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CLASSIFICATION OF SPACE WEATHER COMPLEXES TAKING INTO ACCOUNT CHARACTERISTICS OF PERTURBING SOLAR STREAM AND ITS GEOMAGNETIC DISTURBANCE PARAMETERS

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Abstract. Work is devoted to development of neural network classification of space weather complexes including information about type of solar source, characteristics of perturbing solar streams (solar wind parameters and interplanetary magnetic field components) and parameters of its geomagnetic manifestations in the form of Dst-index dynamics. As result of the executed numerical experiments the basic complexes of space weather, establishing connection between types of solar streams and geomagnetic disturbances of various intensities, are allocated. The allocated complexes will allow carrying out the analysis and specification of influence on Earth magnetosphere of plasma streams from various solar sources, and as forecasting of geomagnetic conditions.

1. Introduction

Classification of space weather complexes has direct relation to an establishment of causal link between solar activity and geomagnetic disturbances. The basic difficulty in its creation is necessity to include the information about characteristics of perturbing solar streams and parameters of their subsequent geomagnetic manifestations. Now as result of carrying out of numerous researches [Tsurutani et al., 1995; Ivanov, 1996; Yermolaev, et al., 2009] the basic types of solar plasma streams and their prominent features are established. To them carry: heliospheric current sheath (HCS), stream from coronal streamers, filament streams, high-speed streams from coronal holes (HSS) and corotation interaction region before them (CIR), and also coronal mass ejections (CME). At movement from Sun CMEs often take the form of closed structures with original behavior of plasma and magnetic field in them – magnetic clouds (MC). Thanks to specific spiral distribution of magnetic field in MC they are one of the most geoeffective plasma structures in solar wind. Because velocities CME/MC usually above velocity of quiet solar wind before them Shock and Sheath – region with sharp change of all interplanetary medium parameters is often formed. Each type of solar stream is characterized by specific dynamic of solar wind parameters (PSW) and interplanetary magnetic field (IMF) components that allows carrying out their identification in interplanetary space.

Despite exhaustive data on solar wind streams the uniform standard classification including as type of solar source, characteristic of plasma stream, and parameters of its geomagnetic manifestations till now is not created. The majority of researches of plasma streams are carried out without attraction of data on their geomagnetic manifestations [Ivanov, 1996; Vennerstroem, 2001; Echer and Gonzalez, 2004]. Attempt to execute neural network classification of space weather complexes taking into account specified above factors has been undertaken in work [Barkhatov, et al., 2006]. The neural network approach for decision of classification problems is perspective. Neural network approach makes it possible division of input images into the set number of classes on the basis of nonlinear correlation processing of experimental data and to state quantitative estimation of results. In the present work as classification tool the neural network on which input characteristics of perturbing solar stream – solar wind density, solar wind velocity, average value of interplanetary magnetic field vector and its components was used. However here the geomagnetic storms divided on intensity of Dst-index on weak, moderated and strong were considered only. The basic condition of successful work of classification neural network is necessity to submit on input of equal duration event. In work [Barkhatov, et al., 2006] this problem was solved by artificial prolongation of short magnetic storms till the sizes of the longest. Besides, in work the big values number in an input signal that complicates work of neural network was used. All it should be reflected in quality of received results.

In the present work contains the development of the neural network method for classification of space weather complexes including the information on characteristics of perturbing solar stream and its geomagnetic manifestations not limited type and duration of geomagnetic disturbance. Here the way of representation of input data, allowed to reduce values number in them, is changed. Also the set of input parameters at the expense of addition southern Bs components IMF, temperatures, dynamic pressure and electric field of solar wind is expanded. In basis of carried out classification of space weather complexes is put on the analysis of communication phases of sudden commencement and main phases of geomagnetic storms with dynamics PSW and IMF perturbing stream. As it is known, what exactly the most intensive physical processes in magnetosphere, connected with arrival the perturbing solar stream to the Earth [Gonzalez et al., 1994].

2. The analysis of geomagnetic disturbances, establishment of their solar sources and corresponding types of plasma streams

Classification of space weather complexes was carried out on hour data of satellite system OMNI about PSW and

IMF for 2000-2007. Is considered 50 isolated low-noises global geomagnetic disturbances of various intensities with duration more than six hours, established on Dst-index dynamic.

According to standard approach geomagnetic disturbances have been divided on intensity on weak (-50 <Dst <-20 nT), moderate (-100 <Dst <-50 nT), strong (-200 <Dst <-100 nT) and extreme storms (Dst <-200 nT) [Gonzalez et al., 1994]. For expansion of analyzed events types in research magnetic disturbance for which was observed only the increase of Dst-index caused by direct influence of solar stream on Earth magnetosphere (DCF) have been added. For the selected geomagnetic disturbances division under form variation Dst on sudden commencement phase on «classical» one-step storms, «non-classical» two-step storms, disturbance only with increase of Dst-index and with increase and insignificant subsequent reduction (-20 <Dst <0 nT) has been carry out. It has been as result allocated eight types of global geomagnetic disturbances: increase of Dst-index (fig. 1a), increase of Dst-index with insignificant subsequent reduction (fig. 1b), weak storms (fig. 1c), moderate classical storms (fig. 1d), moderate non-classical storms (fig. 1e), strong classical storms (fig. 1f), strong non-classical storms (fig. 1g) and extreme storms (fig. 1h). In the further neural network classification will be carry out also on eight classes, according to number allocated to types of global geomagnetic disturbances.

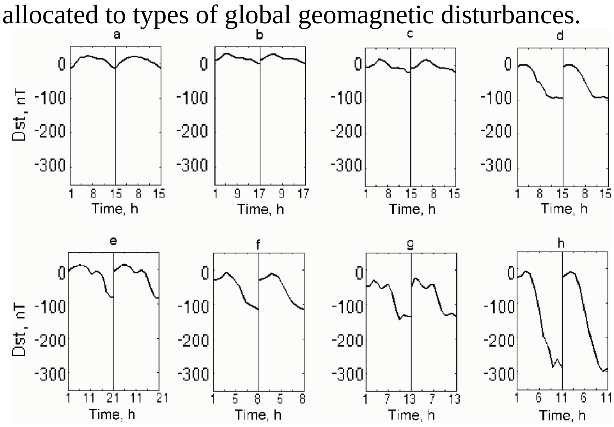

Fig. 1. Dynamics of Dst-index for allocated types of global geomagnetic disturbances (left parts of pictures) and results of processing of Dst-index dynamics spline (the right parts)

Establishment of solar sources for selected geomagnetic disturbances was carried out by the analysis of data solar catalogues, the literature [Lynch et al., 2003; Cane et al., 2003; Leamon et al., 2004; Zhang et al., 2004] and dynamics PSW and IMF in near-Earth space. Following catalogues have been used:

(1) Active prominences and filaments (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_Website/FILAMENTS/)
(2) LASCO CME Catalog (http://vso.nso.edu/cgi/catalogui)
(3) The catalogue of the large-scale phenomena of solar wind for period 1976–2000. (ftp://ftp.iki.rssi.ru/pub/omni/catalog/)
(4) A selected list of solar X-ray events observed by CELIAS/SEM (http://umtof.umd.edu/sem/sem_figs.html)
(5) An incomplete list of possible Interplanetary Shocks observed by the PM (http://umtof.umd.edu/pm/Shocks.html)
(6) Hα solar flares (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_Website/SOLAR_FLARES/FLARES_HALPHA/)
(7) VSO Catalog Search Results GOES X-Ray Catalog (http://vso.nso.edu/cgi/catalogui)

As result of analysis were found solar sources for almost all considered geomagnetic disturbances. However unequivocally to establish type of disturbance solar stream previous some geomagnetic disturbances it was not possible. It is connected with the contradictions encountered in catalogues and literature, and also complicated PSW and IMF dynamics.

3. Neural network classification of space weather complexes

Classification in the present work was carried out by means of special software-computer complex by neural network «layer Kohonen» [Barkhatov and Revunov, 2010]. As input parameters were used: average value of magnetic field vector B, southern Bs magnetic field component, temperature T, hydrodynamic pressure P, electric field VBs of solar wind and Dst-index.

As it was marked above, the basic difficulty of networks classification work is necessity to use of equal length input vectors. Besides, for improvement of network settings quality, the neurons number in input layer, i.e. variables number characterizing dynamics of each input parameter, it is desirable to choose the minimum. In this connection all input data have been presented in form of parametrical vectors. Preliminary dynamics of each parameter has been processed by a cubic spline, to determine its prominent features. For example in Fig.1 in the right parts results of processing by spline of Dst-index dynamics are shown. Further processed parameter dynamics broke into three disturbances, each of which is characterized by the amplitude and duration. Then the input vector can be written down as set of values of amplitudes and durations of each disturbance. As result of this division description of each complex is possible with the six components. On Fig. 2 the example of parametrical vector creation for Dst-index is presented. Duration of disturbance was accepted equal «1» if disturbance lasted less than 24 hours, and «2» – if more than 24 hours. In Table conformity of parametrical vectors component values limits of amplitudes change of input data is presented.

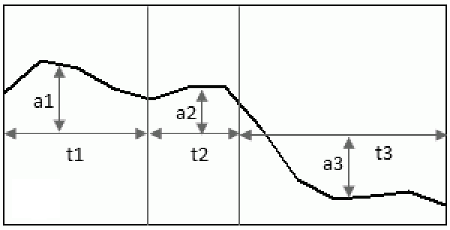

Fig. 2. An example of parametrical vector creation for Dst-index

Table. Conformity of parametrical vectors values to limits of input data changes

Parameter	**Value of parametric vector components for neural network**					
	1	**2**	**3**	**4**	**5**	**6**
Average value of magnetic field vector B, nT	<10	10÷20	20÷30	30÷40	>50	–
Southern component of magnetic field Bs, nT	0÷-5	-5÷-10	-10÷-15	-15÷-20	<-20	–
Temperature T, 10^5 K	<1	1÷2	2÷4	4÷6	>6	–
Pressure P, нПа	<5	5÷10	10÷15	15÷20	>20	–
Electric field, mV·m^{-1}	>-0.1	-0.1÷-0.3	-0.3÷-0.5	-0.5÷-0.7	-0.7÷-1.0	<-1.0
Dst-index, nT	50÷-20	-20÷-50	-50÷-100	-100÷-200	<-200	–

As result of numerical experiments eight complexes of space weather, including characteristics of perturbing solar stream and parameters of its geomagnetic manifestations have been allocated:

Class 1 – geomagnetic disturbances with increase Dst-index, which sources are, streams from coronal streamers or filaments;

Class 2 – geomagnetic disturbances with Dst-index increase and insignificant subsequent reduction, caused by CIR or HSS from coronal holes;

Class 3 – weak magnetic storms which sources were CIR or combination CIR-HSS;

Class 4 – moderate one-step geomagnetic storms caused by interplanetary coronal mass ejection (ICME) in form of MC or ICME with shock;

Class 5 – moderate two-step storms which sources are CIR or combinations CIR-HSS (see for example Fig. 3a);

Class 6 – strong one-step storms caused by combinations of sheath and leading field ICME in form of MC or ICME with shock;

Class 7 – strong two-step storms caused by CIR;

Class 8 – extreme one-step storms caused by combinations of shock, sheath and leading field ICME in form of MC (see for example Fig. 3b).

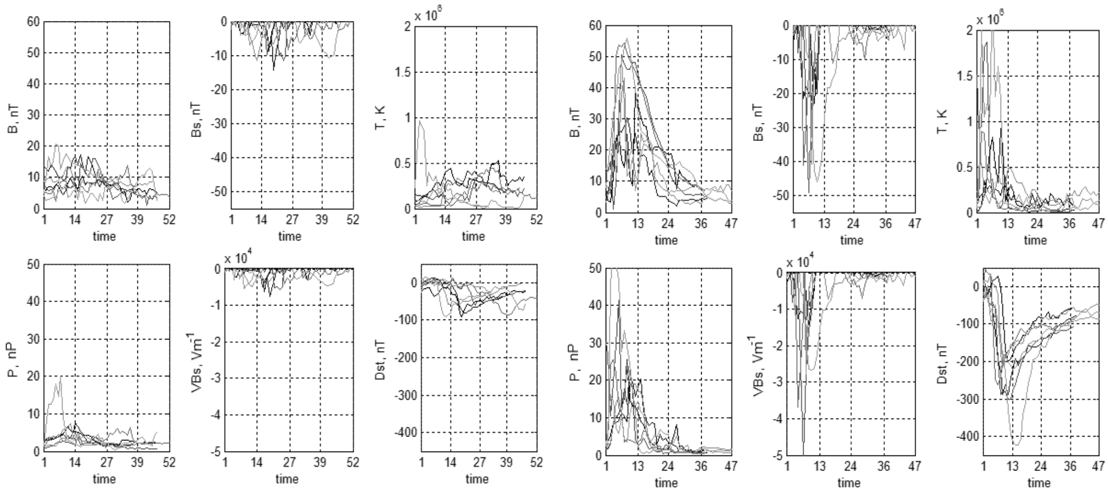

Fig. 3. Dynamics of average value of magnetic field vector, southern component IMF, temperature, dynamic pressure, electric field of solar wind and Dst-index for 5 (a) and 8 (b) space weather complexes

4. Conclusions

Neural network classification of space weather complexes the including representations about solar source, type of perturbing plasma stream and parameters of its geomagnetic manifestations is carry out. Here the classification neural network «layer Kohonen» for which input parameters were average value of interplanetary magnetic field vector, its southern component, temperature, dynamic pressure and electric field of solar wind is applied. Use as the input data parametrical vectors of interplanetary medium parameters has allowed to solve problem of various duration of analyzed events and to improve quality of network settings. As measure of global geomagnetic activity the Dst-index was used. The offered technique neural network classification has provided classification of space weather complexes with high efficiency (~84 %).

As a result of neural network experiments eight space weather complexes is allocated. On their basis probably more detailed studying of influence on Earth magnetosphere of various solar plasma streams. The executed work opens prospects of creation short-term forecast technique of global geomagnetic conditions based on visual observations over solar activity.

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