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FORECAST OF SOLAR AND GEOMAGNETIC ACTIVITY ON THE MACROSCOPIC NONLOCALITY EFFECT

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The macroscopic nonlocality effect appears as correlation of the irreversible processes without any local carriers of interaction. For the random processes there are, besides retarded correlation, unusual advanced one. The long-term experiments with the detectors, containing insulated probe-processes and large-scale natural source-processes with big random component have been revealed the advanced correlations. It allowed to put forward the problem of the use of nonlocal correlations for the forecast of some natural processes. This problem has been solved and demonstrated by the series of the long-term solar and geomagnetic forecasts.

1. Introduction

Any naturalist, not limiting himself artificially by bounds of his peculiar tasks and thus not passing over the difficult universal physical problems, must fall to thinking on concordance of time reversibility in the basic physical theories and visible, one can say, flagrant time irreversibility of the real World. Hadronic mechanics answers to this challenge. Somewhat the similar answer had been suggested by N.A. Kozyrev in the framework of causal mechanics [1 – 4]. Although the main postulate of causal mechanics – fundamental time irreversibility – looked natural, the logical and experimental conclusions were so unexpected (with weakly formalized theory and not too rigorous experiments), that they could not be accepted in due course. After Kozyrev some of his experimental results were successfully reproduced at the different labs (e.g. [5 – 7]), but it did not change the situation in view of unclear-cut formulation of the tested hypothesis and unrigour of the experiments.

One of the most important results of causal mechanics implies that asymmetrical (irreversible) time is an active substance, via which an universal transaction of the distant dissipative processes on any nature is realized and this transaction runs both with retardation and with advancement. The latter gives the possibility, in some sense, to observe the future as an existing reality. This conclusion is striking in itself and paradoxal logically, since the initial postulate was just the most radical statement about irreversibility of time.

In the last decade Kozyrev's idea was developed in connection with two new quantum mechanical ideas: the transactional interpretation [8] and persisting of nonlocal correlations in a strong macroscopic limit [9]. Although a consistent theory remains to be created, understanding of causal mechanics effects as a possible manifestation of quantum nonlocality at the macro-level allowed to perform the rigorous experiments demonstrated availability of advanced correlations [10 – 18].

In this paper we consider the results of contemporary experimental studies, concerning transaction of the large-scale random processes in reverse time. In Sec. 2 and 3 we shortly describe theoretical and experimental background for the last years, when availability of advanced macroscopic nonlocal correlations was proven. It implied the possibility of the forecast of some natural, in particular, solar and geomagnetic processes. In Sec. 4 a pragmatic algorithm for such forecast is considered. In Sec.5 we present the main result – the first practical realizations of solar and geomagnetic forecasts on the macroscopic nonlocality effect. The conclusion is in Sec.6.

2. Theoretical background

By beginning of 90-th the axiomatic of causal mechanics, including the notion of causality itself, had been successfully formalized [19]. By the way the method of causal analysis of experimental data had been suggested and widely tested (e.g. [20 – 24]. Essentially the formalism is as follows.

For any variables X and Y via conditional $H(X|Y)$, $H(Y|X)$ and marginal $H(X)$, $H(Y)$. Shannon entropies the independence functions i are introduced:

$$i_{Y|X} = H(Y|X) / H(Y)\ ,\ i_{X|Y} = H(X|Y) / H(X)\ ,\ 0 \le i \le 1. \quad (1)$$

Values of i characterize one-sided independence of the variables. If, e.g., $i_{X|Y}$ = 0 then X is a single-valued function of Y, if $i_{X|Y}$ =1 then X is independent of Y. Roughly speaking, values of i behave inversely to module of correlation coefficient (more exactly, such analogue is $(1-i_{Y|X})(1-i_{X|Y})$). However in contrast to the correlation function, the independence ones equally fit to any (nonlinear) type of dependence X and Y, but the main thing is they reflect asymmetry typical for causal-effect relationship. It allows to introduce the causality function γ:

$$\gamma = i_{Y|X} / i_{X|Y}\ ,\ 0 \le \gamma < \infty\ , \quad (2)$$

and to define the cause Y and the effect X as variables for which $\gamma > 1$. If $\gamma < 1$, then inversely, X is cause and Y is effect. The case $\gamma = 1$ corresponds to adiabatic (causeless) relationship X and Y. Claim of retardation of effect relative to cause is introduced then as necessary condition of local connection of X and Y. This claim (axiom):

$$\gamma > 1 \Rightarrow \tau = t_Y - t_X < 0 \quad (3)$$

corresponds to the principle of local or strong [25] causality.

The described approach is classical. It had been also generalized to three or more variables (the causal network) [22].

The main constant of causal mechanics [1] is pseudoscalar $c_2 = ae^2 / \hbar$ (a is dimensionless constant) called course of time, which is velocity of cause-to-effect transition at the level of elementary ("contact") link. It is interesting that value of c_2 was determined from the macroscopic experiment with an exited gyro [1] (the close value follows from data of another gyro experiment[7]). In the framework of semiclassical causal analysis [19] the course of time is not constant:

$$c_2 = \frac{e^2}{\hbar} \frac{(1 - i_{Y|X})(1 - i_{X|Y})}{i_{X|Y} - i_{Y|X}}. \tag{4}$$

Since $c_2 < 0 \Rightarrow \gamma > 1$, $c_2 > 0 \Rightarrow \gamma < 1$, $c_2 \to \pm\infty \Rightarrow \gamma \to 1$, one can use c_2 instead of γ for determination of directionality of the causal connection.

In the case of quantum mechanical causal analysis Shannon entropies in Eqs. (1) must be replaced by von Neumann ones. As the conditional entropies can be negative, $-1 \le i \le 1$ and $-\infty < \gamma < \infty$. In particular, the pure entangled state corresponds to $i_{Y|X} = i_{X|Y} = -1$. At the quantum mechanical level the value of γ is insufficient for distinguishing the cause and effect. But we can distinguish them via c_2; e.g. if $c_2 < 0$ then Y is cause and X is effect.

However even if X and Y are related by nonlocal quantum correlation, we have to analyze the classical output of measuring device, therefore we can not obtain the negative conditional entropies. Then, the definition of causality via γ continues to be valid, but the phenomenon of quantum nonlocality satisfies only weak causality principle according to which the effect X must be retarded relative to the cause Y, if Y is controlled (initiated) by an observer[25]. If Y is non-controlled (random), then advancement of X relative to Y is allowed.

Thus, calculating by experimental data $i_{X|Y}$ and $i_{Y|X}$ as function of time shift τ , it is possible, by their minima, to find optimal time shifts corresponding to connection of X and Y. Then, by value of γ relative to 1, it is possible to establish direction of causal connection. In the case if Y is known to be cause (e.g. Y is some measure of a source-process), while X – to be effect (e.g. X is detector signal), then for any classical interaction min $i_{X|Y}$ would observe only at $\tau < 0$, and this minimum would correspond to max $\gamma > 1$. Only for nonlocal transaction of X and Y it is possible $\gamma > 1$ at $\tau > 0$.

Further, Kozyrev had predicted theoretically (though only qualitatively) existence of correlation of any dissipative processes due to time asymmetry, without any local carriers of interaction. He proved it in the various lab [1] and astrophysical [2, 3] experiments. In the latter case he dealt with non-controlled source-processes and discovered besides retarded correlation, unusual advanced one. Our analysis had been shown that properties of Kozyrev's correlations are phenomenologically similar to quantum nonlocal ones considered in the context of transactional interpretation of quantum nonlocality [8], its persisting at the macro-limit [9] and entanglement production due to dissipation [26 – 28]. It allowed to suggest the equation of macroscopic nonlocality, describing factual Kozyrev's results, of the form [10, 11, 13, 14]:

$$\dot{S} = \sigma \int \frac{\dot{s}}{x^2} \delta(t^2 - \frac{x^2}{v^2}) dV , \tag{5}$$

where

$$\sigma \sim \frac{\hbar^4}{m_e^2 e^4} , \tag{6}$$

$v^2 \le c^2$, $\dot{S}$ is the entropy production in a probe process (that is a detector), $\dot{s}$ is density of entropy production in the sources, σ is cross-section of transaction. (The specific dimensionless thermodynamical entropy S here and the entropy of levels H from Eq. (1) are distinguished by the definition spaces of the probability operator and are easily related within the exfoliated spaces theory [24]). The δ-function shows that transaction progresses with symmetrical retardation and advancement. In particular, if the transaction occurs through a medium by diffusion entanglement swapping, then values of resulting retardation and advancement are large.

Eq. (5) in its simplest form does not take into account absorption by the intermediate medium. Its influence, however, is very peculiar. In Narlikar and Hoyle [29] it has been proven that although the equations of Wheeler-Feynman electrodynamics (from which transactional interpretation is originated) are time symmetrical, fundamental time asymmetry represents itself via absorption efficiency asymmetry: while absorption of retarded field is perfect, absorption of advanced one must be imperfect. It leads to the fact that level of advanced correlation through a screening medium may exceed the retarded one.

As it is not possible to observe S and s directly, we have to evaluate for the concrete source and probe processes the theoretical expressions relating the entropies with the observables: $\dot{S} = F(P_d, \{p_d\})$, $\dot{s} = f(P_s, \{p_s\})$, where P_s is measured parameter of the source-process, P_d is the same of the probe-process (detector signal) $\{p\}$ is set of other parameters of the processes, influencing on the entropy, which must be known unless they are stable. This problem is quite solvable [10 – 13, 17].

If we observe the described unusual correlations of the macroscopic processes (*X* and *Y*), how can we prove their nonlocal nature? Suppose some process *X* acts upon a distant process *Z* by means of any local interaction by the causal chain $X \rightarrow Y \rightarrow Z$. The intermediate process *Y* is situated so that local carriers of interaction can not come *Z* avoiding *Y* (e.g. *Y* occupies a spherical layer around *Z*). Then the claim of locality in terms of conditional entropies is:

$$H(Z|XY) = H(Z|Y). \tag{7}$$

Transform the left-hand side of this equation:

$$H(Z|XY) = H(XYZ) - H(XY) = H(XZ) + H(Y|XZ) - H(X) - H(Y|X) = H(Z|X) + H(Y|XZ) - H(Y|X).$$

Substituting the last expression into Eq. (7), we obtain:

$$H(Z|X) - H(Z|Y) = H(Y|X) - H(Y|XZ). \tag{8}$$

As $H(Y|X) - H(Y|XZ) \geq 0$, then $H(Z|X) \geq H(Z|Y)$. Normalize on $H(Z)$:

$$i_{Z|X} = H(Z|X)/H(Z) \geq H(Z|Y)/H(Z) = i_{Z|Y}. \tag{9}$$

Next, rearrange terms in Eq. (8):

$$H(Z|X) - H(Y|X) = H(Z|Y) - H(Y|XZ). \tag{8a}$$

Transform the right-hand side of this equation:

$$H(Z|Y) - H(Y|XZ) = H(YZ) - H(Y) - H(XYZ) + H(XZ) = H(YZ) + H(XZ) - H(XZ|Y).$$

Since $H(YZ) \geq 0$ and $H(XZ) - H(XZ|Y) \geq 0$, then in the left-hand side of Eq. (8a) $H(Z|X) \geq H(Y|X)$. By 7-th Shannon theorem [30] $H(Z) \leq H(Y)$, hence

$$i_{Z|X} = H(Z|X)/H(Z) \geq H(Z|X)/H(Y) = i_{Y|X} . \qquad (10)$$

Eqs. (9) and (10) bring to a Bell-type inequality, its violation is a sufficient condition of nonlocality of correlation *X* and *Z*:

$$i_{Z|X} \geq \max\,(i_{Z|Y}, i_{Y|X}). \qquad (11)$$

In the derivation, the classical property of non-negativity of the conditional entropies has nowhere been used. Taking account of the parallelism of classical and quantum information theory [31] it means that the present derivation holds in terms of von Neumann entropies as well. Next, only the notion of locality but not of the hidden variables has been used. In the pioneer work of J. Bell [32] it was meant that violation of his inequality testified absence of hidden *local* variables. The latter not always was stressed in a large body of the subsequent works dedicated to discussion of like inequalities. Thus we stress that violation of Ineq. (11) does not rule out availability of hidden *nonlocal* variables. A typical hidden nonlocal variable is advanced/retarded Wheeler-Feynman field and its generalization on the quantum amplitudes [8, 25, 29].

3. Experimental background

The experimental problem is to establish a correlation of the entropy changes in a probe-process and in the source-processes according to Eq. (5) under condition of suppression of all classical local impacts (temperature, electromagnetic field, etc).

Two experimental setups for study of the macroscopic nonlocality effect with large-scale natural processes – GEMRC and CAP ones – had been constructed. In the former the detectors of nonlocal correlations based on the spontaneous variations of self-potentials of weakly polarized electrodes in an electrolyte and on the variations of dark current of the photomultiplier were employed. In the latter the detector based on the variations of ion mobility in the electrolyte cell was employed. The theory of detectors allowed to relate the measured signal with the entropy production in the probe process, i.e. to compute the left-hand side of Eq. (5) and consciously to take exhaustive steps on suppressing the local impacts. The design of the detectors and their parameters are described in detail in Ref. [10-13].

For the source-processes, the large-scale helio-geophysical processes with big random component and the determined lab processes (phase transitions) were used. Since in the latter only retarded correlation is observed [33,34], in the following the former are considered. All the results presented below are based on long term series with duration from 1 to 3 years and data sampling from 5^m to 1^h.

The signals of all detectors spaced up at 40 *km* proved to be synchronously correlated. The analysis has shown that they are formed by some common causes, but their influence cannot be local.

Such common causes turned out (in order of decreasing of influence intensity): the solar, synoptic, geomagnetic and ionospheric activity. The advanced response of the detector signals to these processes has been reliably revealed. The retarded response is always less. The order of value of advancement (and retardation) is large – from 10 hours to 100 days. The value of response and the time of advancement increase with the source-process spatial scale.

The main efforts has been concentrated on the solar and geomagnetic activity, because the former is clear cause for the latter, the former is strongest among other sources, while the latter allows the simplest computing of right-hand side of Eq. (5). Both processes have a big random component, the determined component have well known periods and therefore can be easily suppressed by filtration. It was found that detector signals has the biggest correlation with the solar radio wave flux R in the frequency range 610-2800 *MHz* (corresponding to emission from the lower corona-upper chromosphere, i.e. from the level of maximal dissipation in the solar atmosphere) [12]. Within this range an optimal frequency varies from year to year. Concerning the geomagnetic activity, it was found that detectors signals are more correlated not with local variable geomagnetic field, but with *Dst*-index of global geomagnetic activity (the detectors in themselves are completely insensitive to the local influence of the geomagnetic field and solar radio waves, values *Dst* and R are only the parameters reflected the entropy production in the Earth magnetosphere and Sun atmosphere respectively).

For example in Fig. 1, the result of causal analysis of the solar activity R and electrode detector signal U for the year, corresponding to beginning of the present cycle, are shown. In the advanced domain ($\tau > 0$) the values of independence function (U of R) are much lower than in retarded domain ($\tau < 0$) and causality function is much more than 1. The deepest minimum $i_{X|Y} \approx 0.47$ and the highest maximum $\gamma \approx 1.6$ are observed at $\tau = 42^d$. Correlation function maximum at close τ is equal 0.76 ± 0.08 [12, 13].

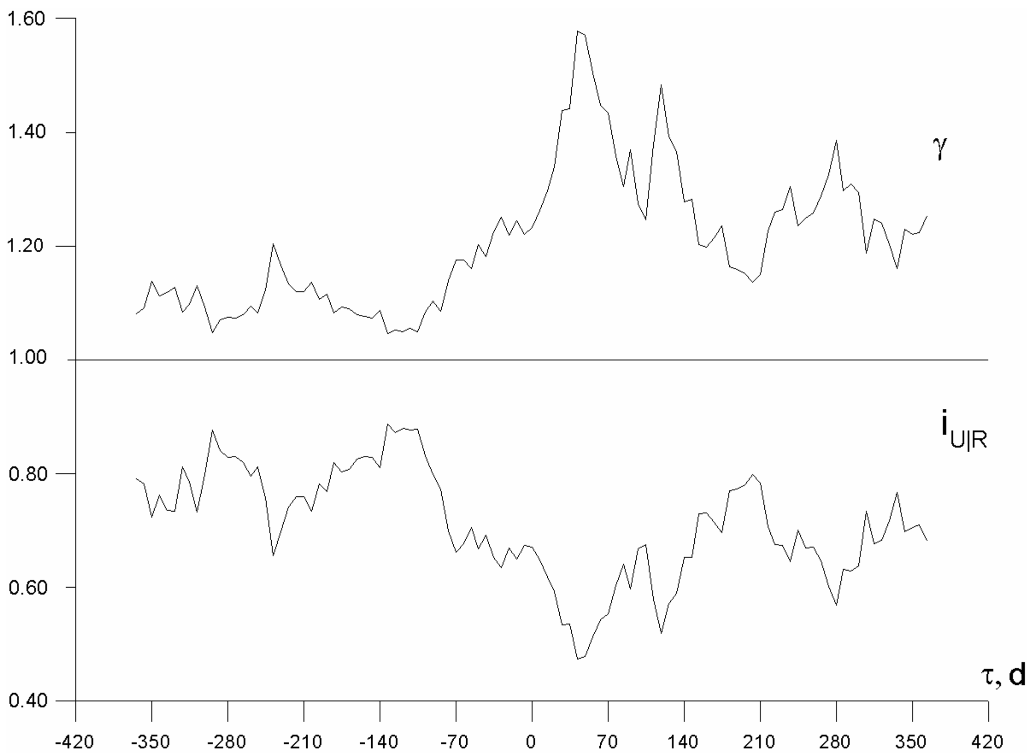

Fig. 1. Independence $i_{U|R}$ and causality $\gamma = i_{R|U} / i_{U|R}$ functions of the detector signal U and solar radio flux R at frequency 2800 *MHz*. Negative time shift τ (days) corresponds to retardation of U relative to R. Realization U 12/11/1996 – 12/10/1997 (realization R begins 1 year before and finishes 1 year after U one).

The position of the main correlation (causal) function maximum (independence function minimum) proved to be rather instable. Although value $\tau = 42^d$ turned out rather typical, it varied for different time series from 33^d to 130^d.

It should be noted, that determined (periodic) components of the source-processes cause only retarded detector response. Therefore to increase the signal/noise ratio in the advanced domain one should suppress by prefiltration the main periodic components corresponding daily, monthly (period of solar rotation) and annual variations and their harmonics. For the example of Fig.1 it turned out low-pass filtration with borderline period $T > 7^d$ was enough, but, as a rule, one need to use wide-band-pass filtration in the period range $28^d < T < 365^d$ or $28^d < T < 183^d$. It is particularly important for detection of advanced correlation for the geomagnetic activity [17]. Maximal advanced correlation observed with optimal prefiltration was 0.92 ± 0.03 for the solar activity [18] and – 0.952 ± 0.04 for the geomagnetic one [17].

It is rather easy to estimate the entropy production in the magnetosphere (due to ohmic dissipation) by *Dst*. It allowed to verify the Eq. (5) by the amplitude spectra of *Dst* and detector signals [17]. In particular, the value of σ was estimated. By data of all three types of detectors σ turned out of order 10^{-20} m^2 in agreement with theoretical prediction (6).

Nonlocal nature of advanced correlation was verified by violation of Ineq. (11). It was done, first, by processes of random variation of lab external (*X*) and detector internal (*Y*) temperatures and detector signal (*Z*) [10, 12, 13] and, second, by solar (*X*) and geomagnetic (*Y*) activities and detector signal (*Z*) [15, 18]. For instance, in the last verification, $X = R$ (at 1415 *MHz*), $Y = Dst$, $Z = U$, $i_{Z|X} = 0.46^{+0.01}_{-0.02}$, $i_{Z|Y} = 0.51^{+0.00}_{-0.02}$, $i_{Y|X} = 0.83^{+0.00}_{-0.02}$. Ineq. (11) is reliably violated, therefore correlation of the solar activity and detector signal is nonlocal. There was also some non-statistical evidence of nonlocality of solar-detector signal relationship (by the individual response to the non-geoactive powerful solar flare) [15].

At last, we could demonstrate the possibility of long-term forecast of random component of the solar, geomagnetic and synoptic activity. It was done by the simplest way – time shift (of optimally filtered) time series by τ corresponding to the main correlation maximum [11-18].

But for the real forecast such simple approach fails since, first, the processes are far from δ - correlated ones, therefore big errors are unavoidable and, second, position of the main correlation maximum is instable because of non-stationarity of the processes and one can use it only for *a posteriori* demonstration.

4. Pragmatic forecasting algorithm

For the solution of the real forecast problem we have elaborated the method, based on the convolution of impulse transfer characteristic with multitude of the preceding detector signal values. On the "training" interval [t_1, t_2] we compute the impulse transfer characteristic $g(\tau)$, which relates the detector signal X and forecasted parameter Y, by solving the following equation:

$$Y(t) = \int_{t_1}^{t_2} g(\tau) X(t-\tau) d\tau. \qquad (12)$$

Eq. (12) in the discrete form is reduced to the system of linear equations $\{\boldsymbol{Y}=\boldsymbol{XK}\}$. The components of $\boldsymbol{K}$ vector are equivalent to coefficients of plural regression (for the case of Gaussian distribution). The number of equations n equals to the advancement of the forecast. $\boldsymbol{X}$ is the square matrix $n\times n$, the strings 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 n+1, etc. The sequential values of the Y are corresponding to the each string of matrix. The system is solved by the Gauss method. The stability of the results are achieved by an optimal regularization.

The computed transfer characteristic then was used for the calculation of the only value of the forecasted parameter with the fixed advancement (which is equal to expected average position of advanced maximum of the correlation function). For this purpose the direct problem (Eq. (12)) is solved on the shifted by one step time interval. On the next step (day) the training interval moved forward and the next value is forecasted. This procedure minimizes influence of non-stationarity. To suppress the residual instability the received sequence goes through an optimal low-pass postfiltration.

The result of this method is equivalent to the plural regression method, but it does not require any hypothesis about the probability distribution. It is essential, for the reason that the distribution of the natural data is not necessary Gaussian.

Note that Eq. (12) is rather universal and convenient for solving of the problem in question, but it could apply to an ordinary deterministic forecast. Hence the algorithm is called pragmatic. But physically there is difference of principle in directionality of causal connection: in our method $Y \rightarrow X$, while in any customary ones $X \rightarrow Y$. Namely time reversal allows to forecast the random processes.

5. Results of experimental forecasting

Although we have to test the described above algorithm on data collected in our experiments previously, we have done it simulating the forecast in real time. We have employed all obtained detector signal continuous time series of sufficient length-not less than one year for *R* and two years for *Dst* (because of shortcoming of the series length, especially valuable with wide-band prefiltration necessary for *Dst*). Only data of the electrode detector *U* (which was the most reliable) satisfied this requirement.

Results of day by day forecasting were compared with factual evolution of *R* or *Dst*. Quality of the forecast was assessed by standard deviation of the forecasting and factual curves (absolute error in corresponding units, i.e. 10^{-22} $Wm^{-2}Hz^{-1}$ for *R* and *nT* for *Dst*).

In Fig. 2 the solar forecast by the same data (and with the same prefiltration $T > 7^d$) as for Fig. 1 is shown. The forecasting curve was postfiltered with $T > 7^d$. Resulting advancement $\tau = 39^d$ and error $\varepsilon = 5.2$ are only slightly less than without postfiltration: $\tau = 42^d$, $\varepsilon = 5.4$.

In Fig. 3 the solar forecast by the longest available time series is shown. Prefiltration in this case was $T > 28^d$, postfiltration – $T > 14^d$. Resulting advancement $\tau = 35^d$, $\varepsilon = 0.88$, while without postfiltration $\tau = 42^d$, $\varepsilon = 1.16$. In this case the utility of postfiltration is clear.

In Fig. 4 the geomagnetic forecast by the same data and with the same postfiltration as for Fig 3. (but with another prefiltration $28^d < T < 364^d$) is shown. Resulting $\tau = 35^d$, $\varepsilon = 1.7$, while without postfiltration $\tau = 42^d$, $\varepsilon = 2.4$.

In Fig. 5 the solar forecast by data of the most recent experiment provided the most advancement is shown. Prefiltration was $28^d < T < 183^d$, postfiltration – $T > 14^d$. Resulting $\tau = 123^d$, $\varepsilon = 2.0$, while without postfiltration $\tau = 130^d$, $\varepsilon = 2.4$.

In Fig. 6 the geomagnetic forecast by the same data and with the same pre- and postfiltration as for Fig. 5 is shown. Resulting $\tau = 123^d$, $\varepsilon = 2.9$, while without postfiltration $\tau = 130^d$, $\varepsilon = 3.5$.

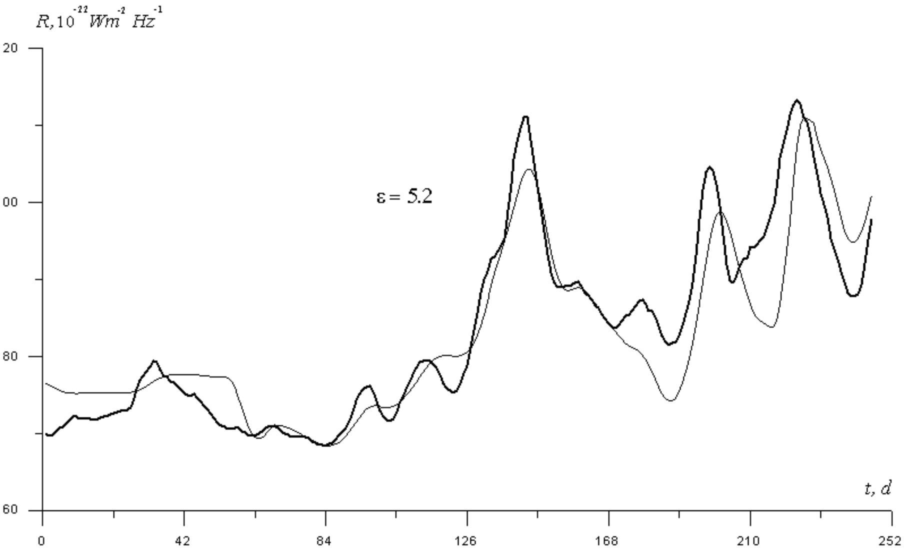

Fig. 2. The forecast of solar activity *R* (at 2800 *MHz*) with advancement 39 days (fine line) compared to the factual curve (thick line). The origin of time count (days) corresponds to 3/21/1997.

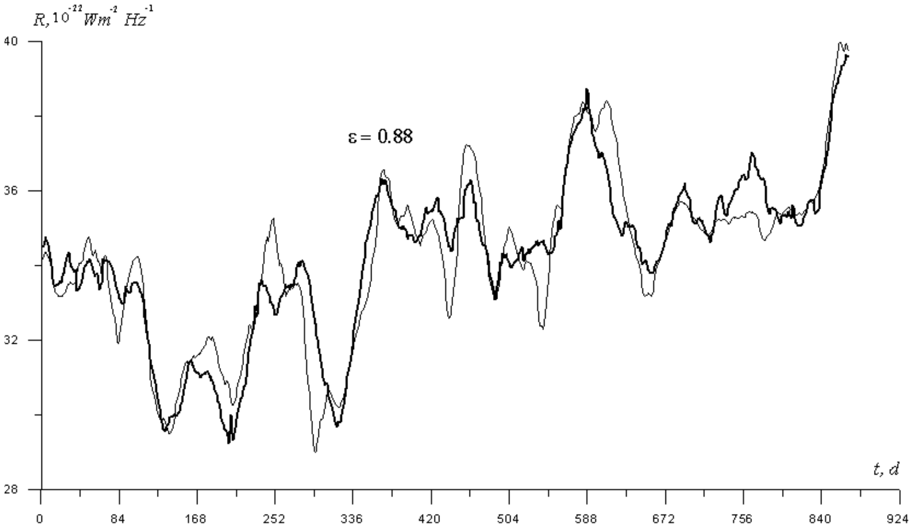

Fig. 3. The forecast of solar activity *R* (at 610 *MHz*) with advancement 35 days (fine line) compared to the factual curve (thick line). The origin of time count (days) corresponds to 3/20/1995.

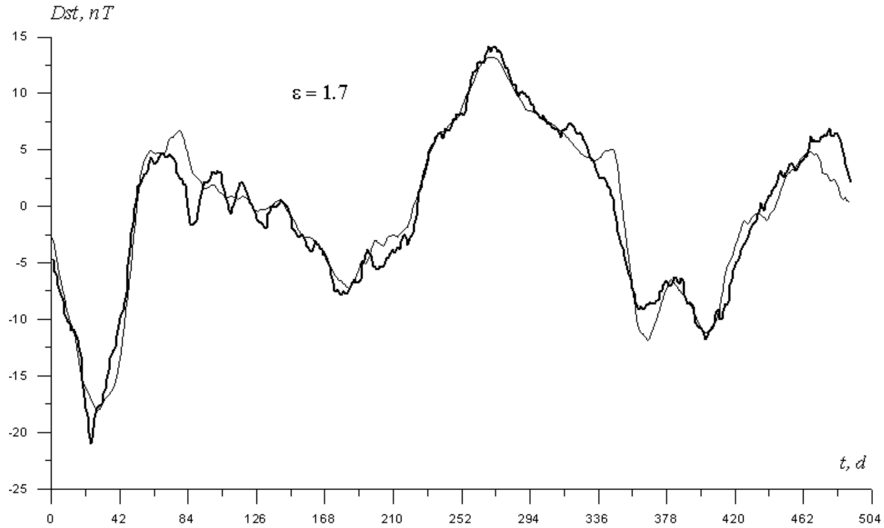

Fig. 4. The forecast of geomagnetic activity *Dst* with advancement 35 days (fine line) compared to the factual curve (thick line). The origin of time count (days) corresponds to 9/19/1995.

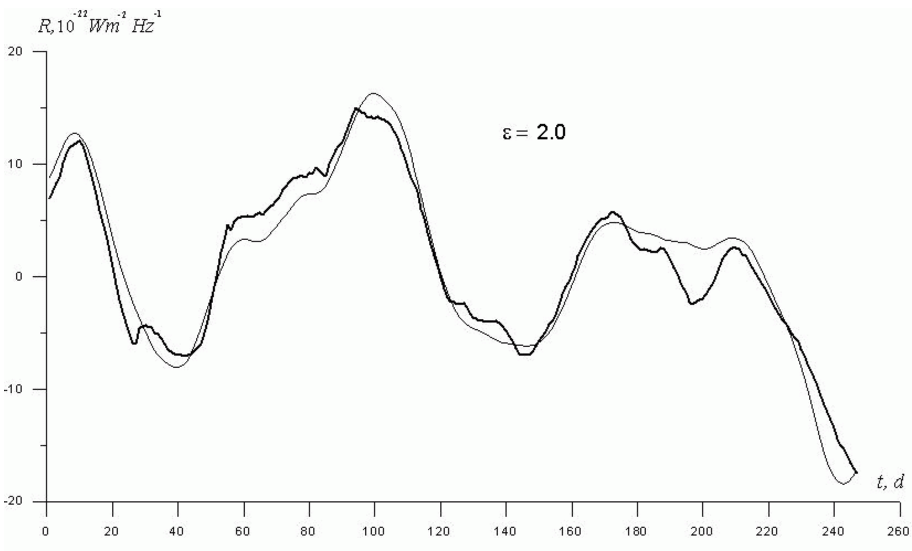

Fig. 5. The forecast of solar activity *R* (at 1415 *MHz*) with advancement 123 days (fine line) compared to the factual curve (thick line). The origin of time count (days) corresponds to 2/20/2003.

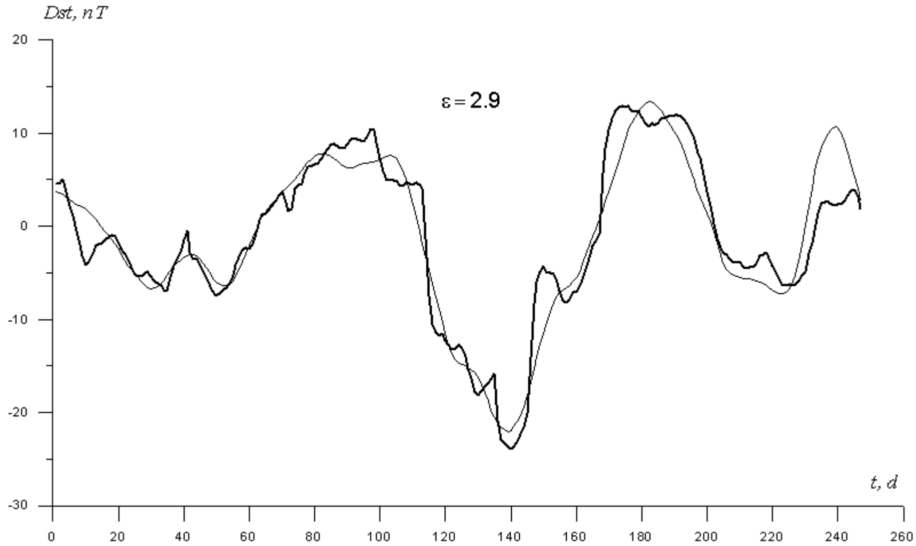

Fig. 6. The forecast of geomagnetic activity *Dst* with advancement 123 days (fine line) compared to the factual curve (thick line). The origin of time count (days) corresponds to 2/20/2003.

As is seen from Fig. 2-6 the forecast quality is wholly satisfactory, the error ε is small as compared with corresponding typical values of *R* or *Dst*.

6. Conclusion

At the contemporary rigour of level, the experiments have confirmed Kozyrev results about surprising manifestation of reversibility in irreversible time – the possibility of observation of the future random states (undetermined by the previous evolution). Of course, the equation of macroscopic nonlocality (5) is as yet not more than heuristic model, therefore development of the underlying theory is extremely burning.

But regardless of the theoretical basis it is possible just now pragmatically to employ the macroscopic nonlocality effect for the long-term forecast of the large-scale natural processes, as it has been proven for the solar and geomagnetic activity. It should be stressed, that the method here presented is unique for the sake of forecasting *random* component of the processes. All existing approaches to the forecasting problem are deterministic (in spite of employment of statistical cross- or auto-regression algorithms), the random component represents for them unavoidable error. Therefore, the method described complements the customary ones.

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