

# Canada's Requirements for Enhanced Geodetic Infrastructure

An Expert Panel Report

CCA | CAC

# Canada's Requirements for Enhanced Geodetic Infrastructure

An Expert Panel Report



COUNCIL OF CANADIAN ACADEMIES
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This project responds to a request from the sponsor, Natural Resources Canada (NRCan), for an independent assessment. The sponsor was not involved in either panel selection or report development; any opinions, findings, or conclusions expressed in this publication are those of the authors and do not necessarily represent the views of their organizations of affiliation or employment.

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The Council of Canadian Academies (CCA) offices in Ottawa are located on the unceded traditional territory of the Anishinaabe Algonquin People, who have cared for these lands for millennia.

The CCA is committed to reconciliation and honouring Indigenous sovereignty. Through our work in providing evidence for decision-making, we recognize that a wide range of knowledges and experiences contribute to building a more equitable and just society. We encourage all who engage with our work to further learn about and acknowledge the past and present context of the land now known as Canada and of the Indigenous Nations and Peoples who steward it.

# Expert Panel

Expert panel members serve as individuals and do not represent their affiliated organizations or employers. Each panel member was selected for their expertise, experience, and demonstrated leadership in fields relevant to this project.

**Denis Hains (Chair),** Guest Professor, Université Laval; President and CEO, H2i Inc. (Ottawa, ON)

**Sunil Bisnath,** Professor, Department of Earth and Space Science and Engineering, Lassonde School of Engineering, York University (Toronto, ON)

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**Xin Wang,** Professor, Department of Geomatics Engineering, University of Calgary (Calgary, AB)

# Message from the Chair

***"Where are you? Where are you going? And when?"***
*Basic questions…requiring geodesy.*

The context and timing of this study could hardly be more critical. As a vast northern country with Arctic and remote regions and significant resources, Canada is at a focal point in a rapidly evolving international landscape. Canada must strengthen its capacity to engage internationally, contribute globally, exercise influence, and safeguard its security and sovereignty.

Yet Canada faces a significant gap in domestic geodetic capacity, compromising resilient positioning and navigation. Reliable geodetic infrastructure and knowledge underpin critical infrastructure, transportation, defence, climate science, economic activity, and technological innovation—all of which require precise and accurate positioning. Without sufficient domestic capability, Canada remains vulnerable to disruption and dependent on external systems and expertise.

A resilient national geodetic infrastructure is therefore essential national infrastructure. Canada must invest in the geodetic infrastructure, expertise, and knowledge needed to know where we are, where things are, and how they change over time, supporting our economy, safety, defence, sovereignty, and ability to act independently. Work to bolster Canada's PNT resilience is already underway, with federal announcements in October 2026 on a Galileo partnership, the *Plan for a Stronger Canada*, and a new PNT resilience framework. At the same time, national capability cannot stand apart from the global geodetic system and network. Canada benefits from this global foundation, but should also actively participate and contribute to its resilience, precision, accuracy, and continuity.

I sincerely thank our expert panel: Sunil Bisnath, David J. Coleman, Steve DeRoy, Georgia Fotopoulos, Gabriela Siles, and Xin Wang; and our seven expert peer reviewers and Bing Chen for their expertise and constructive contributions.

I also recognize the Council of Canadian Academies, under Tijs Creutzberg, President and CEO, and extend particular thanks to Becky Chapman, Alexei Halpin, Vasa Lukich, and Lara Olukolu, for their leadership, analytical work, and support.

It has been a privilege to serve as chair on an issue of strategic importance to Canada and the world.

*Original signed by*

**Denis Hains, D.H.C.**
Chair of the Expert Panel

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As part of the evidence-gathering process, CCA staff conducted interviews to better understand the role of geodetic infrastructure in the Canadian economy and opportunities related to investments in new geodetic infrastructure. On behalf of the panel, CCA staff communicated with the following individuals, who generously shared their experiences and knowledge:

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# Peer Reviewers

This report was reviewed in draft form by reviewers selected by the CCA for their diverse perspectives and areas of expertise. Their anonymized submissions were considered in full by the expert panel. Reviewers were not asked to endorse the conclusions, nor did they see the final draft before its release. Responsibility for the final content of this report rests with the expert panel and the CCA.

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The peer review process was monitored on behalf of the CCA by **Bing Chen,** Dean (Interim), Faculty of Engineering & Applied Science; UArctic Chair in Marine and Coastal Environmental Engineering; and Professor of Civil Engineering, Memorial University of Newfoundland.

# Executive Summary

Geodesy is an inherently global science that lets us measure, understand, and represent the Earth's shape, gravity, and rotation, enabling applications with far-reaching benefits for governments, the economy, and people worldwide. At a global scale, geodetic observations allow us to measure key terrestrial and geophysical properties, including the length of the day, how the ground shifts beneath us, how sea levels fluctuate, and how all these properties are impacted by a changing climate. Geodesy also underpins positioning, navigation, and timing (PNT) services embedded in nearly every major economic sector, while also supporting multiple critical infrastructures, including telecommunications, transportation, finance, and utilities. At the level of the individual, geodetic infrastructure facilitates many everyday activities people take for granted, such as navigating with smartphones and other personal devices, buying goods and services through e-commerce, and accessing emergency services when something goes wrong.

Recognizing the importance of geodetic observing infrastructure, as well as the value of geodetic data, products, and services across the Canadian economy, Natural Resources Canada asked the Council of Canadian Academies (CCA) to convene an expert panel tasked with examining the opportunities and risks associated with renewed domestic investment in geodetic observing infrastructure.

## Answering the charge

### How does geodetic infrastructure[1] impact Canada and its economy?

Geodetic information needs to be as accurate, precise, and reliable as possible to support the many applications built on geodesy. The global system that provides this information includes a wide range of facilities, data, and products, with geodetic observations providing the essential foundation on which the system is built. Four major observation infrastructures form the core of the Global Geodetic Observing System (GGOS). These include global navigation satellite systems (GNSS)—such as the well-known Global Positioning System (GPS)—which the public widely uses because their signals can be accessed through smartphones and other consumer devices. Beyond GNSS, however, geodesy also depends on inputs from very long baseline interferometry (VLBI), satellite laser ranging (SLR), and Doppler Orbitography

1 Based on discussions with the sponsor, the term *geodetic infrastructure* in the charge questions was interpreted as focused on geodetic observing infrastructure supporting the highest accuracy possible for contribution to applications in Canada and globally.

and Radiopositioning Integrated by Satellite (DORIS), along with other techniques such as gravimetry and tide gauges.[2] Each technique contributes to primary geodetic products, including the reference frames essential for linking different physical environments, allowing us to consistently position ourselves and the world around us at local, regional, and global scales. Without accurate reference frames, for example, it would be challenging to superimpose positioning data onto a map.

Quantifying the value of geodetic observing infrastructure is challenging, as geodetic data and products are integrated into many critical infrastructures and value chains across sectors such as construction, resource development, and agriculture, among others. It is clear, however, that geodetic observing infrastructure underpins a wide range of knowledge, services, and applications indispensable to economic prosperity and daily life in Canada. Put simply, nearly every sector and individual, knowingly or unknowingly, benefits from the knowledge and applications enabled by geodesy.

### Does Canada have sufficient infrastructure to meet the needs for its activities reliant on geodetic information?

Canada's geodetic observing infrastructure exhibits notable gaps that limit its ability to meet current and future needs, when considered alongside federal priorities. As a global enterprise, geodesy depends on ground-based infrastructure distributed across the world, but Canada lacks any VLBI or SLR ground stations despite having one of the largest landmasses on Earth. Additionally, compared to peer countries, Canada has a sparse network of continuously tracking GNSS stations (referred to as active control stations), particularly in northern and remote regions.

Many of Canada's national priorities increasingly depend on reliable access to the data and products stemming from geodesy. However, Canada currently lacks sufficient infrastructure to fully support its objectives in several areas, including economic growth, national security and defence, sovereignty, and monitoring the impacts of climate change. Access to high-quality geodetic information is critical to advancing the federal government's economic priorities. For example, major construction and resource projects rely on precise positioning for planning, operations, and monitoring, particularly in remote regions. Reference frames link related assets, such as roads, pipelines, and ports, across Canada's infrastructure network. Improved geodetic information would enable these projects to be completed faster and more easily linked to existing regional, national, and international networks. Emerging

2 Gravimetry directly measures the Earth's gravitational field while tide gauges measure sea level.

technologies such as those based on geospatial/hydrospatial analytics and AI, including digital twins, also depend on accuracy and interoperability to integrate and analyze data sets across sectors, from natural resources to infrastructure management.

Ensuring access to reliable and precise PNT services is also essential to address issues related to sovereignty and defence. Canada's capacity to support navigation and domain awareness for national security currently relies on military-grade PNT services owned by a foreign jurisdiction because Canada does not own or operate a GNSS constellation. This dependence limits Canada's resilience amid increasing disruptions to GNSS. Similarly, Canada's lack of VLBI and SLR infrastructure limits its sovereign ability to oversee space missions and locate space assets, with implications for Canada's economic, defence, and scientific ambitions in the space sector. Geodesy also plays a key role in emergency response and environmental risk assessment, while supporting climate monitoring by enabling precise measurement of sea-level rise and other changes associated with a changing climate. Finally, reliable and precise positioning and location data are needed in light of Canada's commitment to reconciliation with Indigenous Peoples; such data are essential for land claims and needed for resource management and public safety, among other applications. The limitations of Canada's existing geodetic infrastructure may be felt most strongly in the Arctic. The region has the country's lowest density of active control stations, even as its strategic importance grows and the impacts of climate change are most pronounced.

### What are the risks associated with reduced access to high-quality geodetic information, including those related to security?

As noted above, Canada lacks sufficient geodetic observing infrastructure to fully achieve its priorities and leverage geodetic information across the broader economy. Any reduction in Canada's access to high-quality geodetic information, regardless of the cause, would worsen the impacts of these existing gaps. Furthermore, as the effects of climate change increase in magnitude, Canada's gaps in geodetic infrastructure hinder the collection of data needed to better understand climate processes and impacts at regional and global scales, compromising the reliability of climate risk assessment. Without VLBI and SLR stations, Canada relies on international geodetic networks it does not contribute to, benefiting from infrastructure investments by other jurisdictions and from extensive data- and information-sharing practices largely sustained through informal agreements rather than a formal governing framework. While a major GNSS outage is unlikely, local and regional

disruptions caused by spoofing and jamming are becoming increasingly common. Without backup systems, the potential impacts on industry sectors, critical infrastructure, and individuals would be substantial.

The national security, defence, and sovereignty risks associated with insufficient geodetic infrastructure are particularly salient, as these gaps create vulnerabilities and limitations. In the Arctic, a region at the centre of much of the discourse on security and sovereignty, Canada lacks the infrastructure to guarantee PNT services necessary for domain awareness, intelligence, telecommunications, and navigation, among other needs, and relies on another jurisdiction's infrastructure to do so. This reality, combined with the shift in Canadian industrial policy toward defence and dual-use technology, underscores the utility of geodetic infrastructure and sovereign PNT as a pillar of Canada's resilience and security.

### What opportunities are associated with renewed domestic investment in geodetic infrastructure?

Canada has timely opportunities to enhance its geodetic capacity and resilience through strategic investments, strengthening user outcomes, and aligning its global contributions and partnerships with its ambitions as a middle power. A key priority is developing co-located observing sites that integrate multiple core techniques to enable more accurate and resilient global reference frames. Doing so would benefit Canada and provide value to the international community while demonstrating Canada's commitment to a global public good. Such contributions would enhance Canada's credibility and influence over decisions that affect it in the area of geodesy, while bolstering a vulnerable network from which Canada derives benefits. Contributing to global infrastructure networks and having a seat at international tables may be especially relevant given efforts to strengthen relationships, particularly with reliable partners in space, and to align with partner nations on shared priorities (e.g., climate change, defence). Another priority is increasing the density of active control stations, particularly in the Arctic and remote areas, to improve positioning accuracy and support infrastructure development, climate science, and public safety. In addition, enhancing PNT resilience through a Canadian low-Earth orbit (LEO) PNT satellite system could serve several purposes, including reducing dependence on foreign-owned networks and improving service in locations where reliability is limited. Ultimately, a coordinated approach to building sovereign capacity in geodetic observing infrastructure could help Canada establish leadership in priority areas, strengthening its standing as a trusted international partner while delivering lasting economic benefits for all people in Canada.

# Abbreviations

| | |
|---|---|
| CACS | Canadian Active Control System |
| CSRS | Canadian Spatial Reference System |
| DORIS | Doppler Orbitography and Radiopositioning Integrated by Satellite |
| EOP | Earth Orientation Parameters |
| GGOS | Global Geodetic Observing System |
| GIS | Geographic Information Systems |
| GLOSS | Global Sea Level Observing System |
| GNSS | global navigation satellite systems |
| GPS | Global Positioning System |
| HQP | highly qualified personnel |
| IAG | International Association of Geodesy |
| ICRF | International Celestial Reference Frame |
| IGS | International GNSS Service |
| ILRS | International Laser Ranging Service |
| IVS | International VLBI Service for Geodesy and Astrometry |
| ITRF | International Terrestrial Reference Frame |
| LEO | low-Earth orbit |
| MPO | Major Projects Office |
| NAD83 | North American Datum of 1983 |
| NWP | Northwest Passage |
| PNT | positioning, navigation, and timing |
| PPP | Precise Point Positioning |
| SBAS | satellite-based augmentation systems |
| SLR | satellite laser ranging |
| UN-GGCE | United Nations Global Geodetic Centre of Excellence |
| UT1 | Universal Time |
| UTC | Coordinated Universal Time |
| VLBI | very long baseline interferometry |

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1

# Introduction

1.1 The charge to the panel

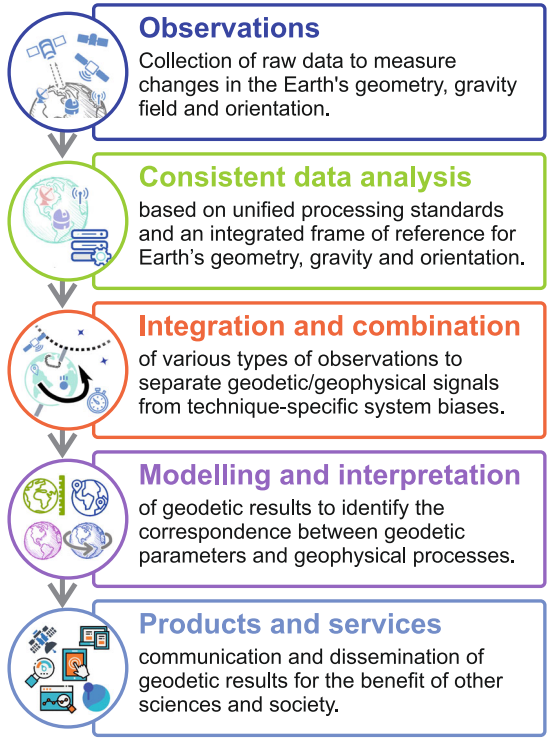
1.2 An understanding of the Earth in four dimensions

In Canada and around the world, a growing number of industries, applications, and activities rely on real-time, accurate information about the Earth. On an individual level, positioning and navigation allow us to determine where we are and how to get where we want to go, and this information has become part of everyday life through smartphones, digital maps (e.g., Google Maps, MapQuest), and many other devices and applications. While the availability of positioning information has become widespread, determining position relies on complex scientific measurements. These measurements depend on a global network of infrastructures that collect data on the impact of a range of internal and external processes influencing the Earth's shape, size, gravity, and rotation. *Geodesy* is the science of measuring these properties, and its application has become integral to the economy and daily life.

The field of geodesy has a lengthy history and may be one of the oldest sciences, as humans have long been curious about the scale of the world around them (Bomford, 1980; Vaníček & Krakiwsky, 1986; Angermann *et al*., 2022). Geodetic measurements have historically relied on basic geometric principles and physical and/or astronomical reference points to determine distances on Earth (Angermann *et al*., 2022). For example, in the third century BCE, the Greek philosopher Eratosthenes determined a reasonable estimate of the radius of the Earth by comparing the angles made by sun rays at two different locations separated by a measurable distance (Matthew, 2023). While a range of tools and approaches have been used to measure and map the Earth over the centuries, more recent technological advances have led to a proliferation of observation techniques in geodesy that are now integrated into a global system (Angermann *et al*., 2022).

Today, geodesy is linked to society through the International Association of Geodesy (IAG)'s Global Geodetic Observing System (GGOS), a network of infrastructures and processes that together yield products and services providing value to a wide range of users (IAG, 2025a) (Figure 1.1). These products and services are foundational for a range of critical infrastructures across society, including transportation, energy, communication, and financial. The essential role and strategic importance of geodesy and the global geodetic

observing infrastructure network are recognized by the United Nations through General Assembly Resolution 69/266, which was adopted in February 2015 (UNGA, 2015).




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**Figure 1.1 Geodesy: From observations to valuable products and services**

Developing geodetic products and services from raw geodetic information involves several essential steps, including observation, analysis, combination, and interpretation.

## 1.1 The charge to the panel

Recognizing the importance of geodetic observing infrastructure, as well as the value of geodetic data, products, and services across the Canadian economy, representatives from the Canadian Geodetic Survey (CGS) at Natural Resources Canada (NRCan, hereafter "the sponsor"), alongside several other

co-sponsoring organizations,[1] asked the Council of Canadian Academies (CCA) to convene an expert panel tasked with examining the opportunities and risks associated with renewed domestic investment in geodetic observing infrastructure through the following questions:



**How does geodetic infrastructure[2] impact Canada and its economy?**

- Does Canada have sufficient infrastructure to meet the needs for its activities reliant on geodetic information?
- What are the risks associated with reduced access to high-quality geodetic information, including those related to security?
- What opportunities are associated with renewed domestic investment in geodetic infrastructure?

To answer the charge, the CCA assembled a multidisciplinary, seven-member expert panel (hereafter "the panel") whose members have backgrounds and expertise in geodesy, geomatics engineering, hydrography, geospatial and hydrospatial data, geographic information systems (GIS), and Indigenous mapping, from both academia and industry. To ensure the integrity of the assessment process, panel members disclosed to the CCA and fellow panelists any conflicts of interest—actual, foreseeable, or perceived—relevant to the issues being discussed, so that these could be managed transparently. Panelists also abided by a confidentiality agreement and code of conduct designed to support an environment that fostered effective and respectful deliberations, was conducive to the free exchange of knowledge, and supported the assessment of evidence.

As part of CCA's process to maintain panel independence, sponsors do not appoint panel members, nor do they engage with the panel during the assessment process, except for the panel's first meeting, when the sponsor is invited to present the charge and answer any panel questions. In this discussion, the sponsor expressed its interest in infrastructure that enables the collection of the raw data used in geodesy (observing infrastructure) and the

1 The Canadian Positioning, Navigation and Timing Board; Fisheries and Oceans Canada; Innovation, Science and Economic Development Canada; Canadian Space Agency; Department of National Defence; Shared Services Canada; and Public Safety Canada.

2 Based on discussions with the sponsor, the term *geodetic infrastructure* in the charge questions was interpreted as focused on geodetic observing infrastructure supporting the highest accuracy possible for contribution to applications in Canada and globally.

benefits those data provide. The panel notes that it did not have the expertise, mandate, or time to conduct a quantitative cost–benefit analysis related to investments in geodetic observing infrastructure. The panel met in person or virtually six times in seven months to review evidence and deliberate on the charge.

## 1.2 An understanding of the Earth in four dimensions

Determining where we and the objects around us are requires an understanding across several dimensions. Knowledge of longitude and latitude, which together provide horizontal location, is sufficient to understand location in 2D—for example, to place a location on a flat map. To find our position in 3D, we need an understanding of vertical location (i.e., height), since objects in the sky and on the ground may share the same 2D coordinates but be separated by kilometres. Measuring these three dimensions requires a detailed understanding of the Earth itself, as its shape, size, gravitation, and rotation all impact where objects are relative to one another. Furthermore, none of these properties is fixed—for example, the shape of the Earth is constantly changing as a result of the movement of tectonic plates, postglacial rebound, tides, and melting sea ice (Angermann *et al.*, 2022). The gravitational field also varies depending on factors like distance to the Earth's core, and—in general—the transport of mass among the Earth's different components (geosphere, hydrosphere, atmosphere, cryosphere, and biosphere).

Gaining an understanding of the Earth and how it is changing also facilitates measurement of a fourth dimension: time. This enables the establishment of a globally accepted time standard that allows everyone around the world to measure time consistently (Box 1.1). Precise standard timing has become critical for a range of infrastructures—including financial and telecommunications infrastructures, and electricity networks—as it ensures synchronization across the full system.

### Box 1.1 Timing concepts

Accurate measurements of the Earth's rotation period can be made through certain geodetic techniques, and permit the determination of Universal Time (UT1) based on the length of the day (Schlüter & Behrend, 2007). To synchronize this timing reference with other clocks, Coordinated Universal Time (UTC) was developed as an additional

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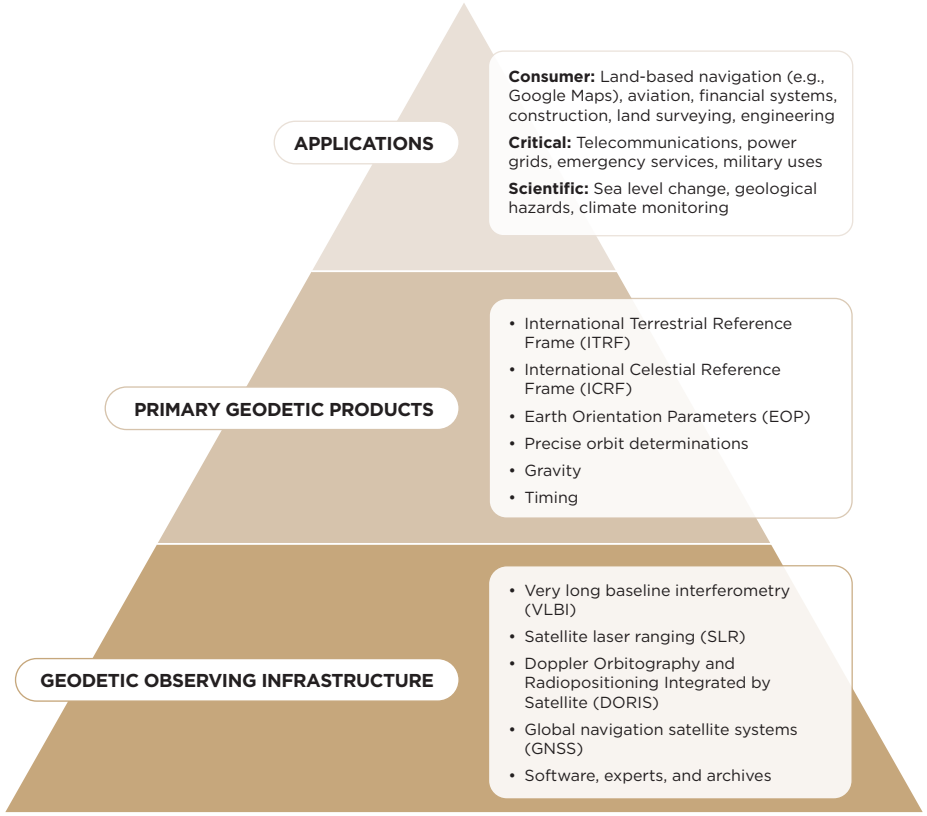
accurate timing reference (Panfilo & Arias, 2019). UTC is based on measurements collected by dozens of metrology laboratories equipped with highly precise atomic clocks; these laboratories are distributed worldwide, including at the National Research Council of Canada. UTC is defined through an algorithm so as to always remain synchronized with UT1 within 0.9 seconds (NRC, 2020; BIPM, n.d.). Several geodetic observation techniques depend on the precise and accurate determination of time in order to enable comparisons between the timing of events measured at spatially separated observing stations (Robertson, 1991). The synchronization of UT1 with UTC, and the time transfer facilitated by space-based geodetic observing infrastructure, mean that geodesy and timing are inextricably linked, with accurate positioning relying on accurate timing and vice versa (Panfilo & Arias, 2019).

## The ability to measure position opens the door to countless applications

Understanding and measuring position in four dimensions helps us better comprehend the world around us and unlocks a range of scientific and other applications across the globe (Figure 1.2). For instance, starting from reference frames (described in more detail below) and other primary geodetic products, geodesy enables the creation of geospatial/hydrospatial data and is subsequently supported by such data. This then opens the door to the many opportunities for GIS to establish new links between a variety of geospatial and other data types. While primary geodetic products themselves are not geospatial data, one cannot exist to a high accuracy without the other. The applications and opportunities associated with knowing your position with high accuracy, for example, would be impossible if you could not superimpose that positioning data (i.e., geospatial data) on a map. Geodesy enables the reference frames that make this layering possible.

The visualization and analysis facilitated by GIS (and enabled by geodesy) have now become integrated into a wide range of government operations, supporting activities such as urban planning, utility management, public health monitoring, emergency services, and disaster response (Campbell & Shin, 2011). GIS is also essential for many industrial applications, including those particularly important to Canada, such as mining, forestry, pipelines,

transportation hubs (e.g., ports), and agriculture. Without the coordinates provided by geodesy acting as a foundation, GIS data from different sources would not align correctly, and reliable spatial analysis would be impossible.




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**Figure 1.2 Geodesy's foundational support of everyday applications**

Geodetic observing infrastructure forms the basis on which an understanding of the size, shape, and position of the Earth can be determined. Information derived from this infrastructure is used to create primary geodetic products, which in turn support a range of consumer, critical, and scientific applications (Noll, 2014; UN-GGCE, 2024a).

## Geodetic observing infrastructure forms the base of geodesy

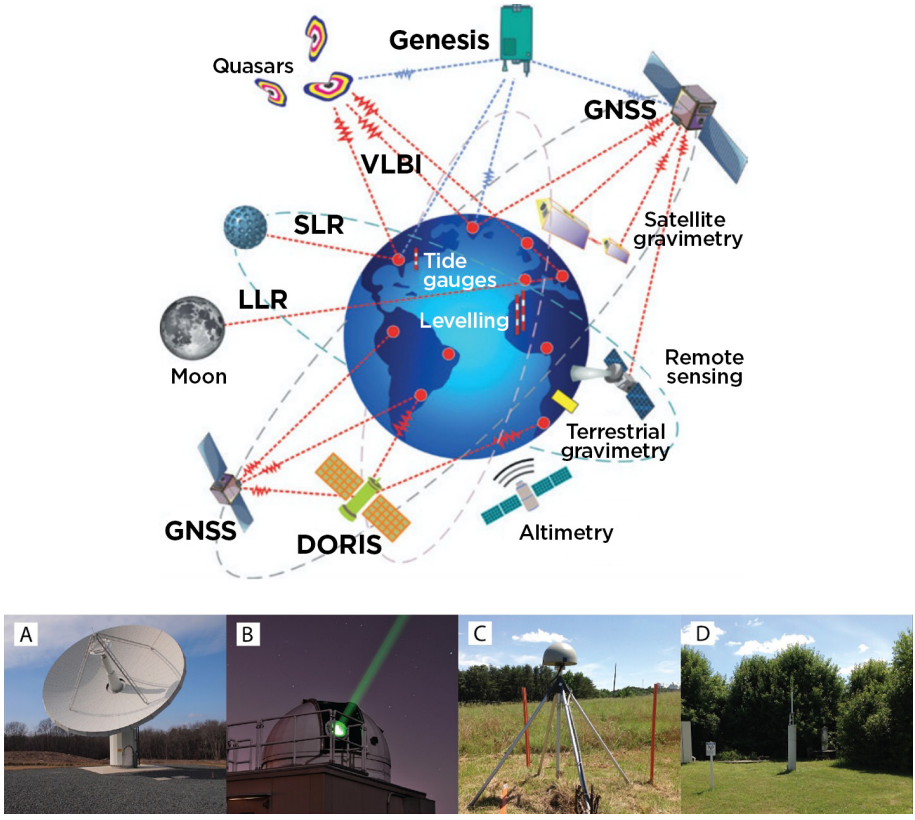
Observatories form the basis of geodesy by providing the data needed to inform subsequent steps in determining location and time. Observations are carried

out using a range of ground- and space-based infrastructures located around the world (Figure 1.3), including four critical techniques that feed into the International Terrestrial Reference Frame (ITRF):

- Very long baseline interferometry (VLBI): a radio astronomy technique that uses radio antennas in different locations on the planet to observe radio waves from very distant quasars; by measuring the difference in arrival times among antennas in a global network, precise distances between the antennas can be determined to glean information about the Earth's shape, rotation, and orientation in space (Shapiro, 1978; Seeber, 2003).
- Satellite laser ranging (SLR): a high-precision measurement of the time it takes for a laser pulse to travel from a ground station to a retroreflector on a satellite and back (i.e., round-trip time), providing the distance between the station and the satellite, orbital tracking, and other information (Tapley *et al*., 1985, 1993). When the same technique is applied to retroreflectors on the Moon, it is known as lunar laser ranging (LLR) (Bender *et al*., 1973; Müller *et al*., 2019).
- Global navigation satellite systems (GNSS): large networks of terrestrial receivers and constellations of satellites that provide high-quality positioning, navigation, and timing information across the globe through radio frequency communications (Dixon, 1991).[3]
- Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS): a satellite-based geodetic observation technique in which a ground station emits a stable frequency that is detected by a satellite. The distance between the two is determined using the Doppler effect, and that information is applied for positioning and orbit determination (Laborde, 1987; Jayles *et al*., 2006).

> Without the coordinates provided by geodesy acting as a foundation, GIS data from different sources would not align correctly, and reliable spatial analysis would be impossible.

3 There are four GNSS, including the United States' Global Positioning System (GPS), Russia's GLONASS, Europe's Galileo, and China's BeiDou (Hofmann-Wellenhof *et al*., 2008). Primary GNSS are supplemented by several additional regional navigation systems and satellite-based augmentation systems (SBAS), which can improve the accuracy of GNSS signals. Among current GNSS, only Galileo is civilian-controlled, while the others, including GPS, are operated by militaries (Hofmann-Wellenhof *et al*., 2008).



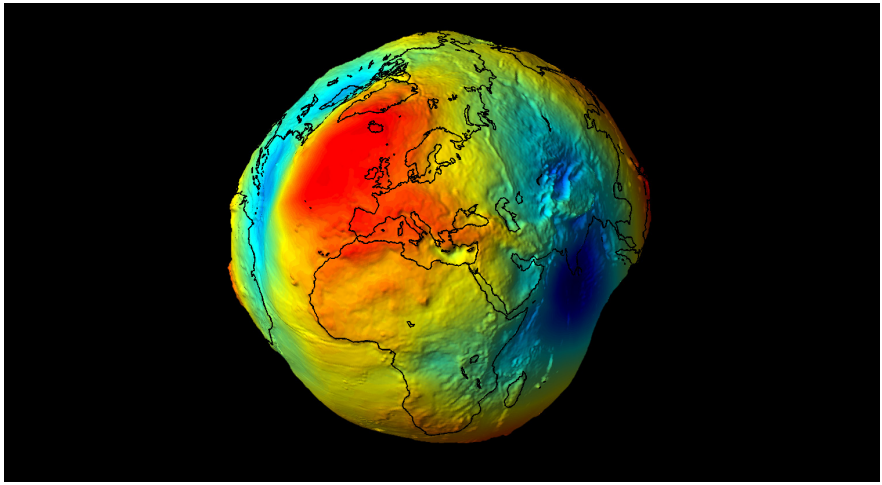

© All rights reserved. Top: Adapted with permission from Sánchez *et al.* (2024); bottom: NASA (2026)

**Figure 1.3 Geodetic observing infrastructure**

A range of observation techniques contributes to the Global Geodetic Observing System (GGOS) (top image). The bottom shows the ground infrastructure for the four core techniques at the Goddard Geophysical and Astronomical Observatory: VLBI (A), SLR (B), GNSS (C), and DORIS (D).

Beyond these four core observation techniques, several other measurement techniques are essential for defining other reference frames. Tide gauges (or water level sensors) are important for the vertical reference frame, as they are used to measure the height of the ocean (i.e., sea level) relative to a fixed point on the land (i.e., a benchmark) (Frederikse *et al.*, 2020; Sánchez *et al.*, 2021). There are specific requirements (e.g., sampling frequency, accuracy levels) for tide gauges that contribute to the Global Sea Level Observing System (GLOSS); ideally, gauges are co-located near land-based GNSS receivers to separate changes in sea level from changes due to land movement (IOC, 2006, 2012).

Gravimetry (both terrestrial and space-based) is also critical for determining elevation and the development of a global, high-quality reference for gravity (Schwarz *et al.*, 1987; Sansò & Sideris, 2013). The geoid is a primary product of gravity field modelling. It approximates mean sea level and is essential to determine heights above sea level (Sansò & Sideris, 2013) (Figure 1.4). Knowledge of the gravity field similarly enables the calculation of several helpful corrections, such as improving height positioning in GNSS (Nelson, 2011; Strugarek *et al.*, 2026). As noted above, atomic clocks are also important for geodesy, as they help enable the precise time and frequency standards required for geodetic observing infrastructure and precise positioning (Nelson, 2011; Panfilo & Arias, 2019).



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**Figure 1.4 Exaggerated Earth geoid as determined by the European Space Agency's Gravity Field and Ocean Circulation Explorer (GOCE) mission**

The geoid represents a gravitational mean sea level, and its shape demonstrates that the gravitational field is not uniform around the Earth. Red regions on the geoid represent areas where gravity is slightly higher than average, while blue regions represent areas where gravity is slightly lower than average. This image is not to scale—the geoid is exaggerated to more clearly show differences in the gravitational field.

## Reference frames and Earth Orientation Parameters are essential products of geodetic observing infrastructure

Observation is only the first step in the process by which geodesy supports services and products that provide value to users (Figures 1.1 and 1.2). The

raw data collected are then analyzed, combined, and interpreted (including through the use of modelling), all of which are reliant on human and physical resources (UN-GGCE, 2024a). Included are geodetic data centres and the operators who collect data from observatories, perform quality checks, then archive and distribute them to the global analysis community. Also included are the analysis and correlation centres that transform data into geodetic products, such as Earth Orientation Parameters (which describe variations and irregularities in the Earth's rotation) and global coordinate reference frames (UN-GGCE, 2024a,b). Several foundational products, upon which additional products and applications can be developed, depend on the data collected by geodetic observing infrastructure. One set of primary products is reference frames, which are essential for describing how the Earth is moving in reference to other celestial objects, and for providing a standardized coordinate system for determining position—as well as other geometric relationships—on or near the Earth (Sánchez *et al*., 2024). Essentially, without an accurate common reference frame, it would be impossible to connect data sets across space and time (e.g., for monitoring sea level rise), and different users might identify objects as being in disparate locations (Box 1.2). The integration of the data provided by geodetic observing infrastructure into national or regional reference frames relies on data and products of geodesy being open and freely available for use by the global community (IAG, 2025a; NRCan, 2025a).

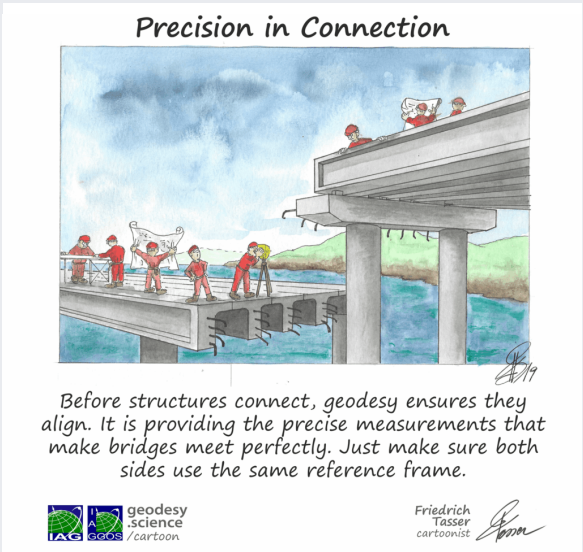
Because understanding where we are involves multiple dimensions (e.g., longitude and latitude, height), we need multiple types of reference frames to determine our position and the positions of points or objects on Earth or in outer space. Some reference frames help define position on the Earth's surface (i.e., terrestrial reference frame) or the Earth's orientation in space (i.e., celestial reference frame), while others are related to physical height (i.e., height reference frame) and gravitational acceleration (i.e., gravity reference frame) (Ma & Feissel, 1997; Drewes, 2009; Petit & Luzum, 2010; Ihde *et al*., 2017; Wziontek *et al*., 2021). Reference frames can be categorized as global (valid for the entire Earth) or regional (tailored to a particular region or country).

In Canada, the most common reference frame for determining latitude and longitude (as used in the Canadian Spatial Reference System, or CSRS) is the North American Datum of 1983 (NAD83), first introduced in 1986 and updated several times since then (NRCan, 2025a). NAD83 is tied to the North American tectonic plate and linked to the International Terrestrial Reference Frame (ITRF); the data are then carried down to provincial and local geodetic networks. NAD83 largely replaced earlier reference frames, such as the North American Datum of 1927 (NAD27), and national and provincial grids have been developed to transform data from legacy frames to the latest version of NAD83

(NRCan, 2025a). The North American Terrestrial Reference Frame of 2022 (NATRF2022) is expected to be adopted in Canada in 2027, replacing NAD83 and mirroring changes made in the United States (Erickson *et al.*, 2019; Bond *et al.*, 2024; NRCan, 2026a). In terms of height, the Canadian Geodetic Vertical Datum of 2013 (CGVD2013) is the reference standard in Canada, having replaced the 1928 version (CGVD28) (NRCan, 2020).

## Box 1.2 Common reference frames ensure consistency in position

Using a common reference frame ensures that the coordinates of applications are consistent. In its absence, the same object might appear to be in a different location on different maps or have different latitude/longitude or height values. In 2003, for example, construction of a bridge connecting Laufenburg, Germany with Laufenburg, Switzerland (the Rhine separates the two towns) faced challenges as engineers in the different countries used different height reference frames (Lewis, 2015). Construction on the German side was based on the North Sea at height zero, while the Swiss side used the Mediterranean Sea as height zero. Although the engineers were aware of the differences between these frames, human error in the conversion meant that when the bridge halves met in the middle, they were separated by 54 cm; half the bridge then needed to be lowered (Lewis, 2015).




Cartoon by Friedrich Tasser, Geodesy Cartoons, https://geodesy.science/cartoon/, used under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence

At global scales, the two main reference frames in use are the International Celestial Reference Frame (ICRF) and, as mentioned, the ITRF (Ma & Feissel, 1997; Petit & Luzum, 2010). The ICRF is defined by the positions of a collection of quasars (measured by VLBI) that are effectively considered stationary. These guide the assignment of coordinates to all other celestial bodies (including artificial satellites) relative to the Earth (Altamimi *et al.*, 2001; Bosy, 2014). As the Earth is continually changing and the precision of measurements is improving, regular updates to reference frames are required to ensure high positioning accuracy (Altamimi *et al.*, 2001). The ITRF is updated periodically based on data collected by the infrastructure associated with the four critical geodetic observation techniques (Petit & Luzum, 2010) listed earlier in this section.

Earth Orientation Parameters (EOPs) are foundational geodetic products that serve to support additional applications. EOPs are time-dependent quantities that describe the Earth's rotation and any related irregularities (Bosy, 2014). EOPs also represent a bridge between the ITRF and ICRF, connecting coordinate systems and, therefore, positions across these two frames, with implications for satellite navigation (Torge *et al.*, 2023). Similarly, precise orbit determination is an important product for geodetic applications such as satellite positioning and orbital monitoring. Precise satellite orbits are essential for Earth observation and remote sensing missions, as high-accuracy knowledge of the satellite's position and velocity in space and time is required (Couhert *et al.*, 2015). Even minor orbit errors can have significant effects, for example, noticeably impacting studies of mean sea level (Beckley *et al.*, 2007).

### The target accuracy and stability goals for primary geodetic products have not been achieved

The desired levels of accuracy and stability for the ITRF are 1 mm and 0.1 mm/yr, respectively, largely predicated on sea level tracking needs (Gross *et al.*, 2009). The accuracy requirements are the same (1 mm) for the static geoid and the EOPs needed for spacecraft tracking and navigation (Ferrándiz *et al.*, 2019; Sánchez *et al.*, 2024). These targets have not yet been achieved (Pearlman *et al.*, 2017; IAG, 2025a). Sánchez *et al.* (2024) explain that "these goals are very ambitious, but they define the requirements for a modern, reliable global geodetic reference frame capable of supporting the management of urgent societal needs caused by the effects of global change and the rising dependence on location-based services." They further note that achieving these goals will require global effort and cooperation.

### VLBI, SLR, GNSS, and DORIS each provide distinct contributions to primary geodetic products

The four primary geodetic observing techniques outlined above work in concert, as no single method can provide all the data needed to inform the products, parameters, and applications illustrated in Figure 1.2. Appendix A details each method's contributions. In some cases, techniques make similar contributions that complement one another or enable inter-technique validation; in other cases, a specific technique may be responsible for a particular observation. For example, VLBI plays a particularly important role in the foundation of reference frames and in synchronized timing because it is the sole technique capable of determining the ICRF and measuring UT1 (Schuh & Behrend, 2012) (recall Box 1.1). The difference between UT1 and time measured by atomic clocks onboard satellites is essential for the GNSS constellations that are used extensively to provide the positioning, navigation, and timing (PNT) information needed by countless scientific and commercial applications, such as weather predictions and banking (GC, 2020; Geoscience Australia, 2023). SLR also plays an important role in tracking GNSS constellations, providing the validation and calibration of orbits determined by other techniques (e.g., GNSS, DORIS), as well as the improvement of dynamic orbit models (Tapley *et al.*, 1985; Urschl *et al.*, 2007).

### Geodesy is a global enterprise with a need for ground-based infrastructure across the world

The ground components of geodetic observing infrastructure must be situated worldwide to ensure consistent and accurate measurements of the Earth's properties (UN-GGCE, 2024a). In short, the absence of geodetic observing infrastructure in a given region negatively affects the quality of primary geodetic products worldwide. Monitoring the Earth's movement and all satellites at all times requires a collective global effort (UN-GGCE, 2024a).

The IAG is the primary coordinating body for the global geodesy supply chain, but ground infrastructure is distributed across the globe and owned and operated by many contributing countries and organizations (including United Nations Member States) (UN-GGCE, 2024a; IAG, 2025b). The governance of geodetic infrastructure differs from that of other global infrastructures as it has been established through scientific collaboration without any formal international governance mechanisms (UN-GGCE, 2026). In comparison, the World Meteorological Organization (WMO) has formal coordinating authority, and the International Civil Aviation Organization has binding standards (UN-GGCE, 2026). The members of the executive and governing boards of IAG

Services (which perform geodetic science and develop products) are not the operators and owners of the physical infrastructure these products rely on (e.g., ground observatories, satellites, analysis centres) (UN-GGCE, 2024b).

The United Nations Global Geodetic Centre of Excellence (UN-GGCE) undertook several listening sessions with the geodesy community as part of the Global Geodesy Needs Assessment. Participants noted that the IAG lacks political advocacy and influence, and that the current governance structure does not adequately support the geodetic value chain, leaving Member States without the authority needed to enforce maintenance and operations standards (Box 1.3). Participants also noted that in the absence of formal agreements governing geodesy, the regional and global bodies that serve as governance mechanisms—and the collaborations among them—are often unfunded or rely on in-kind support, creating barriers to success (UN-GGCE, 2024b).

### Box 1.3 Fragility of the geodetic observing network

Underinvestment in aging stations and equipment reduces the reliability and quality of data produced by this infrastructure, contributing to vulnerabilities in the geodetic observation network (UN-GGCE, 2026). Variability in resourcing across participating jurisdictions can lead to overreliance on well-performing infrastructure out of necessity. When it comes to SLR, for example, fewer than half of global sites contributing to the International Laser Ranging Service (ILRS) meet ILRS performance standards (Rodríguez *et al.*, 2025). Analysis has shown that the hypothetical loss of the two Australian stations would significantly degrade observations at the global scale, as these stations are heavily used due to their reliability (Rodríguez *et al.*, 2025).

## Canada does not possess the full suite of geodetic observing infrastructure

As mentioned above, global distribution of ground-based infrastructure for VLBI, SLR, GNSS, and DORIS is critical for informing global reference frames. Canada is a very large country in terms of physical size—the second-biggest on Earth, with a surface area close to 10 million km$^2$ (UN-DESA, 2026). Despite this, Canada has ground-based infrastructure related to only two of these techniques. While it does not own or operate a global or regional GNSS constellation, it does contribute to the International GNSS Service (IGS, 2026), although there are some concerns related to coverage in the Arctic and

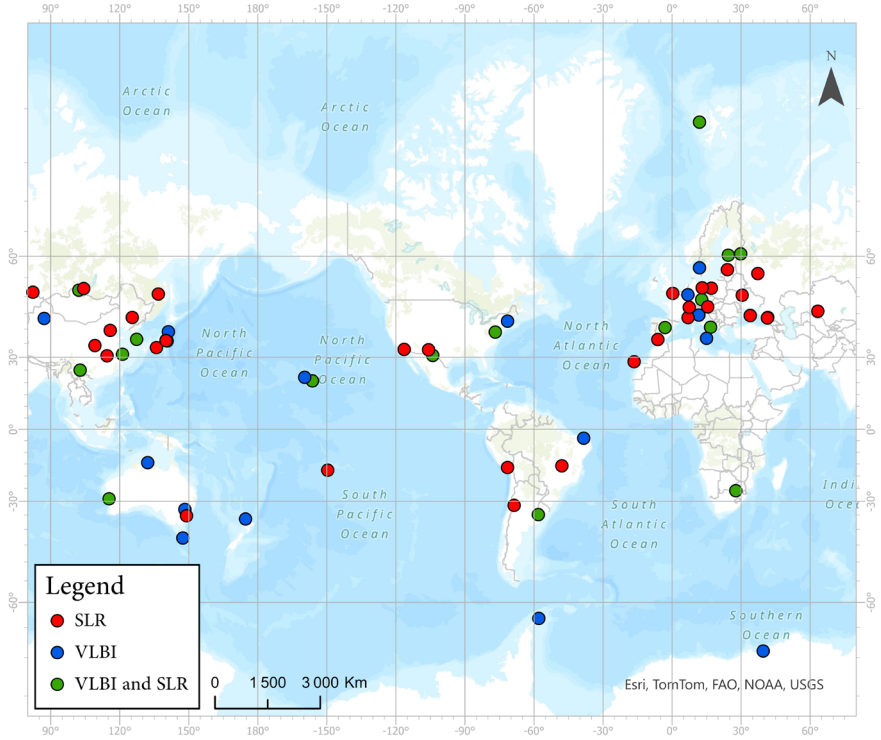
sub-Arctic regions and challenges with GNSS in high latitudes (Section 3.1.2). Canada also hosts two stations in the international DORIS network, which is maintained by France's Centre national d'études spatiales (CNES) (IDS, 2025). Canada has no ground-based presence for the remaining geodetic techniques—VLBI and SLR—anywhere; the country's geographic size and location mean the absence of these infrastructures contributes to a large gap in the global distribution of VLBI and SLR stations (Figure 1.5). Canada was an early leader in VLBI research and had antennas in Algonquin Park, Penticton, Yellowknife, St. John's, and Whitehorse, which have since been decommissioned on the grounds of budgetary efficiency (CBC News, 2006; NRCan, 2025b).



Canada has no ground-based presence for the remaining geodetic techniques—VLBI and SLR—anywhere.

In terms of other observing infrastructure, the Canadian Hydrographic Service operates hundreds of tide and water level gauges, including six tide gauge stations that contribute to GLOSS (GLOSS, 2012, 2026; DFO, 2020). Canada also maintains more than 5,000 gravity-control stations throughout the country, comprising the Canadian Gravity Standardization Network (CGSN) (NRCan, 2022a). NRCan maintains 67 absolute-gravity stations, augmented by 79 other absolute-gravity stations tied to specific projects (NRCan, 2022a). Many of these sites are part of the International Absolute Gravity Database, maintained by the International Gravimetric Bureau (BGI, 2026).

The governance and management systems related to geodesy and geospatial data in Canada are complex and beyond the scope of this report, but some of the key departments, agencies, and organizations are listed in Appendix B.




Data sources: Altamimi *et al.* (2025); ILRS (n.d.-a)

## Figure 1.5 Location of VLBI and SLR ground stations around the world

Positions of the VLBI and SLR ground stations contributing to the Global Geodetic Observing System; note that there are none in Canada. This map is based on the best available knowledge from the sources listed; all stations are subject to outages and may not be continuously active.

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The state of geodetic observing infrastructure across the country is particularly relevant given the federal government's priorities, many of which depend on a strong geodetic foundation and/or access to high-quality geodetic data. Moreover, Prime Minister Mark Carney, when discussing the changing geopolitical context, emphasized the need for the federal government to engage broadly with other middle powers to maximize influence and collaborate toward common goals (PMO, 2026a). Chapter 2 examines these issues in more detail.

2

# Meeting Canada's Geodetic Needs


2.1 Socioeconomic benefits of geodetic observing infrastructure

2.2 Economic growth through infrastructure, technology, and trade

2.3 Sovereignty and security

2.4 Social and environmental priorities

2.5 Summary

## Chapter findings

- Geodetic observing infrastructure underpins a wide range of economic activities, enabling value chains across sectors such as construction, transportation, telecommunications, and agriculture.
- The growing digital economy is increasing demand for geodetic data, as emerging applications such as digital twins, geospatial analytics, and AI rely on accurate positioning to integrate and analyze complex data sets.
- Reliable access to high-precision positioning and timing—among other geodetic products and services—could advance Canada's economic priorities, such as expanding trade, enhancing logistics, and completing major construction projects.
- Geodetic information is essential for a wide range of national policy objectives beyond economic growth, including climate monitoring, public safety, and emergency response, through its role in measuring Earth systems and enabling risk assessment.
- Arctic development, security, defence, and sovereignty are national priorities that depend on reliable positioning and navigation, while the accompanying shipping, resource development, and military activities must reckon with an environment wherein GNSS is unreliable.

This chapter explores the essential function of geodesy in the Canadian economy and how the technology links to Canada's current goals and strategic directions, as articulated in the federal government's main policy thrusts—from security, defence, and sovereignty to climate change. Geodetic data and products already play a critical role for people in Canada and across the economy, and several key priorities going forward will rely on a strong geodetic foundation that Canada currently lacks. Despite the socioeconomic value of geodesy, attributing investments in geodetic observing infrastructure to specific outcomes is challenging. Related value chains are complex, and the activities that produce geodetic products are delocalized, making it difficult to attribute benefits and costs. Looking instead at opportunities, economic studies from several jurisdictions suggest that improvements in the accuracy, reliability, and availability of geodetic data can enable new economic activities and strengthen existing ones in areas that align with Canada's priorities. Beyond economic impacts, geodetic observing infrastructure assists in monitoring the wide-ranging ramifications of

climate change in Canada. It also supports efforts to ensure Canada's national security and demonstrate sovereignty amid a changing geopolitical order. This support is currently provided primarily through infrastructure owned by other jurisdictions, an issue of particular importance in the Arctic, where a confluence of climate, socio- and geopolitical phenomena are unfolding. Laying bare the multiple links to Canada's needs sheds light on the opportunities and risks associated with the current state of national geodetic infrastructure, and whether it is sufficient to meet Canada's goals.

## 2.1 Socioeconomic benefits of geodetic observing infrastructure

Attention to the economic value of geodetic observing infrastructure has grown in recent years because of vulnerabilities in the global network, with accompanying calls to strengthen national capacity across the globe (e.g., UN-GGCE, 2024a). As noted in Chapter 1, geodetic products enable a variety of services and applications, such as locating assets in search-and-rescue or logistics operations, aiding navigation for individuals and freight, and providing the timing needed to facilitate commerce and utilities management, among a growing number of other examples (UN-GGCE, 2026), while also supporting the operation of critical infrastructure (Gov. of Australia, 2024). Other trends are highlighting the value of geodesy as a key pillar of growing sectors. For example, the digitization of geospatial information allows for the measurement, overlaying, and analysis of various forms of geographic data from which insights and value can be derived (NRCan, 2026b). Although the broader geospatial economy is beyond the scope of this report, geodesy and the geospatial/hydrospatial domains are inextricably linked, with geodesy laying the foundation for applications that contribute to growth in the geospatial information market (e.g., MarketsandMarkets, 2026).

Despite the foundational nature of geodetic observing infrastructure in today's economy and society (and related dependencies), and the risks associated with its failure, terms used to describe it often include "invisible" or "hidden" (UNOOSA, 2012; UN-GGCE, 2024a; FrontierSI, 2025a). This can partially be explained by the fact that, at a global level, the backbone of geodetic observing infrastructure is decentralized and publicly funded (Section 1.2), with many of its valuable products (e.g., global reference frames) freely distributed (IAG, n.d.-a). The extent to which geodetic infrastructure underpins societal needs and other critical infrastructure is difficult to monetize, but its importance is difficult to overstate. Some argue that the services and products enabled by geodesy should be considered a national—or even global—utility on par with electricity (Plattard, 2015; armasuisse S+T, 2025; FrontierSI, 2025a).

### Geodesy forms the basis of a robust value chain, giving rise to a growing number of increasingly accurate products and services across a variety of key economic sectors

As shown by Figure 1.1, geodetic observing infrastructure enables the collection of data that can then be analyzed, integrated, and interpreted to create geodetic products. These products form the basis of a value chain with wide-reaching impacts (Figure 2.1). Disentangling what each component of geodetic observing infrastructure contributes to geodesy's overall network is challenging, which complicates the attribution of economic impacts. At a global scale, VLBI, SLR, and DORIS observatories each make distinct contributions to the determination of Earth Orientation Parameters (EOPs) and the International Terrestrial Reference Frame (ITRF), among other products (Section 1.2), such that the total value of these observations is greater than the sum of their parts. Geodetic products (e.g., terrestrial and celestial reference frames) determined through these international efforts are then transmitted to governments or organizations to feed into various applications, such as the Canadian Spatial Reference System (NRCan, 2025a). Geodetic products and related services like positioning, navigation, and timing (PNT) also underpin several economic activities, such as geospatial information analysis and presentation, value-added information products, and location-based services (GeoConnections, 2015), which are then applied to a large and growing variety of industry sectors. These include sectors conventionally linked to geomatics—land surveying, civil engineering, and natural resources—as well as commerce, technology, and other sectors that rely on location-based services (GeoConnections, 2015).

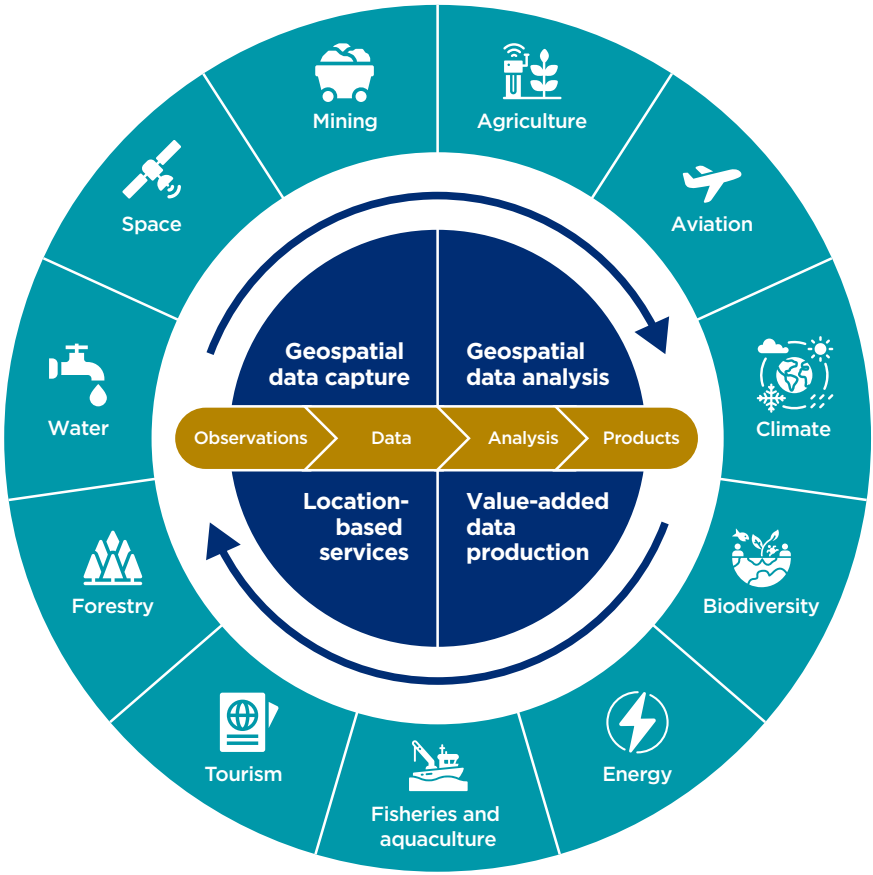



**Figure 2.1 The geodetic observing infrastructure foundation of the geospatial information industry**

Geodetic observing infrastructure collects and analyzes data that are subsequently used to generate products (UN-GGCE, 2024a). These products feed into the broader economy, with value chains linking positioning and timing to a variety of industry needs (e.g., GeoConnections, 2015; EC, 2023). Geodetic products, such as reference frames and EOPs, support geospatial data capture and analysis, enabling value-added information production and location-based services. Industry needs and opportunities to capitalize on these products exist across the value chain (GeoConnections, 2015).

## GNSS demonstrates the value of geodesy, as it enables the public to easily access geodetic data and their benefits

The complex interconnection between the various observing infrastructures contributing to the Global Geodetic Observing System (GGOS) and the resulting

geodetic products makes it challenging to place an economic value on any single component. The value provided by geodesy is influenced by the whole system. That said, GNSS (e.g., GPS) is unique among observing infrastructures because it lets individual users access geodetic data through inexpensive receivers without needing to understand geodesy; this drives numerous novel applications and opens new markets for consumer products (O'Connor *et al.*, 2019). The ubiquity of GNSS receiver technology in devices such as vehicles and smartphones has helped drive market penetration for PNT services through consumer activities such as ridesharing and e-commerce logistics, as well as essential services such as search-and-rescue. As a result, GNSS can be directly linked to a range of socioeconomic benefits. Table 2.1 lists examples across a wide range of sectors and applications; while not comprehensive, it demonstrates the utility of GNSS, which enables access to geodetic products.

## Table 2.1 GNSS uses in selected sectors

| Sector | Role of GNSS |
|---|---|
|  Agriculture | Real-time positioning over wide areas boosts efficiency by enabling precision agriculture. GNSS signals enable cm-level field management and cultivation, and sophisticated farming equipment relies on these signals to automate tasks and distribute seeds and fertilizer efficiently, improving yields while reducing inputs. |
|  Construction | Precise positioning supports project planning, design, and site mapping, and enables machine control to carry out tasks using specialized construction equipment, reducing labour while improving accuracy. Geodetic products (e.g., reference frames) also link projects to existing assets (e.g., roadways). |
|  Finance | Access to Coordinated Universal Time (UTC) allows for accurate timestamping of transactions. UTC can also be defined with high accuracy thanks to the global geodetic network (Box 1.1). Accurate positioning also helps banks better detect potentially fraudulent transactions. |
|  Energy and natural resources | Positioning supports site selection, planning, and monitoring for resource extraction. It supports efficient and safe operations through PNT-based machine control and enables monitoring of hydroelectric infrastructure and hydrological processes, such as changes in water storage. |
|  Infrastructure operations | Access to UTC ensures proper infrastructure operations (e.g., synchronization of power grids and telecommunications networks). It enables long-term infrastructure integrity monitoring through deformation measurements. |
|  Maritime and inland waterways | Positioning and timing provide insights to monitor shipping and port activities while supporting navigation and assisting search-and-rescue. Accurate positioning also enables automated equipment for cargo handling and logistics, improving efficiency and eliminating bottlenecks. |
|  Road and automotive | Navigation assists road users and provides PNT services for autonomous vehicle applications. It also improves logistics operations by optimizing routes and enabling accurate arrival-time determination. |
|  Space | Precise orbit determination provides data to assist spacecraft navigation and positioning, and in doing so, supports Earth observation missions and other activities in the space sector. |

Sources: van Cranenbroeck (2012); EY (2022); EC (2023); LE (2023); EUSPA (2026)

A 2022 study estimated that Canada stood to gain more than $5 billion in economic benefits over a 20-year period thanks to GNSS-based PNT technologies and services, with construction ($1.4 billion), road transportation ($925 million), and agriculture ($867 million) as the leading sectors (EY, 2022).[4] The analysis also segmented the benefits by the level of positioning accuracy and found that sub-metre-level applications accounted for 45% of the benefits, while centimetre-level applications accounted for an additional 45% (EY, 2022). Differences in sectoral needs create different requirements for accuracy. For example, unlocking the economic benefit of automation in agricultural applications requires centimetre-level positioning to perform tasks such as seeding most efficiently (EUSPA, 2023a).

### Canada derives benefits from global geodetic observing infrastructure despite gaps in national capacity, but it is exposed to shifting risk landscapes

Like most jurisdictions, Canada benefits significantly from access to GNSS without owning or operating its own constellation. Canada's ground infrastructure plays an important role in signal processing and analysis (NRCan, 2026d), helping it maximize the accuracy of positioning and timing signals from GNSS satellites. People in Canada, however, depend on access to those signals from one of four currently operational GNSS constellations (Section 1.2). As such, disruptions of these signals threaten Canada's ability to deliver PNT services essential to critical infrastructure and the economy (EY, 2022). GNSS outages can occur due to accidental or deliberate disruption of receivers, through jamming, spoofing, or meaconing.[5] The means to jam or spoof signals, for example, have become more accessible—a development accelerated by recent conflicts (OPS Group, 2024; Cozzens, 2025a) (Figure 2.2). Although intentionally disrupting GNSS signals is illegal in Canada (GC, 1985; ISED, 2025a), the technology for doing so is increasingly accessible and inexpensive (Dunn, 2019). State actors would typically be responsible for service denial over large areas because it requires significant resources and technical capacity (Dunn, 2019), with recent examples of widespread, space-borne jamming operations allegedly originating from a Russian government space asset (Mason *et al*., 2021; Clements *et al*., 2026). GNSS services are thus increasingly vulnerable to tampering at local and regional scales, with implications for Canada given the benefits it derives from their use.

4 Similar analyses have been carried out in foreign jurisdictions, notably in the United States, where several studies have assessed the economic benefits of GPS (the U.S.-operated GNSS) (Pham, 2013; Leveson, 2019; O'Connor *et al*., 2019; Mason *et al*., 2021). O'Connor *et al.* (2019) found that from 1984–2017, GPS contributed more than $1 trillion to the U.S. economy. Additionally, the annual economic benefits arising from GNSS have been estimated at €69 billion in the European Union (EC, 2023), and more than £13 billion per year in the United Kingdom (LE, 2023).

5 These terms describe various ways in which receivers can be overloaded or fed incorrect or inappropriate signals for the purpose of disrupting operations (LE, 2023).

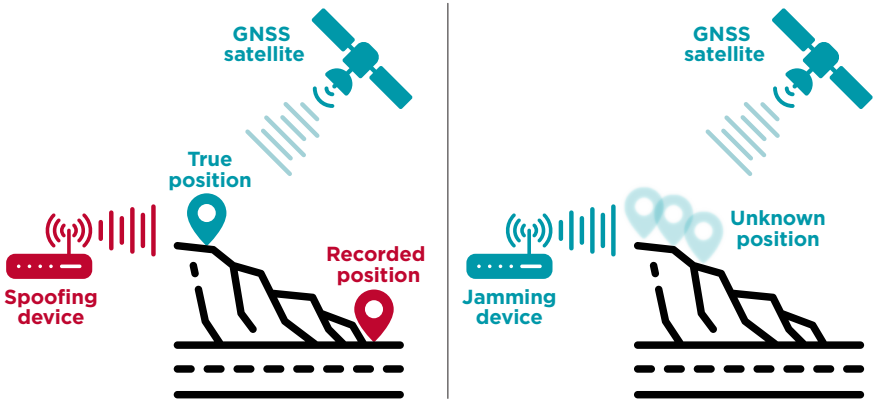



**Figure 2.2 Spoofing and jamming of GNSS signals**

By the time they reach the surface of the Earth, GNSS signals emitted in space are strong enough to be detected using receivers, but weak enough that they can easily be overpowered or interfered with using readily available radiofrequency transmitters. Spoofing of GNSS signals involves the use of such a transmission to interfere with the GNSS signal, such that the receiver reports an incorrect position. Jamming uses stronger signals to overwhelm receivers and degrade the ability to determine positions using GNSS at all (FrontierSI, 2026a).

The vulnerability of different sectors to disruptions in GNSS access, as well as the resulting economic impacts, would be greatly influenced by the duration of a disruption, the location of the outage, and the availability of backups (Mason *et al.*, 2021). Mobile phone networks are highly vulnerable to GNSS outages due to requirements for synchronization and timing data, as well as the absence of a practical backup (UN-GGCE, 2024a). Some banking and business services are so reliant on GNSS for timestamping that they would need to cease operation in the event of a sustained outage (UN-GGCE, 2024a), while others (e.g., stock exchanges) possess holdover capacity through redundant local timing infrastructure (Lombardi, 2021). At a national scale, several studies have benchmarked the enormous costs of a total loss of access to GNSS (O'Connor *et al.*, 2019; Mason *et al.*, 2021; UN-GGCE, 2024a). Such disruptions are improbable because multiple GNSS constellations are available, and would likely occur only in the context of a global-scale conflict (Mason *et al.*, 2021). Several militaries are nevertheless developing physical and cyber threats to GNSS as a form of demonstrated defensive and offensive capabilities in space (Berge & Hiim, 2024; FrontierSI, 2026a).

The panel shares the view that Canada is unlikely to lose complete access to GNSS, but it nevertheless wishes to underscore the above to emphasize that

Canada (and other nations) must reckon with a landscape that has changed since the shared global assets of geodetic observing infrastructure were originally established. In the early days of GPS, for example, the U.S. government could limit the quality of public GPS signals outside of the United States for security or strategic reasons, under a practice known as "selective availability" (RNTF, 2023a; GPS.gov, n.d.-a). However, nearly three decades ago, the U.S. government ended this practice, "recogniz[ing] that GPS plays a key role around the world as part of the global information infrastructure and takes seriously the responsibility to provide the best possible service to civil and commercial users worldwide" (U.S. Department of State, 2000). Not long after this, Canada's federal government discontinued VLBI on the grounds of efficiency (CBC News, 2006), perhaps under the impression that such infrastructure provided diminishing returns on investment during a period when multilateral cooperation was strong and GPS was viewed as a "gift to the world" (RIN, 2026). Presently, the balance of power is being redistributed at a global scale, and space and PNT services are areas of increasing competition (RNTF, 2023b; Elefteriu, 2024). As such, it may be prudent to revisit areas where potential dependencies exist (RIN, 2026) (Section 3.2) given the implications for Canada as it strives toward its priorities.

Canada (and other nations) must reckon with a landscape that has changed since the shared global assets of geodetic observing infrastructure were originally established.

## 2.2 Economic growth through infrastructure, technology, and trade

Several national-scale priorities for economic development have recently been articulated by the federal government. These provide a useful lens for viewing the direct and indirect roles that geodetic observing infrastructure plays in supporting the efficiency and sustainability of key economic activities and in achieving Canada's ambitions.

### Enhanced infrastructure and trade demands require major construction projects and ways to support logistics and shipping

In the face of internal and external factors ranging from stagnant productivity to geopolitical shifts (CCA, 2025; Halpern-Shavim & Balkos, 2026), the federal government has taken several steps to reshape aspects of the Canadian economy through legislation and new government agencies and programs (GC, 2025a,b; PCO, 2026a). Among them is the Major Projects Office (MPO), established in 2025 to coordinate development efforts in national

infrastructure, international and domestic trade, and natural resources (PCO, 2026a,b). As of mid-2026, $126 billion in investments has been committed to several projects and transformative strategies referred to the MPO (PCO, 2026b). These projects include proposals to establish or expand mining operations, build critical infrastructure for energy generation and delivery, target coastal infrastructure related to shipping and trade (of goods and resources), and put in place additional transportation infrastructure with year-round availability in the North (PCO, 2026b). These policies aim to improve the resilience and connectivity of Canada's economy through efforts to build new critical infrastructure, with several sites planned in remote areas (PCO, 2026a,b).

An important common denominator across many of Canada's current economic priorities is construction. GNSS can be used to accomplish low- and high-order construction surveying over wide areas as these infrastructure projects are planned and carried out (EUSPA, 2020). It is also a key contributor to the productivity of mining, to land surveying, to equipment control, and to operations monitoring (O'Connor *et al.*, 2019; EUSPA, 2023b). For example, GNSS-enhanced machine operation allows dozers to achieve grade specifications faster, reducing labour, fuel, and maintenance requirements; this contributes to savings in an area that can be responsible for up to 50% of a mine's operational costs (EUSPA, 2023b). Other emerging forms of autonomous mining being developed and tested in Canada also rely on the availability of precise positioning data and GNSS receivers combined with Internet of Things (IoT) devices to improve safety, reduce operational costs, and streamline workflows (Osborne, 2022; Virani, 2026).

Maritime ports, meanwhile, make extensive use of PNT services to support the efficiency of operations in logistics and navigation (LE, 2023). Geodesy helps reliably bridge the connection between land and sea—for instance, through surveying activities seeking to connect tidal and geodetic datums (Mills & Dodd, 2014), ultimately preserving accurate positioning capabilities across hydrospatial and geospatial environments.

Increasing accuracy in the national reference frame also benefits projects involving corridors that cross jurisdictional boundaries, such as pipelines proposed to support Canada's energy sector (PCO, 2026c). GNSS can be used to improve efficiency in route planning, engineering, and monitoring by allowing high-accuracy positioning over long distances and potentially across borders (e.g., Yildirim, 2013). Pipelines, moreover, need to interface with other structures (e.g., power plants) at their termination. The existence of an accurate reference system to which both the pipeline and its termination can

be tied is also important: if a pipeline and plant use distinct reference systems, a discrepancy at their meeting point would be costly (P. Srajer, personal communication, 2026).

Canada's renewed emphasis on mining, construction, and logistics creates several natural links to geodesy, particularly for reliable, precise positioning and navigation, given the remoteness of many project sites. Several of the above examples can proceed using local control systems, and have historically done so out of necessity. However, it is the panel's view that a bolstered geodetic network in Canada would create an environment where such activities could occur more efficiently, using the highest-quality positioning accuracy while also fostering interoperability and adherence to standards.

### Geodesy for precise positioning is needed to equip the Canadian economy for a digital future built on new services and markets

The digital economy employed 2.48 million people in Canada in 2025, and it comprises a growing share of national economic activity (Anani & Henningsmoen, 2025). Employment in the digital economy includes roles in the technological sector itself, as well as information and communications professionals in a wide variety of industries, including transportation (Box 2.1), agriculture, and utilities (Ivus *et al.*, 2025). The broad nature of the digital economy presents several parallel links to geodesy rather than a single through-line, with opportunities to integrate geodetic products and services into software, databases, and tools.

Canada's renewed emphasis on mining, construction, and logistics creates several natural links to geodesy, particularly for reliable, precise positioning and navigation, given the remoteness of many project sites.

The proliferation of digital tools and sensors, combined with the emergence of AI, is bringing land surveying, geospatial, and hydrospatial fields closer together by automating data acquisition and processing, allowing for seamless connections between fieldwork and the models managed by geospatial and hydrospatial experts in infrastructure projects (Byrne, 2025). Precise positioning is also essential to extract economic benefits from digital tools that use location-based services (O'Connor *et al.*, 2019; LE, 2023), a sector experiencing consistent growth (Shaw, 2024). This sector relies on applications for mobility, fitness, targeted advertising, and financial products, among others (EUSPA, 2026).

## Box 2.1 Navigation for mobility technologies

Direct access to high-quality, real-time positioning data supports ongoing developments in land-, sea-, and air-based autonomous vehicles (CCA, 2021; EUSPA, 2026). Growth in the economic impact of remotely piloted aircraft and advanced air mobility devices is projected to increase by an order of magnitude over the coming decade (NAV CANADA, 2026). Application sectors include agriculture, mining, transportation, and construction, as well as defence and security (NAV CANADA, 2026; Norman, 2026), all of which derive benefits from geodetic products, for instance through operational efficiencies (O'Connor *et al.*, 2019; EY, 2022). For road users, autonomous vehicles rely on a suite of sensors and communication protocols to navigate; accurate and reliable GNSS is essential for determining a vehicle's location, speed, and direction (EUSPA, 2023c).

### Geospatial and hydrospatial digital twins offer potential benefits across multiple critical sectors, including government decision-making

The digital twin model is an increasingly versatile and popular platform, one with substantial potential to support decision-making. Digital twins form "a virtual representation of a physical system (and its associated environment and processes) that is updated through the exchange of information between the physical and virtual systems" (VanDerHorn & Mahadevan, 2021). The creation and use of digital twins rely on a wide variety of data drawn from several sources and sensors, requiring precise time and location to be used in predictive modelling and to generate value (NASEM, 2024). Accurate positioning derived from geodesy provides a common spatial reference across these data sources, enabling them to be integrated and analyzed within a digital twin (ESRI, n.d.). This property also means that geospatial or hydrospatial data can combine or aggregate multiple digital twin assets by allowing for the positioning of each asset accurately within a reference frame (WGIC, 2022). Digital twins are also increasingly employed in infrastructure planning in light of climate risks (ESRI, n.d.). In road projects, they are used in planning phases, construction, and maintenance, as well as in demolition (Yan *et al.*, 2025). Lifecycle management using digital twins hinges on studying processes that cause degradation or physical changes to the system that follow its operation (VanDerHorn & Mahadevan, 2021).

Given the magnitude of Canada's targeted infrastructure investments, it is worth noting that geodetic observing infrastructure has increasingly been

used alongside other sensor technologies to provide passive monitoring of sites through accurate position determination, thereby supporting asset management in large infrastructure projects. For example, since the 1990s, infrastructure deformation has been monitored through geodetic observations (among others) (Chrzanowski & Szostak-Chrzanowski, 2010). GNSS can be used to monitor both the structures and the ground beneath those structures over decades thanks to accurate referencing (Konakoglu *et al*., 2020; EUSPA, 2023d). To monitor dams, for example, GNSS or other space- and ground-based tools can be used to pinpoint displacements relative to a geodetic reference (Chrzanowski, 1990; Konakoglu *et al*., 2020; Sun *et al*., 2025). These approaches can also be configured to support emergency preparedness for disasters or hazards that could ensue (Bond *et al*., 2007). Using digital twins, the collection of degradation-related data can inform decisions around the targeted inspections of an asset, as well as plans for risk mitigation (VanDerHorn & Mahadevan, 2021).

Digital twins reliant on geographic information systems (GIS) are being applied to urban planning, telecommunications networks, public transportation, and utilities management (ESRI, n.d.) (Box 2.2). More broadly, spatial digital twin models can be applied across a range of sectors, including agriculture, resource management, utilities, and transportation (WGIC, 2022). Geospatial or hydrospatial digital twins take advantage of the fact that positioning data can be linked to other thematically important data, such that use cases can support decision-making in other areas (e.g., disaster risk monitoring) (EC, 2024). Several jurisdictions have developed national-scale geospatial digital twins for monitoring natural hazards (e.g., Papyshev & Yarime, 2021; Evans, 2025; BKG, n.d.-a).

Many examples of digital twins in use leverage GNSS (Neugebauer *et al*., 2024). However, a 2024 review of 77 digital twin use cases concluded that many applications under-exploit geospatial information or underestimate its role, highlighting opportunities for growth (Metcalfe *et al*., 2024). In port operations, bathymetry and other geospatial/hydrospatial data are being leveraged in digital twin applications to inform navigation, support operational optimization, and reduce carbon emissions (Eom *et al*., 2023). Resource extraction (e.g., oil and gas, mining) is an application area where the technological maturity of geospatial digital twins is yet to be fully realized and where there is a perceived opportunity to extract additional business value (Hexagon, 2024).

## Box 2.2 Digital twins in Canada

Canadian examples of digital twins are multiplying and could provide value in upcoming infrastructure developments (Future of Infrastructure Group, 2026). For example, the Government of Ontario is pursuing digital twins to accelerate several projects, from highways and utilities to hospitals (Gov. of ON, 2024). Efforts to promote data-sharing in infrastructure projects could additionally help lay the groundwork for promoting digital twins (Future of Infrastructure Group, 2026). This idea was echoed by an expert interviewed by CCA staff who lamented the operational waste of repeated land survey work (P. Srajer, personal communication, 2026). At the policy and regulatory level, mandates that infrastructure projects be digital by default, with provisions around Building Information Modelling (BIM) data—combined with actions to enable early adopters—could stimulate uptake and foster trust (Future of Infrastructure Group, 2026). One of the main pillars for developing digital twins in Canada is a strong data foundation (Future of Infrastructure Group, 2026).

Canada seeks to build on its leadership in AI research, with geospatial AI representing an emerging opportunity given the country's geography and resources. The federal government has consistently focused on developing leadership in AI as a key pillar of Canada's digital economy (Canadian Standards Association, 2026; ISED, 2026a,b). For example, Budget 2025 highlights support for AI infrastructure projects (nearly $1 billion over five years) (GC, 2025b). Some view combining geospatial data with AI as an opportunity to elevate business intelligence through frameworks and tools that aggregate and integrate location data to support decision-making (Innovate UK *et al.*, 2026). In doing so, companies may gain a competitive advantage through improved efficiency and real-time decision-making, such as in the logistics and transportation sectors, since location information can help link disparate data sources (Archacki *et al.*, 2021; Innovate UK *et al.*, 2026). Geospatial and hydrospatial AI is also seen by the Government of Canada as a means to improve national coverage in mapping, and reforms to procurement could provide opportunities for Canadian small- and medium-sized enterprise (SME)s taking part in related economic activities (Gagnon *et al.*, 2026). GIS communities have also begun adopting modern AI tools to lower technical barriers and pave the way for so-called autonomous GIS systems (Akinboyewa *et al.*, 2025).

Combining location data with business intelligence workflows promises to help businesses further personalize the customer experience, particularly in retail, e-commerce, and financial services (Archacki *et al.*, 2021). In an international survey of 500 executives across multiple sectors, 95% of respondents indicated that geospatial data are important for their present business objectives (Figure 2.3). According to a participant in this study, data that less than a decade ago would have been considered "nice to have" are now indispensable. The integration of location data of the highest possible accuracy, in some cases, provides new digital business models, such as those underpinning online food orders where location data are essential for pairing businesses, customers, and delivery drivers (Archacki *et al.*, 2021). The global geospatial analytics market is forecast to surpass US$200 billion by 2030, potentially doubling in size over five years (Precedence Research, 2025).




Data source: Archacki *et al.* (2021)

**Figure 2.3 Valuable use cases for location intelligence in select sectors**

Location intelligence supports a variety of use cases across several key industries, in customer-facing and operational settings alike. The examples in this figure reflect top choices from a survey of business executives who were asked to propose key areas where location intelligence had demonstrated (or is expected to provide) commercial value.



## Geodetic investment needs for economic priorities

Construction projects such as those planned through the MPO demand extensive land surveying, charting, and mapping efforts at their outset to inform site selection and planning, as well as ongoing support for operations in the cases of mining and ports (EUSPA, 2026). The precision required can be mm-level or cm-level in the vertical direction and less than 10 cm in the horizontal direction (EUSPA, 2023b). Similarly, to help realize the benefits of GNSS in the mining sector, approximately 1 cm of precision is needed for the purposes of surveying and machine guidance, with other operational tasks demanding a lower precision of 3–5 m (O'Connor *et al.*, 2019). Construction is estimated to be the sector that stands to gain the largest economic benefit from GNSS over the next 20 years in Canada, with the resource extraction industry the fourth largest (EY, 2022). In land surveying, for example, a U.S. study reported that GNSS use is, for the most part, ubiquitous, except where a physical impediment blocks the signal (e.g., no line of sight) (O'Connor *et al.*, 2019). Substantial economic benefits have been associated with GNSS, arising almost entirely from labour savings (O'Connor *et al.*, 2019; EY, 2022). Without GNSS, land surveying proceeds much more slowly and becomes more costly, with implications for environments where GNSS availability or reliability is inconsistent, such as the High Arctic (O'Connor *et al.*, 2019; Kirkko-Jaakkola *et al.*, 2020). Limitations of GNSS in Arctic and sub-Arctic settings can challenge wide-area surveying using conventional techniques or reduce accuracy, requiring practitioners to innovate (e.g., Brown & McClellan, 2017; Kirkko-Jaakkola *et al.*, 2020). For digital activities, key issues include data access, availability, and quality, as well as supporting elements for managing geospatial data, including policies and infrastructure (NRCan, 2024a, 2026b). Effective integration of relevant data sources is also a challenge, beyond geodetic observing infrastructure considerations (Gagnon *et al.*, 2026). Although geodetic infrastructure does not entirely address the above technology issues, the panel argues that accurate geodetic products promote interoperability and provide a foundation for private-sector innovation based on geospatial information.

## 2.3 Sovereignty and security

Strengthening Canada's national security and demonstrating sovereignty in an increasingly complex geopolitical environment are significant priorities reflected in recent federal policies and budgetary commitments (e.g., PMO, 2026b,c). Geodesy plays an important role in meeting these objectives, particularly by providing precise and reliable positioning and navigation. The Arctic—a low-reliability environment for satellite positioning and telecommunications (Kirkko-Jaakkola *et al*., 2020)—has emerged as a focal point for strategic defence planning (PMO, 2026c). These considerations carry implications for infrastructure planning beyond geodesy, as well as for reconciliation given the federal government's responsibilities under modern treaties signed with Inuit and many First Nations in the North (GC, 1993; CIRNAC, 2015; GC *et al*., 2019). The dual-use nature of space-based infrastructure for geodetic and Earth-observation purposes raises questions about how enhancing geodetic observing infrastructure might align with other dual-use investments to achieve Canada's strategic, security, and military goals. Moreover, the importance of international collaboration in geodesy (Section 1.2) suggests that renewed Canadian contributions could align with other engagement activities with like-minded nations on climate change, security, and science.

### Canada's increased spending on defence and dual-use technologies underscores the overlap of geodesy and defence

PNT technologies—terrestrial, space-based, and emerging (e.g., quantum)—appear on the federal government's Sensitive Technology List and its list of Sensitive Technology Research Areas (ISED, 2025b; PS, 2025). The former invites potentially higher regulatory scrutiny for industrial R&D and commercial activities in these fields, including export control considerations (Nattrass & Carden, 2025). The latter influences publicly funded research related to these technologies, including through restrictions on research partnerships established by Canada's Policy on Sensitive Technology Research and Affiliations of Concern (ISED, 2023a,b).

Federal commitments to increase defence spending are expected to strengthen support for R&D in these and other dual-use technology fields (e.g., through the Defence Industrial Strategy) (PMO, 2026b). R&D in PNT applications suitable for military settings is already supported through projects funded by the Innovation for Defence Excellence and Security (IDEaS) program, such as efforts to study timing in GNSS-denied environments and alternative non-GNSS PNT solutions (DND, 2024a, 2025a) (Section 3.1.3). Murphy *et al*. (2025) argue that R&D may be a key avenue for meeting spending commitments

and linking to other policy areas in science and technology, such as the quantum and space sectors (CSA, 2019; ISED, 2022). The Inuit Nunangat Policy, meanwhile, commits Canada to making investments in multi-purpose (including dual-use) infrastructure in Inuit Nunangat (CIRNAC, 2022; JUS, 2023). Information-sharing is a key dimension of Arctic policy given the transnational dimensions of Arctic priorities (CCG, 2024), and capacity-building in geodesy could benefit Arctic nations through appropriate partnerships and agreements.

### Recent focus on Canada's space sector recognizes the importance of geodesy for supporting priorities

The economic potential of the space sector is a main factor underpinning Canada's space strategy, since the sector has consistently contributed more than $2 billion to Canada's GDP annually over the past five years (CSA, 2019, 2025a). A consulting report by Lundquist *et al.* (2024) suggests that, given Canada's existing strengths and capacities in the space sector, it could be a $40-billion industry by 2040. The space strategy emphasizes the importance of using space to "solve everyday challenges for Canadians," with low-Earth orbit (LEO) solutions for broadband connectivity given as examples; here, the potential for high-quality, space-based PNT solutions across Canada would also apply (CSA, 2019) (Section 3.1.3). Moreover, Canada's defence investments could naturally involve a space-based component given the inherently dual-use nature of the space sector (Space Canada, 2025).

The federal government is responding to the opportunity in the space sector through the Defence Industrial Strategy and related investments (GC, 2025b, 2026a). For instance, $200 million is being allocated over 10 years toward a spaceport facility in Nova Scotia that aims to support satellite missions (ACOA, 2026). Beyond launch capabilities, the Defence Industrial Strategy also emphasizes other dimensions, including intelligence and domain awareness, as well as incentives for space innovation (DND, 2025b; GC, 2026a).

Given the presence of geodetic observing infrastructure in space and the potential for overlapping supporting infrastructure (e.g., monitoring, shared payloads), the dynamics of Canada's activities in the space economy have bearing on geodesy and its products. Geodetic observing infrastructure plays an important role in supporting activities in the space sector by defining the International Celestial Reference Frame (ICRF) used to assign the position of objects in space (Charlot *et al.*, 2020), as well as by measuring the precise orbits of assets through direct observations such as SLR (Tapley *et al.*, 1985; RAEGE, n.d.). The number of these assets is increasing rapidly, with nearly 20,000 satellites in orbit in 2026 (up from 1,000 in 2010) (Orbital Radar, 2026). Precise

orbit determination for satellites allows for monitoring and maintaining their motion—for instance, using SLR and onboard GNSS receivers in emerging LEO constellations (Selvan *et al*., 2023).

VLBI, meanwhile, can be applied to the precise orbit determination of satellites, based on recent studies (Klopotek *et al*., 2020). Using VLBI stations for this purpose allows for effective satellite tracking without relying on SLR, which can suffer from downtime (due to cloud cover) (Dhar *et al*., 2024). Using the global International VLBI Service for Geodesy and Astrometry (IVS) network would allow for the greatest accuracy possible, but national-scale VLBI networks can still achieve low relative errors in orbital parameters without coordinating with stations in the IVS network (Dhar *et al*., 2024). In this respect, the infrastructure could contribute to global efforts while still allowing for space monitoring uses with sovereign interests in mind. Indeed, a private entity offers a space-domain awareness service in Canada through VLBI, using infrastructure formerly owned and operated by the federal government that, until two decades ago, contributed to the global VLBI observing network (Thothx, 2023; NRCan, 2025b).

### Priorities related to sovereignty, national security, defence, and reconciliation are brought together in the Arctic, a region of critical importance

In the Arctic there exists a confluence of commercial, military, scientific, and civilian considerations (SECD, 2023). The consequences of climate change are especially evident in the Arctic (IPCC, 2022) (Section 2.4), underscoring the importance of monitoring northern climate change through national efforts and international scientific collaborations hosted on Canadian territory (ECCC, 2009; NRCan, 2025c; Nassar *et al*., 2026). Increasing geopolitical competition is also being felt in the region (SECD, 2023; Falco *et al*., 2024), leading to investments in dual-use infrastructure such as radar systems as well as other sensing and surveillance infrastructure (e.g., Norman, 2025a,b; GC, 2026b). Geopolitical shifts are spurring other infrastructure development efforts by the federal government to support expanded trade and logistics capabilities in the North (PCO, 2026b). Infrastructure development in the Arctic is costly and logistically challenging (Zerey, 2026). Remoteness is one factor, but climate change also increases infrastructure risks through coastal erosion, sea-level rise, postglacial rebound, permafrost thaw, and extreme weather events (Arctic Council EPPR, 2025). Such projects may therefore require different engineering standards and could potentially benefit from embedded environmental monitoring systems (Zerey, 2026) (Section 2.2). These developments also have

significant implications for Inuit and northern communities more broadly, given the impacts of environmental and ecological change and the widening military footprint in the North (Gov. of NU, 2025).

Erskine and Landry (2026) argue that for these reasons, bolstering Canada's security in the North should focus on regional capacity, alongside broader infrastructure and industrial development, rather than solely on military capacity. For example, changes in sea ice extent brought on by climate change are expanding marine shipping operations in the Arctic (Cao *et al*., 2022; Arctic Council, 2024) and related investments in ports (such as Churchill, Manitoba) are being made in response to increased trade at high latitudes (Cantisani, 2025). The efficiency and safety of maritime navigation, shipping, and logistics are strongly supported by geodesy (particularly GNSS) (LE, 2023). These activities carry accompanying requirements for enhanced search-and-rescue and emergency response capacities, which are also enabled by geodetic observing infrastructure including tide gauges (Byers, 2024)—where alternatives other than satellites may not be available or cost-effective to employ (Mason *et al*., 2021), such as in the North and the Arctic (AEC, 2021).

The Canadian Coast Guard (CCG) Arctic Strategy emphasizes that maritime domain awareness in the Arctic is a focus for security and sovereignty (CCG, 2024). In addition, enabling "safe transit of essential goods and services" in Arctic waters is a central priority, highlighting the need for reliable positioning and navigation solutions. Another priority of the strategy is "modernization and northern adaptation," which seeks to modernize services and be responsive to shifting context in the Arctic, from climate change to national security (CCG, 2024). Although approximately half of the currently navigable portion of Arctic waters in Canada has been charted with hydrographic surveys to a degree that allows for safe navigation, as of 2023 less than 20% of Arctic waters overall have been charted to modern hydrographic survey standards (DFO, 2023). This contributes to marine shipping risks, as uncertainty around depths or the presence of unknown shoals pose hazards to marine transport, in addition to sea ice (Nicoll *et al*., 2024; Knudby, 2025). This is particularly relevant to CCG Arctic activities such as ice-breaking and search-and-rescue, which rely on reliable PNT services and incur tremendous costs from related outages (LE, 2019, 2023; Mason *et al*., 2021). The North lacks connectivity, infrastructure, and modern hydrographic survey data; geodetic observing infrastructure (e.g., precise positioning) and tide gauges could help address some of these deficiencies (CCG, 2024). The demand for CCG support is only poised to grow as economic and national security activities increase in the Arctic (CCG, 2024).

As development proceeds in the Arctic region and populations grow, hydrospatial studies of these waterways could be essential to facilitate the

transportation of goods and materials by deep-draft vessels, since doing so is far more economical than using air or tug and barge (Leyzack, 2011). These studies will also be required for military navigation related to national defence, as well as enabling other economic activities such as fishing, or infrastructure development such as deep-sea cable installation (Alkan & Öcalan, 2013; Austine & Pyne, 2017; Hunt, 2020; Peng, 2021; UKHO, 2024).

### Increasing accessibility of the Northwest Passage has economic, security, and social ramifications, highlighting PNT needs in maritime settings at northern latitudes

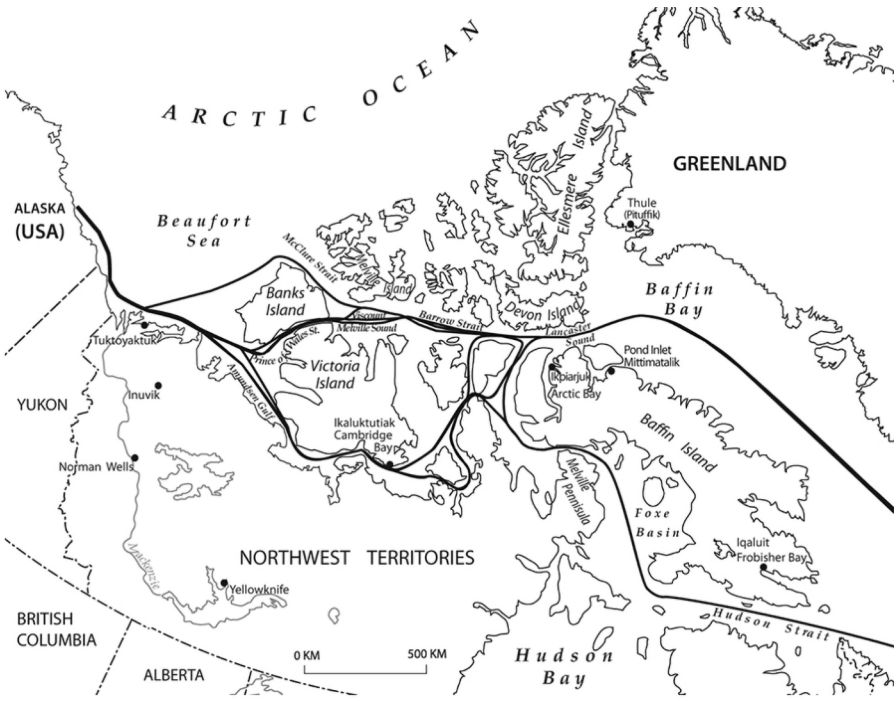
Arctic shipping is increasing as a result of climate change and involves a growing range of vessels travelling over greater distances (Dawson *et al.*, 2018; Ng *et al.*, 2018). This trend is playing out in the Northwest Passage (NWP), a sea lane linking the Pacific and Atlantic oceans that runs along the northern coasts of Alaska and Yukon, then through the Northwest Territories and Nunavut via the Arctic Archipelago (Figure 2.4). The NWP holds significant cultural and social value to Inuit because it connects communities across Inuit Nunangat, from the Bering Sea to Greenland, historically and in the present day (ITK, 2018).

The passage has sovereignty implications; although Canada considers the NWP to be internal waters, this assertion has been disputed by the United States for decades (Lalonde, 2020). Past cooperation treaties succeeded in cultivating a pragmatic relationship around these waters (e.g., GC, 1988), but shifting geopolitical developments have drawn significant attention to the NWP alongside the rest of the Arctic. Beyond the United States, other jurisdictions, such as the European Union, China, and South Korea, have expressed positions that are incompatible with the view of the NWP as internal Canadian waters, with regard to marine shipping (Lalonde, 2020). In turn, the federal government has reiterated its position—to assert its jurisdiction further, it points to policy and capacity-building efforts around the NWP described in several departmental and defence strategies (CCG, 2024; DND, 2024b; GAC, 2024).

The increased attention paid to the NWP by the federal government and international powers has prompted Inuit governments and other Indigenous rights-holders to articulate their security priorities (AFN Yukon Region & NAADSN, 2025; Gov. of NU, 2025; ITK, 2025), encouraging a more holistic approach at the federal level (Lackenbauer *et al.*, 2025). Ensuring that Inuit self-determination is respected in Inuit Nunangat through investments and policy actions is viewed as a key pillar of a sustainable effort to develop defence capabilities (ITK, 2025). Demonstrating sovereignty also means investing in

strong communities, understanding Inuit perspectives on sovereignty and security, adopting a circumpolar perspective, fostering economic development, and recognizing links among climate risks, security, and sovereignty (Gov. of NU, 2025). Moreover, there is an imperative not to perpetuate past injustices in the context of infrastructure development (AFN Yukon Region & NAADSN, 2025).

Despite a reduction in both the extent and duration of ice cover in the NWP, several infrastructure, navigational, and safety considerations persist (Lackenbauer & Lajeunesse, 2014). Ice conditions vary widely along potential shipping routes and defy forecasting efforts, contributing to uncertainty for shipping operators from a scheduling standpoint (Lackenbauer & Lajeunesse, 2014). As such, the NWP is an important route for resupplying northern communities, albeit not yet a major commercial route (Huntington *et al.*, 2023). Over a decade ago, Lackenbauer and Lajeunesse (2014) argued that resolving gaps in knowledge and infrastructure to support safe navigation needed to be prioritized alongside addressing threats to Arctic sovereignty—which have since multiplied (DND, 2024b; GAC, 2024). Such gaps include bathymetry through modern hydrographic surveys, search-and-rescue capabilities, and infrastructure; Canada has only eight coastal Arctic ports with modest capabilities and limited connections to land-based transportation networks (Sheehan *et al.*, 2021; DFO, 2023).




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**Figure 2.4 Main sea route comprising the Northwest Passage**

The Northwest Passage is a major Arctic sea lane made up of several legs that traverse the Arctic Archipelago. Changing sea ice conditions due to climate change have increased access to navigable waters across the passage, with seasonal variability, triggering a growth in shipping traffic (Sheehan *et al.*, 2021; Huntington *et al.*, 2023; Holloway *et al.*, 2024).

## Geodetic investment needs for sovereignty and security priorities

Canada's opportunities in the areas of sovereignty and security are numerous. Needs include fit-for-purpose solutions to support military requirements; capacity to support (maritime and terrestrial) navigation and situational awareness in the North; and capabilities to meet threats to the PNT ecosystem and related risks to critical infrastructure. Access to military-grade GNSS signals is an area where Canada could look to enhance resilience. At present, Canada benefits from access to U.S. GPS

(continues)

(continued)

signals suitable for this purpose (ISED, 2023c), but overreliance on GPS comes at the expense of resilience. In other jurisdictions, such as Australia, analysis has suggested that backup timing infrastructure and a layered approach to PNT are necessary to backstop GPS (FrontierSI, 2025a), in addition to improving awareness of spoofing risks and anti-spoofing measures (FrontierSI, 2025b).

The Canadian Space Agency (CSA) and the European Space Agency (ESA) recently came to a security agreement to allow for greater information-sharing and more opportunity for the Canadian space sector to participate in ESA contracts (Boucher, 2026). As of late 2026, Canada and the EU have begun negotiations toward a framework for increased Canadian access to Galileo (PMO, 2026d); however, it is unclear whether this includes Galileo's encrypted service (EC, 2011; ESA, 2020). Meanwhile, real-time positioning in the Arctic is possible through Precise Point Positioning (PPP) using publicly available GNSS, but its accuracy and availability depend on communication links (to obtain necessary corrections) and access to multiple constellations (Di *et al.*, 2022). Deciding among standalone technologies that deliver local PNT over a limited range (e.g., Calian, 2026), solutions based on signals of opportunity (e.g., DRDC, 2024) (Section 3.1.3), and public investments in area-wide geodetic solutions suitable for defence applications remains an issue.

Investments in modern hydrographic surveys for bathymetry could reduce key safety, ecological, and commercial risks involving the NWP through updated charting (Huntington *et al.*, 2023) while also providing valuable data to support models of ocean tides and coastal dynamics—which also have bearing on navigation (Hayden *et al.*, 2020). Hydrographic data, beyond their uses in navigation, are also increasingly applied in international trade, resource management, environmental stewardship, construction, ice-breaking activities, and search-and-rescue, with implications for emergency planning, science, and the blue economy (IHO, 2023). A recent analysis for the U.K. Exclusive Economic Zone (EEZ) estimated benefits of nearly 90 times the cost when it came to seabed mapping (UKHO, 2024). Although the specific figures are not germane to Canada, and an equivalent study for Canada is not available, it is perhaps notable that the largest contributing sectors to the estimated benefits by far are shipping, ports, and offshore energy, in alignment with infrastructure priorities outlined by the MPO (UKHO, 2024; PCO, 2026b).

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Charting and seafloor mapping rely on geodetic observing infrastructure through the use of positioning (e.g., GNSS) and the geoid to provide information on vertical datum and irregularities beneath the surface (Liebsch *et al.*, 2022). However, geomagnetic storms can degrade GNSS signals, introducing biases and errors in positioning to an extent that requirements for maritime navigation can no longer be met (Špoljar *et al.*, 2021). Unlike the NWP, sea routes along the northern coast of Russia use alternative PNT sources to address GNSS-based navigational challenges (RNTF, 2017), but it should be noted that the volume of marine shipping supported by this infrastructure is considerably higher than the volume along the NWP at this time (Huntington *et al.*, 2023). Alternative PNT sources optimized for delivering services to polar regions could provide the necessary starting point to address gaps in charting (Section 3.1.3).

## 2.4 Social and environmental priorities

Beyond providing products that underpin economic development and support national security, geodesy can also contribute to several other societal priorities in Canada. Climate change poses a serious threat, and geodetic observations are essential for measuring some of its ramifications, while also supporting other efforts in monitoring and climate risk management. Relatedly, observations made using geodetic techniques can shed light on Canada's freshwater resources and how their distribution evolves over time. The role of geodesy in positioning and mapping is also consequential to Canada's efforts toward reconciliation, as it provides essential services in rural and remote areas for land management, navigation, and sovereignty.

### Climate change affects Canada in countless ways, and geodetic observations are needed to monitor its impacts on the shape of the Earth

Climate change imposes substantial costs across Canada's economy, livelihoods, ecosystems, and cultural heritage (Canadian Climate Institute, 2020; Lulham *et al.*, 2023). Climate change can lead to physical changes to the shape of the Earth or the distribution of mass as a result of hydrological phenomena, among others (Métivier *et al.*, 2010). Land deformation, uplift, subsidence, and polar ice melt are all factors that link the ITRF to climate change (Argus, 1996; Métivier *et al.*, 2010; Bock & Melgar, 2016; James *et al.*, 2021; Forbes *et al.*, 2022). Geodetic observations can also shed light on postglacial rebound and other

related deformations arising from geological, climate, and hydrological effects (Métivier *et al.*, 2010; Tsuji *et al.*, 2016; Hayden *et al.*, 2020; James *et al.*, 2021). The melting of glaciers and ice in polar regions has led to a transfer of mass from the poles toward the equator, contributing to changes to the Earth's shape that are driving the slow increase of the planetary length of day (Shahvandi *et al.*, 2024). Glacial retreat measurements and sea-level monitoring rely on the accuracy of geodetic observing infrastructure to inform coastal hazard monitoring (NASEM, 2020; Seeger & Minderhoud, 2026). The International Federation of Surveyors argues that climate resilience increasingly relies on the collection of geospatial and hydrospatial data (FIG, 2026). Such data can inform policy-making and support governance through monitoring, land management, and risk assessment.

### It is essential to measure the amount and distribution of freshwater in Canada, given its importance as a resource and the evolution of flood risks in our changing climate

Canada contains some of the largest reserves of freshwater, total and renewable, in the world (ECCC, 2026). A 2021 survey found that "nearly half of Canadians rate fresh water as Canada's most important natural resource" (ECCC, 2021). Its importance is also reflected in Canada's energy planning, where hydroelectric power features prominently in the federal electricity infrastructure strategy, and large hydroelectric projects are among those being explored by the MPO (NRCan, 2026c; PCO, 2026b). Freshwater and its related ecosystems in Canada are tied to numerous socioeconomic activities beyond electricity production, such as fisheries and ecosystem services (including carbon sequestration) (Pacific Salmon Commission, 2017; ISF, 2024; NRCan, 2026c), and they hold significant cultural value among Indigenous Peoples (ECCC, 2026). Monitoring and stewardship of these resources for scientific, ecological, economic, and sociocultural reasons are increasingly essential as climate change alters freshwater distribution (ECCC, 2026). Changes in precipitation patterns and volumes, including increased rainfall in northern regions, as well as glacial and permafrost melt, are reshaping freshwater systems across Canada (Walvoord & Kurylyk, 2016; Castellazzi *et al.*, 2019; Zhang *et al.*, 2019; Berry *et al.*, 2026).

Geodetic observing infrastructure provides direct and indirect means of monitoring this essential resource. For example, GNSS can be used to measure the deformations at the surface of the Earth associated with changing loads related to hydrological dynamics (White *et al.*, 2022). It can also be used to measure water level changes under circumstances where permanent gauges are impractical to use (NASEM, 2020; Larson & Williams, 2023) (Section 1.2).

Combining those observations with other techniques such as gravimetry allows the observation of processes affecting freshwater over broad temporal and spatial scales (Jaramillo *et al*., 2024). Doing so enables the subsequent estimation of water storage volumes as a function of time, for instance, in response to storm events or seasonal patterns (Fatolazadeh & Goïta, 2021; White *et al*., 2022). Key impacts of these changes include changing flood risks, which have prompted policy initiatives to modernize flood risk assessment, including flood mapping. Remote sensing satellite missions dependent on accurate geodetic information contribute to targets defined in Canada's National Adaptation Strategy, for instance, which speaks of a need for flood hazard mapping to provide evidence that can inform government efforts to identify and prioritize high-risk flood areas (NASEM, 2020; ECCC, 2023). Flood mapping also requires the use of an accurate reference system and geoid, given the importance of elevation, and uses GNSS-related data collection for surveying (NRCan & PS, 2019; ECCC, 2023).

Geodetic products also support various space-based and remote sensing techniques used in freshwater science. They aid in the precise orbit determination of the satellites involved, and they provide reference frames to which sensing data can be accurately linked (NASEM, 2020; Larson & Williams, 2023; ECCC, 2026). Moreover, integrating multidisciplinary data sources is a key practice in watershed management, enabled by geodetic products because position is a shared quantity across multiple data types (ECCC, 2026) (Section 2.2).

### Accurate and precise location data can support Canada's commitment to reconciliation with Indigenous Peoples

Geodetic observing infrastructure and the products it generates can also support reconciliation with Indigenous Peoples in Canada. The *United Nations Declaration on the Rights of Indigenous Peoples Act* Action Plan notes "lands, territories and resources" as priority areas for the implementation of Canadian legislation related to the *United Nations Declaration on the Rights of Indigenous Peoples* (UNDRIP) (GC, 2021; JUS, 2023). In this respect, NRCan is instructed to "develop and implement actions to increase the economic participation of Indigenous Peoples and their communities in natural resource development," within the broader government objective of ensuring that Indigenous Peoples can fully participate in Canada's economy (JUS, 2023). The action plan also speaks to Indigenous oversight of energy infrastructure lifecycles (JUS, 2023). Managing such assets over their lifecycle provides an opportunity to optimize infrastructure performance through ongoing data collection around usage and maintenance, among other considerations (González & Dekyi, 2026). Some

aspects of asset lifecycle monitoring can be enabled by geodetic observing infrastructure and high-quality geodetic products—through deformation monitoring or geospatial digital twins, for example (Section 2.2).

Similar directions are echoed in the Arctic context, where reconciliation is acknowledged as a central objective of the CCG Arctic Strategy (CCG, 2024). This strategy underscores the importance of renewing relationships—for instance, through implementing the Inuit Nunangat Policy (CIRNAC, 2022; CCG, 2024), which emphasizes the need to establish socioeconomic equity (CIRNAC, 2025). This need is defined broadly, but eliminating the discrepancy between major urban centres and the Arctic would reasonably fall within the scope of this objective, in terms of accessing high-accuracy precise positioning and timing (Kirkko-Jaakkola *et al.*, 2020). Although the inequities faced by Indigenous Peoples in Canada are numerous and diverse, lack of access to high-quality geodetic information or PNT means that some economic activities (or productivity gains) may not be uniformly available across Canada (JUS, 2023).

Documenting and mapping Indigenous traditional territories and resources is a way to uphold Indigenous sovereignty in Canadian law and environmental governance regimes (McLain *et al.*, 2013; McIlwraith & Cormier, 2015; Hirt, 2022). Land claim agreements rely on precise location data to help ensure Indigenous rights and titles are upheld (NRCan, 2022b). For example, NRCan's Surveyor General Branch supports the implementation of the *Framework Agreement on First Nation Land Management* (GC, 2022), which provides certainty over the extent of First Nations-administered lands, and the mapping of excluded parcels. This work extends to settlement agreements between the Crown and First Nations related to flooding damages; surveys involve "several challenging complexities involving water boundaries and reserve creation" (NRCan, 2022b). Land claim agreements also rely on accurate and accessible maps and surveys to ensure boundary certainty and prevent future conflicts over boundaries on federal lands (NRCan, 2022b).

### Accurate geospatial data can support the priorities of Indigenous Peoples

Geospatial data may be accessed and deployed through numerous programs and applications, some of which may be beneficial to Indigenous Peoples in achieving their goals, such as in planning, in the documentation of Indigenous knowledges and land uses, and in the management of capital assets (Chayne, 2021). For example, several communities participating in the Aboriginal Aquatic Resource and Oceans Management (AAROM) program carry out activities in geomatics and hydrospatial domains to manage their lands and resources (Indigenous Oceans, 2019). Similarly, given the aforementioned gaps in Arctic

charting, Inuit communities are leading key crowdsourced bathymetry efforts to improve navigation safety (Rondeau *et al.*, 2026). However, geodesy and its products are not the only way to determine location in this context. Maps based on remote sensing systems can be complemented by participatory mapping exercises in which Indigenous epistemologies, ontologies, and methodologies are integrated and blended alongside oral testimonies and lived experiences on the Land (Milton Freeman Research Limited, 1976; Hirt, 2022). These approaches have been used to create atlases, combining various forms of information such as place names and histories, ecological information, land-use patterns, and Indigenous knowledges as manifested in various forms, with several examples in the Arctic (Clyde River Knowledge Atlas, n.d.; GCRC, n.d.). Additionally, mapping exercises done by Indigenous communities are sometimes referred to as *counter-mapping*, where Indigenous groups aim to "challenge the exclusive power over maps of historically dominant actors (states, large corporations, etc.) and to increase their ability to represent themselves" (Hirt, 2022).



## Geodetic investment needs for social and environmental priorities

Canada lacks VLBI and SLR infrastructure that could be used to monitor climate change (Section 1.2). In general, VLBI contributes to defining key reference frames and regular measurements of the Earth's orientation, while also contributing to particular geophysical activities such as measuring continental drift (Angermann *et al.*, 2022; NRCan, 2025b). VLBI, specifically, can be used to monitor integrated water vapour trends, the analysis of which benefits from long and stable measurements (Balidakis *et al.*, 2018). Long-term geodetic observations also provide insight into global sea level change, an important indicator of climate change (Cheng, 2025; Nie *et al.*, 2025). Geodetic observing infrastructure is critical to Arctic environmental research and allows researchers to study and predict key factors such as sea level dynamics through vertical land motion and plate dynamics (Wöppelmann & Marcos, 2016; James *et al.*, 2021), while supporting Earth observation missions through precise orbit determination. Changes in the Earth's distribution of mass, influenced by the balance between water storage and ice cover over decades, for instance, can also be monitored by SLR (Shahvandi *et al.*, 2024; Cheng, 2025; Gałdyn *et al.*, 2026).

## 2.5 Summary

Numerous key national priorities articulated by the federal government rely directly or indirectly on geodetic observing infrastructure and its products. Canada derives several benefits from space-based assets owned and operated by other jurisdictions, as well as the products resulting from global efforts in geodesy. Because of this dependence, in an increasingly fragmented world, Canada lacks resilience and may be hampering its security and economic growth in the near term. Improved geodetic capacity could bolster many of its key priorities—such as growing the economy, asserting sovereignty, expanding trade networks, and fortifying security and defence. Notably, many objectives expressed by the federal government are being operationalized in the Arctic and other remote parts of Canada, where geodetic observing infrastructure is least developed, and services are least available, reliable, and accurate. The manifestations of climate change in the Arctic, such as glacial melt and loss of sea ice, are linked to geophysical consequences that are readily measured using (or thanks to) geodetic infrastructure. These ramifications also affect the lands and waters of northern communities, as well as Canada's national security. This suggests that federal, provincial, and territorial departments and agencies across the public service could benefit from increased capacity to ensure Canada has access to the high-quality PNT needed to carry out government objectives.

Moreover, geodetic observing infrastructure supports a wide range of economic activities, enabling value chains across several key Canadian sectors such as agriculture, energy, and natural resources, where reliable positioning could unlock additional opportunities, lower operational costs, and improve efficiency. Similarly, demand for geodetic products is rising with the continued expansion of the digital economy, as applications such as digital twins, geospatial and hydrospatial analytics, and AI-based systems rely on accurate positioning to integrate and analyze complex data sets. Geodetic information also supports broader public policy objectives—including public safety and emergency response, climate monitoring, and reconciliation—by enabling measurement of Earth system changes to support science, risk assessment, and environmental management.

3

# Opportunities for Renewed Investment


3.1 Investments in geodetic observing infrastructure

3.2 Elements to support renewed investments

3.3 Summary

## Chapter findings

- The panel identified three key opportunities for renewed investment: building co-located core geodetic observing infrastructure, increasing the density of active control stations, and improving the resilience of positioning, navigation, and timing (PNT) provision through low-Earth orbit satellites.
- Strengthening Canada's contribution through investment in co-located core infrastructure would bolster Canada's role and credibility in the international community and improve data accuracy, redundancy, and applicability to Canadian contexts.
- Increasing the density of active control stations across Canada (especially in the Arctic) would allow for more precise and reliable positioning in rural and remote areas, supporting critical infrastructure projects across the country.
- Changing political and environmental contexts are highlighting the need for resilient PNT infrastructure; multiple technologies, including dedicated Canadian low-Earth orbit PNT satellites, offer a promising path forward for Canada's sovereignty goals.
- Any investment in geodetic observing infrastructure also requires (i) policies or strategies to guide investments cohesively, (ii) dedicated and sustained funding, (iii) education and training to develop and maintain access to a pool of highly qualified personnel, and (iv) data infrastructure to collect, manage, and store information in Canada.

Building on the links between geodetic observing infrastructure and Canada's priorities, this chapter examines the opportunities associated with renewed investment. It focuses on two areas: (i) investing in technologies and physical infrastructure to strengthen geodetic observations and resilient positioning, navigation, and timing (PNT) services in Canada, and (ii) investing in the supporting capabilities needed to realize the benefits of geodetic observing infrastructure.

As it weighed these opportunities, the panel looked to promising international practices, as several foreign jurisdictions have employed a variety of approaches to bolster geodetic observing infrastructure and its supporting elements; these may offer opportunities for reliable collaboration and partnership. The panel emphasizes that this chapter does not provide an exhaustive review of existing

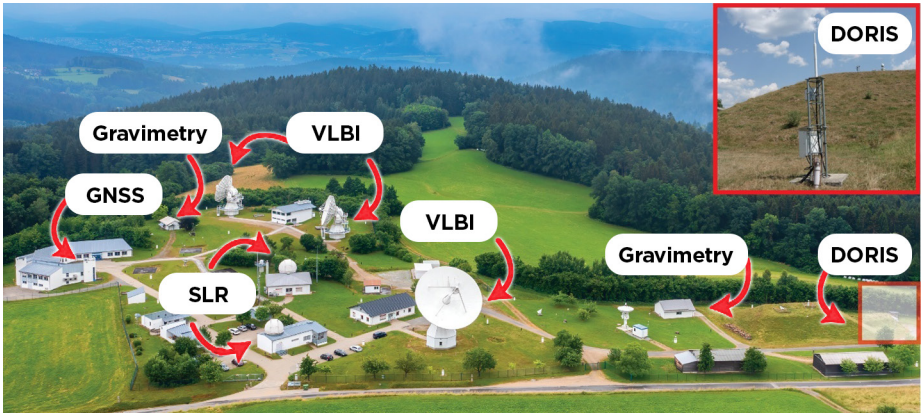
options for geodetic investment, nor does it explore every foreign jurisdiction's approach. Instead, the panel presents a selection of immediate opportunities it believes have potential for success and strategic return on investment in Canada.

## 3.1 Investments in geodetic observing infrastructure

Canada may choose to invest in any number of well-established or emerging geodetic observing infrastructures to support its economic, security, sovereignty, social, and environmental goals. In the panel's view, investing in the co-location of major geodetic observing infrastructures, increasing the density of continuously tracking GNSS stations (referred to as active control stations) in the Arctic and across Canada more broadly, and improving the resilience of PNT provision through technologies such as Canadian low-Earth orbit (LEO) PNT systems, particularly in the Arctic, are key opportunities for exploration. In addition to potential infrastructure investments, supporting elements related to policy and coordination, operational resources, and, perhaps most importantly, human resources have also been identified as key to building capacity (Section 3.2).

### 3.1.1 Building and co-locating new core geodetic observing infrastructure

Generally speaking, a site is considered co-located if it hosts two or more ground stations using key geodetic observing techniques in very close proximity (i.e., within hundreds of metres of each other) (Ray & Altamimi, 2005; Noll, 2014). While *co-location* refers to the infrastructure for VLBI, SLR, GNSS, and DORIS, the panel notes that other instruments could also be co-located (e.g., for measuring absolute gravity, sea level, and meteorological phenomena), providing accurate location data for those instruments and sharing costs associated with installation of utilities (Figure 3.1). Co-location enables analysts to assess and validate the quality and accuracy of each technique's measurements (Noll, 2014; Appleby *et al.*, 2015). Although one co-located site would be a significant contribution from Canada to global geodetic observing infrastructure, given its vast landmass, multiple sites (potentially two or three) would be a more appropriate contribution and would provide a beneficial level of redundancy. To be considered a core Global Geodetic Observing System (GGOS) site, continuous operation is required (Appleby *et al.*, 2015); should instrumentation go down for unforeseen or scheduled reasons, having other stations that could offset the downtime is an advantage (McCallum *et al.*, 2026).



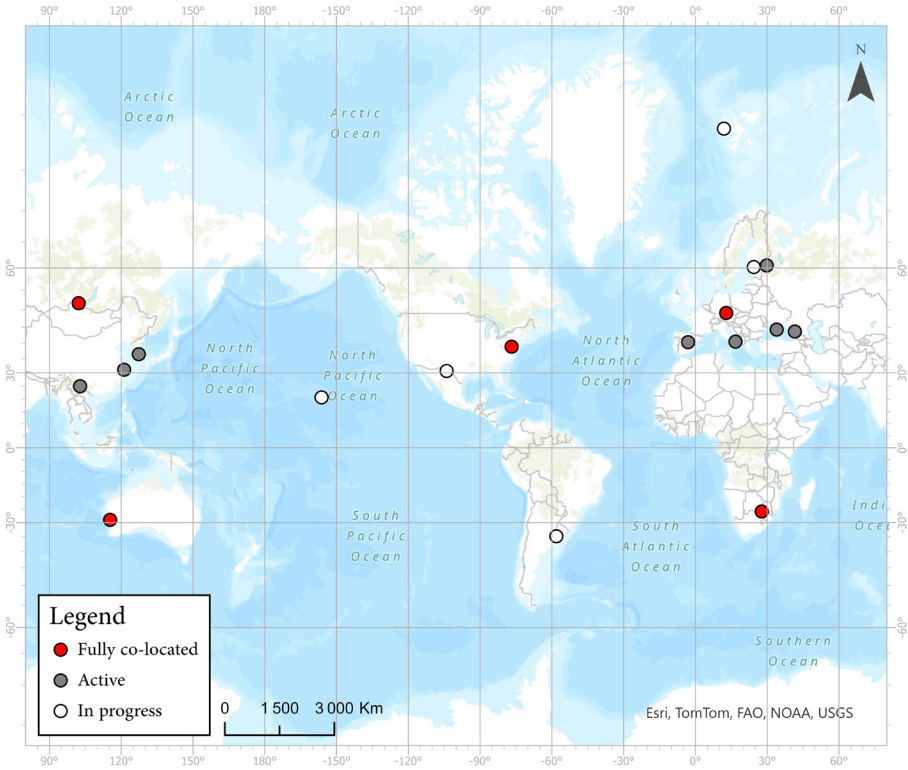

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**Figure 3.1 Co-located geodetic observing infrastructure near Wettzell, Germany**

The Geodetic Observatory Wettzell hosts all four key geodetic observing infrastructures that contribute to the International Terrestrial Reference Frame alongside other techniques, such as gravimetry and tools for environmental monitoring (BKG, n.d.-b). The inset shows a picture of the DORIS beacon, which is hidden behind a hill in the larger image.

## The number of extant co-located sites is insufficient to achieve the desired level of accuracy for the ITRF

Creating an accurate and consistent International Terrestrial Reference Frame (ITRF) requires combined information from the four main geodetic techniques, each with its own unique contribution (Altamimi *et al.*, 2023) (Appendix A). For example, SLR is solely responsible for determining the Earth's centre of mass, also known as the origin of the ITRF. Paired with VLBI, it provides the scale of the ITRF (RAEGE, n.d.). However, the global SLR network is subject to uneven geographic distribution, with several regions, including Canada, completely bare of SLR stations (ILRS, n.d.-b; RAEGE, n.d.) (Section 1.2). This results in data gaps and reduced tracking coverage, degrading the quality of products derived from SLR (RAEGE, n.d.). Similarly, the distribution of VLBI stations is highly uneven, and most are not dedicated VLBI sites, as they also contribute observing time to other radio astronomy priorities (Plank *et al.*, 2015). This issue extends to co-located sites writ large; major deficiencies in the current realization of the ITRF are the small number and poor distribution across the globe of sites having all four space-based techniques co-located, especially VLBI and SLR (Glaser *et al.*, 2019; Delva *et al.*, 2023) (Figure 3.2).




Data sources: IDS (2026); AGGO (n.d.); IAG (n.d.-b); ILRS (n.d.-a)

## Figure 3.2 Distribution of core co-located sites contributing to GGOS

Location of active and in-progress sites where VLBI and SLR are co-located based on best available knowledge from the sources listed; staff note that all stations are subject to outages and may not be continuously active. Most of these sites also have GNSS stations, and several have DORIS alongside other relevant instruments (e.g., for measuring time, gravity, and tides). Only five active sites host all four key observation techniques (making them fully co-located), with two more in progress as equipment is upgraded and tested. Despite its large landmass, Canada has no co-located sites.

Co-located sites are critical because the global geodetic reference frame is reliant on them, in the sense that "each technique makes its measurements in a different way, providing different observables with unique capabilities; together the techniques provide cross-validation and increased accuracy" (Appleby *et al.*, 2015). In theory, 24 to 32 global sites with co-located VLBI and SLR are needed to maintain the ITRF at the desired level of accuracy (1 mm accuracy and 0.1 mm/yr stability), with the VLBI components ideally

being continuously operating and evenly distributed (Pavlis & Kuzmicz-Cieslak, 2008; Gross *et al.*, 2009; NASEM, 2010; Plank *et al.*, 2015). This level of accuracy is required to meet sea-level measurement needs and the increasing measurement capabilities of satellites; the current ground network of stations is insufficient to provide a reference frame that meets the standards described above (Appleby *et al.*, 2015).

### Canada lacks influence on several international decision-making bodies due to a deficiency in geodetic observing infrastructure

As noted in Chapter 1, Canada only contributes to the GGOS through hosting GNSS and DORIS ground stations,[6] and it lacks any VLBI or SLR stations. This lack of infrastructure precludes significant participation in international committees and organizations, limiting Canada's ability to influence decision-making in areas that will affect it. Australia, which also lacks a sovereign GNSS constellation, has invested in other geodetic observing infrastructure (e.g., three VLBI stations), ensuring that it is represented in international organizations that make decisions with implications for that country (IVS, 2026a,b, n.d.-a). Other jurisdictions have invested in new co-location sites, recognizing their importance to the ITRF and other goals (Box 3.1). In the panel's view, Canada would demonstrate leadership by having modern integrated GGOS core stations that host a range of related techniques (e.g., for absolute gravity).

The direct benefits of having a seat at the table may be difficult to quantify, but given the importance of space-based assets in geodesy—and for PNT provision more broadly—it is notable that investments made to meet Canada's needs in geodetic observing infrastructure may also provide opportunities to contribute to Earth observation, among other space-related goals and partnerships (Boasiako, 2026). Future negotiations around space-based activities—such as those linked to Canada's investment of more than $500 million in European Space Agency (ESA) programs (CSA, 2026)—could benefit from the in-kind contributions enabled by the existence of Canada-based geodetic observing infrastructure.

6 Canada also contributes absolute gravity measurements to the International Gravimetric Bureau (BGI), which defines the International Gravity Reference System & Frame (IGRS/IGRF) (BGI, 2026, n.d.). It also contributes tide gauge measurements from six stations to the Global Sea Level Observing System (GLOSS, 2012, 2026).

## Box 3.1 A foreign approach to co-location sites

Norway invested in its co-located Geodetic Earth Observatory through the work of the Kartverket (the Norwegian Mapping Authority) (Kartverket, 2021). Located in Ny-Ålesund on Svalbard, this infrastructure is the world's northernmost operating observatory. In recent years, Kartverket, in partnership with NASA, has invested in the establishment of an SLR system to complement the existing VLBI, GNSS, and DORIS equipment at the station (alongside a tide gauge and gravimeter) (Kartverket, 2021; Nordic Geodetic Commission, 2025; Ny-Ålesund Research Station, n.d.). The rationale for the construction of this co-located station is that it would contribute to the realization of 1 mm accuracy and 0.1 mm/yr stability of the ITRF required by GGOS, advancing climate change research and ensuring accurate GNSS information (Gross *et al.*, 2009; Kartverket, 2021; Ny-Ålesund Research Station, 2022).

### The exact cost of co-located sites varies based on a range of factors, but recent foreign investments provide some insight

While no recent estimates exist for building and operating Canadian VLBI and SLR stations, and costs will depend heavily on the chosen location (e.g., remoteness), recent investments from peer countries offer some insight. Through the "Structure and Evolution of the Australian Continent" program initiated through Australia's national infrastructure strategy, Australia invested in three VLBI telescopes and a software correlator, alongside ~100 GNSS receivers, upgrades to SLR stations, an absolute gravimeter, and three tidal gravimeters (Lovell *et al.*, 2012). In 2008, each station cost approximately AU$2.1 million[7] to establish hardware and infrastructure (J. McCallum, personal communication, 2026). Over the last decade, the operating cost has been ~AU$850,000 per year for staffing and maintenance. A modern station, equipped to contribute to the VLBI Global Observing System, has been estimated to cost at least AU$5 million for the telescope, with additional costs associated with time-keeping, receivers, and sampling system equipment (among others) (J. McCallum, personal communication, 2026). The new geodetic observatory at Ny-Ålesund is estimated to cost NOK300 million, and includes two modern VLBI telescopes (Kartverket, 2021). Another station being built in Gran Canaria, Spain has construction costs estimated at €6 million for a VLBI telescope, GNSS receivers, SLR capabilities, and other instrumentation (IAG,

7 The September 2026 Bank of Canada conversion rates are: 1 Australian dollar = 0.99 Canadian dollars; 1 Norwegian krone = 0.15 Canadian dollars; 1 European euro = 1.61 Canadian dollars.

2025c). The panel notes that without a detailed breakdown of expenditures, it is difficult to determine the true costs of these stations, and the remote location of some of these stations may also contribute to inflated costs.

### Establishing co-located sites in Canada would contribute to the precision and reliability of the ITRF while allowing Canada to participate in international forums

In the panel's view, operating even one domestic co-location site would contribute to the precision and reliability of the ITRF and allow Canada to be involved in its determination through geodetic observations made by VLBI and SLR. Although the ITRF relies on contributions from many countries, a Canadian contribution would make the global reference frame more accurate for Canada's own use, since measurements used by the ITRF define the location of any contributing station precisely, and station positions are thus embedded in how the ITRF is calculated (N. Brown, personal communication, 2026). In the case of VLBI, the addition of new antennas providing critical observations to the global network introduces better redundancy (Plank *et al.*, 2015). VLBI is also being explored as an option for observing satellites, tying together VLBI, GNSS, and LEO PNT more closely (Klopotek *et al.*, 2020; Schunck *et al.*, 2026).

Although the ITRF relies on contributions from many countries, a Canadian contribution would make the global reference frame more accurate for Canada's own use.

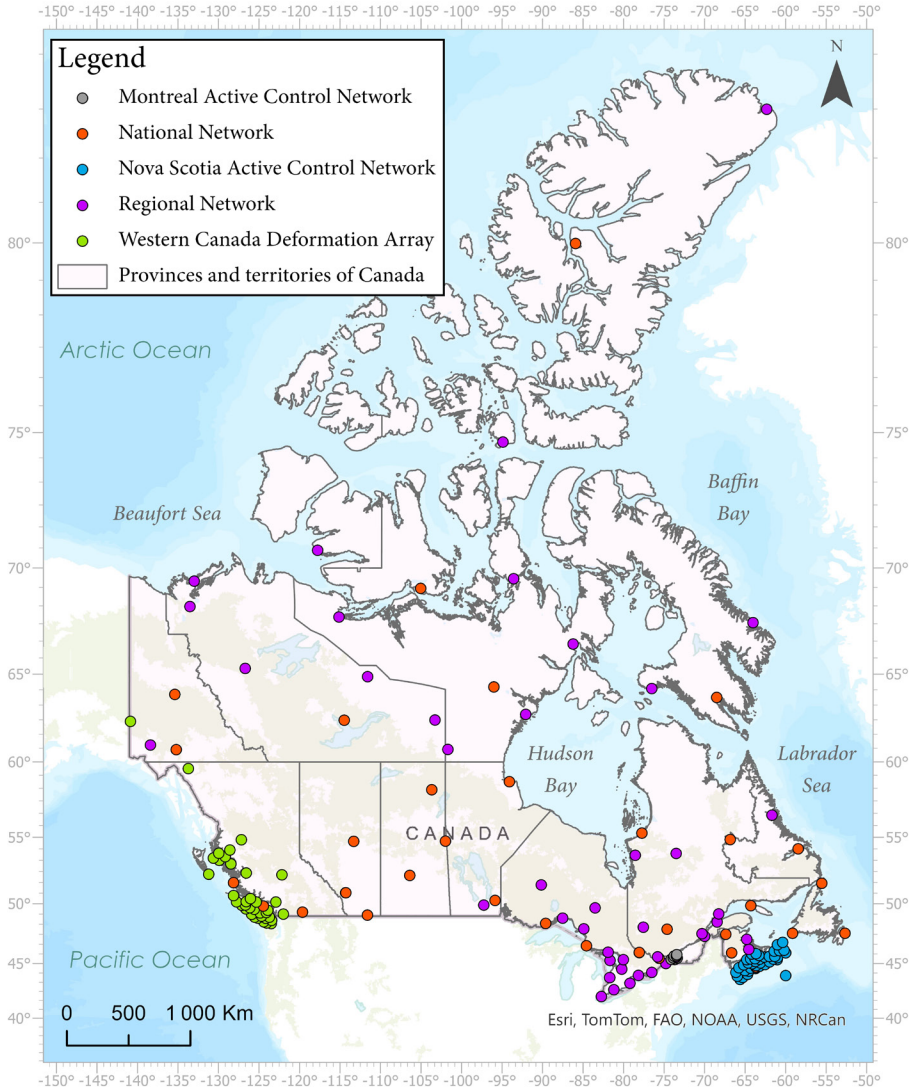
For SLR, models have shown that the theoretical addition of new sites in Whitehorse and Penticton would be beneficial to the global network (Glaser *et al.*, 2019), and although Southern Hemisphere SLR stations are found to be the most valuable in terms of new additions to the network, polar stations are also important for realizing the ITRF (Kehm *et al.*, 2019; Tucker *et al.*, 2023). Through its new SLR station at Ny-Ålesund, Norway is helping to address one of the deficits in the global SLR network (Tucker *et al.*, 2023), but gaps remain. A similar contribution from Canada would increase northern tracking capabilities and provide better global geometry and redundancy, in addition to the overall benefits to the accuracy and reliability of the ITRF.

### New, co-located, core geodetic observing infrastructure: The connection to meeting Canada's geodetic needs

Adding domestic, co-located sites would improve Canada's activities that depend on the ITRF and Earth orientation parameters (EOPs). Strengthening the precision and reliability of the ITRF, in turn, would make it more precise and reliable when applied to Canada, with important contributions to modelling for climate change, sea level rise, postglacial rebound, and other Earth systems processes. Contributing to the global VLBI and SLR network would also enable Canada to influence and contribute to international decision-making forums and strengthen international relationships, such as Canada's link to the ESA; this could, for instance, give Canada leverage in discussions with the European Union regarding possible future space projects and agreements. Domestic VLBI and SLR may also support satellite launch, tracking, and orbit determination, benefiting foreign and Canadian-owned satellite operators.

## 3.1.2 Increasing the density of active control stations

Active control stations (also known as continuously operating reference stations, or CORS) are "reference points on which GNSS receivers are permanently deployed to continuously track all navigation satellites in view" (CGRSC, 2025a). These stations provide corrections for cm-level GNSS positioning, with improved precision as user proximity to the station increases. Networks of active control stations contribute to several applications, including the realization of regional and national reference systems (Box 1.2), the generation of geodetic products (e.g., satellite orbits), Earth systems monitoring (e.g., for earthquakes), and support for location services (commercial or publicly owned), which are critical for surveying and mapping (Altamimi & Gross, 2017; Johnston *et al.*, 2017; NASEM, 2020). Different actors, public and private, may be responsible for maintaining active control stations for various purposes (CGRSC, 2025a). In Canada, the Canadian Active Control System (CACS) is a network of CORS that ties the North American Datum of 1983 (NAD83) and the CSRS to the ITRF and contributes to geoscience activities (e.g., determining the movement of the Canadian landmass through the Western Canada Deformation Array) (Henton *et al.*, 2006; NRCan, 2025a). The national and regional network comprises 89 CACS stations (some of which are part of the International GNSS Service network), alongside provincial and municipal networks (Figure 3.3).




Data source: NRCan (2026d)

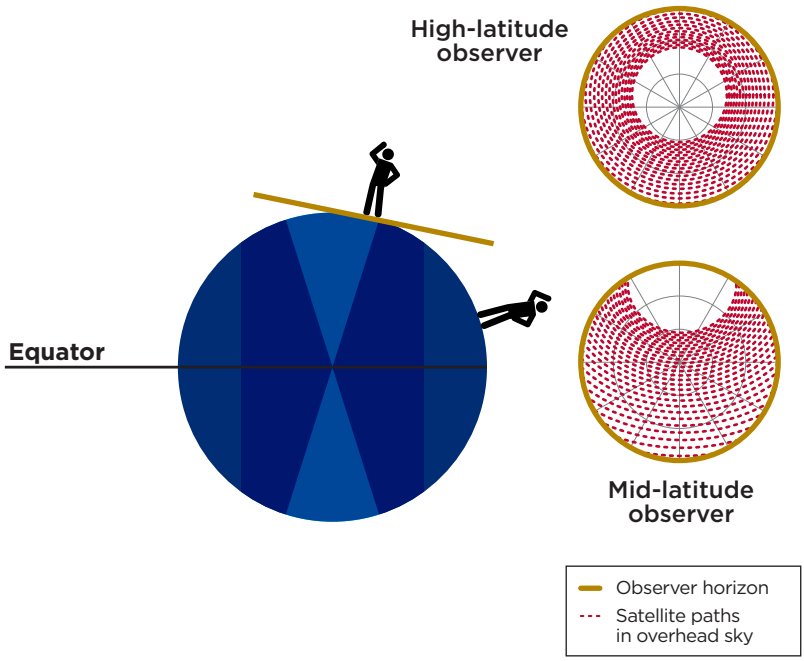
## Figure 3.3 Map of the Canadian Active Control System (CACS)

The CACS consists of continuously tracking GNSS stations, referred to as *active control stations*. They are equipped with "a high precision, dual frequency GNSS receiver, a geodetic quality antenna, and some also include an atomic frequency standard" (NRCan, 2026d).

### Densification of Canada's GNSS observation stations would benefit global geodetic products (e.g., reference frames, Earth systems monitoring) and support Canadian priorities

In the panel's view, both the density and the distribution of active control stations in Canada are insufficient, leaving many regions of the country without geodetic observation data. These data must therefore be extrapolated, meaning they are of lower accuracy and that observations are more difficult to validate. This is especially salient in the Arctic, where GNSS signals are already degraded and subject to lower accuracy than in other parts of the country, due to the reduced visibility of satellites and atmospheric interference (Kirkko-Jaakkola *et al.*, 2020) (Figure 3.4). Canada's network pales in comparison to the density and distribution of sites in other jurisdictions. For example, Australia operates approximately 200 active control stations, averaging 1 per ~38,000 km$^2$, with a relatively even distribution (Geoscience Australia, 2014; Ruddick *et al.*, 2024). In comparison, Canada's 89 national and regional stations result in a distribution of 1 per ~112,000 km$^2$, however they are unevenly distributed and concentrated near the southern border, resulting in large gaps elsewhere in the country (StatCan, 2016; NRCan, 2026d).[8] The Australian approach was deliberate in establishing a relatively homogenous distribution of federally operated stations across the country, in spite of the remoteness of many locations (Geoscience Australia, 2016). Dense networks of active control stations offer benefits beyond their contributions to the ITRF—for instance, by supporting emergency preparedness (Box 3.2). In addition, the closer control stations are to one another, the more accurate error corrections are (e.g., for atmospheric effects) (Kirkko-Jaakkola *et al.*, 2020).

8 In Australia and Canada, additional networks also exist at the subnational level and increase the effective coverage in specific areas (e.g., nearby population centres) (Geoscience Australia, n.d.).




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**Figure 3.4 GNSS satellite paths viewed at high- vs mid-latitudes**

GNSS satellites follow specific orbits around the Earth (blue), which dictate a satellite's relative position with respect to a potential observer on Earth. From the perspective of that observer's receiver, satellites will therefore follow specific paths in the sky corresponding to where the observer is located relative to the orbit (red dashed lines). The orbital planes of each GNSS constellation lie beneath a certain angle with respect to the Earth's poles. As such, there are some locations above the poles where no satellites will be seen overhead, only closer to the horizon (gold line). The difficulty in obtaining satellite signals from several angles overhead has implications for accurate positioning in polar regions.

## Box 3.2 A foreign approach to densification of active control stations

Increasing the density of active control stations could contribute to emergency preparedness in tectonically active regions of Canada (Bond, 2016). The long-term deformation monitoring of various features subject to geophysical loading has been a common application for geodetic

(continues)

(continued)

technologies (Henton *et al.*, 2006), intended to provide advance warning when abnormal behaviour occurs (Bond, 2016). For example, the Geospatial Information Authority of Japan has established more than 1,300 continuously operating GNSS reference stations across the country, with an average distance of ~20 km between them (GSI, 2025a,b). These stations make up the GNSS Earth Observation Network System and are intended to monitor crustal deformation, contribute to surveying activities, provide early earthquake and tsunami warnings, and inform studies of volcanic activity (GSI, 2025b).

Currently, the sparse network of active control stations in Canada necessitates the use of a GNSS post-processing platform known as a Precise Point Positioning (PPP) service (CGRSC, 2025b). This much-appreciated service is free to the public and allows users to input raw GNSS data and receive back highly accurate coordinates without proximity to a base station (CGRSC, 2025b; Papadakis, 2025). Increasing the density of active control stations would allow for improved GNSS signal corrections, since proximity to these stations lets users calculate errors due to atmospheric interference and satellite orbit/clock discrepancies more accurately (Rizos, 2017). In short, the closer a user's receiver is to multiple active control stations, the more consistent and accurate the provided GNSS position is. In the absence of proximal active control stations, local reference frames may be established to provide precise local control for dedicated projects (Junkins & Garrard, 1998). However, this local reference frame would be separate from regional and global reference frames, potentially causing integration problems in the future. Adding active control stations across Canada, especially in rural and remote areas and the Arctic, would improve the efficiency and accuracy of surveying and engineering work for infrastructure and construction (Section 2.2).



## Densifying the network of active control stations: The connection to meeting Canada's geodetic needs

By increasing the density of active control stations in Canada through the CACS, Canada would provide a reliable, precise positioning service and improve the reliability, accuracy, and availability of positioning outside urban areas. This would support activities such as navigation,

(continues)

(continued)

construction, and infrastructure management. Furthermore, larger networks of control stations would strengthen monitoring of climate change and natural hazards (e.g., earthquakes), supporting scientific priorities and public safety.

### 3.1.3 Establishing complementary infrastructure for enhanced PNT resilience

Canada has an opportunity to invest in the resilience of its existing PNT systems, as well as in novel strategies or infrastructure, to ensure resilience amid rapidly changing circumstances. As discussed in Section 2.1, GNSS is vulnerable to disruption through both intentional and unintentional means, and outages would negatively impact numerous sectors in Canada. The following section focuses primarily on GNSS backups, as it is the core provider of PNT services for most applications. Although GNSS augmentation is not geodetic observing infrastructure in the strictest sense, the panel views it as one of the most impactful ways to achieve Canada's broader geodesy goals. The panel emphasizes, however, that any satellite-based GNSS augmentation is reliant on core geodetic observing infrastructure and its products to determine the position of satellites in space in relation to the Earth.

#### There is a range of options that can provide backups to the primary GNSS infrastructure, but their costs and benefits vary substantially

PNT backup options will be specific to user needs and requirements and can involve investment options that strengthen the GNSS backbone, including those related to new space and terrestrial infrastructure, as well as new user costs (e.g., for accessing alternative PNT services) (Mason *et al.*, 2021). In some cases, jurisdictions such as the European Union, India, and Japan have invested in their own global or regional satellite systems to backstop or enhance services provided by GPS or other GNSS (EC, 2025; Gov. of India, n.d.; Gov. of Japan, n.d.). The costs of doing so are quite high, both to establish and to operate (O'Connor *et al.*, 2019; EC, 2021; GPS.gov, n.d.-b). Figures for the Indian system which began operation in 2018 surpassed INR20 billion in infrastructure expenditures alone (Gov. of India, 2018; Reuters, 2022),[9] while South Korea has earmarked US$3.3 billion for a regional navigation satellite system (RNSS) set to become operational by 2035 (Park, 2021).

9 The September 2026 Bank of Canada conversion rate is: 1 Indian rupee = 0.015 Canadian dollars.

Beyond sovereign space-based PNT sources, various jurisdictions are exploring other options. For example, the European Union is considering a combination of space- and ground-based systems to support resiliency, prosperity, and preparedness in the face of threats (Bonenberg *et al*., 2024). A range of ground-based technological options can support resilience (e.g., quantum sensors, fibre-optic timing) (Bonenberg *et al*., 2024; FrontierSI, 2025a). The United Kingdom is investing £155 million to strengthen its PNT infrastructure, including £71 million put toward the development of a program using enhanced long-range navigation (eLoran),[10] wherein ground-based radio towers act as a backup to GPS in the event of a PNT disruption (Luccio, 2021; Cozzens, 2025b; Gov. of UK, 2026). In the United States, a backup system that relies on telecommunications infrastructure and networks is already being pursued, with an emphasis on meeting first-responder PNT needs; in some settings (e.g., urban), this could serve as a backup to GPS (Mason *et al*., 2021).

Other technologies that could provide alternative PNT are pseudolites and purpose-built ranging networks. These networks involve fixed transmitters radiating GNSS-like signals to enable positioning using terrestrial infrastructure (FrontierSI, 2026a). One of the most well-known applications of this approach is Locata, which focuses on GNSS-challenged environments (FrontierSI, 2026b; Locata, n.d.). The Locata system operates at different frequencies than the previously discussed techniques and uses different propagation characteristics, allowing it to provide complementary PNT information that is more resilient to certain interference effects (Thomas *et al*., 2025). In New Zealand, the Port of Auckland gains redundancy through such beacons (Sofranec, 2021); this approach is being studied as a model for other jurisdictions as a local and potentially cost-effective redundancy for GNSS in shipping and logistics (Flytkjaer, 2020; Williams, 2020).

### LEO PNT offers a promising backup to GNSS in Canada, bolstering the resilience of the current PNT system and enhancing service in high latitudes

LEO PNT infrastructure uses LEO satellites to provide PNT information to users. Satellite-based infrastructure for PNT occupies different orbits: GNSS in medium-Earth orbit acts as the primary provider of PNT; augmentation services and regional systems occupy geostationary Earth orbit as a complement to GNSS; and LEO constellations occupy low-Earth orbit, offering alternative and more powerful signal characteristics to act as a backup to GNSS PNT (FrontierSI, 2026b). LEO PNT satellites are much smaller than those used for GNSS and typically occupy orbits of between 500 and 1,200 km altitude,

10 The September 2026 Bank of Canada conversion rate is: 1 U.K. pound sterling = 1.87 Canadian dollars.

resulting in a one-to-two-hour orbital period (FrontierSI, 2024). While not strictly geodetic observing infrastructure, LEO PNT has been proposed as a method to improve resilience in space-based navigation beyond GNSS due to its strong signal, resistance to jamming and spoofing, and potential availability in areas with poor service (Critchley-Marrows & Verspieren, 2023). In the panel's view, a Canadian LEO PNT system could address many gaps in domestic PNT provision, including as a backup during outages and in areas with limited service, particularly in the Arctic and northern regions.

### LEO satellites have properties that benefit certain applications, but they have a smaller range than other constellations

The proximity of LEO satellites to the Earth brings both advantages and drawbacks. One advantage is significantly faster convergence—the speed at which LEO PNT satellites are moving in relation to the receiver means that they can provide clock and orbit updates at much higher rates than GNSS (FrontierSI, 2026b). Autonomous vehicles, for example, can benefit greatly from this characteristic of LEO satellites (Reid *et al*., 2020; VDA, 2026). This rapid change in satellite position can also improve signals in obstructed areas due to higher satellite density and visibility, leading to better accuracy (FrontierSI, 2024). Closer proximity to the Earth results in higher signal strength relative to GNSS, which lowers susceptibility to jamming and spoofing, while increasing the potential to penetrate buildings (FrontierSI, 2024). Depending on location, the distribution of LEO PNT satellites may provide increased positioning precision over GNSS, especially in high latitudes (e.g., the Arctic) where telecommunications solutions based on LEO are already operational (Hodes, 2021; Gala *et al*., 2026). However, lower orbits also mean that LEO PNT satellites have much smaller satellite footprints and thus require much larger constellations to achieve the same area of signal coverage as GNSS (i.e., 200–300 satellites are required to provide the same satellite density achieved by ~30 GNSS satellites) (FrontierSI, 2024). This issue may be mitigated by installing regional LEO PNT infrastructure, reducing the need for full global coverage and focusing satellite visibility on a specific area (FrontierSI, 2026b).

### Early efforts are underway to establish LEO PNT in Canada

LEO satellites have thus far largely been deployed to provide satellite-based communications services, and expanding their use to provide PNT services could be achieved in three different ways: dedicated LEO PNT satellites (e.g., Iridium, n.d.), by opportunistically using signals from LEO satellites intended for other purposes (e.g., Kassas *et al*., 2023), or through hybrid approaches with both communications and PNT capabilities (Critchley-Marrows & Verspieren,

2023). Various jurisdictions are considering LEO PNT as a complement to existing PNT infrastructure or as a standalone system (Box 3.3). For example, Xona Space Systems is developing a LEO navigation system named Pulsar, which aims to achieve "persistent and redundant coverage everywhere on Earth", including in high latitude and remote areas (CSA, 2025b). Xona is also collaborating with the National Research Council of Canada (NRC) to provide a secure and resilient method for time dissemination by broadcasting Coordinated Universal Time (UTC(NRC)) (S. Beattie, personal communication, 2026). In June 2025, Xona launched the first Pulsar satellite and plans to grow its constellation to more than 250 satellites for global coverage (CSA, 2025b). LEO satellites are also being developed for communications needs by Telesat, particularly in Arctic contexts; Telesat has secured a contract to provide the Canadian Armed Forces enhanced Arctic satellite communications capabilities, as a component of Telesat Lightspeed LEO satellites (Telesat, 2026). However, no plans to support PNT integration have yet been announced (FrontierSI, 2026b; Telesat, n.d.).

## Box 3.3 Foreign approaches to LEO PNT

For many countries, LEO PNT is most often considered as a complement to existing space-based PNT infrastructure (e.g., GNSS, RNSS); however, countries may also choose to investigate options for standalone LEO PNT, as is being done in the United Arab Emirates and the United Kingdom (LE, 2023; Symcox, 2025; Thales Alenia Space, 2025; FrontierSI, 2026b). Australia is currently considering options for sovereign satellite capabilities in the defence sector, though the specifics of the system (e.g., whether satellites will have low-Earth or geostationary orbits) have not been finalized due to concerns around costs, features, and vulnerability (Blenkin, 2025, 2026). One of the more advanced public demonstrations of LEO PNT is in the European Union. To supplement Galileo (the EU GNSS constellation), the ESA is developing a LEO PNT system named Celeste, which is intended to test the potential for more accurate, robust, and available PNT services through LEO satellites (ESA, 2022, n.d.). Some of the rationale for the development of this system includes the need for cm-scale precision for navigation that is continuously reliable and able to overcome interference (ESA, 2022). This program is supported through the ESA's Directorate of Navigation's FutureNAV program (ESA, 2022; Delva *et al.*, 2023; Inside GNSS, 2025).

The panel emphasizes that geographic location and specific user needs will dictate the most appropriate resilience approach; private companies may provide their own PNT backups in some locations, for example, while other regions have none. In the panel's view, it is important for cohesive national PNT strategies or policies to provide a solid foundation for the identification and mitigation of risks to PNT service in vulnerable sectors (Section 3.2).



### Complementary infrastructure for PNT resilience: The connection to meeting Canada's geodetic needs

Investing in technologies that provide a backup to GNSS-based PNT provision would enable Canada's security and sovereignty goals, especially in the event of jamming, spoofing, or natural disruptions of GNSS service. LEO PNT systems, in particular, can provide signal coverage in polar regions, improving service for civilian and military uses, with downstream advantages for all aspects of life that rely on precise and reliable PNT (e.g., banking, climate monitoring, communications, transportation and logistics, shipping).

## 3.2 Elements to support renewed investments

Fully realizing the benefits of expanded geodetic observing infrastructure requires investment in key supporting elements. These include financial and human resources to sustain the geodetic supply chain, as well as adequate governance mechanisms that support the integrity and quality of geodetic products (UN-GGCE, 2024a). This section discusses the components needed to support renewed geodetic investments in Canada, including sustained funding for maintenance and operations, training and education for highly qualified personnel (HQP), guiding strategies and policies, and resources to ensure the quality and security of data infrastructure.

### Uniting strategy with vision can support governance and decision-making

Since geodetic information and infrastructure underpin such a wide array of activities, it is difficult to adopt a single approach or articulate a unified vision for decision-making. Despite this, many jurisdictions are becoming increasingly concerned about PNT resilience and turning their attention to

strategies for investment and research in this area (Critchley-Marrows & Verspieren, 2023; Gutierrez, 2026; Inside GNSS, 2026). Canada maintains the Canadian Positioning, Navigation, and Timing Board (PNTB), which acts as a central point of contact for the coordination of PNT issues across civilian and federal domains (Bond, 2022). It also coordinates with foreign governments on civilian PNT matters. The PNTB has explored jamming risk management, PNT infrastructure for automation in transportation, and the costs of GNSS disruptions to multiple economic sectors (Bond, 2022; EY, 2022). Despite work by the PNTB, there is no cross-sectoral policy or legislation that oversees Canada's national PNT activities (FrontierSI, 2025a). In Australia, by contrast, PNT is part of the government's broader Earth Observation from Space Roadmap (ASA, 2021) and geoscience strategy (Geoscience Australia, 2026). Progress has been made, however, with the recent release of the Positioning, Navigation and Timing Resilience Framework, which aims to strengthen PNT resilience in Canada and explicitly highlights the expansion of sovereign geodetic infrastructure as an area of focus (ISED, 2026c). In the panel's view, having a framework, strategy, or policy to support a coherent vision for geodetic investment and growth is necessary for success.

### Canada's geospatial strategy creates an opportunity for renewed investment in geodetic observing infrastructure

In 2026, NRCan released the Collaborative Geospatial Strategy for Canada, created after a 2024 review found that existing supports and systems for managing geospatial information were insufficient for the volume and value being produced (NRCan, 2024a, 2026b). The strategy "establishes a shared framework for a renewed, integrated approach for governance, infrastructure, and collaboration" by building on other strategies (e.g., Canada's Strategy for Satellite Earth Observation), and it reflects commitments made under the renewed Canadian Geomatics Accord 2025–2030 (CCOG, 2025; NRCan, 2026b). The Collaborative Geospatial Strategy for Canada recognizes fiscal realities and opportunities for savings through efficient and coordinated geospatial data infrastructure, and it outlines modern approaches to creating a more secure and trusted spatial data infrastructure in Canada (NRCan, 2026b). In terms of geodetic observing infrastructure, this strategy explicitly recognizes the foundational role that geodetic reference systems play in supporting the entire geospatial ecosystem, stating that "investments in upstream Earth observation systems and in geodetic and geospatial data must be matched by robust downstream infrastructure, technologies, and applications for data access, analysis, and archiving large volumes of data" (NRCan, 2026b).

Within this framing, there is an opportunity for renewed investments in geodetic observing infrastructure, though details on where to focus are lacking. However, some direction for investment may result from the implementation of the newly announced Positioning, Navigation and Timing Resilience Framework (ISED, 2026c). Other jurisdictions have more targeted strategies for geodesy and the various types of geodetic observing infrastructure (Box 3.4). In conjunction with a strategy, Canada could recognize PNT as critical technology (e.g., Reevely, 2023) to ensure adequate resourcing and coordination for robust, resilient infrastructure.

### Box 3.4 A foreign approach to policies and strategies for geodesy

The Lantmäteriet (the Swedish mapping, cadastral and land registration authority) has had a succession of 10-year plans and strategies focused on geodesy in Sweden (Lantmäteriet, 2018, 2026). The most recent plan recognizes the importance of resilience in positioning, discussing the development of tools to provide users with an indication of the reliability of geodetic services, as well as potential alternative methods (Lantmäteriet, 2026). In line with the United Nations' 2015 resolution on the global geodetic reference frame, Lantmäteriet has prioritized geodesy activities both to keep pace with technological developments and to be part of international collaboration in the field of geodesy (Lantmäteriet, 2026).

## Ongoing funding would bolster Canada's geodetic capacity, and the private sector may have a role to play

Any renewed investment in geodetic observing infrastructure requires funding. The need for stable resourcing, in particular, was identified as a key requirement for achieving global geodetic goals by the United Nations Global Geodetic Centre of Excellence (UN-GGCE), which states:

> *Member States and partner organizations agree that all elements of the global geodesy supply chain—ground observatories, data centers, analysis centers and the product development chain—are not resourced with enough money and people to sustain it.*
>
> UN-GGCE (2024b)

Historically, public funding through government programs has largely supported geodetic observing infrastructure, given the complexity and size of observing stations. More recently, the flourishing of space-based investment in the private sector has brought industry to the fore in terms of satellites and the provision of more precise PNT, for a price (e.g., Erwin, 2026; Iridium, n.d.). The Government of Canada could invest in geodetic observing infrastructure in several ways, including public–private partnerships (P3s). P3s are usually used "for the purpose of delivering a project or a service traditionally provided by the public sector" (Bertran & Vidal, 2005). P3s can range from fully public responsibility to fully private responsibility, with many options for shared responsibilities in between (Bertran & Vidal, 2005). Other jurisdictions have deployed them to fund geodetic observing infrastructure. For example, Australia's satellite-based augmentation system (SBAS), SouthPAN, provides Australia and New Zealand with improved, publicly available PNT access through GNSS without having to invest in their own standalone GNSS or RNSS infrastructure (ANAO, 2024). SouthPAN is delivered through a P3, with distinct private partners responsible for implementing the service's ground and space segments, respectively (Geoscience Australia, 2025). If Canada adopted this approach, it would require a Canada-specific model with appropriate federal oversight.

### The supply of HQP is insufficient to meet Canada's geodetic needs

Beyond physical infrastructure, qualified human resources are critical to the global geodetic supply chain (UN-GGCE, 2024b). More specifically, education, training, and capacity-building for the establishment, maintenance, and operation of geodetic observing infrastructure have been identified as crucial needs in modern geodesy, alongside the ability to process, analyze, and interpret data outputs (Keenan *et al*., 2023). Access to a sufficient number of HQP in geodesy is a noted growing challenge, and there is a perceived dearth of these experts at the global level (UN-GGCE, 2024a). The decline in the number of geodesy HQP is not limited to a single country or region; it is an international challenge being addressed at multiple levels, including international working groups, regional bodies, and individual nations (Box 3.5). Maintaining operations and performing tasks at geodetic observing infrastructures calls on expertise beyond geodesy. For example, VLBI stations employ electronic, electrical, and mechanical engineers to deal with hardware and software, alongside geodesists and other scientists (e.g., physicists, radio astronomers) (Baver *et al*., 2026). Like observing infrastructure, analysis and geodetic data centres also require trained staff, including software developers and data analysts (Baver *et al*., 2026).

## Box 3.5 Foreign approaches to the training and education of geodesists

Though not focused exclusively on geodesy, the U.S. National Geospatial-Intelligence Agency has partnered with the University of Missouri–St. Louis to introduce geospatial education from kindergarten through to post-secondary programs (NGA, 2021; Riske, 2026). This program is intended to support the future workforce needed for geospatial activities while also expanding geospatial and geomatics offerings at university and high school levels. The program's design "reflects a shared understanding that workforce readiness is most effective when education, training and applied experience are intentionally aligned" (Riske, 2026). This program is supported by federal funding to develop talent that meets evolving national security and infrastructure needs (Riske, 2026). Another proposed strategy for increasing the global capacity of geodesy is an international master's degree in geodesy taught and granted by different European institutions that would pool their experience and resources (Hanssen *et al.*, 2024). A questionnaire sent to stakeholders in the European geodetic job market[11] found that most respondents considered the availability of MSc graduates in geodesy unsatisfactory and expected demand for such experts to grow. Challenges to recruiting qualified geodetic personnel include a lack of domestic applicants as well as a lack of total applicants. The proposed master's degree would provide students with opportunities to study abroad and earn international experience; more importantly (as mentioned), students would benefit from the shared resources of several institutions. In this way, the burden of resourcing this program would be distributed (Hanssen *et al.*, 2024).

Canada possesses several academic centres and programs to train geodesists, including the University of Calgary, University of New Brunswick, Université Laval, and York University, all of which offer accredited programs in geomatics engineering (Engineers Canada, 2025). However, some of these programs are no longer accepting students and have been subject to limited or declining enrolment for many years (Pagiatakis *et al*., 2009; S. Pagiatakis, personal communication, 2026). Furthermore, many graduates relocate to the United States and Europe (Datta, 2025), possibly due to a lack of domestic opportunities in Canada. Elsewhere, a "national collapse" of U.S.

11 Respondents had backgrounds in surveying and mapping, geospatial technologies, engineering, navigation, Earth sciences, defence, and utilities, across both commercial and government sectors.

geodetic capacity has been described by Bevis *et al.* (2022), particularly from the standpoint of HQP. The retirement of experienced geodesists is another challenge to maintaining capacity. In universities, funding models may favour fields with higher student enrolment, and as experts retire, they may not be replaced (Nordman *et al.*, 2026). The panel notes, however, that this trend may not be observed across all geospatial sectors and that it is difficult to find evidence without tracking graduates.

### Data processing and analysis infrastructure is required to store and transmit the large volumes of data produced by geodetic observing infrastructure

Observation data from geodetic measurements are sent to dedicated data and analysis centres worldwide to be processed, cleaned, and combined for inclusion in the ITRF and for the production of products accessible to users (e.g., IGS, 2025; IVS, n.d.-b). Canada currently runs 1 of 13 International GNSS Service (IGS) analysis centres out of the Canadian Geodetic Survey, contributing to GNSS satellite orbits and clock products (IGS, 2025). It also runs two operational data centres, which maintain contact with Canadian IGS stations and validate, compress, and transmit data to regional or global data centres for further distribution and combination (IGS, n.d.). Because it lacks VLBI or SLR infrastructure, Canada does not participate in processing or analyzing data derived from these techniques. In the panel's view, should Canada pursue investment in VLBI and SLR, data transport, storage, and processing infrastructure would have to be provided in parallel, in order to avoid delays in product creation (Box 3.6).

In Australia, allocations were made for high-performance computing resources applied to VLBI studies (AuScope, n.d.-a). This is to make the most of existing computational infrastructure on Australian territory while building domestic capacity, since reliance on global analysis centres can result in delays in accessing useful data (Geoscience Australia, 2023; AuScope, n.d.-b) (Box 3.6). Data, correlation, and analysis centres for the main geodetic observing infrastructures are distributed globally (IVS, n.d.-c,-d,-e). Canada's renewed commitment to collaboration with international partners (e.g., the ESA) and continued collaboration with the United States (e.g., NASA) provide an opportunity to take on a more robust role in managing and storing these data. In the panel's view, providing additional capacity alongside existing global geodetic data and analysis centres would improve the resilience of the Canadian and global geodetic supply chain overall while allowing Canada to participate more fully in international geodetic organizations.

### Box 3.6 VLBI data needs in Australia

Australia operates three VLBI stations and is in the process of establishing its own VLBI correlator to process the data collected by these stations (AuScope, n.d.-a). Each VLBI observing session lasts approximately 24 hours, producing about 30 terabytes of data (AuScope, n.d.-b). These data are then transferred by fibre-optic connections to a central location, where a supercomputer with one petabyte of data allocated to processing aligns the recorded signals and derives a geodetic dataset, which is then used for further scientific analysis (AuScope, n.d.-a,-b). Prior to the establishment of the data processing centre and fibre-optic connections, Australia's VLBI stations had to ship raw VLBI data on hard drives to data centres in either the United States or Germany (Geoscience Australia, 2023). This process led to a delay of 14 days before the results of these sessions were available for use, impacting the ability of geodesists to effectively monitor Earth system changes and limiting the improvement of PNT accuracy and resilience. Delays in accessing the most up-to-date VLBI information also affected satellite orbit determinations and tracking accuracy for lunar and deep-space missions (Geoscience Australia, 2023).

## 3.3 Summary

The Canadian economy depends on access to high-quality geodetic information across a range of sectors. Enhanced geodetic observing infrastructure across the country would support several Canadian priorities—related to economic development, sovereignty, security, defence, and the environment. Additionally, Canada's lack of VLBI and SLR infrastructure precludes participation in major international decision-making fora, to the detriment of its international reputation and scientific capacity. Canada would therefore benefit substantially, on both local and global levels, from strengthening its domestic geodetic observing capacity. The panel identified key opportunities in investing in co-located sites, increasing the density of active GNSS stations, and building resilient PNT infrastructure. Investments in these technologies offer strong strategic benefits in support of Canada's economic, security, defence, environmental, and social objectives. Realizing these benefits will require dedicated, sustained funding; qualified personnel in the government, academic, and private sectors; a cohesive strategic framework; and adequate data access and processing capacity.

4

# Panel Reflections

An examination of Canada's existing geodetic observing infrastructure, alongside the federal government's needs and priorities, reveals a significant gap. Although Canada was once a leader in geodesy, it now lacks sufficient infrastructure to fully realize its objectives related to economic growth, trade expansion, national security, defence, and sovereignty, among other critical areas. Increased capacity to deliver high-quality geodetic data (e.g., PNT services) would impact several sectors, allowing Canadian innovators to capture many of the growing benefits of the knowledge economy, from digital and software tools to robotics and transportation solutions. There are substantial opportunities to leverage geodetic information across the broader economy, including in agriculture, energy, and natural resource development; to support public safety, defence, and emergency response; and to better understand the impact of climate change across the globe.

The implications for national security and sovereignty are particularly salient given the extent to which Canada's gaps give rise to vulnerabilities and limitations. In the Arctic, a region that is the focus of much of the discourse surrounding security and sovereignty, Canada lacks the infrastructure to guarantee the PNT services necessary for domain awareness, intelligence, and navigation (air, land, sea, and space), among other needs; these services are currently reliant on another jurisdiction's infrastructure. This reality, combined with the shift in Canadian industrial policy toward defence and dual-use technology, underscores the utility of geodetic observing infrastructure and sovereign PNT as a keystone in Canada's resilience and security.

At the global level, Canada operates in an evolving geopolitical landscape in which middle powers can exercise influence through various forms of soft power. Many critical geodetic activities and products depend on globally distributed infrastructure, shared data, and coordinated international partnerships. The extent to which a country participates in these systems can create opportunities to exert international influence and bolster credibility; major GNSS constellations illustrate this dynamic (RNTF, 2023b; Elefteriu, 2024). By providing global services, space-faring nations create dependencies that can be leveraged strategically. At national scales, jurisdictions can also strengthen their position in the governance of global geodesy by contributing reliable, high-demand infrastructure to this inherently fragile network (Rodríguez *et al*., 2025; UN-GGCE, 2026). While some middle-power countries have capitalized on these opportunities, Canada is perceived as not pulling its weight and remains at a disadvantage due to insufficient ground-based infrastructure (given its large landmass), including too few active control stations and a complete absence of VLBI and SLR systems, among other gaps.

Targeted investment in domestic geodetic observing infrastructure would therefore deliver significant national and international benefits. Priority areas include developing co-located observing sites, increasing the density of active GNSS stations, and strengthening resilient PNT systems through conventional land-based and emerging space-based technologies. Advancing these capabilities would support Canada's economic, security, environmental, and social objectives while improving its global standing and influence. A comprehensive approach to building sovereign capacity in geodetic observing infrastructure and its supporting elements, led by government in collaboration with academia and the private sector, could restore Canada's previous leadership in this field and more broadly reinforce its reputation as a reliable international partner. Such an approach could also provide a foundation for growth across the Canadian economy for decades to come.

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# Appendix A: Contributions Made by Principal Geodetic Observations in GGOS Across Core Scientific Domains

| | VLBI | SLR | GNSS | DORIS |
|---|---|---|---|---|
| **Reference frames: Terrestrial (TRF) and Celestial (CRF)** | • TRF station positions and velocities<br>• TRF scale and temporal variations<br>• CRF | • TRF station positions and velocities<br>• TRF scale and temporal variations | • TRF station positions and velocities<br>• TRF network densification | • TRF station positions and velocities<br>• TRF homogeneous network distribution |
| **Precise orbit determination** | | • Accurate satellite ephemerides<br>• Calibration and validation for remote sensing<br>• Sea-level monitoring | • Accurate satellite ephemerides<br>• Calibration and validation for remote sensing<br>• Sea-level monitoring | • Accurate satellite ephemerides<br>• Sea-level monitoring |
| **Earth Orientation Parameters (EOP)** | • Polar motion and rates<br>• UT1-UTC and long-term stability of nutation | • Polar motion and rates<br>• Length of day | • Polar motion and rates<br>• Length of day | • Polar motion and rates<br>• Length of day |
| **Gravity** | | • Static and time-varying coefficients of the gravity field<br>• Total Earth mass<br>• Temporal variations of network origin with respect to Earth centre of mass | | • Static and time-varying coefficients of the gravity field |
| **Timing** | | | • Station and satellite clock solutions<br>• Time and frequency transfer between time laboratories | |

Data source: Noll (2014)

# Appendix B: The Governance and Management Systems Related to Geodesy and Geospatial Data in Canada

In Canada, the operation and maintenance of geodetic infrastructure and the creation of geodetic products are carried out by government, academic, and commercial actors. One key body is the Canadian Geodetic Survey (CGS), which is situated within Natural Resources Canada (NRCan, 2023). NRCan is broadly mandated to oversee mapping, remote sensing, technical surveying, and emergency response through the *Department of Natural Resources Act* and the *Resources and Technical Surveys Act* (NRCan, 2025d). Federal, provincial, and territorial (FPT) collaboration in geomatics is guided by the Canadian Geomatics Accord, originally signed in 2002 and renewed in 2025 (CCOG, 2025). However, no legislative framework exists for "geomatics, spatial data infrastructure and related geospatial networks, coordinating bodies, and committees" writ large (NRCan, 2025d). The National Research Council of Canada (NRC) is responsible for maintaining and distributing official time in Canada; although this is not explicitly geodetic infrastructure, accurate timing is necessary for accurate positioning and vice versa (NRC, 2020) (Box 1.1).

CGS is specifically mandated by a 1909 Order-in-Council "to determine with the highest attainable accuracy the position of points throughout the country…" (PCO, 1909), which is accomplished through the provision of the Canadian Spatial Reference System (CSRS), alongside other related services (NRCan, 2024b, 2025d; Papadakis, 2025). The CSRS is "a collection of standards, models, data products and infrastructure supporting geospatial positioning in Canada. It includes the geometric, height and gravity reference systems" (NRCan, 2025a). Provincial agencies additionally provide geodetic products specific to their region (NRCan, 2025e; e.g., Gov. of BC, 2026).

Providing access to the reference frame is a shared responsibility, operationalized through the Canadian Geodetic Reference System Committee (CGRSC), a working group of the Canadian Council on Geomatics (CCOG) and comprised of FPT partners (CGRSC, 2025c; CCOG, n.d.). CCOG acts as a forum for the coordination of geomatics activities among FPT governments in Canada, to reduce duplication and ensure ready access to geospatial information (CCOG, n.d.). CCOG also facilitates discussions on active and proposed geomatics programming, potential legislation, opportunities for collaboration, national standards, and the sharing of successes and new ideas to be socialized among partners (CCOG, n.d.).

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