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THE CAUSAL RELATIONSHIP BETWEEN THE DYNAMICS OF HIGH-LATITUDE GEOMAGNETIC ACTIVITY AND TYPE OF SOLAR WIND MAGNETIC CLOUD

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Abstract. By the neural network (ANN) method establishes cause-effect relationships of dynamics of high-latitude geomagnetic activity (for AL index) with the type of Solar wind magnetic cloud caused by the parameters of magnetized plasma coronal ejection. As a tool for analyzing nonlinear dependencies a recurrent neural network of Elman type is used. The neural network model is based on the search for optimal physically connected input and output parameters characterizing the effect on the magnetosphere of a specific plasma stream such as a magnetic cloud. The success of restoring the dynamics of AL on the data used as the established nonlinear AL connection with the parameters of the cloud is characterized.

Interplanetary magnetic clouds (IMC) as the studied fluxes like most geoeffective coronal formations are chosen. There is a variety of configurations of magnetic clouds and methods of their influence on the terrestrial magnetosphere, which depends, among other things, on the impact parameters of the cloud. However, a required feature is the rotation of the interplanetary magnetic field (IMF) vector inside the cloud, which ensures the appearance of a geoeffective negative Bz component. The latter, however, does not mean that IMCs always was cause for global magnetic storms, but they often include substorm processes [1].

The structure of fast magnetic clouds is noticeably complicated by the appearance of a shock wave and a turbulent region behind it. In connection with this, it is of interest for the degree of participation of the elements of the structure of magnetic clouds in the formation of high-latitude geomagnetic activity to establish. In this study, as in [2], we apply a neural network approach using a recurrent neural network of the Elman type. As before, we propose the creation of a fast neural network model based on the search for optimal physically connected input and output parameters characterizing the effect on the magnetosphere of a specific plasma flux, depending on the type of magnetic cloud. However, the feature of this research is the use of different neural network architectures is presented.

The study using minute data corresponding to the observation intervals of 52 interplanetary magnetic clouds recorded in 1998-2012 was performed. The parameters of Solar wind were analyzed for each IMC interval: the concentration N and the plasma velocity V and the components of the vector B (Bx, By, Bz) of the interplanetary magnetic field (IMF) in the GSM coordinate system, as well as the Dst and AL values of magnetic activity indices. All data with a 1-min resolution from http://cdaweb.gsfc.nasa.gov is taken. The analyzed IMC intervals into two samples: group 1 - fast clouds with shock waves and a turbulent region (33 cases) and group 2 - slow clouds without shock waves and turbulent regions (19 cases) were divided. In addition, the data intervals (group 3 - 70 cases) corresponding to isolated magnetospheric substorms according to indications of the AL index without specifying the type of plasma flow, but certainly not associated with magnetic clouds were analyzed.

The performed neural network experiments to the search for optimal physically connected input and output parameters characterizing the effect on the magnetosphere of the magnetic clouds under consideration are devoted. In this case characteristic times of the necessary prehistory of dynamics of the cloud parameters for launching substorms were determined. In numerical experiments, a neural network with an external feedback loop was used. This architecture allows to reinforce learning by synthesized within ANN sequences of the AL-index (Fig. 1). Inputs x and z allow to model two different depths of the prehistory (H and P).

Under the depth of prehistory is meant an additional number of parameters at the input of the neural network, simulating a time delay. The external feedback loop is shown in bold lines, on it the sequences y*(t), fed to the main input, are synthesized. At the input z, the depth of the prehistory is P=60 minutes. Such a delay on the outer loop was chosen on the basis of studying the effect of Solar wind energy storage to provide a substorms process [4]. At the input x, the depth of the prehistory H can vary. The only one output neuron y generates a sequence of AL index values.

The search for the optimal depth of the prehistory at input x for the input sequences of IMF components from 30 to 90 minutes in 10 minute increments was carried out. An objective assessment of the quality of the recovery of the AL index was carried out by calculating the classical correlation coefficient R and the efficiency of PE recovery [3] between the real (target) and neural network generated values. As a result, it was found that 90 minutes of the background prehistory of the By and Bz dynamics of the IMF components proved to be most effective for modeling sequences of AL values. The numerical experiments performed with ANN for group 1 produced average values of R = 0.80, PE = 77% and for group 2 - R = 0.92, PE = 81%.

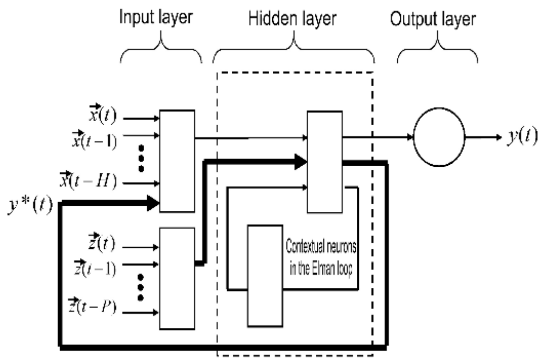

Figure 1

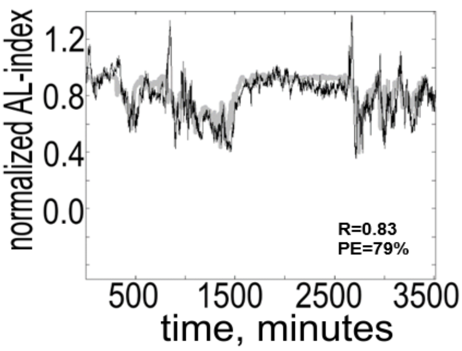

Figure 2

Thus, it was found that the work of neural networks demonstrates the effect of controlling high-latitude geomagnetic activity by the parameters of the magnetic field of the cloud. In experiments to effectively restore the AL index, the need for 90 minutes of the prehistory of the combination of MMP components was shown. It indirectly indicates the dependence of the dynamics of the substorm activity on the structure of the large-scale configuration of the magnetic field of the cloud in the Earth's orbit. The created redundancy of the input array stabilizes the ANN, which by the high quality of synthesis of the amplitude values at the output is demonstrated. In Fig. 2 shows an example of comparing real values of AL-index (gray curve) and simulated ANN (black curve) on June 15, 2005. The abscissa shows the time in minutes, and the ordinate shows the normalized values of the AL index.

The conclusions obtained in the formulation of numerical ANN experiments on the recovery of the AL index indicate the possibility of using ANN as a magnetic cloud detector. The created neural network, using IMF parameters for intervals corresponding to magnetic clouds, is capable of successfully generating an AL index dynamics comparable to the actual situation. Further, we check the capabilities of the ANN on the data intervals of group 3 (70 cases) corresponding to isolated magnetospheric substorms, which are certainly not associated by magnetic clouds. As the results show, if data intervals not corresponding to magnetic clouds (group 3) are fed to ANN inputs, then the quality of recovery of dynamics for AL index drops sharply, even if the data of the same group (R ~ 0.3%, PE ~ 5%). This allows us to state that the network architecture found to the problems of identifying solar plasma streams with magnetic clouds can be applied.

The main conclusions of the study can be formulated as follows:

1. Using By and Bz IMF components that correspond to a magnetic cloud as input parameters of the neural network model taking into account 90 minutes of prehistory is enough to restore the sequence of the AL index.
2. The Elman ANN architecture with an external feedback loop demonstrates a satisfactory recovery of the AL index.
3. The developed model of recovery of the AL index in problems of identifying solar plasma streams with magnetic clouds. Only data intervals corresponding to magnetic clouds can successfully generate an AL index comparable to the actual situation at the output of the neural network model. This is verified on the data intervals of group 3, which, according to the indications of the AL index, correspond to isolated magnetospheric substorms, which are certainly not associated with magnetic clouds.

The completed research researches showed that for the recovery of the AL index sequence with efficiency up to 80% it is sufficient to use the By and Bz IMF components taking into account their 90 minutes of prehistory as input parameters of the neural network model. This means that, during periods of interaction of the Earth's magnetosphere with magnetic clouds, there is a close nonlinear relationship between the level of magnetic activity in high latitudes and dynamics of By and Bz IMF components. The created neural network model with high efficiency to restore both separate substorms and substorms caused by slow magnetic clouds [4] can be used.

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References

[1] Henderson M.G., Reeves G.D., Belian R.D., Murphree J.SD. Observations of magnetosphericsubstorms occurring with no apparent solar wind/IMF trigger // J. Geophys. Res. V. 101. No. A5. P. 10773-10792. doi 10.1029/95JA00186. 1996.

[2] Barkhatov N.A., Vorob'evb V.G., Revunov S.E., Yagodkina O.I., Vinogradov A.B. Demonstration of reflection of solar wind dynamics parameters during formation substorm activity using a predictive tool // Proc. of 39 Annual Seminar «Physics of Auroral Phenomena». PGI. Apatity. P. 27-30. 2016 (in Russian)

[3] Barkhatov N.A., Revunov S.E., Uryadov V.P. Forecasting of the critical frequency of the ionosphere F2 layer by the method of artificial neural networks // Int. J. Geomagn. Aeron. GI2010, doi 10.1029/2004GI000065. 2004.

[4] N.A. Barkhatov, V.G. Vorob'evb, S.E. Revunov, and O.I. Yagodkina Effect of Solar Dynamics Parameters on the Formation of Substorm Activity // Geomagnetism and Aeronomy, 2017, Vol. 57, No. 3, pp. 251–256. © Pleiades Publishing, Ltd., 2017