Cabinet Office

Department for Business Innovation & Skills

Space Weather Preparedness Strategy

Version 2.1

July 2015

1. Executive Summary

This document sets out the nature of the risk to the UK from severe space weather, our progress to prepare for the risk and our priorities for future work. Responsibility for managing the risk passed from the Cabinet Office to the Department for Business, Innovation and Skills in 2015.

This strategy has been produced for Government and local responders to guide preparedness and has been shared with international, industry and academic stakeholders. It is an updated version of the Space Weather Preparedness Strategy produced in July 2014.

Space weather preparedness
The risk of severe space weather was added to the National Risk Assessment in 2011.

The UK approach to space weather preparedness is set out in this document and is underpinned by three elements: designing mitigation into infrastructure where possible; developing the ability to provide alerts and warnings of space weather and its potential impacts; and having in place plans to respond to severe events. Preparation is needed to the national level, with the support of local capabilities to deal with the consequences. This all requires of international co-ordination.

The main challenge we face is that awareness of the risk is low. Much more needs to be done to encourage potentially vulnerable sectors to adopt measures to mitigate the likely impacts.

Space weather and its impacts
Space weather results from solar activity. Solar activity can produce X-rays, high energy particles and Coronal Mass Ejections of plasma. Where such activity is directed towards Earth there is the potential to cause wide-ranging impacts. These include power loss, aviation disruption, communication loss, and disturbance to (or loss) of satellite systems. This includes Global Navigation Satellite Systems on which a range of technologies depend for navigation or timing. The National Risk Assessment sets out the reasonable worst case scenario for this risk, which is based on the 1859 Carrington Event. However, other impactful if less severe events have been seen regularly since that event.

The challenge of space weather events
The main challenges we face in planning for severe space weather events include:

- the difficulty of forecasting events accurately;
- the short warning time to prepare once we have certainty about the speed and size of events;

- understanding potential impacts given the societal and technological developments since the 1859 Carrington Event;
- a lack of capability to monitor the effects of severe events once they start.

The strategic approach to planning for severe space weather events

The Department for Business, Innovation and Skills manages the risk of severe space weather on behalf of the UK and co-ordinates efforts to improve resilience. The Met Office assesses the risk for the National Risk Assessment and operates the UK's forecasting centre for space weather. The UK Space Agency and the Natural Environment Research Council have a role in developing observational capability. A wide range of departments across Government also have a role to play in preparing for this risk, including the Department of Energy & Climate Change, Department for Transport and the Ministry of Defence. A particular area of focus is the need to build resilience of the UK's national infrastructure to mitigate any impacts.

Space weather is a risk which particularly affects technology. Building strategic resilience to space weather necessitates taking into account potential impacts on new technologies, especially Global Navigation Satellite Systems and miniaturisation of circuitry.

Finally, UK resilience builds upon the role that Category 1 and Category 2 responders play during emergencies. This is also true of space weather. This will primarily to be achieved through deployment of capabilities in the same way as for other emergencies which lead to power, transport and other disruption.

Assessment of preparedness

Much has been done to increase the UK's preparedness for major space weather events:

- the National Grid has increased the resilience of its Transmission Network and developed operational plans for severe events;
- the Met Office has opened its forecasting centre in Exeter;
- the UK Space Agency has invested in space weather observation capabilities, raising awareness and in developing modelling and services;
- the aviation sector, which deals with the effects of space weather as an ongoing issue, has been working on how to plan for extreme events;
- central Government have developed co-ordination plans based upon the tried and tested COBR arrangements; and
- there has been extensive engagement at research, operational and now Government level, with international partners, including the US and EU member states.

However, more needs to be done especially in sectors which have had lower awareness of the risks posed by space weather, such as the rail and financial services sectors and local responders.

The importance of public communications

As for any risk, communication with the public is an important component in preparing for and responding to an event. But there are specific challenges for severe space weather due to our limited understanding of likely impacts and ability to forecast major events. Not all impacts may happen during every space weather event but pre-agreed messaging is important to allow rapid and effective communication from Government, if and when they do happen. Work has been undertaken to develop and exercise plans to communicate with the public. These plans focus on raising awareness of what the risk means in practice for the public, how the impacts can be mitigated in a similar way as for other, more familiar risks, and effective co-ordination with other countries that might also be affected. They have also been informed by work undertaken by Sciencewise to engage the public on how to plan for the risk of severe space weather.

Priorities for future work

Although much has been done, more work is needed. Priorities for future work are:

- ensuring that research funding is guided by strategic priorities to help increase resilience to space weather;
- work with international partners to develop ways to fill gaps in space and ground capabilities to monitor and forecast severe events;
- build on work already ongoing with a range of sectors to increase awareness of and resilience to the risk of space weather in the UK, especially in sectors which might feel an impact but awareness is low;
- continue to communicate with the public in a way which builds resilience to this and other risks, without causing undue alarm and fits with wider approaches to warning and informing;
- continue international engagement in order to help increase UK resilience; and
- continue to raise awareness amongst local responders to increase their knowledge of and ability to plan for space weather in a way which is coherent with their wider planning for emergencies.

2. Space weather preparedness

2.1 An overview

Severe space weather was added for the first time to the UK National Risk Assessment in 2011, and the subsequent National Risk Register in 2012.

Public awareness of space weather remains low, but has grown amongst Government and industry. This has led to the mitigation of some of the impacts of space weather and the development of response plans. It has also led to the identification of gaps in knowledge or capability. Proportionate development of capability is vital for ensuring that the UK can plan and respond to severe space weather effectively.

Space weather is a complex and technical issue but many of the potential consequences are common to other risks. These include power loss, interruption to satellite services, transport disruption or loss of communication. Plans to respond to severe space weather can therefore be dealt with under existing plans. But there will be some impacts where existing capability is insufficient. This document highlights these areas.

The potential impacts also have a high degree of interdependency; many of the impacts might well happen at the same time, or in sequence, causing a greater combined effect. Our understanding of these interdependencies is growing but, remains incomplete.

UK and international understanding of how best to mitigate and respond to the effects of space weather is still evolving. Space weather science and research is still a relatively new field. Therefore, links between science and resilience planning are vital components of this strategy.

The UK approach is underpinned by three elements:

- designing mitigation into infrastructure where possible;
- developing the ability to provide situational awareness, alerts and warnings of space weather and its potential impacts; and
- having in place plans to respond to severe events.

Local responders will play a leading role in responding to the effects severe space weather as they would be for other risks identified in the National Risk Assessment. Therefore, our strategy includes working with local responders so they understand the risk, are aware of their role in the response, and know what central Government will be doing at each stage of an event.

The risk from severe space weather is not limited to the UK. The impacts of space weather could occur anywhere, and UK networks and systems might experience knock-on impacts. We are working as part of this strategy with international partners to better understand and plan for the risk. This is essential to ensure a coordinated response. This collaboration needs to continue.

2.2 What is the purpose of the document and who does it apply to?

This document sets out the UK-wide strategy for preparing for, and responding to, the demands of a severe space weather event. It covers the sectors which might be affected by the risk including:

- [electrical] power;
- transport;
- satellite navigation and timing;
- telecommunications; and
- Government, both at central and local levels.

It also covers how to co-ordinate planning across sectors.

The strategy draws on work already undertaken by Government and its stakeholders. It also aims to highlight priorities for the future and to help in the development of updated operational plans by local organisations and emergency planners.

Work is ongoing and, as such, this strategy is not a complete and comprehensive guide to responding to the risk.

This strategy supports the National Space Security Policy, published in April 2014. The National Space Security Policy sets out the approach to the United Kingdom's space security interests which will underpin our prosperity, well-being and security intending to make the United Kingdom more resilient to the risk of disruption to space services and capabilities, including from space weather. Details of the National Space Security Policy are set out in **Annex A**.

3. Space weather and its impacts

3.1 What is space weather?

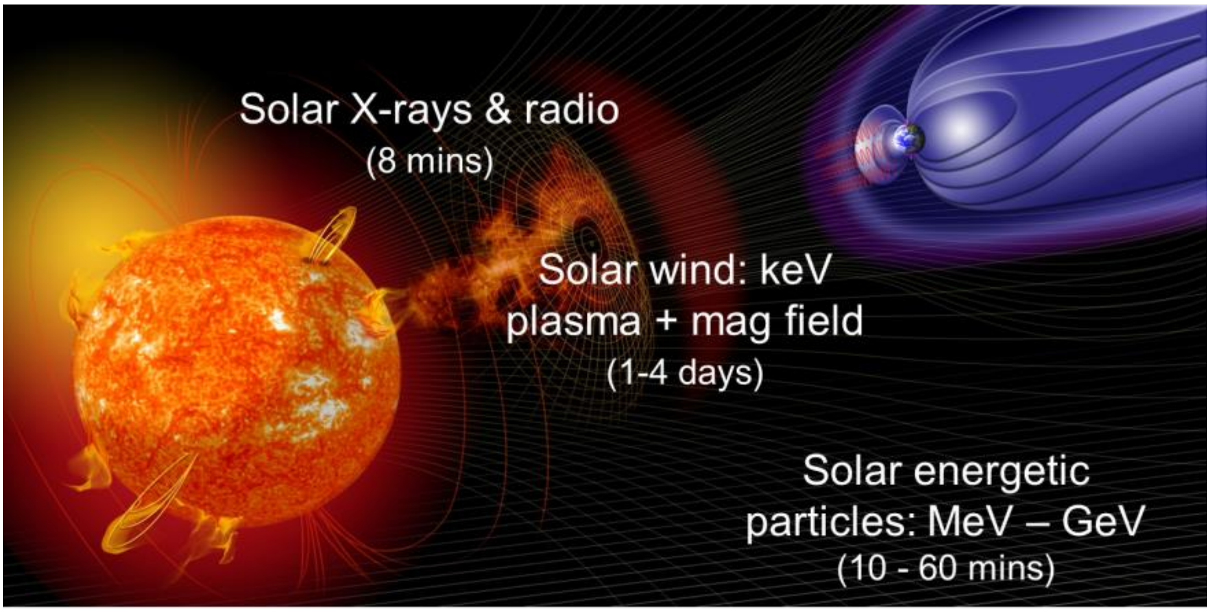
Weather on Earth, such as wind, rain and snow, has different terrestrial impacts and is caused by different meteorological effects. Similarly, space weather has different terrestrial effects and is the result of different types of solar activity. Solar emissions happen on a continual basis but can sometimes be severe and intense. Where the trajectory of solar activity intersects with the orbit of earth there can be detrimental effects to a range of technologies and infrastructure on Earth (see **Annex D** for a diagram of space weather phenomena and their effects).

There are three[1] main components of space weather:

- solar flares;
- solar energetic particles; and
- coronal mass ejections.

Each of these has the potential to cause impacts to Earth and they can occur singularly or in a combination which has the potential to cause a wider range of damaging effects to the UK's national infrastructure.

Fig.1 The different space weather phenomena



[1] Solar wind is also a component of space weather but does not impact the Earth by itself and therefore we include this in reference to CMEs.

i. Solar flares produce intense Ultraviolet and X-Rays that reach the UK within minutes; these cause disruptions to High Frequency (HF) communications, particularly affecting trans-oceanic aviation routes during daytime hours.

ii. Solar energetic particles[2] reach the Earth in less than an hour. These lead to radiation storms that cause:

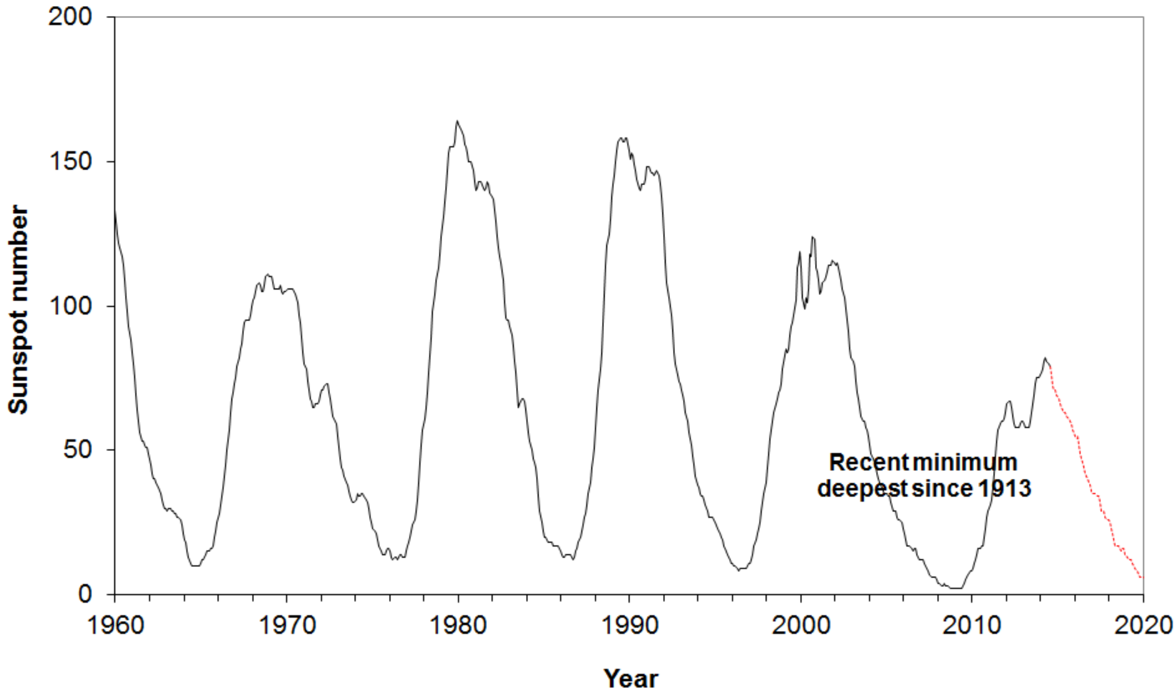
- increased exposure to radiation for passengers and aircrew in flight, particularly at high altitude on polar routes;
- faults in electronic systems at aviation altitudes;
- systems faults and damage to satellites and
- disruption to HF communications at high latitudes, particularly affecting trans-polar aviation routes.

iii. Coronal Mass Ejections are explosive eruptions on the sun, which cause large parts of the corona (the Sun's atmosphere) to blast away. This solar phenomenon is the most concerning element of severe space weather as it has the potential to cause the most severe impacts. CMEs travel much more slowly than radiation from solar flares and solar energetic particles, arriving at Earth between one and four days after being ejected by the sun. Generally, the faster they travel, the greater the magnitude of any impacts. CMEs can cause power outages; disruption of satellite operations and telecommunications services including Global Navigation Satellite Systems.

There is no clear pattern on when these eruptions happen. The sun has an approximately 11 year cycle of activity (see Fig.2), with the current cycle peaking in early 2014.

[2] Electrons, Protons and heavier ions

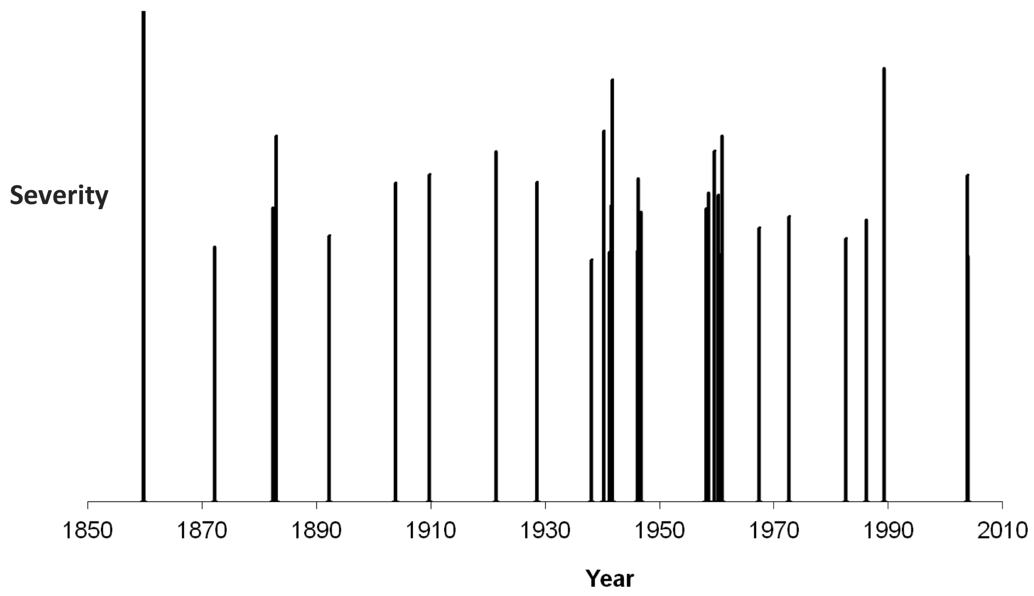
Fig. 2 Space weather cycles of activity



There is no evidence for the likelihood of severe space weather to vary with the solar cycle. Indeed, our reasonable worst case scenario, the Carrington Event (see section 2.2 below), happened during the lowest part of the cycle.

Fig.3 below demonstrates that the most severe events between 1859 and 2003 have been random in both timing and severity.

Fig.3 Major (geomagnetic) space weather events between 1859 and 2003



3.2 Reasonable worst case scenario

The risk of space weather was assessed in accordance to the UK National Risk Assessment process[3] and was added as a medium to high likelihood event with a medium impact score in 2011.

The development of a 'reasonable worst case scenario' ensures that theoretically possible scenarios are discounted should they lead to a disproportionate allocation of resources on the basis of an extremely small probability of occurrence.

The 'reasonable worst case scenario' for severe space weather is based on the Carrington event of 1859, aligned to our current understanding of the vulnerability of modern technologies. It includes theoretical impacts which have not necessarily been proven or tested by a space weather event. As a consequence, there may well be disruptive impacts that are either currently unknown or not fully understood.

The Carrington Event is often described as the 'perfect storm', as it included the strongest recorded incidents of Solar Flare related X-Rays, radiation storm and Coronal Mass Ejection. There have also been a number of less severe but more recent events that help underpin the assessment[4]. Research suggests that a reoccurrence of the Carrington Event has a 1% annual probability.

Scientific research and modelling, along with studies of more recent but less severe events, have been used to estimate the expected modern-day impacts of our reasonable worst case space weather event. It is anticipated that the impacts would be:

- localised power outages;
- disruption of satellite operations, including to Global Navigation Satellite System outages (GPS) and SATCOM disturbances;
- disruption to High Frequency communications;
- increased radiation to aircrew and passengers in flight, particularly over polar regions; and
- further disturbances to small-part electronic systems.

[3] Each risk is scored against five main assessment criteria: fatalities, casualties, social disruption, economic impact and psychological impact.
[5] This includes the storms of 1921, 1960, 1989 and 2003:

- In 1989, Quebec lost power due to a cascade tripping of protection relays; this resulted in 9 hours of power loss for 6 million people. There was also damage to 2 transformers in the UK.
- The Halloween Storms in 2003 resulted in a 1 hour power outage in Malmo. Interruptions also occurred to the operation of 47 satellites, including 1 total loss. The GPS wide area augmentation system in the US, used by the aviation sector went offline for more than a day.
- Records from solar storms in 1921 and 1960 describe widespread radio disruption and impacts upon railway signalling and switching systems.

These impacts are difficult to predict and are best assumptions.

4. The challenge of space weather events

There are significant challenges to planning for severe space weather. These are set out below.

4.1 Forecasting

Forecasting space weather shares much with forecasting weather on Earth. It analyses both observed conditions (obtained from sensors on a mix of satellites and ground-based facilities) and simulation models, which forecasters use to make a prediction. However, space weather prediction has far to go before it develops to the level of terrestrial weather forecasting.

The main impact on the UK is assessed to be from a Coronal Mass Ejection. Most Coronal Mass Ejections are not emitted in the direction of Earth. Those that are typically take 1-3 days to reach us, and we can predict the arrival time to within about 6 hours. Predictions are currently less accurate due to degradation in the satellite capability available to forecasters. Generally speaking, the faster the ejection, the greater the potential impacts. The Carrington Event, for example, travelled to Earth in as little as 18 hours. It is therefore likely that our reasonable worst case scenario would only allow us 12 hours from observation to impact.

4.2 Warning time

Each Coronal Mass Ejection has a magnetic field orientation, much as the Earth does. The magnetic field of a Coronal Mass Ejection has an equal chance of being north or south pointing, whereas the Earth's magnetic field points north[5]. A Northwards oriented magnetic field will have limited interaction with the Earth's magnetic field and therefore impacts will be mainly limited to the radiation impacts on satellites and aircraft. However, a Southwards oriented magnetic field will disrupt the Earth's magnetic field and may have considerable impact on vulnerable systems.

The magnetic orientation of a Coronal Mass Ejection can be measured as it passes the ACE[6] satellite, a million miles from Earth at the L1[7] point. This only gives 15-30

[5] The Earth's field gradually changes over time, and every several hundred thousand years, the North and South Poles will switch places.

[6] Advance Composition Explorer. Launched in 1997 as a scientific mission, it was originally intended to orbit for 5 years. Its observations and data are now relied upon for a number of operational services, and although it is far beyond its expected lifetime, ACE does have enough fuel to last until 2024. ACE will be replaced by the DSCOVR mission launched in February 2015 and that should be ready for operations in summer of 2015.

[7] The Lagrangian points are five positions of orbital configuration where the mix of gravitational forces allows objects to stay in a fixed position relative to Earth.

minutes warning of the polarity of a Coronal Mass Ejection before it reaches Earth. It is therefore only possible to give a 50% likelihood of major impacts until about 30 minutes before impact.

Once the Coronal Mass Ejection reaches the ground, it can take two to three hours for a geomagnetic storm to develop. This short timescale presents challenges for operators of infrastructure at risk from space weather. The biggest area of risk for a Coronal Mass Ejection impacting the Earth is the electricity power grid. Geomagnetically induced currents created from rapid variations in the electrical field during an extreme event can cause power outages. However, there are actions that the National Grid can implement to better protect the power grid. These need time and the 30 minute warning limits the range of mitigating actions that National Grid can take. The National Grid is reliant on the predictions of the Met Office. Protocols have been developed and are in place between the Met Office and National Grid to warn of a forthcoming event and maximise the time for mitigating actions to be taken.

Other major impacts can be caused by solar energetic particles and solar flares but these reach Earth only minutes after ejection from the Sun. This means that warning of such impacts is virtually impossible, and stakeholders will instead only receive alerts as an event is occurring. This is particularly pertinent for aviation and the risk of radiation to passengers and aircrew, as well as the loss of High Frequency communications, satellite communications and navigation.

The aviation sector, including the National Air Traffic Service, the Civil Aviation Authority, and the Department for Transport will need to consider further how to deal with these impacts with little or no warning. Procedures for airlines to follow will be an important aspect of response, and should be agreed nationally, as well as bilaterally and multilaterally with international partners. As part of this work, the UK should continue to work with the International Civil Aviation Organisation on operational procedures, not just forecasts and data.

4.3 Understanding the impacts

A lack of recorded contemporary impacts presents difficulty when using the Carrington Event as the reasonable worst case scenario, although less severe and more recent storms (e.g. 1989 and 2003) provide additional data. The strength, duration and impacts are subject to significant uncertainty. Additional research is needed to understand these impacts further, and ensure we can mitigate against them in the future.

Coordination of bids to Research Councils will help focus on those areas of space weather which cause us most concern and which have the greatest potential impact. The Space Environment Impacts Expert Group, which provides expert advice to Government on this risk, could be a conduit for this.

The L1 point allows the satellite to maintain a constant view of the Sun as seen from the Earth.

4.4 Monitoring

Detecting and monitoring space weather effects, particularly radiation and Geomagnetically Induced Currents can be difficult.

<u>Radiation</u>

There are a limited number of radiation monitors at ground level which are operated on a ‘best endeavours’’ basis and are not operational. The nearest ground level monitor to the UK is in Belgium. But even if this is operational and collecting data, it is unclear how the readings would be gathered and used rapidly within the UK, and there are potential costs associated with doing so. Ground level radiation events can also be extremely localised, so there is no guarantee that Belgium’s monitor would pick up an event in the UK.

There are no radiation monitors on board most aircraft. Radiation levels are instead modelled for aircrew to ensure they don’t go above their regulated annual limit of 20mSv[8]. Therefore, during an event, it will not be possible to advise passengers and aircrew accurately of their exposure to radiation. Some data from satellites combined with data from ground level monitoring could be used to estimate the dose, but this would take time to calculate and it is unclear how reliable the information would be.

Both the monitoring of ground level radiation events and radiation at flight altitude is being considered through the development of a Public Health England report to advice on measures for protecting public health from radiation hazards during an extreme space weather event.

<u>Geomagnetically Induced Currents</u>

During a geomagnetic storm, Geomagnetically Induced Currents caused by the magnetic variations in the Earth’s field will flow along conducting paths such as high voltage electricity transmission lines via transformer groundings (as well as potentially railway lines and, albeit not with acute impacts, oil and gas pipelines). This could cause damage to transmission transformers and therefore possible power outages.

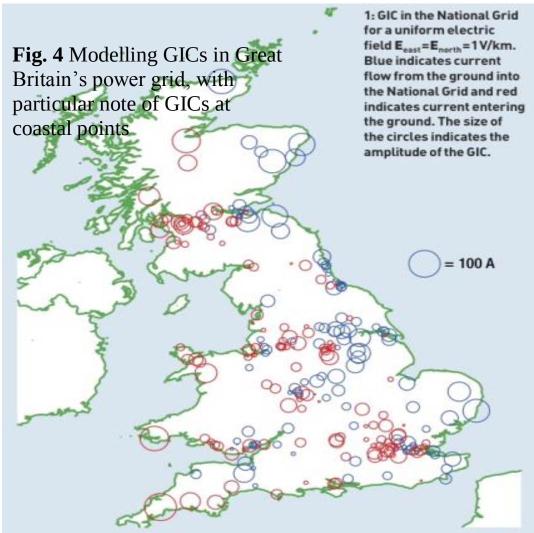


Fig. 4 Modelling GICs in Great Britain’s power grid, with particular note of GICs at coastal points

The British Geological Survey operates magnetic observatories (three in the UK) to continuously measure the Earth’s magnetic field and its variations. Data is available in real time for use by sectors affected by Geomagnetically Induced Currents. More

[8] 20 milisieverts (mSv) is the annual dose limit at which occupational exposure is set. The exposure limit for the public is a recommended 1mSv. See the Royal Academy of Engineering report for further information: http://www.raeng.org.uk/news/releases/shownews.htm?NewsID=825

importantly, the British Geological Survey can also provide forecasts of geomagnetic activity. Combining these approaches in response to geomagnetic activity, whether in power systems or pipelines, is critical if industry is to be fully prepared.

5. The strategic approach to planning for severe space weather events

5.1 Guiding principles of effective emergency response applied to space weather

The guiding principles of effective emergency response (see **Annex E**) apply to all risks; space weather is no different. All those with an interest in space weather impacts need to work together to build resilience to the risk and, in-turn, provide an effective emergency response.

These principles are considered throughout the strategy but apply particularly to the areas below.

5.2 Role and responsibilities

<u>Risk owner and Lead Government Department</u>

In March 2015, the Department for Business, Innovation and Skills took on the role of Lead Government Department for the risk to the UK from severe space weather. The lead Department leads the oversight and co-ordination function of resilience work for. This involves:

- overseeing continued assessment of the risk to ensure that it accurately reflects the underpinning science;
- coordinating delivery of improved resilience and response capability; and
- leading the initial response to any space weather event.

Oversight will be provided by a working group chaired by the Department for Business, Innovation and Skills with representation from across and outside Whitehall. More information on the arrangements for oversight is set out in **Annex C**.

BIS is the overarching department for a number of agencies and organisations that have an interest in space weather science and research, funding, and response planning:

- Met Office
- UK Space Agency
- National Environmental Research Council
- Science and Technology Facilities Council

- Engineering and Physical Sciences Research Council
- Others
- The Met Office provides the assessment of the risk of severe space weather for the National Risk Assessment and the National Security Risk Assessment. The Met Office is responsible for updating the risk description during the biennial National Risk Assessment process. The next National Security Risk Assessment will be completed in May 2017 and the next National Risk Assessment will be produced in 2016.

The Met Office has created the Met Office Space Weather Operations Centre to provide UK focussed forecasts to help mitigate the impacts posed by space weather events.

The UK Space Agency has invested in space weather observational capability and is responsible under the National Space Security Policy for making essential services more resilient to the risk of disruption to space services and capabilities from space weather and for strengthening our ability to understand and forecast space weather events and their effects, as well as ensuring a clearer focus for this work in Government.

Cabinet Office

In April 2013, the Cabinet Office set up a project to accelerate work to increase the UK's preparedness to respond to a space weather event, and to coordinate work across Government and with external partners. More information on the project's aims and objectives are set out in **Annex B**. The project ended in June 2014, and the work transitioned to the Department for Business, Innovation and Skills in March 2015.

Others

Other major players involved in improving UK resilience to severe space weather include (but are not limited to):

- **GO Science**: co-ordinates expert scientific input into resilience work on space weather and other National Risk Assessment risks and convenes the Scientific Advisory Group for Emergencies in the event of an emergency. For space weather, this input is primarily provided via the Space Environment Impacts Expert Group.
- **Department for Energy and Climate Change**: responsible for working with National Grid and others to improve the resilience of the power sector. Assurance on resilience is primarily provided by the Energy Emergencies Executive Committee.

- **Department for Transport**: responsibility for working with industry to improve the resilience of aviation and other modes of transport to the impact of severe space weather.
- **Communities and Local Government**: works with local responders, via Local Resilience Forums, to increase their awareness of the risk and their role in any response.
- **Ministry of Defence**: lead for building the resilience of the military to the effects of space weather.

5.3 Increasing the resilience of the UK's national infrastructure

There is currently nothing we can do to prevent space weather impacting the Earth. However, there are a number of mitigating actions we can carry out to protect our national infrastructure.

The UK's national infrastructure is defined by the Government as:

Those critical elements of infrastructure (namely assets, facilities, systems, networks or processes and the essential workers that operate and facilitate them), the loss or compromise of which could result in:

a) major detrimental impact on the availability, integrity or delivery of essential services – including those services, whose integrity, if compromised, could result in significant loss of life or casualties – taking into account significant economic or social impacts; and/or

b) significant impact on national security, national defence, or the functioning of the state.

National infrastructure is subsequently categorised into thirteen sectors:

- Communications
- Emergency services
- Energy
- Financial services
- Food
- Government
- Health
- Transport
- Water
- Civil Nuclear

- Defence
- Space
- Chemicals

The majority of these sectors might be impacted by a severe space weather event and therefore face decisions about building additional resilience. There are also some cross-sector impacts. This includes technology integral to the delivery of essential services across a number of sectors, such as Global Navigation Satellite Systems reliance and micro-circuitry.

The components for increasing resilience to severe space weather are:

- increasing our understanding of the risk;
- ensuring generic capability planning, including at local level, reflects the impacts of severe space weather wherever possible;
- improving our ability to predict events and alerting relevant sectors as far in advance of events as possible;
- developing key sectors' resilience to space weather and developing new capability where needed whilst avoiding inadvertently increasing vulnerability in the future; and
- having in place plans for a response and exercising these plans.

The affected sectors and their subsequent cross-sector impacts were considered in the Capability Gap Analysis (further information can be found in section 5).

Lead government departments' annual sector resilience plans alert ministers to any perceived vulnerabilities and set out action to improve resilience where necessary.

Generic business continuity planning across sectors is a vital element for ensuring national infrastructure is prepared to deal with the impacts of space weather. Business continuity plans need to have the potential to be scaled up to cover the most severe impacts from a space weather event, as well as to reflect possible concurrency of impacts. Government departments need to work with their stakeholders in relevant industries to ensure this risk has been taken into account alongside business continuity plans.

5.4 Minimising future system vulnerabilities

There have been a number of recorded severe space weather events over the last two centuries. But the advancement of technology and the increases in interdependence of some systems means that infrastructure has become more vulnerable to its impacts in last few decades.

Awareness within some sectors to the risk has grown alongside these developments in technology. But not all impacts have been considered or managed consistently.

Some UK systems are more resilient and robust to space weather than counterparts abroad:

- the GB power grid network is highly meshed and has a great deal of built in redundancy. This potentially makes it less susceptible to space weather effects than power grids in some other countries. Over recent years a more resilient design for new transformers has been used to provide further mitigation.
- the UK's mobile communication stations rely on power. However, they will continue to supply services to customers if timing synchronisation through Global Navigation Satellite Systems link is lost. In North America, an in-built parallel system that needs both power and GPS to function has been introduced, increasing vulnerabilities.

Some of this resilience is not the result of planning for this risk but good fortune. A priority for the future is to ensure we design in resilience to space weather into technology in line with our understanding of the risk. The UK Space Agency has funded work through the ESA programme to develop a coordinated set of service centres that model impacts and provide tailored advice and analysis products to promote and support resilience.

Development of new infrastructure, such as future rail projects, will need to consider all impacts of space weather alongside other resilience issues. Other areas such as aviation and satellites will need to consider space weather impacts on new air and space craft.

All government departments and their stakeholders share this responsibility, not just the lead government department or the risk owner. Industry also needs to be aware of the potential impacts and to build in resilience.

5.5 Warnings and alerts

The Met Office has a collaborative relationship with the US National Oceanic and Atmospheric Administration Space Weather Prediction Centre, which has enabled them to build the knowledge and capability needed to forecast space weather in the UK. That relationship continues today, sharing information, data and expertise and helping to ensure efforts are coordinated internationally[9]. There is also good communication between the Met Office and space weather centres in South Korea and Australia.

[9] The UK and the US signed a memorandum in 2011 to coordinate work in the delivery of space weather alerts to help provide critical infrastructure protection around the world: http://www.metoffice.gov.uk/news/releases/archive/2011/space-weather-collaboration

In December 2013, BIS announced funding of £4.6 million to support Met Office forecasting capability, enabling the Met Office to provide a full 24/7 prediction service 365 days a year.

The Met Office successfully delivered on the first phase of its service in April 2014, providing government and key stakeholders (Civil Aviation Authority, National Grid etc...) with alerts and warnings of the impacts of space weather. This capability will continue to be developed and refined by the Met Office to ensure the service provided meets customers' needs. The second phase of work was delivered in October 2014, and offers an online platform where stakeholders can sign up for specific alerts and warnings. It will also provide further information and data for the public.

The Met Office service is the first step in helping to build the resilience of UK infrastructure and industry, providing the time and information that allows mitigation actions to be taken to protect against the impacts of space weather. The alerts are in the process of being redefined by the Met Office in response to stakeholder feedback.

The information provided alongside the alerts is equally important, and the Met Office has produced a UK impact scale to provide further information on the potential impacts for UK stakeholders. This has helped stakeholders understand what impacts might be seen at each severity level for all space weather phenomena.

The Met Office is also a member of the International Space Environment Services, the international body for space weather, and is a designated Regional Warning Centre. Its role will therefore expand, and there is potential to exploit opportunities to provide other European countries with forecasting services[10].

5.6 Local level response planning

Just as strategic oversight is important response at the local level will be equally significant in providing effective emergency response.

While impacts might be felt across the UK, it will be local areas that will have to deal first and foremost with loss of power, loss of GPS for emergency services, and transport disruptions. The Local Risk Assessment Guidance has therefore been updated for local responders to provide further information on what impacts they should consider predominantly at the local level.

Local partners should be in a position to respond through existing structures when the polarity of a CME is confirmed. But there is still a lack of knowledge about what response might actually be needed. Local partners will also need to sign up to receive Met Office alerts directly as they will not be cascaded from central government. The Met Office is engaging with local partners to expand awareness of

[10] There are other European RWCs in Belgium, Poland and Sweden, although not 24/7 capabilities.

its forecasting and information services, in conjunction with the Department for Communities and Local Government Resilience and Emergencies Division.

6. Assessment of Preparedness

6.1 What has been done so far

Significant progress has been made to improve resilience to severe space weather. This includes, but is not limited to:

- Response plans
  - a Response Guide was drafted in mid-2013 and revised in March 2015 to define the Civil Contingencies Secretariat's internal plans and actions for responding to a severe space weather event. Shared with stakeholders, this document identifies where further information would be sought from other departments and agencies by COBR or the Civil Contingencies Secretariat, and what actions might stem from these.
  - a cross-departmental expert workshop was held in May 2014 to review response plans with departments and key stakeholders, highlighting gaps for future capability building and exercising.
- Assessment of capability
  - a Capability Gap Analysis was produced in late 2013 that identified current sector capability and preparedness, recognised gaps, and prioritised work to build capability. Progress across each sector continues to be tracked.
- Forecasting and Monitoring
  - the Met Office launched their forecasting service in April 2014. It now provides 24/7 warnings and alerts to key stakeholders. This is integral to providing time for government and industry to take mitigating actions to protect against the impacts of space weather.
- Public Communication
  - a cross-departmental and multi-expert workshop was held in January 2015 to review public communication plans with departments and key stakeholders; an agreed public communication plan has now been agreed.
- Warning and informing
  - a Sciencewise project carried out six public dialogue sessions over June, July and September 2014. This dialogue brought members of the public together with space weather and resilience experts to investigate government preparedness and communication relating to space weather. This informed policy on communications with the public and public attitudes to this risk.
- Awareness amongst local responders
  - the Civil Contingencies Secretariat and the Department for Communities and Local Government implemented a programme of awareness raising events with different local responders at Local Resilience Forum meetings,

conferences and events, to help communities better understand and prepare for the risk.
  - the Local Risk Assessment Guidance was updated by the Civil Contingencies Secretariat to reflect the need for further information about the potential impact at the local level.

- Increased international agreement
  - two US/UK cross-Government workshops have taken place. The first, in October 2014, covered impacts on the aviation sector and the second, in February 2015, focused on impacts on the power grid and how to undertake public communication to mitigate the impact of the risk.
  - a number of senior-level presentations have been made to increase awareness of the risk, for example to a meeting of the European Union Directors General, and NATO's Civil Emergency Planning Committee.
  - involvement in the delivery of the European Commission Joint Research Centre power grid conference in October 2013, and the financial sector conference in London in June 2014. Further collaboration with the European Commission Joint Research Centre will take place in September 2015 to railway workshop to investigate the likely impacts of space weather on the sector.
  - good relationships with Governments in Sweden and the US; and between the Met Office and their counterparts in Sweden and the USA. Further interaction with other countries includes South Africa, Canada, Denmark and Ireland.

Developments in Scientific Understanding

The Space Environment Impacts Expert Group was set up to provide expert advice to Government on the Space Environment and its impact on UK infrastructure and business. The group provided advice and support to the Civil Contingencies Secretariat space weather project, and is responsible for providing any potential Scientific Advisory Group for Emergencies with its core membership in the event of a space weather emergency (to in-turn provide advice to COBR). The Space Environment Impacts Expert Group includes a range of experts[11] to ensure all aspects of space weather and the space environment can be considered. The group provides assurance that the latest scientific and expert advice is considered in government, aligning policy, response and resilience with the most recent research.

The Royal Academy of Engineering report, *Extreme space weather: impacts on engineered systems and infrastructure*[12] published in February 2013 identified the impacts for the UK across different sectors. The report's recommendations were

[11] Members of the SEIEG include: British Antarctic Survey, British Geological Survey, Cabinet Office, Civil Aviation Authority, Defence and Scientific Technologies Laboratory, GO Science, Met Office, National Grid, Public Health England, Research Councils UK, Science and Technology Facilities Council, Rutherford Appleton Laboratory Space UKSA, University of Birmingham/Royal Academy of Engineering, University of Surrey.

[12] http://www.raeng.org.uk/news/releases/shownews.htm?NewsID=825

reviewed by the Severe Space Weather Project during 2013 and progress implementing them has been tracked as part of the work of the project. Future work on this risk should continue to do so.

6.2 Preparation and capability by sector

The Civil Contingencies Secretariat project carried out a Gap Analysis in December 2013 which assessed the capability of the UK to respond to a severe space weather event across different sectors and for a number of cross cutting areas of preparedness. This analysis has subsequently been used as the basis of measuring progress for development of capability by each sector, and in the cross cutting areas of planning. From March 2015 the Department for Business, Innovation and Skills will be responsible for monitoring, measuring and co-ordinating progress. Responsibility for delivering progress in each sector will be the responsibility of individual Government departments responsible for that sector working alongside their partners.

Overall response planning

The response to a severe space weather event will be built upon the UK's tried and tested response plans for natural hazards. A Response Guide for use in a severe solar storm was produced in 2013 and updated in July 2015. An accompanying science guidance paper, setting out the scientific response to a major space storm was also produced in early 2014.

This response guide was tested at a cross-sector workshop in May 2014 and revised to reflect the outcome of that event. Development of the response for a severe solar storm has highlighted several areas for future work. The means of contacting members of the expert community in an emergency and convening the Scientific Advisory Group for Emergencies needs to be confirmed formally. The Met Office will work with the Government Office for Science to agreed arrangements. The outcome will then be reflected in the Response Guide and Science Guidance. A subsequent workshop exercising the transition from the Space Environment Impacts Expert Group to the Scientific Advisory Group for Emergencies is needed to identify a threshold for starting the response, familiarise members with the process, and identify the requirement for Sir Mark Walport, Government Chief Scientific Advisor, to become involved.

Modelling and data

Several models support the understanding and forecasting of space weather events. The modelling of space weather events and collection of data relies upon a small number of ground and space based sources Capabilities such as those on the SOHO, ACE and STEREO satellites are primarily research rather than operational orientated and many are reaching the end of their intended lives. The DSCOVR satellite was launched in February 2015 as a replacement for ACE and is expected to become operational later in 2015There are few missions planned that may provide useful data. In addition, we have lost capability provided by the STEREO satellites due to overheating of their radio antennae whilst round the far side of the Sun. This has reduced the accuracy of the Met Office's modelling of severe events. Work with US counterparts and through the European Space Agency is needed to improve the range and resilience of our space based capabilities.

The Scientific Advisory Group for Emergencies is conducting a Scientific Capability Gap Analysis to identify further areas where modelling and data needs to be identified. This will help to identify both the additional scientific capabilities needed and where research might be best focussed to improve UK resilience to severe space events.

Forecasting and monitoring

The foremost global authority for forecasting and monitoring space weather is the Space Weather Prediction Centre, which is part of the US National Oceanic and Atmospheric Administration. Until recently it was the only 24/7 civilian space weather forecasting centre. However, the UK Met Office has now developed its own forecasting and alerting capability which became fully operational in October 2014. The Met Office is refining its alerts in light of feedback from stakeholders to ensure information is tailored to their needs A UK impact scale has been produced to identify UK-specific impacts. The process for providing alerts is also being further refined to make sure that those who need to receive them do so and understand what action they need to take.

Power

The National Grid owns and operates the power grid in England and Wales and operates the power grid in Scotland. EirGrid is the Transmission Systems Operator in Northern Ireland as well as the Republic of Ireland. In February 2015, the UK and Republic of Ireland held a workshop with the US and Canada to share experience on building resilience to major space weather events. Our understanding of the impact of severe space weather on power in the UK relates primarily to the GB grid owned and/or operated by National Grid. More work is needed with partners in the Republic of Ireland on the potential impact on the grid in Northern Ireland.

The GB Power Grid is likely to be more resilient than that of some other countries to the effects of severe space weather for a range of reasons: shorter power lines, a mesh like grid system with the ability to close sections and route power around them and, a more reliant design for new and replacement transformers. In addition, the National Grid has developed operational plans to manage the impact of severe events and now holds additional spare transformers in the event of transformer damage. National Grid exercises these plans on a regular basis.

Nonetheless, for the GB grid, our relatively high latitude, long coast line and geology are factors that increase risk. Here are two potential impacts:

1. Supergrid transformers in GB have been damaged in the past (e.g. in 1989) and a report in 2013 reflected the National Grid assessment that approximately 13

Supergrid transformers might be permanently damaged in a Carrington Scale event. About half of these are judged to be located in Scotland. Of the 13 transformers which could be damaged, it is estimated that only two substations – most likely in more coastal/rural parts of the country – could experience damage to the extent that they were not be able to provide local power supplies. In these areas people might face two to four months of disruption to power supplies and be subject to rota disconnection while the transformers are replaced.

2. Voltage instability could occur and lead to a local (small region) blackout. This would be a short term impact (hours). Preparedness for this impact is being developed through broader work on resilience to the power grid.

There are potential impacts on the oil and gas sectors from a severe event. Oil drilling relies on Global Navigation Satellite Systems for accuracy. Resilience is provided through effective and timely warning of events, which can be provided by MOSWOC, and drilling suspended during an event.

<u>Transport</u>

The impact of radiation on passengers and loss of HF communications are issues where mitigation is already to some extent in place. However, planning for major events is less well developed, especially managing the wide range of impacts which might be experienced during a Carrington scale events.

Work to increase preparedness is taking place with the aviation sector. For example, a workshop, which included the Department for Transport, Civil Aviation Authority, National Air Traffic Services and Cabinet Office, took place in early 2014 to work through the impacts which the sector might face. That event identified a number of areas for further work, including a further assessment on the impact of prolonged loss of all communication frequencies for civil aviation. In addition, further involvement of the sector including airlines and airports might also increase the UK's preparedness to a major event. In October 2014, the UK and US held a joint workshop to agree a collaborative approach to building resilience of the aviation sector.

A major space weather event could lead to network impacts across the globe due to a lack of a coordinated international response. More work with international partners is needed to consider how to respond to an event. This will include bilateral work. For example, a workshop with North American and Irish partners took place in late 2014 to start the process to co-ordinate planning. NATO also held a seminar in October 2014, which included work on managing the impact of a space weather event on civil aviation. The UK and others are also working through the International Civil Aviation Organisation (on its draft Concept of Operations for provision of severe space weather information, although progress is currently slow and more needs to be done to include response plans in that document.

Public Health England is working on a report into solar radiation impacts on public health (see below – public health capabilities). This is needed to make progress on planning the aviation response, including communication with the public following an event. This report is due to be completed in the latter half of 2015.

There is currently a gap in capability to measure and monitor radiation levels on the ground and at altitude and is therefore a gap in our response plan. Resolution of this gap needs to be addressed nationally and internationally in light of the number of non-UK aircraft flying to and from UK airports.

Work started in 2014, with the support of the Association of Train Operating Companies to look at the potential impact on the rail network. This would primarily result from geomagnetic currents flowing along the tracks or the knock-on impacts from a loss of power. The Department for Transport commissioned research into the potential impact. Phase 1 of this work has been completed which identifies potential vulnerabilities to space weather. A second phase to assess the risk further and identify what mitigation needs to be implemented is currently underway. The implications for the rail sector will be explored further at a Joint Research Centre, Swedish, US and UK workshop in London in September 2015.

Maritime faces an impact from loss of HF Communication, disruption to Global Navigation Satellite Systems integral to many maritime systems, and possible disruption to Automatic Identification System signals from ships out of sight of land. More work is needed to plan for how the impacts to maritime will be managed, particularly for busy shipping areas such as the English Channel. Recent development in the eLORAN system offers a potential alternative to Global Navigation Satellite Systems for navigation. However, coverage does not extend fully around the UK at present.

Less work has been done on the impact on other modes of transport, including the potential impacts of geomagnetic currents on local underground and tram systems, or on loss of Global Navigation Satellite Systems on local bus services and road management.

There is a risk of building in future vulnerability into the transport infrastructure, for example increased reliance on Global Navigation Satellite Systems in managing airport approaches for aircraft to minimise noise pollution over populated areas, or in designing new rail infrastructure such as HS2. Decisions on future use of Global Navigation Satellite Systems in transport development need to be taken with the knowledge of this vulnerability and with proportionate mitigation in place.

<u>Satellite sector</u>

Satellites face the impact of space weather on an ongoing basis and are therefore designed to operate in this environment. The Royal Academy of Engineering study indicated that, during a major event, services from a significant proportion are expected to be lost either temporarily or permanently. Damage due to radiation can upset onboard electronic control systems. The impact of radiation on delicate microelectronics may be more important as more functionality is added to payloads.

Satellites that are not lost may suffer rapid aging of solar panels during the event and satellites in low earth orbit will experience increased drag.

Military satellites and navigation satellite systems are critical to UK resilience and are hardened to the effects of space weather. It is unlikely these satellites will be significantly degraded or damaged; nevertheless the transmissions will be degraded, or totally lost, due to ionospheric impacts, especially in the lower frequency bands used for navigation and aircraft communications.

Aviation

The effects seen on satellites caused by the increased radiation environment are also seen to a lesser degree in the electronic control system on aircraft. What is not clear is the extent to which the radiation environment at ground level would be increased, and what the impact might be on electronic systems on the ground. Although the radiation levels would be significantly lower than either in space or at flight altitudes, and so the risk is believed to be relatively low, the gap in knowledge and increasing miniaturisation of electronic systems means that this remains an area of potential vulnerability. The University of Surrey is currently undertaking research work on this issue on behalf of EDF, and the results of that work might provide a better assessment of the risk for aviation.

Telecommunications

Generally, the UK mobile telecoms network is more resilient to the direct effects of space weather than some other countries. This is because Global Navigation Satellite Systems reliance is not built into base stations in the UK to the same extent as it might be in other countries. However, it is important that future developments in the telecommunications network do not design in reliance on Global Navigation Satellite Systems without mitigation to its potential loss in a major space weather event or for other reasons.

However, all telecommunications has a high reliance on power supply and therefore more work with the telecoms industry is needed via the Department for Business, Innovation and Skills on increasing resilience to the potential secondary impacts of a solar storm such as power loss. However, this issue is best taken forward as part of wider telecoms resilience activity.

Transoceanic communications are more resilient to geomagnetic currents than in the past due the modern use of fibre optic cables. However, there is a potential vulnerability due to the reliance on electrical power cables running alongside the fibre optic cables. More work is needed to understand how to improve resilience to the impact of space weather.

Public health

The direct impact on public health from the increased radiation environment, which is most likely to affect the general public if they are travelling by air on trans-oceanic routes during a storm, is assessed to be small.

However, work on this area being led by Public Health England needs to be completed urgently. That work will lead to a report that sets out recommendations for protecting public health from solar radiation[13]. The Executive Summary of this document was ready in 2014; the full report will be published in 2015. Recommendations from the report then need to be followed up government and industry, especially those in the aviation sector. Public communications plans will, if necessary, need to be revised in line with the report's recommendations.

Local response

Much of the response to the impacts to a solar storm, e.g. power loss or transport disruption, would be led by local responders co-ordinated through Local Resilience Forums. The response would be based upon generic plans adapted for the range of effects experienced in any given area. There has been significant work since mid-2013 to increase local responders' awareness of the risk, how they might be affected, and the assumptions of using generic plans to respond to the event locally. This has included presentations to Local Resilience Forums around the UK and involvement of a local area in the cross-sector workshop in May 2014.

However, more work is needed to help local responders plan for the risk. This will include further engagement on what the risk is and how local responders will be involved in the response. But it will also increasingly need to focus on sharing information the stages of a space weather event and what central government will be doing at each stage.

Local response command and control arrangements might be directly impacted by the loss of Global Navigation Satellite Systems. There is an assumption that responders will revert to a paper based system. However, depending on the extent to which Global Navigation Satellite Systems reliance has been embedded in control rooms and how centralised they have become, there might be degradation in response times and effective deployment of plans if there is insufficient familiarity with those back up plans.

The Airwave emergency services communications network has Global Navigation Satellite Systems integrated into its base stations. However, the network is viewed as resilient to the loss of Global Navigation Satellite Systems due to the holdover oscillators which are also integrated into the system.

Other sectors

[13] The PHE report will advise on measures to protect the public from radiation hazards during a space weather event. This will be published by PHE. The Cosmic Radiation Advisory Group is responsible for drafting the report. The group includes: British Airways, British Airlines Pilots Association, Cabinet Office, CAA, Department for Transport, Department of Health, Health and Safety Executive, independent experts, Met Office, NATS, National Physical Laboratory, SolarMetrics, Science and Technology Facilities Council RAL Space, University College London, University of Surrey.

Other sectors are primarily affected directly by loss of Global Navigation Satellite Systems or indirectly by loss of power (e.g. fuel supply, cash supply, high intensity food production, hospitals). Mitigating the side effects of power loss is not covered in detail in this strategy as it forms a core element of broader resilience planning.

Particular work has been done to raise awareness of this risk within the financial services sector, including a workshop with the sector and space weather experts in May 2015. Work is underway to assess the extent to which the sector relies upon Global Navigation Satellite Systems for timing transactions and what impact disruption to Global Navigation Satellite Systems might have. Mitigation is available to the effects of any disruption, for example holdover oscillators, and a Universal Time Signal from the National Physical Laboratory. The Cabinet Office worked with HM Treasury, the European Joint Research Centre and National Oceanic and Atmospheric Administration, to deliver a workshop in June 2014 to raise the financial services sector's awareness of the risk and potential mitigation.

7. Conclusion and priorities for future work

Considerable progress building resilience to severe space weather has been achieved since the risk was first added to the National Risk Assessment in 2011. This includes:

- work by the National Grid to improve the resilience of the Transmission Network to the impact of Geomagnetically Induced Currents, including transformer designs, increasing its stock of replacement transformers and development of operational mitigation plans.
- the publication of the Royal Academy of Engineering report on severe space weather in February 2013.
- the launch of the Met Office forecasting capability in April 2014.
- the production of the COBR response guide for severe space weather and the response guide workshops in December 2012 and May 2014.
- the public communication workshop in January 2015 and Sciencewise public dialogue in June, July and September 2014 and the subsequent production of a communications plan
- the work by the Department for Transport, Civil Aviation Authority and National Air Traffic Service to improve understanding of the potential impacts for aviation.
- development of international networks, including those with key resilience partners in North America and Europe, including a number of successful workshops.
- increased awareness and understanding amongst local responders of their potential role during an event.

But much remains to be done. The following areas are priorities for future work for development of additional resilience including:

- work with international partners to explore potential for operational satellite capability to support improvement and increased resilience for forecasting space weather events.
- working with Research Councils to direct research to areas which will help to increase resilience to severe space weather.
- continued awareness raising amongst local responders to increase awareness and ability to plan for these events (consistent with planning for other risks).
- development of wider understanding of the potential impact on technology reliant on Global Navigation Satellite Systems and development of plans to increase resilience in critical infrastructure.

- build on work with aviation to increase awareness of and resilience to the risk of severe space weather across other modes of transport, including rail, road and maritime.
- Understand the socio-economic consequences of space weather to underpin investment in future capability
- continue international engagement in order to help increase UK resilience. This will include following up recommendations from the workshops with the US in October 2014 and February 2015, further bilateral work with key partners such as the US, Canada and Sweden and multilateral work (through the EU and NATO) International Civil Aviation Organisation over resilience in other countries and therefore make recovery from any event more effective.
- Met Office to work with the Department for Business, Innovation and Skills to seek commercial opportunities for exploiting their expertise in other European countries.
- increase understanding of the potential impact of severe events on electronic systems at ground level.
- Work with the UK Space Agency to encourage the European Space Agency Space Situational Awareness programme to deliver outcomes that support mitigation work by the UK and our international partners.
- help to ensure that technological developments to national infrastructure do not lead inadvertently to decreased resilience to space weather, e.g. through integration of Global Navigation Satellite Systems without informed consideration of the necessary mitigation.

END OF MAIN DOCUMENT

ANNEX A: National Space Security Policy (NSSP)

The National Space Security Policy (NSSP) was published in April 2014. It sets out the approach to the United Kingdom's space security interests that will underpin our prosperity, well-being and security. It has four objectives:

1. To make the United Kingdom more resilient to the risk of disruption to space services and capabilities, including from space weather.
2. To enhance the United Kingdom's national security interests through space.
3. To promote a safe and more secure space environment.
4. To enable industry and academia to exploit science and grasp commercial opportunities in support of national space security interests.

The Policy sets out to make the United Kingdom more resilient to the risk of disruption to space services and capabilities, including from space weather, by:

- Improving understanding of space security risks and dependencies
- Pursuing a proportionate approach to investing in resilience, balancing protective measures with other means of promoting resilience, such as alternative or fall-back capabilities.
- Enhancing the resilience of essential services (e.g. transport and communications) to the disruption of satellite operations, and the adverse effects of space weather
- Strengthening our ability to understand and forecast space weather events and their effects, and ensuring a clearer focus for this work in Government.
- Working with the United States, European Union, Member States and European Space Agency on an integrated approach to security in European space programmes and wider space policy, including infrastructure and systems resilience.

ANNEX B: Cabinet Office space weather project

The Cabinet Office (Civil Contingencies Secretariat), working closely with the Met Office, set up a space weather project as part of its High Impact Hazards programme. The space weather project aimed to increase the UK's preparedness to mitigate and respond to the risk from a severe space weather event. In the first instance, assessing the impacts on the UK of a severe space weather event, identifying capability gaps and, if appropriate, determining what new and/or additional capabilities are required to respond to such an event.

The project was overseen by a Project Board. Populated by government departments, agencies and space weather experts[14], the Board provided guidance and assurance to the project and was, in-turn, overseen by a Programme Board that looked at the two newest high priority National Risk Assessment hazards: Effusive Volcanoes (H55) and Severe Space Weather (H56).

The Cabinet Office space weather project aimed to increase the UK's preparedness to respond to an extreme space weather event by:

- Improving preparedness across Government and an increase ability to respond to and recover from severe space weather.
- Establishing a network of scientific advisers to support the response to a severe space weather event.
- Establishing international operational and policy networks.
- Gaining clearer understanding of our ability to forecast and model the impact on the UK from space weather.
- Improving awareness of space weather amongst Government, local responders and the private sector, including their role in preparing for them.

[14] The following are members of the CO Space Weather Project Board: Cabinet Office; Met Office; Department for Business, Innovation and Skills; Department of Energy and Climate Change; Government Office for Science; Department for Transport; QinetiQ; Rutherford Appleton Laboratory Space; Scottish Government; UK Space Agency.

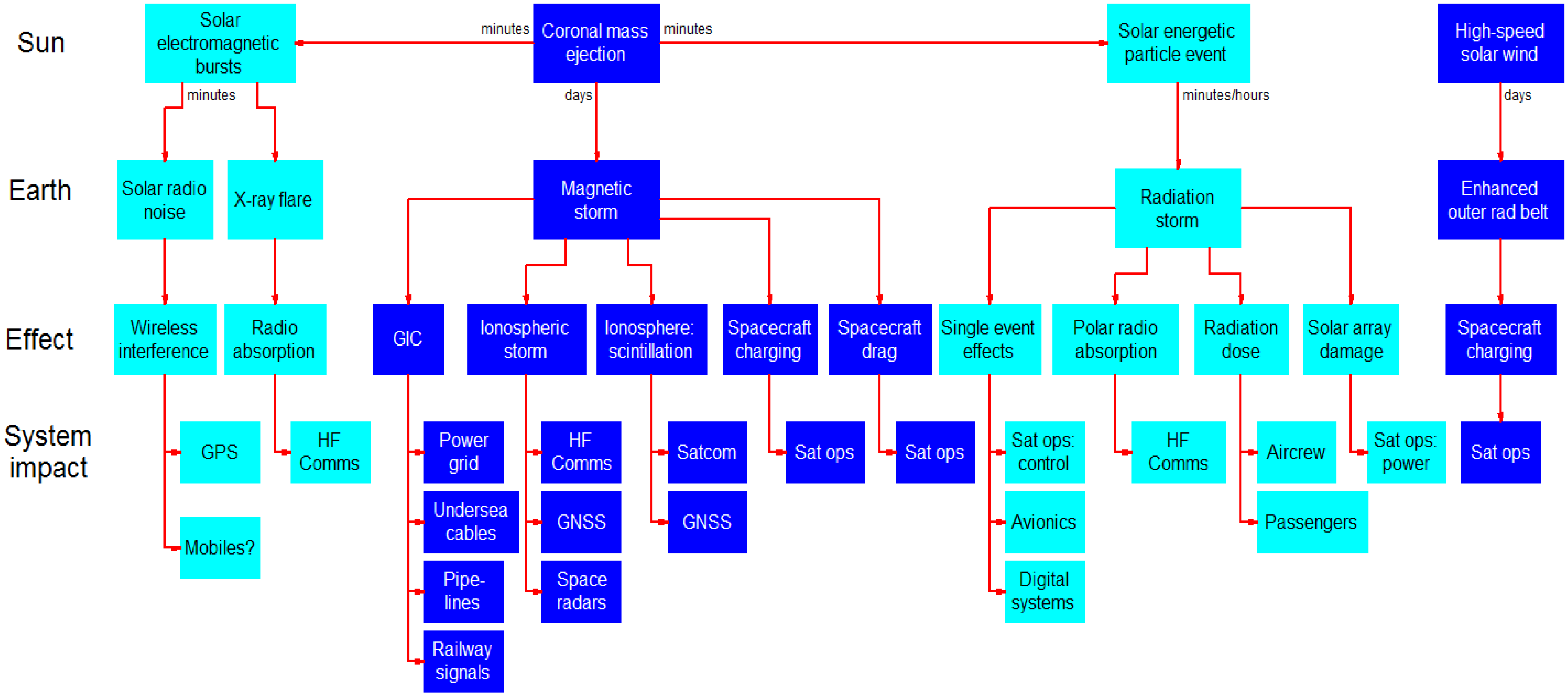
ANNEX C: Working group oversight of the risk

Since April 2013, the Cabinet Office set up a 12 month project to accelerate work to increase the UK's preparedness to respond to a space weather event, and to coordinate work within, and external to government. The project ended in June 2014, and the work transitioned to BIS in March 2015. Oversight will be provided by a 'working group', chaired by BIS. The group will be defined as below:

- The working group will meet every six to eight weeks to oversee the continuing delivery of improved capability, share information and plan wider stakeholder engagement on this risk.
- The membership of the working group has been widened in light of its move from being focused on project decision making to wider liaison and information sharing. For example, FCO, MOD, CLG and HMT have been invited to attend.
- The capability assurance tracker will form the basis of knowledge sharing of work on the risk and ensuring that progress is being made and is effectively coordinated.
- The working group will advise on any issues which need to escalate to NSC (THRC) (R) (O), with the final decision being made jointly by CCS and BIS.
- SEIEG will continue to offer advice to Government on severe space weather. GO Science will take on the lead for liaising with SEIEG, while working closely with BIS

BIS will produce a Terms of Reference for the Working Group in the first half of 2015 and continue to provide oversight and co-ordination for UK resilience building efforts to the risk of space weather.

ANNEX D: Solar phenomena and their impacts



ANNEX F: Guiding principles of effective emergency response

These principles should be applied to the management of any emergency.

Preparedness: All individuals and organisations that might have to respond to emergencies should be properly prepared, including having clarity of roles and responsibilities, specific and generic plans, and rehearsing response agreements periodically.

Continuity: The response to emergencies should be grounded within organisations' existing functions and their familiar ways of working – although inevitably, actions will need to be carried out at greater speed, on a larger scale and in more testing circumstances during the response to an incident.

Subsidiary: Decisions should be taken at the lowest appropriate level, with coordination at the highest necessary level. Local responders should be the building block of response for an emergency of any scale.

Direction: Clarity of purpose should be delivered through an awareness of the strategic aims and supporting objectives for the response. These should be agreed and understood by all involved in managing the response to an incident in order to effectively prioritise and focus the response.

Integration: Effective coordination should exercise between and within organisations and local, regional and national tiers of a response as well as timely access to appropriate guidance and appropriate support for the local, regional or national level.

Communication: Good two-way communications are critical to an effective response. Reliable information must be passed correctly and without delay between those who need to know, including the public.

Cooperation: Positive engagement based on mutual trust and understanding will facilitate information sharing and deliver effective solutions to arising issues.

Anticipation: In order to anticipate and manage the consequences of all kinds of emergencies, planners need to identify risks and develop an understanding of both the direct and indirect consequences in advance where possible.