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MAPPING THE CHARACTERISTICS OF SNOW COVER IN BELARUS

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Abstract. The paper substantiates a necessity to create maps of snow cover characteristics in Belarus. The designed maps can be used by engineers to forecast spring floods on the rivers of Belarus and to assign snow load limits imposed on buildings and structures.

Keywords: creating maps, snow cover characteristics, snow height, snow density, snow water equivalent.

1 Introduction

Snow cover is one of the most important climate forming factors. Snow has a particularly great influence on the climate in the middle latitudes of the northern hemisphere where Belarus is located. It predetermines the pattern of calendar seasons, the annual course of air temperature as well as weather changes during the day. Much of current research is devoted to both the study how climate warming influences the characteristics of snow cover and the study of snow cover as a factor of climate change [1–8, etc.].

Snow cover is a layer of snow on the ground surface that forms as a result of precipitation. Snow cover also includes ice layers that form on the surface of snow and soil and melt water accumulating under the snow.

Different countries have their own history of observations over snow cover, for example [9]. Systematic observations over snow cover in Belarus began in 1891. In the 1930s snow surveying was introduced in addition to observations conducted with permanent snow stakes. Observations done with permanent snow stakes registered every day give us an idea of changes in snow height in winter but they do not show a pattern of its distribution on the ground [10, 11].

In order to characterize a snow cover over all territory, additional snow surveying is carried out in two kinds of areas: 1) open (field, meadow, etc.), 2) protected (in the forest under tree crowns). As a result, we obtain the following data: 1) average values of snow height, its density and water equivalent in the snow cover; 2) patterns of snow cover distribution on various kinds of relief and land surface (within a meteorological station); 3) patterns of changes in snow accumulation and snow melting in time.

The main characteristics of snow cover are its height, density, snow water equivalent and the degree of snow coverage of the corresponding area. Height and density allow us to determine water equivalent in the snow cover. They serve as a basis for hydrological calculations and forecasts, play an important role agricultural decision-making and are also

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widely applied in solving a number of scientific and practical problems. Many researchers point out certain difficulties in determining snow water equivalent directly at meteorological stations. They, therefore, propose to apply methods of remote sensing of the earth [12–14, etc.]. Today, however, in Belarus we can calculate snow water equivalent with sufficient accuracy only with the help of snow surveys carried out on routes near the weather stations.

2 Method

The aim of this research is to study and map the characteristics of snow cover recorded at meteorological stations in Belarus within the representative period of 1944-45–2019-20 and to assess space-time variability of these characteristics and to forecast their dynamics. The study object of this work is such characteristics of snow cover as snow height and snow water equivalent observed at 48 meteorological stations of Belarus within the representative period mentioned above. The study subject of this work is quantitative assessment of the snow cover characteristics and patterns of their space-time distribution over the territory of Belarus.

The methods applied in the research include a space-time analysis of observation data, analytical calculations, mapping.

Mapping snow cover characteristics is of practical significance to us because the maps created in this research can supplement the ones already published, like in [15]. They also can become a basis for creating maps of snow areas [16] which can be applied by engineers to assign snow load limits to buildings and structures. They are also relevant for environmental engineers to predict spring floods in rivers, which is an extremely important issue in Belarus [10, 17].

3 Results and discussion

The initial stage in mapping the characteristics of snow cover is preliminary processing of observation data with the optimization of the location of control points, their quantity and quality. The main task is to process and visualize two-dimensional data sets described by the function $z = f(x, y)$. The logic of work can be represented in the form of three main functional blocks: a) creation of a digital surface model; b) auxiliary operations with digital surface models; c) visualization of the surface.

One of the common tasks in mapping is to study how points are distributed on a 2D surface or map. These points can correspond to the places of taking snow samples, obtaining observations, etc. The task may be to study the uniformity of the distribution of observation points, the density of the distribution or to study the relationship of points with each other. All these questions arise among researchers. Moreover, field observations related to the analysis of the position of points always lead to these or similar problems. The developed methodology is applicable directly to the study of natural phenomena.

It is convenient to divide existing schemes of location of points on maps into three categories: uniform, random and group. Of course, most maps are characterized by patterns of distribution of points that occupy an intermediate position between the listed extreme types, and usually the task is to classify the observed pattern to one of these types.

The optimal number of control points should be specifically justified for each mapped characteristic. If there is a lack of points in the meteorological network, it is necessary to take into account factors of climate formation and indirect physical and geographical signs, by introducing a distribution function of the characteristic under study [18]

$$M_{ij}=f(\varphi_j, \lambda_j, H_j), \qquad (1)$$

where M_{ij} is the value of the physical and geographical characteristics at (j)-point, for (i)-period; φ_j, λ_j, are geographic latitude and longitude, respectively; H_j is absolute elevation of the earth's surface.

Optimization of control points is based on minimizing errors resulting from the construction of certain maps. A map constructed with insufficient data provides only a generalized representation of information.

The assessment of representativeness of the spatial location of observation points can be performed using the criterion (χ^2). In this case, the study area is divided into a certain number of areas containing control points. The sizes of the areas are determined based on the premise of combining the studied characteristics into space-time fields, approximated by spatial correlation functions. Within the selected areas (regions), estimates of representativeness are usually carried out under the assumption that the optimal distance (step) between meteorological stations is 20 km. With the existing density of the meteorological network in local areas (20x20 km), there may be no weather stations at all. On this basis, the boundaries of the isocorrelate fields of the studied characteristics can be used as the boundaries of the regions [10]. The criterion (χ^2) is theoretically independent of the shape and orientation of the regions in space. If the existing meteorological stations are located evenly over the territory, then each selected area will contain an equal number of points. The obtained values (χ^2) are compared with the critical ones, and appropriate conclusions about the representativeness of the spatial location of the observation points are made. This conclusion concerns only the uniformity of the distribution of points over areas of a certain size. It is quite possible that there is a variant of the size of the square (especially if it is smaller than the chosen one), in which the hypothesis of uniformity will be rejected.

The choice of a rational method for mapping the characteristics of the snow cover is based on the following factors: individual characteristics of the object (phenomenon, information), its location, structure; tasks of mapping information; content and type of initial data, methods of their processing, etc.

The most widely known methods of cartographic display of information: icons, line signs, areas, high-quality background, isolines, carto diagrams, cartograms.

Taking into account the above and the fact that maps of snow cover characteristics are intended not only for a general qualitative assessment of the current situation in specific territories but also as a source of quantitative information for researchers and designers, the main method of creating maps is that of isolines and high-quality background. Map created in isolines allow for quick and quite accurate assessment of the meteorological situation in the area where projects of various purposes are designed. They also help to prepare initial data for engineering calculations which are declared by the regulatory and technical documents of the Republic of Belarus but which often lack a basic database. Using the method of high-quality background allows visualizing information even more [15, 18].

The adopted method of mapping should provide a uniquely accurate representation of data at a control point, be continuous within the mapping area. Autocorrelation is assumed at a distance bigger than the average distance between control points. Autocorrelation indicates that the values at adjacent points are closely related. This is confirmed by the performed studies of snowfall synchronicity. In this study we determined some regions that include a certain number of control points [10].

To construct a map it is necessary to prepare a mathematical surface which is divided into square cells that cover the mapped area completely. The smaller the cell, the higher the resolution of the card will be. The task of surface preparation is to determine the values of the studied indicators at the nodes of the adopted grid according to the data of nearby control points. Contours are drawn not from the data of the control points of observation but from the calculated values in the nodes of the network. If the mapped area is divided into large cells then with a smooth slope of the surface, there may be a displacement of individual isolines from the control points with which it should be consistent (the passage of the isoline on the wrong side of the control point).

The majority of known methods for constructing maps in contours evaluate values from nearby control points. In this case, when building a map on a prepared mathematical surface, most of the interpolation nodes will lie in the interval between the values of the control points. The values at the nodes that are outside the control points are obtained by extrapolation and will be close in magnitude to the values of the extreme observation points. The control points in relation to the network node are weighted, and the weights are set depending on their distance from each other. The sum of the weights of the control points of one node is equal to one. In this regard, it is possible to establish the most distant control point from the node of the regular network participating in the assessment. The weighting function of the inverse values of the squares of the distances is scaled, the values taken by it are within $0 \leq w \leq 1$. This process is written in the form [18]

$$w = \left(1 - \frac{D}{D_{max}}\right)^2 \Big/ \left(\frac{D}{D_{max}}\right) \tag{2}$$

where D is the distance to the estimated point; D_{max} is the distance to the most distant point.

A reliable criterion for the correctness of the chosen method is the form of isolines, which shows how accurately the adopted mathematical model describes the control points. It is statistically impossible to establish which method of contouring is more reliable. The decision is made in each specific case, depending on the type of mapped characteristics, the quality of the initial data, their density and the uniformity of the spatial distribution. The main purpose of building a map in contours is to ensure the maximum correspondence of the initial data to the values set by the map.

The most promising, in our opinion, are the following methods for constructing contour maps: that of inverse distances, Kriging, minimal curvature, radial basis functions, Shepard, triangulation. We use all of them but we justify the most acceptable method on the results of map comparison.

When mapping the characteristics of the snow cover on the territory of Belarus, we used a sample of experimental meteorological data at 48 empirical points with distances between them from 48 to 585 km. The degree of spatial continuity of a regionalized variable is expressed by a variogram. If there is data in a scattered set of points and a known variogram form, an independent surface value is estimated at any point not belonging to the sample (Z).

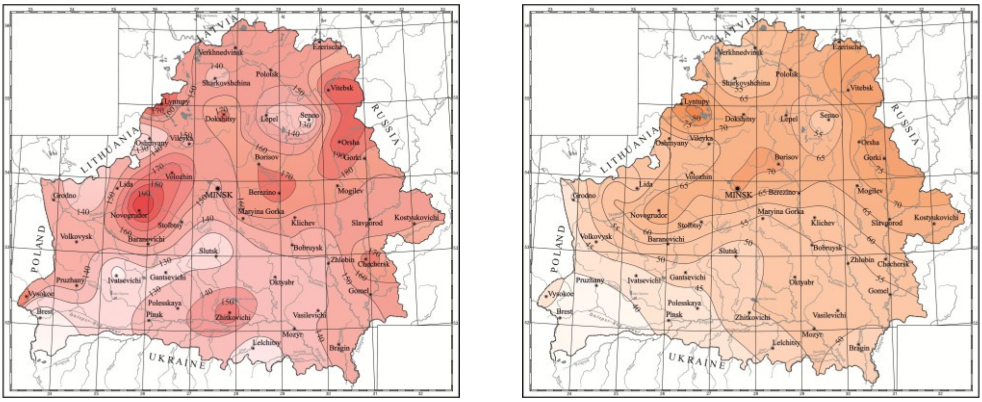
We substantiated Kriging method as the most appropriate for mapping the characteristics of snow cover in isolines because it has optimal statistical properties (measuring the error or uncertainty of the surface depicted by isolines, using a variogram to find the optimal set of weights, estimating the surface at points other than empirical, as a function of distance and weight, varying according to the geographical location of the observation points for the components of the snow cover).

Maps constructed with the use of Kriging method are characteristic of a statistically stationary variable. In fact, in natural processes, it is customary to single out the trend component, in which the calculated values will be systematically underestimated or overestimated which depends on the actual location of observation points for the characteristics of the snow cover and the direction of the trend plane. In this case, the non-stationary regionalized variable is considered as having two components. The trend is the average or expected value of a regionalized variable within an area and it changes slowly, characterizing a non-stationary part of the surface. The remainder is the difference between the actual change and the trend. If the trend is removed from the regionalized non-stationary variable, then the residuals become stationary and Kriging method can be applied to them. In this case, Kriging consists of the following procedures:

- identification of the trend component and its removal;
- carrying out Kriging for the obtained residues at points outside the limits of instrumental observations;
- grouping of the obtained residuals with trend components and obtaining the true surface.

We have widely used mapping methods adapted to the research tasks in the spatial generalization of the main characteristics of the snow cover [19]. Fig. 1a shows a map of the distribution of the maximum water equivalent in snow (mm) on the territory of Belarus, constructed by using Kriging method. Map (Fig. 1a) characterizes the absolute maximums in the formation of snow water equivalent over a long-term period (1944-45 –2019-20).

As can be seen from the map (Fig. 1a), the largest snow water equivalent is confined to the northeastern (Vitebsk, Orsha region), northwestern (Lyntupy) and central (Novogrudok, Berezino) parts of the territory of Belarus. Here, a significant contribution to the snow water equivalent is the height of the terrain as a regional factor (Minsk, Novogrudok, Oshmyany uplands). The smallest snow water equivalent is inherent in the southwest (Brest, Lelchitsy) and northwest (Sharkovshchina, Senno) of the territory of Belarus. The averaged values of the identified maximum values characterize the most typical pattern of forming snow water equivalent in the study area (Fig. 1b). In fig. 1b, there is a similar confinement of the corresponding average maximum values of snow water equivalent (north-western, north-eastern and central parts of Belarus). However, Fig. 1b shows smoother isolines and an increase in snow reserves in the southwest - northeast direction.

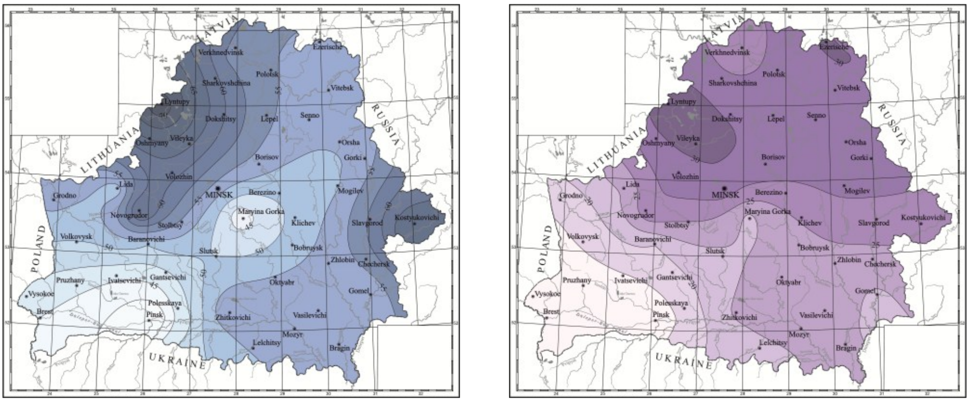


a) b)

Fig. 1. Distribution of maximum snow water equivalent in Belarus, mm: a - maximum, b - average maximum.

It is known that the water equivalent in snow as the main factor of spring floods and a determiner for snow loads imposed on buildings and structures is predetermined by the height of snow cover and its density. Moreover, these parameters are used in conjunction. There are different ratios of density and height of snow in nature, most often there is a shift of the peaks in time by 1-2 decades. The period with the maximum depth of snow cover begins earlier, and then, when the snow melts (in spring and during thaws in the cold period), its thickness decreases but its density increases. The highest snow water equivalent is observed when the values of snow cover thickness and its density are maximum. In this regard, it is necessary to analyse the maximum heights of snow cover and maximum densities.

Fig. 2a shows the maximum snow depth (cm) obtained from snow survey data in the field for the representative period. Fig. 2b characterizes the averaged maximum snow depth for the observation period of 1944-45 - 2019-20. The information presented in fig. 2a and 2b, corresponds to the previously made conclusions about the mechanisms of forming maximum water equivalent in snow. The maximum heights of the snow cover are characteristic of the highlands, their leeward slopes, in particular. They are determined by the global moisture transfer. However, there is also a random component here.



a) b)

Fig. 2. Distribution of snow cover depth in Belarus, cm: a - maximum, b - average maximum.

At the same time, the averaged maximum values of snow cover heights have a vivid latitudinal orientation on the territory of Belarus. They correlate with the temperature and wind regime of this area which depends on the radiation characteristics of Belarus' climate and turbulent heat transfer of the surface atmosphere, which affect the processes of snow melting and evaporation in the southern regions of Belarus. Southern winds prevail on the territory of Belarus in winter.

Forecasting the characteristics of the snow cover can be carried out by identifying trend components, assessing their space-time variability [19–22, etc.]. Snow water equivalent is the main contributor to spring flooding on Belarus' rivers and forming snow loads on structures and buildings. Therefore, its prediction plays an important role. To assess changes in the characteristics of snow cover, we used linear trends for 48 meteorological stations for the entire observation period, starting from 1944-45. The results for the regional centers of Belarus are shown in Table 1, where t is the ordinal number of the year.

As the result of analytical assessment of the curves of moving five-year averages of the maximum and average values of snow water equivalent, snow height, and snow density at 48 meteorological stations in Belarus, we determined regions with positive and negative trends.

Over most of Belarus, there is a tendency for snow water equivalent to decrease by 4-8 mm in 10 years. An increase in snow water equivalent is typical for the catchments of the Western Bug, Pripyat, Berezina, and Dnieper rivers (Fig. 3).

Table 1. Linear trends in snow cover characteristics.

Meteorological station	Maximum snow water equivalent, mm	Snow height, cm
Minsk	$Q = -0{,}4t + 87{,}4$	$h = -0{,}026t + 29{,}88$

Grodno	$Q = –0,103t + 47,06$	$h = –0,020t + 19,06$
Mogilev	$Q = –0,261t + 77,97$	$h = 0,005t + 26,89$
Brest	$Q = 0,072t + 33,5$	$h = 0,047t + 13,54$
Gomel	$Q = 0,113t + 48,01$	$h = 0,110t + 17,57$
Vitebsk	$Q = 0,136t + 74,32$	$h = 0,082t + 25,89$

The map in Fig. 3 shows that the area in the southwest with a positive trend includes Brest, Vysokoe, Pinsk, Volkovysk. The exception is Pruzhany, where the trend is practically unchanged throughout the study period. In the south-east of Belarus, the borders of the area where water equivalent in snow is also increasing include Bragin, Mozyr, Vasilevichi, Gomel, Zhlobin, Bobruisk, Klichev, Berezino. In the northeast, Gorki and Vitebsk also have a positive trend. The rest of the territory of Belarus has a negative trend, i.e. snow water equivalent is decreasing. The exception is Stolbtsy where the trend is positive.

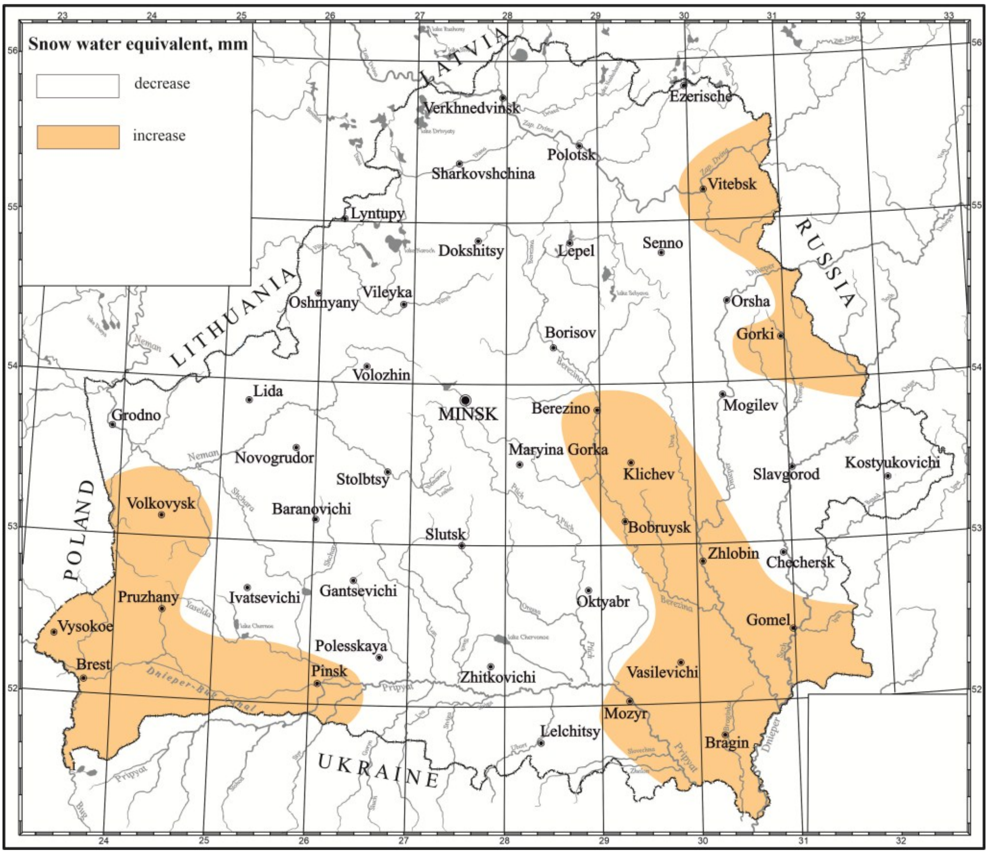


Fig.3. Transformation of maximum values of snow water equivalent in Belarus.

Fig. 4 shows the map of zoning the territory of the Republic of Belarus according to the trends in maximum values of snow cover height.

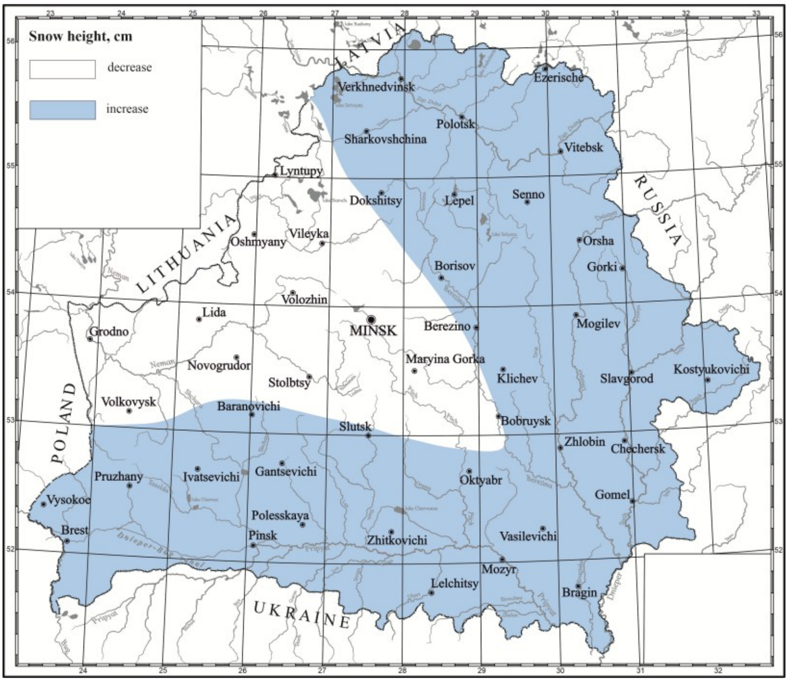


Fig.4. Transformation of maximum values of snow cover height in Belarus.

The map in Fig. 4 shows that snow cover height decreases (negative trend) in the central (Minsk, Maryina Gorka) and north-western part of Belarus (Grodno, Lida, Novogrudok, Lyntupy). However, over most of Belarus (60%), there is a slight increase in the depth of the snow cover. The density of snow cover decreases slightly throughout the study area, which is associated with current climatic changes. Thus, an important task is to determine causes of the current changes, where the leading role belongs to the planetary ones associated with the global climate warming. In this regard, it makes sense to do a joint analysis of snow accumulation with the temperature regime of the area.

4 Conclusion

Mapping the characteristics of snow cover allows us to forecast changes in snow water equivalent, as the main contributor to spring floods in Belarus. To create the maps we used data from meteorological stations together with the results of remote sensing of the earth. The constructed maps with the data about snow water equivalent and snow height at the beginning of flooding make it possible to determine areas in Belarus which are prone to spring flooding. The set of maps presented above is based on the use of representative, appropriately prepared, meteorological observation data analysed and studied in terms of the identified independent structures of space-time fields. However, the main function was assigned to the factor of synchronicity of solid atmospheric precipitation in the cold period. The revealed patterns of spatial distribution of maximum and average maximum density and height of snow cover, the outline of the isolines and the peculiarities of their spatial confinement were used to map the maximum and average maximum snow water equivalent. The proposed set of interconnected contour maps should serve as a basis for zoning the territory of Belarus according to the changes in snow reserves. The maps can also be used to assign snow load limits in the design of various construction projects.

References

1. Diro, G. T., & Sushama, L. (2020). Contribution of snow cover decline to projected warming over North America. *Geophysical Research Letters*. 47. https://doi.org/10.1029/-2019GL084414.
2. Callaghan, Terry & Johansson, et al. (2011). Multiple Effects of Changes in Arctic Snow Cover. *AMBIO A Journal of the Human Environment*. 40. 32-45. https://doi.org/-10.1007/s13280-011-0213-x.
3. Judah L Cohen et al. (2012). Arctic warming, increasing snow cover and widespread boreal winter cooling *Environ. Res. Lett*. 7. https://doi.org/10.1088/1748-9326/7/1/-014007.
4. Jonas Bhend, Janice Bathols and Kevin Hennessy (2012). Climate change impacts on snow in Victoria *The Centre for Australian Weather and Climate Research*. 42.
5. Wang, A., Xu, L., and Kong, X. (2018) Assessments of the Northern Hemisphere snow cover response to 1.5 and 2.0 °C warming. *Earth Syst. Dynam*. 9. 865–877. https://doi.org/10.5194/esd-9-865-2018.
6. Cordero, R.R., Asencio, V., Feron, S. et al. (2019). Dry-Season Snow Cover Losses in the Andes (18°–40°S) driven by Changes in Large-Scale Climate Modes. *Sci Rep*. 9. 16945. https://doi.org/10.1038/s41598-019-53486-7.
7. Callaghan, Terry & Johansson, Margareta & R.D., et al. (2011). Changing snow cover and its impacts. In book: *Snow, Water, Ice and Permafrost in the Arctic (SWIPA)*: Climate Change and the Cryosphere, Chapter: 4, Publisher: Oslo: Arctic Monitoring and Assessment Programme, pp.4 1–4 58.
8. Goodison, B. E. and Walker, A. E. (1993) Use of snow cover derived from satellite passive microwave data as an indicator of climate change. *Annals of Glaciology*. 17. 137–142.
9. Colbeck, S.C. (1987) History of snow-cover research. *Journal of Glaciology*. Special Issue. 60–65.
10. Meshyk, A., Barushka, M, Marozava, V. (2020) Snow as a Contributor to Spring Flooding in Belarus. *Environmental Science and Pollution Research*. 1–11. https://doi.org/10.1007/s11356-020-09638-8.
11. Валуев, В. Е. Изученность и статистические оценки снегозапасов (State of knowledge and statistical assessment of snow water equivalent) / V. E. Valuyev, A. P. Meshyk // *Vestnik Brestskogo Gosudarstvennoro Tehnicheskoro Universiteta: Vodohozyaistvennoye Stroitelstvo, Teploenergetika i Geoekologiya*. – 2013. – № 2. – P. 8–11. (In Russian).
12. Henkel, P., Koch, F., Appel, F., Bach, H., Prasch, M., Schmid, L., et al. (2018). Snow water equivalent of dry snow derived from GNSS carrier phases. *IEEE Trans. Geosci. Remote Sens*. 56, 3561–3572. doi: 10.1109/TGRS.2018.2802494.
13. Appel, F., Koch, F., Rösel, A., Klug, P., Henkel, P., Lamm, M., et al. (2019). Advances in snow hydrology using a combined approach of GNSS in situ stations, hydrological modelling and earth observation—a case study in Canada. *Geosciences* 9:44. doi: 10.3390/geosciences9010044.
14. Dai, L., Che, T., Ding, Y., and Hao, X. (2017) Evaluation of snow cover and snow depth on the Qinghai–Tibetan Plateau derived from passive microwave remote sensing. *The Cryosphere*. 11. 1933–1948. https://doi.org/10.5194/tc-11-1933-2017.
15. Volchak, A., et al. (2017). Atlas: Weather Hazards in Belarus. Moscow. All-Russian *Research Institute for Hydraulic Engineering and Land Reclamation*. 70.
16. Tur, V. et al. (2008) Normalization snow loads for the territory of the Republic of Belarus. *Construction Science and Technology*. 2, 27–45.
17. Volchak, A. A., Meshyk, A. P., Sheshka, M. M. et al. (2016). Floods on the territory of Polesie. *Procedia Engineering*. 162, 91–97. https://doi.org/10.1016/j.proeng.2016.11.020

18. Тур, В. В. Картографирование основных характеристик снегового покрова по результатам комплексной статистической обработки данных метеорологических наблюдений (Mapping of main snow-cover characteristics obtained in the result of an integral statistical analysis of the data of meteorological observation) / V. V. Tur, V. E. Valuyev, S. S. Derechennik, A. P. Meshyk // *Vestnik Brestskogo Gosudarstvennoro Tehnicheskoro Universiteta: Vodohozyaistvennoye Stroitelstvo, Teploenergetika i Geoekologiya*. – 2008. – № 2. – P. 2–10. (In Russian).
19. Мешик, О. П. Особенности оценки запасов воды в снеге и их пространственно-временной изменчивости на территории Беларуси (Peculiarities of assessing water reserves in snow and their spatio-temporal variability in the territory of Belarus) / A. P. Meshyk, V. A. Marozava // *Actual problems of earth sciences: studies of transboundary regions: collection of articles and materials IV Int. scientific*. - practical. conf., to the 1000th anniversary of Brest, 12-14 Sept. 2019 / Brest; ed. A. K. Karabanova [and others]. - Brest: BrSU, 2019. - Part 2 - P. 34–37. (In Russian).
20. Robert A. Metcalfe, James English and James J. Luce (2018) Variability and trends in seasonal snow cover in Ontario from 1980 to 2010 detected using remote sensing. *Ontario Ministry of Natural Resources and Forestry. Science and Research Branch*. Peterborough, ON. Climate Change Research Report CCRR-50. 27 p.
21. Don M. Gray et al. (1978) Snow accumulation and distribution. *Modeling Snow Cover Runof*. 31.
22. Stine Højlund Pedersen, Mikkel P. Tamstorf, et al. (2016) Spatiotemporal Characteristics of Seasonal Snow Cover in Northeast Greenland from in Situ Observations, *Arctic, Antarctic, and Alpine Research*. 48:4. 653-671. https://doi.org/-10.1657/AAAR0016-028.