Migrating from ATS77 to NAD83(CSRS) in Nova Scotia

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Since the late 1970s, the foundation for all survey work in Nova Scotia has been the Nova Scotia Coordinate Control System (NSCCS), which is based upon the Average Terrestrial System of 1977 (ATS77). In the early 2000s, some provincial mapping layers were migrated to the North American Datum of 1983 (based upon the Canadian Spatial Reference System (NAD83(CSRS)), but many still utilize ATS77. In 2012, the province began modernizing its Coordinate Referencing program using Global Navigation Satellite Systems (GNSS) and implementing Active Control Stations (ACSs).

The installation of 40 ACSs across the province between 2012 and 2015 enables the surveying community in Nova Scotia to migrate to NAD83(CSRS) by addressing ongoing accuracy and accessibility needs. The technology has allowed the passive, NAD83(CSRS)-based, Nova Scotia High Precision Network to expand to more than five times its original size. This densification effort has also allowed the transformation model between the two datums to be enhanced.

With the geodetic infrastructure in place, the current primary need is for knowledge and methodologies to facilitate the transition. Two options are presented to aid surveyors and mappers in migrating data from ATS77 to NAD83(CSRS). The first approach utilizes a newly developed grid shift file intended for transforming mapping data and aiding surveyors in relocating boundary evidence, so that it can then be remeasured in NAD83(CSRS). A detailed discussion is provided on the development of grid shift file. The second approach is based upon the derivation of a set of local transformation parameters using a one-to-one sampling of the control monuments used in the historic survey.

Depuis la fin des années 1970, le fondement de tout travail d'arpentage en Nouvelle-Écosse a été le Nova Scotia Coordinate Control System (NSCCS) [système de référencement des coordonnées de la Nouvelle-Écosse] qui est fondé sur le Système de référence terrestre moyen de 1977 (ATS77). Au début des années 2000, certaines couches cartographiques provinciales ont été migrées vers le Système de référence nord-américain de 1983 (qui reflète le Système canadien de référence spatiale [NAD83(SCRS)]), mais plusieurs personnes utilisent encore le ATS77. En 2012, la province a commencé à moderniser son programme de référencement des coordonnées en utilisant le Système mondial de navigation par satellites (GNSS) et en implantant des stations de contrôle actif (ACS).

L'installation de 40 ACS partout dans la province entre 2012 et 2015 permet à la communauté de l'arpentage de la Nouvelle-Écosse de migrer vers le NAD83(SCRS) en répondant aux besoins actuels d'accessibilité et de précision. La technologie a permis au Réseau passif de haute précision de la Nouvelle-Écosse, fondé sur le NAD83(SCRS), de s'étendre à plus de cinq fois sa taille originale. Cet effort de densification a également permis d'améliorer le modèle de transformation entre les deux systèmes de référence.

Avec l'infrastructure géodésique en place, le principal besoin actuellement est que les connaissances et les méthodologies facilitent la transition. Deux options sont présentées pour aider les arpenteurs et les cartographes à migrer les données du ATS77 vers le NAD83(SCRS). La première approche utilise un fichier nouvellement développé de déplacements des points du quadrillage pour transformer les données cartographiques et aider les arpenteurs à relocaliser les preuves de délimitation de façon à ce qu'elles puissent être ensuite mesurées à nouveau dans le NAD83(SCRS). Cet article comprend une discussion détaillée sur le développement du fichier de déplacements des points du quadrillage. La seconde approche émane de la dérivation d'une série de paramètres de transformation locale utilisant un échantillonnage biunivoque des bornes de contrôle utilisées dans l'arpentage historique.

Introduction

Nova Scotia's Coordinate Referencing program is responsible for providing the tools, knowledge and expertise required to enable accurate positioning in the province. It provides the foundation for all survey work, which in turn feeds Nova Scotia's Land Registry system. The program has existed since 1968 and has undergone many changes over this period [*Bond and Robertson* 2015].

In the late 1970s, the Nova Scotia Coordinate Control System (NSCCS) was established through a collaborative effort by the Maritime province's Land Registration and Information Service (LRIS). Over 23 000 Nova Scotia Control Monuments (NSCMs) were installed and measured to provide a comprehensive framework for coordinating property surveys across the province (Figure 1). The system was based upon the Average Terrestrial System of 1977 (ATS77) and was realized primarily using theodolite and electronic distance measurement (EDM) technology.

With the advent of the Global Positioning System (GPS) in the 1980s, the new technology began to reveal distortions in the NSCCS. In the late 1990s, the province implemented a GPS-based system known as the Nova Scotia Coordinate Referencing System (NSCRS) to better support the technology. The passive control monument framework used to realize the NSCRS is referred to as the Nova Scotia High Precision Network (NSHPN). There were 153 NSHPN control monuments established by 2000. Coordinates for the NSHPN were derived from the federal Canadian Spatial Referencing System (CSRS) control network, which utilized the North American Datum of 1983 (NAD83) (referred to as NAD83(CSRS)). The distortions between ATS77 and NAD83(CSRS) are analogous to those seen between the original realization of NAD83 (NAD83(Original)) and NAD83(CSRS) in other parts of Canada.

The less dense NSHPN meant that it was typically more time consuming to relate property surveys to it than to the older framework of the NSCCS. Despite its inferior accuracy, the NSCCS's superior accessibility would extend its use into the 2010s. Over time, many of the original 23 000 NSCMs have been destroyed through construction and natural causes. Once a NSCM is destroyed, the ability to directly observe it in NAD83(CSRS) is lost, eliminating the possibility of defining a direct mapping relationship from ATS77 to NAD83(CSRS).

In 2012, the province began developing a strategy to better execute its Coordinate Referencing program [*Bond* 2015A; 2015B]. The primary focus of the strategy was to provide the surveying community with better access to accurate coordinates in the NAD83(CSRS) datum. This would enable surveys in Nova Scotia to be consistent with the rest of Canada and would minimize the impact of ATS77 distortion on future survey work.

At the core of the strategy were Global Navigation Satellite Systems (GNSS) Active Control Stations (ACSs). By placing these permanent GNSS installations across the

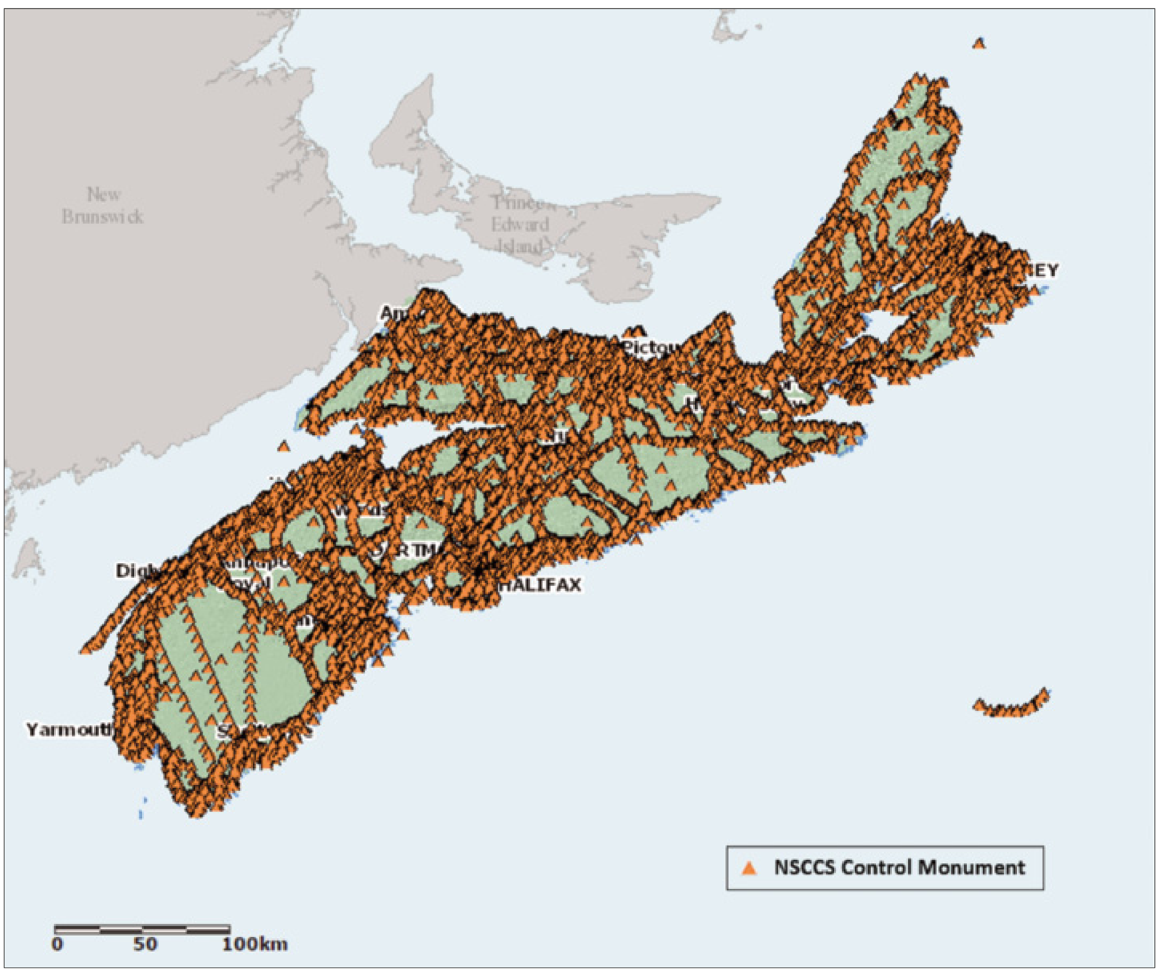

Figure 1: Nova Scotia Coordinate Control System.

province, the surveying industry gained the ability to access real-time, centimetre-level positioning. 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 are also made available for post processing.

The NSACS enables the province to fully migrate from ATS77 to the NAD83(CSRS) by addressing accessibility and accuracy needs. Surveyors in Nova Scotia are now producing survey plans in NAD83(CSRS). A historic moment for the surveying community occurred on October 14, 2016, when the Association of Nova Scotia Land Surveyors (ANSLS) voted in favour of fully migrating to NAD83(CSRS) by December 31, 2017.

In addition to the NSACS, two other needs were identified to facilitate the migration to NAD83(CSRS): a) a densified NSHPN with approximately 10 km spacing in rural areas to enable quality control and conventional base rover setups checks for RTK surveys; and b) tools and techniques to allow historic survey plans and GIS data layers to be migrated from ATS77 to NAD83(CSRS) 2010.0. An extensive database of survey plans produced over the past 35 years exists and it was deemed important to be able to easily leverage that information while working in the NSCRS.

Since 2014, the NSHPN has increased from 161 to 788 NSCMs. Figure 2 illustrates the NSHPN in its current state, which was updated using the NSACS. Most of these NSCMs have coordinates in both the ATS77 and NAD83(CSRS) datum. It was hoped that by significantly increasing the number of sample points, an accuracy suitable for locating boundary evidence would be achieved by the transformation.

This paper discusses two options for migrating spatial data sets from ATS77 to NAD83(CSRS) 2010.0 in Nova Scotia, depending upon desired accuracy. The first approach utilizes a newly developed grid shift file. Although sub-decimetre level accuracy can normally be attained, there are instances where unmodelled biases may introduce biases of up to 1 m. This approach is therefore generally reserved for migrating mapping data sets and for relocating boundary evidence. The second technique leverages new geodetic infrastructure in the modernized NSCRS (NSACS and densified NSHPN) to directly re-observe control monuments used in ATS77-based surveys. This is the only way to reliably model the distortion in ATS77 with a survey grade accuracy of ± 2 cm.

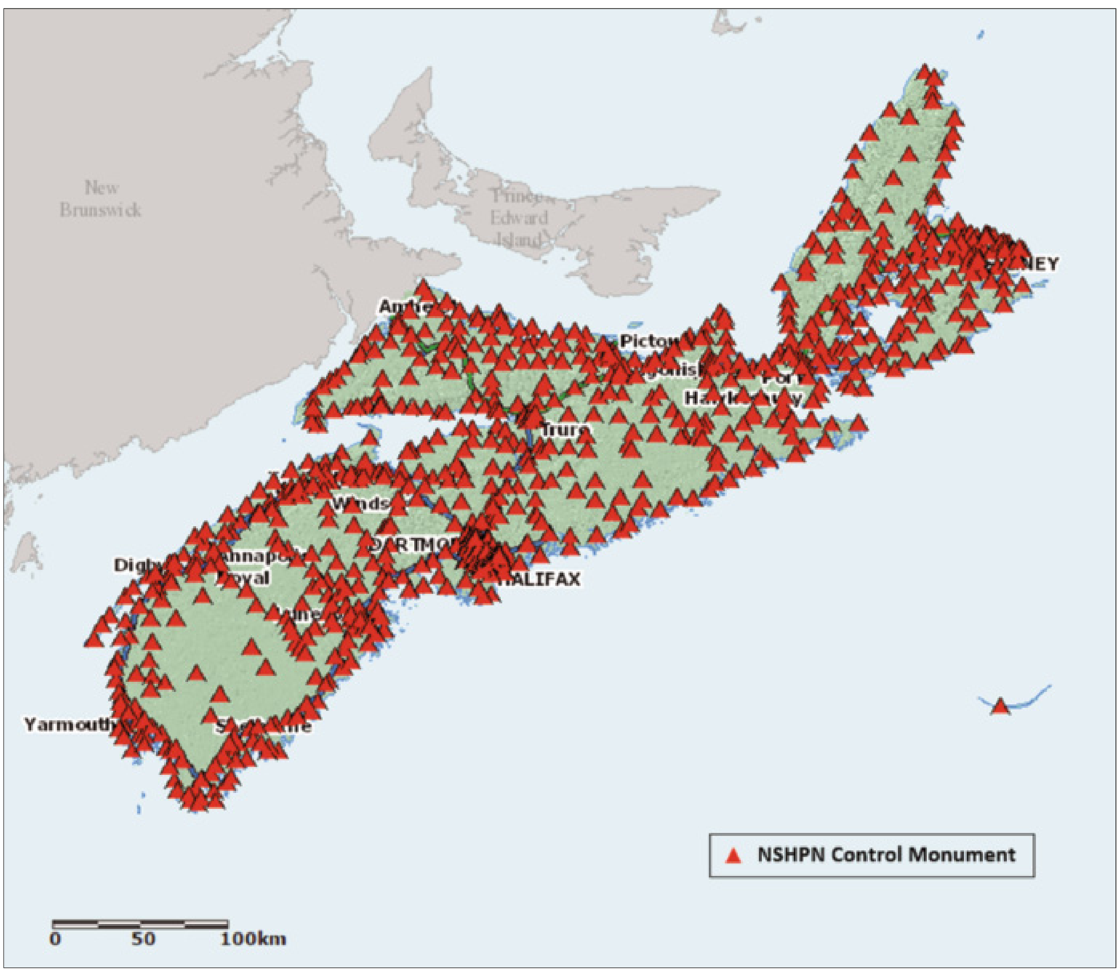

Figure 2: Nova Scotia High Precision Network control monument locations.

Development of Version Two of the Grid Shift File

Various techniques exist for developing a set of transformation parameters to move between geodetic datums. Typically, a set of parameters, which may include shifts, rotations and scale estimates, are utilized. Bursa-Wolf [*Bursa* 1962; *Wolf* 1963], and Molodensky-Badekas [*Molodensky et al.* 1962; *Badekas* 1969] are 3-dimensional coordinate transformations that are commonly employed. Such transformations work well when using sets of coordinates that have homogenous accuracies in both datum.

For this application, the coordinates are not of similar accuracies in both datum. Distortions of several decimetres are present in the ATS77 coordinates, whereas the GNSS-derived NAD83(CSRS) coordinates have consistent accuracies of a few centimetres across the province. The transformation model must account for these distortions.

A similar situation was encountered during the migration from the North American Datum of 1927 (NAD27) to NAD83 in Canada, which led to the development of a suite of software applications by the Geodetic Survey Division (now Canadian Geodetic Survey (CGS)) in the late 1980s and early 1990s. The applications are collectively known as the National Transformation version 2 (NTv2). Distortion modelling was based upon a software application known as Estimation of Secondary Terrestrial Positions for Mapping (ESTPM) [*Blais* 1979]. A second version of ESTPM (ESTPM2) was later developed to enhance distortion modelling capabilities [*Junkins* 1990].

In modelling the transformation, the approximate 3-dimensional relationship between datums is first defined. Predefined values exist in the software. For example, the default transformation parameters between ATS77 and NAD83 in the software are: dX = 0.0 m, dY = 0.0 m, dZ = 4.5 m, rotX = 0.0 s, rotY = 0.0 s, rotZ = 0.164 s, and scale factor = 0.4 ppm. Values can also be estimated by specifying the reference ellipsoid for each datum and by providing sample points that have coordinates in each datum. Ellipsoidal heights are set to 0 for the estimation calculation.

Once the approximate relationship is defined in three dimensions, ESTPM2 is used to model the remaining distorting in two steps using least squares estimation. In the first step, a complex 2-dimensional polynomial is used to model broad trends in the displacements. The user must specify the degree of the polynomial to be used. For example, degree 0 allows for a shift along each axis, degree 1 allows for the shift and a linear scale of each axis, degree 2 allows for a quadratic effect along each axis and degree 3 allows for a cubic effect. Higher order polynomials can more closely fit local phenomenon, but run the risk of diverging from the global fit in extrapolation areas [*Junkins* 1998]. Equation 1 illustrates the 2nd degree 2-dimensional polynomial used in this work. In the second step, remaining differences are modelled locally using a Gaussian weighting function (weighted mean) for each point. Residuals are reported at each point for analysis purposes. For more details on ESTPM2, see *Junkins* [1998].

$$d(x,y) = \alpha_0 + \alpha_1 x + \alpha_2 y + \alpha_3 x^2 + \alpha_4 xy + \alpha_5 y^2 \qquad (1)$$

Where: d(x,y) = distortion at location x, y

With the distortion model defined, a base grid is defined in terms of extent and node spacing. Horizontal shifts are calculated and assigned to the grid nodes using the approximate relationship between the datum. These shifts are then fine-tuned using the ESTPM2 distortion model. The 2-dimensional differences between the original and the transformed grids are the primary output from this estimation process, known as a grid shift file. NTv2's capabilities to handle distortion in the estimation of a transformation model made it a suitable tool for this task. The general steps involved in generating a grid shift file using the NTv2 software are summarized in Figure 3. For a discussion on other approaches for modelling distortion in coordinate transformations, see *Grgic et al.* [2015], *Yun et al.* [2006], and *Oliveria et al.* [2008].

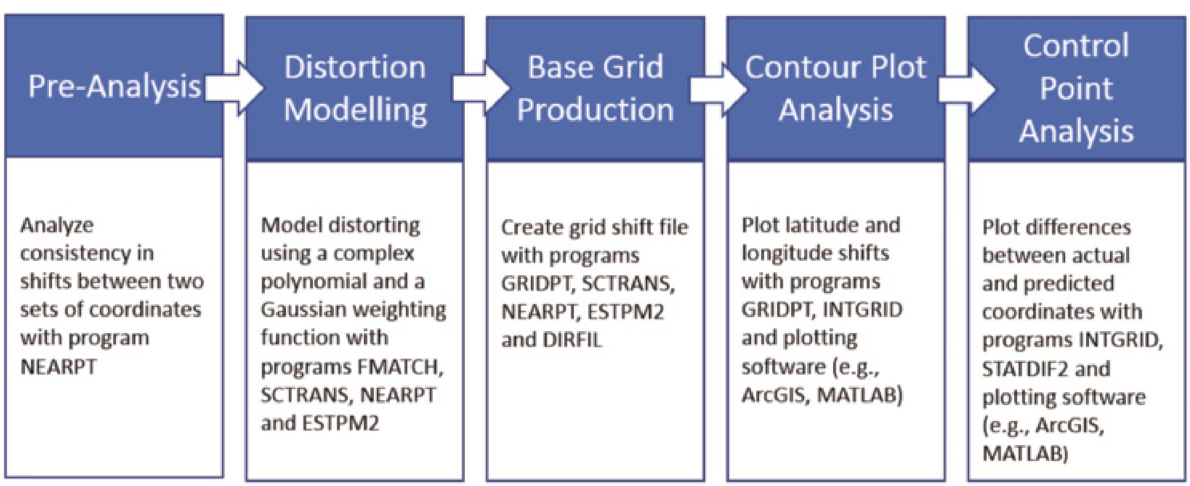

Figure 3: Process for generating a grid shift file using the National Transformation Version 2.

The Original Grid Shift File

In 2001, the province developed and released a grid shift file to transform between ATS77 and NAD83(CSRS) 1997.0. The file was named NS778301.gsb, where the gsb extension represents "grid shift binary." The transformation was calculated using 156 NAD83(CSRS) 1997.0 coordinate values and corresponding ATS77 coordinate values from the NSCCS.

With the recent migration to NAD83(CSRS) 2010.0 in Nova Scotia, it was desired to create a new version of the grid shift file to reflect the new NAD83(CSRS) epoch. Additionally, it was estimated that the average accuracy using the first version of the grid shift file was ± 0.10 m. It was desired to reduce this value to ± 0.05 m, roughly the diameter of a survey marker cap. It was hoped that by significantly increasing the number of sample points, this figure could be achieved.

Design Considerations for the New Grid Shift File

In producing a grid shift file, several factors impact the final product. Very different transformation results may be reached depending upon the approach used. Discussed are some of the key decisions that were made in creating an updated grid shift file for the province.

Distortion Modelling

As a first step, an approximate 3-dimensional datum transformation between ATS77 and NAD83 needed to be defined. The default transformation parameters in the software were used in the initial model. Secondly, the degree of the 2-dimensional polynomial used to model long-range trends not captured by the approximate datum transformation needed to be chosen. The recommendation in the NTv2 documentation was to analyze the change in root-mean-square (RMS) error of the model as the polynomial degree changes. In analyzing the RMS errors, the goal is to identify the point of diminishing returns by increasing the polynomial degree to lower the RMS values, while erring on the side of a lower order polynomial [*Junkins* 1998]. Table 1 summarizes the changes in RMS errors in estimating latitude and longitude as the polynomial degree changes from 0 to 8. A polynomial of degree 5 was used in the first model that was explored.

Being a coastal province, it was desired that the grid shift file could offer accuracy capabilities of ± 0.5 m or better in coastal waters. Without sample points offshore, it would not be possible to achieve significantly better. High Precision Network control points in New Brunswick (N.B.) and Prince Edward Island (P.E.I.) were used to assess accuracy in the offshore. An analysis of the first explored distortion model revealed significant divergence in the offshore areas. As a result, subsequent analysis focused on using lower order degrees of polynomials. Additionally, the possibility of using a custom 3-parameter datum transformation from ATS77 to NAD83 was investigated.

In the final distortion model employed by Version 2 of the grid shift file, a 3-parameter shift was estimated to define the approximate 3-dimensional transformation between ATS77 and NAD83. Table 2 illustrates the estimated shift parameters. A similar approach was leveraged in the original grid shift file, but the values differ slightly since approximately five times as many sample points were used in this estimation process.

In the final distortion model employed by Version 2 of the grid shift file, a 2-dimensional polynomial of degree 2 is used to model large-scale displacement trends. The original version of the grid shift file used a 2-dimensional polynomial of degree 1. The devised model has allowed the desired accuracy to be achieved in coastal waters.

Data Cleaning

The program NEARPT is part of the NTv2 software that allows for the analysis of the consistency of shifts in the immediate neighbourhood of the sample points being considered [*Junkins* 1998]. The major challenge in cleaning the data used in generating the distorting model is distinguishing between gross blunders or discrepancies and large random errors caused by measurement error propagation. Decisions can be subjective, since it is not uncommon to have points flagged as outliers that also have error ellipses larger than 15 cm. The purpose of the model is to capture the distortion, which means including as many points as possible that reflect

Table 1: Summary of root mean square errors relating to polynomial degree choice for distortion modelling.

Polynomial Degree	RMS Lat	RMS Long
0	0.224	0.293
1	0.221	0.208
2	0.203	0.191
3	0.201	0.191
4	0.190	0.185
5	0.175	0.173
6	0.173	0.173
7	0.168	0.172
8	0.165	0.173

Table 2: 3-parameter shift between ATS77 and NAD83(CSRS) 2010.0 (Earth centred, Cartesian values).

dX (m)	dY (m)	dZ (m)
2.26	2.33	3.87

reality. Points that may have moved since ATS77 coordinates were assigned (e.g., monument sliding into a ditch) should not be included in the modelling. In some cases it is not apparent if a monument has been disturbed.

Initial attempts to model the distortion resulted in over 25% of the points being flagged. Several models were implemented to investigate the impact of remedial actions. The following points were noted:

a) In removing flagged points from the model, it was not uncommon for new points to become flagged, which raised the question of whether anything had been gained. This was interpreted to mean that the removed point was a true measure of distortion and should be left in the model.
b) The only certain way to identify blunders was to sample neighbouring points in areas of high distortion by making new observations.
c) In some instances, removing a flagged point from the distortion model and replacing it with a new sample point nearby would improve the agreement between grid shift transformation values (predicted) and measured values. This was interpreted to mean that an outlier was found.

Grid Design

The grid shift file is based upon the sample points in Nova Scotia shown in Figure 4 and is not intended to be used for transformations in neighbouring provinces. In these regions, better performance will be achieved by leveraging transformations designed by the respective provincial authority. The extents of the base grid used for this calculation are also illustrated in Figure 4.

The extents are slightly smaller than those employed in the original version to limit the possibility of use beyond the intended region. Another key difference from the previous version is that the grid spacing has been reduced from a 2-minute grid to a 30-second grid. The higher resolution allows for finer distortion modelling, especially in urban areas where sample points may be separated by only hundreds of metres.

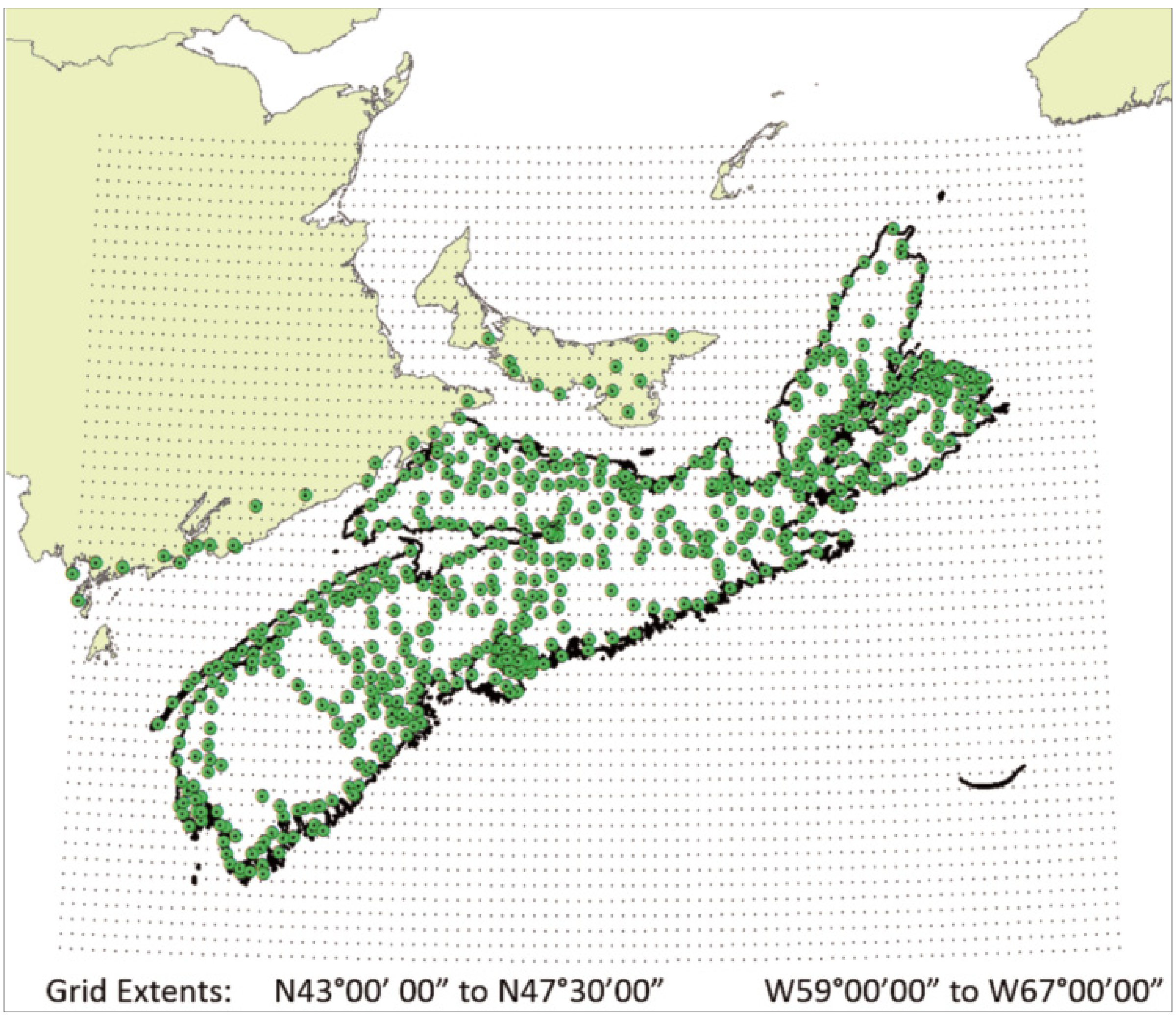

Figure 4: Grid shift file extents with sample points shown as green circles (scale ~1:2 500 000).

Performance Analysis

Before landing on a final version of the grid shift file, areas containing potential blunders were identified that would benefit from further point sampling. Additionally, other sites were chosen to provide a broad cross section of sample points across the province and to address existing deficiencies in NSHPN coverage. Figure 5 illustrates the distribution of the quality control (QC) points used in the accuracy assessment. With the NSACS technology enabling the observations, publishable coordinates for 136 points were generated over a 3-week period through a collaborative effort with the provincial Department of Natural Resources.

The performance of the grid shift file can be assessed by comparing observed and predicted NAD83(CSRS) 2010.0 coordinates for the points used in the modelling. Two scenarios were considered in assessing the performance of the grid shift file. In the first assessment, the QC points were not used in the distortion model. This results in a pessimistic estimate since the final model employed in the grid shift file does leverage these points. In the second assessment, all points including the QC points were used in the distortion model. This results in an optimistic estimate. The final distortion model used in the new version is based upon 888 sample points, including 17 points from N.B. and 12 from P.E.I.

In the first assessment, when the predicted NAD83(CSRS) 2010.0 coordinates were compared with the observed values, an average accuracy of ± 0.075 m was determined. Predicted values were also calculated using the original grid shift file (NS778301.gsb), for which an average agreement of ± 0.115 m was determined. Ten points in high distortion areas were removed from this accuracy estimate since the ATS77 coordinate values were flagged as blunders. The average agreement in these areas with high distortion was ± 0.850 m using the original grid shift file and ± 0.550 m using the new grid shift file.

In the second assessment, an average accuracy of ± 0.041 m was determined. The largest difference was 1.66 m, which occurred at NSCM 212527 in McArras Brook, north of Antigonish. Twenty-five points were identified as having gross errors and were removed from the average accuracy

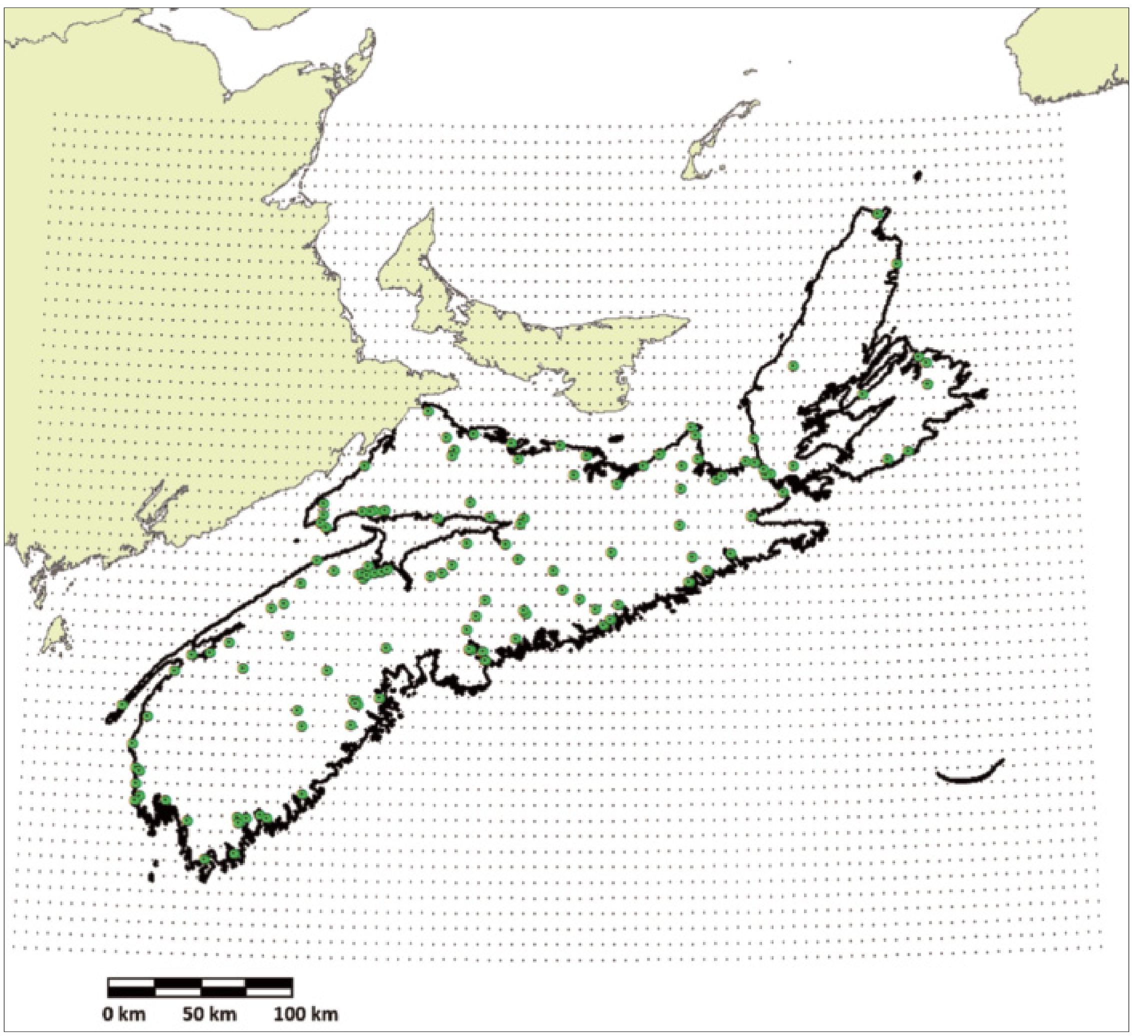

Figure 5: Grid shift file quality control points indicated by green circles.

calculation. Table 3 and Figure 6 summarize the distribution of accuracy of the points. Figure 7 illustrates the estimated accuracy at each point. Figure 8 and Figure 9 show contours of the latitude and longitude shifts applied by the grid shift file. Dense contours represent rapidly changing grid shift values and therefore probable areas of high distortion.

In the Halifax-Dartmouth-Bedford-Sackville region, 89 points were used to quantify performance. An average accuracy of ± 0.027 m was calculated with the largest difference being 0.26 m at NSCM 204968. In the Sydney region, 19 points were used to quantify performance. An average accuracy of ± 0.023 m was calculated with the largest difference being 0.08 m at NSCM 201411. As previously discussed, the above accuracy estimates are optimistic since the final model incorporates the test points.

Table 3: Distribution of grid shift accuracy.

Accuracy range	# Pts	%
0 cm ≤ Accuracy < 5 cm	642	72
5 cm ≤ Accuracy < 10 cm	155	17
10 cm ≤ Accuracy < 20 cm	63	7
Accuracy ≥ 20 cm	35	4

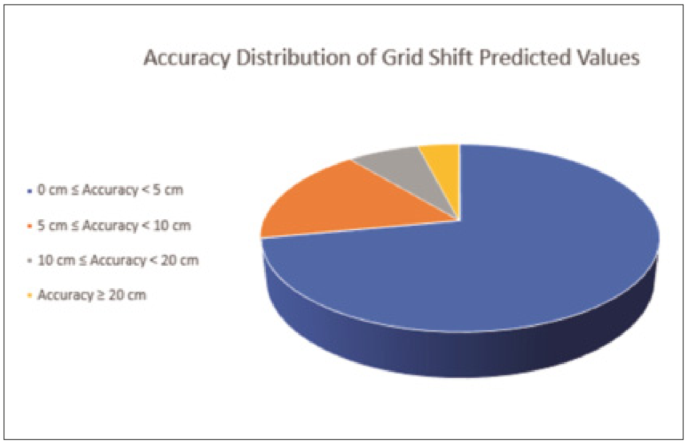

Figure 6: Accuracy distribution of grid shift predicted, coordinate values.

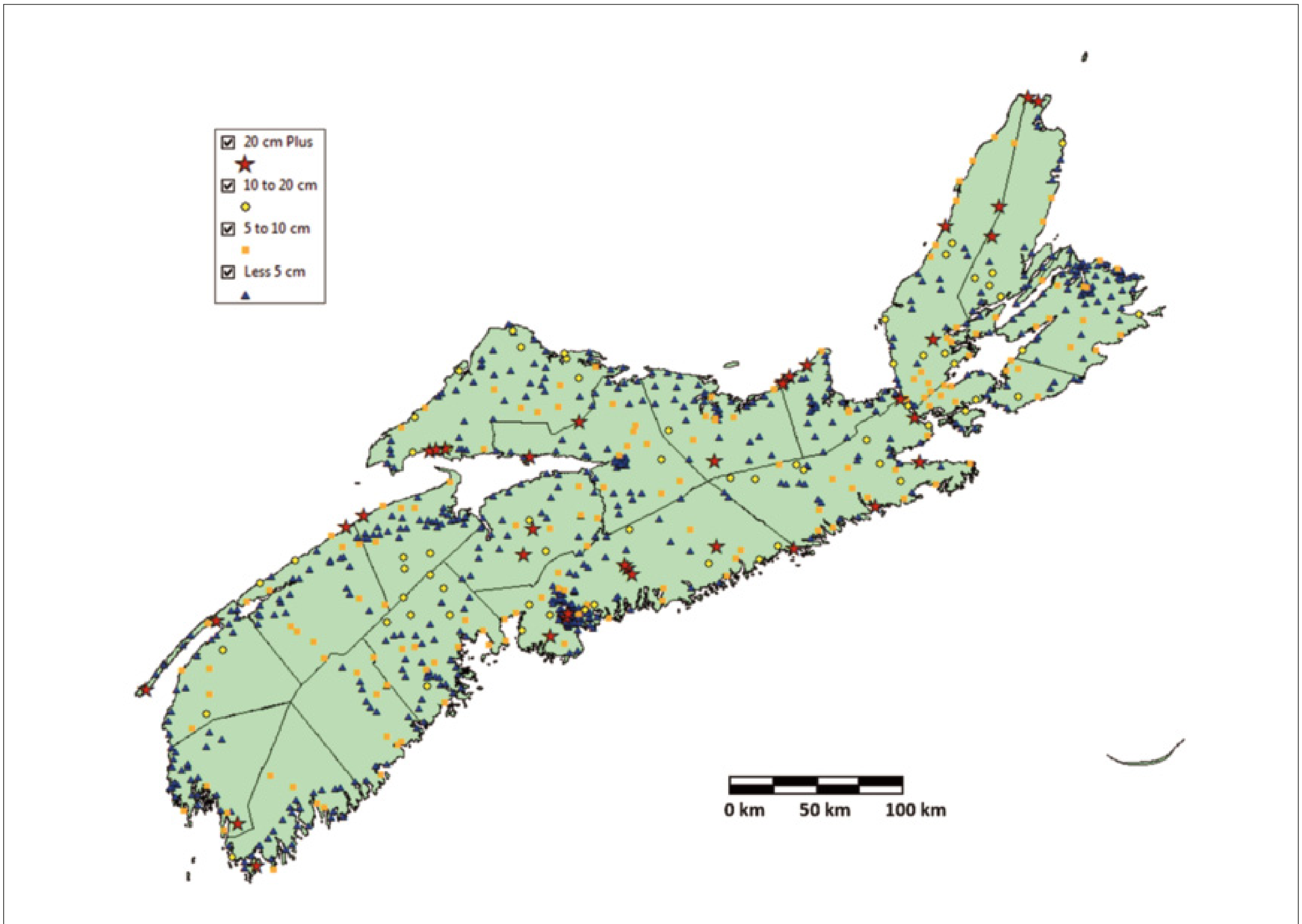

Figure 7: Differences between measured and grid shift transformed NAD83(CSRS) 2010.0 coordinates.

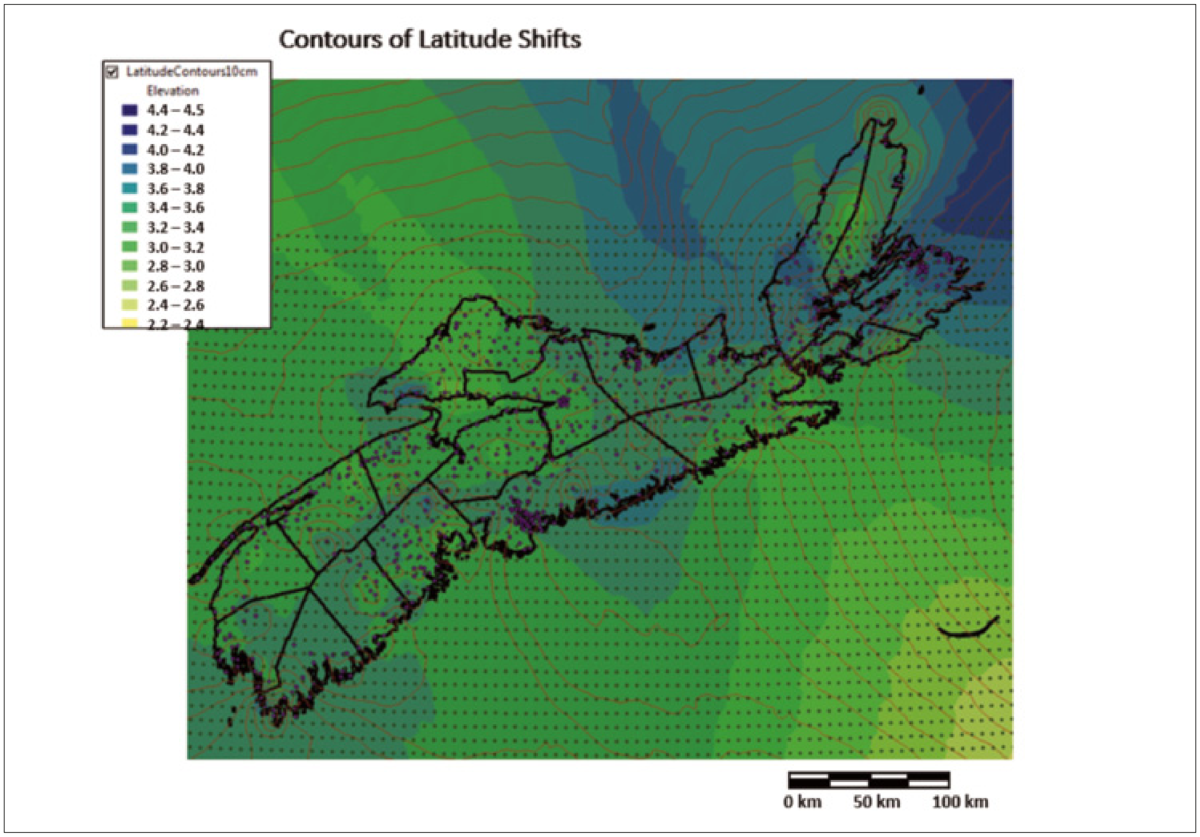

Figure 8: Contours of latitude shifts.

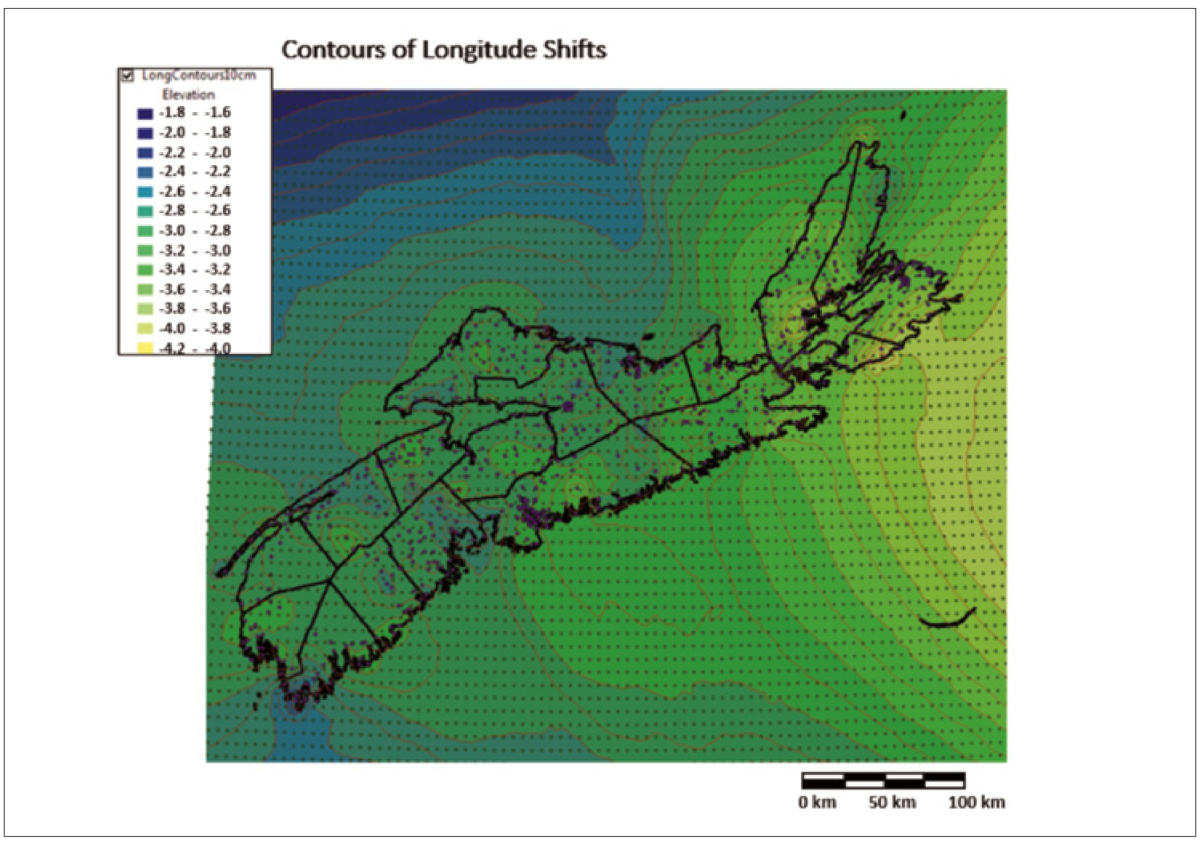

Figure 9: Contours of longitude shifts.

For comparison purposes, a 2-minute grid was also created and evaluated using the same distortion model. The 2-minute grid provided an average accuracy of ± 0.048 m. The main benefit in using the 30-second grid was that it accommodated regions which have a denser point sampling. The drawback is that it had a larger file size. The 2-minute grid is 0.5 megabytes in size, whereas the 30-second grid is 8 megabytes. NTv2 also allows a hybrid grid of varying densities to be stitched together, which allows higher accuracy to be achieved with smaller file sizes. The approach is more complicated and the additional effort required could not be justified given present capacities for memory storage.

A true statement of the accuracy of the new grid shift value likely lies between the optimistic estimate of ± 0.041 m and the pessimistic estimate of ± 0.071 m. This is on par with the targeted value of ± 0.050 m. Using the same sample points, the average accuracy of the original grid shift file was estimated at ± 0.115 m. An improvement in performance of approximately 50% has occurred using the new version.

In beginning this effort, it was hoped that by increasing the sample points threefold, the average accuracy would similarly improve. The number of sample points was increased by six times the number that was used in the first version of the grid shift file. Although significant improvement has been achieved, the findings of this effort indicate that a point of diminishing returns has been reached. The underlying distortion in the ATS77-based NSCCS limits further accuracy improvement in a general transformation model to NAD83(CSRS). To achieve a survey grade accuracy of ± 0.020 m in the transformation, there is no substitute for performing a direct sample of the previous control point. Even though the accuracy of the grid shift file may appear satisfactory in the area of interest, there is no way to know with certainty that another control point complies with the overall model without sampling it.

Grid Shift File Applications

There are three intended applications of the grid shift file:

Coordinate Transformation Web Service: The province's primary coordinate transformation tool will be updated to provide a transformation between ATS77 and NAD83(CSRS) 2010.0

Desktop Applications: The grid shift file will be made available for use with geographic information systems (GIS) and Computer-Aided Designed (CAD) software to facilitate the transformation of existing data sets.

Field Use: The grid shift file will enable boundary retracement surveys. Most Global Navigation Satellite Systems (GNSS) field controllers accept '.gsb' files or a converted form to enable real-time coordinate transformations in the field. The grid shift file allows surveyors working in NAD83(CSRS) to efficiently relocate boundary evidence coordinated in ATS77. Once located, the positions can be measured in NAD83(CSRS). Because the Modified Transverse Mercator (MTM) projection was used in the NSCCS and is also used with the NSCRS, bearings and distances can be directly compared in the two datum and should agree within the measurement precision of the instrumentation used. An exception occurs when underlying NSCCS distortion alters bearings. In this case, the measured angles and distances should still agree and can be used to validate relative location of boundary evidence. By assigning NAD83(CSRS) coordinates to the new survey plan, complications caused by the underlying distortion will be mitigated. Having accurate coordinates assigned to the boundary evidence will assist in re-establishing location in future surveys.

One of the limitations of the grid shift file is converting coordinates on projects following a straight line over long distances, such as transmission lines or highway construction. The grid shift transformation does not preserve collinearity that may have existed in the ATS77 datum [*Leblanc* 2016]. In such cases where it is critical to preserve the relative relationship between points, the techniques later discussed should be utilized.

Migrating Mapping Data

With an average accuracy of approximately ± 0.050 m being achieved by Version 2 of the grid shift file, it will serve as a useful tool for migrating provincial spatial data sets from ATS77 to NAD83(CSRS) 2010.0. In some circumstances where the distortion from ATS77 exceeds the accuracy of the base mapping layer, remedial action will need to be introduced on a case-by-case basis to reconcile differences.

For mapping applications where the base data layer may only have 1 m resolution or lower, an unmodelled 0.5 m distortion in the grid shift file may not be significant when overlaying features. Presently, mapping imagery with decimetre-level resolution can be captured. The imagery being collected by the Nova Scotia Topographic Database program, for example, is of this quality and boundary lines shifted by distortion would be apparent when superimposed on this data layer. When higher levels of accuracy are required, the techniques described in the subsequent section may need to be employed.

Migrating Survey Plans

In analyzing the performance of the new grid shift file, it is apparent that discrepancies of over 0.2 m exist between a small number NSCMs in the province. In the example illustrated in Figure 10, the same property is surveyed in ATS77 with a total station using two different sets of NSCMs. The example illustrates a translation in the results caused by a large distortion between the pairs of NSCMs. The distortion could also be more complicated by including rotation effects, but is kept simple here for illustrative purposes. The solid property line represents the boundary location as measured from NSCMs 1 and 2, while the dashed property line represents the boundary location as measured from NSCMs 3 and 4. The relative shape of the boundary is the same regardless of the set of NSCMs used. Both surveyors would have met surveying standards of practice with respect to traverse closure errors.

For guaranteed survey grade accuracy when migrating ATS77-based survey plans, distortion must be quantified for each NSCM used in the survey by observing it in NAD83(CSRS). In the simplest case, a single NSCM was used to conduct an ATS77 survey through a GNSS base/rover setup. The survey plan generated from this survey could be migrated by determining NAD83(CSRS) coordinates for the original base station. A 3-parameter shift could then be calculated and applied to all points on the survey plan. If GNSS base/rover setups were used on different NSCMs during a survey, the above procedure can be repeated for each NSCM setup.

If a network adjustment was used to calculate ATS77 coordinates on a survey plan using multiple NSCMs, then local transformation parameters will need to be estimated using these NSCMs. Analysis will be required to determine the number of transformation parameters required (i.e., translation, rotation and scale) to meet accuracy requirements. The quality of the transformation will be limited by the variability in distortion amongst the NSCMs used.

Complications arise with these approaches when the NSCMs used in the ATS77 based survey are no longer usable (e.g., they are disturbed, destroyed or overgrown). In such circumstances, the coordinated evidence on a survey plan (e.g., survey markers) may be observed to help derive the required transformation parameters. Depending upon the size of the survey, it may be more efficient and the results more reliable to re-survey the project in NAD83(CSRS) 2010.0, then to derive transformation parameters from field evidence and apply them. Once a survey is migrated to NAD83(CSRS), it is no longer dependent upon NSCMs for re-establishing coordinates.

To prevent distortion from the NSCCS from appearing in NAD83(CSRS)-based survey plans, NAD83(CSRS) coordinates derived from either a grid shift file or from a local transformation should not appear on a survey plan. Only observed NAD83(CSRS) coordinates derived directly from the NSCRS or CSRS (using Precise Point Positioning) should appear on a survey plan. NAD83(CSRS) coordinates for NSCMs can be submitted online through the Coordinate Referencing Viewer to help further densify the NSHPN and expedite the migration process [*Bond* 2015B].

The ANSLS's decision to migrate survey work from ATS77 to NAD83(CSRS) 2010.0 comes at a critical juncture where base layer imagery can expose distortions in the NSCCS. By migrating to NAD83(CSRS), an order of magnitude in accuracy is restored between mapping and survey work. It will be necessary to update the process for maintaining the province's Crown Lands and Property Records databases so that survey plans submitted in NAD83(CSRS) 2010.0 retain their full accuracy and match mapping layers. This can only be achieved by maintaining the boundary fabric in NAD83(CSRS) instead of ATS77.

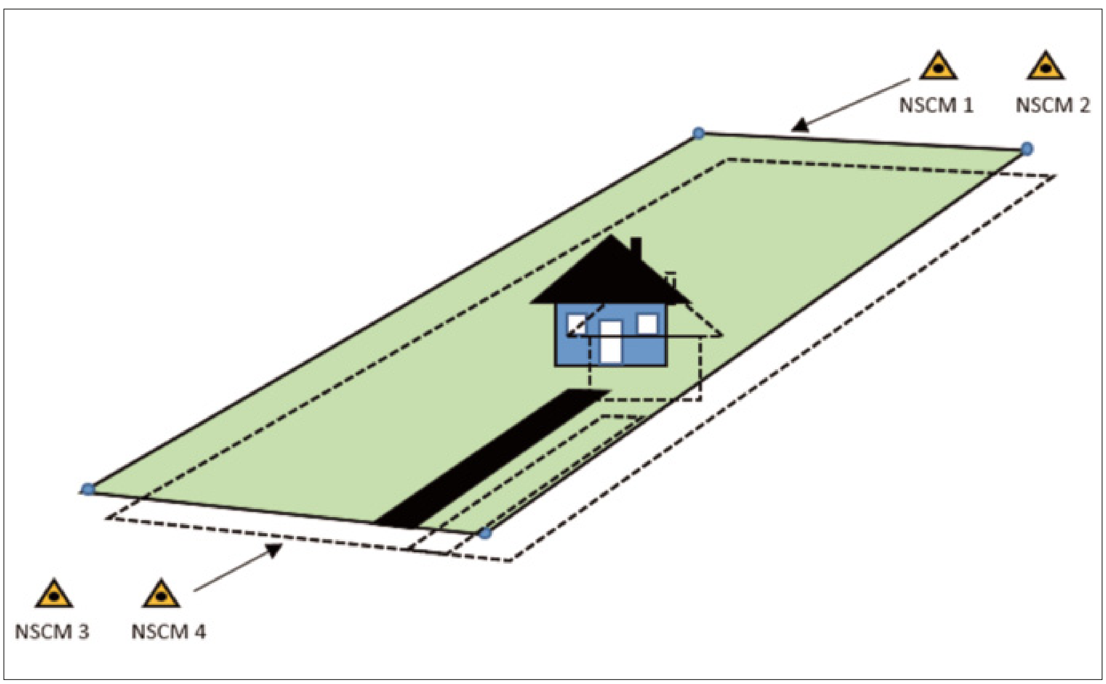

Figure 10: Two surveys conducted on the same property using different control monuments.

Table 4: Comparison of Version 1 and Version 2 of the NS ATS77 to NAD83(CSRS) Grid Shift File.

Characteristic	Version 01	Version 02
Name	NS778301.gsb	NS778302.gsb
Sample Points Used	127 NS, 17 NB, 12 PEI	859 NS, 17 NB, 12 PEI
Destination Datum	NAD83(CSRS) 1997.0	NAD83(CSRS) 2010.0
Estimated Accuracy	12 cm	5 cm
Polynomial Degree for Distortion Model	1	2
Nominal Shift Pararmeters for ATS77 to NAD83(CSRS)	dX = 2.20 m dY = 2.24 m dZ = 3.81 m	dX = 2.26 m dY = 2.33 m dZ = 3.87 m
Grid Extents	N 42°30’00” to N 48°00’00” W 58°30’00” to W68°00’00”	N 43°00’00” to N 47°30’00” W 59°00’00” to W 67°00’00”
Grid Spacing	2 minutes	30 seconds

Construction Surveys in Progress

In some cases, an existing project such as a new section of highway under construction may already be coordinated in ATS77. The layout of the project can still be conducted without having to modify the coordinates. If, however, one of the NSCMs upon which the design work is based becomes destroyed over the course of the project and the NSCM had significant distortion, there would be no way to replicate the design coordinates for that section of highway. For this reason, it is recommended that any NSCMs used on projects during this transition period be observed so that they have NAD83(CSRS) coordinates. By connecting the survey to the NSCRS, coordinates on the project site can be accurately re-established irrespective of NSCM.

Summary and Conclusion

A new version of the grid shift file has been created for transforming between ATS77 and NAD83(CSRS) 2010.0. By increasing the number of sample points by over six times what was used in Version 1, the updated grid shift file improves the overall accuracy of the transformation by approximately 50%. The estimated average accuracy for Version 2 is ± 0.050 m, although distortions of over 1 m exist. A point of diminishing returns has been reached in terms of achievable accuracy. Table 4 summarizes the characteristics of Version 1 and Version 2.

The grid shift file’s intended uses are to: a) facilitate the migration of mapping data from ATS77 to NAD83(CSRS) 2010.0, and b) enable the location of boundary evidence coordinated in ATS77 while working in the NSCRS. For applications that require a transformation accuracy of a few centimetres, direct observations of the NSCMs used to derive coordinate values on a survey plan are needed. When the NSCMSs no longer exist, the relationship may be derived by observing field evidence coordinated in ATS77. Although there may be additional work required initially in making the transition to NAD83(CSRS), the migration will eliminate the dependency upon NSCMs for re-establishing coordinate values and create long-term efficiencies.

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