Institute of Geodynamics
Romanian Academy

Project

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

Program TE, Contract 21/5.10.2011

Stage I, December 15 2011

Synthesis

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 re-analyzed 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) time-scales, between climate parameters and those of solar and geomagnetic activity at local, regional and continental geographical scales.

The stage report is structured in chapters, according to the objectives of the 2011 stage of the working plan of the project.

In *Chapter 1*, entitled „**Synthesis of studies regarding imprints in the terrestrial climate of solar and geomagnetic variability**", the main results regarding this aspect, rather controversial and debated in the scientific literature, are reviewed. Though the fact the energy coming from the Sun is the driver of the climate system is recognized, the controversies are related to the mechanisms controlling the climate variability at decadal time-scales, as satellite measurements showed that total solar irradiance variation is of only 0.1% during a solar cycle.

The solar activity could influence the terrestrial climate in various ways and at various time-scales, both directly, by long-term modifications of the solar radiative emission affecting the energy balance of the Earth's surface, and indirectly, by effects of the solar wind on magnetosphere and ionosphere (geomagnetic activity) and by the cosmic ray flux modulated by combined effects of the heliospheric and terrestrial magnetic fields. The solar influence on climate cannot be directly measured, but correlations between the solar activity and climate parameters were found, such as the well known correlation between the mean temperature of the Northern Hemisphere and the length of the solar cycles, published by Friis-Christensen and Larsen in 1991, that inspired numerous other publications.

The influence of the geomagnetic activity as forcing factor on climate variations was studied as well, various authors finding significant positive correlations at the 99% confidence level with the sea level pressure or the surface temperature in areas such as Central and Southern Europe, the south-eastern area of North America, the West Atlantic, and negative in North Atlantic and Canada. Correlations in terms of running averages with a window of 11 years between the solar calm diurnal geomagnetic variation, produced by the so-called ionospheric dynamo controlled by the solar radiation in the ultraviolet range of the spectrum, the time series of sunspots, solar irradiance, and global mean temperature were also found. These studies showed the divergence between the trend of solar/geomagnetic and climate indices that started to manifest after 1980 and could indicate the predominance of the effect of anthropogenic greenhouse gases in the recent evolution of the climate.

In the scientific report for this stage, studies that demonstrated, based on more rigorous methods for data analysis, that at the level of the 11-year cycle the observed correlations might not be significant, are presented. It is to emphasize that, in case of the long-term variation, the authors of the present report demonstrated, in one paper published in 2008 and in another one published in 2010 as a result of research undertaken within the frame of a previous contract (IDEI no.151/2007), that the solar and heliospheric variability, as well as the geomagnetic one, have common properties at the time-scale of Hale (22 years) and Gleissberg (80-90 years) cycles. These conclusions include also the total solar irradiance, one of the factors that can influence the terrestrial climate. In the same contract, studies started previously, in the contract MENER 405/2004, regarding the variability of climate parameters characterizing the Romanian and European territories at the two temporal scales were elaborated and finalized. The analysis carried out for 21 stations in Europe with data starting from 1900 and 14 stations in Romania and 4 at other locations in Europe, with data from the last 150 years, rendered evident strong, coherent signals at the time-scales of Schwabe and Hale solar cycles as well as the presence of a variation at the 40-year temporal scale possibly related to the internal dynamics of atmosphere.

In *Chapter* 2, entitled „**Review of methods for the data time series analysis**”, 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:

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

of which coefficients a_j determine the solutions $X(t)$ at discrete moments t = 0, 1, 2, …, n, …. 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 ´60 and ´70 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, …, 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 fractuation analysis (DTA) 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. The method was applied by dr.Cristian Şuţeanu (St.Mary University, Halifax, Canada) to the series of daily data (maxima, minima, and the mean of the two) provided by meteorological stations in the Atlantic Canada and will be applied to climate parameters from Europe, North America and other areas within the frame of the present contract. 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 $1 \le i \le N$ 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.

In *Chapter* 3, entitled „**Initiation of the data bank of the project**", all data regarding solar activity, geomagnetic activity and climate parameters are described. The web pages of the world data centers and publications from which data of interest can be retrieved are indicated.

In *Chapter* 4, entitled „**Dissemination of results. Initiation of the web page of the project**", the way the project results are disseminated is presented. It is mentioned:

(1) *Papers presented at scientific meetings*:

- "Long-term climate variations. Relationship with solar/geomagnetic activity"
- "Solar variability and space weather"

defended by Dr. Venera Dobrică and, respectively, by Dr. Crişan Demetrescu in the frame of a scientific seminar organized at the Environmental Science Department of the St.Mary University, Halifax, Canada, with the occasion of the working visit during November 9-24, 2011, of the two researchers.

(2) the web page of the project: http://www.geodin.ro/PN_II_2011/engl/index.html, that contains information regarding the project, the objectives and stages, as well as the components of the scientific team of the project has been initiated. The page will be completed throughout the project.

Project Director,

Dr.**Venera Dobrică**