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CLASSIFICATION APPROACH TO THE ANALYSIS OF MAGNETIC DISTURBANCES IN AURORAL REGION AND THE MAGNETIC DISTURBANCE AT MIDDLE AND LOW LATITUDES

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Abstract. The degree of geomagnetic storms main phase intensity and duration on the presence or absence of nonlinear connection between ring current components (symmetrical and asymmetrical parts) and the auroral electrojets is studied. For this purpose the classification analysis of 30 single-step geomagnetic storms main phases is made by Kohonen neural network. The intensity of considered current systems was estimated by the values of corresponding indices - SYM, ASY for symmetric and asymmetric parts of ring current, and the AU, AL for eastward and westward electrojets. On the base of classification under SYM, AU and SYM, AL parameters it was established that in the same class enter events corresponding to "classical" geomagnetic storm development with have small amplitude and duration. When it was classified by two indices, one of which is ASY index, in one class entered intense and long duration storms.

1. Introduction

Recent studies devoted to magnetospheric and ionospheric current systems development during geomagnetic storm are demonstrated the connection between low-latitude disturbances caused by activation of ring current symmetric and asymmetric parts with disturbances in the auroral region [*Grafe et. al., 1997; Kamide et. al., 1998; Huang and Foster, 2007*]. For example, in paper [*Sun and Akasofu, 2000*] it was shown that during geomagnetic storms the ring current is saturated with ions O+ which enters along field lines during magnetospheric substorms development. This means that ring current and auroral electrojets constitute a unified ionospheric-magnetospheric current system. In the papers [*Barkhatov et. al., 2008; Barkhatov et. al., 2007*] the connection between indices which characterizing the development of the symmetric (SYM) and asymmetric (ASY) ring current parts with intensity indices of eastward (AU) and westward (AL) electrojets was searched on examples of specific geomagnetic storms. On the base of linear correlations between specified indices at main phases intervals was established a connection between mid-latitude and auroral current systems. But it should be noted that there is a view about an absence of direct connection between these currents [*Grafe and Feldstein, 2000*]. According to this assumption, current systems develops independently of each other and the occurrence of correlation between corresponding intensity indices is consequence of their common source. Thus the problem of current systems development and integration is still not fully investigated.

The main purpose of this paper is the identification of common patterns in magnetospheric and ionospheric current systems dynamics that determine the presence or absence of nonlinear connection between ring current elements and auroral electrojets for various intensity storms. For these aim the neural network approach is applied using Kohonen artificial neural network (ANN). At the same time the nonlinear connection between studied currents is established using Elman ANN algorithm with feedback and Fuzzy logic network.

2. Used data and research methods

A study of nonlinear connection was conducted for the main phases of 30 single-step classical geomagnetic storms of various intensity ($-300 \leq Dst \leq -50$ nT) for pairs of indices SYM-AU, SYM-AL, ASY-AU and ASY-AL for the period from 2000 to 2003. The analyzed events selection held by Dst index.

Since the nonlinear connection between mid-latitude and auroral geomagnetic activity indices have ambiguous character, their detection was performed using two neural networks types - ANN Elman algorithm with feedback and Fuzzy logic network. ANN training in each experiment was always performed anew at one of events and 29 remaining events consistently offered it as a test. In the learning process it has weights adjustment, i.e., ANN establishes the connection between SYM, ASY indices and AU, AL indices within the main phase of particular geomagnetic storm. The estimation of restoration quality of auroral electrojet intensity indices under ring current intensity indices was performed by calculation of linear correlation between the real and reconstructed sequences. The restoration was considered satisfactory if the correlation coefficient is higher than 0.4. The presence of linear correlation shows that the connection between midlatitude and auroral current systems has the same character as in learning event. The absence of linear correlation indicates that a new event have fundamentally different nature.

Thus on the base of these results we can identify general trends in development of unified ionospheric-magnetospheric current system for different geomagnetic storms.

By the results of experiments it was found that during magnetic storm main phase there is a strong connection between magnetospheric and ionospheric current systems. Therefore the possibility of acceptable neural network restoration of auroral electrojet intensity indices (AU, AL) under ring current intensity indices (SYM, ASY) exist. Fig. 1 shows an example of AL index restoration under ASY index.

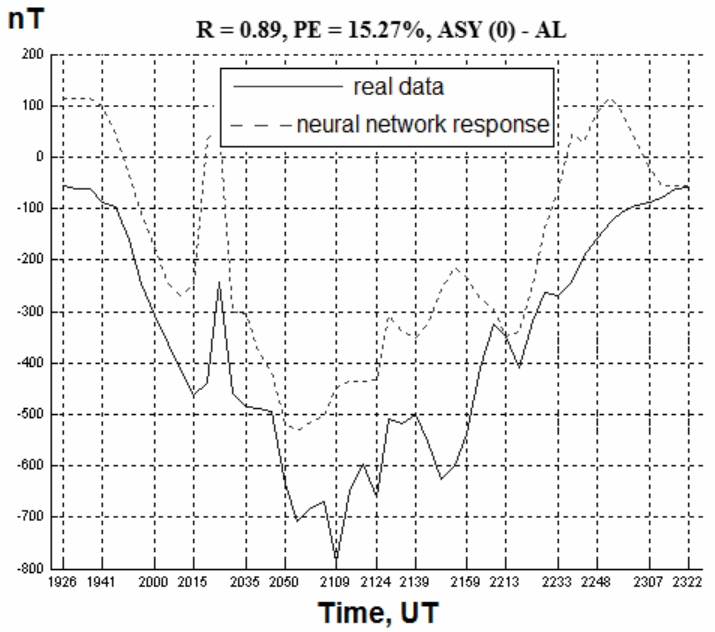

Figure 1. Restoration of AL index under ASY index by Elman neural network

It should be noted that during geomagnetic storms the mid-latitude and auroral current systems may have a relative time shift in the development due to different mechanisms of their formation [*Francia et. al., 2004; Barkhatov et. al., 2007; Barkhatov et. al., 2008*]. In this study on the base of non-linear relationships analysis, the time shift in development of ring current symmetric part and auroral electrojets is established. For pair SYM-AU nonlinear correlations were searched with time shifts 0; 30 and 60 minutes and index SYM delayed relative to AU. For pair SYM-AL similar experiments were carried out using neural networks with time shifts 0; 60 and 120 minutes, and the index SYM delayed relative to AL. The obtained results indicate the existence of time delay in development of ring current symmetric part relative to eastward electrojet for 30 minutes and westward electrojet for 60 minutes. This means that the ring current is generally characterized by a time delay in the development relative to auroral electrojets for geomagnetic storms of varying intensity.

For pairs ASY, AU and ASY, AL similar analysis was not performed because of executed earlier study [*Barkhatov et. al., 2007; Barkhatov et. al., 2008*]. It was found that the asymmetric ring current during the main phase of a geomagnetic storm develops synchronously with auroral electrojets.

3. Statistical analysis of neural network restoration results of AU, AL indices

Statistical analysis of neural network experiments results was performed by calculating the ratio of cases number with satisfactory correlation for each indices pair to the total number of possible combinations for all geomagnetic storms events. For pairs SYM-AU and SYM-AL the analysis was carried out with previously established time delays.

The results showed that for pairs of indices SYM-AU and ASY-AL it is the largest number of events with correlation coefficient > 0.4 between the real and restored sequences. This means that the corresponding current systems have a stable relationship and a similar scenario within geomagnetic disturbances of varying intensity. For pair of SYM-AU this may be due to activation of corresponding current systems by a single source. The current system of ring current symmetric part indeed is enclosed and does not need a union with auroral electrojets. For pair ASY-AL significant correlation can be explained by union of corresponding current systems. This conclusion is consistent with results of [*Grafe et. al., 1997; Barkhatov et. al., 2007; Barkhatov et. al., 2008*].

To establish the additional features of the nonlinear connection of asymmetric ring current with auroral electrojets, it has been calculated a number of satisfactory restored cases. This analysis allows determining how typical for geomagnetic storm main phase development of an event is.

Fig. 2 shows the results of counting the number of satisfactory restoration for pairs of indices ASY-AU and ASY-AL. The *x* axis marked a sequence numbers of events and the *y* axis - number of satisfactory restorations. In gray shows the results for pair ASY-AU, in black - for pair ASY-AL.

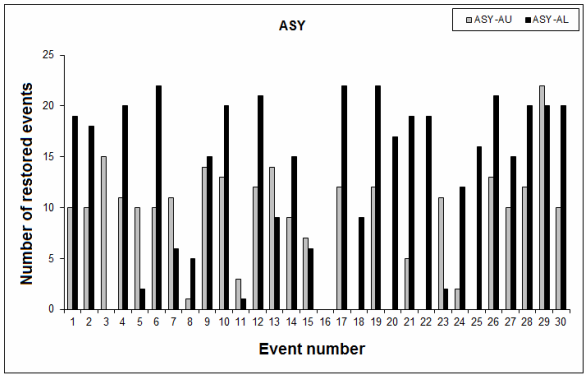

Figure 2. The number of satisfactory restored cases of each considered event

When considering the obtained results it can be found that for pairs ASY-AU and ASY-AL exist events restored equally well (9, 29) and equally poor (11, 15, 16). But for most events there is a "balance shift" of AU index to index AL: if for pair ASY-AU a number of satisfactory restorations of specific event is large, at the same time for pair ASY-AL for the same event the number of satisfactory restorations will be small, and vice versa. According to Fig. 2, for the greatest number of cases the "shift" takes place in pair ASY-AL direction. Thus the good connection of asymmetric ring current with westward electrojet obtained in papers [*Grafe et. al., 1997; Barkhatov et. al., 2007; Barkhatov et. al., 2008*] and confirmed in the present study may be explained by the fact that within geomagnetic storm main phase a westward electrojet usually developed intensively then eastward electrojet.

Under the assumption that the asymmetric ring current forms with eastward and westward electrojets a single ionospheric-magnetospheric current system, it can be concluded that the presence of "balance shift" for pairs ASY-AU and ASY-AL indicates the degree of each electrojet development. In other words, if one of electrojets developed significantly, then the other has a poor development. This may mean that the eastward and westward electrojets have the same energy budget.

4. Classification approach to analyzing the connection between magnetic disturbances in the auroral region and magnetic disturbance at middle and low latitudes

Considered in this paper geomagnetic storms have different intensity and the main phase duration. Despite the fact that the time behavior of Dst index for all events considered above have the "classical" form, the dynamics of symmetric and asymmetric ring current parts and auroral electrojets within different events differs substantially. To establish the influence degree of SYM, ASY, AU and AL dynamics for the presence or absence of nonlinear connection between corresponding indices, it has been carried out the classification of all events by the Kohonen neural network. The classification was carried out by two parameters that are consistent with studied pairs of indices: SYM and AU; SYM and AL; ASY and AU; ASY and AL. In each experiment a neural network was proposed to divide all 30 events in the two classes. Fig. 3 shows an example of events classification under parameters ASY, AL. According to the results, the first class in the main has short-time events with low intensity, and the second class – long-time and intensive events.

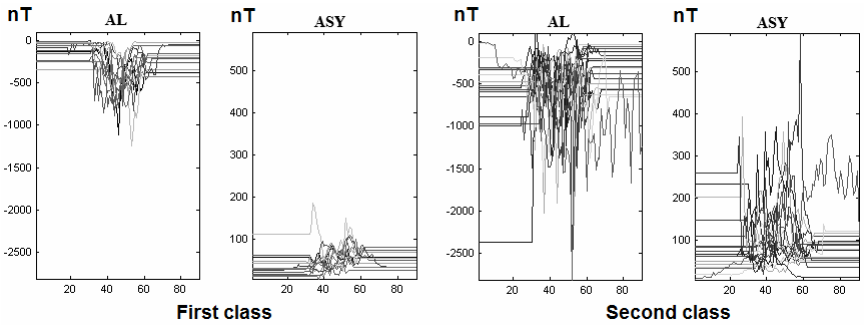

Figure 3. Example of 30 geomagnetic events classification under ASY, AL parameters

In the classification of the studied events was only under SYM and AU parameters, in the first class misses 80% satisfactorily restored events. Events that are rare in the neural network restoration classified bad - they are divided between two classes are almost equally. In the classification only under the parameters SYM and AL neural network puts 90% satisfactorily reconstructs events in the first class. Events what are rare in the restoration, as well as for the previous pair, divided equally between the classes. According to classification results, for SYM and AU, SYM and AL parameters well restored events share a common view of the symmetric ring current and auroral electrojet dynamics. Almost all of these events have a small amplitude and duration and correspond to the "classical" development of geomagnetic storms and substorms. It can be assumed that the physical ionospheric and magnetospheric processes in them are of the same nature and develop the same scenario.

In the classification of 30 events under the parameters ASY and AU similar patterns is observed: 80% of the events, the most common in restoration, were in the same (second) class, and events with poor neural network restoration virtually not classified. The second class, as mentioned above, consists of intensity and long-time duration events. For the ASY and AL parameters present a very different picture of events distribution. Events common in the restoration is equally divided between the classes. However 90% of rare restoration events neural network puts in second class.

Thus, the classification under two parameters, one of which is ASY index, the main number of events often (ASY and AU) or rarely (ASY and AL) occurring in the restoration, gets into the class of intensity and long-time duration events. In the case of ASY and AU parameters in this class were the "classic" events that occur frequently in the restoration. In the case of ASY and AL parameters in this class were "non-classical" events that are least likely to meet in restoration. This fact confirms the hypothesis of existence of ionospheric-magnetospheric current system, the components of which are asymmetric ring current and both auroral electrojets. In other words, if in such current system ASY-AU connection is strong, the connection ASY-AL is almost obscure, and vice versa. This conclusion fully confirms the results of Sec. 2, Fig. 2.

5. Conclusions

In this study by a method of neural network classification investigated the influence degree of indices SYM, ASY, AU and AL dynamics for the presence or absence of the nonlinear connection between the corresponding current systems on the main phases of geomagnetic storms of varying intensity. The results of the events classification is established that a good restoration AU and AL indices under index SYM occurs in most cases for short-time main phases of geomagnetic storms with small or moderate amplitude ("classical" geomagnetic storms and substorms). In the classification of ASY, AU and ASY, AL parameters noted the presence of "balance shift" in development of auroral electrojets in relation to each other: if it is significant development of westward electrojet, eastward electrojet is underdeveloped, and vice versa. It can be assumed that the current system of asymmetric ring current, and the eastward and westward electrojets have overall energy budget. This confirms the hypothesis about integration of these current systems at magnetic storm main phase.

At the same time demonstrated the presence of the nonlinear connection between symmetric, asymmetric ring current parts and auroral electrojets. For this purpose by neural network method was performed restoration of eastward (AU) and westward (AL) electrojet intensity indices under intensity indices of symmetric (SYM) and asymmetric (ASY) ring current. According to results of statistical analysis of all number restored by Elman ANN and Fuzzy events was marked 30 minute time delay in development of symmetric ring current relative to eastward electrojet and 60 minute delay relative to the westward electrojet.

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