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ACTIVE LAYER THERMAL REGIME IN TWO CLIMATICALLY CONTRASTED SITES OF THE ANTARCTIC PENINSULA REGION

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ABSTRACT. *Permafrost controls geomorphic processes in ice-free areas of the Antarctic Peninsula (AP) region. Future climate trends will promote significant changes of the active layer regime and permafrost distribution, and therefore a better characterization of present-day state is needed. With this purpose, this research focuses on Ulu Peninsula (James Ross Island) and Byers Peninsula (Livingston Island), located in the area of continuous and discontinuous permafrost in the eastern and western sides of the AP, respectively. Air and ground temperatures in as low as 80 cm below surface of the ground were monitored between January and December 2014. There is a high correlation between air temperatures on both sites (r=0.74). The mean annual temperature in Ulu Peninsula was -7.9ºC, while in Byers Peninsula was -2.6ºC. The lower air temperatures in Ulu Peninsula are also reflected in ground temperatures, which were between 4.9 (5 cm) and 5.9ºC (75/80 cm) lower. The maximum active layer thickness observed during the study period was 52 cm in Ulu Peninsula and 85 cm in Byers Peninsula. Besides climate, soil characteristics, topography and snow cover are the main factors controlling the ground thermal regime in both areas.*

Régimen termal de la capa activa en dos áreas climáticamente contrastadas de la Península Antártica

RESUMEN. *El permafrost controla los procesos geomorfológicos en las regiones libres de hielo de la Península Antártica (AP). Las tendencias climáticas futuras conllevarán cambios significativos en el régimen térmico de la capa activa y en la distribución del permafrost, y por ello, se necesita una mejor caracterización de su estado actual. Con este objetivo, esta investigación se centra en la Península Ulu (isla James Ross) y la Península Byers (isla Livingston), áreas emplazadas en zonas de permafrost continuo y discontinuo del este y oeste de la AP, respectivamente. Las temperaturas del aire y de suelo hasta 80 cm fueron monitorizadas* *entre enero y diciembre de 2014. Existe una alta correlación entre la temperatura del aire en ambos sitios (r = 0,74). La temperatura media anual en la Península Ulu fue de -7,9ºC, mientras que en la Península Byers fue -2,6ºC. Las temperaturas del aire más frías registradas en la Península Ulu también se detectaron en las temperaturas del suelo, que fueron entre 4,9 (5 cm) y 5,9ºC (75/80 cm) más frías. El espesor máximo de la capa activa durante el período de estudio fue de 52 cm de la Península Ulu y 85 cm en la Península Byers. Además del clima, las características del suelo, la topografía y la cubierta de nieve, son los principales factores que controlan el régimen térmico del suelo en ambas regiones.*

Key words: Antarctic Peninsula, James Ross Island, Livingston Island, active layer, air and ground temperatures.

Palabras clave: Península Antártica, isla James Ross, isla Livingston, capa activa, temperaturas de suelo y de aire.

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1. Introduction

The air temperature in the Antarctic Peninsula region (AP) increased locally by ca. 2.5ºC since the mid-20th century (Turner *et al*., 2005) with one of the fastest warming rates on Earth. In the ice-free areas of the AP region, this warming has had a significant impact on terrestrial and aquatic ecosystems (Bockheim *et al*., 2013). Since the International Polar Year (2007-2009), an increasing interest of the cryospheric community has been directed towards understanding the active layer dynamics and permafrost distribution in the Antarctic Peninsula region. Most of the studies have focused on the western part of AP, mainly on the South Shetlands region (Ramos and Vieira, 2003; Ramos *et al*., 2008; de Pablo *et al*., 2013, 2014; Goyanes *et al*., 2014), while only a few studies examined the state and characteristics of permafrost in the eastern part of AP (e.g. Hrbáček *et al*., in press). Over the last few years some studies provided a brief comparison between active layer conditions on the western and eastern sides of the AP summarizing primary information such as permafrost temperatures or maximum active layer thickness (ALT) (e.g. Vieira *et al*., 2010; Bockheim *et al*., 2013). However, these studies have not compared active layer thermal regimes in both regions.

This research focuses on two sites located on James Ross Island (eastern AP) and Livingston Island (western AP). While permafrost distribution is known to be continuous on James Ross Island (Davies *et al*., 2013), it is discontinuous in the lowlands of the Livingston Island turning to continuous in elevations above 150 m (Vieira *et al*., 2010). The main purpose of this study is the comparative examination of the ground thermal regime on both sites in order to better understand the factors controlling active layer dynamics in the AP region.

2. Study sites

This work focuses on two large ice-free areas located on islands on both sides of the AP region: (a) Ulu Peninsula (ca. 180 km^2), James Ross Island, eastern AP, and (b) Byers Peninsula (ca. 60 km^2), Livingston Island, western AP (Figs. 1 and 2).

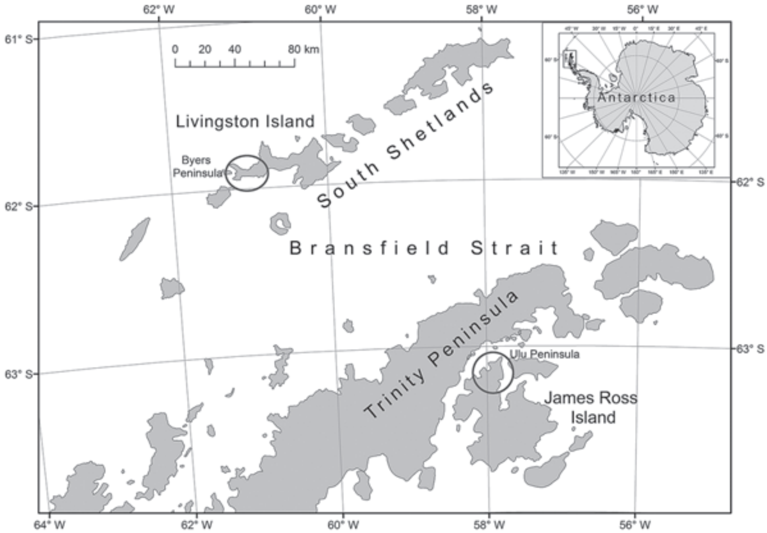

Figure 1. Location of Ulu Peninsula (James Ross Island) and Byers Peninsula (Livingston Island) in northern Antarctic Peninsula region.

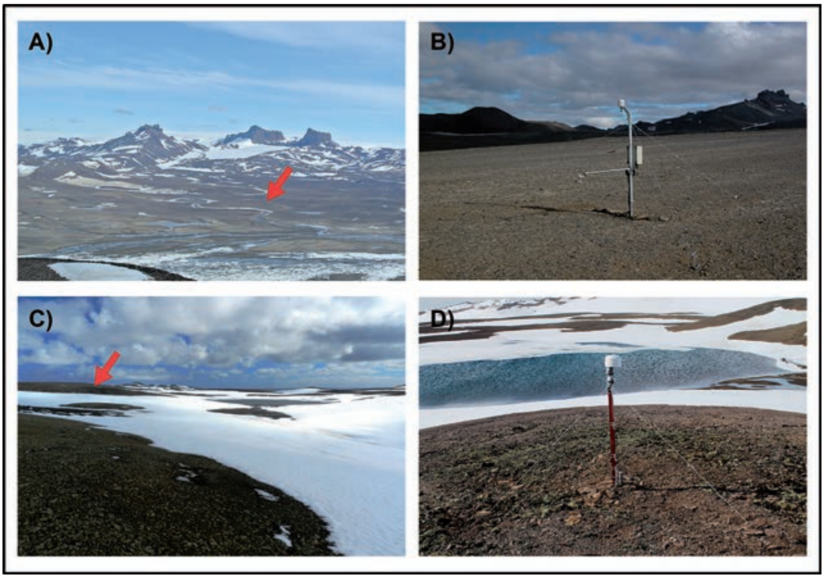

Figure 2. View to study sites and its vicinity at Ulu Peninsula (A, B) and Byers Peninsula (C, D).

2.1. James Ross Island - Ulu Peninsula

Climate of the Ulu Peninsula corresponds to semi-arid polar continental regime (Martin and Peel, 1978) with mean annual air temperature (MAAT) at sea level of -6.8°C for the period 2006-2011 (Láska *et al*., 2012). The annual amplitude of air temperatures exceeds 40°C with summer maxima >10°C and winter minima <-30°C. Precipitation shadow effect caused by Trinity Peninsula (Davies *et al*., 2013) significantly affects precipitation, mainly in the form of snow during the winter season. The estimated annual precipitation is 400-500 mm (van Lipzig *et al*., 2004), although high wind speeds cause irregular deposition and significant snow removal from the landscape (Nývlt *et al*., 2016) and therefore the maximum thickness of snow layer does not exceed 0.3 m in flat areas (Zvěřina *et al*., 2014; Hrbáček *et al*., in press).

The deglaciation of the lowermost parts of the Ulu Peninsula started around 12.9 ka (Nývlt *et al*., 2014) and only small glaciers remained here until present days (Engel *et al*., 2012). The landscape of the Ulu Peninsula has been, besides glacial erosion and accumulation, sculpted by paraglacial and periglacial processes (Davies *et al*., 2013). Permafrost on Ulu Peninsula is continuous (Bockheim *et al*., 2013) with an approximate thickness of 67 m according to geoelectrical measurements (Borzotta and Trombotto, 2004). ALT is strongly influenced by local lithology and varied between 52 and 85 cm on three sites during the period 2012-2015 (Hrbáček *et al*., submitted). The study site on James Ross Island is located in the central flat part of Ulu Peninsula, at Abernethy Flats, 41 m a. s. l. on a flat terrain (<2°). (Table 1). Fine-grained calcareous sandstones and siltstones of the Alpha Member and Santa Marta Formation of Late Cretaceous age (Olivero *et al*., 1986; Crame *et al*., 1991) form study site. The superficial part is generally weathered to form loose sandy regolith with occasional gravel clasts mostly of James Ross Island Volcanic Group basalts; finer fraction is generally blown away (Davies *et al*., 2013). Vegetation cover is very scarce with concentration spots mostly along streams, or around seal carcasses (Nývlt *et al*., 2016).

Table 1. Geographical characteristics of the study sites.

Site	Locality	Latitude Longitude	Altitude (m a. s. l.)	Slope
Abernethy Flats, Ulu Peninsula	James Ross Island	63º52’30’’ S 58º57’10’’ W	41	0-2°
Domo, Byers Peninsula	Livingston Island	62º37’19’’ S 60º58’33’’ W	45	0-2°

2.2. Livingston Island - Byers Peninsula

Byers Peninsula shows a cold and wet oceanic climate with MAAT of -2.8ºC at 70 m a. s. l. for the period 2002-2010. The maximum daily air temperature does not exceed 10 °C with mean summer maximum of 2.7°C, while the minimum temperature during the winter rarely drops below -25 °C, with a mean winter daily minimum of -9.8°C (Bañón *et al*., 2013). Estimated precipitation is ca. 500-800 mm in the form of both rain and snow in the summer and snow in winter, resulting in snow cover for 8 to 9 months per year (Bañón *et al*., 2013, Navarro *et al*., 2013).

The Byers Peninsula is composed mainly of mudstone, sandstone, conglomerate and volcanic and volcanoclastic rocks of the Late Jurassic to Early Cretaceous age, intruded by igneous bodies (López-Martínez *et al*., 1996). Vegetation cover is very scarce and mostly concentrated on the marine terraces surrounding the main plateau. Byers Peninsula constitutes the largest ice-free area of the South Shetland Islands (SSI), with ca. 60 km^2. The area has been deglaciated during the Holocene following the eastward retreat of the Rotch Dome glacier (Oliva *et al*., 2016). The relief of Byers Peninsula is organized around a central plateau (70-100 m) surrounded by Holocene marine terraces and the present-day beaches, with a few isolated hills exceeding an elevation of 140 m rising above the plateau (López-Martínez *et al*., 2012). A wide range of periglacial processes and landforms are distributed across the ice-free landscape of Byers Peninsula. The study site is located near Domo Lake, at 45 m a. s. l., on a flat hilltop above the lake with an inclination of 0-2° (Table 1). Soils have a very low organic matter content and are composed of coarse-grained sediments, with abundant gravels in a sandy-silty matrix, which conditions water circulation through the soil in summer (Navas *et al*., 2008). The area is continuously affected by very strong winds that effectively redistribute snow cover.

3. Material and Methods

This study analyses the data obtained during the period from 29 January 2014 to 5 January 2015 on the two aforementioned sites. The study period was constrained by the availability of data from Byers Peninsula. Two sets of devices were used to monitor ground and air temperatures on each site (Table 2).

Table 2. Main characteristics of the devices used in this research.

Locality	Type	Sensor	Height/depth (m)	Resolution (ºC)	Accuracy (ºC)
James Ross Island, Ulu Peninsula	**Air temperature**	EMS 33	2.0	0.01	0.15
	Soil profile	Pt100	5, 10, 20, 40, 50, 75	0.01	0.15
Livingston Island, Byers Peninsula	**Air temperature**	Tynitag	1.5	0.02	0.25
	Borehole	Ibutton (DS1922L)	5, 10, 20, 40, 60, 80	0.0625	0.5

Air temperature in Ulu Peninsula was measured at 2.0 m above ground using EMS 33 sensor and ground temperature was measured using platinum resistance probes Pt100/8 installed along a profile at depths of 5, 10, 20, 30, 40, 50 and 75 cm. Sensors were connected to a V12 data logger (EMS Brno) recording data every 30 minutes. In Byers Peninsula, air temperature was measured at 1.5 m above ground using Tynitag (Plus 2) sensor and ground temperatures were monitored with a chain of iButtons DS1922L thermometers at depths of 5, 10, 20, 40, 60 and 80 cm placed inside a sealed PVC-cased borehole. Air and ground temperatures were measured every 120 minutes.

Raw data were used for the calculation of daily mean, maximum and minimum temperatures and amplitude values. Ground temperatures were plotted as isopletes using the kriging interpolation approach in Surfer 11 software (Golden Software), which allowed comparison between sites. Small differences for deeper level temperatures on the two sites are because the lowest loggers are set up at 75 and 80 cm at Ulu Peninsula and Byers Peninsula, respectively (referred to 75/80 cm throughout the text). Ground thermal dynamics for each depth was described using following thermal parameters commonly used in recent studies on active layer properties in the AP (e.g. Guglielmin *et al.*, 2008; de Pablo *et al*., 2013; Hrbáček *et al.*, submitted; Oliva *et al.*, submitted).

1. The thawing and freezing seasons were defined from the daily thermal regime at 5 cm. Our data were limited to the end of thawing season 2013/14 and beginning of thawing season 2014/15.
2. The active layer thickness was determined using the deepest position of the 0°C isotherm by interpolation (Ulu Peninsula) and extrapolation (Byers Peninsula), respectively.
3. Thawing degree-days (TDD) and freezing degree-days (FDD) were calculated as sums of mean daily temperatures above 0°C and below 0°C, respectively for both air temperature (TDD_A/FDD_A) and ground temperature (TDD_G/FDD_G).
4. Thawing days are days with minimum temperature above 0.5°C; freezing days are days with maximum temperature below -0.5°C; freeze-thaw days show both maximum above 0.5°C and minimum below -0.5°C; and isothermal days show daily temperatures between 0.5°C and -0.5°C.

The freezing n-factor is a ratio between FDD_G and FDD_A at 5 cm for indirect determination of snow cover effect on ground temperature during freezing season (Karunarante and Burn, 2003). The thawing n-factor was calculated separately for the period before 29 January to 31 October 2014, which represents the end of thawing seasons 2013/14 and for the period 1 November 2014 to 5 January 2015 representing the early beginnings of thawing season 2014/15. TDD during freezing season was found as negligible, therefore this period was added to thawing seasons 2013/14.

Finally, correlation analysis to compare daily means for both air and ground temperature at 5 cm between Ulu Peninsula and Byers Peninsula has been undertaken to determine the relationship of these factors. All results showed significant relationship in level of significance 0.01.

4. Results

4.1. Ulu Peninsula

The main characteristics of both air and ground temperatures at Ulu Peninsula for 29 January 2014 to 5 January 2015 are presented in Table 3 and Fig. 3a, 3b. Mean air temperatures averaged -7.9°C, with a maximum of 12.3°C (1 November) and a minimum of -32.9°C (18 August). Consequently, the annual amplitude of air temperatures reached 45.2°C. The warmest month was December, with a mean air temperature of -1.0 °C and the coldest one was August (-16.0°C). During the entire study period TDD_A reached 140°Cday, from which TDD_A 37°Cday (29 January to 7 March) and 21°Cday (26 November to 5 January) while TTD_A 82°Cday were observed during freezing seasons (8 March to 25 November). FDD_A reached -2528°Cday, from which -2385°Cday were recorded during the freezing season (Fig. 4).

Table 3. Basic statistics of air temperature (AT) and ground temperature (GT) at Ulu Peninsula and Byers Peninsula in period 29 January 2014 to 5 January 2015.

Parameter	Ulu Peninsula			Byers Peninsula		
	Mean	Max	Min	Mean	Max	Min
AT	-7.9	12.3	-32.9	-2.6	6.1	-13.5
GT 5 cm	-6.2	21.1	-18.6	-1.3	17.9	-9.9
GT 10 cm	-6.5	12.7	-17.5	-1.2	7.0	-7.7
GT 20 cm	-6.3	7.7	-15.9	-1.1	4.6	-5.5
GT 40 cm	-6.3	2.6	-14.2	-0.9	3.8	-3.7
GT 50 cm	-6.4	0.3	-13.4	--	--	--
GT 60 cm	--	--	--	-0.8	2.5	-2.9
GT 75 cm	-6.6	-0.9	-12.4	--	--	--
GT 80 cm	--	--	--	-0.7	0.2	-2.4

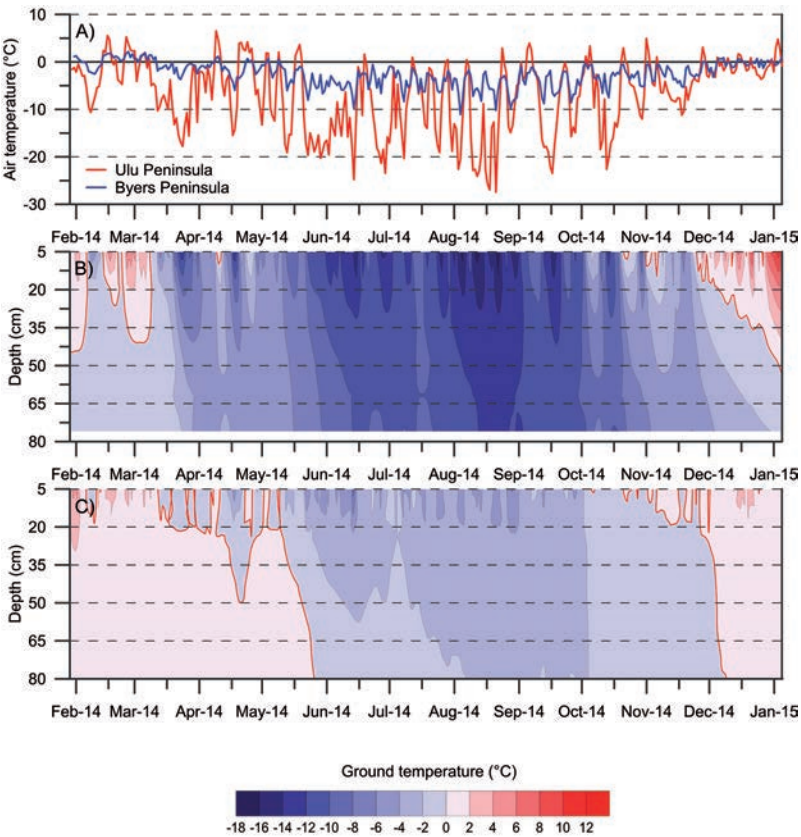

Figure 3. Variability of mean daily air temperature (a) and ground temperature at Ulu Peninsula (b) and Byers Peninsula (c) in period 29 January 2014 to 5 January 2015. Red lines in (b) and (c) plots represent 0ºC isotherm.

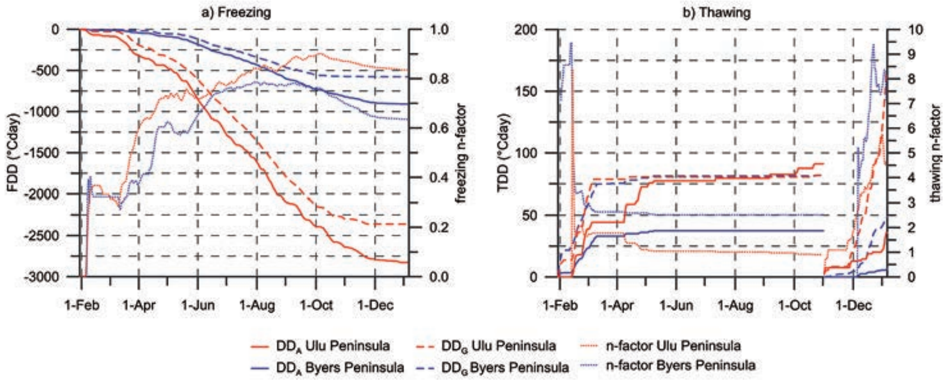

Figure 4. Seasonal evolution of freezing (FDD) and thawing (TDD) degree days (DD) of air temperature (AT) and ground temperature (GT) and freezing and thawing n-factor at Ulu Peninsula and Byers Peninsula in 2014.

Mean ground temperatures during the study period gradually decreased with depth from -6.2°C (5 cm) to -6.6°C (75 cm) (Table 3, Fig. 5a). Similarly, maximum ground temperatures decreased from 21.1°C at 5 cm (3 January) to -0.9°C at 75 cm (13 March), as well as minimum ground temperature, which ranged between -18.6°C at 5 cm (22 August) and -12.4°C at 75 cm (25 August). The highest mean monthly ground temperature from 5 to 40 cm depth was observed in December (3.3°C at 5 cm to -0.3°C at 40 cm) while at 50 cm (-0.6°C) and 75 cm (-1.4°C) was in February.

The end of the thawing season 2013/14 occurred between 29 January and 7 March 2014 while the beginning of the thawing season 2014/15 encompassed period from 26 November 2014 to 5 January 2015. There was only one day between refreezing at depths 5-10 cm (7 March) and 20-30 cm (8 March), while the active layer at lower depths (40 to 75 cm) was already frozen by the end of thawing season 2013/14. The thawing of the active layer started in 26 November and reached 50 cm until 3 January 2015.

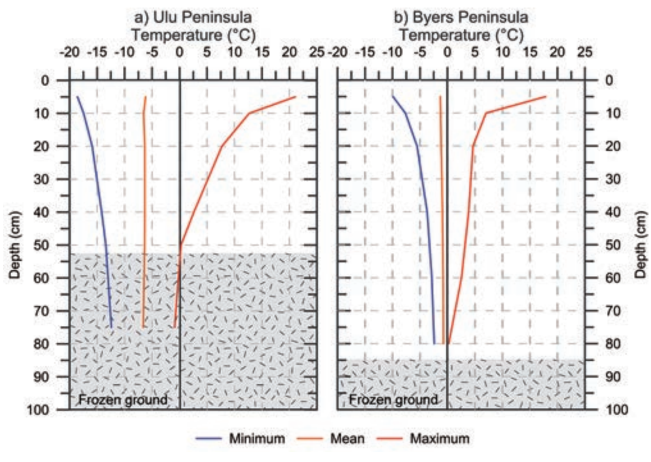

Figure 5. Vertical profiles of ground temperature at Ulu Peninsula (a) and Byers Peninsula (b) in 2014.

ALT reached 52 cm during the thawing season 2014/15 (5 January 2015), and only 45 cm during the thawing season 2013/14 (29 January 2014). Active layer remained frozen during the freezing season (8 March to 25 November), with only several days in March and November during which a thin near-surface layer up to 5 cm thawed.

The main thermal parameters for Ulu Peninsula are summarized in Table 4, showing large variability with depth. TDD_G rapidly decreased from 5 cm (251.1°Cday) to 40 cm (13°Cday) and was not observed at 75 cm. The regime of TDD_G at 5 cm was similar to TDD_A. In total, TDD_G at 5 cm reached 81°Cday before 7 March while 159°Cday after 26 November. Thawing n-factor varied between 1.77 (end of thawing season 2014/15) and 4.65 (beginning of thawing seasons 2014/15) (Fig. 4b). TDD_G at 5 cm reached only 12°Cday during freezing season. Although the TDD_G were highest at 5 cm, the number of thawing days was maximum at 20 cm with 25 days observed. (Table 4).

Table 4. Thermal characteristics of active layer at Ulu Peninsula and Byers Peninsula in period 29 January 2014 to 5 January 2015.

Site	Depth	TDD	TD	FDD	FD	FT-D	IT-D
Ulu Peninsula	5 cm	251	11	-2361	223	35	0
	10 cm	144	16	-2378	267	24	0
	20 cm	85	25	-2250	268	0	5
	40 cm	13	5	-2176	277	0	25
	50 cm	0	0	-2176	318	0	9
	75 cm	0	0	-2257	342	0	0
Byers Peninsula	5 cm	134	22	-577	147	48	37
	10 cm	82	33	-507	153	6	88
	20 cm	61	30	-453	160	0	123
	40 cm	55	35	-366	161	0	135
	60 cm	42	8	-312	178	0	151
	80 cm	27	0	-280	182	0	159

TD – number of thawing days

FD – number of freezing days

FT-D – number of freeze-thawing days

IT-D – number of isothermal days

Contrary to TDD_G, FDD_G increased with depth from 5 cm (-2361°Cday) to 40 cm (-2176°Cday) and decreased down to 75 cm (-2257°Cday). Freezing n-factor reached 0.82 in December, though the value ranged between 0.70 and 0.90 during the winter months (Fig. 4a). The total number of freezing days gradually increased from 5 cm (223 days) to 75 cm (342 days). Isothermal days characterized by low amplitude of ground temperature around 0°C were observed between 20 and 50 cm, with the maximum at 40 cm (25 days). On the other hand, freeze-thawing days were detected at near-surface layer, only at 5 and 10 cm depths. The scatter of freeze-thawing days was very small comparing the end of the thawing season 2013/14 from February to April (17 freeze-thawing days) and the early beginning of the thawing season 2014/15 from October to December (18 freeze-thawing days). Freeze-thawing days occurred most frequently in November (9 days), while in April and October only 4 days were recorded (Fig. 6a).

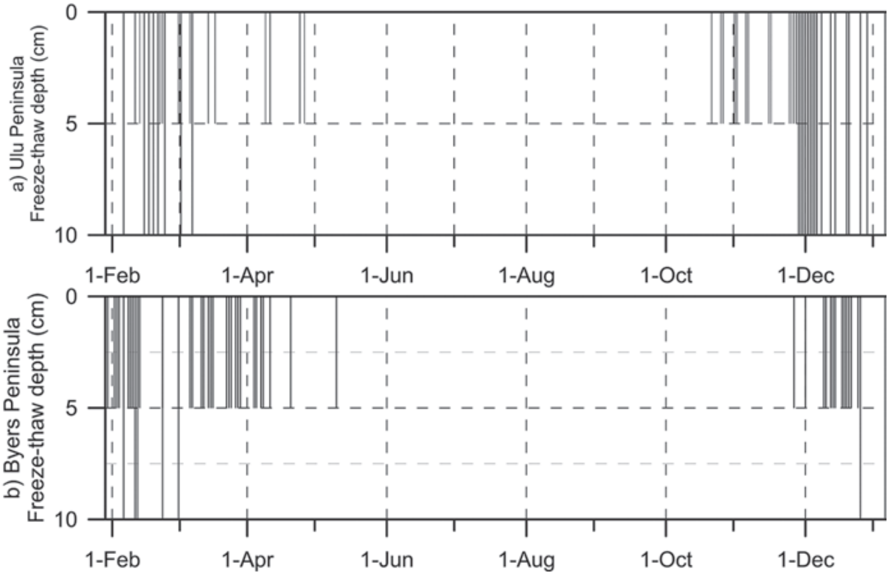

Figure 6. Freezing-thawing days calendar at depths 5 and 10 cm at Ulu Peninsula (a) and Byers Peninsula (b) in 2014.

4.2. Byers Peninsula

The main thermal characteristics recorded during the study period in Byers Peninsula are presented in Table 3 and Fig. 3a, 3c. The mean air temperature during study period reached -2.6°C. The maximum air temperature reached 6.5°C (24 December), while the minimum dropped to -13.5°C (4 August) making thus an annual amplitude of only 20.0°C. The highest mean monthly air temperature was recorded in February (0.3°C), while the coldest month was August (-5.6°C). The TDD_A reached only 44°Cday, with an irregular distribution between the thawing periods 2013/14 from 29 January to 12 March (33°Cday) and from 2 November to 5 January (7°Cday). The total sum of FDD_A reached -909°Cday, from which -808°Cday was calculated for the freezing season (13 March to 1 November).

The average ground temperatures during the study period slightly increased with depth from -1.3°C at 5 cm to -0.7°C at 80 cm (Table 3, Fig. 5b). The maximum ground temperatures reached 17.9°C at 5 cm (20 December) and decreased with depth to 0.2°C at 80 cm (from 29 January to 22 May). The minimum ground temperature of -9.9°C was recorded at 5 cm (14 June), while the minimum at 80 cm was -2.4°C

(1-3 September). The highest mean monthly ground temperature was recorded in February at depths from 5 cm (1.6°C) to 60 cm (0.5°C), while at 80 cm mean monthly ground temperature reached 0.2ºC, same value as maximum, due to constant ground temperature from February to April.

The thawing season 2013/14 ended on 12 March, though the active layer rethawed at 5 cm depth during several events until 5 May. The deeper layers of the profile remained thawed until 26 May, when the active layer at 80 cm was frozen. The beginning of the thawing season 2014/15 occurred on 2 November; however, there was not sharp boundary between freezing and thawing seasons similarly as the end of thawing seasons 2013/14. Active layer thawing events were observed since 6 October. ALT reached 85 cm during the thawing season 2013/14 and 82 cm during the beginning of the thawing season 2014/15.

The TDD_G gradually decreased with depth from 134°Cday (5 cm) to 27°Cday (80 cm). Most of the TDD_G were detected before 12 March (78°Cday), while only 49.0°Cday after 2 November. Thawing n-factor varied between 2.63 (end of thawing season 2014/15) and 7.15 (beginning of thawing seasons 2014/15). The TDD_G at 5 cm reached 7.0°Cday only during freezing season (Fig. 4b). The number of thawing days gently increased from 5 cm (22 days) to 40 cm (35 days), decreasing to only 8 days at 60 cm (Table 4).

The FDD_G increased with depth from 5 cm (-577°Cday) to 80 cm (-280°Cday). The freezing n-factor reached 0.64 in December, while it ranged from 0.75 to 0.78 during the winter season from June to September (Fig. 4b). Similarly, the total number of freezing days (FDD_G) increased from 147 days at 5 cm to 182 days at 80 cm. The highest occurrence of isothermal days (159) was observed at 80 cm and gradually decreased to 37 days at 5 cm (Table 4). The freeze-thawing days were only detected at 5 and 10 cm (Fig. 6b). In total, up to 48 freeze-thaw days were recorded at 5 cm unevenly distributed between the period before mid-May (34 days) and the period from November to December (14 days). The total number of freeze-thaw days at 10 cm was significantly lower, with only 6 days: 5 in February and only 1 day in December.

5. Discussion

The studied sites at Ulu Peninsula and Byers Peninsula have similar topography, but are located in different climate settings, which make them suitable for ground thermal regime inter-comparison.

5.1. Air temperature differences

The air temperature over period February 2014 to January 2015 (-2.6°C) in Byers Peninsula was similar as MAAT (-2.6°C) in the period 2007 to 2012, during which MAAT ranged between -1.7°C and -3.3°C (Bañón *et al.*, 2013; de Pablo *et al.*, 2014). Generally, the interannual differences of air temperatures on Livingston Island are lower than on Ulu Peninsula. Here, mean air temperature during the study period (-7.9°C) was slightly lower than MAAT at Abernethy Flats over the period of 2006-2014 (-7.5°C), however the MAAT varied between -5.0°C and -10.3°C (Hrbáček *et al.*, submitted, unpublished data). From this point of view, air temperatures at both sites were very close to average thermal conditions during last several years.

The differences in the regime of air temperatures between both sites are shown in Fig. 3a and Table 3. The mean period air temperature was 4.4°C higher in Byers Peninsula, though the absolute maximum air temperature was 6.2°C higher at Ulu Peninsula. Remarkably, the minimum air temperature was 19.4°C lower at Ulu Peninsula. In general, the air temperature regime at Ulu Peninsula corresponds to a more continental climate pattern, with high oscillations of mean daily temperatures ranging between -25°C and 5°C during winter, while at Byers Peninsula daily temperatures during this season typically ranged between -10°C and 0°C (Fig. 3). The different climate resulted in substantial differences in daily mean air temperatures between Ulu Peninsula and Byers Peninsula, which varied between -21.2°C to 7.4°C (Fig. 7).

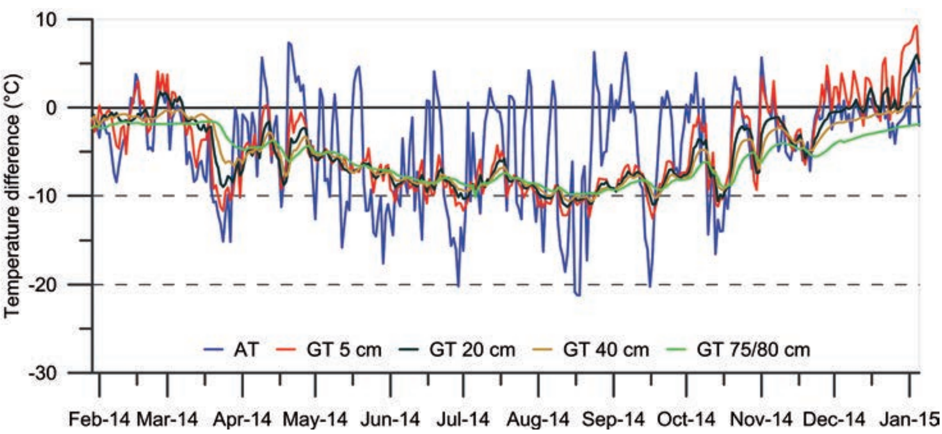

Figure 7. Differences of mean daily air temperature (AT) and ground temperature (GT) at 5, 20, 40 and 75/80 cm between Ulu Peninsula and Byers Peninsula in 2014.

The different climate conditions were well documented by the TDD_A and FDD_A. TDD_A was higher by 96°Cday at Ulu Peninsula during the study period. The main differences were observed during freezing seasons (TDD higher by 78°Cday at Ulu Peninsula) and between 1 November and 5 January (TDD higher by 14ºCday). On the other hand, FDD_A was -1920°Cday lower at Ulu Peninsula.

Despite significant differences observed in the variability of air temperatures, the correlation between mean daily temperatures at Ulu Peninsula and Byers Peninsula resulted in r=0.74, without any time-lag (Fig. 8c). This partly confirms the modelled results of King and Comiso (2003), which suggested a correlation of r>0.75 between James Ross Island and the South Shetland Islands during the winter months.

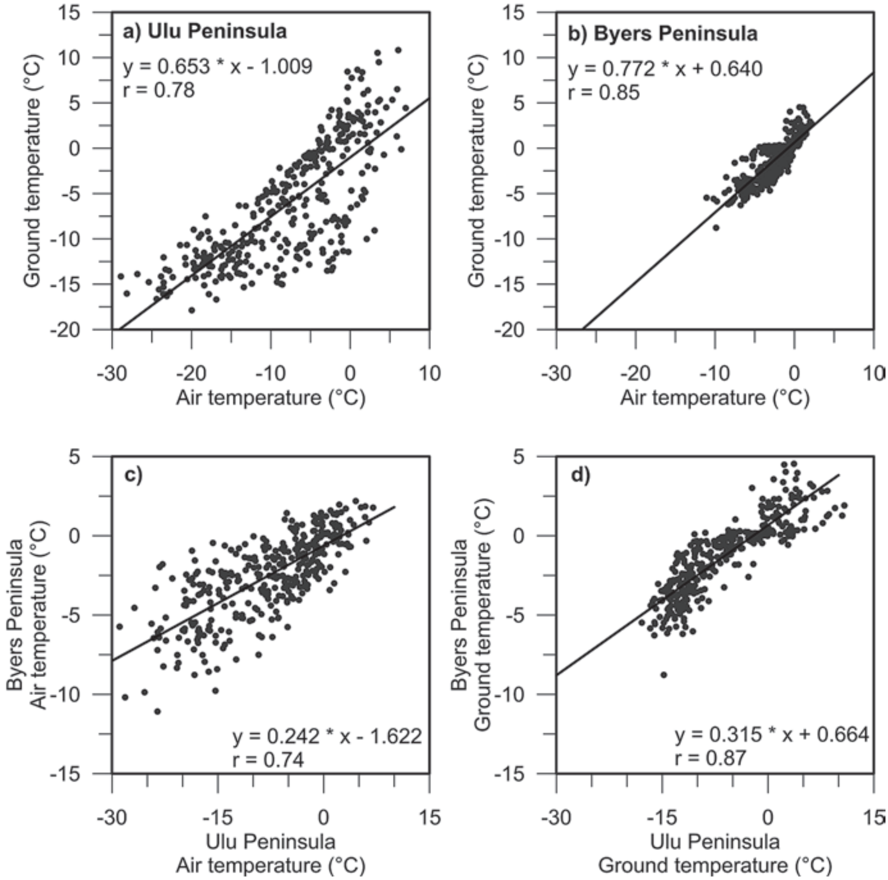

Figure 8. Correlation analysis of mean daily air temperature vs mean daily ground temperature 5 cm at Ulu Peninsula (a) and Byers Peninsula (b); mean daily air temperatures (c) and mean daily ground temperatures (d) at Ulu Peninsula vs Byers Peninsula in 2014.

5.2. Ground temperature

Two very different active layer thermal regimes were observed at Ulu Peninsula and Byers Peninsula. The mean period ground temperature was lower at Ulu Peninsula (-4.9°C at 5 cm and -5.9°C at 75/80 cm), showing warmer ground at Byers Peninsula. The ground temperature at 5 and 20 cm was 12.5°C higher at Byers Peninsula between 11 April and 22 October, but in December was 9.3°C higher at Ulu Peninsula. Ground temperatures at 40 cm depth were up to 10.5°C higher during the period 29 January to 30 December at Byers Peninsula and the difference at 75/80 cm depth was between 1.6 and 10.2° C, always warmer at Byers Peninsula (Fig. 7).

Despite the lower mean period ground temperature, maximum ground temperatures and TDD_G were higher in the upper 20 cm at Ulu Peninsula, while the maximum and TDD at lower depths, were higher at Byers Peninsula. The most pronounced differences were observed in the development of TDD_G at 5 cm. Its total sum at Ulu Peninsula (251°Cday) was almost twice higher than at Byers Peninsula (134°Cday). During the period from 1 November 2014 to 5 January 2015 the TDD reached more than three times higher values at Ulu Peninsula (167°Cday) than at Byers Peninsula (49°Cday). However, the lower levels were significantly warmer at Byers Peninsula, where the total sum of the TDD_G decreased gently with depth up to 27°Cday at 80 cm, while the TDD_G decreased very rapidly to 0°Cday only at 50 cm depth at Ulu Peninsula. Similarly, the total number of thawing days increased with depth up to 40 cm (with 8 days observed at 60 cm at Byers Peninsula), while the increment of thawing days was observed up to 20 cm (with 5 days only at 40 cm at Ulu Peninsula).

The most significant differences between both sites are related to the thawing seasons 2013/14 and 2014/15. Although the thawing season 2013/14 at 5 cm ended in 12 March, the active layer in the deeper parts of the profile remained unfrozen until 26 May, with a maximum thickness estimated at 85 cm at Byers Peninsula. In contrast, at Ulu Peninsula active layer, completely froze between 7 (5-10 cm) and 8 (20-30 cm) March and reached maximum ALT (45 cm) in 29 January. The thawing season 2014/15 started between 2 November (Byers Peninsula) and 26 November (Ulu Peninsula). Despite higher temperatures and rapidly increasing TDD at near-surfaces depths was observed at Ulu Peninsula, active layer thawed much more quickly in Byers Peninsula, and a thickness of ca. 82 cm was detected at the beginning of December, while only 52 cm was observed at Ulu Peninsula in 5 January 2015.

The mean daily temperature could drop below -14°C at 40 cm depth at Ulu Peninsula, while ground temperature did not drop below -4°C at the same depths at Byers Peninsula. Very intensive active layer freezing was observed at Ulu Peninsula as suggested by the FDD_G, about four times lower at 5 cm and even eight times lower at 75/80 cm comparing to Byers Peninsula. Similarly, the number of freezing days was significantly higher at Ulu Peninsula with respect to Byers Peninsula: 223 vs. 147 (5 cm) to 342 vs. 182 (75/80 cm) days.

5.3. Factors affecting the active layer thermal regime

The data confirms earlier results and conclusions suggesting significant differences both in air temperatures and in active layer thermal dynamics between ice-free areas in the eastern and western sides of the AP (Bockheim *et al*., 2013; Hrbáček *et al.*, in press). However, this study is the first comparison between ground thermal regimes on two sites within these regions.

The differences of the active layer thermal regime between both sites were highly affected by differences of air temperatures. In both sites a close relationship was found between air temperature and ground temperatures, reaching r=0.78 and r=0.85 at Ulu Peninsula and Byers Peninsula, respectively (Fig. 8a, b). This suggests air temperature as very important driver affecting daily regime of ground temperature during the whole year. The flattening of scatter plots around 0°C, which is typical for snowy conditions, was only limited in case of Byers Peninsula (Fig. 8b). Analysing the relationship between mean daily ground temperatures at 5 cm in Ulu Peninsula and Byers Peninsula showed even a closer correlation of r=0.87 than was determined for air temperature, which reveals similar patterns of near-surface thermal regime in both sites (Fig. 8d).

Snow cover, thickness and duration, is of paramount importance for the ground thermal regime. Although snow cover data were not available for both sites, freezing n-factors were used as indicators of the presence of snow. The freezing n-factor around 0.90 during the winter months showed a very limited insulating effect of snow at Ulu Peninsula, which is typical for this area (Hrbáček *et al*., in press). Lower value of freezing n-factor, around 0.60, suggests a more significant effect of snow as thermal insulator in Byers Peninsula. However, other studies at Byers Peninsula showed even lower n-factors, around 0.30, typical for sites or seasons with longer persistence of snow cover thicker than 60 cm (de Pablo *et al*., 2013). While there were no studies describing the active layer thermal regime under significantly different snow conditions on James Ross Island, the active layer was found thicker (ca. 130 to 150 cm) on sites with more persistent snow cover with thickness more than 60 cm at South Shetlands (de Pablo *et al*., 2014; Oliva *et al*., submitted).

An important but still very little known factor affecting active layer thermal regime is local lithology. A preliminary study suggests lithological and physical properties are the most important factors causing local differences in active layer thermal regime and its thickness on James Ross Island (Hrbáček *et al*., submitted). Similarly, the lithology was found very important factor affecting active layer thermal regime and its thickness on Livingston Island. In different sites of Livingston Island, Hurd Peninsula, Ramos and Vieira (2009) modelled ALT in bedrock ranging even between 2 and 5 m.

6. Conclusions

This study presents a preliminary analysis of air and ground temperatures during 2014 at two sites of the western (Byers Peninsula, Livingston Island) and eastern part (Ulu Peninsula, James Ross Island) of the Antarctic Peninsula. The comparison provides a better understanding of the main patterns of active layer thermal regime in both regions and gives insights about the factors controlling ground temperatures, which can be summarized as follows:

1. Both areas are affected by different type of climate regimes. Higher mean air temperatures were recorded in Livingston Island (-2.6ºC), with lower temperature amplitude (20ºC), while in James Ross Island mean annual air temperatures were significantly lower (-7.9°C), although with a higher amplitude (45.2ºC).

2. The mean ground temperatures at 5 cm were significantly higher in Livingston Island (-1.3°C) than in James Ross Island (-6.2°C), while the TDD_G at 5 cm

was much higher at James Ross Island (251 °Cday) than at Livingston Island (134°Cday).

3. In Livingston Island, thaw depth varied between 82 (15 December 2014 to 5 January 2015) and 85 cm (29 January 2014 to 24 May 2014). In James Ross Island, the active layer thickness ranged between 45 cm (29 January 2014) and 52 cm (2015).

This preliminary work will be complemented during the coming years with more intensive collaboration and coordination between research teams working on South Shetlands and James Ross Island on active layer characteristics in the AP region. Although we found that the active layer thermal regime at near-surface depths in both sites was strongly affected by air temperature (high correlations between mean daily temperatures on Livingston Island and James Ross Island have been found), other parameters such as lithology, moisture, snow cover thickness and persistence probably have a major effect on the variability of the active layer dynamics. These preliminary findings will be complemented in future studies for a better understanding of the active layer dynamics across the AP region.

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