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# Introduction

Space weather has a variety of impacts on technology, both in space and on the ground. In space, the impacts include health risks to astronauts due to radiation exposure and physical risks to satellites and their electrical components due to energetic electrons and solar protons. Space weather has wide ranging impacts on Earth, for example due to the effects of geomagnetic storms on the electrical power grid and the use of space-based services such as satellite communications and global navigation satellite systems (GNSS), and the increase in radiation exposure to passengers and crew on international flights over the polar regions. Because of the interdependencies between infrastructure sectors, impacts on one sector can cause significant impacts on other sectors.

# Project Objectives

The primary objectives of this study were to: assess and quantify the socioeconomic impact of various space weather threats; evaluate the economic cost of space weather as reliance on technology increases; review current efforts to detect, warn and mitigate space weather events on Canada's infrastructure; and facilitate an exchange of information on the study findings with key stakeholders (Canadian government, industry and academia). To support longer term planning, the study will be used as a basis for developing the business case for a space weather strategy and/or program. This strategy will help to: (a) ensure that all reasonable means are in place to deal with security issues; and (b) ensure that the investment made is commensurate with the importance of the subject.

# Approach

The study relied upon a literature review, key informant interviews, telephone surveys and a stakeholder consultation workshop as the primary research methods. A three-phase approach to the analysis of the socioeconomic impacts of space weather disturbances included: development of a set of socioeconomic impact indicators; assessment of the economic impact of space weather for three scenarios representing different levels of space weather activity; and identification of mitigation strategies or needs for a higher resilience to space weather events in Canada. The study does not measure the likelihood of a space weather event, and should not be read as a vulnerability study.

Initial research was conducted in two areas to provide a solid foundation for the subsequent data collection and analysis phases.

Firstly, a review and assessment of previous space weather socioeconomic impact studies provided insights and identified good practices that were incorporated in the design of the impact assessment methodology. A key finding was that no consensus has yet been reached by practitioners on the best approach and methodology for estimating socioeconomic impacts of space weather. Estimation of space weather socioeconomic impacts continues to be affected by the following challenges:

- complexity and lack of understanding of impacts;
- lack of experience with extreme space weather during the space age, which leads to many assumptions;
- opposing views on the impact of space weather;
- uncertainty in the extent and nature of technical impacts on systems;
- lack of collaborative work between space physicists, engineers and economists; and
- reliance on qualitative assumptions.

Secondly, research on space weather related activities in Canada, United States, Australia and United Kingdom resulted in an inventory of space weather players (service providers and clients) in Canada, and provided information on how Canada compares with the other jurisdictions on the delivery and use of space weather information. A key finding was that Canada's *An Emergency Management Framework for Canada* (Third Edition, May 2017) mentions terrestrial weather as a hazard, but not space weather. By comparison, the UK included space weather as a risk to its National Risk Register in 2012 and the US approved a *National Space Weather Strategy* and a *National Space Weather Action Plan* in 2015.

The space weather socioeconomic impact methodology took into account the following considerations:

- *Impact mechanisms*, including geomagnetic induced current, deep dielectric charging, surface charging, ionospheric scintillation, atmospheric heating, geomagnetic disturbance, HF radio interference, radiation and solar cell degradation.
- *Impacted infrastructure*, including electrical power grid, satellites, polar aviation, polar marine transportation, magnetic surveying, directional drilling, pipelines, GNSS positioning, navigation and timing (PNT), surveying and precision farming.
- *Impact extent*, using the point of view of the economy as being of primary interest, with costs to infrastructure providers and users translated into economic GDP impact using an input-output model.
- *Mitigation possibilities*, which are dealt with by infrastructure operators by making investments in three areas: design, backup and actions.
- *Impact experience* that infrastructure sectors and their users have, which depends on the level of space weather that creates an impact and the significance of the effect.

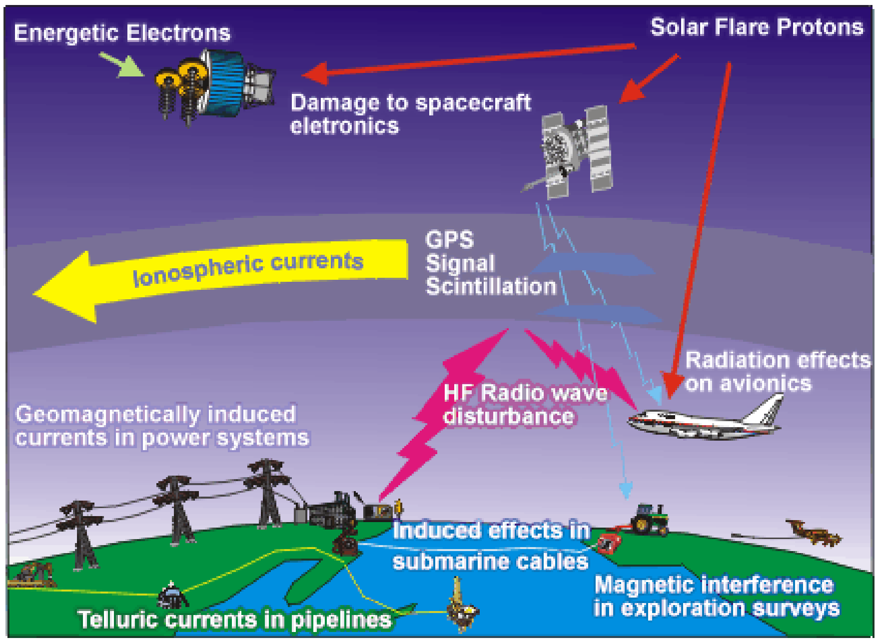
# Key Study Findings

## Space Weather Impacts

Space weather describes the variations in the environment between the Sun and Earth and the phenomena that impact systems and technologies in space and on Earth. The situation is illustrated in Figure 1. The sun emits energy during eruptions known as solar flares in the form of electromagnetic radiation (radio waves, infra-red, light, ultraviolet, X-rays). Energetic electrically charged particles may also be emitted as a result of the flaring process.

Clouds of magnetized plasma, referred to as Coronal Mass Ejections or CMEs, are sometimes ejected into space. The CMEs and electromagnetic and particle radiation may interact with the Earth's outer atmosphere and (geo)magnetic field in complex ways, causing concentrations of energetic particles to collect and electric currents to flow in regions of the outer atmosphere (magnetosphere and ionosphere). In addition, coronal holes that release high-speed streams of plasma into the solar wind may also be geo-effective. CMEs and coronal holes can trigger geomagnetic storms in our magnetosphere causing a range of impacts on ground-based and space-based infrastructure.

**Figure 1: Space Weather Effects on Infrastructure**



Source: Natural Resources Canada (http://www.spaceweather.gc.ca/tech/se-en.php)

The form of that impact is summarized as follows:

- *Electrical Power Grid* – Geomagnetically Induced Currents (GICs) can lead to transformer half-cycle saturation resulting in failure, voltage instability, increased reactive power consumption and/or unwanted relay operations, which can threaten system stability and potentially result in blackouts.
- *Satellites* – Deep dielectric charging and surface charging can result in temporary anomalies in system function or system failure. The loss of solar cell efficiency due to degradation over the life of the satellite means that larger solar cell arrays are required, increasing capital costs and launch costs. Atmospheric heating increases the drag on satellites in low earth orbit (LEO), requiring them to expend propellant to raise their orbit and thus reducing their lifespan. The weight of extra propellant increases launch costs.
- *Satellite Communications* – Ionospheric scintillation can interfere with satellite communications.
- *Polar Aviation* – Ionospheric scintillation and gradients can interfere with reception and integrity of GNSS position signals,

resulting in the need to use less accurate alternative navigation techniques. HF radio interference can restrict communications or require the use of more expensive satellite communications. To protect aircrew and passengers from high radiation levels, aircraft may be diverted to lower altitudes or alternate routes resulting in increased fuel costs and flight delays.

- *Polar Marine Transportation* – Ionospheric scintillation and gradients can interfere with reception and integrity of GNSS position signals, resulting in the need to use less accurate traditional navigation techniques. HF radio interference can restrict communications or require the use of more expensive satellite communications.
- *Magnetic Surveying* – Magnetic disturbances can interfere with magnetic survey data, resulting in the delay of operations or the need to resurvey.
- *Directional Drilling* – Magnetic disturbances can interfere with drill positioning, resulting in operations delays or the need to re-drill.
- *Pipelines* – GICs can accelerate corrosion of buried pipelines and interfere with pipeline surveying, resulting in delays or resurveys.
- *GNSS Positioning, Navigation and Timing* – disturbances in the ionosphere can disrupt reception and integrity of GNSS position and timing signals.
- *Surveying* – Ionospheric scintillation and gradients can interfere with reception and integrity of GNSS position signals, resulting in the delay of operations or the need to use less efficient methods.
- *Precision Farming* – Ionospheric scintillation and gradients can interfere with reception and integrity of GNSS position signals, resulting in the delay of operations or the need to use less efficient methods.

## Current Supply and Use of Space Weather Information

Within Canada's infrastructure sectors there are varying levels of knowledge and understanding of space weather and its impacts on systems and operations. Understandably, this level is relatively high in those sectors that are most impacted (e.g. electrical power grid, aviation, satellites) and relatively low in those that have historically been least impacted (e.g. GNSS timing, marine transportation, precision farming). What is often lacking in organizations is a detailed understanding of specific space weather impacts relative to other impacts (e.g. the amount of pipeline corrosion attributable to telluric currents due to space weather compared to corrosion due to other factors).

The primary supplier of space weather information in Canada, Natural Resources Canada's (NRCan) Canadian Space Weather Forecasts Centre (also known as Space Weather Canada), has a solid clientele within the user community. Other sources of information used by the infrastructure sectors include the US Space Weather Prediction Centre and online services such as spaceweather.com. The study identified some 240 organizations in Canada that are prospective users of space weather services.

## Economic Impacts of Space Weather

There are various points of view in assessing the economic impact of space weather events:

- *Service Providers* – impacts from investment in prevention, loss of revenue if the investment in prevention is not considered, is not entirely successful or is not possible, and damage remediation.
- *Industrial Service Users* – impacts from investment in backups, and loss of revenue as a result of losing access to the infrastructure.
- *Consumer Service Users* – impacts from loss of consumer surplus[1] as a result of losing access to the infrastructure. It is important to note that such losses do not factor into traditional economic statistics.
- *Economy* – the net economic value taken out of the economy by space weather events. The usual metric of this is the change in GDP.

Note that a loss to one sector of the economy can result in a gain to another sector, which means that individual economic actors cannot be considered in isolation when determining economy-wide impacts[2]. For this reason, care must be taken when trying to add impacts from different points of view, since in most cases the impacts are not simply additive.

This study's point of view is primarily the economy – however, other perspectives were considered in determining the impact on the economy. From the economy's point of view, many of the alternative perspectives may net to close to zero. Take, for example, the short-term loss of revenue to the electric utility as a result of a blackout. From the economy's point of view, that loss of revenue is partially offset by cost savings to consumers of the electricity they do not purchase that can then be used to purchase other things (although, given a positive consumer surplus, they presumably would prefer to have the electricity over the cost savings).

In this study, costs to infrastructure providers and users have been translated into economic GDP impact using an input-output model.

The assessment of economic impacts was based on three impact scenarios: Scenario 1: Limited impacts (minutes to 2-hour service denial), Scenario 2: Short-term impacts (24-hour service denial); and Scenario 3: Long-term impacts (14-day service denial for electrical power grid infrastructure, 1-year loss of Wide Area Augmentation System (WAAS)). Table 1 provides a summary of the economic impacts of space weather on Canada's infrastructure sectors.

The table clearly demonstrates the wide variation in economic impacts of space weather, with Scenario 1 impacts ranging from $0 (electrical power grid, polar marine transportation, and precision farming) to $238.2 million (pipelines sector), Scenario 2 impacts ranging from $0 (polar marine transportation) to $1,091.8 million (electrical power grid) and Scenario 3 ranging from $0 (polar marine transportation) to $54,945.8 million (electrical power grid

[1] Consumer surplus is an economic measure of consumer benefit. It is calculated by analyzing the difference between what consumers are willing and able to pay for a good or service relative to its market price, or what they actually do spend on the good or service. (Wikipedia)

[2] Other studies have taken other points of view; for example, that of insurance providers.

**Table 1: GDP Impacts of Space Weather on Canada's Infrastructure Sectors**

| Infrastructure Sector | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| Electrical Power Grid | $0 | $405.7 M – $1,091.8 M | $20,682.2 M – $54,945.8 M |
| Satellites | $0.6 M | $287.7 M | $576.1 M |
| Polar Aviation | $1.4 M – $28.0 M | $1.4 M – $28.0 M | $1,750.0 M (all aviation) |
| Polar Marine Transportation | $0 | $0 | $0 |
| Magnetic Surveying | $1.4 M – $7.0 M | $1.4 M – $7.0 M | $1.4 M – $7.0 M |
| Pipelines | $238.2 M | $238.2 M | $238.2 M |
| Surveying | $0.8 M – $1.7 M | $0.8 M – $1.7 M | $0.8 M – $1.7 M |
| Precision Farming | $0 | $0.5 M | $0.5 M |
| **TOTAL** | **$243.0 M – $276.1 M** | **$950.2 M – $1,669.4 M** | **$23,249.2 M – $57,519.3 M** |

Given the dependence of the whole economy on electricity, it is not surprising that the largest economic impact is on the Electrical Power Grid sector. It is possible that a significant or catastrophic space weather event (Scenarios 2 or 3) could force a temporary shutdown of a portion of the electrical power grid, which would have two impacts: utilities would lose the revenue for the amount of electricity that would otherwise be sold; and industrial users of electricity would suffer operational disruptions. However, since much activity could be rescheduled for a later time, the impact on the economy is not equal to 100% of the activity that would otherwise occur. Rather, studies have shown that the potential impact could be reduced to only 20% of normal GDP activity if all mitigation is capable of being implemented.

Some previous studies have considered scenarios where space weather has resulted in damage to many large transformers that would require more than a year to replace. Based on the most recent literature reviewed and consultations with representatives of the Canadian electrical power grid, such scenarios are not considered plausible for a number of reasons:

- The electrical power grid would collapse before any widespread transformer damage.
- Utilities have taken measures to protect networks from damage.
- Modern transformers may not be as susceptible to GIC damage.
- Transformer replacement times should be much shorter under emergency conditions.
- Other measures could be taken to bypass damaged transformer.

Three other sectors that are also significantly impacted by space weather are Satellites, Aviation, and Pipelines. Under Scenarios 2 and 3, satellite operators can potentially incur substantial costs associated with satellite failures and offloading of services to other operators and pipeline operators can incur costs associated with accelerated corrosion of pipelines and possibly delays in pipeline testing. Under Scenario 3, the loss of WAAS services would result in aviation operators experiencing increases in airline costs and decreases in labour productivity.

## Social Impacts of Space Weather

As with the economic impacts, there is considerable variation in the social impacts of space weather on Canada's infrastructure sectors. Across all of the sectors, the impacts under Scenario 1 are limited to minor inconveniences for infrastructure operators or their customers. Under Scenarios 2 and 3, additional social impacts may be experienced in some sectors, for example disruptions of business system operations, increased risk of accidents, disruptions in telecommunications, weather forecasting, medical care and emergency response services, loss of heating, and increased environmental degradation. However, for electrical power interruptions longer than approximately four days, the social impacts become very difficult to predict. No attempt has been made in this study to translate non-monetary social impacts into economic metrics.

## Mitigation of Space Weather Impacts

The study research and consultations suggest that in most sectors there are measures that can mitigate the impacts of space weather. Some infrastructure operators have already implemented some of these; others are still considering what is most appropriate for their situation (see Table 2). Infrastructure operators are making investments in three mitigation areas: i) *design* – pre-event design modifications of infrastructure components; ii) *backup* – alternative technologies and commercial arrangements that are implemented as necessary during space weather events; and iii) *actions* – mitigation actions taken during or following space weather events as necessary. While those consulted generally express a strong awareness of space weather impacts and confidence in their mitigation measures, there is strong interest in additional research to bolster their understanding of impacts. In addition, within the space weather community more broadly, there is concern that organizations have been lulled into a sense of complacency by the very limited space weather activity in the past 10-15 years, resulting in mitigation measures that may not be adequate.

**Table 2: Mitigation Measures Applicable to Infrastructure Sectors**

| Design | Backup | Actions |
|---|---|---|
| **Electrical Power Grid** | | |
| Improved network design<br>Improved operational procedures<br>Installation of GIC monitors | Operators – backup transformers<br>Customers – backup generators | Activate emergency procedures<br>Replace damaged transformers<br>Activate backup generators |
| **Satellites** | | |
| Hardening of spacecraft<br>Hardening of electronics<br>Increased solar panel size<br>Addition of extra fuel<br>Improved operational procedures | Backup satellites<br>Offloading arrangements | Activate emergency procedures<br>Delay critical maneuvers<br>Burn more fuel to correct orbit<br>Repair damages |

| Design | | Backup | Actions |
|---|---|---|---|
| **Polar Aviation** | | | |
| *Radiation* | No | No | Re-route flights to lower latitudes or altitudes<br>Delay flights<br>Control the amount of exposure to aircrew flying over the poles |
| *HF Radio* | No | Satellite communications (SatCom) | Switch communications to SatCom |
| *GNSS* | Improved receiver designs<br>Augmentation systems | Other navigation means (ground aids, inertial) | Switch to backup means |
| **Polar Marine Transportation** | | | |
| *HF Radio* | Improve polar SatCom coverage | Satellite communications (SatCom) | Switch communications to SatCom |
| *GNSS* | Improved receiver designs | Other navigation means (nav aids, inertial) | Switch to backup means |
| **Magnetic Surveying** | | | |
| Magnetometer placement in survey areas | | No | Delay surveys |
| **Directional Drilling** | | | |
| Use of Interpolation In-Field Referencing (IIFR) model<br>Use of Disturbance Function method<br>Magnetometer placement in drilling areas<br>Operational procedures for regular correction of drill head direction | | No | Delay drilling |
| **Pipelines** | | | |
| Installation of cathodic protection systems<br>Installation of GMD monitoring devices<br>Test station facilities incorporating corrosion protection (CP) coupons | | No | Delay testing surveys |
| **GNSS Positioning and Navigation** | | | |
| Improved receiver designs<br>Multiple satellite constellations<br>Improved augmentation systems | | Other positioning and navigation methods | Switch to backup methods |

| Design | Backup | Actions |
|---|---|---|
| **GNSS Timing** | | |
| Improved receiver designs<br>Multiple satellite constellations | Other precise timing methods (e.g. atomic clocks) | Switch to backup methods |
| **Surveying** | | |
| Improved receiver designs<br>Multiple satellite constellations | Other surveying methods (total stations, electronic theodolites) | Delay surveys<br>Switch to backup methods |
| **Precision Farming** | | |
| Improved receiver designs<br>Multiple satellite constellations | Other farming methods | Delay farming operations<br>Switch to backup methods |

## Space Weather Awareness

In the global context, space weather awareness is growing, as indicated by a number of recent initiatives[3].

In the Canadian context, the majority of consultation respondents felt strongly that the federal government has a role to play in further raising awareness of the risks of space weather and providing advice on how to mitigate the impacts of severe disturbances, and expressed interest in training to raise the awareness of the risk and impacts of space weather within their organizations. While there is a relatively high level of awareness and use of the Canadian government's space weather services, there were a number of suggestions for future improvements in the government's services and role (e.g. more information on the probability, duration and intensity of events and thresholds of concern for each infrastructure sector, higher levels of local/regional detail, an ongoing national forum for exchange of information and experiences in dealing with space weather, and more predictable/regular research funding to assist utilities to study risk modeling, improve simulations and identify system vulnerabilities). In order to assess such space weather risks on infrastructure such studies should be completed as a follow-on to this study.

## Interest in Improvements to Space Weather Services

In order to manage the risk of space weather impacts, organizations need information upon which to base the formulation of their mitigation measures and to take action in the case of significant events. Space weather services such as Space Weather Canada provide this information to users in Canada. The following paragraphs discuss the value of improving such services to each of the infrastructure sectors against the backdrop of

[3] For example, establishment of the Space Weather Expert Group by the United Nations Committee on the Peaceful Uses of Outer Space, release of national space weather strategies in the US and UK, the development by the North American Electric Reliability Council (NERC) of electric grid guidelines and the approval by the International Civil Aviation Organization (ICAO) of Standards and Recommended Practices (SARPs) for space weather advisories and appointment of global space weather centres for aviation.

the socioeconomic impacts of space weather events and Table 3 illustrates the strength of interest. Specifically, they address the question, "How much would improvements in space weather services and additional research benefit this infrastructure sector?"

### *Electrical Power Grid*

Canada's electrical power grid is arguably the infrastructure sector that is most impacted by space weather. Electric utilities make use of the space weather services provided by Space Weather Canada, but they are not dependent upon this information (e.g. some use GIC monitors on their systems as well). However, there is significant interest in improvement of the government's services, including more precise forecasting, additional geomagnetic monitoring sites and more research to address critical knowledge gaps.

### *Satellites*

Satellites are also significantly impacted by space weather. Given that the primary mitigation strategy is design, the use of space weather services is primarily limited to supporting decision-making related to the timing of critical satellite maneuvers. Although consultations with industry representatives revealed limited interest in additional research and improved forecasting, the literature review identified ongoing concerns in the satellite industry about the difficulty of identifying whether or not an anomaly is the result of space weather.

### *Polar Aviation*

The aviation sector employs space weather services to help identify when re-routing of polar flights is necessary because of space weather impacts on aircraft avionics and crew (i.e. risk of radiation exposure). ICAO has identified needs in both areas, and Canada will be part of an ICAO global center for space weather advisories for aviation.

### *Polar Marine Transportation*

Information about space weather impacts on the use of GNSS in marine transportation is being added to the Space Weather Daily Bulletin issued by NRCan.

### *Magnetic Surveying*

This sector's use of space weather services primarily supports decision-making related to potential delays in surveys due to significant space weather events. Consultations with industry representatives revealed some interest in improved forecasting and additional research.

### *Directional Drilling*

The primary use of space weather services within this sector is for awareness of significant events that may impact drilling operations. Some interest was expressed during consultations in additional research.

### *Pipelines*

The pipeline sector uses space weather information for planning, and potential postponement, of corrosion testing surveys. During consultations, interest was expressed in both space weather services improvements and additional research.

### *GNSS Positioning, Navigation and Timing*

It is important to note that use of space weather services within the broad GNSS user community may increase in the future as reliance on GNSS becomes even greater and expectations of higher precision continue to grow (e.g. in the automated vehicles industry).

*Surveying*

The surveying sector's use of space weather information assists with planning, and potential postponement, of surveys.

*Precision Farming*

The precision farming sector uses GNSS augmentation systems to mitigate the impacts of position errors caused by space weather.

**Table 3: Needs for Improved Space Weather Services and Additional Research**

| Infrastructure Sector | Space Weather Services | Space Weather Research |
|---|---|---|
| Electrical Power Grid | Very High | Very High |
| Satellites | Low | Medium |
| Polar Aviation | High | High |
| Polar Marine Transportation | Medium | Low |
| Magnetic Surveying | Medium | Medium |
| Directional Drilling | Low | Medium |
| Pipelines | High | High |
| GNSS Positioning, Navigation and Timing | Low | Low |
| Surveying | Low | Low |
| Precision Farming | Low | Low |

**Legend:**

Very High
High
Medium
Low

# Recommended Canada Space Weather Strategy

Based on the study findings, it is **recommended that a Canada Space Weather Strategy (CSWS) be developed**. There is an increasing recognition worldwide that Space Weather Monitoring and Forecasting is required to protect space assets, ground assets and ultimately human lives against risks originating in space. Space weather events can have a significant impact on Canada's critical infrastructure, which is essential to national security, the economy and the health of Canadians, including the electrical power grid, the transportation networks and space systems (satellites and their ground facilities). Concerns are growing about the complexity and interconnectivity of critical infrastructure and our increasing dependency not only on a requirement for near-continuous availability of electrical power, but also on space-based technologies such as cellular/mobile telephones, the Internet and Global Navigation Satellite Systems (GNSS)/Global Positioning Systems (GPS). When emerging technologies like autonomous vehicles are introduced, our reliance on GNSS/GPS with higher precision will increase.

Feedback from stakeholders in this study suggests a strong interest within the space weather community for the federal government taking a stronger leadership role in coordinating Canadian space weather activities. There is growing recognition in this country of the risks to an increasingly integrated critical infrastructure from severe space weather events. While many stakeholders believe that they have acceptable impact mitigation measures in place, there are fundamental knowledge gaps in assessing the technological impacts from extreme space weather events. To address this requires knowledge of realistic benchmarks of the levels of space weather disturbance which should be applied to models of the relevant infrastructure, recognizing the importance of accurate representations of how the technology is implemented, as well as a realistic assessment of the different sizes of space weather disturbances at different geographic locations. In relation to Canada, the high latitude location of infrastructure often means the impacts can be significantly larger than those experienced, for example, by infrastructure further south in the United States.

There is also strong interest in improved space weather services and additional research on the specific impacts in different sectors. A coordinated effort to address this interest with a formal Canada Space Weather Strategy (CSWS) will be welcomed by the community.

The recommendation proposes the following goals for the CSWS:

1. **Improve Understanding of Space Weather Impacts:** While infrastructure operators appear to be confident in their preparations to mitigate space weather impacts, there is strong interest in additional research to bolster their understanding of impacts. It was noted by interviewees and survey respondents that more funding for research on space weather impacts and mitigation is needed; Canada is far behind the US & UK[4]. There is interest in understanding more about probabilities of severe events and in higher fidelity impact studies and risk assessments based on improved benchmarks.

2. **Increase Services Tailored to Canadian Latitudes:** In order to manage the risk of space weather impacts, organizations need information upon which to base the formulation of their mitigation measures and take action in the case of significant events. It was noted by interviewees and survey respondents that information on the duration, intensity and geographic area (specific to Canadian latitudes) of space weather events is needed (i.e. US National Oceanic and Atmospheric Administration's (NOAA) forecasts are not always suited for Canada). There is also interest in extending the geomagnetic monitoring network.

3. **Promote Greater Awareness of the Risks and Impacts of Space Weather Events:** The majority of respondents felt strongly that the federal government has a role to play in raising awareness of the risks of space weather and providing advice on how to mitigate the impacts of severe disturbances. Many noted that Canada had fallen behind and expressed concern that other countries, particularly the US and UK, are much more proactive in both raising awareness of the risks and making investments in space weather services. It was also suggested that "space" be added to the list of Canada's critical infrastructure sectors, and included in future editions of *Canada's Emergency Management Framework* and *National*

[4] For example, the UK's new £ 8 M Data and Analytics Facility for National Infrastructure (DAFNI) is helping researchers to analyse the resilience of interdependent critical infrastructure, among other things. (https://www.dafni.ac.uk/)

*Strategy and Action Plan for Critical Infrastructure*.[5]

4. **Create a Space Weather Preparedness Plan:** The creation of a Space Weather Preparedness Plan would require a coordinated approach across all government departments/agencies (possibly lead by Public Safety Canada), academia and commercial partners to ensure a streamlined process. Key stakeholders would include federal departments of Transport, Defence and Natural Resources, as well as provincial and local government and private sector infrastructure operators. It would address how each government department should react in response to a severe space weather event (i.e. roles and responsibilities) as well as the selection of a singular entity that would play the coordination role.

5. **Continue and Enhance International Engagement:** Engagement with the international community on observation infrastructure, data sharing, numerical modeling and scientific research should be continued and enhanced where appropriate. Enhanced collaboration can also provide solutions to regional challenges associated with space weather and exchange of best practices between Canada and the international partners. Overall this will help to strengthen global capacity to respond to extreme space-weather events. Progress is being made in this area with the recent release of voluntary guidelines by the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS). The 21 agreed guidelines promote broader international collaboration and address the policy, regulatory, operational, safety, scientific, technical and capacity-building aspects of space activities including space weather. The implementation of these guidelines will support the development of practices to mitigate risks associated with the conduct of outer space activities so that present benefits can be sustained and future opportunities realized.

[5] Note that the Government of Australia has already taken similar action, in recognition of the increasing reliance on space-based infrastructure.