agriculture

MDPI

Article

# The Transformation of Agro-Climatic Resources of the Altai Region under Changing Climate Conditions

**Nina Maximova [1], Komali Kantamaneni [2,*], Gennady Morkovkin [3], Darya Arnaut [3] and Louis Rice [4]**

1 Department of Natural Resources Management and Geo-Ecology, Altai State University, Prospekt Krasnoarmeyskiy, Lenina, 61a, Barnaul, Altayskiy Kray 656049, Russia; ninmaxim@mail.ru
2 Research, Innovation and Enterprise, Warsash School of Maritime Science and Engineering East Park Terrace, Solent University, Southampton SO14 OYN, UK
3 Department of Soil Science and Agrochemistry, Altai State Agricultural University, Prospekt Krasnoarmeyskiy, 98, Barnaul, Altayskiy Kray 656049, Russia; ggmork@mail.ru (G.M.); arnautdv@mail.ru (D.A.)
4 Department of Architecture and the Built Environment, University of the West of England, Bristol, Frenchay Campus, Bristol BS16 1QY, UK; louis.rice@uwe.ac.uk
* Correspondence: Komali.kantamaneni@solent.ac.uk; Tel.: +44-023-8201-6970

Received: 26 January 2019; Accepted: 15 March 2019; Published: 28 March 2019

**Abstract:** This research examines the transformation of the agro-climatic conditions of the Altai region as a result of climate change. The climate of the Altai region in Russia is sharply continental and characterized by dry air and significant weather variability, both in individual seasons and years. The current study is determined by the lack of detailed area-related analytical generalizations for the territory of the Altai region over the past 30 years. Most of the published data dealing with an integrated analysis of the agro-climatic conditions in the Altai region date back to the late 1960s and early 1970s; in most cases, this data is from climate reference-books based on the generalized data from the first half of the 20th century. To make accurate forecasts and to efficiently manage agricultural production in the Altai region, area-related data on the state and dynamics of agro-climatic changes have been analysed. The results reveal that in the period between 1964 and 2017, significant climatic changes occurred in the territory of the Altai region. These climatic changes affected the growing season length, which increased due to a shift in the dates of the air temperature transition above 10 °C, to earlier dates in spring and to later dates in autumn. Furthermore, the current study also revealed that the foothills of the Altai Mountains are the most moistened parts of the region and the Kulunda lowland is the most arid part. In the Altai region, the accumulated temperatures and amounts of precipitation during the growing season increased significantly, and the values of integrated coefficients and indices that reflect the moisture supply conditions for the territory also changed significantly. Based upon the results, a schematic map of the current precipitation distribution on the Altai region's territory has been generated. These results and this map may be used to conduct more detailed studies in the field of agro-climatology and to update the current borders of agro-climatic areas and revision of the agro-climatic zonation scheme.

**Keywords:** agro-climatic resources; Altai region; climatic changes; agriculture

## 1. Introduction

There is substantial concern regarding the influences of climate change and its variability on agricultural production across the world [1–3]. Topographical patterns of food production are affected by climatic variables such as temperature, precipitation, as well as the frequency and severity of extreme events [4–6]. Mjachina et al. [7] and Blumberga et al. [8] state that agricultural production is based upon the bio-production potential of the natural environment, and climate is a determining factor. Global warming has impacted agriculture in multiple ways since the 19th century [9]. The last five decades have also witnessed a continuing decline of food production in the world caused by unstable and intense climatic conditions such as high temperatures, as well as extended and colder winters [10,11]. Meanwhile, agricultural trade has grown dramatically due to an upsurge in mean annual air temperature throughout Russia [12,13]. The range of the mean annual temperature fluctuations throughout the country reached 3–4 °C while that for the globe slightly exceeds 1 °C) [14–16]. According to the Federal Service for Hydrometeorology and Environmental Monitoring of Russia, over the past 100 years (1907–2006), countrywide warming was 1.29 °C as compared to the reported average global warming of 0.74 °C (IPCC, 2007). Over the past 35 years, significant interannual variations of mean temperature have been observed against the background of a steady temperature increase [17] (Figure 1). Climate change has caused alterations in the distribution areas of flora species [18]. The main factors that determine crop zonation include the heat supply of the area, temperature fluctuations, and suitability of the length of warm, frost-free periods and growing season length to the cultivated crop requirements [19].

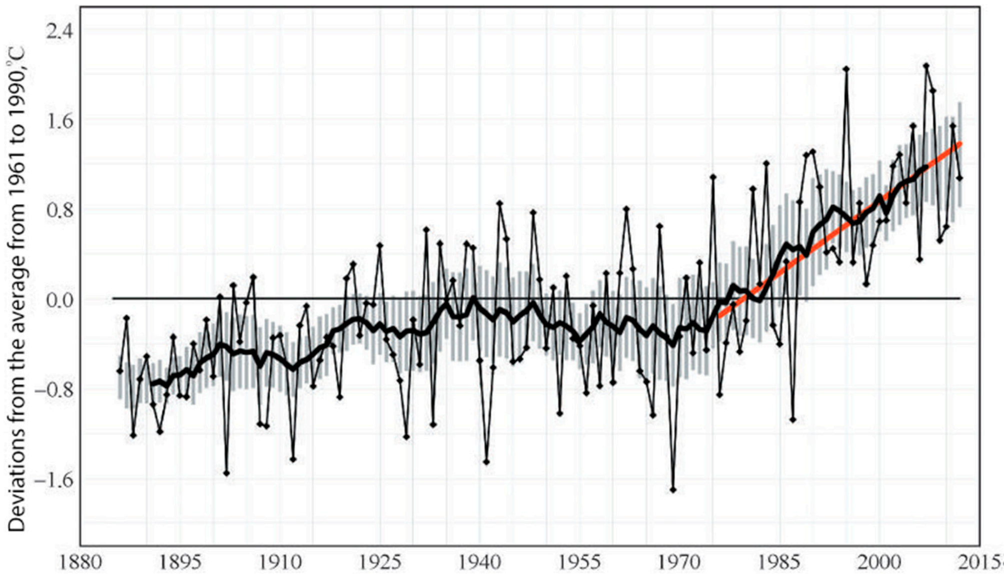


**Figure 1.** The changes in anomalies of average annual surface air temperature over the territory of Russia during 1886–2012. The anomalies are calculated as deviations from the averages for 1961–1990. The bold curve shows the smoothed course of temperature (11-year moving averages). Vertical segments show a 95% confidence interval for 11-year averages. The red line is the trend for 1976–2012 [17].

In recent years, in Russia, agroclimatological areas have been affected by global climate change, possible estimates of agro-climatic resources, and the adaptation of agricultural production. The main agro-climatic resources of the territory are determined by the indicators: heat supply, moisture supply and winter conditions. These indicators are developed on the basis of meteorological and agrometeorological observations. An important condition for the placement of agricultural flora in the territory is its agro-climatic zoning. Due to the geographical location and relief features of the Altai region, the climatic conditions are crucial for agriculture. The identification and use of potential climate resources are of distinct, practical importance [20]. The geographical position of the Altai Territory in the depth of the continent provides a relatively uniform flow of radiant energy. The relevance of this research is determined by the lack of detailed area-related analytical generalizations for the territory of the Altai region over the past 30 years. Most of the published works dealing with an integrated analysis of the agro-climatic conditions in the Altai region date back to the late 1960s and early 1970s; in most cases these works use the data of climate reference-books based on the generalized data from the first half of the 20th century [21–23]. To enable forecasts and to efficiently manage agricultural production in the Altai region as well to fill the research gap, area-related data on the state and dynamics of agro-climatic changes have been analysed. The research goal was to study the change of the state of agro-climatic resources of the Altai region under a changing climate.

## 2. Study Area

The Altai region (Figure 2) is located within two physico-geographical countries—West Siberian and Altai-Sayan countries. This location determines the climatic differences in the plain and the foothill and low mountain parts of the region. A significant part of the region lies within the plain and this leads to the distinct manifestation of heat and moisture zonation [24]. The openness of the territory from the north and west contributes to the penetration of the Arctic and tropical air masses, which lead to weather condition variability, and the intensive development of atmospheric processes [25]. The position of the Altai region between 51–54° N latitudes determines a significant amount of possible radiation [26].

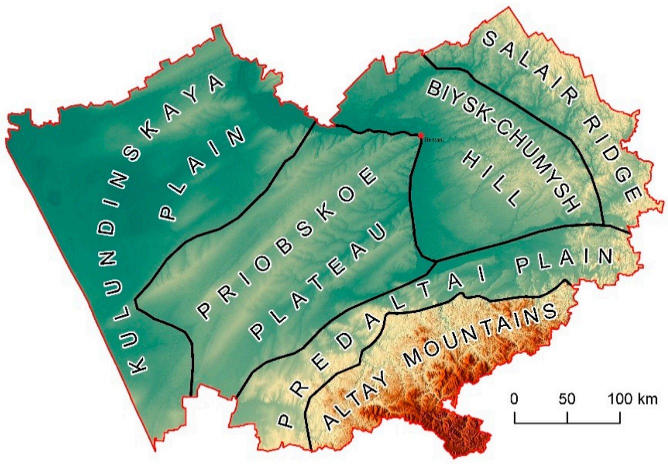


**Figure 2.** Physiographic map of the Altai region.

The region's territory features a high sun angle in the summertime (60–66°) and a long light day (up to 17 h). In the winter, when the sun angle is 13–19°, the energy supply is significantly reduced [27]. The climate of the Altai region is sharply continental. It is characterized by dry air, relatively low rainfall throughout the year, and significant weather variability both for individual seasons and years [28,29]. The general climatic features are determined not only by the geographical setting of the region, but also by the impact of the air masses, of different characteristics and origins, arriving in this territory. A long and cold winter, a dry and cold spring, a short and hot summer, and a warm and moderately wet autumn characterize the climate of the region. The entire territory of the Altai region is characterized by a mean annual air temperature of 1.4 °C. The coldest month is January (−17.9 °C), and the warmest month is July (+19.9 °C) [21,23]. The continental climate of the region is also distinguished by considerable diversity in the territory (Figure 3). The precipitation amount increases West-to-East (from 250 mm to 600 mm per year) [30,31], and the heat amount increases from Northeast to Southwest and South (Shulgin, 1948). Accordingly, the vegetation and soil cover changes from West to Southeast. Across Russia, moistening both on yearly and seasonal scales, increased slowly throughout the grain belt from 1936 to the early 1990s, i.e., for over 50 years [32–34]. In the Northwestern part of the grain belt, there was a decreasing trend in the yearly moistening. At the same time, there was no change in moistening at the beginning of the 21st century in the rest of the grain belt towards the east (part of the Central Chernozem region, the Volga region, the Trans-Volga region, the Pre-Ural region and West Siberia). It is important to emphasize that the change of summer moistening does not contradict the general positive trend of the yearly moistening, but it is more heterogeneous in this territory.

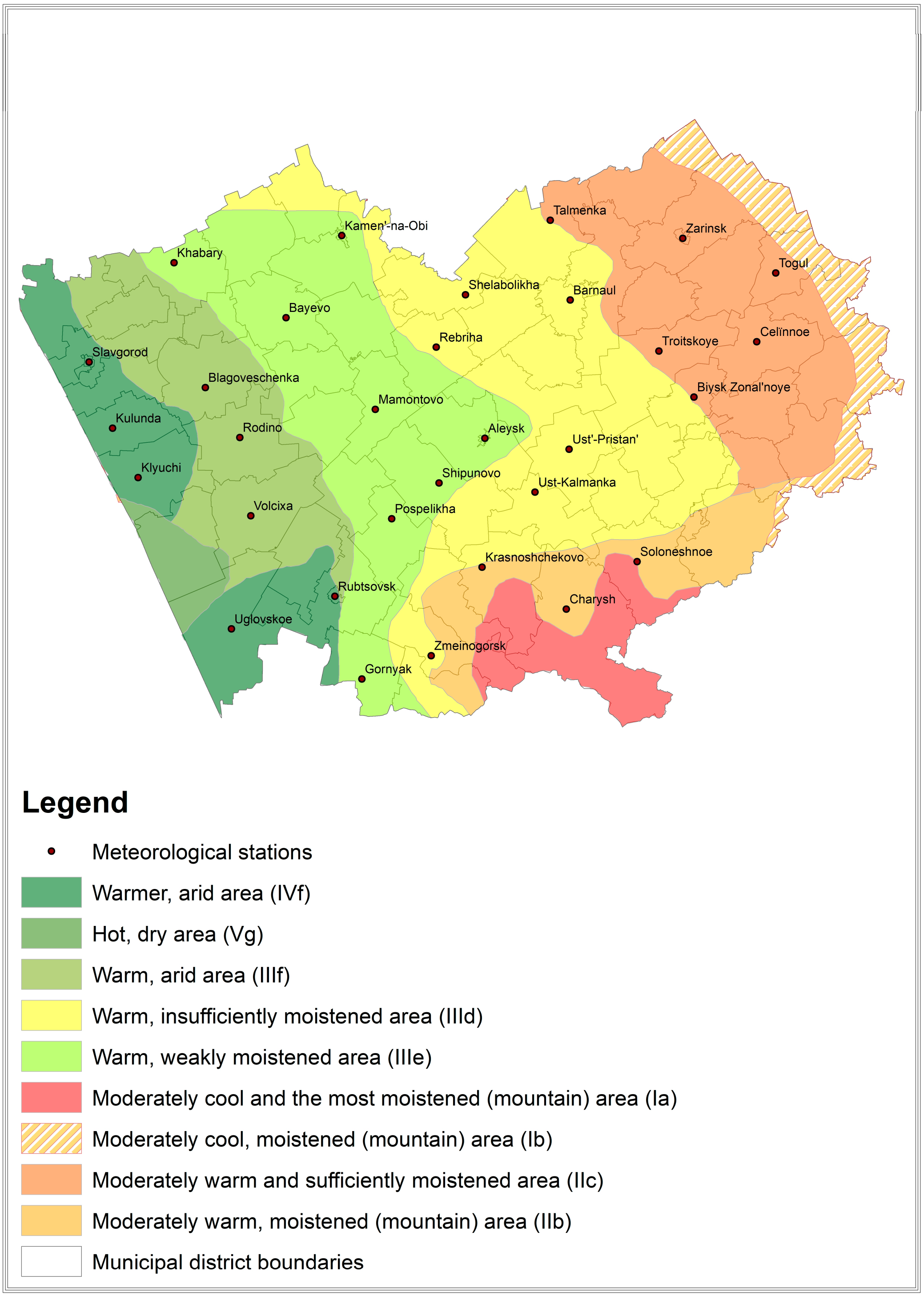


**Figure 3.** Agro-climatic zonation of the Altai region. Modified from Agro-climatic resources of the Altai Territory 1971 [22].

## 3. Data and Methods

The baseline data for this study were the file materials of the Altai Center for Hydrometeorology and Environmental Monitoring. The main information sources are the Agrometeorology yearbooks. The study includes the data from 31 meteorological stations (Figure 4) operating in the Altai region having continuous observation series from 1964 to 2017. For the value of the norm, data from the Handbook on the Climate of the USSR are taken, in which the averaging for 1881–1960 was [35]. The probabilities of climatic elements are derived from a series of observations over 30–35 years [36]. This research presents a comprehensive assessment of the state and dynamics of the main area-related agro-climatic indices which may be used to adjust the boundaries of the agro-climatic zones of the Altai region.

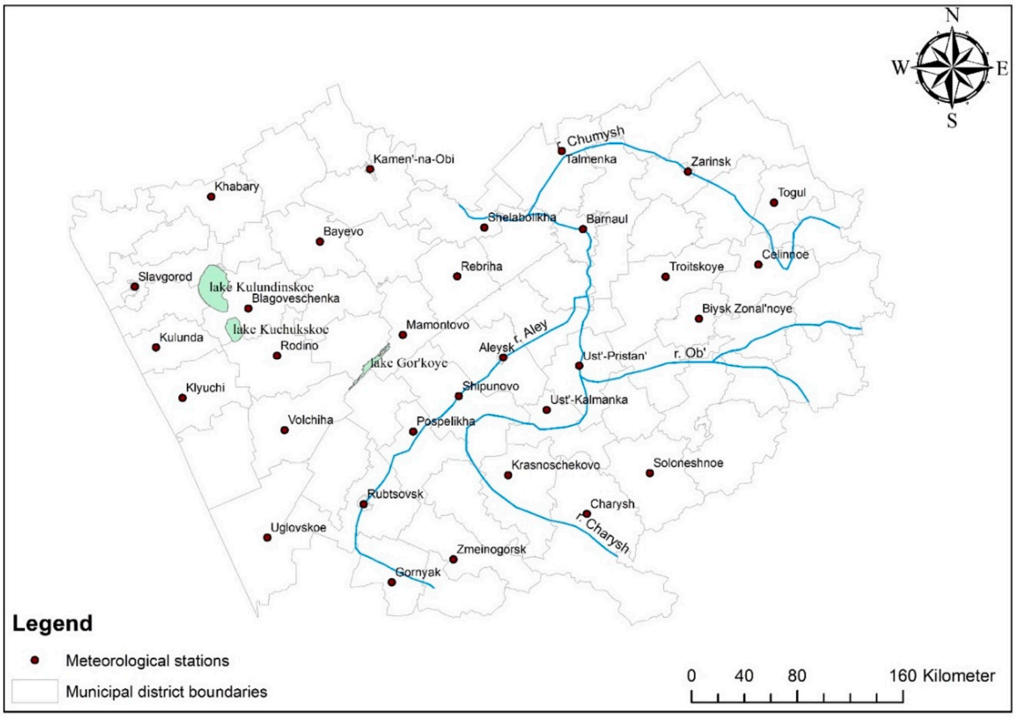


**Figure 4.** Meteorological stations of the Altai Region.

The research goal was to study the change in the state of agro-climatic resources of the Altai region under a changing climate, and determine possible adjustments of the current boundaries of the agro-climatic areas to optimize the placement and cultivation of adapted crops. The research targets were the agro-climatic resources of the region: heat supply, moisture supply, growing season length and their changes in time intervals for the agro-climatic areas of the Altai region. Agro-climatic resources are defined as a set of conditions that determine the yields of the crops cultivated in a region and the productivity of farm animals [37]. Data analysis was carried out by using the following statistical (mathematical formula) procedures: Equation (1) and Geographical Information Systems (GIS). Trends in time series were appraised by the 'least squares method'. The reliability of detected trends was evaluated using student's criterion at a 5% significance level. Correlation analysis was used for the assessment of the spatial and temporal consistency of meteorological parameters. To analyse the dynamics of moisture supply in the agro-climatic regions of the Altai region, with respect to climate change trends, calculations were conducted of the amount of precipitation per year and the growing season (with the air temperature of more than 10 °C).

The calculation of the dates of steady transition of temperatures through a specific limit is determined by comparing the positive and negative deviations of the sums of average daily temperatures from the specified limit. A positive deviation is considered when the average daily temperature exceeds the limit. For the date of steady temperature transition through 10 °C in spring, the first day of the period is taken where the sum of positive deviations exceeds the sum of negative deviations for any of the subsequent periods with negative deviations. A similar process determines the date of steady transition in the autumn The calculation of the first and last days of the growing season is conducted by considering the average daily temperatures for the spring months between April and June and for the autumnal months between August and October; all periods with positive and negative deviations are found, and for each period the sum of the positive and negative deviations is calculated. Then, the obtained amounts of positive and negative deviations are compared, and guided by the above rules, determine the periods of days that can be taken as the beginning (spring) or end (autumn) of a steady transition of temperature through 10 °C.

To assess the growing season, we have taken a period with air temperatures above 10 °C, which coincides with the beginning and end of the active growing season of most agricultural crops in the Altai Territory [38]. The values of the hydrothermal coefficient of Selyaninov (HTC) at the meteorological stations were conducted.

$$\text{HTC} = \frac{R * 10}{\sum t} \tag{1}$$

where $R$ is the total precipitation in millimeters over a period with temperatures above 10°; $\Sigma t$ is the accumulated temperatures in degrees during the same period. Hydrothermal coefficient (HTC) is a characteristic of the moistening of a territory (moisture supply). Spatial analysis of the studied characteristics and visualization of its results performed by ArcGIS version 10.3.1 (Esri, Redlands, CA, USA) and graphs have been created by Python 3.6 + matplotlib 3.0.2.

## 4. Results and Discussion

### *4.1. The Change of Heat Supply of the Territory*

Based on calculations of the data collected from the 31 meteorological stations, the Altai region's mean annual air temperature and mean July temperature increased (Figure 5). Heat supply was increased in all agro-climatic areas and meteorological stations of the Altai region; this is a favorable factor for agricultural production. However, the adaptation of Russian agriculture to climate change in the 21st century should be based, among other things, on the optimization of winter and spring crop ratios, the extension of the areas under warm-season, as well as stubble crops and the development of irrigated agriculture.

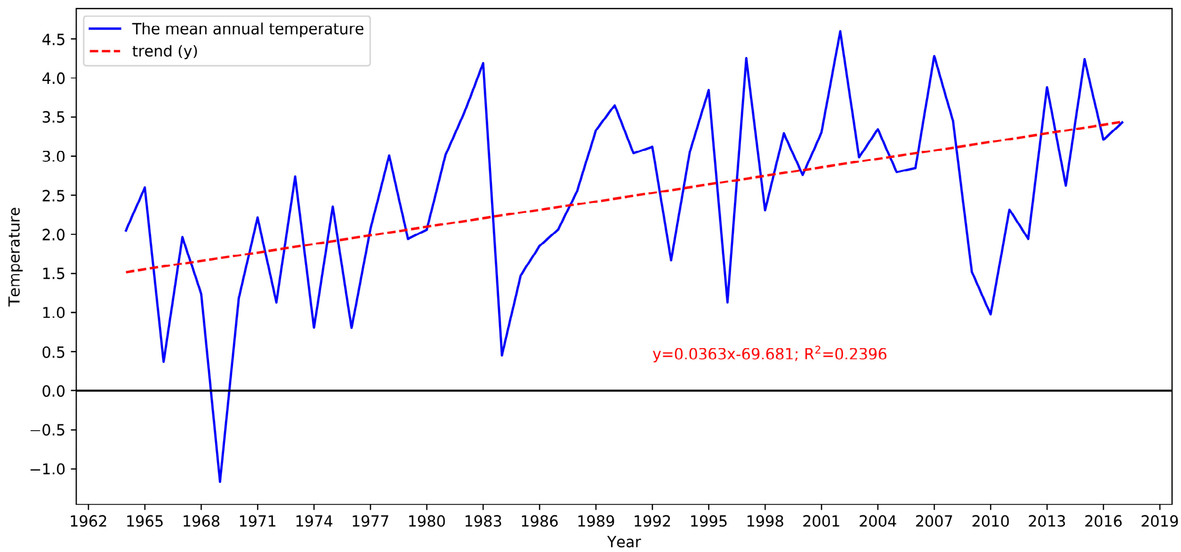


**Figure 5.** The mean annual temperature dynamics in the Altai region (1964–2017).

### *4.2. Assessment of Moistening and Moisture Availability*

The obtained results were averaged according to the agro-climatic areas (Table 1).

**Table 1.** Assessment of moistening in the agro-climatic areas.

| Agro-Climatic Area | Yearly Precipitation Amount, mm | | The Amount of Precipitation for the Period with a Temperature above 10 °C, mm | | % of Precipitation of the Period with Temperature above 10 °C per Year | HTC | |
|---|---|---|---|---|---|---|---|
| | Normal 1881–1960 | 1964–2017 | Normal 1881–1960 | 1964–2017 | 1964–2017 | Normal 1881–1960 | 1964–2017 |
| Moderately warm, moist, mountain area (IIb) | 520 | 555 | 250–300 | 372 | 67 | 1.6–1.4 | 1.8 |
| Moderately warm moistened area (IIc) | 470 | 517 | 225–250 | 295 | 57 | 1.4–1.2 | 1.4 |
| Warm insufficiently moistened area (IIId) | 450 | 467 | 225–250 | 264 | 56 | 1.2–1.0 | 1.1 |
| Warm weakly moistened area (IIIe) | 350 | 380 | 150–200 | 225 | 59 | 1–0.8 | 1.0 |
| Warm, arid area (IIIf) | 300 | 320 | 140–175 | 194 | 64 | 0.8–0.6 | 0.8 |
| Warmer, arid area (IVf) | 260 | 312 | 140–160 | 193 | 62 | 0.8–0.6 | 0.8 |

According to the obtained results, the precipitation amount during the growing season in all areas has increased and exceeds the upper normal values. The percentage of precipitation during the growing season in all areas does not exceed 70% and averages 61.8% for the region. When averaged, the HTC in all agro-climatic areas reaches the upper limit; while for individual meteorological stations, this index is above the average and exceeds the normal values. In the moderately warm, moist, mountain areas, the HTC exceeds the upper normal values and amounts to 1.8 (Figure 6). The results obtained are consistent with the data from studies conducted for the south of West Siberia [38] which revealed steadily increasing trends of growing season precipitation in most parts of the territory, but nevertheless, the moistening coefficient of the HTC in the studied territory changed slightly.


**Figure 6.** Hydrothermal coefficient of the growing season.

The current distribution of growing season precipitation is presented in Figure 7. The foothills of the Altai Mountains are the most moistened parts of the region; the most arid part, with critical values less than 200 mm, occupies a significant part of the Kulunda lowland.

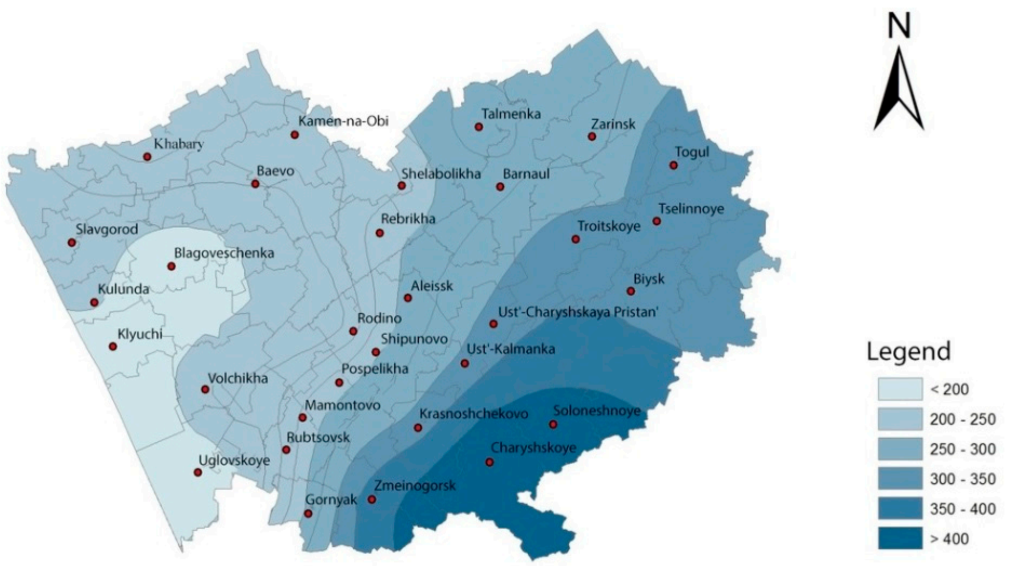


**Figure 7.** Schematic map of growing season precipitation distribution, mm.

The temporal dynamics of the yearly precipitation amounts, growing season precipitation and HTC are shown in Figures 8 and 9.

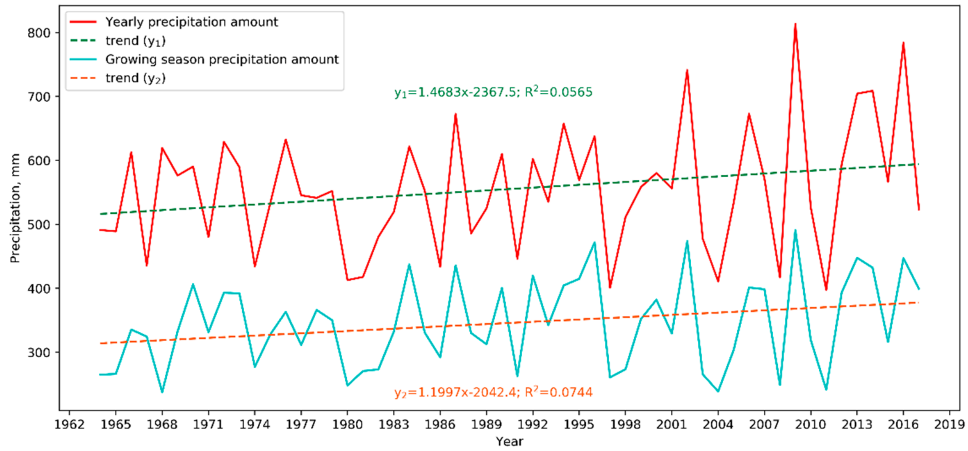


**Figure 8.** Precipitation dynamics in the moderately warm, moist, mountain area.

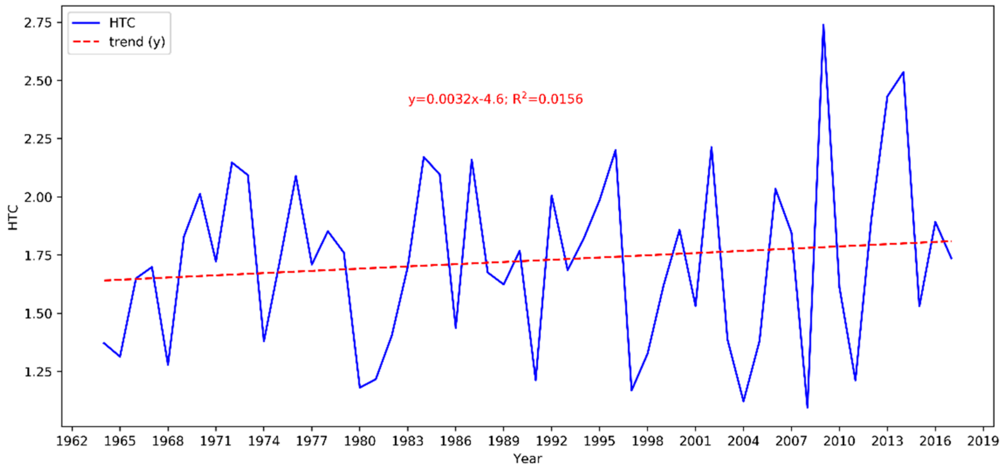


**Figure 9.** HTC dynamics in the moderately warm, moist, mountain area.

The observations in the moderately warm, moist, mountain agro-climatic areas between 1964 and 2017 reveal the increase of total yearly precipitation and total growing season precipitation with a more intense increase of growing season precipitation than in other areas. Growing season precipitation, as a percentage of the total yearly precipitation, increased during this period. The HTC in this area has increased most significantly compared to the rest of the region's territory; notably there are positive trends in the dynamics of precipitation and HTC in other agro-climatic areas.

## *4.3. Assessment of Growing Season Length*

When describing agro-climatic resources, special attention is paid to the growing season. The growing season is the period of a year when plant growth and active development under given climatic conditions are possible [39]. The temperatures at the beginning and at the end of crop growth [36] are taken as the climatological characteristics of a growing season. For a territory with a temperate climate, the growing season corresponds to a timespan of a calendar year when the mean daily air temperature exceeds 10 °C. The beginning of late spring crop sowing and the termination of killing frosts are associated with the temperature transition above 10 °C.

To assess the change of the growing season length, the data on the transition date of the mean daily air temperature above 10 °C in spring and autumn was selected from agro-climatic yearbooks. Based on these data, the growing season length in days was calculated. In a similar way, the lengths of the periods with the mean daily air temperature above 0 °C and above 5 °C were calculated and grouped according to the agro-climatic areas of the Altai region (Table 2). The averaged data of the USSR Climate Reference-Book [35] were taken as the normal; the data averaging was made for 1881–1960. The normal indices were not calculated for all observation points as some of them had a short observation series or did not exist yet.

**Table 2.** The number of days with temperature above 10 °C, days.

| Agro-Climatic Area | The Length of the Period with Temperature above 10 °C, Days | | Change in the Length of the Period with Temperature above 10 °C |
|---|---|---|---|
| | Normal 1881–1960 | Over a Period of 1964–2017 | |
| Moderately warm, moist, mountain area (IIb) | 127 | 136 | +9 |
| Moderately warm moistened area (IIc) | 124 | 132 | +8 |
| Warm insufficiently moistened area (IIId) | 130 | 138 | +8 |
| Warm weakly moistened area (IIIe) | 131 | 138 | +7 |
| Warm, arid area (IIIf) | 134 | 141 | +7 |
| Warmer, arid area (IVf) | 138 | 144 | +6 |
| Average in the region | 131 | 138 | +7 |

For each calculation period in the agro-climatic areas of the Altai region, lengthening is observed (Table 2). On the average in the region, the length of the period with temperatures above 10 °C has increased by 7 days. In terms of this index, these areas come close to the mean Russian values, but in some agro-climatic areas, the changes in growing season length are much lower than the Russian indices. This index is also below the Russian values in Transbaikalia [40], its greatest increase, which amounted to more than 10 days, occurred mainly in the southern part of that region belonging to the agricultural zone. The 'Overall Summary of the Roshydromet Second Assessment Report on Climate Change and its Effects on the Territory of the Russian Federation' states that between 1976 and 2012, the growing season (the period of a year with the mean daily temperature above 10 °C) has lengthened by 14–16 days on average [17].

To assess the shift in the length of the period with temperatures above 10 °C, we calculated the transition date shift of the mean daily temperature above 10 °C in summer and autumn. For a large part of the observation points, the average dates of the air temperature transition above 10 °C in spring fall on the first ten-days of May. For many meteorological stations, the shift of the transition date from the second ten-days of May to the first ten-days can be seen. On average for the region, the deviation from the normal is four days. The deviation from the normal in the autumn period is not that significant, although on average, the shift of the transition date of the mean daily temperature above 10 °C to a later date also occurs. In the autumn, the date shift occurred either within one ten-day period, or from the second to the third ten-days; with on average, a shift of 3 days. Therefore, based on the research, it may be concluded that over the period between 1964 and 2017, the length of the period with temperatures above 10 °C lengthened by seven days as compared to the normal, on average, in the agro-climatic areas of the Altai region. All observation points reveal the shift of the spring date of the steady transition of the air temperature above 10 °C, which corresponds to the beginning of the growing season, to an earlier date; from the second to the first ten-days of May. In the autumn, the transition date shifted to a later date in the second half of September.

## 5. Conclusions

The climatic changes (heat supply, moisture supply, and growing season length and time intervals for the agro-climatic areas) of the last few decades, observed throughout the Altai region, have a significant impact on the development of agriculture. In this regard, it is essential to use up-to-date indices that reflect the current agro-climatic features for this territory; this may become an important factor for increasing agricultural output. The climate has an influence on human and agricultural activity in Siberia, as agrometeorological indices are characterized by inter-annual variability and determine the generally low level of crop yields and significant yield variations over the years. Over the course of the research, the current state of knowledge in Russian literature and the agro-climatic resources assessment techniques were reviewed. A large part of the Russian methods and techniques belong to the second half of the 20th century. There are few examples of data or research work devoted to the assessment of agro-climatic conditions at the present time, and to a large extent, they deal with the improvement of existing techniques. The assessment scheme of agro-climatic resources of any territory remains unchanged for a long time in this context, with the main constituents being the assessment of the growing season length, and the dates of steady temperature transition above 10 °C, heat supply of a territory and the conditions of moistening and moisture supply. Integrated techniques are supplemented by an assessment of the cold period conditions, soil and climatic conditions, and phenomena harmful to agriculture. One of the main difficulties in performing such assessment work is the lack of data, data incompleteness and the discontinuity of observation series. This paper analyses the spatial and temporal structure of the agro-climatic resources. It is shown that over the period from 1964 to 2017, significant climatic changes occurred in the territory of the Altai region and this affected agro-climatic characteristics. In the study period, the growing season length in the Altai region increased due to a shift in the dates of the air temperature transition above 10 °C to earlier dates in spring and later dates in autumn. The accumulated temperatures and amount of precipitation during the growing season increased; the values of integrated coefficients and indices that reflect the conditions of moisture supply to the territory also changed. The research reveals that more detailed studies in the field of agro-climatology are required, updating the current borders of agro-climatic areas, and revision of the agro-climatic zonation schemes. More detailed data will enable the issue of crop production efficiency to be addressed more competently, accurately and effectively.

**Author Contributions:** N.M., G.M. and D.A. designed the study. N.M., K.K. and L.R. wrote the paper; N.M., K.K. and L.R. modified the manuscript.

**Funding:** This research received no external funding.

**Conflicts of Interest:** This manuscript has not been previously published and is not under consideration in the same or substantially similar form in any other peer-reviewed media. To the best of my knowledge, no conflict of interest, financial or otherwise, exists.

## References

1. McMichael, A.J.; Woodruff, R.E.; Hales, S. Climate change and human health: present and future risks. *The Lancet* **2006**, *367*, 859–869. [CrossRef]
2. Carnicer, J.; Coll, M.; Ninyerola, M.; Pons, X.; Sanchez, G.; Penuelas, J. Widespread crown condition decline, food web disruption, and amplified tree mortality with increased climate change-type drought. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 1474–1478. [CrossRef]
3. Mourtzinis, S.; Ortiz, B.V.; Damianidis, D. Climate change and ENSO effects on Southeastern US climate patterns and maize yield. *Sci. Rep.* **2016**, *6*, 29777. [CrossRef] [PubMed]
4. Tebaldi, C.; Hayhoe, K.; Arblaster, J.M.; Meehl, G.A. Going to the extremes. *Clim. Chang.* **2006**, *79*, 185–211. [CrossRef]
5. Rosenzweig, C.; Tubiello, F.N. Adaptation and mitigation strategies in agriculture: An analysis of potential synergies. *Mitig. Adapt. Strateg. Glob. Chang.* **2007**, *12*, 855–873. [CrossRef]
6. Paparrizos, S.; Maris, F.; Weiler, M.; Matzarakis, A. Analysis and mapping of present and future drought conditions over Greek areas with different climate conditions. *Theor. Appl. Climatol.* **2018**, *131*, 259–270. [CrossRef]
7. Mjachina, K.V.; Baynard, C.W.; Chibilyev, A.A.; Richardson, R.D. Landscape disturbance caused by non-renewable energy production in a semi-arid region: A case study on the Russian steppe. *Int. J. Sustain. Dev. World Ecol.* **2018**, *25*, 541–553. [CrossRef]
8. Blumberga, A.; Bazbauers, G.; Davidsen, P.I.; Blumberga, D.; Gravelsins, A.; Prodanuks, T. System dynamics model of a biotechonomy. *J. Clean. Prod.* **2018**, *172*, 4018–4032. [CrossRef]

9. Lobell, D.B.; Schlenker, W.; Costa-Roberts, J. Climate trends and global crop production since 1980. *Science* **2011**, *333*, 616–620. [CrossRef] [PubMed]
10. Wegren, S.K. Food security in the Russian Federation. *Eur. Geogr. Econ.* **2013**, *54*, 22–41. [CrossRef]
11. Dow, K.; Downing, T.E. *The Atlas of Climate Change: Mapping the World's Greatest Challenge*; University of California Press: Oakland, CA, USA, 2016.
12. Dhillon, R.; von Wuehlisch, G. Mitigation of global warming through renewable biomass. *Biomass Bioenerg.* **2013**, *48*, 75–89. [CrossRef]
13. Rylko, D.; Jolly, R.W. Russia's new agricultural operators: their emergence, growth and impact. *Comparative Econ. Stud.* **2005**, *47*, 115–126. [CrossRef]
14. Pavlov, A. Current changes of climate and permafrost in the Arctic and sub-Arctic of Russia. *Permafr. Periglac. Proc.* **1994**, *5*, 101–110. [CrossRef]
15. Gruza, G.; Ran'kova, E.Y. Climate oscillations and changes over Russia. *Rus. Acad. Sci. Atmos. Ocean. Phys.* **2003**, *39*, 145–162.
16. Demezhko, D.Y.; Gornostaeva, A. Late Pleistocene–Holocene ground surface heat flux changes reconstructed from borehole temperature data (the Urals, Russia). *Clim. Past* **2015**, *11*, 647–652. [CrossRef]
17. Jasukevic, V.; Sobolev, V. *Second Roshydromet Assessment Report on Climate Change and its Consequences in Russian Federation*; Roshydromet: Leningrad, Russia, 2014.
18. Vinogradova, V.; Titkova, T.; Belonovskaya, E.; Gracheva, R. Vozdeistvie izmeneniya klimata na gornye landshafty Severnogo Kavkaza (The impact of climate change on mountain landscapes of the North Caucasus). *Sovrem. Probl. Distantsionnogo Zondirovaniya Zemli Kosmosa* **2015**, *12*, 35–47.
19. Grinevetsky, S.R.; Zonn, I.S.; Zhiltsov, S.S.; Kosarev, A.N.; Kostianoy, A.G. *The Black Sea Encyclopedia*; Springer: Berlin, Heidelberg, 2015; ISBN 978-3-642-55227-4.
20. Van Geel, B.; Bokovenko, N.; Burova, N.; Chugunov, K.; Dergachev, V.; Dirksen, V.; Kulkova, M.; Nagler, A.; Parzinger, H.; Van der Plicht, J. Climate change and the expansion of the Scythian culture after 850 BC: A hypothesis. *J. Archaeol. Sci.* **2004**, *31*, 1735–1742. [CrossRef]
21. Slyadnev, A.; Sennikov, V. Teplo-i vlagoobespechennost'vegetatsionnogo peri-oda sel'skokhozyaystvennykh kul'tur na yugo-vostoke Zapadnoy Sibiri (lesostep'i step'). *Geogr. Zapadn. Sibiri Klimatol.* **1969**, *42*, 21–34.
22. Chernikova, M.I. (Ed.) *Agroclimatic Resources of the Altai Region*; Gidrometeoizdat: Leningrad, Russia, 1971; 156p. (In Russian)
23. Sennikov, V.A.; Slyadnev, A.P. *Agroklimaticheskie Resursy Yugo-Vostoka Zapadnoy Sibiri i Produktivnost Zernovykh Kultur [Agro-Climatic Resources of the South-East of West Siberia and Grain Crop Productivity]*; Hydrometeoizdat Publ.: Leningrad, Russia, 1972; 150p. (In Russian)
24. Tushinsky, G.; Akifyeva, K.; Volodicheva, N.; Kondakova, N.; Kravtsova, V.; Konstantinova, G.; Rakita, S.; Troshkina, E. Avalanches of the USSR. Physics of Snow and Ice. In Proceedings of the International Conference on Low Temperature Science, Sapporo, Japan, 14–19 August 1966; Volume 1, pp. 1295–1309.
25. Garms, E.O.; Sukhova, M.G.; Zhuravleva, O.V.; Karanin, A.V.; Minaev, A.I. Distinctness and Endemicity of the Vegetative Cover of Altai Transboundary Mountain Region and its Conservation as a Part of the Strategy for Altai Sustainable Development. *J. Environ. Manag. Tour.* **2017**, *8*, 686–695.
26. Buslov, M.; Saphonova, I.Y.; Watanabe, T.; Obut, O.; Fujiwara, Y.; Iwata, K.; Semakov, N.; Sugai, Y.; Smirnova, L.; Kazansky, A.Y. Evolution of the Paleo-Asian Ocean (Altai-Sayan Region, Central Asia) and collision of possible Gondwana-derived terranes with the southern marginal part of the Siberian continent. *Geosci. J.* **2001**, *5*, 203–224. [CrossRef]
27. Eichler, A.; Olivier, S.; Henderson, K.; Laube, A.; Beer, J.; Papina, T.; Gäggeler, H.W.; Schwikowski, M. Temperature response in the Altai region lags solar forcing. *Geophys. Res. Lett.* **2009**, *36*. [CrossRef]
28. Schlütz, F.; Lehmkuhl, F. Climatic change in the Russian Altai, southern Siberia, based on palynological and geomorphological results, with implications for climatic teleconnections and human history since the middle Holocene. *Veg. Hist. Archaeobot.* **2007**, *16*, 101–118. [CrossRef]
29. Enkhtaivan, D. Physical-geographical characteristics of the Altai region. In *Environmental Security and Sustainable Land Use-with Special Reference to Central Asia*; Springer: Dordrecht, the Netherlands, 2006; pp. 349–351.
30. Slyadnev, A. *Ocherki Klimata Altayskogo Kraya*; Altai knizhnoye izdatel'stvo: Barnaul, Russia, 1958.

31. Schiemann, R.; Lüthi, D.; Vidale, P.L.; Schär, C. The precipitation climate of Central Asia—Intercomparison of observational and numerical data sources in a remote semiarid region. *Int. J. Climatol. J. R. Meteorol. Soc.* **2008**, *28*, 295–314. [CrossRef]
32. Zolotokrylin, A.; Cherenkova, E. Changes of indicators of the rate of heat and humidity, bioreproduction in zonal plain landscapes of Russia in the second half of XX century. *Izv. Ross. Akad. Nauk Ser. Geogr.* **2006**, *3*, 19–28.
33. Zolotokrylin, A.; Cherenkova, E. Area of Russia's arid plain lands. *Arid Ecosyst.* **2011**, *1*, 8–13. [CrossRef]
34. Cherenkova, E. Quantitative Evaluation of Atmospheric Drought in Federal Districts of the European Russia. *Izv. RAN Ser. Geogr.* **2013**, *6*, 76–85.
35. Mazhitova, G. Soil temperature regimes in the discontinuous permafrost zone in the East European Russian Arctic. *Eurasian Soil Sci.* **2008**, *41*, 48–62. [CrossRef]
36. Kelchevskaya, L.S. *Metody Obrabotki Nablyudeniy v Agroklimatologii: Metodicheskoe Posobie [Methods of Observation Processing in Agro-Climatology: Study Guide]*; Hydrometeoizdat: Leningrad, Russia, 1971; 215p. (In Russian)
37. Bulgakov, D.S.; Rukhovich, D.I.; Shishkonakova, E.A.; Vil'chevskaya, E.V. Separation of agroclimatic areas for optimal crop growing within the framework of the natural–agricultural zoning of Russia. *Eurasian Soil Sci.* **2016**, *49*, 1049–1060. [CrossRef]
38. Kühling, I.; Broll, G.; Trautz, D. Spatio-temporal analysis of agricultural land-use intensity across the Western Siberian grain belt. *Sci. Total Environ.* **2016**, *544*, 271–280.
39. Khromov, S.P.; Mamontova, L.I. *Meteorologicheskiy Slovar [Meteorological Dictionary]*; Hydrometeoizdat Publ.: Leningrad, Russia, 1974; 568p. (In Russian)
40. Obyazov, V.A.; Noskova, Y.E.V. Long-term changes in agro-climatic resources of Transbaikalia. *Vestn. Zabaykalskogo Gos. Univ.* **2015**, *8*, 20–29. (In Russian)