Water temperature regime of selected lakes on James Ross Island during 2015 austral summer

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Abstract

Five lakes on the northernmost tip of James Ross Island (JRI), Ulu Peninsula, were selected to study their water temperature regime and relationship to atmospheric factors. Different genetic types of lakes were selected to cover not only influence of atmospheric parameters but also the morphology of lakes. Water temperature of all lakes showed strong similarities in the reaction to atmospheric factors no matter its genetic type or morphological properties, which were only second order factors shaping the general trends into more individual temporal patterns. All lakes are characterised by strong diurnal regime with maximum temperatures in late afternoon and minimum early morning. Most stable conditions were found in Monolith Lake and Triangular Lake, the first one with the biggest volume and regular inflow and outflow of water, the second one with semi-permanent ice cover protecting the water column from larger fluctuations caused by atmospheric factors. The most unstable environment was found in Shallow Lake, small shallow temporary lake with variable water level. Spatio-temporal issues of temperature relationships between water body and the terrestrial environment were shown with IR camera timelapse shooting on the example of Shallow Lake.

Key words: lakes, water temperature, James Ross Island, atmospheric influences

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Introduction

Lake ecosystems represent most significant hotspots of life in the Antarctic terrestrial environment (Vincent et Laybourn-Parry 2008). They provide liquid water as a necessary condition for life in the often arid, almost desert, environment. Therefore, it is essential to monitor and observe physico-chemical conditions of lakes and also their biota systematically. At the moment, the question of long term climate trends arises (*e.g.* Vaughan et al. 2003, Turner et al. 2005) and lake ecosystems are rather

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reliable and robust indicators of environmental changes. Due to systematic monitoring, it is possible to capture these long-term trends.

James Ross Island (JRI) and specifically Ulu Peninsula is one of the most important ice free areas in Antarctica representing some 1.2% of ice free areas in the whole Antarctica. More than half of the presently ice-free surfaces on JRI (312 km^2; 12.5% of JRI total area) are located on the Ulu Peninsula ([1] - BAS 2005). This vast area and relatively old deglaciated surfaces resulted in evolution of large number of lake ecosystems. The origin of some lakes has been dated to more than a thousand years ago (*e.g.* Björck et al. 1996) with possible origin of some lakes even earlier as the beginning of deglaciation of northern JRI is dated to 12.9 ± 1.2 ka BP (Nývlt et al. 2014). Many lakes were connected with glacier environment in time of their origin or are connected with glaciers even up to present (proglacial lakes, kettle lakes). The diurnal regime of atmospheric temperature and radiation is relatively well developed due to the position of study area on 63° 50´ S. The mean annual air temperature is -6.8°C (2006–11) (Láska et al. 2012) and mean daily temperatures above 0°C typically occur only for 2 months each summer (December–January), with hourly maximum and minimum values of 10°C and -5°C, respectively (Láska et al. 2011). This results in large variation in lake water temperature as well. Lakes on JRI were studied in the past especially for their paleoenvironmental role in the ecosystem (*e.g.* Björck et al. 1996, Ingólfsson et al. 1992, Lirio, unpublished data), also as an important environment for algae and cyanobacteria (*e.g.* Komárek et al. 2008, 2012; Strunecký et al. 2012, Váczi et Barták 2011a). An important part of the work has been done on diatoms that can serve as paleoindicators of environmental changes (*e.g.* Kopalová et al. 2011, 2013; Zidarova et al. 2009, 2016; van de Vijver et al. 2010).

According to Nedbalová et al. (2013), where the only physico chemical description of the lakes has been made, the lakes of Ulu Peninsula could be divided into six genetic types (the lakes included in the present study are given in parantheses): a) stable shallow lakes on higher-lying levelled surfaces; b) shallow coastal lakes (Shallow Lake); c) stable lakes in old moraines (Monolith and Phormidium lakes); d) small unstable lakes in young moraines (Bibby Lake); e) deep cirque lakes; f) kettle lakes (Triangular Lake). A comparison of temperature records between two lakes on JRI has been published by Váczi et al. (2011b). Hydrological dynamics and suspended sediment transport through water streams on JRI are discussed in Kavan et al. (2017). This can have a significant impact on physico-chemical properties of lakes as relatively large part of lakes are fed by rivers and streams.

Material and Methods

Five lakes were selected to cover various lake types at different localities within the Ulu Peninsula on JRI. Location of the studied lakes is presented in Fig. 1. Basic morphometric characteristics are summarised in Table 1. Temperature was measured by automatic temperature sensors Minikin T (EMS Brno, Czech Republic; accuracy ± 0.15°C) in Triangular Lake, Monolith Lake, Shallow Lake. DipperLog (Heron Instruments, Dundas, Canada) was used in Bibby Lake and Phormidium Lake. All localities were measured in 1-hour interval, sensors were deployed in 20 cm depth or as deep as possible where shallower water.

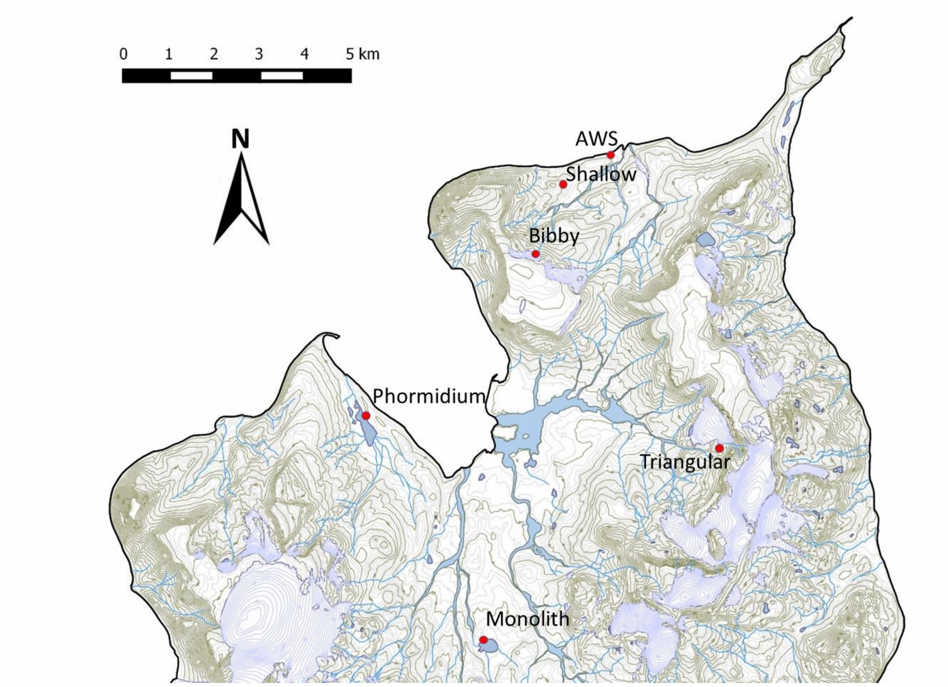

Fig. 1. Study area, location of selected lakes and automatic weather station (AWS) based on CGS (2009 - [2]).

In addition to water temperature measurement in Phormidium Lake an additional sensor (Minikin T, EMS Brno) was deployed some 1 km upstream the inflow to compare temperature regimes between stream and lake environment.

Meteorological data were derived from the automatic weather station (AWS) located in the vicinity of Johann Gregor Mendel station at 10 m a.s.l.. Air temperature was measured at 2 m above ground using EMS 33 sensor (accuracy ± 0.15°C; EMS Brno, Czech Republic). Air pressure and global radiation were measured using a TMAG 518 N4H barometer (accuracy ± 0.5 hPa; CRESSTO, Czech Republic) and an EMS11 radiometer (calibration error <7%; EMS, Brno, Czech Republic).

Apart from the temperature regime, manual discharge measurements on the outflow of Phormidium Lake were also carried out (FlowTracker ADCP handheld device, YSI SonTek, San Diego, USA) together with automatic hydrostatic pressure/ water level observations (DipperLog, Heron Instruments, Canada, accuracy ± 0.15°C and ± 0.05% for hydrostatic pressure measurements). These were then used to calculate the flow discharge curve and continuous time series of outflow discharge was constructed on this basis.

Spatial and temporal thermal properties of Shallow Lake during a day phase were studied using an IR thermal camera (Flir E6, Flir systems, Nashua, USA, accuracy < 0.06°C) on February 14th 2015. A 30 minute interval of recording has been used to capture all important daily phases of lake water temperature and surface temperature around the lake and their interactions. The emissivity was set up to 0.95 for all the pictures and the study design was similar as described in Cardenas et al. (2014).

lake	GPS S	GPS W	altitude (m a.s.l.)	lake area (m²)	maximal depth (m)	volume (m³)
Triangular	63°51'39.00"	57°50'48.71"	169	2970	2.0 A	3564
Bibby	63°48'52.83"	57°56'14.18"	250	7439	2.7	7880
Phormidium	63°51'8.31"	58° 0'4.36"	10	158100	0.3	18220
Monolith	63°53'47.28"	57°57'22.38"	67	93050	2.2	116600
Shallow	63°48'35.35"	57°55'6.90"	47	875	0.3	175

Table 1. Location and basic morphometric characteristics of studied lakes (modified from Nedbalová et al. 2013).

Results

Lake comparison

All lakes exhibited similar water temperature record with strong diurnal pattern (Fig. 2). Average temperature for all five lakes was rather variable and was affected by location of the lake and its morphometry. The lowest average temperature was found in Triangular Lake (0.3°C), which was almost completely ice covered, on the other hand, the highest temperature was in Phormidium Lake (5.8°C) thanks to its large area and low depth. All the lakes exhibited important diurnal regime (Fig. 3) with maximum differences ranging from 2.7°C in Triangular Lake (24th January) up to 16.2°C in Shallow Lake (5th February) within one day. The average daily variability was higher in shallow lakes, such as Phormidium or Shallow Lake (8.7°C and 8.3°C respectively), and much lower in Triangular and Bibby lakes (1.4°C and 2.8°C). Monolith Lake with large area and rather moderate depth (around 3 m) stays in the middle of the range with average daily variations of 4.6°C.

All lakes show a strong positive correlation of water temperature with basic atmospheric factors such as air temperature, surface temperature and radiation. These relationships are summarised in Table 2.

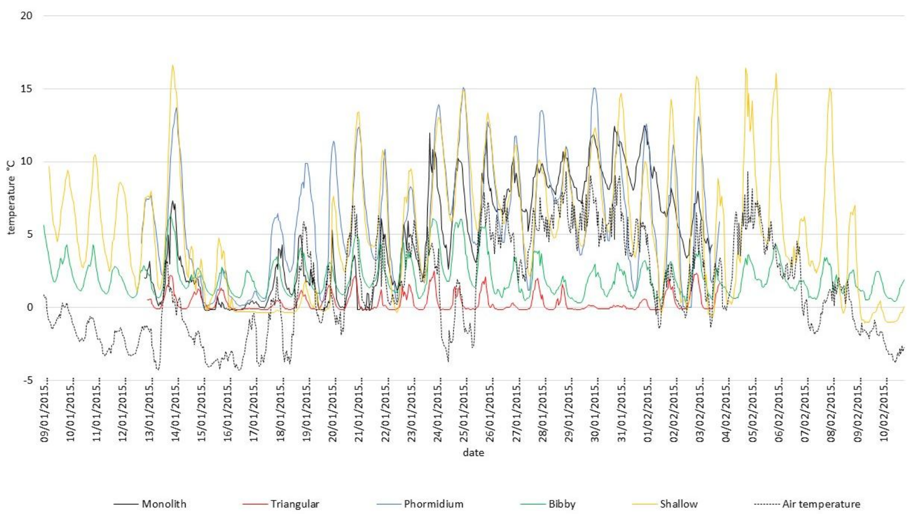

Fig. 2. Seasonal water temperature record in the selected lakes and air temperature.

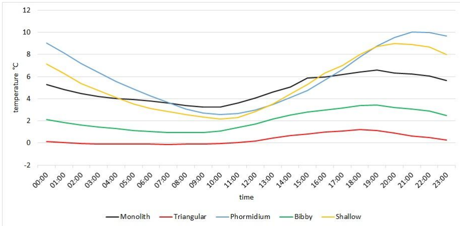

Fig. 3. Average diurnal water temperature regime calculated from January 14th to February 4th 2015.

Correlation was also calculated for lag time values (Table 2 b) and individual lag time for each variable is summarised in section c) of Table 2. The highest correlation is found between air temperature and water temperature in Monolith Lake (0.76), the lowest in Bibby Lake (0.26). Correlation between water temperature and radiation has an opposite pattern, where Bibby Lake shows the highest correlation (0.73) whereas only 0.28 for Monolith Lake.

a)

actual values	Monolith Lake	Triangular Lake	Bibby Lake	Shallow Lake	Phormidium Lake	Phormidium Stream
air temperature	0.73	0.21	0.25	0.48	0.47	0.48
surface temperature	0.69	0.43	0.49	0.54	0.49	0.65
radiation	0.18	0.61	0.60	0.23	0.07	0.53

b)

values with lag time	Monolith Lake	Triangular Lake	Bibby Lake	Shallow Lake	Phormidium Lake	Phormidium Stream
air temperature	0.76	0.21	0.26	0.55	0.59	0.50
surface temperature	0.73	0.43	0.53	0.68	0.74	0.69
radiation	0.28	0.67	0.73	0.55	0.62	0.68

c)

lag time (hours)	Monolith Lake	Triangular Lake	Bibby Lake	Shallow Lake	Phormidium Lake	Phormidium Stream
air temperature	2	0	1	3	4	1
surface temperature	2	0	1	3	4	1
radiation	3	1	2	4	5	2

Table 2. Correlation matrices of studied lakes' water temperature with basic atmospheric variables (Phormidium Stream added for comparison); a) correlation of actual values; b) best correlation coefficients with lag time; c) lag times (in hours) where the best correlation was found.

Phormidium Lake and Stream

The differences in temperature regime of the Phormidium Lake and Phormidium Stream on its inflow to the lake were observed (Fig. 4). In general, about 2 hours shift in average diurnal regime of water temperature was recorded. The stream temperature reacted more quickly than the temperature in the lake leading to more variable temperature regime often dropping down to zero or even sub-zero temperatures during night and increasing above 16°C during the day time peaks. The average diurnal temperature regime varied from zero up to 8°C for inflow and from 2°C to 10°C in case of the lake environment.

Rating curve was constructed from 7 manual discharge measurements and used for reconstruction of discharge during the study period (Fig. 5a). Discharge on outflow of the lake was found to be relatively stable ranging from almost 0 $m^3 s^{-1}$ during the freezing events up to almost 0.5 $m^3 s^{-1}$ during the high temperature/radiation days. Two important low flow events were observed. One at the beginning of the study period accompanied by sudden drop of water temperature (also by few consecutive days of below zero air temperatures), the second one at the end of the study period without any important drop of water temperature. In the meantime, the discharge at the lake outflow was oscillating around 0.4 $m^3 s^{-1}$ with rather stable conditions independently on the water temperature parameters (Fig. 5b).

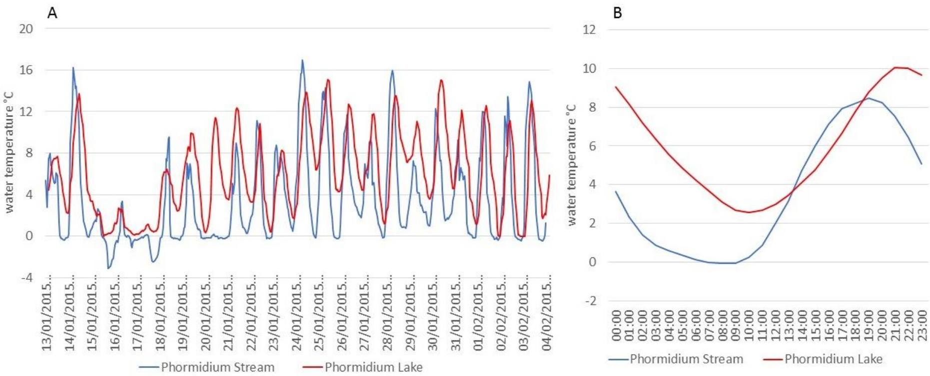

Fig. 4. Seasonal water temperature record (a) and average diurnal regime of Phormidium Stream and Phormidium Lake (b) from January 13th to February 4th 2015.

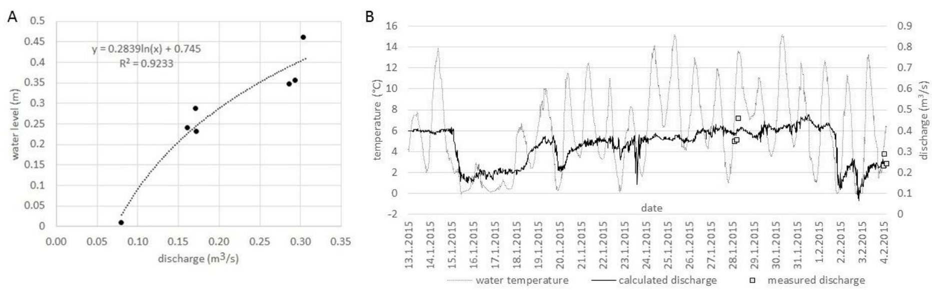

Fig. 5. Discharge from Phormidium Lake **A**) rating curve for Phormidium Lake outlet; **B**) discharge and water temperature time series together with manually measured discharge.

Shallow Lake and surrounding as seen by IR camera

One day survey with IR camera has been carried out at the Shallow Lake to provide information on thermal properties of the lake and its direct surroundings. Temperature of both lake and rock environment was increasing accordingly to the increase of air temperature and more importantly of global radiation. All basic atmospheric variables together with chosen IR pictures are demonstrated in Fig. 6. The daily trend was, however, interrupted around 15:00 UTC by sudden change in weather conditions lead by important rain event. This has completely overcome the effect of air temperature and incoming radiation as the wet surface became rather uniform in its emissivity. The interactions between different surfaces of lake and its surroundings appear rather negligible in such circumstances.

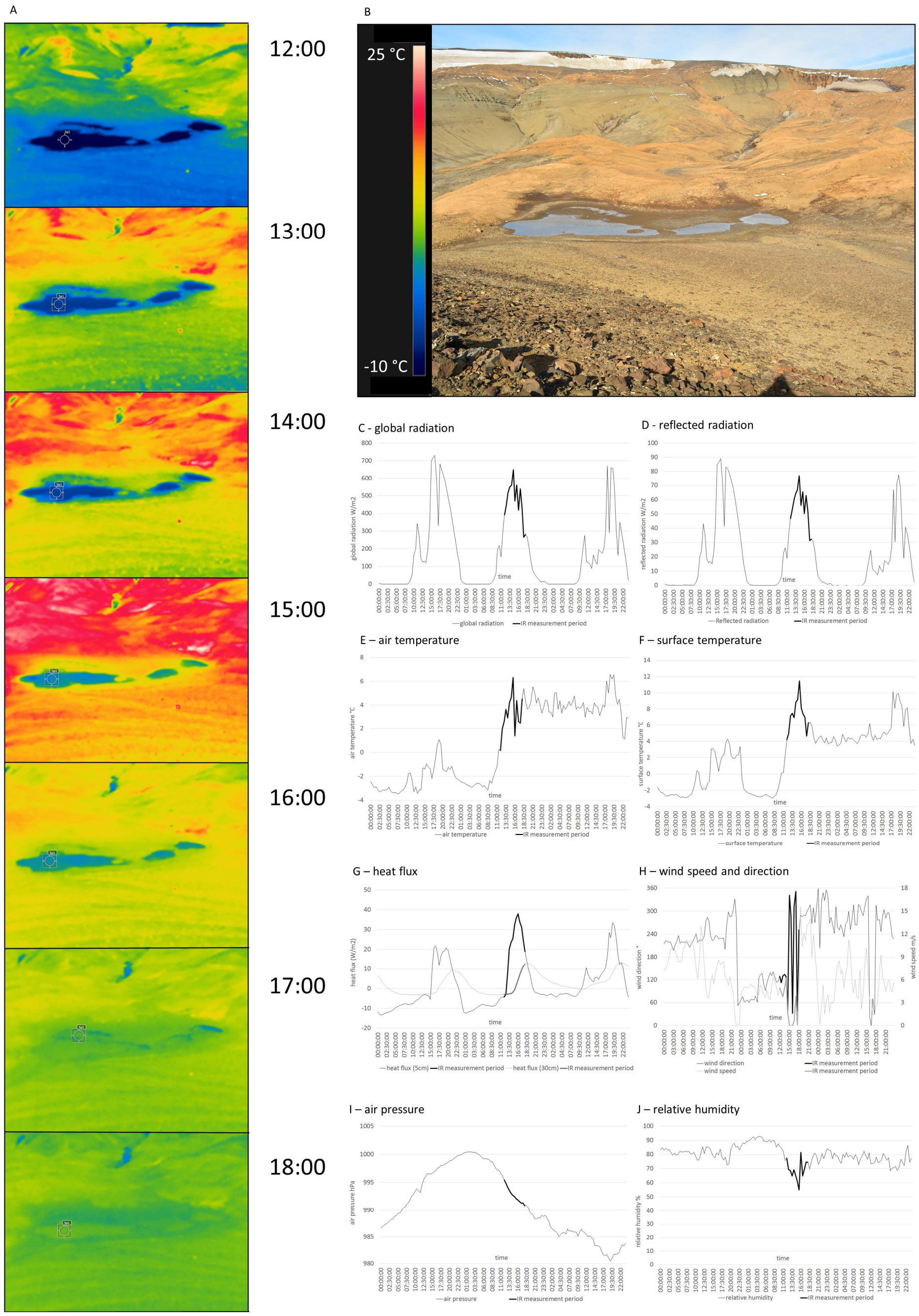

Fig. 6. Spatio-temporal thermal properties of Shallow Lake on February 14th (IR camera captures) compared with detailed atmospheric properties during the period February 13th – 15th 2015; A – IR camera captures of Shallow Lake; B – Shallow Lake in visible spectrum; C – global radiation; D – reflected radiation; E – air temperature; F – surface temperature; G – heat flux; H – wind speed and direction; I – air pressure; J – relative humidity.

Discussion

As shown above, all lakes have specific thermal characteristics corresponding well to their morphology and location. Lowest average temperature was found in Bibby and Triangular lakes. These are small unstable lakes in young moraines that are relatively deep and located at higher elevations. On the other hand, the highest average temperatures were found in Shallow Lake and Phormidium Lake where the relatively large area combined with its shallow depth profile makes them a perfect environment for using the solar energy to heat up quickly during the day phase. Monolith Lake with its approximate maximal depth of 3 metres and relatively large area stands in the middle when considering thermal properties. The general trend of water temperature in all lakes is similar and corresponds well to overall atmospheric conditions in the region (*see* Fig. 2 for comparison with air temperature). However, as demonstrated on example of these five lakes, seasonal temperature record reflects also well the specific conditions of each individual lake – *e.g.* morphometric characteristics, altitude or flow regime. Even though all the lakes are located quite close to each other, their individual temperature pattern is rather unique following its unique characteristics. Similar unique pattern with common general trends was shown in comparison for two lakes in Váczi et al. (2011b) or Nedbalová et al. (2013) from different localities on JRI. Similar general pattern of seasonal lake water temperature modified by individual lake properties and altitude was shown for ten lakes of a small alpine region as well (Livingstone et al. 1999).

Timing of the daily maximum peak temperature reflects also the morphology of each lake. The connectivity of lakes with hydrologic systems also plays an important role in water temperature properties (Arp et al. 2006, 2012). Important inflow of water into Phormidium Lake caused delay in timing of daily temperature maximum that is shifted towards 22:00 UTC in average (*see* Fig. 3). Heated water from upstream is flowing into the lake with a delay and thus shifting the daily phase of about two to three hours in comparison with not connected lakes such as Shallow or Triangular Lakes. This has an important effect on productivity and thermal optima for aquatic life (Baker 2016).

The source water that feeds the lake plays an important role as well. It is supposed that more important snow melt at the beginning of the season supports lakes even through the night phase (if temperatures are not significantly below zero) causing less important variability in lake inflow. When the snow cover and seasonal snowpatches are depleted at the end of the season, main source of the lake water become thawing permafrost. This is of course accompanied by generally lower inflow of water and reduced variability as the water path is longer through the substrate. This should have an effect to water temperature as well, however the timeseries used for this study is not long enough to prove this general pattern.

Atmospheric factors influencing water temperature regime are illustrated in the correlation matrices (Table 2) and divides the studied lakes in a similar way as the average water temperatures. Triangular and Bibby Lakes water temperature show strong correlation with radiation and only week with air temperature on one hand. On the other hand, water temperature in Shallow and Phormidium Lakes is mainly driven by surface temperature. Monolith Lake stays apart with air temperature as a leading factor. Radiation being a principal factor influencing water temperature regime in Bibby and Triangular is probably caused by semipermanent ice cover isolating water body from direct influence of air temperature and dominantly reacting to radiation going through the thin ice layer. This corresponds to almost no lag time in reaction to radiation

(1 hour for Triangular Lake and 2 hours for Bibby Lake).

The relationship between lake and its surroundings was studied using IR camera. In general, the lake environment thanks to its physical properties has larger inertia reacting more smoothly to actual atmospheric conditions than surface in its surroundings. Obviously, the setting of emissivity to 0.95 corresponds well to measurement of water environment and makes the absolute temperature values of surrounding surface not reliable enough. However, the general insight into the thermal properties and its dynamics in time and space are well illustrated (Fig. 6). Morning phase starting at 9:00 local time (12:00 UTC) demonstrates the cool surface of both lake and its surroundings. As the sun continues to shine the bare surface heat up quickly whereas the water body is heating smoothly. The typical afternoon phase was interrupted by sudden rain event as visible in the pictures from 17:00 UTC and further, leading to uniform surface temperature of the whole scene.

To conclude, the seasonal water temperature records of five lakes of different origin is valuable especially for possible comparison to assess the effects of changing climate in the future. Such records can help to understand behaviour of freshwater ecosystems throughout the period of abrupt climate changes (Castendyk et al. 2016). This can affect not only lakes themselves, but also their biota as shown for example in Nedbalová et al. (2017).

References

ARP, C. D., GOOSEFF, M. N., BAKER, M. A. and WURTSBAUGH, W. (2006): Surface-water hydrodynamics and regimes of a small mountain stream–lake ecosystem. *Journal of Hydrology*, 329: 500-513.

ARP, C. D., WHITMAN, M. S., JONES, B. M., KEMNITZ, R., GROSSE, G. and URBAN, F. E. (2012): Drainage network structure and hydrologic behavior of three lake-rich watersheds on the Arctic coastal plain, Alaska. *Arctic, Antarctic, and Alpine Research*, 44: 385-398.

BAKER, M. A., ARP, C. D., GOODMAN, K. J., MARCARELLI, A. M. and WURTSBAUGH, W. A. (2016): Stream-Lake interaction: Understanding coupled hydro-ecological systems. 321–348. In Jones, J. B. & Stanley, E. (2016): Stream ecosystems in a changing environment. pp 548.

BJÖRCK, S., OLSSON, S., ELLIS-EVANS, C., HÅKANSSON, H., HUMLUM, O. and DE LIRIO, J. M. (1996): Late Holocene palaeoclimatic records from lake sediments on James Ross Island, Antarctica. *Palaeogeography Palaeoclimatology Palaeoecology*, 121: 195–220.

CARDENAS, M. B., DOERING, M., RIVAS, D. S., GALDEANO, C., NEILSON, B. T. and ROBINSON, C. T. (2014): Analysis of the temperature dynamics of a proglacial river using time-lapse thermal imaging and energy balance modelling. *Journal of Hydrology*, 519: 1963–1973.

CASTENDYK, D. N., OBRYK, M. K., LEIDMAN, S. Z., GOOSEFF, M. and HAWES, I. (2016): Lake Vanda: A sentinel for climate change in the Mc-Murdo Sound Region of Antarctica. *Global and Planetary Change*, 144: 213-227.

INGÓLFSSON, Ó., HJORT, C., BJÖRCK, S. and SMITH, R. I. L. (1992): Late Pleistocene and Holocene glacial history of James Ross Island, Antarctic Peninsula. *Boreas*, 21: 209-222.

KAVAN, J., ONDRUCH, J., NÝVLT, D., HRBÁČEK, F., CARRIVICK, J. L. and LÁSKA, K. (2017): Seasonal hydrological and suspended sediment transport dynamics in proglacial streams, James Ross Island, Antarctica. *Geografiska Annaler: Series A, Physical Geography*, 99: 38-55.

KOMÁREK, J., ELSTER, J. (2008): Ecological background of cyanobacterial assemblages of the northern part of James Ross Island, Antarctica. *Polish Polar Research*, 29: 17-32.

KOMÁREK, J., ELSTER, J. and KOMÁREK, O. (2008): Diversity of the cyanobacterial microflora of the northern part of James Ross Island, NW Weddell Sea, Antarctica. *Polar Biology*, 31: 853-865.

KOMÁREK, J., NEDBALOVÁ, L. and HAUER, T. (2012): Phylogenetic position and taxonomy of three heterocytous cyanobacteria dominating the littoral of deglaciated lakes, James Ross Island, Antarctica. *Polar Biology*, 35: 759-774.

KOPALOVÁ, K., NEDBALOVÁ, L., DE HAAN, M. and VAN DE VIJVER, B. (2011): Description of five new species of the diatom genus Luticola (Bacillariophyta, Diadesmidaceae) found in lakes of James Ross Island (Maritime Antarctic Region). *Phytotaxa,* 27: 44-60.

KOPALOVÁ, K., NEDBALOVÁ, L., NÝVLT, D., ELSTER, J. and VAN DE VIJVER, B. (2013): Diversity, ecology and biogeography of the freshwater diatom communities from Ulu Peninsula (James Ross Island, NE Antarctic Peninsula). *Polar Biology,* 36: 933-948.

LÁSKA, K., BARTÁK, M., HÁJEK, J., PROŠEK, P. and BOHUSLAVOVÁ, O. (2011): Climatic and ecological characteristics of deglaciated area of James Ross Island, Antarctica, with a special respect to vegetation cover. *Czech Polar Reports,* 1: 49-62.

LÁSKA, K., NÝVLT, D., ENGEL, Z. and BUDÍK, L. (2012): Seasonal variation of meteorological variables and recent surface ablation / accumulation rates on Davies Dome and Whisky Glacier, James Ross Island, Antarctica. Geophysical Research Abstracts 14: EGU2012–5545.

LIVINGSTONE, D. M., LOTTER, A. F. and WALKER I. R. (1999): The decrease in summer surface water temperature with altitude in swiss alpine lakes: acomparison with air temperature lapse rate. *Arctic, Antarctic, and Alpine Research*, 31: 341-352.

NEDBALOVÁ, L., NÝVLT, D., KOPÁČEK, J., ŠOBR, M. and ELSTER, J. (2013): Freshwater lakes of Ulu Peninsula, James Ross Island, north-east Antarctic Peninsula: origin, geomorphology and physical and chemical limnology. *Antarctic Science,* 25: 358-372.

NEDBALOVÁ, L., NÝVLT, D., LIRIO, J. M., KAVAN, J. and ELSTER, J. (2017): Current distribution of the Antarctic fairy shrimp (*Branchinecta gaini*) on James Ross Island and Vega Island, north-eastern Antarctic Peninsula. *Antarctic Science,* doi: https://doi.org/10.1017/S0954102017000128.

NÝVLT, D., BRAUCHER, R., ENGEL, Z., MLČOCH, B. and ASTER TEAM (2014): Timing of the Northern Prince Gustav Ice Stream retreat and the deglaciation of northern James Ross Island, Antarctic Peninsula during the last glacial–interglacial transition. *Quarternary Research,* 82: 441-449.

STRUNECKÝ, O., ELSTER, J. and KOMÁREK, J. (2012): Molecular clock evidence for survival of Antarctic cyanobacteria (Oscillatoriales, *Phormidium autumnale*) from Paleozoic times. *FEMS Microbiology Ecology*, 82: 482-490.

TURNER, J., COLWELL, S.R., MARSHALL G.J., LACHLAN-COPE, T.A., CARLETON, A.M., JONES, P.D., LAGUN, V., REID P. and IAGOVKINA, S. (2005): Antarctic climate change during the last 50 years. *International Journal of Climatology*, 25: 279-294.

VÁCZI, P., BARTÁK, M. (2011a): Summer season variability of dissolved oxygen concentration in Antarctic lakes rich in cyanobacterial mats. *Czech Polar Reports*, 1: 42-48.

VÁCZI, P., BARTÁK, M., NEDBALOVÁ, L. and ELSTER, J. (2011b): Comparative analysis of temperature courses in Antarctic lakes of different morphology: Study from James Ross Island, Antarctica. *Czech Polar Reports*, 1 (2): 78-87.

VAN DE VIJVER, B., STERKEN, M., VYVERMAN, W., MATALONI, G., NEDBALOVÁ, L., KOPALOVÁ, K., ELSTER, J., VERLEYEN, E. and SABBE, K. (2010): Four new non-marine diatom taxa from the Subantarctic and Antarctic regions. *Diatom research*, 25: 431-443.

VAUGHAN, D. G., MARSHALL, G. J., CONNOLLEY, W. M., PARKINSON, C., MULVANEY, R., HODGSON, D. A., KING, J. C., PUDSEY, C. J. and TURNER, J. (2003): Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change*, 60, 243-274.

VINCENT, W. F., LAYBOURN-PARRY, J. (2008): Polar lakes and rivers. Oxford: Oxford University Press, 327 p.

ZIDAROVA, R., VAN DE VIJVER, B., MATALONI, G., KOPALOVÁ, K. and NEDBALOVÁ, L. (2009): Four new freshwater diatom species from Antarctica. *Cryptogamie Algologie*, 30: 295-310.

ZIDAROVA, R., KOPALOVÁ, K. and VAN DE VIJVER, B. (2016): Ten new Bacillariophyta species from James Ross Island and the South Shetland Islands (Maritime Antarctic Region). *Phytotaxa*, 272: 037-062.

Web sources / Other sources

[1] BAS (2005): Antarctic factsheet, geographical statistics. Available from: https://www.bas.ac.uk/wp-content/uploads/2015/05/factsheet_geostats_print.pdf

[2] CGS (Czech Geological Survey). (2009): James Ross Island – northern part. Topographic map, 1:25 000. Prague: Czech Geological Survey.