Carpathian Journal of Earth and Environmental Sciences, September 2011, Vol. 6, No. 2, p. 289 - 302

ANALYSIS OF GLOBAL SOLAR RADIATION AND PRECIPITATION TRENDS IN CLUJ-NAPOCA, ROMANIA, OVER THE PERIOD 1921-2009

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Abstract: The evolution of annual global solar radiation (GSR) and precipitation trends in Cluj-Napoca, Romania, was analyzed for the period 1921 to 2009. In order to sustain the results from Cluj-Napoca, we had to add into analysis other two surroundings stations: Bistrita and Sibiu, because using only one meteorological station might be considered irrelevant. Also, we used into analysis the sunshine duration to make a good comparison with the evolution of global solar radiation. Four test methods have been performed on the data to test the series for homogeneity as follows: the Pettitt's test, the standard normal homogeneity test (SNHT) for a single break, the Buishand range test and the Von Neumann's ratio test. Different statistical procedures like regression models, Runs test and cumulative curve of the global solar radiation and precipitation standardized anomaly were used to find the most appropriate expression of the annual mean GSR and average amount of precipitation interannual evolution. The parametric analysis with regression models showed significant increasing trends for global solar radiation, sunshine duration and precipitation, the quadratic trend model providing a better fit than the linear and exponential models. To verify if the radiation, sunshine duration and precipitation variations were caused by trend or oscillation in the data, we used in the nonparametric analysis the Runs test. The results of Runs test detected significant trends for GSR and sunshine duration at Bistrita and Sibiu. Concerning to precipitation, the test didn't clearly detect any trend or oscillation at the three stations. The shape of the cumulative curve suggests that in the last two decades the general tendency is towards increasing annual global solar radiation at all three stations and the observed fluctuations represent a microcycle or microcycles (for example, Sibiu), as a result of the normal variations of the climate, which in the last few years is/are reacting to the solar variations. The decreasing tendency of the annual precipitation could be ascribed to solar activity, which is known that plays an important role in influencing the precipitation on land, and the consequence of this fact is that precipitation is closely related to the variation of sunspot numbers. Therefore, it is the most probably that this increasing in GSR and increasing/decreasing in precipitation represents the ascensional or descensional parts of some natural micro-oscillations due to solar activity/variations and natural climate variability.

Key words: Annual global solar radiation; sunshine duration; annual mean precipitation; quadratic trend; Runs test, radiation and precipitation standardized anomalies, 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). Even relatively small changes in the means and in variations of climate variables can induce a considerable change in the variability and/or in the severity of extreme events (Hennessy & Pittock, 1995; Colombo et al., 1999).

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.

There are only a few investigations of precipitation variability based on measured data. Diaz et al. (1989), analyzed the temporal variability of secular precipitation over the Northern Hemisphere, and found different seasonal trends; a negative trend during summer and autumn, and a positive trend in winter and spring. Karl and Knight (1998) analyzed daily precipitation data from the U.S. for the period 1910–1996 and found an approx. 10% increase in annual precipitation. Such increase in most cases occurred because of a greater number of rainy days, with the greatest contribution arising from large number of extreme precipitation events, indicating increased precipitation variability. The most recent investigations of precipitation trends and variability of the 20th century by New et al. (2001) based on the grid data sets revealed secular increasing trends in different domains, for example 8.9 and/or 41.6 mm/100 yr for global data set and in the mid-latitudes (40–60^{o}N) in the Northern Hemisphere, respectively, in many regions accompanied by the increasing wet spells frequency.

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.

Since the precipitation is probably one of the most registered meteorological variables, correlation models based on precipitation data are especially interesting to estimate amount of solar radiation in countries with lack of direct measurements.

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^{o}47’N/23^{o}34’E and height about 414 m above sea level.

We had to add into the analysis other two surroundings stations: Bistrita (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 they are 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). Many scientists believe an increase in temperature could lead to a more intense water cycle. The rates of evaporation from soils and water, as well as transpiration from plants, could increase. Therefore, the amount of precipitation could also increase.

3. DATA AND METHODS

Using the Angstrom-Prescott equation, the global solar radiation data were calculated from the monthly sunshine hours, which were taken from the Meteorological Yearbooks (MY) and the NCDC (National Climatic Data Center) web page (http://www7.ncdc.noaa.gov/IPS/mcdw/mcdw.html) at the section Monthly Climatic Data for the World (MCDW). Also, monthly precipitation data were taken from the MY and MCDW.

The analysis was made for 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). We added into analysis also sunshine duration to make a good comparison with the evolution of global solar radiation.

Four test methods have been performed on the data to test the series for homogeneity as follows: the Pettitt's test (Pettitt, 1979), the standard normal homogeneity test (SNHT) for a single break (Alexandersson, 1986), the Buishand range test (Buishand, 1982), and the Von Neumann's ratio test (Von Neumann, 1941). The first three ones, under the alternative hypothesis, assume that a break in the mean is present and allow identifying the time at which the shift occurs. The Von Neumann ratio test assumes, under the alternative hypothesis, the series is not randomly distributed and not allow detecting the time at which the change occurs (it gives no information on the year of the break). The performing of these homogeneity tests was made with the statistical analysis software XLSTAT.

The radiation, sunshine duration and precipitation 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 trend model is the default model used in trend 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 (Hobai, 2009). But it is not obligatory that the trend should be linear, it could have unlinear models. 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.

In order to make a good analyze of these trends, we used two statistical programs for the global solar radiation, sunshine duration and precipitation dataset, EViews (3.0) and Minitab. The annual time series were computed using EViews software. The coefficient of determination (R^2) was performed with the EViews program. 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 precipitation and time. When R^2 is 1.0, the relationship is perfect linear. The Minitab program was used to compute the 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, we can decide which model is the most proper by comparing the fits of the different methods.

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

$$\mathrm{MAPE} = \frac{\sum_{t=1}^{n} \left| \frac{y_t - \hat{y}_t}{y_t} \right|}{n} \cdot 100, \quad (y_t \neq 0) \qquad (1)$$

Where: y_t represents the actual value, $\hat{y}_t$ is the fitted value, and 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:

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

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:

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

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):

$$R_s = \left[a + b\frac{n}{N} \right] \cdot R_a, \quad (4)$$

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 and 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):

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

$$N = \frac{24 \cdot \omega_s}{\pi}, \quad (6)$$

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).

$$d_r = 1 + 0.033 \cdot \cos\left(\frac{2\pi J}{365} \right), \quad (7)$$

$$\delta = 0.409 \cdot \sin\left[\frac{2\pi J}{365} - 1.39 \right], \quad (8)$$

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

$$\omega_s = \arccos\left[-\tan(\varphi) \cdot \tan(\delta) \right]. \quad (9)$$

Another way to test if there is a trend or an oscillation in the data is represented by the non-parametric test, namely Runs test. This test 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. The Runs test, also called Wald–Wolfowitz test and recommended by the World Meteorological Organization (WMO, 1983), 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 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 (above or below the mean), Minitab program performs a test to determine if there are variations in the data due to trends or oscillations.

A modality to emphasize the periods with surplus or deficit of the annual mean global solar radiation and precipitation comparative with the multiannual mean is represented by the cumulative curves of the global solar radiation and precipitation standardized anomaly. 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:

$$\text{GSRSA}_i = \frac{X_i - X}{\sigma_i}; \ \text{PSA}_i = \frac{X_i - X}{\sigma_i}. \quad (10)$$

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

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 PSA uses the GSRSA and PSA values calculated for consecutive years. The plotted points have the values a_n calculated with the formula:

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

4. RESULTS AND DISCUSSION

4.1. Homogeneity tests

The homogeneity of the 89 annual global solar radiation, sunshine duration and precipitation time series for the period 1921–2009 has been tasted. In table 1, the annual results of the Pettitt, Standard Normal Homogeneity Test (SNHT), the Buishand range and the Neumann tests applied to global solar radiation, sunshine duration and precipitation data are shown.

Examples of change points detected for GSR at Cluj-Napoca, Bistrita and Sibiu stations are presented in figure 1a, b and c, along with the mean of the two-subintervals.

The annual results of the Pettitt, SNHT and the Buishand range tests applied to the global solar radiation at Cluj-Napoca show the 1985/1986 shift point (Fig. 1a) as the year at which the change occurs (change point). This upward shift is statistically significant at 0.01 level. The significant value of the Von Neumann test indicates the series is not randomly distributed (Data are not homogeneous). The results for precipitation indicate there is no date at which there is a significant change in the data and, therefore, the data are homogeneous at this station. As for sunshine duration, the results show there are three different significant break years (change points) and the data are not homogeneous.

Two of the tests (the Pettitt and Buishand tests) show a significant upward shift in 1985/1986 for GSR (Fig. 1b) at Bistrita station, while at Sibiu station only SNHT shows a significant upward shift in 1989/1990 for GSR (Fig. 1c). The significant results of the Von Neumann test indicate the data are not homogeneous at these two stations. The results for precipitation at two these stations are similarly with the ones from Cluj-Napoca. As for sunshine duration, the results of tests show, at Bistrita, the 1985/1986 shift point is the year at which the change occurs (the Pettitt and Buishand tests), while the 1944/1945 shift point is the break year at Sibiu (SNHT). According to the Von Neumann test, the data are not homogeneous at these two stations.

As the applied tests show that in the case of precipitation there is no significant change point at all these three stations, for the global solar radiation and sunshine duration the upward shift was truly significant. In 1997, Monastersky (1997) said the sunlight hitting the Earth was slightly brighter than ten years ago according to a study of satellite instruments that monitor solar radiation because, between 1986 and 1996, the intensity of solar radiation increased by 0.036 percent. Hence, we consider that the upward shift in global solar radiation can be attributed to the variances in solar output.

Table 1. Annual results of the Homogeneity tests for mean global solar radiation (GSR), sunshine duration (N) and precipitation (PP) at Cluj-Napoca, Bistrita and Sibiu over the period 1921–2009.

	CLUJ-NAPOCA			**BISTRITA**			**SIBIU**		
	Annual			**Annual**			**Annual**		
HOMOGENEITY TEST	**GSR**	**PP**	**N**	**GSR**	**PP**	**N**	**GSR**	**PP**	**N**
Pettitt's test	742.0** 1985[1]	488.0 1991[1]	820.0** 1967[1]	1124.0*** 1985[1]	388.0 1994[1]	1133.0*** 1985[1]	610.0 1989[1]	359.0 1982[1]	708.0* 1944[1]
Standard Normal Homogeneity Test (SNHT)	13.611** 1985[1]	7.270 1993[1]	16.052*** 1947[1]	27.954*** 1989[1]	5.895 2003[1]	27.727*** 1989[1]	9.707* 1989[1]	4.616 2003[1]	10.564* 1944[1]
Buishand's test	15.502** 1985[1]	9.811 1993[1]	17.510*** 1955[1]	21.837*** 1985[1]	6.763 1994[1]	21.821*** 1985[1]	12.318 1989[1]	8.095 1982[1]	13.474* 1944
Von Neumann's test	1.518*	1.763	1.460**	0.937***	1.753	0.914***	1.248***	1.691	1.262***

*Significant at 0.05 level, **significant at 0.01 level, ***significant at 0.001 level.
[1]The year at which the change occurs (break year).

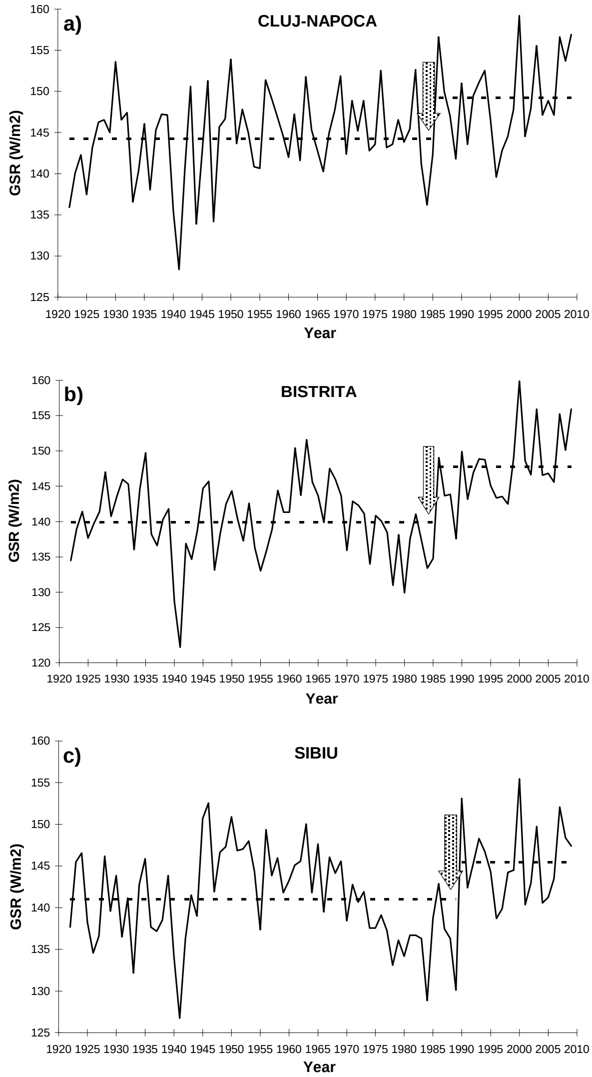

Figure 1. The averages of the two sub-intervals along with the change points detected for annual mean global solar radiation at Cluj-Napoca, Bistrita and Sibiu stations.

4.2. Trend analysis of radiation, sunshine duration and precipitation time series

At Cluj-Napoca, it can be observed an increasing trend of the mean global solar radiation (GSR) during the period 1921–2009 (89 years) (Fig. 2). The observed variability between different years showed a positive slope of 0.094 Wm^{-2}/year, with a standard deviation (S.D.) of 5.628 W/m^2 and a coefficient of variation (C.V.) of 0.04%, while the multiannual mean was 145.562 W/m^2 (Fig. 2). Application of the homogeneity tests divided the study period into two sub-periods based on statistical criteria. Therefore, comparing the mean GSR of 144.204 W/m^2 for the period 1921–1985 with the mean of 149.238 W/m^2 for the period 1986–2009, it can be observed an increasing with 5.034 W/m^2. It is known that solar radiation at the Earth's surface is not constant over time but varies considerably over decades due to solar activity. Therefore, we conclude that in the analyzed period the increase in GSR can be ascribed to solar fluctuations which are generated by solar activity.

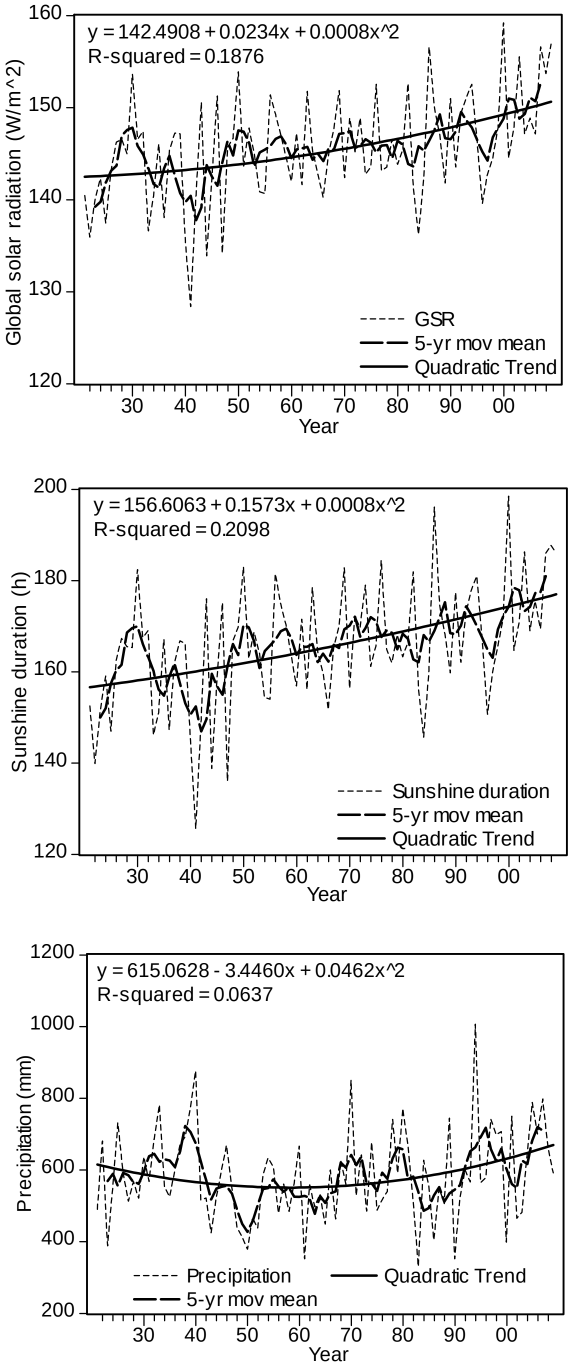

Figure 2. Five-year moving averages and quadratic trends of annual mean global solar radiation (GSR), sunshine duration and precipitation at Cluj-Napoca, 1921-2009.

The multiannual mean sunshine duration during the analyzed period (1921–2009) is 165.7 h, while the standard deviation is 13.1 hours and coefficient of variation is 0.1%. An increasing trend is shown in figure 2 being similar with the one from Cluj-Napoca. The results of the homogeneity tests show there are three different significant break years (change points) and the data are not homogeneous. This makes it almost impossible to select the correct change point in the observed time series to compare two sub-periods. The main feature of sunshine duration fluctuation in the study period is its sharp decreases at the beginning of the 1940s after a maximum at the end of the 1920s as well its sharp increase at the end of the 1990s after a minimum at the middle of the 1980s. According to Angel & Korshover (1978), long-term (climatological) changes in area cloudiness represent the main cause of the observed changes in sunshine duration. It is known that clouds absorb or reflect solar radiation, reducing the Sun's energy to reach the Earth's surface, which results in a cooling of the Earth's climate. Hence, if skies are cloudy by day, less of the sun's energy reaches the Earth's surface, which causes the Earth to heat up more slowly. This leads to cooler daily maximum temperature. Instead, in the absence of any clouds, the actual duration of sunshine can increase.

The multiannual mean precipitation at Cluj-Napoca station during the period 1921–2009 is 583.4 mm, while the standard deviation is 125.9 mm and coefficient of variation is 0.2%. According to the homogeneity tests, there is no date at which there is a significant change in the data because the data are homogeneous. Therefore, we can't have two sub-periods for this variable. In figure 2, it can be seen a slightly increase in precipitation, but this is due to an oscillation (see the Runs Test section).

At Bistrita, during the period 1921–2009, the GSR shows an increasing trend (Fig. 3) and the annual mean is 142.019 W/m^2. The observed variability between different years showed a positive slope of 0.106 Wm^{-2}/year, with a standard deviation of 6.292 W/m^2 and a coefficient of variation of 0.04%. According to homogeneity tests, the study period was divided into two sub-periods being similar with the ones from Cluj-Napoca. If we compare the annual mean GSR of 139.893 W/m^2 from the first period (1921–1985) with the mean of 147.775 W/m^2 from the second period (1986–2009), it can be observed an increasing with 7.882 W/m^2.

The multiannual mean sunshine duration during the analyzed period (1921–2009) is 159.6 h, while the standard deviation is 14.7 hours and coefficient of variation is 0.1%. A positive trend is shown in figure 3, which is generally similar with the one of GSR. The homogeneity tests indicate the data are not homogeneous and the significant change point divided the study period into two sub-periods based on statistical criteria. By comparing the mean sunshine duration of 154.6 h for the period 1921–1985 with the mean of 173.1 h for the period 1986–2009, it can be observed an increasing with 18.5 h. The main feature of sunshine duration fluctuation at this station is represented by its sharp decrease at the beginning of the 1940s after a maximum at the middle of the 1930s as well its sharp increase at the end of the 1990s after a minimum at the end of the 1970s.

The mean annual precipitation during the period 1921–2009 is 681.4 mm, while the standard deviation is 131.9 mm and coefficient of variation is 0.2%. In figure 3, it can be shown that the trend is positive according to the quadratic equation. This insignificant increasing is due to an oscillation (according to Runs test). As the data are homogeneous at this station, too, we can't have two sub-periods.

At Sibiu, the mean annual GSR during the analyzed period is 141.996 W/m^2. The observed increasing trend shows an insignificant slope of 0.029 Wm^{-2}/year, with a S.D. of 5.594 Wm^{-2} and a C.V. of 0.04%. As the homogeneity tests indicated the 1989/1990 shift is the break year, the study period was divided into two sub-periods. Comparing the means for the periods 1921–1989 (140.993 W/m^2) and 1990–2009 (145.454 W/m^2), it can be observed an increasing with 4.461 W/m^2. It is important to notice that the first period (1921–1989) of the annual mean is longer than the similar periods from the other two stations taken into consideration.

The multiannual mean sunshine duration is 153.5 h, while the standard deviation is 12.8 hours and coefficient of variation is 0.1%. A positive trend is shown in figure 3, which is generally similar with the trend of GSR. The homogeneity tests shows the data also are not homogeneous and the significant change point divided the study period into two sub-periods based on statistical criteria. By comparing the mean sunshine duration of 146.2 h from the first period (1921–1944) with the mean of 156.2 h from the second period (1945–2009), it can be observed an increasing with 10.0 h. The main feature of sunshine duration fluctuation at this station is its sharp decreases at the beginning of the 1940s after a maximum at the middle of the 1930s as well its sharp increase at the end of the 1990s after a minimum at the beginning of the 1980s.

The mean annual precipitation is 640.7 mm, while S.D. is 110.2 mm and C.V. is 0.2%. There is no significant change point according to the homogeneity tests because the data are homogeneous. Hence, we can't have two sub-periods for this variable. It can be seen a slightly decrease in precipitation (Fig. 3), but the trend is not significant according to the Runs Test.

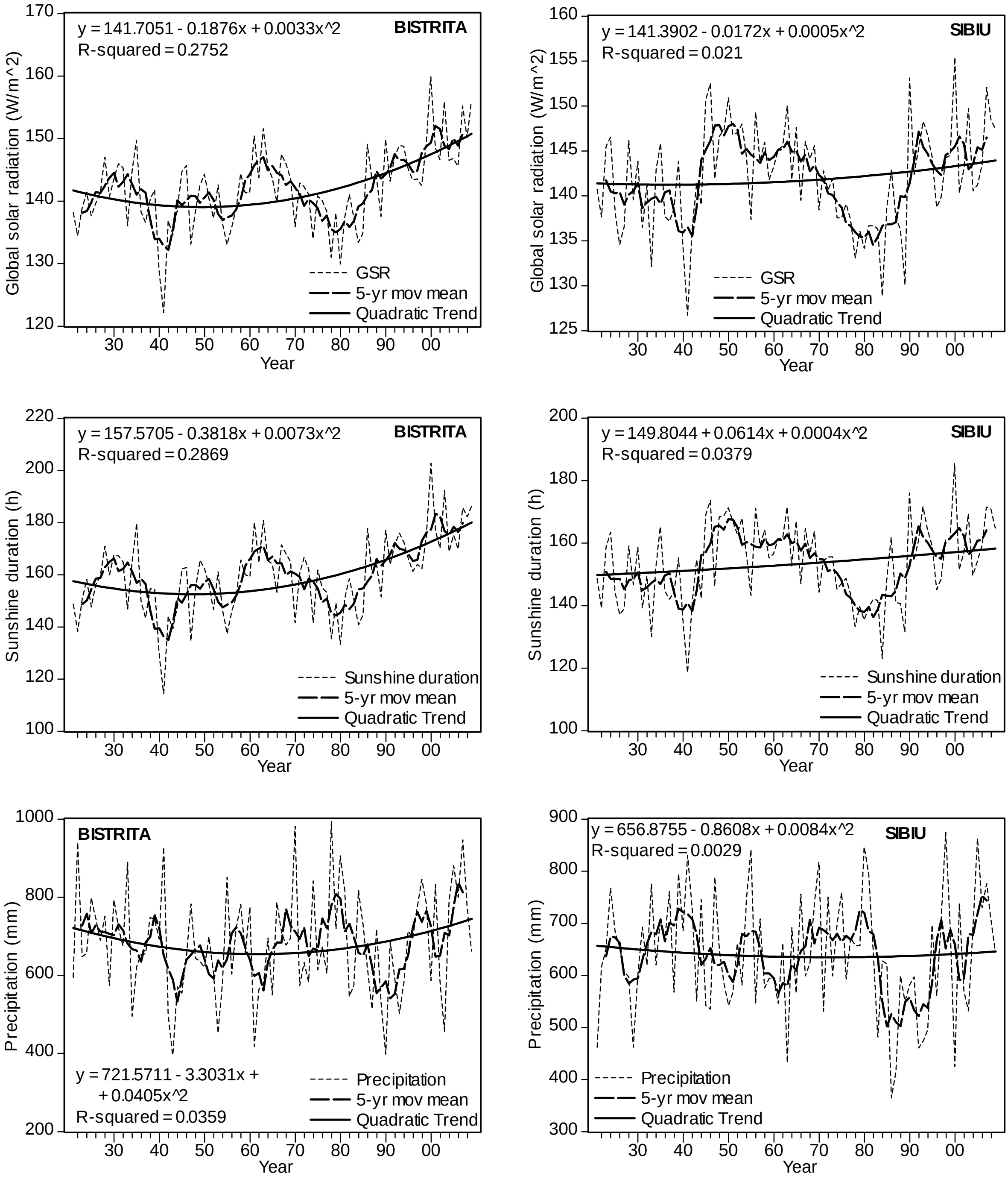

Figure 3. Five-year moving averages and quadratic trends of annual mean global solar radiation (GSR), sunshine duration and precipitation at Bistrita and Sibiu, 1921–2009.

In table 2 is presented the performance of each model for Cluj-Napoca meteorological station. Comparing with the linear and exponential model, the values of R^2 for the quadratic model both for radiation (0.1876) and for sunshine duration (0.2098) and precipitation (0.0637) are higher even if they are 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 and sunshine duration) for the quadratic model compared to the linear and exponential models; therefore, the quadratic trend model seems to provide the better fit. The quadratic regression equations indicate that during the period 1921–2009 all three analyzed variables (annual mean GSR, sunshine duration and precipitation) increased at this station (Fig. 2).

In the case of Bistrita and Sibiu (Table 3), R^2 has the higher values for the same quadratic estimating equations. At Bistrita, all measures of accuracy for the three variables have lower values also for the quadratic model. At Sibiu, the situation is a little different because the quadratic model for GSR and sunshine duration is sustained only by MSD, MAPE and MAD having the lower values for the linear and exponential model (see Table 3). In this case, it seems the linear model is the most appropriate for the annual mean GSR and probably one of the model types at Sibiu, but as the values of these indicators are very close to the ones of the quadratic model and the values of R^2 for this model type are the highest, we can consider the quadratic model adequate for these two variables. As for the precipitation, the quadratic model is sustained only by MAD and MSD, MAPE having the lower value for the exponential model. But, because only one value does not indicate the quadratic model, we can consider this model is the most appropriate for the annual mean precipitation at Sibiu.

According to the quadratic equations, during the period 1921–2009, the annual mean GSR, sunshine duration and precipitation increased at Bistrita (Fig. 3). At Sibiu, only the GSR and sunshine trends increased, while the precipitation trend slightly decreased (Fig. 3). Considering that the quadratic model found at Cluj-Napoca is generally sustained by almost 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 precipitation evolution in the Cluj-Napoca area.

The increasing trend of annual mean GSR on long-term is sustained by an increasing trend on short-term, too, and could be ascribed to solar activity. According to assumptions of Erlykin et al. (2009), less than 14% of the observed global warming since 1956 is attributable to changes in solar irradiance.

Table 2. Characteristics of the model types for annual global solar radiation, sunshine duration and precipitation at Cluj-Napoca station (1921-2009).

Annual mean global solar radiation (GSR)					
Model Type	Trend	MAPE (%)	MAD (W/m^2)	MSD [(W/m^2)^2]	R^2
Linear	+	2.8599	4.1464	25.6601	0.1807
Quadratic	+	2.8541	4.1374	25.4445	0.1876
Exponential	+	2.8528	4.1385	25.6519	0.1794
Average annual sunshine duration					
Model Type	Trend	MAPE (%)	MAD (h)	MSD (h^2)	R^2
Linear	+	5.778	9.403	134.414	0.2084
Quadratic	+	5.765	9.381	134.167	0.2098
Exponential	+	5.761	9.398	134.499	0.2054
Average annual precipitation					
Model Type	Trend	MAPE (%)	MAD (mm)	MSD (mm^2)	R^2
Linear	+	17.7	97.4	15426.0	0.0163
Quadratic	+	17.1	94.1	14681.6	0.0637
Exponential	+	17.1	96.5	15597.0	0.0116

* + Denotes positive trend.

Table 3. Characteristics of the model types for annual global solar radiation, sunshine duration and precipitation at Bistrita and Sibiu stations (1921-2009).

	BISTRITA					**SIBIU**				
	Annual mean global solar radiation (GSR)					**Annual mean global solar radiation (GSR)**				
Model Type	Trend	MAPE (%)	MAD (W/m^2)	MSD [(W/m^2)^2]	R^2	Trend	MAPE (%)	MAD (W/m^2)	MSD [(W/m^2)^2]	R^2
Linear	+	3.0829	4.3442	32.1676	0.1783	+	3.1616	4.4691	30.3865	0.0179
Quadratic	+	2.9488	4.1554	28.3726	0.2752	+	3.1778	4.4922	30.2902	0.0210
Exponential	+	3.0761	4.3382	32.0992	0.1724	+	3.1633	4.4749	30.3970	0.0174
	Average annual sunshine duration					**Average annual sunshine duration**				
Model Type	Trend	MAPE (%)	MAD (h)	MSD (h^2)	R^2	Trend	MAPE (%)	MAD (h)	MSD (h^2)	R^2
Linear	+	6.529	10.138	171.621	0.2017	+	6.863	10.352	155.845	0.0376
Quadratic	+	6.378	9.903	153.306	0.2869	+	6.876	10.372	155.791	0.0379
Exponential	+	6.516	10.151	170.944	0.1900	+	6.853	10.372	156.104	0.0362
	Average annual precipitation					**Average annual precipitation**				
Model Type	Trend	MAPE (%)	MAD (mm)	MSD (mm^2)	R^2	Trend	MAPE (%)	MAD (mm)	MSD (mm^2)	R^2
Linear	+	16.4	104.9	17150.4	0.0026	–	14.9	89.5	11993.3	0.0009
Quadratic	+	16.0	102.6	16578.5	0.0359	–	14.8	89.1	11968.9	0.0029
Exponential	+	16.1	105.1	17318.2	0.0014	–	14.7	89.7	12094.6	0.0026

* + Denotes positive trend, – denotes decreasing trend.

It is known there is increasing evidence that solar radiation at the Earth's surface is not constant over time but varies considerably over decades due to solar activity. This is in accordance with the results presented by Wild (2009) who showed that there is increasing evidence that the amount of solar radiation incident at the Earth's surface is not stable over the years but undergoes significant decadal variations. We conclude that the increasing trend in global radiation can be attributed to the variances in solar output.

It has been known for some time that there is a statistical relation between solar activity and the precipitation on the land on the Earth's surface. Many scientists from the different fields of research have obtained a lot of proofs that indicate the annual precipitation is closely related to the variation of sunspot numbers, and that solar activity probably plays an important role in influencing the precipitation on land (Zhao et al., 2004).

In this study, the increase or decrease of the precipitation can be explained by some manifestations of global climate change which are visible in its evolution (Dragota & Kucsicsa, 2011) or can be ascribed to 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 precipitation is more probably not an expression of the global climatic changes but a meteorological variation.

Though the physical process of solar influence remains still unclear, it is quite possible that the variability of solar activity can affect the evolution of precipitation in the study area. However, it is difficult enough to interpret the above results in terms of cause and effect because we need more time and studies in the future to understand the relationship between solar radiation and precipitation. There is also a need to know more about the interaction of physical processes that determine the evolution of climate.

4.3. Runs 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:

$$p'-\text{value} = \text{cdf}(Z), \quad (13)$$

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

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

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:

$$E(\text{runs}) = 1 + \frac{2 \cdot A \cdot B}{N}, \quad (15)$$

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:

$$\sigma^2 = \frac{2 \cdot A \cdot B \cdot (2 \cdot A \cdot B - N)}{N^2 (N-1)}. \quad (16)$$

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

$$p''-\text{value} = 1 - \text{cdf}(Z), \quad (17)$$

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. As the *p-values* for trends (0.750) and oscillation (0.250) are greater than the *α-level* of 0.05, we can say the test is not significant. 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. Also, for sunshine duration, the *p-values* for trends (0.456) and oscillation (0.544) are greater than the *α-level* of 0.05 and indicate an insignificant trend. As for the precipitation, the observed number of runs above and below the mean (42) is less than the expected number of runs (45), so we can say that is suggested a trend. The *p-values* for trends (0.512) and oscillation (0.488) are greater than the *α-level* of 0.05, so the test is not significant. 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, 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. A trend is indicated for sunshine duration because the *p-*

value for trend (0.0001) is less than *α-level* of 0.001. As for the precipitation, the observed number of runs above and below the mean (43) is less than the expected number of runs (45.4), so we can say that is suggested a trend. The *p-values* for trends (0.601) and oscillation (0.399) are greater than the *α-level* of 0.05, and the test is not significant. As the value for oscillation is closer to the *α-level* than the value for trend, we can say that an oscillation has a bigger probability than a trend.

In the case of Sibiu, 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. A trend is indicated for sunshine duration, too, because the *p-value* for trend (0.016) is less than *α-level* of 0.05. As for the precipitation, the observed number of runs above and below the mean (42) is less than the expected number of runs (45.5), so this could indicate a trend. The *p-values* for trends (0.456) and oscillation (0.544) are greater than the *α-level* of 0.05, the test being not significant. The value for trend is closer to the *α-level* than the value for oscillation, so we can say that a trend would have a bigger probability than an 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 suggested for global radiation even if the *p-values* are not statistically significant. But as the *p-values* indicate trends for GSR at Bistrita and Sibiu, which are statistically significant, as well sunshine duration, we can consider this as a sign for a possible trend at this station. The trend for sunshine duration at Cluj-Napoca is sustained by the significant trends from the other two stations. As for the precipitation, an oscillation is more probably than a trend at Cluj-Napoca being sustained by a possible oscillation at Bistrita. As the *p-values* for trend and oscillation are almost equal at Sibiu and the other two stations indicated an oscillation, we can say an oscillation is more probably than a trend at this station, too. Because we obtained four *p-values* below *α-level* of 0.05, we can conclude that there is a strong and special variation in GSR and sunshine duration trends due to solar activity. No special variation due to trend or oscillation was found for precipitation.

4.4. Cumulative curves of the global solar radiation and precipitation standardized anomalies

The periods characterized by accumulations of the GSR/precipitation surplus or deficit can be shown on the curves represented in figure 4. The descending curve covers a period when the GSR/PP deficit is accumulated and on the ascending curve the surplus is accumulated. When the curve crosses the zero threshold-value (the zero value of GSRSA/PSA) then the deficit (if the values are less than zero) or surplus (if the values are greater than zero) anterior accumulated is neutralized.

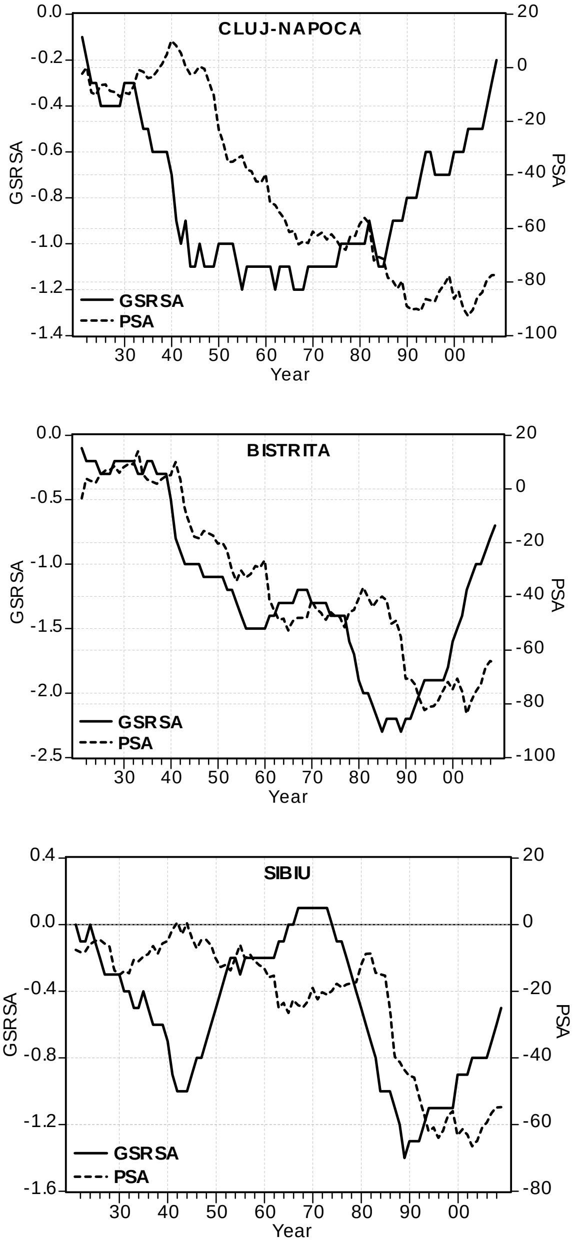

Figure 4. Cumulative curves of the GSR and precipitation standardized anomalies at Cluj-Napoca, Bistrita and Sibiu (1921–2009).

As it can be shown in figure 4, during the period 1921–2009, two periods were detected at Cluj-Napoca by the cumulative curve of standardized anomaly for annual global solar radiation: 1921–1985 and 1986–2009. The annual GSRSA showed a decreasing for the first period until 1985 and then an increase after that year, which was close enough to the zero threshold-value. The annual GSR deficit anterior accumulated from the first period is not neutralized by the annual GSR surplus from the second period because the curve doesn't cross the zero-value of GSRSA, but it could be possible to be neutralized in the next years. 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 precipitation, it is observed that during the period 1921 to 1940, the annual precipitation deficit from the first part of the period is neutralized by the surplus from the second part, while in the second period (1941–2009) the annual precipitation surplus from the first part of the period is neutralized by the deficit from the second part (Fig. 4). This might be connected with the fact that the GSR increased in the last decades and implicit also the annual mean temperature was higher in the last decades. Another fact is that variations of solar activity reaching the Earth have an important role in influencing the precipitation on land, like the fact the precipitation is closely related to the variation of sunspot numbers (Zhao et al., 2004). It is considered that the whole analyzed period represents a cycle on a microclimatical scale.

The shape of the cumulative curve of the annual GSRSA at Cluj-Napoca is not similar with the one from Bistrita (Fig. 4) and Sibiu (Fig. 4). Also, it is important to notice that neither at Bistrita nor at Sibiu the shape of the cumulative curve of the annual GSRSA is similar with each other.

The situation at Bistrita is the same with the one from Cluj-Napoca concerning to the annual GSR deficit anterior accumulated from the first period (1921–1985) and the GSR surplus from the second period (1986–2009). And here too, the curve doesn't cross the zero-value of the annual GSRSA (Fig. 4). At Sibiu, there seem to be two groups of the two periods on the curve represented in Fig. 4 concerning to the annual GSRSA. In the first period (1921–1973) the GSR deficit from the first part of the period is neutralized by the surplus from the second part, while in the second period (1974–2009) the GSRSA is decreasing and the deficit from the first part of the period is not neutralized by the surplus from the second part. As for the annual precipitation, the shape of the cumulative curve of the PSA at Cluj-Napoca is generally similar with the one from Bistrita (Fig. 4) and Sibiu (Fig. 4). The differences between them are very small, like the fact that the neutralization of the precipitation surplus began a little more rapidly at Bistrita and Sibiu comparing with Cluj-Napoca.

The shape of the cumulative curve suggests that in the last two decades the general tendency is towards increasing annual global solar radiation at all three stations and the observed fluctuations represent a microcycle or microcycles (for example, Sibiu), as a result of the normal variations of the climate, which in the last few years is/are reacting to the solar variations. The decreasing tendency of the annual precipitation could be ascribed to solar activity, which is known that plays an important role in influencing the precipitation on land, and the consequence of this fact is that precipitation is closely related to the variation of sunspot numbers.

5. CONCLUSIONS

In this study, the evolution of global solar radiation and precipitation tendency in Cluj-Napoca was analyzed for the period 1921–2009 (89 years). In order to sustain the results from Cluj-Napoca, we also used data from two neighboring stations, namely Bistrita and Sibiu. Also, we added into analysis sunshine duration to make a good comparison with the evolution of global solar radiation.

It was observed that during the studied period, the mean annual GSR, sustained by sunshine duration, and precipitation generally showed an increasing tendency according to quadratic equation.

The values of R^2 (the coefficient of determination) and the three accuracy indicators (MAPE, MAD, MSD) indicated that generally the quadratic model is the most suitable for the annual mean GSR, sunshine duration and precipitation evolution at all three meteorological stations considered because provides a better fit than the linear and exponential models. According to the quadratic model, the GSR, sunshine duration and precipitation increased at Cluj-Napoca and Bistrita, while at Sibiu, the situation was a little different. Here, only GSR and sunshine duration showed an increasing tendency, while the precipitation showed a slightly decreasing trend.

The multiannual mean GSR, sunshine duration and precipitation were also statistically examined by Runs Test. The results of the test based on the number of runs above and below the mean indicated no special variation in the GSR, sunshine duration and precipitation data at Cluj-Napoca station and an oscillation would be more probably than a trend for GSR and precipitation. But as the *p-values* indicate trends for GSR at Bistrita and Sibiu, which are statistically significant, as well sunshine duration, we can consider this as a sign for a possible trend at this station. The trend for sunshine duration at Cluj-Napoca is sustained by the significant trends from the other two stations. As for the precipitation, an oscillation is more probably than a trend at Cluj-Napoca being sustained by a possible oscillation at Bistrita. As the *p-values* for trend and oscillation are almost equal at Sibiu and the other two stations indicated an oscillation, we can say an oscillation is more probably than a trend at this station, too. At Bistrita and Sibiu, the test indicates that there is a special variation in the GSR and sunshine data and a trend is suggested as the *p-values* are below *α-level* of 0.05. There is no special variation for precipitation at these two stations, but an oscillation is suggested.

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 micro-oscillations of the multiannual GSR and precipitation are also supported by the shape of the GSRSA and PSA cumulative curve at all the three stations involved.

The significant increasing trend of the GSR can be ascribed to solar activity. There is increasing evidence that the amount of solar radiation incident at the Earth's surface is not stable over the years but undergoes significant decadal variations. Hence, we conclude that the increasing trend in global solar radiation can be attributed to the variances in solar output.

In this study, the increase or decrease of the precipitation can be explained 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 precipitation is more probably not an expression of the global climatic changes but a meteorological variation. Though the physical process of solar influence remains still unclear, it is quite possible that the variability of solar activity can affect the evolution of precipitation in the study area. However, it is difficult enough to interpret the above results in terms of cause and effect because we need more time and studies in the future to understand the relationship between solar radiation and precipitation. There is also a need to know more about the interaction of physical processes that determine the evolution of climate.

Therefore, it is the most probably that this increasing in GSR and increasing/decreasing in precipitation represents the ascensional or descensional parts of some natural micro-oscillations due to solar activity/variations and natural climate variability.

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Received at: 12. 12. 2010
Revised at: 10. 06. 2011
Accepted for publication at: 18. 06. 2011
Published online at: 22. 06.2011