RATIONALE AND REQUIREMENTS FOR A EUROPEAN SPACE WEATHER PROGRAMME

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ABSTRACT

The European Space Agency funded two consortia to conduct a Space Weather Programme Study between 1999 and 2001. As part of the Alcatel led consortium, we conducted a user survey to identify market sectors affected by space weather (SW), identify user problems, and user requirements. We find that even though there is a strong US SW programme with data freely available, 88% of those who responded would support a European SW programme. We find that users require better prediction, modelling, and post event analysis as well as more complete observations of the sun-earth system. We report examples of mitigating action that users can take in response to warnings and recommend setting up user groups to focus on specific areas of SW. We find there is a need for more cost benefit analysis, scientific research, understanding, and education about space weather.

1. INTRODUCTION

During 2000-2001 the European Space Agency funded two Space Weather Programme Studies. As part of the study led by Alcatel Space of Paris, we carried out a survey of existing and potential users of a space weather (SW) programme. The object was to identify market sectors affected by space weather, identify their problems, determine user requirements, and assess the potential benefits of a European SW Programme. Here we present a summary of our analysis. More details are given in the ESA reports [1, 2].

2. MARKET SURVEY

We sent an aide memoire to more than 72 contacts in different countries and obtained 50 responses, 18 from the UK, 11 from France, 4 from Germany, 6 from Sweden, 4 from Canada and 7 from the USA. From the response we identified several market sectors adversely affected by SW. They are given in Table 1.

There are several reasons why SW is becoming more important. First is the growth of markets that use or operate through space. For example, it is estimated that there are about 600 satellites in orbit (250 in geostationary) valued between US$50-100B. Over the next 10 years the Teal Group forecast over 900 launches worth more than US$ 90B commercial. The main areas for market growth include navigation, internet access and communications. The total annual market in telecommunications is expected to grow from US$20B to US$100B over the next 10 years [3]. Europe is an important player in the construction of spacecraft and has two of the five major prime contractors, Alcatel Space and Astrium. In the year 2000 Europe won 16 orders to construct telecommunications spacecraft compared to 13 for the USA. Also, more than 60% of space insurance is done through London. These are just a few examples where Europe has a big stake in global markets that are forecast to increase.

Market Sectors affected by Space Weather	Number of interviews and responses
Satellite Design	4
SatelliteOperators including: Communications Broadcasting Remote sensing Navigation Science	6
Space Agencies including: Man in space	2
Launch Operators	1
Defence including: HF communications Over the horizon radar Surveillance Navigation Submarine communications	4
Civil Aviation	7
Ground based systems including:	
Power generation and supply	6
Prospecting for minerals oil and gas	1
Oil and gas pipeline distribution	2
Railways	1
Insurance	4
Tourism	1
Research	5
US Space Weather/Education	2
Other	4
Total	50

Table 1. Response to market survey.

Deregulation of markets is a driver for SW. As a result, there are financial imperatives to work existing technology closer to the limits which then becomes more susceptible to SW. Deregulation drives competition which is driving the use of new technology, new design and new systems. For example, miniaturisation of electronics now means that electronic components can be damaged by the passage of a single energetic charged particle, mainly ions and heavy ions. Extending design life, and improving spacecraft reliability are ways of reducing cost for the users and require better knowledge of the space environment and its effects.

Another important driver is legislation. For example, new EU legislation (Directive 96/29/EURATOM, 2000) requires airlines to assess the radiation dose to aircrew. While the galactic cosmic ray component is relatively well known, the dose from a solar energetic particle (SEP) event is much more difficult to calculate. There is no reliable way to predict the occurrence or duration of SEP events at present, and so the dose assessment is done retrospectively. One SEP event of the strength of the 1956 event could put aircrew on high altitude (17 km) and transpolar routes over the 6 mSv/yr level whereupon individual monitoring is require. Business jets tend to fly above the commercial jets on trans-atlantic routes and there is a trend to fly commercial airliners at higher altitudes.

Commercial companies and organisations such as Space Agencies are driven by the need to run a profitable enterprise, and hence must consider cost benefit and health and safety. However, national defence is also affected by SW but has a different driving force: the need to know. If command and control can no longer communicate with their forces at a remote location, or if the operation of surveillance spacecraft and radars providing early warning and are severely impaired, they need to know the reason why, is it due to SW or is it a hostile act? - and they need to know as soon as possible. Defence require reliable predictions of periods of reduced capability due to SW so that alternative systems can be used.

Apart from the general drivers, several other issues came to light during our study. The tendency to break large companies into smaller companies leads to loss of expertise in some areas, and requires time to be regained. Furthermore, since the severest SW effects generally follow the eleven year solar cycle (but with a phase shift), the turnover of people within this timescale can also lead to loss of expertise. More generally, lack of knowledge about SW and its true impact on operations means that in many cases no full cost benefit analysis has been done. As a result it is very difficult to quantify the cost to business and society. Commercial sensitivity is another issue. For example, data on satellite anomalies is available for scientific satellites for analysis in relation to SW, but data for commercial spacecraft generally is not. Since the cost of a modern communications spacecraft is of the order of US$200M and since the design life is being increased to 10 years or more, any suggestion that one prime contractor is more susceptible to SW than another could impact sales for the prime contractor and insurance for the operator. Since scientific satellites are generally very different to commercial spacecraft, analysis of scientific data may not be representative of commercial problems. In some cases there may be conflicting interests too. For example, if satellite insurers identified SW as a significant risk they may demand either new design protection or higher premiums. This is not in the interest of operators, and would impact prime contractors.

3. USER PROBLEMS RELATED TO SW

From our survey we identified many problems related to SW. Here they are grouped by market sector. Only a list of the problems is provided, and some comments on the main cause. More details are given in [1, 2] and references therein.

Spacecraft design

- Internal charging and electrostatic discharge
- Surface charging and electrostatic discharge
- Single event effects (SEE)
- Sensor interference
- Cumulative radiation dose
    - Degradation of components
    - Reduction in solar cell power
- Surface erosion
- Mechanical damage – micro-particle impacts

Most of these problems arise from the space radiation environment. From our survey internal charging was said to be the most important problem. Mechanical damage from micro-particle impacts is included here since the particle orbits are affected by atmospheric drag, and since impact can trigger electrostatic discharges (ESD).

Satellite operators

- Satellite anomalies
    - Phantom commands
    - Mode switching
    - Parts failure
- Atmospheric drag
    - Loss of directional pointing
    - Loss of stability

    - Uncontrolled re-entry
    - Collision with debris
    - Launch trajectory errors
- Scintillations and ionospheric irregularities
    - Loss of navigation signal phase and amplitude lock

Generally the problems faced by designers are also the concern of the operators. Anomalies can result in minor memory upsets that can be reset from the ground, to parts failures, and in extreme cases to the total loss of spacecraft. Cumulative effects on solar cells that reduce power, and increased atmospheric drag that requires fuel to correct essentially limits operational lifetime.

Space insurance

Space insurance is concerned with any events that result in parts failures and reduced operational lifetime that would trigger payouts. For example, some policies pay out once half the spacecraft operational capacity is lost. They have an interest to see that all risks are identified, and that reasonable precautions are taken in the design, launch and operation of spacecraft.

Space agencies

- Radiation dose to astronauts
- Other problems as for operators and designers

Launch operators

- Launch trajectory errors due to atmospheric drag
- Radiation dose to payload

Aviation

- Radiation dose to aircrew
- Radiation dose to avionics
- Disruption to HF communications
- Errors in aircraft positioning on approach

Power generation and supply

- Geomagnetically induced currents (GIC)
    - Power surges
    - Network supply interruptions
    - Transformer damage
    - Reduced component lifetime

Oil and gas pipeline distribution

- GIC
    - Disruption to protection systems
    - Enhanced pipeline corrosion and reduced lifetime

Aerial surveying

- Corrupt data due to variations in the Earth's magnetic field

Drilling for oil and gas

- Errors in navigating drill heads due to variations in the Earth's magnetic field

Defence

- Loss of HF communications
- Loss of HF direction finding
- Clutter in over the horizon early warning radars
- Reduced accuracy in navigation and targeting
- Disruption to submarine communications at ELF/VLF
- Increased noise in optical sensors due to auroral light emissions
- Other problems as for satellite design
- Other problems as for satellite operators

The problems for defence were deduced from what we know from civil research using HF transmitters, coherent scatter radars, GPS signals, ELF/VLF receivers and optical sensors on spacecraft. There are probably more defence systems affected than we are aware of.

The main concerns for defence are the possible false identification of a hostile act, reduced capability in communications, surveillance and early warning. Prediction of SW events enables heightened vigilance and the use of alternative systems.

4. ECONOMIC IMPACT

An estimate of the direct economic impact of SW was attempted as part of the work inside our consortium. The annual loss was estimated to be €200M per year [4], mainly due to satellite operations and power distribution. Since this is a global figure, the loss to Europe, estimated by gross domestic product (30-40%), is €55-85M per year [4]. It should be noted that this is very uncertain estimate due to the lack of data available. It does not take account of the indirect costs to society that arise from lack of service or power outages. Furthermore, it does not take account of the cost of measures needed to assess radiation dose to aircrew or to protect astronauts. No estimates of the cost to defence are included, either as interruptions to their operations or for the precautions they take. Finally, the figures are based on past events. They do not take account of the growth of satellite systems or our future reliance on them. On the other hand, how much loss would be saved as a result of a European SW programme is unclear. What is clear is that there is a need for more market research and cost benefit analysis that takes account of all these factors. Outside Europe, other countries such as the USA have decided that a large investment in SW is justified.

5. MITGATING ACTION

A SW prediction service only makes sense if the users can take some avoiding action to minimise loss or in some cases develop new business. There are several types of actions users can take. In general terms prediction of adverse events enables better planning, such as

- Having more staff available to deal with potential problems
- Suspending non-routine operations
- Switching off non-essential systems
- Having backup systems immediately available
- Curtailing activities
- Optimising operations
- Use of alternative systems

Predictions of 'all clear' are just as important as warning of disruptive events.

6. SYNTHESIS OF USER REQUIREMENTS

We have broken down user requirements into 4 types

- Prediction of SW events
- Prediction of physical quantities that directly impact the users
- Continuous measurements of the sun-earth system
- Post event analysis

Prediction of events such as coronal mass ejections, solar flares, interplanetary shocks, geomagnetic storms, provides some measure of warning and is important for post event analysis in assessing impact. It can also provide higher visibility with the public than simply predicting that a certain quantity will increase or decrease. In general users require

- The probability that an event will occur
- When the event will occur
- How severe the disruption will be
- Where the disruption will occur
- How long the disruption will last

Predictions of physical quantities are required to assess the risk of damage or disruption. Here one should consider the using the concept of risk for non-specialist users to make predictions more understandable.

Continuous measurements of the sun-earth system are essential for confirmation of predictions, determining the state of the system, and determining when it has relaxed back to a quiet state. Continuous measurements are essential for nowcasts, and for post event analysis.

Post event analysis is essential for real long-term progress. The main objective is to design systems that are sufficiently robust to withstand SW events. The major requirements are better characterisation of the system, both static models and dynamic models, determination of extremes, probability of occurrence, duration and location of regions affected. Post event analysis provides physical understanding, feeds back into better design, model development, predictions, and risk assessment.

There are several issues regarding a prediction service that users require. They include

- Continuous data coverage
- Continuous access to data
- Reliable source data
- Backup and redundancy
- Reliable predictions
- Timely predictions
- Understandable predictions
- Visualisation
- Authoratitive predictions
- Coordinated and quality controlled predictions
- Tailored predictions
- All clear predictions

At present there are several regional warning centres in Europe. If this model is developed, then quality control and coordination to prevent conflicting predictions is highly desirable. If predictions are used to protect health and safety, or once given would entail considerable operational disruption, they require the stamp of authority which would come from an internationally respected organisation.

7. TIMESCALES AND RELIABILITY

The timescales and reliability required for predictions, based on a user response, is given in Table 2. Here we give a target reliability that should take account of the number of times an event is predicted and is correct (a hit), incorrect (false alarm), as well as the number of times a null event is predicted and is correct (correct rejection), and is incorrect (a miss) [5].

At present we can only achieve 95% reliability through a nowcast of an event in progress. However, a nowcast can still enable mitigation. For example, a solar energetic particle event may last 2 or three days enabling re-routing of aircraft, or flights at lower altitudes if the radiation dose is sufficiently high. Another example is that the energetic particle flux in the radiation belts may be enhanced 2-3 days after the start of a magnetic storm so that operators can still take action. Even now, the UK national grid acts on warnings that may only give 1 hours' notice.

Prediction	Timescale	Target reliability
Warning	2-3 days	65%
Warning/prediction	3-6 hours	65-95%
Warning/prediction	1 hour	95%
Nowcast	now	95%

Table 2. Timescales and reliability.

8. RESEARCH

More research, both basic and applied, is required to meet the users needs. SW is multi-disciplined subject and draws on research in several different areas including the physics of the sun, solar wind, magnetosphere, ionosphere, atmosphere and solid earth. It requires data from ground and space. Examples of where more basic research is required include the physics of coronal mass ejections, the evolution of the solar wind from the sun to the earth, triggering of magnetic storms and substorms, acceleration and loss of particles in the radiation belts, the electrodynamic coupling between the magnetosphere and the ionosphere, ionospheric scintillations, irregularities, and atmospheric heating.

9. EDUCTION AND PUBLICITY

There have been several well-known occasions when spacecraft have failed on orbit during magnetic storms [6] and when there have been power blackouts during SW events, such as the Quebec 1989 event [7,8]. These have produced many anecdotes and cost estimates on their impact. However, there are little or no market surveys or cost benefit analysis of the full commercial impact of SW due to the many smaller events, or to determine the risk of occurrence and impact to society. We suggest that such cost benefit analysis is essential to identify the relative importance of SW in comparison to other events or failures. Even to conduct such cost benefit analysis costs time and money and therefore business managers and decision makers must be convinced that SW is important and impacts their operations. More education and publicity about SW events is one way to influence decision makes to take SW seriously and conduct these analyses. SW is also of great interest to the public as coverage of recent events has shown.

10. SUMMARY AND RECOMMENDATIONS

We found that 88% of people who responded to our survey support a European SW programme. However, while data and predictions are freely available from other sources, especially NOAA, they would not pay for a general service, only for specialist services. There are examples of companies buying tailored services already, for example, the UK National Grid pays Metatech for predictions of GICs, British Geological Survey provides services for Scottish Power and the oil exploration industry, and the Swedish Space Research Institute in Lund provide services for the Swedish power supply industry.

In general users say they require more complete data, more analysis to characterise the system, better models both static and dynamic, more reliable predictions and better understanding. It is clear that more research and post event analysis is required to achieve these goals, both to understand the basic physics, underlying processes and their linkages, to develop more reliable predictions and for feedback into design. User involvement is essential to identify clear objectives and to develop a SW programme that serves their needs. We suggest that user groups should be set up to address three priority areas

- Radiation effects on humans
- Radiation effects on space systems
- Effects on ground based systems

User groups should be broadly based and bring together science, technology and end-users.

A European SW programme would have strategic benefits. For example, defence would benefit from a civilian programme through the collection of additional data, new models and interpretation, and through the free exchange of data from the scientific community around the world that may not be directly available for defence otherwise. It would provide European infrastructure and opportunities for commercial spin-off companies. There are opportunities for European autonomy, through collection and provision of data, leadership, through new methods of reliable forecasting and analysis, collaboration within Europe, through dedicated teams to solve critical problems, and collaboration external to Europe through satellite missions, exchange of data and research.

A European SW programme would help the competitiveness of European industry through reduced loss, enable better health and safety and compliance with new EU legislation, and provide improved national security. Education and publicity is an essential requirement of SW to promote awareness, to ensure cost benefit analysis is given high priority, and to assess the knock on impact on business and society, both now and into the future as we rely more and more on space systems.

11. ACKNOWLEDGEMENTS

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