Mem. S.A.It. Suppl. Vol. 9, 120

Memorie della
Supplementi

ANN prediction of the Dst index

G. Pallocchia, E. Amata, G. Consolini, M.F. Marcucci, and I. Bertello

Istituto Nazionale di Astrofisica Istituto di Fisica dello Spazio Interplanetario Via del fosso del cavaliere 100, 00133 Roma, Italy. email: giuseppe.pallocchia@ifsi.rm.cnr.it

Abstract. We describe an artificial neural network algorithm for the prediction of the Dst index, developed in the framework of the Pilot Project on Space Weather Applications of the European Space Agency. We then discuss the need to develop a similar algorithm based on IMF data only and report on preliminary work and tests for such an algorithm.

Key words. Sun-Earth relations

1. Introduction

Geomagnetic storms are characterised on the ground by sudden and intense drops of the horizontal component of the Earth's magnetic field which can last from hours to several days. A measure of the effect of storms on the ground magnetic field is provided by the Dst (Disturbance Storm Time) index, which is calculated on an hourly basis from the measurements made by a network of four ground magnetometer stations close to the equator. In the past years, many studies have been made to quantitatively predict Dst based on differential equations (see e.g. Burton et al. (1975), Fenrich and Luhmann (1998), O'Brien and McPherron (2000)), or on artificial neural networks (see, e.g. Wu and Lundstedt (1997) and Lundstedt et al. (2002)). All such models use, as their inputs, IMF and plasma parameters of the solar wind measured at L1, thus allowing on average a one hour ahead calculation of the Dst index. Here we describe an ANN operational algorithm developed at IFSI in the framework of the Pilot Project on Space Weather Applications of the European Space Agency. Moreover, we discuss the need to develop a similar algorithm based on IMF data only and report on preliminary work and results from such an algorithm.

Send offprint requests to: G. Pallocchia

2. Dst forecasting through Artificial Neural Networks and the IFSI model

Many recent works (see e.g. Klimas et al. (1996) and Consolini and Chang (2001)) describe the Earth's magnetospheric response to solar wind changes as highly organized and complex and characterised by non linear dynamics. For its modeling in recent years Artificial Neural Networks (ANN) have been used, as they may capture the hidden parallel interactions of a given input-output system and reproduce its transfer function. Among ANN's the Elman's networks (Elman 1990) are particularly suitable to the Dst index prediction because their internal recurrence allows the implicit implementation of time dynamics (Wu and Lundstedt 1997) through the use of hidden neuron layers.

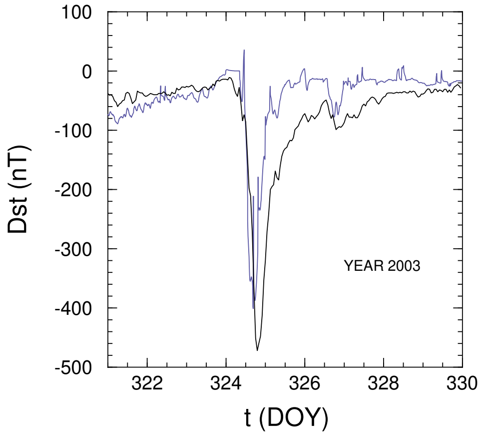

Fig. 1. Comparison between Kyoto provisional Dst (black line) and IFSI ANN Dst (blue line) from day 321 to day 330 of 2003.

In the past for all models of Dst forecasting the inputs comprised of both solar wind plasma and IMF measurements. Following this approach, an Elman's IFSI algorithm has been developed having the following structure: 8 normalised inputs, i.e. hourly averages of solar wind speed and density and of various combinations of the IMF components; 4 context units; 1 hidden layer with 4 neurons; 1 output neuron, which linearly combines the four hidden layer outputs.

The output of the i-th hidden layer neuron at the time t (in hours) is

$$x^i(t) = \tanh(w^u_{ij}u^j(t) + w^c_{il}c^l(t)). \quad (1)$$

where j and l are sum indices, ranging from 1 to 8 and from 1 to 4 respectively, u_j are the eight input lines, c_l are the four context units, which at time t equal the outputs of the hidden layer neurons at the time t-1, $w^{u_{ij}}$ and $w^{c_{il}}$ are the weights of the connections between i-th hidden layer neuron and, respectively, the j-th input and the l-th context unit.

The network weights connections $\boldsymbol{w}$ were then determined by minimizing the cost function (Lundstedt et al. 2002) over a training set of 6000 hours extracted from a data base of WIND and ACE hourly averages of IMF and solar wind parameters measured close to the L1 libration point between 1995 and 2002.

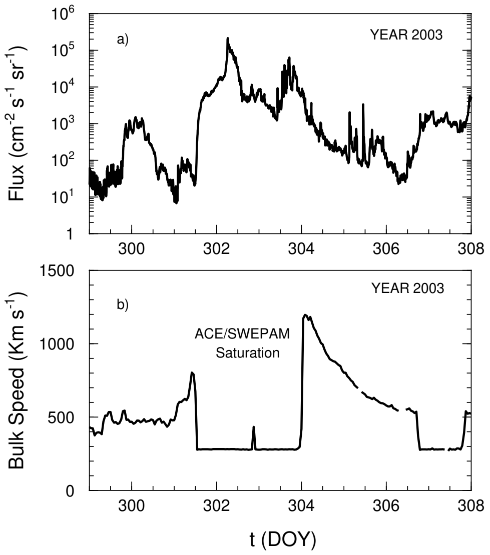

Fig. 2. Top panel: flux of protons of energy greater than 1MeV observed by the geostationary GOES 11 satellite between day 299 and day 308, 2003. Bottom panel: Real time speed transmitted to the ground by the ACE SWEPAM solar wind plasma instrument for the same time period.

Fig. 1 shows a comparison of the IFSI Dst algorithm (in red) with the observed Dst (in black) for the 21 November 2003 storm. We see that the main phase of the storm is correctly forecast, although the storm recovery occurs somewhat more slowly than forecast.

3. Dst forecasting through IMF only

The use of both IMF and plasma input data is a serious operational constraint, as during disturbed periods solar wind plasma instruments can saturate for hours or even days. In such cases, the real time plasma parameters either are wrong, which produces unreliable Dst forecast, or are missing altogether, which makes the forecast impossible. As an example, we recall the loss of plasma parameters suffered by the ACE L1 monitor on days 302 and 303 of 2003. Fig. 2 shows in the bottom panel the solar wind speed measured in real time by the SWEPAM instrument on board the

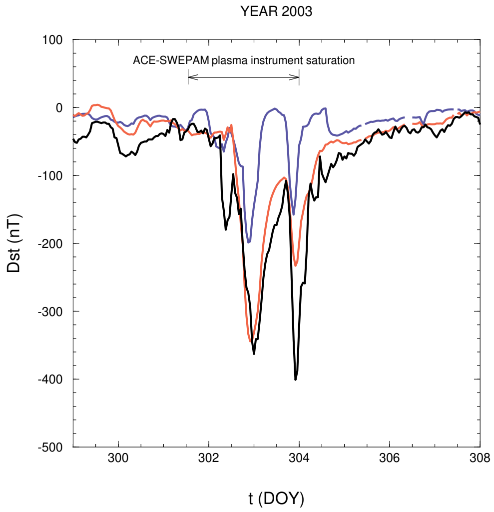

Fig. 3. Comparison between the Kyoto provisional Dst (black line), the IFSI ANN Dst (blue line) and the IFSI IMF ANN Dst (red line) between day 299 and day 308, 2003.

ACE spacecraft close tot the L1 libration point between day 299 and 308, 2003. It is clear that from 12.00 UT on day 302 and 00.00 UT on day 304 SWEPAM was saturated and provided an anomalous low value of the speed. Correspondingly, in the top panel the total flux of energetic protons of energy greater than $1MeV$ measured by the geostationary satellite GOES 11 was particularly high. Such transitory malfunctions do not affect magnetometers. Moreover, the expected operational life of the magnetometers is far longer than that of the plasma instruments. On the basis of these considerations, we are developing an Elman's network based on IMF only, using the same data base referred to in the preceding section. Fig. 3 shows a comparison of the output of the new algorithm (in red) with the Kyoto provisional Dst (black line) and with the Dst forecast through the already described IFSI algorithm (blue line) for the period from day 299 to day 308, 2003. At the top of the figure, a horizontal line marks the the ACE plasma saturation. We see that the old IFSI algorithm largely underestimates the two subsequent storms. It is reasonable to argue that its residual correlation with the Kyoto Dst is due only to its IMF inputs. On the contrary, we notice that the new algorithm reproduces perfectly the first storm and produces a better forecast for the second storm as well, although it underestimates its minimum value. Work is in progress to refine this new algorithm and it is planned to fully describe it in a future paper.

Acknowledgements. The authors thank the ACE and WIND teams for making the real time and verified data available. This work was partially supported by the ESA contract N.17032/03/NL/LvH in the framework of the Pilot Project on Space Weather Applications.

References

Burton, R., K., et al., 1975, JGR, 80, 4204

Consolini, G. and Chang, T., S., 2001, SSR, 95, 309

Elman, J., L., 1990, Cognit. Sc., 14, 179

Fenrich, F., R. and Luhmann, J., G., 1998, GRL, 25, 2999

Klimas, A., J., Vassiliadis, D., Baker, D., N. and Roberts, D., A., JGR, 1996, 101, 13089

Lundstedt, H., Gleisner, H. and Wintoft, P., 2002, GRL, 29, 34

O'Brien, T., P. and McPherron, R., L., 2000, JATP, 62, 1295

Wu, J. and Lundstedt, H., 1997, JGR, 102, 14255