Dealing With Distortion in NAD83 (Original)

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Where Does the Distortion Come From?

GPS positioning has allowed surveyors to make accurate measurements over long distances with minimal error propagation. Additional redundancy possible with GPS control scenarios allows for easier blunder detection. This contrasts with classical control techniques that are characterized by error propagation: each set of observations between existing control points relies on the results of a previous set or sets of observations. The errors that accumulate in classical control methods can include undetected blunder and systematic error. These can be pronounced in a long chain of observations.

The existing primary network in Canada was recomputed as part of the North American Datum 1983 (NAD83), a reference system based on BIH Terrestrial System 1984 (BIH84) and using the GRS80 ellipsoid parameters. Later, this framework was densified using existing classical measurements - those that had formed part of NAD27 and subsequent measurements.

One advantage of NAD83 is that transformation parameters are maintained which relate key points in the datum to the International Terrestrial Reference Frame (ITRF) which in turn can be related to WGS84, the reference frame for GPS. This allows the use of GPS positioning techniques for surveying in NAD83.

The primary disadvantage of NAD83 (Original) is that the errors propagated by older classical measurements have led to widespread distortion between framework points in the datum. These distortions may have only minimal effect locally as points from the same network that are in close proximity often *relate* to one another with minimal error. As the error propagates over long distances, however, we find that the distortion can be large in scale and highly variable. This can also be the case in local situations where different network layers with different distortion overlap one another. Thus, the accessible ground points of NAD83 (Original) are not directly compatible with GPS techniques in the sense that they are a system that might work well locally but do not work well regionally.

How Can We Measure Distortion?

Distortion in NAD83 (Original) can be determined by sampling points from that system with high accuracy positions using NAD83(CSRS).

The Canadian Spatial Reference System (CSRS) realization of NAD83 eliminates legacy terrestrial observations. It provides high-accuracy GPS connections to the NAD83 framework points in a top-down hierarchy as follows:

The Canadian Active Control System (CACS);

The Canadian Base Network (CBN);

Provincial High Precision Networks (HPN), and

Non-network techniques like NRCan's Precise Point Positioning (PPP), which can be as accurate as the HPN.

Subsequent project networks have been completed to densify NAD83 (CSRS) using high-accuracy GPS methodology by various agencies at all levels. Survey control forming part of NAD83 (CSRS) is relatively distortion-free. Long-distance connections can be made from network to project points with a high level of accuracy and reliability. CSRS can be considered to be accurate to 2 cm locally and to 5 cm in an absolute sense.

In Figure 1, one can see some different network configurations in both CSRS and Original. Some highways feature new CSRS and new Original ('new' points being those resulting from modern GPS techniques). Some have a mix of CSRS interspersed with Original and some have only Original.

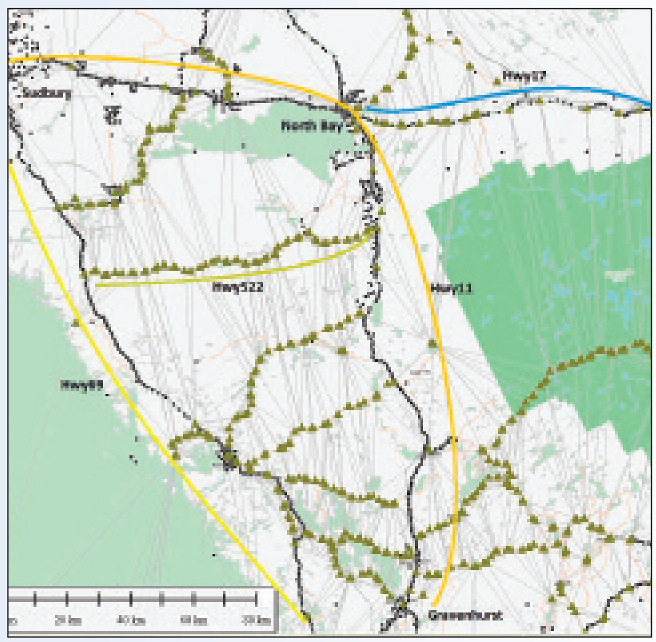

Figure 1. Map showing part of the Ontario Control Survey System. The Black dots are control points in NAD83 (Original) only. The brown triangle points have been surveyed in both NAD83 (Original) and NAD83 (CSRS).

The Original control exists in different orders of accuracy with different density. There are also block networks in Ontario featuring both CSRS and Original. Lastly, there are areas where there is no control at all. In such areas, CSRS can easily be established with PPP, but there may be little option to establish meaningful NAD83 (Original) with compatible distortions.

So What's the Problem?

Land surveyors working on the ground still need to work in NAD83 (Original) and they often need to work in this older system over long distances. These distances often exceed the threshold where acceptable *local relative accuracy* gives way to unacceptable *absolute accuracy* due to distortion. Examples of such projects include almost any route-type work:

Project control for highway engineering;
Ground control for aerial photography;
Pipeline and hydro corridor surveys;
Rail surveys.

The distortion in NAD83 (Original) can also become a problem over short distances where different networks of different network layers or epochs, particularly route surveys, intersect.

With a large existing investment in NAD83 (Original) data products, it is questionable whether agencies can reasonably make a wholesale switch to NAD83 (CSRS). Routes are additionally complicated by the notion of 'chainage & offset' that is still used as a practical reference system. This is particularly the case along highways or pipeline valve-sections where the connection from one spot to another is documented by standardized planimetric dimensions (tangent distances, standard curve data).

Visualizing the NAD83 (Original) Distortions

To further examine the issue of distortion, we looked at control surveys in the context of Ontario highways. While one could point to the geometry and related lack of redundancy in highway surveys as a source of error, highways provide much of the access to survey control and they are a large part of the reason the control exists in the first place. It is worth remembering that large errors also exist in block networks. Viewing situations along linear routes makes it easier to visualize the overall problem.

For each highway, survey control that is realized in both NAD83 (Original) and in NAD83 (CSRS) within a 5 km buffer of the roadway was retrieved from COSINE, the Ontario provincial survey control database. Differences between Original and CSRS were calculated and plotted in both latitude and longitude.

The goal was to examine the scale, direction and variability of the component differences between the original system and the modern system. Graphs provide the opportunity to identify trends:

- where transformations between the two can be calculated,
- to estimate the potential accuracy of such transformations and
- to determine the extent to which a transformation might be applied.

NAD83 (CSRS) is accessible both through existing monuments and through the use of NRCan's Precise Point Positioning (PPP) service. With a suitably accurate transformation, NAD83 (CSRS) can be used to provide access to NAD83 (Original) over longer distances than the local areas over which it can now be used. Where CSRS is not available, Original must be sampled and computed on CSRS to determine a transformation.

Though the entire province was analyzed, we can look at four cases to help illustrate what is happening. Each case corresponds to areas marked on Figure 1.

Figure 2 shows Highway 17 from Mattawa to North Bay. This route has mixed NAD83(Original) 2nd and 3rd order control, overlaid by CSRS every 2-10 kilometres. With this sample rate, it may be possible to determine a 10 cm accuracy transformation, depending on the original survey. There is one point at kilometer 278 which disagrees to its neighbors by 20 centimetres, though they are only 100 metres apart. Because there are numerous nearby points that agree with each other, it is likely safe in this case to omit that point.

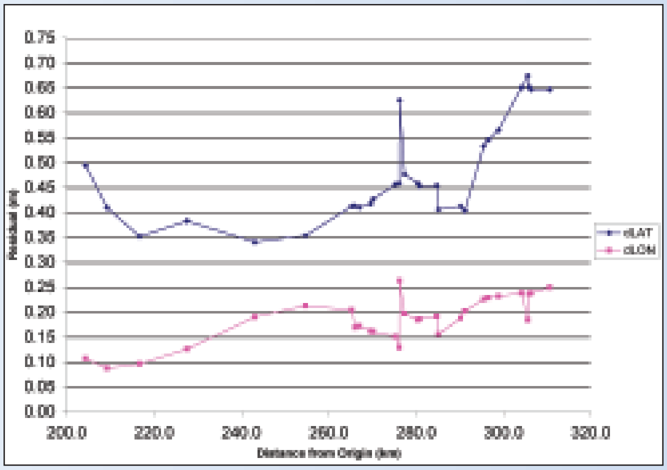

Figure 2.

Figure 3 shows a section of Highway 11 from Bracebridge to North Bay, then west to Sudbury. Note the one metre difference in longitude over this portion. Since there are large distances between many of the points that have both Original and CSRS, we have no picture of what the Original distortions are in these intervals.

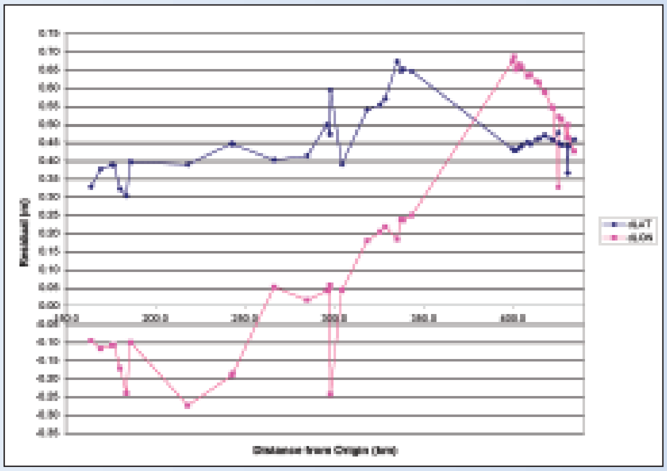

Figure 3.

When involved in projects that extend beyond a 'local' limit of perhaps 5 km, surveyors should complete additional control surveying to establish the relationship between

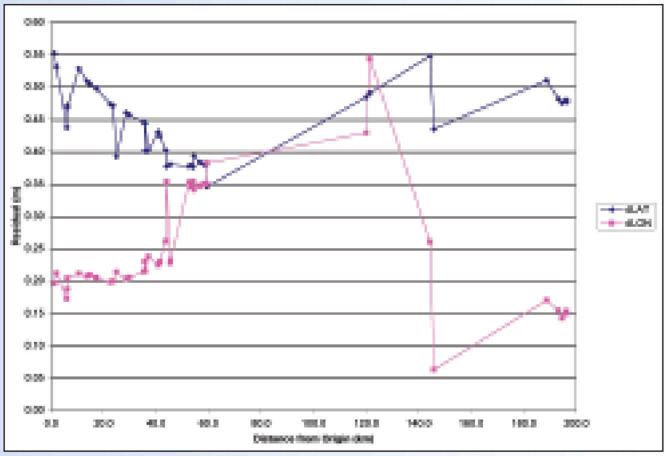

Figure 4.

NAD83 (Original) and CSRS.

Figure 4 shows Highway 69 from Mactier to Sudbury. The first portion has reasonably dense and well-behaved points. The second area is much sparser— note the extreme shift at kilometer 130. In this area observations must be made on Original points to determine what is happening.

Figure 5 shows Highway 522 from Highway 69 to Highway 11. This highway was recently surveyed with new control in both systems using GPS techniques. There is overall tilt in longitude, presumably due to the fact that Highway 11 had not previously been connected to Highway 69 in this area.

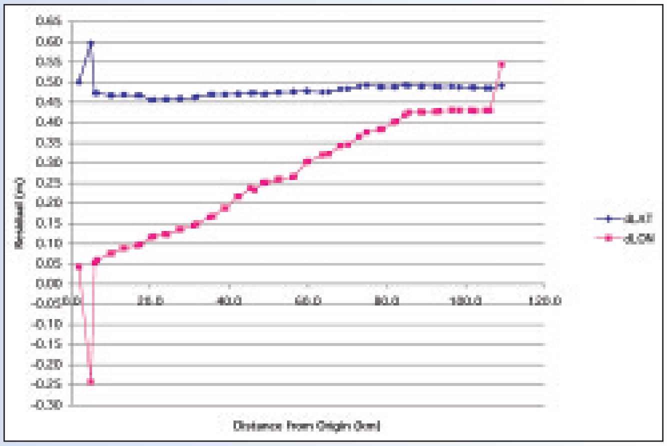

Figure 5.

Because this highway features new control in both CSRS and Original and no pre-existing Original control was established there to constrain and distort the network, one similarity transformation might be sufficient to model the distortion along this entire highway at the 5-10 cm level. This graph illustrates the minimal distortion provided by GPS techniques as well as the scale of distortion that is introduced when these high-precision measurements are constrained by older control at the ends of the highway. Thankfully in this case there is a trend that can be used to correct the distortion.

Four cases have been shown. Other areas in the province are better, some are worse, and for many others there is no information at all. This poses a problem. In the absence of observations or data for an area, it is difficult or impossible to know how much measurement is needed in order to achieve required results.

Here are a few general characterizations that may be helpful:

Because they provide more opportunities for blunder detection, block surveys are less prone to distortion than linear networks. This does not mean you can ignore the problem. The City of Toronto, for example, has up to 30 cm in their classical system (in this case NAD27). Fortunately the City has created a reasonably dense and accurate transformation and has published it.

Some highways which have *only* new CSRS and new Original are generally well-behaved, but may have significant overall trends.

Highways previously surveyed using classical methods but augmented later with GPS surveys, and thus constrained to distortion-prone classical observations, could have unpredictable behavior.

Areas with no CSRS have unknown behavior, and need to be sampled.

Third order traverses from one network layer generally have good point-to-point agreement and exhibit overall trends, but can have magnitude shift of 20 cm in 10 km!

Because local control values override all other values, there is little meaning in using remote 1st and 2nd order monuments for most surveys.

Areas distant from Original control effectively have no datum.

Some Practical Advice

Rules of thumb can be applied when dealing with projects requiring results in NAD83 (Original):

Fitting to the published control that is located closest to the project is generally safe. You need to confirm against blunders such as point movement with an independent check.

If you use GPS and are determining a transformation, then sample at a density that will meet the error budget.

2 cm < 1 km

5 cm < 3-5 km

10 cm < 5-10 km, and so on…

When working on large projects, it is good practice to define the distortion by computing CSRS and Original for each point. In this way all parties on the project can share the same accuracy. Completing your computations in CSRS is also a good check of the internal consistency of your work.

Store your raw data! If you determine a transformation to fit to NAD83 (Original) on a project, then submitting RINEX data to NRCan's PPP service could give you good CSRS coordinates for your bases, which you could use to recompute your survey in both systems if the need arises. Data storage is expected practice in any case.

The provincial grid shift (CSRS.GSB), or its derivatives, **are not suitable** for high accuracy work with NAD83 (Original) unless you know they meet the accuracy in a given project area.

Any single point, including CSRS, can be wrong (movement, clerical error, blunder, etc.). Points do not stand alone; they must be confirmed.

A Word on Modeling the Differences

Similarity transformations (site calibration or one step transformation), grid shifts, single point shifts, TIN shift, Kriging, polynomials: these are all names for mathematical methods of modeling and applying differences between two coordinate sets. They all rely on two sets of coordinates – the source and the destination.

The simplest method is to measure one point, compute the shift, measure another point, and compare the shift. If the difference in the shifts is within the error tolerance for your project and the points are close enough to represent the local datum, then you have determined a relationship between the two coordinate sets in that area.

More comprehensive methods have the surveyor measure local points and enter published values. GPS real time software computes the difference between internal and external values and applies a similarity transformation. Residuals from the transformation must be carefully analyzed in the context of control configuration to determine correctness.

Note that depending on the size of a project, any of these methods may require piece-wise analysis (the project may have to be broken down into several parts) to achieve the required accuracy.

Some manufacturers provide for the application of a grid shift transformation. Unfortunately, there is no transformation that can be trusted for high accuracy in all regions. They are, by nature, pre-computed and are subject to slow update rate (i.e. cannot be updated on a project). The manufacturers themselves stipulate limitations to their reasonable use.

Regardless of technique, it is important to sample NAD83 (Original) at a suitable interval, and check the application of your model.

Parting shots...

The issue is not new in the sense that NAD83 (Original) distortion was there long before surveyors started running around with GPS equipment. The places where modern GPS techniques have overlaid or augmented NAD83 (Original) control provide a characterization of existing distortion. Places without GPS control have not yet had the picture of distortion 'discovered'. Continued examination of the issues will lead to better understanding.

NAD83 (Original) cannot be used as a black box. If you make checks and fit to local control (through data or observations) then you can continue to use the system safely. Watch out for projects where distortions make effects over larger areas.

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