Site transformations: simple is better

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Imagine you had the choice between a high-performance race car, a reliable ute or a DIY jeep that you've cobbled together in your own garage... which one would you pick? Well, the race car may be the height of German engineering, but will probably not be much fun on a 4WD track... you'd want the ute for that. Taking the DIY jeep for a spin on a German autobahn will almost certainly also end in tears. But at least, if it breaks down, you'll know exactly how to fix it!

The same principle applies to transformations. There are plenty of options to transform coordinates between different datums or reference frames. Some transformations are very rigorous and use lots of parameters, while others 'cut' corners and use simplifications. The selection of a particular transformation method very much depends on what you want to do with it.

In this article, we demonstrate that a simple block shift in Easting, Northing and Height is sufficient to transform Real Time Kinematic (RTK) or Network RTK (NRTK) observations obtained through CORSnet-NSW onto local ground control for surveys requiring centimetre-level accuracy, provided AUSGeoid09 is applied. We analysed an extensive dataset consisting of 2,200 occupations in seven study areas spread out over eastern NSW to come to this conclusion.

CORSnet-NSW

CORSnet-NSW is a rapidly growing network of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) providing fundamental positioning infrastructure for New South Wales that is accurate, reliable and easy to use.

To utilise CORSnet-NSW in concert with local ground control marks on public record in the state's Survey Control Information Management System (SCIMS) database, a site transformation is required. This process is also known by brand or industry specific terms such as site calibration, localisation, or a 'nudge'.

Site transformation

A site transformation accounts for any differences between the legal coordinate system as realised by SCIMS, i.e. GDA94(1997), and observations in the more homogenous GDA94(2010) realisation of the national datum as provided by CORSnet-NSW (see *Position* 50, Dec 2010).

It involves observing several established ground control marks of sufficient quality immediately surrounding (and, if present, within) the survey area. Existing local control in the survey area should not be ignored, provided it is of a quality that you deem 'fit for purpose'. The site transformation should only be applied to observations within the area encompassed by the control marks used (i.e. avoid extrapolation).

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A transformation is then calculated between the coordinates observed using CORSnet-NSW and the published local SCIMS coordinates. This is typically done via a menu tool in the GNSS rover software. Once the site transformation is found acceptable, it is automatically applied by the rover. Real-time GNSS positioning is then expressed in coordinates compatible with the existing local ground control network.

CORSnet-NSW users have several options in regards to which site transformation method is used. We compared three of these methods using Leica Viva GNSS equipment.

7-parameter similarity transformation

The well-known 7-parameter similarity transformation is the high-performance race car of transformations. It is based on Cartesian coordinates (X,Y,Z) and accounts for the difference between two, 3-dimensional reference frames. It applies seven parameters (three translations along the coordinate axes, three rotations about the axes and one scale factor) and preserves the relative shape of the network.

At least three common points (i.e. ground control marks) are required to determine the transformation parameters. All of these common points must be known in horizontal position and height. In this study, we performed the 7-parameter transformation by using the Leica 'Classic 3D' transformation.

Horizontal and vertical (hz & vt) transformation

This transformation can be interpreted as the reliable ute that doesn't need such a perfect working environment. It treats the horizontal and vertical components separately. As a result, it can mix and match control that is known in position and height, in position only or in height only. Another significant benefit of decoupling horizontal and vertical components is that any errors in the height control do not affect horizontal control (and vice versa).

The horizontal transformation applies coordinate shifts along the Easting and Northing axes, a rotation about the vertical axis and a scale factor. The height shift is generally based on a best-fitting, tilted plane through the available height control.

A minimum of three common points with 3-dimensional control information (or the equivalent distributed over a larger number of control marks) are needed to reliably determine the transformation parameters. It is also possible, if necessary, to use fewer common points by reducing the number of parameters determined. But fewer common points also means less redundancy.

This method provides some flexibility to the user because the same transformation tool can be applied for all jobs, regardless of how many control marks are incorporated. We performed this transformation by using the Leica 'Two-Step' transformation.

Block shift

This 3-parameter transformation is the minimalist DIY jeep that can easily be assembled in your own garage. It is simple, and you know exactly what each part is doing.

This transformation applies an average shift along the Easting, Northing and Height axes. Each component is treated separately, and neither rotation nor scale factor are determined. If necessary, as in areas of sparse control, only one common point is sufficient to determine the transformation parameters (albeit without any redundancy).

As with the hz & vt method, the same transformation method can be applied for all jobs, independent of how many control marks are incorporated. Nevertheless, it is strongly recommended and good practice to use all available control to determine reliable transformation parameters and avoid extrapolation.

Again, the decoupling of horizontal and vertical components means that errors in the height control do not affect horizontal control (and vice versa). We performed this transformation in a spreadsheet by simple (unweighted) averaging of the difference between raw CORSnet-NSW observations and the given control coordinates. The same results can be achieved in the field by using the Leica "TwoStep" method and setting scale and rotation parameters to zero, and the height model to "Avg Height Shift".

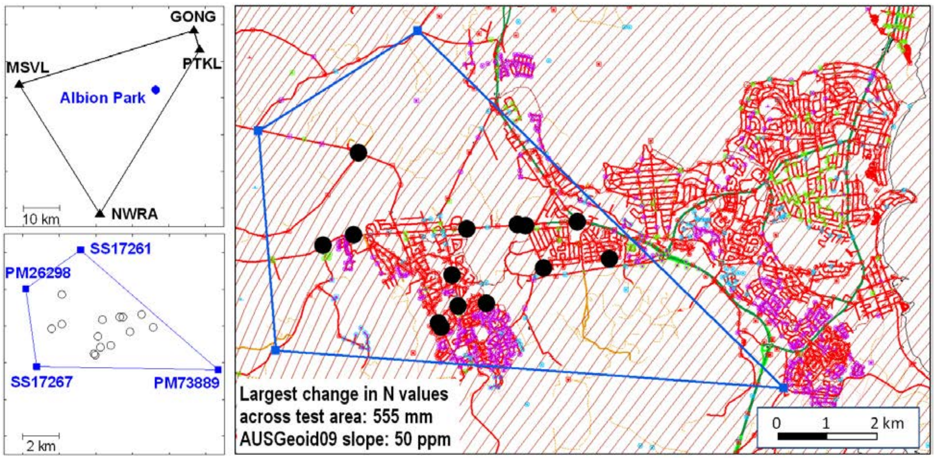

Figure 1. Albion Park test area, showing surrounding CORSnet-NSW sites (black triangles), site transformation points (blue squares), test points (black circles) and AUSGeoid09 contours (10 mm).

Dataset and testing areas

To compare the performance of these site transformation methods in a practical real-time scenario, we determined RTK and NRTK solutions on a number of established marks at seven different test areas distributed across eastern NSW.

Figure 1. shows one of these test areas, Albion Park. We selected at least four control marks of the highest class and order

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possible to calculate the site transformation parameters at each test area, and also selected a minimum of 11 established marks as test points.

We occupied all marks using both RTK and NRTK but only report on the NRTK results here. NRTK has the same 'look and feel' as single-base RTK and is just as easy to use, but provides better positioning results (see *Position* 56, Dec 2011).

The site transformation points were observed once each for 5 minutes (doing 7 independent rounds to determine 7 unique site transformations at each test area). The test points were occupied for 1 minute (each with 10 rounds of observations).

Note that this procedure is not best practice, but was used to highlight the effect of individual control observations on the resulting transformation. By repeating our testing multiple times, we knew we had enough occupations to identify outliers.

Instead, site transformation control points should always be occupied at least twice, for a minimum of 2 minutes using the averaging technique, as described in the new NSW Surveyor General's Direction No. 12 "Control Surveys and SCIMS". Obviously, the quality of the GNSS observations (and the SCIMS coordinates) on the control marks affects the coordinate output (rubbish-in-rubbish, out principle).

Initial comparison of transformation methods

For each test area, we determined the deviations from SCIMS in the horizontal (i.e. distance from official position) and vertical coordinate component. Figures 2a. and 2b. show the results for Albion Park when AUSGeoid09 was applied. Each transformation method is represented by a different symbol. For every test point surveyed, each of the ten 1-minute occupations is shown individually.

The 7-parameter transformation and the hz & vt transformation (blue circles and red squares) yield essentially identical results in both horizontal position and height. At several marks, the block shift transformation (purple triangles) provides slightly better agreement with SCIMS (circled in solid green). At other marks, the block shift performs slightly worse (circled in dashed black). The remaining study areas showed comparable results.

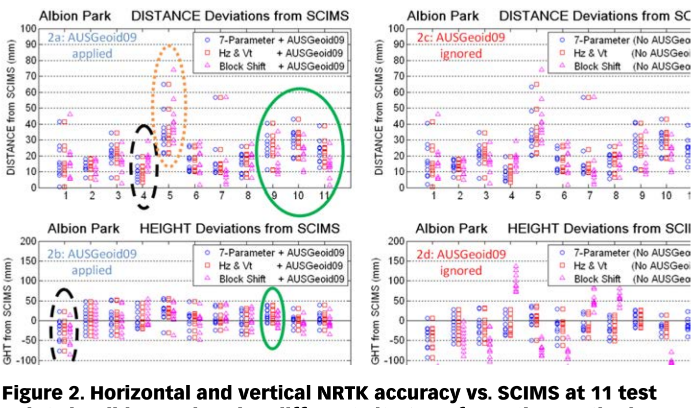

Figure 2. Horizontal and vertical NRTK accuracy vs. SCIMS at 11 test points in Albion Park, using different site transformation methods (with and without AUSGeoid09).

In isolated cases we found a consistent offset from the official SCIMS coordinates, regardless of the site transformation used (circled in dotted orange). This indicates a possible issue with the published SCIMS coordinates (e.g. due to mark movement) and shows that poor control can be identified with redundant observations.

Importance of AUSGeoid09

To investigate the effect of ignoring AUSGeoid09 in the site transformation process, we repeated the above analysis without the use of AUSGeoid09 (Figures 2c and 2d). As expected, the results for the horizontal component are almost identical for all three transformation methods when compared to those results obtained with AUSGeoid09.

Not surprisingly, however, there are significant differences in the vertical component, particularly in regards to the block shift. If AUSGeoid09 is ignored, the block shift in height is determined as the average difference at the site transformation control points between the GNSS-observed ellipsoidal heights and the official orthometric AHD71 heights stated in SCIMS.

Consequently, the block shift is unable to account for any changes in AUSGeoid09 values within the survey area. As this can lead to height errors of several decimetres, AUSGeoid09 should always be applied in the site transformation.

Repeatability and utility of site transformation parameters

We analysed the repeatability of transformation parameters by inspecting the parameters obtained from the seven unique site transformations performed in each test area.

Firstly, the 7-parameter transformation parameters are not intuitive in any way. They refer to Cartesian coordinate axes, with an origin at the centre of the Earth. All of the 7 parameters are large and vary considerably between repeated site transformations (e.g. several tens of metres in the translation parameters to account for cm-level differences at the measured marks).

The parameters for the other two transformation methods are much more intuitive, because they separate horizontal and vertical coordinate components and refer to grid coordinates. They are also much more repeatable, changing by only small amounts between different transformations. As a result, it is much easier to notice when something goes wrong and to detect 'unreasonable' parameters caused by incorrect measurement or control.

Applying a different site transformation generally results in only a small change to the transformed coordinates of the test points (at the cm level). However, this statement is only valid if no local distortion and no change in CORS coordinates and/or SCIMS coordinates has taken place between repeats.

In practice, it is strongly advised against using a site transformation that was calculated a considerable time before the survey takes place. It is GNSS good practice to perform (or confirm) a site transformation at the start of every real-time survey.

Effect of site transformation geometry

Did you know that adopting a site transformation (or changing to a new site transformation) can cause your transformed

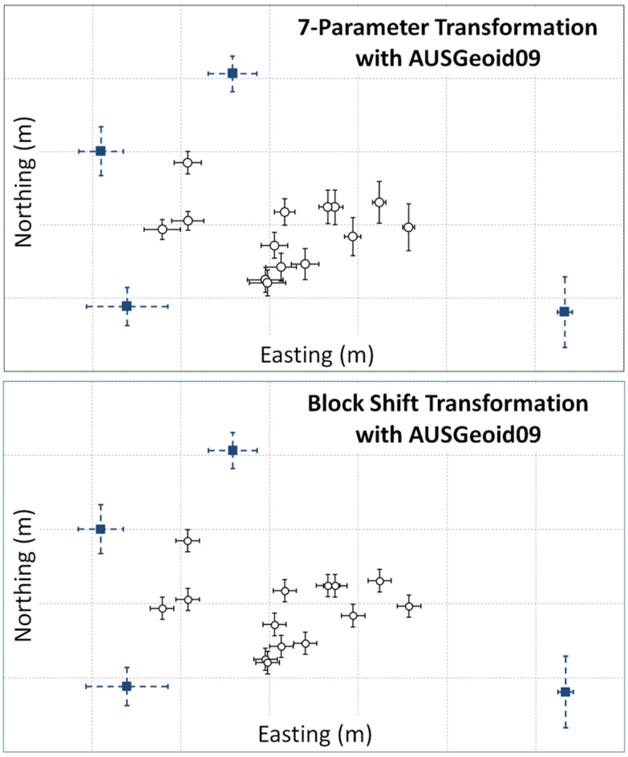

Figure 3. Variability of horizontal output coordinates at each test point (black circles), solely due to the geometry and observation variability of the control points (blue squares), in Albion Park. All 'error' bars are scaled to increase visibility.

coordinates to change by different amounts depending on their location relative to the control marks?

Figure 3. illustrates the difference in transformed coordinates that can result from changing the site transformation. The location of the control points is shown as blue squares with the variability of the seven control point occupations (one for each unique site transformation) indicated by 'error' bars showing the range of coordinates used to compute the transformation (i.e. raw point observations, with no transformation applied).

The location of the test points is shown as black circles with 'error' bars indicating the effect that the seven unique site transformations have on the transformed coordinates of a single occupation at each test point. All 'error' bars have been scaled (by the same amount) to improve visibility.

Both the 7-parameter and the hz & vt (not shown) transformations introduce variability in the transformed coordinates depending on the relative geometry of the control and test points. These two transformation methods are designed to stretch and skew the transformation in order to fit the observations (including their error) to the SCIMS coordinates (including their error) at the given control marks, by massaging any differences into extra parameters.

For example, the control point in the south-eastern corner of the test area exhibits a much larger variability in Northing than in Easting between the seven occupations. Since this particular control point is located at some distance from the others, the transformation is strongly rotated to accommodate any errors at this control point. As a result, the test points in the vicinity exhibit the same behaviour.

In contrast, the effect of the block shift is uniform across all test points (no scaling or rotating) and generally of a smaller range (better precision). Notably, the variation in transformed coordinates at the test points is independent of the geometry of the control points. It is the same for all test points in the area.

In practice, this means that applying a new block shift transformation will change all existing observations by exactly the same amount. Also, you can be confident that you know exactly what is happening to your coordinates!

Outlier identification at control marks

GNSS rover software generally reports the residuals of the site transformation calculation (at the control marks) to help the user identify outliers. These residuals are the differences in Easting, Northing and Height between transformed and given control point coordinates.

Because the block shift transformation does not scale or rotate the observations, it does not 'hide' any errors. Consequently, it is easy to identify control marks (or observations at those marks) that do not fit with other control nearby.

> *"… the DIY jeep that you know like the back of your hand is much more powerful than anticipated and has outperformed both the ute and the race car."*

In contrast, the 7-parameter and hz & vt transformations use additional scale and rotation parameters to fit the observations to the control marks as well as possible. This may 'hide' any existing outliers. With the limited (or minimum) number of control points often used to determine the site transformation, finding errors in observations or control coordinates is therefore more difficult (or impossible) with these two methods.

In the Albion Park test area, only the block shift transformation method was able to highlight an apparent error of 40 mm in the official position of one of the control marks. Even though this may be 'fit for purpose', such a mark should be used with caution in the site transformation. If possible, extra or alternative control marks should be employed in the area.

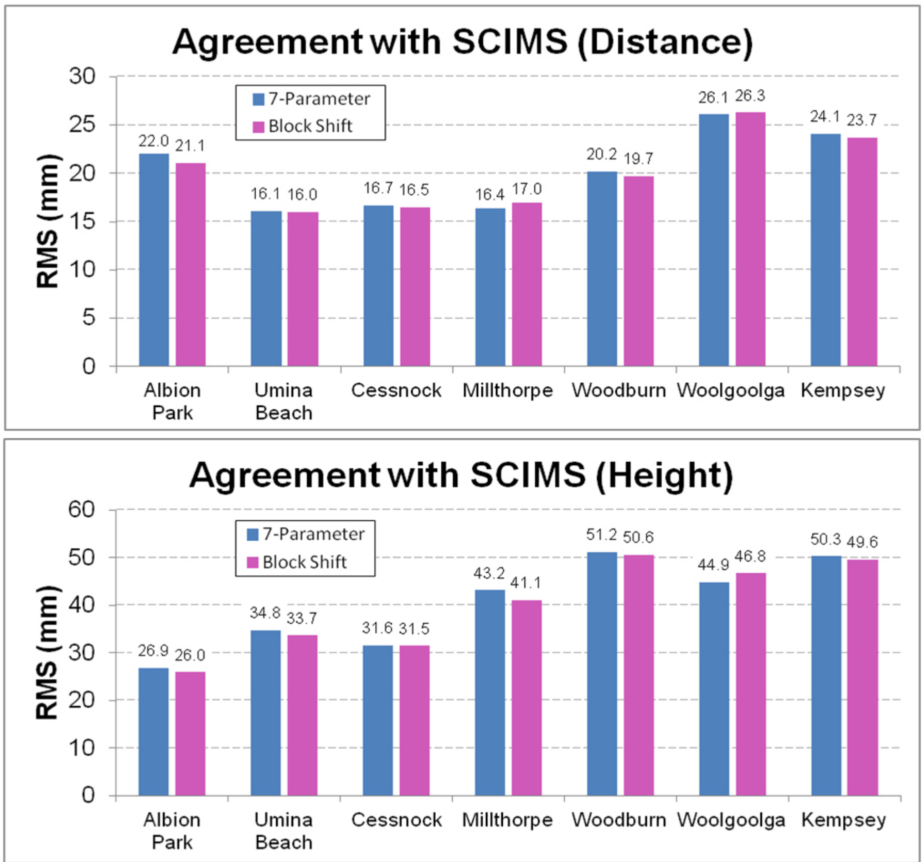

Figure 4. Agreement with SCIMS, quantified by the average Root Mean Square (RMS) in millimetres, for 7-parameter and block shift transformations (AUSGeoid09 applied) in each test area.

Agreement with SCIMS in all test areas

To assess the effect of the different site transformation methods on the transformed test point coordinates in practice, we analysed the agreement with SCIMS in each of the seven test areas. There was hardly any difference (<2 mm) between the three transformation methods in practice, provided AUSGeoid09 is applied (Figure 4.). Since the 7-parameter transformation has shown to produce almost identical results to the hz & vt transformation, the figure only shows the 7-parameter transformation and the block shift.

Conclusion

To use CORSnet-NSW real-time positioning services in concert with local SCIMS marks in New South Wales, a site transformation is required. Based on an extensive dataset, we have shown that a simple block shift is sufficient to transform RTK or NRTK observations onto local SCIMS control for surveys requiring centimetre-level accuracy, provided AUSGeoid09 is applied.

Compared to the more complex 7-parameter and hz & vt transformations, the block shift returns similar or better agreement with SCIMS and has a number of additional benefits. By using a block shift, transformation parameters are more intuitive, outliers in control are easier to detect, the site transformation can be computed with a single control mark if necessary, the geometry of the control marks does not affect the transformation results, and any errors in height control or height observations do not map into horizontal results.

So, in regards to site transformations, the DIY jeep that you know like the back of your hand is much more powerful than anticipated and has outperformed both the ute and the race car. Bugger me…

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