Reference System Modernization in Canada

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SUMMARY

The United States National Geodetic Survey (NGS), as part of its reference system modernization, is planning to adopt a new geometric reference frame for the U.S. in 2025, called the North American Terrestrial Reference Frame of 2022 (NATRF2022). This new reference frame will be based on ITRF2020 and separated from the North American Datum of 1983 (NAD83), the currently adopted frame in both Canada and the U.S., by up to 1.5 metres along the Canada-U.S. border. The Canadian Geodetic Survey (CGS) also plans to adopt NATRF2022 as a new national standard in parallel with U.S. adoption. NGS and CGS are collaborating to define and realise NATRF2022 to ensure reference frame compatibility across both countries. In parallel, CGS is leading an effort to adopt NATRF2022 as a unified reference frame across provincial and other Canadian jurisdictions, which have the authority to adopt reference systems used within their own jurisdictions. In this paper, we describe Canadian considerations for the definition and realisation of NATRF2022, and outline efforts and challenges in migrating to and maintaining NATRF2022 as a unified reference system throughout all jurisdictions in Canada. We will also discuss a new geoid-based height system called the North American-Pacific Geopotential Datum of 2022 (NAPGD2022), to be adopted by the U.S. together with NATRF2022, and its implications for Canada, where a geoid-based height system, the Canadian Geodetic Vertical Datum of 2013 (CGVD2013), has been in place since 2013.

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1. BACKGROUND

The U.S. National Geodetic Survey (NGS) is planning to modernize the National Spatial Reference System beginning in 2025. This includes replacing the existing North American Datum of 1983 (NAD83) with a new geometric reference system called the North American Terrestrial Reference Frame of 2022 or NATRF2022 (NGS, 2021a), and replacing the North American Vertical Datum of 1988 (NAVD 88) with a new geopotential vertical datum called the North American-Pacific Geopotential Datum of 2022 or NAPGD2022 (NGS, 2021b). Canada and the U.S. have collaborated on reference system definition and adoption for over a century and are continuing to collaborate on the definition of NATRF2022 and NAPGD2022. The goal for these modernized reference systems is to define and implement them in a way which serves the needs of both Canada and the U.S. in the current global digital geospatial economy, and well into the future as the need for more accurate, timely, and consistent positioning increases. This collaboration also ensures consistency along the Canada-U.S. border and increases the likelihood of these new systems being supported by the commercial geospatial software providers. This paper will focus on the Canadian implementation of NATRF2022 and an updated version of CGVD2013.

2. NATRF2022: AN IMPROVED GEOMETRIC REFERENCE SYSTEM

The current federally adopted geometric reference frame in Canada is NAD83(CSRS) v7. NAD83 is a plate-fixed reference system. However, it is offset from the centre of mass of the earth by approximately 2.2 metres, and it has a residual motion of approximately 2 mm/year with respect to the North American tectonic plate in Canada.

NATRF2022 will be aligned and equivalent to the International Terrestrial Reference Frame of 2020 (ITRF2020) at epoch 2020.0 (NGS, 2021a), and therefore will be a truly geocentric reference system that is more compatible with GNSS and modern applications such as automated transport and mass market positioning. Like NAD83, NATRF2022 will drift away from ITRF2020 to follow the motion of the North American Plate (Figure 1). This motion will be modelled by a rotation around an Euler pole, defined by an improved set of rotation parameters (NGS, 2022).

Since NATRF2022 is defined to be a geocentric reference system, removing the 2.2 metre non-geocentricity in NAD83, there will be horizontal differences of up to 1.5 metres between these reference systems across Canada (Figure 2). Since this 1.5 metre difference will impact many, if not most geospatial users, an important aspect of this reference system modernization

will be ensuring that stakeholders are aware of these changes and have the tools available to migrate their existing geospatial datasets to the new modernized reference systems.

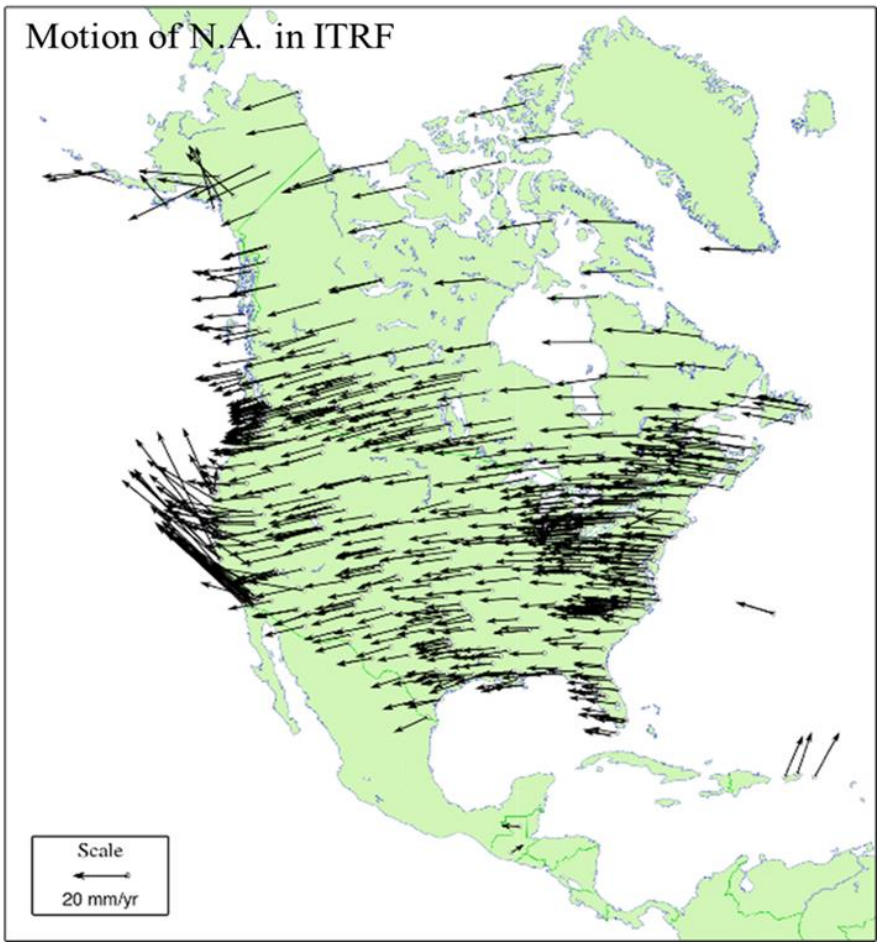

Figure 1: The motion of GNSS stations in North America, showing the rotation of the plate around an Euler pole off the west coast of South America.

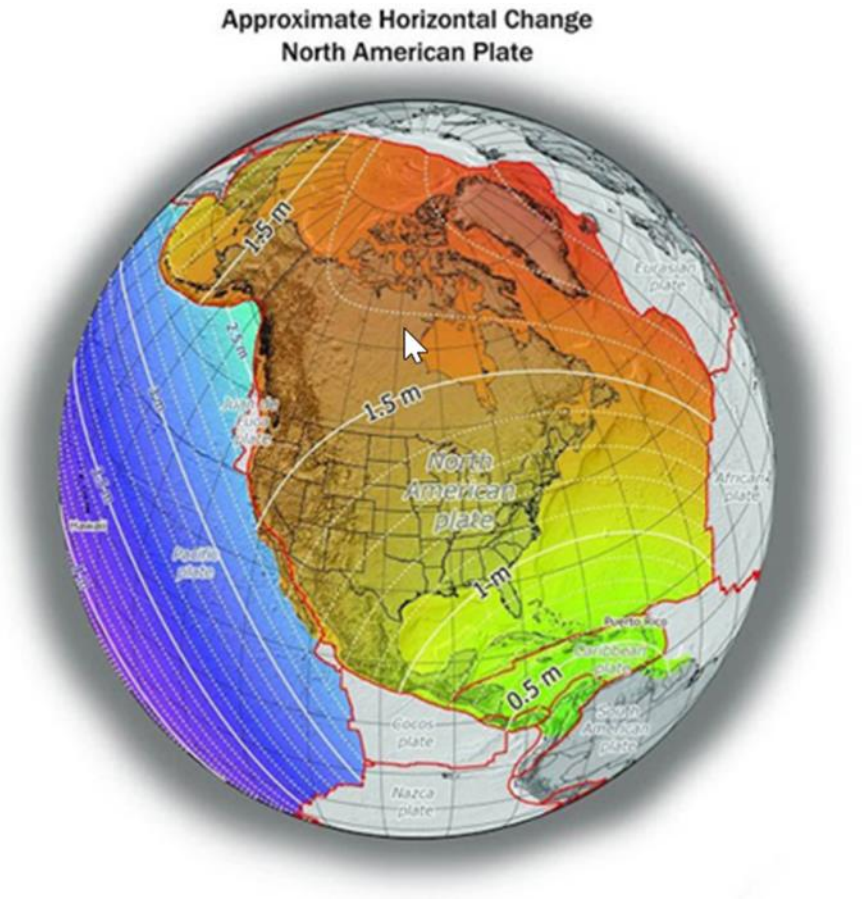

Figure 2: The approximate change in horizontal position between NAD83 and NATRF2022 will be up to 1.5 metres in Canada (NGS, 2021a).

3. NATRF2022: A DYNAMIC REFERENCE SYSTEM

NATRF2022 is defined as a dynamic reference system, meaning that coordinates change in time (NGS, 2021a). To model the change of coordinates in time, NATRF2022 will include an Intra-Frame Deformation Model (IFDM), to account for any residual and/or local motions within the plate-fixed reference frame. The IFDM can be used for propagating coordinates to different epochs. For Canada, this is not a major change since NAD83(CSRS) is already defined as a dynamic reference system and includes a national model of 3D crustal motion (CGS, 2022). Canadian users are therefore already experienced with managing epoch transformations (see section 5 below).

As part of its NATRF2022 adoption, Canada initially plans to adopt a similar IFDM model as our existing NAD83(CSRS) v7 Velocity Grid - NAD83v70VG (Figure 3), where a glacial isostatic adjustment (GIA) model is used to interpolate beween the sparse network of GNSS stations in northern Canada (CGS, 2022). Eventually, however, the IFDM is expected to include more complex dynamic motions (e.g., position offsets, seasonal signals, and post-

seismic deformations), and each country's implementation of this could be somewhat different. Outreach efforts, including discussions with geospatial software developers, has and will continue to emphasize the importance and challenges of using modern dynamic geometric reference systems.

Planning for the IFDM is still on-going, and although each country's implementation may be somewhat different, the plan is to have compatible models at the Canada-U.S. border.

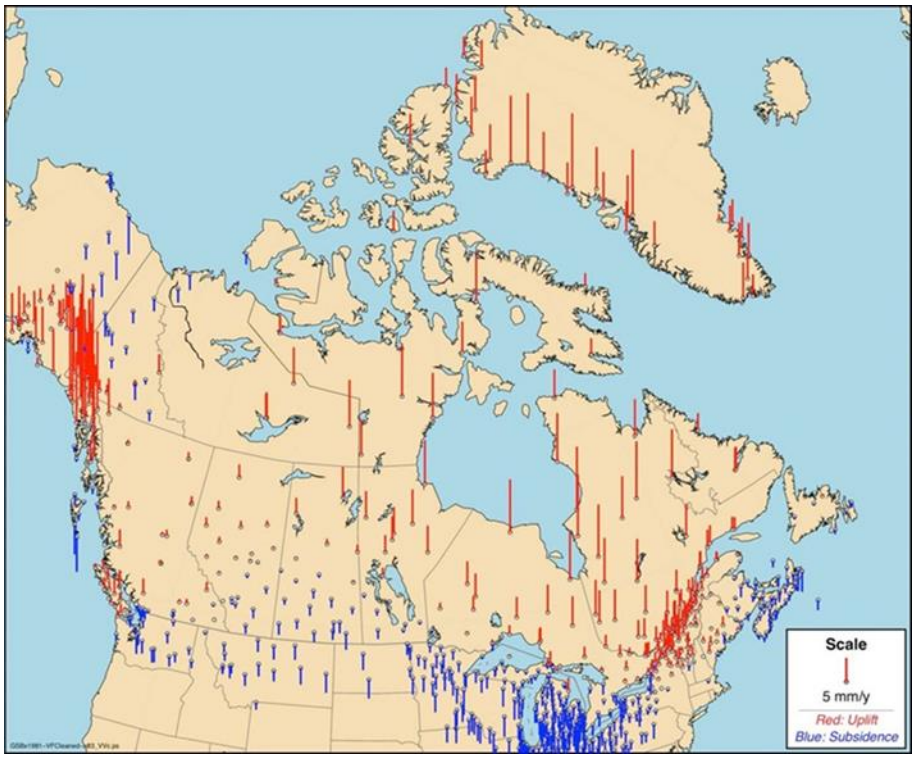

Figure 3: Observed vertical crustal motion as defined by the NAD83(CSRS) v7.0 crustal velocity model (Robin et al., 2020).

4. CGVD2013 / NAPGD2022: FOR CANADA, ONLY AN UPDATE

The current federally adopted height system for Canada is CGVD2013, which is realized by a gravimetric geoid model and is compatible with GNSS positioning. As part of their reference system modernization, the U.S. is also planning to adopt, for the first time, a geoid-based height system called NAPGD2022. Both CGVD2013 and the planned NAPGD2022 will be defined by the same equipotential surface W_0 = 62,636,856.0 m^2/s^2, which approximates the coastal MSL for North America and was agreed upon by CGS and NGS in 2012 (Véronneau and Huang, 2016).

CGS and NGS are also collaborating to develop a common geoid model for North America. They have released the first experimental combined models, called xGEOID20 models A and B, in 2022 (Wang et al., 2022). Figure 4 shows the geoid height differences between the CGSA and NGS BougA geoid models.

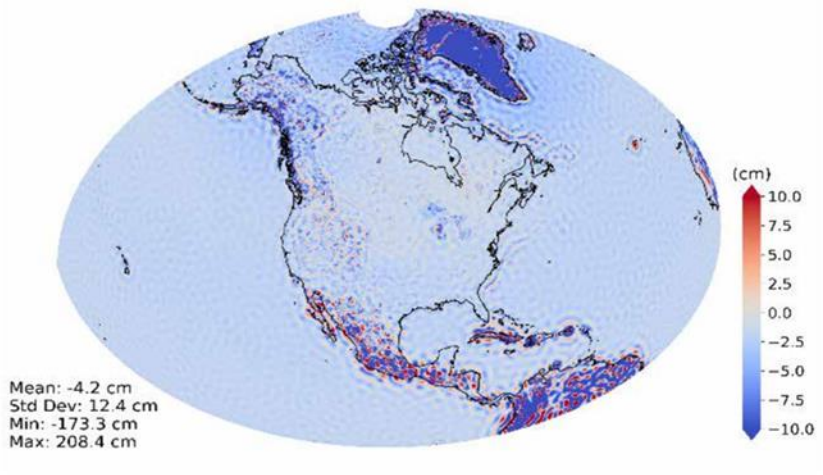

Figure 4: Geoid height differences between NGS and CGS models (CGSA minus BougA), performed as part of Experimental GEOID 2020 (Wang et al., 2022).

CGVD2013 is currently realized by the Canadian Gravimetric Geoid model of 2013 — Version A (CGG2013a). However, when the U.S. adopts NAPGD2022 in 2025, Canada plans to adopt an updated realization of CGVD2013, using an improved geoid model compatible with the one which will realize NAPGD2022. There will remain one difference between the NAPGD2022 and CGVD2013 implementations in 2025, as the U.S. is planning to also adopt a dynamic component to their geoid model (NGS, 2021b) while Canada does not (at least initially). The magnitude of this component is small, ranging from -2 mm to +1 mm per year across Canada. Therefore, based on client feedback, Canada decided not to initially include the dynamic component as part of the CSRS. Instead, CGS will update the adopted geoid model as needed and make the dynamic component available for scientific purposes only.

5. CGS TOOLS SUPPORTING THE MODERNIZED REFERENCE SYSTEM

To make it practical for geospatial professionals to work in new reference frames, tools will be needed to access the new frames, move from one frame to another, and from one epoch to another. CGS provides a suite of online tools and data products which allow users to access and work in the dynamic ITRF and NAD83(CSRS) geometric frames, as well as the CGVD2013 vertical datum. Prior to the 2025 adoption of NATRF2022, the NRCan tools and data products will be updated to support this new reference system. Table 1 provides a list of some of the more important CGS tools and data products which will be updated to support the modernized reference systems. Additionally, many geospatial users rely on commercial

and/or open-source software. To address these needs, CGS and NGS are holding discussions with geospatial software developers to ensure their products will support the migration to, and operation in, both NATRF2022 and NAPGD2022/CGVD2013. Additionally, CGS and NGS are committed to releasing their geodetic grids using a common and internationally recognized standard, such as the OGC's proposed GGXF format.

Table 1: CGS tools and data products supporting reference frame access and their required updates to support the modernized reference systems.

Tool/Product	Description	Required Update
CSRS-PPP	A service which allows users of GNSS to collect data in the field and upload to CGS. Within minutes, they receive an estimate of their geometric position(s), in either NAD83(CSRS) or ITRF; and their orthometric height(s) in either CGVD2013 or CGVD28; along with quality estimates and a report for visual quality control.	Support for NATRF2022 and the new realization of CGVD2013
TRX	A tool that supports the transformation of coordinates between NAD83(CSRS) and ITRF; and the propagation of NAD83(CSRS) or ITRF coordinates from one epoch to another using the national velocity grid.	Support for NATRF2022 and the updated IFDM
GPS-H	A tool that converts NAD83(CSRS) or ITRF ellipsoidal heights to orthometric heights in CGVD2013. Also converts between vertical datums.	Support for the updated realization of CGVD2013; support new standard geodetic grid format
Geoid Models	Gridded CGVD2013 geoid heights aligned to either NAD83(CSRS) or ITRF2008.	Support for updated realization of CGVD2013 aligned to NATRF2022; support new standard geodetic grid format
Transformation Parameters	Official transformation parameters between NAD83(CSRS) and ITRF realizations.	Provide official transformation parameters between NATRF2022 and NAD83(CSRS)/ITRF
Published coordinates and velocities for CACS stations	Online tool to access Canadian Active Control System (CACS) station coordinates, velocities, and uncertainties in either NAD83(CSRS) or ITRF, and at different epochs.	Publish coordinates and velocities in NATRF2022, support updated IFDM

National Velocity Model	3D grid of crustal motion in NAD83(CSRS) v7.	Support updated IFDM in NATRF2022, and new standard geodetic grid format
Commercial RTK compliance program	Program where interested commercial providers of precise positioning services share their data with CGS, who estimate and provide official NAD83(CSRS) v7 reference station coordinates.	Provide reference station coordinates in NATRF2022

6. UNIFIED REFERENCE FRAMES IN CANADA

In Canada, CGS has the mandate to define, maintain, and provide national scale access to the reference frame. However, delivering the reference frame, for example prescribing use or providing densified access, is a shared responsibility. This is managed collaboratively through the Canadian Geodetic Reference System Committee (CGRSC), a subcommittee of the Canada Council on Geomatics. The CGRSC is lead by CGS and has representation from federal and provincial government organizations which provide geodetic infrastructure and services.

CGRSC agencies, and in particular the provinces, have the mandate to adopt and regulate the use of a specific reference frame realization for their jurisdictions. For this reason, there are currently many different versions and epochs of NAD83(CSRS) adopted across Canada (Figure 5), and adoption has happened at different times (Figure 6). Since NAD83 was first adopted in Canada there has never been a time when all federal and provincial geodetic agencies were working in the same realization of the reference frame.

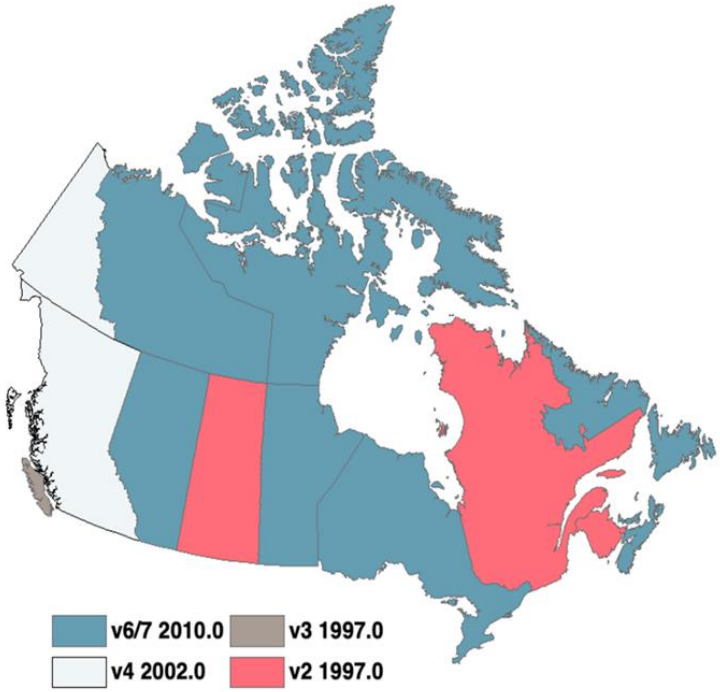

Figure 5: Versions and epochs of NAD83(CSRS) currently adopted in the provinces (updated from Erickson et al., 2019).

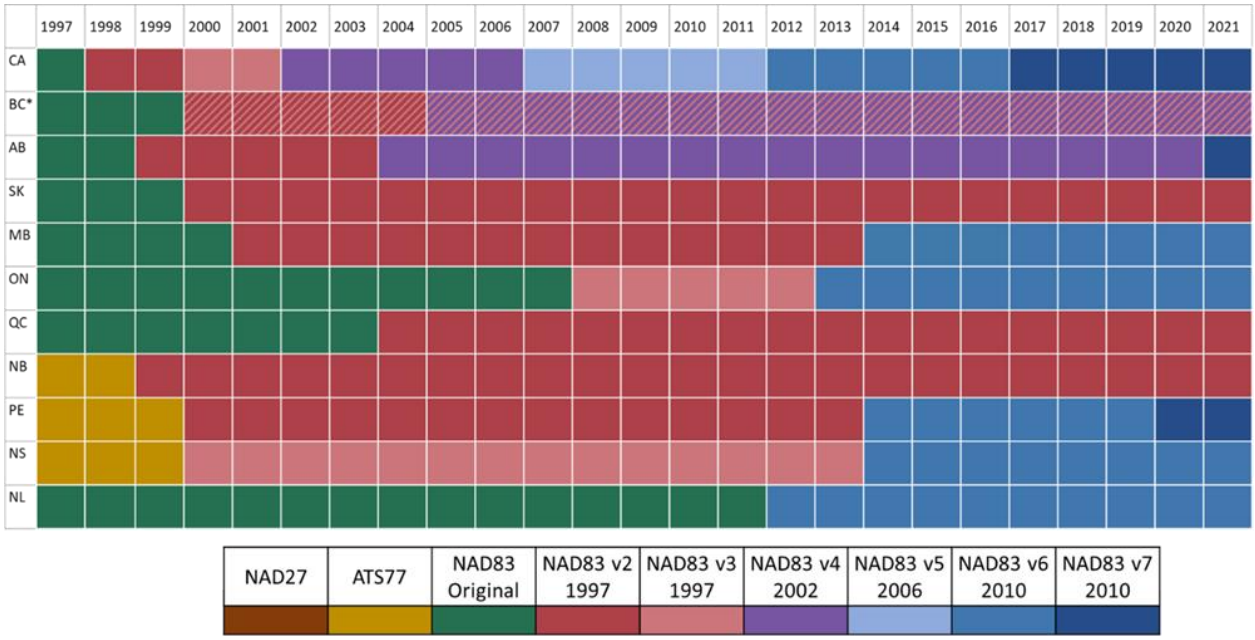

Figure 6: History of adoption of NAD83(CSRS) versions by Canadian provinces since its initial release.

Differences between the versions of NAD83(CSRS) are mostly due to using different reference epochs and can reach magnitudes of up to 20cm. These differences are not huge, and can be managed technically, but for many precise applications they can cause inefficiencies or, even worse, blunders. For example, many providers of precise positioning (e.g., network RTK services) in Canada are national or international in scale. The need to support different versions of the reference frame is inefficient and unnecessarily complicates projects spanning jurisdictions. A similar scattered approach to the adoption of NATRF2022 will give rise to 1.5 metre differences at jurisdictional boundaries, leading to even greater inefficiencies, and possibly blunders an order of a magnitude larger in the future. Similarly, some provinces have not yet adopted CGVD2013, and are defining strategies to adopt the new version being realized in 2025.

The CGRSC members see the adoption of NATRF2022 and CGVD2013 as an opportunity to not only modernize the national reference frame, but also to unify reference frames across Canada. The CGRSC has developed a roadmap towards a nationally coordinated adoption of NATRF2022. This roadmap was developed to highlight and track the key components of the project which were broadly grouped under: analysis, outreach, and implementation. Most of the effort to date has been towards the analysis phase which includes:

- A review of geodetic capacity in the various jurisdictions,
- Identifying the regulatory requirements which would need to be updated,
- Developing jurisdictional strategies for migrating official/published coordinates and data layers to these new datums,
- Stakeholder outreach, primarily for professional surveying associations and geodetic agencies, and
- Identifying any commercial software requirements.

Much work remains towards a unified adoption of NATRF2022 and CGVD2013 in Canada, but through the CGRSC a plan is being developed. The biggest challenge will be securing the required resources and expertise to adopt and maintain unified reference frames across all jurisdictions.

7. SUMMARY

Canada will adopt NATRF2022 and an updated realization of CGVD2013 at the federal level in 2025 in parallel with the U.S. adoption of NATRF2022/NAPGD2022. NATRF2022 will be a fully dynamic datum as NAD83(CSRS) has been since 2006 (Figure 7). The new realization of CGVD2013, will be based on an improved static geoid model, compatible with the one which will realize the planned U.S. height system NAPGD2022.

CGS and NGS are collaborating on defining the new datums, ensuring they will be compatible across the border, agreeing on new standards for geodetic gridded data, and

ensuring that users have the data, tools, and services needed to migrate to these new or updated reference systems.

The biggest challenge in Canada will be to adopt and maintain a modernized, unified reference system across all jurisdictions. Federal and provincial geodetic agencies are working together within the CGRSC to build a plan to adopt NATRF2022 and CGVD2013 with the aim of unifying mandated reference frame usage across the country.

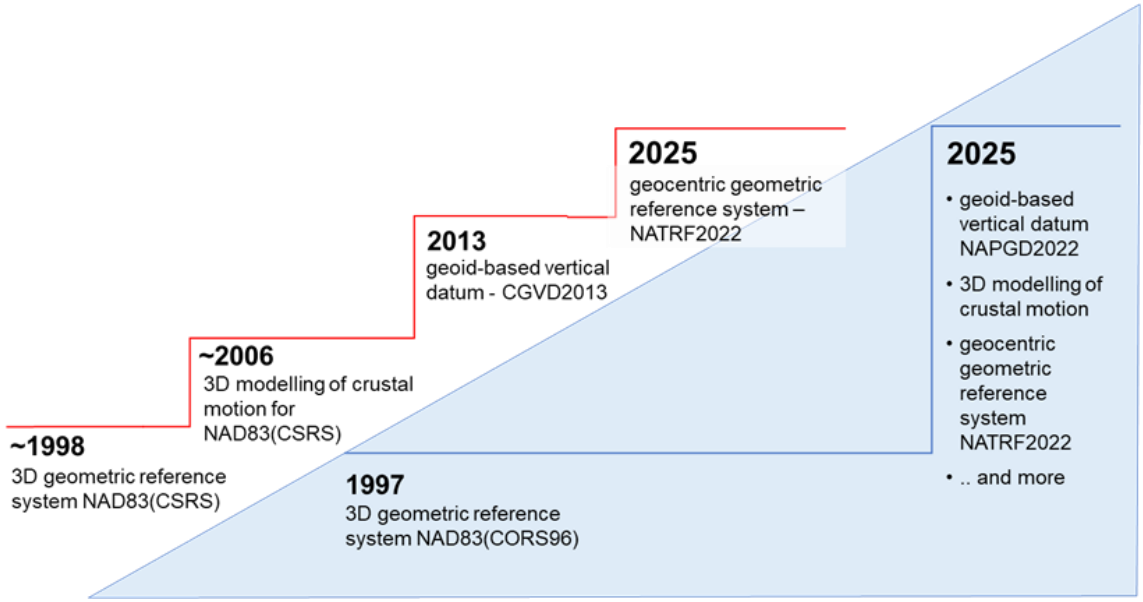

Figure 7: Canada has been modernizing in steps, whereas the U.S. is modernizing all at once (diagram is for illustration and is not comprehensive).

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