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REPORT
ON RESEARCH WORK

REGION-WIDE GLACIER MASS BALANCE ASSESSMENTS AND INVENTORY OF ACTIVE ROCK GLACIERS IN THE ZHETYSU ALATAU USING REMOTE SENSING DATA

(final)

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ABSTRACT

The report 112 p., 1 b., 40 fig., 8 tab., 103 sour., 4 apdx.

GLACIERS, GLACIER MASS BALANCE, EARTH REMOTE SENSING, SAR INTERFEROMETRY, ROCK GLACIERS, ZHETYSU ALATAU

The research objectives are the glaciers and rock glaciers of the Zhetysu Alatau.

Project goal – assessment of detailed region-wide glacier elevation changes and calculation of geodetic mass balance with high temporal and spatial resolution and inventory of active rock glaciers over the Zhetysu Alatau by optical and radar images.

Research methods - Space monitoring, SAR interferometry, geodetic mass balance estimation method, analysis of space-time data.

The results of the work and their novelty:

– 2020 y. – Data base of archival and relevant remote sensing data of various types and resolutions for the territory of Zhetysu Alatau; Detailed review of previous studies.

– 2021 y. – Developed updated catalogue of glacier and rock glaciers and location of ELA over the Zhetysu Alatau: Updated reports about the glacier characteristics, area shrinkage rate; Updated catalogue of active rock glaciers using SAR and Google Earth images; Updated reports about equilibrium-line altitude (ELA) for glacierized regions of Zhetysu Alatau; Accuracy information of glacier mapping.

– 2022 y. – Gained knowledge about the region-wide glacier elevation changes and mass balance for the Zhetysu Alatau using remote sensing data.

The scope of the results: glaciology, water resources, hydrology, meteorology, remote sensing, ecology.

Recommendations for the implementation of research results: The results of the work can be used by organizations and research institutes in the field of water resources, glaciology, hydrology, ecology and emergency situations.

The economic efficiency or significance of the work is determined by the fact that the results can contribute to the long-term economic development of Kazakhstan through their use in planning the use of water resources, can help reduce dangerous processes associated with glaciers, in the development of new knowledge necessary to solve economic, scientific and practical problems.

Forecast assumptions about the development of the object of study: Our methods of studying the glaciers of the Zhetysu Alatau using remote sensing data can be applied to the study of glaciers throughout Kazakhstan.

SUMMARY

LIST OF ABBREVIATIONS AND SYMBOLS

In this research report, the following abbreviations and symbols are used:

LIDAR	– Light Detection and Ranging
DB	– Database
PO	– Software
USGS	– United States Geological Survey (Геологическая служба США)
RS	– Remote sensing
DEM	– Digital elevation model
SAR	– Synthetic aperture radar
ГНСС	– Global Navigation Satellite System
ELA	– Equilibrium line height
GIS	– Geoinformation system
GPS	– Global Positioning System
SRTM	–Shuttle Radar Topography Mission
IGS	– International GNSS Service
AF	– Air Force
MSS	– Multispectral Scanner
TM	– Thematic Mapper
ETM +	– Enhanced Thematic Mapper Plus
КА	– Satellite
GAMMA	– Interferometric processing software
OLI	– Operational Land Imager

INTRODUCTION

Наименование проекта: Region-wide glacier mass balance assessments and inventory of active rock glaciers in the Zhetysu Alatau using remote sensing data. State registration number 0120PK00317.

Research work is carried out within the framework of the state order for the implementation of a scientific and (or) scientific and technical project under the budget program 217 "Development of Science" on the priority "Information, telecommunication and space technologies". IRN AP08856470.

The basis for the implementation of research: the decision of the National Scientific Council on grant funding for the priority "Information, telecommunications and space technologies" (minutes No. 5 of October 14, 2020), an agreement with the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan No. 252 of November 12, 2020.

The customer for the implementation of the state order is the "Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan" (SC MSHE RK).

Project implementer: Subsidiary Limited Liability Partnership "Institute of the Ionosphere" (SLLP "II").

Implementation period: 2020-2022.

Amount of funding: for 2020 - 2022 is 60,946,460.26 thousand tenge, including by years: 2020 - 16,698,272.26 thousand tenge, 2021 - 19,499,500.33 thousand tenge, 2022 - 24 748,687.67 thousand tenge.

The object of research is the glaciers and rock glaciers of the Zhetysu Alatau.

Research methods - Space monitoring, SAR-interferometry, geodetic method for mass balance estimation, analysis of spatio-temporal data.

Project goal – assessment of detailed region-wide glacier elevation changes and calculation of geodetic mass balance with high temporal and spatial resolution and inventory of active rock glaciers over the Zhetysu Alatau by optical and radar images.

The main objectives of the research for the first stage (2020): Selection of archival and relevant remote sensing data of various types and resolutions for the territory of Zhetysu Alatau, a detailed review of previous studies.

Expected results: Data base of archival and relevant remote sensing data of various types and resolutions for the territory of Zhetysu Alatau; Detailed review of previous studies.

Main research objectives for the second stage (2021): Identifying and mapping of glaciers and rock glaciers, delineation of ELA over the Zhetysu Alatau.

Expected results: Updated catalogue of glacier and rock glaciers and location of ELA over the Zhetysu Alatau.

The main objectives of the research for the third stage (2022): Assessments of region-wide glacier elevation changes and mass balance for the Zhetysu Alatau using remote sensing data.

Expected results: Knowledge about the region-wide glacier elevation changes and mass balance for the Zhetysu Alatau using remote sensing data.

In 2020, archival and current remote sensing data of various types and resolutions were selected for the territory of Zhetysu Alatau. A detailed review of the literature on the main objectives of the project was carried out, published materials on the study of the mass balance of glaciers, active rock glaciers and the dynamics of the area of glaciers were analyzed. A database of archival and actual data of remote sensing of the Earth of various types and resolutions for studying the glaciers of the Zhetysu Alatau has been created.

In 2021, glaciers were mapped from remote sensing data using a semi-automatic band ratio technique. Zhetysu Alatau rock glaciers are identified and mapped using high-resolution Google Earth optical imagery.

Glaciers were detected in all seven river basins for the Zhetysu Alatau. For this purpose, satellite images of the Landsat series were considered, covering the territory of the Zhetysu Alatau (Kazakhstan part) from 1989 to 2020, at the end of the ablation period (the end of the summer season). On the basis of natural and climatic characteristics (the presence of clouds, fog, the amount of snow cover, etc.), a selection of satellite images suitable for analysis was carried out, namely, for 2001, 2012 and 2016. The area of glaciers on the selected satellite images was determined by the method of semi-automatic ratio of bands. An analysis was made of the rate of reduction in the area of glaciers. Interferometric processing by the SBAS (Small Baselines) method of radar data from the Sentinel-1 satellite for ascending and descending orbits was carried out. Zones of horizontal and vertical displacements are revealed. Zhetysu Alatau rock glaciers have been identified and mapped using high-resolution Google Earth optical imagery. Using the results of radar interferometry, active rock glaciers are classified according to their displacement velocity. For general statistics, both inactive and relict rock glaciers are determined.

In 2022, bistatic digital elevation models were created using remote sensing data. The microwave penetration was corrected according to the SRTM-X and SRTM-C data. The densities of glaciers in the study area were determined. Changes in the height of the surface of glaciers in time are determined and calculated, and changes in volume are converted into a mass balance of glaciers. An assessment is made of the accuracy of calculating the mass balance of glaciers.

Our method for calculating the geodetic mass balance of glaciers is based on the DEM difference. To calculate the change in the height of the glacier surface, two DEMs were compared: the historical (SRTM) and the current DEM. Using high-precision radar data, an actual DEM was built.

The height difference arising from the different possibilities of penetration through the surface of the C-band and X-band microwave radiation is taken into account. With a longer wavelength, the -C band set to SRTM penetrates deeper into the ice/snow surface than the -X band. The SRTM-X and SRTM-C DTMs were also corrected before differentiation, and offset corrections were applied to the height difference map. As the height increases from the foot to the summit, clearer ice is exposed, and the layer of dry snow/firn on the surface becomes more and more thick. Correspondingly, the penetration depth of the C-band also increases, reaching a maximum at the highest base of the firn.

Nuth and Kääb's methodology was used to estimate changes over time when comparing digital elevation models for 2000 (Shuttle Radar Topography Mission DEM) and 2013 (TerraSAR-X/TanDEM-X). This technique includes the stages of horizontal co-registration of compared digital models based on reference points obtained over stable regions and calculation of height changes. The resulting height change file was used to calculate the geodetic mass balance, taking into account that the ice density is 850 ± 60 kg m^{-3}.

The justification for the need for research is determined by the fact that the results obtained can contribute to the long-term economic and social development of Kazakhstan through their use in planning the use of water resources, can help reduce dangerous processes associated with glaciers, in the development of new knowledge necessary to solve economic, scientific and practical tasks. The development of modern methods of space research, including methods of remote sensing of the Earth and optical and radar satellite imagery, will increase the level of efficiency of scientific research, the scientific and technical potential and the competitiveness of scientific organizations and their teams.

The relevance of research is due to the need to assess and monitor the dynamics of changes in glaciers and rock glaciers, the mass balance of glaciers in the entire mountain range, where ground-based data are practically absent. The obtained research results will allow studying the country's water resources in the context of climate change. In Kazakhstan, the areas of modern glaciation are the eastern and southeastern mountains - Altai, Saur, Zhetysu (Dzhungar) Alatau, Ile-Alatau (Northern Tien Shan), Kungei-Alatau, Terskey-Alatau, there are 2724 glaciers with an area of glaciation of 2033 km2, however, ground-based glaciological measurements continue only in one Tuyuksu glacier. With a positive result of scientific research on the Zhetysu Alatau, we can apply this technology to assess the mass balance throughout the glacial mountain system of Kazakhstan.

At the moment, the introduction of tools and methods of geodetic, remote sensing of the earth, allowing to reconstruct the time series of the annual mass balance, is an important task. Using several methods together will allow you to determine the annual mass balance for a large area with minimal cost.

The novelty and prospects of the program lies in the fact that for the first time a detailed assessment of the geodetic mass balances of glaciers and an inventory of active rock glaciers of the entire Zhetysu (Dzhungar) Alatau on a regional scale are proposed using Earth remote sensing data with high temporal and spatial resolution. Our methods of studying the glaciers of the Zhetysu Alatau using remote sensing data can be applied to the study of glaciers throughout Kazakhstan.

The scientific and practical significance of the research lies in the fact that within the framework of the project tasks are planned that contribute to a more detailed study and understanding of the impact of climate change on water resources in general, and in particular on rock glaciers. The significance of these works is confirmed by discussions at international conferences held in many countries of the world. Work in this direction is carried out within the framework of large-scale international projects covering many countries of near and far abroad (Switzerland, Germany, China, Norway, France, India, Pakistan, Nepal, etc.). Over the years, the project executors have participated in the creation of theoretical and practical groundwork in this area, and also have publications in rating journals.

Better monitoring of the rate of glacier melt and their current state of mass balance are important steps towards minimizing the negative effects of this degradation through improved planning and management of water resources and infrastructure development planning.

Degree of implementation, recommendation for implementation. The results of the work can be used by organizations and research institutes in the field of water resources, hydrology and ecology, in the field of protecting the population, farm facilities and the environment from natural and man-made emergencies.

Communication of this work with other research works. Research in the declared project is a logical continuation and the next stage of the scientific work carried out in 2012-2015. in this direction, which is confirmed by publications.

Information about the scientific and technical level of work, information about the metrological support of research. The proposed topic has no analogues in Kazakhstan, it is carried out by a team with high professional training, extensive experience in research activities and international cooperation. Satellite technologies used in the project, remote sensing measurements data and methods of their processing determine the high scientific and technical level of the project.

Competitiveness of developments: Availability at the Institute of the Ionosphere of its own modern experimental, material and technical base, provision with highly qualified scientific and technical personnel; the presence of scientific relations with domestic and foreign research institutes makes it possible to successfully complete the Project and obtain relevant and competitive results at a high scientific level.

Forecast proposals for the development of the object: Our methods of studying the glaciers of the Zhetysu Alatau using remote sensing data can be applied to study the glaciers of all Kazakhstan.

List of titles of interim reports by stages: In the course of the research work, an interim report was prepared and passed the state acceptance and examination, which are stored in the Funds of the National Center for State Scientific and Technical Expertise of the Republic of Kazakhstan:

1) Region-wide glacier mass balance assessments and inventory of active rock glaciers in the Zhetysu Alatau using remote sensing data (Interim report) / SLPP "Institute of the Ionosphere": PI. Kaldybaev A.A. - Almaty, 2020. - 54 p. - No. GR 0120RK00317. –Inv. No. 0220RK01950.

2) Region-wide glacier mass balance assessments and inventory of active rock glaciers in the Zhetysu Alatau using remote sensing data (Brief information) / SLPP "Institute of the Ionosphere": PI. Kaldybaev A.A.- Almaty, 2021. - No. GR 0321PK00610. – IRN № AP08856470-KC-21

THE MAIN PART OF THE RESEARCH REPORT

1 Justification of the choice of research direction

Glaciers play a key role in the hydrological cycle of Central Asia [1-2]. It has been demonstrated that even a basin with a <5% glacier surface fraction can provide a significant contribution of ice melt to summer runoff, when water is most needed for irrigation [3–4]. Zhetysu (Dzhungar) Alatau is surrounded by arid lowlands and deserts, where irrigation during the growing season often depends on the melting of glaciers [4, 5].

The rate of reduction in the area of glaciers in different parts of the Tien Shan mountain system is different, in the western part -0.7%, in the northern part -0.37% and -0.76%, in the central part -0.11% and the eastern part 0 .35% [6]. This intense decline in glacier area is consistent with earlier findings that the greatest rate of glacier decline occurred on the outer peripheral ridges of the Tien Shan, with lower ridge elevations near densely populated foothills. Our previous results on the assessment of the reduction in the area of glaciers confirmed this [6, 7]. The scientific question is - what about the altitude changes and the mass balance of glaciers in these areas? The answer can be obtained only after conducting research based on the data and methods of processing remote sensing. Here it is important to study not only the area, but also altitude changes, mass balance and volumes of glaciers. And also, an equally important scientific issue is the inventory of active stone glaciers of the Zhetysu Alatau, which has never been carried out. All these questions can only be answered by conducting a detailed comprehensive study on monitoring, mass balance assessment and inventory of active stone glaciers using archival (for the last 50-60 years) and actual space images of medium and high resolution.

There are several mass balance measurement methods used by different researchers: glaciological (or traditional) measurements, geodetic method, accumulation Area Ratio method, hydrological method, gravimetric method. Due to the lack of ground measurements, relatively low mountains, small size of glaciers, cloudy weather, in Zhetysu Alatau the most promising methods are geodetic methods that measure differences in the height of the glacier surface. Satellite data can greatly increase the number of measured glaciers, the time period covered, and the parameters that can be estimated and analysed.

A geodetic method based on comparison of topographic data can be applied on a regional scale to small glaciers in remote areas using satellite data. This method allows increasing the number and variety of glacier measurements (eg glacier size, thickness, percentage of rock fall coverage). DEMs can be created using airborne or space based techniques using optical imaging photogrammetry, radar imaging interferometry and LIDAR scanning.

World experience shows that to assess the mass balance, DEMs for different dates were mainly used, which made it possible to perform a comparative analysis of the study area. Optical satellite data are used to map the glacier boundary, supporting the results with higher resolution satellite imagery, thermal imagery. The dynamics of change is assessed by comparing actual data with historical satellite images.

The main output of this project will be an up-to-date assessment of changes in glacier heights and calculation of the geodetic mass balance on a regional scale with high temporal and spatial resolution. We also plan to create for the first time a catalog of the active stone glaciers of the Zhetysu Alatau that have not been studied so far using effective methods of SAR interferometry and high-resolution optical and radar images.

As part of our study, we cover the period over the past 50-60 years, where there is no assessment of the mass balance of glaciers. Single ground-based mass balance measurements were made only on reference glaciers until the 1990s. Our ongoing catalog of active stone glaciers is an important study, since we are developing it for the first time for the Zhetysu mountain system, covering all river basins in the area using modern effective remote sensing methods, such as SAR interferometry, Band ratio, etc.. Additionally, we determine the dynamics of reduction the area and number of glaciers since 1956, the height of the equilibrium line (ELA), the density and volume of glaciers in the study area.

2 Assessment of changes in the area of glaciers and physical and geographical features of the Zhetysu Alatau

2.1 Review of literature on the study of changes in the areas of glaciers of the Zhetysu Alatau

Cherkasov (2001) [8, 9] divided the history of glaciological studies of the Zhetysu Alatau into four periods: 1840-1917. (I-period), 1918-1956 (II-period), 1957-1991 (III-period) and 1992-to. present time.

Glaciological research in the I period was mainly carried out by employees of the Russian Glaciological Society and the Migration Department of Land Management of Russia. They studied the main geographical and morphological parts of the glaciers. Then there was the first glaciological discovery and contact with the glaciers of the Zhetysu Alatau. Schrenk organized an excursion to the Baskan River and measured the snow line during his explorations of the Balkhash and Alakol lake basins in 1840. Later, Semenov-Tyan-Shansky visited and reported on constant snowfalls in the basins of the Kora, Koksu and Lepsy rivers in 1856–1857 [10].

In period II, new Soviet research began. The first Soviet inventory of glaciers in Central Asia, published by Kozhenevsky in 1930, included information on identification names and geographic coordinates of glacier tongues for 71 glaciers located in Zhetysu-Alatau. The first research works related to mass balance measurements, glacier thickness, dynamics and hydrological regime of glaciers, melting and runoff of glaciers were carried out by Palgov in 1947-1952 [9, 10].

III period of glaciological research began with the implementation of the program of the International Geophysical Year. During this period, for the first time, a comprehensive study was carried out using aerial photographs.

The first detailed inventory of the Zhetysu Alatau glaciers, the USSR Glacier Catalog, was published in 1980 and is based on aerial photographs from 1956. Cherkasov (2004) [11] compiled a second inventory of glaciers using topographic maps at a scale of 1:25,000 based on aerial photographs taken in 1972, and two more glacier surveys were carried out for the 1990s and 2000s. However, these inventories remained unpublished [9, 10]. These studies are based on drawing the contour of the glacier on topographic maps. The average error in measuring the area, the basins of the Koksu and Karatal rivers amounted to 6.71% and 4.79%, respectively [3].

The glaciers of the Dzungarian Alatau part within Kazakhstan are well studied and mostly documented by Cherkasov (1969, 1970, 1975, 1980, 2002) and in recent works (Seversky 2016 Vilesov et al., 2013;). For this region, unified cadastres of glaciers for 1956, 1972, 1990, 2000 and 2011 were prepared. Further, inventories of glaciers in the Balkhash-Alakol basin (including Zhetysu Alatau) for 2000 and 2011 were carried out, identical in content to the above catalogs, were prepared on the basis of 1: 25,000 scale maps of the state survey and Landsat space images [12]. According to published results, for the period 1956-2011, the rate of glacier reduction was 0.779% per year. The highest rate of decline was shown by the southern and western regions of Zhetysu Alatau, showing - 0.862% and - 0.802%, while the northern and eastern regions showed - 0.698% and - 0.780%, respectively. Glaciological studies of the Bortala River in the eastern part of the Zhetysu Alatau, which is located on the territory of China, were published by the researcher Wang et al., (2014) [13]. They found a relatively low level of glacier reduction for the Zhetysu Alatau - 0.32% per year.

Our studies [6, 7] on the assessment of the reduction in the area of glaciers in the Karatal River basin confirmed the expected and widely published trend in the reduction of glaciers [14, 15]. However, our results, where the rate of decline is between -0.8% and -1% per year for the periods 1956-1989 and 1989-2012 showed the highest reduction rate compared to other glaciated regions of Central Asia, including Altai, Tien Shan and Pamir [16-19].

The results of previous studies showed large differences in different parts of the Tien Shan: - 0.76% a-1 (mid-1970s - mid-2000s; [19]) in the Western Tien Shan; -0.38% a-1 (1963–2003; [20]) and - 0.76% a-1 (1963–2000; [21]) in the Northern Tien Shan; - 0.11% a-1 (1975-2008; [22]) in the Central Tien Shan and - 0.35% a-1 (1963-2000; [23]) in the Eastern Tien Shan. This intense decrease in glacier area is in close agreement with previous studies, which showed that the greatest loss of glacial area occurred in the outer ridges of the Tien Shan and peripheral, lower ridges near heavily urbanized areas [24].

The rapid reduction in the area of glaciers was probably associated not only with the location of the study area on the periphery of the Zhetysu Alatau, where climatic conditions are less favorable than the inner ridges, but also with the relatively smaller size of glaciers with the complete absence of moraine cover. Differences in glacier shrinkage between sub-basins can be explained by differences in size, orientation, and local climatic conditions.

Despite the vulnerability of the glaciers of the Zhetysu Alatau with record area reduction in the region, ground monitoring and actual work on the area assessment in recent years, starting from 2012, have not been carried out.

2.2 Physical and geographical features of the location of the Zhetysu Alatau

Geographical position. ZhetysuAlatau (Dzhungar Alatau) is a mountain system stretching from west-southwest to east-northeast along the state border between the Republic of Kazakhstan and the People's Republic of China. Most of it is located in Kazakhstan. Within China, the Zhetysu Alatau extends approximately to 81 E, i.e., to Lake Sairamnur, where the Borokhoro ridge connects it with the Eastern Tien Shan [25, 26]. Its southern border is the Ile

River, the northern one is the Balkhash Plain, the northeastern one is the Alakol Lake and the Dzhungar Gates. (Picture 1).

The length of the North Central Range is about 400 km, and the South - 300 km. The Northern Zhetysu Alatau includes the main ridge of the mountainous country, it is the longest and highest. The ridge sublatitudinally stretches for 260 km, reaching the highest elevation of 4622 m. Its most significant spurs are Kungei and Tastau. The Southern Zhetysu Alatau includes the Toksanbay and Bedzhintau ridges with many spurs. Here, in the Muztau mountain range, there is the highest peak of the Southern Zhetysu Alatau - 4370 m [79].

The total area of the Zhetysu mountain system, including the basin of the river. Borotala in China is about 40,000 km^2 km [25]. In the view of a number of scientists, Zhetysu Alatau is an independent mountain system, separated from the main chains of the Tien Shan by the Ili depression. Meanwhile, its orographic and geological connection with the Eastern Tien Shan is quite obvious. Therefore, the Zhetysu Alatau mountain system should be considered not independent, but belonging to the larger Tien Shan megasystem [25].

The northern and western sides of the Kazakhstan part of the Dzungarian Alatau border on the deserts of the Balkhash region, such as Saryesik-Atyrau, Zhalkum, Arkarly and others. The Dzungarian pass is famous in Central Asia for the strongest winds blowing in it at times; the prevailing winds here are: northwestern (Saikan) and southeastern (Evgei or Dzungarian wind) raging in autumn and spring. These winds, including warm westerly winds, kicking up dust from the desert, play a key role in the health of the region's glacial systems (Figure 2.1).

Orography and relief. The Dzungarian mountainous country is represented by the Dzungarian Alatau and its numerous spurs lying between the Alakul depression and the valley of the river. Ile. The northern slopes of the main ridge are gentle and are distinguished by wide leveled surfaces with a clearly pronounced stepwise relief depression. The southern slopes also have a stepped relief, but unlike the northern slopes, they are steeper and strongly dissected. The watersheds of the main ranges are characterized by typical alpine landforms with a maximum height of 4500-5000 m. Its east and south are distinguished by a dry continental climate [27].

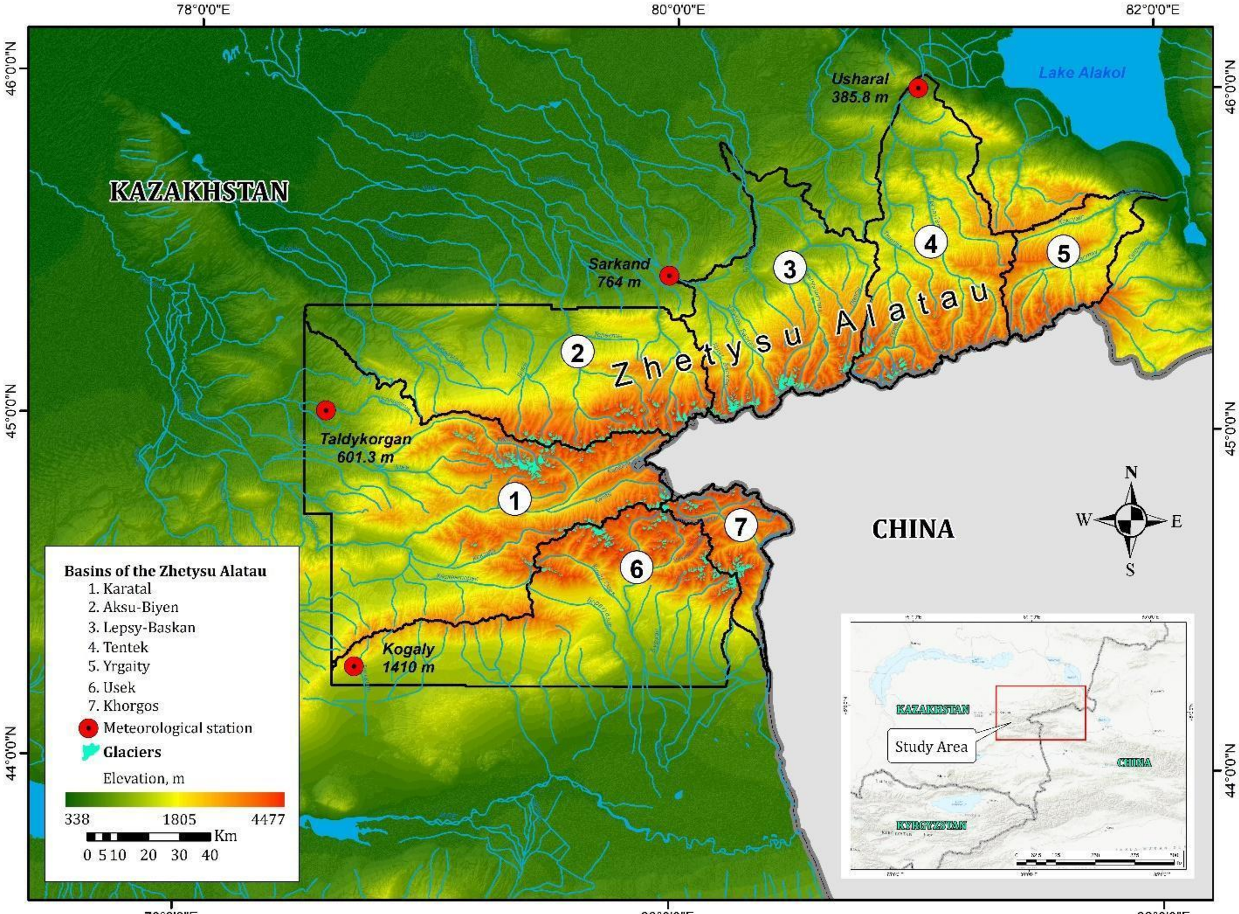


Figure 2.1 - Geographical location of Zhetysu Alatau

Climatic conditions. The climate of the region under study is mainly continental. Zhetysu Alatau is in the sphere of influence of arctic, polar and tropical air masses, which undergo significant transformation on the way to it. Arctic air masses come from the north and northwest, from the regions of the Barents and Kara Seas. More often they come in the first half of the winter period. Their invasion is accompanied by a sharp drop in air temperature.

The average annual rainfall is 600-800 mm, in the southeast - 400 mm. In the western part, the largest annual amount of precipitation in the entire range of altitudes falls in the basin of the river. Chizha (1400-1600 mm), advanced towards the moisture-carrying air masses.

The average long-term air temperature in the lower part of the glacial zone (at altitudes of 3200-3600 m) during the accumulation period is -8 ... -10 °C, in the upper part (above 4000 m) it drops to -14 ... -16 °C. As the terrain rises above sea level, differences in climatic conditions are clearly manifested. According to the climate reference [28], the coldest month is January, the temperature of which ranges from -7.5 (Sarkand MS) to -13.2 °C (Usharal MS). The warmest month is July, its temperature in the foothill areas reaches 24.3 °C, in the mountains - 17.7 °C. The region's climate is characterized by well-developed temperature inversions, i.e., temperature increases with elevation. The minimum air temperature in the flat area drops to an average of -

18.3 ° C, in mountainous areas to -13.4 ° C. The absolute minimum reaches - - 44 ° C, and the absolute maximum is 44 ° C. A warm period with an average daily temperature air above 0 ° changes from 116 days in to 137 days in mountainous areas. The duration of the frost-free period in most of the territory is 123-161 days. Spring frosts stop mainly at the end of April (April 23-29), and the first autumn frosts in most areas are observed at the end of September and the beginning of October.

The annual rainfall ranges from 298 mm to 520 mm in the mountains. In the warm period of the year (from April to October), 50-65% of the annual precipitation falls. The average annual wind speed is 1.1-2.7 m/s. Steady snow cover is observed in late November - early December. Its descent is observed in the third decade of March. The duration of the period with stable snow cover is 111-155 days. The average of the maximum heights of snow cover during the winter does not exceed 15-33 cm [29]

Thus, the differences in the absolute heights of the mountain relief of the Zhetysu Alatau and its morphology cause a wide variety of climatic conditions.

2.3 Relevance of research and mapping of glaciers based on remote sensing data

In regions with little summer precipitation, glaciers play an important role in river flow regimes, as meltwater from ice is released when other sources, such as snowmelt, are depleted [15, 30]. Their function as "water towers" becomes especially important in arid and semi-arid regions where there is a seasonal lack of water due to precipitation [31,32]. This situation is well reflected in the Tien Shan, where glaciers make a significant contribution to the summer freshwater supply in the densely populated arid lowlands of Kazakhstan, Kyrgyzstan, Uzbekistan, Turkmenistan, and Xinjiang/China [15, 17, 33].

Most of Central Asia is characterized by a semi-arid and arid climate. Therefore, areas near shallow groundwater, rivers and lakes are characterized by unique water-dependent ecosystems and human communities that have developed over millennia in close interaction with limited natural water resources [3].

It has been demonstrated that even a basin with a <5% glacier surface fraction can provide a significant contribution of ice melt to summer runoff, when water is most needed for irrigation [3, 4].

The population of arid and semi-arid lowland regions (oases and irrigated agricultural lands) of Central Asia largely depends on river waters coming from mountainous regions [24]. The glaciers of the Tien Shan mountain system provide water to the depressions of Kazakhstan, Kyrgyzstan and Uzbekistan, which are among the largest irrigated areas in the world [32].

Zhetysu(Dzungarian) Alatau is surrounded by arid lowlands and deserts, where irrigation during the growing season often depends on the melting of glaciers. In the region under consideration (in the Kazakhstani part), the waters of the Karatal, Koksu, Lepsy, Aksu and other rivers are intensively used for irrigation. In the basins of these rivers, the water withdrawal for irrigation of almost 200 thousand hectares is estimated at 1.3 km^3/year. Rational water use for irrigation and hydropower needs is impossible without comprehensive information about the change (decrease) in the area and volume of glaciers, which causes a reduction in the long-term moisture reserve in them, a decrease in glacial runoff, and a violation of the natural self-regulation of river flow. This problem is solved by monitoring modern glaciation, which should be carried out not for 1–2 “reference” glaciers of a mountainous country where field observations are carried out (an example is the well-known Tuyuksu glacier in the Zailiysky Alatau), but for large glacial systems in general, numbering hundreds and thousands of glaciers. It is also necessary to assess the rate of reduction of ice reserves and the prospects for the existence of these systems in the near and distant future [34].

The first detailed inventory of the glaciers of the Zhetysu Alatau, the Catalog of Glaciers (Catalogue of Glaciers of the USSR, 1980), was published in 1980 and is based on aerial photographs from 1956. Cherkasov (2004) compiled a second glacier inventory using 1:25,000 scale topographic maps based on aerial photographs taken in 1972, and two more limited glacier surveys were carried out in the 1990s and 2000s. These inventories, however, remained unpublished reports [35].

In subsequent years, several authors studied the change in the area of glaciers in the entire Zhetysu Alatau and its subregions, which estimated the overall decrease in the area of glaciers [6,7,12].

In particular, among these works, Seversky and others [12] made a general analysis and assessment of changes in the area of glaciers in all parts of the Zhetysu Alatau (in 1956, 1972, 1990, 2000 and 2011). In their study, they analyzed changes in the area of glaciers between 1956 and 1972 based on the catalog of glaciers of the USSR, which was created using topographic maps at a scale of 1:25,000 based on aerial photographs taken in 1972. The catalog of glaciers of the ZhetysuAlatau for 2000 and 2011, identical in content to the catalogs mentioned above, was prepared on the basis of maps of the state survey at a scale of 1: 25,000, satellite images of Landsat 7 ETM +, a digital elevation model (DEM) and surface control points.

According to their research, in the period 1956-2011, the area of glaciers in the Zhetysu Alatau decreased from 813.9 km^2 to 465.17 km2, and the annual rate of reduction was 0.78%. However, in the studies of Seversky et al., a general analysis was made of the assessment of the change in the area of glaciers of the Zhetysu Alatau, the change in glaciers in individual river basins was not fully shown by their individual morphometric characteristics (average size of glaciers, location features in the altitudinal zone, aspects, etc.). etc.).

Thus, changes in the surface area of the glaciers of the Zhetysu Alatau, including individual basins, remain poorly understood.

The purpose of this article is to compile an updated inventory of the Zhetysu Alatau glaciers in the Kazakh part based on remote sensing data.

This paper presents a detailed analysis of the area of the Zhetysu Alatau glacier for 1956-2001, 2001-2012 and 2012-2016 using well-established semi-automatic methods based on band ratios [36].

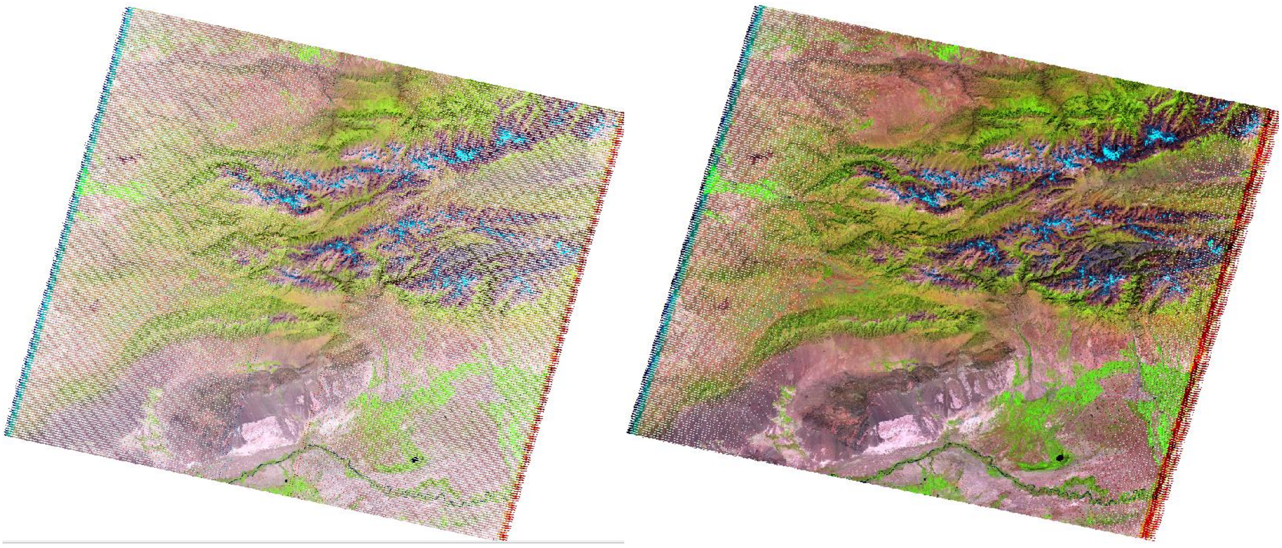
2.4 Description of data and methods used to estimate glacial loss

Data. To solve the tasks set, this paper considers images from the Landsat series satellites covering the territory of the Zhetysu Alatau (Kazakhstan part) from 1989 to 2020, at the end of the ablation period (the end of the summer season). On the basis of natural and climatic characteristics (the presence of clouds, fog, the amount of snow cover, etc.), a selection of satellite images suitable for analysis was carried out, namely, for 2001, 2012 and 2016.

Four Landsat 7 ETM+ and three Landsat 8 OLI images were used for glacier mapping. All images were downloaded from the USGS resource (https://earthexplorer.usgs.gov/) at Level 1T. A panchromatic channel with a resolution of 15 m was used to improve the quality of the maps (Table 2.1).

Due to the unfavorable natural and climatic characteristics of the Landsat 7 ETM+ images for 2001, covering the eastern part of the Zhetysu Alatau, an additional image from the Landsat 7 ETM+ satellite of 2002 was used.

Since Landsat 8 OLI was launched only in 2013, and the Scan Line Corrector (SLC) in the ETM+ instrument (Landsat 7) failed in 2003, the 2012 ETM+ images require pre-processing, namely the Gap filling process, that is, filling in the missing pixels. This procedure was carried out in ENVI software using the Gap Fill module. The images from 2012 were used as the “master file”, and the images from 2011 were used as the “slave file” (Figure 2.2).



Before pretreatment After pretreatment

Figure 2.2 - Before and after the Gap fill process (2012)

In addition, in addition to the 2016 Landsat OLI satellite images, the 2015 Landsat OLI images were used due to improved shadow conditions, which in turn allows more detailed mapping of glaciers.

The satellite imagery available on Google Earth for glacier contouring served as a visual guidance tool, with data coming primarily from very high resolution optical sensors such as QuickBird, Worldview, Pléiades 1A and 1B, and SPOT 6 and SPOT 7 (GoogleEarth 2017), unfortunately, they were not available for all regions.

The ALOS PALSAR DEM was used to extract watersheds and topographic information for the glacier inventory. Also, when analyzing the dynamics of changes in the area of glaciers, the 2nd edition of the 13th volume of the catalog of glaciers of the USSR (glaciers on the territory of Zhetysu Alatau) 1969, 1970, 1975 and 1980, published on the basis of aerial photographs of 1956, was used.

Table 2.1 - List of Landsat scenes used in this study

WRS2 path-row	Date	Satellite and sensor	Spatial resolution (m)	Suitability of scenes	Suitability of scenes
148-029	22 August 2001	Landsat ETM+	15/30/60	Main	
147-029	18 August 2002	Landsat ETM+	15/30/60	Additional Information	seasonal snow
147-029	13 August 2012	Landsat ETM+	15/30/60	Main	
148-029	20 August 2012	Landsat ETM+	15/30/60	Main	
147-029	01 September 2016	Landsat OLI	15/30/60	Main	seasonal snow, shady areas
148-029	24 September 2016	Landsat OLI	15/30/60	Main	seasonal snow, shady areas
148-029	21 August 2015	Landsat OLI	15/30/60	Additional Information	

Research methods. Scientists have used various methods to extract glacier boundaries, including manual visual interpretation, band ratio thresholding method, normalized snow cover index method, and band ratio thresholding method combined with visual interpretation [36-38].

Studies have shown that the fringe ratio thresholding method, based on multispectral remote sensing images combined with visual interpretation, is relatively accurate in delineating glacier boundaries [40].

Several presentations at the GLIMS workshop demonstrated methods for the automatic extraction of clean or lightly contaminated glacial ice.

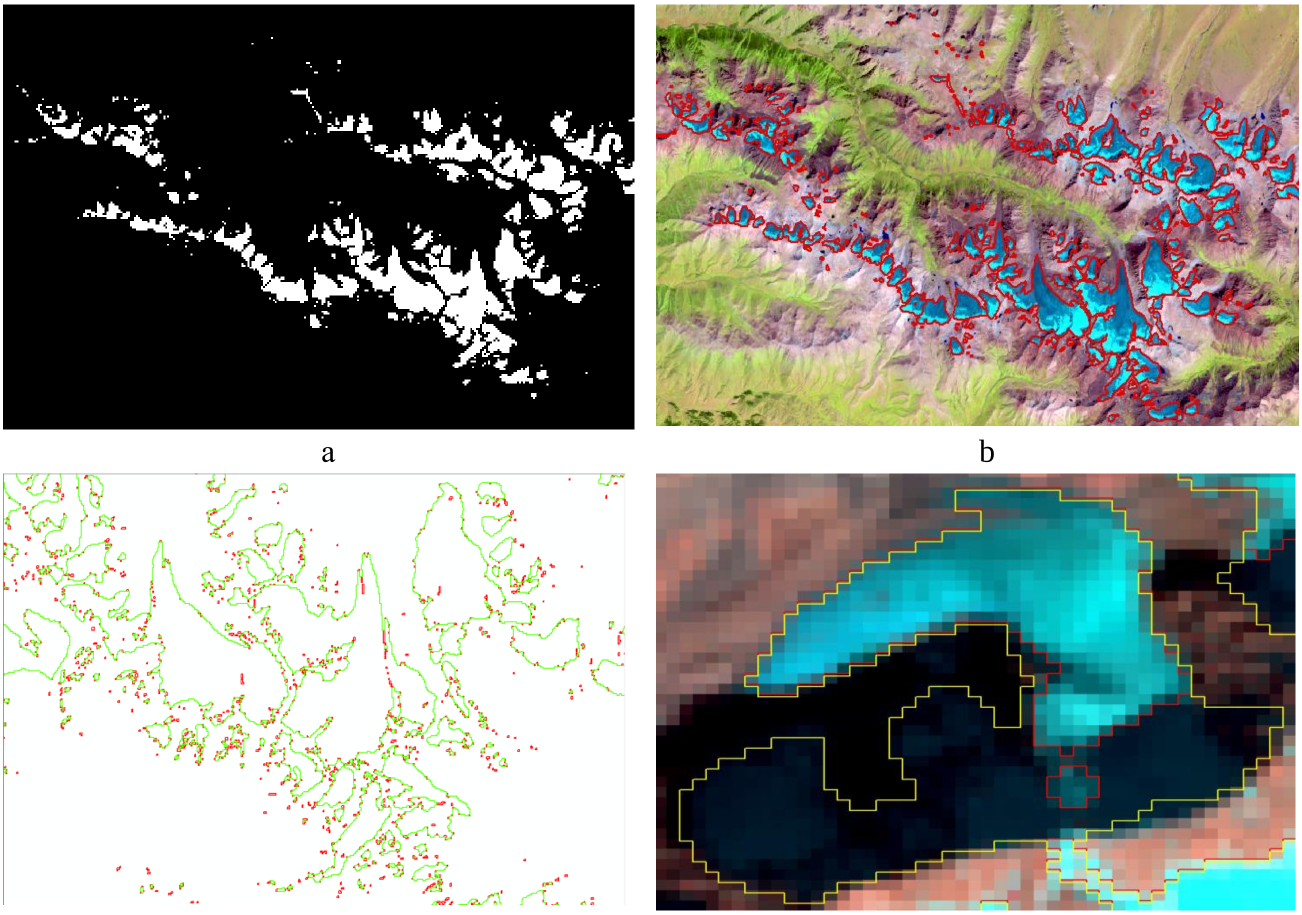
F. Paul [38, 40] further carried out a thorough comparison of various methods, including the band ratios of Landsat ETM + (Band 3 / Band 5, Band 4 / Band 5), Landsat OLI (Band 4 / Band 6, Band 5 / Band 6), as well as median filter and subtraction of dark objects [38]. According to his research, the Landsat ETM +(TM 3/5), Landsat OLI (OLI 4/6) ratio is a reliable, simple and accurate method, in some ways even better than manual delineation (i.e. not generalized and consistent for the entire Scenes The advantage of this method is that clear ice can be identified even under (optically) thin clouds and in shadow areas (Figure 2.3).

Taking into account the above research methods, in our work we used the band ratio in combination with the manual correction method to highlight the boundaries of glaciers in the Zhetysu Alatau region. First, binary images of the glacier area were obtained using the band ratio (Landsat ETM+: Band 3/Band 5, Landsat OLI: Band 4/Band 6), and after retesting, the threshold value was chosen in the range of 1.5~2, one. Meanwhile, smaller image elements were removed using a 3 by 3 median filter and then converted to a vector file for further editing (Figure 2.3). [38, 40]

Due to the spectral similarity of clasts on and off glaciers, there is still no method to automatically map clasts from a large number of glaciers using only optical satellite imagery. Thus, several studies have tested combined approaches that typically include topographic information derived from DEM and other data [16, 41, 42, 43]. However, all methods require lengthy manual post-processing, and the quality of the results depends to some extent on the experience of the analyst.

In this work, during the determination of the contour of the glacier tongues for 2001, the boundaries of the glaciers were digitized using the ETM + (B6) thermal channel and the final vector was superimposed on the hillshade obtained from the 1999 SRTM DEM. Since there was no available DEM for 2012 and 2016, only the ETM+ (B6) and OLI (B10) thermal channels, respectively, were used to digitize the contour of the glacier tongues. The end results were overlaid onto the Google Earth environment and analyzed again.

To map the shadow areas, we used Band 2 with a threshold of 7400 (manually obtained) and SRTM HillShade calculated using the sun's azimuth and other parameters, as in the Landsat imagery metadata. We got glaciers in shadow areas as the intersection of Band 2>7400 and Hillshade <= 0 (less than or equal to 0).



a b c d

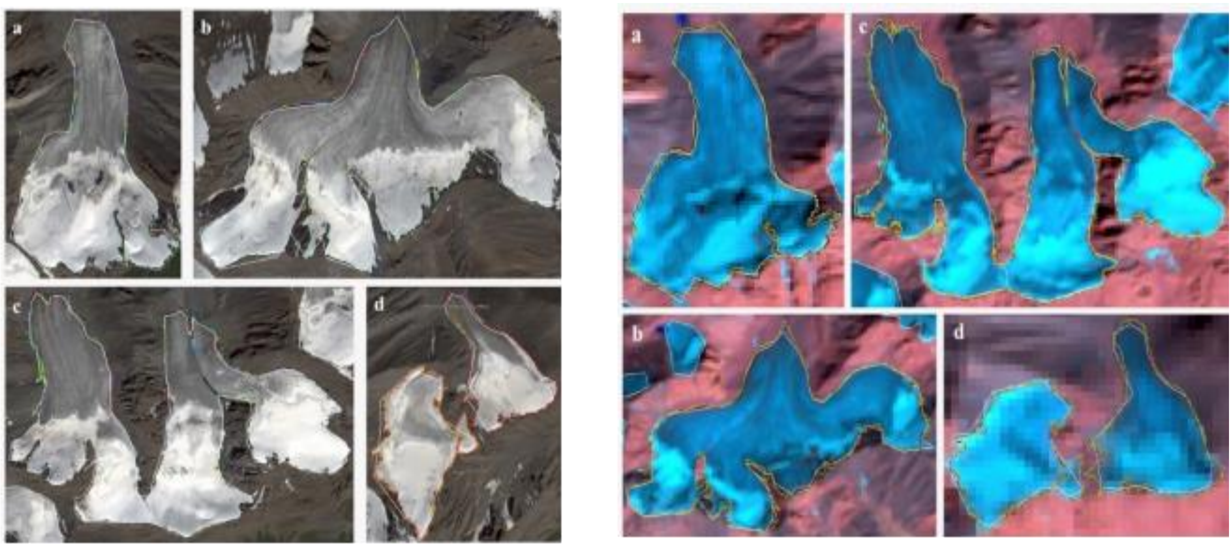
Figure 2.3 - Mapping of glaciers using the semi-automatic band ratio technique. a) TM3/TM5, OLI4/OLI6; b) after filtering (median filter 3x3), c) raster to vector format conversion; d) mapping of glaciers in the shadow area

Estimation of the glacier mapping uncertainty is necessary to assess the significance of derived glacier changes and avoid misinterpretation of mapping. In our previous study [6], we estimated the uncertainty by the buffer method suggested by Granshaw and Fountain (2006) and Bolch and others (2010). The buffer size was chosen to be half of the estimated RMSE, i.e. 7.5 m to each side. The resulting accuracy depends mostly on the size of glaciers, and for this region accuracy was within ±5%.

We have also determined uncertainty with other independent way - multiple digitization, one of the best method to determine precision of a dataset generated by one analyst is the multiple digitizing of glacier outlines [44] (Table 2.2 and Figure 2.4). This gives the most realistic (analyst-specific) estimate for the provided dataset. Despite its higher workload, it is recommended using this method instead of Literature value or Buffer method. Following Paul et al (2013) [45], to determine the precision of the digitizing, we manually digitized 4 differently sized glaciers independly five times (one time every day) using reference dataset with high resolution. Then, the resulting average areas were compared with the area obtained automatically by TM. Standard deviation (std – based on delinations by multiple digitalization divided by the mean glacier area for all outlines) and difference between the manually and automatically derived area is around 1-3.5 and 2-4.5%, respectively.

Table 2.2 - Comparison of glacier area values

Glaciers	Manually delineated							Automated with TM	Std %	Diff %
	1 day	2 day	3 day	4 day	5 day	mean	mean-koef			
1	1,4356	1,4085	1,4271	1,4193	1,4302	1,4241	1,4105	1,3958	1,0	1,99
2	2,7081	2,7114	2,7147	2,7275	2,7253	2,7174	2,6913	2,6600	1,2	2,11
3	4,1658	4,1790	4,1970	4,2279	4,2338	4,2007	4,1604	4,0010	3,8	4,75
4	0,3853	0,3860	0,3877	0,3941	0,3923	0,3891	0,3853	0,3716	3,6	4,49



a b

Figure 2.4 - The results of the accuracy assessment on (a) on high-precision Google Earth images (b) on Landsat 8 satellite images

2.5 Results of identification and mapping of the glacier area of the Zhetysu Alatau

2.5.1 Change in area and number of glaciers

This study identified 897 glaciers in 2001, 842 in 2012 and 813 in 2016, which were listed in the Glacier Catalog with a total area of 517.4, 453.7 and 414.6 km^2, respectively (Table 2.3).

Table 2.3 - Changes in the number and area of glaciers for 1956-2016

Pools of Zhetysu Alatau	1956	2001	2012	2016	1956-2001	1956-2016	2001-2012	2001-2016	2012-2016	The average size in 2001
	km^2	km^2	km^2	km^2	%	%	%	%	%	
1	2	3	4	5	6	7	8	9	10	11
Karatal	202,5(285)	126,5(231)	110,3(221)	102,6(220)	-37,5(0,8)	-49,3(-0,8)	-12,8(-1,2)	-18,9(-1,3)	-7(-1,7)	0.54
Aksu-Biyen	140,4(135)	93,4(133)	83,1(127)	77,1(127)	-33,5(-0,7)	-45,1(-0,8)	-11(-1)	-17,5(-1,2)	-7,2(-1,8)	0.70
Lepsy-Baskan	154(116)	103,8(112)	93,7(111)	88,4(105)	-32,6(-0,7)	-42,6(-0,7)	-9,7(-0,9)	-14,9(-1)	-5,7(-1,4)	0.91
Tentek	75,2(94)	49,7(85)	41,8(73)	36,9(58)	-33,9(-0,8)	-51,4(-0,9)	-15,8(-1,4)	-26,4(-1,8)	-12,6(-3,1)	0.57
Yrgaity	13,1(22)	10(21)	8,2(18)	6,9(17)	-23,5(-0,5)	-47,7(-0,8)	-18,4(-1,7)	-31,6(-2,1)	-16,2(-4,1)	0.47
Usek	144,8(233)	84,9(219)	73,4(202)	64,6(197)	-41,4(-0,9)	-55,4(-0,9)	-13,6(-1,2)	-23,9(-1,6)	-12(-3)	0.38
Khorgos	83,5(100)	49(96)	43,2(90)	38,5(89)	-41,3(-0,9)	-53,9(-0,9)	-11,9(-1,1)	-21,6(-1,4)	-11(-2,7)	0.50
Glaciers <0.005 km^2	18,9(385)	5,1(143)	3,7(96)	3(83)	-72,9(-1,6)	-84,1(-1,4)	-27,4(-2,5)	-41,4(-2,8)	-19,3(-4,8)	0.02
General	813,6(1370)	517,4(1040)	453,7(938)	414,6(896)	-36,4(-0,8)	-49(-0,8)	-12,3(-1,1)	-19,9(-1,3)	-8,6(-2,2)	0.6

The total reduction in glacier area between 1956 and 2001 was -36.4 ± 2.8% or 296.2 ± 8.3 km^2, decreasing from 813.6 km2 to 517.4 ± 14.5 km^2, while how the number of glaciers decreased from 985 to 897. During the period from 1956 to 2016, the area of glaciers decreased by - 49 ± 2.8% or 399 ± 11.2 km^2 (from 813.6 km^2 to 414.6 km^2), the number of glaciers decreased from 985 to 813.

From 2001 to 2012, the area of glaciers decreased by 12.3 ± 2.8%, i.e. from 517.4 ± 14.5 km^2 to 453.7 ± 12.7 km^2; 5 km^2 to 414.6 ± 11.6 km^2.

In the period from 2001 to 2012, the number of glaciers in the Zhetysu Alatau (Kazakhstan part) decreased from 897 to 842, and in the period from 2001 to 2016 from 897 to 813 glaciers. In the period from 2012 to 2016, the total area of glaciers decreased by 8.6 ± 2.8% and decreased from 453.7 km^2 to 414.6 km^2.

In addition, in Zhetysu Alatau in 1956 there were 385 glaciers with an area of less than 0.1 km^2. In 1956, the total area of these glaciers were 18.9 km2, in 2001 their area decreased to 5.1 km^2, in 2016 to 3 km^2.

In the study of changes in the glacial region of the Zhetysu Alatau, 7 large river basins were considered. The largest number of glaciers is concentrated in the northern part (38.1% in

2001, 39.9% in 2016), the smallest number is in the eastern part (11.5% in 2001, 10.5% in 2016) (Figure 2.5).

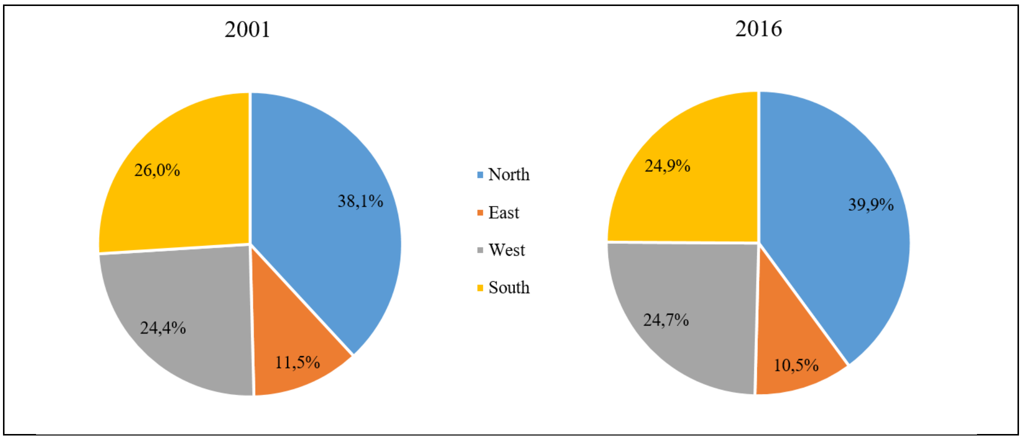


Figure 2.5 - Distribution of glaciers in Kazakhstan's Zhetysu-Alatau by regions, %

Western Zhetysu Alatau. River basin Karatal is the largest basin in the western part of the Zhetysu Alatau, covering an area of 19,100 km^2; the total area of the four sub-basins studied here is 4370 km^2. The Karatal River originates on the northwestern slopes of the central ridge of the Zhetysu Alatau. It is formed by the confluence of the Kora, Chizhin and Tekeli rivers [9], and further along the plain it meets its largest tributary, the Koksu River (46).

Most of the glaciers in the Karatal river basin (western part) face north (north, northwest and northeast) and are located between 3000-4000 m above sea level. The largest area of glaciers was located between 3400-3600 m above sea level, and most of them were concentrated in the sub-basins of the Kora and Koksu rivers.

The vast majority (91%) were small glaciers (<1 km^2) that covered more than half of the total glaciation area. There were only four large glaciers with an area from 4 to 10 km^2, but they accounted for 23.5% of the total glaciation area in the study region, [6] the average size of glaciers in the Karatal river basin is 0.54 km^2 (2001).

According to the catalog of glaciers of the USSR for 1956, 172/75 and 1979, the total area of glaciers in the Karatal river basin was 202.5 km^2, 176.0 km2 and 167.4 km^2, respectively.

Based on the analysis of Landsat ETM+/OLI satellite data, 231 glaciers were identified in 2001, 221 in 2012 and 220 in 2016, which were listed in the Glacier Catalog with a total area of 126.5, 110.3 and 102.6 km^2, respectively.

In total, in the western part of the Zhetysu Alatau, the area of glaciers in 1956 - 2016 decreased by 37.5 ± 2.8% or 99.9 ± 2.8 km2. From 2001 to 2016, the area of glaciers decreased by 18.9 ± 2.8% or 23.9 ± 0.7 km2 (Table 2.3).

Eastern Zhetysu Alatau. The eastern part of the object of study includes the basins of the Tentek and Yrgaity rivers, located in the eastern part of the Northern Central Ridge of the

Zhetysu Alatau mountain system. The Tentek River is formed from the confluence of two large rivers: the First and the Second Tentek within the Kolpakov intermountain depression.

In 1956, there were 94 glaciers with a total area of 75.2 km^2 in the Tentek River basin; in 2001, 85 glaciers with a total area of 49.7 ± 1.4 km^2 were mapped, and in 2016 58 glaciers with a total area of 36.6 ± 1.02 km^2 (Table 2.3).

The vast majority of glaciers (92.3%) in the basin The Tentek River is located in the first Tentek. Almost all glaciers of the second Tentek are glaciers with an area of less than 1 km^2.

In general, the area of glaciers in the Tentek River basin for the period 1956-2001 decreased by 33.5 ± 2.8% or 25.5 ± 0.7 km^2. From 1956 to 2016, the area of glaciers decreased by 51.4 ± 2.8% (38.6 ± 1.1 km2), from 2001 to 2016 by 26.4% ± 2.8% (13.1 ± 0.4 km^2).

The basin of the Yrgaity River is the easternmost on the northern slope of the hr. Zhetysu Alatau. The Yrgaity River also has two components: the right one is the Tastau River and the left one is the Koksuat River.

In 1956, there were 22 glaciers with an area of 13.1 km2 in the basin, and in 2001 - 21 glaciers with a total area of 10.0 ± 0.3 km^2. In 2016, 17 glaciers had a total area of 6.9 ± 0.2 km^2 (Table 2.3).

The area of glaciers in the Yrgaity basin for 1956-2001 decreased by 23.5 ± 2.8% or 3.1 ± 0.09 km^2. From 2001 to 2016, the area of glaciers decreased by 31.6 ± 2.8% or 3.1 ± 0.09 km^2.

Southern Zhetysu Alatau. The southern part of the object of study consists of the basins of the Khorgos, Usek, Chizhin, Tyshkan and Burkhan rivers, located in the Southern Central Ridge of the Zhetysu Alatau (within the Republic of Kazakhstan).

The southern part of the Zhetysu Alatau is characterized by a large number of glaciers, and is also characterized by high rates of glacier reduction relative to the studied region.

The Khorgos River basin is located in the eastern region of the South Central (within the Republic of Kazakhstan) ridge of the Zhetysu Alatau. In 1956, there were 100 glaciers with a total area of 83.6 km^2, in 2001 the area of glaciers decreased to 49.0 ± 1.4 km^2, and the number decreased by 4 and amounted to 96. By 2016, 89 glaciers with an area of 38.5 ± 1.1 km^2 remained in the basin (Table 2.3).

The Usek River, originating on the southern slopes of the Toksanbai and Tyshkantau ranges of the Zhetysu Alatau, is the main center of glaciation in the southern part of the studied territories. About 60% of all glaciers in the southern part of the Zhetysu Alatau fall in the Usek River basin and the number of glaciers is second only to the Karatal River basin in the western part. In 1956, there were 180 glaciers in the Usek River basin with a total area of 102 km^2. By 2001 there were 219 glaciers with a total area of 84.9 ± 2.4 km^2, 2012 202 glaciers with a total area of 73.4 ± 2.0 km^2, and in 2016 197 glaciers with a total area of 64.6 ± 1.8 km^2 (Table 2.3).

The largest glacier in the basin of the Usek – Glaciologov River is numbered 290, with an area of 4.0 ± 0.1 km^2.

In addition, the glaciers of the southern part of the Zhetysu Alatau (according to the 1956 catologist) include 9 glaciers of the Chizhin River basin with a total area of 17.1 km^2, 38 glaciers of the Tyshkan River basin with a total area of 23.9 km^2 and 5 glaciers of the Burkhan River basin with an area of 1.8 km^2. In 2016, there were 8 glaciers with a total area of 7.2 km^2 in the Chizhin River basin, 35 glaciers with a total area of 10.7 km^2 in the Tyshkan basin, and 4 glaciers with a total area of 0.3 km^2 in the Burkhan basin.

In general, the area of glaciers in the southern part of the Zhetysu Alatau in 1956-2001 decreased (Khorgos - 41.3%, Usek, Tyshkan, Burkhan – 41.4%) by 41.4 ± 2.8% or 94.4 ± 2.6 km^2. From 2001 to 2016, the area of glaciers decreased (Khorgos – 21.63%, Usek, Tyshkan, Burkhan – 23.9 %) by 22.8 ± 2.8% or 30.8 ± 0.9 km^2 (Table 2.3).

Northern Zhetysu Alatau. The northern part of the Zhetysu Alatau consists of the basins of the Biyen, Aksu, Sarkan, Baskan and Lepsy rivers, located in the Western and central parts of the Northern Central Ridge. The main part of glaciers by occupied area (about 40%) are concentrated in the northern part of the Zhetysu Alatau.

The average size of glaciers in the territory is larger than in other parts (Lepsy-Baskan 0.9 km^2, Aksu-Biyen 0.7 km^2) and annual melting rates are also lower than in other areas (Lepsy-Baskan 1956-2016 0.7%, Aksu-Biyen 1956-2016 0.8%).

The westernmost basin of the northern Zhetysu Alatau is the Biyen River basin. In 1956 there were 23 glaciers with a total area of 27.1 km^2 in the Biyen River basin. By 2001 there were 22 glaciers with a total area of 18 ± 0.5 km^2, in 2012 there were 21 glaciers with a total area of 15.9 ± 0.4 km^2, and in 2016 there were 21 glaciers with a total area of 14.7 ± 0.4 km^2.

The basins of the Aksu and Sarkan rivers are bounded on the west by the Biyen spur of the Northern Central Ridge, and on the east by the Sarkan spur of the same ridge.In 1956, there were 112 glaciers with a total area of 113.4 km^2 in the Aksu and Sarkan River basins. By 2001, there were 111 glaciers with a total area of 75.6 = 2.1 km^2, and in 2016 106 glaciers with a total area of 62.3 = 1.7 km^2 (Table 2.3).

The basins of the Lepsy and Baskan rivers are bounded in the east by the Tentek (eastern part), and in the west by the Sarkan spurs. In 1956, there were 117 glaciers with a total area of 154 km^2 in the basin of the Lepsy and Baskan rivers. By 2001 there were 112 glaciers with a total area of 105.9 ± 3 km^2, in 2012 111 glaciers with a total area of 99.4 ± 2.8 km^2, and in 2016 105 glaciers with a total area of 14.7 ± 0.4 km^2.

In general, the area of glaciers in the northern part of the Zhetysu Alatau in 1956-2001 decreased (Aksu-Biyen – 33.5%, Lepsy-Baskan – 32.6%) by 33 ± 2.8% or 97.3 ± 2.7 km^2. From

2001 to 2016, the area of glaciers decreased in the basins of the Aksu-Biyen rivers -17.5 ± 2.8%, Leps -Baskan – 14.9 ± 2.8 or 16.3 ± 0.5 km^2, 15.4 ± 0.4 km^2 (Table 2.3).

2.5.2 Characteristics of glaciers

The largest area of glaciers in the Zhetysu Alatau is occupied by glaciers up to 1.0 km^2 in size for all three periods of time. In total, about 90% of the glaciers of the Zhetysu Alatau are glaciers with an area of up to 1 km^2. Glaciers with an area of more than 1 km^2 make up more than 10%, but in general, in the covered area of the glaciers of the Zhetysu Alatau, it is 60%.

In 2001, in Zhetysu Alatau there were 124 glaciers with an area of more than 1 km^2 (of which 3 glaciers >10 km^2), in 2012 there were 111 glaciers (of which 1 glacier >10 km^2), and in 2016 their number decreased by another 10 glaciers and amounted to 101 glaciers. In 2016, there were no glaciers larger than 10 km2 in Zhetysu Alatau.

We identified 897 glaciers in 2001, 842 in 2012 and 813 in 2016, which were included in the Glacier Catalog with a total area of 517.4, 453.7 and 414.6 km^2, respectively (Table 2.3). Thus, the total change in the area for the period 1956–2001, based on the mountainous regions identified by us, was -37.5%. Change in area for 2001–2012 amounted to -12.3%, and the change in area for 2012-2016. amounted to -8.6%; over the entire period, the total area of glaciation decreased from 813.6 km^2 (985 (> 0.005 km2) glaciers) in 1956 to 414.6 km^2 (813 (> 0.005 km^2) glaciers) in 2016, i.e., by 49 % for 60 years.

All glaciers were continuously shrinking during the entire study period. Our results show that the loss of the glacier area of the Zhetysu Alatau for 2001-2016 amounted to 19.9% (1.3% per annum).

The average glacier size for the entire mountainous region was 0.58 km^2, with a class 1.0–5.0 km2 glacier dominating with a total area of 221.5 km2 (Figure 2.6a), which is 42.8% of the total area. Of these, 38% is concentrated in the northern part (basins of the Aksu-Biyen, Lepsy-Baskan rivers) of the Zhetysu Alatau.

The average size of glaciers concentrated in the northern part of the Zhetysu Alatau is enlarged in comparison with other parts. The average size of glaciers distributed in the northern part is 0.7-0.91 km^2 (basins of the Lepsy-Baskan and Aksu-Biyen rivers), while the average size of small glaciers is common in the southern (Usek - 0.38 km2) and eastern (Yrgaity - 0.47 km^2) parts (Table 1).

The 0.1–0.5 km^2 size class glacier had the largest number (381 glaciers) in 2001 (Figure 2.6b).

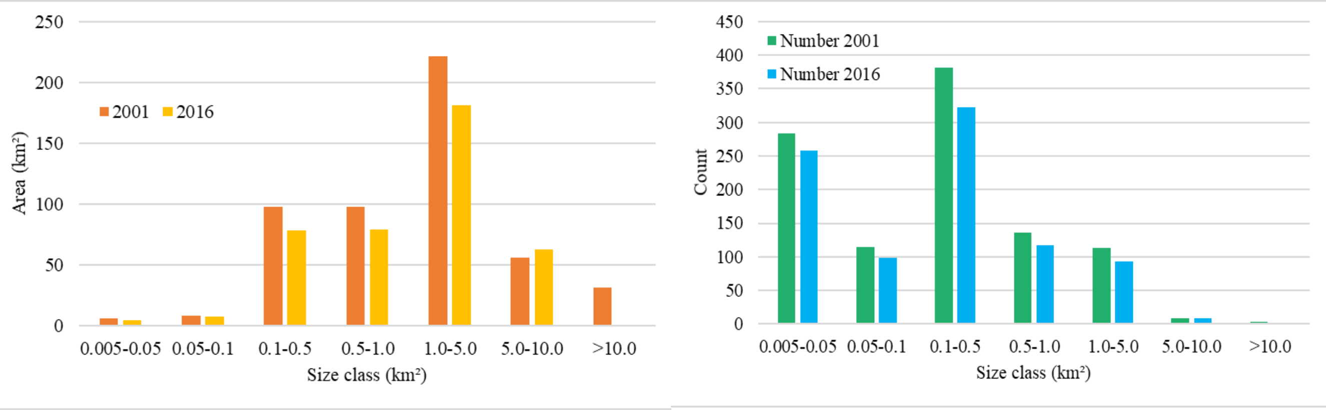
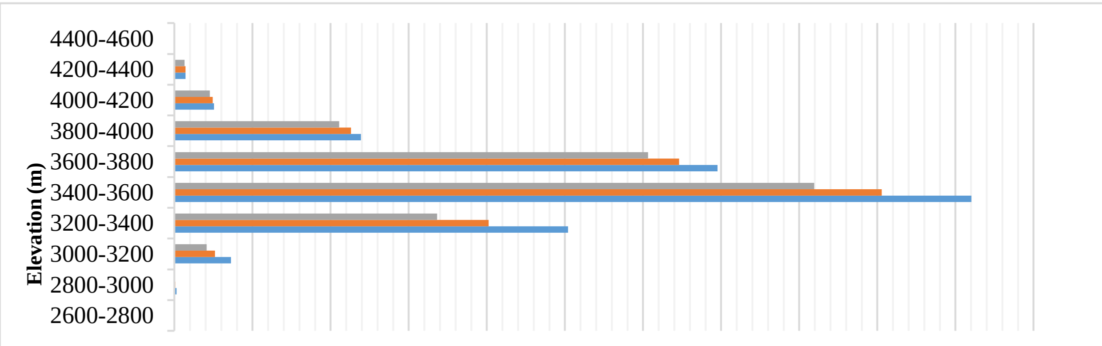


Figure 2.6 - Glacier area and area loss by glacier size class for 2001-2016.

Most of the area of the Zhetysu Alatau glaciers faces north (north, northwest and northeast) (Figure 2.8a) and is located at an altitude of 3000 to 4000 m above sea level (Figure 2.7). Altitude location of the glaciers of the Zhetysu Alatau, it is mainly distributed in the altitude range of 3000 - 4000 m (Figure 2.7). The largest area of glaciers was located between 3400 and 3600 m above sea level. About 40% of the glaciers of the Zhetysu Alatau are located at altitudes of 3400-3600 m, almost 30% - at altitudes of 3600-3800 m and about 18% - at altitudes of 3200-3400 m (Figure 2.7).



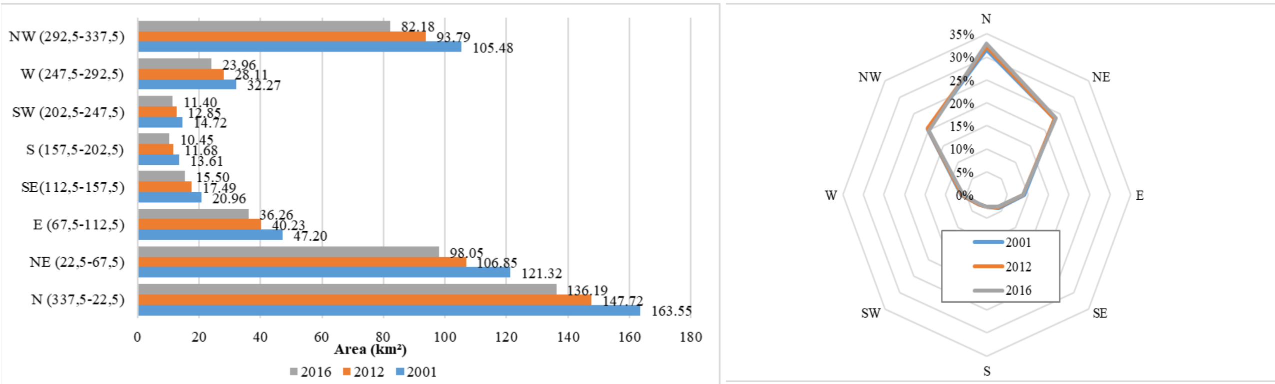
	2600-2800	2800-3000	3000-3200	3200-3400	3400-3600	3600-3800	3800-4000	4000-4200	4200-4400	4400-4600
2016		0,11	8,24	67,23	163,83	121,25	42,18	9,08	2,59	0,14
2012		0,21	10,35	80,46	181,15	129,26	45,18	9,81	2,84	0,14
2001	0,007	0,52	14,48	100,77	204,08	139,05	47,73	10,15	2,88	0,14

Area (km²)

Figure 2.7 - Distribution of glacier areas and their changes depending on the height interval in Zhetysu (Dzhungar) Alatau.

Glaciers with northern, northeastern and northwestern exposure are the most extensive in ZhetysuAlatau, covering (by 2016) 136.19 ± 3.8 km^2, 98.05 ± 2.7 km^2 and 82.18 ± 2.3 km^2, respectively, and together they account for 76.3% of all glaciers (Figure 2.8a). The southern, southeastern and southwestern sides occupy 10.45 ± 0.3 km^2, 15.5 ± 0.4 km^2 and 11.4 ± 0.3 km^2, respectively, and together they account for 9% of all glaciers. The western side occupies 23.96 ± 0.7 km^2, respectively 5.7%, and the eastern side 36.26 ± 1 km^2, respectively 9% (Figure 2.8b).

The most intensive reduction in the area of glaciers of the Zhetysu Alatau in the period from 2001 to 2016 was observed in the southern (Usek, Khorgos) and eastern (Rgayty, Tentek) parts compared to other parts. The rate of reduction in the area of glaciers during the study period was in the basin of the river. Usek - 23.9%, Khorgos - 21.6%, Rgayty - 31.6%, in the basin of the river. Tentek - 26.4%.



a b

Figure 2.8 - Distribution of glacier areas by aspects in 2001–2016

The ends of the glacier are located at an average minimum height of 3407 m above sea level, and the average maximum height is 3746 m above sea level. Figure 2.9a shows the distribution of glacier area according to maximum and minimum heights. This means that large valley glaciers have lower ends and smaller glaciers have higher end positions. Also, the color-coded map in Figure 2.9b shows the spatial distribution of mean height for glaciers larger than 0.01 km^2 in 2016.

In 2016, there were 3 large glaciers along the Zhetysu Alatau with a total area of 28.6 km^2. Two of them are Kolesnik (9.6 km^2) and Bereg (9.5 km^2) glaciers in the northern part (in the Lepsy river basin) and Bezsonov (9.4 km^2) in the western part (in the Karatal river basin). As we have already noted, in 2016 there was no glacier with an area of more than 10 km2 along Zhetysu Alatau.

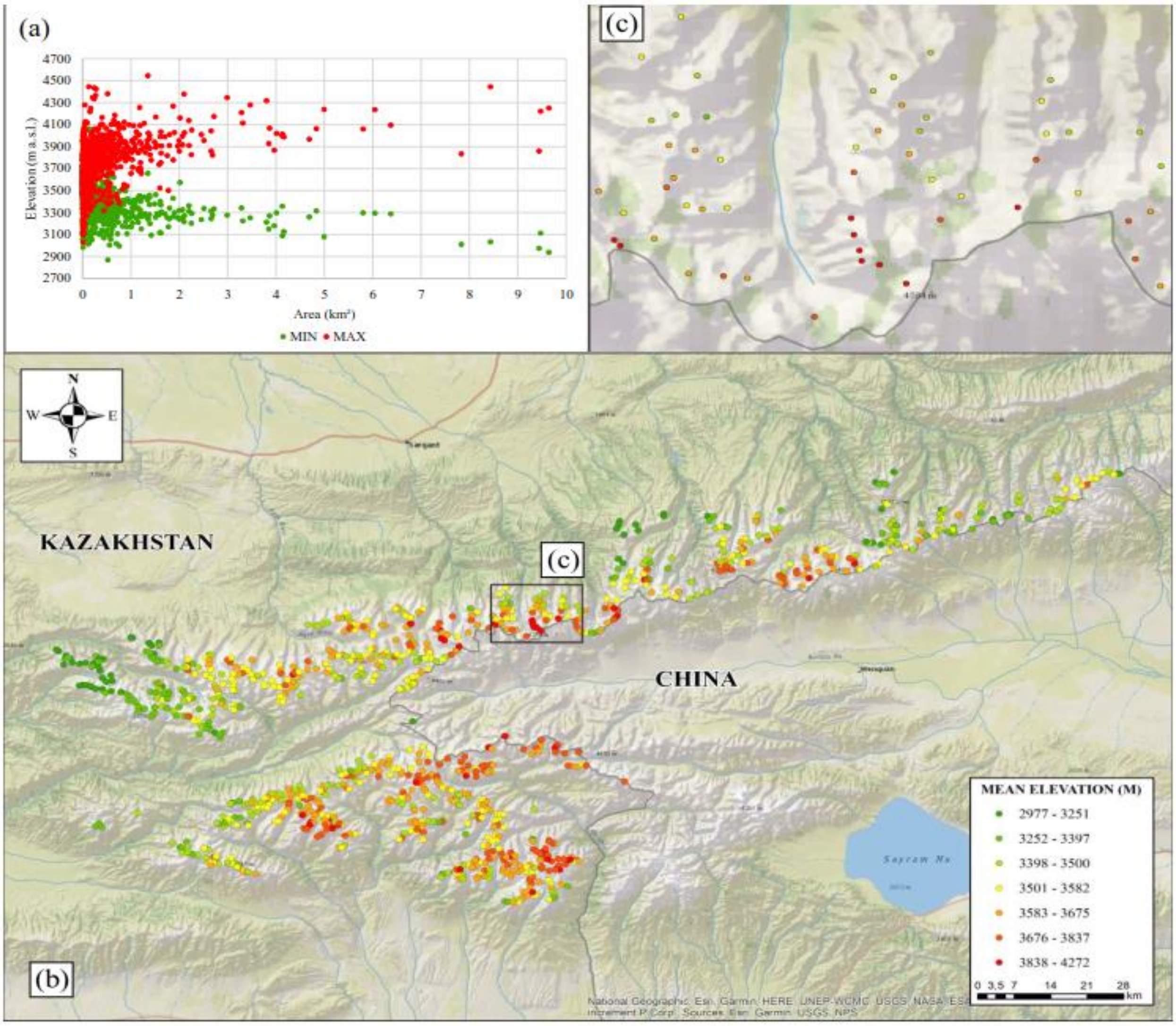


Figure 2.9 - Spatial distribution of the average height of the glaciers of the Zhetysu Alatau

2.5.3 Change in glacier area in 2001-2016

As part of this study, 897 glaciers were identified in 2001, 813 in 2016, which were listed in the Glacier Catalog with a total area of 517.4 and 414.6 km^2, respectively (Table 2.3). The results of the study of changes in the area of glaciers show that in the period from 2001 to 2016, the glaciers of the Zhetysu Alatau have significantly decreased (Figure 2.10). The total loss of ice area between these two periods was 102.8 ± 2.9 km^2 or 19.9 ± 2.8% (-1.3% yr^{-1}).

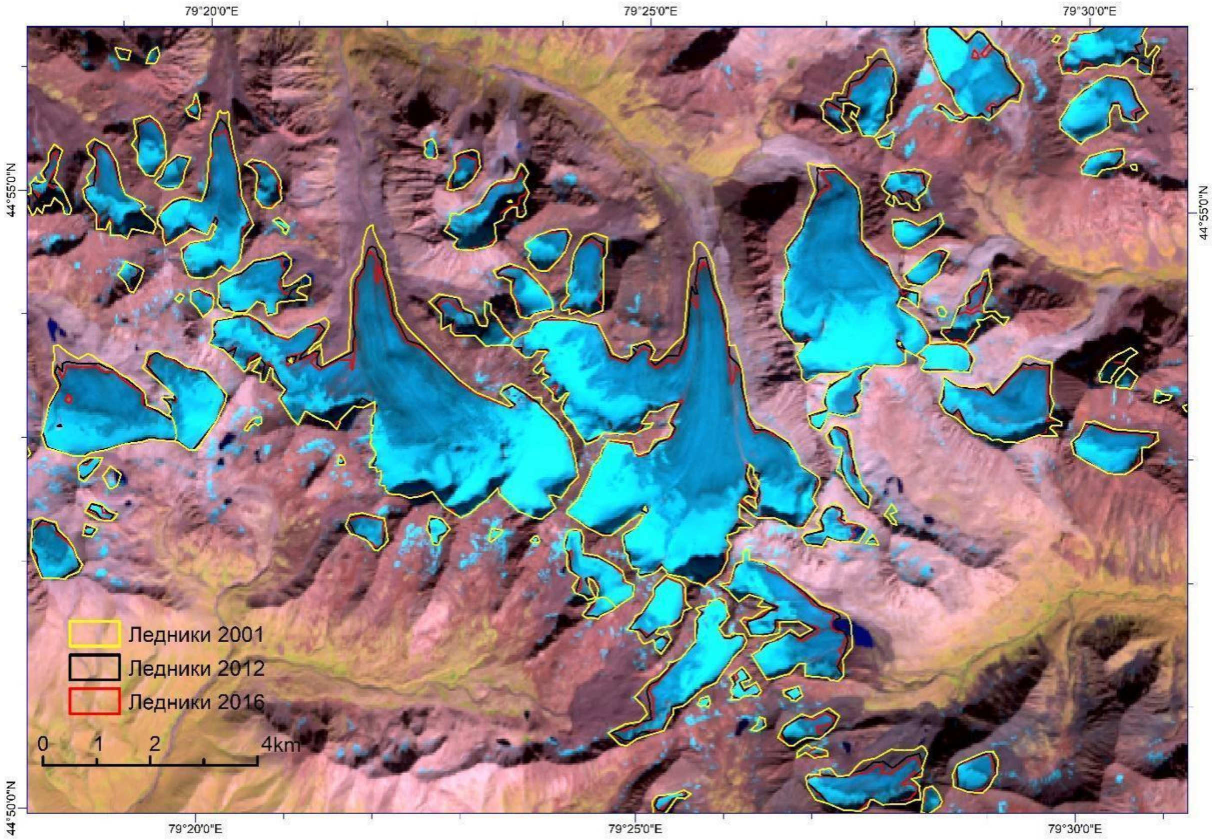


Figure 2.10 - An example of changes in the area of glaciers for 2001-2016 in the Karatal river basin

The highest rate of reduction in the area of glaciers was observed in the Eastern (Yrgaity, Tentek) and Southern (Usek, Khorgos) parts of the Zhetysu Alatau.

For the period 2001-2016. the area of glaciers in the eastern part decreased from 59.7 ± 1.7 km^2 to 43.8 ± 1.2 km^2, i.e., in the basin of the river. Yrgaity by 31.6% (-2.1% year^{-1}), in the basin of the river. Tentek by 26.4% (-1.8% yr $^{-1}$).

While the rate of reduction in the area of glaciers in the northern (Aksu-Biyen, Lepsy-Baskan) and western (Karatal) parts of the Zhetysu Alatau was relatively low. In the period from 2001 to 2016, the area of glaciers belonging to the basin of the Karatal (western) river decreased by 18.9% (-1.3% year $^{-1}$), in the Aksu-Biyen (northern) rivers this figure was 17.5% (-1.2% yr $^{-1}$). The smallest reduction in the area of glaciers in all parts of the Zhetysu Alatau was noted on the glaciers of the Lepsy-Baskan rivers belonging to the northern part. Between 2001 and 2016, the area of glaciers in this basin decreased by 14.9%, and the annual reduction rate was 1% per year.

The average size of the Zhetysu Alatau glaciers in 2001 was 0.58 km^2, in 2016 the average size decreased by 0.51 km^2. There was a decrease in the average size of glaciers in all areas, however, only the glaciers of the Tentek River Basin (eastern part) increased from 0.57

km^2 to 0.63 km^2 on average. This is due to the melting of small glaciers in this basin. As an example, in 2001 there were 90 glaciers in the Tentek river basin with a total area of 11.1 km^2 up to 0.5 km^2 in size, in 2016 their total area was 5.7 km^2, almost halved and 45 glaciers remained .

Analysis of the relative area change compared to the initial glacier area indicates a large relative loss of smaller glaciers (0.01 to 0.1 km^2) (Figure 2.11).

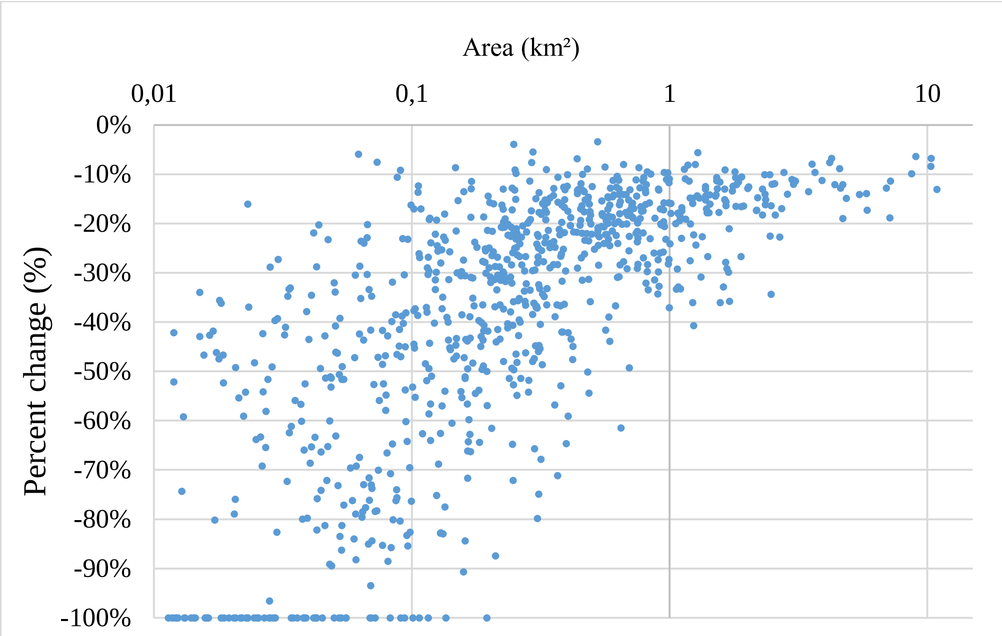


Figure 2.11 - Dot plot of relative changes in glacier area compared to initial glacier size for 813 glaciers during 2001-2016

For larger size classes (>1.0 km^2), the loss factors are smaller and more similar. The difference in sink rate between the northern and western slopes is insignificant. Overall, and similar to most other regions of the world, the observed relative rates of area loss decrease as glaciers increase.

However, there was a wide variation in losses, especially for smaller glaciers, while there were glaciers in all size classes that only slightly decreased. The absolute area loss was higher for larger glaciers (Figure 2.12) and the average glacier height increased by 24 m, while the average minimum glacier height increased by 42 m from 3367 to 3409 m above sea level over 2001–2016 (Figure 2.13).

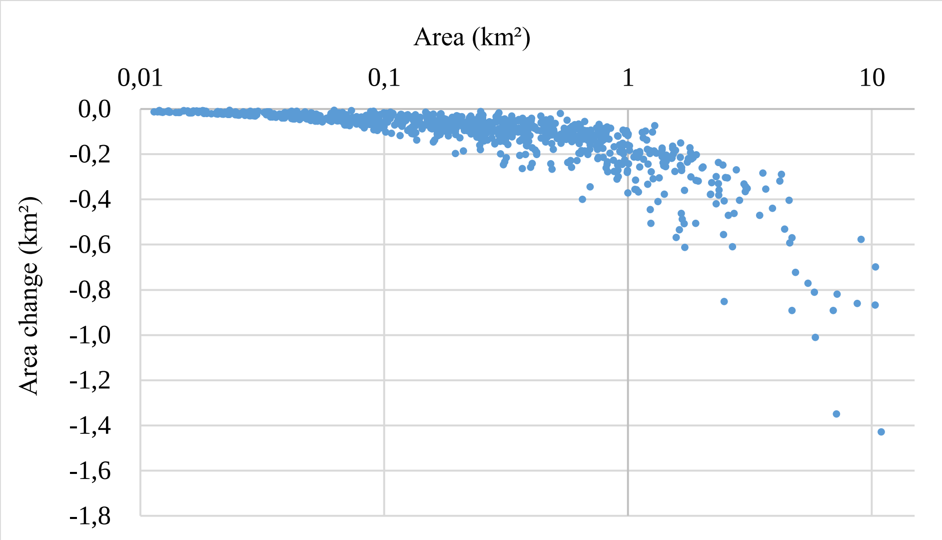


Figure 2.12 - Dot plot of absolute changes in glacier area compared to the initial size of the glacier in 2001-2016

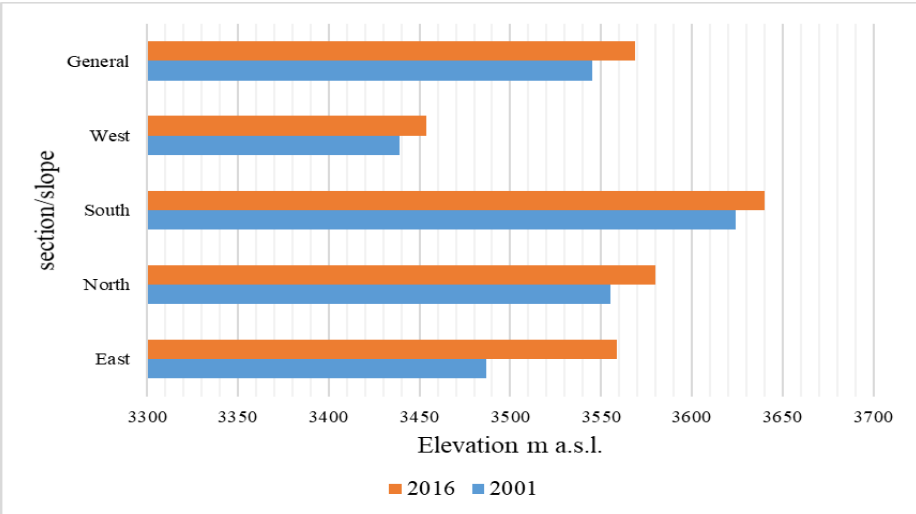


Figure 2.13 - Change in the average minimum height of the Zhetysu Alatau glaciers for 2001-2016

The area changes of the glaciers investigated in the Zhetysu Alatau confirmed an expected and widely published trend of glacier shrinkage [14, 15]. However, with the shrinkage rate of about -0,8% and -1,3% a^{-1} for the periods of 1956-2001 and 2001-2016, our results for this study area showed a highest shrinkage rate and it compared to other glacierized areas of Central Asian mountains, including Tien Shan, Altai and [16, 17, 18]. It should be noted that the rate of glacier shrinkage has accelerated significantly, which is -0.8%, -1.1% and -1.3% a-1 for the periods of 1956-2001, 2021-2012 and 2012-2016, respectively. In addition, the speed of acceleration is significantly higher compared to other regions of the Tien Shan mountain system [12,17,47-49].

This intensive decrease of glacier area is in close agreement with previous researches, which showed that the most glacierized area loss happened in the outside ridges of the Tien Shan and the peripheral, lower altitude ridges [24]. The glaciers in the outer ranges of Tien Shan that receive the highest precipitation volumes are particularly sensitive to climatic changes due to their large mass-turnover rates. Glaciers in the inner ranges react with larger time lags to climate change, because accumulation and thus mass turnover of the mainly cold glaciers are relatively small [24]. The relative insensitivity of glaciers in the inner ranges is further accentuated by the higher average altitude, as the ELA varies from 3500 to 3600 m a.s.l. in the outer ranges to 4400 m a.s.l. in the inner ranges. Regionally varying result to climate change implies that glacier decrease is less influenced in the continental inner ridges than in the more moisture outer ridges.

Regions with mostly small-sized ices are more sensitive to change due to smaller glaciers have a shorter response time to climate change [53]. It is also reported, that smaller glaciers, with a greater area-to-margin-length ratio, decreases quicker than bigger ices under the same melting speed [52]. In the Zhetysu Alatau, the vast majority of glaciers were small, with sizes less than 1 km^2. Small glacier areas covered more than half of the total area, which is usual in mid-latitude ranges. Our results indicated that the mean size of the glaciers of Zhetysu Alatau of was 0.57 km^2 in 2001. The difference in the shrinkage rates of glacier areas among the basins can be explained by the difference in mean size and aspect.

Although climate warming has been the main cause of glacier changes during the last 56 years, the topographic factor also plays an important role. An additional reason for greater area loss may be the lower elevation of the glaciers in the Zhetysu Alatau compared to other regions of the Tien Shan. A rise in average temperature, with no change in precipitation, will result positive change of the ELA by about 150 m for each degree [53]. At lower elevations, such an upward shift of the ELA raises the risk of the entire area of glaciers falling into the ablation zone (Fig. 2.14). Increase in temperature results to: (1) rising energy available for glacier- and snow-melt; (2) less snow accumulation; and (3) lower albedo of the glacier surface [50]. The temperature increase caused the rainfall rate to increase, rather than snowfall in the high altitude glacierized areas, leading to a reduction of accumulation and the acceleration of ablation, especially during the summer [51]. Between 1960 and 2020, two climatic factors – increased temperature and slight decreased precipitation – led to significant glacier area loss.

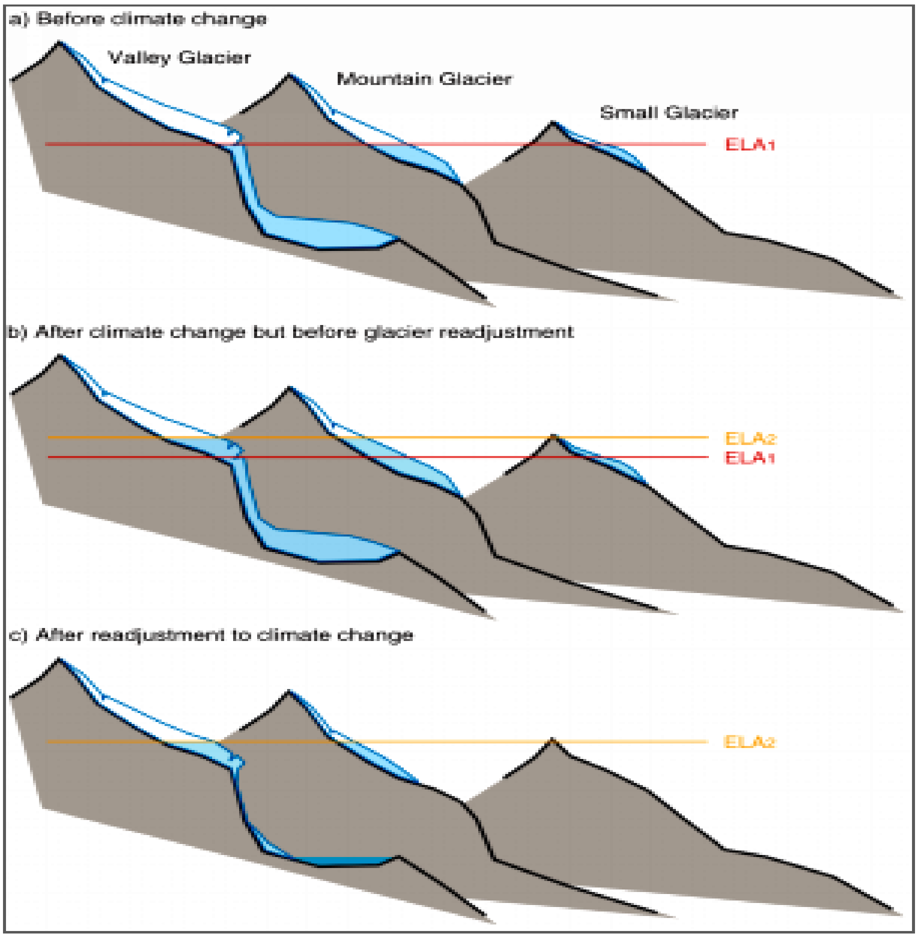


Figure 2.14-Schematic of three types of glaciers located at different elevations, and their response to an upward shift of the equilibrium line altitude (ELA) [53]

3 Identification and mapping of active rock glaciers of the Zhetysu Alatau using SAR and Google Earth images

Since there are many variants of definitions of the term rock glacier, different researchers interpret it differently. For example, the authors of [54] explain this as a mixture of debris and ice on mountain slopes, which can accumulate, deform under the action of gravity and form amazing reed formations of viscous flow up to a kilometer wide and up to several kilometers long. According to the author [55], rock glaciers can be defined as "a visible manifestation of cumulative deformation as a result of long-term creep of mixtures of ice and debris in permafrost," which was also followed by the researcher [56] in his works. In other papers [57], it was said that rock glaciers are reed or lobed landforms on high mountain slopes, usually consisting of a mixture of loose rock fragments and ice.

In this paper, we adhered to the definition from the International Permafrost Association [58], which states that rock glaciers are clastic landforms formed as a result of former or current creep of frozen ground (permafrost), found in a landscape with the following morphology: front part (mandatory criterion), flanks (mandatory criterion), and possibly a ridged and grooved surface (optional criterion) (example in Figure 3.1). That is, rock glaciers are landforms that carry clasts with uplift areas (original zone or root zone) to their front (front).

Rock glaciers are a common occurrence in the Northern Tien Shan, and their descriptions are first found in the sources of the first half of the 20th century, starting with the measurement of the rock glacier front in 1923 [59]. These rock glaciers were thought to be primarily of periglacial origin, but may contain sedimentary ice. One of the latest studies of rock glaciers in the Zhetysu Alatau region [60] identified about 850 active rock glaciers according to aerial photography in 1969, 1979 and 1984 at a scale of 1:10,000. But descriptions and detailed ground-based geodetic measurements were found only for one of them - rock glacier Nizkomorenny [61.]. Of the interesting points in [60], it was noted that the altitudinal boundaries of active rock glaciers are 200–300 meters lower than in the well-studied region of the Trans-Ili Alatau of the Tien Shan mountain system.

However, no more recent data or research results were found for the Zhetysu Alatau region, so the inventory work was started from scratch and has so far been carried out for the Aksu and Lepsy river basins of the Zhetysu Alatau. Therefore, the main task of the work was to compile an initial digital catalog according to international standards and evaluate the kinematic performance of rock glaciers in the region.

3.1 Classification of rock glaciers by activity

An active rock glacier is a landform that is currently transporting sediment from the root zone to its front. It is characterized by a steep front (steeper than the angle of repose) and possibly flanks with fresh exposed material at the top [58]. The displacement rate can vary from tens of centimeters to several meters per year [62]. The transitional (intermediate) type includes those rock glaciers that have ice in their composition and it moves at a speed of less than one decimeter per year. Depending on the topographic and climatic context, transitional rock glaciers can either evolve into a relict (degraded) or active state. A relic rock glacier is a landform that no longer transports sediment from the root zone to its front due to permafrost depletion, i.e., does not move and does not have ice in its composition. Relic glaciers are usually found at lower elevations than active glaciers.

The International Permafrost Association's Rock Glacier Inventory and Kinematics Initiative Group, established in 2018 [63], intends to support the development of generally accepted basic concepts and standard guidelines for the inventory of rock glaciers in mountainous permafrost regions [58]. One of the most important elements to be included in standardized rock glacier inventories is kinematic information. Since indirect kinematic information is often inaccurate as it relates to operator interpretations, the result of visual observation of morphological (for example, fore angle) indicators associated with vegetation [64] can be extremely unsatisfactory. Recently, more accurate approaches based on remote sensing data [65] have been developed to characterize the kinematics of a rock glacier on a large scale [66, 67].

In this context, part of the European Space Agency (ESA) Permafrost Climate Change Initiative (Permafrost_CCI), the so-called CCN2 project (https: //climate.esa.int/en/projects/permafrost/; last accessed: October 10, 2021 .).) – in line with the basic concepts proposed by the IPA Action Group [58] – specific guidance has been developed [61] for the systematic integration of kinematic information into RoGI using interferometric synthetic aperture radar (InSAR) data. Now the workflow is reduced to outlining moving areas (MA) and assigning a speed class based on the results of the interferometric analysis; Attribute information is filled in according to IPA standards.

Figure 3.1 - Geomorphology of the rock glacier
(active rock glacier Nizkomorenny, Lepsy river basin)

3.2 Description of data and methods used for rock glacier inventories

According to the guidelines of the International Permafrost Association [61], the systematic inventory procedure for rock glaciers consists of three steps, described below and illustrated in Figure 3.2. This diagram [67, 68] was adapted to the conditions and the availability of initial data for the region under study. Two basic approaches were used as the main methodology: Geomorphological and Kinematic. In this regard, the general workflow for creating an inventory of rock glaciers consists of the following steps: generating an estimate of LOS surface velocity from Sentinel-1 InSAR data [56, 66, 70]. Then, manual interpretation of the rock glacier contours based on optical satellite images in the Google Earth environment by visual interpretation of their geomorphological features, described in the IPA and ICIMOD manuals.

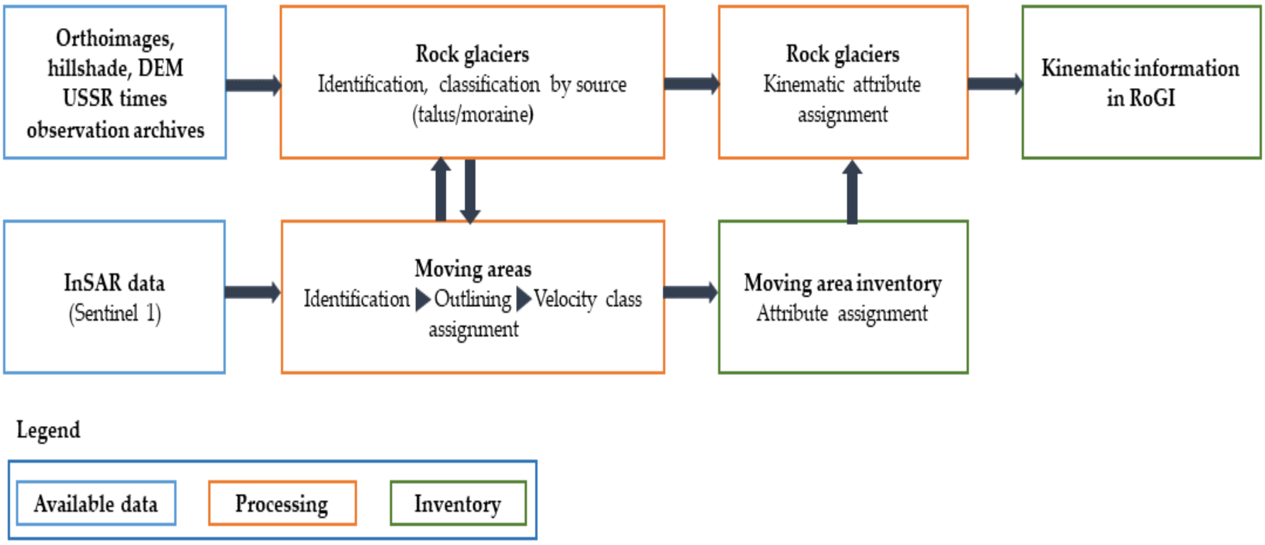


Figure 3.2 - Conceptual diagram of a standardized method for creating a moving area inventory and RoGI, including kinematic information. The analysis is performed in a GIS environment

Geomorphological approach. The geomorphological approach is based on visual detection using high resolution imagery and DTM products. Surface texture and morphometric analysis can also be used for this purpose. This is a classical approach, which can also be supplemented by field measurements. This method allows to produce an exhaustive list of supposed moving and stationary landforms, the distinction of which (activity classes) is primarily based on geomorphological characteristics. Photogrammetry and LiDAR DEM imaging, when available, facilitate the identification of rock glaciers in forested areas.

A geomorphological inventory of rock glaciers was made using high resolution remote sensing data available on the Google Earth, Bing Maps, Zoom Earth and SAS platforms. Planet according to the method [71] using the descriptions given in [58]. Google Earth data has been applied in a number of areas of scientific research. Google Earth uses images from SPOT satellites or Digital Globe products (eg Ikonos, QuickBird, WorldView) at a resolution similar to aerial photographs. The images were geotagged with a DTM based on Shuttle Radar Topography Mission (SRTM) data, which has a resolution of 90 m in the study area. In addition, Google Earth supports convenient GIS tools that facilitate the formation of a custom database that can be exported as KML files and converted into shapefiles for further analysis in a GIS environment [71]. Google Earth has previously been used as a platform for rock glacier mapping in British Columbia, the Bolivian Andes, the Hindu Kush-Himalaya region, and the Himalayas of Nepal [71]. In the absence of any spectral and spatial information about the images used, quantifying the uncertainty in the inventory was difficult. However, in a similar place [71], the accuracy of the images turned out to be sufficient for this purpose.

Rock glaciers are classified as transient or active based on their surface velocity. Rock glaciers with no clear surface velocity only fire if the InSAR sensitivity in that area is low, in which case they fire with indeterminate activity. Debris-covered glaciers and rock glaciers are two ends of a continuum. Debris-covered glaciers with visible bodies of ice upslope are not included in the rock glacier inventory.

Also, we classified rock glaciers by origin: moraine and scree [54.]. For talus rock glaciers, we have adopted the definitions of the detailed surveys. Protalus lobes and protalus ridges underlie landforms composed of debris mantles, scree slopes, or rock walls.

Kinematic approach. The differential interferometry method detects the movements of the earth's surface using the phase difference between two radar images taken at different times. Since the phases of the differential interferogram are wrapped in the range from -π to π, one phase cycle corresponds to half the wavelength (for example, 2.8 cm for the C range of surface displacements along the direction of the radar sighting beam [66].

In this work, images from the Sentinel-1 satellites of the SLC level were used, which is freely available from the Alaska Satellite Facility (https://asf.alaska.edu/) resource, where it is also possible to select a stack of images for multi-pass processing. The wide swath (IW) mode has a resolution of 20 m in azimuth and 5 m in range. The selection of radar images was based on the following criteria: the survey period was 5 years from August 8, 2017 to September 28, 2021 with a seasonal restriction (only 2 months of August and September were selected), the total number of images was 25 for ascending and 26 for descending orbits. To achieve high interferometric coherence, a maximum time base of 48 days was chosen. According to the specified criteria, 49 interferometric pairs were built for images in the upward survey geometry and 52 pairs for the downward survey. Main survey parameters: ascending orbit: path 158, frame 142, IW acquisition mode; descending orbit: path 136, frame 441.

According to the recommendations from the International Association for Permafrost, observations from radar data should be with the most minimal time interval. Data from Sentinel-1 satellites make it possible to compile a chain of radar images with a time base of 12 days (regardless of weather conditions). But in view of the fact that the displacement velocity can exceed the sensitivity range of the radar wave, according to the Guidelines, it is necessary to verify the selected sections of active glaciers according to multipass interferometry data with differential interferograms. An informative example of the selection of radar images and speed levels is illustrated in Figure 3.3.

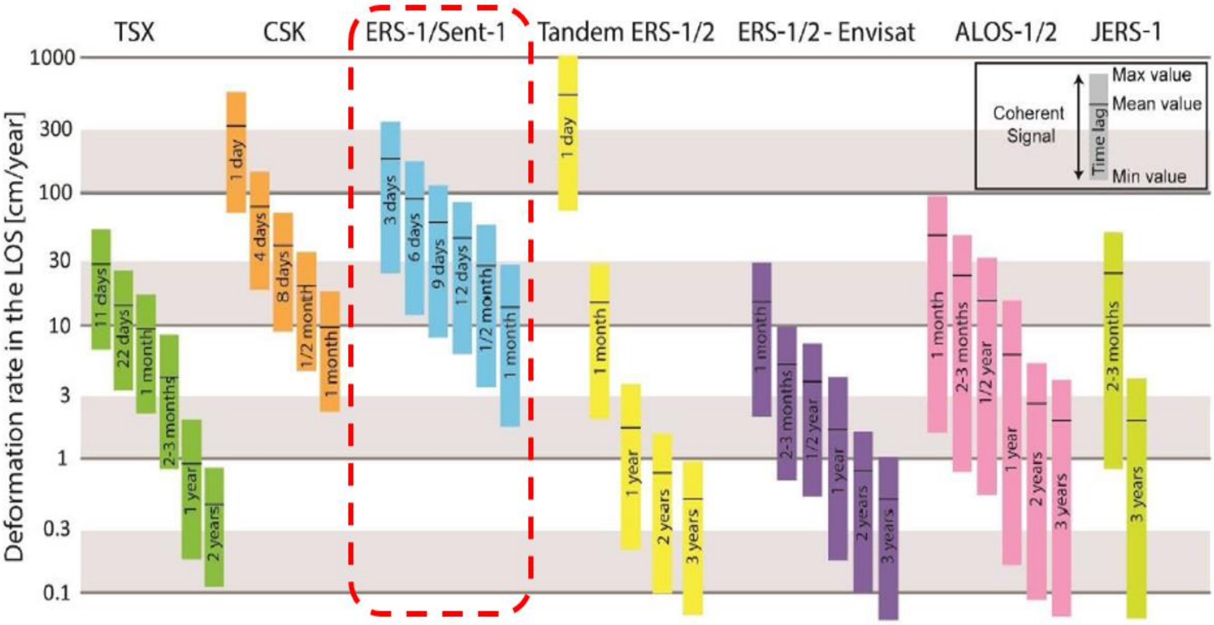


Figure 3.3 - Criteria for selecting SAR systems depending on the observed levels of movement speeds

The processing of a series of images was carried out using the Intermitted SBAS method [72] or discrete SBAS, when the time line is set rigidly and the processing of the entire stack with broken links is started (due to the inclusion of only a few months in processing). The discrete SBAS method interpolates the time periods when the pixel coherence falls below the selected coherence threshold on some interferograms, and also leads to a significant improvement in spatial coverage compared to the original SBAS algorithm for study areas with partial vegetation [73].

Interferometric processing was performed using the ENVI software with an additional SARScape multimodule (©Sarmap SA, 2001 – 2020). Stack processing was performed in the standard settings of the Sentinel TOPSAR mode and according to the pipeline (processing steps) in the SBAS module. The technological chain of processing multipass radar data is shown in Figure 3.4.

Then the values of displacement velocities from LOS units were converted into values of vertical velocities in millimeters. The resulting raster surfaces of vertical velocities were cut from a vector file with geomorphological contours of rock glaciers; from the stripped values, the maximum and minimum speed indicators were extracted into the attribute information. Raster surfaces, prior to cutting geomorphological contours, also underwent an additional procedure for evaluating all selected moving areas in order to validate and cut off moving areas whose kinematic nature is associated with slope processes and other phenomena. When re-comparing the geomorphological contours of rock glaciers and the raster of motion velocities, several objects were refined and supplemented. To move into the kinematic categories, a classification was made into seven classes (< 1, 1, 1–10, 10, 10–100, 100, and > 100 cm/yr). The choice of kinematic classes was made according to the proposals of the international working group [58]. In cases where the calculated speed was close to the upper limit of the speed class, the DGA was assigned to this faster class, because the one-dimensional line-of-sight measurement provided by radar interferometry represents only one motion component and thus typically underestimates the actual three-dimensional surface motion [56]. The same was done with the natural temporal variations in surface displacement rates; i.e., if two or more classes were present during the observation time interval, the highest displacement speed was used to determine the speed class.

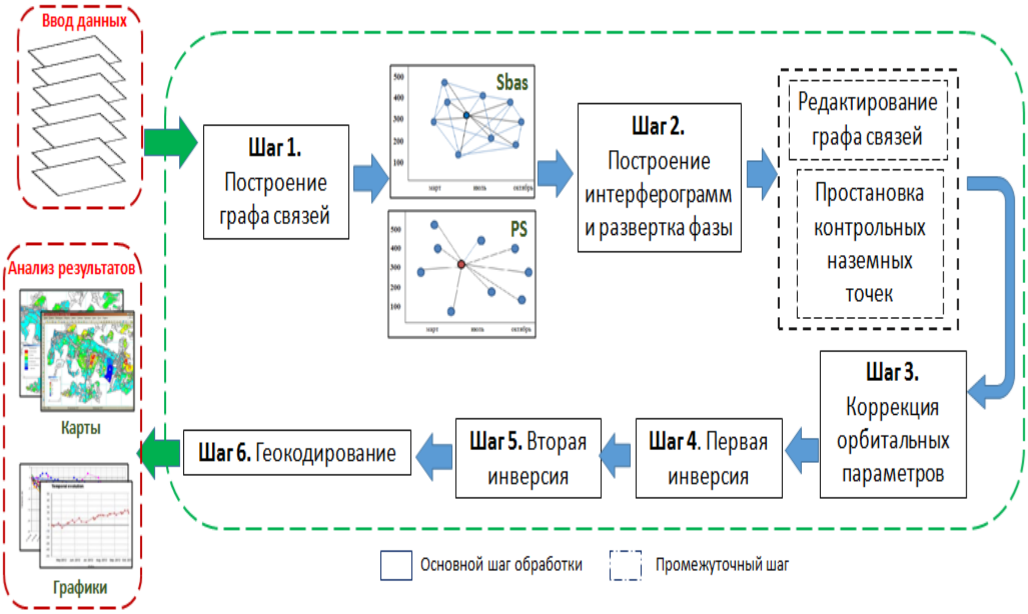


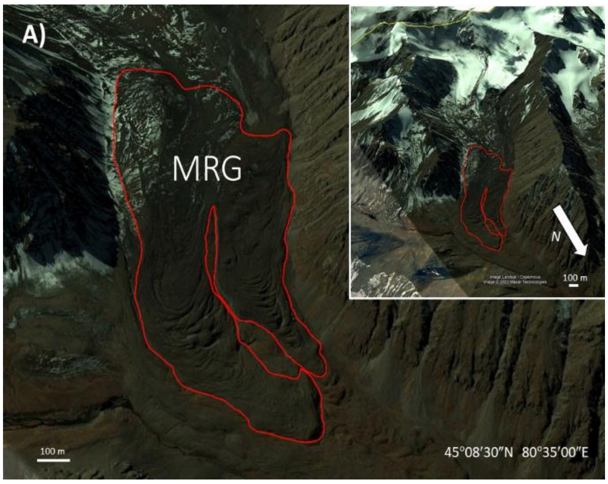
Figure 3.4 – Technological chain of multipass radar data processing by PS and SBas methods of SARScape software

3.3 Inventory results

Perhaps for the first time since the 1990s, work was carried out to identify rock glaciers in the basins of the Lepsy and Aksu rivers of the Zhetysu Alatau and their detailed digital catalog was compiled in accordance with international standards [APPENDIX B].

A total of 848 rock glaciers were identified with an area of more than 83.4 km^2 and with an average lower limit at an altitude of 3018 m above sea level; the average area of individual units was 0.10 km^2. The largest rock glacier in the area has an area of 1.53 km^2, while the smallest rock glacier has an area of about 0.003 km^2.

Several rock glaciers were also found in the study area with several episodes of activity, where newer blades dominated older sites. Complex rock glaciers with more than one root zone are most common in the study area. In addition, rock glaciers are classified according to the type of origin: scree and moraine (Figure 3.4). Figure 3.5 shows the location of rock glaciers in the Zhetysu Alatau.



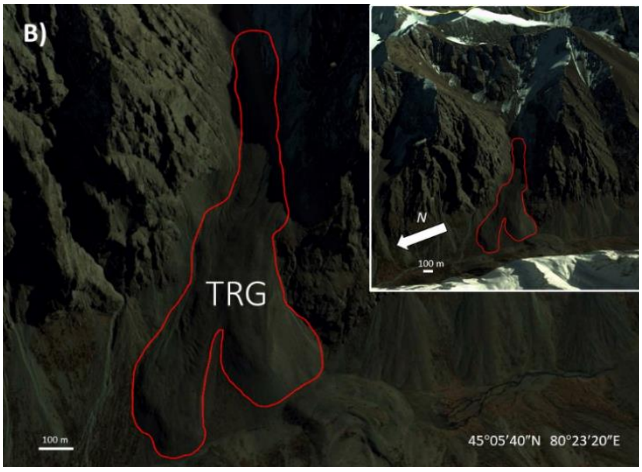


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Figure 3.4 - Google Earth images of (a) a typical moraine rock glacier (MRG) and (b) a scree rock glacier (TRG). The insets show the topographic and morphological features surrounding the same rock glaciers

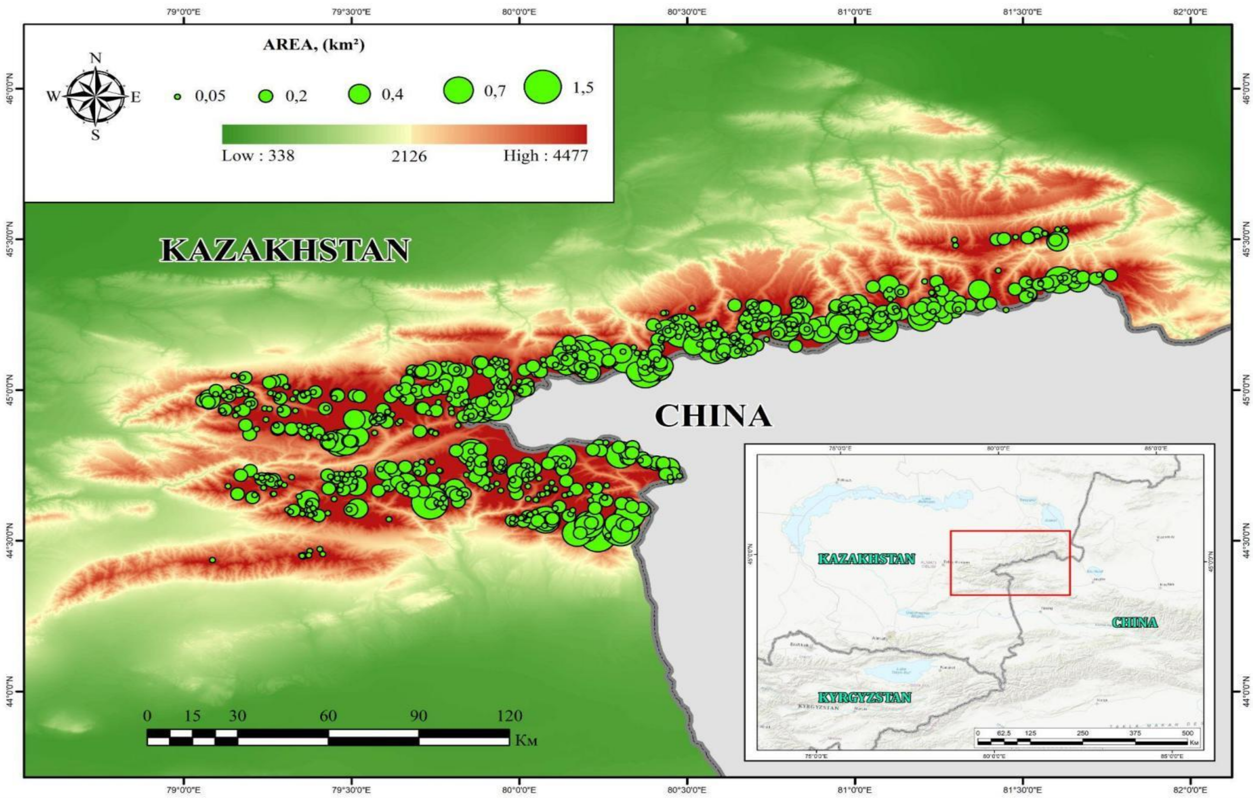


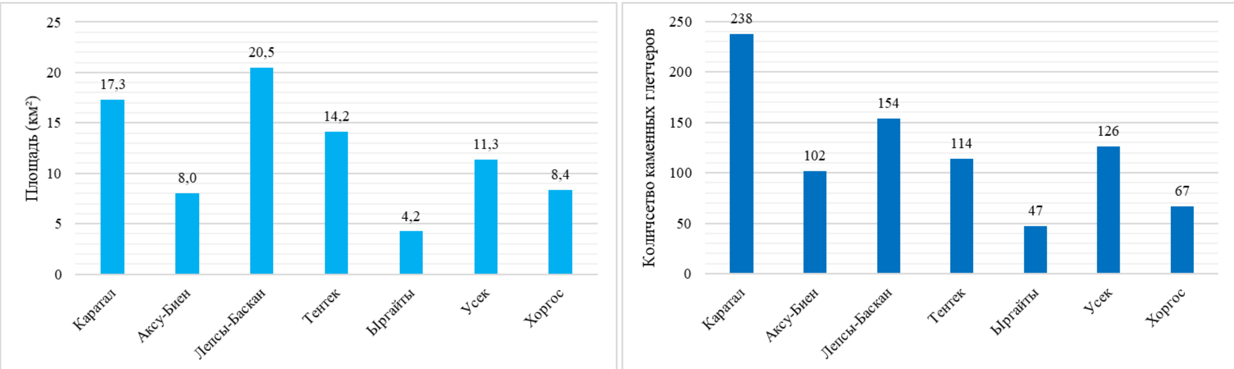
Figure 3.5 - Topographic map of Zhetysu Alatau. The green circles represent rock glaciers. The size of the circle represents the area of the rock glacier

According to the results of the analysis, it was found that the north-facing slopes are more favorable for the formation of rock glaciers than the south-facing slopes, which is associated with lower solar radiation on the slopes of the northern exposure. The number of rock glaciers inventoried in this study can be considered a conservative estimate as, due to limitations in remote sensing data and human factors, more rock glaciers in this area cannot be ruled out. Table 3.1 lists the main characteristics of rock glaciers obtained from the analysis.

Table 3.1 - Main characteristics of rock glaciers in Zhetysu Alatau

	Area (км²)	Slope (°)	Altitude (m)	Pot. Radiation (W/m²)	Minimum altitude at the front (m)	Maximum altitude of rock glaciers (m)
Mean	0,10	16,7	3082	1032527	3018	3141
Std deviation	0,13	4,7	219	87594	230	219
Minimum	0,003	7,2	2032	819113	1924	2121
Maximum	1,53	42,3	3684	1252952	3640	3726

In terms of pools. Most rock glaciers were found in the Karatal river basin - 238 pieces with a total area of 17.3 km^2 (Figure 3.6a, b). The lowest rates of glaciers both in number and area are in the Yrgaity river basin - 47 pieces with a total area of 4.2 km^2. Perhaps this is due to the fact that the territory of the Yrgaity river basin itself is the smallest. Also, in this basin there are the least glaciers. Although Karatal is the leader in terms of quantity, rock glaciers in the Lepsy-Baskan basin predominate in terms of area.



a b

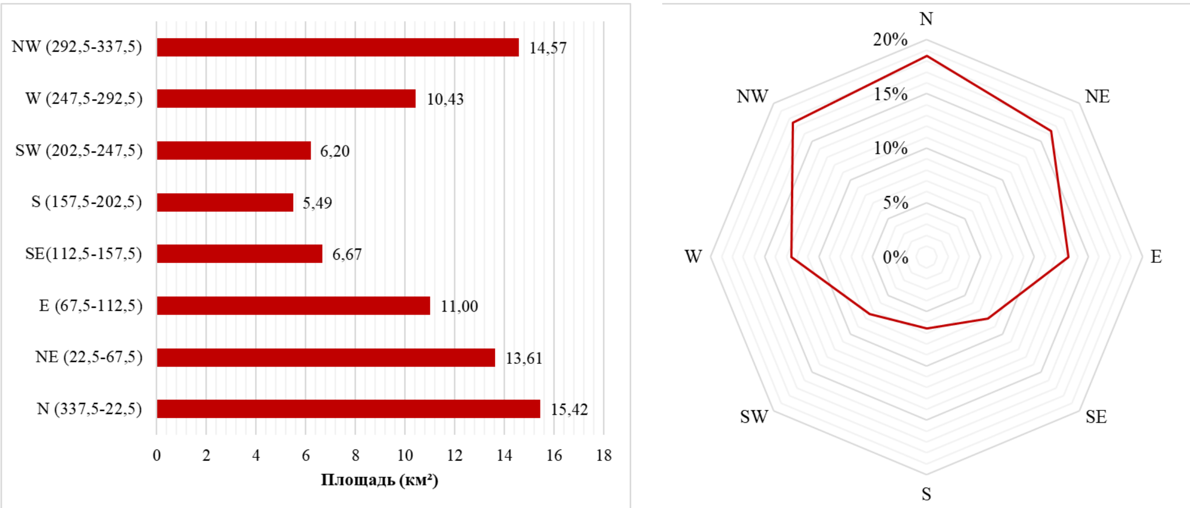
Figure 3.6 - Distribution of rock glaciers in the context of basins by (a) area and (b) number

Additional geomorphological characteristics. About 52.3% of the total area (or 30 km^2) of rock glaciers is located on slopes with a northern exposure: 18.5% in the northern, more than 16.3% in the northeastern and almost 17.5% of the northwestern exposures. On slopes with western and eastern exposures, 12.5% and 13.2% of the total area of rock glaciers, respectively, formed. Only 22% of rock glaciers, covering 18.36 km^2 of area, were formed on south-facing slopes. On the slopes of the southeastern exposure (SE) 8% of rock glaciers formed, in the southwest (SW) 7.4% and in the south (S) only 6.6% (Figure 3.7 a, b).

The overall analysis showed that glaciers developed at lower elevations in the northern aspects and at higher elevations in the southern aspects. Significant variability was observed in the aspect distribution of the rock glaciers area.

The northern (N) slopes have a large area of rock glacier, followed by the northwest (NW) and northeast (NE). In total, more than 15.4 km^2 of the rock glacier area is located on the northern slopes (Figure 3.7 a).

Potential incoming solar radiation (PISR). Another important factor controlling the development of rock glaciers is the subsurface thermal regime, which is influenced by solar radiation. For this, the potential of incoming solar radiation from the 30-meter SRTM DEM was calculated for the period from June 01 to September 30 (ablation season). Figure 3.8 shows the PISR variations depending on the viewing angle. The average value of PISR for the northern and southern slopes is 9.58×10^5 W m^{-2} and 11.9×10^5 W m^{-2}, respectively. South-facing rock glaciers generally receive higher PISR than their north-facing counterparts. Since most rock glaciers are north oriented, we conclude that lower PISR slopes favor the presence of rock glaciers. This is likely because the lower PISR helps to keep the underground ice inside rock glaciers.



a b

Figure 3.7 - Distribution of rock glaciers by aspect: a) area ratio (km^2) per aspect; b) Percentage of area per aspect

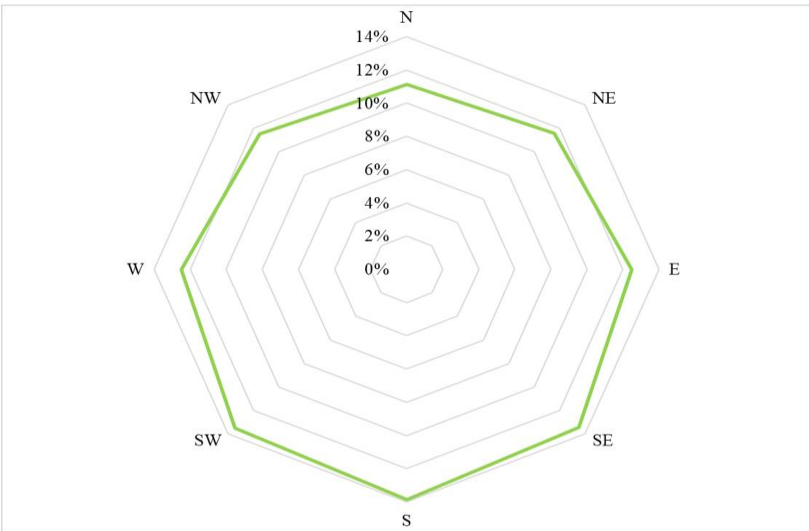
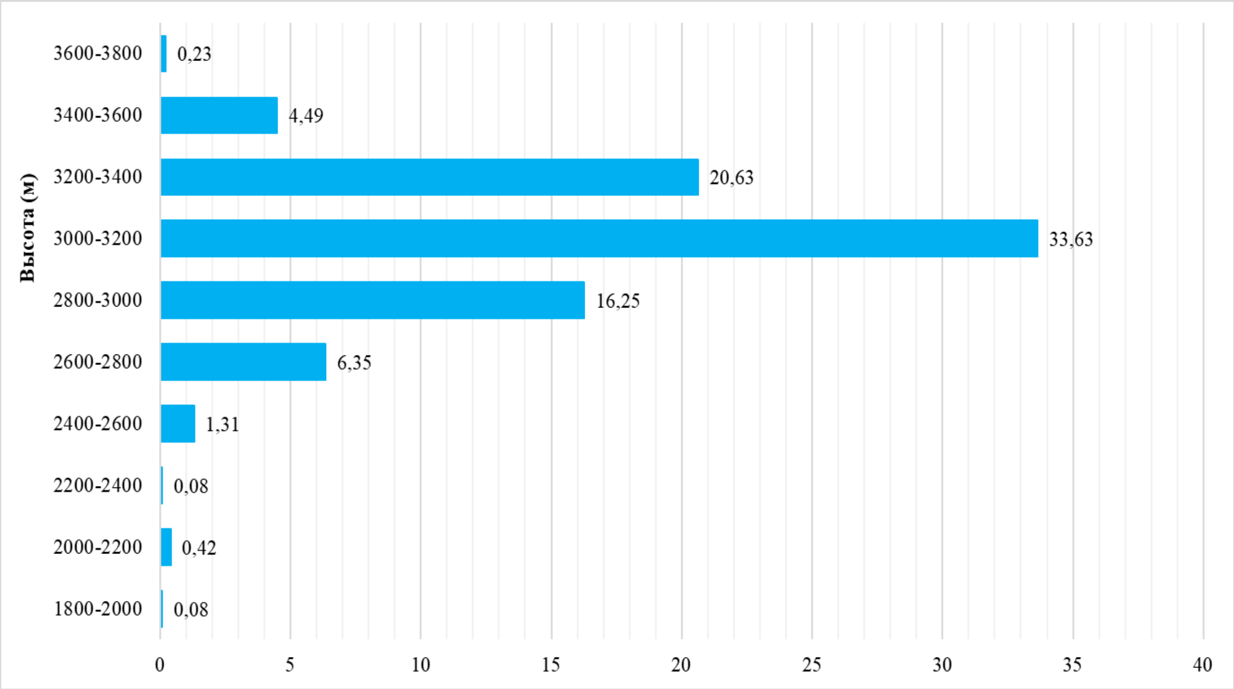
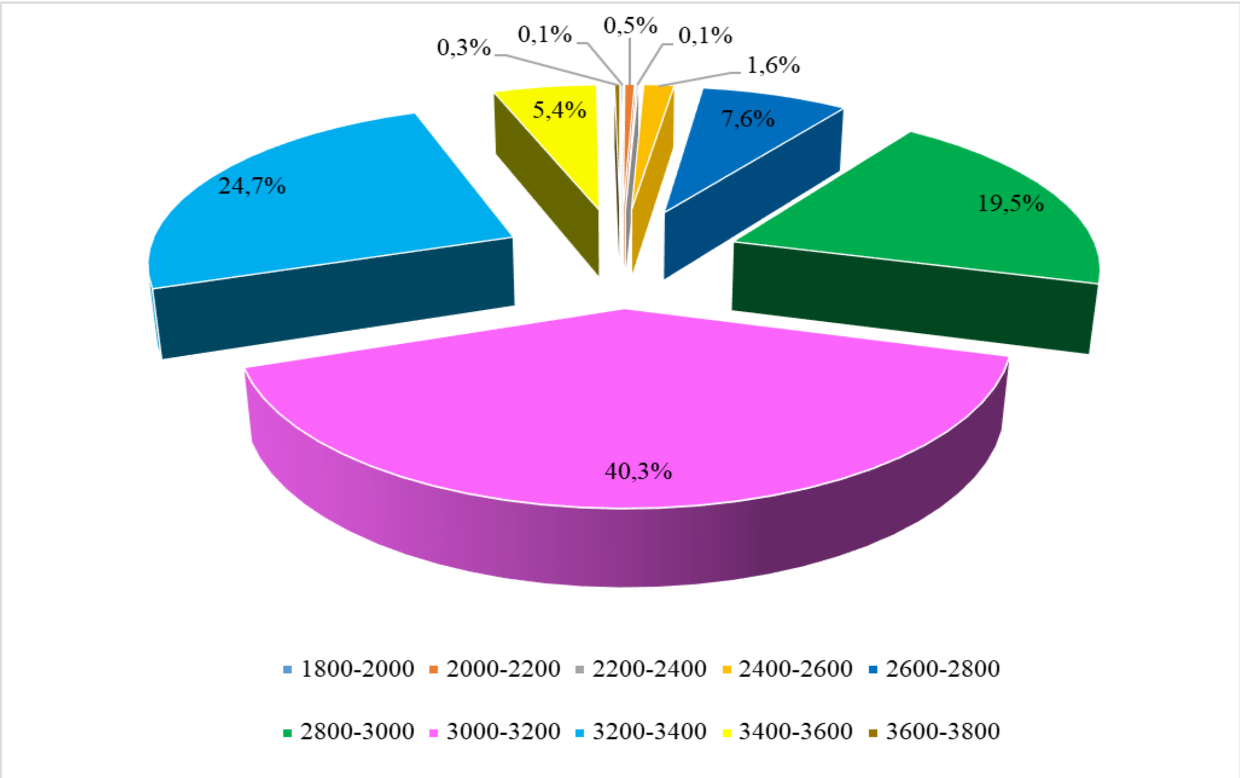


Рисунок 3.8 – PISR (*10^5 Wm^{-2})

Height distribution. The largest area of rock glaciers is located between 2800-3400 meters above sea level and is 70.51 km^2. This is almost 84.5% of the total area of the inventoryed rock glaciers (Figure 3.9 a, b). Of these, 33.63 km^2 or 40.3% of the total area lies at an altitude of 3000-3200 meters above sea level. Least of all are located between 1800-2400 and 3600-3800 and in total is less than 1%.



a



b

Figure 3.9 - Distribution of rock glaciers by height: a) ratio of area (km^2) to height; b) Percentage of area per height

Accuracy score. Accuracy was assessed by two operators by isolating the boundaries of three active rock glaciers once each day for three days (Figure 3.10). All three rock glaciers are of moraine origin.

ARG - 1	ARG - 2	ARG - 3

Figure 3.10 - Polygonal outlines of rock glaciers

When mapping, the fronts of the main languages were plotted on the map with a small difference, and the minimum height of each AWG remained almost unchanged. Rooting zones demonstrate higher variability, which significantly affects the variability of the maximum height (Difference in the height of the root zone between two operators: 1-ARG - 14m, 2-ARG - 35m, 3-ARG - 8m). The sides of the third AWG remained identical for both operators during all three days, while opinions were divided regarding the first and second AWG. One operator singled out, in the main, the most obvious creeping beats. The other also included scree cones. For ARG-3, the average area for the first operator is 0.58 km^2, for the second - 0.598 km^2, for ARG-2 - 0.198 km^2 and 0.24 km^2, respectively (Table 3.2).

Table 3.2 - The results of the assessment of accuracy by two operators

Operator 1				Mean (кm^2)
	Day – 1 (кm^2)	Day – 2 (кm^2)	Day – 3 (кm^2)	
RG-1	0,572916	0,586109	0,582255	0,580426
RG-2	0,194221	0,198028	0,202213	0,198154
RG-3	0,906863	0,911821	0,913899	0,910861
Operator 2				Mean (кm^2)
	Day – 1 (кm^2)	Day – 2 (кm^2)	Day – 3 (кm^2)	
RG-1	0,615497	0,601093	0,577631	0,598073667
RG-2	0,240758	0,239961	0,239547	0,240088667
RG-3	0,963554	0,888456	0,917465	0,923158333

Also, glaciers, as the main source of rock glaciers of moraine origin, are rapidly decreasing in size. According to the authors of [12], the rate of annual reduction of glaciers in the basins of the Aksu-Biyen and Lepsy-Baskan rivers for the period from 1956 to 2011 is 0.7%. According to [74] for the period 2001–2016. the Aksu-Biyen and Lepsy-Baskan glaciers shrank in area by 1.2% a^{-1} and 1% a^{-1}, respectively. In the future, this accelerated drying rate may lead to more moraine rock glaciers in the region. It is generally believed, and many scientists think, that glaciers with less favorable climatic conditions turn into rock glaciers [75].

After that, a comparison was made between the ratio of the area occupied by rock glaciers and the area of glaciers in the study area (Figure 3.11). The area of glaciers in the region was obtained from Kaldybaev et al. [74]. The ratio between the area of rock glaciers and the area of glaciers for the Lepsy basin was significantly higher than for the Aksu basin. This ratio can be considered as an indicator of the predominance of glacial and periglacial activity in the region. It can be concluded that periglacial activity in the Lepsy basin prevails over glacial activity. However, this analysis was simply an attempt to understand the relationship and should be treated with caution due to the lack of comprehensive field observations and validation.

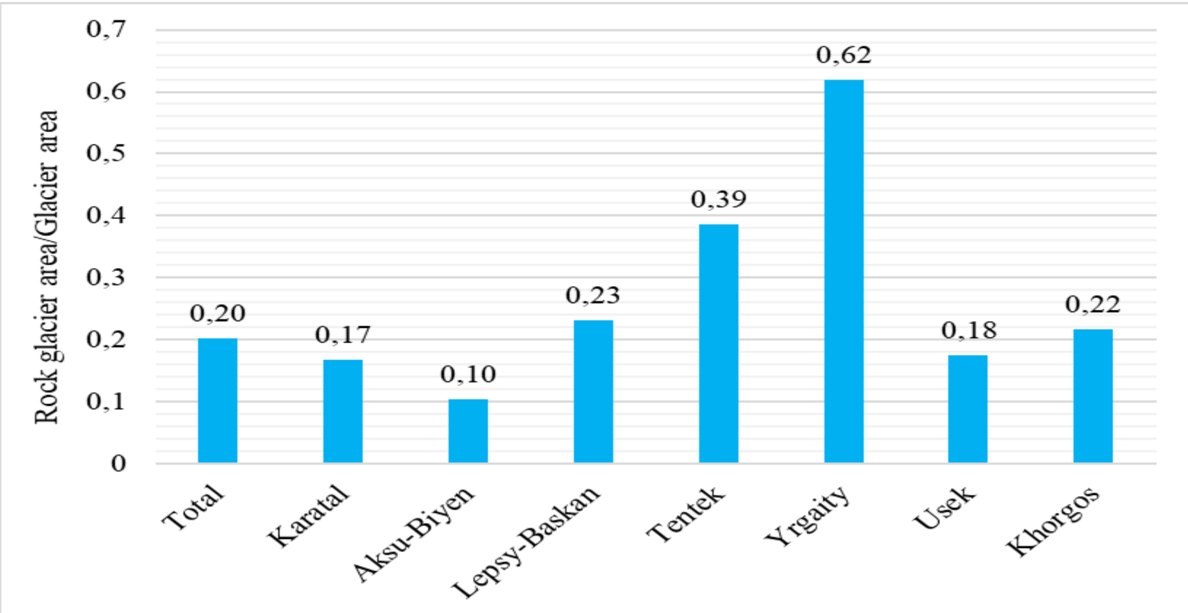


Figure 3.11 - Distribution of the ratio between the area of the rock glacier and the total area of the glacier

3.4 Estimation of the displacement rate of rock glaciers on the example of two basins

Quantitative analysis of the distribution of identified rock glaciers showed the following distribution over the combined watersheds of Aksu and Lepsy. Thus, 102 RG units have been allocated for the Aksu basin, and 154 units for the Lepsy basin.

Aksu river basin. In the Aksu river basin, 93 active rock glaciers have been identified, with a displacement rate of up to 240 mm per year (Figure 3.12); 8 units fell into the transitional category and one is classified as relic. The lower elevation mark at which active rock glaciers are located in the basin is 3100 m, the maximum value is 3700 m.

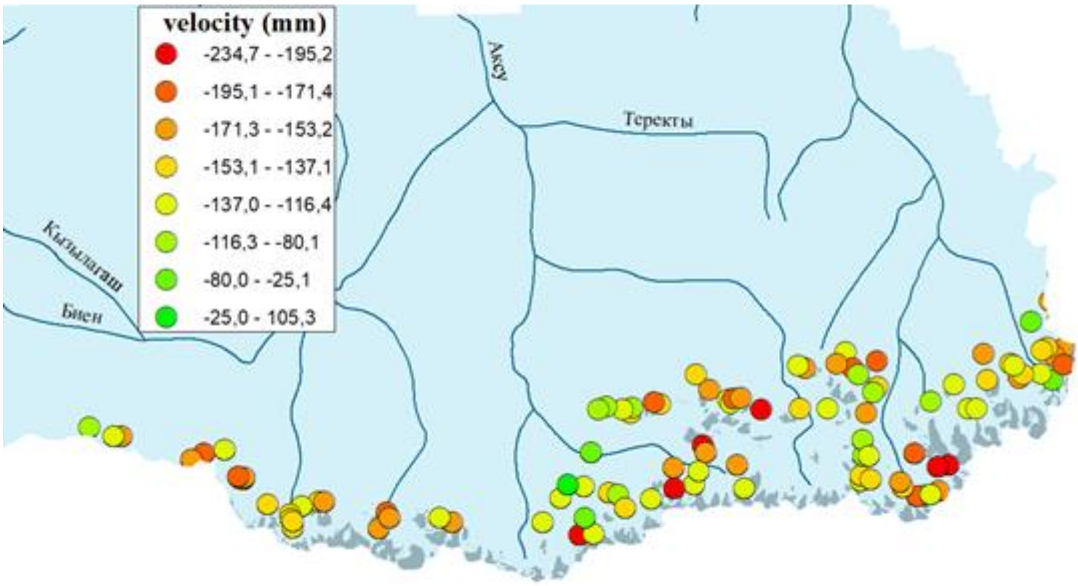


Figure 3.12 – Values of rock glacier displacements in the united Aksu catchment area

Basin of the Lepsy River. In the Lepsy river basin, 154 rock glaciers have been identified, of which 111 units are active, 39 in the transitional category and 4 in the relict category. The displacement rate in the analyzed basin was also -252 mm/year (Figure 3.13). The lower and upper heights of the location of active rock glaciers range from 2600 - 3720 m.

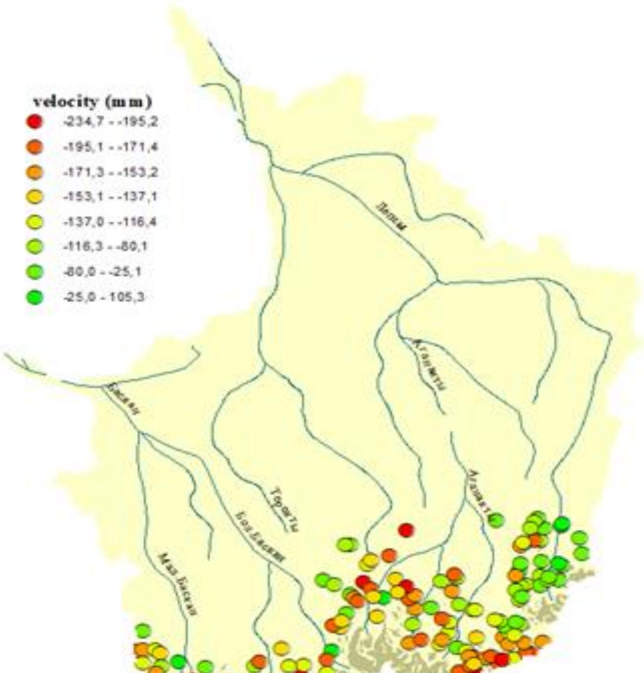


Figure 3.13 - The result of the inventory of rock glaciers for the integrated Lepsy catchment area

An analysis of the distribution of the velocity field made it possible to identify several groups of rock glaciers with a similar pattern of velocity distribution over the body of the glacier (Figure 3.14):

a) the first type - the main distribution of moving areas in the middle of the body of a rock glacier;

b) the second type - the location of the moving areas closer to the forehead of the rock glacier;

c) the third type is a complex distribution of moving sections in several areas in one glacier body.

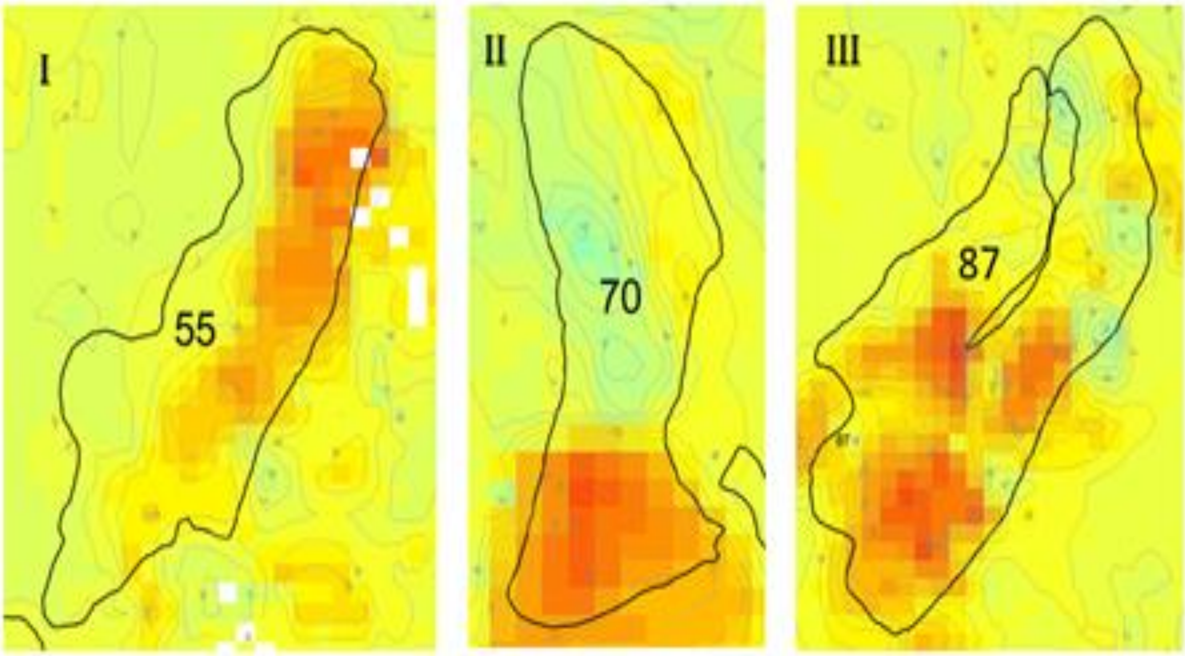


Figure 3.14 - Examples of displacement fields by types of velocity distribution

3.4.1 Updating quantitative information on glacier height ranges

In [76], the author noted, most likely as of 1988, that active rock glaciers in the Zhetysu Alatau region were located in the altitude range from 2300 - 3500 m, according to the data of Soviet expeditions and field observations. For the sections of the two basins analyzed in this work, the following altitude ranges were identified from 2600 - 3720 m, which means an increase in the lower limit of the placement of rock glaciers by 300 m higher and an increase in the upper limit by 220 m (Figure 3.15).

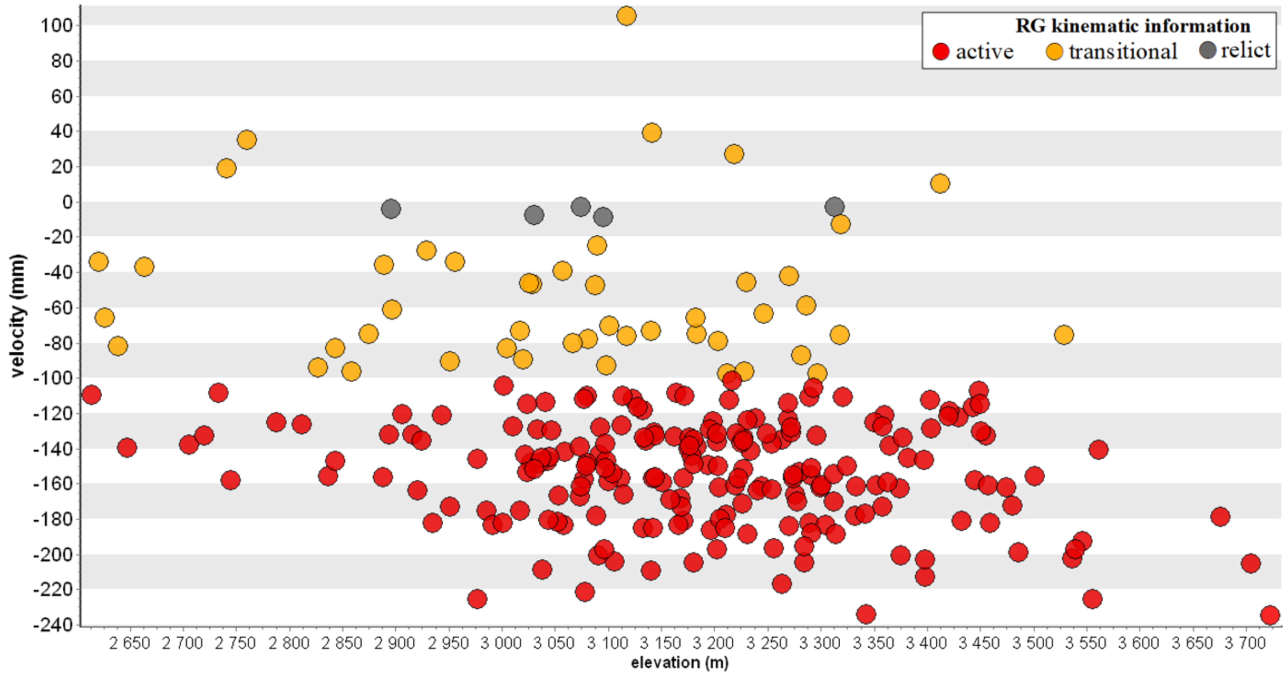


Figure 3.15 - Distribution of kinematic activity of rock glaciers in height

3.4.2 Building a digital data catalog that meets international standards

For the entire period of observations of rock glaciers in the Zhetysu Alatau, a practical catalog was not developed, there were only oral reports from researchers and some field observations of individual rock glaciers. In [76], the author claims that there are at least 900 active rock glaciers in the entire Zhetysu Alatau, while no specific works, inventories or catalogs have been found in the archives. In this work, for the first time, we have digitalized rock glaciers in the combined watersheds of the Aksu and Lepsy rivers of Zhetysu Alatau and compiled an international catalog.

An interesting fact is that the most of the studied rock glaciers of Central Asia is located in this region - it is Nizkomorenny (Figure 3.1). The first cycles of observations on it were started back in 1948 by the researcher Palgov N.N. [61] and beyond were continued until the 1990s. The formation of the rock glacier is associated with the glacier located above, from which the moraine broke off and began to move down the slope with a steepness of 15 degrees, acquiring the form of a rock glacier. The steepness of the frontal ledge is 40–45°. For 34 years (observation periods 1949-1953-1959-1964-1970-1982), the modules of the surface velocity of the rock glacier was 0.17 m/year, the maximum was 0.35, and the total value of its movement was 8.91 m [77].

In the above series of differential interferograms (Figure 3.16) for the Nizkomorenny rock glacier, three areas of movement are clearly distinguished: in the central part of the rock glacier, significant changes in the movement field are noted over 48 days; motion zones are also noted on two frontal slopes of the glacier. It should be noted that the two main frontal slopes move with different signs of movement - the first actively gives off mass, while the second accumulates. Despite the fact that this rock glacier has been defined as active for more than 70 years, but the movement rates are insignificant (from -15- -30 mm/year), its unique location of the frontal slopes near the river allows it to exist and remain active.

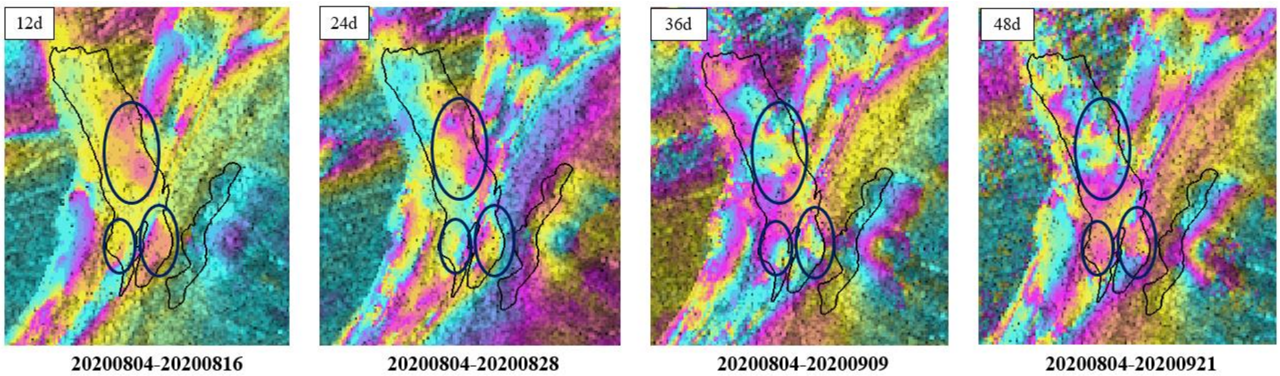


Figure 3.16 - an example of a series of differential interferograms for the rock glacier Nizkomorenny

Commentary on interferograms. In terms of kinematic information collection methods, InSAR time series analysis has great potential for monitoring low-amplitude movement velocities, but this method is not without significant limitations.

The main limitations that arise in the calculation of displacements by radar interferometry methods are a) the lack of calculation of displacements measured on moving sections; calculation of displacement projection along the slope provides information on displacements in 3D projection, it is worth noting that the magnitudes of displacements of moving sections on the northern and southern sides are calculated less accurately, even when processing data from the ascending and descending orbits of the satellite; b) the next disadvantage is related to the inaccuracy in estimating low-speed moving sections (displacement rates less than 3 cm per year), since interferograms with a long time line contain too much noise, while it is slow-current displacements that are better distinguished from pairs with a large time interval.

The sensitivity problem of InSAR is well known and causes problems, especially for landforms with small displacement amplitudes. Projecting the LOS displacement onto the intended direction of travel (i.e., along the steepest slope) does provide more representative results [78] but their velocities are probably still somewhat underestimated. Rock glaciers in areas with poor InSAR sensitivity are included in the inventory even if their line-of-sight velocity is <1 cm/yr for this reason. Their activity is classified as "undefined".

4 Assessment of changes in elevation and mass balance of glaciers on a regional scale for the Zhetysu Alatau using remote sensing data

Glacier mass balance measurement is a process that tracks the growth and loss of a glacier volume in a balance year or a fixed year. If, in a given period, a glacier receiving the same amount of rain and snow (accumulation) that it loses to melt and runoff (ablation) is said to be balanced. If the accumulation exceeds the ablation, the mass balance is considered positive, and subsequently thickens and can move forward. Otherwise, the mass balance is correspondingly negative; the glacier is thinning and may retreat.

To understand the processes occurring in glaciers, it is important to understand the volumes of outcome and income of masses of snow and ice that make up the body of the glacier. One of these indicators is such a criterion as the mass balance of the glacier. There are many different methods for measuring it.

The most promising of them are methods based on the use of remote sensing data, since they give a general picture of the ongoing processes without the need to equip expeditions, which in any case cannot cover the entire territory of the basin, but provide only fragmentary information. Remote sensing method make it possible not only to estimate the areal characteristics of glaciers, but also the rate of decrease in their volumes through multi-temporal digital elevation models built on their basis.

Monitoring of temporal changes in geodynamic and morphological processes, in this case for high mountain conditions, is reduced to measuring changes in the height of the earth's surface, based on the built digital elevation models and recording changes in areal characteristics of ice and snow cover. When identifying altitude changes that occur over time, it is advisable to use digital elevations models formed at different time intervals. The use of DEM from sources such as SRTM and TanDEM-X is acceptable for glacier monitoring [79], where sub-annual glacier temporal changes are measured in meters. While other changes in the earth's surface are much smaller.

4.1. Literature review on estimating the mass balance of glaciers

The first long-term monitoring of the glaciers mass balance in Kazakhstan began in the 1960s-1970s on the Shumsky (Dzhungar Alatau), Central Tuyuksu (Northern Tien Shan) glaciers during the International Hydrological decade (1965-1974) [80,81].

The monitoring included extensive mass balance measurements of nine Tien Shan glaciers (eg Central Tuyuksu, Golubin, Karabatkak, Abramov in the USSR and Urumqi No. 1 glacier in China). However, the selected medium-sized glaciers for which long-term observations were made are not fully representative of the entire range of glacier sizes and types and climate throughout the Tien Shan, and mass balance estimates were based on different methodological approaches, making it difficult to direct comparison. Re-observations are being resumed and historical mass balance data are being reconstructed to close gaps in the mass balance time series since 2010 in the framework of international and national projects [82].

At the moment in Central Asia, only five glaciers are observed, three of which are located in the Altai and two in the Tien Shan. But despite this, the data obtained from these glaciers are insufficient for studying the glaciers of the Zhetysu Alatau. The main reasons for this are expensive technologies and inaccessibility of glaciers, field work can be complicated by a short time frame, limited resources, difficult terrain and unpredictable weather. However, the development of space technology has made it possible in the 21st century to use data from remote sensing to assess the glaciers mass balance [83].

To assess the glaciers mass balance of the Zhetysu Alatau, complex work was not carried out, but mainly work was carried out only on the Shumsky and Muravlev glaciers. The mass balance of glaciers in the Zhetysu Alatau has been predominantly negative over the past few decades, as evidenced by the retreat of the ends of many glaciers and the reduction in their areas. The results of the work of P.A. Cherkasov show that in the river basins of western orientation in the Zhetysu Alatau, glaciers lose 1.1% of their mass per year, which leads to their unstable state compared to the ice reserves in 1970.

Despite the importance of glaciers, mass balance and other traditional glacier monitoring activities were discontinued after the collapse of the USSR in the 1990s, including for the Shumsky glacier, which is the reference glacier of the Zhetysu Alatau mountains.

Jacob et al. [84] presented Worldwide estimates of glacier mass balance based on GRACE data for the period 2003-2010, including separate estimates for the Tien Shan and Pamir/Kunlun Shan mountains (scores of -5 ± 6 GT a^{-1} and -1 ± 5 GT a^{-1}, respectively). Their approach is still affected by large uncertainties (over wide intervals) which are mainly due to the coarse resolution of the GRACE data and the geophysical models used to reduce signals other than glacier mass signals. For the Central Asian highlands, Güntner et al. [20] aim to reduce this uncertainty. Thus, gravity data may become an acceptable alternative for large scale mass balance estimates in the near future.

Studies of the mass balance of glaciers in Central Asia and the Tien Shan were carried out by geodetic methods, with glaciological measurements, as well as using data from remote sensing, and modeling of the mass balance of glaciers at the regional and local levels was carried out [85]. The use of geodetic methods for the Inner and Central, northwestern Tien Shan showed good agreement of the results with glaciological measurements and data obtained by ASTER from 2004 to 2012 [86].

But despite these works, high time resolution regional mass balance time series for the Zhetysu Alatau are still missing.

4.2. Methodology for calculating the change in the surface elevation of the glacier over time and assessing the accuracy

Our method for calculating the geodetic mass balance of glaciers is based on the DEM differencing. To calculate the change in the elevation of the glacier, two DEMs were compared: historical and modern DEM.

Elevtaion changes were estimated by mapping the differences between the SRTM and TanDEM-X data based on the methodology developed by Nuth & Kaab [87] and implemented in the DEMCOMPARE Python library. Our method is a set of procedures for co-registration of two digital models by minimizing the RMS error only in regions with a stable surface, while unstable regions, including all glacial regions, were excluded from the calculations.

Our methodology includes the stages of horizontal co-registration of compared digital models based on reference points obtained over stable regions and calculation of elevation changes. The resulting elevation change file was used to calculate the geodetic mass balance, taking into account that the ice density is 850 ± 60 kg m^{-3}.

In the course of the calculation, we took into account the elevation difference arising from the different possibilities of penetration through the surface of the C-band and X-band microwave radiation. With a longer wavelength, the C band set to SRTM penetrates deeper into the ice/snow surface than the X band. The SRTM-X and SRTM-C DEMs were also corrected before differentiation, and offset corrections were applied to the height difference map. As the height increases from the tongue to the summit, clearer ice is exposed, and the layer of dry snow/firn on the surface becomes more and more thick. Correspondingly, the penetration depth of the C-band also increases, reaching a maximum at the highest base of the firn.

A study by V. Aizen [88], as well as a study by Podgórski [89], shows the applicability of SRTM and Tandem-X data to assess changes in the thickness and volume of mountain glaciers. Although SRTM data are biased on steep slopes due to overlaps and shadows, major long-term changes in stable and accumulation zones are well identified. Even with all the shortcomings, SRTM and Tandem-X data are freely available and make it easier to obtain regional variations in glacier thickness/volume.

Due to the fact that glaciers, like all natural objects, are subject not only to long-term changes, but also have an intra-annual trend of changes. So in the winter period, they are characterized by a significant increase in volumes in high-mountainous areas, in the so-called accumulation zone up to the equilibrium zone. As noted above, the SRTM and TanDEM-X

DEMs, although they were obtained approximately in the same season, but with a very large time lag as a result, all this ambiguity in the accumulation zone and stability of the glacier body is considered incorrect to consider these data. Also due to the fact that the main focus of this study is directed to the ablation zone, i.e., the determination of the long-term trend in the rate of glacier mass consumption in the ablation zone. Thus, the obtained data on changes in the glacier elevation in the zone corresponding to the zones of accumulation were attributed to the zone of equilibrium.

It is very important to evaluate the accuracy of the results before interpreting them. In this study, several sources of uncertainty considered when estimating thickness change. Firstly, this is the error in measuring the height difference. Theoretically, the height difference of stable regions should be equal to zero. Assuming that glacial and non-glacial height differences are common and have the same measurement accuracy, we can take the standard deviation (STD) of the height difference across stable regions to estimate the height difference measurement error. However, as practice has proven, the height difference between two mountain DEMs obtained using remote sensing methods inevitably contains a significant amount of outliers. Our method is a set of procedures for co-registration of two digital models by minimizing the RMS error only in regions with a stable surface, while unstable regions, including all glacial regions, were excluded from the calculations. After the correction according to our method, the average height difference between the two DEMs was less than 0.8 meters, which is well within the accuracy limits of the original DEMs.

The second source of uncertainty was the penetration correction error in the C band, i.e. 0.5 m. The upper parts of the glacier should undergo only a slight change in thickness, in our work we took this into account. For the glacier boundary, we considered the difference in average thickness change caused by the exclusion of vertex samples as an additional source of uncertainty. In addition, the uncertainty caused by the error in determining the boundaries of the glacier was calculated (third source). By setting a 15m buffer zone along the contours of the glacier, we obtained the rate of change in the thickness of the glacier with a negligible difference.

4.3 Methodology for converting glacier volume into glacier mass balance

Calculations of the mass balance began to be carried out from the end of the 19th century. There are two main methods of its calculation, instrumental and geodetic, at present, geodetic methods for its calculation are widely used, due to the fact that the accuracy of the constructed digital models has increased many times over in comparison with earlier works based on the construction of a DTM from stereo images due to insufficient contrast stereo images of white surfaces.

The geodetic mass balance technology is estimated from calculated volume changes based on topographic data. In addition, it is necessary to have an idea about the density of increasing and decreasing volumes. In general, the procedure for calculating the mass balance is reduced to the following steps. The DEM difference is calculated, obtained from data of different times t0 and t1. The duration of observation Δt = t0 - t1, in different cases can vary from a year to several years. Then, based on the obtained data, the resulting height difference was recalculated into the geodesic mass balance [90] using formula (1):

$$Bgeod_{|t_0-t_1|} = \frac{\bar{\rho} \times r^2 \times \sum_{i=1}^{p} \Delta h(x)}{S} \quad (1)$$

where ρ = 850 kg/m^3 is the average density of the glacier [91],

r - spatial resolution of the raster,

Δh - the resulting difference in heights of digital elevation models in each pixel x,

p - number of raster pixels characterizing the glacier

S is the average area of the glacier during the observation period.

This approach to calculating the mass balance, based on the registration of changes in altitude, is reduced to the arithmetic sum of the mass balance and ice movement, in fact, it assumes that the change in the volume of the glacier depends only on the change in mass. In fact, the change in the height of the glacier depends not only on the mass balance, but also on the movement of ice.

The unit kg/m^2 is usually replaced by millimeters of water equivalent, mm w.e. This replacement is convenient in that 1 kg of water with a density of 1000 kg/m^3 has a thickness of exactly 1 mm with a uniform distribution of 1 m^2. Units kg/m^2 and mm w.e. are numerically identical. More formally, the metric water equivalent (m w.e.) is an extension of the SI, which is obtained by dividing the ratio of a certain mass and unit area, by the density of water (Formula 2), ρw:

$$1 \text{ m w.e.} = 1000 \text{ kg} * \text{m}^{-2} / \rho_w \quad (2)$$

4.4 Input DEM data for mass balance calculation

SRTM DEM. The international mission to obtain data from a digital elevation model (DEM) of the Earth's territory was carried out in February 2000 from the space shuttle "Shuttle" using a radar interferometric camera and two radar sensors SIR-C and X-SAR installed on board the spacecraft. Approximately 12 terabytes of radar data was captured, covering land from 60°N. up to 54°S The SRTM C-band data exists in several versions: the preliminary version was released in 2003, the fourth version of the SRTM V4 data is currently available. SRTM data is distributed in several resolutions - a grid with a cell size of 1x1 arcsecond and 3x3 arcseconds. According to the specification, the RMSE accuracy is ≤ 16 m, which most closely matches the LE-90 criterion. The original SRTM heights were calculated relative to the WGS84 ellipsoid and then the EGM96 geoid separation values were added to convert to geoid heights.

The SRTM mission was also equipped with the X-SAR instrument (German Aerospace Center (DLR) with the participation of the Italian Space Agency (ASI)). The resulting data set was named SRTM/X-SAR or SRTM-X for short. The grid resolution is high - 25 meters. SRTM-X DEM became available in May 2011.

The data in the X band has mostly single coverage of the survey, except for the intersection nodes of the survey tracks, in contrast to the survey in the C band, which was carried out from different viewing angles and survey angles. Thus, the resulting digital model built from the C-band data has better spatial coverage and quality, especially in places with a large surface slope. The poor quality of SRTM-X DEM data in high terrain areas is due to the angle of incidence of the survey beam.

When applying data in different wavelength ranges, it is important to take into account the different depths of their penetration into snow and ice. Previous studies have shown that penetration depth is affected by carrier frequency, snow and ice density, and their water content. Considering that the TanDEM-X and SRTM-X surveys were carried out at the same time of the year, and the carrier frequencies of the sensors are the same, it is assumed that the penetration depth should be the same for these data sets. Since the penetration depth of the X-band waves is much smaller than the penetration depth of the C-band waves, and the X-band waves are practically reflected from the surface, the difference in the penetration depth of the two bands can be considered as the penetration depth of the C-band waves relative to the surface.

Before determining the wave penetration difference, outliers in the values were eliminated using the 5% and 95% quantiles obtained from the statistical analysis. Determining the difference in penetration depth was carried out by comparing the SRTM-C DTM and the SRTM-X DEM, at a preselected area of the spatial intersection of the two datasets. Since the wave penetration difference should not exceed 10 m [92], all difference values greater than 10 m were defined as outliers and were not taken into account in the assessment. The height difference between SRTM-C and DEM SRTM-X obtained in this way on glaciers can be considered as the depth of penetration of C-band waves in the study area and used in further calculations [93].

The TanDEM-X mission formed a bistatic radar mission consisting of two nearly identical satellites flying at controlled distances of 250 and 500 meters. The main goal of the mission is to create a global digital elevation model.

The TanDEM-X DEM product is a Digital Terrain Model, that is, it includes various types of vegetation and other man-made objects. According to the technical documentation, the absolute horizontal and vertical accuracy of the product is less than 10 m. The relative vertical accuracy is equal to slopes at a height of 20% or lower at a height of 2 m and for slopes over 20% at a height of 4 m [94].

4.5 Results of the assessment of the mass balance of the Zhetysu Alatau glaciers

We have evaluated changes in the height and mass balance of glaciers on a regional scale for the Zhetysu Alatau according to Earth remote sensing data.

Table 4.1 and Figure 4.1 show the values of glacier mass balance calculated in the context of basins. According to our data, the regional average value of the mass balance per year for the Zhetysu Alatau glaciers averaged -0.44 m w.e. a-1. These mass balance indicators are in good agreement with the GLIMS (Global Land Ice Measurements from Space) data [95]. According to GLIMS, the mass balance of Zhetysu Alatau for the period from 2000-2016. was in the region of 0.4 m w.e. a-1.

It has been established that the fastest mass loss occurs in the Yrgaity and Tentek basins, where it is -0.59 w.e. a-1. and -0.55 w.e. a-1. , respectively. And in the Aksu, Lepsy and Karatal basins, the relatively slowest loss is -0.35, -0.38 and -0.40 w.e. a-1, respectively. The rate of mass loss correlates well with the loss of glacier area. Table 4.1 shows the calculated areal characteristics of glaciers for 2000-2016. Interestingly, the smallest Yrgaity glacier has the highest reduction rate and reaches 2.1% per year, it should also be noted that it has the lowest maximum point of altitude above sea level. which clearly shows that most of it is in the ablation zone. Larger glaciers have a large margin of safety, the reduction rate of which varies from 1.8 to 1.0% per year. The three largest glaciers shown below, which have the lowest rates of glacier shrinkage, are located much higher than the others, and the Lepsy-Baskan glacier, which has the lowest rate of 1, has the highest maximum point of the glacier body.

Table 4.1 - Mass balance and characteristics of Zhetysu Alatau glaciers in the context of basins

	Volume reductions for the period 2000-2013 (km³)	Average Volume Reduction per year 2000-2013	mass balance (m w.e. a^{-1})	Total area 2001 (km²)	Average size 2001 (km²)	Area reduction rate per year 2001-2016	Average height 2001 (m)	Min height 2001 (m)	Max height 2001 (m)
Karatal	-0,98	-0,08	-0.40	126,5	0,55	-1,3%	3439	2722	4104
Aksu Biyen	-0,62	-0,05	-0.35	93,4	0,7	-1,2%	3557	3001	4347
Lepsy-Baskan	-0,77	-0,06	-0.38	103,8	0,91	-1,0%	3551	2923	4545
Tentek	-0,55	-0,04	-0.55	49,7	0,57	-1,8%	3496	3041	4063
Yrgaity	-0,12	-0,01	-0.59	10,0	0,47	-2,1%	3456	3102	3909
Usek	-0,79	-0,06	-0.51	84,9	0,38	-1,6%	3598	3175	4175
Khorgos	-0,47	-0,04	-0.50	49,0	0,51	-1,4%	3674	3126	4299
Total	-4,29	-0,33	-0.44	517,4	0,57	-1,3%	3545	2722	4545

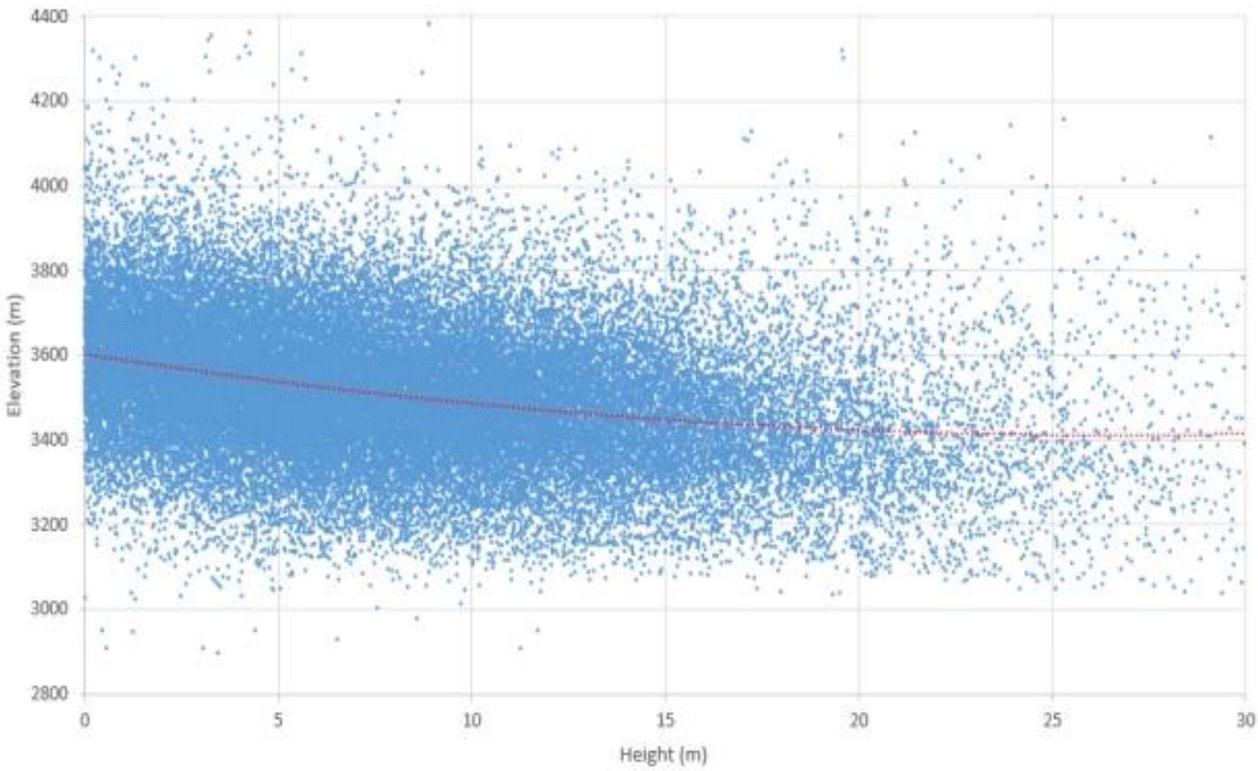


Figure 4.1 - Balance curve for the entire Zhetysu Alatau

Figures 4.2 and 4.3 present a map illustrating the general view of the recorded altitude changes in the context of glacier boundaries as of 2001. The characteristics of some glaciers are shown in Table 4.2.

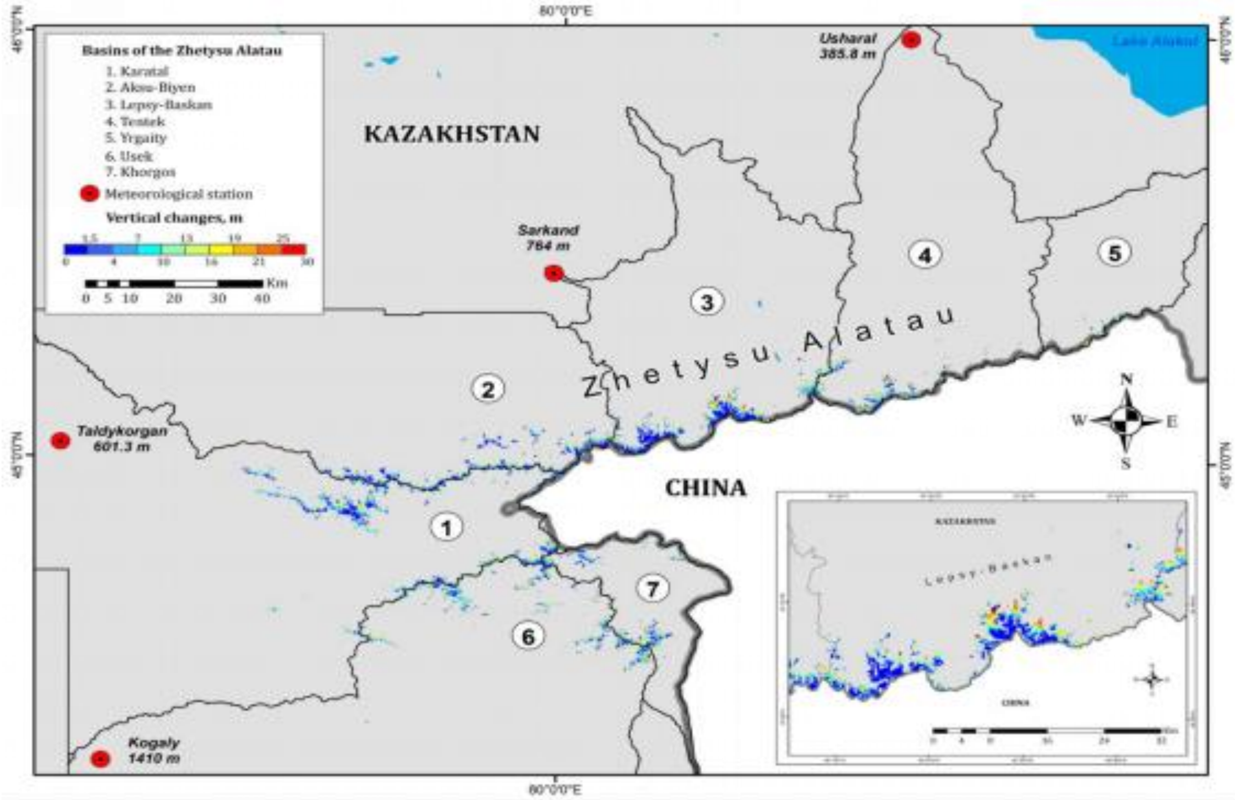


Figure 4.2 - General view of altitude changes in the territory of Zhetysu Alatau for the period from 2000 to 2013, within the boundaries of glaciers as of 2001

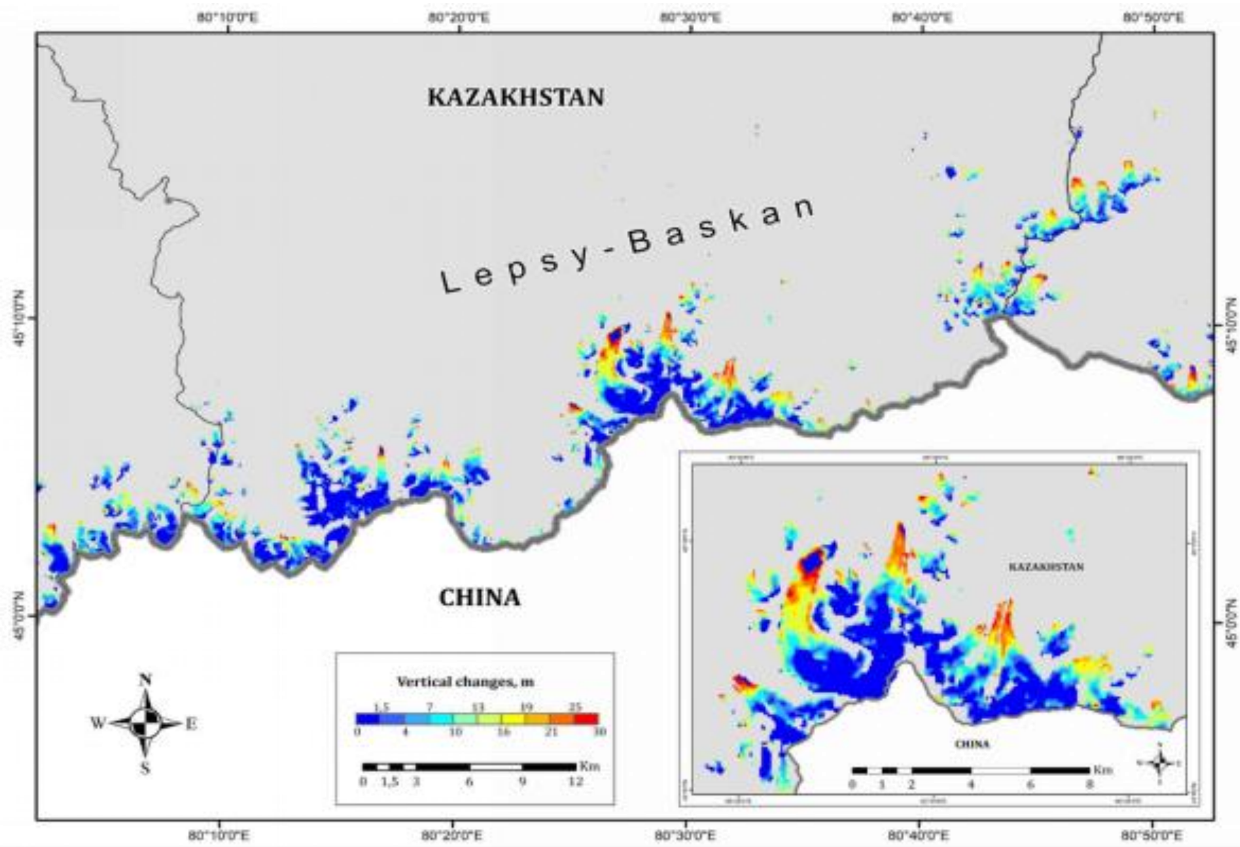


Figure 4.3 - An enlarged view of altitude changes for the Lepsy-Baskan basin for the period from 2000 to 2013, within the boundaries of glaciers as of 2001

Table 4.2 - Selected glaciers with characteristics

Glaciers area (km²)	Name №	Area in 2001 (km²)	Total mass loss 2000-2013 (km^3)	Weight loss per year	Elevation 2001 (m)	Min height 2001 (m)	Max height 2001 (m)
5-10	Berg (214)	10,90	-0,075	-0,0058	3606	3076	4215
	Abay (166)	9,01	-0,029	-0,0022	3809	2959	4443
1-5	Arkasheva (267)	4,85	-0,044	-0,0034	3688	3625	3766
	Khayerdala (16)	4,38	-0,032	-0,0025	3592	3199	3995
0-1	Lagernyi (272)	0,72	-0,006	-0,0004	3520	3298	3646
	Kaskabulak (95)	0,20	-0,005	-0,0004	3771	3495	4160

Kalesnik (9.64324 km^2, as of 2016) and Berg (9.47278 km^2, as of 2016) are typical medium-sized glaciers located in Zhetysu Alatau (Figure 4). An analysis of the spatial distribution of glacier altitude changes shows that the glacier equilibrium zone is located at altitudes close to 3400 meters above sea level. Above this mark, there is an accumulation zone, which is not considered in this study. At altitudes below the conditional mark of the equilibrium zone, two more zones can be distinguished with a step of ~ 100 m. As shown in Figure 4.4, on the example of the Berg glacier, at altitudes between 3400 and levels below 3300 meters there is a moderate increase in the values of the difference in height, which indicates the presence of active processes of melting glaciers, and below the level of 3200 a sharp increase in the processes of melting.

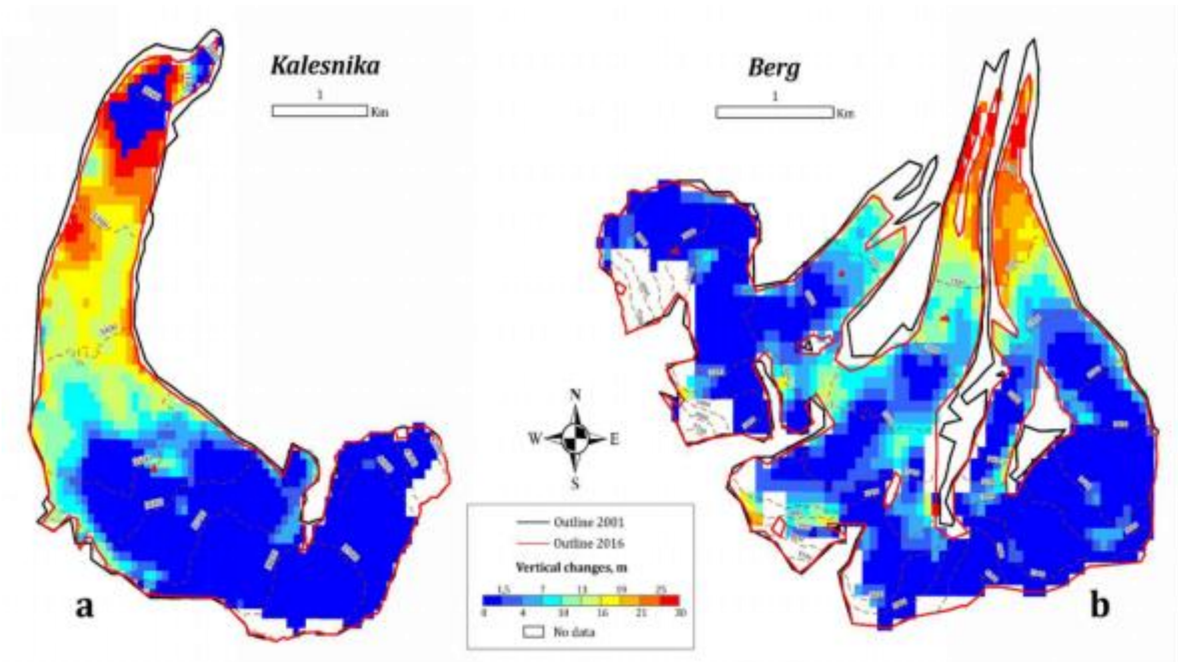


Figure 4.4 - Overview maps of altitude changes for the Kalesnik (a) and Berg (b) glaciers, Zhetysu Alatau with plotted glacier boundaries as of 2001 and 2016

A similar picture can be observed on the Bezsonov glacier, one of the largest Zhetysu Alatau glaciers, located on the southern slope, in the upper reaches of the Kora gorge. The upper limit of which is located at an altitude of 3919.7 meters above sea level and is located in the accumulation zone. It is believed that the firn line for the glaciers of the Dzhungar Alatau ranges from 3480 to 3840 above sea level, depending on the exposure and morphological type of glaciers. As can be seen from Figure 4.5, which illustrates the average annual rate of altitude change for the Bezsonov glacier. The data obtained show that on the Bezsonov glacier, as well as on the Kalesnik and Berg glaciers considered above, at altitudes above 3400 meters, focal zones appear with a negative trend in altitude change, which increases exponentially.

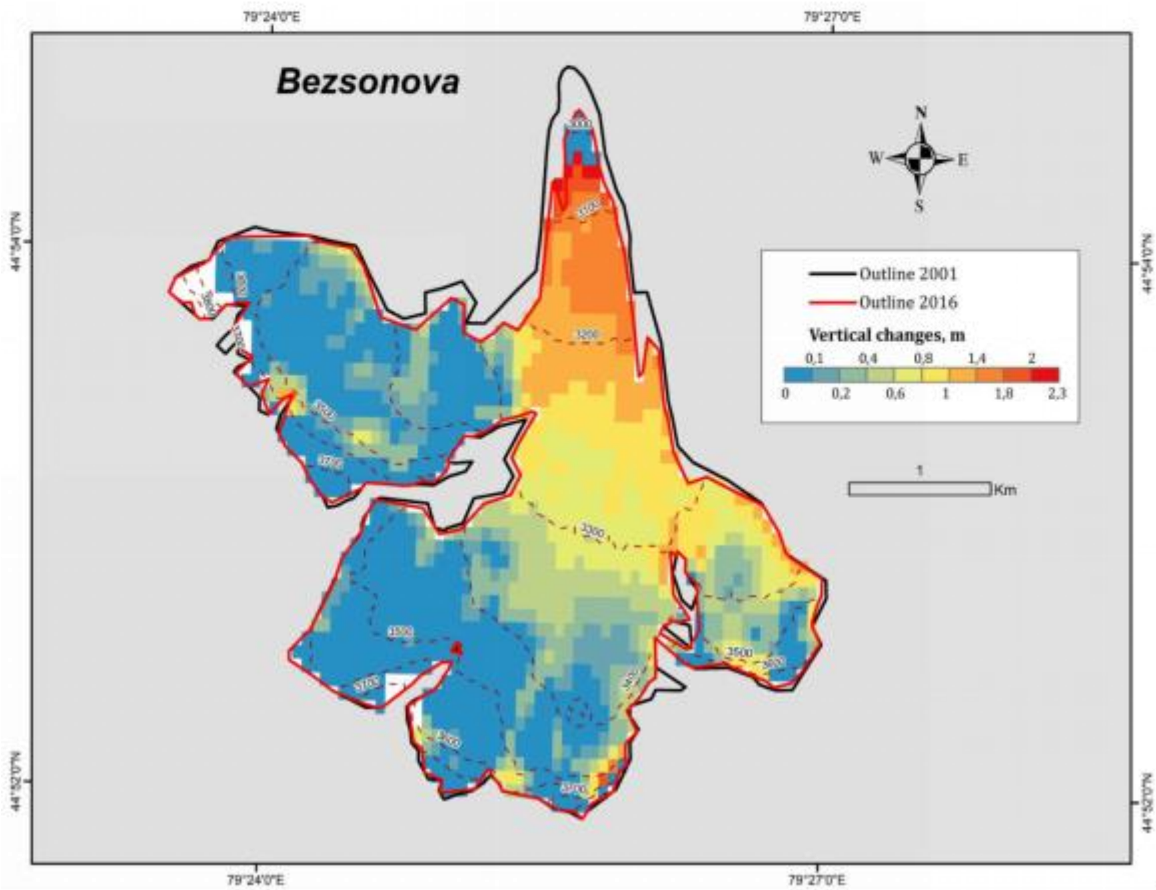


Figure 4.5 - Average altitude annual changes for the Bezsonov glacier with plotted glacier boundaries as of 2001 and 2016

Figure 4.6 shows the balance curve for the Bezsonov glacier, which shows a close relationship between the dependence of the distribution of the height of the glacier surface decline over the period from 2001 to 2013. from height. Based on the obtained linear regression, it became possible to extrapolate these changes in heights to areas where the results of comparing the DEM according to the SRTM and TanDEM-X data are too large.

On the basis of the obtained linear regression of the dependence of height change on height above sea level calculated on the basis of the point cloud, an extrapolation was carried out to that part of the glacier where the calculated height changes were absent.

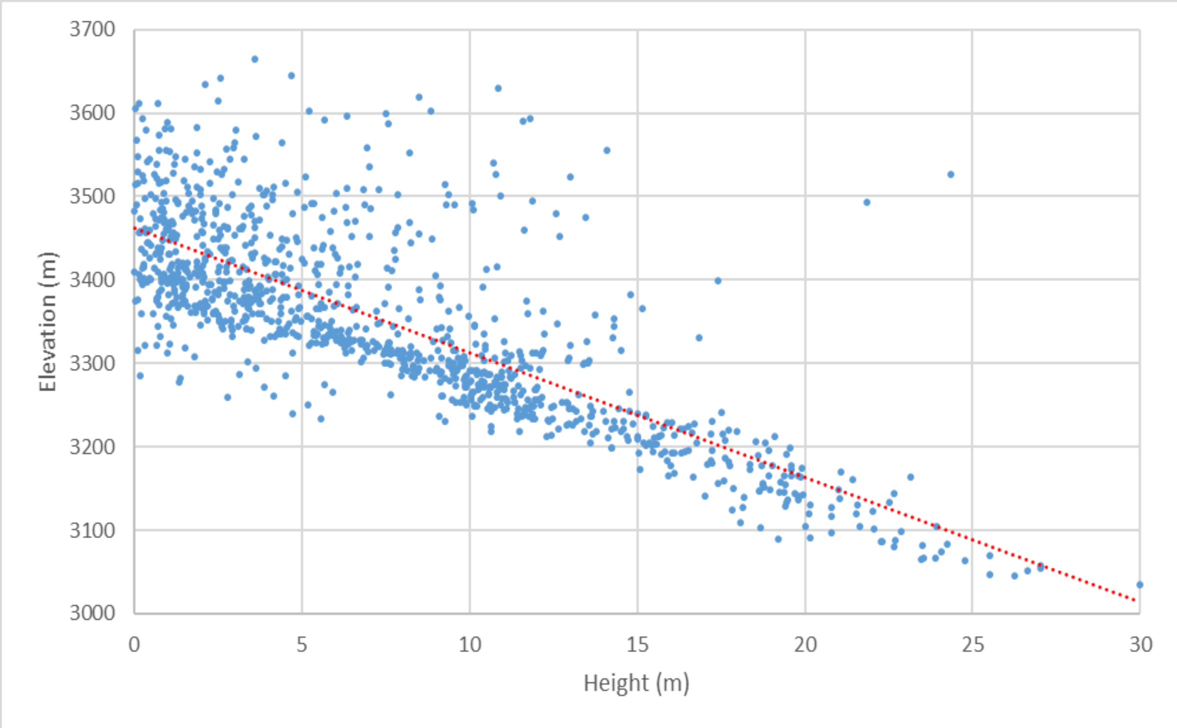


Figure 4.6 - Balance curve for the Bezsonov glacier

The data obtained in this work are in good agreement with the values of other studies, both regional and local.

Estimated characteristics of the mass balance for the entire Tien Shan region of early studies show that in this region in all regions the mass balance is negative, but the value differs between basins. In the Tien Shan, region-wide geodetic mass balance estimates agree that glaciers have lost mass over the past two decades. Estimates of mass change range from about -0.3 m w.e. a^{-1} to −0.7 m w.e. a^{-1} [32, 79]. Accelerated mass loss has been reported in most regions since the 1970s [15]. No significant acceleration in glacier mass loss since the turn of the century has been found using mass balance modeling limited by the snow line [96]. However, an increase in interannual variability was observed, indicating a change in the mass balance regime from more continental to more maritime. The largest geodetic mass loss was observed in the Eastern Tien Shan. The lowest rates of weight loss are noted in the Central Tien Shan. A comparison of various geodetic estimates showed good agreement for the Inner and Central Tien Shan [79, 97]. For the above two regions, the average mass loss obtained using ASTER is approximately -0.5 m w.e. a^{-1} and −0.4m w.e. a^{-1}, respectively, is calculated from 2004 to 2012.

Published estimates of mass change for the Pamirs show a rather large discrepancy and vary from a balance close to balanced (from +0.14 to -0.13 m w.e. a-1; [79,97, 98]). to strongly negative mass balances (from -0.48 to -0.52 m w.e. a^{-1};). There are still discrepancies between the estimates, leading to disputes about the ambiguous mass balance regime and its change. Important methodological differences, the quality of the original data, inconsistent study periods, and spatial divisions may explain these differences to some extent. Compilation and re-evaluation of various published geodetic estimates yielded an average mass loss of 0.26 m w.e. a^{-1} for the Western Pamirs and balanced budgets for the Eastern Pamirs (-0.02 m w.e. a^{-1}) for the period after 2000. This is consistent with recent geodetic estimates by Barandun [96], who report -0.37 ± 0.42 mw.e. for the Western Pamirs and +0.19 ± 1.47 m w.e. for the Eastern Pamirs. In the literature, there are also references to mass balance estimates only for Zhetysu Alatau according to the studies cited in Fanny Brun [95] the mass balance of the Zhetysu Alatau glaciers for the period from 2000-2016. was in the region of 0.4 m w.e. a^{-1}.

4.6 Main climate trends of Zhetysu Alatau

For a more detailed analysis of the reason for the sharp reduction in the glacier, we used climate data from four stations located near the Zhetysu Alatau. These stations are located in the foothills (about 380-1410 m above sea level) and since 1960 have been providing daily long-term records of temperature and precipitation. Table 4.3 provides information on the geographical location of meteorological stations in the study area.

Estimation of spatio-temporal variability of temperature and precipitation in the study area was made on the basis of the analysis of data from long-term observations of meteorological stations. Data from the meteorological stations of Usharal, Taldykorgan, Sarkand and Kogaly Meteorological station (MS) were used. The data of the Republican Hydrometeorological Fund RSE "Kazhydromet" for the period from 1960 to 2021 were used (Figures 4.7-4.10).

Many domestic scientists are studying climate change trends in the Republic of Kazakhstan, taking into account the various tasks of economic sectors [99-103]. Studies have shown that a steady increase in the average annual air temperature is observed throughout the territory of Kazakhstan. According to [103], the average increase in the average annual air temperature over the territory of Kazakhstan is 0.32 ºC every 10 years. In the annual amounts of atmospheric precipitation, there is a slight upward trend (by 2.6 mm/10 years), mainly due to spring season precipitation, when the increase in some western and northern regions is 10-20%/10 years. In autumn, the amount of precipitation decreases, in some western and southern regions by 2-12%/10 years. All trends in the average annual and seasonal precipitation over the territory of Kazakhstan are statistically insignificant.

The analysis of the tendencies of changes in the characteristics of the climatic regime for the period under study was carried out on the basis of the calculated linear trends in the series of observations using the least squares method.

Table 4.3 - Geographic location of selected weather stations

	Meteorological station (MS)	Terrain altitude (N,m)	Coordinates	Description
1	Usharal	385.8m	46° 10' N, 80° 56' E	It is located in the desert-plain region of the Alakol depression. The surrounding area is the valley of the Tentek River, originating from the northern slopes of the Zhetysu Alatau
2	Taldykorgan	601.3	45° 01' N, 78° 22' E	in the foothill region of the Zhetysu Tien Shan, in a wide intermountain valley
3	Sarkand	764	45° 25' N, 79° 55' E	Located on the northern slopes of the Zhetysu Alatau
4	Kogaly	1410	44° 29' N, 78° 39' E	Located in the mountainous area of Zhetysu Alatau

The obtained estimates of air temperature trends showed that the temperature rise occurs at all stations in all seasons and months of the year. However, there are some features in the rate of increase in air temperature. The most noticeable increase in the average annual temperature is in the desert-plain zone of the Alakol depression (Usharal MS), the average rate of change is 0.29 ºC / 10 years. The lowest rates of temperature change are observed in the mountainous areas of Zhetysu Alatau (Kogaly MS), where the average rate of change was 0.12 ºC/10 years. Trends in summer temperature changes (June-August) showed that in mountainous and foothill areas they have the highest values and range from 0.19 ºC/10 years (Kogaly MS) to 0.25 ºC/10 years (Taldykogan MS) and the lowest values on Usharal MS (0.12 ºC/10 years). An analysis of trends in change has shown that a steady increase in air temperature has been observed in the study area over the past decades.

In the trends of the average annual precipitation over the territory, there is a tendency to an increase in annual precipitation (up to 11 mm / 10 years), the only exception is the Sarkand MS, where there is a slight decrease in precipitation. At the same time, in the last years of 2019 and 2020, there was a deficit of atmospheric precipitation at the three studied stations of the MS Taldykorgan, Usharal and Kogaly. Moreover, the smallest anomalies were observed at the Usharal MS (12-64 mm), the largest at the Kogaly mountain station - 183 mm, which is 65% of the norm.

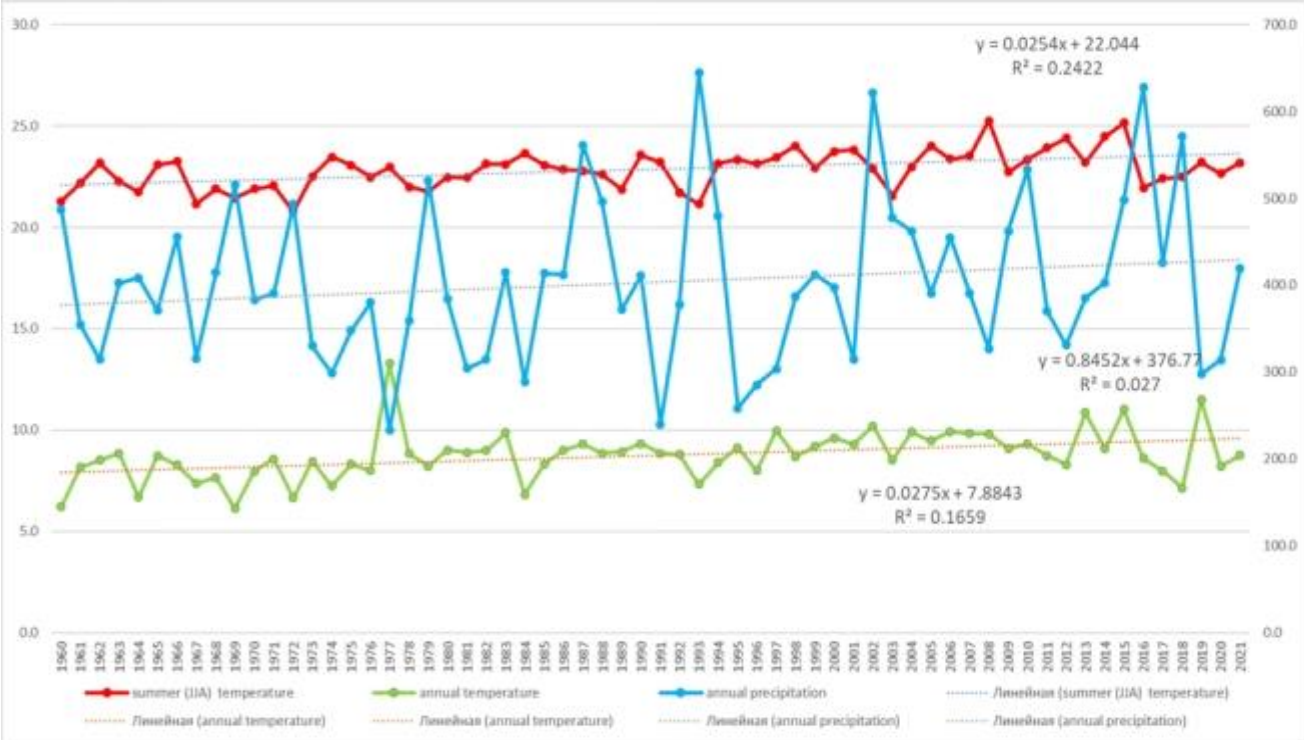


Figure 4.7 - Annual and summer (June-August) temperature and annual precipitation at Taldykorgan MS

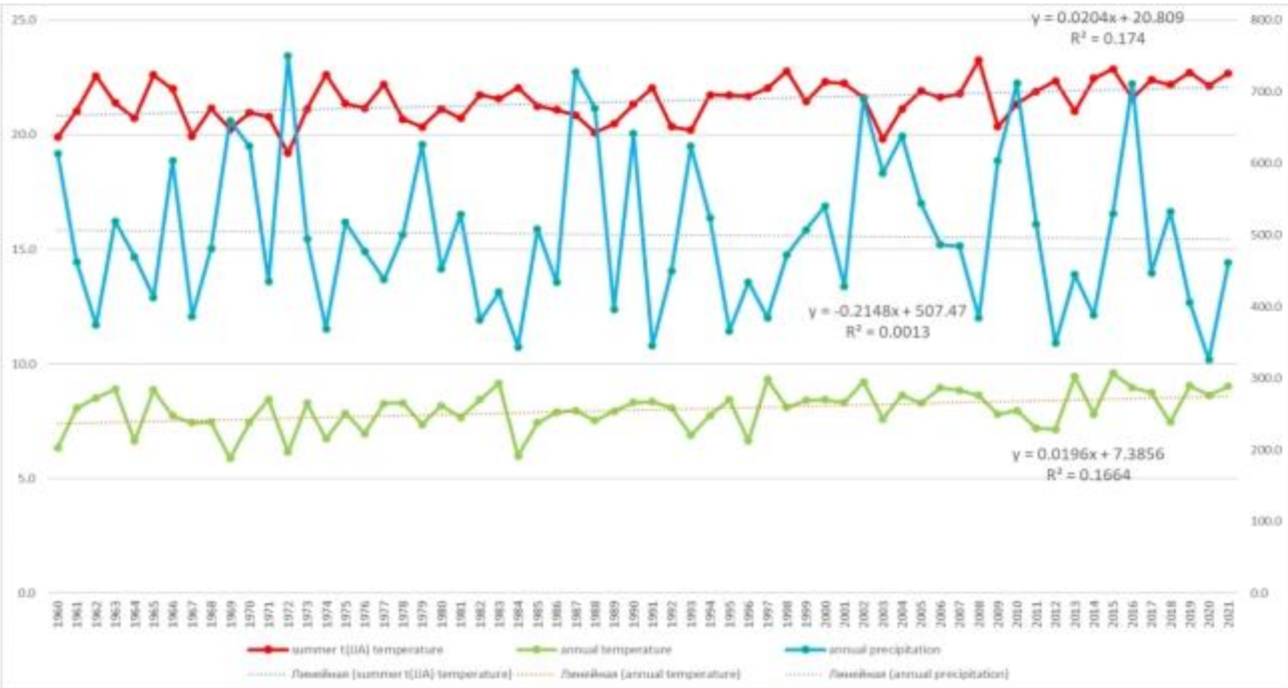


Figure 4.8 - Annual and summer (June-August) temperature and annual precipitation at Sarkand MS

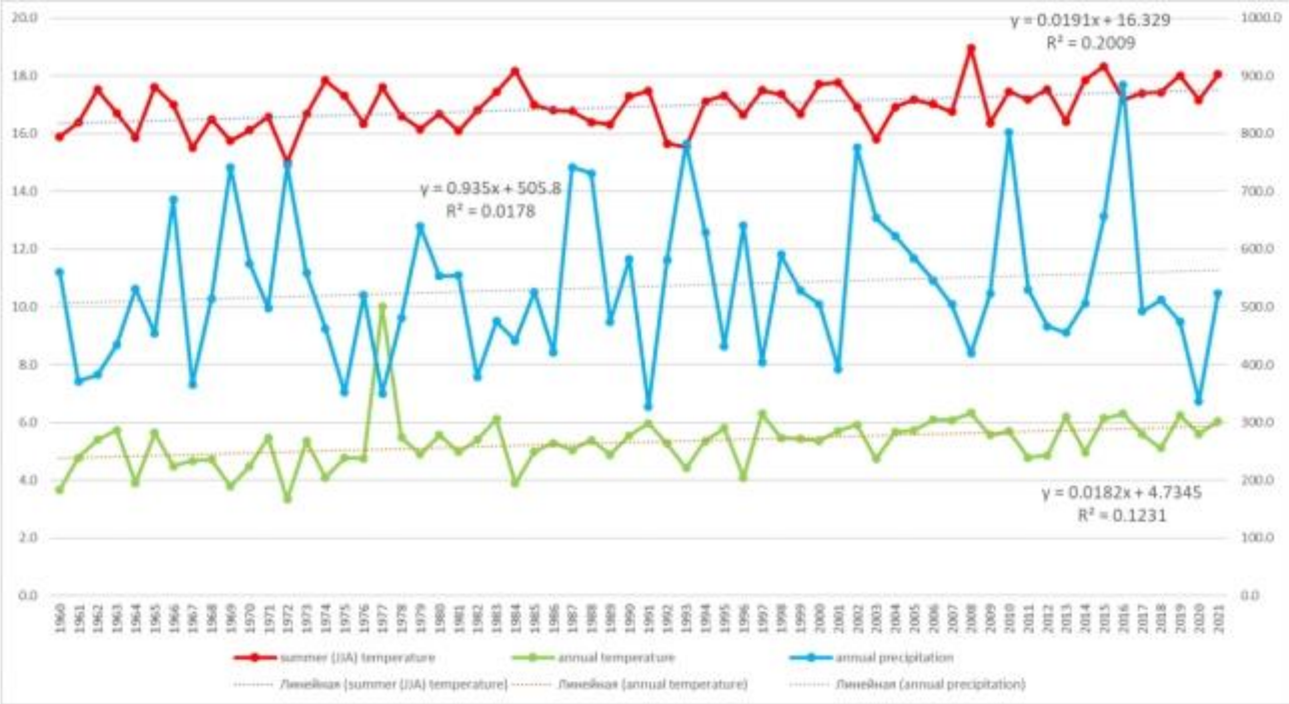


Figure 4.9 - Annual and summer (June-August) temperature and annual precipitation at Kogaly MS

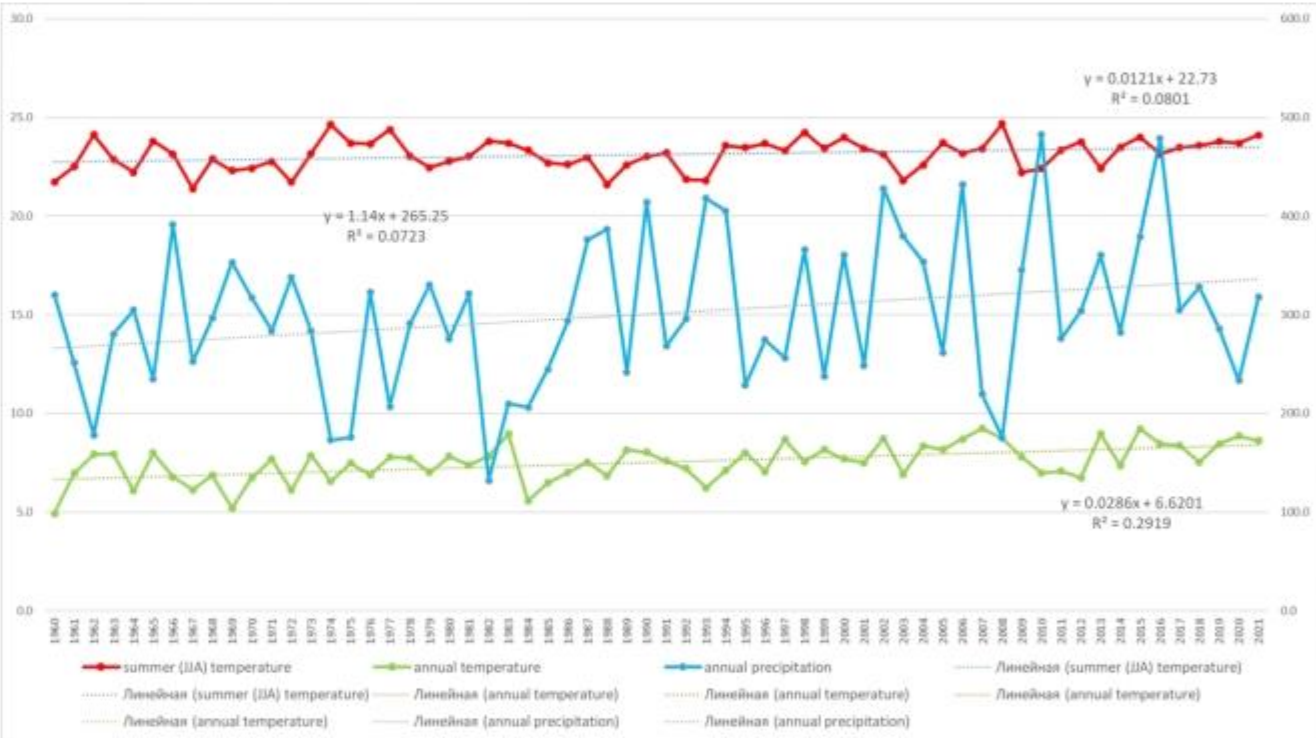


Figure 4.10 – Annual and summer (June-August) temperature and annual precipitation at Usharal MS

Thus, in contrast to the air temperature, the change in the precipitation regime in the study area is a more variegated picture. The time series of anomalies in annual precipitation totals for the period 1960-2021 give a general idea of the nature of modern changes in the precipitation regime. In the last 40-year period, there were no long-term trends; there was an alternation of short periods with positive and negative anomalies in the amount of precipitation.

Climatic conditions play a major role in the state of glaciers. The location of the region under study on the periphery of the Tien Shan mountain system has less favorable climatic conditions than the inner ranges. Two main climatic factors, a significant increase in temperature and a slight change in precipitation, played a major role in the negative balance of glaciation in the Zhetysu Alatau.

CONCLUSION

1) Brief conclusions on the results of the research:

In 2020, archival and current remote sensing data of various types and resolutions were selected for the territory of Zhetysu Alatau. A detailed literature review on the main objectives of the project was carried out, published materials on the study of the glaciers mass balance, active rock glaciers and the glacier area change were analyzed. A database of archival and actual data of remote sensing of various types and resolutions has been created for the study of the Zhetysu Alatau glaciers.

In 2021, glaciers were mapped from remote sensing data using a semi-automatic band ratio technique. The rock glaciers of the Zhetysu Alatau have been identified and mapped using high-resolution Google Earth optical and SAR imagery.

Glaciers were detected in all seven river basins for Zhetysu Alatau using Landsat satellite images from 1989 to 2020, at the end of the ablation period (end of the summer season). On the basis of natural and climatic characteristics (the presence of clouds, fog, the amount of snow cover, etc.), a selection of images suitable for analysis was carried out, namely, for 2001, 2012 and 2016. The area of glaciers on the selected satellite images was determined by the semi-automatic band ratio technique. Detailed analysis was made of the rate of shrinkage in the glaciers area.

As a result, 897 glaciers were identified in 2001, 842 in 2012 and 813 in 2016, which were listed in the Catalog of Glaciers with a total area of 517.4, 453.7 and 414.6 km^2, respectively. The largest area of glaciers in the Zhetysu Alatau is occupied by glaciers up to 1.0 km^2 in size for all three periods of time. In total, about 90% of the glaciers of the Zhetysu Alatau are glaciers with an area of up to 1 km^2. Glaciers with an area of more than 1 km^2 make up more than 10%, but in general, in the covered area of the glaciers of the Zhetysu Alatau, it is 60%.

The total reduction in glacier area between 1956 and 2001 was -36.4 ± 2.8% or 296.2 ± 8.3 km^2, decreasing from 813.6 km^2 to 517.4 ± 14.5 km^2, while how the number of glaciers decreased from 985 to 897. During the period from 1956 to 2016, the area of glaciers decreased by - 49 ± 2.8% or 399 ± 11.2 km^2 (from 813.6 km^2 to 414.6 km^2), the number of glaciers decreased from 985 to 813.

In the period from 2001 to 2012, the number of glaciers in Zhetysu Alatau (Kazakhstan part) decreased from 897 to 842, and in the period from 2001 to 2016 from 897 to 813 glaciers. In the period from 2012 to 2016, the total area of glaciers decreased by 8.6 ± 2.8% and decreased from 453.7 km^2 to 414.6 km^2.

In addition, in Zhetysu Alatau in 1956 there were 385 glaciers with an area of less than 0.1 km^2. In 1956, the total area of these glaciers was 18.9 km^2, in 2001 their area decreased to 5.1 km^2, in 2016 to 3 km^2.

Interferometric processing by the SBAS (Small Baselines) method of radar data was carried out. Zones of horizontal and vertical displacements are revealed. Zhetysu Alatau rock glaciers have been identified and mapped using high-resolution Google Earth optical and SAR imagery. Using the results of radar interferometry, a classification of active rock glaciers was carried out according to their displacement velocity. For general statistics, both inactive and relict rock glaciers are included.

The study provided the first comprehensive up-to-date documentation on the characteristics of rock glaciers in the Zhetysu Alatau.

A total of 848 rock glaciers were identified with an area of more than 83.4 km^2 and with an average lower limit at an altitude of 3018 m above sea level; the average area of individual units was 0.10 km^2. The largest rock glacier in the area has an area of 1.53 km^2, while the smallest rock glacier has an area of about 0.003 km^2. The displacement rate of rock glaciers in the Zhetysu Alatau reached 252 mm/yr.

Most of them had a northern (northern, northeastern, northwestern) orientation, which indicates the important role of solar insolation in their formation and preservation. Slopes with lower PISR favored the development of rock glaciers. The height of rock glaciers generally increased from east to west and decreased from south to north, indicating the effect of latitude and longitude on rock glacier height.

The most amount of rock glaciers were found in the Karatal river basin - 238 pieces with a total area of 17.3 km^2. The lowest rates of glaciers both in number and area are in the Yrgaity River basin - 47 pieces with a total area of 4.2 km^2. Perhaps this is due to the fact that the territory of the Yrgaity river basin itself is the smallest. Also, in this basin there are the least glaciers. Although Karatal basin is the leader in terms of quantity, rock glaciers in the Lepsy-Baskan basin predominate in terms of area.

This inventory has provided a baseline dataset for further studies of rock glaciers as a reservoir, as well as permafrost for slope instability, water resources, and emissions.

In 2022, an assessment was made of elevation changes and mass balance of glaciers on a regional scale for Zhetysu Alatau based on remote sensing data. Our method for calculating the geodetic mass balance of glaciers is based on the DEM differencing. The elevation difference arising from the different possibilities of penetration through the surface of the C-band and X-band microwave radiation is taken into account. The method used includes the stages of horizontal co-registration of compared digital models based on reference points obtained over stable regions and calculation of elevation changes.

According to our data, the regional average value of the mass balance per year for the Zhetysu Alatau glaciers averaged -0.44 m w.e. a^{-1}. These mass balance indicators are in good agreement with the GLIMS data. It has been established that the fastest mass loss occurs in the Yrgaity and Tentek basins, where it is -0.59 w.e. a^{-1}. and -0.55 w.e. a^{-1}, respectively. And in the Aksu, Lepsy and Karatal basins, the relatively slowest loss is -0.35, -0.38 and -0.40 w.e. a^{-1}, respectively. The rate of mass loss correlates well with the loss of glacier area.

For a more detailed analysis of the reason for the sharp reduction in the glacier, we analyzed climate data. Estimates of air temperature trends showed that the temperature rise occurs at all stations in all seasons and months of the year. Rates of temperature change are observed in the mountainous areas of Zhetysu Alatau (Kogaly MS), where the average rate of change was 0.12 ºC/10 years. Trends in summer temperature changes (June-August) showed that in mountainous and foothill areas they have the highest values and range from 0.19 ºC/10 years (Kogaly MS) to 0.25 ºC/10 years (Taldykogan MS). An analysis of trends in change has shown that a steady increase in air temperature has been observed in the study area over the past decades.

In the trends of the average annual precipitation over the territory, there is a tendency to an increase in annual precipitation (up to 11 mm / 10 years), the only exception is the Sarkand MS, where there is a slight decrease in precipitation. At the same time, in the last years of 2019 and 2020, there was a deficit of atmospheric precipitation at the three Taldykorgan, Usharal and Kogaly stations.

It has been established that climatic conditions play a main role in the state of glaciers. The location of the region under study on the periphery of the Tien Shan mountain system has less favorable climatic conditions than the inner ranges. Two main climatic factors, a significant increase in temperature and a slight change in precipitation, played a main role in the negative balance of glaciation in the Zhetysu Alatau.

2) Evaluation of the completeness of solutions to the tasks. Planned tasks for 2020-2022 for the project were fully implemented in accordance with the schedule (APPENDIX A), there were no adjustments or reductions.

3) Recommendations and background data on the specific use of the results.

The results of the work can be used by organizations and research institutes in the field of water resources, glaciology, hydrology, ecology and emergency situations. Application area: glaciology, water resources, hydrology, meteorology, remote sensing, ecology.

4) Evaluation of the technical and economic efficiency of implementation. The introduction of R&D at this stage was not envisaged. The project has a non-commercial research character. The social demand and economic interest in the implementation of the project is determined by the fact that the results obtained can contribute to the long-term economic and social development of Kazakhstan through their use in planning the use of water resources, can help reduce dangerous processes associated with glaciers, in the development of new knowledge necessary to solve economic, scientific and practical tasks.

5) Evaluation of the scientific and technical level of R&D implementation in comparison with the best achievements in this field. The satellite technologies used in the project, remote sensing data and their processing methods determine the high scientific and technical level of the project. Experimental and theoretical studies were carried out at a high scientific and technical level, the results obtained correspond to accepted standards in terms of quality. The work was carried out with the participation of specialists with many years of experience in this field. Information on training is given in Appendix D.

6) Information about publications:

In 2020-2022, 1 scientific work was published in domestic scientific journals in the CQASE (Committee for Quality Assurance in the Sphere of Education) list, 2 articles in peer-reviewed scientific journals indexed in the Web of Science database, 1 article in the proceedings of an international conference in the Scopus database, 2 articles are under review for publication in peer-reviewed scientific publications indexed in the Web of Science database, 1 article has been prepared for submission in peer-reviewed scientific publications indexed in the Web of Science database. Abstracts have been accepted and it is planned to participate in 2 international conferences with an oral presentation (Appendix B).

7) Personnel training: Young scientists take part in the project: S.M. Nurakynov - PhD student of KazNTU named after. Satpaeva with a degree in Geodesy, N.K. Sydyk, D.V. Chepashev - PhD students of KazNU. al-Farabi with a degree in Space Engineering and Technology, K.B. Zulpykharov - PhD student of KazNU. al-Farabi with a degree in Land Management, A.S. Urazaliev - PhD student of KazNTU named after. Satpaeva with a degree in Geodesy, Eliseeva A.V. - Master of KazNU named after. al-Farabi with a degree in Cartography, A.A. Merekeev - undergraduate KazNU named after. Al-Farabi majoring in Geoinformatics

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APPENDIX A

Calendar plan for the implementation of research works

ПРИЛОЖЕНИЕ А

Календарный план работ за 2020-2022 гг.

к договору от «12» ноября 2020 г. №252

1. ДТОО «Институт ионосферы»

1.1. По приоритету: 3. Информационные, телекоммуникационные и космические технологии.

1.2 По подприоритету: 3.3. Космические технологии; 3.3.3 Развитие научной и экспериментальной базы исследований дальнего и ближнего космоса.

1.3 По теме проекта: ИРН AP08856470 Оценка баланса массы ледников в региональном масштабе и инвентаризация каменных глетчеров Жетысуского Алатау с использованием данных дистанционного зондирования.

1.4 Общая сумма проекта 60 946 460,26 (шестьдесят миллионов девятьсот сорок шесть тысяч четыреста шестьдесят) тенге 26 тиын, в том числе с разбивкой по годам, для выполнения работ согласно пункту 3:

- на 2020 год - в сумме 16 698 272,26 (шестнадцать миллионов шестьсот девяносто восемь тысяч двести семьдесят две) тенге 26 тиын;

- на 2021 год - в сумме в сумме 19 499 500,33 (девятнадцать миллионов четыреста девяносто девять тысяч пятьсот) тенге 33 тиын;

- на 2022 год - в сумме 24 748 687,67 (двадцать четыре миллиона семьсот сорок восемь тысяч шестьсот восемьдесят семь) тенге 67 тиын.

2.1. Характеристика научно-технической продукции по квалификационным признакам и экономические показатели

2.1 Направление работы: Исследование ледников с использованием данных ДЗЗ, оценка баланса массы ледников в региональном масштабе, а также инвентаризация активных каменных глетчеров Жетысуского Алатау по оптическим и радиолокационным снимкам.

2.2 Область применения: гляциология, водные ресурсы, гидрология, физическая география, ЧС.

2.3 Конечный результат:

- за 2020 год: База архивных и актуальных данных дистанционного зондирования Земли различного типа и разрешения для территории Жетысуского Алатау; Подробный обзор предыдущих исследований;

- за 2021 год: Обновленный каталог ледников и каменных глетчеров и расположение высоты равновесной линии (ELA) над Жетысуским Алатау: Обновленные отчеты о характеристиках ледника, скорости сокращения площади ледников для исследуемого района, Обновленный каталог активных каменных глетчеров с использованием снимков SAR и Google Earth, Обновленные отчеты о высоте равновесно линии (ELA) для оледенения Жетысуского Алатау, Информация о точности картирования ледников;

- за 2022 год: Знание о изменениях высоты и баланса массы ледников в региональном масштабе для Жетысуского Алатау по данным дистанционного зондирования Земли: Цифровые модели рельефа для Жетысуского Алатау с использованием данных дистанционного зондирования; Информация о характеристиках проникновения микроволн; Информация о средней плотности ледников исследуемого района; Изменение высоты поверхности ледников во времени и баланс массы ледников; Информация о точности расчёта баланса массы ледников.

Будут опубликованы 2 публикаций в рецензируемых зарубежных научных изданиях, индексируемых Web of Science, входящих 1-3 квартили или имеющих процентиль по CiteScore в базе Scopus не менее 50, а также не менее 1 статьи в рецензируемом зарубежном или отечественном издании с ненулевым импакт-фактором, рекомендованном КОКСОН.

2.4 Патентоспособность: отсутствует объект патентования.

2.5 Научно-технический уровень (новизна): Впервые предлагается детальная оценка баланса массы ледников всего Жетысуского Алатау в региональном масштабе с использованием данных дистанционного зондирования Земли с высоким временным и пространственным разрешением. Будет применяться геодезический метод оценки баланса массы ледника путем использования архивных и актуальных цифровых моделей рельефа. Впервые будет составлен каталог каменных глетчеров. Будет обновлен каталог ледников и определена динамика сокращения ледников для исследуемого региона.

2.6 Использование научно-технической продукции осуществляется: Исполнителем

2.7 Вид использования результата научной и (или) научно-технической деятельности: Отчет о НИР, научные публикации. Будут опубликованы в рецензируемых физических научных изданиях, доложены на международных конференциях, также будут использованы студентами соответствующих специальностей при разработке дипломных проектов.

3. Наименование работ, сроки их реализации и результаты

Шифр задания, этапа	Наименование работ по Договору и основные этапы его выполнения*	Срок выполнения*		Ожидаемый результат*
		начало	окончание	
		2020 год		
1	Отбор архивных и актуальных данных ДЗЗ различного типа и разрешения для территории Жетысуского Алатау; Детальный обзор предыдущих исследований.	октябрь 2020 г.	декабрь 2020 г.	База архивных и актуальных данных дистанционного зондирования Земли различного типа и разрешения для территории Жетысуского Алатау; Детальный обзор предыдущих исследований.
		2021 год		
2.	Идентификация и картографирование ледников и каменных глетчеров, определение высоты равновесной линии (ELA) над Жетысуским Алатау.	январь 2021 г.	15 ноября 2021 г.	Будет идентификация и картографирование ледников и каменных глетчеров, определение высоты равновесной линии (ELA) над Жетысуским Алатау.
2.1	Картографирования ледников по данным дистанционного зондирования с использованием полуавтоматической	январь 2021 г.	июнь 2021 г.	Будет проведено картографирование ледников по данным дистанционного зондирования с использованием полуавтоматической методики

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	методики соотношения полос (band ratio).			соотношения полос (band ratio). Обновленные отчеты о характеристиках ледника, скорости сокращения площади ледников для исследуемого района.
2.2	Идентификация и картирование активных каменных глетчеров с использованием снимков SAR и Google Earth.	июль 2021 г.	15 ноября 2021 г.	Будет проведено идентификация и картографирование активных каменных глетчеров с использованием снимков SAR и Google Earth. Обновленный каталог активных каменных глетчеров.
2.3	Определение высоты равновесной линии (ELA) для оледенения Жетысуского Алатау; Оценка точности картографирования ледников.	октябрь 2021 г.	15 ноября 2021 г.	Будут определены высоты равновесной линии (ELA) для оледенения Жетысуского Алатау; Оценка точности картирования ледников.
2022 год				
3.	Оценка изменений высоты и баланса массы ледников в региональном масштабе для Жетысуского Алатау с использованием данных дистанционного зондирования Земли.	январь 2022 г.	1 ноября 2022 г.	Оценка изменений высоты и баланса массы ледников в региональном масштабе для Жетысуского Алатау по данным дистанционного зондирования Земли. Будут опубликованы 2 публикаций в рецензируемых зарубежных научных изданиях, индексируемых Web of Science, входящих 1-3 квартили или имеющих процентиль по CiteScore в базе Scopus не менее 50, а также 1 статья в рецензируемом зарубежном или отечественном издании с ненулевым импакт-фактором, рекомендованном КОКСОН.
3.1	Создание бистатических цифровых моделей рельефа с использованием данных дистанционного зондирования.	январь 2022 г.	июнь 2022 г.	Цифровые модели рельефа с использованием данных дистанционного зондирования.
3.2	Коррекция микроволнового проникновения по данным SRTM-X и SRTM-C; Определение плотности	март 2022 г.	июнь 2022 г.	Коррекция микроволнового проникновения по данным SRTM-X и SRTM-C; Определение плотности ледников исследуемого района.

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	ледников исследуемого района.			
3.3	Определение и расчет изменения высоты поверхности ледников во времени и преобразование изменения объема в баланс массы ледников.	июль 2022 г.	1 ноября 2022 г.	Будут определены и рассчитаны изменения высоты поверхности ледников во времени и преобразование изменения объема в баланс массы ледников.
3.4	Оценка точности расчёта баланса массы ледников.	октябрь 2022	1 ноября 2022 г.	Оценка точности расчёта баланса массы ледников.

От Заказчика:
Председатель
ГУ «Комитет науки Министерства образования и науки РК»

_____________ **Курмангалиева Ж.Д.**

М.П.

От Исполнителя:
Директор
ДТОО «Институт ионосферы»

_____________ **Жантаев Ж.Ш.**

М.П.

Ознакомлен:
Научный руководитель проекта

_____________ **Калдыбаев А.А.**
(подпись)

Name of work, terms of their implementation and results

№ п/п	Name of tasks, activities for the implementation of project objectives	Project start date (dd/mm/yy)	Duration (at months)	Expected results of the project (in the context of tasks and activities)		
				2020	2021	2022
1.	Selection of archival and relevant remote sensing data of various types and resolutions for the territory of Zhetysu Alatau; A detailed review of previous studies.	01/10/2020-31/12/2020	3	Data base of archival and relevant remote sensing data of various types and resolutions for the territory of Zhetysu Alatau; Detailed review of previous studies.		
2.	Identifying and mapping of glaciers and rock glaciers, delineation of ELA over the Zhetysu Alatau:	01/01/2021-31/12/2021	12		Updated catalogue of glaciers and rock glaciers and location of ELA over the Zhetysu Alatau	
2.1	Delineation of glacier outlines using remote sensing data using semi-automated band ratio technique	01/01/2021-31/06/2021	6		Updated reports about the glacier characteristics, area shrinkage rate	
2.2	Identifying and mapping active rock glaciers using SAR and Google Earth images	01/07/2021-31/12/2021	6		Updated catalogue of active rock glaciers using SAR and Google Earth images	
2.3	Delineation of equilibrium-line altitude (ELA) for glacierized regions of Zhetysu Alatau; Estimation of the accuracy of glacier area outline.	01/9/2021-31/12/2021	3		Updated reports about equilibrium-line altitude (ELA) for glacierized regions of Zhetysu Alatau; Accuracy information of glacier mapping.	
3.	Region-wide glacier elevation changes and mass balance for the Zhetysu Alatau using remote sensing data	01/01/2022-31/12/2022	12			Knowledge about the region-wide glacier elevation changes and mass balance for the Zhetysu Alatau using remote sensing data

3.1	Creation of bi-static digital elevation models using remote sensing data	01/01/2022-31/06/2022	6			Digital elevation models for the Zhetysu Alatau using remote sensing data
3.2	Microwave penetration correction using SRTM-X and SRTM-C data; Determination of density for the glaciers of study area;	01/03/2022-31/06/2022	3			Information about penetration characteristics of microwaves; Mean density information for the glaciers of study area;
3.3	Detect and measure surface elevation change over time and conversion from volume change to mass balance of glaciers;	01/07/2022-31//12/2022	6			Surface elevation change over time and mass balance of glaciers;
3.4	Estimation of the accuracy of mass balance products	01/09/2022-30/12/2022	3			Accuracy information of mass balance assessments.

APPENDIX B

List of published works and information on participation in conferences

1. Kaldybayev A, Chen Ya. Assessment of changes in the area of glaciers in the northern part of the Zhetysu Alatau based on remote sensing data // Bulletin of KazNU. Geographic series. - 2022. - No. 3. (Impact factor in the Kazakhstan citation base 0.049) (published in Russian)

2. Zhantayev Zh., Nurakynov S., Kaldybayev A A Sydyk N. The role of Web-Based GIS system in the control and prevention of natural and manmade hazards in Kazakhstan // 20h International Multidisciplinary Scientific Geoconference SGEM. – 2020. Albena, Bulgaria, 2020. (Scopus, Percentile – 17) (published in English)

3. Issanova, G., Abuduwaili, J., Tynybayeva, K. Kalybayeva A, Saduakhas A, Kulymbet K, Kaldybayev A, Erlan G, Tanirbergenov S. Soil salinisation as a land degradation process in the dried bed of the North-eastern Aral Sea, Kazakhstan. Arabian Journal of Geoscience 15, 1055 (2022). https://doi.org/10.1007/s12517-022-09627-w (Percentile -54) (published in English)

Accepted for publication:

4. Tokbergenova A, Zulpykharov K, Kaliyeva D, Esanbekov M Assessment of the current soil-reclamation state of the soils of Myrzashol in the Kazakhstan part (The Hungry Steppe) Polish Journal of Environmental Studies, 2022. (PJOES-00775-2022-03) (Percentile -55) (published in English)

Under review:

5. Kaldybayev A., Zulpykharov K., Nurakynov S. Merekeev A. Nyssanbayeva A., Issanova G. Accelerated glacier area loss in the Zhetysu (Dzhungar) Alatau for the 1956-2016 // Remote Sensing: Special Issue “Satellite Earth Observation of Climate Change Effects on Glaciers and Ice Sheets” ISSN 2072-4292 (WoS: Q1, Percentile -91) (will be published in English)

6. Kaldybayev A., Sydyk N., Yelesseeva A. Issanova G. The first inventory of the rock glaciers of the Zhetysu Alatau: the basins of the Aksu and Lepsy river // Remote Sensing: Special Issue “Remote Sensing of the Cryosphere” ISSN 2072-4292 (WoS: Q1, Percentile -91) (will be published in English)

Accepted oral presentation at the international conference:

7. Kaldybayev Azamat, Wang Sonam, «Glaciers cover changes in Snow Leopards' habitats Dzhungar Alatau Tien Shan Mountains Central Asia areas» in Resilience Center (ARC) Conference 2022 “Water-Food-Energy Nexus in Ecosystems” Seoul, Korea 2-5 November

8. Offline participation with an oral presentation at the conference “The Cryosphere and Associated Hazards in High Mountain Asia under the Conditions of Climate Change” organized by UNESCO, November 1-4, 2022 in Almaty, Kazakhstan.

Prepared for submission:

9. Kaldybayev A., Chepashev D, Sagatdinova G, Assessment of Changes in glacier mass balance for Zhetysu Alatau using remote sensing data. International Journal of Remote Sensing

APPENDIX C

Catalog of stone glaciers of Zhetysu Alatau

	Karatal										
No	OBJECTID	FID	Area	X	Y	MIN	MAX	RANGE	MEAN	STD	MEDIAN
1	1	0	0,151	79,198	44,732	1993	2265	272	2128,2	63,7	2128
2	2	1	0,034	79,466	44,706	3047	3117	70	3091,7	16,3	3095
3	3	2	0,035	79,448	44,638	3136	3196	60	3163,0	15,4	3159
4	4	3	0,013	79,389	44,590	3267	3301	34	3281,8	6,4	3282
5	5	4	0,036	79,238	44,675	2781	2910	129	2856,2	33,1	2860
6	6	5	0,068	79,457	44,708	2875	2960	85	2917,1	20,8	2917
7	7	6	0,010	79,375	44,623	2999	3043	44	3021,6	10,3	3024
8	8	7	0,051	79,327	44,600	2821	2923	102	2886,4	22,0	2887
9	9	8	0,028	79,309	44,602	2902	2931	29	2913,1	7,0	2912
10	10	9	0,031	79,376	44,465	2870	2922	52	2893,2	14,8	2889
11	11	10	0,017	79,354	44,447	2982	3011	29	2995,8	7,6	2995
12	12	11	0,043	79,369	44,452	2883	2940	57	2913,4	10,8	2915
13	13	12	0,038	79,157	44,936	2984	3047	63	3018,2	15,4	3019
14	14	13	0,019	79,217	44,871	3122	3186	64	3152,5	15,9	3152
15	15	14	0,029	79,278	44,973	3082	3117	35	3100,3	8,4	3100
16	16	15	0,098	79,421	44,938	3171	3260	89	3217,2	18,6	3215
17	17	16	0,016	79,425	44,940	3218	3252	34	3238,6	9,3	3240
18	18	17	0,028	79,417	44,840	3155	3211	56	3181,9	12,0	3183
19	19	18	0,025	79,736	44,863	2991	3026	35	3010,1	6,9	3012
20	20	19	0,016	79,740	44,862	3049	3096	47	3067,8	10,5	3066
21	21	20	0,005	79,739	44,861	3076	3117	41	3092,1	10,9	3089
22	22	21	0,192	79,834	44,912	2505	2634	129	2561,1	25,9	2559
23	23	22	0,011	79,887	44,921	3116	3171	55	3141,8	15,6	3140
24	24	23	0,096	79,703	44,863	2491	2627	136	2562,5	25,6	2564
25	25	24	0,208	79,536	44,900	2586	2767	181	2667,4	38,1	2663
26	26	25	0,026	79,585	44,916	3004	3070	66	3043,2	19,4	3044
27	27	26	0,018	79,608	44,927	3449	3484	35	3464,4	8,1	3465
28	28	27	0,031	79,607	44,924	3304	3412	108	3338,6	29,0	3328
29	29	28	0,018	79,730	44,924	2779	2812	33	2790,1	9,0	2787
30	30	29	0,036	79,797	44,937	3120	3193	73	3161,1	13,7	3163
31	31	30	0,057	79,890	44,961	2964	3059	95	3002,7	21,3	3003
32	32	31	0,022	79,184	44,997	2446	2511	65	2484,2	14,3	2485
33	33	32	0,629	79,859	44,793	3134	3442	308	3242,5	44,3	3241
34	34	33	0,195	79,924	44,937	3172	3300	128	3229,1	20,2	3229
35	35	34	0,402	79,933	44,942	3230	3443	213	3326,6	48,8	3320
36	36	35	0,099	79,596	44,933	3299	3428	129	3352,0	29,6	3353
37	37	36	0,009	79,202	44,985	2870	2882	12	2877,8	3,5	2878
38	38	37	0,009	79,199	44,985	2878	2902	24	2887,6	6,2	2886
39	39	38	0,022	79,164	45,000	2614	2666	52	2641,7	13,0	2644
40	40	39	0,101	79,163	44,996	2670	2805	135	2732,1	30,8	2730

41	41	40	0,019	79,147	44,999	2707	2767	60	2740,3	14,0	2741
42	42	41	0,024	79,148	45,002	2609	2666	57	2640,6	12,7	2641
43	43	42	0,010	79,148	45,004	2550	2618	68	2584,0	19,4	2585
44	44	43	0,088	79,134	44,981	2613	2719	106	2671,1	26,4	2674
45	45	44	0,009	79,138	44,977	2728	2798	70	2759,6	18,3	2757
46	46	45	0,009	79,119	44,982	2631	2695	64	2658,0	14,7	2658
47	47	46	0,030	79,187	44,986	2931	3000	69	2969,1	15,0	2971
48	48	47	0,029	79,432	44,841	3119	3145	26	3134,8	5,6	3136
49	49	48	0,008	79,565	44,894	2648	2737	89	2685,3	22,6	2682
50	50	49	0,022	79,567	44,898	2627	2689	62	2661,5	15,8	2662
51	51	50	0,012	79,579	44,906	2860	2934	74	2901,2	21,2	2905
52	52	51	0,008	79,581	44,904	2998	3061	63	3033,2	17,4	3033
53	53	52	0,010	79,576	44,904	2820	2871	51	2847,4	14,2	2847
54	54	53	0,060	79,572	44,902	2718	2810	92	2773,8	22,9	2777
55	55	54	0,042	79,592	44,909	2994	3054	60	3022,4	13,1	3023
56	56	55	0,032	79,621	44,919	3337	3371	34	3350,4	8,3	3349
57	57	56	0,028	79,639	44,890	3165	3199	34	3178,1	8,1	3176
58	58	57	0,083	79,712	44,940	3032	3113	81	3061,4	13,7	3060
59	59	58	0,096	79,707	44,940	3076	3167	91	3110,2	17,3	3109
60	60	59	0,019	79,752	44,857	3062	3124	62	3081,9	16,5	3076
61	61	60	0,005	79,750	44,855	3129	3146	17	3137,2	4,3	3138
62	62	61	0,037	79,840	44,908	2763	2906	143	2826,1	36,7	2823
63	63	62	0,069	79,855	44,920	2570	2697	127	2636,0	25,6	2633
64	64	63	0,015	79,857	44,914	2887	2976	89	2934,6	24,4	2936
65	65	64	0,033	79,833	44,955	3021	3085	64	3054,6	15,4	3055
66	66	65	0,030	79,799	44,924	3002	3072	70	3040,8	16,5	3042
67	67	66	0,096	79,096	44,998	2655	2762	107	2698,8	19,0	2700
68	68	67	0,030	79,095	44,986	3056	3096	40	3071,5	9,5	3071
69	69	68	0,045	79,739	44,761	2940	3051	111	2982,3	24,5	2979
70	70	69	0,028	79,710	44,762	2835	2984	149	2900,9	43,0	2893
71	71	70	0,053	79,660	44,745	3002	3133	131	3046,3	29,3	3040
72	72	71	0,116	79,628	44,730	3113	3259	146	3156,6	25,5	3153
73	73	72	0,055	79,261	44,699	2781	2892	111	2843,1	24,6	2848
74	74	73	0,081	79,170	44,717	2779	2893	114	2841,3	26,4	2840
75	75	74	0,098	79,160	44,655	2979	3141	162	3066,2	38,2	3075
76	76	75	0,286	79,371	44,635	2576	2901	325	2787,7	78,4	2794
77	77	76	0,205	79,508	44,903	2830	3179	349	3013,9	83,9	3031
78	78	77	0,055	79,593	44,935	3312	3396	84	3341,1	14,2	3340
79	79	78	0,059	79,584	44,908	2888	2968	80	2932,5	15,9	2933
80	80	79	0,079	79,605	44,894	2984	3172	188	3054,3	41,8	3044
81	81	80	0,011	79,086	44,436	2752	2798	46	2772,8	11,5	2772
82	82	81	0,024	79,414	44,456	3014	3040	26	3024,9	5,9	3023
83	83	82	0,042	79,405	44,472	2711	2794	83	2758,2	21,1	2759
84	84	83	0,026	79,372	44,452	2934	2961	27	2945,4	7,1	2943
85	85	84	0,038	79,367	44,451	2902	2988	86	2946,8	20,5	2948
86	86	85	0,028	79,355	44,452	2846	2912	66	2878,4	19,2	2880

87	87	86	0,014	79,351	44,451	2865	2897	32	2882,7	7,9	2884
88	88	87	0,009	79,353	44,449	2916	2955	39	2935,3	8,6	2935
89	89	88	0,031	79,429	44,591	3268	3350	82	3314,4	20,8	3316
90	90	89	0,007	79,318	44,596	3054	3072	18	3064,3	4,6	3065
91	91	90	0,010	79,372	44,586	3186	3215	29	3199,5	7,2	3199
92	92	91	0,004	79,378	44,584	3272	3287	15	3279,3	4,1	3279
93	93	92	0,027	79,382	44,588	3223	3279	56	3250,1	13,0	3251
94	94	93	0,010	79,381	44,587	3234	3260	26	3246,0	7,0	3246
95	95	94	0,006	79,385	44,607	3310	3359	49	3329,4	12,1	3327
96	96	95	0,009	79,374	44,602	3132	3161	29	3146,7	7,6	3146
97	97	96	0,012	79,367	44,602	3061	3093	32	3081,2	7,7	3082
98	98	97	0,187	79,383	44,621	3045	3203	158	3112,8	26,2	3117
99	99	98	0,036	79,353	44,589	3011	3068	57	3043,3	13,7	3045
100	100	99	0,063	79,402	44,583	3143	3230	87	3193,1	19,5	3195
101	101	100	0,011	79,344	44,647	2741	2814	73	2781,3	17,5	2782
102	102	101	0,183	79,249	44,704	2661	2873	212	2778,7	52,5	2790
103	103	102	0,012	79,248	44,711	2520	2593	73	2568,6	20,1	2576
104	104	103	0,024	79,239	44,706	2640	2718	78	2686,9	19,2	2690
105	105	104	0,022	79,211	44,651	3045	3112	67	3083,9	15,1	3089
106	106	105	0,067	79,205	44,644	3040	3090	50	3068,3	11,7	3070
107	107	106	0,065	79,272	44,694	2903	3008	105	2960,6	23,1	2962
108	108	107	0,129	79,262	44,703	2670	2780	110	2737,1	20,5	2739
109	109	108	0,012	79,259	44,703	2723	2741	18	2733,4	4,5	2735
110	110	109	0,019	79,237	44,701	2798	2849	51	2822,9	14,7	2820
111	111	110	0,035	79,233	44,709	2617	2723	106	2671,9	26,8	2671
112	112	111	0,008	79,232	44,708	2728	2756	28	2741,3	7,4	2741
113	113	112	0,056	79,232	44,705	2762	2833	71	2811,1	15,8	2816
114	114	113	0,027	79,220	44,710	2733	2812	79	2763,1	15,2	2762
115	115	114	0,018	79,217	44,713	2725	2774	49	2747,0	13,1	2745
116	116	115	0,018	79,132	44,681	2928	3004	76	2977,7	17,3	2982
117	117	116	0,010	79,268	44,655	2832	2882	50	2853,8	13,3	2852
118	118	117	0,037	79,267	44,655	2761	2841	80	2808,0	19,8	2811
119	119	118	0,010	79,300	44,684	3004	3042	38	3024,5	10,1	3022
120	120	119	0,031	79,280	44,692	2871	2945	74	2907,4	18,9	2903
121	121	120	0,019	79,280	44,689	2899	2958	59	2925,3	14,0	2925
122	122	121	0,061	79,268	44,703	2664	2882	218	2814,9	54,4	2831
123	123	122	0,033	79,322	44,710	2826	2884	58	2859,1	11,8	2861
124	124	123	0,010	79,288	44,692	2899	3002	103	2950,6	30,7	2950
125	125	124	0,054	79,428	44,717	2590	2757	167	2685,6	38,9	2686
126	126	125	0,025	79,437	44,712	2737	2806	69	2770,8	16,9	2770
127	127	126	0,052	79,432	44,673	3070	3130	60	3105,3	14,8	3105
128	128	127	0,094	79,476	44,669	3075	3144	69	3110,8	11,3	3112
129	129	128	0,024	79,466	44,668	3103	3186	83	3149,7	23,4	3153
130	130	129	0,009	79,468	44,685	2801	2829	28	2816,1	5,6	2815
131	131	130	0,118	79,494	44,682	2962	3068	106	3027,3	24,2	3029
132	132	131	0,148	79,498	44,684	2925	3053	128	2991,4	26,0	2993

133	133	132	0,261	79,515	44,682	3044	3174	130	3120,9	27,5	3129
134	134	133	0,028	79,458	44,706	2954	3037	83	2987,8	21,0	2983
135	135	134	0,034	79,510	44,696	3302	3432	130	3375,2	33,7	3379
136	136	135	0,060	79,486	44,704	3045	3187	142	3128,7	41,5	3143
137	137	136	0,035	79,475	44,702	3100	3169	69	3133,3	17,1	3129
138	138	137	0,019	79,481	44,703	3088	3111	23	3096,7	4,5	3097
139	139	138	0,028	79,481	44,716	2789	2914	125	2847,9	28,4	2848
140	140	139	0,020	79,488	44,718	2856	2903	47	2878,0	12,0	2878
141	141	140	0,089	79,495	44,709	3060	3123	63	3104,0	13,8	3107
142	142	141	0,011	79,503	44,720	2884	2918	34	2900,6	8,2	2900
143	143	142	0,018	79,502	44,721	2853	2895	42	2872,3	10,3	2871
144	144	143	0,006	79,470	44,722	2805	2845	40	2831,2	10,2	2832
145	145	144	0,022	79,520	44,723	2984	3049	65	3010,4	16,8	3008
146	146	145	0,100	79,617	44,742	2892	2965	73	2929,2	17,8	2926
147	147	146	0,066	79,527	44,730	2859	2934	75	2904,2	16,1	2908
148	148	147	0,031	79,585	44,737	2767	2823	56	2796,0	13,8	2796
149	149	148	0,251	79,601	44,734	2987	3140	153	3087,0	35,9	3094
150	150	149	0,013	79,693	44,754	2688	2745	57	2716,2	14,8	2715
151	151	150	0,037	79,697	44,726	2997	3062	65	3029,9	16,7	3029
152	152	151	0,048	79,735	44,764	2867	2942	75	2913,7	22,7	2919
153	153	152	0,072	79,812	44,799	3074	3193	119	3134,5	25,4	3134
154	154	153	0,014	79,856	44,796	3125	3160	35	3140,7	8,3	3139
155	155	154	0,303	79,856	44,794	3135	3279	144	3223,8	38,0	3215
156	156	155	0,110	79,884	44,804	3240	3317	77	3280,8	17,3	3282
157	157	156	0,323	79,920	44,961	2800	3114	314	2916,8	85,6	2888
158	158	157	0,038	79,925	44,957	3107	3160	53	3138,1	12,6	3141
159	159	158	0,385	79,953	44,975	3043	3263	220	3179,7	38,5	3182
160	160	159	0,210	79,935	44,972	2849	2973	124	2920,9	27,1	2924
161	161	160	0,019	79,841	44,960	3153	3215	62	3192,3	15,6	3197
162	162	161	0,029	79,847	44,962	3328	3401	73	3367,0	16,6	3369
163	163	162	0,039	79,589	44,908	2952	3054	102	2999,6	23,5	3003
164	164	163	0,119	79,280	44,870	3122	3252	130	3185,7	27,3	3186
165	165	164	0,056	79,299	44,930	3000	3085	85	3037,6	19,8	3035
166	166	165	0,006	79,287	44,935	2999	3015	16	3007,5	4,1	3007
167	167	166	0,006	79,287	44,934	3026	3040	14	3033,3	4,1	3033
168	168	167	0,048	79,241	44,939	2691	2806	115	2759,1	23,6	2763
169	169	168	0,003	79,256	44,937	2928	2949	21	2938,8	6,1	2939
170	170	169	0,024	79,258	44,990	2748	2779	31	2766,5	7,1	2767
171	171	170	0,015	79,325	44,969	3234	3278	44	3257,6	11,4	3256
172	172	171	0,035	79,332	44,931	3013	3114	101	3060,2	25,6	3055
173	173	172	0,056	79,124	44,935	2810	2895	85	2859,6	19,3	2863
174	174	173	0,009	79,114	44,932	2808	2837	29	2824,1	8,7	2825
175	175	174	0,020	79,119	44,925	2993	3103	110	3046,1	35,5	3043
176	176	175	0,098	79,178	44,933	2911	2945	34	2931,9	6,0	2933
177	177	176	0,030	79,160	44,938	2945	2991	46	2969,6	9,4	2971
178	178	177	0,020	79,193	44,954	2816	2877	61	2843,6	14,3	2842

179	179	178	0,106	79,200	44,955	2845	3034	189	2969,7	39,8	2982
180	180	179	0,029	79,203	44,956	2952	3023	71	2988,4	17,2	2985
181	181	180	0,087	79,703	44,734	2921	3104	183	3007,4	47,8	2996
182	182	181	0,047	79,938	44,986	3249	3313	64	3282,6	13,1	3283
183	183	182	0,026	79,912	44,984	3322	3404	82	3361,6	19,9	3363
184	184	183	0,026	79,914	44,985	3345	3407	62	3378,7	15,9	3379
185	185	184	0,029	79,911	44,980	3310	3382	72	3355,5	16,9	3358
186	186	185	0,049	79,853	44,945	3202	3288	86	3244,8	19,7	3250
187	187	186	0,042	79,814	44,981	3357	3491	134	3416,0	32,4	3410
188	188	187	0,226	79,818	44,976	3297	3415	118	3365,1	23,4	3369
189	189	188	0,042	79,790	44,970	3292	3385	93	3348,1	25,1	3355
190	190	189	0,042	79,759	44,959	3137	3191	54	3164,4	12,6	3165
191	191	190	0,094	79,752	44,932	3102	3234	132	3181,3	29,1	3188
192	192	191	0,012	79,645	44,897	3028	3063	35	3046,0	8,2	3046
193	193	192	0,544	79,912	44,943	2768	3179	411	3026,4	88,6	3043
194	194	193	0,258	79,902	44,940	2943	3152	209	3066,5	39,2	3078
195	195	194	0,548	79,887	44,935	2633	3170	537	2855,8	148,0	2828
196	196	195	0,033	79,892	44,921	3202	3279	77	3238,4	17,5	3238
197	197	196	0,232	79,864	44,924	2586	2752	166	2632,7	35,3	2620
198	198	197	0,032	79,569	44,858	2979	3040	61	3007,0	10,3	3008
199	199	198	0,207	79,519	44,846	3031	3151	120	3095,3	28,9	3103
200	200	199	0,121	79,500	44,830	3046	3272	226	3152,9	60,7	3162
201	201	200	0,083	79,495	44,830	3068	3221	153	3150,1	47,2	3154
202	202	201	0,151	79,491	44,831	3140	3257	117	3196,1	26,5	3198
203	203	202	0,530	79,482	44,828	2940	3321	381	3139,3	86,1	3125
204	204	203	0,561	79,465	44,825	2891	3241	350	3090,8	84,5	3087
205	205	204	0,270	79,452	44,827	3044	3268	224	3184,7	60,2	3208
206	206	205	0,027	79,430	44,843	3164	3250	86	3207,0	23,7	3205
207	207	206	0,019	79,439	44,847	3223	3248	25	3234,6	5,9	3234
208	208	207	0,091	79,439	44,842	3130	3313	183	3194,1	50,8	3187
209	209	208	0,128	79,439	44,838	3096	3274	178	3151,5	44,4	3138
210	210	209	0,339	79,439	44,829	2808	3155	347	3000,7	89,6	3021
211	211	210	0,076	79,433	44,824	2759	2897	138	2829,2	33,9	2834
212	212	211	0,013	79,422	44,843	3257	3313	56	3283,2	15,3	3285
213	213	212	0,045	79,404	44,844	3137	3190	53	3162,5	13,3	3162
214	214	213	0,050	79,371	44,845	2971	3078	107	3020,8	25,6	3018
215	215	214	0,019	79,370	44,842	3065	3126	61	3103,5	14,6	3107
216	216	215	0,077	79,400	44,860	3149	3288	139	3217,4	33,3	3218
217	217	216	0,134	79,389	44,869	3259	3400	141	3337,8	30,6	3342
218	218	217	0,034	79,376	44,866	3278	3363	85	3323,1	21,4	3324
219	219	218	0,057	79,361	44,865	3169	3274	105	3205,1	24,1	3200
220	220	219	0,044	79,360	44,877	3252	3351	99	3299,9	27,4	3298
221	221	220	0,025	79,344	44,882	3319	3361	42	3329,9	8,1	3328
222	222	221	0,054	79,321	44,872	3094	3279	185	3172,0	50,9	3169
223	223	222	0,071	79,322	44,869	3017	3184	167	3086,4	54,6	3059
224	224	223	0,070	79,281	44,874	3202	3332	130	3265,7	31,9	3262

225	225	224	0,018	79,276	44,882	3381	3410	29	3398,9	7,6	3399
226	226	225	0,046	79,245	44,902	3249	3282	33	3271,9	6,4	3273
227	227	226	0,065	79,073	44,959	2860	3064	204	2982,1	55,6	2992
228	228	227	0,110	79,068	44,969	2799	2926	127	2857,5	26,2	2853
229	229	228	0,235	79,077	44,968	2893	3071	178	2983,6	39,1	2982
230	230	229	0,104	79,288	44,973	3131	3255	124	3192,0	25,0	3194
231	231	230	0,022	79,282	44,981	2992	3049	57	3015,2	9,5	3016
232	232	231	0,043	79,274	44,982	2950	3048	98	2998,9	27,6	2996
233	233	232	0,039	79,267	44,988	2781	2851	70	2812,7	16,1	2811
234	234	233	0,162	79,056	44,965	2609	2812	203	2727,2	56,6	2736
235	235	234	0,107	79,196	44,853	2483	2701	218	2574,7	54,5	2566
236	236	235	0,041	79,154	44,916	2950	3049	99	2996,3	24,1	2992
237	237	236	0,060	79,184	44,884	2738	2852	114	2806,1	24,8	2812
238	238	237	0,037	79,817	44,883	2912	2982	70	2946,9	16,3	2946
	Aksu-Biyen										
	OBJECTID	FID	area	X	Y	MIN	MAX	RANGE	MEAN	STD	MEDIAN
239	1	0	0,065	79,523	44,979	3225	3301	76	3259,3	16,2	3258
240	2	1	0,193	79,510	44,981	3283	3404	121	3359,4	26,1	3361
241	3	2	0,047	79,386	44,993	3183	3234	51	3209,2	9,0	3212
242	4	3	0,021	79,369	44,990	3124	3221	97	3180,1	24,5	3181
243	5	4	0,051	79,359	44,975	3131	3194	63	3159,3	14,9	3156
244	6	5	0,023	79,356	44,984	2988	3043	55	3014,3	13,4	3014
245	7	6	0,031	79,358	44,981	3008	3045	37	3026,1	8,1	3027
246	8	7	0,079	79,268	45,028	2925	3001	76	2970,0	16,0	2974
247	9	8	0,174	79,289	45,031	2746	2924	178	2848,3	43,6	2851
248	10	9	0,063	79,183	45,041	2548	2745	197	2654,3	54,5	2654
249	11	10	0,139	79,359	44,979	3013	3203	190	3080,1	43,6	3069
250	12	11	0,125	79,392	44,993	3158	3222	64	3193,1	11,4	3195
251	13	12	0,141	79,456	44,985	3055	3270	215	3163,1	59,4	3159
252	14	13	0,045	79,448	44,974	3356	3457	101	3412,8	25,5	3411
253	15	14	0,004	79,305	45,011	3013	3038	25	3025,7	6,6	3027
254	16	15	0,061	79,459	44,981	3055	3100	45	3077,4	11,1	3078
255	17	16	0,020	79,334	44,992	2994	3035	41	3015,7	10,2	3017
256	18	17	0,007	79,308	45,010	3072	3089	17	3080,1	4,7	3079
257	19	18	0,010	79,309	45,011	3047	3073	26	3063,7	6,5	3066
258	20	19	0,037	79,303	45,012	2964	3044	80	3008,1	18,5	3009
259	21	20	0,051	79,254	45,024	2922	3024	102	2968,3	23,9	2971
260	22	21	0,034	79,175	45,041	2613	2720	107	2670,5	31,0	2673
261	23	22	0,030	79,150	45,048	2536	2639	103	2598,1	29,3	2605
262	24	23	0,076	79,616	44,978	3339	3421	82	3387,5	14,4	3390
263	25	24	0,022	79,654	44,969	3485	3537	52	3514,2	12,3	3516
264	26	25	0,063	79,669	44,969	3307	3420	113	3341,1	28,5	3333
265	27	26	0,050	79,659	45,004	2838	2944	106	2880,8	28,5	2874
266	28	27	0,018	79,685	45,000	3038	3098	60	3072,5	14,4	3073

267	29	28	0,123	79,694	44,998	2916	3024	108	2970,1	19,8	2971
268	30	29	0,056	79,728	44,995	3373	3451	78	3418,2	17,0	3420
269	31	30	0,035	79,751	45,018	3004	3115	111	3055,7	23,2	3061
270	32	31	0,117	79,772	45,006	3161	3272	111	3210,9	23,4	3213
271	33	32	0,038	79,824	45,003	3406	3443	37	3426,4	7,3	3427
272	34	33	0,205	79,817	45,020	3184	3241	57	3213,7	12,2	3214
273	35	34	0,127	79,666	45,029	2561	2664	103	2597,9	21,1	2596
274	36	35	0,118	79,782	45,035	3384	3540	156	3479,7	40,6	3486
275	37	36	0,227	79,785	45,029	3153	3501	348	3303,3	85,7	3298
276	38	37	0,217	79,738	45,065	3115	3365	250	3227,4	50,4	3214
277	39	38	0,102	79,788	45,075	3214	3333	119	3268,2	34,8	3265
278	40	39	0,054	79,807	45,067	3151	3225	74	3179,3	13,8	3180
279	41	40	0,098	79,811	45,065	3174	3249	75	3214,0	14,8	3214
280	42	41	0,046	79,813	45,068	3150	3226	76	3187,3	12,9	3187
281	43	42	0,055	79,820	45,069	3210	3280	70	3252,6	19,1	3256
282	44	43	0,193	79,842	45,061	3075	3285	210	3174,3	54,7	3165
283	45	44	0,146	79,910	45,061	3132	3360	228	3265,4	60,3	3273
284	46	45	0,055	79,887	45,090	3168	3274	106	3225,8	26,4	3231
285	47	46	0,144	79,880	45,092	2851	3144	293	3026,1	79,4	3045
286	48	47	0,018	79,928	45,102	3057	3093	36	3072,5	9,1	3071
287	49	48	0,032	79,961	45,095	3073	3169	96	3125,6	23,0	3127
288	50	49	0,017	79,962	45,077	3309	3382	73	3346,3	19,9	3347
289	51	50	0,021	79,957	45,073	3367	3450	83	3413,5	22,8	3416
290	52	51	0,079	79,950	45,058	3126	3254	128	3201,5	28,8	3207
291	53	52	0,039	80,035	45,020	3640	3723	83	3683,6	18,3	3687
292	54	53	0,126	80,023	45,019	3559	3705	146	3638,1	29,7	3641
293	55	54	0,170	80,010	44,998	3222	3350	128	3284,2	22,1	3283
294	56	55	0,111	80,016	45,066	3082	3212	130	3136,5	29,3	3140
295	57	56	0,179	80,055	45,061	3063	3180	117	3121,6	28,1	3119
296	58	57	0,108	80,040	45,079	3129	3272	143	3207,5	35,0	3210
297	59	58	0,225	80,141	45,082	3146	3270	124	3220,1	30,9	3223
298	60	59	0,018	80,074	45,082	3252	3291	39	3274,2	10,9	3276
299	61	60	0,129	80,152	45,105	3229	3363	134	3299,9	31,1	3302
300	62	61	0,053	80,144	45,099	3218	3312	94	3283,8	22,9	3295
301	63	62	0,072	80,119	45,124	2877	3017	140	2958,1	32,9	2957
302	64	63	0,110	80,024	45,001	3402	3475	73	3448,0	17,9	3451
303	65	64	0,060	79,635	44,996	2883	3047	164	2951,8	40,6	2944
304	66	65	0,008	80,136	45,106	3064	3073	9	3068,0	2,3	3068
305	67	66	0,107	80,130	45,086	3044	3134	90	3098,4	14,3	3099
306	68	67	0,012	80,107	45,084	3040	3104	64	3073,1	16,1	3072
307	69	68	0,076	80,111	45,086	2923	3037	114	2973,5	27,9	2972
308	70	69	0,014	80,071	45,101	3040	3074	34	3059,2	8,6	3060
309	71	70	0,077	79,944	45,008	3285	3358	73	3329,5	16,0	3332
310	72	71	0,018	80,002	44,997	3169	3211	42	3185,5	9,3	3185
311	73	72	0,063	80,016	44,998	3317	3377	60	3351,2	13,7	3354
312	74	73	0,033	79,987	45,004	3198	3325	127	3260,1	34,1	3256

313	75	74	0,021	79,984	45,008	3190	3278	88	3246,3	21,5	3250
314	76	75	0,048	79,999	45,029	3547	3676	129	3623,2	34,9	3633
315	77	76	0,042	79,944	45,012	3331	3397	66	3372,8	12,4	3374
316	78	77	0,041	79,946	45,027	3123	3228	105	3184,4	29,4	3186
317	79	78	0,297	79,946	45,039	2867	3217	350	3041,8	111,7	3050
318	80	79	0,028	79,936	45,090	3119	3205	86	3163,2	23,3	3161
319	81	80	0,033	79,919	45,094	3117	3158	41	3142,3	9,4	3143
320	82	81	0,061	79,707	45,058	3134	3180	46	3144,3	8,3	3142
321	83	82	0,051	79,709	45,062	3104	3164	60	3134,6	17,1	3137
322	84	83	0,120	79,699	45,061	3108	3227	119	3183,4	25,2	3189
323	85	84	0,029	79,881	45,061	2913	2977	64	2938,5	15,4	2938
324	86	85	0,018	79,775	45,086	2994	3030	36	3010,9	9,7	3010
325	87	86	0,076	79,731	45,066	3092	3210	118	3154,2	26,1	3155
326	88	87	0,167	79,683	45,062	2893	3077	184	3023,3	37,2	3035
327	89	88	0,044	79,674	45,060	2969	3098	129	3044,6	28,0	3045
328	90	89	0,068	79,777	45,015	3026	3113	87	3054,9	20,5	3048
329	91	90	0,153	79,701	44,989	3003	3097	94	3042,0	17,4	3039
330	92	91	0,082	79,660	44,981	3146	3246	100	3195,2	22,2	3198
331	93	92	0,026	79,643	45,006	2786	2896	110	2822,7	27,4	2817
332	94	93	0,110	80,152	45,093	3368	3433	65	3403,5	16,1	3405
333	95	94	0,069	80,130	45,104	3028	3097	69	3062,4	16,3	3062
334	96	95	0,065	80,098	45,094	3094	3177	83	3132,6	20,9	3133
335	97	96	0,110	79,952	45,027	2940	3128	188	3006,2	48,5	2988
336	98	97	0,037	79,954	45,010	3026	3079	53	3053,5	14,5	3054
337	99	98	0,079	80,102	45,092	3122	3202	80	3169,8	13,5	3172
338	100	99	0,118	79,941	45,086	3075	3172	97	3122,8	25,2	3119
339	101	100	0,141	80,063	45,061	3079	3296	217	3183,9	51,0	3193
340	102	101	0,052	79,752	45,003	3322	3398	76	3371,4	19,0	3374
	Lepsy-Baskan										
	OBJECTID	FID	area	X	Y	MIN	MAX	RANGE	MEAN	STD	MEDIAN
341	1	0	0,032	80,662	45,159	2858	2916	58	2883,7	13,3	2884
342	2	1	0,015	80,651	45,153	3086	3154	68	3125,4	16,5	3127
343	3	2	0,045	80,660	45,158	2830	2894	64	2862,1	16,0	2861
344	4	3	0,008	80,678	45,212	3053	3137	84	3090,1	21,4	3092
345	5	4	0,051	80,728	45,217	3166	3313	147	3251,5	42,0	3243
346	6	5	0,011	80,681	45,211	3080	3179	99	3119,2	27,3	3115
347	7	6	0,006	80,682	45,212	3145	3204	59	3179,5	16,4	3182
348	8	7	0,032	80,676	45,210	2953	3076	123	3018,6	36,2	3017
349	9	8	0,120	80,673	45,228	2872	3064	192	2975,9	53,8	2983
350	10	9	0,086	80,676	45,235	2938	3115	177	3052,7	43,4	3062
351	11	10	0,109	80,702	45,260	3069	3114	45	3095,8	7,2	3097
352	12	11	0,107	80,703	45,221	3134	3293	159	3204,9	35,7	3207
353	13	12	0,085	80,703	45,211	3132	3228	96	3186,3	24,5	3191
354	14	13	0,027	80,734	45,232	3013	3073	60	3047,3	12,0	3051

355	15	14	0,096	80,729	45,234	2786	3028	242	2951,2	66,0	2973
356	16	15	0,066	80,733	45,276	2653	2754	101	2692,3	22,8	2690
357	17	16	0,069	80,733	45,278	2635	2730	95	2671,9	21,2	2667
358	18	17	0,068	80,708	45,274	2928	3025	97	2972,2	25,4	2969
359	19	18	0,104	80,653	45,165	2740	3144	404	2920,3	128,9	2899
360	20	19	0,096	80,646	45,172	2737	3001	264	2866,1	67,0	2852
361	21	20	0,034	80,639	45,173	2975	3143	168	3067,0	45,4	3067
362	22	21	0,029	80,669	45,221	3060	3168	108	3128,3	25,4	3133
363	23	22	0,041	80,713	45,217	2899	2956	57	2929,9	14,0	2931
364	24	23	0,086	80,707	45,149	3224	3271	47	3248,5	7,3	3249
365	25	24	0,068	80,689	45,136	3190	3289	99	3234,9	23,1	3231
366	26	25	0,049	80,683	45,136	3199	3333	134	3287,9	33,9	3297
367	27	26	0,223	80,680	45,147	3031	3146	115	3079,0	25,2	3074
368	28	27	0,032	80,138	45,139	3027	3078	51	3051,5	12,5	3051
369	29	28	0,444	80,147	45,126	3058	3262	204	3164,1	39,6	3170
370	30	29	0,020	80,146	45,140	2890	2921	31	2908,6	6,9	2912
371	31	30	0,008	80,163	45,140	2979	3005	26	2993,1	6,1	2994
372	32	31	0,221	80,210	45,059	3066	3446	380	3214,9	111,0	3164
373	33	32	0,100	80,214	45,055	3163	3475	312	3301,7	83,6	3293
374	34	33	0,126	80,190	45,062	3189	3263	74	3230,7	15,4	3230
375	35	34	0,079	80,166	45,080	3431	3556	125	3507,4	30,1	3515
376	36	35	0,021	80,189	45,079	3092	3183	91	3122,0	24,9	3112
377	37	36	0,158	80,167	45,075	3391	3488	97	3432,5	21,3	3429
378	38	37	0,105	80,175	45,074	3299	3398	99	3346,9	27,7	3343
379	39	38	0,051	80,183	45,077	3201	3291	90	3244,2	24,3	3241
380	40	39	0,602	80,190	45,095	2653	3242	589	2920,0	186,7	2891
381	41	40	0,228	80,179	45,102	3144	3375	231	3265,8	47,4	3254
382	42	41	0,728	80,195	45,126	2388	3090	702	2708,4	170,3	2694
383	43	42	0,589	80,173	45,122	2992	3269	277	3163,3	63,6	3183
384	44	43	0,025	80,165	45,115	3246	3271	25	3256,6	6,3	3256
385	45	44	0,026	80,170	45,136	3064	3095	31	3081,7	6,4	3083
386	46	45	0,015	80,216	45,106	3006	3082	76	3032,9	15,8	3033
387	47	46	0,341	80,222	45,103	2924	3295	371	3101,7	93,1	3095
388	48	47	0,678	80,235	45,120	3000	3283	283	3161,8	62,3	3168
389	49	48	0,199	80,411	45,139	2898	3217	319	3137,4	62,2	3149
390	50	49	0,094	80,405	45,130	2838	2986	148	2920,7	41,3	2937
391	51	50	0,041	80,422	45,165	2992	3078	86	3041,4	22,4	3042
392	52	51	0,053	80,404	45,115	3056	3192	136	3136,9	34,9	3143
393	53	52	0,013	80,409	45,101	3365	3450	85	3406,8	23,4	3404
394	54	53	0,098	80,413	45,167	2887	2991	104	2945,6	21,5	2949
395	55	54	0,135	80,431	45,181	2894	3016	122	2954,3	25,3	2956
396	56	55	0,055	80,399	45,216	2473	2620	147	2551,4	36,4	2554
397	57	56	0,020	80,415	45,212	2789	2823	34	2806,4	9,5	2807
398	58	57	0,296	80,437	45,200	2674	2927	253	2804,3	70,0	2788
399	59	58	0,921	80,484	45,197	2553	3134	581	2857,2	160,7	2882
400	60	59	0,146	80,528	45,185	2992	3203	211	3116,4	47,3	3123

401	61	60	0,066	80,519	45,195	3042	3132	90	3097,0	23,4	3099
402	62	61	0,161	80,550	45,186	2744	3083	339	2941,4	88,4	2942
403	63	62	0,008	80,500	45,218	2670	2703	33	2688,3	8,9	2689
404	64	63	0,319	80,524	45,168	2934	3216	282	3096,1	79,7	3110
405	65	64	0,247	80,520	45,148	3158	3312	154	3248,5	31,2	3255
406	66	65	0,013	80,537	45,152	3142	3191	49	3167,0	9,9	3167
407	67	66	0,026	80,564	45,216	2552	2607	55	2580,9	12,5	2580
408	68	67	0,048	80,580	45,204	3048	3106	58	3078,3	13,0	3077
409	69	68	0,045	80,585	45,219	2939	3110	171	3025,5	44,5	3023
410	70	69	0,020	80,582	45,223	2890	3015	125	2948,0	35,6	2941
411	71	70	0,047	80,460	45,234	3128	3163	35	3145,1	7,3	3147
412	72	71	0,034	80,491	45,243	3087	3137	50	3103,7	11,8	3101
413	73	72	0,011	80,515	45,271	2936	2973	37	2956,9	10,2	2957
414	74	73	0,337	80,575	45,157	2732	3133	401	2948,3	81,3	2937
415	75	74	0,811	80,585	45,143	2902	3201	299	3051,7	77,4	3057
416	76	75	0,211	80,599	45,139	3010	3264	254	3106,7	61,7	3087
417	77	76	0,070	80,609	45,133	3075	3169	94	3133,2	27,1	3141
418	78	77	0,232	80,604	45,132	3062	3224	162	3129,4	42,0	3116
419	79	78	0,037	80,611	45,116	3315	3375	60	3352,8	15,8	3353
420	80	79	0,121	80,590	45,116	3352	3546	194	3474,9	42,6	3483
421	81	80	0,147	80,576	45,171	2877	3178	301	3067,6	78,5	3086
422	82	81	0,138	80,566	45,174	3194	3308	114	3262,0	24,7	3266
423	83	82	0,063	80,590	45,190	2794	3036	242	2933,1	69,6	2934
424	84	83	0,097	80,627	45,130	3228	3299	71	3275,4	15,3	3277
425	85	84	0,087	80,562	45,146	3121	3198	77	3160,2	15,1	3160
426	86	85	0,082	80,566	45,151	3035	3163	128	3102,2	41,2	3108
427	87	86	0,115	80,666	45,130	3118	3224	106	3168,4	25,8	3161
428	88	87	0,013	80,659	45,146	3084	3148	64	3112,9	17,0	3112
429	89	88	0,096	80,644	45,126	3199	3310	111	3255,2	25,1	3257
430	90	89	0,185	80,634	45,133	3112	3229	117	3176,0	26,5	3176
431	91	90	0,016	80,650	45,129	3288	3343	55	3320,3	15,4	3323
432	92	91	0,147	80,614	45,154	3078	3225	147	3156,1	32,0	3155
433	93	92	0,038	80,527	45,199	3002	3049	47	3026,0	9,9	3026
434	94	93	0,036	80,437	45,256	2884	3012	128	2961,8	27,8	2970
435	95	94	0,034	80,429	45,255	2739	2855	116	2791,8	28,8	2789
436	96	95	0,007	80,455	45,214	3179	3208	29	3194,9	7,3	3195
437	97	96	0,023	80,466	45,207	2770	2941	171	2858,2	48,9	2860
438	98	97	0,010	80,517	45,209	3114	3136	22	3127,3	5,7	3129
439	99	98	0,041	80,503	45,204	2993	3055	62	3028,5	15,7	3032
440	100	99	0,008	80,467	45,238	2983	3029	46	3002,4	10,1	3002
441	101	100	0,032	80,442	45,197	2830	2885	55	2866,0	10,4	2866
442	102	101	0,093	80,469	45,199	2579	2652	73	2617,8	15,1	2619
443	103	102	0,011	80,474	45,177	2978	3019	41	3000,7	11,3	3000
444	104	103	0,014	80,700	45,284	2845	2870	25	2854,3	5,1	2853
445	105	104	0,057	80,694	45,281	2927	2998	71	2961,2	16,3	2962
446	106	105	0,019	80,695	45,260	3136	3167	31	3155,5	8,1	3158

447	107	106	0,048	80,689	45,274	2995	3062	67	3025,2	15,2	3025
448	108	107	0,023	80,675	45,254	3198	3237	39	3222,8	8,9	3224
449	109	108	0,029	80,679	45,257	3150	3227	77	3181,6	21,1	3176
450	110	109	0,062	80,642	45,281	2571	2879	308	2734,3	77,6	2740
451	111	110	0,015	80,715	45,221	2848	2902	54	2877,0	11,9	2878
452	112	111	0,052	80,668	45,206	2759	2840	81	2811,1	15,6	2815
453	113	112	0,012	80,608	45,184	2634	2726	92	2690,2	24,5	2696
454	114	113	0,007	80,612	45,184	2769	2909	140	2833,9	37,9	2832
455	115	114	0,116	80,606	45,121	3196	3291	95	3256,9	20,6	3256
456	116	115	0,180	80,610	45,125	3152	3258	106	3203,7	21,5	3207
457	117	116	0,076	80,447	45,194	2877	2937	60	2907,3	13,9	2907
458	118	117	0,035	80,425	45,172	3103	3171	68	3142,0	19,1	3138
459	119	118	0,251	80,391	45,099	2537	3090	553	2768,3	149,5	2736
460	120	119	0,085	80,374	45,099	2961	3078	117	3031,5	24,8	3037
461	121	120	0,120	80,383	45,097	2585	2843	258	2656,2	62,5	2630
462	122	121	0,034	80,368	45,110	3192	3257	65	3238,7	14,1	3241
463	123	122	0,028	80,372	45,123	2710	2789	79	2747,7	20,4	2745
464	124	123	0,023	80,351	45,123	2752	2809	57	2779,1	13,5	2779
465	125	124	0,020	80,341	45,141	2801	2850	49	2817,1	11,0	2814
466	126	125	0,199	80,265	45,093	3244	3450	206	3351,1	43,4	3356
467	127	126	0,149	80,266	45,098	3235	3362	127	3286,3	26,6	3287
468	128	127	0,358	80,266	45,106	3037	3364	327	3200,5	60,8	3201
469	129	128	0,015	80,192	45,078	3051	3108	57	3081,9	13,9	3083
470	130	129	0,041	80,190	45,059	3233	3285	52	3262,4	12,5	3262
471	131	130	0,321	80,304	45,122	3081	3279	198	3189,3	49,3	3185
472	132	131	0,040	80,309	45,127	3022	3055	33	3040,8	6,9	3043
473	133	132	0,502	80,314	45,102	3133	3403	270	3271,1	64,7	3272
474	134	133	0,228	80,426	45,079	3354	3527	173	3459,0	40,4	3466
475	135	134	0,059	80,420	45,090	3468	3562	94	3530,7	24,2	3539
476	136	135	0,230	80,389	45,058	3101	3309	208	3195,4	41,5	3195
477	137	136	0,019	80,374	45,075	3001	3094	93	3049,8	23,1	3048
478	138	137	0,150	80,374	45,068	2909	3098	189	3024,0	43,9	3027
479	139	138	0,083	80,420	45,083	3352	3430	78	3388,7	17,3	3388
480	140	139	0,667	80,412	45,074	3057	3413	356	3246,1	86,8	3251
481	141	140	0,030	80,391	45,067	3111	3178	67	3147,7	15,8	3151
482	142	141	0,084	80,371	45,091	2900	3347	447	3132,2	129,0	3137
483	143	142	0,050	80,676	45,168	3182	3321	139	3242,2	37,5	3242
484	144	143	0,072	80,673	45,195	3154	3290	136	3229,5	35,9	3228
485	145	144	0,100	80,669	45,170	3040	3182	142	3130,3	30,7	3138
486	146	145	0,141	80,761	45,245	2980	3056	76	3019,9	12,6	3017
487	147	146	0,126	80,759	45,263	2871	2954	83	2917,4	19,3	2919
488	148	147	0,193	80,705	45,236	3006	3176	170	3100,7	34,6	3100
489	149	148	0,100	80,678	45,198	3003	3099	96	3057,5	21,9	3059
490	150	149	0,054	80,667	45,156	2938	3034	96	3002,5	17,0	3005
491	151	150	0,126	80,147	45,160	2465	2622	157	2543,6	41,3	2543
492	152	151	0,283	80,351	45,061	3291	3461	170	3401,8	36,4	3413

493	153	152	1,530	80,373	45,063	2733	3320	587	3011,0	146,0	2975
494	154	153	0,424	80,392	45,072	2765	3115	350	2998,9	79,7	3028
	Tentek										
	OBJECTID	FID	area	X	Y	MIN	MAX	RANGE	MEAN	STD	MEDIAN
495	1	0	0,118	80,845	45,235	2570	2959	389	2783,3	99,4	2781
496	2	1	0,312	81,256	45,280	2937	3165	228	3038,9	47,5	3044
497	3	2	0,044	81,232	45,260	3293	3384	91	3345,5	20,1	3349
498	4	3	0,238	81,371	45,333	2833	3140	307	2990,2	63,4	2987
499	5	4	0,030	80,736	45,168	3426	3490	64	3463,1	17,3	3465
500	6	5	0,107	80,823	45,146	3270	3410	140	3345,8	31,8	3348
501	7	6	0,024	80,766	45,187	3466	3516	50	3487,9	12,8	3486
502	8	7	0,117	80,783	45,202	2876	3055	179	2939,6	52,1	2915
503	9	8	0,552	80,794	45,205	2750	3150	400	2896,8	97,4	2870
504	10	9	0,128	80,769	45,209	3204	3437	233	3349,6	60,2	3356
505	11	10	0,061	80,809	45,222	3088	3325	237	3219,2	65,5	3221
506	12	11	0,008	80,803	45,219	3187	3273	86	3230,4	23,0	3231
507	13	12	0,042	80,817	45,215	2681	2877	196	2777,7	54,8	2778
508	14	13	0,004	80,817	45,217	2893	2925	32	2907,4	9,0	2908
509	15	14	0,242	80,827	45,226	2670	3216	546	2995,2	150,4	2990
510	16	15	0,085	80,828	45,231	2868	3151	283	3029,0	71,3	3033
511	17	16	0,082	80,823	45,237	3235	3363	128	3302,3	34,1	3296
512	18	17	0,272	80,844	45,265	2903	3088	185	2982,5	35,6	2980
513	19	18	0,078	80,837	45,291	3067	3150	83	3109,9	15,6	3108
514	20	19	0,021	80,818	45,283	3210	3238	28	3226,7	6,5	3228
515	21	20	0,206	80,980	45,282	2598	2855	257	2730,6	69,7	2721
516	22	21	0,030	80,989	45,267	3051	3107	56	3075,5	13,2	3075
517	23	22	0,170	80,984	45,271	2936	3050	114	3014,6	22,3	3020
518	24	23	0,035	80,837	45,300	2961	3007	46	2984,1	10,8	2985
519	25	24	0,051	80,827	45,290	3124	3162	38	3148,8	7,3	3149
520	26	25	0,022	80,832	45,293	3039	3118	79	3076,3	20,2	3074
521	27	26	0,058	80,853	45,202	2721	2973	252	2804,2	65,8	2779
522	28	27	0,048	80,857	45,202	2673	2785	112	2731,7	28,9	2733
523	29	28	0,079	80,858	45,187	3083	3158	75	3133,5	19,6	3138
524	30	29	0,131	80,878	45,215	2780	2970	190	2886,8	45,2	2887
525	31	30	0,430	80,903	45,200	2880	3129	249	2990,9	54,4	2985
526	32	31	0,071	80,908	45,195	3010	3087	77	3044,2	20,2	3045
527	33	32	0,257	80,978	45,186	3140	3278	138	3210,6	30,9	3210
528	34	33	0,056	80,970	45,188	3302	3385	83	3341,2	24,5	3340
529	35	34	0,477	80,975	45,213	2925	3124	199	3019,0	45,2	3015
530	36	35	0,246	80,954	45,218	3058	3266	208	3164,6	44,1	3150
531	37	36	0,296	80,944	45,231	2621	3035	414	2934,6	98,9	2981
532	38	37	0,072	81,024	45,214	2820	2942	122	2893,3	33,0	2900
533	39	38	0,047	80,992	45,207	2909	2979	70	2936,2	17,0	2934
534	40	39	0,275	81,040	45,234	2956	3130	174	3042,0	28,7	3046

535	41	40	0,019	81,033	45,232	3140	3217	77	3182,6	19,9	3186
536	42	41	0,692	81,030	45,248	2766	3158	392	2941,0	106,7	2902
537	43	42	0,025	81,007	45,258	3005	3061	56	3033,6	11,6	3034
538	44	43	0,188	81,018	45,257	2873	3110	237	2980,1	68,6	2976
539	45	44	0,095	81,028	45,235	3076	3197	121	3158,4	24,9	3163
540	46	45	0,026	81,043	45,229	3101	3132	31	3115,6	6,8	3117
541	47	46	0,120	81,032	45,256	2703	2788	85	2753,9	18,2	2753
542	48	47	0,162	80,942	45,275	2515	2982	467	2797,3	131,9	2839
543	49	48	0,119	80,944	45,280	2447	2859	412	2672,9	112,7	2663
544	50	49	0,038	80,961	45,270	2997	3070	73	3028,3	16,8	3029
545	51	50	0,038	80,967	45,274	2849	2932	83	2878,6	20,0	2873
546	52	51	0,097	80,970	45,271	2917	3045	128	2992,4	33,2	2993
547	53	52	0,081	80,998	45,278	2934	3137	203	3003,5	47,7	2992
548	54	53	0,055	81,075	45,241	3050	3162	112	3108,0	24,9	3109
549	55	54	0,048	81,081	45,251	2899	2955	56	2932,7	14,7	2934
550	56	55	0,149	81,095	45,244	3036	3140	104	3090,2	21,6	3093
551	57	56	0,058	81,056	45,222	3180	3326	146	3275,4	34,3	3288
552	58	57	0,351	81,065	45,222	2960	3185	225	3069,3	49,0	3071
553	59	58	0,073	81,078	45,218	3104	3236	132	3183,4	26,0	3186
554	60	59	0,033	81,100	45,228	3236	3288	52	3260,2	8,7	3260
555	61	60	0,081	81,119	45,250	3159	3286	127	3244,7	31,9	3253
556	62	61	0,098	81,177	45,265	3066	3168	102	3101,0	18,8	3103
557	63	62	0,130	81,220	45,253	3141	3340	199	3226,4	42,4	3207
558	64	63	0,061	81,197	45,273	2844	2969	125	2910,1	30,3	2911
559	65	64	0,063	81,209	45,285	2980	3085	105	3024,2	26,6	3019
560	66	65	0,179	81,229	45,288	3069	3211	142	3152,6	34,5	3148
561	67	66	0,011	81,230	45,321	2962	3055	93	3010,8	26,0	3011
562	68	67	0,003	81,228	45,323	3026	3049	23	3038,2	7,0	3039
563	69	68	0,014	81,229	45,323	3059	3143	84	3102,3	21,5	3102
564	70	69	0,099	81,258	45,260	3165	3238	73	3204,8	16,3	3207
565	71	70	0,216	81,270	45,292	2830	3050	220	2925,1	58,7	2907
566	72	71	0,158	81,279	45,263	3063	3245	182	3157,6	41,9	3156
567	73	72	0,128	81,298	45,260	2995	3227	232	3156,1	57,2	3186
568	74	73	0,050	81,311	45,272	3238	3318	80	3276,6	15,8	3280
569	75	74	0,067	81,286	45,275	2827	3048	221	2943,6	58,9	2949
570	76	75	0,077	81,311	45,292	2876	2991	115	2924,8	24,9	2923
571	77	76	0,107	81,287	45,309	2564	2874	310	2695,8	84,6	2676
572	78	77	0,116	81,243	45,360	2315	2696	381	2514,8	104,6	2508
573	79	78	0,034	81,207	45,360	2184	2377	193	2274,1	53,3	2275
574	80	79	0,026	81,103	45,333	2980	3090	110	3042,7	28,2	3048
575	81	80	0,155	81,105	45,318	2705	3030	325	2901,8	83,9	2909
576	82	81	0,004	81,105	45,302	2866	2888	22	2877,7	6,3	2877
577	83	82	0,024	81,119	45,271	3020	3062	42	3050,4	10,3	3055
578	84	83	0,057	81,115	45,270	3082	3149	67	3126,0	13,6	3129
579	85	84	0,013	81,124	45,263	3062	3087	25	3075,3	5,4	3076
580	86	85	0,053	81,054	45,343	2824	2929	105	2865,4	23,0	2862

581	87	86	0,026	81,136	45,325	2772	2849	77	2806,2	20,7	2804
582	88	87	0,172	81,340	45,282	2759	3192	433	2954,5	120,8	2924
583	89	88	0,051	81,235	45,273	3187	3300	113	3260,4	30,5	3272
584	90	89	0,176	80,777	45,192	3108	3278	170	3189,5	45,1	3178
585	91	90	0,071	80,770	45,188	3291	3395	104	3345,2	24,0	3342
586	92	91	0,006	80,804	45,201	3198	3233	35	3218,7	9,2	3219
587	93	92	0,192	81,382	45,282	3150	3272	122	3199,1	23,3	3195
588	94	93	0,046	81,307	45,267	3233	3320	87	3269,7	17,5	3265
589	95	94	0,176	81,244	45,247	3210	3317	107	3249,0	15,9	3248
590	96	95	0,116	81,270	45,241	3172	3253	81	3211,8	14,7	3213
591	97	96	0,606	81,201	45,239	3085	3348	263	3198,8	61,1	3180
592	98	97	0,304	81,196	45,248	3029	3160	131	3097,0	29,0	3098
593	99	98	0,104	81,139	45,328	2567	2690	123	2647,2	24,0	2654
594	100	99	0,267	80,809	45,210	2634	2791	157	2728,7	33,7	2735
595	101	100	0,049	80,984	45,198	3018	3074	56	3048,5	15,3	3051
596	102	101	0,044	80,980	45,198	3066	3156	90	3112,6	21,4	3120
597	103	102	0,058	80,972	45,197	3223	3327	104	3269,2	24,0	3268
598	104	103	0,058	81,019	45,215	2860	2967	107	2922,1	26,3	2930
599	105	104	0,492	81,084	45,205	3126	3283	157	3193,7	21,7	3197
600	106	105	0,082	81,092	45,228	3122	3222	100	3165,5	23,5	3161
601	107	106	0,244	81,086	45,248	2930	3066	136	2999,8	31,3	3003
602	108	107	0,084	81,139	45,253	2989	3089	100	3041,2	19,7	3042
603	109	108	0,219	81,100	45,348	2895	3058	163	2986,7	38,3	2990
604	110	109	0,228	81,006	45,285	2482	2883	401	2720,6	96,6	2736
605	111	110	0,048	81,297	45,498	2753	2846	93	2789,1	22,2	2784
606	112	111	0,023	81,300	45,479	2786	2844	58	2816,6	12,4	2818
607	113	112	0,083	81,260	45,330	2898	3056	158	2979,2	33,0	2984
608	114	113	0,012	81,245	45,336	2789	2859	70	2824,4	17,1	2826
	Yrgaity										
	OBJECTID	FID	Area	X	Y	MIN	MAX	RANGE	MEAN	STD	MEDIAN
609	1	0	0,044	81,450	45,265	3117	3183	66	3154,4	13,3	3154
610	2	1	0,079	81,541	45,521	2791	2891	100	2835,2	22,4	2836
611	3	2	0,019	81,604	45,533	2842	2896	54	2862,4	14,3	2858
612	4	3	0,068	81,444	45,502	2991	3159	168	3073,0	33,8	3071
613	5	4	0,030	81,479	45,507	2901	2962	61	2923,8	13,7	2922
614	6	5	0,057	81,517	45,506	2929	3035	106	2982,5	26,3	2981
615	7	6	0,050	81,515	45,506	2941	2999	58	2971,5	11,9	2972
616	8	7	0,043	81,569	45,518	2947	2986	39	2963,9	8,6	2963
617	9	8	0,035	81,564	45,521	2918	2969	51	2944,9	10,3	2945
618	10	9	0,014	81,566	45,519	2949	2989	40	2963,0	8,6	2961
619	11	10	0,030	81,624	45,535	2803	2844	41	2828,1	10,7	2831
620	12	11	0,009	81,628	45,528	2967	3002	35	2981,1	9,8	2980
621	13	12	0,292	81,603	45,493	1924	2121	197	2031,5	42,0	2034
622	14	13	0,077	81,597	45,498	2098	2157	59	2131,0	12,4	2133

623	15	14	0,041	81,427	45,396	2777	2846	69	2815,0	14,8	2817
624	17	15	0,144	81,402	45,288	3024	3149	125	3085,3	35,7	3086
625	18	16	0,147	81,762	45,380	2969	3120	151	3053,7	30,5	3057
626	19	17	0,067	81,717	45,369	2925	3002	77	2972,8	16,9	2978
627	20	18	0,558	81,609	45,365	2855	3169	314	3016,5	72,3	3017
628	21	19	0,016	81,728	45,383	2796	2875	79	2837,1	21,2	2840
629	22	20	0,075	81,679	45,374	2804	2959	155	2882,8	32,3	2878
630	23	21	0,105	81,666	45,373	2596	2794	198	2687,0	44,9	2679
631	24	22	0,234	81,665	45,358	2965	3146	181	3073,4	37,4	3074
632	25	23	0,145	81,654	45,357	3157	3326	169	3245,1	39,9	3244
633	26	24	0,037	81,653	45,368	2990	3064	74	3034,2	17,1	3036
634	27	25	0,191	81,652	45,380	2547	2980	433	2776,7	111,3	2773
635	28	26	0,063	81,628	45,369	2958	3045	87	3014,9	20,7	3021
636	29	27	0,038	81,624	45,372	2894	2969	75	2931,0	23,2	2933
637	30	28	0,046	81,615	45,365	2935	3080	145	3010,6	30,5	3011
638	31	29	0,018	81,611	45,372	2828	2868	40	2853,4	9,8	2856
639	32	30	0,106	81,591	45,361	3086	3191	105	3132,7	24,5	3131
640	33	31	0,056	81,571	45,355	3131	3186	55	3166,0	13,2	3170
641	34	32	0,161	81,575	45,351	3151	3237	86	3188,9	16,0	3188
642	35	33	0,120	81,579	45,345	3228	3285	57	3252,7	9,9	3252
643	36	34	0,102	81,558	45,351	3143	3237	94	3193,5	16,5	3195
644	37	35	0,049	81,553	45,356	3025	3103	78	3050,7	15,2	3047
645	38	36	0,031	81,553	45,352	3066	3158	92	3105,1	24,2	3103
646	39	37	0,096	81,549	45,350	3027	3089	62	3050,0	11,8	3048
647	40	38	0,070	81,509	45,309	3189	3304	115	3256,7	24,7	3263
648	42	39	0,091	81,521	45,319	3113	3257	144	3172,8	32,8	3167
649	43	40	0,038	81,523	45,315	3148	3230	82	3196,4	20,0	3196
650	44	41	0,106	81,522	45,314	3158	3263	105	3207,6	19,2	3206
651	45	42	0,097	81,510	45,357	3306	3380	74	3338,5	14,3	3335
652	46	43	0,042	81,520	45,357	3101	3154	53	3125,8	12,7	3125
653	47	44	0,078	81,423	45,500	2986	3102	116	3030,9	25,5	3032
654	48	45	0,193	81,476	45,334	2616	3044	428	2843,3	120,3	2856
655	49	46	0,031	81,543	45,510	2978	3028	50	3003,4	10,4	3006
	Usek										
	OBJECTID	FID	area	X	Y	MIN	MAX	RANGE	MEAN	STD	MEDIAN
656	1	0	0,021	79,854	44,770	3425	3471	46	3448,3	11,2	3449
657	2	1	0,080	80,119	44,613	3290	3483	193	3397,5	43,1	3400
658	3	2	0,618	80,192	44,538	2849	3261	412	3106,9	95,4	3130
659	4	3	0,226	80,080	44,564	3018	3288	270	3134,4	64,1	3113
660	5	4	0,535	80,077	44,569	3047	3449	402	3224,5	101,3	3211
661	6	5	0,113	80,098	44,565	3157	3561	404	3340,7	93,2	3340
662	7	6	0,078	80,098	44,573	3178	3315	137	3241,8	27,1	3242
663	8	7	0,116	80,094	44,571	3122	3266	144	3179,1	29,7	3175
664	9	8	0,119	80,181	44,526	3134	3349	215	3222,7	50,4	3224

665	10	9	0,413	80,172	44,525	2974	3220	246	3096,8	43,5	3104
666	11	10	0,067	80,215	44,560	3093	3228	135	3148,0	31,7	3141
667	12	11	0,250	80,220	44,566	3133	3382	249	3259,2	57,4	3263
668	13	12	0,244	80,197	44,552	2829	3050	221	2933,8	40,7	2938
669	14	13	0,411	80,208	44,554	2975	3228	253	3097,1	61,4	3093
670	15	14	0,042	80,061	44,652	2854	2974	120	2909,9	30,6	2909
671	16	15	0,030	80,026	44,639	2718	2857	139	2814,3	25,7	2820
672	17	16	0,153	79,610	44,682	2934	3091	157	3010,5	40,8	3008
673	18	17	0,077	79,876	44,723	3096	3183	87	3140,3	17,1	3143
674	19	18	0,047	79,912	44,720	3367	3439	72	3411,6	14,4	3411
675	20	19	0,049	79,933	44,690	3288	3361	73	3327,5	17,8	3329
676	21	20	0,032	80,069	44,654	2937	3032	95	2982,1	22,5	2982
677	22	21	0,101	80,012	44,564	3273	3402	129	3328,4	27,9	3321
678	23	22	0,036	79,979	44,559	3012	3199	187	3107,8	45,8	3107
679	24	23	0,101	79,979	44,567	3071	3273	202	3165,7	44,6	3163
680	25	24	0,131	80,049	44,572	3310	3509	199	3410,1	41,4	3410
681	26	25	0,073	80,054	44,566	3409	3546	137	3492,1	32,9	3503
682	27	26	0,102	80,041	44,558	3066	3225	159	3158,2	37,4	3166
683	28	27	0,034	79,989	44,569	3186	3239	53	3208,1	11,2	3210
684	29	28	0,020	80,010	44,578	2947	2987	40	2968,7	9,2	2968
685	30	29	0,046	80,014	44,576	3025	3174	149	3119,6	34,6	3127
686	31	30	0,019	80,005	44,575	3110	3201	91	3174,9	20,0	3180
687	32	31	0,091	80,026	44,580	3083	3223	140	3145,2	35,5	3145
688	33	32	0,015	80,032	44,586	3189	3264	75	3228,5	19,1	3228
689	34	33	0,017	80,030	44,585	3110	3187	77	3156,1	17,6	3159
690	35	34	0,021	80,036	44,720	3248	3314	66	3272,9	16,2	3270
691	36	35	0,044	80,028	44,718	3183	3266	83	3225,9	20,2	3228
692	37	36	0,214	79,994	44,726	3218	3384	166	3293,9	35,4	3297
693	38	37	0,037	80,058	44,707	3265	3325	60	3302,2	14,8	3306
694	39	38	0,105	80,012	44,718	3119	3219	100	3185,3	19,5	3189
695	40	39	0,079	80,010	44,728	3143	3242	99	3177,3	20,5	3176
696	41	40	0,068	80,027	44,717	3165	3264	99	3197,7	23,9	3191
697	42	41	0,014	79,895	44,753	3452	3498	46	3471,6	11,1	3471
698	43	42	0,009	79,894	44,753	3437	3451	14	3442,7	3,7	3442
699	44	43	0,031	79,898	44,754	3471	3544	73	3503,3	17,0	3502
700	45	44	0,055	79,887	44,764	3475	3526	51	3494,9	11,9	3494
701	46	45	0,023	79,980	44,701	3116	3155	39	3132,3	9,1	3131
702	47	46	0,054	79,989	44,695	3004	3119	115	3053,3	26,7	3054
703	48	47	0,155	79,984	44,680	3173	3250	77	3217,9	14,0	3221
704	49	48	0,038	80,025	44,680	3001	3064	63	3042,0	12,9	3045
705	50	49	0,007	80,049	44,635	3128	3166	38	3144,0	9,9	3143
706	51	50	0,010	80,051	44,635	3125	3156	31	3138,0	6,6	3137
707	52	51	0,035	80,082	44,657	3139	3196	57	3172,2	13,0	3171
708	53	52	0,036	80,086	44,659	3183	3217	34	3201,8	8,5	3202
709	54	53	0,034	80,105	44,667	3289	3332	43	3313,0	7,3	3314
710	55	54	0,028	80,107	44,671	3437	3463	26	3452,6	5,8	3454

711	56	55	0,027	80,135	44,651	3079	3142	63	3107,0	16,7	3105
712	57	56	0,031	80,144	44,653	3252	3335	83	3291,3	18,9	3294
713	58	57	0,026	80,151	44,655	3304	3342	38	3329,5	8,4	3332
714	59	58	0,014	80,019	44,702	2880	2922	42	2901,1	11,2	2901
715	60	59	0,021	80,082	44,675	3458	3482	24	3475,0	5,6	3477
716	61	60	0,045	80,263	44,511	3080	3141	61	3107,3	15,3	3105
717	62	61	0,020	80,265	44,517	3045	3133	88	3096,1	20,6	3096
718	63	62	0,049	80,153	44,588	3069	3175	106	3124,2	21,3	3129
719	64	63	0,016	80,159	44,601	3440	3484	44	3466,3	11,9	3469
720	65	64	0,014	80,047	44,595	3007	3072	65	3040,9	17,9	3039
721	66	65	0,104	80,147	44,582	2999	3056	57	3023,8	11,3	3023
722	67	66	0,019	80,106	44,608	3049	3110	61	3086,1	15,8	3089
723	68	67	0,015	80,106	44,607	3114	3174	60	3144,0	15,9	3144
724	69	68	0,116	79,938	44,758	3465	3559	94	3507,5	20,5	3509
725	70	69	0,093	79,943	44,748	3411	3503	92	3465,3	22,0	3470
726	71	70	0,033	79,943	44,744	3381	3432	51	3408,6	10,5	3409
727	72	71	0,032	79,917	44,680	3020	3068	48	3044,5	10,8	3046
728	73	72	0,012	79,901	44,675	2856	2902	46	2879,5	10,4	2880
729	74	73	0,021	79,903	44,677	2868	2921	53	2886,9	11,9	2885
730	75	74	0,022	79,849	44,755	3250	3344	94	3293,5	27,1	3293
731	76	75	0,042	79,771	44,680	3226	3267	41	3244,6	9,1	3245
732	77	76	0,231	79,663	44,692	3061	3301	240	3163,6	50,4	3152
733	78	77	0,101	79,690	44,679	3357	3430	73	3392,6	19,5	3393
734	79	78	0,049	79,611	44,571	3202	3279	77	3230,4	18,9	3222
735	80	79	0,331	79,517	44,607	2818	3208	390	3090,9	98,3	3125
736	81	80	0,032	79,493	44,604	3052	3099	47	3075,2	11,3	3074
737	82	81	0,077	79,498	44,603	3073	3244	171	3184,7	40,5	3197
738	83	82	0,136	79,580	44,666	2690	2834	144	2775,4	32,3	2781
739	84	83	0,070	79,652	44,677	2907	2979	72	2944,7	14,9	2944
740	85	84	0,020	79,765	44,623	3383	3450	67	3416,7	18,1	3422
741	86	85	0,043	79,773	44,640	3355	3477	122	3405,4	26,8	3401
742	87	86	0,195	79,801	44,660	3125	3294	169	3218,9	38,3	3222
743	88	87	0,014	79,822	44,657	3064	3091	27	3076,0	6,8	3075
744	89	88	0,029	79,774	44,610	3274	3319	45	3295,7	10,3	3296
745	90	89	0,013	79,838	44,654	3095	3157	62	3136,1	14,3	3139
746	91	90	0,024	79,834	44,652	3071	3130	59	3096,2	14,3	3094
747	92	91	0,073	79,836	44,656	2873	3070	197	2997,3	48,5	3006
748	93	92	0,061	79,812	44,651	3264	3349	85	3314,1	20,2	3321
749	94	93	0,014	79,908	44,673	3047	3103	56	3079,5	14,2	3083
750	95	94	0,006	79,945	44,667	3510	3544	34	3525,4	8,2	3525
751	96	95	0,077	79,892	44,697	3281	3355	74	3306,6	12,2	3305
752	97	96	0,044	80,097	44,692	3168	3220	52	3187,8	11,7	3186
753	98	97	0,176	79,991	44,656	3035	3184	149	3129,1	30,4	3136
754	99	98	0,053	79,682	44,663	3233	3326	93	3276,1	19,4	3275
755	100	99	0,008	79,661	44,657	3201	3250	49	3221,6	12,8	3220
756	101	100	0,020	79,659	44,682	2999	3080	81	3024,8	21,9	3017

757	102	101	0,047	79,765	44,731	3383	3456	73	3417,7	17,1	3417
758	103	102	0,020	79,762	44,733	3463	3497	34	3481,6	6,9	3482
759	104	103	0,039	79,605	44,675	3135	3212	77	3169,6	15,0	3169
760	105	104	0,103	79,637	44,695	3289	3384	95	3334,9	19,9	3338
761	106	105	0,057	79,715	44,663	3305	3360	55	3339,1	11,0	3342
762	107	106	0,715	79,734	44,627	2906	3330	424	3127,0	97,6	3147
763	108	107	0,080	79,739	44,624	2961	3077	116	3031,8	27,3	3038
764	109	108	0,033	79,757	44,621	3179	3252	73	3206,3	13,5	3207
765	110	109	0,138	79,759	44,643	3306	3406	100	3354,5	24,7	3355
766	111	110	0,022	79,754	44,627	3116	3163	47	3139,5	10,5	3139
767	112	111	0,062	79,817	44,629	2896	3043	147	2971,2	34,7	2966
768	113	112	0,222	79,807	44,673	2777	3027	250	2913,2	60,5	2920
769	114	113	0,075	79,743	44,704	3181	3268	87	3231,0	20,7	3231
770	115	114	0,143	79,864	44,749	3212	3427	215	3345,5	54,2	3352
771	116	115	0,035	79,948	44,761	3499	3546	47	3522,1	11,8	3523
772	117	116	0,068	79,942	44,762	3555	3619	64	3592,5	16,7	3595
773	118	117	0,049	79,949	44,740	3474	3541	67	3509,1	14,5	3513
774	119	118	0,104	79,943	44,742	3367	3454	87	3416,9	26,3	3416
775	120	119	0,061	79,883	44,737	3101	3163	62	3134,7	15,9	3136
776	121	120	0,041	79,842	44,719	2792	2924	132	2849,4	35,2	2843
777	122	121	0,076	79,869	44,712	3333	3391	58	3367,8	11,3	3368
778	123	122	0,039	79,989	44,572	3156	3184	28	3174,7	5,5	3175
779	124	123	0,013	79,980	44,574	3157	3181	24	3170,1	6,4	3170
780	125	124	0,045	80,075	44,550	3029	3272	243	3140,6	64,7	3126
781	126	125	0,773	80,234	44,518	2508	3521	1013	3140,8	258,6	3213
	Horgos										
	OBJECTID	FID	Area	X	Y	MIN	MAX	RANGE	MEAN	STD	MEDIAN
782	1	0	0,143	80,321	44,551	3152	3352	200	3232,8	39,8	3234
783	2	1	0,149	80,309	44,556	3259	3454	195	3342,5	47,5	3330
784	3	2	0,202	80,304	44,524	3008	3251	243	3155,2	58,7	3177
785	4	3	0,504	80,322	44,574	3106	3429	323	3285,7	69,4	3286
786	5	4	0,220	80,287	44,556	3341	3476	135	3407,6	35,4	3408
787	6	5	0,749	80,301	44,539	2735	3275	540	2999,6	121,7	2999
788	7	6	0,131	80,237	44,815	3410	3542	132	3452,0	27,0	3446
789	8	7	0,623	80,302	44,785	3053	3235	182	3154,3	36,3	3157
790	9	8	0,092	80,337	44,812	3423	3531	108	3482,5	23,5	3485
791	10	9	0,058	80,323	44,791	3204	3242	38	3223,6	9,5	3225
792	11	10	0,163	80,317	44,790	3164	3314	150	3234,5	29,1	3232
793	12	11	0,176	80,367	44,775	3379	3523	144	3439,5	33,4	3429
794	13	12	0,112	80,327	44,772	3185	3405	220	3249,8	53,2	3231
795	14	13	0,164	80,321	44,773	3168	3512	344	3326,3	90,8	3318
796	15	14	0,066	80,458	44,724	2786	2964	178	2867,0	45,7	2866
797	16	15	0,161	80,111	44,760	3215	3390	175	3313,7	43,5	3318
798	17	16	0,056	80,086	44,756	3235	3313	78	3270,7	17,0	3273

799	18	17	0,117	80,024	44,756	3097	3165	68	3130,9	14,6	3132
800	19	18	0,005	80,254	44,643	2825	2858	33	2843,7	8,0	2844
801	20	19	0,085	80,259	44,633	3079	3210	131	3147,1	29,1	3148
802	21	20	0,018	80,212	44,634	2670	2739	69	2698,0	16,6	2694
803	22	21	0,054	80,140	44,698	3188	3251	63	3225,6	8,6	3225
804	23	22	0,431	80,126	44,774	3343	3560	217	3445,0	51,7	3448
805	24	23	0,113	80,236	44,641	3115	3417	302	3248,1	65,6	3241
806	25	24	0,008	80,134	44,774	3328	3376	48	3348,0	10,9	3348
807	26	25	0,059	80,086	44,756	3237	3306	69	3288,3	18,5	3294
808	27	26	0,078	80,129	44,735	3104	3177	73	3138,6	15,9	3140
809	28	27	0,498	80,329	44,585	3199	3630	431	3428,7	91,9	3437
810	29	28	0,108	80,365	44,607	2943	3143	200	3066,0	44,2	3073
811	30	29	0,171	80,371	44,600	2638	2945	307	2823,5	82,5	2820
812	31	30	0,035	80,014	44,750	3347	3424	77	3375,7	16,1	3372
813	32	31	0,039	80,023	44,748	3247	3350	103	3320,3	23,2	3326
814	33	32	0,018	80,132	44,748	2687	2708	21	2698,9	6,0	2701
815	34	33	0,153	80,126	44,746	2703	2806	103	2746,2	18,9	2743
816	35	34	0,067	80,134	44,760	2944	3233	289	3081,4	70,9	3081
817	36	35	0,188	80,325	44,622	2918	3222	304	3091,7	69,0	3099
818	37	36	0,069	80,336	44,613	3200	3313	113	3269,8	21,7	3276
819	38	37	0,138	80,304	44,624	2894	3053	159	2975,8	32,4	2971
820	39	38	0,059	80,225	44,608	2900	2973	73	2938,5	16,1	2938
821	40	39	0,166	80,171	44,671	3029	3186	157	3121,8	31,0	3123
822	41	40	0,017	80,255	44,642	2810	2876	66	2846,7	16,9	2847
823	42	41	0,029	80,260	44,683	3050	3196	146	3112,2	38,7	3103
824	43	42	0,164	80,046	44,739	3077	3304	227	3200,8	50,0	3195
825	44	43	0,049	80,037	44,736	3305	3364	59	3335,1	12,4	3335
826	45	44	0,053	80,296	44,810	3487	3547	60	3517,1	17,2	3521
827	46	45	0,157	80,330	44,792	3216	3293	77	3255,3	14,9	3256
828	47	46	0,053	80,336	44,791	3279	3348	69	3312,3	16,8	3310
829	48	47	0,033	80,361	44,767	3270	3327	57	3300,4	15,2	3300
830	49	48	0,059	80,375	44,764	3332	3439	107	3401,5	30,1	3413
831	50	49	0,112	80,380	44,760	3246	3395	149	3308,3	28,0	3309
832	51	50	0,090	80,410	44,760	3442	3541	99	3494,3	22,5	3491
833	52	51	0,143	80,405	44,754	3298	3431	133	3372,5	34,6	3361
834	53	52	0,080	80,428	44,749	3359	3493	134	3433,5	29,8	3435
835	54	53	0,078	80,427	44,753	3381	3435	54	3405,9	11,4	3406
836	55	54	0,061	80,429	44,757	3427	3487	60	3457,0	14,1	3457
837	56	55	0,327	80,445	44,743	3095	3496	401	3303,6	100,0	3291
838	57	56	0,046	80,477	44,714	2542	2774	232	2657,0	60,0	2665
839	58	57	0,019	80,452	44,706	2711	2810	99	2763,5	24,5	2764
840	59	58	0,009	80,449	44,711	2938	3001	63	2972,6	17,4	2977
841	60	59	0,009	80,450	44,697	2265	2365	100	2309,8	27,0	2304
842	61	60	0,051	80,436	44,721	3107	3311	204	3211,3	48,2	3215
843	62	61	0,022	80,258	44,825	3428	3483	55	3457,6	12,9	3457
844	63	62	0,110	80,242	44,799	3267	3448	181	3357,2	41,2	3356

845	64	63	0,052	80,219	44,802	3283	3349	66	3319,8	16,2	3318
846	65	64	0,077	80,227	44,675	2594	3180	586	2916,0	154,2	2918
847	66	65	0,007	80,207	44,680	2765	2857	92	2815,0	25,4	2818
848	67	66	0,015	80,211	44,685	3081	3239	158	3161,6	45,0	3169

APPENDIX D

Personnel training

2020:

- Passage of professional (industrial) practice in the laboratory "Cartography and GIS" DTOO "Institute of the Ionosphere" 3 students of KazNITU named after Al-Farabi - Nurzhan K.K., Tazhibaev A.O., Zulpykharov K.B.

- PI Kaldybayev A.A., lectured to 1st year undergraduates at the Faculty of Geography and environmental sciences, Al-Farabi Kazakh National University, Course topic: Current problems of glaciology

- Chief researcher Kaldybayev A.A., took part in the "Interstate program of innovative cooperation of the CIS member states for the period 2021-2030" (Minsk, January 22-23, 2020)

- Seniour researcher Nurakynov S.M. took part in an online format in the 20th international scientific and interdisciplinary conference "SGEM Geo & Expo 2020" with the report "Monitoring of oil pollution in the Caspian Sea Using Sentinel-1 and Sentinel-2 Images" and "The role of Web-Based GIS system in the control and prevention of natural and manmade hazards in Kazakhstan", at the Geoinformatics and remote sensing section.

- Leading Engineer Aset Urazaliev took part in an online format at the International Scientific and Technical Conference "Energy, Infocommunication Technologies and Higher Education" with the report "Construction of a mathematical model of geodynamic processes of the earth's crust of a seismically active region of Kazakhstan using satellite measurement data" (Almaty, 10 -12 October 2020)

2021:

- Passage of research practice in the laboratory "Cartography and GIS" DTOO "Institute of the Ionosphere" undergraduate KazNU named after Al-Farabi - Merekeev A.A.

- PI Kaldybayev A.A., lectured to 1st year undergraduates at the Faculty of Geography and environmental sciences, Al-Farabi Kazakh National University, Course topic: Current problems of glaciology

- Chief researcher Kaldybayev A.A., took part in the "Interstate program of innovative cooperation of the CIS member states for the period 2021-2030" (Almaty, January, 2021)

2022:

- Leading researcher Zulpykharov K.B. took part in the international conference of students and young scientists "FARABI ALEMI" (Almaty, April 6-8, 2022).

- Researcher Merekeev A.A. took part in the international conference of students and young scientists "FARABI ALEMI" (Almaty, April 6-8, 2022).

- Researcher Merekeev A.A. defended his master's thesis on the topic "Monitoring and assessment of the degree of fire hazard of the territories of Kazakhstan based on the use of satellite information" (Faculty of Geography and Nature Management, Department of Cartography and Geoinformatics, KazNU named after al-Farabi).

- Eliseeva A.V. and Merekeev A.A. took part in panel discussions on modern trends in the development of GIS and remote sensing (Astana, September 29-30, 2022)