The Forecast of Climate Changes in Altai-Sayan Mountain Country till 2030

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The paper presents the method developed for spatial generalization of surface air temperature and precipitation applicable to GIS and a reanalysis. By the example of the Altai-Sayan mountain country, it was shown that relative variations in surface air temperature and precipitation expressed in percent of average long-term values were uniform throughout. The forecast of climate change was performed for the mountain country up to 2030. Temperature decrease in January (~ 20%) with its increase in March and April (> 20%) are expected. In the rest months, temperature will remain approximately the same. The predicted changes in precipitation will vary depending on months.
Keywords: air temperature, precipitation, spatial generalization, mountain area, Altai, Sayan

Introduction. Mountains are characterized by complex vertical and horizontal differentiation of climate. In this connection, the analysis of long-term changes in meteorological factors is laborious and often impossible because of the lack of necessary observations. The method developed for spatial generalization of average monthly temperature of the surface air layer and monthly precipitation provides an adequate assessment of their monthly and long-term dynamics with due regard for spatial differentiation of climate [1]. Such an assessment can be made for arbitrary parts of the mountain territory, even at the absence of meteorological observations.

The Altai-Sayan mountain country selected as a test region consists of a fan-shaped system of ridges stretching in the north-west direction. It is the highest mountain region of Siberia (300-4500 m a.s.l.). An important feature of the country is its landscape diversity (glacial-nival, tundra, alpine and subalpine meadows, forest, steppe and semi-desert). It serves as a mountain catchment area for such large rivers of Siberia as the Ob and the Irtysh.

The main objective of the research was a long-term forecasting the changes in air temperature and precipitation throughout the study area. It was expected to perform the reanalysis having scarce initial data on monthly and interannual dynamics of temperature and precipitation.

Source data and methodology. To assess the climatic situation in the Altai-Sayan mountain country, 11 still operating weather stations were used (Tab. 1). The country's climate, including average monthly air temperature and monthly precipitation, are largely formed by general atmospheric circulation processes [2]. Average long-term values of the selected factors (1951-2017) for the study territory are given in Tab. 2.

Table 1. The geographical location of reference weather stations in the Altai-Sayan mountain country.

N	Weather station	WMO index	Latitude	Longitude	Altitude a.s.l, m
1	Biysk-Zonal[1]	29939	52° 41'	84° 56'	222

2	Zmeinogorsk[2]	36038	51° 09'	82° 10'	354
3	Kamen’-on-Ob[1]	29822	53° 49'	81° 16'	127
4	Kara-Tyurek[2]	36442	50° 02'	86° 27'	2601
5	Kuzedeevo[3]	29849	53° 20'	87° 11'	293
6	Kyzyl-Ozek[2]	36055	51° 54'	86° 00'	324
7	Rebrikha[1]	29923	53° 05'	82° 20'	218
8	Slavgorod[1]	29915	52° 58'	78° 39'	125
9	Soloneshnoye[2]	36045	51° 38'	84° 20'	409
10	Ust-Koksa[2]	36229	50° 16'	85° 37'	977
11	Yaylu[2]	36064	51° 46'	87° 36'	482

Note: 1 – the plains adjacent to the Altai Mountains; 2 – The Altai mountains; 3 – the Kuznetsk intermountain basin.

Table 2. Mean long-term values of air temperature and precipitation for the study area.

Climatic characteristics	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Temperature, °C	–16,0	–14,6	–8,0	2,2	10,5	15,7	17,8	15,3	9,6	2,1	–7,3	–13,3
Precipitation, mm	21,9	19,5	22,3	40,7	58,3	71,1	81,9	73,0	50,9	49,4	39,5	30,6

Temperature and precipitation for each month of each year were expressed in percent of their average long-term value for a certain month [1]; its choice was made using the least standard deviation characterizing the scatter of the obtained values for all data. Then, temporal dynamics of factors (expressed in percent) was calculated for individual weather stations with further averaging the data from all 11 stations for each month of each year. Thus, the long-term dynamics of air temperature and precipitation, which reflected the meteorological situation throughout the Altai-Sayan mountain country during the observation period, was established. Microsoft Office Excel 2003 was used to calculate long-term trends of both factors for each month of the year in order to perform a multi-year forecast up to 2030.

Results and discussion. Cold and warm periods of the year can be specified by average long-term values of mean monthly air temperature (Tab. 2). Taking into account “the effect of altitude” determined by temperature inversions in winter and atmospheric circulation processes in summer, we attributed 10-12, 1-4 months of the year to the cold period, while 5-9 – to the warm one [1]. The identification of such periods provides the best calculation accuracy and the possibility of forecasting the monthly and interannual dynamics of the selected factors (expressed in percent). It also best reflects the spatial uniformity of them throughout the mountain country due to atmospheric circulation processes. January and July are taken as reference months distinguished by the best “meteorological” correlation with all months for cold and warm periods, correspondingly. Just these months demonstrate the lowest dispersion in relative air temperature for all weather stations.

On the territory of Russia, the secular climate cycle having three phases (1918-1950, 1951-1983, 1984-2016) with certain statistical regularities of interannual changes in temperature and precipitation [3] was formed. Influenced by anthropogenic factors, meso- and macro-scale processes of moisture and heat transfer in the atmosphere become less stable. Therefore, it is reasonable to use the third 33-year phase of the cycle – the closest to the forecast period of 2019-2030. The figure presents air temperature and precipitation trends obtained for this phase in the just terminated secular climate cycle.

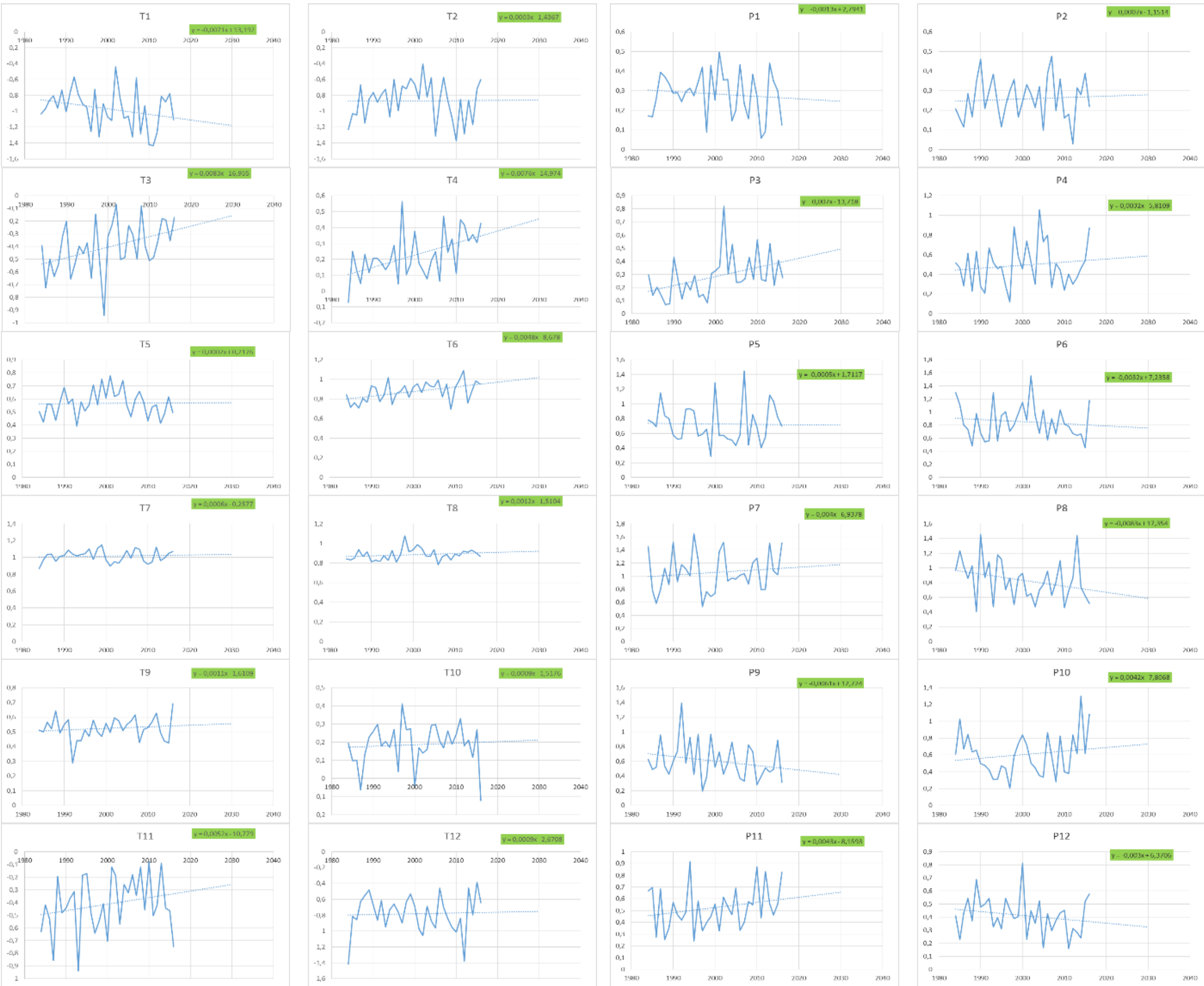

Fig. Trends in relative air temperature (T) and precipitation (P) for 12 months of 1984-2016.

The traditional description of long-term changes in air temperature and precipitation in the mountains is rather imprecise. We give a more adequate description of climatic trends, when changes in average monthly air temperature and monthly precipitation for cold and warm periods of the year are expressed in percent of their in-situ average long-term values [4-7]. These trends shown in the figure can be used in long-term forecasts. The greatest variation in temperature is expected in January (cooling by ~ 20% by 2030) and March-April (warming >20%). Precipitation will be changed markedly and variously in most months of the year.

The method for spatial generalization of meteorological factors allows to solve the second part of the problem, i.e. their reanalysis for the mountains. One can easily perform the reanalysis for mean monthly temperature and monthly precipitation through their calculation in percentage of in-situ mean monthly values. For transition to the generally accepted units of measurements (°C, mm), one needs just January/July mean long-term values of temperature and precipitation for the study area. This method also makes it possible to reconstruct the missing data in the long-term series of meteorological observations much better as compared to their substitution by appropriate mean-long-term values [1].

Conclusion. The method proposed for spatial generalization of climatic factors is applicable to plains [4-7] and mountain areas as well. The method-based prediction of relative changes in surface air temperature and precipitation for the Altai-Sayan mountain country was made up to 2030. The novelty of this method is in calculations made in percent of mean long-term values for the reference months (January and July). The defined long-term dynamics of climatic factors is uniform throughout the analyzed territory, regardless of its orographic and climatic heterogeneity.

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