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The influence of solar radiation on the evolution of climate characteristics in the area of Cluj-Napoca and environs

Ph.D. Thesis Summary

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KEYWORDS: global solar radiation, temperature, precipitation, the equation of Ångström-Prescott, evolution of the three variables (global solar radiation, temperature and precipitation), homogeneity tests, Runs test, cumulative curves of the standardized anomalies, Pearson's correlation.

Introduction

To understand climate change awareness of the city perimeter and know current trends of global solar radiation, sunshine, temperatures and rainfall (the main climate characteristics which were taken into account in this study), research undertaken include both general conditions of climate area which the city of Cluj-Napoca is located and specific climatic conditions of the city perimeter.

Analysis of climatic factors and elements, namely the global solar radiation, sunshine duration, temperature, rainfall, humidity and pressure, was based on annual and monthly data taken from the Meteorological Yearbook of R.S. Romania and the site from NOAA NCDC, (National Climatic Data Center - National Oceanic and Atmospheric Administration), http://www7.ncdc.noaa.gov/IPS/mcdw/mcdw.html in the section "Monthly Climatic Data for the World (MCDW) ".

In this paper, the emphasis is on the study of mean values of global solar radiation, sunshine, temperature and rainfall in the analyzed region (area of Cluj-Napoca).

The intensity of solar radiation (radiative forcing) changes the heating, and this directly affects the Earth's surface evaporation and heat gently. In addition, increasing temperature tends to increase evaporation, leading to a larger increase in the amount of precipitation (Solomon et al., 2007). Globally, there was no general significant increasing trend in rainfall during the last century, although trends have varied widely by region and over time.

Analyzed temperatures generates, sometimes, climatic risk by very high or low values that can affect the population and living standards, can jeopardize crops (summer), may affect water supply, can cause problems to communications paths, etc..

Also, the emphasis is on the study of rainfall that are responsible for production of phenomena triggered in the chain, in a trend of "cascade system" (Bogdan, 2003, *Bogdan, 2004). Effects consist of landslides, destruction of communications paths, the emergence of epidemic, reducing living standards, etc..*

Statistical analysis applied in this study tries to connect the global solar radiation, temperature and rainfall trends in this area, with so-called global climate changes. Despite various theories that refute or confirm the climatic changes, is generally accepted ideea that the Sun plays a leading role in global warming, particularly because of solar cycles (Tung and Camp, 2008) leading to an increase in temperature. This increased in the last 100 years and in the recent decades, the heating rate was accelerated (Solomon et al, 2007). Many scientists believe that an increase in temperature could lead to a circuit of more intense water cycle. Evaporation rates of surface soil and water, and the results of sweat plants could grow. Therefore, also the rainfall could increase.

The main purpose of this PhD Thesis is to analyze and interpret phenomena and climate processes (eg solar radiation, temperature and precipitation) which emphasized on the principle of causality between themselves, allowing not only understanding the stage of change of phenomena, but also their tendency of evolution.

Special thanks, in particular, to Ph.D professor Constantin Cosma and Dumitru Ristoiu, who guided my first steps in scientific research, but also how, with great professional competence, wisdom and generosity supportted me from the start to finish in my work.

I am grateful to my wife for warmth and understanding that she surrounded me, for continuous support and confidence that she gave to me throughout of my doctoral studies.

Chapter 1

History of the city development and climate observations at Cluj-Napoca

Chapter 1 is a brief history of the development history of Cluj-Napoca and climatological observations and researches in this city.

Chapter 2

The genetic factors of the climate in the area of Cluj-Napoca

Like in all regions of the world, climate in the area of Cluj-Napoca is generated by three major factors: radiative, dynamic and physical-geographical factors. General fund of the climate is given by the city's geographical location, the overall conditions of the relief, and its stand against the main components of the general circulation of the atmosphere.

Chapter 3

Climatic characteristics

General climatic conditions of Cluj-Napoca reflects broadly the specific climate regions of the western hills of the country. Some aspects that distinguish it from surrounding areas resulting from its position at the crossroads of three major physical and geographical units: the Apuseni Mountains, Transylvania Plain and Someș Plateau with better individual climatic conditions, and the aspect of relief.

Of climatic characteristics, which establish the climatic specific of the study area and were analyzed in Chapter 3, we include: air temperature, air humidity, cloudiness and sunshine duration, rainfall and air pressure.

Chapter 4

The influence of solar radiation on the evolution of the main characteristics of climate in the area of Cluj-Napoca

4.1 Solar radiation. Overview.

Solar radiation is a set of waves or particles emitted by the Sun with a temperature of about 5800 K (5527 °C) and are the main natural source of the Earth's energy. At a distance of 150 × 106 km intensity of monochromatic radiation received from the Sun for a large part of the spectrum is much smaller than the one emitted by the Atmosphere-Earth system at equivalent wavelengths (Ristoiu, 2005). This is the radiation from the visible spectrum.

Because of the large distance between the Sun and Earth (150 × 106 km) and relatively small range land (6370 km), only the first billionth of the total energy emitted by the Sun reaches the upper atmosphere (1368 Wm^2), but enough energy resources to ensure the land. Considering the fact that 30% of incident radiation is reflected back into space (albedou), the total energy received by Earth is about 10^{17} W (Beer et al., 2006).

Solar radiation are directly transmitted to Earth (thermal radiation) or mediated by certain particles (corpuscular radiation). These rays are emitted as a spectrum, of which for the weather phenomena a greater importance have ultraviolet radiation, visible radiation and infrared radiation.

Travelling the Earth's atmosphere, solar radiation undergoes its influence and the result of this influence is to reduce solar energy reaching the surface crust. An important factor is the mass of travelled atmosphere, which differs greatly and depends on the height of the Sun above the horizon. Travelling atmosphere, some solar radiations are absorbed selectively by different gases and its components (O_2, CO_2, O_3, H_2O) or overall by particles in suspension (powder, dust). Other radiations are diffused in the atmosphere or reflected by this one.

4.2 The evolution of global solar radiation trend at Cluj-Napoca for the period 1921-2009

4.2.1 Introduction

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 şi 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. 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 Ångström (*Ångström, 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.

4.2.2 Localizarea zonei de studiu

Cluj-Napoca, belonging to Cluj County of Romania, is located in the central part of Transylvania (North-West of Romania), in a region surrounded by hills, more exactly in the valley of the Someşul Mic River (Fig. 4.1). This lies at the confluence of the Apuseni Mountains, Someș Plateau and Transylvania Plain.

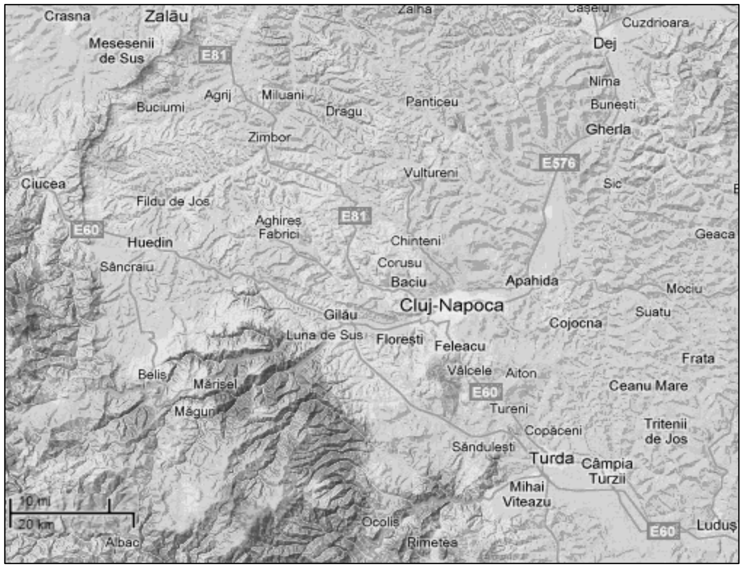


Figure 4.1. *Geographical location of the study area (Cluj-Napoca)*

The meteorological station in Cluj-Napoca is located at about 46°47'N/23°34'E and height about 414 m above sea level.

4.2.3 Data and methods

Using the Ångström-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. The analysis was made for an 89-year period (1921–2009).

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 Ångström-Prescott formula (*Martinez-Lazono et al., 1984*; *Gueymard et al., 1995*):

$$R_s = \left[a + b\frac{n}{N}\right] \cdot R_a, \tag{4.1}$$

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.

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.

The extraterrestrial radiation (R_a) and the monthly maximum possible sunshine duration (N) are given by (*Allen et al.*, *1998*):

$$R_a = \frac{24(60)}{\pi} G_{sc}\, d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right] \tag{4.2}$$

$$N = \frac{24 \cdot \omega_s}{\pi}, \tag{4.3}$$

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).

$$d_r = 1 + 0.033 \cdot \cos\left(\frac{2\pi J}{365}\right) \tag{4.4}$$

$$\delta = 0.409 \cdot \sin\left[\frac{2\pi J}{365} - 1.39\right] \tag{4.5}$$

$$\omega_s = \arccos\left[-\tan(\varphi)\tan(\delta)\right], \tag{4.6}$$

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

Using the least squares method, the linear model was chosen in this study because is the most used and the simplest model for an unknown trend in this type of analysis. To analyze the evolution of global solar radiation, the data were subjected to a 5-year running mean to find the trends. In order to simplify the trend, a linear trend line was added to the series.

As it is known, there are different statistical tests considering trend analysis (Haan, 1977; Bobee and Ashkar, 1991; Salas, 1992). Therefore, in order to analyze any possible trend in the time series, the statistical significance was determined by the Mann–Kendall and Student's *t* tests.

4.2.4 Results and discussion

4.2.4.1 Annual global solar radiation trends

The mean annual global solar radiation along with 5-year moving mean and trend line is presented in Fig. 4.2. Table 4.1 shows mean, regression slope estimate, Mann-Kendall (M-K) and *t*-test statistics, standard deviation (S.D.) and coefficient of variation (C.V.) for the monthly, seasonal and annual GSR of Cluj-Napoca station for the period 1921–2009.

Table 4.1. *Statistical results for the global solar radiation at Cluj-Napoca (1921–2009).*

Season	Mean (W/m^2)	Slope (Wm^{-2}/year)	M–K	t–Test	S.D. (W/m^2)	C.V. (%)
Months						
December	38.019	0.029	0.106	1.766	4.097	10.8
January	46.635	0.068	0.223[2]	3.049[2]	5.729	12.3
February	78.254	0.108	0.191[2]	2.624[1]	10.384	13.3
March	128.995	0.086	0.110	1.538	13.702	10.6
April	176.828	0.251	0.253[3]	3.749[3]	17.430	9.9
May	226.801	0.164	0.146[1]	1.873	21.621	9.5
June	247.536	0.246	0.169[1]	2.652[2]	23.240	9.4
July	255.865	–0.008	–0.031	–0.112	18.014	7.0
August	224.297	0.044	0.068	0.627	17.303	7.7
September	161.879	–0.021	–0.013	–0.350	14.486	8.9
October	106.199	0.130	0.158[1]	2.788[2]	11.774	11.1
November	55.432	0.009	0.050	0.321	6.830	12.3
Seasons						
Winter	54.303	0.070	0.243[3]	3.921[3]	4.674	8.6
Spring	177.541	0.168	0.246[3]	4.031[3]	10.913	6.1
Summer	242.566	0.094	0.144[1]	1.958	11.845	4.9
Autumn	107.837	0.039	0.073	1.300	7.401	6.9
Annual	145.562	0.093	0.268[3]	4.380[3]	5.628	3.9

[1]Significant at 0.05 level, [2]significant at 0.01 level, [3]significant at 0.001 level.

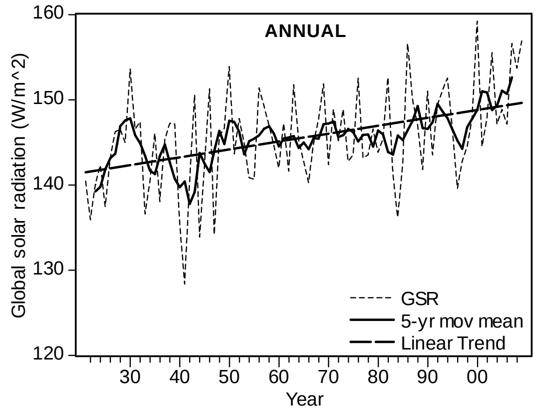


Figure 4.2. *Five-year moving average and trend line of annual GSR at Cluj-Napoca (1921-2009).*

At Cluj-Napoca meteorological station was observed a considerable variability between different years, with a standard deviation of 5.628 W/m^2 and a coefficient of variation of 3.9%, while the multiannual mean global solar radiation (GSR) during the period 1921–2009 (89 years) was 145.562 W/m^2 (*Tahâș et al., 2011 a*). An positive slope of 0.093 Wm^{-2}/year was noticed for annual mean GSR. According to the M-K and *t*-tests, this increasing trend is statistically significant at 0.001 level. In the studied period, the year 2000 had the greatest annual mean value (159.21 W/m^2), while the year 1941, with 128.373 W/m^2, had the lowest value.

4.2.4.2 Seasonal global solar radiation trends

On a seasonal scale, an estimate of positive slope is observed for all seasons (Fig. 4.3). The greatest increase in global solar radiation during the year occurred in spring (0.168 Wm^{-2}/year). On the contrary, autumn season had the lowest increase (0.039 Wm^{-2}/year).

The other seasons, summer and winter, had an increasing trend rate of 0.094 Wm^{-2}/year and 0.070 Wm^{-2}/year, respectively. The Mann-Kendall and *t*-tests indicate that the increasing trend is statistically significant at 0.001 level for winter and spring seasons. For summer season, the trend is significant at 0.05 level according to M-K test, while *t*-test does not indicate any particular significant trend. The autumn season shows no significant trend.

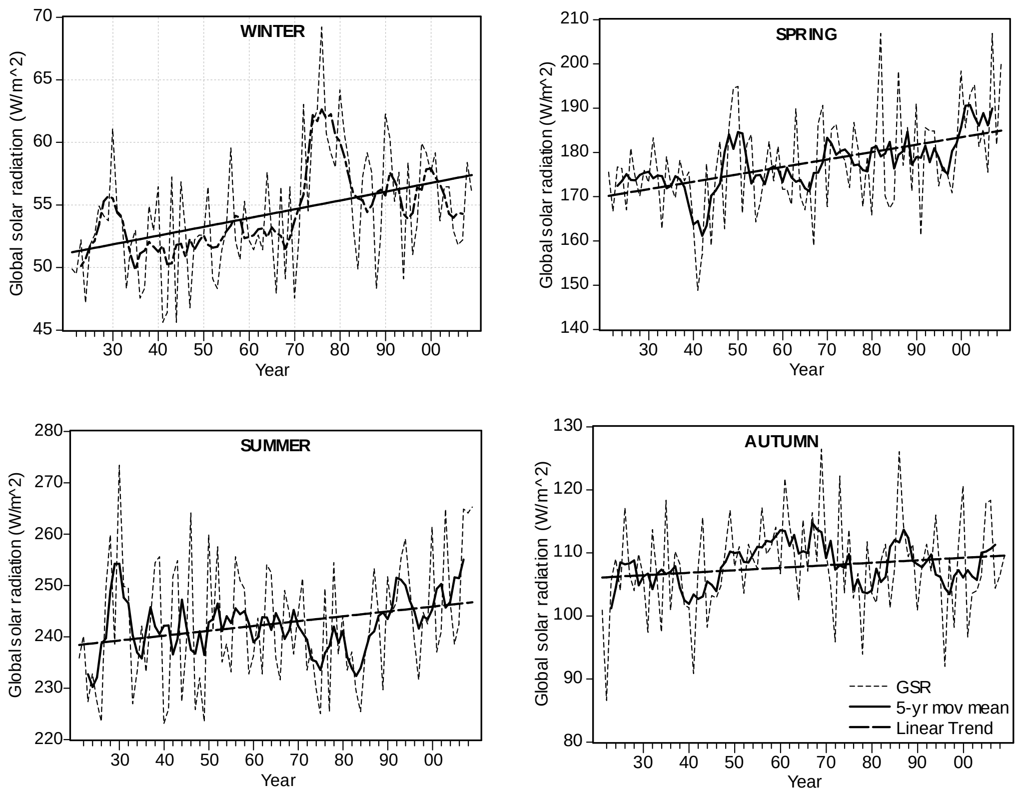


Figure 4.3. *Five-year moving averages and trend lines of seasonal GSR at Cluj-Napoca (1921-2009).*

The results for the monthly mean are also displayed in table 1. An estimate of positive slope is noticed in a majority of the months of the year, except months of July and September which show a negative slope.

4.2.4.3 ***Runs Test***

Another way to test if there is a trend or an oscillation in the data is represented by the non-parametric test named 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 after Abraham Wald (1902 –1950) and Jacob Wolfowitz (1910 – 1981) and recommended by the World Meteorological Organization (*1983*), is considered to be one of the easiest to apply procedure for testing randomness (*Koutras and Alexandrou, 1997*) or when you want to determine if the order of responses above or below a specified value is random.

A run is a series of consecutive points that are either all above or all below the regression line. In other words, a run is a consecutive series of points whose residuals are either all positive or all negative. 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.

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:

$$p' - value = cdf\,(Z)\ , \tag{4.7}$$

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

$$Z = \frac{O\,(runs) - E\,(runs)}{\sqrt{\sigma^2}}, \tag{4.8}$$

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:

$$E\,(runs) = 1 + \frac{2 \cdot A \cdot B}{N}, \tag{4.9}$$

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:

$$\sigma^2 = \frac{2 \cdot A \cdot B \cdot \left(2 \cdot A \cdot B - N\right)}{N^2\,(N-1)}. \tag{4.10}$$

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

$$p'' - value = 1 - cdf\,(Z)\ , \tag{4.11}$$

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

At Cluj-Napoca station, for annual global solar radiation (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 results of the Runs test are 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 would be more appropriate to say that an oscillation has a bigger probability than a trend.

Concerning to the seasons, Runs test shows no special variation, although it would indicate a trend for summer and winter, because the *p-values* for trend are smaller than the *p-values* for oscillation, and an oscillation for spring and autumn, as the *p-values* for oscillation are smaller than the *p-values* for trend.

The only month which Runs test shows a special variation is April. As the observed number of runs above and below the mean (34) is statistically less than the expected number of runs (45.5), we can say that is suggested a trend. The *p-value* for trend (0.014) is smaller than the *α-level* of 0.05 and we can say the data strongly indicate a trend.

The results of this test show that though there is no *p-value* obtained for annual and seasonal global solar radiation below *α-level*, most of these *p-values* are closer to this level. Hence, we can consider this is a sign for a possible oscillation in evolution of GSR.

4.3 Solar radiation and temperature

4.3.1 Introduction

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 and Cermak, 2003*). 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., 2011 b*).

The main cause that influences the temperature is attributed to solar activity as it is known that along the centuries solar variations have influenced temperatures on the Earth.

4.3.2 Data and methods

The monthly temperature and sunshine duration data were taken from the Meteorological Yearbooks (MY) of Romania 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.

We had to add into the analysis other two surroundings stations: Bistrița (367 m altitude) and Sibiu (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. Also, we analized 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 (*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.

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 temperature 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:

$$EPMA = \frac{\sum_{t=1}^{n} \left| \frac{y_t - \hat{y}_t}{y_t} \right|}{n} \cdot 100, \quad (y_t \neq 0) \tag{4.12}$$

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:

$$DMA = \frac{\sum_{t=1}^{n} \left| y_t - \hat{y}_t \right|}{n}. \tag{4.13}$$

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:

$$DMP = \frac{\sum_{t=1}^{n} \left| y_t - \hat{y}_t \right|^2}{n}. \tag{4.14}$$

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.

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 and temperature standardized anomaly (GSRSA and TSA) are calculated in the same way as the precipitation standardized anomaly (*Maheras et al., 1999*) with the formulas:

$$ASRSG_i = \frac{X_i - X}{\sigma_i}; \quad AST_i = \frac{X_i - X}{\sigma_i}. \tag{4.15}$$

where *i* is the period for which GSRSA or TSA 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 temperature, σ_i represents the annual standard deviation of the monthly mean value of GSR or temperature.

The standard deviation is calculated with the formula:

$$\sigma_i = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X)^2}{n-1}}, \tag{4.16}$$

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:

$$a_n = \sum_{i=1}^{n} ASRSG_i, \quad a_n = \sum_{i=1}^{n} AST_i. \tag{4.17}$$

4.3.3 Results and discussions

4.3.3.1 <u>Homogeneity tests</u>

The homogeneity of the 89 annual global solar radiation, sunshine duration and temperature time series for the period 1921–2009 has been tasted. In table 4.2, 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 temperature data are shown.

Table 4.2. *Annual results of the Homogeneity tests for mean global solar radiation (GSR), sunshine duration (N) and temperature (T) at Cluj-Napoca, Bistrița and Sibiu over the period 1921–2009.*

HOMOGENEITY TEST	CLUJ-NAPOCA			BISTRIȚA			SIBIU		
	Annual			Annual			Annual		
	GSR	T	N	GSR	T	N	GSR	T	N
Pettitt's test	742,0** 1985[1]	557,0 1993[1]	820,0** 1967[1]	1124,0*** 1985[1]	709,0* 1993[1]	1133,0*** 1985[1]	610,0 1989[1]	637,0* 1958[1]	708,0* 1944[1]
Standard Normal Homogeneity Test (SNHT)	13,611** 1985[1]	11,662* 2006[1]	16,052*** 1947[1]	27,954*** 1989[1]	16,461** 1998[1]	27,727*** 1989[1]	9,707* 1989[1]	9,911* 2006[1]	10,564* 1944[1]
Buishand's test	15,502** 1985[1]	11,929 1993[1]	17,510*** 1955[1]	21,837*** 1985[1]	14,681** 1993[1]	21,821*** 1985[1]	12,318 1989[1]	11,471 1958[1]	13,474* 1944
Von Neumann's test	1,518*	1,493**	1,460**	0,937***	1,505**	0,914***	1,248***	1,421**	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).

4.3.3.2 Trend analysis of radiation, sunshine duration and temperature time series

At Cluj-Napoca, it can be observed an increasing trend of the mean global solar radiation, sunshine duration and temperature during the period 1921–2009 (Fig. 4.4).

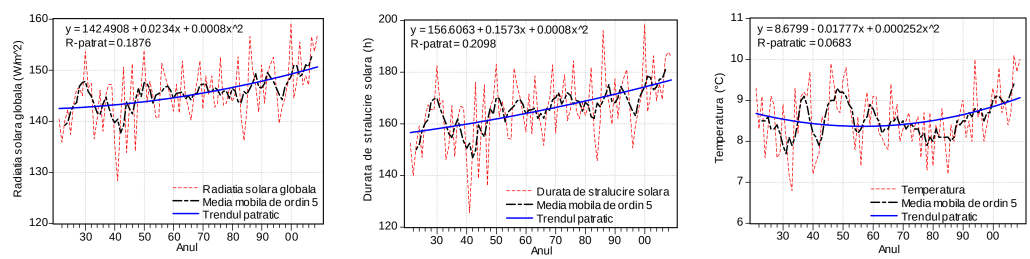
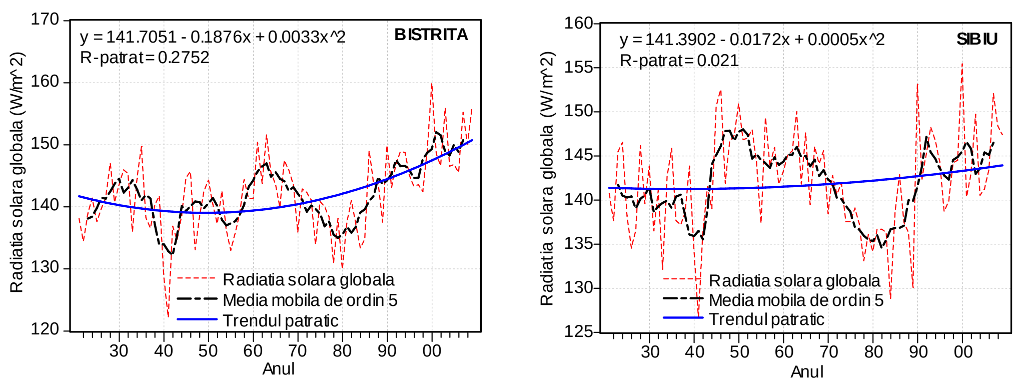


Figure 4.4. *Five-year moving averages and quadratic trends of annual mean global solar radiation (GSR), sunshine duration and temperature at Cluj-Napoca, 1921-2009.*



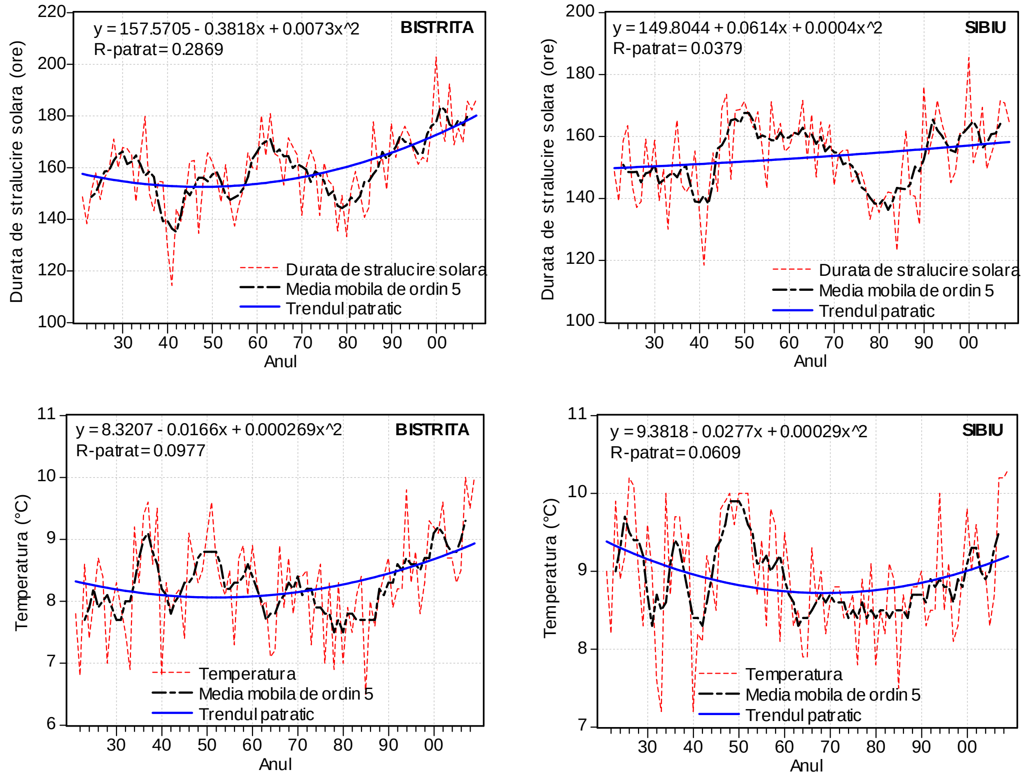


Figure 4.5. *Five-year moving averages and quadratic trends of annual mean global solar radiation, sunshine duration and temperature at Bistriţa and Sibiu, (1921-2009).*

In Table 4.3 and 4.4 is presented the performance of each model for Cluj-Napoca, Bistriţa and Sibiu.

Tabelul 4.3. *Characteristics of the model types for annual global solar radiation, sunshine duration and temperature 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 temperature					
MODEL TYPE	TREND	MAPE (%)	MAD (°C)	MSD (°C^2)	R^2
Linear	+	6.6658	0.5625	0.4967	0.0249
Quadratic	+	6.5994	0.5558	0.4746	0.0683
Exponential	+	6.6331	0.5616	0.4974	0.0258

* + Denotes positive trend.

Tabelul 4.4. *Characteristics of the model types for annual global solar radiation, sunshine duration and temperature at Bistrița and Sibiu stations (1921-2009).*

	BISTRIȚA					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 temperature					Average annual temperature				
MODEL TYPE	TREND	MAPE (%)	MAD (°C)	MSD (°C^2)	R^2	TREND	MAPE (%)	MAD (°C)	MSD (°C^2)	R^2
Linear	+	7.1404	0.5801	0.5527	0.0547	–	6.6198	0.5836	0.5287	0.0057
Quadratic	+	7.1280	0.5778	0.5275	0.0977	–	6.4610	0.5692	0.4993	0.0609
Exponential	+	7.1063	0.5796	0.5533	0.0522	–	6.6048	0.5843	0.5295	0.0045

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

By using the Pearson's *r* correlation, it has been found a relationship between the global solar radiation and temperature.

4.3.3.3 ***Runs Test***

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 and temperature and a trend for sunshine duration 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 temperature, a trend is more probably than an oscilation at Cluj-Napoca being sustained by a trend at Bistrița and Sibiu.

4.3.3.4 ***Cumulative curves of the global solar radiation and temperature standardized anomalies***

The periods characterized by accumulations of the GSR/temperature surplus or deficit can be shown on the curves represented in Fig. 4.

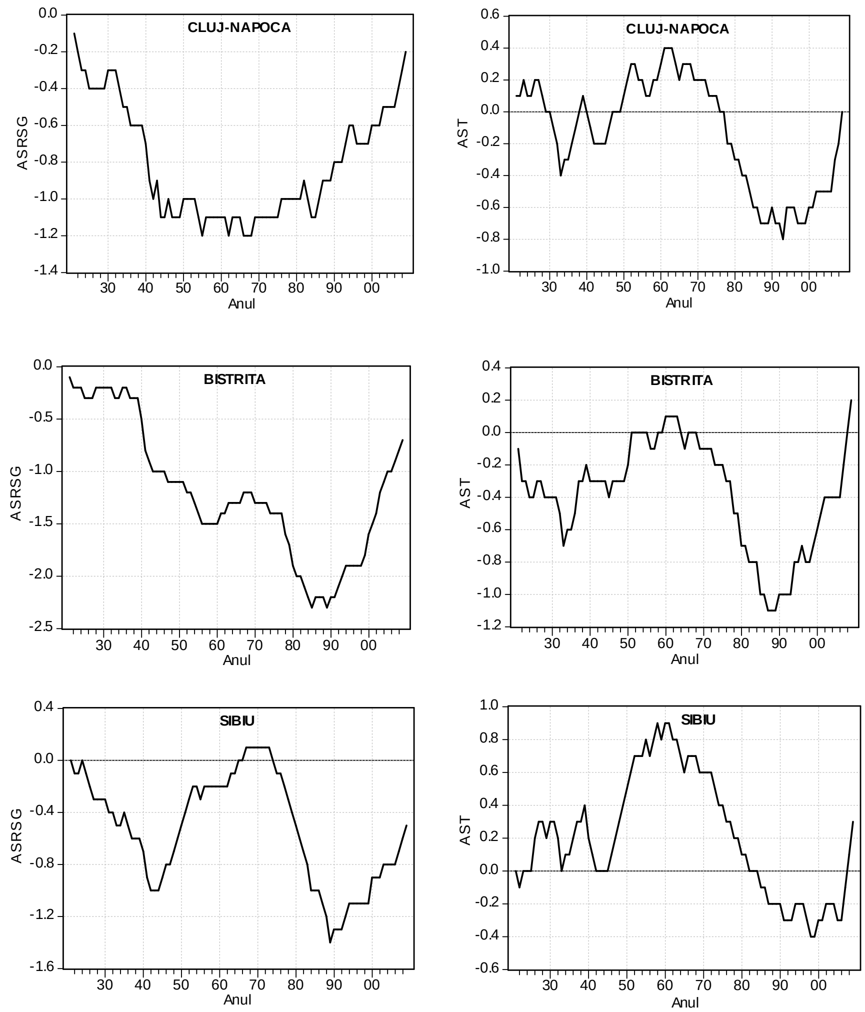


Figure 4.6. *Cumulative curves of the GSR and temperature standardized anomalies at Cluj-Napoca, Bistrița and Sibiu (1921–2009).*

4.3.3.5 ***Correlation between solar radiation and temperature***

By using the Pearson's r correlation, it has been found a positive relationship between the global solar radiation and temperature, both at Cluj-Napoca, and Bistrița and Sibiu for the period 1921-2009. On short-term, at Cluj-Napoca we have also a positive relationship (*Tahâș et al., 2011 b*).

Table 4.5. *Correlation between annual global solar radiation and temperature at Cluj-Napoca, Bistrița and Sibiu stations (1921-2009).*

TOWN	STATISTIC CORRELATION	
	Correlation coefficients	p (uncorrelation)
CLUJ-NAPOCA	0.30	0.00345*
BISTRIȚA	0.39	0.00010**
SIBIU	0.35	0.00064**

*Significant at 0.01 level, **significant at 0.001 level.

4.4 Solar radiation and precipitation

4.4.1 Introduction

There is strong evidence that rainfall changes associated to global warming are already taking place on both global and regional scales (*Schönwiese şi Rapp, 1997; Hulme et al, 1998*; *Rodriguez-Puebla et al, 1998*; *Trenberth, 1998*; *Dohetry et al, 1999*; *Osborn et al, 2000*; *IPCC, 2001*). The trend was globally positive throughout the 20th century, although large areas were characterized by negative trends (*IPCC, 2001*).

They have demonstrated that during recent decades precipitation has tended to increase in the mid-latitudes, decrease in the Northern Hemisphere subtropical zones, and increase generally throughout the Southern Hemisphere. However, these large-scale occurrences incorporate considerable spatial variability.

For example, in the Cluj-Napoca area, the time series analysis of the precipitation and solar radiation was made on a long-term and this revealed, generally, increasing trends of these variables, being statistically significant (*Tahâş et al., 2011 a*).

4.4.2 Data and methods

The precipitation data were taken from the Meteorological Yearbooks (MY) of Romania and the NCDC (National Climatic Data Center) web page (http://www7.ncdc.noaa.gov/IPS/mcdw/mcdw.html).

4.4.3 Results and discussion

4.4.3.1 <u>Homogeneuty tests</u>

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 4.6, 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.

Table 4.6. *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).

4.4.3.2 <u>Analysis of radiation, sunshine duration and precipitation time series</u>

Evolution of global solar radiation, sunshine duration and precipitation trends at the three stations added into analysis are shown in Figure 4.7 and 4.8. You may notice a slight increase in rainfall, but this is due to an oscillation (*Tahâş et al., 2011 a*).

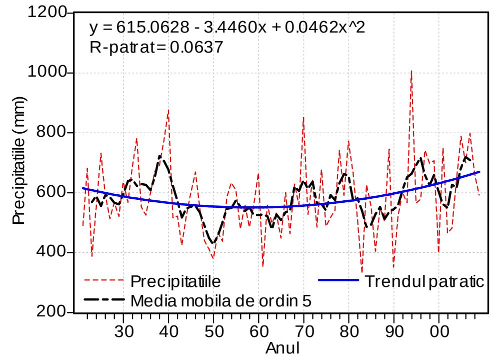


Figure 4.7. *Five-year moving averages and quadratic trends of annual mean global solar radiation (GSR), sunshine duration and precipitation at Cluj-Napoca, 1921-2009.*

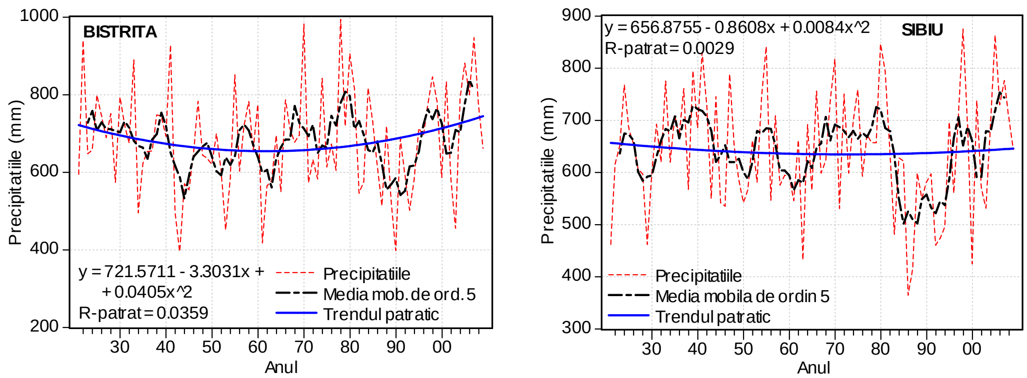


Figure 4.8. *Five-year moving averages and quadratic trends of annual mean global solar radiation, sunshine duration and precipitation at Bistrița and Sibiu, (1921-2009).*

By using the Pearson's *r* correlation, it has been found a relationship between the global solar radiation and precipitation.

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, according to Zhao et al. (*2004*), 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.

Table 4.7. *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 4.8. *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.

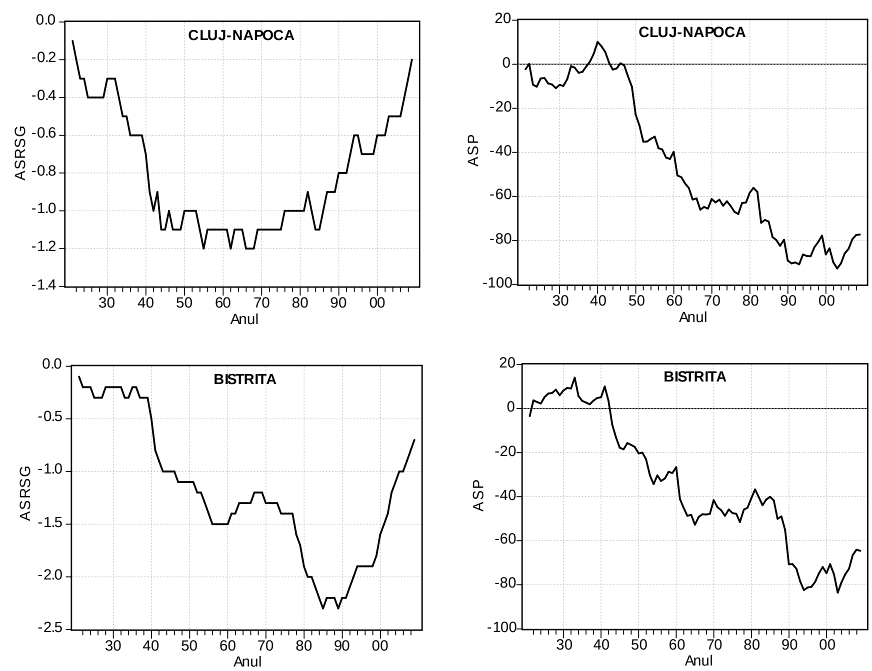
4.4.3.3 Runs Test

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.

4.4.3.4 ***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 4.9.

The shape of the cumulative curve of the PSA at Cluj-Napoca is generally similar with the one from Bistrita (Fig. 4.9) and Sibiu (Fig. 4.9). 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.



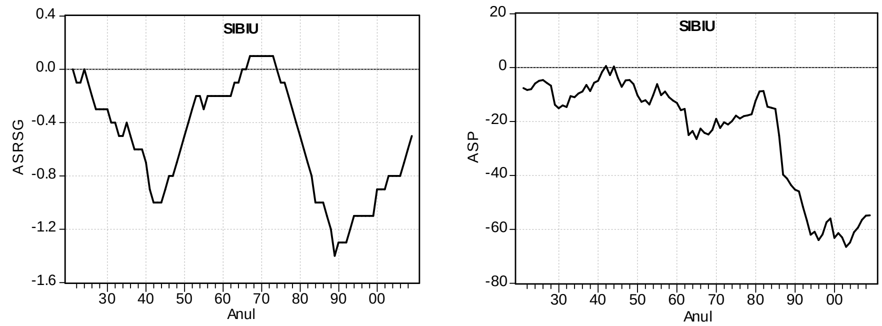


Figure 4.9. *Cumulative curves of the GSR and precipitation standardized anomalies at Cluj-Napoca, Bistriţa and Sibiu (1921–2009).*

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.

4.4.3.5 <u>Correlation between solar radiation and precipitation</u>

By using the Pearson's *r* correlation, it has been found a negative relationship between the global solar radiation and precipitation, both at Cluj-Napoca, and Bistriţa and Sibiu for the period 1921-2009.

Table 4.9. *Correlation between annual global solar radiation and precipitation at Cluj-Napoca, Bistriţa and Sibiu stations (1921-2009).*

TOWN	**STATISTIC CORRELATION**	
	Correlation coefficients	p (uncorrelation)
CLUJ-NAPOCA	-0.15	0.16037
BISTRIŢA	-0.31	0.00295*
SIBIU	-0.33	0.00173*

*Significant at the 0,01 level.

Chapter 5

Conclusions

In this study, the evolution of global solar radiation, temperature 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 Bistriţa 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 temperature 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, temperature 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, temperature 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 temperature and precipitation showed a slightly decreasing trend.

The multiannual mean GSR, sunshine duration, temperature 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, temperature and precipitation data at Cluj-Napoca station and an oscillation would be more probably than a trend. 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. Concerning to temperature, we can say 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, it is more appropriate to say that an oscillation has a bigger probability than a trend. 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 Bistrița 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/significant variation for temperature and precipitation at these two stations, but a trend, respectively 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, temperature and precipitation are also supported by the shape of the GSRSA, TSA 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 (*Tahâș et al., 2011 a*).

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.

The increase of temperature trend for the city can be ascribed to an increase in cloudiness. The increase in cloudiness is usually associated with the increase in temperature (*Gadgil și Dhorde, 2005*). Also, the heat island effect is responsible for increase of temperature because the built up areas are hotter than nearby rural areas (*Tahâș et al., 2011 b*).

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 (*Tahâș et al., 2011 a*). 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 temperature and precipitation represents the ascensional or descensional parts of some natural micro-oscillations due to solar activity/variations and natural climate variability (*Tahâș et al., 2011 a*).

By using the Pearson's *r* correlation, it has been found a positive relationship between the global solar radiation and temperature, both at Cluj-Napoca, and Bistrița and Sibiu for the period 1921-2009. On short-term, at Cluj-Napoca we have also a positive relationship (*Tahâș et al., 2011 b*). Concerning to precipitation, it has been found a negative relationship between the global solar radiation and precipitation, both at Cluj-Napoca, and Bistrița and Sibiu for the period 1921-2009.

Bibliography (selection)

1. Alexandersson H., (1986). *A homogeneity test applied to precipitation data*. J. of Climatology, 6, 661-675.

2. Allen R.G., Pereira L.S., Raes D., Smith M., (1998). *Crop evapotranspiration. Guidelines for computing crop water requirements*. FAO Irrigation and Drainage Paper 56, Rome, 301.

3. Almorox J. and Hontoria C., (2004). *Global solar radiation estimation using sunshine duration in Spain*. Energy Conversion and Management, 45, 1529–1535.

4. Ångström A., (1924). *Solar and terrestrial radiation*. Quart. J. Roy. Met. Soc., 50, 121–125.

5. Beer J., Vonmoos M., Muscheler R., (2006). *Solar variability over the past several millennia*. Space Science Reviews, 125: 67–79, DOI: 10.1007/s11214-006-9047-4.

6. Bobee B., Ashkar F., (1991). *The Gamma family and derived distribution applied in hydrology*. Water Resources Publications, USA.

7. Bodri L. and Cermak V., (2003). *High frequency variability in recent climate and the North Atlantic Oscillation*. Theor. Appl. Climatol. 74, 33–40.

8. Bogdan Octavia, (2003). *Riscul de mediu şi metodologia studierii lui. Puncte de vedere*. Riscuri şi catastrofe, II, Editor: Sorocovschi, V., Editura Casa Cărţii de Ştiinţă, Cluj-Napoca, pp. 27-38.

9. Bogdan Octavia, (2004). *Riscuri climatice. Implicaţii pentru societate şi mediu.* Rev. Geogr., Serie nouă, X/2003, pp. 73-81.

10. Buishand T.A., (1982). *Some methods for testing the homogeneity of rainfall data*. Journal of Hydrology, 58, 11-27.

11. Dohetry R.M., Hulme M., Jones C.G., (1999). *A gridded reconstruction of land and ocean precipitation for the extended Tropics from 1974–1994*. Int. J. Climatol. 19, 119–142.

12. Gadgil A. and Dhorde A., (2005). *Temperature trends in twentieth century at Pune, India*. Atmospheric Environment **39**, 6550–6556.

13. Gueymard C., Jindra P., Estrada-Cajigal V., (1995). *A critical look at recent interpretations of the Angström approach and its future in global solar radiation prediction*. Solar Energy, 54(5):357–63.

14. Haan C.T., (1977). *Statistical Methods in Hydrology*. The Iowa State Univ. Press, Ames.

15. Hulme M., Osborn T.J., Johns T.C., (1998). *Precipitation sensitivity to global warming: comparison of observations with HadCM2 simulations*. Geophys. Res. 94, 1195– 1210.

16. Jin Y.-H., Kawamura A., Jinno K., Berndtsson R., (2005). *Nonlinear multivariable analysis of SOI and local precipitation and temperature*. Nonlinear Processes in Geophysics 12, 1, 67–74.

17. Karl T.R., Knight R.W., and Plummer N., (1995). *Trends in high-frequency climate variability in the twentieth century*. Nature 377, 217–220.

18. Koutras M.V., Alexandrou V.A., (1997). *Non-parametric randomness tests based on success runs of fixed length*. Statistics & Probability Letters 32, 4, 393-404.

19. Lozowski E.P., Charlton R.B., Nguyen C.D., Wilson J.D., (1989). *The use of cumulative monthly mean temperature anomalies in the analysis of local interannual climate variability*. Journal of Climate, 2, 9, 1059-1068.

20. Maheras P., Xoplaki E., Kutiel H., (1999). *Wet and dry monthly anomalies across the mediterranean basin and their relationship with circulation, 1860-1990*. Theoretical and Applied Climatology, 64, 3-4, 189-199.

21. Martinez-Lazono J.A., Tena F., Onrubia J.E., De La Rubai J., (1984). *The* *historical evolution of the Angström formula and its modifications: review and bibliography*. Agric Forest Meteoral, 33:109–18.

22. Moberg A., Jones P.D., Barriendos M., Bergström H., Camuffo D., Cocheo C., Davies T.D., Demarée C., Martin-Vide J., Mangeri M., Rodriguez R., și Verhoeve T., (2000). *Day-today temperature variability trends in 160- to 275-year-long European instrumental records.* J. Geophys. Res. 105, 22, 849–22, 868.

23. Osborn T.J., Hulme M., Jones P.D., Basnett T.A., (2000). *Observed trends in the daily intensity of United Kingdom precipitation*. Int. J. Climatol. 20, 347–364.

24. Pettitt A.N., (1979). *A non-parametric approach to the change-point problem*. Appl. Statist., 28(2), 126-135.

25. Prescott J.A., (1940). *Evaporation from a water surface in relation to solar radiation*. Trans. R. Soc. Sci. Austr., 64, 114–125.

26. Rebetez M., (2001). *Changes in daily and nightly day-to-day temperature variability during the twentieth century for two stations in Switzerland*. Theor. Appl. Climatol. 69, 13–21.

27. Ristoiu D., (2005). *Fizica mediului-Atmosfera*. Editura Napoca Star, Cluj-Napoca.

28. Rodriguez-Puebla C., Encinas A.H., Nieto S., Garmendia J., (1998). *Spatial and temporal patterns of annual precipitation variability over the Iberian Peninsula*. Int. J. Climatol. 18, 299–316.

29. Salas J.D., (1992). *Analysis and modeling of hydrologic time series*. In: Handbook of Hydrology, (Ed. D.R. Maidment), McGraw Hill Book Company, USA, chapter 19.

30. Schönwiese C.D., Rapp J., (1997). *Climate Trend Atlas of Europe Based on Observations 1891–1990*. Kluwer Academic Publishers, Dordrecht.

31. Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M. and Miller H.L. (eds.), (2007). *Climate Change 2007: The Physical ScienceBasis. Contribution of Working Group I to the Fourth Assessment Report of the*

Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 p.

32. **Tahâș S.V.**, Ristoiu D., Cosma C., (2011 a). *Analysis of global solar radiation and precipitation trends in Cluj-Napoca, Romania, over the period 1921-2009*. Carpathian Journal of Earth and Environmental Sciences, Vol. 6, No. 2, p. 289 – 302.

33. **Tahâș S.V.**, Ristoiu D., Cosma C., (2011 b). *Trends of the global solar radiation and air temperature in Cluj-Napoca, Romania (1984-2008)*. Rom. Journ. Phys., Vol. 56, Nos. 5-6, P. 784-789, Bucharest.

34. Trenberth K.E., (1998). *Atmospheric moisture residence times and cycling: implications for rainfall rates with climate change*. Clim. Change 39, 667– 694.

35. Tung K.K. and Camp C.D., (2008). *Solar Cycle Warming at the Earth's Surface in NCEP and ERA-40 data: A linear Discriminant Analysis*. Journal of Geophysical Research, 113, D05114, doi:10.1029/2007JD009164.

36. Von Neumann J., (1941). *Distribution of the ratio of the mean square successive difference to the variance*. Ann. Math. Stat., 12, 367-395.

37. World Meteorological Organization, (1983). *Guide to climatological practices*, Second edition. No. 100, 5.30 p.

38. Zhao J., Han Y.B. și Li Z.A., (2004). *The Effect of Solar Activity on the Annual Precipitation in the Beijing Area*. Chin. J. Astron. Astrophys. Vol. 4, No. 2, 189–197.

39. ***Clima Republicii Socialiste România, (1962), vol. I, p.115, Bucureşti.

40. ***IPCC (2001). *Climate change 2001: synthesis report. Contribution of Working Group I and III to the Third Assessment of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge University Press, Cambridge.

41. *** http://www7.ncdc.noaa.gov/IPS/mcdw/mcdw.html

42. *** http://www.tutiempo.net/en/Climate/Romania/RO.html