Department for
Business, Energy
& Industrial Strategy

UK Severe Space Weather Preparedness Strategy

September 2021

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Ministerial Foreword

As the events of 2020 have reminded us, we live in an ever-changing world, and must be ready to respond to a range of risks. This Government understands that good management of risk is essential for contingency planning, increasing the likelihood that services we rely on will be available for citizens to use and ensuring that we can protect people's health and safety.

Space weather is an everyday phenomenon that, in the vast majority of cases, causes no significant effects on Earth. However, a severe space weather event is a risk that, as much as we may hope it will never occur, we must adequately prepare for. That is why this document sets out a five-year vision for enhancing our resilience to the risk of such an event and details the steps we will take to achieve this.

The UK is home to one of a small handful of global forecasting centres, the Met Office Space Weather Operations Centre (MOSWOC). It is the only such centre in Europe and is staffed 24/7/365 by space weather experts. Meanwhile, cutting edge research by British scientists and institutions continues to develop our understanding of this ever-advancing field. Thanks to their efforts, we increasingly learn more and more about how a severe space weather event could impact life in the UK and the services and infrastructure on which we all rely.

As our understanding of space weather matures, rapid technological changes continue to revolutionise almost every aspect of day-to-day life. This means that it is incumbent on Government, critical industries, and local responders to continually assess and improve their readiness and preparedness for such an event.

I am deeply grateful for the progress that has been made so far in ensuring our preparedness for a severe space weather event, following the Government's publication of the last Space Weather Strategy in 2015. This new strategy looks ahead over the next five years and sets out a roadmap for the steps we must take as a country to ensure that our readiness continues to match the latest understanding of the impacts of severe space weather.

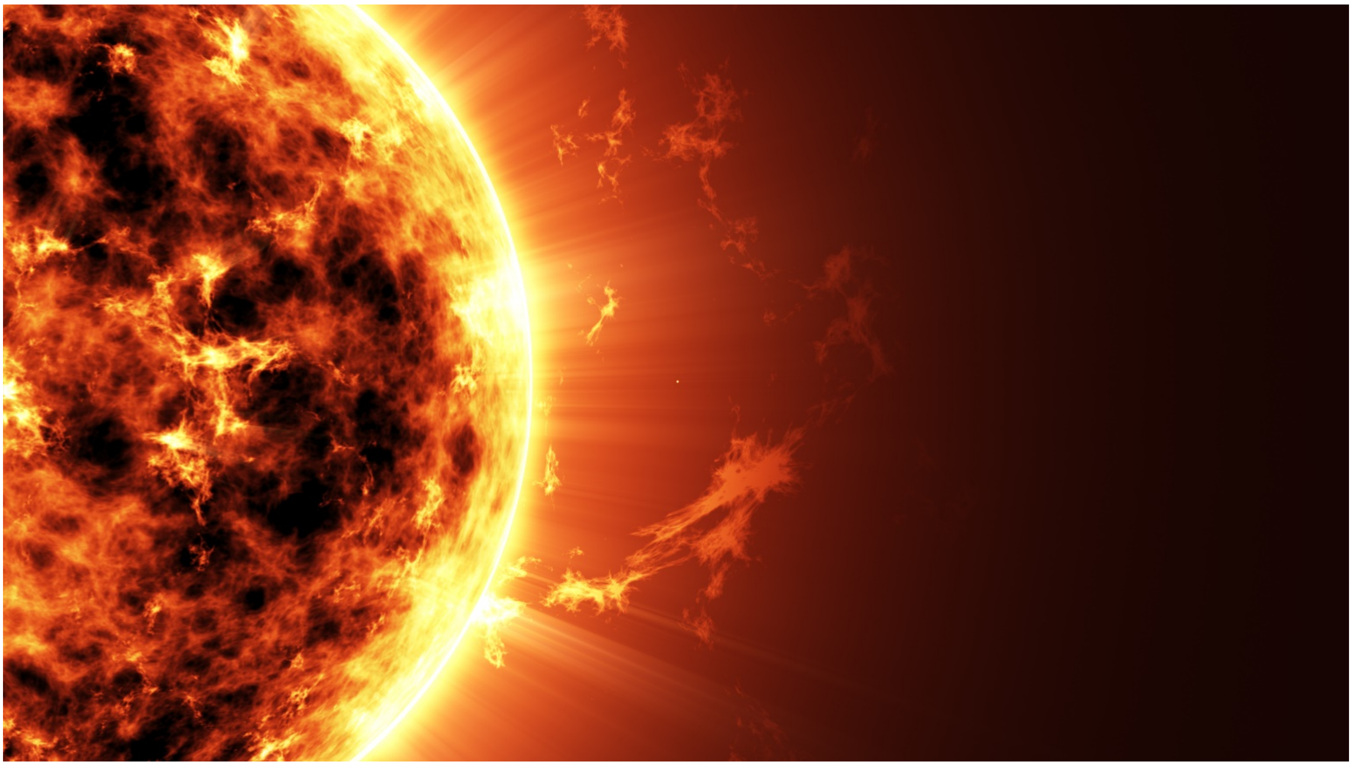
The scale of a severe space weather event, and the interconnectedness of the modern world means we must work closely with international partners to prepare for and respond to this risk. The UK's readiness to collaborate and work collectively to meet the challenges of severe space weather is at the heart of this strategy.

The actions that we will take because of this strategy will mean that the UK continues its leading role internationally, while also ensuring that – using a foundation of extraordinary scientific research and forecasting ability – we are sufficiently prepared for a severe space weather event.

The Rt Hon George Freeman MP

Minister for Science, Research and Innovation

Executive Summary



Space weather is a collective term used to describe variations in the Sun, solar wind, magnetosphere, ionosphere, and upper atmosphere that can influence the performance of a variety of technologies, and that can also endanger human health and safety.

Day-to-day space weather, much like terrestrial weather, most often occurs with no tangible disruptive impacts. This strategy is instead focused on the rare events that could have a significant impact to our infrastructure or vital services, and we will define as severe space weather.

This strategy directly supports the aims of the 2021 Integrated Review of Security, Defence, Development and Foreign Policy by seeking to build our resilience to the risk of severe space weather, whilst also making science and technology integral to addressing this risk.

Commitments

The commitments that this strategy makes are summarised into three "pillars":

The **Assess Pillar** focuses on enhancing our understanding of severe space weather, its impacts, and our ability to forecast events. It covers three key areas:

- Increasing our Observational Capability: This highlights the UK's continuing support for a European Space Agency mission to launch a new spacecraft (the "L5" mission). In conjunction with a US-launched spacecraft, this will significantly enhance our ability to forecast severe space weather events.

- Increasing our Forecasting Capability: This highlights the UK's existing £19.9m programme of investment into the pull-through of space weather research that will boost our ability to forecast space weather and its impacts.
- Understanding the Impacts: The strategy proposes undertaking targeted work to better understand the impact of space weather on areas including the safety of aircraft, human health, and Position, Navigation and Timing services (for example Global Navigation Satellite Systems).

The **Prepare Pillar** focuses on increasing the resilience of essential infrastructure and services. It builds on the outcomes of the Assess Pillar and focuses on minimising the impacts of a severe space weather event. It focuses on two key areas:

- Developing and Testing Response Plans: The strategy focuses on ensuring that Government Departments and industry have robust response plans for a severe space weather event.
- Developing Mitigation Options: The strategy envisages industry forums and task groups developing measures, which could include incorporating Met Office forecasts into their work or upgrading technological systems, to be more resilient to severe space weather, and conducting regular exercises.

The **Respond & Recover Pillar** focuses on ensuring the UK can respond to events effectively and recover from them quickly. The main commitment is:

- International Collaboration: The UK will deepen co-operation with international partners by establishing a real-time communication system that would allow mutual sharing of data during a severe space weather event.

Introduction

Space weather is a collective term used to describe a range of phenomena originating from the Sun that can impact on the technology we use on Earth and in the near-Earth environment[1]. Space weather occurs continuously, every day, much like terrestrial weather, and with no tangible disruptive effects. The most recognisable and visible effects of space weather are the Auroras (such as the Aurora Borealis, or “Northern Lights”).

However, space weather in its more severe form can cause significant disruption to everyday technologies such as Position, Navigation and Timing (PNT) systems (for example Global Navigation Satellite Systems (GNSS)), satellites, and radio communications, as well as our critical infrastructure such as transportation networks, and the electricity grid.

The UK Government regularly publishes a National Risk Register which assesses risks that can cause significant human, economic, environmental, and infrastructure damage. Severe space weather was added to this register in 2011 to reflect that whilst a severe event is unlikely to occur, there would be wide-ranging and significant impacts were it to happen. Severe space weather is also featured in the latest National Risk Register, published in 2020.[2]

[1] In this region, the magnetic fields and particles of the solar wind interact with the magnetism of Earth and its atmosphere, resulting in a variety of effects. These include the formation of the terrestrial magnetosphere (the magnetic 'bubble' around Earth), and links from this to the Earth's upper atmosphere, giving rise to ionospheric currents and the aurora.

[2] 2020 National Risk Register

This new Severe Space Weather Preparedness Strategy outlines our approach to managing the risk to the UK of a severe space weather event and looks to build on steps taken by Government, academia, industry, and international partners in recent years to increase our resilience to the risk. For the next five years, this document will be the basis for enhancing the UK’s resilience to a severe space weather event.

1.1 Roles and Responsibilities

The Department for Business, Energy and Industrial Strategy (BEIS) is the Lead Government Department for the risk of severe space weather. BEIS is therefore responsible for coordinating a Cross-Government work programme to ensure that appropriate preparedness and mitigation measures are in place so that impacts from severe space weather are minimised.

The UK Space Agency (UKSA) is an Executive Agency of BEIS and works with BEIS to deliver the UK’s civil space programme. In addition to this, the UKSA is also responsible for engaging with owners and operators of the UK’s space-based capability, to ensure their equipment is resilient and able to withstand a severe space weather event.

The UKSA also works to proactively to identify international partners and works collaboratively with these partners to develop the infrastructure needed to understand and monitor space weather.

BEIS, in collaboration with the Ministry of Defence and UKSA, has also developed a National Space Strategy that sets out the UK’s ambition for broader space policy going forward. This Severe Space Weather Preparedness Strategy supports the aims of the National Space Strategy, by ensuring that severe space weather is a risk that is appropriately managed, which enables the UK to pursue its wider ambitions for space.

The Met Office, also an Executive Agency of BEIS, provides world-leading space weather forecasting services alongside terrestrial weather services through the MOSWOC. It issues forecasts and warnings 24/7, to Government, emergency services, and critical infrastructure operators, as well as the public. The information and expertise it provides helps to build awareness of the risk that severe space weather poses to essential services, as well as increasing their resilience.

The Met Office has been delegated ownership of the severe space weather risk by BEIS, meaning that they are responsible for monitoring the risk and supporting national mitigation strategies.

1.1.1 Government, Academia, and Industry

We work with a range of stakeholders across Government, academia, and the private sector to manage the risk of severe space weather, including:

- **Lead Government Departments** (LGDs): Government Departments have day-to-day policy oversight of sectors that contain national infrastructure. These Departments play a key role in ensuring that industry partners have appropriately assessed the risk and have plans to mitigate the risk of severe space weather impacts to essential infrastructure and services.

- **Devolved Administrations**: Responsibilities for sectors can differ depending on whether they are reserved or devolved. However, the consequential management of risks, including severe space weather, is devolved to the three Devolved Administrations. That said, the UK Government and Devolved Administrations work closely together to minimise impacts and this document should serve as a strategy for all nations in the UK to boost our resilience to the risk.
- **Local Resilience Forums** (LRFs): These are multi-agency partnerships of emergency responders and supporting agencies, formed under the provisions of the Civil Contingencies Act 2004. Based on Police areas of the UK, they collaborate to plan and prepare for a response to emergencies and produce a community risk register. LRFs are not legal entities and do not have powers to direct their members but they ensure effective delivery of the duties of their individual members under the Act. These include undertaking a local assessment of risk, planning for emergencies, planning for business continuity management, publishing information about risk assessments and plans, and making arrangements to warn and inform the public.
- **The Academic Community**: The UK is home to world leading experts in academia who are crucial for deepening our understanding of space weather. Government works closely with the Space Environment Impacts Expert Group (SEIEG)[3], a group of academics from UK Universities and Research Councils, working alongside industry subject matter experts and Government department representatives, to ensure that our understanding of space weather impacts is continually updated as space weather science continues to evolve. Membership of SEIEG is available at **Annex A**.

  Research Councils, industry and laboratories, including the Science and Technologies Facilities Council (STFC), Natural Environment Research Council (NERC), Royal Academy of Engineering, and universities, play a key role in developing the UK's satellite observational capability that monitors solar activity, contributing to the development of space infrastructure, and enabling development and implementation of forecasting tools at the Met Office.

  The two Research Councils (STFC and NERC) also play a key role in supporting other academic community projects in space weather. In particular, they jointly run the £19.9m Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR) programme, which is supporting the development of space weather models, their transition into use at the Met Office, and the development of new instruments (both space-based and ground-based) to supply data for those models.

  The Royal Academy of Engineering can draw on the most senior and respected engineers in the country to provide national leadership. In 2013 it published a report entitled "Extreme space weather: impacts on engineered systems and infrastructure", to help guide national space weather policy.

[3] Membership of SEIEG is available at Annex B.

- **Industry:** Many of the essential services that we all rely on, on a day-to-day basis, are owned and operated by private companies, e.g. electricity, telecommunications, etc. Given the broad nature of space weather and the infrequency of severe events it is often a challenge to draw together a comprehensive view of the impacts. Though we have a good understanding of the primary impacts, there is limited understanding of secondary and tertiary impacts in sectors owing to the increasing degree of interconnectedness of our infrastructure and systems. This, combined with a differing level of prioritisation of the severe space weather risk against a backdrop of other threats and hazards that Government Departments and sectors plan for, has led to a mixed level of engagement and risk mitigation measures being implemented.

  To make this strategy a success, preparedness and resilience of critical infrastructure and services to a severe space weather event must be increased. This can only be achieved by working in partnership with the different sectors and industries.

  Going forward, we must further develop engagement with industry partners, proactively facilitating communications with academia and government so that the space weather risk is sufficiently understood and can be proportionately mitigated.

1.1.2 How we work together

Following a recommendation from the Royal Academy of Engineering[4], BEIS established a Cross-Government Severe Space Weather Steering Group (SSWSG) in 2015, dedicated to increasing the resilience of our critical infrastructure to the impacts of severe space weather. Lead Government Departments, academia, and industry experts come together in the group to drive forward work programmes to achieve this. The SSWSG, led by BEIS, will oversee the implementation of this strategy. Membership of the SSWSG is available at **Annex B**.

1.1.3 Working with international partners

Space weather is a global phenomenon, and its impacts span international boundaries. In many cases, mitigating these impacts will require a co-ordinated international effort. For example, air travel in and out of the UK relies on close collaboration between the systems and aviation authorities of many different countries. When a severe space weather event occurs, flight operations may be restricted or curtailed with large scale disruption to schedules arising as a result, and the safety of crew and passengers will need to be safeguarded. International co-ordination is essential, as there will likely be a need to share information quickly, in a standardised format, to enable mitigating actions to be implemented swiftly and safely.

The development of space-based infrastructure, such as satellites to support our understanding and forecasting of space weather, requires international collaboration. Additionally, the UK works with our international partners to forecast space weather and assess the risk from severe space weather events. Key partners include the European Space Agency (ESA), the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) in the United States.

[4] Extreme space weather - Royal Academy of Engineering

This strategy envisages the UK continuing to play a leading role globally in both furthering the understanding of space weather and preparing for the effects of severe space weather events.

1.3 The Three Pillars

Our Severe Space Weather Preparedness Strategy sets out a plan to enhance the UK's resilience to severe space weather events using three pillars. Each pillar sets out an area of focus for enhancing our resilience to severe space weather events and represents an important stage in the process of understanding, preparing, and responding to a space weather event. The three pillars are:

- ASSESS: Enhancing our understanding of severe space weather, its impacts, and our ability to forecast events.
- PREPARE: Increasing the resilience of essential infrastructure and services on which we rely.
- RESPOND & RECOVER: Ensuring we can respond to events effectively and recover from them quickly.[5]

The activities and outcomes set out under each pillar are interrelated and directly support one another. This strategy also refers to a number of policies that will be added to over time to support the pillars and drive forward Government's work to enhance resilience to this risk.

[5] Consequence management is devolved and so relevant response and recovery planning will be for Devolved Administrations to decide upon.

Space Weather Explained

Space weather is a collective term used to describe variations in the Sun, solar wind, magnetosphere, ionosphere, and upper atmosphere, that can influence the performance of a variety of technologies, and which can also endanger human health and safety.

Day-to-day space weather, much like terrestrial weather, most often occurs with no tangible disruptive impacts. This strategy is instead focused on the rare events that could have a significant impact to our infrastructure or vital services, which we will define as severe space weather. Examples of severe space weather include:

- Solar Flares are explosive releases of electromagnetic radiation from the Sun's atmosphere. The radiation from a solar flare reaches Earth in about 8 minutes and can cause radio blackouts of High Frequency (HF) communications used by aircraft on the sunlit hemisphere.
- Solar Radio Bursts also reach the Earth in about 8 minutes. These can be a threat to GNSS service performance in the hemisphere facing the sun.
- Solar Energetic Particles (SEPs) are emitted from the Sun in the form of electrons, protons and ions and arrive at the near-Earth environment in 12 – 15 minutes. SEPs can damage satellites, such as GNSS, communication satellites and earth monitoring satellites, as well being the driver of atmospheric radiation storms.

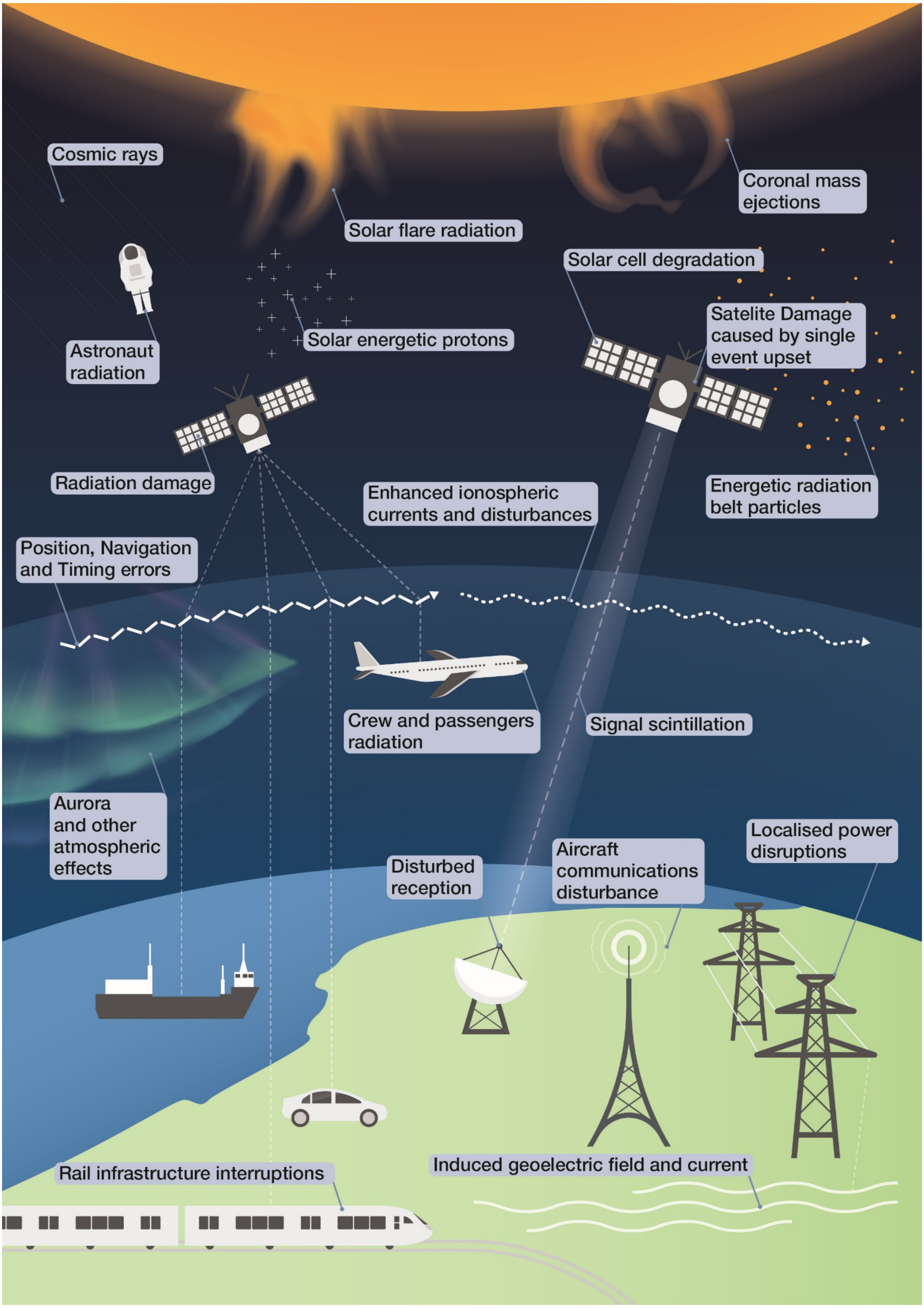
- Coronal Mass Ejections (CMEs) eject plasma from the Sun's corona, carrying with it a magnetic field. CMEs typically take about 1 – 4 days to reach Earth (with the fastest known transit time being just under 15 hours). On arrival at the Earth, they drive geomagnetic storms if their magnetic orientation is opposite to the geomagnetic field. These storms induce electric fields in the Earth that drive disruptive electric currents into ground-based conductors including the power network. Geomagnetic storms can also disturb the ionosphere disrupting the operation of HF communications, GNSS, and satellite communications.
- High-speed solar wind streams (HSS) are streams of plasma that flow out of regions of the Sun where its magnetic field connects out to interplanetary space. When a HSS passes over the Earth, it exposes many important satellites to a much harsher radiation environment and risks damage to them. Similar radiation risks can arise from CMEs but are usually of shorter duration.

2.1 Previous Space Weather Events

During periods of increased solar activity during the 11-year solar cycle (the cycle that the Sun's magnetic field undergoes approximately every 11 years), CMEs and solar flares are more common, with the Sun sometimes producing multiple events a day. However, a severe space weather event, while very rare, could occur at any point during the solar cycle.

Historic severe space weather events have caused widespread and significant impacts. The Carrington Storm of 1859, and another storm in May 1921, are understood to be the most severe space weather events in recent history and caused widespread disruption of telegraph and telephone communications - the aurora reached as far south as the Caribbean and southern California. However, since then smaller-scale events have occurred that have caused disruption to different sectors including:

- **Electricity Distribution**: A 1989 geomagnetic storm induced electric currents in transformers at the Hydro-Quebec power plant, melting transformer coils. Voltage instability subsequently caused a widespread power loss during the Canadian winter. In 2003, a geomagnetic storm impacted several power lines and transformers in Scandinavia and caused permanent damage to infrastructure in South Africa.
- **Telecommunications**: In 1972, there was major disruption of telephone lines in the US mid-West. In 2017, a geomagnetic storm affected radio frequency and satellite communication systems around the world.
- **Transport**: in 2003, air traffic was affected when a space weather storm impacted communication and navigation systems. In 2017, civil airliners were re-routed to avoid air space regions with an increased risk of radiation impacts.
- **Satellite Systems and Services**: A 2003 geomagnetic storm temporarily disrupted satellite services, and in one case permanently damaged space borne infrastructure. In 2017, a geomagnetic storm caused anomalies for a number of communications and Position, Navigation and Timing satellites, including over Europe.


Cosmic rays
Coronal mass ejections
Solar flare radiation
Solar cell degradation
Satelite Damage caused by single event upset
Astronaut radiation
Solar energetic protons
Radiation damage
Enhanced ionospheric currents and disturbances
Energetic radiation belt particles
Position, Navigation and Timing errors
Crew and passengers radiation
Signal scintillation
Aurora and other atmospheric effects
Disturbed reception
Aircraft communications disturbance
Localised power disruptions
Rail infrastructure interruptions
Induced geoelectric field and current

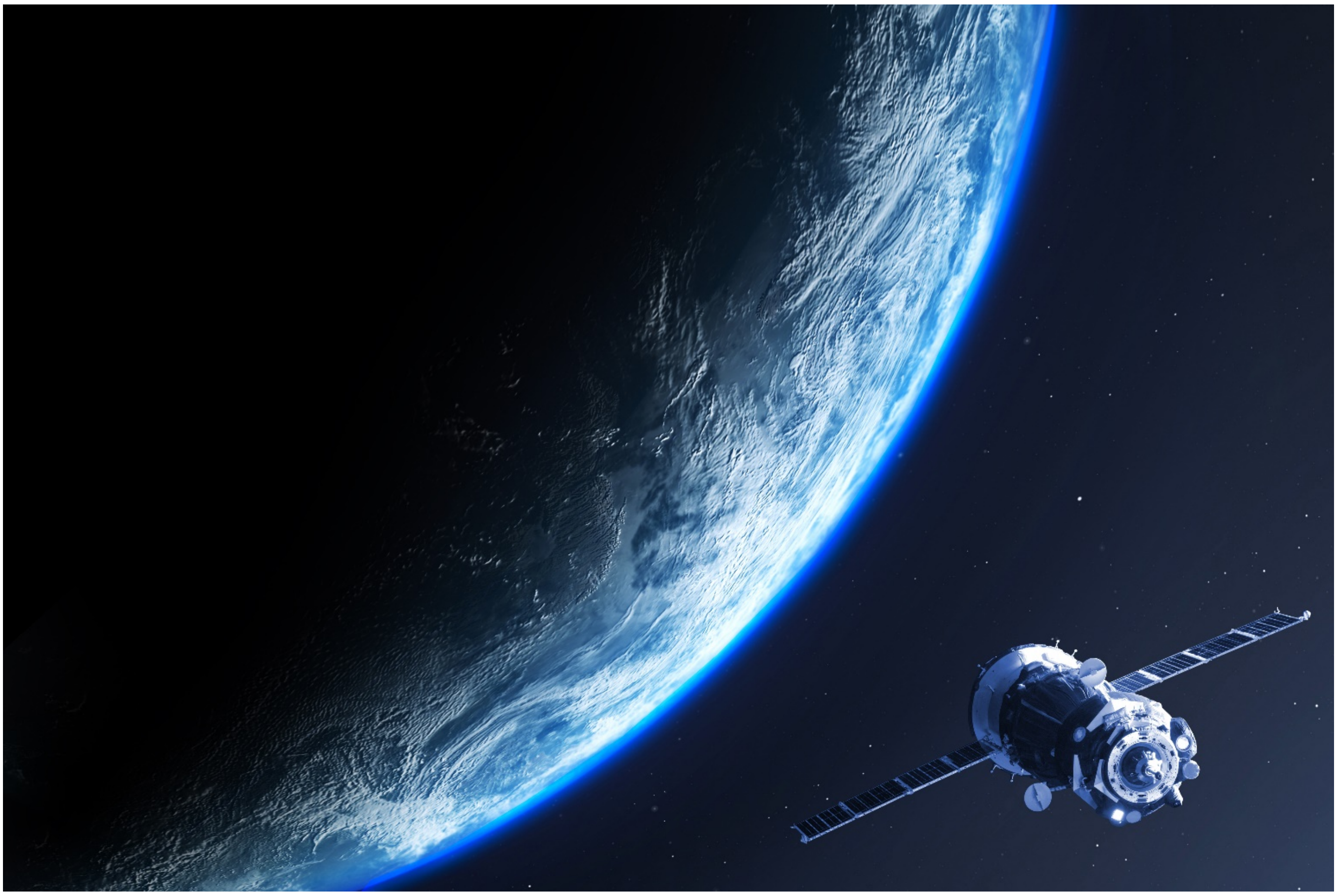
2.2 Taking Action Now

The UK is a world leader in space weather forecasting, and significant steps have been taken by Government to enhance our resilience to the risk of severe space weather. However, by setting out this five-year vision, we will be able to ensure that the UK's resilience continues to match the latest scientific understanding of space weather and its impacts, particularly as the technology that drives essential services becomes ever more sophisticated.

Acting now will mean that by 2026, the end of this strategy's lifespan, the UK's resilience to a severe space weather event will have been further increased. This will help support the UK's ambitions for space, ensuring that our ground and space-based infrastructure are resilient to the effects of severe space weather.

Pillar 1: ASSESS

Enhancing our understanding of severe space weather, its impacts, and our ability to forecast events.



3.1 Ambition

BEIS, in collaboration with the Ministry of Defence and the UKSA, has developed a National Space Strategy which sets out our national ambition for space and bring long term strategic and commercial benefits to our country. A key part of this ambition will be in ensuring that, just as we have a good understanding of terrestrial weather events and their impacts, we develop an improved level of understanding for severe space weather events.

No severe space weather events have impacted on Earth in recent times, with the largest event in recent history being in 1859 - long before many of the contemporary technologies that we rely on every day were invented. Continued technological advancement means that potential space weather impacts will change over time, and that we must always refresh our understanding of the risk so that we are well informed about what effects a severe event would have on Earth in the modern day. This understanding is vital for the resilience of our infrastructure in space, in the air, on the ground, and the services that rely on them.

We must therefore proactively assess and research how severe space weather could affect our interests. Accordingly, the ASSESS Pillar will focus on three key areas:

- Investing in space-based infrastructure such as satellites to help us better observe and monitor space weather.
- Improving our scientific understanding of space weather and associated forecasting services so we can better exploit the data that satellites provide us with.
- Developing our understanding of how severe space weather can affect people, our infrastructure, and day-to-day business operations.

The outputs from the ASSESS Pillar will also help us identify where we need to take action to minimise the impacts of a severe space weather event, so that Government, industry, and local responders can put the necessary mitigations and measures in place to prepare for an event. It will give us the knowledge and capability and understanding to better prepare – the focus of the second pillar.

3.2 Progress & Policies

This section sets out the progress that we have made to increase our level of understanding of space weather, and improve observational and forecasting capabilities, and the policies that will be followed over the next five years to build on what has already been accomplished.

3.2.1 Observational Capabilities

Observational capability, or our ability to monitor the Sun to detect severe space weather events, is crucial because it provides the Met Office Space Weather Operation Centre (MOSWOC) with the data needed to produce accurate and timely forecasts.

In 2019, the UK Government announced ambitions to work more closely with the United States National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) to further develop our space-based forecasting capabilities.

International collaboration is key because the UK currently has no operational space-based observational capability. By working with international partners, the UK can play a leading role in launching new satellites that will provide significant improvements to our operational forecasting services.

As such, the UK has committed to playing a leading role in the European Space Agency's (ESA) mission to launch a new spacecraft to the L5 Lagrange point. Meanwhile, a complementary follow-on mission by the United States to the L1 Lagrange point is also being developed to ensure that our ability to make operationally relevant, in-situ measurements of Earth-bound CMEs does not become degraded in years to come.

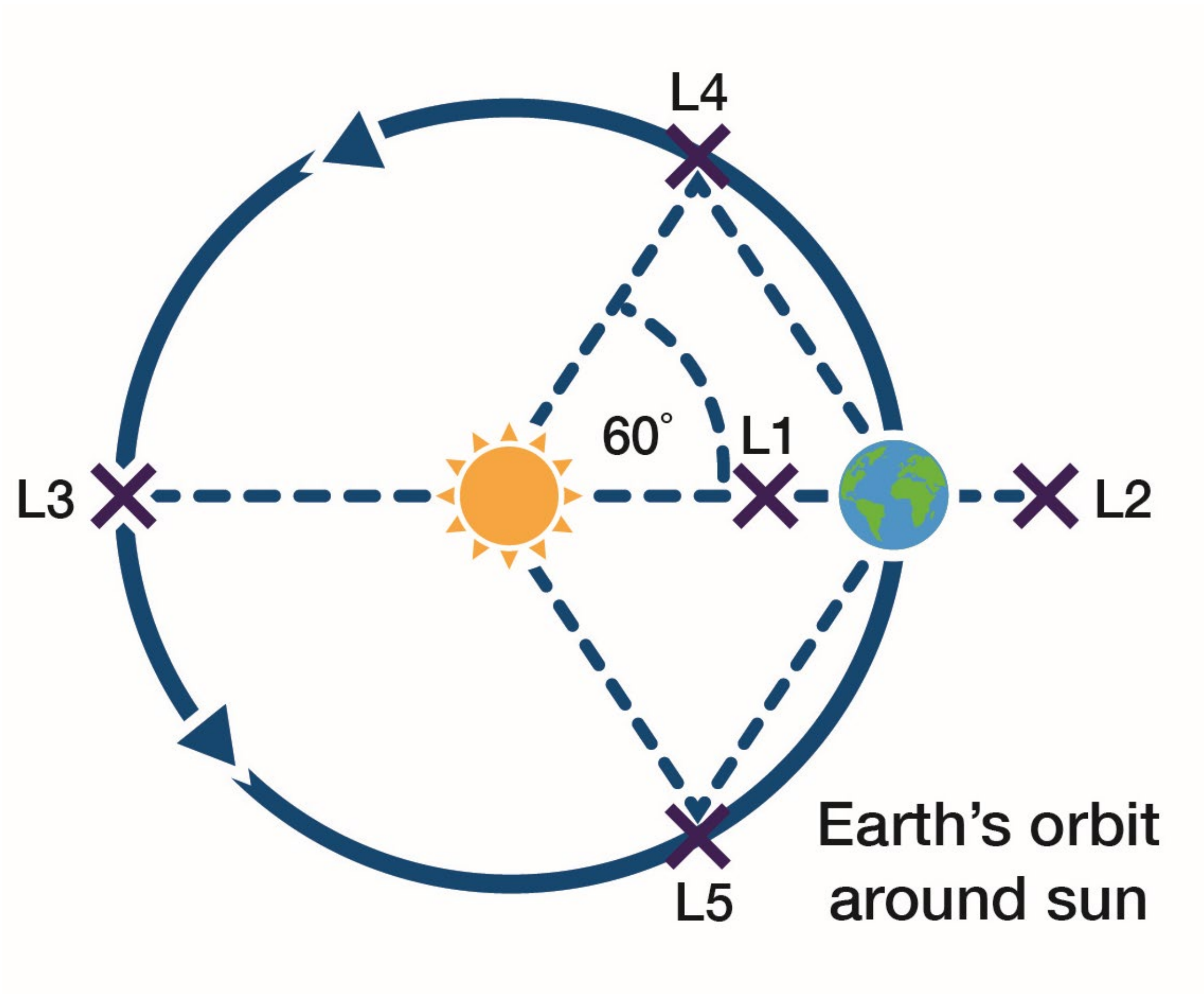
A satellite at L1 lets us look at space weather from a "face-on" view, and a satellite at L5 lets us look at space weather from a "side-on" view." Taken together, with both L1 and L5 we will be able to access early warning information of in-transit solar eruptive events, as well as viewing them in "3D" to get a more accurate picture of them. This "3D" view helps the Met Office to create a more accurate and confident forecast for space weather events, meaning we can better assess the risk from them, and deploy mitigation plans more accurately.

These observations will greatly contribute to our forecasting capabilities. In addition, the "sit and stare" nature of the mission, with continuous observations of the surface and atmosphere of the Sun, the inner heliosphere, and in the in-situ solar wind, will provide a long-term, continuous data set that will greatly enhance our understanding of space weather, facilitating science and leading to better forecast models.

Making a leading contribution to a spacecraft mission to deliver monitoring capability serves as a key opportunity for the UK to demonstrate competency, capability, and reliability through international collaboration in providing operational space-based infrastructure.

Case Study: L5

L5 refers to the 5th Lagrange point of the Sun-Earth gravitational system. A Lagrange point is a point in space where the gravitational pull of two large objects creates a point of equilibrium. This means that any spacecraft that is positioned at a Lagrange point would stay permanently in the same place, relative to the Earth and Sun, so space weather can always be observed from the same relative position.



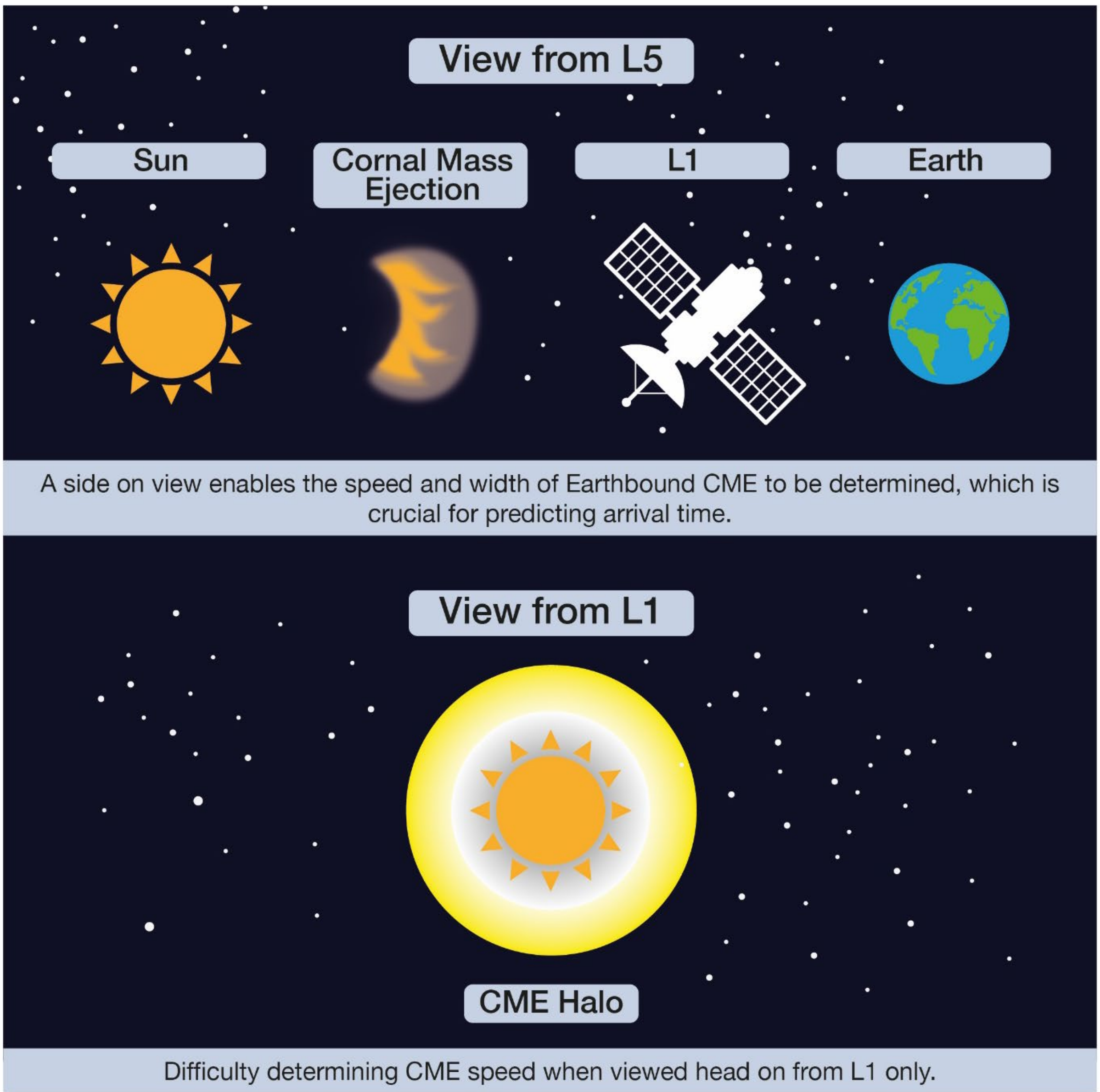
Coronal Mass Ejections (known as CMEs) are large ejections of magnetic field and plasma from the atmosphere of the sun and can reach the Earth in about 15 – 96 hours, depending on their speed and direction. Given the right conditions, a geomagnetic storm associated with CME arrival at Earth could cause disruption across a range of services, including the electricity network, and global satellite and navigation networks.

Given the broad range of potential impacts, accurately forecasting CME arrival time is crucial for reducing the impact to infrastructure on Earth. However, determining the direction, speed, and width of CMEs is challenging with the satellite imagery we currently have available to us.

A spacecraft at L5 would provide a unique perspective on the Sun-Earth system, and an "early warning" viewpoint of what we can expect to be directed towards the Earth.

Observational capability delivered through a satellite at the L5 position would allow a better calculation of these factors and greatly increase the precision of CME arrival forecasts.

Observations of the Sun, together with in-situ measurements of the solar wind and interplanetary magnetic field made at L5, will enable early monitoring and assessment of the sources of solar eruptions (active regions) and be indicative of the solar wind conditions that will be experienced at Earth within a few days. Solar winds are important in assessing the potential for CMEs to result in geomagnetic storms on Earth and for forecasting energetic solar particles impacts that can damage satellites and electronics and deliver radiation doses to people.



An L1/L5 combination enables accurate speed, width, direction, and in-situ measurements (e.g. magnetic field orientation) of an Earth-bound CME to be determined

3.2.2 Forecasting Capabilities

In the same way as forecasting terrestrial weather allows us to prepare for events like storms and flooding, forecasting potential severe space weather is crucial. Forecasting allows essential services to receive advanced warning of events so that they can prepare and take the necessary action.

The UK is a world leader in space weather forecasting and is home to one of only three space weather prediction centres globally that are staffed with space weather experts. MOSWOC provides space weather predictions on a 24/7 basis, and produces a range of daily reports, forecasts, warnings, and alerts of space weather over the following few days to Government, the responder communities, owners and operators of critical infrastructure, and the public.

By using observational capabilities like satellites to monitor the Sun, the probability of space weather events can be forecast. This can very often provide advance warning of large events a day or more in advance. It is important to note, however, that the elapsed time from observing a large CME lifting off the Sun to realising impacts on Earth can be as little as 15 hours. Further to this, certainty over the magnitude of the most severe CME events can only be determined with around 10 – 20 minutes notice, as the CME passes over the spacecraft in the L1 position. The information that MOSWOC provides is therefore crucial for helping to prepare for potential severe space weather events, giving us as much time as possible to take mitigating action.

The 2015 Space Weather Preparedness Strategy highlighted the importance of academic research into severe space weather. Though MOSWOC grants us a world-leading space weather prediction service, continual improvement of its ability to forecast space weather will ensure that its services match the latest scientific understanding of space weather and its consequences. It is vital that we maintain and improve this key national asset.

In 2019, the Government announced a major programme of investment of £19.9m to pull-through space weather research into operations and upgrade MOSWOC. This key research project, known as the Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR) programme, is being managed through UK Research and Innovation and is being delivered by the Science and Technology Facilities Council (STFC) and the Natural Environment Research Council (NERC). Its output will boost the UK's modelling capabilities for predicting space weather effects and transition these models for operation at MOSWOC. The SWIMMR programme will enhance our ability to deliver warnings, forecasts, and advice pertinent to various critical concerns such as:

- Radiation effects on satellites, spaceflight, and aircraft.
- Space weather impacts on communication and global positioning systems.
- Risks to ground-based infrastructure such as energy infrastructure.

In addition to furthering our understanding of space weather and its impacts, the outputs of SWIMMR will be directly aligned to enhance MOSWOC's forecasting capabilities by improving the ability of the Met Office to predict space weather events, and therefore reduce their potential impacts on the UK. However, while the SWIMMR programme will boost our capability significantly, space weather remains an evolving field with much scope for further research after the programme's conclusion.

3.2.3 Understanding of impacts

Our understanding of space weather has continued to develop.

The 2015 Space Weather Preparedness Strategy identified Global Navigation Satellite Systems (GNSS) as a priority area for research. In 2018, the Government published the Blackett Review that further identified the threat that space weather could pose to space-based infrastructure – in particular to satellites that provide Position, Navigation and Timing services – and the implications this would have for the UK's critical services and infrastructure that are dependent on them. Government is now taking action on the recommendations that this Review made through an Implementation Group.

In July 2020, the STFC published the 2nd revised edition "Summary of Space Weather Worst-Case Environments", which was prepared by the expert SEIEG group. This gives a detailed overview of sector-specific impacts of space weather events and is used to underpin the assessment of the space weather risk in the National Risk Register.

Expert and academic communities have made great progress in modelling the likely impacts from space weather. However, there are specific areas highlighted in the STFC report that require further work to fully assess the potential impacts of a severe space weather event. These areas include:

- Transport, including rail, maritime, and aviation.
- Telecommunications.
- Global Navigation Satellite Systems.

Government will continue to work with the academic community and industry partners to address gaps in our understanding and put in place the measures that are needed to reduce, mitigate, and manage these impacts. It is also vital that we continually review our impact analysis of the effects of a severe space weather event to ensure our understanding reflects scientific and engineering advances.

3.3 The Government's Commitments on Assessing the Risk from Severe Space Weather

Significant progress has been made to improve our capabilities in this area, but more action is needed over the next five years to ensure our resilience. To improve our readiness, the Government will commit to a series of actions that will be undertaken during the five-year life of this strategy.

The commitments identified under the ASSESS pillar are:

- By 2023, BEIS will lead a programme of work with Government Departments, academic and industry partners to identify the primary impacts of a space weather event, based on the latest understanding of impacts. Government Departments will, where needed, work with international partners to achieve this. As part of this:
    - To ensure we understand impacts on energy infrastructure, BEIS will work with the electricity sector to refresh its understanding of the impacts of a severe space weather on electricity infrastructure, as well as supply. The scope of the impact analysis will be extended to include new technologies such as interconnectors and wind farms.
    - To ensure we understand impacts on aviation, the aviation industry, with support from academic partners, will continue to develop a better understanding of the impact of radiation effects on technologies critical to the industry, including onboard electronic devices.
    - To ensure we understand impacts on transport networks, Government will work with academic and industry partners to further understand the impacts on the safety and operability of the GB rail and road networks as well as the maritime sector.
    - To ensure we understand impacts on telecommunications, the telecoms sector will seek to build on existing work to understand the impacts of space weather on telecommunication networks, including consideration of any specific impacts on 5G.

    - To ensure we understand dependencies on space capabilities, the UKSA and Government Departments will assess the dependencies of ground-based services on space capabilities such as GNSS and understand how disruption to these services will impact other sectors, such as finance, health, food, water, and emergency services.
    - To ensure we understand health impacts of space weather, Government will assess the impacts of radiation exposure on people on the ground, in the air and in space during a severe space weather event.

- By 2024, the series of targeted research and development activities currently being delivered through the SWIMMR programme will be completed, leading to enhancements in MOSWOC's ability to forecast space weather. Beyond 2024, Government and the academic community will develop a potential pipeline for further research activity.
- The UKSA will continue to take a leading role in the ESA "L5" mission to the Lagrange 5 point.
- Government will drive greater public awareness of space weather, through support of public dialogue studies and the use of social media to promote space weather. This commitment is ongoing and will continue to be delivered by the Met Office.

Pillar 2: PREPARE

Increasing the resilience of essential infrastructure and services on which we rely.

4.1 Ambition

The key ambition of the PREPARE Pillar is to increase our preparedness for a severe space weather event. This will build on the work done through the ASSESS Pillar, as we continue to develop our understanding of the impacts of space weather on critical infrastructure and services.

This ambition can only be achieved through close, collaborative working between Government, industry, and Local Resilience Forums (LRFs). Our ambition is for critical industries to take appropriate steps so that in the event of a severe space weather occurrence, the impacts to our day-to-day services are limited and can be managed with minimal disruption.

The PREPARE Pillar will focus on the following areas:

- Developing proportionate measures that will further increase the resilience of critical infrastructure and services to a severe space weather event. This will build on the good work that has already been undertaken by industry.

- Effectively utilising the existing governance structures that have been put in place across Government to co-ordinate our approach to risk-preparedness.
- Ensuring that robust response plans for a severe space weather event are in place across Government and industry, and that LRF contingency plans can withstand severe space weather impacts.
- Working closely with international partners, through holding joint exercises, and mutual sharing of data on the impacts of severe space weather.

The PREPARE Pillar will ensure we have measures in place to reduce the impacts of a severe space weather event. In parallel, Government and industry will be developing plans to RESPOND to and RECOVER from an event, which is the focus of the third pillar.

4.2 Progress & Policies

This section sets out the progress that Government, industry, and local responders have made to increase resilience to the risk, and how we will collaborate to enhance mitigations and response plans to further build this resilience. It also details how we will approach management of the risk across Government, as well as our intention to work closely with international partners to prepare for a severe space weather event.

4.2.1 Engagement with Industry

Government works with the operators of essential infrastructure to ensure resilience to risks. Since Severe Space Weather was identified as a risk in 2011 in the National Risk Register, Government has been working with critical infrastructure and services to increase their preparedness for a severe space weather event.

The electricity sector is one example of an industry that has made significant progress in this area, developing, and installing new infrastructure that is less susceptible to the effects of severe space weather. National Grid have embedded, tailored services provided by MOSWOC to inform effective mitigation processes and resilience planning.

Case Study: National Grid & Severe Space Weather

Great Britain has one of the most resilient electricity networks in the world. In 2013, the Royal Academy of Engineering produced a landmark report that examined the impacts on engineered systems and infrastructure from severe space weather. Impacts were detailed in the report and can be summarised as localised power disruptions, which in some rural and coastal areas could last several weeks or months.

As part of this, the National Grid Electricity System Operator, which is responsible for operating Great Britain’s national electricity transmission network, worked with subject matter experts following the publication of this report to further develop their understanding of risks to the power grid. However, the electricity industry has put in place measures and mitigations to ensure impacts are limited.

Potential impacts include:

- Around 13 transformers in Great Britain could be damaged and taken out of service. The time to repair would be between weeks and months.

- Local electricity interruptions of a few hours.

- Coastal and rural places would be more at risk of disruption because there is less transformer redundancy.

The Government, working in partnership with the National Grid Electricity System Operator and other energy infrastructure providers, has taken significant steps to use this understanding to increase the preparedness of our electricity system for a severe space weather event. In particular, National Grid has been able to carry out a series of improvements to make our electricity system more resilient to space weather.

The actions that the electricity sector has been able to undertake include:

- Developing a real-time monitoring and warning system, which provides detailed forecasts of whether the electricity network will be affected and, if so, which parts. Existing plans are in place between the Met Office and National Grid to warn them of significant events.

- Increasing the number of transformer spares to help minimise timescales to replace damaged equipment.

- Gradually replacing high voltage transformers with new designs that are more resilient and resistant to extra currents.

- Undertaking emergency exercises aimed at improving knowledge, resilience, and response capability.

If MOSWOC was to forecast any possible impacts on the electricity transmission system from severe space weather, National Grid Electricity System Operator could take similar action as it would if regular severe weather were forecast. These include:

- Scheduling extra back-up generation to reinforce the system and help deal with voltage fluctuations.

- Bringing all transformers into service to share the load of the induced currents.

- Halting maintenance work to increase the connectivity of the network and to help disperse the induced currents.

Reaching this level of understanding and preparedness has only been possible through close working between BEIS, the industry, and MOSWOC.

National Grid, and the broader energy sector, are a prime example of what can be achieved through collaboration between industry, government, and academia. We want this progress to be emulated across all our critical sectors.

4.2.2 Governance Structures

The Government's role is to ensure that all sectors are preparing adequately for a severe space weather event. The UK Government already has the governance structures in place to achieve this. BEIS works closely with the Cabinet Office Civil Contingencies Secretariat (CCS) on preparedness, resilience, and emergency planning for risks including severe space weather and existing response structures such as the robust cross government COBR response can be stood up should a severe space weather event occur, to provide a unified response across Government.

This strategy envisages that the structures we have established continue to be used, to ensure that the necessary progress is made to address this risk.

National Security Council

The National Security Council is the senior decision-making body for the Government on national security issues, chaired by the Prime Minister.

When Severe Space Weather was added to the National Risk Register in 2011, Government Departments were required to report to the National Security Council on the steps being taken to increase the resilience of their critical sectors to a severe space weather event. This ensures that the risk of such an occurrence is visible and is being adequately managed and addressed.

Severe Space Weather Steering Group

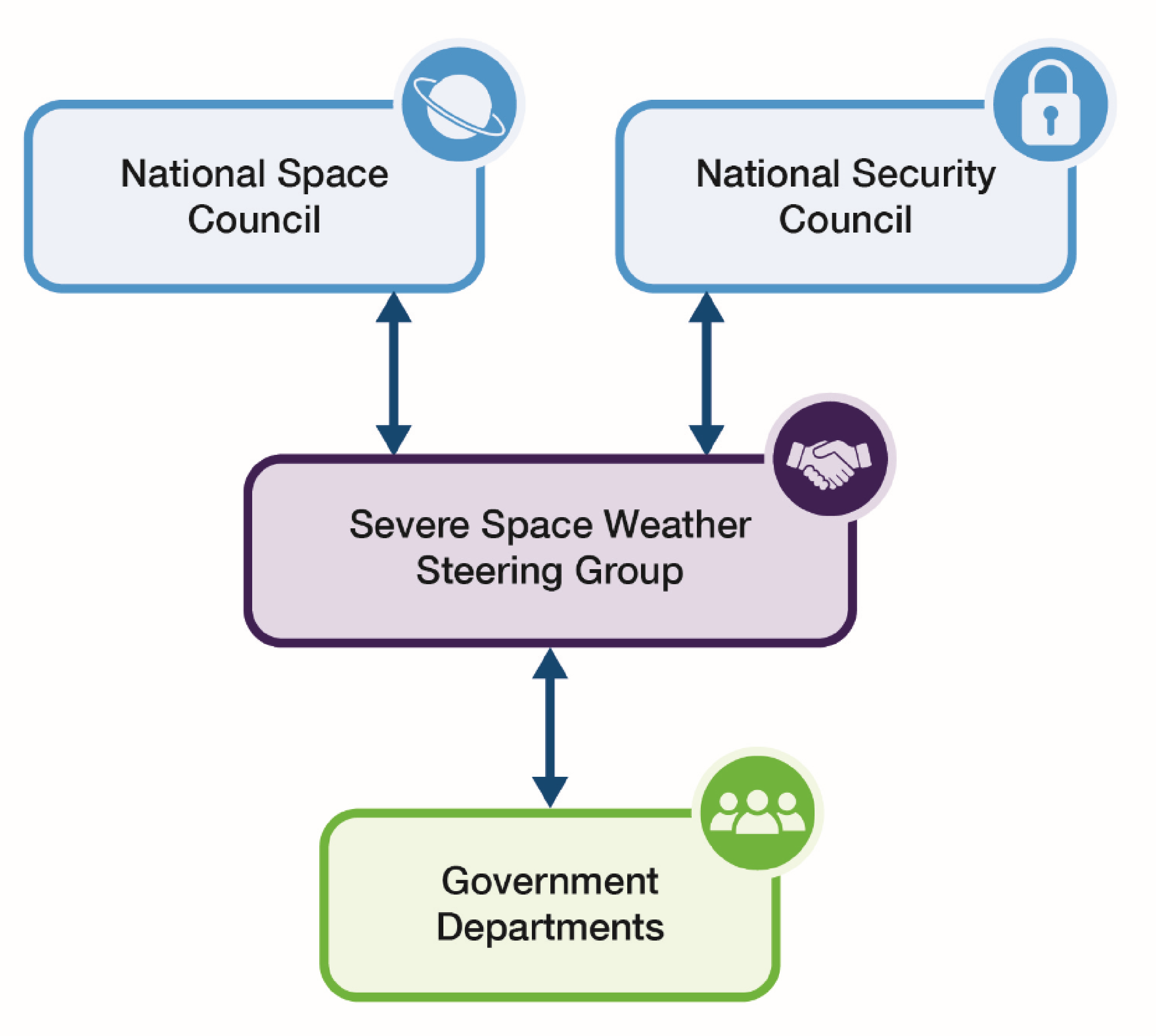
Establishing a group to drive forward risk preparedness for a severe space weather event was a key commitment of the 2015 Space Weather Preparedness Strategy. In line with this priority, this group was founded for Government Departments and expert academic advisors to co-ordinate and drive forward work on severe space weather resilience. The Steering Group will be responsible for overseeing the implementation of this strategy and will monitor progress on actions across all three pillars.

The Steering Group will also ensure that the implementation of this strategy directly supports the aims of the 2021 Integrated Review of Security, Defence, Development and Foreign Policy.

The Steering Group has also engaged internationally, representing the UK at international space weather conferences, including the European and US Space Weather Weeks.

National Space Council

The National Space Council is a new Cabinet sub-Committee that has been established to reflect the increasing criticality of, and reliance on, space capabilities and the wide range of government interests and investments in this area. The Council aims to take a new more holistic national stance on strategic space issues and coordinate the investment and requirements across Government.



4.2.3 Establishing Response Plans

Response plans are a set of processes that Government, local responders or industry will follow in the event of an incident such as a severe space weather event. They detail the steps that will be taken during an incident to ensure a rapid and effective response.

Local Resilience Forums have well-developed response plans to many of the impacts of severe space weather, a priority set out by the 2015 Space Weather Preparedness Strategy.

Across different essential services, such as electricity and satellite communications, response plans have been put in place by different industry sectors to address the risk from severe space weather.

Building on the work that has already taken place to improve resilience, under this pillar, Government will develop response plans to support their industry partners to manage and monitor disruption to essential services and capabilities. These plans will cover areas such as:

- The formal notification processes to local responders.
- Defined distinctions between the roles HMG Departments play.
- How Government will support industry sectors.
- How industry will respond to a severe space weather event, and what action they need to take.
- How we will work with international partners to ensure that cross-border issues are addressed effectively in response plans.

These plans should be exercised and regularly updated. This will build on Government Departments' ongoing programme of work to enhance resilience of critical infrastructure of services.

Case Study: Ministry of Defence, Airbus Defence and Space, and Skynet 5

Enhancing resilience to a severe space weather event is a key focus for the operation of satellites, including the UK Military satellite communication provision, known as "SKYNET 5".

Over recent years, Airbus Defence and Space, working with UK STRATCOM Defence Digital, Dstl, and MOSWOC, have established, tested, and implemented robust procedures which set out the immediate actions that should be taken to minimise disruption to SKYNET services in a severe space weather event.

The Severe Space Weather Procedure was iteratively developed following initial engineering-level appraisal of the potential impact of severe space weather to SKYNET 5 Spacecraft, Ground Systems, and services.

Table-Top exercises bringing together Spacecraft Controllers, System Engineers, UK STRATCOM Defence Digital, the UK Space Operations Centre, industry, and MOSWOC supported the development of an Extreme Space Weather Procedure. This also helped to determine the nature of usable space weather forecast information and the level of general understanding and training in space weather effects that needed to be established.

Since 2014, real-time exercises have taken place which have involved the Ministry of Defence as well as the US Department of Defence. In co-operation, Airbus Defence and Space, and MOSWOC developed a specific forecast product for SKYNET 5, known as the "HOLI Alert system". HOLI Alerts allow the rapid activation of contingency planning to deal with forecast space weather conditions with minimal interpretive delay.

These exercises were crucial in refining the SKYNET 5 severe space weather procedures and in training staff. The value of the SKYNET 5 severe space weather procedure was demonstrated in September 2017, where a complicated operational situation was effectively supported during a challenging Space Weather event.

The effectiveness of SKYNET 5 Extreme Space Weather Procedure relies on three principal components:

1. A maintained and retained-by-exercise understanding of the potential impact of Extreme Space Weather.

2. Specific-to-SKYNET 5 notification products – the HOLI Alerts – produced by MOSWOC.

3. Effective control of the response to the evolving Space Weather situation by the SKYNET 5 Spacecraft Management Authority (SMA), following the implementation of established operational procedure.

Whilst the SKYNET 5 Extreme Space Weather procedure is of proven effectiveness, it is important to note that development of a severe space weather response relies upon a tailored understanding of the effects to the specific systems. However, steps such as undertaking the initial appraisal of the risk, table-top exercises, and then live exercise stages in developing a response are applicable to many different sectors.

4.2.4 International Response Co-ordination

Central to this new strategy is recognition of the fact that space weather is a global phenomenon. A severe space weather event will not just affect the UK, or any one country, but likely a significant proportion of an entire hemisphere. Successfully responding to a severe space weather event will require international co-operation to ensure that cross-border services can recover.

The 2015 Space Weather Preparedness Strategy identified international engagement as a necessary step to boost resilience. Government Departments and the Met Office have therefore continued to engage with international partners and organisations such as NATO, mutually enhancing our preparedness for this risk.

The US National Space Weather Strategy and Action Plan shares this vision, setting out a recognised interest to exercise space weather internationally. This strategy supports that vision. UK Government Departments and industry response plans will, where relevant, reflect how crucial international co-operation is to the response and recovery process.

Response plan exercising will prioritise the involvement of international partners to fully simulate a real severe space weather event.

4.3 The Government's Commitments on Preparing for the Risk of Severe Space Weather

Our preparedness for a severe space weather event has significantly improved since the publication of the 2015 strategy, but this chapter has identified key areas in which we must make further progress over the next five years. In order to achieve this, the Government will commit to a series of actions that will be undertaken during the five-year life of this strategy.

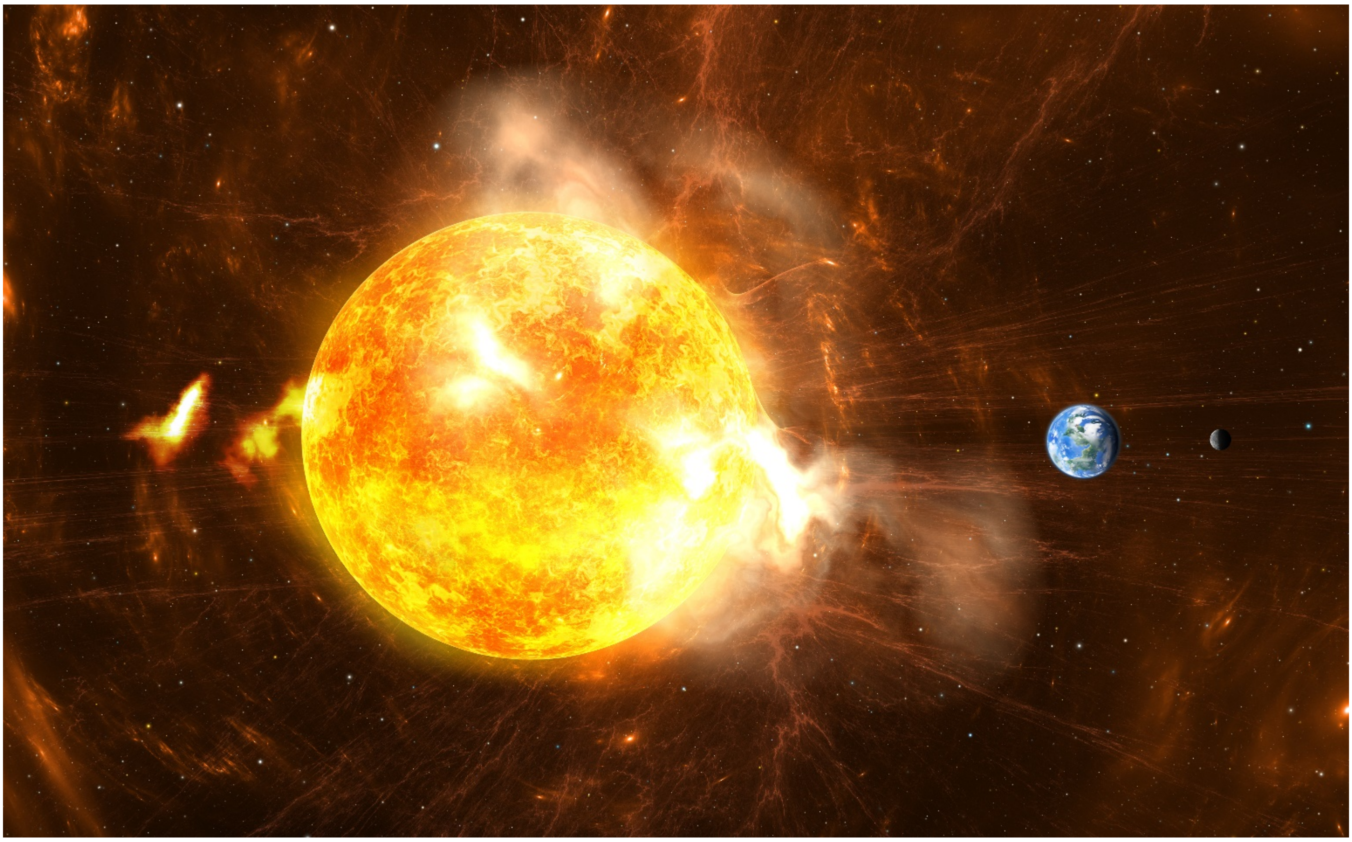
The commitments identified under the PREPARE Pillar are:

- Government Departments will continue to work with national infrastructure owners to identify and develop further measures to enhance and further develop response plans to minimise the impacts of a severe space weather event to essential services.
- Industry-led task groups should develop proportionate measures that will further increase the resilience of critical infrastructure and services to a severe space weather event. Where possible these groups should report on progress publicly.
- These measures, which must be developed by 2026, will match the latest understanding of space weather and include:
    - Having assessed the dependencies of ground-based services on space capabilities such as Position, Navigation and Timing systems and satellite communications, the UK Space Agency will consider whether further mitigations or actions need to be taken to enhance resilience.
    - Government and the downstream electricity sector will consider whether further mitigations are required.
    - The aviation sector will, with the support of the Government, assess space weather risks and ensure that proportionate mitigations and measures to minimise the impact of severe space weather events are in place. These should reflect the recommendations in the Civil Aviation Authority Publication “Impacts of space weather on aviation” (CAP1428, Issue 2, October 2020).
    - Road, rail, and maritime sectors will consider proportionate measures that may help to ensure that national transport systems can withstand a severe space weather event.
    - Government Departments will work with industry stakeholders to embed the enhanced MOSWOC forecasting, and warning services developed through the SWIMMR programme, into their business-as-usual activity. This will increase the UK’s preparedness and resilience to a severe space weather event.
    - Government Departments, industry and Local Resilience Forums will ensure their response plans are clearly linked to space weather and match the latest understanding of the impacts of severe space weather.
    - Government Departments will lead or participate in sector, cross-sector, and international exercises at least once every 2 years to test their response plans and procedures. Plans will be reviewed and updated to incorporate any feedback or lessons learned to improve preparedness and resilience.
- Government Departments and the Met Office will examine opportunities for enhancing real-time international response collaboration during a severe space weather event. The Met Office will also examine opportunities for real-time sharing of forecasting with international partners.

- The Severe Space Weather Steering Group will continue to co-ordinate ongoing work to increase resilience. The SSWSG will ensure that discussions at the National Space Council and National Security Council are developed and informed by the work being driven forward by this strategy.

Pillar 3: RESPOND & RECOVER

Ensuring the UK can respond to events effectively and recover from them quickly.



5.1 Ambition

While severe space weather events which cause disruption on Earth are rare, they can and do happen. It is the responsibility of Government and the operators of critical infrastructure and services to ensure that when such an event occurs, we can respond to events effectively and recover from them quickly.

Government understands the need for quick and effective responses to events such as severe space weather. Government works on a continual basis to improve our resilience and improve response procedures. The ambition for the final pillar, RESPONSE & RECOVER, is that we build on the ongoing work that has been done across sectors, and the outputs of the first two pillars, and formalise our approach to responding to and recovering from a severe space weather event.

This will rely on rapid implementations of the response plans and preparation work that has been undertaken as part of the second pillar. It therefore focuses on two key areas:

- Effective response to, and recovery from, a severe space weather event.
- Streamlining the sharing of space weather data with international partners.

Doing so requires understanding and preparation – which are both the focus of the first two pillars of this strategy. The work that has taken place under the first two pillars culminate to enable this final pillar.

5.2 Progress & Policies

The UK has not had to respond to a severe space event in modern times, but nonetheless we have made significant progress in responding to the risk. Government has extensive experience in responding to risks, and industry have analysed the risk and made significant preparation for it. We know that key to a successful response and recovery is:

- The effective dissemination of accurate information to industry and the public.
- The rapid establishment of response structures to co-ordinate recovery efforts.
- Rapid and clear international communication.

Currently space weather data is often captured and stored in different formats, meaning that there can be barriers to sharing information. Given the potentially rapid nature of a severe space weather event, there is a need for instantaneous communication to manage cross-border impacts successfully.

This pillar therefore envisages that the UK and international partners will establish a real-time information sharing system that will enable all partners to share data quickly, in a standardised format that can be easily accessed and utilised by all.

5.3 The Government's Commitments on Responding & Recovering from the Risk of Severe Space Weather

This third and final pillar therefore includes the following commitments:

- Government Departments and the Met Office will explore opportunities for international standardisation of space weather data with bilateral partners to mutually enhance forecasting capabilities and data sharing during an event. This is a priority shared by international partners including the United States of America, Finland, and the Netherlands. This work should reduce barriers to sharing information and establish common formats for recording data, so that data can be quickly used when shared internationally.
- Government Departments and the Met Office will explore opportunities for installing a new instant communication service that connects international space weather forecasting centres in real-time. This service will allow the UK and our international partners to respond quickly to a severe space weather event. The service can also be used outside of response situations to foster mutual understanding and common procedures.

- The Met Office will develop a cross government space weather communication strategy, which identifies public communications lines to be disseminated in a severe space weather event by 2022.

Annex A: Membership of the Space Environment Impacts Expert Group

Bath University

British Antarctic Survey

British Geological Survey

Civil Aviation Authority

CSDRadConsultancy

Defence Science and Technology Laboratory

Essex University

Imperial College

Lancaster University

Met Office

National Grid Electricity System Operator

Public Health England

RAL Space

SolarMetrics

Spire Global UK Limited

Surrey University

UK Space Agency

University of Birmingham

The group is also attended by BEIS and GO-SCIENCE.

Annex B: Membership of the Severe Space Weather Steering Group

Academic Advisors

Department for Business, Energy and Industrial Strategy

Department for Digital, Culture, Media & Sport

Department for Environment, Food and Rural Affairs

Department for Transport

HM Treasury

Ministry of Defence

Ministry of Housing, Communities & Local Government

Public Health England

Science and Technology Facilities Council

The Cabinet Office

The Civil Aviation Authority

The Government Office for Science

The Met Office

The Northern Ireland Executive

The Scottish Government

The UK Space Agency

The Welsh Government

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