Contemporary climatic changes in the Predbaikalie region

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Abstract
The analysis of long-term changes of the major climate variables was conducted using a time series of observations from meteorological stations that had continuous observations from 65 up to 120 years. The surface air temperature in the region is characterized by considerable temporal variability which is most apparent in the winter months and thus in the annual values. The positive regional trends of the surface air temperature vary from 0.2 to 0.6 ◦C per decade. On a century time scale, a tendency for a reduction of the annual precipitation totals prevails. However, the trend values are much lower than the interannual variability of precipitation.

Analyzing the historical climatic conditions of the Baikal Region, we found that the occurrence of drought is possible in any month of the vegetation period, particularly in May, when the maximum numbers of dry years (33–64%), and the years with strong droughts (8–15%) were documented. The influence of climatic conditions on annual wood growth was studied using the response function technique. Results of this analysis show that in the Middle Priangarye region, the greatest impact upon the tree ring growth of pine reflects the mean April temperature, and in the Upper Priangarye region, annual atmospheric precipitation totals (for the hydrological year) control this growth.

Keywords: climate change, Predbaikalie, surface air temperature, precipitation, short-wave solar radiation, hydrothermal coefficient, drought, excessive moistening, coefficient of continentality, radial wood growth

1. Introduction

The climate change issue attracts the attention of researchers and is among the most important natural science issues. Climate trends of meteorological variables are presented in a number of publications and support the opinion that climate warming has been occurring in recent decades (IPCC 2007). Furthermore, there is evidence that contemporary warming is occurring on the background of 500 000 years of a slow decrease in global surface air temperatures (Kotlyakov 2005).

Surface air temperature change is one of the most important indicators of climate change; therefore, particular characteristics of its seasonal cycle, the secular trends and interannual variability are well studied. The current data indicate that the surface air temperature increased by 0.2 ◦C during the 20th century (Israel et al 2001, IPCC 2007).

The global warming was temporally heterogeneous. Three periods are singled out: warming within the intervals of 1881–1945, a slight cooling of the Northern Hemisphere during the 1946–75 period and intense warming thereafter. These periods are characterized by spatial inhomogeneity, i.e. in some areas the warming is more intensive and in some regions even cooling had occurred (IPCC 2007, Anisimov et al 2003). The largest positive trends in annual surface air temperature are observed mainly in the continental interior of the extratropics (Predbaikalie, Central Yakutia and the far east of Russia) up to 2–3.5 ◦C over a 100 year period (Novorotsky 2004, Gruza and Rankova 2004). Our study region is within this area.

Our primary objectives in this study are to describe the spatial distribution and temporal structure of long-term climate changes over the Predbaikalie area and to reveal the influence of the Angara River cascade reservoirs on these changes.
2. The study area

The Predbaikalie area is situated in the temperate latitudes of the Northern Hemisphere in Eurasia within latitudes 52–62 N and longitudes 95–118 E. Predbaikalie is located in a zone of active interaction of eastern and western air masses in a region with a prolonged cold season, an anticyclonic synoptic situation (Siberian high) and a continental climate. Annual air temperatures in Predbaikalie are below zero (from −0.9 to −8.8 °C). Annual and diurnal temperature ranges are high due to its distant location from oceans. Annual precipitation totals vary from 260 mm at Lake Baikal to 1400 mm in the Eastern Sayan Mountains. About 75% of precipitation occurs during the warm period from April to November (Scientific and Applied Handbook . . . 1991).

Altitude zones of soil and vegetation cover include steppe, mountain and taiga landscapes. Middle mountain relief dominates the area.

The Predbaikalie area is a region of inner-continental Asia where climatic changes have strongly developed during the last few decades. Analysis of natural and climatic changes over the studied area is important because this area has large water reservoirs (Lake Baikal, Angara River cascade), and large contrasts in land cover with a background of intense human activity. The southern boundary of the permafrost lies within the studied area.

3. Data and methods

We are assessing the long-term changes in key climate characteristics (temperature, precipitation and solar radiation) in Predbaikalie for the period of instrumental observations. Long-term observations exist at meteorological stations of the Roshydromet Irkutsk district for periods from 65 to 120 years. These stations cover the primary landscape zones of the study area. Fifty-six weather stations were used to analyze temporal variations in temperature and precipitation, and ten actinometrical stations were used to study short-wave solar radiation (Handbook on Climate . . . 1969–72; Meteorological Monthly Bulletin 1966–2000). Monthly mean, annual and extreme values of the studied climatic characteristics were used. Linear trend coefficients (using ordinary least-squares regression) are calculated for each station to characterize the intensity of climatic changes.

The variation in wetness and dryness conditions was studied using the renowned Selyaninov hydrothermal coefficient (HTC) (Selyaninov 1928) and Ped’s index (S.) (Ped’ 1975)

\[ HTC = \frac{\sum R}{0.1 \sum T}, \]

where \( \sum R \) is precipitation total for the growing season (in millimeters) and \( \sum T \) is the accumulated mean daily surface air temperatures above 10 °C for the same period.

Using the HTC, we assessed dry conditions in steppe and forest-steppe landscapes across the south of Eastern Siberia for the period of active vegetation (June–August). The following thresholds were used to define a drought condition, HTC = 0.8 or less, and HTC values of 0.4 or less indicated severe droughts.

\[ S_i = \frac{\Delta T}{\sigma_T} - \frac{\Delta R}{\sigma_R}, \]

where \( \Delta T, \Delta R \) are the anomalies (deviations from the long-term mean) of monthly mean air temperatures and the amount of precipitation, and \( \sigma_T, \sigma_R \) are their standard deviations.

Negative values of \( S_i \) characterize the months/seasons that were excessively humid, and the degree of humidification increases with a decrease of \( S_i \). Positive \( S_i \) values are associated with drier atmospheric conditions, which increase with the \( S_i \) increase. Drought conditions are characterized by the indices: \( 1 < S_i < 2 \) as a weak drought, \( 2 \leq S_i < 3 \) as a medium drought, and \( S_i \geq 3 \) as a strong drought. Excessively humid conditions are characterized by the indices: \( -2 < S_i < -1 \) as slightly wetter than usual, \( -3 < S_i \leq -2 \) as moderately wet conditions, and \( S_i \leq -3 \) indicates very wet conditions.

The climate within the reservoir area is continental, with severe long and dry winters and warm summers with abundant rainfall. These climate features are closely connected with the peculiarities of the physical and geographical areas and the atmospheric circulation. To determine the climatic impacts of the Bratsk and Ust-Ilim reservoirs on the surrounding areas, we selected a subset of surrounding meteorological stations. Some of them were previously located within the bed of current reservoirs and were thereafter moved away from the flood zone (Chama, Bratsk, Ust-Uda, Balagansk, Shamanovo). Other stations were moved insignificantly (by 1–5 km) when filling the reservoirs (Tangui, Rasputino). The subset also includes stations located at some distance from these artificial water bodies (Angarsk, Cheremkhovo, Golovinskoye, Zalari, Lukinovo, Ust-Orda, Bekhan). These stations were used to assess the influence of the reservoir area on the changes of individual climate variables. In addition, the reference weather stations not exposed to water reservoirs (so-called ‘continental’; Zima, Nizhneudinsk, Shitkino, Zhigalovo, Bayanday, Maximovo) were used, thereby providing the background regional climatic conditions (figure 1).

The importance of temperature for theoretical climatology and its use in numerous applications necessitates an in-depth analysis of its pattern and changes. Therefore, we assessed the mean monthly surface air temperature for January, May, July and November, the mean annual surface air temperature during the entire observation period, and the absolute monthly and annual maximum and minimum temperatures in the 21 pairs of stations, where 15 pairs belong to the Bratsk reservoir and six to the Ust-Ilim reservoir. The selection of stations was carried out based on the principle of minimum relocation distance of stations after filling the reservoir. The months were chosen in order to trace the impact of reservoirs on the surface air temperature in all seasons. While doing this, the temperature contrast (water–air) and reservoirs’ ice regimes were taken into account.

We used the coefficient of continentality defined by Gorchinsky:

\[ K = C \frac{A - 12 \sin \varphi}{\sin \varphi}, \]
where $A$ is the annual range of temperature, and the expression $12 \sin \varphi$ characterizes the average annual range of temperature over the ocean within the zone between $30^\circ$N and $60^\circ$N. Thus, the actual annual amplitude is subtracted from the annual latitudinal range that is characteristic for a ‘mean oceanic climate’. The coefficient $C$ is determined from an assumption that an average continentality over the ocean (i.e. $A = 12 \sin \varphi$) is equal to 0, and for the Siberian standard of continentality, the Verkhoyansk city is equal to 100. After some transformations, formula (1) becomes:

$$K = \frac{1.7A}{\sin \varphi} - 20.4. \quad (2)$$

We calculated the $K$-coefficients before and after filling of the reservoirs according to formula (2) and compared their values.

Samples of ordinary pine tree ($Pinus sylvestris$ Ledeb.) were used for dendroclimatic analysis. This tree has pronounced annual rings, long life, ecological flexibility, and its radial increments are highly sensitive to environmental factors. Because of its eco-biological properties, the pine tree occupies the warmest and driest places, and is thus subjected to a strong influence from the steppe which makes an impact on the spread of steppe species in grass coverage and underbrush.

Long and uniform series of observations are the most valuable for detection of climatic variations over recent decades and for calibration of the models of the relation between tree rings series and other data. The computation and analysis of the function of radial increments’ responses on basic climatic factors were performed using the program packages DPL-99 (the RESPO program) and ‘STATISTICA V.5’. The method of principal components, which employs the correlation matrix decomposition in terms of orthogonal functions, was used to estimate the dependence of tree increment variability on various factors. To estimate correctly the climatic component in a tree increment, the age trend should be filtered out. The process of low-frequency filtration of a series from aging variability is realized by a standardization procedure (Fritts 1976). Standardization of absolute chronologies provided the standard (Std) and residual (Res) chronologies. The residual chronologies resulted from modeling by an autoregression (AR) process (Cook 1985) or by a process of autoregression moving average (ARMA) (Guiot 1986) which removed the autocorrelation component from the chronologies. The autoregression order was determined after Akaike’s information criterion (Akaike 1974).

4. Results and discussion

4.1. Regional climatic changes

Regional changes in short-wave solar radiation are affected by contaminants of natural and anthropogenic origin (industrial emissions, volcanic eruptions, the smoke originating from forest fires, etc). A steady decrease in the arrival of total and direct radiation, and a certain increase in the scattered component are dominant for all weather stations.

The surface air temperature in the region is characterized by significant temporal variability, which is most noticeable in the winter months and thus in the mean annual temperatures. In almost all areas of the Irkutsk region, a significant increase in mean annual surface air temperature has been observed since the mid-1960s.

It should be noted that while the southern part of the Irkutsk region during the entire observation period is characterized by a systematic increase in mean annual temperatures, for the stations located farther to the north the trend sign changed from negative to positive in the late 1960s. Thus, the trends varied dramatically across the region, with an average change at the network of selected weather stations equal to $0.39$ °C per decade.

The average deviation of annual mean temperature at the meteorological observing stations over the period 1960–2000 is $0.4–0.7$ °C. The contribution to the total variance of the trend does not exceed 15% up to 1960 at the meteorological observing stations of Prebaikalia, but in the second half of the 20th century it reached 40%. Moreover, the maximum values are found in large industrial centers. The contribution to the variance of the trend throughout the period of instrumental records is 3–8% in sparsely populated areas.

The linear warming trend of the global average temperature over the last 50 years is $0.13$ °C (0.10–0.16 °C) per decade (IPCC 2007). Changes in air temperature in the western Baikal region occur simultaneously with the global changes, but regional trends are 3–4 times higher than global ones. Studies by other authors confirm the assertion that the
most significant changes in air temperature are observed in the inland areas of Eurasia. The temperature trends for the period of most intense warming in Russia are on average 0.43 °C per decade (Assessment Report 2008, Gruz and Rankova 2004). Regions with a strong continental climate similar to Predbaikalie have temperature trends of 0.4–0.6 °C per decade (Transbaikalia and Yakutia), while regions with a softer climate, like the Amur, Primorie, Western Siberia have trends of 0.2–0.3 °C per decade (Novorotsky 2004, Obyazov 1999, Assessment Report 2008).

Temperature change in the United States and the global mean have some similarity, but they are not congruent. In particular, evidence for long-term warming in this century is less convincing for the United States than it is for the rest of the world. The US temperature increased by about 0.3 °C between the 1970s and the 1990s (Hansen et al 1999).

According to modern studies (Earth System Atlas 2010), warming is strongest over the continental interior areas of the Northern Hemisphere. Northwestern North America warmed at a rate of 1.6–1.8 °C per decade (for the period 1966–2005). Interior regions of Asia have trends of 0.5–0.8 °C but areas close to oceans have smaller trends (0.2 °C). Strongly warming areas exist in Greenland (0.7 °C per decade).

Precipitation is one of the most essential climate variables. The spatial heterogeneity of its distribution over Predbaikalie is stipulated by a complex combination of orographic factors and atmospheric circulation. A decreasing tendency prevails in long-term annual precipitation changes. However, at all sites the trend values are significantly lower than the interannual precipitation variations.

Thus, an increase in mean annual surface air temperatures in the late 20th century over the territory of Predbaikalie is observed, together with a decrease in annual precipitation and incoming surface short-wave solar radiation (figure 2).

In addition to studying variations of separate climatic variables, it is worthwhile to investigate some integral climate characteristics of practical importance, e.g. different humidity and/or aridity indices, that in most cases are constructed as combinations of surface air temperature and precipitation values. Drought frequency (using our threshold definition) was calculated for each month of the warm season and for the entire vegetation period. June is a ‘critical’ month for humidification; in the period of vigorous cyclonical activity in July and August a sufficient or even excessive moistening is usually registered. Averaging of HTC for the entire vegetation period results in an increase of the mean HTC value, which smooths the differences in moisture conditions among the individual months (Gustokashina and Maksyutova 2004).

Ped’ (1975) proposed a landscape index $S_i$ as more appropriate to study and compare droughts in different landscapes. Drought or excessive moistening of a particular region in a definite season is characterized not by absolute values of temperature and precipitation, but by their anomalies from climatological norms (long-term mean values).

Results based on the analysis of $S_i$ variations largely repeat those based on Selyaninov’s coefficients, due to a high correlation between them (Gustokashina and Maksyutova 2006).

For the Predbaikalie area, tendencies for changes of the aridity index $S_i$ were calculated for a 60 year period (1940–2000) and the trends in most cases were found to be statistically insignificant.

The period of instrumental observations for most of the stations in Predbaikalie began after the 1940s. We made an attempt to assess the previous years, having calculated all indices for long-term meteorological station the Irkutsk Observatory, where contemporary meteorological observations have been carried out since 1882. This analysis shows that in the past 70 years, the number of weak atmospheric droughts in all months of the vegetation period has increased (and the number of weak excessively wet periods has decreased).

We found an increase in moderate droughts in all months, a decrease in the occurrence of moderately wet periods in May–June, and an increase in July–September. For the phenomena of severe drought and strong excessive moistening, an increase of severe dry conditions in early summer and an increase in occurrence frequency of excessive moistening periods in August–September were found (figure 3).

4.2. Influence of reservoirs on climate

Reservoirs represent one of the forms of human influence on regional hydrothermal conditions. Their construction causes significant changes in the microclimate of the coastal zone and further inland. The temperature regime within the coastal area depends not only on the general circulation patterns, but also on...
exposure to the nearby water body. The level of the influence of the water body depends upon the distance from the coast, the depth of the reservoir and its size, the prevailing wind direction, season, latitude, and on the moisture regime of the area. We investigated the impact of large reservoirs (such as Bratsk and Ust-Ilim) on the changes in surface air temperature and precipitation in surrounding areas.

The Bratsk reservoir, one of the largest in Russia, is located in the south of the Central Siberian Plateau, along the rivers Angara, Oka, Iya, and their tributaries. It was filled from 1 September 1961 to 14 September 1967 with varying intensity depending upon the introduction of hydroelectric power work units and the dam’s characteristics. The water surface area of the reservoir reaches up to 5470 km², and the storage capacity up to 170 km³. In Russia, the Bratsk reservoir is the second largest according to area after the Samara reservoir (6450 km²), but its volume is three times larger. The average depth of the reservoir is 31 m, and is up to 155 m at its deepest (Bratsk Reservoir 1973). The Ust-Ilim reservoir is located in the valley of the Angara River and its tributary the Ilim river. It was formed while constructing the Ust-Ilimsk Hydro-Power Plant and is the third in the Angara cascade. The Ust-Ilim reservoir was filled during 1974–77. It is also considered a large artificial water body; its water surface area can be as large as 1883 km². The depth of the reservoir at the hydroelectric dam is 90 m. The mean depth increases downstream of the dam and varies in the range of 16–49 m, with the maximum depth from 29 to 94 m (Voropayev and Avakian 1986).

The climate within the reservoir area is continental, with severe long and dry winters and warm summers with abundant rainfall. These climate features are closely connected with the peculiarities of physical and geographical areas and the atmospheric circulation.

The first ice formations on reservoirs appear in November. At this time, the maximal warming impact of the reservoir must occur at relatively low temperatures and water temperature close to 0°C. In January the reservoirs are completely covered by ice; the ice cover begins to break down in May, and the situation is reversed to the November condition. In July, the water temperature of the reservoirs reaches its maximum (Hydrometeorological Regime... 1978).

We estimated an increase in mean surface air temperature in November after the construction of reservoirs to be equal to 2.5–3.0°C, while in all coastal stations a decrease in maximum July temperatures by 1.0–2.0°C is observed.

Analysis of spatial differences in surface air temperature between the pairs of stations, one of which is located within the zone of the reservoir and the other certainly outside of it (located far away), revealed the warming impact of the reservoirs in the cold months (November and January). That is, for the period after 1968 at the stations of the Bratsk reservoir, and after 1977 at the stations of the Ust-Ilim reservoir, spatial differences not only increased in absolute values, but also changed sign. The maximum change in surface air temperature differences, which characterize the most intense warming impact of the reservoirs in the Bratsk reservoir, are observed at stations Bratsk, Kaltuk and Zayarsk (3.7, 1.9, 1.5°C in January, and 2.2, 3.1, 2.7°C in November, respectively). In the region of the Ust-Ilim reservoir, the biggest changes were observed at the stations Zheleznogorsk (3.8°C in January), and New Igirma (2.5°C in January and 2.8°C in November). A cooling effect is observed at most stations in May. In July, no significant differences of mean monthly air temperature were found. The specifics in differences identified by our analyses are consistent with the change of the temperature contrast between air and water in the reservoirs.

Extreme temperatures have also changed their values with the reservoirs’ construction. An average of the absolute minimum for all considered coastal stations, located at a

**Figure 3.** The frequency of drought occurrence and periods of excessive moisture in Irkutsk.
distance of not more than 10 km from the coast, has increased by 5.9°C after construction of the reservoirs compared to the period before their filling. The largest increase of absolute minima is seen at the station Bratsk (−8.7°C). The changes in the absolute maxima at coastal stations are not so large. On average, their values are close to −0.5°C, and the largest changes are observed in Bratsk (−2.2°C) and Zheleznogorsk (−2.5°C). This suggests that the cooling effect of these two reservoirs appears to be much weaker than the warming effect.

The absolute amplitude of the annual cycle of surface air temperature decreased by 2.8°C on average at the coast of the Bratsk reservoir, and by 4.2°C at the coast of the Ust-Ilim reservoir. The largest decrease was again in Bratsk (−15.1°C). However, the overall regional increase of winter temperatures played an important role in the observed changes, apart from the impact of the reservoir.

Vendrov et al (1968) argued that the climate continentality decreases in the reservoirs’ zone of influence compared with the period prior to their establishment. This analysis shows that at almost all stations (except Lukinovo and Kochenga) the coefficient of continentality decreased on average by 4–5%. Thus, after filling of these reservoirs, the climate of their coastal areas has become milder. Near the Bratsk reservoir, the greatest changes occurred at stations Balanskiy (−6.5%), Shamanovo (Kaltuk) (−6.6%) and Bratsk (−8.6%). Near the Ust-Ilim reservoir, the greatest changes occurred at stations Ilimsk (Zheleznogorsk) (−10.4%) and Nevon (−7%). However, we cannot assume a general decrease of the regional climate continentality due to the influence of the Bratsk and Ust-Ilim reservoirs. Such changes occurred only in the areas adjacent to the reservoir that do not exceed 10 km. The conclusion about the decrease of continentality of coastal areas is consistent with the findings of others (Vendrov et al 1968, Vendrova 1970, etc).

The analysis of the changes in the mean seasonal and annual precipitation over areas adjoining reservoirs led to the following conclusions: after the filling of reservoirs in May–June and July–August, as well as for the entire year, the precipitation totals decreased by 14%, 10% and 9% respectively. In September and October the precipitation amount decreased (by ∼9%) at 25 of the considered stations and increased (by ∼9%) at the rest (three stations), making the regional precipitation change insignificant in these months. In November and December half of the stations, which include all ‘mainland’ stations, show a reduction in precipitation (by 11%), and the other half an increase (by ∼15%) (Gustokashina and Balybina 2005, Bezrukov et al 2000).

The use of spatial differences was an attempt to remove from consideration the influence of global climate fluctuations. After construction of the Bratsk reservoir, at the stations located on its shores, the decrease in the average precipitation in May–June and November–December slowed down. However, the change in the differences was negligible and (most likely) a consequence of the introduction of wetting corrections in all time series in 1966–67 (Schwer 1976). In July–October, the temperature contrast of ‘air–water’ is significant, hence evaporation from the reservoir surface increases, so we could expect increases in the probability of formation of clouds and precipitation. However, after the construction of the reservoirs, seasonal precipitation totals decreased rapidly at all coastal stations in July and August, compared with the ‘continental’ sites. This effect was previously observed in the surrounding regions of other reservoirs (Voropayev and Avakian 1986) where a large, relatively cold water body suppresses convection in the middle of summer. So far, we can only state significant changes in mean annual precipitation at the stations located near the reservoirs in Predbaikalie.

The most significant changes in precipitation influenced by reservoirs are observed directly at the shore and at a distance of 3–5 km away from it. Farther away from the water body, we see a decrease in the reservoirs’ impact. The results of correlation analysis show that the distance from the water area to the station affects the change in precipitation, but only in November and December ($r = −0.34$ that is statistically significant at the 0.05 level). In other months, these coefficients are insignificant, indicating that the fluctuations of seasonal and annual precipitation are not strongly defined by the reservoirs’ impact. It should be noted again that the precipitation changes are observed at both coastal and ‘continental’ stations, which means that they have a regional nature.

The above provides our estimates of the impact of the Bratsk and Ust-Ilim reservoirs on the precipitation and temperature of the surrounding land. Below we summarize them. This impact on surface air temperature of the adjacent land is sufficiently strong to be documented (and the warming effect of reservoirs is more pronounced than the cooling effect). However, this more significant effect of warming may occur on the background of a general regional surface air temperature increase in the cold season. A decrease in precipitation occurs everywhere in Predbaikalie. However, after the construction of the Bratsk and Ust-Ilim reservoirs, at stations located directly on their coasts or within a few kilometers from the water area, seasonal precipitation and average annual totals decrease even faster than at the ‘continental’ stations outside the zone of the reservoirs’ impact. We do not speak about a catastrophic decrease in rainfall due to the reservoirs’ construction, because in the last few decades there were years when the region received less rainfall than normal (70–80%). For example, station Vikhorevka, located 35 km away from the reservoir, received in 1989 an annual rainfall that was 73% of the long-term mean value. Finally, let us remember that Predbaikalie is within the zone of scarce water resources where annual precipitation totals may be as low as 250–300 mm, and a decrease (during the dry years) across East Siberia by 30–50 mm is significant for this area. Figure 4 conceptually depicts the above conclusions and shows that at the stations located at the reservoirs, compared to the ‘continental’ stations, changes in air temperature and precipitation are expressed strongly in the winter months. The influence of the reservoirs on the air temperature in summer and precipitation throughout the year is nearly absent (except for the stations located directly on the reservoir).
Table 1. Correlation coefficients of indices of atmospheric circulation (according to Dzerdzeewsky’s classification) and radial increment of pine tree rings.

| Period     | Groups of atmospheric circulation forms | Regions of Predbaikalie                                      |
|------------|-----------------------------------------|------------------------------------------------------------|
|            |                                         | Middle Angara Region | Upper Angara Region | Ol’khon Region |
| Winter     | Zonal western and stationary position    | 0.41 | 0.31 | 0.15 |
|            | Meridional northern and zonal eastern    | −0.21 | 0.17 | 0.33 |
| Summer     | Zonal western                          | 0.35 | 0.42 | 0.28 |
|            | Zonal western and meridional southern   | 0.18 | 0.16 | 0.24 |

The correlation coefficient between the series of continentality and the tree rings width for the period before the reservoir infilling is 0.33, but after the infilling it became equal to −0.05. Thus, we can say that as a result of smoothing of the temperature regime, which is a limiting factor for radial wood growth, the surface air temperature in the cold season has lost its controlling role in the pine productivity.

Atmospheric circulation is a global factor controlling climatic conditions of the region, and as a consequence the dynamics of its biosphere productivity (in particular, tree growth). Various versions of classification of atmospheric processes are used for analyzing the changes in the general atmosphere circulation (we used two such classifications of synoptic processes proposed by Girs (1971) and Dzerdzeevsky (1975)). These classifications are built with consideration of the direction of leading air flows and are consistent with the position and orientation of the high-altitude troughs and ridges. The Dzerdzeevsky classification is more detailed and has distinct morphological features which allow allocation of periods with different modes of circulation more confidently. Below we present the results of research on the relationship between atmospheric circulation and the dynamics of tree ring growth in the territory of Predbaikalie. We have considered three plots located in different physiographic conditions of Predbaikalie: the Middle Angara Region, the Upper Angara Region and the Ol’khon Region.

Figure 6 shows the dynamics of Dzerdzeevsky circulation types in summer over the Northern Hemisphere from 1900 to 2002 and radial growth of pine in various parts of Predbaikalie. Changes in the frequency of the atmospheric circulation types and the dynamics of tree radial growth occurred after the 1950s. Significant relationships (correlation coefficients up to 0.42) between these parameters are observed in the period from 1951 to 2002 (table 1), while the 50 year rates of change do not exceed 0.1. For a definition and description of Dzerdzeevsky circulation types, see Dzerdzeevsky (1975).

5. Conclusions

Over the territory of Predbaikalie, an increase in the mean annual surface air temperature in the late 20th century is observed, as well as lower annual precipitation totals and smaller values of incoming short-wave solar radiation. Maximal rates of warming have been recorded since the mid-1980s. Regional trends in air temperature exceed global tendencies by 1.5–2.5 times.
Figure 5. Dynamics of climate continentality and tree ring width (in the vicinity of the town of Bratsk).

Figure 6. Frequency occurrence of the Dzerdzevsky circulation types in the summer season, and annual radial increments of pine tree rings in different regions of Predbaikalie.
We assessed arid conditions in steppe and forest-steppe landscapes within the south of Eastern Siberia for the period of active vegetation (June–August) and found that June is a ‘critical’ month for humidification of the region. Thereafter in July and August, a period of vigorous cyclonical activity usually occurs, causing a sufficient or even excessive moistening of the region.

The Bratsk and Ust-Ilim reservoirs have an impact on the air temperature of the adjacent land (and the cold season warming effect is more pronounced than the warm season cooling effect). However, a more significant effect of warming may be seen on the background of a general regional surface air temperature increase in the cold season. Due to smoothing of the seasonal amplitudes of the temperature after the construction of the reservoirs, the surface air temperature has lost its dominant role as a limiting factor in radial tree ring growth. Systematic changes in the frequency of the occurrence of atmospheric circulation types and the dynamics of tree ring radial growth were observed after the 1950s.

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