Estonian Journal of Earth Sciences, 2013, **62**, 1, 26–32 doi: 10.3176/earth.2013.03

Interannual variability of ice and snow cover of a small shallow lake

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Received 7 December 2011, accepted 2 October 2012

Abstract. The interannual variability of ice and snow of small shallow Lake Vendyurskoe (Karelia, Russia) is investigated on the basis of long-term records (1994–2011). The water temperature, thickness of the snow and ice, as well as incident, reflected and penetrating through the ice fluxes of solar radiation were registered. The lake surface albedo in spring varied widely from 0.95 (fresh snow, sunny weather) to 0.1 (water on the ice surface). The heat balance of the lake surface (solar and effective long-wave radiation, evaporation and condensation, turbulent heat transfer) was estimated for the period of melting. The amount of heat accumulated in the sub-ice layer during the spring convection was assessed. Estimates of the proportion of solar radiation on the melting of ice and water heating in the under-ice layer during the spring thaw were carried out.

Key words: albedo, lake ice, melting, solar radiation, heat balance, convection.

INTRODUCTION

In winter, snow and solid ice prevent a direct contact between the lake and the atmosphere. Ice cover of small lakes usually consists of two main layers – a congelation (crystalline, black) and snow (white) ice (Leppäranta & Kosloff 2000; Petrov et al. 2005; Lei et al. 2011). During the main part of winter, the heat flux at the water–sediment boundary determines the heat balance of shallow lakes. In spring, the flux of solar radiation penetrating the ice increases with melting (Petrov et al. 2005; Jakkila et al. 2009). The study of optical properties of ice and snow and under-ice light in the lakes is of growing interest in modern research (Bolsenga 1981; Arst 2003; Leppäranta 2003). The density, texture and structure of snow and ice are changing during the melting. This leads to considerable variability in optical properties of the ice sheet in time and space (Petrov et al. 2005; Leppäranta et al. 2010) and requires the accumulation of a large amount of field data for parameterization of solar radiation absorption in snow and ice. The purpose of this study is to analyse the data on the ice regime of a small lake collected over a long period and consider the major components of heat balance of the lake surface in spring.

MATERIALS AND METHODS

The study was conducted on Lake Vendyurskoe (62°10′N, 33°10′E) located in northwestern Russia. Lake Vendyurskoe is a small shallow lake of glacial origin (surface area 10.4 km^2, volume 54.8×10^6 m^3, maximum and average depths 13.4 and 5.3 m, respectively). Information on the weather conditions during springs 1999–2011 was obtained from the weather station ‘Petrozavodsk’ located about 70 km from Lake Vendyurskoe. The correlation coefficient of temperature and absolute air humidity at ‘Petrozavodsk’ and at the weather station near Lake Vendyurskoe was 0.95. Data on the water temperature, ice and radiation regime were collected during the winters of 1994–2011. The ice and snow thickness measurements were performed at 22 stations in mid-April (Fig. 1). The incident, reflected and penetrating through the ice solar radiation were measured at the ‘Solar radiation’ station with a Star-shaped pyranometer (Theodor Friderich & Co, Meteorologische Gerate und Systeme, Germany) and a M-80m universal pyranometer produced in Russia. The devices were intercalibrated under different weather conditions. The albedo was measured with the M-80m universal pyranometer and a digital millivoltmeter. The thermistor chains were used for temperature measurements during 1994–2011 (‘T-chains’ stations in Fig. 1). The duration of the ice period, spring convection, temperature and thickness of the convective layer were determined using the thermistor chains data. Sensors TR-1 (Aanderaa Instruments, Norway, accuracy ±0.15 °C) were used in 1994–2006, and temperature loggers TR-1050 (RBR, Canada, accuracy 0.002 °C) have been used since 2007. The equipment capacities are shown in Malm et al. (1997) and Leppäranta et al. (2010).

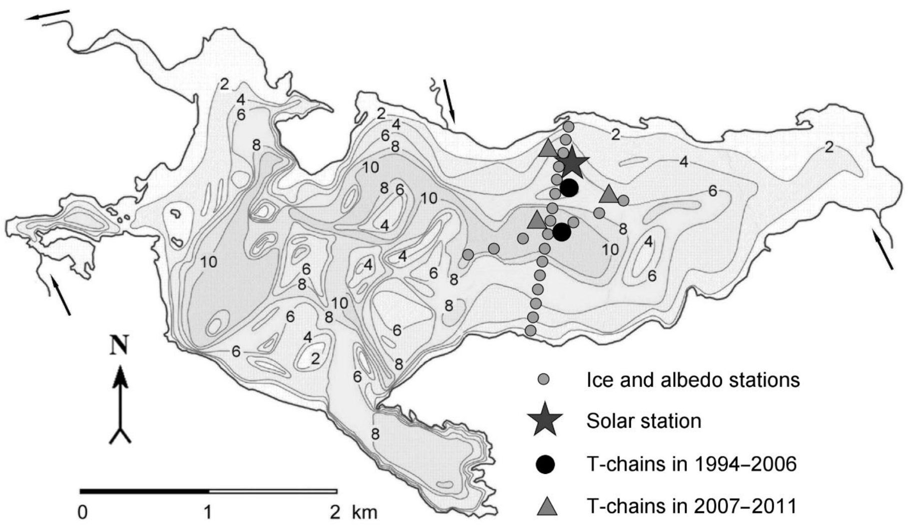

Fig. 1. Bathymetric map of Lake Vendyurskoe with location of the measurement stations.

The change in the heat content of the water column between the start of convection and ice-break was evaluated. The heat content of the water column was calculated with the equation

$$Q_{\mathrm{HC}} = \int_0^H \rho c_p T(z,t)\,dz, \qquad (1)$$

where ρ and c_p are the density and specific heat of water, respectively; T is temperature, expressed in °C and H is water depth (m).

The main components of surface heat balance were evaluated using the equation

$$Q_{\mathrm{HB}} = Q_{\mathrm{RAD}} + Q_{\mathrm{EFF}} + Q_{\mathrm{EC}} + Q_{\mathrm{TURB}}, \qquad (2)$$

where Q_{RAD} is the solar radiation absorbed by snow or ice, Q_{EFF} is the effective long-wave radiation (the difference between the outgoing long-wave radiation of the Earth's surface and the downward infrared radiation from the atmosphere), Q_{EC} is the reduced heat by evaporation and an increase in the condensation, Q_{TURB} is the turbulent heat exchange with the atmosphere. The quantity Q_{RAD} is calculated as follows:

$$Q_{\mathrm{RAD}} = (1-A) I_{0,N}, \qquad (3)$$

where A is the albedo.

In the case of clear sky the quantity I_0 is used in Eq. (3):

$$I_0 = I_{\mathrm{MAX}}\, p(\sin\varphi \sin\delta + \cos\varphi \cos\delta \cos t), \qquad (4)$$

where $I_{\mathrm{MAX}} = 1367$ W m^{-2} is the solar constant, p is the transparency of the atmosphere (in our calculations $p = 0.73$ was established from measurements of solar radiation over Lake Vendyurskoe in April during clear sky periods), φ is latitude, δ is the declination of the Sun and t is time (hours).

In the case of cloudy sky the quantity I_N enters Eq. (3):

$$I_N = I_0 \cos[1.483(N-0.22)\cos(0.497h)]. \qquad (5)$$

Equation (5) has been derived as a result of approximation of the data from Ivanov (1975). Cloudiness was expressed in fractions of a unit $N = (N_{\mathrm{T}} + N_{\mathrm{L}})/2$, where N_{T}, N_{L} are the total and lower cloudiness and h is the solar elevation angle (Piotrovich 1958). The effective long-wave radiation is

$$Q_{\mathrm{EFF}} = Q_{\mathrm{LAKE}} - Q_{\mathrm{ATM}}. \qquad (6)$$

Here

$$Q_{\mathrm{LAKE}} = \beta \sigma T_{\mathrm{SUR}}^4, \qquad (7)$$

where β is the coefficient of greyness ($\beta = 0.95$ for water and ice; $\beta = 0.98$–0.99 for snow (Odrova 1979)), $\sigma = 5.67\times10^{-8}$ J c^{-1} m^{-2} K^{-4} is the Stefan–Boltzmann constant and T_{SUR} is the ice or snow surface temperature (°K). In Eq. (7), it was assumed that the temperature of the ice surface was equal to air temperature for its negative values, otherwise ice temperature was assumed to be zero.

To calculate the long-wave radiation from the atmosphere, the approach proposed in Kuzmin (1961) was used:

$$Q_{\mathrm{ATM}} = 0.61\sigma T_{\mathrm{AIR}}^{4} + 0.045\sqrt{E_{\mathrm{AIR}}}[1 + 0.24N_{\mathrm{L}} + 0.12(N_{\mathrm{T}} - N_{\mathrm{L}})], \tag{8}$$

where T_{AIR} is air temperature (°K) and E_{AIR} is the absolute air humidity (mb).

To estimate fluxes of heat on evaporation, condensation and turbulent heat exchange, the empirical equations from Piotrovich (1958, 1968) were used:

$$Q_{\mathrm{EC}} = (4.89 + 3.56W_{200})(E_0 - E_{\mathrm{AIR}}), \tag{9}$$

$$Q_{\mathrm{TURB}} = (2.86 + 2.1W_{200})(T_{\mathrm{SUR}} - T_{\mathrm{AIR}}), \tag{10}$$

where E_0 is humidity at the snow–air boundary at 100% saturation (mb) and W_{200} is the wind speed at 2 m height (m s^{-1}).

To calculate Eq. (10), T_{SUR} (for a range of air temperature from 0 to -10 °C) was estimated using the air temperature and humidity, wind velocity at 2 m, thickness and thermal conductivity of ice and snow and effective radiation (Piotrovich 1968):

$$T_{\mathrm{SUR}} = \frac{(0.01 + 0.003W_{200})T_{\mathrm{AIR}} - 0.00143Q_{\mathrm{EFF}} - (0.007 + 0.0051W_{200})(6.0 - E_{\mathrm{AIR}})}{0.013 + 0.005W_{200} + \dfrac{0.00312}{H_{\mathrm{ICE}} + H_{\mathrm{SNOW}}(\lambda_{\mathrm{ICE}}/\lambda_{\mathrm{SNOW}})}}, \tag{11}$$

where H_{ICE} and H_{SNOW} are thicknesses of ice and snow (m) and λ_{ICE} and λ_{SNOW} are thermal conductivity of ice and snow, respectively.

RESULTS AND DISCUSSION

Ice cover appeared on Lake Vendyurskoe from the first days of November to mid-December in different years (Table 1), depending on weather conditions. Early freezing occurred if there was a cold anticyclonic weather pattern in mid-October–early November, while later freezing occurred when the cyclonic warm weather pattern predominated in November–early December. In early November, the lake usually froze during a calm cold night. Late freezing could happen even at a relatively strong wind, for example, in December 2008 the lake froze over when the average wind speed was 4 m s^{-1}. The water mass of the lake was already significantly cooled by the beginning of December, and even strong wind did not prevent the freezing of the lake. Ice-break occurred from 1 to 19 May in different years.

The duration of the ice-covered period varied from 146–149 (2008/2009 and 2009/2010) to 192 (1994/1995) days. The exact dates of freezing for years 1993, 1997, 2000–2002, 2006 and dates of ice breaking for years 2001, 2004–2007 are unknown. We used unpublished data on ice events in Lake Syamozero, located 20 km southwards from the study area, as approximate values of the listed dates. Efremova & Pal′shin (2011) showed that the average depth is the most powerful predictor for the average freezing dates for the lakes with the same latitude and height above sea level, whereas dates of ice breaking are well correlated with the surface area of the lake. The surface area of Lake Syamozero significantly exceeds that of Lake Vendyurskoe, but the average depths of both lakes are similar. Lake Syamozero usually completely froze 1–2 days later than Lake Vendyurskoe, except in the autumn of 2003, when the difference in the dates of freezing for these lakes was 7 days (Table 1). The difference in dates of ice-breaking on these two lakes was several days. Using the data on Lake Syamozero, we can estimate the duration of ice cover on Lake Vendyurskoe in 1993–1994, 1997–1998 and for a period from 2000 to 2007.

Ice cover of Lake Vendyurskoe usually consisted of two layers (white and congelation ice, Table 2). In some years, a mixture of snow with water (slush) was observed between white and congelation ice. The ice reached its maximum thickness at the end of March. The thickness of the congelation ice was usually 50–70% and white ice 30–50% of the total ice thickness. The ratio of congelation and white ice changed, depending on weather conditions (air temperature, precipitation amount, frequency and duration of thaws). The minimum total thickness of ice was observed in mid-April 2007 and 2010 (0.38 m), the maximum in mid-April 1996 (0.80 m). In the past seven years, the ice thickness was lesser and the ice-covered period was shorter than at the beginning of the study (1995–2003). Reduced ice thickness and increase in the frequency of warm winters in recent years are unlikely a manifestation of global warming, but rather a result of local climate variability.

Intensive snow and ice melting was observed in April (about 0.01–0.03 m day^{-1}) (Table 2). With the change in the density, structure and the optical properties of ice and snow, also surface albedo decreased. The value of the albedo depends on the state of the lake surface, weather conditions and the solar elevation angle. The different states of the lake surface in spring were observed (fresh snow in freezing weather, melting snow, solid white ice, melting white ice with water). The values of the

Table 1. The dates of freezing and ice-break of lakes Vendyurskoe (V) and Syamozero (S) and the duration of the ice period in different years

Year	Freezing		Ice-break		Ice, days	
	V	S	V	S	V	S
1993/1994	–	5 Nov	9 May	12 May	–	188
1994/1995	7 Nov	8 Nov	19 May	21 May	192	194
1995/1996	7 Nov	9 Nov	14 May	20 May	189	193
1996/1997	12 Dec	12 Dec	14 May	19 May	153	158
1997/1998	–	5 Nov	11 May	17 May	–	193
1998/1999	10 Nov	10 Nov	1 May	–	172	–
1999/2000	15 Nov	16 Nov	29 Apr	1 May	164	167
2000/2001	–	25 Nov	–	1 May	–	157
2001/2002	–	11 Nov	3 May	5 May	–	175
2002/2003	–	2 Nov	13 May	16 May	–	195
2003/2004	18 Nov	25 Nov	–	12 May	–	169
2004/2005	17 Nov	19 Nov	–	11 May	–	173
2005/2006	4 Dec	5 Dec	–	9 May	–	156
2006/2007	–	8 Nov	–	7 May	–	180
2007/2008	15 Nov	17 Nov	10 May	10 May	177	175
2008/2009	10 Dec	10 Dec	8 May	12 May	149	153
2009/2010	6 Dec	–	1 May	–	146	–
2010/2011	21 Nov	–	1 May	–	161	–

– No data.

Table 2. The thickness of the snow (S), total ice (I), congelation ice (CI), white ice (WI) and the melting rate (MR) in mid-April in different years; the duration of convection (C), the thickness (H_{ML}) and the temperature (T_{ML}) of the mixed layer, as well as an increase in the heat content of the water column during the period of convection (ΔQ_{HC})

Year	H, m				MR, m day^{-1}	C, days	Mixed layer		ΔQ_{HC}, MJ m^{-2}
	S	I	CI	WI			H_{ML}, m	T_{ML}, °C	
1994	0.09	0.68	0.46	0.22	–	33	8	4.4	72
1995	0.12	0.80	–	–	0.02	33	9.3	3.8	55
1996	0.02	0.63	0.42	0.21	0.01	33	7	3.8	60
1997	0.01	0.65	–	–	0.01	28	9.1	3.7	73
1998	0.01	0.67	0.57	0.10	0.03	20	9.2	3.8	45
1999	0	0.60	0.35	0.25	0.02	29	6.1	4.1	59
2000	–	–	–	–	0.03	28	8.75	3.8	63
2002	0	0.64	0.35	0.25	0.005	36	–	–	–
2003	0.01	0.65	0.38	0.27	0.01	33	6.7	3.2	39
2004	0	0.62	0.35	0.27	0.015	–	–	–	–
2005	0	0.50	0.26	0.24	0.003	32	–	–	–
2006	0.02	0.51	0.31	0.20	0.015	29	–	–	–
2007	0.05	0.38	0.31	0.07	0.02	–	–	–	–
2008	0	0.59	0.38	0.21	0.003	36	7.2	4	71
2009	0.02	0.58	0.37	0.21	0.03	23	8.4	3.6	67
2010	0	0.38	0.26	0.10	–	30	10.5	3.8	81
2011	0.01	0.59	0.43	0.16	0.02	25	9.5	4	64

– No data.

albedo for fresh snow (0.8 ± 0.15), snow (0.6 ± 0.2), white (0.35 ± 0.1) and congelation ice (0.2 ± 0.1), and water on the surface of ice (0.15 ± 0.05) were obtained. The resulting range of the variability of the snow and ice albedo is in good agreement with data from other sources (Bolsenga 1977; Jakkila et al. 2009). The albedo decreased with increasing air temperature and snow-ice melting, but a cold snap and snowfalls could increase its value.

The duration of the convection period varied in different years from 20 (1998) to 36 (2002, 2008) days (Table 2). The temperature of the convective layer was about 4 °C and its thickness reached 6–10 m at the ice-break moment. The flux of solar radiation penetrating the ice increased with melting of snow and ice. Water temperature in the under-ice layer increased and spring under-ice convection started in early April. The heat that accumulated in the under-ice layer during the period of convection varied from 39 to 81 MJ m^{-2} in different years.

The heat balance of the lake surface was negative during winter, but became positive in spring, due to increase in solar radiation. We evaluated the main components of surface heat balance and estimated the accumulated amount of heat during the convection (Table 3). The ratio of individual components remained nearly constant in different years. In March, the heat balance of the lake surface was predominantly negative, mainly due to the long-wave radiation heat loss. The radiation balance of the lake surface $(Q_{\mathrm{RAD}} + Q_{\mathrm{EFF}})$ became positive in April when solar radiation rapidly increased. The amount of the heat of solar radiation that accumulated during convection exceeded by 25–70% the heat loss by effective long-wave radiation in different years (Table 3). The contribution of heat loss by evaporation to the overall surface heat balance at that period was minimum, since the distribution of warm and moist air $(E_{\mathrm{AIR}} > 6.1\,\mathrm{mb})$ over the lake often had the opposite effect – condensation. For example, for April 1999 and 2000 the average condensation predominated over evaporation (positive values of ΣQ_{EC}, see Table 3). The turbulent heat exchange with the atmosphere became negative at air temperatures below zero and positive at positive air temperatures.

Table 3. The accumulated amount of the main components of the ice surface heat balance during the spring convection (MJ m^{-2})

Year	ΣQ_{RAD}	ΣQ_{EFF}	ΣQ_{EC}	ΣQ_{TURB}	ΣQ_{HB}
1999	224	−68	11	98	264
2000	220	−61	23	104	285
2002	194	−139	−23	104	137
2003	250	−72	−6	88	260
2005	276	−120	−13	52	196
2006	358	−116	−25	79	296
2008	363	−146	−23	87	280
2009	279	−76	−13	98	287
2010	278	−110	−10	64	222
2011	264	−101	−12	71	223

A comparison of the change in the heat content of the water column during convection $(\Delta Q_{\mathrm{HC}}$, Table 2) and heat accumulated due to solar radiation $(\Sigma Q_{\mathrm{RAD}}$, see Table 3) shows that about 25% of solar radiation penetrates the ice and heats water, and the remaining part is expended on the melting of ice and snow. The same result was obtained in the Finnish Lake Pääjärvi (Jakkila et al. 2009), where the heat budget in April was governed by solar radiation and the estimate of the proportion of solar radiation passing through the ice and melting snow and ice was similar to ours.

The surface heat balance changed from early April to May in all years of observation (Fig. 2). In April, daily variability of components of the surface heat balance sharply increased with an increase in the solar flux and growth of daily fluctuations in air temperature. The maximum daily variation was observed for short-wave solar radiation, high for turbulent heat exchange with the atmosphere and minimum for effective long-wave radiation. The heat balance was usually positive in the daytime, which caused the melting of snow and ice, and sometimes negative during night.

CONCLUSION

The present study demonstrates a wide interannual variability of the ice regime of a small shallow Lake Vendyurskoe (dates of freezing and ice-break, duration of ice cover and spring under-ice convection, thickness and structure of the ice sheet), as well as elements of the heat balance at the ice surface in spring (solar and effective long-wave radiation, evaporation and condensation, turbulent exchange with atmosphere). The dates of freezing and ice breaking vary considerably from year to year. The earliest freezing took place in early November with a sharp decrease in air temperatures and calm conditions (corresponding to an anticyclonic weather pattern). The lake froze in early December if the cyclonic weather pattern (warm and windy local weather) prevailed in November. Dates of freezing are more sensitive to changes in air temperature and wind than the dates of ice breaking. Therefore, the interannual variability of freezing dates was over a month, while the variability in the dates of ice breaking did not exceed 20 days. Intensive melting of snow and ice begins with increasing solar radiation (about 0.01–0.02 m per day) in mid-April. At the same time decrease in the surface albedo from 0.6–0.95 (snow) to 0.1 (water on the ice surface) was observed.

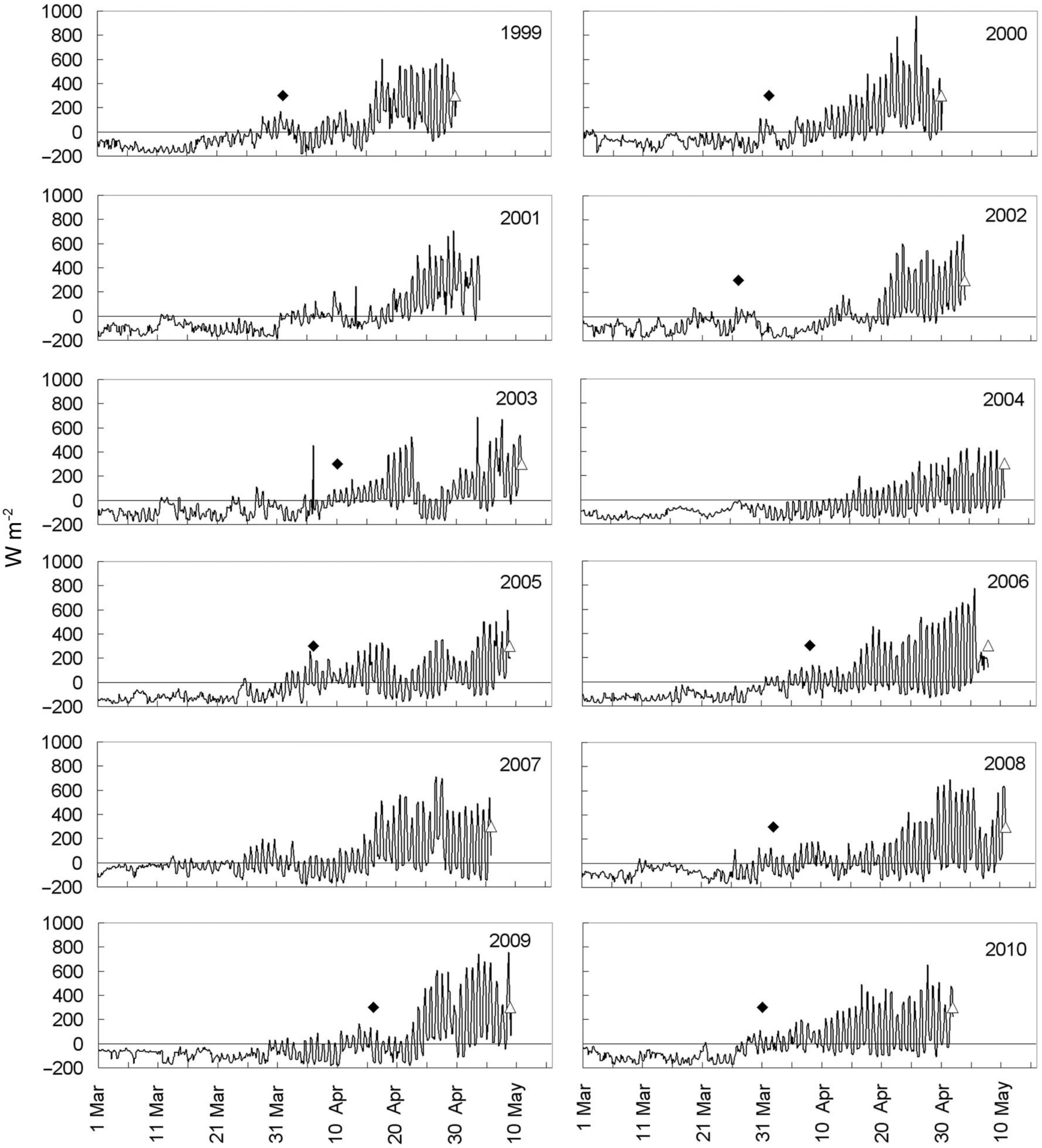

Fig. 2. Surface heat balance during the spring thaw in different years. The black diamond indicates the beginning of under-ice convection, white triangle – breaking of the ice.

Heat loss due to effective long-wave radiation played a leading role in the heat balance of the lake surface during early and middle winter. In April, the surface heat balance had undergone substantial changes. At that time, solar radiation played a key role. Short-wave solar radiation reached 63–84% and the turbulent exchange with the atmosphere was 16–37% of the positive part of heat balance. Heat loss (effective long-wave radiation) was still significant during this period. The effective long-wave radiation was comparable to the turbulent heat transfer and comprised 25–65% of solar radiation. The contribution of heat loss by evaporation was minimum during spring, averaging about 10% of the negative part of the heat balance. About 25% of solar radiation transmitted through the upper boundary of the ice sheet penetrated through it and was used to warm up water; the rest was spent on the melting of ice.

Lake Vendyurskoe is a typical representative of a wide group of shallow Karelian lakes of water-glacial genesis (Terzhevik et al. 2010). So, the results obtained in this study can be treated as characteristic of such lakes. In particular, the date of freezing may be similar for Lake Vendyurskoe and lakes with comparable values of average depth.

Acknowledgements. The present study was supported by the Russian Academy of Science and the Russian Fund of Basic Research (project 10-05-91331-DFG, in co-operation with IGB and University of Helsinki).

REFERENCES

Arst, H. 2003. *Optical Properties and Remote Sensing of Multicomponental Water Bodies*. Springer, 231 pp.

Bolsenga, S. J. 1977. Preliminary observations on the daily variation of the albedo. *Journal of Glaciology*, **18**, 517–521.

Bolsenga, S. J. 1981. Radiation transmittance through lake ice in the 400–700 nm range. *Journal of Glaciology*, **27**, 57–66.

Efremova, T. & Pal′shin, N. 2011. Ice phenomena terms on the water bodies of Northwestern Russia. *Russian Meteorology and Hydrology*, **36**, 559–565.

Ivanov, G. S. (ed.). 1975. *Okeanograficheskie tablitsy* [*Oceanographic Tables*]. Gidrometeoizdat, Leningrad, 477 pp. [in Russian].

Jakkila, J., Leppäranta, M., Kawamura, T., Shirasawa, K. & Salonen, K. 2009. Radiation transfer and heat budget during the ice season in Lake Pääjärvi, Finland. *Aquatic Ecology*, **43**, 681–692.

Kuzmin, P. 1961. *Protsess tayaniya snega* [*The Process of Melting Snow*]. Gidrometeoizdat, Leningrad, 456 pp. [in Russian].

Lei, R., Leppäranta, M., Erm, A., Jaatinen, E. & Pärn, O. 2011. Field investigations of apparent optical properties of ice cover in Finnish and Estonian lakes in winter 2009. *Estonian Journal of Earth Sciences*, **60**, 50–64.

Leppäranta, M. 2003. Investigation of ice and water properties and under-ice light fields in fresh and brackish water bodies. *Nordic Hydrology*, **34**, 245–266.

Leppäranta, M. & Kosloff, P. 2000. The structure and thickness of Lake Pääjärvi ice. *Geophysica*, **36**, 233–248.

Leppäranta, M., Terzhevik, A. & Shirasawa, K. 2010. Solar radiation and ice melting in Lake Vendyurskoe, Russian Karelia. *Hydrology Research*, **41**, 50–62.

Malm, J., Terzhevik, A., Bengtsson, L., Boyarinov, P., Glinsky, A., Palshin, N. & Petrov, M. 1997. Temperature and salt content regimes in three shallow ice-covered lakes: 1. Temperature, salt content, and density structure. *Nordic Hydrology*, **28**, 99–128.

Odrova, T. V. 1979. *Gidrofizika vodoemov sushi* [*Hydrophysics of Land Reservoirs*]. Gidrometeoizdat, Leningrad, 311 pp. [in Russian].

Petrov, M., Terzhevik, A., Palshin, N., Zdorovennov, R. & Zdorovennova, G. 2005. Absorption of solar radiation by snow-and-ice cover of lakes. *Water Resources*, **32**, 496–504.

Piotrovich, V. 1958. *Obrazovanie i staivanie l′da na ozerakh-vodokhranilishchakh i rashchet srokov ledostava i ochishcheniya* [*Formation and Melting of Ice on Lakes, Reservoirs, and the Calculation Time of Purification and Freeze-up Ice*]. Gidrometeoizdat, Moscow, 192 pp. [in Russian].

Piotrovich, V. 1968. *Rashchety tolshchiny ledianogo pokrova na vodokhranilishche po meteorologicheskim dannym* [*Calculation the Thickness of Ice Cover on the Reservoirs Using Meteorological Elements*]. HMC works, **18**, Gidrometeoizdat, Leningrad, 136 pp. [in Russian].

Terzhevik, A., Pal′shin, N., Golosov, S., Zdorovennov, R., Zdorovennova, G., Mitrokhov, A., Potakhin, M., Shipunova, E. & Zverev, I. 2010. Hydrophysical aspects of oxygen regime formation in a shallow ice-covered lake. *Water Resources*, **37**, 662–673.

Väikese madala järve jää- ja lumikatte varieeruvus aastate lõikes

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Uuriti väikese ja madala Vendjurskoje järve (Karjala, Venemaa) jää- ning lumikatte varieeruvust aastate lõikes (1994–2011) veetemperatuuri, jää ja lume paksuse ning saabuva, tagasihajunud ja jääkatet läbinud päikesekiirguse mõõtmiste alusel. Jääkatte albeedo varieerus kevadel 0,95-st (värske lumi, päikeseline päev) 0,1-ni (vesine jää). Sulamisperioodil arvutati jääpinna energiabilanss (päikesekiirgus ja efektiivne pikalaineline kiirgus, aurumine ning kondenseerumine, turbulentne soojaülekanne), samuti jääaluses veekihis kevadise konvektsiooni tingimustes akumuleeritud soojusenergia, mille alusel hinnati päikesekiirguse osakaalu jää sulamisprotsessis ja jääaluse veetemperatuuri tõusus.