Polarforschung 85 (2), 117–118, 2015 (erschienen 2016)

Rapid Melting of Fast-Ice in the Buor-Khaya Bay

by Peter V. Bogorodski[1*], Alexander P. Makshtas[1*] and Vasily Y. Kustov[1]

Abstract: In this extended abstract data of Buor-Khaya Bay fast-ice radiation measurements and thermodynamic properties are presented and analysed. The thermo-metamorphic transformations of fast-ice, including rapid melting of its upper surface layer, and melt pond formation are described. The data of observations are compared with estimations of the melting snow cover evolution from a conceptual thermodynamic model.

Zusammenfassung: Dieser Beitrag beschreibt die Ergebnisse von Strahlungsmessungen und thermodynamischen Eigenschaften des Festeises der Buor-Khaya-Bucht im Laptewmeer. Es werden thermo-metamorphe Veränderungen von Festeis einschließlich der Schmelzprozesse der Oberflächenschicht sowie die Entwicklung von Schmelztümpeln beschrieben. Die Daten der Beobachtungen werden mit Ergebnissen eines konzeptionellen thermodynamischen Modells zur Abschätzunge der Schmelzentwicklung der Schneedecke verglichen.

INTRODUCTION

The exclusive role of melt ponds in sea ice melting indicates that a further progress in climate prediction in the Arctic is partly defined by the development of melt-pond parameterisations and its incorporation into general sea-ice models. Certain advancements in the solution of this problem are described by, e.g., Pedersen et al. (2009) and Flocco et al. (2010). Nevertheless, to ensure that parameterisations are realistic it is necessary to understand and prove the physical mechanisms of melt-pond formation and evolution. This is possible only on the basis of remote sensing or field observations. The latter investigations are regularly performed on fast-ice of the Tiksi Gulf near Hydrometeorological Observatory Tiksi during spring. Below, the results of field observations and numerical calculations with a conceptual thermodynamic model of fast-ice melting in late spring 2011 are presented. The period was characterised by rapid melt-pond formation. During 72 hours, the whole visible area of fast-ice with thickness exceeding 2 m was covered by a meltwater layer of 20–25 cm depth.

FIELD OBSERVATION

The observations were conducted at the Sogo Bay, the southwest part of the Tiksi Gulf at the northeastern coast of Yakutia in late spring to early summer 2011. The Sogo Bay with an area of about 16 km^2, a mean water depth of 3–4 m, and salinity from 5 to 10 PSU (practical salinity unit) is part of the Tiksi Gulf connected with the Buor-Khaya Bay, Laptev Sea. The area is covered with fast sea ice from late of October to early July. Mean ice thickness before beginning of melting is 2.2 m. The maximal thickness is up to 2.5 m.

RESULTS AND CONCLUSIONS

The albedo of melt ponds changes from 0.1 to 0.5 (Eicken et al. 2004) and is significantly smaller compared to the albedo of snow-covered and bare sea ice (0.84-0.87 and 0.6-0.65, respectively, Perovich 1996). Intensive absorption of solar radiation determines a specific role of melt ponds in the disintegration of sea ice. In spring 2011, extensive investigations of melt ponds evolution have been conducted on fast-ice of the Buor-Khaya Bay in the Laptev Sea. The results of field observations are presented in Figure 1. During May 28 to 29, 2011, a rapid increase of air temperature up to +12 °C took place. It led to the onset of snow cover melting accompanied by

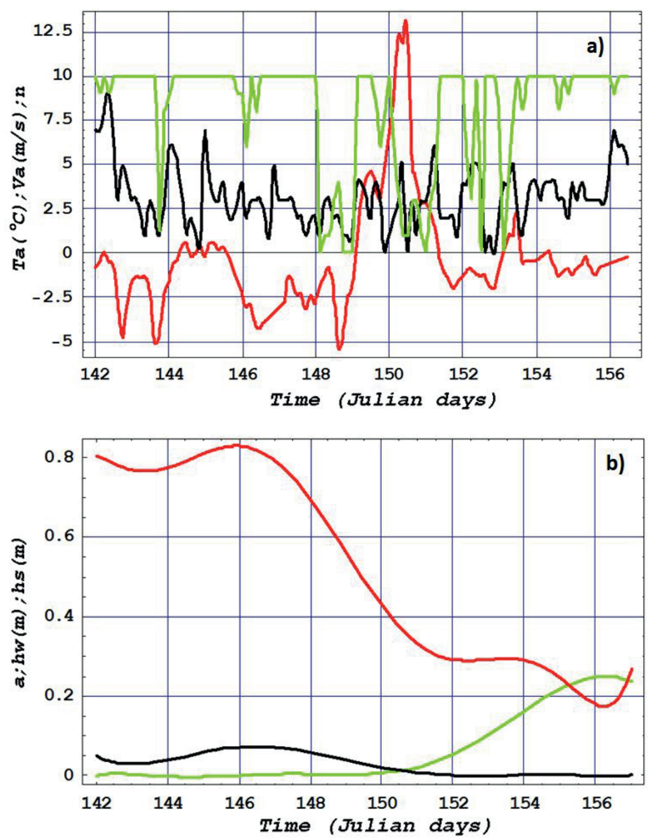

Fig. 1: Time series of (a): air temperature Ta (in °C) (red), wind velocity Va (in m/s) (black) and total cloudiness n (in 10/10 fraction) (green). (b): integral surface albedo a (red), snow thickness hs (in m) (black) and melt-pond depth hw (in m) (green).

Abb. 1: Zeitreihen (a): Lufttemperatur Ta (°C) (rot), Windgeschwindigkeit VA (in m/s) (schwarz) und Bewölkungsgrad n (in 10/10 Bedeckungsgrad) (grün). (b): integrale Oberflächenalbedo a (rot), Schneedicke hs (in Meter) (schwarz) sowie Schmelztümpel-Tiefe hw (in Meter) (grün).

doi:10.2312/polfor.2016.008

[1] Arctic & Antarctic Research Institute (AARI), St. Petersburg, Russia.
[*] Corresponding authors: <makshtas@yahoo.com>, <bogorodski@aari.ru>

This extended abstract was presented as an oral presentation at the International Conference "Our Climate – Our Future: Regional perspectives on a global challenge", 6–9 October 2014 in Berlin, Germany.
Manuscript received 01 June 2015; revised version 15 April 2016; accepted 28 April 2016.

a decrease of surface albedo from 0.8 to 0.25. The melt ponds formation started during May 30. During the next days, intensive surface melting continued, leading to melt ponds deepening and their subsequent joining into one pool. Practically during one day (May 31), the whole fast-ice surface in the visible area transformed to a giant melt pool with 20–25 cm depth.

For the description of the observed rapid fast-ice melting the conceptual thermodynamic model by Bogorodskii & Pnyushkov (2000) is used. The model describes different stages of fast ice evolution: melting without forming of molten zones at the upper surface; melting of snow, melting of ice at the upper and bottom boundaries. The model is based on the heat diffusion equation and uses the following approximations: linear temperature profiles in snow and ice (assumption of quasi-stationarity); the temperatures of outer interfaces of sea ice correspond to the temperatures of thermodynamic equilibrium; shortwave radiation is absorbed by snow – ice upper surface, seepage is prescribed. The first assumption leads to the system of equations of the heat and mass balances of the upper and lower boundaries of sea ice. Boundary conditions and parameterisations of energy exchange processes on the outer interfaces are the same for all stages of ice transformation. The results of the modelling for different seepages are presented in Figure 2a.

Figure 2 illustrates that the seepage rate could be the important parameter for the description of melt-pond formation. Unfortunately, its values are still questionable. Taylor & Feltham (2004) proposed different seepage rate values for low (0-1.5 cm/day), average (1.5-2.0 cm/day), and high (>2.0 cm/day) sea-ice melting, but they specify its constant magnitudes for the whole period of melt-pond formation. However, for the initial period of sea-ice melting it is difficult to imagine that the drainage rates are constant, because during the formation of drainage channels the freezing of infiltrated water takes place under negative temperatures within the ice cover (Tyshko et al. 2000). For this reason we determine seepage rates as linearly increasing from 0 cm/day at the beginning of melt-pond formation to a maximum value of 0 cm/day, 1 cm/day and 2 cm/day during the last day of observations. The comparison of Figures 1b and 2a show the best agreement between observed and calculated melt pond depth for seepage equal 0.

Using the data on melt-pond depth evolution, it is possible to compare estimations of the relative area covered with melt ponds, based on parameterisation as developed by Pedersen et al. (2009), with observational data. The results of the calculations with parameterisation, using our estimates of melt pond depth for different seepage rates, together with data of direct observations are shown in Figure 2b. The time lag of the relative area calculated with parameterisation is approximately 5 days. The reason of such delay could be due to the differences of the surface topography of sea-ice cover (flat or ridged), forming under different weather conditions. A full paper on this topic is published by Makshtas et al. (2012) in Russian.

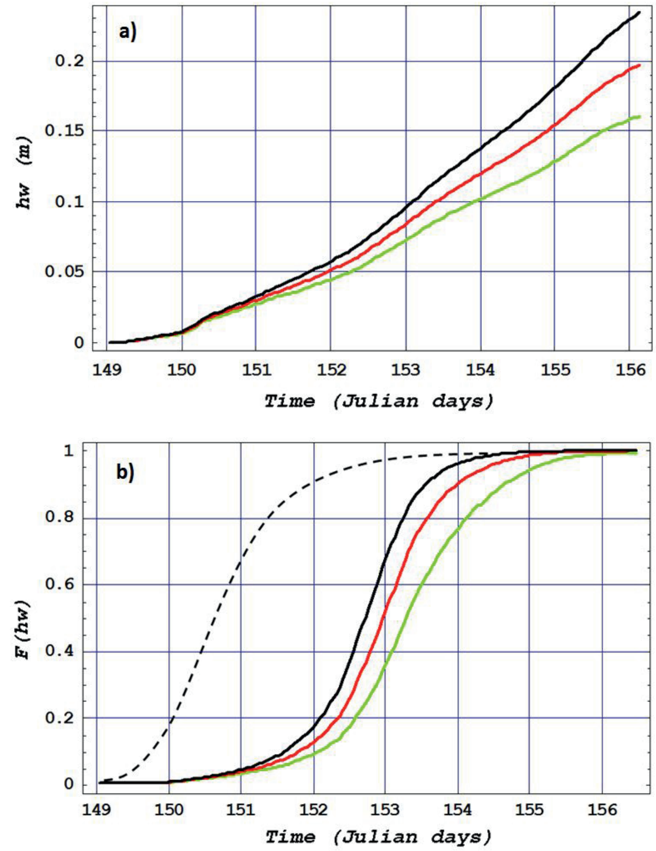

Fig. 2: Temporal evolution of (a): melt pond depth hw for seepage rates 0 cm/day (black), 1 cm/day (red), and 2 cm/day (green); (b): relative area occupied by melt ponds according to observational data (dashed line) and calculated with parameterisation (Pedersen et al. 2009) for seepage rates 0 cm/day (black), 1 cm/day (red) and 2 cm/day (green).

Abb. 2: Zeitliche Entwicklung (a): Schmelztümpel-Tiefe hw für Sickerraten von 0 cm/Tag (schwarz), 1 cm/Tag (rot) und 2 cm/Tag (grün); (b): der durch Beobachtungsdaten (gestrichelte Linie) abgeschätzten relativen Schmelztümpel-Fläche im Vergleich zu der mit Hilfe der Parametrisierungen nach Petersen et al. (2009) berechneten Fläche für Sickerraten von 0 cm/Tag (schwarz), 1 cm/Tag (rot) und 2 cm/Tag (grün).

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basis Research (Project 14-05-00408), Roshydromet (Project 14-05-00408), and the Otto Schmidt Laboratory (OSL). The authors would like to thank Aleksey Marchenko and an anonymous reviewer for helpful comments and suggestions on an earlier version of this extended abstract.

References

Bogorodskii, P.V. & Pnyushkov, A.V. (2011): Influence of melt pond on the formation of the multiyear sea ice cover.- Oceanology 51: 224-231 (in Russian).

Eicken, H., Grenfell, T.C., Perovich, D.K., Richter-Menge, J.A. & Frey, K. (2004): Hydraulic controls of summer Arctic pack ice albedo.- J. Geophys. Res. 109(C08007), doi: 10.1029/2003JC001989.

Flocco, D., Feltham, D.I. & Turner, A.K. (2010): Incorporation of a physically based melt pond scheme into the sea ice component of a climate model.- J. Geophys. Res. 115 (C08012), doi: 10.1029/2009JC005568.

Makshtas A.P., Bogorodsky P.V. & Kustov V.Yu. (2012): Quick melting of fast ice in the Sogo Bay (Tiksi Bay) in spring 2011.- Problemy Arctic and Antarctic 1(91): 37-47 (in Russian).

Pedersen, C.A., Roeckner, E., Lüthje, M. & Winter J.-G. (2009): A new sea ice albedo parameterization including melt ponds for ECHAM5 GCM.- J. Geophys. Res. 114 (D08101) doi: 10.1029/2008JD010440.

Perovich, D.K. (1996): The optical properties of sea ice.- Monogr. Ser. 96-1, Cold Region Res. and Eng. Lab., Hanover, N.H.

Taylor, P.D. & Feltham, D.L. (2004): A model of melt pond evolution on sea ice.- J. Geophys. Res. 109 (C12007), doi: 10.1029/2004JC002361.

Tyshko K.P., Cherepanov, N.V. & Fedotov V.I. (2000): Kristallicheskoe stroenie morskogo ledyanogo pokrova.- St.Petersburg, Gidrometeoizdat 1-66 (in Russian).