7th LAKES 2024 Workshop on Parameterization of Lakes in Numerical Weather Prediction and Climate Modelling

Parameterization of lake ice structure: the role of precipitation and air temperature

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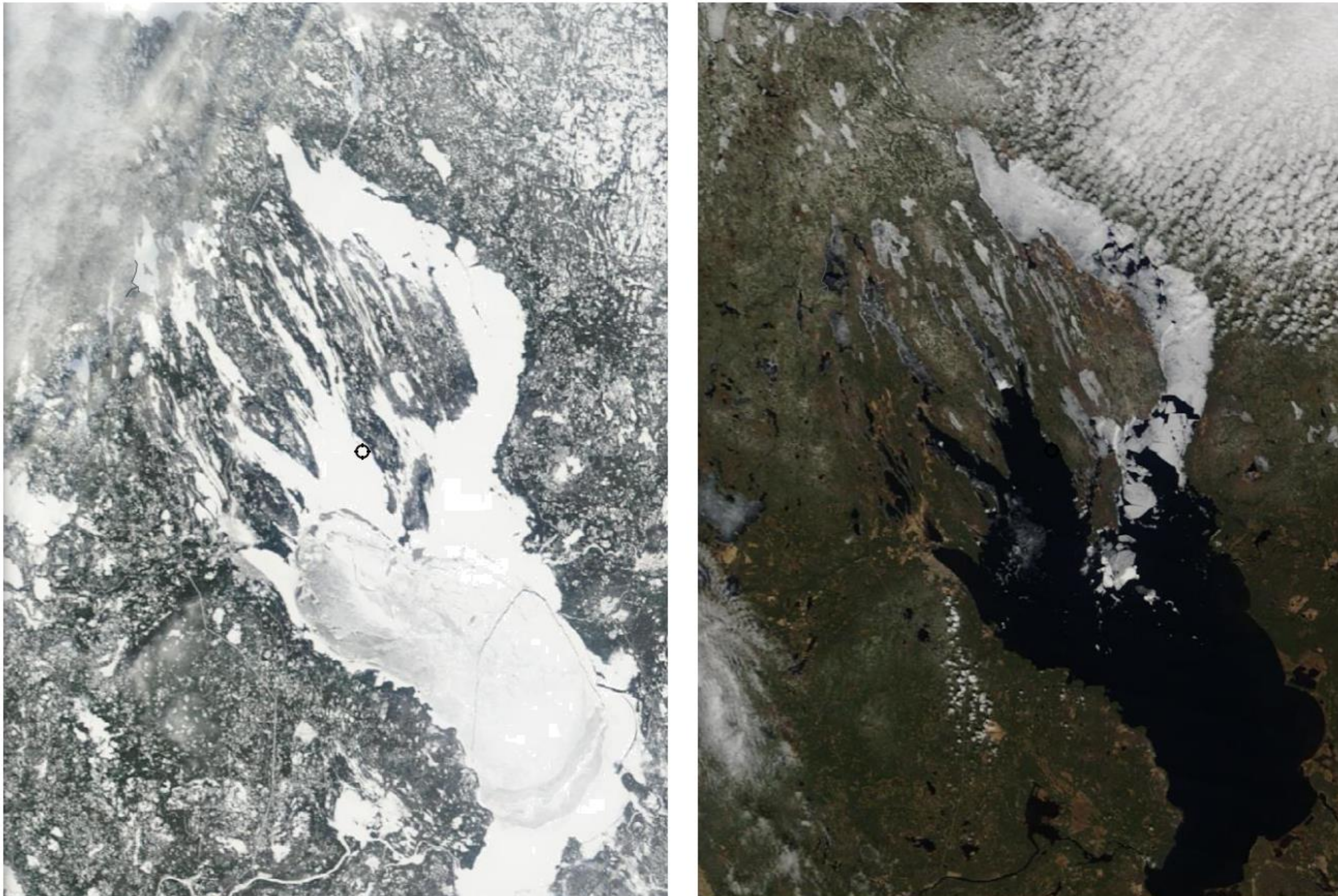
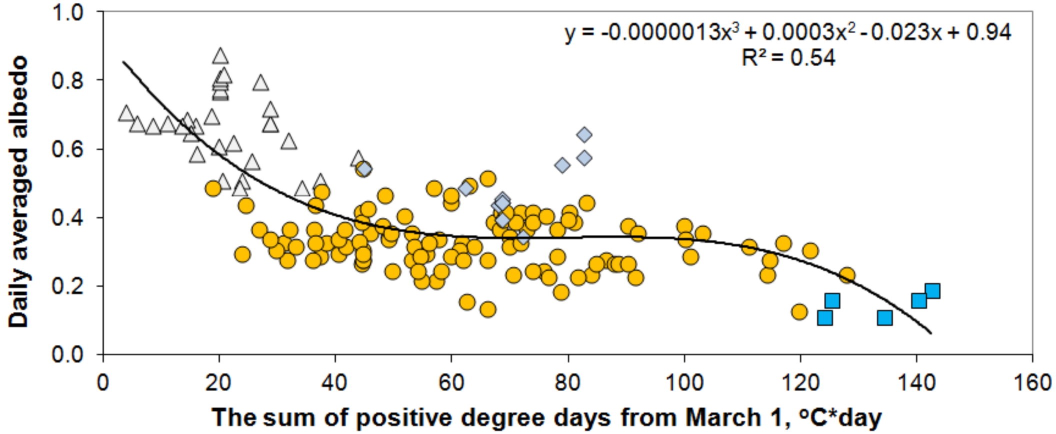
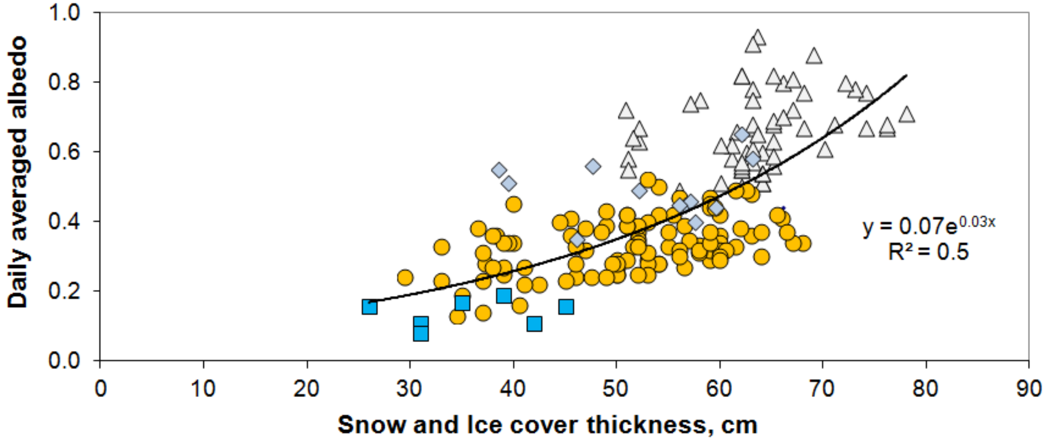
Onega Lake

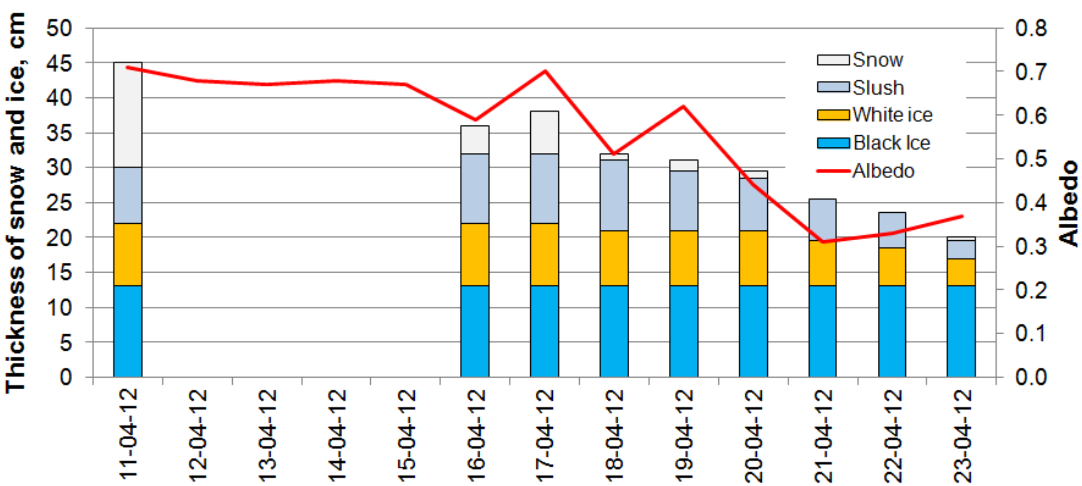
February 27, 2023

May 3, 2024




y = -0.0000013x³ + 0.0003x² - 0.023x + 0.94
R² = 0.54
Daily averaged albedo
The sum of positive degree days from March 1, °C*day
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
160


y = 0.07e^0.03x
R² = 0.5
Daily averaged albedo
Snow and Ice cover thickness, cm
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
90


Thickness of snow and ice, cm
Albedo
Snow
Slush
White ice
Black Ice
Albedo
50
45
40
35
30
25
20
15
10
5
0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
11-04-12
12-04-12
13-04-12
14-04-12
15-04-12
16-04-12
17-04-12
18-04-12
19-04-12
20-04-12
21-04-12
22-04-12
23-04-12


Fresh snow


White ice
24 4 2009


Black ice

Climate change and lake ice cover

Fig. 1 Long-term records of mean: **a** freeze-up, **b** break-up and **c** ice-cover duration for northern-hemisphere lakes. The plots present a 2007 update by B.J. Benson and J.J. Magnuson (Koç et al. 2009) of data originally presented by Magnuson et al. (2000)

Multilayer white ice, small forest lake Karelia, spring 2024

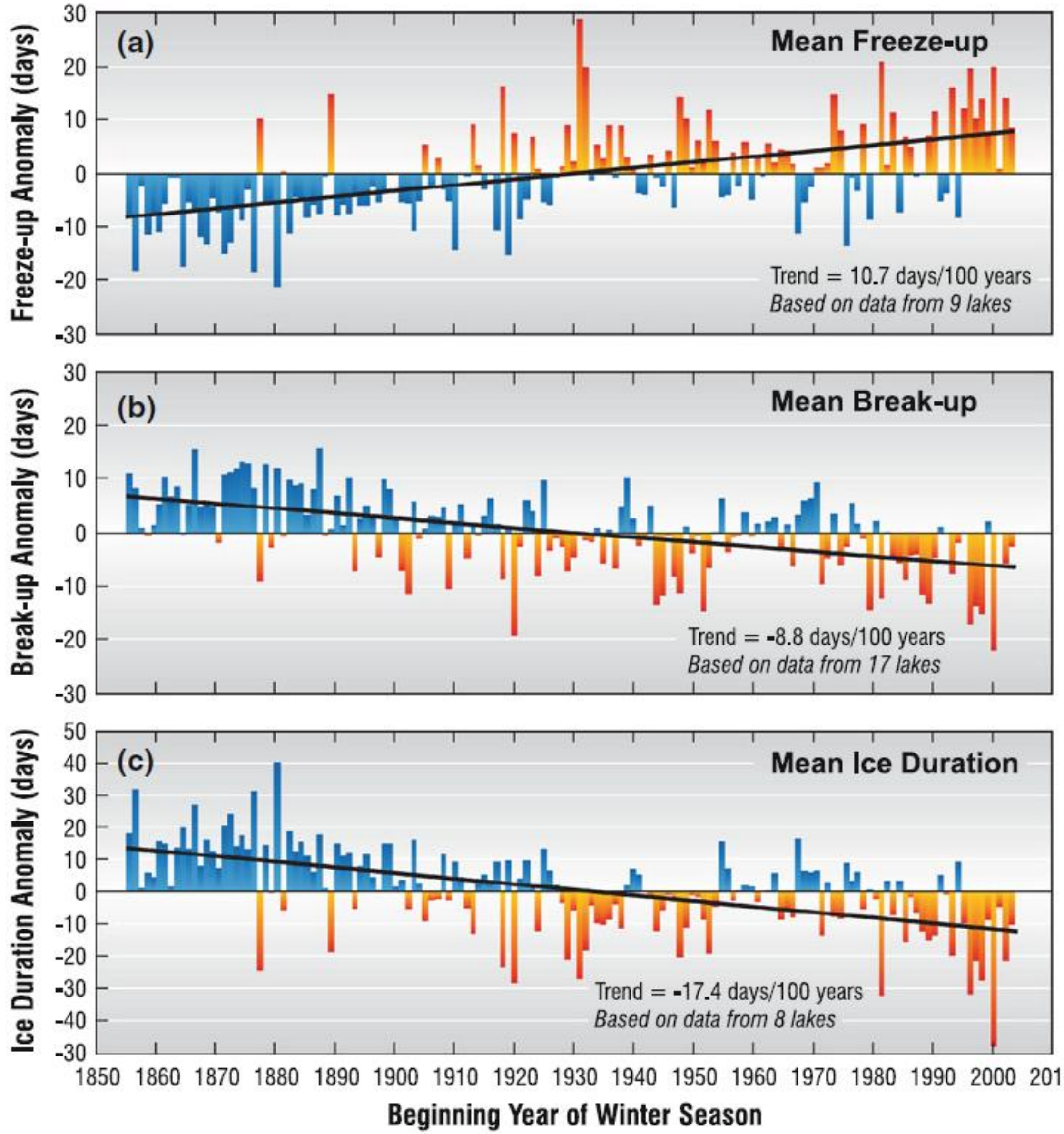
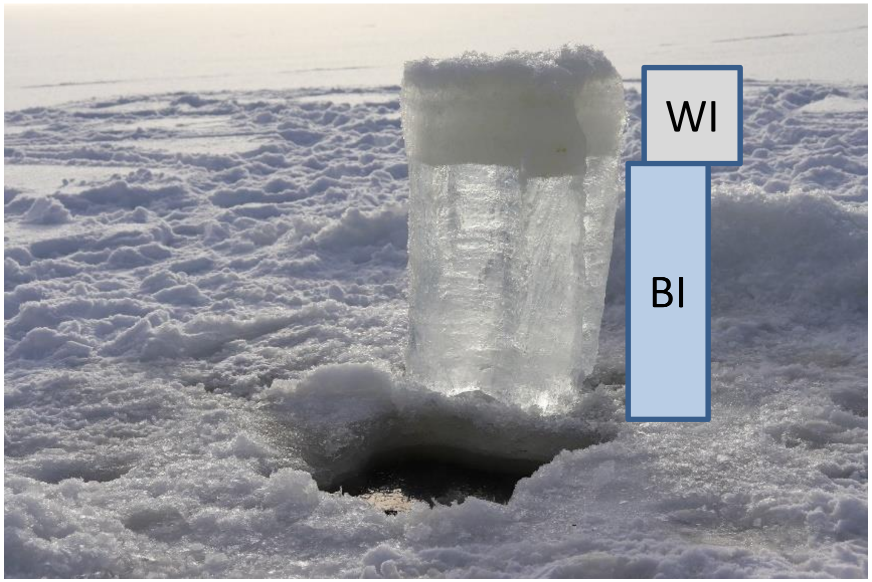


Figure from: Prowse et al., 2011

White and black ice

February 2023, small lake near Petrozavodsk,
photo by Maria Dmitrieva



Lake Vendyurskoe, April 2005

Lake ice composition: model and field measurements

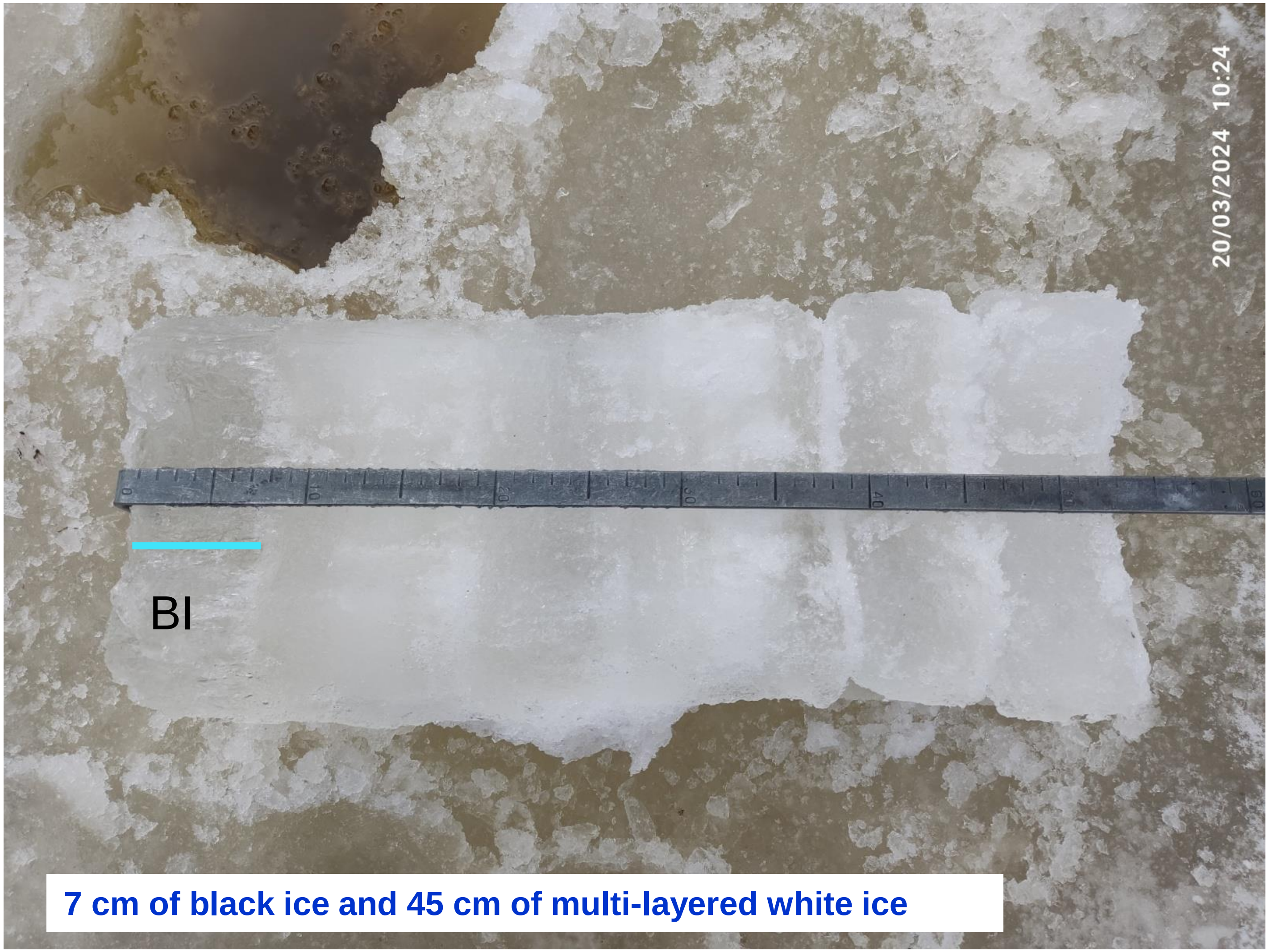
(1) Ariano S.S., Brown L.C. (2019) Ice processes on medium-sized north-temperate lakes. Hydrological Processes. 2019, 33(18):2434-2448 https://doi.org/10.1002/hyp.13481
the evolution of ice on three Canadian lakes over the course of two winters,
weekly field measurements, conditions of white ice formation, air temperature fluctuations across 0°C,
significant early winter white ice growth limiting black ice growth later in winter

(2) Weyhenmeyer G.A. et al. (2022) Towards critical white ice conditions in lakes under global warming // Nature Communications. 2022. V. 13. P. 4974. https://doi.org/10.1038/s41467-022-32633-1
a global sampling campaign IceBlitz within GLEON (https://gleon.org), the abnormally warm winter 2020-2021, the proportion of white ice increased during the winter
white ice prevailed at the end of winter

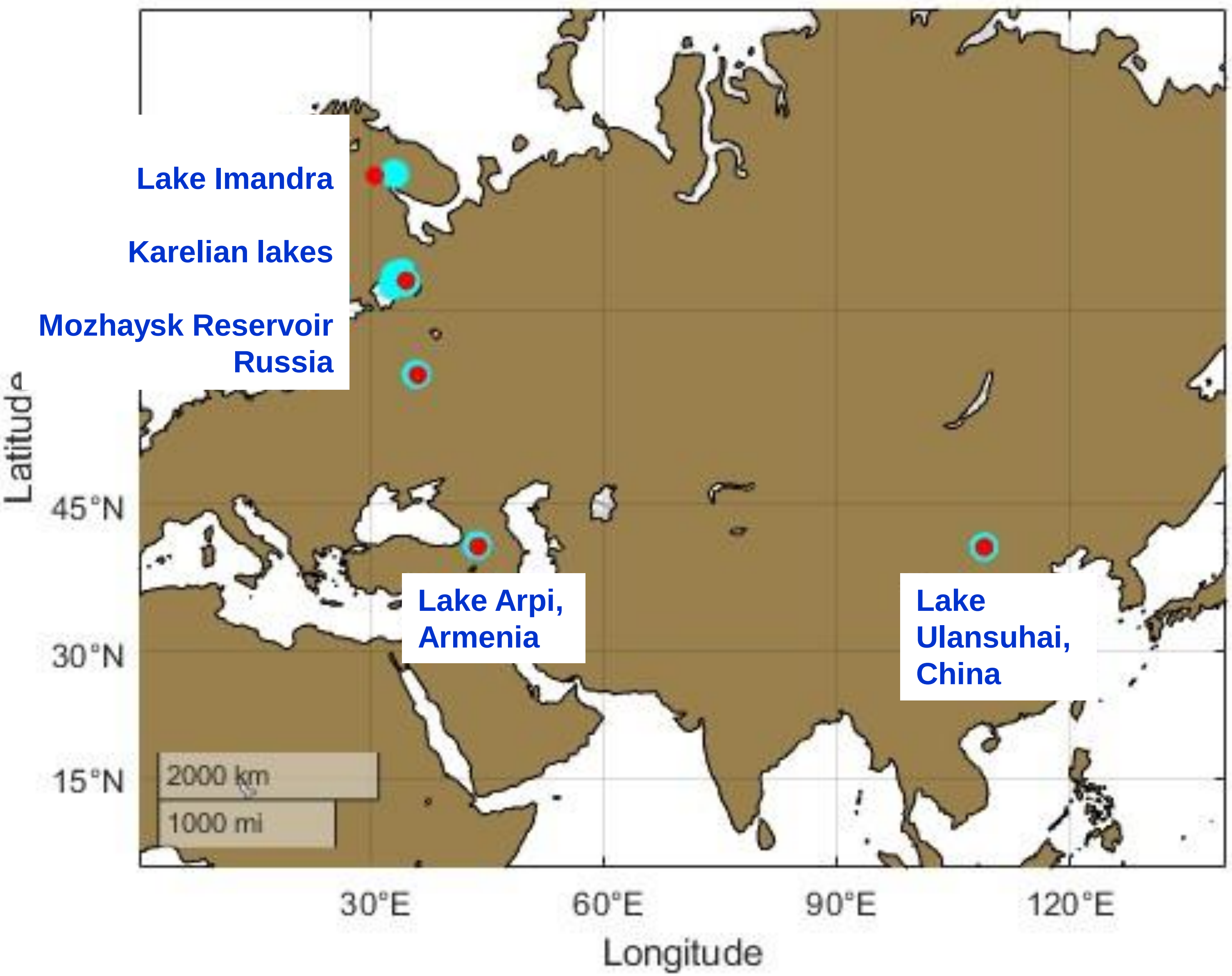
(3) Ohata, Y.; Toyota, T.; Fraser, A.D. (2017) The role of snow in the thickening processes of lake ice at Lake Abashiri, Hokkaido, Japan // Tellus A Dyn. Meteorol. Oceanogr. 2017, 69, 1391655.
The role of snow in the thickening of lake ice

(4) Vikström K., Weyhenmeyer G., Jakobsson E., Peternell M. (2024) Rapid lake ice structure changes across Swedish lakes puts public ice safety at risk // Ambio, 1-13 https://doi.org/10.1007/s13280-024-02067-8
21 Swedish lakes
Five decades
rapid decrease in thickness of black ice
decrease in thickness of black and white ice as the number of thaw days increases

The goal of this study was to identify the features of modern changes in ice phenology, and snow and ice cover composition of lakes of different regions against the background of regional climatic variability.



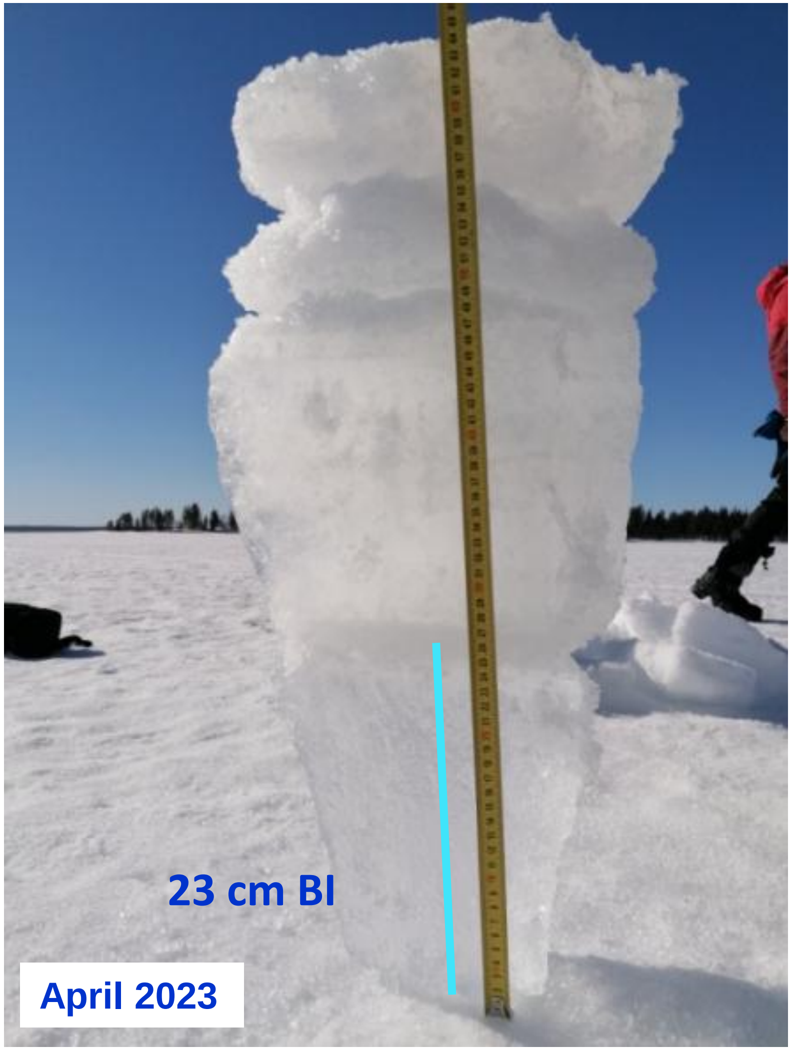
Small forest lake near Petrozavodsk, Karelia, March 2024


Lake Imandra
Karelian lakes
Mozhaysk Reservoir
Russia
Lake Arpi,
Armenia
Lake
Ulansuhai,
China
Latitude
45°N
30°N
15°N
2000 km
1000 mi
30°E
60°E
90°E
120°E
Longitude

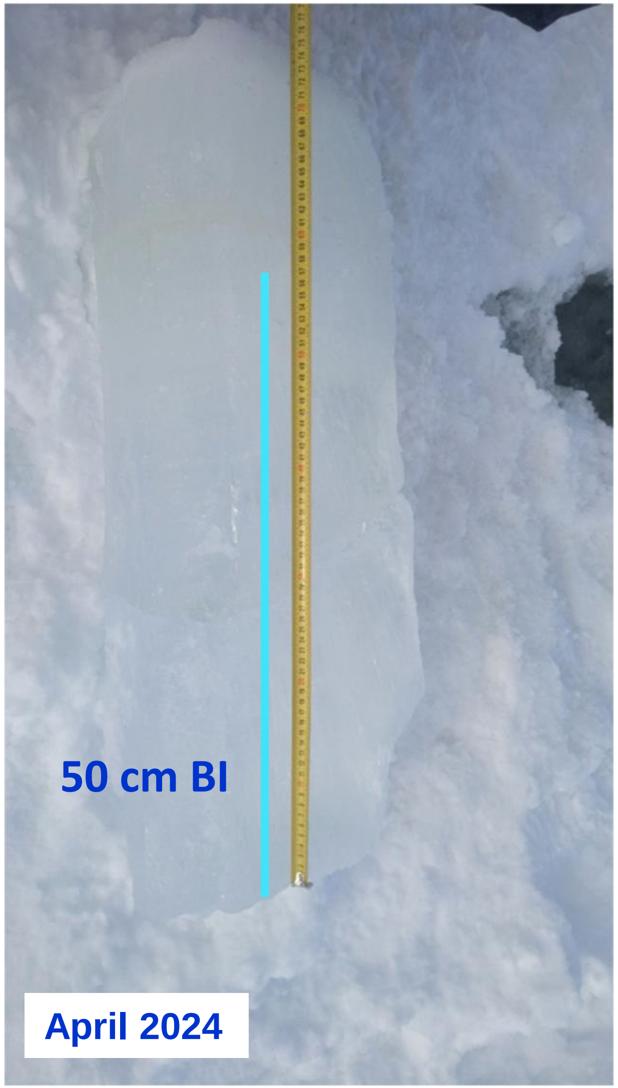
Lake, Region	Coordinates	Altitude, m	Area, km²	Volume of water, km³	Average / Maximum depth, m	Type of measurements - Years of measurements
Lake Imandra, Kola Peninsula	N67°40′ E 33°00′	127	876	11.2	16/67	[1]IT, [2]IC – 2021, 2023, 2024
Lake Vendyurskoe, Karelia	N 62°10′ E 33°10′	143	10.1	0.061	6.1/12.1	IT – 1995-2000, 2002-2018, 2020-2024 IC – 1997, 1999, 2000, 2002-2018, 2020-2024 [3]IPh –1994-2024
Lake Kroshnozero, Karelia	N 61°40′ E 33°07′	94	8.9	0.0505	5.7/12.6	IT, IC – 2021-2024
Lake Vedlozero, Karelia	N 61°33′ E 32°45′	76.6	57	0.407	7.0/14.8	IT, IC – 2021-2024 IPh – 1950-2021
Lake Forest Lamba, Karelia	N61°44′, E 34°15′	157	0.012	No data	No data	IT, IC – 2023, 2024
Lake Chetyreverstnoe, Karelia	N 61°44′ E 34°26′	102.2	0.118	0.000373	3.2/4.6	IT, IC – 2023, 2024
Lake Chudesnaya Lamba, Karelia	N62.286224 E34.017191	67	0,0069	No data	4.9/8.9	IT, IC – 2024
Mozhaysk Reservoir, Moscow region	N 55°35′ E 35°50′	183	30.7	0.221	22.5	IT – 1971-2024 IC – 1972, 1983, 1984, 2010, 2011, 2013, 2016, 2019-2024 IPh – 1962-2022
Lake Ulansuhai, Inner Mongolia	N 40°56′ E 108°52′	1019	233(306)	0.328	1.12/2.5	IC – 2021-2023
Lake Arpi, Armenia	N 41°03′ E 43°37′	2022	20	0.1	4.2/8.0	IPh – 1952-1975 (data averaged over the period)

[1] IT – Ice Thickness, [2]IC – Ice Composition, [3]IPh – Ice Phenology.

Arctic zone: Lake Imandra



14 April 2023. Total ice 66.5, snow on ice 9 cm, black ice is 23 cm, and three white ice layers are 20, 6, and 7 cm, separated by a layers of wet snow 3.5 and 4 cm.

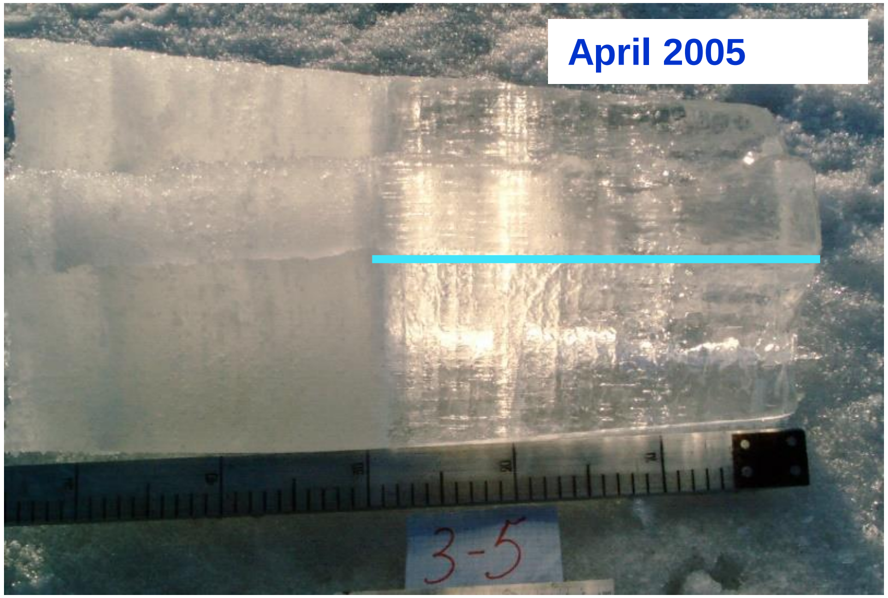


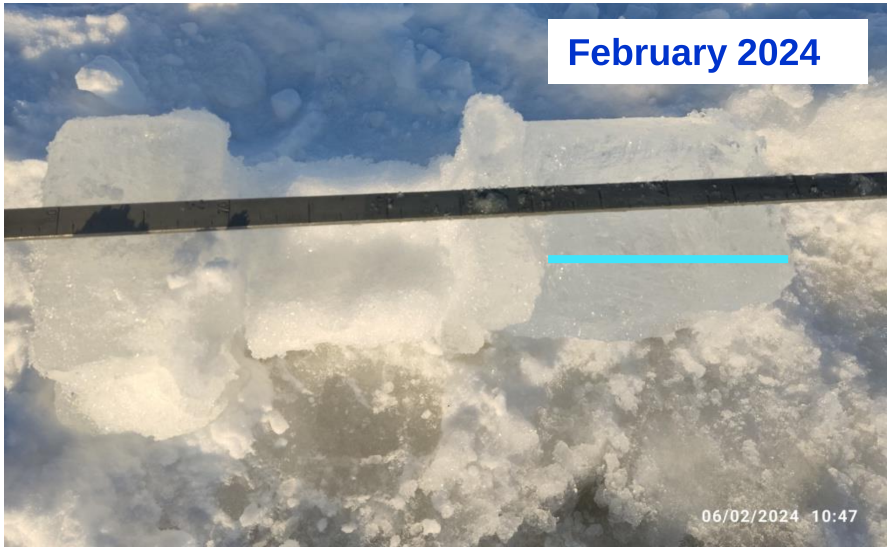
20 April 2024. Total ice 75 cm; black ice 50 cm, white ice 20 cm.

Boreal lakes: Karelia

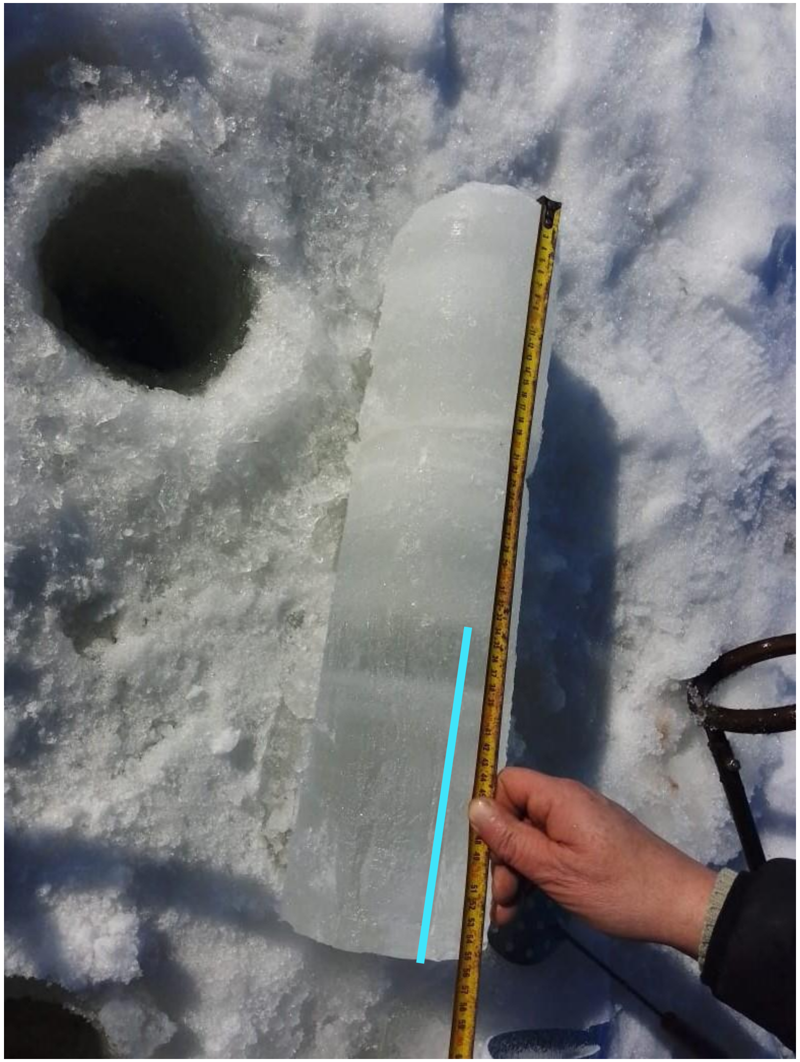
Small lake near Petrozavodsk

Lake Vendyurskoe





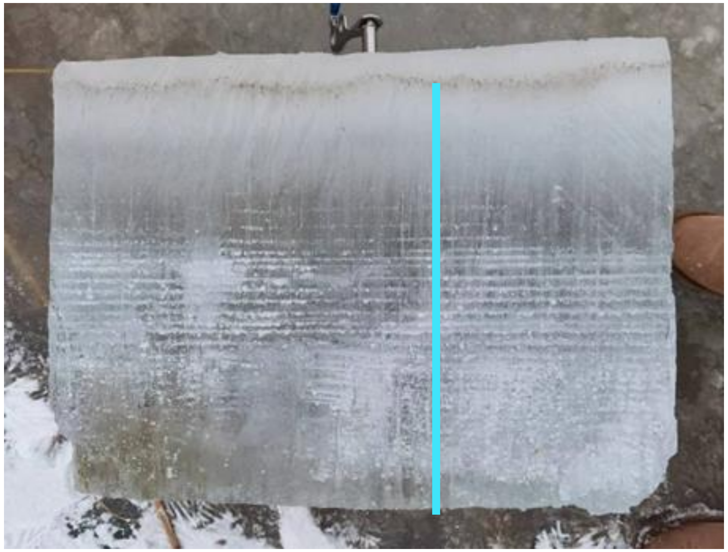
Temperate zone: Mozhaysk Reservoir



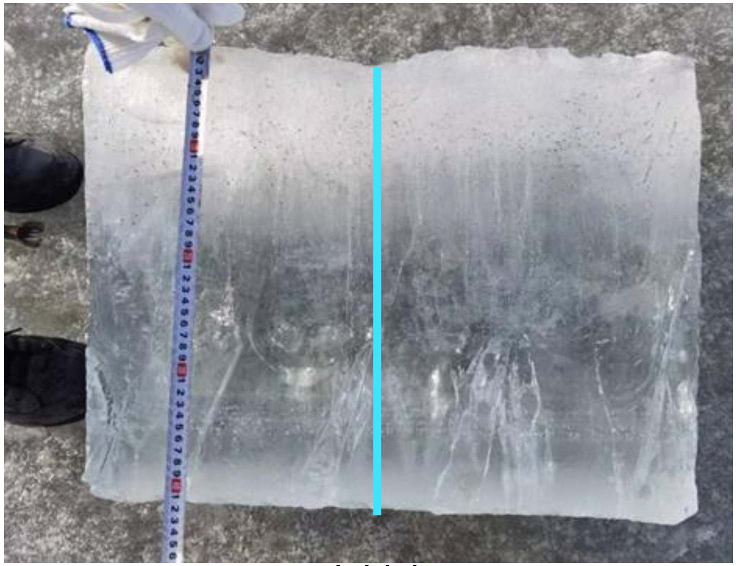
March 3, 2024. Total ice 56 cm; black ice 22 cm, white ice 34 cm.

February 3, 2021. Total ice 36 cm; black ice 19 cm, white ice 17 cm.

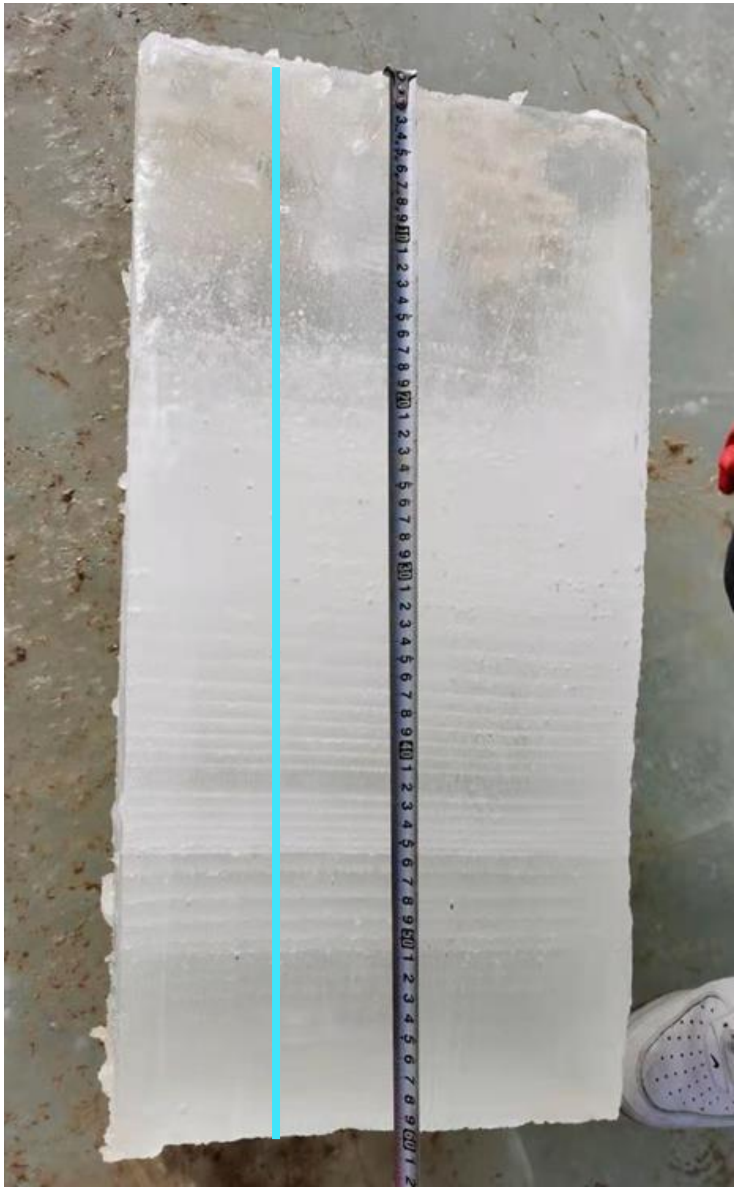
Arid zone: Lake Ulansuhai



Feb. 9, 2023: total thickness: 52.5 cm, white ice: 2-3 cm

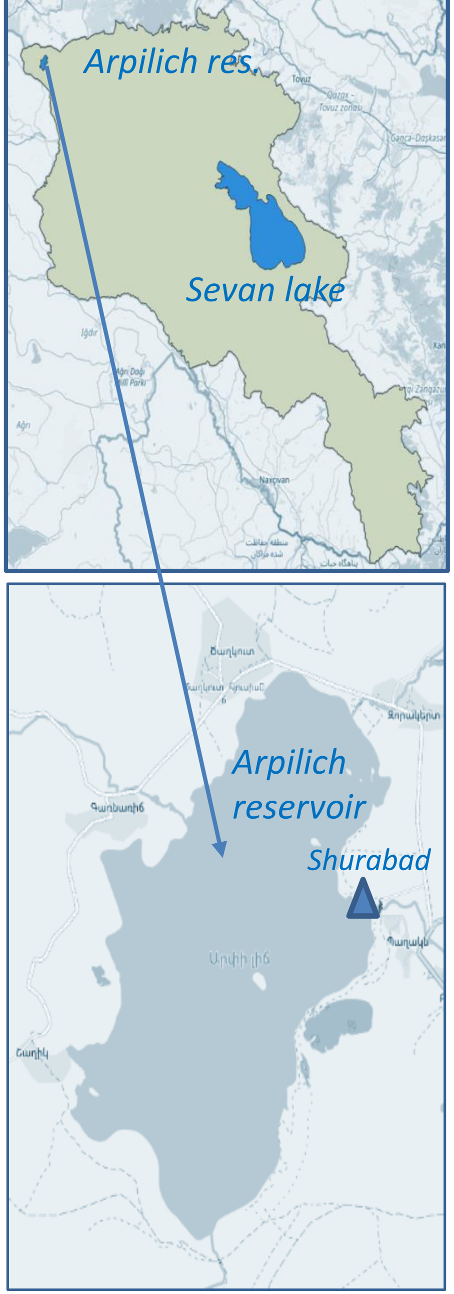


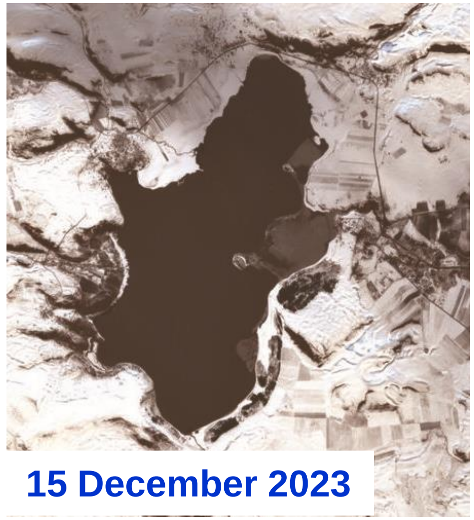
Mar. 6, 2022, total thickness: 41.3 cm, no white ice



Jan. 15, 2021, total thickness: 59.5 cm, no white ice

Arpi Lake ice regime

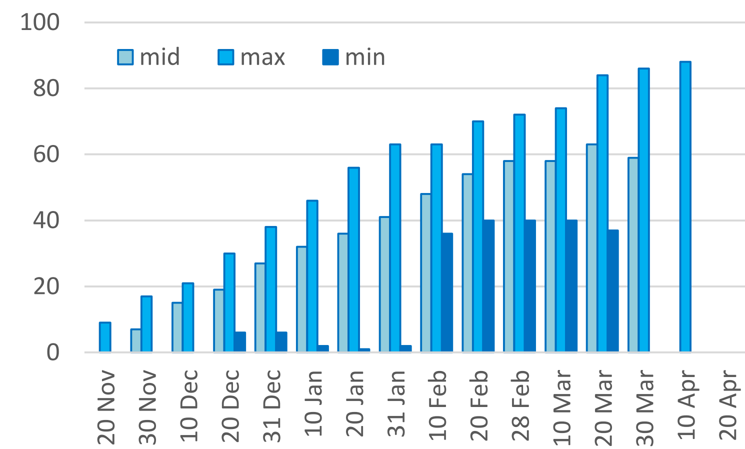


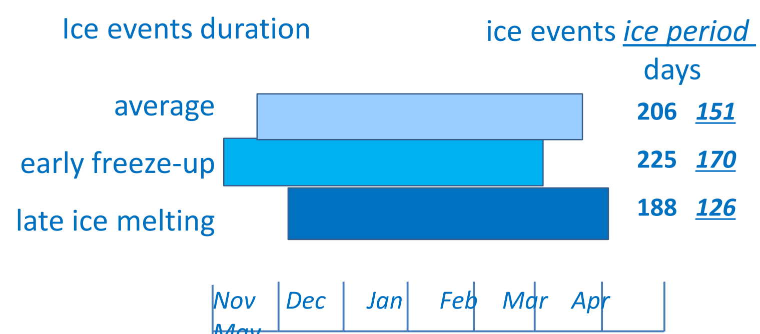

15 December 2023


13 April 2024

The height above sea level is 2022 m
The area of the water surface is 20 km²
The average depth is 4.2 m, the maximum is 8.0 m
The catchment area is 4750 km²
The volume of water is 0.1 km³

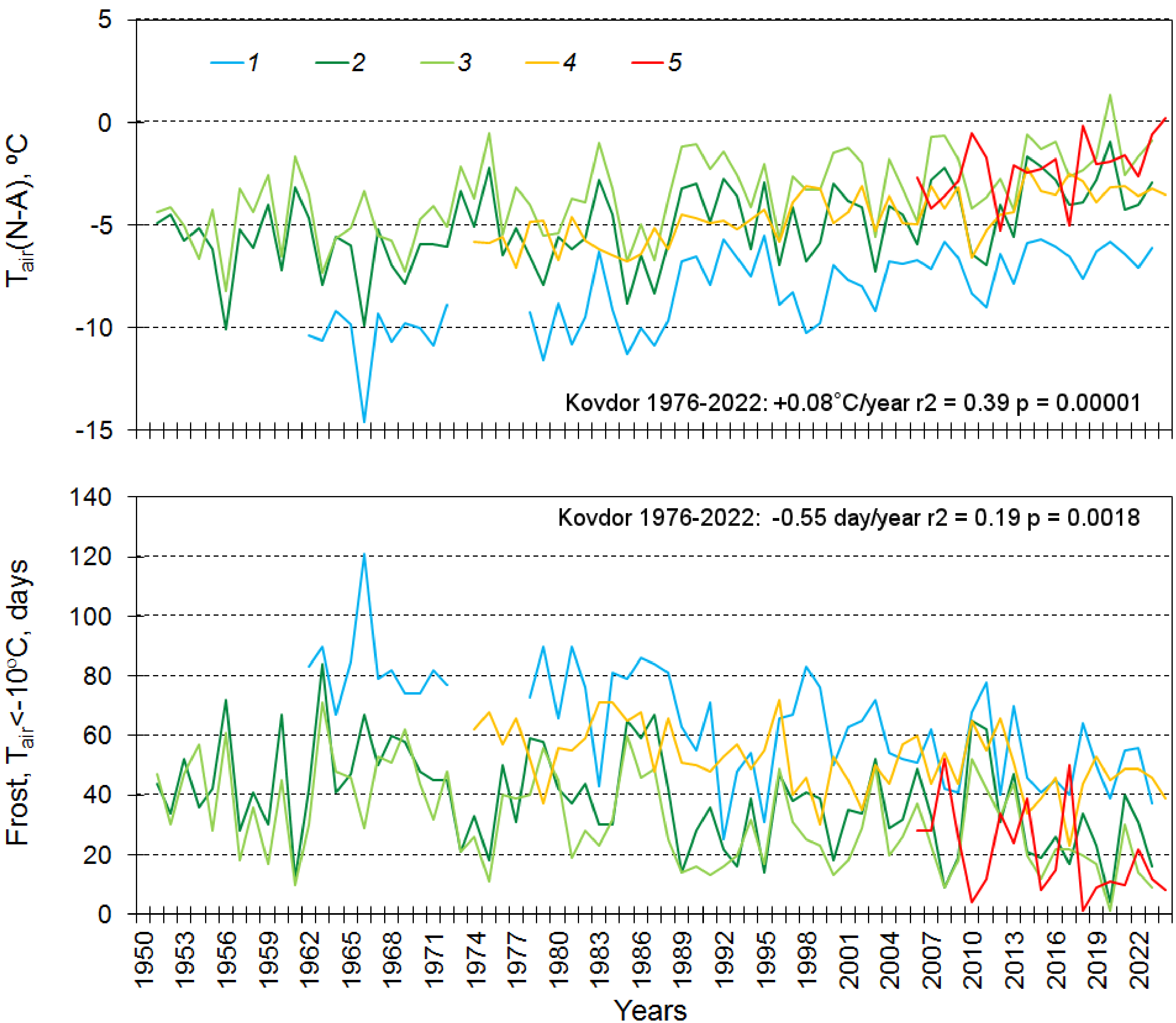
Ice thickness (cm) on Arpilich res. - v.Shurabad (1954-1970)





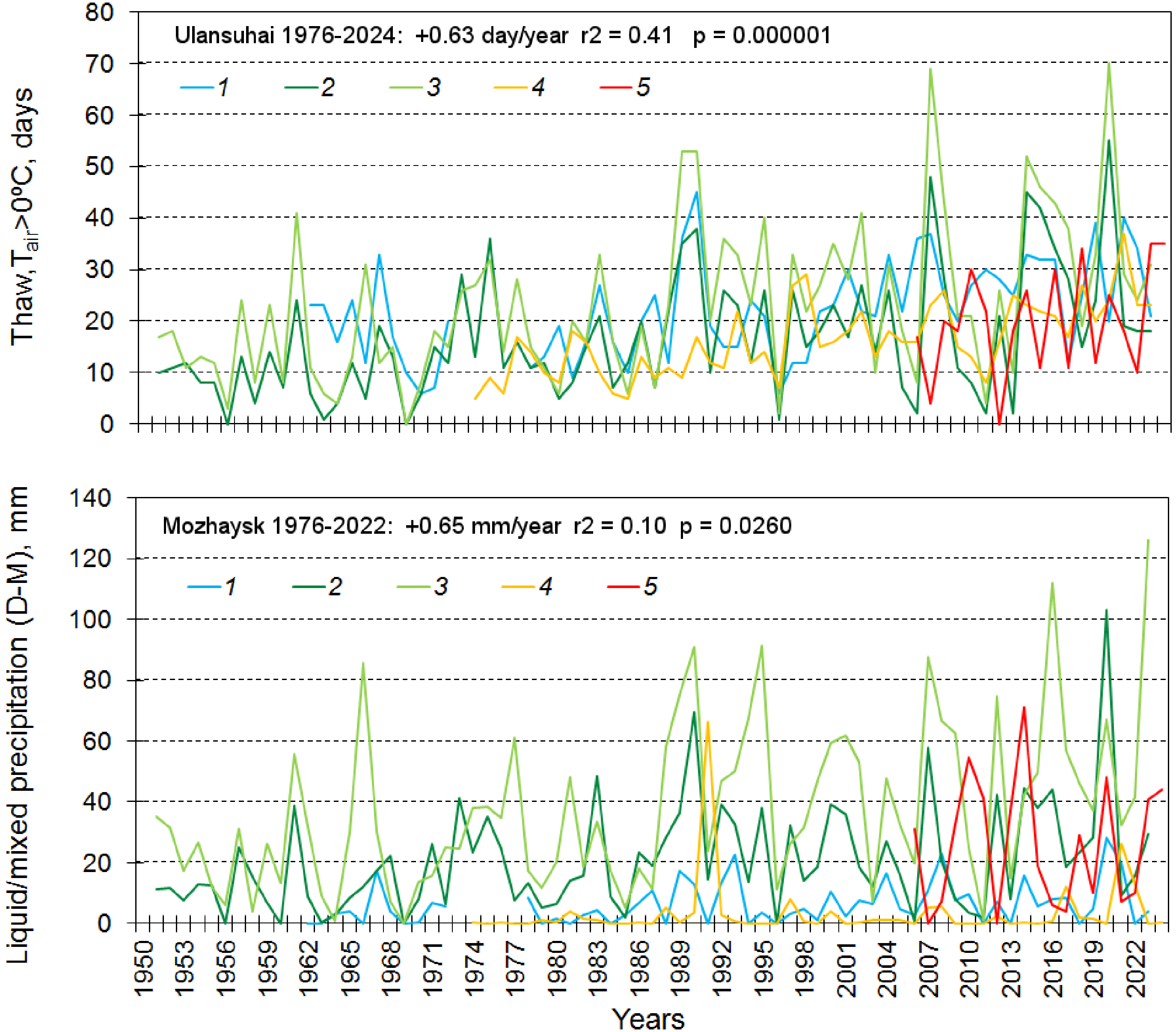
The work is supported by the Ministry of Education, Science, Culture and Sports of Armenia (project – 23IRF-1E02: IMpact of Past And Current Trenchant climatic and environmental changes on Armenian Highland lake ecosystems – **IMPACT)**

Tair (N-A) and days with Tair<-10°C in December-March



1 – Kovdor
2 – Petrozavodsk
3 – Mozhaysk
4 – Ulansuhai
5 – Amasia

Thaws (Tair>0ºC) and liquid/mixed precipitation (D-M)



1 – Kovdor

2 – Petrozavodsk

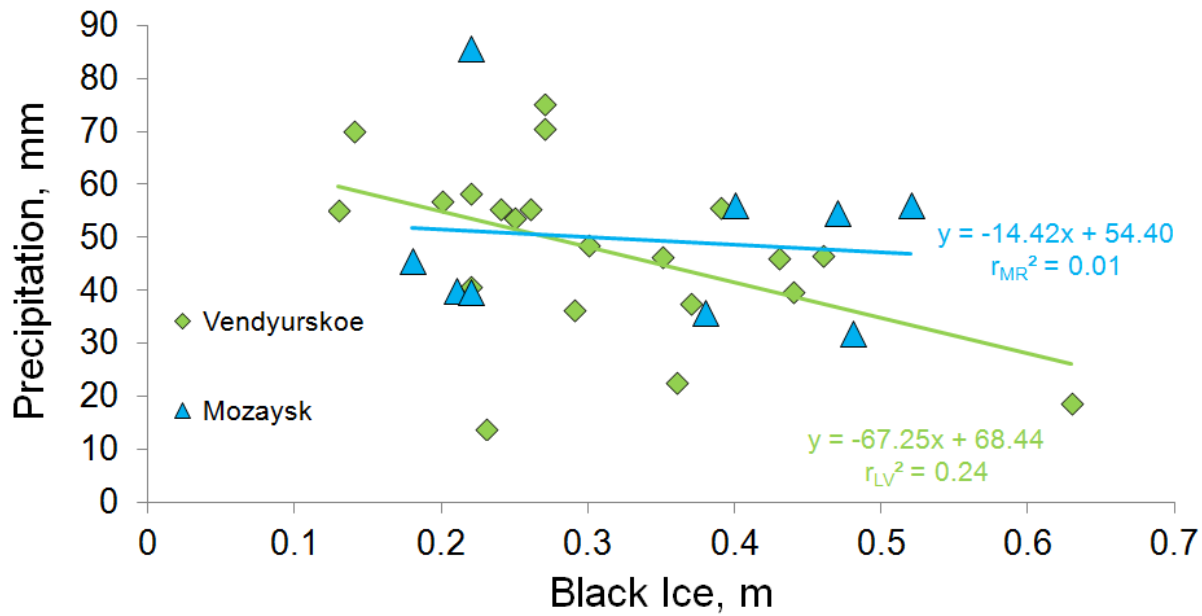
3 – Mozhaysk

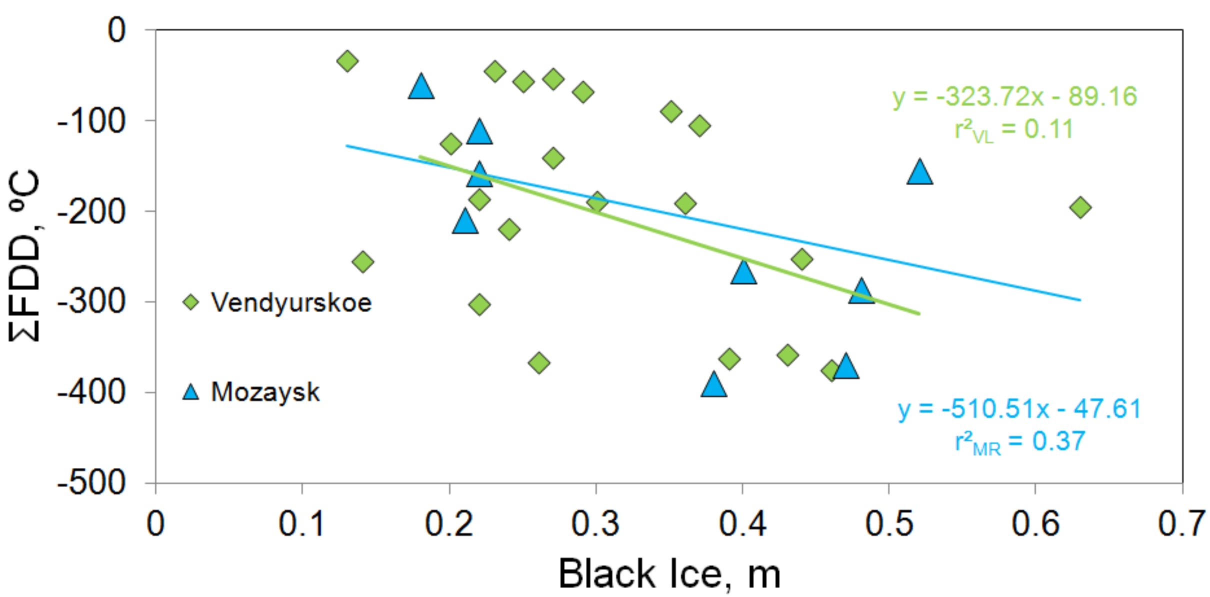
4 – Ulansuhai

5 – Amasia

Lake	Parameter	Years	b	r^2	p
Lake Vendyurskoe	Ice duration	1995-1999, 2008-2013, 2015-2024	**-0.54 day/year**	$r^2 = 0.12$	$p = 0.1242$
	Ice-on	1994-1998, 2003-2005, 2007-2023	+0.26 day/year	$r^2 = 0.05$	$p = 0.2951$
	Ice-off	1994-2000, 2002-2003, 2008-2013, 2015-2024	-0.19 day/year	$r^2 = 0.11$	$p = 0.0985$
	Total ice thickness	1995-2000, 2002-2018, 2020-2024	-0.52 cm/year	$r^2 = 0.24$	$p = 0.0083$
	Black ice thickness	1997, 1999-2000, 2002-2018, 2020-2024	**-0.83 cm/year**	$r^2 = 0.36$	$p = 0.0015$
Lake Vedlozero	Ice duration	1950-2021	**-0.33 day/year**	$r^2 = 0.20$	$p = 0.0001$
		1993-2021	**-0.93 day/year**	$r^2 = 0.24$	$p = 0.0061$
	Ice-on	1950-2020	+0.22 day/year	$r^2 = 0.13$	$p = 0.0027$
		1993-2021	+0.54 day/year	$r^2 = 0.13$	$p = 0.0485$
	Ice-off	1951-2021	-0.15 day/year	$r^2 = 0.19$	$p = 0.0002$
		1993-2021	-0.40 day/year	$r^2 = 0.24$	$p = 0.0067$
Mozhaysk Reservoir	Ice duration	1961-2021	**-0.50 day/year**	$r^2 = 0.20$	$p = 0.0003$
		1993-2020	**-1.05 day/year**	$r^2 = 0.22$	$p = 0.0110$
	Ice-on	1961-2020	+0.36 day/year	$r^2 = 0.17$	$p = 0.0011$
		1993-2020	+0.60 day/year	$r^2 = 0.08$	$p = 0.1546$
	Ice-off	1962-2023	-0.14 day/year	$r^2 = 0.08$	$p = 0.0316$
		1993-2020	-0.30 day/year	$r^2 = 0.13$	$p = 0.0521$
	Total ice thickness	1972-1999, 2003-2017, 2019-2021	-0.38 cm/year	$r^2 = 0.24$	$p = 0.0006$
	Black ice thickness	1982, 1983, 2009, 2010, 2012, 2015, 2018, 2020-2024	**-0.20 cm/year**	$r^2 = 0.32$	

Lake ice composition and meteorological parameters





Lake ice composition modelling

(1) ***MyLake – is a one-dimensional lake ice model : ice cover duration and ice composition.***
Saloranta T.M., Andersen T. (2007) MyLake - A multi-year lake simulation model code suitable for uncertainty and sensitivity analysis simulations, Ecological Modelling, 207(1):45-60. https://doi.org/10.1016/j.ecolmodel.2007.03.018.
Dibike Y. et al. (2011) Response of Northern Hemisphere lake-ice cover and lake-water thermal structure patterns to a changing climate. Hydrological Processes. 2011. Special Issue: Canadian Geophysical Union - Hydrology Section 25(19): 2942-2953 https://doi.org/10.1002/hyp.8068
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Julien Bellavance: ***julien.bellavance.1@ulaval.ca***, *Université Laval (Canada)*
Francois Clayer: ***francois.clayer@niva.no***, *Norwegian Institute for Water Research (Norway)*

(2) **General Lake Model (GLM 3.0) – is *a one-dimensional open-source code: ice cover duration and ice composition***
Hipsey et al. (2019) A General Lake Model (GLM 3.0) for linking with high-frequency sensor data from the Global Lake Ecological Observatory Network (GLEON), Geosci. Model Dev., 12, 473–523, https://doi.org/10.5194/gmd-12-473-2019
Person responsible for model simulations in ISIMIP2b simulation round
Klaus Joehnk: ***Klaus.Joehnk@csiro.au***, *CSIRO (Australia)*
Robert Ladwig: ***ladwigjena@gmail.com***, *Center for Limnology, University of Wisconsin-Madison (USA)*

(3) *Arctic Lake Biogeochemistry Model (ALBM) - is a one-dimensional process-based coupled lake hydrodynamic and biogeochemistry model: snow-white ice-black ice simulation and ice phenology*
Tan et al., (2018) A Small Temperate Lake in the 21st Century: Dynamics of Water Temperature, Ice Phenology, Dissolved Oxygen, and Chlorophyll a, Water Resour. Res., 54, 4681–4699.
https://doi.org/10.1029/2017WR022334
Person responsible for model simulations in ISIMIP2b simulation round
Zeli Tan: ***tanzeli1982@gmail.com***, ***0000-0001-5958-2584***, *Pacific Northwest National Laboratory (USA)*

Thanks for your attention!

Climate change and lake ice composition: multi layered ice of Karelian lakes in spring 2022