The U.S. is replacing NAD83 with NATRF2022: what this means for Canada

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Abstract: In 2022, the U.S., as part of its reference system modernization, will replace its North American Datum of 1983 (NAD83) with a new North America Terrestrial Reference Frame (NATRF2022), creating 1.3 to 1.5 m horizontal coordinate differences at the Canada—U.S. border with respect to Canada’s NAD83(CSRS). Never before have such significant differences existed between our two countries’ reference frames. This paper reviews why the U.S. is making this change and then looks at Canada’s situation with respect to reference frames. There are compelling reasons for Canada to follow suit and move to NATRF2022 within a decade, but there are also major challenges. Whether or not Canada follows the same path, there is much work to be done to prepare Canada for the U.S.’ move to NATRF2022. This paper is intended as a first step to inform the Canadian geospatial community of the U.S.’ move to NATRF2022 and what it means for Canada.

Key words: NATRF, NAD83, Reference frame, CSRS, GNSS


Introduction

The Canadian Geodetic Survey (CGS) and the U.S. National Geodetic Survey (NGS) have collaborated for more than a century providing the fundamental reference system for latitude, longitude, and height within their respective countries, thus providing the basis for mapping, engineering works, and other activities where position matters. The science and technology available for determining one’s position has improved dramatically over this time and continues to improve, driving associated demands of the underlying reference system. Canada and the U.S. have made significant improvements to realizations of the North American Datum of 1983 (NAD83), their reference system for horizontal positioning, while still maintaining compatibility with each other. This means it is easy for users to work with geospatial data that stretches into both countries (e.g., a Canadian map crossing into the U.S. or vice versa would be seamless since they would be based on the same reference system). This is about to change.

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In 2022, the U.S., as part of its geodetic reference system modernization, will replace NAD83 with the new North American Terrestrial Reference Frame of 2022 (NATRF2022), resulting in 3D coordinate changes of up to 2 m. Along the Canada—U.S. boundary, horizontal differences will range from 1.3 to 1.5 m as illustrated in Fig. 1. Never before have such significant differences existed between the Canadian and U.S. reference frames.

Fig. 1 – Approximate horizontal (left) and vertical (right) coordinate difference between NAD83 and NATRF2022. Based on original figures from National Geodetic Survey (2019b).

What will this mean for users? Suppose someone is positioning in Canada using GNSS (Global Navigation Satellite System) in real-time and continues positioning after crossing the border. Once in the U.S., their coordinates will be wrong by over a metre with respect to the adopted NATRF2022 in the U.S. With an awareness and understanding of the reference system in use and having the correct metadata and transformation to account for this, the difference can be readily handled from a technical perspective. The challenge will be to manage this, and ensure users are aware of it. Thus, it is worth reviewing the reasons the U.S. is making this change, Canada’s situation, and our future direction.
Background

A bit of background on the evolution of NAD83 is needed to understand some of the U.S.’ rationale for moving to NATRF2022. For a comprehensive coverage of NAD83, see Craymer (2006). In the 1990s, it was realized that NAD83 was not geocentric but, rather, was offset by 2.2 m. Around the same time, advances were happening at the international level. Positioning and geodesy are very much dependent on collaboration amongst countries from around the world, as global observations are needed to understand the size and the shape of the Earth and to position ourselves upon it. In 1992, the International Association of Geodesy (IAG) adopted a resolution, which included the following two recommendations (IAG 1992):

“1) that groups making highly accurate geodetic, geodynamic or oceanographic analysis should either use ITRF directly or carefully tie their own systems to it”

“4) that for high accuracy in continental areas, a system moving with a rigid (tectonic) plate may be used to eliminate unnecessary velocities provided it coincides with the ITRS at a specific epoch.”

Abiding with this resolution, Canada and the U.S. redefined NAD83 in relation to the International Terrestrial Reference Frame (ITRF) through a seven-parameter transformation and kept it aligned to the North American plate by using the NUVEL-1A estimate of plate motion. Canada’s revised reference system was named NAD83(CSRS), where CSRS stands for the Canadian Spatial Reference System. Unlike the traditional NAD83 [now known as NAD83(Original)], which was defined in terms of horizontal coordinates of physical monuments in the ground called control points, NAD83(CSRS) is a fully three-dimensional system (latitude, longitude, and ellipsoidal height) but its origin is still offset by 2.2 m from the Earth’s true geocentre. Because NAD83(CSRS) is defined in relation to ITRF through a relatively simple mathematical transformation, users can now determine their 3D positions using precise point positioning (PPP) without the need to occupy control points (Héroux et al. 2006).

Modernization of the National Spatial Reference System within the U.S.

About two decades later, the U.S. NGS launched its plan to improve the U.S. National Spatial Reference System (NSRS) and has since detailed these plans in three blueprint documents (NGS 2017a, NGS 2017b, NGS 2019a). The plan includes replacing NAD83 with the new NATRF2022 and replacing their North American Vertical Datum of 1988 (NAVD 88) with a new North American-Pacific Geopotential Datum of 2022 (NAPGD2022).

The U.S.’ key driver for replacing NAD83 with NATRF is well conveyed by Smith (2010):

“The future of positioning is GNSS. The underlying reference frames for all GNSS systems are geocentric.”

“...technology is changing so fast that soon stand-alone GNSS users will have access to inexpensive multi-constellation positioning devices that can achieve sub-meter accuracy. As this happens, a horizontal discrepancy in the national datum up to two meters will cause a variety of difficulties. For example, maps of roads in the USA may have NAD 83 coordinates, but personal navigation units work in WGS 84 (whose origin is geocentric to within a few centimeters) ... Under such a scenario, comparing WGS 84 coordinates of the car to NAD 83 coordinates of the
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mapped roads will mean up to 2 meters of error that could cause incorrect lane
determinations.”

“It is impractical to assume that the appropriate datum transformation would be coded
accurately in every personal handheld positioning device to correct for this ... Even today there
persists software which treats WGS 84 as equivalent to NAD 83. Rather than risk life and
property to such misunderstandings, NGS feels that a geocentric datum is the best approach.”

Even higher stand-alone accuracy than described by Smith has been demonstrated by Laurichesse and
Banville (2018) in “Instantaneous centimeter-level multi-frequency precise point positioning”, driving
associated demands of the underlying reference system.

The U.S.’ plan to replace NAVD 88 with NAPGD2022 for its vertical datum is motivated by the “fragile,
inaccurate, and rapidly deteriorating” network of vertical control points used to access NAVD 88 (Smith 2010). Canada shared similar motivation when it modernized its height system in 2013 to one that
would “allow users of space-based positioning technologies access to an accurate and uniform vertical
datum everywhere across the Canadian landmass and surrounding oceans” (Véronneau et al, 2006). The
Canadian Geodetic Vertical Datum of 2013 (CGVD2013), a GNSS-compatible height system, replaced the
traditional levelling-based Canadian Geodetic Vertical Datum of 1928 (CGVD28). See Véronneau and
Huang (2016) and Huang and Véronneau (2013) for more information on CGVD2013, its definition, and
adoption. In fact, when the US adopts NAPGD2022, it will be moving to the same height system as
CGVD2013. The only difference may be its name.

Canada’s situation

This brings us to our current situation in Canada. In this description, we use the terms reference system
and reference frame, where “reference system” is a theoretical concept that is defined by a set of
parameters and conventions and “reference frame” is the concrete realization of a reference system
(Petit and Luzum, 2010; Thériault, 2010). In nomenclature, when we describe frames, the name includes
both the system and the frame.

Canada’s current geometric and height reference frames respectively are as follows:

- NAD83(CSRS) version 7 epoch 2010.0
- CGVD2013(CGG2013A), where CGG is the Canadian Gravimetric Geoid

Positions change with time due to motions of the Earth’s surface (crust). Although NAD83(CSRS)
accounts for the overall motion of the North American tectonic plate (about 2 cm per year), the
remaining changes within Canada can still reach about 1 cm per year. Over time these changes can
accumulate to become quite significant. Terrestrial reference frames and GNSS are so accurate now that
such crustal motions are easily measurable. Therefore, we must consider the epoch (i.e., date) when
working with coordinates. In Canada, full three-dimensional models of crustal motions have been in use
for many years. At the international level, new ITRF realizations are periodically released as more data
and improved modelling become available. For each ITRF release, CGS has collaborated with the U.S. to
update the transformation to NAD83 and update the epoch. CGS has then computed the best
coordinates for that epoch, updated the crustal model, and released a new NAD83(CSRS) version and
epoch. Information about current frames for NAD83(CSRS) and CGVD2013 and related reference system tools, data, and coordinates are available from the Canadian Geodetic Survey website (Natural Resources Canada 2019).

In the U.S., such time dependency has not been fully implemented with NAD83. Only the time dependency of horizontal coordinates have been modelled. The U.S. is addressing this as part of their modernization plan.

Canada faces a challenge not experienced by the U.S., related to the governance of reference frames. In the U.S., definition and adoption of reference frames for the entire country resides at the federal level, with the U.S. NGS. In Canada, although definition of the reference frame resides at the federal level with CGS, the adoption for use is a provincial responsibility. Over time, this has resulted in a situation where provinces are now using different versions and epochs of NAD83(CSRS), as shown in Fig. 2. This can cause confusion not only for users, but also for commercial providers of positioning services working in more than one province. The province to province coordinate differences between different NAD83(CSRS) versions and epochs can range up to several centimetres and need to be properly addressed. Although not as large as the differences between NAD83(CSRS) and NATRF2022, they are still significant.

Adding to the challenge, is a shortage or lack of geodetic capacity in provinces and territories across Canada (Natural Resources Canada, 2018). There are limited resources to manage reference systems across the country, let alone implement any changes.

**Fig. 2:** NAD83(CSRS) versions adopted in Canada as of September 2019. Year indicates the reference epoch associated with the coordinates. The base map is from ©OpenStreetMap contributors.
While developing Canada’s strategy to address the upcoming changes to the U.S. National Spatial Reference System and in particular their adoption of NATRF2022, we also have the opportunity to address our own challenges and develop a means for delivering and maintaining a unified reference system throughout Canada.

**Considerations**

There are many considerations regarding Canada’s future direction related to NATRF2022. If we adopt NATRF2022 throughout Canada, GNSS users would be directly compatible with reference systems used by GNSS (i.e., ITRF, WGS84, PZ-90) and all positioning in Canada and the U.S would be with respect to the same system — supporting up to centimetre accuracy. This in turn would result in the following:

- autonomous vehicles and drones utilizing a common system throughout Canada and the U.S.;
- cross-border projects such as transportation infrastructure, watershed management, and pipelines, seamlessly working with geospatial data;
- GNSS and geospatial service providers offering consistent services across Canada and the U.S.;
- general users of GNSS and geospatial data experiencing heightened data compatibility and accuracy.

Together these would strengthen Canada’s role in the geospatial digital economy and in management of our environment and climate adaptation.

There would also be the following challenges in the adoption of NATRF2022:

- in the short term, there could be added confusion during the transition;
- for many users at present, their concern is local relative accuracy and the current system is serving their needs, and therefore, they may not be motivated to change;
- the cost and resources to convert some datasets (especially non-digital ones) can be very significant.

In addressing the implications of NGS’ modernization plan, we are not starting from zero. Since 2010, CGS has collaborated with NGS towards the development and implementation of a 4D (latitude, longitude, ellipsoidal height, and time) spatial reference system for North America comprised of NATRF2022 and NAPGD2022 and, in doing so, has promoted standards applicable for the entire continent. For instance, it was through this collaboration that the geopotential surface used for defining NAPGD2022 is the same as that used in CGVD2013. CGS is also working to develop the tools needed to transform between NAD83(CSRS) and NATRF2022. However, these are small initial steps in light of the breadth and significance that the U.S.’ move to NATRF2022 will have on Canada.

**Next steps**

Considering the current situation, there are strong, compelling reasons for moving to NATRF2022 in Canada within a decade. It is part of ensuring Canada’s reference system will be ready for centimetre positioning by everyone, everywhere. At the same time, it is recognized that such a change would require major cost and efforts for those working with geospatial data across the country.
Whether or not Canada follows suit and moves to NATRF2022, there is mandatory work that needs to be carried out within geodetic communities across the country, communicating and developing the technical tools needed to support positioning once the U.S. moves to NATRF2022.

Canada has a forum for federal-provincial collaboration related to Canadian reference systems. The Canadian Geodetic Reference System Committee (CGRSC) is a working group of the Canadian Council of Geomatics (CCOG) that “plans and coordinates maintenance and improvement of the Geodetic Reference System in Canada as a standard for the positioning of geographically referenced information related to the Canadian landmass and territorial waters” (CGRSC 1995, 2019). This paper is intended as a first step to inform the public of the coming U.S. reference frame changes and what they mean for Canada. We welcome your comments. They may be addressed to the CGRSC at feedback-commentaires@cgrsc.ca.

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References


