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THE INFLUENCE OF SOLAR ACTIVITY PHENOMENA ON THE EARTH TEMPERATURE VARIATIONS

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ABSTRACT

A possible effect of solar activity on the earth ground-level temperature has been studied on basis of measurements of superficial temperature in Tacubaya, Stockholm, Tartus and Vilnius. Both the conventional methods of spectral analysis and autoregression methods have been used to detrmine common cyclicities. Preliminar results reveal not only the presence of common *cyclicities in all data under investigation, but also the existence of some delays between solar activity and metereological processes.*

1. INTRODUCTION

A global description of the complex phenomena of Solar-Terrestrial Physics was reviewed by Pérez-Peraza (1990). Furthermore, in previous works we have discussed the influence of solar activity (SA) on hydrological processes (Libin et al., 1989; Pérez-Peraza et al., 1996) and on climatological processes (Libin et al., 1992). Besides, the climatological and hydrological variations as well as the variations of cosmic ray intensity, the medical-biological processes have also been discussed in terms of the same processes in the sun and in the interplanetary space (e.g. King, 1975); that is, the powerful interplanetary shock waves, solar flares, the high speed streams of the solar wind and the sectorial structure of the interplanetary magnetic field. Consequently, we consider that a detailed analysis of the behavior of temperature variations on different sites of the earth surface is very important, to determine correlational relationships of frequence-dependent behavior and quasi-stable nature between this parameter and Solar Activity.

2. METHODS OF SIMULTANEOUS ANALYSIS OF THE TEMPERATURE AND SOLAR ACTIVITY

The analysis of solar activity parameters (the number of Wolf, W, the sunspots surface, S, the intensity of the coronal line of 5303 Å, the solar radio-emission in 10.7 m) and the temperature was previously carried out by means of traditional methods of correlational and spectral analysis (Libin et al., 1992), and autoregressive (AR) spectral analysis Pérez-Peraza et al., 1996).

Though the traditional methods of pure analysis are usually very useful, however, they have some limitations, so that it is often convenient to use them together with other independent methods for determination of periodicities. In fact, in the reconstruction of the statistical characteristics of a series of processes these acquire a time-dependent nature. In such a case the concept of spectrum itself becomes indefinite, and the classical transformation based on the methods of the Fourier fast-transform and Blackman-Tuiki give often wrong results: the determination of quasi-stationary segments by the usual method presents a number of difficulties (Dragan et al., 1984). Such segments when they exist, may be short, so that with a reduced amount of data the Fourier method does not give good results avoiding the distinction among close frequencies. As it is well known the separation between close frequencies is one of the basic points of the problem in consideration, since each one of them may be related to different physical mechanisms of interaction of the heliophysical and meteorological parameters (Libin et al., 1987). Under this context it is convenient the employment of AR spectral analysis. For instance, the frequency separation may be done by the autoregressive (AR) methods that essentially are based on the assumption that the studied process may be described by an autoregrssive model in the following form,

$$X_{t+1}=\sum_{l=0}^{p} a_{l+1} X_{t-l}, \quad t = 0,\ 1,\ 2\ldots \qquad (1)$$

where the order p is to be determined. In this assumption the AR coefficients are determined in one or other way, and the order is chosen in the most convenient form. Once the order and the coefficients are known the spectrum is univocally determined. The employment of different algorithms (of the kind of the method of Berg, Levinson-Derbina, Proni and their modifications) give satisfactory results within the frame of the described methodology. To refine the performances of the method we assume that the process in consideration may be described by an AR model in which the coefficients are time-dependents, so that eq. (1) may be rewritten as

$$X_{t+1}= \sum_{l=0}^{p} a_{l+1}(t) X_{t-l}, \quad t = 0,\ 1,\ 2,\ \ldots \qquad (2)$$

then, such a process is not in the steady-state. Each coefficient is represented as a development with respect to a given system of functions $\{\varphi_k\}$ as

$$a_l(t) = \sum_{k=1}^{N} C_{lk}\varphi_k(t) \tag{3}$$

where the coefficients to be determined are the $\{C_{lk}\}$. In particular, for such a complete system of functions the series $\{1, \chi,, \chi^2, ...\}$ may be chosen To determine the number N of the development (3) and the order p of the model (2) the coefficients $\{C_{lk}\}$ must be determined, and this may be done by the least square method in such a way to select them in an optimal manner. This methodology allows to introduce the concept of "*instantaneous spectrum*" for a time-dependent process. At every moment t^* the parameters $\{C_{lk}\}$ have a corresponding AR model with known constant coefficients:

$$a_l(t^*) = \sum_{k=1}^{N} C_{lk}\varphi_k(t^*) \tag{4}$$

This is an instantaneous process at the moment t^* which may be prolongated up to the infinity. Such a process is in steady-state, and its corresponding spectrum may be calculated analytically in an univocal form by means of the coefficients given in (4). We will designate the spectrum of the "*retained*" process at the moment t^* as the "*instantaneous spectrum*". Developing a sequence of instantaneous spectra, as a function of t^*, we are able to study the observed restructuration of the process.

The described methodology contains methods of direct Fourier transform and their modifications, methods based on AR models and on the method of instantaneous spectra. Depending on specific situations, they are employed under different combinations, allowing in that way to study the time series with higher precision and a best control of the obtained results.

On basis to all those methods we developed a system of data processing which takes into account some additional features: filtration of low and high·frequencies, exclusion of regular variations, estimation of dismatches in the process (calculation of the basic statistics that characterize the process). For computational applications the data processing system has been constrained with the following restrictions:

1. Enlarged dialogue with the user.
2. Possibility of data processing in different media.
3. Possibility of creation and growth of a data bank.
4. Fast access to any segment of the series.
5. Graphical output of results: particularly, the creation of a dynamical table for the spectrum restoration of the process.

A block-schema of the program of the AR spectral analysis is shown in Fig. 1 where it can be appreciated the final results of the test calculations with the ARMA methods (Mathematical Autoregression) in graphical form, [panel (a)], and in numerical form by means of a special table, [panel (b)], so that the user may choose the required information in the more convenient form to his purposes. For calculations it has been used the function $S(t) = \sin(f_o + \Delta f_k) + \sin f_1 + \sin f_2$, where Δf_k changes in every step of the ARMA program. Calculation are based in a number of basic steps: preparation of data and their screen presentation, choice of the interval for the ARMA spectral analysis (Libin et al, 1987), fixation of the initial and final points of the interval to be analyzed, calculation of the correlation functions and the crossed correlations, as well as the symmetric and asymmetric components, choice of the order of the AR model describing each one of the processes, choice of the order of the ARMA model for each process in such a form to minimize the noise level in the process of selection of the model's order, and at last, obtention of the final results.

3. THE ANALYZED DATA

The analysis was carried out over the monthly averages of the measurements of superficial temperature in Tacubaya (México), Stockholm (Sweden), Tartu (Estonia) and Vilnius (Lituania) for the period 1910-1992. In Figs. 2(a)-(b) we present data of the temperature and solar activity observations. After the choice of the analysis interval (in this work we selected as the fundamental interval the SA cycle) the correlation and crossed correlation functions were calculated. In Figure 3 it is presented the calculated functions (ρ) for the temperature series of Estonia and México. Figs. 4(a)-(b) were used to determine the orders of the AR models of each one of the analyzed series. In the lower graphic it is indicated the error marge of the calculation of the different orders; this can be studied up to the order 10. Fig. 6 is the one that helps the user of the data processing system to determine the order of the ARMA model.

After obtaining from Fig. 5 the results for the chosen orders, one proceeds to precise the order of each one of the analyzed processes by comparing the obtained spectra (graphics A) with the standard ones (graphics B) in Figs. 6(a)-(b) and with the refinements of those orders by the residual noise in each process [Figs. 6(c)-(d)]. The final results are shown through the series of graphics presented in Fig. 7.

4. CALCULATION OF THE SPECTRAL PARAMETERS

The calculation of the spectral characteristics of each one of the analyzed processes were carried out by spectral analysis; that is, by determining the amplitudes and frequencies of the relevant waves. In Figs. 8(a)-(d) we present results corresponding to double-cycles of the SA from 1776-1835 for different orders of the ARMA models, as well as the results of the calculations of the crossed spectra of SA and temperature for the same periods [Figs. 9(a)-(c)]. It can be observed that there is a quasi-absolute agreement between the relevant frequencies (periods of 2-4 and 9-11 years) and the dephasages between the processes. In Figs. 10(a)-(c) to 16(a)-(c) we present the crossed amplitudinal spectra (a), the coherence spectra (b) and the phase spectra (c) for each one of the SA cycles in the period 1913-1992 that were calculated on basis to the monthly averages. The remarkable temperature oscillations of 12 months related to the variations of SA (with correlational coefficient of ~ 1) and the oscillations with periods close to 3 months have a purely climatological nature (seasonal changes).

Similar calculations on basis to annual averages of temperature and SA of Estonia give important results for subsequent investigations. In Figs. 17(a)-(c) to 21(a)-(c) we present the amplitude spectra (a), phase spectra (b) and coherence spectra (c) for the temperature and double-cycles of SA in the period 1866-1992 (Figs. 17 for short period variations, Figs. 18-21 for long term variations). There is a remarkable high reliance of the temperature oscillations (constantly present with periods of 9-11 years) and the 3-4 years oscillations related to SA (having a less stationary nature). The analysis through all the studied years (1886-1992) confirms the following results [Figs. 22(a)-(c)]: there is clearly very remarkable 11 years waves in temperature, the 3-4 years oscillations balance mutually and the phase spectra show dephasages of the temperature variation that agree correctly with the results of other works where the influence of SA on geophysical and hydrological processes is also studied. In Figs. 23(a)-(c) we present the cross total DSA (dynamical spectral analysis) of the Estonian temperature and SA for the period 1910-1992.

It is highly significant that analogous results are obtained with the measurements of temperature in other sites. In Figs. 7 and 24(a)-(f) we present the final results concerning the calculations of the spectral characteristics of the temperature in Estonia (ARMA 1) and in México (ARMA 2), as well as the amplitudinal crossed spectra of phase and coherence of the period 1921-1987. The obtained results show total agreement between the behavior of temperature oscillations with period of 11 years (coherence coefficient = 1) and the time-dependent nature (climatological) of the oscillations with periods of 3-4 years. An analogous coincidence is obtained with the temperature series of Sweden-Lituania [Fig. 25(a)] and with Estonia-Lituania [Fig. 25(b)].

The obtained results are confirmed with the graphic analysis of temperature in Tacubaya (México) and the SA: the 11 and 22 years waves clearly detach, and so do the spectral characteristics calculated on basis to monthly values. The results of these calculations lead to the establishment of a probable inter-correlation between the processes in the sun (SA) and in the earth atmosphere (behavior of the temperature in different sites of the earth surface, the lakes level and the wind velocity). At the light of this feature, the solution of the problem related to the determination of the mechanisms of the great-scale atmospheric process and in attempting the forecast of these processes it is necessary to consider the phenomena taking place in the sun and in the interplanetary medium, as well as the cosmic radiation observed at the earth level.

5. POSSIBLE MECHANISMS OF THE INFLUENCE OF SOLAR ACTIVITY

According to the works of King (1975), Mustel (1981), Durovic (1983), German and Goldberg (1981), Vitinsky et al. (1986) and Kondratiev (1985, 1989, 1991) the possible mechanisms of the influence of cosmic factors in the low layers of the earth atmosphere are:

1. Astronomical mechanisms based on the variation of the solar constant.
2. Infrared emission produced during magnetic substorms.
3. Solar wind influence on the parameters of the atmospheric electricity.
4. Condensation mechanisms.
5. Ozone mechanisms.
6. Hydrodinamical influence of the upper and lower layers of the atmosphere.

An essential factor in any of the described mechanisms is the heat flux from external sources: e.g., solar flares, interaction of the solar plasma with the magnetosphere, magnetic substorms, atmospheric convection, penetration of particles in polar zones, generation of additional amounts of nitrogen bioxide and ozone in the low stratosphere by galactic and solar cosmic rays, influence of the SA on the atmospheric electric field and others.

As possible mechanisms of solar-terrestrial interaction the following can be mentioned: the solar heating of the troposphere (the modulation of the radiation in 0.1% leads to a variation of 0.02-0.04 mb in the superficial pressure); the heating of the troposphere by the terrestrial radiation (for a compensation of the solar radiation in 0.1% the superficial temperature must be modified by ~ 0.2 K); direct heating of the upper levels (with the subsequent oscillatory transport toward lower levels); indirect heating (through the variation of the refection height of the hydrodinamic waves which depends on the zonal component of the wind, which in turn depends on the heating by ozone); trigger mechanisms (which producee the internal instability of the troposphere); the cloudy cover (by means of the variation of the number of condensation nuclei); generation of vorticity (through the anomalous vertical motions) and the variation of the phase and amplitude of the solar thermal tides.

Variations of climate and temperature in the north hemisphere agree in good extent with the variations of the geomagnetic pole on the earth surface. We claim that a possible mechanism for this relation may be the following: solar particle fluxes produce global perturbations of the earth magnetosphere resulting in the generation of electric fields in the external magnetosphere, and so, the production of intense electric currents in the polar caps, "the auroral electrojet". Due to those currents there is a catastrophic increase of geomagnetic activity (by a factor of ten or more) that leads to the heating of the low atmosphere and to a decrease of the atmospheric pressure in the magnetic pole zone, in an amount enough high for the cyclone (which is formed in the geomagnetic pole region) provoke variations in the whether and climate all around the neighbor areas.

6. CONCLUSIONS

Investigations around the problem of the relation of meteorological weather with SA and the solar wind may be classed in three groups: (1) climate variations in the course of hundreds and thousands of years; (2) variations correlated with the 11 and 22 years cycles of the SA; (3) variations in the course of some days. In any case, to study the atmospheric processes of short and long period the consideration of the influence of SA is an essential fact, using for this goal data of the indexes of geomagnetic activity, cosmic ray

As remarked by Sherstiukov and Loginov (1986), the nature of such relationships is highly sensitive to the spectra of electromagnetic and corpuscular emissions from the sun, to the temporal state of the solar and interplanetary fields (e.g. Mayaud, 1977; Ariel et al., 1986), to the earth heliolatitude and to the geographic zone of the studied atmospheric process (Lastovička, 1987). For this reason, the modelation of the SA action on the atmospheric circulation must consider any other complementary information, since the only use of the Wolf number index for interpreting long-period interactions is not always appropriate (Mayaud, 1977).

REFERENCES

Ariel, N. Z,, Shakhmeyster, V. A., and Murashova, A.V., Spectral Analysis of characteristics of the interchange of energy between ocean and atmosphere, Meteorologia and Gidrologia **2**, 49-53, 1986 (In Russian).

Djurovic, D., Short-period geomagnetic, atmospheric and earth rotation variations, Astron. & Astrophy. **118**, 26-28, 1983.

Dragan, Ya. P., Rojzhkov, V.A. and Yavorsky, N. N., Application of methods of the theory of periodical correlational stochastic functions for probability analysis oceanic time series, in **Probability Analysis and Modeling of Oceanic Processes**, GMI Publ. House, Leningrad, pp. 4-23, 1984 (In Russian).

German, J. and Goldberg, R. A., **Sun, Weather and Climate**, Pergamon Press 1984.

King, J. W., **Sun-Weather Relationships**, Aeronaut. & Astronaut. **13**, p.10, 1975.

Kondratiev, A. Y. and Nikolsky, G. A., The Solar Constant and Climate, Solar Phys. **89**, p. 215, 1983.

Kondratiev, A. Y. and Nikolsky, G.A., Some results of studying the relationships between meteorological parameters and solar activity, Solar-Terrestrial Physics Newsletters **89-1**, p. 31, 1989.

Kondratiev, A. Y. and Nikolsky, G. A., Influence of Solar Activity upon the lower atmosphere, Proc. of the IUGG Assembly, p. 226, 1991.

Lastovička, J., Influence of the IMF sector boundaries on cosmic rays and tropospheric vorticity, Stud. Geophys. et Geod. **31-2**, 213-218, 1987.

Libin, I. Ya., Mikalayunas, M. and Yudakhin, K. F., Variations of Cosmophysical and heliophysical parameters in the 18-21 cycles of solar activity, Geomagnetizm i Aeronomia **27-3**, 483-486, 1987.

Libin, I. Ya. and Jaani, A., Influence of variations of solar activity on geophysical and hydrological processes, *Izvestia AN Estonii*, **38-2**, 97, 1989. (In Russian).

Libin, I. Ya., Gulinsky, O. B., Guschina, R.T., Modeling the mechanism of heliophysical parameters influence on atmospheric processes, *Kosmicheskie luchi* **26**, p. 22, 1992 (In Russian).

Mayaud, P. N., On the reliability of the Wolf number series for estimating long-term periodicities, J. G. R. **82-7**, 1271-1272, 1977.

Mustel, E. R., The reality of solar-atmospheric relations and the changes of atmospheric circulations, Etudes du Soleil et Climat, Toulouse, p. 151-161, 1981.

Pérez-Peraza, J., "Space Plasma Physics", in Annals of the Space Conference of the Americas: perspectives of cooperation for the develpment, edited by the PUND of UN, Vol 1, 96- 113, 1990.

Pérez-Peraza, J., Leyva, A., Zenteno, G., Valdés-Barrón, M., Libin, Ya., Yudakhin, K., Sizova, N. and Jaani, A., Influence of solar activity variations on hydrological processes:spectral and autoregressive analysis of solar activity and levels of Lakes Patzcuaro and Tchudaskoe, 1996 (This Issue).

Sherstiukov, B. G. and Loginov, V. F., The short-term cyclic variations in the low atmosphere and the heliophysical processes, GMI Publ. House, Moscow, 1986 (In Russian).

Vitinsky, Yu. I., Konetzky, M. I. and Kuklin, G. V., Statistics of the sun's spot formation activity, Nauka Publ. House, Leningrad, 1986 (In Russian).

FIGURE CAPTIONS

Fig. 1.- Block-scheme of the Dynamical Spectral Analysis (DSA) programm (a) and results of testing runs (b).

Fig. 2.- Data series of temperature and solar activity (Wolf Number) used in this work.

Fig. 3.- The self and cross-correlation functions for Estonian and Mexican temperaure series:

$$\rho(k) = (1/N-1) \sum_{t=1}^{N-k} ([x \;-\bar{x}]/\bar{x})([x \quad - \bar{x}]/\bar{x})$$

Fig. 4.- Computer display used to determine the order of the AR models of the solar activity series (a) and the temperature series (b) (the Estonian one in this example).

Fig. 5.- Computer display used to determine the order of the ARMA models.

Fig. 6.- Computer display used to precise the order of the ARMA model of the series. (A) the obtained spectra, (B) the standard spectra: examples (a) and (b) for SA and Estonian temperature series, and (c) and (d) the corresponding residual noise.

Fig. 7.- Example of the final computer display of the DSA programm results for the Estonian and Mexican temperature series.

Fig. 8- Results of the DSA of solar activity for the period Jan. 1776 - Dec. 1835. Employed ARMA orders are: (6,2) in (a), (5,3) in (b) (6,3) in (c) and (7,3) in (d).

Fig. 9.- Amplitude co-spectra of solar activity and Estonian temperature series from (a) Jan. 1776 - Dec. 1795, with ARMA orders (1-6,2)

and (2-6,3), (b) Jan. 1796 - Dec. 1815, ARMA orders of (1-6,3) and (2-5,3), (c) Jan. 1816 - Dec. 1835, ARMA orders of (1-7,3) and (2-7,4).

Fig. 10.- The cross DSA for Estonian temperature and SA monthly series from 1913 to 1924 and orders of the ARMA models of (1-4,3) and (2-4,3): (a) Amplitude Spectrum, (b) Coherence Spectrum, (c) Phase Spectrum.

Fig. 11.- Idem Fig. 10 for the period 1924 - 1934 and ARMA orders (1-4,5) and (2-5,4).

Fig 12.- Idem Fig. 10 for the period 1934 - 1945 and ARMA orders (1-4,4) and (2-4,5).

Fig 13.- Idem Fig. 10 for the period 1945 - 1955 and ARMA orders (1-4,5) and (2-4,4).

Fig 14.- Idem Fig. 10 for the period 1955 - 1965 and ARMA orders (1-4,4) and (2-5,5).

Fig 15.- Idem Fig. 10 for the period 1965 - 1977 and ARMA orders (1-4,5) and (2-5,4).

Fig 16.- Idem Fig. 10 for the period 1977 - 1986 and ARMA orders (1-4,3) and (2-4,3).

Fig 17.- Idem Fig. 10 from 1986 to 1992, and ARMA orders (1-4,5) and (2-3,5) (short period).

Fig 18.- Idem Fig. 10 from 1866 to 1890, for annual series and ARMA orders (1-4,1) and (2-4,1) (short period).

Fig 19.- Idem Fig. 10 from 1891 to 1915, for annual series and ARMA orders (1-5,1) and (2-3,5).

Fig 20.- Idem Fig. 10 from 1915 to 1934, for annual series and ARMA orders (1-4,3) and (2-5,3).

Fig 21.- Idem Fig. 10 from 1934 to 1955, for annual series and ARMA orders (1-3,4) and (2-4,3).

Fig 22.- Idem Fig. 10 from 1954 to 1977, for annual series and ARMA orders (1-5,1) and (2-4,1).

Fig 23.- Idem Fig. 10 from 1910 to 1992, for annual series and ARMA orders (1-5,3) and (2-4,2).

Fig. 24.- The final results of the cross DSA of the Estonian and Mexican temperatute monthly series: a) 1924 - 1934, ARMA orders (1-5,4) and (2-4,5), b) 1934 -1945, ARMA orders (1-5,5) and (2-5,5), c) 1945 - 1955, ARMA orders (1-4,4) and (2-4,4), d) 1955 - 1965, ARMA orders (1-4,4) and (2-4,3), e) 1965 - 1975, ARMA orders (1-4,5) and (2-4,5), f) 1975 - 1985, ARMA orders (1-3,3) and (2-5,1).

Fig. 25.- The final results of the cross DSA for: a) Lituanian and Swedish temperature monthly series, from 1913 to 1977 and ARMA orders (1-4,1) and (2-4,2) and b) Lituanian and Estonian temperature monthly series from 1913 to 1992 and ARMA orders of (1-4,1) and (2-4,3).