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Glacio-hydrometeorological monitoring in the Inner Tien Shan

○Rysbek SATYLKANOV, Daniyar SAYAKBAEV, Bakytbek ERMENBAEV, Bakyt JAKEEV, Kenji TANAKA, Temur KHUJANAZAROV, Sanjar SADYROV, Chihiro HIRAOKA

Modern climate change has led to a severe degradation of glaciers in the Tien-Shan Mountains. This process's negative consequences could affect the Kyrgyz Republic due to the importance of hydropower and agriculture. Previous continuous observations of the glaciers were halted at the end of the 90s until mid of 2000s. Restoration of the monitoring will help understand the state of the glaciers and the flow into the country's main hydraulic systems of the country; additionally will provide crucial information on the impacts of climate change on the water and glacial resources of the region. Meteorological observations in the Inner Tien Shan have a long history and began in 1881. Intensive observations of glaciers and high mountains only started in 1962-1979, which defined glacier catalog and estimated available resources around 650-700 km^3.

The current stage of glaciation development in the Inner Tien Shan is characterized by the retreat of the marginal parts of the glaciers and decreased volume. This trend has accelerated significantly since 1977. In this regard, glacier degradation in the arid regions of Central Asia, where glacial recharge has a significant share in the river flow, is especially acute. Accelerated glacial melt creates additional risks for sustainable development and regional water, energy, and food security. Considering that the rivers originating on the slopes of the Tien Shan provide water for about 100 million people, concern associated with the current and projected reduction of mountain glaciation is serious since glaciers provide up to 70% of river runoff in dry years.

The high-mountain and nival belts of the Inner Tien Shan are characterized by maximum precipitation in summer and a small amount in winter. In the Chon Kyzyl Suu River, the annual amount of precipitation in the range of heights from 1740 to 2555 m increases by 28-31 mm per 100 m; in 2555 to 3300 m, the altitude gradient of precipitation is 29-30 mm per 100 m. However, in the Tien Shan's inner regions, the amount of atmospheric precipitation is only 300-400 mm, so the glacial feeding of the rivers is of particular importance. According to current estimates, after 1972, the volume of river flow within Kyrgyzstan increased by an average of 6.2%. The total average annual inflow from the flow formation zone of all rivers of the Issyk-Kul Basin in the period 1942-1972 increased by 10 m^3/s or 8.5% and can be attributed to an increase in glacial runoff. When calculating and modeling runoff, accurate information about the change in the size of glaciation is required. Such information will provide a realistic assessment of the various components' contributions to the water balance equation.

Glaciers' response to climate change is most evident in the variations of the annual mass balance parameters. Therefore determination of the mass balance through complex glaciological research predicts the dynamics of glaciation. Usually, the Tien Shan glaciers' mass balance is calculated using either the stratigraphic system (STR) or the fixed data method (FXD). The STR stratigraphic system assumes obtaining the necessary data by measuring

semi-stationary studies when each year the change of "balance" years occurs on the same day - October 1, in contrast to the fixed date system of FXD.

Starting from 2013, our center fully restored monitoring on 3 stations in the Chon-Kyzyl-Suu:

1. Lake Kara-Bulun, lakeside zone, 1609 m.
2. Chon-Kyzyl-Suu station, forest zone, 2555 m.
3. Kara-Batkak, nival-glacial zone, 3300 m.

Observations on this vertical profile allow to study climate change dynamics at different altitudes and refine climate models developed by global climate change in the Central Asian region.

One of the main glaciological observation sites is Kara Batkak glacier, conducting following observations: glacial *(maximum snow storage, ablation around the glacier, linear displacement of the front mark Glacier)****;*** meteorological (*temperature, air humidity, precipitation);* hydrological *(a measurement of water levels and discharge during ablation at the source of the Kashka-Tor river).* Meteorological observations on the Kara-Batkak glacier started in 1956, at an altitude of 3415 m, with daily and weekly average data measured manually. In July 2017, a new observation station on the glacier was established in collaboration with Kyoto University. The station is equipped with an ultrasonic sensor to measure the melting surface of the glacier. Several meteorological stations installed at the Chon-Kyzyl-Suu hydrometeorological station on altitude of 2555m measure various parameters, starting from 2012. Stations include Viasala and Licor AMCs with a 3D acoustic anemometer and a gas analyzer and Snow Water Equivalent sensor from Innova SnowFox. The transition from the previous analog to digital stations with hourly discreteness of parameter measurement will make it possible to measure datasets correctly. Correction and comparison of manual and automatic observation datasets will help create a continuous historic dataset in the area, including different elevation levels.

Fig.1. Observation station at the Karabatkak glacier.

Glacier melting and discharge are controlled on the Kashka-Tor gauging station (3260 m). Historical observations are available between 1956 and 1969. In 2013, hydrological observations were restored and starting from 2015, automatic level sensors (loggers) were used.

It has been established that the average long-term temperature in Kara-Batkak is -3.3 °C, in winter temperatures drop to -12-15 °C, and in summer they rarely exceed + 5..8 °C. The average long-term annual rainfall is 862 mm, which is 35% more than at the Chon-Kyzyl-Suu base station, almost 1000m lower due to the altitudinal gradient and air masses exhibition to the glacier.

The mass balance of the Tien Shan reference glaciers over the past 60 years - since the beginning of monitoring (1957-2018) - was generally negative and amounted to -399 mm SWE in Tuyuksu; -491 mm SWE in Kara Batkak; -370 mm SWE in Sary Tor. It is possible to characterize the evolution of the Tien Shan glaciation as a whole extrapolating from these reference glaciers. In terms of their morphological characteristics, most of the glaciers in this basin have many similar features; therefore, the Kara-Batkak glacier can represent most of them.