Statistical estimation of the effect of precipitation redistribution using the historical regression method

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Abstract. Precipitation has significant natural variations in time and space. The calculation of the probability of increasing or decreasing the amount of precipitation against the background of their natural variability as a result of work on active influences is not an easy task. A statistical assessment of the effect of the redistribution of precipitation in the protected and control areas was carried out using the historical regression method.

Introduction
The water resources of our planet should be treated very carefully, considering water as a special kind of raw material, without which life on Earth is impossible. Water is used at all stages of human development and serves as one of the important products for each individual. Therefore, the fresh water consumed in economic activity by weight is an order of magnitude higher than all other raw materials in the aggregate. In The earth's biosphere, fresh water is 2.5%, but more than 99% of this water is in the form of snow and ice. Rivers and lakes contain 93 thousand cubic km of water at a time. Over the past 50 years, the consumption of fresh water has increased 4 times from 1000 cubic km to 4100 cubic km per year. 70% of the water is used for agriculture, and the remaining 30% is used in industry and utilities [4].

Materials and research methods
Currently, due to the acute shortage of fresh water, many countries of the world are forced to take certain measures to solve this problem. Therefore, active actions on clouds for the purpose of artificial increase in precipitation are one of the ways to solve this problem. But there is still no consensus on how these works affect the precipitation regime of neighboring territories. Moreover, this is difficult to estimate in the North Caucasus, since natural fluctuations in precipitation are extremely variable in space and time. This uneven distribution is due to the physical and geographical location of the region, where the Main Caucasian ridge runs on the one hand, and the black sea is close on the other. Figure 1 shows the time course of the average precipitation for the 15-year period before the start of work on artificial increase in precipitation, which fell on the territory of the Stavropol territory (PT) and its neighboring control (CT) and adjacent territories (AT).
Figure 1. Time course of precipitation (may-august) in the control and protected areas: 1-CT, 2-PT and 3-AT

The time course of precipitation over the entire region shows that precipitation over the entire territory has quasi-periodic fluctuations with cycles from 2 to 6 years. The years of maximum and minimum for all the studied areas coincide. The analysis of the time stroke also shows that in the period from 1971 to 1977 there is an increase in precipitation on the protected, control, adjacent and throughout the study area, and from 1977 to 1979 there has been a steady decreasing trend in average rainfall for the season (may-august) throughout. A certain synchronicity of this pattern is most likely due to the fact that the main amount of precipitation falls during frontal processes that take place throughout the region.

In this regard, a statistical assessment of the physical effect of the impact of artificial increase in precipitation in the Stavropol territory on the regime of liquid precipitation in neighboring territories was carried out using the historical regression method.

Research results and discussion
The presence of a high correlation of precipitation between the compared territories and the absence of influence of active impacts on the control territories allows using this method. The basic data on which the method is based are averaged precipitation data for the spring-summer season (may-august) from individual weather stations. Averaging precipitation makes it possible to reduce the coefficient of variation of precipitation. The calculation period was chosen from 1970 to 1985, since 1986 on the territory of the Stavropol territory, work was started on active effects on convective clouds in order to artificially increase precipitation, in connection with which the natural mode of precipitation was violated.

The data of statistical analysis of one-dimensional series for four compared pairs of territories (CT₁, CT₂, CT₃, CT₄ and AT₁, AT₂) are presented in table 1. These are the values of the correlation coefficients (r) between the sedimentary series of the adjacent territory (AT) and the control territories (CT) with estimates of their calculation errors (S) for the period of time before active impacts, the values of the linear regression coefficients between the sedimentary series (x-y) and the resulting linear regression equation [2].

Table 1. Statistical analysis data
Statistical specifications | Compare pairs of precipitation series
---|---|---|---|---
| $X_1$–$y_1$ | $X_2$–$y_1$ | $X_3$–$y_2$ | $X_4$–$y_2$
$r \pm S_r$ | 0.8 ± 0.09 | 0.7 ± 0.13 | 0.7 ± 0.13 | 0.7 ± 0.13
$\rho$ | 0.7 ± 0.14 | 0.6 ± 0.11 | 0.5 ± 0.15 | 2.2 ± 0.09
regression equation | $0.7x + 38$ | $0.6x + 25.2$ | $0.5x + 21.3$ | $2.2x + 19.3$
$\pm S$ | ±11.4 | ±11.4 | ±10.3 | ±7.9

An analysis of the data given in table I allows us to use any regression ratio in calculating the effect of artificial increase in precipitation on the precipitation regime in the adjacent territory.

The regression relationship between CT and AT before the start of work on active impacts (1970 - 1985) and on active impacts (1986 - 1997) in the Stavropol territory is shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Regression relationship of precipitation of adjacent (y) and control (x) territories 1– in the period before the start of work, 2 - in the period of active impact

In figure 1, the confidence interval of the regression equation is indicated by dashed lines. Confidence interval for the regression equation obtained between the precipitation of the control (x) and adjacent (y) territories:

\[ y = 0.7x + 38 \]  \hspace{1cm} (1)

The correlation coefficient between precipitation CT and AT is equal to $r = 0.8$.

In order to test the hypothesis about the significance of the sample correlation coefficient, it is necessary, at a significance level of 0.05, to check the null hypothesis that the general correlation coefficient is equal to zero $H_0: r = 0$. A random variable is accepted as a criterion for testing the null hypothesis [3].

\[ T = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} = \frac{0.8\sqrt{16-2}}{\sqrt{1-0.8^2}} = 4.93 \]  \hspace{1cm} (2)

According to the significance level of 0.05 and the number of degrees of freedom $k$, we find from the student distribution table the critical point of the two-sided critical region $t (0.05; 16) = 2.12$

Since $T > t$, we reject the null hypothesis. Therefore, the sample correlation coefficient is significantly different from zero, i.e. precipitation in the adjacent and control areas are correlated. The
error in determining the expected amount of precipitation at AT₁ by the regression equation (1) is equal to the standard deviation from the regression equation:

\[ S = S_{AT} \sqrt{1 - r^2} \]  

\[ S = \pm 19.1\sqrt{1 - 0.8^2} = \pm 11.4 \text{ (mm)} \]  

The confidence interval of the regression equation (1) is found by the formula:

\[ y_{AT,est.} = \bar{y}_{AT} + a(x_{ct} - \bar{x}_{ct}) \pm t_{\alpha} \sigma_{AT} \sqrt{\frac{1-r^2}{n-2}} \times \sqrt{1 + \left( \frac{x_{ct} - \bar{x}_{ct}}{\sigma_{ct}} \right)^2} \]  

Calculations by formula (3) show that the error of the regression equation at a significance level of 10% is on average \( \bar{s} = \pm 5.7 \text{ mm} \). As can be seen from Figure 1, the actual amount of precipitation in the adjacent territory over the years of active impacts lies outside the confidence interval of the regression equation. In Figure 1, the confidence interval of the regression equation is indicated by dashed lines. Thus, in a statistical assessment by the method of historical regression of the effect of redistribution of precipitation, we obtain that the amount of additional precipitation for the season should be \( \Delta y > 11.4 \text{ mm} \), so that with a confidence probability of 68% we can talk about a significant redistribution effect. If we consider the entire period of active impact works (12 years), we find that the amount of additional precipitation of 5.7 mm is significant at a significance level of 0.5.

Summary
Based on studies of the climatic characteristics of the North Caucasus from 1958 to 2009 [1], it was found that over the past 50 years, a steady tendency has been observed throughout the region for changes in temperature and humidity, as well as precipitation and the climate as a whole. Therefore, in order to analyze the effect of redistribution of precipitation due to active impacts for each individual season with active impacts, it is necessary to determine which year it belongs to - with excess or deficit of precipitation.

References
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