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BRIEF COMMUNICATIONS

The Effect of Solar-Activity Variations on Hydrological Processes. Autoregressive Analysis of the Solar Activity and Levels of Terrestrial Lakes

Ya. I. Libin*, R. T. Gushchina*, J. Peres-Peraza, A. Leyva***, and A. Yani*****

** Institute of Terrestrial Magnetism, the Ionosphere and the Radio-Wave Propagation, Russian Academy of Sciences, Troitsk, Moscow oblast, 142092 Russia*
*** Instituto de Geophysica, National University of Mexico, Mexico D.F., Mexico*
**** Estonian Meteorological Institute, Ravala street 8, Tallinn, EEOO1 Estonia*

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Abstract—Possible sources of the solar activity effect on hydrologic processes on the Earth's surface are discussed. It is shown that data on cosmic rays must be included to account for the solar and geomagnetic activity effect on the lower atmosphere and climate.

INTRODUCTION

The question of solar activity effect on terrestrial hydrologic and climatic processes was repeatedly discussed in the literature [1–5]. A search for unstable and quasi-stable correlations between hydrologic processes and solar activity is the essential point of the present work. The first attempts in this direction were made by the authors in 1989, but the obtained results [6, 7] needed verification and confirmation. The qualitatively new statistical methods [7] and approach to calculations applied for revealing correlations between different processes, as well as the elaborated original scheme of modeling a mechanism of heliophysical and geophysical processes [8], enabled the authors to test the reliably of the earlier results.

1. In order to reveal the delays, to refine their values and to study the common cycles in databases for the water content of closed ecosystems (lakes) and solar activity events, both the traditional technique of spectral analysis (developed under the assumption that the processes being discussed are quasi-stationary) and the technique of autoregressive spectral analysis (applicable to unsteady processes) were used.

The analysis was performed on the basis of monthly mean values of solar activity (sunspot area, *HL*-index, radio emission at 10.7 cm), of cosmic-ray spectra, and of the isolated-lake levels measured in Mexico (Patsquaro), Estonia–Russia (Chudskoe), Russia (Caspian sea and Lake Baikal), Turkmenia (Aral sea) for the period 1850–1992. The analysis began with a choice of the respective intervals for data processing. For this, we referred to the solar activity cycles and then glided over the whole data array with a step of 5 years so that only two neighboring results appeared to be partially dependent; after choosing, the calculations were started according to the standard procedure described in [7].

In [6, 7] the results of detailed calculations of spectral characteristics of the water content (level) in the Chudskoe lake are presented together with those of the solar activity. The presence of the statistically valuable variations of the water content with periods on the order of 2.6–4.1, 9.0–11.2, 22, and 80–90 years was revealed, with a delay of the water content relative to the solar activity ranged from 1.5 to 3–4 years and was dependent on the solar activity cycle. For the odd cycles, the maximum of water content is delayed with respect to the minimum solar activity by two years, for the even ones the delay is about three years. The structures of the water-content histograms for even and odd cycles are different, and this difference points to a prevalence of a 22-year cycle in the hydrological processes [7].

A comparison between spectral characteristics of hydrologic parameters and simultaneous spectra of galactic and solar cosmic rays [9–16] demonstrated a good agreement both in the frequency and phase (in 1952–1992 the variations with periods of 3–5 months, 1 year, 2–4 years and 11 years were observed in cosmic rays, correlated with the solar activity and the temperature during the same period).

It should be noted that all the calculations performed for the water-content (level) variations in the Lake Chudskoe took a lot of time. For this reason, before starting similar calculations for the Caspian and Aral seas, the lakes Baikal and Patsquaro (Mexico), we decided to use the other possibilities i.e., comparing temporal and spectral variations of different isolated lakes and, if coincidental, to not perform the Blackman–Tayky analysis for the rest data, but to begin immediately with the autoregressive analysis.

Besides, one should remember that mutual power spectra [8] yield reliable quantitative statistic estimates of the interrelation between observed processes and

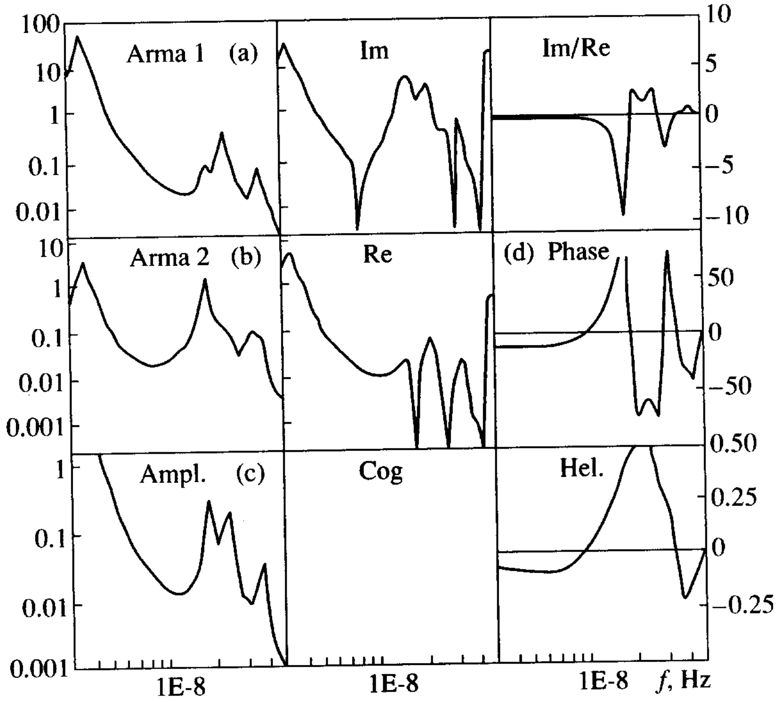

Fig. 1. Amplitude spectra of (a) solar activity; (b) water level; (c) mutual amplitude; and (d) phase spectra.

enable us to evaluate their mutual shift in time. However, a wide variety of reliability among identified correlations appears on the boundary of the confidence level. Besides, the reliability of results is to a great extent determined by the skill of the researcher (an option of the analysis technique and methods of evaluating the verity of the results). For this reason, the autoregressive analysis was used as a criterion of verity.

The autoregressive analysis differs from standard methods by an opportunity to estimate the correlations between the analyzed data sets with 100%-reliability in the frequency domain, and it is most important that this method is applicable to the analysis of quasi-stationary (sometimes, even to non-stationary) processes, such as the data sets for the water level and solar activity. On the other hand, one should remember that all the amplitude estimates, resulting from the autoregressive analysis, are relative, and so they cannot absolutely conform to the initial data sets, although their temporal behavior is well suited to a comparison. In other words, although we cannot exactly coordinate the results of calculations of the amplitude spectra with the initial database, nevertheless, their temporal dynamics is unambiguously followed.

2. The summary of calculations of the variation of spectral characteristics for Lake Chudskoe, performed in the framework of APMA model on the 5th–7th order for a period of 1921–1932, is presented in Fig. 1 (the amplitude spectra of the solar activity (a), water-content (level) variations (b), mutual amplitude spectra (c), and the mutual phase spectrum (d)). The results obtained will be analyzed below, but here we would like to call attention to clearly pronounced variations of the water level with periods of 1.5–2.0 and 9.06 years associated with the solar activity.

Analogous measurements for other periods yielded similar pictures: the presence of periods on the order of 2–4 and 9–11 years associated with the solar activity and characterized by similar types of the water level delays with respect to the solar activity of the even and odd cycles. (Besides, as well as for the other meteorological and hydrologic parameters, on the background of comparatively stable 11-year and 22-year variations of the water level, unsteady oscillations with shorter periods from several months to 2–4 years are clearly identified. These oscillations are not observed in every solar activity cycle, but they repeat the solar-activity rhythm quite well.)

In order to insure that the obtained estimates are reliable, we decided to carry out the complete autoregressive analysis of the water level oscillations and variations of the solar activity in the following sequence:

(a) ARMA-analysis of the water-content (level) oscillations for the lakes Patsquaro, Baikal and Chudskoe and for the Caspian sea during 1950–1987;

(b) ARMA-analysis of the level oscillations for the lake Chudskoe and for the solar activity during the same period;

(c) ARMA-analysis of the level oscillations for the lake Patsquaro and solar activity;

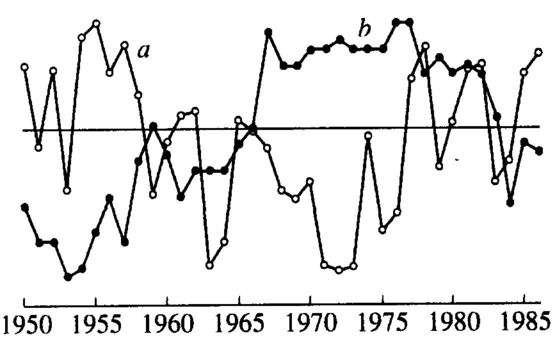

Fig. 2. Water level dynamics for the lakes (*a*) Patsquaro and (*b*) Chudskoe during 1950–1987.

(d) ARMA-analysis of the variations of the lake levels and of other meteohydrologic parameters and the variations of galactic cosmic rays on the ground (from the data of the cosmic-ray observatories in Moscow and Mexico).

Figure 2 exhibits the behavior of the levels for the lakes Patsquaro (a) and Chudskoe (b) during 1950–1987. At least two remarkable features are seen in the both curves: 22-year variations are easily identified, and, the most important, oscillations in both lakes are in the opposite phases. The calculations of the mutual correlation function yield anticorrelation on the order of 0.6–0.7 with a delay on the order of 1–2 years. The analysis of the behavior of the Chudskoe lake and Lake Baikal does not result in such a picture, although the 22-year wave is seen in a behavior of the water content for all the regions. (The analysis for the lakes Patsquaro and Baikal gives a picture similar to Fig. 2 but the anticorrelation is on the order of 0.3.)

Autoregressive analysis between the lake oscillations and variations of the solar activity based on average annual data revealed the presence of oscillations with periods of 4, 11 and 22 years. In this case a coherence of both processes is extremely high, and for the (2–4)-year and 22-year oscillations the coherence coefficient (square correlation coefficient at a given frequency) equals 0.8, and for 11-year oscillations it is 0.6.

A comparison of the amplitudes of both processes demonstrates the relative excess of 40–60% in the level oscillations of the Chudskoe lake (associated with solar activity) as compared to the Caspian sea and to Lake Baikal, and the excess of 100–120% as compared to the Patsquaro lake. The ARMA-analysis of the lake levels and the solar activity variations enabled us to draw the following conclusions important for further calculations: a dynamics of the water-level oscillations in isolated lakes completely follows the solar activity variations, the delays of the water levels, relative to the solar activity, coincide with the delays of other hydromteorologic processes and reflect a unitary mechanism of the solar activity effect on the climate of the Earth. The results of calculations of ARMA-spectra of the solar activity during 1950–1987, water levels and mutual spectra fairly confirm the solar origin (coherence coefficients on the order of 0.9) of a source of quasi-biennial, (4–5)-year, 11- and 22-year oscillations.

CONCLUSION

Thus, an application of the complex spectral technique available at present and a comparison of the results of different spectral calculations show that the source of the level variations of isolated lakes is connected with the solar activity cycle and its effect on the atmosphere of the Earth [17, 18].

The results of a number of works provide the ground for the use of the autoregressive prognostic model [17] to predict the water content of closed lakes and for the model accuracy to be at least twice as good after refining the set of the used predictors (the first estimates yield the quantitative prognoses with an error on the order of 45–70%). In this case the results obtained argue the necessity of including the data on cosmic rays in agreement with the proposed Pudovkin–Raspopov mechanism [19].

The calculations performed point to a probable interrelation between the processes on the Sun and in the atmosphere of the Earth; the studies of a delay of the atmospheric processes and solar activity dynamics point to the existence of the stable shifts in time between these processes of 12–36 months, that is concordant with the results of calculations used different techniques.

Moreover, a simultaneous analysis of the water levels in different points on the Earth together with solar activity (similar to the temperature analysis) a choice of the solar activity indices is not of crucial importance, and so the sunspot area, in our opinion, appears to be the most acceptable index for calculations in the autoregressive models [17].

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