FORECASTING OF HF PROPAGATION WITH USE OF ARTIFICIAL NEURAL NETWORKS*

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ABSTRACT

On the basis of artificial neural networks (ANN) technology, the algorithm 0,5-3 hours forecast of one of the key parameters of ionospheric HF radio channel – a maximum observed frequency (MOF) is developed. For analysis the data on oblique LFM sounding obtained on the Inskip (England) – Rostov-on-Don (Russia) path are used. Researches have captured a time interval containing various geophysical conditions. The connection of the MOF with changes of the key parameters of the solar wind and the interplanetary magnetic field, determining the sequence of magnetospheric-ionospheric disturbance development resulting in changes of HF radio communication conditions is established. The characteristic time intervals of the ionospheric reaction are determined.

INTRODUCTION

The reliability improvement of short-wave (SW) radio communication remains actual despite of the development of alternate ways of information transfer. For this purpose the forecasting of ionospheric parameters for time intervals from 30 minutes up to several hours is necessary. The forecasting based on improvement of physical ionospheric models frequently fails if too many ionosphere-magnetosphere connections are taking into account. In the work [1] on the basis of the artificial neural networks (ANN) technology the algorithms of forecasting of a critical frequency of the ionospheric F2-layer for the time periods – 1, 2, 3 hours and more were developed. The basic result this work was the efficiency improvement of the forecast when solar wind (PSW) and interplanetary magnetic field (IMF) parameters and geomagnetic disturbance indexes were additionally used.

Advanced in [1, 2] ANN method is used in the present work for prediction of a basic parameter of ionospheric HF radio channel – maximum observed frequency (MOF). The research is carried out using the data of the oblique chirp sounding obtained on the Inskip (England) – Rostov-on-Don (Russia) path at distance of 3050 km. The observation on the given path were conducted in 2003 during half of a year in different geophysical conditions. In the given work the original data for a bi-monthly interval April-May, sufficient for ANN training and check of its forecast efficiency are used.

The purpose of the work is development of algorithm and technique of ionosphere MOF forecasting for the 0,5-3 hours time interval using the global geomagnetic disturbances Dst index and key parameters of near-earth space. These parameters include the solar wind velocity (V), temperature (T) and density (N), vertical component and module of the interplanetary magnetic field (Bz and |B|), power of X-radiation (X-rays) and data on presence of fast corpuscles of different energies (Particles). All of them including data on Dst index were obtained to the address [3].

RESEARCH OF CORRELATION BETWEEN MOF AND KEY GEOEFFECTIVE PARAMETERS OF THE INTERPLANETARY ENVIRONMENT

The necessity of limitation of a number of solar-magneto-ionospheric connections for fulfillment of the successful MOF forecast by the ANN method has prompted the search of most effective of them. For this purpose all additional to MOF series parameters were analyzed their applicability as the learning data. The research was executed separately by intervals with quiet (April 11-12; May 16-17) and perturbed (April 4-8, May 7-9, May 27-30) solar wind defined by the level of solar activity [4]. On these intervals (three active and two quiet) the coefficient of correlation between flows of values of each parameter (Dst, N, V, T, Bz, X-rays,

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Particles) and MOF was calculated. Thus the calculation was conducted in view of different temporary delays in PSW and IMF in relation to MOF, originating from time of disturbance transfer in the solar wind from space vehicle to the magnetosphere and its response. The delays from 0 up to 4 hours every 30 minutes were considered. Thus dynamics of an appropriate correlation coefficient was investigated.

It was established that varies parameters differently influence on the MOF behavior in disturbed and quiet intervals. At the moment of solar activity the MOF profile is noticeably cut up. At the moment of flare (beginning of a disturbed interval) correlation MOF with power of X-radiation (X-rays) and data about presence of fast particles of different energies was studied. At the moment of arrival of the emission to the boundaries of the magnetosphere (end of a disturbed interval) the correlation with MOF was calculated for density (N), velocity (V), vertical component IMF (Bz) and separately for power of X-radiation and data about presence of fast particles of different energies. Such division is explained by the fact that at the moment of flare the X-radiation and fast particles can influence the MOF behavior earlier then the remaining parameters. At the time of emission arrival all parameters are equivalent as X-radiation and the fast particles basically can be generated directly on arriving abrupt changes of the environment and magnetic field parameters. As a result of the analysis of correlation dynamics the following results are obtained.

- The correlation coefficient of density with MOF at the time of disturbance arrival at additional delay in 3-4 hours relatively to MOF can reach 0.7.
- Correlation of velocity with MOF at 2-4 hours delay can reach 0.9.
- The coefficient of correlation Bz with MOF is very low (0-0.2), sometimes an essential anticorrelation (up to – 0.7) at 2.5 hours delay is observed.
- During the flare the correlation coefficient of X-ray parameter with MOF grows with increase of delay and reaches a maximum 0.4 at 3.5- 4 hours delay. At the time of disturbance arrival correlation coefficient is low. The level of X-radiation at the moment of arrival does not exceed average values.
- During a flare the correlation of «Particles» parameter with MOF is low (0.2 – 0.4) or an anticorrelation (up to – 0.9) at 0.5 - 2 hours delay is observed. At the time of disturbance arrival the correlation with MOF is high (up to 0.9) at 2- 4 hours delay.

ESTABLISHMENT OF OPTIMUM DELAY TIME FOR IMF AND PSW PARAMETERS

The determination of the most expedient MOF delay relatively considered parameters of the solar wind and interplanetary magnetic field requires research executed with the help of ANN technique. For this purpose an experimental two-layer Elman ANN (5 neurons in each layer) applied in [1] was used. From two available intervals of the data the April interval as less perturbed was selected for its training and testing. The program for input data package preparation created the arrays containing two parameters – MOF series and module IMF |B| series. In each array 1 to 4 hours delay with a step of 30 minutes was applied to parameter |B|. After training the ANN gave the MOF forecast for 1 hour. As a criterion of ANN training quality the mean square error (MSE) was selected, calculated between the really registered MOF and obtained by ANN MOF series. At the end of each numerical experiment the MSE was calculated for both training (first half of April interval) and for test sequence (second half of interval). The analysis has shown that network error at the test interval with parameter |B| delayed for 2.5-3.5 hours is below than for all remaining cases. The same at a training interval the error starts to reduce with increase of delay starting from 2.5 hours. This can be explained by the fact that such a delay of additional parameter for ANN is preferable. The training and testing thus happens more correctly and effectively. This result agrees well with the previous research of correlation connection between parameters. Further it was decided to apply 3 hours delay for PSW and IMF for April and May intervals.

SEARCH FOR ADDITIONAL INPUT PARAMETERS AND THEIR COMBINATIONS FOR FORECAST QUALITY IMPROVEMENT

One of the tasks of this research was to study the necessity of division of the MOF forecasting technology for quiet and perturbed intervals. As it was shown in the previous research taking into account additional parameters during ANN training in perturbed intervals should increase quality of the forecast. The check of this hypothesis has required additional numerical experiments with ANN. The same ANN types – type 1 for long-term and type 2 for the short-term forecast were applied. For research the May interval was selected as the most continuous and containing both quiet and perturbed intervals in both training and testing sequences. The first half of this May data array was used for network training, the second – for double testing. For the first time testing was conducted only within a quiet interval (May 16-20), the second time – only within perturbed one (May 27-31). It was found that the use of additional parameter in the input data array for the perturbed interval always augments forecast quality (up to 12%), and for quiet interval – insignificantly changes it or even makes it a bit worse. The forecast quality for the perturbed interval is low at training a network only by previous history as the MOF profile is strongly cut up. It is necessary to supplement network input data by the information on accompanying processes, such as: X-ray power, current global geomagnetic conditions, solar wind density. This circumstance becomes even more significant when forecast period is increased.

RESULTS OF NUMERICAL EXPERIMENTS FOR FULL APRIL AND MAY INTERVALS

In the given section the problem on additional parameter for forecast within April and May interval is researched. The most successful combinations of available data series are investigated. Such a study is prompted by ANN technique features – number of parameters used for network training should be limited to prevent an overload of a network (adaptation to large data arrays and increase of training time).

The recommended additional parameters were selected according to following criteria:

- Addition of additional parameter leads to decrease of mean square error (MSE) comparing to training by previous history.
- Presence of additional parameter in the learning data array stabilizes network activity during training and testing that is manifested in rare failure and unsatisfactory outcomes when ANN is restarted.
- Addition of additional parameter results in increase of correlation and forecasting effectiveness on testing data interval which is unfamiliar to the network.

Numerical experiments with ANN have shown the necessity of introduction of additional parameters or their combination in a training sequence for longer forecast periods. The reason is that the information only about a previous history of a process becomes insufficient for successful forecasting. The additional information caused by the physical nature of connection MOF with parameters of a near-earth space is necessary.

After realization of numerical experiments the most successful combinations of input data were finally selected for ANN training for different time periods.

- To increase forecast quality (up to 100%) to 0.5 hour information on previous history is enough for the network. In this case introduction of additional parameter does not influence forecasting effectiveness.
- Addition of Dst index or X-ray power for 1 hour forecast promotes recovery of the MOF profile with up to 95% accuracy.
- 1.5 hours MOF forecast with 89% accuracy can be carried out when X-ray power or Bz component of IMF delayed in 3 hours MOF is introduced into the training data array.
- At 2 hours MOF forecasting the introduction of Dst index, X-ray power or Bz components of IMF delayed in 3 hours to training sequence allows to obtain the forecast with 81% accuracy.
- Recovery of MOF profile at 2.5 hours forecast is possible with 72% accuracy if training data array contains Dst index, X-ray power or Bz component of IMF delayed in 3 hours.
- The ANN is capable to carry out short-term forecast for 3 hours with up to 65% accuracy when Dst index, Bz component of IMF delayed in 3 hours or combination of parameters [N, V, T] also delayed in 3 hours relatively MOF are added to the information on previous history.

QUALITY IMPROVEMENT OF MOF RECOVERY USING A BRANCHY NETWORK WITH ADDITION OF HIGH ORDER DERIVATIVES

The given research is directed on short-term forecast quality improvement with a help of a new strategy of ANN training and testing. In the previous numerical experiments it was shown that addition of the first derivative in the number of training parameters essentially facilitates network activity on MOF recovery. The new numerical experiments were directed to increase the 2-3 hours MOF forecast effectiveness with a help of consecutive introduction of the second and third order MOF derivative to a number of network training parameters. The diagrams in a Fig. 1 illustrate forecast quality dynamics in each series of numerical experiments. In these experiments either Dst index, X-ray, or Bz component of IMF delayed in 3 hours relatively MOF was introduced as additional parameter. These parameters gave approximately identical contribution to forecast quality change. As one can see in the given diagrams presence of these parameters at the short-term forecast increases quality of MOF forecasting.

CONCLUSION

The given research is devoted to development of maximum observed frequency forecast algorithm for 0.5-3 hours time interval on the basis of the artificial neural networks technology. The technique of forecast is applied to the data on oblique chirp sounding obtained on the Inskip – Rostov-on-Don path. The executed researches have included a temporal interval containing different geophysical conditions. The connection of MOF with Dst index variations and X-ray power is detected. The characteristic temporal intervals of ionospheric response to changes of key parameters of solar wind and interplanetary magnetic field determining magnetospheric-ionospheric disturbance sequence were determined.

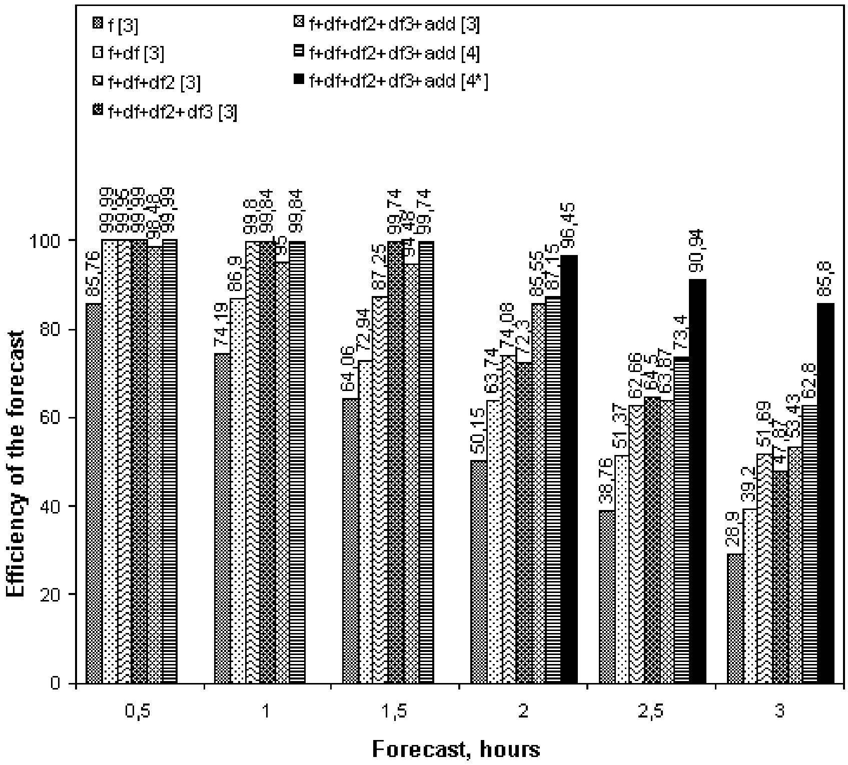

Fig.1. Dynamics of MOF forecast effectiveness within the April interval at consequent addition of high order derivatives and additional parameter during branchy network training. The columns correspond to consequent addition of derivatives (df, df2, df3) and additional parameter (add) to the training array. In square brackets the network type is noted. The sign «*» means application of correction to a responsive signal.

The branchy networks work more steadily. When such networks training is restarted the quality of its training changes less noticeably and as a consequence the forecast quality from experience to experience practically does not change and unsatisfactory results occur extremely seldom. The best results (up to 99%) at 0.5-1.5 hours MOF forecast are obtained using such branchy ANN. The same network carries out the forecast at 2 hours with accuracy of 94% and higher. The 2.5 and 3 hours forecast is carried out with efficiency of 91% and 88% respectively.

The advantage of the ANN method at time series recovery is their applicability for «on line» forecast mode. Obtaining a continuous data array (for example, on the Internet) the network is capable to create a forecasting series and if necessary to correct the training level. Such strategy ensures the most reliable forecast in a real-time mode.

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