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Method of ionospheric data analysis based on a combination of wavelet transform and neural networks

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Abstract

The paper presents a hybrid system based on a combination of wavelet filtering operations and regression neural networks. The system is adapted to analyze the ionosphere data obtained at "Paratunka" station (Kamchatka). Testing of the system has shown its efficiency in the tasks of analysis of characteristic properties of ionospheric data and detection of anomalies occurring during disturbed periods. For a detailed analysis of anomalies, computing solutions based on the application of continuous wavelet transform and threshold functions were suggested. The developed computational tools were implemented in software environment (http://aurorasa.ikir.ru:8580).

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Keywords: wavelet-transform; neural networks; critical frequency of the ionosphere; ionospheric storms; anomalies; magnetic storms

1. Introduction

The paper is aimed at the creation of theoretical and software means for analysis of ionospheric parameters and detection of disturbances during increased solar activity and geomagnetic storms. Ionosphere is considered to be a region of the atmosphere which begins at the altitude of about 60 km and stretches to the altitude of 1000 km and higher [1-4]. Propagation of the significant part of radio wave spectrum is determined by the ionosphere and

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investigation of ionospheric characteristics allows us to use it as an indicator of the processes occurring in the upper atmosphere. The main sources of ionization of the ionosphere are the Sun ultraviolet and X-ray radiation, solar wind flux particles reaching the altitudes of the ionosphere through the magnetosphere in a complicated way, cosmic rays and meteors [1]. Ionospheric parameters considerably change with altitude. They depend on solar activity cycle, geomagnetic conditions, geographic coordinates and contain characteristic diurnal and seasonal changes [3-7]. One of the important tasks of ionospheric parameter analysis is the monitoring of ionospheric state and detection of anomalies [3-8] which have negative impact on satellite system operation and propagation of radio communication. At present, the technologies of observation of the near Earth space and data analysis methods are being intensively developed [9-11]. However, the capabilities of analysis and forecast of ionospheric state are still quite limited. Of important scientific and applied significance are the empiric methods and technical means of detection and identification of anomalous behavior of the ionosphere [7, 12].

Ionospheric data have a complicated structure and disturbing factors of different nature make the direct application of traditional methods of time series analysis ineffective [13, 14]. For the moment, the most developed empirical model of the ionosphere is the International reference IRI model [12, 15], which is based on a wide range of ground and space data. The quality of its estimates is significantly affected by the presence of recorded data in a definite region [12]. New developments of empirical models applying the methods of pattern recognition and neural networks (NN) [3, 8] allow us to improve the quality of forecast in comparison to IRI model. They are implemented easily in automatic mode and are quite flexible. The disadvantage of such models is their strong dependence on input data, their integrity and relatively low level of noise. Recent investigations show that representation of ionospheric parameters on the basis of nonlinear adaptive approximating schemes [2, 16-20] is natural and the most effective for their pre-processing and independent analysis. The methods of decomposition into empirical modes [19, 20] and adaptive wavelet decompositions [2, 16-18] based on this approach are intensively developing at present.

Based on a complex approach applying multiresolution wavelet analysis (MRA) and neural networks, the authors of the paper modeled a characteristic variation of the ionospheric process. During magnetic storms, anomalous disturbances in foF2 were detected which were reflected in the modeling results. Application of MRA to detect a smoothed (trend) component of foF2 time series allowed us to improve the quality of solution of the problem based on neural networks. Methods of continuous wavelet transform and threshold functions were used for the detailed analysis. Tests were carried out on the data of ionospheric F2 layer critical frequency (foF2). The data were obtained at «Paratunka» site (Paratunka, Kamchatskiy kray, IKIR FEB RAS).

2. Description of the method

2.1. Data decomposition based on MRA

In the function of the reference space of initial data $f_0(t)$ we consider a closed space with resolution $j=0$: $V_0 = clos_{L^2(R)}(2^0\phi(2^0 t-k)) : k \in Z)$, generated by a scaling function $\phi \in L^2(R)$ [21]. Based on the MRA, the time series $f_0(t)$ is represented in the form of linear combination of different-scale components, smoothed one $f\left[2^{-m}t\right]$ of scale *m* and detailing ones $g\left[2^j t\right]$ of scales $j=\overline{-1,-m}$ [18]:

$$f_0(t) = \sum_{j=-1}^{-m} g\left[2^j t\right] + f\left[2^{-m}t\right] \tag{1}$$

where different-scale detailing components $g\left[2^j t\right] = \sum_k d_{j,k}\Psi_{j,k}(t)$, $d_{j,k} = \langle f, \Psi_{j,k}\rangle$, Ψ is the basic wavelet, j is resolution; *approximating component* $f\left[2^{-m}t\right] = \sum_k c_{-m,k}\phi_{-m,k}(t)$, $c_{-m,k} = \langle f, \phi_{-m,k}\rangle$, ϕ is a smoothing scaling function. The inferior index *0* corresponds to the initial resolution of the data.

Scheme of data representation based on function (1) is shown in Fig. 1.