

Droughts and Excessive Moisture Events in Southern Siberia in the Late XXth - Early XXIst Centuries

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Abstract. In recent years much research has been devoted to global and regional climate changes. Special attention was paid to climate extremes, such as droughts and excessive moisture events. In this study the moisture and aridity of Southern Siberia are estimated using web-GIS called “CLIMATE”. The system “CLIMATE” is part of a hardware and software cloud storage complex for data analysis of various climatic data sets, with algorithms for searching, extracting, processing, and visualizing the data. The ECMWF ERA-Interim reanalysis data for Southern Siberia (50-65°N, 60-120°E) from 1979 to 2010 with a grid cell of 0.75×0.75° is used. Some hydrothermal conditions are estimated using the so-called Ped index (S_i), which is a normalized indicator of the ratio of air temperature to precipitation. The mountain regions of Eastern Siberia are becoming more and more arid each month during the last 30 years. In Western Siberia, aridity increases in May and decreases in June, in the other months positive and negative trends are found. The greatest differences between the trends of the aridity index (S_i), air temperature, and precipitation are observed in July.

1. Introduction

The global and regional climate changes have been intensively discussed in the recent years by scientific community [1, 2]. Monthly and annual air temperature and atmospheric precipitation are usually analyzed. Changes in extreme values of air temperature and precipitation are analyzed rarely. Extreme climate parameters are associated with drought and excessive moisture periods.

A drought is a complex natural phenomenon with strong regional anomalies of temperature and humidification [3]. A drought is defined as a period in which humidity is below a statistical average expected for that location. It is part of natural variability of climate and weather. Due to the complex structure of a drought, scientists are usually limited to studying one of its aspects. Depending on the purpose of study, they investigate atmospheric drought or soil drought only. Unfavorable weather or climatic conditions significantly reduce the agricultural potential of climate. Active heating and relative air desiccation occur at an atmospheric drought. At the same time, there is no precipitation and large incoming solar radiation.

Various approaches to the definition of drought are widely discussed depending on characteristic types and conditions of drought formation. Some representative aridity indices were developed [4-7], catastrophic droughts were analyzed [8-10], and a catalog of droughts was composed [11].



There is no clearly expressed periodicity in droughts or a certain trend in the frequency and intensity of droughts over the territory of Russia in the 20th century. A tendency to increase the frequency of droughts is observed only in some regions [1].

Traditionally, aridity/moisture is assessed in a manual or semi-automatic mode for a restricted area with data from weather stations (observation data). This approach requires significant time for long-term observation data processing and characterizes the aridity and moisture of a territory only in regions where weather stations exist. For vast areas of Siberia and Far East where the weather station data are highly sparse and irregular, this approach significantly reduces the reliability of the obtained results. Using the global retrospective analysis (re-analysis) data causes difficulties too. Large volumes of data (up to several terabytes) require powerful computing complexes for processing and a large storage space, and the dedicated file formats used for storing the data require specific programming skills.

2. Objects, data and methods

In this paper we estimate the aridity/moisture of the territory with the ERA-Interim reanalysis data using a new program module of a previously developed web-GIS “CLIMATE” [12]. The system “CLIMATE” is based on a combined use of web and GIS technologies. It is part of a hardware and software complex for “cloud” storage data analysis using various climatic data sets, as well as algorithms for searching, extracting, processing, and visualizing the data. This system significantly facilitates and accelerates the analysis of big volumes of geospatial data, allowing the researchers to perform complex climate data analysis using desktop PCs with internet connection. At present the system already has many computational modules that allow calculating both the standard statistical characteristics of meteorological values and the extreme indices recommended by the World Meteorological Organization (WMO) Expert Team on Climate Change Detection and Indices (ETCCDI, <http://etccdi.pacificclimate.org/>), as well as the Selyaninov hydrothermal coefficient [13].

Due to the fact that in the studied territory of Southern Siberia (50°-65° N, 60°-120° E) there is a great variety of landscapes, it was decided to assess the hydrothermal conditions using the so-called Ped index (S_i) [6], which is the dimensionless normalized difference of air temperature and precipitation.

$$S_i = \frac{\Delta T_i}{\sigma_T} - \frac{\Delta P_i}{\sigma_P}, \quad (1),$$

where i is the number of a certain period, $\Delta T_i = T_i - T_{norm}$ is the temperature anomaly in the i -th period, T_{norm} is the long-term average temperature, σ_T is a standard deviation of temperature. The notations are similar for precipitation (P).

The web-GIS “CLIMATE” was extended by a software module to calculate the Ped hydrothermal index. The module was developed using an Interactive Data Language (IDL 6.0). The algorithm was based on formula (1). The ECMWF (European Centre for Medium-Range Weather Forecasts, UK) ERA-Interim reanalysis data [13] on air temperature and the sum of precipitation at the Earth’s surface were used. The Ped hydrothermal index was calculated for the territory of Southern Siberia (50°-65° N, 60°-120° E) from 1979 to 2010, which allows obtaining spatial assessments of aridity/moisture of the territory in contrast to the existing assessments of other authors.

In [13, 15] it was established that the reanalysis and observation data show a slight difference in the air temperature values (the average difference is -0.86°C) and a significant discrepancy (49% on average) in the precipitation. To improve the quality of the precipitation reanalysis data, we use an approach that was presented in a previous study [13]. According to this approach, the daily precipitation reanalysis data on the reanalysis grid are interpolated for the coordinates of weather stations using a previously developed software module for the correction of reanalysis data. 127 weather stations with most complete and homogeneous time series of observations were used. Then the precipitation was corrected using a bilinear regression equation. The correction was performed

individually for each year and month of the vegetation period (from May to September) for the study area. The observation data on daily precipitation were taken as a dependent variable, and the reanalysis daily precipitation interpolated for the coordinates of weather stations were taken as an independent variable. The obtained coefficients of bilinear regression were applied to the precipitation reanalysis data. The final step of the calculation and analysis corrected the reanalysis data and was carried out for the hydrothermal Ped index and its components (average monthly temperature and corrected monthly precipitation). This approach allowed us to characterize the hydrothermal conditions not only for the coordinates of weather stations, but also for complicated orographic conditions in areas with a sparse observation network.

3. Results and discussion

The long-term monthly average temperature of the study area changes during the warm period (May–September) from -1 to $+25$ °C of the study area (Figure 1). In general, the latitudinal distribution of monthly average temperature is observed for all months. In Eastern Siberia the orography violates to a certain extent the pattern. The surface elevation varies from 0 (West Siberian Plain) to 4506 m a.s.l. (Belukha mountain, Altai) over the study area. The annual maximum of air temperature is observed in July. The highest air temperatures were recorded in the south-west of the territory ($+25$ °C, Northern Kazakhstan). The July air temperature decreases to $+17$ °C as a function of latitude. The July air temperature does not exceed $+10$ – 12 °C in the mountain regions of Altai and Sayans. The monthly air temperature in the mountains of Transbaikalia (Stanovoy Highland) increases to 13 – 15 °C in July. In June and August, the general patterns of air temperature distribution are the same as in July with lower air temperature values (ranging from $+7$ to $+21$ °C). The air temperature difference between the north and south of the territory is greatest in May, when in the south-west the monthly air temperature increases to $+16$ °C and in the northern areas the air temperature is below 0 °C.

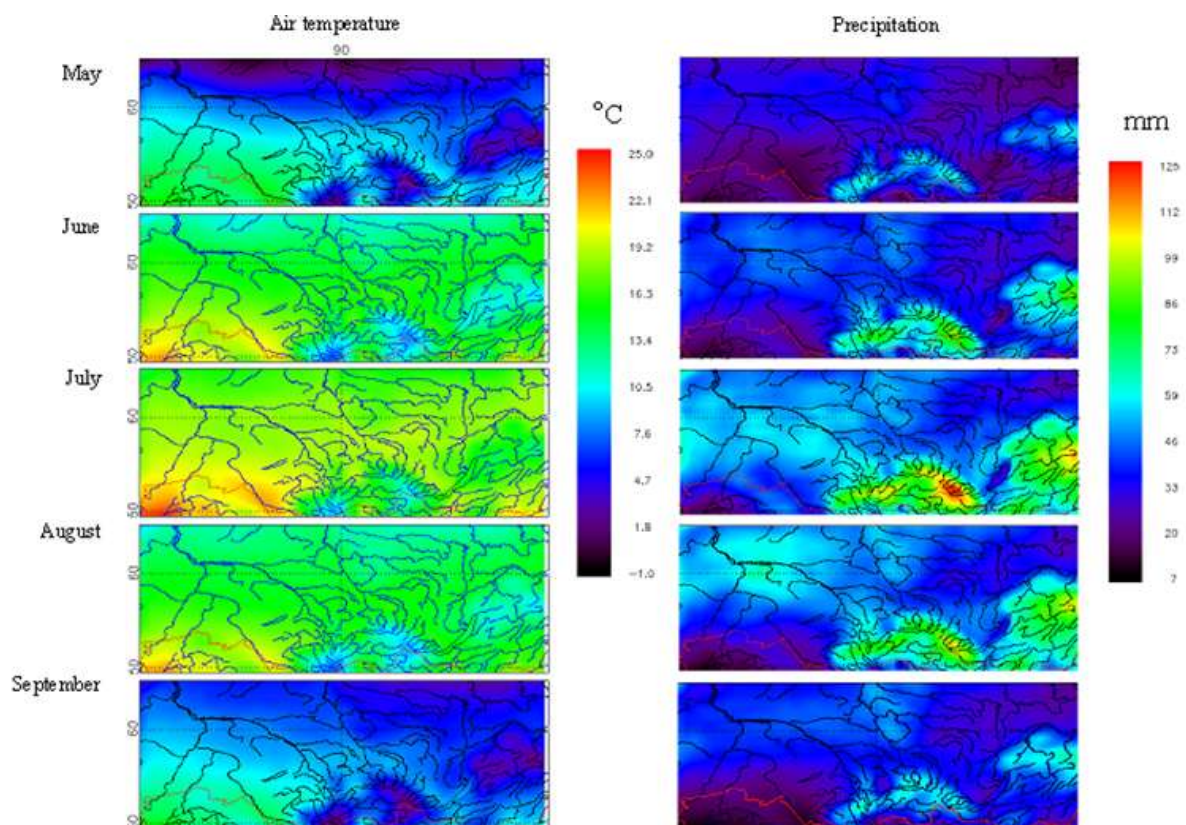


Figure.1. Long-term (1979-2010) average monthly air temperature and sum of precipitation.

The spatial distribution of trends of the monthly air temperature varies during the warm period (Figure 2). In May, for the most part of the study area, the air temperature increases with a rate of 0.3–0.7 °C / 10 years. Maximum trends (up to 1 °C / 10 years) are observed in the central part of Western Siberia. Negative trends (about –0.2 °C / 10 years) are recorded in the Altai-Sayan region and to the north of the basin of the Nizhnyaya Tunguska river. The temperature decreases in June and July in Western Siberia, but in Eastern Siberia the temperature increases. The maximum difference in the distributions of trends over the territory is observed in July in the south. The temperature trends vary from –0.65 °C / 10 years in the south-west to +1.2 °C / 10 years in the south-east. At the same time, the temperature trends in the north are minimal in modulus in July. In August and September, in the west and south-east an increase in the air temperature is observed (with rates from +0.4 to +0.8 °C / 10 years). No significant trends are observed in the rest of the territory (with rates from –0.05 to +0.2 °C / 10 years).

The distribution of monthly precipitation over the territory differs from the distribution of monthly air temperatures. The spatial distribution of precipitation for each month is similar. The maximum value (up to 125 mm) is recorded in the mountain areas (Altai, Western and Eastern Sayan, Khamar-Daban, Stanovoy Highland), and a minimum (less than 10 mm) is observed in the south-west of the territory. The greatest moisture is observed in the study area in July, and the least moisture is observed in May. The trends of monthly precipitation during the warm period are different. In most cases the trends are negative. The minimum precipitation reduction (with rates of about –30 mm / 10 years) is observed in Eastern Sayan in July. The maximum increase in precipitation (up to +14 mm / 10 years) is observed in the central part of the territory in the basins of the Ob and Yenisei rivers.

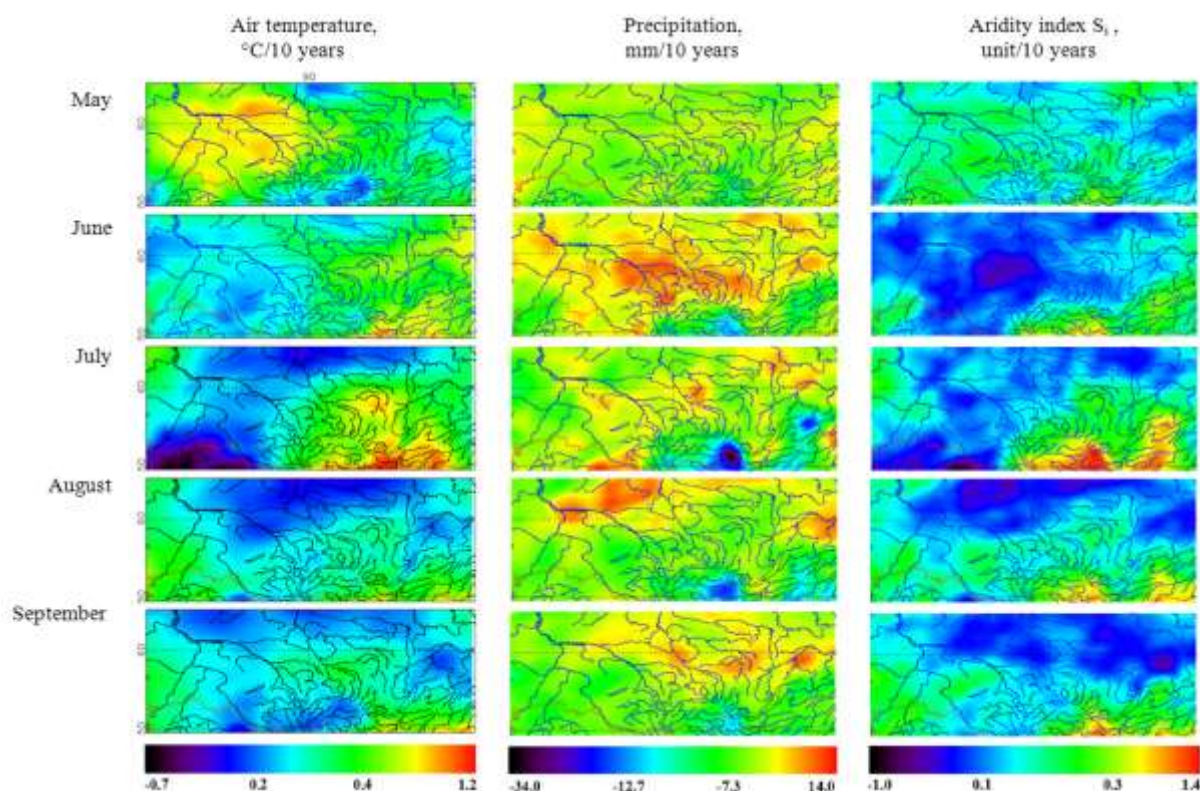


Figure 2. Trends of climate characteristics for 1979-2010.

The changes in the complex hydrothermal Ped index S_i were analyzed. The hydrothermal conditions in different months of the study area are not the same. In May, for most of the territory the aridity increases. A small decrease in S_i is observed only in the mountains of Transbaikalia. In June,

the moisture increases in the central regions of Western Siberia, while the south of Eastern Siberia becomes more arid. In July, a stable increase in the S_i index occurs. The trends of the index vary from -1.0 to +1.4 units / 10 years. The area of the maximum increase in moisture shifted to the northern regions of Kazakhstan. In August, an increase in aridity is observed in the southern regions of the study area, and a decrease in aridity is observed in the northern regions. A latitudinal type of trend distribution exists in September. The trends are distributed from positive values in the south to negative trends in the north of Siberia.

4. Conclusions

According to the results of our study, the mountainous areas of Eastern Siberia are becoming more and more arid each month. In Western Siberia, aridity increases in May and decreases in June. In July, August, and September positive and negative trends are evenly distributed. The increase in aridity of the territory is associated with both the increasing temperature and decreasing precipitation. Conversely, in the areas where an increase in precipitation and a decrease in average monthly temperature are observed, some excessive moisture is observed. The greatest differences between the distributions of trends of the S_i index itself and its components are observed in July.

The results of the study are in good agreement with the conclusions obtained earlier in the analysis of droughts and periods of excessive moisture made in [16]. However, in the previous studies only point data of weather stations were analyzed. In the present paper, some spatial hydrothermal characteristics obtained from the ERA-Interim reanalysis data were studied. A good agreement between the results of the study was obtained due to the preliminary correction of the reanalysis data.

The developed software module and the web-GIS "CLIMATE " significantly facilitate and speed up the calculation of the aridity/moisture index for the study area using observation and reanalysis data. The web-GIS "CLIMATE" provided a tool to calculate and visualize the hydrothermal conditions using the Ped index for the territory of Southern Siberia from 1979 to 2010. It allowed us to estimate the spatial distributions of hydrothermal conditions for the study area. The results of the calculations are represented in net CDF files, georeferenced maps, and layers available as downloadable files via web services [17]. They can be easily transferred to online and desktop GISs for further cross-analysis with other spatial products, e.g. for the estimation of the impact of droughts on vegetation productivity. Since the hydrothermal indices are integral characteristics of the heat-moisture conditions of an area, special attention should be paid to the quality of the initial data. Adjustment of reanalysis daily precipitation data using the bilinear regression equation allows us to correctly estimate the spatial distributions of the Ped index, to increase the quality of droughts detection and estimation of excessive moisture conditions in the study area.

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