514	0	0,76*	0,12*	0,13*	-0,07*	0,45*
			5	0,76*	0,12*	0,14*	-0,04*	0,39*
			10	0,73*	0,11*	0,13*	-0,04	0,36*
			20	0,67*	0,09*	0,11*	-0,04	0,34*

Note: Temp.= temperature. Precip.= precipitation. * $p<0,05$.

The monthly mean soil and air temperatures obtained in the monitoring sites are shown in Figure 2. The air temperature was more similar to the surface soil temperature at site B. This is because site B was located at an elevation similar to the meteorological station, where they collected atmospheric data, which shows the change in microclimate that occurs in areas in close proximity of this region. It was observed that surface soil temperature in the depth of 10 cm is higher in summer compared to the deeper layers, a fact which is reversed in winter mainly due to the large amount of snow deposited on the soil surface in that period. There was also a slowing of the average temperature of soil in relation to the air. According to Setzer *et al.* (2004) this can be explained by the deepening slow-line freezing of the soil due to its constitutuents, i.e., a solid and porous materials, so that soil is not an efficient heat conductor.
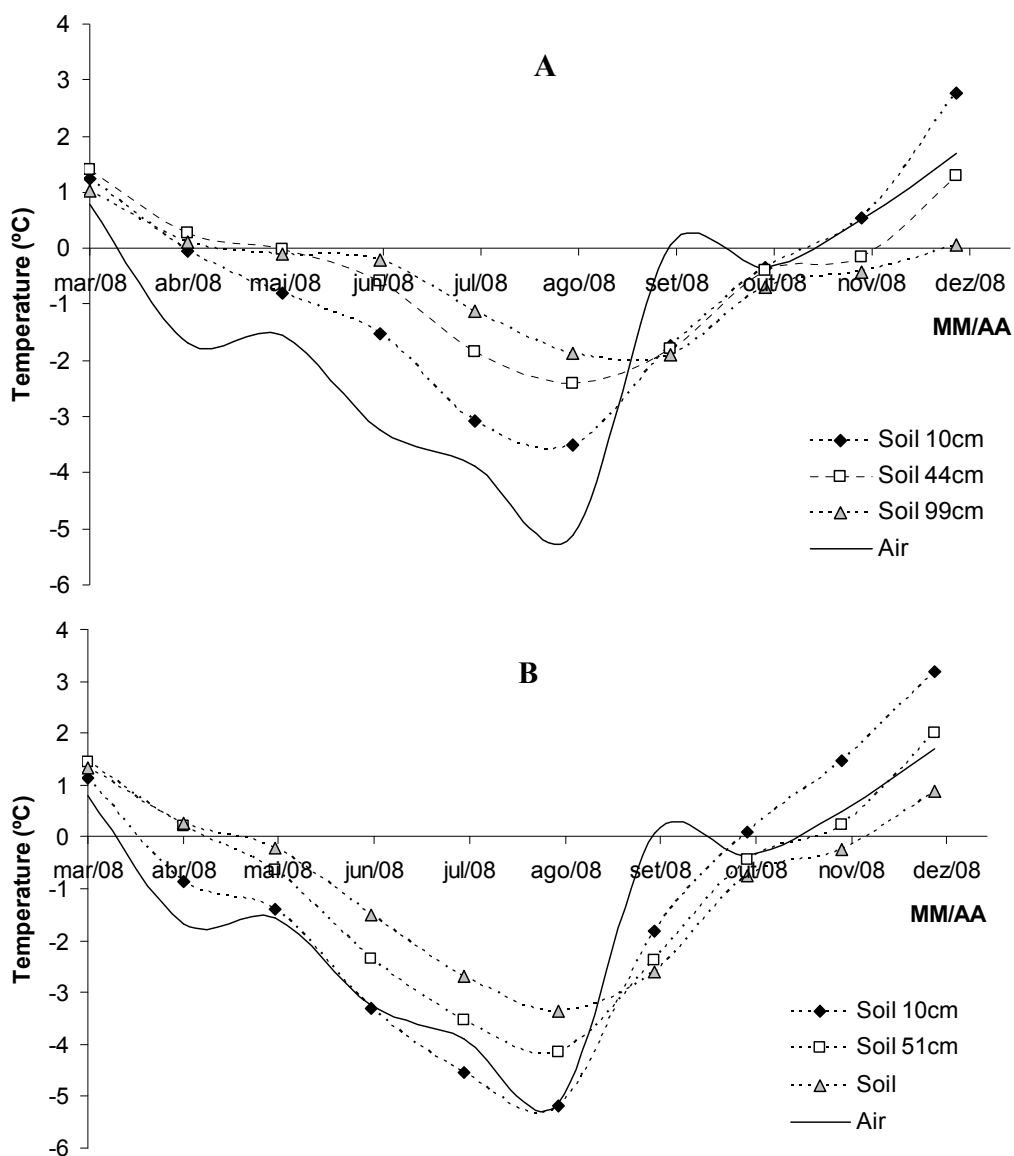
Figure 2. Soil and air temperature in A and B sites.

Conclusion

The air temperature was the atmospheric factor that had higher correlation with soil temperature. Precipitation and solar radiation also showed a significant correlation. The humidity and the winds seem to influence the soil temperature near the surface. A sampling of temperature and other physical factors in new areas may provide data for future environmental modeling of the region.

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Cryosols as a test of our knowledge of Earth as a system: Review

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Abstract
Cryosols are a key component of the cryosphere and, therefore, play a major role in the earth's energy, water, and geochemical cycles. Several examples are given to demonstrate how Cryosols have contributed to our increased understanding of earth's dynamic systems. Cryosols may account for up to 50% of the global soil organic carbon pool. Atmospheric temperatures have increased by ±3ºC over the past decades in arctic and Antarctic regions. Based on studies of active-layer dynamics and carbon budgets, continued warming may initiate a positive feedback mechanism whereby carbon stored in the near-surface permafrost may be released to the atmosphere as CO_2. Polar soils and the underlying permafrost are a major source of other biospheric greenhouse gases, including CH_4, and N_2O. Radioactive fallout, toxic metals, and other anthropogenic pollutants have accumulated in polar soils and have impacted terrestrial, aquatic, and marine ecosystems. Polar soils are important for studying extremophiles such as endolithic lichens in Antarctica and microorganisms in 2-8 million-year-old permafrost in Siberia and Antarctica. Antarctic soils have been used for interpreting features and processes on Mars, including patterned ground, thermokarst, and rock glaciers. Finally, polar soils are an important component of environmental observatories and provide a data repository for studying environmental change.

Key Words
Polar soils, Gelisols, cryosphere, earth-system science

Introduction
Polar soils comprise 18×10^6 km^2 or about 13% of earth's land surface (Bockheim and Tarnocai, in press). The main feature of polar soils is the presence of permafrost within 1 to 2 m of the surface that leads to the formation of patterned ground on the surface and frost mixing (cryoturbation) in the soil. Approximately 80% of the soils in the polar regions are identified as Cryosols or Gelisols in modern global soil-taxonomic schemes. In the recent past, the study of polar soils was considered to be a purely academic exercise. However, in the past 15 years, cryopedology has emerged as a powerful sub-discipline of soil science that has contributed greatly to our understanding of earth systems. The primary aim of this review paper is to illustrate the interactions of Cryosols with earth's dynamic systems.

Cryosols, the cryosphere, and earth-system science
One of the great scientific challenges of the 21st century is to forecast the future of planet Earth. Writing of this challenge relative to global warming, John Lawton (2001) states: "we find ourselves, literally, in uncharted territory, performing an uncontrolled experiment with planet Earth that is terrifying in its scale and complexity" (p. 1965). From these challenges has emerged the discipline of Earth System Science (ESS), which includes the main components of planet Earth—the atmosphere, the hydrosphere, the cryosphere, the geosphere, the biosphere, and the pedosphere (Figure 1).
The cryosphere covers a substantial amount of Earth's surface and includes water in solid form, including sea ice, lake ice, river ice, snow cover, glaciers, ice caps and ice sheets, and permafrost. The cryosphere and its extensive cover of Cryosols is an integral part of the global climate system with important linkages and feedbacks generated through its influence on surface energy and moisture fluxes, clouds, precipitation, hydrology, and atmospheric and oceanic circulation. Through these feedback processes, Cryosols play a significant role in global climate and in climate model response to global change.

Cryosols and the global carbon cycle
Cryosols contain approximately over 1700 Gt of soil organic carbon (SOC) in the upper 3 m, which accounts for about 50% of the world's SOC (Tarnocai *et al.* 2009). In arctic tundra soils, a large portion (approximately 81%) of SOC is stored below the seasonal thaw layer (active layer) in the near-surface permafrost (transition layer) to depths in excess of 300 cm (Bockheim and Hinkel 2007; Tarnocai *et al.* 2009). Atmospheric temperatures have increased by ±3ºC over the past three decades in arctic and Antarctic regions. Studies of active-layer dynamics and carbon budgets suggest that continued warming may initiate a positive feedback mechanism whereby carbon stored in the near-surface permafrost may be released to the

atmosphere as CO_2. (Schuur *et al.* 2008). At the present time, our knowledge is insufficient to describe the interactions between the components of the Earth system and the relation between the carbon cycle and other biogeochemical and climatological processes (Falkowski *et al.* 2000). However, the arctic may be viewed as a bellwether for the global implications of climate change (Corell 2006).
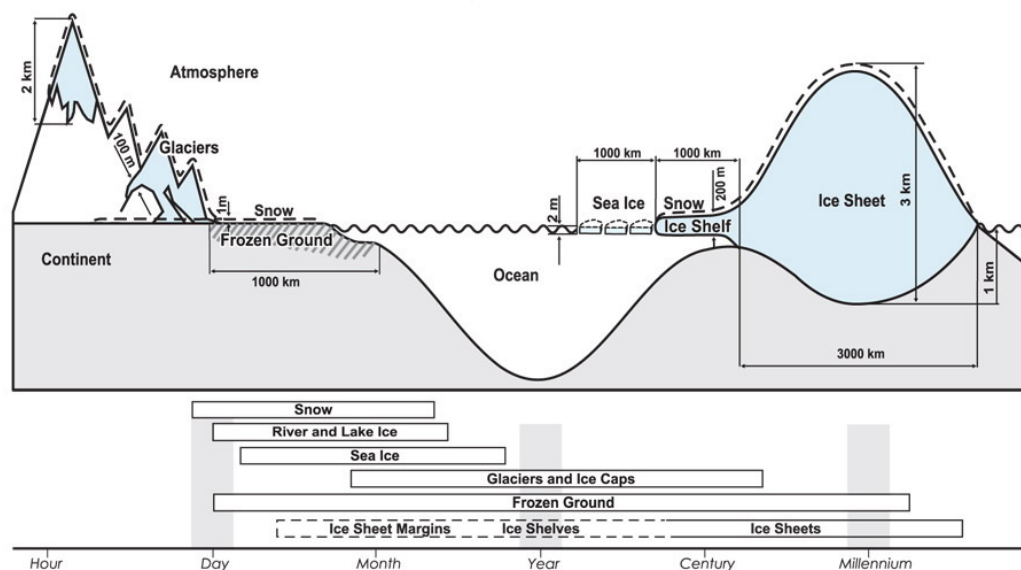

Figure 1. Components of the cryosphere and their typical time scales (IPCC 2007).

Examples of Cryosols and our knowledge of Earth as a system
Six examples are given to illustrate the role that the study of Cryosols has played in the emerging discipline of ESS.

Cryosols and biospheric gases
Trace gas fluxes in polar regions have attracted substantial attention in recent years, because of the large quantites of carbon and nitrogen stored there and the associated feedbacks to climate change. The primary trace gases of concern are carbon dioxide, methane, and N_2O. Whereas arctic Cryosols currently are considered to be in balance relative to CO_2 inputs and outputs, they are a source for CH_4 (Christensen *et al.* 2008). Large methane and nitrous oxide "bursts" have been observed from Cryosols during the onset of freezing (Li *et al.* 2007; Mastepanov *et al.* 2008). Experimental studies suggest that warming of shallow arctic seas may activate archaeal microbial communities and generate large amounts of CH_4 from submarine permafrost (Koch *et al.* 2008). There are approximately 10 Tg of methane C as gas hydrates (clathrates) in the world's oceans and submarine permafrost (Kvenvolden and Lorenson 2001).

Cryosols and anthropogenic pollutants
During the winter the circumarctic air mass becomes polluted by anthropogenic pollutants from fossil fuel combustion, smelting and industrial processes from regions to the south. Polar regions have accumulated, via long-range transport, toxic constituents such as mercury and other heavy metals, radioactive fallout and other pollutants. These pollutants have not only caused an "arctic haze," which threatens the world energy balance, but also they have impacted terrestrial, aquatic, and marine ecosystems (Barrie *et al.* 1992; Aarkrog 1994). Many of the world's largest petroleum reserves exist in permafrost regions such as Alaska and northern Russia. As these reserves are exploited for fossil fuels, spills and leaks can be expected. Unfortunately, there is insufficient information regarding the bioremediation of Cryosols contaminated by petroleum hydrocarbons (Van Stempvoort and Biggar 2008).

Cryosols and extremophiles
An extremophile is an organism that thrives in and even may require physically or geochemically extreme conditions that are detrimental to the majority of life on Earth. Cryosols and the underlying permafrost are important for studying extremophiles. Friedmann (1982) discovered "cryptoendolithic" microorganisms, primarily lichens, in Antarctic Cryosols and rocks. These microorganisms survive not only by adaption to low temperatures, but also by changing their mode of growth, being able to grow between the crystals of

porous rocks. The yearly gross productivity of the cryptoendolithic microbial community may contribute substantially to the SOC levels founds in Antarctic Cryosols (Friedmann *et al.* 1993). Significant numbers of microorganisms of various ecological and morphological groups have been preserved in ancient permafrost at temperatures ranging from -9 to -13°C and depths of up to 100 m (Gilichinsky *et al.* 1992). This preservation has been observed both in the arctic and the Antarctic (Gilichinsky *et al.* 2007) and in sediments ranging between 2 and 8 million years in age (Figure 2).
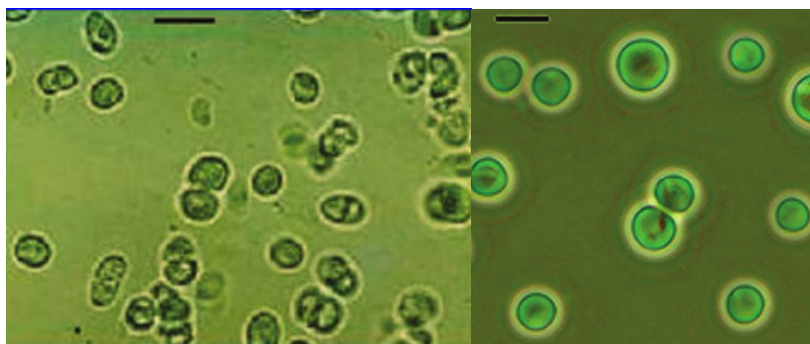

Figure 2. Cyanobacteria from the contemporary surface layer (left) and ancient permafrost (right) from Beacon Valley, Antarctica (Gilichinsky *et al.* 2007).

Cryosols and extraterrestrial systems
Cryosols have been used as both Martian and lunar analogues. For example, the Antarctic Dry Valleys have been considered an analog of the environment at the surface of Mars because of the hyper-acid, cold-desert conditions (Wentworth *et al.* 2005; Marchant and Head 2007). Moreover, geomorphic features in the region have been useful in interpreting features on Mars, including patterned ground, thermokarst and rock glaciers suggesting ice-rich permafrost, drop moraines, and gelifluction lobes (Figure 3).
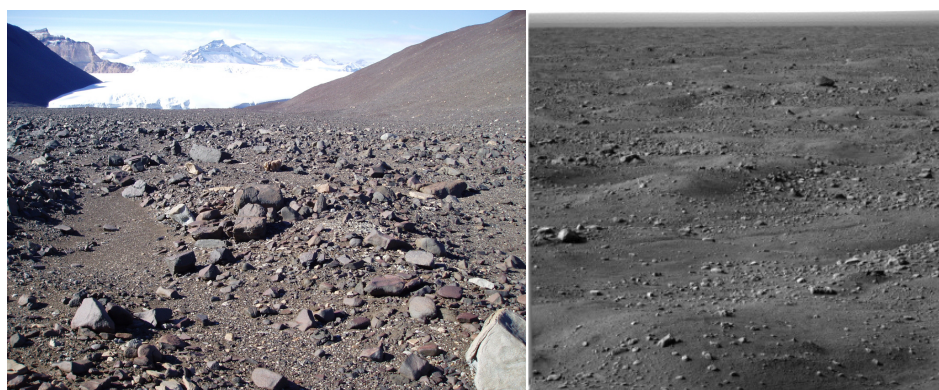

Figure 3. Patterned ground in Antarctica (left; photo by J. Bockheim) and on Mars (right; photo by M. Mellon).

Cryosols and environmental observatories
Environmental observatories are established to provide long-term, multi-faceted research observations to detect how the environment is changing. The Barrow (Alaska) Environmental Observatory, a 3,000-ha research reserve, was established in 1992 to encourage long-term research on permafrost, including Cryosols. The observatory is one of 23 terrestrial field bases established across the circumarctic to improve comparative observations and access information on environmental change in the North (http://www.scannet.nu/content/view/136/166/). Antarctic Specially Protected Areas (ASPAs) were established as part of the Antarctic Treaty to protect outstanding environmental, scientific, historic, aesthetic or wilderness values, or a combination of these values. At the present time, 67 sites have been established throughout the Antarctic region (≥60ºS). A permit is required to enter an ASPA.

Cryosol databases for earth systems modeling

There are several Cryosol databases that are useful for modeling earth sciences. These include databases stored at the National Snow & Ice Data Center (NSIDC; http://www.nsidc.org), the *Atlas of Northern Circumpolar Soils* (http://eusoils.jrc.ec.europa.eu/library/Maps/Circumpolar/Index.html); the Northern & Mid Latitudes Soil

Database (NMLSD; http://daac.ornl.gov/SOILS/guides/mid_latitude_soils.html); the U.S. Department of Agriculture, National Resources Conservation Service soil data mart (http://soildatamart.nrcs.usda.gov/) and Landcare Research New Zealand's Antarctic soils database (http://soils.landcareresearch.co.nz/contents/ SoilData_About.aspx?currentPage=SoilData_About&menuItem=SoilData).

Conclusions
Cryosols are a key component of the cryosphere and play an important role in earth's systems, including the global C cycle, the transfer and accumulation of anthropogenic pollutants, the evolution of ancient microorganisms in permafrost, the study of extraterrestrial systems, and monitoring environmental change. Cryosol databases will continue to serve in modeling earth systems.

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Decreasing soil-frost depth and its influence on the snowmelt infiltration in Tokachi, Hokkaido, Japan

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Abstract
A dramatic reduction in soil frost depth occurred in the Tokachi region in northern Japan over the last 20 years. Since soil frost strongly affects snowmelt infiltration and runoff, the reduction in frost depth may have altered the water and nutrient cycles in this region. Soil temperature, water content, matric potential, and snowcover were monitored to quantify snowmelt infiltration flux at an agricultural field for five winters that had various soil frost conditions. When snowmelt began, the soil frost was 0.1 to 0.2 m thick in three winters and was absent in two other winters, providing a unique opportunity to compare snowmelt infiltration under frozen and unfrozen conditions. Most of the snowmelt water infiltrated into the soil under both frozen and unfrozen conditions indicating that the frozen soil layer of less than 0.2 m did not impede infiltration. Previous frost conditions in agricultural fields was simulated by the snow removal manipulation, which induced deep penetration of the freezing front. The snowmelt infiltration was restricted by a thick (about 0.4 m) frozen layer in this field. These results imply that a regional-scale change in the soil water dynamics has probably occurred with the reduction of frost depth in Tokachi.

Key Words
Soil freezing, snowcover, soil water flux, soil temperature, arable field, climate change.

Introduction
The depth of soil frost and the length of the frozen period are decreasing in cold regions around the world as a result of climate warming (e.g., Cutforth *et al.* 2004; Fruenfeld *et al.* 2004). The reduction of frost depth and the frozen period has important implications for hydrology in winter and early spring because the condition of the frozen soil layer strongly affects the amount and timing of snowmelt infiltration.
Potato producers in the Tokachi region of eastern Hokkaido (Figure 1) have recently noticed a significant reduction in frost depth. They rely on the soil frost to kill the potatoes left in the soil after harvest, which would become weeds when other crops are grown in the following year. Therefore, effects of climatic variability on soil frost have major implications on agricultural practices. However, there is little scientific knowledge about the effects of climate change on frost depth in this region. Moreover, very limited knowledge about the relationships between the frost depth and snowmelt infiltration makes it difficult to reveal the hydrological shift in this region. To overcome these problems, we analysed the frost depth data for the past 20 years, which was measured at the experimental field in the National Agricultural Research Center for Hokkaido Region (NARCH) located in the central part of Tokachi (Figure 1). The trend of frost depth was also estimated from the air temperature and thickness of snowcover to examine whether the same trend would be observed in other part of Tokachi. We also established a soil and snow monitoring site in the experimental field in NARCH, equipped with tensiometer, soil temperature and water content sensors, and meteorological instruments in the fall of 2001 to quantify the amount of snowmelt infiltration in recent years. The snow-removal treatment was operated in the winter of 2005-2006 to simulate the snowmelt infiltration in the past at Tokachi. The objective of this study is to reveal the change in soil-frost depth during the recent 20 years and gain insight into the influence of frost-depth reduction on the agricultural environment of Tokachi.

Methods
Analysis of the long-term data of frost depth and freezing index
The field data of the soil-frost depth in recent years (from 1986-2005) was collected in the experimental field at NARCH (42°53'N, 143°05'E) using a frost tube filled with 0.03 % methylene blue solution (e.g., Iwata *et al* 2008). Between 1979 and 2000, mean annual precipitation was 969 mm and mean monthly air temperature was -8.7 °C for January and 18.1 °C for July at the Memuro meteorological station, located 2.5 km west of NARCH(Japan Meteorological Agency, 2008) (Figure 1).

Under the snow-free surface condition, annual maximum frost depth was strongly correlated with freezing index, which is a cumulative temperature index given by the summation of daily average air temperature for days with an average temperature below 0°C (e.g., Lunadini 1981). Fukuda (1982) and Tsuchiya (1985) reported that frost depth was strongly correlated with freezing index until the snow depth reached 0.2 m (F_{20}), and proposed the following equation

$$D_{max} = \alpha \sqrt{F_{20}} \tag{1}$$

where D_{max} is the annual maximum frost depth and α is an empirical coefficient that integrates the effects of land topographical factors and soil thermal properties. Since α does not change by year for a given location, trends in D_{max} correlate with $\sqrt{F_{20}}$. Therefore, we used $\sqrt{F_{20}}$ to estimate the trend of D_{max} from the air temperature and thickness of snowcover at each meteorological station (Figure 1). The air temperature data from 1965 to 2005 were used for the calculation.

Mann-Kendall rank statistic was used to judge whether the trend of the frost depth or $\sqrt{F_{20}}$ is significant or not (see Hirota *et al.* (2006) for detailed calculation methods).
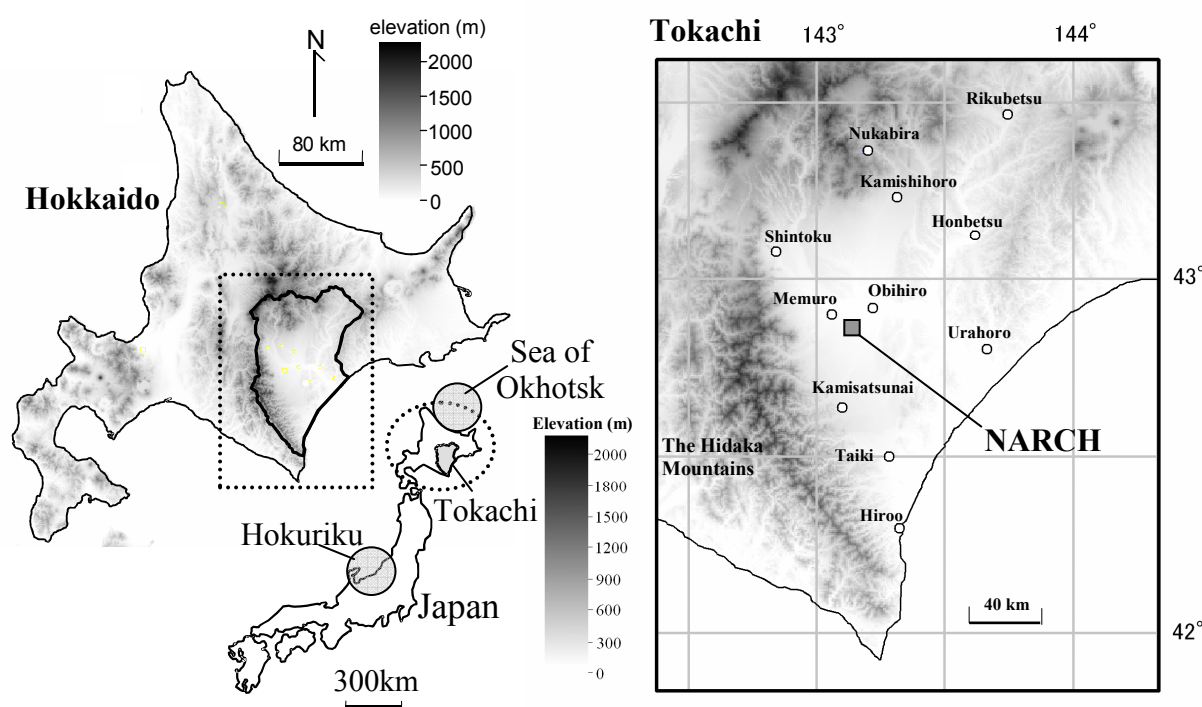

Figure 1. Location of the study site and the meteorological station used by Japan Meteorological Agency. Open circles and a solid square in the right panel mean the location of the meteorological stations and the study site in NARCH, respectively.

Site instrumentation for the measurement of soil water movement during the winter period

Soil water content was monitored using water content reflectometers (WCR) (CS615, Campbell) or time domain reflectometry (TDR) system (TDR100, Campbell) at a depth interval of 0.1 m from 0.05 to 1.05 m. The soil samples were collected from individual soil horizons to calibrate the probes in the laboratory. The water content measured by TDR in frozen soil is generally considered to represent liquid water content, as the dielectric permittivity of ice is similar to that of solid soil particles. Soil matric-potential below the frozen layer was measured continuously through the winter using tensiometers specifically designed for monitoring the potential of unfrozen soil below the frozen soil layer (Iwata and Hirota 2005a, b). Soil temperature was monitored using copper-constantan thermocouples installed from the surface down to 1.0-m depth. Soil was considered frozen when the temperature was below 0°C. A heat-flux plate (REBS, HFT1.1) was installed at a depth of 0.02 m to monitor ground heat flux. Precipitation was measured using an overflow-type tipping-bucket rain gauge with a heated water reservoir and a windshield. These data were collected automatically using data logger. Snowcover thickness and snow water equivalent (SWE) were measured manually twice a week. SWE was measured using a 50-mm internal diameter aluminum snow-survey tube. The study was conducted from November 2001 to April 2006. In the winter of 2005-2006, a similar new study plot was prepared next to the original plot, and simulated the snow and soil frost conditions in the past at Tokachi by the snow removal operation.

Estimation of snowmelt infiltration
Snowmelt infiltration was estimated from the water balance method (Iwata *et al.* 2008). To evaluate the snowmelt infiltration in recent years, we divided the snowmelt period into two, the early and late snowmelt periods. The early snowmelt period starts at the beginning of the snowmelt period and ends when the continuous increase of the water at the soil layer to the depth of 1 m (ΔS) finishes. Since ΔS was much greater than the amount of percolation to below 1 m during this period, we evaluated the snowmelt infiltration (ΣI_{nf}) from:

$$\Sigma I_{nf} = \Delta S \qquad (2)$$

Late snowmelt period was the period just after the early snowmelt period. In contrast to the early snowmelt period, the percolation to below 1-m depth was much greater than ΔS in the late snowmelt period. Therefore, the soil water flux in the subsoil, which was calculated from Darcy's law for unsaturated soil using the tensiometer data, was used to evaluate the snowmelt infiltration (see Iwata *et al.* (2008) for the detailed calculation methods).

These methods will not be applicable for a thicker (>0.2 m) frozen layer (e.g., Tokachi in the past) because of the large amounts of ice melting, which can not be monitored using our soil moisture censors (TDR or WCR), increasing the uncertainty of the infiltration estimation using the water balance equation. Therefore, the following liquid-base water balance equation was used to evaluate the cumulative snowmelt infiltration (ΣI_{nf}) at the field which simulated past field conditions by using the snow removal treatment.

$$\Sigma I_{nf} = \Delta S - \Sigma I_m - \Sigma q \qquad (3)$$

where ΣI_m is the amount of ice melt in the frozen layer and Σq is the cumulative soil water flux (positive upward) at 1-m depth. The ΣI_m was calculated from soil temperature and heat flux plate data using the heat balance method (see Iwata *et al.* (in review) for detailed calculation methods).

The amount of snowmelt infiltration was compared with the amount of snowmelt, which was calculated from the measurement of SWE on the ground and precipitation (Iwata *et al.* 2008).

Results
Frost depth in recent 20 years
Figure 2 shows the maximum frost depth monitored from 1986 to 2005 at the experimental field of NARCH (Figure 1). The average annual maximum frost depths were 0.38 and 0.13 m during 1986-1996 and 1997-2005, respectively, suggesting a reduction of the frost depth. The decreasing trend was statistically significant at a confidence level of $P < 0.05$. The decreasing trends of $\sqrt{F_{20}}$ were also statistically significant in most of the meteorological stations in Tokachi (Figure 1), suggesting that a regional-scale reduction in the frost depth had occurred in the last 20 years in this region. These are induced by the increased occurrence of heavy snowfall in early winter, decreasing the effective time window for soil-frost penetration (Hirota *et al.* 2006). The major decrease in $\sqrt{F_{20}}$ started from mid to late 1980's. The timing coincided with the sharp decreases of snowfall in the Hokuriku region of Japan (Figure 1) and the amount of drift ice in the southern part of the Sea of Okhotsk (Figure 1), which are regarded as indicators of the strength of the East Asian winter monsoon activities (Hirota *et al.* 2006).
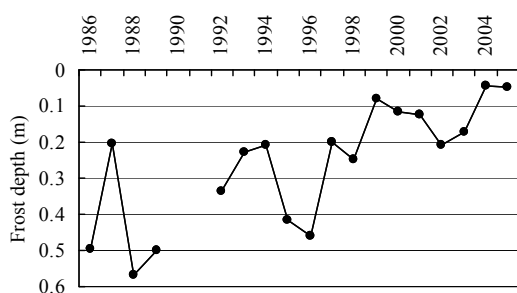
Figure 2. The annual maximum frost depth monitored at NARCH (Hirota *et al.* 2006).

Present snowmelt infiltration
The ΣI_{nf}, during the early snowmelt period was almost the same as the cumulative snowmelt (ΣM) regardless of the presence or absence of the frozen layer (Table 1). The ΣI_{nf} and ΣM were also similar in the late snowmelt period dor both frozen and unfrozen winters although the snowmelt rate (i.e., rate of water input) in this period was greater than that in the early snowmelt period (Iwata *et al.* 2008). These results indicate that most of the snowmelt-water will infiltrate into the soil even when a thin frozen layer exists during the snowmelt period.

Table 1. Frost depth before the snowmelt period, Amount of snowmelt water (ΣM), and cumulative snowmelt infiltration (ΣI_{nf}) during the early snowmelt period.

Year	Frost depth (m)	ΣM (mm)	ΣI_{nf} (mm)	$\Sigma I_{nf} / \Sigma M$
2002	0.17	119	109	0.92
2003	0.09	87	93	1.07
2004	0	39	40	0.98
2005	0	40	37	0.93
2006	0.10	41	35	0.85

Snowmelt infiltration 10 to 20 years ago

To simulate snowmelt infiltration, snowcover was removed after each snowfall event, several times between December 19, 2005 and January 13, 2006. The snow was put back on this field to prevent further penetration of the freezing front in January. As a result, the maximum frost penetration depth, which occurred in late February, was 0.43 m. The maximum thickness of the snowcover was 0.43 m, which was comparable to the maximum thickness of snow cover in the past Tokachi. The snowmelt period was started on March 10 and snowcover disappeared on March 22. The values of ΣI_{nf} and ΣM during the snowmelt period were 26 and 126 mm, respectively, suggesting the limitation of the snowmelt infiltration by the thick snow cover. The difference between ΣI_{nf} and ΣM, which is considered to be the sum of runoff and the change in surface storage, was 100 mm on March 22. This implies the substantial amount of surface runoff or prolonged surface ponding after the snowmelt period.

Conclusion

These results suggest that major shifts in the winter soil water dynamics and snowmelt runoff generation have probably occurred at NARCH as frost depths decreased from > 0.4 m to 0.05-0.2 m over the last 20 years. Since the meteorological factors causing the shift observed at the Memuro study site will also affect the entire Tokachi region, the hydrological shift (i.e. soil water and snowmelt runoff) may be occurring at a regional scale, affecting the soil water and nutrient cycles in winter and early spring and the snowmelt runoff regime.

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Isotopic evidence for the provenance and turnover of organic carbon by soil microorganisms in the Antarctic dry valleys

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Abstract
The extremely cold and arid dry valleys in the Southern Victoria Land region of Antarctica are one of the most environmentally harsh terrestrial ecosystems supporting organisms. The dry valleys are characterized by a combination of low temperatures and lack of liquid water that severely limit the abundance and activity of terrestrial organisms. Nevertheless, the soils contain organic C and N, a relatively large proportion of which is inorganic N, emit CO_2 produced by heterotrophic respiration and support active communities of heterotrophic soil organisms. The biogeochemical transformations of carbon and other nutrients in the dry valleys soils are exclusively driven by microorganisms. The dry valleys lack vascular plants and the cryptogamic vegetation is both sparse and inconspicuous. In situ primary production by mosses, lichens, terrestrial cyanobacteria and algae, including production in cryptic microbial communities that grow endolithically (literally growing in the interstitial spaces in fissured rock, where there may be more liquid water and where they are protected from the radiation and the abrasive and drying effects of the wind), is very limited. However, there are several other potential sources of organic C and N to support terrestrial heterotrophs, including redistributed detritus from modern lacustrine cyanobacteria, marine detritus, and the remnants of ancient organic deposits from palaeo-lakes, which is also believed to be of algal and cyanobacterial origin. The natural abundance of ^{13}C and ^{15}N in source organic materials and soils have been examined to obtain evidence for the provenance of the soil organic matter. The organic matter in soils remote from sources of liquid water or where lacustrine productivity was low had isotope signatures characteristic of endolithic (lichen) sources, whereas at more sheltered and productive sites, the organic matter in the soils that was a mixture mainly lacustrine detritus and moss-derived organic matter.

Key Words
Antarctica, Dry Valleys, $\delta^{13}C$, $\delta^{15}N$.

Introduction
The Antarctic dry valleys in the Southern Victoria Land region of Antarctica are characterized by a combination of low temperatures and lack of liquid water that severely limit the abundance and activity of terrestrial organisms. However, the soils contain organic C and N, a relatively large proportion of which is inorganic N (Burkins *et al.* 2000; Barrett *et al.* 2002; Barrett *et al.* 2005; Elberling *et al.* 2006), emit CO_2 produced by heterotrophic respiration (Burkins *et al.* 2002; Parsons *et al.* 2004; Barrett *et al.* 2006a; Elberling *et al.* 2006; Hopkins *et al.* 2006a, 2006b) and support active communities of heterotrophic soil organisms. The dry valleys lack vascular plants and the cryptogamic vegetation is both sparse and inconspicuous. *In situ* primary production by mosses, lichens, terrestrial cyanobacteria and algae, including production in cryptic microbial communities that grow endolithically is very limited. However, there are several other potential sources of organic C and N to support terrestrial heterotrophs, including redistributed detritus from modern lacustrine cyanobacteria (Parker *et al.* 1982; Greenfield 1998; Elberling *et al.* 2006; Hopkins *et al.* 2006b, 2008a), marine detritus (Burkins *et al.* 2000), and the remnants of ancient organic deposits from palaeo-lakes, which is also believed to be of algal and cyanobacterial origin (Burkins *et al.* 2000; Hendy 2000; Hall *et al.* 2000, 2001; Hall and Denton 1995; Moorhead 2007). Burkins *et al.* (2000) used the natural abundances of ^{13}C and ^{15}N of organic C and N in soils from the Taylor Valley and various organic materials as signatures for organic C and N from different sources to show that sites at greater altitude had isotopic signals approaching that of endolithic autotrophs whilst those at lower altitudes had signals approaching that of lacustrine detritus (see also Barrett *et al.* 2006b). This is consistent with the

organic C contents of the soils being greater close to the edges of lakes and ponds (Moorhead 2007; Elberling *et al. 2*006; Hopkins *et al. 2*008a) and these areas being hot-spots of biological activity in the dry valleys (Elberling *et al. 2*006; Gregorich *et al. 2*006; Hopkins *et al. 2*006a, 2006b, 2008a). Based on indirect geomorphic evidence, Burkins *et al.* (2000) also proposed that there is an additional source of organic matter derived from palaeo-lake sediments that has been redistributed in the landscape by subsequent glacial processes. This proposition has become assimilated as one of the elements of the so-called "legacy" hypothesis that contributes to ecosystem processes in the Antarctic dry valleys (Barrett *et al. 2*006b). However, estimates of the turnover time of soil organic C for the dry valleys are in the range of a few decades to about 150 years (Burkins *et al. 2*002; Elberling *et al. 2*006; Barrett *et al.* 2006a, 2006b) which suggests that legacy C can only make a minor contribution to contemporary C cycling.

Our objectives were to examine natural abundance isotope evidence for different sources of organic matter in dry valley soils and estimate the relative contributions from the principal organic sources to the soil organic matter, to extend the number of locations for which isotopic data for the soil organic C and N have been collected, and to estimate the decomposition rate of the soil organic C.

Methods
Soil and sites
Soil samples were collected from sites in the Garwood, Wright, Victoria and Taylor Valleys from the 0 to 5 cm depth. Three types of identifiable organic matter were collected at different sites in the dry valleys and used as reference source materials for ^{13}C and ^{15}N signatures: (1) Lacustrine detritus comprising cyanobacterial mat from the littoral region of the lake floating foam from the lake surface produced as cyanobacteria and algae decayed, cyanobacterial detritus stranded at high–water marks around the lake edge, wind-blown organic detritus caught in sediment traps, and surficial mats of the cyanobacteria, *Nostoc commune* and *Phormidium* sp. (2) Cyanobacterial beds buried between 8 and 20 m above the current level of Lake Vanda from the region where preserved cyanobacterial beds have been dated to between 3000 and 1900 ^{14}C years BP. (3) Moss samples were obtained by separating moss (*Bryum* sp.) growing hypolithically in soil. (4) Samples of endolithic communities were obtained from rocks.

Isotopic analysis
The δ^{13}C and δ^{15}N values of the soils and organic materials were determined by isotope ratio mass spectrometry after acidification to remove inorganic C. Isotopic comparisons were expressed in parts per thousand (‰) depletion of ^{13}C or ^{15}N (negative δ values) relative to the conventional standards, Vienna Pee Dee Belemnite (V-PDB) for δ^{13}C and atmospheric N$_2$ for δ^{15}N values.

Results and Discussion
The δ^{13}C values of the mosses and endolithic materials are consistent with that of C3 photosynthesis (typically -25 to -30‰). In contrast, the less ^{13}C-depleted signal for the cyanobacterial material agrees with fractionation associated with CO_2 concentration mechanisms in cyanobacteria and the diffusion limitations of dissolved inorganic C which leads to relatively less ^{13}C-depletion in the biomass. Our δ^{13}C values for lacustrine detritus were in the range -8 to -15‰, which fits well with the value of -10 to -11‰ for coastal ponds in the Garwood Valley. The δ^{15}N values of the lacustrine materials, relatively close to 0‰ indicate a contribution from biological N fixation. The possibility of biological N fixation in endolithic communities cannot be excluded, but N fixation is thought to be exceptional in these communities. The δ^{15}N values of the endolithic materials and mosses were strongly ^{15}N-depleted, which may indicate assimilation of ^{15}N-depleted sources such as soil nitrate, which can be strongly depleted in the dry valleys and elsewhere in Antarctica. In the absence of a conspicuous source or sources of organic matter from *in situ*, contemporary primary producers, the provenance of organic matter in dry valleys soils is complex (Figure 1). Based on positions in the isotope bi-plot, the organic matter in the Garwood Valley soils had the largest proportion derived from lacustrine detritus compared to soils from the other valleys. Our previous studies (Elberling *et al. 2*006; Hopkins *et al. 2*008a) indicated an important contribution from lacustrine detritus, but the present study confirms that the lacustrine material subsidises the terrestrially-derived organic matter arising from either endolithic organisms or mosses, or both. The Wright Valley soil organic C and N appeared to be derived principally from endolithic material. The Victoria Valley soil had δ^{15}N value close to that of the moss, but the variation associated with the δ^{15}N value Victoria Valley soil was large and the idea that mosses made a major contribution to this soil cannot be reconciled with the conspicuous absence of mosses, so it is more likely that endolithic materials contributed to the Victoria Valley soil. In the Wright Valley and Tayleo Valley soils, the δ^{15}N values were close to that of the endolithic materials, which is consistent with the δ^{13}C
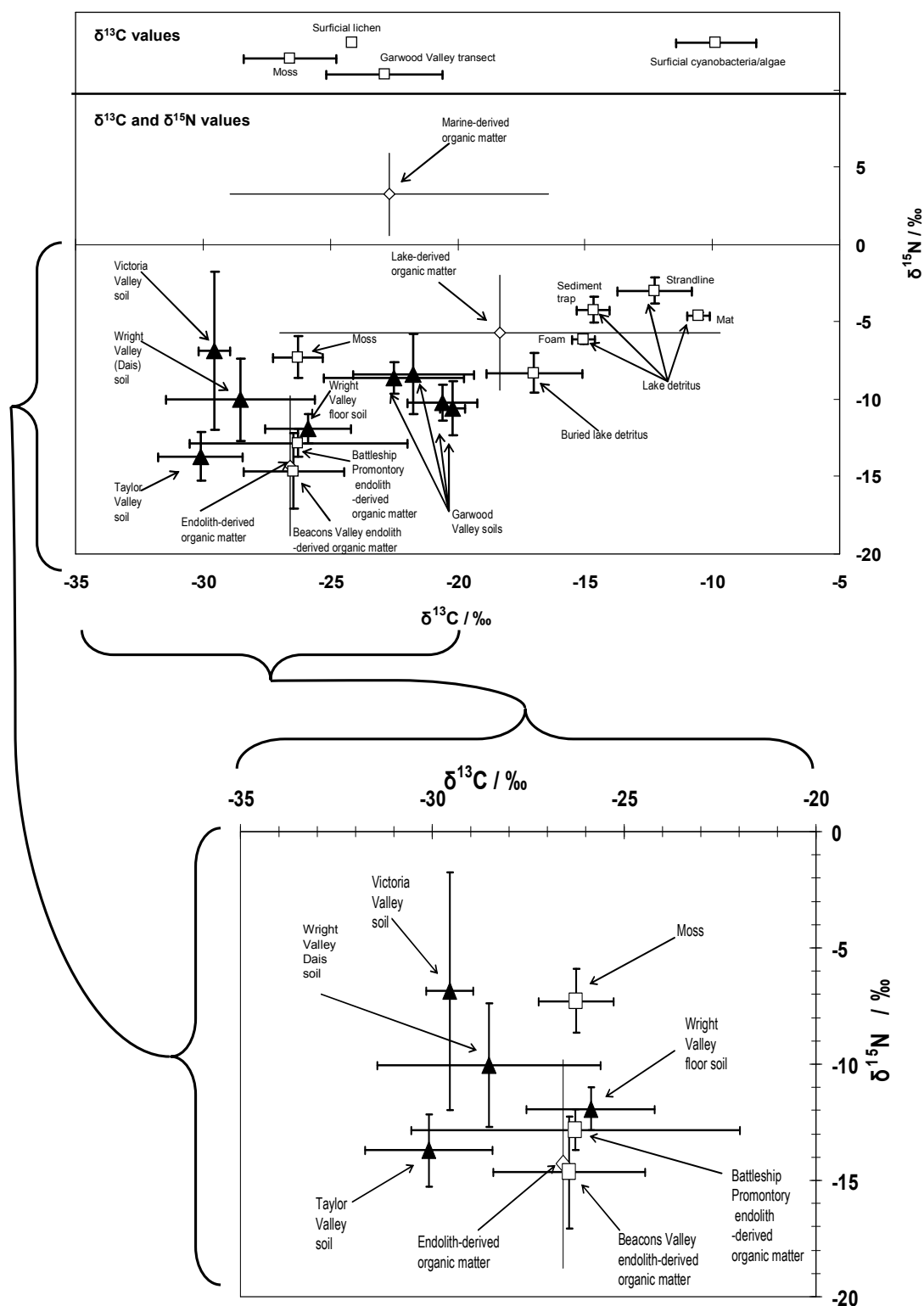
values for these soils.

Figure 1. Isotope bi-plot for organic materials of different biological origins and soils from the dry valleys. The values plotted are the mean δ¹³C and δ¹⁵N values and the bars are ± standard deviations. The open squares (□) with bold bars are the values for the source organic materials from this study; the open diamonds (◊) with regular, uncapped bars are the values for the source materials from Burkins *et al.* (2000); the triangles (▲) with regular bars are the values for the soils. The lower panel shows the δ¹³C- and δ¹⁵N-depleted part of the isotope bi-plot expanded for clarity, and the δ¹³C values of samples for which we only have ¹³C data at the top of the figure.

Conclusion

Under the sheltered conditions of the Garwood Valley, where there is relatively abundant modern lacustrine detritus, this material makes a significant contribution to the soil. In the Garwood Valley, the soil organic C and N contents are greater than the other valleys, perhaps suggesting that lacustrine productivity subsidises soil resources above that of the indigenous, terrestrially derived organic matter. We have commented previously about the dual role of the lacustrine detritus, contributing both exploitable resources and possibly viable organisms to soils that would otherwise be even more impoverished than they are currently, and the present results provide further evidence to support this internal redistribution of resources. We propose that depletion ^{13}C and ^{15}N in the soils is associated both with increasing recalcitrance of the source material entering the soils and increasing dryness such that the lacustrine materials which are apparently relatively labile make a progressively smaller contribution to the soil organic matter at dry compared to wetter sites. These hypotheses may be tested by increasing the range of soils analysed to include soils from valleys or sites within valleys that fall at intermediate positions of the wetness gradient between the Garwood Valley at the wet (and relatively productive) extreme and the Wright Valley, Victoria Valley and Taylor Valley sites we have examined at the dry (and less productive) extreme and by a comparative study of the decomposition kinetics of the different organic material.

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Monitoring the active layer in Maritime and Peninsular Antarctica

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Abstract
This paper presents the active layer monitoring network in Maritime and Peninsular Antarctica established as part of the Brazilian activities for the IPY. Fifteen sites are already operating at King George and Livingstone Islands, and at the Antarctic Peninsula (Hope Bay). The sites consist of precision thermistors arranged as a vertical array with probes at different depths down to 1 meter. Soil moisture probes were placed at the bottommost layer at each site. All probes were connected to a Campbell Scientific CR 10 data logger recording data at hourly intervals. Soil chemical, physical, mineralogical and micromorphological characteristics are determined for each of the monitored sites using classical soil survey procedures. One year of data for four sites at the Keller Peninsula provide evidence of the effect of altitude. For all sites, the permafrost was expected to occur deeper than one meter from the surface. The highest site had the coldest temperature regime over the monitored period. Long term monitoring will allow a better understanding of the effects of climate change on the functioning of Antarctic terrestrial ecosystems.

Key Words
Climate change, permafrost, soils

Introduction
Cryosols are typical of polar and subpolar regions and have, as their main characteristic, the presence of permafrost. In Antarctica, there is still scarce data regarding permafrost distribution. The depth, distribution and overall characteristics of permafrost are the result of the thermal equilibrium between several environmental factors such as local climate, soil water content, and slope position.

In the current global warming scenario, permafrost studies are of special interest (Nelson and Anismov 1993; Ramos and Vieira 2003). The soil temperature regime is an important indicator of climatic regime, reflecting long term tendencies. The depth of frost penetration depends mainly on the intensity and duration of the cold, snow cover, precipitation and cloud cover. The continuous monitoring of soil temperature allows the identification of distinct events, such as the summer thaw period, of limited duration, and the longer winter period, during which temperatures remain below $0^{\circ}C$ (Guglielmin *et al.* 2008).

Maritime Antarctica has been increasingly recognized as a key region for monitoring climate change. Despite this recent interest, few investigations of thermal conditions of the active layer and permafrost in ice-free areas are based on continuous year-round measurements (Cannone *et al.* 2006; Ramos and Vieira 2003). Several international efforts are being made in order to fill this information gap and gather spatially distributed data to allow more robust and reliable analysis of the effects of climate change on active layer in Antarctica, such as the projects Thermal State of Permafrost (TSP) and Antarctic and Sub-Antarctic Permafrost, Soils and Periglacial Environments (ANTPAS) (Vieira *et al.* 2008).

The objective of the present work is to report the installation of active layer monitoring sites along a latitudinal and pedological gradient within the scope of the Brazilian funded IPY project entitled *Permafrost dynamics, characterization and mapping of Cryosols from Maritime and Peninsular Antarctica in a climate change scenario.* Data for 2008 is presented for four sites from Keller Peninsula

Methods
Monitoring sites are being installed at the most expressive ice-free areas at the South Shetlands Archipelago (King George, Livingstone and Deception Islands), as well as at the northernmost part of the Antarctica Peninsula and islands located in the Weddell Sea (Seymour and James Ross), constituting a latitudinal gradient with climatic and pedological differences.

The active layer monitoring sites consist of precision thermistors arranged as a vertical array with probes at different depths down to 1 meter. Soil moisture probes were placed at the bottommost layer at each site. All probes were connected to a Campbell Scientific CR 10 data logger recording data at hourly intervals
Soils chemical, physical, mineralogical and micromorphological characteristics were determined for each of the monitored sites using classical soil survey procedures (Simas *et al.* 2008). Soil samples are collected and submitted to laboratory analyses. General characteristics such as altitude, geomorphology, and vegetation type, were registered for each site. Additional soils were collected and analysed in order to characterize the main soil type for each ice-free area. Based on high resolution satellite images, soil maps were produced. Fifteen sites are in operation (Table 1) and four others will be installed in the near future in order to complete the network (Figure 1). Due to the proximity of the Brazilian Comandante Ferraz Station, which makes access to the systems easier, eight sites are located in Keller Penninsula, King George Island. For this area, it will be possible also to compare the effects of topography and different vegetation covers on the thermal dynamics of the soils. Apart from these, the following sites are already operating (Table 1): Livingstone Island (2 sites in Byers Peninsula), Antarctic Peninsula (one site in Hope Bay), King George Island (one site in Potter Peninsula and 2 sites in Fildes Peninsula).

In the present paper we present soil temperature from 13/03/2008 to 10/01/2009 for sites 1, 4, 6 and 8, in Keller Peninsula which form an altitudinal sequence developed from basaltic-andesitic materials. All four sites are devoid of vegetation. According to the Ferraz Station metereological data air temperature varied from -14°C to $+5^{o}$C in the studied period, with mean value of -1°C.

Table 1 – Sites in operation.

Site	UTM (21 E)		UTM	Altitude	Location
	E	N	Fuse	(m)	
1	427137	3115583	21 E	28	Keller
2	426511	3115084	21 E	34	Keller
3	426610	115905	21 E	259	Keller
4	426663	3116587	21 E	196	Keller
5	426004	3116940	21 E	45	Keller
6	424084	3116257	21 E	31	Keller
7	426174	3115459	21 E	89	Keller
8	427053	3115790	21 E	49	Keller
9	426431	3115419	21 E	112	Keller
10	413784	3096573	21 E	70	Potter
11	871370	3080448	21 E	65	Fildes
12	865940	3077672	21 E	95	Fildes
13	441165	3109959	21 E	85	Lions Rump
14	598797	3053099	20 E	108	Byers
15	499560	2969987	21 E	50	Hope Bay

Results
The dataset shows clear differences between soil temperature variations for the studied sites (Table 2). Site 1, presented the coldest regime as shown by the highest number of days with mean temperature <=0°C and lowest mean temperature values. April marked the beginning of continuous freezing for all monitored layers, and Site 1 was the first to present all layers in continuous freezing and the last to start thawing. Site 3 was the first to start the continuous thawing, starting at October 18th. At the other sites, continuous thawing of the surface layer starts in November. The bottommost layer at Site 1 starts continuous thawing only in the beginning of January.

All monitored layers at the four sites presented positive temperature during part of the year, indicating that the permafrost occurs at deeper layers (Figure 2). The bottommost layer at Site 1 presented the lowest maximum temperature (1°C) and presented only 34 days in which the mean temperature was > 0°C.
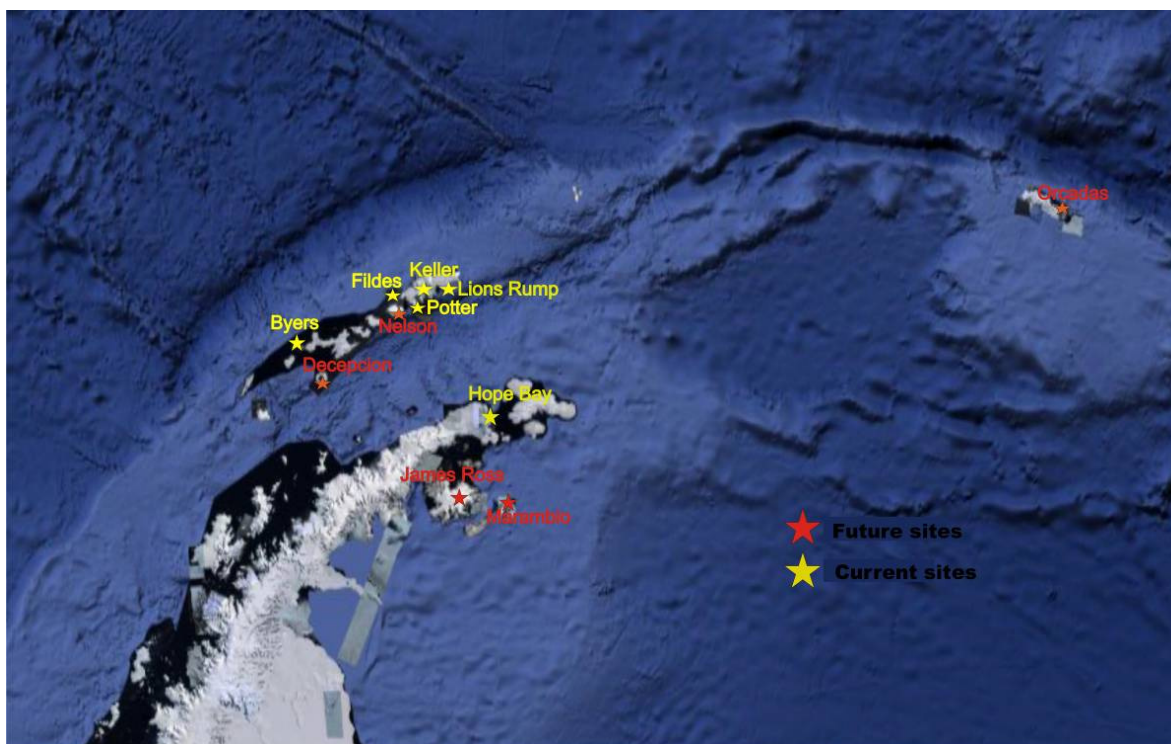
Figure 1. Current and future sites for long term monitoring of active layer in ice-free areas of Antarctic Region 8.

Table 2. Temperature data for the different soil layers at Sites 1, 2, 3 and 4, Keller Peninsula.

|	Site 1 - 196 m.a.sl.				Site 2- 49 m.a.s.l.			Site 3 - 34 m.a.s.l.			Site 4m – 28 m.a.s.l		
Depth of sensor (cm)	10	33	56	78	10	51	92	10	45	80	10	44c	99
days <=0°C	243	242	254	278	209	211	218	196	197	182	234	197	248
days >0°C	69	70	58	34	103	101	94	116	115	130	78	115	64
Min T°C.	-8	-7	-6	-5	-8	-6	-5	-8	-6	-5	-6	-4	-3
Max T°C.	5	4	2	1	6	4	3	7	5	4	5	4	2
Mean	-2	-2	-2	-2	-1	-1	-1	-1	-0	-0	-0	-0	-0
Stand. Dev.	3	2	2	2	3	2	2	3	3	2	2	1	1
Isothermal days	64	60	93	95	52	77	98	42	73	92	98	130	149
Start continuous freezing	8/04	9/04r	13/04	11/04	9/04	26/04	28/04	9/04	15/04	19/04	9/04	19/04	17/04
Start continuous thawing	22/11	27/11	20/11	5/01	10/11	20/11	2/12	18/10	6/11	17/11	21/11	29/11	21/11
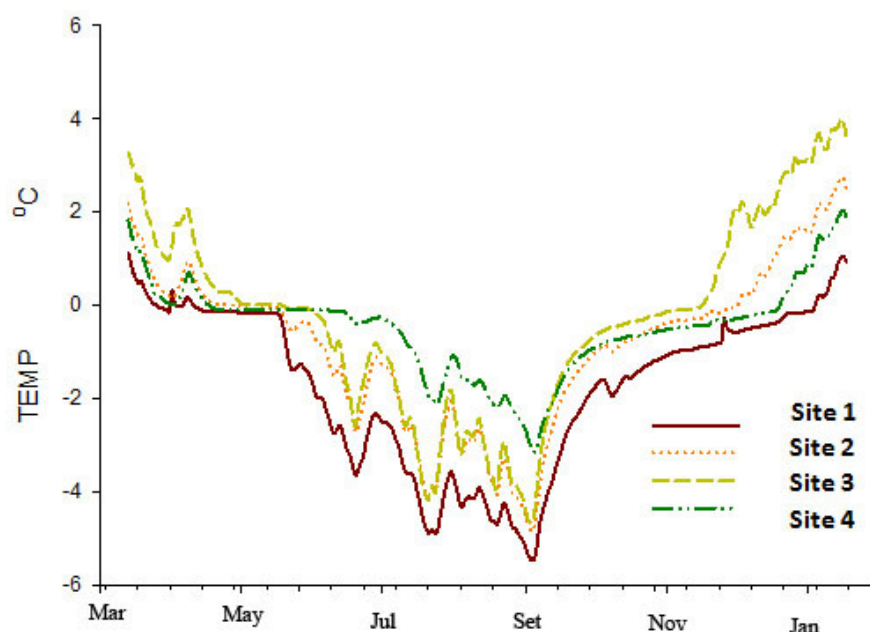
Figure 2. Mean daily temperature for the bottommost layer of Sites 1, 2, 3 and 4, Keller Peninsula, evidencing that at all Sites temperatures were above zero during part of the monitored period.

Conclusion

This initial data set allows only a preliminary interpretation of the temperature variation for the studied sites and no major conclusions are possible at this moment. Anyhow, the data evidences the effect of altitude in soil temperature, indicating that at higher altitudes the permafrost table is closer to the surface and that the permafrost table starts deeper than one meter from the surface at the studied sites. Nevertheless, these results are extremely important for future evaluation of soil temperature. In January 2010, data for the other operating sites will be downloaded as well as a second year data for the sites at Keller Peninsula. As more the spatial and temporal variation. Long term monitoring will allow a better understanding of the effects of climate change on the functioning of Antarctic terrestrial ecosystems. This will allow a better understanding of the general temperature pattern along the studied transect.

Acknowledgements

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Soils of mid and low antarctic: diversity, geography, temperature regime

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Abstract
The study of the Russian stations areas of Antarctica is very important in world soil geography as it is a kind of transit in soil-forming conditions between Dry Valleys from one side and Grearson Hills and Antarctic islands on the other one having been studied earlier by soil scientists from New Zealand, USA, Brazil and Germany. As for soil classification in the study areas Leptosols (Entisols) predominate but not Cryosols (Gelisols). The thawing depth of soils is more than the thickness of loose materials, cryoturbations are not well pronounced, and the thawing depth in sandy and stony materials here is often more than 1 m. So, Nudilithic Leptosols or Lithic Cryorthents predominate among soils. All the regions of the Russian Antarctic stations may be referred to two soil geographical divisions - Low-Antarctic humid barrens (Bellingshausen stations at King George Island) and Mid-Antarctic semihumid transitional zone between Cold deserts and humid Antarctic barrens (Novolazarevskaya, Molodezhnaya, Progress, Mirnyi, Leningradskaya, Russkaya stations on the continent).

Key Words
Soils, Antarctic, diversity, genesis, geography, temperature regime.

Introduction
Nowadays, the majority of Antarctic soil investigations are taking place in West Antarctic – mostly in Dry Valleys, McMurdo Sound and King George Island (Bockheim 2002; Bockheim and Balks 2008; Campbell and Claridge 1987). Much less is known for Mid Antarctic of the East Antarctic: the northernmost Grearson Hills were studied for their soils (Beyer and Boelter 2007) as well as Bunger Hills (Glazovskaya 1958) and a part of Enderby Land (MacNamara 1969). The study of the Russian station areas in Antarctic is very important in world soil geography as it is a kind of transit in soil-forming conditions between Dry Valleys from one side and Grearson Hills and Antarctic islands from another one.
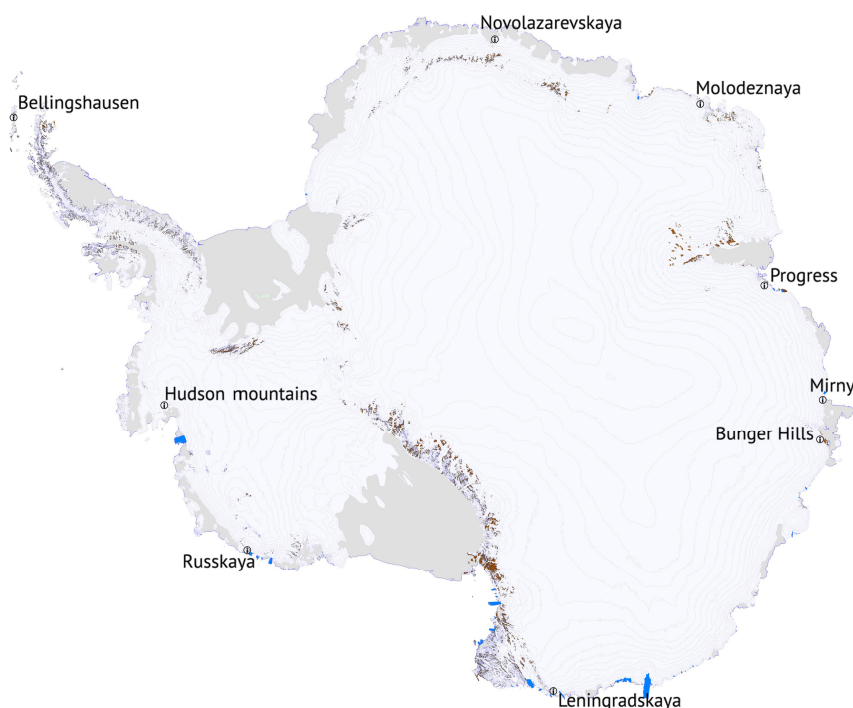

Figure 1. Antarctic map by Antarctic Digital Database with points of soil investigations.

Objects and methods
The soil study of all coastal Russian Antarctic stations Novolazarevskaya (coordinates 70°46'S, 11°50'E), Molodezhnaya (67°40'S, 45°23'E), Progress (69°23'S, 76°23'E), Mirny (66°33'S, 93°01'E), Leningradskaya (69°30'S, 159°23'E), Russkaya (74°46'S, 136°52'W) and the station Bellingshausen (62°12'S, 58°56'W) on the King George Island, as well as of Hudson mountains (74°33'S, 99°09'W), Lindsey Island (73°76'S, 102°00'W) were carried out (Figure 1). The field soil description and the microscopic analysis were fulfilled. Soil organic matter (SOM) analysis was done according to Ponomareva and Plotnikova method for humic (ha) and fulvic acids (fa) extraction and C and N contents were determined by wet combustion (Tyurin and Kjeldahl methods respectively). Microbial biomass was measured by fumigation method (Jenkinson 1998) and metabolic quotient was calculated as basal respiration/microbial biomass ratio (Method of Soil Analysis 1994). Ground temperatures were measured by U12 HOBO loggers (Onset corp).

Results
Soil diversity.
The following groups of soils were distinguished.
1) Organo-mineral soils with macro-profiles (induced by input of organic material from the ocean – «ornithogenic» и «post-ornithogenic») – the active interaction of guano with soil minerals takes place here. Humus content was maximal in soils of penguin beaches, but the level of microbiological activity here was the lowest. Microbiological transformation of organic matter appeared to be more intensive in soils with decayed and leached guano. Intensive processes of weathering start in these post-ornithogenic soils. Soils under the plants residues are characterized by prevailing of fulvic acids over the humic acids. The average Cha/Cfa ratio is 0,5. It was less in Hudson mountains and maximum in some sub-Antarctic soils. Soils of littoral organic material accumulation shows the higher amount of raw organic matter in organic horizons. Here humus is not associated with soil mineral part. These two soil types – under guano and littoral algae layers are typical for sea-shore territories. Meanwhile, some soils under penguin guano forms even in continental parts, situated at 4-5 km from seashore.

2) Organo-mineral soils with micro-profiles (first centimeters depth) within fine-earth material under mosses, lichens and algae. Soils of continental Antarctica contain about 0.3-1.0% of organic carbon or less, while in some sub-Antarctic soils this parameter rises up to 3% (table 1). The content of carbon that can be potentially mineralized was higher in sub-Antarctic soils and in all ornithogenic soils. It is explained by high amount of fresh organic matter and climatic specificity of the landscapes. Humus of continental soils was more stable to mineralization than maritime soils' organic matter. SOM from King George Island was more enriched by nitrogen in comparison to SOM of continental soils. Microbial biomass was on the same level in all continental soils, but in some soils of King George Island it was essentially higher than in continental ones. Metabolic activity was essentially higher in all soil of sub-Antarctic which very good corresponds with the mineralization losses of SOM. Micromorphological study shows the higher degree of plant residues decaying and humification in sub-Antarctic soils than in continental ones by the climatic reasons. Period of biological activity is about 60 days in sub-Antarctic, while it is not more than 15 days in continental Russkaya station.

Table 1. Soil organic matter characteristics for upper horizons.

C total, %	C/N	Cha/Cfa	Cha/Ctotal, %	Microbial biomass, µg/g	Metabolic quotient
			Russkaya station		
0,27	15,8	0,39	9.3	490	0.01
			Leningradskaya station		
0,48-1,02	14,0-19,9	0,33	6.9-8.2	310	0.06
			Hudson mountains		
0,42-0,67	49,1 -78,4	0,12	5.0-6.0	300	0.01
		Bellingshausen station (King-George)			
0,61-3,00	6,5-12,2	0,17-0,73	3-7.3	310-740	0.09-0.26

3) Ahumic soils (by J.Tedrow) - soils with anisotropic profiles on fine earth materials without macroscopic life; the anisotropy is formed by abiogenic processes (cryogenic structure formation and blow-out of the fine earth from upper horizons). Such soils occupy large areas in continental part. These soils show strong weathering process which expressed in salts accumulation in whole profile and formation of salts crusts, which good correspond with data, obtained previously (Bockheim and McLeod 2006).

4) Endolithic soils - the results of the pedogenesis here is intra-fissure fine earth and newly formed minerals of iron (hydr)oxides bringing to both intra-fissure space and rock surface the brown and red colors (Figure 2). They are the most widely spread soils in Antarctic. The life in continental Antarctic save itself in stones as the fine earth is not reliable due to strong winds (Friedmann and Ocampo 1976). The great amplitude of rock temperature results in numerous small fissures in granites and gneiss which are colonized by autotrophic algae under transparent minerals, e.g. quartz. The role of these organisms in transformation of minerals is very important. In these small fissures the processes of iron-containing silicates weathering, releasing of ferrous forms from mineral lattice and their oxidation take place. Due to these processes surface and intrafissual films of brown (7.5YR) and even red (up to 10R) colors form on the rocks having initial Munsell hue of 5Y and 2.5Y. Besides that in stone blocks the etching of feldspars and quartz also takes place as well as the formation of fine sand and silt material (Figure 2).

Soil classification
As for soil classification in the study areas Leptosols (Entisols) predominate but not Cryosols (Gelisols). The thawing depth of soils is often more than the shallow depth of loose materials, cryoturbations are not well pronounced, and the thawing depth in sandy and stony materials here is often more than 1 m, especially on the northernmost stations (Figure 3). So, Nudilithic Leptosols or Lithic Cryorents predominate among soils. The strong transformation of iron (hydr)oxides in Antarctic soils to be taken into account for soil classification needs the widening of the WRB criteria for Chromic prefix, as now it is only fit for loose subsurface horizons. Some films on the stone surfaces are characterized by a high content of iron (up to 15%) and aluminum (up to 10%). The Si/Fe+Al ratio here is about 2-3 which is a result of amorphous iron and aluminum accumulation in films. At the same time the surfaces of stones could be enriched by organic matter, locally concentrated here due to the activity of epilitic communities of fungi, algae and lichens. Soils of King George Island were classified as ornithosols (Leptosols Ornitic), Lithic Leptosols and Haplic Leptosols. Soils in a very windy and cold valley near the Russkaya station besides Cryosols were represented by Lithic Leptosols, while soils of Leningradskaya station and in Hudson mountains were Haplic Leptosols and Lithic Leptsols. Lindsey Island was covered by actual ornithosols and post-ornithogenic soils.
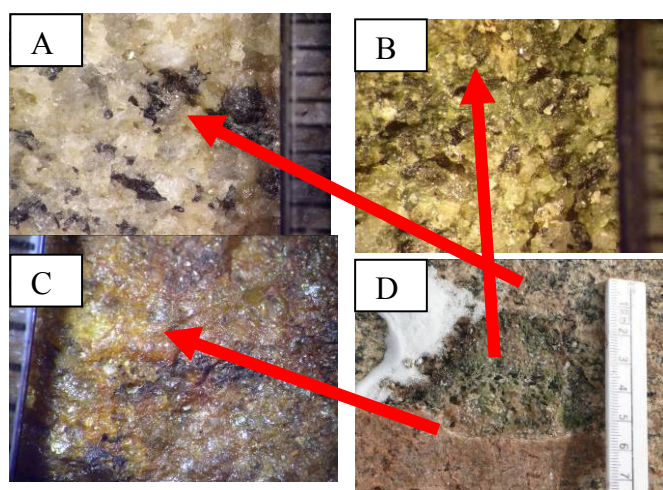

Figure 2. Microphotographs of endolithic soils near Molodeznaya station: A – fresh enderbite (granite with hornblende) rock surface; B – zone of weathering of Fe containing minerals and fine earth formation; C – reddish polished film on the rock surface; D – general view of endolithic soils.

Soil geography
All the regions of the Russian Antarctic stations may be referred to two soil geographical divisions – Low-Antarctic humid barrens (Bellingshausen stations, King George Island) and Mid-Antarctic semihumid transitional zone between Cold deserts and humid Antarctic barrens (Novolazarevskaya, Molodezhnaya, Progress, Mirny, Leningradskaya, Russkaya stations). There is some difference within the second division related to humidity. The southernmost stations (Novolazarevskaya, Russkaya) have more severe and arid conditions. Soils of maritime Antarctica are acid, with low content of exchangeable bases, profile-differentiated in chemical composition. These soils were formed on moraines, fluvioglacial sands and alluvium, while soils from continental Antarctica were formed on debris of massive crystalline rocks. Salts and iron films are revealed only in continental soils. Smectite dominates in clay fraction of all soils, but sometimes illite and kaolinite occur. Profile distribution of mineral was strongly affected by stratigraphy of

parent materials. Soils of Russkaya and Leningradskaya stations as well as soils of Hudson mountains do not show the process of secondary clay minerals formation. Here only mechanical crushing of minerals occurs with strongly expressed corrasion of the surface. The maximum intensity of weathering and formation of secondary mineral was revealed in soils of King-George Island.

Temperature regime
The permafrost and soil mean annual temperature on King-George Island is close to zero (-0,25^{o}C). Such temperature indicates the north border of permafrost in Antarctic and the probability of permafrost degradation and disappearance of permafrost-affected soil in the case of warming.
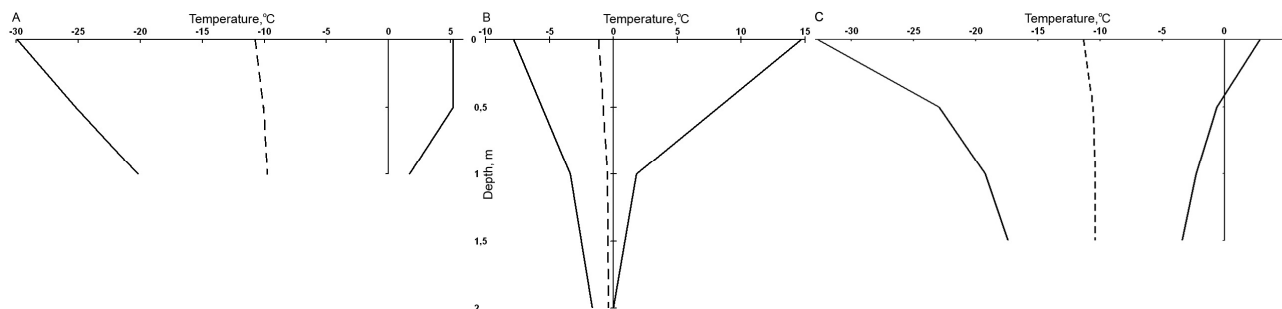

Figure 3. Soil temperature regime during the year on Molodezhnaya (latitude is 67°40'S) (A), Bellingshausen (62°12'S) (B) and Russkaya (74°46'S) (C) stations.

Conclusion
This study shows the diversity of soils in previously unexplored regions of Eastern and Western Antarctic most of which can be attributed to Mid-Antarctic semihumid transitional zone between Cold deserts and humid Antarctic barrens. Both Nudilithic Leptosols and Cryosols predominate in ice-free oases, and areas of Leptosols are even larger. The endolithic soils formed by interactions of cryptoendolithic algae and lichens with minerals in cryogenic superficial cracks of solid rocks are widespread in oases. The depth of active layer on the continent is close to or even more than 1 m because of coarse texture of substrates and thin, if any, organic horizon. King-George Island is on the north border of permafrost in Antarctic. The gained data give the additional material for the Soil Data Base of Antarctic, which is being created now in the context of ANTPAS program.

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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 ^{o}C, 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-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 (/^{o}C). 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.
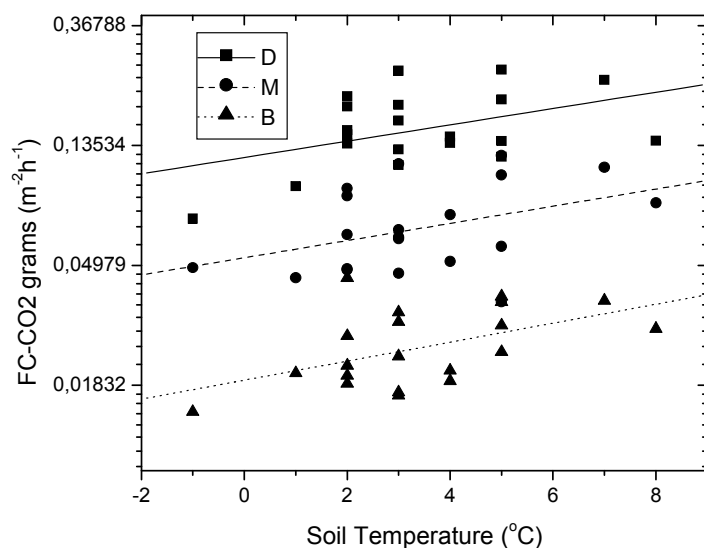

Figure 1. C-CO$_2$ emissions in function of soil temperature for the studied soil covers. D = *Deschampsia antarctica,* M = mosses and B = bare soil. N=22.

The B coefficients for all studied situations were statistically similar and a mean value of 0.073 /^{o}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^{o}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).
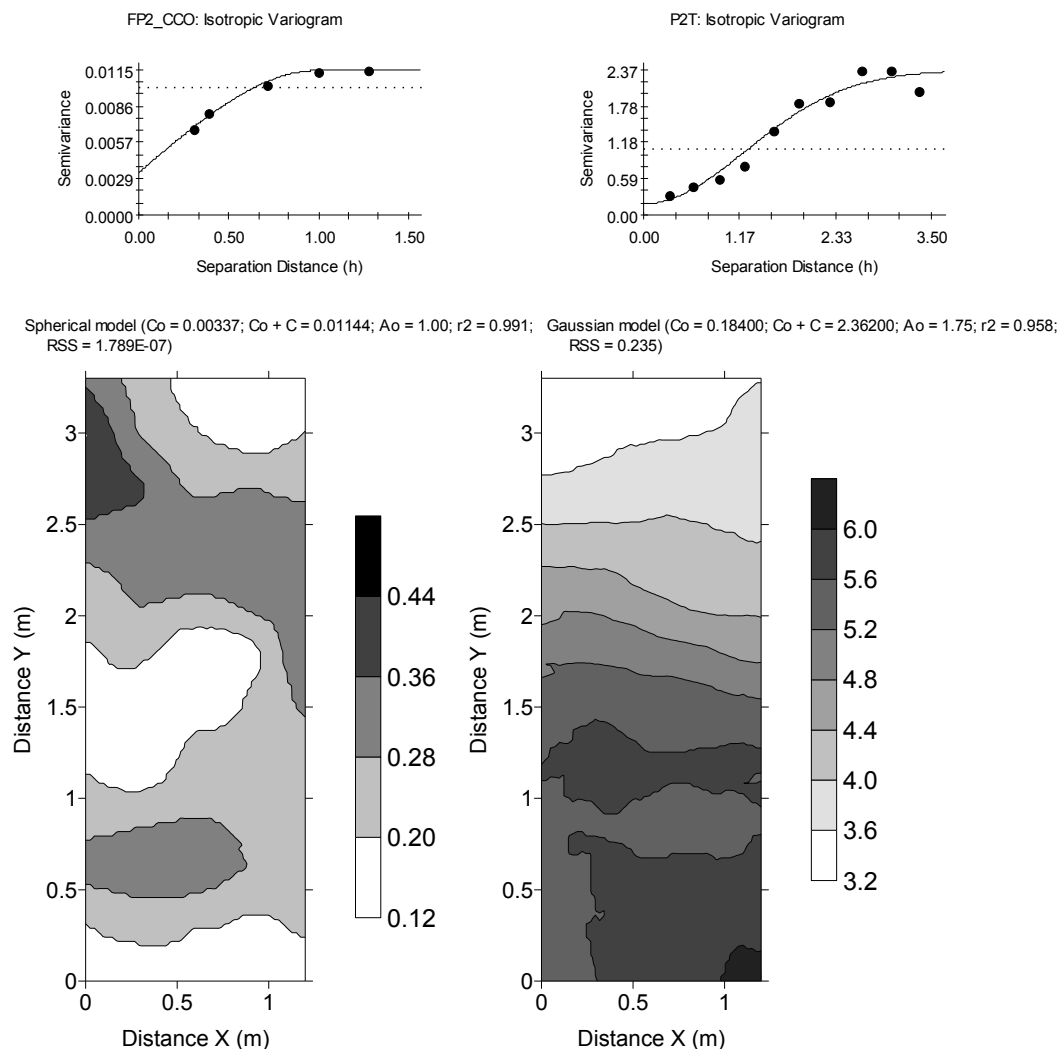
FP2_CCO: Isotropic Variogram

P2T: Isotropic Variogram

Spherical model (Co = 0.00337; Co + C = 0.01144; Ao = 1.00; r2 = 0.991; RSS = 1.789E-07)

Gaussian model (Co = 0.18400; Co + C = 2.36200; Ao = 1.75; r2 = 0.958; RSS = 0.235)

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^oC 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.

Acknowledgements

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