FINNISH SPACE WEATHER INITIATIVES

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ABSTRACT

This paper reviews Finnish space weather activities. Finland has strong traditions and active research programmes in the field of solar-terrestrial physics, which provide a good background for application-oriented work on space weather. In fact, space weather effects on ground technological systems have been studied in Finland for more than 20 years, much longer than the term "space weather" has been in use. Finnish scientists have also become involved in the initial steps of joint European space weather activities.

1. BACKGROUND FOR FINNISH SPACE WEATHER ACTIVITIES

In a country that is located in the auroral zone, time-variable space environment effects can be seen by naked eye in the form of northern lights. Therefore, the concept of space weather means something also for people outside the scientific community, and it is only natural that the strongest fields in Finnish space research are the magnetospheric and ionospheric physics. This background also gives a solid basis for the present and future space weather activities.

For space weather applications, the key interest lies within the potentially harmful effects of the solar-terrestrial coupling. As a matter of fact, research in the field of solar-terrestrial physics in Finland once started from studies of space environment effects on ground, when the predecessor of the Finnish Meteorological Institute (FMI) was founded as a Magnetic Meteorological Observatory in 1838. Auroral imaging using all-sky cameras started much later in 1957, and as part of the International Magnetospheric Study (IMS) in the late 1970's the magnetic observation network was expanded and a new ionospheric radar system, STARE, was established. Today Finland operates and maintains a large network of ground-based magnetometers, radar systems, and all-sky cameras partly through international collaboration. In 1987 Finland joined ESA as an associate member, and became a full member in 1995. The first Finnish PI-instrument onboard an ESA spacecraft was the energetic particle instrument ERNE onboard SOHO (Ref. 1); also here the Finnish involvement is directly relevant to space weather.

The Finnish solar-terrestrial research activities cover the entire space weather chain from the Sun through the solar wind, magnetosphere, and ionosphere to the effects on ground. While there is a distinction between basic solar-terrestrial physics research and space weather applications, it is evident that the Finnish involvement in space weather efforts has its roots in the strong scientific community in the field of space physics.

In this review we briefly describe the Finnish expertise and present observational capabilities (section 2). A few examples of application projects are given in section 3 and some future plans and opportunities in section 4.

2. FINNISH SPACE WEATHER RESOURCES

2. 1. Expertise in physics

Solar physics is studied in Finland at the University of Helsinki, the University of Oulu the University of Turku, and the Helsinki University of Technology. The expertise ranges from long-term activity examined using sunspot databases to rapid energy release and particle acceleration in active processes observed at the Metsähovi Radio Observatory and by the ERNE instrument on SOHO.

The long-term solar studies are combined with magnetic activity observations at the Finnish Meteorological, where the records of the surface magnetic field variations extend back to 1844 (Ref. 2). The long time series gives unique possibilities for investigations of the variability of the space environment in climatological time-scales, now that the consequences of space climate on the atmosphere in the solar cycle time scale have gained renewed attention (Ref. 3).

The space weather events influence the atmosphere also in shorter time scales. Energetic particles that penetrate down to few tens of km can create chemical chain reactions, which may lead to destruction of mesospheric, and possibly also stratospheric, ozone. These effects are critically important when the anthropogenic effects to the ozone layer are evaluated (Ref. 4). The FMI has a wide program in monitoring stratospheric ozone, and efforts to examine the effects of the solar variability and magnetospheric activity on these measurements are conducted together with the Sodankylä Geophysical Observatory of the University of Oulu.

Basic research in magnetospheric physics is conducted at the Finnish Meteorological Institute, at the University of Oulu, at the University of Helsinki, and at Sodankylä Geophysical Observatory. The research program covers a wide range of topics; particularly relevant for space weather are, e.g., energy input from the solar wind into the magnetosphere, energy dissipation during storms and substorms, magnetospheric modelling during active periods, particle tracing in time-dependent magnetospheric configurations, magnetosphere-ionosphere coupling studies, and radio wave propagation in the ionosphere. At present, the FMI group is the only one in Europe running a global 3-D magnetospheric simulation code including the solar wind, the magnetosphere, and the ionosphere (Ref. 5).

In addition to the extensive scientific experience, there is expertise in certain technological space weather applications. FMI has conducted both theoretical and application-oriented studies of geomagnetically induced currents (GIC) in electric power transmission lines as well as in gas and oil pipelines (Ref. 5). Furthermore, FMI scientists have participated in spacecraft charging investigations as a spin-off from scientific expertise in electric probes.

In addition to the extensive scientific program, Finland has also expertise in some technological space weather applications. The FMI group has conducted both theoretical and application-oriented studies of geomagnetically induced currents (GIC) in electric power transmission lines as well as in gas and oil pipelines (Ref. 6). Scientists at FMI have also contributed to spacecraft charging investigations utilising expertise gained in scientific use of electric probes.

To summarise, the scientific programs of the Finnish space physics groups give strong background for future work in space weather applications. Especially in the fields of magnetospheric modelling and effects induced on ground systems the Finnish expertise has been internationally recognised.

2.2. Observational capabilities

In general, space weather observations can be divided into comprehensive real-time observations for operational use and observations needed in post-event. The operational requirements are global and hence no small country alone is able to maintain substantial independent observational facilities for this purpose. Although the present observational capabilities in Finland have been developed for scientific purposes, some of them are readily usable for space weather applications.

2.2.1. Solar observations

The Metsähovi Radio Observatory performs observations of active solar phenomena, e.g. flares. The 14-m radio telescope is used for solar observations 4–12 weeks annually. The observations are analysed in collaboration with other solar observatories and earth-orbiting spacecraft observations of X-ray and energetic particle fluxes.

The energetic particle instrument ERNE is an important component in the suite of SOHO instruments for studies of the solar energetic particle events. These bursts of very high-energy particles are among the most important space weather effects dictating the spacecraft design requirements. Furthermore, the energisation of charged particles associated with solar flares and coronal mass ejections (CMEs) is one of the most critical issues in space physics. Figure 1 shows two examples of energetic particles associated with Earthward-directed coronal mass ejections (Ref. 7). The real-time availability of these measurements is dependent on the SOHO tracking schedules.

2.2.2. Ground-based ionospheric observations

Northern Fenno-Scandia is one of the most favourable regions to monitor the auroral phenomena, and, consequently, an extensive network of ground-based observation facilities has been set up in Finland and Scandinavia partly through Finnish national efforts and partly through wide international collaboration.

Finland participates in several ionospheric radar systems that have been established in the Arctic region. The European Incoherent Scatter (EISCAT) facility and the EISACT Svalbard Radar (ESR) are powerful research tools, but are not suited for monitoring purposes. More continuous observations of ionospheric plasma drifts and electric fields are provided by coherent radars. At present there are two such systems located in Finland: one of the two Scandinavian Twin Auroral Radar Experiment (STARE) radars, and one of the two Cutlass radars of the Super Dual Auroral Radar Network (SuperDARN). The Cutlass measurements are becoming available in real time on January 1999; they will then be merged with measurements from other SuperDARN radars to create a convection pattern over the northern polar regions.

Figure 1. *ERNE observations of protons during two CME events (April 7–11 and May 12–16, 1997). Intensities are 1-hour averages and energy channels are from top to bottom 1.6–3 MeV, 3–6 MeV, 6–12 MeV, 12–24 MeV, 24–48 MeV. The vertical dashed lines represent the time of the shock passage as observed by CELIAS/MTOF proton monitor (From Ref. 7).*

The FMI maintains and operates the IMAGE magnetometer chain, which now extends from Nurmijärvi in the Southern Finland to the Arctic Archipelago of Svalbard and from the Norwegian coast to the Kola peninsula in the east-west direction. The chain thus covers subauroral, auroral, and polar cap latitudes, and is large enough to monitor phenomena that have typical scale sizes of about 1000 km. The data are presently obtained once per day from the stations for cost reasons, but the technology for real-time monitoring is readily available.

Finland operates a variety of optical instruments, riometers, and ionosondes. Many of these instruments can be used in real-time monitoring of space weather events much more efficiently than they are today. The network of all-sky CCD cameras maintained by the FMI and the riometers maintained by the Sodankylä Geophysical Observatory are operated continuously, other instruments are used in a campaign-oriented mode.

The FMI is currently developing a comprehensive ionospheric monitoring system, which comprises the IMAGE magnetometer network, network of 5 or more all-sky cameras, and the STARE radar system. Data from this MIRACLE (Magnetometers, Ionospheric Radars, All-sky Cameras Large Experiment, Ref. 8) network are presented in a common database, where quick-look time series plots are updated daily.

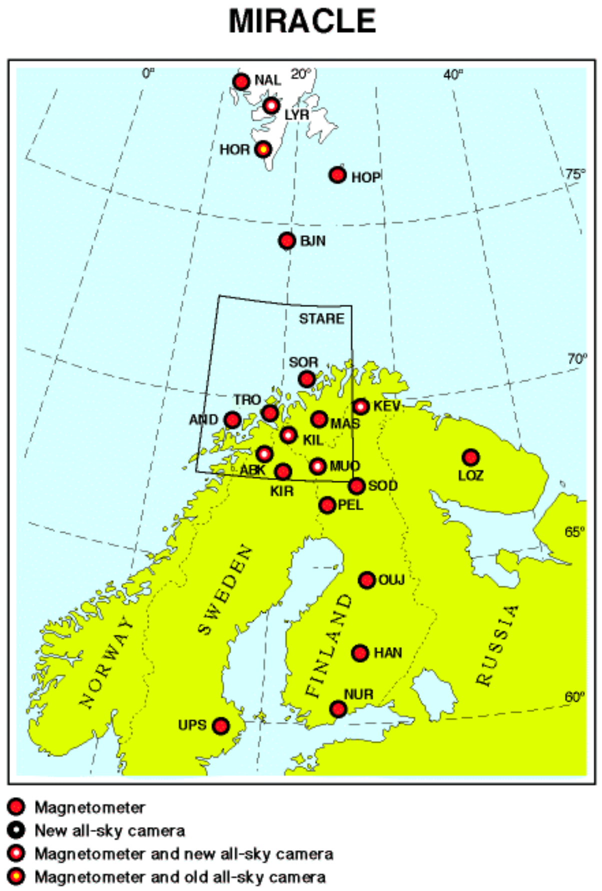

Figure 2. *The MIRACLE complement of instruments: The magnetometer locations, all-sky camera locations, and STARE field of view are indicated. In the same area, also the EISCAT, ESR, and CUTLASS radars are operated.*

The status and opportunities for extensive ground-based monitoring of space weather look promising within Europe. Space weather applications also provide motivation for further development of the Finnish ground-based observing facilities and their real-time data acquisition and distribution systems.

3. APPLICATION PROJECTS

3.1. ESA Contract SPEE

During 1996–1998 FMI led an ESA Contract named the Study of Plasma and Energetic Electron Environments and Effects (SPEE). The project was conducted jointly by the Finnish Meteorological Institute in Helsinki and the Swedish Institute of Space Physics (IRF) in Kiruna, Uppsala, and Lund. The goals of this study were to gain better understanding on spacecraft charging on polar orbiting satellites (IRF-Uppsala), to investigate satellite anomaly forecasting based on anomaly data bases created from measurements made at geostationary orbit (IRF-Kiruna), to summarise the European modelling capabilities in space weather (FMI, Ref. 9), and to determine requirements for establishing a European Space Weather Programme (FMI, Ref. 9). (The documentation of the project can be found on the www-server http://www.geo.fmi.fi/spee/ that was developed as a part of the project). This project gave valuable insight to both opportunities and problems of creating a more coherent European approach to space weather. As one of the main conclusions it was recommended that ESA should take a more active role in co-ordinating European efforts in this field (Ref. 9).

3.2. Evaluating the effects of geomagnetically induced currents

Several investigations of geomagnetically induced current (GIC) effects on high-voltage power transmission lines have been conducted by the FMI group since 1977. The largest project was performed in collaboration with Imatran Voima Oy Power Company during 1991–1992 (Ref. 10). Another important GIC effect is corrosion of gas pipelines; investigation of effects on pipelines was started at the FMI in 1988. At present the FMI has a contract with the natural gas Pipeline Company GASUM Oy for the period 1998–1999. Studies concerning effects on pipelines in Southern Sweden are also underway in collaboration with Swedish scientists.

3.3. Forecasting northern lights

Space weather has also positive effects; in particular the beautiful auroral displays during clear winter nights visible at high latitudes. Accurate forecasting of auroras is as difficult and challenging as prediction of the economically more important risks for technological systems. The FMI provides three-night auroral forecasts with expected cloudiness to tourist hotels in Lapland. This service has become very much appreciated by foreign tourists who do not have a chance to see auroras at home.

4. FUTURE PLANS

The basic research in space physics has its place in the Finnish space research regardless of the future of space weather activities. However, we expect that increasing emphasis on operational space weather applications will benefit also the basic research because the strong requirements for usable space weather models and forecast tools pose a significant challenge on fundamental space physics research as well Some of the existing plans for space weather applications are summarised here; the rapidly growing interest in space weather will quite likely add more to the list in the near future.

4.1. Magnetospheric modelling

The FMI has two complementary approaches for modelling the near-earth plasma environment. The global magnetohydrodynamic (MHD) simulation code takes solar wind measurements as input and produces the temporal evolution of the fields and plasmas in the magnetosphere - ionosphere system. Thus, this model has capability to forecast active events one hour in advance, or the time it takes solar wind to travel from the upstream monitor to the subsolar magnetopause. This model is currently in scientific use, and will be further tested in the near future utilising data from the International Solar Terrestrial Physics programme. With the evolution of more powerful computers, such models hold great potential for accurate prediction of the near-earth plasma environment and field configurations.

The empirical event-based magnetospheric magnetic field models (Refs 11, 12) describe the magnetic field by fitting a model field to observations. The electric field is computed from the temporal changes in the magnetic field. The trajectories of energetic particles in the inner magnetosphere are then computed using the drift approximation and the model fields. These models have been used in scientific analyses and will be further tested by intercomparisons with data and the MHD codes. These models provide means to monitor the magnetospheric state in a more global sense using only one-point or single-parameter measurements and a powerful tool for post-event analysis. These models will be developed toward more real-time use in the near future.

4.2. Geomagnetically induced currents

Due to Finland's location below the auroral current systems, the geomagnetically induced currents will remain a more immediate concern than they are in Central Europe. The measurements at high-voltage transmission lines will continue, although the Finnish network has not yet suffered of serious problems. Furthermore, the corrosion effects of natural gas pipelines are a permanent feature. The Finnish pipeline network is expected to expand in the future toward Sweden and the investigations of GIC effects will be continued.

Also other potential ground-based customers of space weather services are being sought. For example, railway equipment can be susceptible to GIC effects; the FMI is considering possibilities of measurements and malfunction analyses in this sector.

4.3. Space climate

The main driver of studies of space climate is probably its potential effects on the atmospheric climate and thus on life on Earth. While the anthropogenic causes of the ozone hole have dominated the public debate, it is clear that it is equally important to evaluate the natural causes of the global change. Scientists from the FMI, the University of Helsinki, and the Sodankylä Geophysical Observatory are initiating several studies of space climate effects on the atmosphere, which will be further activated when ESA's ENVISAT will start producing global measurements of the upper atmospheric constituents.

4.4. ESA activities

FMI became involved in the emerging ESA space weather activities through the SPEE project. This study led us to the conclusion that ESA is the right European organisation to have the leading role in the European space weather programme. The Finnish space weather community is prepared to participate in future efforts of establishing such a programme. Participation in technical studies on space weather modelling, forecasting, spacecraft charging, or other issues is also viewed with great interest.

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