

Regional manifestations of present climate change in the Altai, Siberia

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Abstract. This study summarizes results of investigations of present climate change in the Altai area, southern Siberia, delivered by weather stations situated at different altitudes and specific topo-geographical conditions, in terms of its feedback to local environments. The meteorological data based on long-term observations indicate an increase of regional humidity reflected by bulk annual precipitation rate in the mountain areas, where positive and negative seasonal temperature fluctuations are observed. Raising annual temperature in the Altai, following the N-S geographic transect, trigger a progressive melting of glaciers, a localized degradation of mountain permafrost in the alpine zone (> 2 500 m a.s.l.) and an increased number of frost-free days in lowlands. The associated environmental transformations include shifts in mountain biotopes: expansion of the tree-line into alpine tundra, a geo-botanical restructuring of alpine xenotheric meadows and changes in behavior of some fauna species, such as earlier arrival of migratory birds for nestling. Climate-change-linked economic effects may in long-term positively promote production in agriculture and forestry.

Keywords: climate change, Gorno Altai, Siberia, meteorology observations, biodiversity, environmental transformations

1. Introduction

The aim of investigations has been mapping of the regional present-climate-change manifestations in the Altai area (the Gorno Altai Republic of the Russian Federation) in terms of the main weather change trends and related regional environmental transformations as well as potential risks to local biota, including a biodiversity loss. Apart of standard atmospheric measurements, the main long-term observation aspects, following the topographic gradient of the Altai (300-4500 m a.s.l.), involve climato-geographic factors (melting of glaciers, degradation of permafrost, rise of snow-line) as well as bio-geographic factors (changes in the mountain biotopes, i.e. arid steppe / forest-steppe / boreal tundra-forest / alpine tundra, and restructuring of the Altai ecosystems). A modelling of a possible socio-economic feedback has been performed, particularly in respect to agricultural, forest and tourist economy. Results and implication are principally used in environmental management of protected natural areas of Gorno Altai and for a central governmental planning of sustainable development of the Gorno Altai Republic.

A series of weather stations (WS) is positioned in diverse physiogeographic areas of Gorno Altai for measurement of the standard atmospheric factors (amount of precipitation, temperature changes, wind-direction, atmospheric pressure, ground-frost and permafrost table). The WS Kyzyl-Ozek is situated in the Northern Altai (330 m), the WS Ust'-Kan in the Kanskaya Depression of the Central Altai (1037 m) and the WS Kosh-Agach in the high-mountain semi-desertic steppe of the Chuyskaya Depression of the southeastern Altai (1758 m) near the border with Mongolia. The weather databases include systematic meteorological data for the 1961- 2009 period. Comparative subsequent studies performed on a larger geographic scale in the broader Altai –Sayan Eco-Region will assess the rate of the observed precipitation increase in the mountain areas and, on contrary, the progressing rate of aridization and desertification in the lowland parkland-steppe regions.

2. Geographic location and natural setting

The Russian Altai (Gorno Altai) is the major mountain system of southern Siberia {Belukha Mt., 4506 m), adjoining in the south-east the Mongolian Altai through the Tabon-Bogdo-Ula massive (Nairamdal Mt., 4356 m) and the Southern (Kazakh) Altai in the south (3483 m). The monitored territory is characterized by a rather diverse physiography with high mountain massifs in the south and east, and open lowlands in the north and west. The Altai Mountains, the Kuznetskiy Alatau and the Western Sayan Mountains form together a major natural barrier delimiting the southern geographic margin of Siberia north of the Mongolian and Kazakh Altai and the adjoining steppes. In the north, the topography of the Altai foothills gradually passes into the North Altai Plains (200-300 m asl.) of the upper Ob Basin, representing the marginal parts of the West Siberian Lowland. Hydrologically, the area belongs to the Ob River drainage system with the Katun, Biya, Irtysh and Tom' River being the main tributaries.

The topography of the Altai alpine mountain zone (elevations > 3000 m asl) is built by major ridges of the central, eastern and southern zone (the Katun, Northern & Southern Chuya, Sailyugen and Chikhacheva Range) and high-mountain plateaus (Ukok and Chulyshman) located in the 2000-2500 m altitude. The lower relief zone (>1200 m) includes more than 50% of the Gorno Altai mountain area and represents relics of old denudation surfaces covered by more recent Pleistocene deposits derived during the past glaciations [1,2]. The geographic configuration of the mountain ranges influenced the regional atmospheric circulation over the mountains and the adjacent parkland-steppes of south-west Siberia [3,4].

The present climate is strongly continental with major seasonal temperature deviations between the northern lowlands and the southern mountains. In winter, except for the highest elevations, climatic conditions in the mountains are generally less severe than in the open northern steppes, and a microclimate prevails throughout the year in some protected locations in the Altai Mountains (i.e., in the upper Biya, Katun', Chulyshman and the lower Chuya River basins) with a relatively thin snow cover during winter. Annual temperatures as well as precipitation rate vary greatly reflecting particular topographic settings. Most of the precipitation falls on the W/NW slopes in the northern and central Altai, while the southern areas are more arid. In the Chuya Depression (1800-2000 m asl), which is one of the coldest and most continental places in the Altai, the average July temperature is +25°C, whereas the average January temperature is -33°C, but can occasionally drop to -60°C. Most of the region is underlain by perennial mountain permafrost with an active thaw layer only 30-70 m thick.

The lowland Altai vegetation is characterized by open steppe-parkland with mosaic and open birch and pine forests. Mixed southern taiga (with larch, spruce, pine, Siberian pine /*Pinus sibirica*/, fir and birch) covers most of the lower mountain zone replaced by the alpine vegetation with pine, larch and dwarf birch at higher elevations (>1500 m asl.). Semi-desert communities with admixture of plant taxa characteristic of the Mongolian steppes are found in the upland depressions of the southern Altai. The present soil cover corresponds to the zonal vegetation distribution. In the northern lowland basins and plains, steppe chernozems prevail with seasonally saturated luvisolic soils formed in more humid locations in river valleys. Kashtanozems and podzolic forest soils prevail in the lower mountain areas; thin brunisols and tundra regosols are found in the (sub)-alpine zone; and kashtanozems, brown calcareous soils or solonets appear in the high-mountain basin (Chuya and Kuray Depression) and on the upland plateaus (Ukok) [5].

The Altai represents a key area for conserving unique alpine habitats of the Central Asian mountain system. The entire region is characterized by an extreme geographic and topographic diversity, with arid steppes, southern taiga, alpine zone and upland plateauism and a strongly continental climate with hot summers and very cold winters [6]. Each of these zones includes specific biotic communities of plants and animals, many of which are threatened due to the ongoing reduction of their pristine natural mountain habitat by modern anthropogenic as well as natural factors related to climate change [7].

Present climate change variations reflect the regional physiogeographic and atmospheric conditions as well as the topographic configuration having a principal bearing to seasonality, annual temperature and precipitation rates.

3. Palaeo-climatic perceptions

Past climate changes had significantly influenced development of the broader Altai region triggered by the late Tertiary orogenesis. The marked Quaternary climatic changes are evidenced by the preserved palaeo-landscape forms in both the mountain and steppe regions, as well as by the glacial and sedimentary geology, palaeoecology and geoarchaeology proxy records indicating long-term variations in temperature and humidity. Following the generally warmer Early Pleistocene (>740 ka) climates witnessed by the distribution of deeply weathered red palaeosols, the increased continentality and relief gradient during the Middle and particularly the Late Pleistocene (>10 ka) led to establishment of the present-type forest-steppe / semi-desert during warm

stages, and the periglacial arid steppe during cold stages correlated with the glaciations in the southern Altai Mountains, and loess deposition in the northern and western foothills. The mapped glacial and high-resolution loess-palaeosol sections, and contextual environmental archaeology data from the Pleistocene occupation sites provide new evidence of a rather pronounced natural dynamics [1,8]. Spectacular glaciofluvial terraces in the principal mountain valleys indicate presence of deep ice-dammed last glacial lakes documented from other parts of the Altai that were subjected to cataclysmic drainages during deglaciations [9].

4. Biodiversity impact to climate change

The central/southern Altai region belongs to the most pristine natural areas of the World, including the Plateau Ukok being the Natural World Heritage site (UNESCO). Despite this fact and mobilized nature protection activities, a progressing environmental change and degradation of the present environments is going on as a result of complex climatic processes related to global warming causing shifts in local ecosystems. These reflect an increased solar radiation and a reduced annual precipitation in some parts of the Altai, contributing to restructuring of the local biotic zones and exposing pressure to some flora and fauna species. Raising summer temperatures also lead to the regional aridization, permafrost degradation, but also to an increased ablation of the retreating mountain glaciers, reaching maximum up to 20 m *per* year on the Southern Altai Range [10].

The present climate change studies in Gorno Altai have followed the objective of establishment of an integrated and sustainable programme on the Altai nature preservation, respecting the local aspects, as well as the social-economic needs of the area. The main goal is to promote a system of effective land use in balance with conservation of globally significant species of plants and animals endemic of mountain regions in their pristine natural habitat [11]. This integrated multi-disciplinary study and management approach includes a synthesis of the existing information and new geographical, ecological, biological as well as social and cultural studies linked to the present climate change feedback to the steppe and mountain Altai ecosystems [12]. The long-term aims of multidisciplinary investigations focus on the extent of the current natural degradation and present anthropogenic threats in order to determine the main aspects and priorities for protecting the remaining and biologically rich habitats and intact, although potentially fragile, mountain ecosystems. Modeled analyses of the regional / national nature park and nature reserve GIS databases can further redound to creation and a subsequent implementation of an uniform trans-border biodiversity protection strategy based on an effective assessment of the specific mountain and parkland-steppe ecosystems of the broader Altai territory subjected to present climate change [13].

5. Present climate development in the Altai – summary

Summary data from the meteorological observations:

- Seasonal fluctuations of precipitation throughout the Gorno Altai North-South geographic transect (Fig. 1).
- Average annual air temperature and precipitation at the Kyzyl-Ozek WS site, northern Altai (Fig. 2).
- Five-year temperature fluctuations at the Gorno Altai weather stations during the period 1961-2005 (Fig. 3)
- Correlation of average seasonal air temperature (°C) for the periods 1961-2005 and 2001-2005 (Fig. 4)

6. Conclusion

The long-term atmospheric meteorological observations at the weather stations located in the most present-climate-change-diagnostic geomorphic setting coupled with environmental studies allow the following conclusions:

- Landscape response to climate warming is more distinct in the high mountain zone. The upper tree line has moved to the tundra zone. Young growth of larch and cedar forests has come up from the height of 2000 – 2200 m to the height of 2400 – 2500 m.
- The moisture regime and regional circulation has increased under influence of the ongoing mountain glacier melting (up to 20 m per year), also reflected by a buried ice and permafrost degradation. Dwarf plant species get bigger forms, and early alpine meadow species developed in a full cycle including blooming and fruiting.
- The Gorno Altai region shows a positive trend of high precipitation where positive, and negative seasonal temperature fluctuations can be observed.
- Because of an earlier spring season, the average time of arrival of birds (including close and distant migrants) to their nesting sites has shifted to earlier periods.
- A decrease in the number of days with a stable snow cover and an increase in the length of a frost-free period have influenced the biotic structure and agricultural conditions considerably.

- Mountain steppes are being gradually transformed into semi-desertic steppes due to a progressing aridization.
- A complex evaluation of the main natural (including soil cover erosion, desertification and industrial resource exploitation) can contribute to establishment of an integrated concept of biodiversity protection strategies, environmental hazard monitoring as well as implementation of effective nature conservation rules.

The results inferred from the historical and present meteorological data as well as the climate change proxies are used in assessing the ongoing and future climate change feedbacks to the Altai landscape with implications to environmental management, biodiversity protection plans and the present / perspective sustainable socio-economic development of the Gorno Altai Republic, with an optimal planning of exploitation of natural resources.

7. References

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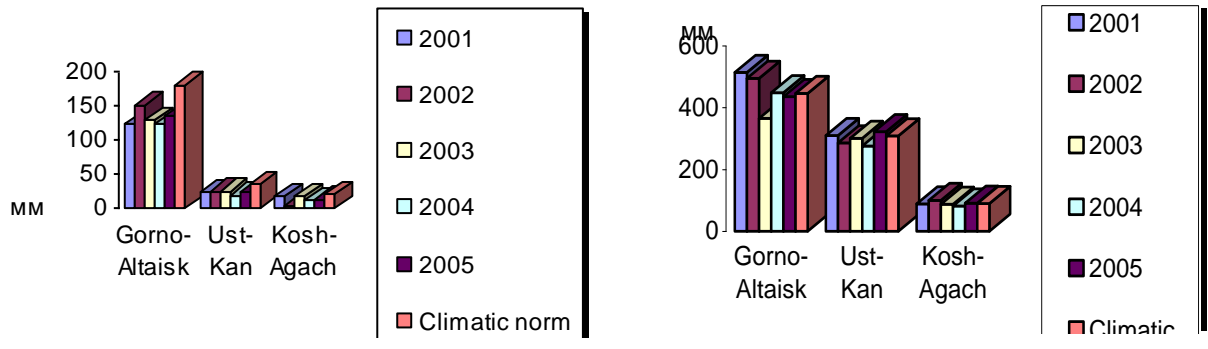


Fig. 1: Fluctuations in precipitation for the cold period (November-March) and the warm period (April-October) at the Gorno-Altai (north Altai), Ust-Kan (central Altai) and Kosh-Agach (southeastern Altai) stations. Despite precipitation variability, a reduction of the annual total precipitation is observed. The precipitation reduction is primarily in the cold seasonal periods.

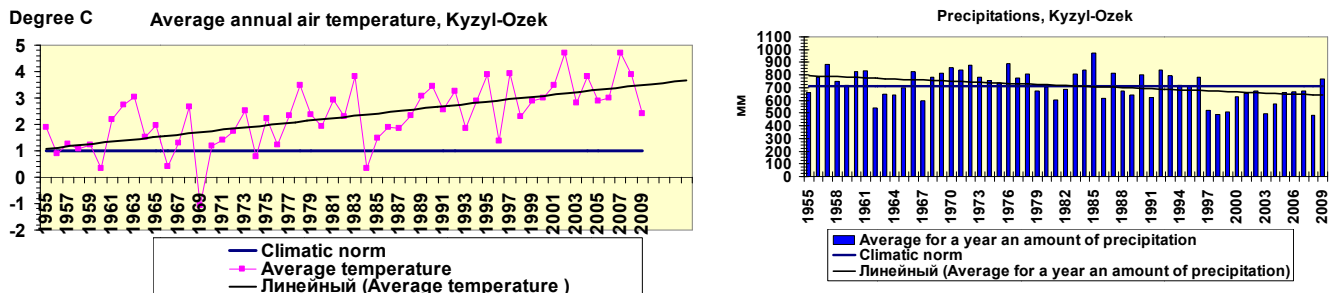
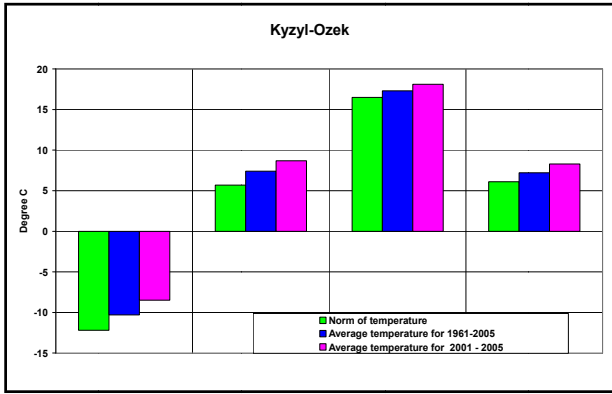
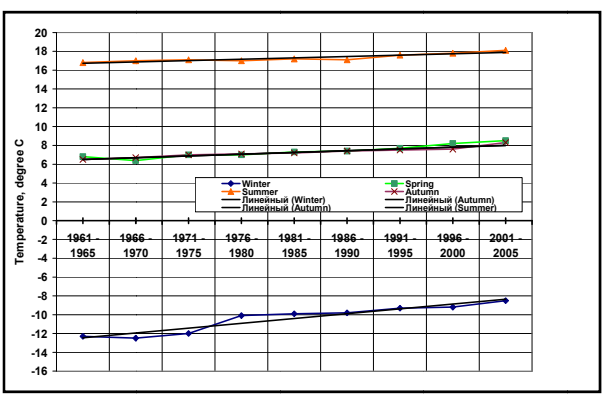
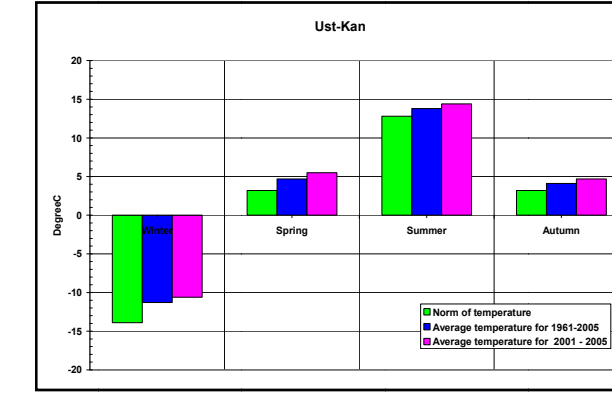
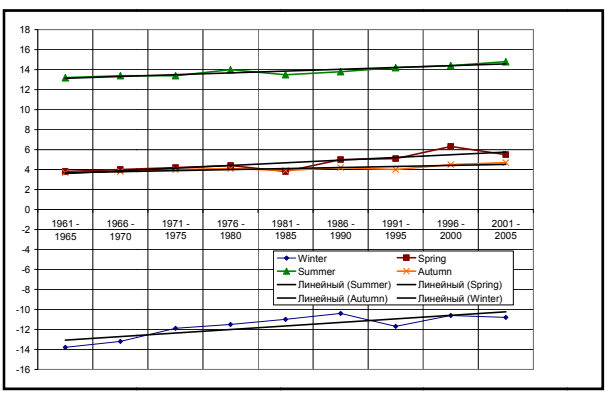


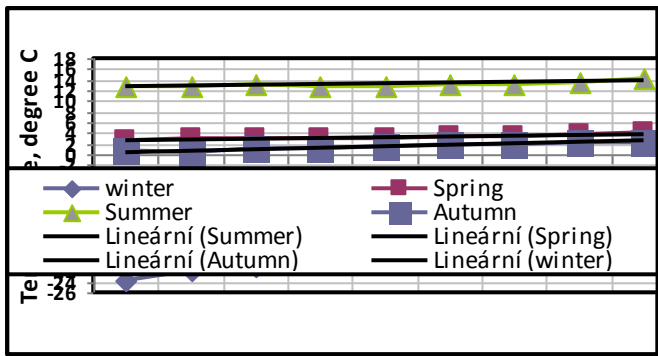
Fig. 2: Average annual air temperature and precipitation at the Kyzyl-Ozek site, northern Altai. The Altai region shows, at a long term, a considerable positive trend of high precipitation, where positive and negative seasonal temperature fluctuations can be observed (the 1955-2009 year record).



Kyzyl-Ozek (northern Altai)



Ust'-Kan (central Altai)



Kosh-Agach (southeastern Altai)

Fig.3: Five-year temperature fluctuations at the Altai weather stations during the period 1961-2005 (winter-spring-summer-fall seasons). In the central and southeastern Altai, the temperature change was weaker in extreme years than in the northern Altai, most probably a result of the high stability of a climate-forming role of the Asian anticyclone. Over the last 10 years, the mean winter temperature was higher than the climatic norm by up to 10,9 °C (Kyzyl-Ozek), 3,1 °C (Ust'-Kan) and 4,3 °C (Kosh-Agach). For the period 1961-2009, winter was correspondingly warmer at Kyzyl-Ozek by 1,7 °C, spring by 1,6 °C, summer by 0,8 °C and fall by 0,9 °C; Ust'-Kan – increased temperature by 2,4 °C (winter), 1,7 °C (spring), 1 °C (spring and fall); Kosh-Agach – winter by 4 °C (winter), 1,5 °C (spring), 0,8 °C (summer), and 0,7 °C (fall).

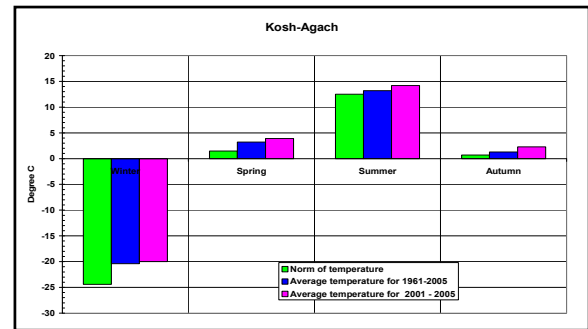


Fig. 4: Correlation of the average seasonal air temperature (°C) at the Kyzyl-Ozek (northern Altai), Ust'-Kan (central Altai) and Kosh-Agach (southeastern Altai) weather stations for the periods 1961-2005 and 2001-2005. The average measured long-term temperature as well as a seasonal temperature rise from spring to summer with minimum values in winter. A trend of a gradual temperature increase in the spring-summer-fall seasons at the expense of winter temperatures is evident.