ESA SPACE WEATHER PROGRAMME STUDY MARKET ANALYSIS - FINAL REPORT

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1 INTRODUCTION

1.1 Context

This is the final market analysis report produced under ESTEC contract number 14070/99/NL/SB by ESYS plc. It contains results of the analysis of potential beneficiaries of an ESA Space Weather (SW) programme.

The context for this study has been summarised in the 1999 ESTEC report 'State of the art of SW modelling and proposed ESA strategy'[1]. Although identifying that US SW activities are further ahead than in Europe, Koskinen and Pulkkinen highlight the fact that Europe has world leading skills and expertise in certain significant SW disciplines. These include scientific and engineering competencies in solar-terrestrial physics, modelling of SW phenomena and effects of the space environment. Modelling, forecasting and the application of neural network analysis are other areas of significant European leadership.

In spite of the achievements of the European scientific community, illustrated recently by the successful launch of the Cluster II mission, its main weakness is the scattered and distributed nature of effort. Lack of dialogue and co-ordination may be putting Europe at a disadvantage and is certainly not maximising efficiencies and cross-fertilisation.

The European SW Programme Study has therefore been initiated to examine how European efforts can be co-ordinated and what structures need to be put in place to ensure European leadership at a global scale. This paper supports this effort by identifying the nature of demand for SW information, the opportunities that exist to meet these demands and how the range of market requirements might best be served.

1.2 Aims and objectives

Undoubtedly, SW has become an increasingly important topic and has recently obtained significant media coverage driven by the recent solar maximum and events such as the launch of Cluster II. However, one question that needs to be addressed is whether there is significant social or economic benefit in providing SW information services. This will be an important consideration in determining the extent to which Europe should unify and/or expand its existing SW science and technology programmes.

The main objective of this report is to assess the commercial benefit of a European SW Programme. To do this, the report examines the various areas where SW has an economic or social impact on society. The magnitude of these impacts helps determine the commercial and strategic drivers of a more unified European SW initiative.

1.3 Methodology

There are three stages to the methodology taken in this analysis, as illustrated by Figure 1-1. The first stage involves desk-based research to identify SW phenomena and impacts on different economic and social sectors. This research is complemented by the expert opinion of the study team.

[1] State of the art of SW modelling and proposed ESA strategy, 1999, H. Koskinen and T. Pulkkinen, ESTEC/Contract No. 11974/96/NL/JG(SC).

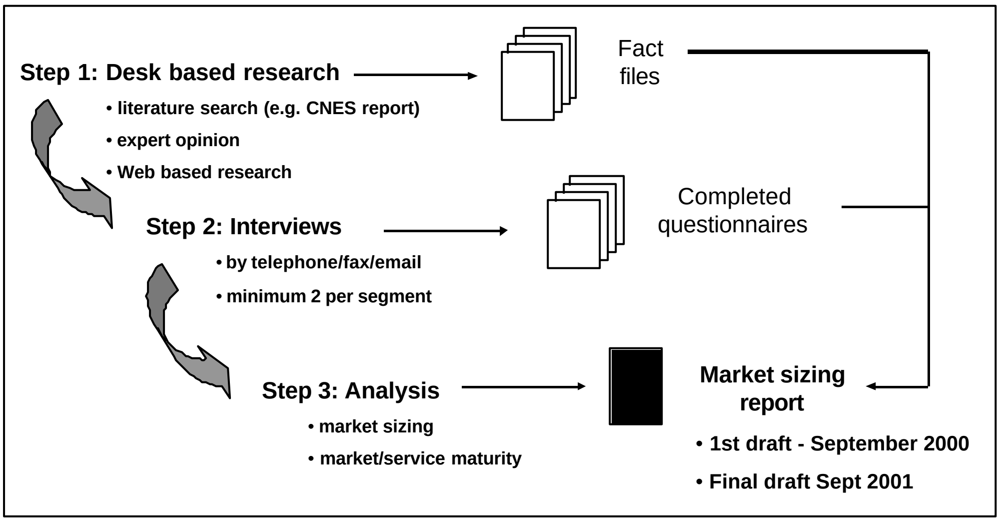

Figure 1-1: Market analysis methodology

The second stage of the process involved direct interviews with targeted user organisations. Finally, the results of the interviews were analysed to determine the key drivers and requirements for a SW service. This report summarises these findings and makes recommendations regarding the impact of commercial considerations on the formation of an ESA SW Programme.

1.4 Interviews

To support the background research on this topic and check expert opinion against user opinion, interviews have been carried out directly with representatives from a number of segments. The original intention was to carry out at least two interviews within each user segment. The range of interviews is summarised in Table 1-1.

Market segment	Number of interviews completed
Satellite infrastructure[2]	12
Ground infrastructure	10
Human	7
Communications and navigation	4
Insurance	4
Other	12
Total	**49**

Table 1-1: Number of interviews completed

1.5 Document structure

In order to assist the reader, Chapter 2 begins with a definition of SW, SW models and products and the end users addressed in this study. The impacts of SW are then explored in both economic and social terms in Chapter 3. To understand further the requirements for SW services, chapter 4 summarises user needs and the level of understanding and maturity of the user segments. Chapter 5 then assesses the value of the main markets for SW services before chapter 6 concludes with the opportunities for a European Space Weather Programme and recommendations for its implementation.

[2] Includes satellite design, manufacture and operation, space agencies and launch services.

1.6 Acknowledgements

This report has been produced with the assistance of my colleagues within the Alcatel Space Weather Programme Study Team and their efforts are gratefully acknowledged. Thanks are also extended to the many industry representatives who agreed to be interviewed and provided valuable input to the study.

2 SPACE WEATHER EFFECTS

2.1 Definition of SW

The definition of SW provided for this study is stated as:

"*Events originating from the sun that may damage space-borne and ground-based technological systems in the near earth space environment and, in the worst case, endanger human life and health".*

Although this definition focuses on negative impacts, there are also positive elements to SW. Phenomena such as the Aurora Borealis/Australis are some of natures greatest wonders and opportunities exist for the prediction of their occurrence with great public appeal.

SW is a relatively new term for a discipline that draws upon a range of scientific domains including solar-terrestrial physics (STP), plasma physics, atmospheric physics, solid earth geophysics and advanced computational techniques (e.g. neural networks). Our scientific understanding of basic physical processes underpins the ability to forecast SW phenomena and potential impacts on human and natural systems with varying degrees of success.

It is not the intention of this document to provide an in-depth description of the whole SW scenario. However, to provide the reader with the context needed for the market analysis, different elements of SW and their significance are summarised in Table 2-1. In addition to this, the goals of the US National SW Programme[3] are included to illustrate some current objectives for SW modelling and forecasting services.

2.2 Dealing with Space Weather

As indicated in Table 2-1, SW causes considerable damage to terrestrial and in-orbit systems. The three major responses for dealing with SW impacts can be defined as:

- Engineering solutions – systems designed for risk avoidance;
- Forecasting, warning and monitoring – leading to informed preventative action;
- Post event analysis – examination of potential cause and effect providing feedback recommendations for improved systems design or forecasts.

A suitable engineering solution is one of the most common methods for dealing with a SW risk. One example of this is the protection of sensitive electronic components from particle bombardments with a fine layer of gold. Where engineering solutions do not provide full protection, forecasting and warning of impending hazard (in the same way that terrestrial weather forecasts are provided) can allow time for preventative action to be taken. This may involve turning off sensitive systems or temporarily reducing system loading.

Since we do not understand fully the risk posed by SW and cannot always determine the cause-and-effect relationship, post event analysis (i.e. the examination of environmental factors that may have lead to system disruption or failure) will always be required. The outcome of this process usually feeds back as recommendations for either better engineering solutions or improved forecast and monitoring services.

[3] The National SW Program, The Implementation Plan, 2nd edition, July 2000.

Domain	Significance to SW	Goal of US NSWP
Coronal Mass Ejections	Expulsions of material from the Sun responsible for large, non-recurrent geomagnetic storms.	Specify and forecast occurrence, magnitude and duration
Solar activity, flares	Produce and accelerate energetic protons to very high speeds. Extremely damaging to spacecraft and humans*.	Specify and forecast occurrence, magnitude and duration
Solar and galactic particles	Protons, alpha particles, neutrons and heavy ions, the latter being particularly damaging to human tissues* and causes single event upsets.	Specify and forecast at satellite orbit and on ground
Solar rays/UV/EUV/soft x-rays	Solar radiation at these wavelengths has a direct impact on the Earths atmosphere.	Specify and forecast spectral intensity and temporal variations
Solar radio radiation/burst	Can have an impact on communication systems.	Specify and forecast intensity and variations
Solar wind	Fast solar wind streams cause acceleration of energetic electrons.	Specify and forecast solar wind density, velocity, magnetic field strength and direction
Magnetospheric particles and fields	Dynamic events that can lead to injection of electrons and ions into the inner magnetosphere. Cause satellite charging and contribute to induction of currents in high latitude power lines.	Specify and forecast global magnetic field, magnetospheric electrons and ions, and strength and location of field-aligned current systems; specify and forecast high-latitude electric fields and electrojet current systems
Geomagnetic disturbances	Effects produced by the complex coupling of the Earth's magnetic field and the magnetosphere.	Specify and forecast geomagnetic indices and storm onset, intensity and duration
Radiation belts	Trapped energetic electrons and ions in the Earth's magnetic field that can damage in-orbit systems and affect human health*.	Specify and forecast trapped ions and electrons from 1 to 12 R_E
Aurora	Effect produced by charged particles entering and colliding with the Earth's atmosphere.	Specify and forecast aurora optical and UV background and disturbed emissions, the equatorward edge of the auroral oval and total auroral energy deposition
Ionospheric properties	Include electron density, electron and ion temperature and composition. Variations and relations affect scale and variability of geomagnetic storms and substorms.	Specify and forecast electron density plasma temperature, composition and drift velocity throughout the ionosphere
Ionospheric electric field	Drives currents and produces Joule heating, both important elements in geomagnetic storms.	Specify and forecast global electric field and electrojet current systems
Ionospheric disturbances	Impact upon radio wave propagation. Ionosphere and magnetosphere closely linked.	Specify and forecast sudden and travelling ionospheric disturbances; specify and forecast critical propagation parameters
Ionospheric scintillation	Ionospheric variations produce variable scintillation of radio waves affecting satellite navigation systems.	Specify and forecast between 200 and 600 km
Neutral atmosphere (thermosphere and mesosphere)	Chemical, radiative and dynamic processes impact the distribution of energy and constituents throughout the upper atmosphere. Impact of SW on Earth's climate to be fully understood.	Specify and forecast density, composition, temperature and velocity from 80 to 1500 km

* Human effects are only a serious consideration in space or at high altitude.

Table 2-1: Elements of SW

In order for any of these solutions to be effective, reliable data acquisition and modelling techniques are required.

2.3 SW modelling and products

2.3.1 Types of SW model

The Sun-Earth interaction is a complex situation made up of an effectively infinite number of processes involving solar activity, the interplanetary medium, the magnetosphere, ionosphere and Earth upper atmosphere. While a complete unified model is probably out of reach, many smaller models exist to model various aspects of SW in the same way that the Earths terrestrial climate is modelled. Koskinen and Pulkkinen group current state of the art models into one of the following 7 categories:

- Models for solar activity;
  - Solar proton models;
  - Modelling of CMEs and flares;
- Models for solar wind properties;
- Models for solar wind-magnetosphere interaction;
  - Empirical models for magnetospheric configuration;
  - Three dimensional magnetohydrodynamic simulations;
- Models for the inner magnetosphere;
  - Magnetospheric specification and forecast model (MSFM);
  - Salammbo (French version of MSFM);
  - Radiation belt models;
- Ionospheric models;
- Atmospheric models;
- Predictions based on non-linear and AI methods.

It is not necessary in this document to explain fully what each of these models is intended for. However, the list illustrates the wide range and complexity of issues at stake in SW forecasting.

Figure 2-1 illustrates the pivotal role that modelling plays in the process of SW information reaching the end user. It is worth noticing that some end users will be qualified to receive raw or pre-processed data directly, such as qualified space environment engineers working for satellite manufacturers. However, it is assumed that most non-scientific/academic users access products such as indices or warnings that are a product of the modelling process.

It should also be noticed that a growing number of users buy in value added services in order to make SW information products more immediately useful to their operations. This is the case in market sectors such as power distribution and oil prospecting where there is a small but growing commercial market for SW modelling services.

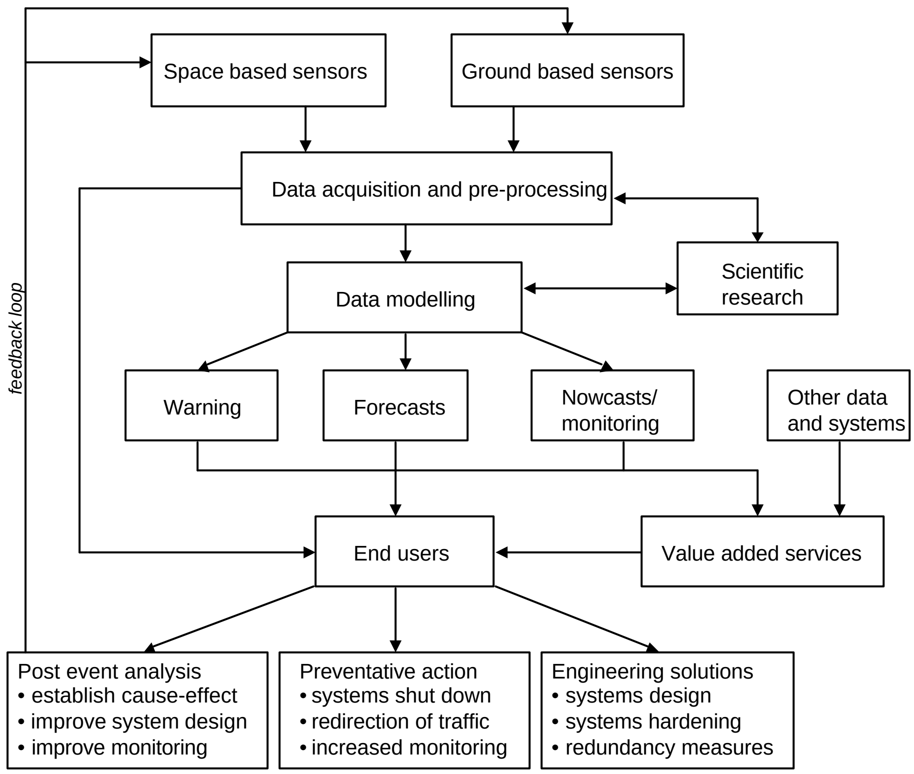

Figure 2-1: SW supply chain

2.3.2 SW products

Figure 2-1 indicates that the output of the modelling process is a selection of products or services. Many models have a purely scientific purpose and yet it is this output which is of most interest to operational, non-academic users. The types of output of relevance to the markets examined here are classified as follows:

- Forecasts;
- Warnings;
- Nowcasts;
- Value added products.

Forecasts seek to give a variety of temporal assessments of SW conditions with varying accuracy. Long range solar forecasts look days to weeks in advance and lack accuracy in timing of events. Shorter term forecasts look hours to days ahead using solar wind observations, in-situ magnetospheric data and modelling.

Warnings are intended to give less than 24 hours advance indication of events that are likely to be harmful to infrastructure or humans. Often models can only give a few minutes warning.

Nowcasts are situation reports based on real-time data. Global information is provided about the magnetosphere which can be useful for aurora monitoring and ground system management.

It is precisely because not all users are experts in the interpretation of SW data or indices that value added products and services are starting to appear. Users that do not have the time or personnel to manage their own requirements will outsource effort to third parties.

These third parties can be either public or commercial organisations. A clear example of this is in the power distribution industry which is seeing the introduction of commercial systems for the modelling and management of SW data and its impact on wide area power grids.

2.3.3 Current modelling capability

In spite of the number of scientific and commercial models that exist, the SW community is, by its own admission, still some way from the complete satisfaction of user needs. It may be that user needs are not sufficiently well defined that this is so but still the sheer size of the modelling task and the scarcity of data inputs ensure that a lot of work is still to be done. Table 2-2 gives the NSWP assessment of the status of SW modelling for a range of SW domains and products.

	Warning	Nowcast	Forecast	Post-analysis
Solar/interplanetary	Fair/poor	Fair/poor	Fair/poor	Fair
Magnetosphere	Poor	Fair/poor	Poor	Fair/poor
Ionosphere	Poor	Fair/poor	Poor	Fair
Neutral atmosphere	Poor	Fair/poor	Poor	Fair/poor

Table 2-2: Current capabilities for various levels of SW service according to the US NSWP. The grading is poor, fair, good.

Table 2-2 indicates a level of immaturity and uncertainty about future capability that means it is difficult to place a high confidence level on the potential size of the market for SW information. The immediate need is product rather than market development and thus a considerable and sustained emphasis on scientific research is still required. Until a deeper understanding of the processes has been achieved, research will play a key role in developing the models required to further the application of SW monitoring and modelling.

2.4 Defining the user

For the purposes of this document, users are defined as those with an interest in SW from a commercial or operational point of view. Users in the science and research sense are not included except where they are undertaking studies on behalf of commercial and operational users.

2.5 Military interests in SW

It should be noted that military interests have not been addressed in this document. The role of military organisations in support of SW initiatives (and other similar initiatives involving satellite monitoring such as meteorology and satellite navigation) tends to be more complex and fundamental than a simple supplier-customer relationship. It is certain that there would be military interest in a European SW Programme for issues such as high frequency communications outages but this document does not attempt to quantify or justify this interest.

3 ECONOMIC AND SOCIAL IMPACTS OF SPACE WEATHER

3.1 Negative economic impacts

Losses caused either directly or indirectly as a result of a SW event can be classed as negative economic impacts. It is important to understand the magnitude and diversity of these losses in order to make sense of the emerging market for SW services and the characteristics of the users that employ them.

The areas where losses are known to be caused by SW activity are:

- Satellite operations;
- Power generation and distribution networks;
- HF communications;
- Insurance.

Care must be taken assessing losses to insurers since this can in effect be double accounting. Insurance is simply one way of mitigating loss which otherwise would be borne solely by the insured.

3.1.1 Satellite operations

The main concern of satellite operators is to protect and develop revenue. One study (Koskinen et al, 1999) reports about 31 types of irregularity on spacecraft with more than 1000 anomalies, spacecraft charging, altitude control difficulties or power perturbations. In general, losses to satellite operators caused by SW events can range from between a few thousand dollars for temporary service outages up to $200 million, the cost of replacing a whole satellite. The real economic cost of a lost satellite is even greater taking into account lost revenues and secondary impacts on the end customers.

Economic loss can occur in three ways which are summarised in Table 3-1. The loss figures given are an attempt to provide a normalised assessment of financial impacts of SW on satellite systems. No one can be certain of the exact magnitude of these losses since the link to SW is often difficult to prove. However, this approach helps us to realise that SW has a significant impact upon the satellite business whether public or private, insured or not.

Loss type	Cause	Frequency of event	Annualised loss
Complete satellite failure	Deep dielectric charging	Rare (<3 per solar cycle)	~ €30-60M[4]
Service outage	Single event upset/anomaly Phantom command Ionospheric disturbance	Frequent (up to 60 anomalies per annum)	~ €30M[5]
Shortened satellite lifetime	Radiation damage Surface charging Atmospheric drag (fuel)	Rare (<10 per solar cycle)	~ €5-10M[5]

Table 3-1: Cause, frequency and estimated size of losses to satellite operators due to SW

[4] ESYS estimate based on 1 satellite losses per cycle at a cost of €200 per craft and associated revenue loss.
[5] CNES report estimate.

The total annualised loss estimated here is between €70-100M per annum. The true figure may be higher as a result of the cautiousness of commercial satellite operators to release financial data and the difficulty in quantifying the impacts on numerous scientific missions.

Indirect losses as a cause of satellite failure can also be generated. This might include the impact on client business through loss of service. There are no reliable figures for estimating the value of these losses.

3.1.2 Power generation and distribution

Incidences of SW affecting power systems have been experienced for more than 60 years. In March 1940, the first SW cases were recorded on the US East Coast causing power disturbances and malfunctioning relays. SW-related magnetic storms can cause currents to build up in power distribution networks which are known as Geomagnetically Induced Currents or Potential (GIC or GIP). If not managed properly, the power grid can become overloaded and lead to transformer failure. The economic impacts of this can be severe and include direct and indirect losses.

Direct losses are the cost to the power generator or distributor of replacing ruined equipment or lost service revenues. Indirect losses can be much larger since they include the total costs of lost economic and social activity due to loss of power.

The biggest known example of this occurred in 1989 when the Hydro-Quebec power company in Canada experienced a massive service outage widely acknowledged to have been caused by SW-related GICs. Power throughout a whole region was lost for 9 hours with an estimated economic cost of approximately $6 billion. Furthermore, Hydro-Quebec subsequently had to invest $1.2 billion in system hardening and upgrading.

Smaller scale incidents can also have serious economic consequences with individual transformers costing many millions of dollars to replace.

A summary of SW events affecting power systems is given here:

- March 1940 – first cases of GIC recorded on US East Coast causing power disturbances and misoperating relays;
- March 1989 – entire Hydro-Quebec system blacked out affecting 6 million people when GIC caused voltage collapse and equipment failure. The **direct** cost of system recovery and hardening to Hydro-Quebec was in the region of CAN$1.2 billion. The **indirect** cost was much higher and the Oak Ridge National Laboratory estimated that a slightly more severe storm affecting a US power grid could cause up to $6 billion worth of economic loss;
- March 1989 – nuclear plant in New Jersey loses a generation step-up transformer worth $millions;
- March 1989 – in Sweden, seven 130 kV-lines tripped and large fluctuations in power transmission were noted. Sydkraft measured a 5 degree increase in the temperature of a rotor in a nuclear plant;
- 1992 – Allegheny Power noted rapid heating of one of its transformers.

The economic impact of GIC caused failures are clearly intermittent but potentially catastrophic. The 1989 storm event has been compared to Hurricane Hugo or a San Francisco earthquake in its capacity to disturb electricity distribution. To date Europe has escaped an event on the scale of the Hydro-Quebec failure (attributed to use of higher quality transformers and less system loading) but the unpredictable nature of the phenomena and the increasing pressure on existing systems in Europe means that a large failure becomes more likely. At a recent SW conference in Greece, a representative of the UK National Grid power company indicated that their decision to purchase a SW monitoring system was underpinned by the potential catastrophic impact of UK power outage. Power companies in Sweden are showing an interest in SW monitoring systems for the same reason.

Estimating the annual loss due to SW is extremely difficult given the lack of financial data. The issue is further complicated by the catastrophic, intermittent nature of the risk. Having said this, normalising the cost of hardening the Hydro-Quebec system gives a conservative estimate of €100million per annum. This of course does not include the indirect losses due to power loss.

3.1.3 Communications

Satellite, cable and terrestrial wireless communications face SW risks in one form or another. Temporary service losses caused by ionospheric interference with satellite communications can lead to €100,000's worth of lost revenue. This might be as a result of redirection of traffic through alternative systems or the increased manpower required to bring operations back into line.

Wireless cellular networks are said to experience service impacts especially at certain times during the day when the Sun is low on the horizon although this may be a result of increased system noise temperature as the Sun appears in the antenna patterns and not SW. In any case, it has not been possible to collect enough data to estimate service losses which are assumed to be minor in comparison with other service issues, such as network congestion. However, cellular operators do pay for SW information services illustrating that there is a concern.

The major impact of SW is on government and military communications networks which operate at longer frequencies and for which a real economic value cannot be estimated at this time. However, service outages could have considerable consequences for European security and should be the subject of further study.

A conservative estimate would put economic impacts on communications systems at €10 million per annum.

3.1.4 Insurance

Insurers of satellites systems have seen a steady increase in the value of claims paid out for in-orbit failures. Some of this is potentially attributable to SW effects and insurers are starting to become interested in how to reduce such losses.

A recent presentation by C Kunstadter of US Aviation Underwriters[6], Inc suggests that SW "has been suggested as a cause or contributor to over $500 million in insurance claims in the past four years". In addition to insured losses, Kunstadter identifies SW as the cause of many more cases of loss or reduced capability and redundancy. In spite of many years of business, the effects of SW are poorly understood by the space insurance community.

[6] Space Insurance: Perspectives and Outlook, C.T.W. Kunstadter, US Aviation Underwriters, Inc at the First S-RAMP Conference, Sapporo, Japan, October 2000.

3.1.5 Summary of economic losses

Table 3-2 summarises the individual event and annualised losses attributable to SW.

Sector	Magnitude of individual events	Annualised loss estimate
Satellite operations	Total loss: €100-200M Service outage: €100K	€70-100M
Power distribution	Catastrophic event: €6B Transformer loss: €1-2M	€100M
Communication	Service outage: €100K	€10M
Total		€180-210M

Table 3-2: Summary of economic losses

The European share of these losses is unknown but could represent approximately 30-40% based on GDP estimates. One can therefore estimate that European society experiences between €55-85M of loss per annum. This figure is highly uncertain and does not include the full range of indirect impacts of SW effects (i.e. such as those impacts of lost communication or broadcasts). Better evidence of SW related losses is required in order to produce a true picture. This could form one of the main elements of a SW programme; the collection of more reliable loss data.

3.2 Positive economic impacts

SW can also create positive economic benefits. This includes:

- Products and services designed to help avoid or mitigate negative economic impacts;
- Services associated with SW-related natural phenomenon.

As with terrestrial weather, a sizeable body of activity can be generated around the understanding and prediction of SW phenomenon.

One of the more startling and beautiful effects of SW is the Aurora Borealis and Australis. Human fascination with such events has led to a small but useful niche in predicting an Aurora for the clients of tourist agencies and airlines. IFR in Lund is already serving various Swedish companies with predictions of Aurora on a commercial basis.

3.3 Social impacts of SW

3.3.1 Space and aviation

Direct impacts are most readily identified as health hazards posed to astronauts or airline crew and passengers that fly regularly at high altitude. Astronauts are particularly at risk with exposure equivalent to 8 chest x-rays being experienced during severe solar storms. This risk is the reason why Space Shuttle crew have to time their space walks carefully. The advent of the International Space Station is highlighting this health risk once again.

The exact cause and effect of radiation exposure on airline crew is not fully understood although significant studies are underway with EC support to improve our understanding. Aircrew are designated by both the EC and the Federal Aviation Administration (FAA) as increased radiation exposed workers and therefore have to be protected by law. Different studies put the increased risk of SW-induced cancer at between 1% and 25%[7] while others make the point that one rare solar energetic particle event may contribute up to 20% of the recommended received dose.

Although the true impact is difficult to assess and is still the subject of various studies, suffice to say that the increasing level of global travel and new regulations on permissible exposure levels mean that SW will remain an important issue for many years to come.

3.3.2 Navigation

There are an estimated 250 million users of GPS and this figure grows by 256,000 every month[8]. Satellite navigation is becoming a standard technology for a wide array of products and services including in-car navigation, fleet and asset tracking, personal outdoor navigation and digital mapping and surveying. The future will see the importance of satellite navigation increase as Europe builds and launches its own system called Galileo. In addition to this, programmes such as EGNOS (European Geostationary Navigation Overlay System) are being introduced to allow GPS usage for safety critical application such as en route aircraft navigation.

One of the key error factors in navigation systems is ionospheric scintillation of the signal. Normally this can be accounted for by using either dual band systems or post processing of position data using differential techniques. However, severe solar storms could introduce errors which cannot easily be accounted for and this has an implication especially for safety critical systems. If systems cannot be relied upon during such storms, then the risk of this occurrence must be known and alternative methods used. As global economic and social systems increasingly rely on this technology, so support services to manage and ensure integrity of the system are required.

3.3.3 Rail networks and trains

Evidence that SW induced signalling errors in rail networks have been noticed and in some cases even blamed for subsequent accidents. There is some scepticism about the cause and effect relationship in this case, but if a clear link is proved then there will be safety implications for many rail network operators. Given the key strategic role that rail networks play in the modern economy, this could be a significant driver for SW services.

3.3.4 Summary of social impacts

Direct and indirect social impacts derive from our increasing reliance upon technological systems that can be harmed by SW. This includes the examples of space infrastructure and power generation and distribution systems mentioned above. Aviation, satellite navigation and rail networks are sectors where the impact of SW is more social than economic. Given the growing importance of each of these sectors in modern society, services that can accurately monitor and predict SW events and impacts will continue to grow in importance.

[7] Personal communication from F Jansen.

[8] US Department of Commerce report.

4 USER CHARACTERISATION AND REQUIREMENTS

4.1 User segmentation

"The identification of users of SW products or SW modelling is one of the most critical issues for the development of SW activities." Koskinen and Pulkkinen, 1998.

SW exerts a range of effects upon a wide array of human and technological systems. In order to be able to evaluate the potential market for SW products and services sensibly, a logical way of segmenting users into categories that link the users in a systematic manner is needed.

Various approaches to market classification were examined including those from SEC Boulder, the CNES report and the paper by Koskinen and Pulkkinen. Table 4-1 presents the segmentation chosen for the purposes of this market analysis.

Segment category	Sub group	SW impacts/effects	SW Products/service
Satellite infrastructure	• Satellite operators • Satellite manufacturers • Launch operators	• Spacecraft charging • Deep dielectric charging • Anomalies • Gradual degradation • Electronic and sensor upsets • Sensor interference • Altitude decrease due to increased atmospheric drag • Problems with attitude control systems	• Forecasts/warnings/nowcasts • Post-event analysis
Ground infrastructure	• Power generators and distributors • Pipeline operators • Railway companies • Cable companies	• GIC/GIP • Pipeline erosion • Rail switching problems	• GIC monitoring services (incorporating forecasts/warnings/nowcasts)
Human factors	• Airline crew • Frequent travellers • Man in space • Space tourists	• Health problems/issues	• Exposure levels
Communications and navigation	• GPS users • HF communications • Terrestrial mobile network operators	• Loss or degradation of service due to ionospheric influences	• Forecast/warning/nowcast
Insurance	• Primary insurers • Reinsurers	• Claims related to/caused by SW events	• Information, science, understanding, post event analysis
Related industries	• Oil and gas prospectors • Entertainment and SW tourism • Agriculture • Climate modelling • Education	• Aurora, space environment	• GIC forecast • Radiation doses on flight routes, SW as SMS on mobile phones

Table 4-1: Market segmentation

The main criteria used to justify this segmentation are:

- Type of impacts experienced;
- Type of required product/service.

The segments in Table 4-1 represent groups or communities of users that exhibit similar characteristics and requirements under these criteria.

The first segment, satellite infrastructure represents a relatively autonomous grouping that reflects the established satellite manufacture, launch and operation community. This group is mature in its understanding of the space environment and related hazards and many information requirements are common to all parties. The interrelationships that exist between the sub-groupings also define this sector. For instance, a satellite operator will define the specification to which a manufacturer must design and build a satellite. This will include levels of system resilience, redundancy and life expectancy.

The ground infrastructure segment is slightly less homogenous although the impacts and effects of SW are very similar for each sub-group. The main unifying factor lies in the similarity of service requirements that exist which has encouraged an embryonic service industry.

The third category represents human interests and the impact that SW can have on health and well being. However, this does not imply that the individuals themselves would be interested in purchasing SW information services but rather the airlines and space agencies that employ them. While different types of monitoring service may be required to serve each sub-group, the main unifying factor is the understanding of the real impact of high altitude radiation exposure on human health.

Communications and navigation sectors are unified in the impact that the ionosphere has on operations. In particular, ionospheric impacts on the burgeoning satellite navigation sector are an intrinsic fact of life. As GPS-based (and possibly the forthcoming European Galileo system) systems are integrated as an essential daily service, so assurances are required that service continuity and integrity can be maintained.

The insurance industry is a peculiar sector that actually has interests in virtually all other sectors. The interest of insurance companies in SW is driven by the desire to reduce losses and manage risk more efficiently. The principle is similar to the interest taken in reduction of fire hazard in the home, for example, which leads to incentives to install smoke detectors and other measures. SW is a risk and insurance companies make it their business to understand that risk and the impact it has on their own business, as well as that of their customers. In this way, insurers will be a driving force behind the need to better understand and monitor SW impacts, encouraging companies to be more proactive in their attempts to minimise risk.

The last segment represents a group of emerging sectors. None has very similar characteristics other than the potential impacts or opportunities offered are just beginning to be understood.

4.2 Satellite infrastructure

4.2.1 Overview

This sector consists of three major sub groups:

- **Satellite operators**

About 75 major commercial satellite operators exist globally operating in the following sectors:

- Communications;
- Broadcasting;
- Navigation;
- Earth Observation;
- Science.

The number of satellite operators is not growing substantially whereas the growth in service providers that offer targeted products and services is starting to expand in response to new opportunities in Internet and multimedia. Ultimately it is the satellite operators that are responsible for specifying, launching and managing satellite constellations. For this reason, this category has the greatest requirement for SW information.

- **Satellite manufacturers**

Prime satellite manufacturers are few in number although a network of hundreds of specialist component, payloads, software and other systems manufacturers exist globally. In Europe, Alcatel Space Industries, Astrium, Bosch Telecom and Alenia are the major commercial players while Hughes (whose satellite construction business is in the process of transferral to Boeing Corporation), Lockheed Martin, Orbital Sciences, TRW and Space Systems/Loral dominate the US industry. ESA, CNES, ASI, NASA, NASDA and ISRO are the other major global players.

Although 1999 was a bad year for the satellite sector, business is still looking good for the manufacturers with business being driven by the large constellations of next generation broadband systems. The phenomenal growth in global Internet traffic is supporting enthusiasm for these systems which are due to be launched over the next 3-4 years.

- **Launch operators**

Currently only Arianespace (Ariane 4 and 5), Boeing Corporation (Delta), International Launch Services (Atlas, SeaLaunch, Proton and Angara), Orbital Sciences (Pegasus, Taurus) and various Russian, Japanese and Chinese government organisations are active in the launch services market.

Table 4-2 shows the estimated demand for international launch services through to 2010.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total	Avg
Payloads													
GSO forecast (COMSTAC)	30	31	35	31	32	31	30	28	30	29	30	337	30.6
LEO forecast (FAA)	23	19	29	74	62	59	74	45	37	56	74	552	50.2
Total payloads	53	50	64	105	94	89	103	72	67	84	104	**889**	**80.8**
Launch demand													
GSO Medium-to-heavy	26	26	30	25	25	23	21	20	21	20	21	258	23.5
LEO Medium-to-heavy	6	6	8	8	5	5	14	10	8	4	8	82	7.5
LEO small	7	7	9	13	13	10	10	9	9	13	14	114	10.4
Total launches	39	39	47	46	43	37	45	37	39	36	43	**454**	**41.4**

Table 4-2: Commercial space transportation payload and launch projections[9] (COMSTAC & FAA, 2000)

4.2.2 Trends and drivers

The main trends in the satellite industry are:

- **Increased size and power of GEO satellites**
  Growth in satellite bus and payload sizes (4000-5500kg and 5500kg+ categories) is driven by the need for more powerful communication capability and capacity. This means the satellites are more expensive and potential losses would be higher.
- **Increased number of large LEO constellations**
  Exploitation of Ku and Ka bands for broadband satellite services and the launch of global mobile satellite communications systems is driving the market for constellations of multiple satellites. Although difficulties are being experienced by systems such as Iridium and ICO, it is envisaged that the market will settle as the right economic models are found for exploitation.
- **Sustained growth in market for satellite services**
  General sustained demand for satellite services for broadcasting, data communication networks, navigation and Earth observation. This is illustrated in Figure 4-1.

9 2000 Commercial Space Transportation Forecasts, May 2000, Federal Aviation Administration's Associate Administrator for Commercial Space Transportation (AST) and the Commercial Space Transportation Advisory Committee (COMSTAC).

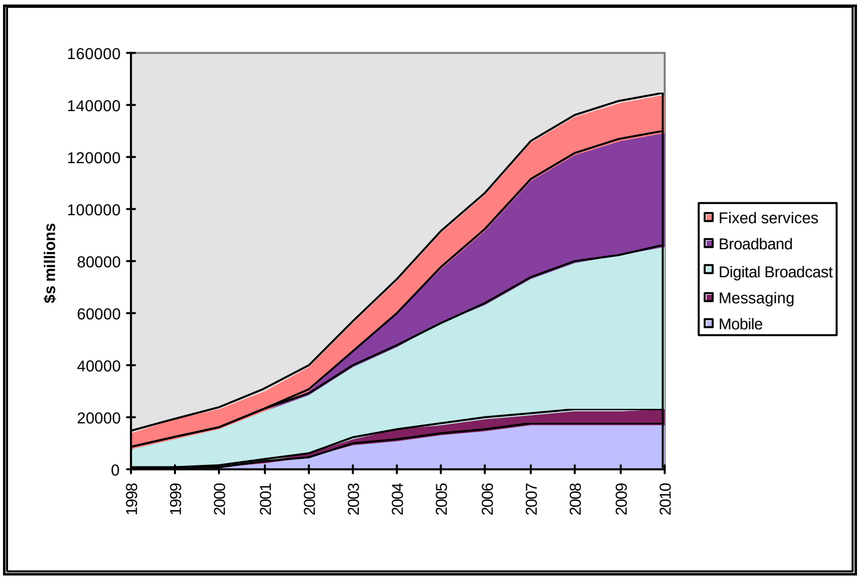

Figure 4-1: Growth forecasts for satellite communication services

These trends ensure that there will be a consistent and increasing need for systems to support this growing industry.

At the same time, various drivers that impact the need for and use of SW services can be summarised as:

- **Competition driving operators closer to margins**
  Satellite services, as with many other major industrial sectors is becoming a more global and competitive market. This can force operators to work closer to system limits than would normally be advised which can increase the exposure to losses caused by external events.
- **Drive to cut manufacture costs**
  At the same time, competition between satellite manufacturers means that trade-offs between cost and system reliability have to be made. This is a commercial risk and can mean that systems are not as hardened to SW effects as they maybe once were.
- **Miniaturisation of electronics**
  Developments in semiconductor and other electronic technology means that components are getting smaller and hence more susceptible to particle impact.
- **Greater use of OTS commercial components**
  As part of the drive to reduce cost, commercial components are more frequently used in satellite design. However, these components are not designed to withstand SW and will fail more often if not properly protected.

In spite of the apparent increased requirement, the importance of SW services has to be weighed against the use of other mitigation techniques such as system design and redundancy. However, the final report of the International Space University, Summer Session 1996 (Vienna) concluded that a potential market will be in space environment predictions.

4.2.3 Requirements for SW services

The impacts of SW on satellite and launch systems and the current methods for dealing with the problems created are summarised in Table 4-3.

Problems encountered	Possible causes	Loss potential	Current response	Type of warning or prediction
Deep dielectric charging	MeV electrons MeV and GeV protons	Possible total satellite loss (~$100-200m)	System specification e.g. hardening	Post event analysis of radiation environment
Single event upsets and anomalies	Cosmic rays MeV protons KeV and MeV electrons	Temporary service outage	24 hour monitoring Switch off non-essential systems	Radiation environment
Surface charging	KeV electrons	Degradation of internal and external components	Monitor situation Use back up resources	Low energy radiation environment
Increased atmospheric drag	Atmospheric heating Joule heating Particle precipitation	Service outage (~$100k's) Shortened life span	Modify launch sequences Re-align satellite orbit	Atmospheric density and temperature profile
Radiation damage	Energetic protons	Shortened life span Loss of service revenues (~$100k's) Possible insurance claim	Redundancy Back up systems	Radiation environment
Loss of data (comms and EO)	Ionospheric disturbances/irregularities	Loss of service revenues ($100k's) Image degradation	Redirect comms traffic Turn sensors off	Radiation environment Ionospheric disturbances
Magnetic reversal causing satellite spin (affects satellites with magnetorquers)	Change in magnetic environment	Service outage (~$100k's)	Use alternative propulsion systems to regain control	Magnetic environment

Table 4-3: Impacts of SW on satellite systems and services

Of the issues facing satellite operators and manufacturers, by far the biggest are deep dielectric charging cases. This can cause arcing which in turn can render a whole satellite lost. Single event upsets or phantom commands are a very common occurrence but tend to be dealt with very quickly by ground staff. Surface charging and radiation damage are both accepted features of the space environment and contribute to general shortening of the satellite life span. In some cases though, extreme radiation conditions can subject a satellite component to rapid shortening of life expectancy within only a few minutes-hours. This is particularly the cases for solar panels which by nature are constantly facing the Sun.

Atmospheric drag increases when the atmosphere heats and expands. This can pull a satellite out of orbit which is especially important in the case of satellites that rely heavily on accurate altitude measurements to fulfil its purpose (such as an altimetry mission). To reorbit a satellite takes up fuel and time, both of which have an economic impact. Image degradation and loss of communication link both affect the satellites ability to carry out tasks and can lead to lost revenues, especially in the communication scenario where data must be transmitted via an alternative route.

Finally, for satellites that use magnetorquers for orbit control and manoeuvrability, changes in magnetic conditions can cause loss of satellite control. This is becoming less of a problem however as satellites are equipped with alternative propulsion mechanisms.

From this analysis, we can derive three kinds of activity that could benefit from SW forecasting and monitoring services:

- **Design of satellites**

System hardening and redundancy is the most common method of protecting against SW impacts. Satellite specifications aim to withstand the worst case scenario. Events have shown this has not always been the case, probably for some of the reasons outlined above. Certainly no satellite can achieve complete immunity and operators have to constantly monitor space conditions to ensure continuity.

- **Operations**

During operations there is actually very little an operator can do to respond to a SW event, especially where continuity of service must be guaranteed. During severe solar storms, non essential system can be turned off or the satellite realigned to protect solar panels but this is normally only possible for scientific missions. Commercial operators still have to monitor the satellite in any event and respond to any problems. In this case, a SW forecast system is still useful and most satellite operators use this.

- **Post event analysis of anomalies**

Probably the greatest need for SW services and information is for the analysis of satellite anomalies post event. This analysis is often required very quickly in order to determine whether the space environment or some other factor is responsible for system failure. This is extremely important in the case of insured losses.

Currently, most satellite operators use freely available information sources on the Web (i.e. from NOAA SEC or one of the ISES centres) but this has many limitations. Data sources must be improved for:

- Reliability – most available predictions are extremely unreliable with success factors in the region of 30-40%;
- Exhaustiveness – current sources of data are sparse given the size of the phenomena and more information is required regarding the nature of particles, energy ranges and models for reconstructing the space environment.

4.2.4 Market awareness and penetration

The satellite industry must be considered as a mature user in terms of understanding of SW phenomena. This can also be said of the penetration of use of current SW services such as the NOAA SEC. From interviews carried out, nearly all use output from SEC even though it is acknowledged to have limited use.

Two examples can be given of satellite operators and their current response to SW risk. For example, Intelsat have in place a four pronged strategy to deal with risks from SW:

- rigorous satellite specification – satellites should be designed to tolerate a worst-case scenario. Manufacturers are expected to exceed design requirements building in monitoring systems, back up systems and redundancy;
- ground monitoring systems – continuous verification of proper on-board configuration which identifies anomalies within seconds of occurrence;

- satellite control centre staffing – engineers on call 24 hours a day ready to respond to events and take necessary action;
- close contact with the satellite community – dialogue maintained with other satellite owners/operators, academic institutions and satellite manufacturers to ensure all possible mitigation strategies are known.

Launching spare satellites to provide redundant capability is also another common procedure and there are complex methodologies in place to assess how much redundancy is required in order to ensure continuity of service.

Telesat Canada is another operator that has carried out extensive studies to ascertain the reasons for certain failures experienced by their satellites[10]. According to them, from studies based on an internal database of more than 800 anomalies (itself an indicator of the frequency of events), the following conclusions reached were:

- Dominant SW effects are internal electrostatic discharges and photo-emission induced surface charging;
- No two satellites behave the same;
- Meaningful conclusions require parallel evaluation of many factors.

4.2.5 Summary

Satellites face the most immediate threat from SW and satellite manufacturers, operators and launchers are best placed to understand the problems and determine the most appropriate risk management response. Indications are that in spite of the limited accuracy of currently used SW forecasts, the vast majority of satellite companies still use them.

Satellite operators and manufacturers in particular require good space environment information for post event anomaly analysis. Lessons from this can then be fed back into better system design or mitigation strategies. There is a certainly a requirement for new and complementary sources of data that can contribute to the reliability and exhaustiveness of SW forecasting.

4.3 Ground infrastructure

4.3.1 Overview

Society in the developed world increasingly relies upon fixed infrastructure networks for energy, distribution or raw materials, communications and transportation. The integrity of these systems is vital to the continued functioning and efficiency of national and regional economies. As pressure upon these systems increases, so does the requirement to monitor and manage them in order to avoid costly service breakdowns and outages.

Three major sub-segments make up this category and each experiences similar problems created by SW albeit the final result can differ quite dramatically. These sub-segments are summarised in Table 4-4

[10] SW anomalies on Telesat satellites & related design issues, June 2000, Robin Gubby and John Evans, Telesat Canada, Space Storms and SW Hazards, Crete, Greece.

Sub-group	Industry structure	Relative numbers

Power generation and distribution	Generally divided between:
	• generation companies
	  • hydro, oil, coal, nuclear
	• distribution companies
	  • national, regional
	• regulators (where applicable)
		• 100-200 companies in US and Europe of interest to SW modelling companies

Pipeline operators	• Oil/gas companies – drive need for new and existing pipes • Specialist contractors – build and maintain under contract • Government regulators – provide overall framework and some management of nationally strategic networks	• Few 100's
Railway companies	• Either one company on a national basis or infrastructure provider, operating companies and regulator in deregulated markets	• 10's of infrastructure providers (responsible for signalling) • Railway equipment producers (high power semiconductors)

Table 4-4: Main ground infrastructure players and relative numbers

Impacts of SW are relatively well known in the power and pipeline sectors and there are signs of a commercial value added services sector emerging. For example, power companies in Sweden have a strong interest in SW and have for many years studied SW effects in association with Swedish scientists. The power generation and distribution holds by far the most promise for the application of SW services and provides the focus for this section.

4.3.2 Trends and drivers

- **Power generation and distribution**

Electricity is one of the most valuable of all modern society needs. It underpins virtually every industry and activity known to man from large industrial operations to basic requirements for heat, light and entertainment at home. Any risk to these services has to be fully understood and accounted for in day to day operation. The following drivers and trends at work in this sector make this more important:

- **Need to provide uninterrupted power supply** – too many necessary and safety critical systems rely on electrical power for there to be power supply outages. Stable, reliable power supply is one of the major economic necessities for a modern market economy;
- **Increasingly aged supply infrastructure** – one interviewee pointed out that a major problem facing the developed world is the increased pressure being put on distribution networks that they were never designed to handle;
- **Deregulation and liberalisation of energy markets** – increased privatisation of energy markets and introduction of open competition is impacting European and US energy sectors. One impact is the need for suppliers to increasingly operate close to the safety margins;
- **Financial and legal implications of service down time** – in addition to lost operating revenue when systems are down, an increasing threat is that of legal action in such cases. There are at least two incidences of court cases in the US involving electricity companies that are being sued for not meeting service obligations;

- **Impacts of problems on stock market values** – all of the above issues have to be seen in the light of the bottom line, the need to retain market value and capitalisation.

These forces require that all energy companies put in place risk management and mitigation strategies that deal with both the physical and ultimate financial risks.

- **Pipeline operators**

Significant sums of money invested in the infrastructure necessary to transport oil and gas from the well site to the refinery. Operators then have the task of managing the infrastructure to ensure its integrity. Previously the oil companies themselves would have performed this role but increasingly such non-core tasks have been outsourced to specialist companies.

Government departments may also be involved where there are strategic national or security issues involved. In new production regions, extraction companies generally have to enter into significant discussion with government authorities to obtain extraction licenses which includes pipeline planning permission when appropriate.

- **Railway companies**

In many nations, rail is experiencing both a renaissance in terms of strategic importance but also a crisis in terms of funding and safety. UK and Germany in particular are two major economic powers that have vast infrastructure investment needs and have both experienced high profile disasters in recent years.

Risk from SW is not yet a major driving issue but it can be assumed that any further threat to safety and revenues will be seriously considered.

4.3.3 Requirements for SW services

Magnetic storms produced by solar activity create large currents that flow between the ionosphere and the magnetosphere. These storms are highly dynamic and can induce currents in the Earth and long conductors at the Earth's surface such as power lines and pipelines.

These currents are known as Geomagnetically Induced Currents (GIC) or Geomagnetically Induced Potential (GIP) and their impacts and causes are summarised in Table 4-5. Only a few amps are required to create problems and yet GICs of up to 100 amps and more have been detected in the grounding connections of transformers in affected areas.

Problems encountered	Possible causes	Loss potential	Current response	Type of warning or prediction required
Transformer failures and regional blackouts in electrical power systems	GIC build up saturates transformers leading to trip outs or complete system failure	Extremely high. Individual transformer cost = $ several million Knock on effects up to $6 billion System upgrading ~ $billions Annualised loss estimate ~ $100 million	Install transmission line serial capacitors Use value added SW monitoring systems form commercial vendors	Network modelling and monitoring
Pipeline corrosion	GIC at earthing points	Cost of hardware	Install cathodic system Insert insulation sections High resistance pipe coating	Network modelling and monitoring
Tripping of railway signals	GICs in rail lines	Unknown, but risk to passenger safety in question	None known	Network modelling and monitoring
Power device failures	Cosmic ray air shower	Failure of power device in rail engines	Reduction of maximum field within device by appropriate design	Not defined

Table 4-5: Impacts of SW on ground infrastructure systems

Impacts can be classed as either cumulative or sporadic. Cumulative impacts include the gradual effect of SW over a long period of time and this is the case with pipelines that are corroded slowly, albeit at an accelerated rate from natural corrosion. This issue is usually dealt with by installing a cathodic system of pipeline insulation. Alternatively, pipe can be covered with a high resistance coating. Although these solutions are not always completely satisfactory, there is no real evidence that pipeline operators use a SW forecast service since there is little they can do about it.

The worse problems are those that are sporadic and which lead to catastrophic failure. This was the case as described in chapter 3 leading to complete outage of power for a whole region of Canada.

Different geographical regions tend to experience differential GIC hazards. Figure 4-2 illustrates the situation in the Northern Hemisphere indicating the relationship between storm intensity and latitude. While Northeastern US, Canada and Northern Europe (esp. Scandinavia) are the areas at highest risk of GIC impacts, Figure 4-2 illustrates that a much wider area is at significant risk. Indeed, high GIC counts have been measured as far south as the equator.

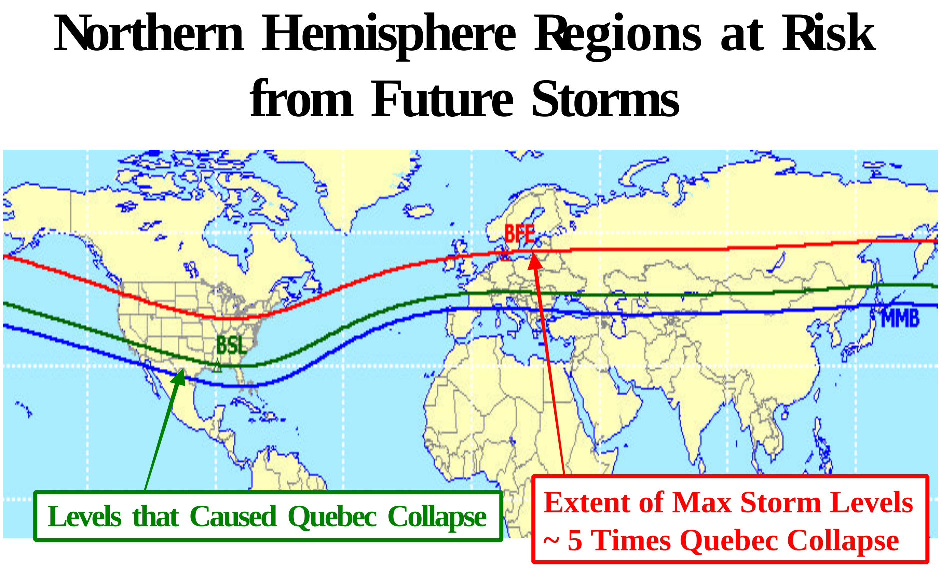

Figure 4-2: Geographic variability of risk relative to the 1989 storm[11]

The actual factors involved in the level of GIC risk for any region are complex and include:

- Latitude;
- Geologic conditions (esp soil type);
- Proximity to water;
- Size and density of network;
- Magnitude of storm.

This means that services to the power distribution sectors require more than simply forecasts of an event. A SW forecast has to be coupled with a knowledge of the infrastructure and local conditions on order to assess potential impact and required preventative action. Since power companies can do something about the threat once perceived, such as re-routing power or lowering the system loading, a market for services exists.

The rail sector is too immature at this stage to have formed the ideal response strategy.

4.3.4 Market awareness and penetration

The power distribution sector is extremely mature in terms of the widespread understanding of the threat posed by SW. Power companies across the world have experienced SW events since the 1940s and have managed the threat accordingly. However, the severe storm events of 1989 and 1991 and the economic upheaval they caused to certain power systems has caused the industry to rethink how it approaches the threat of SW. This has lead to the emergence of various SW services and renewed R&D efforts in partnership with scientific experts.

[11] From Mr J. Kappenman, Metatech: *The Footprints of a Superstorm can be extensive, the above diagram shows regions of the Northern Hemisphere that can be exposed to intense storm activity such as the Great Geomagnetic Storm of March 1989. For perspective, the level of storm severity that precipitated the Hydro Quebec collapse was observed at locations as far south as those depicted by the green contour line, which would encompass most of North America and Europe (as shown in green). Much stronger intensities were observed at more northerly locations (as outlined in red), these intensities are approximately 5 times more severe than the levels that triggered the Hydro Quebec collapse. Levels at one-half the intensity of those that triggered the Hydro Quebec collapse have also shown capable of causing power reliability problems which for this storm extended to even lower latitudes (as shown in blue).*

In a similar manner, pipeline companies are aware of the problem but tend to need engineering solutions and are not interested greatly in forecast services.

The impact of SW on rail networks only just seems to be emerging as a threat and this market is assumed to be immature with low penetration rates in terms of companies performing R&D.

4.3.5 Summary

Some of the greatest economic and social impacts are experienced by the power distribution sector. This explains why there has been significant activity over many years to understand the problem and design strategies to deal with it.

The main option across all sectors is to engineer a solution so that both cumulative and sporadic events are manageable. In events or situations where this is not possible forecast and monitoring services are required to help manage the problem in real time. This is the basis for the commercial SW service described in the next chapter.

4.4 Human

4.4.1 Overview

Two human activities place people into areas where they can receive natural radiation doses at dangerous levels: aviation and space travel. Although the two activities are not linked necessarily, the impact of radiation on the human body is. Exposure to high levels of radiation can affect humans in many ways and the most well known is to accelerate the onset of cancer. Other effects are experienced and one example is astronauts reporting flashes in their vision due to radiation particles moving through the retina.

On the basis of schedules published in multilateral airline schedule guides, it is estimated that at the end of 1998 there were some 715 air carriers world-wide providing scheduled passenger services (international and/or domestic) and about 70 operating scheduled all-freight services. Compared with the same period in 1997, this represents a net overall increase of about 10 air carriers.

4.4.2 Trends and drivers

Global travel means that the aviation sector is seeing consistent growth in distances travelled and numbers of passengers. Figure 4-3 illustrates the current and projected growth for world-wide air traffic showing consistent increases in scheduled services out to at least 2005.

At the same time, the major driver for SW services is the legislative requirement to monitor and protect staff from high radiation dose. The EC directive 96/29/Euratom of May 1996 requires all airlines to limit the exposure of aircrew to solar and galactic cosmic rays. The directive is particularly concerned for pregnant aircrew and the protection of unborn children. Airlines are currently deciding how best to deal with this directive.

Space travel is also seeing growth driven by the International Space Station (ISS). Astronauts from many nations will be involved with ISS and so far the data to monitor exposure levels come mainly from the US.

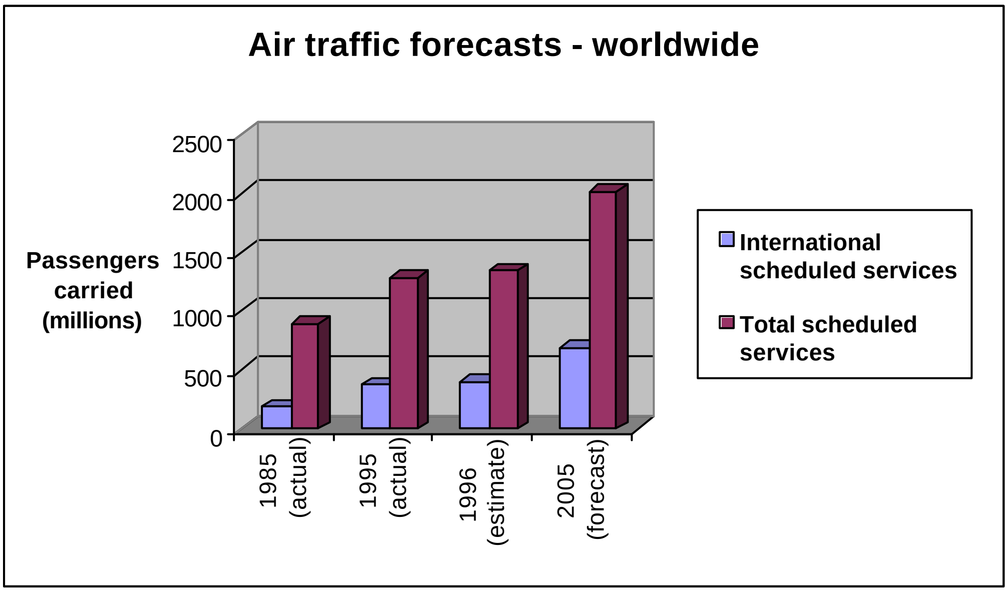

Figure 4-3: World-wide air traffic forecasts

4.4.3 Requirements for SW services

There are three possible responses to the issue put forward by the CNES report:

- On board dosimeters to monitor actual radiation levels on each flight;
- Individual staff dosimeters in the form of a badge;
- Estimation of dose received during each flight according to journey, altitude and prevailing SW conditions.

The first two options are deemed to be too expensive and unreliable. Dosimeters are already used on aircraft such as Concorde but are purported to be only 30-40% accurate. They are also expensive to install and maintain. The other limitation is the fact that they cannot forecast conditions and provide warnings to staff who may have already received high doses. Staff with individual badges would experience the same problem.

The most useful approach seems to be a monitoring system based on a database of flight details (including journey path and altitude) coupled with forecasts and real time monitoring of space environment conditions. Software provided to the airlines could ingest data supplied from a central service in order to estimate individual staff exposures and predicted exposures. It is unlikely that airlines would ever go as far as grounding a whole flight due to SW forecast, but individual staff could be re routed should they be in danger of exceeding recommended doses.

- **Dosage limits**

There is some controversy over the guidelines with regards to recommended dose received. Although many quote figures from the EC guidelines, interviews with various authorities reveal that there is actually no specified limit.

Stated exposure limits are 100 mSv over 5 years and 50 mSv in any 1 year. However national authorities are free to set their own limits and in the UK the limit is 20 mSv in any one year. The 'trigger' point (i.e. the level at which exposure levels start to become dangerous) is 6 mSv and UK airlines aim to keep aircrew below the 6 mSv dose level. If any aircrew reach this level they will be rostered onto other routes to reduce exposure.

Average estimated doses per flight are about 1-3 uSv/hr on short haul (hence shorter flight time and lower altitude) and 5uSv/hr on long haul flights. The London to New York average dose is 40uSv.

SW prediction services become important when storms occur that will exceed average doses. Prediction, warning and nowcast of solar proton events are very important to the aircraft industry and action can be taken, especially for long, trans-polar routes.

As well as re-routing staff, actions that can be taken to mitigate the problem in flight include:

- Re-route aircraft;
- Fly at lower altitudes, but not always possible over high terrain;
- Land aircraft, not easily possible over polar routes;
- Ground aircraft;
- Computer prediction program for aircrew exposure (route dose).

Grounding an aircraft due to SW has never been necessary even during 24 years of flying Concorde at the highest altitudes.

One particular requirement is the need to have the dose measured at different aircraft altitudes. This has a direct impact on the cost of action taken. For instance, flying at lower altitudes increases the cost of fuel. Airlines may also be forced to fly on more southerly and lower altitude routes. This means that accuracy of warnings or forecasts has to be high (i.e. > 95%).

In the future, high altitude, high speed aircraft will be at even greater risk from SW and will require careful management in order to protect crew and passengers.

4.4.4 Market awareness and penetration

Awareness of SW problems is very high among both space groups responsible for astronauts and airlines responsible for their crew. Although US airlines do not have regulatory drivers to monitor SW, many still use SW provided by the Federal Aviation Authority (FAA). In Europe, the EC directive ensures that all airlines are aware of the problem and most authorities and carriers already take some kind of action.

Some interviewees quote that the companies selling value added information services to the power distribution community are now trying to do the same with the aviation sector. No one has yet bought such a service, but the opportunity does exist to assist airlines meet their obligations most efficiently. Most respondents suggest that the best way of doing this however would be through a public agency rather than a commercial organisation.

4.4.5 Summary

Aviation is a critical economic sector and has huge responsibilities in terms of human safety. The most obvious risk is that of air crashes but SW is also a key concern to all airlines. In Europe, EC legislation ensures that it is a topic to be addressed and the industry is currently evaluating how to meet its obligations. Forecasts, warnings and nowcast are all required and commercial companies are already trying to fill this niche. Since the EC has not provided airlines with the means to meet their obligations (in the same way that the US FAA provides a low cost software package) there is an opportunity to provide a service. The question is whether this should be a public or commercial service. Most interviewees preferred the former option in order to put a stamp of reliability and authority on it.

Increasing numbers of European astronauts involved with the ISS also means Europe has an obligation for their safety. No commercial benefit can be seen in this and it may not be right to rely on US data alone to meet these obligations.

4.5 Communication and navigation

4.5.1 Overview

Users of satellite navigation, HF communication links and terrestrial mobile networks are all linked by the fact that ionospheric scintillation effects can cause service degradation and temporary loss. Although the economic impacts are not usually significant, the disruption can be dangerous in the case of safety critical systems or just a nuisance in other cases. Mobile phone networks are reported to experience increased dropout rates from 2% to 8-9% during solar flare events.

Table 4-6 provides an overview of the types of affected parties and the number so end user ultimately affected.

Affected parties	Numbers affected	End users affected
GPS operators	• US DoD • Russian Glonass operators • DGPS operators (2 companies) • Galileo (2008 onwards) • EGNOS (2002 onwards)	>250 million
Mobile communication network operators	>100	Billions
Airlines (HF comms)	>100	N/a

Figure 4-6: Wider impacts of SW on communications and satnav users

4.5.2 Trends and drivers

The main trends applicable to this sector are the increasing reliance upon mobile communication and satellite navigation. Cellular phone companies are already some of the worlds largest companies by capitalisation and the race is on for global dominance with mergers, acquisitions and alliances taking place continually. Forthcoming UMTS systems will expand service capabilities and increase the role of mobile communications in the life of every citizen.

As mentioned previously, satellite navigation applications are proliferating with millions of users worldwide using GPS either standalone or as part of an embedded application. The growth of satellite navigation applications is being driven by various factors:

- Falling cost of components;
- Mass manufacture of receivers;
- Bundling of navigation and communications equipment to create complete ‘infomobility’ applications;
- Forthcoming systems such as EGNOS and Galileo to widen the market and produce safety critical services.

4.5.3 Requirements for SW services

Although mobile communications represents one of the world's largest economic sectors, the true impact of SW has yet to be proved. This means that it very difficult to obtain real evidence of the impact of SW beyond proving the basic physical interactions. There is also a limit to what mobile network operators can do in the light of a forecast or warning. Traffic cannot be routed differently since this depends wholly on the position of the subscriber. Hence while some network operators are showing interest in SW impacts, there is little evidence yet that a clear requirement for a SW service exists.

Satellite navigation operators and large end users both need to ensure that the measurements provided are reliable. However, the majority of users are not too concerned with accuracy of the service and hence would not need to know what impact SW was having on the service.

The real impact is where safety critical systems are concerned. Since this is mainly an issue for the forthcoming Galileo system, it is difficult to assess what requirements exist. However, it is assumed that the Galileo operator will be very interested in using SW information where it would impact the ability to offer the certified or safety of life systems being considered.

Users of HF communications such as airlines certainly do have a requirement for SW information. One interviewee in particular is looking to provide a basic SW forecast service to pilots through their regular information service. This will be for information purposes only to warn pilots if they can expect any interference with communications links.

A bigger future issue might be the number of non-personal communication systems that utilise terrestrial mobile communications networks (GSM and UMTS). Some estimates by Japanese industry state that future market penetration will be 310% of the current mobile market. This figure is attributable to the number of machine applications in use such as meter reading that would eventually outnumber personal use. Loss of service due to SW effects would then have a service implication and possible legal and financial liabilities.

4.5.4 Market awareness and penetration

Awareness is assumed to be highest among the network operators responsible for mobile communications, HF communications and satellite navigation systems. Among this group, a reasonable proportion understand the implications of SW and utilise some kind of information source.

At the end user level, the awareness is extremely low. Certainly most users of mobile phones and satellite navigation equipment will be unaware of the role that ionosphere plays in the accuracy and reliability of the service provided.

4.5.5 Summary

The sectors examined in this section represent some of the key economic building blocks of the modern world. The low priority of SW impacts in these sectors make it difficult to see a large demand for SW services. Closer interaction with key sector representatives will be required to fully understand the role for SW and a European SW programme.

4.6 Other sectors

4.6.1 Insurance

The insurance industry is peculiar in that it has an interest in virtually every other sector. This interest is either internal (i.e. in order to reduce losses to the insurance industry itself) or external (i.e. looking help others reduce their own risk profile). There is also the chance that new types of risk can create new insurance markets.

The most mature sector related to SW is the space insurance sector, a sub group within the wider insurance industry. Recent years have seen increases in claims and erosion of profit margins. Hence the sector is looking to reduce losses by either gaining a better understanding of the risks involved or stipulating measures for risk mitigation. This drives the sectors interest in SW.

Through the TSUNAMI initiative (a research programme representing UK insurance interests), the UK space industry is trying to determine more clearly the link between in-orbit satellite losses and SW. The results are not yet available. At the same time, an interesting study into the potential for an onboard monitor (or 'black box') to be placed on each satellite to monitor local conditions at the time of failure is also underway. The box would be extremely small (the size of a tea-cup) and would send a continuous feed of environmental data back to a processing facility. In the event of a failure, the data sent would be examined to ascertain if any SW variable was responsible. Should this idea succeed, there will be a substantial market for both the hardware (in the order of hundreds of black boxes) and the services to provide monitoring and analysis of data.

The insurance industry may support this idea if it would help getting hold of data that could prove cause of failure. Resistance is likely to come from the satellite manufacturing community who will not wish to add extra payloads and may not wish to be implicated if a failure is the result of faulty manufacture.

In non-space sector, the insurance community is just beginning to examine the effects of SW and how this may impact their own business and the business of their customers. Swiss Re have recently issued a report looking at a wide range of SW issues written in layman's terms. One of the best achievements of this document will be to widen awareness to SW phenomena and potentially create interest from new sectors into how SW impacts their business.

4.6.2 Directional drilling

The UK BGS provides services to oil and gas prospectors that use sensitive drilling equipment to look for new deposits. These instruments use a combination of giro and magnetic techniques which are susceptible to disturbance by external conditions. BGS use their ground geomagnetic network to provide hourly corrections to the prospectors during drilling missions.

This is a small niche market which is not completely relevant to the study since it involves only ground measuring equipment and does not involve a forecast element.

4.6.3 Tourism agencies

The positive effects of SW (i.e. Aurora Borealis) has created a small market for predictions of when this phenomena will occur. The predictions are passed onto tourist agencies and airlines that wish to inform their customers of when an Aurora might be visible.

The University of Alaska provide continuous Web based readings while organisation such as the Lund SW Centre provide a value added prediction service to a small number of clients.

4.6.4 Climate modelling

An emerging discipline is the impact of SW on terrestrial weather systems. This is very much in the research phase but shows promise as an input to terrestrial weather prediction models.

5 MARKETS FOR SPACE WEATHER SERVICES

5.1 Defining market for SW services

Most SW information, including hazard warnings and current space environment conditions, comes via public services although there are a few examples of commercial value added and software providers appearing. Markets for SW information and services can be divided into three broad categories.

- Public information services;
- Contract R&D;
- Commercial value added services.

5.2 Public information services

5.2.1 Definition

Free SW information services come from publicly funded research or academic institutes. Information is provided either through a Web based interface or through e-mail. These services tend to underpin the activities of contract R&D services and commercial value added services.

5.2.2 Main players

- **NOAA Space Environment Centre (SEC), Boulder**

Employing about 80 scientists, SEC is the main single centre for SW predictions in the world. It has a threefold mission to:

- Synthesise and disseminate past, present and forecast information concerning the space environment to users and value added organisations;
- Perform R&D into space environment phenomena;
- Provide an expert role to satellite operators.

Part of the centre operates 24 hours a day collecting and analysing data from ground based networks, sensors on board meteorological satellites (GOES and TIROS), the ACE satellite (monitoring solar wind at L1) and other scientific satellites. SEC has developed its own models for processing the data and providing a range of forecast, warning and nowcast information services which are freely available to users on the Internet.

Much of the SEC funding comes from the US Military whose prime interest is in SW impacts on communications and navigation equipment. This again signifies the potential importance of the military sector within any European initiative.

The interviews carried out during this study indicated that a high proportion of organisations experienced in analysing SW data (esp. satellite operators) utilise the information services provided by SEC. Although it is widely acknowledged that the forecasts produced tend to be unreliable, the fact that they are freely available makes them a valuable source of information.

- **International Space Environment Service (ISES) network of ground monitoring stations.**

A network of national centres has formed under the ISES title to collect and distribute data for SW forecasting. Centres in Ottawa, Boulder, Tokyo, Sydney, Peking, New Delhi, Moscow, Warsaw, Prague, Paris and more recently Lund exist to serve local needs as well as providing a global network. These centres tend to be research laboratories that have government support to join the network.

A main drawbacks of this network in comparison with SEC is the lack of 24 hour a day operation and the small size of most centres that precludes them from investing in the size of modelling research now required to improve forecast services.

Some centres perform a strategic national forecasting role and take on contracts for certain governmental, military and commercial clients. For instance, the CLS Prediction Service (formerly the Paris-Meudon Centre) provides daily data and standard forecasts free of charge to about 50 users by email. The main 'free' users include research laboratories and telecommunications companies (including France Telecom, Deutsche Welle and Marconi).

- **Special interest groups**

Many groups or co-operatives exist as a result of a common experience of SW and seek to share ideas, experience and expertise usually at no cost. Although not strictly a public information service, many are supported by public agencies. One example is the Nordic GIC Network which links power distribution companies across Sweden, Finland, Norway and Denmark.

5.2.3 The role of public services

Since the service provided within this category are provided free of charge, it is not possible to put a monetary value of the size of the market. These organisations exist for the public good and underpin further commercial activity.

One sector which has not been addressed in this document but which forms a major part of the work of SEC is public awareness and education. During recent solar activity, the SEC website had over 2.3 million hits in one 24 hour period illustrating how important a resource the service has become. Without the existence of the public services it is highly unlikely that the SW market would have progressed as far as it has today.

5.3 Contract R&D

5.3.1 Definition

Contract R&D is defined as those ad-hoc contracts placed with SW experts, research groups and academic institutions for one off studies and services. Examples of these occur in virtually every market segment addressed in this document.

5.3.2 Main players

- **Individual specialist SW centres**

In addition to being part of the ISES network CLS also provides specific services are also provided under contract to groups such as ESA, CNES, NASA, ISRO, Matra Marconi Space (now Astrium and Aerospatiale (now EADS). Many of these contracts are purported to be technical studies into spacecraft anomalies, validation of scientific experiments and satellite orbit and re-entry calculations. The total value of these contracts is unknown.

Other examples of institutions that provide ad-hoc commercial services include MSSL, BAS and RAL in the UK.

- **National Geological Survey groups**

Geological Survey groups have a long history of involvement in space weather phenomena and many operate ground geomagnetic monitoring networks. This expertise has often been used on a commercial basis to research SW impacts or provide forecast services. The British Geological Survey (BGS) are known to provide expertise and services on a contractual basis to oil and gas prospectors, power distribution companies, satellite operators, space agencies and pipeline operators.

The Canadian Geological Survey is also well known for its work with the North American power distribution companies.

- **Academic research groups**

Many academic groups are involved in providing ad-hoc services and taking on R&D contracts for government and commercial organisations.

5.3.3 Market sizing

It is estimated that the market for contract R&D services is approximately €4-5M per annum. This is based on estimated contract values for current services provided to satellite manufacturers and operators, power distribution companies, airlines, oil and gas prospectors and insurance companies.

This figure is unlikely to grow substantially although it is expected that there is enough momentum and interest in SW to sustain R&D spending at this level for at least the next 5-10 years.

5.4 Commercial value added services

5.4.1 Definition

Commercial value added services are those that take basic or raw SW information and package it in a new or specialist way for a target market, charging for access to the 'value added' service in some way. The price paid by the customer for access to the service is related to the amount of extra value provided by the commercial entity over and above what is already available from elsewhere (i.e. SEC own SW forecasts).

5.4.2 Main players

- **Commercial suppliers**

There are two categories of commercial organisation that derive value adding business from SW related impacts:

1. Value added monitoring services;
2. Software companies.

The main example of a value added company is Metatech, a US company that provides bespoke SW monitoring systems to power distribution companies. This service entails modelling a power distribution network and integrating this with real time SW data, especially solar wind information from the ACE satellite. Metatechs first (and currently only) commercial customer for this service is the UK National Grid which is responsible for managing and maintaining the UK power distribution network.

Although software companies such as Sterling Software have been involved in this market, it now seems that some convergence has taken place and Metatech are now responsible for the software systems that have been developed by Sterling.

In addition to the Metatech system, a group called the SUNBURST network operates in the US which is a joint venture between the EPRI and 16 US and Canadian utilities companies. It costs approximately €60k to join the network which provides access to the required software and an Internet linked data and forecast network. It is assumed that Metatech provide the basic forecast service in addition to its overseas clients. The UK National Grid was actually quoted in one article as having joined the SUNBURST network.

5.4.3 Market sizing

The market for commercial services is currently estimated to be worth approximately €1-2M per annum. The growth in this industry will depend upon the rate of uptake by power distribution companies of the Metatech services and the acceptance of forecast services by sectors such as satellite operators, airlines and telecommunications companies.

5.4.4 Future potential

The total addressable market for power companies is in the region of €10M per annum (assuming that 200 power companies purchased a €50K service). However, it is unlikely that 100% market penetration will occur due to the following factors:

- Existing relationships with other organisations;
- Variability in customers own perception importance of SW impacts;
- Unreliability of forecasts.

Similar factors plus the fact that they can receive information free at the moment limit the potential for satellite operators to use commercial services. To convince satellite operators to use a commercial service will require a significant step forward in reliability of forecasts which requires more data and better modelling techniques.

Airlines seem to prefer the use of a public service although there is probably a low barrier to paying a reasonable price for it. US airlines already pay €70 for software provided by the FAA. Including regular SW forecasts, warnings and nowcasts within an integrated package would be very attractive to airlines. EC approval of the service would guarantee uptake.

Telecommunications companies already purchase basic services but the development of this market is uncertain. Clear cost benefit analyses will be required and reliable data services upon which to base serious operational decisions.

6 SUPPORTING A EUROPEAN SPACE WEATHER PROGRAMME

6.1 Responses from interviews

Interviewees were asked various questions to gauge their attitude towards the construction of a formal European SW programme. The responses to these questions provide a level of market support that would be missed if the direct economic benefits were the sole means of judging market requirement.

The following questions were put to interviewees:

- *In principle, would you support ESA in developing a SW programme*
- *Would you like to be involved in future developments of the study?*
- *What are your views on the most appropriate way for ESA to co-operate with potential users ?*
- *What other partners should be involved ?*

The answers to these questions are summarised as follows.

- **Public support for a European SW programme**

The vast majority of interviewees support the creation of a European SW programme. 88% responded positively to this across all market sectors. The only area of non-approval was in the telecommunications sector which sees a reduced need to monitor SW activity.

In spite of the difficulty in quantifying the impacts of SW and the benefits of SW services, the fact that the majority of potential users support the creation of a programme is a significant fact. Although users were not questioned about whether they would contribute to a SW programme, the response at least supports the proposal in theory and provides a basis to pursue concrete political and financial support once a more formal programme proposal is in place.

- **User commitment to providing representation**

Supporting the above comments, 69% of interviewees also indicated an interest in joining a User Forum to provide representation on user requirements an to help steer a SW programme appropriately. Once again, this support comes from across the range of market sectors and the enthusiasm of users to be actively involved should be captured through some form of ongoing industry consultation.

Many have made the point that definition of user needs and providing a user driven rationale to any European SW programme is a key requirement. The outcome of this study supports the assertion that users are willing to commit time and effort to providing a user point of view.

- **Attitude towards type of service required**

Interviewees were given various choices when asked how ESA should interact with users of a SW service. Table 6-1 shows the range of responses given. The majority of respondents believe that a European SW service should be a publicly provided service. The same number also believe that industry should be involved in programme operation.

This latter point implies that specific market sector expertise should be combined with the pure SW expertise to determine realistic service outputs for each market sector. For example, those involved in the aviation industry in the UK believe a co-operation between ESA and organisations such as the National Radiological Protection Board should be pursued. This would presumably place a 'stamp of approval' on any information provided that would reassure the user community.

Options	Response
Involve industry representatives in programme operation	38%
Encourage commercial services to be brought to market	19%
Provide SW services directly to users	19%
Provide SW services through a public service entity (e.g. Eumetsat)	38%

Table 6-1: User perspective on model for a European SW service

Of less interest is the encouragement of commercial services. The main exception to this is the power distribution sector which clearly sees the provision of value added services as the main way in which information regarding SW activity and its impact should be obtained. However, this conclusion may be clouded by the vested interests of the interviewees concerned. Wider consensus is needed to validate this assertion.

- **Attitude towards co-operation with the US**

As well as indicating that various industrial or sector organisations should co-operate on a European SW programme, some respondents also suggested that Europe should seek to co-operate closely with the US. This makes sense from a user perspective given that SW is a global phenomena and users are not usually concerned about where the information comes from as long as it is reliable. Joint European-US efforts would certainly make the information derived more robust and potentially more accurate.

6.2 Opportunities

Following on from an assessment of user interviews, the following opportunities have been identified during this study.

- **New data sources**

Most existing services and work have been based on sparse data points. This is probably the main reason for the low levels of reliability of existing forecast services. Most users require a much higher confidence level, especially of they are going to pay for the service. This can only be achieved by supplying new data sources that meet the requirements of the modelling community.

A European SW programme can make an extremely valuable contribution to the improvement of the forecasts and SW information currently available. In addition, a focus on improved modelling would maximise current European expertise and broaden influence at a global level.

- **Independent data sources**

Although many users of SW information use the freely available services from SEC, a large proportion would welcome secondary data sources to complement and improve these existing US forecasts. This is especially true of the satellite operator community and value added service suppliers.

There is also an argument to say that in certain circumstances, Europe should have the capability to provide its own assessment of events and not rely fully on the provision of information from third parties. As Europe pursues more collaborative space ventures, such as the proposed Galileo satellite navigation mission, this issue will become more pronounced.

- **Improved modelling and forecasting capability**

Perhaps the most critical need is to improve forecast/warning/nowcast capability. Although information with a low accuracy or reliability is still of use (especially when free) improved modelling techniques will increase the attractiveness of service to users and provide better incentive to pay for them. Therefore a lot more product development work is required before an significant market development can occur.

The scientific requirement for access to data for research is probably the single greatest driver for European SW programme. At this stage however, little work has been done to assess the impacts and benefits from a scientific point of view making it difficult to compare with other economic and social arguments.

- **User involvement**

One of the key success factors behind the SEC was the early involvement of key user groups representatives. The possible initiation of a European Space Weather Programme would be the ideal opportunity to involve commercial partners and define aims and objectives in conjunction with them. However, it would be premature to envisage a high level of private investment at this stage. Some co-investment in product or service development can be anticipated once the data supply, models and forecasts can be improved.

6.3 Benefits

Certain benefits can be envisaged from a European SW programme and can be placed into three categories:

- Commercial;
- Public;
- Strategic.

- **Commercial benefits**

The commercial market for SW services is currently very limited representing an estimated €5-6M per annum in commercial revenues. However, most sectors are in the early stage of development and lack of data sources and the reliability of current forecast model output hamper the services.

Currently US companies represent the majority value adding sector and Europe should be examining efforts to ensure opportunities for non-US firms are maximised. Europe has key expertise (especially in Scandinavia, France and the UK) which could develop into a value adding capability and should be encouraged where possible.

Already the Lund Space Weather Centre has been set up under the guidance of Henrik Lundstedt and has ambitious plans to provide a wide range of SW services and products to users in the following markets:

- Space manufacturers and operators;
- Launcher manufacturers;
- Telecommunication companies (satellite and terrestrial);
- Airline operators and manufacturers;
- Power companies;
- Survey companies;

- Insurance industry;
- Climate modellers;
- Tourist industry.

A European SW programme would help maximise the opportunity for such organisations to provide a differentiated market offering and remove the business risk associated with reliance upon a few sources of data.

- **Public good benefits**

Although commercial service revenues are currently low, the sectors affected by SW are some of the most critical to the health and well being of the public at large. Power, travel and our ability to communicate are all impacted by SW events. Although Europe has so far escaped a major catastrophe on the scale of the 1989 Hydro-Quebec event, a significant risk of major upheaval exists and this is reflected in the range of companies and organisations taking steps (albeit very limited at this stage) to mitigate any problems that occur.

SW is analogous to the terrestrial weather scenario is that its impact are felt across a wide range of sectors and the task of modelling and forecasting future events is notoriously difficult. It would seem that SW could be treated in a similar manner in the first instance allowing commercial benefits to spin off as and when the are mature enough.

- **Strategic benefits**

In line with the previous statement, it would seem that the greatest strategic benefit would be gained through co-operation, both within Europe and with international partners. Clearly, the very least that should happen is the co-ordination of European efforts for the benefit of European science, industry and public. However, SW is such a huge phenomena, it would seem unlikely that any one group could meet all the demands of data collection, analysis and modelling that would optimise the usefulness of SW services.

In addition, it is clear that individual events (such as the March 1989 storm) have had widespread geographic impacts. This suggests that international collaboration in dealing with this global phenomenon is important.

Many respondents expressed the view that ESA should press ahead with a SW programme and that they would be supportive of it. In addition to this though, a similar number advised co-operating with international partner (especially the US) where possible.

The final issue to raise here is that of European independence. As ESA and the EC seek closer ties, illustrated by the formation of a common space policy, the number of joint European missions is going to increase. This includes proposals such as Galileo and GMES that will both involve the build and launch of hardware. Given the uncertainty in international relations, Europe must become self-reliant in provision of the support services and data required to allow such missions to perform adequately.

6.4 Prioritising action

The mpacts of SW are felt across a wide array of market sectors and this study has identified the main sectors of current concern. In order to consider how to prioritise elements of a future SW programme, the market sectors defined in this study were classified accord to both their respective market maturity and impact.

Market maturity is defined as a combination of the following factors:

- Market awareness;
- Market penetration;
- Model maturity ;
- Data availability.

Market impact is defined as a combination of the following factors:

- Economic impact;
- Strategic value;
- Social impact;
- Scientific importance.

By scoring each market (applying a value of 0, 1 or 2 depending on low, medium or high importance, respectively) and then plotting the results, one can get a relative assessment of market priority, as shown in Figure 6-1.

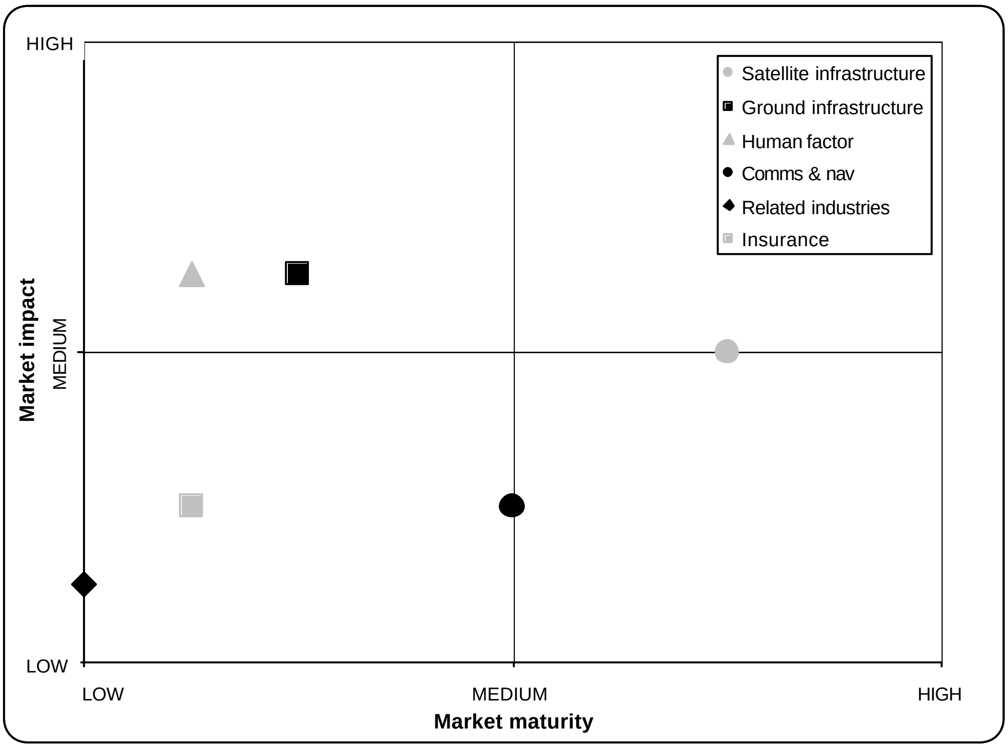

Figure 6-1: Assessment of market priority

Figure 6-1 shows that the two markets of relatively high market impact (i.e. ground infrastructure and human factors) are also relatively immature. This implies that much work is necessary to respond fully to the impacts of SW in these markets. Conversely, satellite infrastructure is relatively mature but is also a high impact market.

Given this analysis, the priority markets for a future ESA SW programme are defined as:

- Ground infrastructure;
- Human factors (especially aviation);
- Satellite infrastructure (esp. satellite services and operators).

7 CONCLUSIONS

It is concluded that:

- SW is a significant issue that has substantial economic and social impacts on society.

- Each year, economic losses as a result of SW run in many tens of millions of Euro.

- Europe has a world leading capability in SW monitoring and modelling which must be supported and given the best environment in which to flourish and continue to lead global science.

- Commercial opportunities are currently limited although the availability of more and better data, development of better SW forecast models and a conducive commercial environment could see this figure increase substantially.

- There is substantial user support for a European SW programme with 88% of interviewees saying they would in principle support such a programme.

- Europe should proceed with a SW programme that:

  - Provides independent data acquisition and monitoring capability, possibly within the auspices of a European public service entity;
  - Maximises European collaboration as well as co-ordination with US counterparts;
  - Provides a forum for user representation to drive requirements and service evolution;
  - Focuses on the priority markets of ground infrastructure, human factors and satellite infrastructure.

It is also recommended that:

- The estimated costs of a SW programme be measured against the potential additional benefits to be derived over and above that which is already available from other sources. Such a cost-benefit analysis is necessary given the proportion of benefits that are social and scientific in nature and not a direct economic impact.

- A long term plan for user representation be defined that provides an open forum for expression of information and service requirements.

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APPENDIX B: Market maturity and impact scoring

Definitions

Market maturity factors:

- Market awareness: General awareness of the problems/threats posed by SW;
- Market penetration: measure of use of SW services;
- Model maturity: maturity of modelling techniques used in this sector;
- Data availability: availability of required data sources.

Market impact factors:

- Economic impact: Relative magnitude of economic losses due to SW;
- Social impact: Relative magnitude of potential social impact (i.e. health risk, loss of services);
- Strategic importance: relative importance to European strategic concerns (e.g. independence, security, etc);
- Scientific value: relative value to scientific community.

Scoring

Market maturity	Market awareness	Market penetration	Model maturity	Data availability	Score
Satellite infrastructure	2	2	1	1	6
Ground infrastructure	1	0	1	0	2
Human factor	1	0	0	0	1
Comms	1	1	1	1	4
Insurance	1	0	0	0	1
Related industries	0	0	0	0	0

High	2
Medium	1
Low	0

Market impact	Economic impact	Social impact	Strategic importance	Scientific value	Score
Satellite infrastructure	2	1	1	0	4
Ground infrastructure	2	1	2	0	5
Human factor	0	2	2	1	5
Comms	1	0	1	0	2
Insurance	1	0	1	0	2
Related industries	0	0	0	1	1

High	2
Medium	1
Low	0