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WATER RESOURCES AND THE REGIME OF WATER BODIES

Space and Time Differentiation of Snow Cover in the Kasmala River Basin, Altai Krai

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Abstract—The results of route snow surveys of 2011–2014 in the Kasmala River basin, which is typical of the southern forest-steppe of Altai Krai, are analyzed. The interannual differentiation of the major snow cover characteristics is considered along with the factors that have an effect on the snow accumulation rates in different types of geosystems in the basin.

Keywords: snow cover, maximal snow water equivalent, southern forest steppe

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INTRODUCTION

Geographic studies of snow cover are aimed to collect data on its spatial distribution, accumulation dynamics, duration, snow-melting conditions, water equivalent, etc. The data of snow cover observations can be used to solve various problems: studying the climatic and hydrological regimes of territories, the development of agrometeorological and hydrological forecasts, the assessment of environmental changes (including climate variations), etc. [21].

Snow cover is a key landscape-forming factor. It largely determines the functioning of landscapes in winter [14]. Under the conditions of the general lack of hydrometeorological information, the data on the major characteristics of snow cover are key quantitative characteristics of functioning of geosystems, which can be used to analyze their dynamic states.

The data on the space and time variations of snow cover are commonly collected by route snow surveys, which provide data on the types of geosystems of interest. Notwithstanding the steady enhancement of the potential of modeling and remote sensing studies of snow accumulation processes [12, 16, 23, 27], this approach is still in wide use [3, 17, 18], in particular, in combinations with other methods [2, 8].

In the steppe and forest-steppe zones of the southern Western Siberia, water is a deficient resource and its deficiency is the major factor that limits the functioning of landscapes. Considering that the major portion of surface runoff in these areas forms during spring snow melting, the use of snow cover characteristics as dynamic characteristics of geosystems is of use in landscape (landscape–hydrological) studies in the basins of small and medium rivers in the steppe and forest-steppe zones [24, 25].

These aspects determine the need to organize ground based snow-measurement studies within several years in a representative river basin in the southern Western Siberia.

MATERIALS AND METHODS

The study was carried out in the Kasmala River basin (the area of 1768.48 km2, with the outlet section in Rogozikha Village), located on Ob Plateau (Altai Krai). This choice of the study region was due to its zonal homogeneity and representativeness for the southern Western Siberia [9]. The main elements of the first-order landscape structure in the basin under consideration (its structural–functional parts) are the southeastern macroslope of the Kulundinsko-Kasmalinskii Ridge, the northwestern macroslope of the Kasmalinsko-Barnaul'skii Ridge, and the bottom of the Kasmalinskaya ancient flow gully, which separates these Ridges, and a small part of which is the contemporary valley of the Kasmala River.

According to the data of the Rebrikha meteorological station, Altai CHMS (from 1940 to 2014), located in the Kasmala River basin, the average January temperature is −7.1°C, and that of July is +19.5°C. The annual precipitation averages 401.4 mm, and that over winter season is 109.7 mm. The duration of snow cover is 125–130 days [5].

The study was carried out by landscape route method [4, 15] in the period of maximal snow accumulation (mid-March) during 4 years: 2011–2014. The majority of measurements were carried out at

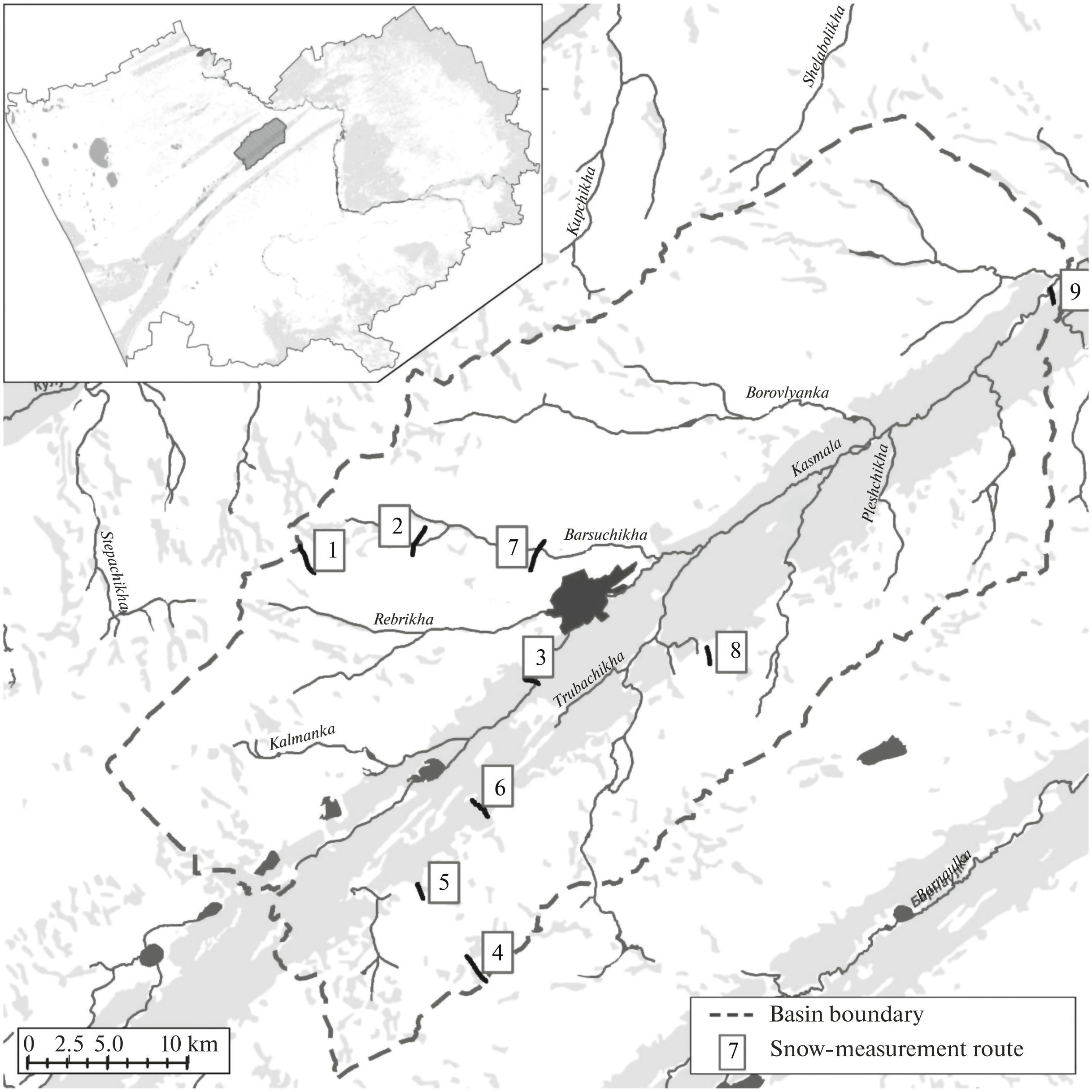

Fig. 1. Schematic map of snow-measurement routes in the Kamsala River basin and the position of the basin in the Altai Krai.

nine permanent routes (Fig. 1) with lengths from 1 to 2.5 km, the total length of the routes was ~12 km. Samples for measuring snow density were taken by a snow sampler VS-43. The routes were chosen for the measurements to cover all major typological elements of the landscape structure: water-divide and gentle-slope surfaces of the Ridges (conventionally "the main surface"), occupied mostly by arable land; small-leaved forest outliers, valley–ravine network (areas of ravine forests, floodplain meadows, etc.), pine forest in the trough of ancient watercourse, and the contemporary valley of the Kamsala River. On the main surfaces of Ridges, the areas without the effect of forest belts were predominantly chosen for the study. In addition, the analysis used observation data in permanent snow-measurement routes of meteorological stations Rebrikha (1966–2014), Barnaul, and Baevo (2011–2014) [5].

The calculations included the evaluation of snow density (r, g/cm3) and snow water equivalent (SWE, mm), statistical processing of data with the evaluation of standart deviation (s), the coefficients of variation (Cv), and the standard error of the mean values (mHrW) of these characteristics. Calculated for the basin as a whole were also the values of the main characteristics of snow cover, averaged with weights proportional to the areas of landscape types. The coefficients of snow accumulation were calculated for major

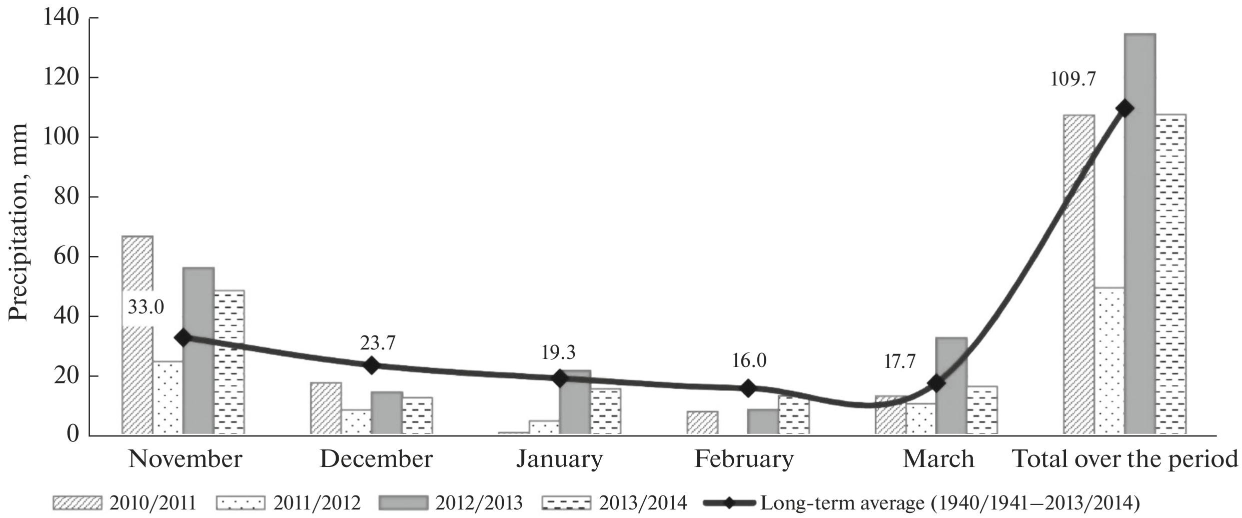

Fig. 2. Precipitation of the cold season at Rebrikha meteorological station, mm.

types of geosystems for each observation year. They were calculated as the ratio of snow water equivalent in particular type to the snow water equivalent at background areas. In this study, the background areas were taken to be the geosystems of gently sloping surfaces of Ridges, where the effect of forest outliers is absent, but all other factors have their effect. This somewhat differs from the conventional approaches, where the indicator (background) areas are taken to be those in which the effect of any factors of snow cover redistribution is minimal [7, 11].

The objective of this study is to determine the actual relationships between the values of snow accumulation in different parts of the basin and the identification of the leading factors of this process.

RESULTS AND DISCUSSION

The Analysis of the Meteorological Conditions of the Cold Season of 2010/2011–2013/2014

Data of meteorological observations over winter seasons preceding the snow surveys were analyzed (similar to hydrological years). In the further analysis of the data of snow-measurement observations, the years, corresponding to hydrological years, are also given.

The winter seasons considered in the study are also very contrasting in terms of the major meteorological characteristics (Figs. 2–5). The key characteristic—the total precipitation of the cold season (Fig. 2)—clearly distinguishes very wet 2012/2013 (70% of the maximum over the entire observation period, taken into account in the calculations, starting from winter 1940–1941); medium years of 2010/2011 and 2013/2014, and the very dry 2011/2012 (absolute minimum over the entire observation period). Medium-wetness years differed in the temperatures of winter season with considerable variations of mean monthly values of the temperature (late February or early December temperature minimums). The plot of mean daily temperatures (Fig. 3) shows several thaws in the winter of 2013/2014. The driest winter of 2011/2012 features the lowest mean monthly air temperatures and the weakest winds (Fig. 4). The main wind activity was recorded in the early winter months, when more than half of the total winter precipitation fell. In combination with an abrupt drop in the mean daily temperature, this had a considerable effect on snow accumulation.

According to the snow surveys at Rebrikha meteorological station, the mean annual value of maximal snow storage on a permanent field route in mid-March is 96 mm (the observations on this rout have been made since 1977), and that on a forest route was 119 mm. Snow-measurement routes, as well as the meteorological station, are situated in the left-bank part of the Kamsala River basin, near the western margin of Rebrikha Village. The relative snow abundance (the ratio of maximal snow storage in a year to its normal value) were 0.9 for 2010/2011, 0.7 for 2011/2012, 1.6 for 2012/2013, and 0.8 for 2013/2014. Therefore, in this period, the winter seasons of 2010/2011 and 2013/2014 can be referred to medium-snow; 2011/2012, to nearly low-snow; and 2012/2013, to snow-abundant (one of the maximums over the entire observation period).

The winter periods of the years under consideration differ in their main meteorological characteristics. This allows us to identify some regularities in the space and time variations of snow cover characteristics as a function of variations in meteorological conditions.

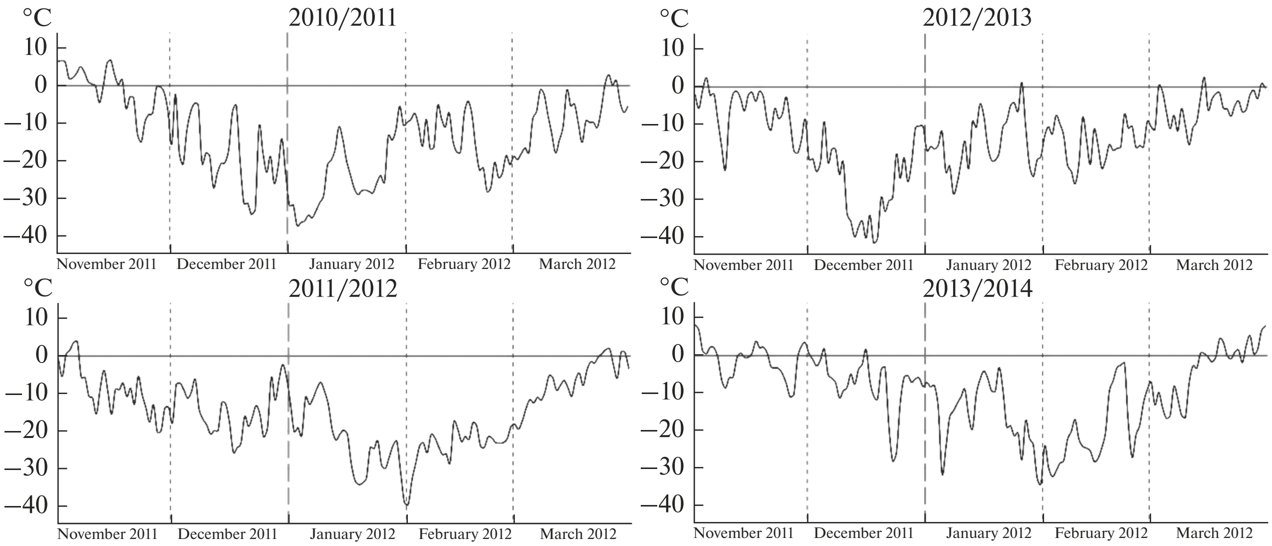

Fig. 3. Average daily air temperature of the cold season in 2010/2011–2013/2014.

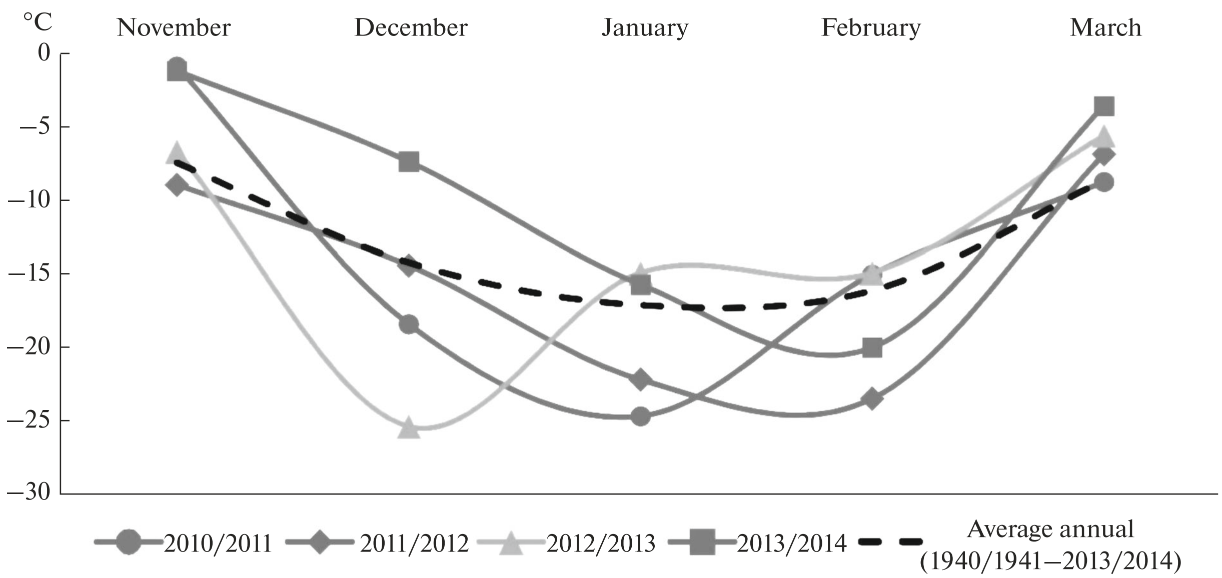

Fig. 4. Average monthly air temperature in the cold season at Rebrikha meteorological station.

Specific Features of the Interannual Variations of Snow Cover at the Level of Large Structural-Functional Parts of the Basin

The results of the authors' studies (Tables 1, 2) are in good agreement with the data collected on the routes of snow-measurement surveys at Rebrikha meteorological station; they also fall within the range of values of the normal maximal snow water equivalent (from 50 to 100 mm), typical of the southern Western Siberia [1]. However, there are some discrepancies, caused, primarily, by the positions of the permanent routes of the meteorological station. These routes pass in the close vicinity to the meteorological station, on the western periphery of Rebrikha Village. The forest route passes in its marginal part; and the field route, on the open surface of the Kulundinsko-Kasmalinskii Ridge, though close to the edge of the forest. Clearly, the snow accumulation on the route can show the effect of various local factors, e.g., higher wind activity and a complex configuration of wind flows near the forest, the presence of a considerable portion of small-leaved species in the stand composition (as is typical of the marginal parts of the forest, which suffer largest anthropogenic impart), etc. All these factors can contribute to both increase and decrease of snow water equivalent relative all other surfaces of the Ridges.

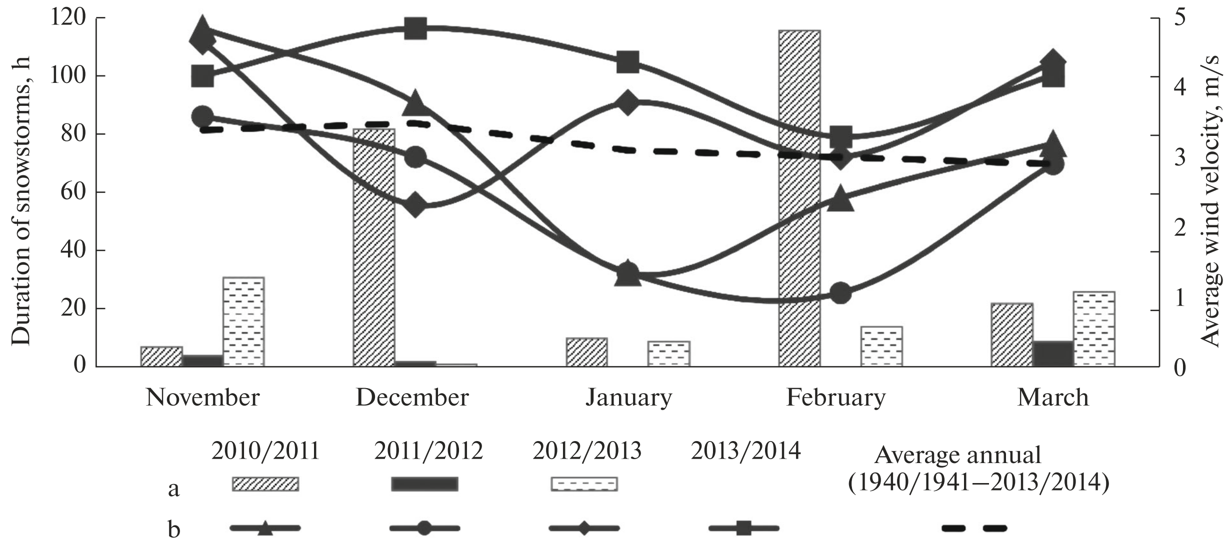

Fig. 5. (a) Duration of snowstorms, h and (b) average wind velocity, m/s, in the cold season at Rebrikha meteorological station (atmospheric observations were not carried out at this meteorological station in 2013/2014).

This is confirmed by the comparison of data with those from other meteorological stations, situated in the subzone of the southern forest steppe—Baevo and Barnaul. The former station is situated on the western boundary of this subzone at the passage to dry steppe, and the latter, on the eastern boundary at the passage to the subzone of the median forest steppe. However, the snow water equivalent on the route of Baevo meteorological station is sometimes greater than those in Barnaul (the winter of 2011/2012). The snow water equivalent evaluated on the field route of Rebrikha meteorological station and by the authors' data are mostly larger than those at Barnaul meteorological station.

Passing to the analysis of the data of snow surveys, we have to explain the difference in the data sets for the two similar parts of the basin—Ridge surfaces. First of all, this is due to the difference in the morphological structure of landscapes. The right side of the basin—the northwestern macroslope of the Kasmalinskii–Barnaulskii Ridge—has an area 524.5 km^2 (more than by half) less than the opposite Ridge. Very widespread features of this Ridge are small-leaved forest outliers and much less developed drainage network. The left side—the southeastern macroslope of the Kulundinskii–Kasmalinskii Ridge is well drained by small rivers and intermittent streams with a developed drainage network, in which small-leaved forests grow. The survey covered the geosystem most typical of each Ridge, thus allowing lesser number of measurement to be carried out in the drainage network of the right side and no measurements to be carried out in the separate forest stands on the left side. These factors should be taken into account in the direct comparison of data on each Ridge. However, the regularities of snow accumulation typical of them can be revealed in the analysis of individual similar classes of locations, primarily, by the main surfaces of Kulundinsko–Kasmalinskii and Kasmalinskii–Barnaul'skii Ridges.

A feature of snow accumulation throughout the observation period is the excess of snow depth (on the average, by 12%) on the main surface of the Kasmalinskii–Barnaul'skii compared with the Kulundinsko–Kasmalinskii Ridge. In this case, the average snow density on the surface of the Kulundinsko–Kasmalinskii Ridge is higher (on the average, by 11%), and the snow water equivalent on the left side of the basin is often larger than that on its right side.

It can be supposed that the cause of the considerable difference in snow cover density is the lower wind velocity between the closely located Kasmalinskaya and Barnaul'skaya pine forest stripes and the insolation macroexposure of the slopes of the Kulundinsko–Kasmalinskii Ridge. The effect of wind on snow consolidation is known to be largest in the areas where thaws and liquid precipitation are rare in winter [10]. The effect of strip pine forests on the attenuation of winds was also mentioned [22]. The larger intensity of winds on the surface of the Kulundinsko–Kasmalinskii Ridge is indirectly confirmed by the absolute maximums of snow water equivalent values (for the entire basin) on the downwind slopes. The coefficients of variation of snow depth on the left side are also somewhat higher for all types of geosystems (Table 3).

Unlike the Ridge surfaces, the snow cover on the bottom of the Kasmalinskaya ancient flow gully is more uniform (to a larger extent, in the forest part). The coefficients of variations of snow Depth show no abrupt variations (27–35%). In this case, the average snow depth in each observation year (Table 1) is com-

Table 1. Main characteristics of snow cover in the Kasmala River basin and nearby areas (data, except for meteorological station routes, are given with a standard error; the short dash means no observations carried out; the longer dash means no data available; weighted mean values are given for the entire basin)

Area	Number of snow depth/density measurements				H_{av}, cm				ρ_{av}, g/cm^3				SWE, mm			
	2010/2011	2011/2012	2012/2013	2013/2014	2010/2011	2011/2012	2012/2013	2013/2014	2010/2011	2011/2012	2012/2013	2013/2014	2010/2011	2011/2012	2012/2013	2013/2014
Kulundinsko-Kasmalinskii Ridge	891/23	282/31	212/27	212/24	37 ± 0.5	31 ± 0.5	69 ± 2	33 ± 1	0.20 ± 0.01	0.19 ± 0.01	0.29 ± 0.01	0.27 ± 0.01	71 ± 8	57 ± 3	198 ± 13	96 ± 14
Main surface	603/19	201/24	138/16	140/14	32 ± 0.4	28 ± 0.4	65 ± 1	28 ± 1	0.20 ± 0.01	0.19 ± 0.00	0.30 ± 0.01	0.29 ± 0.02	68 ± 8	54 ± 2	190 ± 12	74 ± 4
Drainage network	212/3	80/7	72/11	69/9	48 ± 2	37 ± 1	77 ± 4	44 ± 2	0.18 ± 0.01	0.18 ± 0.02	0.29 ± 0.01	0.23 ± 0.01	69 ± 16	68 ± 8	209 ± 29	128 ± 36
Kasmalinsko-Barnaul'skii Ridge	263/6	199/23	239/32	240/26	40 ± 0.8	36 ± 0.4	79 ± 1	37 ± 1	0.18 ± 0.03	0.18 ± 0.00	0.25 ± 0.01	0.22 ± 0.02	73 ± 7	70 ± 4	198 ± 7	72 ± 4
Main surface	165/4	103/12	138/17	142/16	35 ± 1	34 ± 0.4	72 ± 1	30 ± 1	0.17 ± 0.04	0.20 ± 0.00	0.27 ± 0.01	0.24 ± 0.02	65 ± 7	72 ± 2	189 ± 6	66 ± 4
Forest outliers	98/2	76/8	89/12	85/9	50 ± 1	39 ± 0.1	91 ± 2	47 ± 1	0.17 ± 0.00	0.18 ± 0.01	0.24 ± 0.01	0.18 ± 0.02	90 ± 3	74 ± 9	222 ± 15	84 ± 9
Drainage network	–	21/3	12/3	13/2	–	35 ± 1	81 ± 4	48 ± 4	–	0.16 ± 0.01	0.19 ± 0.02	0.17 ± 0.02	–	55 ± 6	155 ± 8	61 ± 9
Ancient flow gully	355/10	191/21	95/16	135/19	41 ± 1	29 ± 0.4	76 ± 2	38 ± 1	0.16 ± 0.01	0.19 ± 0.01	0.21 ± 0.01	0.18 ± 0.01	66 ± 8	60 ± 4	150 ± 10	68 ± 4
Pine forest	268/6	157/18	75/13	108/16	42 ± 1	29 ± 0.0	84 ± 1	40 ± 1	0.15 ± 0.02	0.19 ± 0.01	0.20 ± 0.01	0.17 ± 0.01	58 ± 10	62 ± 3	163 ± 10	67 ± 2
Kasmala River valley	35/2	34/3	20/3	27/3	35 ± 3	30 ± 0.3	45 ± 4	29 ± 2	0.17 ± 0.01	0.16 ± 0.03	0.29 ± 0.03	0.20 ± 0.01	73 ± 21	51 ± 14	96 ± 7	71 ± 29
Total for the basin	1509/38	672/75	546/75	587/69	36 ± 0.4	31 ± 0.3	72 ± 1	33 ± 1	0.18 ± 0.01	0.19 ± 0.00	0.27 ± 0.01	0.24 ± 0.01	66 ± 5	61 ± 2	184 ± 6	75 ± 5
Permanent snow-measurement route Rebrikha HMS ("field")	–	–	–	–	30	25	56	30	0.28	0.25	0.27	0.24	84	63	151	72
Permanent snow-measurement route Rebrikha HMS ("forest")	–	–	–	–	46	35	78	–	0.17	0.17	0.21	–	78	60	164	–
Permanent snow-measurement route HMS Baevo ("field")	–	–	–	–	20	28	27	23	0.25	0.17	0.35	0.20	53	48	103	46
Permanent snow-measurement route HMS Barnaul ("field")	–	–	–	–	37	24	54	28	0.22	0.19	0.32	0.22	81	46	173	62

Table 2. Standart deviation (σ, the first number) and the coefficient of variation (*Cv*, %, the second number) for the observed snow cover characteristics in the Kasmala River basin

Area	H_{av}, cm				ρ_{av}, g/cm^3				SWE, mm			
	2010/11	2011/12	2012/13	2013/14	2010/11	2011/12	2012/13	2013/14	2010/11	2011/12	2012/13	2013/14
Kulundinsko-Kasmalinskii Ridge	16/44%	8/28%	25/36%	17/50%	0.06/28%	0.03/15%	0.04/12%	0.06/23%	37/51%	15/26%	68/35%	69/72%
Main surface	10/31%	5/19%	16/25%	11/39%	0.1/29%	0.02/12%	0.04/13%	0.07/23%	35/52%	11.0/20%	48/25%	14/19%
Drainage network	23/49%	11/31%	34/44%	20/47%	0.01/6%	0.05/25%	0.03/11%	0.04/18%	28/41%	21/31%	92/44%	107/84%
Kasmalinsko-Barnaul'skii Ridge	12/31%	5/15%	15/19%	12/32%	0.06/38%	0.02/12%	0.05/19%	0.09/40%	17/24%	17/25%	42/21%	20/28%
Main surface	9/25%	4/12%	9/12%	7/23%	0.08/49%	0.02/8%	0.05/17%	0.1/39%	14/22%	8/12%	24/13%	15/22%
Forest outliers	12/24%	6/15%	15/16%	9/19%	0.00/0%	0.02/13%	0.04/16%	0.06/36%	4/5%	26/35%	53/24%	26/31%
Drainage network	–	4/13%	13/16%	14/28%	–	0.01/7%	0.04/20%	0.03/15%	–	11/19%	14/9%	8/14%
Ancient flow gully	13/31%	6/21%	20/27%	9/23%	0.04/23%	0.03/16%	0.05/25%	0.02/13%	24/35%	16/27%	42/28%	19/28%
Pine forest	9/22%	5/18%	11/13%	6/15%	0.04/32%	0.02/12%	0.04/20%	0.02/12%	23/39%	15/24%	36/22%	9/14%
Kasmala River valley	18/53%	10/33%	17/37%	12/41%	0.01/4%	0.05/34%	0.05/19%	0.02/12%	29/40%	25/48%	13/13%	50/71%
The basin as a whole	15/39%	8/24%	21/27%	13/37%	0.06/30%	0.03/14%	0.05/21%	0.07/33%	31/44%	17/27%	56/30%	45/57%

Table 3. The coefficients of snow accumulation in different parts of the Kasmala River basin

Characteristic of the area	2010/2011	2011/2012	2012/2013	2013/2014	Average
Drainage network*	1.0	1.1	1.0	1.6	1.2
Forest outliers*	1.3	1.2	1.2	1.2	1.2
Pine forest	0.9	1.0	0.9	1.0	0.9
Contemporary valley of the Kasmala River	1.0	0.9	0.5	1.0	0.9

* For the basin as a whole.

parable with that on the right side, and more frequently exceeds that on the left side of the basin. The snow water equivalent in the bottom of the Ancient flow gully is less than that on the Ridges because of the lesser snow density (it rarely exceeds 0.20 g/cm^3).

Comparison of Snow Water Equivalent in a Forest and on Open Surfaces of the Ridges

The effect of coniferous forest on snow accumulation is dual. On the one hand, the interception of falling snow by forest canopy facilitates its evaporation, thus reducing the snow storage. On the other hand, forest contributes to an increase in precipitation and a decrease in wind speed and protects the snow under forest cover against evaporation, blowing out, and melting during thaws, thus facilitating snow accumulation [3, 7, 10, 11]. These means that the problem of the comparison of snow water equivalent values in the forest and open areas in different seasons or in different locations is of great importance.

The snow accumulation in forests (including coniferous) is believed to be generally higher than that in open areas [6, 10, 11, 20]. This regularity has been formulated based on a large body of experimental data of snow surveys, mostly in the zones of mixed forests, taiga, and subtaiga, as well as in mountain forests [20], i.e., in the areas where forest distribution is governed by zonal or orographic factors. Coefficients of snow accumulation for the area under study, calculated by data of snow surveys on meteorological stations, are given in [6, 13]. The coefficient of snow accumulation, equal to 1.67, is given in [6] for Rebrikha meteorological station. However, the data raise some doubts, as, for example, the values of snow storage for the Ust'-Volchikha meteorological station (dry steppe) are far in excess of those at Rozhnev Log meteorological station (southern forest-steppe). We suppose that local differences exist in snow accumulation between the routes at the meteorological stations and, possibly, in observation periods (no specifying data are available). A coefficient of snow accumulation for the entire forest-steppe zone of the West Siberian Plain was estimated in [13] at 1.68 based on studies in several regions, mostly, in deciduous forests.

It is of interest to consider the retention of solid precipitation by forest cover, in particular, coniferous. The amount of snow intercepted by the canopies of coniferous trees is known to increase with the canopy density and the total solid precipitation. According to [11], the relative snow retention does not depend on the total winter precipitation. A formula for calculating the snow intercepted by crowns is also given in [11] along with the coefficient of snow retention for spruce (0.37) and pine (0.22) forests. The analysis of the results derived from a considerable empirical material in the North America [28] showed similar tendencies.

The issue of retention of solid precipitation by the crowns has been studied in detail for the Minusinskaya Depression [7]. The share of solid precipitation intercepted there by the canopies of pine trees was estimated at 20–36%, depending on the background precipitation.

According to studies carried out in North America [26, 29], the interception of solid precipitation is largest in early winter; it can reach 44% in December and 30% by the start of snow melting in April. The proportion of precipitation intercepted by the end of winter is equivalent to sublimation losses and, for pine trees, amounts to 30–32% of the total accumulation in winter. The difference between the intercepted and evaporated precipitation is due to the snow that has fallen from canopies [26, 29].

The average coefficient of snow accumulation, calculated by the data of Rebrikha meteorological station (since 1977—from the start of the use of field route) is 1.2, thus suggesting some predominance of the processes of snow accumulation in the forest. The analysis of a long-term series of snow accumulation coefficients shows that the value of this coefficient varies over time and can fall below unit in years with different snow abundance.

According to the authors' data, the values of snow water equivalent on water-divide and gently sloping surfaces of Ridges (the right and left sides, excluding forest outliers and valleys) in three years out of four (2010/2011, 2012/2013, 2013/2014) were found to be larger than those in a pine forest. This relationship was expressed in terms of snow accumulation coefficients (Table 3). Such regularity can also be seen in the routes of the meteorological station in 2010/2011 and 2011/12 (in 2011/2012, the ratio of snow on steppe Ridges and in pine forest is close to unit). In 2012/2013, the considerable difference between snow storage in open areas, according to the authors' observations and by data of the meteorological station, makes this difference impossible to trace. The difference can be caused by local factors, associated, primarily, with intense snow-storm-induced redistribution, caused by the specific position of the route, as it has already been mentioned above.

The data of the authors' observations cover much more types of geosystems in both Ridges and in the Ancient flow gully. Basing on these data, we can suppose that the interception of precipitation by tree canopies is a key factor of snow cover redistribution, and the excess of snow water equivalent values on water-divide and slightly sloping Ridge surfaces over those in pine forest is a typical phenomenon. Similar regularities are typical of the Priobskie pine forests, which refer to the zone of median forest steppe [19]. The observed depth of snow cover is 8–12 cm greater than that in open areas (high river terraces), a feature which, at low density, leads to similar values of snow water equivalent. As the compaction of snow cover in forests is mostly due to its own weight, its density in a stripe pine forest of the southern forest-steppe is somewhat less than that in Priobskie pine forests because of the different amounts of precipitation.

An unusual year was 2011/2012, when the coefficient of snow accumulation was close to unit (both by the data of meteorological station and by the authors' measurements). Basing on the available data, we can conclude that, in years with small amount of snow and weak winds, the contrast between the values of snow storage in forests and open areas should increase in Ridges because of the absence of intense snowstorm transport and weaker evaporation of snow during snow storms against a constant value of its retention by tree crowns. However, one should take into account the losses of snow storage on Ridges at the beginning of winter of 2011/2012, considered above. At low temperature, the sublimation losses were relatively small, which also increased the probability of snow falling from branches and, accordingly, contributed to an increase in snow storage in the forest.

It is worth noting that most researchers in this field have studied boreal or mountain forests, where the regularities of input, accumulation, and evaporation of precipitation differ from those in forest-steppe. In the territory under consideration, the issue of snow interception by canopies is of extreme importance, because the amount of winter precipitation is not large and the share of intercepted precipitation (of which a considerable portion will evaporate) is of considerable importance. The interception losses have a considerable effect on the formation of snow storage under forest canopy. The role of this factor decreases with increasing precipitation.

Major Local Factors Affecting the Redistribution of Snow: Slopes, Aspects, and Vegetation Cover

As mentioned above, the snow water equivalent and the snow depth are maximal on the downwind northeastern and northern (because of the predominantly southwestern winds) and the neighboring parts of the bottoms of ravines, gullies, and small-river valleys. In snow-abundant years, the snow water equivalent here is in excess of 400 mm (snow cover thickness is >150 cm), in median-snow years, >300 mm (snow depth is ~100 cm) and even in low-snow years, the snow water equivalent reaches 160 mm, which is twice the average over the basin.

The coefficient of snow accumulation in the drainage network varies from 1.0 to 1.6; it increased in the windiest season of 2013/2014. The calculations took into account the slopes of all aspects, though the windward (southern and southwestern) slopes of Ridges and erosion forms commonly show snow cover with a depth 2–2.5 times less.

It can be also mentioned that snow storage is commonly higher on the left side of the basin. However, the most important factor that has an effect on the character of snow accumulation is the differences in the landscape structure of the Ridges, which has been mentioned above. At lower wind activity, the conditions for snow accumulation in the drainage network on the Kasmalinskii–Barnaul'skii Ridge are less favorable than those on the opposite side of the basin. The coefficient of variation of snow storage is also higher there (up to 84%).

The exposition-related variations of snow cover characteristics on the bottom of the Kasmalinskaya gully are insignificant. The major factor of the differences in snow distribution is the character of vegetation. Contrast in this respect are forested areas, on the one hand, and river floodplains within the modern valley of the Kasmala River, on the other hand. The coefficient of snow accumulation in valley geosystems varies very widely: from 0.5 to 1.0. The diversity of the underlying surface (a combination of swampy depressions and meadows) in relatively small areas causes a nonuniform distribution of snow. The coefficient of variations of snow water equivalent is always very high here (up to 71%); it decreases only in snow-abundant years.

The highest coefficient of snow accumulation (1.23) within the basin is typical of birch and birch–aspen forest outliers. Snow storage here is commonly highest in the basin. The variability of snow storage is also slightly higher here, primarily, because of the greater accumulation of snow on forest edges. A regularity can be seen here: snow depth in sparse forest outliers (because of cutting or fires) is, on the average, 14% higher than that in denser forest stands.

CONCLUSIONS

In the observation years—2011–2014—the Kamsala River basin showed contrast weather conditions in winter. Under specific landscape conditions, the meteorological conditions are reflected in the spatial differentiation of major characteristics of snow cover.

A difference was found in the snow accumulation conditions on the Kulundinskii–Kasmalinskii (the left side) and Kasmalinskii–Barnaul'skii (the right side) Ridges. It manifests itself in an increase in the average thickness of snow cover (on the average, by 11%) on the main surface of the right side of the basin, while the left side most often shows higher snow density (on the average, by 12%) and variability of all other characteristics of snow cover). This may be due to the different Ridge areas, the distances between forest belts, and, as a consequence, different wind regime. The results of studies have shown that snow water equivalent values can be greater on the main surface of either right or left side of the basin, depending on the weather conditions in the particular winter period.

In pine forests of the Ancient flow gully, the snow cover is more uniform than that on Ridges. The values of maximal snow storage within pine forests are less than its average value on the main surface of the Ridges. This is due to snow interception by tree canopies. This can be a phenomenon typical of stripe pine forest in the forest-steppe and steppe zones.

On the right side of the Kasmalinskii–Barnaul'skii Ridge, the key snow-accumulating role belongs to small-leaved forest outliers. On the left side of the Kulundinskii–Kasmalinskii Ridge (the left side), which shows much wider occurrence of erosion relief forms, this role belongs to valleys and gullies, on the downwind slopes of which, snow water equivalent values was maximal over the entire basin (more than 300 mm in snow-abundant years).

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