RTN–101:

RTN Geodesy and "Geoddity" (Part 9)

>> By Gavin Schrock, LS

"Cheshire cat," Alice began rather timidly,"Would you tell me please which way I ought to go from here?"

"That depends a good deal on where you want to go," said the cat.
– Lewis Carroll

Where to Go with Your RTN?

To the centimeter and beyond? Then you'll need to start with a centimeter-level network that can get you there. Though there are a lot of moving parts to a Real-time Network (RTN) and elements that require rigorous configuration, monitoring, and care, none carries as big a bite as the underlying geodesy.

The typical expectations for an RTN are to achieve centimeter-level precisions. The rationale for the development of a network and the expected cost-benefit hinges on such precisions. The network infrastructure must have centimeter-level positional integrity, both individually and collectively. Moreover, each of the continuously operating reference stations (CORS) has to be stability monitored to a few millimeters, and must have positional integrity relative to all other network CORS.

There are several approaches to this, the most fundamental element of an RTN. These range from treating the RTN as if it were in a geodetic vacuum to directly tying it to a national adjustment, with many variations along the way. Each approach can produce high precisions, and may be driven by direct user needs, lack of an involved qualified geodesist, or a need for expedience and simplicity. None of these approaches can magically remove the need for good surveying practices, or recommended field or office calibration (also called localization or adjustment depending on the manufacturer). Calibration will be examined in subsequent installments.

Where is Zero-Zero-Zero?

Just give me the coordinate! Gulp. *What adjustment? What projection? Based on which control system? Tied to whose published values? According to who?* These are common questions, and the answers typically involve ties to physical monumentation and published values.

GPS/GNSS deals with truly earth-centered systems and CORS are fast becoming primary monumentation reference systems. In many ways they can be simpler to understand than legacy reference systems. *Just give me the latitude and longitude.* Gulp. *Which one? According to who? Which ellipsoid?*

GPS/GNSS constellations are tracked relative to earth-centered reference systems. The orbital and ephemeral data are expressed in the terms of positions relative to an earth-center, typically the WGS84 ellipsoid. Geoid models and national geoid difference models are relative to such ellipsoids, though local geoid difference models may or may not. Geoids will be examined in subsequent installments.

The NAD83 earth-centered system was established with measurements taken in 1980. It was adopted internationally as the GRS80 (Geodetic Reference System 1980). The U.S. military, responsible

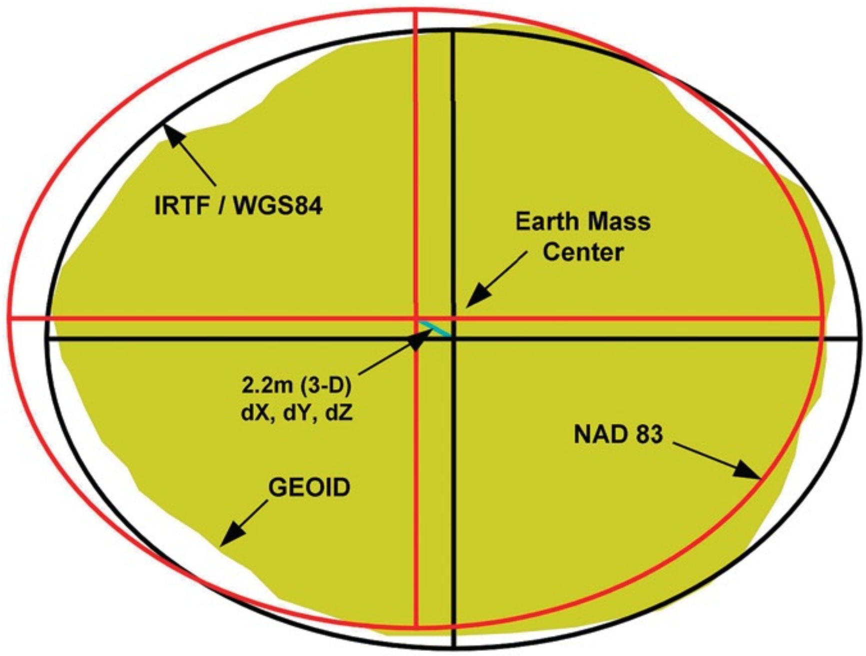

Figure 1 ITRF/WGS84 and NAD83 ellipsoids

for the GPS system, further refined the ellipsoid and called it WGS84. It is used by the military for all GPS tracking. Keep these two ellipsoids in mind; the GPS system "thinks" in WGS84, but U.S. surveying generally "works" in NAD83. Not really a problem; there is a transformation.

The U.S. military and many other regions of the world have adopted the WGS84 ellipsoid, but most other earth-centered reference systems in the U.S. are expressed relative to the NAD83 ellipsoid. There is a difference in the "center" of around 2m, but this is not a problem as the equipment and software are all capable of doing on-the-fly Molodensky (Google it!) transformations (**Figure 1**). This is wonderful, except that many mapping folks who leave their gear in WGS84 default settings wonder why they have a few extra feet of error when comparing to published NAD83 values. Just tell them that is why surveyors ought to be doing the mapping (just kidding).

The constellations are tracked relative to the ellipsoid though ground infrastructure, and VLBI (Very Long Baseline Interferometry) aligning to distant celestial bodies. Reference networks are further aligned to these, like the EUREF CORS in Europe, AFREF under way in Africa, and the NGS CORS in the U.S. Pinning down an RTN to such systems would of course get one closer to geodetic nirvana, but then there is a question of how to translate this to ground-based reference frameworks and the published values thereof.

As national adjustments (interpretations of ellipsoid value tied to such tracking systems) have improved in network accuracies, some of the most commonly used legacy adjustments, even those only a decade past, may not meet the centimeter-level precisions needed by RTN. Therein lies the dilemma: tie such reference systems and calibrate to local and/or legacy adjustments, or pin the RTN to local or legacy adjustments and perhaps need to calibrate less?

NGS Adjustments

An excellent treatise on the saga of NGS adjustments by Maralyn L. Vorhauer of the NGS appeared in the May 2007 issue of American Surveyor. The NGS has now released the national readjustment of 2007, dubbed NSRS 2007 (National Spatial Reference System). This latest adjustment now provides network accuracies that, with little exception, meet the RTN centimeter-level criteria.

Legacy adjustments, to include those from the early 90s, typically do not (**Figure 2**).

The legacy systems were amazing feats in themselves, considering the resources and methods available at the time. With the advent of GPS as a tool, it became cost-effective to tighten the adjustments. Prior to the most recent adjustment, most states were adjusted individually (with varied resources) with feathering of values between states. Some states fared better than others, but it is not uncommon to find a decimeter of variance in network accuracy of HARN within a single state.

States with adjustments updated in the late 90s started reaching the centimeter-level network accuracy of the 1998 national adjustment, though still by state, often with feathering in-between.

Many local high precision reference and control networks were developed or updated in the early 90s, using GPS as a cost-effective tool in their development. But many held legacy systems like HARN as their "zero". This is fine at the local level, as the few nearest HARN may have been very tight in respect to each other. To compound this issue, many GISs (that "discovered" State Plane

NETWORK	CIRCA	NETWORK ACCURACY	LOCAL ACCURACY
NAD 27	1927–1986	10 Meters	First-Order (1 part in 0.1 million)
NAD 83	1986–1990	1 Meter	First-Order (1 part in 0.1 million)
HARN	1987–1997	0.1 Meter	B-Order (1 part in 1 million)
CORS	1998	0.02 Meter – Horizontal 0.04 Meter – Ellipsoid Height	
NSRS CORS	2007	0.01 Meter – Horizontal 0.02 Meter – Ellipsoid Height	

Figure 2 Legacy National Reference Systems

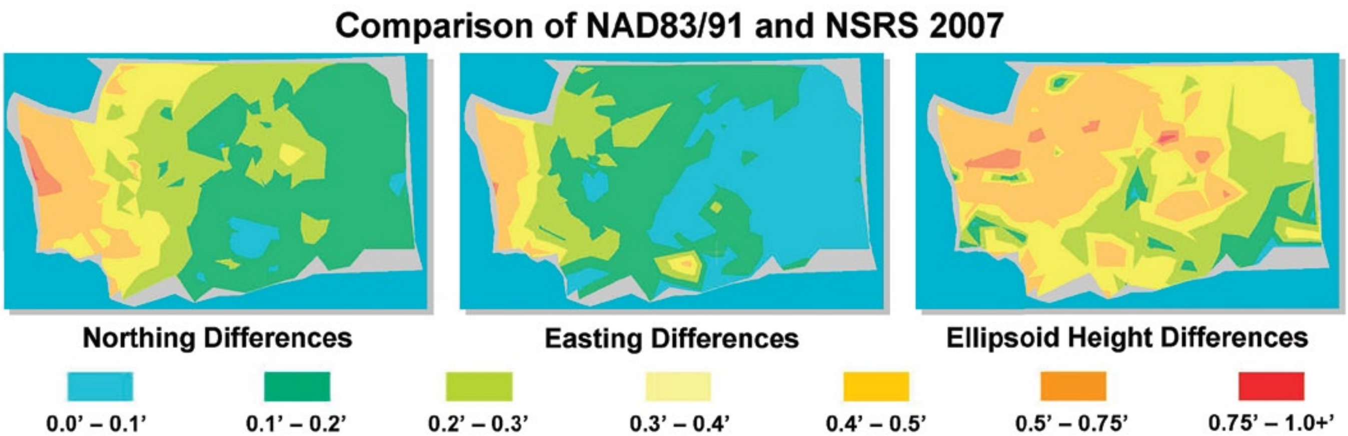

Figure 3 Comparison of reference systems, Washington State.
Source: Larry Signani, LS, W&H Pacific

projections as reference conventions) rely on the legacy systems for a "zero". This is great at the city and county level, but as an RTN often develops across much wider areas, legacy systems can be the "kiss of death". You cannot "rubber sheet" CORS positional values in an RTN.

Such a dilemma faced the Washington State Reference Network (WSRN), a regional cooperative RTN. The initial core of the network was localized around the central Puget Sound (Seattle *et al*) and was fixed to a handful of local HARN NAD83/91. Cool! Local surveyors often groused about the regional NGS CORS values: "They are centimeters off!" Of course a response could be "Off from what?" Seems they were often comparing CORS values to local HARN (**Figure 3**). Even if there was a lot of slop (and this was often exaggerated), why would you want to hinge your RTN to it?

As the network expanded to encompass much of the state, network accuracies of local HARN exceeded what the RTN needed, and the software got pretty upset. A move to the NAD83/98 derived values made this quite manageable. Yes, folks need to crack the manuals and learn how to calibrate, but they are soon happier with the higher precisions.

A move to NSRS 2007 is planned later this year. Though the differences between 98 and 2007 are minimal, the issue of the legacy feathering between states will be removed.

A further benefit of using the NSRS 2007 adjustment will be fidelity to the respective regional NGS CORS, and applicability of national geoid difference models. Tests of mixing and matching adjustments of one circa with geoid difference models of another (*e.g.,* NAD83/98 and Geoid 96) can yield disastrous results.

Pinning Your RTN to the NGS CORS

If you need to pin to the NGS CORS and national adjustment you have several tools available: collecting data from each of your RTN CORS and doing a big adjustment to the regional NGS CORS. This may not be viable with something like a single set of four-hour observations. It is not sufficient to just process a few hours of baselines and then just keep hitting the "adjust" button until it looks good (**Figure 4**).

A good start is to run and OPUS session (yes, OPUS for the skeptics). But we are talking about 15-30 days of data. You are well within the centimeter-level with such a process. A good second step is to process several days of data against NGS CORS data; this is important to further refine the vertical component. This can be repeated with just adjacent RTN and NGS CORS, or better still, all in the RTN.

Many of the RTN in the U.S. employ this or similar methods. Some may decry that there are not specific published guidelines for this process. On one level, it is just a good post-processing practice, and there is plenty written on that subject.

While the NGS is not directly involved in services specific to RTN CORS geodesy, their own guidelines for Cooperative CORS are a good benchmark. The NGS is openly speaking about RTN and how to best support these efforts. A core working group has been formed by NGS to study this and there are staff coordinators dedicated to this. Your input, feedback, and participation will be key in this process; work though your state NGS advisors.

The NGS CORS / National Adjustment track is not the only way to make an RTN work. There are some other philosophies and approaches tried and employed across the U.S. and the world, but there are caveats attached to each.

Let it Float?

One approach lets the RTN software do the work. The generalized notion is to hold the value of one station. The value of the "zero" station just needs to be expressed in the terms of an earth-centered reference system (*e.g.,* WGS84, NAD83, ITRF). It cannot be truly "assumed" (you can calibrate your field work to your assumed systems later as a user, but the RTN cannot start that way). The reason for at least minimal fidelity to the earth-centered systems is so that the almanac and ephemeral data will sync up. Some folks establish the values for a single initial station through a rigorous adjustment to regional NGS CORS, local HARN (or other adjustments), or to local control systems that were at least tied in some manner to something they could derive an earth-centered system value from.

Once you have established your "zero" station, the CORS positional integrity monitoring component of the respective RTN software can take over. As the raw observations stream in from each station, new positions are calculated, constrained to each of the surrounding stations and pinned down to the "zero" station.

These RTN software monitoring applications are pretty amazing. Leave it running long enough and you can tighten things down to millimeters with station spacing as much as 100km (though not recommended). Nice! You have an RTN running and the monitoring is all green lights and you may have the sub-centimeter network accuracy you wanted. It takes a lot of faith in that one initial adjustment, though.

Your network is tight in and unto itself, but may not match anything on the ground. Your users will have to calibrate, or otherwise work in a completely relative mode. If this is acceptable, no harm done (maybe).

"Backing-in" Local Values

Another approach that seeks to reduce or eliminate local calibration is to work from local (legacy or other) control systems. One could derive the values for an RTN CORS by a tie or adjustment to the published values of a nearby control monument (on whatever local system is desired). Some use the geoid values for local orthometric values to "back-in" an ellipsoid value for a CORS.

How that translates to the values derived for the next RTN CORS down the line depends a lot on how tight the local control is. It is not uncommon for users in different regions covered by an RTN to desire ties to completely different control systems, which is perhaps fine if pre-defined sub-networks are developed within the RTN, but the RTN will not like this if viewed as a whole.

Vertical

For reasons stated earlier, the RTN needs to work in ellipsoid values. Live, eat, and breathe ellipsoid values. One could put purely orthometric values into the RTN software. This will only work if said values have sufficient network accuracy. It goes without saying that for the most part the state of vertical reference systems (beyond small local systems) are much more problematic than horizontal. Good vertical is much harder to achieve over wide regions or states. Legacy vertical systems are typically not earth-centered, and geoid difference models alone may not suffice. A program of CORS-based control and high order digital level runs can bridge this gap.

It is no surprise that Height Modernization initiatives, particularly those under the NGS Height Modernization program, include ties to NGS and RTN CORS. In this manner, GPS observations can greatly augment leveling.

Figure 4 One cannot compromise on the relative positional integrity of RTN CORS

Adjacent and Overlapping RTN

Overlapping networks of varied geodetic approaches can cause a lot of heartburn, and can even be exploited in an equipment "shootout", but can ultimately coexist if the requisite field and/or office calibrations are exercised. Adjoining or overlapping RTNs can even share data from CORS; each network applies its own value to the respective CORS.

A lofty but easily achievable goal is for RTNs to be on the same reference system as an adjacent, overlapping or inclusive RTN. This doesn't just make life easier for the user by putting everyone on the same system, but helps RTN operators maintain the integrity of their own infrastructure with external data.

Active Control

Imagine monuments that indicate their positions 24 hours a day to the millimeter. When you look at a published value for a monument you have to wrestle with issues of currency (epoch) and what methods were used to derive the value. While the legal value of cadastral monuments is not disputed, and maintenance of such control is essential, the costs associated with maintaining extensive geodetic control monumentation is being questioned. No one is suggesting elimination of physical control, but only to suggest active control as a cost-effective solution for establishing, updating and maintaining the respective geodetic values thereof.

RTNs can and do serve as default reference systems for real-time and post-processing. Many regions, states and countries are valuing their RTN CORS as default active control reference systems. In Germany the semi-governmental cooperative of RTN called SAPOS applies standards and guidelines to each member RTN. Developing countries with very loose (or non-existent) legacy control systems are opting to go straight to RTNs as their reference frameworks. In the U.S. the national reference systems is CORS-based. It is not too hard to see where this is all going. *"Curiouser and curiouser," said Alice.*

Gavin Schrock is a surveyor in Washington State where he is the administrator of the regional cooperative real-time network, the Washington State Reference Station Network. He has been in surveying and mapping for more than 25 years and is a regular contributor to this publication.