Kaldybayev A.A., Vilesov E.N., Issanova G.T.

Understanding the rapid shrinkage of glaciers in the Karatal river basin

Glaciers are among the world's best recorders of, and first responders to, natural and anthropogenic climate change and provide a time perspective for current climatic and environmental variations. According to our previous results, glaciers in the Karatal river basin shrinking faster than other glacierized catchments of Central Asian mountains, including Tien-Shan, Altai and Pamir. In our investigation, we consider and discuss the possible factors of dramatically decreasing glaciers in the Karatal river basin, and their role in glacier fluctuation. We conclude that considered glacierized basin are located in the most unfavorable conditions for glaciation, and as a result showed a higher shrinkage rate than other glacierized regions of the Central Asia from 1956 to 2012.

Key words: glacier shrinkage, Karatal river basin, topographic factors, climate change.

Қалдыбаев А.А., Вилесов Е.Н., Исанова Г.Т.

Қаратал өзені алабындағы мұздықтардың жылдам еруінің факторлары

Мұздықтар дүниежүзіндегі ең үздік регистраторлардың бірі болып табылады. Олар табиғи және антропогендік сипаттағы климаттың өзгеруіне бірінші болып жауап береді, сонымен қатар уақыт бойынша қазіргі кездегі климаттық және экологиялық өзгерістердің алдағы өрбуін көрсетеді. Біздің алдыңғы зерттеу нәтижелерімізге сәйкес Қаратал өзені алабындағы мұздықтар басқа Орталық Азия тауларындағы, соның ішінде Тянь-Шань, Алтай және Памирдің су жинау алаптарындағы мұздықтарға қарағанда тез еріп жатқаны байқалды. Аталған зерттеу жұмысында Қаратал өзені алабындағы мұздықтардың жылдам еруінің факторлары және олардың мұздықтар ауытқуындағы ролі қарастырылып, талданды. Зерттеліп отырған мұздықты аймақ ең қолайсыз жағдайда орналасқандықтан 1956-2012 жылдар аралығында Орталық Азиядағы басқа мұздықты аймақтардың ішінде жоғары жылдамдықта қысқаруға ұшыраған деген қортындыға келдік.

Түйін сөздер: мұздықтың азаюы, Қаратал өзен алабы, топографиялық факторлар, климаттың өзгеруі.

Калдыбаев А.А., Вилесов Е.Н., Исанова Г.Т.

Факторы ускоренного сокращения ледников бассейна реки Каратал

Ледники являются одними из лучших в мире регистраторов и первыми реагируют на изменение климата природного и антропогенного характера, показывают перспективу современных климатических и экологических изменений во времени. Согласно нашим предыдущим результатам, ледники бассейна реки Каратал сокращаются быстрее, нежели ледники других водосборов гор Центральной Азии, в том числе Тянь-Шаня, Алтая и Памира. В данном исследовании рассмотрены и обсуждены возможные факторы резкого сокращения ледников бассейна реки Каратал и их роли в колебаний ледника. Мы пришли к выводу, что рассматриваемый оледененный бассейн расположен в самых неблагоприятных условиях для оледенения. В результате он имеет более высокую скорость сокращения, чем другие оледененные регионы Центральной Азии с 1956 по 2012 год.

Ключевые слова: сокращение ледника, бассейн реки Каратал, топографические факторы, изменение климата.

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[1,2*]Kaldybayev A.A.,[1]Vilesov E.N., [3]Issanova G.T.

[1]Al-Farabi Kazakh National University,
Kazakhstan, Almaty
[2]Institute of Ionosphere, NCSRT,
Kazakhstan, Almaty
[3]U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry,
Kazakhstan, Almaty
*E-mail: azamatkaldybayev@gmail.com

UNDERSTANDING THE RAPID SHRINKAGE OF GLACIERS IN THE KARATAL RIVER BASIN

Introduction

Mountain glaciers are a sensitive indicator for climate change [1] as well as essential water storage areas on a seasonal, mid-term, and long-term time scale [2]. Various researches based on remote sensing methods founded that Central Asian glaciers has accelerated their shrinkage at the last several decades [3-5], mainly those that are located on the peripheral regions of the Tien Shan [2,6]. Glacier retreat will continue to be a crucially important topic during the next century in regards to the hydrological regime of the Central Asian regions. It is more important when the mountains are surrounded by deserts and oases, where irrigation time usually relies on glacier melt [2]. In the Karatal river basin (KRB), these situations can be found, where the water is formed mostly in glacierized catchments that drain into dry lands. The runoff generated in KRB is used for hydropower production at four hydroelectric power stations and further downstream for irrigation in south-eastern Kazakhstan.

The area changes of the glaciers investigated in the Karatal river basinconfirmed an expected and widely published trend of glacier shrinkage [7,8]. However, with the shrinkage rate of about -0.8% to -1% a^{-1} for the periods of 1956-1989 and 1989-2012, our results for this study area [12] showed a highest decreasing rate and it compared to other glacierized areas of Central Asian mountains, including Altai, Tien Shan and Pamir [3,4, 9,10].

The purpose of this investigation is comprehensive discussion of shrinkage rate of glacierized regions of Central Asia by comparing the glacier's climatic condition, their topographic and geometric characteristics.

Reasons for glacier shrinkage
Glacier shrinkage and climate

Of all the factors contributing to glacier variation, climate change may be the most important [11]. Glacier fluctuations on timescales longer than a century are controlled mainly by temperature,not precipitation. Glacier fluctuations on timescales shorter than 10 years, or in a limited spatial scale, are determined by precipitation [11].

The linear trend analysis [12] of average annual, summer (JJA) temperature from close Taldykorgan station showed that the mean rate of temperature increase was 0.43 °C (10a)-1, while the summer (JJA) temperature rose 0.28 °C (10a)-1. However, from 1960 to 2007, records at the same station displayed a slight decrease in annual precipitation. 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 [11, 13,14]. 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. Between 1960 and 2007, two climatic factors – increased temperature and slight decreased precipitation – led to significant glacier area loss[12].

Glacier shrinkage and location

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. Results among previous studies showed big variations in different parts of Tien Shan: -0.76% a^{-1} (mid-1970s - mid-2000s [10]) in western Tien Shan; -0.38% a^{-1} (1963–2003[15]) and -0.76% a^{-1} (1963–2000 [16]) in northern Tien Shan; -0.11% a^{-1} (1975-2008 [17]) in central Tien Shan and -0.35% a^{-1} (1963-2000 [5]) in eastern Tien Shan. 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 close to heavy urbanized areas [6]. The study by Aizen et al. [15]for 1977–2003 in the inner region of Tien Shan and [18] for 1971–2002 in the western Tien Shan indicated a glacial decrease of 8–9% or 0.26–0.29% a^{-1}, while in the peripheral ranges of the northern Tien Shan shrank remarkably faster. For instance, a study by Bolch [3] for Zailiyskiy (Ile) and Kungey Alatau found a shrinkage rate of -0.73% a^{-1} for 1955-1999. The research by Kokarev and Shesterova[19] studied glacier areas in the southern part of Zhetysu Alatau in a region close to our study area, and the shrinkage rate was also quite high, at about -0.86%per year. [2] mapped glaciers in the Big Naryn basin during the year 2007. By comparing their results with the Soviet glacier inventory (1955), they reported that the rate of decrease varied from -0.27% to -0.81% a^{-1} between mountain ranges, showing an increasing shrinkage rate from the inner to outer parts.

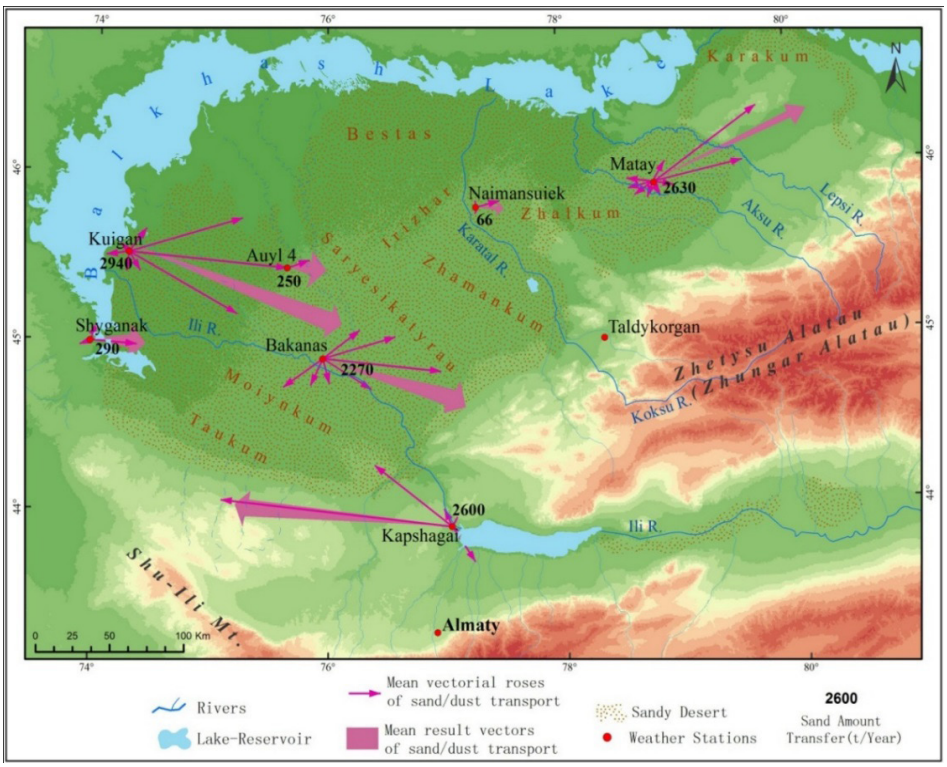
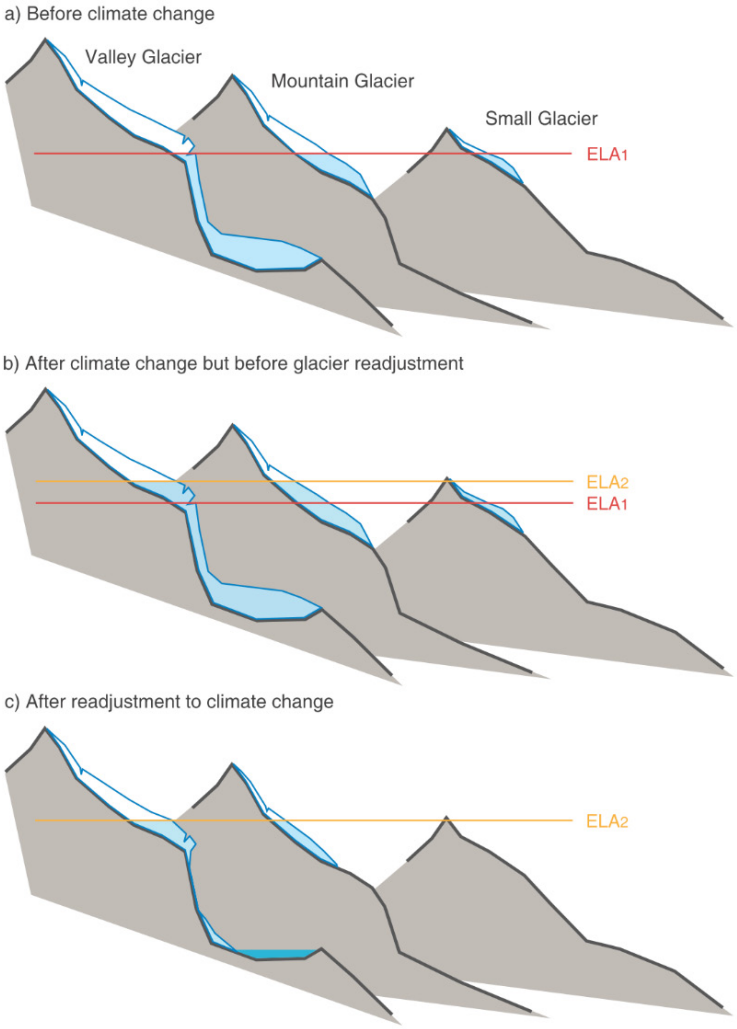


Figure 1 – Sand/dust movement direction in the southern Pre-Balkhash deserts [24]

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 [6,20]. 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.

Glacier shrinkage and topography

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 Karatal 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 [25]. 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).



Note: a) For a given climate, the ELA has a specific altitude (ELA1), and all glaciers have a specific size;b) Due to a temperature increase, the ELA shifts upwards to a new altitude (ELA2), initially resulting in reduced accumulation and larger ablation areas for all glaciers; c) After glacier size has adjusted to the new ELA, the valley glacier (left) has lost its tongue and the small glacier (right) has disappeared entirely

Figure 2 – Schematic of three types of glaciers located at different elevations, and their response to an upward shift of the equilibrium line altitude (ELA)(from IPCC [25])

In our study [12], all elevations showed a reduction of glacier areas during 1989-2012; however the largest area changes occurred on the western and north-western aspects. South-facing glaciers were not widespread in the study area, but individual glaciers showed a remarkable reduction in glacier area. Previous researches published that the most active decreasing is monitored at the ice bodies situated on the southern aspects, while ice bodies on northern aspects are more steady [9,10], because of south-facing aspects get a more part of radiation and a more part of energy for glacier melt [7]. Moreover, because of the greater incoming solar radiation, especially on the southern aspects, because of the general trend of increasing temperatures after the late 1970s [21]. Additionally, most ranges of the Zhetysu Alatau, which are oriented to the west (Fig. 1), are also under the influence of summer warm westerly that originate over the deserts located to the south of Lake Balkhash [22,23]. The exposition to moisture air masses and dominating wind directions are strongly controlling the ELA elevation on ice [2]. Furthermore, the westerlies are long distance carriers of fine-grained loess from the deserts of Central Asia to Tien Shan (Fig. 1)[23, 24], which pollutes glacial surfaces, intensifying the melting rate [21]. Especially glaciers located on the western slopes that face strong winds and dust storms from the desert could be contaminates more intensively. The frequency of dust storms directed to part of the Zhetysu range has increased during the last few decades (Fig. 1) [24], so the shrinkage rate of our study area, located in the western Zhetysu Alatau, is almost three times as severe (-0.86% per year) as the Bortala River in the eastern Zhetysu Alatau (-0.32% per year) [11]. Ice melting can be significantly altered by debris on glacier surface. However, due to low elevation in the eastern part of Tien Shan thick debris cover on glaciers of KRB almost absent.

Glacier shrinkage and size

Regions with mostly small-sized ices are more sensitive to change due to smaller glaciers have a shorter response time to climate change [26,27]. 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 [28]. In the Karatal river basin, 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 [12] indicated that the mean size of the glacier area in the Karatal river basin was 0.588 km^2. The difference in the shrinkage rates of glacier areas among the sub-basins in our research territory can be explained by the difference in mean size and aspect. For example, Terisakkan had the highest rate of shrinkage, reaching -39% from 1989-2012. The mean size of the glaciers in Terisakkan was almost two times smaller than those in the Kora sub-basin, where the shrinkage rate was -21% for the same period.

Other factors

A misclassification of snow patches as glaciers leaded to the overestimation of losses in number. Due to the delineation of first Catalogue of Glaciers is neither published in detail nor reproducible, this possibility cannot be validated [2]. In previous published works [29,30], where original images of the Catalogue of Glaciers were available, researchers have re-calculate glacierized area and found around 5% of differences between their calculations and the Catalogue of Glaciers. Errors in the Catalogue of Glaciers may also be the reason of more number rate of vanished ice bodies.Nevertheless, this results fluctuates widely, depending on the used image quality, human impact and debris on glacier surface [30]and therefore is not necessarily representative for the whole Catalogue of Glaciers [2].

It is also reported that [6], intensive urbanized areas can impact negativly on glaciers fluctuation. Investigated glaciers located closely to urbanized areas, the distance between the glacier and Tekeli town is aproximatly only 40 km.

All listed factors (Fig. 3) together made the most unfavorable conditions for glaciation in the Karatal river basin, thus led to significant area loss.

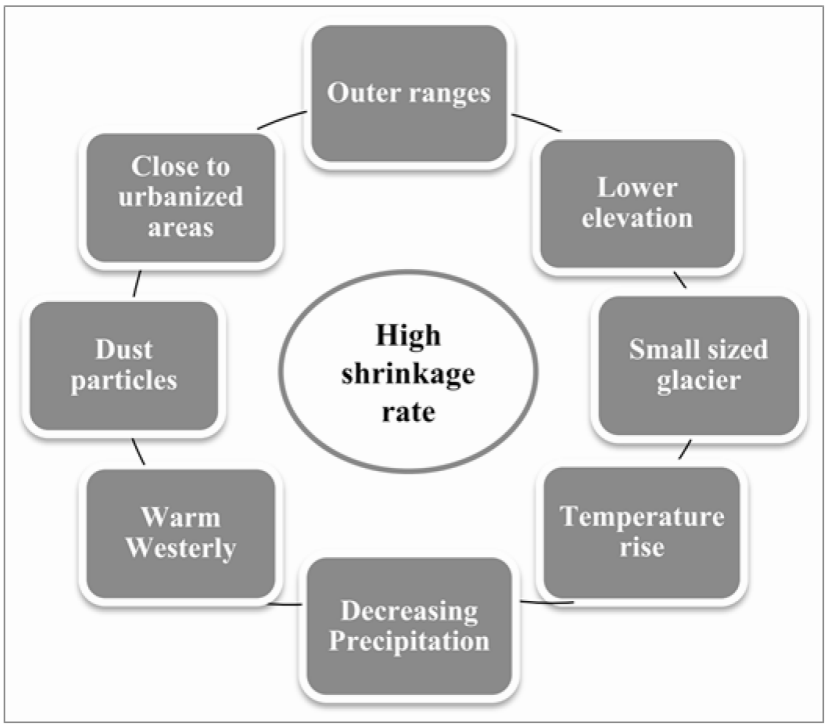


Figure 3 – All factors of shrinking glaciers

Conclusion

The rapid shrinking rate was likely connected not only to the location of our study area in the periphery of the Zhetysu Alatau, which had less favorable climatic conditions than the inner ranges, but also to the comparatively smaller glacier sizes with a complete absence of debris cover. The differences in glacier area shrinkage among the close basins can be explained by variations in sizes, orientations, and local climate conditions. No glaciers advanced during our periods of investigation.

Climatic condition play basic role on glacier status. Two main climatic factors, statistically significant temperature increasing and precipitation slight decreasing, played the main cause in the glacierized area loss in the Karatal river basin.

We conclude that glacierized areas of the Karatal river basin are located in the most unfavorable conditions for glaciation, and as a result showed a higher shrinkage rate than other glacierized areas of the Tien Shan.

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