TECHNICAL CONSIDERATIONS FOR MODERNIZING NOVA SCOTIA'S COORDINATE REFERENCING SYSTEM

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The Nova Scotia Coordinate Referencing System (NSCRS) is Nova Scotia's current framework for providing location-based information. The NSCRS is the foundation for the province's geographic data, including the land administration system. In 2012, the province began developing a modernization strategy to better execute its coordinate referencing program to address ongoing accuracy and accessibility needs. A network of active control stations (ACSs) tracking global navigation satellite systems (GNSS) is at the core of the new strategy. In addition to providing better accuracy and accessibility to the NSCRS, the technology has created new opportunities to sustain its passive control infrastructure.

In 2015, the installation of 40 ACSs across the province was completed, providing industry with access to real-time, centimetre-level positioning. Over the course of the NSCRS modernization project, several technical considerations needed to be addressed pertaining to the design of the network, location of the ACSs, flow of the ACS data and the crowd sourcing of GNSS observation data to maintain the passive control system. These technical considerations are reviewed and the solutions implemented to address the needs of this initiative are presented.

Le Système de référence des coordonnées de la Nouvelle-Écosse (SRCNE) est le cadre actuel de la Nouvelle-Écosse pour fournir de l'information géoréférencée. Le SRCNE est le fondement des données géographiques de la province, y compris celles du système d'administration des terres. En 2012, la province a commencé à développer une stratégie de modernisation pour mieux exécuter son programme de référencement des coordonnées dans le but de répondre aux besoins constants de précision et d'accessibilité. Un réseau de stations de contrôle actif (SCA) qui fait le suivi du Système mondial de satellites de navigation (GNSS) est au cœur de la nouvelle stratégie. En plus d'assurer une plus grande précision et une meilleure accessibilité au SRCNE, la technologie a créé de nouvelles possibilités pour soutenir son infrastructure de contrôle passif.

En 2015, on a terminé l'installation de 40 SCA partout dans la province, ce qui a donné à l'industrie un accès au positionnement en temps réel au niveau centimétrique. Au cours du projet de modernisation du SRCNE, il a fallu tenir compte de plusieurs considérations techniques concernant la conception du réseau, l'emplacement des SCA, le flux des données des SCA et la production participative des données d'observation GNSS afin de maintenir le système de contrôle passif. Ces considérations techniques sont examinées et les solutions mises en œuvre pour répondre aux besoins de cette initiative sont présentées.

Introduction

Since 1968, the Province of Nova Scotia has carried out a mandate of providing a coordinate referencing system for its citizens. Land administration, property management, engineering, construction and mapping are examples of activities that depend on an underlying coordinate referencing system that is reliable and accurate. Nova Scotia has a rich history in its coordinate referencing program, which is described in *Bond* [2015A].

The Nova Scotia Coordinate Referencing System (NSCRS) is Nova Scotia's current framework for providing location-based information. The NSCRS is the foundation for the province's geographic data. It also enables various legislation, including the *Land Registration Act*, the *Crown Lands Act* and the *Land Surveyors Act*. Over the past several decades, the state of the province's coordinate referencing infrastructure has steadily declined as the program's human and financial resources have been reduced. As a result, risks and inefficiencies associated with this decaying infrastructure have increased.

In 2012, the province began developing a strategy to better execute its coordinate referencing program. At the core of the strategy were global navigation satellite systems (GNSS) active control stations (ACSs). By placing these permanent GNSS installations across the province, the surveying industry gained the ability to access real-time positioning with centimetre precision. Additionally, significant economic opportunities emerged with respect to machine automation in the agriculture, construction and navigation industries. Most importantly, the technology provided a viable method of maintaining NSCRS infrastructure going forward. A more detailed discussion on the modernization strategy can be found in *Bond* [2015B].

Presently, 40 ACSs span Nova Scotia to form the Nova Scotia Active Control Stations (NSACS) network. The NSACS are utilized by GNSS network real-time kinematic (NRTK) service providers to offer high-accuracy positioning services. Archived data from the NSACS is also made available for post-processing.

The NSACS have provided a tool to enable the province to fully migrate from the Average Terrestrial System of 1977 (ATS77) to the North American Datum of 1983 (NAD83), an effort that began in the late 1990s. Surveyors are now producing survey plans in NAD83 as realized through the Canadian Spatial Reference System (CSRS)—"NAD83(CSRS)." NAD83(CSRS) allows surveyors to work in a datum that supports the full accuracy of GNSS.

The integration of the NSACS into the NSCRS introduced several logistical and technical considerations. This paper captures some of the key issues that were addressed when modernizing the NSCRS through ACS technology. An outlook on future modernization initiatives is also provided.

NSACS Network Design

The original purpose of the NSACS network was to address the accuracy and accessibility needs of the surveying community. The goal was to provide access to real-time positioning accuracies of better than ±3 cm horizontally and ±4 cm vertically within cell coverage areas, anywhere in the province. In areas without cell coverage, the same level of accuracy would be achieved using post-processing techniques. Field experience and cellular coverage maps provided by cellular service providers indicate that approximately 85% of the province has access to cellular coverage and, therefore, high-accuracy, real-time GNSS positioning.

Specifications for NTRK accuracy are typically in the range of ±10 mm + 0.5 ppm horizontally and ±15 mm + 0.5 ppm vertically (1 ppm = 1 mm/km from reference station). For single reference station RTK, the ppm component is twice as large [*Trimble* 2016]. To achieve the desired positioning accuracy, a nominal spacing of 80 km could be used. With an 80-km spacing between ACSs, the user remains within 40 km from the nearest ACS in a worst case scenario. This leads to an expected uncertainty of ±(10 mm + 20 mm = 30 mm) horizontally and ±(15 mm + 20 mm = 35 mm) vertically. In designing the NSACS network, a targeted ACS spacing of 50 km was used for two main reasons:

1. System redundancy—In the event of an ACS failure, it was desired to have backup coverage to maintain minimum system performance and alleviate the operational pressures of ensuring uptime. With a 50-km spacing between ACSs, in a worst case scenario the user would be 25 km from the nearest ACS. This would lead to an expected uncertainty of ±(10 mm + 12.5 mm = 22.5 mm) horizontally and ±15 mm + 12.5 mm= 27.5 mm) vertically. If a station goes offline, the nearest station could be as far as 50 km away, leading to an expected uncertainty of ±(10 mm + 25 mm = 35 mm) horizontally and ±(15 mm + 25 mm = 40 mm) vertically. The desired horizontal accuracy is exceeded by 5 mm in the worst case scenario, but the extra cost associated in moving to a tighter spacing could not be justified. Increased occupation times or local, single baseline RTK can be used when necessary.
2. Highly variable troposphere—Being a coastal province, Nova Scotia is susceptible to highly variable weather conditions from one region to the next. It was anticipated that the theoretical NRTK accuracy values may not be achieved in this environment.

Leveraging existing provincial buildings that could provide Internet connections and power would significantly reduce costs. Towns separated by approximately 50 km were identified across Nova Scotia as potential ACS locations. Site visits were conducted to identify buildings that complied with best practices for ACS site selection. In most instances, schools tended to be the best option. GNSS data was acquired and examined for each site and a spectrum analyzer was used to identify potential sources of interference on the tracked GNSS frequencies.

Figure 1 illustrates the final design of the NSACS network that was installed. It was desired to locate the ACSs as close to the coast as possible to maximize the NRTK zone for which GNSS corrections could be interpolated. Population density and available infrastructure ultimately dictated where ACSs were installed. The following design considerations are noteworthy:

1. Over one third of Nova Scotia's population is located in the Halifax, Dartmouth, Sackville and Bedford regions and, as a result, a significant percentage of the province's land transactions and construction occur there. It was desired to have ACS redundancy in this area so that if there was an ACS outage, NRTK performance would minimally degrade. Fall River (FALL), Halifax (HALI) and Brookside (BKSD) ACSs were put in place to address this need.
2. There is very little development and low population density in southeast Cape Breton near Fourchu. It was more cost effective and deemed more beneficial to locate two stations in Arichat (ACHT) and Louisbourg (LSBG) than to install a solar powered ACS in Fourchu. The Louisbourg ACS also offers redundancy for the densely populated Sydney area.
3. It was desired to tightly integrate the NSACS to the Canadian Spatial Reference System (CSRS). The Canadian Active Control System (CACS) station HLFX provided a direct link. With approval from Canadian Geodetic Survey, the Canadian Base Network stations in Tusket and Baddeck were augmented with GNSS equipment to make them active. This configuration provides three continuously observed points of integration with the CSRS.
4. The majority of the province's population is located along the coast. The interior of the province is sparsely populated and provides few opportunities for locating an ACS. In southwest Nova Scotia, the Caledonia (CLDA) station was installed to densify the network and to try to maintain the 50-km spacing inland. In the northern mainland, there is a void near Trafalgar where infrastructure does not exist to host a site. Middle Musquodoboit (MMSQ) was the nearest location that could help fill the void. It is approximately 80 km between New Glasgow (NGLW) and Sheet Harbour (SHBR) ACSs, so NRTK accuracy is still expected to be acceptable for most survey applications in this interior region.

Figure 1: NSACS network.

Installation

In order to construct the NSACS network, installation specifications (*Best Practices for GNSS NRTK Service Providers Operating in Nova Scotia* [*Bond* 2016]) were developed for the contractor. *The Guidelines for New and Existing Continuously Operating Reference Stations (CORS)* [*NGS* 2013] served as the foundation for these specifications. One of the main reasons for implementing such specifications was to ensure the long-term stability of the ACS monuments so that coordinate values would remain accurate over time. All NSACS are currently located on buildings using an antenna mast as the survey monument, except for two CBN concrete pillars that were augmented with GNSS equipment.

Particular concern was given to selecting survey monument locations for the NSACS that would minimize daily and seasonal thermal influences. Only masonry buildings and buildings with a steel structure to which the antenna mast could be attached were used. Additionally, the buildings required a concrete foundation and antenna mast locations were kept below three stories high.

The impact of thermal effects in one dimension can be approximated using the relationship shown in Equation 1:

$$\Delta L / L = \alpha \Delta T \qquad (1)$$

where L = original length, ΔL = change in length, α = coefficient of thermal expansion (12×10^{-6} for concrete at 20°C) and ΔT = change in temperature.

The height of a GNSS antenna attached to a concrete building three stories high is about 9 m. Using the above equation, for every 1°C temperature change, a change in height of approximately 0.1 mm can be expected. A 10°C temperature change could change the antenna height by 1 mm. In Canada, where temperatures can vary more than 50°C between summer and winter, this can lead to 5-mm height differences due to seasonal variations. The 3-dimensional, volumetric effects of thermal expansion would lead to larger values than the linear scenario presented.

Figure 2 and Figure 3 illustrate the 3D position time series of two NSACS, Digby (DGBY) and Baddeck (BDCK), in 2015. DGBY is attached to the steel structure of a school and BDCK was installed on an existing CBN concrete pillar (see Figure 4). It can be seen that seasonal variations of 5 mm or more are not uncommon in the solutions, particularly in the height component. During the winter months, DGBY illustrates sawtooth jumps in the height component, which is a typical signature of snow or ice buildup on an antenna followed by melting [*Craymer* 2015]. For engineering applications requiring the highest accuracy, 3D time series plots like the ones presented can be used to determine offsets from published coordinates for the period of interest.

ACS Coordinate Assignment

When the first NSACS were installed, the Canadian Geodetic Survey (CGS) of Natural Resources Canada (NRCan) did not have a formal compliancy process in place for coordinate assignment for ACSs. Often, GNSS service providers would submit several days of observation data for a station to NRCan's Precise Point Positioning (PPP) service to determine coordinates.

To evaluate the suitability of this technique for determining coordinates for the NSACS network, a comparison between differential and absolute GNSS processing results was conducted. For this exercise, two weeks of data from the eight original NSACS stations installed in southwest Nova Scotia (Cambridge (CAMB), Lawrencetown (LTWN), Digby (DGBY), Meteghan (MTGN), Tusket (TSKT), Shelburne (SHEL), Liverpool (LVPL), Hebbville (HEBB)) and from the Halifax (HLFX (CACS)) station were used. Figure 5 illustrates the location of the stations and the baselines used in the network adjustment for the differential processing.

PPP results were obtained by submitting data to NRCan's online service. For each station, 24-hour solutions were obtained and average coordinates were determined over a 2-week period. Differential results were obtained using Leica Geomatics Office software and standard processing parameters. The baselines shown in Figure 5 were calculated using 24-hour observation sessions over the two-week period. Stations HLFX (CACS) and TSKT (CBN) were held fixed during the network adjustment.

Table 1 summarizes the differences in the Cartesian coordinate values obtained using the two processing methodologies. The largest 3-dimensional discrepancy between the two approaches was 12 mm. For the purpose of this exercise, the agreement was deemed satisfactory. Better agreement may have been achieved by modifying processing parameters or by using scientific software, but this was beyond the scope of the investigation. The PPP approach took less than half of the processing time required to do the network adjustment on the differential baselines. It also presented fewer

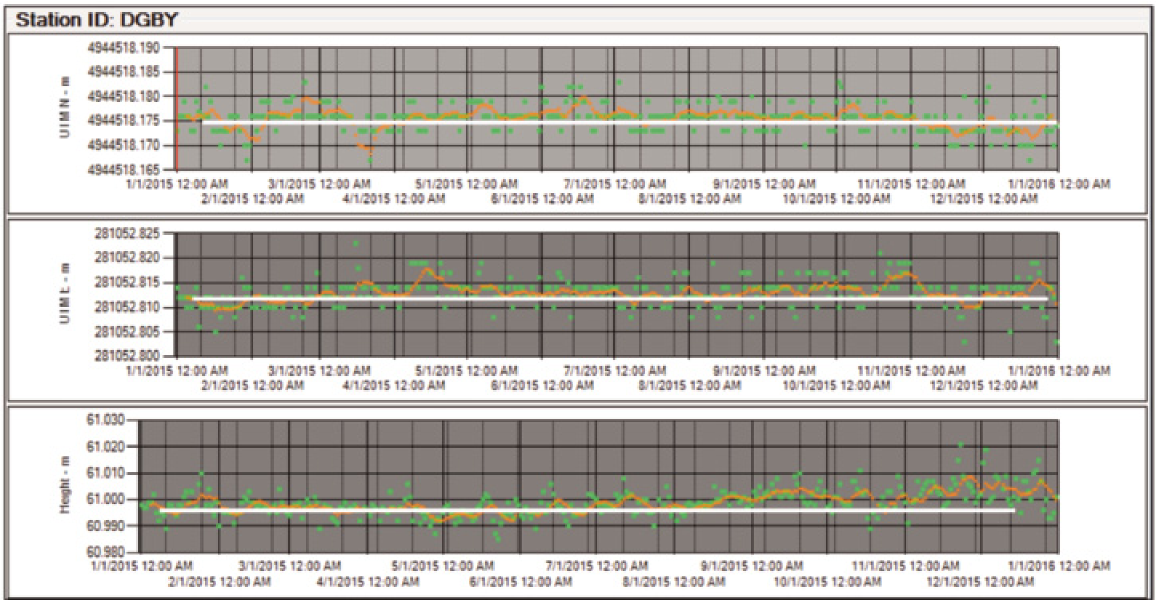

Figure 2: 3D position time series of DGBY ACS in 2015. Green dot = daily solution, orange dot = weekly solution, white line = published value.

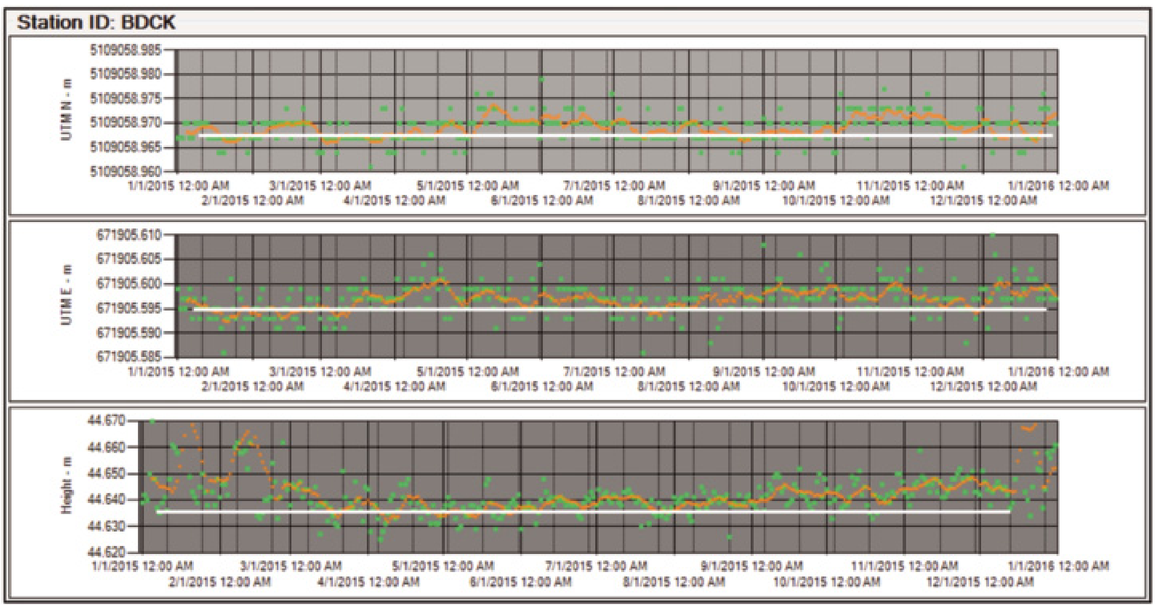

Figure 3: 3D position time series of BDCK ACS in 2015. Green dot = daily solution, orange dot = weekly solution, white line = published value.

Figure 4: DGBY (left) and BDCK (right) ACS coordinate assignment.

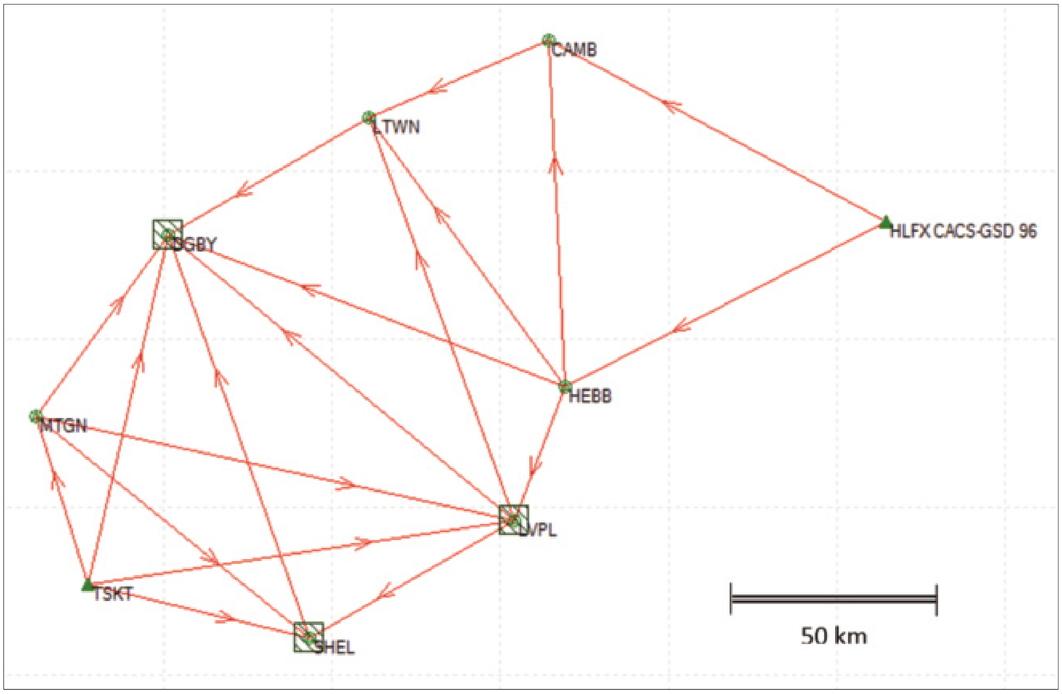

Figure 5: Network used for comparing differential and absolute GNSS processing techniques.

Table 1: Cartesian coordinate differences between differential and absolute GNSS processing methodologies.

Name	ΔX m	ΔY m	ΔZ m	Δ3D m
CAMB	0.011	0.002	0.001	0.012
DGBY	0.003	0.000	0.008	0.009
HEBB	0.005	0.008	0.005	0.010
LTWN	0.003	0.000	0.008	0.008
LVPL	0.009	0.000	0.001	0.009
MTGN	0.008	0.002	0.002	0.008
SHEL	0.008	0.006	0.002	0.010

opportunities for error and required much less geodetic expertise to execute. It was evident that the PPP approach provides an efficient tool for government agencies and private industry to deliver high-accuracy geodetic coordinates.

NSACS IT Architecture

The implementation of the NSACS created a new product that would facilitate the development of a sustainable coordinate referencing program. Specifically, the data streams generated by each ACS could be licensed to GNSS NRTK service providers to offset operational costs. The GNSS NRTK service providers utilize the data to offer services to their clients that enable instantaneous, centimetre-level positioning.

In the operational model, a primary GNSS NRTK service provider is responsible for ensuring uptime of the system, including each of the NSACS and a server running a Networked Transport of Radio Technical Commission for Maritime Services (RTCM) data via Internet Protocol (NTRIP) caster. Initially it was intended that each service provider would have direct access to an independent data feed from each ACS. Bandwidth demands rendered this approach not feasible, especially for sites that could only be accessed using a cellular modem. The NTRIP caster allows data to be streamed to one central location for redistribution to service providers, lessening bandwidth demands at the ACS. In case of a local Internet outage at the ACS, most sites use a cellular modem as the redundant mechanism to stream data to the NTRIP caster.

Each service provider uses the GNSS data from the NSACS to model corrections using proprietary software. Clients subscribe to the service provider's corrections service to allow them to obtain instantaneous centimetre-level positioning accuracy. Typical applications include machine automation for highway construction, precision agriculture and surveying. Each GNSS-equipped device must be connected to the Internet to receive the GNSS NRTK corrections. This is typically achieved using cellular communications.

Data flow begins when observations are made at the GNSS receiver every second. The data is streamed to the system administrator's server running an NTRIP caster. Typically this is accomplished using a local area network (LAN) connected to the Internet. If a LAN is not available or the LAN goes offline, a cellular modem is used as a backup mechanism for streaming data to the NTRIP caster. GNSS NRTK service providers can subscribe to the NSACS data distributed through the NTRIP caster. The NSACS data allows the service provider to model high accuracy GNSS corrections in the coverage area and distribute these to their clients over the Internet. The ability to receive GNSS NRTK corrections is dependent upon both ACS coverage and cellular coverage. Figure 6 illustrates the flow of data through the NSACS.

Growing the NSHPN

The NSACS provides a gateway to high-accuracy positioning anywhere in the province. The existence of a widespread active control system does not, however, negate the need for passive control. A passive system (1) provides an independent field check on the active system, which should be performed as a best practice; (2) allows users to employ a reference and rover setup when cellular coverage is not available or when the user does not have an NRTK subscription; and (3) provides an important link to historic survey work in previous datum and allows transformation parameters to be defined between coordinate systems.

In 2012, the Association of Nova Scotia Land Surveyors (ANSLS) was polled to determine how many of the original 23 000 Nova Scotia Control Monuments (NSCMs) should be maintained to meet industry needs. The majority of respondents indicated a value between 500 and 5000 NSCMs [*Bond* 2012], roughly equivalent to a NSCM spacing between 2.5 km and 10 km. This poll was conducted prior to the existence of the NSACS network.

The ATS77 to NAD83(CSRS)1997.0 grid shift file released in 2001 has an accuracy, on average, of approximately ±15 cm. Through the NSCRS modernization effort, it was desired to attain a grid shift transformation accuracy of ±5 cm, which is roughly the diameter of a survey marker cap. The grid shift file generated in 2001 utilized 156 monuments having ATS77 and NAD83(CSRS)1997.0 coordinate values. It is hoped that by tripling the number of monuments used in the calculation, the grid shift transformation accuracy will improve by a similar magnitude.

From a sustainability perspective, it appears that 500 NSHPN monuments can be maintained using the existing survey resource pool within the Nova Scotia government. There are over 50 survey technologists and surveyors in the Departments of

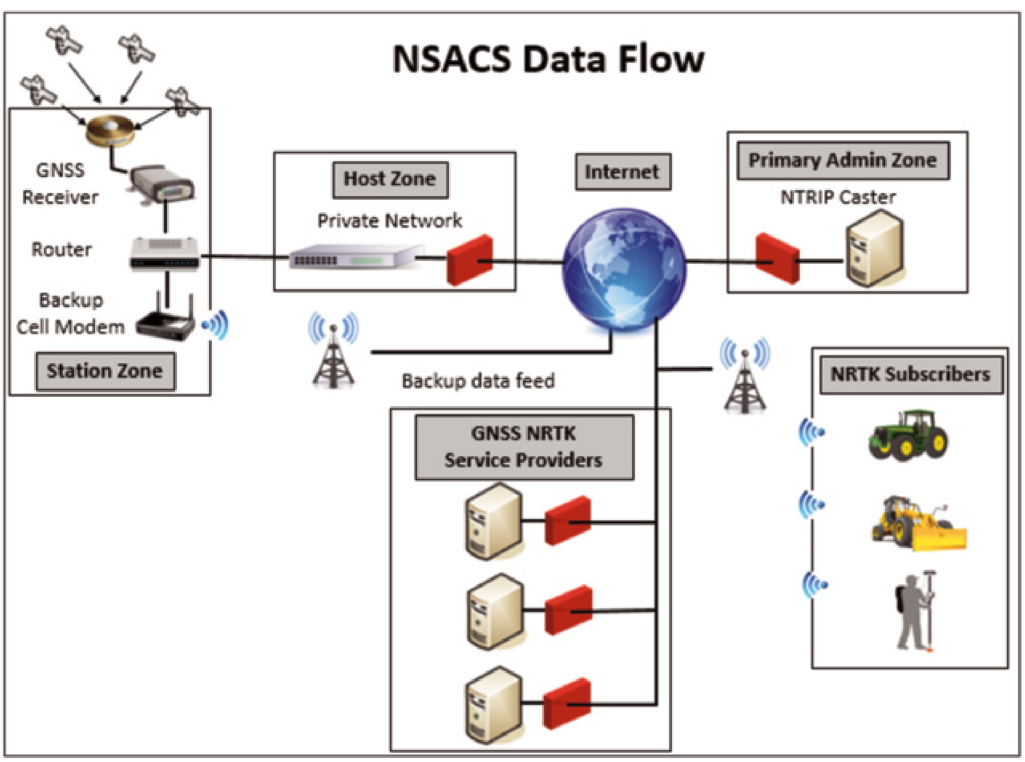

Figure 6: NSACS data flow.

Natural Resources and Transportation and Infrastructure Renewal collectively. If each resource re-observes and clears vegetation around 5 NSCMs each year, theoretically 1250 NSCMs can be maintained on a 5-year maintenance cycle. The observation of NSCMs is part of this group's daily work and the formalization of a maintenance schedule should not place undue burden on these resources. New strategies and technologies have been developed and integrated to also allow industry to contribute to the expansion and upkeep of the NSHPN on an as-needed basis, as subsequently described.

Leveraging the NSACS Network

With the NSACS network in place, an individual can actively contribute to the upkeep of the passive network and expansion of the NSHPN. Centimetre- to sub-centimetre-level position updates on existing NSCMs can be provided in real-time or in post-processing by leveraging NSACS data. Ten-minute or longer occupations are recommended on NSHPN monuments to allow averages of real-time solutions to approach sub-centimetre level. By comparison, when the original NSHPN was observed in the late 1990s, five or more teams of surveyors were required to observe NSHPNs simultaneously using 8 to 12-hour sessions. As was the case then, at least three occupations are also required now to update a NSHPN coordinate to published status. What used to take 24–36 hours of observation time can now be achieved in 30 minutes. Not having to coordinate simultaneous observations with another observer provides tremendous flexibility in conducting maintenance on passive control. In effect, the NSACS can be considered a crew of permanent GNSS observers working 24/7 to facilitate the work of individual surveyors.

To update an existing NSCM with ATS77 coordinates to publishable NAD83(CSRS) values, the following observation requirements are followed:

a) At least two observers must contribute using different sets of equipment;
b) Observation sessions must be 10 min or longer;
c) Observations should be recorded at a 1-s data rate to allow for post processing in case of a discrepancy;
d) Observation sessions must be separated by more than 0.5 h;
e) There must be at least 24 h between 2 sessions;
f) The coordinate spread must be <20 mm horizontally amongst 3 sessions;
g) The coordinate spread must be <30 mm discrepancy vertically amongst 3 sessions; and
h) Site setup photos must be provided showing the antenna type, antenna height, levelled bubble and, when applicable, tip of the bipod over the NSCM mark (see Figure 7).

Figure 7: sample NSHPN observation photos.

Since site sketches are no longer being produced, the surveyors are asked to submit photos showing the north, east, south and west quadrant views around the NSCM as well as of the general site area. It is highly recommended that a fixed height tripod or bipod is used to reduce the chances for antenna height errors. As coordinates are submitted, the NSHPN coordinate status progresses, as illustrated in Table 2. Only published coordinates should appear on a survey plan.

Targeted Crowd Sourcing

In order to promote the growth and maintenance of the NSHPN, functionality was built into the province's coordinate data distribution tool to accept NSCM observation data and status information. Initially, Nova Scotia Land Surveyors (NSLSs) was targeted as the primary group that would be qualified to contribute to the initiative. NSLSs have an account that allows them to submit observed NAD83(CSRS)2010.0 UTM coordinate values, raw data, photos and other site information to keep the NSCRS database current (see Figure 8). Cellular coverage information is also logged to help users predict when NTRK may or may not be available. Over time, this functionality may open up to other geomatics professionals.

Coordinate Considerations

In generating coordinate values for the modernized NSCRS, several logistical and technical considerations arose. Some of the key issues are subsequently discussed.

Datum Selection

Since the late 1990s, the province has been migrating its spatial data from ATS77 to NAD83(CSRS). The main consideration in selecting a working datum for the modernized system was the particular realization of NAD83 upon which to standardize. The NSHPN established in the late 1990s was realized using NAD83(CSRS) V3.0 values of the CBN at epoch 1997.0. At the time of this initiative, the federal standard had moved to NAD83(CSRS) V6.0 at epoch 2010.0. It was decided to also migrate to this standard for the following reasons:

1. Few, if any, survey plans were created in NAD83(CSRS)1997.0 V3.0, so there was an opportunity to easily embrace the latest standard.
2. Height values on federal survey monuments were published in CGVD2013 at epoch 2010.0. Being in the same epoch would help reduce confusion when comparing provincial height values.
3. Epoch 2010.0 represented the closest time to when the NSACS installation began (2013). By moving to a newer epoch, less extrapolation using the velocity model would be required than for Epoch 1997.0. Prior to 2013, only five CBN and one CACS station were used in calculating the velocity model for Nova Scotia. After 2015, 40 NSACS will also be used to define the velocity model for Nova Scotia. By moving the standard epoch to 2010.0, there is less opportunity for accuracy loss caused by the less dense velocity observations between 1997 and 2015. Since the NSACS will continually sample the velocity of Nova Scotia in the future, the province should realize the full benefit of future velocity models developed by NRCan that incorporate NSACS observations.

Table 2: NSHPN coordinate status progression.

# Sessions	Coordinate Status
1	Provisional (unverified)
2	Pre-Published (once verified)
3	Published (twice verified)

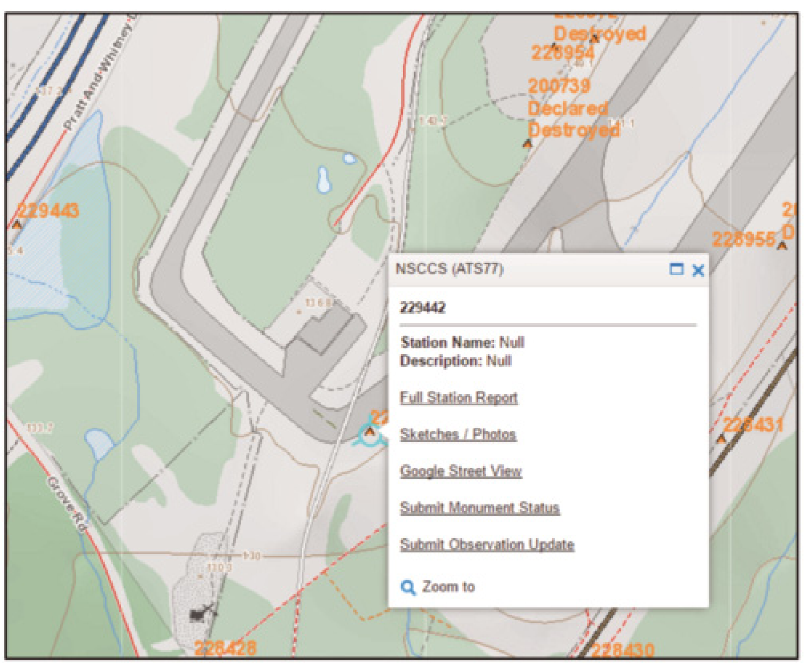

Figure 8: Data submission functionality.

Projection Selection

When NSHPN coordinates were published in 2000, only UTM values were projected. The ANSLS (the primary user group of the NSCRS) requested that 3° zone, Modified Transverse Mercator (MTM) coordinates also be released. The primary reason for this request was to minimize the impact of scale factors when doing survey work with combined total station and GNSS instrumentation. The scale factor in MTM is 0.9999 at the secant lines versus 0.9996 for UTM. A hidden benefit in using MTM values with NAD83(CSRS) was that NSCCS coordinates were projected using MTM and therefore bearings and distances on historic ATS77 survey plans could be directly compared.

To distinguish between ATS77, NAD83(CSRS) 1997.0 and NAD83(CSRS) 2010.0 MTM values, it was requested that the underlying datum could be discerned directly from the coordinate value. When the MTM projection was created for Nova Scotia in the late 1970s, two 3° zones between 60°–63° (Zone 4) and 63°–66° (Zone 5) were established with false eastings of 4 500 000.000 m and 5 500 000.000 m, respectively. In the modernized system, the same zone definitions are used except that the false eastings have an additional prefixing digit to represent the datum. NAD83(CSRS)1997.0 MTM Zone 4 and Zone 5 false eastings are 14 500 000.000 m and 15 500 000.000 m, respectively, while NAD83(CSRS)2010.0 MTM Zone 4 and Zone 5 false eastings are 24 500 000.000 m and 25 500 000.000 m, respectively. Although NAD83(CSRS)1997.0 MTM coordinates were generated for the original NSHPN, it is not anticipated that these values will be used on survey plans, since future work will be conducted in NAD83(CSRS)2010.0.

UTM values are also still published for large scale work and mapping applications. UTM coordinate values were not published in the NSCCS and consequently the risk of mistaking UTM coordinates in different datum is less likely.

Coordinate Calculations

With limited geodetic capacity, it is critical that coordinate calculations are kept to a manageable workload to sustain the NSCRS. In the modernized system, more onus is placed on system users and on network real-time kinematic processing technology to provide coordinate updates. By integrating quality control mechanisms, manual data processing can be kept to a minimum.

Based upon field experience with NRTK using the NSACS, it has been found that 10-minute GNSS observation sessions can routinely provide accuracies of ±2 cm horizontally and ±3 cm vertically, or better, in good GNSS conditions. These coordinates can be submitted by users and combined with other observations to produce highly accurate values.

The sourcing of coordinate data from a targeted user group (NSLSs) provides some assurance of the quality of the data. Photo evidence helps identify possible error sources relating to the equipment setup and hardware. Other quality control is used to identify duplicate data entries, data submissions for wrongly identified NSCMs and for outlier observations. In the case of a detected outlier, post-processing can be performed using the user's submitted 1-Hz raw observation data to further investigate the submitted coordinate values.

Although standard deviation and error ellipse information are sourced in the coordinate data submissions, inconsistencies between GNSS manufacturers in estimating coordinate uncertainties does not allow for a homogenous combination of coordinate data using covariance matrix weighting. Instead, coordinates are combined using a weighted average based upon session length where the unit weight is based upon a 10-minute observation session.

Coordinate Uncertainties

In Nova Scotia, coordinate values have not historically been published with uncertainty values. In the modernized system, uncertainties are published to provide the user with an indication of coordinate quality. As previously mentioned, inconsistencies exist between GNSS manufacturers when estimating coordinate uncertainty. Uncertainty values calculated by one manufacturer may be more than five times smaller or larger than those calculated by another manufacturer when observations are made in the same environment. An alternative estimation technique was required to provide users with a value reflecting accuracy rather than precision.

Based upon hundreds of GNSS observations using NRTK and the NSACS, it has been determined that for a 10-minute observation session, a coordinate uncertainty of ±2 cm horizontally and ±3 cm vertically can routinely be achieved in good GNSS conditions. Observations near an ACS can provide better accuracy, but to simplify the estimation, a single value was used to reflect regions of the NSACS distant (greater than 20 km) from an ACS. Consequently, some coordinate uncertainty estimates may be pessimistic. Equations 2 and 3 can be used to estimate the horizontal component and vertical component uncertainties of coordinates calculated through this process, where S is the session length in minutes. For example, a 40-minute session would result in horizontal component and vertical component uncertainty estimates of ±10 mm and ±15 mm respectively.

$$\sigma_{horizontal}\left[mm\right] \cong \pm\sqrt{\frac{\left(20\left[mm\right]\right)^2}{S\left[min\right]/10\left[min\right]}} \qquad (2)$$

$$\sigma_{vertical}\left[mm\right] \cong \pm\sqrt{\frac{\left(30\left[mm\right]\right)^2}{S\left[min\right]/10\left[min\right]}} \qquad (3)$$

The estimation model has weaknesses since it does not account for increased error introduced by site conditions, which normally are reflected in the variance-covariance matrix, and it does not account for location within the NSACS network. It does, however, provide users with a reasonable estimate of accuracy based upon expected performance and session length. Post-processing of all raw data using scientific software would allow a rigorous accuracy estimate to be obtained for coordinate values, although even these estimates tend to be overly optimistic. Additionally, the time commitment required to do this is not sustainable for a single resource.

Outlook

For the NSCRS modernization effort to be considered a success, adoption of the implemented technologies and strategies by the surveying community must occur. The main indicator that this has taken place will be when the majority of survey plans submitted for registration are coordinated in NAD83(CSRS). Increased operational efficiencies introduced by the modernized system should promote this migration.

To further support the migration from ATS77 to NAD83(CSRS), an accurate transformation tool is required. A grid shift file is currently available to transform between ATS77 and NAD83(CSRS) 1997.0 with an average accuracy of approximately ±15 cm. Preliminary testing of a new grid shift file that was developed using data collected in southwest Nova Scotia has indicated that an average transformation accuracy of ±5 cm may be attainable [*Gale and Kaul* 2016]. Once the NSHPN densification effort is completed in central and northern Nova Scotia over the upcoming months, a new grid shift file that encompasses the whole province will be developed.

Although the modernization effort has focused on meeting the needs of the surveying industry, other significant economic opportunities can be realized through machine automation using the NSACS. The technology is currently being used on highway construction projects to achieve finished grade much more quickly than using traditional stakeout methods. The blades of graders are being automatically guided to follow predetermined digital elevation models. Similar opportunities exist for precision agriculture and autonomous navigation. A dedicated education and awareness effort will be required to fully realize the potential of the technology.

Summary

In 2012, the Province of Nova Scotia began an effort to modernize its coordinate referencing program to address the needs of its users. ACS technology was the foundation of the modernization effort. The infrastructure presented new opportunities for delivering high-accuracy positioning throughout the province.

The pursuit for millimetre-level accuracy with GNSS requires meticulous attention to detail. It is only now, with the 40 ACSs comprising the NSACS network installed, that an appreciation can be had for the technical considerations required in implementing such a system. Several important lessons have been learned from this initiative:

a) Designing an ACS network with station failover redundancy by limiting ACS spacing can significantly reduce operational stresses. A trade-off occurs between increased redundancy and increased cost.
b) For the most precise engineering applications, 3D position time series can be used to calculate offsets from published ACS values, which can be applied as position corrections.
c) In this scenario, it made the most sense to bring data from each ACS to a central point for distribution instead of distributing several data streams directly from the GNSS receiver. This reduced bandwidth requirements at the host ACS site.
d) Targeted crowd sourcing of surveyors provides an effective means of updating and maintaining passive control. By building quality control mechanisms into the crowd sourcing interface (e.g., sourcing appropriate photos, checking that entry values are within range), the integrity of the coordinate updates can be upheld.
e) Crowd sourced variance-covariance matrix information is inconsistent between manufacturers. Alternative means of estimating coordinate uncertainty are required to provide system users with reasonable accuracy estimates.

Through this modernization effort, new efficiencies have been gained for delivering coordinate referencing capabilities in the province. Infrastructure and software tools have been put in place to allow stakeholders to contribute to the maintenance of the system through minimal additional work. The higher-functioning system will lead to better spatial data and a more accurate boundary fabric for the province.

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References

Bond, J. 2012. Association of Nova Scotia Land Surveyors (ANSLS) survey on the NSCRS. Internal document Department of Service Nova Scotia and Municipal Relations.

Bond, J. and W. Robertson. 2015A. The evolution of Nova Scotia's coordinate referencing systems. *Geomatica.* 69(4): 407-418.

Bond, J. 2015B. Modernization of the Nova Scotia coordinate referencing system through active control technology. *Geomatica.* 69(4): 419-431.

Bond, J. 2016. Best practices for GNSS NRTK service providers operating in Nova Scotia. Department of Internal Services, Province of Nova Scotia. *https://geonova.novascotia.ca/coordinate-referencing*

Craymer, M. 2015. Personal communication. Reference Frames and Earth Dynamics Coordinator, Canadian Geodetic Survey, Natural Resources Canada.

Gale, D. and B. Kaul. 2016. Development of an updated grid shift file for southwest Nova Scotia. University of New Brunswick Technical Report in fulfillment of GGE 4700.

NGS. 2013. Guidelines for new and existing continuously operating reference stations (CORS). National Geodetic Survey, National Ocean Survey, NOAA, Silver Spring, MD 20910, January 2013. *http://geodesy.noaa.gov/CORS/Establish_Operate_CORS.shtml*

Trimble. 2016. Trimble NetR9 Datasheet. *http://trl.trimble.com/docushare/dsweb/Get/Document-689228/022506-128G_NetR9_DS_4pnl_0815_LR.pdf*

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