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IR^3 FEATURE ARTICLES

Editorial Corner

Dr. Robyn Fiori

About the Editor

Dr. Robyn Fiori is a research scientist for the Canadian Hazards Information Service of Natural Resources Canada specializing in space weather. Her research is applied to the development and improvement of space weather tools and forecasts to be used by operators of critical infrastructures and technologies in Canada. As well, it has been published in numerous peer reviewed scientific journals, including the Journal of Geophysical Research, the Journal of Atmospheric and Solar-Terrestrial Physics, and Space Weather. Dr. Fiori received her B.Sc., M.Sc., and Ph.D., from the University of Saskatchewan, Department of Physics and Engineering Physics while studying in the Institute of Space and Atmospheric Studies.

This Issue

The fifth issue of IR^3 describes some of the potential vulnerabilities faced by critical infrastructure and the challenges experienced by operators and executives to ensure smooth operation before, during, and after an event.

Although many of us use Global Navigation Satellite Systems (i.e., GPS) on a regular basis in our cars or on our phones for positioning purposes, few fully understand the considerable role GNSS timing plays in a wide range of essential industries and services. Dr. Calvin Klatt discusses the critical role of GNSS timing and the numerous risks, both intentional and unintentional that threatens safe reception of timing information. His discussion of mitigation efforts and opportunities provides critical infrastructure operators with the information they need to properly assess the vulnerability of their systems to the interruption of GNSS timing data.

One possible culprit in disrupting GNSS signals, which has the potential to impact a range of critical infrastructure, simultaneously, is space weather. Dr. Hing-Lan Lam points out the need for space weather forecasting to increase infrastructure resilience. He narrates the evolution of space weather monitoring and forecasting in Canada, including the development of the Canadian Space Weather Forecast Centre which strives to provide reliable space weather forecasts for the benefit and protection of impacted infrastructure.

Dr. Chigomezyo Nigwira and Dr. Antii Pulkkinen seek to enhance infrastructure resilience to space weather on a national level through the understanding of extreme space weather events with a focus on impacts to electrical power systems. They highlight the pressing need to define the severity of extreme space weather conditions to safeguard industry from potential impacts.

Mitch Jardine and Russell King raise awareness meant to guide a range of agencies involved in security and risk management regarding the management of supply chain disruptions. They stress the importance of communication within and between the hierarchical levels which form during security and emergency events. This communication is vital to best coordinate efforts leading to improved resilience.

A new topic for IR^3 is broached by Jim Tweedie of the Canadian Gas Association who discusses the principles of respect, safety, and security in handling potential confrontation during protests. In dealing with interactions between workers and protesters, the safety and rights of both sides must be taken into consideration. Potential situations, possible solutions, and recommendations are offered to protect the well-being of all parties involved.

Bill Isaacs closes Issue 5 with recommendations on the post incident review process in the wake of an emergency situation and how to build an atmosphere within an organization that encourages employee participation and achieve winning results.

Next Issue

For Issue 6 we invite authors working in academia or industry to contribute articles relating to their experience in the field of infrastructure resilience. Draft articles of 3000-4000 words are requested by early February. You may not have much time or experience in writing ‘academic’ articles, but IR^3’s editorial board can provide guidance and help. Your experience is valuable and IR^3 provides an ideal environment for sharing it.

Precise Timing from Global Navigation Satellite Systems & Implications for Critical Infrastructure

***"By putting forward the hands of the clock you shall not advance the hour"* (Victor Hugo)**
… but could you disrupt Canada's electrical system?

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Abstract

Global Navigation Satellite Systems (GNSS), such as the well-known U.S. GPS, have had a profound influence on society through its provision of reliable and precise position, navigation and timing services. While the timing information provided by GNSS is less well-known by the public, it is of considerable importance in the Telecommunication, Energy and Banking Sectors. In January 2016 timing information from many GPS satellites was in error, causing systems to fail and widespread concern. In addition to such failures, jamming, space weather and spoofing are significant concerns. The extent of risk to specific critical infrastructure in Canada is variable and the overall risk is not well known. System operators are challenged to consider the extent to which the systems under their control are vulnerable to timing failures and how they should respond in the event of a failure. The federal government is considering possible investments in wide-area monitoring and/or timing services to support critical infrastructure.

I. Overview

The Canadian Federal GNSS Coordination Board (FGCB), chaired by Peter Sullivan of Natural Resources Canada (NRCan), was established to coordinate federal government activities related to GNSS. Because of NRCan's extensive technical knowledge of and reliance on GNSS systems, the department is in a position to provide significant leadership in Canada. This report represents an NRCan contribution to FGCB efforts.

To enable synchronization and time stamping of automated processes, reliable and very precise timing can be obtained from GNSS. Studies have been conducted about the risk to Critical Infrastructure from GNSS failures, including timing failures. Public Safety Canada and the Department of Defence sponsored the Canadian "Assessment of the Use of Global Navigation Satellite Systems in Support of National Infrastructure", completed in 2012 (classified).

GPS timing has now been in use for more than 30 years with exceptional service quality. Application areas include telecommunications, electric power transmission, time-stamping in financial, legal and other transactions, scientific timing and computer network time synchronization. In general, industries consulted have reported that multiple layers of backup capability exist and that contingency plans are in place to provide protection against outages.

While the risks are considered low, the sense within government agencies involved is that considerable complacency exists about signal disruption and that for GNSS timing there is considerable uncertainty regarding the magnitude of the risk. Since the U.S. and Canadian studies were conducted, a number of changes have occurred which suggest that these risks are increasing. As a result, the FGCB is engaged in advising GNSS users about the vulnerabilities and the need for backup systems: This article in part reflects this broad government effort.

Similar risk assessments have been conducted by other nations. In particular, the U.S. Department of Homeland Security (DHS), Office of Infrastructure Protection, completed the 2012 National Risk Estimate: Risks to U.S. Critical Infrastructure from

Global Positioning System Disruptions, with broadly similar conclusions to the Canadian study (see 1). In June 2016, the DHS Science and Technology Resilient Systems Division announced a solicitation for "Assured Timing for Critical Infrastructure" indicating ongoing concern within DHS.

We know that risk is dependent on the magnitude of the hazard, as well as on vulnerability. There is clear evidence of increasing hazard, as discussed in the sections below, but the vulnerability is system dependent. Perhaps, as a result, there are conflicting reports about the extent of the risk and the need to respond.

The author of this report does not have expertise in the technical aspects of timing in the telecommunications, energy or banking industries. As a result, we seek to communicate to industry the hazard, leaving detailed assessment of risk to others better placed to respond.

II. Threats to GNSS Time Dissemination

In January 2016, we witnessed an event in which timing information failed on approximately half of the satellites in the GPS constellation (see 2 and 3). This generated concern internationally and across government in Canada. Several news stories detailed the resulting problems. Failures in GNSS timing could result from blunders such as this or from unintentional jamming (radio frequency interference), intentional jamming, space weather, or spoofing (intentional data falsification). There is evidence indicating that jamming and spoofing are rapidly growing concerns.

Intentional Jamming

GNSS relies on very weak signals from satellites at an altitude of around 20,000 kilometres, making the system vulnerable to accidental or deliberate interference.

While illegal, low-cost electronic devices that prevent GNSS receivers from working are easily purchased or manufactured. Such devices, also known as "personal privacy devices", are used to prevent vehicle tracking by thieves and others concerned about privacy.

See Figure 1 for an online advertisement of such a device. It is illegal to possess a GPS jamming device in Canada.

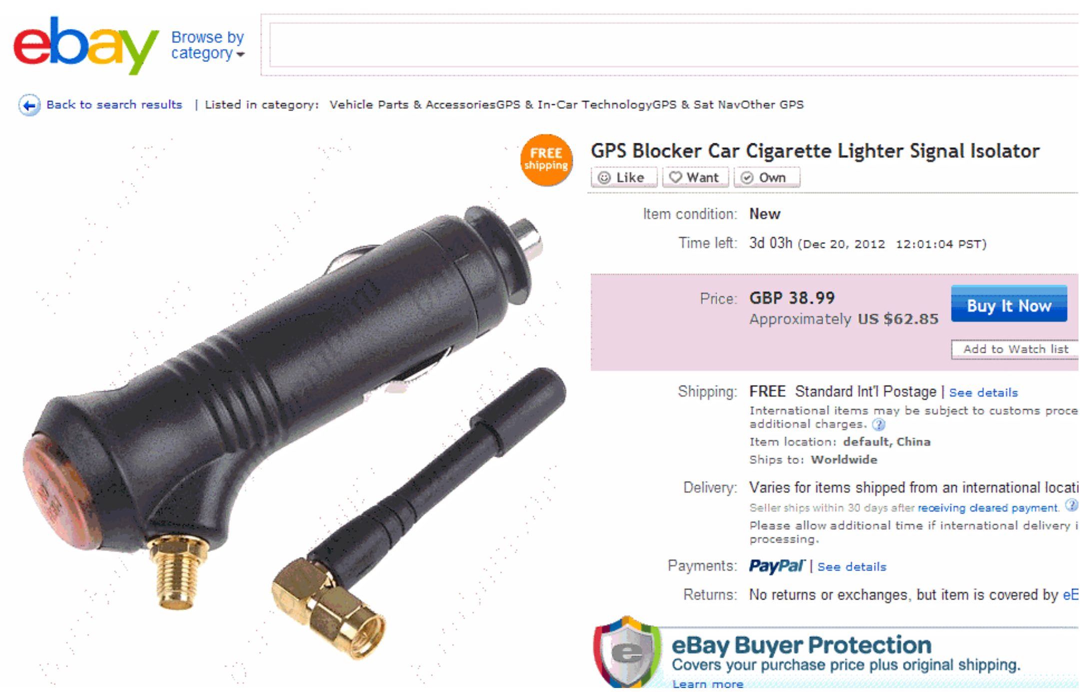

Figure 1: GPS jammer available for purchase

Jamming incidents at the Newark airport in New Jersey are well documented. The airport suffered problems over several years related to drivers on the New Jersey Turnpike with jammers. In 2012, the U.S. Federal Communications Commission issued a fine for a jamming incident involving a pickup truck near this airport (see 4). A number of Canadian airports suffered similar problems in 2015, and recent studies in Ottawa and Montreal suggest that GNSS jammers are in regular use on major highways in Canada.

Documented incidents are primarily related to positioning and navigation applications, but we can be certain that GNSS timing devices near major highways are affected by this problem. As such interference grows, periods of GNSS outage will grow. How will such systems respond?

Radio Frequency Interference (unintentional jamming)

Weak GNSS signals are vulnerable to unintentional interference by more powerful terrestrial broadcasts. This threat to GNSS was brought into focus at the highest levels of the U.S. Government in recent years with the debate over the potential use of spectrum adjacent to that used by GPS by a wireless communications system (LightSquared, see 5). The high power broadcast proposed by LightSquared was considered a major threat to GNSS systems and was eventually blocked by the U.S. Federal Communications Commission. The LightSquared application and subsequent FCC decision were highly controversial.

A more mundane example is that of Moss Landing Harbor near Monterey Bay, California (6). Frequent problems with GPS caused significant impact on ship navigation and with the operations of a research institute (timing). Navigation in the harbour was frequently limited to radar systems, which many users were unfamiliar with. With much difficulty, the problems were traced to three VHF/UHF television antennas on individual boats. These antennas jammed GPS up to one mile out to sea.

One can imagine a similar situation in the port of Montreal: GNSS signals jammed in a 1-2 km region would affect transportation, as well as timing signals used in the banking and telecommunications sectors.

Space Weather

The Canadian Space Weather Forecast Centre in Ottawa is operated by NRCan with support from the Canadian Space Agency and in partnership with the National Research Council. Solar radiation impacting the Earth's atmosphere causes ionization in the ionosphere of which the level varies with the season and phase of the solar cycle. During extreme space weather conditions, the ionosphere is highly perturbed with wide and irregular variations in the ionization. Unusually high ionosphere total electron content (ionization), as well as rapid variations in this electron content are two effects that have been identified as factors leading to GNSS positioning and timing errors. For example, in December 2006 a solar radio burst affecting GPS receivers was reported and well documented (10).

Spoofing

Spoofing is a situation in which one person or program successfully masquerades as another by falsifying data, and thereby gaining an illegitimate advantage. *GNSS spoofing* involves devices that create false signals to fool GNSS receivers into thinking that they are at a different location or different time.

The Iranian government claimed in December 2011 that spoofing was used by their cyberwarfare unit to commandeer and safely land a U.S. drone (UAV) in December 2011. While initially disputed, U.S. President Obama eventually acknowledged that the aircraft was a U.S. drone and requested that Iran return it. It remains unclear whether spoofing was used to control the UAV (see 7).

GNSS spoofing can be used to falsify timing information (banking, energy sector), but has been considered a very low risk due to the technical barriers in producing believable but fake GNSS signals. This perception changed as a result of research presented at the DEF CON 23 Hacking Conference in August 2015. At this event, Chinese security researchers demonstrated a low-cost GPS signal emulator using cheap, off-the-shelf components and open source code (see 8).

At the time of writing (2016-07), there are no confirmed examples of malicious GNSS spoofing attacks.

GNSS Operations Errors or Failures

GNSS systems are ultimately operated by humans, and errors or blunders are a possibility, albeit unlikely. In January 2016, a significant error in GPS ground control software caused global problems with timing. The software issue resulted in the upload of erroneous data to satellites, causing an error in the broadcast time offset between GPS system time (used in positioning and navigation) and Coordinated Universal Time (UTC). Because GPS time was accurate the effect was limited to timing users relying on UTC (see 2).

According to the official Air Force press release on the "GPS Ground System Anomaly" (see 3),

"On 26 January at 12:49 a.m. MST, the 2nd Space Operations Squadron verified users were experiencing GPS timing issues.

- *Core navigation systems were working normally, and the coordinated universal time timing signal was off by 13 microseconds which exceeded the design specifications.*
- *The timing error was not attributable to any type of outside interference, such as jamming or spoofing.*
- *The issue was resolved at 6:10 a.m. MST; however, global users may have experienced GPS timing issues for several hours."*

The error was identified during a period when erroneous data was being uploaded to GPS satellites. Thus the incorrect UTC time offset parameters were broadcast by those satellites with the new software, while the correct UTC values continued to be broadcast by the other satellites. Effects were widely reported in the media (see 2). Nearly all documented problems were in the telecommunication industry.

III. MITIGATION EFFORTS AND OPPORTUNITIES

In the U.S. an alternative backup system (eLoran) is being considered to deal with GNSS vulnerability, with a recent (April 20, 2016) public event at the New York Stock Exchange specifically addressing threats to timing systems (see 9).

In Canada the Department of Fisheries and Oceans (Canada Coast Guard) provides navigation support in Canada's oceans via provision of precise GNSS-based services. The Coast Guard operated the Loran-C navigation system in Canada until 2010, a system that incorporated Cesium atomic clocks at the transmission tower reference stations. The Coast Guard are assessing the need for a GPS backup system in Canada.

The National Research Council (NRC) is responsible for the definition and dissemination of official time in Canada, UTC (NRC), NRC realization of Coordinated Universal Time (UTC). The NRC is developing a Remote Clock solution that would be capable of dealing with interference or spoofing. Such clocks would meet the demand for reliable and traceable very high accuracy time service access across Canada.

The solution is based on high quality local clocks continuously measured against UTC (NRC) and controlled from the NRC time laboratory. While the method is based on GNSS signals for time transfer, it is far less vulnerable to spoofing and jamming. A network of NRC Remote Clocks over a wide geographic area will improve the quality of the local traceable time dissemination via data networks (Network Time Protocol [NTP] and Precision Time Protocol [PTP]).

At the Canadian Geodetic Survey, Natural Resources Canada, GNSS satellite orbital and onboard clock information is continually monitored in order to provide precise positioning services to Canadian industry, government and geoscience. Primary uses are in land surveying, engineering works (including the oil and gas industry), and geoscientific investigations related to the Earth's large scale deformation (climate change, seismic hazards, etc.).

This continuous monitoring of GNSS satellites provides the Geodetic Survey with the ability to monitor GNSS time at each satellite and thus monitor overall satellite constellation health. Such a system is sensitive to GNSS constellation errors or widespread problems, such as some space weather events, but would not be useful for local interference/spoofing (unless it occurs in the region of an NRCan GNSS tracking station). Figure 2 illustrates the location of the NRCan GNSS tracking stations (operated by NRCan's Canadian Geodetic Survey and Geological Survey of Canada).

GNSS data are streamed to NRCan from this network and from similar networks operated by international partners. Precise information about satellite clock behavior is obtained from this data enabling a near real-time assessment of each satellite's status.

Figure 3 illustrates a minor timing event for GPS satellite PRN11. The satellite clock rate broadcast to users is shown in green. The clock rate estimated by NRCan is shown in red, while the blue line is a smoothed estimate. At the end of the day on April 15, 2016, we see a discrepancy between the broadcast clock rate and the NRCan estimated rate. The difference is small, but clearly visible on this graph, illustrating the extraordinary precision of the NRCan system. The discrepancy lasts for approximately 5 hours and amounts to a total time error of approximately 3ns (equivalent to less than 1 meter in position). The operators of GPS did not issue a notice for this event, presumably because this is well within the specifications for the system.

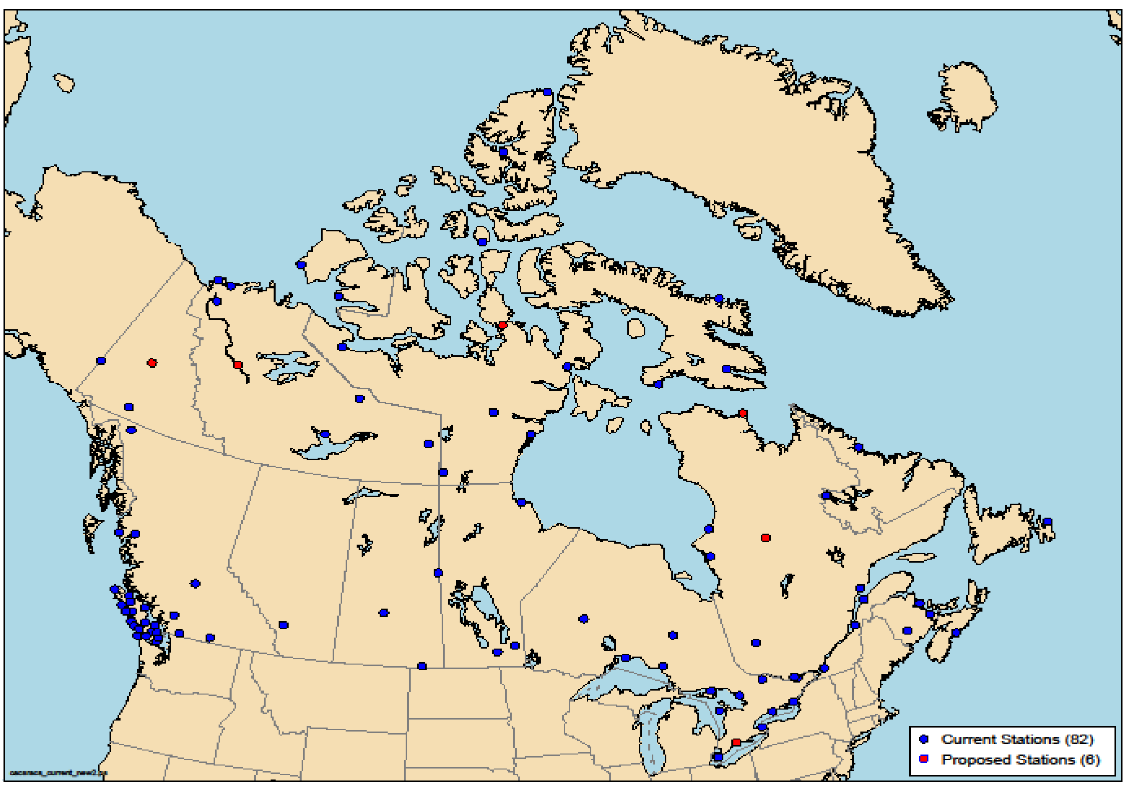

Figure 2: NRCan GNSS tracking stations (as of 2016-05)

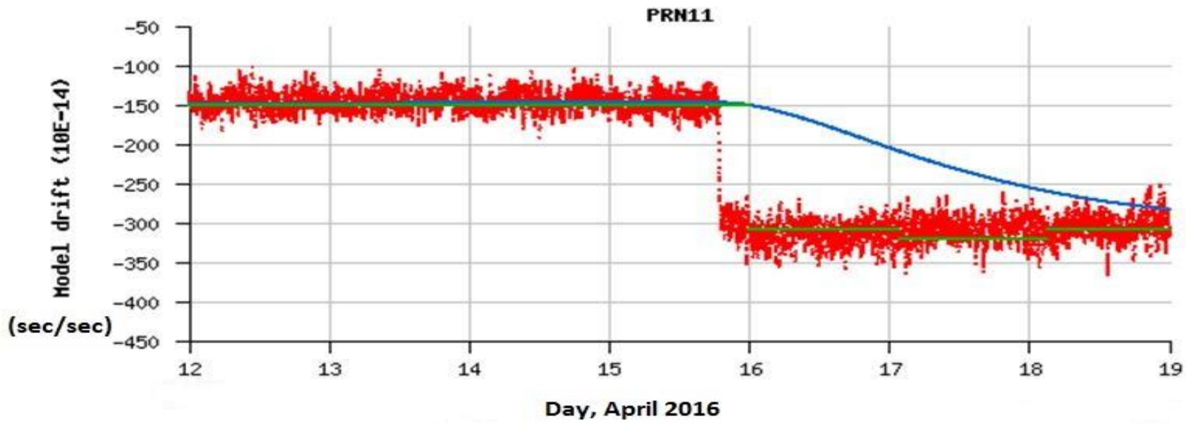

Figure 3: GNSS Time Integrity Monitoring

NRCan's GNSS networks are not currently designed for 24/7 integrity monitoring and automatic issuing of related alerts. Operationalizing the systems for such purposes would require significant further investment (i.e. 24/7 support, improved system-wide redundancy). NRCan is seeking input on whether wide-area monitoring is important for critical infrastructure protection.

IV. Conclusion

In light of the risks presented, operators of critical infrastructure are challenged to ensure that they have properly assessed the vulnerability of their systems to timing problems. For some applications/users the NRC and NRCan solutions may be useful to meet critical infrastructure needs.

A GNSS workshop is being organized by the Federal GNSS Coordination Board for October 21, 2016, in Ottawa. The workshop organizers have reached out to interested industry and government representatives. The workshop will include an update on GPS and Galileo constellations, applications and vulnerabilities. Contact the author for further information.

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About the Author

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Calvin has a B.A.Sc. in Electrical Engineering (U. Alberta), an M.A.Sc. in Engineering Physics (UBC) and a Doctorate in Space Science (York U).

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The Genesis and Development of Space Weather Forecast in Canada

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Abstract

Critical infrastructures, such as power grids and pipelines on ground, and satellites in space are subject to the impact of space weather. Power lines and pipelines are long grounded conductors where geomagnetically induced currents (GICs) can flow and cause damages as a consequence of geomagnetic disturbances. Satellite surface can be penetrated by energetic particles that can result in spacecraft operational anomalies and even failures as a consequence of enhancement of particle fluxes during a space weather episode. The resilience of critical infrastructures can be dependent upon space weather forecasts that alert stakeholders to take preventative measures to safeguard their systems. Space weather forecast in Canada has its beginning in simple one-zone magnetic forecast dispatched by the Ottawa Magnetic Observatory in the 1970s. The Ottawa observatory is linked to the very first Canadian magnetic observatory established in Toronto in the 1830s, and the magnetic legacy of Canada can be traced to early explorers who took magnetic measurements in Canada. The humble beginning of the Ottawa Magnetic Observatory issuing simple forecasts has blossomed into a Canadian Space Weather Forecast Centre (CSWFC), which is a full-fledged Regional Warning Center (RWC Canada) of the International Space Environment Service (ISES). This article presents a history of geomagnetism in Canada from early explorers to the present day magnetic network, and an account of the evolution of space weather forecasting from the early day forecasts by the Ottawa Magnetic Observatory to the present day forecasts by CSWFC.

I. Introduction

The collapse of the Hyrdo-Quebec power grid on March 13, 1989 [Czech et al., 1989], that plunged the province into darkness for 9 hours, affecting 6 million people due to the geomagnetic storm of March 13, 1989 [Hruska et al., 1990; Boteler and Jansen van Beek, 1993] and the consecutive failures of Telesat Canada's Anik-E1 and E2 satellites on January 20, 1994, that disrupted telephone services to remote northern communities and wreaked havoc with television and computer data transmission across Canada for hours due to the prolonged enhancement of relativistic electron fluxes in geostationary orbit [Lam et al., 2012] are examples of the impact of space weather upon society's critical infrastructures. To help alleviate such impacts, space weather forecasts are needed to warn stakeholders before the space weather episode arrives so that preventative actions can be taken. The Canadian Space Weather Forecaster Centre (CSWFS) in Ottawa provides such a space weather forecast service.

The seed of CSWFS's present forecasting service was planted when the Ottawa Magnetic Observatory undertook to produce the first magnetic forecast in Canada at the request of geophysical prospecting companies in the 1970s. The root of the Ottawa observatory can be traced to the building of the very first Canadian magnetic observatory on what is now the University of Toronto campus in the 1830s. The strong geomagnetic tradition in Canada can go even further back to the early explorers who made magnetic measurements in Canada. All these will be covered under Genesis, which will also touch upon things related to geomagnetism in Canada, such as the government agencies involved in the government magnetic network, non-government magnetic network, magnetic instrumentation, etc.

The sections under development will delve into details of the development of space weather forecast in

Canada in the decades to come after the first magnetic forecast was produced by the Ottawa Magnetic Observatory up to the present day.

The objective of this article is to consolidate relevant materials pertaining to the geomagnetic legacy and the development of space weather forecast in Canada into one convenient place for easy reference since the two are related to each other with the latter being a consequence of the former.

II. The Genesis of Space Weather Forecast in Canada

Canada has a geomagnetic heritage dating back to the early days when a mariner's compass was used in navigation and exploration. Canada also has a tradition of installing ground magnetic observatories ever since the first magnetic observatory was established prior to the birth of Canada. The genesis of space weather forecast in Canada is due to this strong Canadian geomagnetic legacy, as shown below.

Early Explorers Involved in Magnetic Observations

Magnetic observations were taken by mariners and explorers to aid with navigation long before geomagnetism evolved into a distinct discipline in the 19^{th} century. As early as 1534, Jacques Cartier, a French explorer, took declination measurements near the mouth of the St. Lawrence River [Ganong, 1964]. In 1604, Samuel de Champlain, the Father of New France, made magnetic observations in Halifax. Later, magnetic measurements were made in Quebec (1642) and in Montreal (1700. During voyages of the Hudson's Bay Company (which is the oldest commercial corporation in North America) into Hudson Bay, magnetic recordings were taken as early as 1668 at Fort Albany and later in 1725 at York Factory. It was customary, starting in 1668, for some Hudson's Bay Company captains to make regular magnetic declination observations during their annual trading trips to Hudson Bay. In 1778, Captain James Cook made observations at Nootka Sound on Vancouver Island. From 1819 to 1826, John Franklin recorded numerous magnetic observations during his widely distributed expeditions in Canada (These accounts are in Madill [1928]). In the early 19^{th} century, on voyages in search of the Northwest Passage in Canada's high arctic by the British navy, magnetic observations were made not only of declination, a component of interest in navigation, but also of inclination and total intensity of the magnetic field, thus signifying that terrestrial magnetism was no longer considered just as a navigation tool, but a subject worthy of study in its own right [Cawood, 1977]. Meanwhile, the north magnetic pole was located for the first time by James Ross on June 1, 1831 [Ross, 1834]. In the middle of the century from 1834 to 1846, the trade routes of the Hudson's Bay Company were traced by John Lefroy, then the director of the Toronto Magnetic Observatory, for the purpose of making an extensive magnetic survey of western Canada under the auspices of the Royal Society. Lefroy also initiated auroral observations that showed aurora were seen further south in Canada than in Europe [Lefroy, 1883]. These early auroral observations were the first indication that the auroral oval (which was unknown then and whose concept came much later) lies further south in Canada than in Europe.

The First Magnetic Observatory in Canada

In 1839, Edward Sabine, a foremost figure in the "magnetic crusade" to establish magnetic observatories throughout the British Empire in the 19^{th} century, built the very first Canadian magnetic observatory on what is now the campus of the University of Toronto. The Toronto Magnetic Observatory became fully operational in September 1840, 27 years before the birth of Canada, and had been one of the principal magnetic stations of the world until the turn of the century. This was a continuation of the long legacy of magnetic observations in Canada by early European explorers dating back to the 1500's, as mentioned in the last section. Sabine was the builder of other magnetic observatories in the British colonies, such as Cape of Good Hope, St. Helena (in the South Atlantic), and Tasmania. He put the early Toronto magnetic data to good use in works related to space weather, albeit unknowingly, since the term space weather was unknown then. He discovered the correlation between intensity variations of magnetic disturbances at Toronto and sunspot variations [Sabine, 1851; 1852] and found connections between magnetic storms and aurorae [Smith, 1989]. Sabine was the first to recognize the influence that solar activity has on Earth's magnetic environment, by means of Canadian ground data, thus cementing Canada's important role in the history of space weather as a discipline.

The establishment of the Toronto Magnetic Observatory, which has the distinction of being the oldest scientific institution in Canada, marked the beginning of a Canadian tradition of installing magnetic stations in the years to come, and lay the foundation for the Canadian Space Weather Forecast Centre in the future. The subsequent extensive magnetic network has enabled Canadian researchers to contribute significantly to studies related to space weather. As an historical note, the Toronto Magnetic Observatory was under the auspice of the Meteorological Service of Canada which was a branch of the Department of Marine and Fisheries then.

Government Magnetic Network

Although due care was taken to house the Toronto Magnetic Observatory in a magnetically clean environment, the advent of electric streetcars near the university campus began to cause interference to magnetic measurements. Thus in 1898, the Toronto Magnetic Observatory was forced by the "modern" mode of transportation to move to Agincourt, which is located north of Toronto about 12 miles from the original site. A few years later, in 1905, the Dominion Observatory was founded in Ottawa. Though it was primarily an astronomical observatory, scientists there (and at its successors later) periodically tracked the northward drift of the north magnetic pole [*Serson*, 1982]. Shortly after its founding, the Dominion Observatory began a comprehensive magnetic survey of Canada [French, 1932] that was to be repeated periodically in later years, in the hopes of obtaining a good measure of the magnetic delineation of the whole country over time. It is worth noting that the Dominion Observatory made notable contributions to the study of the Sun, an aspect of the astronomical function of the Observatory that continued with new solar instruments, both at optical (reflecting telescope of the Ottawa River Solar Observatory) and at radio frequencies (Algonquin Radio Observatory Solar Interferometer). Following the closure of the Dominion Observatory in 1970, the astronomical work was transferred to NRC. In the meantime, a second magnetic observatory was established in 1916 at Meanook, Alberta, under the direction of the Toronto office of the Meteorological Service of Canada. However, in 1936, both Agincourt and Meanook observatories were consolidated as branches of the Dominion Observatory, which established more observatories in later years. For example, two observatories at Resolute Bay and Baker Lake, in the Canadian polar region specifically, to observe magnetic variations at high latitudes were established after World War II. Three additional observatories at Fort Churchill, Yellowknife and Victoria were built during the International Geophysical Year (1957–1958). In March 1969, the Agincourt Observatory was closed because of steadily increasing industrial interference and highway construction near the site, thus ending about 70 years of magnetic recording from that location, and 129 years of the continuous record from the Toronto region which began in 1840. The Agincourt Observatory was replaced by the Ottawa Observatory, which became fully operational on July 1, 1968. Though all aspects of the Dominion Observatory were reorganized in 1970 according to new science governance objectives, the Ottawa Magnetic Observatory and its predecessors laid the foundation for modern space weather forecasting in Canada.

In an historical context, the Canadian government magnetic observatories have been under the auspices of Meteorological Service of Canada (in the 1800's), Dominion Observatory (1905-1970), Earth Physics Branch (EPB) of Energy, Mines, and Resources (EMR) (1970-1986), and now Natural Resources Canada (NRCan). EPB, in 1986, became part of the Geological Survey of Canada of EMR. In turn, EMR, in 1995, amalgamated with Forestry Canada to form NRCan. Currently, NRCan operates the Canadian Magnetic Observatory System (CANMOS) network of 14 observatories that automatically record the variations of the Earth's magnetic field digitally with the latest technology.

The magnetic observatory data have been used to produce magnetic charts, magnetic indices, and magnetic models of the International Geomagnetic Reference Field (IGRF) and the Canadian Geomagnetic Reference Field (CGRF). The data are also utilized by researchers in studies related to space physics and geomagnetism. Space weather products generated by NRCan using the magnetic data include magnetic forecasts; energetic, geomagnetically-trapped electron forecasts; and simulations of geomagnetically induced currents (GICs) for power grids and pipelines.

The Canadian Magnetic Observatory System (CANMOS)

The instruments used to measure the magnetic elements in the early days did not undergo any fundamental changes until the development of the fluxgate sensor in the 1930's [Gordon and Brown, 1972]. In 1947, Paul Serson of the Dominion Observatory was the first to use a fluxgate sensor, mounted on a nonmagnetic theodolite, to measure declination, inclination, and total intensity. Serson [1957] described a prototype recording fluxgate magnetometer developed for use in Canada. Automatic digital recording of magnetic data at Canadian magnetic observatories was introduced in 1969. The development of the automatic magnetic observatory system (AMOS) at the Earth Physics Branch, which was the successor of Dominion Observatory, resulted in the "transfer of technology to industry" in 1973 for the marketing of a commercial magnetic recording product. The conversion of all government magnetic observatories from analogue to automatic digital recording was completed by 1974. Since then, continuous upgrade and refurbishment have resulted in the latest Canadian Magnetic Observatory System (CANMOS), which provides greater stability than previous systems by means of an in-house designed tilt-correcting suspension for mounting the sensor that eliminates the pier tilt problem [Trigg and Olson, 1990]. The system also carries a highly accurate temperature-compensated crystal oscillator. CANMOS includes a commercial tri-axial ring core fluxgate magnetometer that samples the magnetic field at 8 Hz, a proton precession magnetometer that samples the field at 5-second intervals, and various storage media such as ZIP disks with outputs for 1-second, 5-second, and 1-minute data streams. The system also consists of a personal computer that controls all peripherals and records the data, which, while being stored on disk, are also transmitted to the data center in Ottawa via satellite and internet in near realtime, as well as to other centers of the International Real-time Magnetic Observatory Network (INTERMAGNET), which is the global network of magnetic observatories committed to adhere to a set of standards.

Non-Government Magnetic Networks

Monitoring Earth's magnetic field in Canada involves not only the federal government, as discussed above, but also universities. For example, in the summer of 1969 and early 1970s, a line of up to 9 magnetic stations of a three-component fluxgate magnetometer of the type described in Serson [1957] was established in western Canada along the corrected geomagnetic meridian of ~ 301^0 E by the University of Alberta's Institute of Earth and Planetary Physics. The distribution of magnetometers in Canada from north to south along a longitude allowed for the first time a closer look at the latitudinal characteristics of ground magnetic signatures of ultra low frequency (ULF) magnetospheric waves and ionospheric currents. Studies utilizing the data have shed light on some important magnetospheric phenomena. For instance, the observations of the latitude-dependent characteristics of ULF magnetic pulsations by Samson et al. [1971] led to formulation of the influential steady state field-line resonance model of Chen and Hasegawa [1974] and Southwood [1974].

The meridian line of magnetometers in Alberta discontinued operations in the Spring of 1972. However, in the mid 1970's the University of Alberta re-established four magnetometer stations in western Canada while the Earth Physics Branch of EMR operated three more magnetic stations in Central Canada in addition to the existing magnetic network, both as Canada's contribution to the International Magnetospheric Study (IMS) (which was an internationally coordinated observations principally from spacecraft and ground-based facilities over a three-year period 1976-1978). These stations supplied ground magnetic data necessary to supplement the IMS satellite program. The IMS network completed a crossed array, providing coverage for the studies of magnetospheric phenomena not only latitudinally, but also longitudinally [e.g. Lam, 1980].

In the 1980's, under the International Solar-Terrestrial Physics (ISTP) program, a ground-based auroral observation network known as the Canadian Auroral Network for Open Unified Study (CANOPUS) was set up in Canada to provide ground data to complement satellite observations. The CANOPUS magnetometer array was operated by the University of Alberta from 1986 to 2005. In the 2000's, as the ISTP program was winding down, the CANOPUS magnetometer array was continued and expanded into a magnetometer array known as the Canadian Array for Realtime Investigation of Magnetic Activity (CARISMA). The CARISMA array spans from near the Alaskan border to the west of Hudson Bay and from the Canadian arctic to near the U.S. border. Thus the University of Alberta's CARISMA and NRCan's CANMOS together provide a good magnetic coverage of Canada, especially along a north-south meridian known as the 'Churchill Line' in central Canada around 95^0 W.

Taking advantage of Canada's unique geographic location to study space weather, foreign scientists have also established ground stations on Canadian soil. For example, Boston University and Augsburg University have established a magnetic array with eight high-time resolution magnetometers and four standard observatories in eastern Arctic Canada in and around the footprint region of the cusp. The array is appropriately called The Magnetometer Array for Cusp and Cleft Studies (MACCS).

The unparalleled vantage point to observe space from the ground in Canada allows Canadian scientists to leverage this asset to participate in NASA's five-satellite constellation of the THEMIS (abbreviation for The History of Events and Macroscale Interactions During Substorms) mission launched in February 2007. To complement THEMIS, ground observations are needed to provide an overview of the magnetosphere since even a five-satellite constellation can only sample a particular region of space. The Canadian networks of magnetometers and all-sky imagers operated by the University of Alberta and the University of Calgary respectively supplement THEMIS substorm observations.

Summary

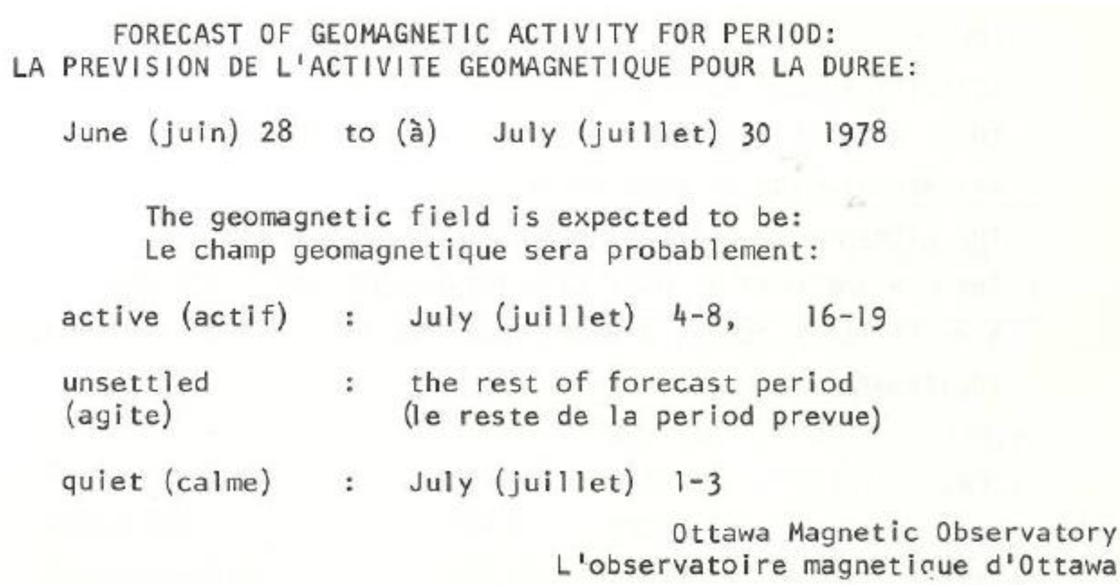
Canada has the largest landmass under the polar and auroral regions, with the north magnetic pole embedded on the Arctic Ocean and the curve of maximum auroral occurrence extending across the northern territories from the mouth of Mackenzie River to Labrador. Thus Canada is a region ideally suited for the study of space weather. The extensive network of ground-based magnetic monitors in Canada attests to this strategic location of Canada on the globe to remotely sense space above and to monitor space weather. The present day magnetic network is the descendent of Canada's long geomagnetic odyssey, which is the genesis of space weather forecast in Canada.

III. The Development of Space Weather Forecast in Canada

Natural Resources Canada (NRCan)'s Geomagnetic Laboratory operates the Canadian Space Weather Forecast Centre (CSWFC) in Ottawa. CSWFC is International Space Environment Service (ISES)'s Regional Warning Centre (RWC), and is mandated to provide space weather forecasting services for Canada. This section traces the development of Canadian space weather forecasting from its inception in the Ottawa Magnetic Observatory in the early 1970s to the present day operation by CSWFC.

1970s: The Inception Years

The Ottawa Magnetic Observatory, established in 1968, descended directly from the oldest scientific institution in Canada—the very first Canadian magnetic observatory that was built in Toronto in 1839 and became fully operational in 1840. A couple of years after routine operation started, the Ottawa Magnetic Observatory began receiving inquiries from the geophysical exploration industry for geomagnetic outlooks to be used in scheduling their field campaigns. Because of increasing requests, a magnetic forecast service was inaugurated in 1974. A quote from Hruska [1979] says: "Beginning in 1974, the Ottawa Magnetic Observatory, Earth Physics Branch, issues a '27-day Forecast of Geomagnetic Activity' every three weeks especially designed for use by mining and geophysical survey companies and by various government agencies". In those early days, the magnetic forecast service provided only a long-term forecast (up to a month in advance). In 1976, short-term forecasts (up to 3 days in advance) were introduced, and disseminated via local radio and telex, which were both later replaced by telephone answering service in 1979. Both types of forecasts predicted qualitative magnetic activity level in simple descriptive terms of active, unsettled, and quiet for the entire country. In addition to forecasts, a review of magnetic activity was also included in the disemantation so that geophysical prospectors could discern whether their survey results were due to magnetic signatures of buried targets of potential economic importance or due to natural magnetic disturbances. An example of the long-term magnetic forecast issued for July 1978 is shown in Figure 1.



FORECAST OF GEOMAGNETIC ACTIVITY FOR PERIOD:
LA PREVISION DE L'ACTIVITE GEOMAGNETIQUE POUR LA DUREE:

June (juin) 28 to (à) July (juillet) 30 1978

The geomagnetic field is expected to be:
Le champ geomagnetique sera probablement:

active (actif) : July (juillet) 4-8, 16-19

unsettled (agite) : the rest of forecast period (le reste de la period prevue)

quiet (calme) : July (juillet) 1-3

Ottawa Magnetic Observatory
L'observatoire magnetique d'Ottawa

Figure 1: Qualitative one-zone magnetic forecast issued by the Ottawa Magnetic Observatory (after Hruska [1979]).

In the late 1970s, a survey of 70 users indicated that 28% of users were involved in Ground Survey (General), 22% in Mineral Exploration, 20% in Observatory Work, 19% in Airborne Survey, 8% in Research, 3% in Telluric Method, 1% in Education, and 17% was classified as Other that includes information, calibration, radio communications-citizen bands, etc. [Hruska, 1979].

1980s: The Evolution Years

The qualitative magnetic forecast for the entire country was inadequate to characterize the diverse magnetic behaviour of Canada because the territory exhibits different latitudinal magnetic characteristics, as recognized very early on by Whitham et al. [1960]. Thus the original qualitative one-zone forecast needed to be refined. By the mid-1980s, sufficient experience had been gained such that separate forecasts for the three distinct magnetic zones in Canada (polar cap, auroral, and subauroral) could be made [Hruska and Coles, 1987]. Although the boundaries between the three magnetic zones can change depending upon the levels of magnetic activity, for practical purpose, the zones for a three-zone forecast are defined as follows: polar cap, above 70^0 N; auroral zone, 55^0 to 70^0 N; subauroral zone, below 55^0 N. The qualitative one-zone long-term forecast was to be replaced by a quantitative three-zone forecast, which is based on a daily index called DRX that is defined as the daily mean of 24 hourly ranges (i.e. maximum minus minimum during each hour) in the X component of the magnetic field measured at a magnetic observatory. Initially, the three-zone forecast was attempted manually using a forecaster's skill, judgement and intuition. However, this kind of forecasting is subjective and dependent entirely upon a forecaster's experience and expertise. Hence, it was desirable to take the bias and subjectivity of humans out of forecasting and place the forecasting process on an objective basis based on numerical techniques. To this end, a linear prediction filter was developed [Lam, 1987]. After testing this numerical method of forecasting on about one and half years of data, the linear prediction technique was implemented in early 1986, and has been used routinely to produce the long-term three-zone forecast since then. The forecasts are presented in a graphical format for each zone for up to 27 days in advance (long-term forecasts can be viewed on the web page of Long Term Magnetic Review and Forecast via the Government of Canada's Space Weather Canada portal to be given later). In the meantime, short-term forecasts were updated every morning manually and voice recorded on telephone to provide a qualitative geomagnetic outlook for the three zones for up to 3 days. As before, a review of magnetic activity accompanied both kinds of magnetic forecasts.

In 1986, in recognition of the forecasting work done in Canada, the International Ursigram and World Day Service (IUWDS), the predecessor of the International Space Environment Service (ISES), invited the Ottawa Magnetic Forecast Service to join IUWDS as an Associate Regional Warning Centre (ARWC). The invitation was accepted with the establishment of ARWC Ottawa.

1990s: The Automation Years

The 9-hour Quebec power blackout caused by the March 13, 1989 magnetic storm (mentioned in Section I) demonstrated the necessity of enhancing the forecasting service by developing the ability to respond quickly to sudden changes in the state of the geomagnetic field. Thus the need for automatic updated forecasts 24 hours a day, 7 days a week, was recognized. The addition of satellite telemetry to Canadian magnetic observatories during the early 1990s, along with other developments in rapid data transfer via the Internet, rendered the geomagnetic, solar, and solar wind data available in near realtime, allowing automated forecasting systems to be operationally viable.

In order to automate the short-term forecast, the qualitative forecast needed to be replaced by a quantitative forecast so that judgemental procedures used in the qualitative forecast could be replaced by computer programs that could be run automatically. To this end, a quantity known as hourly range in the X component (HRX) is used (see Figure 5 in Coles and Lam [1998]) in algorithms that produce the short-term forecast. As an historic note, Whitham et al. [1960] very early on chose hourly range in magnetic field components as a parameter in their studies on the latitudinal characteristics of magnetic activity in Canada after considering the relative merits of various measures of magnetic activity at high latitudes.

An hourly automated forecast system was implemented in June 1995 based on the near real-time data, which were processed, sorted, and analysed automatically. Based on a statistical study of solar events and magnetic disturbances [Lam and Samson, 1994] and on a statistical study of long-term diurnal magnetic variations that had provided typical daily variation curves, dubbed the "iron curves", for the different regions, a series of pre-defined rules were derived. A weighted combination of these "iron curves" and HRX data for the latest 24 hours plus a further weighting based on recent solar activity incorporating, if any, occurrence of coronal mass ejections and the presence of coronal holes, as well as recent solar wind data all in combination with the empirical rules derived from statistical studies provide the basis for the quantitative forecasting; thus inputting near real-time data into the forecast engine outputs the quantitative forecasts. The entire process was repeated every hour, taking advantage of any new solar, solar wind, or magnetic data that had been received and providing an automatically updated forecast hourly.

With the advent of the World Wide Web in the 1990s, both the long-term and short-term magnetic forecasts were beginning to be made available on the internet. The long-term forecasts had been customarily faxed to about 10 users and mailed to about 350 users that included exploration geophysical companies, aeromagnetic surveyors, amateur ham radio enthusiasts, satellite operators, GPS users, pipeline operators, electric power utilities, the military, university researchers, general public, and a service company in the now demised World Trade Center in New York City. The number of users on the mailing list had been stable in the 1990s and saw little increase, probably due to the easy access of the long-term forecasts via the web.

Within this decade in 1992, ARWC Ottawa became a full-fledged Regional Warning Centre (RWC) of Canada of IUWDS, which changed its name to International Space Environment Service (ISES) in 1996. The Ottawa Magnetic Forecast Service became the Canadian Space Weather Forecast Centre (CSWFC).

ISES as an international consortium of regional space weather forecast centres is growing rapidly, as witnessed by the additions of four new members during the last couple of years. With ISES as a brand becoming more recognized, it is worthwhile to recall how the name ISES came into being. During the Fifth Solar-Terrestrial Prediction Workshop held at Hitachi, Japan on January 23-27, 1996 (this turned out to be the very last Solar-Terrestrial Prediction Workshop ever held since the first such workshop was started in Boulder in April 1979). One evening during the workshop, representatives from ten regional warning centers gathered together to decide on the name change for IUWDS. Several names were suggested, including International Space Environment (ISE), International Space Environment Organization (ISEO), and, of course, International Space Environment Service (ISES). After some discussion, there was overwhelming support for the name ISES that was proposed by Peggy Ann Shea of Air Force Research Laboratory, Hanscom AFB (now retired). Hence, ISES was born in 1996, replacing IUWDS that had been in existence since 1962.

2000s: The Consolidation Years

The new Millennium saw the consolidation of the delivery of the forecast products via the internet and the refinement of the product outputs. During this decade, the CSWFC short-term forecast was updated automatically every 15 minutes (i.e. the entire automatic forecast process mentioned in the last section that used to be repeated every hour was now repeated every 15 minutes), and disseminated over the internet. (Updating the forecast every 15 minutes is the standard currently adhered to). The frequent updates can quickly accommodate sudden changes in space weather conditions. This kind of dynamic forecast at CSWFC is unique and is an improvement over the common practice of producing a forecast that remains static for a day, unchanged until the next day at a prescribed time, as is customarily done elsewhere.

Furthermore, magnetic forecasts are provided not only for the three magnetic zones as in the earlier decades, but also for different Canadian regions, as well as for locales immediate to where the magnetic observatories are positioned. The outputs of the forecast take a variety of forms ranging from simple text to tabular to graph to map. Should space weather conditions warrant them, major storm watches are issued automatically, superimposed on the pre-existing forecasts to alert users. Since HRX values vary widely for stations located at different magnetic zones for a given level of magnetic activity (for example, a HRX value that corresponds to quiet level in the auroral zone would correspond to active level in the subauroral zone), HRX is converted to a common scale of Kr. Kr is defined regionally over one hour and is similar to a planetary Kp index that is defined globally over three hours as both indices have values ranging from 0 to 9. The use of Kr facilitates the automatic issuance of storm warnings, should a number of stations exceed a certain Kr threshold.

In this decade, in addition to the long-term and short-term magnetic forecasts, forecast of energetic electron fluence (i.e. accumulation of flux in a day) in geostationary orbit was implemented in 2002 based on the geosynchronous electron's relationship with magnetic activity observed at a station in the auroral zone in proximity to field lines threading geostationary satellites at 6.6 R_E [Lam, 2004]. Although high-speed solar wind streams are known to be precursors to electron flux enhancement (e.g. Paulikas and Blake, 1979), a prediction scheme based on satellite data will result in no electron forecast if solar wind speed data are unavailable due to telemetry problem or data contamination etc. On the other hand, an electron prediction scheme based on data from a robust ground magnetometer, as is done here, will ensure no interruption of electron forecast because reliable ground magnetic data are always available from several stations in the auroral zone. The electron forecast was a response to the failures of the two Canadian Anik E telecommunication satellites on January 20, 1994, as mentioned in Section I, and the subsequent identification of high fluxes of energetic electrons as the culprit [Baker et al., 1994].

The presence of the auroral oval over a large portion of its territory makes Canada particularly vulnerable to space weather effects. Geomagnetic disturbances due to the intensification of current flowing in the auroral oval can induce electric fields that drive geomagnetically induced currents (GICs) in long conductors, such as power lines and pipelines in Canada. These induced currents can cause power outages and pipeline corrosion. Thus research on the effects of GICs on power grids and pipelines has been rigorously pursued at CSWFC. This research has enabled CSWFC to develop a variety of services to simulate induced current flows in pipelines and power grids [Trichtchenko and Boteler, 2004].

In this decade, CSWFC started establishing an array of relative ionospheric opacity meters (riometers) [Danskin et al., 2008]. Riometers are essentially radio receivers of cosmic radio noise. Riometers are inexpensive tools to monitor radio wave propagation conditions in Canada, as increases in ionization in the ionosphere due to solar flares or energetic particle precipitations or night-time auroral particle precipitation would result in the attenuation of the radio wave energy. Radio wave absorptions are associated with poor high frequency (HF) radio wave propagation conditions. Since ionospheric absorptions can disrupt vital radio communication between ground and polar flights (where HF radio communication is the only option as satellite communication in the polar region is impossible with geostationary satellites below the surface horizon), CSWFC's riometer data would serve a growing need for improved information about HF radio conditions in Canadian air space.

2010s: The Current and Future Years

Two fronts are being pursued to improve CSWFC's forecasts. A physics-based approach involving modeling of solar eruptions is being developed with the aim of simulating the paths of eruptions from Sun to Earth in a cluster of high-performance computers on a timely basis for operational use. Statistical studies are also being carried out to derive new algorithms utilizing a wealth of well-archived and easily accessible solar, solar wind, and geomagnetic data for incorporation into CSWFC's evolving robust forecast machine to produce better forecasts.

The network of riometers is being expanded. Given the increasing air traffic above the Canadian polar region, thanks to the growing tie between North America and China, adverse space weather conditions are becoming a concern in transpolar flights—such space weather can interfere with HF radio communications and pose radiation hazards for passengers and crews. The expanding riometer network at high latitudes to monitor radio absorptions will help to formulate tools to nowcast and forecast HF radio propagation conditions, as well as energetic protons that precipitate to the polar cap and penetrate living tissues at high altitudes.

On the housekeeping side, the faxing of the long-term magnetic forecast and review to about 10 clients and the mailing to about 350 clients was stopped in 2010 because of increasing hits to the long-term forecast web page. However, there are about 60 die-hard users who still prefer to have the forecast "pushed" to them rather than "pulling" the forecast themselves from CSWFC's web, thereby requiring the dispatch of the long-term forecast to them via email. For outreach, RSS feed was introduced in 2011. Twitter (@SpaceWeatherCa) has also been used since 2014 as another social media outreach tool to update the public on stormy geomagnetic conditions in Canada.

The highlights of this decade thus far have been the successful implementation of the GIC Simulator [Boteler et al., 2014] for the critical infrastructure of power utilities in 2013, and the daily issuance of Space Weather Bulletin beginning April 6, 2011, to the Government Operations Centre (GOC) of the Government of Canada. The GIC Simulator is a desktop application that simulates the magnitude of GICs in power grids, based on power system configurations and specifications, as well as on magnetic field variations that the system is subjected to. The simulator is currently being used by a number of power utilities in Canada. The GOC uses the information contained in the Space Weather Bulletin in their daily briefing and disseminates storm watches to stakeholders of critical infrastructures should such warnings be evoked in the Bulletin. The daily bulletins for a given calendar year are collated together with highlights of some worth noting space weather conditions of that year into a Geological Survey of Canada Open File that is to be published yearly. The first such open file series covering all the bulletins in the first year of dissemination is given by Fiori et al. [2012]

Summary

This section has covered the period from the first magnetic forecast by the Ottawa Magnetic Observatory to the present day forecast by the Canadian Space Weather Forecast Centre (CSWFC). The time span has been divided into decades from 1970s to 2010s, and the forecasting endeavours for each decade have been highlighted. CSWFC's space weather forecasting services mentioned in previous sections can be accessed via the Government of Canada's Space Weather Canada portal: http://spaceweather.ca/, and details on space weather products and forecast verification are given by Trichtchenko et al. [2009]. Users without easy internet access in situations like during field campaigns can dial 1-613-992-1299 (which has been used since 1979) for the recorded magnetic forecast and review message that is automatically updated hourly at quarter after the hour. As mentioned in the last section, an RSS feed and Twitter are also available as outreach tools.

Finally, to conclude this section on the development of space weather forecast in Canada, the photos of CSWFC and a map of the CSWFC's ground monitors, as well as bibliography on space weather are presented.

Figure 2 shows the outside and inside of the CSWFC where space weather forecast is made. Figure 2a shows the Geomagnetic Laboratory of Natural Resources Canada (NRCan) that houses CSWFC and the Ottawa Magnetic Observatory on the outskirts of the city of Ottawa in an environment devoid of artificial magnetic interferences. Figure 2b shows a forecaster giving a space weather talk while Figure 2c and 2d show forecasters discussing solar and ground observations respectively in the operational room of the CSWFC.

Figure 2a: CSWFC's outside.

Figure 2b: A forecaster giving a space weather talk at CSWFC.

Figure 2c: Forecasters discussing solar observations at CSWFC.

Figure 2d: Forecasters discussing ground observations at CSWFC.

Figure 3 is a map showing the Canadian government magnetic network equipped with the Canadian Magnetic Observatory System (CANMOS) currently being used by the CSWFC for space weather forecasting, as well as the locations of NRCan riometers used by the CSWFC to infer HF radio propagation conditions. Both the Dip Pole (north magnetic pole) and the Dipole Pole (north geomagnetic pole) are shown on the map. The north magnetic pole, where the magnetic dip (inclination) is vertical, is determined by direct observation or by model calculations. The location of Dip Pole on the map (83.95^0 N, 120.72^0 W) is the north magnetic pole based on the most recent magnetic survey carried out by NRCan in April 2007 [Newitt et al., 2009]. The north geomagnetic pole is derived from a reference model approximating the Earth's magnetic field as that of a centered dipole, and is useful in scientific studies. The location of the Dipole Pole on the map (80.4^0 N, 72.7^0 W) is the north geomagnetic pole for 2016 based on the latest version of the International Geomagnetic Reference Field (IGRF-12). The auroral oval bounded by two dashed curves is also indicated to illustrate the strategic geomagnetic position of Canada for space weather monitoring. The auroral oval was transcribed from the NOAA Space Weather Prediction Center's auroral oval map (extrapolated from measurements from NOAA's National Polar-orbiting Operational Environmental Satellite System) for November 28, 2010 at 0623 UT (when the longitude of ~95°W was around local midnight and the estimated magnetic index *Kp* was 2). It should be noted that the auroral oval is not static, but can contract and expand depending on geomagnetic activity. For example, the midnight equatorial boundary of the oval can reach the northern states in the central United States when *Kp* is 5. The poles and the oval on the map delineate projections of the outer magnetosphere (magnetosphere being a magnetic shield protecting the Earth from the onslaught of solar wind emanating from the Sun) and its boundary with the inner magnetosphere onto Canadian territory, demonstrating that ground monitors on Canadian soil have "front row" seats for observing space weather phenomena. By the same token, Canada is also vulnerable to the adverse effects of space weather that impact critical infrastructure for precisely the same reason it remains an ideal place in which to observe space weather. Thus CSWFC's research and forecasts are crucial in helping to fulfil the goal of protecting critical infrastructure in Canada from the hazards of space weather.

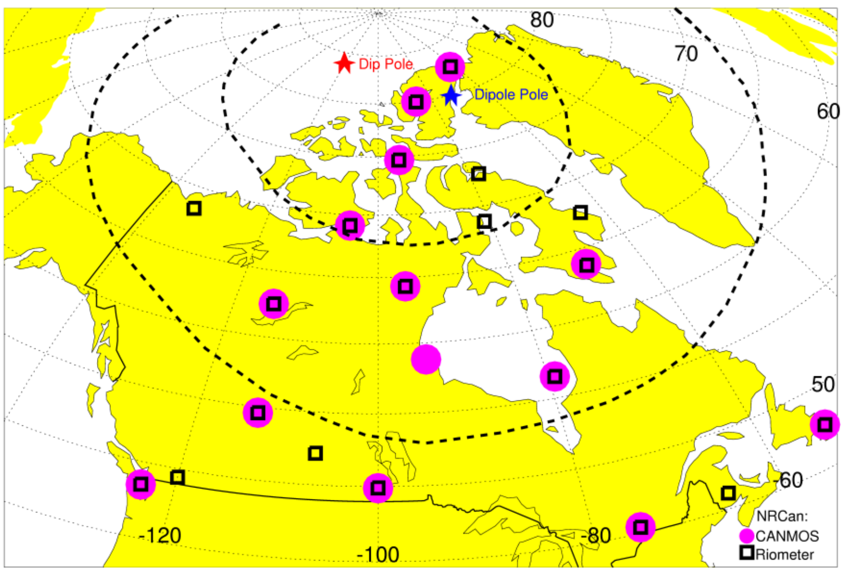


Figure 3: CSWDFC's ground monitors for space weather. See text for details.

To end this section, a bibliography of relevant space weather publications by CSWFC staff are provided (references quoted in previous sections will not be repeated here) as an educational resource for readers desiring to pursue the subject matter further.

An overview of space weather and potential impacts on power systems in Canada is given by Fiori et al. [2015]. One of the largest space weather events of Solar Cycle 23 occurred in November 2004 that involved nine halo coronal mass ejections interacting in the interplanetary medium on their way towards Earth and posed considerable challenges to regional warning centers to make forecasts, and the insight into the complexity of this event is provided by Trichtchenko et al. [2007]. Three case studies, each tracing an entire space weather episode from its inception on the Sun, propagation through the interplanetary medium manifestation on the ground as intense magnetic and electric fluctuations, and its eventual impact on power systems on the Earth, are featured in Lam et al. [2002]. Based on photospheric field observations on the Sun, Nikolic et al. [2014] have developed a numerical framework for operational solar wind prediction. Based on Advanced Composition Explorer (ACE) satellite data, Lam [2009] has shown the utilization of low-energy energetic particles in solar wind to gauge the geo-effectiveness of a coronal mass ejection, the precursory attribute of particle enhancements for geomagnetic disturbance, and the use of maximum particle enhancement to forecast the subsequent maximum geomagnetic disturbances in Canada's three magnetic zones. In an attempt to develop better forecasts of geomagnetic activity, hourly ranges of geomagnetic data have been analyzed by Danskin and Lotz [2015] with a focus on how the data is distributed. Daytime continuous magnetic pulsations [Lam, 1989a] are a signal source for geomagnetic sounding to sense subsurface conductive structures, but a noise source for magnetic surveys to delineate buried targets of potential economic importance. Lam [1989b] has formulated a procedure to predict optimum geomagnetic conditions for magnetotelluric induction imaging during high pulsational activities, and for resource exploration during low pulsational activities. Lam [2006] has developed an index for night-time irregular magnetic pulsations that can be used to nowcast substorms, which is an intense localized night-time magnetic disturbance due to a sudden and explosive energy release process on the night side (whose manifestations include northern light display, thereby implicating that the pulsation index can be used to nowcast aurora). For pipelines and power systems, Boteler [2013] has developed a versatile technique to model GICs for the former, while Boteler [2014] has examined the methodology of simulating GICs for the latter. GIC risk due to storm sudden commencements (SSC) has been assessed by Fiori et al. [2013] with identification of the current systems responsible. Although power transmission lines and pipelines are different infrastructures, they are basically long grounded conductors, and so Trichtchenko [2016] has tackled the electromagnetic induction in a multi-layered infinitely long cylinder embedded in a uniform media that is regarded as a proxy for such conductors, and proposed a simple approximate analytical formula that can be used in space weather applications. Extreme geomagnetic and geoelectric disturbances that could happen once in 50 and 100 years have been assessed by Nikitina et al. [2016] using extreme value analysis, and their results are useful to assess impact from space weather to critical infrastructure like power systems and other technology.

IV. Conclusion

According to a Chinese proverb which says that if you drink the water, think about the source of that water (饮水思源) thus with the resilience of infrastructure in Canada, such as power grids, pipelines, and satellite assets dependent upon space weather forecast, it is worthwhile to trace the linkages that eventuate to the current space weather forecast endeavour in Canada. We have, thereby, taken a journey back in time to pay homage to the early explorers who carried out magnetic measurements, then to the establishment of the very first Canadian magnetic observatory, to the expansion of Canada's magnetic network, to the first magnetic forecast by the Ottawa magnetic observatory, to the establishment of the Canadian Space Weather Forecast Centre (CSWFC), and the evolution of the forecast service during the intervening years from the early days of the Ottawa Magnetic Observatory to the present day of the CSWFC. Pausing at this point in time and reviewing the past before expanding work in other areas of space weather serve to preserve the corporate memory before it is lost, and also as a reminder of the overarching goal of the CSWFC, which is to strive to provide good forecasting services that can benefit infrastructure providers to mitigate space weather impacts upon their systems.

About the Author

****Hing-Lan LAM*** *holds a Ph.D. in Geophysics from the University of Alberta and is a senior research scientist at the Canadian Hazard Information Service and Public Safety Geoscience Program, Natural Resources Canada, Ottawa. He was involved in geothermal studies related to geothermal energy potential in Alberta and heat flow in the Western Canadian Sedimentary Basin. He has been engaged in geomagnetism pertaining to induction and magnetic pulsations. He is now focussed on space weather work, both in research and in operation. He has developed algorithms to forecast geomagnetic activity and to predict energetic electrons. While carrying out research that can lead to the improvement of space weather products and services, he continues to contribute to the smooth functioning of the Canadian Space Weather Forecast Centre.*

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Understanding and Defining Extreme Space Weather

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Abstract

Space weather-driven geomagnetically induced currents (GIC) are known to disrupt operation of man-made technological systems. Even though numerous complexities, such as ground conductivity, conductor system configuration, and other engineering details, including high-voltage power transformer design are critical for in-depth assessment of the GIC threat, the geoelectric field is the primary quantity driving GIC that can provide an indication for the potential GIC hazard. Our understanding of space weather interaction with the Earth's upper atmosphere has significantly advanced in the last 30 years; however, our knowledge of detailed spatiotemporal characteristics related to geomagnetic superstorms is still limited. One of the key challenges is to understand the basic processes that initiate the development of dynamic magnetosphere-ionosphere currents, which in turn lead to the largest surface geoelectric fields. To enhance national preparedness, it is critical that we understand these processes in order to address strategic goals highlighted in the National Space Weather Strategy and Action Plan.

I. INTRODUCTION

Space weather is a term which basically describes the conditions on the Sun, in the solar wind, and in the near-Earth space environment that can impact the performance and integrity of a range of space-borne and ground-based technological systems, and affect human activities or health on Earth and in space. Space weather is a highly complex and multi-faceted phenomenon, but just like terrestrial weather, space weather is pervasive and its impact is a major challenge to compensate.

Concern about the vulnerabilities of technological infrastructure to Earth-directed space weather events has significantly grown in the last two decades. Space weather-driven geomagnetically induced currents (GIC) can disrupt operation of man-made technological systems, such as power transmission grids, oil and gas pipelines, and telecommunication cables (*Boteler and Jansen van Beek*, 1999; *Pirjola*, 2000; *Molinski et al.*, 2000). The threat of adverse impacts on critical technological infrastructure like power grids has prompted renewed interest in extreme space weather (e.g., *Thomson et al.*, 2011; *Pulkkinen et al.*, 2012; *Ngwira et al.*, 2013, 2014; *Pulkkinen et al.*, 2015a; *Ngwira et al.*, 2015). The ultimate challenge for the scientific community is to **gain better understanding** of extreme storms, knowledge that will ensure we can more accurately predict extreme events.

II. SPACE WEATHER AND GEOMAGNETIC DISTURBANCES

Space weather origins can be traced back to the Sun. Large, violent eruptions of solar material from the Sun's corona, known as coronal mass ejections (CMEs), are the main source of major geomagnetic storms in the Earth's upper atmosphere. Figure 1 shows an extreme ultraviolet image of the Sun taken by an extreme ultraviolet telescope (EIT) aboard the NASA/ESA Solar and Heliospheric Observatory (SOHO) that has been super imposed on a SOHO large angle and spectrometric coronagraph (LASCO) C2 instrument image of the CME. The LASCO coronagraph instrument enables observation and estimation of the properties of CMEs as they propagate in the solar corona. Propagation of individual CMEs typically take one to three days to reach the Earth depending on the speed of the CME, but very fast-moving, extremely rare CMEs can travel in less than 24 hours. The CME speed can be classified according to the "CME SCORE" scale created by scientists at the Space Weather Research Center (SWRC) operating at the NASA Goddard Space Flight Center (GSFC) (*Evans et al.*, 2013).

During periods of high solar activity, the Sun can launch several CMEs towards Earth. CMEs contain plasma and an embedded solar magnetic field known as the interplanetary magnetic field (IMF). When Earth-directed CMEs interact with the magnetosphere, a region in the upper atmosphere dominated by Earth's magnetic fields, they trigger geomagnetic disturbances (GMDs) that affect the global magnetic field. The most intense disturbances are produced when the IMF orientation is oppositely directed to the Earth's magnetic field, a condition often referred to as a southward IMF. Under southward IMF conditions, the coupling process can transfer CME mass, momentum, and energy into the Earth's near-space environment at a significantly high rate. This enhanced input stimulates a chain of complex dynamic processes within the magnetosphere-ionosphere coupled system that drives phenomenon, such as auroral displays at high-latitude locations and GIC.

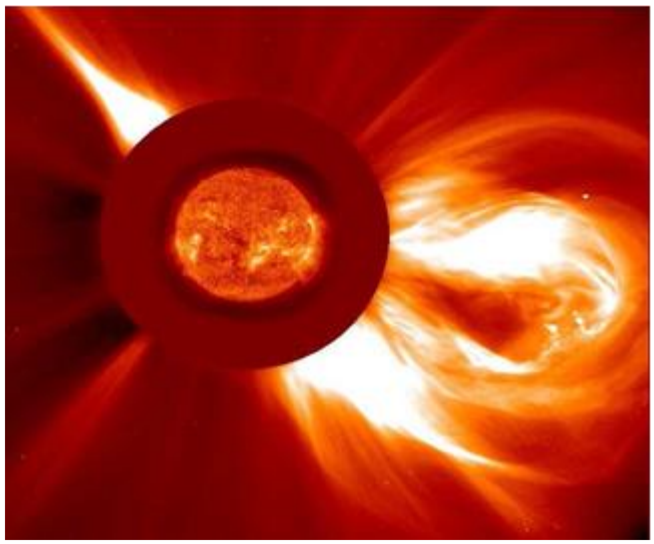

Figure 1: Image of a CME blasting off the solar surface on December 2, 2003. Captured by NASA/ESA SOHO spacecraft.

III. IMPACT ON ELECTRICAL POWER SYSTEMS

From a GIC perspective, the key aspect of dynamic magnetosphere-ionosphere processes is the variation in near-space electric current systems. Intense time-varying currents cause rapid fluctuation of the geomagnetic field on the ground. A variety of critical infrastructures can be disrupted by GMD events, as pointed out above. However, electric power systems constitute probably the most critical technological infrastructure vulnerable to GIC effects, and are singled out in this paper.

The physical principle of the flow of GIC in technological systems is fundamentally based on Faraday's law of induction: a changing magnetic field induces currents in conductors. More accurately, Faraday's law relates the formation of the geoelectric field to temporal variation of the geomagnetic field. This electric field is responsible for currents that flow on electrical power grids. In general, the level of GIC flowing through a power transmission node is determined by a combination of the horizontal geoelectric field on the Earth's surface, which is a function of the Earth's geological structure, and the characteristics of a specific power system (e.g., *Molinski et al.*, 2000; *Pirjola*, 2000).

Rarely occurring geomagnetic superstorms can cause severe effects to the electric grid. Collapse of the Hydro-Quebec power network grid in Canada during the March 13, 1989 superstorm is a dramatic reminder of the detrimental impact space weather-driven GIC can have on power systems. The GIC produced during this superstorm caused a blackout of the entire Hydro-Quebec network on a time scale of just under two minutes (*Boteler*, 2001; *Bolduc*, 2002, and references therein). The power outage was the result of widespread transformer saturation and affected 6 million people for about 9 hours. During the same event, a generator step-up power transformer was destroyed in New Jersey, USA.

More recently, the Halloween storm of October 2003 caused failure of a high-voltage power transmission system in Malmo, Sweden (e.g., *Pulkkinen et al.*, 2005; *Wik et al.*, 2008, 2009). This incident caused a power blackout that lasted for about an hour and left around 50,000 customers without electricity (*Wik et al.*, 2008). In South Africa, at a mid-latitude location that was previously considered much less prone to GIC impacts, possible transformer damages were reported during the same storm of October 2003 (*Gaunt and Coetzee*, 2007).

In May 2013, the Federal Energy Regulatory Commission directed the North American Electric Reliability Corporation (NERC) to develop reliability standards that address GMD impact on the reliable operation of the Nation's bulk power system in response to acknowledged major GMD threats. Following this order, NERC has been working on GMD mitigation standards that include "Benchmark Geomagnetic Disturbance Event Description" (2014). In this context, one of the major requirements for analysis of the GIC hazard is a specification of the geoelectric field at spatial scales relevant for specific power systems.

IV. Forecasting and Mitigation

Reducing the nation's vulnerability to space weather has been identified as a national priority by The White House-led National Science and Technology Council (*National Space Weather Strategy*, October 2015). GIC was also identified as the top threat in this document. Goal 1 of the National Space Weather Strategy and Action Plan includes extracting information about 1 in 100-year geoelectric fields and theoretical maximums.

To mitigate for solar extreme events requires a number of technology-specific approaches which come down to engineering out as much risk as is reasonably possible and/or adopting operational strategies to deal with the eminent risk. To assess the geomagnetic hazard to power systems, it is helpful to be able to simulate the GIC produced during extreme GMD events.

A number of methods have been developed for power system analysis as applied to modeling GIC (*Lehtinen and Pirjola*, 1985; *Zhang et al.*, 2012; *Bernabeu*, 2013; *Boteler*, 2014; *Boteler and Pirjola*, 2014, and references therein). Geoelectric fields in the near vicinity of the power network are used as voltage sources or equivalent current sources in the transmission lines (e.g., *Boteler*, 2014). For the engineering community, this is the parameter that must be provided from the forecast. Therefore, forecasting space weather events with sufficient lead time and accuracy is critical for developing appropriate operational strategies.

To achieve a more reliable forecast framework, several space-based and ground-based instruments are required to monitor the storm progress from onset of activity on the solar surface through to its impact on Earth. These monitors provide the essential measurements needed to test and improve modeling techniques. Figure 2 shows simulation outputs from the Wang-Sheeley-Arge (WSA)-ENLIL model (*Arge and Pizzo*, 2000; *Odstrcil et al.*, 2004) depicting the propagation of an Earth-directed CME that impacted the magnetosphere on July 20, 2016. The simulations were performed using the facilities available at the Community Coordinated Modeling Center (CCMC) operating at NASA-GSFC.

Over the last decade, significant progress has been made in our forecasting ability, but accurately forecasting GMD events is still a major challenge that requires further improvement in modern techniques to deliver actionable information. There are a number of ongoing efforts to improve these techniques (e.g., *Owens et al.*, 2014; *Devos et al.*, 2014; *Pulkkinen et al.*, 2015b).

Irrespective of forecasting ability, space-based and ground-based observations of the Sun and the near-Earth space environment provide critical information for the mitigation of extreme space weather events. As mentioned above, modeling and interpretation of space weather events rely strongly on the availability of quality geospace observations. Our limited knowledge about the temporal and spatial variability of magnetosphere-ionosphere currents is partly due to the difficulty of making observations everywhere simultaneously. Ideally, all of the electrodynamic parameters required for modeling would be routinely measured at high resolution throughout the globe. In reality, what is available is a sparse collection of single-point measurements irregularly located in time and space. Therefore, more geospace observations are needed to improve the accuracy of our forecasting capabilities.

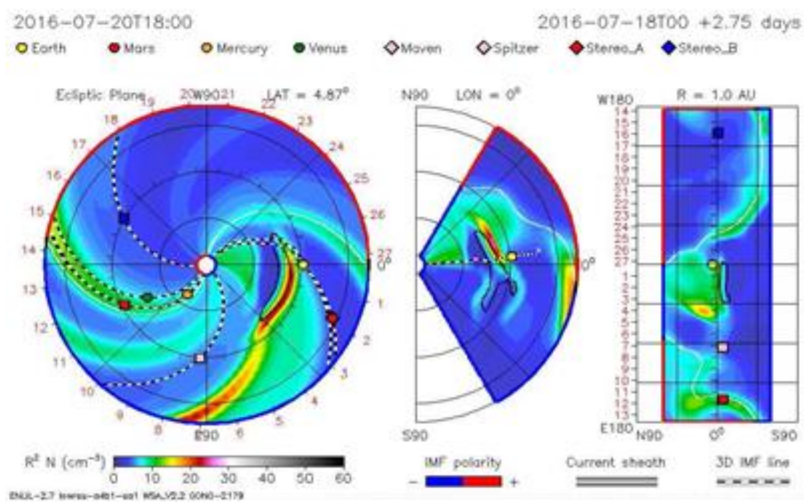

Figure 2: Simulation outputs from the WSA-ENLIL model showing CME propagation that arrived at Earth on July 20, 2016. The dots and squares show the location of Earth, other planets, and various NASA spacecraft (as labeled). Model run was performed at the CCMC.

V. Understanding and Defining Extremes

Understanding extreme space weather events is among the most pressing scientific objectives of our time. One of the key disputes is on defining severe/extreme conditions that might plausibly impact our technology. Like most of the major scientific challenges in the geosciences, there is increasing recognition that an integrated approach involving multiple disciplines will be needed to advance the knowledge of extreme events that amplify geomagnetic hazards.

In the past three decades, our knowledge of various aspects of space weather has vastly improved even though understanding the dynamic response of the near-Earth space environment to extreme space weather is still a serious challenge. Even more challenging is to understand the fundamental processes that control the development of dynamic magnetosphere-ionosphere currents that generate large geoelectric fields on the ground (e.g., *Ngwira et al*., 2015; *Pulkkinen*, 2015, and references therein).

For example, *Ngwira et al.* (2015) used ground-based magnetometer data to infer geoelectric fields for twelve extreme geomagnetic storms that occurred between the years 1982–2005. They showed that maxima of the geoelectric field enhancements were localized, and that the structure of these localized extremes at single sites differed greatly from globally and regionally averaged fields. However, the physical processes that control the development of these localized extreme maxima have not been sufficiently explored. For geomagnetically induced current (GIC) applications, it is critical that we understand the complex processes that control currents in the magnetosphere and ionosphere.

Generally, there are a range of parameters used to define intensity of events, but from a GIC perspective, it is the geoelectric field extreme that must be defined. Given that, it is worth noting that the geoelectric field intensity is closely related to fluctuations in the geomagnetic field, per Faraday's law, and not the amplitude of the storm as defined by DST index.

Therefore, storm-time variability of the geoelectric field is a reflection of dynamic processes in the magnetosphere-ionosphere coupled system. Understanding the spatiotemporal variation of magnetosphere-ionosphere currents also requires acknowledge of changes in the driving processes that regulate the state of the whole system, which is the solar wind in this case. Enriching our knowledge of the interaction between the solar wind and the magnetosphere-ionosphere is identified as one of the top priorities in space weather.

It is important to realize that GMD events have low occurrence frequency, but potentially high impact. Arguably the Carrington storm of September 1859 is the most extreme event on record. For our community this presents a special opportunity to study extreme events, but obviously no upstream solar wind measurements were available at that time. On the ground, magnetic recordings of the Carrington superstorm are sparse (e.g. *Tsurutani et al.*, 2003), and most of the recordings went off-scale during the peak of the storm (see e.g., *Nevanlinna*, 2008; *Cliver and Dietrich*, 2013, and references therein). Any attempts to model the Carrington event are limited by this problem. Nevertheless, in the last two solar cycles, we have had other extreme events, such as the March 1989 and Halloween storm of October 2003 that have negatively impacted some power grids, as discussed above. Even with these storms or other less extreme storms, we presently do not have sufficient measurements of extreme events to adequately understand and/or accurately predict/forecast them. Therefore, there is still a lot more to accomplish as a community to advance our understanding of and later on define extreme space weather in the context of expected impact.

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About the Authors

**__Chigomezyo NGWIRA__, Ph.D., is a Research Associate in the Department of Physics at The Catholic University of America (CUA). He received his Ph.D. in experimental Space Physics from Rhodes University, Grahamstown, South Africa in April 2012. Dr. Ngwira moved to Washington DC to take up a postdoctoral appointment at CUA in March 2012. At the same time, he had also been engaged as a Science collaborator with the CCMC at NASA Goddard Space Flight Center, in Greenbelt, Maryland, USA.*

Dr. Ngwira's research focuses on space weather, particularly on the response of the Earth's upper atmosphere and on ground effects. He has spent a bit of time on examining the density of the ionosphere, a layer of electrically charged particles that can distort and impede radio signals. At CUA/NASA-GSFC Dr. Ngwira has worked on projects focused on understanding the influence of extreme space weather on GIC, and on the development of GIC forecasting tools. In 2014, he was recognized by the American Geophysical Union for making "significant contributions in the application and use of the Earth and space sciences to solve societal problems" and received the AGU Science for Solutions Award.

**__Antti PULKKINEN,__ Ph.D., is currently Director of Space Weather Research Center (SWRC) operated at NASA Goddard Space Flight Center.*

Dr. Pulkkinen received his Ph.D. in theoretical physics from the University of Helsinki, Finland in 2003. Subsequently he joined the nonlinear dynamics group at NASA Goddard Space Flight Center (GSFC) to carry out his postdoctoral research 2004-2006. Dr. Pulkkinen's Ph.D. and postdoctoral research involved studies on both ground effects of space weather and complex nonlinear dynamics of the magnetosphere-ionosphere system. 2011-2013 Dr. Pulkkinen worked as an Associate Director of Institute for Astrophysics and Computational Sciences and as an Associate Professor at CUA. At CUA Dr. Pulkkinen launched a new Space Sciences and Space Weather program crafted to educate the next generation space weather scientists and operators.

Dr. Pulkkinen has been leading numerous space weather-related projects where scientists have worked in close collaboration with end users. In many of these projects, his work has involved general empirical and first-principles modeling of space weather and investigations of effects on manmade systems in space and on the ground. Recently Dr. Pulkkinen has been leading the development of space weather forecasting activity at NASA GSFC. The new SWRC activity provides space weather services to NASA's robotic missions.

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Supply Chain Risk Analysis and Management – Concept of Operations

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Abstract

The New Brunswick (NB) Department of Public Safety (DPS), Office of the Provincial Security Advisor (OPSA) operates a Critical Infrastructure Program (CIP) to develop trusted relationships, implement an all-hazards risk management approach, and enable the exchange of information with critical infrastructure owners and operators. The CIP supported the Supply Chain Risk Analysis and Management Project [CSSP-2013-CP-1027; Canadian Safety and Security Program], which considered supply chain risks to the Energy, Food, and Transportation Sectors. The overall purpose of the project was to create a Concept of Operations (CONOPS) and Decision Support Tool (DST), to identify and manage risks to CI supply chains in NB.

The CIP was integral to the successful completion of the Supply Chain Risk Analysis and Management Project [CSSP-2013-CP-1027; Canadian Safety and Security Program] by creating a mechanism whereby CI owners and operators can freely exchange concerns, including those involving supply chains, and work collaboratively with the NB government to address them within this project. Engagement of CI owners and operators, as part of the CI Program was connected with CI owners and operators' engagement for the Supply Chain Risk Analysis and Management Project [CSSP-2013-CP-1027; Canadian Safety and Security Program]. A subset of key CI Program participants contributed to the Supply Chain Risk Analysis and Management Project.

The purpose of the CONOPS is to suggest and articulate the objectives, processes and overall framework necessary to guide governments, departments and agencies within the security and emergency management realm to manage supply chain disruptions.

This suggested CONOPS does not replace the need for users to articulate, within their own frameworks, the legislation, directives and operational plans (OPPLANs) necessary to describe the manner in which the organization/jurisdiction will operate and interact within and amongst their levels of various coordination and decision-making. This CONOPS proposes a tier-based structure that underpins this concept aligning peer-to-peer collaboration, leading to decisions and actions. Levels of coordination are expressed as Gold (executive level), Silver (senior operational level), and Bronze (tactical level) lines of coordination. Within each level, committees, organizations and agencies operate across functional lines to share information and formulate decisions, leading to coordinated efforts during security and emergency events.

I. PURPOSE

This supply chain, CONOPS, is part of the Defence Research and Development Canada Centre for Security Science funded project on Supply Chain Risk Analysis and Management (New Brunswick Department of Public Safety; [CSSP-2013-CP-1027; Canadian Safety and Security Program]). The goal of this project is to develop a CONOPS and DST that can be used to analyse and manage risk within Canadian CI networks.

This report draws data from supporting research conducted by project partners, including Dalhousie University (DAL), *Conceptual/Contextual Framework for Critical Infrastructure Protection Supply Chain Issues*, the Conference Board of Canada (CBoC), *Estimating the Economic Impact of Critical Infrastructure Disruptions*, and Gowling, Lafleur, Henderson LLP *Federal legislative and legal analysis with respect to information sharing affecting security intelligence and law enforcement and critical infrastructure communities*. The research conducted has contributed foundational knowledge, identifying gaps in terms of a portable security and emergency event coordination methodology.

One aspect of this report serves as an overview highlighting the types of engagement DPS has with private-sector owners and operators to facilitate this process. Successful adoption of a CONOPS construct should enable a mechanism whereby CI owners and operators can freely exchange all-source information and work collaboratively with government partners. This report details the integration of CI owners and operators into current public-sector CONOPS in terms of the decision/influence cycle for all phases of a security or emergency management event: mitigation, preparedness, response and recovery. Once operationalized, this CONOPS should address supply chain and all-hazard security and emergency events. This CONOPS is designed to work in tandem with the current NB Provincial Security Event Management Plan (PSEMP), an annex to the NB Provincial Emergency Plan.

II. Engagement

DPS, through the OPSA, has developed a relationship model that organizes CI stakeholders, government agencies and CI owners and operators, so they can best use and mutually benefit from the structure suggested. Findings from the Defence Research and Development Canada Centre for Security Science funded project on Supply Chain Risk Analysis and Management [CSSP-2013-CP-1027], reveals the importance of establishing formalized partnerships with CI owners, operators and governments, in order to provide direction and coordination between and amongst partners [1]. The various levels of engagement across established governance networks allows for purposeful information sharing, communication, analysis and collaborative decision-making.

The NB government recognizes that most supply chain issues do not fall under direct provincial control and therefore require commitment from private-sector partners in order to establish governance during operations. Private-sector CI owners and operators maintain integral organizational processes, enabling them to manage events within their own scope. Private-sector stakeholders are often the owners and operators of CI, highlighting the importance of solid and mature relationships between government and private-sector partners. Strong commitment and shared processes between public and private sectors will ensure that information necessary to support essential decisions, which support formal and adhoc “on the fly” informal relationships, becomes a shared responsibility when the ability to manage events extends beyond the ability of a single sector. It is also the role of CI programs to facilitate the coordination of a reliable flow of information from government to private-sector owners and operators.

Engagement of CI owners and operators must be inclusive in nature, and should recognize the regional, provincial, and national dimensions and differences in terms of CI and interdependency of CI, thus allowing government and the private sector to maximize coordination, and reduce duplication of effort. Development of regional, provincial, territorial and other governance models, such as Operational Plans (OPPLANs) or Standard Operating Procedures (SOPs) are the critical next phase of adopting and expanding upon a structured CONOPS.

Suitable mechanisms may already exist in certain sectors and jurisdictions while others will require development, taking into account existing legislative and regulatory constraints. According to the research undertaken by Gowling, Lafleur, Henderson LLP, in their paper titled, *Federal legislative and legal analysis with respect to information sharing affecting security intelligence and law enforcement and critical infrastructure communities*, problems persist with respect to sharing of information between the federal government, the Security, Intelligence, and Law Enforcement (SILE) community, and CI owners and operators. This includes issues related to cultural and legal factors. Issues stem from federal departments and agencies that have difficulty supporting their interpretation of the law or legislative provisions for not sharing information, acting instead on the assumption that sharing information in some circumstances would contravene the principles of the Privacy Act [2].

III. Structure

The interdependent nature of CI and supply chain management circumvents isolating any one sector during a supply chain disruption. Addressing the interconnected nature of CI also requires establishing a governance structure that extends beyond sectoral boundaries, and fosters a collaborative network in support of analysis and decision-making. Adopting an inclusive strategy, bringing together private- and public-sector partners, promotes and supports timely and accurate information; thereafter information can be shared across sectors and jurisdictions. In NB, such a structure exists, and is utilized upon recognition of a perceived threat or disruption to CI and/or supply chains. In accordance with the PSEMP [3], NB utilizes the organizational structure illustrated at ***Figure 1***.

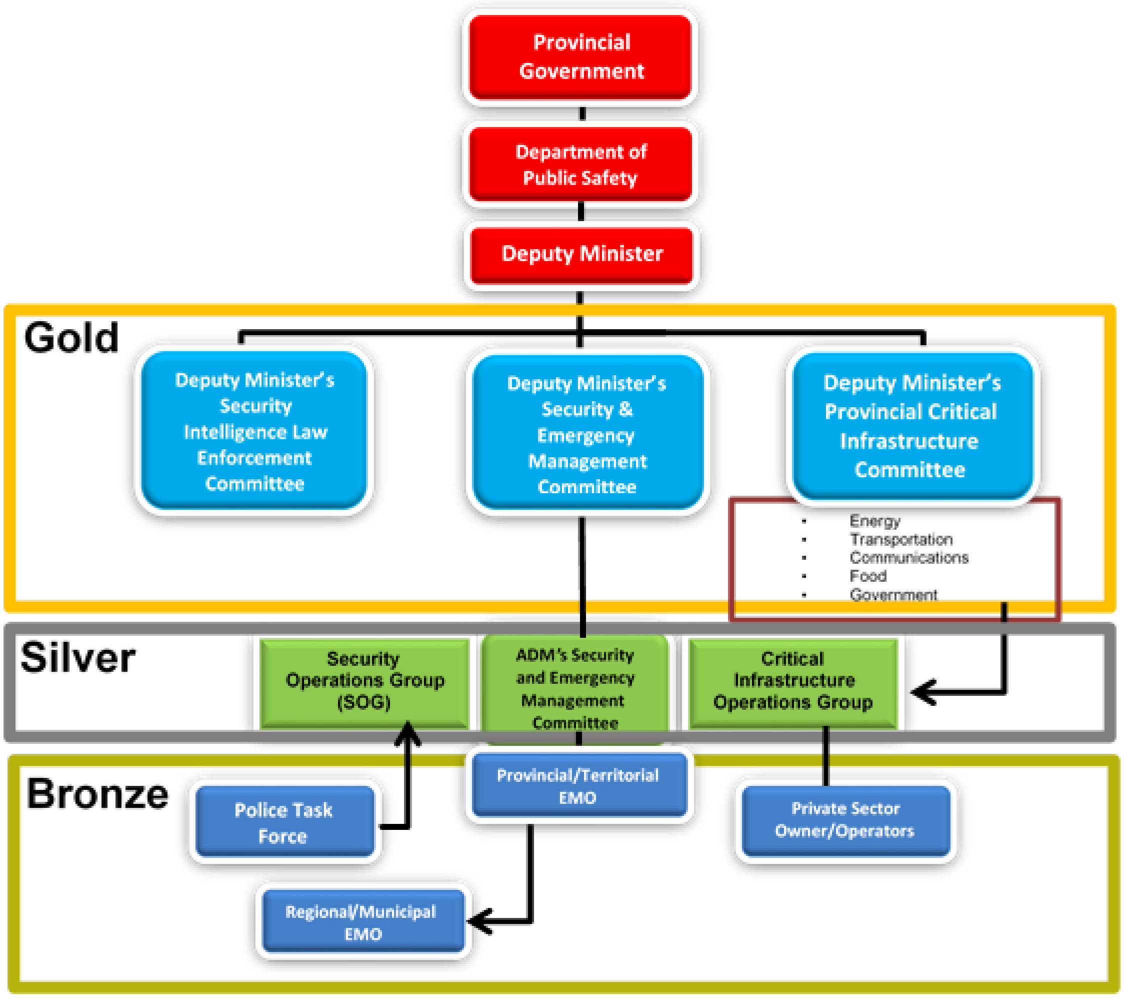

Figure 1: Proposed Governance Structure

In this membership structure, organizations are arranged into operational elements based upon the Gold/Silver/Bronze model developed by the United Kingdom (UK) Metropolitan Police Service in 1985 [4]. Within jurisdictions, tactical command structures may vary between Incident Command System (ICS), Incident Management System (IMS), and Emergency Site Management System (ESM). Regardless of the tactical command system employed to coordinate the actions at the Bronze level, there exists no conflict in terms of the ability to successfully share information amongst and between organizations operating within the Bronze level dealing with a security or emergency event. In turn, no tactical command system precludes sharing information during events with Silver or Gold level membership. Differences in committee or organization naming conventions expressed within ***Figure 1*** should ideally remain fundamentally the same in terms of functionality. Using such a codified structure will facilitate direct coordination among federated and non-federated, government and private-sector partners during events. The structure includes the following bodies discussed in ***Section IV Membership and Responsibilities***.

IV. MEMBERSHIP AND RESPONSIBILITIES

Gold Representation

The Gold level is the highest level of the governance structure. This level exercises control and coordination of information and resources between and amongst the Silver and Bronze levels, in order to provide over-arching governance of available resources and information. This level of representation is not present at the site of a security or emergency event. Rather, the representation expressed at this level gathers when necessary and collaborates on the development of strategy. Gold level representatives are most often executive-level management with the ability to make decisions within and outside policy, budget and mandate. In NB, all Gold level DM-led committees are comprised of executive level peers. If members of the Gold level representation from various organizations are not physically co-located, a continuous flow of information is affected by a reliable and sustainable means, such as videoconference or telephone (teleconference), which are ideally secure systems. Members within the Gold level can also include private-sector CI owners and operators at the executive level.

Silver Representation

Silver level representation is the operational level that proposes and/or receives strategic direction, advice, and federal/provincial/territorial information from Gold level representatives within organizations. The organizational leadership representation within the Silver level has the ability to make decisions within policy, budget and mandate. In turn, Silver level organizations and committees implement direction, coordinate, and assist the actions executed by Bronze level members/organizations. Silver level representation commonly incorporates senior most management reporting directly to executive management designated from within government and private-sector partners. In most instances, organizations and members within the Silver level are co-located. However, as with the Gold level, communication and coordination between and amongst Silver level members and organizations is effected via videoconference or telephone (teleconference), when it is not possible for members to co-locate due to time and space constraints.

Generally, Silver level membership gleans initial analysis; formulates strategic advice; develops operational options and priorities; works toward reaching consensus; represents their respective organizations; and ensures coordinated actions, necessary to address the event, are conducted.

Bronze Representation

Bronze level members and organizations report directly to Silver level organizations, and by design, these groups execute decisions at the tactical level. Often, Bronze level members will be located or staged at or near the scene of a security or emergency event, and are expected to respect the chain of command expressed within the respective group's construct. A fundamental objective of Bronze level representation is to ensure peers communicate with fellow peers at the tactical level, conduct operations, and report up the chain of command.

V. Relationships

The complexity of CI interdependency issues, cascading effects and resultant impacts, in terms of supply chain management, demand effective implementation and coordination between and amongst the various levels. Success or failure in security or emergency events depends upon these activities.

A collaborative approach to deal with CI interdependency issues/events requires mutually beneficial partnerships at the Gold, Silver and Bronze governance levels. The committees and subcommittees illustrated in ***Figure 1*** reflect a partnership model enabling governments and CI stakeholders to undertake a wide range of activities (e.g. risk assessments, legal/political/regulatory implication assessments), unique to a given event or operation. The internal and complementary mechanisms within the various levels will also enable collaboration and information sharing activities among CI sector partners, enabling the systematic analysis and execution of risk management and decision-making during security or emergency management events.

Recognizing the interconnected nature of supply chains and CI, which enables their effectiveness, supply chains will be confronted with ongoing challenges in terms of sector interdependency. For example, an energy sector producer, such as an oil or natural gas producer, relies heavily upon other CI sectors, such as transportation (rail and road), and communications, to effectively transport and track shipments, delivery and payment. During an event, if a road or rail network is interrupted, commodities, and those elements integral to the production of those commodities, will not be delivered on time and on target. The subsequent downstream effects may also extend across other CI sectors. Therefore, representatives within the Gold, Silver, and Bronze structures should adopt a fundamental approach that focuses on common goals of society, security and effective commerce.

Interaction among committee stakeholders at all levels should also take into account Priority Information Requirements (PIRs) that are unique in their definition and purpose, depending on the specific event or operation. PIRs are critical to inform and inspire decision-making, and in devising later courses of action to address changing event parameters. PIRs are also central to enhancing cooperation, which will be beneficial during current and future operations.

VI. Information Sharing and Priority Information Requirements

Taken from Canadian Forces (CF) doctrine, PIRs are defined as “intelligence requirements for which a commander has an anticipated and stated priority in his task of planning and decision-making” [5]. Each participating organization will have unique PIRs that guide decision-making at various levels of an organization, which need to be communicated to committees within the structured model illustrated in ***Figure 1***.

Since Canada’s CI is owned or operated by various organizations, both public and private, a mechanism is essential to enable the effective passage of critical information, prior, during, and after an event or operation. This flow of information is crucial in informing efficient analysis and subsequent risk management activities, thus enabling decision-makers during a security or emergency event.

Specifically, organizations should have access to, and possess the following information:

a) Government officials and CI owners and operators with safety and protection responsibilities should possess relevant information regarding CI within their jurisdictions. The groups should share information regarding CI interdependencies, while also managing known or potential threats to their own infrastructure(s), in order to ensure business continuity; and

b) First responders and SILE should possess sufficient CI information by owners and operators to plan and execute their emergency management roles.

To overcome significant differences in cultures and established ways of doing business, collaborating organizations must have a clear and compelling rationale for working together particularly during the response phase of a security or emergency event. Collaboration may be imposed externally through legislation or can be achieved from the understanding of the mutual benefits of collaborative work, including information sharing. In either case, collaborative efforts require CI owners and operators working across organizational lines to define and articulate a common outcome or purpose they are seeking to achieve.

The more information available to organizations about threats and vulnerabilities, the greater ability they possess to understand and prepare for risks and the assurance of CI continuity. Information essential to share among stakeholders should be comprehensive to include threats, vulnerabilities, events, protection and mitigation measures and best practices. Information sharing can be viewed as a means to better manage risk, resulting in a better ability to assist collaboratively in deterring, preventing, mitigating and responding to threats.

Crucial to facilitating a flow of information between CI owners and operators and governance structures is ensuring an environment of trust and confidentiality. Mechanisms, such as Memorandums of Understanding and/or Agreement (MOU/MOA) enable a trustworthy exchange between CI partners, while technological systems ensure secure transmittal of timely and often sensitive information. Setting the conditions for confidential information exchange compliments the governance structure and re-enforces the necessity for peer-to-peer and inter-level lines of communication defined in ***Figure 1***. Taking measures to provide adequate protection of information once shared is essential to maintaining and enhancing partnerships and mutual trust. A comprehensive study on information sharing and protection is covered in the Defence Research and Development Canada Centre for Security Science funded project on Information Sharing Protocol – Concept of Operations (New Brunswick Department of Public Safety; [CSSP-2013-CP-1026]; Canadian Safety and Security Program). Accessing the project deliverables requires permission from DRDC/CSS. www.ttcp.drdc-rddc.gc.ca

Prior to sharing information, organizations must consider what information is critical to their operation before an event or emergency. As previously mentioned, the critical information an organization deems necessary to optimize their business practices are known as PIRs: information that is essential, or even critical for decision-making. To understand the information requirements, analysts must understand the context under which the decisions must be made, and be familiar with the respective organization's decision cycle and procedures.

To define the PIRs required by decision-maker(s), six primary questions need to be answered:

1. What is the decision that needs to be made?
2. When does the decision need to be made?
3. Is this a new situation – something not seen before – or is this a familiar situation?
4. How is the situation being framed in the media and social media?
5. Who is making the decision?
6. How does the decision-maker formulate his/her decisions?

The first four questions focus on the situation (event/emergency/threat) at present, and should be addressed first, whereas the final two questions focus on the individual(s) making decisions, and can be addressed secondarily. Responses to the above questions will assist in determining PIRs and will guide critical information sharing, resulting in a decision-making process that better manages known and unknown risks.

Information protection compliments information sharing and builds the foundation for collaborative efforts to strengthen the resiliency of CI. Improving the process of defining and sharing relevant PIRs can potentially enhance the timely exchange of actionable information in terms of actual or perceived risks, and can promote effective risk management activities. Irrespective of existing federal, provincial and territorial legislation, or a lack thereof, governments should aim to be as open as possible regarding on the sharing of all relevant information.

Suitable mechanisms may already exist in certain sectors and jurisdictions, while others will require development, taking into account existing legislative and regulatory constraints. According to the research undertaken by Gowling Lafleur Henderson LLP, in their paper titled *Federal legislative and legal analysis with respect to information sharing affecting security intelligence and law enforcement and critical infrastructure communities*, problems persist with respect to the sharing of information between the federal government, SILE community, and CI owners and operators, including issues related to cultural and legal factors. The issue stems from federal departments and agencies having difficulty supporting their interpretation of the law or legislative provisions for not sharing information, acting instead on the assumption that sharing information in some circumstances would contravene the principles of the Privacy Act [6].

VII. COMMUNICATION

a. General

Critical to the effective conduct of a security or emergency management event are codified Lines of Communication (LOCs) between and amongst a collection of government, SILE agencies, and private-sector CI owners and operators. Routine, operational, and emergency public communication (information) that is an institutionalized process is critical to ensure collaboration, analysis, decision-making and to maintain public confidence. To maintain situational awareness, while supporting decision-makers, all potential factors that may affect an operation require an exchange of information types that can lead to actionable intelligence. As mentioned, existing and practiced information-sharing agreements will assist, while communication (outside of technological systems in support), take the form of routine, operational and emergency public information prior to, during, and after an event.

b. Routine and Operational Communications

Routine and operational communications can be defined as the ability to develop, coordinate, disseminate information, alerts, warnings and notifications within government, to other public- and private-sector and CI partners, and to first responders [7]. The communication interface illustrated in ***Figure 2*** describes the various types of routine and operational communication that can occur between government, SILE and private-sector stakeholders.

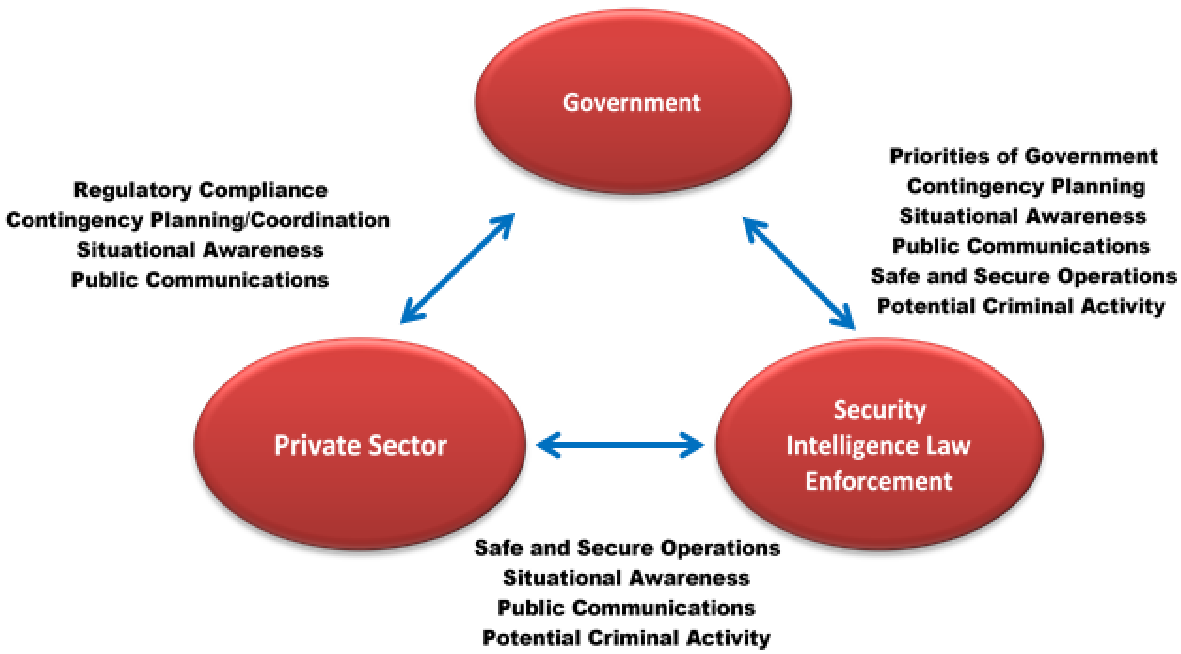

Figure 2: Communication Interface

Common communication exchanges between government, private sector, and SILE may include:

- Regulatory Compliance
- Contingency Planning/Coordination
- Situational Awareness
- Public Communications
- Priorities of Government
- Safe and Secure Operations
- Potential Criminal Activity

c. Government

During a security or emergency management event, including a disruption to CI supply chains, the relevant governance level (federal, provincial, territorial or municipal), would coordinate LOCs. Coordination can also include potential international collaboration between a state and province, or between Canada and the U.S. Regardless, government(s) will be intimately involved in organizing and facilitating information exchange, in accordance with the categories mentioned in ***Figure 2***, and thus government response to an event must provide an environment whereby information flows freely between government and stakeholders.

d. Private Sector

Communication exchanged between private sector, government, and the SILE community includes the various information types listed in ***Figure 2***. Interaction, in terms of passage of information and communication between the private sector, government and SILE community includes a certain level of complexity since disparate private-sector organizations are not normally mandated to disclose organizational business processes. Private-sector organizations should be continually engaged through government, CI and other programs in order to enhance partnerships and trust, which will improve information exchanges. In accordance with the organizational structure in ***Figure 1***, levels of management within private-sector organizations can also form part of government-led committees and organizations, thereby increasing stakeholder engagement and improving communication nexus.

e. Security Intelligence Law Enforcement (SILE)

The SILE community is charged with the responsibility for overall public safety and reports to government as part of their mandate and responsibilities. At the same time, the SILE community interacts on an ongoing basis with the private sector. SILE activities and the actionable intelligence that is later shared are informed through use of an intelligence-action cycle. During a security or emergency management event, the SILE realm should use the intelligence cycle. It is important to emphasize that information is considered raw data until it has been processed through an intelligence cycle. The intelligence cycle is the method of processing raw data (information) into refined intelligence for sharing by all partners, when possible, in support of decision-making. The intelligence cycle is a continuum of five steps, as illustrated in **Figure 3**. Once raw information has been developed into actionable intelligence during the analysis phase, the finished intelligence product must be disseminated between and amongst the various levels (Gold/Silver/Bronze), in order to inform strategic level decision-making. The dissemination of intelligence can also form the basis (depending on release), of public and CI owners and operators' emergency communication during security and emergency management events. Protocols should be in place to determine the dissemination of confidential or sensitive intelligence. It is recommended that a comprehensive Information Security Assessment (ISA) be utilized when determining the release of intelligence. *See Information Sharing Protocol (New Brunswick Department of Public Safety; [CSSP-2013-CP-1026] for an example of the NB ISA model.*

VIII. Conclusion

The purpose of this CONOPS was to suggest and articulate the objectives, processes and overall framework, complimenting established processes across jurisdictions and governments to manage supply chain disruptions. This suggested CONOPS does not replace the need for users to articulate, within their own frameworks, the legislation, directives and OPPLANs required to react to security and emergency management events. The goal of the proposed CONOPS was to facilitate a framework that could be implemented by CI owners and operators working in conjunction with government.

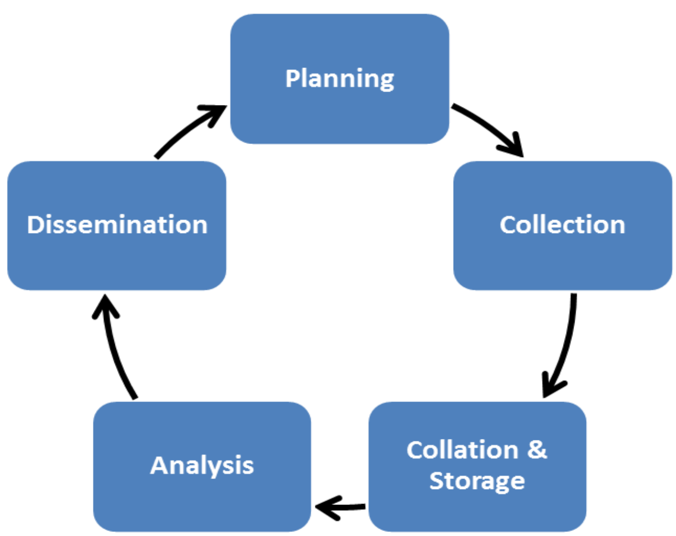

Figure 3: Intelligence Cycle

This CONOPS proposed a tier-based structure that underpins this concept aligning peer-to-peer collaboration, leading to decisions and actions. Levels of coordination were articulated as Gold (executive level), Silver (senior operational level), and Bronze (tactical level) lines of coordination. Within each level, committees, organizations and agencies operate across functional lines to share information and formulate decisions, leading to coordinated efforts during security and emergency events. Using such a codified structure will facilitate direct coordination among federated and non-federated, government and private-sector partners during events. While this tier-based methodology structure has been in existence since the mid-1980s, CI owners and operators have been slow to adopt these or similar frameworks.

CI reinforces the safety and security of citizens and the economy and can be disrupted by deliberate, accidental and natural events. Identifying and mitigating vulnerabilities in relation to the interdependencies between sectors is at the core of CIP. A system does not yet exist to identify gaps and encourage collaboration that mitigates risks amongst governments and CI owners and operators. This report attempts to addresses this gap.

Principle to the CONOPS was the development of key relationships, allowing private-sector owners and operators to raise their concerns and operational needs with government and increase dialogue outside and within security and emergency events. In keeping with the federal landscape, this CONOPS was designed with national portability in mind, where themes and guidance laid out within this report could be applied to varying degrees to federal, provincial and territorial concepts and protocols.

Additional conclusions and takeaways can be found in ***Section 8*** of the *CONOPS Validation Survey Analysis* accompanying the Supply Chain Risk Analysis and Management (New Brunswick Department of Public Safety; [CSSP-2013-CP-1027; Canadian Safety and Security Program], which was completed in tandem with various provincial and federal CI owners and operators and other stakeholders within the emergency management realm.

For the complete CONOPS report, please see Supply Chain Risk Analysis and Management – Concept of Operations [CSSP-2013-CP-1027].

About the Authors

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*Russell KING** *holds a Bachelor of Military Arts and Science Degree through The Royal Military College of Canada, focussing mainly on International Affairs. He completed 30 years of service with the CF, retiring in 2013 as a senior officer. He held various command and staff positions throughout his career and completed four consecutive tours: Bosnia-Herzegovina in 1999; Ethiopia-Eritrea in 2001; Haiti in 2004; and Afghanistan in 2007. Russ also completed the CF, two-year Joint Staff and Command Programme. In September 2013, he joined the Department of Justice and Public Safety, NB EMO, as an Operations and Training Officer, and after completing two years, joined the Office of the Provincial Security Advisor (OPSA), as the Critical Infrastructure Program Manager.*

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Respect, Safety, Security: CGA Health and Safety Guidance for Protests

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Canadian Gas Association (CGA) membership represents 98% of the natural gas distribution industry in Canada, delivering energy to 6.75 million customers through over 450,000 kilometers of pipeline infrastructure. Our members have a long history of promoting continuous improvement in safety, operations and integrity management and are committed to three *Guiding Operational Principles*:

- Continue to lead in the efficient design, construction, operation and maintenance of Canada's natural gas delivery systems through a culture focused on public and worker safety, reliability, security and resilience
- Continuously improve through ongoing learning, innovation and sharing of knowledge while committing to an open and transparent dialogue with all stakeholders
- Pursue an aspirational goal of a faultless safety, integrity and reliability record, together with exemplary environmental leadership and stewardship

Constant efforts are underway in the areas of public and worker safety and energy security and resilience via cooperative industry and government work on topics, such as Physical and Cyber Security, Asset and Integrity Management, Emergency Planning, Preparedness and Recovery, Damage Prevention and the general sharing of best practices. However, changing needs around the security of energy delivery systems and indeed all Canada's critical infrastructure must be addressed almost daily.

It is understood that the building, operation, maintenance and security of critical energy infrastructure is an owner/operator responsibility managed in concert with government and public input and opinion. A great number of steps have been taken to address safety, security and resilience of supply, the environment, cultural understanding, the regulatory perspective, and just as importantly, industry workers and public safety by all organizations thinking globally while still acting locally in what appears to be a universal not-in-my-backyard climate.

Certainly the natural gas delivery industry in Canada places the greatest value on respect for individuals' rights for expressing their opinions and the safety and security of all Canadians. The energy industry does want and need to address all stakeholders' comments and concerns via transparency, consultation and rational discussion, but the reality at times is not so orderly or logical.

There are cases where there is significant opposition to certain of our industry's operations or projects involving protests (lawful or unlawful) at or around member offices, facilities or in-field projects.

In those cases, the primary concern must always be the safety, security and well-being of all involved in any such situations/scenarios, industry workers, the public and protesters, while continuing to show respect for every Canadian's democratic rights.

The key question becomes how do organizations feasibly protect everyone's interests and safety while continuing to provide an essential public service?

From a health and safety perspective, there is clearly a need to ensure natural gas delivery industry workers have the basic skills, knowledge and training to be able to manage situations where others may seek to oppose and/or impede work, projects or any other energy-related activity.

Any such situations/scenarios can involve lawful or unlawful protests, and each organization has basic protocols/procedures in place to ensure that all responses and reactions are safety-based and these protocols/procedures are also being considered for integration into training, work management and workplace safety toolkits.

To assist its members, the CGA Health and Safety Committee developed a high-level selection of points and strategic options/guidance that organizations can pick and choose from, based on their needs and specific jurisdictions, i.e. options for members' consideration.

It must be noted that these points and options are not intended to be the sole source of information or guidance about this subject, but rather a collection of different industry approaches. It is also understood that where protesters' actions are no longer legal and/or threaten the safety and security of any stakeholder, police interaction/intervention must also be considered.

Here are some sample scenarios and situations with potential actions that workers can consider.

- Protestors show up and/or shout verbal abuse at a work site from a distance, but with no physical threat:
    - Notify the Supervisor, immediately.
    - Continue working, but be very aware of your surroundings.
    - Site personnel should begin to log everything related to the occurrence while immediately notifying Management.
- If there is a risk to workers safety, i.e. protesters are actively trying to obstruct workers from continuing to work or are physically threatening workers:
- Disengage from work activity
- Calmly stop working and do not react or engage in abusive discussion
- Notify the Supervisor immediately and ask for support
- Supervisors must immediately notify management and consider notifying the police/authorities
- Log everything related to the occurrence and protect personal safety at all times.
- Protesters have begun pushing/spitting on/blowing horns in workers ears, throwing rocks, wood or other debris at you (all of these actions are assault):
    - Disengage from work activity immediately
    - Notify the Supervisor immediately and the supervisor notified is to immediately notify police/authorities and management
    - Together with any witnesses at the site, if safe to do so, record any occurrences via video/photos/ voice recording.

It must be noted at this point that many security professionals feel <u>any</u> on-site discussions/ interactions between stakeholders could create unsafe situations.

The statements in this article are not intended to override those concerns, and it is understood that each organization will develop its own protocols.

Wherever possible avoid interaction with protestors, but if interaction is unavoidable, upon being approached:

- ❑ Do not cross protest lines. If it is imperative you do cross a protest line, see the section on "Entry into an Office, Facility or In-field Project"

- ❑ Do not engage in confrontation or discussion; be cordial, respectful and patient if interaction is required
- ❑ Do not attempt to block or impede a protest
- ❑ Respect the rights of protestors to pass out information and communicate peacefully
- ❑ **IF at any time you feel your physical safety or security are being threatened or believe a situation unsafe for workers, the public and/or protesters have been or are being created, do not hesitate to involve the police/local authorities**

Understanding that interaction is not the recommended course of action where protesters have come to an office, facility or in-field project site, here are some quick tips for workers and supervisors that can be considered for such situations.

Don't react immediately:

- Take a moment to assess the situation and give thought to your words and actions
- Avoid interaction with protestors and do not cross protest lines if possible

If interaction is unavoidable, the goal is to de-escalate the situation.

- Communication should be respectful, but only if it can be done safely

Practice "active listening":

- Assess what is being said for review when discussing next steps with your supervisor

Keep all communications positive:

- Focus on what you CAN DO and not on what you can't do

Avoid ultimatums

- Keep the situation flexible, cordial and relaxed if possible

Assume you are being recorded

- Be aware of how response(s) could look or sound in various media as it is very likely someone will be recording all actions on site, and there is no guarantee that those persons will publicize a complete record of everything that happened

Never respond with physical force

- The safety of every stakeholder is paramount and any form of physical reaction has the potential to unsafely elevate situations

Designate someone to log all actions/activities

- And to call 911 if required

Essentially:

When interaction is required, here are five potential guiding principles when dealing with protesters:

1. **Ask your questions sincerely:**
   - "What are your concerns?"
   - "What brings you here?"
   - "Have you attempted to have your concerns addressed in the past? If so, what have you done and what was the result?"

2. **Reflect emotions:**
   - "I can see that this issue is very important to you."
   - "I can see that this is very upsetting."
   - "I can see that you are very passionate about this issue."

3. **Reinforce positive behaviors:**
   - “Thank you for remaining calm, it is much easier for me to hear your concerns.”

4. **Refer questions to those more knowledgeable:**
   - “Unfortunately, I am unable to answer your question, but I can provide you with the name of a contact who will be better able to respond.”

5. **If someone is cursing or yelling:**
   - “We want to hear what you have to say, but I will need you to stop shouting (cursing) so I can better understand your concerns.”
   - “I am treating you with respect, and I would appreciate the same in return.”

Steps for consideration by supervisors after having been notified of protester activity occurring:

1. Notification of management
   - ❑ Decisions around the next steps will most likely be made after a detailed evaluation, with input from workers, supervisors and the authorities, is completed.
   - ❑ Where the safety of any stakeholders is being or could be compromised, immediately review responses to unsafe/unlawful acts with police/local authorities and management.
2. Documentation will be required
   - ❑ Start a personal log; ensure that any video/written documentation is gathered for post event review as a full investigation may be required;
   - ❑ Be prepared to accept instructions regarding the next steps that will be required (including statements around the event)

Note: Any interaction with the media should only be considered after consultation with management as stakeholders safety must always remain the most important focus.

Entry into an office, facility or in-field project

- ❑ If there appears to be a protest or blockade at an entrance you typically use, try an alternate entrance into the office building, facility or in-field project.
- ❑ Where no alternate entrance exists, respect the protesters’ rights and rather than crossing the protest line, avoid the area and monitor the situation for an appropriate time to enter the building, facility or in-field project without interacting with protestors.
- ❑ Do not become involved in any discussions, arguments or altercations.
- ❑ Whether driving, walking or biking to the building or site, be prepared to stop. If you are driving, operate your vehicle in a safe and lawful manner. Be prepared to wait until you can safely proceed.
- ❑ Remain calm and maintain eye contact with those people closest to your entry pathway.

Canada and the world as a whole benefits from the safety, security and resilience of energy delivery systems, but increasingly every energy-related event attracts significant attention impacting the ability to work safely while retaining the public acceptance necessary to continue to provide essential services.

In considering how to manage and react to protest situations and the use of the points and suggestions made, it must always be remembered that the over-arching principle is **Respect, Safety and Security** for the well-being of everyone; industry workers, the public and protesters.

About the Author

**__James TWEEDIE__ is the Director, Operations, Safety and Integrity Management at the Canadian Gas Association.*

In his role at CGA, Jim has been involved in files such as energy security, damage prevention, health and safety, RNG, and asset management, renewal and integrity, just to name a few.

Before joining the CGA, Jim had an extensive 35-year career with Enbridge Gas Distribution. From 2004 to 2008, Jim was Manager of Operations, Eastern Region for Enbridge, where he garnered much of his knowledge and expertise in the natural gas distribution industry.

Prior to this, Mr. Tweedie was a Manager of Construction and acting Regional Manager of Enbridge's Eastern Region. Additionally, he has worked on a number of international gas distribution feasibility studies and construction evaluation projects in Turkey, Mexico, and Malaysia.

Jim is currently the co-chair of NRCan's Critical Infrastructure; Energy and Utility Sectors Network and a past Chair of the Board & current Executive Committee member of the Canadian Common Ground Alliance.

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Stepping Up to the Plate: Developing a Positive Incident Review Process

W.T. (Bill) Isaacs C.E.T.*
President, Crisis Leadership Ltd.

Your company or agency has just experienced an emergency situation. This could have been a significant event, such as a natural disaster, terrorism threat or a fire. Even, it may have been a localized workplace violence incident or safety accident. The response was based on your current Emergency Response or Security Plans, recovery from the emergency situation was based on your Business Continuity Plans or other procedures, the media's requests were managed as per your organizations Crisis Communication Plan. When the dust clears and normal operations return, you ask yourself *"I wonder how we really did?"*

Many companies and agencies ask themselves this question after an emergency situation and some do something about it by performing an incident review or post emergency review. Regardless of what you call it, I find that although an incident review process is performed by many, few perform it well. How these reviews are performed and what you do with the information you gather is critical to your company's success and resilience when the next emergency develops. Let's examine what people involved in leading the post incident review should consider when designing and completing it.

A question I am often asked is *"Why go through the effort? We did OK."* If you don't, you will fall prey to the same problems and issues that plagued you during your last incident. The only way to truly go down the road of continuous improvement is by learning from your mistakes and taking action to enhance your internal procedures or processes.

I have found that over one-third of all issues raised from a company's incident review are procedure or process related, one-third are communication related issues while the last third are miscellaneous in nature. The post emergency review is a safe atmosphere to discuss issues and arrive at action items or recommendations for improvement. A thorough and disciplined incident review process will drive better results to build more resilient processes going forward.

Culture is Key

Employees must feel comfortable about talking openly and honestly regarding what happened during an emergency situation. The discussion must focus only on the facts and not on personalities. Determining the root cause of the incident is important, but arriving at valuable recommendations for possible improvement is the main objective. In order for employees to "Step Up To The Plate", they must feel they are in a safe environment and have trust in your company's intention that what may be broken will be fixed as part of your continuous improvement process. If you build a credible incident review process, credible results will follow. Remember this is not a finger pointing exercise, focusing on finding fault may force compliance, but it will not build a continuous improvement culture. Develop a documented process to follow up on any recommendations and determine if they can be implemented. While a new idea may sound valid during the discussion phase, it may later be determined that it cannot be implemented for engineering or practical reasons. Thus always document these recommendations so that they must be reviewed by your internal subject matter experts to determine if the recommendation can be implemented. *"Say what you will do, then do what you say."*

Lastly, one of the most key aspects of an incident review is protecting the information you receive from the post emergency review. Some organizations differentiate between an incident review and an incident investigation. The incident investigation process would be utilized after a more severe issue where the findings may want to be legally reviewed before they must be shared. Sometimes the circumstances of an incident could involve proprietary processes of an internal procedure or involve sensitive personal details (i.e., following a workplace violence incident). Some of the gaps identified or recommendations made following the incident could be potentially embarrassing to an organization or agency if leaked externally. These details can be protected, if it is not negligent to do so, by circulating them only to those who have responsibility for the issue. Ensure policies are in place to ensure employees do not prematurely share the information externally. If legal issues are a risk and the findings need to be protected under solicitor/client privilege, follow your organization's process to involve legal services.

If potential company policy culpability issues surface by an employee or by the organization, it is best to set those issues aside to be reviewed later by a smaller team staffed by internal subject matter experts. Those pointed discussions will be held behind closed doors and the documented results of those discussions will be shared on a "need to know" basis. If the series of events prove to be of a serious nature, then external regulatory or even police services may have to be brought in. The incident as a whole can and should still be reviewed to determine if improvements can be made to the organization's response, repair or recovery processes.

Imagine the facilitation of your internal incident review process much like playing baseball. If you are asking your employees to step up to the plate, then there should be rules to the game and steps along the way to achieve winning results.

1st Inning

Develop your incident review criteria and document the review process guidelines to follow as these will become the rules of the game. The guidelines around the threshold of when an incident would require an incident review should be laid out. Consider examples, such as critical injuries, severe customer impacts, identified procedure, process or training gaps, etc. Develop criteria as to who is responsible for organizing the review meeting, who should attend, who will take minutes and, most importantly, establish your rules around who is to follow up on any recommendations or action items recognized. Identify who will facilitate the discussion. I recommend a facilitator who is well respected in your organization and has the ability to separate any internal departmental bias. Alternatively, bring in an external subject matter expert who can either facilitate or assist in the process.

2nd Inning

As soon as possible after the incident, gather your documentation. Time heals all wounds, but it also causes memories to fade. Pull your information from the Incident Commanders notes, call or dispatch logs, and incident event logs from your Emergency Operating Center (EOC). Use copies of maps or even engineering drawings if they pertain to the incident. Also, gather copies of your internal procedures or processes that apply to the circumstances you will be reviewing.

3rd Inning

Armed with information, build a timeline of the incident. Document when the emergency started, then identify major decision points or significant events that occurred through to the end of the incident. This is important as this becomes your batting order as you walk through the incident. Whoever is going to lead the meeting should review this information in detail prior to the incident review. You may think this is understood, but it is imperative that everyone in attendance understands the circumstances of the event and the flow of the incident.

4th Inning

Have all interested parties attend the meeting. Missing one key group means you could lose valuable input. In these meetings, a person's role in the emergency situation should not matter – management/ non-management, unionized/non-unionized employees or contractors. If they had a key role in the original incident, they should have a voice. Like other issues, this is a balance. Try to keep the number of attendees manageable. Too few and you may be missing some key players, too many and the meeting may grow out of control.

5th Inning

Set your incident review date as soon as possible after the actual incident. This is going to be one of the most difficult activities. With the hectic schedules and workload your organization is experiencing, this will not be easy. Two weeks after is ideal, but not always possible. Two months after may be easier to organize, but memories fade and other priorities may come into play.

6th Inning

Logistics are important. Find a location for the meeting that is large enough to comfortably hold everyone. If attendees are comfortable, they will feel more like contributing to the discussion. Schedule breaks when appropriate, this is not designed to be an endurance run. Set an appropriate time to complete the review. You will need to get through the details, but you also do not want some discussions to drag on. End the meeting when you committed to end it. If further discussion is required, then schedule another meeting rather than force everyone to sit through a discussion that may not concern them.

7th Inning

Walk through the incident details, don't run. Rushing through a critical incident review may cause you to miss important details or recommendations. People need to feel they are being heard and their opinions matter. People remember close to 90% of what they experience as opposed to only 10% of what others tell them. People speak more transparently after triumphing over difficult situations and are more comfortable in sharing their experiences.

8th Inning

Ask questions… *"If the same incident occurred today, what would you do differently?"* After been involved in hundreds of emergency situations, I have found that there is always something you would do differently.

9th Inning

Document your results. If possible, having a person designated as the scribe will make sure the recommendations or action items were properly captured. A person in a support role who was more removed from the emergency situation works best. This also allows the person leading the review to focus on the discussions being held and manage the meeting to conclusion. Be sure to identify who owns the takeaways and establish what a reasonable timeline would be to review and complete each item. This will demonstrate that the organization is serious about saying what they will do and doing what they say. If you utilize root cause analysis software, such as TapRoot or other models, these details are a must to determine the root cause of the incident.

Post Game Analysis

When the Post Incident Review is complete be sure to circulate the results to the stakeholders and meeting attendees. They need to see the results of their effort and ensure the correct context of the recommendations put forward. Once approved, this document serves as a reminder to follow up on any takeaways they may have. When developing your incident review process, identify how often the review process owner is required to circle back with the recommendation owners to verify their status. If it was important enough to talk about and document as a take away, it is important enough to ensure it was completed. Verification once each quarter is a good guideline as it gives everyone time to complete the recommendation which may require some resources or financial commitment in a particular business quarter. Follow-up also builds credibility with senior management and your employees in your process.

You should also consider categorizing your recommendations and/or root causes by type. For example, recommendation categories could involve training issues, procedural gaps, safety recommendations, and/or even change management issues, etc. This gives you the option of performing quarterly or year-end analysis from your reviews by category. This data can be very helpful in focusing only on what is broken and identifying the solutions quickly. Analysis from the facts you gathered can remove any personal agenda issues plus saves time and minimizes wasted energy.

By building a resilient incident review process you will now be able to measure over time how effective your emergency response or business continuity plans are instead of just wondering. It will also demonstrate the strengths in your processes, as well as areas for improvement. If managed properly and consistently, building a resilient incident review process will become a valuable tool to demonstrate continuous improvement in your organization.

Go ahead, step up to the plate…you're up.

About the Author

Bill ISAACS has over 40 years of experience in the natural gas industry and has held positions of increasing responsibility, including engineering, gas transmission and distribution field operations, operations training and Emergency & Security Management.*

Bill is an original member of the Technical Committee responsible for the development of CSA Standard Z246.1 Security Management for the Petroleum and Natural Gas Industry, as well as the Technical Committee for CSA Standard Z246.2 Emergency Preparedness and Response for the Petroleum and Natural Gas Industry.

He has performed emergency recovery work for natural gas systems in the damaged areas of Hurricane Katrina and Hurricane Sandy. He is the recipient of the 2013 Canadian Gas Association's Lifetime Safety Achievement Award and has been published in the Ontario Technologist and the Infrastructure Resilience Research Group, Faculty of Engineering & Design Carleton University.

Recommended Critical Infrastructure Security and Resilience Readings

Felix Kwamena, Ph.D.*

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"Deterrence in Cyberspace: Different Domain, Different Rules" by Liam Nevill and Zoe Hawkins, July 2016, International Cyber Policy Centre, Australian Strategic Policy Institute (ASPI)

"The Big Hack: A Scenario that Could Happen Based on What Already Has" by Reeves Wiedeman, June 13, 2016, New York Magazine, http://nymag.com/daily/intelligencer/2016/06/the-hack-that-could-take-down-nyc.html#

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"Cyber Security of Energy Systems: Institutional Challenges" by Jennifer F. Sklarew, May/June 2016, The CIP Report

"***Visual Motifs in Islamist Terrorism: Applying Conceptual Metaphor Theory***" by Jonathan Matusitz & James Olufowote, Journal of Applied Security Research, Vol. 11, Issue 1 (2016)

"***Developing a Pay Scale for Security Guards: 5-Point Factor Evaluation Approach"*** by Gabriel Agboola Adetula, Journal of Applied Security Research, Vol. 11, Issue 1 (2016)

"***Toward Understanding the Linguistics of Terrorist and Radical Groups" b***y Abuelenin Atef, Journal of Applied Security Research, Vol. 11, Issue 1 (2016)

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"Creativity and Innovation in Security Technology" by Ross Johnson, Utilities Security Council, The Current, July 2016, ASIS International

Al-Qaeda, ISIL and Their Offspring: Understanding the Reach and Expansion of Violent Islamist Extremism Highlights from the Workshop 29 February 2016, Canadian Security Intelligence Service

"15 Years Later, 85 Canadian Real Estate Firms not Compliant with Anti-Money Laundering Rules" by Alexandra Posadzkiby Alexandra Posadzki Canadian Press, 24 May 2016

"The Evolving Challenges for Explosive Detection in the Aviation Sector and Beyond", by Robert Liscouski & William McGann, CTC Sentinel, Vol. 9, Issue 5 (May 2016)

Joint Electromagnetic Pulse Resilience Strategy: A collaborative Effort of the U.S. Department of Energy and the Electric Power Research Institute, July 2016

An Energizing Policy: America and the Middle East in an Era of Plentiful Oil" by Patrick Clawson and Simon Henderson, July 2016, The Washington Institute for Near East Policy.

"Identifying Security Checkpoint Locations to Protect the Major U.S. Urban Areas" by Daniel M. Watkins, Leticia Cuéllar, Deborah A. Kubicek, Erick Rodriguez, Phillip D. Stroud, Homeland Security Affairs, Volume 11, Article 8, September 2015

"August 2016 Terrorism: The Numbers", Homeland Security News Wire, http://www.homelandsecuritynewswire.com/dr20160902-august-2016-terrorism-the-numbers

"Shale Gas Availability, CO_2 Emissions, Electricity Generation Mix and Power Sector Water Use: EMF 31 Scenarios Results for the U.S.", by Nadejda Victor and Christopher Nichols, IAEE Energy forum, Vol. 25, Second Quarter 2016

"Analyzing the Geopolitics of Natural Gas with the Global Gas Model: Subsidized LNG Exports from the U.S. to Eastern Europe", by Fabian Stähr and Reinhard Madlener

"Why Economists and Energy Efficiency Practitioners Need to Work Together to Improve Energy Efficiency Programs", by Steven Nadel

"U.S. Natural Gas (LNG) Exports: Opportunities and Challenges", by Ronald D. Ripple

"Is U.S. LNG Competitive? From Need to Import to Must Export", by Michelle Michot Foss and Gülen, IAEE Energy Forum, Vol. 25, Third Quarter 2016

"Cost Overruns in Norwegian Oil and Gas Projects: A Long-tailed Tale", by Atle Oglend, Petter Osmundsen and Sindre Lorentzen

"Nearshore Versus Offshore: Comparative Cost and Competitive Advantages", by Henrik Klinge Jacobsen, Pablo Hevia-Koch and Christoph Wolter

"Changing Oil Market Fundamentals and the Implications for OPEC Production Strategy", by Daniel Scheitrum, Amy Myers Jaffe and Lew Fulton

"The Political Economy of Carbon Pricing", by G.G. Dolphin, M.G. Pollitt and D.M. Newbery

Assessing the Impact of Renewable Support Policies – Modeling Investors and Investment Decisions", by Francesco Hipp and Christoph Weber

“Can Accounting Inventory Data Shed Light on Physical Oil Market Speculation?” by Ivan Diaz-Rainey, Helen Roberts and David Lont

“Uncertainty in Benefit Cost Analysis of Smart Grid Demonstration-Projects in the U.S., China, and Italy”, by Nihan Karali Gianluca Flego, Jiancheng Yu, Silvia Vitiello, Dong Zhang and Chris Marnay

“Policy Design and Environmental Benefits of Electric Vehicles, by Amela Ajanovic and Reinhard Haas

“Cross-Border Effects of Capacity Remuneration Schemes in Interconnected Markets: Who is Free-Riding?” By Xavier Lambin and Thomas-Olivier Léautier

“Reducing Rebound Without Sacrificing Macroeconomic Benefits of Increased Energy Efficiency?” By Karen Turner, Gioele Figus, Patrizio Lecca and Kim Swales, International Association for Energy Economics, Vol. 25, Bergen Special Issue 2016

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INFRASTRUCTURE RESILIENCE RESEARCH GROUP (IRRG)

UPCOMING EVENTS

FALL/WINTER 2016

EVENT	DATE / LINK
Fall 2016 Training Courses	September to December 2016 https://carleton.ca/irrg/training/
Symposium on Security and Infrastructure Resilience, " The Challenges of Dealing with Natural Resources Development Projects and Activism", Fairmont Chateau Laurier Hotel, Ottawa, Ontario	November 14 – 15, 2016 https://carleton.ca/irrg/cu-events/2016-symposium-on-critical-infrastructure-and-resilience/
The Dean's Annual Lecture Series – Infrastructure Security and Resilience, Carleton University, Ottawa, Ontario	November 15, 2016 https://carleton.ca/irrg/cu-events/2016-the-deans-annual-lecture-series-infrastructure-security-and-resilience

SPRING 2017

EVENT	DATE / LINK
International Urban Security and Resilience Conference, Workshop and Exhibition, The Sheraton Centre (Toronto, Ontario)	Tuesday, May 16, 2017 to Friday, May 19, 2017 https://carleton.ca/irrg/2017-urban-security-and-resilience-conference-workshop-and-exhibition