UDC 556.12 **IRSTI 37.21.25**

CHANGES IN SPATIAL DISTRIBUTION OF SNOW DEPOSIT DURING 2001…2022 IN EAST KAZAKHSTAN

A.G. Terekhov*[1,2], N.N. Abayev[2]

[1] Institute of Information and Computing Technology MES, Almaty, Kazakhstan
[2] RSE Kazhydromet, Almaty, Kazakhstan
E-mail: aterekhov1@yandex.ru

In recent years, regional satellite products that provide high spatial and temporal resolution for describing snow cover parameters have become publicly available. These products offer the most accurate estimates for steppe areas, where interference from forest cover is minimal. Regular data grids provide new opportunities to analyze the spatial characteristics of snow coverage in territories that previously could not be obtained from meteorological station data. This study investigates the long-term changes in the large-scale spatial distribution of water reserves in the snow cover in the Abai and East Kazakhstan regions. These characteristics of the snow cover can also experience transformations, which are driven by climate change. The Abai and East Kazakhstan regions of Kazakhstan, with a total area of about 0.27 million km², are located in the center of the Eurasian continent. This paper describes the transformation of the large-scale spatial distribution of the snow cover on the analyzed territory from 2001 to 2022. The Snow Water Equivalent Anomaly (SWEA) product on March 1 was used as the initial data, which has a daily update and a resolution of 1 km and is available on the USGS FEWS NET portal. It was found that the large-scale spatial distribution of positive anomalies of the water equivalent of the snow cover on the analyzed territory varied between 2001…2022, with an increase in situations characterized by a decrease in the typical size of zones with positive anomalies of water reserves in the snow. This effect is partly synchronized with similar phenomena described for large mountainous countries of Eurasia, where the average area of clusters forming an area with a positive anomaly of water reserves in snow decreased tenfold from 2001 to 2019, from approximately 10000 km² to 1000 km².

Keywords: snow cover, snow water equivalent anomaly, distribution of snow deposits in the territory, long-term changes, climate change.

Accepted: 29.03.2023
DOI: 10.54668/2789-6323-2023-108-1-35-41

INTRODUCTION

The impact of climate change on the snow cover parameters of Northern Eurasia has been extensively considered in the scientific literature (Bulygina et al., 2009, 2011; Dye, 2002; Kitaev et al., 2005). Earlier studies relied on observational data from a network of ground-based weather stations. The development of satellite research has provided an additional source of information on the state of snow cover (Bormann et al., 2018). In recent years, regional products describing snow cover parameters, including snow height and water equivalent of snow, with high spatial and temporal resolution have become publicly available, such as the USGS/EROS developments hosted on the USGS FEWS NET Data Portal platform. The validation of the «Snow Depth FEWS NET» product showed good correspondence with ground-based meteorological data (Terekhov et al., 2020b), allowing them to be used in describing the snow cover of Kazakhstan (Terekhov et al., 2019, 2020a, b). The availability of regular data grids with a short period (1 km for FEWS NET products) describing the long-term characteristics of snow

cover offers new possibilities for analyzing the spatial (morphological) characteristics of snow cover. These characteristics of the snow cover, which refer to the features of the spatial distribution of snow reserves, can also experience transformations driven by climate change.

The study conducted by Terekhov and Makarenko (2020) described significant changes in the morphological characteristics of snow cover in the high-altitude zone of Eurasia, including the largest mountainous countries such as the Tien Shan, Pamir, Karakorum, Hindu Kush, Kun-Lun, and Himalayas. It was shown that there was a tenfold decrease in the average area of clusters forming a territory with a positive anomaly over 19 years (from 2001 to 2019), from approximately 10000 km² to 1000 km². Furthermore, the study showed that large-area anomalies that were typical in the early years of the 21-st century were replaced by groups of relatively small and isolated zones, especially after 2015. It was assumed that similar changes could take place in other places in Eurasia.

MATERIAL AND METHODS

The purpose of this study was to assess the long-term changes in the spatial distribution of the snow cover of Eastern Kazakhstan. This steppe and semi-desert territory is located in the eastern part of the Kazakh Uplands (Aksoran 1565 m) and the western part of the Altai Mountains (Belukha 4506 m), the long-term humidification regime of which can be synchronized with the large mountainous countries of Eurasia. The study area covered the Abai and East Kazakhstan regions of Kazakhstan, with an area of approximately 0.27 million km², as illustrated in Figure 1. The climate of the region is highly continental and arid, with annual precipitation ranging from 150 to 1500 mm (in the mountains). Solid precipitation during the cold period plays a significant role in the water balance of the territories. The amount of snow accumulated in winter significantly affects the volume of spring flooding (Terekhov et al., 2016) and the soil moisture reserves in the first half of the growing season, which determines the great practical interest in this natural resource at the regional level.

As initial data, the Snow Water Equivalent Anomaly product (SWEA) was used, which has a daily update and a resolution of 1 km and is available on the USGS FEWS NET portal (as shown in Figure 2).

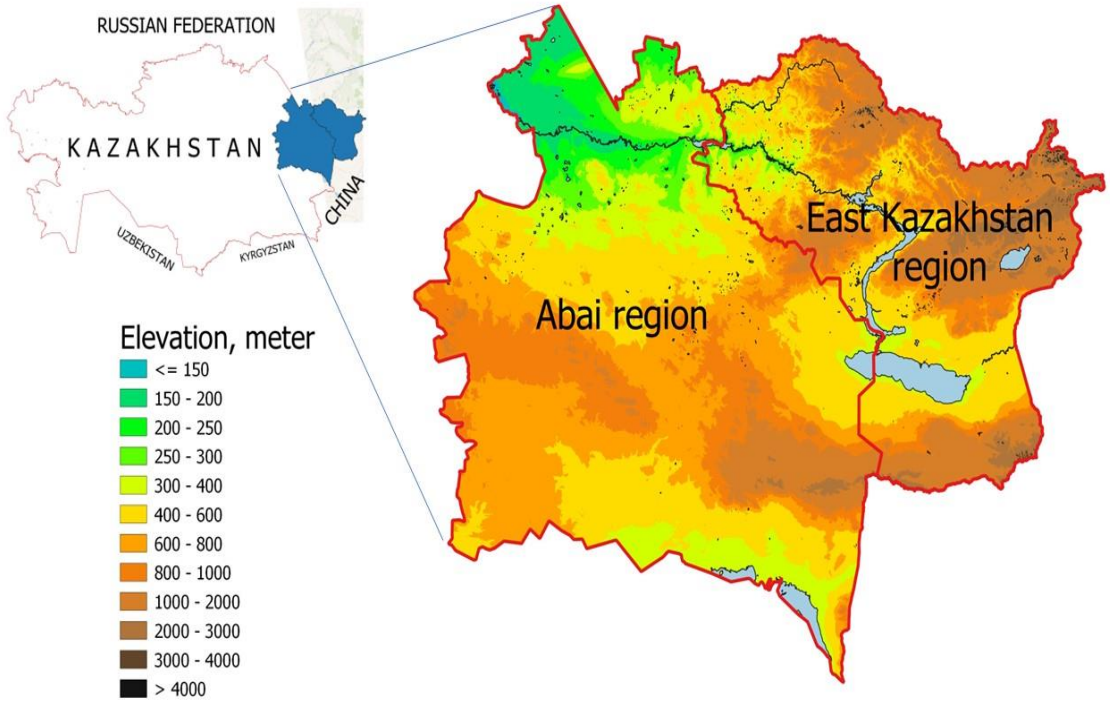

Fig. 1. *Physical Map of the Abai and East Kazakhstan Regions of Kazakhstan.*

March 1 was chosen as the key date when the snow cover in the test area had fully formed, and the process of its spring melting began. Figure 3 presents the maps of anomalies of the water equivalent of snow on March 1 for the 22 spring seasons from 2001 to 2022. The depth of the archive allows for a comprehensive analysis of long-term changes in snow cover in the study area.

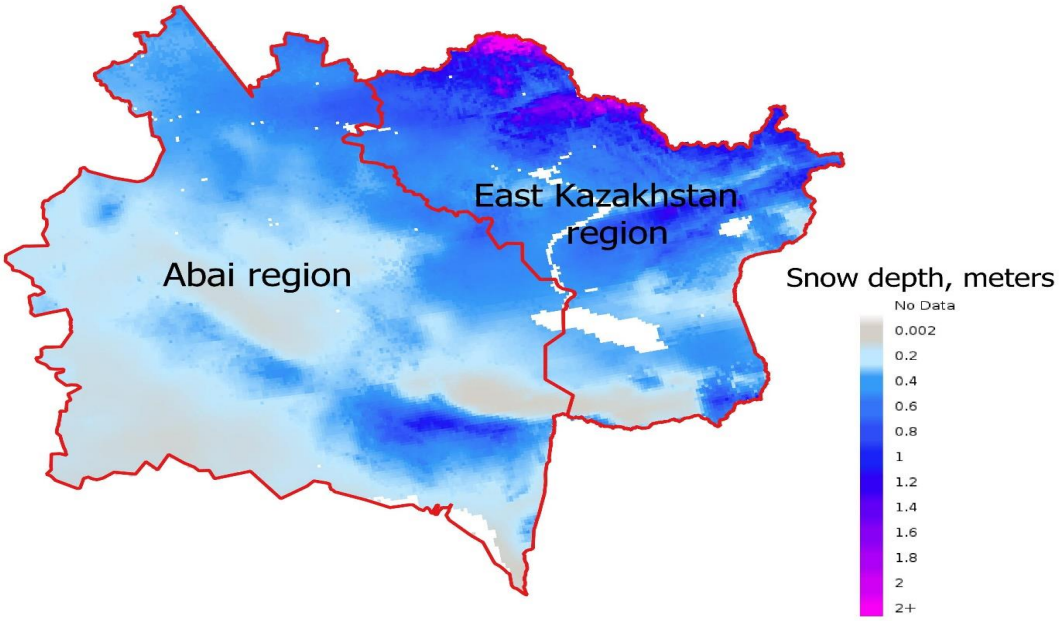

Fig. 2. *An example of a daily snow depth map according to the "Snow Depth" FEWS NET product (resolution 1 km) for January 30, 2021.*

RESEARCH RESULTS AND DISCUSSION

The morphology of the contour maps of anomalies of snow reserves (snow water equivalent) can be numerically described, as noted by Terekhov and Makarenko (2020). However, due to the significant influence of boundary conditions, the analyzed area is not large enough to obtain reliable results. Furthermore, the possibilities of expanding the analysis area are limited by the existing climatic zonality. Therefore, the long-term changes in the morphology of the snow cover were evaluated only qualitatively. Several maps showing the distribution of water reserves in the snow cover on March 1 were generated, as shown in Figure 3. Two of the most typical scenes were selected for 2001 and 2016, which illustrate the direction of the recent changes in the snow cover morphology of the region, as illustrated in Figure 4.

The snow cover in Kazakhstan is primarily formed by moisture transported via atmospheric transport, mainly from the Atlantic Ocean. The spatial distribution of snow reserves in the region is determined by various synoptic processes that bring solid precipitation, such as warm air intrusions (southern intrusions) or cold air (arctic intrusions). The strength and proximity of the Siberian anticyclone also play a crucial role in shaping the snow cover. The anticyclone forms a temperature inversion in the region of its influence, which affects the relationship between precipitation and altitude. Therefore, changes in the characteristics of the Siberian anticyclone over the years have a significant impact on the morphology of the snow cover in central and eastern Kazakhstan.

CONCLUSION

The observed increasing frequency of events in the study area (2016, 2017, 2019) shows a significant decrease in the typical size of zones with positive anomalies of snow reserves, as illustrated in Figure 3. This phenomenon is synchronized with similar processes described for the largest mountainous countries of Eurasia, including the Tien Shan (7439 m), Pamir (7719 m), Karakorum (8614 m), Hindu Kush (7708 m), Kun-Lun (7723 m), and Himalayas

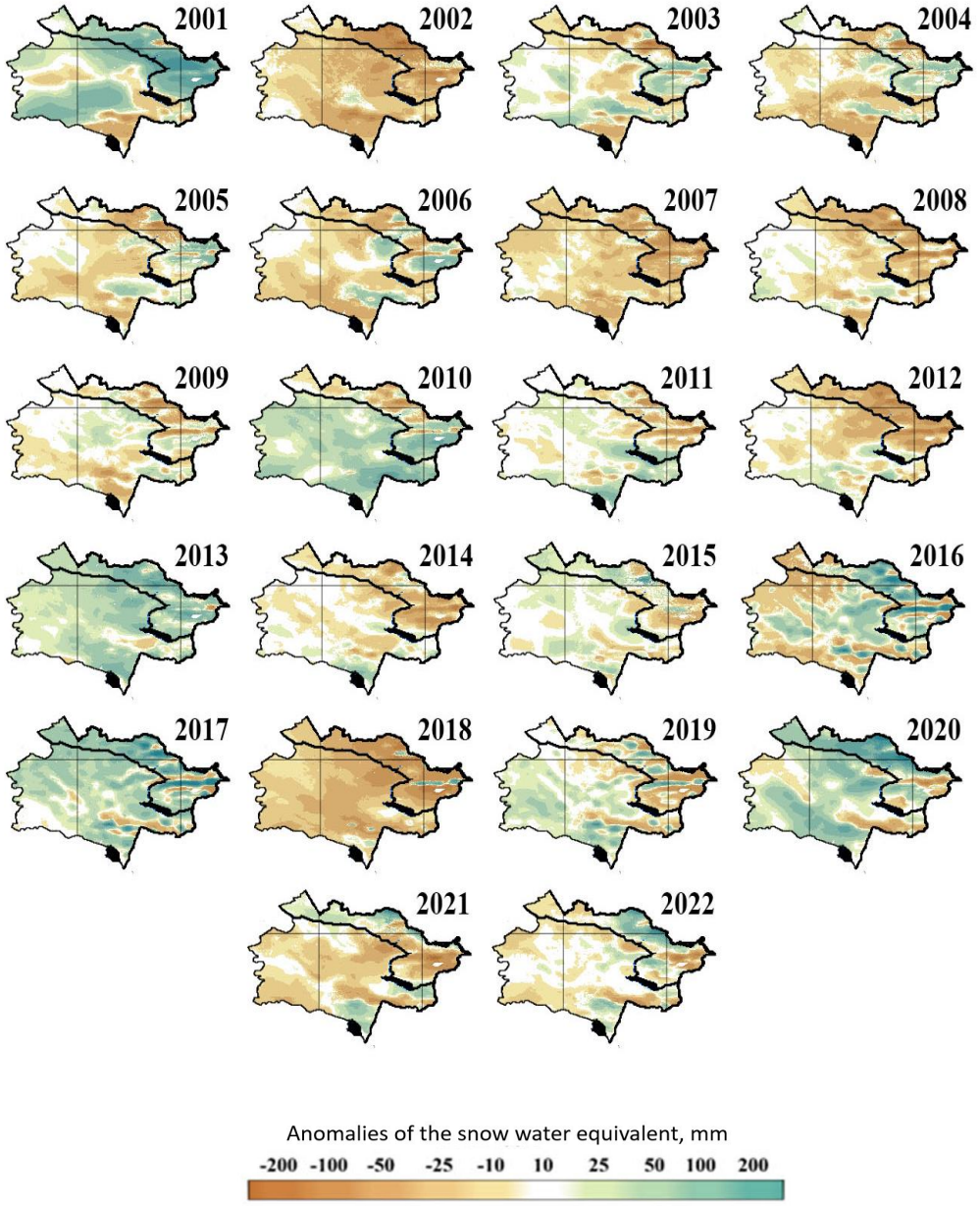

Fig. 3. *Anomalies of the water equivalent of snow cover (deviations from the average level from 2001...2021) on March 1 in the territories of Abai and East Kazakhstan regions. Source of information: FEWS NET portal.*

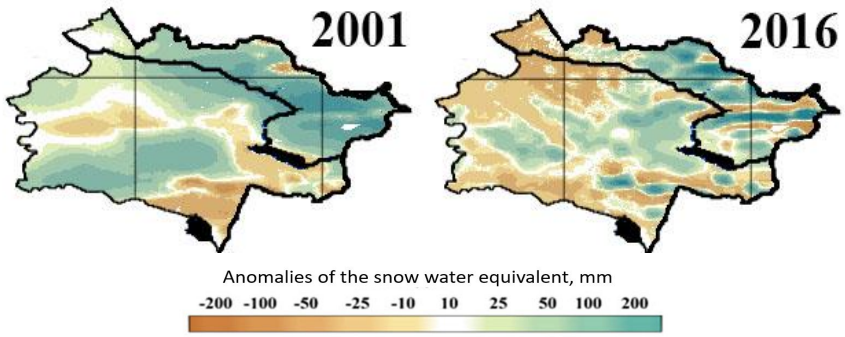

Fig. 4. *Anomalies of the water equivalent of snow cover (deviations from the average level from 2001...2021) on March 1 in the Abai and East Kazakhstan regions in 2001 and 2016 are illustrated. Differences in the spatial distribution of water reserves in the snow are highlighted, with zones of positive anomalies. Source of information: FEWS NET portal.*

(8848 m) (Terekhov and Makarenko, 2020; Report on Climate Features in the Russian Federation for 2022). Therefore, the zone of multiyear changes in the spatial distribution of the snow cover in Eurasia can be expanded to include part of the lowland massifs of the Kazakh Uplands (1565 m) and the Altai Mountains. The work was carried out with the support of funding from the Ministry of Science and Higher Education of the Republic of Kazakhstan, project No. BR 18574144.

REFERENCES

1. A report on climate features on the territory of the Russian Federation in 2022. – Moscow, 2023. – 104 p.
2. *Terekhov A.G., Pak I.T., Dolgikh S.A.* Satellite observations of the anomalous spring flood at the lower reach of the Ayaguz River in 2016. 2016, Vol. 13, No. 4, p.273–276, DOI: 10.21046/2070-7401-2016-13-4-273-276.
3. *Terekhov A.G., Abayev N.N., Yunicheva N.R.* Anomalous snowy regime at 2019 year and long-term trends in snow depth in Kazakhstan, 2019, Vol. 16, No. 5, pp. 351–355, DOI: 10.21046/2070-7401-2019-16-5-351-355.
4. *Terekhov A.G., Ivkina N.I., Abayev N.N., Galayeva A.V., Yeltay A.G.* (2020a) Streamflow response of the Ural River to basin snow depth changes during 2001–2019, 2020, Vol.17, No.5, p.181-190, DOI: 10.21046/2070-7401-2020-17-5-181-190.
5. *Terekhov A.G., Ivkina N.I., Yunicheva N.R., Vitkovskaya I.S., Yeltay A.G.* Snow cover changes of the Kazakhstan dry steppes and semi-deserts on the basis of River Emba basin studies, 2020, Vol.17, No. 2, p. 101-113, DOI: 10.21046/2070-7401-2020-17-2-101-113.
6. *Terekhov A.G., Abayev N.N., Vitkovskaya I.S., Pak A.A., Yegemberdyeva Z.M.* Links between the vegetation state over Tien-Shan mountains and North Atlantic Oscillation indices of the upcoming season, 2020, Vol. 17, No.2, p. 275-281, DOI: 10.21046/2070-7401-2020-17-2-275-281.
7. *Terekhov A.G., Ivkina N.I., Yunicheva N.R., Vitkovskaya I.S., Yeltay A.G.* Snow cover changes of the Kazakhstan dry steppes and semi-deserts on the basis of River Emba basin studies, 2020, Vol.17, No. 2, pp. 101-113, DOI: 10.21046/2070-7401-2020-17-2-101-113.
8. *Bormann K.J., Brown R.D., Derksen C., Painter T.H.* Estimating snow-cover trends from space// Nature Clim. Change. 2018, V.8, P. 924-928, DOI:10.1038/s41558-018-0318-3.
9. *Bulygina O.N., Groisman P.Ya., Razuvaev V.N., Korshunova N.N.* Changes in snow cover characteristics over Northern Eurasia since 1966// Environ. Res. Lett. 2011, V.6, No. 045204, DOI: 10.1088/1748-9326/6/4/045204.
10. *Bulygina O.N., Razuvaev V.N., Korshunova N.N.* Changes in snow cover over Northern Eurasia in the last decades// Environ. Res. Lett. 2009, V.4, No. 045026, DOI: 10.1088/1748-9326/4/4/045026.
11. *Dye D. G.* Variability and trends in the annual snow-cover cycle in Northern Hemisphere land areas, 1972–2000// Hydr. Proc. 2002, V.6, Iss.15, P. 3065-3077, DOI: 10.1002/hyp.1089.
12. *Kitaev L., Førland E., Razuvaev V., Tveito E.O., Krueger O.* Distribution of snow cover over Northern Eurasia// Hydr. Res. 2005, V.36, No 4-5, P. 311-319, DOI: 10.2166/nh.2005.0024.

ОБ ИЗМЕНЕНИЯХ В ПРОСТРАНСТВЕННОМ РАСПРЕДЕЛЕНИИ ЗАПАСОВ СНЕГА В ВОСТОЧНОМ КАЗАХСТАНЕ В ПЕРИОД 2001…2022 ГОДОВ

А.Г. Терехов*[1,2], Н.Н. Абаев[2]

[1] Институт информационных и вычислительных технологий, Алматы, Казахстан
[2] РГП «Казгидромет», Алматы, Казахстан
E-mail: aterekhov1@yandex.ru

В последние годы в открытом доступе появились региональные спутниковые продукты, описывающие параметры снежного покрова с высокой пространственно-временной детализацией. Наиболее точные оценки эти продукты дают для степных территорий, где помехи от лесного покрова минимальны.

Регулярные сетки данных открывают новые возможности в анализе пространственных характеристик снежного покрытия территорий, которые ранее не могли быть получены на основе данных метеорологических станций. В работе рассмотрены многолетние изменения в крупномасштабной пространственной организации запасов воды в снежном покрове в Абайской и Восточно-Казахстанской областях. Эти характеристики снежного покрова, также могут испытывать трансформации, драйверами которых выступает изменение климата. Абайская и Восточно-Казахстанская области Казахстана, с суммарной площадью около 0,27 млн. км² расположены в центре материка Евразия. В работе описано явление трансформации крупномасштабной пространственной организации снежного покрова на анализируемой территории в период 2001…2022 гг. В качестве исходной информации использовался продукт – аномалия водного эквивалента снега (Snow Water Equivalent Anomaly) на 1 марта, с разрешением 1 км, который доступен на портале USGS FEWS NET. Было получено, что крупномасштабная пространственная организация положительных аномалий водного эквивалента снежного покрытия на анализируемой территории в период 2001…2022 гг. варьировалась. Наблюдалось учащение ситуаций, характеризующихся уменьшением типичных размеров зон с положительными аномалиями запасов воды в снеге. Зарегистрированный эффект отчасти синхронизирован с аналогичными явлениями, описанными для крупных горных стран Евразии, где средняя площадь кластеров, формирующих территорию с положительной аномалией запасов воды в снеге, уменьшилась в период с 2001 по 2019 гг. в 10 раз, примерно с 10000 км² до 1000 км².

Ключевые слова: снежный покров, аномалии водного эквивалента снега, распределение запаса снега на территории, многолетние изменения, изменение климата.

2001-2022 ЖЫЛДАР АРАЛЫҒЫНДА ШЫҒЫС ҚАЗАҚСТАНДА ҚЫСҚЫ КЕЗЕҢДЕ ЖИНАҚТАЛҒАН ҚАР ҚОРЛАРЫННЫҢ КЕҢІСТІКТІК ТАРАЛУЫНДАҒЫ ӨЗГЕРІСТЕР

А.Г. Терехов*[1,2], Н.Н. Абаев[2]

[1] Ақпараттық және есептеуіш технологиялар институты, Алматы, Қазақстан
[2] «Қазгидромет» РМК, Алматы, Қазақстан
E-mail: aterekhov1@yandex.ru

Соңғы жылдарда кеңістіктік-уақыттық қар жамылғысының параметрлерін жанжақты сипаттайтын аймақтық жерсеріктік өнімдер көпшілікке қол жетімді болды. Бұл өнімдер орман алқаптарынан кедергілер аз болатын жазық аумақтарға дәл баға бере алады. Біртекті торланған алқаптағы мәліметтер бұрын сонды метеорологиялық станциялардың деректері негізінде қолжетімсіз болған, аумақтардың қар жамылғысының кеңістіктік сипаттамаларын талдауда жаңа мүмкіндіктер ашты. Жұмыста Абай және Шығыс Қазақстан облыстарында қар жамылғысындағы су қорының ауқымды кеңістіктік таралымының көпжылдық өзгерістері қарастырылды. Қар жамылғысының бұл сипаттамалары климаттың өзгеруі салдарынан болатын трансформацияларға ұшырауы мүмкін. Қазақстанның Абай және Шығыс Қазақстан облыстары, жалпы ауданы шамамен 0,27 млн. км² құрайтын Еуразия материгінің орталығында орналасқан. Жұмыста аталған аумақтарда 2001…2022 жылдар аралығындағы қар жамылғысының кең ауқымды кеңістіктік таралуының өзгеруі сипатталған.

Бастапқы ақпарат ретінде USGS FEWS net порталында қол жетімді 1 км ажыратымдылықпен 1 наурыз күнгі (Snow water Equivalent Anomaly) қардың су қорының аномалиясы пайдаланылды. 2001…2022 жылдар аралығында аумақта қар жамылғысының су қорының оң ауытқуларының кең ауқымды кеңістіктік таралуы әртүрлі болды. Қардағы су қорының оң ауытқулары бар аймақтардың типтік мөлшерінің төмендеуімен сипатталатын жағдайлардың көбеюі байқалды. Тіркелген әсер Еуразияның ірі таулы аумақтары үшін сипатталған ұқсас құбылыстармен сәйкес келеді, мұнда қардағы су қорының оң аномалиясы бар аумақты құрайтын кластерлердің орташа ауданы 2001…2019 жылдар аралығында шамамен 10000 км²-ден 1000 км²-ге дейін 10 есе азайған.

Түйін сөздер: қар жамылғысы, қардың су эквивалентінің ауытқулары, аумақтағы қар қорының таралуы, көпжылдық өзгерістер, климаттың өзгеруі.