Permafrost and active layer research on James Ross Island: An overview

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Abstract

This study summarizes the current state of the active layer and permafrost research on James Ross Island. The analysis of climate parameters covers the reference period 2011–2017. The mean annual air temperature at the AWS-JGM site was -6.9°C (ranged from -3.9°C to -8.2°C). The mean annual ground temperature at the depth of 5 cm was -5.5°C (ranged from -3.3°C to -6.7°C) and it also reached -5.6°C (ranged from -4.0 to -6.8°C) at the depth of 50 cm. The mean daily ground temperature at the depth of 5 cm correlated moderately up to strongly with the air temperature depending on the season of the year. Analysis of the snow effect on the ground thermal regime confirmed a low insulating effect of snow cover when snow thickness reached up to 50 cm. A thicker snow accumulation, reaching at least 70 cm, can develop around the hyaloclastite breccia boulders where a well pronounced insulation effect on the near-surface ground thermal regime was observed. The effect of lithology on the ground physical properties and the active layer thickness was also investigated. Laboratory analysis of ground thermal properties showed variation in thermal conductivity (0.3 to 0.9 W m^{-1} K^{-1}). The thickest active layer (89 cm) was observed on the Berry Hill slopes site, where the lowest thawing degree days index (321 to 382°C·day) and the highest value of thermal conductivity (0.9 W m^{-1} K^{-1}) was observed. The clearest influence of lithological conditions on active layer thickness was observed on the CALM-S grid. The site comprises a sandy Holocene marine terrace and muddy sand of the Whisky Bay Formation. Surveying using a manual probe, ground penetrating radar, and an electromagnetic conductivity meter clearly showed the effect of the lithological boundary on local variability of the active layer thickness.

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Key words: active layer, ground thermal regime, climate, snow cover, ground physical properties

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Introduction

The active layer, a surficial part of permafrost, where seasonal thawing occurs, represents one of the most important cryospheric components of the terrestrial ecosystems in Antarctica. Over recent decades the thermal regime and thickness of the active layer have been closely monitored because of the sensitive response to climate change (*e.g.* Bockheim et al. 2013). The active layer thermal state and active layer thickness (ALT) are highly variable across the ice-free areas of Antarctica. A mean annual near-surface ground temperature close to 0°C and the ALT exceeding 150 cm are observed in the warmest parts of the western Antarctic Peninsula region, whereas in the coldest part of Victoria Land, the mean annual near-surface ground temperature drops below -20°C and the ALT is a few centimetres only (Adlam et al. 2010, Vieira et al. 2010, Guglielmin et al. 2014a, Hrbáček et al. 2018).

The active layer investigations in Antarctica started in 1960s in McMurdo - Dry Valleys of Victoria Land, where the largest ice-free areas in the whole Antarctica are located. (Bockheim 1995). Investigations have continued until the present day (Campbell and Claridge 2006) and in 1999 were extended with a continuous monitoring of the selected soil parameters (Adlam et al. 2010). In other parts of Antarctica, the main growth of the active layer monitoring network occurred during and after the International Polar Year in 2007–2009 (Vieira et al. 2010). Knowledge of the overall state of the active layer in Antarctica has improved significantly. Besides a general evaluation of the active layer thermal regime and the ALT, the most important study topics over the last decade were the effect of snow on active layer thermal regime (*e.g.* Guglielmin et al. 2014b, de Pablo et al. 2017, Oliva et al. 2017), the identification of the role of geology in the active layer dynamics (*e.g.* Hrbáček et al. 2017a, b), the quantification of the role of climate (*e.g.* Lacelle et al. 2016), or vegetation cover (*e.g.* Cannone et al. 2006, Cannone and Guglielmin 2009).

The largest ice-free areas in the Antarctic Peninsula region are located on the James Ross Archipelago (Hrbáček et al. 2017b). In contrast to geological (Bibby 1966, Smellie et al. 2013) or glaciological research (Aristarain and Delmas 1981, Rabassa et al. 1982), which has a long tradition in the region, the periglacial research remained limited to rather general surveys only. Until recently, the most important research conducted in this region was the field mapping of periglacial features on Vega Island (Ermolin et al. 2002), Seymour Island (Ermolin et al. 2004) and James Ross Island (Strelin and Malagnino 1992, Lundquist et al. 1995, Davies et al. 2013). Furthermore, morphology and structure of rock glaciers were investigated on James Ross Island (Strelin and Sone 1998, Fukui et al. 2007). Research into permafrost and the active layer was limited to the estimation of permafrost thickness on James Ross Island and Seymour Island (Fukuda et al. 1992, Borzotta and Trombotto 2004) and ALT on James Ross Island in the elevated Rink Point mesa (Mori et al. 2006).

This study provides an overview of the recently published results of the active layer thermal dynamics and ALT research on four sites on Ulu Peninsula, James Ross

Island. The results published in several studies have been updated with new datasets, as well as with field and laboratory analyses of selected physical parameters. In particular, we focused on the analysis of:

1) Active layer thermal regime and the ALT near Johann Gregor Mendel station (AWS-JGM) in the period 2011 to 2017,

2) the effect of air temperature and snow cover on ground temperature,

3) the effect of lithology on ALT variability.

Study area

Our study area is located on Ulu Peninsula, north-western James Ross Island (Fig. 1). The basement of Ulu Peninsula is composed of Neogene volcanic rocks, which build the elevated volcanic mesas. The low-lying areas comprise Cretaceous sedimentary rocks, which are partially covered by Neogene to Quaternary unlithified sediments of glacial, glaciomarine, marine, colluvial, alluvial, fluvial and lacustrine origin (Mlčoch et al. 2018).

The area of Ulu Peninsula is mostly ice-free with more than 300 km^2 of deglaciated surfaces (Kavan et al. 2017). The deglaciation along the northern coast of the Ulu Peninsula started 12.9 ± 1.2 ka ago and continued throughout the Holocene (Nývlt et al. 2014). Now only small glaciers remain on the high-altitude plateaus and in deep valley heads (Rabassa et al. 1982). The majority of surfaces are bare ground (Fig. 2). The vegetation is limited to specific spots with sufficient water availability during the summer season or around randomly distributed seal carcasses that provide a supply of nutrients (Barták et al. 2016, Nývlt et al. 2016).

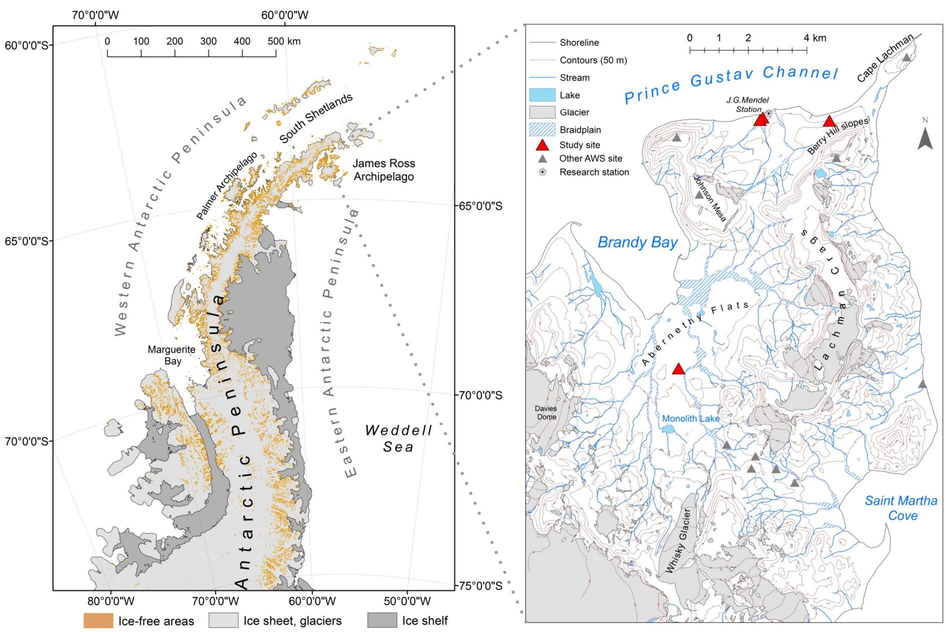

Fig. 1. Regional setting and the localization of the study sites on James Ross Island.

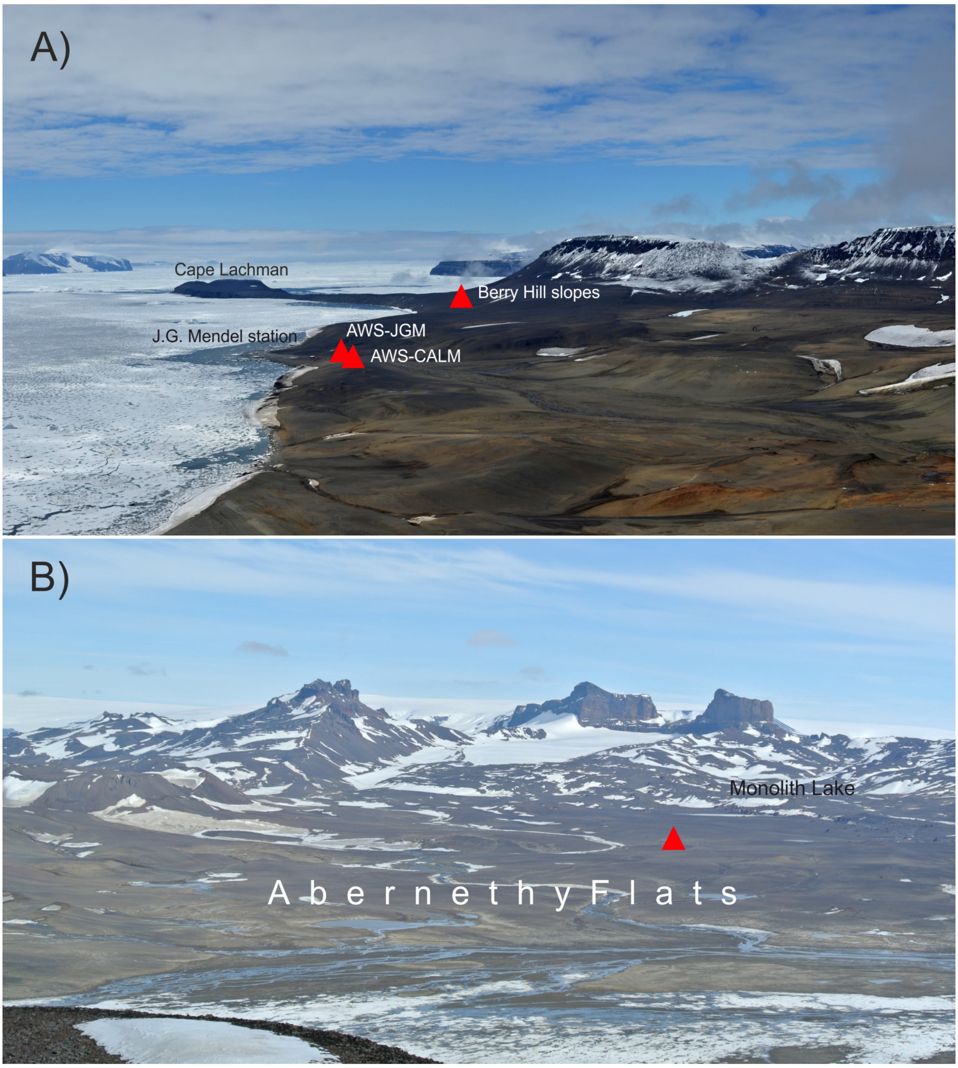

Fig. 2. The pictures of the northern coastal part of Ulu Peninsula (A) and the Abernethy Flats lowland (B). The red triangles indicate the position of the study sites.

The climate of JRI is classified as semi-arid polar continental affected both by moist oceanic and cold dry continental air masses (Martin and Peel 1978). Mean annual air temperature (MAAT) in the period 2006 to 2015 ranged from -7.0°C at sea level to -8.0°C at 375 m a.s.l. (Ambrožová and Láska 2016). Precipitation is predominantly in the form of snow and its annual rate is estimated between 200 and 500 mm (van Lipzig et al. 2004). The snow cover is usually redistributed by strong winds and its maximum accumulation on flat surfaces ranges from 30 to 50 cm (Hrbáček et al. 2016a, Kňažková et al. 2020).

Methods

Measurement setting

The active layer monitoring on James Ross Island is based on ground temperature and thaw depth measurement. A network of automatic weather stations (AWS) has been gradually established since 2006.

The air and ground temperatures are measured every 30 or 60 min. using resistance thermometers Pt100/8 with an accuracy of ± 0.15°C. The air temperature is measured 200 cm above the ground surface. Ground thermometers are located at 5, 10, 20, 30, 50 and 75 cm depths, on some sites supplemented by depths of 2, 100, 150 and 200 cm. The network covers the altitude from 10 m a.s.l. to 400 m a.s.l. and include various lithologic units. Data have been published from four sites with the code names AWS-JGM, AWS-CALM, the Abernethy Flats and Berry Hill slopes (Hrbáček et al. 2016a, b; 2017a, b). In order to better understand the spatial variability of the active layer thickness, CALM-S (Circumpolar Active Layer Monitoring-South) grids have been established. Firstly, CALM-S JGM containing both AWS-JGM and AWS-CALM has been set up in 2014. The network was extended in 2017 with CALM-S Berry Hill slopes and CALM-S Abernethy Flats. Ground temperature measurements on each site are complemented by spatial monitoring of the ALT using mechanical probing. In addition, the ALT on the CALM-S JGM site was measured with ground penetrating radar (GPR) and an electromagnetic conductivity meter (CMD) over the 2016/17 and 2017/18 summer seasons. The depth axis of GPR profiles was converted from the time axis using a wave velocity of 0.08 m ns^{-1} determined from the manual probing and from the position of the relevant reflector in radargrams. The velocity of 0.08 m ns^{-1} falls within the range of values between 0.06 and 0.11 m ns^{-1} reported for typical active layer and damp sandy deposits (Hunter et al. 2003, Sass 2008).

The ground temperature data presented in this study come from the reference site AWS-JGM (10 m a.s.l.) recorded between 1/2011 and 2/2017. The ground temperature measurement at AWS-JGM started in 2006, but as it contains numerous measurement gaps, the 2006-10 data were not included in the analysis of the annual ground temperature regime. The ground temperature was measured every 30 min. and the data were used for the calculation of daily mean temperatures according to which the mean annual values for the period March-February were calculated. This period was found to represent the ground thermal conditions better, since it covers the whole of the thawing and the whole of the freezing season (*e.g.* Hrbáček et al. 2017b). The freezing degree days (FDD) and thawing degree days (TDD) were calculated for air and 5 cm depth as sum of the negative and positive daily mean temperatures, respectively. ALT is determined as the maximum annual depth of 0°C isotherm interpolated from the annual maximum temperature measured by the deepest sensor in the active layer and the uppermost sensor in the permafrost.

Ground sampling and analysis

In order to improve knowledge of the active layer state on James Ross Island, the ground temperature measurements were complemented with the laboratory analyses. The ground sampling at the four sites with the most extensive active layer monitoring (AWS-JGM, AWS-CALM, Abernethy Flats and Berry Hill slopes) was conducted during the austral summers from 2014 to 2017. The texture of the samples (< 2 mm) was analysed in two steps: a) the fractions > 63 μm were determined based on wet sieving; b) the fractions < 63 μm were determined using the X-ray attenuation method (Micromeritics, Sedigraph III Plus). The distribution of the sand (0.063-2.0 mm), silt (0.002-0.063 mm) and clay (< 0.002 mm) fractions were determined according to WRB particle scale ([1] - IUSS Working Group WRB, 2014).

Ground thermal properties (conductivity, diffusivity and capacity) were analysed on intact samples with a volume of 500 cm^3, collected at depths of 10 and 30 cm, using the laboratory analyser ISOMET models 104 and 2104 (Applied Precision, Bratislava). Gravimetric soil moisture of the samples was calculated as air-dried at 105°C for 24 h to determine the total water content in the samples. Subsequently, dry bulk density was calculated. Surficial volumetric soil moisture was measured directly in the field using the portable device Campbell Scientific Hydrosense II with time-domain reflectivity sensor CS658 of 12 cm length.

Results

The air and ground temperature in 2011–2017

The MAAT at the AWS-JGM site was -6.9°C in the 2011-2017 period, which was only 0.1°C higher than in the period 2006–2015 (Ambrožová and Láska 2016). The MAAT varied between -3.9°C (2016/17) and -8.2°C (2011/12). The maximum daily air temperature of 13.3°C was observed in March 2015, while the minimum of -34.2°C was observed in August 2014. The annual temperature regime was characterised by a high amplitude reaching up to 40 to 45°C every year (Fig. 3). Mean annual ground temperature (MAGT) at 5 cm depth was -5.5°C in the 2011-2016 period and it varied between -3.3°C (2016/17) and -6.7°C (2012/13). The maximum daily ground temperature at 5 cm was 19.6°C in January 2016, the minimum reached to -27.7°C in July 2013. The amplitude of ground temperature at 5 cm varied between 39 and 47°C in individual years (Fig. 3).

From the perspective of active layer evolution, the most important part of the year is the thawing season which usually occurs in the period from November to March and it is delimited by positive surficial ground temperature. In the 2011–2017 period, the mean air temperature in the thawing season was between 0.5°C (2015/16) and -1.1°C (2013/14). The mean ground temperature at 5 cm was higher, between 5.1°C (2015/16) and 2.3°C (2011/12). The highest TDD_{AT} (211°C·day) was in 2015/16 while TDD_{GT5} (551°C·day) in 2016/17. The lowest TDD_{AT} was recorded in 2013/14 (61°C·day) whereas TDD_{GT5} reached its minimum in 2012/13 (358°C·day) (Fig. 4).

The freezing season usually covers the period from March to November. The freezing season typically has completely frozen ground, which does not melt, even during the events of positive air temperature typical for winter months at the margin of Antarctica. Mean seasonal air temperature was between -6.7°C in 2016 and -13.7°C in 2011 and the mean seasonal ground temperature was between -8.6°C in 2016 and -13.4°C in 2011.

We also recorded and analysed the ground thermal regime at 50 cm depth, which represents the deepest part of the active layer close to the mean position of the permafrost table. Similarly to the depth of 5 cm, the MAGT at the depth of 50 cm was -5.6°C. It varied between -4.0°C in 2016/17 and -6.8°C in 2015/16.

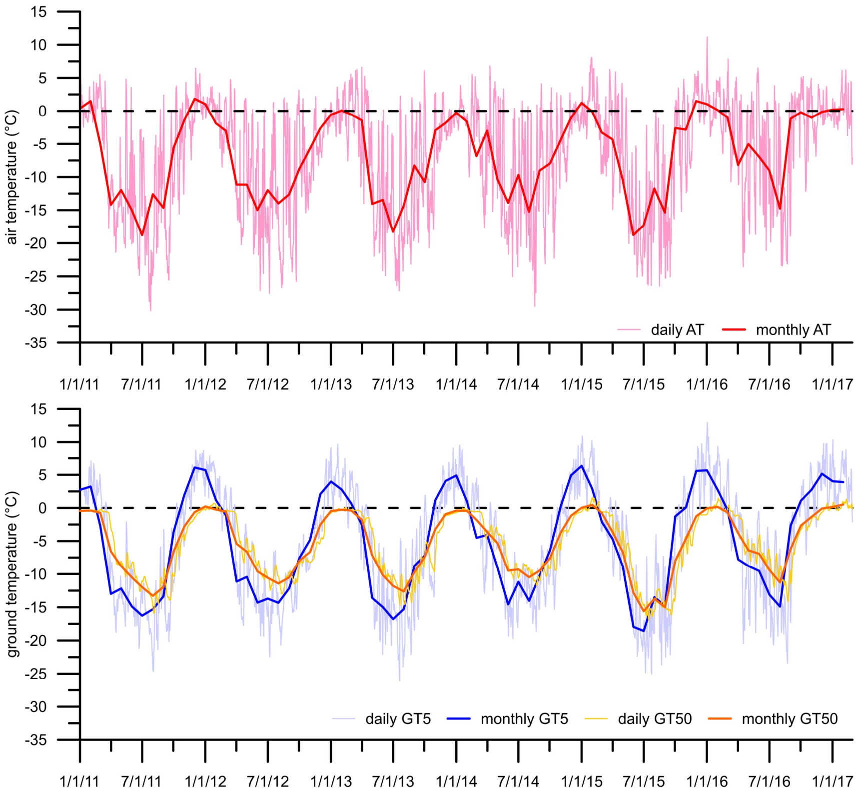

Fig. 3. The variability of mean daily and monthly air temperature (AT) and ground temperature at 5 cm (GT5) and 50 cm (GT50) on AWS-JGM in the period January 2011 to February 2017.

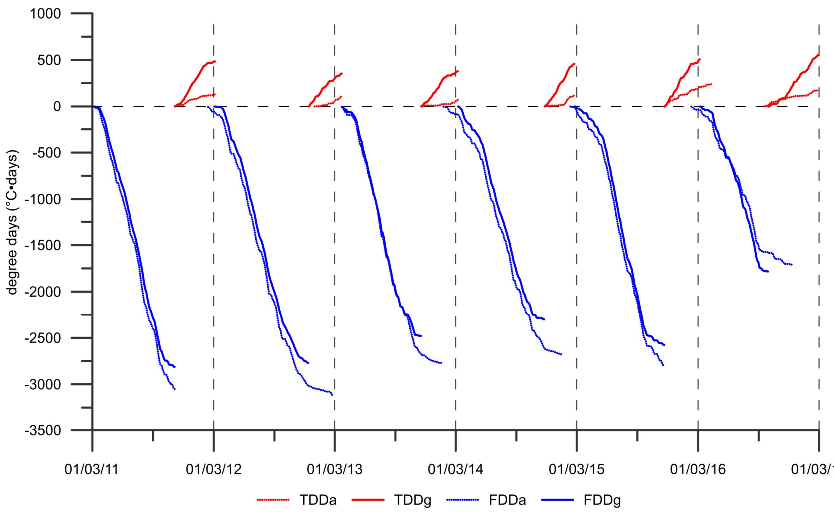

Fig. 4. The seasonal evolution of thawing degree days of air (TDDa) and ground (TDDg) and the freezing degree days of air (FDDa) and ground (FDDg), on AWS-JGM in the period March 2011 to February 2017.

The maximum ground temperature at 50 cm reached 1.6°C in February 2015, the minimum was -17.0°C in July 2015. The highest TDD_{GT50} reached 26 C·day in 2015/16 and 2016/17, while no TDD_{GT50} value occurred in 2013/14. The mean ALT in the period 2011-2017 was 59 cm and it ranged between 51 cm (2013/14) and 66 cm (2016/17).

Air temperature is one of the most important factors affecting the active layer thermal regime in Antarctica (*e.g.* Cannone et al. 2006, Guglielmin 2006, Lacelle et al. 2016). Hrbáček et al. (2016a) analysed the relationship between air temperature and ground temperature in snow-free and snow-covered conditions showing the best correlation r = 0.90 for the snow-free conditions. Table 1 presents the results of a correlation analysis between air temperature and ground temperature at 5 cm for the summer period (DJF), winter period (JJA) and the whole calendar year for the particular periods between 2011 and 2015. We found a high variability in the cases of DJF (r = 0.57 to r = 0.81) and JJA (r = 0.59 to r = 0.87). The most stable correlations were calculated for the annual data, where correlation coefficients varied between 0.80 and 0.89.

	2011/12	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**
JJA	0.69	0.76	0.86	0.67	0.59	0.87
DJF	0.80	0.71	0.58	0.70	0.76	0.66
MAAT	0.89	0.81	0.88	0.80	0.86	0.85

Table 1. The correlation coefficients between the air and ground temperature for the winter months (JJA), summer months (DJF) and the year (MAAT).

Effect of snow cover on ground thermal regime

The effect of snow cover on active layer thermal regime is generally considered as very limited on James Ross Island as a result of irregular snow deposition and limited snow cover thickness (Hrbáček et al. 2016a). The premise of a low insulating effect of snow cover was confirmed by the analysis of freezing n-factor. The n-factor value only rarely dropped below 0.90 at the end of the freezing season suggesting very good atmosphere-ground interaction with only a thin layer of snow < 10 cm having a low insulating effect (*e.g.* Smith and Riseborough 2002).

The reanalysis of the published snow thickness and ground temperature amplitude data by Kňažková et al. (2020) during the winter of 2017 on the Abernethy Flats showed the occurrence of a more compact and thicker snow cover than was observed on JGM station in the period 2011-2013 (Hrbáček et al. 2016a). Snow cover persisted for 196 days with a mean depth of 19 cm and the maximum depth of 49 cm (Fig. 5). Despite these conditions, the mean ground temperature amplitude at 5 cm was 2.3°C and in 15 isothermal days, the amplitude dropped below 0.3°C only during the period with consistent snow cover. However, a well-pronounced insulating effect of snow, characterised by the isothermal regime of the ground, was observed by Kňažková et al. (2020) around the hyaloclastite breccia boulders. In this case, the natural obstacles of the boulders caused the formation of snow accumulation reaching up to 70 cm in thickness. The effect of such thick snow cover resulted in > 175 isothermal days in the ground (Fig. 5).

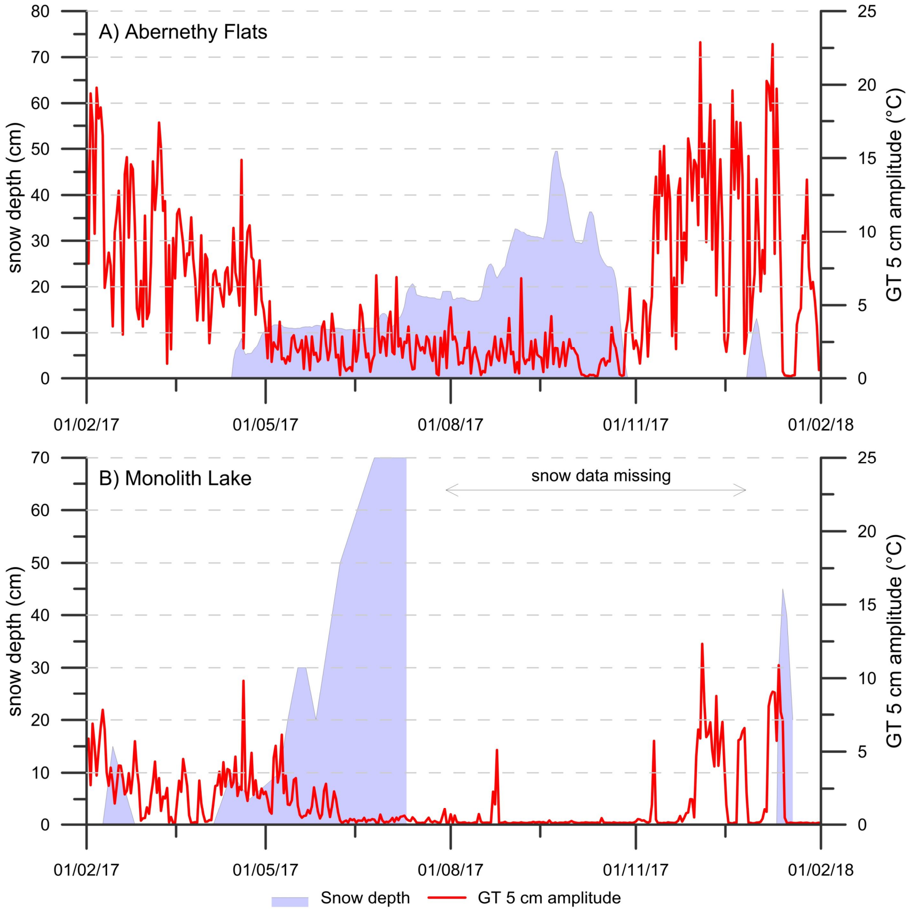

Fig. 5. The evolution of snow cover and ground temperature amplitude at 5 cm (GT 5 cm) at the Abernethy Flats and Monolith Lake sites in the period February 2017 to February 2018. Adapted from Kňažková et al. (2020).

Physical properties of the active layer

The prevailing grain size at the study sites is sand which accounts for 50 – 75% of ground samples (Table 2). Clay is the second dominant fraction at sites on Cretaceous sedimentary rocks while silt is more common at the sites on Neogene to Quaternary sediments (Table 2). The higher share of fine fractions in Cretaceous sedimentary rocks corresponds with their marine origin. The Whisky Bay sedimentary rocks out-cropping at the CALM site were deposited in a submarine fan or slope apron environment (Ineson 1986), where a mixture of terrestrial and marine pelagic derived particles can be expected. The Alpha Member of the Santa Marta Formation which out-crops at the Abernethy Flats site is a muddy sandstone originating from the continental shelf (Olivero et al. 1986). The Late Miocene sedimentary rocks of the Mendel Formation at the Berry Hill slope site are represented by a wide variety of terrestrial tills, glaciomarine sediments and open marine inner- to mid-shelf marine deposits (Nývlt et al. 2011), which results in high textural variability in the strata. The sand-rich Holocene marine sediments at the AWS-JGM site were accumulated in intertidal and supratidal (beach) environments, where most of the fine-grained material was already removed by the sedimentary processes associated with the deposition of these strata (Stachoň et al. 2014).

Site	Lithology	Sand	Silt	Clay	ω	λ	C
AWS-JGM	Holocene marine sediments	75%	15%	10%	10%	0.3	0.8
AWS-CALM	Cretaceous sedimentary rocks (Whisky Bay Fm.)	50%	23%	27%	18%	0.7	1.9
Berry Hill slopes	Neogene glacigenic, glaciomarine and marine sedimentary rocks (Mendel Fm.)	62%	22%	16%	22%	0.9	1.8
Abernethy Flats	Cretaceous sedimentary rocks (Alpha Member, Santa Marta Fm.)	53%	22%	25%	17%	0.5	1.5

Table 2. The ground physical properties at the study sites AWS-JGM, AWS-CALM, Berry Hill slopes and Abernethy Flats. *Notes*: ω - Gravimetric Moisture, λ - Thermal conductivity (W m^{-1} K^{-1}), C - Thermal capacity (MJ m^{-3} K^{-1}).

The moisture content of the soils generally corresponds well with the amount of clay and the proportion of fine pores. However, the highest soil water content was at the Berry Hill slope site, where snowmelt from the north-western slope of Berry Hill determines the water saturation of the active layer. Even small differences in moisture content can have an important effect on ground thermal properties (*e.g.* Farouki 1981, Abu-Hamdeh and Reader 2000). Thus, the highest thermal conductivity (0.9 W m^{-1} k^{-1}) was detected at the Berry Hill slopes. The lowest thermal conductivity (0.3 W m^{-1} k^{-1}) and the lowest thermal capacity (0.8 MJ m^{-3} k^{-1}) were recorded at the AWS-JGM site.

The role of lithology as the dominant factor affecting ground physical and thermal conditions has already been demonstrated for James Ross Island (*e.g.* Hrbáček et al. 2017a, b). In the study comparing the sites on the Abernethy Flats and the Berry Hill slopes, the role of lithology was established, based on the geochemical composition of the material, with a higher content of minerals with lower thermal conductivity on the Abernethy Flats (Hrbáček et al. 2017a). Laboratory analysis of soil thermal properties showed that the thermal conductivity on the Berry Hill slopes was almost twice that at Abernethy Flats (Table 2).

To demonstrate the role of lithology we compared $TDD_{GT5\ cm}$ and ALT observed during the thawing seasons 2014/2015 and 2015/16 at four study sites. The thickest active layer was detected at the site with the lowest $TDD_{GT5\ cm}$ (Berry Hill slopes, Table 3), where the highest thermal conductivity was detected (Table 2). On the contrary, the shallowest active layer was observed at the site with the highest $TDD_{GT5\ cm}$ (AWS-JGM) and the lowest thermal conductivity (Table 2).

The most pronounced effect of small-scale lithological differences was observed on CALM-S JGM (Hrbáček et al. 2017b). The probing of thawing depth showed pronounced differences between the part of the CALM-S JGM composed of the sediments of the Holocene marine terrace (representative site AWS-JGM) and the Cretaceous sedimentary rocks (representative site AWS-CALM). Beside the differences in ALT, diverse lithology also affected the moisture content in the ground. The surficial soil moisture measured on the CALM-S JGM showed a similar pattern to the distribution of ALT with the highest values (> 25 %) occurring in the southern part of CALM-S JGM composed of Whisky Bay Formation sedimentary rocks.

The position of the lithological boundary was confirmed using an electromagnetic conductivity meter (CMD), which showed differences between the sandy ground of the Marine terrace and the muddy sand of the Whisky Bay Formation (Fig. 6). It was not possible to detect, with any certainty, the boundary between the active layer and permafrost using CMD. However using GPR, it was possible to detect the position of the active layer/permafrost boundary clearly for most of the CALM-S area. GPR also showed the variability of the active layer thickness between the grid nodes in which mechanical probing was conducted (Fig. 6C, 6D). The signal attenuation between 0 and 10 m within the profile 2 (Fig. 6D) was caused by the muddy sand ground texture of the Whisky Bay Formation and higher soil moisture, in which the majority of the electromagnetic energy was lost in the conduction process.

Discussion

In the line with the important progress in the active layer monitoring since the International Polar Year in 2007–2009 (Vieira et al. 2010), several studies from the Antarctic Peninsula region have been published (Table 4). When compared to other sites in the Antarctic Peninsula region, the climate of James Ross Island is the coldest with MAAT and MAGT being 2–5°C lower. However, TDD_{GT} suggests that the summer conditions on James Ross Island are warmer than most other sites in the Antarctic Peninsula region. The ALT was highly spatially and temporally variable in all of the areas. On James Ross Island the ALT can reach up to 125 cm, but the most typical values were between 50 and 85 cm. At the sites in the western Antarctic Peninsula, the active layer was usually deeper than on JRI (Table 4).

We also analysed the relationship between air temperature and ground temperature at 5 cm. The high correlation between air and ground temperature points to a very good atmosphere-ground heat exchange. The lower correlations in winter months were presumably a consequence of more common occurrences of snow (*e.g.* Zhang and Stamnes 1998). Changes in the air-ground temperature relationship during the summer months can be affected by the variability of the summer solar radiation (*e.g.* Lacelle et al. 2016) and the depth of snow cover.

Snow cover is well known to be an important factor affecting the ground thermal regime (*e.g.* Zhang et al. 2005). In the Antarctic Peninsula region, the role of snow was well described from the South Shetlands (*e.g.* de Pablo et al. 2017, Oliva et al. 2017), where snow causes a shortening of the thawing season and a decrease in the ALT. A cooling effect of snow accumulations exceeding 60 cm was reported from Rothera Point (Guglielmin et al. 2014b). The effect of snow cover on ground thermal regime on JRI was less important even when the snow cover reached about 50 cm (Fig. 5A).

Study site	**$TDD_{GT5\ cm}$ (°C·day)**		**ALT (cm)**	
	2014/15	**2015/16**	**2014/15**	**2015/16**
AWS-JGM	456	506	63	65
AWS-CALM	418	478	86	87
Berry Hill slopes	321	382	89	89
Abernethy Flats	370	385	60	68

Table 3. The variability of thawing degree days at 5 cm depth ($TDD_{GT5\ cm}$) and active layer thickness (ALT) in period 2014/15 and 2015/16.

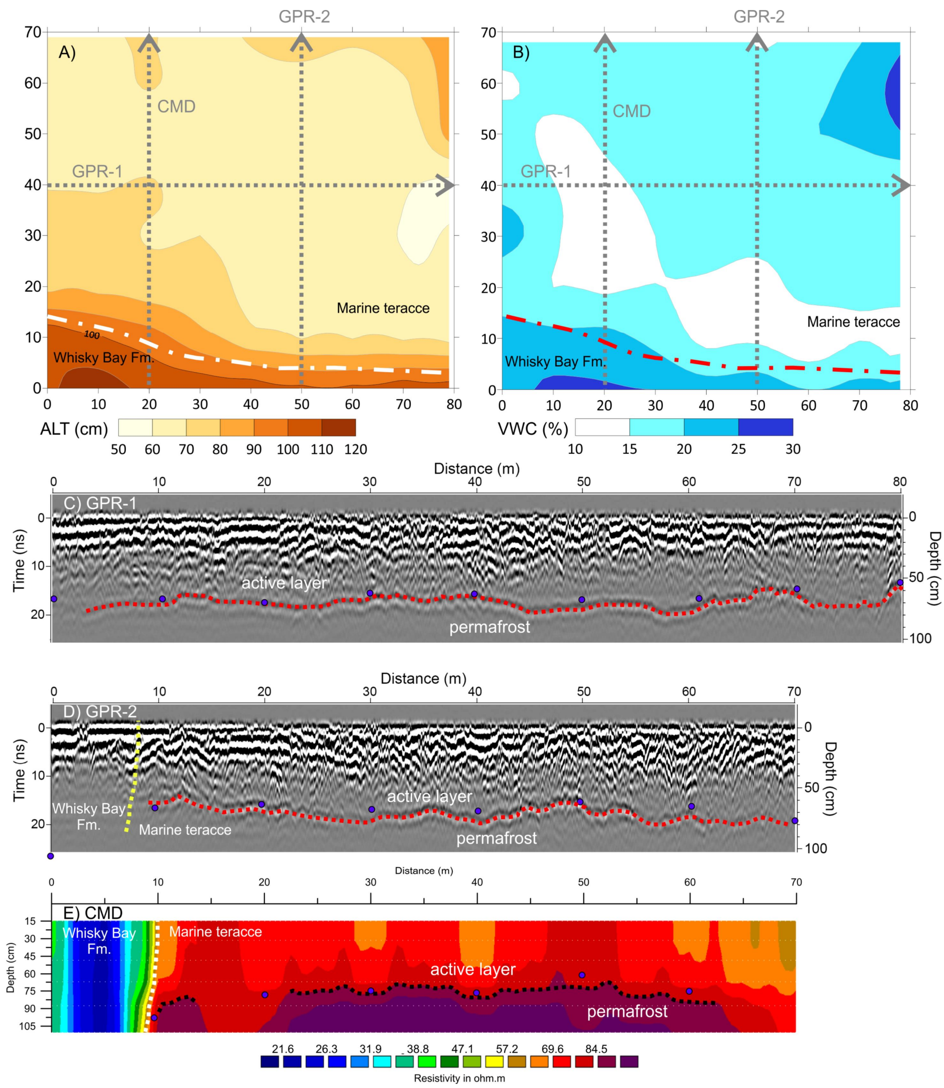

Fig. 6. The variability of the active layer thickness (ALT) and surficial soil moisture (VWC) on the CALM-S JGM site in 23 February 2018. The dotted lines and arrows indicate the position and direction of the ground penetrating radar profiles shown on panel C and D.

Study area	Site	Period	Coordinates	MAAT	MAGT	TDD_{GT5} (C·day)	ALT	References
James Ross Island	AWS-JGM	2011–2017	63° 48′ S 57° 52′ W	-6.9°C	-5.6°C	350 to 550	50 to 65 cm	Hrbáček et al. 2016a, 2017b, this study
	AWS-CALM	2014–2016	63° 48′ S 57° 52′ W	-7.2°C	-5.3°C	420 to 460	85 to 125cm**	Hrbáček et al. 2017b
	Abernethy Flats	2012–2014	63° 53′ S 57° 57′ W	-7.7°C	-6.6°C	270 to 370	52 to 64 cm	Hrbáček et al. 2017a
	Berry Hill slopes	2012–2014	63° 48′ S 57° 50′ W	-7.0°C	-6.1°C	300 to 320	85 to 89 cm	Hrbáček et al. 2016b, 2017a
Trinity Peninsula	Hope Bay	2009–2011	63° 44′ S 56° 59′ W	-5.5°C	N/A	100 to 140*	73 to 128 cm	Schaefer et al. 2017
King George Island	Low Head	2011–2015	62° 08′ S 58° 08′ W	-3.1°C	-1.6°C	280 to 440	98 to 106 cm	Almeida et al. 2017
	Bellingshausen	2006–2016	62° 12′ S 58° 56′ W	-2.3°C	-0.6°C	–	60 to 90 cm**	Hrbáček et al. in press
Livingston Island	Limnopolar Lake	2009–2012	62° 39′ S 61° 06′ W	-2.5°C	-0.8°C	110 to 290	>130 cm	de Pablo et al. 2014
	Byers Peninsula	2014	62° 37′ S 61° 00′ W	-2.7°C	-0.7 to -1.3°C	50 to 135	85 to 115 cm	Hrbáček et al. 2016b Oliva et al. 2017
Deception Island	Irizar	2011	62° 59′ S 60° 40′ W	-3.1°C	-2.2°C	–	80 to 100 cm	Goyanes et al. 2014, Hrbáček et al. in press
	Crater Lake	2006–2014	62° 59′ S 60° 42′ W	-2.8°C	-1.6°C	–	34 to 45 cm**	Ramos et al. 2017
Adelaide Island	Rothera Point	2009–2012	67° 33′ S 68° 07′ W	-3.7°C	-2.3 to -3.8°C	190 to 600	76 to 140 cm	Guglielmin et al. 2014

Table 4. The climate characteristics mean annual air temperature (MAAT), mean annual ground temperature at 5 cm (MAGT), thawing degree days at 5 cm (TDD_{GT5}) and active layer thickness (ALT) on the sites in Antarctic Peninsula region. *Notes*: * - at 10 cm depth, ** - maximum values probing within CALM-S site.

Therefore, the importance of snow cover as an insulating layer can be assumed to only determine ground thermal regime in special cases when the snow accumulation is also affected by local topography (Kňažková et al. (2020).

The last examined factors were related to the lithological and ground properties. The differences in the lithological properties seem to be the crucial factor affecting the ALT on JRI. However, only fragmentary data is available for the western Antarctica Peninsula except for Livingston Island (Correia et al. 2012) and Adelaide Island (Guglielmin et al. 2014b).

Conclusions

The main progress in active layer research on James Ross Island was achieved during the last 5 years. Our investigations of different factors affecting the active layer thermal regime and thickness suggest that lithology of a particular site is the most important parameter. Lithology significantly affects the grain-size distribution, which determines water storage capability of the ground as well as ground thermal properties. Notable progress was also achieved in the study of effects of snow cover on the active layer thermal regime. In the initial study, only a limited snow cover effect was proposed, whereas the recent data indicates snow may have some insulating effect on the ground thermal regime on James Ross Island. However, the presence of snow is strongly dependent on the local topography and the occurrence of specific landforms enabling snow accumulation.

Upcoming active layer research should focus more closely on the bio-geochemical properties of the ground and their relationship to the ground physical properties, lithology and topography. Another challenge is using empirical models for filling the gaps in the datasets and the reconstruction of the ground thermal regime and active layer thickness. The current and upcoming results from James Ross Island, as the largest ice-free area in the region, will also contribute to an improvement in the overall understanding of active layer dynamics and permafrost soil functioning in Antarctica.

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