BUILDING SPACE WEATHER PREPAREDNESS AND RESILIENCE IN EUROPE

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Abstract

Space weather is a set of phenomena now recognised as a significant natural hazard, with the potential to disrupt many technologies that are critical to the functioning of modern societies. It arises when phenomena on the Sun and in near-Earth space generate adverse environmental conditions for technologies operating in space, in Earth's atmosphere and on the surface of our planet. As a result the space weather community has focused significant effort on building links with the operators of those technologies – to raise awareness of the impacts of space weather and to explore how science can be applied to mitigate those effects. However, it is now clear that space weather is also an issue for governments because many of the technologies impacted by space weather support critical national infrastructures such as power, aviation, satellite timing and location, and a host of other satellite-based services. Thus space weather is integral to the analysis and planning of national and international resilience against natural hazards. Thus this talk will argue that efforts build space weather preparedness in Europe must engage governmental risk managers and policymakers, as well as end users in industry, and link with their efforts to mitigate other natural hazards. Space weather should be integrated into an all-hazards approach as is already being considered in Sweden and the UK. The space weather community has much to give to, and much to learn from, such engagement.

Introduction

Space weather is a concern for modern societies because it has the potential to disrupt a wide range of technologies on which those societies depend. The long distance transmission of electrical power is the outstanding example today. The use of electrical devices is deeply and ubiquitously embedded into the way most of us live our lives - and gives us a quality of life that previous generations did not have. But in most countries this is heavily dependent on the supply of electricity from distant power stations – some that exploit local energy sources (e.g. hydro, wind, coal) and some we wish to place far from population centres (e.g. nuclear). It is this long distance transmission that has created the vulnerability to space weather, since it increases the risk that significant geomagnetically induced currents (GIC) enter the power grid and its transformers. Other technologies vulnerable to space weather, e.g. satellite timing and location, digital systems, radio communication, are now increasingly embedded into our lives. They are all being used to deliver innovative products and services that will add to quality of life and stimulate economic activity.

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The widespread use of technology is fundamental to way we live today and has done much to improve peoples' lives. But it has also made us vulnerable to any factor that can disrupt technology. Space weather, especially its extreme forms, is a prime natural example of a factor that can do this. It has the potential to disrupt many different technologies at the same time and over wide areas of the Earth as shown in Table 1 below.

Table 1. Examples of space weather impacts on critical technologies

Space weather effects	*Impact*
Geomagnetic storms and high-speed solar wind streams	Strong GIC in power grids leading to widespread blackouts and damage to some transformers. Also potential for GIC to disrupt operations of optical fibre cables used for trans-oceanic telephone and internet communications.
	Strong ionospheric scintillation over populated areas across mid-latitudes leading to loss of signals from many satellite services, particularly timing and location signals, but also many conventional satellite communications services.
	Global disruption of HF radio communications, with potential impact on trans-oceanic air travel
	Electrical charging of spacecraft in key operational orbits leading to anomalous satellite behaviour and consequent interruption of services, and potentially damage to spacecraft.
Solar radiation storms	Disruption of digital systems on satellites leading to anomalous satellite behaviour and consequent interruption of services. During a very severe event anomaly rates may outstrip the ability of operators to fix problems and lead to a large scale interruption of satellite services.
	Disruption of digital systems on aircraft, especially at high and mid latitudes. This could cause unexpected flight behaviour and necessitate corrective action by pilots, possibly repeated actions when an intensive storm causes multiple disruptions.
	Blackout of HF radio communications in polar regions, with potential impact on trans-polar air travel, e.g. US-Asia routes
Solar radio bursts	Strong interference with satellite location and timing signals on the dayside of the Earth
Solar flares	Blackout of HF radio communications on the dayside of the Earth, with potential impact on trans-oceanic air travel

This vulnerability to technological disruption, and hence to space weather, has arisen in much less than a human lifetime. Fifty years ago, the advanced countries may widespread use of older less vulnerable technologies, many dating back to the nineteenth or early twentieth century. For example there was widespread local production of energy for homes, industry and transport by direct use of fossil fuels (especially coal). Also many of the vulnerable technologies were used only for specialised services in government and industry (e.g. digital systems and radio communications) or had not even been invented (satellite timing and location). This older world experienced many severe space weather events but these had only limited effects, mainly the disruption of long distance communications by telegraph, telephone and radio. These effects are well-documented in newspapers and books of the era [e.g. 1,2], but for most people they were just a fascinating news story. Very few human activities of that era required rapid communications between different countries.

Thus the vulnerability of modern economies and societies to space weather has emerged very recently. We have a reasonable grasp of the basic science that underpins the subject and of the potential impact on technologies (though much work still needs to be done to deliver good quality forecasts and mitigation of space weather). But we have barely started to understand the wider implications of space weather for society. What do the science and the technological impacts imply in terms of wider risks? These include economic and social disruption, psychological impact and possibly even threat to life.

In the rest of this paper I argue that we need to put more focus on these wider risks from space weather, to do that on a secure foundation in our understanding of the relevant science and engineering, but also to address the human factor – the need for awareness of space weather and to understand its implications for people who operate and use vulnerable technologies.

Shifting the focus from users to resilience

The space weather community has traditionally sought to address with the adverse impacts by building links with the operators of vulnerable technologies, e.g. radio systems, power grids, satellites, etc. This has had much success in supporting the engineering mitigation of space weather, where the role of the expert community has been to specify the likelihood of different levels of adverse space weather [3]. This has allowed engineers to trade off the level of space weather protection against the cost of providing that protection. As a result many vulnerable systems have high resilience against most space weather conditions, e.g. satellites are typically designed to withstand space weather up to a level that has low likelihood (say 5%) during their design life (5% corresponds roughly to a 1-in-200 year event for a 10 year design life).

This approach has also encouraged the growth of services that help operators of vulnerable technologies to deal with specific space weather events. These services include:

a) Forecasts, so operators can take short-term measures that further improve the resilience of their systems (often incurring extra costs that are appropriate only in the short-term).
b) Nowcasts, so operators can quickly identify if problems are caused by space weather and thus take appropriate action (and avoid inappropriate actions). It facilitates the resilence provided by skilled operations teams.
c) Post-event analysis, so operators can learn lessons and enhance the resilience of their systems.

These services are generally focused on specific problems such as GIC, spacecraft effects, radio communications and impact on aviation. These reflect the nature of the market for space weather services as discussed in the early space weather market studies funded by ESA [4]. This showed that there is a set of niche markets for space weather services, where each niche can support services targeted on a specific space weather impact. However, the study also suggested that these niche markets will not, of themselves, support underlying service components, e.g. monitoring and forecasting key drivers such as the state of the solar wind impacting Earth's magnetosphere. The users surveyed in the study appreciated that those underlying components are essential to development of high-quality space weather services, but saw them as a public sector function, akin to the publicly supported elements of meteorological services. They saw the role of the market being to add value to the public sector services, i.e. generating products that are customised to the needs of specific users and expressed in language and formats that are easily assimilated by those users.

Thus the provision of underlying service components has only made progress where there is governmental support, most notably in the United States. The US National Space Weather Program coordinates a wide of space weather activities including the provision of space weather alerts, watches and warnings by NOAA's Space Weather Prediction Center (SWPC) and the work of many other US agencies, notably NASA and Department of Defense, to collect the data needed by SWPC and other space weather services. SWPC is also the major US focus for international exchange of space weather data. Several other countries now have publicly-funded space weather centres, including Australia, Canada, Korea, and South Africa.

In Europe there is a mix of national provision and European provision through the space weather element of ESA's Space Situational Awareness programme and the ESA space weather activities that led up to that [4,5,6,7,8]. Many European groups also participate in international activities including the International Space Environment Service [9] and broader programmes for international exchange of space weather data. However, these activities are still largely motivated by a bottom-up approach to space weather – the service providers seeking users for their services and users seeking solutions to their problems.

All these groups look to governments to pull things together by supporting the underlying services (monitoring and basic forecasting of space weather) that will enable growing provision of space weather services. However, we still lack a compelling rationale for why governments should use public funds to do this – especially given the many other important demands on those funds. This is the key conceptual step that the European space weather community needs to make – to improve awareness that space weather is fundamental to the future resilience of societies and economies in Europe and around the world. A deeper European engagement in space weather activities will protect our interests and offer opportunities to provide services to a global market.

Resilience and Government

There is growing recognition around the world that societies and economies need to be more resilient against unexpected events – and that Governments must take the lead in ensuring this resilience. These unexpected events include malicious threats, major accidents and natural hazards. Space weather falls firmly in the latter category. It is a natural phenomenon whose extremes have the potential to cause extensive economic and societal disruption, as discussed in the introduction to this paper. It differs from many natural hazards in that it has little or no potential to directly injure or kill people[2]. Its impact on people is indirect – it first disrupts a wide range of advanced technologies; this disruption then undermines the operation of critical infrastructures (power, finance, transport, communications) thereby triggering widespread disruption of economic and societal activities [10, 11]. Some of these disruptions have the potential to put lives at risk, e.g. by undermining the ability of emergency services to respond quickly, by disrupting the supply and storage of medicines, by introducing unexpected errors into navigation systems.

It is these knock-on effects that make space weather a major concern for governments. They reflect the interconnectedness of our modern world – whereby a disruption in one part of the world or in one technology can spread around the globe with unexpected adverse consequences for people far from the source of the disruption. Space weather is far from unique in this respect – many other natural hazards can cause similar knock-on effects. A recent prime example was the 2010 eruption of the Eyjafjallajökull volcano. This was a direct threat to humans only in close proximity to the volcano, prompting evacuations from areas at risk. But the technological impact of the resulting ash cloud (i.e. the risk to operation of jet engines) caused major disruption to flights over western Europe at distances up to 3000 km from the volcano. This had huge impact on both individuals and businesses around the world who needed to use civil aviation in western Europe to travel or to transport goods. A widely-cited example of the knock-on effect was disruption to the horticultural industry in Kenya, which uses air freight to transport fresh flowers, fruit and vegetables for sale across Europe (generating about 4% of Kenya's GDP).

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[2] The one substantive direct threat to human health is increased radiation dose on long-haul flights during the most intense solar radiation storms. These are likely to result in single flight doses that exceed the 1 mSv annual legal limit for the general public. But there is a growing scientific debate on the health implications of such doses and much doubt that they are a significant health risk.

The knock-on effects of space weather were analysed in the recent OECD study on Geomagnetic Storms [11], which forms part of a wider OECD project on Future Global Shocks [12].The study on Geomagnetic Storms showed how the direct technological impacts of a severe space weather event could ripple outwards to disrupt public and private activities across some 30 different sectors that are all vital to any advanced country. The disruption could continue for several weeks after the event and, in some cases, escalate (e.g. if contingency measures exhaust the available physical and human resources).

Thus there is growing awareness that severe space weather is a factor that needs to be considered in national emergency planning alongside other more familiar risk factors such as the many manifestations of severe weather (heat waves, extreme cold, flooding, …) and pandemic disease. Severe space weather is now being factored into national risk assessments in several countries including Sweden [13], the UK [14] and the US [15]. The UK assessment was published in January 2012 and included several less familiar risks – not only space weather but also volcanic risks, both the ash risk recently demonstrated by Eyjafjallajökull and the risk to humans, animals and crops from volcanic gases such as sulphur dioxide, chlorine and fluorine. The latter is a good example of how historical evidence (in particular the 1783-84 eruption of Grimsvötn) can inform current risk assessments.

Figure 1. UK risk matrix for natural hazards and major accidents

The UK assessment is that severe space weather is a significant risk, comparable to heat waves and extreme cold, as shown in the risk matrix in Figure 1. The assessment also recognises that space weather science is a relatively young field and its impacts on modern society are only recently coming to the fore as our dependence on technologies vulnerable to space weather increases. Thus the assessment is driving further work to better understand and plan for the expected impacts of a severe space weather event. In particular, it provides the impetus to bring together space weather experts, industry and government so they can build a common understanding of the problem and of ways to mitigate the problem. For example, it is important for scientists to understand how space weather actually impacts the operation of vulnerable technologies – which impacts are easily overcome and which have substantial impacts on the operation of those technologies and on the customers who rely on those technologies. Equally it is important to raise operator awareness of what science can deliver for them. One key issue here is the ability of science to describe risks that transcend personal and organisational memory. Another is that advancing scientific knowledge can provide a basis for better mitigation of space weather risks – that there is scope for innovation that can improve resilience against those risks.

But to achieve this, it is vital to embed space weather in the wider agenda of improving economic and societal resilience to natural hazards – and to recognise that governments are key players in that agenda.

An all-hazards approach

The inclusion of space weather in the resilience agenda will also drive its inclusion in an all-hazards approach to assessing, monitoring and managing natural hazards. This is an important and valuable trend – it enables governments and operators to apply generic mitigation techniques where different hazards have similar impacts on vulnerable technologies. An obvious example is generic measures to restore electric power after a blackout, whether caused by space weather or by normal weather. The all-hazards approach also enables the different scientific communities that understand different risks to work together and to exchange ideas. Experience shows that such exchanges between different scientific communities can be a major stimulus to advancing knowledge and to deploying it for economic and societal impact.

Conclusions

In summary, the space weather expert community needs to engage with the wider agenda on improving economic and societal resilience against future risks – and in particular to integrate space weather into the study, mitigation and management of all natural hazards. The science of space weather needs to be integrated into the study of natural environments and the hazards that they pose for human activities. Space weather measurements and forecasting should be part of the operational activities that increasingly give us good awareness of environment risks (and hence the ability to mitigate those risks). In short, space weather is now a fundamental part of the human environment here on Earth, and we should treat as that.

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Biographies

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