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# SYNTHETIC SCIENTIFIC REPORT

## Contract no. 21/5.10.2011

## Program TE

Project:

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

October 2011- October 2014

Project Director,

Dr. Venera Dobrică

**October, 2014**

## 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, 2013, and 2014) 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”, “Analysis of solar/geomagnetic signatures in reanalyzed data from NCEP/NCAR and ERA40 databases at various tropospheric levels”**. The report is structured in five 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), the Wavelet Haar Analysis, 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 and ERA40 databases.

*Chapter IV*, entitled ***”*** **The analysis of the solar/geomagnetic signal in data from the NCEP/NCAR and ERA40 reanalysis databases for various tropospheric and stratospheric levels*”***, presents the results of the project regarding variation trends and variability in reanalysis data of temperature at four tropospheric and stratospheric levels (surface, 200 mb, 100 mb, and 10 mb), related to the solar activity and the geomagnetic one, at temporal scales of 11 and 22 years.

The report ends with *Chapter V*, entitled ***”Conclusions. Dissemination of project results”***, a chapter destined to the main results obtained during the project, as well as to the dissemination of these results both through presentations at national and international scientific sessions and through scientific papers published in indexed journals (Thomson web of science or other international databases).

# 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.

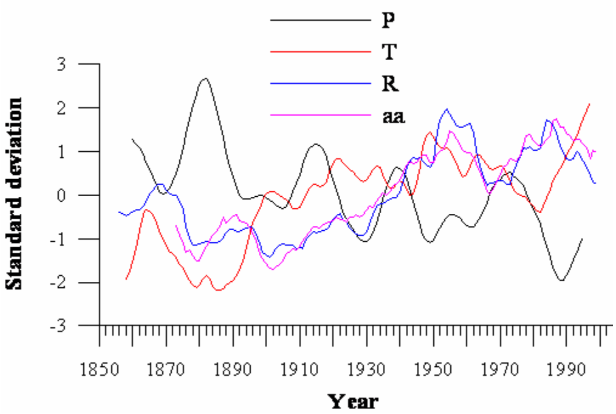

Fig. I.1. The interdecadal trend in precipitation (P), temperature (T), sunspot number (R), geomagnetic activity index (aa)

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).

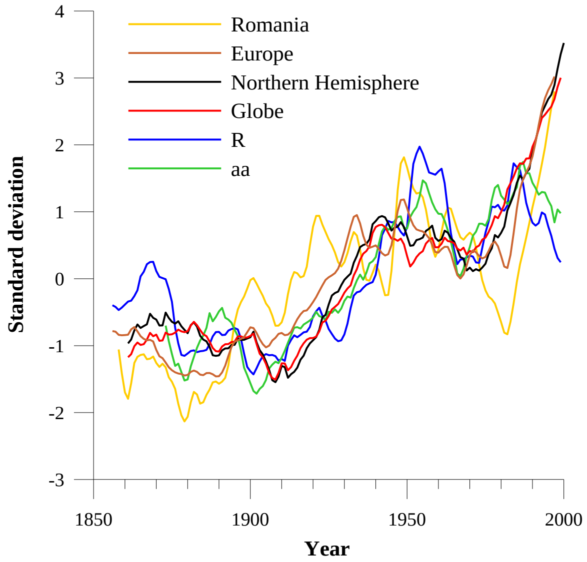

Fig. I.2. Comparison in 11-year averages terms between temperatures and the solar and geomagnetic activities

### 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.

Also, diurnal averages of surface air temperature, in the time interval 1895-2008 from 10 stations in Atlantic Canada have been used in our study.

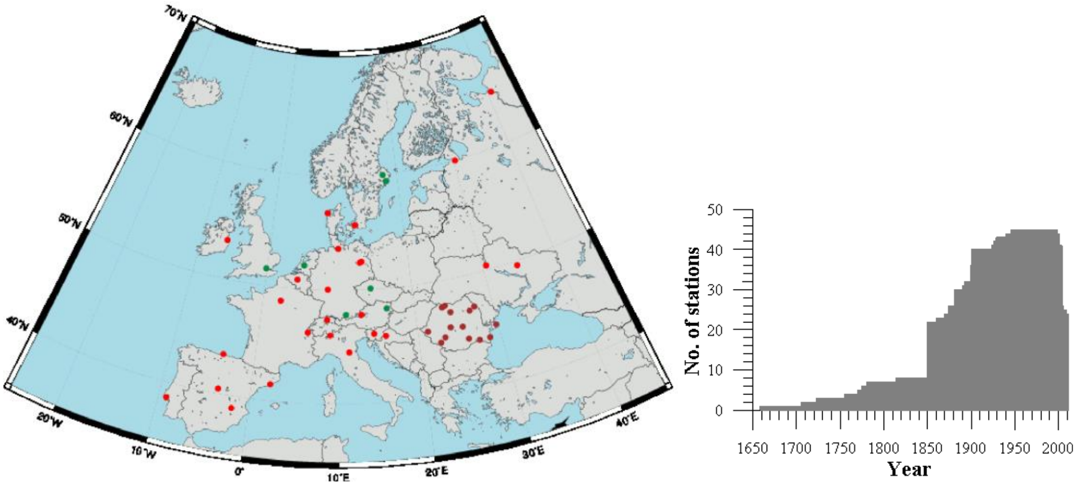

Fig. I.3 – Left: location of weather stations used in the project (brown symbols – 14 stations in Romania; red symbols – 24 European stations; green symbols – 7 European stations with long records). Right: the temporal coverage

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 $\sigma^2$ 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:

- 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 $1 \leq i \leq N$ 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.

*The Haar wavelet method*, similar to the detrended fluctuation analysis, analyzes the natural variability in air temperature series using the wavelet approach (Lovejoy et al. 2012). The analysis proceeds according to the same methodology as DFA, except the fluctuation dimmension can be chosen among „mother" waveforms, the Haar waveform allowing an easyest implementing and interpreting.

### II.2. Determining variability patterns in the surface air temperature and precipitation

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

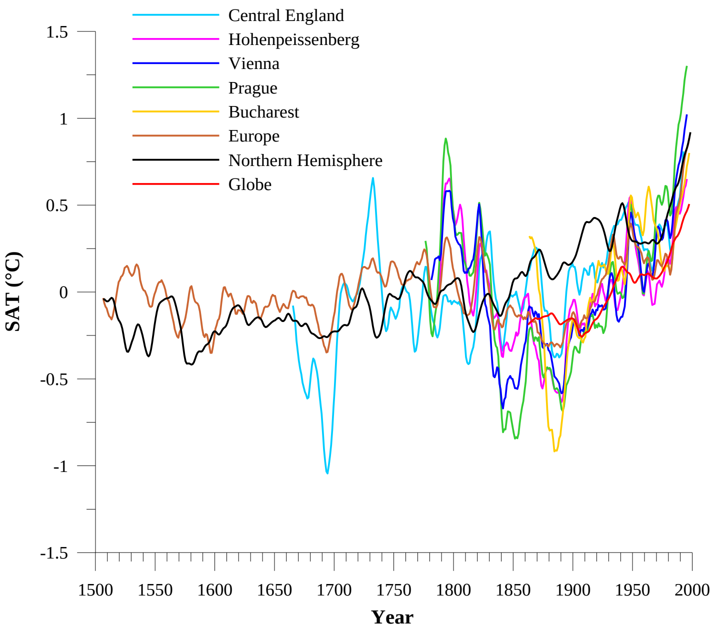

Fig. II.1. Multi-decadal anomalies in the evolution of surface air temperature relative to the mean for 1961-1990, in case of several European stations and of the entire northern hemisphere

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.

### 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.

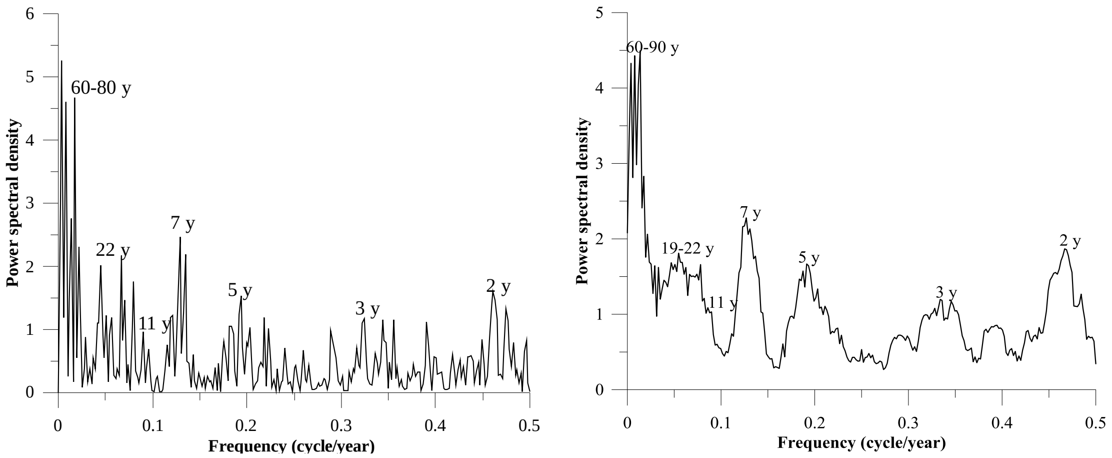

Fig. II.2. The power spectrum for air temperature at DeBilt weather station, by FFT (left) and MTM (right)

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

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.

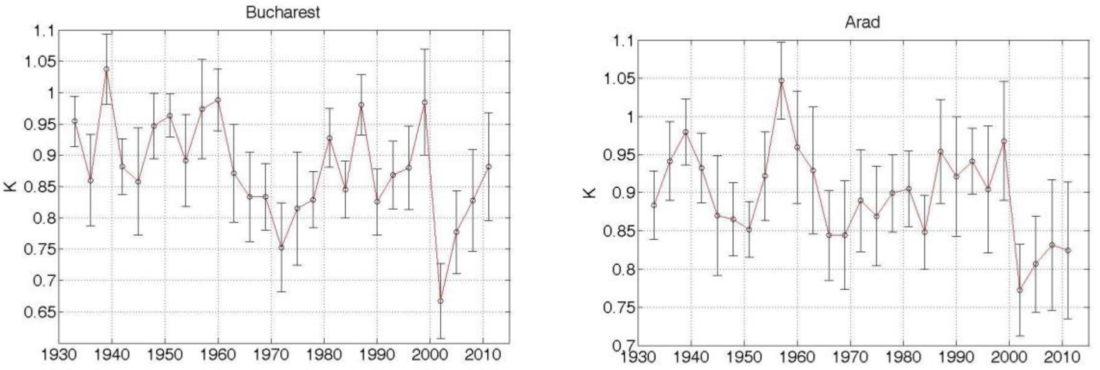

Fig.II.3. The scaling exponent for Bucuresti (left) and Arad (right) for the mean daily temperatures (right)

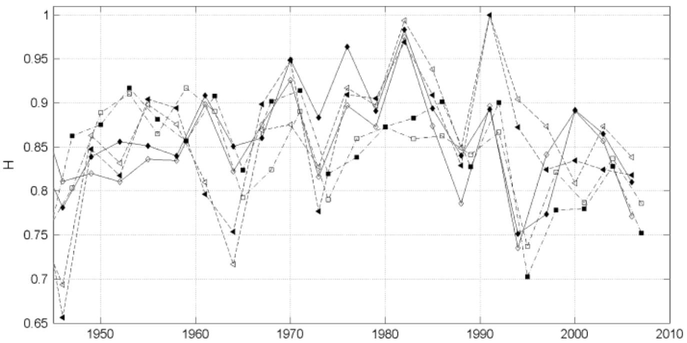

Fig. II.4. The scaling exponent for three weather stations in the Arctic Canada, for the daily minimum (filled symbols) and daily maximum (empty symbols) temperature

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.

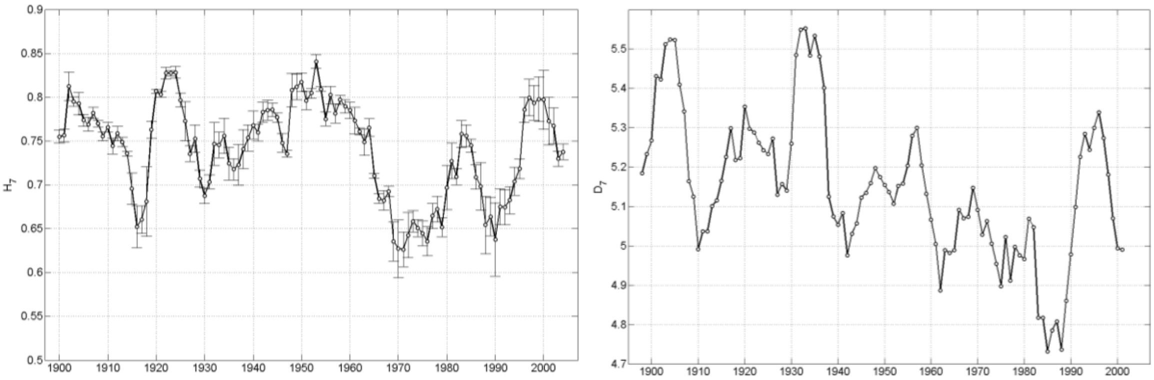

Fig. II.5. The Hurst exponent by Haar wavelet analysis (H) for minimum daily SAT at Frederikton (left) and the Euclidian distance (D) for an average year at Miramichi (right)

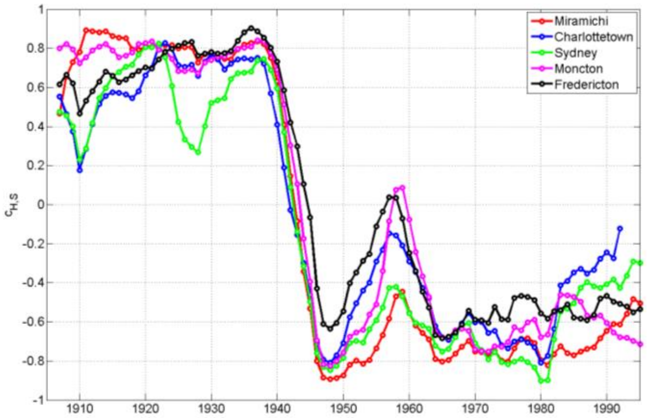

Fig. II.6. The multidecadal variation of the correlation between H and S

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.

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# Chapter III. Analysis of solar/geomagnetic signals in data from meteorological stations and in reanalysed data from the NCEP/NCAR and ERA40 databases

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.

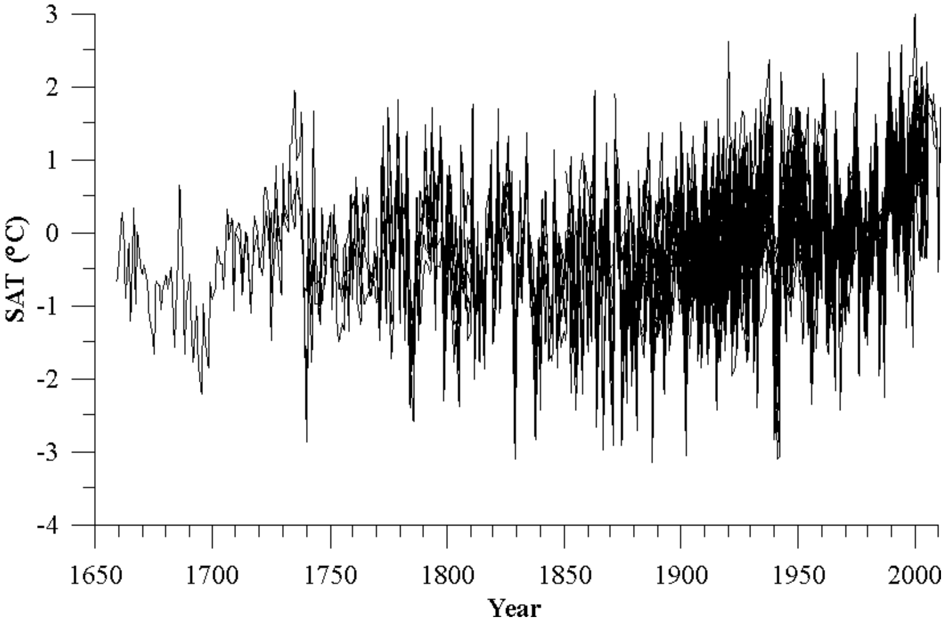


Fig. III.1. Temperature anomaly relative to the average for 1961 – 1990 for the 45 weather stations used in the project

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 and ERA40 databases, corresponding to three temperate climate continental areas in the northern hemisphere have been selected as well. The three areas are: Europe, 92 nodes between 10°W-45°E and 45-52.5°N, North America, 52 nodes between 90-120°W, 45-52.5°N, and Asia, 52 nodes between 90-120°E, 45-52.5°N. The temperature evolution in the time interval 1948 – 2012, for the midlatitude band 45-52.5°N is shown in Fig. III.2.

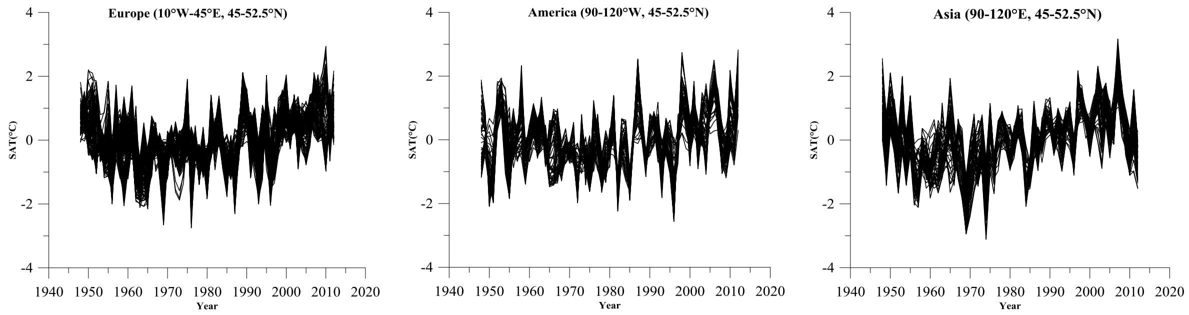


Fig. III.2. Temperature anomaly relative to the average for the time interval 1948 – 2012 in the latitude band 45-52.5°N, from NCEP/NCAR data

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.

An example of data treatment, in case of one of the longest record available – DeBilt station (1706-2011), is given in Fig. III.3. 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).

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.

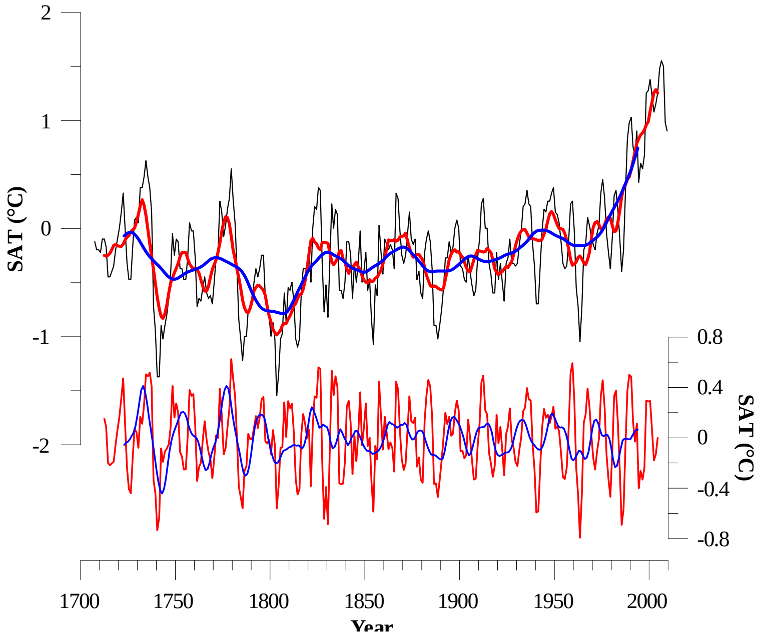


Fig. III.3. Example of processing the SAT time series in case of DeBilt station (1706-2011)

### III.2. Comparison between observed temperatures and NCEP/NCAR and ERA40 data

The reanalysis data are a result of simulation of observed data by means of models of atmospheric circulation and of its evolution. As it was presented in Chapter II, the result, given by the two databases mentioned, allows obtaining time series for a network of uniformly distributed nodes, at several altitude levels, and maps of the geographical distribution of parameters of interest. It is expected that reanalysis data do not reproduce exactly the measured ones, but for the present study is important that the variability of parameters be as less as possible affected by modelling. In Fig. III.4, we show as examples in case of a few stations the comparison between measured values and modelled ones for the closest node of the network in the two databases. General differences that may reach 2-3°C between the two kind of data are seen, but the variation trend and the variability are the same.

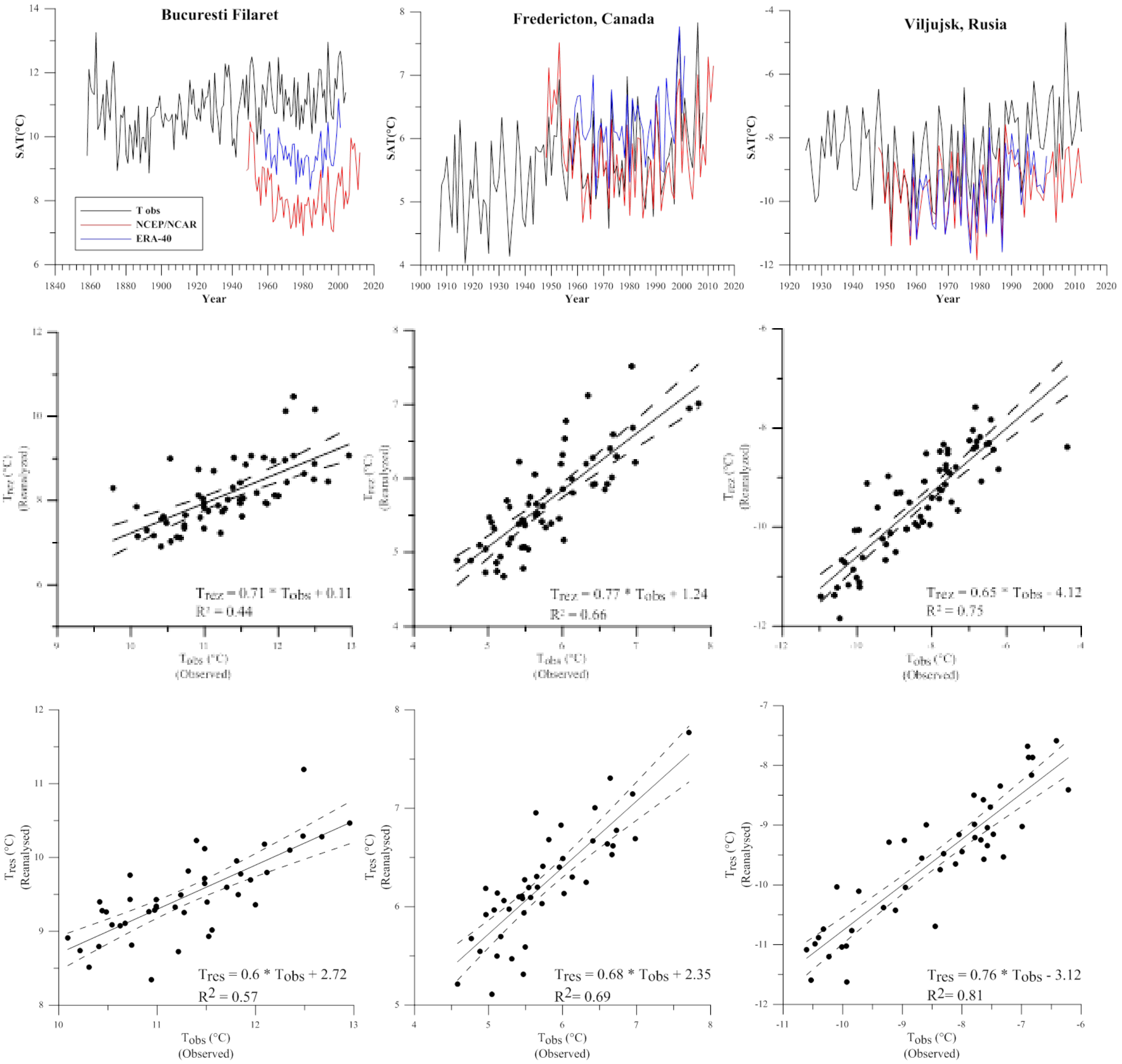


Fig. III.4. Upper panels: comparison between observed temperatures (black) and reanalysed data from NCEP/NCAR (red) and ERA40 (blue) databases. Middle: correlation plots between NCEP/NCAR reanalysis data and observed temperatures. Lower panels: correlation plots between ERA40 reanalysis data and observed temperatures

### III.3. The Danube discharge as an integrator of precipitation in its upper and middle basin

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, 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.

We compared both the Danube discharge at Orsova (the hydrological station at the entry in Romania) with the average precipitation in the upper/central basin, and the average precipitation in the lower basin with the difference between the discharge at downflow station Ceatal and the upflow Orsova. In the first case 17 weather stations in Central Europe located in the Danube upper and middle basins were used, while in the second case data from 10 stations in the basins of tributary rivers down stream of Orsova were considered. In the present report we show as an illustration results for the first case (Fig. III.5). A very good correlation can be seen, with a correlation coefficient of 0.69 at the 95% confidence level.

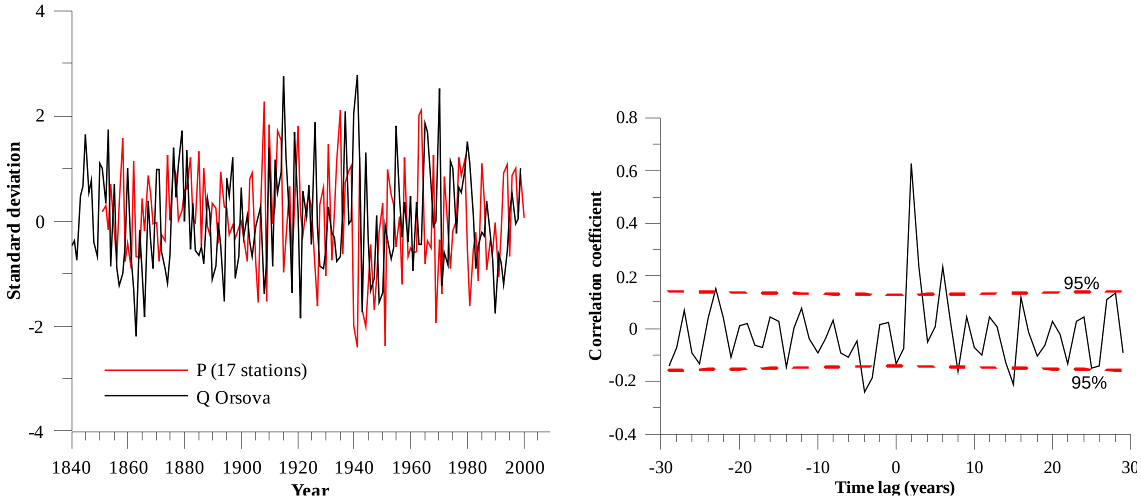


Fig. III.5. The evolution of precipitation in the upper and middle Danube basins and river discharge at Orsova (left); corrlelation coefficient (right)

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.6. 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.

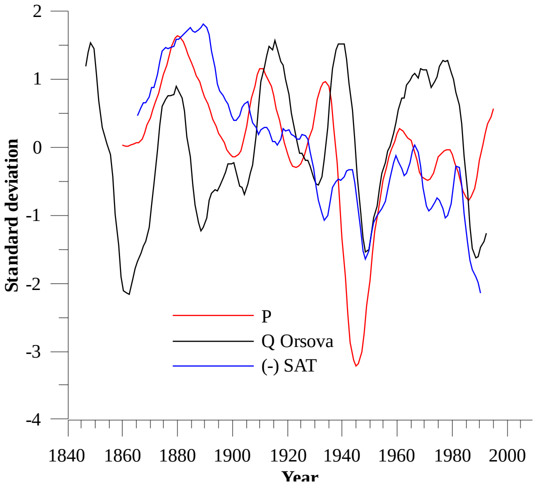


Fig. III.6. Trends of precipitation (red) and temperature (blue) in the upper and middle Danube basin as compared to discharge at Orsova

### III.4. Trends and solar/geomagnetic signals in reanalysis data

The reanalysis data were processed the same way as observation ones to obtain the 11- and 22-year signals for the three continental areas of the study. They are shown in Figs. III.7 and, respectively, III.8., for NCEP/NCAR data. The signals for various nodes were superimposed to illustrate the coherence of the signals.

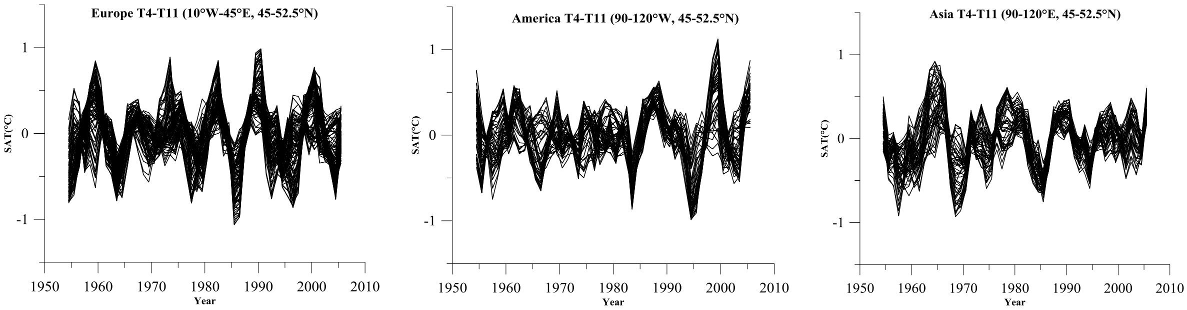


Fig. III.7. The 11-year variation in NCEP/NCAR reanalysis data for the three continental areas

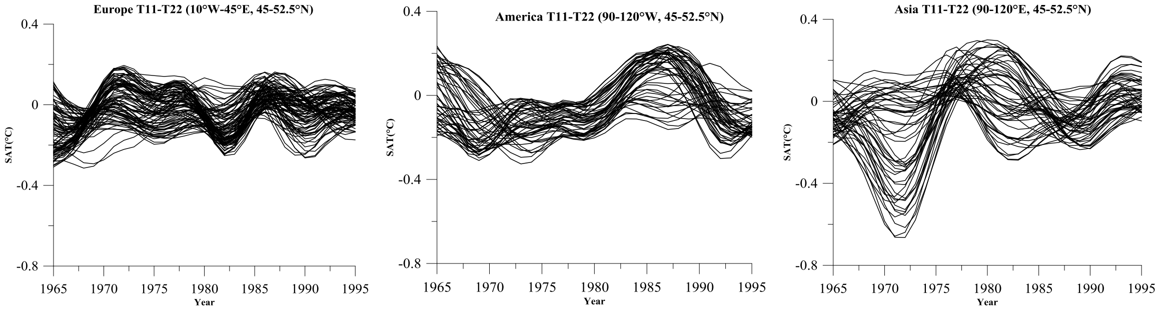


Fig. III.8. The 22-year signal in NCEP/NCAR reanalysis data

### III.5. Analysis of correlation between 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.9 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.

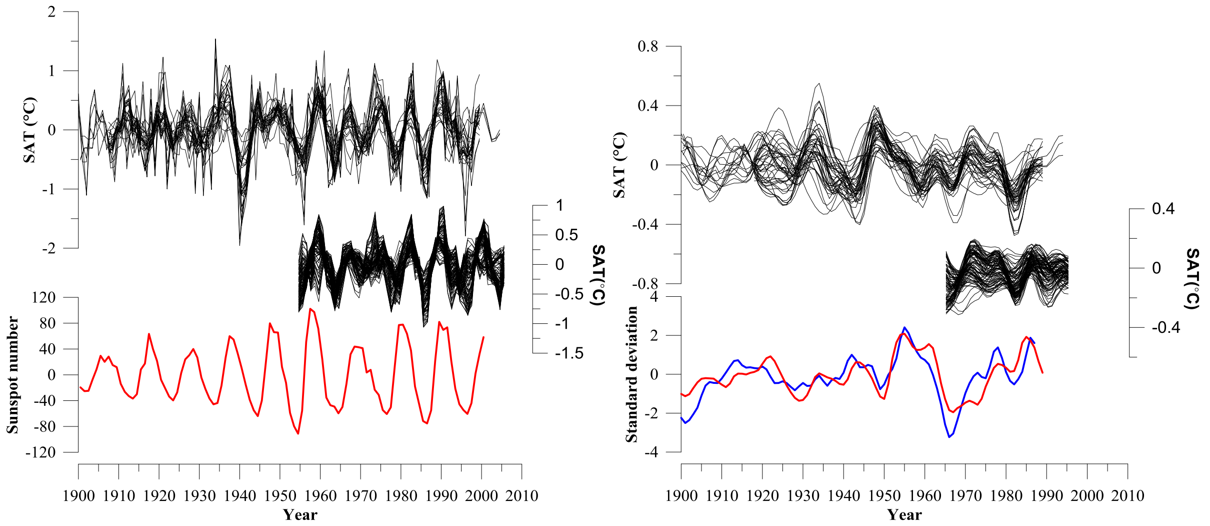


Fig. III.9. The 11-year (left) and the 22-year signal (right) in European observed data (upper plots), European reanalysed data (middle plots) as compared to the solar (red) and geomagnetic (blue) signals (lower plots)

The statistical correlation between the solar and the temperature signals for the two temporal scales is presented in Fig. III.10. 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.

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.

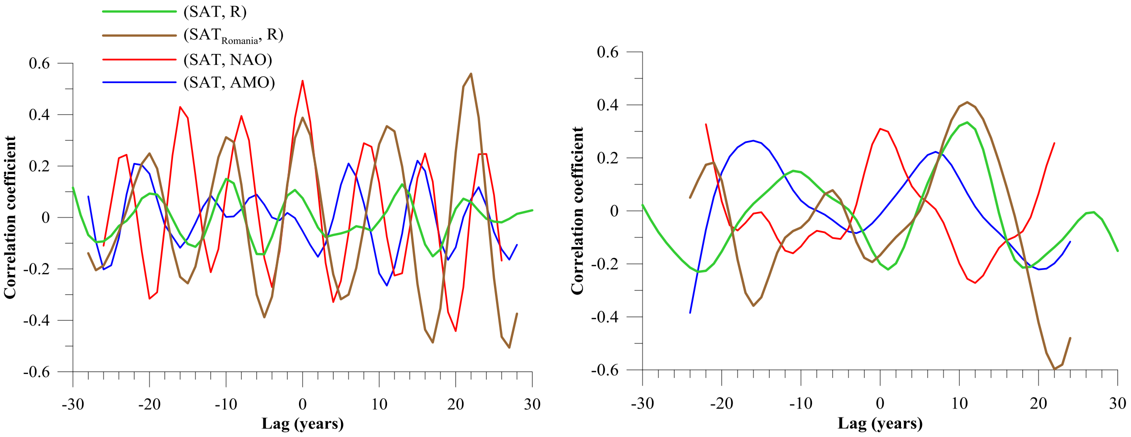
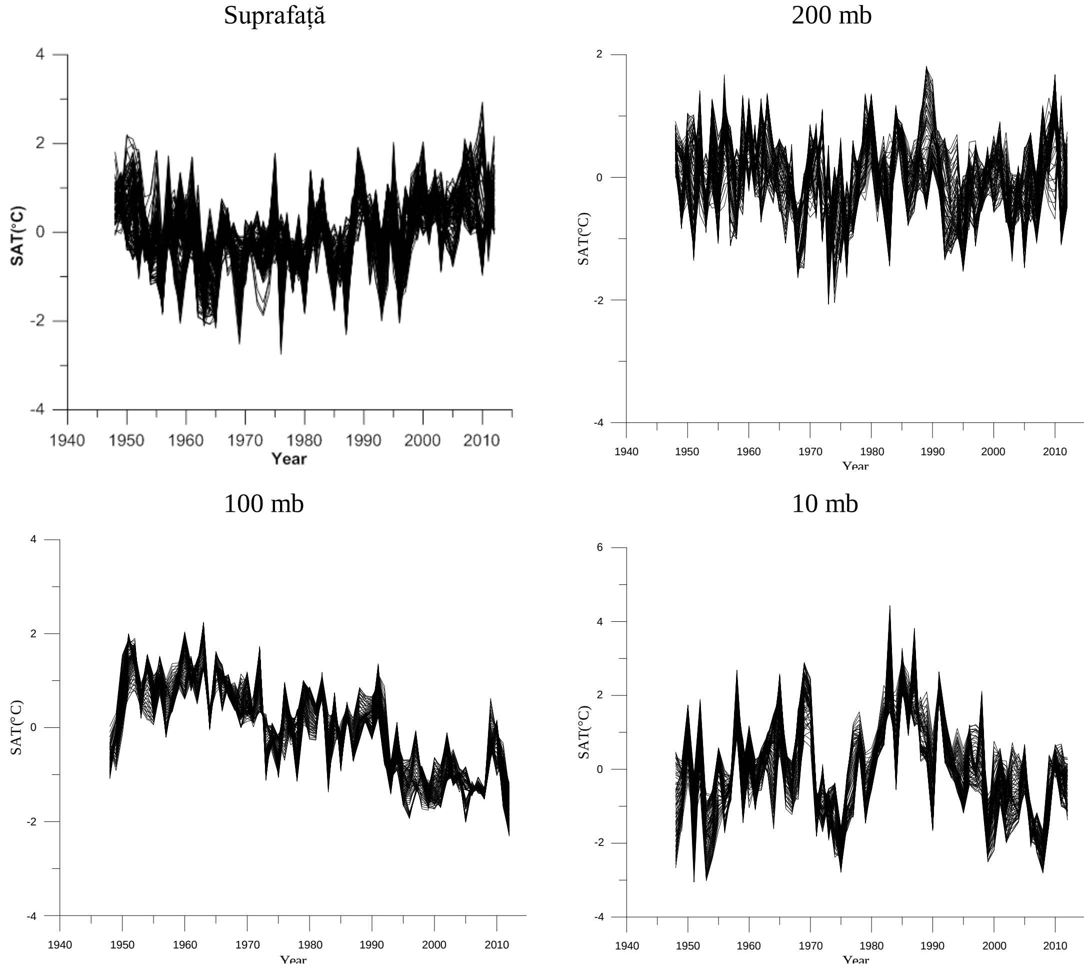


Fig. III.10. Correlation coefficients for sunspot numbers, NAO and AMO indices, and air temperature for Europe and Romania, in case of 11-year (left) and 22-year (right) signals

# Chapter IV. The analysis of the solar/geomagnetic signal in data from the NCEP/NCAR and ERA40 reanalysis databases for various tropospheric and stratospheric levels

In the last stage of the contract, the problem of the vertical distribution of temperatures and of solar and geomagnetic signals in climatic data, analysis made possible based on data provided by the two databases, NCEP/NCAR and ERA40, has been studied.

We show, as an example, in Fig. IV.1, temperature time series extracted from the NCEP/NCAR database for Europe, at four altitude levels: surface, 200 mb, 100 mb, 10 mb. For the analyzed upper levels too, one can remark the coherence of the temporal evolution of temperatures, noticed in previous stages of this research for the surface.



Suprafață

200 mb

100 mb

10 mb

Fig. IV.1. Superposed time series for the 92 nodes of the NCEP/NCAR network in the European temperate climate area, at four altitude levels

The coherence of the temporal evolution of temperatures in the network nodes allows illustrating the data processing, described in the previous sections, by means corresponding to each of the continental areas tackled in this contract, as shown in Fig. IV.2. Plots in the upper part of each panel refer to the mean time series and tendencies at two time scales, while plots in the lower parts refer to the mean 11-year signal (red) and to the 22-year signal (blue).

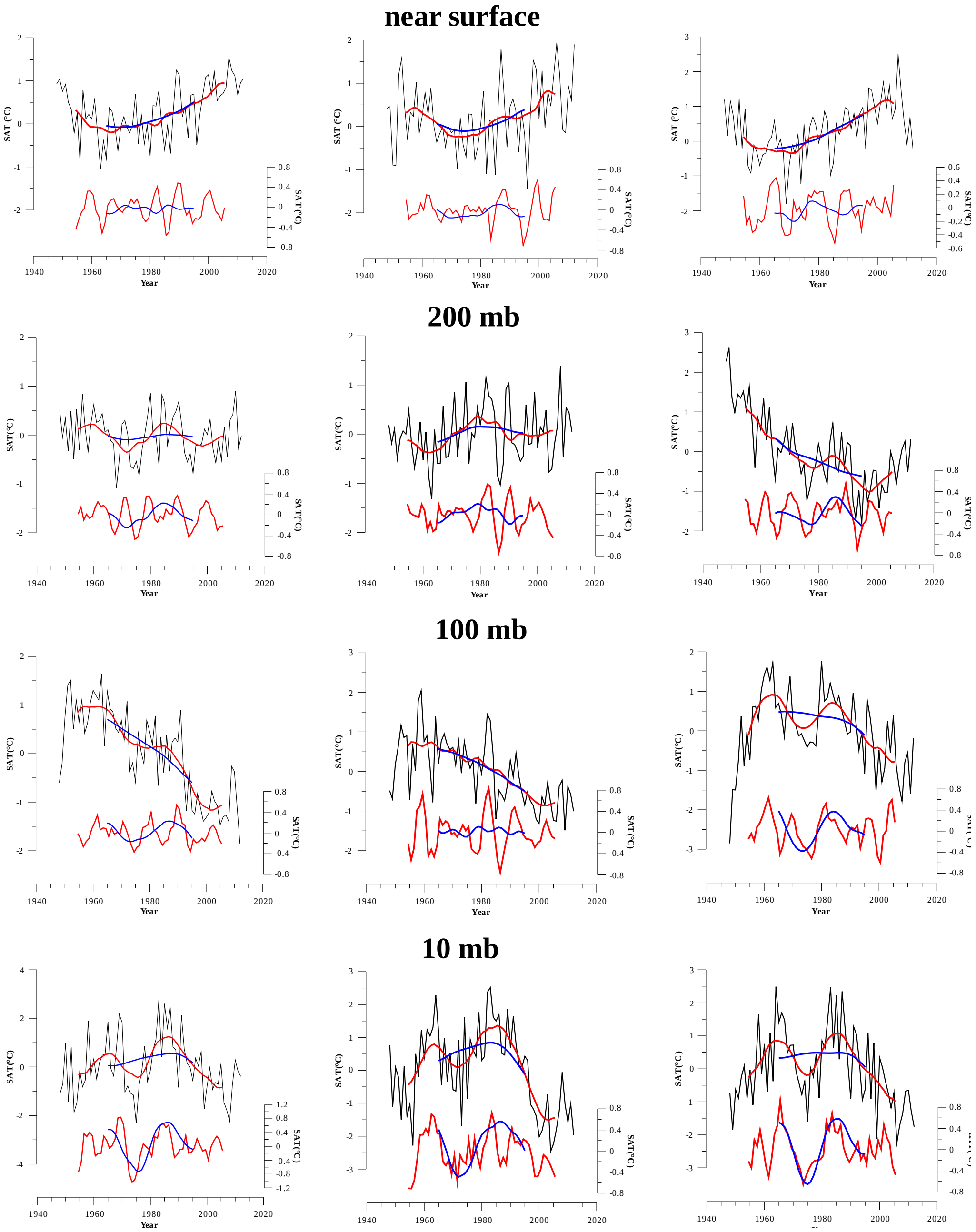


Fig. IV.2. Time series with average data for three temperate climate continental areas, Europe (left column), North America (middle column), and Asia (right column). With red and blue lines the interdecadal and centennial trends, in the upper plots of each panel, and the 11- and 22-year signals in the lower plots. The four rows correspond to the tropospheric and stratospheric levels of the study as marked

The 11- and 22-year signals in case of European nodes are superimposed in Fig. IV.3. For comparison we also plotted the signals in the observed data (the longer time series) and in the solar activity (red) and geomagnetic activity (blue).

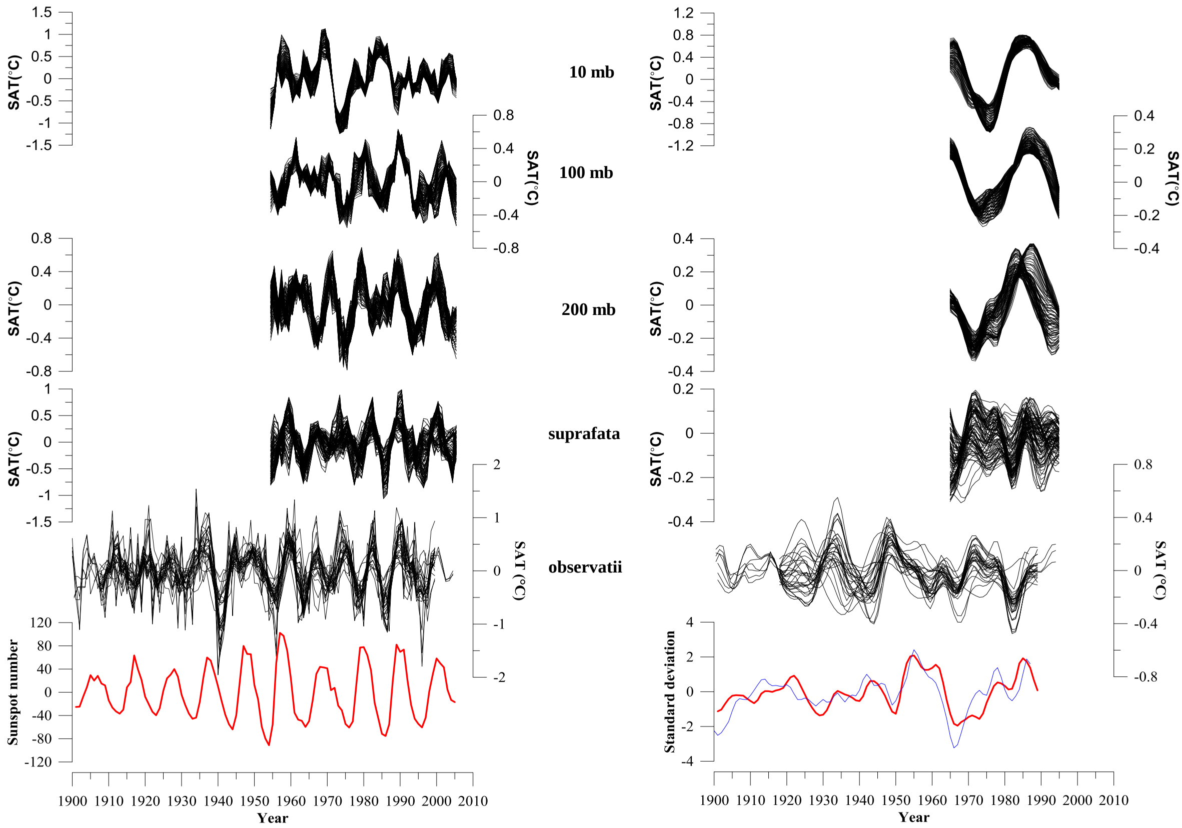


Fig. IV.3. Solar/geomagnetic signals in temperature data at time scales of 11 and 22 years for the European nodes at the four altitude levels as marked

Analyzing the results on variation trends and solar/geomagnetic signals, presented in Figs IV.1-3, we arrived at the following:

While the surface temperature shows, as we mentioned in Chapter III, a minimum in the 1970’s followed by a general increse since, at upper levels in the troposphere and stratosphere the trend changes: at the troposphere/stratosphere limit (the 200 mb level, ~12 km altitude) temperatures oscillate (amplitude 1-2°C) around a relative constant average value, at the 100 mb level (~16 km), in the stratosphere, the trend shows a decrease by 0.5°C/decade, and at the 10 mb level (~32 km) the trend shows strong oscillations, with well marked minima (1950, 1975, 2008) and maxima (1968, 1985). When the three temperate climate continental areas are compared (Fig. IV.2), the trends are similar. However, an exception is noted for the 200 mb level, where different average trends characterize the temporal evolution, constant for Europe and North America, but strongly decreasing in Asia similar to the decreasing trend for all three areas at the 100 mb level.

The 11- and 22-year signals in the temperatures at the four levels are robust, similar for all network nodes, as it can be seen in Fig. IV.3, that shows the superimposed results for the European temperate area. In the same figure the signals from NCEP/NCAR temperatures are compared with the signals in observed temperatures (the longer time series) and solar (red line) and geomagnetic activities (blue line). The two signals are present at all investigated altitudes. An increase of the amplitude signals with altitude can also be noticed. It is interesting that the 22-year signal becomes clearer and less dependent on the node location as the altitude level increases. For all three continental areas a comparison of the 11- and 22-year signals can be done, in terms of average values for the area, using Fig. IV.2. Differences between areas are noticed, strengthening previous conclusions regarding the regional, not global scale at which signatures of the solar/geomagnetic activity are seen in temperature. This important conclusion finds its illustration in Fig. IV.4, in which we give the geographical distribution of the 11- and 22-year signals at the four altitude levels of this study, for two moments: year 1979 – solar activity maximum (solar cycle 22), and year 1996 – solar activity minimum (cycles 23-24).

The result of the cross-correlation analysis of the 11-year signal in temperature and in the solar and geomagnetic activity is presented in Fig.IV.5. The left panel regards the correlation with R and the right one the correlation with aa. The correlation coefficients are significant at the 95% level. They are larger for Europe (0.62, respectively 0.61) than for North America (0.32 și 0.37) or Asia (0.29 și 0.25). As regards the phase difference we note: (a) it is larger by 1 year in case of T/aa than in case of T/R, which is to be expected taking into account that the geomagnetic activity is a consequence of solar activity and its action on climate is not as direct as the action of the solar activity on climate and (b) the phase difference is different for the three continental areas (0 and, respectively, 1 year for Europe, 2-3, respectively 4 years for North America, 2-3, respectively 3 years for Asia). Such lagged signals have been identified and discussed by Gray et al. (2013) in case of sea level pressure and sea surface temperatures. These authors retrieved an 11-year signal with a time lag of several years.

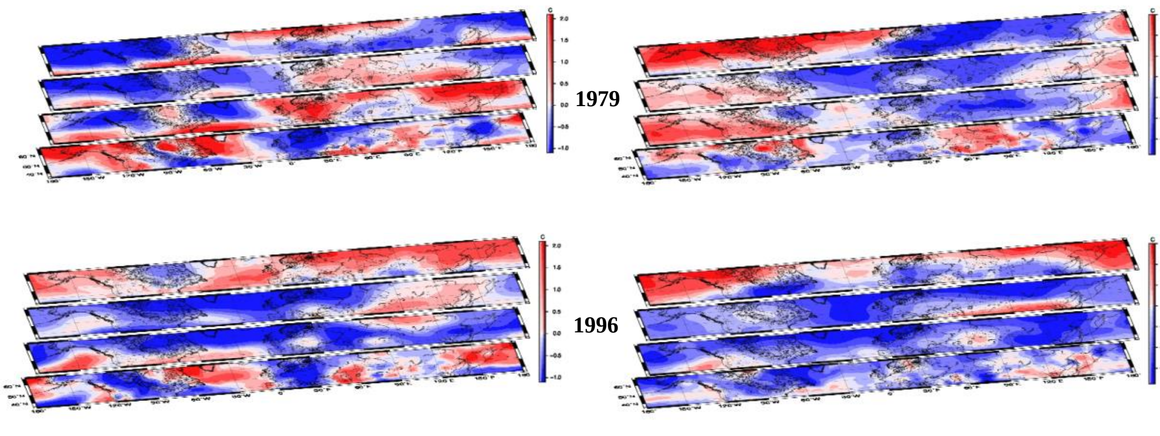


Fig. IV.4. The geographical distribution of 11-year signals (left) and 22-year signals (right) for the years 1979 and 1996 in NCEP?NCAR data

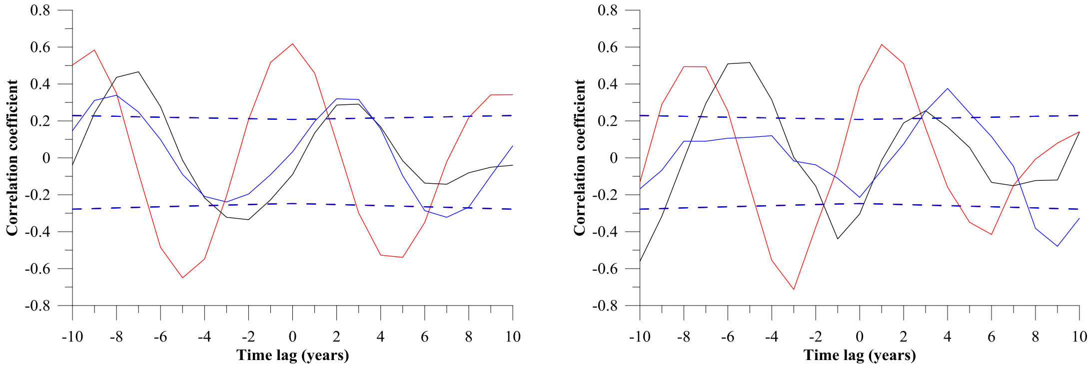


Fig. IV.5. Cross-correlation analysis for SAT/R (left) and SAT/aa (right) for the 11-year signal. Europe (red), North America (blue), Asia (black). Dashed lines mark the 95% significance level

Next, we show in Fig. IV.6, for the surface and for the 10 mb altitude, the geographical distribution of correlation coefficients between the 11- and 22-year signals in temperature and the solar activity in the left panels and the distribution of correlation coefficients between temperature time series and geomagnetic activity in the right panels.

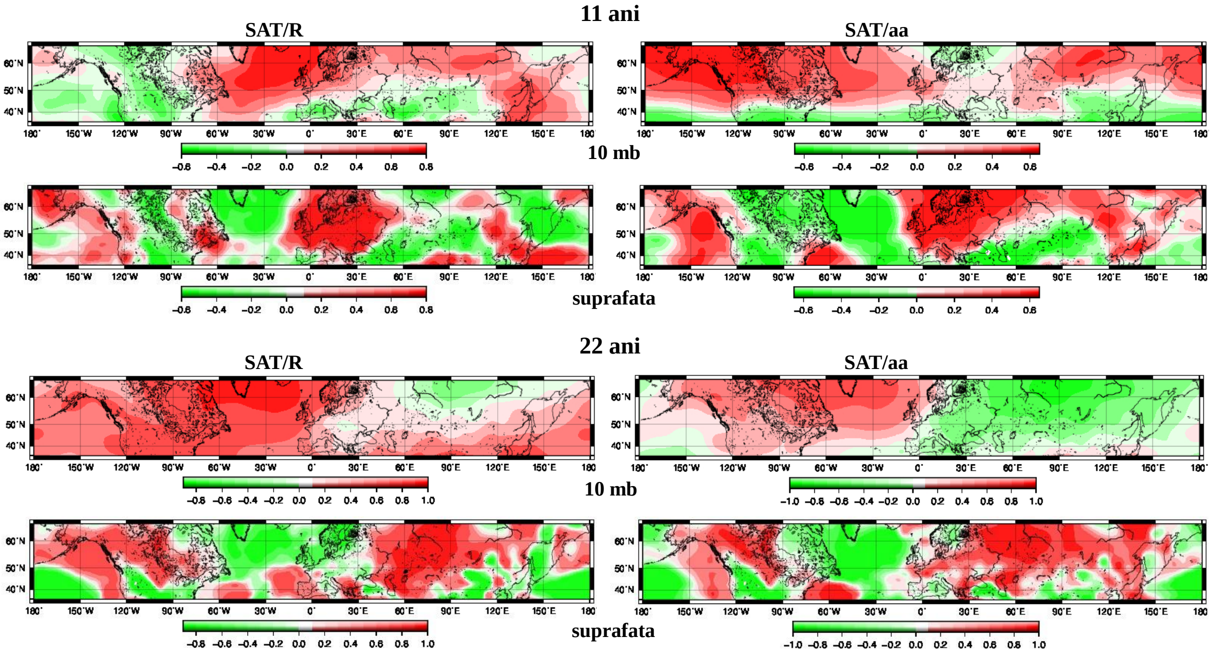


Fig. IV.6. Correlation maps between 11- and 22-year signals in temperature (SAT) and the corresponding signals for the solar (R) and the geomagnetic (aa) activity

Fig. IV.6 first reveals differences between the surface and stratospheric levels. These are to be expected, as the solar forcing acts differently in troposphere compared to the stratosphere. Other conclusions regarding the compared signals are:

(a) for the surface level:

- resemblance of the geographical distribution of correlations between 11- and 22-year signals in temperatures and in the solar and the geomagnetic activity;
- the correlation manifests at regional scale, as there are areas where the temperature signals are positively correlated with solar and geomagnetic signals (Europe, Atlantic Canada, western North America, northern Asia) and areas where the correlation is negative (North America, Atlantic Ocean, Central and Southern Asia), in case of the 11-year signal. In case of the 22-year signal, the surface characterized by positive correlation is larger;

(b) for the 10 mb level:

- in case of the 11-year signal there are differences regarding the correlation with the solar activity and with the geomagnetic activity (e.g. North America: negative correlation with the solar activity, positive with the geomagnetic activity). The correlation of the 22-year signal in temperature with the corresponding signals in solar and in the geomagnetic activity is more uniform, only two areas, with correlations of opposite signs being mapped (western and eastern hemispheres).

In Fig. IV.7 the geographical distribution for the year 1979 of the 11- and 22-year signals at the four levels (surface, 200 mb, 100 mb, 10 mb) retrieved from the ERA40 data is shown. A comparison with NCEP/NCAR data (see the upper part of Fig. IV.4) indicates a good resemblance. Only the 22-year variation at the 10 mb level shows a smaller amplitude in the ERA40 data: the minimum in the eastern hemisphere, in blue for NCEP/NCAR data is represented in white-light red in the ERA40 data.

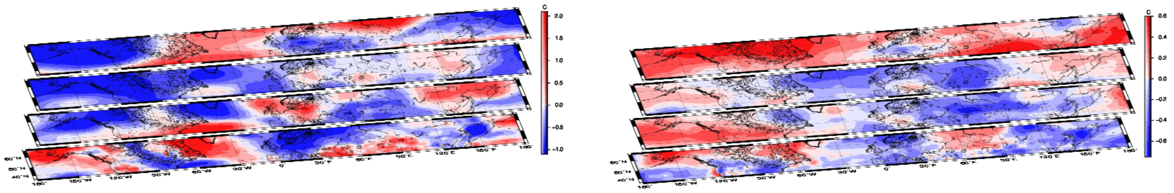


Fig. IV.7. Maps of the 11-year signal (left) and 22-year signal (right) for 1979 in ERA40 data

We underline the fact that there is not yet a direct physical explanation for the effects on climate, detected in the frame of the contract and presented in this report. Our conclusions, however, lead to the opinion that the dependence of the climate evolution on the variations of solar activity is a regional rather than a global effect (Lockwood, 2012). The 22-year signal was too short for a definite conclusion on its evolution be drawn.

## References

Gray, L.J., Scaife, A.A., Mitchell, D.M., Osprey, S., Ineson, S., Hardiman, S., Butchart, N., Knight, J., Sutton, R., Kodera, K. (2013), A lagged response to the 11 year solar cycle in observed winter Atlantic/European weather patterns. J. Geophys. Res.: Atmos., 118, 13405-13420, doi:10.1002/2013JD020062.

Lockwood, M. (2012), Solar Influence on Global and Regional Climates. Surv. Geophys., 33, 503–534, doi:10.1007/s10712-012-9181-3.

# Chapter V. Conclusions. Dissemination of results

## V.1. General conclusions

The interdisciplinary research proposed for the project entitled ”The solar and geomagnetic activity and their influences on the terrestrial environment. Case study - climate”, had as objective the identification of long-term signatures of natural external forcings, solar activity and geomagnetic activity, on the terrestrial climate. The study was carried out based on both spectral analysis and techniques to investigate the variability pattern of available long-term climate time series and on statistical long-term correlation analysis, at time scales of the 11-year (Schwabe) and 22-year (Hale) solar cycles, between air temperature at several levels in the troposphere and stratosphere from databases of observation and reanalyzed (NCEP/NCAR, ERA40) data and solar/geomagnetic activity.

An important part of the research concerned retrieving trends in the surface air temperature evolution using spectral analysis and techniques to investigate the variability pattern of climate, on available long-term time series of observation data. Among the derived conclusions, we shortly mention:

- in case of daily time series, patterns are characterized by scaling properties between 1-2 months and 5-8 years. The scaling coefficients are within 0.70±0.05 for most of the stations considered in the study, indicating the variability persistance;
- DFA and Haar analyses, applied to successive temporal windows show that scaling properties vary significantly in time, the variability of the air temperature pattern fluctuating at multidecadal time scales. Generally, the persistance changes occur at regional scale, depending only little on local factors;
- the absence of consensus in the scientific literature on the pattern variability could partly be explained by the fact that the evolution of the Earth’s surface air temperature, like many other natural patterns, cannot be completely characterized by any of the time series analysis methods alone. To characterize the pattern several methods should be used simultaneously. Moreover, neither of the methods used in the present study did demonstrate the existence of a simple trend in changing the variability. So, the frequently asked question related to the contemporary global change, regarding the increase of variability in the last decades, cannot get a simple answer. Having in view the nature of variability, we do not think that this situation will improve, even if new and more powerful analysis methods would retrieve other interesting aspects of the pattern change.

As regards the effects of natural forcing of the solar activity and geomagnetic activity on climate, study allowed by the existence of reanalysis data for a network of 2.5x2.5 degrees on latitude and longitude in NCEP/NCAR and ERA40 databases, the main conclusions are:

- the variability of observation time series was also found in the reanalysis data of the two considered models (NCEP/NCAR and ERA40 data bases), fact that allowed our study on the three continental areas with temparate climate of the northern hemisphere (Europe, North America, Asia), for four altitude levels (surface, 200 mb, 100 mb, 10 mb);
- the surface temperature shows a minimum in the 1970s, followed by a general increase since. At higher levels the trend changes: at the troposphere/stratosphere limit (the 200 mb level, about 12 km altitude) temperatures oscillate (amplitude of 1-2°C) around an approximately constant value in the analysed time interval, while at the 100 mb level (~16 km), in the stratosphere, temperatures show a decreasing trend (~0,5°C/decade). At the 10 mb level (~32 km) the trend is oscillating, with well defined minima at 1950, 1975, 2008 and maxima at 1968 and 1985. The evolution trends are similar for the three areas with temperate climate, with the exception of the 200 mb time series for Asia, that show decreasing temperatures similar to the trends at the 100 mb level for all three areas;
- the 11- and 22-year signals in temperatures at the four levels are robust ones, similar in all network nodes. The two signals are present at all investigated altitudes. Also, an increase of signals amplitude with the level altitude can be noticed, as well as the fact that the 22-year signal is clearer and less dependent on the grid node location as the altitude is higher;
- the comparison of the 11- and 22-year signals in temperature with the solar and geomagnetic activity shows differences between various areas, demonstrating that the effects of solar/geomagnetic activity is felt in temperatures at regional, not global scale;
- the cross-correlation analysis between the 11-year signal in temperature and corresponding ones in solar and geomagnetic activities produced significant correlation coefficients at the 95% level, larger for Europe (0.62/ 0.61) than for North America (0.32/0.37) and Asia (0.29/0.25);
- the phase difference between the compared time series is larger by 1 year in case of T/aa than in case of T/R, what is to be expected, having in view that the geomagnetic

activity is a result of the solar activity and its action on the climate is not as direct as that of the solar activity. The phase difference differs for the three continental areas (0 and, respectively, 1 year for Europe; 2-3, respectively 4 years for North America; 2-3, respectively 3 years for Asia), in line with similar published results obtained for other climatic parameters (sea level pressure, sea surface temperature);

- for higher altitude levels our analysis found differences from the surface, which indicate the different action of the solar forcing in troposphere and stratosphere;
- in case of the 11-year signal the correlation between the compared signals is observed at a regional level. There are areas with positive correlation between the signal in temperature and the solar and the geomagnetic activity (Europe, Atlantic Canada, western North America, northern Asia), and areas with negative correlation (North America, Atlantic Ocean, Central and southern Asia. In case of the 22-year signal, the surface characterized by positive correlation is increased;
- for the 10 mb level, in case of the 11-year signal there are differences between correlations with the solar activity and correlations with the geomagnetic activity (e.g. North America: negative correlation with solar activity, positive with geomagnetic activity). The correlation of the 22-year signal in temperature with the 22-year signal in solar and geomagnetic activity is more uniform, only two large areas with opposite sign correlation – western and eastern hemispheres – being singled out.

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To end, we emphasize the fact that we do not have yet a direct physical explanation for the effects of the solar and geomagnetic forcings on climate, that we studied within the frame of the contract and reported in the present synthesis. Our conclusions, however, are in line and strengthen the opinion that the dependence of the climate evolution on the variations of solar activity is a regional rather than a global effect (Lockwood, 2012). Also, the variability of the pattern of air temperature temporal evolution, tackled in the frame of this contract, is such that it cannot allow a simple answer on the increase of variability related to contemporary global warming.

We consider that the research of the kind we undertook in this contract shoud be continued further, by including all seven available altitude levels and other climatic parameters (e.g. precipitation, air pressure, sea surface temperature), on one hand, and by extending it to other areas, with different climate characteristics, on the other.

### V.2. Dissemination of project results

In the time interval covered by the project (2011-2014), four research stages at The Department of Environmental Sciences of St. Mary University, Halifax, Canada, have been fulfilled by the project Director, Venera Dobrică, and by a member of the project team, Crisan Demetrescu. 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. The project Director took a course entitled ”Statistical downscaling of global climate models”, at University of Prince Edward Island, to get acquainted to the SDSM 5.1.1 (Statiscal Downscaling Model), a computer code aiming at statistical downscaling the meteorological information provided by global circulation models.

During the project, the team members actively participated to national and international workshops, presenting 19 oral or poster papers, that can be viewed on the web page of the project and at the item RST-Indicatori.

Three papers were published and one is under evaluation in ISI-indexed journals, and one paper was accepted by a journal indexed in other international databases. The list follows:

1. 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.
2. Suțeanu, C., Statistical Variability and Persistence Change in Daily Air Temperature Time Series, Pure Applied Geophysics, 2014, doi: 10.1007/s00024-014-0878-8.
3. Suțeanu, C., Pattern Variability in Arctic Air Temperature Records, Surveys in Geophysics, 2014, doi: 10.1007/s10712-014-9293-z.
4. Pîrloaga, R., Dobrica, V., The North Temperate Climate on long-term timescales. Connection to solar variability, Romanian Journal of Physics, 2014, under evaluation.
5. Dobrica, V., Demetrescu, C., Stefan, C., Pîrloaga, R., Effects of the solar variability on the North temperate climate, Romanian Geophysical Journal, 2014, accepted.

The results of the project will also be published in two more papers, in preparation, that will be submitted to ISI-indexed journals:

1. Dobrica, V., Demetrescu, C., Mares, I., Mares, C., Solar signatures in the long-term evolution of the Lower Danube discharge and corresponding climate variations in the Upper and Middle Danube basins.

2. Dobrica, V., Pirloaga, R., Stefan, C., Demetrescu, C., Inferring geoeffective solar variability signature in stratospheric and tropospheric NH temperatures.

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

Director proiect,

Dr. Venera Dobrică