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IR³ FEATURE ARTICLES

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Editorial Corner

Dr. Robyn Fiori

About the Editor

Dr. Robyn Fiori is a research scientist specializing in space weather for the Canadian Hazards Information Service at Natural Resources Canada. Her research is applied to developing and improving space weather tools and forecasts to be used by operators of critical infrastructures and technologies in Canada. Dr. Fiori's research has been published in numerous peer-reviewed scientific journals, including the Journal of Geophysical Research; 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 at the Institute of Space and Atmospheric Studies. She can be reached at robyn.fiori@canada.ca.

This Issue

IR^3 Issue 13 presents three systems aimed to improve the resiliency of critical infrastructure and wraps up with a hard look at what the term 'resilience' really means and how to quantify it.

This issue begins with **Alison Bird, Henry Seywerd, John Adams, Steve Crane,** and **Dr. David McCormack** describing Natural Resources Canada's efforts in mitigating the risk of critical infrastructure to natural hazards through a national Earthquake Early Warning system. This network will focus on regions of moderate to high earthquake risk in Canada along the west coast of British Columbia, eastern Ontario, and southern Quebec. The success of this system will be ensured through a broad range of outreach activities that encourage awareness and uptake to ensure that both people and systems respond to the intended alerts.

Looking up from the ground, **Chuanlei Liu** describes the potential of Health Canada's Fixed Point Surveillance network for monitoring and forecasting space weather in Canada. The network has expanded over the last 20 years into a country-wide network of more than 80 stations and monitors environmental radiation for health risk assessment. However, the system has also been shown to observe space weather events and could prove to be a component of improved space weather services in Canada.

Returning Author **Graeme Maag**, and **Emmanuel Papanagiotou** from GlobVision describe the company's efforts in improving the resilience of space infrastructure. GlobVision accomplishes this by developing integrated and automated web services that provide space situational awareness and domain awareness.

Finally, **Bill Isaacs** shares his perspective on the word 'resilience' and its context in modern society. He defines a resilience metric to allow a business to benchmark, then builds an attainable strategy for improvement.

Next Issue:

We invite authors to contribute additional articles for Issue 14 relating to their experience in the field of infrastructure resilience. **Draft articles of 2,500 - 4,000 words are requested by February 20, 2023**. 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.

National Earthquake Early Warning System Will Mitigate Impacts of Earthquakes to Critical Infrastructure in Canada

Alison L. Bird, Henry C.J. Seywerd, Stephen Crane, John Adams, David A. M^{c}Cormack
Natural Resources Canada

Abstract

Natural Resources Canada (NRCan) is developing a national Earthquake Early Warning (EEW) system for regions of moderate to high earthquake risk in Canada. The EEW sensor network will be focused along the west coast of British Columbia, eastern Ontario, and southern Quebec, as strong earthquakes expected within these zones will cause significant damage and other impacts to structures, systems, humans, and the environment. In order for the EEW system to be effective, people and systems must respond appropriately to EEW alerts, reducing harm and disruptions to operations.

Earthquakes in Canada

Canada is a seismically active country (**Figure 1**), with the majority of earthquakes occurring along the west coast of British Columbia (BC) where two major plate boundaries lie: 1) the dominantly transform Queen Charlotte Fault along Haida Gwaii, an archipelago off the northern BC coast (its sideways motion is similar to that of the San Andreas Fault), and 2) the northern portion of the Cascadia Subduction Zone, which extends from the northwestern tip of Vancouver Island south to northern California. Subduction zones generate megathrust earthquakes which are the largest seismic events in the world, often over magnitude 9 like the 2010 Maule earthquake off Chile and the 2011 Tohoku earthquake off Japan which can generate devastating tsunami waves.

There is also considerable earthquake activity in eastern Ontario and southern Quebec, particularly along the Ottawa and St. Lawrence River valleys, including the Charlevoix region where the seismic hazard is somewhat lower than in BC but where the exposed population is greater and the built environment is generally more vulnerable. As a result, the overall seismic risk is similar in eastern as in western Canada.

Although populations are smaller and there is less infrastructure in the north, there are seismically active regions: in the Yukon, where continental faults extend into Yukon Territory from Alaska and compression is accommodated along the Mackenzie Mountains; and in the eastern Arctic, a region still experiencing crustal flexure from a post-glacial rebound. There is also moderate hazard from earthquakes in areas of Atlantic Canada.

In order to monitor earthquakes, Natural Resources Canada (NRCan) operates a national network of over 200 seismic stations, primarily distributed in areas of high seismic hazard, recording over 5,000 earthquakes annually. In several urban areas of Canada, including Vancouver, Victoria, Ottawa, Montreal, and Quebec City, earthquakes are the greatest single-event risk for loss of life and economic impact (Insurance Bureau of Canada with AIR Worldwide, 2013).

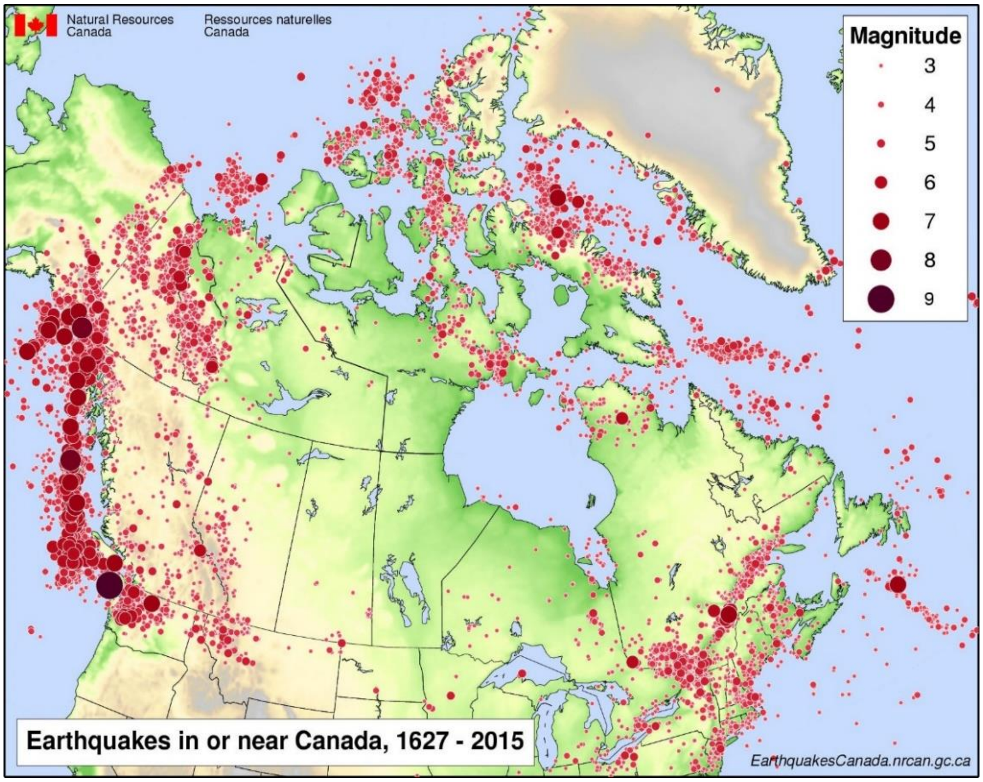


Figure 1: Map of historical earthquake activity in Canada (Natural Resources Canada). Note that instrumental recording of earthquakes began in 1898, with Milne seismometers installed at Victoria, BC, and Ottawa, Ontario, but with modern seismic monitoring commencing in 1927 in southern Canada, and a national network established in the early 1960s.

Earthquake risk is partially mitigated through seismic provisions within the National Building Code of Canada (NBCC; National Research Council, 2015); a map representing seismic hazards as used in the code is shown in **Figure 2**. The NBCC currently addresses seismic requirements for new buildings, although there are some requirements for older structures if substantial refurbishment or change of occupation/use is carried out. Modern seismic design provisions of the NBCC are primarily intended to minimize life safety risks due to structural damage under strong earthquakes. While tall buildings designed under current standards are expected to achieve this life safety goal, a large number of tall buildings were constructed prior to the adoption of what are now considered suitable levels of seismic reinforcement. For instance, roughly 65% of tall (>8 stories) buildings in the City of Vancouver were constructed prior to 1980 (Kakoty, Dyaga, & Hutt, 2021). Kakoty, *et al*. (2021), estimates that the annualized collapse risk of these older buildings is roughly five times higher than that of modern designs.

As a result of seismic provisions and building construction methods in North America, however, people are more likely to be injured from falling debris, such as ceiling tiles, light fixtures, furnishings, and loose objects, than by structural building damage. In order to promote personal protective actions from both structural damage and debris fall, NRCan supports the annual ShakeOut earthquake drill, during which people practice responding to earthquake shaking, primarily to “Drop, Cover, and Hold On” (Earthquake Country Alliance).

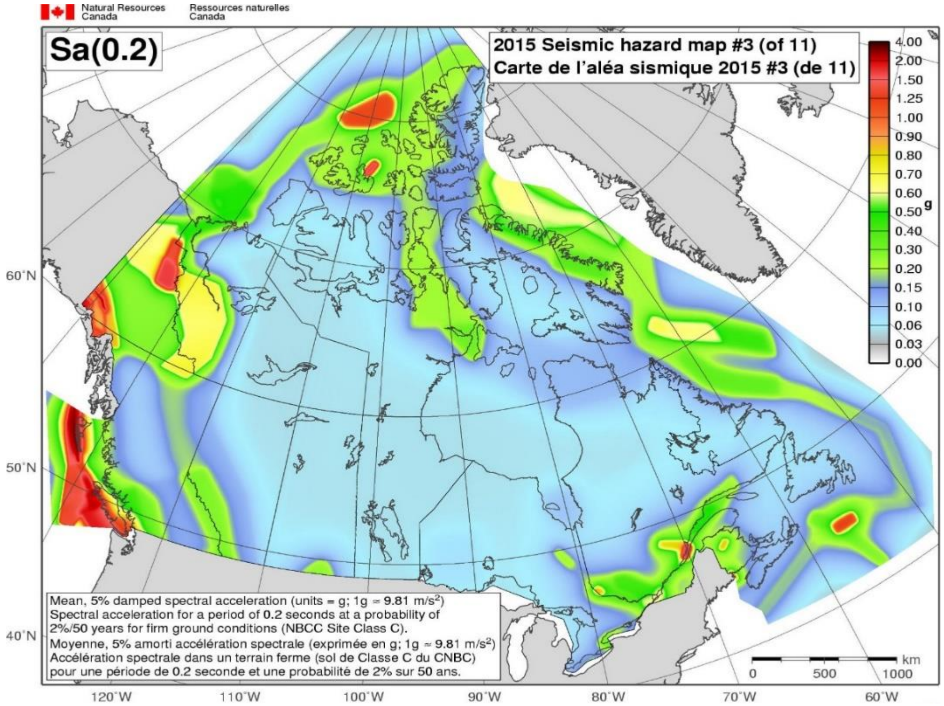


Figure 2: Map of Spectral Acceleration as used to inform seismic provisions within the National Building Code of Canada (2015) indicates Canada's highest hazard lies along the west coast of British Columbia but also a significant hazard in Yukon Territory, eastern Ontario, southern Quebec, and remote areas of the Arctic.

Earthquake Early Warning

Earthquake Early Warning (EEW) can provide from seconds to tens of seconds of warning of strong shaking following an earthquake. EEW systems have proven successful in a number of countries. Japan installed the first regional EEW system, with initial alerts delivered to hospitals and rail systems in 2005 (Kiyomoto, et al., 2005); gradually alerting was added to other critical infrastructure, schools, and, eventually, the public in 2007 (Japan Meteorological Association, 2007). In the United States, the first phase (without public alerting) of an EEW system went into operation in California in the Fall of 2019. This was shortly before the Ridgecrest sequence of earthquakes, during which the system worked well for both the magnitude (M_w) 6.4 foreshock and M_w 7.1 mainshock and provided the opportunity to fine-tune the system's software (Chung, et al., 2020). In early 2020, this system was extended into Oregon and Washington (Washington Military Department, 2021). NRCan is currently implementing an EEW system based on and connected to the U.S. system, and using their ShakeAlert® software (United States Geological Survey). It will focus on areas of high seismic risk in Canada (i.e., where there is both high seismic hazard and either critical infrastructure or large population concentrations).

Early warning systems work because there are different types of seismic waves emitted during an earthquake and they move at different speeds (**Figure 3**). Nearby EEW sensors detect the first energy to radiate from an earthquake, the P-wave, which rarely causes damage. The sensors transmit this information to data centers where rapid processing estimates the location and magnitude of the earthquake, and forecasts ground shaking across the region. This method can provide a warning before the arrival of the S-waves, which produce the strong shaking that usually causes most of the damage. The EEW system continues to monitor seismic data and updates shake forecasts, as required; very large earthquakes can take minutes to rupture and the magnitude, and hence projected area and level of impact, can increase over time.

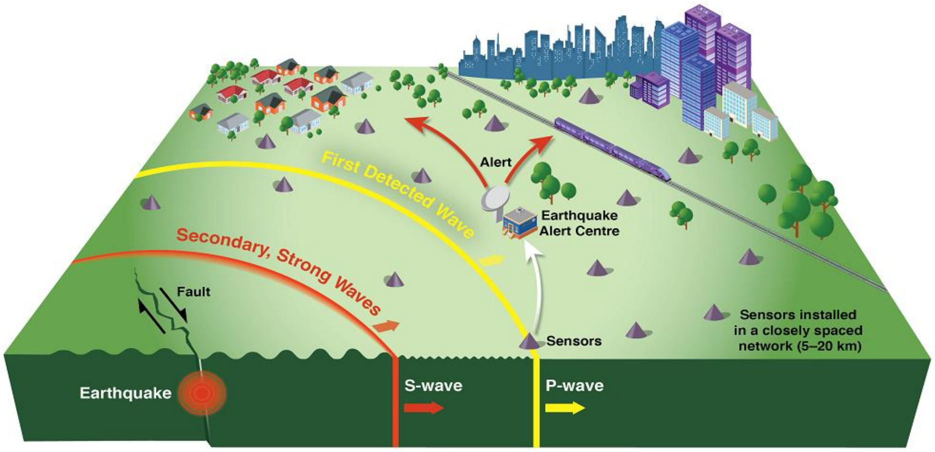


Figure 3: Principles of an EEW System

Canada's EEW System Development

The key components of the system will be dense networks of sensors, high-speed communications equipment, computer centers capable of processing sensor data within a tight timeframe, and a dissemination system for alerting people and infrastructure within Canada. The sensor network will consist of several hundred accelerometers optimized for fast response and spaced about 20 km apart in most high-risk areas of concern (**Figure 4**). Various modes of communication will reduce the likelihood of common failure points. Event processing will occur at multiple secure data centers, providing redundancy.

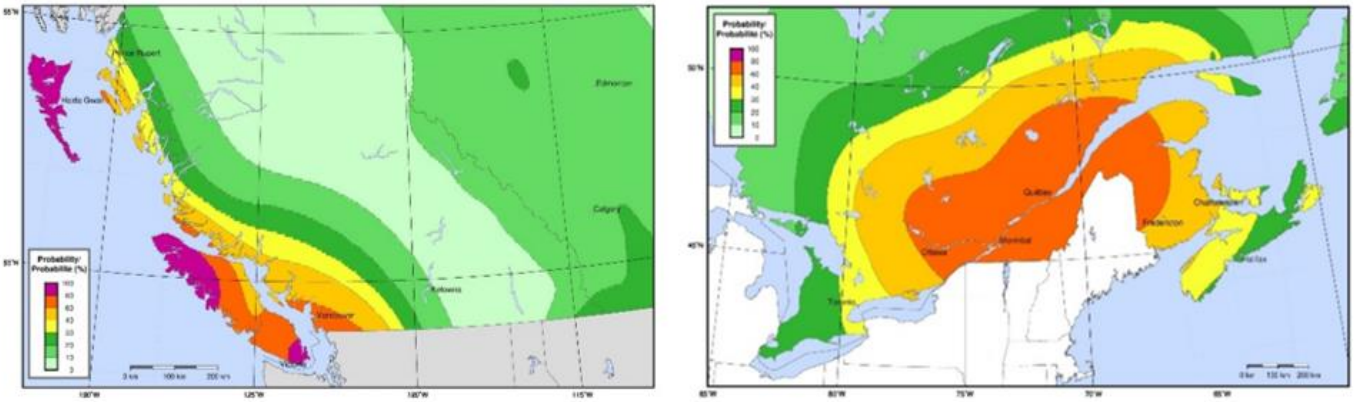


Figure 4: Simplified hazard maps showing the probability of strong shaking in western and eastern Canada.
The EEW system will cover major population centers and critical infrastructure within many of the higher-hazard (magenta and orange) areas.

In an effort to secure the optimal distribution of EEW sensors, NRCan is collaborating with Provinces, Territories, First Nations, and others, to encourage the hosting of sensor stations on their properties. At the time of printing, station hosts had been established formally or in principle for virtually all core stations. EEW station equipment had been installed at 41% of the target sites in BC, and 20% in eastern Canada.

A key consideration for a Canadian system is the proximity of at-risk areas to the border with the United States. Earthquakes and their seismic waves can cross borders, placing Canadian communities and critical infrastructure at risk from earthquakes originating in the United States; the U.S. is likewise at risk from earthquakes originating in Canada. Consequently, Canada and the U.S. are working together to share data from sensors and use the same software. The intention is to make the systems fully interoperable, providing seamless coverage in border areas and preventing inconsistent alerts.

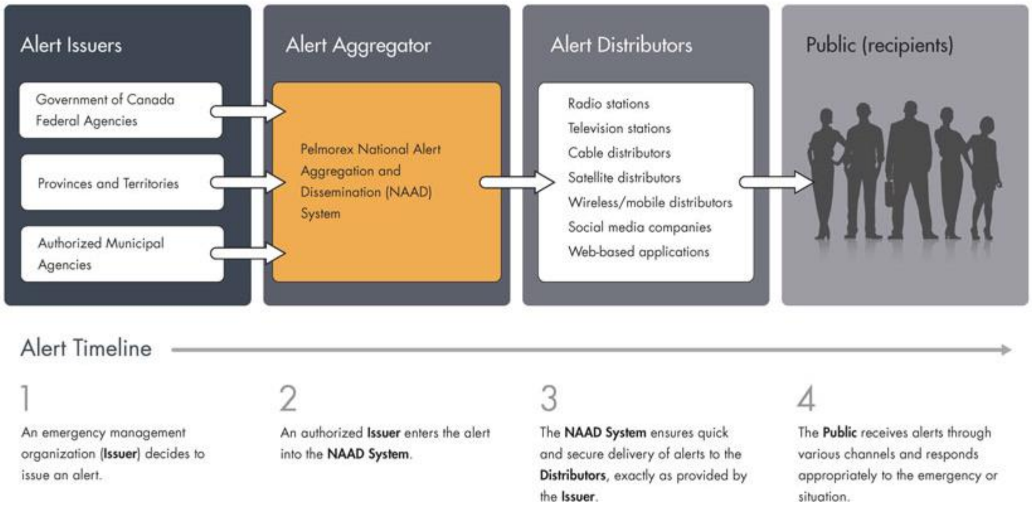
Constraints on EEW

Earthquake Early Warning (EEW) systems do not alleviate the need for other earthquake risk mitigation (such as building codes), preparedness (securing building contents), or response measures (drop, cover, and hold on).

There are some limitations to the effectiveness of earthquake early warning systems. EEW systems provide only short-term warnings immediately after an earthquake initiates and cannot predict seismic events. Warnings will only be provided for earthquakes that have a possibility of harm. Additionally, sites close to an earthquake's epicenter could be within the event's "late alert zone", where alerting is not possible.

Dissemination of EEW Alerts and Protective Actions

Dissemination of alerts in Canada will be via the National Public Alerting System (NPAS; Public Safety Canada, 2020). The initial alert messages to the general population will convey simple information, e.g. "EARTHQUAKE: drop, cover, hold on NOW!" - provided using the process shown in **Figure 5**. The National Public Alerting System (NPAS) already provides warnings of impending severe weather and other threats. Distribution is via various means, including radio, television, and cellular telephone. Current generation cell phone networks may be insufficiently fast for effective alerting to large numbers of subscribers; the need for cellular provision of alerts has been recognized and it is expected that speed and reliability will improve as systems migrate to 5G networks.



1 An emergency management organization (**Issuer**) decides to issue an alert.

2 An authorized **Issuer** enters the alert into the **NAAD System**.

3 The **NAAD System** ensures quick and secure delivery of alerts to the **Distributors**, exactly as provided by the **Issuer**.

4 The **Public** receives alerts through various channels and responds appropriately to the emergency or situation.

Figure 5: Alert Dissemination Process of the National Public Alerting System (Public Safety Canada)

In addition, the alerting system will provide more detailed messages, containing site-specific parameters, to technically capable end users. Such tailored messages can be used to trigger automatic protective actions, which are important given the short warning times expected. In other EEW systems, these types of messages have been used, for example, to slow and stop trains, put industrial equipment into a safe state, close access to tunnels and bridges, and secure hard drives in data centers (**Figure 6**). Messages can include information such as earthquake magnitude and location, as well as forecasted ground motion values and shaking intensity for potentially impacted geographical areas (ShakeAlert® Earthquake Early Warning System, 2021).

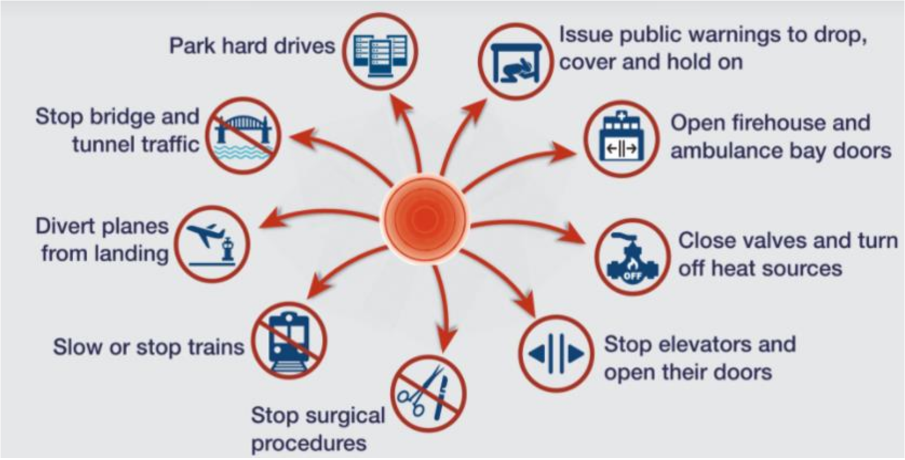


Figure 6: Typical safe response actions that could be taken upon receipt of an EEW alert (Earthquake Country Alliance).

Ensuring the Success of EEW

Canada's Earthquake Early Warning (EEW) system will mitigate earthquake impacts through timely notification to (and appropriate response actions by) emergency measures organizations, critical infrastructure (CI) operators, other industrial facilities, and the public. To ensure appropriate protective actions are taken, an effective EEW system requires a culture of awareness, achieved through a substantial, coordinated public education campaign. NRCan is therefore working with federal, provincial, and public safety organizations, private and international collaborative partners (such as the United States Geological Survey), and Non-Governmental Organizations (ShakeOutBC; GrandeSecousse; ShakeOutYT), to ensure authoritative, consistent, and accessible EEW messaging is available to the public and technical users. Additionally, NRCan will be working with Indigenous partners to provide educational materials and guide engagement in First Nations communities. Social science understanding of risk perception and response actions is similarly steering the education of various demographics, using different learning environments (Sumy, et al., 2020) and how each EEW event can be exploited as a "teachable moment" (McBride, et al., 2020).

Engagement with Critical Infrastructure Operators and Technical Providers

In support of the above-mentioned communications activities, NRCan will be hosting workshops and other outreach activities with CI operators to ensure they are aware of the benefits of installing systems that will automatically translate EEW alerts into protective actions. Consultation with workshop participants will also inform the format and content of tailored alerts to CI operators' systems and staff.

In parallel, NRCan will be encouraging technical providers in Canada to develop such automated devices for the country's various CI sectors.

Next Steps

NRCan's EEW system is currently being implemented, with completion slated for 2024. Major activities include procurement and installation of sensors and communications networks, development and adaptation of software systems, integration with alert distribution systems, and the creation of public information campaigns and outreach to potential EEW users.

Conclusions

With the ability of humans and automated systems to take safe protective actions before the arrival of strong shaking, the national EEW system will contribute to Canada's efforts to meet the recommendations within the United Nations Sendai Framework for Disaster Risk Reduction (United Nations Office for Disaster Risk Reduction, 2015).

NRCan's broad range of outreach activities, with the help of numerous partners, will ensure a culture of awareness is developed in at-risk regions of Canada, resulting in a potentially significant reduction in human injuries and lower infrastructure losses.

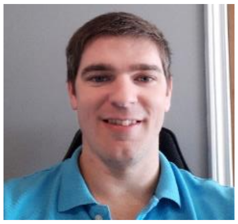
About the Authors

Henry Seyward, *Program Manager for the Earthquake Early Warning at Natural Resources Canada, is heading the effort to establish a national system for providing rapid warnings to mitigate the effects of major earthquakes. He has been involved in emergency management at NRCan for over 10 years including overseeing the refurbishment of Canada's seismic monitoring network and leading its nuclear emergency response team.*

Prior to joining NRCan, Henry held diverse positions in industry and research, including the development of equipment for medical imaging and performing fundamental research in high-energy physics. https://orcid.org/0000-0003-4876-730X.

Dr. David McCormack *is the Director of the Canadian Hazards Information Service at NRCan. https://orcid.org/0000-0002-8866-4834.*

Alison Bird *has been working as an Earthquake Seismologist at NRCan since 2000, analyzing and researching western Canada's earthquakes, and routinely responding to the wake of significant events. She visited Haida Gwaii as part of a response team after the 2012 magnitude 7.8 earthquake, and participated in a project to develop a comprehensive risk assessment for Canada. In 2020, she joined the Earthquake Early Warning project as Liaison & Outreach Officer, helping to establish an EEW system for Canada. Alison is involved in numerous outreach activities, and is passionate about seismic-resistant engineering, encouraging mitigation practices for at-risk communities, and educating the public about earthquake hazards. She is on the Board of Directors for the BC Earthquake Alliance and on the Organizing Committee for the annual Great British Columbia ShakeOut earthquake drill. https://orcid.org/0000-0001-9019-0992.*



Steve Crane *has been working as a Research Scientist at Natural Resources Canada since 2017, after completing a Ph.D. from Carleton University. His research at NRCan has covered many aspects of EEW including assessing network design, applying EEW to Canada, modeling EEWS performance, and testing EEW algorithms in Canada.*

John Adams *has been working as a Research Scientist at Natural Resources Canada since 1980, and has been involved in all aspects of the earthquake program, from running field aftershock surveys to managing the program, and from creating national seismic hazard maps to participating in post-earthquake engineering reconnaissance visits. He has been involved in improving seismic hazard estimates for Canada since 1986, and helped design the sensor layout for the EEWS. https://orcid.org/0000-0003-1437-7178.*

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Health Canada's Fixed Point Surveillance Network for Space Weather Monitoring and Forecasting Applications

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Abstract

This work presents Health Canada's Fixed Point Surveillance (FPS) network and discusses its potential for space weather monitoring and forecasting applications. The network comprises about 80 3x3 inch sodium iodine spectrometers across Canada and registers cosmic radiations by a high-energy channel on a 15-minute basis. The long-term cosmic ray variation due to the solar cycle effect can be observed by the FPS. A few examples of transient solar event detections have been demonstrated in support of the use of FPS for space weather applications. The work required for forecasting has also been addressed.

Introduction

Space weather can be understood as a combination of solar energetic eruptions and their associated adverse impacts on our health and technological-based activities [Hanslmeier, 2007]. As the driving source, the solar activities of most relevance and geo-effectiveness are fast solar wind streams from coronal holes and sporadic solar outbursts, such as solar flare and coronal mass ejections. Accompanied by the embedded magnetic field, these plasmas stream and expand outward from the Sun at high speed. As directed to Earth, they interfere with Earth's magnetosphere and cause disturbances in the magnetospheric-ionospheric space.

Specifically, these disturbances can intensify the ring current in the magnetosphere and induce ionospheric currents. These variable currents, in turn, cause magnetic field variations at ground level, undermining the normal operation of these long electrical conducting systems such as railway signaling systems, pipelines and power grids [Bothmer and Daglis, 2007]. In space, changing plasma density and electric potential can affect satellite operation and on-board instruments by a means of charge accumulation, electric discharge and less likely direct interaction. Moreover, considerable variation of the ionospheric plasma condition can disrupt telecommunications in radio, mobile phone, television, as well as the global position system [Bothmer and Daglis, 2007]. Space weather events can also pose biological hazards to astronauts and aircrews.

Today, space weather monitoring and forecasting rely on continuous observation of solar activity, monitoring ionospheric conditions, and measurements of solar wind and magnetic field from deep space to the ground. These involve a variety of space-borne instruments operating far into the heliosphere (i.e., the Lagrange point L1 of the Sun-Earth system), magnetosphere (i.e., at geosynchronous orbit) and planetary space (e.g., low Earth orbit), as well as ground-based observatories that monitor solar activity, geomagnetic field variation and ionospheric conditions [Bothmer and Daglis, 2007].

At ground level, the Cosmic Ray (CR) monitoring networks, including the global Neutron Monitoring (NM) and Muon Detection (MD) networks, can also play an important role in space weather research and applications. These networks provide valuable information on the variation of interplanetary particles travelling through space which can be used to study, characterize and model space weather. When combined with global ground observations and modelling, CR variations in the interplanetary space can be inferred and characterized in near real-time (e.g., on an hourly basis). By looking for certain specific precursory signatures in these variations, interplanetary disturbances could be detected before they interfere with and disrupt near-Earth's environment [Belov, 2018; Munakata, 2000]. A typical alert time of several hours to 24 hours is found to be practically possible [Papailiou, 2012; Leerungnavarat, 2003].

Owing to the nature of the space weather events (fast approaching and global impact) and our limited resources and capabilities in detecting/forecasting them, international collaboration is needed in order to achieve reliable early alerts. One key ingredient for success is the provision of as much credible monitoring data as possible to cover disturbance spaces, parameterize the physical dynamics and attributes, and characterize the manifesting effects of space weather events. At the national level, coordinating efforts are also required to be prepared for such events, understand and mitigate the potential impacts, and help build resilience. In Canada, the Canadian Hazards Information Service (CHIS) at Natural Resources Canada is responsible for providing services on space weather monitoring and forecasting.

This article introduces Health Canada's Fixed Point Surveillance (FPS) network and discusses its potential for space weather monitoring and forecasting applications. Being a ground-based gamma radiation monitoring system, FPS can also respond well to CR muons and electromagnetic components. Its data can be valuable for space weather applications in that it provides a different but complementary perspective in comparison to the global NM and MD networks. This type of data can also supplement the space weather resources at CHIS, which currently relies on geomagnetic, ionospheric and satellite observations. Moreover, the wide geographic coverage of FPS within the region susceptible to geomagnetic substorms makes it especially interesting and promising in space weather studies.

Fixed Point Surveillance Network

The Fixed Point Surveillance (FPS) network development began about two decades ago, and now represents a countrywide network comprising of 84 stations. These stations cover Canada's major municipalities and areas in proximity to ports or nuclear power plants. Geographically, the network extends northward to the Arctic (Resolute, Nunavut), south to the Canada-United States border, and coast to coast from west to east. The elevation ranges from a few to a thousand meters above sea level. A map of the FPS station deployment is shown in **Figure 1**, where a system refers to a group of individual stations.

The network is designed for environmental radiation monitoring and health risk assessment purposes. This is accomplished using a 3x3 inch sodium iodide spectrometer (i.e., RS250/RS252 detector from Radiation Solution Incorporated) at each station. The data collection, sampling, transmission, and processing are automated. In the normal operation mode, each data sample has a 15-minute temporal resolution. However, this can switch to minute-by-minute sampling in the case of a nuclear emergency.

Figure 2 shows a typical 15-minute spectral data collected at the Ottawa station. The spectrum shows several characteristic gamma peaks from terrestrial radionuclides and a CR channel that registers signals above 3 MeV. By coupling appropriate dose calibration coefficients, the terrestrial dose results can be calculated from this spectrum. All results are routinely published at Health Canada's open data portal, and fed into EURDEP (European Radiological Data Exchange Platform[1]) and IRMIS (IAEA International Radiation Monitoring System[2]) in near real-time.

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[1] EURDEP real-time monitoring website: https://remon.jrc.ec.europa.eu/About/Rad-Data-Exchange

[2] IAEA IRMIS website: https://iec.iaea.org/IRMIS/

Figure 1: Health Canada's Fixed Point Surveillance network. 1: Pickering system; 2: Gentilly system; 3: Bruce system; 4: Darlington system; 5: Toronto system; 6: Ottawa Valley system; 7: Point Lepreau system; 8: Vancouver Island system; 9: Halifax system; and the regional system (10: Amherstburg; 11: Vancouver; 12: Yellowknife; 13: Regina; 14: Calgary; 15: Winnipeg; 16: Thunder Bay; 17: Montreal; 18: Charlottetown; 19: St. Johns; 20: Whitehorse; 21: Iqaluit; 22: Resolute; 23: Haida Gwaii; 24: Saskatoon; 25: Kelowna; 26: Fredericton; 27: Edmonton). Markers 1 and 4, marker 8, and marker 7 are hidden behind markers 5, 11, and 26, respectively. A system here refers to a group of individual stations.

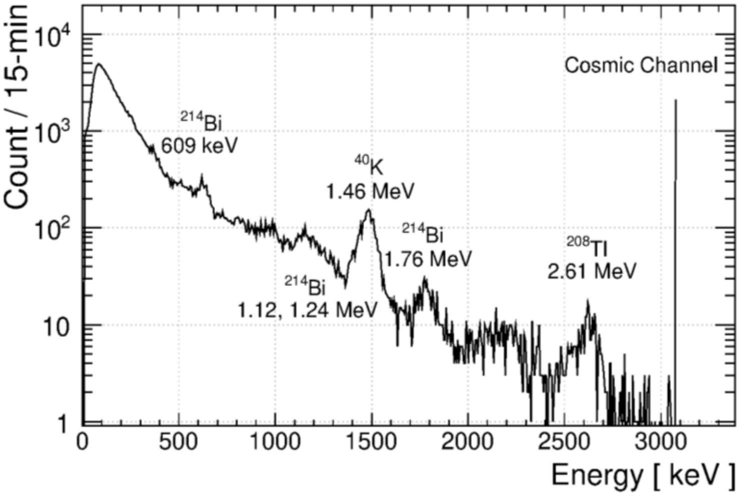

Figure 2: A typical 15-minute energy spectrum showing characteristic peaks of terrestrial radionuclides and a cosmic ray

The CR channel shown in Figure 2 forms the basis of cosmic ray monitoring in this work. In theory, this channel can register signals from all types of secondary CR components (i.e., $\mu^{+/-}$, $e^{+/-}$, p, γ and n). A rough analytical estimation and a dedicated coincidence experiment suggest that the major contributors are CR muons and electromagnetic components ($e^{+/-}$ and γ), whereas the hadronic contribution arising from protons and neutrons is small. Based on the coincidence measurement conducted in Ottawa in July 2016, the muon proportion in the CR channel accounts for about 50% in this specific case [Liu, 2018]. This actually agrees well with the analytical estimation within 15% accuracy. The second large contributor is from electromagnetic components, which are expected to give about 30-40% of the signals. The rest is from protons and neutrons. Monte Carlo simulation can provide more detailed and precise information about these contributions.

The Long-Term Solar Cycle Effect Observed in FPS

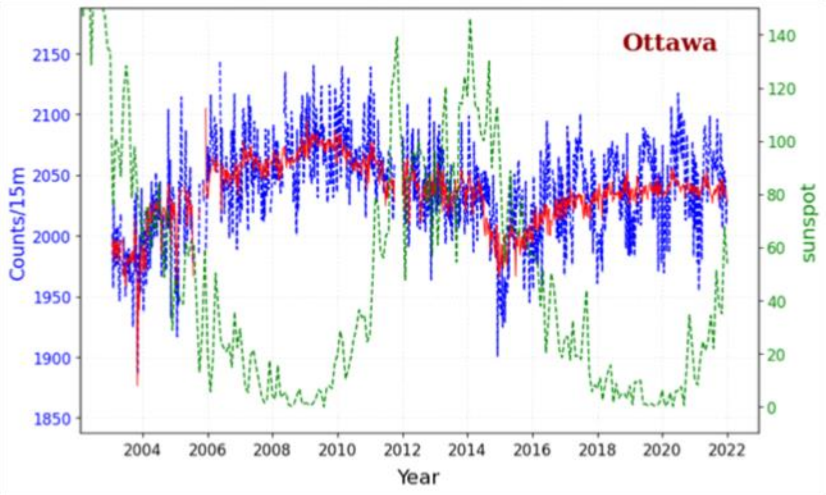

Figure 3: The long-term cosmic ray variations observed at the Ottawa station: the raw data (blue trace), atmospheric effect corrected data (red trace), and the sunspot observations (green trace).

In **Figure 3**, the long-term CR monitoring data in Ottawa is shown to demonstrate the network's response to solar cycle variations. Here both raw and corrected data exhibit a long-term variation trend that anti-correlates with solar activities represented by sunspot number. The anti-correlation is a result of shielding effects of the solar wind on the galactic CR component, and the observation of this co-varying tendency in FPS can be considered as an empirical support on the CR response in the CR channel. The large fluctuations found in the raw data are due to atmospheric effects (e.g., pressure and temperature variations). In environmental dosimetry, these fluctuations result from realistic effects that should be included in dose estimations. However, space weather studies are more interested in CR variations outside the Earth's atmosphere, so these effects should be corrected.

Observations of Space Weather Events in FPS

Besides the solar cycle effect, some transient solar events have also been observed in the FPS network. These include one Ground-Level Enhancement (GLE) event and many strong Forbush Decrease (FD) events. The GLE event is a solar event that can register a sudden and sharp increase at the global NM stations. It is typically initiated by solar energetic particles above 500 MeV and occurs about once a year on average.

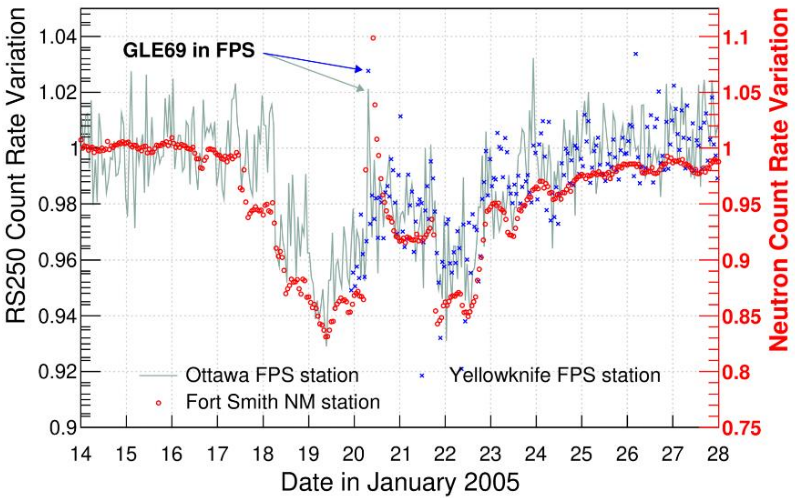

Figure 4: The January 2005 GLE69 event observed in FPS data. The actual enhancement level in the neutron data (red circles) was far above this figure's upper limit; the truncation was for showing the FPS variations clearly. Here, all count rates are normalized to their respective background rates prior to the first FD event (Jan 17, 2005) in this figure.

Figure 4 shows the GLE69 event observed by two FPS stations and the Fort Smith neutron station, which can be seen as the sudden rising on January 20th at 7:00AM UTC. At the NM stations located in/near Canada (including the Fort Smith station), strong increases were recorded with an enhancement level greater than 300% using 1-minute data. At the Yellowknife FPS station, an increase of 16% was observed based on the 15-minute data, implying 12- to 15-fold less sensitivity in FPS response relative to neutron detectors [Liu, 2019]. The complicated feature shown after January 17th in this Figure is due to multiple FD events that took place around that period of time.

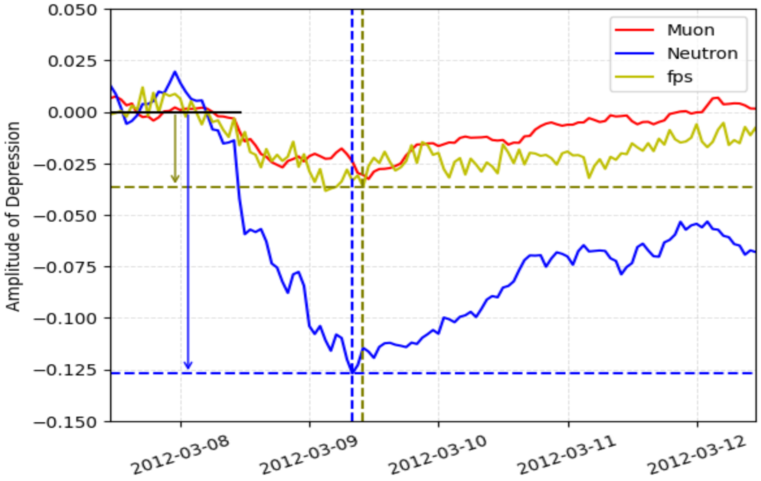

Figure 5: An example of the FD event observed in the FPS Pickering station. The black horizontal line is the baseline from which the amplitude of suppression is determined. The vertical dashed lines mark the times when the maximum FD effects occur, whereas the horizontal dashed lines indicate amplitudes at the minima.

Different from GLE events, FD events refer to a sudden or gradual decrease in the galactic CR intensity. The decreasing phase can last for a period of minutes to hours, followed by a gradual recovery that can last from hours to days. The FD events occur more often than GLE events; more than a hundred FD events can be recorded in a year at ground-based monitoring networks, depending on the phase of solar cycle.

An example of an FD event observed in the FPS network is shown in **Figure 5**. Throughout this study period, all three monitoring networks (FPS, NM, MD) observe a common pattern: starting with a weak pre-increase, followed by about 21-hour gradual decrease period before attaining its minimum and ending with a long recovery phase. The height from the baseline to the minimum is defined as the maximum amplitude of depression.

For a list of strong FD events that were observed in FPS, the maximum amplitudes of depression were calculated in all three monitoring networks and compared. The comparison helps characterize the relative sensitivity of each type of instrument in response to FD events. The results suggest that FPS has a comparable sensitivity to the MD detector under consideration, but is two- to three-fold less sensitive than NM detectors.

Implication for Space Weather Monitoring and Forecasting

As a network originally designed for terrestrial radiation monitoring, the FPS' potential as a space weather monitoring and forecasting network has been demonstrated in the previous two sections. Being an existing and still growing network, FPS has a good geographical coverage above the mid-latitude of North America and can perform near real-time monitoring on a 15-minute basis. Therefore, the FPS network is readily available for space weather monitoring provided the atmospheric effects are corrected in real-time.

Regarding space weather forecasting, of most concern is the solar events that cause strong geomagnetic disturbances and consequently lead to social disruption and economic losses. These events are normally associated with strong FD effects, to which all these ground-based CR monitoring networks respond well. With global NM and MD data, a technique has been developed to predict these events [Belov, 2018; Munakata, 2000]. The technique largely relies largely on detection of the CR anisotropy that is caused by the impending FD events or geomagnetic storms but can arrive to Earth ahead of them [Leerungnavarat, 2003; Munakata, 2000]. This precursor anisotropy can provide a typical lead time of several hours to 24 hours [Papailiou, 2012; Leerungnavarat, 2003].

In this technique, a global monitoring network is required. The combination of the FPS network with the same or similar detection system existing in other continents could satisfy the global coverage requirement. Additionally, complicated modelling and intensive computations are needed to account for both the atmospheric and geomagnetic impacts on CR variations. This is probably the most challenging part for applying FPS to space weather forecasting. Data statistics are also a key factor influencing the accuracy on forecasting. The current practice in both NM and MD networks is based on the hourly data, of which the statistical uncertainty should be below 1%. A single FPS station has an uncertainty normally greater than 1%. However, a cluster of closely located stations (e.g., the Pickering stations) can be a simple way to meet the statistical requirement.

Conclusions

In this work, Health Canada's Fixed Point Surveillance (FPS) network was introduced with an emphasis on its cosmic ray response. The long-term cosmic ray variations observed in FPS demonstrate its response to the changing solar cycle. The observations of transient solar events support the application of FPS for cosmic rays and space weather monitoring.

In comparison with neutron and muon detectors, the FPS can respond to Forbush Decrease effects in a similar way. The sensitivity of FPS network to these events is found about two to three times less than neutron monitoring networks, but comparable to muon detector networks. Similar techniques could be used in the FPS network to forecast space weather events as progress is made on the network's geographic coverage and modelling.

Acknowledgement

The author thanks Dr. Larisa Trichtchenko and Dr. Robyn Fiori at Natural Resources Canada for their encouragement on this project, and the advice and comments they provided following through this work. This work could not have been accomplished without the contributions of all FPS team members at Health Canada who keep the network well maintained, calibrated, and in operation for collecting all these data.

About the Author

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GlobVision's Commitment to Space Infrastructure Resilience

Graeme Maag and Emmanuel Papanagiotou
GlobVision Inc.

The space environment is characterized by the strongest of paradoxes. First of all, it is both new and old at the same time. While pre-dating Earth itself, it is only during the last 70 years that humanity seeks to untap its wealth of opportunities. In addition, space is both empty and crowded at the same time. Although interplanetary distances are quite vast in comparison to human scale, there is only a limited volume of space around Earth that is both practically and commercially useful (E.g. the narrow geostationary belt at roughly 42,000 km above Earth). There are more than 50 nations that operate in space, all competing for a share of this limited resource. Space is a congested, contested and competitive environment. Analogous to access to potable water and space will drive the rate of development for all countries as we wrap up the first quarter of the 21st century.

Virtually all aspects of modern life depend on space infrastructure: navigation, telecommunications & broadcasting, disaster management, climate change, and agriculture monitoring are only a few. Besides *space exploration* and its very many scientific, educational, and motivational advantages, space provides us all with essentially three functions without which we could not function efficiently:

1. *Communications* allow us all to stay connected, conduct business, resolve global challenges, and seek entertainment and leisure.
2. *Remote Sensing* allows us to monitor our planet and its resources/environment providing immeasurable benefits for farmers and fishers, urban planners, meteorologists, and environmentalists that measure and track the damage that we continue to do to our planet and those that monitor our coastlines.
3. PNT (Position, Navigation and Timing) provides us the ability to determine our location accurately and precisely, in three dimensions, and to navigate, from place to place with efficiency, anywhere in the world.

Space infrastructure is exposed to a constant level of threats and hazards, whose attribution can range from naturally occurring and unintentional events to deliberate and well-planned actions. For example, bursts of solar flares and turbulent periods of geomagnetic activity are caused due to the Sun's activity and interaction with the Earth's magnetic field. Such anomalous events can disrupt satellite communications, degrade navigation quality, or jeopardize Earth observation missions due to noisy imaging products. Those same consequences may also be the result of intentional actions from hostile actors that seek to revise the balance of power amidst a multi-modal, multi-variate, multi-focal geopolitical environment and challenge the current status quo. Other examples of space hazards include satellite collisions, object re-entries back to Earth's atmosphere, Rendez-vous and Proximity Operations (RPOs) between spacecraft, as well as Radio Frequency Interference (RFI), the latter being a combinatorial problem of interactions between satellite networks, Earth ground stations, and space weather. Attributing such events to specific causes and discerning intentions of actions in space forms one of the components of awareness in space.

To add to all this, space infrastructure is extremely remote and cannot be serviced ad-hoc, at least cost-effectively, with the exception of recent, novel, yet sparse on-orbit servicing demonstration missions (e.g. MEV-1, MEV-2). It is, therefore, clear that satellites must be operationally efficient and continuously monitored so that their expected lifespan is assured and even exceeded. Avoiding a collision by performing a small life-saving maneuver will shorten the satellite lifetime in the long run, but that cost is negligible when it comes to debris mitigation, and keeping space clean for everyone.

Within the above context, the term that encapsulates the process of determining and monitoring the precise locations of space assets along with the identification and characterization of related threats is known as ***Space Situational Awareness***, or ***SSA***. Conducting SSA has become an increasing priority for both commercial and military satellite Owners/Operators (OOs). The growing number of space assets in both Geosynchronous and Low Earth Orbit environments has urged stakeholders to take action and mitigate threats that risk rendering Earth space inoperable. A collision in space generating tens of thousands of debris will inevitably lead to the exponential growth of additional risks, not all of which will be avoidable, ultimately leading to the realization of the Kessler Syndrome – cascading collisions.

Outside the community of OOs, the military community at large has embraced the use of SSA in daily operations. Within such a framework, the space environment consists of yet another physical domain of operations along with land, sea, and air domains. The interactions among these domains and the need for interoperability and joint multi-domain operations are well understood in military doctrine. It quickly becomes clear that simply determining the location of satellites in space is not enough. Each space asset is affected by other phenomenologies: radio frequency assignments, reversible and irreversible Anti-Satellite (ASAT) capabilities, etc. Some analyses such as RFI require accurate information residing in non-physical domains. For example, frequency assignment information belongs in the cyberspace domain. As such, the role of SSA is elevated, and the term ***Space Domain Awareness***, or ***SDA***, is coined and used to encapsulate this wider variety of ontologies and tasks. At a multi-domain scale, the interaction among assets residing in any physical domain of operations is a key concept of ***All-Domain Operations*** and ***Pan-Domain Awareness, or PDA***. Such concepts have been adopted by commercial entities that rely on space infrastructure for their daily operations. These include air, marine, and land transportation, and distribution systems that deliver everything we consume, including our internet connectivity, the nightly news, Amazon packages, and favorite Netflix shows.

Being heavily reliant on infrastructure exposed to constant and growing risk is common in other environments. Monitoring of aging bridges, dams, and buildings all exposed to harsh weather conditions and large temperature swings require the development of safety-critical applications that promptly and accurately report their status. These applications are also required to predict trends and root-cause analyses through powerful data analytics and Artificial Intelligence.

GlobVision, having substantial experience in infrastructure monitoring, has collaborated with the Department of National Defence (DND) and the Canadian Space Operations Center (CANSpOC) and has developed ***SSA*** and ***SDA*** solutions that address the latest needs in space and multi-domain awareness. As more commercial entities become conscious of the vast potential of “connecting the dots” between their commercial business and space, more of those multi-domain interactions will be defined, mapped, and built. Ultimately, those interactions will require information from all domains, leading up to the envisioned realization of Pan-Domain Awareness. GlobVision is well-positioned for this future transformation.

It needs to be highlighted that SSA, SDA and PDA matters to all government organizations and commercial businesses, as their role breaks away from the strict mandate of monitoring satellites, and moves up to extracting information and inferences that affects all commercial aspects on Earth; thus making this knowledge non-exclusive to military entities. The above realization is practically demonstrated from the *U.S. Space Policy Directive 3*, signed in 2018. According to the latter presidential decision, there is a mandate to transfer all ownership of Space Traffic

Management tasks from the U.S. *Department of Defense* to the *Department of Commerce*.

SSAVision – Space Situational Awareness

GlobVision has developed SSAVision in response to the ever-evolving daily space operational needs of DND and CANSpOC. SSAVision has been in active use by DND and CANSpOC for over five years, supporting space operations 24/7. SSAVision is an integrated and automated web service providing Space Situational Awareness (SSA) and informed decision-making capabilities to spacecraft operators for the protection, ongoing reliability, and resilience of space assets.

SSAVision acquires high-fidelity data from multiple data sources, then automatically applies advanced and innovative analysis algorithms to the data and presents the results to spacecraft operators. Data collection is fully automated and does not require any time from users for its smooth operation. Data is updated continuously, in short time intervals, and at different frequencies based on how often the data is produced from each individual provider. As data gets updated, all SSA analyses are updated as well to reflect the latest changes. Automation of data and analyses provides substantial time savings to oversubscribed personnel, allowing them to focus on more critical tasks and on what matters most.

SSAVision is being constantly enhanced with new features, following DevSecOps methodologies. GlobVision employs Agile principles for rapid development and testing, and uses Configuration and Change Management for version control, creation of baselines for releases, and management of change requests.

SCOP – Space Domain Awareness

GlobVision's Space Common Operating Picture, or SCOP, is an *advanced* and *configurable System-of-Systems* web service providing a *common operating picture*, *situational awareness*, and *informed decision-making* for space and multi-domain operations. SCOP *integrates* and *aggregates* heterogeneous data from *multiple international sources*, layered on top of SSAVision, and provides critical and reliable multi-domain analyses results that can be shared with authorized users or other COP systems.

SCOP was developed with support from DND. GlobVision has demonstrated SCOP to key stakeholders within the Canadian Armed Forces, where it has been acclaimed and received strongly positive feedback for its innovative nature. SCOP was selected as one of only six solutions to be presented during NATO Space Pitch Day in June 2021. During these venues, there was a clear consensus that SCOP is unique, powerful, and crucial to the success of Allied space and multi-domain operations, hence a clear indication of international demand for Canadian technology.

Initially, SCOP was developed to provide expedited decision-making information and insight to support Canadian defense operations globally. Eventually, it became clear that it can be equally useful on a larger scale, able to connect multiple departments and organizations and enable their operations, planning, and decision-ready insight.

SCOP provides unprecedented interoperability, multi-domain, secure, consolidated SDA data federation, analysis, visualization, and dissemination capabilities. By providing a reliable, repeatable and scalable framework, SCOP allows space asset stakeholders to leverage Space Domain Awareness for intelligent operations and planning.

SCOP integrates technologies under a single architecture that manages and automates data federation, enables multi-domain analysis, exposes a secure API for data sharing (i.e. creates interoperability with other COP systems), and transforms analyzed data to actionable intelligence. SCOP is designed to be used eloquently by space analysts and decision-makers alike. The target audience is civilian/military organizations consisting of teams with varying backgrounds and skills. Its modular ontology model is geared towards addressing the evolving needs of its users. As mentioned, it is envisioned that those needs will converge toward Pan-Domain Awareness.

SCOP was developed following DevSecOps and Agile methodologies, with a strong commitment to Configuration and Change Management.

SCOP is a comprehensive, operational SDA and Common Operating Picture platform for processing and visualizing multiple streams of data, monitoring space-based systems, and assessing space environment threats. It is a decision support tool for stakeholders of space and ground operations, with leading data sharing and interoperability features, and a low total cost of ownership.

Through continuous monitoring and health assessment of satellites, SCOP ensures the continuity of SDA as a backbone for modern defense, communication, intelligence and security establishments, with a clear vision towards Pan-Domain Awareness operations.

The Road to Pan-Domain Awareness

As discussed, space user communities have understood that Space Traffic Management and Space Domain Awareness is not the upper limit for leveraging space capabilities. Space can be viewed as the interconnecting medium of all terrestrial business. For instance, consider the following example: Using GPS data, railroad traffic data can be ingested into relevant systems (such as GlobVision's RailNet, an intelligent optimization tool for railway operations) and correlated with weather conditions as reported from Low Earth Orbit satellite data, along with SAR imagery products that can inform about change detection of forests and other natural resources. Fusing and processing of all these datasets can produce a holistic view and identify if train traffic may pose a risk of sparking a wildfire, in this example, along the rail network.

Conclusion

GlobVision's 25-year focus on three market sectors: 1. *Space, Aerospace and Defence; 2. Utilities and Infrastructure; and 3. GIS and Remote Sensing* has led, and continues to lead, to the very real culmination of the aggregation of multi-domain awareness, based on advanced data analysis and the creation of useful and actionable information, into a true, intelligent System-of-Systems.

It is our firm belief that, while as is often the case, the initial application for this System-of-Systems was driven at the defense level, the applications for Pan-Domain Awareness will apply to activities such as Public Transportation, Health Care delivery, and logistics of every description.

GlobVision is enabling a significantly better understanding of a host of environments using a broad set of robust, proven, and trusted tools and intelligence that is anything but "artificial".

About the Authors

***Graeme Maag** has over 40 years of experience in various technical and commercial roles in both small businesses and very large businesses. Prior to joining GlobVision some 8 years ago, he spent almost 2 decades in the space and defence sector and as much time at the helm of a private business.*

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To Be Resilient is Not to be Resistant.

W.T. Isaacs C.E.T.
President, Crisis Leadership Ltd.

The word resilience is commonly used and has remained even more popular since the COVID-19 Pandemic. In the late 90's, organizations were commonly using the term "preparedness" to address their ability to respond to emergency and security hazards or threats. With the evolving effects of climate change and business needs came significant changes to the hazard and threat landscape, along with higher expectations for an organization's ability to respond. As company ER (Emergency Response) and Security plans became more detailed and sophisticated in the mid to late 2000's, the term resilience started to be utilized more frequently. What does this term mean to you? Is your organization resilient?

There are many definitions of resilience. When referring to an organization's level of resilience, I prefer to say:

> *"Resilience is the capacity of a dynamic system to adapt successfully to challenges that threaten the function, survival or future development of the system."*
>
> Whereas *"Preparedness is the quality or state of being prepared such as the fact of being ready for something."*

The distinction between '**resilience**' and '**preparedness**' is similar to the distinction between 'climate' and 'weather'. Climate is how the atmosphere "behaves" over relatively long periods of time above a large area; whereas weather is the condition of the atmosphere over a short period of time above a smaller area. Your company's resilience is like Climate in that it is the strategic ability of how you deal with challenges over a long period of time and throughout your entire organization. On the other hand, your level of preparedness is similar to Weather as it is your ability to react to circumstances over a shorter period of time by department(s) or a small area. A company's level of preparedness could vary across the organization based on the local priority that is placed on being prepared. To be resilient is a goal, not an end result. The plans you develop may make you resilient today, but without regular review, tomorrow may bring a new set of circumstances not experienced before that will challenge emergency response or conventional security wisdom.

I believe resilience is a holistic term. For an organization to be resilient, the company's Business Continuity Plans, Emergency Response Plans, Security Management Plans, Crisis Communication Plans, etc., must all be linked, tested, and continually updated to remain effective. I have seen numerous examples proving the adage "Prevention is always less costly than response.''

I don't believe that successful organizations are resistant to making their company more resilient. However, it requires money, resources, and meeting ever-challenging compliance goals. In a regulated critical infrastructure sector, each company strives to meet or exceed the regulations set out by the provincial or federal regulator. As regulations change, they are often tightened up due to changing conditions in the industry or reoccurring events. For an organization to prove they are complying with regulations, it often takes the development of additional documentation or processes that capture its compliance process. Monitoring compliance is a good thing, but it does add time and sometimes already stretched resources in order to demonstrate it. Updating and regular testing of emergency plans and processes to increase resiliency can sometimes get postponed due to other competing priorities.

One area that quite often gets overlooked is the '**crisis management structure**' the organization is utilizing (assuming they have one). At the strategic level, this team of senior leaders must be able to work together effectively, be disciplined in their commitment, and be able to communicate concisely internally, as well as externally. I have seen numerous examples over the years when this critical crisis management team has been established, then over time as people change roles or leave the company, the list is not adequately maintained, or the contact information is out of date. Thus, making the quick mobilization of this critical team of leaders ineffective as time is wasted looking up new cell numbers or determining who replaced whom. Not to mention, have these new members of this critical team been trained to know what is expected of them, and did they have the opportunity to experience an exercise or a real event to witness the team dynamics in real-time. If a company can update its customer information data or inventory levels on a regular basis, how hard could it be to create a process to maintain your emergency contact staffing listings across the company on a scheduled basis? Emergency events do not care about the time of day, the time of the year, company boundary lines, or even if you are prepared. They just happen, and often when you least expect it or can least afford it. **Resilience over resistance**.

The shooting at the National War Memorial in Ottawa on October 22, 2014, that took the life of Nathan Cirillo, and the threat to Prime Minister Justin Trudeau after an armed man rammed the gate of Rideau Hall with a pickup truck to gain access to the grounds on July 6, 2020, have made their mark on the interpretation of domestic terrorism preparedness. It is now time for a fresh look, considering pandemics, local human-caused and natural catastrophes, ever-changing technology supporting cyber threats, reoccurring natural threats (like wildfires, floods, and tornados), and aging domestic infrastructure. The current landscape of the emergency response actions required and the readiness of public and private agencies in a globally interconnected world has left a deep scar on domestic preparedness. Our determination of resilience and how risk is evaluated both nationally and internationally should be reviewed. Government agencies and nongovernmental organizations will have to adapt to the changing landscape by being resilient, not just prepared when addressing their response level against multi-vectored threats.

In order to deal with this changing threat environment, measurement of your company's resilience is a tough achievement. In many circumstances, only reviewing the results of a live event can demonstrate the level of resiliency an organization exhibited. Understandably, many private-sector companies are hesitant to move forward on resilience projects because of the uncertainties associated with their return on investment (ROI). Developing the parameters needed to project the ROI of dollars and personnel resources allocated to programs and resilience-focused projects designed to create/improve resilience will be a challenge. Especially in a category where they are already deemed compliant will be a major political and fiscal challenge going forward.

Metrics will need to be developed to specify how a business can attain a level of resilience that measurably surpasses anything that reflects the current situation. Experts concede that the creation and improvement of resilience metrics will require the development of a realistic yet visionary strategy. A substantial amount of effort and resources will be required to support this interdisciplinary effort, which must be orchestrated by a combination of leaders from private and public sector stakeholders. These efforts should also include academia and other impacted agencies and organizations. Other key sectors such as public health, telecommunications, financial institutions, insurance, and others who set operational standards could also share the responsibility of defining the roadways and metrics used for attaining resilience.

At the risk of oversimplifying this challenge, consider a proposed philosophical formula:

$$\boldsymbol{R} = \ (\boldsymbol{H\&S} + \boldsymbol{Rp} + \boldsymbol{C}) \div \boldsymbol{F}$$

- **R = Resilience factor total** – The total resilience score becomes the quotient from the equation of the most significant applicable factors for that sector. Comparing this number to year-after-year totals the level of compliance could be monitored.

- **H&S = Health & Safety metric -** Results from local Health authorities and company safety records depicting any injuries to the general public and/or employees during any incidents.
- **Rp = Response metric** – Results from response times to incidents or results from exercises as monitored by the company and/or local jurisdictional requirements.
- **C = Compliance & Communication metrics** – Measurement results from compliance audits by regulators, company audits and/or financial stakeholders. These results could also include external and internal communication measurement results to the public and/or stakeholders.
- **F = Frequency of incidents and exercises** – This element becomes the divisor to establish the metric results based on the number of incidents or exercises where this practice was utilized. This number demonstrates if the number of incidents is increasing or is an entity increasing its number of exercises to practice their processes.

The establishment of these metrics will be a huge undertaking, but the benefit to establishing a common resilience factor would be key to measure an organization's progress. This massive effort must be both knowledge-based and strategically realistic in terms of what may lie ahead. The end result would be a new and more measurable type of resilience built on a platform of current societal expectations and modernization. If this could be accomplished, we could move forward with a more standardized approach to measure our resilience against the worst effects of the man-made and environmentally caused natural disasters that now plague us going forward.

If an organization, either private or public is not willing to be involved in establishing their resilience benchmarks, then one could assume it may be resistant to this change or require further justification for the benefits. After all, what gets measured gets managed. This will be a long-term effort that will, in all probability, encounter strong opposition from many stakeholders and experience at least a few periodic setbacks along the way. If your organization is committed to being truly resilient, it must remain focused on its commitment to achieving a measurable degree of resilience that may be very different from but nonetheless superior to the present-day system.

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 entered the consulting field ten years ago starting Crisis Leadership Ltd., working with numerous organizations, and assisting them in the development, application, and compliance of emergency response and security plans.

He is eager to share his knowledge and firsthand experience in the development, implementation, and measurement of the effectiveness of emergency response and security management programs.

He has performed gap analysis and peer review inspections pertaining to energy sector security management plans, as well as emergency management plans.

Also, Bill has developed effective post-incident investigation processes to field incidents and leads a crisis leadership training program designed for industry leaders to assist them in leading during crisis situations.

In addition to this, he regularly speaks to energy emergency and security management programs at sector conferences and security briefings. He was past Chair of the Emerging Issues Working Group for the National Strategy for Critical Infrastructure Protection, and Energy & Utilities Sector Network held in Ottawa.

Education and Training:

- *Member of the Ontario Association of Certified Engineering Technicians & Technologists*
- *Member of the Ontario Association of Emergency Managers*
- *Associate member of the Ontario Association of Chiefs of Police*
- *Member of the Canadian Association of Threat Assessment Professionals*
- *Associate Member of Association of Infrastructure Security and Resilience Professionals*

As well, Bill is an active original member of the Technical Committees responsible for the development of:

- *CSA Standard Z246.1 Security Management for the Petroleum and Natural Gas Industry and*
- *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.

Bill 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 Publication, Faculty of Engineering & Design, Carleton University.

Recommended Critical Infrastructure Security and Resilience Readings

Felix Kwamena, Ph.D.*
Email: felix.kwamena@carleton.ca

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