# STUDY OF A EUROPEAN SPACE WEATHER PROGRAMME

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## ABSTRACT/RESUME

This paper summarises work on an ESA-funded study of a European space weather programme. We first outline the study methodology with an emphasis on the systems approach adopted and the importance of the underpinning scientific knowledge. We then present some key results emerging from this not-yet-completed study. The emphasis is to give the reader a flavour of those results, rather than a detailed justification.

## 1. BACKGROUND

ESA has funded two parallel studies on a European Space Weather programme. These studies are charged to investigate the benefits of, and need for, such a programme – and then to establish the possible content and organisation of that programme. This paper is a short report on one of the two studies – namely that led by RAL. This study has been carried out by a consortium of six groups:

- Rutherford Appleton Laboratory, UK (RAL)
- Qinetiq, UK (formerly Defence Evaluation and Research Agency)
- Astrium, UK
- Finnish Meteorological Institute (FMI)
- Office National d'Etudes et de Recherches Aérospatiales, Département Environnement Spatial, France (ONERA-DESP)
- Belgian Institute for Space Aeronomy (BIRA)

The study started in April 2000 and will complete (delivery of a draft final report to ESA) in November 2001. The aim of this short paper is to give a flavour of the emerging results from the study.

## 2. SYSTEMS APPROACH

An important aspect of the study is the use of a systems approach. This is illustrated by the study logic shown in Fig. 1 below. We started by establishing requirements for a space weather system (left hand side of Fig. 1) and then using these to build up a specification of the content of that system (right hand side of Fig. 1). Throughout this process we maintain traceability from each step to the next. Thus it will be straightforward to adapt the study results in response to changes at any point in the study logic.

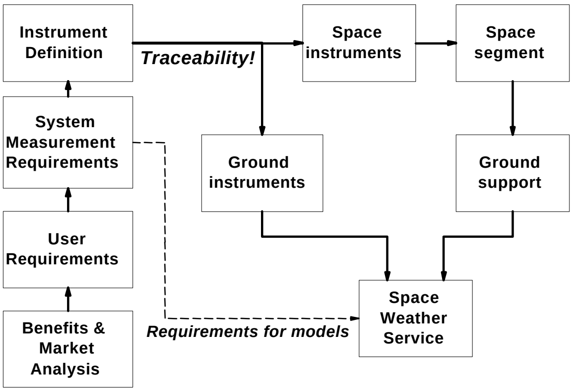

Fig 1. Simplified study logic. This logic is underpinned by our scientific knowledge of space weather.

The requirements analysis started by identifying the potential benefits of a space weather programme - and by interviewing potential users in order to understand their perception of space weather, its impact on their activities and the likely demand for services to help them manage those impacts.

The market analysis was a key step since it established a set of raw requirements for space weather services. These were then interpreted to produce a set of "user requirements", giving a clear specification of the products required from a space weather service. The next step was to identify the measurements required to generate those products. The resulting “system measurement requirements” identified:

- The physical parameters to be measured
- The locations at which those measurements should be made
- The required time resolution of the measurements
- The models which may be used to derive the products from the measurements

The final step of the requirements analysis was to consolidate the system measurement requirements so that only unique requirements are listed. In effect we identified synergies where one measurement can service multiple user requirements. This is a key aspect of the systems approach. It exploits our knowledge of the underpinning science to produce an efficient service and eliminate duplication.

Given the consolidated system measurement requirements, we then proceeded through a series of steps to build a specification of the space weather service as follows:

*Instrument Definition.* The CSMRs were analysed to identify the instruments needed to make these measurements. The result was two lists: (a) space-based instruments (including options to use various different orbits), and (b) ground-based instruments.

*Space Segment.* The list of space-based measurements was then analysed to explore how those measurements might be satisfied: (a) by existing and planned missions, (b) by hitch-hiker solutions – space weather instruments flown on other missions, and (c) by dedicated space weather missions. The hitch-hiker and dedicated options were then analysed to establish the necessary space architecture (e.g. orbits, numbers of spacecraft and ground stations). At this point the merits and demerits of different orbits were explored into order to select from options established by the instrument definition. Finally, having established a space architecture, we specified how this might be implemented in terms of existing European space platforms (dedicated missions) or classes of potential hosts (hitch-hikers).

*Ground support.* Having established a specification of for the space segment, we then analysed the ground segment required to support the various space segment options, e.g. services such as instrument and spacecraft commanding, ground stations for uplink and downlink, telemetry processing and data reduction to physical parameters, spacecraft tracking, orbit determination and prediction, attitude maintenance, etc.

*Ground instruments.* In this case, we first investigated how much these can be supported by maintenance and augmentation of existing ground-based systems. We also identified options for future development of ground-based systems.

*Space Weather Service.* In this final step we specified how to build the service that takes parameters from space and ground measurements, converts them to useful products and delivers them to prospective users.

## 3. OUTREACH

Perhaps the most important result to emerge from the study is the need for outreach, i.e. to improve understanding of space weather among various target groups. The requirements work, in particular the market analysis, has shown a critical need to improve knowledge of space weather among potential users across Europe. Key target groups for outreach are:

*End users*, i.e. the organisations whose activities are directly impacted by space weather. It is particularly important to inform technical managers in these organisations so that they can assess the impact of space weather on the systems for which they are responsible.

*Decision-makers.* This is a wide set of people whose decisions affect the operation of systems impacted by space weather. They include senior management (especially non-technical management) of organisations impacted by space weather, regulatory authorities where these oversee the operation of those organisations and, of course, governments.

*Commentators.* This is the body of experts outside industry and government which provides specialist commentary on issues affecting specific technological activities. Typical examples would be technical journalists (most technological sectors have a lively set of specialist journals) and consultants. They are often in the vanguard for exploring new issues and acting as a source of information for specialists in industry and government.

*Students.* These are the young people who will become members of the three previous groups. Thus we should encourage them to gain some appreciation of space weather issues during their studies.

## 4. NICHE OPPORTUNITIES

Our study shows that there is significant user demand in Europe for specific and well-targeted space weather services, e.g. power systems, airlines, geological surveys/drilling. Users are willing to pay for services that interpret space weather measurements to generate products that they can use - without themselves having to gain specialist knowledge of space weather or its impact on their systems.

This user demand provides a series of niche opportunities that may be exploited by industry, government laboratories and academia. Such services can be efficiently developed by a bottom-up approach that encourages competition between providers, i.e. a market approach is appropriate to provision of specialist services to end users (but see section 5.1).

What also follows here is that there is no user demand for an overarching service. The integration of space weather activities across different user needs must be justified by the underpinning science, i.e. that different users are affected by factors that are inter-related. A simple example is that high-frequency radio propagation and over-the-horizon radar respond to ionospheric critical frequency whereas global positioning system measurements respond to total electron content. But science tells us that these are both functions of the same parameter – namely the height profile of plasma number density in the ionosphere. The critical frequency is determined by the peak of that profile while total electron content is the integral of that profile.

## 5. DATA INFRASTRUCTURE

### 5.1 The need for public sector funding

The provision of specialist services to end users, as discussed in the previous section, depends on access to basic data on the behaviour of the space environment (e.g. sunspot number, geomagnetic indices, ionospheric data, interplanetary magnetic field, etc.). Our study shows that, while users are prepared to pay for interpretation of those data, they are not prepared to pay for its collection. They consider that the collection of "basic scientific data" is a public sector responsibility. This is an important message. There is some pressure from government bodies in Europe that end users should pay for collection of basic data. This probably reflects a lack of understanding of space weather issues and demonstrates the need for better outreach with respect to decision-makers.

### 5.2 Ground versus Space observations

Many space weather parameters can be measured from the ground. Furthermore, the scope of such measurements is likely to increase with advances in scientific understanding and technological capability. Such measurements have practical advantages over space-based measurements. They avoid the extra costs associated with: (a) qualifying instruments for space flight, and (b) launch and operations. It is also vastly easier to maintain and upgrade ground-based measurements. Thus we consider that space-based measurements can only be justified on qualitative grounds, e.g.

- practicability (e.g. UV and X-ray imagery)
- high quality (e.g. stray light in visible-wavelength coronagraph)

### 5.3 Telemetry

Telemetry is a critical factor for space weather measurements. Near real-time telemetry is usually needed; our survey of space instruments showed that the maximum gap that can be allowed in the telemetry stream is usually less than 20 minutes and often down to a few seconds. This demand drives the space architecture (orbits, numbers of spacecraft and ground stations). We find that geosynchronous and L1 are good locations for space weather measurements since they allow continuous observation periods with just a few spacecraft and ground stations. In contrast, we find that low Earth orbit has limited utility for space weather work because it drives you to use larger numbers of spacecraft and ground stations.

The central role of telemetry will drive space weather missions to use architectures that are fundamentally different from the typical architecture of an ESA science mission. The latter use state-of-the-art space techniques in order to do cutting-edge science, but they can usually wait several days to get the data back, e.g. with the present Cluster mission, data may not arrive at ESOC until 1 to 3 days after being recorded on the one of the spacecraft. In contrast space weather monitoring needs near real-time telemetry as we have already discussed and would be adequately served by using well-established space measurement techniques.

### 5.4 Options for space observations

A key issue for in the ESA studies is whether to use: (a) existing and planned missions, (b) hitch-hikers – space weather instruments on other spacecraft, or (c) dedicated space weather missions. We have looked at all three options.

*Existing/planned.* There are only a few existing/ planned European missions that make measurements relevant to space weather. The most notable is, of course, SOHO; there are also a range of smaller missions such as the German CHAMP mission. The scope of this option increases significantly if co-operation with non-European (and especially US missions) is considered.

*Hitch-hikers.* This is an excellent option for some specific problems, e.g. there are good possibilities for radiation belt monitoring at geosynchronous orbit using hitch-hiker instruments on the many spacecraft placed in that orbit, e.g. meteorological satellites. However, hitch-hikers can address only a subset of space weather issues.

*Dedicated missions.* This option has some key advantages: (a) it is good (and often required) for measurements that require orbits not usually visited by other spacecraft, e.g. L1; (b) one can put several space weather instruments on one launch, which may reduce overall costs, and (c) one launch could place several spacecraft in orbit, which may again reduce costs. Some examples of possible dedicated missions are shown in the table below. This outlines four possible missions giving the types and locations of measurements together with a brief rationale for making that measurement. Note that we have split L1 measurements over two spacecraft each optimised to its measurements. This is an interesting question – is it better to build small satellites optimised to particular functions or to combine measurements on a single spacecraft with the compromises that will then arise?

Table 1. Ideas for dedicated space weather missions

| *Measurement* | *Location* | *Rationale* |
|---|---|---|
| Solar wind/ interplanetary magnetic field | L1 spinner | Need a successor for ACE (+ Wind?) |
| Solar observation | L1 stabilised | As above but for SOHO |
| Radiation belt monitor | GTO-like | Outer belt dynamics not yet understood |
| Solar observation | Off Earth-Sun line (L4/L5) | Would be invaluable - but challenging in terms of telemetry and delta-V (velocity). |

The solar wind/ interplanetary magnetic field measurements at L1 are a particularly interesting case. These measurements have strong requirements on magnetic cleanliness and interference from thruster firings. Thus they may be better satisfied on a separate spacecraft.

### 5.5 Options for ground observations

Europe has a wealth of ground-based measurements related to space weather. As part of our study we carried out a survey of European space weather resources. This identified some 180 resources of which 105 were ground measurements. These mainly focus on observations of the Sun (23%), the ionosphere (34%) and ground-effects (37%).

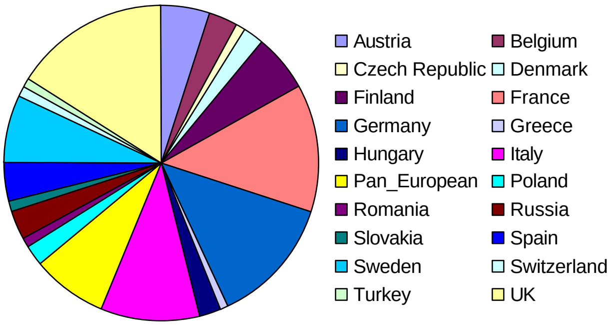

Fig 2. Ground-based space weather measurements by country

These measurements are spread over many European countries as shown in Fig. 2. There are strong activities in France, Germany, Italy, Scandinavia and the UK. There is also a strong Pan-European element. There is clearly a good base for further European collaboration and co-ordination

Some examples of ground-based space weather measurements are shown in the table below. The Net column indicates where a network of observatories is required in order to obtain a global or regional view of space weather conditions. The Index column indicates where measurements can yield a useful index such as Kp or sunspot number.

Table 2. Ground-based space weather measurements.

| Measurement type | Net | Index |
|---|---|---|
| Cross-tail electric field (high-frequency backscatter radar network, i.e. SuperDARN) | Y | |
| Geomagnetic indices | Y | Y |
| Geomagnetic variations | Y | |
| Ionospheric critical frequencies | Y | Y |
| Ionospheric total electron content | Y | |
| Interplanetary scintillation (remote sensing of heliospheric density and velocity) | Y | Y |
| Secondary neutron fluxes | Y | |
| Solar 10.7 cm radio emission (Penticton index) | | Y |
| Solar surface magnetic field (magnetograph) | | |
| Sunspot number | Y | Y |

We particularly highlight two items (high-frequency backscatter radar and interplanetary scintillation) as remote sensing techniques with potential for development to provide useful measurements.

## 6. STUDY REPORTS

The key reports from our study will be made publicly available once they have been completed. You can download them as PDF files from our web site at http://www.wdc.rl.ac.uk/SWstudy. Some reports are already available and other will follow towards the end of 2001.

## 7. ACKNOWLEDGEMENTS

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