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SYNTHETIC SCIENTIFIC REPORT

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Project:

„Solar and geomagnetic activity and their influences on the terrestrial environment. Case study – climate”

October 2011- December 2013

Project Director,

Dr. Venera Dobrică

December, 2013

Introduction

The project aims at consolidation and development of the research carried out in the last several years in the Institute of Geodynamics, regarding the influence of the solar and geomagnetic activity on the climate at local scale (Romanian territory) and continental scale (Europe). The main objectives of the project are:

(1) Analysis of solar and geomagnetic activity and of climatic parameters, such as air temperature and precipitation, based on indices that describe them, existing in various data bases, both observational and reanalyzed and distributed in uniform networks, with an aim at recovering tendencies and periodicities characterizing the variability of climate and of solar/geomagnetic activity.

(2) Study of long-term statistical correlations, at the Schwabe (11 years) and Hale (22 years) solar cycles time-scales, between climate parameters and those of solar and geomagnetic activity at local, regional and continental geographical scales.

The present report comprises the synthetic presentation of results of the four stages (2011, 2012, and 2013) carried out in the project, entitled respectively **“Review of the literature and of existent data”, “The analysis of solar/geomagnetic signatures in data from meteorological stations at local, regional, and continental scales”, “Analysis of solar/geomagnetic signatures in reanalyzed data from NCEP/NCAR and ERA40 databases”.** The report is structured in four chapters, as follows:

In *Chapter I*, entitled **“Introductory notions. The data bank of the project”**, results from literature as regards the fingerprint in the terrestrial climate of solar and geomagnetic variability are reviewed. Also, data relative to the solar activity, geomagnetic activity and climatic parameters are described. The web addresses of the world data centers and publications from which data of interest can be extracted are given.

In *Chapter II*, entitled **”Determining trends in the evolution of surface air temperature and precipitation using various spectral analysis techniques”,** the main methods used in the advanced analysis of meteorological data, such as the Singular Spectral Analysis (SSA), the Maximum Entropy Method (MEM), the Multi-Taper Method (MTM), the Detrended Fluctuation Analysis (DFA), as well as the results obtained in the project regarding their application to data from the project bank are presented.

The *Chapter* III, entitled **”Analysis of solar/geomagnetic signals in data from meteorological stations and in reanalysed data from the NCEP/NCAR and ERA40 databases”**, is dedicated to results obtained by statistical correlation analysis regarding the effect of the external forcing of the solar/geomagnetic activity on climatic parameters, using data from meteorological stations and reanalysis data from NCEP/NCAR database.

The report ends with *Chapter IV*, entitled ***”Dissemination of project results. The web page of the project”***, a chapter destined to the dissemination, where the published papers and workshop presentations of the project results are reviewed.

Chapter I. Introductory notions. The data bank of the project

I.1. Introduction

A great number of studies published so far show that the variable, energetic solar emission is linked to climatic variability. Though it is well established that the Sun defines the terrestrial climate, providing energy to the climate system through the received radiation, the role of the solar variability is far from being clear. The solar variability can affect the environment in many ways, according for instance to a review published by Haigh (2007). A number of studies (Usoskin et al. 2005; Beer et al., 2006) indicated that solar variations have had an impact on climate prior to the industrial period, during Holocene (the last 11,000 years). Recently, solar effects on climate have been detected at time scales of 100 years and less (Dobrica et al., 2009; Dobrica et al., 2010). Three main mechanisms have been proposed for the solar influence on climate at century time scale:

– variations of the total solar irradiance (TSI) (Foukal et al., 2006; Frölich, 2006; Solanki and Krivova, 2004; Wang et al., 2005);

– variations of solar irradiance in the ultraviolet (UV) part of the spectrum, larger than TSI ones. They would influence the troposphere via the atmospheric layer above, the stratosphere;

– ionization of atmosphere by cosmic radiation (Usoskin and Kovaltsov, 2006; de Jager and Usoskin, 2006), that leads to changes in atmosphere properties, particularly regarding cloud formation.

The solar influence on climate cannot be directly measured. However, correlations between indices of solar activity and climatic parameters, such as the well known correlation between the mean temperature of the northern hemisphere and solar cycle length (Friis-Christensen and Lassen, 1991), have been found. Recently, studies focused on the Sun-climate relationship at time scales of 11 years solar cycles, using surface climatic parameters such as surface temperature in continental and oceanic areas, precipitation, atmospheric pressure (Le Mouël et al., 2005; van Loon et al., 2007; Le Mouël et al., 2008, 2009; Dobrica et al., 2009, 2010), or parameters characterizing higher atmospheric layers (Labitzke, 2005; Haigh, 2007). An example of *empirical approach* is the study of Friis-Christiensen and Lassen (1991), that correlated the length of the 11-year solar cycle to the mean northern hemisphere temperature in terms of the anomaly relative to the time interval 1951-1980. Mitchell (1979) presented the relationship between drought indices for the western United

States and the solar magnetic cycle (Hale cycle, 22 years). The influence of the solar activity on precipitation, less studied than the temperature case, have been rendered evident for the Beijing area (Zhao et al., 2004) and for three areas in South Africa (King, 1975). In the first case variations with periods of 11, 22, 33, and 72 years have been isolated, and in the second case it was shown that the smoothed annual precipitation varies with the double sunspot cycle

The geomagnetic activity is controlled by the solar activity and depends on the solar cycle phase. The geomagnetic activity is the result of variable current systems that form in the magnetosphere and in the ionosphere as a consequence of the interaction of the solar wind and heliospheric magnetic field with the magnetosphere. The geomagnetic activity is described by means of the so-called geomagnetic indices. Out of the indices designed to give a global image of the magnetosphere degree of disturbance, the **aa** index covers the longest time interval, as its time series starts in 1868. The long term evolution of the geomagnetic activity, its resemblance with the solar cycles of activity, and the peculiarities of the 11-year cycle in **aa**, such as a secondary maximum in the descending phase of the solar cycle and the increase of its minimum values in the 20th century, have been discussed by a number of authors (e.g. Cliver et al., 1998; Stamper et al., 1999). Demetrescu and Dobrică (2008) tackled the relationship between the solar activity described by the sunspot number time series, total solar irradiance, and geomagnetic activity at large temporal scale, namely Hale (22 year) and Gleissberg (80-90 years) cycles.

The geomagnetic activity as a forcing factor of climate variations was studied in a lesser number of papers (Cliver et al., 1998; Bucha şi Bucha Jr., 1998, 2002); statistically significant correlation coefficients were found between the geomagnetic activity and climatic parameters such as sea level atmospheric pressure and surface air temperature.

The connection between the solar activity and the geomagnetic one is much better understood than the possible causal link between climate and the solar or geomagnetic activity. The existence of such links, the relative contribution of the solar and/or geomagnetic effects on climate, as well as the associated physical processes are still under debate and that will be the case for some time on.

I.2. The solar signal in time series of temperature and precipitation at Romanian and European scale

In this Section we review the results obtained by the project team (Dobrica et al., 2009; 2010) in defining solar signals in temperature and precipitation data at local (Romania) and continental (Europe) scale. The temporal scale is extended in these studies beyond the

11-year variation, to the time scale of variations related to the solar magnetic cycle (Hale, 22 years).

The correlation between solar and geomagnetic activity and temperature and precipitation in Romania has been investigated for interdecadal trends (does not contain periods at the time scale of 10-11 years) (Fig. I.1) and centennial trends (does not contain variations at the 22- and 30-year time scales), periods present both in the solar and geomagnetic activity and in the studied climatic parameters. We noticed that as the averaging window width is increasing the correlation is improving, but the trend in temperatures remains in phase with the solar and geomagnetic activity. The trend in precipitation is out of phase with the solar/geomagnetic activity. It is to be remarked that on long term the link between climatic parameters and the geomagnetic activity seems to be stronger than the one with the solar activity.

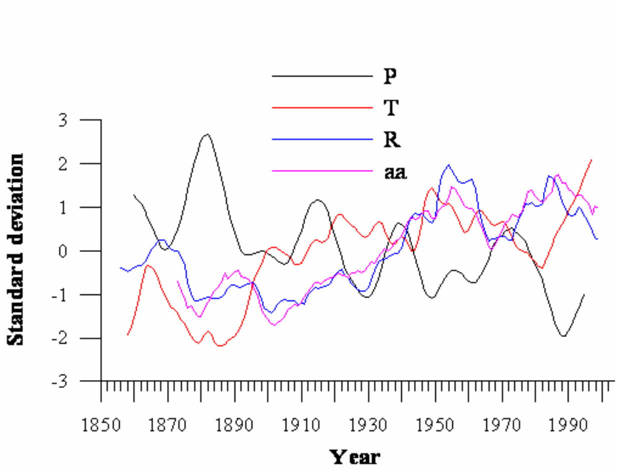

Fig. I.1. The interdecadal trend in precipitation (P), temperature (T), sunspot number (R), geomagnetic activity index (aa)

In Fig. I.2 we superimposed, in terms of 11-year averages, a local time series (the average temperature for 14 stations in Romania), average time series for Europe, northern hemisphere, and globe, the sunspot number, the geomagnetic index aa.

The figure shows:

(1) the well-known correlation between solar and geomagnetic activity and the mean temperature for the northern hemisphere (Friis-Christensen and Lassen,1991; Le Mouel et al., 2005);

(2) the pronounced discrepancy of temperature trends and the solar/geomagnetic ones after 1980-1990, that might be the expression of the anthropogenic effect of green house gases (Le Mouel et al., 2005);

(3) the faster increase of temperatures in comparison with the solar and geomagnetic activities before 1940-1950;

(4) differences between local temperatures (averages for the Romanian territory, averages at European scale) and averages at larger scales (northern hemisphere, globe).

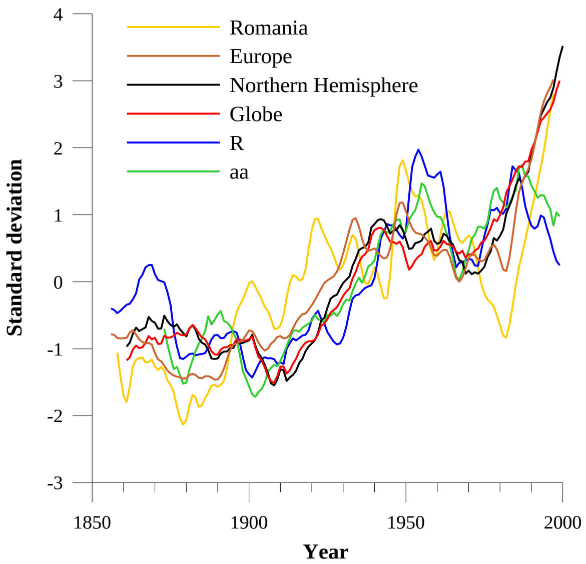

Fig. I.2. Comparison in 11-year averages terms between temperatures and the solar and geomagnetic activities

I.3. Data bank of the project

The data bank of the project was built using information managed by data centers and/or published in the scientific literature, concerning the solar activity, the geomagnetic activity, and climatic parameters. They are shown in the following table.

Parameterl	**Time Interval**	**Source**
R	1700-2007	ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT NUMBERS/INTERNATIONAL/yearly/YEARLY
TSI	1964-2007	ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_IRRADIANCE
aa	1868-2007	http://isgi.cetp.ipsl.fr/lesdonne.htm (Mayaud, 1972; 1980)
T, P	1901-2012	www.eca.knmi.nl/dailydata/ European Climate Assessment & Dataset (ECA&D) (Klein Tank et al., 2002)
T, P	1948-2012	http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html (Kalnay et al., 1996)
T, P	1957-2002	http://data-portal.ecmwf.int/data/d/era40_daily/ (Uppala et al., 2005)

Initially, the data bank of the project was built with observational monthly averages of temperature and precipitation from 14 weather stations in Romania between 1850-2004, annual averages from several European stations with long records (London (1659-1999), DeBilt (1706-2011), Uppsala (1723-2011), Stockholm (1756-2011), Prague (1770-2002), Vienna (1775-2002) and Hohenpeissenberg (1781-2002)), and daily means from 24 European stations between 1900 and 2011. The spatial and temporal coverage of data are illustrated in Fig. I.3.

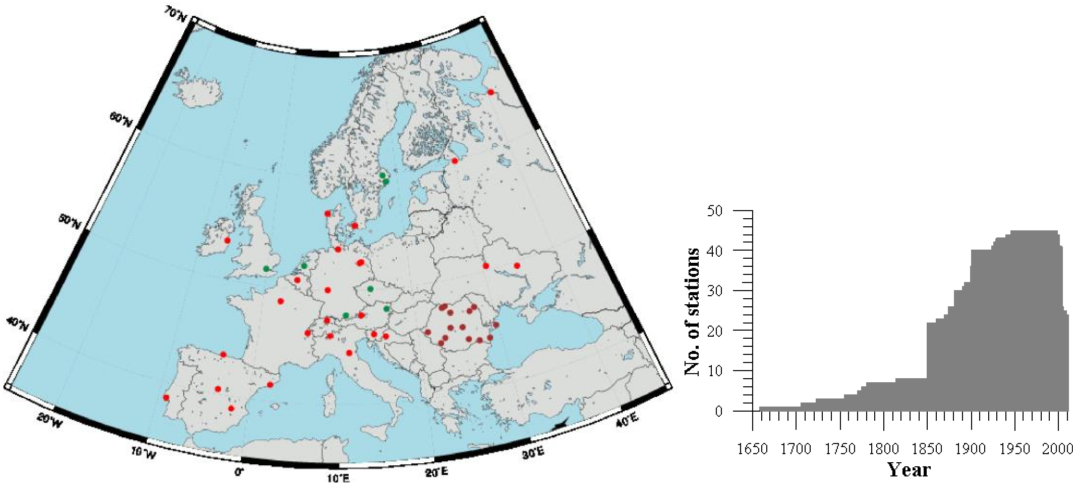

Fig. I.3 – Left: location of weather stations used in the project (brown symbols – 14 stations in Romania; red symbols – 24 European stations; green symbols – 7 European stations with long records). Right: the temporal coverage

Besides the istrumental information from European weather stations, we also used reconstructions of temperatures at European scale (Mitchell and Jones, 2005, based on instrumental data for 1900-2004 and on the reconstructions published by Luterbacher et al. (2004) and Xoplaki et al. (2005), for the interval 1500-1900), at northern hemisphere scale (Moberg et al., 2005, for 1791-1979, based on tree ring, marine, and lacustrine sediment studies; Jones et al., 2006, instrumental data for 1980-2005), and at global scale (Jones et al., 2006, instrumental data for 1856-2005).

The NCEP/NCAR database

The NCEP/NCAR database is a result of cooperation between the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) in USA, called the Reanalysis NCEP/NCAR Project. The aim of the project was to produce a data bank on atmospheric fields for a 51 years time span beginning with 1948.

Reanalysis led to two types of data, namely:

- one dataset regarding the distribution of parameters describing atmospheric fields in a 4-D network (horizontal resolution of 2,5x2,5 degrees latitude and longitude), as a result of modelling the atmospheric parameters;

- the observational dataset, organized in a coherent system (common format BUFR) that also includes information on data quality.

The model has a temporal coverage with 4 values/day, daily values, and monthly values, beginning with 01/01/1948. On long term the monthly averages are derived from 1981 – 2010 data. Data are available for the surface or near-surface (0.995 sigma level), or the entire atmosphere (eatm). They are divided in 7 files: pressure level, surface, surface fluxes, other fluxes, tropopause, derived data, spectral coefficients.

The ERA40 database

ERA40 is a database developed by the European Center for Medium Weather Forecast (ECMWF), comprising reanalysed data from September 1957 to August 2002.

Data have a spatial resolution of 2,5 x 2,5 degrees too and are available from the server http://data-portal.ecmwf.int/data/d/era40_daily/.

To use data on climatic parameters, one has to access the data server ECMWF, select ERA40, select period (september 1957-august 2002), select the time window (6, 12, 18 hours), choose one of several of the 56 climatic parameters. Data are uploaded as a plot or file with the extension .grib.

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Chapter II. Determining trends in the evolution of surface air temperature and precipitation using various spectral analysis techniques

II.1. Classical and nonlinear methods for time series data analysis

In this chapter, the main methods used in the advanced analysis of meteorological data, such as singular spectrum analysis (SSA), the maximum entropy method (MEM), the multi-taper method (MTM), and the detrended fluctuation analysis (DFA) are presented.

In time-series analysis, two types of approach are used, referring the temporal and, respectively, spectral domain. In the context of linearity, in which the physical sciences in the last two centuries evolved, the physical system producing the time-series might be described by means of an ordinary linear differential equation (ODE), with random forcing:

$$X(t+1)=\sum_{j=1}^{M} a_j X(t-M+j)+\sigma\xi(t), \qquad (1)$$

of which coefficients a_j determine the solutions $X(t)$ at discrete moments $t = 0, 1, 2, \ldots, n, \ldots$. The random forcing $\xi(t)$ is supposed to be white in time, meaning uncorrelated from t to $t+1$, and Gaussian at each t, with a constant variance equaling the unity. The spectral approach is motivated by the observation that the most regular behaviour of a time-series is periodical and, consequently, the aim is to determine the periodical components of time-series by computing periods, amplitudes, and phases.

In the ′60s and ′70s of the last century it was discovered that the most part of irregularities observed in a time-series, traditionally attributed to the contribution of an infinite number of independent contributions (degrees of freedom) to the linear system, can be generated by the non-linear interaction of some degrees of freedom, in the frame of a deterministic aperiodicity concept (or „chaos”).

The starting point of the *singular spectrum analysis* (SSA) is the inclusion of the time-series $\{X(t): t = 1, \ldots, N\}$ in a vector space of dimension M, that is to represent the series as a trajectory in the phase space of the hypothetical system that generated $\{X(t)\}$. Equivalently, the behaviour of the system is represented by a sequence of „images” of the series through a running window of M points. A sequence $\{\tilde{X}(t)\}$ of M-dimensional vectors from the original time-series X is constructed, using delayed copies of the scalar data, sequence indexed with $t = 1, \ldots, N'$, where $N' = N - M + 1$, operation on which the decomposition and reconstruction of the signal with an improved signal/noise ratio are based.

Both deterministic processes and the stochastic ones can be characterized by a function of frequency *f*, instead of time *t*. This function, *S* (*f*), is called power spectrum or spectral density. A very irregular movement shows a smooth and continuous spectrum, that indicates that all frequencies from a given frequency band are excited by that process. On the other hand, a periodical process or a quasi-periodical one, is described by a single line or, respectively, by a finite number of lines in the frequency domain. Between these extrema, deterministic non-linear processes, but „chaotic", can have spectral maxima superposed on a continuous, irregular background.

The maximum entropy method (MEM) is based on the approximation of the studied time-series by a linear autoregressive process (eq.1) of the order *M*, *AR* (*M*). Given the time-series {*X* (*t*): *t* = 1, …, *N*}, supposed to be generated by a zero mean and σ^2 variance stationary process, a number M' + 1 autocorrelation coefficients $\left\{\hat{\phi}_X(j): j = 0,...,M'\right\}$ is calculated according to

$$\hat{\phi}_X(j) = \frac{1}{N+1-j}\sum_{t=1}^{N-j} X(t)X(t+j) \qquad (2)$$

In the absence of *a priori* information on the process that generated the time-series *X* (*t*), M' is arbitrary and should be optimized. The spectral density $\hat{S}_X$ associated to the most stochastic and less predictable process having the same autocorrelation coefficients $\hat{\phi}$ is determined.

Multi-taper method (MTM) is, at odds with the MEM, a non-parametric method, in the sense that it does not use a model depending of a parameter for describing the process that generated the analyzed time-series. MTM reduces the variance of the spectral estimates by using a small number of tapers (compare with the unique taper of data or the spectral window used in classical methods).

The detrended fluctuation analysis (DFA) is used to identify patterns present in air temperature time-series from a multi-scale perspective, because it has the capacity to identify scaling aspects in the time-series even in the presence of the trends of unknown origin and form. Introduced first by Peng et al. (1994) and improved by Kantelhardt et al. (2001) the DFA is a nonlinear method successfully applied in evaluation of natural climatic variability.

In short, the working methodology implies, at the beginning, elimination of seasonal variation which amplitude dominates fluctuations at other time scales, followed by the analysis proper that consists in:

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- the time-series is divided in sections of length *s*; in turn, various lengths are chosen, corresponding to a range of temporal time-scales;

- for each section *m* (*s*) the *N* degree polynomial that fits the data is calculated, $p_{m,N}$ (*i*), with $1 \le i \le N$ and the difference between the signal *Q*(*i*) and the polynomial is determined:

$$Q_s(i) = Q(i) - p_{m,N}(i)$$

as well as the mean square of these differences, $F_s^2(m) = \langle Q_s^2(i) \rangle$.

- The results for all sections are averaged, obtaining

$$F(s) = \left[\frac{1}{r} \sum_{m=1}^{r} F_s^2(m) \right]^{1/2} ,$$

where *r* is the number of the sections of dimension *s*.

- The power law defining the relation between *f* and *s*, is searched for a range of scales:

$$F^{(N)}(s) \alpha\, s^k ,$$

finding the exponent *k*. The latter characterizes the scaling behaviour of the pattern in data. The *k* value indicates persistence ($k > 0.5$), antipersistence ($k < 0.5$), or uncorrelated noise ($k = 0.5$) in data. Analyzing the *k* exponent for the chosen stations and territories allows studying effects of various kinds of processes that influence climate in the given points.

II.2. Determining the trends in the evolution of surface air temperature and precipitation using various spectral analysis techniques

Assessing the climate variability depends on the existence and accuracy of records of climatic parameters, such as air temperature or precipitation. The most important information on the air temperature is based on averages computed for individual observation points, or for area of various sizes (Fig. II.1). To find tendencies and periodicities in data, both standard spectral analysis and non-linear analysis techniques were used: the Fast Fourier Transform (FFT) or the Multi-Taper Method (MTM) and, respectively, the Detrended Fluctuations Analysis (DFA) and the Haar wavelet method

The evolution of temperature at Earth's surface (SAT) can be described in several ways, and pattern analysis methods contributed to determining some characteristics of this evolution and of the processes implied. However, a certain method can reveal only some facets of the complexity of a pattern. Assessing the SAT *variability* and its change in time is of great importance to understanding climate processes, as well as assessing the implications of climate changes on ecosystems, human helth etc. An as complete as possible assessment of pattern variability is also important for testing the products of a climate model (Vyushin et al., 2004; Rybski et al., 2008). The variability characterizing the entire recorded time series has been studied by means of methods in a large spectrum (Walsh et al., 2005; Timlin and Walsh, 2007; Box, 2002; Box et al., 2009). Changes of the variability at various time scales were less studied and often the conclusions of these studies are not consistent, as the review published by Walsh et al. (2011) shows.

Within the frame of this project three related aspects of variability change have been studied, namely:

a. *Statistical moments* for each year. They give information on the distribution of values, ignoring, of course, the real sequence of the values. Of the statistical moments we mention the standard deviation, S, that proved useful to the present study.

b. *Signal persistency*. This aspect was approached to render evident characteristics of values succession at various temporal scales. The signal persistency was evaluated for time intervals from weeks to years and decades, being quantified by means of the Hurst exponent. Two method were used: (i) the fluctuation analysis (Detrended Fluctuation Analysis, DFA, and (ii) the Haar wavelet analysis. Both methods are based on evaluation of the relationship between the magnitude of the fluctuations and their temporal scale. Both of them consider segments of a length *s*, for various temporal scales. In DFA one calculates the polynom of degree N (N = 1, 2, … 7), fitted for each segment, then the mean square difference between the polynom and the signal, which then is averaged for all segments F(s). The Haar analysis is based on a different method to evaluate the fluctuations: computing, for each point *x* in the time series the difference from the mean of (x + s/2) and (x – s/2). The two methods lead to similar results, but the second one is more rapid and gives results easier to interpret, with smaller incertitude intervals.

c. *The distance from the mean year, D.* This is given by the mean for each day of the year, computed for the entire data set, for each station. Then the Euclidian distance is calculated for each of the analysed windows.

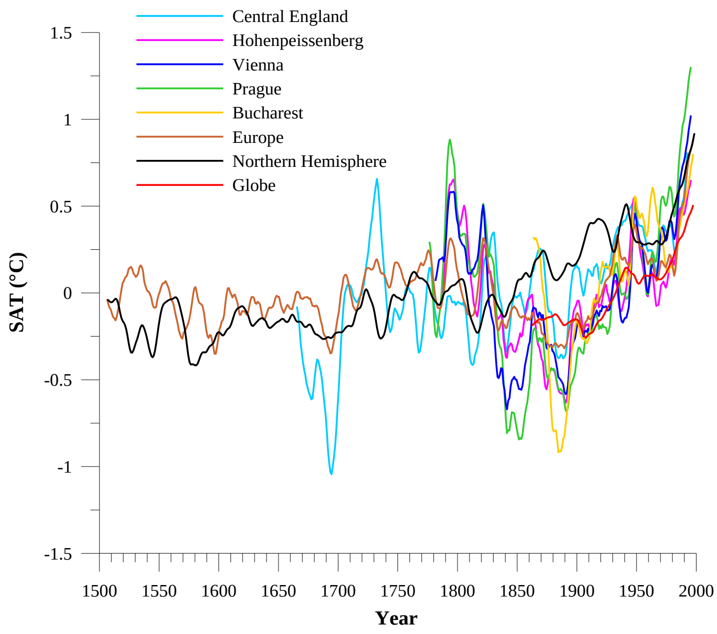

Fig. II.1. Multi-decadal anomalies in the evolution of surface air temperature relative to the mean for 1961-1990, in case of several European stations and of the entire northern hemisphere

II.3. Obtained results

In the following we give, as examples, (a) the result we obtained by spectral analysis techniques FFT and MTM in case of one of the longest instrumental record (1706-2011), namely DeBilt station, The Netherlands, and (b) the results obtained by using nonlinear techniques of analysis of the maximum and minimum temperatures recorded at weather stations in two areas, namely the maritime provinces of Canada, for which Suteanu (2010) singled out processes significantly influencing the air temperature, and Romania, previously studied by Dobrică et al. (2009).

The classical spectral analysis (Fig. II.2) of the time series indicates the presence of short-term variations (2-7 years), variations with a period of ~11 years, and variations with longer periods, of 22-30 years or even longer, of ~80 years, which superpose in the analysed signal.

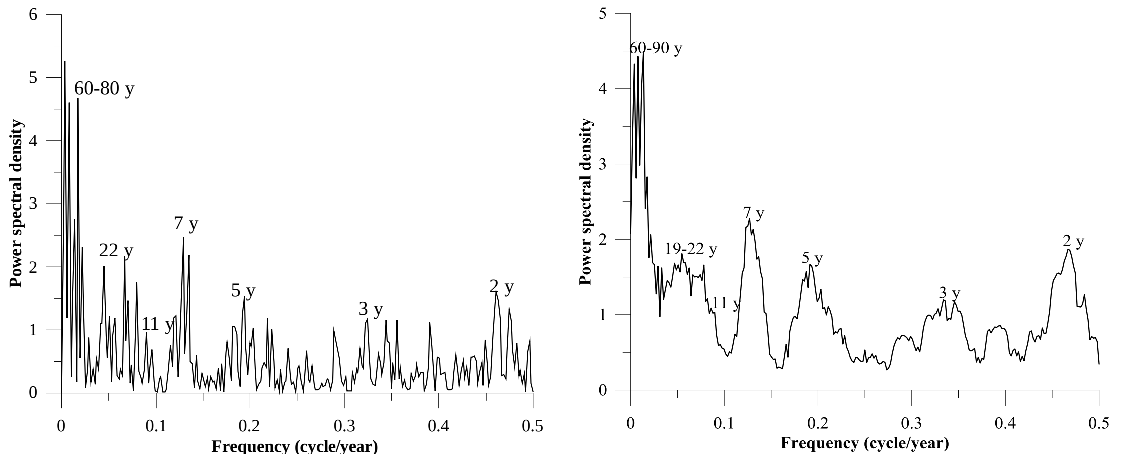

Fig. II.2. The power spectrum for air temperature at DeBilt weather station, by FFT (left) and MTM (right)

The DFA nonlinear method was applied to daily temperature date from several stations on the Romanian territory (Fig. II.3) and Arctic Canada (Fig. II.4). The method is used to identify patterns in the air temperature time series from a multi-scale perspective, as it has the capacity to identify scaling aspects in time series even in the presence of trends of unknown origin and form, determining a scaling exponent, denoted *k* or *H*, that characterizes the scaling behaviour of the pattern in data. As it was mentioned, the value of *k* indicates persistency (*k* > 0,5), antipersistency (*k* < 0,5), or uncorrelated noise (*k* = 0,5) in data. The analysis of the k exponent allows the study of the effects of various processes that influence the climate in the given points

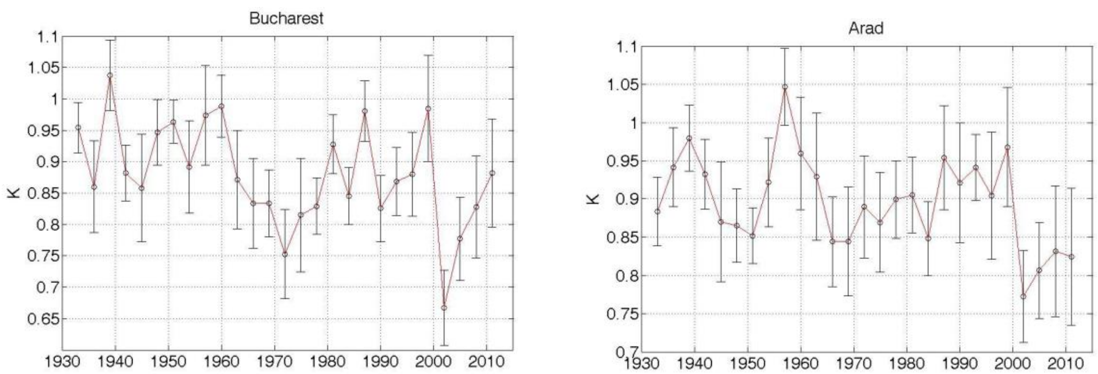

Fig.II.3. The scaling exponent for Bucuresti (left) and Arad (right) for the mean daily temperatures (right)

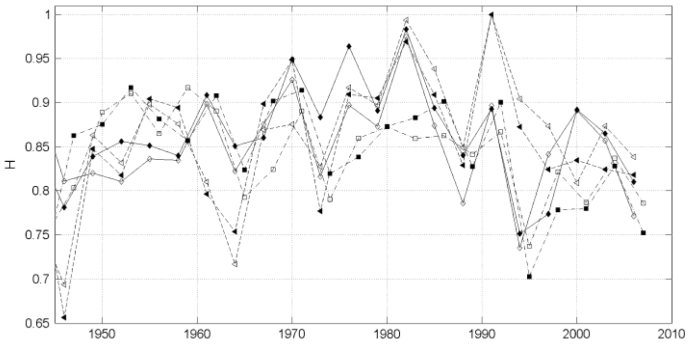

Fig. II.4. The scaling exponent for three weather stations in the Arctic Canada, for the daily minimum (filled symbols) and daily maximum (empty symbols) temperature

Among the conclusions of the undertaken analyses, we shortly mention:

- the patterns in case of daily tempreature series are characterized by scaling properties between 1-2 months and 5-8 years;
- the scaling coefficients cover the interval 0.70±0.05 for the great majority of the stations included in the study;
- the DFA analysis applied to successive temporal windows shows that scaling properties significantly vary in time;
- the patterns of temporal changes underline common aspects between stations, despite sometime large distances between stations (in Arctic Canada) and different geographical characteristics;
- generally, the change of the persistence occurs at regional scale, depending only little on local factors.

To assess the possibilities of the three methods described above (statistical moments, signal persistency, distance from the mean year) regarding the climate natural variability, the minimum daily temperatures at Arctic Canada stations were considered. The three methods were applied both to the entire time series and to windows of various lengths, between 2 and 7 years. The window width (or length) does not play a major role, in accordance with other studies (Walsh et al., 2005; Şuţeanu and Mandea, 2012). In Fig. II.5 we show results for two of the methods, namely the Haar analysis and the distance from the mean year, for a window of 7 years (H_7 – left, D_7 – right). The variability of the SAT pattern is significantly changing in time. The relations between the parameters reflecting the variability, S, H, D, also change in time, so we studied the correlation between the three, based on running windows.

The change in time of the relations between S, H, and D illustrates the degree to which these parameters capture different aspects of the temperature pattern. For the Canadian stations a positive correlation between S, H, and D could be identified for the time interval from the first recordings (end of the 19th century) to the 1940's, when the correlation changes significantly in all cases. It is interesting that the pattern change could be clearly identified only through the common analysis of the three parameters reflecting the variability, as the temporal analysis, separately applied, would not give any indication of detecting such a pattern change. In Fig. II.6 we illustrate this result in case of the correlation between H and S.

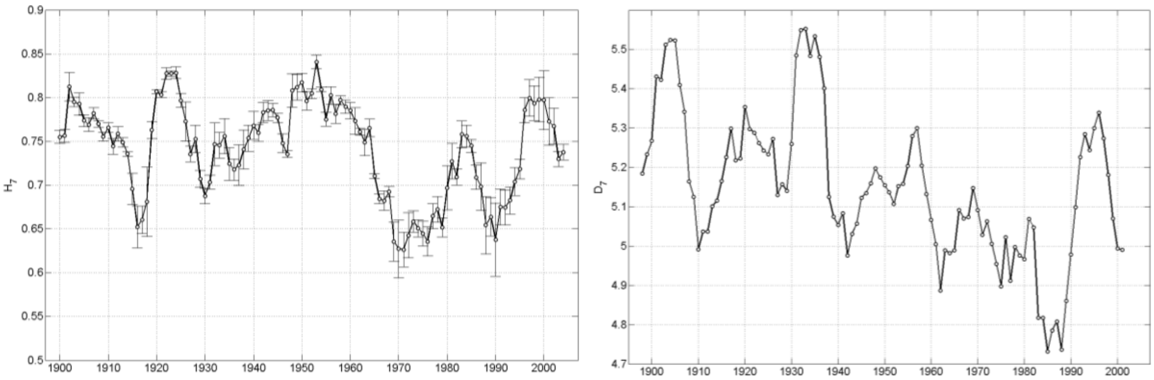

Fig. II.5. The Hurst exponent by Haar wavelet analysis (H) for minimum daily SAT at Frederikton (left) and the Euclidian distance (D) for an average year at Miramichi (right)

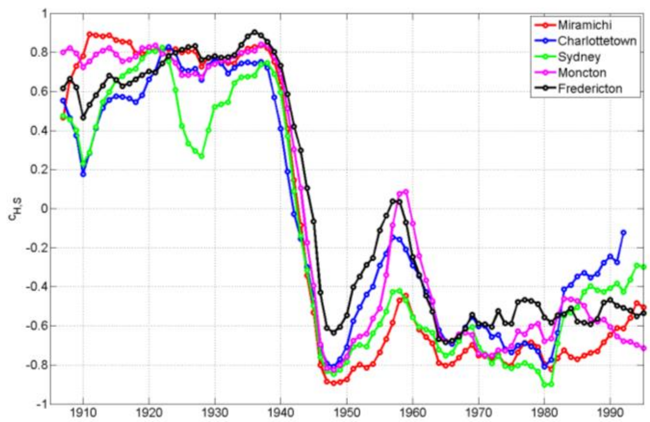

Fig. II.6. The multidecadal variation of the correlation between H and S

Though each of the determined parameters irregularly vary in time, their correlation is more stable. In the illustrated case the positive correlation that dominates the interval 1900-1940 decreases abruptly and, with the exception of a maximum at the end of the '50s, it remains negative to the end of the data series.

Our study shows that the minimum temperatures are generally characterized by a higher persistance and less variability than the maximum temperatures. The variability of the SAT pattern fluctuates at multidecadal time scales.

The lack of consensus on the pattern variability and its temporal change might partially be explained by the fact that the temporal evolution of the SAT pattern, as is the case of many other natural patterns, cannot be completely characterized by neither method for time series analysis. That is why to characterize a pattern several methods should be used. Moreover, none of the methods used in the present study demonstrated the existence of a simple trend in variability changes. Contrary, in all cases irregular increasings and decreasings were identified. This is a reason why the often asked question regarding the increase of the variability in the last decades cannot receive a simple answer. Considering the nature of the variability, we do not think this situation will change, even new and more powerful methods will render evident other interesting aspects of the pattern change.

The analysis of a river discharge can provide information on the climate evolution in its catchement basin, due to the fact that the evolution of temperatures and precipitation in the basin reflects themselves in the discharge. That is why we investigated, in the frame of the project, the discharge of the Danube river in connection with the precipitation recorded at weather stations located in the river basin. The interdecadal and centennial trends in precipitation (P) at metstations in the Danube basin, precipitation that was analysed in relation to the Danube discharge recorded at four hydrological gauges in its lower segment. Applying the MTM spectral analysis on precipitation at Sibiu weather station and on Danube discharge data, presented in Fig. II.7, we found a similar behaviour as temperature data, with short period variations (2-7 years), decadal variations with a period of about 11 years, and of longer period variations, of 22/30 years and even longer.

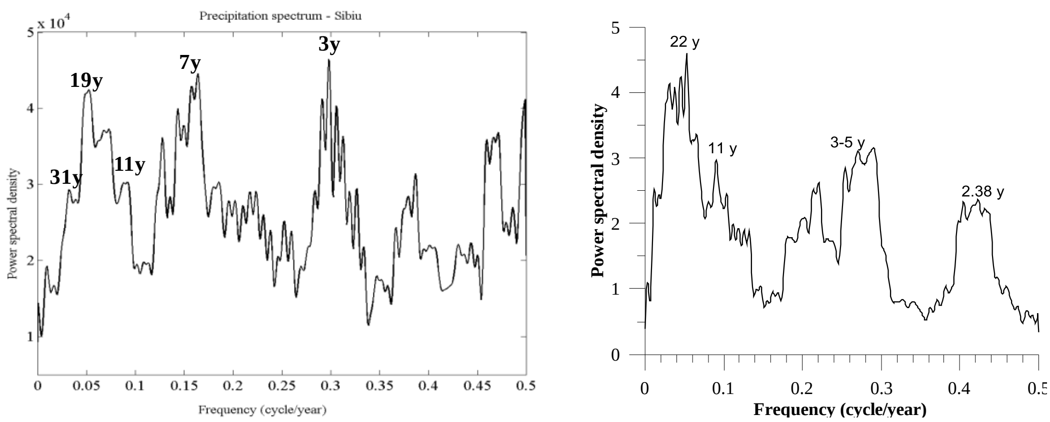

Fig. II.7. The MTM power spectrum for precipitation (left) and Danube discharge (right)

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Chapter III. Analysis of solar/geomagnetic signals in data from meteorological stations and in reanalysed data from the NCEP/NCAR

The effect of the external forcing of the solar/geomagnetic variability on climatic parameters at local, regional and continental scales have been investigated by means of statistical correlation analysis. The long-term correlation analysis was based on indices describing the solar and the geomagnetic activities and on surface air temperature recorded at weather stations over Romania and over Europe. The study has been extended to all continental areas with temperate climate in the northern hemisphere (Europe, North America, Asia) using reanalysed data provided by the two databases mentioned in the chapter title.

III.1. Climatic parameters. Evolution and processing method

Data from the project bank that was described in Chapter I of the present report, were processed to give annual mean values of the surface air temperature (SAT). In terms of the anomaly with respect to the average value for the time interval 1961 – 1990, the temporal evolution of temperature for all 45 weather station in Europe (see Fig. I.3 for locations) is presented in Fig. III.1.

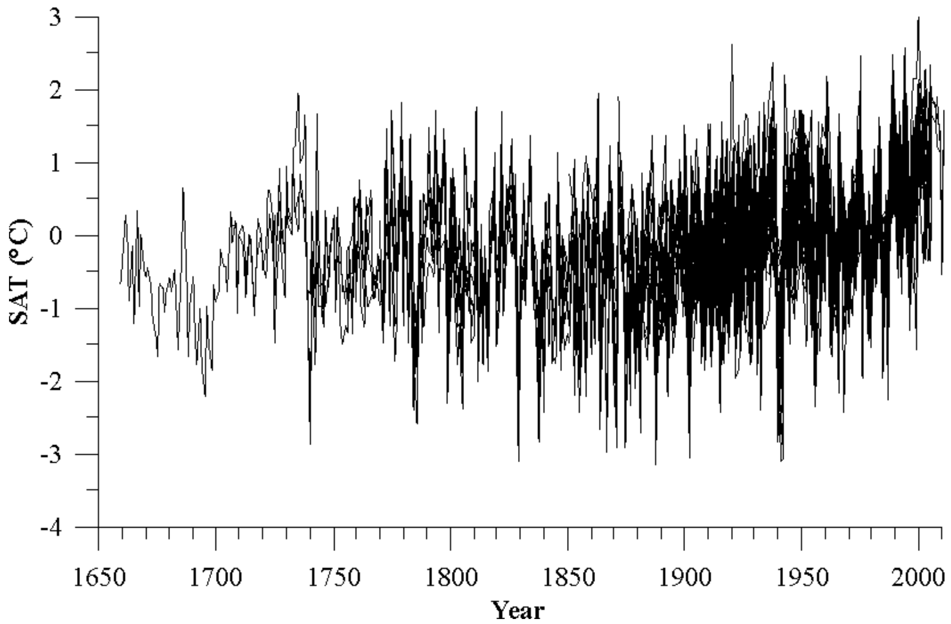


Fig. III.1. Temperature anomaly relative to the average for 1961 – 1990 for the 45 weather stations used in the project

One can notice, on one hand, the similitude of recorded temperatures and, on the other, differences in amplitude of superimposed time series. Also, a remarkable minimum is seen in the 1940s. In the last five decades, an increase by about 1°C that started in the 1970s, can be remarked.

Data from NCEP/NCAR database have also been processed, corresponding to a number of 299 network nodes for the European continent. The temperature evolution in the time interval 1948 – 2012, for the midlatitude band 45-52.5°N is shown in Fig. III.2.

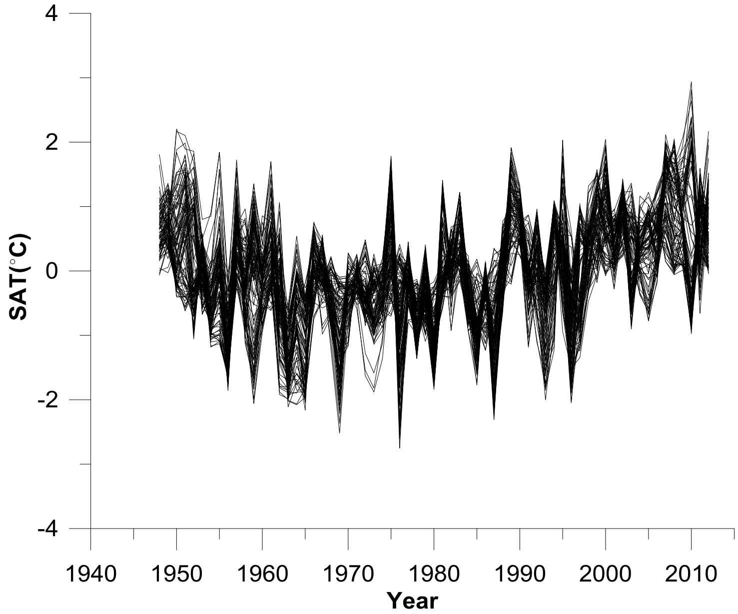


Fig. III.2. Temperature anomaly relative to the mean for 1948-2012, midlatitude band 45-52.5°N from NCEP/NCAR data

The distribution of the mean annual temperature at the European scale, from reeanalysis data, at two moments, 1965 and 1995, the first being a year of minimum temperature and the second being placed on the increasing temperatures corresponding to the global increase in the 20th century (Fig. III.2), is presented in Fig. III.3. One remarks the increase of the mean annual temperature of about 1.3°/decade for North and North-East Europe, while the increase is of only 0.3°/decade for Central and Western Europe.

As we mentioned in Chapter II, trends and periodicities in these data were determined using various spectral analysis, classic and nonlinear techniques. Variations of short period, 2 to 7 years, decadal variations with a period of about 11 years, and longer period variations, of

22-, 30-year and even longer, were shown to be present.

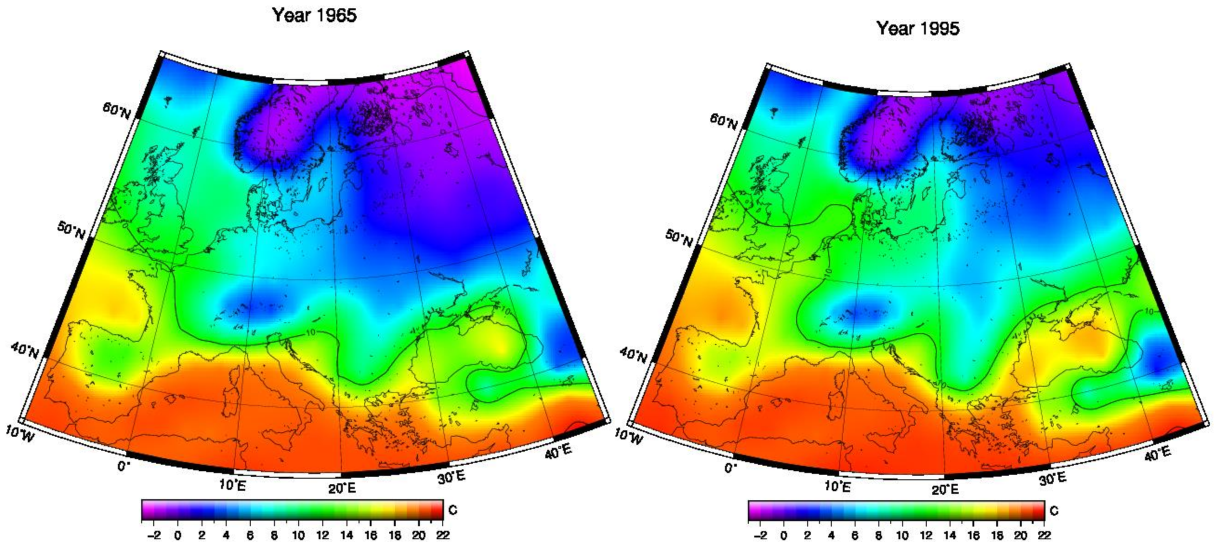


Fig. III.3. Annual mean temperature distribution at European continental scale from NCEP/NCAR data, at 1965 left) and 1995 (right)

An example of data treatment, in case of one of the longest record available – DeBilt station (1706-2011), is given in Fig. III.4. The surface air temperature time series is plotted in the upper part of the figure. After filtering out the short period variations, the time series was successively filtered by running windows of 11 years (red curve) and 22 years (blue curve). Differences between filtered time series define the so-called 11-year and 22-year variations plotted in the lower part of the figure (red and, respectively, blue lines).

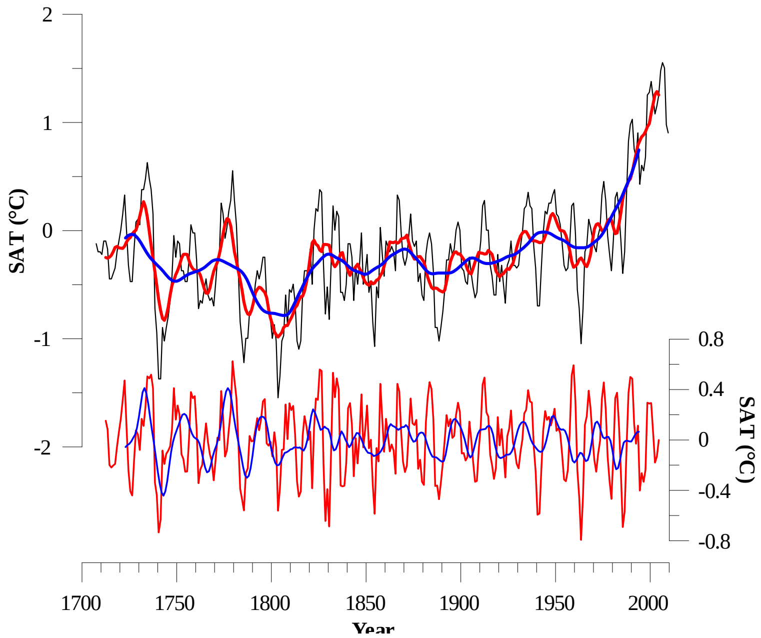


Fig. III.4. Example of processing the SAT time series in case of DeBilt station (1706-2011)

Besides decadal variations, one can notice a variation with a period of 30-40 years, with an amplitude as high as 0.3-0.4°C. The 11-year variation has amplitudes of 2-3°C, while the 22-year one is characterised by amplitudes of 0.6-0.8°C.

The reanalysis data were processed the same way as observation ones to obtain the 11- and 22-year signals for the continental area of the study. In Fig. III.5 an overview of the two variations is presented for the years 1965 and 1995.

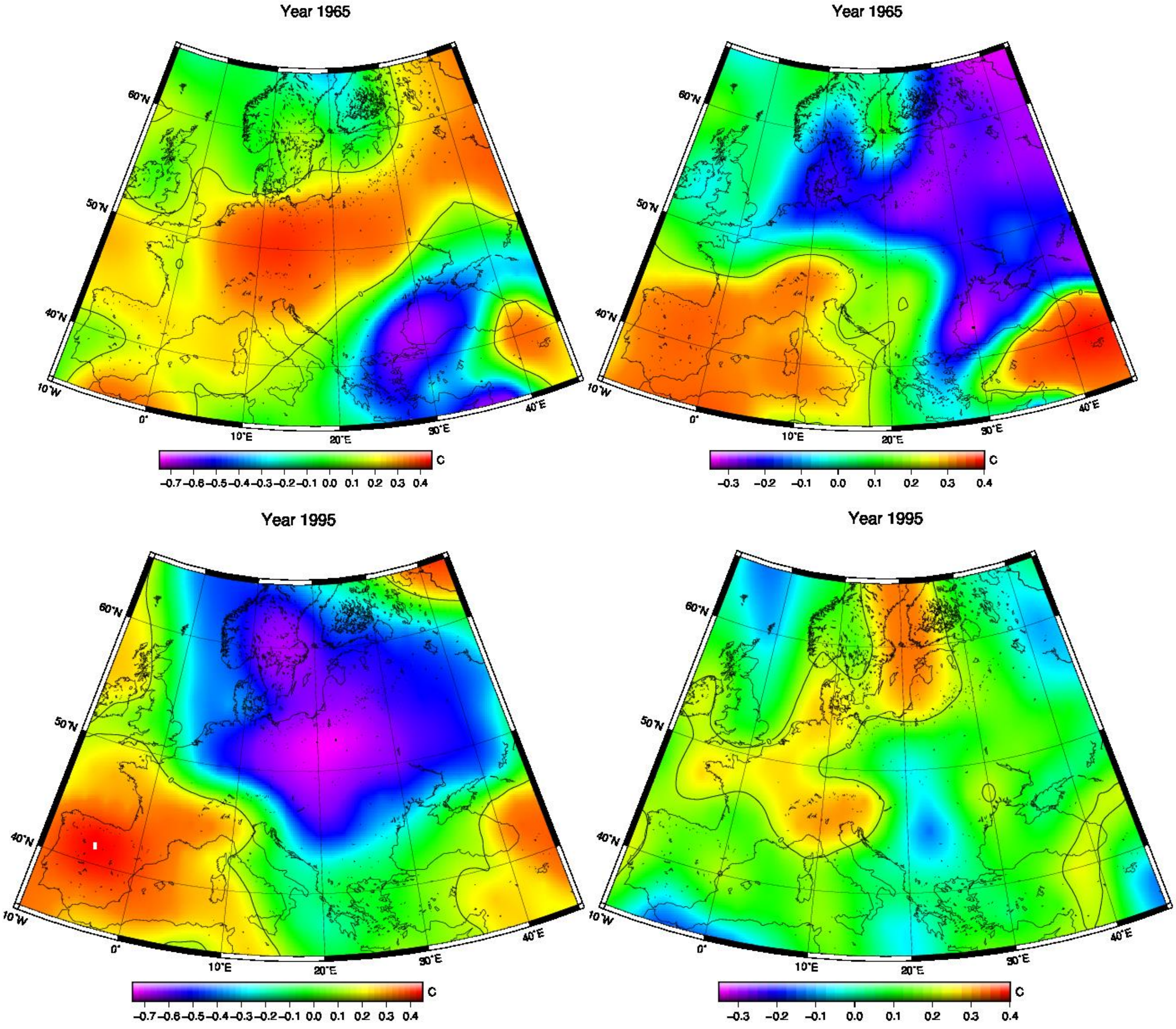
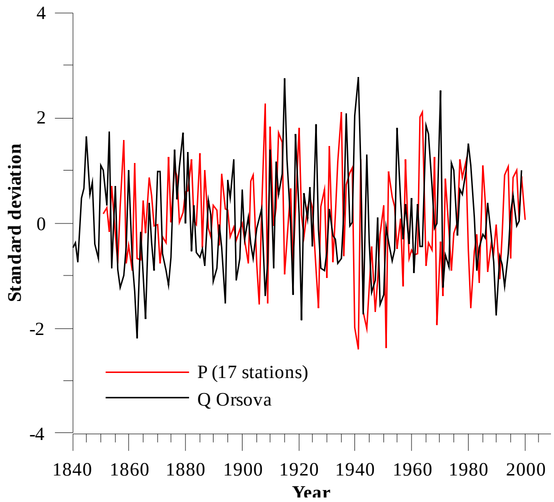


Fig. III.5. The geographical diswtribution of amplitudes of the 11-year (left) and 22-year (right) variations, from NCEP/NCAR data, at 1965 and 1995

It is to be remarked that the signal of the 11-year solar cycle in data (left) has different geographical distributions in the two year of the 11-year variation minimum, 1965 and 1995. In the first case Central and North-Eastern Europe is dominated by a minimum relative to the

South-Eastern area, and in the second case to contrastant areas are visible, a minimum in the Eastern and North-Eastern Europe and a maximum in the South-Eastern Europe. The signal of the 22-year cycle (right) also shows temporal variations of its geographical distribution. The study will be continued in the next stage of the project.

In the present contract we also analysed the link between the precipitation at meteorological stations in the Danube basin and the Danube discharge at for gauge stations on the Romanian territory, namely Orşova, Ceatal, Sulina and Sf. Gheorghe. In Fig. III.6 we compare the Danube discharge at Orşova (the station at the entry of Danube in Romania) with precipitation in the upper and middle Danube basins, based on data from 17 meteorological stations. The correlation is very good, of .69 at the 95% confidence level.



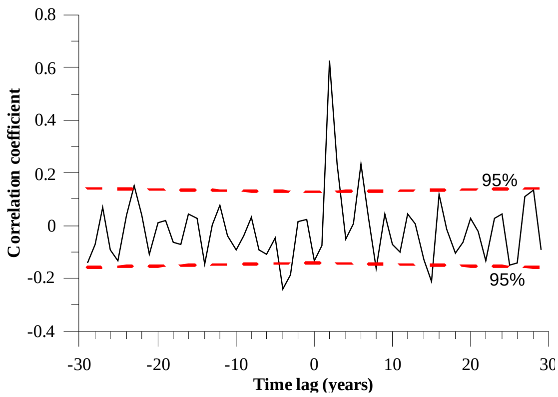


Fig. III.6. Evolution of precipitation in the upper and middle Danube basins and the Danube discharge at Orşova (left) and the correlation coefficient (right)

The analysis in terms of running averages with 11- and 22-year windows shows that discharge data at Orsova have significant variations at decadal, interdecadal and centennial time scales, as it can be seen in Fig. III.7.

The amplitudes indicate a significant effect of solar activity cycles on the climate in Central and Eastern Europe, in particular on the precipitation in the area.

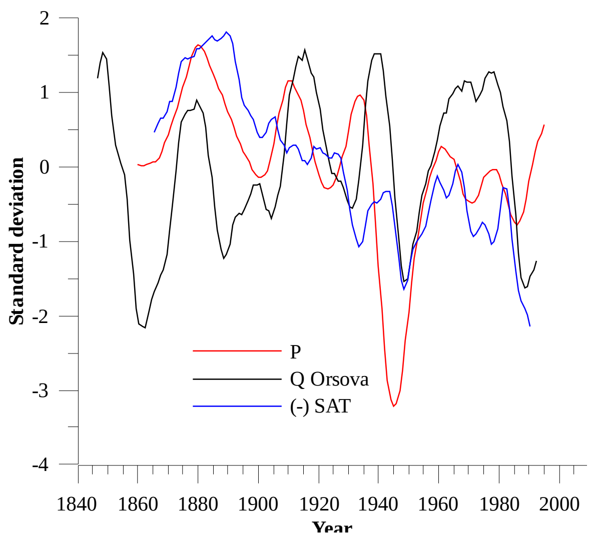


Fig. III.7. Trends of precipitation (red) and temperature (blue) in the upper and middle Danube basin as compared to discharge at Orsova (black)

III.2. Correlation analysis for climatic and solar/geomagnetic parameters

As we have already mentioned, the solar influence on climate cannot be directly measured, but, however, correlations between solar activity and climatic parameters have been found.

The long-term correlation analysis was carried out using indices that describe the solar/geomagnetic activity (sunspot number/aa geomagnetic index) and surface air temperature, parameters we have in the project data bank. In this project, strong, coherent solar/geomagnetic signals have been rendered evident in climatic parameters at time scales of the Schwabe (11 years) and Hale (22 years) solar cycles, at regional and continental scales. In Fig. III.8 we show the two signatures in case of observed and reanalysis temperatures, as well as the same signals in solar and geomagnetic activities. The amplitudes (maximum-minimum) of these signals are of 2-3°C, in case of the 11-year signal, and 0.6-0.8°C in case of the 22-year signal.

The statistical correlation between the solar and the temperature signals for the two temporal scales is presented in Fig. III.9. A good correlation is seen with solar activity in case of temperature at local scale (Romania, r=0.4, statistical significance over 95%) when compared to the continental scale (Europe, 0.2-0.3). The time lag is around 0 in case of the 11-year signal, but ~10 years in case of the 22-year one.

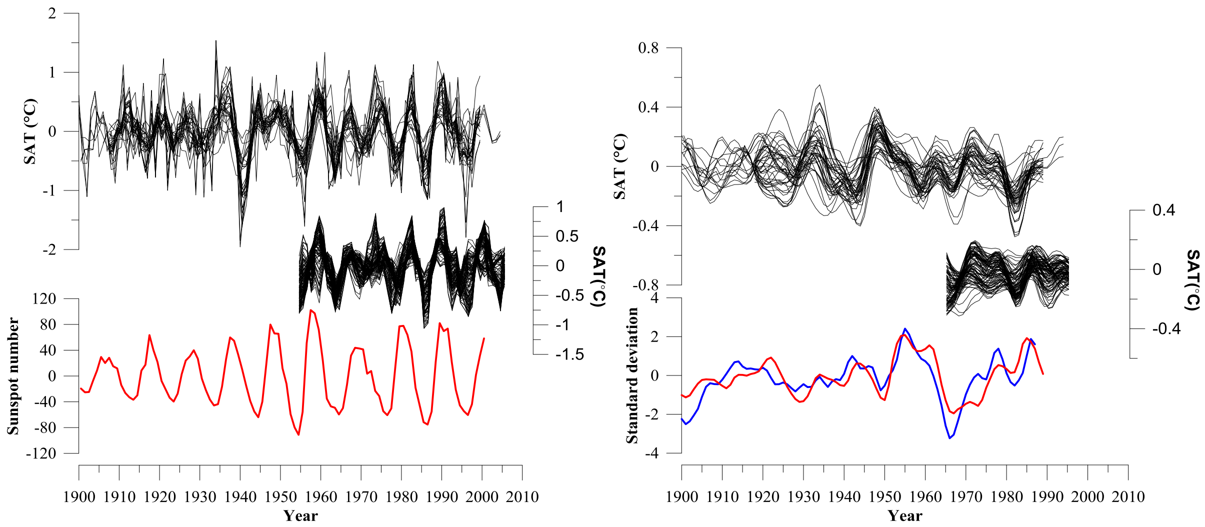


Fig. III.8. The 11-year (left) and the 22-year signal (right) in European observed data (upper plots), European reanalysed data (middle plots) as compared to the solar (red) and geomagnetic (blue) signals (lower plots)

We also investigated efects of the Atlantic Ocean variability on the air temperature at continental scale, using the climatic indices NAO (North Atlantic Oscillation) and AMO (Atlantic Multi-decadal Oscillation). An increased correlation (r=0.5, 95% confidence level), in phase, is seen between the air temperature and NAO, one of the most important modes of the climatic variability in Europe, forboth time scales. AMO, the mode of natural variability of climate at long, 60-80 years, timescales is present in the air temperature at a smaller intensity than NAO (r=0,2, statistical significance over 95%), with a lag of 6-8 years. The results are illustrated in Fig. III.9.

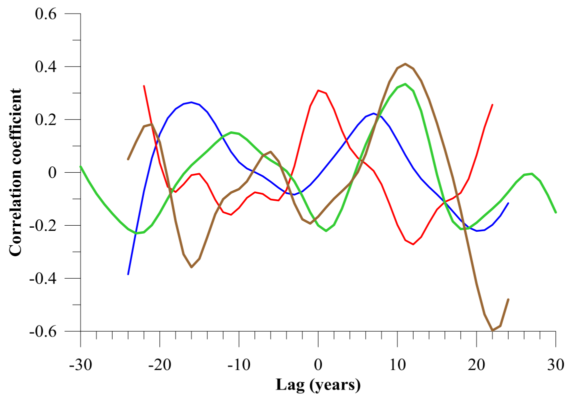


Fig. III.9. Correlation coefficients for sunspot numbers, NAO and AMO indices, and air temperature for Europe and Romania, in case of 11-year (left) and 22-year (right) signals

Chapter IV. Dissemination of results. The web page of the project

In the time interval covering the project to date (2011-2013), research stages have been performed annually by the project director, Venera Dobrica, and by one of research team members, Crisan Demetrescu, at the Environmental Sciences Department of the St. Mary University, Halifax, Canada. Also, a PhD student had a research stage at Bonn University, Germany, for time series analysis and methods to derive the confidence level of the correlation of two time series.

During the project, the team members actively participated to national and international workshops, participations that can be viewed on the web page of the project and at the item RST-Indicatori.

The paper: Suțeanu, C., Mandea, M., Surface air temperature in the Canadian Arctic: scaling and pattern change, Meteorol. Atmosph. Phys., 2012, doi : 10.1007/s00703-01200206-8 was published.

The web page of the project, containing information on project description, project objectives, scientific plan, scientific staff, and results, can be consulted at the address: http://www.geodin.ro/PN_II_2011/engl/index.html. he web page is periodicaly completed.

Director proiect,

Dr. Venera Dobrică