STATISTICAL ANALYSIS OF GLOBAL SOLAR RADIATION AND TEMPERATURE TRENDS AT CLUJ-NAPOCA, ROMANIA (1921-2009)

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***ABSTRACT**: The evolution of annual global solar radiation (GSR) and temperature trends in Cluj-Napoca, Romania, was analyzed for the period 1921 to 2009. Different statistical procedures like t-test, regression models, Runs test and cumulative curve of the radiation and precipitation standardized anomaly were used to find the most appropriate expression of the annual mean GSR and temperature interannual evolution. In order to sustain the results from Cluj-Napoca, we also used data from two neighboring stations, namely Bistrita and Sibiu. The parametric analysis with regression models shows significant increasing trends, the quadratic trend model providing a better fit than the linear and exponential models. According to the quadratic model, the GSR increased with 8.419 W/m^2 at Cluj-Napoca, 9.443 W/m^2 at Bistrita and 2.429 W/m^2 at Sibiu, while the temperature increased with 0.4°C at Cluj-Napoca and 0.6°C at Bistri?a and decreased with 0.2°C at Sibiu. It is the most probably that this increasing in GSR and increasing/decreasing of temperature is rather the ascensional or descensinal parts of some natural micro-oscillations due to the natural climate variability or solar variations.*

***Keywords**: Global solar radiation; annual mean temperature; quadratic trend; Runs test, radiation and precipitation standardized anomaly, microcycles.*

1. Introduction

It is known that the climate is variable on all time scales, and for a better understanding of the nature of the climate changes the attention must be focused not only to the course of the mean climate characteristics, but also to the changes in climate variability and climate extremes. It was demonstrated in several works (Katz & Brown, 1992; Rebetez, 1996; Wilks & Riha, 1996; and the references therein) the importance of including the variability characteristics into the climate change studies. An impact on climate change would result from changes in climate variability or from the extreme event occurrence rather than from an increase in the mean temperature itself (Houghton et al., 1996).

Numerous studies of the surface air temperature (SAT) variability in fact revealed definite decreasing variability trends in SAT records (Karl et al., 1995; Moberg et al., 2000; Rebetez, 2001; Bodri & Cermak, 2003). Thus, the investigations of variability likewise the investigations of warming trends can be further used for the validation of the simulated models for various scenarios of greenhouse-gas emission and land use. But these results depend on the period and the region considered. The situation is even more noticeable with additional associated climatic variables, such as precipitation, solar radiation, etc. For example, in the Cluj-Napoca area, Romania, the time series analysis of the temperature and solar radiation was made on a short-term and this revealed increasing trends of these variables, being statistically significant (Tahâş et al., in press).

Radiative forcing alters heating, and at the Earth's surface this directly affects evaporation as well as sensible heating. Further, increasing temperatures tend to increase evaporation which leads to more precipitation (Solomon et al., 2007). Globally there has been no statistically significant overall trend in precipitation over the past century, although trends have varied widely by region and over time.

Knowledge of local solar radiation is essential for many applications, including architectural design, solar energy and irrigation systems, crop growth models and evapotranspiration estimates (Almorox & Hontoria, 2004). Unfortunately, solar radiation measurements are not easily available for many countries as the measurement equipment and techniques involved are expensive. Therefore, it is rather important to elaborate methods to estimate the solar radiation on the basis of meteorological data (Al-Lawati et al., 2003). Over the years, many models have been proposed to predict the amount of global solar radiation using various parameters. The most widely used method is that of Angstrom (Angstrom, 1924), who proposed a linear relationship between the ratio of average daily global radiation to the corresponding value on a completely clear day and the ratio of average daily sunshine duration to the maximum possible sunshine duration. Prescott (1940) put the equation in a more convenient form by replacing the average global radiation on a clear day with the extraterrestrial solar radiation.

2. Description of study area

The studied area, the city of Cluj-Napoca, belonging to Cluj County of Romania and having a surface area of 179.5 square kilometers, is located in the central part of Transylvania, in a region surrounded by hills, more exactly in the valley of the Someşul Mic River. The city has a continental climate, characterized by warm dry summers and sometimes cold winters. The climate is influenced by the city's proximity to the Apuseni Mountains, as well as by urbanization. Some West-Atlantic influences are present during winter and autumn. The meteorological station in Cluj-Napoca is located at about 46°47’N/23°34’E and height about 414 m above sea level.

We had to add into the analysis other two surroundings stations: Bistri?a (situated in the north of Transylvania on the Bistrita River, at 367 m altitude) and Sibiu (set in the Cibin Depression in the south of Transylvania, at 444 m altitude), because using statistical information from only one meteorological station might be considered irrelevant. Even if these two stations are not situated in the analyzed area, the variations of solar radiation and precipitation at Cluj-Napoca would be more credible if it is sustained by similar results at the neighboring stations.

This analysis tries to connect the radiation and precipitation trends of this area with the so-called global climatic changes. In spite of different theories which infirming or non-infirming the climatic changes, it is generally accepted the idea that the Sun plays a main role in global warming, especially due to solar cycles (Tung & Camp, 2008) which lead to an increase of temperature. This has increased over the last 100 years, and in the last decades, the warming rate has been accelerated (Solomon et al., 2007).

3. Data and methods

Using the Angstrom-Prescott equation, the global solar radiation data were calculated from the monthly sunshine hours and were taken from the Meteorological Yearbooks (MY) and Monthly Climatic Data for the World (MCDW). Also, monthly temperature data were taken from the MY and MCDW.

The analysis is based on data collected at Cluj-Napoca station (latitude: 46°47’N; longitude: 23°34’E; altitude: 414 m) and other two surroundings stations: Bistrita (latitude: 47°09’N; longitude: 24°31’E; altitude: 367 m) and Sibiu (latitude: 45°48’N; longitude: 24°09’E; altitude: 444 m) for an 89-year period (1921–2009).

The radiation and temperature trends are usually emphasized through the linear model, which is the most used and the simplest model for an unknown trend in this type of analysis. It is known that, in statistics, the linear model is specially used in time series analysis. The linear model assumes that the rate of increase or decrease is constant and this type of trend model is very sensitive to outliers, abnormally high or low values at the start or end of a series having a disproportionate influence upon the estimated slope. But it is not obligatory that the trend should be linear, it could have unlinear models. In order to find out which is the most suitable trend model in this study, we chose among the linear, quadratic and exponential models calculated through the least squared method.

To do a good analyze of these trends, we used two statistical programs for the global solar radiation and temperature dataset, EViews (3.0) and Minitab. The annual time series were computed using EViews software. Linear regressions of the annual time series of these two variables at the used stations over the period 1921–2009 were calculated in order to detect the increasing or decreasing trends. There are different statistical methods considering trend analysis (Haan, 1977; Bobee and Ashkar, 1991; Salas, 1992). One of them is the Student's t-test, which is a common method for trend analysis of climatic parameters (Chattopadhyay & Hulme, 1997). The Student's *t*-test along with the coefficient of determination (R^2) was performed with the same EViews program. The *t*-test method (Snedecor & Cochran, 1989) was used to confirm the significance of the observed trends. R^2 has values between 0 and 1. The closer is R^2 to 1, the stronger is the intensity of the connection between the two variables which here are solar radiation or temperature and time. When R^2 is 1.0, the relationship is perfect linear. The Minitab program was used to compute three measures of accuracy in order to determinate the precision of the fitted values: Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD) and Mean Squared Deviation (MSD). Though these three indicators are not very informative by themselves, they are used to compare the values obtained by using different trend models. For all three measures, the smaller the value, the better the fit of the model. Using these statistics to compare the fits of the different methods, we can decide which is the most proper model.

MAPE measures the accuracy of fitted time series values. It expresses accuracy as a percentage:

$$\text{MAPE} = \frac{\sum \left|(y_t - \hat{y}_t)/y_t\right|}{n} \times 100, \quad (y_t \neq 0) \qquad (1)$$

where: *y* represents the actual value,
ŷ represents the fitted value,
n is the number of observations.

MAD measures the accuracy of fitted time series values. It expresses accuracy in the same units as the data, which helps conceptualize the amount of error:

$$\text{MAD} = \frac{\sum_{t=1}^{n} \left|y_t - \hat{y}_t\right|}{n} \qquad (2)$$

MSD is always computed using the same denominator, *n*, regardless of the model, so you can compare MSD values across models. MSD is a more sensitive measure of an unusually large forecast error than MAD:

$$\text{MSD} = \frac{\sum_{t=1}^{n} \left|y_t - \hat{y}_t\right|^2}{n} \qquad (3)$$

If the global solar radiation (R_s) is not measured with pyranometers, it is usually estimated from sunshine hours and it can be calculated with the Angstrom-Prescott formula (Martinez-Lazono et al., 1984; Gueymard, 1995):

$$R_s = \left(a + b\frac{n}{N}\right) R_a \qquad (4)$$

where:

R_s and R_a are the global solar radiation and extraterrestrial radiation, respectively, on a horizontal surface;

n is the actual number of monthly sunshine hours;

N is the maximum possible number of monthly sunshine hours;

n/N is relative sunshine duration;

a gives the fraction of R_a reaching the Earth on cloud-covered days when n = 0, *b* is the coefficient of regression;

(*a* + *b*) represents the fraction of R_a reaching the Earth on clear-sky days, when n = N.

Studies on the *a* and *b* coefficients of Angstrom's formula have previously been published by Baker & Haines (1969) and Panoras & Mavroudis (1994). Variations in the *a* and *b* values are explained as a consequence of local and seasonal changes in the type and thickness of cloud cover, the effects of snow covered surfaces, the concentrations of pollutants and latitude (Linacre, 1992; Boisvert, 1990).

Based on measurements made at various locations on the Earth, Allen et al. (1998) recommended the values of *a* = 0.25 and *b* = 0.50 in estimating R_s, when there is available data on sunshine duration and direct measurements on R_s are missing. Therefore, the above *a* and *b* values will be used in our study. The extraterrestrial radiation (R_a) and the monthly maximum possible sunshine duration (*N*) are given by (Allen et al., 1998):

$$R_a = \frac{24(60)}{\pi} G_{sc}\, d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right] \quad (5)$$

$$N = (24 \times \omega_s)/\pi \quad (6)$$

where: G_{sc} is the solar constant = 0.0820 (MJ m^{-2} min^{-1}), d_r is the inverse relative distance Earth-Sun, ω_s is the sunset hour angle. The hour angle, expressed in radians, is measured at sunset when the sun's center reaches the horizon. φ is the latitude of the site (radians) and δ is the solar declination (radians).

$$d_r = 1 + 0.033 \times \cos(2\pi J/365) \quad (7)$$

$$\delta = 0.409 \times \sin[(2\pi J/365) - 1.39] \quad (8)$$

where *J* is the 15^{th} day of each month in the year (for monthly calculations).

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)] \quad (9)$$

Another way to test if there is a trend or an oscillation in the data is represented by the non-parametric tests. The non-parametric testing is an alternative to the linear and nonlinear trend models, because it does not assume that the data follow a specific distribution and it is less sensitive to extreme values. One of the non-parametric tests recommended by the World Meteorological Organization (WMO, 1983), and which is used here, is the Runs Test. This test is considered to be one of the easiest to apply procedure for testing randomness (Koutras & Alexandrou, 1997) or when you want to determine if the order of responses above or below a specified value is random. The procedure is based on the Wald-Wolfowitz test, developed in 1940 by the Romanian born US statistician Abraham Wald (1902–1950) and the Polish born US statistician Jacob Wolfowitz (1910–1981).

The Runs test shows if the time series are influenced by some special causes. The test is based on the idea that the variation which can occur in a process can be common or special. The common variation is a natural part of all processes in the environment. The special variation is unavoidable in most every process and is due to additional factors which came from outside the system and can cause recognizable patterns, shifts or trends in the data. As Hobai (2009) said, it can be difficult to detect the signal of the special variation because it is hidden in the common variation. Based on the number of runs, Minitab program performs a test to determine if there are variations in the data due to trends or oscillations. The test is based on the number of runs above or below the mean.

A modality to emphasize the periods with surplus or deficit of the annual mean global solar radiation and temperature comparative with the multiannual mean is represented by the cumulative curves of the global solar radiation and temperature standardized anomalies. In the climate research, the concept of the cumulative analysis is largely used (Lozowski, 1989; Jin et al., 2005), because it is based on the idea that the climate expresses not only its parameters at a given moment, but also their cumulative effects.

The global solar radiation standardized anomaly (GSRSA) is calculated in the same way as the precipitation standardized anomaly (Maheras et al., 1999) with the formulas:

$$GSRSA_i = \frac{X_i - X}{\sigma_i}, \quad TSA_i = \frac{X_i - X}{\sigma_i} \quad (10)$$

where *i* is the period for which GSRSA or TSA is calculated (year in this case), X_i is the mean global solar radiation/temperature of the interval *i*, X is the multiannual mean global solar radiation/temperature, σ_i represents the annual standard deviation of the monthly mean value of GSR/temperature.

The standard deviation is calculated with the formula:

$$\sigma_i = \sqrt{\frac{\sum_{i=1}^{n} (X_i - X)^2}{n-1}} \quad (11)$$

where *n* represents the length of the time series, which here is 89. The cumulative curve of GSRSA and TSA uses the GSRSA and TSA values calculated for consecutive years. The plotted points have the values a_n calculated with the formula:

$$a_n = \sum_{i=1}^{n} GSRSA_i, \quad a_n = \sum_{i=1}^{n} TSA_i \quad (12)$$

4. Results and discussion

4.1. Trend analysis of radiation and temperature time series

At Cluj-Napoca meteorological station, the multiannual mean global solar radiation (GSR) during the period 1921–2009 (89 years) is 145.562 W/m^2.Comparing the mean GSR of 143.765 W/m^2 during the period from 1921 to 1965 with the mean of 147.399 W/m^2 during the period from 1966 to 2009, it can be observed an increasing with 3.634 W/m^2. It is known that solar radiation at the Earth's surface is not constant over time but rather varies considerably over decades. We refer here to changes in the amount of total solar radiation and this is due to solar activity. We conclude that in the analyzed period the annual mean GSR increased.

The multiannual mean temperature at Cluj-Napoca station during the period 1921–2009 (89 years) is 8.6°C. The mean temperature for the period 1921–1965 is 8.5°C and for the period 1966–2009 is 8.6°C, so it can be seen an increasing with 0.1°C. This slightly increasing could be due to an oscillation, an expression of the normal variations of the climate.

At Bistrita meteorological station, during the period 1921–2009 (89 years), the annual mean GSR is 142.019 W/m^2. The mean GSR in 1921–1965 period is 140.388 W/m^2 and in 1966–2009 is 143.686, so it can be seen an increasing with 3.298 W/m^2. The mean annual temperature during the period 1921–2009 is 8.3°C. By comparing the means of 1921–1965 (8.2°C) and 1966–2009 (8.4°C) periods, the annual temperature also increased with 0.2°C.

The mean annual GSR at Sibiu during the period 1921–2009 (89 years) is 141.996 W/m^2. Comparing the means during the periods from 1921 to 1965 (142.459 W/m^2) and 1966 to 2009 (141.522 W/m^2), it can be observed a decreasing with 0.937 W/m^2. The mean annual temperature during the period 1921–2009 is 8.9°C. If we compare the means of 1921–1965 (9.0°C) and 1966–2009 (8.8°C) periods, we observe the annual temperature also decreased with 2.0°C.

In table 1 is presented the performance of each model for Cluj-Napoca meteorological station. Comparing with linear and exponential model, the value of R^2 for the quadratic model both for radiation (0.1876) and for temperature (0.0683) is higher even if it is quite far from the ideal linearity indicating that this model is the most adequate.

Also, almost all the three accuracy indicators have lower values (except MAPE that has a lower value for the exponential model in the case of the GSR) for the quadratic model compared to the linear and exponential models; therefore, the quadratic trend model seems to provide the better fit.

According to the quadratic model, for the period from 1921 to 2009, it can be observed an increasing trend of the global solar radiation (Fig.1a) and temperature (Fig.1b). The regression equation of the radiation and temperature shows that in the whole period of 89 years (1921-2009), both the mean GSR and mean temperature raised with 8.419 W/m^2 and 0.4°C, respectively. Unlike the radiation trend, which is not statistically significant for the quadratic model (it is significant only for the linear model at 0.001 level), the temperature trend is significant for the quadratic model at 0.05 level.

Table 1. Annual GSR and temperature at the Cluj-Napoca station (1921-2009). Characteristics of the trend models and statistical significance of their equations tested by t-test.

Annual mean global solar radiation (GSR)							
Trend model	Trend[a]	MAPE (%)	MAD (W/m^2)	MSD [(W/m^2)^2]	Estimating equation	Calculated t and t^{2b}	R^2
Linear	0	2.8599	4.1464	25.6601	$y = 141.487 + 0.0926x$	4.3807**	0.1807
Quadratic	0	2.8541	4.1374	25.4445	$y = 142.4908 + 0.0234x + 0.0008x^2$	0.8536	0.1876
Exponential	0	2.8528	4.1385	25.6519	$y = 141.344e^{0.0006x}$	-	0.1794
Annual mean temperature							
Trend model	Trend[a]	MAPE (%)	MAD (°C)	MSD (°C^2)	Estimating equation	Calculated t and t^{2b}	R^2
Linear	0	6.6658	0.5625	0.4967	$y = 8.3586 + 0.0044x$	1.4916	0.0249
Quadratic	0	6.5994	0.5558	0.4746	$y = 8.6799 – 0.0177x + 0.000252x^2$	2.0003*	0.0683
Exponential	0	6.6331	0.5616	0.4974	$y = 8.322e^{0.0005x}$	-	0.0258

[a] : Denotes positive trend; [b] *Significant at 0.05 level; **significant at 0.001 level

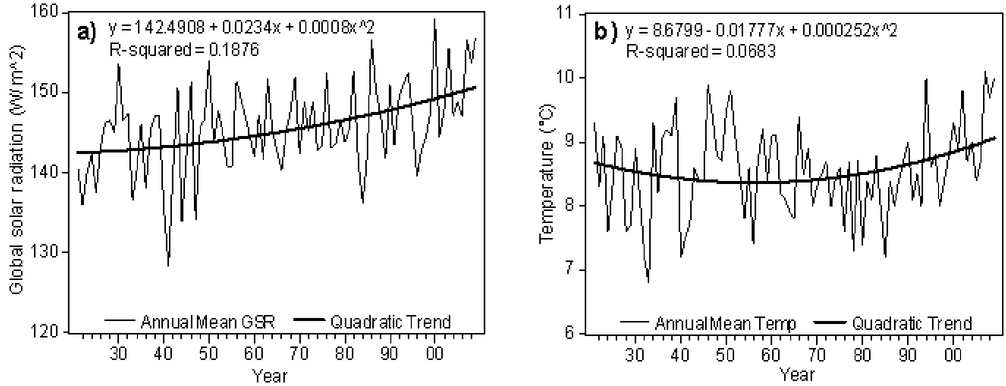

Fig. 1. The annual mean GSR (a) and temperature (b) (thin line) and the quadratic trends (thick line) at Cluj-Napoca, 1921-2009.

In the case of Bistrita and Sibiu stations (Tab. 2), R^2 has the higher value for the same quadratic estimating equations. At Bistrita, the measures of accuracy for the GSR have lower values also for the quadratic model, while for the temperature the quadratic model is sustained only by MAD and MSD, MAPE having the lower value for the exponential model. At Sibiu, the quadratic model for the GSR is sustained only by MSD, MAPE and MAD having the lower values for the linear model. In this case, it seems the linear model is the most appropriate for the annual mean GSR and temperature at Sibiu meteorological station, but the values of these indicators are very close.

As for the temperature, all the three accuracy indicators have lower values for the quadratic model. The quadratic equation indicates that in 1921–2009 period the annual mean GSR and temperature increased at Bistrita with 9.443 W/m^2 and 0.6°C, respectively. At this station, the increasing trend for solar radiation is significant at 0.01 level, while for the temperature is significant at 0.05 level. At Sibiu, the GSR increased with only 2.429 W/m^2 and temperature decrease with 0.2°C (Fig.2). Here, only decreasing trend for temperature is statistically significant at 0.05 level.

Table 2. Annual GSR and temperature at the Bistrita and Sibiu stations (1921-2009). Characteristics of the trend models and statistical significance of their equations tested by t-test.

BISTRITA							
Annual mean global solar radiation (GSR)							
Trend model	Trend[a]	MAPE (%)	MAD (W/m^2)	MSD [(W/m^2)^2]	Estimating equation	Calculated *t* and t^{2b}	R^2
Linear	0	3.0829	4.3442	32.1676	$y = 137.4935 + 0.1028x$	4.345***	0.1783
Quadratic	0	2.9488	4.1554	28.3726	$y = 141.7051 - 0.1876x + 0.0033x^2$	3.3916**	0.2752
Exponential	0	3.0761	4.3382	32.0992	$y = 137.392e^{0.0007x}$	-	0.1724
Annual mean temperature							
Trend model	Trend[a]	MAPE (%)	MAD (°C)	MSD (°C^2)	Estimating equation	Calculated *t* and t^{2b}	R^2
Linear	0	7.1404	0.5801	0.5527	$y = 7.9779 + 0.0069x$	2.2442*	0.0547
Quadratic	0	7.1280	0.5778	0.5275	$y = 8.3207 - 0.0167x + 0.0002x^2$	2.0249*	0.0977
Exponential	0	7.1063	0.5796	0.5533	$y = 7.9460e^{0.0008x}$	-	0.0522
SIBIU							
Annual mean global solar radiation (GSR)							
Trend model	Trend[a]	MAPE (%)	MAD (W/m^2)	MSD [(W/m^2)^2]	Estimating equation	Calculated *t* and t^{2b}	R^2
Linear	0	3.1616	4.4691	30.3865	$y = 140.7196 + 0.029x$	1.2607	0.0179
Quadratic	0	3.1778	4.4922	30.2902	$y = 141.3902 - 0.0172x + 0.0005x^2$	0.5226	0.021
Exponential	0	3.1633	4.4749	30.3970	$y = 140.602e^{0.0002x}$	-	0.0174
Annual mean temperature							
Trend model	Trend[a]	MAPE (%)	MAD (°C)	MSD (°C^2)	Estimating equation	Calculated *t* and t^{2b}	R^2
Linear	–	6.6198	0.5836	0.5287	$y = 9.0112 - 0.0021x$	-0.7063	0.0057
Quadratic	–	6.4610	0.5692	0.4993	$y = 9.3818 - 0.0277x + 0.0003x^2$	2.2501*	0.0609
Exponential	–	6.6048	0.5843	0.5295	$y = 8.9737e^{-0.0002x}$	-	0.0045

[a] + Denotes positive trend, – denotes decreasing trend.

[b] *Significant at 0.05 level, **significant at 0.01 level, ***significant at 0.001 level.

Considering that the quadratic model found at Cluj-Napoca is generally sustained by the same trend at Bistrita and Sibiu, it can be admitted that this trend is the most suitable to describe the annual mean GSR and temperature evolution in the Cluj-Napoca area.

The increasing trend of annual mean GSR could be ascribed to solar activity. It is known that the solar cycle has a great influence on space weather, and is a significant influence on the Earth's climate since luminosity has a direct relationship with magnetic activity (Willson and Hudson, 1991). A recent theory claims that there are magnetic instabilities in the core of the Sun that cause fluctuations with periods of either 41,000 or 100,000 years. Solar activity minima tend to be correlated with colder temperatures, and longer than average solar cycles tend to be correlated with hotter temperatures. The increase or decrease of the temperature can be explained only by an unperiodical variation of the climate at a microregional scale. Because the climatic changes are produced at a very large time scale, this tendency of the temperature is more probably not an expression of the global climatic changes but a meteorological variation (Rusu, 2007).

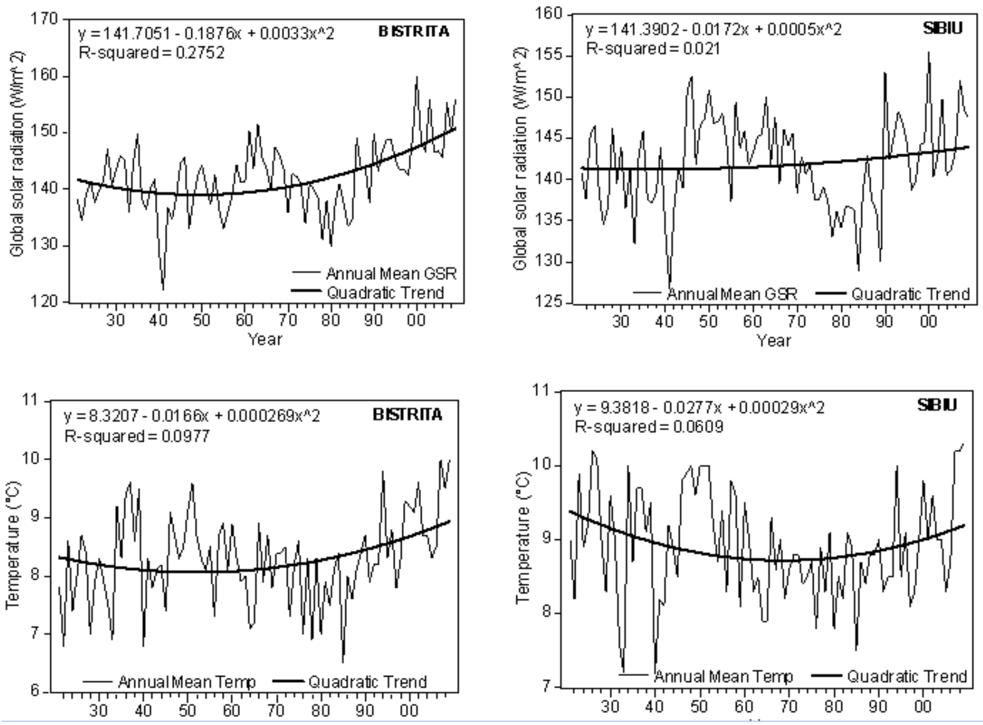

Fig. 2. The annual mean GSR and temperature (thin line) and the quadratic trends (thick line) at Bistrita and Sibiu, 1921–2009

We can suppose that the increasing tendency of global radiation and increasing/decreasing tendency of temperature in the last decades is the ascensional or descensinal part of some microcycles because the quadratic model is one of best fitted trend models.

This is in accordance with the results of other researches (Le Mouël et al., 2005; Miyahara et al., 2008), who revealed a positive correlation of the air temperature with the solar and geomagnetic activity, in terms of 11 and 22-year, supporting the cyclical evolution of the climatic parameters.

4.2. Runs Test (Non-parametric test)

The test compares the observed number of runs with the expected number of runs above and below the mean. When the observed number of runs is statistically greater than the expected number of runs, then oscillation is suggested; when it is statistically less than the expected number of runs, then a trend is suggested.

In a standard normal distribution, the formula of the *p-value* for trends, noted here p'-value, is next:

$$\textbf{p' - value = cdf(z)} \qquad (13)$$

where: *cdf* is the cumulative probability to *Z* which is calculated with the formula:

$$Z = \frac{O(runs) - E(runs)}{\sqrt{\sigma^2}} \qquad (14)$$

where: *O* (runs) is the observed number of runs above and below the mean, *E* (runs) is the expected number of runs above and below the mean and σ^2 is the variance of the expected number of runs distribution.

E (runs) is calculated with the formula:

$$E(runs) = 1 + \frac{2*A*B}{N} \qquad (15)$$

where: *A* is the number of observations above the comparison criteria (k), *B* is the number of observations below or equal to *k*, and N is the total number of observations (sum of *A* and *B*). The variance σ^2 is given by the formula:

$$\sigma^2 = \frac{2*A*B(2*A*B - N)}{N^2(N-1)} \qquad (16)$$

The *p-value* for oscillation, noted here p''-value, in a standard normal distribution is:

$$\textbf{p'' - value = 1 - cdf(z)} \qquad (13)$$

where *cdf (Z)* has the same significances as above.

In Cluj-Napoca case, for the GSR, the observed number of runs above and below the mean (44) is less than the expected number of runs (45.5), so we can say that is suggested a trend, but the difference between them is very small. The *p-values* for trends (0.750) and oscillation (0.250) are greater than the *α-level* of 0.05, so the test is not significant. Therefore, we can conclude that the data does not strongly indicate a trend or oscillation, but as the *p-value* for oscillation is smaller than the *p-value* for trend, then it is more appropriate to say that an oscillation has a bigger probability than a trend. As for the temperature, also the observed number of runs above and below the mean (43) is less than the expected number of runs (45.5), so we can say that is suggested a trend, but the difference between them is very small. The *p-values* for trends (0.595) and oscillation (0.405) are greater than the *α-level* of 0.05, so the test is not significant. We can conclude that the data does not strongly indicate a trend or oscillation, but as the *p-value* for oscillation is smaller again than the *p-value* for trend, then it is more appropriate to say that an oscillation has a bigger probability than a trend.

At Bistrita meteorological station, for the GSR, the observed number of runs above and below the mean (24) is less than the expected number of runs (45.5), and the *p-value* for trend (0.0001) indicates a trend. Therefore, the test is statistically significant for the *α-level* of 0.001. As for the temperature, the observed number of runs above and below the mean (38) is less than the expected number of runs (44.8), so we can say that is suggested a trend. The *p-values* for trends (0.140) and oscillation (0.860) are greater than the *α-level* of 0.05, but this time the value for trend is closer to the *α-level* than the value for oscillation.

In the case of Sibiu station, the observed number of runs above and below the mean (34) is less than the expected number of runs (45.5), so this indicates a trend. The *p-value* for trend (0.014) shows the test is significant for the *α-level* of 0.05. As for the temperature, the observed number of runs above and below the mean (39) is less than the expected number of runs (45.4), so this could indicate a trend. The *p-values* for trends (0.169) and oscillation (0.831) are greater than the *α-level* of 0.05, but the value for trend is closer to the *α-level* than the value for oscillation.

As a consequence, the results of this test show that the situation at Cluj-Napoca is different from that of the other two stations because an oscillation is indicated for global radiation and temperature, while at Bistrita and Sibiu the *p-values* indicate trends for both variables (GSR and temperature) being statistically significant. Because we obtained two *p-values* below *α-level*, we can conclude that there is a strong proof that there is a special variation in GSR trends due to solar activity. No special variation due to trend or oscillation was found for temperature. However, at Cluj-Napoca station the closest *p-value* to *α-level* (0.05), obtained in the Runs test, was *p-value* (for global radiation) for oscillation (0.25), so we could consider this as a sign for a possible oscillation.

4.3. Cumulative curves of radiation and temperature

The periods characterized by accumulations of the GSR and temperature surplus or deficit can be observed on the curves (fig. 3). The descending branch covers a period when the solar radiation deficit is accumulated and on the ascending branch the surplus is accumulated. Because the curve doesn't cross the zero-value of GSRSA then the deficit (when the values are lower than zero) anterior accumulated is neutralized. As for the temperature, the descending branches cover two periods when the temperature deficit is accumulated and on the ascending branches the surplus is accumulated. When the curve crosses the zero-value of TSA then the deficit (if the values are lower than zero) or surplus (if the values are larger than zero) anterior accumulated is neutralized.

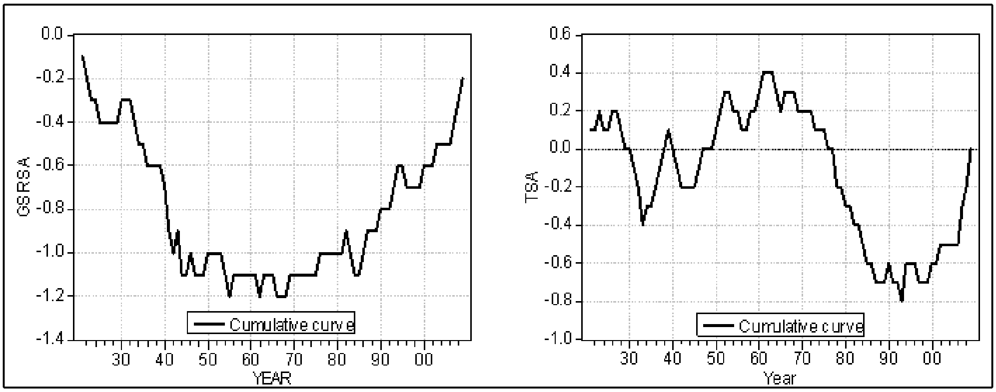

Fig. 3. Cumulative curves of the GSR and temperature standardized anomalies at Cluj-Napoca (1921–2009).

As it can be seen in the fig. 3, at Cluj-Napoca during 1921–1968 period, the GSRSA shows a decreasing, then, in spite of intermittent increases and decreases, indicates an increasing which is almost close to the zero threshold-value. During the whole period of 89 years (1921-2009), there is only a GSR deficit and no surplus. In other words, the GSR deficit is not neutralized by the GSR surplus. We can consider that the whole analyzed period represents a cycle on a microclimatical scale which can be ascribed to solar activity. As for the TSA, during the whole analyzed period (1921-2009), this shows more parts of the periods of temperature deficit and surplus. During 1921-1933 period, the TSA shows a decreasing and then, in spite of intermittent decreases, an increasing from 1934 to 1963, where the curve crosses the zero-value of TSA. It can be observed that the temperature deficit from the first part of the period is neutralized (equalized) by the surplus from the second part. In 1921-1963 period the temperature deficit from the first time of the period is neutralized by the surplus from the second part. In the 1964-2009 period, the temperature deficit from the third part of the period is not neutralized by the surplus from the last part. It is possible this deficit to be neutralized in the next years. However, we consider that the whole analyzed period represents more cycles on a microclimatical scale.

The shapes of the cumulative curves of the GSRSA and TSA at Bistrita are generally similar with the ones from Cluj-Napoca unlike the ones from Sibiu (Fig. 4).

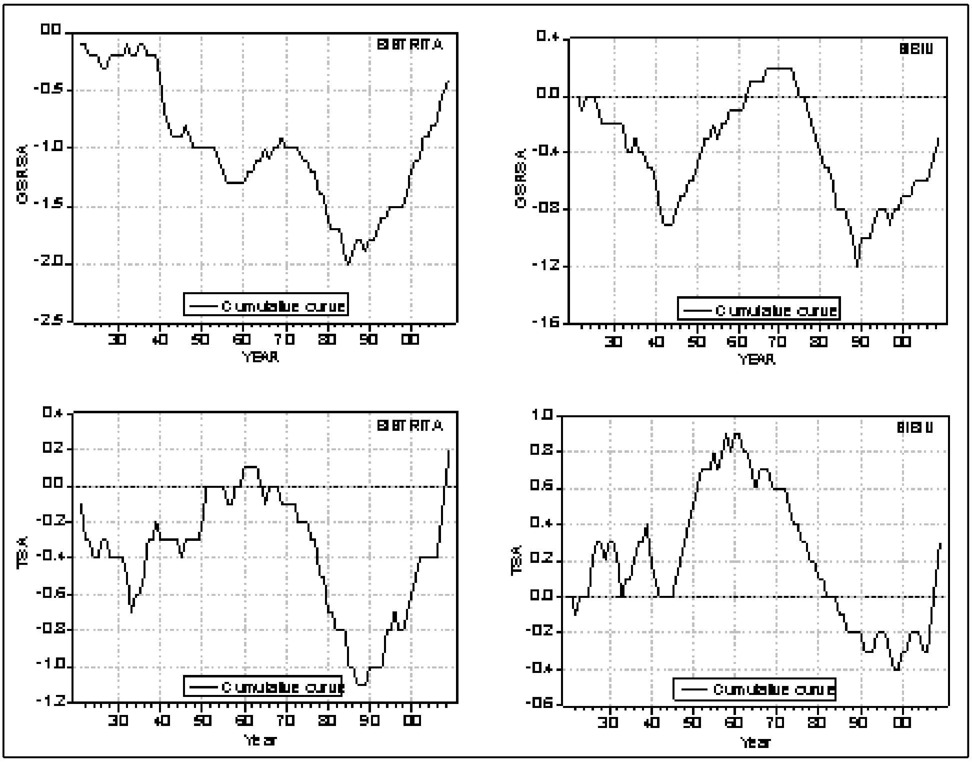

Fig. 4. Cumulative curves of the GSR and temperature standardized anomalies at Bistrita and Sibiu (1921–2009)

At Bistrita, the GSR deficit is not neutralized by the GSR surplus. Instead, there are two periods with temperature deficit that are neutralized by the two periods with temperature surplus. At Sibiu, the GSR deficit is neutralized by the GSR surplus just once. There are two periods with temperature deficit that are neutralized by the two periods with temperature surplus. It is interesting to note that the GSR deficit from the last few years for all three stations was not neutralized. Instead, the neutralization of the temperature deficit from the last few years for all three stations began more rapidly at Sibiu and Bistrita comparing with Cluj-Napoca. This is a consequence of the fact that the annual mean temperature in the last few years was higher or almost equal at Sibiu and Bistrita comparing with Cluj-Napoca.

This might be ascribed to solar variations and anthropical interventions on the local environment.

The shapes of the cumulative curves suggest that the increasing tendency of the annual mean GSR and temperature and the observed fluctuations represent some microcycles, expression of the normal variations of the climate, which in the last few years is reacting to the solar variations and anthropical interventions.

5. Conclusions

The increasing tendency and variability of the global solar radiation and temperature in Cluj-Napoca have been investigated in this study. The analysis has been performed using the time series of the annual mean GSR and temperature recorded in a 89-year period (1921–2009) at the Cluj-Napoca meteorological station. In order to sustain the results from Cluj-Napoca, we also used data from two neighboring stations, namely Bistrita and Sibiu.

It was found that during this period, the mean annual GSR and temperature showed significant increasing and warming tendency. The values of R^2 and the three accuracy indicators (MAPE, MAD, MSD) are indicating that the quadratic model is the most suitable for the annual mean GSR and temperature evolution at all three meterorological stations considered. According to the quadratic model, the GSR and temperature increased with 8.419 W/m^2 and 0.4°C at Cluj-Napoca, with 9.443 W/m^2 and 0.6°C at Bistrita. At Sibiu, the situation is a little bit different because the GSR increased with only 2.429 W/m^2 and temperature decreased with 0.2°C. Given the fact that the quadratic model provides a better fit than the linear and exponential models and the two variables were examined by Runs test, we consider that at Cluj-Napoca, the increasing of GSR is due to a micro-oscillation while the increasing of temperature is due to a trend.

At Bistrita and Sibiu the increasing/ decreasing of GSR is generally due to the trends as the *p-values* also indicating statistically significant trends. Also, the increasing/ decreasing of temperature is due to the trends being statistically significant even if the *p-values* are not significant and indicate trends.

Because Runs tests showed some special variations, we think that the microcycles suggested in this paper are caused principally by the natural variability of the climate, especially by solar activity. We can conclude that these microcycles are periodical because the time series of 89-years record at these stations are long and help us to determine accurately the long-term periodicities and to make a generalization.

These trends and micro-oscillations in the multiannual GSR and temperature are also supported by the shapes of the GSRSA and TSA cumulative curves at all the three stations involved.

The significant increasing of the GSR could be ascribed to the natural climate variability or solar variations. The increasing/decreasing temperature might be a part of the global warming phenomenon or can be related to the natural climate variability or solar variations or can be a result of all these.

By definition, the climate of a specified location cannot be considered a constant environmental factor because of the systematic forcing changes (like the variations of the Earth's orbit or the amount of solar energy at different latitudes) and because it has low frequency fluctuations. It is difficult to surprise the natural variability of a climatic element in a statistical analysis.

So, it is the most probably that this increasing in GSR and increasing/decreasing of temperature is rather the ascensional or descensinal parts of some natural micro-oscillations due to the natural climate variability or solar variations.

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