Canada's New Vertical Datum

By Philippe Lamothe, Marc Véronneau, Morgan Goadsby and Ron Berg

Introduction

What is height modernisation? Height modernisation is the introduction of a new vertical datum for Canada, compatible with modern positioning technologies. In November 2013, the Geodetic Survey Division (GSD) of Natural Resources Canada (NRCan) will nationally release the Canadian Geodetic Vertical Datum of 2013 (CGVD2013). This new vertical datum will progressively replace the current Canadian Geodetic Vertical Datum of 1928 (CGVD28) adopted by a federal Order in Council in 1935. The national release of CGVD2013 brings three very important changes. First, the new vertical datum will be defined by an equipotential surface and not by mean sea level at specified tide gauges. Second, it will be realized by integrating gravity data instead of adjusting a network of levelling lines. And third, the vertical datum will be accessible throughout Canada using a geoid model instead of a network of benchmarks with published elevations. But most importantly, CGVD2013 will be compatible with Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS).

Transition from CGVD28 to CGVD2013

The levelling technique has served the Geodetic Survey of Canada well over the last century in establishing a precise national vertical datum. The technique has barely changed over the years. Naturally, instrumentation has improved and improvements such as motorized levelling and digital instruments have been introduced, but levelling still remains a time consuming method that is cost effective only over short distances. It still requires measuring the height difference between two graduated rods that are about 100 metres apart, making the technique prone to systematic errors, especially when the vertical datum extends across a country as large as Canada.

Over the last 100 years, more than 80,000 federal first-order benchmarks have been installed across Canada on some 160,000 km of levelling lines. The benchmarks are located mostly along major roads and railways in the southern half of the country, meaning that most of Northern Canada's established benchmarks are not tied to CGVD28. Today, many of these benchmarks are destroyed or could be considered unreliable as they have not been surveyed for many decades.

CGVD28 was defined by mean sea level at five tide gauges: Yarmouth and Halifax on the Atlantic Ocean, Pointe-Au-Père on the St-Lawrence River, and Vancouver and Prince Rupert on the Pacific Ocean. In addition, the establishment of CGVD28 included the set elevation of a benchmark in Rouses Point, New York (next to Lake Champlain) accepted as fixed by the US and Canada in March 1925. By constraining CGVD28 to sea level on the east and west coasts, the assumption was made that the Pacific and Atlantic oceans at the gauges were at the same zero elevation. In fact, this is not the case. The Pacific Ocean near Vancouver is about 55 cm higher than the Atlantic Ocean near Halifax. This incorrect assumption, as well as other systematic errors (e.g. inaccurate gravity data, vertical crustal motion), has created distortions in the datum. These contribute long wavelength errors in CGVD28 that range from approximately -65 cm to +50 cm across Canada.

The alternative approach to spirit levelling for the realization of a vertical datum is geoid modelling. If the two approaches were errorless, they would define the same datum. A vertical datum realized with spirit levelling only provides height values at benchmark locations. On the other hand, the geoid model is realized in relation to an ellipsoid (e.g. GRS80) and represents a continuous surface known everywhere across the Canadian territory. This allows for complete national coverage and compatibility with GNSS.

Thanks to GNSS, users can recover heights with respect to an ellipsoid with centimetre accuracy at any location. However, a height above an ellipsoid does not have any physical meaning as water could flow from a lower ellipsoidal height to a higher ellipsoidal height. For meaningful elevations, the GNSS ellipsoidal heights must be converted to orthometric heights. This is done through the use of a geoid model which gives geoid heights, that is, the separation between the ellipsoid and geoid as shown on Figure 1. The geoid height (N) establishes the connection between ellipsoidal height (h), which can be obtained by GNSS, and the orthometric height (H): $H = h - N$.

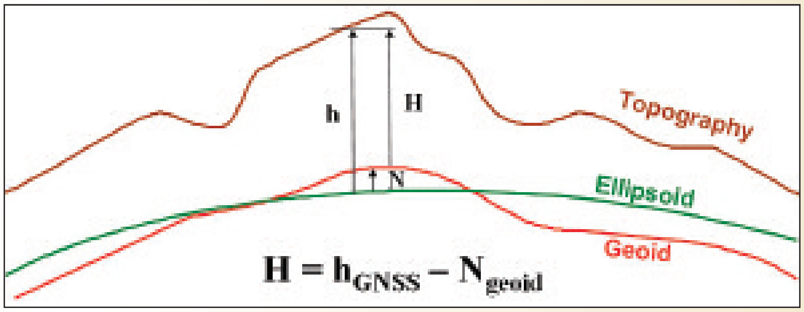

Figure 1: The orthometric height (H) is the separation between the geoid and topography. It is determined by the difference between the ellipsoidal height (h), measured by GNSS, and the geoid height (N), interpolated from a geoid model. An orthometric height difference (ΔH) can also be determined by levelling technique.

Thus, the application of the geoid model for height determination involves a simple subtraction, as long as the

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ellipsoidal heights and geoid heights are in the same reference frame (e.g. NAD83(CSRS)).

As for the accuracy of the geoid model (or calculated orthometric heights), this is determined through analysis of error propagation in the modelling. The current published geoid model, the Canadian Gravimetric Geoid model of 2010 (CGG2010), has an absolute accuracy of 2 cm for most regions outside the Western Cordillera at the 67% confidence interval, or 1 sigma. In rough terrain, the accuracy approaches a decimetre. The relative precision of the geoid model is generally 1 to 2 cm for baselines as long as 100 km, even in the Rocky Mountains. The forthcoming geoid model, CGG2013, which realizes the new vertical datum CGVD2013, will be published with an uncertainty model that estimates its absolute accuracy with respect to the reference equipotential surface. The current precision and accuracy of the geoid model can support most of our national height referencing requirements.

Monumented height network in CGVD2013

CGVD28 will continue to co-exist with CGVD2013, but NRCan will no longer maintain the network of first-order benchmarks, which have already started to deteriorate over the last 20 years. The national monumented network for heights, at the highest level, now consists of the stations forming the Canadian Active Control System (CACS) and the Canadian Base Network (CBN). Densification is provided by the provincial High Precision Networks (HPN) and Real Time Networks (RTN) from public and private providers. In Ontario, the Ontario High Precision Network (OHPN) now consists of over 7,500 stations related to the NAD83(CSRS) epoch 2010.0 realization. Both OHPN station data and private sector RTN station data are available through the provincial geodetic database known as COSINE (COntrol Survey INformation Exchange) provided by the Ontario Ministry of Natural Resource (MNR).

CGVD2013 heights of existing NRCan primary first-order benchmarks will be published alongside the old CGVD28 heights. This requires an overall readjustment of the levelling networks. It should be noted however that the historic levelling observations have their limitations and the new adjustment will not account for or correct for benchmark instability, nor for changes in the Earth's crust (uplift/subsidence) that affect the accuracy of individual benchmark heights. The availability of heights referenced to the new datum for the existing network will greatly facilitate the transition to the new datum. To help ease the potential burden associated with moving information to a new datum, NRCan will provide transformation and other software tools to support the conversion of existing data sets from CGVD28 to the new datum. These tools will be discussed in more detail below.

MNR will be establishing the Height Modernisation Working Group in Ontario this fall. This Working Group will include representatives from MNR, Ministry of Transportation Ontario (MTO), other provincial government ministries, Ontario municipalities and Conservation Ontario (which represents Conservation Authorities within Ontario). The Ontario Height Modernisation Working Group will look at the specific needs of Ontario regarding:

- Potential readjustment of secondary and tertiary levelling networks on the new CGVD2013,
- Planned transition to the new vertical datum in Ontario, including timing, communication to user community and duration of the maintenance of the former datum, and
- Tools or resources needed to meet the specific needs of Ontario users.

In anticipation of a potential future vertical readjustment in Ontario, MNR and MTO have begun reviewing existing provincial secondary and tertiary levelling networks for quality and consistency, and will determine the availability of the appropriate digital data for readjustment.

Data impacts

The implementation of CGVD2013 corrects for the distortions in CGVD28 that range from -65 cm and +55 cm. The largest absolute changes will be in the Maritimes where the new datum will be higher by 65 cm, meaning lower elevations for the region. In the Rocky Mountains, the datum will be lower by 50 cm, meaning higher elevations. Figure 2 shows the changes for Ontario.

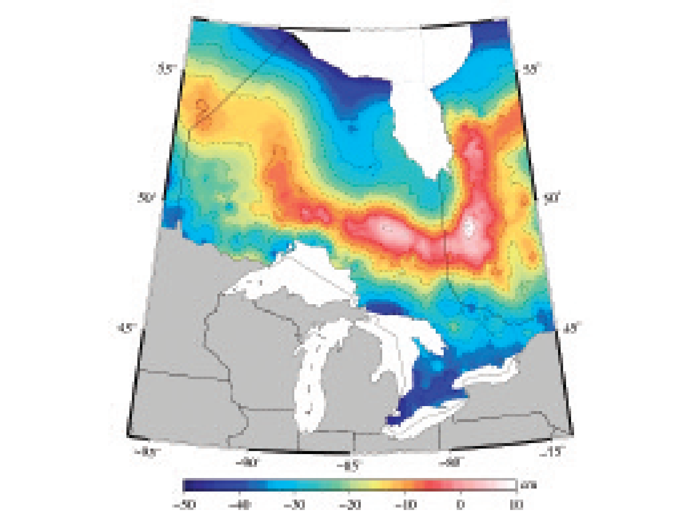

Figure 2: The separation between CGVD28 and CGVD2013 in Ontario: HTv2.0 - CGG2010 (W_0 = 62,636,856.0 m^2s^{-2}). Contour interval: 5 cm.

The zero elevation is the equipotential surface (W_0 = 62,636,856.0 m^2s^{-2}), which represents the coastal mean sea level for North America. The selection comes from an agreement between the Geodetic Survey Division of Natural Resources Canada and the US National Geodetic Survey. This potential value also coincides with the value already adopted in conventions by two international scientific organisations to represent the global mean sea level. The agreed upon surface between Canada and USA lies below the coastal Pacific sea level (near Vancouver) by 17 cm and above the coastal Atlantic Sea level (near Halifax) by 38 cm. This means that the eastern coastline in the area of Halifax will have a negative elevation of -38 cm while the western coastline for the area of Vancouver will have a positive elevation of 17 cm.

The Canadian coastline does not have a zero elevation because the ocean, like land, has a permanent topography not directly associated with gravity. It is referred to as the Dynamic Ocean Topography or Sea Surface Topography. Globally, the Dynamic Ocean Topography ranges roughly from -1.5 metres to 1.5 metres in reference to the geoid, which is truly a level surface.

The impact of these differences on users will depend on the required accuracy, location and size of their project. There are three main categories of users. The first category comprises those who require CGVD28 heights with a few metres of accuracy (e.g. digital elevation model). In this case, the difference between CGVD28 and CGVD2013 can be neglected. Those who require precision of less than 10 centimetres along corridors of tens of kilometres (e.g. LiDAR survey) make up the second category. For these users the difference between CGVD28 and CGVD2013 must be considered. Lastly, the third category represents those who transfer heights with precision of less than 2 cm over small regions (e.g. municipal infrastructure). For these users the difference between CGVD28 and CGVD2013 should be considered, but generally applying a constant offset will suffice.

Ontario professional land surveyors should also play a substantial role in mitigating the impact of the new vertical datum by providing appropriate advice and expertise to their clients and stakeholders.

Conversion tools

If you are using NRCan primary first order benchmarks established by levelling, you can continue to do so for the time being as the benchmarks, even though they are not maintained, will still be available. The only difference is that the GSD website database will provide two heights at each benchmark: a CGVD28 elevation and a CGVD2013 elevation. The easiest approach for conversion will be to make use of a grid reflecting the difference between CGG2013 (realization of CGVD2013) and HTv2.0 (which represents CGVD28) - see Figure 2. The limited precision of the conversion should be carefully considered in view of user requirements. Ultimately, for the highest accuracy conversions, the best approach is to conduct GNSS surveys on benchmarks.

GNSS users can install their own benchmarks, on demand and at a location that is practical for them. They can then proceed with a local survey by levelling or using the GNSS technique. The following approaches can be used to determine the ellipsoidal heights of new benchmarks:

- Submit RINEX files to NRCan's CSRS - Precise Point Positioning (PPP) software to obtain coordinates (latitude, longitude, ellipsoidal and orthometric heights) for your GNSS based control;
- Perform differential GNSS with respect to Active Control Points, stations of the Canadian Base Network or provincial High Precision Network or any other stations with a precise ellipsoidal height in NAD83(CSRS); and
- Perform a Real Time Kinematic (RTK) survey using corrections from public or private providers with reference stations integrated into NAD83(CSRS).

Thus, there are several options for determining ellipsoidal heights. Once you have established your GNSS heights, it is only a question of subtracting the geoid height from the geoid model CGG2013 instead of any previous models that you used. By doing so, you will immediately be in the new vertical reference system for Canada, a system which may become seamless across North America in the future.

On-line and stand-alone applications are available on the NRCan website to help with this transition. GPS-H can be used to convert ellipsoidal heights to orthometric heights. It enables the use of any geoid model and works with different types of coordinate systems (geographic, UTM, MTM, and Cartesian) and different geometric reference frames (NAD83(CSRS) and ITRF). Also available is TRX, new software that transforms coordinates between different geometric reference frames, epochs and coordinate systems.

Conclusion

NRCan will nationally release a new vertical datum in November 2013, called the Canadian Geodetic Vertical Datum of 2013 (CGVD2013) that is realized by a geoid model compatible with the GNSS positioning technique. This new vertical datum will provide national coverage. It must be emphasized that CGVD28 will continue to co-exist during a transition period, but NRCan will no longer maintain the primary first-order levelling networks. However, this is not the end of spirit levelling as the technique of choice for many local surveying projects. The difference between CGVD2013 and CGVD28 will range between -65 cm and +55 cm and has a long wavelength pattern.

NRCan's existing monumented first-order levelling network will be readjusted by constraining it to orthometric heights derived from ellipsoidal and geoid heights at selected sites across Canada. The adjustment will make use of historical levelling data. Local height differences will maintain the same relative precision of a few millimetres (assuming the benchmarks are stable), but country-wide these values will change as indicated by the range above. NRCan will be providing on-line and stand-alone tools to ease the adoption of a modernized height system. Further information can be found at: http://webapp.geod.nrcan.gc.ca/geod/.

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Summer 2013 Article Update

In the article "Correcting Errors in Registered Reference Plans", published in the Ontario Professional Surveyor, Volume 56, No. 3, Summer 2013, Frank Bowman and Christina Porretta wrote about a recent Ontario Court of Appeal decision in *MacIsaac v. Salo*. That case provides surveyors with a mechanism for correcting mistakes relating to boundaries in parcel registers. It also held that only an up-to-date survey can confirm the location of the boundaries of a parcel of land as they exist on the ground. The application filed by the defendant Salos for leave to the Supreme Court of Canada was dismissed in its entirety on August 15, 2013. Therefore, the Court of Appeal's decision stands as the most current law in Ontario regarding rectification of a reference plan.