THE SWEDISH SPACE WEATHER INITIATIVES

H. Lundstedt

Solar-Terrestrial Physics Division, Swedish Institute of Space Physics,
Box 43, SE-221 00 Lund, Sweden

ABSTRACT

A brief presentation is given of space weather initiatives, started at the Swedish Institute of Space Physics (IRF). The first Swedish nano-satellite for space weather monitoring is planned to be launched in December 1999. All divisions of IRF participated in the ESTEC project "A study of plasma and energetic electron environment and effects (SPEE)". In Lund, a space weather program was initiated several years ago. A collaboration with users, of space weather information and prediction, within the industry has been going on for many years. Today real-time predictions, based on ACE solar wind data, are available on the web from Lund. The Lund division has been suggested to become a regional warning center. A future space weather center in Lund is also discussed.

Key words: space weather; intelligent nano-satellites; intelligent hybrid systems; real-time predictions; users and space weather effects; space weather center.

1. INTRODUCTION

John Freeman introduced the term "space weather" to focus on applications within space physics. The most often used definition of space weather is the one given by National Space Weather Program (1995), "space weather refers to conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life oer health".

Space weather and effects are problems of such complexity and multiparameter character that it has been difficult use conventional methods. However, artificial intelligent methods, such as neural networks, have been shown to be very powerful. The Lund Space Weather model is therefore mainly based on neural networks.

The aim of the space weather initiatives should be to mitigate the effects of space weather. It is therefore important to have users in mind when the work is carried out. Who experiences the effects? We need to work on increasing the awareness of space weather and effect among people. Education and public outreach play a very important role. It is important that people in decision positions and also the next generation i.e. students and children become aware of the effects space weather. The society is becoming more and more susceptible to the effects of space weather because it is becoming dependent on advanced technology and large interconnected computer and power systems.

2. THE KIRUNA DIVISION

The first Swedish nano-satellite (i.e. a satellite with mass in the 5 kg range or less) Munin (Figure 1) [Norberg et al., 1998], dedicated to space weather monitoring, is planned for launch in December 1999.

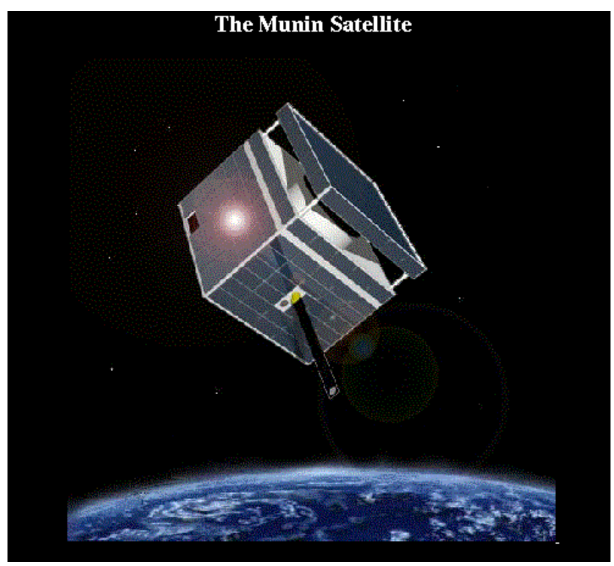

Figure 1. The first Swedish nano-satellite for space weather monitoring to be launched in December 1999.

Munin will give us pictures of the auroral oval size and also give us information about the electron and ion distributions. The information will be directly available on the internet. This information will be used for predictions of space storms. The nano-satellites represent a new important step towards satellites with short turn-around periods, that has been taken by the Swedish Institute of Space Physics [Lundin, 1998]. These satellites can use state of the art technology and explore the latest science. The second nano-satellite to be launched is Hugin [Norberg et al., 1998], a satellite that will test AI-controlled functions on board. Clusters of intelligent nano-satellites would be very interesting for space weather monitoring.

All divisions of IRF have contributed to the ESTEC project "A study of plasma and energetic electron environment and effects" (SPEE). The study was organized under the leadership of the prime contractor, the Finnish Meteorological Institute, Geophysical Research (FMI/GEO), with two divisions IRF-Kiruna and IRF-Uppsala as subcontractor. The Technical Officer at ESTEC was A. Hilgers [Koskinen et al., 1998].

Spacecraft anomaly forecasts, using local environment data, were developed in Kiruna [Andersson et al., 1998].

Space weather's influence on climate, particularly long-term and solar-cycle changes in the middle and upper atmosphere, is studied at the Environment and Space Research institute (MRI).

3. THE UMEÅ DIVISION

New AI-related tools for understanding and analyzing space weather data have been developed at Umeå. Studies of the sunspots number, with the use of wavelet transforms, have revealed new features in the data [Liszka, 1998]. These methods make it possible to separate the dynamical signal from noise.

4. THE UPPSALA DIVISION

New and better indices, characterizing geomagnetic activity, have been developed in Uppsala. The new auroral oval indices makes it possible to also describe dayside geomagnetic activity but also distinguishing between active and extreme activity [Opgenoorth et al., 1997]. Real-time PC-indices are planned, together with FMI and AARI in St. Petersburg, to be available next year.

In Uppsala they contributed to the SPEE project by analyzing and modelling the charging effects on satellites [Koskinen, et al., 1998].

The Uppsala division is as the Kiruna division involved in several space weather related EISCAT projects.

Both divisions also participate in networks of ground based space weather observations. MIRACLE is such a multi data network under development by FMI and Uppsala.

5. THE LUND DIVISION

5.1. The Lund Space Weather Program

We are developing a model and predictions of the space weather and effects based on intelligent hybrid systems (Figure 2). From data about the solar and solar wind activity, the space weather and effects are predicted on time scales from minutes to years [Lundstedt, 1998].

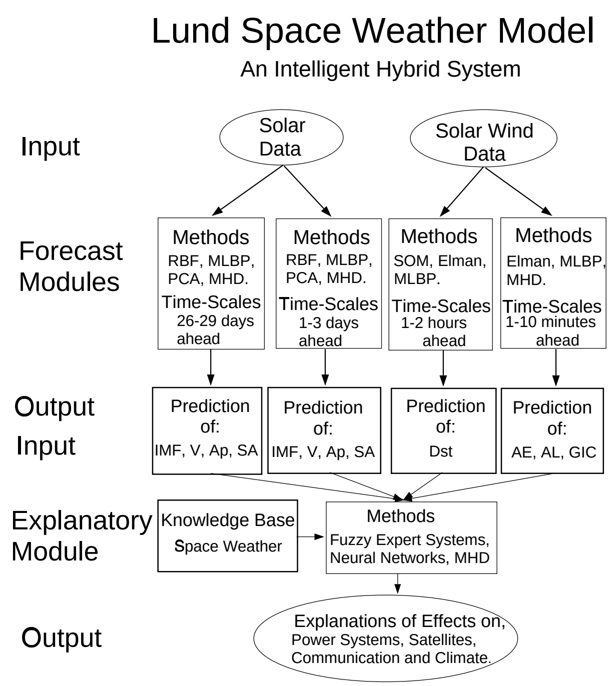

Figure 2. The Lund Space Weather Model is an intelligent hybrid system that predicts and models the space weather.

The work on the Lund Space Weather Model has resulted in three dissertations: Space Weather Physics - Dynamic Neural Network Studies of Solar Wind-Magnetosphere Coupling [Wu, 1997]; Space Weather Physics - Prediction and classification of solar wind structures and geomagnetic activity using artificial neural network [Wintoft, 1997]; Solar Wind-Driven Geomagnetic Activity Modelled with Neural Network [Gleisner, 1997].

Two workshops on "Artificial Intelligence Applications in Solar-Terrestrial Physics" have been held in Lund, 1993 [Joselyn et al., 1993] and 1997 [Sandahl and Johnsson, 1998]. Discussions on a third in 2001 have started.

We started in the late 80-ies to use AI-techniques for modelling and predictions of the space weather. First inductive expert systems were used [Lundstedt, 1990]. However, we quickly found neural networks were much more powerful [Lundstedt, 1991; Lundstedt 1992]. We now mainly use different types of neural networks for modelling and predictions of the space weather and effects.

Neural networks can e.g. be introduced by a description of their architectures or from their function.

Neural networks consist of interconnected processing units, often non-linear, called neurons. These neurons are often very simplified models of the nerve cells of the brain. Each neuron has a state, and the network can then be described by a state vector. The trajectories of the state vector could converge into an attractor, and for a chaotic system to a strange attractor. The input of the network is the state at time zero and the output is the final state. Is this way the neural network is a model of a non-linear chaotic dynamic system.

We could however also look upon neural networks as black boxes and describe their function as a mapper of an input vector to an output vector. The state of the space weather (of e.g. the earth's magnetosphere/ionosphere) can be studied by mapping an input vector describing e.g. the solar and solar wind state to an output vector describing the magnetosphere and ionosphere state (Figure 1). The mapping function is the predictor and model. Artificial neural networks (ANN) (Haykin, 1999) now work very well as mappers. We have mainly used feed-forward Multi-Layer Backpropagation networks (MLBP), self-organized map neural networks (SOM), radial-basis function networks (RBF) and recurrent Elman neural networks as mappers.

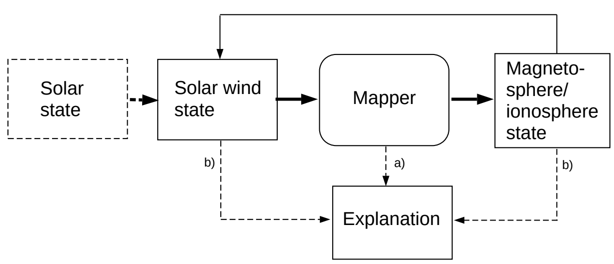

Figure 3. The figure shows how the solar wind magnetosphere coupling can be modelled/predicted by a mapping, here a nonlinear dynamic neural network, from the solar/solar wind state to magnetosphere/ionosphere state. .

The modelling capability of the ANN can be ascribed to its ability to learn the mathematical function underlying the system operation. If the network is designed and trained properly, it can perform generalization rather than simple curve fitting. Any continuous function can be implemented by a three-layer feedforward neural network. The ANNs can be used as a preprocessor: If the ANN cannot map the input patterns accurately, then some input variables are probably missing. If an input variable can be removed without hurting the network performance, then the variable is probably irrelevant. The ANNs can also work as as postprocessor: From the ANN model new connections and relations may be found. A network can actually improve the theoretical model, by finding new relationships we had not thought about. When a neural network has been trained and tested, it can be considered as a model. By changing the input values to the input layer the network's response and output can be studied. From that an understanding of what the neural network has learned can be derived. Another way to understand the neural network is to study how the knowledge is acquired by the ANN (i.e. the mapper and b in Figure 3). The knowledge of an ANN is encoded by i) the network architecture itself, ii) the activation functions and iii) the weights. The task of extracting explanations (or rules) from a trained network is therefore to interpret in a comprehensible form the collective effects of i), ii) and iii). Many algorithms have been developed, by e.g Mark Craven [Craven, 1998]. A comparison between analogue models, expressed with differential equations, and neural networks can also lead to a better understanding of what the neural network has learned.

Lund Space Weather Model (Figure 3) consists of the above mentioned mappers or modules, each predicting the space weather and effects on a specific time ahead. The LSWM is also intended to explain possible effects of the space weather on power systems, satellites, avionics, communication and climate/weather.

5.2. Real-time Predictions

An accurate and physically based description of the solar activity (SA) is very important in many cases, e.g. for predictions of coronal mass ejections (CMEs), daily predictions of geomagnetic activity, drag effects on satellites, effects on radio propagation, effects on tropospheric weather and climate. A relationship between the tropospheric storminess (vorticity area index) and the cosmic ray intensity was e.g. studied by Lundstedt [1984]. The variation of the cosmic ray intensity was in that study related to solar activity and and crossings of solar wind interaction regions.

The sunspot number is the most often used indicator of the solar activity. However, it is well-known that the sunspot index is not a very accurate indicator. The main advantage is the long time-series of data. However, it is not long enough to determine whether the solar dynamo is chaotic or not [Mundt et al., 1991]. A more direct and physical based indicator would be the solar magnetic flux. The MDI instrument on board the ESA/NASA spacecraft SOHO, produces an image of the solar magnetic flux every 96 minutes. Even 1 min bursts of images of the solar magnetic flux can be produced. Movies of these images or magnetograms (see figure 4) have shown to us a new very active sun [Hoeksema, 1998].

Even the global solar magnetic field was found to change on a short time-scale. Zhao et al., [1998] found that the halo CME event of January 6 1997 was associated with a change of the large-scale solar magnetic field [Wu et al., 1998a].

In a study in progress Lundstedt found that a global change of the large-scale magnetic field can be associated with most reported CMEs during for cases in 1996 and 1997.

We have also started to use the solar mean field, computed by Todd Hoeksema at Stanford University from MDI observed magnetograms, as a new indicator of the solar activity (Figure 5). The new mean field data can be obtained with as high temporal resolution as 1 min to 96 min. Many new very interesting

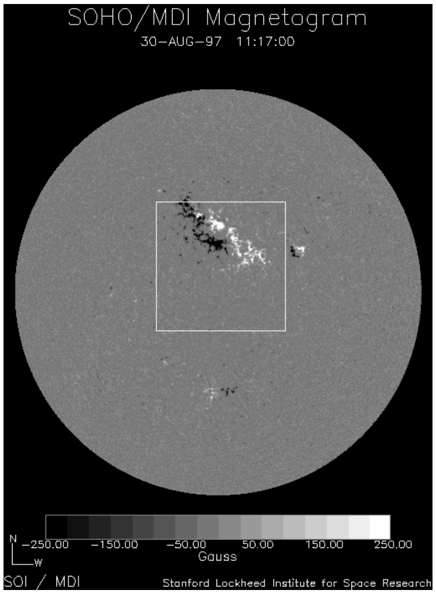

Figure 4. A SOHO magnetogram. A large active region is seen on the solar center.

features were seen in that new data set. A very important question is whether CMEs can be detected in that data or not. If so, then that would be very important for daily predictions of the space weather. We have now started to model and predict the solar mean field with the use of neural networks. Mean field measurements are easy to make and an instrument to measure the mean field from a nano-satellite sounds like a very attractive idea.

Many groups have used AI-techniques the solar wind data to predict geomagnetic storms [Lundstedt, 1997], as defined by the D_{st}-index. Different solar wind parameters have been selected as inputs for the neural networks. Most often, the solar wind velocity (V), density (n), and the southward directed magnetic field (B_z), for a time history, have been used. However, the electric field (E_y) and dynamic pressure (p) and the other magnetic field components and standard deviation have also been used as inputs. A MLNBP [Lundstedt and Wintoft, 1994] easily learns to predict the initial phase and main phase of a geomagnetic storm, but not the recovery phase. When we extended our study to Elman networks, i.e. recurrent backpropagation networks, then all the phases of the geomagnetic storm and all intensities of storms were possible to predict 1-3 hours ahead. As an average for the test data predictions one hour ahead the correlation coefficient between the observed and predicted reached 0.92 and the corresponding prediction efficiency (1 - average relative variance) was 85%. For predictions two hours ahead (Figure 6) the correlation between the observed and predicted D_{st} reached 0.90 and the corresponding prediction efficiency was 82%. Predictions up to 9 hours [Wu and Lundstedt, 1997a; 1997b] are still operationally useful if not physically.

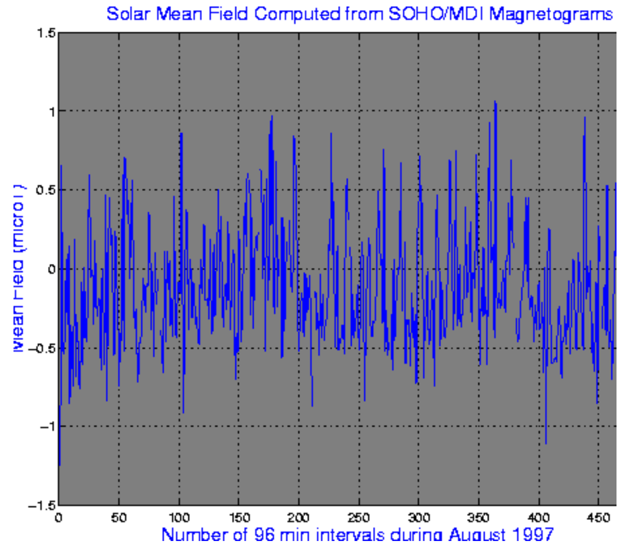

Figure 5. The solar mean field in μT computed from SOHO magnetograms.

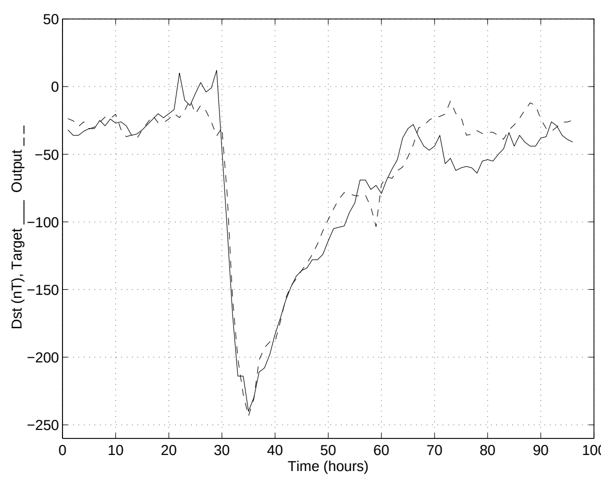

Figure 6. The solid line represents the observed D_{st} and the dashed line represents the predicted D_{st} two hours ahead with an Elman neural network.

A natural extension of our studies of geomagnetic storms was to try to predict geomagnetic disturbances on shorter time-scales 1-5 minutes. We started by predicting the AE-index (Figure 7) from solar wind data [Gleisner and Lundstedt, 1997]. With the solar wind variables n, V, B_y, B_z as input to the network, 76% of the AE index variance was accounted for.

The research work is now converted into real-time predictions. We started by showing that the famous 6-11 January event of 1997 with the associated satellite anomaly event, should have been possible to predict from WIND data and our developed neu-

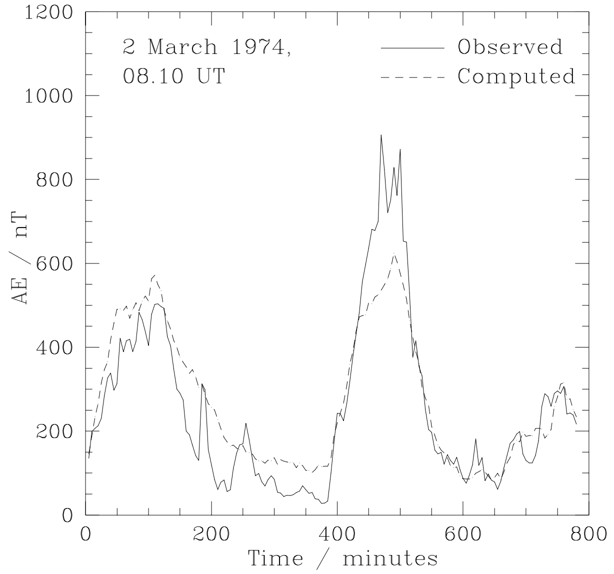

Figure 7. The solid line represents the observed AE and the dashed line the predicted AE with the use of a neural network.

ral networks (Wu et al., 1998a). Real-time predictions are now available on our web pages in Lund. Neural networks have been trained with solar wind data of several solar cycles to predict geomagnetic indices, such as AE, Dst and Kp (Figure 8). Access to real-time solar wind data from the spacecraft ACE of NASA/NOAA makes is possible to offer real-time predictions several hours ahead.

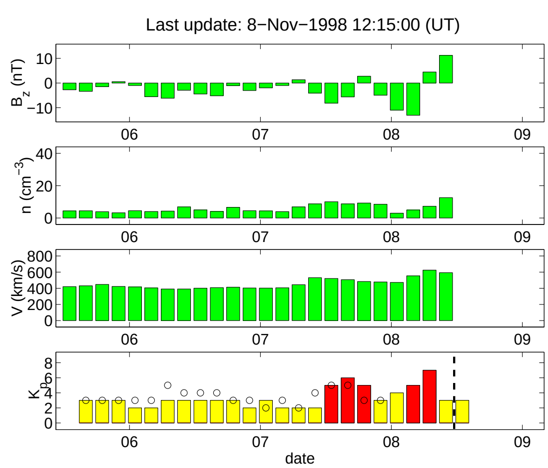

Figure 8. Real-time predictions of Kp index.

Real-time predictions of geomagnetic activity can be used as input to predictions of satellite anomalies. In the ESTEC SPEE study it was shown that the total predictions rate was 80% for events on METEOSAT-3, using neural networks trained with Kp values as input [Wu et al., 1998b]. Next step would be to use examples of anomalies for more satellites, increase the time resolution and try to make predictions for a specific satellite position.

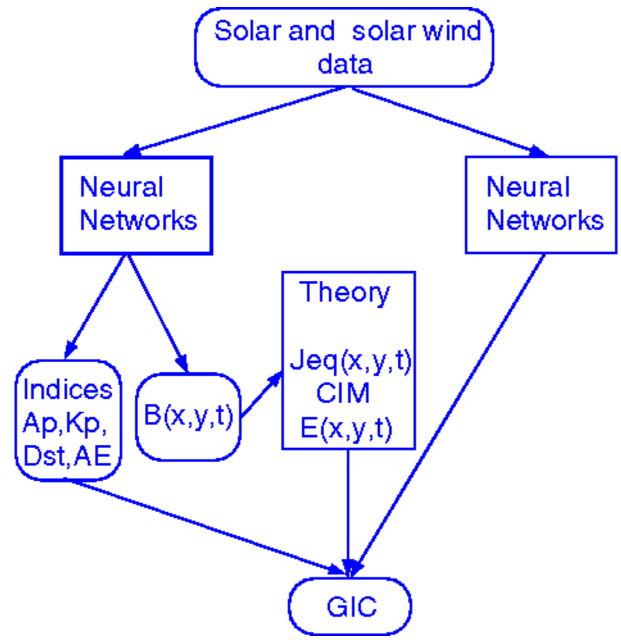

Figure 9. Real-time predictions of geomagnetically currents (GICs).

Real-time predictions of geomagnetic activity can also be used as input to neural networks, trained to predict geomagnetically induced currents [Pirjola, 1998; Lundstedt, 1993]. However, what we work on at present is to predict the local geomagnetic field variation and from that calculate the GIC (Figure 9).

Predictions of the plasma frequency foF2, an indicator of the radio communication conditions in the ionosphere, are studied with neural networks in i a collaboration with the Rutherford Appleton Laboratory. The networks are trained to predict foF2 days ahead from solar, solar wind and geomagnetic activity as input data [Wintoft and Cander, 1998a;1998b]. Such a prediction is shown in figure 10.

For the implementation of the Lund Space Weather Model on a platform independent environment, we have developed toolboxes in Java. Today we have a Neural Network Toolbox in Java [Eriksson, 1998] and a Space Weather Viewer in Java [Martinez, 1998].

We will now apply for to become a regional warning center of ISES. Discussions have taken place. We will offer real-time predictions based on intelligent hybrid systems.

5.3. Collaborations with Industry and Users

Space weather effects on power systems have been observed by Swedish power companies since 1940. The contacts with Swedish power companies, such as Sydkraft AB, also started many years ago. Very close contacts exist today, where e.g. power companies have funded research positions. Predictions of

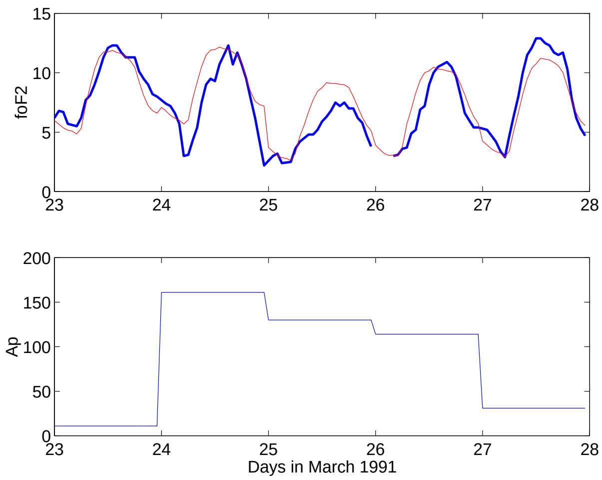

Figure 10. Real-time predictions of foF2 and associated geomagnetic activity.

geomagnetic activity are offered to power companies. Several meeting have been held together. An informal mini conference is planned for the spring 1999 in Lund about how to predict space weather effects on power systems. Space weather scientsists and people from power companies are expected to attend. Collaborations with power companies include both electrical (e.g. Sydkraft AB) and natural gas pipeline (e.g. SydGas AB) power companies.

An example of an effect of a gemagnetically induced current on a power system is illustrated in Figure 11. A temperature increase was measured in a rotor of a nuclear plant in Sweden in connection with the severe geomagnetic storm (Ap = 246) of March 13/14 1989. Many other effects were observed in the Swedish power systems.

Another example of the effects of GICs on power systems is illustrated in Figure 12. Geomagnetically induced currents can initiate corrosion in natural gas pipelines. GICs are therefore continuously measured by the Swedish gas pipeline company SydGas. Severe gemoagnetic activity (Ap = 96) occurred on May 4, 1998, that caused the geomagnetically induced potentials plotted in Figure 12.

The effects of space weather induced geomagnetically induced currents (GIC) are also of concern to railway companies (e.g. Banverket) and tele communication companies (e.g. Televerket). Contacts with these companies have therefore also been taken.

It was recently shown [Johansson et al., 1997] that electronics on board aircrafts may be effected by cosmic rays and other energetic particles. We will again investigate if predictions of these events can be done. A collaboration with SAAB/Ericsson Avionics has been initiated.

The ESTEC/ESA project, earlier mentioned, showed that it is possible to predict satellite anomalies with the use of neural networks. Swedish satellite companies are therefore also addressed.

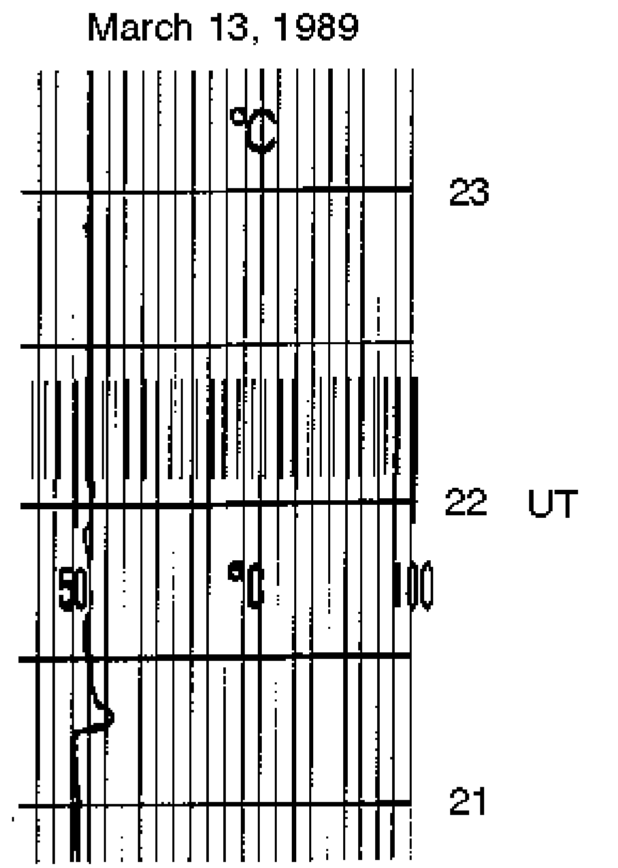

Figure 11. A 5 C degrees increase in the temperature of a rotor in a nuclear plant in Sweden, caused by geomagnetically induced currents as a result of the severe geomagnetic storm of March 13, 1989.

The work on predicting the radio communication conditions has also led to contact with telecommunication companies (Televerket, Ericsson) in Sweden.

All these industrial applications have encouraged us to continue to work on implementing and customizing real-time predictions with explanations, i.e. in accordance to the first plans of the Lund Space Weather Program.

5.4. Helios - a future space weather center

A future space weather center (Helios - http://www.astro.lu.se/~henrik/helios.html) in Lund has been discussed with politicians, businessmen and within research organizations. An international reference scientific group has been established (http://www.astro.lu.se/~henrik/heliosrefgroup.html). The Center is planned to consist of a research division (earlier solar-terrestrial physics division), research companies and an information center (Figure 13).

The first step toward Helios was taken when the solar-terrestrial physics division moved to Ideon, a

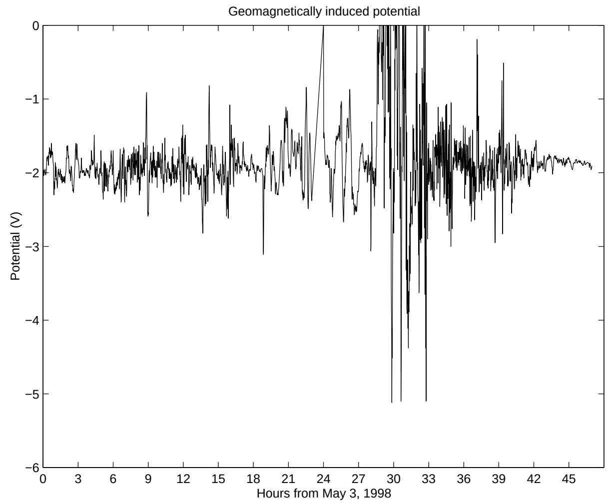

Figure 12. Geomagnetically induced potentials, measured in Southern Sweden for the geomagnetic storm event May 4, 1998, by the gas pipeline company SydGas.

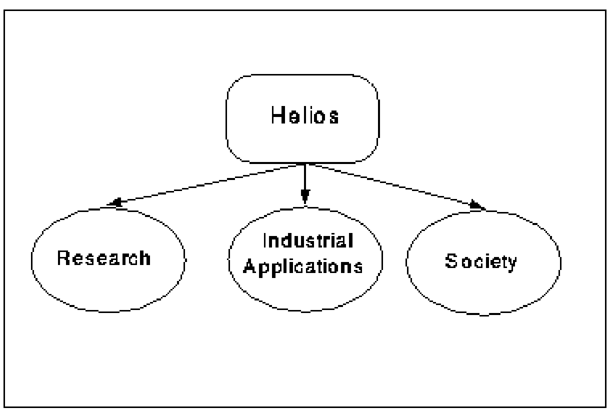

Figure 13. A future space weather center under discussion: devoted to research, industrial applications and information about space weather and effects to the society.

science and technology park. Ideon hosts ove 130 high-tech companies, such as the research division of the tele communication company Ericsson. Being among these companies, potential space weather customers, will play an important role for us.

5.5. A satellite antenna in Lund

An 11 meter antenna for downloading e.g. solar wind data from ACE and data from IMAGE has been discussed and evaluated (Lundstedt et al., 1998). The antenna is planned to be located in Lund and remotely controlled from ESRANGE close to Kiruna.

5.6. A Forum for Space Weather and Effects

The Space Weather Euro News (SWEN) has become an important space weather forum for gathering information,
discuss initiatives and activities. We have archived issues of SWEN from the start. Issues are available at http://www.astro.lu.se/~henrik/spweuro.html.

We would also very much welcome the start of a space weather journal, a journal where methods of forecasting, effects, user requirements and current space weather could be discussed. We have several journals for publishing results with solar-terrestrial physics, but no space weather results.

5.7. Outreach

Increasing the awareness of space weather and its effects is not just a lot of fun but also very important. We have therefore developed extensive web pages on the subject (see http://www.astro.lu.se/~henrik). After many years of contacts with the press and media, a very important media-network, has been developed. Today several TV programs have been produced about space weather and effects, in science programs and even in children programs (Figure 14).

Figure 14. How space weather is presented to children in Swedish Television. We of course have to wear silver space suites if we are going to talk about space weather!

I must say the biggest challenge is to address children, but also the most rewarding if you manage to get them interested. In their future I am sure the weather (the tropospheric) reporters also will talk about the space weather and its expected effects.

6. CONCLUSIONS

Solar-terrestrial research in Sweden has a long history of aurora studies in northern Sweden and solar studies in southern Sweden. The effects of space weather have also been observed for many years. Space weather and its effects are very real problems and challenges in Sweden. For example there exists since many years a space weather program in Lund. Today real-time predictions of geomagnetic activity are available on the web pages from Lund.

The approach of the Lund division, to use AI methods for mapping one state to another state of the space weather, has been very fruitful. Explaining the mapping has also given us new theoretical knowledge. The mapping can easily be used for practical usage. Our next step will now be to further coordinate the research work, industrial applications and outreach activities by creating a space weather center or institute: Helios.

ACKNOWLEDGMENTS

I like to thank prof Rickard Lundin of IRF-K, prof Ludwik Liszka of IRF-Um and prof Herman Opgenoorth of IRF-U for the information about the space weather initiatives at their divisions of IRF. We are also very grateful for the access of SOHO magnetic field data, WIND and ACE data, making it to possible to develop real-time space weather predictions. We also like to thank the Swedish Space Board, for supporting the SOHO project.

REFERENCES

Andersson, L., Prediction of Times with Increased Risk of Internal Charging on Spacecraft, volume, 1998.

Craven, M., Understanding Models Learned by Neural Networks, in the Proceedings of "AI Applications in Solar-Terrestrial Physics", July 29-31, 1997 in Lund, Sweden, edited by I. Sandahl and E. Jonsson, *ESA WPP-148*, April 1998.

Eriksson, B., A Neural Network Toolbox in Java - For Predictions of Space Weather, Degree project from Department of Space Physics, Umeå, 1998.

Gleisner, H. and H. Lundstedt, Response of the auroral electrojets to the solar wind modeled with neural networks, *J. Geophys. Res.,* 102, 1426 9, 1997.

Gleisner, H., Solar Wind-Driven Geomagnetic Activity Modelled with Neural Networks, *Ph. Licentiate Thesis*, Lund University, Sweden, 1997.

Haykin S., *Neural Networks - a comprehensive foundation*, Prentice-Hall, 1999.

Hoeksema, J.T., The Actively Quiet Sun - The View from SOHO, in the Proceedings of "AI Applications in Solar-Terrestrial Physics", July 29-31, 1997 in Lund, Sweden, edited by I. Sandahl and E. Jonsson, *ESA WPP-148*, April 1998.

Johansson, K., P. Dyreklev and B. Granbom, Space Weather Effects on Aircraft Electronics, in the Proceedings of "AI Applications in Solar-Terrestrial Physics", July 29-31, 1997 in Lund, Sweden, edited by I. Sandahl and E. Jonsson, *ESA WPP-148*, April 1998.

Joselyn, J., H. Lundstedt and J. Trollinger editors of *the Proceedings of the International Workshop on Artificial Intelligence Applications in Solar-Terrestrial Physics*, Lund, Sweden, 22-24 September 1993.

Koskinen, H., L. Eliasson, B. Holback, L. Andersson, A. Eriksson, A. Malkki, O. Norber, T. Pulkkinen, A. Viljanen, J. -E. Wahlund and J. -G. Wu, Space Weather and its Interaction with Spacecraft, *Summary Report of Study of Plasma and Energetic Electron Electron Environment and Effects, ESTEC/Contract No. 11974/96/NL/JG(SC)*, 1998.

Liszka, L., Decomposition of Time Series, in the Proceedings of "AI Applications in Solar-Terrestrial Physics", July 29-31, 1997 in Lund, Sweden, edited by I. Sandahl and E. Jonsson, *ESA WPP-148*, April 1998.

Lundin, R., From Mini - to Nanosatellites: Intelligence in Space Science, in the Proceedings of "AI Applications in Solar-Terrestrial Physics", July 29-31, 1997 in Lund, Sweden, edited by I. Sandahl and E. Jonsson, *ESA WPP-148*, April 1998.

Lundstedt, H., Influence of Interplanetary Interaction Regions on Geomagnetic Disturbances and Tropospheric Circulation, *Planet. Space Sci.*, 32, 1541-1545, 1984.

Lundstedt, H., An inductive expert system for solar predictions, in *Proceedi ngs of Solar-Terrestrial Prediction Workshop, in Leura Australia October 16-20, 1 989*, Eds. Thompson, R.J., Cole, D.G., Wilkinson, P.J., Shea, M.A., Smart, D. and Heckman, G,. 125-129, 1990.

Lundstedt, H., Neural networks and predictions, in *IAGA programs and abstract t*, XX General Assembly, IUGG, Vienna, 1991.

Lundstedt, H., Neural networks and predictions of solar-terrestrial effects, *Planet. Space Sci.*, 40, 457-464, 1992.

Lundstedt, H., Neural network predictions of solar induced disturbances in the power system of southern Sweden, in *the Proceedings of the International Workshop on Artificial Intelligence Applications in Solar-Terrestrial Physics, 22-24 September, Lund, Sweden*, edited by Joselyn, J., H. Lundstedt and J. Trollinger, 1993.

Lundstedt, H. and P. Wintoft, Prediction of geomagnetic storms from solar wind da ta with the use of a neural network, *Ann. Geophysicae*, 12, 19-24, 1994.

Lundstedt, H., AI Techniques in Geomagnetic Storm Forecasting, in AGU *Geophy sical Monograph 98 on Magnetic Storms*, edited by B. T. Tsurutani, W. D. Gonzalez , Y. Kamide and J. K. Arballo, 1997.

Lundstedt, H., Lund Space Weather Model: Status and Future Plans, in the Proceedings of "AI Applications in Solar-Terrestrial Physics", July 29-31, 1997 in Lund, Sweden, edited by I. Sandahl and E. Jonsson, *ESA WPP-148*, April 1998.

Lundstedt, H., Lundin, R. and Marcus, L., Heliosstation, *Report in Swedish*, 1998.

Martinez Juan, J. L., A Space Weather Viewer in Java, in the Proceedings of "AI Applications in Solar-Terrestrial Physics", July 29-31, 1997 in Lund, Sweden, edited by I. Sandahl and E. Jonsson, *ESA WPP-148*, April 1998.

Mundt, M.D., W.B. Maguire II and R. R.P. Chase, Chaos in the Sunspot Cycle: Analysis and Prediction, *J. Geophys. Res.*, 96, 1705, 1991.

Norberg, O, Barabash, S, Andersson, L., Eklund, U., Winningham, J.D., Lindblad, T.Hugin and

Munin: Autonomous, Low Cost, Space Weather Nanosatellites, *this volume*, 1998.

Opgenoorth, H. J., M. A. L. Persson, M. Lockwood, R. Stamper, M. Wild, R. Pellinen, T. Pulkkinen, K. Kauristie, T. Hughes, and Y. Kamide, A new family of geomagnetic disturbance indices, *The Source Book for Cluster Ground - Based Coordination*, ed. by H.J.Opgenoorth and Mike Lockwood, *European Space Agency*, ESA-SP1198, pp 49-64, 1997.

Pirjola, R., Power and Pipelines (Ground Systems), *this volume*, 1998.

Sandahl. I. and E. Jonsson, editors of the Proceedings of AI Applications in Solar-Terrestrial Physics, July 29-31, 1997 in Lund, Sweden, *ESA WPP-148*, April 1998.

Wintoft, P., Space Weather Physics: Prediction and classification of solar wind structures and geomagnetic activity using artificial neural networks, *Ph.D Thesis*, Lund University, Sweden, 1997.

Wintoft, P., and Lj.R. Cander, Short-term prediction of foF2 using time-delay neural networks, XXIII General Assembly of the European Geophysical Society, Nice, France, 20-24 April, 1998, To appear in Annales Geophysicae, Vol. 16, 1998a.

Wintoft, P., and Lj.R. Cander, 24-hour predictions of foF2 using time-delay neural networks, Submitted to Radio Science, 1998b.

Wu, J.-G., and H. Lundstedt, Geomagnetic storm predictions from solar wind data w ith the use of dynamic neural networks, *J. Geophys. Res.*, 102, 14255, 1997a .

Wu, J.-G., and H. Lundstedt, Neural network modeling of solar wind-magnetosphere interaction, *J. Geophys. Res.*, 102, 14457, 1997b.

Wu, J.-G., Space Weather Physics: Dynamic Neural Network Studies of Solar Wind-Magnetosphere Coupling, *Ph.D Thesis*, Lund University, Sweden, 1997.

Wu, J.-G., H. Lundstedt, P. Wintoft and T.R. Detman, Neural network models predicting the magnetospheric response to the 1997 January halo-CME event, *Geophys., Res. Lett.*, 25, 3031, 1998a.

Wu, J. -G., H. Lundstedt, L. Andersson, L. Eliasson, and O. Norberg, Study of plasma and energetic environment and effects, Technical note Work package 220, ESTEC/Contract No. 11974/96/NL/JG(SC), 1998b.

Zhao, X., J.T. Hoeksema and P.H. Scherrer, Applications of SOI-MDI Magnetic Image s-1 Possible Changes of Large-scale Photospheric Magnetic Fields and the 6 Januar y 1997 CME, *http://quake.stanford.edu/ zhao/istp97.1.html*, 1997.