ESA REPORT ON SPACE WEATHER: LOOKING FOR THE ROLE OF ESA ON THE INTERNATIONAL SPACE WEATHER SCENE

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ABSTRACT

Space weather is a rapidly growing field of applied space research. While the US space research and applications communities already have organised their activities under a national programme, Europe is just starting this process. This report is based on findings of an investigation conducted under an ESTEC contract on space environment effects on satellites and European capabilities in the field of space weather modelling. It is recommended that ESA should take an active role in the development of European space weather activities.

1. INTRODUCTION

As space weather is a new concept, its content and meaning are under continuous development. Quite generally space weather is understood to refer to the time-variable conditions in space environment that may damage space-borne or ground-based technological systems and, in the worst case, endanger human health or life. While this definition is rather negative, the physical phenomena related to space weather are extremely interesting and under active basic research, and also include positive effects such as the beautiful auroral displays in the polar regions. The most important social and economical expectations for space weather activities are based on prospects of avoiding the consequences of space weather events either by system design or by efficient warning and prediction services allowing for preventive measures to be taken.

Presently the most advanced approach to space weather is formulated in the US National Space Weather Program (NSWP) (Ref. 1) which is a joint undertaking of several US institutions and agencies (NASA, NSF, NOAA, DoD, etc.) to co-ordinate American space weather activities. The NSWP is a result of an initiative of the Solar-Terrestrial Physics (STP) community based on the expectation that both research and application communities would benefit from a concerted approach to this complex of problems. The international STP community has independently advocated the scientific aspects of space weather. Space weather symposia are on the agenda of all major scientfic conferences on solar-terrestrial physics. Scientific unions, such as the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) and the Committee on Space Research (COSPAR), are developing their working structures to support space weather research through interdisciplinary actions joining scientists from solar, magnetospheric, and ionospheric physics.

In Europe space weather efforts have been starting more slowly but are steadily gaining momentum. Within ESA the Space Environments and Effects Analysis Section (TOS-EMA) at ESTEC have contracted out a number of space weather-related projects. The present report is based on one of these, the Study of Plasma and Energetic Electron Environments and Effects (SPEE). It was conducted jointly by the Finnish Meteorological Institute and the Swedish Institute of Space Physics. The goals of this study were to gain better understanding on spacecraft charging on polar orbits, to investigate satellite anomaly forecasting based on anomaly data bases on geostationary orbit, to summarise the European modelling capabilities in space weather, and to determine requirements for establishing a European Space Weather Programme. The present report deals with this last task. The underlying document (Ref. 2) is publicly available through the WWW server "http://www.geo.fmi.fi/spee/" which was developed as a part of the contract. The server also contains technical notes of the work packages of the project, charging data base from the Swedish Freja satellite, and a useful selection of space weather links worldwide, including a simple search tool.

This report is organised as follows. In section 2 the domain of space weather is discussed from various viewpoints. Section 3 deals with space weather activities in Europe. In section 4 the main recommendations of the SPEE study are presented and section 5 gives some concluding remarks.

2. DOMAIN OF SPACE WEATHER

In principle, there is nothing new with space weather. The STP community has been investigating the physics behind space weather phenomena from the dawn of space research and spacecraft engineers and operators have developed methods to avoid space weather-induced technological problems from the time of the first space missions. What is new, is the progress toward organised efforts to improve the practical solutions to space weather problems. Why this is happening now, has at least two important reasons: Our present society has become deeply dependent on reliable space systems and will become even more dependent in the future. On the other hand, the STP science has progressed to a stage where possibilities for useful space weather forecast models are expected to be available within a foreseeable future.

The ultimate source of most space weather phenomena is the Sun and a control of space weather effects on technological systems requires thorough understanding of Solar-Terrestrial Physics: the physics of the intercoupled plasma environments of the solar wind, the magnetosphere, the ionosphere, and the atmosphere. Although STP research and space weather activities are closely linked, the difference between them is the more practical flavour of the latter. Thus a distinction between these concepts can, and should, be made: Basic research in the field of STP is necessary for space weather applications, whereas space weather research is an application-oriented discipline stimulating research of various problems in STP. Finally, any space weather activity must ultimately address the needs of the applications community, e.g., engineers and operators. Identification of user needs is paramount but, as yet, one of the most unclear parts of the activity.

2.1. Space weather vs. atmospheric weather

Before we go to further to specific space weather activities, it is useful to compare space weather with atmospheric weather. It is quite likely that the design of future space weather activities will, to a large extent, utilise the experience from meteorological services. This is already now a fact at the only operational space weather centres, the Space Environment Center (SEC) of NOAA, and the 50th Space Weather Squadron of the US Air Force, both in Colorado, USA.

However, there are important differences between the atmospheric and space weather systems:

1) While many meteorological processes are localised and it is possible to make good limited-area weather forecasts, space weather is always global in the planetary scale. This arises from the large spatial scale-sizes of the solar-terrestrial plasma systems and the long correlation times of these plasmas. The most important and most dramatic effects originating from the Sun disturb the Earth's plasma environment, the magnetosphere, which responds to these disturbances globally.

2) Space weather events occur over a wide range of time scales: the entire magnetosphere responds to the solar-originated disturbances within only a few minutes, global reconfiguration takes a few tens of minutes, and sometimes extreme conditions may remain for much longer periods. The fastest signal in the global magnetospheric system is associated to the so-called Storm Sudden Commencement (SSC): ground based magnetometers react immediately to a significant change in the magnetopause current system when a strong solar wind disturbance hits the magnetosphere. At the slowest end the enhanced fluxes of energetic particles in the radiation belts decay in time scales of days, months, or even years.

3) Our means to monitor space weather are much more limited than our ability to install weather stations on the Earth's surface. Space weather prediction schemes must be capable of functioning with input from only a few isolated measurements of the upstream solar wind conditions and magnetospheric parameters. Successful space weather activities are performed on a global scale, merging space-borne and ground-based observational capabilities.

4) From mathematical modelling point of view it is important to note that while atmospheric dynamics can successfully be described in terms of hydrodynamics in local thermodynamic equilibrium, space weather requires development of tools of not only within magnetohydrodynamics but also consideration of non-equilibrium processes in tenuous space plasmas. This introduces a completely different level of complexity to the numerical modelling efforts.

2.2. Engineering approach vs. forecasting

We may think two complementary approaches to space weather. The first is the traditional engineering approach to avoid space weather-related problems by designing as “weather-proof” systems as possible. This is a valid strategy that is based on experience from previous technological successes and failures, on increasing knowledge of materials, and on capability to specify the space environmental conditions that the spacecraft is expected to encounter during its mission. Improved understanding of space weather is needed both in the post-analysis of anomalies that have taken place and in environment specification. A drawback of aiming at fully weatherproof spacecraft is a risk to expensive over-designs.

The second approach is to develop better real-time warning and forecasting methods for hazardous conditions. In operative services the requirements of predictions or forecasts are quite different from the requirements in scientific studies of cause and effects. A scientist can use long time to establish the connection from a solar surface feature to the following disturbance in energetic particle fluxes on geostationary orbit but a real space weather forecaster needs tools to predict in advance what will happen at agreeable accuracy. To develop such tools is a substantial challenge to the STP science whose extent may not yet be fully appreciated by the science nor the application communities. In order to really improve our forecasting capabilities we need considerable efforts to improve the understanding of the whole chain of physical processes from the Sun to the upper atmosphere. In addition to the modellers this also challenges the organisations responsible for observations. Real-time space weather activities require continuous, well-co-ordinated, and rapidly distributed observations in the same way as in atmospheric weather services. Today we are far from this goal.

2.3. Space weather and its effects

Another useful way of determining the domain of space weather is to make a distinction between the physics of space weather itself and its effects on technological systems. The STP research contributes to the first whereas the second belongs to the field of spacecraft engineering, including research in materials, electronics, telecommunication systems, etc.

Practically all spacecraft are susceptible to space weather disturbances. Most anomalies are harmless, and relatively easy to recover from, but sometimes the problems become serious. Thus it should be very useful to closely monitor what kind of environmental effects a particular spacecraft is sensitive to and this way to learn to be alerted and also avoid complicated manoeuvres during bad space weather. Because really serious hazards take place only seldom, the fatal events may be combinations of design problems, aged components or units, and severe environmental stress.

The effects of space weather are variable. Spacecraft components are affected by spacecraft charging, deep discharges, anomalous behaviour of complicated systems, gradual degradation, sensor interference, and so on. The orbits of spacecraft may drop in altitude due to increased atmospheric drag during solar particle events. This is also a problem with launch and reentry of large space vehicles. Space weather effects on communication lines on the ground were the first reported problems already in the 1840's. Today the problems include disturbances in the global positioning systems (GPS), satellite-to-ground communications, and propagation of radio waves (HF, VHF). The manned space flights are expected to be an increasing customer group of space weather services in future and also high-altitude/polar air-flights are susceptible for increased radiation risks. Finally, the ground-based power distribution systems, both electrical transmission lines, and oil and gas pipelines, suffer from geomagnetically induced current effects, particularly close to the auroral regions.

Our present society is already highly dependent on smooth daily operations of space systems and future will become even more so. A new group of space systems are the polar/ high-inclination telecommunications satellites, such as the newly deployed Iridium network of 66 operational spacecraft, with a number of spare units, or the planned Teledesic and Celestri systems with a large number of satellites crossing the flux tubes of radiation belts and the auroral zone. Also the technological development toward more miniaturised circuits may lead to increased risks due to single event hazards. Thus it is quite realistic to predict that space weather has bright future and it is right now when also Europe must become organised in this field.

3. SPACE WEATHER IN EUROPE

Europe has a strong STP science community, own spacecraft industry, and several satellite operators. These are the basic elements that are necessary for space weather activities. However, these resources are scattered all around Europe, often to small and relatively weak units that work with some specific aspect of space weather do not co-operate very efficiently. When European opinions of space weather were investigated as a part of the SPEE study, a realistic although a bit cynical comment was that "individuals and groups will make 'Space weather' whatever best suits their needs". This is certainly happening everywhere, also in Europe, but it should not be seen in negative light only. While it is obvious that not all work reported, e.g., in this workshop will ever mature to real space weather applications, it is important that the dialogue has started and many different ideas presented. We do not yet know how the future European space weather scene will look like, but it is this ground from which it will eventually grow.

3.1. European strengths

It appears to be widely acknowledged that the basic solar-terrestrial physics research in Europe is of high scientific quality. The number of European scientific satellites in this field is not large but the European research groups are, in addition, actively involved in most major foreign, particularly US, programmes and together cover all fields relevant to space weather research.

Europe has also a leading role in one of the most critical research areas. SOHO is an outstanding and unique tool for studies of the origins of space weather. When we aim at significant improvements in forecasting of space weather, we simultaneously require progress in understanding the processes in the Sun and in the solar wind, which cause the space weather near the Earth.

Another field where Europeans have taken a prominent role is the radiation belt modelling. The series of TREND studies conducted by IASB/BIRA in Brussels with their collaborators are recognised worldwide as major steps forward. Here the role of ESTEC has been also been important.

Furthermore, the expertise at ESTEC in various spacecraft-environment interactions is a concrete European strength. ESTEC is the central node of European space technology with good contacts to all major players in this field.

3.2. European weaknesses

Probably the most severe problem in Europe are the scattered resources. This is a general concern in all fields where no single European country or institution is strong enough to be independent. The only cure to this is organised co-operation.

Another identified weakness is lack of structure on which to base the co-operation. This is only partially true because we have ESA. This particular workshop is a clear sign that ESA is the right organisation for future European space weather activities. Through their practical experience on spacecraft-environment interactions TOS-EMA already have realised the needs for and possibilities of a more active role in this field. However, improving of space weather models requires enhanced efforts from the science community as well. Thus far the ESA Science Programme has not taken any visible role in space weather.

In space observations and in space weather-related modelling Europe is clearly behind the US. This is based on two facts that will remain there for foreseeable future. The American fleet of spacecraft with space physics instrumentation is much larger than the European as is the American space physics community. However, the observational needs are truly global and it may not be very rational to aim at autonomy in this sector. Instead, a joint worldwide observational network where different capabilities complement each other looks a much more valuable goal.

The contacts between space science and applications communities in Europe are either weak or non-existent. However, already the present embryonic phases of space weather activities have improved this and if we will succeed in creating a co-ordinated European Space Weather Programme, the future looks much better in this respect as well.

4. A ROLE FOR ESA

How to proceed toward a European Space Weather Programme is not only a scientific and technological problem but also very much a question of European space policy. In practice there are two different routes to take: a consortium of national institutes or an ESA-lead programme. Of course, it is quite reasonable to ask whether we need an own programme, or would it be more efficient to join the American efforts. It has also been suggested that the European Union should be made a co-ordinating body but that does not look very practical. EU does not have own expertise in space science and technology. EU can, of course, support, e.g., networks of national groups in space weather-related research. This is actually a recommendable strategy for groups seeking funding in space weather research.

4.1. Background for recommendations

The national institutions interested in space weather form, in any case, the elements of European space weather activities. None of them, nor any ESA country alone, is expected to be able to support an independent full-scale space weather activity. More limited, localised space weather centres are, on the other hand, quite possible, and would be valuable as parts of an international space weather system. There are embryos of such, e.g., the Solar-Terrestrial Laboratory of the Swedish Institute of Space Physics in Lund and the ISES Regional Warning Centres, of which the Western Europe RWC is located in Meudon. Furthermore, several groups, e.g., MSSL, BIRA/IASB, DERA, ONERA-CERT, IRF, FMI, TOS-EMA, and many others, already have activities which can contribute significantly to a European space weather network.

A comment we received during the SPEE study was: “Europeans have difficulties to agree upon anything.” Thus it may well be that the only way of organising a rationalised European space weather activity is to have an authoritative organisation to supervise the development. For this we have ESA and space weather can be argued to be a classic example of agency responsibility. At present ESA's engagement in space weather is in the technological sector. ESTEC has good expertise on the design of spacecraft and on single event effects. TOS-EMA at ESTEC has resources for internal activities and controls some amount of funds within TRP for limited studies, such as SPEE, TREND, SPENVIS, and SEDAT. The present space weather funding is a vanishingly small part of the total annual R&D budget of ESA.

4.2. Recommendations

To speed up the process of creating a European space weather agenda the STP community could be of considerable help. In the US the NSWP was realised very much by the pressure from the science community and it seems that this pressure is increasing in Europe as well. Note, however, that in the US space sciences and engineering have a tradition of cross-fertilisation, which is much weaker in Europe. In Europe a particularly authoritative body is the ESA Science Programme. Thus it is recommended that:

* ESA Science Programme should take space weather on its agenda.

* A formal Science/Technology Interdisciplinary Space Weather Programme which reports to SPC/SSWG and IPC should be formed.

It is unrealistic to expect large investments in space weather research from the already tight ESA science budget. At the beginning our recommendations do not require large funds and could be realised, e.g., by some increase of TRP funding and matching the activity with the Science Programme. The scientific supervision could be defined as a part of the mandate of SSWG, or a small ad-hoc working group could be formed to define the ESA Space Weather activities. This group should involve the present expertise at ESTEC and the future activities should be closely co-ordinated with the more technologically oriented projects of ESTEC. It is of crucial importance, however, that ESA will make a long-term commitment to its involvement in space weather: ESA is dependent on space weather as long as ESA remains a space mission agency.

4.3. Possible level of concerted European approach

Our third recommendation is that:

* ESA should initiate work to establish a European Space Weather Data and Model Centre (EDMC; either centralised or distributed with a central core). This Centre should have as its goal to become a European Data, Model, and Specification Centre (EDMSC), and it should look for a workable solution for a full-scale European Space Weather Centre (ESWC).

For simplicity, we call these units here “Centres” although the final solution may be a decentralised structure. This is a hierarchical sequence: EDMSC or ESWC cannot do without having data and models, and if a centre is able to forecast, it can provide environment specifications and nowcasting as well. Thus the rapid flow of reliable data is basis of everything. At present this is the worst technical bottleneck.

4.3.1. European Data and Model Centre (EDMC)

The mission of EDMC would be twofold. It should create links to all relevant data for space weather services and be able to provide up-to-date data services to engineers, operators, and scientists. It should also collect available models and have sufficient expertise to work for conversion of these models toward operational applications, resembling the "rapid prototyping" of NOAA/SEC. It is likely that models having significant operational capability will be protected by patents. A natural task for the EDMC would be to take care of the necessary agreements concerning the user rights and in this way also guard the interests of the patent holders.

This operation could be started with a staff of 10–20 persons equally divided between data and model specialists. For evaluation of the models sufficient scientific expertise is necessary.

The centre would not need to be centralised. It needs a headquarter but otherwise it can be distributed provided that the nodes of the distributed system are strong enough for efficient operation. Both centralised and distributed systems have their advantages and problems. A distributed system could more easily get local support and thus the whole system could be more extensive. On the other hand, this approach requires binding commitments from all parties to guarantee efficient communication and most likely causes increased interface costs. A recommendable compromise would be a central EDMC with local affiliations responsible for products within their local expertise. This solution would probably provide the best outcome for least initial cost to the organisation(s) supporting EDMC.

It should be noted that TOS-EMA already now has activities toward this direction through some of their own activities and contracts such as TREND, SPENVIS, SPEE, and SEDAT (cf. http://www.estec.esa.nl/wmwww/wma/).

4.3.2. European Data, Model, and Specification Centre (EDMSC)

This centre should do everything EDMC would and, in addition, provide post-analysis and nowcasting services to customers. EDMSC needs everything there is in an EDMC and scientific and technical staff for analysis and nowcasting. Here a centralised core where the most critical work is performed may be the most efficient structure. Also the staff must be sufficient, at least 20–30 persons.

4.3.3. European Space Weather Centre (ESWC)

This would be a logical third step based on the above centres. It may not be a realistic near-time goal in Europe and will require a thorough market and cost-benefit analysis. Even without such analysis it looks reasonable that it should be realised in close collaboration with other organisations, particularly NOAA/SEC and ISES. In addition to tasks of EDMSC, ESWC needs 24-hour operations, fast communication lines, and extensive supercomputer resources. A minimum staff of 50 persons is a reasonable estimate.

5. CONCLUDING REMARKS

During the last few years European space weather activities have started to gain momentum. At this early stage the whole concept is under evolution and no clear European approach has been defined. Europe has all necessary elements for a viable space weather programme but science and application resources are scattered to different countries and organisations. It is necessary to look for a co-ordinated approach toward a European Space Weather Programme. It is recommended that ESA should assume a more active role in fostering this co-operation. On the technological sector this can be build upon the already existing activities at ESTEC. However, also the scientific work needs better co-ordination than today and it is recommended that SPC/SSWG should take space weather on its agenda. This does not require immediate investments in new space missions from the ESA Science Programme budget. Furthermore, it is important that the European space weather activities co-operate with the American efforts.

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