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Autoprediction of Dst index using neural network techniques and relationship to the auroral geomagnetic indices

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RESUMEN

Posibilidades de predecir las variaciones de Dst basándose en sus valores previos fueron estudiados usando un perceptron de multicapas con alimentación directa. Fue encontrado que el índice Dst puede ser autopredicho con unas horas de anticipación. Ambas fases (principal y de recuperación) son predichas correctamente con hasta 3 horas de anticipación. Pero para predicciones más avanzadas se observa un desplazamiento entre la posición del mínimo de Dst observado y el predicho. El uso de diferentes índices de chorro auroral como parámetro de entrada mostró que existe una baja correlación entre ellos y el Dst. Tormentas débiles y moderadas son bien predichas, en cambio los valores de predicción para Dst para tormentas más intensas son menos negativas que los mínimos observados; este resultado podría estar relacionado con la conocida saturación de índices de chorro auroral durante el desarrollo de tormentas intensas. Predicciones con base en el índice PC muestran mejor correlación con Dst. A pesar de que la amplitud de variación de Dst no se reproduce correctamente, no existe el desplazamiento temporal entre el mínimo de Dst medido y predicho.

PALABRAS CLAVE: Dst, predicción, redes neuronales.

ABSTRACT

The possibility of prediction of Dst variations using previous Dst values has been studied using a feedforward multi-layer perceptron. It was found that the Dst index can be autopredicted a few hours ahead. Both main and recovery phases of geomagnetic storms are accurately predicted up to 3 hours in advance. But, for more advanced predictions, a time shift between observed and predicted Dst minima is observed. The use of auroral electrojet indices as input has shown that there exists a slight relationship between these indices and Dst variation at least one hour ahead. Weak and moderate geomagnetic storms are predicted well, but the predicted Dst values for more intense storms are less negative than the observed minima, this may be related to the known saturation of auroral electrojet indices due to intense storm development. A prediction based on the PC index shows better correlation with Dst. Although the amplitude of Dst variation is not reproduced correctly, there is no time shift between measured and predicted location of Dst minima.

KEY WORDS: Dst, prediction, neural networks.

INTRODUCTION

Prediction of geomagnetic activity is one of the most important problems in the physics of the magnetosphere. It is now well known that geomagnetic storms at Earth are associated with the passage of southward directed interplanetary magnetic fields (IMF), persisting for sufficiently long intervals of time (see González *et al.*, 1994 for a review].

Most of the authors have concentrated on forecasting geomagnetic activity by looking for different ways to relate the solar wind parameters and geomagnetic activity indices. Correlation studies, linear filter analysis, nonlinear input/output analysis, and analytical models (see Detman and Vassiliadis, 1992] for a review) are used. The best long-time Dst prediction has been reached by applying neural networks [Lundstedt and Wintoft, 1994; Wu and Lundstedt, 1997]. In a first paper, the main phase has been predicted quite well using feedforward multilayer perceptron. But the recovery phase has not been modeled correctly. The Elman recurrent network applied in the second paper was succesful in overcoming this deficiency. This can be explained by taking into consideration that interplanetary medium parameters are related to the injection function only. The loss processes which determine the decay of ring current - like conversion of energetic ions into neutrals, direct particle precipitations into the auroral ionosphere, Joule heating, etc. - have intrinsically magnetospheric origin. Inclusion of recurrent connections in the neural network serves as a short-term memory about the previous stage of the magnetosphere.

RELATIONSHIP BETWEEN DST AND OTHER INDICES

The relationship between the Dst-index to other geomagnetic indices has been analysed in Akasofu, 1981; Saba *et al.*, 1994. It was found that peak Dst values correlate best (correlation coefficient of 0.87) to the time integral of AE during the preceding 10 hours from Dst minimum. On the other hand, it was found that at the moderate storm level, AE and absolute values of Dst grow together in a linear relation. However, for more intense storms, AE index saturates at a level of about 1000 nT due to the shift of the auroral electrojets to subauroral latitudes.

Correlation and cross correlation functions. We obtained the correlation and cross correlation functions for the time series of Dst, different auroral electrojet and polar cap indices with the objective of evaluating their predictability. The correlation time obtained for a 1983 time series is much larger for Dst index (t_c=30.67) larger than the correlation times of auroral electrojet (t_c = 7.62, 5.59, 2.38, and 10.31 for AE, AL, AO, and AU, respectively) and PC (t_c =4.44) indices, and the Dst correlation function decreases slowly having a number of maxima. This means that the Dst index has a structure which differs notably from other indices. Long correlation time manifests the fact that the random component is very low and that the Dst-index is more dependent on its neighbors than are other analysed indices.

The relationship between Dst and other indices may be established analyzing the cross correlation function between them a few hours before. Figure 1 shows cross correlation coefficient between the Dst index and one of the auroral electrojet or PC indices. As seen, auroral electrojet AL index shows the best and AU the worse correlation with Dst, and PC index has considerably larger cross correlation with the auroral electrojet indices similar to obtained by Wu and Lundstedt [1997] for solar wind parameters.

PREDICTION OF DST USING NEURAL NETWORKS

Network Arquitecture. We used the simple feedforward multilayer perceptron, which is capable of mapping an input vector to an output vector from examples with known answers. In our case, the network consists of one input, one hidden, and one output layers. The hidden layer creates a representation of the features in the input vector ξ. The output O_i^μ of a single hidden-layer neural network with an input pattern μ is given by

$$O_i^\mu = g_1\left(\sum_j w_{ij} g_2\left(\sum_k w_{jk}\xi_k^\mu\right)\right) \tag{1}$$

where w_{ij} and w_{jk} are the weights between the input and hidden layer and between the hidden and the output layer, respectively.

The transfer functions ($g_{1,2}$) are chosen as hyperbolical tangents. The weights are updated by the gradient descent algorithm according to

$$\Delta w(t+1) = -\eta\nabla_w E + \alpha\Delta w(t) \tag{2}$$

where η, the learning rate, and α, the momentum term, are used to smooth or speed up the learning process and avoid local minima. In our case, the input layer has 8, the hidden layer has 26, and the output layer 1 neurons. η=0.01 and α=0.5, which correspond to the case of noisy data. Initial weights are 0.3. The stop training criterion is 200 000 events from the minimum average error. It is necessary to stress that these types of neural networks are generally used for recognition problems. The learning patterns are presented randomly and the network remembers the shape of the input data and has no memory about the previous stages of the system. Here the information about the previous stages of the magnetosphere is included in the input by mapping the previous Dst from 8+t_d to 1+ t_d, where t_d is the time delay, which varies between 1 and 8 for different networks.

Error estimation. The accuracy of our predictions is estimated by calculating the linear prediction-target correlation coefficient a

$$\rho = \frac{\sum_{\mu=1}^{N}\left(T^\mu - \langle T\rangle\right)\left(O^\mu - \langle O\rangle\right)}{\sqrt{\sum_{\mu=1}^{N}\left(T^\mu - \langle T\rangle\right)^2}\sqrt{\sum_{\mu=1}^{N}\left(O^\mu - \langle O\rangle\right)^2}} \tag{3}$$

where T is the target.

RESULTS

We have chosen a 1983 database, because they are very representative of geomagnetic activity including the presence of 8 strong geomagnetic storms with the minimum intensity below -100 nT, although no ‘’superstorm’’ occurred. The Dst time series has been divided into 16-hour time intervals, in which first 8 hours have been assigned as input and subsequent 8 hours as output in different networks to predict Dst from 1 to 8 hours in advance. Subsequently, we have trained similar networks using AL or PC indices as input and one of Dst indices from 1 to 8 hours ahead as output. The 1983 data were used as training (477 samples), and 1980 data as validation set (8752 patterns of 8 hours, shifted 1 hour every following pattern to obtain continuous picture). Table 1 shows obtained linear correlation coefficient between real and predicted predicted Dst-variation obtained for different input parameters.

	1	2	3	4	5	6	7	8
Dst	0.95	0.93	0.88	0.85	0.82	0.78	0.75	0.72
AL	0.72	0.71	0.70	0.68	0.66	0.65	0.63	0.61
PC	0.66	0.66	0.66	0.64	0.63	0.63	0.61	0.59

As seen, Dst index gives much more accurate prediction than the other indices. Figure 2 shows the results of pre-

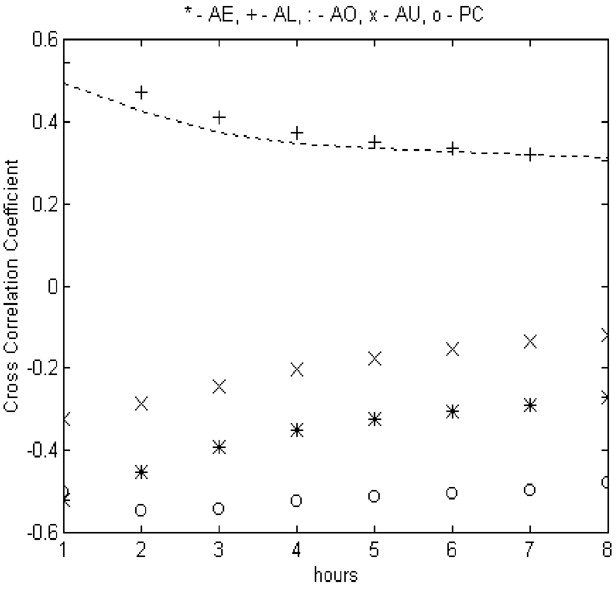

Fig. 1. Cross correlation coefficients between Dst, auroral electrojet, and PC indices

diction of Dst one and four hours in advance. As seen, in case of the Dst input the network predicts well all phases of the geomagnetic storm Day 42-44, 1980 4 hours ahead. But for more advanced prediction, a pronounced time shift in peaks is observed. In the case of the AL input, the predicted Dst index reproduces moderate variations in Dst but does not reproduce the geomagnetic storm. We believe that the principal cause of this is the well known saturation of auroral electrojet indices due to displacement of the auroral oval to the lower latitudes during geomagnetic storm development. Prediction based on the PC index shows better correlation with Dst. Although the amplitude of Dst variation is not reproduced correctly, there is no time shift between measured and obtained location of Dst minima.. The PC index is able to predict Dst decreases up to 8 hours in advance. We believe that this result may be improved significantly by taking into consideration seasonal and daily variations in the ionospheric conductivity and also improving the network with one more layer.

4 CONCLUSIONS

This is one of the first attempts to predict the Dst variation based on measurements at ground level. Large autocorrelation time allows Dst to be autopredicted well a few hours ahead, but the prediction for more than 4 hours is difficult because of observed time shift between the location of predicted and observed maxima. Auroral electrojet did not show to be useful for the prediction. The principal cause of this may be the shift of the auroral oval to the lower latitudes during geomagnetic storm development. In contrast, PC index may be potentially useful for the prediction, but it is necessary to solve the problems related to the variation in ionospheric conductivity. The use of PC index is also attractive because it is the only index accesible in real time.

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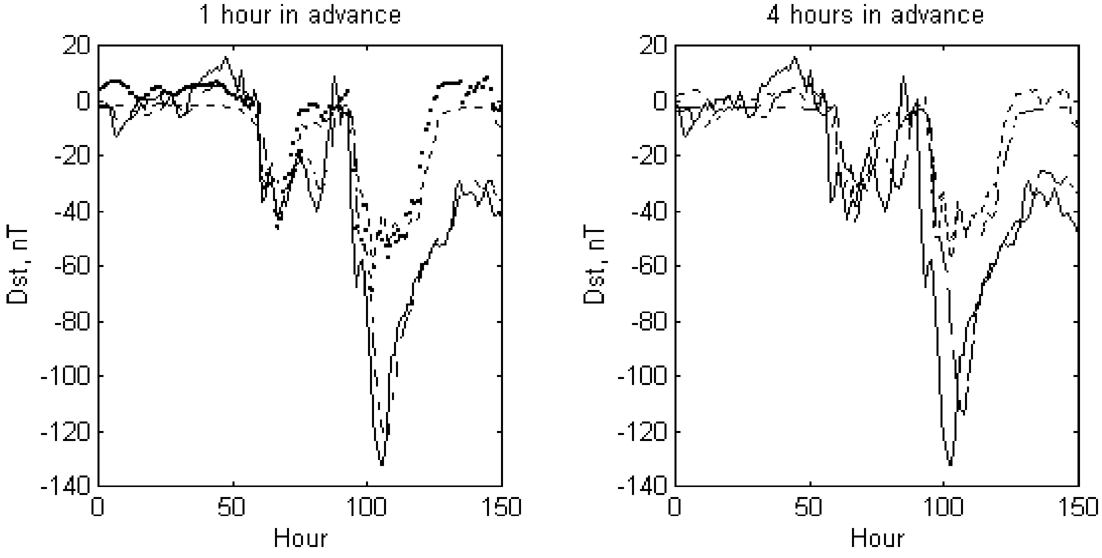

Fig. 2. Measured (solid) and predicted values of Dst one and four hours in advance for different inputs: Dst (dashed), AL (dashdotted), and PC (dotted).

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