Neural Network Prediction of Dst during the Campaign

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1. The operational model of Elman Recurrent NNs

Neural network (NN) methods are a kind of artificial intelligence and have been used to investigate geomagnetic responses to the solar wind (Lundstedt and Wintoft, 1994). Wu and Lundsred 1997 investigated the use of the Elman-type NN method as a prediction method. The operational model has to be strong enough to account for all data measured by the spacecraft and produce good predictions at any time. We developed some models that use three parameters of the solar wind, - solar wind velocity V, density N and IMF Bs in the solar magnetospheric coordinate (GSM) - as version 1 models that were used as training time series. One of them, the Model A listed in Table 1, has been working for a year. Models B and C - the inputs of which were V, N, IMF Bx, By, Bz, and the total of IMF (Bt) - were evaluated in 1978 and between February1998 and October 1998. We have received telemetry signals from the Advanced Component Explorer (ACE) spacecraft and sent the data to NOAA to get raw real time solar wind data in order to predict some kind of space weather. An Elman NN is a two-layer back propagation network with feedback connections from the hidden layer to its input. The output from the hidden layer at the previous time step is fed back to input layer as true input. This feedback (recurrent network), that appears to have an integral property, suggests that the system has a dependence on the time continuation.

2. Training time series

We made an operational model (Model A/version 1) for predicting Dst using OMNI data produced by the National Space Science Data Center (NSSDC). In the first step, the training time series (the time span of which is 5077 hours) was constructed 50 active periods from 1978 to 1982. This model was evaluated using the 1978 data that did not include the training periods. Model A, which has been working in good capability using the raw Real Time Solar Wind data (RTSW/ACE) since April 1998 (http : // www.crl.go.jp/uk/ uk223/service/nnw/index.html), predicted the maximum strength of the Dst 2 hours ahead to within an error of about 25% for almost all storms.

Table 1. Characteristics of models,

	Conditions	Time span	Number and kinds of input	
Model A	Fundamentally storm time	5077 hours	3: Density, Velocity, IMF Bs	Version 1
Model B	Fundamentally storm time	5077 hours	6: Density, Velocity, IMF Bx, By, Bz, and Bt	
Model C	Storm and Quiet time	9058 hours	6: Density, Velocity, IMF Bx, By, Bz, and Bt	Version 2

Bs is the southward component of IMF Bz (The northward component of IMF Bz was set to 0).
Bt shows the magnitude (total) of IMF.

Many NN models, candidates for Version 2, were made just after Version 1 by using the training time series constructed from 6 parameters, Bt, Bx, By, Bz, the density, and the velocity. Each model was weakly dependent on the characteristic of the training time series.

Models A and B were trained by fundamentally storm period duration 5077 hours. Model C, on the other hand, the time span of which was 9058 hours, was trained by using the storm and quiet period data. All models include 50 active periods that have more than 60 storms, because each active period has more than one storm. The training time series including active and quiet period seems to make a good model. Because Model C gives stable predictions during active periods, we evaluated Model C after February 1998 by using the science data and, confirmed the suitability of model C.

3. Prediction of Dst using Model C during the first ISES S-RAMP

In the top panels of Figures 1-3, the provisional Dst produced by C 2 center of the University of Kyoto from the data gathered by ground stations is illustrated by solid curves. The dotted curves show the 2-hour forecasts of Dst by using the raw RTSW data. In the middle panels, the solar wind velocity (solid curve) and the number density (dotted curve) are plotted over ranges from 0 to 1000 km/sec and from 0 to 100 p/cc. The bottom panels show the Bz component (solid) and the magnitude (dotted) of the interplanetary magnetic field plotted over a range from +20 to –20 nT. As shown in Figure 1, the period from 1 to 10 September was characterized by a moderate Dst due because the level of the interplanetary Bz was low (negative or positive). The science data of IMF during this period improved the correlation coefficient (CC) between the provisional Dst computed by the ground stations and forecasted Dst from 0.68 to 0.9 and the root mean square error (RMSE) from 17.7 to 10.6 nT.

Figure 2 indicates that Dst was near 0 on September 11 in spite of the high velocity (~ 550 km/sec) due to the almost positive Bz. In the middle of September the valleys of slowly fluctuating Dst index were synchronized with the fluctuating negative Bz. The storm that started on 12 September seems to have been caused by a coronal hole. The active geomagnetic field on 15 September, having a high-speed solar wind, seems to have been caused by CME. The error of a forecast using raw (RTSW) data is very small. The science data of IMF during this period improved the CC from 0.87 to 0.9 and the RMSE from 11.6 to 9.7 nT.

Figure 3 shows the storms forecasted using the data observed by the ACE spacecraft. Although the second storm that started at 13UT on 26 September had levels of velocity and density similar to those of the first storm that started at 13UT on 22 September, the magnitude of second storm was lower than that of the first storm because of the relatively low negative IMF Bz. The science IMF data improved the error of the forecast from 36% to 30%. The IMF Bz is thus confirmed to be the principal parameter affecting Dst

The neural networks were trained using the data gathered during the period of maximum solar activity (1978-1982), but we used this model in a phase of increasing solar active period from April 1998. Model C was evaluated by using the data observed by the ACE spacecraft from February to October of 1998. During that time there were 11 disturbances that had the minimum Dst less than –80 nT. The differences between the minimum Dst forecasted using the science data of ACE and the final Dst measured by ground stations were small than almost 20 % for 10 disturbances. It seems that the Dst index predicted from solar wind parameters are in approximate agreement with the Dst index measured by the ground stations during different phase of solar activity.

There are some problems as follows:

1) The correlation of solar wind parameters between the halo orbit and the earth is sometimes not as good as we had hoped. [Crooker et al. 1982, Paularena et al. 1998, Richardson, J. D. et al 1998]

2) Our prediction system, like others applied to physical problems, is not perfect and we did not use many parameters such as some kind of fluctuation term and the temperature effect, etc.

In the first step, we could get good forecasted Dst in spite of some problems for the prediction at the halo orbit around the 1st Lagrangian point.

4. Remarks

The first version of Model A has been working since April 1998. (http: // www.crl.go.jp/uk/uk223/service/nnw/index.html)

The prediction model as the version 2 has been developed and evaluated by OMNI data and ACE data in 1978 and 1998.

The science IMF Bz data (final processed data) improved the correlation coefficient between the provisional Dst and forecasted Dst to 0.9 during the Campaign except for one storm.

The principal source of geomagnetic disturbance is reconfirmed by the forecast model to be IMF Bz. We should forecast the long time span of Bz using any means.

Acknowledgments.

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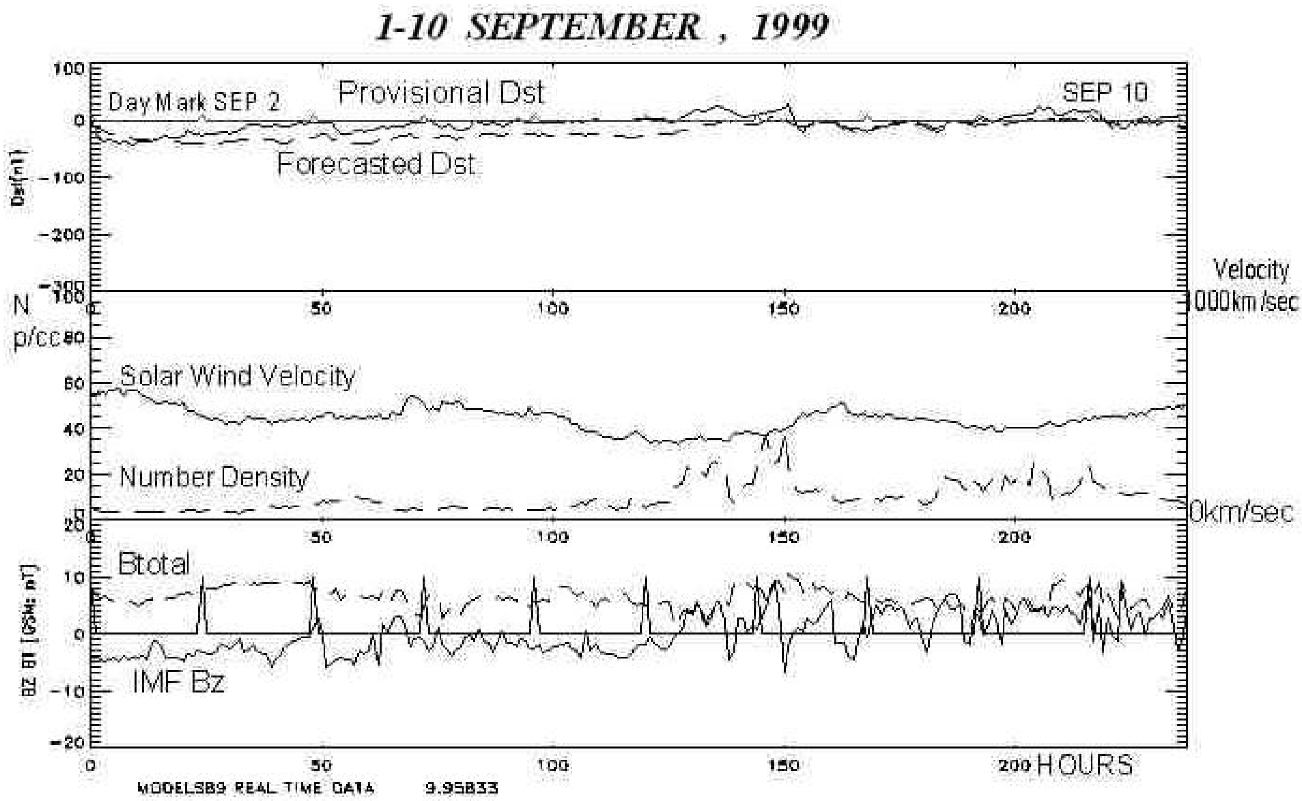
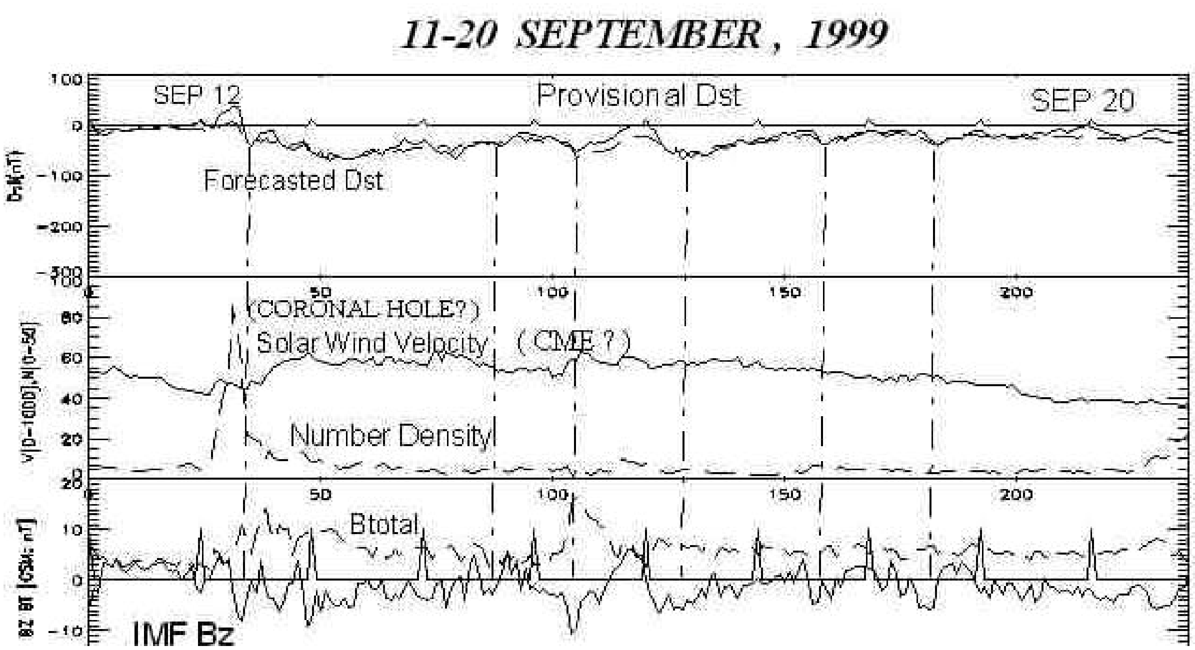


Figure 1



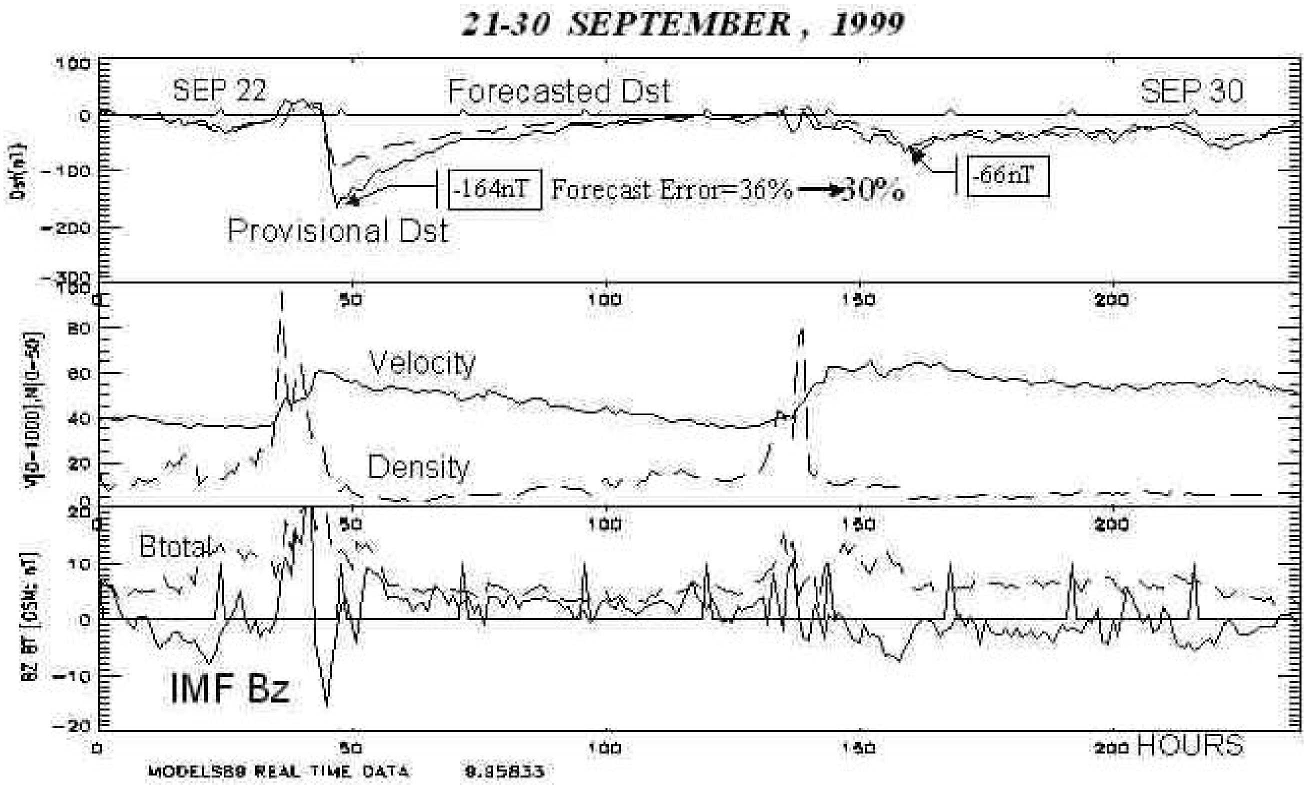

21-30 SEPTEMBER , 1999
SEP 22
Forecasted Dst
SEP 30
-164nT
Forecast Error=36% → 30%
-66nT
Provisional Dst
Velocity
Density
Btotal
IMF Bz
HOURS
MODELS89 REAL TIME DATA 9.95833

Figure 3