Aufeis of the North-East of Russia in changing climate

*Olga Makarieva[1,2], Andrey Shikhov[3], Nataliia Nesterova[2,4], Andrey Ostashov[2]

[1]Melmikov Permafrost Institute, Yakutsk, 677010, RUSSIA
[2]St.Petersburg State University, St. Petersburg, 199034, RUSSIA
[3]Perm State University, Perm, 614990, RUSSIA
[4]State Hydrological Institute, St. Petersburg, 199053, RUSSIA
**omakarieva@gmail.com*

ABSTRACT

The distribution of aufeis in the North-East of Russia in current climate is being studied and compared to the period of 70 years ago. Landsat images for the period of 2013-2017, topographic maps and historical Cadastre of aufeis (1958) have been used to compile spatial geodatabase of aufeis in the basins of thee large rivers of permafrost – the Yana, Indigirka and Kolyma (total area more than 1.2 mln. km^2). The satellite-derived total area of aufeis is 2167 km^2 of 3429 aufeis fields, while historical Cadastre (1958) contains data of 2561 aufeis fields with total area of 4009 km^2. The comparison of recent and historical data has shown that aufeis conditions have changed since the mid-20th century indicating the changes of hydrological regime and permafrost conditions in studied area.

KEYWORDS

taryn-aufeis; the North-East of Russia; climate change; groundwater; streamflow; surface and ground water interactions

1. INTRODUCTION

Giant aufeis are ice fields that occur annually in the river valleys as a result of layer-by-layer freezing of streamed groundwater (Figure 1). According to rough estimates, the area of groundwater aufeis in Siberia and the Far East is more than 42, 000 km^2 (Alekseev 1987).

The changes of streamflow are observed in the permafrost domain. Recent studies presented the rates of streamflow changes but the reasons of hydrological regime transformation are still discussed (Tananaev et al. 2016; Makarieva et al. 2019a). Hydrological role of aufeis is the seasonal redistribution of groundwater component of river streamflow. Aufeis dynamic can be traced by remote-sensing data and used as the indicator of the changes of the surface and groundwater interactions in poorly-gauged permafrost basins (Yoshikawa et al. 2007; Makarieva et al. 2019a). Aufeis is the important element of water balance in cold regions (Ensom et al. in preparation).

The aim of the study was to develop the GIS database of recent aufeis fields in three basins of large Arctic rivers of the North-East of Russia – the Yana, Indigirka and Kolyma with total area of more than 1.2 mln km^2 and compare it with historical Cadastre of aufeis published in 1958.

2. STUDY AREA

North-East of Russia is famous for the vast distribution of aufeis. The region includes Chukotka and the Verkhoyansk-Kolyma mountainous system.

Assessed water storage in aufeis of Chukotka in spring is about 1.4-1.6 km^3. Approximately 50% of aufeis fields do not fully melt during the summer and about 1-5% of their volume remains for the following year. The number of aufeis fields per unit area increases with higher elevation; at the same time, there is a pronounced tendency of growth of the average thickness of aufeis deposits from 1.5 m on the coastal plains to 3.0 m high in the mountains (Alekseev et al. 2011).

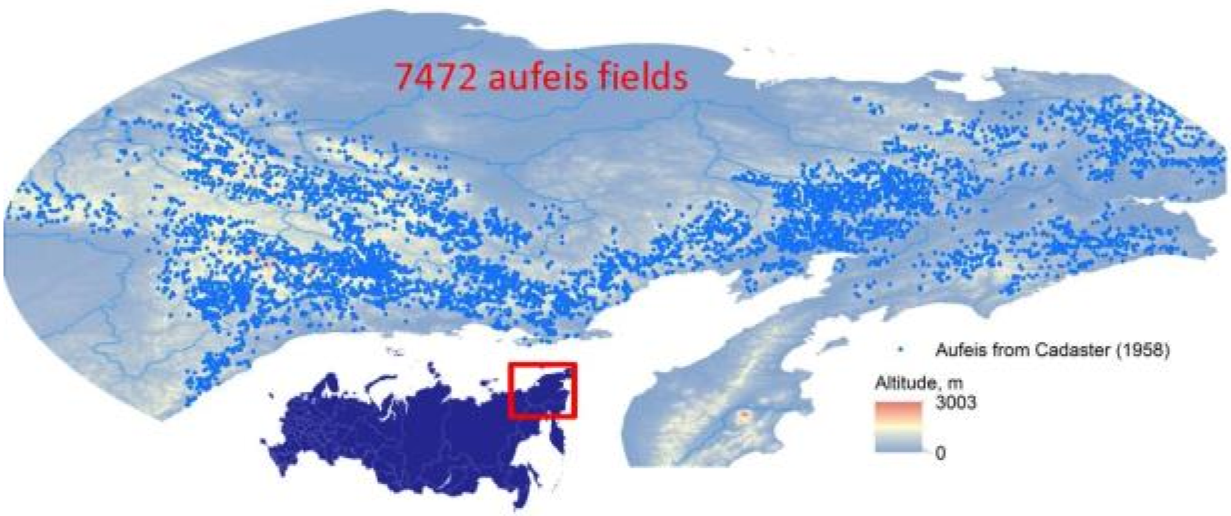

Figure 1 General overview of study area including the distribution of aufeis fields in the North-East of Russia according to the Cadastre (1958)

The Verkhoyansk-Kolyma highland is characterized by the most severe climate in Asia. The thickness of continuous permafrost in the watershed divides reaches 500-600 m, and in the bottoms of the river valleys it ranges from 150 to 200 m. The water-bearing taliks are located mainly in depressions of the relief along tectonic faults, under the river beds and large lakes of glacial origin. Aufeis on average occupy 1.0-1.2% of the territory, while a significant part of them belongs to the category of giant.

Simakov and Shilnikovskaya (1958) developed the Cadastre of aufeis of this region based on air-photo interpretation data and field geological surveys which contains the data on 7,472 aufeis fields with total area 10,445 km^2 and the areas of individual aufeis fields varying from 0.01 to 82 km^2. 10% of the largest aufeis fields make up about 60% of their total area in the Cadastre. Most aufeis is located in the elevation band of 1000–1200 m (Makarieva et al. 2019b). The elevation band of 200–300 m is characterized by the location of giant aufeis fields (Figure 2), including the largest in the world, the Bolshaya Momskaya naled (aufeis), which length is about 26 km, maximum width reaching 10 km and the area amounting up to 82 km^2.

Figure 2 The example of aufeis field in the upstreams of the Kolyma River. Stratified ice of about 0.5 m depth can be seen at the right photo. The photo is taken by O. Makarieva on the 24th of July, 2016.

3. METHODS

The methods applied in this study are in detail described by Makarieva et al. (2019a). The Normalized Difference Snow Index (NDSI) was used to detect aufeis. It was calculated according to the formula (Hall et al. 1995):

$$NDSI = (GREEN – SWIR1)/(GREENC + SWIR1)$$

where SWIR1 is reflectance in the mid-infrared band (1.56–1.66 μm for the Landsat-8 images), and GREEN is reflectance in the green band (0.525–0.6 μm for the Landsat-8 images). Following Hall et al. (1995), the threshold value for snow and ice has been set at 0.4.

Aufeis detection in the basin of the Yana, Indigirka and Kolyma River basins was conducted based on the Landsat-8 OLI satellite images, from 2013 to 2017, downloaded from the United States Geological Survey web-service. We selected late spring images (between 15 May and 18 June) to detect the maximum possible number of aufeis fields and their maximum area, since in June they melt intensively. There was between 1% and 20% of cloudiness in some images.

Apart from the Landsat images, the digital terrain model with a spatial resolution of 250m was used to build a network of thalwegs within the study basin. This is essential for semi-automated separation of the aufeis from snow-covered areas in late spring Landsat images. Based on the preliminary analysis of aufeis location in relation to the network of thalwegs created, a 1.5 km wide buffer zone was used.

4. RESULTS

The results of the comparison of the historical and modern data collection are presented in Table 1 and at Figures 3-4. In total for three basins, 1803 aufeis fields from the Cadastre (1958) were found by the Landsat images and 1043 aufeis fields from the Cadastre (1958) with total area 620 km^2 were missing in recent images. 2066 new aufeis fields with total area of 522 km^2 were discovered on recent images in the study area.

The main sources of uncertainty in both datasets are the following. The Cadaster (1958) provides an area of aufeis glades but not the aufeis itself. Late Landsat images may underestimate the area of aufeis fields due to its ablation in comparison with the maximum values.

Table 3 Data correlation of aufeis based on the Cadastre (1958) and the Landsat images

River Basin	Data source	Matching aufeis	Not matching aufeis
Yana	Cadaster (1958)	68 (616 km^2)	117 (122 km^2)
	Landsat	262 (320 km^2)	321 (107 km^2)
Indigirka	Cadaster (1958)	634 (1905 km^2)	262 (159 km^2)
	Landsat	611 (1037 km^2)	602 (250 km^2)
Kolyma	Cadaster (1958)	1101 (1606 km^2)	664 (339 km^2)
	Landsat	1073 (714 km^2)	1143 (165 km^2)

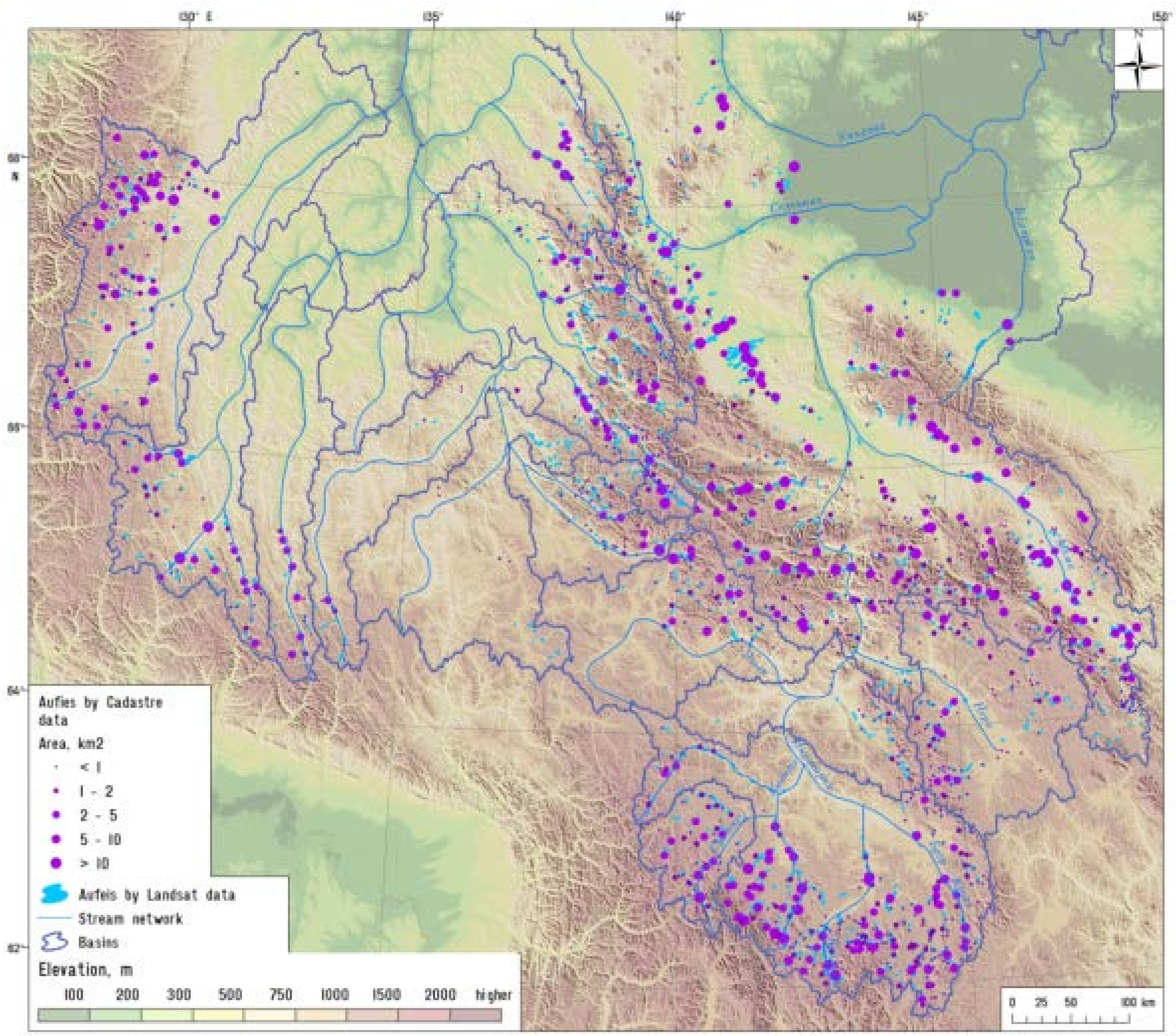

Figure 3 Aufeis in the Yana and Indigirka River basins according to the Cadastre (1958) and recent Landsat images

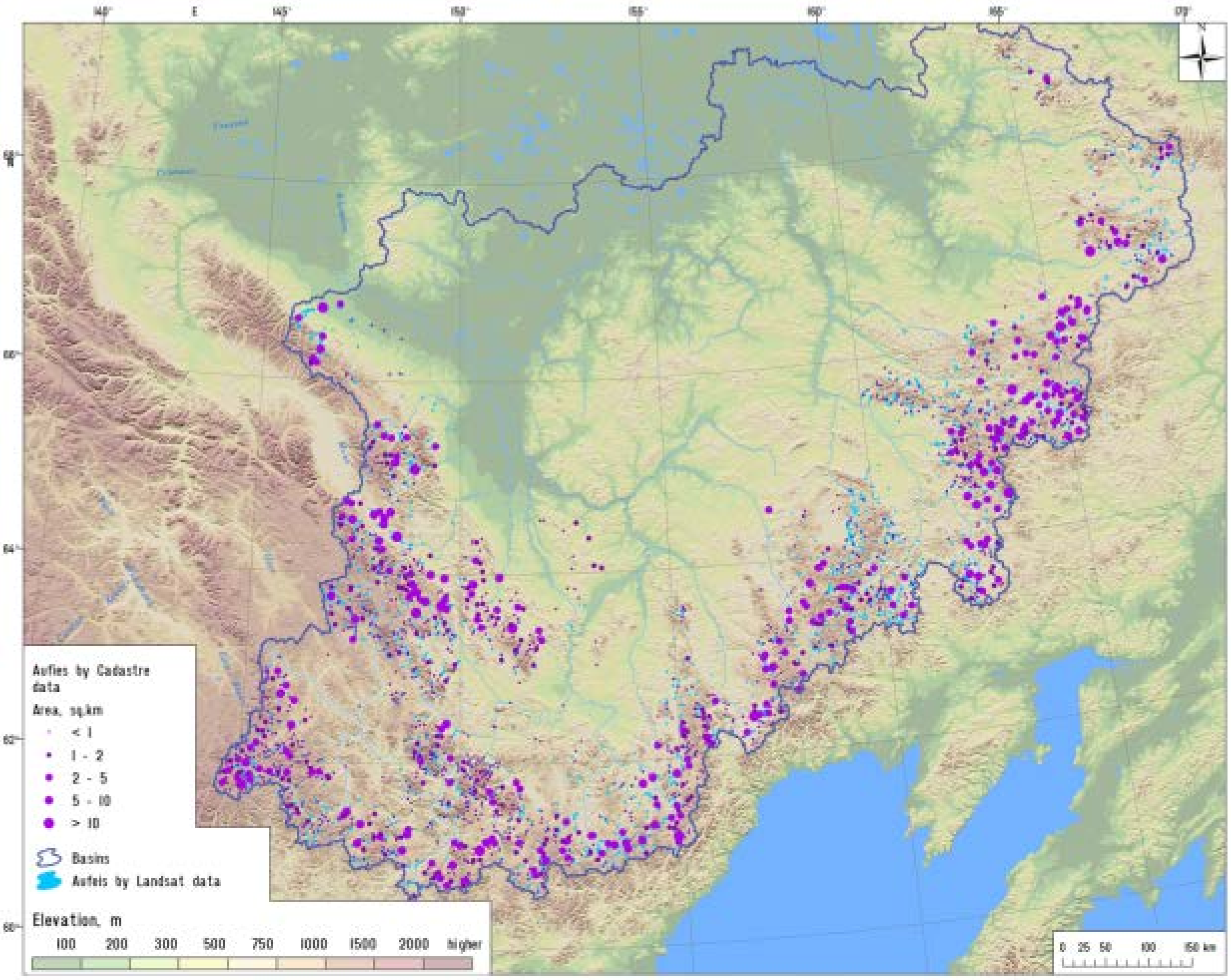

Figure 4 Aufeis in the Kolyma River basins according to the Cadastre (1958) and recent Landsat images

5. CONCLUSIONS

Developed database contains the coordinates and characteristics of 896 aufeises with total area of 2064 km^2 at the Indigirka River basin, 385 aufeises with total area 738 km^2 at the Yana River basin and 1765 aufeises with total area 1945 km^2 at the Kolyma River basin. Recent satellite-derived total aufeis area is 1.6 - 2.2 times smaller than stated in the Cadastre (1958).

Simultaneously, the historical Cadastre archive is lacking data on over 2050 aufeis that were identified using satellite images. This suggests that the Cadastre data is incomplete, while there may also have been significant change in aufeis formation conditions in the last half century.

6. ACKNOWLEDGMENT

The study was funded by the Russian Geographical Society.

7. LIST OF REFERENCES

Alekseev, V. R. 1987 *Naledi.* Novosibirsk, Nauka, Moscow

Alekseyev, V.R., Gorin, V.V., Kotov, S.V. 2011 Taryn aufeis in the Northern Chukotka. *Lyod i Sneg (Ice and Snow)* (4) 85–93

Cadastre to the map of the naleds of the North-East of the USSR: Scale 1 : 2 000 000, 1958 Edited by Shilnikovskaya, Z. G. Central complex thematic expedition of the North-Eastern Geological Survey, Magadan, 398 pp., 1958 (in Russian)

Ensom, T., Alekseev, V.R., Kane, D.L., Makarieva, O.M., Marsh, P, Morse, P.D. 2019 The Distribution and Dynamics of Aufeis in Permafrost Regions, *Permafrost and Periglacial Processes*, in preparation.

Hall, D. K., Riggs, G. A., Salomonson, V. V. 1995 Development of methods for mapping global snow cover using Moderate Resolution Imaging Spectroradiometer (MODIS) data, *Remote Sens. Environ.*, 54, 127–140

Makarieva, O., Nesterova, N., Post, D. A., Sherstyukov, A., and Lebedeva, L. 2019a Warming temperatures are impacting the hydrometeorological regime of Russian rivers in the zone of continuous permafrost, *The Cryosphere*, 13, 1635-1659, https://doi.org/10.5194/tc-13-1635-2019

Makarieva, O., Shikhov, A., Nesterova, N., and Ostashov, A. 2019b Historical and recent aufeis in the Indigirka River basin (Russia), *Earth Syst. Sci. Data*, 11, 409-420, https://doi.org/10.5194/essd-11-409-2019

Simakov, A. S., Shilnikovskaya, Z. G. 1958 *Map of the naleds of the North-East of the USSR Scale 1 : 2 000 000*, The North-Eastern Geological Survey of the Main Directorate of Geology and Subsoil Protection, Central complex thematic expedition, Magadan, 1958 (in Russian)

Tananaev, N. I., Makarieva, O.M., Lebedeva. L.S. 2016 Trends in annual and extreme flows in the Lena River basin, Northern Eurasia, *Geophys. Res. Lett.*, 43, 10,764–10,772, doi:10.1002/2016GL070796

US Geological Survey Server: available at: http://earthexplorer.usgs.gov, last access: 15 July 2019.

Yoshikawa, K., Hinzman, L. D., and Kane, D. L. 2007 Spring and aufeis (icing) hydrology in Brooks Range, Alaska, *J. Geophys. Res.-Biogeosci.*, 112, 1–14