INNOVATION
EXPLORATION
OBSERVATION
INSPIRATION

Space Weather Socioeconomics Impact Study on Canadian Infrastructure

Pierre Langlois
Solar-Terrestrial Science

Canadian Space Agency | Agence spatiale canadienne

Canada

Space Weather in Canada

- 1970s
  - Space weather forecasting started
- 1989
  - Hydro-Québec blackout
  - Space weather forecasting went to 7 day/week operation
- 2018
  - No Space Weather Policy, Strategy, or Action Plan
  - Canada initiates a Socioeconomic Impact Study

Increasing Space Weather Awareness

2008: US National Research Council
Severe Space Weather Events—Understanding Societal and Economic Impacts Workshop Report

2011: Office of Risk Management and Analysis, US Department of Homeland Security
"Geomagnetic storms" OECD report

2015: US National Space Weather Strategy and Action Plan

2008 — 2011 — 2013 — 2015 — 2017

2013: UK's Royal Academy of Engineering
"Extreme space weather: impacts on engineered systems and infrastructure"

2015: UK Space weather preparedness strategy

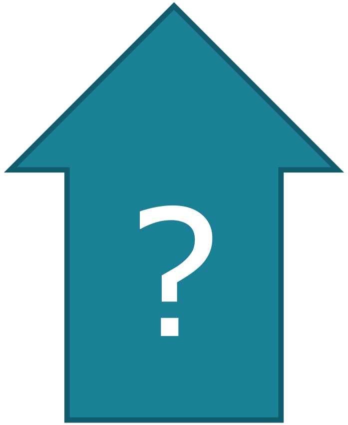
2017: United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) recommends socioeconomic analysis by member states

Assessing cost

- Difficult to survey industry on actual outages
- Space weather events are rare and most critical infrastructure have not been exposed to a 1 in a 100 year event

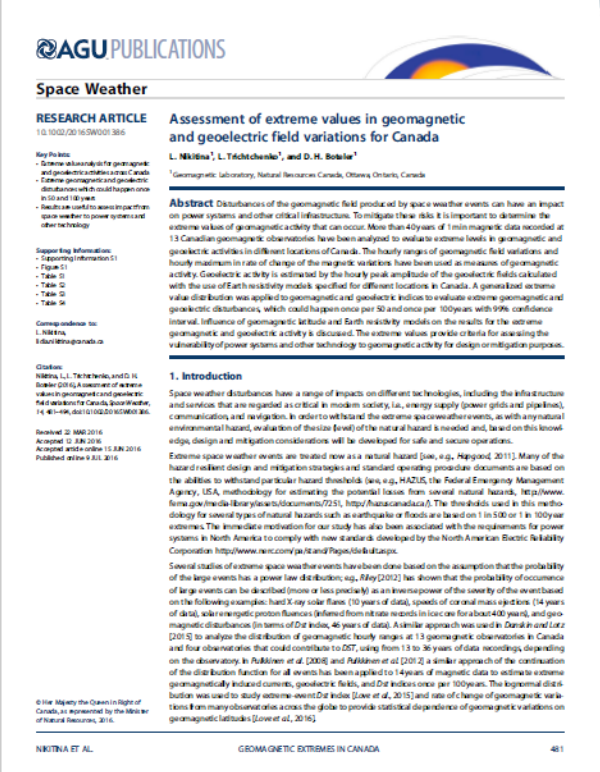
Assessing Socioeconomic Impact

$$\mathit{Cost\ of\ space\ weather} \approx \sum_{\mathit{events}} \begin{pmatrix} \mathit{probability} \\ \mathit{of\ event} \end{pmatrix} \times \begin{pmatrix} \mathit{Cost\ of} \\ \mathit{an\ event} \\ \mathit{if\ it\ occurs} \end{pmatrix}$$



Natural Resources Canada

- Host the Canadian Space Weather Forecast Centre
- Operate the Canadian magnetic observatory network
- Applied rigorous extreme value statistics methodology to assess the probability of a large event
  - Nikitina, L., Trichtchenko, L., Boteler, D.H. Assessment of extreme values in geomagnetic and geoelectric field variations for Canada (2016) *Space Weather*, 14, 481–494



AGU PUBLICATIONS

Space Weather

RESEARCH ARTICLE

10.1002/2016SW001386

Key Points:
- Extreme value analysis for geomagnetic and geoelectric activities across Canada
- Extreme geomagnetic and geoelectric disturbances which could happen once in 50 and 100 years
- Results are useful to assess impact from space weather to power systems and other technology

Supporting Information:
- Supporting Information S1
- Figure S1
- Table S1
- Table S2
- Table S3
- Table S4

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Assessment of extreme values in geomagnetic and geoelectric field variations for Canada

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Abstract Disturbances of the geomagnetic field produced by space weather events can have an impact on power systems and other critical infrastructure. To mitigate these risks it is important to determine the extreme values of geomagnetic activity that can occur. More than 40 years of 1 min magnetic data recorded at 13 Canadian geomagnetic observatories have been analyzed to evaluate extreme levels in geomagnetic and geoelectric activities in different locations of Canada. The hourly ranges of geomagnetic field variations and hourly maximum in rate of change of the magnetic variations have been used as measures of geomagnetic activity. Geoelectric activity is estimated by the hourly peak amplitude of the geoelectric fields calculated with the use of Earth resistivity models specified for different locations in Canada. A generalized extreme value distribution was applied to geomagnetic and geoelectric indices to evaluate extreme geomagnetic and geoelectric disturbances, which could happen once per 50 and once per 100 years with 99% confidence interval. Influence of geomagnetic latitude and Earth resistivity models on the results for the extreme geomagnetic and geoelectric activity is discussed. The extreme values provide criteria for assessing the vulnerability of power systems and other technology to geomagnetic activity for design or mitigation purposes.

1. Introduction

Space weather disturbances have a range of impacts on different technologies, including the infrastructure and services that are regarded as critical in modern society, i.e., energy supply (power grids and pipelines), communication, and navigation. In order to withstand the extreme space weather events, as with any natural environmental hazard, evaluation of the size (level) of the natural hazard is needed and, based on this knowledge, design and mitigation considerations will be developed for safe and secure operations.

Extreme space weather events are treated now as a natural hazard [see, e.g., *Hapgood*, 2011]. Many of the hazard resilient design and mitigation strategies and standard operating procedure documents are based on the abilities to withstand particular hazard thresholds (see, e.g., HAZUS, the Federal Emergency Management Agency, USA, methodology for estimating the potential losses from several natural hazards, http://www.fema.gov/media-library/assets/documents/7251, http://hazuscanada.ca/). The thresholds used in this methodology for several types of natural hazards such as earthquake or floods are based on 1 in 500 or 1 in 100 year extremes. The immediate motivation for our study has also been associated with the requirements for power systems in North America to comply with new standards developed by the North American Electric Reliability Corporation http://www.nerc.com/pa/stand/Pages/default.aspx.

Several studies of extreme space weather events have been done based on the assumption that the probability of the large events has a power law distribution; e.g., *Riley* [2012] has shown that the probability of occurrence of large events can be described (more or less precisely) as an inverse power of the severity of the event based on the following examples: hard X-ray solar flares (10 years of data), speeds of coronal mass ejections (14 years of data), solar energetic proton fluences (inferred from nitrate records in ice core for about 400 years), and geomagnetic disturbances (in terms of *Dst* index, 46 years of data). A similar approach was used in *Danskin and Lotz* [2015] to analyze the distribution of geomagnetic hourly ranges at 13 geomagnetic observatories in Canada and four observatories that could contribute to *DST*, using from 13 to 36 years of data recordings, depending on the observatory. In *Pulkkinen et al.* [2008] and *Pulkkinen et al.* [2012] a similar approach of the continuation of the distribution function for all events has been applied to 14 years of magnetic data to estimate extreme geomagnetically induced currents, geoelectric fields, and *Dst* indices once per 100 years. The lognormal distribution was used to study extreme-event *Dst* index [*Love et al.*, 2015] and rate of change of geomagnetic variations from many observatories across the globe to provide statistical dependence of geomagnetic variations on geomagnetic latitudes [*Love et al.*, 2016].

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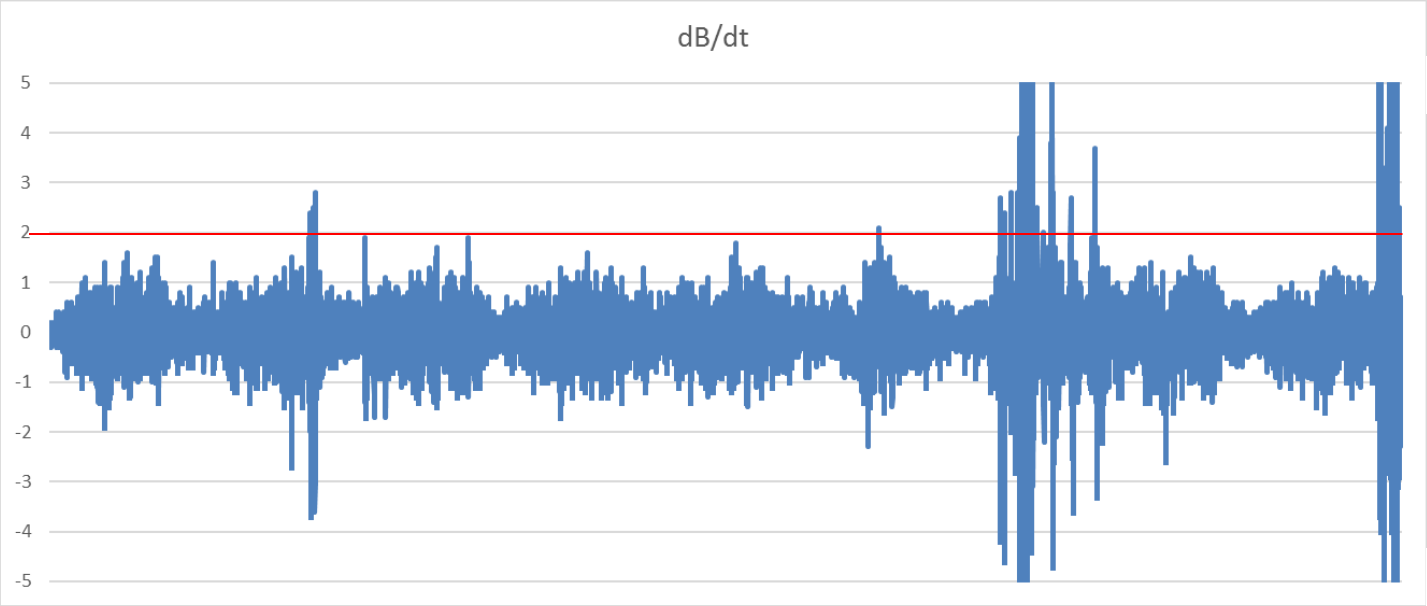
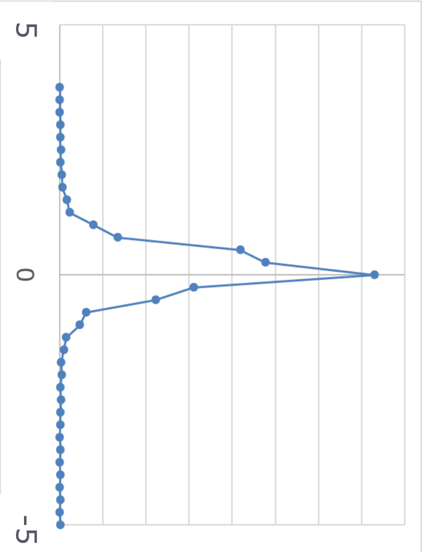
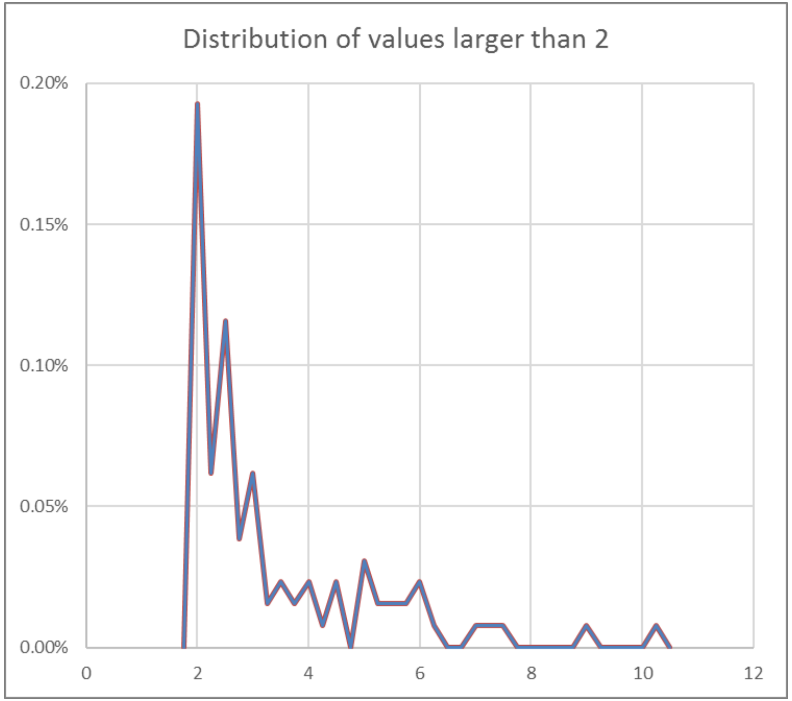
Histogram of time series





Histogram of extreme values



Type 1: Gumbel law:

$$G(z) = \exp\left\{-\exp\left(-\left(\frac{z-b}{a}\right)\right)\right\} \text{ for } z \in \mathbb{R}.$$

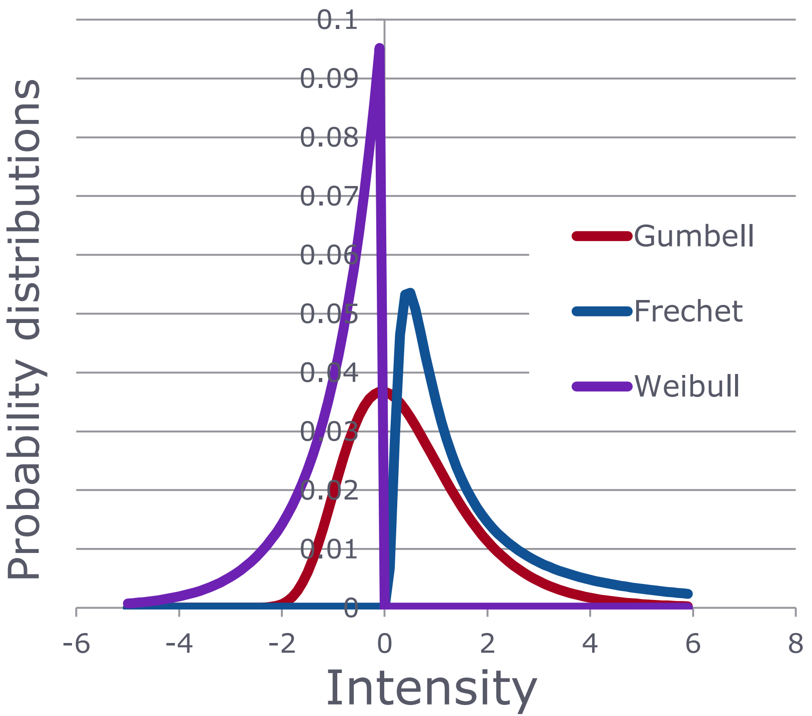
Type 2: Fréchet Law:

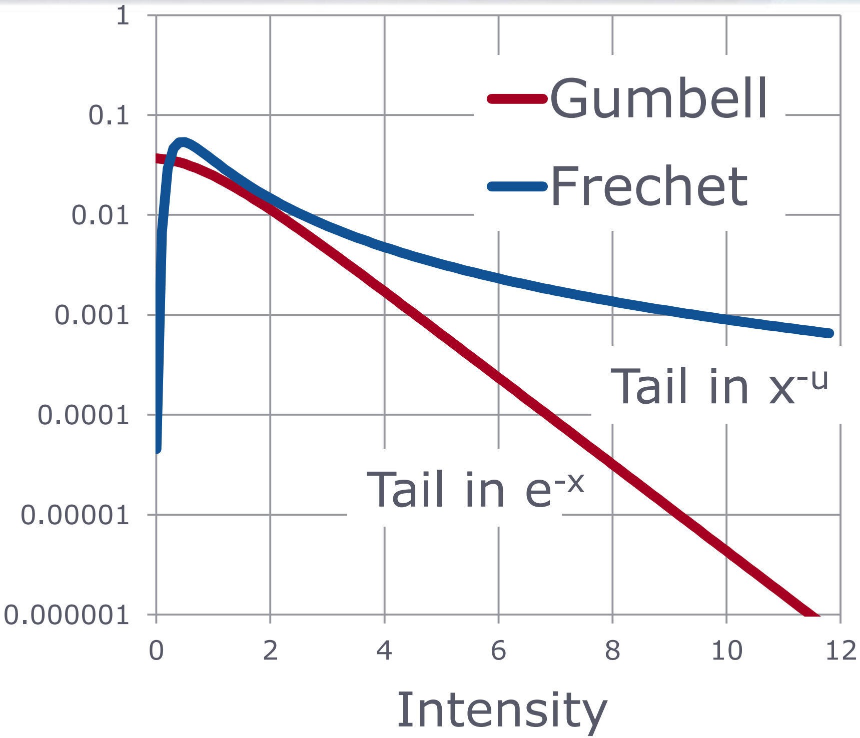
$$G(z) = \begin{cases} 0 & z \leq b \\ \exp\left\{-\left(\frac{z-b}{a}\right)^{-\alpha}\right\} & z > b. \end{cases}$$

Type 3: Weibull law

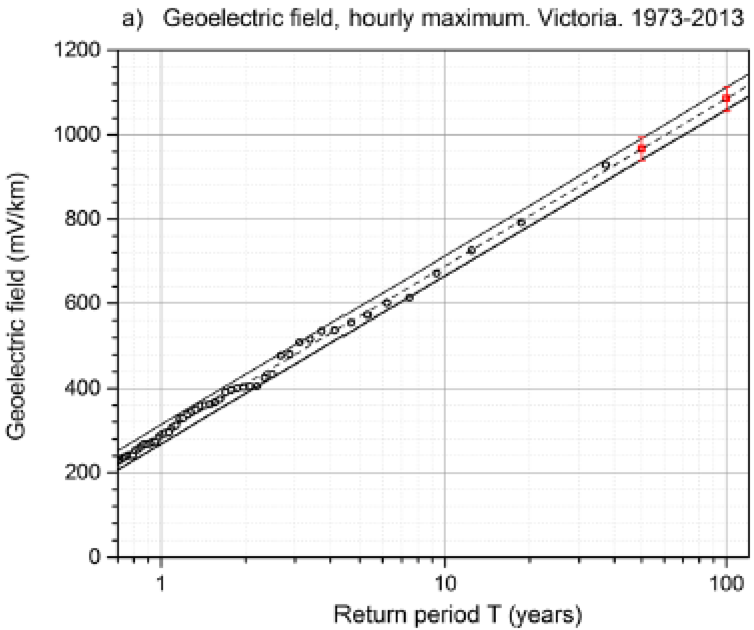
$$G(z) = \begin{cases} \exp\left\{-\left(-\left(\frac{z-b}{a}\right)\right)^{\alpha}\right\} & z < b \\ 1 & z \geq b \end{cases}$$

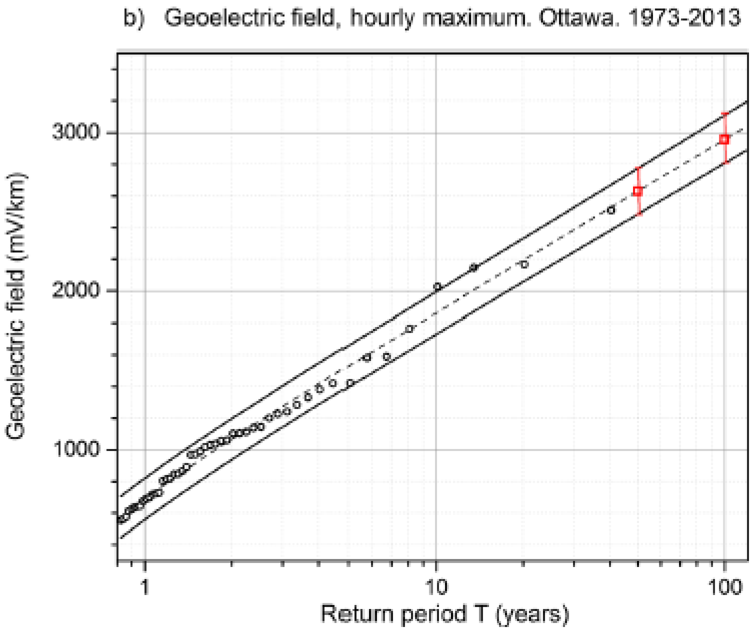
Extreme Value Distributions





Predicting 50 year and 100 year values





Fitting of the peak geoelectric fields (circles) in Victoria and Ottawa to an extreme value distribution (dashed line) with 99% confidence intervals (solid lines). The predicted values once per 50 years and once per 100 years are denoted by red squares.

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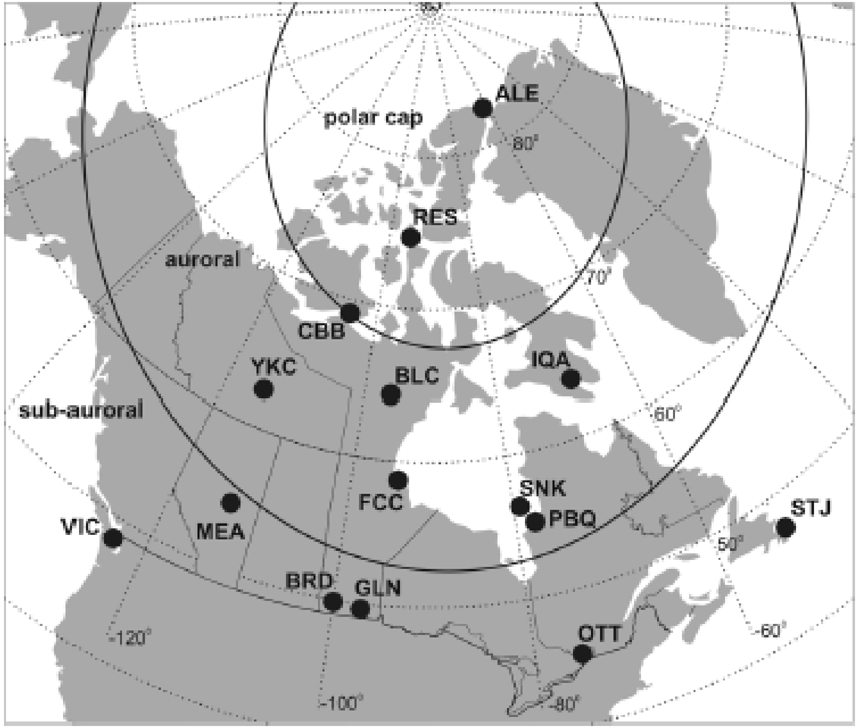
Assessment of extreme values in geomagnetic and geoelectric field variations for Canada



Geomagnetic Observatory	Code	Number of Years of Data Availability
Victoria	VIC	41 years
Ottawa	OTT	41 years
St. John's	STJ	42 years
Brandon/Glenlea	BRD/GLN	31 years
Meanook	MEA	42 years
Poste de-la-Baleine/Sanikiluaq	PBQ/SNK	30 years
Fort Churchill	FCC	41 years
Yellowknife	YKC	39 years
Baker Lake	BLC	40 years
Iqaluit	IQA	17 years
Cambridge Bay	CBB	42 years
Resolute	RES	40 years
Alert	ALE	29 years

Canadian Geospace Observatory

Data SIO, NOAA, U.S. Navy, NGA, GEBCO ©Google, US Dept of State Geographer, Image Landsat/Copernicus Imagery Date: 12/13/2015 54°04'30.13" N 94°41'54.28" W elev 267 m eye alt 4953.88 km

Assessing Socioeconomic Impact

$$Cost\ of\ space\ weather \approx \sum_{events} \begin{pmatrix} probability \\ of\ event \end{pmatrix} \times \begin{pmatrix} Cost\ of \\ an\ event \\ if\ it\ occurs \end{pmatrix}$$

this study

Space Weather Socioeconomics Impact Study on Canadian Infrastructure

- The goal of the study is to measure the Canadian Critical Infrastructure sensitivity to space weather
  - What kind of space weather are you sensitive to?
  - What level of space weather are you sensitive to?
  - What are the consequences if that level is reached?
  - What are your mitigation strategies?

Socioeconomic study

- Hickling Arthurs Low Corporation selected through competitive process
  - Contract was awarded November 2017
  - Expected end date: March 2019

Progress report

- Literature review
- Preliminary consultation on space weather with representatives of different sectors has taken place
- Questionnaire is being produced
- Survey will be performed during the Summer
- A Consultation workshop will be held to discuss the results (September timeframe)
- Final report expected March 2019

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