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Water-balance and hydrology research in a mountainous permafrost watershed in upland streams of the Kolyma River, Russia: a database from the Kolyma Water-Balance Station, 1948-1997

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Abstract: As of 2017, 70 years have passed since the beginning of work at the Kolyma water-balance station (KWBS), a unique scientific research hydrological and permafrost catchment. The volume and duration (50 continuous years) of hydrometeorological standard and experimental data, characterizing the natural conditions and processes occurring in mountainous permafrost conditions, significantly exceeds any counterparts elsewhere in the world. The data are representative of the vast territory of the North-East of Russia. In 1997, the station was terminated, thereby leaving Russia without operating research watersheds in the permafrost zone. This paper describes the dataset containing the series of daily runoff from 10 watersheds with area from 0.27 to 21.3 km^2, precipitation, meteorological observations, evaporation from soil and snow, snow surveys, soil thaw and freeze depths, and soil temperature for the period 1948-1997. It also highlights the main historical stages of the station's existence, its work and scientific significance, and outlines the prospects for its future, where the Kolyma water-balance station could be restored to the status of a scientific research watershed and become a valuable international center for hydrological research in permafrost. The data is available at https://doi.pangaea.de/10.1594/PANGAEA.881731.

Keywords: water-balance and hydrological research, continuous permafrost, Kolyma River, Kolyma water-balance station, streamflow, thaw/freeze depth, precipitation, snow cover, evaporation from soil and snow

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1. Introduction

In 2017 we celebrate 70 years since work on organizing the Kolyma Water-Balance station (KWBS) began. This hydrological and permafrost research catchment has accumulated standard and experimental data unique both in terms of their amount and duration.

In the paper «Save northern high-latitude catchments» Laudon et al. (2017) recognize the KWBS as a currently functioning scientific station, even though scientific research was suspended here 20 years ago, and nowadays only standard observations at the meteorological site and the runoff gauge are carried out.

Eurasia contributes 75 % of the total terrestrial runoff to the Arctic Ocean and three of the four major Arctic rivers are located in Siberia (Shiklomanov et al. 2002). Peterson et al. (2002) suggested that the net discharge from the six largest Eurasian rivers flowing into the Arctic Ocean (Severnaya Dvina, Pechora, Ob', Yenisey, Lena, and Kolyma) increased by 7% during the 20th century. As it is also mentioned by Laudon et al. (2017), the number of scientific and hydrological research stations in the Northern regions of the world has decreased by 40%, and it happened alongside the most significant climate change in the Arctic in recorded history.

The Kolyma Water Balance Station (KWBS) is located in the headwaters of the Kolyma River, in a mountainous region of continuous permafrost (Fig. 1). Runoff formation conditions at the station are representative for an immense territory of the upper Kolyma River basin and mountainous regions of North-East Russia. Although there are large mountainous areas in other cold regions of the world in Canada, the USA and Europe, the combination of extremely severe climate and continuous permafrost creates unique conditions in North-East Russia.

To the best of our knowledge, the first systematic cold-region hydrology observations in North America begin not earlier than the 1960s. The Caribou-Poker Creeks Research Watershed was established in 1969 (Hinzman et al., 2002).

At the KWBS there were 10 hydrological gauges at catchments ranging between 0.27 and 21.3 km^2, two meteorological plots, 55 (in total) precipitation gauges, over 30 frost tubes (cryopedometers), several groundwater wells, evaporation, water-balance and runoff plots. In addition, regular snow surveys were conducted, as well as experimental investigations of specific hydrological and permafrost processes.

During the period 1948 to 1997, the KWBS accumulated a huge amount of data on hydro-meteorological and special observations of a unique duration (40-50 years) that characterize the natural setting, which, on the one hand, are nearly ungauged, and on the other hand, are representative of the vast territory of North-East Russia and to some extent of other alpine cold-climate areas in Europe and North America. The data were published in 40 reports, the first one covering the period 1948-1957. Following issues were published annually (KWBS Observation's materials, 1959-1997).

After 1997, water balance observations at the KWBS were ceased. One weather station and five runoff gauges functioned at the KWBS up to mid-June, 2013, when an extreme flash flood destroyed four level gauges. Nowadays only standard observations are conducted at the Nizhnyaya meteorological site and at the Kontaktovy (Nizhny) runoff gauge.

Observation results were reflected in more than 250 publications, dedicated to different aspects of runoff formation in the continuous permafrost region, active layer dynamics, underlying surface structure and its influence on hydrological processes. Based on the KWBS materials, the following research was carried out:

- water balance formation (Boyarintsev, 1980; Boyarintsev, Gopchenko, 1992; Kuznetsov et al., 1969; Suchansky, 2002; Zhuravin, 2004; Lebedeva et al., 2017),
- peak and spring flood runoff in small rivers in the permafrost zone (Boyarintsev, 1988),
- base flow (Boyarintsev, Nikolaev, 1986; Glotov, 2002),
- principles of runoff cryo-regulation (Alekseev et al., 2011),
- ice content dynamics of rocky talus deposits (Bantsekina, 2001),
- processes of intra-ground condensation (Reinyuk, 1959; Bantsekina et al., 2009; Boyarintsev et al., 1991),

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- floodplain taliks in continuous permafrost (Mikhaylov, 2013) and many others.

Collected data were also used for development and testing different geoscience models of:

- runoff formation (Gusev et al., 2006; Kuchment et al., 2000; Vinogradov et al., 2015; Lebedeva et al., 2015; Semenova et al., 2013),
- climatic aspects (Shmakin, 1998),
- land surface and vegetation dynamics (Tikhmenev, 2008).

In this paper, we present a hydrometeorological and permafrost related dataset for 50 years from 1948 – 1997 for the Kolyma Water-Balance Station (KWBS), the Kontaktovy Creek watershed, which is representative for vast mountainous territories of continuous permafrost zone of Eastern Siberia and the North-East of Russia. This dataset is unique in terms of its volume and duration of hydrometeorological standard and experimental data. It may be used in many research tasks, but is of particular importance in studying runoff formation processes and model development in permafrost regions.

2. Site description

The Kolyma water-balance station is located in the Tenkinsky district of the Magadan region of Russia within the Upper-Kolyma highland. The station's territory – the Kontaktovy Creek catchment with area 21.3 km^2 – is a part of the Pravy Itrikan River which flows into the Kulu River basin, which is the right tributary of the Kolyma River. The station is located 16 km from the Kulu village settlement. It is characterized by a mountain landscape, typical for the upper reaches of the Kolyma River. The territory of the basin is severely cut up with creek valleys. These valleys are narrow, with steep slopes, and watershed lines are mostly well delineated. Absolute elevations of the basin range between 823 m a.s.l. near the Kontaktovy Creek outlet and 1700 m a.s.l. at watershed divides. The length of the creek is 8.9 km. The catchment is extended in the latitudinal direction and has an asymmetric shape. The slopes of the catchment area have mainly southern exposure (53% of the slope area), the slopes of the northern and eastern exposure have a 24% share, the western – 23%. The density of river network in the basin is 2.5 km per square km. The main river canal is meandering. The steepness of the slopes ranges from 200 to 800‰ (Fig. 1).

The station is located in the continuous permafrost zone. Permafrost thickness varies from 120 to 210 m in valleys and can reach 300-400 m in highlands, following the relief. Seasonal soil thaw depth depends on slope exposition, altitude and landscape and changes from 0.2-0.8 m on north-facing slopes to 1.5-3.0 m on south-facing ones.

KWBS is situated in the transitional zone between forest-tundra and coniferous taiga. Soil types vary from stony-rock debris to clayey podzol with partially decayed organic material underlain by frozen soil and bedrock. Most of the KWBS area is covered by rocky talus, practically without vegetation (34%). Dwarf cedar and alder shrubs are common at south-facing slopes and cover about 27% of the territory. Larch sparse woodland with moss-lichen cover is typical for steep north-facing slopes (12%). Open terrain larch wood (15%) and swampy sparse growth forest with minimal permafrost thaw depth, constant excessive stagnant moisturizing, tussock or knobby microrelief (12%) characterize creek valleys. The estimates of landscape distribution are given here after Korolev (1984).

2.1 History of KWBS

The Kolyma water balance station (KWBS) was established on October 15, 1947 and was initially known as the Itrikanskaya runoff station of the Dalstroy (Far North Construction Trust organized in 1931) Hydrometeorological Service. In 1948-1956 and 1957-1969 it was called the Kulinskaya and the Kolyma runoff station respectively. The primary goal of this station was studying runoff formation processes in small river catchments in mountain permafrost landscapes, typical for northeast USSR.

As soon as May, 1948, the first runoff observations at the Kontaktovy Creeks and Vstrecha brook were launched, as well as regular observations at the Nizhnyaya weather station

(850 m a.s.l.). A few months later, on September 1, 1948, observations at the Verkhnyaya weather station (1220 m a.s.l.) were started. In 1948, stage gauges Sredny, Nizhny and Vstrecha were equipped with automatic water level recorders, gauging footbridges and flumes.

During the period 1949-1957, at the Vstrecha brook catchment, a rain-gauge network was organized. Runoff gauges at the Severny, Dozhdemerny, Vstrecha brooks were equipped with various hydrometric facilities. Observations on soil, water and snow evaporation, soil freezing and thawing commenced, as well as experimental observations at a runoff plot.

At the end of the 1940s and early 1950s, technical staff of the station were mainly former convicts. During the first few years, the workers of the station built houses for themselves, collected firewood and organized the household. The winter of 1955-56 appeared to be especially severe for the staff, since due to the deep snow cover it was difficult to move around the territory of KWBS, there was no transport connection with the Tenkinskaya highway, delivering of firewood, needed for heating houses and service buildings, was also difficult. When it was impossible to get to the highway by car, bread and mail were delivered from the Kulu village settlement utilizing horses once every 7-10 days.

Twenty to twenty five staff members were accommodated in three small huts, hardly suitable for living. That winter they mainly had to collect and prepare firewood in the afternoon; in the morning everybody had to go (despite their rank or position) in deep snow and at -50°C to the nearest small river valley looking for firewood, then they pulled it back home, where they were firing furnaces. Only by the time it got dark, it became warm enough to stay in the work-room and they could start observation data processing.

The working day lasted till 10 or 11 p.m. Since there was no electricity, they used kerosene lamps filled with a mixture of petrol and salt. In summer 1956 there were only 13 people left at the station, some of them were taken to help with haymaking to prepare hay for their subsidiary holding that consisted of two cows and a horse (as recollected by the Chief of the station V.G. Osipov, the hydrologist-technician A.I. Ipatieva, Informational letter…, 1988).

In 1957 the station was handed over to the jurisdiction of the Kolyma Hydro-meteorological service administration, and in 1958 it was partially connected to electricity. At that time there were active steps taken toward fitting out the station with new types of devices and equipment, engaging new specialists in hydro-meteorology, and building accommodation facilities.

In 1960 runoff observations at the Yuzhny brook were begun, rationalization of the precipitation network was continued, and radio rain gauges were installed.

In 1963 two new water-balance sites (##2 and 3) were organized.

In 1968 runoff measurements were started at the unique research object, at the Morozova brook catchment, which has no vegetation cover and is composed of rocky talus.

In 1969 the Kolyma runoff station was renamed into the Kolyma Water Balance station (KWBS). In these years there was a transition to broad experimental water balance observations of all of its elements and to an enhanced technical level of research.

Since 1970, the KWBS carried out snowpack observations at avalanche sites of the Tenkinskaya road, as well as stratigraphy, temperature and physical and mechanical properties of snow at four sites. Since 1980 there were introduced additional observations on dynamics of icing formation at the Kontaktovy creek. In 1982 observations on soil moisture were started at 3 agro-hydrological sites at the fields of the «Kulu» state farm.

In 1976 the station hosted a delegation of USA scientists. They highly praised the professional and personal qualities of the station's staff members, their commitment, on which extensive field studies and theoretical works were based, despite the equipment being rather simple and living conditions extreme. According to Slaughter and Bilello (1977), the data recorded at the KWBS, were unique and unprecedented for world practice.

Since the beginning of the 1990s, the research program at the station has been gradually cutting back. After 1997, water balance observations at the KWBS were ceased. One weather station and five runoff gauges functioned at the KWBS up to mid of June, 2013, when an

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extreme flash flood destroyed four level gauges. Nowadays only standard observations are conducted at the Nizhnyaya meteorological site and at the Kontaktovy (Nizhny) runoff gauge.

3. Data description

3.1 Meteorological observations

The observations of meteorological elements were carried out at three meteorological stations in different periods (Fig. 2). The database includes daily values of air temperature, water vapour pressure, vapour pressure deficit, atmospheric pressure, wind speed, low and total cloud amount, and surface temperature (Table 1).

The meteorological station Verkhnyaya (1220 m a.s.l., 1948-1972) was located in the upper reaches of the Dozhemerny brook in the saddle between two hills. The horizon is closed by the hills from the south and north which are at 30-40 m distance from the site. The horizon is open from the east and west, strong winds are observed here. The surface at the station plot is hummocky, covered with grassy vegetation with no woody vegetation around it. The nearest building – the station house – was located 48 m away from the station plot. The depth of seasonal thaw of permafrost reaches 1.5 m.

The meteorological station Nizhnyaya (850 m a.s.l., 1948-1997) is located on the edge of a larch forest, on the terrace-watershed between the Kontaktovy creek and the Ugroza brook, which has a slight slope to the SW. The nearest trees are located 50 m away, the buildings – 100 m from the station. The site is surrounded by mountains up to 1400 m a.s.l., the nearest of them are at a distance of 200-500 m. The angle of the horizon is 11 degrees. The height of the weather vane is 11.3 m. The surface at the station plot is covered by hummocks, with moss, peat and individual bilberry and blueberry bushes. The area is surrounded by a sparse larch forest from the north, east and south. The depth of permafrost seasonal thaw reaches 1.5 m.

The meteorological station Kulu (670 m a.s.l., 1981-1991) was located on the right cliff of the broad valley of the Kulu river. The slope has a western exposure (4-6 degrees). The angle of the horizon is 4 degrees. The height of the weather vane is 10.7 m. The area is surrounded by larch trees of 6-8 m height from the west, north and east. The soils are loamy with the inclusion of small gravel. The underlying surface consists of berry, grass and sphagnum mosses, sometimes bare soil. The depth of seasonal thawing of permafrost reaches 1.8-2 m.

In September 1992, the Kulu station (635 m a.s.l., 1992-1997) was moved to the residential building of the KWBS at the south-eastern part of the Kulu village. Residential and technical buildings are located around the meteorological plot. There was a road to the south of the station. The soil is marshy, covered with rubble and grass. The angle of the horizon is 4 degrees. This new location of the Kulu station is marked as Kulu2 station in the database.

The observations at all meteorological plots were conducted according to the program of a meteorological station of the 2nd category.

The climate of the study area is severely continental with harsh long winters and short but warm summers. Average annual temperature at the Nizhnyaya meteorological plot during 1949-1996 is -11.3 °C. Mean monthly temperature in January was -33.6 °C, in July +13.2 °C (Fig. 3-4). The absolute minimum daily temperature of -53.0 °C was registered in 1982 and the absolute maximum daily temperature was +22.8 °C (1988). The period of negative air temperatures lasts from October to April, freeze-free period is, on average, 130 days long.

Air temperature inversions are observed at the KWBS. In December air temperature gradient reaches +2.0, in May it accounts for -0.5°C $(100\ m)^{-1}$ respectively. Mean wind velocity is more than twice higher at Verkhnyaya station in comparison with Nizhnyaya station (3.0 and 1.3 m s^{-1} accordingly).

3.2 Precipitation

In total, the precipitation was observed at 47 gauges within KWBS territory during different periods. Continuous daily all-year around precipitation data is available for the period 1948-1997 for the gauge (#12) at meteorological station Nizhnyaya and for the gauge (#54) at

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meteorological station Kulu for 1981-1997. Four gauges have the data of daily totals during warm season for the period for more than 30 years and another 18 gauges for different shorter periods. Usually the start of daily observations at those gauges was initiated by the beginning of snowmelt period and lasted until the end of September. Monthly sums of precipitation were measured at 30 gauges, 10-days and 5-days sums – at 21 and 18 gauges respectively.

Rain-gauge stations for measuring daily precipitation totals in 1948 were equipped with the Nipher-shielded rain gauges and later – with the Tretyakov-shielded precipitation gauges. In 1948-1958 the observations were carried out with both devices in parallel, after 1959 only Tretyakov gauges were used.

There were three main types of precipitation gauges which were used at the KWBS – the Tretyakov, the Kosarev and pit rain gauge (Fig.5). In 1960-1963 there was an attempt to register precipitation with automatic radio-precipitation gauges, but due to improper performance of the devices those observations were stopped.

In 1988, precipitation observations at the KWBS were carried out with 36 precipitation and rain gauges, distributed relatively evenly throughout the area and altitudinal zones. Average density of the precipitation network at that time accounted for 1.6 units per 1 km^2.

Precipitation at Nizhnyaya meteorological plot in the 1949-1997 period varied from 229 (1991) to 474 (1990) mm per year with mean value of 342 mm. Maximum and minimum amount of precipitation is observed in July and March and account for 71 and 7 mm respectively (Fig. 4-5).

3.3 Snow surveys

Snow cover at KWBS is formed in the first weeks of October, and melts in the third week of May. Snow cover observations were started in 1950 and initially conducted at two catchments, at two meteorological plots and four typical squares. In 1959-1960 the number of catchments with snow surveys reached five. Up to 1971, snow surveys were conducted once per month starting in November and finishing in May at small catchments (the Severny, Yuzhny, Dogdemerny and Vstrecha) and once before spring snowmelt at the Kontaktovy – Nizhny. Since 1972, the observations were reduced to one survey per year (usually at the end of April) for all watersheds. Table 2 shows the number of snow routes, their total length and number of measurement points, including their distribution among different landscapes of the catchments (Fig. 6). Snow depth was measured every 10 m, snow density – every 50 m.

Mean, maximum and minimum observed snow water equivalent (SWE) before spring freshet at the Kontaktovy – Nizhny accounted for 121, 213 (1985) and 59 (1964) mm respectively in the 1960-1997 period. In general, rocky talus and tundra bush landscape are characterized by lower SWE due to wind blowing. Much snow is accumulated in the forest landscape. However, at the Morozova brook watershed which is fully covered by rocky talus landscape, mean SWE before snowmelt was estimated as 161 mm with the maximum value of 298 mm observed in 1985 reaching 0.99 m snow height (Table 3, Table 4, Fig. 7).

3.4 Soil evaporation

From 1950 to 1953, five soil evaporation plots were opened at the sites with diverse underlying surfaces and different expositions and altitudes. The plots were equipped with the Rykachev and Gorshenin evaporimeters with evaporation area 1000 cm^2. The observations until 1958 are considered to be approximate due to the absence of accompanying rain gauges and scales of required accuracy. From 1958 to 1966, the measurements were conducted at the soil evaporation plot, located near the Nizhnyaya weather station. The observations of evaporation were carried out with two evaporimeters GGI-500 and the Rykachev evaporimeter, precipitation – with a rain pit-gauge. Three soil evaporation sites were established in different landscapes – in the Vstrecha (1967), Morozova (1971) and Yuzhny (1977) brooks basins. The measurements were carried out with standard weighing evaporimeters GGI-500-50, which, due to the physical proximity of permafrost, were changed to GGI-500-30, meaning that their height was decreased to 30 cm.

Average values of annual soil evaporation were previously estimated by Semenova et al. (2013) and Lebedeva et al. (2017) based on partial KWBS data set as the following: 140 mm for larch and swampy sparse growth forest, 110 mm in dwarf cedar and alder shrubs of tundra belt, and about 70 mm for rocky talus. This database presents full data of observations which allow for correction of the values as described below.

The highest values of soil evaporation during the summer period were observed at the larch forest (site 9) and reached 136 mm. At a similar landscape (site 1), this value is lower, at 119 mm, which indicates the influence of local factors. The lowest values of soil evaporation are 104 mm at the plot located at dwarf cedar tree bush (site 7). In July, soil evaporation values range from 33 to 40 mm, depending on the landscape. In September, the contribution of evaporation decreases to 14-24 mm (Table 5).

3.5 Snow evaporation

Snow evaporation observations were conducted at the KWBS from 1951, but only the data for the period 1968-1992 is considered to be consistent and reliable and is published in described database. From 1968 to 1981, the observations were conducted with standard evaporimeters GGI-500-6 at weather plot Nizhnyaya. In 1981 the snow evaporation observations were transferred to the Kulu weather plot and lasted till 1992.

Observations of evaporation from snow were made mainly in the fall (September, October) and in the spring (May - March). During winter months (January - February), the observations were made only until 1973, because the amount of evaporation from snow proved to be extremely insignificant for water balance. In the spring, during the intensive snowmelt, additional weighing of the evaporimeters was carried out every 3-6 hours. In the database, the evaporation values for night (20-8 hours) and daytime (8-20 hours) intervals are presented, only those values that correspond to a full 12-hour period of observations are published. The accuracy is 0.01 mm. The average values of evaporation from snow in mm per day are as follows: January-February – -0.04; March – +0,09; April – +0,40; May – +0.74; September – +0,20; October – +0,01. Typical values of evaporation from snow for 1976-1977 are presented at Fig. 8.

3.6 Thaw/freeze depth

Since 1952, the observations on permafrost seasonal thaw dynamics were conducted at the KWBS. Danilin cryopedometers were installed at permafrost observation sites (Snyder et al., 1971) which mostly were located in the approximate vicinity of Nizhnyaya and Verkhnyaya weather stations at the slopes with different aspects and landscapes. During 1952-1997 38 cryopedometers were functioning in total. The longest observation period is 33 continuous years (cryopedometer 17.5 located at the forest with bushes, maximum thawing is 130 cm, 1964-1997). The deepest values of thawing were observed in rocky talus landscape and can reach more than 240 cm. The shallowest values of thawing range from 60 to 70 cm at swampy forest. Thawing of soils at the forest zone varies in large ranges and depends on the location of the cryopedometer at a slope (Table 6, Fig. 9). Despite the fact that permafrost observation sites were equipped with special bridges for observers to come close (Fig. 5), eventually surface damage in the area where the device was installed began to influence thaw depth.

3.7 Streamflow

Runoff observations were carried out at 10 catchments: the creek Kontaktovy (the gauges Verkhny, Sredny, Nizhny), brooks Morozova, Yuzhny, Vstrecha, Vstrecha (the mouth), Dozhdemerny, Severny, Ugroza (Fig. 10). Key characteristics of the catchments are listed in Table 7. All the water level gauges were equipped with «Valdai» water level recorders, as well as needle and hook water level gauges. In spring and autumn, when recorders did not work properly due to ice on the creeks, discharge was measured more frequently, every 4 hours. To

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prevent the recorder floats from freezing, the wells were heated with electric bulbs. At small Morozova and Yuzhny brooks runoff was measured by means of a V-notch weir, at the Severny brook – with a flow measuring flume.

Flow at KWBS begins in May, most of it occurs in summer. For the summer period, rainfall floods are typical (Fig. 11).

In October, small creeks freeze completely. Along the whole length of the Kontaktovy Creek, channel taliks can be found. They go all the way through the layer of alluvial sediments and their depth reaches 15 m in the cross section of the Nizhny hydrological gauge (Mikhaylov, 2013). Taliks freeze in winter only partially.

Annual flow depth of the Kontaktovy stream basin with area 21.3 km^2 (average altitude 1070 m) is 281 mm for the period 1948-1997, it increases with the elevation and at the Morozova catchment (mean elevation 1370 m, basin area 0.63 km^2) reaches 453 mm (1969-1996). The flow from south-facing (Severny) and north-facing (Yuzhny) micro-watersheds with area of 0.38 and 0.27 km^2 are 227 and 193 mm for the period 1960-1997 respectively.

In the database, mean daily values of streamflow are presented.

4. Data availability

All data presented in this paper are available from the “PANGAEA. Data Publisher for Earth & Environmental Science” (see Makarieva et al., 2017, https://doi.pangaea.de/10.1594/PANGAEA.881731). The directory includes 12 elements:

1. daily precipitation time series at different gauges within Kolyma Water-Balance Station (KWBS), 1948-1997;
2. daily runoff time series at different gauges within Kolyma Water-Balance Station (KWBS), 1948-1997;
3. evaporation time series at different sites within Kolyma Water-Balance Station (KWBS), 1950-1997;
4. meteorological observations at different sites within Kolyma Water-Balance Station (KWBS), 1948-1997;
5. monthly precipitation time series at different gauges within Kolyma Water-Balance Station (KWBS), 1948-1997;
6. precipitation (10 day sum) time series at different gauges within Kolyma Water-Balance Station (KWBS), 1962-1997;
7. precipitation (5 day sum) time series at different gauges within Kolyma Water-Balance Station (KWBS), 1966-1997;
8. snow survey line characteristics within Kolyma Water-Balance Station (KWBS), 1959-1997;
9. snow survey time series at different sites within Kolyma Water-Balance Station (KWBS), 1950-1997;
10. soil temperature time series at the Nizhnyaya meteorological station within Kolyma Water-Balance Station (KWBS), 1974-1981;
11. thaw depth and snow height time series at different sites within Kolyma Water-Balance Station (KWBS), 1954-1997;
12. evaporation time series from snow within Kolyma Water-Balance Station (KWBS), 1968-1992.

5. The future of the KWBS

In summer 2016, with the assistance of Melnikov Permafrost Institute of Siberian Branch of Russian Academy of Science, a group of specialists, consisting of representatives of different scientific institutions, conducted a reconnaissance survey of the KWBS in order to find out if it was possible to carry out scientific research and stationary monitoring of permafrost and

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hydrological processes at the station. Despite rather difficult logistic access to the KWBS, it was considered possible to organize accommodation and provision of the station for the period of summer expeditions. At first, the main goal of research resumption at the station would be a renewal of regular observations of runoff, meteorological elements and active layer dynamics at three small catchments (Morozova, Yuzhny, Severny) and the KWBS main-stream outlet (Nizhny gauge) using advanced equipment with automatic data recording. As a result, some unique runoff observations series – over 60 years long – will be continued, which will allow for evaluation of climatic impact on permafrost and provide a scientifically based forecast on current and future climate change impact on the hydrological regime.

During short 3-4 week field trips at the beginning and at the end of the warm (and hydrological) season, it would be also possible to study specific processes of runoff formation under permafrost conditions. Slope runoff occurs unevenly, and is concentrated in particular areas, the drainage zones or preferential path flows. Reconnaissance surveys of the Kontaktovy creek catchment at the KWBS territory, 2016, revealed that there are several types of such zones of slope runoff concentration. Another possible scientific task is to evaluate the role of cryogenic redistribution of runoff, which regularly occurs due to ice freezing-melting in coarse-grained slope deposits. Similar studies have already been carried out in mountain regions of permafrost, including the KWBS (Sushansky, 1999; Bantsekina, 2001; Bantsekina, 2002; Boyarintsev et al., 2006). Another research issue is the study of floodplain taliks (Mikhaylov, 2013) and aufeises (Alexeev, 2016) and their impact on hydrological processes in the mountainous part of the continuous permafrost zone. Field trips for a limited group of scientists could be covered with relatively modest financial support through research grants. In the future, could the aim is for the KWBS to get back its status of a research station, to receive state funding, obtain sponsor support from gold mining companies of the Magadan region and become an international center for complex studies in the field of permafrost hydrology.

The KWBS is situated in the region where monitoring of natural processes is extremely sparse. From 1986 to 1999, the number of hydrological gauge stations in Far-East parts of Siberia decreased by 73% (Shiklomanov et al., 2002). Resumption of water balance observations and organization of complex research of permafrost, climate, and landscape, hydrological and hydrogeological processes based on data collected at the KWBS would make it possible to get new data, representative for the understudied territory of the Arctic in the context of environmental changes. Considering insufficient knowledge about this territory and available long-term data, the KWBS has the prospect to become a highly demanded complex international center for testing natural process models at different scales – from point to regional, – validation of remote sensing products and a place for multidisciplinary field research.

More than 20% of the Northern Hemisphere is covered by permafrost. Three of the four largest rivers of the Arctic Ocean basin flow through Siberia. Many studies highlight ongoing and intensifying changes of water, sediment and chemical fluxes at all spatial scales but mechanisms of changes and future projections are highly uncertain. There are no research centers that could conduct focused studies of hydrological processes at catchments in the permafrost region in Russia. The KWBS incorporation into the international network for monitoring natural processes in cold regions (Interact, SAON, CALM, GTN-P, etc.) could significantly enhance international cooperation for better understanding of cold-region hydrology for the last 70 years, present and future.

Nowadays, the resumption of continuous observations and research at the Kolyma station appears to be a critical task due to increased interest in the natural processes of the Arctic region. Present-day data, following the KWBS long-term observations series, could become a valuable indicator of climate change and a basis for studying its impact on the state of the permafrost and its associated hydrological regime. Currently, as the station infrastructure is still partly intact, and some of the specialists who worked at the KWBS are still active and willing to help, it is necessary to gain attention and support from the Russian and international scientific community regarding the renewal of the KWBS before it is too late.

6. Conclusions

The presented dataset describes water balance, hydrometeorological and permafrost related components at small research watershed in mountainous permafrost zone of North-East Russia, the Kolyma water-Balance Station (KWBS). It includes 50 years of continuous daily meteorological and streamflow data for main meteorological plot and runoff gauge of KWBS and daily data of shorter periods for another two meteorological sites and 9 runoff gauges. Meteorological data includes values of air temperature, water vapour pressure, vapour pressure deficit, atmospheric pressure, wind speed, low and total cloud amount, and surface temperature. The dataset also includes all-year daily, warm period daily, 5-, 10-days and monthly sums for 47 (in total) precipitation gauges within KWBS territory for different time spans over the period 1948-1997. It also contains soil evaporation data from different landscapes, snow evaporation series from two sites; snow surveys results for different watersheds within KWBS, as well as thaw/freeze depths at more than 30 observational sites.

The dataset is important because it characterizes the natural settings, which, on the one hand, are nearly ungauged, and on the other hand, are representative for the vast mountainous territory of Eastern Siberia and North-East Russia. It is unique because it combines water balance, hydrological and permafrost data which allow for studying permafrost hydrology interaction processes within the range of all scientific issues, from models development to climate change impacts research.

7. Author contribution

O. Makarieva and N. Nesterova digitized and prepared the dataset for publication with assistance from L. Lebedeva and S. Sushansky. The data were collected in 1948-1997 by Hydrometeorological Service of USSR and Russia and published in Observation Reports (1948-1997).

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Table 1 List of meteorological observation data

<table>
<tr><th>Station</th><th>Nizhnyaya</th><th>Verkhnyaya</th><th>Kulu</th><th>Kulu2</th></tr>
<tr><td>Latitude</td><td>61.85</td><td>61.86</td><td>61.88</td><td>61.88</td></tr>
<tr><td>Longitude</td><td>147.67</td><td>147.61</td><td>147.43</td><td>147.44</td></tr>
<tr><td>Elevation, m</td><td>850</td><td>1220</td><td>670</td><td>635</td></tr>
<tr><td>Air temperature</td><td rowspan="2">1948-1997</td><td rowspan="2">1948-1972</td><td colspan="2" rowspan="8">1981-1991
1992-1997</td></tr>
<tr><td>Water vapour pressure</td></tr>
<tr><td>Vapour pressure deficit</td><td>1974-1997</td><td>n/a</td></tr>
<tr><td>Atmospheric pressure</td><td>1951-1997</td><td>1951-1972</td></tr>
<tr><td>Low cloud amount</td><td rowspan="4">1948-1997</td><td rowspan="4">1948-1972</td></tr>
<tr><td>Total cloud amount</td></tr>
<tr><td>Wind speed</td></tr>
<tr><td>Surface temperature</td></tr>
</table>

Table 2 Number of snow routes, their total length and number of measurements points – maximum and minimum values within the whole period of observations

Watershed	Period	N	L	MP
Yuzhny	1960-1997	4	1400-1540	144-154
Severny	1950-1997	4/10	1950/2130	23/207
Morozova	1968-1997	2/5	960/2645	98/534
Ugroza	1983-1997	1	1200	120
Dozhdemerny	1959-1971	3	3240/5720	327/575
Vstrecha	1950-1997	1/17	2110/10850	119/1091
Kontaktovy	1960-1997	2/4	4830/13100	485/1314

N – amount of snow routes; L – total length of the route, m; MP – amount of snow thickness measurement points.

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Table 3 Mean, maximum and minimum observed snow water equivalent (SWE) (mm) before spring freshet at different landscapes of the Kontaktovy creek watershed, 1960-1997

Landscape	SWE		
	mean	max (1985)	min (1964)
Forest	144	265	79
Dwarf cedar tree bush	127	247	39
Rocky talus	100	182	46
Boulders	66	127 (1974)	2
Kontaktovy Creek	121	213	59

Table 4 Mean, maximum and minimum snow water equivalent (SWE) (mm) before spring freshet at different watersheds within KWBS

Watershed	Period	SWE		
		mean	max	min
Yuzhny	1960-1997	121	166	70
Severny	1950-1997	126	232	62
Morozova	1968-1997	161	298	71
Ugroza	1983-1994	133	200	93
Dozhdemerny	1959-1971	82	111	53
Vstrecha	1951-1997	123	213	60

Table 5 Mean evapotranspiration (mm) in June – September at different landscapes of KWBS

# site	Landscape	Period	Elevation, m	Slope aspect	Jun	Jul	Aug	Sep	Total*
1	Larch forest	1962-1997	850	n/a	35	37	30	17	119
6	Swampy sparse growth forest	1969-1982	970	North	37	38	30	19	124
7	Dwarf cedar tree bush	1972-1997	1020	n/a	30	33	25	17	104
8	Dwarf cedar tree bush	1976-1997	900	South	47	40	30	14	131
9	Larch forest	1982-1992	669	West	36	39	37	24	136

*the sum for warm period

Table 6 Maximum depth of thawing at the different landscapes

# site	Watershed	Landscape	Period	Elevation, m	Maximum depth of thawing, cm
1	Kontaktovy	Forest	1954-1966	841	150
6	Dozdemerny	Rocky talus	1960-1965	1048	>240
9	Severny, Ugroza	Rocky talus	1954-1966; 1977-1978	986	168
12	Vstrecha, Severny	Dwarf cedar tree bush at rocky talus	1954-1962; 1966-1968; 1971-1997	866	157
15	Dozdemerny	Dwarf cedar tree bush at rocky talus	1958-1968; 1970-1982	952	>150
17	Vstrecha	Forest	1960-1965, 1969	914	>124
18 bh7	Kontaktovy	Peat bogs	1959-1960	835	69
18 bh8	Kontaktovy	Peat bogs	1959-1960	835	64

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Table 7 The characteristics of KWBS watersheds

Code	Catchment (creek – outlet)	Period	Area, km^2	X	Y	Stream length, km	Mean watershed width, km	Mean stream slope, ‰	Mean basin slope, ‰	Catchment altitude (max-min, mean), m	Mean annual flow, mm	Maximum observed daily discharge, m^3s^{-1}
1104	Yuzhny	1960-1997	0.27	61.84	147.66	0.51	0.35	235	303	1110-917, 985	193	0.14
1107	Severny	1958-1997	0.38	61.85	147.66	0.74	0.38	175	388	1300-880, 1020	227	0.18
1103	Morozova	1968-1996	0.63	61.84	147.75	0.97	0.45	326	649	1700-1100, 1370	453	0.44
1624	Ugroza	1983-1991	0.67	61.86	147.67	0.9	0.74	218	461	1270-914, 1260	354	0.27
1106	Dozhdemerny	1952-1971	1.43	61.86	147.63	0.87	0.99	220	432	1450-950, 1180	208	0.31
1105	Vstrecha	1949-1997	5.35	61.85	147.66	3.4	1.5	92	346	1450-833, 1060	237	3.15
1100	Kontaktovy – Verkhny	1973-1980	5.53	61.84	147.70	2.8	2.1	185	473	1700-909, 1070	317	2.52
1625	Vstrecha – the mouth of Ugroza Cr.	1984-1996	6.57	61.84	147.66	3.6	1.8	76	406	1450-831, 1070	283	2.6
1101	Kontaktovy – Sredny	1948-1997	14.2	61.84	147.67	6.2	2.8	65.2	413	1700-842, 1120	289	7.02
1102	Kontaktovy – Nizhny	1948-1997	21.3	61.85	147.65	7.1	3.7	57.6	413	1700-823, 1070	281	8.15

Fig. 1 The view of the Kolyma Water Balance Station, August 2016 (photo by O. Makarieva)

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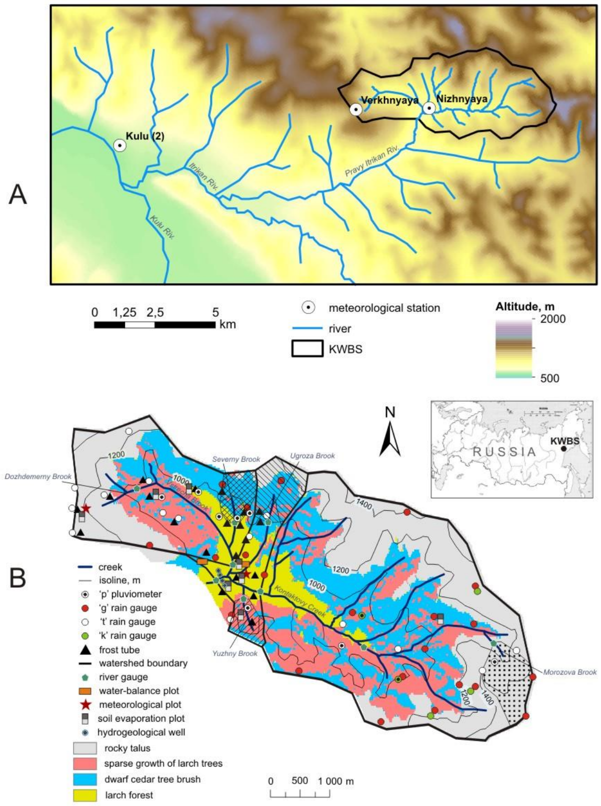

Fig. 2 Scheme of the Kolyma Water Balance Station (KWBS) indicating the location of observation sites

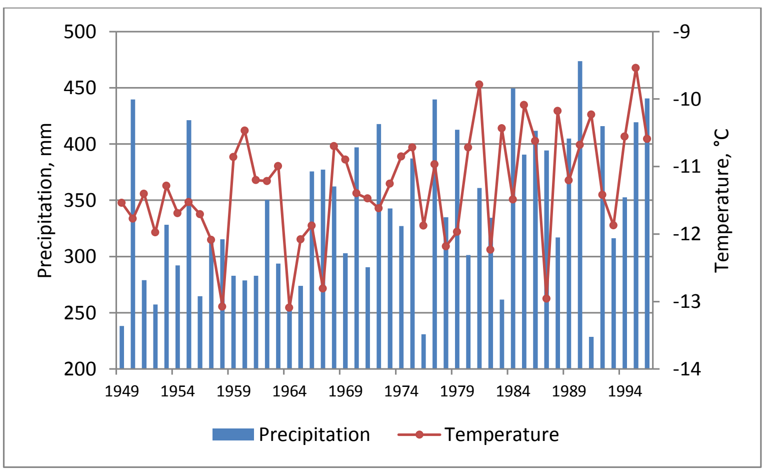

Fig. 3 Annual precipitation (mm) and air temperature (°C) at Nizhnyaya weather station, 1949-1996

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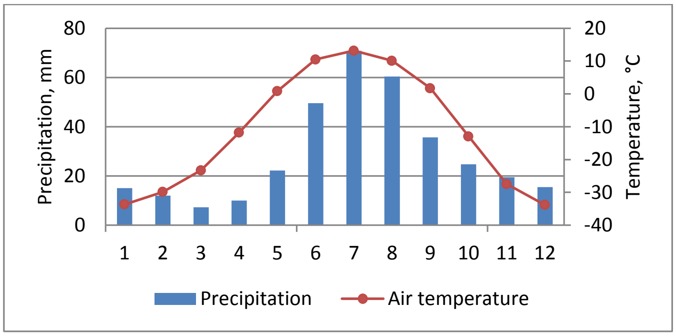

Fig. 4 Mean monthly precipitation (mm) and air temperature (°C) at Nizhnyaya weather station, 1949-1996

Fig. 5 Meteorological observations: rain-gauge plot #2, 1959.

Fig. 6 Snow survey at the Kontaktovy creek catchment (A, B) and measurement of snow density (C), 1960

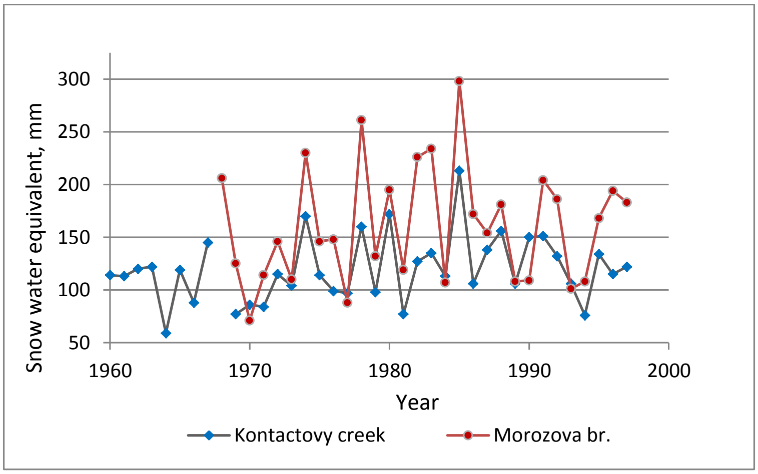

Fig. 7 Snow water equivalent at the Kontaktovy creek and Morozova br.

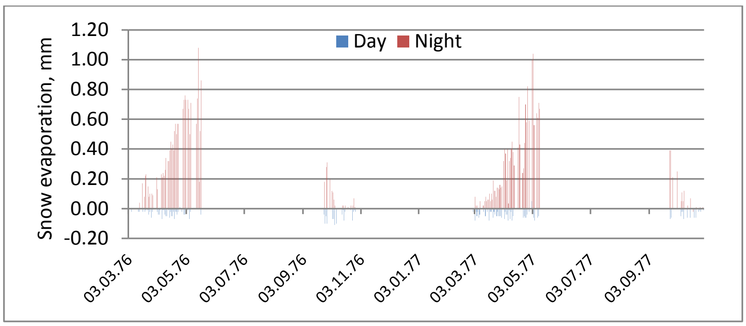

Fig. 8 Snow evaporation (mm) during day and night period, 1976-1977

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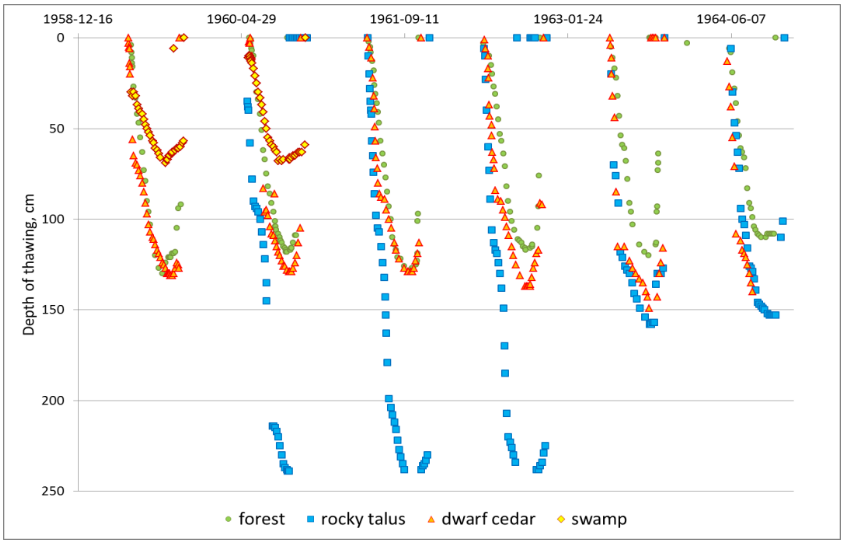

Fig. 6 Depth of ground thawing at the different landscapes of KWBS

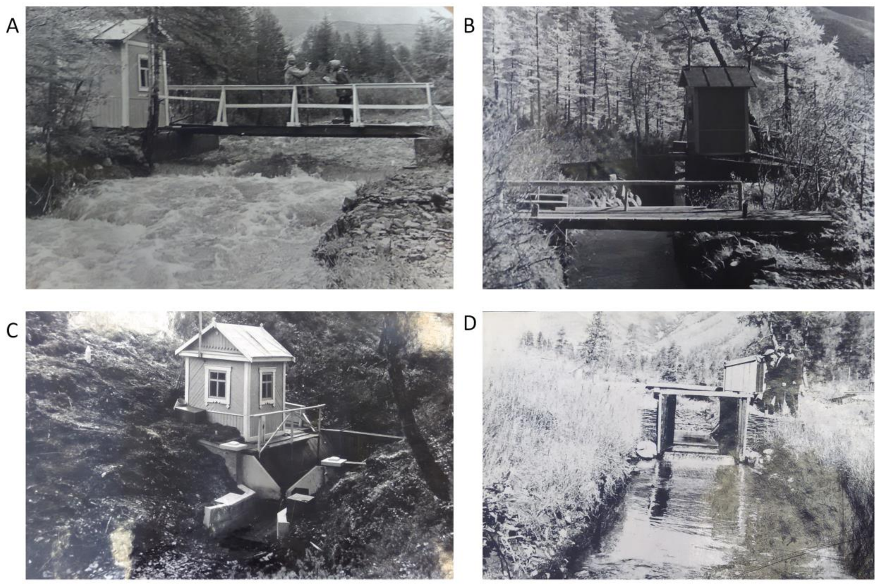

Fig. 7 Runoff observations: A – runoff gauge at the Kontaktovy creek, 1979; B – runoff gauge at the Dozhdemerny creek, 1959; C – runoff gauge at the Yuzhniy creek, 1960; D – runoff gauge at the Vstrecha creek, 1953.

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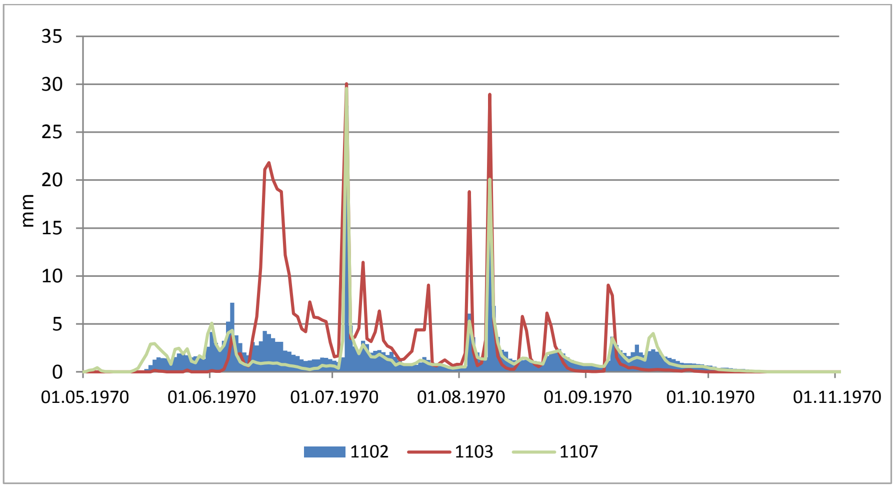

Fig. 11 Flow depth (mm) at the Kontaktovy creek – Nizhny (1102), Severny br. (1107) – south-facing slope with cedar dwarf bush landscape and Morozova br. (1103) – rocky talus landscape at watershed divides, 1970