

Present Climate Developments in Southern Siberia (1963-2017 years)

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Abstract. Siberia is a key region for mapping the climate development in north-central Eurasia in terms of global climatic change. The territorial relief creates a major orographic barrier for atmospheric streams influencing the regional altitudinal weather zonality. Systematic 55-year (1963-2017) weather observations along the 700 km N-S latitudinal transect across the southern Siberian plains and the adjoining ranges of the Altai-Sayan Mountains document progressing seasonal temperature and humidity shifts. Regionally uniform trend provides evidence of the strengthening climate continentality over Siberia also manifested by the pronounced seasonal temperature regime with increased thermally positive and negative air temperature anomalies. A landscape response to a climate warming is particularly evident in the high mountain zone. The present thermal conditions with raised MAT contribute to the progressing melting of mountain glaciers and degradation of permafrost in the alpine zone, as well as aridization of the parkland-steppe areas that are being partly transformed into continental semi-arid to desertic steppes. The associated environmental transformations trigger shifts in the local biotopes and ecosystems, with an altitudinal expansion of taiga-forest into the alpine tundra belt and xerothermic grassland invasions in the foothills.

1. Introduction

The purpose of present studies in southern Siberia is to study the regional manifestations of climate trends for the last 55 years (1963-2017). These spatially encompass the northern plains and the southern mountain ranges of the Altai and Sayans Mountains (altitudinal gradient of 180-4000 m asl.). The studies are aimed at documenting the influence and reflection of the present global climate change and the related environmental transformations in southern Siberia in terms of raised natural risks, and shifts in pristine biota, including a biodiversity loss. The unique location in the centre of Eurasia characterized by a significant continental climate regime underlines the fundamental relevance of the systematic weather observations in this particular area. This study summarizes the results of meteorological observations on directions and rates of the present climate development over southern Siberia based. Except of the standard atmospheric data assembling and a regional weather-change



modeling, the main long-term observation aspects also involve other factors related to a climate change feedback (melting of the Altai and Sayan glaciers, degradation of mountain permafrost, rise of present snow-line) as well as the bio-geographic factors (environmental changes in the mountain steppe / forest-steppe / boreal tundra-forest / alpine tundra biotopes, and restructuring of the local ecosystems).

2. Geography and Natural Environments of the Study Area

The territory encompasses the Altai (Gorno Altai) and Sayan Mountains which forms the main mountain system of southern Siberia adjoining in the SE the Mongolian Altai by the Tavon-Bogdo-Ula massive (Nairamdal Mt., 4356 m) and the Southern (Kazakh) Altai (3483 m) in the south (Figure 1). This vast area of over 1 mil km² is characterized by a very diverse physiography with high mountain massifs in the southern and eastern regions, and open lowlands in the north and west. The Altai Mountains (Belukha Mt., 4506 m asl.), the adjoining Kuznetskiy Alatau (2171 m asl.) and the Western Sayan Mountains (3492 m) jointly create a major natural barrier delimiting the southern geographic limits of Siberia bordering the West Mongolian Altai, the Chinese Altai and the Southern Altai of East Kazakhstan, with the adjoining steppes, ultimately influencing the regional atmospheric circulation pattern and its dynamics. In the west, the continental topography gradually passes into the North Altai Plains (200-300 m asl.), representing the marginal parts of the West Siberian Lowland, and into the Minusinsk Depression further east. The Western Sayans form the eastern continuation of the Altai Mountains through the Shabin-Davana Mountain junction, stretching for ca. 500 km (89° - 96° E). The Eastern Sayans extend 1,000 km from the Yenisei River at 92° E to the southwest end of Lake Baikal at 106° E. The area is drained by the Ob River with the Katun and Biya Rivers, being the main tributaries, and by the Yenisei River in the eastern part, jointly constituting a major drainage system of Siberia (Figure 2).

The regional topography of the high alpine zone (>3000 m asl. altitude) is built by the central, eastern and southern mountain ranges (the Katun, Northern & Southern Chuya, Sailyugen, Chikhacheva, Kaltanovskiy and et. Ranges) separated by mountain valleys, basins and plateaus (Ukok and Chulyshman) located in the 2000-2500 m altitude [1]. The lower regional relief zone (>1200 m asl.) covers more than 50% of the Gorno Altai and Sayan territory and represents relics of old (pre-Quaternary) denudation surfaces mantled by more recent Pleistocene and Holocene deposits accumulated by glacial, gravity slope and aeolian processes. Mountain depressions hosting Pleistocene ice-dammed lakes (the Kuray & Chuya Basin of southern Altai) or representing tectonic grabens (Teleckoye Lake of the NW Altai and the Tuva Basin surrounded by the West Sayan Mnts.) constitute the key territorial relief elements reflecting a most intensive seasonal weather change and climate-related nature transformations. The topogeographic configuration of the mountain ranges influences the atmospheric circulation and the annual weather regime over the Altai-Sayan area and the adjacent parkland-steppes of south-west Siberia [2, 3]. Marked Quaternary past climatic changes are evidenced by an impressive geomorphology, including preserved paleo-landscape forms in the mountain, foothill and steppe areas, as well as by related glacial and sedimentary geology, paleoecology pedology and cultural paleoclimate proxy records, indicating pronounced long-term regional variations in air temperature and humidity [4, 5].

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 local microclimate prevails throughout the year in some protected locations in the Altai Mountains (the upper Biya, Katun', Chulyshman and the lower Chuya River basins) with a relatively thin snow cover during winter [6, 7]. Annual temperatures as well as precipitation rates vary greatly, reflecting particular topographic settings. Most of the annual precipitation falls on the W/NW slopes in the northern and central Altai, while the southern areas became more arid. In the Chuya Depression (1800-2000 m asl.), which is one of the 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 $-60\text{ }^{\circ}\text{C}$. Most of the local area is underlain by perennial mountain permafrost with an active thaw layer only 30-70 m thick.

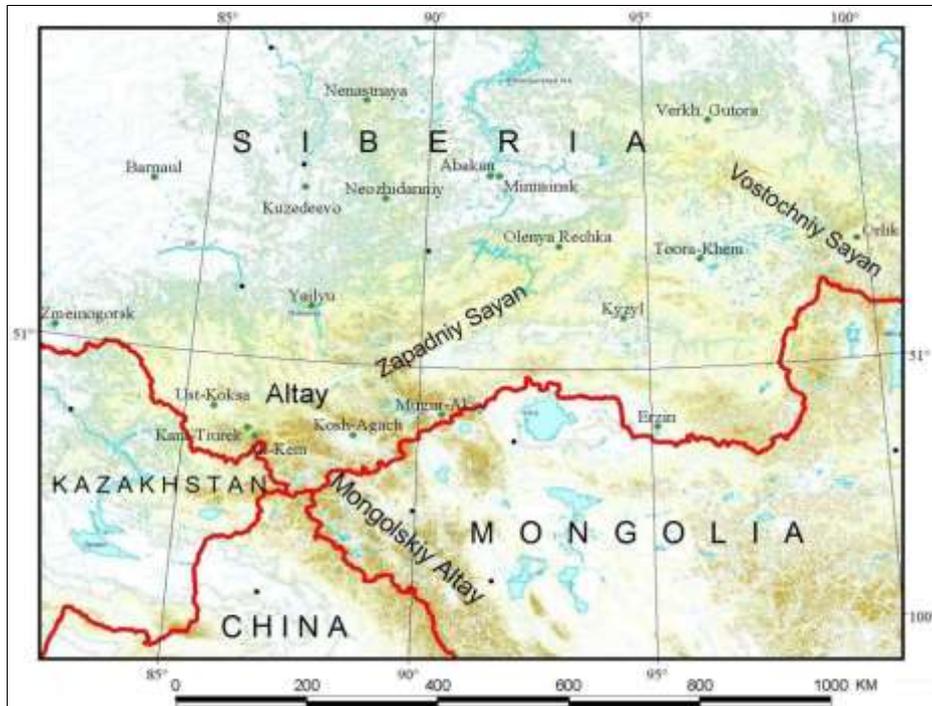


Figure 1. Geographical location of the study area in southern Siberia with the spatial and topographic distribution of the monitoring weather stations

The lowland (200-500 m asl.) vegetation of southern Siberia is formed by the open steppe-parkland with mosaic birch-pine forests. Mixed taiga covers most of the foothill and the lower mountain zone (500-1500 m asl.), gradually passing at higher elevations (1500-2500 m asl.) into the alpine tundra with the Siberian pine, larch and dwarf birch. Semi-desert communities with an 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. Dark chernozems characterize the northern plains and lowland basins; brunisolic forest soils prevail in the lower elevation mountain zone, tundra regosols; coniferous taiga podzols in the (sub)-alpine zone; and calcareous soils and solonets are found in ground-water saturated settings of the intra-mountain basins (Chuya and Kuray Depression) and on the upland plateaus (Ukok). Present weather variations reflect the regional physiogeographic and atmospheric conditions as well as the topographic configuration that has the principal bearing to seasonality, annual temperature and precipitation regimes. The local soil distribution and the pedogenic classification corroborates the records of (fossil) palaeosols expressing a patterned cyclic past climate development [8].



Figure 2. A diversity of the zonal topographic reliefs along the N-S geographic transect of the Altai-Sayan region of southern Siberia with specific climatic and environmental conditions. **A.** northern parkland-steppes, 180-300 m asl (the Ob River basin, SW Siberia); **B.** mixed (pine-spruce-birch) taiga of the northern Altai foothills, 500-800 m asl. (Gorno Altai); **C.** coniferous taiga of the central mountain zone, 1500-2300 m asl. (North Chuya Range); **D.** alpine tundra-forest zone (2300-4000 m asl.) (the Karalakh valley, Southern Altai Range); **E.** semi-desertic steppes of intermountain basins, 1200-2000 m asl. (the Chuya Basin, south-east Gorno Altai); **F.** mountain steppes, 2500 m asl. (Plateau Ukok, the Tabon-Bogdo Ula Range, Southern Altai).

3. Study Objectives, Geographical Context and Methods

This study summarizes results of the investigations of present climate change in south-central Siberia delivered by nineteen weather stations situated at different altitudes and specific topo-geographical conditions in terms of its feedback on local natural and settlement environments. The main research objective is evaluation of the 55-year weather regime and air temperature fluctuations in order to assess the present (and a near-future) climate development across the principal geographic zones in southern Siberia. The 19 weather stations (WS) are positioned in diverse physiogeographic areas (of the Altai Krai, the Gorno Altai Republic, Khakassia, Buryatia and the Tuva Republic) following the territorial continental topographic gradient (180-4500 m asl.), providing regular daily measurements of standard atmospheric parameters (i.e., precipitation and temperature changes, wind-direction, atmospheric pressure, ground-frost and permafrost table).

Table 1. Topographic, altitudinal and geographic characteristics of the weather stations [9]

№	Weather Station (WS)	Long.	Lat.	Alt. (m)	Geographic position
1	Barnaul	53°26′	83°31′	183	Ob Plateau, SW Siberia
2	Zmeinogorsk	51°09′	82°10′	354	Altai Foothills (Kolyvan Range)
3	Ust'-Koksa	50°16′	85°37′	977	Uymonskaya Basin
4	Ak-Kem	49°55′	86°32′	2050	Katun' Range
5	Kara-Tiurek	50°02′	86°27′	2600	Katun' Range (southern Gorno Altai)
6	Kosh-Agach	50°00′	88°40′	1759	Chuya Basin (SE Gorno Altai)
7	Yailyu	51°46′	87°36′	482	Abakan Range foothills (Teleckoye Lake)
8	Nenastnaya	54°45′	88°49′	1186	Kuznetskiy Alatau Mnts.
9	Kuzedeevo	53°20′	87°11′	293	Gornaya Shoria Mnts.
10	Neozhidanny	53°17′	89°04′	527	Abakan Range
11	Abakan	53°46′	91°19′	254	Minusinsk Basin
12	Minusinsk	53°43′	91°42′	254	Minusinsk Basin
13	Mugur-Aksy	50°23′	90°26′	1850	Tsagan-Shibetu Range
14	Oleniya Rechka	52°48′	93°14′	1404	West Sayan (Aradansk Range.)
15	Verkhnyaya Gutara	54°13′	96°58′	983	Central Sayan
16	Orlik	52°30′	99°49′	1376	Eastern Sayan
17	Kyzyl	51°43′	94°30′	626	Tuva Basin
18	Toora-Khem	52°28′	96°06′	919	Todzhinskaya Basin
19	Erzin	50°16′	95°07′	1100	Ubsu-Nur Basin

The analyzed summary databases include systematic meteorological data for the 1963-2017. The principal meteorological data included measurements of MAT and average seasonal near-ground air-temperature and humidity fluctuations for the winter (December, January, February) spring (March, April, May), summer (June, July, August) and fall (September, October, November) periods. The complete databases have been used for evaluation of regularities as well as anomalies of the present weather regime and represent the framework for prognosis of a future territorial climate development for the following decades.

The climate-change investigations encompass an extensive territory of southern Siberia of the Ob River drainage system in the west and the Yenisei River drainage system in the east, geographically delimited by 49°55′- 54°45′ N and 82°10′- 99°49′E (the spatial position range of the weather stations). The N-S geographic transect of the monitored area runs over about 700 km through all the topographic and environmental zones from the northern steppe plains at the south-eastern margin of the West Siberian Lowland, across the Altai-Sayan foothills, and the low-, mid- and high-mountains, representing the principal mountain ranges of southern Siberia adjacent to the Kazakhstan-Chinese-Mongolian boarder. The corresponding continental relief gradient rises from 183 m asl. (Barnaul WS)

to 2600 m. asl. (Kara-Tiurek WS), accounting for a total of 2417 m of the vertical regional elevation difference.

The altitudinally lowest study area (Barnaul WS) is characterized by open-parkland-steppes of the Siberian loess belt of the 150-400 m asl. elevation with a chernozemic soil cover depending on the particular (well- or less-drained) geo-setting [9]. This topo-geographically weakly differentiated undulating relief of old (pre-Quaternary) denudation surfaces is marked by the most prominent climate continentality with warm to hot summers and rather cold winters. The front-mountain / foothill zone (400-800 m asl.) of a mixed (deciduous-coniferous) southern taiga with a more balanced annual weather regime is formed by isolated hills and topographic tectonic elevations, representing transitional relief ramparts between the open northern Siberian plains and the southern Altai-Sayan mountain system. The primary Hercynian orogenic geological structure is mantled by the surficial Quaternary aeolian and gravity-flow colluvial formations (Zmeinogorsk and Kuzedeevo WS). The low-mountain boreal taiga forest zone situated between the foothills and the mid-mountain zone (800-1300 m asl.) is characterized by altitudinal landscape changes of 100-300 m of the NW-SE oriented ranges (Neozhidanny and Yailyu WS). The mid-mountain zone (1300-2000 m asl.) encompasses more than a half of the monitored southern Siberian territory. The vertical elevation amplitude ranges from 200-300 m to 700-800 m, corresponding to the ca. 10-20°/40-50° slope inclination gradient, respectively (Nenastnaya, Mugur-Aksy, Oleniya Rechka, Verkhnyaya Gutara and Orlik WS). The high-mountain zone includes over 20% of the territory subjected to the meteorological observations, with rocky low-hill, alpine and active erosional surface reliefs (Ak-Kem and Kara-Tiurek WS). Specific regional geo-topographic features related to climate-change studies in the Gorno Altai and the Sayan regions constitute continental basins and inter-mountain depressions with local altitudinal variations of 200-400 m asl. (Ust'-Koksa, Abakan, Kyzyl, Toora-Khem, Erzin WS) up to 1300-2000 m asl. (Kosh-Agach WS), respectively. The size of these regional geomorphic forms enclosed by mountain chains is ca. 100-170 x 20-100 km. Their geographic location implies either an accumulation relief or a recessional denudation relief, with the latter particularly characteristic of the high-mountain basins of the Central Altai (the Kosh-Agach WS in the Chuya Basin).

4. Weather Monitoring Results

In dependence of the dominant regional climatic conditions, the thermal regime of the mountain areas is significantly differentiated. The mean seasonal winter temperature varies from -5 to -27 °C. The principal reason for these differences in winter temperatures is presence and seasonal functioning of the Asian anticyclone inversions together with higher frequencies of warm foehn winds in the southerly located mountain valleys with gravitational cold-air flows moving from the mountain slopes down into the basins. In spring, the vertical climatic zonality within the geographic N-S transect across southern Siberia is re-established, following a seasonal disintegration of the central Asian Anticyclone regime. In the low-mountain areas and foothills, mean July temperature is around 16-19 °C, in the mid-mountain zone 12-15 °C, and in the basins and depressions 13-21 °C; in the high-mountain zone it drops to ca. 6 °C.

Equally, the regional humidity regime is not uniform and largely depends on local topo-geographic conditions. The maximum precipitation rates are on the NW slopes exposed to atmospheric stream fronts; the minimum precipitation rates in the arid intermountain basins enclosed by mountain ranges and in other precipitation-shadowed geomorphic locations. One of the main factors regulating the atmospheric humidity is mean annual air humidity that fluctuates over the mountain territories of the Altai and Sayans from 62 to 80 %. The highest annual precipitation / air humidity rate in southern Siberia has been observed in the Kuznetskiy Alatau Mountains, Gornaya Shoria Mountains, the Kuznetsk Basin, Rudny Altai and the NE Altai. A low-humidity regime, on the contrary, is associated with the regions of an intensified foehn wind activity (Belya, Chemal, Katon-Karagay, Ust'-Kan) and in the basins with a prevailing arid continental climate (Kosh-Agach, Kyzyl WS). The principal Kyzyl-Ozek WS is situated in the Northern Altai (330 m), the Ust'-Kan WS in the Kanskaya Depression of the Central Altai (1037 m) and the Kosh-Agach WS in the high-mountain semi-desertic

steppe of the Chuyskaya Depression of the southeastern Altai (1758 m) near the border with Mongolia. In general, the relative air humidity is maximal in winter (with the exception of places with an increased foehn-wind activity), and minimal in summer. The highest frequency of precipitation days (when humidity in daily hours reaches 80%) is in the low- and mid-mountain taiga-forest zone as well as in the high alpine regions of the Altai and Sayan Mountains. In the Kuznetskiy Alatau Mountains (Central Rudnik WS) and on the main water-divides of the Katun' Range (Kara-Tiurek WS), the average number of humid days throughout the year is about 138. In the river valleys and the intermountain basins, the number of humid days varies from 30 to 80.

The analyzed summary data display distinct seasonal temperature variations across the monitored terrains. During the particular calendar seasons, the cyclic atmospheric conditions can change relatively markedly from an anticyclone-dominated cold and low-precipitation weather regime to a more dynamic cyclone regime with shifting warm and cold atmospheric fronts bringing precipitations mainly during spring and fall. In the mountain territories, the present weather and climate characteristics have become more differentiated under the influence of the regional relief and the geographic configuration well-reflected in the locally specific thermal and atmospheric circulation pattern. The most prominent positive temperature deviations / rises recorded by the seasonal analysis of the weather-station records corroborate the bulk MAT values. These are uniformly the highest for the winter and spring periods across the entire investigated territory of southern Siberia with clearly the maximum values in the mountain basins and the inter-continental depressions of southern Siberia (the Tuvinskaya, Todzhinskaya and Chuyskaya Basins) (figure 3). This progressive climate change is well evident in the long-term archival meteorological records. In the 1960's, the mean winter temperature in these areas was below $-30\text{ }^{\circ}\text{C}$, whereas in the 1990's already only $-25\text{ }^{\circ}\text{C}$. This warming trend continues until today in correspondence with an overall territorial winter temperature increase by up to $4\text{--}5\text{ }^{\circ}\text{C}$, except for a short-term cooling in 2006-2007 with MAT around $-28\text{ }^{\circ}\text{C}$.

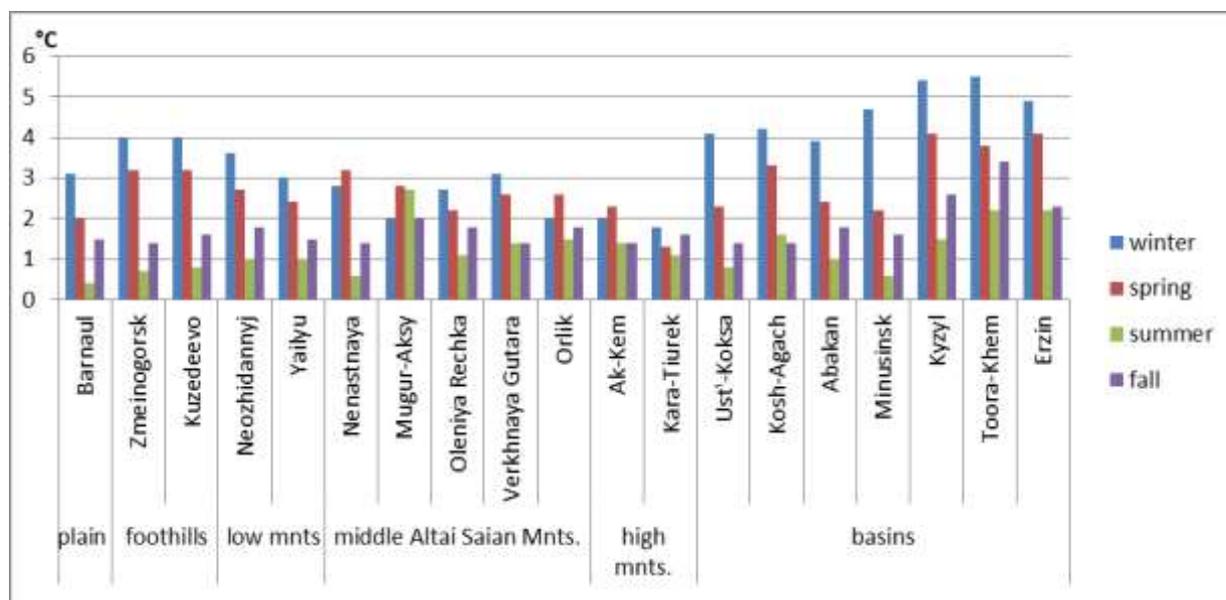


Figure 3. Rate of the mean seasonal temperature increase in respect to the MAT for the period 1963-2017 with a linear-trend prognosis of a near-future development

The present results show the major altitudinal deviations, temperature gradient and MAT variation range of $10\text{--}11\text{ }^{\circ}\text{C}$. Despite this overall trend, pronounced annual air temperature deviations have been recorded. At all high topographic locations, this present climate change displays a certain synchronicity. A minimal MAT rise has been documented at the meteorological observation stations (Kara-Tiurek, Ak-Kem, Oleniya Rechka) in the high mountain areas of southern Siberia (the Western

Sayan and Gorno Altai Mnts.), whereas a maximum progressing climate warming is in the major inter-mountain depressions (Kosh-Agach, Erzin, Kyzyl and Toora-Khem WS). Numbers of frost-free days are also increasing (180 in the Chuya Basin, Kosh-Agach WS) with the strengthening trend of climate continentality (figure 4).

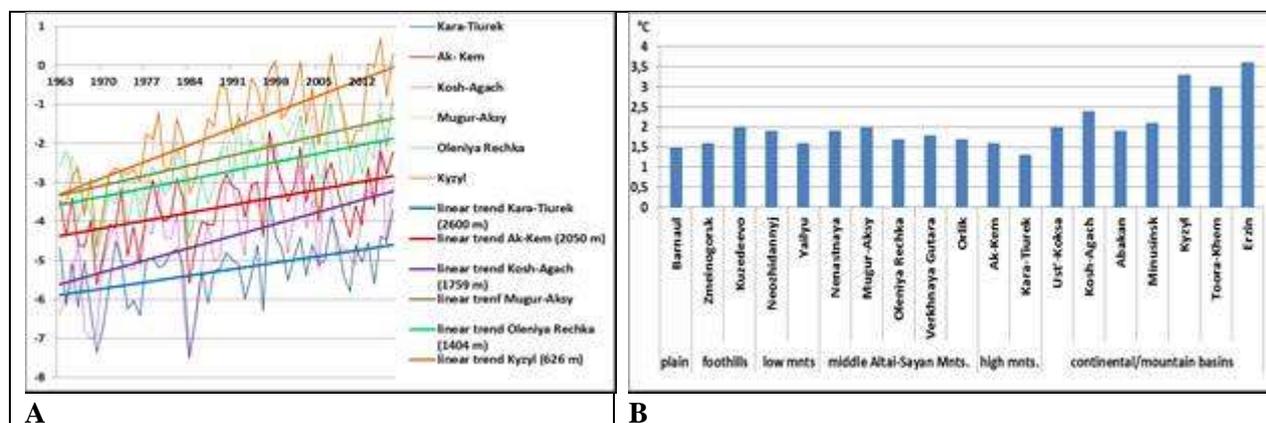


Figure 4. Increased temperature rate in respect to the MAT at the monitored locations (weather stations, **B**) following the topographic gradient from the northern plains to the southern mountain regions for the 55 year observation period (1963-2017) with a linear-trend prognosis (**A**)

5. Climate Developments in Southern Siberia: A Summary

Comparative analyses of the historical and the present meteorological databases provide eloquent evidence on the changing climate in southern Siberia with the trend of a strengthening continentality. Both current and archival data from systematic long-term weather observations manifest thermal differences in respect to the particular topographic mountain locations.

The corresponding seasonal climate shifts have been recorded in the frame of five-year temperature fluctuations at the Gorno Altai weather stations during the period 1963-2017 (winter-spring-summer-fall). In the central and southeastern part of Gorno Altai, an absolute temperature change in extreme years was weaker than in the northern Altai, most probably a result of a high stability of the Asian anticyclone. Over the last 10 years, the mean winter temperature was significantly higher than the climatic norm (MAT) by up to 10,9 °C at the Kyzyl-Ozek WS (north Altai), by 3,1 °C at the Ust'-Kan WS (Central Altai), and by 4,3 °C at the Kosh-Agach WS (SE Altai). For the period of 1961-2009, winters at Kyzyl-Ozek were correspondingly warmer in average by 1,7 °C, springs by 1,6 °C, summers by 0,8 °C and falls by 0,9 °C; at Ust'-Kan – winters by 2,4 °C warmer, springs by 1,7 °C, summers and falls by 1 °C; in Kosh-Agach – winter by 4 °C warmer, springs by 1,5 °C, summers by 0,8 °C, and falls by 0,7 °C. Evidence on the changing seasonal thermal balance from the above weather stations is manifested by a progressing air temperature rise for the periods 1961-2005 and 2001-2005. The average near-ground air temperature (winter – spring – summer – fall) displays a bulk thermal seasonal rise from spring to summer and minimum values in winter. A trend of the gradual air temperature increase in the spring-summer-fall seasons at the expense of the winter temperatures as well as the cumulative long-term MAT increase is thus well evident.

Another proxy line of the present climate development is reflected by the fluctuations in precipitation for the cold period (November-March) and the warm period (April-October) at the Gorno Altaisk (NE Altai), Ust'-Kan (Central Altai) and Kosh-Agach (SE Altai) weather stations. Despite the precipitation variability, a reduction of the annual total has been observed in the Altai. Overall, precipitation reductions occur primarily in the cold period (October to March), being most noticeable at the Ust'-Kan and Kosh-Agach WS with less than 50 mm of the total precipitation volume (figure 5). Most winter precipitation falls on the north Altai slopes. The precipitation volumes during the warm (April to September) period are more balanced and gradually decrease following the raising relief gradient due to a lee-side slope shading of the north-western humid atmospheric streams.

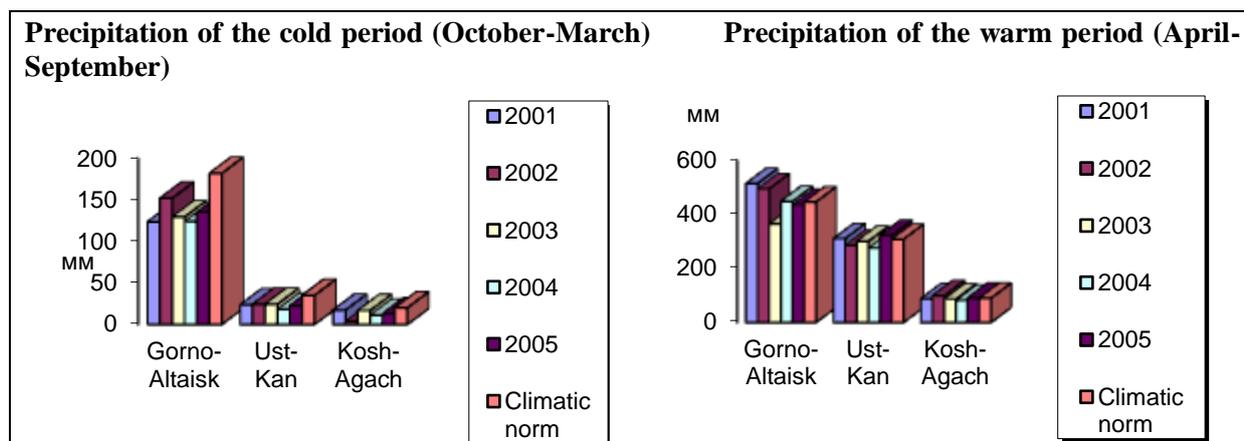


Figure 5. Comparison of short-term seasonal fluctuations of precipitation throughout the Altai Mountains N-S geographic transect

The reported results on the present climate change in the broader Altai-Sayan Eco-Region corroborate the precipitation increase trends in the mountain areas and, on contrary, the progressing rates of aridization and desertification in the lowland steppe regions as well as in the intra-mountain basins of the southern Altai area [7, 9 and 12].

6. Conclusions

The reported results of the modern, 55-year (1963-2017) systematic meteorological observation in the Altai and Sayan region along the N-S and W-E geographic transects display significant annual as well as seasonal temperature and humidity variations with a definite trend of climate warming corroborating the present climate change in the continental Eurasia. This process is well-evident by the consistent meteorological data despite short-term seasonal and/or annual air temperature deviations in respect to the MAT or seasonal temperature values. Particularly winter and spring mean air temperatures have significantly increased, amounting up to 3-4° C in the lowland and foothill regions during the past 50 years. A minimal MAT rise is in the high mountain areas, whereas the maximum progressing climate warming has been observed in the inter-mountain continental depressions. The meteorological data also indicate an increase of regional humidity reflected by the bulk annual precipitation rates in the foothills and the mountain areas, where positive and negative seasonal temperature fluctuations are recorded. In places of the higher topographic relief, the moisture regime and atmospheric circulation dynamics is being accentuated. This definite climate-change trend has been recorded in conjunction with the related natural transformations throughout the entire southern Siberian territory as manifested by the expansion of grasslands in the foothills and by the rise of tree-line in the alpine mountain zone.

Raising annual temperatures trigger a progressive melting of glaciers, a localized degradation of the mountain permafrost in the alpine zone (> 2 500 m asl.), and bring an increased number of frost-free days in the northern lowlands. The associated ecological processes include shifts in the mountain biotopes: an expansion of boreal taiga forests (now with limits at 2100-2300 m asl.) into the alpine tundra zone, a geo-botanical restructuring of xerothermic alpine meadows and concomitant biological changes in behavior of some fauna species, such as earlier arrival and a later departure of migratory birds for nestling. On the contrary, a progressing aridization of the mountain parkland-steppe areas due to the strengthened continental climate regime with high solar radiation with increased number of sunny days and a precipitation decline lead to a gradual transformation into semi-arid parkland steppes and semi-desertic steppes.

The implications resulting from the historical and present meteorological data analysis as well as the climate change proxies can be eventually used in the assessment of the ongoing and future climate change feedbacks to the southern Siberian environments with implications to management of natural

resources, biodiversity protection and the present/perspective sustainable socio-economic development, with an optimal planning of exploitation of natural resources. The present climate change-linked economic effects may, on long-term, positively promote production in agriculture and forestry over the monitored territory due to ameliorated weather conditions and expansion of arable lands and taiga forests, respectively. On contrary, a complex evaluation of the main natural climate-triggered risks (including soil cover erosion, desertification and industrial resource exploitation) can ultimately contribute to establishment of an integrated concept of effective nature protection strategies in the Altai and Sayan Eco-Region, and an environmental hazard monitoring related to present climate change.

References

- [1] Rudoy A et al 2004 Ukok The Past, Present and Future (Barnaul, Altai State University Press) 174 p
- [2] Sherstyukov B 2008 Regional and Seasonal Regularities of Present Climate Change (Obninsk) p 246
- [3] Gruza G and Ran'kova E 2009 Evaluation of climate changes on the territory of the Russian Federation Meteorology and Hydrology chapter 11 pp 15-29
- [4] Sukhova M 2010 Ecological and climatic potential of mountain areas (Saarbrücken) LAP LAMBERT Academic Publishing p 312
- [5] Sukhova M 2011 The dynamics of present changes of the main meteorological parameters of surface atmosphere (the Altai pilot study) Adaptation Ability to Climate Change in the Altai-Sayan Eco-region Proceedings of the Scientific Workshop (Barnaul: Altai State University) pp 8-18
- [6] Climate change and biodiversity of the Russian part of the Altai-Sayan Ecoregion 2013 (Krasnoyarsk: City) pp 327
- [7] Geography of Siberia at the beginning of the XXI century: a monograph in 6 volumes 2016 vol 5 Western Siberia (Novosibirsk, Russia: Academic publishing house Geo) p 447
- [8] Velichko A 1993 Evolution of Landscapes and Climates of Northern Eurasia Late Pleistocene - Holocene Elements of Prognosis vol 1 Regional Paleogeography RAN Institute of Geography (Moscow: Nauka) p 302
- [9] Kharlamova N 2013 Evaluation and forecast of the current climate change in the Altai region: monograph (Barnaul, Russia: Alt. University) p 156
- [10] Chlachula J 2003 Recent Advancements in climate and ecology studies of the Altai region Materials of the Second International Scientific Practical Conference (Karaganda State University 4-5 December 2003) part 1 pp 27-30
- [11] Kharlamova N 2010 Climate change trends in the Altai-Sayan region Climate Change and Biodiversity Conservation in the Altai-Sayan Eco-region: Papers of the International Meeting Ust-Koksa (Barnaul, Russia) pp 10-15
- [12] Sukhova M and Zhuravleva O 2018 Changes in the temperature of air and draft in intermediary potteries of the Southeast and Central Altai News of the Russian Academy of Sciences Geographical series 6 pp 93-101