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WP500. European Co-ordination

# Roadmap for European co-ordination in space weather

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# 1 Preface

## 1.1 Document change record

| Issue | Date | Notes/remarks |
|---|---|---|
| 0.6 | 02 Nov 2001 | Draft for internal review |
| 1.0 | 19 Nov 2001 | First formal issue. Revised after internal review |
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## 1.2 Purpose of the document

This document presents a plan to co-ordinate European space weather resources.

## 1.3 Important Documents

We list here the various documents used as source material for this report. These include both hardcopy and web sources. Documents may be referenced in the text and this is indicated by a series of characters enclosed in square brackets, e.g. [ITT].

| | |
|---|---|
| AAG | Area of Astrogeophysics Research, http://astrogeofisica.univaq.it/en/meteo.asp |
| COST271 | COST 271 - Effects of upper atmosphere on terrestrial and Earth-space communications, http://www.cost271.rl.ac.uk/ |
| CTIP | Coupled Thermosphere-Ionosphere model, http://cat.apg.ph.ucl.ac.uk/model1.html |
| ECSS | European Co-operation for Space Standardisation (ECSS), ECSS E-10-04 - see http://www.estec.esa.nl/wmwww/wma/ecss.html |
| EOS | "In Brief - Here comes the Sun", *EOS, Transactions of the American Geophysical Union*, Vol 81, No. 30, p334, 25 July 2000 |
| HIPPARCOS | http://www.estec.esa.nl/wmwww/wma/hipp_rad_back.html |
| IFD | Ionospheric Forecasting Demonstrator, http://rasp.dera.gov.uk/ifs/ifs.html) |
| IGRF | International Geomagnetic Reference Field, http://www.ngdc.noaa.gov/IAGA/wg8/igrf2000.html |
| IGY | http://www.wdc.rl.ac.uk/wdcmain/gdhomepg.html |
| INAG | Ionosonde Network Advisory Group, http://www.ips.gov.au/INAG/ |
| INTERMAG | The International Real-time Magnetic observatory Network, http://www.gsrg.nmh.ac.uk/intermagnet/ |
| ISO | For reports on space weather induced glitches on ISO see http://www.iso.vilspa.esa.es/instr/SWS/doc/sol_fl/proton_event2.html and http://www.iso.vilspa.esa.es/users/expl_lib/CAM/glitch_lib/glitch_lib.html |
| JOSO | Joint Organisation for Solar Observations, http://joso.oat.ts.astro.it/ |
| LUND | http://www.irfl.lu.se/ |

| | |
|---|---|
| PNST | Programme National Soleil-Terre, http://www.medoc-ias.u-psud.fr/pnst/pnst1.htm |
| SAAPS | Development of AI Methods in Spacecraft Anomaly Predictions, http://www.irfl.lu.se/saaps/ |
| SCALES | NOAA space weather scales, http://sec.noaa.gov/NOAAscales/ |
| SDARN | Super Dual Auroral Radar Network, http://superdarn.jhuapl.edu/ |
| SWAP | Space Weather in the Antares Programme, http://akseli.tekes.fi/Resource.phx/tivi/antares/en/swape.htx |
| SWR_CAT | ESWS-RAL-RP-0001 Catalogue of European Space Weather Resources |
| TTP | ESA Technology Transfer Programme, http://www.esa.int/ttp/ |
| WDC | http://www.wdc.rl.ac.uk/wdcmain/guide/wdcguide.html |
| WP110 | Benefits of a European Space Weather Programme, ESWPS-DER-TN-0001 |
| WP421 | A definition of instruments needed for space weather measurements, ESWS-RAL-TN-0001 |

### *1.4 Definitions, acronyms and abbreviations*



| | |
|---|---|
| ACE | Advanced Composition Explorer |
| BNSC | British National Space Centre |
| CCIR | International Radio Consultative Committee |
| CCSDS | Consultative Committee for Space Data Standards |
| CDF | Common Data Format (NASA) |
| CELIAS | Charge, Element, and Isotope Analysis System |
| CERN | European Centre for Nuclear Research |
| CHAMP | CHAllenging Microsatellite Payload |
| CNES | Centre National d'Etudes Spatiales |
| CNRS | Centre National de la Recherche Scientifique |
| COST | Co-operation on Science and Technology (EU) |
| DLR | Deutsche Forschungsanstalt fuer Luft- und Raumfahrt |
| ECSS | European Co-operation for Space Standardisation |
| EIT | Extreme ultraviolet Imaging Telescope |
| EGS | European Geophysical Society |
| ESA | European Space Agency |
| ESF | European Science Foundation |
| ESO | European Southern Observatory |
| EU | European Union |
| EUMETSAT | European organisation for the exploitation of METeorological SATellites |
| FAGS | Federation of Astronomical and Geophysical Services |
| GPS | Global Positioning System |
| IACG | Inter-Agency Co-ordination Group |
| IAGA | International Association of Geophysics and Aeronomy |
| ICSU | International Council for Science |
| IGS | International GPS Service for Geodynamics |
| INAG | Ionosonde Network Advisory Group |
| IPR | Intellectual Property Right |
| ISES | International Space Environment Service |

| | |
| --- | --- |
| ISO | International Standards Organisation |
| ITU | International Telecommunication Union |
| LASCO | Large Angle and Spectrometric Coronagraph |
| L1 | Lagrangian point 1 (1500000 km sunward of Earth) |
| N/a | Not applicable |
| NASA | National Aeronautics and Space Administration |
| NOAA | National Oceanic and Atmospheric Administration |
| PI | Principal Investigator |
| RAL | Rutherford Appleton Laboratory |
| SOHO | Solar and Heliospheric Observatory |
| SSWG | Solar System Working Group (ESA) |
| STP | Solar Terrestrial Physics |
| TBC | To be confirmed |
| TBD | To be done |
| THEMIS | Télescope Héliographique pour l'Étude du Magnétisme et des Instabilités Solaires |
| TM | Telemetry |
| URL | Uniform Resource Locator |
| UK | United Kingdom |
| URSI | International Union of Radio Science |
| US | United States |
| WDC | World Data Centre |
| W3C | World-Wide Web Consortium |
| XDF | EXtended Data Format (NASA) |
| XML | Extenisble Markup Language |

# 2 Introduction

The main aim of Work Package 500 (Programme structure and organisation) is to analyse existing and planned European space weather resources and to propose a roadmap for their optimisation in a future space weather programme. A secondary aim is to provide a list of ESA-specific actions as requested by, and agreed with, the Agency.

The first step in this work package was to survey the existing and planned resources. The results of that survey have been presented in the Catalogue of European space weather resources [SWR_CAT]. The Catalogue is underpinned by a database of European space weather resources, which was used to provide the statistical data presented in that report. That database has now been used to provide the additional statistical data that are presented in this document. Note that the database has been updated with additional information since issue 1.0 of the Catalogue was released. Thus an updated version (1.1) of the Catalogue has been released in parallel with this document and is consistent with the data presented in this document.

In this document we use the survey results to discuss how these space weather resources might be co-ordinated in a European space weather programme. The document is structured as follows:

- In section 3 we make a broader synthesis of the survey results to provide an overview of the space weather scene in Europe.
- In section 4 we discuss the requirements for co-ordination and optimisation. The aim here is to identify the key issues that will assist the development and exploitation of Europe’s potential to carry out space weather activities – and thus deliver the consequent benefits [WP110].
- In section 5 we develop a model of how space weather assets might be co-ordinated within a European context and explore how the above requirements can be addressed within that model.
- In section 6 we summarise our conclusions as a table of the steps needed to co-ordinate European space weather resources. This is a roadmap of the required steps. It is also presented graphically in the form of a Gantt chart.
- In the Appendix (section 7) we discuss the impact of space weather on ESA's own activities and propose a list of ESA specific actions.

# 3 The Space Weather scene in Europe

## 3.1 Introduction

As a first part of this study we undertook a survey of European assets that can be used for space weather activities. The methodology, results and limitations of that survey are presented in detail in the "Catalogue of European Space Weather Resources" [SWR_CAT]. However, it is useful to summarise some key points here:

Europe already has substantial assets that can be used in space weather activities. The survey identified a total of 222 assets[1], which are broken down into different areas as shown in the pie chart below. These areas are:

| Resource Type | Description of asset type | Number of assets |
|---|---|---|
| Concept | Intellectually developed concept relevant to future space weather activities | 2 |
| Data centre | Centre which archives and disseminates data that may be relevant to space weather | 15 |
| Ground-station | Station for reception of spacecraft telemetry - and possibly uplink of commands | 3 |
| Historical | Record of historical space weather activity that may illuminate future programmes | 2 |
| Information | Source of general information (not just data) relevant to space weather | 11 |
| Instrument | Scientific instrument that can be used for measurements of parameters relevant to space weather | 45 |
| Measurement | Service that provides regular measurements of parameters relevant to space weather | 99 |
| Model | Model or software from which space weather products are or might be provided | 21 |
| Network | Group of people and/or organisations that plays a role in European space weather activities | 13 |
| Platform | Expertise in micro- and nano-satellites | 11 |
| | TOTAL | 222 |

**Table 1. Types of space weather resources in the Catalogue**

Note that all assets in this table and the following figure are counted equally. We have made no attempt to judge the relative merits of different assets- see [SWR_CAT].

[1] The survey data were collected through a variety of sources including contributions solicited by notes to the community, web searches, etc. Further inputs are welcome – please contact Mike Hapgood (Email: mailto:M.Hapgood@rl.ac.uk.

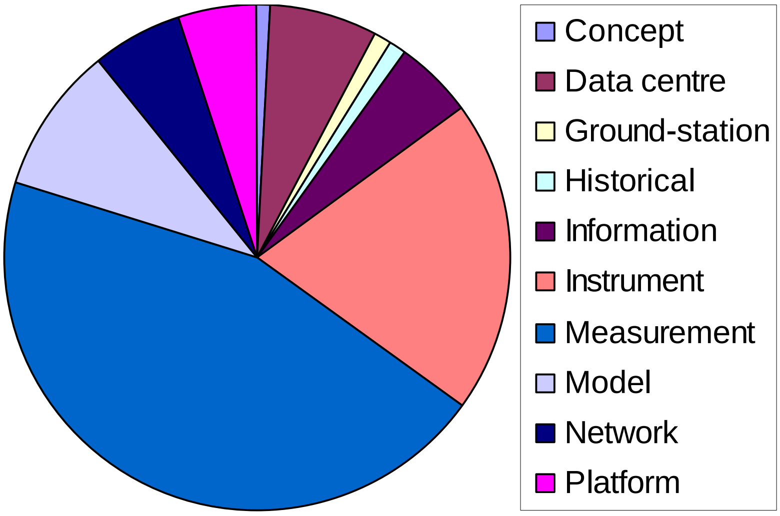


**Figure 1 Distribution of catalogued space weather resources by type**



These assets are largely associated with the European solar-terrestrial physics (STP) community. This is to be expected, as STP is the branch of science that provides the knowledge underpinning space weather activities. Europe has a long and continuing strong presence in the international STP community and this is reflected in the strong base of existing assets.

## *3.2 Measurements*

By far the largest group of assets is that of instruments which measure parameters relevant to space weather. These are predominantly ground-based assets (95 out of 99) though the space-based assets include the two best-instrumented STP space missions now in operation – namely the SOHO mission to study the Sun and the Cluster mission to study the Earth's magnetosphere.

### 3.2.1 Space assets

These two missions are an excellent illustration of two key aspects of European expertise in space instrumentation: (a) that Europe has huge experience in developing and flying space instrumentation, but (b) there is also a strong tradition of collaboration with US space groups. For example, Cluster has 10 instruments led by European PIs and one led by a US PI. But most of the 10 European-led instruments also have major US participation. Similarly SOHO has 9 instruments led by European PIs and 3 led by US PIs. This theme of Europe-US collaboration carries forward into US-led missions, e.g. the NASA Stereo mission has one European PI (out of 4) and major participation by several other European groups.

The European Heritage/Expertise in space instrumentation has been discussed more deeply in the Instrument Definition study. Thus we do not pursue that issue further here. For more information please see section 2.6.5 of the Instrument Definition study report [WP421]. This provides a table of European Heritage/Expertise on a variety of recent and current missions – and indicates space instrument expertise in at least 10 ESA member states and in the Agency itself.

In summary Europe has a strong heritage in the development of space instrumentation that can measure space weather parameters. That heritage is supplemented by strong synergy with comparable work in the US.

### 3.2.2 Ground-based assets

The ground-based measurements include both core STP monitoring and specialised research instruments. The core monitoring systems include solar and geomagnetic observations, ionosondes, GPS monitors and neutron monitors. Many of these instruments are modern instances of long-established monitoring programmes[2]. Most have now made the transition from analogue to digital techniques that is essential for the future exploitation of their data. Thus they provide a strong basis on which a European space weather programme could be developed.

It is important to note that European ground-based monitoring programmes are not confined to the measurement sites in Europe. There is also a strong European presence in Antarctica where France, Italy and the UK all have strong programmes. France and the UK also support monitoring at sub-Antarctic sites such as Kerguelen and the Falkland Islands.

Note also that ground-based STP measurements in polar regions are particularly valuable as one can infer much about magnetospheric dynamics (and the consequential space weather effects) from monitoring phenonema in the polar ionosphere, e.g. plasma flows and electric currents. Europe has a strong involvement in such measurements through the Antarctic measurements discussed above and even more strongly through measurement programmes in Arctic and sub-Arctic Europe, e.g. Iceland, Scotland, Scandinavia and Svalbard.



Among the specialised research instruments we particularly identify the high-frequency backscatter radars that form a European component of the global SuperDARN network. Of the 17 radars currently operational, 5 are supported by European countries (3 by the UK and 2 by France). SuperDARN is potentially a very interesting space weather tool because it measures ionospheric convection, i.e. the plasma flows in the high-latitude ionosphere, over large parts of both polar regions. These flows are directly coupled to the equivalent flows in the magnetosphere and so the ionospheric measurements provide a way of viewing magnetospheric dynamics. That view is not readily obtained from spacecraft measurements as it would require a flotilla of dozens if not hundreds of spacecraft.

Other ground-based research techniques that may be relevant for space weather activities include solar observations and interplanetary scintillation. The solar observations include magnetographs (essential for predicting the heliospheric magnetic field), H-alpha observations and, of course, sunspot observations (to maintain the 250-year sequence of sunspot numbers which is vital for studying long-term change). There is strong European heritage in both areas.

However, we also note that many ground-based research instruments are too specialised to be directly applicable to space weather activities but are, of course, of fundamental importance in STP research that contributes scientific underpinning to space weather activities. One example of this is the EISCAT radar system. When used in its prime mode this provides precision measurements of

[2] Most ground-based STP programmes date from at least the International Geophysical Year in 1957/8, which saw major investment in STP research – including a major international effort to standardise data products and data exchange - see [IGY]. Some European ground-based programmes long pre-date even this - especially magnetic observations, e.g. the Greenwich/Abinger/Hartland series started in 1868 and continues today.

ionospheric conditions at a small number of locations. Thus EISCAT has been and remains of fundamental importance for a whole range of scientific studies that need that precision. But what EISCAT does provide for a space weather programme is an example of successful European co-operation in running ground-based systems. It was founded in 1975 as a partnership of Finland, France, Germany, Norway, Sweden and the UK. Its subsequent success has now attracted interest from a non-European partner – namely Japan – and the latter is now a full member of the EISCAT Scientific Association, the legal entity which runs the EISCAT systems.

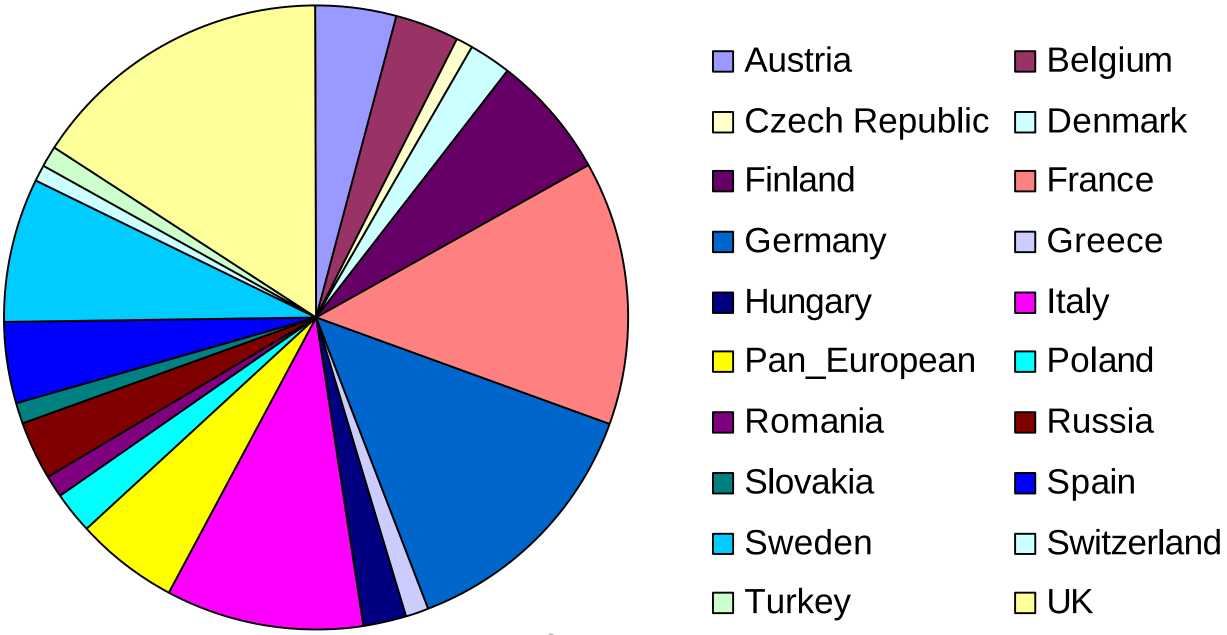


**Figure 2. Distribution of catalogued ground-based measurements by country**

The pie chart above shows the distribution by country of the 95 ground-based measurements in the Catalogue. This is just a simple count of assets but nonetheless reveals several interesting features:

1. Most European countries have some involvement in ground-based measurements relevant to space weather.
2. The biggest players are those countries with a strong interest in STP namely France, Germany, Italy, the Scandinavian countries and the UK.
3. There are already several Pan-European projects relevant to space weather, e.g. the EISCAT radars and their ancillary measurements in Northern Scandinavia and the THEMIS solar observatory on Tenerife.
4. One apparent anomaly in the chart is the absence of any measurement from Norway. This is largely explained by the fact that Norway hosts many of the Pan-European facilities.
5. One feature not shown in the chart is that many of these ground-based measurements form part of global measurement projects such as SuperDARN [SDARN] and Intermagnet [INMTERMAG].

In summary, we note that (a) interest and involvement in ground-based measurements of space weather parameters is spread all over Europe, and (b) the community already has significant experience of coming together to build Pan-European and global projects. There is a firm basis to develop a ground-based component in a European space weather programme.

### 3.3 Modelling

Another important asset in space weather activities is modelling. This provides the means by which measurements of space weather parameters can be converted to useful parameters. Our survey of space weather resources identified some important modelling efforts in Europe. However, this aspect of the survey was strongly dependent on the personal knowledge of the compilers (47% of models were tracked by personal knowledge compared with only 14% of measurements). Thus we suspect that there are many other modelling efforts not detected by the survey. (A more targeted survey might be useful as part of any future studies.)

The models recorded by the survey include both numerical and physical models. Numerical models include traditional models such as the International Geomagnetic Reference Field [IGRF] but are now dominated by the use neural network techniques. There are several world-class applications of neural networks in Europe. For example, the Lund group has successfully applied networks to several space weather problems such as prediction of geomagnetic indices based on L1 measurements of the heliospheric medium - see [LUND]. There is also some excellent work on applying neural networks to the “dirty” datasets (i.e. subject to noise and data gaps) that are so common in space weather measurements [IFD]. In physical modelling Europe also has some world-class applications, e.g. the coupled thermosphere-ionosphere model at University College London [CTIP]. An important aspect of physical modelling is such modelling is not (and should not be) restricted to the near-Earth environment. The application of modelling techniques to different solar system environments such as Mars, Jupiter and Titan is a powerful way of testing the models’ ability to represent the essential physics – and thus helps to improve applications to space weather. There is already much European interest in such applications.

Modelling activities in Europe are still predominantly carried out on the basis of individual groups. There are good links between modelling groups – for example through the normal scientific exchange at meetings. Such links have also been reinforced by exchange visits, e.g. as supported by various EU Framework programmes. The recent advent of Grid technology may lead to a greater convergence of the modelling community – since it provides a convenient framework for distributed development and execution of models. The Grid is the subject of national funding initiatives (e.g. in the UK). There are also at least two pan-European initiatives to support GRID work in ways that may be of value for space weather activities. ESA’s SpaceGrid initiative includes an explicit space weather task, while the EU-funded DataGrid initiative is expected to support work to use Grid technology to improve handling of solar data.

In summary, there is a substantial modelling community in Europe, which could contribute significantly to building a European space weather programme. But further work is required to better understand the full capabilities of that community.

### 3.4 Collaborative traditions

An important but less tangible asset for space weather activities in Europe is the existence of a set of collaborative traditions on which it can build.

First and foremost there is the tradition of European collaboration that has developed over the past half century. There are now a large number of cases in which European countries have worked together to their mutual benefit. The EU is, of course, the prime example. ESA is another relevant example. But there are also many other examples such as EUMETSAT, ESO, EISCAT, CERN, etc.

There are also good examples of non-governmental organisation at the European level for example EGS.

Secondly there is also a tradition of co-operation at a technical level. For example the underpinning science of solar-terrestrial physics is a strongly collaborative discipline – because of the great scientific value that it gains through combination of data from different instruments and from theory and modelling. This applies not only to STP as a basic science but also in more application orientated areas such as ionospheric propagation of radio waves.

### 3.5 Networks

This group of assets is the set of pan-European groups that have come together to address various space weather problems. They are concrete examples of the collaborative traditions discussed above.

One important class of programmes is national programmes to address space weather issues or related programmes such as co-ordinated measurements of parameters relevant to space weather. Examples of national programmes include

- *Programme National Soleil-Terre* in France [PNST]. This is run under the auspices of CNRS and has space weather as one of its four themes.
- *Space Weather in the Antares Programme* in Finland [SWAP]. This is a programme of basic space research and new instrument development funded via the Antares Programme of the Academy of Finland.

Below the national level there are also some regional groupings such as the *Area of Astrogeophysics Research* consortium in Italy [AAG].

On the European level a prime example of a network is the series of programmes to address problems in ionospheric propagation of radio waves – COST 271 and its predecessors [COST271]. These have been organised under the EU COST framework. This is a system in which the EU encourages the formation of networks to address specific problems in science and technology by co-ordinated action across the EU/EEA member states and many other states associated with COST (e.g. most East European states are associated, as is the United States). The EU provides funding for the programme co-ordination, e.g. funding a secretariat to provide an executive office for that co-ordination. The funding for technical work must come from other sources such as national programmes. We note here that a proposal to develop a COST programme aimed at generic space weather issues has emerged from discussions in the ESA Space Weather Working Team.

There are a variety of other European networks relevant to space weather. These include:

| Name | Description |
| --- | --- |
| Spacecraft Plasma Interactions Network in Europe | Network to share resources and to co-ordinate efforts in all domains related to the interaction of spacecraft with the space plasma. |
| Space Processes and Electrical Changes Influencing Atmospheric Layers | ESF Network to generate global, regional & local models to relate electrical changes in ionosphere to the distribution of galactic, solar & magnetospheric charged particles, to quantify the relationship between these & the distribution of cloud and rainfall. |
| Joint Organization for Solar Observations | Group set up in 1968/69 to search for an "ideal" observatory site, construct a "Joint European Solar Observatory", a "Large European Solar Telescope" and stimulate more effective solar research in Europe. Led to current facilities at Tenerife & La Palma |
| European Solar Magnetometry Network | collaboration of eight European solar physics research groups. funded by a grant from the EU TMR programme for 4 years from May 1, 1998. integrates development and usage of European solar telescopes with space observation, data interpretation and theory |

**Table 2. European networks working on topics related to space weather**



The key point here is that the existence of networks linking space weather activities within Europe demonstrates that there is already much experience in building a co-ordinated European approach to these issues. That experience shows that there are tangible benefits to all participants. It also provides good examples of how people in Europe are working together to achieve good results.

### *3.6 Conclusions*

In conclusion Europe already has substantial assets that could form the basis of a space weather programme. These include a strong heritage in space instrumentation, a strong programme of relevant ground-based measurements and, most importantly, all these already have considerable experience of collaborative working across Europe.

# 4 Requirements for co-ordination and optimisation

The review in the previous chapter has shown that Europe has considerable potential to address the problems associated with space weather. So the challenge is to identify what is required to develop and exploit that potential – and to do so in a way that yields tangible benefits across Europe. We have identified several generic requirements that need to be addressed. These are listed below and then discussed in detail in sections 4.1 to 4.5.

1. **Inventory**. This is the requirement to know what space weather resources exist in Europe, i.e. people and groups who wish to work with European space weather assets must be able to find out what those assets are.
2. **Technical standards**. This is the requirement to encourage the operators of those assets to deliver an appropriate level of service, e.g. to deliver data products to a standard format and resolution, to provide good quality of service in a cost-effective manner. Users will not use services from space weather assets unless they know what they can expect to receive. Furthermore, they will find it easier to use services if these deliver to suitable standards (which indeed is the purpose of having standards).
3. **Interfaces**. This is the requirement to manage the interfaces between the various space weather resources.
4. **Targeting**. This is the requirement to meet user needs at the appropriate level and to avoid under- or over-provision of services.
5. **Support**. This is the requirement to establish a secure basis for the political and financial support of a space weather service. Without that support there can be no space weather service.

Note that some of these requirements will give rise to items that can be regarded as intellectual property, e.g. the inventory and technical standards. It will be important to manage the resulting intellectual property rights in a way that ensures effective community access to those properties, e.g. free of charge or by payment of a modest fee.



## *4.1 Inventory*

An inventory of space weather resources is a key starting point for any co-ordination of space weather activities in Europe. The catalogue developed in this study is a first cut at this, but it provides only a snapshot at the time of compilation. Furthermore, it is inevitably an incomplete snapshot owing to the limited information available to the compilers. So what is critical for the future is (a) to extend that first version (e.g. to address problems reported by the compilers and by comments on the study reports) and (b) to maintain that inventory against changes in space weather resources. This is a straightforward task – what is needed is to identify an entity to do the task and the resources to support the necessary work by that entity. There are many organisations in Europe that have the necessary expertise so the main issue for co-ordination is finding the necessary funding.

## *4.2 Technical standards*

We must recognise that there is already a wealth of technical co-ordination in the various disciplines that go to make up space weather activities. This is illustrated in the figure below. This shows the wide range of relevant technical co-ordination that is already carried out by international scientific and technological bodies (such as ISO, URSI, IAGA, ICSU, CCIR/ITU, CCSDS, IACG and W3C) and their specialist sections. Standards and guidelines for instrument operation (red) are provided by both specialist groups (INAG, IAGA Division 5 and IGS) and by broader groups such as ISES and the ICSU Panel on World Data Centres. Similarly for data systems (pink) we can draw on standards developed by CCSDS and W3C; NASA is a generous provider of support for standards and works with ESA through the IACG. Finally we should note that ESA is involved in space standards through ECSS. Many of these bodies, in particular CCSDS and ECSS, work closely with the International Standards Organisation.

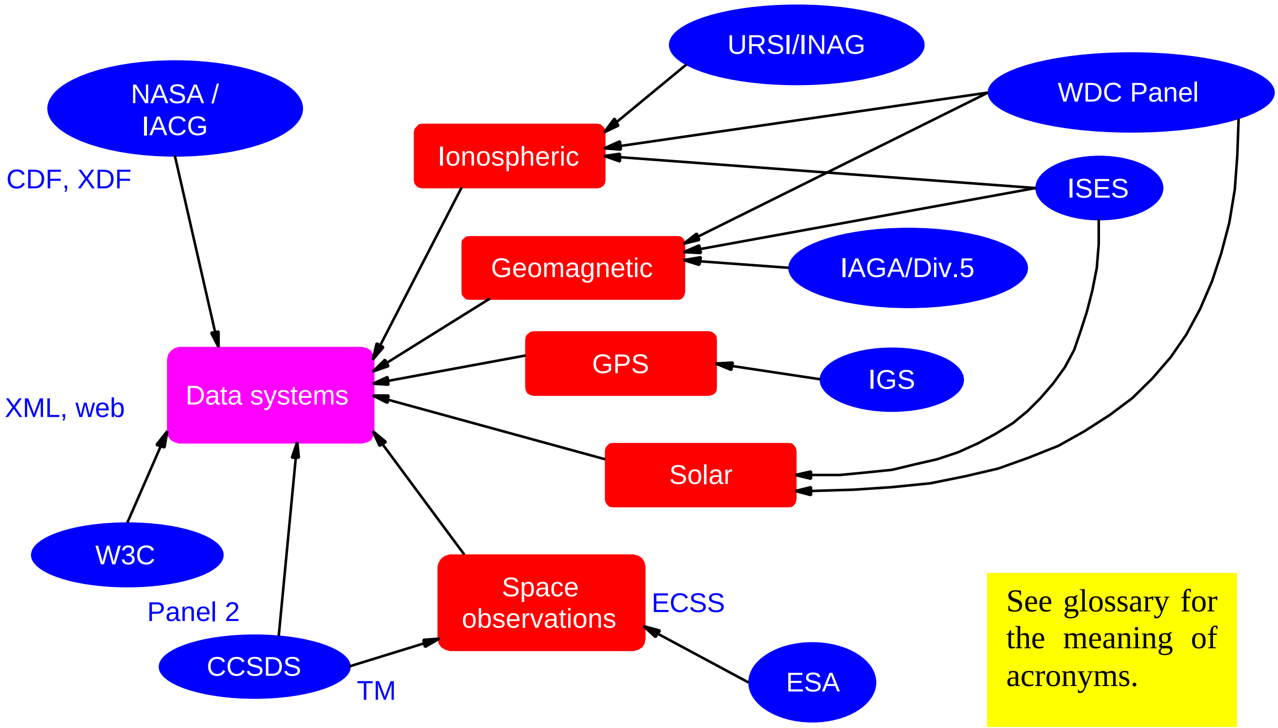


**Figure 3. Some of the bodies that carry out technical co-ordination for the measurement and dissemination of data relevant to space weather.**

The aim of European co-ordination for space weather should be to work through these bodies, e.g. by ensuring that their work is known among the European space weather community, and by ensuring that the interests of that community are represented to those bodies. Thus what is required is to establish a liaison between a European space weather programme and these technical bodies, e.g. existing European members of those bodies might be asked to act in that role. The alternative option is develop independent standards for a European space weather programme. That would be to ignore a global community of relevant expertise and to create extra unnecessary work. Thus the alternative option is not pursued further here.

Of course there remains one critical issue for both the user interface and operations – namely when is it appropriate to use particular standards? This is ultimately a matter of judgement by the managers of space weather services. That judgement can only be gained through prior technical experience.

Note that the use of standards must not drive services to a common minimum. It is important to ensure that services have the freedom to raise standards to meet any growth in user needs.

### 4.3 Interfaces

Given the large and diverse set of space weather assets in Europe, it will be a major task to co-ordinate their interfaces with each other and with other space weather activities. This will be a key management issue for any space weather programme. What is needed is a management scheme to record and document interface agreements, to ensure regular verification of interfaces against those standards and to monitor changes in interface agreements. The use of standards will help here in that agreements on specific interfaces can be simplified by making reference to publicly available standards.

### 4.4 Targeting

The aim of this requirement is to ensure that space weather needs are better matched to real capabilities. European co-operation can identify opportunities to share resources so that organisations can combine to address under- and over-provision of services. If there were an under-provision that no one organisation could address, co-operation would allow us to build groups of organisations that have the necessary capability. Similarly, if there is an over-provision (through multiple service providers) the responsible organisations could combine to provide a single service and thus reduce costs. Note that these issues of under- and over-provision can operate within a single European country - especially the larger countries - but they become much more important when considered at a pan-European level.



Examples of targeting include:

- Ensuring that monitoring networks (magnetometers, ionosondes, GPS, etc) have a spatial distribution that matches the natural variability due to space weather effects. There is an old tradition of each country in Europe operating one or more monitoring stations on its national territory. This can result in some monitoring stations being closely located but separated by national boundaries. An important aim of European co-operation could be to gradually improve the distribution of monitoring stations.
- Encouraging development of better instruments for space weather monitoring. This is especially true for space instrumentation where we need to address issues such as miniaturisation (thus increasing flight opportunities) and robustness (to maintain monitoring during extreme space weather events[3]). Targeting can help here by encouraging collaboration where this will pool resources to achieve a better product. But it will also be important not to discourage competition, as that is also a powerful incentive to deliver better products. Thus it will be important to strike a balance here.

### 4.5 Support.

Almost all measurements of parameters relevant to space weather are publicly funded. It is very likely that this position will continue into the future. The market survey performed as part of this study [WP120] showed that end users of space weather services were very reluctant to pay for such data collection. They clearly expect this to be publicly funded - as are other forms of environmental monitoring - and will pay only for specialist services that interpret the data collected. This message

[3] For example during the November 2000 solar proton event the L1 plasma measurements on ACE were rendered useless by solar proton effects on the sensor. Fortunately the plasma sensor on SOHO was more robust and provided an alternative source of these data.

is an important one and needs to be carried to the appropriate bodies. Thus there is a need for a co-ordinated action across Europe:

- to explain the benefits of space weather activities,
- to explain the technical and financial circumstances in which those activities are carried out,
- to encourage political and financial support for space weather.

This could be considered as an advocacy network for space weather.

### 4.6 Summary of requirements

The requirements are summarised in the following table:

| *Requirement* | *Co-ordination issues* | *Optimisation issues* |
|---|---|---|
| Inventory | Good knowledge of assets is basis for co-ordination | N/a |
| Technical standards | Use of existing standards | Standards reduce costs and improve service usability, they contribute to quality and cost effectiveness |
| Interfaces | Management of interfaces | Use standards to facilitate interface management |
| Targeting | Right services | Pooling of resources reduces costs |
| Support | Secure political and financial support | N/a |

**Table 3. Summary of requirements for European co-ordination.**

# 5 Co-ordination of European assets

## *5.1 Model for co-ordination*

In the European context we assume that a distributed model of co-ordination is essential - as the activities to be addressed are funded by a variety of different bodies. Most funding comes from public sector sources but those sources may be regional, national or pan-European in nature. Thus the co-ordination must be able to respond to that diversity of funding sources and hence a distributed system is required. For this to succeed the various funding bodies will have to co-ordinate the ways in which they establish their requirements with respect to space weather. The model must include mechanisms to do this - as we discuss below.

The figure below shows a simple distributed model to describe a key subset of space weather activities - namely (a) the monitoring of space weather parameters at a number of sites (M1, …, Mn), (b) their delivery to one of a set of data centres (DC1, …, DCm) where they may be used to generate space weather products, (c) the exchange of measured parameters and products between those data centres, and (d) the delivery of products from the data centres to users (who may be end users or value-added service providers).

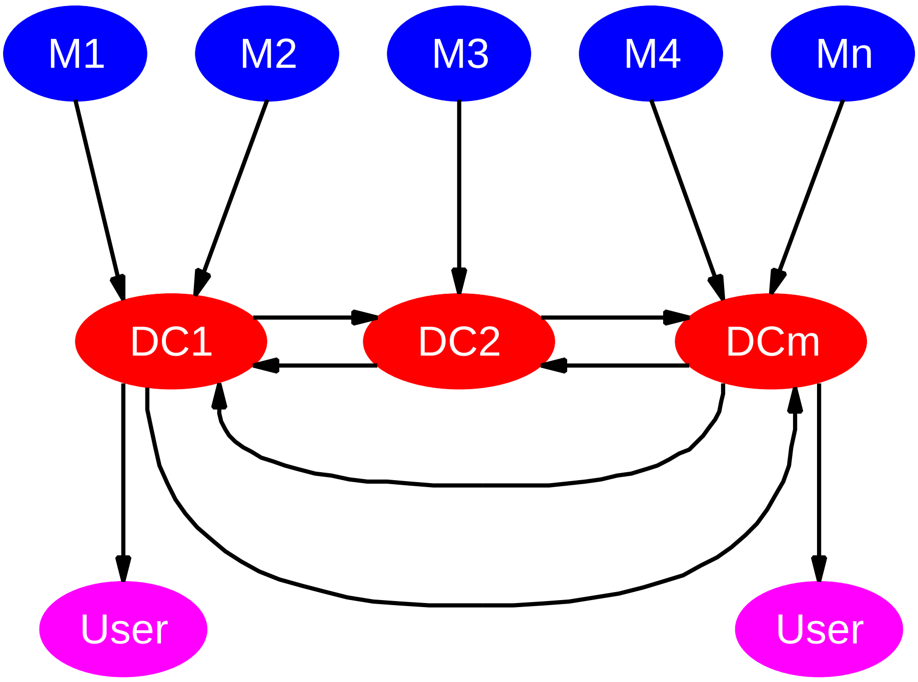


**Figure 4. Simple model showing flows of space weather data**

This model may be generalised to include modelling centres and service providers. That does not alter the general principles. We have a network of nodes of different types. Some nodes send out data, some nodes receive data and some nodes do both functions. No single node is the centre of the network.

How can we build and operate such a network? Management is the key issue as we would need to co-ordinate the actions of staff running the various different nodes. The following management functions may be identified:

- A board to make policy decisions that affect the network. The membership should include a representative of each body that funds part of the network. It would be the top-level management committee, so attendees should be senior managers with authority to commit resources to implement decisions of the board. The terms of reference of the board should include a procedure to make decisions in disputed cases (and thus membership of the network would require acceptance of that procedure).
- A working group to develop technical policy prior to its review by the board. This should be an open group in which any person working for the network can participate. To be effective the group requires a good chairperson who can steer debates to obtain results that can then be passed up for decision by the board. The group may work by appointing members or sets of members to address specific issues. These sub-groups should be established informally as needed.
- A co-ordinator team to act as the focal point for particular management issues. The work of this team may need to be funded in some centralised manner though the team itself could be distributed. It would then co-ordinate its day-to-day work via modern electronic methods such as internet and regular teleconferences.

One example of a network organised in this fashion is the Cluster Science Data System (CSDS), which is responsible for processing and disseminating various data products from ESA's Cluster mission. CSDS is executed by a mixture of national facilities (in Austria, France, Germany, Hungary, Sweden, UK and US) plus some ESA facilities. Similarly funding is divided between national and ESA sources. The construction and verification of CSDS was managed according to the model above and its successful operation is now being managed in the same way.



## 5.2 *Meeting the requirements*

### 5.2.1 Inventory

This can be addressed by maintaining an inventory of the European assets that have the potential to be members of the network. This is one example of a task for the co-ordination team discussed above.

It may be useful for the inventory to include some assessment of the relative merits of different assets. In this case it will be important for the technical working group to develop and agree the criteria on which that assessment should be based. Such agreement will be vital if the assessment of relative merits is to be seen as fair.

The arrangements for funding and managing the inventory must include an agreement with the inventory host on the management of the IPR on the inventory and on access rights to the inventory. These must ensure community access to the inventory whilst adequately rewarding the inventory host for their efforts.

### 5.2.2 Technical standards

This is primarily an issue for the technical working group. That is the forum in which use of technical standards should be discussed so that the technical staff who have to implement those standards are deeply involved in the debate. To inform that debate it will be important to ensure that the membership of the technical working group includes people who are familiar with existing standards. Ideally the membership should include people who are also involved in groups developing standards (as discussed in previous chapter) and who are willing to act as points of contact between the two activities. This is important to ensure that the views of the space weather community are represented in future development of standards.

The adoption of specific standards by the network is ultimately a decision for the board but that decision must be made on the basis of recommendations from the technical working group. It is important that the board does not try to usurp this role (even if inadvertently) and thus exclude important inputs from working level staff.

It will be important to document decisions with respect to standards and make the relevant information available to the network. This is another task for the co-ordination team. The mandates of the technical working group and the co-ordination team should specify how to manage the IPR of documents relating to standards. We propose that copyright of each document should remain with the author who created it - but that the document should be freely distributable by all funding organisations represented on the management board. It will be important to consider if that distribution should be restricted to non-commercial purposes only. However, we recommend against that on the grounds that open distribution of standards for commercial purposes is of strategic benefit as it can stimulate commercial activities based on those standards.



### 5.2.3 Interfaces

The key issues here are documentation and verification. It will be important to agree how each interface is to be operated and to record that agreement in a formal document that is signed off by official representatives of the groups on both side of the interface. In principle, there could be an interface control document (ICD) for each interface - but this would lead to an explosion of paperwork and thus great expense. Instead we propose that there should be an overall interface control document for each generic class of interface and that each specific interface is recorded in a separate appendix to that document. The maintenance of each overall document should be tasked to a member of the co-ordination team. The ICD should include a simple procedure for changing interface status.

Verification of correct operation is an important issue for interfaces. This is essential when the interface is first established but it would be appropriate to provide for occasional re-testing. Such tests may be initiated on demand if there is a problem or as part of periodic audits to confirm correct operation is maintained. We propose that the co-ordinator for each generic class of interfaces is charged to develop a suitable test procedure (it may be included in the ICD) and to provide a simple form which can be used for formally recording the execution of the test.

The co-ordinators should provide regular reports on the status of interfaces, e.g. new agreements, changes in existing agreements, results of testing. These reports should be circulated to both the technical working group and the board. In the event of problems these may be first dealt with by the technical working group and escalated to the board if no agreement can be achieved at the working level.

### 5.2.4 Targeting

This is primarily a matter for the board since the main issue here is resource sharing. But before making such decisions the board may ask the technical working group to provide advice. This may be done, for example, by setting up an ad-hoc sub-group that involves some or all working-group members with expertise in the specific issues to be considered.

Another key management issue in targeting of space weather activities is the need to maintain a balance between co-ordination and competition. Getting this right is a matter of judgement. Hence this is a matter for the board since its members are intended to be senior managers who one may expect to have the experience that should provide the judgement.

### 5.2.5 Support

Again this is primarily a matter for the board since it is a matter of building links with funding authorities. The key activity here will be to develop a set of concepts that can be used to promote space weather activities in Europe – to describe what these activities are and what they provide and to demonstrate that this is a relevant activity that deserves support. The board will need to take a lead in developing those concepts but should be able to call on the technical working group to assist in the process. To be successful the concepts will need the support of the great majority of the space weather community in Europe –the working group provides the means to seek and test that support.

It will also be necessary to develop a set of materials (graphics, briefing notes, web presentations, etc.) that implement these concepts for use in a promotional campaign. This task may be broken down into different elements and then assigned to various members of the technical working group who are willing and interested to pursue this work. There also needs to be a central repository of these materials – that would be an appropriate task for a member of the co-ordination group.

# 6 The Roadmap

Here we list a series of steps that will implement the co-ordination ideas discussed in the previous chapter. These are listed in the table below together with an indication of the expected timescale of each step.

| ***Step*** | ***Proposed timescale (months)*** |
|---|---|
| ***Develop terms of reference for a European space weather network*** | 0 to6 |
| ***Establish Board and Technical Working Group*** | 6 |
| ***Develop first promotional campaign - also develop first inventory*** | 6-12 |
| ***TWG review of appropriate standards, establish links with standards bodies*** | 6-24 |
| ***Board review of targeting of space weather assets*** | 6-24 |
| ***Seek long-term funding for co-ordination group*** | 12-24 |
| ***Carry out promotional activities and continue to develop campaign*** | 12-24 |
| ***Publish first list of recommended standards*** | 24 |
| ***Publish proposals for targeting of space weather assets*** | 24 |
| ***Initiate maintenance of inventory by co-ordination group*** | 24 |
| ***Continuing promotional work - also pursue ideas for targeting*** | 24-36 |
| ***Develop generic interface documentation*** | 24-36 |
| ***Initiate maintenance of interface documentation by co-ordination group*** | 36 |
| ***Generic ICDs open to signature*** | 36 |
| ***Continuing work on operational programme*** | 36 onwards |
| | |

**Table 4. Roadmap for co-ordination of European space weather resources**

These steps can also represented graphically in the form of a Gantt chart as shown on the next page. This form of presentation is more descriptive as it allows us to show the logical links between steps (shown by arrowed lines) as well as the overall timeline.

| ID | Task Name |
|---|---|
| 1 | **Core management** |
| 2 | Develop terms of reference |
| 3 | Establish Board and Technical Working Group |
| 4 | Seek long-term funding for co-ordination group |
| 5 | **Support** |
| 6 | Develop first promotional campaign |
| 7 | Carry out promotional activities and continue to develop campaign |
| 8 | Continuing promotional work |
| 9 | **Inventory** |
| 10 | Develop first inventory |
| 11 | Initiate maintenance of inventory by co-ordination group |
| 12 | **Standards** |
| 13 | TWG review of standards, establish links with standards bodies |
| 14 | Publish first list of recommended standards |
| 15 | **Targetting** |
| 16 | Board review of targeting of space weather assets |
| 17 | Publish proposals for targeting of space weather assets |
| 18 | Pursue ideas for targeting |
| 19 | **Interfaces** |
| 20 | Develop generic interface documentation |
| 21 | Initiate maintenance o fICDs by co-ordination group |
| 22 | Generic ICDs open to signature |

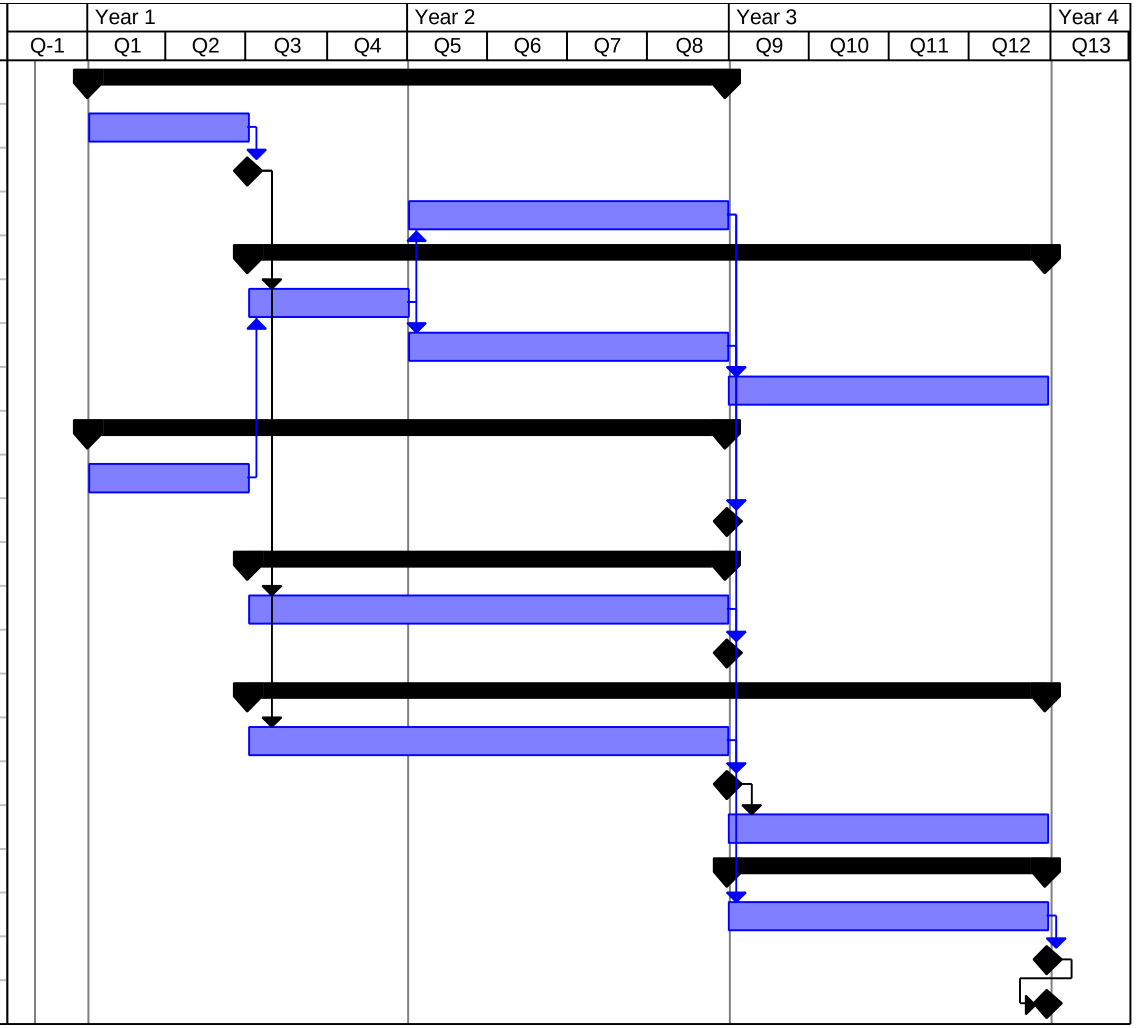


**Figure 5. Schedule for co-ordination of European space weather resources**

# 7 Appendix. Space weather as an issue for ESA

Space weather should have a pervasive influence within ESA. It is an issue that affects most of Agency's activities. Most obviously space weather can affect the operation of ESA spacecraft in a number of ways (see table below for examples). This implies a need that space weather effects are taken into account during the design of ESA spacecraft, their payloads and ground segment, i.e. that designs should be space weather tolerant where that it is required and a practicable solution exists. It also implies a need for operations staff to be aware of space weather issues and to take these into account in planning operational activities and especially when dealing with spacecraft problems.

**Table 5. Space weather effects on ESA activities**

| *Effect* | *Cause* | *Example* |
|---|---|---|
| Interference with spacecraft sub-systems | Solar protons | SEUs on Cluster instruments |
| Interference with sensors | Solar protons, radiation belts | Snowstorms on SOHO/LASCO, glitches in the detectors on ISO [ISO], background noise in Hipparcos star mapper |
| Degradation of solar arrays, | Solar protons | Cluster, HST |
| Degradation of signals used in active remote sensing | Ionospheric disturbances | |
| Interference with spacecraft uplink and downlink | Ionospheric disturbances | All missions - but especially important when running close to link margins (e.g. apogee, low elevation from ground station) |



The Agency is well on top of the design issue. For example, it has recently led provision of a standard for the mission analysis of space weather issues prior to spacecraft design [ECSS_SE]. Furthermore, space weather impacts are a recognised part of the review process that monitors the design and build of spacecraft. However, the Agency's handling of space weather as an operational issue is less clear. There are no systematic management requirements for handling space weather as an operations issue. For example:

- as a criterion prior to critical operations (e.g. launch, manoeuvres, etc). The launch of the first pair of Cluster-II spacecraft in July 2000 is perhaps a case in point. If the launch had not been delayed due to ground system problems, it would have taken place at the height of the "Bastille Day" storm. There was no prior assessment of the risks posed by major storms or monitoring of forecast data[4]. A rapid decision had to be taken on the day when the risk was explicitly reported to ESA by the US Space Environment Center [EOS]. An explicit requirement for space weather criteria prior to critical operations (even if just to say there is no dependence) would be a useful step forward.
- collection of useful ancillary data on space weather effects, e.g. anomaly reports, noise in spacecraft sensors, etc. This has been the subject of initiatives for specific cases, e.g. the

[4] The forecast was reported in media a day before the launch. For example, the BBC teletext news service juxtaposed reports of the expected storm activity with its reports of preparations for the Cluster-II launch.

anomaly database at IRF Lund [SAAPS], the study of Hipparcos star mapper noise and its origin in space weather effects [HIPPARCOS]. These initiatives are to be commended. They indicate that much useful data exists within the Agency and could be made available to the broader European space community given an appropriate lead within the Agency.

The need for ESA to take account of space weather in design and operations also implies a need to continue to encourage appropriate scientific and technological research. Most importantly, there is a need to maintain and improve understanding of the impact of space weather: (a) on technological systems used on ESA spacecraft, and also (b) on humans in space (because ESA has an increasing interest in manned space flight). This issue should cover both better design to improve protection from adverse effects of space weather and better tools to predict, monitor and analyse those effects. We note that the Agency has already supported many initiatives in these areas. We commend that and encourage continuation of those initiatives.

These applications studies must be supported by a good understanding of the underpinning science. Thus there is also a need to identify weakness in that understanding and to encourage work to overcome those weaknesses. This is a difficult area for the Agency because it touches on the remit of the Science Programme, where the principal criterion for selection of new projects is, and rightly is, the requirement to address cutting edge science. Thus there is a need for the Agency to work with the scientific community to identify space weather problems that can be considered as cutting edge science – and to encourage proposals for new projects to address these problems. These are not hard to find – many space weather problems raise fundamental issues in plasma physics. Examples include particle acceleration (relevant to solar proton events and the radiation belts) and large scale flows in collisionless plasmas (relevant to the propagation and evolution of the solar wind). These are cutting edge problems in that we seek to understand the behaviour of very complex systems.



This leaves open the question of how to address weaknesses in our understanding that are not cutting-edge science. If any such exist, they must be treated as applications studies, i.e. something to be pursued outside the Science Programme, and where funding must be justified on the basis of providing knowledge to improve real world applications.

Finally, we must note that space weather is very relevant to ESA’s general role of advancing European awareness of, and interest in, space activities and issues. Given the potential impact of space weather on human activities (in space, in the air and on the ground), it should be part of general awareness of space issues. Thus the Agency has a clear mandate to promote European awareness of space weather issues.

We also note that there is a synergy between space weather and the general promotion of space awareness. Space weather is a very convenient way to promote general interest in space. It is a subject that has a strong appeal to public interest – as shown by the public response to major space weather events – while providing a way to introduce some of the important concepts behind space flights, e.g. orbits, radiation, different regions of space, spacecraft design and operations.

### 7.1 ESA-specific actions

On the basis of the discussion above, we propose the following ESA-specific actions with respect to space weather:

1. To continue and build on existing standards and tools for consideration of space weather as a design issue and to ensure that there is adequate awareness of these standards and tools across all ESA Directorates.
2. To improve operational awareness of space weather issues:
   - by requiring that space weather criteria are specified for critical operations of ESA spacecraft. There should be separate criteria for different classes of space weather (e.g. using the NOAA scales of space weather conditions[5] [SCALES]). Null criteria will be common but should be explicitly stated as such.
   - by ensuring that ESA staff have access to advice on the formulation of these criteria and to the data needed to use them.
   - by introducing more systematic collection and dissemination of relevant ancillary data from ESA spacecraft, e.g. anomaly reports, sensor noise. The data should be collected in electronic form and archived in a manner that facilitates retrieval by professional teams across Europe.
3. To continue to support technological and science applications research aimed at improving efforts to understand and mitigate space weather effects on space activities (e.g. spacecraft systems, sensors and telemetry links).
4. To encourage scientific research that addresses fundamental physical problems whose solution can advance our understanding of space weather. These problems should be addressed by working with the European space science community to develop proposals for world-class projects that can be proposed to the ESA Science Programme and to national funding bodies. A continuing liaison with the European Science Foundation (as the association of national funding bodies across Europe) will be important here.
5. To promote public awareness of space weather issues across Europe. This should be considered as part of the general task of raising European awareness of space issues. Indeed, space weather may be an attractive vehicle for promoting a range of space issues.



[5] It might be helpful for ESA to encourage NOAA to promote these scales as an ISO standard - thus facilitating their world-wide usage.