Long-term hydrometeorological observations (1952–2020) at the Lammin-Suo Peatland Station, north-west Russia

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SUMMARY

This article presents the long-term (1952–2020) hydrometeorological observation dataset collected at the Lammin-Suo mire, Leningrad region, Russia. The Lammin-Suo mire is an active (currently peat forming) ombrotrophic mire with intensive peat accumulation and pine - shrub - *Sphagnum* microtopes, and is thus an example of the most common type of peatland in Eastern Fennoscandia. The data are representative of the wetland taiga region of north-west Russia and can be used to characterise the hydrometeorology and climate of peatland basins and to assess the response of hydrological cycling in peatland basins to changes in climate. The research at the Lammin-Suo Peatland Station focuses on hydrology, meteorology, soil processes and the landscape evolution of the peatland. The dataset includes air temperature, air humidity, atmospheric pressure, wind speed and direction, cloudiness, precipitation, evaporation, snow depth, peat temperature, peatland water level, groundwater level and temperature. Trend analysis shows a statistically significant warming of the air, peat and groundwater, an increase in precipitation, trends of increasing flow in some peatland streams and a decrease in snow cover duration and thickness. The article also provides an assessment of the water balance of the Lammin-Suo mire based on observational data. The database presented and described here is available for download at https://doi.org/10.5281/zenodo.5060039.

KEY WORDS: climate change, database, microtope, ombrotrophic mire, trend analyses, water balance

INTRODUCTION

Long-term hydrometeorological observation stations in the northern latitudes have been significantly reduced in recent years, even though these observations are important for water resource assessment and forecasting in a changing climate (Laudon *et al.* 2017). Wetlands are widespread in northern latitudes, and more than 50 % of the world's wetlands are peatlands (Bragg *et al.* 2003). Peatlands can store large amounts of water, help maintain river flows in dry periods, and make a large contribution to the attenuation of flood peaks (Blackwell & Maltby 2006). Peatlands are a significant carbon store, contain 3–10 times more organic carbon than other terrestrial ecosystems (Joosten *et al.* 2016), and play an important role in climate regulation (Beaulne *et al.* 2021). Considering that over 20 % of north-western Russia is covered with peatlands, studying them is one of the most prioritised hydrological objectives for the region (Boch & Smagin 1993).

The creation of a network of hydrometeorological stations on peatlands in Russia was started in the middle of the 20th century and, at its peak, the network comprised eight peatland stations. The Lammin-Suo Peatland Station (LSPS) was opened in 1950 for the experimental study of wetlands, the development and testing of new measurement devices and methods of observation, and for the training of students and specialists in hydrometeorology. Since then, regular observations of the water table depth in peat (16 peat water wells), groundwater level (13 groundwater wells), stream runoff (five runoff gauges), precipitation (seven rain and snow gauges), meteorology (two meteorological stations), evapotranspiration, peat temperature, snow cover (depth and water content), etc. have been carried out. Now the LSPS is one of only two peatland stations that are still in operation, being a part of the Main Experimental Base of the State Hydrological Institute which also includes the channel hydraulic laboratory, the metrology department, the hydrophysical laboratory, and the remote sensing laboratory (http://www.hydrology.ru/struktura).

The Lammin-Suo mire is located in the north-west of Russia and, according to peatland classification, belongs to the raised bogs, also called ombrogenous mires (Joosten & Clarke 2002). This is the most widespread peatland type in the north-west of Russia, comprising 75–80 % of the total area of mires in this territory (Romanova 1961). In terms of the composition of peatland microtopes Lammin Suo is representative of all peatlands in the forest zone of north-west Russia (Novikov & Batuev 2019).

Based on the observations at LSPS, guidelines were developed for calculating runoff from peatlands (Batuev 2011), various studies related to runoff processes were carried out (Ivanov 1957, Novikov 1991), freezing and thawing, evaporation (Kalyuzhny & Lavrov 2012), hydrophysics (Romanov 1961, Lavrov & Kurbatova 2005), and hydrochemical composition (Potapova & Novikov 2006). In 1976 the Lammin-Suo mire was added to the list of protected areas of Russia to preserve the natural regime of the peatland. Since 2018, the LSPS has been part of the INTERACT (International Network for Research and Monitoring in the Arctic) network of ground field stations, which provides an opportunity for international scientific groups to visit and the development of international cooperation in the study of wetlands (https://eu-interact.org/). Currently, observations are ongoing. In recent years, changes in microtopes and the water regime of the mire have been monitored in connection with climate change (Zhuravleva *et al*. 2023).

The purpose of this article is to present the results of long-term observations at the Lammin-Suo peatland station and analyse changes in the water regime of the mire. All the observational data used in this work are available in the Zenodo database https://doi.org/10.5281/zenodo.5060039. This study highlights the importance of long-term hydrometeorological monitoring programmes on peatlands.

METHODS

Study site

The Lammin-Suo mire (60° 14' 45'' N, 29° 48' 38'' E) is located on the Karelian Isthmus in the north-west of Russia (Figure 1), 40 km from the city of Saint Petersburg. The mire lies in a hollow, elongated from north-west to south-east for 2 km and about 1 km wide, located on the water divide between the Sestra and Chernaya rivers which are part of the Gulf of Finland basin. The area surrounding the peatland is a hilly-hollow, kame-esker (kame-åsar) landscape. The Lammin-Suo mire belongs to the raised bog type

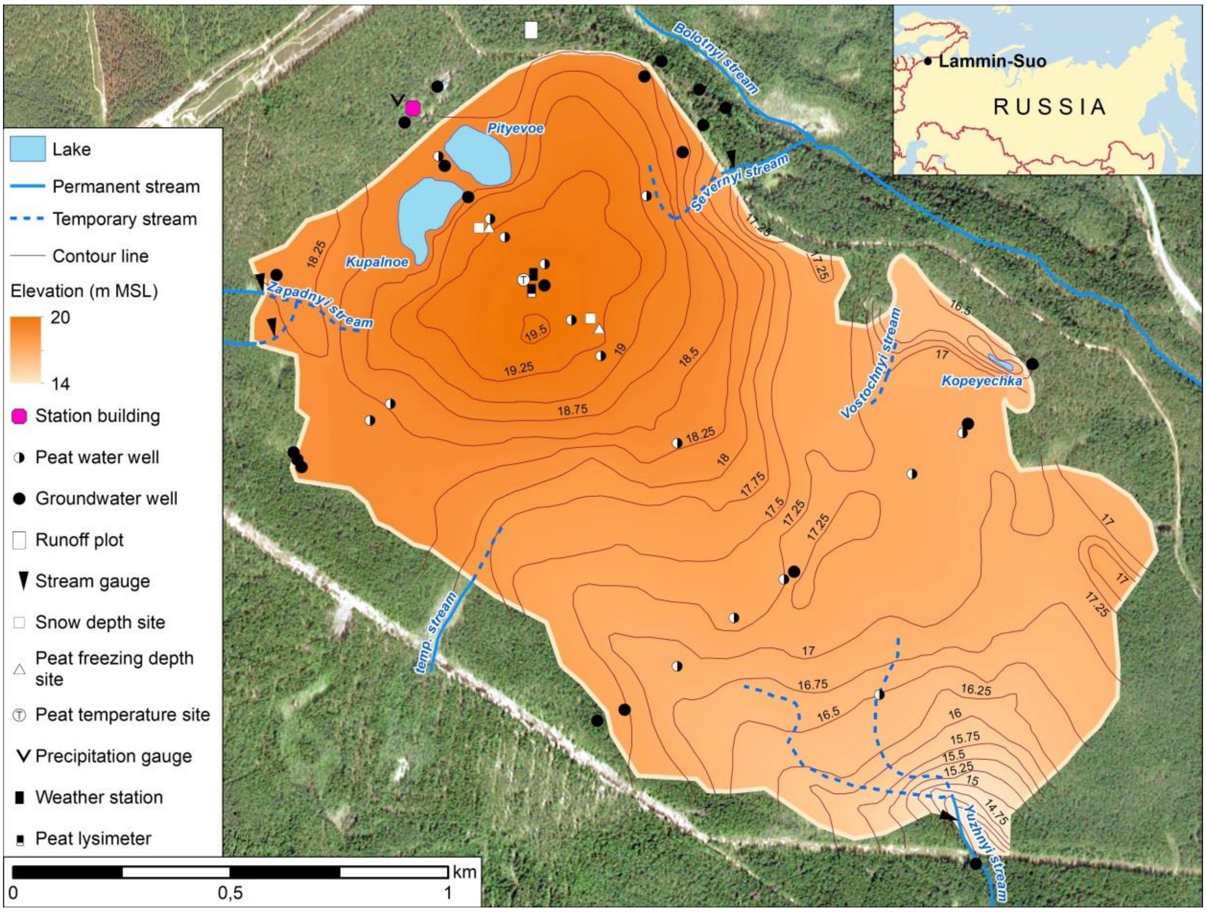


Figure 1. Map of the LSPS indicating locations of observations.

(Galkina 1946). The area of the mire is 1.84 km^2, the average thickness of the peat is 1.9 m, and the maximum depths under the dome reach 4.3 m.

The climate of the area where the peatland station is located is classified as humid continental (*Dfb*) according to the Köppen-Geiger classification (Beck *et al.* 2018). The moderating influence of the Baltic Sea, located around 7 km from the LSPS, results in short but warm, humid summers and long, moderately cold and wet winters.

The Lammin-Suo mire massif is drained by a network of five permanent streams and one temporary stream (Table 1). There are three internal lakes, namely Lakes Pityevoe and Kupalnoe which are separated by a narrow peat-covered stretch of land, and Lake Kopeyechka located at the edge of the eastern part of the mire (Table 2). There are also four water reservoirs on the mire that are completely covered by layers of peat.

The Lammin-Suo mire massif consists of 17 types of microtopes (Minayeva *et al*. 2017) or microlandscapes (Ivanov 1953). A peatland microtope is defined as a peatland area occupied by distinctive vegetation, characterised by the same microrelief and water regime (Ivanov 1953, Minayeva *et al*. 2017).

The forest group of peatland microtopes is distributed mainly in the forest half-ring along the edge of the mire and on its marginal slope (rand). The forest group of peatland microtopes covers 18 % of the total area of the mire. This group is characterised by a well-developed tree layer of pine (*Pinus uliginosa* and *Pinus Litwinow*), and the most common microtope of the forest group is pine - *Sphagnum* - cottongrass - shrub (Figure 2).

The four microtopes belonging to the moss-forest group are quite widespread in the Lammin-Suo mire and together occupy up to 19 % of the mire area. These microtopes are found both on the edge and in the centre of the mire. The tree layer consists of *Pinus Litwinow* and *Pinus Willkommii*, and its height and density are lower than in forest microtopes.

The moss group of microtopes is currently distributed in the central part of the mire. This group is characterised by well-developed moss (*Sphagnum*) and shrub cover, and a tree layer of pine with a crown density of 0.1–0.3. It has covered 7–27 % of the mire area in different observation years.

The moss - grass group is represented by seven microtope types and is widespread in the Lammin-Suo mire, occupying 40 % of the mire area. This group of microtopes is characterised by well-developed moss - grass cover and a sparse or completely absent tree layer (Figure 3).

Table 1. Some characteristics of streams draining the Lammin-Suo mire.

Stream	Catchment area (km^2)	Lakes (%)
Yuzhnyi stream	1.18	0.0
Severnyi stream	0.37	4.1
Zapadnyi stream 1,2	0.32	5.6
Vostochnyi stream	0.10	0.0

Table 2. Characteristics of the peatland lakes.

Lake	Surface area (m^2)	Water volume (m^3)	Average/ maximum depth (m)
Kupalnoe	17900	66900	3.7/10.1
Pityevoe	15300	65750	4.3/12.2
Kopeyechka	5600	13200	2.35/5.7

Figure 2. The forest group of peatland microtopes in the southern part of the Lammin-Suo mire.

Figure 3. The moss - grass group of peatland microtopes in the central part of Lammin-Suo mire.

The complex group of microtopes, which occupies 14 % of the mire area, is represented by one type of microtope - a ridge-hollow complex.

Dry valleys surrounding the mire are covered by coniferous forests with a predominance of pine and spruce. Deciduous species (birch, aspen) are found as individual trees and in small groups (Figure A1 in the Appendix).

An analysis of geobotanical survey materials and a comparison of typological maps from 1950 and 2014 show that changes in the typological characteristics of the Lammin-Suo mire have occurred over this period (Figure 4). There has been a noticeable change in forest growth on individual peatland microtopes. The slopes and edges of the mire have become more forested, as a result of which microtopes that formerly belonged to moss or moss - grass microtope groups have changed to moss - forest and forest groups. Thus, the changes in the typology of the Lammin-Suo mire that have occurred over the last sixty years indicate intense dynamics of peatland microtopes that are apparently related to anthropogenic effects (an increase in the atmospheric deposition of nitrates) and climate change (Novikov & Batuev 2019).

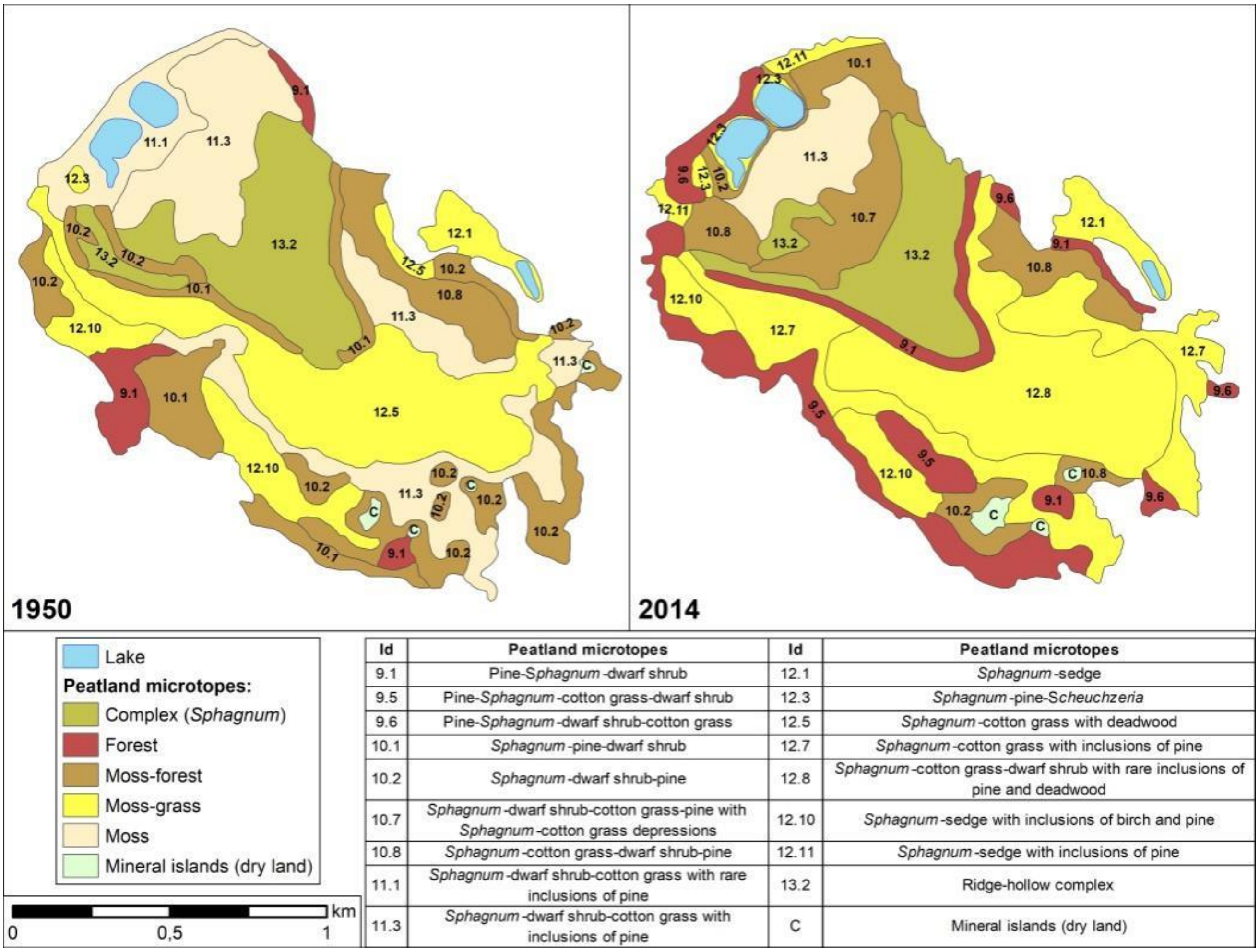
Ninety-five percent of the peat is composed of *Sphagnum*-type peats. The most common are *S. fuscum*, cottongrass - *Sphagnum*, cottongrass and complex peat which account for 32, 18, 15 and 13 % of the peat reserves, respectively. Pine - cottongrass, cottongrass - *Sphagnum* and cottongrass types of (bog) peat often lie directly on the mineral floor of the bog. Fen (birch, tree - sedge, sedge - *Sphagnum*, *Scheuchzeria* and horsetail) peat types are found only in the bottom layers on the edge of the mire and make up about 5 % of the total peat reserves.

Observation network: general information

The observation network of the Lammin-Suo peatland station (Figure 5, Tables A1 and A2 in the Appendix) consists of:

1. Two meteorological stations (1 active, 1 closed).

2. Seven precipitation gauges (2 active, 5 closed).



Id	Peatland microtopes	Id	Peatland microtopes
9.1	Pine-*Sphagnum*-dwarf shrub	12.1	*Sphagnum*-sedge
9.5	Pine-*Sphagnum*-cotton grass-dwarf shrub	12.3	*Sphagnum*-pine-*Scheuchzeria*
9.6	Pine-*Sphagnum*-dwarf shrub-cotton grass	12.5	*Sphagnum*-cotton grass with deadwood
10.1	*Sphagnum*-pine-dwarf shrub	12.7	*Sphagnum*-cotton grass with inclusions of pine
10.2	*Sphagnum*-dwarf shrub-pine	12.8	*Sphagnum*-cotton grass-dwarf shrub with rare inclusions of pine and deadwood
10.7	*Sphagnum*-dwarf shrub-cotton grass-pine with *Sphagnum*-cotton grass depressions	12.10	*Sphagnum*-sedge with inclusions of birch and pine
10.8	*Sphagnum*-cotton grass-dwarf shrub-pine	12.11	*Sphagnum*-sedge with inclusions of pine
11.1	*Sphagnum*-dwarf shrub-cotton grass with rare inclusions of pine	13.2	Ridge-hollow complex
11.3	*Sphagnum*-dwarf shrub-cotton grass with inclusions of pine	C	Mineral islands (dry land)

Figure 4. Maps showing the microtopes recorded at the Lammin-Suo mire in 1950 (left) and 2014 (right).

3. Two setups for measuring peat temperature profiles (1 active, 1 closed).
4. Four sites for measuring evapotranspiration (1 active, 3 closed).
5. Five stream gauges on watercourses starting in the peatland (4 active, 1 closed) and active, 8 closed).one site (runoff plot) for measuring surface water inflow from the surrounding kames.
6. One lake water level gauge and 22 peat water level wells (11 active, 11 closed).
7. Twenty-one deep groundwater level wells (13
8. Six sites for the observation of peat freezing/thawing (2 active, 4 closed).

Until 2000, all data collected at the Lammin-Suo station were published on paper (only), as monthly tables compiled into annual reports. From 2000, the data were presented electronically (only) as Excel spreadsheets of the same structure. To prepare the dataset, all of the paper reports were manually digitised. The data are presented in time series. After preliminary analysis, obvious outlier values (outside reasonable limits) were filtered out and marked with a “QC” (quality control) value equal to zero.

All measurements at the LSPS are reported in local time, which coincides with the Moscow time zone (currently UTC+3). However, direct recomputing into UTC is complicated because, historically, several different patterns of daylight saving time (summer time) have been introduced and cancelled in the USSR and Russia. Therefore, the timestamps in the dataset have been left ‘as-is’, i.e. they are reported in the local time that was used during the year of observation.

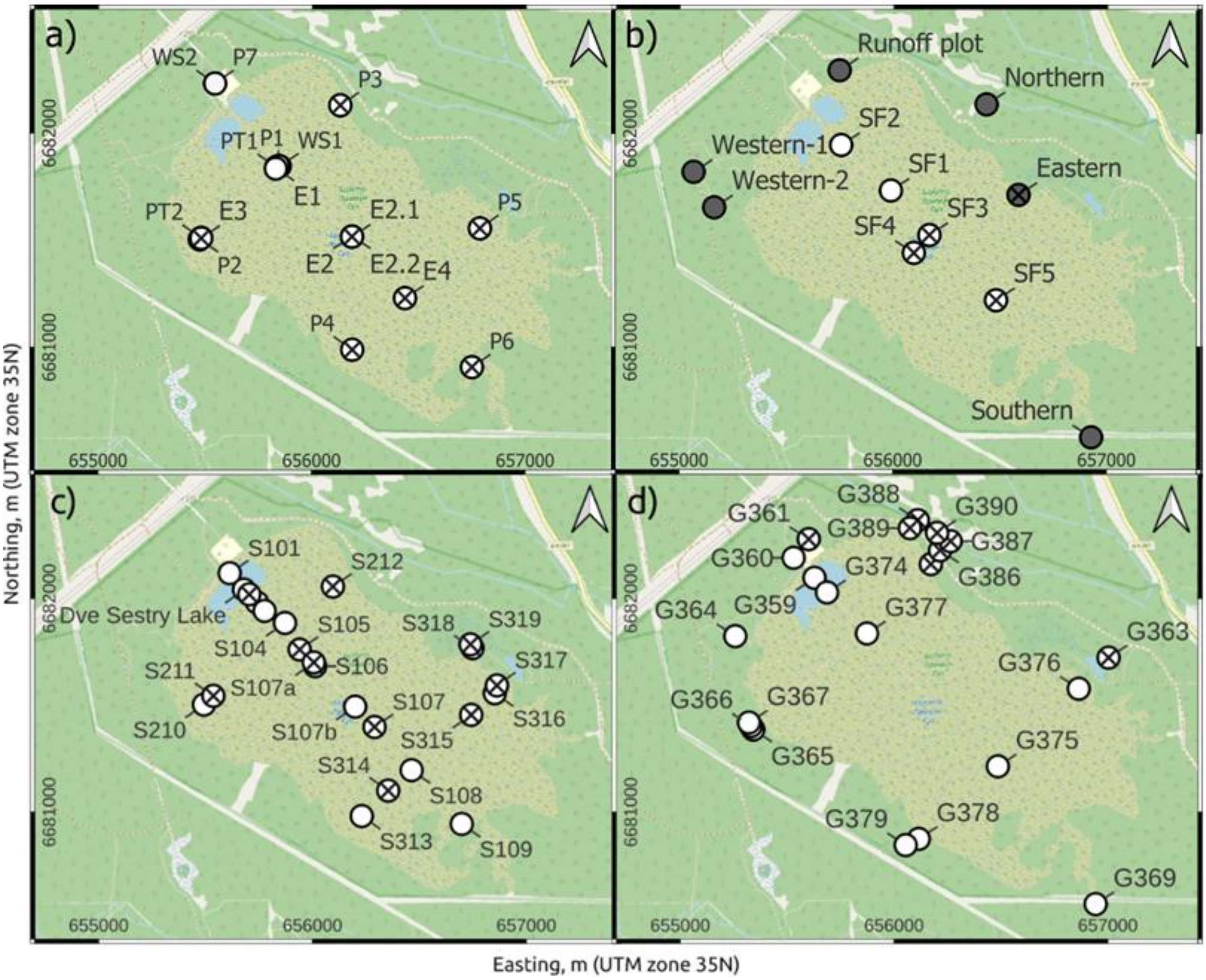


Figure 5. Locations of instruments belonging to the observational network of the Lammin-Suo Peatland Station: a) weather stations (WS), precipitation gauges (P), evapotranspiration measurement sites (ET), and peat temperature measurement profiles (PT); b) discharge measurement gauges (Zapadnyi-1,2, Severnyi, Eastern, Yuzhnyi, Runoff plot) and peatland freezing sites (SF); c) peat water wells (S) and lake water level (Kupalnoe Lake); and d) groundwater wells (G). A cross within the circle means that observations are no longer taken.

Meteorological data

Meteorological observations at the LSPS started in 1952. Until 1965 the observations were conducted simultaneously at two meteorological stations, one (Bolotnaya station WS1) located on the peatland itself and the other (Sukhodol'naya station WS2) surrounded by boreal spruce and pine forest on the elevated kame landform near the station building (Figure 6). Bolotnaya station, where observations are ongoing, is situated on the top of the mire dome where the surrounding vegetation includes *Sphagnum*, dwarf shrub, cottongrass and sparse pine trees. During 1952–1965 air temperature, air humidity, wind speed and depth of snow cover were measured four times per day. In 1965, the observations at the Sukhodol'naya station ended and the frequency of measurements at the Bolotnaya station was increased to eight per day. Details of the instrumentation and the observation timetable are provided in Table A1.

Air humidity is measured in two ways, with a hygrometer (only) in winter, and with a hygrometer and a hygrograph in summer. Hygrometer M-19 is a hair hygrometer. The length of human hair changes depending on humidity, the change in length is amplified by a mechanism and indicated on a scale (Table A1). Hygrograph M-21AC is a hair hygrometer with a clock-driven drum on which the measurement data are recorded for 24 hours per day.

The speed and direction of the wind are measured using Weathervane FVL installed at a height of 10 metres on a M-82-I meteorological mast (Table A1). The wind speed is determined visually as the angle of deflection of the metal plate, whilst the wind direction is indicated by the direction of weather vane rotation.

Precipitation and snow cover

Precipitation is now measured at two gauges, namely P1 located within Bolotnaya meteorological station and P7 at the Sukhodol'naya station (Figure 5a). These two series have been ongoing without major interruptions since May 1952. Historically, there were five additional gauges (numbered 2 to 6) on the mire. These raingauges were measured during the growing season only (from April/May to October) between 1963 and 1976 (1975 for P6)

Precipitation is measured once per day (at 15:00) in winter and twice per day (9:00 and 15:00) in summer. The precipitation data are given as a daily total in mm. Precipitation form (solid or liquid) has been recorded only since 1964. The instrumentation is uniform, with all the gauges being the well-known Tretyakov non-recording precipitation gauge (Figure 7). Detailed accuracy reports on the use of this instrument can be found in Yang *et al.* (1995) and Yang & Simonenko (2014).

Peat temperature and surface freezing/thawing

Observations of peat temperature at the LSPS are carried out at two locations, namely PT1 and PT2 (Figure 5a).

Monitoring of peat temperature started in 1953 at one site near the Bolotnaya meteorological station. Until 1958, soil point electro-thermometers were used for these measurements. The data are noisy and contain a significant number of outliers, presumably owing to the low precision of the equipment (Table A2). The data are included in the dataset as a separate file.

Since 1954, the peat surface temperature has been measured with thermometer TM-3 in summer and with low-degree thermometer TM-9-1 during winter;

Figure 6. Photographs of the Bolotnaya meteorological station in 1960 (left) and 2021 (right).

the temperature of the shallow horizons at 5–15 cm with thermometer TM-5; and the temperature at 20–320 cm with soil-depth thermometers TM-10. In summer 1963, additional measurements were started in the south-western part of the mire and these continued until 1994. Until the end of 1976, peat temperatures were reported as daily means. In 1977, shallow measurements (5–15 cm) ceased but other data were reported as instantaneous values at particular times. The frequency of these measurements ranged from one to three observations per day. The only observation time available throughout the whole period of 1976–2020 is 15:00. A detailed description of observations is provided in Table A2. The longest homogenous series starting from 1954 is the one recorded at the peat surface on the dome of the mire, using maximum thermometer TM-1 and minimum thermometer TM-2.

Observations of the freezing and thawing of the peat surface are carried out at several fixed locations SF1–5 (Figure 5b). The size of these sites is 250 m^2 (50 × 50 m). The freezing depth measurements are paired according to the character of the microrelief, either on a hummock and in a depression or on a ridge and in a hollow. The paired measurements are made at each of the four corners of the site, without disturbing the snow cover (Table A3). Each year, the observations start in autumn once the average daily air temperatures are persistently below freezing, and are then repeated every ten days until the peat is completely thawed. These measurements continue nowadays at only two sites (SF1 and SF2). The longest series starting from 1954 is the one recorded at SF1.

Evapotranspiration

Evapotranspiration (ET) is measured directly by the weighing method, using the peat lysimeter model GGI-B1000 (Toebes & Ouryvaev 1970) which contains a peat monolith with natural vegetation. Measurements are performed every ten days during the growing season, to determine the amount of ET between observations. This is done by measuring the mass of the peat monolith, taking into account the precipitation that fell during the same period and the peat water level.

Lysimeters were initially installed at six sites located in different microtope types (Figure 8). Observation intervals for all the lysimeters are listed in Table A4. Two ET measurement setups E2.1 and E2.2, installed at the same location but in different microtopes, were substituted after 1970 with the single station E2 (Figure 5a). After 1976, all observation sites except E1 were closed. Only one measurement site is currently in operation, and this site provides the longest ET time series from the Lammin-Suo peatland.

Evapotranspiration is measured only during the warm half of the year. Exact dates of the start and end of ET observations are chosen every year using mean daily temperature trends. Typically, observations span the period from April to the end of October and are made three times a month, once between the 1st and 11th days, once between the 11th and 21st, and once between the 21st and the last day of the month. First and last thirds may be truncated at the start and end of the observation season, meaning that each observation period may include a number of days between 1 and 11.

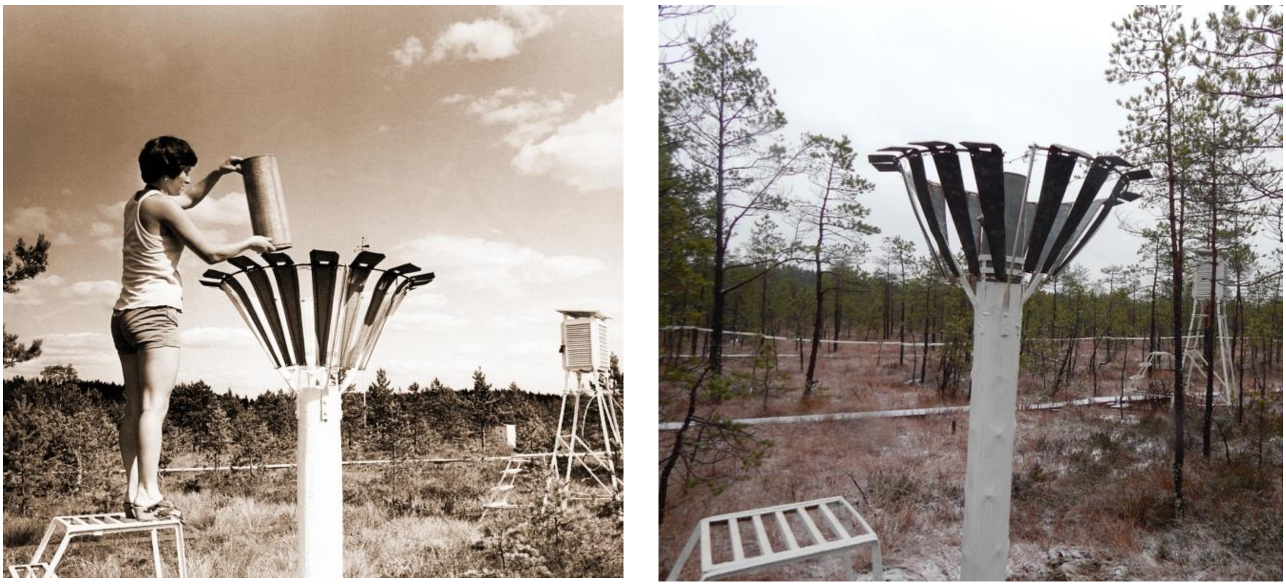


Figure 7. The Tretyakov precipitation gauge at Bolotnaya station in 1960 and 2021.

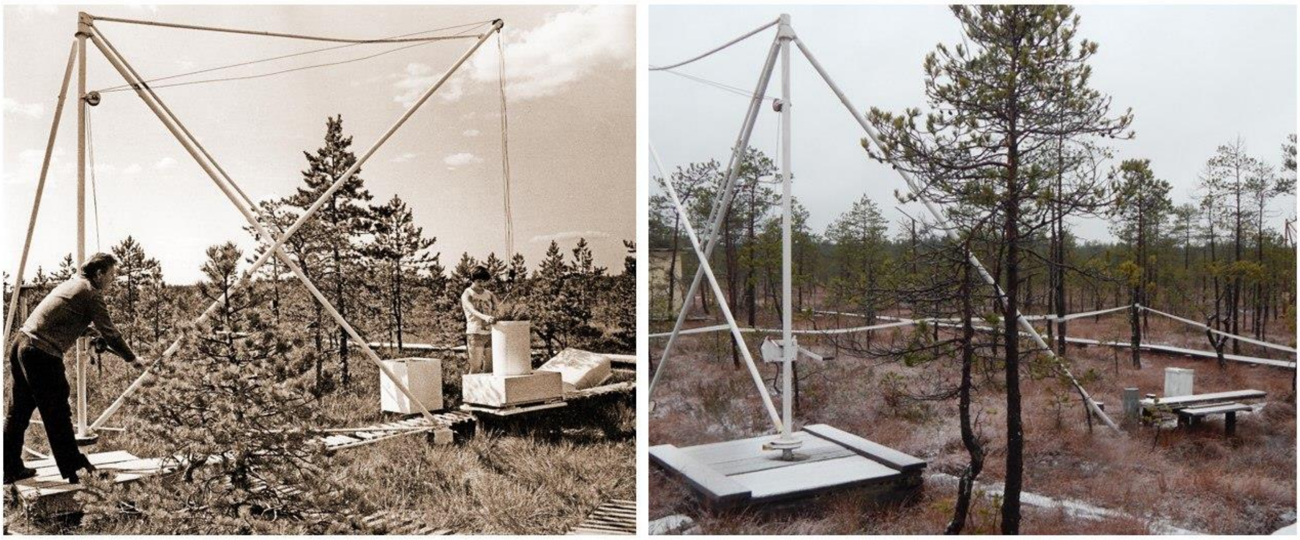


Figure 8. Peat evaporimeters in 1960 and 2021.

Water discharge

Four permanent watercourses and a single temporary one discharge water from the mire. Each of the streams is equipped with a thin-walled triangular (V-notch) weir with wooden inlet and outlet channels (Figure 9). Float water level recorders are installed on the weirs. Two types of recorders are used at the Lammin-Suo station - model GR-38 on the Zapadnyi 1, 2 and Severnyi streams, and the “Valday” level recorder on the Yuzhnyi stream and at the Runoff site drainage area (Table A2). The water level is recorded continuously during the warm period of the year by a pen-on-paper strip chart recorder. These observations are supplemented by manual measurement of the level every five days year-round.

The relationship between stage (H) and discharge (Q) is established for each stream gauge by measuring the stage and corresponding discharge. Then, rating curves are developed for each gauging station based on the Q-H relationships and regular calibrations.

Water inflow into the mire as slope runoff is measured at the Runoff plot (Figure 1), which is located on the slope of the esker ridge at the north-western edge of the mire. The catchment area of the plot is 400 m^2 (20 × 20 m) and the average longitudinal slope is 15 %. Runoff from the plot enters the drainage gutter which directs it into a tank housed in a special pavilion. A “Valday” level recorder installed in the tank detects level changes continuously during the warm season. Simultaneous manual measurements of the level are carried out once a day.

Figure 9. The thin-walled triangular (V-notch) weir on the Zapadnyi stream 1.

Peat water level

Water levels are measured manually inside peat water wells and at the level gauge on the Kupalnoe lake. The surface of the lake is covered by a floating mat of vegetation. Measurements are made once every five days throughout the year except at the reference well S104, where observations were daily until 1986 and subsequently daily during the warm period and once every five days in winter. The peat water levels are measured relative to the peat surface level in the area around each well. All of the wells and their observation periods are listed in Table A3. The longest time series (71 years) are available from nine wells (Table A5).

Peatland surface elevation

Observations of peatland surface elevation are carried out by the linear elevation method. The principle of the method is to determine the height of the peatland surface at a number of points along a line of a certain length (elevation line). The elevation line crosses an area with uniform vegetation, physical conditions and microrelief. One absolute surface elevation is obtained for each elevation line through static processing of the measured values. The elevation lines are centered on groundwater and peat water wells. Measurements are performed during the growing season, once every five years.

Groundwater level and temperature

Groundwater levels in mineral soil were measured manually inside groundwater wells. The depths of the wells range from 2 m to 18.4 m. Measurements are made daily or once every five days throughout the year. Groundwater levels are given relative to the surface elevation of the area around each well, with surface elevations measured every five years (1970–1995). Since 1965, 21 wells have been installed (5 wells within the mire and 16 wells in the surrounding forest) (Figure 5d). Currently, only 13 wells are being monitored (Table A6).

Water temperature in the groundwater wells was measured manually with a meteorological mercury thermometer (TM-10). Measurements were taken on the 10^{th}, 20^{th} and last day of every month of the year (Table A2).

Statistical analysis

For the available data collected from LSPS during 1952–2020, we carried out trend analysis using the Mann–Kendall test criterion with significance level $\alpha = 0.05$ (Mann 1945, Kendall 1975) and Sen's slope estimator (Sen 1968).

Water balance estimation

We assessed the Lammin-Suo mire water balance based on observations from the period 1956–2020. Although observations at LSPS began in 1952, the measurements of some elements of the water balance began later: evapotranspiration in 1956; slope inflow to the mire from the runoff plot in 1963; and runoff from the Zapadnyi stream in 1955.

A general form of the water balance equation (in mm) is as follows:

$$P + Qslope - E - Esnow - Qstream + W = S \quad [1]$$

where P is the sum of daily precipitation (including rainfall and snow) from the gauge P1 during the hydrological year, $Qslope$ is the slope inflow measured at the Runoff plot (but note that calculation of the water balance from 1956 to 1962 did not take this factor into account), and E is evapotranspiration measured in the LSPS (E1) during the warm season. $Esnow$ (evaporation from snow) was calculated using Kuzmin's simplified formula (Kuzmin 1972) which is recommended for calculating evaporation over a month or longer periods (Lavrov 2023):

$$Esnow = 0.5n(e_0 - e) \quad [2]$$

where n is the number of days in the time interval chosen for the estimation, e_0 is the water vapour pressure at the height of the air temperature (WS1), measurement, e is the saturated water vapour pressure at the measured temperature of the snow surface temperature. $Qstream$ is the observed total runoff from the Lammin-Suo mire during the hydrological year, including runoff via the streams Yuzhnyi, Severnyi and Zapadnyi 1, 2. From 1971 to 1988, the total runoff also includes runoff via the Yuzhny ochnyi stream. W is the change in water storage in the active layer (acrotelm) of the Lammin-Suo mire, calculated from changes in the peat water level at the central well S104 (Brust *et al*. 2018) as follows:

$$W = \Delta z(1 - (SV + FP)) \quad [3]$$

where Δz is the change in the average annual peat water level, SV is the volume of peat substrate and FP is the volume of permanently water-filled fine pores (Romanov 1961). S is the water balance discrepancy including diffuse (surface or subsurface) water outflow/inflow at the boundaries of the mire and the measurement error of water balance elements.

RESULTS

Meteorological variables

Figure 10 shows the intra-annual variability of air temperature at the Bolotnaya station during the observation period 1967–2020. Daily mean air temperatures are typically above zero in the months between May and October. Therefore, the data are analysed by hydrological years (01 November in any given year to 31 October in the following year).

A maximum daily air temperature of +35.8 °C was recorded on 07 August 2010, during the extraordinary 2010 heatwave in western Russia (Dole *et al.* 2011, Otto *et al.* 2012). The minimum daily air temperature of -45.6 °C that was observed on 12 January 1987 is about 10 °C below the lowest record from the weather station in St. Petersburg.

Mean air temperatures in summer increased steadily during the observation period. The trend is significant ($\alpha = 0.05$) and equals +0.19 °C per decade or about +1.4 °C since 1967 (Table A7). An increase in the winter means began only in the late 1980s. A report about climate change in Russia (Frolov *et al*. 2014) suggests that the breakpoint in the climatic time series for the Russian territory occurred in 1976. Since then, the average winter warming at Lammin-Suo peatland equals +1.04 °C per decade, which is much more prominent than the summer warming and, moreover, is the highest value within the European part of Russia (Frolov *et al*. 2014). As a result, the winter of 2019–2020 was the first with a positive mean temperature of +0.1 °C (Figure 11). The year 1989 was the warmest overall, with an annual average air temperature of +5.8 °C; while 1987 was the coolest year with an annual average temperature of +1.2 °C.

Mean air humidity also increased over the period 1952–2020. The trend is significant ($\alpha = 0.05$) and equals +0.16 mbar per decade and the wind speed at LSPS decreased by 0.09 m s^{-1} (Table A7).

Precipitation and snow

Averaged intra-annual variability of the precipitation is shown in Figure 12. Solid precipitation was never observed between mid-May and the beginning of October, while liquid precipitation may occur year-round.

Comparing the two longest precipitation series (1952–2020) from gauges P1 (Bolotnaya) and P7 (Sukhodol'naya) does not indicate any significant difference between precipitation measured inside and outside the mire. Comparing the time series of precipitation amounts measured at different gauges over the longest available overlapping intervals using Pearson correlation reveals high coefficients (0.97–0.99) amongst all instruments. This means that trends can be analysed based solely on one of the gauges.

While the overall trend in the total precipitation amount is positive (Figure 13a) and equal to +36.8 mm per decade, the data demonstrate a short period of reduced precipitation between the late 1980s and mid-1990s. The fraction of solid precipitation decreases by 1.3 % per decade, which is consistent with the increase of winter air temperature (Table A7). The amount of snowfall and the snow/precipitation (S/P) quotient during the winter of 2019/2020 were the lowest on record owing to high winter air temperatures (Figure 13b).

Snow depth is an average of three measurements taken daily at three snow gauges installed at the Bolotnaya weather station. Maximum snow cover thickness of 119 cm was reported in March 1984. The

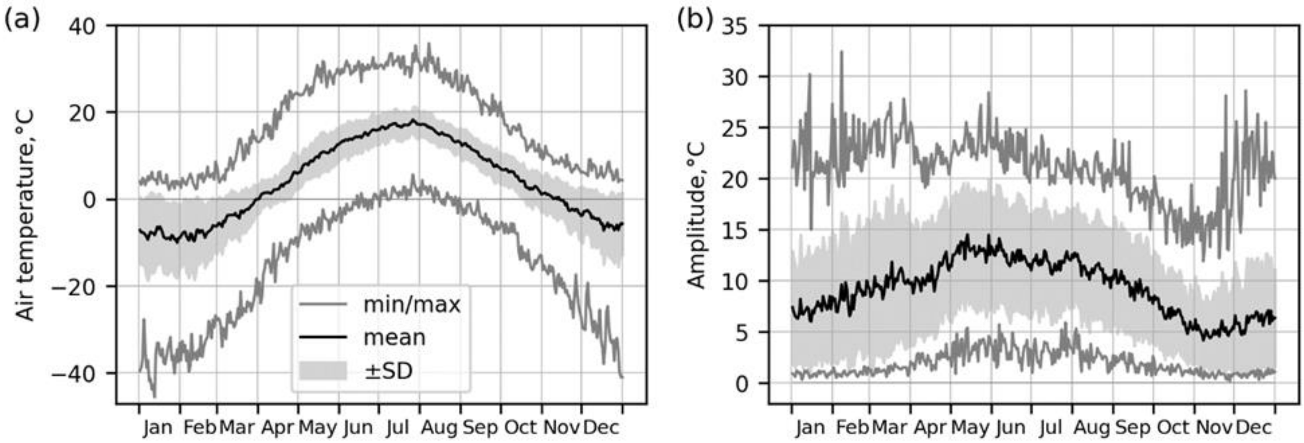


Figure 10. Intra-annual variability of the air temperature (a) and its daily amplitudes (b) during 1967–2021 at the Bolotnaya meteorological station.

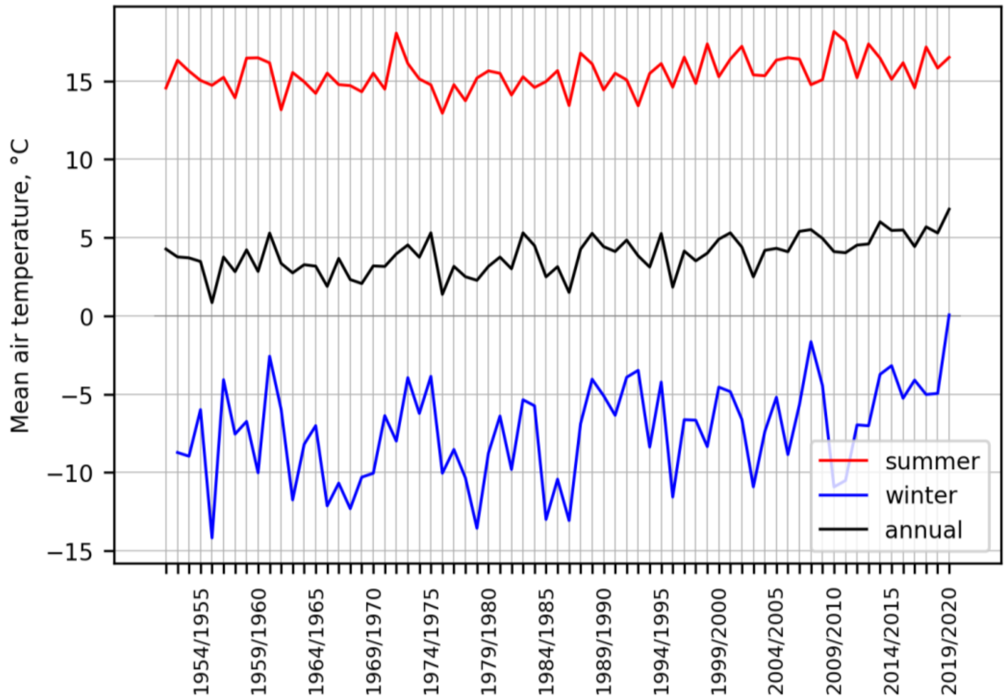


Figure 11. Mean summer (Jun–Aug) and winter (Dec–Feb) temperatures at the Lammin-Suo peatland by hydrological year starting 01 November.

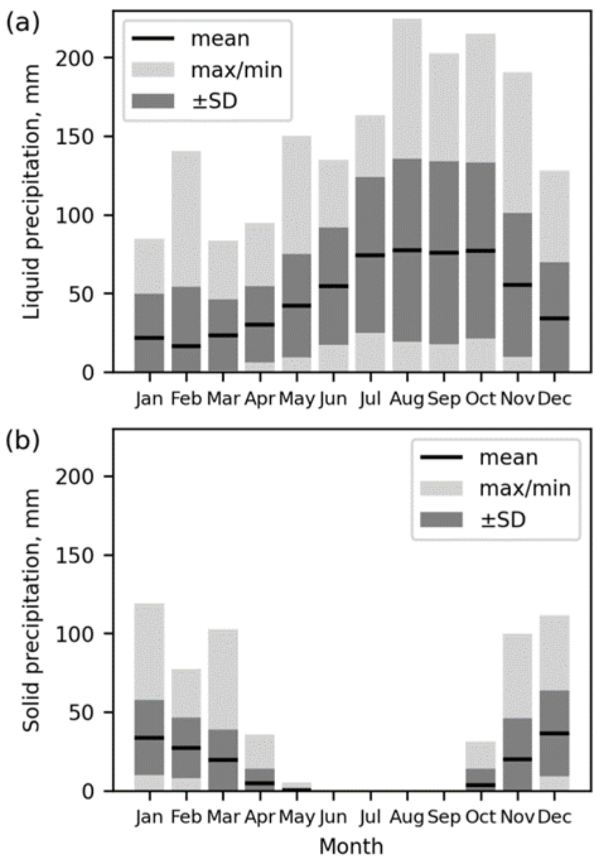


Figure 12. Averaged intra-annual variability of the monthly amounts of (a) liquid and (b) solid precipitation at gauge No. 1, 1967–2021.

series from the Lammin-Suo peatland demonstrates the change in trend in the late 1980s (Figure 14). This change is consistent with the regime shift detected for all of the Eastern Baltic countries (Jaagus *et al*. 2017, 2018). The trend since 1988/1989 is about -4.7 cm per decade (Table A7). While the total amount of solid precipitation measured at the gauges over the entire period does not decrease, the rising air temperature results in a higher frequency of thaw periods.

Peat temperature and surface freezing/thawing

The peat temperature observations since 1977, reported as hourly values, are presented in the form of averaged intra-annual plots in Figure 15. The variation of surface peat temperature is generally synchronous with changes in air temperature. Annual amplitudes decrease and the time delay of the maximum annual temperature increases with depth. Cross-correlation between peat temperature time series at different depths indicates time lags between the peat surface and underlying layers of 21 days at 20 cm, 30 days at 40 cm, 47 days at 80 cm, 74 days at 160 cm and 151 days at 320 cm. As a result of the time delay, the maximum peat temperature at 320 cm depth is observed during December. The temperature of the peat below 40 cm depth never falls to the freezing point of water, at least in daytime (15:00).

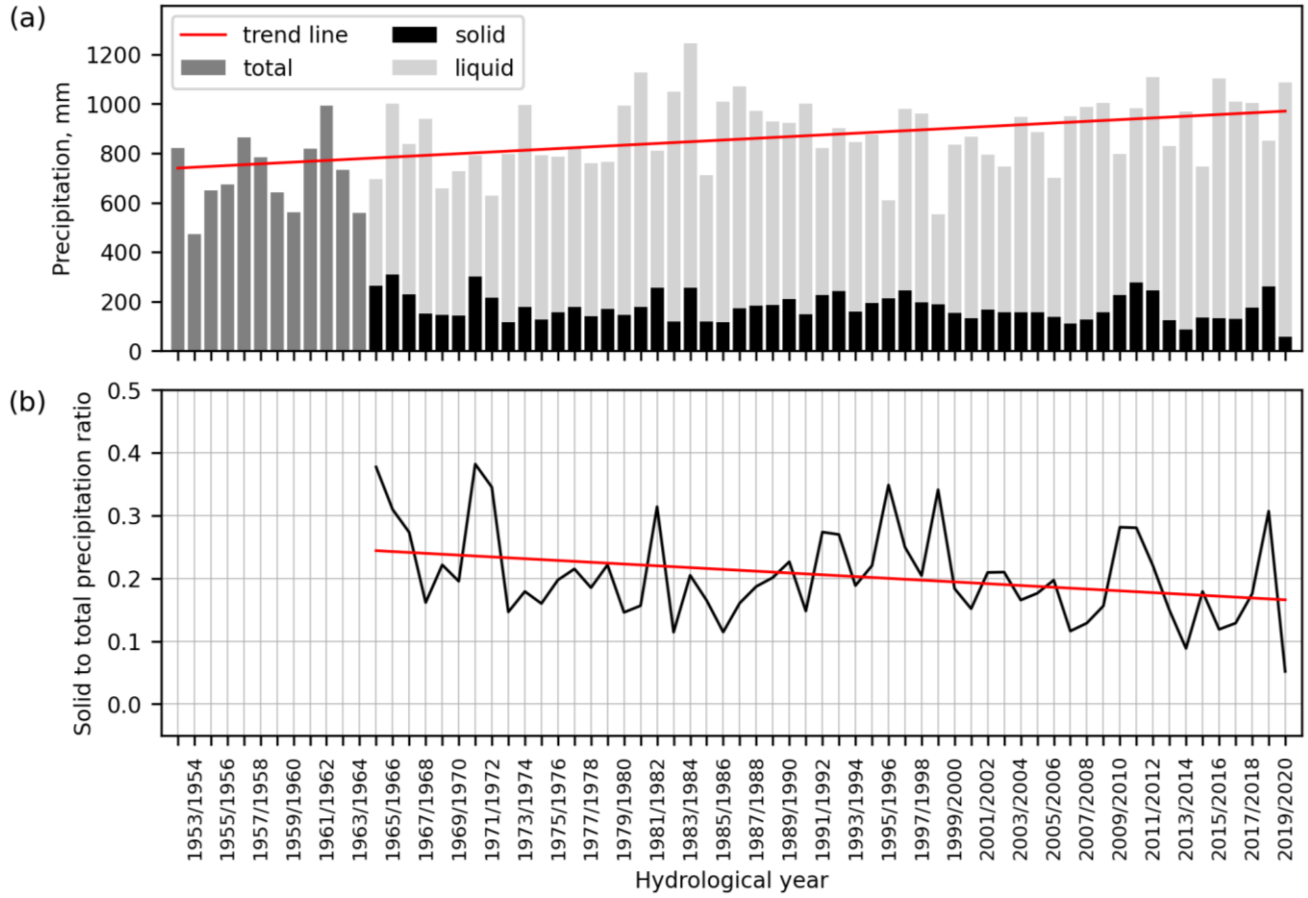


Figure 13. Precipitation amounts (a) and the solid to total precipitation (*S*:*P*) ratio expressed as the quotient *S*/*P* (b) per hydrological year, as measured with gauge P1 at the Lammin-Suo peatland.

Annually averaged values of peat surface temperature during the two homogeneous parts of the data series from site 1 are shown in Figure 16. The two parts cannot be compared directly because daytime temperature (at 15:00 hours) was recorded after 1976 whereas the earlier values are daily averages. However, both parts demonstrate an increase in surface temperature (the trend since 1976 is significant +0.62 °C per decade) and the warming reaches the underlying peat layers (the trend at 320 cm, which is the maximum available depth, is +0.24 °C per decade).

Since our records began in 1954, the depth of the frozen layer has exceeded 40 cm only once, in February–March 1973 at 42 cm depth in both hummock SF5 and hollow SF3. The possible reason is that 1973 had the least snow accumulation during the 20th century. Interannual variability of surface freezing at the site is shown in Figure 17.

Evapotranspiration

Evapotranspiration during the warm season (end of April to beginning of October) decreased. The trend is significant (α = 0.035) and equals -10.0 mm per decade (Table A7).

The maximum annual evapotranspiration (446 mm) was recorded in 1966, and the minimum (171 mm) in 1978. The variability (interannual and intra-annual) of evapotranspiration measured at the Lammin-Suo station is shown in Figure 18.

Water discharge

The largest stream of the LSPS (Yuzhnyi stream) provides 64 % of the total flow, while Zapadnyi stream 1 and 2 provide 20 % and Severnyi stream provides 16 %. Most of the flow at the LSPS occurs in spring (April and May), and there is minimal flow in winter (January and February) and summer (June and July). Rainfall floods are typical for the end of summer and autumn (Figure 19).

Due to the decrease of *S*/*P*, we observe a gradual lowering of the spring water level maximum during the snowmelt season. The observed increase in runoff and precipitation does not occur in a uniform manner. Over the period 1950–2020, the amount of annual precipitation increased by 230 mm while the total

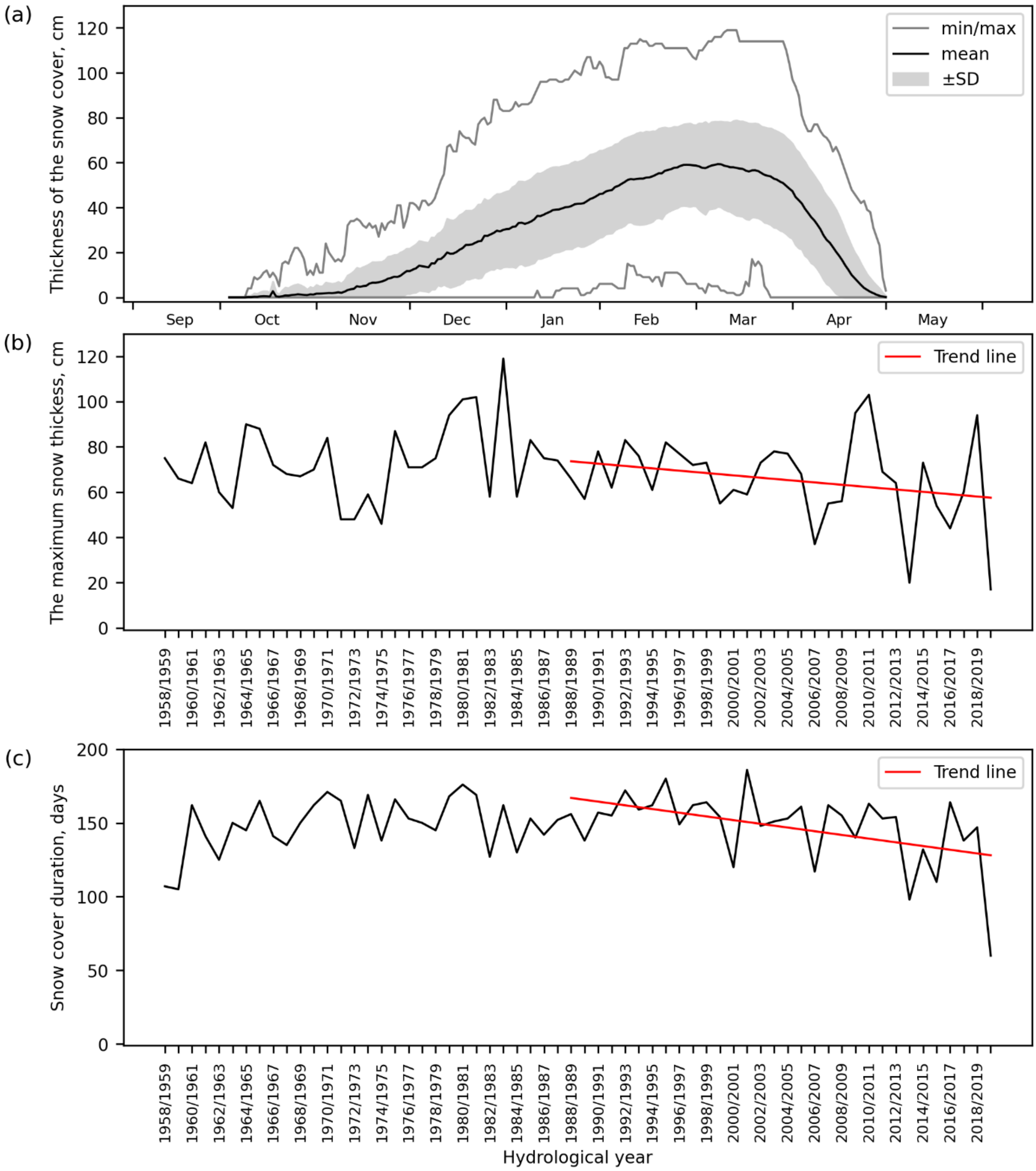


Figure 14. Intra-annual variability of the thickness of snow cover (a), the maximum snow thickness during the spring season (b), and the number of days with snow cover (c) at the Lammin-Suo peatland.

runoff increased by only 87.5 mm (Figure 20). This is probably due to afforestation of the edges and central part of the mire, which has been observed since 1990. Canopy growth and increased root uptake reduce the net input of water to the peatland due to increased interception and transpiration.

The analysis of stream runoff shows a general increase (of 15.6 mm decade^{-1}) in annual values for the mire (Figure 21) although statistically significant positive trends were demonstrated in only two streams, namely Severnyi (northern) (1.57 mm decade^{-1}) and Zapadnyi (western) (3.79 mm decade^{-1}).

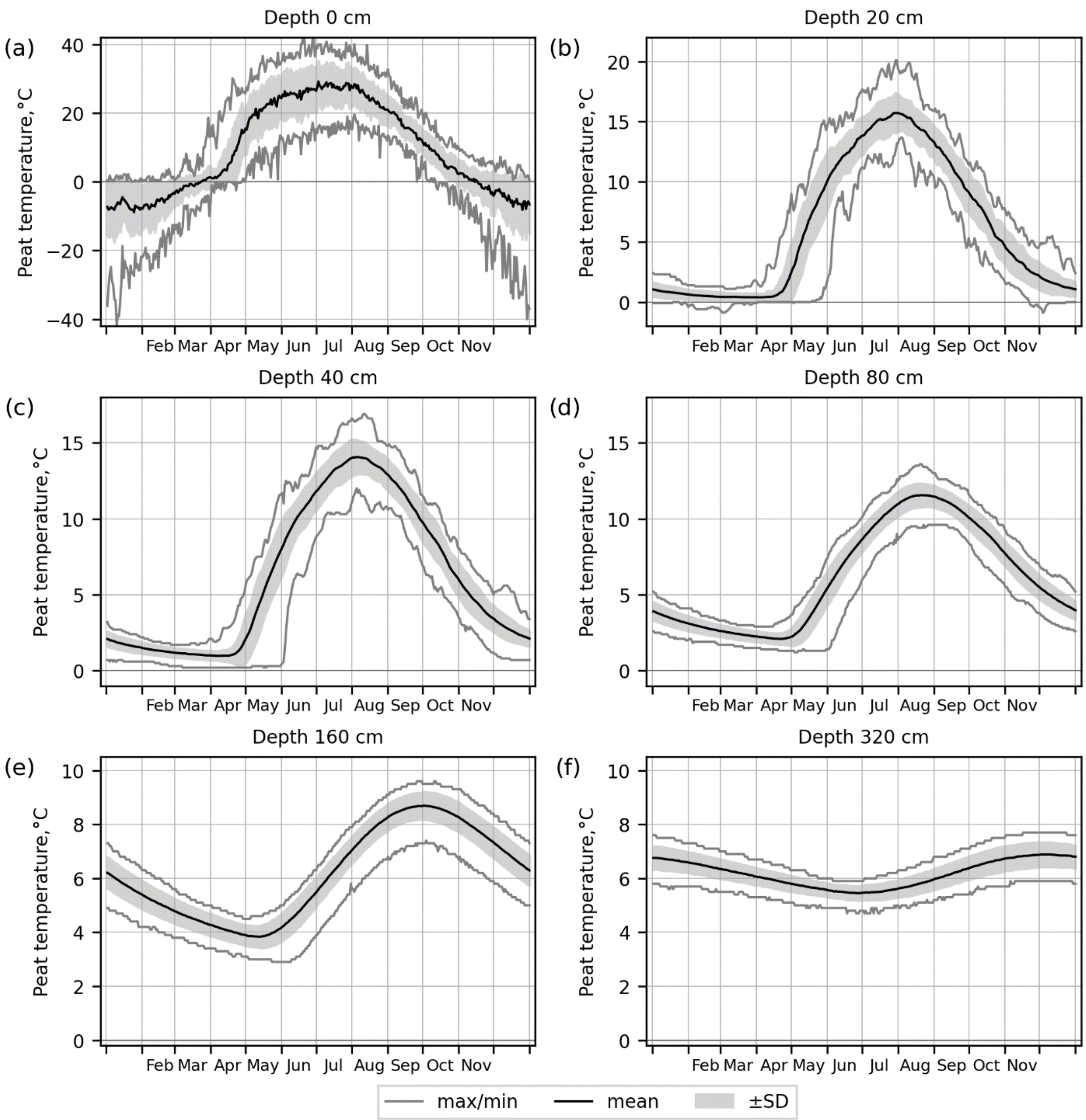


Figure 15. Intra-annual variability of the peat temperature (15:00) at different depths during 1977–2020. Note the different vertical scales.

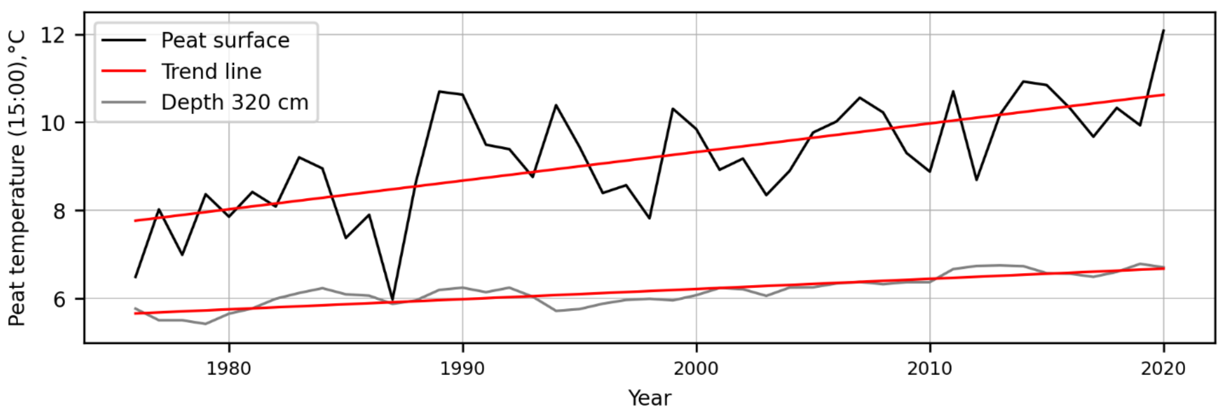


Figure 16. Mean annual temperatures of peat at the Lammin-Suo Peatland Station.

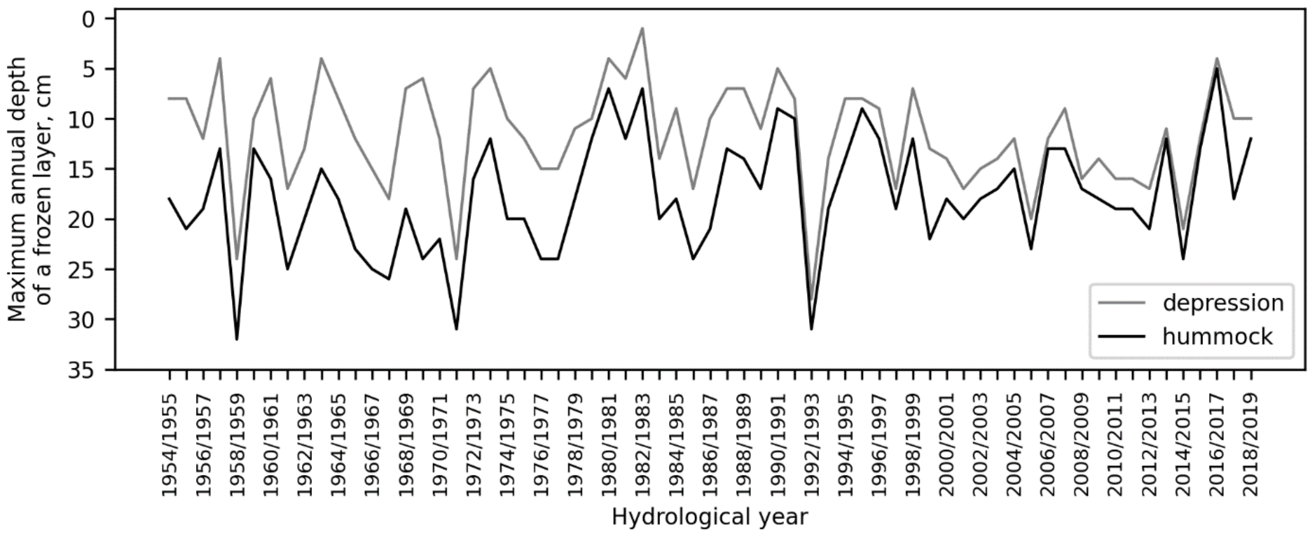


Figure 17. Maximum annual depths of the frozen surface layer of peat.

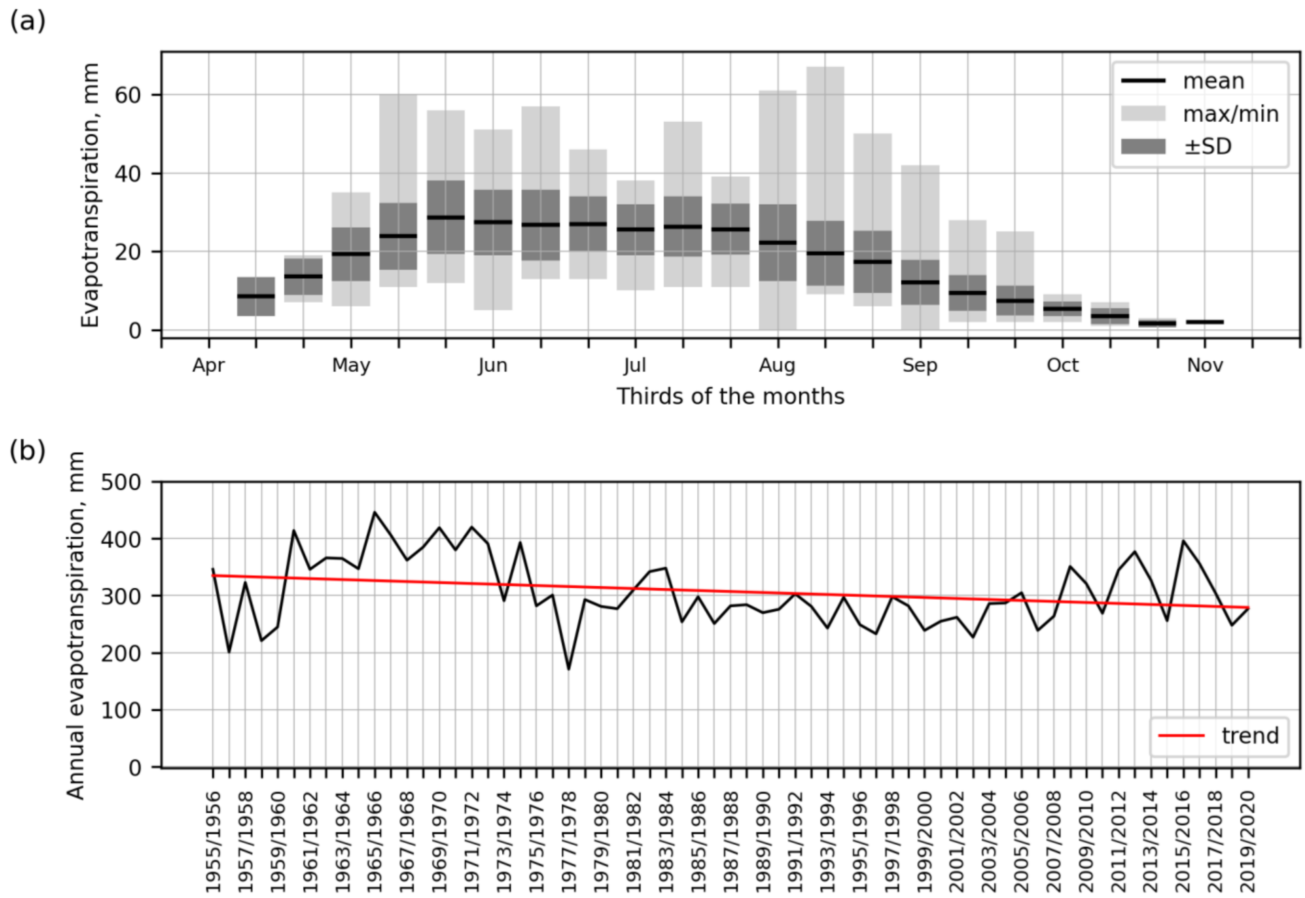


Figure 18. Intra-annual (a) and interannual (b) variability of measured evapotranspiration at the Lammin-Suo station during 1956–2020, site E1.

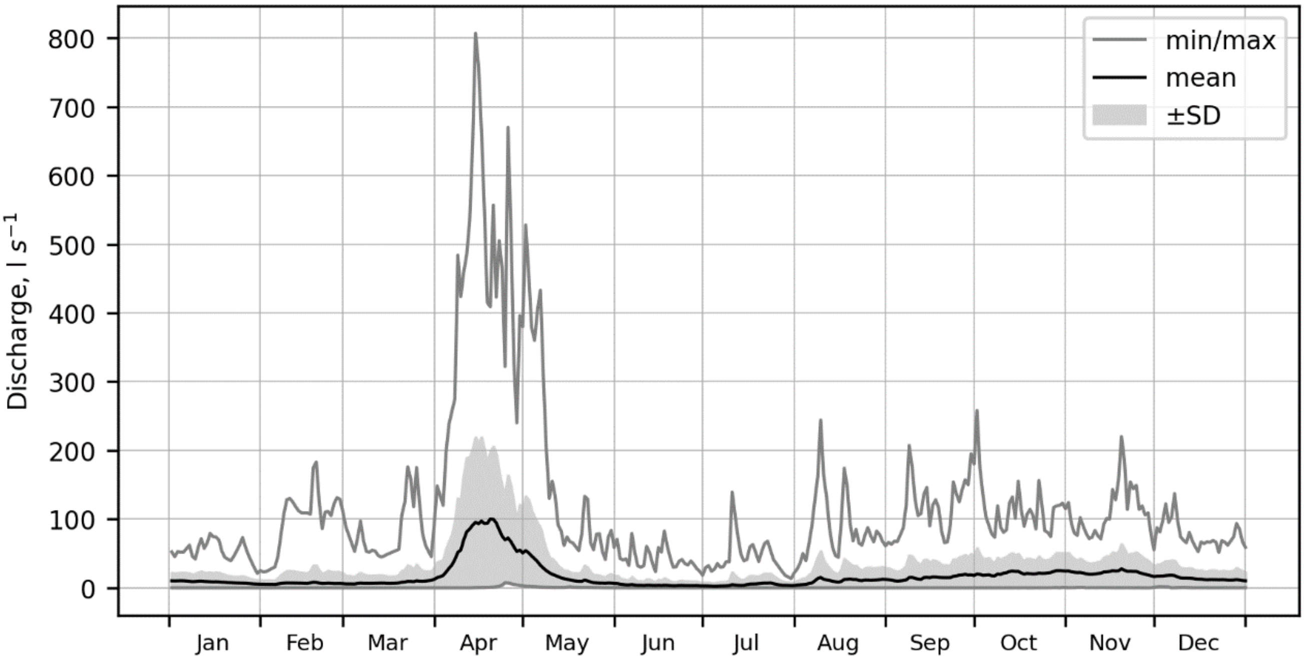


Figure 19. Averaged (1950–2020) hydrograph for the Yuzhnyi stream flowing from the Lammin-Suo peatland.

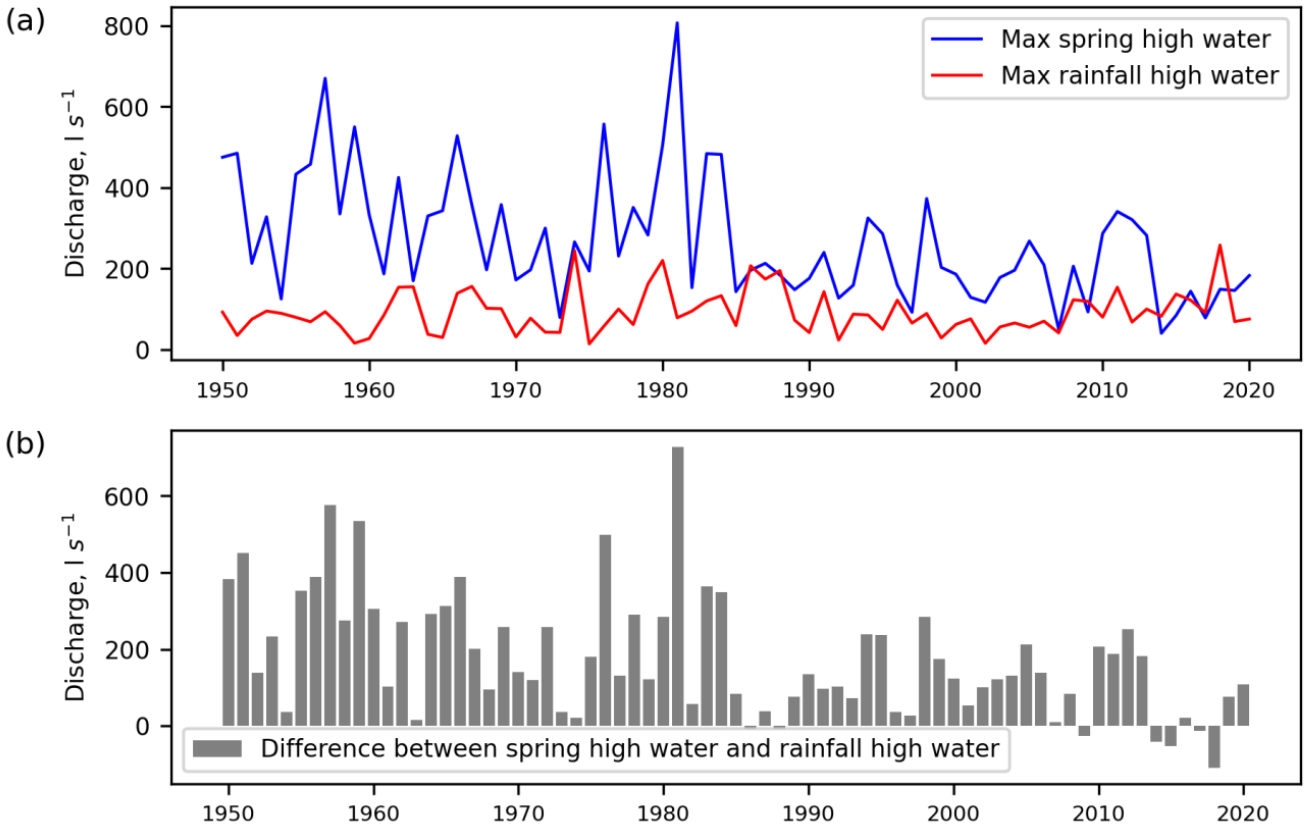


Figure 20. Decadal changes in high water levels caused by spring snowmelt and by rainfall for the Yuzhnyi stream flowing from the Lammin-Suo peatland.

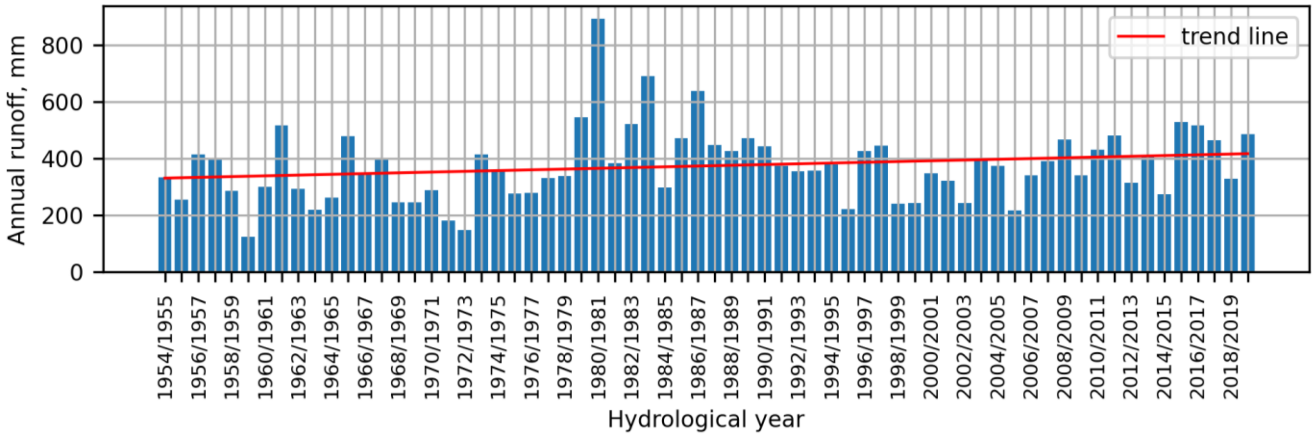


Figure 21. Interannual variability of total runoff from the Lammin-Suo peatland.

Peat water level

Peat water level values and their long-term regimes are determined mainly by the location of the well within the mire. Considering the long-term fluctuations of water level in the peat, wells located in the central part of the mire will deliver the smallest values and wells on the edges of the mire the largest.

The average annual value of peat water level ranges from -11 cm (S313) to -41 cm (S109) relative to the surface of the mire. The highest average levels are observed at wells S210 (-12 cm) and S313 (-11 cm), located on the southern edge of the mire (Figure 22). In the central part of the mire, where the peat capacity is maximum (wells S102a, S103, S104), the long-term average peat water level is -20 cm and has changed only slightly over the 70-year observation period. The lowest long-term average water level (-41 cm) was observed at well S109, located in the south-eastern part of the mire.

There has also been a dramatic drop in the peat water level. Since 1980, the water level in the vicinity of S109 has dropped by more than 30 cm. The annual average value for the entire observation period is -41 cm, while the lowest annual average value of -68 cm was observed in the 2018–2019 hydrological year.

Peatland surface elevation

Surface elevation in different parts of the mire changed in various ways. Data on peatland surface dynamics is limited to the period 1965–1995 because measurements were not made from 1995 to 2020. In the part of the mire with the maximum peat thickness (the area around wells 102a, 103 and 104), changes in surface elevation were smallest and did not exceed 3 cm. A positive increase in surface elevation is observed in the area of wells 101 (+9 cm), 106 (+10 cm) and 109 (+11 cm). Near to well 106, the ridge-hollow microtope changed to a moss-forest microtope due to the desiccation of hollows. In the area of well 109, forest growth is observed. The greatest lowering of the peatland surface was recorded on the mire edges where moss - grass microtopes predominate (0.24 cm at well 108, -0.17 cm at 210, -0.25 cm at 313) (Figure 23).

Groundwater level and temperature

The long-term mean groundwater position ranges from 0.09 m above the soil surface in well 364 to -7.29 m in well 377 located in the central part of the mire. At most wells, the minimum annual average levels of GW were observed in the period 1965–1979 and the highest in the period 1980–1989. In the period 2010–2020, a gradual increase in the level of GW is observed at all wells.

The largest ranges of average annual GW level are observed at wells 360, 369 and 376 (Figure 24). At well 360, which is located on the slope of the kame ridge, the range of the annual average values is 1.8 m and the long-term average GW level is -4.6 m. Well 369 is located on the south-eastern edge of the swamp next to the Yuzhnyi stream, and here the range of annual average GW level is 1.6 m while the long-term average level is -1.28 m. At well 376, located on the north-eastern edge of the swamp, the amplitude of annual average GW level fluctuation is 1.7 m and the long-term average level is -3.2 m.

Intra-annual changes in the groundwater level have a delay relative to the peat water table of about 1–2 months (Figure 25).

Groundwater temperature averaged across the eight wells (Figure 26) increased by 0.27 °C per decade, or by 1.22 °C during the last 45 years (1975–2020).

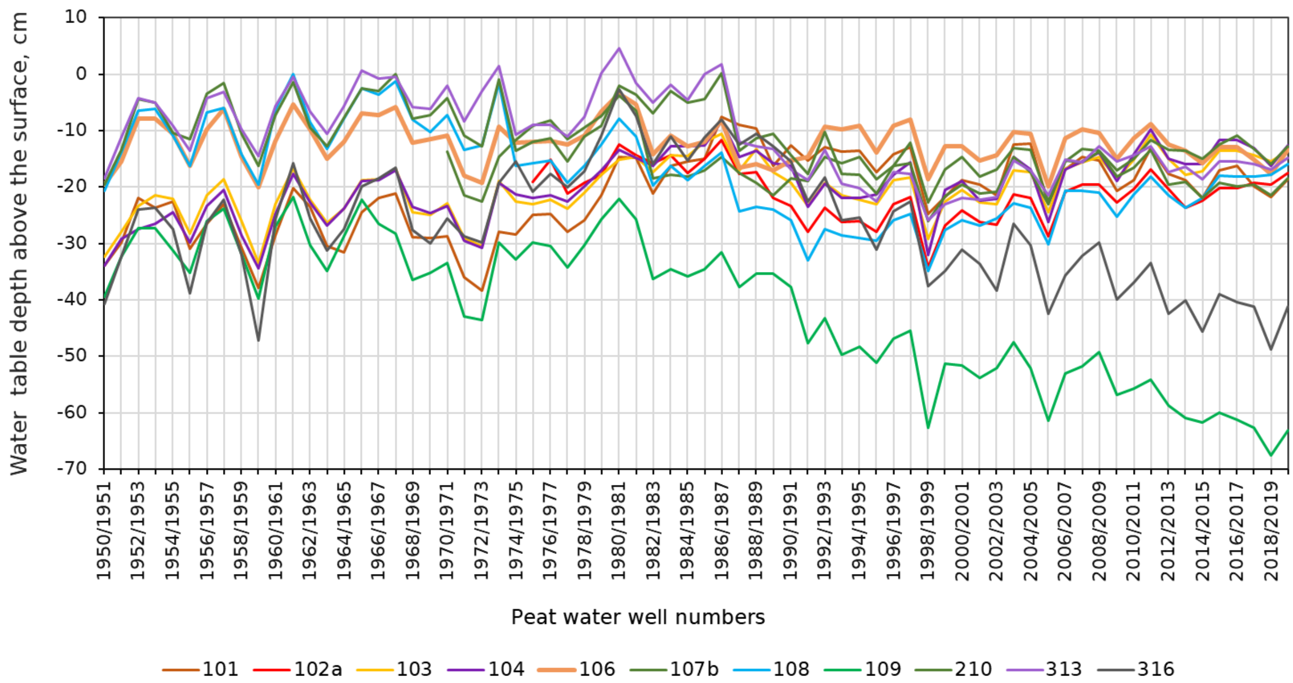


Figure 22. Annual average values of the peat water level at the LSPS.

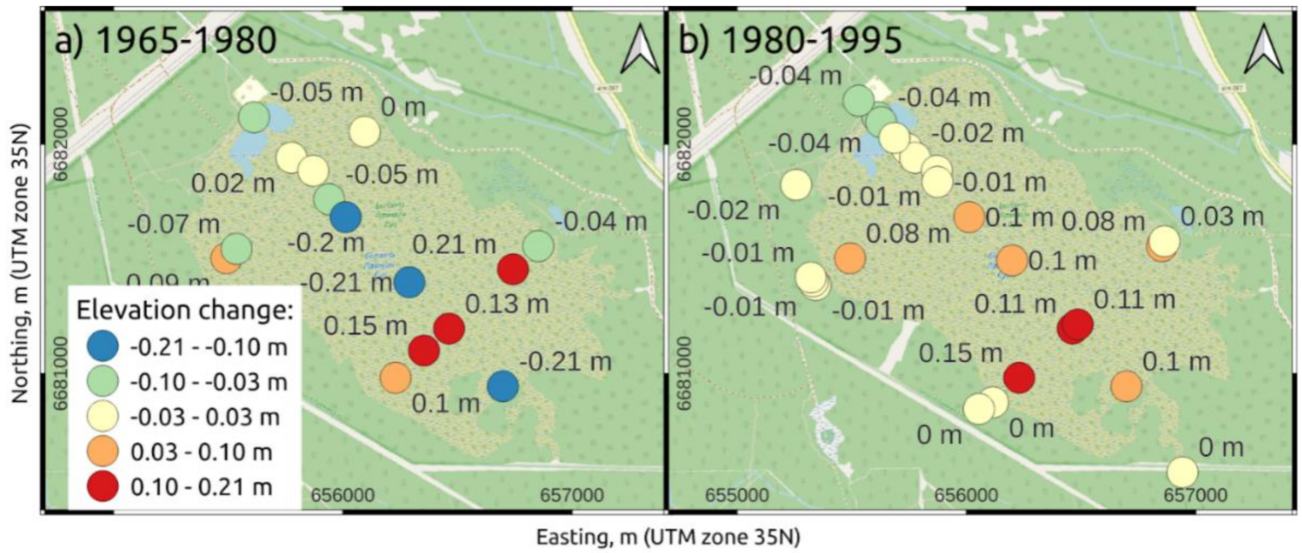


Figure 23. Surface elevation changes at the Lammin-Suo peatland measured near the wells. Base map and data from OpenStreetMap and OpenStreetMap Foundation.

Water balance estimation

Table 3 shows estimated components of the Lammin-Suo mire water balance for three periods. These periods were determined using homogeneity tests of stream runoff series performed by Zhuravleva *et al*. (2023). From these tests we identified change points within the record of total stream runoff in 1978 and 1990.

The components of the water balance for each hydrological year (1956–2020) are shown in Table A8. The water balance discrepancy is positive and varies from 35 to 137 mm.

The main water balance components of the Lammin-Suo mire are precipitation (*P*), evapotranspiration (*E*) and stream runoff (*Qstream*). Annual values of net precipitation (*P - E*), *Qstream* and water balance discrepancy (*S*) are shown in Figure 27. In 1956–1977, negative values of the water balance discrepancy were periodically observed. In the early 1980s, net precipitation and

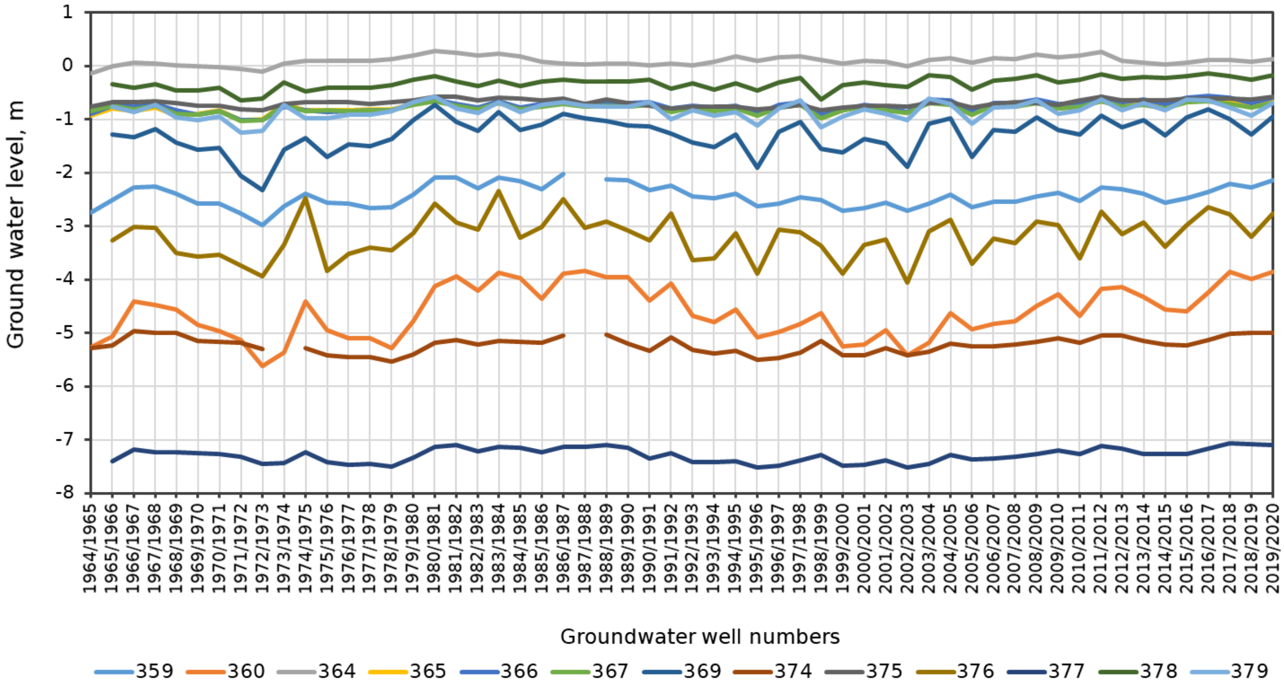


Figure 24. The average annual values of the groundwater level at the LSPS.

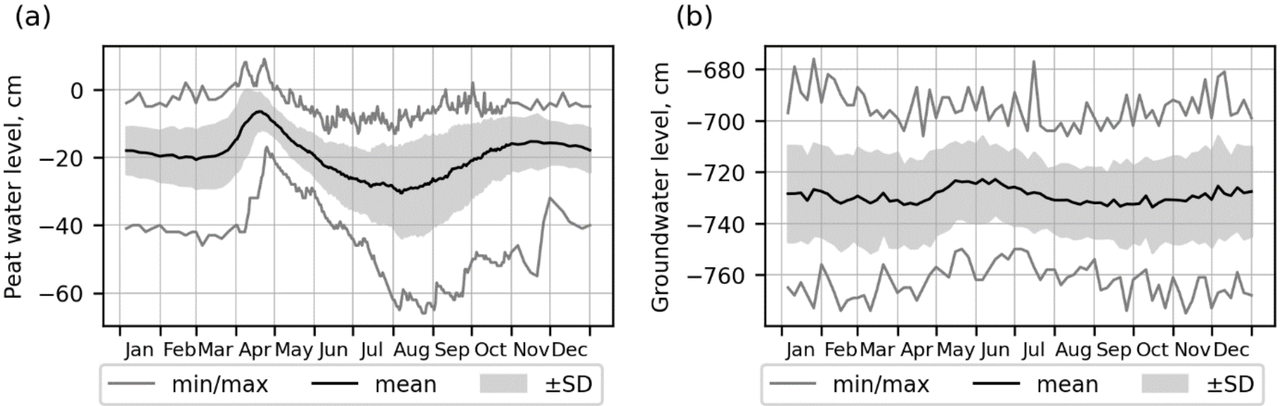


Figure 25. The averaged intra-annual variability of peat water levels (S104) and groundwater levels (G377) at the LSPS.

stream runoff increased, and in the late 1980s the difference between net precipitation and stream runoff increased. This is probably due to an increase in diffuse outflow of water from the mire through its borders, that bypasses the main streams. In recent years, we have observed that the stream network in the Lammin-Suo mire has begun to change. Temporary watercourses have emerged within the mire - on its south-western margin as well as next to the Yuzhnyi stream - during periods of snowmelt and heavy rainfall. Thus, there is now a need for the introduction of additional measurements to take into account all components of the water balance of the Lammin-Suo mire.

DISCUSSION

The dataset introduced by this article contains the results of a long-term study of the hydrological and meteorological regimes of a boreal basin peatland located in north-west Russia. It includes almost 70 years of measurements collected at the Lammin-Suo Peatland Station from 01 January 1952 to 31 December 2020, comprising air temperature and humidity, atmospheric pressure, wind speed and direction, cloudiness, precipitation, evaporation, snow depth, peat temperature, peat water level, groundwater level and temperature. These records will enable the tracing of modern climatic changes.

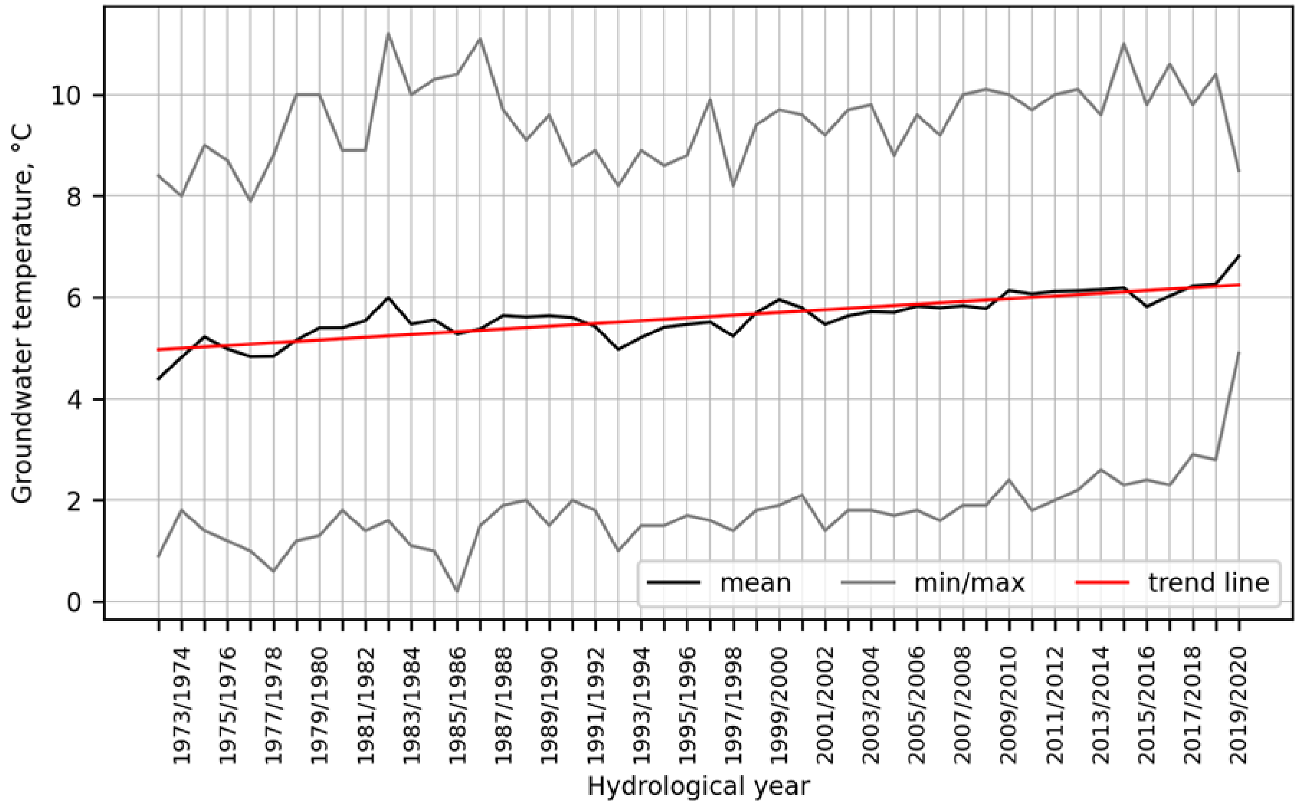


Figure 26. Groundwater temperature averaged between the eight wells with the longest uninterrupted observation series.

Table 3. Water balance components (mm) for the Lammin-Suo mire for three stationary periods.

Water balance component (mm)	Period		
	1956–1978	1979–1990	1991–2020
Ptotal	780	987	888
E	340	291	288
Esnow	92	83	88
Etotal	432	374	376
Qslope	12	17	13
Qstream	326	545	388
W	1	1	0
S	35	86	137

The trend analysis shows that current climate warming affects all components of the ecosystem (air, groundwater and peat), reaching the deepest layers of the peat deposit. Moreover, precipitation and the flow in some of the streams draining the peatland have increased while the duration and thickness of snow cover have decreased. The observed changes in vegetation are mainly related to the increased proportion of the tree component.

Observations at the LSPS are ongoing and the monitoring programme will be expanded to include measurements of the biogeochemical cycle and greenhouse gas emissions. All data presented and described in this article can be downloaded from the open access repository Zenodo via the link https://doi.org/10.5281/zenodo.5060039. The database will be updated (no more than once per year) as new data become available. We encourage other peatland researchers to use these rare and unique data, which may be useful in advancing our understanding of hydrological and meteorological processes in natural boreal peatlands as well as in improving hydrological models.

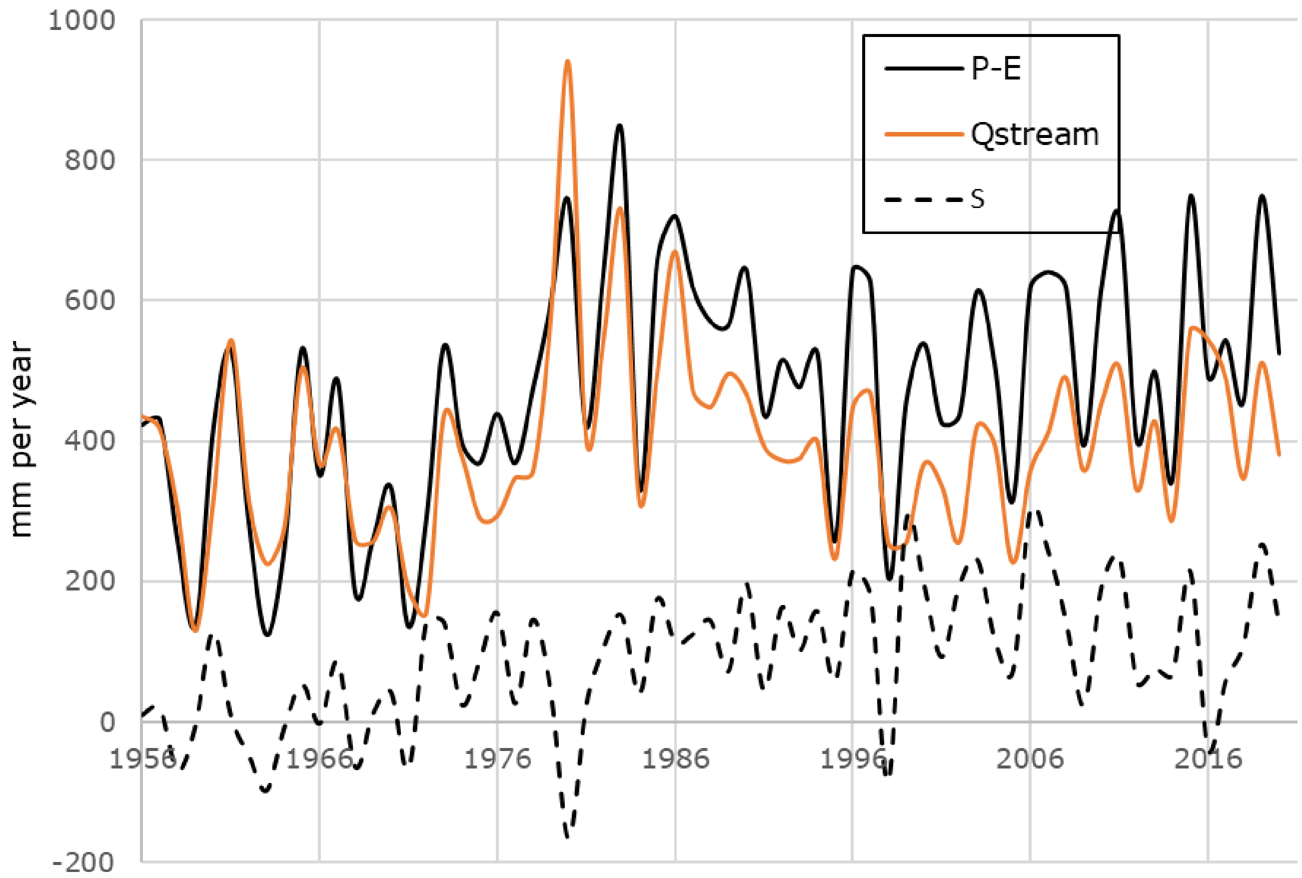


Figure 27. Annual water balance components (precipitation (*P*), evapotranspiration (*E*), stream outflow ($Qstream$) and water balance discrepancy (*S*) for the LSPS over the period 1956–2020.

AUTHOR CONTRIBUTIONS

ADZ initiated the study and wrote the main part of the manuscript. VIB made baseline analyses of the data. AVT and TVS digitised all of the older paper reports to obtain the whole archive in electronic form, made analyses of the data and created most of the Figures and Tables. LSK made maps for the manuscript. The data were collected by SSC and BVY, together with many other people. All authors contributed to the interpretation of results and to the writing of the final manuscript.

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Appendix

Figure A1. Orthomosaic map of the Lammin-Suo mire by Edward Kazakov, 03 Sep 2019. The light area indicates extent of the survey, and yellow spots possible defects resulting from different lighting conditions.

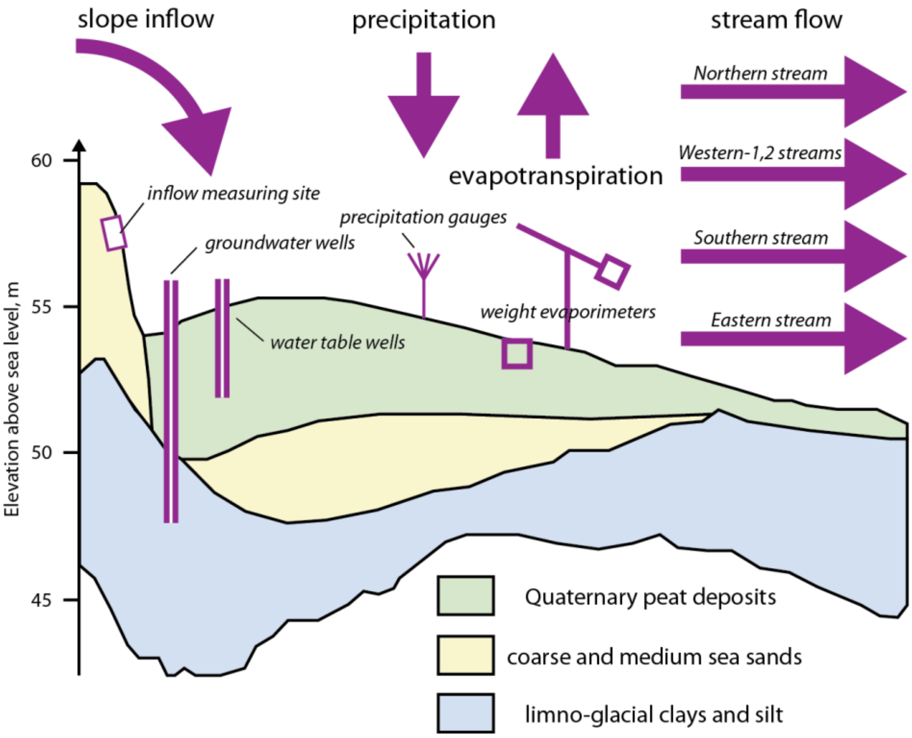

Figure A2. Schematic representation of a longitudinal cross-section of the Lammin-Suo peatland showing the water-balance components measured.

Table A1. Meteorological instrumentation, observation timetable and data availability. B: Bolotnaya station; S: Sukhodol'naya station.

Instrumentation	Observation timetable	Data availability
Air temperature (°C)		
Instant: thermometer TM-4	4 times per day (1:00, 7:00, 13:00, 19:00) until 31 Dec 1965 (B+S) 8 times per day (every 3 hours starting from 00:00) after 01 Jan 1966 (B only)	B: 01 Jan 1952 – 31 Dec 2020 S: 01 May 1952 – 31 Dec 1965
Daily mean: thermometer TM-4	daily, by averaging instant measurements (B+S)	
Daily maximum: thermometer TM-1	daily (B+S)	
Daily minimum: thermometer TM-2	daily (B+S)	
Wind speed (m s^{-1})		
Meteorological mast M-82-I, weathervane FVT / FVL	4 times per day (1:00, 7:00, 13:00, 19:00) until 31 Dec 1965 (B only) 8 times per day (every 3 hours starting from 00:00) after 01 Jan 1966 (B only)	B: 01 Jan 1952 – 31 Dec 2020
Partial water vapour pressure in the air (mbar)		
Meteorological hair hygrometer M-19	4 times per day (1:00, 7:00, 13:00, 19:00) until 31 Dec 1965 (B+S) 8 times per day (every 3 hours starting from 00:00) after 01 Jan 1966 (B only)	B: 01 Jan 1952 – 31 Dec 2020 S: 01 May 1952 – 31 Dec 1965
Atmospheric pressure (mbar)		
Aneroid barometer MD-49-2	03:00 during 01 Jan 2012 – 31 Dec 2019 (B only) 15:00 after 01 Jan 2020 (B only)	B: 01 Jan 2012 – 31 Dec 2020
Total and low-level cloud cover (tenths of the sky)		
Visually	4 times per day (1:00, 7:00, 13:00, 19:00) until 31 Jul 1952 3 times per day (07:00, 13:00, 19:00) during 01 Aug 1952 – 20 Nov 1963 4 times per day (1:00, 7:00, 13:00, 19:00) during 21 Nov 1963 – 31 Dec 1965 4 times per day (03:00, 9:00, 15:00, 21:00) during 01 Jan 1966 – 31 Jul 1976 3 times per day (9:00, 15:00, 21:00) in 01 Aug 1976 – 10 May 1978 2 times per day (9:00 and 15:00) since 11 May 1978 – now	B: 01 Jan 1952 – 31 Dec 2020

Table A2. Measuring equipment information (instrumentation data). All equipment used at the Lammin-Suo station is certified in accordance with state standards of the Russian Federation: [1] State Standard No. 112-78; [2] The Approval Certificate No. 3460-03; [3] The Approval Certificate No. 6115-96; [4] The Approval Certificate No. 15114-96; [5] The Approval Certificate No. 3743-73; [6] The Approval Certificate No. 60193-15; [7] Technical description TU 25-04-1623-76; [8] Technical description TU 25-19-1440-78; [9] Technical description TU 25-11-1441-78.

Equipment [device documentation]	Measured characteristic (unit)	Measuring range	Scale division	Basic absolute error
Meteorological instruments				
Thermometer TM-4 [1]	Air temperature (°C)	-35 to +40 °C	0.2 °C	-30 to 0 °C ±0.3 °C 0 to +40 °C ±0.2 °C
Maximum thermometer TM-1 [1]	Air temperature (°C)	-35 to +50 °C	0.5 °C	-35 to -20 °C ±0.8 °C -20 to -10 °C ±0.5 °C -10 to +50 °C ±0.4 °C
Minimum thermometer TM-2 [1]	Air temperature (°C)	-50 to +40 °C	0.5 °C	-50 to -40 °C ±1.5 °C -40 to -30 °C ±1.0 °C -30 to -20 °C ±0.8 °C -20 to +40 °C ±0.5 °C
Thermograph M16-AC [2]	Air temperature (°C)	-45 to +45 °C	1 °C	±1 °C; ±5 min day^{-1}
Hygrometer M-19 [3]	Air humidity (%)	0–100 %	1 %	±10
Hygrograph M-21AC [4]	Air humidity (%)	30–100%	2%	±10
Aneroid barometer MD-49-2 [5]	Atmospheric pressure (mbar)	600–790 mbar	1 mbar	-10 °C to +50 °C ±8 mbar
Tretyakov non-recording precipitation gauge [6]	Precipitatiom (mm)	0–10 mm	0.1 mm	±0.1 mm
Meteorological mast M-82-I, weathervane FVL [7]	Wind speed (m s^{-1})	1–20 m s^{-1}	2 m s^{-1}	2 m s^{-1}

Equipment [device documentation]	Measured characteristic (unit)	Measuring range	Scale division	Basic absolute error
Peat temperature				
Thermometer TM-3 [1]	Peat surface temperature in summer (°C)	-35 to +60 °C	0.5 °C	-35 to -20 °C ±0.7 °C -20 to +60 °C ±0.5 °C
Thermometer TM-9-1 [1]	Peat surface temperature in winter (°C)	-60 to +20 °C	0.5 °C	-60 to -50 °C ±2.0 °C -50 to -40 °C ±1.5 °C -40 to -30 °C ±1.0 °C -30 to -20 °C ±0.8 °C -20 to +20 °C ±0.5 °C
Thermometer TM-5 (Savinov thermometer) [1]	Peat-depth temperature (°C)	-10 to +50 °C	0.5 °C	±0.5°C
Thermometer TM-10 [1]	Peat-depth temperature (°C)	-20 to +30 °C	0.2 °C	-20 to -10 °C ±0.3 °C -10 to +30 °C ±0.2 °C
Runoff of the peatland streams				
Thin-walled triangular weir (V-notch)	Water discharge ($m^3 s^{-1}$)	0.00003–0.577 $m^3 s^{-1}$	0.00001 $m^3 s^{-1}$	$0 < H < 0.4$ m 1 % $0.4 < H < 0.6$ m 2 %
Water-level gauge with recorder “Valday” [8]	Water level per minute (cm min^{-1})	level 0–6 m	0.5 mm	time ±3 min level ±5 mm
Water-level gauge with recorder GR-38 [9]	Water level per minute (cm min^{-1})	level 0–6 m	0.5 mm	time ±3 min level ±5 mm
Evapotranspiration				
Peat evaporimeter model GGI-B-1000 (Toebes & Ouryvaev 1970)	Evaporation from the surface peat layer (mm)	0–100 mm	1 mm	0.5 ±1 mm

Table A3. Surface freezing observation sites at the LSPS.

Site name	Observation period	Microrelief types
SF1	1954–2020	*Sphagnum*, dwarf shrub, inclusions of pine
SF2	1989–2020	*Sphagnum*, dwarf shrub, cottongrass, inclusions of pine
SF3	1954–1991	*Sphagnum*, cottongrass, dwarf shrub, inclusions of pine; ridge-hollow complex (ridge)
SF4	1954–1989	*Sphagnum*, dwarf shrub, pine (forest ring)
SF5	1954–1991	*Sphagnum*, cottongrass, dwarf shrub, inclusions of pine and deadwood

Table A4. Data availability for the lysimeters at the Lammin-Suo peatland.

Site name	Observation interval	Seasons observed
E1	12 May 1956 – 21 Sep 2020	65
E2.1	01 Jun 1962 – 01 Oct 1970	9
E2.2	01 Jun 1962 – 01 Oct 1970	9
E2	05 May 1971 – 11 Jul 1976	6
E3	02 Jul 1966 – 21 Sep 1976	11
E4	01 May 1968 – 01 Oct 1974	7

Table A5. Availability of data from peat water wells at the LSPS.

Well number	Available data	Years observed	Well number	Available data	Years observed
S101	31 Dec 1950 – 31 Dec 2020	71	S210	31 Dec 1950 – 31 Dec 2020	71
S102	31 Dec 1950 – 31 Dec 1989	40	S211	31 Dec 1950 – 31 Dec 1989	40
S102a	31 Dec 1975 –31 Dec 2020	46	S212	31 Dec 1950 – 31 Dec 1984	35
S103	31 Dec 1950 – 31 Dec 2020	71	S313	31 Dec 1950 – 31 Dec 2020	71
S104	31 Dec 1950 – 31 Dec 2020	71	S314	31 Dec 1950 – 31 Dec 1989	40
S105	31 Dec 1950 – 31 Dec 1989	40	S315	31 Dec 1950 – 31 Dec 1989	40
S106	31 Dec 1950 – 31 Dec 2020	71	S316	31 Dec 1950 – 31 Dec 2020	71
S107	31 Dec 1950 – 31 Dec 1989	40	S317	31 Dec 1972 – 31 Dec 1989	18
S107a	31 Dec 1970 – 31 Dec 1975	6	S318	31 Dec 1978 – 31 Dec 1989	12
S107b	1970 31 Dec – 31 Dec 2020	51	S319	31 Dec 1978 – 31 Dec 1989	12
S108	31 Dec 1950 – 31 Dec 2020	71	Kupalnoe and Pityevoe lakes (level gauge)	31 Dec 1968 – 31 Dec 2020	53
S109	31 Dec 1950 – 31 Dec 2020	71			

Table A6. Availability of data from groundwater wells at the Lammin-Suo peatland station.

Well number	Available data	Years observed
G359	09 Jan 1974 – 31 Dec 2020	47
G360	09 Jan 1974 – 31 Dec 2020	47 (with gaps)
G362	09 Jan 1974 – 20 Aug 1983	10
G364	09 Jan 1974 – 31 Dec 2020	47 (with gaps)
G365	09 Jan 1974 – 31 Dec 2020	47
G366	09 Jan 1974 – 31 Dec 2020	47
G367	09 Jan 1974 – 31 Dec 2020	47
G369	09 Jan 1974 – 31 Dec 2020	47 (with gaps)
G374	09 Jan 1974 – 31 Dec 2020	47 (with gaps)
G375	09 Jan 1974 – 31 Dec 2020	47
G376	09 Jan 1974 – 31 Dec 2020	47
G377	09 Jan 1974 – 31 Dec 2020	47
G378	09 Jan 1974 – 31 Dec 2020	47 (with gaps)
G379	09 Jan 1974 – 31 Dec 2020	47
G386	10 Jan 1974 – 10 Feb 1986	13
G387	10 Jan 1974 – 10 Mar 1986	13
G388	10 Jan 1974 – 10 Mar 1986	13
G389	10 Jan 1974 – 10 Mar 1986	13
G390	10 Jan 1974 – 10 Mar 1986	13

Table A7. Linear trend estimates of the Lammin-Suo mire hydrometeorological characteristics.

Hydrometeorological characteristic	Linear trend coefficient (decade^{-1})	Significance level (Mann 1945, Kendall 1975)	Period	Figure
Annual air temperature (°C)	0.34	0.000	1951–2020	Fig. 11
Air temperature (summer) (°C)	0.19	0.006	1951–2020	Fig. 11
Air temperature (winter) (°C)	1.04	0.003	1976–2020	Fig. 11
Peat surface temperature (°C)	0.62	0.000	1976–2020	Fig. 15
Peat temperature at depth 320 cm (°C)	0.24	0.000	1976–2020	Fig. 15
Groundwater temperature (°C)	0.27	0.000	1972–2020	Fig. 26
Precipitation (mm)	36.80	0.0001	1953–2020	Fig. 13
Ratio of solid precipitation (%)	-1.30	0.035	1965–2020	Figs. 12,13
Maximum snow cover thickness (mm)	-5.40	0.12	1976–2020	Fig. 14
	-4.70	0.01	1988–2020	Fig. 11
Snow cover duration (days)	-3.30	0.12	1976–2020	
	-7.50	0.02	1988–2020	
Evapotranspiration (mm)	-10.00	0.035	1956–2020	Fig. 18
Air humidity (mbar)	0.16	0.05	1952–2020	
Wind speed (m s^{-1})	-0.09	0.000	1952–2020	
Total flow (mm)	15.60	0.06	1955–2020	Fig. 21
Flow (Severnyi stream)	1.57	0.04	1955–2020	
Flow (Zapadnyi stream 1,2)	3.79	0.000	1955–2020	

Table A8. The Lammin-Suo water balance components (mm) for each hydrological year (1956–2020).

Water Balance component	Hydrological year								
	1956	**1957**	**1958**	**1959**	**1960**	**1961**	**1962**	**1963**	**1964**
Ptotal	865.0	783.3	641.6	560.5	818.5	992.2	732.3	558.5	695.6
E	346.0	201.0	323.0	221.0	245.0	414.0	346.0	366.0	365.0
Esnow	95.0	152.0	62.0	201.0	156.0	48.0	102.0	68.0	84.0
Etotal	441.0	353.0	385.0	422.0	401.0	462.0	448.0	434.0	449.0
Qslope	-	-	-	-	-	-	-	14.6	11.2
Qstream	435.1	416.5	301.1	129.6	314.1	543.6	315.4	224.3	275.1
W	21.5	5.8	-24.2	-13.7	26.3	21.9	-16.1	-12.1	9.2
S	10.4	19.6	-68.7	-4.8	129.7	8.5	-47.2	-97.3	-8.1
	1965	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**
Ptotal	1002.1	838.5	938.2	659.1	726.4	791.1	627.2	796.0	995.2
E	347.0	446.0	406.0	362.0	385.0	419.0	380.0	420.0	391.0
Esnow	123.0	41.0	45.0	113.0	81.0	37.0	111.0	87.0	68.0
Etotal	470.0	487.0	451.0	475.0	466.0	456.0	491.0	507.0	459.0
Qslope	9.8	12.8	7.4	33.1	10.9	6.4	7.7	12.0	5.9
Qstream	503.4	366.1	415.5	258.4	256.5	304.4	188.9	156.0	436.8
W	15.3	0.0	7.5	-22.8	-2.9	5.8	-21.5	-2.6	36.5
S	53.8	-1.8	86.6	-64.0	11.9	42.9	-66.5	142.4	141.8
	1974	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**
Ptotal		822.7	759.4	764.4	992.6	1128.2	811.6	1049.6	1245.1
E	291.0	393.0	282.0	301.0	171.0	293.0	281.0	277.0	310.0
Esnow	104.0	25.0	101.0	89.0	119.0	103.0	104.0	114.0	92.0
Etotal	395.0	418.0	383.0	390.0	290.0	396.0	385.0	391.0	402.0
Qslope	11.7	11.5	5.9	10.6	18.1	8.8	14.3	14.1	11.8
Qstream	378.0	290.6	293.1	347.2	355.2	573.1	939.1	403.2	548.3
W	-6.6	-2.9	2.9	-5.8	8.6	11.3	15.7	-8.2	-3.8
S	24.9	87.3	155.4	27.0	145.9	43.6	-165.9	23.3	107.3
	1983	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**
Ptotal	1010.1	712.7	1010.1	1071.4	972.1	927.5	923.6	1000.8	822.8
E	342.0	348.0	254.0	298.0	251.0	282.0	284.0	270.0	276.0
Esnow	62.0	33.0	98.0	52.0	102.0	75.0	74.0	86.0	109.0
Etotal	404.0	381.0	352.0	350.0	353.0	357.0	358.0	356.0	385.0
Qslope	23.7	19.9	14.3	39.8	8.5	17.7	10.5	19.4	25.3
Qstream	725.5	312.4	496.2	670.0	471.6	448.2	495.8	466.8	392.4
W	12.0	0.0	0.0	22.6	-30.8	4.1	-7.9	0.0	-26.5
S	151.3	39.2	176.2	113.8	125.2	144.1	72.4	197.4	44.2

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Ptotal	901.0	845.4	874.0	610.7	978.5	960.3	554.1	834.3	868.1
E	303.0	281.0	243.0	297.0	249.0	233.0	298.0	282.0	239.0
Esnow	82.0	87.0	105.0	55.0	85.0	101.0	50.0	97.0	89.0
Etotal	385.0	368.0	348.0	352.0	334.0	334.0	348.0	379.0	328.0
Qslope	4.2	9.1	31.0	29.3	8.6	13.4	13.5	53.2	17.1
Qstream	372.3	374.6	399.0	232.3	447.5	467.6	253.6	254.8	366.6
W	15.3	-9.5	0.0	2.9	10.3	7.5	-50.4	32.6	6.6
S	163.2	102.4	158.0	58.6	215.9	179.6	-84.4	286.3	197.2
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Ptotal	795.6	747.0	947.0	886.8	700.1	949.2	987.4	1004.7	798.4
E	255.0	262.0	227.0	286.0	287.0	305.0	239.0	264.0	351.0
Esnow	114.0	48.0	106.0	92.0	98.0	25.0	107.0	120.0	53.0
Etotal	369.0	310.0	333.0	378.0	385.0	330.0	346.0	384.0	404.0
Qslope	12.4	13.9	14.9	10.2	10.7	10.3	8.3	10.6	6.7
Qstream	336.6	256.1	421.1	394.0	226.5	356.9	411.4	490.4	357.4
W	-9.5	0.0	24.5	-7.5	-28.3	28.3	5.6	4.1	-19.1
S	92.9	194.8	232.3	117.5	71.0	300.9	243.9	145.0	24.6
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Ptotal	983.6	1109.1	828.5	969.6	745.2	1104.0	1009.6	1003.6	850.0
E	321.0	269.0	344.0	377.0	327.0	254.0	396.0	356.0	303.0
Esnow	44.0	119.0	83.0	93.0	72.0	101.0	120.0	103.0	89.0
Etotal	365.0	388.0	427.0	470.0	399.0	355.0	516.0	459.0	392.0
Qslope	7.2	4.1	5.5	9.7	9.5	4.4	11.6	6.9	11.3
Qstream	453.2	505.3	329.5	428.1	288.1	556.7	544.2	488.0	345.9
W	19.1	16.5	-20.6	-3.8	0.0	18.0	0.0	-4.2	-12.0
S	191.7	236.4	56.9	77.4	67.6	214.7	-39.0	59.3	111.4
	2019	**2020**							
Ptotal	1087.9	894.9							
E	245.0	277.0							
Esnow	93.0	92.0							
Etotal	338.0	369.0							
Qslope	4.3	8.2							
Qstream	511.0	380.2							
W	10.0	-14.0							
S	253.2	140.1							