Final Technical Report

CRRP2017-05MY-Demberel

Climatogenic transformation of the alpine landscapes in Mongolian and Russian Altai

The following collaborators worked on this project:

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Project Overview

Project Duration	**:**	July 2017 - July 2019 (2 years)
Funding Awarded	**:**	82,000
Key organisations involved	**:**	1. Otgonbayar Demberel, Khovd State University, Mongolia, 2. Fukui Hiromichi, Chubu Institute for Advanced Studies, Chubu University, Japan 3. Pavel S. Borodavko, Institute of Monitoring of Climatic and Ecological Systems of the Siberian Branch of Russian Academy of Sciences, Tomsk State University, Russian Federation 4. Natalia Malygina, Institute for Water and Environmental Problems, Siberian Branch of the Russian Academy of Sciences, Russian Federation

Project Summary

Climate change affects the world's mountain regions and may jeopardize the important services (e.g. drinking water supplies, hydropower generation, agricultural suitability) provided by the mountains. This is especially important for mountain areas located within the boundaries of several countries, for example, the Altai Mountains that stretch over four countries (China, Kazakhstan, Mongolia and Russia). Furthermore, research addressing the relations between climate changes and a dynamic alpine landscape is currently becoming more relevant in connection with the need for reliable predictive conclusions. The goal of this project is a quantitative estimation of climatic changes (past and present) in the Mongolian and Russian Altai, the reflection in spatio-temporal changes of the mountain landscapes and the identification of irreversible changes in the morphological structure. Project results are the quantification of relations between climatic parameters and changes in landscape structure of mountain glacial basins, instrumental and remote monitoring of the nival-glacial and cryogenic landscapes conditions as well as the dynamics of slope processes. These findings will be the basis for the development of regional policies and intergovernmental cooperation, taking into account the interest of local communities.

Keywords: Climate change, Altai, glacial landscapes, permafrost

Project outputs and outcomes

Outputs

A. Electronic database of climate of 35 to 40 weather stations of studied regions and thematic map landscape of studied area
B. Observation data from 3 to 4 key points of studied regions, data sharing workshop
C. Publish scientific research papers on the results of the research project in international scientific professional journals, to send a report to funding organization

Outcomes

A. Improving knowledge about weather conditions of Great Altai, which is the base for the prediction of consequences of climate change.
B. The latest observation data from key points have been processed and presented to local communities of Russian and Mongolian parts of Great Altai. The recommendations for adaptation to the changes in natural conditions have been introduced in an accessible form. The process of collecting and processing scientific data has led to the beginning of a career of young researchers and students of higher education in the field of climate change.
C. Research and collaborative network have been established among the participants of the project (Russia, Mongolia and Japan). The results of the investigation were published and presented in Russia, Mongolia, China and the United Kingdom.

Key facts/figures

1. The key regularities of climate-related transformation of spatial properties of different-altitude limnic systems over a half-century were revealed on the basis of field studies and geoinformation analysis of remote sensing data carried out in the Great Altai. It is established that limnosystems occupying the initial and final elements of the drainage hydronets of the Great Altai are characterized by instability and pronounced asynchrony of changes in their horizontal structure. The increase of the average annual air temperature by 2.3^0 C to 2.6^0C over a half-century period was expressed in the increase of the water areas of periglacial limnic systems to 30%, and a reduction (from 15% to 38%) of the area of drainage reservoirs. It is established that the most resistant to climatic influences are lake systems, confined to the transit elements of hydronet.

2. In the course of the project, the causes and spatial-temporal regularities of processes of glacial debris and mudflow in the Altai mountains. The main trigger of mudflow formation in the nival zone is glacial lakes formed at the stages of active degradation of glaciation. The vast majority of such lakes are confined in front of glacial terminus and moraine complexes of the little ice age at altitudes from 2700 to 2900 m. The appearance and increase in the area of 47 glacial lakes over the past 50 years have been established on the basis of the analysis of polychronous spatial data and expeditionary studies in the three main glacial-mudflow areas.

Field studies, conducted at the model site in the upper reaches of the Akkol valley (South Chuya ridge), revealed areas of progressive removal of dead ice from the body of the dam of the Akkol glacial lake. The development of this process is a potential threat and it can cause a catastrophic descent of the reservoir.

3. The classification mapping of the aufeis types has been held for of the Chuya basin. The presence of three ice zones ranked according to the altitude position is established: ground aufeis, river and spring aufeis, preglacial aufeis. The dynamics of changes in the areas of aufeis of the Chuya basin was established since 1987 to 2018 with the help of GIS analysis of polychrome remote sensing materials.

4. Analysis of geothermal monitoring data for the period 2009-2019 showed steady warming (by 0.3 – 0.4°C) and an increase of the thickness (by 20-25%) of the active layer of permafrost of the Greater Altai. Degradation of the permafrost zone caused the activation of cryogenic landslides, subsidence and thermokarst.

5. Studies have found that climatic changes in recent centuries have led to significant and irreversible changes in the spatial structure of the nival-glacial landscapes of the highlands of the Mongolian Altai. The total area of deglaciation of the Sutai, Tsambagarav and Sair Uul massifs in the Western Mongolia

increased by 48. 5 sq. km and, the major sites of glaciation in the Russian Altai (Katunskiy, Severo-Chuyskiy, South-Chuysky ranges) for the half of century increased by 175 sq. km. since the maximum little ice age (about 24 sq km falls on the last 50 years). The glacial area of the Sair Uul massif has decreased by 50 per cent since 1968. The magnitude of climate uplifting landscape zone in the mountain-glacial basins of the Great Altai reached 180-200 m. The subglacial deposits passed into the category of subaeral deposits in the belt of deglaciation of ridges under the influence of the changed climatic background. The newest periglacial and limno-periglacial landscapes began to form on the young lithogenic basis.

6. During the implementation of the project, a set of information and educational measures aimed at reducing the risk and vulnerability of the population of the Great Altai from natural hazards caused by climate change in recent decades has been developed and tested.

Publications

Journal articles:

Borodavko, P.S. (2018). Climatogenic Transformation of Nival-Glacial Landscapes of Western Mongolia and Their Consequences. The Successes of Modern Science Earth Science Section 11 (2), pp 311-316. (*in Russian Language*) doi: 10.17513 / use.36945

Borodavko, P. S., Volkova, E. S., Melnik, M. A., Litvinov, A. S., & Demberel, O. (2018, November). Climate change impact on high-altitude geomorphological systems. In *IOP Conference Series: Earth and Environmental Science* (Vol. 211, No. 1, p. 012004). IOP Publishing. doi: 10.1088/1755-1315/211/1/012004

Korf, E. D., Filandysheva, L. B., Naranhuu, E., & Otgonbayar, D. (2018, December). Georesources of the Greate Altai as a Basis for the Creation of a Transnational Geopark. In *IOP Conference Series: Earth and Environmental Science* (Vol. 204, No. 1, p. 012018). IOP Publishing. doi: 10.1088/1755-1315/204/1/012018

Malygina, N. S., Eirich, A. N., Barlyeva, T. V., & Papina, T. S. (2018, November). Isotope composition of macrocirculation processes responsible for precipitation in the Altai mountains. In *IOP Conference Series: Earth and Environmental Science* (Vol. 211, No. 1, p. 012008). IOP Publishing.

Mitrofanova, E. Y., Kuriatnikova, N. A., Malygina, N. S., & Demberel, O. (2019). Альго-пыльцевой мониторинг в Алтайском биосферном заповеднике (Республика Алтай, Россия). *Acta Biologica Sibirica*, *5*(2), 60-67.

Volkova, E. S., Melnik, M.A. and Litvinov, A.S. (2019). The newest processes of formation relief of the permafrost of the Great Altay. Eurasian Union of Scientist 7 (64), pp. 6-10 DOI: 10.31618/ESU.2413-9335.2019.6.64.250

Conference paper/presentation

<u>Year 2019</u>

Otgonbayar, D. (2019, May 25-26). Climate Change and Glacier Dynamics in Mongolian Altay. Paper presented at Workshop On Human-Environment Interactions in The Middle-High Latitudes and High Altitudes of Eurasia, Lanzhou, China

Pavel, S. B., Alexey, S. L., Ekaterina, D. K. and Otgonboyar, D. (2019 January). Postglacial limnogenesis of South East Altay. Paper presented at Natural Condition and Territorial Location Aspects Influencing in Socio-Economic Development, Ulaanbaatar, Mongolia.

Pavel, S. B., Alexey, S. L., Ekaterina, D. K. and Otgonboyar, D. (2019 January). The concept of Transnational Geopark on the territory of Greate Altai. Paper presented at Natural Condition and Territorial Location Aspects Influencing in Socio-Economic Development, Ulaanbaatar, Mongolia.

Year 2018

Borodavko, P. S., Volkova, E. S., Melnik, M. A and Litvinov, A. S. (2018, July 5-11). Climate change impacts on high-altitude geomorphological systems. Paper presented at International Conference and Early Career Scientists School On Environmental Observations, Modeling and Information Systems (Enviromis–2018), Tomsk. Russia (pp 12-15).

Borodavko, P.S., Otgonbayar, D. and Litvinov A. S. (2018, August 3-5). Modern Relief Genesis in the Cryolithozone of the Great Altay. Paper presented at XIII Ubsunur International Symposium: Ecosystem Central Asia: Research, Save And Using Management. Ulaangom Mongolia

Borodavko, P.S., Otgonbayar, D. and Litvinov A. S. (2018, August 3-5). The latest relatedness Large permafrost of the Altai. Paper presented at XIV Ubsunur International Symposium: Ecosystem of Central Asia: Research, Conservation, Rational Use. UVS Aimak Oz, Mongolia.

Filandysheva, L., Borodavko, P., and Korf, E. (2018, September 5-6). Applied aspects of tourism of transnational areas. Paper presented at Natural and Artificial Environments. The Cultural Perspective.: Tmu-Tsu, Tomsk, Russia (pp. 141-146)

Korf, E. D. (2018, November 28-30). Renewable Energy Sources and Sustainable Tourism in Mountain Areas: The Case of Geopark Altai. Paper presented at Workshop Sustainable Energy and Climate Change in Russia: Policies, Discourses and Narratives, Nottingham, United Kingdom.

Korf, E. D. and Naranhuu, E. (2018 October). The Perspective of the Geotourism Development on the Transnational Territory of the Great Altai. Paper presented at International Conference of the Opportunities of the Local Geography and Tourism Development in the Siberian and Bordering Territories, Tomsk, Russia (pp. 67-70).

Litvinov, A. S. (2018, November 28-30). Permafrost of the Highlands in a Changing Climate: Risks and Prospects for the Local Communities of the Altai Mountains. Paper presented at Paper presented at Workshop Sustainable Energy and Climate Change in Russia: Policies, Discourses and Narratives, Nottingham, United Kingdom.

Malygina, N., Eirikh, A.N. and Papina, T.S. (2018, July 5-11). Macrocirculation Processes Responsible for Precipitation and their Isotope Composition in Altai. Paper presented at International Conference and Early Career Scientists School On Environmental Observations, Modeling and Information Systems (Enviromis–2018), Tomsk. Russia (pp 34-38)

Otgonbayar, D. (2018, April 17 & 27. Climate–related changes in the high mountain terrain of Russian and Mongolian Altai. Paper presented at Conference of Teachers and Researchers of Khovd State University, Khovd, Mongolia.

Otgonbayar, D. (2018, August 25-27). Modern Glaciation Ridge Sutai (Mongolian Altai). Paper presented at Climate Change and Glacier. Scientific Conference, Ulgei. Mongolia.

Otgonbayar, D. (2018, May 17). Climate and Landscape transformation of Mongolian Altai. Paper presented at Scientific Conference: Water Resources Problem of the Western Region, Khovd, Mongolia.

Year 2017

Borodavko, P. S. (2017, October 16-19). The Newest Relief Genesis of the Great Altai Highlands. Paper presented at All-Russian Scientific and Practical Conference with International Participation: Modern Problems of Geography and Geology: To The 100th Anniversary of The Opening of a Natural Branch in Tomsk State University, Russia

Borodavko, P. S., Litvinov, A. S. and Otgonbayar, D. (2017, September 20-22). Thermokarst limnogenesis of the Mongolian Altai highmountains. Proceedings of the Natural Conditions, History and Culture of Western Mongolia and Adjacent Regions (pp. 62-66)

Borodavko, P. S., Otgonbayar, D., Redkin, A. G., Volkova, E. S., Otto, O. V., Melnik, M. A. and Litvinov, A. S. (2017, September 20-22). Climate-related transformation of the nival-glacial systems of Sutai massive (Mongolian Altai). Proceedings of the Natural Conditions, History and Culture of Western Mongolia and Adjacent Regions (pp. 55-62)

Harlamova, N. P., Rotanova, I. N. and Otgobayar, D. (2017, September 20-22). Actual problems of studying the climate of the Altai region (Western Mongolia, Altai Territory and the Republic of Altai). Proceedings of the Natural Conditions, History and Culture of Western Mongolia and Adjacent Regions (pp. 170-176)

Otgonbayar, D. (2017, October 27-28). Modern Glaciation ridge Sutai (Mongolian Altai). Paper presented at Geography Ecology Altay: Save And Sustainable Development, Gorno-Altaisk, Russia.

Otgonbayar, D., Borodavko, P.S. and Litvinov, A. S. (2017, October 27-28). Climate related changes in the alpine landsystems of Mongolian and Russian Altai. Paper presented at Geography and Ecology of Altay: Save and Sustainable Development. International Scientific and Practical Conference, Gorno-Altaisk, Russia.

Redkin, A.G., Rotanova, I.N., Otto, O.B., Suhova, M.G., Kocheeva, N. A. and Otgonbayar, D. (2017, September 20-22). On the prospects of conservation and development of the geological heritage of the Greater Altai. Proceedings of the Natural Conditions, History and Culture of Western Mongolia and Adjacent Regions (pp. 385-388)

Pull quote

Korf E.D., researcher assistant, junior researcher of the Institute of Monitoring of Climatic and Ecological Systems (IMCES) SB RAS:

“Thanks to the project "Climate transformation of the Mongolian and Siberian Altai" the close cooperation of Institute of Monitoring of Climatic and Ecological Systems (IMCES) SB RAS and Hovd University. In my opinion, one of the important results of Russian and Mongolian scientific institutions cooperation was the project of the Transnational Geopark "Altai", the development of which serves the close long-term friendly collaboration between Russia and Mongolian scientific and socio-economic terms. In addition, the operation of the Transnational Geopark will ensure timely and effective communication of the latest scientific information related to transformation of the landscapes due to the climate change to the local residents, which will allow them to minimize the loss associated with changes in the natural environment.”

Igor Vaisbrot, Tomsk State University. GIS Research assistant:

Participation in the project «Climatogenic Transformation of the Alpine Landscapes in Mongolian and Russian Altai» (CRRP2017-05MY-Demberel) has enabled me to gain an insight into the current trends in the climatic conditions of the Altai Mountains and to see how these changes affect to natural landscapes. I had the opportunity to get acquainted in practice with modern methods of climate research, which was of particular interest. I was able to collect extensive factual material, as participated in the project, and use some modern research techniques, later served as the basis for writing a master's degree. Honors degree of diploma was at National Research Tomsk state University in June 2019

IWEP

Institute for Water & Environmental Problems
Siberian Branch of the Russian Academy of Sciences

The research group of Dr. Otgonbayar Demberel had finished project «Climatogenic Transformation of the Alpine Landscapes in Mongolian and Russian Altai». Analysis of meteorological data and reanalysis identified current climate change in Altai Mountains and projected future climate changes this mountain region. Moreover, many landscape transformations associated with climate change have already manifested themselves in the Altai mountains. Received future changes at different climate scenarios provide a scientific basis in developing measures to adapt to these changes. I sincerely appreciate contribution the team of research collaborators, who achieved the excellent results and APN which has chosen this project.

Deputy Director on Science of Institute for Water and Environmental Problems, Siberian Branch of the Russian Academy of Sciences, Doctor of Biology
Dmitry M. Bezmaternyh,

14.08.2019

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Glossary of Terms

GIAS - Geoinformation and analytical system
EvCLiD - Evolution and Climatogenic Landscape Dynamics
DBASE – Data Base
DEM – Digital Elevation Model
NASA - National Aeronautics and Space Administration
SRTM – Shuttle Radar Topography Mission
EOSDIS - Earth Observing System Data and Information System
ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer
ETM - Enhanced Thematic Mapper.
GDEM - Global Digital Elevation Model
NCEI - National Centre for Environmental Information
NOAA - National Oceanic and Atmospheric Administration
ETCCD - Expert Team on Climate Change Detection and Indices
IPCC - Intergovernmental Panel on Climate Change

Funding sources outside the APN

- Institute of Monitoring of Climatic and Ecological Systems SB RAS will provide the local researcher's compatible condition, and study supports for purchasing of automatically weather stations and drone for the aerial surveys ($5400).
- Chubu University will support the highest technology and condition to researchers working in the project. Purchasing of the hardware and software for the processing of spatial data ($ 1600).
- Khovd State University, Mongolia will provide the local researcher's salary and working good condition and workshop expense and publication expense. Purchasing of the field equipment (tents, sleeping bags, clothes et al.) ($ 2500).
- Institute for Water and Environmental Problems SB RAS will provide the local researcher's compatible condition and study supports. Purchasing of devices for the equipment automatically thermal boreholes. ($2500).

Acknowledgements

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Introduction

The Relief and Environment of the Earth is developing under the influence of exogenic and endogenic factors. The inflow of solar energy is the main source of energy of exogenic processes occurring in the hypergenesis zone. Climatic conditions create a characteristic relief, form elements and regime of the hydrographic network, set the boundaries of glaciation, for tens and hundreds of thousands of years. Heat and moisture balance determines the type and structure of any landscape. A. A. Grigoryev and M. I. Budyko are explored relationship between the ratio of heat and moisture and the type of landscapes, with the result that formulated the law of geographic zonality, in the middle of the last century. The law of geographical zonality shows that the spatial distribution of geographical zones is determined by the distribution of the solar energy balance and the ratio of the radiation balance to the amount of heat required evaporating the annual precipitation. I. A. Volkov studying the similarity of the characteristics of latitudinal geographical zones on the plains and vertical landscape zones in the mountains, came to the conclusion that the thickness of The earth's atmosphere has a distinct stratification and is divided into several hydrothermal layers, each of which is characterized by a corresponding dominant balance of heat and moisture.

The deep transformation of climatic conditions caused a change in the high-altitude position of each hydrothermal layer of the atmosphere, which in turn led to the spatial displacement of the boundaries of latitude geographical zones on the plains and vertical landscape zones in the mountains, in the era of Quaternary glaciation. The surface areas that were previously included in any natural zone or belt, shifted to other zones due to the changed conditions of heat and moisture, with a completely new landscape-forming environment.

The glaciation of the Russian and Mongolian Altai developed and reached its maximum size during the period of planetary cooling and a decrease in regional summer temperatures by 4,5-5 ^{0}C, in the late Neopleistocene. The snow line lowering amounted to 800-850 m, and accordingly shifted the borders of the hydrothermal zones. Glaciated areas have been steadily declining since the last glacial maximum. Periglacial landscape formed after displacement upward of the boundaries of hydrothermals and landscapes zones, which causes a radical restructuring released from the ice of the terrain. Periglacial landscapes are important structural elements of high-mountain geosystems. Periglacial landscapes of the Mongolian Altai are characterized by youth and expressed dynamic caused by active nival, cryogenic and gravity processes. Climate is the main factor in the formation of periglacial landscapes, as it determines the dynamics of glaciation, surface runoff and the nature of exogenous processes.

Methodology

The geographical setting of the study area

Altai Mountains (Figure 1.1), Russian Altay, Mongolian Altayn Nuruu, Chinese Altai Shan, complex mountain system of Central Asia extending approximately 2,000 km in a southeast-northwest direction from the Gobi Desert to the West Siberian Plain, through China, Mongolia, Russia, and Kazakhstan. The jagged mountain ridges derive their name from the Turkic-Mongolian altan, meaning "golden."

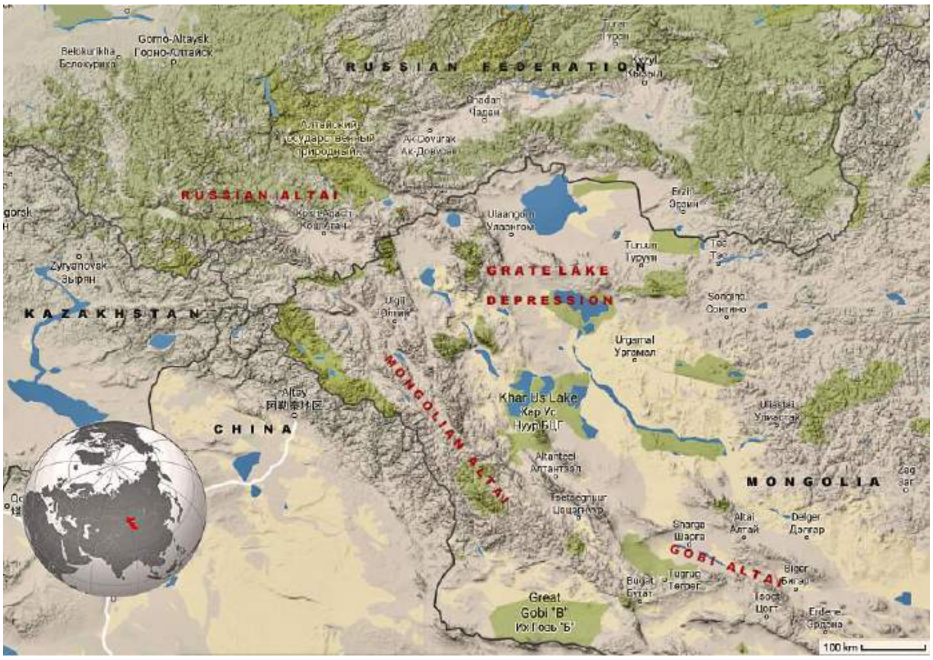


Figure 1.1. Location and Physiogeography of the Altai region.

The Russian Altai represents the highest part of the Altai-Sayan mountain system. They are located between 48–52° N and 84–90° E, and cover an area about of 200 000 km^2. The region has borders with Mongolia and China in the south and Kazakhstan in the west.

The climate of the Russian Altai is determined by three major factors: (1) its location in temperate latitudes of the Northern hemisphere; (2) a dominant direction of water-carrying air mass transport from the Atlantic to the east; (3) the effect of the powerful Asian anticyclone with frosty weather and a cloudless sky in winter-time (an absolute minimum air temperature of −62°C was recorded at the Kosh-Agach meteorological station in 1969). The rate of precipitation decreases from west to east and the glaciers' equilibrium-line altitude increases from 2200 up to 3200 m above sea level in the same west to east direction. Accordingly, the accumulation rate at the glaciers equilibrium-line altitude decreases from 3500 to 500–1000 mm in water equivalent.

In the central part of the area, mountain ridges and massifs reach elevations of 3000–4000 m. Numerous forms of recent glaciation are obvious here. The highest peak is Mount Belukha (4506 m above sea level, the highest point in Siberia), where the largest glaciers in the area, with a size of 12 to 21 km^2, are located. In the Central Altai (where the Katunsky, North-Chuysky and South-Chuysky Ranges are situated), the Alpine type of glaciation is characteristic, with a prevalence of valley and cirque-valley glaciers with extensive, steep accumulation zones and less steep glacier tongues located at the bases of ancient cirques and trough valleys. The glaciers are non-uniformly distributed over the territory being grouped around the highest mountain peaks and massifs (World Atlas, 1997). According to the Catalogue of glaciers, about 1030 glaciers with a total area of 805 km^2 and volume of 42.5 km^3 have been recorded in the Altai region (Catalogue of glaciers of the USSR, 1978; Narozhniy and Nikitin, 2003). The Mongolian Altai is a mountain system consisting of several parallel ridges, stretching for 1000 km from North to South-East and separated by longitudinal tectonic valleys. The main ridges of The Mongolian Altai are 3200-3500 m high, the peaks are mainly plateau-shaped, and the highest mountains are characterized by Alpine relief. Rocks consist of granite, porphyry, porphyrite and shale. The Mongolian Altai is continued by the lower ridges of the Gobian Altai, which do not form a single massif. The North-Eastern part of the system is bordered by the Great Lakes Depression. The Mongolian Altai is adjacent from the North to The Russian Altai. The Tavan Bogd massif is the main orographic knot of the Mongolian Altai, the highest point – Nairamdal mount - 4356 m. Atmospheric circulation of the region of research has a characteristic feature, the predominance throughout the year of westerlies air mass transfer and the development of cyclonic activity on the arctic and polar fronts. Annual precipitation is typical for areas with continental climate. Winter precipitation falls in the first half of winter (November to December), more than half of the total, this period is characterized by unstable cyclonic weather. Winter passes against a background of high pressure, during the main period (from January to March). Precipitation amount during this period is small. Cyclonic activity is enhanced in the spring, as a result, the amount of precipitation increases slightly and reaches a maximum by July. Features of the relief have the main influence on the thermal regime of the region, these are the values of the absolute height and characteristics of the snow cover. Minimum air temperatures are observed in January, the maximum in July. Air temperatures accurate calculation is possible for the slopes of the ranges Sutay and Tsambagarav according to the data from nearest weather stations, taking into account the established gradient (0,58-0,59 ^{0}C per 100 meters of climb), in the summer.

The ranges of Altai Mountains are considerable amplitude of the elevations that defines a highly dissected terrain and extensive development of the phenomena of vertical zonation. The mountain system has a high position above the ocean level and even with relatively small fluctuations in heights (200 - 300 m) it is possible to observe a natural belt change of vegetation. North-Western Mongolia and South-Western Altai regions are extended continental climate, here is widely represented arid type of altitudinal zonation. This type of altitudinal zonation is characterized by large amplitude of belt shifts - from deserts or desert steppes in the foothills to high-mountainous wolds on the summit surfaces. Some belts are reduced or completely absent, on the ranges of Sutai and Tsambagarav, especially forest, when there is direct contact of the Alpine belt with the dry and desert steppe. The exposure of the slopes is of particular importance in the distribution of plant communities.

Figure 1.2. The glaciers of the Northern slope of Tsast-Uul mountain knot.

Tsambagarav ridge is located in the central part of The Mongolian Altai (Figure 1.2), bordering to Great Lakes Depression. Mountain knot is separated from the main ridges straight tectonogenic the gully/hollow. The ridge stretches in the North-Western direction for 30-35 km, and in the meridional 25 km, and has a trapezoidal shape in the scheme. The ridge refers to the system Hungin-Nuruu, according to their morphostructural elements and is a strongly dissected highland. Mountain knot Tsambagarav consists of 3 massifs: Tsast-Uul, Huh-Nuruu-Uul, Yamat-Uul. The absolute height within the mountain knot Tsambagarav change from 2840 m to 4193 m. The 40 glaciers are concentrated in the nival-glacial belt of the Tsambagarav mountain knot. Regional climatic conditions and features of the ridge structure determined the spatial distribution (up to 40% of the rock glaciers are confined to the slopes of the Northern and North-Eastern expositions) and the morphology of glacial formations (valley, corrie-valley, corrie, hanging and flat-tops glaciers).

The Sutay ridge is located in the southern part of the Mongolian Altai and belongs to the area of epiplatformic orogenesis. This area composed of strongly dislocated sedimentary-volcanic rocks of the lower and middle Paleozoic and is distinguished by a complex tectonic structure. The ridge has a typical Alpine appearance with characteristic attributes - a dense network of corries, narrow ridges - arets and deeply embedded troughs (Figure 1.3). The Sutay ridge was subjected to repeated glaciation in Quaternary time, as evidenced by a number of classical forms (glacial-exarational, glacial-accumulative and fluvioglacial), preserved in the relief of glacial valleys and intervalley spaces.

Figure 1.3. Hanging and flat-tops glaciers on the Northern slope of Sutai ridge.

The Sutay ridge is the most southern center of the glaciation of the Mongolian Altai. The lower limit of the nival-glacial belt of the ridge is 150-200 m higher than in other glacial regions of Western Mongolia. Modern glaciation of the Sutay ridge is 14 glaciers of the four morphological types: flat-top, hanging, corrie, and corrie-valley. The glaciers are concentrated in the altitude belt from 3600-4150 m and have North exposure. The most important features of the relief, determining the morphological features of the Sutay glaciers:

- flat, plateau-like apical part of the watershed, which are the basin of accumulation for snowdrift, corrie and hanging glaciers;
- stepped slopes near to the tops, which contributes to the concentrated accumulation of snow-firn masses;
- inherited the orientation of the main snow accumulation basin related to the dominant Western moisture transfer.

Sair Uul ridge is a major structural and topographic culmination that has formed between divergent splays of the regionally extensive Hoh Serkh dextral strike-slip fault. The eastern side of the range is bounded by a linear fault that appears on satellite imagery to link northwards with the Chikhtein fault. This fault cuts through glacial deposits suggesting Quaternary movement and it is interpreted to have a reverse component of motion responsible for uplift of the eastern side of Sair Uul. The western side of Sair Uul is bounded by several thrust faults which has also uplifted the range. The range is therefore interpreted to be a structural pop-up with asymmetric flower structure geometry. The range was not studied in detail; however, fault scarps cutting alluvium were observed front a distance along the range's NW Mountain suggesting Quaternary movement. Major glacial valleys and streams within the range drain eastwards suggesting bulk eastward tilting due to thrusting on the west side (Figure 1.4).

Figure 1.4. The glaciers of Tsagangol valley. Western slope of Sair Uul ridge

The Alpine zone of the Altai ranges is characterized by significant amplitudes of daily temperatures, frequent zero mark crossing in spring and autumn create favorable conditions for the development of mechanical weathering, and as a result, lead to the formation of numerous rock-falls, placers and scree on the watersheds and slopes of the valleys. Modern relief formation zoning processes causes high values of altitude and relative height, differences in the compose and structure of rocks, changes in the height of temperature conditions and precipitation regime.

Figure 1.5. Semi desert landscapes of the Great Lakes Depression

Great Lakes Depression a vast tectonic depression in the western Mongolia. The basin is located between the Mongolian Altai, the Khangai, and the Tannu-Ola range. Area, more than 100,000 sq km. Gently sloping rockdebris and clay plains alternating with areas of low hills and isolated granite outliers and massifs dominate the relief (Figure 1.5). Elevation ranges from 750-800 m to 1,500-2,000 m. The basin is composed primarily of Anthropogenic alluvial, lacustrine, and eolian deposits. The climate is sharply continental with temperatures ranging from -50°C to 35°C. Precipitation is 100-150 mm a year and up to 350 mm in the mountains and in the north. Among the large lakes in the basin are Ubsu-Nur and Khyargas-Nuur (salt-water) and Khara-Nur and Khara-Us-Nur (freshwater); there are also solonchaks. The principal rivers are the Kobdo, Dzabkhan, and Tes-Gol.

Distribution of permafrost on the territory of the Altai Mountains

Permafrost is widespread on the territory of the Altai Mountains quite widely and unevenly, largely due to the extreme continental climate of the region (Figure 1.6). Average annual air temperatures fall in some regions to -10 °C, and a small amount of precipitation is distributed over the territory is extremely unequally. Mosaic climatic characteristics affect the specificity of the properties of frozen ground - from seasonally to permanently frozen ground, having a continuous, discontinuous and island bedding.

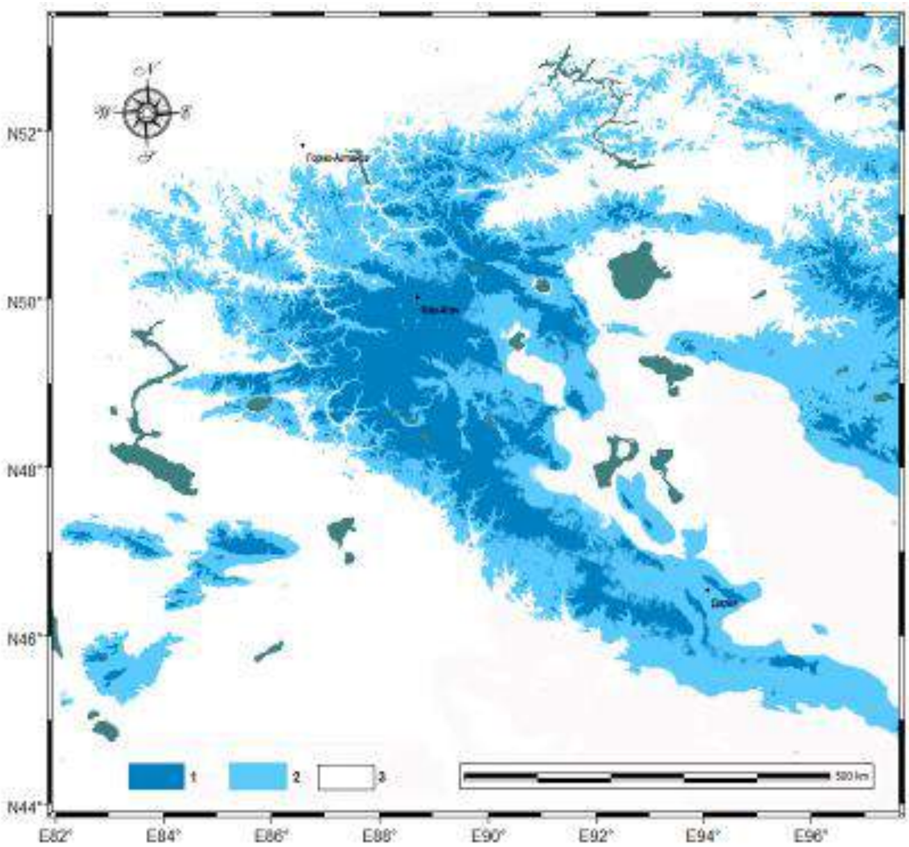


Figure 1.6. The distribution of the permafrost rocks in the Altai Mountains 1 – the belt of discontinuous permafrost; 2 – the belt of island spread of permafrost and continuous permafrost; 3 – the area of seasonal ground freezing.

Permafrost has almost continuous distribution in the South-Eastern part of the Altai. The continuous permafrost is replaced by discontinuous and sporadic permafrost, in the direction to the West and North-West. The zone of seasonal freezing of rocks is located along the Northern and Western outskirts of Altai. Chuya basin located at an altitude of 1750 - 2000 m is almost completely covered by permafrost. Continuous distribution of permafrost in the Chuya basin is disturbed by taliks. The taliks is located along the valley of Chuya River and usually have a narrow elongated shape. Taliks formed under the valleys of rivers and numerous lakes. Taliks can be formed under any depressions not only on the plains basins, but also in upland areas where there are conditions for the accumulation of rainwater and melt water. The Kurai basin, located in close proximity to the Chuya basin, but has a hypsometrically lower level (1500 - 1600 m) and has slightly different conditions. Permafrost is absent in the central part of the Kurai basin, or has island development. The narrow zone of discontinuous permafrost is located on the left bank of the Chuya River and on the outskirts of the Kurai basin, and then - on the slopes of the basin - permafrost have a continuous distribution. The depth of the permafrost zone of the Altai Mountains is generally correlated with the duration of freezing of rocks and is associated with the location of the section to a certain high-altitude geocryological zone. The depth of permafrost in the zone of sporadic distribution is 6 - 90 m, discontinuous permafrost – 50 - 160 m, continuous permafrost- 80 - 600 m, but can presumably reach in the highlands 1000 m. The Sukor massif has absolute height in the range of 2800-2900 m and separates the Kurai and Chuya basins, the depth of the permafrost here is 350-400 m. The average annual temperature of rocks in the Altai region varies in a wide range - from +6,5 to -7 °C. In the permafrost layer, the findings of large deposits of ground ice of different origin: segregated ice, intrusive ice and massive wedge ice. Quite a large ice bodies buried by moraines.

Recent cryogenic processes are manifested in the formation of specific forms of cryogenic microrelief, the analysis of which allows us to judge the intensity of their development and the degree of distribution within the study area.

Frost fracturing of rocks occurs both in the areas of development of frozen layers, and outside them — in the areas of seasonal freezing and thawing. Cracking is subject to both rock outcrops on the surface of the day or lying at a shallow depth, and loose sediments, performing intermountain basins and river valleys. The formation of frost cracks and polygonal formations is the main effect of the cracking process. Frost fracturing is most often found in the rear parts of floodplains, I and II terraces, as well as on lake-proluvial and fluvioglacial plains. Cryogenic polygon formations are to the West of the mouth of the river Kuraika, to the East of the village of Telengit-Sortogoy, South-West of the village of Chagan-Uzun, North-West of the village Tolbo-sum (Mongolia) and elsewhere. Frost fracturing is actively developing on saline soils. The width of the cracks is up to 30 cm, but sometimes they reach 1 m. The depth of cracks is up to 60 cm, they narrow downwards, at the bottom they develop ice wedges, or accumulate crumbled from the surface or squeezed out of the walls of loose material.

Frost weathering is widespread on bare or thinly covered loose sediments on slopes and watersheds. This process is most active in the highlands; it is associated with fluctuations in the temperature of rocks, which, like fluctuations in air temperature, can be daily and seasonal. This type of cryogenic landscapes widely represented within the studied ranges of Sutay and Tsambagarav. Forms of frost weathering: blockfields, blockstripes, altiplanation terrace are typical for relatively well-moist areas of slopes, within the subnival zone, where the temperature of the near surface layer of air and the upper horizons of soils often pass through 0 °C. Frosty weathering associated with seasonal freezing of rocks plays an important role. As a result of frosty weathering there is a rough crushing of rocks, leading to the formation of blockfields, block streams, blocky placers on flat watersheds. Frosty weathering in combination with gravitational processes leads to the formation of landslide-talus deposits on the slopes and the corresponding forms of relief.

Frosty sorting results in a concentration on the surface of the coarse-grained material, at the base of which a relatively homogeneous, predominantly clayey thickness is formed. This produced a variety of microforms: stone polygons, stripes, rings, etc. Stone polygons are often found on gravel-covered watersheds and floodplain terraces, i.e. on flat horizontal or inclined (up to 4°) surfaces composed of loose sediments with inclusions or predominance of coarse-grained material with close occurrence of groundwater or the presence of perched groundwater. They are observed on the outskirts of the Chuya basin, on watersheds of the South-Eastern slope of the Sutay ridge and in other places. Polygons are typically 1-3 m across, although smaller and larger shapes are found.

Frosty heaving occurs in areas of permafrost or in areas where the depth of seasonal freezing reaches water-saturated loose sediments. Ice mounds formed as a result of this process, the mounds are seasonal and perennial.

Seasonal ice mounds occur in the valleys of the rivers Chagan, Elangash, Irbistu, Kok-Uzek, to the North of the village of Kosh-Agach wetland on the rear parts of the floodplains and low terraces and in the valleys of small rivers and streams. The formation of ice mounds is connected with the freezing of the ground water table or perched groundwater. Ice mounds have a round or oval shape, height 1-2 m, flat or dome-shaped top and broken cracks. Under a layer of vegetable soil in the nuclei of the mounds lie lenses of pure ice or frozen rocks. Such mounds are formed in winter and destroyed in summer.

Perennial mound of cryogenic heaving – hydrolaccoliths or pingo (figure 1.7), common in the valleys of the rivers and cut off parts of lake basins, on the surface of the floodplains and low terraces, lacustrine-proluvial and glacial plains. Composed of Quaternary deposits, but occasionally observed in Neogene rocks, they are characteristic of parts of the Chuya basin.

Figure 1.7. The Pingo with thermokarst funnel at the base. South-West from Beltir village, Russian Altai

The hydrolaccoliths are developed both single and their groups. Frosty mounds have rounded dome-shaped, 5-10 m high, rarely up to 15 m, with a diameter of tens to hundreds of meters with convex or flat tops and steep slopes, sometimes clipped with thermal abrasion. The nuclei of frost mounds contain solid ice or icy rocks. Frost mounds occur with nuclei completely filled with water (the mounds were opened in the summer), with hollow, partially filled with water, and ice cores, under which there were cavities filled with water, often under pressure. The dynamics of hydrolaccolith were studied near the village of Tebeler. Permafrost is stored at a depth of 1.5 m, in perennial mounds of cryogenic heaving, composed mainly of loams and clays, even in late summer. Permafrost lies at a depth of 3 m (in July), in perennial mounds of cryogenic heaving, composed of pebble and sand-pebble deposits. Thermokarst funnels with a depth of 0.5 to 3 m are located in the central parts of the degrading heave cryogenic mounds, some of them are filled with water formed by pulling out ice nuclei.

Thufurs differ from the thermokarst mounds of smaller dimensions: at a height of 0.2 m and their diameter does not exceed 1.5 m; it is believed that they are formed only in areas of seasonal freezing of loose rock. "Turf cover tussocks" have a height of up to 0.5 m with a diameter of up to 2 m, a rounded convex shape, with the surface covered with turf: the upper part of these tussocks is composed of clay or loam, and clastic rocks are located at some depth and only occasionally bulge to the surface, forming blockfields. In the village of Kurai the process of frosty heaving sometimes complicates the construction processes and leads to deformation of buildings.

Figure 1.8. Thufurs in the floodplain of Chuya River. Kurai depression, Russian Altai.

Thermokarst is developed in Chuya, Kurai basins, to the South-East from Tsgannur (Ehen-Nur lake). Thermokarst leads to the formation of thermokarst funnel and thermokarst lakes, thermokarst depression. Thermokarst funnels encountered on the first flood plain terrace of the river Chuya in the Chuya valley, in the interfluve rivers Chuya - Tete and Kurai basin in the upper reaches of Tydtugem. Thermokarst funnels developed on alluvial deposits have a rounded, rarely rectangular or polygonal shape, a depth of 0.5—0.7 m and a diameter of 1-3 m, their bottom is lined with pebble-boulder material, sometimes the funnels are filled with water.

Figure 1.9. Thermokarst landscapes in the Eshtic-Kol valley. Kurai Depression

Thermokarst forms in the valley of the river Eshtic-Kol (Figures 1.8, 1.9) there are sink-hole, often rectangular and square in plan, with a size of 10-150 m with a depth of 10 m. In the bare walls of these thermokarst dips, up to 6 m high, it is observed that from above to a depth of 1.5 m melt loams lie, and below — clay, overflowing with plant residues and pierced with veins of ice. Relict thermokarst depressions are widely developed in the marginal parts of the Chuya basin and the Sailyugem plateau on lake-proluvial deposit, conventionally dated to the middle – late neo-Pleistocene. Thermokarst depressions have a depth of from 0.2 to 1.5 m, diameter from 6 to 25 m, occasionally up to 50 m, rounded or elongated shape and sloping sides.

Solifluction widely developed on the ridges Chikhacheva, Saylyugem, South Chuiskiy, Kuraiskiy, Sutay and other places. Solifluction usually confined to the steep slopes 3-20° in the mountains and in intermountain basins (on existing terrain irregularities). The process of solifluction reaches the highest intensity in the Chuya basin with frequent change of the freezing — thawing cycle in the surface layer of rocks, which is typical for the spring months, when, according to long-term data, the repeatability of the daily amplitude of air temperatures over 10°C reaches 76.8% (April) and 81.7% (may). Cryogenic slipout are failures of the thawed layer of soil on the turf cover slopes of various steepness, morphology and exposure. Special studies of the mechanism of splits are based on the assumption of the existence of so-called defects in the strength of the soil – lenses of liquid soil near the front of thawing ice-bearing loam. The subsurface fusion of lenses, the size of which in the plan is from millimeters to meters, gradually acquires an avalanche character, and because of their pressure state, the absorption of each next lens is accompanied by increasing hydraulic pressure jumps (blows). If the force of the next hydraulic shock exceeds the amount of forces to break and cut the sod-ground layer, it loses its stability and the liquid loamy "grease" moves down the slope of the pores. If the force of the next hydraulic shock exceeds the amount of forces to break and cut the sod-ground layer, then this layer loses its stability and on the liquid loamy "grease" moves down the slope. Breakdowns of extensive layers of sod and soil, the volume of which sometimes amounts to tens of thousands of m^3, rushing down the slopes, cut, tear and deform the surface, which morphologically manifests itself in the form of powerful lateral shafts of extrusion, crumpling and tilting up to several meters high. Solifluction terraces are the most common forms of solifluction on the Altai. Solifluction terraces located usually in several tiers, the height of their scarps from 0.5 to 4 m, length 10 to 30 m, and the predominant width of 5-10 m, in the form they have a festoon shape. The surface of the terraces is sloping down the relief, often complicated by cracks and funnels.

Aufeis widespread on many rivers, lakes and in areas of groundwater seepage (Figure 1.10). The volume of aufeis reaches annually 200— 220 million m^3, as evidenced by calculations made only in part of the Altai Mountains. The total volume of aufeis can be much smaller in some years. River aufeis formed on almost all small rivers: in the expansion of river valleys freeze watercourses, and sometimes alluvium with underchannel water. Water comes to the surface of the ice cover, in the presence of underground power sources in the upper valleys, which leads to an increase in the volume of ice. Aufeis are classified by the form on a flat, occupying the cleared space, the icy hillocks round shape with a diameter of 50 m at a height of 7 m and the hanging ice; the first two types can be encountered in all parts, the third only in the highlands. The size of aufeis are diverse: aufeis on the river Chuya near Kosh-Agach in the winter of 2017-2018 occupied an area of about 28 km^2 at a thickness of 0.5—2 m, on river Ustyd in 2018-2019 was formed of aufeis with an area of 15 km^2. The formation of aufeis begins in October - November, melting occurs in April — May, but many aufeis, often stored until August, and in the most severe years do not have time to melt completely. Underground aufeis occured in the Kurai basin; they lie at a depth of 0.6—1 m and are formed on wetlands of river valleys; on the surface in such cases, a variety of microform cryogenic relief.

Figure 1.10. Aufeis on Tuyaryk river. Upper image – September 18, 2018, down image - April 4, 2019

GIS techniques and data sourses

The climatic changes of the last decades entailed significant and irreversible changes in the spatial structure of the nival-glacial, cryogenic and aqutic landscapes of Russian and Mongolian Altai which are expressed in the formation of the latest morphosculpture. Geoinformation and analytical system (GIAS) "EvCLiD" (Evolution and Climatogenic Landscape Dynamics) developed, tested and implemented in use for quantitative assessment of landscape transformation. The system is created in the open package software environment Microdem/TerraBase V.16.0, Petmar Trilobite Breeding Ranch® - GIS freeware simple for using, but efficient tool for storing, visualizing, and analyzing spatial data. The databank is the information basis of GIAS "EvCLiD", organized in the form of catalogs, including sheets of topographic base scale 1:25000 (Table 1.2), thematic databases in DBASE format, and materials of polychronous remote sensing. The spatial data of GIAS "EvCLiD" are given in a uniform datum (WGS 84) and transformed into a UTM projection, vector maps are presented in the format of Shape-files. Aster Global DEM (V.2) and NASA SRTM matrix with a resolution of 1 arcsec, was used as a digital elevation model. The databank of GIAS "EvCLiD" was formed from open network portals and file archives of the USGS Geological survey (Global Data Explorer http://gdex.cr.usgs.gov/gdex/, Earth Explorer https://earthexplorer.usgs.gov/), NASA (EOSDIS https://reverb.echo.nasa.gov/reverb), Roscosmos (Geoportal http://gptl.ru/). The catalog of polychronous remote sensing data includes high-resolution multispectral digital images from Landsat 8, Landsat 7 ETM+, Landsat 5, ERTS, WorldView -2, monochrome images KH-4B (Table 1.1). Geocorrection and abstracting imagery from the satellite KH-4B was performed according to the characteristic points, which was taken to be the intersection of landscape contours, headlands of rock, the mouth of the tributaries, the characteristic curves of channels and other objects displayed on aerial photographs. The number of the reference points was at least twenty in all cases.

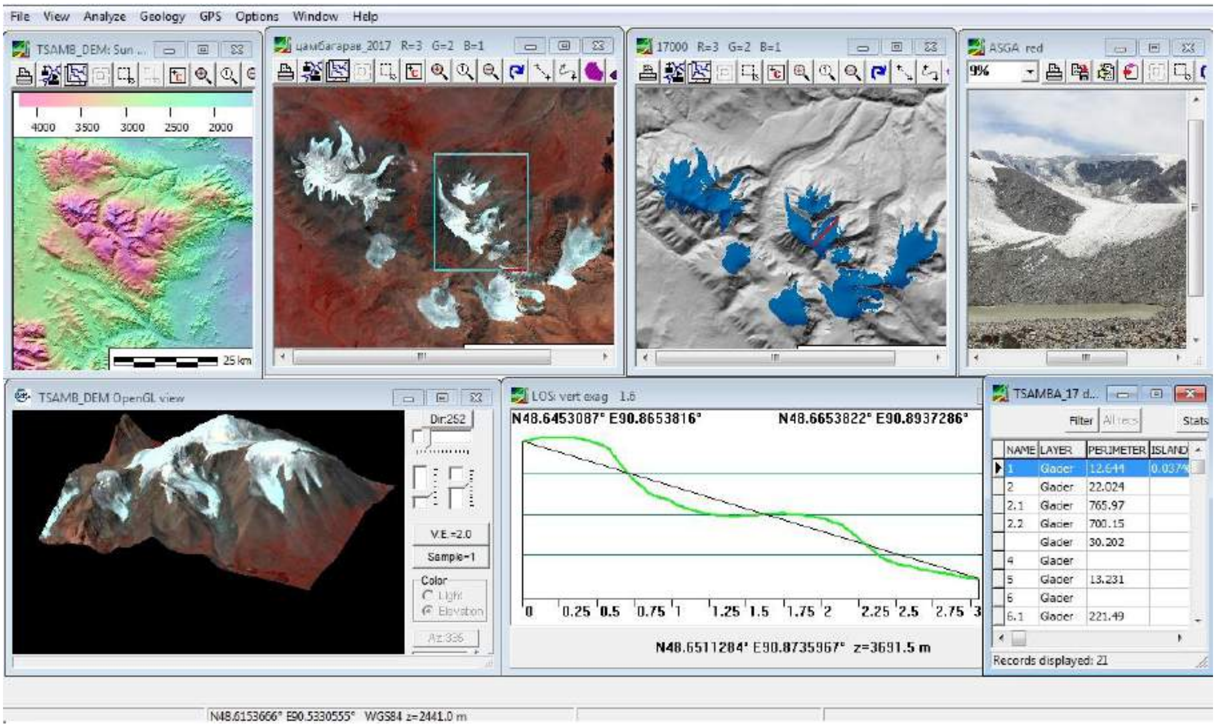


Figure 1.11. Screenshot of the GIAS "EvCLiD" interface with “Tsambagarav project

Table 1.1. The GIAS EvCliD catalogue of collected remote sensing data

Sensor	Scene ID	Date
Landsat 8	*LC81420262016226LGN00*	*2016-08-13*
	LC81410272015216LGN00	*2015-08-04*
	LC81410262015200LGN00	*2015-07-19*
Landsat 7 ETM+	*LE71420262015231EDC00*	*2015-08-19*
	LE71410262015208EDC00	*2015-07-27*
	LE71410262004210PFS01	*2004-07-28*
	LT51420262004193BJC00	*2004-07-11*
	LE71410272003207ASN02	*2003-07-26*
	LE71410272002220SGS00	*2002-08-08*
	LE71410262002220SGS00	*2002-08-08*
	LE71420262002195SGS00	*2002-07-14*
Landsat 5	*LT51420262011228IKR00*	*2011-08-16*
	LT51410262010218IKR00	*2010-08-06*
	LT51410262001209BJC00	*2001-07-28*
	LT51410262000207BJC00	*2000-07-25*
	LT51410261998217BJC00	*1998-08-05*
	LT51420261998208BJC00	*1998-07-27*
	LT51410261996196BJC00	*1996-07-14*
	LT51420261995216BJC00	*1995-08-04*
	LT51420261991221BJC00	*1991-08-09*
	LM51410261991198AAA03	*1991-07-17*
	LM51410271991198AAA03	*1991-07-17*
	LT51410261991198XXX03	*1991-07-17*
ERTS (Landsat 2)	*LM21530261977261AAA03*	*1977-09-18*
	LM21530261977225TGS03	*1977-08-13*
KH-4B	*DS1104-1055DF007*	*1968-08-11*
	DS1104-1055DA013	*1968-08-11*
WorldView - 110	*1030010048939200*	*2015-08-19*

Table 1.2. The GIAS EvCliD catalogue of collected topographic maps

Scale	Index
1:500000	*M-45-2; M-45-4; M-46-1; M-46-2; M-46-3; M-46-4; L-46-1; L-46-2;*
1:200000	*M-45-16; M-45-17; M-45-18; M-45-22; M-45-23; M-45-24; M-45-28, M-45-29; M-45-30; M-45-35; M-45-36; M-46-07; M-46-08; M-46-09; M-46-10; M-46-11; M-46-13; M-46-14; M-46-15; M-46-16; M-46-17; M-46-19; M-46-20; M-46-21; M-46-22; M-46-23; M-46-24; M-46-25; M-46-26; M-46-27; M-46-28; M-46-29; M-46-30; M-46-31; M-46-32; M-46-33; M-46-34; M-46-35; M-46-36; L-46-01; L-46-02; L-46-03; L-46-04; L-46-05; L-46-06; L-46-07; L-46-08; L-46-09; L-46-10; L-46-11; L-46-12; L-46-14; L-46-15; L-46-16; L-46-17; L-46-18;*
1:100000	*M-45-056; M-45-057; M-45-058; M-45-059; M-45-060; M-45-068; M-45-069; M-45-070; M-45-071; M-45-072; M-45-080; M-45-081; M-45-082; M-45-083; M-45-084; M-45-093; M-45-094; M-45-095; M-45-096; M-45-104; M-45-105; M-45-106; M-45-107; M-45-108; M-45-116; M-45-117; M-45-118; M-45-119; M-45-120; M-45-129; M-45-130; M-45-131; M-45-132; M-45-141; M-45-142; M-45-143; M-45-144; M-46-037; M-46-038; M-46-039; M-46-040; M-46-041; M-46-042; M-46-043; M-46-044; M-46-045; M-46-049; M-46-050; M-46-051; M-46-052; M-46-053; M-46-054; M-46-055; M-46-056; M-46-057; M-46-061; M-46-062; M-46-063; M-46-064; M-46-065; M-46-066; M-46-067; M-46-068; M-46-069; M-46-073; M-46-074; M-46-075; M-46-076; M-46-077; M-46-078; M-46-079; M-46-080; M-46-081; M-46-082; M-46-083; M-46-084; M-46-085; M-46-086; M-46-087; M-46-088; M-46-089; M-46-090; M-46-091; M-46-092; M-46-093; M-46-094; M-46-095; M-46-096; M-46-097; M-46-098; M-46-099; M-46-100; M-46-101; M-46-102; M-46-103; M-46-104; M-46-105; M-46-106; M-46-107; M-46-108; M-46-109; M-46-110; M-46-111; M-46-112; M-46-113; M-46-114; M-46-115; M-46-116; M-46-117; M-46-118; M-46-119; M-46-120; M-46-121; M-46-122; M-46-123; M-46-124; M-46-125; M-46-126; M-46-127; M-46-128; M-46-129; M-46-130; M-46-131; M-46-132; M-46-133; M-46-134; M-46-135; M-46-136; M-46-137; M-46-138; M-46-139; M-46-140; M-46-141; M-46-142; M-46-143; M-46-144; L-46-001; L-46-002; L-46-003; L-46-004; L-46-005; L-46-006; L-46-007; L-46-008; L-46-009; L-46-010; L-46-011; L-46-012; L-46-013; L-46-014; L-46-015; L-46-016; L-46-017; L-46-018; L-46-019; L-46-020; L-46-021; L-46-022; L-46-023; L-46-024; L-46-026; L-46-027; L-46-028; L-46-029; L-46-030; L-46-031; L-46-032; L-46-033; L-46-034; L-46-035; L-46-036; L-46-039; L-46-040; L-46-041; L-46-042; L-46-043; L-46-044; L-46-045; L-46-046; L-46-047; L-46-048; L-46-051; L-46-052; L-46-053; L-46-054; L-46-055; L-46-056; L-46-057; L-46-058; L-46-059; L-46-060; L-46-063; L-46-064; L-46-065; L-46-066; L-46-067; L-46-068; L-46-069; L-46-070; L-46-071; L-46-072;*

Mapping and spatial data processing

The nival-glacial and cryogenic landscapes of the key locations was mapped using visual interpretation of remotely sensed data following a pre-defined set of criteria (Heyman et al., 2008). A combination of Landsat 7 ETM+ imagery (30 m resolution) and the ASTER Global DEM was used as the primary data source. All mapping was performed and compiled using on-screen digitizing of landforms. The mapping was performed at on-screen scales ranging from 1:30,000 to 1:60,000. Multiple RGB band combinations were used in the mapping, including both ‘true’ (RGB: 5,4,2) and ‘false’ Infra Red (IR) (RGB: 4,3,2) color composites of Landsat 7 ETM+ imagery. Furthermore, standard image enhancement procedures for satellite imagery, such as contrast stretching and histogram equalization, were adopted to improve the landform spectral signature strength. Finally, we also performed pan sharpening of the false IR color composites using the panchromatic band (15 m resolution) to significantly enhance the sharpness of the imagery. A semi-transparent layer of satellite imagery was draped over the ASTER Global DEM data in a Microdem/Terra Base V. 16.0 environment to aid landform interpretation in complex topography. The mapping was checked in several key areas during 2017 field investigations in the Mongolian Altai (Figure 1.11).

Vectorization of glacial and thermokarst lakes was made on direct signs of interpretation on materials of space survey (WorldView -2, KH-4B). The main interpretation features of surface waters were: smooth photo tone and specific monotone or expressive structure of water image; shape of lakes and water bodies attachment to depressed relief elements. The lake are interpreted, when it became apparent their shape. Even very small lakes could be identified among a large cluster of lakes, in the images they are depicted in the form of small points.

Vectorization of glacial landscape elements were carried out in manual mode. The SRTM NASA Matrix and ASTER GDEM V.2 were used in the calculation of the area of three-dimensional surface of glaciers, as a digital elevation model. Verification of the reference points of the digitized polygons, conducted in the field, revealed the measurement error not exceeding 8-10%. The boundaries of the glaciers of Little Ice Age were reconstructed on the well-expressed in the relief of the marginal moraine complexes.

The hydrographical measurements were carried out by ultrasonic devices in combination with GPS localisation from a small rubber boat. The device used for bathymetric surveying contains a Leica SR 9500 DGPS and a two-ray echo sounder working in the 50–200 kHz frequency band. It is capable of measuring water depths from 0.5 to 100 m with an estimated error of less than 0.1 m. Sounding points were located along cross-sections spaced at 15–30 m. with centimeter accuracy in horizontal position. For calculations of lakes volumes, average depths and lake bed configuration, we employed GIAS "EvCLiD". A data logger MDS Dipper-T by SEBA Hydrometrie used for measurements of water regime of Sofiyskoe Lake during one year. Accuracy for temperature measurements >= 0,15 OC, pressure accuracy better then 0,1%. A data logger for measurements of annual fluctuation of the water level was installed in Lake in summer 2017.

The 3 new boreholes up to 3.5 m deep was drilled on Ehen-Nuur key site at the 2106 m a.s.l., Kosh-Agach and Tuyaryk key sites for geothermal measurements. A thermistor chain and logging system were installed in the borehole. The thermistor chain installed in borehole consists of 35 negative temperature coefficient resistors type YSI 44031. Their accuracy without calibration is +/- 0.1C over the whole measurement range and there is no significant drift at low temperatures. The sensors in the chain are installed in steps of 10 cm.

Ground-penetrating radar data were collection, processing and interpretation in 2018. GPR data were collected along profiles across the landslides located on right bank of Chagan-Uzun River, proceeding from east to west using a PulseEKKO Pro GPR system (Figure 1.12) (Sensors & Software Inc., Mississauga, ON, Canada) with 100MHz antennas. The antennas were arranged in a parallel broadside configuration spaced 1m apart and were moved with a step size of 0.25m along tape measures laid on the ground. The time window used for the surveys was 260 ns. A grid of three profile lines 100m long and spaced at 20m intervals was established over through the landslide using compass, measuring tape and fixed ground-pegs. All profile lines were surveyed to define the topography using a Geodimeter total station. Approximate georeferencing of profile terminations was accomplished using a Garmin hand-held global positioning system. Data processing used EKKO42 and EKKO_view2 (Sensors & Software Inc.) and includes dewow, AGC gain (maximum 200), trace-to-trace average of two and down the trace average of two, followed by migration. Topographic correction was applied using a velocity of 0.135mns−1 derived from curve-fitting calibration with diffraction hyperbolae as well as a common mid-point survey. The latter procedure produced corrected radar sections with reflection events in their true subsurface positions. The migration restored depths and dipping reflections. Without migration, the cross-sets appeared planar but after migration some were seen to be asymptotic. GPR interpretation The reflections on GPR profiles in sediments are attributed to changes in the complex dielectric properties of layers within the sediments owing to changes in sediment fabric including the grain size, grain shape and compaction of sediments, as well as associated changes in porosity and water content.

Figure 1.12. The view of ground-penetrating radar PulseEKKO Pro GPR

During fieldwork in 2018-2019, we used DJI Mavic Air Fly drone to survey permafrost and glacial landscapes in Russian Altai. The resulting imagery has spatial resolutions of 0.05 and 0.1 m respectively and is of suitable resolution to be able to determine the changes in landscapes structure.

Assessments and projections of climate change

Studies of changes in the hydrothermal regime on the territory of the Mongolian and Russian Altai, carried out on the basis of processing and analysis of indicators of international weather data base NOAA"s National Centers for Environmental Information (NCEI) (access Mode: http://ftp.ncdc.noaa.gov/pub/data/gsod/) during the period from 1958 to 2017 for 14 weather stations that have different time series of observations. The weather stations of Altai, Uliastai, Hovd, Ulaangom, and

Ulgi have the greatest periods of observations of the temperature regime 60 years (1958-2018 years). Weather stations Omno-Gobi, Tolbo, Baitag have observations for 30 years (1984-2001). The remaining six stations have a period of observation only for the last 18 years (2000-2018). Data on precipitation in the database are also the most complete for only the last 18 years and for some individual stations only for 10 years. The mathematical processing of the NCEL meteorological data was performed by converting the information into an Excel application, where the indicators from the traditional U.S. Customary System were transferred to the international system of units (SI). The reliability of the data is confirmed by the results of statistical analysis and comparison with some similar studies (Mongolia Second.., 2014). For a diverse assessment of the reliability of climate changes and their forecasting in Russian and Mongolian Altai, we used the initial data of meteorological stations located at altitudes of about 1000 m or more, as well as data on extreme indices and reanalysis. According to Report «Mountain Watch: environmental change and sustainable development in mountains» (2002) in the mountains separated categories of mountain terrain: 1) > 4 500 m; 2) 3 500 – 4 500 m; 3) 2 500 – 3 500 m; 4) 1 500 – 2 500 m and slope >2°; 5) 1 000 – 1 500 m and slope > 5°; 6) 300 – 1 000 m and local elevation range > 300 m (Mountain Watch, 2002). Since the last category includes a local range of heights, we relied on data from stations located about 1000 meters and above. In Russian and Mongolian Altai Mountains, only five meteorological stations are located at altitudes of about 1000 m and higher (Hovd 48.00° N, 91.4° E, 1400 m a.s.l.; Kara-Tureck 50.0°N, 86.4°E, 2600 m a.s.l.; Kosh-Agach 50.00°N, 88.4°E, 1760 m a.s.l.; Ulangom 49.9° N, 92.1° E, 939 m a.s.l.; Ulgii 48.9° N, 91.9° E, 1716 m a.s.l.; Ust-Coksa 50.30°N, 85.6°E, 978 m a.s.l.) and have a continuous series of observations. Therefore, we used data from these meteorological stations from the following sources. OSCAR/Surface is the World Meteorological Organization's official repository of WIGOS metadata for all surface-based observing stations and platforms (https://www.wmo-sat.info/oscar/). OSCAR is a resource developed in support of Earth Observation applications, studies and global coordination. It contains quantitative user-defined requirements for observation of physical variables in application areas of WMO (i.e. related to weather, water and climate).

Additionally, we used the data from the official site of the All Russian Research Institute of Hydrometeorological Information – RIHMI-WDC (http://meteo.ru/english/data/) for the stations located in the Russian part of the Altai. These meteorological data sets were automatically checked for quality control before being stored at the RIHMI-WDC and they were checked for the homogeneity. The RIHMI is the major source of official information of the Russian meteorological stations. The temperature and precipitation series of Mongolian meteorological stations were provided by National Agency for Meteorology and Environmental Monitoring of Mongolia (http://namem.gov.mn/eng/). Data quality control and homogeneity assessments was conducted and performed using Methods of State Hydrological Institute and Voeikov Main Geophysical Observatory (Bogdanova et al., 2010; Gavrilova, 2010; Bulygina et al., 2013) and RClimDex and RHtest software (http://etccdi. pacificclimate.org/software.shtml). In this study, we use the classical Mann-Kendall test was used to check whether there is a trend in temperature and precipitation time series (Mann, 1945; Kendall, 1975). In addition, the nonparametric Mann–Kendall–Sneyers test (Mann, 1945; Kendall, 1975; Sneyers, 1975) was applied to determine the occurrence of step change points of temperature and precipitation. Let x1,...,xn be the data points. One then defines in which is the number of elements xj preceding xi (j<i) and such that xj < xi. Under the null hypothesis, the test statistic is normally distributed with the mean and the variance given by:

$$t_k = \sum_{i=1}^{k} n_i \quad (1)$$

$$\bar{t}_k = E(t_k) = k(k-1)/4 \quad (2)$$

$$\bar{\sigma} t_k^2 = var(t_k) = k(k-1)(2k+5)/72 \quad (3)$$

uk as the normalized variable statistic calculated as follows:

$$u_k = (t_k - \bar{t_k})/\sqrt{(\bar{\sigma}\, t_k^2)} \quad (4)$$

Long-term trends of temperature and precipitation were determined as the slope of linear regression line of the mean temperature and precipitation during the studied time interval by using the method described by Li et al. (2013) and Malygina et al. (2017). For climate change analysis were applied data from atmospheric reanalysis described in NCAR climate data guide (https://climatedataguide.ucar.edu/data-type/atmospheric-reanalysis). The first reanalysis is a reanalysis NCEP-NCAR (https://climatedataguide.ucar.edu/data-type/atmospheric-reanalysis). NCEP-NCAR (R1) is the original reanalysis effort. It uses a frozen global state-of-the-art global data assimilation system (as of 11 January 1995). The original database was enhanced (additional, quality checked datasets) by NCAR's Data Support Section. Originally planned to span 1957-96 ("40-Year Reanalysis Project"), it was extended back to 1948 and continues to this day. Key strengths NCEP-NCAR reanalysis: 1) Global Data Set; 2) Longest running reanalysis that uses rawindsonde data; 3) Used in many publications so it can be used as a baseline reference for many computations. Key limitations NCEP-NCAR reanalysis: 1) Antiquated (1994) data assimilation/model; 2) Low spatial and temporal moisture variability over oceans (mainly model 'first guess' fields) relatively poor Southern Hemisphere.

The second reanalysis is a reanalysis ERA-Interim (https://climatedataguide.ucar.edu/data-type/atmospheric-reanalysis). Using a much improved atmospheric model and assimilation system from those used in ERA-40, ERA-Interim represents a third generation reanalysis. ERA-Interim now extends back to 1979 and the analysis is expected to be continued forward until the end of 2018. It provides hourly estimates of atmospheric variables, a horizontal resolution of 31 km and 137 vertical levels from the surface to 0.01 hPa. Key strengths: 1) Spatially and temporally complete data set of multiple variables at high spatial and temporal resolution; 2) Improved low-frequency variability (compared to ERA-40) 3) Improved stratospheric circulation (compared to ERA-40). Key limitations: 1) Too intense of a water cycling (precipitation, evaporation) over the oceans; 2) In the Arctic: positive biases in temperature and humidity below 850hPA compared to radiosondes; does not capture low-level inversions. Climate change studies often analyze extreme climate events. There is no unique definition of what constitutes a climate extreme given variations in regions and sectors affected (Stephenson et al., 2008). Much of the available research is based on the use of so-called «extremes indices» (Zhang et al., 2011). These indices can either be based on the probability of occurrence of given quantities or on absolute or percentage threshold exceedances (relative to a fixed climatological period) but also include more complex definitions related to duration, intensity and persistence of extreme events. Table 1.3 lists some specific indices that appear widely in the literature. These indices have been generally chosen for their robust statistical properties and their applicability across a wide range of climates. Another important criterion is that data for these indices are broadly available over both space and time. The existing near-global land-based data sets cover at least the post-1950 period but for regions such as Europe, North America, parts of Asia and Australia much longer analyses are available. The same indices used in observational studies are also used to future climate changes (IPCC, 2014).

Table 1.3. Definitions of extreme temperature and precipitation indices used in IPCC (https://www.ipcc.ch/; Zhang et al., 2011)

Index	Descriptive name	Definition	Units
TXx	*Warmest daily Tmax*	*Seasonal/annual maximum value of daily maximum temperature*	*0C*
TNx	*Warmest daily Tmin*	*Seasonal/annual maximum value of daily minimum temperature*	*0C*
TXn	*Coldest daily Tmax*	*Seasonal/annual minimum value of daily maximum temperature*	*0C*
TNn	*Coldest daily Tmin*	*Seasonal/annual minimum value of daily minimum temperature*	*0C*

TN10p	*Cold nights*	*Days (or fraction of time) when daily minimum temperature <10th percentile*	*days (%)*
TX10p	*Cold days*	*Days (or fraction of time) when daily maximum temperature <10th percentile*	*days (%)*
TN90p	*Warm nights*	*Days (or fraction of time) when daily minimum temperature >90th percentile*	*Days (%)*
TX90p	*Warm days*	*Days (or fraction of time) when daily maximum temperature >90th percentile*	*Days (%)*
RX1day	*Wettest day*	*Maximum 1-day precipitation*	*mm*
SDII	*Simple daily intensity index*	*Ratio of annual total precipitation to the number of wet days (≥1 mm)*	*mm day–1*
R95p	*Precipitation from very wet days*	*Amount of precipitation from days >95th percentile*	*mm*
CDD	*Consecutive dry days*	*Maximum number of consecutive days when precipitation <1 mm*	*days*

Extremes temperature and precipitation indices were derived from Climdex indices (https://www.climdex.org/about/project/). The Climdex indices can help us understand patterns in temperature and precipitation extremes: how they change from year to year or from place to place. Climdex offers 27 indices, all derived from daily temperature and precipitation data. These indices are a standardised set recommended by the CCI/WCRP/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI). The standardization of these indices allows researchers to compare results across time periods, regions and source datasets. The scientific community has defined a several scenarios climate changes for the Fifth Assessment Report (AR5) of Intergovernmental Panel on Climate Change (IPCC) in coupled Model Intercomparison Project (CMIP). CMIP is a collaborative framework designed to improve knowledge of climate change. The most recently completed phase of the project (2010-2014) is CMIP5. CMIP5 included more metadata describing model simulations than previous phases. A main objective of the CMIP5 experiments is to address outstanding scientific questions that arose as part of the IPCC process, improve understanding of climate, and to provide estimates of future climate change that will be useful to those considering its possible consequences. The AR5 IPCC summarizes information of CMIP5 experiments, while the CMIP5 experimental protocol was endorsed by the 12th Session of the WCRP Working Group on Coupled Modelling (WGCM). The CMIP5 simulations were performed with prescribed CO2 concentrations reaching: 421 ppm (RCP2.6), 538 ppm (RCP4.5), 670 ppm (RCP6.0), and 936 ppm (RCP 8.5) by the year 2100 (https://www.ipcc.ch/) (Table 1.4).

Table 1.4. Projected change in global mean surface air temperature for the mid- and late 21st century relative to the reference period of 1986–2005 (https://www.ipcc.ch/)

Scenario	**Global Mean Surface Temperature Change (0C) mean (likely range)**	
	2046-2065	**2081-2100**
RCP2.6	*1.0 (0.4 — 1.6)*	*1.0 (0.3 — 1.7)*
RCP4.5	*1.4 (0.9 — 2.0)*	*1.8 (1.1 — 2.6)*
RCP6.0	*1.3 (0.8 — 1.8)*	*2.2 (1.4 — 3.1)*
RCP8.5	*2.0 (1.4 — 2.6)*	*3.7 (2.6 — 4.8)*

For projected future climate and extreme climate changes we use CMIP5 (full set) and GCM: CMIP5 extremes. CMIP5 (full set) includes multiple realizations of each model, downweighed such that the weight of each model is again the same. GCM: CMIP5 extremes is the extremes indices. They have computed various indices of extremes from the daily CMIP5 data. At the moment only the annual values are available, so for instance the maximum daily rainfall amount for each year (Rx1day) or the highest maximum temperature in a year (TXx).

SEM–based study of pollen and algae spectra

Important components of terrestrial landscapes are plants that respond to climate change through shifts in phenology and through changes in pollen deposition. In aquatic landscapes, changes in the species composition and the number of algae can be a response to climate change. The Altai State Natural Biosphere Reserve (Russian Altai) became the main model training ground for studying the responses to these changes. On the territory of the reserve, the main phenological events are recorded, which are presented in the annual reports of the "Chronicle of Nature". To calculate the phenological response of plants, data on the occurrence of phenological events and most often all temperature indicators are used (Chuine et al., 2010). Moreover, it is assumed that the influence of other abiotic factors, including the length of the photoperiod and the start date of snow melting (Dunne et al., 2004), cannot significantly affect changes in phenological parameters. Based on the phenological data of a number of taxa and temperatures, the phenological response to changes in the thermal regime will be calculated, i.e. it is estimated how the dates of the start of dusting (flowering) change from year to year with changing temperatures. In Altai State Natural Biosphere Reserve, we conducted a study of spore-pollen and algological spectra selected according to the requirements of the international Pollen Monitoring Program (Tauber traps). Traps were removed at the end of the growing season, the volume of samples taken was measured, and placed in airtight containers in order to prevent secondary ingress. 40% formalin was added to each sample container to stop the development of microflora and the safety of objects. To determine the spore-pollen and algological spectra, we used electron microscopy. Electron microscopy allows investigating biological objects such as cells, cellular organelles, bacteria, viruses, biogenic macromolecules, etc., under the highest magnification possible in biological research. There are two main fields in the electron microscopy: scanning (raster) electron microscopy (SEM) being applied for rather thick sections of the biological samples, and transmission electron microscopy (TEM) being applied for the thin sections (Inkson, 2016).

For studying samples at high resolution (zoom range: 5–300.000) we applied a Hitachi SEM S-3400N (Japan).For SEM, a biological specimen is normally required to be completely dry, since the specimen chamber is at high vacuum. Worth noting that water is an essential component of living biological samples, together with complex organic macromolecules such as proteins, lipids, and carbohydrates (Echlin, 2009). Cells cleaning are done with hydrogen peroxide or concentrated acids and washed in distilled water. Hard silicon frustules of diatoms, dinoflagellates, cysts of chrysophycean algae or dense organic shells (like pollen) can be examined with little treatment, but living cells and tissues and whole, soft-bodied organisms require special chemical fixation to preserve and stabilize their structure. Fixation is usually performed by incubation in a solution of a buffered chemical fixative, such as glutaraldehyde, sometimes in combination with formaldehyde and other fixatives. We used glutaraldehyde with a phosphate buffer as a fixative (note: a buffer maintains pH at a physiological level. The method described by Felgenhauer B.E. (1987). In opinion of (Kamzolkina, Bogdanov, 2017), the authors of Microscopy Manual, such fixation forms cross-links among molecules of cellular substances thus providing a strong cell carcass and preventing substance loss that allows to preserve a cell volume. After cleaning and fixation, the dry specimens are mounted on an aluminum specimen stubs using an adhesive such as epoxy resin or electrically conductive double-sided adhesive tape. The specimens suspended in the small volume of the water dropped on the stubs, dried and sputter-coated with gold/palladium alloy before examination in the microscope Hitachi SEM S-3400N. Additionally, we analyzed the influence of synoptic conditions on the intake of pollen, spores and algae with atmospheric precipitation in the conditions of Russian Altai.

1. Results & Discussion

Temperature and precipitation changes from meteorological station data in Altai Mountains

For climate change analysis, we used data from six meteorological stations(Figure 2.1 a) located at altitudes of about 1000 m and higher in Russian (Kara-Tureck – 50.0°N, 86.4°E, 2600 m a.s.l., Kosh-Agach – 50.00°N, 88.4°E, 1760 m a.s.l., Ust-Coksa – 50.30°N, 85.6°E, 978 m a.s.l.) and Mongolian (Hovd – 48.00° N, 91.4° E, 1400 m a.s.l., Ulangom – 49.9° N, 92.1° E, 939 m a.s.l., Ulgii – 48.9° N, 91.9° E, 1716 m a.s.l., Ust-Coksa – 50.30°N, 85.6°E, 978 m a.s.l.) Altai Mountains. Based on Mann-Kendall test, it was shown that the annual temperature (1979-2017) in Altai Mountains was +0.05^{0}C, while the trend was 0.21^0 C per decade (Table 2.1, Figure 2.1). The annual temperature in Mongolian Altai was positive (+1.08^{0}C) and higher than in Russian Altai (-0.77^{0}C). The trend of temperature changes in Mongolian and Russian Altai was positive and amounted to +0.25^0 C per decade and +0.19^{0}C per decade (Figure 2.2 and 2.3).

Table 3.1.Annual temperature in Altai Mountains

Period	Altai Mountains (^{0}C)	Mongolian Altai (^{0}C)	Russian Altai (^{0}C)
1979-2017 (all period)	+0,05	+1,08	-0,77
1979-1997 (first period)	-0,27	+0,87	-1,14
1998-2017 (second period)	+0,32	+1,28	-0,46

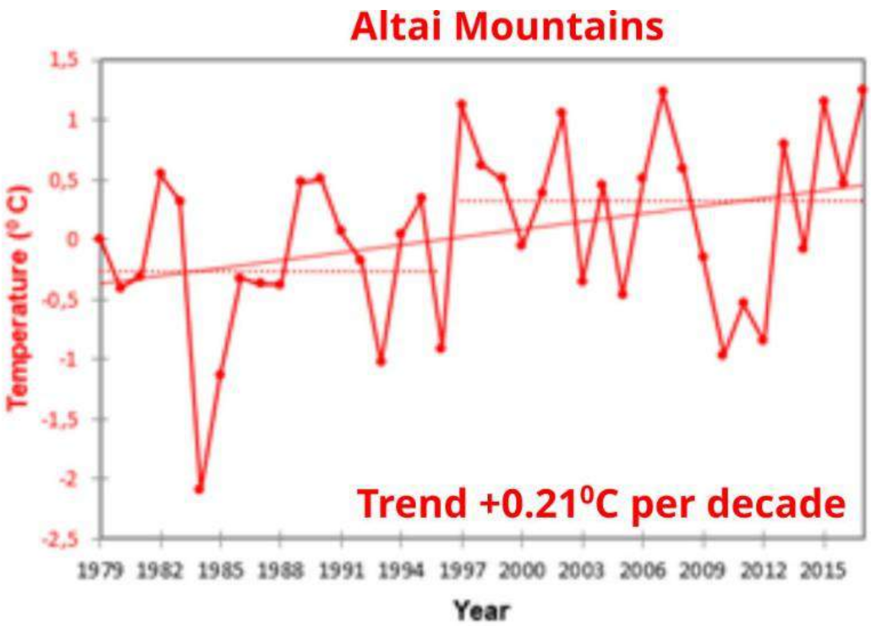


Figure 2.1. Annual and trend temperature in Altai Mountains

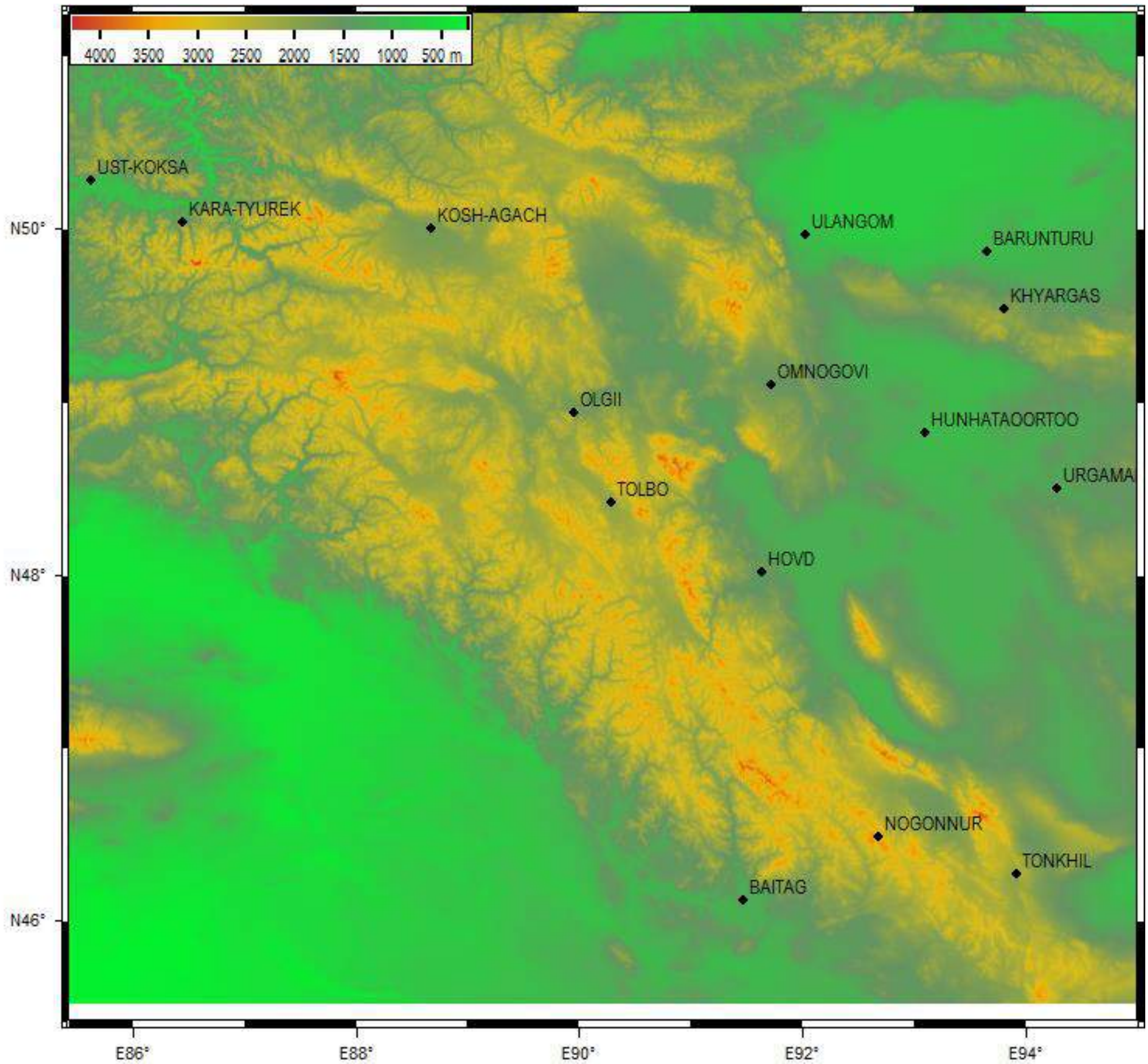


Figure 2.1a The location of meteorological stations in the Altai region

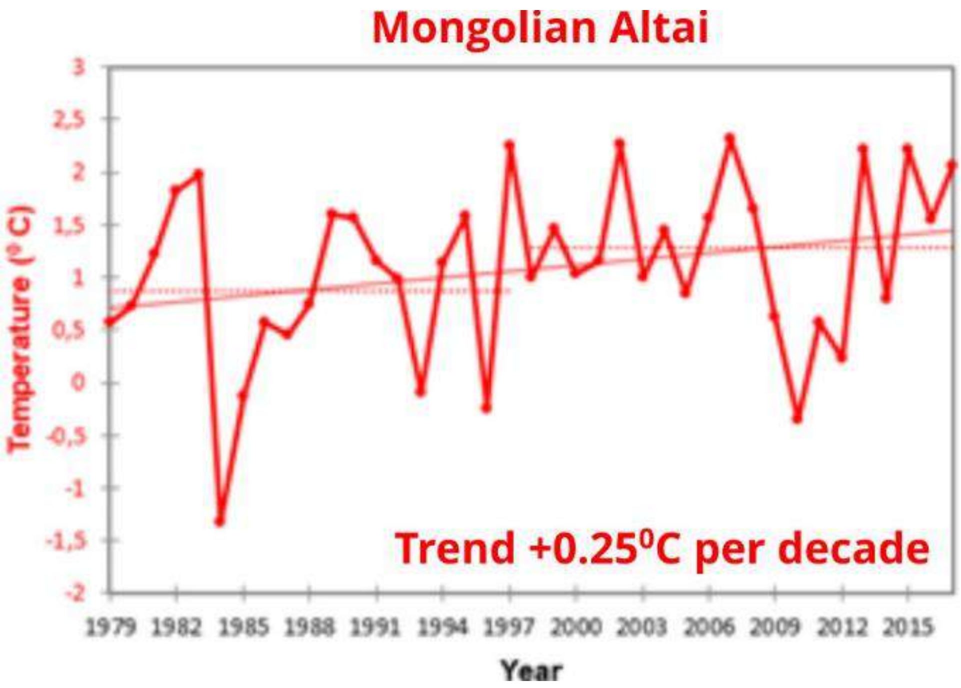


Figure 2.2. Annual and trend temperature in Mongolian Altai Mountains

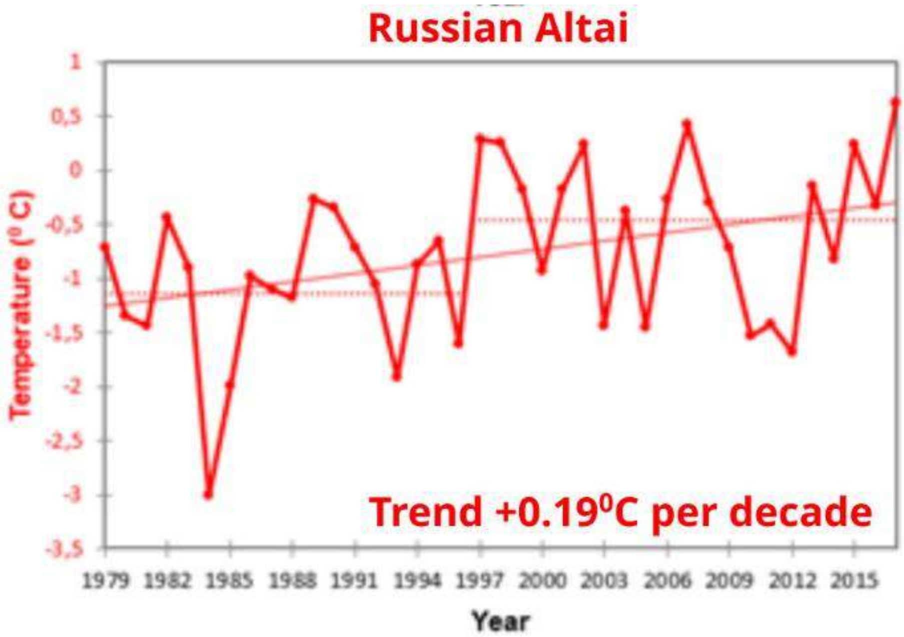


Figure 2.3. Annual and trend temperature in Russian Altai Mountains

Based on the step change analysis, the studied period (1979-2017) was divided into two time subintervals at the step change point. Step change points were found on temperature in 1997 (Figure 2.1-2.3). The annual temperature in Altai Mountains was negative (-0.27^{0}C) until 1997, and became positive after that (+0.32^{0}C) (Table 2.1). Annual temperature in Mongolian and Russian Altai in the second period was significantly higher than in the first selected periods.

The annual precipitation in the Altai Mountains in 1979-2017 was 400 mm, while the trend of changes was negative -1.4 mm yr-1 per decade (Table 2.2 and Figure 2.4). The annual minimum values are characteristic of Mongolian Altai (213 mm), in contrast to Russian Altai (665 mm), however, trends in both regions were negative (Figure 2.5 and 2.6).

Table 2.2. Annual precipitation in Altai Mountains

Period	Altai Mountains (mm)	Mongolian Altai (mm)	Russian Altai (mm)
1979-2017 (all period)	400	213	665
1979-2002 (first period)	421	252	685
2003-2017 (second period)	367	188	624

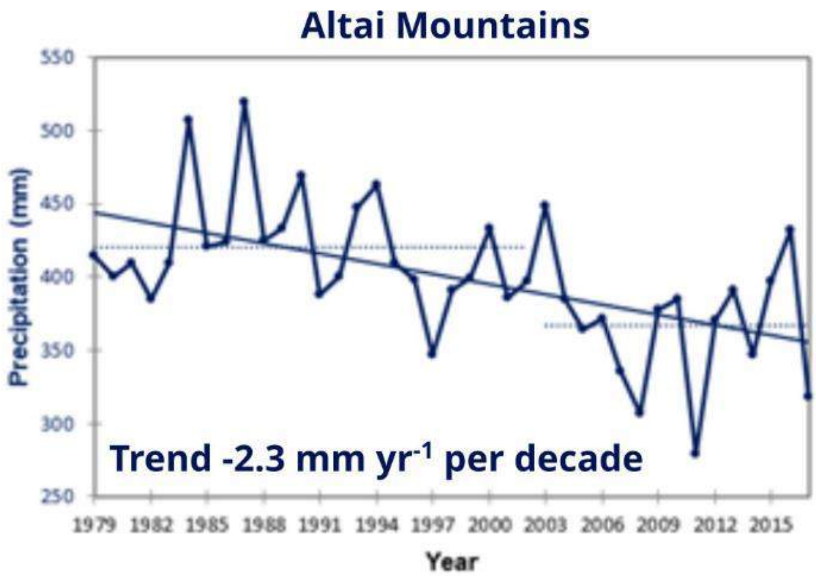


Figure 2.4. Annual and trend precipitation in Altai Mountains

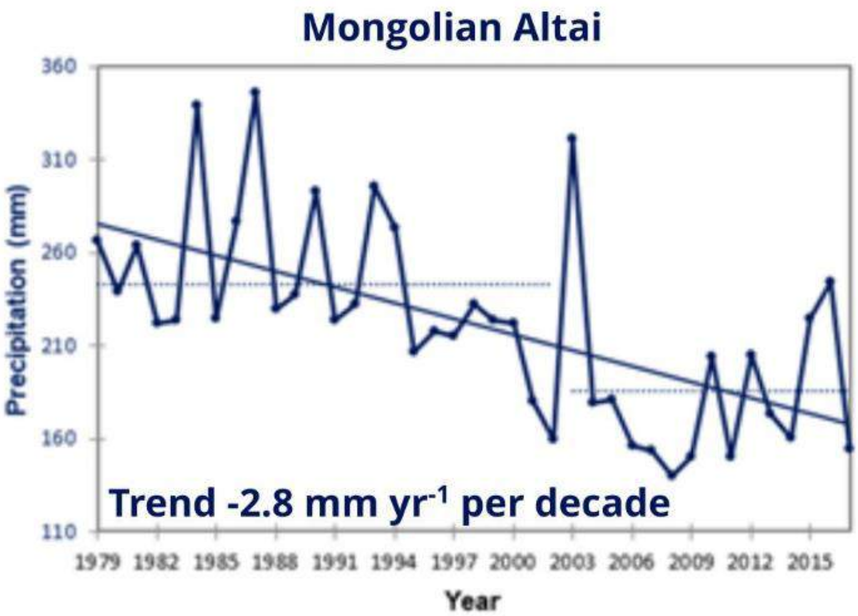


Figure 2.5. Annual and trend precipitation in Mongolian Altai

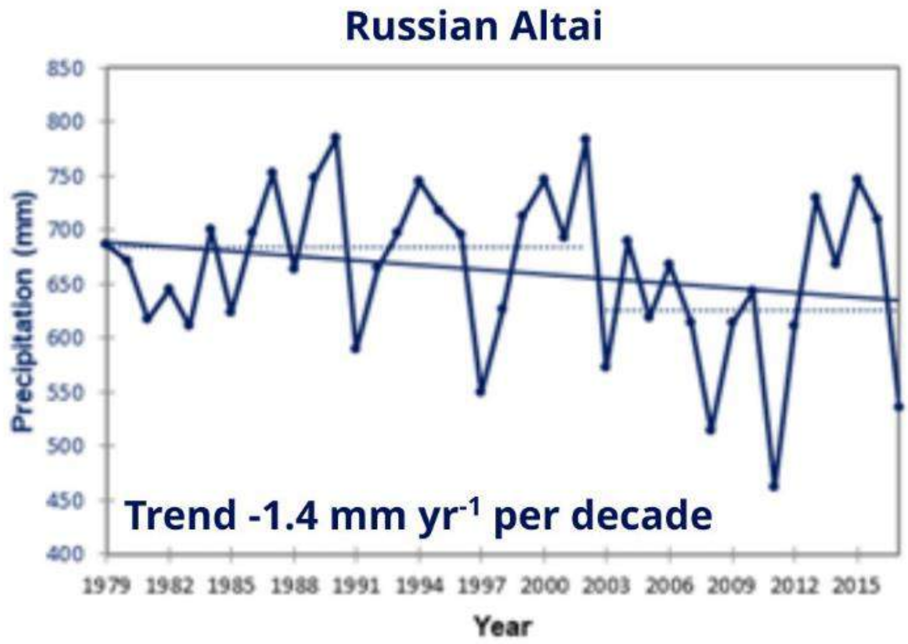


Figure 2.6. Annual and trend precipitation in Russian Altai

Based on the step change analysis, step change points on precipitations were found in 2003. Precipitation in the second period (2003-2017) declined relative to the first period (1979-2002) from 421 mm to 362 mm in Altai Mountains, as well as in Mongolian and Russian Altai (Table 2.2).

2.2 Observation and reanalysis data in Altai Mountains

In this study, we compared the average temperature and precipitation data obtained at meteorological stations in Altai Mountains with the reanalyses (NCEP/NCAR – Figure 2.7 and ERA-Interim – Figure 2.8) for the boundaries of Altai Mountains (85^{0}E - 92^{0}E, 48^{0}N - 52^{0}N). The results of comparisons of annual temperatures are presented in Table 2.3.

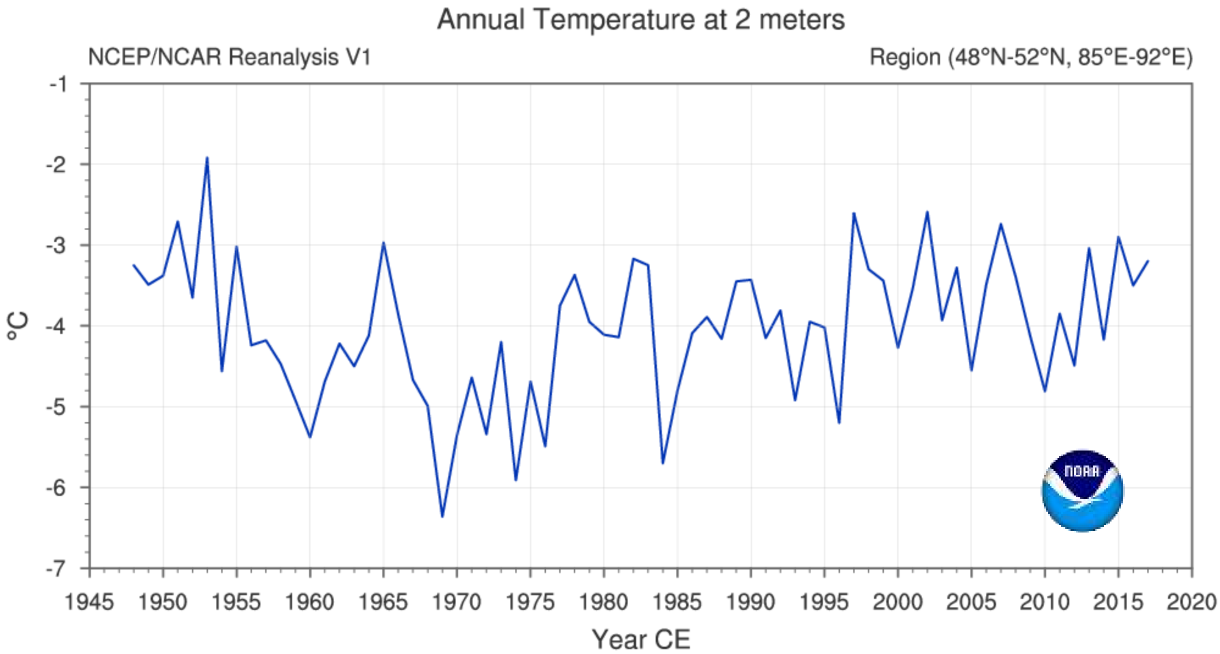


Figure 2.7. Annual temperature in Altai Mountains by NCEP/NCAR reanalysis (https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html)

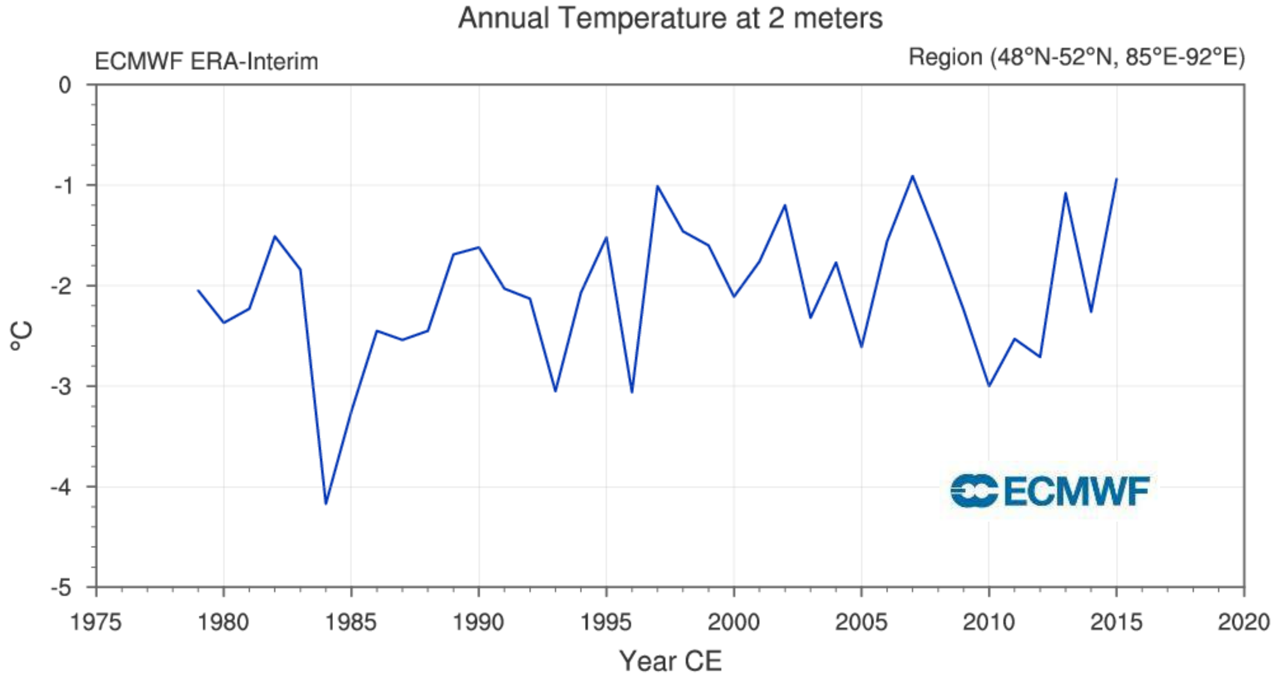


Figure 2.8. Annual temperature in Altai Mountains by ERA-Interim reanalysis (https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim)

Table 2.3. Annual temperature in Altai Mountains by observation and reanalysis data

Period	**Station**	**NCEP/NCAR**	**ERA-Interim**
Annual(^{0}C)			
1979-2017 (all period)	+0.05	-4.02	-2.07
1979-1997 (first period)	-0.27	-4.04	-2.27
1998-2017 (second period)	+0.32	-3.63	-1.87
Trend(^{0}C per decade)			
1979-2017 (all period)	+0.21	+0.16	+0.17

The annual temperatures from NCEP/NCAR (-4.02^{0}C) and ERA-Interim (-2.07^{0}C) are much more negative (about 2 ^{0}C) than according to meteorological stations (+0.05^{0}C). This is due to the fact that different data sources were analyzed. The temperature difference for two periods (1979-1997 and 1998-2017) was about the same as for the whole period (1979-2017). However, the values of the positive trends in reanalysis NCEP/NCAR (+0.16^{0}C per decade) and ERA-Interim (+0.17^{0}C per decade) are close both among themselves and with the values (+0.21^{0}C per decade) obtained from meteorological stations.

Based on global temperature anomaly data from the Global Historical Climatology Network-Monthly (GHCN-M) data set and International Comprehensive Ocean-Atmosphere Data Set (ICOADS), which have data from 1880 to the present, we calculated the temperature, which was +0.18^{0}C per decade for 1896-2018 (Figure 2.9).

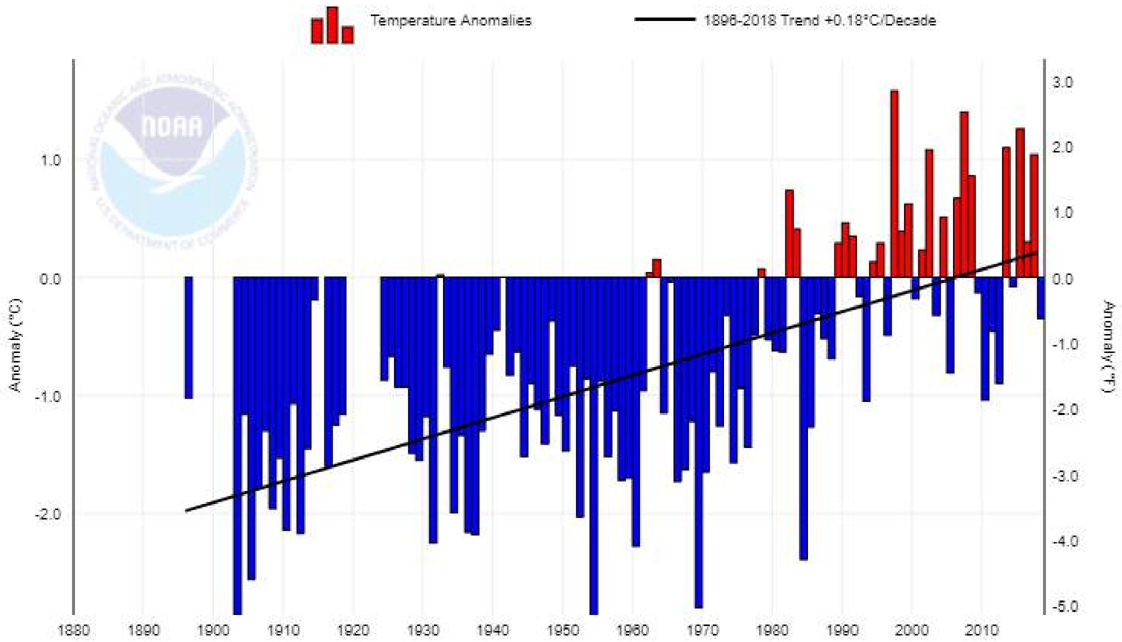


Figure 2.9. Temperature in Altai Mountains 1896-2018 (https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets)

We calculated the warmest and coldest years coordinated average anomalies with respect to the 1981 to 2010 (Figure 2.10). The warmest years were in the last 30 years, the coldest ones – until the 1970s with the exception of 1984. The trends for 2019 are still unclear, however, the beginning of the year is essentially a year for warmer years.

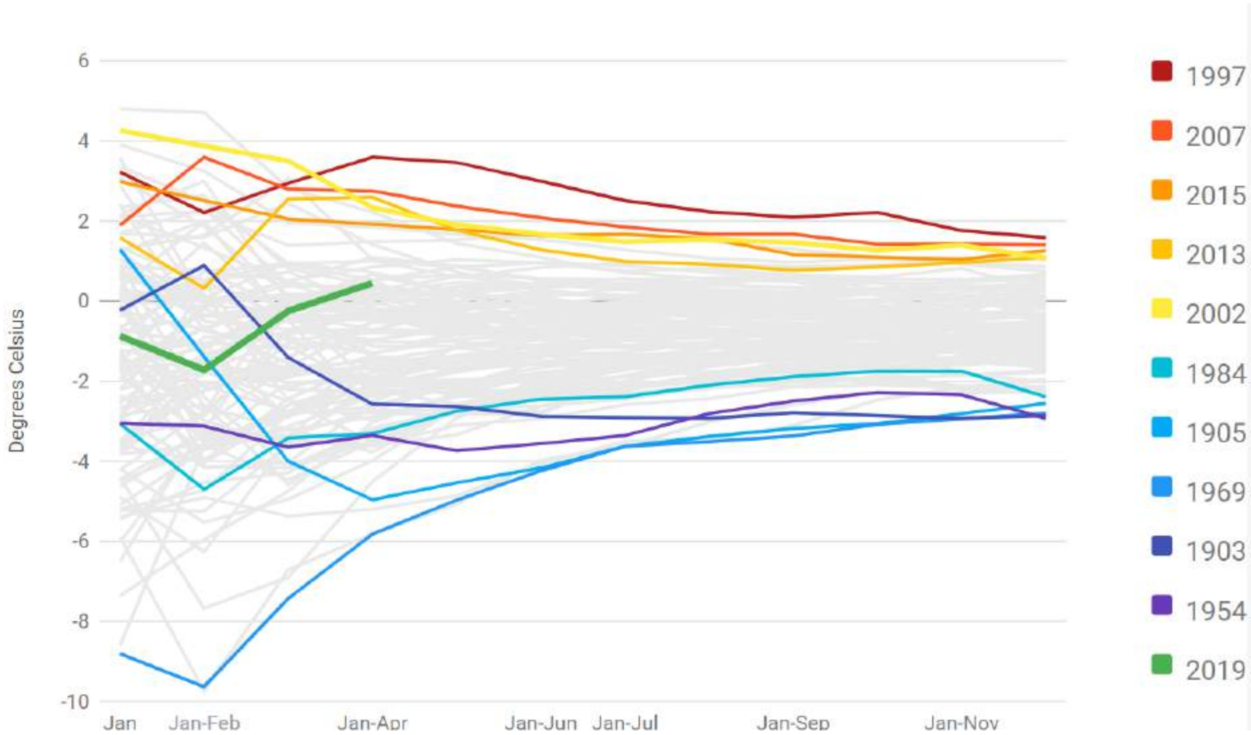


Figure 2.10. Temperature in Altai Mountains 1896-2018 [https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets]

Changes in precipitation according to reanalyses NCEP/NCAR and ERA-Interim in Altai Mountains presented in figures 2.11 and 2.12 and Table 2.4.

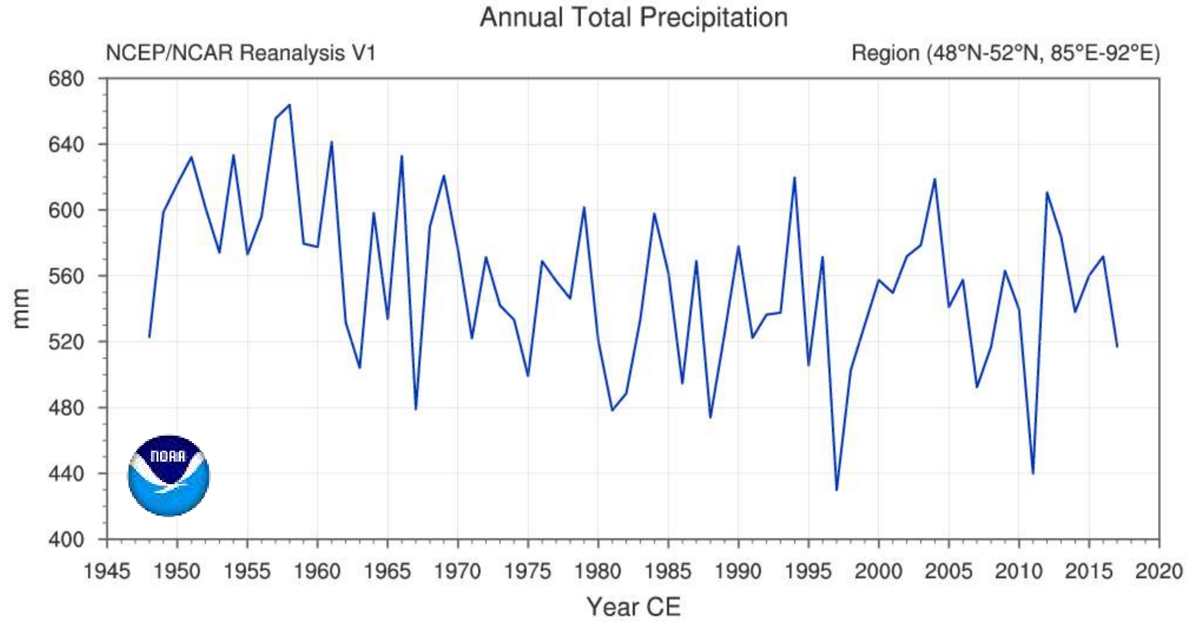


Figure 2.11. Annual precipitation in Altai Mountains by NCEP/NCAR reanalysis (https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html)

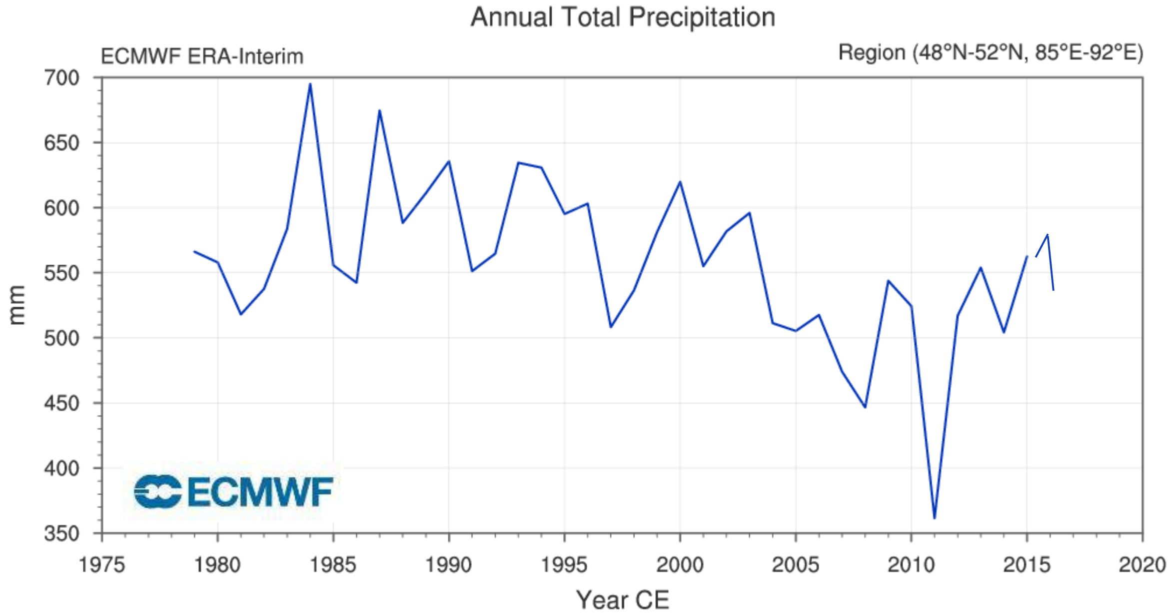


Figure 2.12. Annual precipitation in Altai Mountains by ERA-Interim reanalysis [https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim]

Table 3.4.Annual precipitation in Altai Mountains by observation and reanalysis date

Period	Station	NCEP/NCAR	ERA-Interim
Annual(mm)			
1979-2017 (all period)	400	541	558
1979-2002 (first period)	420	537	585
2003-2017 (second period)	367	549	502
Trend(mm yr^{-1} per decade)			
1979-2017 (all period)	-2.3	+4.3	-2.8

According to meteorological stations data, the annual precipitation from NCEP/NCAR and ERA-Interim was more than 150 mm. A positive trend was obtained from NCEP/NCAR (+4.3 mm yr^{-1} per decade), while a negative trend was obtained from ERA-Interim and meteorological stations (-2.3 mm yr^{-1} per decade and -2.8 mm yr^{-1} per decade, respectively). The results indicate the need to attentive use the data from NCEP/NCAR in Altai Mountains.

Thus, the temperature in Altai Mountains, in the period of 1979-2017, increased by both meteorological stations (trend +0.21^{0}C per decade) and NCEP/NCAR (trend +0.16^{0}C per decade) and ERA-Interim reanalysis (trend + 0.17^{0}C per decade). The results of the trends are consistent with trends calculated for 1896-2018 (trend + 0.18^{0}C per decade). However, the average temperatures for these reanalysis (NCEP/NCAR and ERA-Interim) and meteorological stations differ significantly due to the difference in data (primary data and reanalysis). Based on «step change point», it is shown that the most intense warming has been observed in the last 20 years (since 1997), both in Russian and Mongolian Altai with similar warmest years during this period.

The precipitation in Altai Mountains is decreasing two times faster (trend -2.3 mm yr^{-1} per decade) compared to Mongolian Altai, unlike Russian Altai. This trend is confirmed by the results of calculations for the ERA-Interim reanalysis (trend -2.3 mm yr-1 per decade). According to NCEP/NCAR reanalysis, the obtained trends give a positive position (trend +4.3 mm yr-1 per decade), in contrast to the trends obtained from two other sources (meteorological stations and ERA-Interim). Based on the “step change point”, it was shown that the most dramatic decrease in precipitation, both in Russian and in Mongolian Altai, occurred in 2002.

Extreme climate indices in Altai Mountains

We analyzed changes 12 extreme climate indices for Altai Mountains. Annual maximum value of daily maximum temperature or warmest daily (Tmax about +36^{0}C) was in 1992, 2002 and 2005 (Figure 2.13).

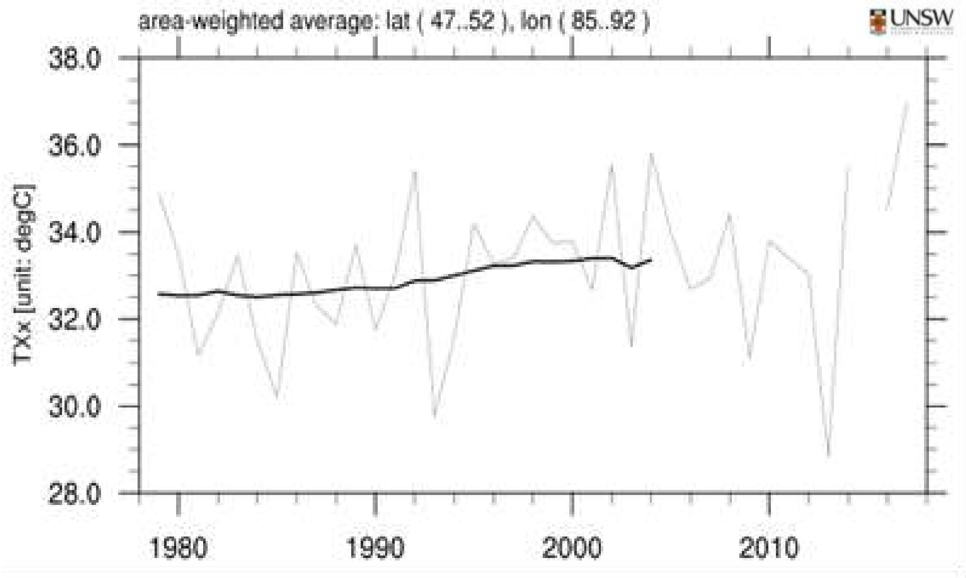


Figure 2.13. Warmest daily Tmax (TXx) (www.climdex.org)

Warmest days with minimum temperature (about +17^{0}C) were in 1993 and 2015 (+12.5^{0}C) (Figure 2.14).

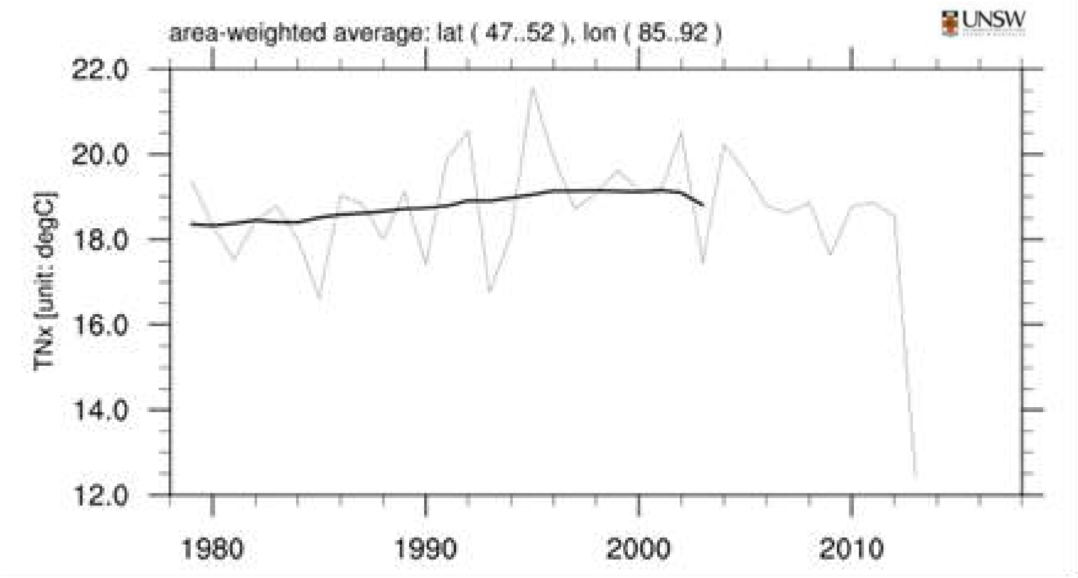


Figure 2.14. Warmest daily Tmin (TNx) [www.climdex.org]

The annual minimum value of the daily maximum temperature (about -30^{0}C) was in 1984 and 2001 (Figure 2.15), at this time Mongolia (Mongolian Altai, Hovd aimag) was experiencing drought and dzud (Sternberg, 2018).

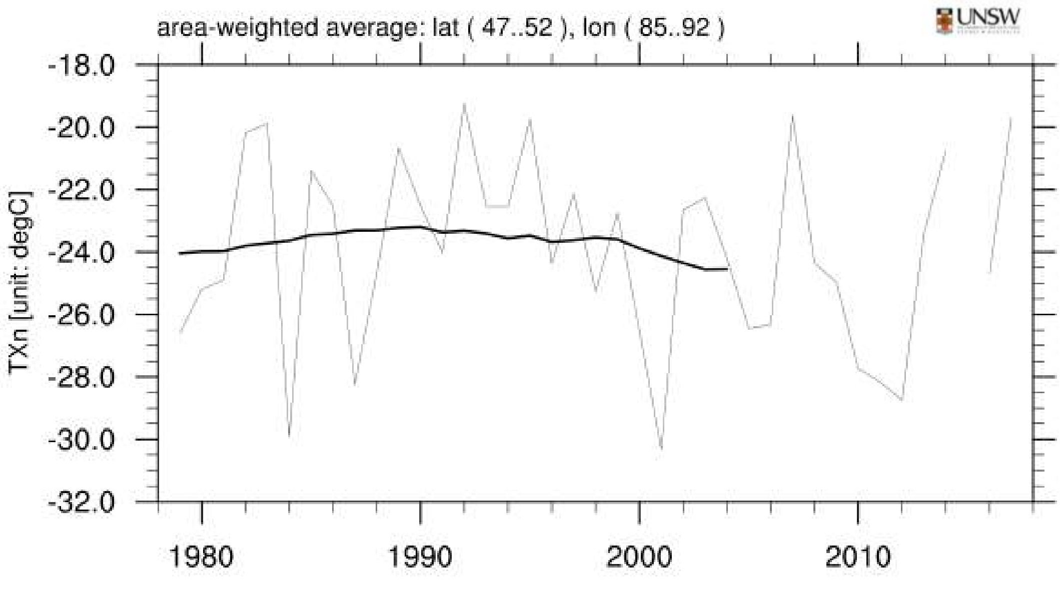


Figure 2.15. Coldest daily Tmax (TXn) (www.climdex.org)

The annual minimum value of daily minimum temperature (about -40^{0}C) was in 2001 (Figure 2.16), when observed dzud in Mongolia with significant losses livestock (Sternberg, 2018).

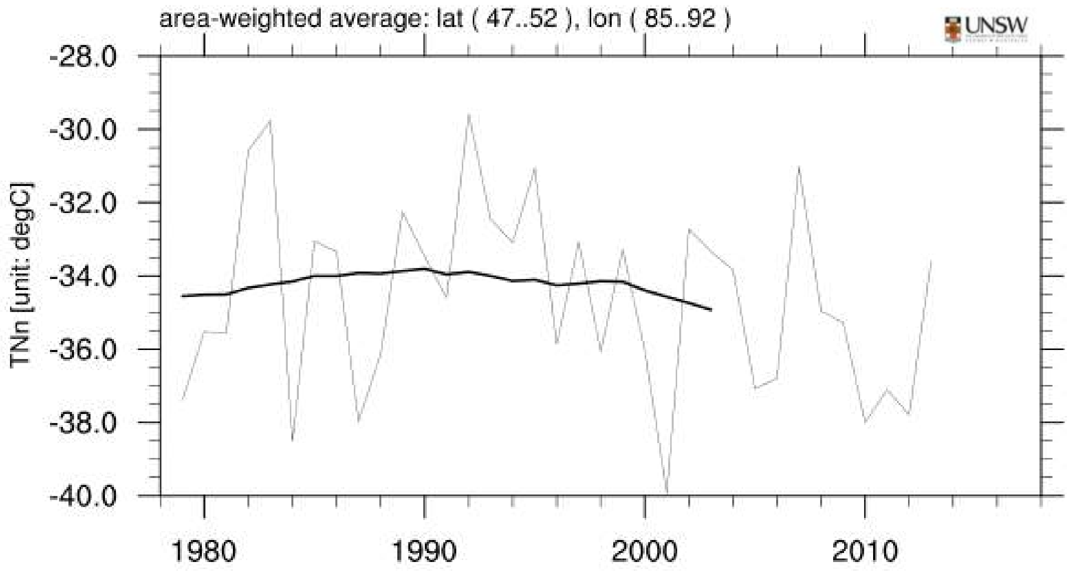


Figure 2.16. Coldest daily Tmin (TNn) (www.climdex.org)

Maximum number of days when daily minimum temperature <10th percentile (cold nights) (Figure 2.17) was in 1984 (drouth in Mongolian Altai (Sternberg, 2018) and 2010 (dzud in Hovd aimag (Sternberg, 2018).

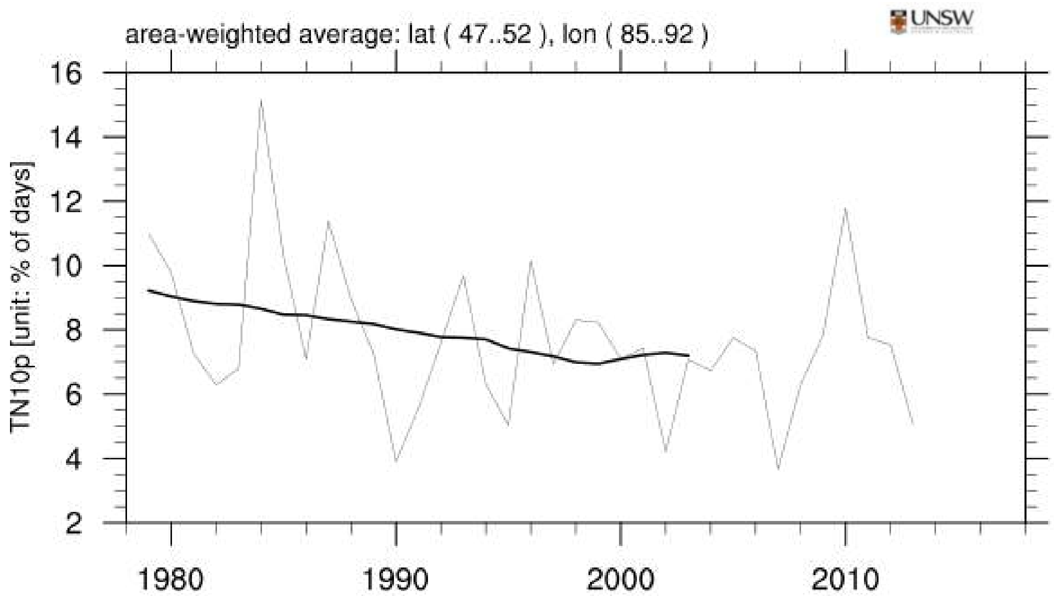


Figure 2.17. Cold nights (TN10p) [www.climdex.org]

Maximum amount of days when daily maximum temperature <10th percentile (cold days) (Figure 2.18) was in 1984 and 2010 (extreme events in Mongolian Altai).

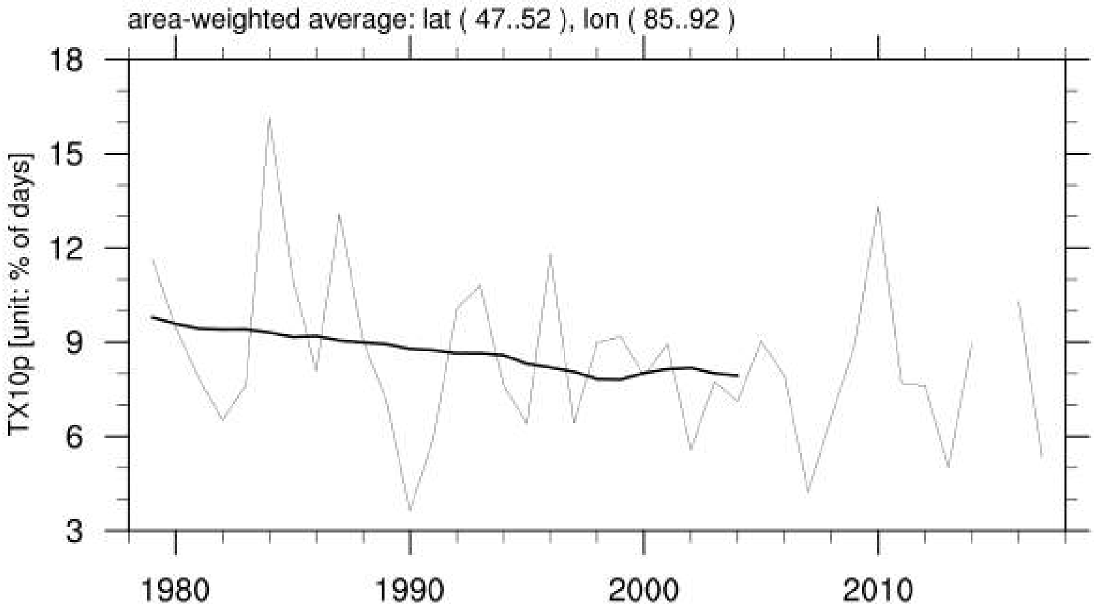


Figure 2.18. Cold Days (TX10p) (www.climdex.org)

Maximum number of days when daily minimum temperature >90th percentile was in 1997 (about 20%) (Figure 2.19) and there was a tendency to increase.

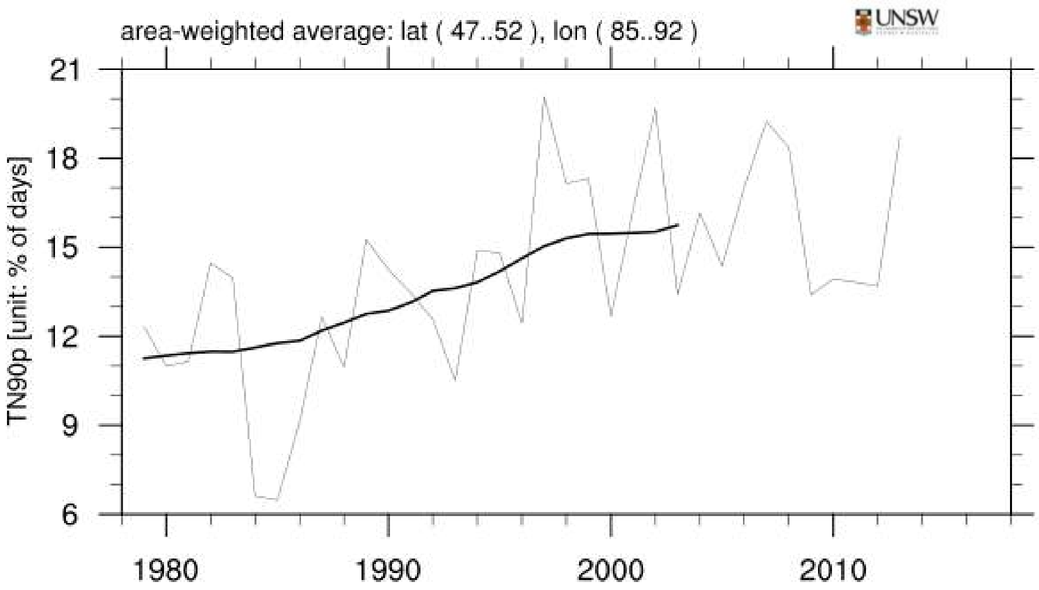


Figure 2.19. Warm nights (TN90) (www.climdex.org)

A similar trend was observed for days (or fraction of time) when the daily maximum temperature > 90th percentile, the maximum of which was also in 1997 (Figure 2.20).

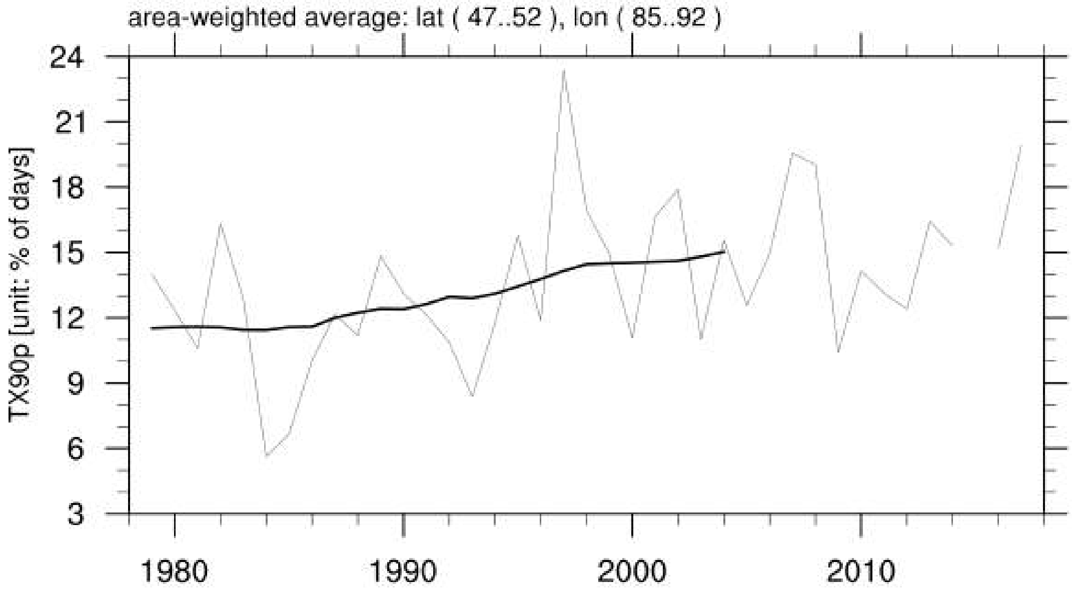


Figure 2.20. Warm days (TX90p) [www.climdex.org]

Wettest day (maximum 1-day precipitation) was in 2001, when in Mongolia due to snowstorms observed the dzud (Sternberg, 2018) (Figure 2.21).

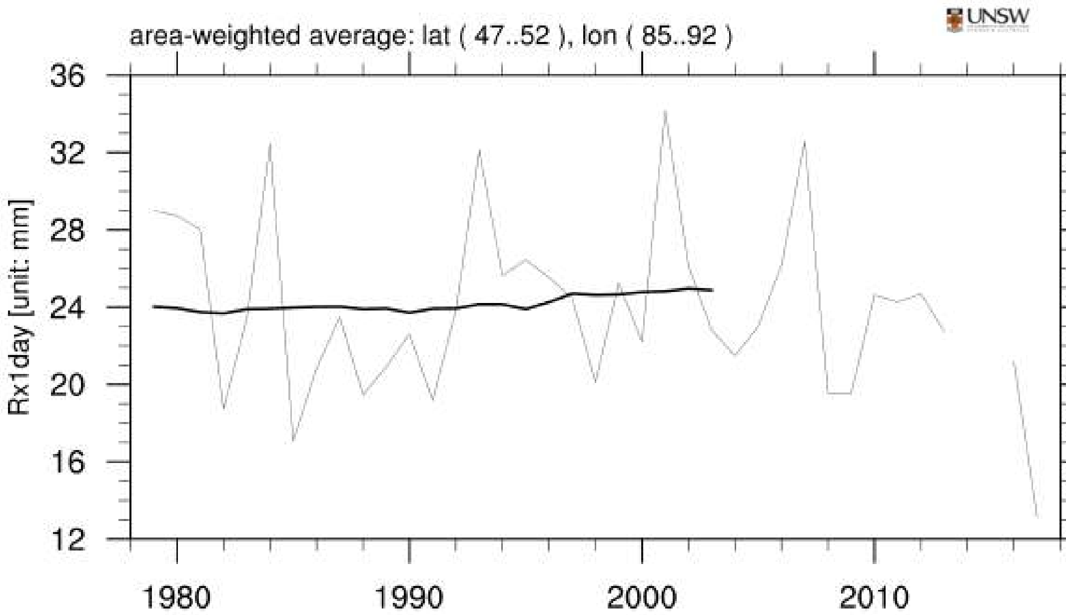


Figure 2.21. Wettest day (RX1day) [www.climdex.org]

Maximum ratio of annual total precipitation to the number of wet days (≥1 mm) was in 2007 (Figure 2.22).

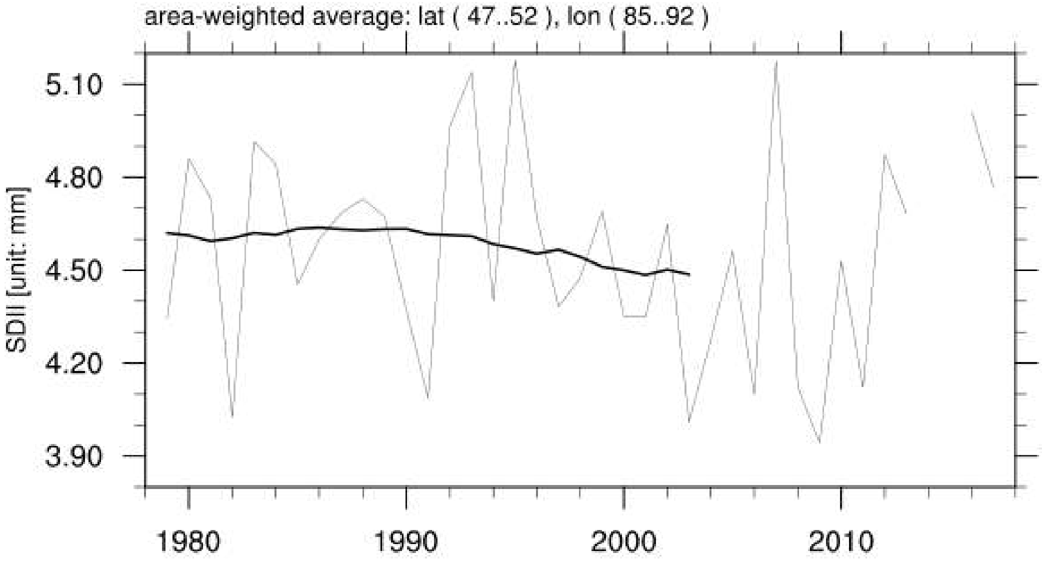


Figure 2.22. Simple daily intensity index (SDII) [www.climdex.org]

Most precipitation during very wet days was in 1990s (1991, 1993 and 1995) and there was a tendency to increase (Figure 2.23).

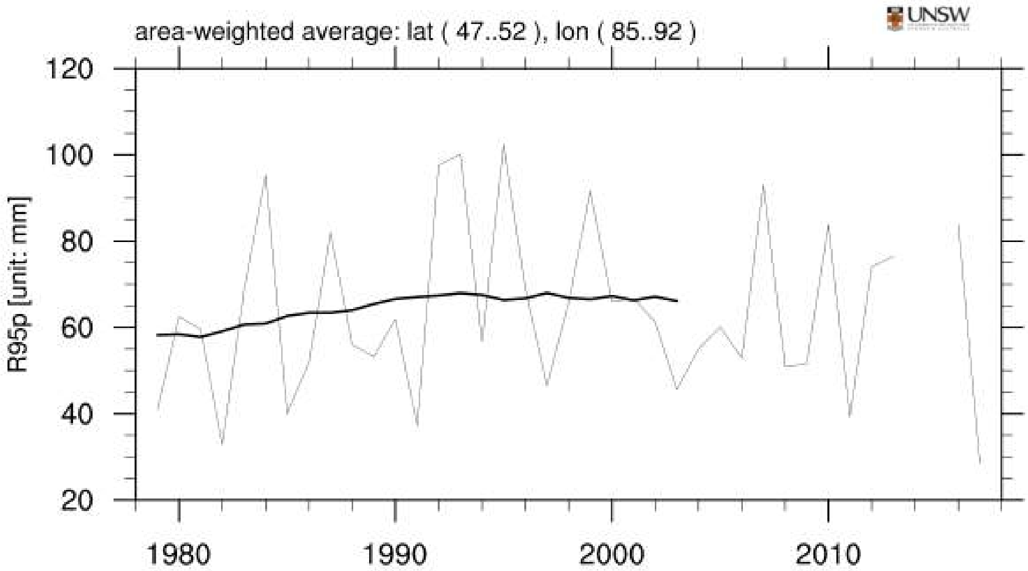


Figure 2.23. Simple daily intensity index (SDII) [www.climdex.org]

Maximum number of consecutive days when precipitation <1 mm (Figure 2.24) was in 2012 (about 77 days) and 2017 (about 82).

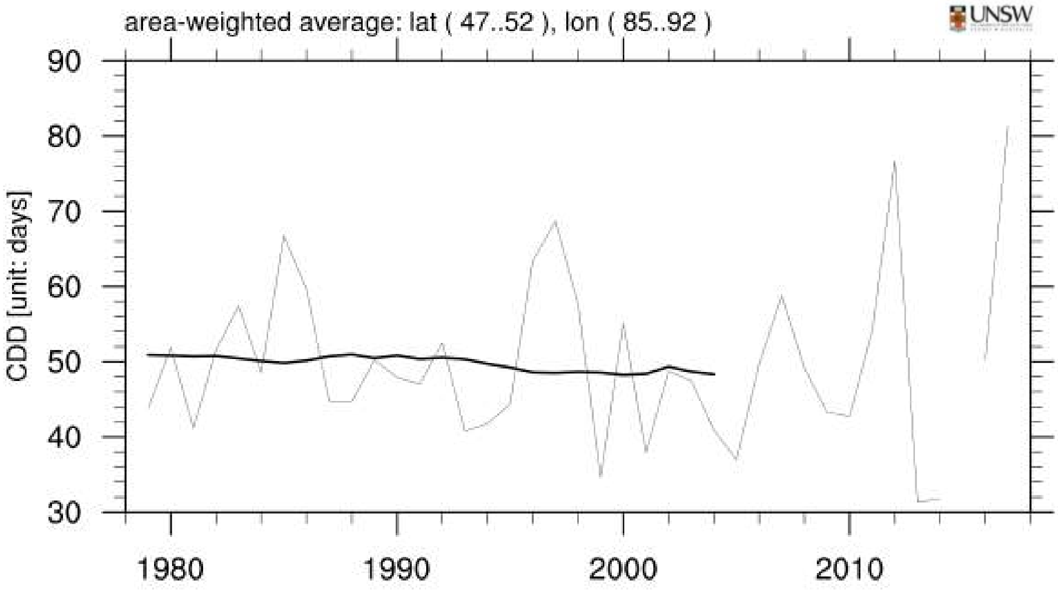


Figure 2.24. Consecutive dry days (CDD) [www.climdex.org]

The analyze of changes for extreme climate indices in Altai Mountains (1979-2017) showed the following. The number of «Cold days» and «Cold nights» decreases, and the temperatures for these periods increase. All this happens against the background of an increase in the number of «Warm days» and «Warm nights» and an increase in their temperatures. At the same time, there are no uniform trends in changes for extreme indices of precipitation. It is important that during the years of maximum manifestation of some extreme climate indices in Altai Mountains, namely in Mongolian Altai (Hovd aimag), there were extreme climatic events that manifested themselves in catastrophic droughts and dzud.

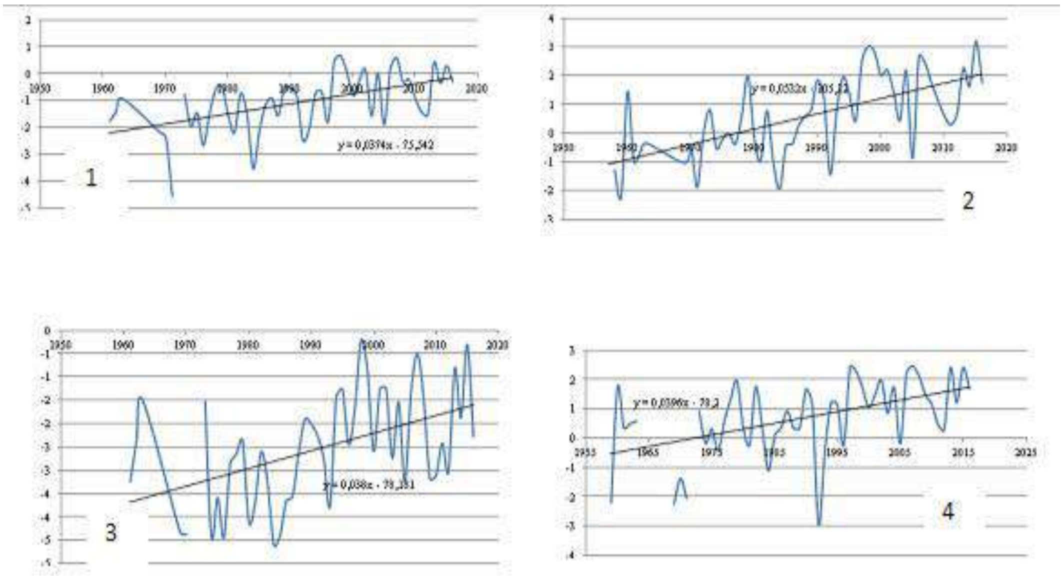
Climate changes in Western Mongolia

The analysis of the average annual temperature showed its steady positive growth in all weather stations for the period from 1958 to 2017, it was 2.3 °C; the highest value of 3.1°C was observed at the station Hovd, located at medium-high levels in the Central part of the study area. The average annual temperature for four weather stations in Western Mongolia was negative – -1.06°C. The average annual temperature at the weather station Ulgi was positive only. The standard deviation by year was about 1 °C for all the stations listed (Table 2.5, Figure 2.25).

Table 3.5. The changes of Temperature and Precipitation in the weather stations located on the territory of the Western Mongolia during the period from 1958-2017.

The name of the weather station	Elevation, m ASL	Ratio of temperature trend	Temperature change during the study period, ^{0}C	Average annual temperature, ^{0}C	Standard deviation, ^{0}C
Altai	2181	+0,037	+2,07	-1,01	0,96
Uliastai	1759	+0,026	+1,53	-1,85	1,01
Ulgi	1715	+0,039	+2,22	+0,74	1,24
Hovd	1405	+0,053	+3,07	-0,96	1,37
Ulaangom	939	+0,037	+2,03	-2,53	1,19

The highest values of average annual temperatures occurred for the period 1990-2000, in which there was a fluctuation in the amplitudes of average annual temperatures from the mean annual value of 2 °C to 5 °C.



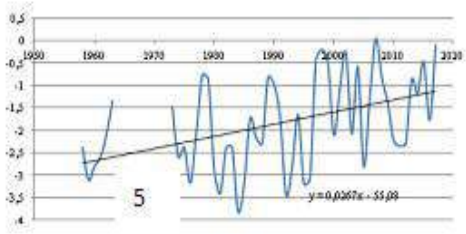


Figure 2.25. Average annual temperature (^0C) dynamics for the period from 1958 to 2017 for five stations: 1. Altai, 2. Hovd, 3. Ulaangom, 4. Ulgi, 5.Uliastai.

Table 2.6.The changes of Temperature and Precipitation in the weather stations located on the territory of the Western Mongolia during the period from 1984-2017.

The name of the weather station	Elevation, m ASL	Ratio of temperature trend	Temperature change during the study period, ^{0}C
Altai	2181	+0,048	+1,54
Uliastai	1759	+0.044	+1,41
Ulgi	1715	+0,057	+1,82
Hovd	1405	+0,059	+1,89
Ulaangom	939	+0,050	+1,60
Omno-Gobi	1590	+0,030	+1,29
Baruunturuun	1232	+0,052	+1,66
Baitag	1186	+0,048	+1,53

Table 3.7.Temperature and precipitation changes, in the weather stations located on the territory of the Western Mongolia during the period from 2000-2017.

The name of the weather station	Elevation, m ASL	Ratio of temperature trend	Temperature change during the study period, ^{0}C	Average annual precipitation, mm	Standard deviation, mm	Variation coefficient, %
Altai	2181	+0,017	+0,27	182,37	54,90	30
Uliastai	1759	+0,019	+0,30	210,49	62,66	30
Ulgi	1715	+0,019	+0,30	112,85	25,19	22
Hovd	1405	+0,017	+0,27	124,00	46,43	37
Ulaangom	939	+0,013	+0,21	133,34	42,70	32
Omno-Gobi	1590	+0,021	+0,36	133,34	42,70	32
Baruunturuun	1232	-0,013	-0,21	220,52	55,43	25
Baitag	1186	+0,077	+1,23	90,29	41,35	46
Erdeni	2417	+0,163	+1,90	60,01	25,70	43
Tolbo	2101	+0,043	+0,67	187,78	112,43	60
Tonhil	2095	+0,053	+0,74	97,97	30,34	31
Nogoonnuur	1480	+0,126	+0.04	98,58	33,17	34
Urgamal	1263	+0,135	+1,89	99,18	37,25	38
Hunhataoortoo	1051	+0,083	+1,20	127,06	80,37	63

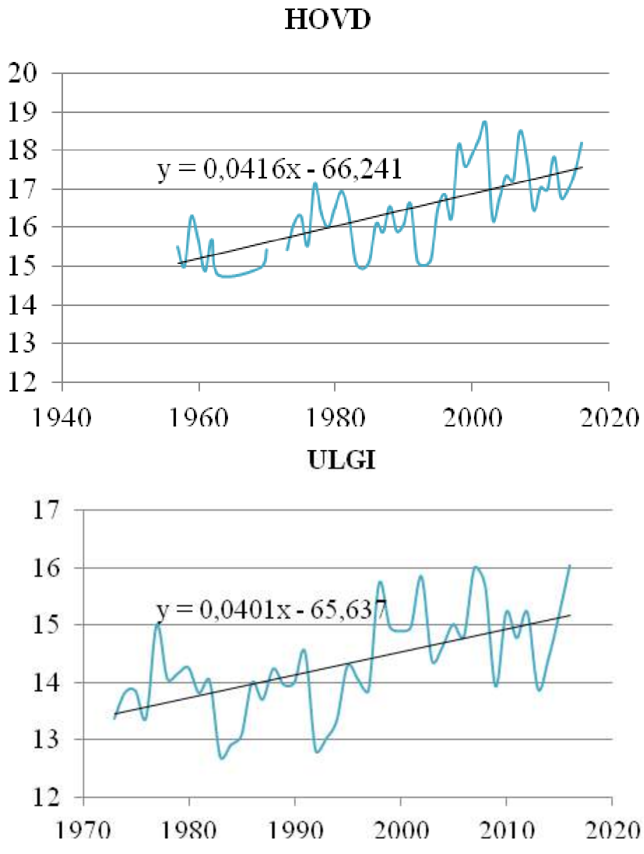


Figure 2.26. Average summer temperature dynamics (from June to September) for 1958-2017

The average annual temperature may drop to minus 5 °C in some years (e.g., Altai weather station), and in some years rise to plus 3 °C (e.g. weather station Hovd). Data for the period 1960-70 are incomplete for some weather stations, therefore have a discrete character. Analysis of data for the 30-year observation period also showed a positive trend with angular coefficients from 0.030 to 0.059; for this period, the temperature increase was less than for 60 years period – the average warming was 1.6 °C (Table 2.6).

The weather data are presented for the period from 2000 to 2017 (Figure 2.27, Table 2.7) for a larger network of weather stations, which fairly evenly covers the territory of Western Mongolia. A number of data analyzed by the thermal regime showed a further steady increase in average annual temperatures, with the exception of the weather station Baruunturuun, located in the North-East of the study area. The positive growth of average annual temperatures was observed in all stations – about 0.6 °C, the highest value of 1.9 °C was on the weather station Erdeni, which has the highest absolute altitude (2417 m).

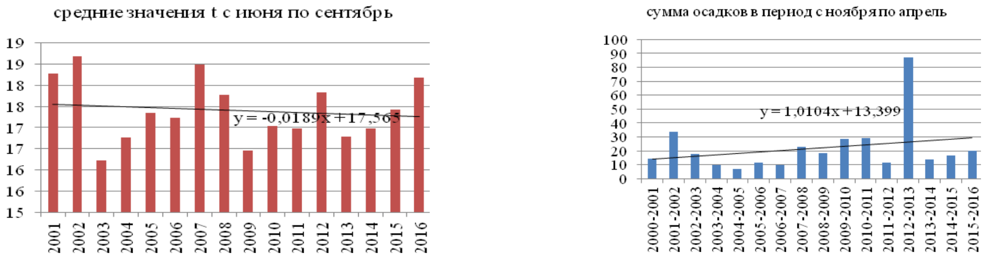
The dynamics of the average temperature of the ablation period (average temperature from June to September) and the dynamics of the amount of winter precipitation (the amount of precipitation from November to April) were analyzed additionally (Figure 2.26, 2.27).

The average annual air temperature growth was 2.6°C for weather stations Hovd for the 60-year period; for Omno-Gobi - 1,29°C, for 30-year period; for Tolbo - 0,67°C, for the last 18 years. The value of total winter precipitation was high oscillatory in the years of observations, both in the area of the investigated ridge and throughout Western Mongolia.

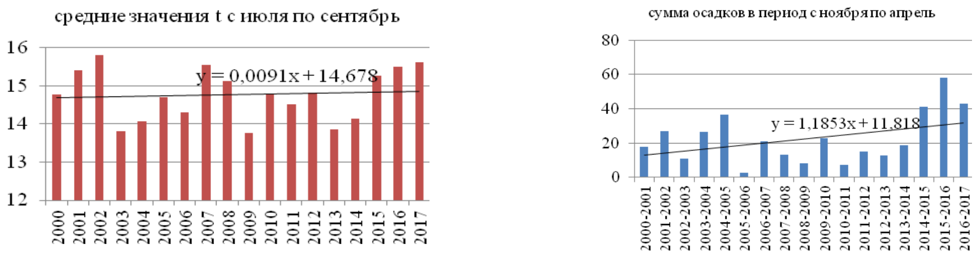
The Great Lakes Basin is one of the largest drainage basins in Central Asia, where a large number of freshwater and salt lakes are located. The recent water balance of most lakes is negative and dominated by evaporation (Sevast'yanov, Shuvalov, 1994). The temperature and precipitation render the greatest impact on the water balance change in the Great Lakes Basin, because the value of water balance of the lakes depends on the difference in the amount of annual precipitation and evaporation, which, in turn, depends on the temperature of the warm period. In this study we analyzed the average temperatures, rainfall, the number of days with wind more than 4 m/s and their predominant direction, the number of dry winds and their predominant direction, as well as the number of days with humidity less than 30% for the summer period.

The analysis of data on the average annual air temperature of the most weather stations revealed a steady increase of the temperature, which corresponds with data of the studies on temperature changes in Mongolia (America's Climate.., 2011; Mongolia Second.., 2014). The positive trend was observed with angular coefficients from 0.030 to 0.059 for the 30-year observation period in Western Mongolia; for the 60-year period – the average warming was 1.6 °C.

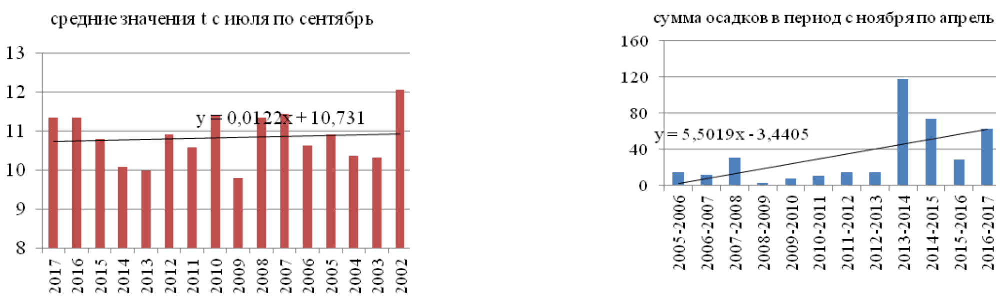
HOVD



OMNO-GOBI



TOLBO



ULGI

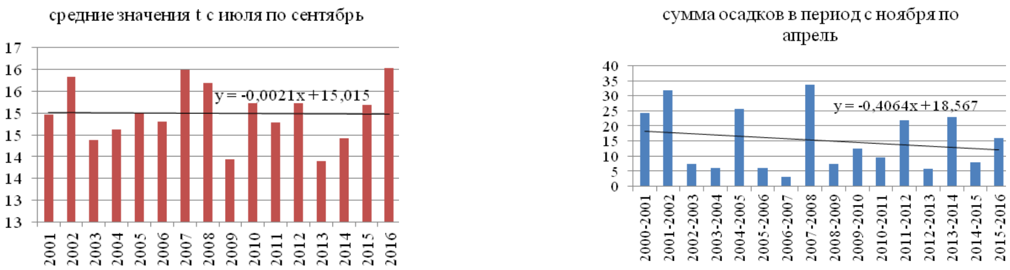


Figure 2.27. Dynamics of average summer temperatures and the amount of winter precipitation during the 2000 – 2017

The analysis of the temperature regime over the past two decades has shown a pronounced latitudinal zonality: the average annual temperatures is less than -2°C in the area adjacent to lake Ubsu-Nur, while this figure exceeds +3°C in the Shargain-Gobi basin. However, the study of the dynamics of the temperature regime gives another picture. There is a steady increase in average annual temperatures, which is 0.6°C in the whole territory of the Great Lakes Basin with the exception of the

North-Western border. There is only a slight decrease of 0.2°C recorded by the station Baruunturuun. The largest increase of the average annual temperature is observed in the Central part of the basin at Urgamal station, where the increase is 1.9 °C (Table 2.8, Figure 2.28).

Table 2.8. The change of temperature and precipitation for weather stations located on the territory of Western Mongolia for the period 2000-2018 years.

Station	h_{abs}, m	$\bar{t}$, ^{0}C	Δt, °C	k	σ, °C
Altai	2181	-0.46	+0.27	+0.017	0.77
Uliastai	1759	-1.30	+0.30	+0.019	0.86
Ulgi	1715	1.46	+0.30	+0.019	0.79
Hovd	1405	1.52	+0.27	+0.017	1.03
Ulaangom	939	-1.94	+0.21	+0.013	0.97
Omno-Gobi	1590	-0.38	+0.36	+0.021	1.34
Baruunturuun	1232	-2.71	-0.21	-0.013	1.01
Baitag	1186	3.12	+1.23	+0.077	1.01
Tolbo	2101	-2.42	+0.67	+0.043	0.74
Tonhil	2095	0.12	+0.74	+0.053	0.71
Nogoonnur	1480	0.65	+0.04	+0.126	0.68
Urgamal	1263	0.88	+1.89	+0.135	1.40
Hunhataoortoo	1051	1.00	+1.20	+0.083	1.05

Note: h_{abs} – absolute altitude above sea level, $\bar{t}$ – annual mean temperature, Δt – the change in mean annual temperature, k – the coefficient of the trend, σ – mean square deviation.

The precipitation regime of this territory is characterized by heterogeneity and instability: the coefficient of variation exceeds 40% for some stations. Spatial analysis of the average annual precipitation showed that the highest values of this indicator are associated with stations located on the periphery of the boundaries of the Great Lakes Basin, and in the Central part of the basin the value of the precipitation ranges from 90 to 140 mm per year.

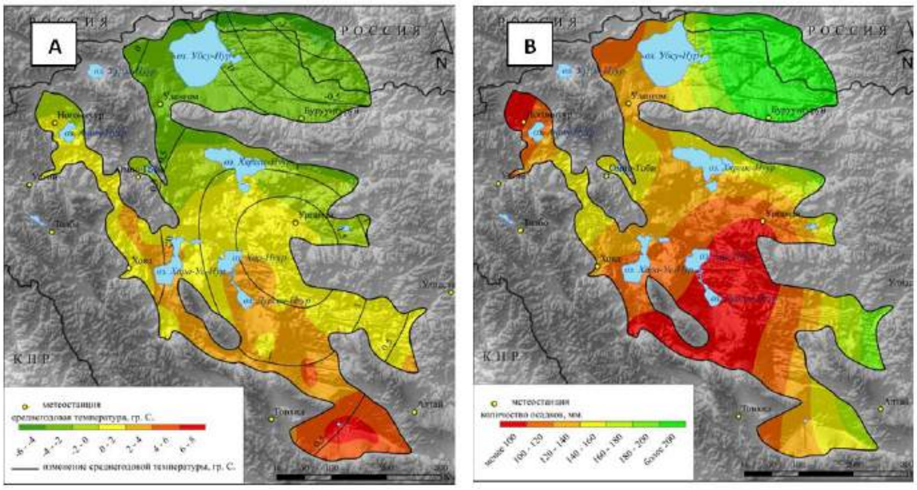


Figure 2.28. Characteristics of temperature and humidity conditions of the Great Lakes Basin in Mongolia for the period 2000-2018.: A – the average annual temperature and its changes; B – the average annual rainfall and their changes.

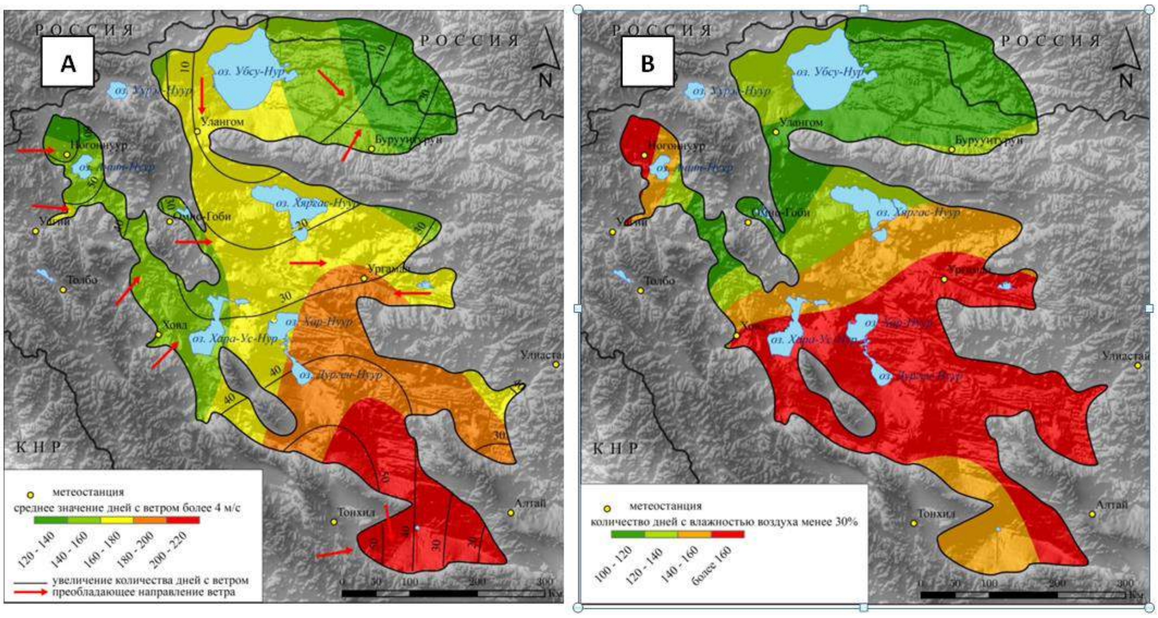


Figure 2.29. Characteristics of wind activity and humidity of the Great Lakes Basin for the period 2000-2018.: A – average annual values of days with wind more than 4 m/s and their changes; B – average annual values of the number of days with humidity less than 30% and their changes.

The average wind speed is 4 m / s in 144 days in year in Buruntorun, Nogonnuur and Khovd and to 180 days in a year in Ulangoma, Ulgi and Urgamal. The highest wind activity indicators are observed in the Shargain-Gobi basin, where it exceeds 207 days in a year. During the study period, the steady growth of days with wind speed 4 m/s is recorded throughout in the entire territory of the Great Lakes Basin (Figure 2.29).

The largest number of days with humidity less than 30% in the warm season of the year is observed by the weather stations located in the vicinity of lake Achit-Nur (Ulgi and Nogoonnuur) and in the Central part of the Basin of Large Lakes (Hungui and Hovd), here the indicator is more than 160 days per season. The lowest value (98 days per season) of this indicator is observed at the Tolbo station, which has the highest absolute height (Figure 2.29). The largest number of days with humidity less than 30% in the warm season of the year is observed in the weather stations located in the vicinity of lake Achit-Nur and in the Central part of the Great Lakes Basin, here this feature is more than 160 days per season. The lowest value (98 days per season) of this indicator is observed at the Tolbo station, which has the highest absolute height (Figure 2.29). Also at this station during the study period, there was not a single dry wind, i.e. winds at a speed of 6 m/s or more at a relative humidity of less than 30% and a temperature of +25°C or more. In the area of the station Ulgi dry wind occur more often than at other stations, about 13 days a year, the largest number falls on 2010 – 22 times and 2017 – 21 days.

The increase of the average temperatures and number of the of days with dry winds over 20-year period affected the levels of drainless lakes in the Great Lakes Basin, which show a steady decline: the level of lake Khyargas Nur Lake decreased by 5 meters over the 20-year period (Figure 2.30).

Figure 2.30. Strandlines on the North shore of Khyargas Nuur Lake shows decreases in water level during the past 20 years

In the face of Climate warming, most glaciers of Altai Mountains have been retreating, resulting in an increase in the number and size of dammed lakes are generated by moraines after the retreat of glaciers which block the drainage of rivers. The failure of naturally dammed lakes is the source of the largest floods in Earth's history; they exceed precipitation caused events by magnitudes (O'Connor et al. 2002, Herget 2005). Natural dams consist of glacier ice, moraines, landslide deposits and block the drainage of rivers to lakes of variable size and duration. The failure of the dams can release large amounts of accumulated water abruptly by outburst floods without prior warning (Vinogradov 1977, Costa 1988, Costa & Schuster 1988, Walder & Costa 1996, Clague & Evans 2000, Korup & Tweed 2007). Due to the current global retreat of most mountain glaciers it might be expected, that the number of outburst floods related to the failure of naturally dammed lakes could even increase (Chen et al. 2007). In the Altai Mountains, and specifically in the Tsambagarav (Figure 3.25) and South-Chuya ridges a marked decrease of the glaciated area has occurred since the end of the Little Ice Age, and it has been accelerated since the last decades of the 20th century. In the belt of recent deglaciation of the Tsambagarav ridge, was noted the appearance and increase in the area of the waters of 8 glacial lakes (Figure 3.31). The vast majority of lakes which formed within fifty years dedicated to foreground modern glaciers (moraine-dammed lake and lake of intermoraine depressions) and glacial-accumulative complexes of the Little Ice Age (thermokarst lakes). The periods of increased activity of glacial and thermokarst limnogenesis (1992-1998, 2012-2016) were revealed by means of geoinformation analysis of polychronous spatial data.

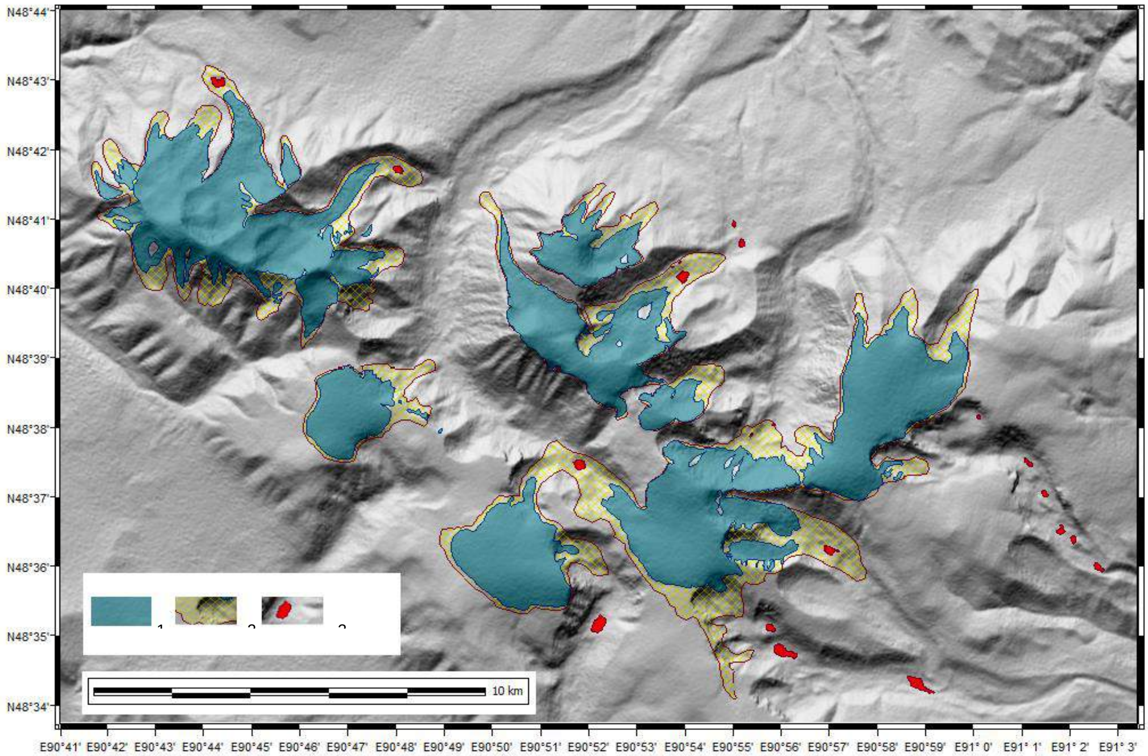


Figure 2.31. Spatial distribution of glacial lakes in the Tsambagarav massive. 1 – The position of glaciers in 2017, 2 – the area of deglaciation from Little Ice Age, 3 – glacial lakes.

The floods triggered by glacial lake outbursts have repeatedly caused disasters in various high-mountain regions of the world. The relatively rapid recession of glaciers in the Altai Mountains and formation of glacial lakes in the recent past have increased the risk of GLOF in the countries of Russia and Mongolia.

For hazard assessment we have studied one of glacial lake in the Akkol valley – Sofiyskoe Lake. The lake was formed in the area of the Little Ice Age terminal moraine complex of Sofiyskiy glacier (South Chuya range). The age of the lake does not exceed 150 years, which is clearly seen in the photo of 1898. At the end of the 19 th century, the lake was a small temporary glacial pond located near to the glacier (Figure 2.33). According to our investigations the lake has a size of up to 860 m to 610 m resulting in a surface of 0.42 km² and a depth of up to 32 m. (Figure 2.32). The water surface of the lake is situated in an elevation of 2455 m above sea level. The formation of the dam is obvious. It is the Little Ice Age terminal moraine complex of Sofiyskiy glacier. Due to the relative long lasting extension position of the glacier, clastic material transported by the ice accumulated up to heights of tens of meters including parts of dead ice remaining. The melting of dead ice and the decay of permafrost initiated first depression where precipitation and meltwater accumulates to first lakes. The process of dumping the dead ice was specific: the yield of debris of the internal and the surface moraine was so intense that it "booked" the ice in some parts of the tongue on its front and protected from the intense ice melting.

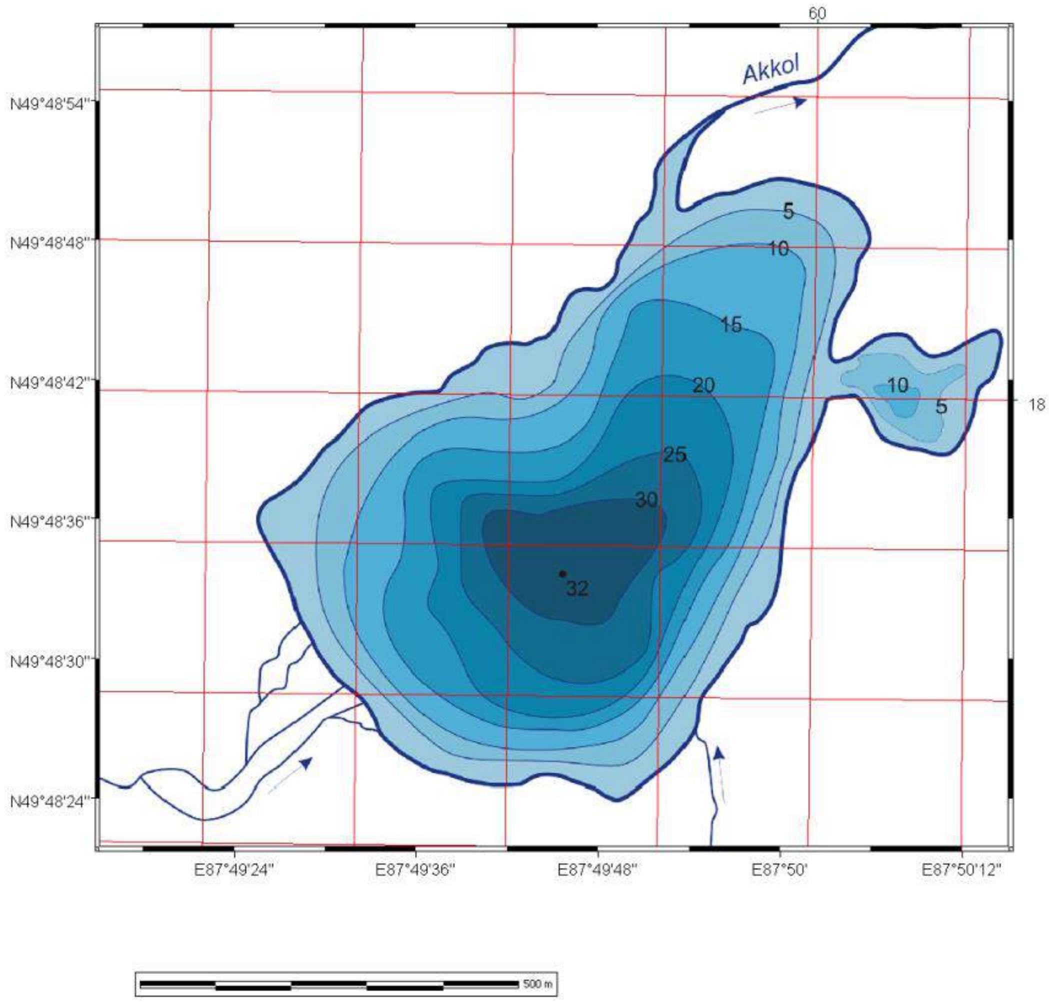


Figure 2.32. The Bathymetric map of Sofiyskoe lake based on the echo sounder survey

Figure 2.33. Sofiyskoe Lake at the initial stages of formation. Historical photo of Vasily Sapozhnikov, 1898 (up) andview of the lake in 2018 (down)

While melting took place at the uncovered glacier tongue, and buried ice remained and became disconnected from the glacier itself. Recently, more than 30 thermokarst lakes developed on the surface of the terminal moraine complex and therefore within the dam of the lake. The maximum height of the dam is approximately 87 m while the lake upstream drains by a lateral spillway. As typical for the moraine, the grain size composition consists of any size of clasts from clay to big boulders. The petrographic composition of these deposits can be differentiated from debris from the lateral slopes, but consisting both of not solutable metamorphic rock, grey gneiss on the one and slates on the other side. The terminal moraine complex is largely turf covered, in depressions bush vegetation is growing next to first young larch. A few kinds of lichens grow here: Rhizocarpon geographicum, Xanthoria elegans, Dimilaena oreina, Aspicilia disertorum. Their analysis confirms the age estimations of the moraine as deposit from the Little Ice Age extension of the glaciers above. By data logger MDS Dipper-T by SEBA Hydrometrie, water level and water temperature were measured continuously between summer 2017 and autumn 2018 (Figure 2.34).

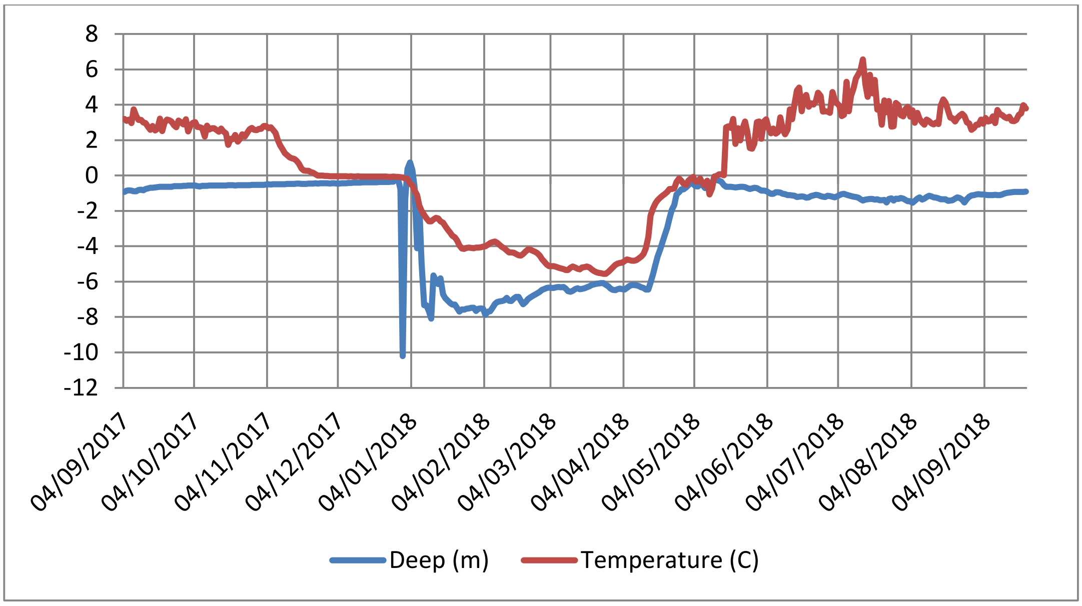


Figure 2.34. Water level and water temperature of Sofiyskoe Lake

The data indicate, that logger was installed to a depth of 1,8 meters, in early November, the thickness of ice in the lake reached a level logger and it was completely frozen in ice. Further decline in the level the lake continued in due to termination of the glacier ablation. Perhaps the peaks observed in the beginning of January, associated with destruction of ice covering the lake. As a result, data logger turned out in the air. It caused such incorrect figures. In late May, the lake level returns to its maximum summer level. While the mean temperature of the water in the lake in August is about 4°C, this water at least partly also percolates through the moraine dam. Indicator are some of the thermokarst lakes which are filled by milky colour glacial meltwater while neighbouring lakes contain clear water from precipitation only. These indicate potential instability of the dam in addition to the lateral extension, characteristic for thermokarst lakes in general. The clearest example of this occurred over the past 57 years by the degradation of the wall between the large lake Sofiyskoe, and a small thermokarst lake near the main lake. For 1952 year, it was 82 meters between these two lakes (Figure 2.35).

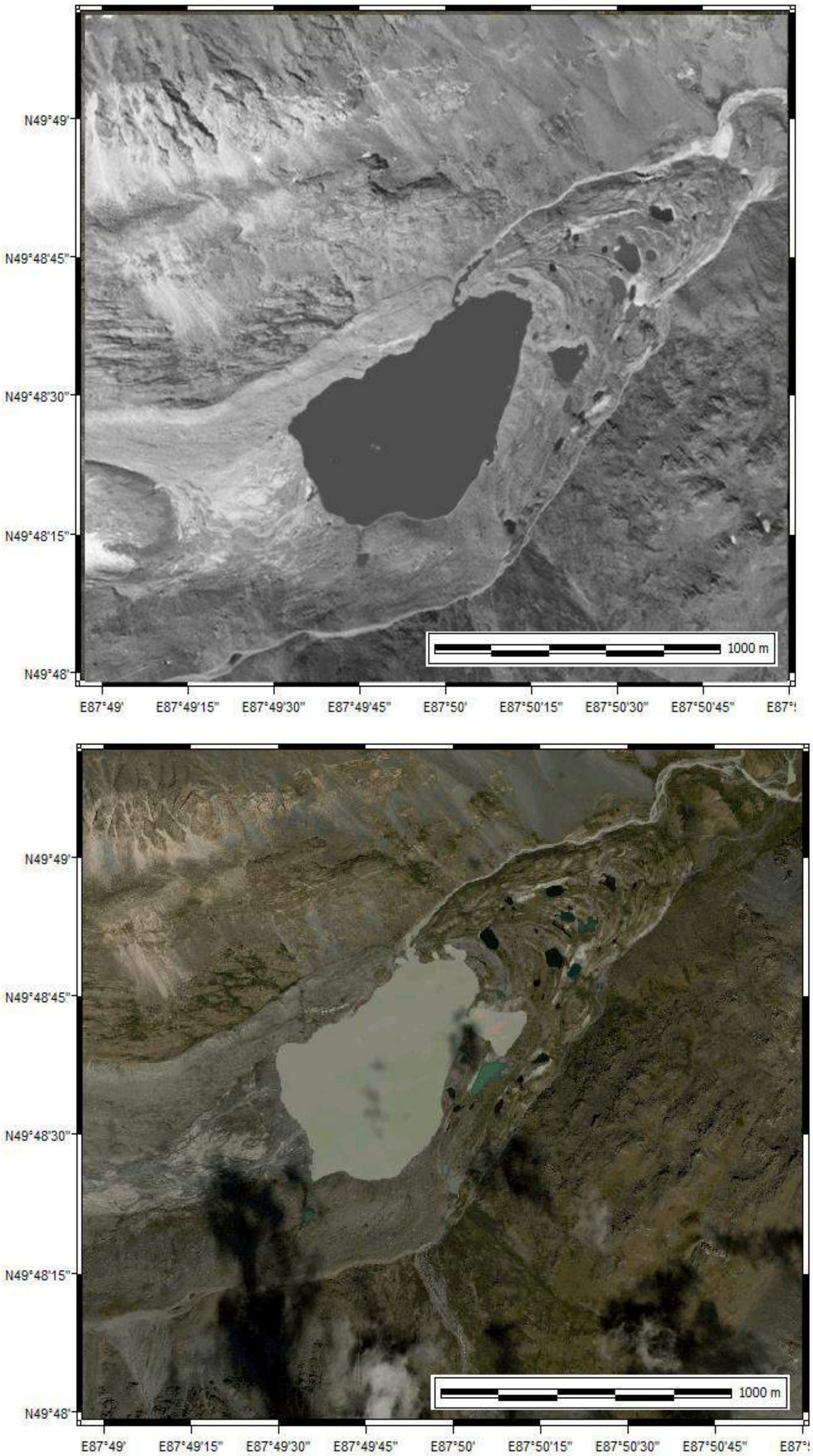


Figure 2.35. Aerial photo of the Sofiyskoe Lake in 1952 year (up), and WorldView3 image, 2016 (down)

In the 2009 the remaining wall is almost completely disappeared and the lakes became connected. The thermokarst basin immediately became filled with milky glacial meltwater. Other thermokarst lakes within the moraine already drained abruptly with the formation of a significantly incised drainage channel. In the context of the recent warming trend resulting in a probably increased lateral extension of other lakes, additional even larger drainage events should be expected in the near future.

When acted upon by external forces such as heavy rainfall, rapid melting of dead ice, Sofiyskoe lake can become extremely dangerous, easily forming outburst flood, which can potentially spread to the Chagan-Uzun river basin and develop GLOF disasters. For the hazard assessment the location of the nearest settlement of Beltir located 30 km from the lake should receive further attention. On the other hand, after the destruction of the intensive earthquake of 2003, the settlement has only a very small number of residents, living in houses rather high above the river channel and its neighbouring floodplain. The area in between is only temporary inhabited in summer times by local farmers. Due to the specific interactive processes of thermokarst lakes and meltwater percolation through the dam, Sofiyskoe lake and its dam should receive further addition in the future. To prevent a possible disaster, it is necessary to artificially reduce the level of the lake by deepening of the natural spillway. This most utilized method consists of the cautions digging down of a breach which enables the water to run off.

The processes of thawing of ground ice from the day surface play an important role in the transformation of landscapes in the high-mountains of the Altai. In this regard, a special emphasis in the research was made on the assessment of the rate of development of thermokarst lakes in modern conditions. The dynamics of thermokarst processes is studied using the materials of multi-temporal space survey, drones photo images and ground observations. The analytical processing of remote sensing data showed a widespread and steady increase in the number and area of thermokarst lakes within the moraine complexes of the little Ice Age of the Altai (Figure 2.36).

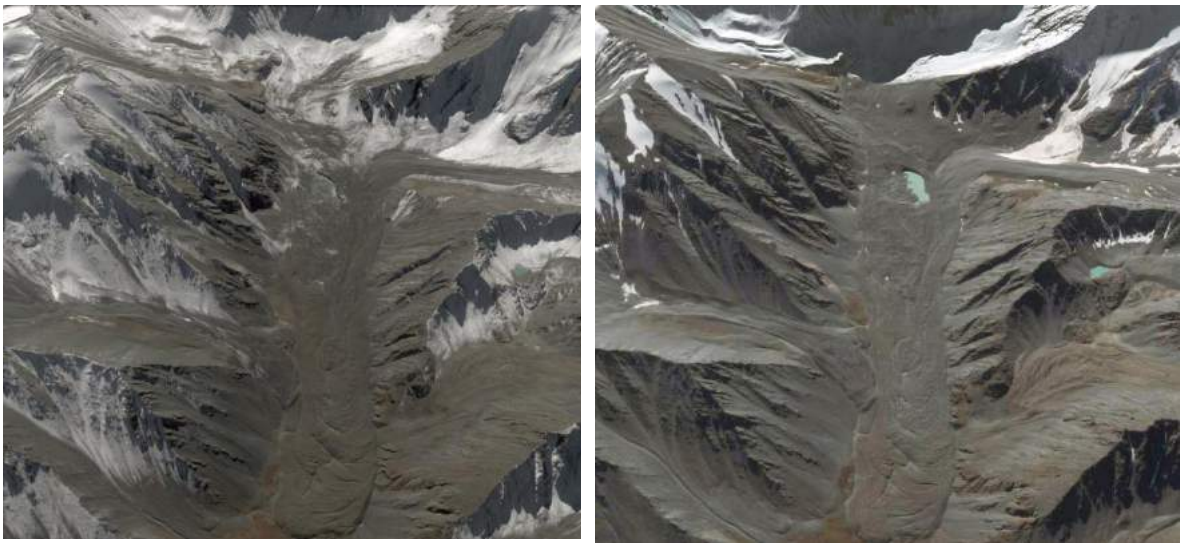


Figure 2.36 . Drone aerial images of Kalynagach LIA moraine complex (South Chuya Range) made in 2017 (up) and 2019. Within three years on the surface of the moraine formed thermokarst lake with length of 400 m and a depth of 12 m

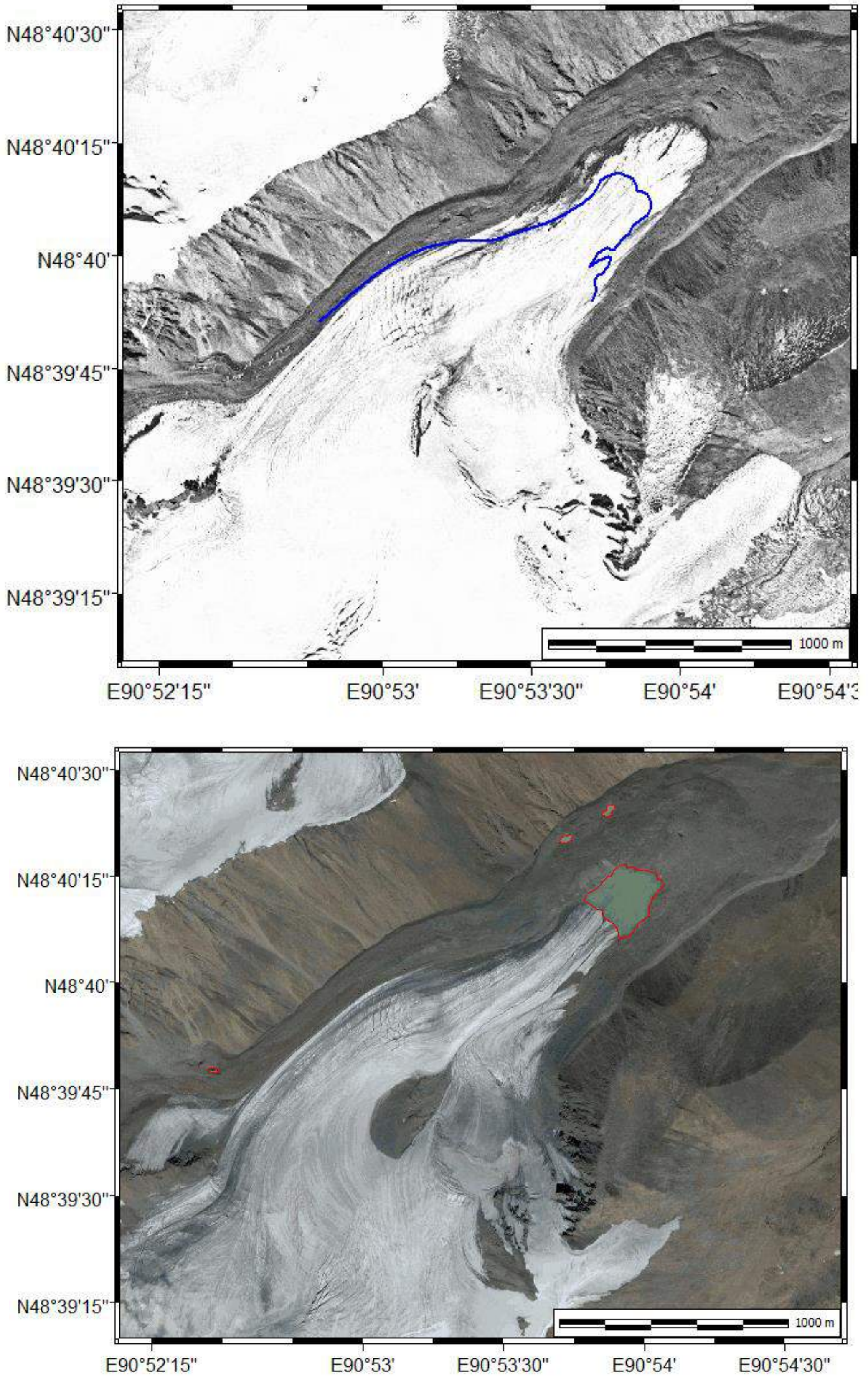


Figure 2.37 .Comparative GIS analysis of Tumurt mountain-glacial basin (Tsambagarav massive). The blue line on the upper image (sensor KH-4B, 1968-08-11) showing position of Tumurt glacier terminus in 2015. The red lines on the lower image (sensor WorldView – 110, 2015-08-19) indicate the contours of lakes formed within LIA moraine from 1968 to 2015.

Traces of glaciers advance in the Little Ice Age (17-19 centuries) expressed in the form of terminal and lateral moraine complexes clearly preserved in the relief of the valleys of the Sutay, Tsambagarav and Sair Uul ranges (Figure 2.38). The main morphological feature of the complexes is the existance of a ridge of the frontal moraine, reliably recognized by the materials of space survey, and used by us as a reference point for the reconstruction of the spatial characteristics of the nival-glacial zone for the period of the Little Ice Age (Figure 2.37).

Figure 2.38. The Little Ice Age moraine below the right-side valley glacier in the Yamaat mountain-glacier basin, Tsambagarav massive, Aug 2017 (Upper photo) and frontal part of the Little Ice Age terminal moraine of Tsagangol glacier, Sutai ridge, Aug 2017 (Lower photo)

Glacial landscapes occupied 16.02 sq. km of Sutay Range and were distributed on 99,104 square kilometers within the range Tsambagarav in the maximum transgressive stage of the little ice age, based on 3D topography. The decrease in regional temperatures by 0.6-0.8 °C caused the inversion of the lower boundary of the ice belt, which reached 200 meters. Thickness of valley glaciers in the basin of the river Tsagangol two times superior to the modern, in a number of mountain-glacial basins. The thickness of glaciers was reconstructed by the hypsometry of lateral moraines.

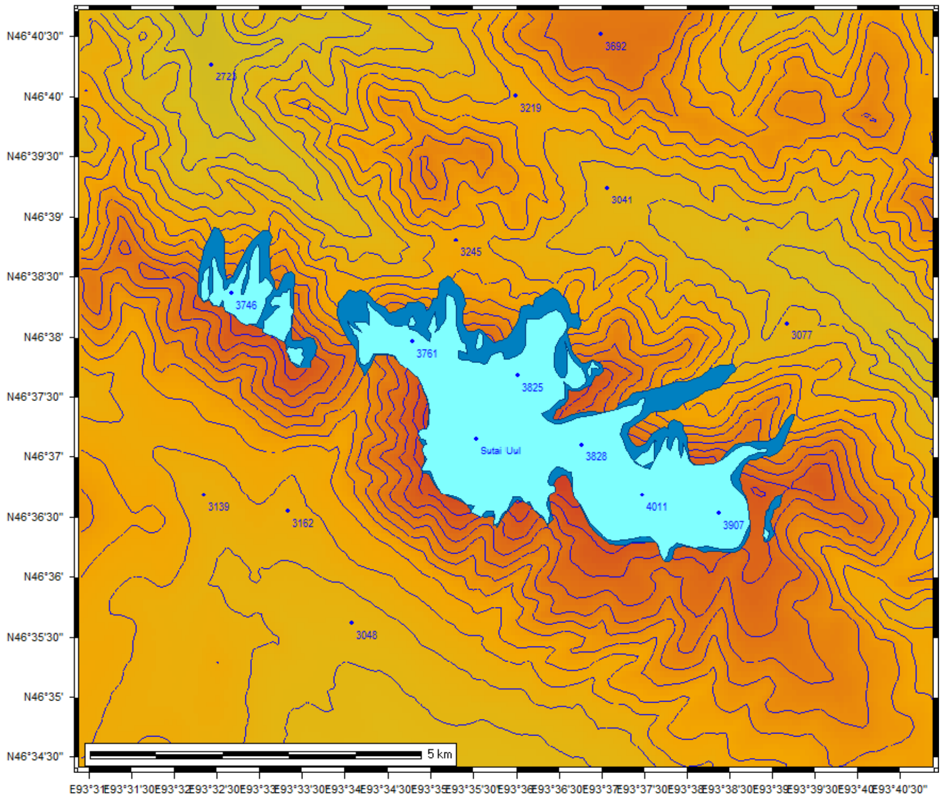


Figure 2.39. The dark blue colour filling on the image show Little Ice Age glacial extension in the Sutai ridge. Light blue colour filling show the position of glaciers in 2017.

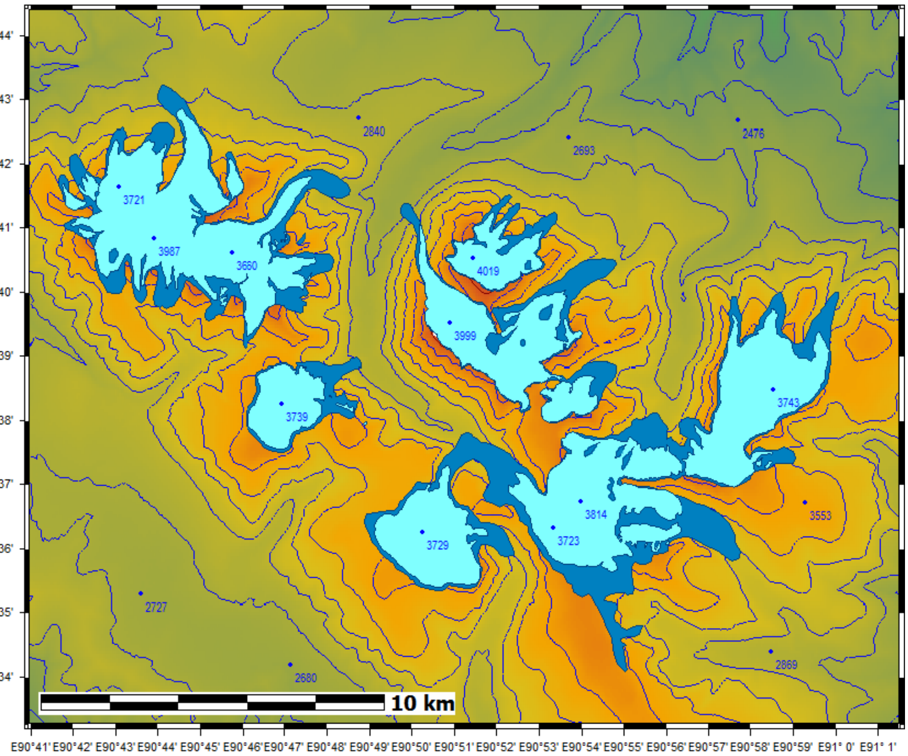


Figure 2.40. The extends of glaciers of Tsambagarav massive in the Little Ice Age maximum (dark blue color filling) and position of glaciers in 2017 (light blue color filling)

The climate change in the post-maximum phase of the Little Ice Age resulted in a spatial transformation of the nival-glacial belt of the ridges, expressed in a progressive reduction in the size of the glaciation and the uplifting of its lower vertical limits. The total area of the Sutai ridge glaciation has decreased to 11.21 sq km (Figure 2.39), and the Tsambagarav massive to 66.57 sq km, by August 2017 (Figure 2.40). But most important data were received in the Sair Uul range – the total area of this center of glaciation has decreased to 4.92 sq km since 1968 (10.34 sq km) approximately by 50 %. The glacier has been decreased almost by 1 % per a year (Figure 2.41)

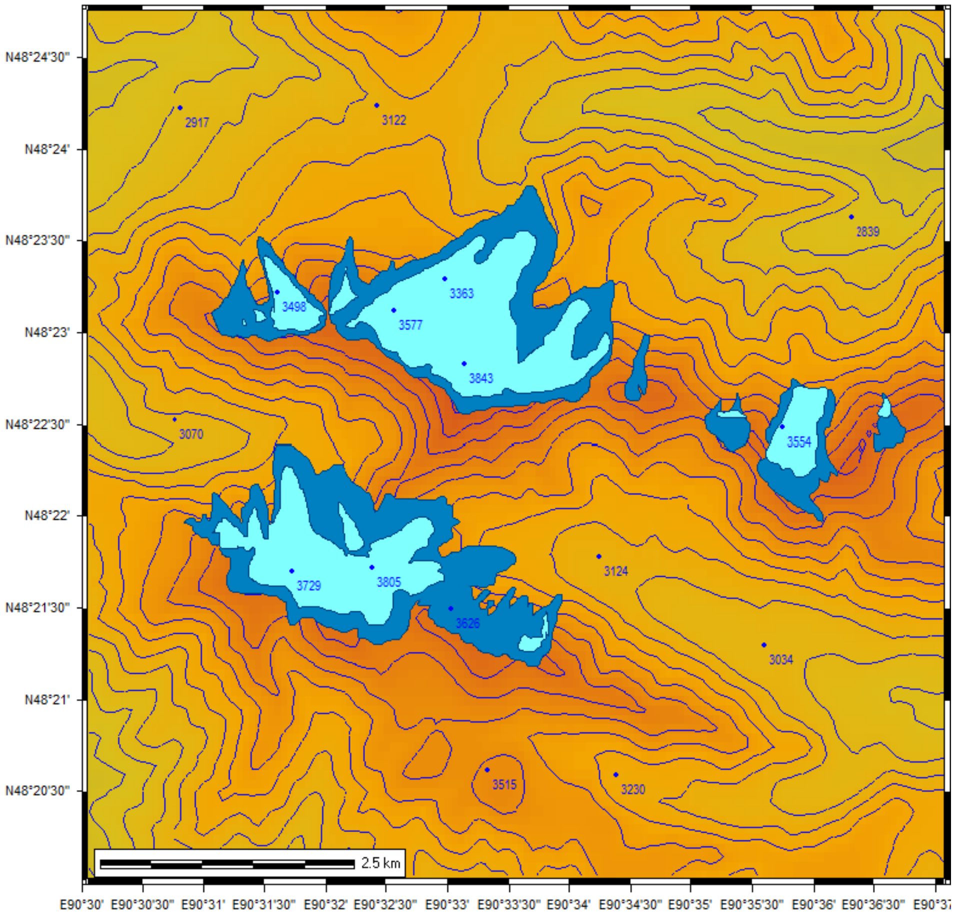


Figure 2.41. The dark blue color filling show position of glaciers in 1968 in the Sair Uul ridge. Light blue color filling show glacial extension the in 2018.

Investigation of permafrost degradation

Investigation in the Chuya basin showed that the thickness of the seasonally thawed layer varies from 0.5 to 5 m, in some years reaching large values. The maximum thickness of active layer of permafrost discovered in the coarse deposit (pebbles, boulders with gravel) lacustrine-proluvial and fluvioglacial sediments. In deluvial-proluvial deposits (rubble with loamy aggregate), the thickness of the active layer is usually 1-2 m, in moraines 1.5—2 m, occasionally up to 3 m, in Neogene clays — about 1 m . In the area of Tashanta village, the depth of thawing is 2.2—3 m, here under a layer of sandy loam-rubble sediments with a capacity of 1.5—2 m lie pebbles with sand aggregate.

Field geothermal observations revealed that the minimum depth of the spring-summer thawing is fixed in peaty rocks is 0.8 m on the test site of Ehen-Nuur in 2017. The maximum depth of the active layer (up to 5 m) was observed in coarse-grained, boulder-pebble, limnic and fluvio-glacial deposits.

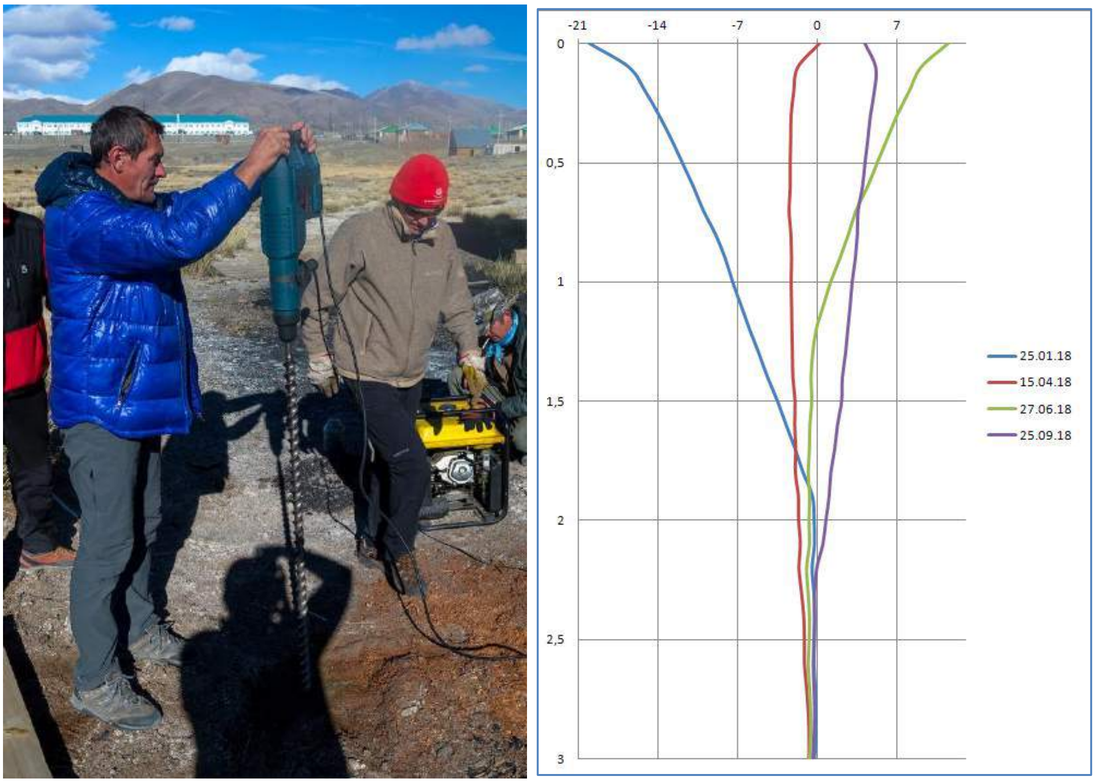


Figure 2.42. Drilling of borehole for permafrost geothermal monitoring on Kosh-Agach key location and thermal data from this borehole logging system.

The analysis of thermal data from Kosh-Agach borehole showed that active near-surface freezing of the active layer began in October and reached maximum depths by the second decade of February, during the observation period of 2018-2019. Stable thawing of seasonally frozen layer was observed in April. The top layer is about 20 cm deep warmed up to 15 °C to the middle of summer, and in the end of August this temperature penetrated to a depth of 75-85 cm. The maximum thawing up of ground to a depth of 2,3 m was recorded at the end of September: rocks at this depth warmed up to 0,5 °C (Figure 2.42).

Three new boreholes up to 3,5 m deep was drilled in Chuya Basin (Tuyaryk, Kosh-Agach and Kyzyl-Chin) at the level 1750 m a.s.l., a thermistor chain and logging system were installed in the borehole. The complete view of temperature graph obtained from the borehole Tuyaryk, for two years period (Figure 2.43). It is possible to visually analyze temperature changes at different depths and in different periods of the year.

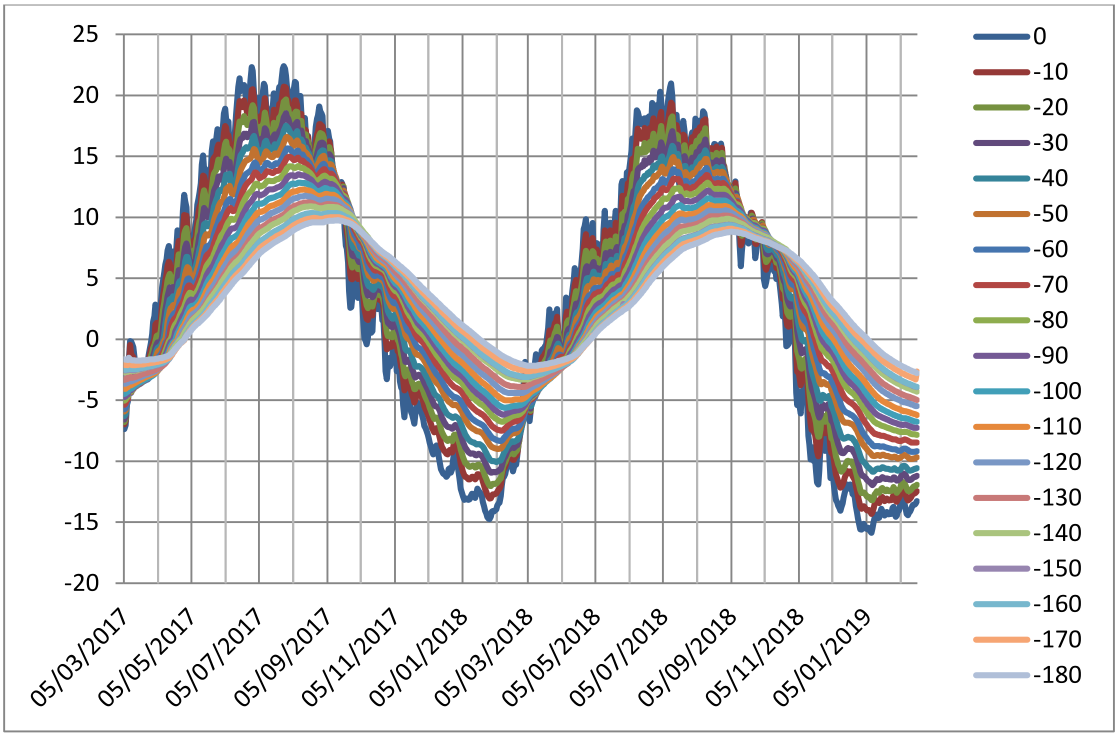


Figure 2.43. Thermal data graph from Tuyaryk borehole

In the Kurai steppe there is a close structure of seasonal thawing of permafrost. The thickness of the active layer varies here from 0.65 to 5 m. Freezing of rocks begins at the end of October and usually reaches a depth of 6 m, according to observations in boreholes drilled in the Kurai basin. The depth of freezing of bedrock on the outskirts of the Kurai depression is 5-12 m. In the Chuya basin freezing begins in October too.

The lower boundary of the seasonally frozen layer has a maximum depth in the middle of winter, during the greatest cold, and in January reaches 6.5 m, and as the air warming gradually approaches the surface, on the floodplain of the river Chuya. Thawing of the seasonally frozen layer usually begins in April. We have investigated thermokarst lakes of the Chuya and Kuray basins. The research indicator of thermokarst lakes dynamics – their water area, the method of determining the water area – the analysis of multi-temporal satellite images for 1968 and 2018. The total area of lakes, charted in the Central part of the Chuya depression for 1968, is 6.27 km^2, however, for 2018 the total area of water areas is 4.47 km^2 (Figure 2.44). Thus, the total area of thermokarst lakes in the Central part of the Chuya basin decreased by 40.3% in 50 years, while the disappearance of some small lakes and the formation of new lakes, and an increase in their total number. So, in the Corona image for 1968 deciphered 79 lakes, and in 2018 - 85 lakes. The water areas of some lakes decreased to 73 %, for example, the surface area of one of the lakes of the Uch Teles group decreased from 0.87 km^2 to 0.24 km^2. The area of mirrors of many lakes remained almost unchanged.

The tendency of swallowing and reduction of the water area of the old thermokarst lakes is noted at lower hypsometric levels, in zone of discontinuous permafrost, with the simultaneous appearance of young, due to intensive subsurface thawing of ice-bearing loose sediments.

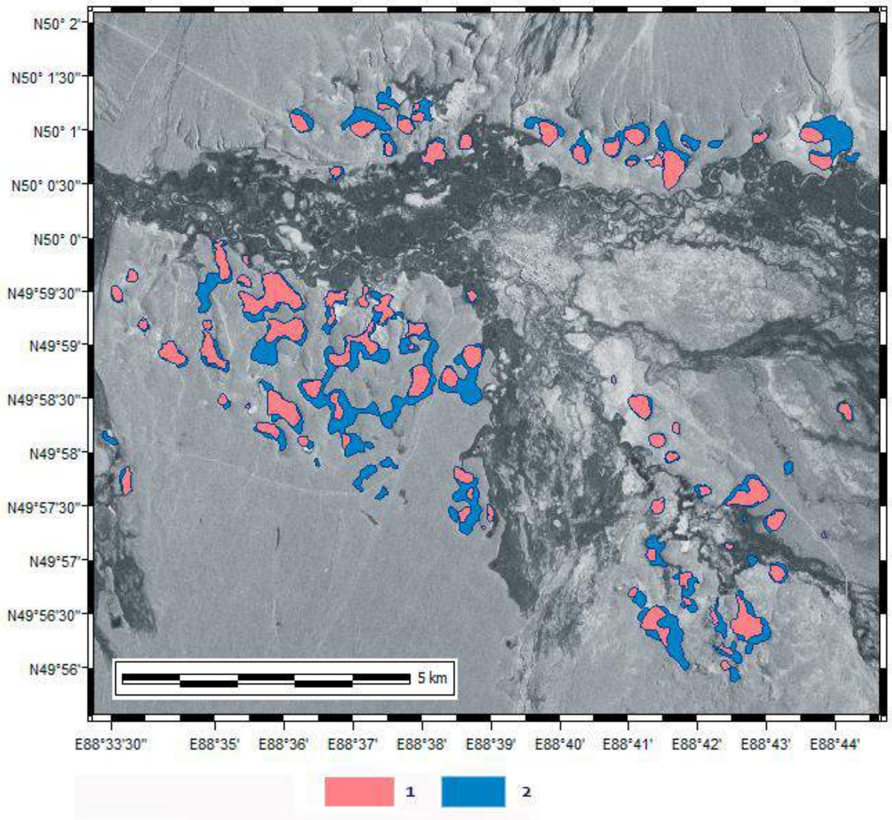


Figure 2.44. Comparative geoinformation analysis of thermokarst lakes water areas in the Central part of the Chuya basin: 1 - contours of water bodies in 2018, 2 – in 1968.

Absolutely different situation is observed on the plateau Eshtic-Kol. There were 68 lakes mapped in the picture of 1968, and 112 reservoirs – in the picture of 2018. We marked the unification of some lake groups into a single reservoir and the emergence of 52 new lake formations. The total area of lakes in the Eshtic-Kol increased by 52 % (Figure 2.45). The least altered of the area's major water bodies, e.g. lake Dzhangyskol.

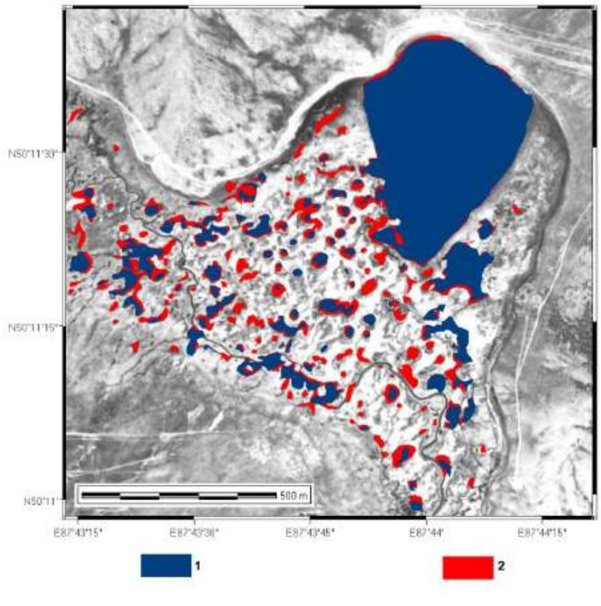


Figure 2.45. Comparative GIS analysis of the waters of the thermokarst lakes of the Eshtic-Kol: 1 - contours of water bodies in 2018, 2 - in 1968.

The response of the cryolithozone to the processes of global climate change is extremely important for the population of the territory affected by these phenomena. The degradation of permafrost poses obvious threats to infrastructure facilities, imposes restrictions on the economic regime and the livelihoods of local residents.

The intensification of landslide processes is another major problem that has emerged in recent years as a result of climate change. Which also affect the infrastructure of areas, block roads, and threaten communications (eg power lines).

A steady increase in the depth of seasonal thawing in the study area was reflected in the formation of landslides formed from the soils of the seasonally thawed layer on the slopes on the surface of highly loamy clay rocks. In the mouth of the right bank of the valley of the Chagan-Uzun river, 27 cryogenic landslides and splits formed over the past 10 years have been mapped and studied (Figure 2.46).

Figure 2.46. Cryogenic landslides on the right bank of the Chagan-Uzun river (Aerial drone photo)

The process of landslide formation is activated in especially hot years, as a result of the wall of subsidence exposed permafrost. Upon contact with warm air, the melting process is accelerated and conditions are laid for the continued active growth of the area of already formed landslides.

Modern cryogenic landslides began to form actively on the right bank of the Chagan-Uzun River since 1998 and are a direct consequence of global climate change (Figure 2.47). The air temperature increase leads to a more active melting of permafrost, the layer of loose sediments is moistened and becomes heavier and when the critical mass is reached, the landslide area slides along the solid frozen horizon down the slope. A significant increase of scale of development of this phenomenon has been observed in recent years. The local increase in precipitation in the last two summer seasons also contributes to the intensification of this process.

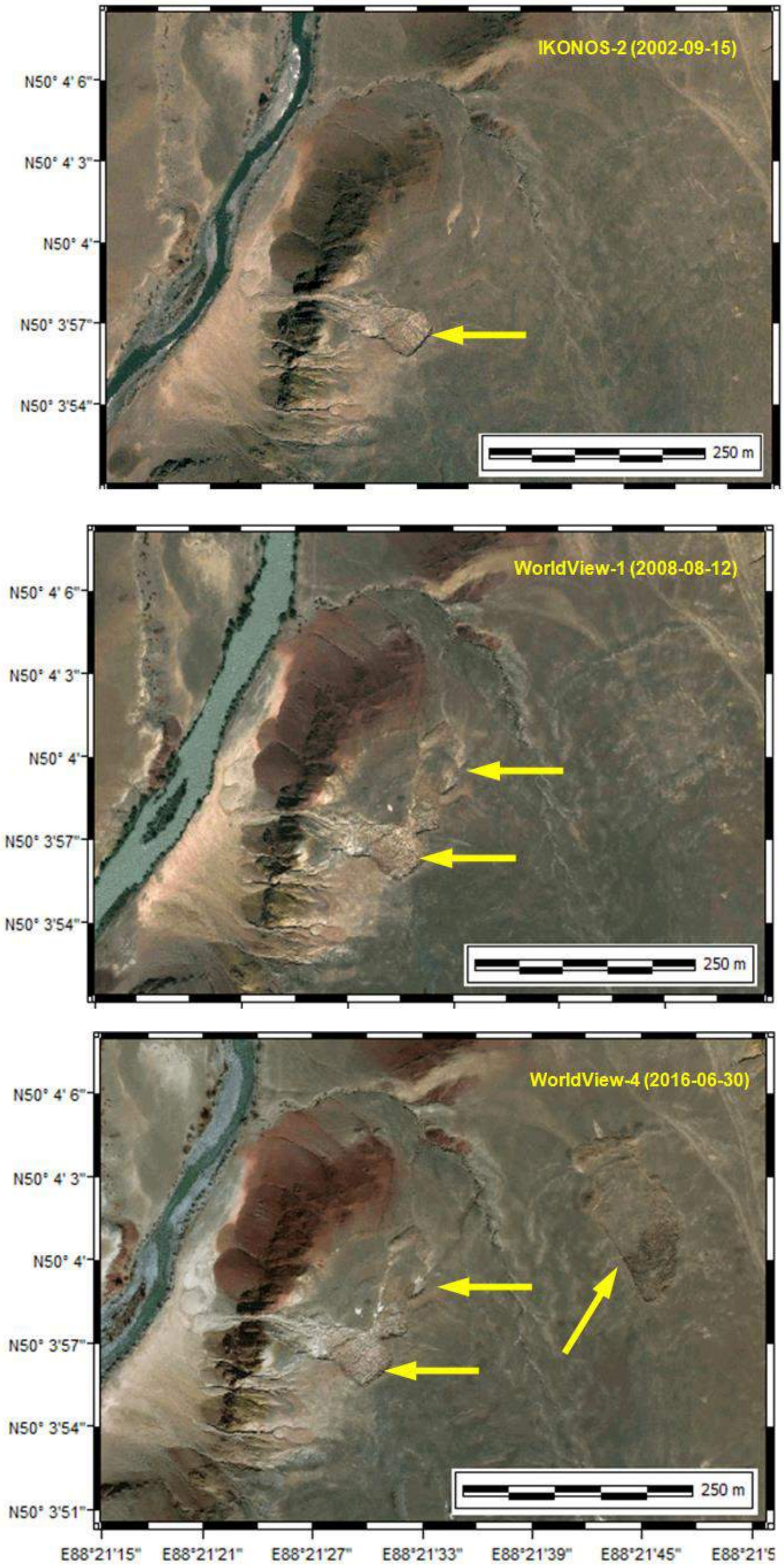


Figure 2.47. The stages of landslide forming of the right bank of the valley of the Chagan-Uzun river based on the GIS techniques

A GPR survey was conducted at one of the key sites of cryogenic landslide development, on the right bank of the Chagan-Uzun river near the confluence with Chuya (Figure 2.48). To clarify the mechanism of formation and study of the internal structure of rocks subjected to landslide.

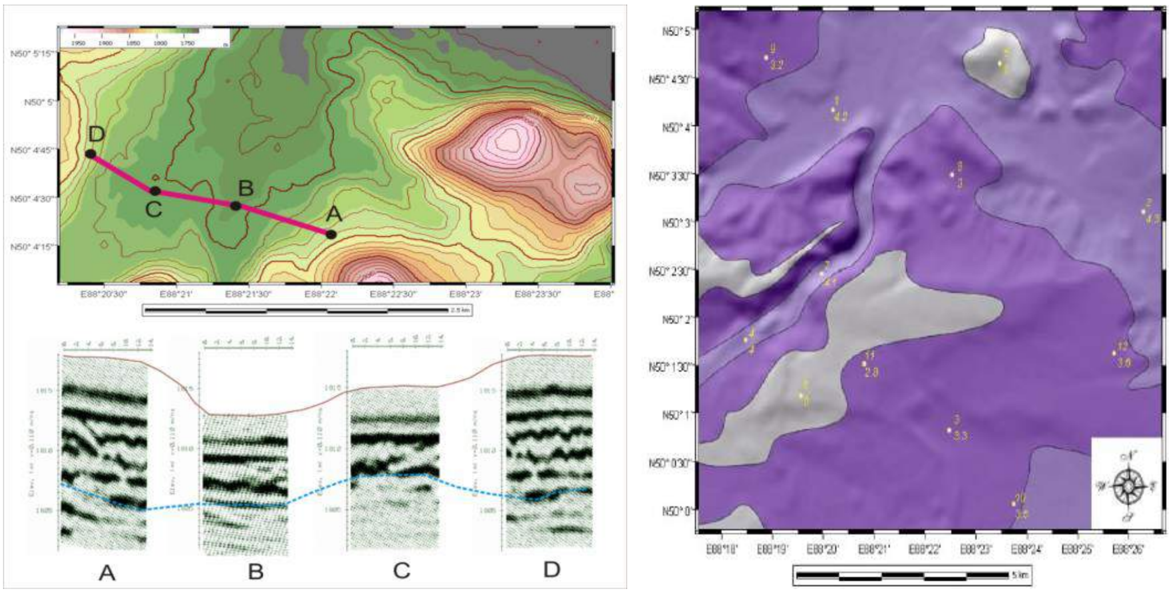


Figure 2.48. Consolidated GPR profile through the valley of the Chagan-Uzun (left) and Fragment of the map of the depth of the active layer at the maximum of seasonal thawing (right)

Aufeis widespread on many rivers, lakes and in areas of groundwater seepage (Figure 3.49). The size of aufeis are diverse: aufeis on the river Chuya near Kosh-Agach in the winter of 2017-2018 occupied an area of about 28 km^2 at a thickness of 0.5—2 m, on river Ustyd in 2018-2019 was formed of aufeis with an area of 15 km^2. The formation of aufeis begins in October - November, melting occurs in April — May, but many aufeis, often stored until August, and in the most severe years do not have time to melt completely. Aufeis blocks roads and trails, but at the same time significantly affect the water balance of the region.

Figure 2.49. Balchash river channel. October 2018 (top photo), may 2019 (bottom), the channel is completely covered with aufeis.

Clear illustration of climate changes and the associated degradation of permafrost is the threat of destruction of capital structures as a result of rapid warming. As a result of the thawing and correspondingly changed hydrogeological conditions, the capital buildings built without taking into account engineering solutions aimed at protection from the effects of permafrost began to lose stability, which eventually led to the destruction of the village Kazak-Sortogoy (Figure 2.50).

Figure 2.50. The remains of the village of Kazak-Sortogoy, destroyed in result of degradation of permafrost.

Modern capital construction is carried out taking into account these features. To prevent the destruction of buildings as a result of cyclic freezing-thawing, or as a result of the complete degradation of permafrost, large houses are built on stilts (Figure 3.51).

Figure 2.51. The new school building was built with the use of technologies taking into account the presence of permafrost.

Spore-pollen spectra and phenological response to climate change in Altai Mountains

Climatic changes are manifested both in phenological changes and in changes in spore-pollen and algological spectra. In Altai State Natural Biosphere Reserve (Russian Altai), we estimated the phenological response of 26 taxa for two selected time intervals of changes in the thermal regime in the Altai mountains, i.e. calculated changes in the dusting start dates against the background of rising temperatures (Table 2.9).

Table 2.9. Phenological response to temperature changes in Altai State Natural Biosphere Reserve

Period	Day/^{0}C	Day/10 years
1979-1997	2.2±0.9	1.7±0.3
1998-2017	0.9±0.4	1.1±0.6
1979-2017	1.8±0.5	1.2±0.4

The results showed that with an increase in temperature by 1^{0}C in the period 1979-2017, there was a shift in the beginning of dusting by an average of 1.8 days, which corresponds to 1.2 days in 10 years. Moreover, in the first period (1979-1997) the phenological response was most pronounced and amounted to 2.2 Day/^{0}C or 1.7 Day/10 years. The obtained results of the phenological response, as well as the values of the temperature increase, are in very good agreement with the data for the Northern Hemisphere 1.1 ± 0.6 Day/10 years (Penuels et al., 2012). It shows that vegetation in Altai Mountains, as the most important component of landscapes, is sensitive to climate change.

Also, in Altai State Natural Biosphere Reserve, we conducted a study of spore-pollen and algological spectra selected according to the requirements of the international Pollen Monitoring Program. Microscopic analysis of samples taken on Yailu meteorological station and in Kyga Bay (Lake Teletskoye) identified pollen grains of wood (*Pinus sylvestris*, *Betula* sp., *Acacia dealbata*, *Populus* sp.), grassy (*Carex* sp., family *Asteraceae*, *Chenopodiaceae*, *Fabaceae*, *Poace*, *Ranunculaceae*, *Brassicaceae* as well as *Thalictrum* sp.) and shrubs (family *Ericaceae*) (Figure 2.52). All found pollen grains belong to anemophilous plants whose pollen has some morphological features (the presence of air sacs, smooth exina\surface), which allows them to be transported over considerable distances.

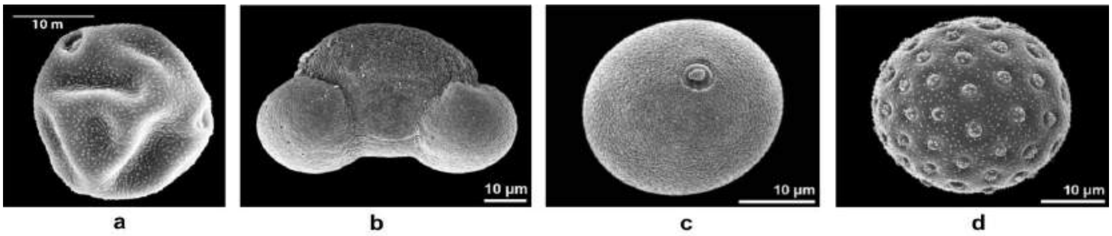


Figure 2.52. Pollen grains interpreted in selected samples

In Yailu meteorological station samples, cereal pollen (family *Poaceae*) prevailed – 35% with the second important representatives of the buttercup (family *Ranunculaceae*) – 22.8%, which is five and three times more than in samples taken in Kyga Bay (Table 3.10). Moreover, in the last samples, birch pollen makes up about a quarter of the pollen spectrum, while in the sample from Yailu single pollen grains of this taxon were found. Approximately equal amounts of *P. sylvestris* pollen, representatives of families *Rosaceae* and *Fabaceae*, as well as *Thalictrum* sp. were identified. The pollen spectrum of samples taken in Yailu was represented by fewer taxa and does not include pollen grains of *Acacia dealbata, Carex* sp., *Populus* sp. and representatives of *Chenopodiaceae*, whereas pollen grains of representatives of *Brassicaceae* and *Ericaceae* were not determined in samples of Kyga Bay.

Table 2.10. The composition and percentage of pollen grains in samples, collected at two stations of the near Lake Teletskoye territory in 2017

Taxon	Station, %	
	Kyga Bay	Yailu
Acacia dealbata	9,76	–
fam. *Asteraceae*	7,32	12,28
Betula sect. *Albae*	24,39	1,75
fam. *Chenopodiaceae*	7,32	–
Carex sp.	9,76	–
fam. *Fabaceae*	4,88	5,26
Pinus sylvestris	7,32	7,02
fam. *Poaceae*	4,88	35,09
Populus sp.	4,88	–
fam. *Rosaceae*	9,76	7,02
fam. *Ranunculaceae*	7,32	22,81
Thalictrum	2,44	1,75
fam. *Brassicaceae*	–	3,51
fam. *Ericaceae*	–	1,75

Note “-” - not found

Along with pollen grains, microscopic algae of 14 taxa from seven departments, large systematic units, were revealed, and almost the same number of taxa — eight and ten — was revealed at two different stations (Table 2.11).

Table 2.11. List of algae taxa collected on the near Lake Teletskoye territory in 2017

Taxon	Station	
	Kyga Bay	Yailu
CYANOBACTERIA		
Aphanothece clathrata W. et G.S. West		+
Gloeocapsa alpina Näg. emend. Brand		+
G. minuta (Kütz.) Hollerb.		+
Microcystis pulverea (Wood) Forti emend. Elenk.	+	
Unidentified spherical Cyanobacteria	+	
Unidentified ellipsoid. Cyanobacteria	+	
CHRYSOPHYTA		
Chrysococcus rufescens Klebs		+
Cyst of *Chrysophyceae*	+	+
BACILLARIOPHYTA		
Navicula sp.	+	
CRYPTOPHYTA		
Cryptophyceae sp.	+	
EUGLENOPHYTA		
Trachelomonas hispida (Perty) Stein emend. Defl.	+	
CHLOROPHYTA		
Closteriopsis acicularis (G.M. Smith) Belcher et Swale		+
Sphaerocystis planktonica (Korsch.) Bourr.		+
XANTHOPHYTA		
Botrydiopsis arhiza Borzi		+
Unidentified spherical yellow-green algae		+
Hyphae, sporangia and spores of aquatic mushrooms	+	+
Total: 14	8	10

Unicellular algae were mainly represented in the sample taken in Kyga Bay, only *Microcystis pulverea* from cyanobacteria belongs to the colonial forms, but the cells of its colonies are small (up to 1 μm), which allows them to be transported over considerable distances. In addition to *M. pulverea*, other cyanobacteria, larger (up to 4 μm), were also found, but we were not able to determine their species affiliation. Among golden algae, cysts, or stomatocysts, spherical with a smooth surface, were found, while among the diatoms – the only frustule of the small-cell pennate diatom *Navicula* usually habits in rivers and littoral zone of lakes, which cannot be determined in an aqueous preparation. One flagellar form of cryptophytic algae was found too, and the lorica of *Trachelomonas* from Euglenophytes was marked. In general, it can be more likely to say that the algae identified in the samples taken from Kyga Bay could develop in numerical small reservoirs in the vast territory of the Lake Teletskoye basin.

The composition of algae found in precipitations on the Yailu terrace, is significantly different from that in Kyga Bay. Cyanobacteria *Aphanothece clathrata*, *Gloeocapsa alpina*, and *G. minuta* were noted here. All these algae are colonial forms, as well as *M. pulverea*. But, while cells of *A. clathrata* are quite small, the diameter of the cells of *Gloeocapsa* species is somewhat larger, and often their colonies have the appearance of films on some substrates. They can get into the air masses when pieces of films are detached from the surface of the rocks, or when coastal rocks are flooded during the flood period and when they are washed away from the substrate, go into plankton and then fall into the air with water drops. Widespread species include *G. alpine*, which develops on wet rocks, which can be found in the mountainous conditions of Lake Teletskoye and its basin. The discovery of *G. minuta*, which often develops in the plankton of swamps and brackish water bodies, less often on wet rocks (Gollerbach et al., 1953), is very interesting. Apart from cysts, spherical lorica of *Chrysococcus rufescens* were found among golden algae. This small-celled species lives in the plankton of various water bodies throughout the year (Matvienko, 1954). Its distinctive feature is the massive development in some periods of the year, as a result of which it can probably more often than other species capture with water drops and be transported through the air. Interestingly, cysts were found at both points of the coastal territory. In the lake itself, one can find various morphotypes of stomatocysts of golden algae, therefore, their detection in precipitation is quite logical. In addition to cysts, numerous hyphae, sporangia, and spores of aquatic mushrooms were discovered in Yailu, which populated the aquatic environment of the storage boxes. In the sample, unidentified algae of the species, presumably their yellow-green algae division, forming extensive colonies in the mucus, were identified. In general, the composition of algae in precipitation, which were collected on the terrace of Yailu, more diverse in composition. The detected algae may well inhabit both Lake Teletskoye and the reservoirs of its catchment basin, which may indicate a significant contribution of local circulation flows to the penetration of microscopic biological objects into precipitation.

It should be noted, that the samples contained not only unicellular small-sized representatives of the algal population of water bodies, but also colonial and coenobial forms, which in principle should not be transported with air masses due to their larger size. Most likely, some initial cells got into the samplers, from which later colonies, coenobia and thalli can be developed, since the water in the boxes was probably throughout the entire exposure period due to the large amount of precipitation. In addition to algae, a large number of hyphae, sporangia and spores of aquatic fungi were revealed in the samples. All of this could develop in a sample collection tank after spores of fungi and single algae cells got into it.

The distribution of biological aerosols, in particular pollen and algae, is associated primarily with meteorological parameters. Each taxon of higher plants has a certain dusting rhythm (daily, seasonal, annual), which can vary depending on weather conditions. For example, the concentration of pollen increases at a sufficiently high temperature, and the amount of precipitation helps to reduce it, but at the same time gives an impetus to the development of algae.

An analysis of meteorological situations from July to October 2017 showed that the average temperature of the period under consideration was within the 1981–2010 climate norm. The difference in average monthly temperatures by 0.2° C was noted only in September. This fact confirms that plant dusting occurred according to the phenological phases characteristic of this region. The total amount of precipitation was 25% higher than the climatic norm (1981-2010) and from July to September, 4 mm fell more monthly. In October, precipitation was half the norm, but the large amount of precipitation that had previously occurred could contribute to the accumulation of water in the samplers, which subsequently led to the development of colonial and coenobial forms, as well as sporangia and spores of aquatic fungi.

Pollen and algae in precipitation are reliable markers of atmospheric transport in the region (Malygina, 2018). In this regard, the study of their composition and amount in precipitation is essential in determining the main / prevailing trajectories of air mass movements at one time or another. Moreover, the study of the distribution of pollen and algae in precipitation at the local level can complement the data on the study of atmospheric transport of submicron aerosol particles.

To evaluate regional and local sources of biological objects from July to October 2017, the backward trajectories of the air masses were constructed using the HYSPLIT model (Figure 2.53). The trajectories were calculated with a resolution of 30 days, each new trajectory on the date of precipitation was constructed after 6 hours (if the duration of the precipitation exceeded this time interval) at an average height of 430 meters.

The constructed backward trajectories made it possible to determine the direction of movement of the air masses for each analyzed month, with a selected percentage contribution (see the scale in Figure 2.53). Most often in July, the air masses were west and southwest at the regional level and northwest at the local one. In the month of August, air masses coming from the northwest and west made a significant contribution. The contribution of the southwestern component at the regional level increased in September, amid the prevalence of the northwestern component. At the local level in October, the air masses were south and southeast, as well as at the regional level. Thus, for each month, territories were determined at the local and regional level that could serve as sources of biological aerosols in the studied samples.

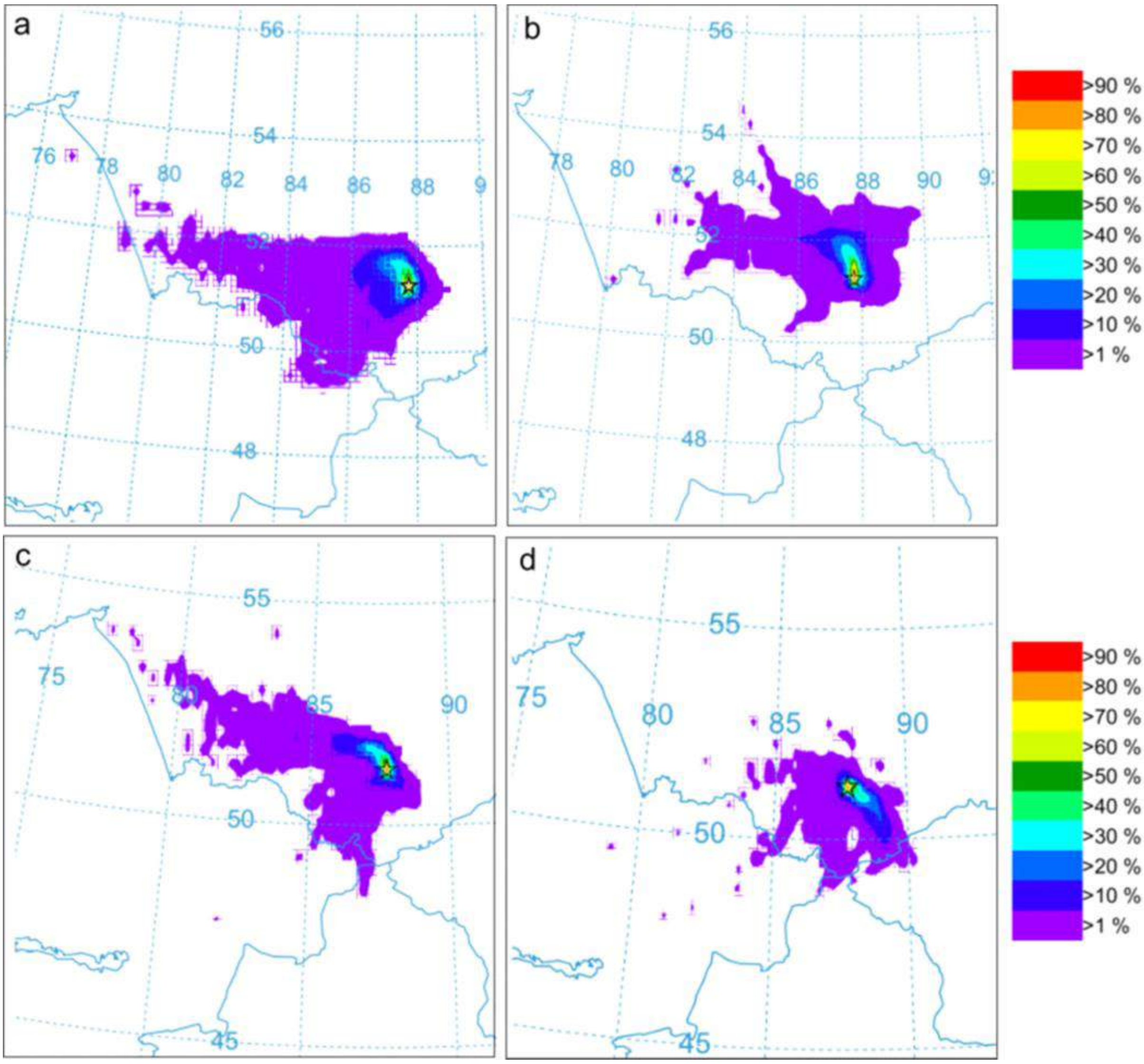


Figure 2.53. Backward trajectories of air masses for each month of observations

(a - July, b - August, c - September, d - October)

Thus, the pollen spectrum of samples taken from July to October 2017 in Altai State Biosphere Reserve, represented by pollen grains of woody, grassy and shrub taxa. 14 taxa were revealed, and the presence of pollen grains corresponds to the phenological phases of the season. The algological composition of the samples was presented by 14 taxa of algae from seven departments. And on the basis of the analysis of backward trajectories of the air masses and the spore-pollen analysis of precipitation, territories were identified that could serve as sources of biological aerosols in the samples under study. The implemented approach, which made it possible to determine, both at the local and regional levels of the territory from which biological aerosols could come, can be applied in other regions, including mountainous.

Projected future climate changes in Altai Mountains

For projected future climate changes in Altai Mountain we use CMIP5 (full set) 2020-2100 [https://climexp.knmi.nl]. All four scenarios (RCP 2.6, RCP 4.5, RCP 6.6 and RCP 8.5) were considered.

According to scenario RCP 2.6, the temperature in Altai Mountains does not increase by more than 0.5^{0}C, but in the other three scenarios it will increase significantly. Maximum increases (by almost 5^{0}C) temperatures by 2100 are possible with scenario RCP 8.5 (Figure 2.54).

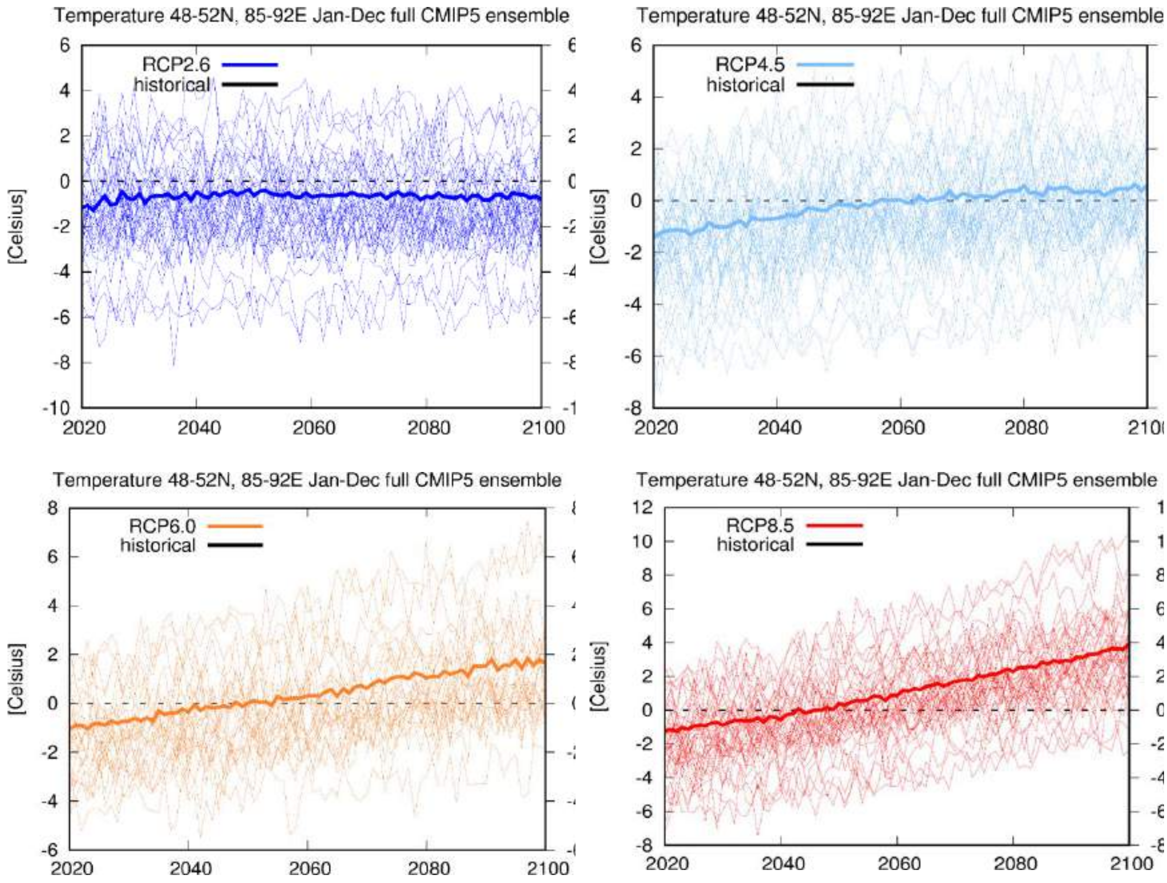
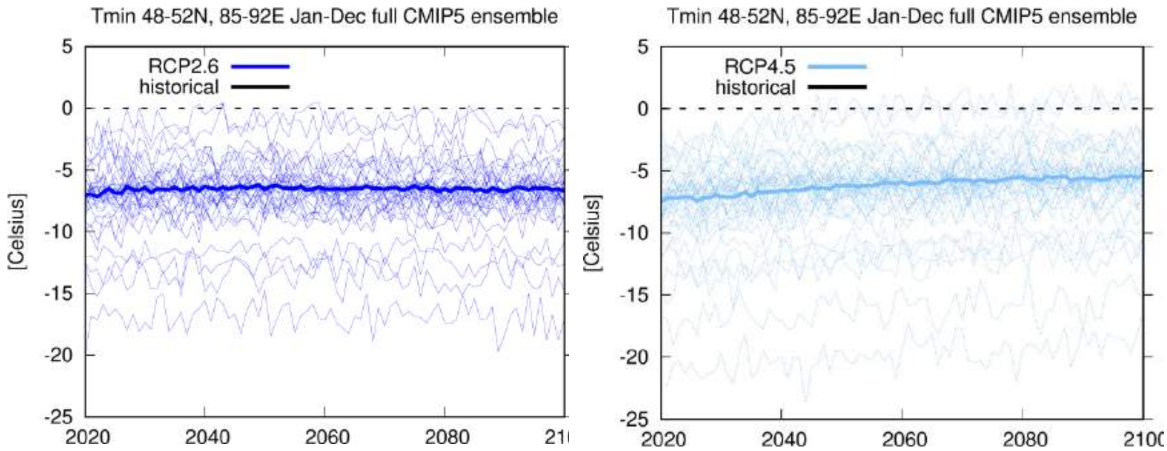


Figure 2.54. Projected future temperature changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

Changes close to the temperature are predicted to change the minimum temperature in Altai Mountains: from 0.5 to 5 ^{0}C, with «soft» (RCP 2.6) and «hard» (RCP 8.5) scenarios (Figure 2.55).



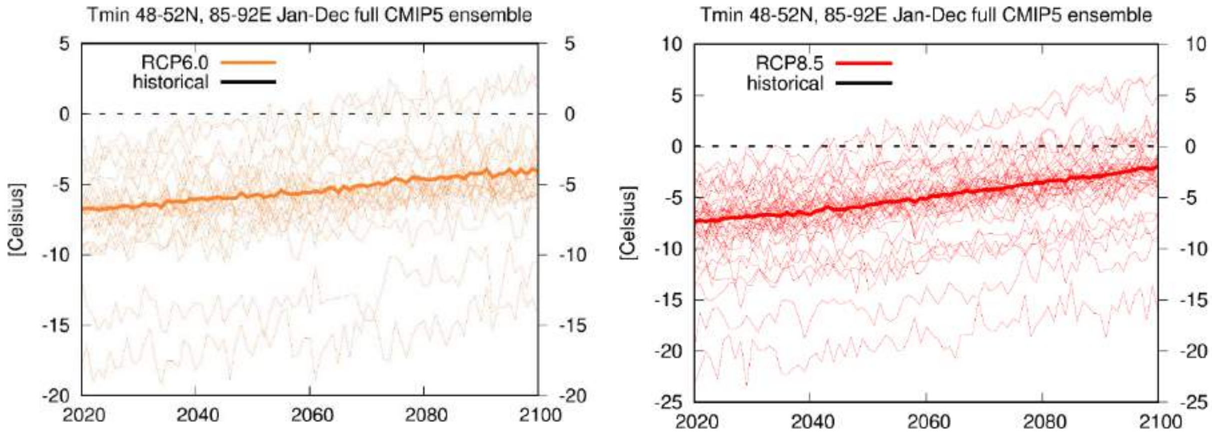


Figure 2.55. Projected future min temperature changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) [https://climexp.knmi.nl]

Changes in the maximum temperature are projected by the year 2100 in Altai Mountains as for the minimum temperature, i.e. from 0.5^0C (RCP 2.6) to 5^0C (RCP 8.5) (Figure 2.56).

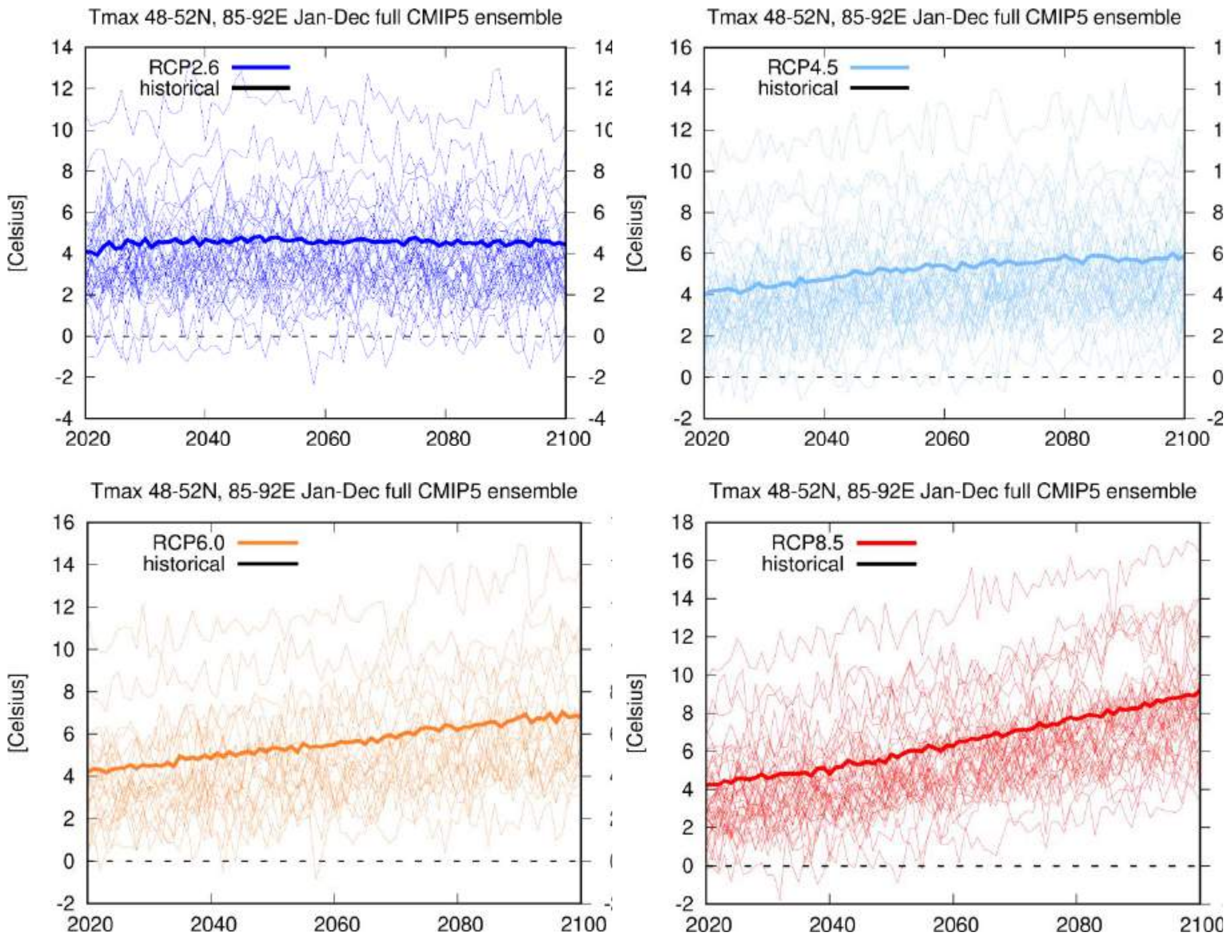


Figure 2.56. Projected future max temperature changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

In contrast to temperature, no significant changes in precipitation are expected: from 0 mm/day change for scenario RCP 2.6 to 0.2 mm/day for scenario RCP 8.5 (Figure 2.57).

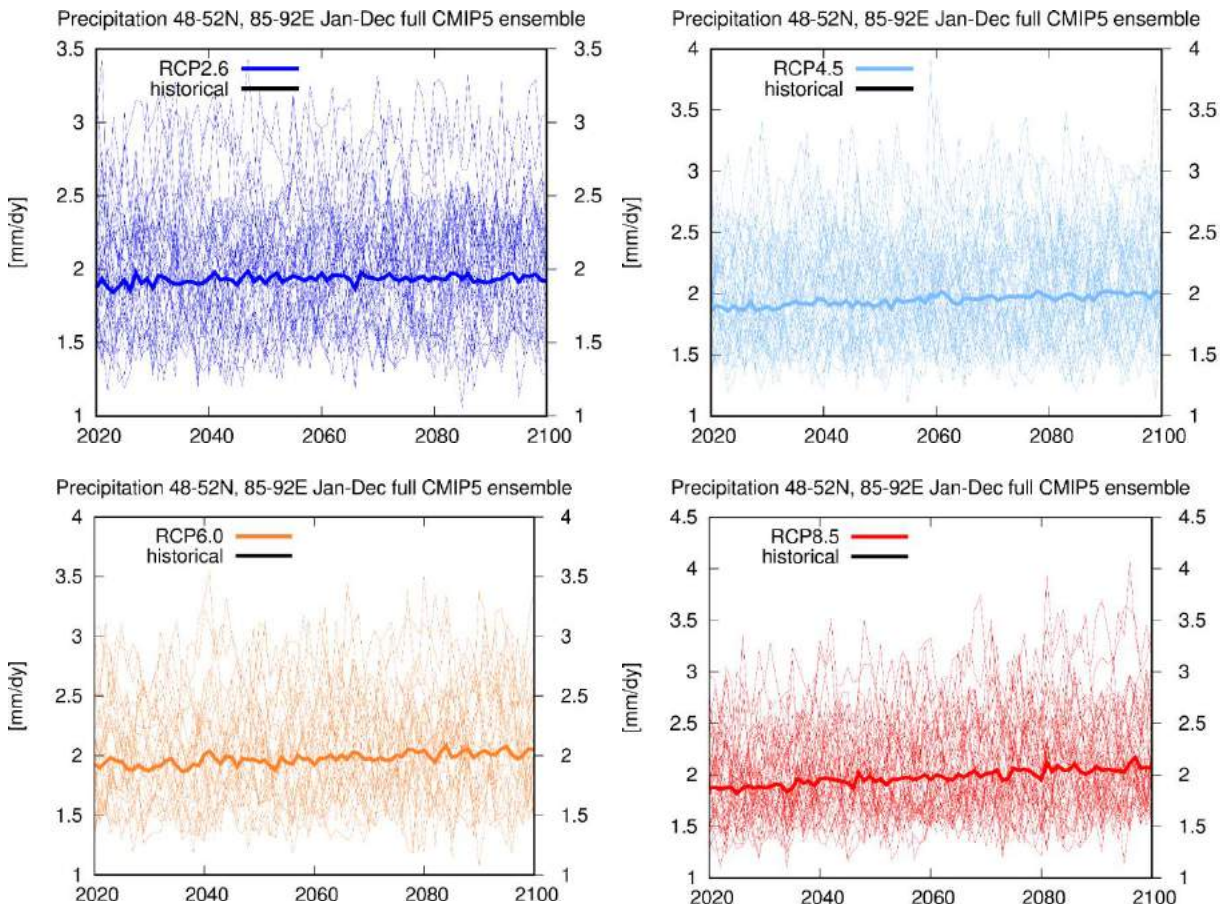
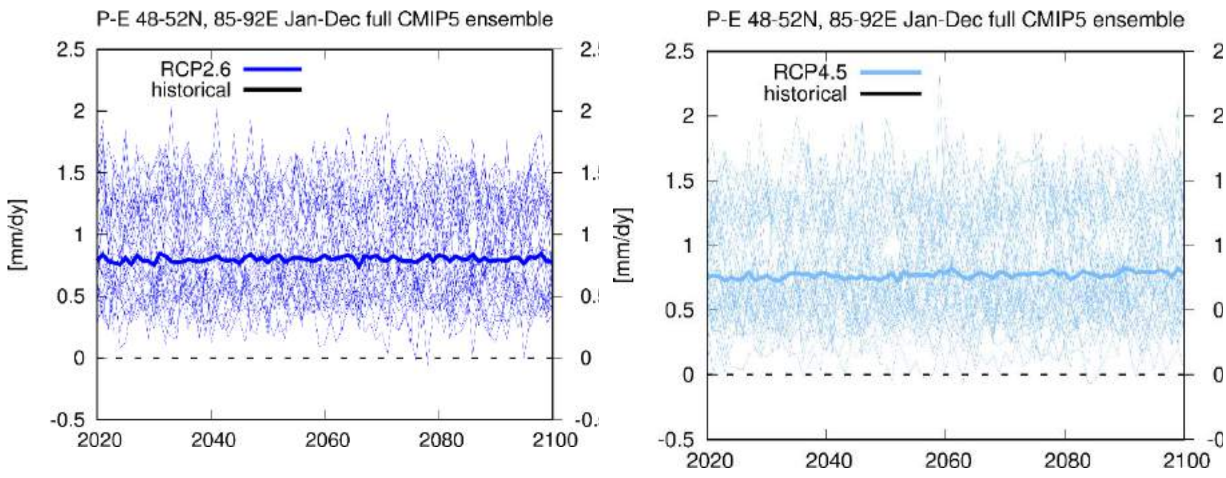


Figure 2.57. Projected future precipitation changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

Under all four scenarios (RCP 2.6, RCP 4.5, RCP 6.6 and RCP 8.5), precipitation-evaporation by 2100 in Altai Mountains will be at the same level (Figure 2.58).



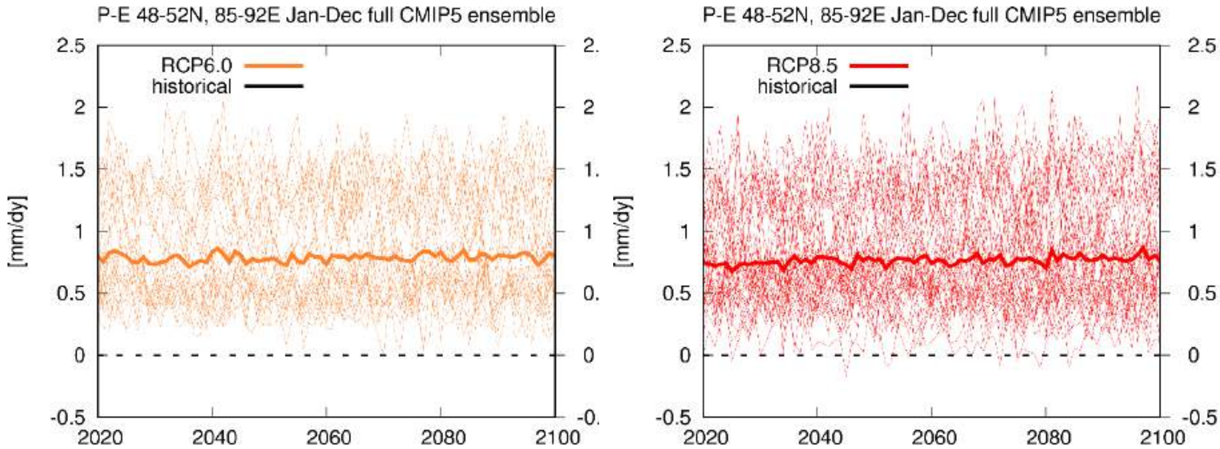


Figure 2.58. Projected future Precipitation-Evaporation changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

For projected future extreme climate changes, we use GCM: CMIP5 extremes. GCM: CMIP5 extremes is the extremes indices, which are calculated computed various indices of extremes from the daily CMIP5 data. At the moment only the annual values are available, so for instance the maximum daily rainfall amount for each year (Rx1day) or the highest maximum temperature in a year (TXx).

Projections of future changes (RCP 2.6, RCP 4.5, RCP 6.6 and RCP 8.5) show that annual maximum value of daily maximum temperature (or warmest daily Tmax) by 2100 will hardly change with RCP 2.6 and will increase to the maximum (5^0C) with RCP 8.5 (Figure 2.59).

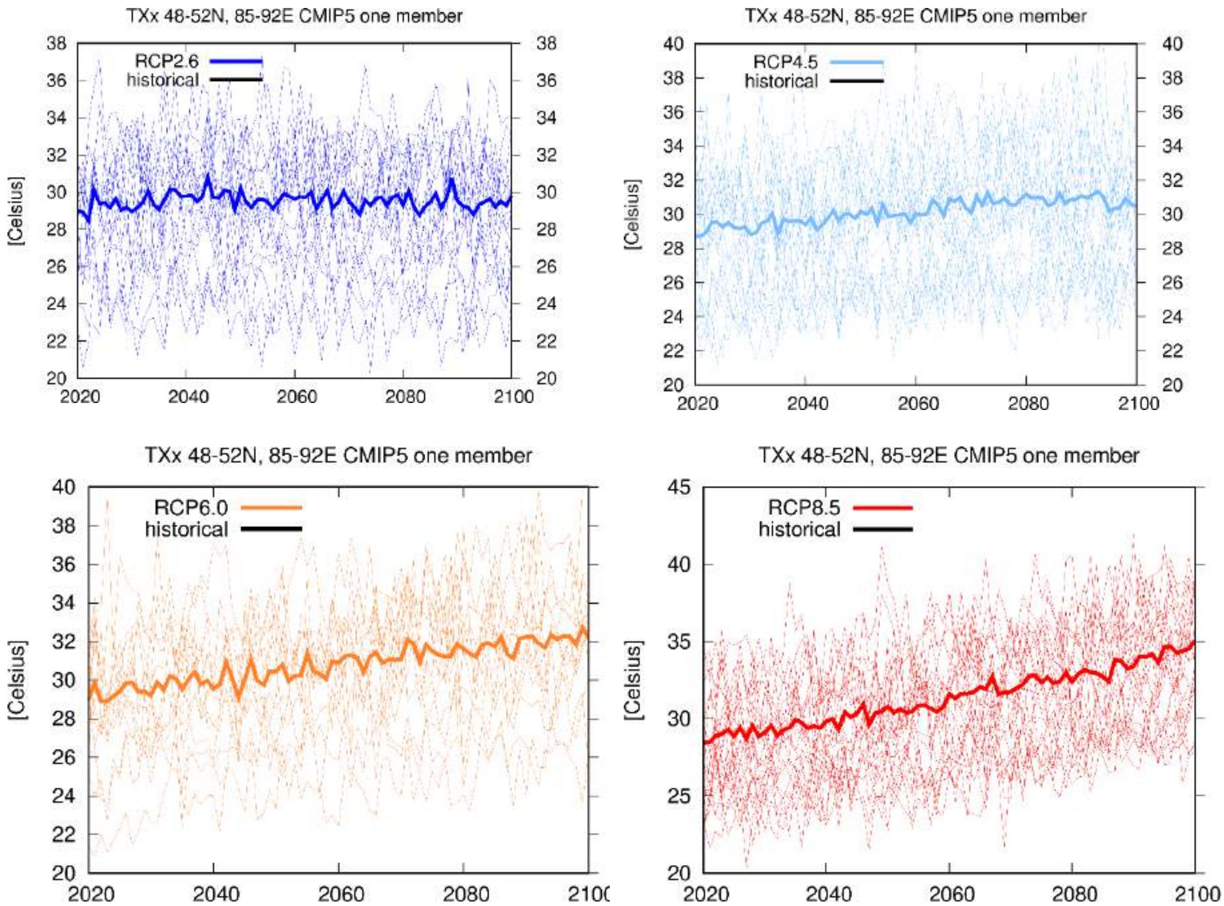


Figure 2.59. Projected future warmest daily Tmax changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

Changes in Annual maximum value of daily minimum temperature (Warmest daily Tmin) will be the same as the changes in warmest daily Tmax, namely the temperature rise in RCP 8.5 by 5^0C (Figure 2.60).

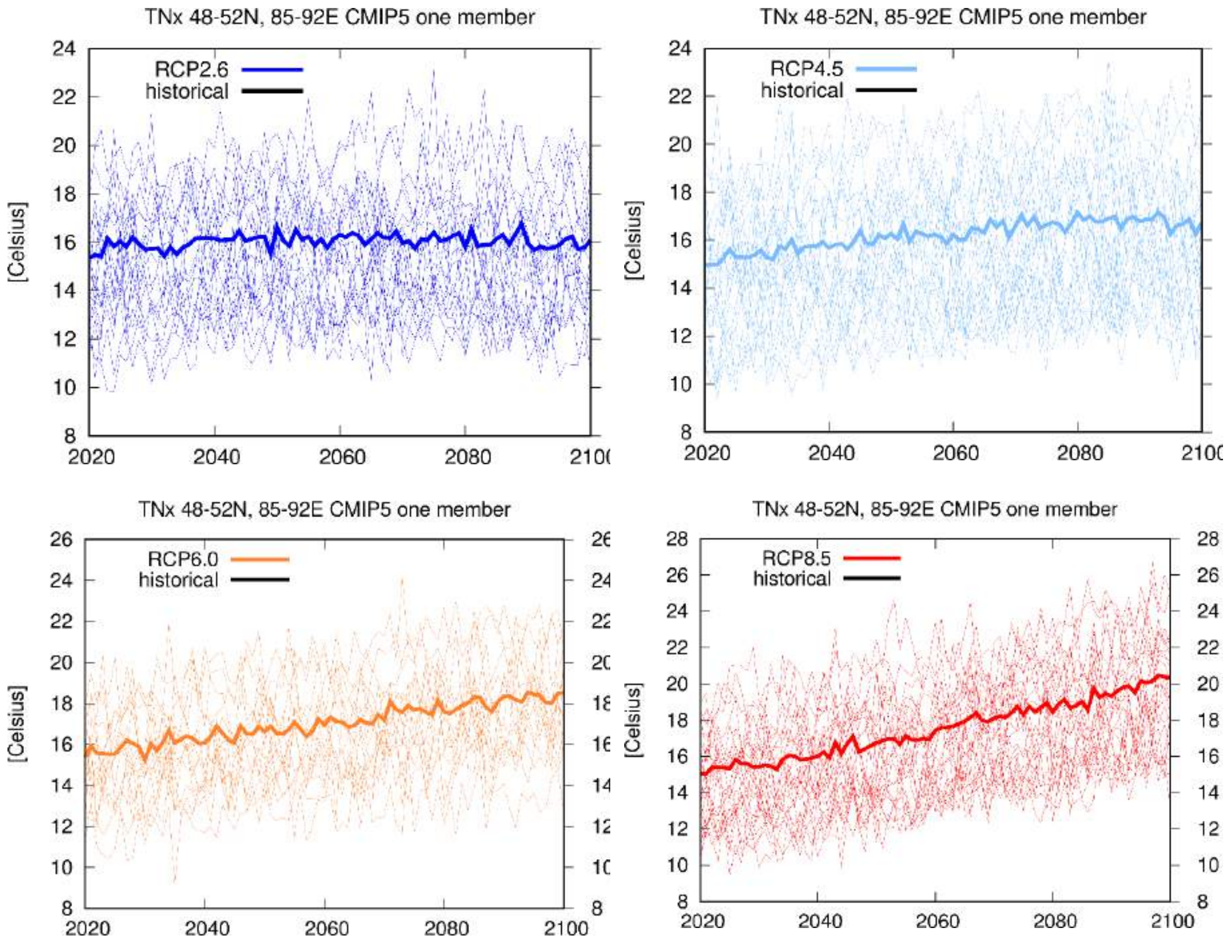


Figure 2.60. Projected future warmest daily Tmin changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

As with increasing temperatures (Tmax and Tmin) with warmest daily, the temperature rise will also be at an annual minimum value of daily maximum temperature, and will be less than a degree at RCP 2.6 and about 5^0C degrees at RCP 8.5 (Figure 2.61).

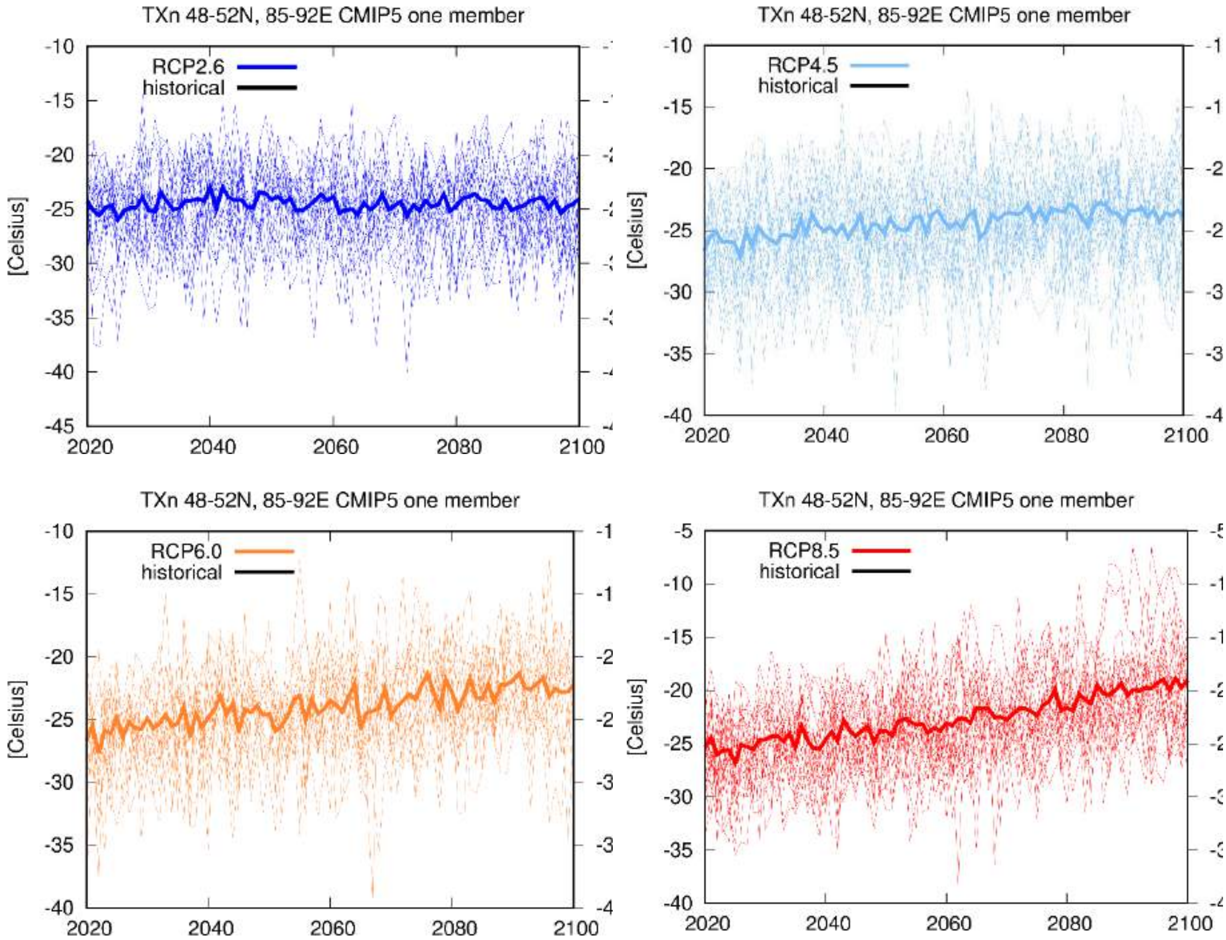
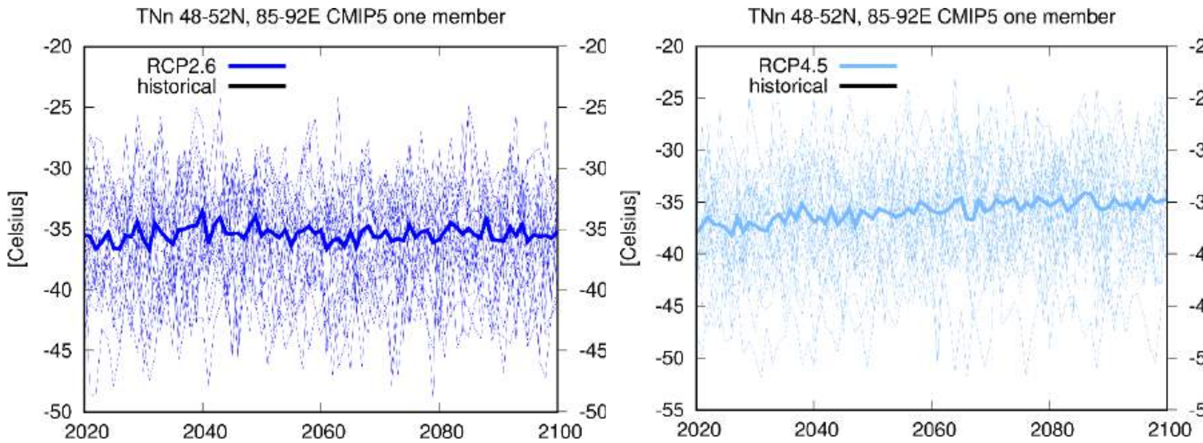


Figure 2.61. Projected future coldest daily Tmax changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

Annual minimum value of daily minimum temperature will be changed in the same way as coldest daily (Figure 2.62).



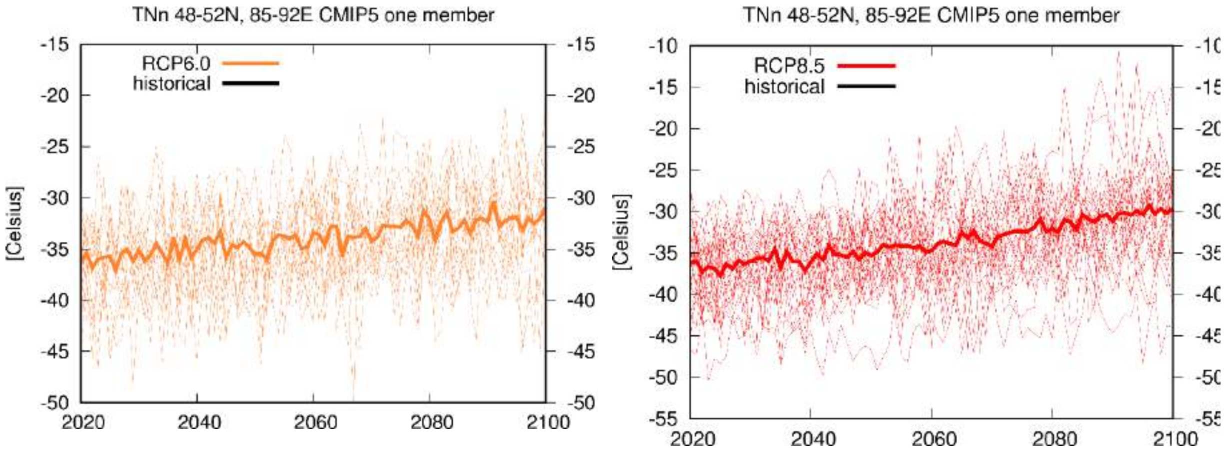


Figure 2.62. Projected future coldest daily Tmin changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) [https://climexp.knmi.nl]

The number of days when the daily minimum temperature <10th percentile at RCP 2.6 decreases by less than 1%, while at RCP 8.5 more than 5% and becomes less than 1% (Figure 2.63).

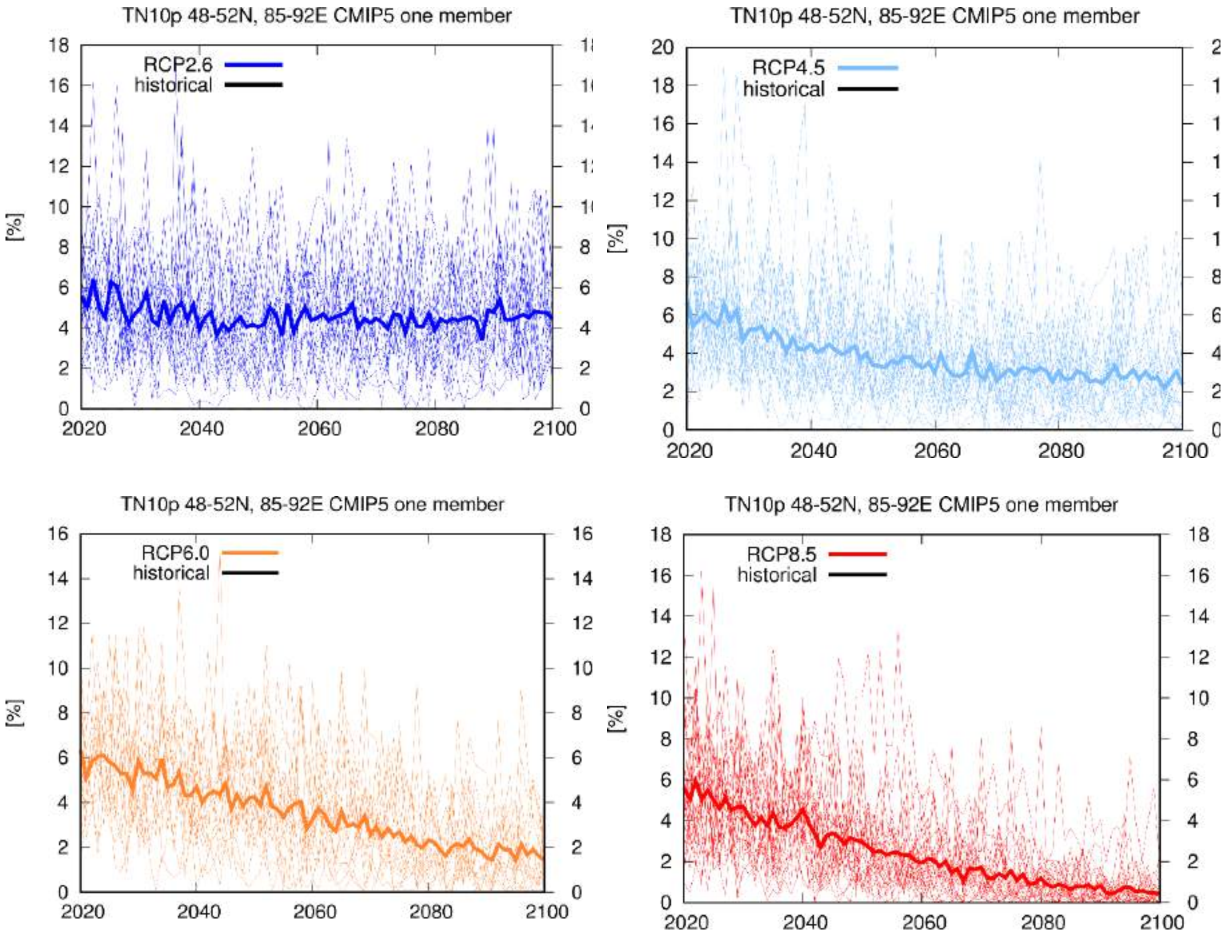


Figure 2.63. Projected future cold nights (TN10p) changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

Changes to days (or fraction of time) when daily maximum temperature <10th percentile will be the same as changes to cold nights (Figure 2.64).

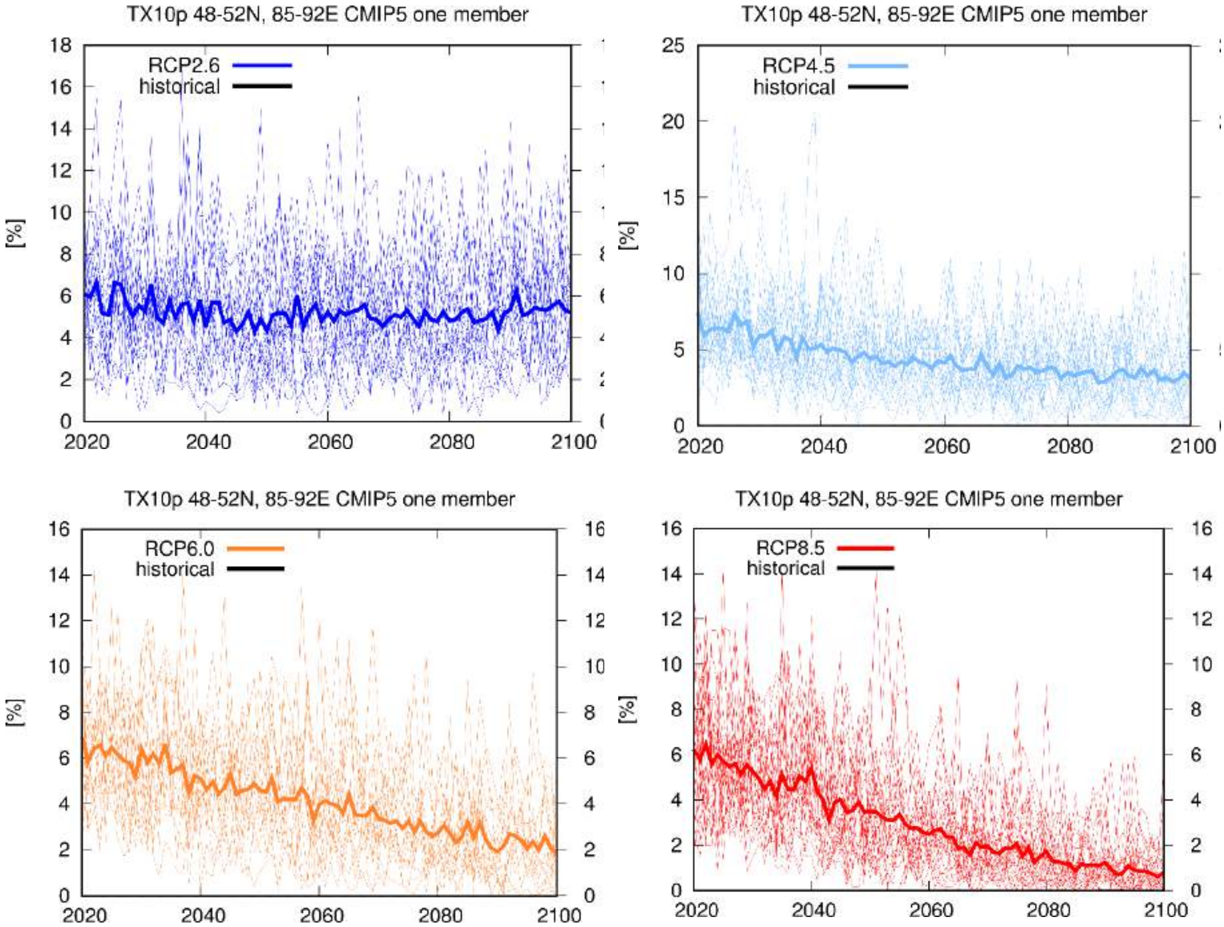
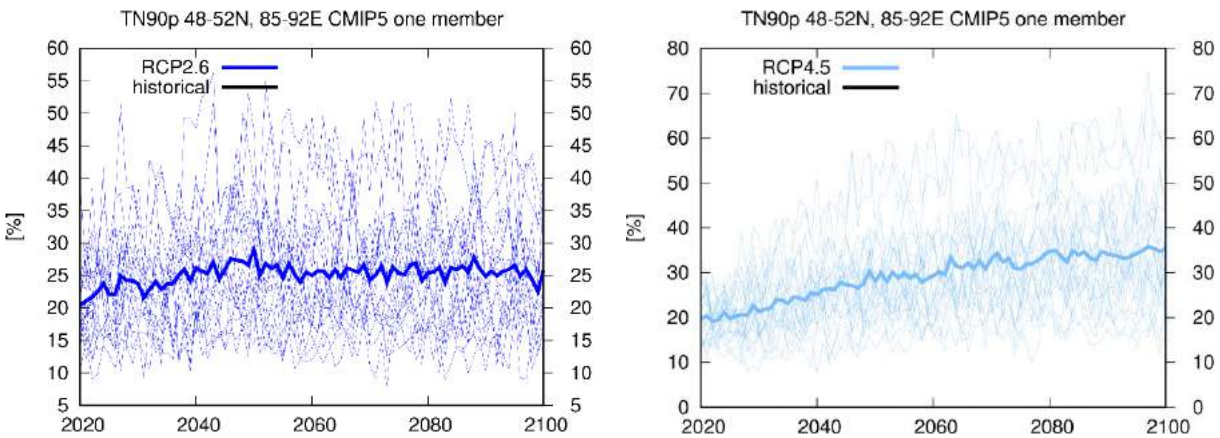


Figure 2.64. Projected future cold days (TX10p) changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

The number of days when the daily minimum temperature> 90t percentile under RCP 2.6 does not increase significantly, while for RCP 8.5 it will grow by 45% and will be about 65% of the total number of days per year, and will be almost 240 days per year (Figure 2.65).



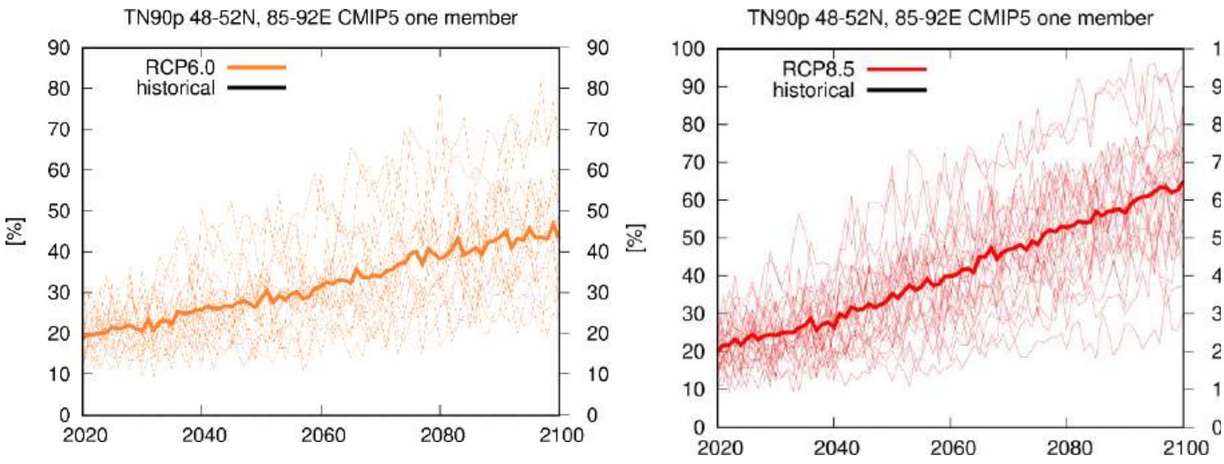


Figure 2.65. Projected future warm nights (TN90p) changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

The number of days when the daily maximum temperature> 90th percentile does not greatly increase under RCP 2.6 and will increase by more than 40% under RCP 8.5 (Figure 2.66).

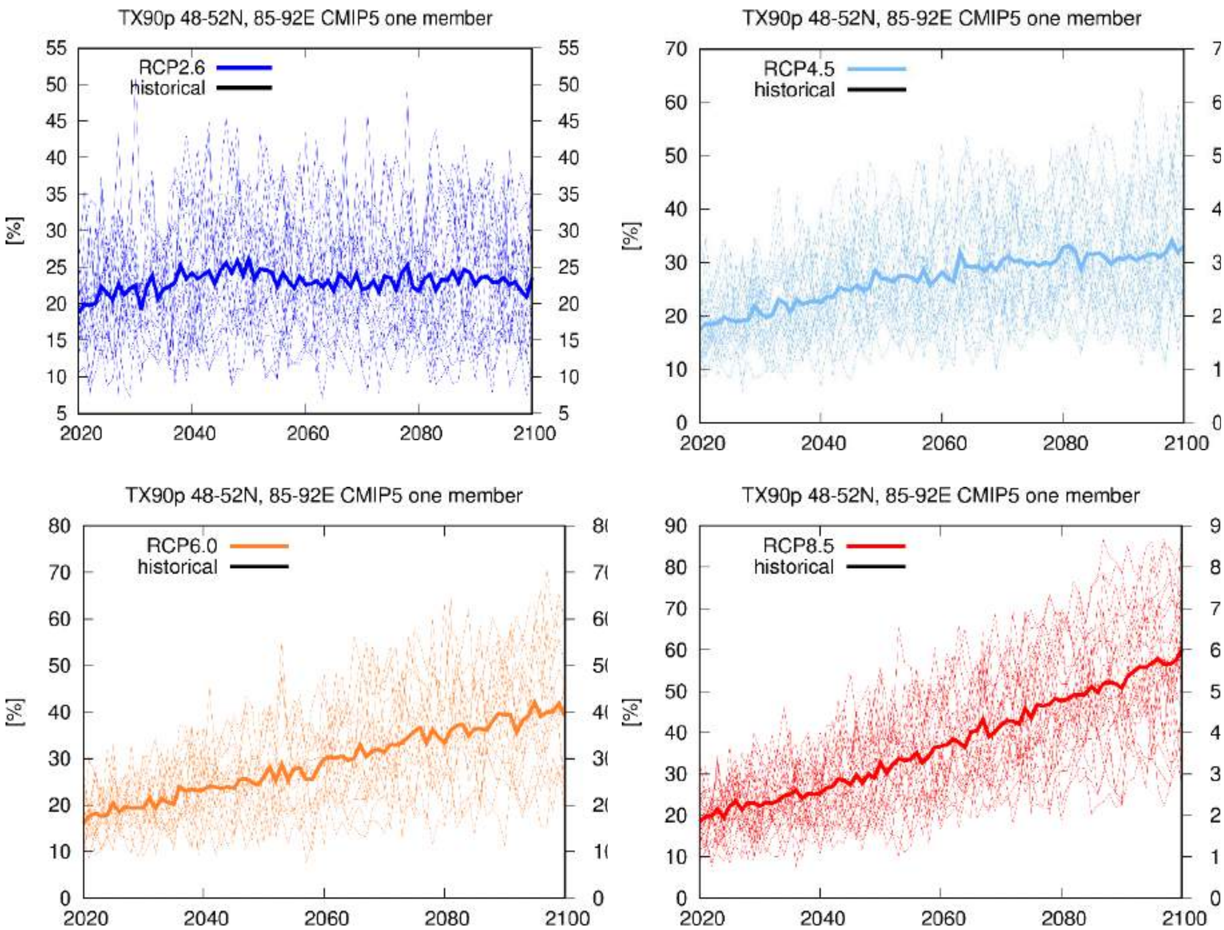


Figure 2.66. Projected future warm days (TX90p) changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

Maximum 1-day precipitation in the Altai Mountains by 2010 for RCP 2.6, RCP 4.5 and RCP 6.0 almost does not change, while by RCP 8.5 it will increase by 5 mm/day (Figure 2.67).

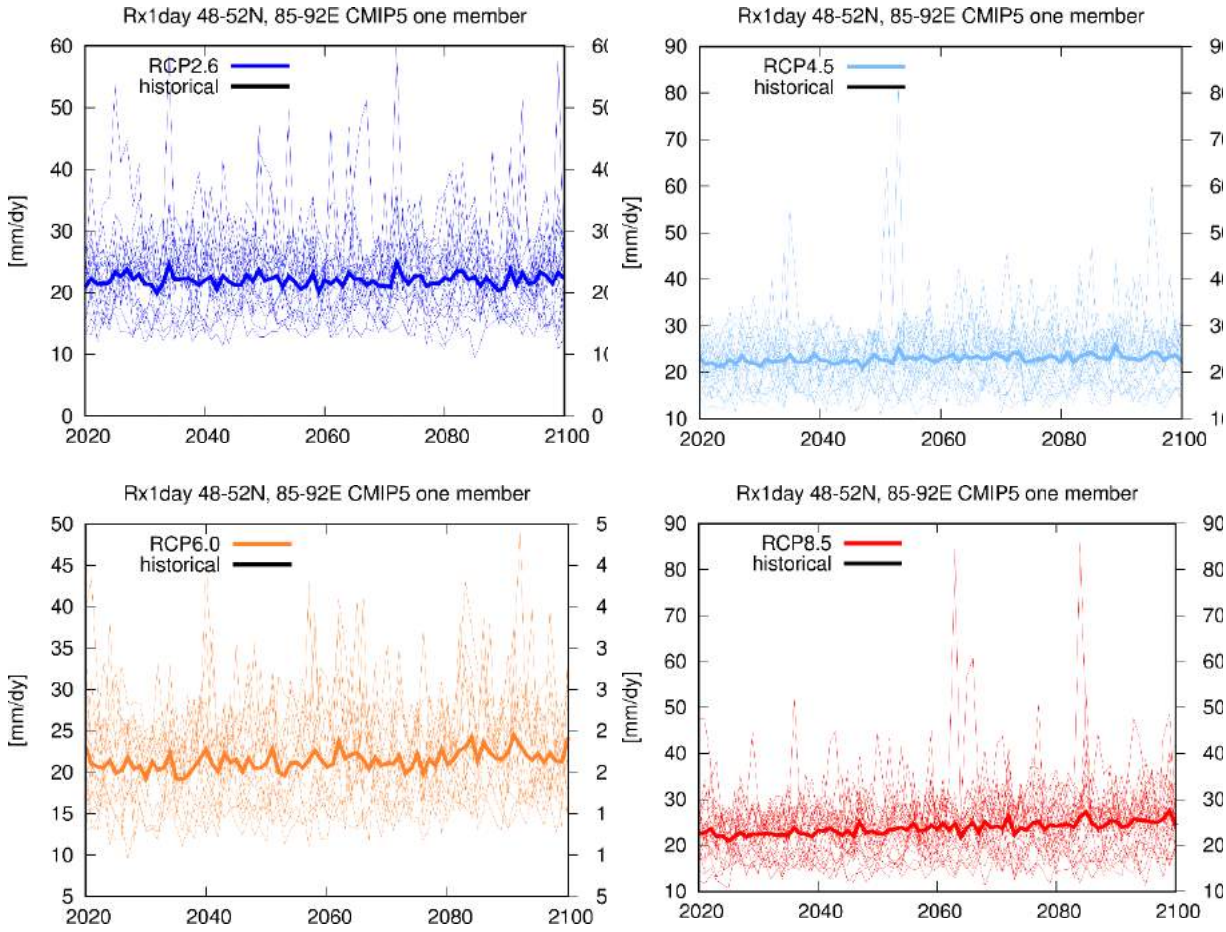
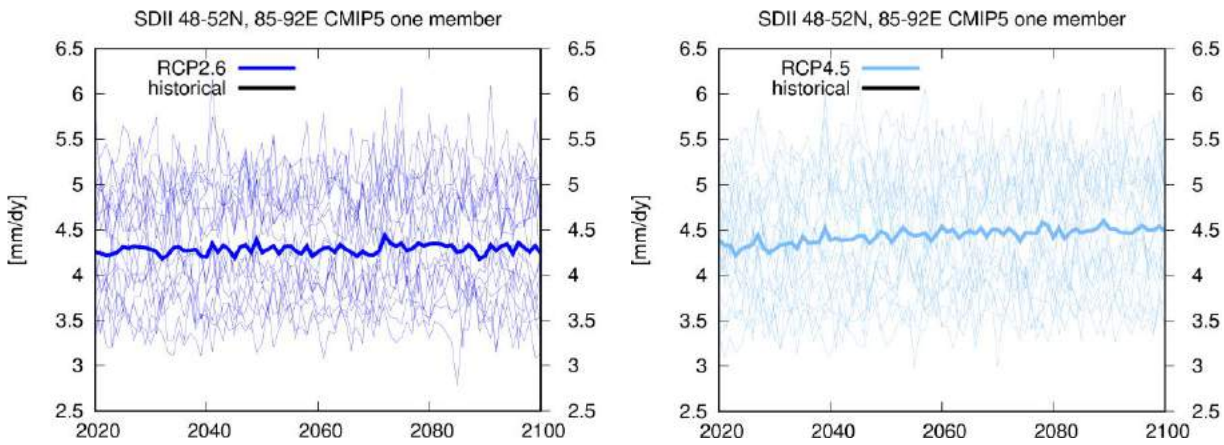


Figure 2.67. Projected future wettest day (RX1day) changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

Changes in ratio of annual total precipitation to the number of wet days (≥1 mm) by the year 2100 will not exceed 0.5 mm/day even in the most “hard” scenario RCP 8.5 (Figure 2.68).



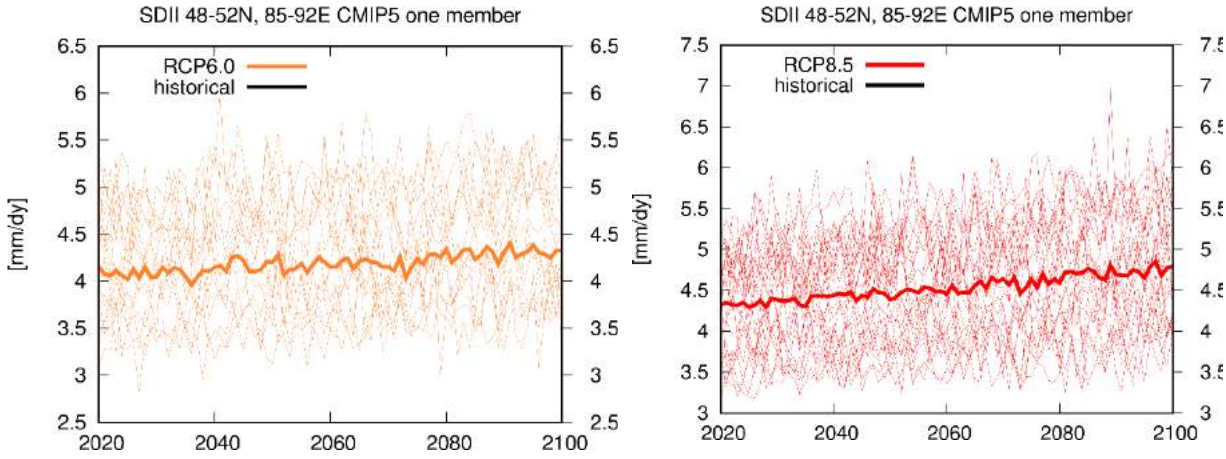


Figure 2.68. Projected future simple daily intensity index (SDII) changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

There will be almost no change in amount of precipitation from days> 95th percentile under RCP 2.6 by 2100, while by RCP 8.5 there will be an increase of almost 50 mm/year (Figure 2.69).

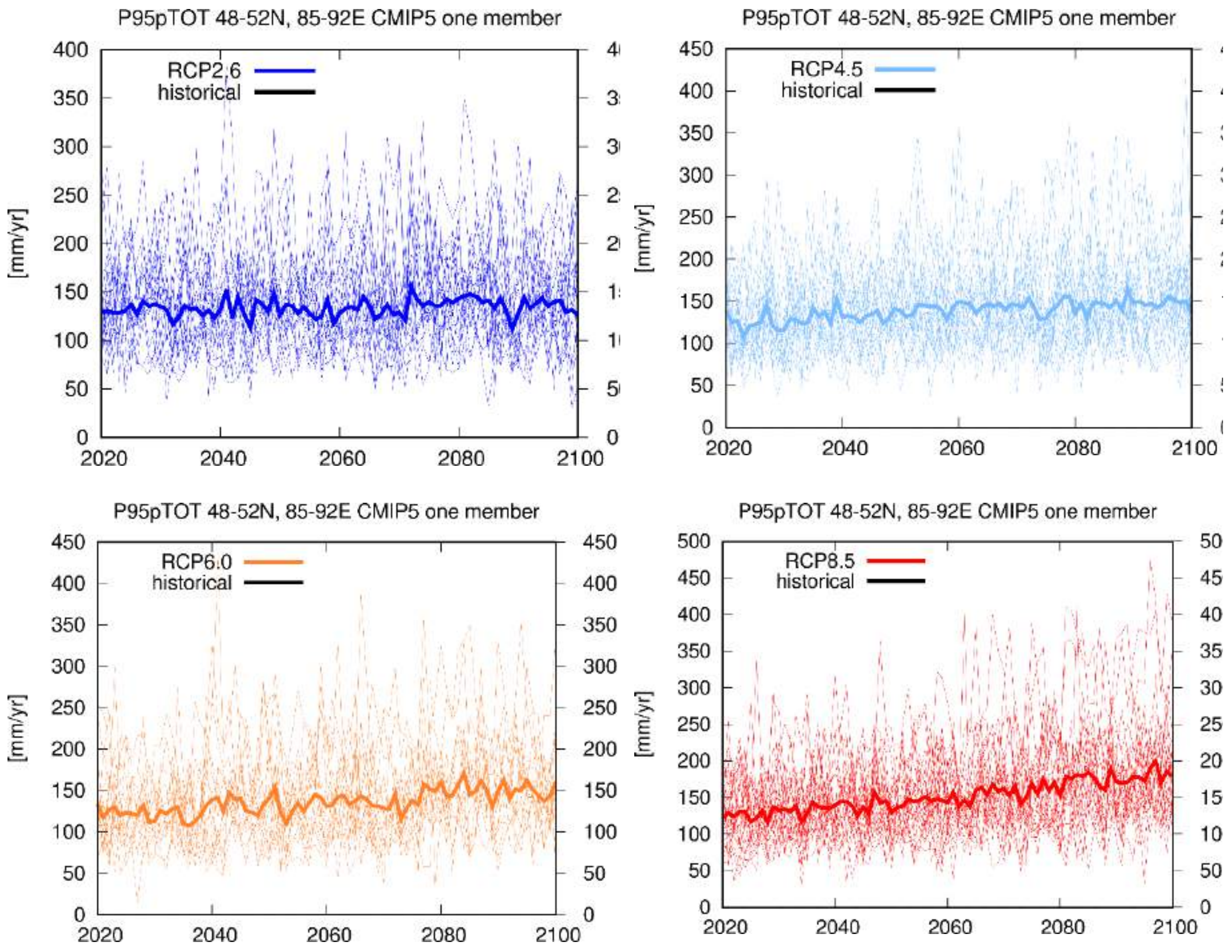


Figure 2.69. Projected future precipitation from very wet days (R95p) changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

Maximum number of consecutive days when precipitation <1 mm to 2100 in Altai Mountains will not change, only with RCP 8.5 it will increase no more than 1-2 days (Figure 2.70).

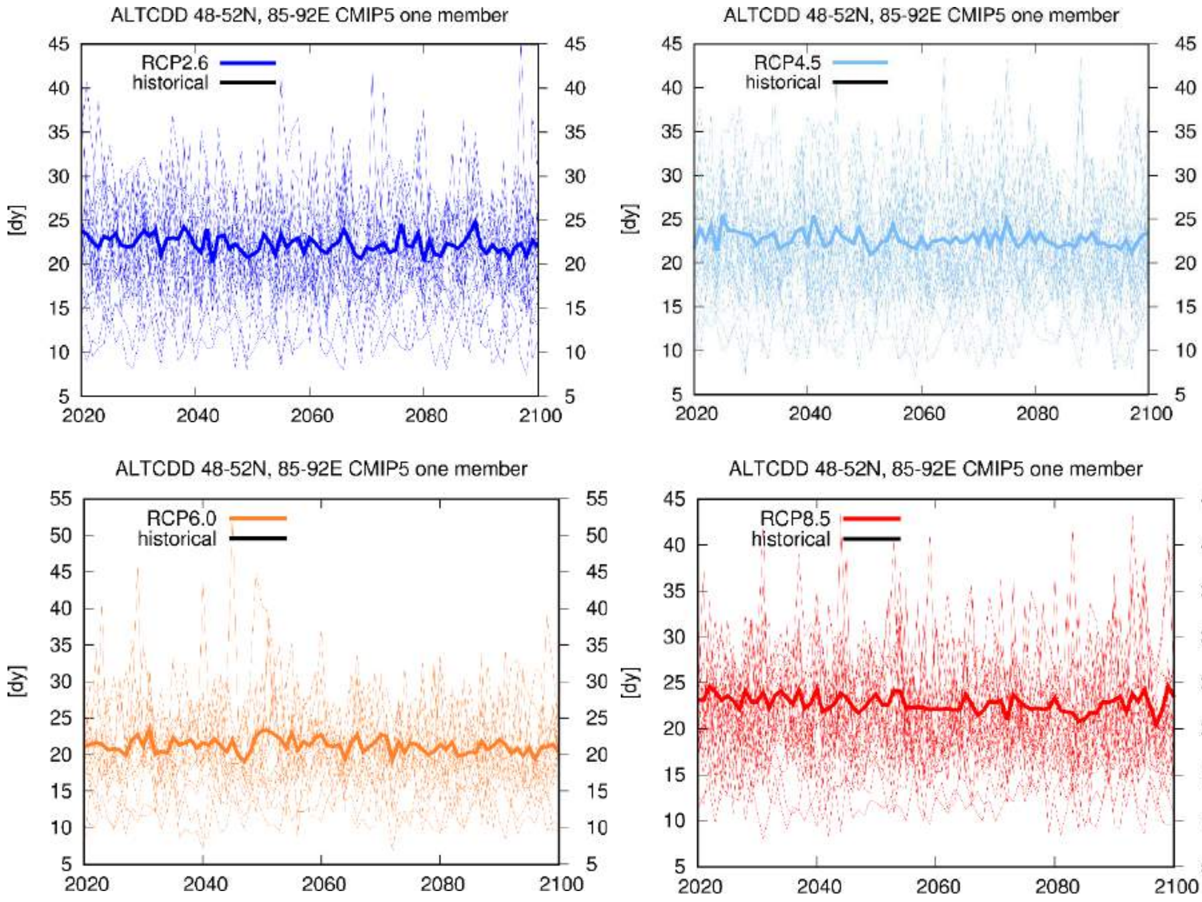


Figure 2.70. Projected future consecutive dry days (CDD) changes in Altai Mountains (KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)) (https://climexp.knmi.nl)

Thus, in the Altai Mountains, by the end of the century, the temperature is projected to increase from 0.5^{0}C (RCP 2.6) to 5^{0}C (RCP 8.5), with no significant increase in precipitation (up to 0.2 mm for RCP 8.5), and the precipitation-evaporation rate will be the same. Based on projected future of temperature changes and values of phenological response to these changes, their future can be predicted. Under RCP 2.6, the temperature in Altai Mountains will increase by 0.5^{0}C, respectively, the phenological dates will shift by 0.9 days, and with RCP 8.5, the temperature will shift by 5^{0}C, and the dates by 9 days. The temperature increase at RCP 8.5 to 5^{0}C will be by 2100 in Altai Mountains in the warmest daily and on warmest nights. But, the number of cold days and nights will decrease and the number of warm days and warm nights to 2100 for RCP 8.5 will increase by 40-45%. At the same time, the wettest day can increase by 5 mm/day at RCP 8.5 and daily intensity index will be an increase of almost 50 mm/year by 2100.

Measures to adapt the local population to natural changes

The first Russian project of UNESCO Geopark "Altai" was established by the Decree №461 of the Altai Republic on December 31, 2015. Its management was entrusted to The State Budgetary Institution of the Republic of Altai "The center of the tourism and entrepreneurship development of the Altai Republic". The project of Geopark "Altai" is located on the territory of the Kosh-Agach, Ongudai and Ulagan regions of the Altai Republic with an area of 14,500 km^2, the Geopark is defined as "tourist and recreation zone, where the objects of geological heritage are part of an integrated concept of conservation, education and sustainable development of the territory, which traced the close relationship between geodiversity, biodiversity and culture, and between tangible and intangible heritage of the Altai Republic".

According to the definition of UNESCO, the Geopark is a territory, geological objects of which are the main part of the unified concept of preservation of natural heritage, education and economic growth strategy of the region. The activity of the Geopark UNESCO is aimed at three main objectives: conservation of the geological heritage of the territory, popularization of geological and ecological knowledge and achievement of gradual but constant improvement of the quality of life of the population of the territory.

The popularization of the scientific knowledge about transformation of the natural landscapes is achieved with the interaction with the locals through scientific informational events, organized in the tourist information centers, and promotion of scientific research in the Geopark. The activities of the Geopark and its tourist information centers are aimed an improving of the socio-economic situation of the local population. Interaction of tourist information centers of the Geopark, local residents and local authorities allows solving social and economic problems of the area.

We developed and applied research program Past Present Future for monitoring and research of dynamically changing landscapes of the Geopark “Altai” in the framework of the project "Climate transformation of the Mongolian and Siberian Altai", carried out with the support of the Fund Asia-Pacific Network for Global Change (APN). The program Past Present Future provides monitoring of actively changing geosystems and geographical objects in order to identify and assess threats to natural attractions and the local population. As a part of the work on the APN project. This program implemented using the geographic information analytical system, which is created for studying of landscape changes. And also program includes working with indigenous people through the tourist information centers of the Geopark.

There has been significant transformation of landscapes expressed in the reduction in the area of nival zone and changing of the areas of the lakes in different landscape zones, the emergence and change of cryogenic landscapes (the appearance of mounds of swelling, polygons, frost cracking, cryogenic landslides, intensification of the processes of solifluction).In general, there is an uplifting of all landscape zones. The landscape changes due to changing climate.

As part of the Past Present Future program, we studied the attitude of local residents to the current changes in the natural environment. Climate-related changes in landscapes were noticed by local residents and affected their economic activities. We conducted a survey of the population of Kosh-Agach district engaged in tourism and agriculture (Figure 2.71, 2.72). The survey involved 157 people. One hundred percent of respondents noted climate change, expressed in a significant cooling of the winter and summer periods, but, at the same time, seventy-three percent of respondents noted the warming of the climate in the off-season. The majority of the respondents (sixty-eight percent) reported an increase of the precipitation observed by residents over the past five years in summer and winter periods. In addition, the vast majority of people (eighty-two percent) indicated that the landscapes are changing significantly, namely, residents note changes in riverbeds, the appearance of landslides, subsidence. Such phenomena have a negative impact on the work of the district's farms, however, the majority of respondents (ninety-one percent) note that it is difficult to adapt to climate and landscape changes. The majority of local residents suffer material losses due to the ever-changing natural environment, mainly, due to the destruction of infrastructure and changes in grazing conditions (Figure 2.73).

Figure 2.71. Questionnaire of local farmer Metreeva Tamara 55 years old about climate-related changes in the landscapes by researcher assistant Korf Ekaterina in July of 2019.

Figure 2.72. Questionnaire of the local resident and director of tourist camping Ayabas M. about climate change in Altai Mountains by researcher assistant Korf Ekaterina in July of 2019.

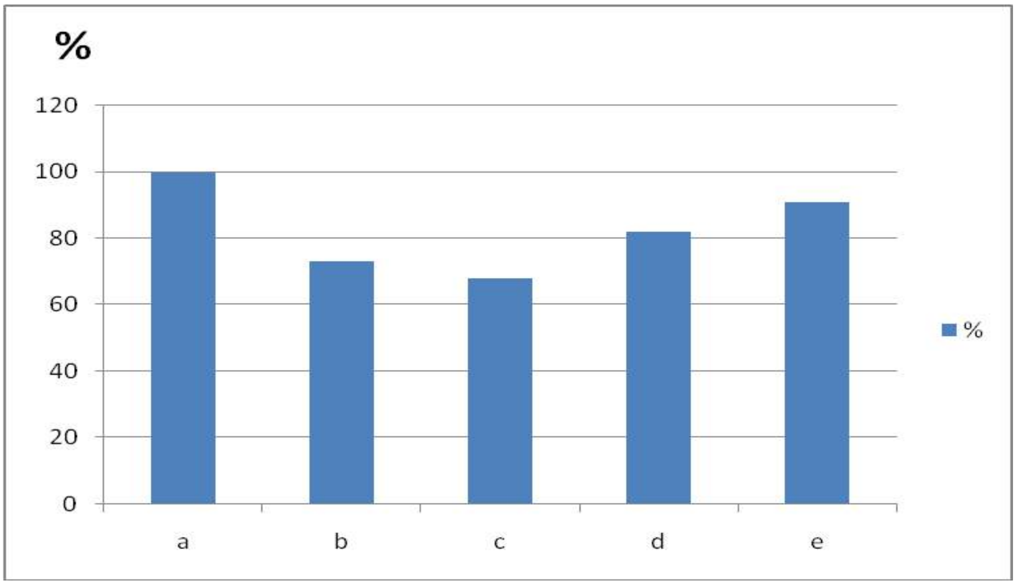


Figure 2.73. The results of the questionnaire: a. respondents noted climate changing b. respondents marked the warming of the off-seasons c. respondents marked an increase of the precipitation d. respondents marked that the landscapes are changing significantly e. respondents marked that it is difficult to adapt to the climate changes.

The main traditional occupation of the residents of the Kosh-Agach district of the Altai Republic and Mongolian Altai is extensive cattle breeding, in this regard, the level of life of the population depends on the state of pastures. We recommended to the locals to make hay reserves in case the usual places for grazing become inaccessible in order to reduce the material losses associated with the influence of climatic factors on the state of pastures. Also it is extremely important to take into account possible changes in the landscape before the designing new buildings and engineering structures, in this regard, local governments and residents are encouraged to keep in touch with scientists engaged in the study of such processes to choose the place and method of construction.

The latest scientific information on landscape changes caused by climate change is brought to the population of the region through the tourist information centers of the Geopark, which are the best and effective way to notify residents and prepare them for changes in the natural environment. Thus, the scientific data obtained during the APN project on climate-related transformation of landscapes, threats to people and their economy associated with them, and measures to prevent and reduce material losses, were distributed through the tourist information centers of the Geopark "Altai", which allowed residents to respond promptly and clearly to external changes and be ready for them. In addition, we have developed educational tours for Geopark:

a. to the glaciers of the Altai Mountains in order to be able to compare with the old photos, how much the glacial cover of mountain peaks has decreased due to climate warming
b. in the traditional mountain village of Kokorya, for the study of life of the population of the Altai Republic, local traditions and practices, the main kinds of income-generating activities, all of which may be under threat due to climate change
c. to the demonstration facilities which is using new energy-efficient technologies and renewable energy sources (Kosh-Agach solar power station)

The tours programs successfully used by tourist informational centers Kizil-Chin and Tuyaryk.

Media training on climate change and its consequences in the Altai Mountains

For the most effective and rapid dissemination of information on the impact of climate change on people's lives, it is necessary to increase the level of knowledge of people who influence public opinion (journalists and bloggers). There is an educational project "Media training for young journalists and bloggers on climate change in mountain regions on the example of Altai" was developed in 2018 (Figure 3.74). 18 journalists - participants of the training from Tomsk, Barnaul, Gorno-Altaysk were selected according to the previously announced competition. According to the project, the participants were selected only from mountain areas, where people are interested in covering the problems of climatic changes in the nature. Media training was held in Tomsk from 15 to 18 October of 2018.

Participants were provided with the latest scientific information on the problem of climate change and its consequences globally and for the Altai. Journalists learned about the possibilities of mitigating human impact on the climate, and were able to see clearly that such technologies are already being implemented in the mountainous regions of Altai. The journalists prepared and published materials on climate change and its consequences in the Altai Mountains as a result if the training. The reporting works of the participants of the media training differed in a much deeper understanding of the topic compared to their previous works. They used new unusual methods of presenting the material, as well as all the information and recommendations that bloggers have learned during the training.

Figure 3.74. Participants of Media training on climate change and its consequences in the Altai Mountains in October of 2018 in Tomsk

The results of the project showed that the chosen format of training allows journalists to become more familiar with the problem and to significantly improve their professional skills in the preparation of materials on environmental topics.

Thus, the latest scientific information related to climate change, its effects and measures to prevent associated with it losses, brought to the residents of the Altai Mountains by two effective ways: through the tourist information center of the Geopark "Altai" and through journalists and bloggers.

Conclusions

The Planetary climate experienced significant changes during the 20th century. Global changes consist in raising the main characteristic of the Earth's climate - global temperature. Modern climatic changes are clearly demonstrated in all regions of the Earth. The average air temperature has increased by 0.74 °C, since the beginning of the 20th century, and about two-thirds of this growth has occurred since the 1980s. Each of the last three decades was warmer than the previous one. The air temperature was higher than in any previous decade, since 1850. (Washington, D. C, 2011). Warming was accompanied by climatic anomalies everywhere, as a result of which regional climates underwent significant changes, which was most clearly expressed by the beginning of the XXI century. The analysis of climatic changes (temperature and precipitation) in Altai Mountains showed step change points, namely a significant temperature increase in 1996 and precipitation in 1980. The most significant increase in temperature when comparing two intervals (1957-1995 and 1996-2017) occurred in autumn (1.28^{0}C) and spring (1.13^{0}C), while for annual and summer the average temperature increase was approximately the same (0.86). The maximum increase in mean precipitation from the first (1957-1979) to the second (1980-2015) period was obtained for the annual and summer (more than 25 mm), a smaller increase for spring (5 mm).

The analysis of medium-period observations showed that the average annual air temperature in Western Mongolia increased by 2.07 °C. Climatic changes have led to significant and irreversible changes in the spatial structure of the nival-glacial and cryogenic systems of the highlands of the Mongolian Altai. The area of deglaciation total increased by 37.5 sq. km, from the time of the maximum of the Litlle Ice Age (about 18 sq.km in the last 50 years) on the mountain ranges of Sutai and Tsambagarav. Landscape belts moved due to climatogenic uplifting to a height of 180-200 m in the mountain-glacial basins of the Mongolian Altai. Subglacial deposits became subaerial, under the influence of a changed climatic background, in the deglaciation zone of the ridges. The newest periglacial and limno-periglacial landsystems began to be formed on a young lithogenic basis.

The key regularities of climate-related transformation of spatial properties of different-altitude limnic systems over a half-century period of time were revealed on the basis of field studies and geoinformation analysis of remote sensing data carried out in the Great Altai. It is established that limnosystems occupying the initial and final elements of the drainage hydronets of the Great Altai are characterized by instability and pronounced asynchrony of changes in their horizontal structure. The increase of the average annual air temperature by 2.3^0 - 2.6^{0}C over a half-century period was expressed in the increase of the water areas of periglacial limnic systems to 30%, and a reduction (from 15 to 38%) of the area of drainage reservoirs. It is established that the most resistant to climatic influences are lake systems, confined to the transit elements of hydronet. In the course of the project, the causes and spatial-temporal regularities of processes of glacial debris and mudflow in the Altai mountains. The main trigger of mudflow formation in the nival zone are glacial lakes formed at the stages of active degradation of glaciation. The vast majority of such lakes are confined in front of glacial terminus and moraine complexes of the little ice age at altitudes from 2700 to 2900 m. The appearance and increase in the area of 47 glacial lakes over the past 50 years have been established on the basis of the analysis of polychronous spatial data and expeditionary studies in the three main glacial-mudflow areas. Field studies, conducted at the model site in the upper reaches of the Akkol valley (South Chuya ridge), revealed areas of progressive removal of dead ice from the body of the dam of the Akkol glacial lake. The development of this process is a potential threat and it can cause a catastrophic descent of the reservoir.The classification mapping of the aufeis types has been held for of the Chuya basin. The presence of three ice zones ranked according to the altitude position is established: ground aufeis, river and spring aufeis, preglacial aufeis. The dynamics of changes in the areas of aufeis of the Chuya basin was established since 1987 to 2018 with the help of GIS analysis of polychrome remote sensing materials.The Analysis of geothermal monitoring data for the period 2009-2019 showed a steady warming (by 0.3 – 0.4°C) and an increase of the thickness (by 20-25%) of the active layer of permafrost of the Greater Altai. Degradation of the permafrost zone caused the activation of cryogenic landslides, subsidence and thermokarst. Studies have found that climatic changes in recent centuries have led to significant and irreversible changes in the spatial structure of the nival-glacial landscapes of the highlands of the Mongolian Altai. The total area of deglaciation of the Sutai, Tsambagarav and Sair Uul massifs in the Western Mongolia increased by 48. 5 sq. km and, the major sites of glaciation in the Russian Altai (Katunskiy, Severo-Chuyskiy, South-Chuysky ranges) for the half of century increased by 175 sq. km. since the maximum little ice age (about 24 sq km falls on the last 50 years). The glacial area of the Sair Uul massif has decreased by 50 per cent since 1968. The magnitude of climate uplifting landscape zone in the mountain-glacial basins of the Great Altai reached 180-200 m. The subglacial deposits passed into the category of subaeral deposits in the belt of deglaciation of ridges under the influence of the changed climatic background. The newest periglacial and limno-periglacial landscapes began to form on the young lithogenic basis.

During the implementation of the project, a set of information and educational measures aimed at reducing the risk and vulnerability of the population of the Russian and Mongolian Altai from natural hazards caused by climate change in recent decades has been developed and tested.

Future Directions

In the course of the project, the causes and spatial-temporal regularities of processes of glacial debris flow in the Altai Mountains. The main trigger of mudflow formation in the nival zone is glacial lakes formed at the stages of active degradation of glaciation. The vast majority of such lakes are confined in front of glacial terminus and moraine complexes of the little ice age at altitudes from 2700 to 2900 m. These hazardous lakes will be the next object of our researches.

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http://meteo.ru/english/data/

http://namem.gov.mn/eng/

http://etccdi. pacificclimate.org/software.shtml

https://climatedataguide.ucar.edu/data-type/atmospheric-reanalysis

https://www.ipcc.ch/

https://www.climdex.org/about/project/

https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html

https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim

https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets

https://www.climdex.org

https://climexp.knmi.nl

Appendix

Appendix 1.1 Inception Workshop, Khovd, Mongolia, 15-17 Sept 2017

APN CRRP project "Climatogenic transformation of the alpine landscapes in Mongolian and Russian Altai"

Inception Workshop:

Climatogenic transformation of the alpine landscapes in

Mongolian and Russian Altai

Khovd, Mongolia, 15-17 Sept 2017

Background:

Climate change affect the world's mountain regions and may jeopardize the important services (drinking water supplies, hydropower generation, agricultural suitability) provided by the mountains. This is especially important for mountain areas located within the boundaries of several countries, for example, the Altai Mountains that stretch over four countries (China, Kazakhstan, Mongolia and Russia). Furthermore, research addressing the relations between climate changes and a dynamic alpine landscape is currently becoming more relevant in connection with the need for reliable predictive conclusions. The goal of this project is a quantitative estimation of climatic changes (past and present) in the Mongolian and Russian Altai and their reflection in spatio-temporal changes of the high-mountain glacial landscapes and the identification of irreversible changes in their morphological structure. Project results are the quantification of relations between climatic parameters and changes in landscape structure of mountain glacial basins, instrumental and remote monitoring of the state of the nival-glacial and cryogenic landscapes, the dynamics of slope processes and detailed data observations of snow, soil and vegetation of the test locations. These findings will be the basis for the development of regional policies and of intergovernmental cooperation, taking into account the interest of local communities.

Objectives

The main objectives of the workshop are:

- Review the project goals and expected outcome.
- Review and confirm project key sites
- Finalize the project methodology and plan of investigation

Workshop program and agenda

Date: 15-17 September 2017

Place: Khovd state university, Main building, Lecture Hall, Khovd, Mongolia.

Date/Time	Events name /topic	Moderator
15 Sep 10^{00}-10^{10}	The opening speech	**Dr. V. sainbayar** Rector Khovd State university Dr. D. Otgonbayar Leader of the project
10^{10}-11^{10}	Review the project goals and expected outcome	Dr. D. Otgonbayar Leader of the project Dr. Borodavko P.S (TSU, IMCES RAS, Russia)
11^{10}-12^{00}	Discussion	
12^{00}-13^{00}	Lunch	
13^{00}-14^{00}	Presentation of project fieldwork photo ‘’Climatogenic transformation of the alpine landscapes in Mongolian and Russian Altai’’ Mr. Alexey Litvinov	
14^{00}-16^{00}	Exchange knowledge, information and discussion	

16 September 2017

Date/Time	Events name /topic	Moderator
10^{00}-10^{10}	Review and confirm project key sites	Dr. D. Otgonbayar Leader of the project Dr. Borodavko P.S (TSU, IMCES RAS, Russia)
10^{10}-11^{10}		
11^{10}-12^{00}	Discussion	
12^{00}-13^{00}	Lunch	
13^{00}-14^{00}	Finalize the project methodology and plan of investigation Project team	
14^{00}-16^{00}	Exchange knowledge, information and discussion	

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Appendix 1.2 Thematic Workshop, Mongolia

APN CRRP project "Climatogenic transformation of the alpine landscapes in Mongolian and Russian Altai"

Thematic Workshop:

Remote sensing monitoring and GIS analysis of environmental change in key high mountain regions of Mongolian Altay

Khovd, Mongolia, 15-17 April 2018

Background:

This workshop provides participants with an introduction to the principles of geographic information systems (GIS) and remote sensing, and the application of these techniques to the monitoring of environmental change. The first part of the workshop focuses on GIS, where the structure and format of GIS data, data input and transformation, database compilation, and the use of search criteria and spatial modeling to carry out suitability mapping are examined. In remote sensing, the focus is the capture and processing of satellite images, and how data from various satellite platforms are used in the project. The workshop is strongly computer-based, and participants will gain experience in the use of Microdem/Terrabase - free GIS and remote sensing software.

a. Learning outcomes

On successful completion of the course participants will be able to:

1. Understand the principles of remote sensing and digital image processing;
2. Understand the principles of geographic information systems (GIS);
3. Gain experience in the applications of remote sensing and GIS to solving problems of environmental sciences.
4. Gain experience in the use of image processing and GIS software.

b. Content

1. Principles of aerial photography and satellite remote sensing
2. Sensor types and platforms used
3. Digital image processing
4. Remote sensing applications in the environmental sciences
5. Principles of GIS
6. Data collecting, input, processing and manipulation
7. Search and querying and spatial modeling
8. Terrain analysis for glaciological and geomorphologycal investigations

Workshop program and agenda

Date; 10-13 April 2018

Place; Khovd state university, Main building, Lecture Hall Kovd, Mongolia.

11 April 2018

Date/Time	**Events name /topic**	**Moderator**
10^{00}-10^{10}	• Principles of aerial photography and satellite remote sensing • Sensor types and platforms used	Dr. Boradavko P.S (TSU, IMCES RAS, Russia)
10^{10}-11^{10}	Review the project goals and expected outcome	Dr. D. Otgonbayar Leader of the project Dr. Boradavko P.S (TSU, IMCES RAS, Russia)
11^{10}-12^{00}	Discussion	
12^{00}-13^{00}	lunch	
13^{00}-14^{00}	Presentation of project fieldwork photo ''Climatogenic transformation of the alpine landscapes in Mongolian and Russian Altai''	
14^{00}-16^{00}	Exchange knowledge, information and discussion	

12 April 2018

Date/Time	**Events name /topic**	**Moderator**
10^{00}-10^{10} 10^{10}-11^{10}	• Digital image processing • Remote sensing applications in the environmental sciences	Dr. Boradavko P.S (TSU, IMCES RAS, Russia)
11^{10}-12^{00}	Discussion	
12^{00}-13^{00}	lunch	
13^{00}-14^{00}	• Principles of GIS • Data collecting, input, processing and manipulation Finalize the project methodology and plan of investigation	
14^{00}-16^{00}	Exchange knowledge, information and discussion	

Participants list

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Kebesh	Moldir		Geography and Geology	Teacher of Geography (Grad)-I
Holaman	Mahuza		Geography and Geology	Teacher of Geography (Grad)-I
Rizabek	Sandigish		Geography and Geology	Teacher of Geography (Grad)-I
Rentsen-Ochir	Bayantogtoh		Geography and Geology	Teacher of Geography (Grad)-I
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Russian federation

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Appendix 1.3 Inception Workshop, Tomsk, Russia, 08 November 2018

APN CRRP project "Climatogenic transformation of the alpine landscapes in Mongolian and Russian Altai"

Inception Workshop:

Climatogenic transformation of the alpine landscapes in

Siberian Altai

Tomsk, Russia, 08 November 2018

On November 8, a scientific workshop «Climatogenic transformation of the alpine landscapes in Siberian Altai» was held at Tomsk State University (TSU). It was initiated by Institute of Monitoring of Climatic and Ecological Systems of the Siberian Branch of the RAS (IMCES SB RAS), which is part of the SecNet. Pavel S. Borodavko, Associate Professor at Faculty of Geology and Geography of TSU, Head of the Laboratory for Self-Organization of Geosystems (IMCES) was the representative of IMCES. Undergraduates of Faculty of Geology and Geography and researchers at IMCES were the participants of workshop.

First of all, the organizers presented their research project conducted in Mongolia for sampling and monitoring. Within the framework of this project, researchers carried out a series of expeditions.

Then the participants of workshop discussed this project. The methods used by researchers were interesting for the scientists of TSU's BIOCLIMLAND Center of Excellence. TSU's researchers use the similar methods in their projects. Thus, TSU and IMCES once again highlighted common scientific interests in field of research and educational activities. Colleagues from IMCES ready to work with undergraduates of the autonomous master's program (AMP) of TSU "Siberian and Arctic Studies". It is a good opportunity for students to gain expert knowledge.

At the results of the workshop, participants reached the agreements:

1. Organization of a research project involving foreign partners and applying for funding through the APN (Asia-Pacific Network for Global Change Research).
2. Organization of a regular joint scientific workshop of TSU and IMCES.
3. Involving employees of IMCES to participate in the AMP «Siberian and Arctic Studies» of Trans-Siberian Scientific Way Research Center.

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Георазнообразие

Appendix 1.4 Inception Workshop, Bayan Olgii, Mongolia, 19-20 December 2018

APN CRRP project "Climatogenic transformation of the alpine landscapes in Mongolian and Russian Altai"

Inception Workshop:

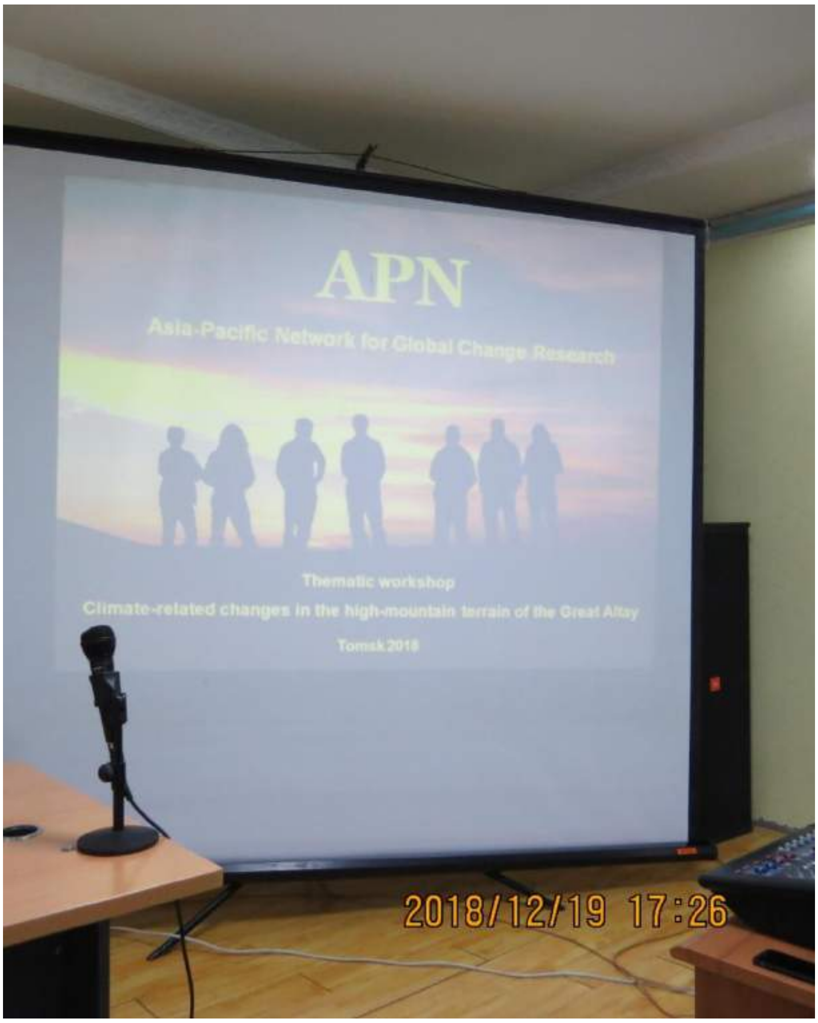
Reducing of negative consequences and adaptation to climate changes for highland of Great Altai

Bayan Olgii, Mongolia, 19-20 December 2018

In the face of Climate warming, most glaciers of Altai Mountains have been retreating, resulting in an increase in the number and size of dammed lakes are generated by moraines after the retreat of glaciers which block the drainage of rivers. The failure of naturally dammed lakes is the source of the largest floods in Earth's history; they exceed precipitation caused events by magnitudes. Natural dams consist of glacier ice, moraines, landslide deposits and block the drainage of rivers to lakes of variable size and duration. The failure of the dams can release large amounts of accumulated water abruptly by outburst floods without prior warning. Due to the current global retreat of most mountain glaciers it might be expected, that the number of outburst floods related to the failure of naturally dammed lakes could even increase. Disastrous mudflows generated by GLOFs are a frequent phenomenon in the Altai region. Single events are described, while systematic investigations, spatial differentiations and assessment of hazardous lake are missing for most parts.


2018/12/19 17:59


2018/12/19 18:55


APN
Asia-Pacific Network for Global Change Research
Thematic workshop
Climate-related changes in the high-mountain terrain of the Great Altay
Tomsk 2018
2018/12/19 17:26

Participants list

No	Name of participants	Organization	Position	E-mail
1.	Pavel S. Borodavko	IMCES SB RAS	Leading researcher	bor@ggf.tsu.ru
2.	Otgonbayar Demberel	Khovd state university	Lecturer	icecore_ot@yahoo.com
3.	Beket Uliqpan	Branch of Khovd state university	Professor Dr	beketu@yahoo.com
4.	Serjuma Bafar	Department of the Hydrometeorological and environment center of Bayan-Ulgii	Engineer	Serjuma_91@yahoo.com
5.	Jura	Department of the Hydrometeorological and environment center of Bayan-Ulgii	Engineer	
6.	Amanbai	Department of the Hydrometeorological and environment center of Bayan-Ulgii	Engineer	
7.	Bulganbaatar	Department of the Hydrometeorological and environment center of Bayan-Ulgii	Engineer	
8.	Nagashbek	Department of the Hydrometeorological and environment center of Bayan-Ulgii	Engineer	Beckstar_365@yahoo.com
9.	Serikjan	Department of the Hydrometeorological and environment center of Bayan-Ulgii	Engineer	Serikjan0004@yahoo.com
10.	Meduhan	Protected area of Mongolian Altai mountain	Director	Medukhan@yahoo.com
11.	Altingul	Branch of Khovd state university	Student	
12.	Ainek	Branch of Khovd state university	Student	
13.	Zolbayar Jargalsaikhan	Khovd state university	Teacher	
14.	Kinalgan Jilkaidar	Khovd state university	Director	

Appendix 1.5 Inception Workshop, Belokurikha, Russia, 14 June 2019

Asia-Pacific Network

Collaborative Regional Research Program

Project «Climatogenic Transformation of the Alpine Landscapes in Mongolian and Russian Altai» (CRRP2017-05MY-Demberel)

Workshop «**Understanding the regional pattern and projected future climate changes in Mongolian and Siberian Altai**»

Belokurikha, Russia, 14 June 2019

The main objectives of workshop:

- Climate change in Mongolian and Russian Altai
- Biodiversity in aquatic ecosystems of Siberian Altai and its response in various paleoarchives
- Pollen spectra as an indicator of climate change in Altai
- Projected future climate changes (scenarios)
- Impact of climate change on key sector and associated risks

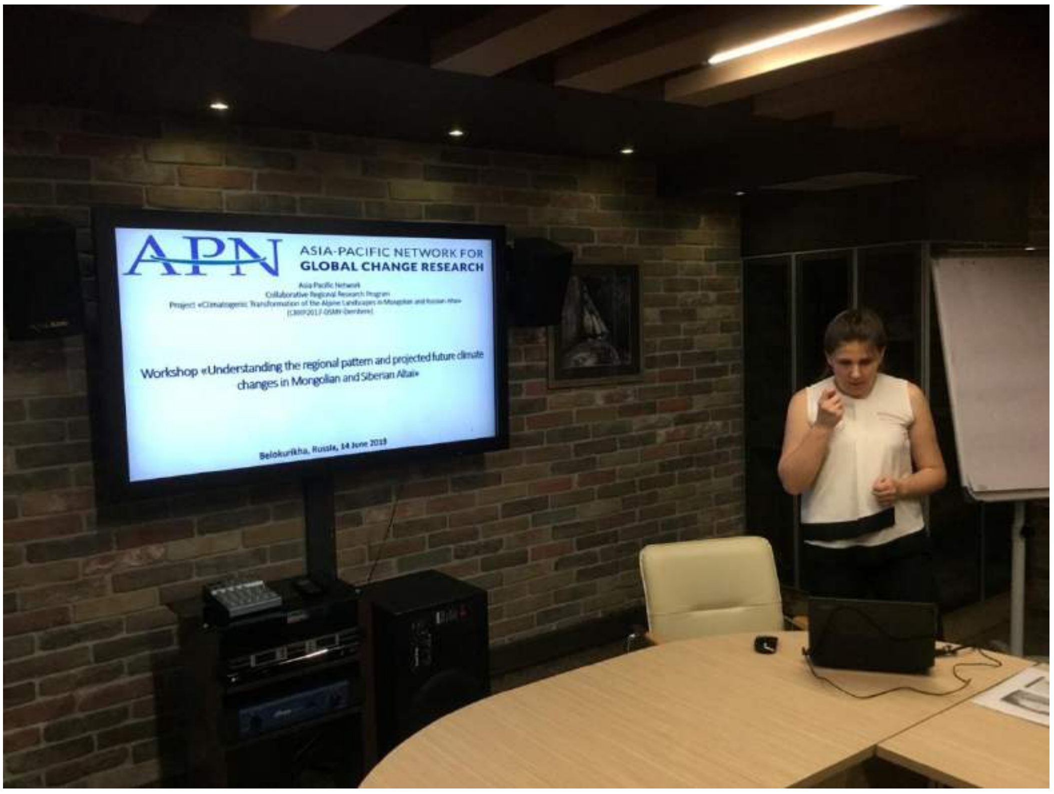
14 June, 2019
(Business hotel "Russia", 34, Slavskogo St., Belokurikha, Russia)

11:00-12:30 Workshop

11:00-11:10 Opening. Dr. Natalia Malygina (IWEP SB RAS) and Dr. Otgonbayar Demberel (Hovd University)
11:10-11:30 «Climate change in Mongolian and Russian Altai» Dr. Natalia Malygina (IWEP SB RAS)
11:30-11:50 «Biodiversity in aquatic ecosystems of Siberian Altai and its response in various paleoarchives» Dr. Elena Mitrofanova (IWEP SB RAS)
11:50-12:10 «Pollen spectra as an indicator of climate change in Altai» PhD. Natalia Kuryatnikova (IWEP SB RAS)
12:10-12:30 «Projected future climate changes (scenarios)» Dr. Natalia Malygina (IWEP SB RAS)
12:30-13:30 Diner
13:30-15:00 Workshop
13:30-14:00 «Impact of climate change on key sector and associated risks» Dr. Natalia Malygina (IWEP SB RAS)
14:00-14:40 Discussion
14:40-15:00 Closing Dr. Natalia Malygina (IWEP SB RAS) and Dr. Otgonbayar Demberel (Hovd University)

Participants list

№	Surname	First name	Gender	Organisation	Position
1.	Demberel	Otgonbayar	Female	Khovd state university	Lecturer
2.	Dugeree	Odonchimeg	Female	Khovd state university	Lecturer
3.	Batbayar	Davaa-Erdene	Male	Administration of Khovd aimag	Politician
4.	Purevbaatar	Myagmartuvshin	Male	Audit office at pre administration of Khovd aimag	Senior specialist
5.	Erdene	Batmonkh	Male	Branch of State bank in Khovd	Economist
6.	Magsarjav	Jargalsaikhan	Female	local-owned enterprise Shim Us	Head of water quality laboratory
7.	Shileg	Batzorig	Male	Medicine and Health organization of Khovd aimag	Driver
8.	Budee	Nyamdelger	Male	Administration Khovd aimag	Economist




Altai Mountains

List of conferences attended sharing APN project results:

1. MODERN PROBLEMS OF GEOGRAPHY AND GEOLOGY: TO THE 100TH ANNIVERSARY OF THE OPENING OF A NATURAL BRANCH IN TOMSK STATE UNIVERSITY: IV All-Russian Scientific and Practical Conference with International Participation, Tomsk, October 16-19, 2017

Borodavko P.S. The newest reliefogenesis of the Great Altai highlands

2. NATURAL CONDITIONS, HISTORY AND CULTURE OF WESTERN MONGOLIA AND ADJACENT REGIONS XIII international scientific conference Barnaul, 20-22 September 2017

Borodavko, P. S., Litvinov A. S., Otgonbayar D. Thermokarst limnogenesis of the Mongolian Altai highmountains

Borodavko P. S, Otgonbayar D., Redkin A. G., Volkova E. S., Otto O. V., Melnik M. A., Litvinov A. S. Climate-related transformation of the nival-glacial systems of Sutai massive (Mongolian Altai)

3. GEOGRAPHY ECOLOGY ALTAY: SAVE AND SUSTAINABLE DEVELOPMENT, Gorno-Altaisk, 27-28 October 2017

Otgonbayar D Modern Glaciation ridge Sutai (Mongolian Altai)

4. CLIMATE CHANGE AND GLACIER, Ulgei. Mongolia, 25-27 August 2018

OTGONBAYAR D, BORODAVKO, P. S., LITVINOV A. S CLIMATE RELATED CHANGES IN THE ALPINE LANDSYSTEMS MONGOLIAN AND RUSSIAN ALTAI

5. ECOSYSTEM CENTRAL ASIA: RESEARCH, SAVE AND USING MANAGEMENT , Ulaangom Mongolia, 03-05 August 2018

Borodavko, P. S., Otgonbayar D., Litvinov A.S. Modern relief genesis in Cryolythozone Great Altay

6. WATER RESOURSE PROBLEM WESTERN REGION, Khovd. 17 May 2018

Dr. Otgonbayar D ''Climate and Landscape transformation of Mongolian Altai''

7. CONFERENCE OF TEACHERS AND RESEARCHERS OF KHOVD STATE UNIVERSITY, KHOVD. 27 APRIL 2018

Dr. Otgonbayar D., Climate –related changes in the high mountain terrain of Russian and Mongolian Altai

8. INTERNATIONAL CONFERENCE AND YOUNG SCIENTIST SCHOOL ON ENVIRONMENTAL OBSERVATION, MODELING AND INFORMATION SYSTEMS ENVIROMIS 2018, Tomsk, Russia, July 5–11, 2018.

Dr. Borodavko P. S., Volkova E. S., Melnik M. A., Litvinov A.S The impact of climate change to the alpine geomorphic system

9. WORKSHOP SUSTAINABLE ENERGY AND CLIMATE CHANGE IN RUSSIA: POLICIES, DISCOURCES AND NARRATIVES, Nottingham, United Kingdom, 28-30 November 2018

Korf E.D. Renewable energy sources and sustainable tourism in mountain areas: the case of geopark Altai

Litvinov A. S. Permafrost of the highlands in a changing climate: risks and prospects for the local communities of the Altai mountains.

10. **WORKSHOP ON HUMAN-ENVIRONMENT INTERACTIONS IN THE MIDDLE-HIGH LATITUDES AND HIGH ALTITUDES OF EURASIA" LANZHOU, CHINA 25-26.MAY 2019**

Dr. Otgonbayar D Climate change and glacier dynamics in Mongolian Altay

PHOTO DOCUMENTATION OF THE CONFERENCES

GEOGRAPHY ECOLOGY ALTAY: SAVE AND SUSTAINABLE DEVELOPMENT, Gorno-Altaisk, 27-28 October

Beginning of the conference

Reporting Otgonbayar D

CLIMATE CHANGE AND GLACIER , Ulgei. Mongolia, 25-27 August

Participants of conference all 150

Participants from Khovd university

Report of project leader Otgonbayar D

ECOSYSTEM CENTRAL ASIA: RESEARCH, SAVE AND USING MANAGEMENT , Ulaangom Mongolia, 03-05 August

Participants of the conference

Report of project team Dr. Borodavko P.S., Otgonbayar D

Project team with the Advisor to the Minister of Nature and Tourism Mongolia

We were introducing our project results and future plan to Minister Advisor

"WORKSHOP ON HUMAN-ENVIRONMENT INTERACTIONS IN THE MIDDLE-HIGH LATITUDES AND HIGH ALTITUDES OF EURASIA" LANZHOU, CHINA 25-26.MAY 2019

Prof. Otgonbayar participated by the topic ‘’Climate change and glacier dynamics in Mongolian Altay”’

Asoc.Prof Munkhbayar “Archeological evidence of prehistoric human activities in the Altay region of Western Mongolia”

International Workshop «Sustainable Energy and Climate Change in Russia: policies, discourses and narratives». Nottingham, UK, 28-30 november 2018

Fieldtrip to the key locations in the Russian Altai.

Aktru valley, North Chuya Range

Field and research assistant Alexey Litvinov checks the installed meteo equipment in the Aktru valley

Akkol valley, South Chuya range

Young pingo in the bottom of the Akkol valley near Beltir village.

Campsite in the upstream of the Akkol valley.


Sofiyskiy Glacier and moraine-dammed lake


Express analysis of electrical conductivity of water from the stream

Bathymetric survey of Sofiyski Lake

Mongolian Altai. Tsambagarav ridge

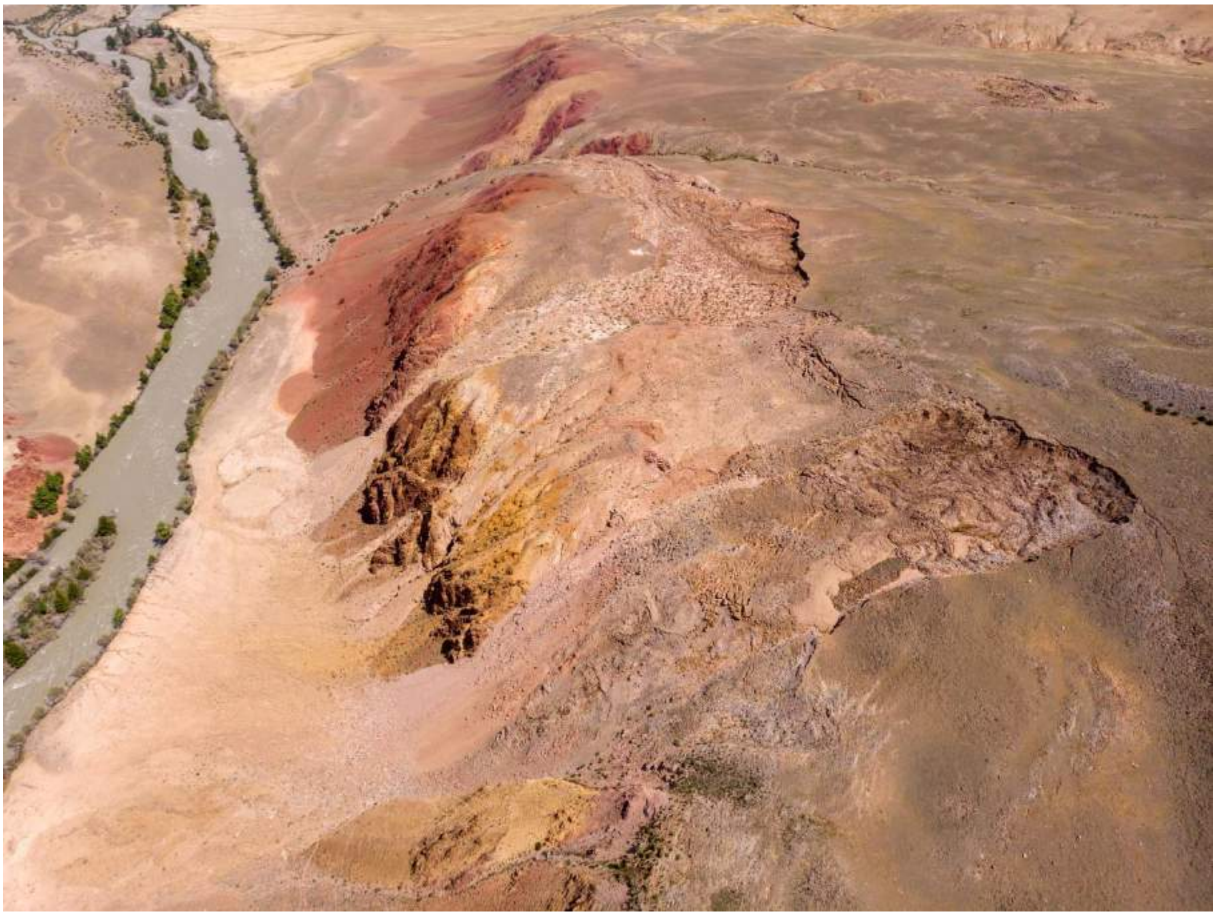
Tumurt Glacier and Tumurt Lake

Field campsite in the Ulan Asga valley

The view of Yamaat valley glaciers from the Yamaat pass

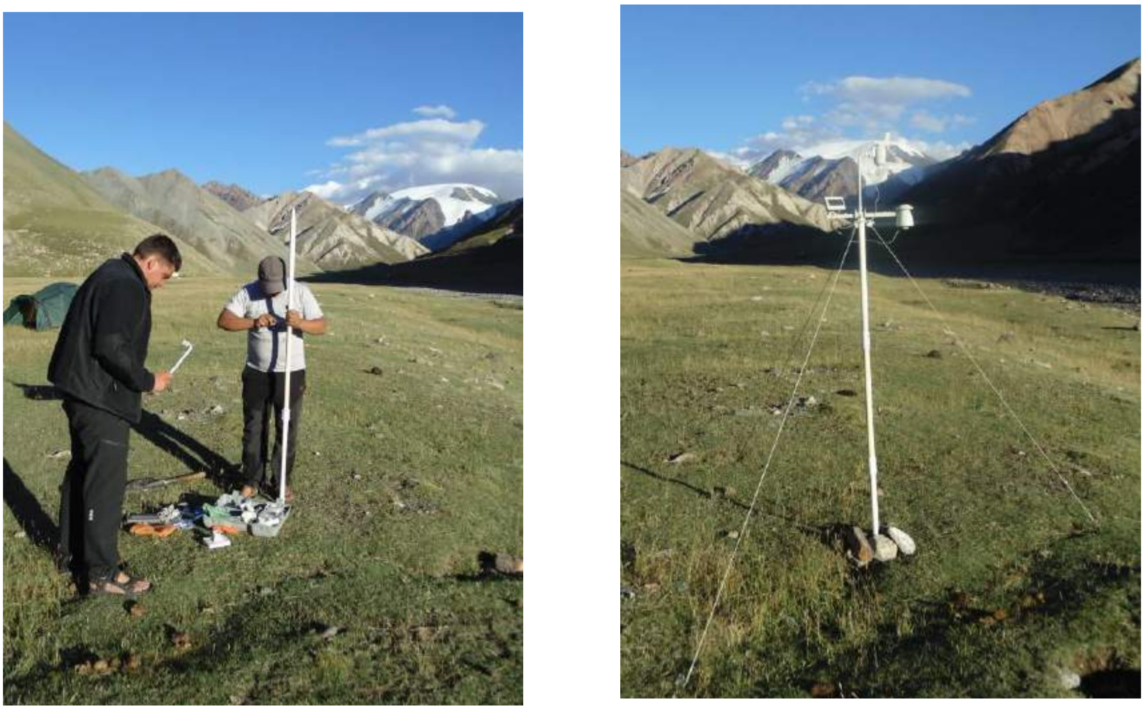
Ulan Asga glaciers

Using drone for aerial photography



Mongolian Altai. Sutai Ridge

Crossing of Hushuut River



Installing of Weather equipment. Sutai ridge.

Left tributary of Tsagan Gol River

Dr. Borodavko, LIA terminal moraine and hanging glaciers of Tsagan Gol

Bathymetric survey of Sofiyski Lake