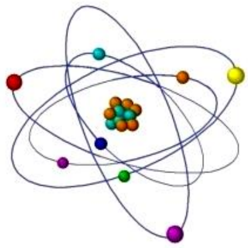
COMPARATIVE STATISTICAL ANALYSIS OF ANNUAL VARIATION OF THE INTENSITY OF GALACTIC COSMIC RAYS (IN TBILISI, ALMATY, APATITY, MOSCOW, NOVOSIBIRSK AND ROME)



***Amiranashvili A.G., Bakradze T.S., Erkomaishvili T.G., Ghlonti N.Ya.**

Iv. Javakhishvili Tbilisi State University, M. Nodia Institute of Geophysics

*Corresponding author: avtandilamiranashvili@gmail.com

ABSTRACT: *Results of comparative statistical analysis of annual variation of the intensity of neutron component of galactic cosmic rays (CR) in Tbilisi, Almaty, Apatity, Moscow, Novosibirsk and Rome in 1995-2014 are presented. In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods of random events and methods of mathematical statistics for the non-accidental time-series of observations. In particular, the following results are obtained. In Tbilisi, twenty-year averages of CR intensity are lower than in Almaty, Moscow and Novosibirsk, and higher than in Apatity and Rome. The linear correlation coefficient for real values of CR intensity between Tbilisi and other measurement points varies from 0.73 (Tbilisi-Apatity pair) to 0.81 (Tbilisi-Rome pair). Almaty and Rome are the most optimal measurement points for recovering missing data on the intensity of cosmic rays in Tbilisi. The time variability regression equations of galactic cosmic rays intensity for Almaty has the form of the third order polynomial, for all other measurement points - the fifth order polynomial. The linear correlation coefficient for trend + background components of values of CR intensity between Tbilisi and other measurement points varies from 0.78 (Tbilisi-Apatity pair) to 0.87 (Tbilisi- Almaty pair). The linear correlation coefficient for random components of values of CR intensity between Tbilisi and other measurement points varies from 0.27 (Tbilisi- Almaty pair) to 0.65 (Tbilisi – Moscow and Tbilisi - Rome pairs). Connection of linear correlation coefficient between different components of galactic cosmic rays intensity in Tbilisi and in other measurement locations (real data, trend + background and random components) with distance from Tbilisi have the form of the second power polynomial. Real data on the CR intensity for Tbilisi are very highly representative at a distance of up to 500 km from the measurement point and highly representative at a distance of at least 3200 km from this city.*

Key words: galactic cosmic rays, neutron monitors, trend

INTRODUCTION

The study of cosmic rays, including galactic cosmic rays, is the most important experimental problem since they largely determine the most diverse processes occurring in the earth's atmosphere [1,2]. Thus, in many countries of the world, including Georgia, the intensity of the neutron component of galactic cosmic rays has been monitored for several decades [3-5].

In addition to traditional studies of various aspects of cosmic ray variations [6–8], a significant number of works are devoted to studying the relationship between cosmic radiation and the formation of aerosols in the atmosphere [9–13], general climatic effects of cosmic rays [14–16], and the influence of cosmic ray variations on such climate elements, such as cloudiness and air temperature [17-23], etc. Much attention is paid to the environmental aspects of cosmic radiation, including the study of their impact on human mortality [12, 24-26].

A number of the above mentioned studies were carried out at the M. Nodia Institute of Geophysics, TSU. In particular, in [9] has been proposed the scheme of the interaction of atmospheric aerosols and convective clouds, and also generation in the atmosphere and clouds of condensation, crystallization nuclei and ice crystals with allowance to ionization (including cosmic) and electrization processes occurring in the atmosphere.

In continuation of [9], the papers [10-12] present the results of studying the influence of cosmic radiation on the formation of secondary aerosols in the atmosphere associated with the formation of clouds.

The study of the relationship between annual variations in the intensity of galactic cosmic rays and the variability of cloudiness and air temperature in Tbilisi according to the data of 1963-1990 is presented in [18]. The paper [19] considers the results of the study of the connection between annual variations of intensity of galactic cosmic rays and the changeability of the total cloudiness, atmospheric precipitation and air temperature in 1966-2015 in Tbilisi. The statistical characteristics of the indicated parameters (trends, random component, linear correlations between real and random components, etc.) are studied. In particular, it was found that, within the variation range, the contribution of the studied parameters to atmospheric precipitation variability is as follows: total cloudiness - 17.1%, real values and random components of cosmic ray intensity - 37.8% and 28.0%, respectively.

Results of the study on influence of variations of the annual intensity of neutron component of galactic cosmic rays on the mortality of the population of Georgia in 1995-2014 in [26] are presented. In particular, the previously obtained results on a direct correlation between the intensity of cosmic rays and total mortality of the population have been confirmed. However, as it turned out, an increase in the intensity of cosmic rays mainly increases the mortality rate of the male part of the population of Georgia. The mortality rate of women is very weakly dependent on the galactic cosmic ray’s influence.

It should be noted that at various cosmic ray monitoring stations, including Tbilisi, gaps in the series of observations are possible for various reasons. Therefore, it is very important to conduct a correlation and regression analysis of the connection between the series of measurement data at different stations. Such an analysis makes it possible to choose the most optimal station for recovering missing data, or for directly using the data of this station for a period of time with no measurements in the area under study. Note that a similar technique is widely used in meteorology [27].

Results of comparative statistical analysis of annual variation of the intensity of neutron component of galactic cosmic rays in Tbilisi, Almaty, Apatity, Moscow, Novosibirsk and Rome in 1995-2014 are presented below.

STUDY AREA, MATERIALS AND METHODS

Study area – Tbilisi (Georgia), Almaty (Kazakhstan), Apatity, Moscow, Novosibirsk (Russia) and Rome (Italy)–fig. 1. Distance from Tbilisi: Almaty – 2640 km, Apatity – 2970 km, Moscow - 1650 km, Novosibirsk – 3170 km, Rome – 2680 km.

Data about annual values of intensity of neutron component of galactic cosmic rays (CR) for Tbilisi is obtained at the Cosmic Rays Observatory of M. Nodia institute of geophysics. Data about CR for Almaty, Apatity, Moscow, Novosibirsk and Rome taken from - http://cr0.izmiran.ru/common/links.htm. All data are corrected for atmospheric pressure. The period of observation is 1995 - 2014. The unit of measurement is imp/min, omitted from the text and tables below.

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods of random events and methods of mathematical statistics for the non-accidental time-series of observations [28-30].

The following designations will be used below: Min – minimal values, Max - maximal values, Range - variation scope, St Dev - standard deviation, Cv, % – coefficient of variation (Cv = 100·St Dev/Average), R - coefficient of linear correlation, Ra – coefficient of autocorrelation with lag = 1 year, Rk - Kendall rank correlation coefficient, Rs- Spearman's rank correlation coefficient, R^2 – coefficient of determination, K_{DW} – Durbin-Watson Statistic, Rand – random component of time-series of observations, α- the level of significance, Real - measured data. The curve of trend is equation of the regression of the connection of the investigated parameter with the time at the significant value of the coefficient of determination and such values of K_{DW}, with which the residual values are accidental.

A background component usually enters into the curve of trend. The value of background component is most frequently unknown. From the physical aspect, random component can be represented in the form: Rand = Res + absolute value of the min value of Res. In this case random components have positive values with the minimum value = 0 (if the value of background component is known, the min Rand will be = Back). Accordingly, Trend+Back (sum of the trend and background components of time series) will be a curve of equation of the regression of the connection of the investigated parameter and the time minus absolute value of the min value of Res. So, Real = (Trend+Back) + Rand.

Fig. 1. Location of galactic cosmic rays measurement locations.

The degree of linear correlation was determined in accordance with [28]: very high correlation ($0.9 \le R \le 1.0$); high correlation ($0.7 \le R < 0.9$); moderate correlation ($0.5 \le R < 0.7$); low correlation ($0.3 \le R < 0.5$); negligible correlation ($0 \le R < 0.3$).

A comparison of mean values of CR in Tbilisi and another measurement locations were produced with the use of Student's criterion.

RESULTS

The results in table and fig. 2-6 and tables 1-5 are presented.

In fig. 3 and table 1 the time series of real data of annual variation of the intensity of neutron component of galactic cosmic rays in Tbilisi, Almaty, Apatity, Moscow, Novosibirsk and Rome in 1995-2014 and statistical characteristics of these data are presented.

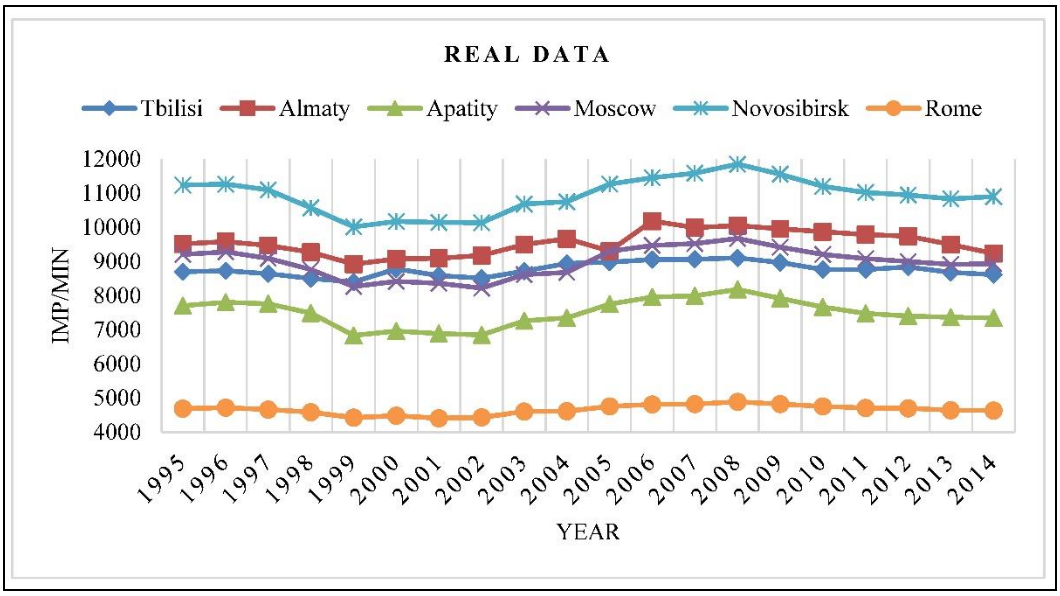


Fig. 2. Time series of real data of galactic cosmic rays intensity at measurement locations.

Table 1. Statistical characteristics of real data of galactic cosmic rays intensity at measurement locations.

Variable	Tbilisi	Almaty	Apatity	Moscow	Novosibirsk	Rome
Max	9100	10182	8177	9670	11845	4883
Min	8396	8919	6829	8214	10012	4404
Range	704	1263	1348	1456	1833	479
Average	8763	9541	7494	8967	10928	4652
St Dev	201	359	401	435	525	137
Cv, %	2.3	3.8	5.4	4.9	4.8	2.9
	Correlation Matrix					
Tbilisi	1	0.80	0.73	0.76	0.78	0.81
Almaty	0.80	1	0.81	0.83	0.85	0.88
Apatity	0.73	0.81	1	0.98	0.98	0.96
Moscow	0.76	0.83	0.98	1	0.99	0.98
Novosibirsk	0.78	0.85	0.98	0.99	1	0.98
Rome	0.81	0.88	0.96	0.98	0.98	1

As follows from Table 1, the average, maximum, and minimum real values of the CR intensity at the measurement points are, respectively, the following: Tbilisi – 8763, 9100 and 8396; Almaty – 9541, 10182 and 8919; Apatity - 7494, 8177 and 6829; Moscow -8967, 9670 and 8214; Novosibirsk – 10928, 11845 and 10012; Rome – 4652, 4883 and 4404. In general, for all measurement points, the variations in the CR intensity values in the time series of observations are small.

The greatest variations in the real values of the CR intensity are observed in Apatity (Cv = 5.4 %), the smallest - in Tbilisi (Cv = 2.3 %). In Tbilisi, twenty-year averages of CR intensity are lower than in Almaty, Moscow and Novosibirsk, and higher than in Apatity and Rome. The lowest values of CR intensity in Rome in comparison with other observation points are due to the sensitivity of the equipment and the measurement technique.

The linear correlation coefficient for real values of CR intensity between Tbilisi and other measurement points varies from 0.73 (Tbilisi-Apatity pair) to 0.81 (Tbilisi-Rome pair). In all cases - high correlation.

Note that Almaty and Rome are the most optimal measurement points for recovering missing data on the intensity of cosmic rays in Tbilisi. Although, if necessary, the data of all other stations may well be acceptable. The same is acceptable for any other station (table 1).

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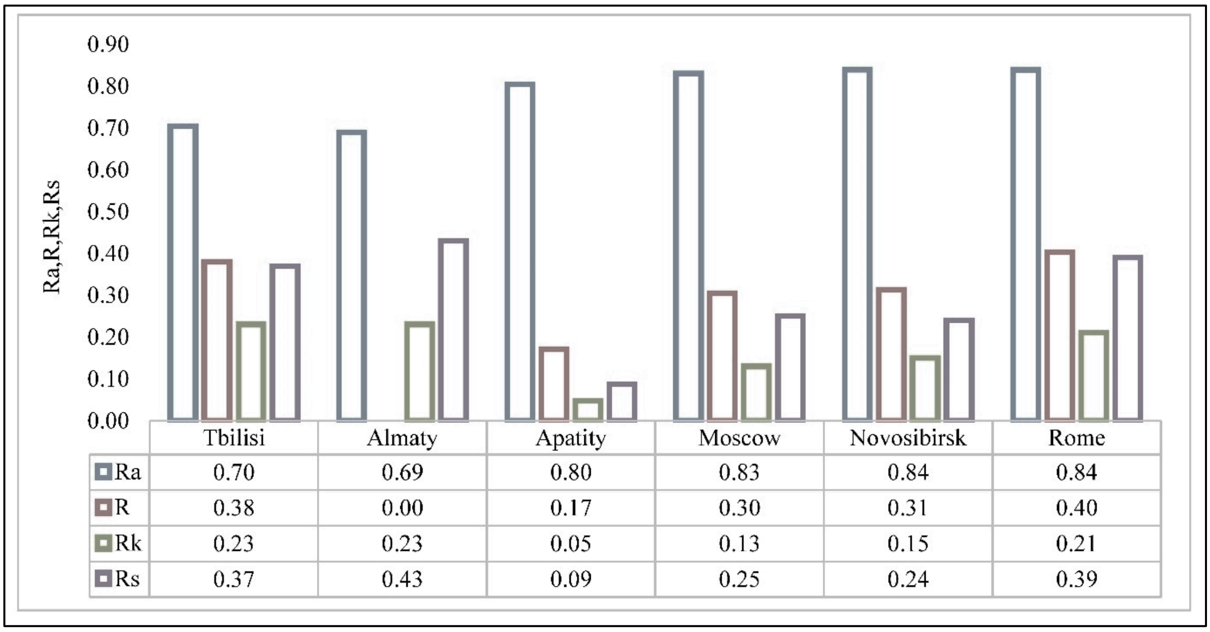

Fig. 3. Indicators of stability over time of time series of galactic cosmic rays intensity at measurement locations.

In fig. 3 data about indicators of stability over time of time series of galactic cosmic rays intensity in measurement locations are presented. Thus, the Ra values for all measurement points are significant only with a lag = 1 year and vary from 0.69 (Almaty) to 0.84 (Novosibirsk and Rome). Values of R between CR intensity and time are more or less significant for all measurement points except Almaty. Values of Rk and Rs between CR intensity and time are more or less significant for all measurement points except Apatity. Thus, all series of observations are non-random to some extent and depend on time. Accordingly, to construct regression equations for the dependence of CR intensity values on time (trends) methods of mathematical statistics for the non-accidental time-series of observations are used.

Table 2. Types of time variability regression equations of galactic cosmic rays intensity at measurement locations.

Location/Variable	Regression Equation	R^2	K_{DW}
Tbilisi	Fifth order polynomial	0.783	2.13
Almaty	Third order polynomial	0.783	2.27
Apatity	Fifth order polynomial	0.922	2.35
Moscow	Fifth order polynomial	0.933	2.28
Novosibirsk	Fifth order polynomial	0.946	2.33
Rome	Fifth order polynomial	0.932	2.44

In table 2 data about types of time variability regression equations of galactic cosmic rays intensity in measurement locations are presented. As follows from table 2, this dependence for Almaty has the form of the third order polynomial, and for all other measurement points - the fifth order polynomial.

In fig. 4 and table 3 the time series of trend + background components of annual variation of the intensity of neutron component of galactic cosmic rays in Tbilisi, Almaty, Apatity, Moscow, Novosibirsk and Rome in 1995-2014 and statistical characteristics of these data are presented.

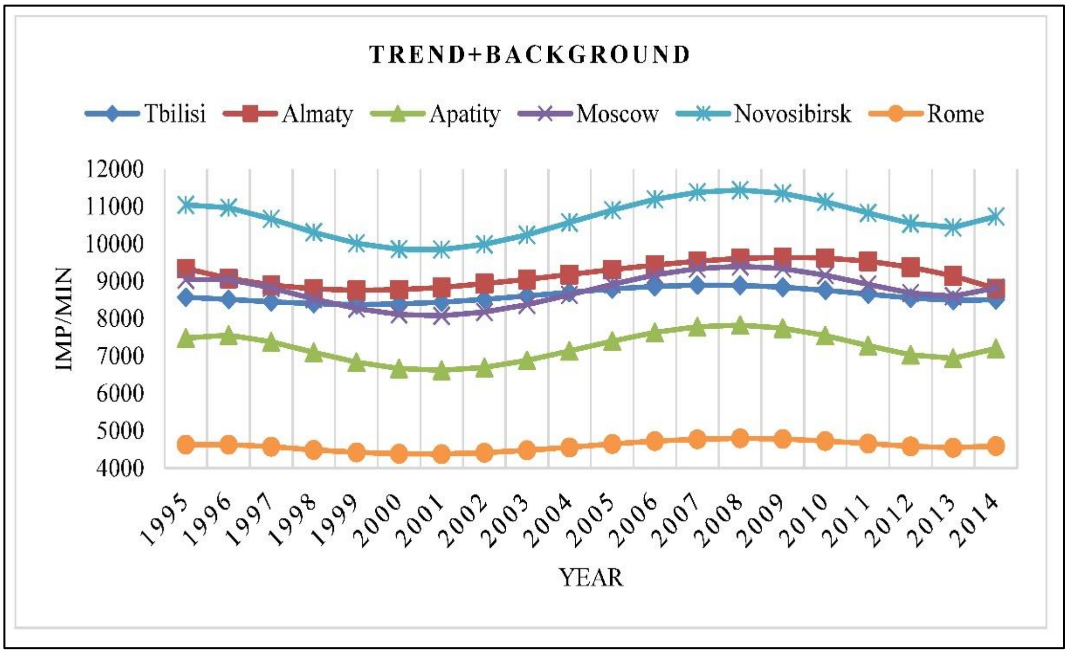

Fig. 4. Time series of trend + background components of galactic cosmic rays intensity at measurement locations.

Table 3. Statistical characteristics of trend + background components of galactic cosmic rays intensity at measurement locations.

Variable	Tbilisi	Almaty	Apatity	Moscow	Novosibirsk	Rome
Max	8893	9638	7823	9397	11433	4792
Min	8372	8754	6613	8073	9842	4376
Range	521	884	1210	1324	1591	416
Average	8607	9180	7232	8767	10665	4586
St Dev	178	318	385	420	511	132
Cv, %	2.1	3.5	5.3	4.8	4.8	2.9
	Correlation Matrix					
Tbilisi	1	0.87	0.78	0.79	0.83	0.86
Almaty	0.87	1	0.76	0.81	0.83	0.87
Apatity	0.78	0.76	1	0.99	0.98	0.96
Moscow	0.79	0.81	0.99	1	1.00	0.99
Novosibirsk	0.83	0.83	0.98	1.00	1	0.99
Rome	0.86	0.87	0.96	0.99	0.99	1

The average, maximum, and minimum values of the trend + background components of CR intensity at the measurement points are, respectively, the following: Tbilisi – 8607, 8893 and 8372; Almaty – 9180, 9638 and 8754; Apatity - 7232, 7823 and 6613; Moscow - 8767, 9397 and 8073; Novosibirsk – 10665, 11433 and 9842; Rome – 4586, 4792 and 4376 (table 3).

As in the previous case (table 2) the greatest variations in the trend + background components values of the CR intensity are observed in Apatity (Cv = 5.3 %), the smallest - in Tbilisi (Cv = 2.1 %). In Tbilisi, twenty-year averages of trend + background components of CR intensity are lower than in Almaty, Moscow and Novosibirsk, and higher than in Apatity and Rome.

The linear correlation coefficient for trend + background components of values of CR intensity between Tbilisi and other measurement points varies from 0.78 (Tbilisi-Apatity pair) to 0.87 (Tbilisi-Almaty pair). In all cases - high correlation.

Finally, in fig. 5 and table 4 the time series of random components of annual variation of the CR intensity in measurement points in 1995-2014 and statistical characteristics of these data are presented.

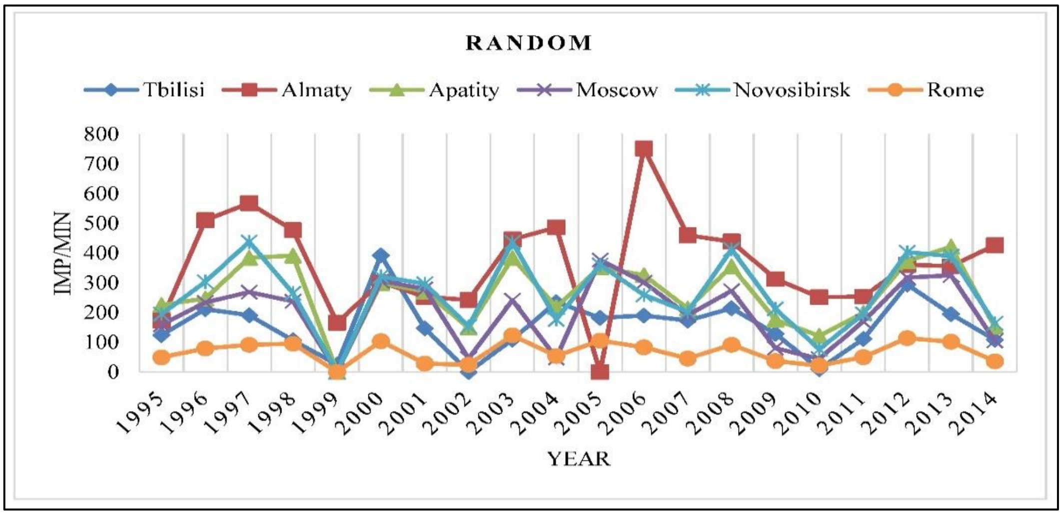

Fig. 5. Time variability of random components of galactic cosmic rays intensity at measurement locations.

Table 4. Statistical characteristics of random components of galactic cosmic rays intensity at measurement locations.

Variable	Tbilisi	Almaty	Apatity	Moscow	Novosibirsk	Rome
Max	392	750	421	376	437	122
Min	0	0	0	0	0	0
Range	392	750	421	376	437	122
Average	157	361	262	200	262	66
St Dev	94	167	112	112	122	36
Cv, %	59.7	46.3	42.6	56.3	46.5	54.3
	Correlation Matrix					
Tbilisi	1	0.27	0.56	0.65	0.61	0.65
Almaty	0.27	1	0.35	0.16	0.28	0.30
Apatity	0.56	0.35	1	0.87	0.92	0.91
Moscow	0.65	0.16	0.87	1	0.85	0.82
Novosibirsk	0.61	0.28	0.92	0.85	1	0.88
Rome	0.65	0.30	0.91	0.82	0.88	1

The average and maximum values of the random components of CR intensity at the measurement points are, respectively, the following: Tbilisi – 157 and 392; Almaty – 361 and 750; Apatity - 262 and 421; Moscow – 200 and 376; Novosibirsk – 262 and 437; Rome – 66 and 122. Minimum value of the random components of CR intensity at all measurement points is 0 (table 4).

The greatest variations in the random components values of the CR intensity is observed in Tbilisi (Cv = 59.7 %), the smallest - in Apatity (Cv = 42.6%). In Tbilisi, twenty-year averages of random components of CR intensity are lower than in all measurement points, except Rome.

The linear correlation coefficient for random components of values of CR intensity between Tbilisi and other measurement points varies from 0.27 (Tbilisi- Almaty pair, negligible correlation) to 0.65 (Tbilisi – Moscow and Tbilisi - Rome pairs, moderate correlation).

In table 5 data about the relationship between mean values of different components of galactic cosmic rays intensity in measurement locations are presented.

Table 5. Relationship between mean values of different components of galactic cosmic rays intensity in measurement locations.

Variable	Tbilisi	Almaty	Apatity	Moscow	Novosibirsk	Rome
Rand/Real, %	1.79	3.79	3.50	2.23	2.40	1.42
Rand/Trend+Back, %	1.82	3.94	3.63	2.28	2.46	1.44
Trend+Back/Real, %	98.2	96.2	96.5	97.8	97.6	98.6

As follows from table 5 the range of these ratios is as follows: Rand/Real – from 1.42 % (Rome) to 3.79 % (Almaty); Rand/Trend+Back - from 1.44 % (Rome) to 3.94 % (Almaty); Trend+Back/Real - from 96.2 % (Almaty) to 98.6 % (Rome). For Tbilisi, these ratios are respectively equal to 1.79 %, 1.82 % and 98.2 %.

In fig. 6 data about the connection of linear correlation coefficient between different components of galactic cosmic rays intensity in Tbilisi and in other measurement locations with distance from Tbilisi are presented.

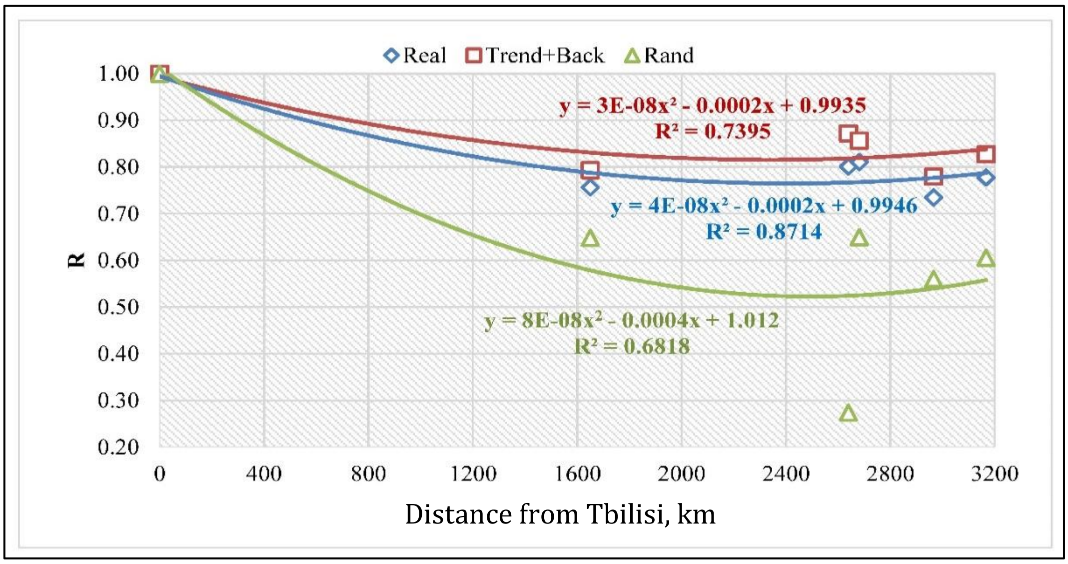

Fig.6. Connection of linear correlation coefficient between different components of galactic cosmic rays intensity in Tbilisi and in other measurement locations with distance from Tbilisi.

As follows from fig. 6 all these dependences have the form of the second power polynomial. In particular, it should be noted that the real data on the CR intensity for Tbilisi are very highly representative at a distance of up to 500 km from the measurement point ($R \geq 0.9$) and highly representative at a distance of at least 3200 km from this city ($0.7 \leq R < 0.9$).

CONCLUSION

In the future, we plan to conduct a similar study for time series of monthly values of cosmic ray intensity.

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