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Solar Activity Variations and Their Possible Effects on Long-Term Variations of the Surface Air Temperature

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Abstract—Mean monthly and annual values of the near-ground temperature (T), intensity of cosmic rays (ICR) and solar-activity indices (SA) observed at different stations were used for mutual autoregressive analysis of the pairs: T–SA, T–ICR, ICR–SA, and T–T. A comparison of spectral characteristics of the atmospheric parameters and cosmic rays with similar solar activity spectra shows a good agreement both in the frequency range, and in the phases of the processes. The results are considered from the viewpoint of their connection with possible mechanisms for the SA and ICR effects on the state of the lower atmosphere, and it is shown that the selected parameters reflect the real physical processes but for a choice of the SA indices, which is inessential for analysis of the near-ground temperature behavior.

1. A sufficient number of publications are devoted to solar activity effects on hydrological and climatic processes [1–6]. Climatologic and hydrological variations, as well as some other events (cosmic ray intensity, medical-biological parameters) are affected by the general processes in the interplanetary space and on the Sun, such as powerful interplanetary shock waves, solar flares, high-speed solar wind, sectorial structure of the interplanetary magnetic field, etc. It should be noted that spectral analysis of the hydrometeorological data was already carried out earlier [7–10]. In contrast to them, in the present work the qualitatively new statistical and computational methods are applied to reveal a correlation between different processes, and, in particular, the original statistical approach is used for modeling the correlation between heliophysical and geophysical events [11–15]. We could not miss the fortunate opportunity to use the available means for a thorough analysis of the surface temperature variations in different regions of the Earth to reveal quasi-stable frequency-dependent correlation between the temperature and the solar activity.

2. The analysis of the solar activity parameters (the Wolf numbers, sunspot areas, intensity of the coronal emission 5303 Å, *HL*-index, solar radioemission at 10.7 cm) and the temperature was performed both by means of the traditional technique of correlation and spectral analysis [10] and with the use of autoregressive spectral analysis [16, 17].

A substantial transformation of the statistical characteristics occurs in certain processes under consideration (i.e., they transform to non-stationary processes). In these case, a definition of the spectrum becomes uncertain, and the classic transformation based on the technique of the fast Fourier (FFT) and Blackman-Tayky transformation frequently yields incorrect results. In order to overcome these difficulties, the authors of [15, 17] proposed to describe a process under study by the autoregressive model with time-dependent coefficients.

The technique under consideration realizes all currently available approaches: the methods of FFT and its modifications, the procedures based on autoregressive models, and the technique of instantaneous spectra. Some auxiliary procedures are also carried out: the filtering of low and high frequencies, elimination of regular variations [10], evaluation of the process disorder (i.e., a rise of non-stationarity), and calculation of the general statistical characteristics of the process.

The process of calculation is based on a series of fundamental procedures: the data preparation and outputting of the results to a display both in numerical and graphic forms; a choice of a range for the analysis; setting up the initial and the final points of the range; or different filters operation; calculations of correlation and cross-correlation functions for input and (or) filtered data (as well as their symmetric and non-symmetric components [11]); selection of order for the autoregressive model describing each of the processes; selection of the order of *ARMA*-model for further calculations of spectral characteristics; correction of the *ARMA*-model order for each of the processes by

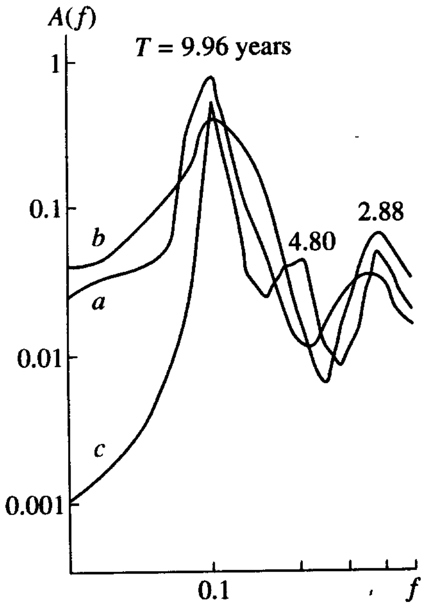

Fig. 1. Cross-correlated amplitude spectra of the solar activity and the temperature for different regions: Mexico (*a*), Russia (*b*), and Estonia (*c*).

means of minimizing the noise level for the selected orders of the models; and, at last, deriving the final results (the amplitude, phase, and coherence spectra).

3. Analysis was performed from mean monthly values of the air surface temperature in Russia (St. Petersburg), Mexico (Takubaya), Estonia (Tartu), Sweden (Stockholm), and Lithuania (Kaunas) for the period 1976–1995. After a choice of the respective intervals for the analysis (we referred to the solar activity cycles, and then moved along the entire data array, with the step of five years, so that only two adjacent results appeared to be partially dependent), the calculations started according to the standard procedure described above.

The spectral characteristics were calculated for each of the data arrays by means of the autoregressive spectral analysis (the amplitudes and frequencies of the identified oscillations were determined). The results of these calculations for the solar activity (SA) for its double cycles from 1976 till 1995, and similar results of the SA and the temperature cross-correlation spectra for the identical periods demonstrate practically exact coincidence of identified frequencies (corresponding to periods of about 4 and 12 months and 2–4 and 9–11 years), and a coincidence of delays between the long-period processes (2–3 years). These results are correspondent to the results of the other studies [4, 5, 18].

Similar calculations, which used the mean annual values of the solar activity and the temperature in different regions, show (see Fig. 1*a–c*) that the temperature variations with periods of about 2–4 and 9–11 years associated with similar solar activity variations are identified with a high reliability. The dynamics of the variations are also coincident: if the 9–11-

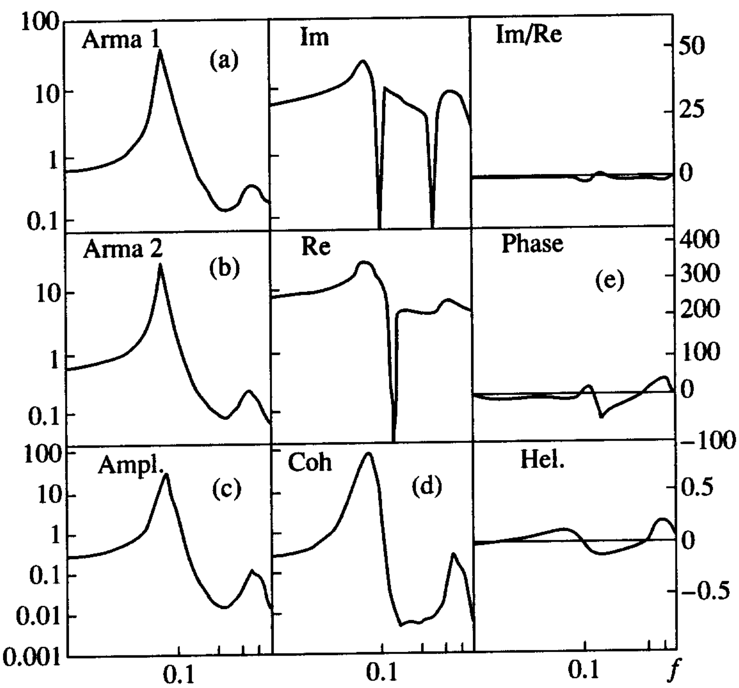

Fig. 2. Spectral characteristics of the temperature (a) in Estonia and (b) Mexico; (c) cross-correlated amplitude; (d) coherence spectrum; and (e) phase spectrum for 1921–1987.

year variations are permanent, the variations with periods of 2–4 years have a more random character; however, that is also concordant with a behavior of the similar SA variations. In this case, the phase spectra exhibit the delays of temperature variations concordant with the results of studies of the solar activity effects on geophysical and hydrological processes [7, 10–15].

Similar (or different) results for temperatures, recorded in different regions of the Earth, tend to acquire a great deal of importance in this situation. Figure 2 displays the temperature spectral characteristics calculated for Estonia (*ARMA*1) and Mexico (*ARMA*2), and the cross-correlated spectra of the amplitude, phase, and coherence for 1921–1987. Our results show that the characteristics of the temperature variation with a period of about 9–11 years (the coherence coefficient is close to 1) are completely coincident, while the variations with a period of 2–4 years are non-stationary with respect to solar activity (but both series are also satisfactorally cross-correlated in the 2–4-year variations). A similar coincidence is observed both in the cross-correlated database pairs for Sweden–Lithuania, Russia–Mexico, Russia–Estonia, and Estonia–Lithuania, and in the analysis of the temperature in these regions with respect to the solar activity. It should be noted that the simultaneous analysis of the *T–T* pairs for different regions of the Earth enables a substantial elimination of the intense processes inside the atmosphere, which do not correlate with the solar activity [18].

The use of different solar-activity indices for the analysis of the temperature variations yields practically the same result, independent of index type. However, the use of S (sunspot areas) seems the most convenient for calculations, as a considerably long-term database is available, and at the same time, the error comes to 3% with different indices used.

4. Our results are confirmed by the results of harmonic analysis of the temperature in Mexico (Takubaya) with respect to the solar activity (11- and 22-year temperature variations associated with the SA, which were obtained earlier for the other regions, are well identified) and as well by the results of calculations of the temperature spectral characteristics in Takubaya with respect to the solar activity inferred from monthly means for 1912–1992. Moreover, a detailed analysis [9, 10, 11] of 11-year and 22-year temperature variations in all of the studied regions on the Earth are concordant with our results—in the temperature variations the 22-year cycle prevails over the effects of SA.

The comparison of spectral characteristics of the atmospheric parameters with similar spectra of galactic and solar cosmic rays [8, 10, 19–26] demonstrates a good agreement both in the frequency and in the phase domains (in 1952–1992, the correlation of the variations of cosmic rays with the SA and the temperature variations with the periods of 3–5 months, 1-, 2–4-, and 11-years were observed, which were coincident with the solar-activity and the temperature variations during the same period). The most convincing result was obtained by the authors from a comparison of the calculated amplitude and phase spectra of the temperature during the period 1937–1979 in Estonia and Sweden with the data on cosmic rays for the same period (with the ionization chamber at Huankayo station for 1937–1953, and the neutron monitor at Climax for 1953–1979) and the solar activity. Both the variations, common for all the data arrays with periods of 10.5, 2–3.7, and 1.3–1.7 years and practically simultaneous changes of phases of all of the detected variations were revealed near 1958. The last result agrees to a degree with the model [18] of the solar activity effects on climate.

CONCLUSION

Our results manifested the presence of a probable intercorrelation between processes on the Sun and in the Earth's atmosphere. The analysis of a delay between the atmospheric processes and the solar activity demonstrated the existence of stable shifts in the range of 12–36 months between the processes, and these results are in good agreement with those obtained by means of other calculation techniques.

It is also found in a combined analysis of the air temperature in different regions on the Earth's surface and the solar activity, that a choice of the solar activity index is not a deciding factor and it is sunspot area in the equatorial zone of the photosphere that is, apparently, the most acceptable index for the calculations.

In order to solve the problems associated with the origin of the terrestrial large-scale processes in the atmosphere or to develop a prognostic model of the climatic or hydrological processes, one should take into account both the solar-activity in the interplanetary-space variations, and also the cosmic-ray variations recorded on the ground of the Earth. Our calculations confirm the efficiency of the SA effects on the meteorological parameters under study [18].

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