THE USE OF MAXIMUM SNOW WATER EQUIVALENT AS THE CHARACTERISTICS OF THE WINTER STATES OF LANDSCAPES (BY THE EXAMPLE OF THE KASMALA RIVER BASIN, ALTAI KRAI, RUSSIA)

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Abstract.
N. Beruchashvili in his works provided the basis for the concept of landscape (natural territorial complexes) state, which refers to the certain ratio of the structure parameters and functioning in some period of time during which the specific input influences transform into some certain output functions. N. Beruchashvili also noted the difficulties of landscape states studying, requiring first of all the extensive stationary researches. He also indicated the necessity of researching such landscape characteristics which would be closely connected with the processes of functioning and at the same time would be available for the field work.

In the conditions of Siberia, the landscapes are influenced by the snow cover for a long time, which is one of the main indicators of their functioning in the winter period. The snow cover reflects the contrast of the weather conditions and determines the amount of moisture to be later consumed by landscapes.

The paper describes the possibility of using the maximum snow water equivalent for the characteristics of the landscapes states in the winter period. The basic sources are the data of the route snow surveys (2011-2014) carried out in some small lowland river basin in the South of Western Siberia in the period of maximum snow accumulation.

Regression analysis was used to identify the relationships between the snow water equivalent and the main characteristics of the landscape components. Slopes and aspects developed from the high resolution digital elevation model and also land cover data of the study site are used as the characteristics of the landscape components. At the final stage, the cartographic interpretation of the spatial variation of the snow water equivalent in the basin using the identified patterns was carried out.

Key words: winter states of landscapes, South of Western Siberia, SWE

Introduction.

In the conditions of temperate latitudes, landscapes are for a long time being influenced by snow cover, which largely determines their functioning in the winter period. Snow cover influences most of the processes occurring in the landscapes. Ultimately the water content in snow determines river runoff during spring flood.

Thus, snow cover acts as a system-forming element in the winter landscape states [1]. The concept of the landscape (natural territorial complex) state was developed in N. Beruchashvili's works. This concept [2, 3] refers to the ratio of the structure parameters and functioning of landscapes within a certain period during which the particular input impacts (solar radiation, precipitation, etc.) transform into the certain output functions (runoff, an increase of phytomass, etc.).

The majority of researchers build the classification basing on the duration of landscape states. The landscape states are divided into intra-annual, annual and multi-annual [4]. Among intra-annual states there are intra-daily, daily ("stexes" by N. Beruchashvili), weather-based (or circulating), intra-seasonal and seasonal.

In the USSR and Russia, the winter states were researched at several physical-geographic stations, the work results were summarized in several publications [4, 5-6]. N. Beruchashvili and P. Ryazanov conducted the comparative analysis of winter states of the USSR South mountain landscapes [7]. Besides, the stationary observations of snow cover on landscape basis were carried out in the Minusinsk basin

[21]. Snow cover and its relation with landscape structure and a variety of landscape processes were also studied in landscape ecology [8-10], mostly in the mountain area research.
In this paper, we consider winter states as an integral part of multi-annual states, without detailing inside the winter period. Accordingly, we use the snow water equivalent (SWE) in the maximum snow accumulation period as an indicative parameter reflecting the specific block of the landscape functioning in multi-annual mode. The snow water equivalent is an integral indicator depending on the depth and density of snow, respectively the final value of SWE is influenced by: amount precipitation, termal, insolation and wind regimes during all winter period and a number of other factors.
Certainly, a similar value of snow water equivalent may be formed under the influence of a completely different set of factors; however, using the data of meteorological observations it is possible to identify the drivers in a particular winter period.
The amount of snow accumulation essentially depends on the landscape characteristics such as slope, aspect, altitude and land cover type. Many of the regional models spatial distribution of snow water equivalent are based on the dependence between snow accumulation amount and landscape parameters values in the observation points [11-16]. It is also important that the SWE in the maximum snow accumulation period is the functioning indicator available for field research. The necessity of finding such indicators was pointed to by N. Beruchashvili [3].
Thus, the research general algorithm consists of the following steps:
1) conducting snow observations over several winter periods and collecting the data of different landscape characteristics for the basin;
2) identifying the common features of spatial-temporal differentiation of snow cover in the basin and the relations with meteo conditions in different periods;
3) searching the relationships between snow accumulation amount and landscape characteristics, constructing the cartographic model of SWE distribution in the basin;
4) analysis the ranges of snow accumulation variation in different landscapes.
The structure of landscape units reflecting the spatial distribution of snow cover, in our opinion, can be considered as the partial landscape structure in winter states. In this case, the snow accumulation amount acts the certain emergent property [17], is determined by the characteristics of landscape components and is subject to the definite type of relationships.

Study area.
The studies were conducted in the model basin of the Kasmala River (1768,5 km^2, the closing shot in Rogozikha Village), located on the Ob plateau (the Altai Krai). The choice of the study area (Fig. 1) is explained by its zonal homogeneity and representativeness for the South of Western Siberia [18].

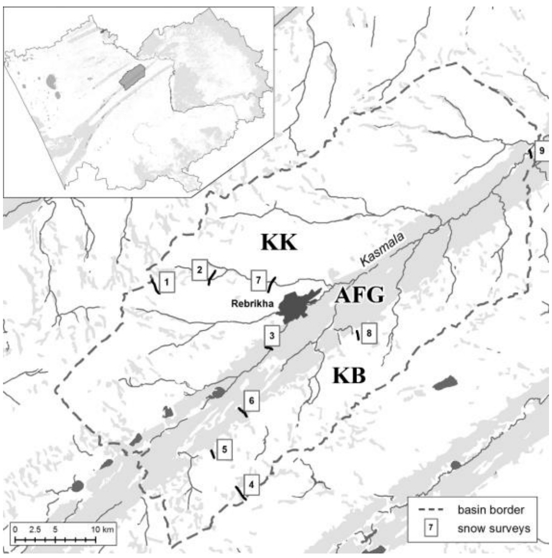

Figure 1. **Location of snow surveys in the Kasmala River basin and the position of the model basin within the Altai Krai territory.**

The basic elements of landscape structure within the considered basin are South-Eastern slope of the Kulunda-Kasmala (KK) ouval, North-Western slope of Kasmala-Barnaulka (KB) ouval, occupied mostly by farmland with areas of small-leaved forests, the bottom of Kasmala ancient flow gully (AFG), only a small part of which is occupied by the valley of the Kasmala River. This part of the area is covered mainly by pine forests, with the participation of meadows and small-leaved forests.
According to the data provided by Rebrikha meteostation [19], located in the basin of the Kasmala River, (from 1940 to 2014): average January temperature is 17,1 °C, average July temperature is +19,5 °C. The annual precipitation in average is 401,4 mm, in winter period – 109,7 mm. The duration of snow cover period is 125-130 days.

Methods

The snow cover study was carried out by snow surveys method in the period of maximum snow accumulation (the second decade of March) for 4 years (2010/11–2013/14). The total length of routes was about 12 km (more than 700 measurements of snow depth and more than 70 density measurements in each of the observation years).
The routes were laid in such a way as to cover all the major elements of landscape structure by observations. The comparison of the depth data and the water equivalent values allowed us to obtain the linear regression for each of the basin parts (R^2 = 0,8–0,9), which was used in calculating the SWE.
We used the data of meteorological observations and snow surveys at the permanent route of Rebrikha meteorological station [19].
The main data to obtain the information about the characteristics of the landscape components were the digital elevation model (5 m grid cell) and the land cover map containing 16 types of units. In addition, we used the data about the lithological content of the surface deposits.
To assess the relationships between the values of snow water equivalent and the characteristics of the landscape components the stepwise regression was applied. 5 grades of slopes, 8 aspects grades, 8 types of lithological composition of surface deposits and 16 types of land cover as independent predictors. More precisely the gradation of these characteristics is shown in the paper [20].

Results and discussion

The data in this paper are given in winter periods prior to the observations (similar water years). The winter periods under study are very contrast by the main meteorological parameters, there are several key features.

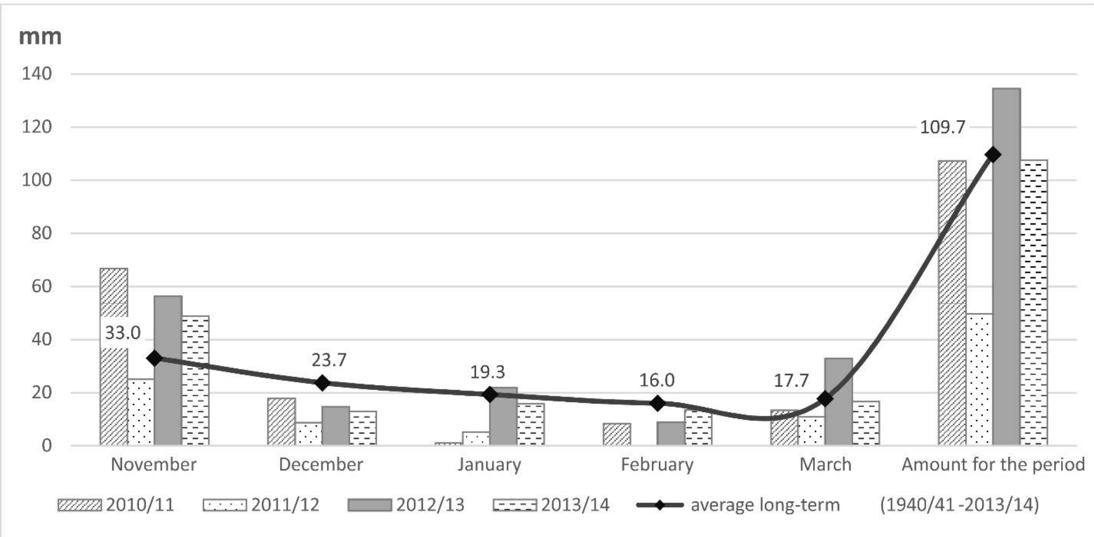

Figure. 2. **Amount of precipitation in the winter period by Rebrikha meteo station** [19]

According to the amount of precipitation in the winter period (Fig. 2) there can be clearly distinguished: very humid 2012/13 (70% of max), medium – 2010/11 and 2013/14, and very dry 2011/12 (the absolute minimum for the whole period of observations).
According to the snow surveys by Rebrikha meteo station, the average multi-annual value of the maximum SWE on the permanent field route in the second decade of March is 96 mm (the observations on the route being held from 1977), on the forest route – 119 mm. Snow-surveys as well as the meteo station, are located in the KK part of the basin, near the western edge of Rebrikha Village. The coefficients of snow accumulation (the ratio of an annual maximum of SWE to the multi-annual average value) for the considered winter periods were as follows: 2010/11 – 0,9; 2011/12 – 0,7; 2012/13 – 1,6; 2013/14 – 0,8. Thus, among the considered years, the winter of 2010/2011 and 2013/14 can be attributed to mid-snowy, 2011/12 – close to low-snowy, 2012/13 – obviously high-snowy (one of the maximum for the whole period of observations).
Now let us consider some general features of the landscape differentiation of snow accumulation in the basin. There is some difference in the conditions of snow accumulation between KK and KB ouvals. It is revealed itself in the increase of the average depth of snow cover (11% in average) on the surface of KB, while on KK mostly higher is the snow density (12% in average) and the variability of all the main characteristics of snow cover. The reasons for this may be differences in the ouval area, the distance between the pine forest strips and consequently different intensity of wind events. In the result, depending on the specific conditions of the winter period, the maximum SWE value may be higher on the surface of one or the other ouval.
In the pine forests of AFG the snow cover lies more evenly. Besides, it is noted that maximum SWE values are less within the pine forest than in average on the main surface of the ouvals. Apparently, the reasons of this phenomenon is interception of snow by the canopy, in conditions of less precipitation compared with boreal forests.
Within Kasmala-Barnaulka ouval small-leaved forest outlier play the most important role in the snow-accumulating process. For the opposite ouval characterized by a much greater development of erosive forms of relief, such items will be valleys and ravines on the leeward slopes of which there is maximum snow accumulation within the entire basin (more than 300 mm in high-snowy years).
The results of the regression analysis indicate the presence of valid relationships between the SWE values and landscape parameters. However, a small value of the multiple correlation coefficients, which ranges from 0,23 to 0,38 ($F = 10{,}9–47{,}5$, $p<0{,}000$), indicates that snow accumulation depends on many local factors that have not been or cannot be taken into account. This is also illustrated by the fact that the most important predictors from year to year can change. For example, in the windiest years (2010/11 and 2013/14), those become the slope parameters, in the low-snowy years (2011/12) – parameters of the surface sediments lithology.
In general, the quality of the obtained models does not allow to use them as predictive and requires further improvement. However, at this stage, it reflects the existence of valid relationships between the functional parameters and characteristics of landscape components.
Land units reflecting the characteristics of snow accumulation were obtained empirically based on the area specifics and the regression analysis. There were selected the following parameters: slopes, aspects, the generalized groups of land cover types.
The maximum slopes within the basin are limited to 9°, the greater part is the almost flat surface with gradients up to 3°. Thus, hypothetically we differentiated two types of surfaces (flat and slope). Based on this, exposure was defined only for the second group of units. The exposure parameters were combined into 4 groups – "N-NE", "E-SE", "S-SW", "W-NW". The choice of such a gradation is based on the location of the basin along the longitudinal axis SW-NE and southwest direction of the prevailing winds.
Of the total number of land cover types, there were allocated 4 groups similar in the snow accumulation. Among different forest types, the most contrast are pine serried and small-leaved (birch, aspen, poplar, willow) forests. Serried pine trees can intercept up to 30% of precipitation, most of which evaporates

[21, 22], in deciduous forests intercept is actually absent. In addition, intermediate types (pine-sparse, small-leaved-pine, pine-leaved, small-leaved wetland) due to interception of snow have been classified into one group with small-leaved forests. Two more groups consist of grasslands, meadows and their derivatives, and also reed.

As a result of combining the chosen parameters, there were obtained 16 types of units, which are characterized by certain peculiarities of snow accumulation. The fragment of the obtained cartographic model is shown in Fig. 3. In addition, units were grouped according to their belonging to one of three parts of the basin (KK, KB, AFG).

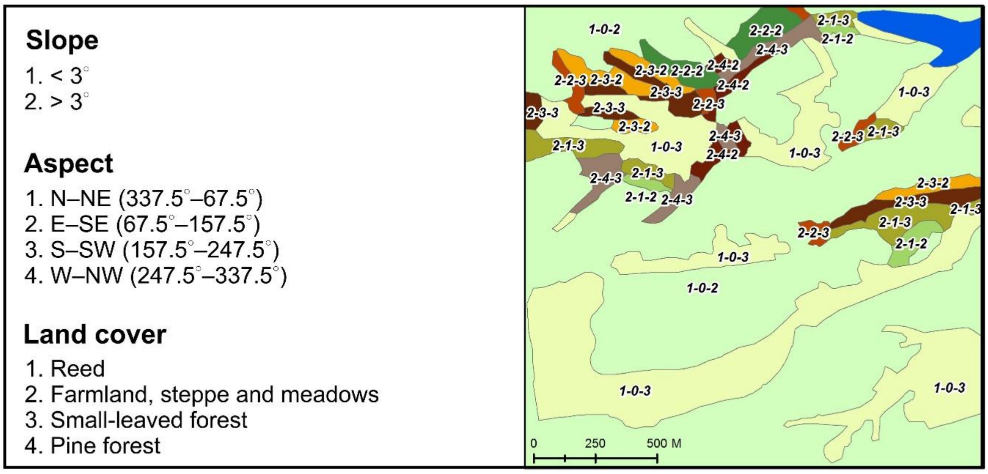

Figure 3. **The fragment of landscape units structure and the gradation of landscape parameters**

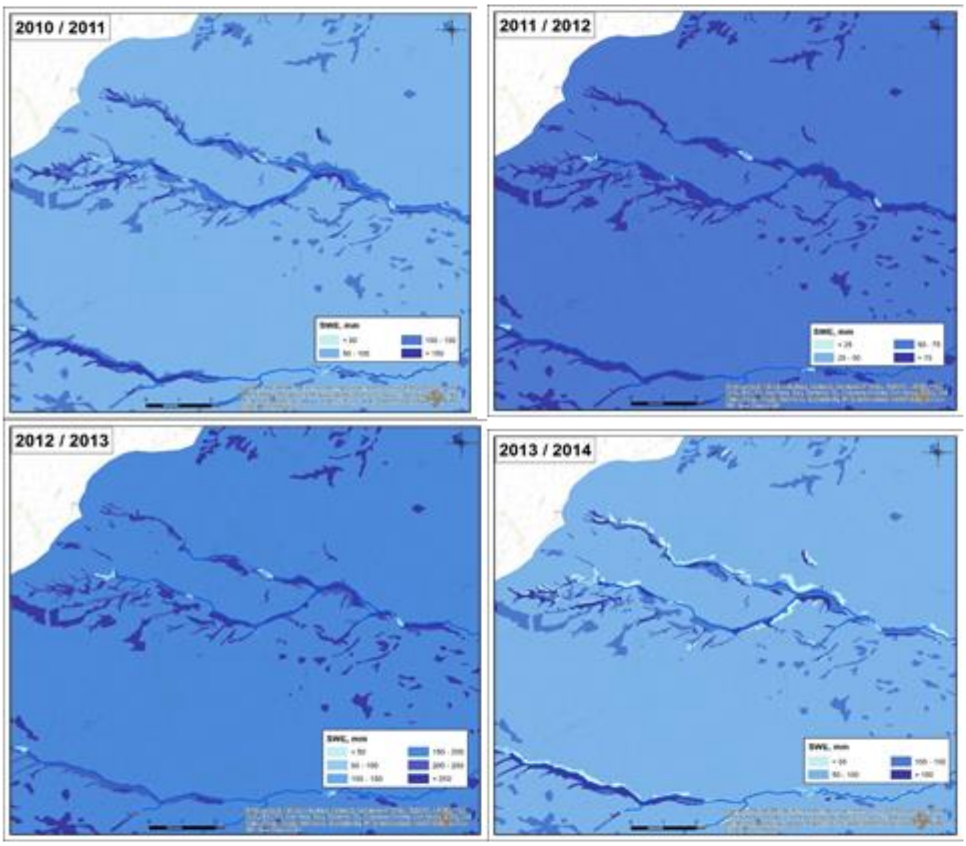

Figure 4. **The maps fragments of SWE distribution in different landscapes**

The SWE values were distributed according to the obtained units. The number of measurements per one site is different, 10 SWE values were taken minimum per one site. Data from different structural-functional parts divided into subsamples by spatial units were tested for the validity of differences between them using dispersion analysis. Data processing showed the valid differences ($p < 0,05$).
The number of units was not covered by observations, either not covered by them in full. In majority those are sloping surfaces within the ouvals that had equivalents, similar in exposure characteristics (leeward/windward), or locations which are very rare within the basin (for example, forests on the windward slopes). In such cases, values were extrapolated from the units with similar characteristics.
Within the bottom of AFG the characteristics of mesorelief have little effect on the conditions of snow accumulation, more important is the vegetation cover. So here the values of snow water equivalent were assigned based on the types of land cover, without exposure differentiation.
Finally, the calculation of average values of snow water equivalent was produced on various types of units for individual years of observations (2010/11–2013/14). Figure 4 presents the maps fragments of maximum SWE in the four years of observations. Used here is the common scale of SWE (50 mm) in order to be able to assess the differences in absolute values in different precipitation years. The only exception is made for observations in 2011/12 when the SWE value varied 43–98 mm, and using standard gradation could not allow to show spatial differences.
The variability of SWE in landscape units is very considerable. Figure 5 presents the ranges of SWE variation in the most characteristic landscape units. Within Kulunda-Kasmala ouval (indicated by index KK) the range of variation is extremely high. Maximum snow accumulation is accounted for snowy North-Eastern slopes (index KK:2-1-3). It is expected that this uneven redistribution depends on the wind. Significantly less variable snow accumulation is from year to year within the pine forests in the AFG and on the surface of Kasmala-Barnaulka ouval (indexes AFG and KB respectively). Here the influence of wind redistribution is reduced, which to some extent smooths out fluctuations.

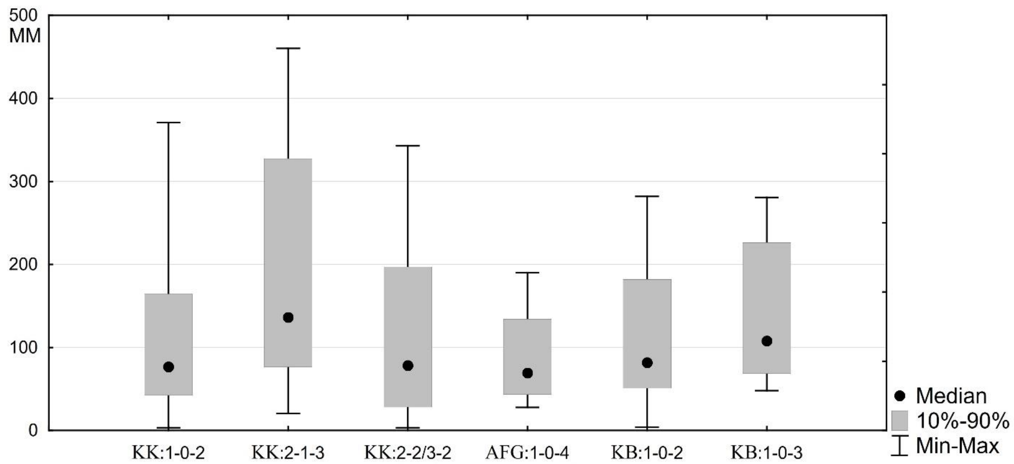

Figure 5. **Variation of snow accumulation in the most typical landscape units**

Conclusions
In ungauged areas for comprehensive characteristics of landscapes states it is advisable to study them on the basis of separate processes which may be indicators of the landscape functioning in a certain period. One of these parameters is snow water equivalent in the period of maximum snow accumulation. It is indicative for winter conditions and are closely linked to landscape parameters.
Regression analysis and mapping of snow cover distribution in different landscape units allowed to identify the peculiarities of the landscapes functioning in winter conditions.
On the surface of ouvals the significant role is played by wind redistribution of snow combined with the characteristics of mesorelief and vegetation. Here consistently high is snow accumulation in small-leaved

forest outlier and on the leeward slopes. In condition of pine forest in the bottom of ancient flow gully, the spatial distribution is more equal and the maximum snow water equivalent values are determined more by the background precipitation.

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