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GEOPHYSICS

Forecast of Geomagnetic and Solar Activity on Nonlocal Correlations*

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The article is devoted to the experimental study of the possibility of long-term forecasting of a random component of geomagnetic and solar activity on the base of macroscopic nonlocality effect. The forecasting algorithm, employing the nonlocal correlation detector measurements, is suggested. Its efficiency is proved on data of the long-term experiments in the regime of real forecast simulation with advancement up to four months. All methods employed at present of the forecast of geomagnetic activity operate with its components determined by external factors and its own evolution (even if statistical approaches are used). However, a random (spontaneous) component is rather essential because the forecasted system is complicated in a synergetic sense, the typical feature of which is instability caused by the trajectory divergence in the phase space. It is not very important for the short-term geomagnetic forecast, because the external factors, i.e., the solar activity and interplanetary medium state, are already given by the observations. Therefore, the unpredictability of many of the solar activity manifestations, e.g., flares, is not important. However, for the long-term geomagnetic forecasts, which are explicitly or implicitly based on the solar activity forecast, the random component is comparable with the determined one (and exceeds it for catastrophic events). Thus, the impossibility of taking into account the random component degrades the accessible accuracy and advancement of the forecast. The recently discovered effect of macroscopic nonlocality gives a basic possibility of the random component forecast. This effect, the nature of which apparently consists in persisting of correlations of the entangled states formed by the dissipative processes [1, 2] at the macro-level [3], is manifested in correlations of any dissipative process without any local carriers. The equation of macroscopic nonlocality [4–7] based on transactional interpretation of the nonlocal correlations [8] relates the entropy productions in the probe-process and source-process with symmetrical retardation and advancement. It means for random processes the possibility of observation of unusual advanced correlations of the random processes. Moreover, owing to the lower efficiency of absorption of the Wheeler–Feynman advanced electromagnetic field by the intermediate medium [9], the advanced correlations may exceed retarded ones. In wide series of geophysical experiments [4–7, 9–14], these peculiarities of macroscopic nonlocal correlations have been reliably confirmed. As the detectors, the lab probe spontaneous processes were used under conditions of exclusion of all possible local impacts (temperature variations and so on). Most data have been acquired with detectors based on the spontaneous variation process of self-potentials of weakly polarized electrodes in an electrolyte (the theory of detectors, their design, and parameters are described in [4–6, 10]). The most interesting results were obtained in study of relationship of the probe-processes with various helio-geophysical processes with a big random component, especially geomagnetic (characterized by the *Dst* index) and solar (characterized by the radio wave flux *R*) activity. In the last case, it has been found that in the range of 9 standard frequencies (245–15 400 MHz) the greatest correlation with the detector signals is observed in the band 610–2800 MHz, i.e., with some displacement relative to that usually employed in the study of solar–terrestrial relationships of the 10.7 cm (2800 MHz) wave. For suppression of autocorrelation, universally known determined (periodic) components were removed from data by band-pass or low-pass prefiltration. In the cross-correlation function of the activity index (*Dst* or *R*) and detector signal obtained after the prefiltration, the advancement of the main correlation maximum relative to the detector

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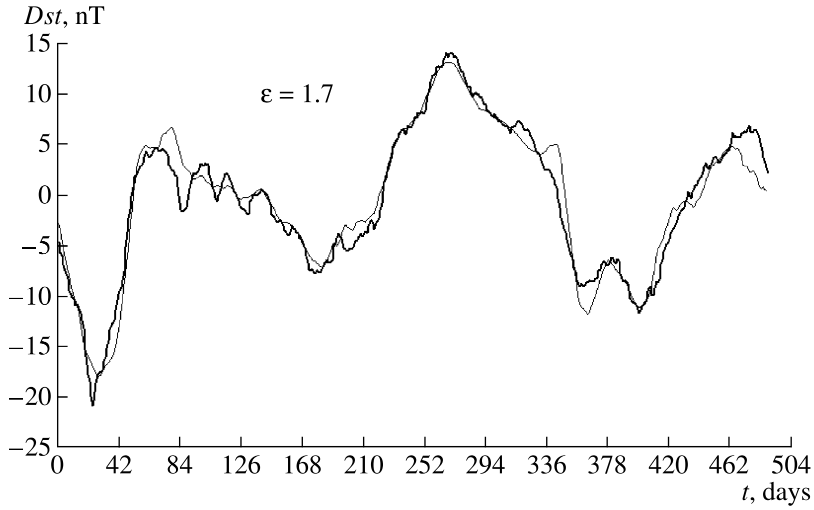

Fig. 1. The forecast of geomagnetic activity with advancement 35 days (fine line) compared to the factual curve (thick line). The origin of time count (days) corresponds to September 19, 1995.

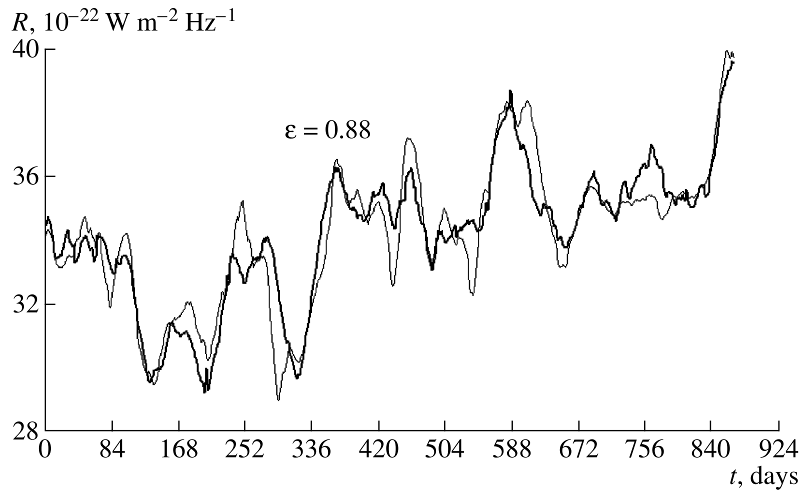

Fig. 2. The forecast of solar activity with advancement 35 days compared to the factual curve. The origin of time count corresponds to March 20, 1995.

signal proved to be large (33–130 days), while its level was sufficiently high (0.5–0.9). This fact allowed to demonstrate the possibility of the forecast of the random component of the solar and geomagnetic activity by the detector signal by means of shift of the realizations [6, 7, 10–14].However, such a simple approach is invalid for the real forecast because of the following reasons: (i) the processes are far from δ-correlated ones; therefore, big errors are unavoidable; (ii) position of the main correlation maximum is instable because of nonstationarity of the processes and one can use it only for a posteriori demonstration. For the solution of the real problem, the algorithm has been elaborated based on the convolution of impulse transfer characteristic with the multitude of the preceding detector signal values. On the "training" interval $[t_1, t_n]$, the impulse transfer characteristic $g(\tau)$ is computed, which relates the detector signal X and forecasted parameter (activity index) Y with advancement $\Delta t = t - t_n$ by solving the convolution equation:

$$Y(t) = \int_{t_1}^{t_n} g(\tau) X(t-\tau) d\tau. \quad (1)$$

Solving of Eq. (1) in the discrete form is reduced to the system of linear equations $\{\mathbf{Y} = \mathbf{XK}\}$. The components of **K** vector are equivalent to coefficients of plural cross-regression (for the case of Gaussian distribution). The number of equations n equals the advancement of the forecast. **X** is the square matrix $n \times n$, the strings of which are formed from values of the detector signal on the training interval. The first string consists of the values with time index from 1 to n; the second, from 2 to

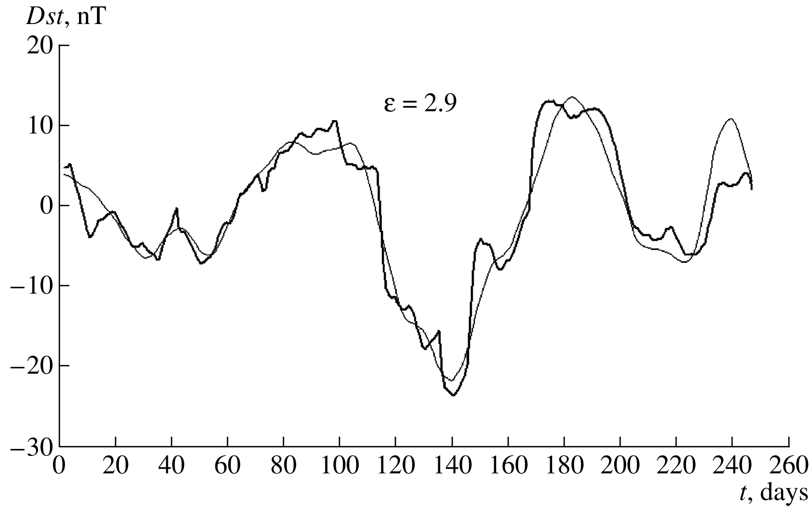

Fig. 3. The forecast of geomagnetic activity with advancement 123 days compared to the factual curve. The origin of time count corresponds to February 20, 2003.

$n + 1$; and so on. The sequential values of Y are corresponding to each string of the matrix. The system is solved by the Gauss method. The stability of the results is achieved by an optimal regularization. Practically, the advancement is chosen equal to the expected average position of the correlation maximum. The total training interval for Y ends by the last observed value; for X, by the preceding Δt. The computed transfer characteristic in such way is then used for the calculation of the only value of the forecasted parameter Y with the advancement Δt. For this purpose, the direct problem (1) is solved by X interval ended by the last observed value. On the next day, the training interval is moved forward and the next value Y is forecasted. Such a procedure allows us to minimize influence of nonstationarity. To suppress the residual instability, the received sequence goes through an optimal low-pass postfiltration. This method is more preferential than the plural regression method (based on correlation matrix calculation) often employed in the akin context of uncertainty of the cross-correlation function maximum, because the suggested method does not require any additional hypothesis about the probability distribution. It is essential because the distribution is very seldom the eigendistribution, which is needed for uniqueness of the traditional solution of the regression problem, and it is not nearly always Gaussian, which is needed for correspondence of this solution to the maximal likelihood criterion. For test of the method in the regime of real forecast simulation, all obtained data of the natural experiments with nonlocal correlation detectors by duration of hourly measurements not less than two years have been employed [7, 11–14]. Such series turned out to be two (both with the electrode detectors). Results of day-by-day forecasting series (with duration less than observed ones at the expense of corresponding prefiltration and employment of initial segments as training ones) were compared with factual evolution of *Dst* or R. Quality of the forecast was assessed by standard deviation of the curves ε in corresponding absolute units, i.e., nT for *Dst* and 10^{-22} W m^{-2} Hz^{-1} for R. The optimal postfiltration in all cases had pass period $T > 14$ days. Based on the algorithm described above, every point of the forecasted curves presented below is the result of computation by selected observed data, minimal volume of which is determined by the forecast advancement (determining duration of the training interval) and by the filter parameters. It should be stressed that only the long-period random component is forecasted; i.e., the forecast is background, although the nonlocality effect in itself admits the forecast of individual powerful events [11]. Figure 1 shows the geomagnetic forecast by the first (and the longest available) time series. Observed data were prefiltered in the band pass 28 days < T < 364 days. Advancement of the forecast $\Delta t = 35$ days (error $\varepsilon = 1.7$). Without postfiltration $\Delta t = 42$ days, but $\varepsilon = 2.4$. Figure 2 shows the solar forecast by the same series. Prefiltration $T > 28$ days. Advancement is the same; i.e., $\Delta t = 35$ days, error $\varepsilon = 0.88$. Without postfiltration, $\Delta t = 42$ days, $\varepsilon = 1.16$. Figure 3 presents the geomagnetic forecast by the second series (data of the last experiment showed availability of nonlocal correlations with the most advancement [13, 14]). Prefiltration 28 days < T < 183 days. Advancement $\Delta t = 123$ days, $\varepsilon = 2.9$. Without postfiltration, $\Delta t = 130$ days, $\varepsilon = 3.5$. Figure 4 shows the solar forecast by the same series as for the case of Fig. 3. Prefiltration is the same: $\Delta t =$ 123 days, $\varepsilon = 2.0$. Without postfiltration, $\Delta t = 130$ days, $\varepsilon = 3.5$.Thus, employment of nonlocal correlation allows us to realize the background long-term forecast of geomagnetic and solar activity with accuracy acceptable for all the practical purposes. This idea may also be implemented for the forecasts of the dissipative processes with big random component in other geospheres, e.g., for the seismic activity.

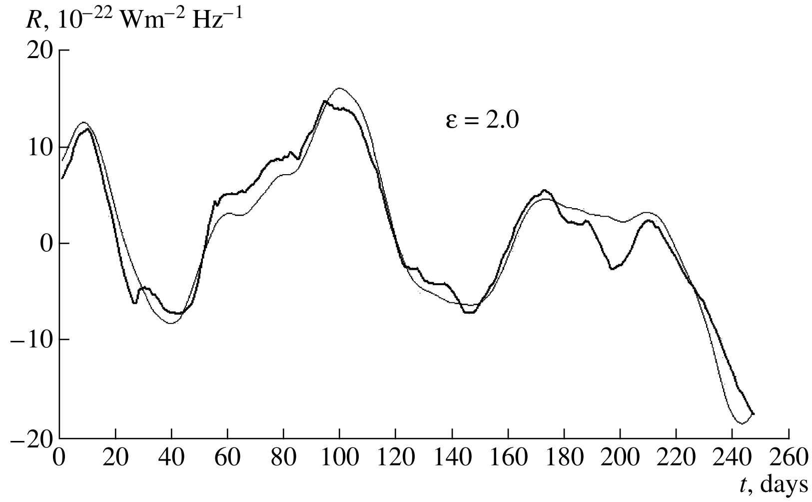

Fig. 4. The forecast of solar activity with advancement 123 days compared to the factual curve. The origin of time count corresponds to February 20, 2003.

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