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Site Transformations: A Block Shift in Thinking

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ABSTRACT

In order to use CORSnet-NSW in concert with local Survey Control Information Management System (SCIMS) marks in New South Wales (NSW), a site transformation (also known as a site calibration or localisation) is required. This site transformation accounts for any differences between the legal coordinate system as realised by SCIMS, and observations in the more homogenous GDA94(2010) realisation of the national datum as provided by CORSnet-NSW through Real Time Kinematic (RTK) or Network RTK (NRTK) services. This paper demonstrates that a simple block shift in Easting, Northing and Height, using AUSGeoid09, is sufficient to transform RTK or NRTK observations onto local SCIMS control for surveys requiring centimetre-level accuracy. At each of seven test areas distributed across eastern NSW, a minimum of 4 control marks (each with 7 observations) and a minimum of 11 test points (each with 10 rounds of observations) have been occupied using both RTK and NRTK. From the NRTK data, multiple unique site transformations are computed for each test area. Comparisons are made between a 7-parameter similarity transformation, a 4-parameter horizontal transformation plus separate height shift and a simple block shift, all with and without applying the AUSGeoid09 model. Compared to the other more complex transformations, the block shift returns similar or better agreement with SCIMS control marks 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.

KEYWORDS: *CORSnet-NSW, site transformation, control, block shift, distortion.*

1 INTRODUCTION

The Geocentric Datum of Australia (GDA94) is the basis for horizontal geodetic infrastructure in Australia (ICSM, 2006), while vertical coordinates are referred to the Australian Height Datum (AHD71) (Roelse et al., 1971). For a review of coordinate systems, datums and associated transformations in the Australian context the reader is referred to Janssen (2009). A review of Australian height systems and vertical datums can be found in Featherstone and Kuhn (2006).

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 (Janssen et al., 2011; LPI, 2012a). The network also provides stimulus for innovative spatial applications and research using satellite positioning technology. It is built, owned and operated by Land and Property Information (LPI), a division of the NSW Department of Finance & Services. CORSnet-NSW currently (February 2012) consists of more than 80 CORS tracking multiple satellite constellations, and efforts are underway to expand the network to over 120 stations by the end of 2013.

In order to use CORSnet-NSW in concert with local ground control marks on public record in the state's Survey Control Information Management System (SCIMS) database (LPI, 2012b), a site transformation (also known as site calibration or localisation) is required. This 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 through Real Time Kinematic (RTK) and Network RTK (NRTK) services (Janssen and McElroy, 2010; Janssen et al., 2011).

This paper demonstrates that a simple block shift in Easting, Northing and Height, using the latest geoid model for Australia (AUSGeoid09, see Brown et al., 2011), is sufficient to transform RTK or NRTK observations onto local SCIMS control for surveys requiring centimetre-level accuracy. An extensive dataset consisting of 2,200 occupations using RTK and NRTK in seven study areas distributed across eastern NSW has been gathered to investigate the effect of applying different site transformation methods. Multiple unique site transformations are computed for each test area. Comparisons are then made between a 7-parameter similarity transformation, a 4-parameter horizontal transformation plus separate height shift and a simple block shift, all with and without the AUSGeoid09 model. This paper reports on the results obtained using the NRTK datasets collected in the seven test areas. As expected, the NRTK results showed slightly superior precision and accuracy compared to RTK, but both techniques exhibited the same behaviour.

2 SITE TRANSFORMATIONS

The GDA94(2010) realisation of the national datum is essential to provide real-time users in NSW with reliable, horizontal positioning at the 2-centimetre or better level (Janssen and McElroy, 2010). As a result, CORSnet-NSW users obtain positions referenced to GDA94(2010). While this is suitable for applications where users are interested only in absolute accuracy and repeatability (e.g. precision agriculture), spatial professionals are generally required to connect to the existing local survey control network due to legislative and/or contractual requirements or to be compatible with spatial data already referenced to local control. In order to obtain output that is consistent with local ground control marks in NSW, it is therefore essential to perform (or confirm) a site transformation for every CORSnet-NSW real-time survey where existing survey control is located nearby.

The site transformation is performed by observing several established ground control marks of sufficient quality *immediately surrounding* (and, if present, within) the survey area, i.e. the network should not ignore or span existing local control. The transformation is then calculated between the coordinates observed from CORSnet-NSW, in GDA94(2010), and the local

SCIMS coordinates, in GDA94(1997). This is typically achieved via a menu tool incorporated in the GNSS rover software. Once the site transformation is performed and found acceptable, it is automatically applied by the rover, and real-time GNSS positioning is then reported in coordinates compatible with the existing local control network. It is important to note that the site transformation should only be applied to observations *within* the area encompassed by the control marks used, i.e. extrapolation should be avoided. The use of site transformations is already established good practice to reduce the effect of distortions in GDA94(1997). However, in NSW it is now essential to account for the larger differences in coordinates between the two realisations of GDA94.

In an ideal world, real-time GNSS positioning should be directly compatible with coordinates specified on local survey ground control marks. Therefore a consistent, state-wide geodetic infrastructure based on GDA94(2010) coordinates, or something similar, is the ideal solution. The planned introduction of a new static national datum for Australia (tentatively called GDA2020), based in large part on GNSS observations, is expected to solve this problem in the near future. Theoretically, this will remove the need for site transformations, but GNSS best practice will continue to require sufficient observations at control marks to validate results.

In the meantime, CORSnet-NSW users have several options in regards to the method applied to perform the required site transformation. This paper compares a 7-parameter similarity transformation, a 4-parameter horizontal transformation plus separate height shift (here termed “horizontal and vertical” transformation, or simply “hz & vt”) and a simple block shift, all with and without the AUSGeoid09 model, in order to determine which method is the most suitable in practice.

2.1 7-Parameter Similarity Transformation

The 7-parameter similarity transformation is also known as Helmert transformation. It is based on Cartesian coordinates (X,Y,Z) and accounts for the difference between two 3-dimensional reference frames by applying seven parameters: three translations along the coordinate axes, three rotations about the axes and one scale factor. It assumes that the scale factor is the same in all directions, and thus preserves the relative shape of the network while modifying the underlying point coordinates.

It is important to note that at least three common points (i.e. ground control marks) are required to determine the transformation parameters, and all common points must be known in horizontal position and height. This well-known transformation is used extensively as a tool to transform between global and national datums (e.g. Altamimi et al., 2011; Haasdyk and Janssen, 2011, 2012). In this study, the 7-parameter similarity transformation was performed as the Leica “Classic 3D” transformation.

2.2 Horizontal and Vertical (Hz & Vt) Transformation

This transformation treats the horizontal and vertical components separately, by combining a 4-parameter horizontal transformation with a separate height shift. 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 though the available height control. This separation of horizontal and vertical components was achieved by employing the Leica “TwoStep” transformation (Leica

Geosystems, 2004). This method initially transforms the observed coordinates to a different ellipsoid if required (which was not necessary in this case, so a ‘null’ transformation was applied). The method then employs the true map projection on which the ground control coordinates are based (i.e. Universal Transverse Mercator projection in the case of SCIMS) to achieve preliminary Easting, Northing and Height coordinates for comparison against expected SCIMS coordinates. The main benefit of decoupling the horizontal and vertical components in the transformation is that any errors in the height control do not affect horizontal control (and vice versa).

A minimum of three common points is required to reliably determine the transformation parameters. However, the common points can be matched in position and height, in position only or in height only. This transformation is also possible with less than three common points, simply resulting in a reduction of the number of parameters determined. This provides some flexibility to the user, i.e. the same transformation methodology can be applied for all jobs, independent of how many control marks are incorporated. However, it is important to note that the quality of the transformation may suffer if less than three common points with 3-dimensional control information (or the equivalent distributed over a larger number of control marks) are used.

2.3 Block Shift

This 3-parameter transformation applies an average origin shift, resulting in a simple block shift along the Easting, Northing and Height axes. Each component is treated separately, and neither rotation nor scale factor are determined. Only one common point is sufficient to determine the transformation parameters (albeit without any residuals). As with the hz & vt method, the same transformation methodology can be applied for all jobs, independent of how many control marks are incorporated. However, it is strongly recommended and good practice to use a minimum of three common points with 3-dimensional control information (or the equivalent distributed over a larger number of control marks) to reliably determine the transformation parameters. As mentioned earlier, the decoupling of horizontal and vertical components means that any errors in the height control do not affect horizontal control (and vice versa).

In this study, the block shift transformation was performed by simple (unweighted) averaging of the difference between coordinate observations and expected control coordinates. Alternatively, the Leica “TwoStep” method can be used by setting scale and rotation to zero, and the height model to “Avg Height Shift”. Both methods return the same results.

3 DATA COLLECTION AND TESTING METHODOLOGY

In order to investigate the performance of different site transformations in a practical real-time scenario, RTK and NRTK solutions were obtained on a number of established marks. A minimum of 4 control marks (each with 7 observations) and a minimum of 11 test points (each with 10 rounds of observations) have been occupied using both RTK and NRTK. This test was performed at each of seven test areas distributed across eastern NSW. The test areas exhibited a range of NRTK scenarios and cell sizes routinely encountered in practice. All observations were performed with a high-quality bipod for rover antenna stability, using Leica Viva GNSS receivers. Absolute antenna modelling was applied to all GNSS rovers involved (Janssen and Haasdyk, 2011a).

Between four and six established survey control marks were selected as site transformation points to determine the site transformation parameters. These were chosen to be of the highest class and order possible, i.e. A1 horizontal and LCL3 vertical, or better. Detailed definitions of the terms class and order can be found in ICSM (2007) and LPI (2012c). In each study area, each control mark was observed only once for 5 minutes, i.e. not following best practice as described in LPI (2012c), using NRTK and applying the averaging technique. This was followed immediately after re-initialisation by another occupation using single-base RTK. The coordinates obtained were used to determine site transformation parameters (separately for RTK and NRTK). The observations were accepted if the resulting 7-parameter transformation produced residuals not exceeding 25 mm in Easting and Northing, and not exceeding 50 mm in height.

This procedure was repeated several times over multiple days to obtain seven unique site transformations each for NRTK and RTK, for each study area. It should be noted that, when using RTK/NRTK in practice, site transformation points should always be occupied at least twice, for a minimum of two minutes using the averaging technique, as described in LPI (2012c). The first observation determines the GDA94(2010) coordinates, and additional observations provide redundancy. For this study, however, it was decided to perform a single long occupation of each control mark (but repeated for each unique transformation) to highlight the effect of individual control observations on each resulting transformation, considering that a sufficient number of observations was available to determine any outliers.

Within the area surrounded by the site transformation points, 11-15 high-quality established marks with a class/order of at least B2 horizontal and LCL3 vertical (or B2 vertical if not optically levelled) were selected as test points. These test points were chosen to exhibit ‘typical’ conditions accepted for GNSS surveys, i.e. a good skyview with low to moderate obstructions. Test points were observed for 1 minute using NRTK (applying the averaging technique), followed immediately after re-initialisation by another occupation using single-base RTK. After all test points were occupied once, the procedure was repeated to obtain 10 rounds of observations on each test point at different days and times of day. The fieldwork consisted of 2,200 separate occupations and was conducted over several days in January and February 2011.

Using the Leica Viva Simulator, each of the seven unique NRTK or RTK observation sets at the control marks was used to determine the 7-parameter, horizontal and vertical (hz & vt), and block shift transformation parameters, all with and without AUSGeoid09. These parameters were then applied to the 10 repeat observations at the test points, in Leica Geo Office (LGO). The agreement of the output coordinates with SCIMS was assessed in Excel and Matlab. It should be noted that the same results would have been obtained by computing and applying any of these site transformations in the field, in real-time.

For each of the seven study areas, Figures 1-3 show the location of the test points surrounded by the site transformation points and the closest CORSnet-NSW sites, as well as a map indicating the slope of AUSGeoid09 across the area (using 10 mm contours). Most of the test areas are relatively small (less than 3 km across) and have a correspondingly small change in AUSGeoid09 values (ΔN <30 mm). The exceptions are Albion Park and Woolgoolga which are larger areas and exhibit large changes in AUSGeoid09 (about 12 and 6 km across, with ΔN of 555 mm and 299 mm respectively). The slope of the AUSGeoid09 model is somewhat similar in all areas, ranging from 18 ppm to 56 ppm. Notably, in all areas, the AUSGeoid09 model is little more than an inclined plane. It should be noted that NRTK operation in the Woodburn, Woolgoolga and Kempsey study areas (Figure 3) is for testing purposes only, due to the larger than recommended inter-CORS distances currently available in these areas.

This extensive dataset has previously been used to investigate NRTK and single-base RTK performance using CORSnet-NSW in terms of precision (repeatability) and accuracy as compared to local SCIMS control (Janssen and Haasdyk, 2011b, 2011c). More detailed information about the seven study areas can be found in these publications. As mentioned earlier, the present paper focuses on the analysis of site transformations obtained using NRTK observations, due to their superiority in regards to precision and accuracy compared to single-base RTK.

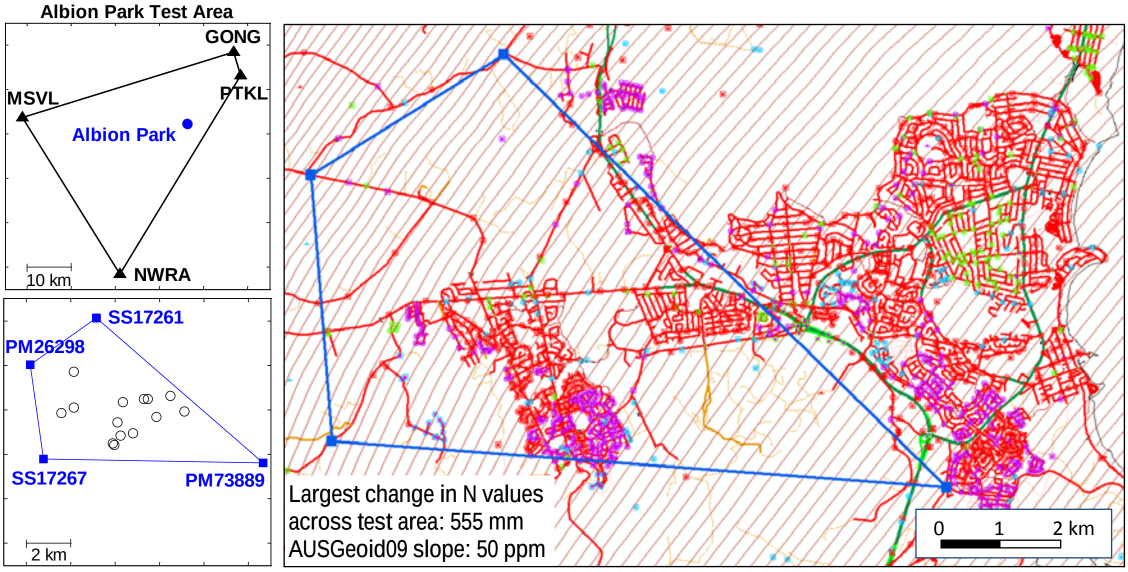


Figure 1: Albion Park test area, showing surrounding CORSnet-NSW sites (black triangles), site transformation points (blue squares), test points (black circles) and AUSGeoid09 contours (10 mm).

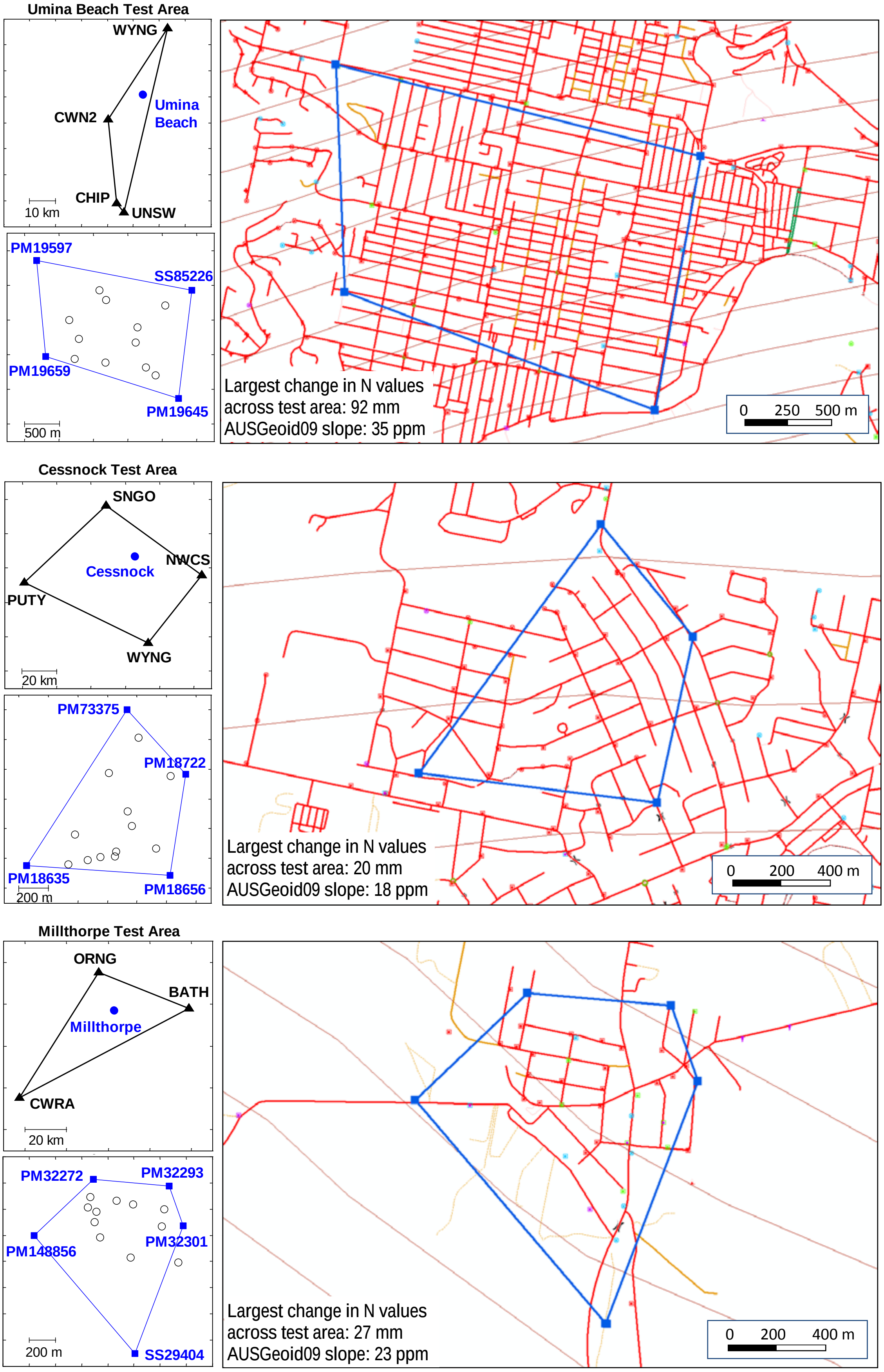


Figure 2: Umina Beach, Cessnock and Millthorpe test areas, showing surrounding CORSnet-NSW sites (black triangles), site transformation points (blue squares), test points (black circles) and AUSGeoid09 contours (10 mm).

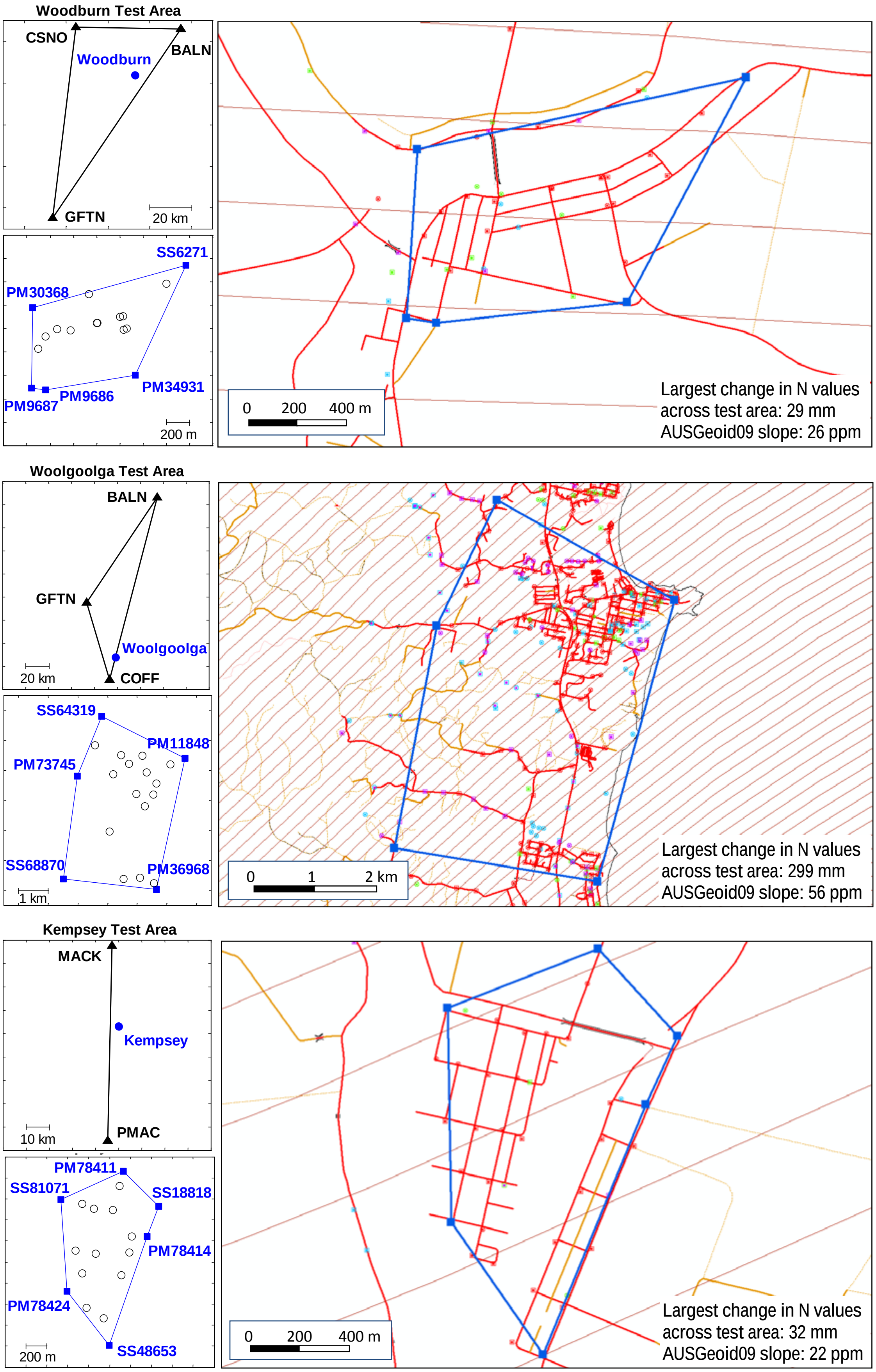


Figure 3: Woodburn, Woolgoolga and Kempsey test areas, showing surrounding CORSnet-NSW sites (black triangles), site transformation points (blue squares), test points (black circles) and AUSGeoid09 contours (10 mm). Note that NRTK operation in these three areas is for testing purposes only.

4 DATA ANALYSIS AND RESULTS

4.1 Initial Comparison of Transformation Methods and Importance of AUSGeoid09

The performance of the 7-parameter, hz & vt and block shift transformations was assessed by comparing real-time observations on established marks in the seven study areas against their published SCIMS coordinates. As an example, Figure 4 shows the resulting deviations from SCIMS in the horizontal (i.e. distance from official position) and vertical coordinate component for the Albion Park test area. For every test point surveyed, each of the ten 1-minute occupations is shown individually. AUSGeoid09 was applied, and only the first of the seven site transformations of each method (here represented by different symbols) was considered in this figure.

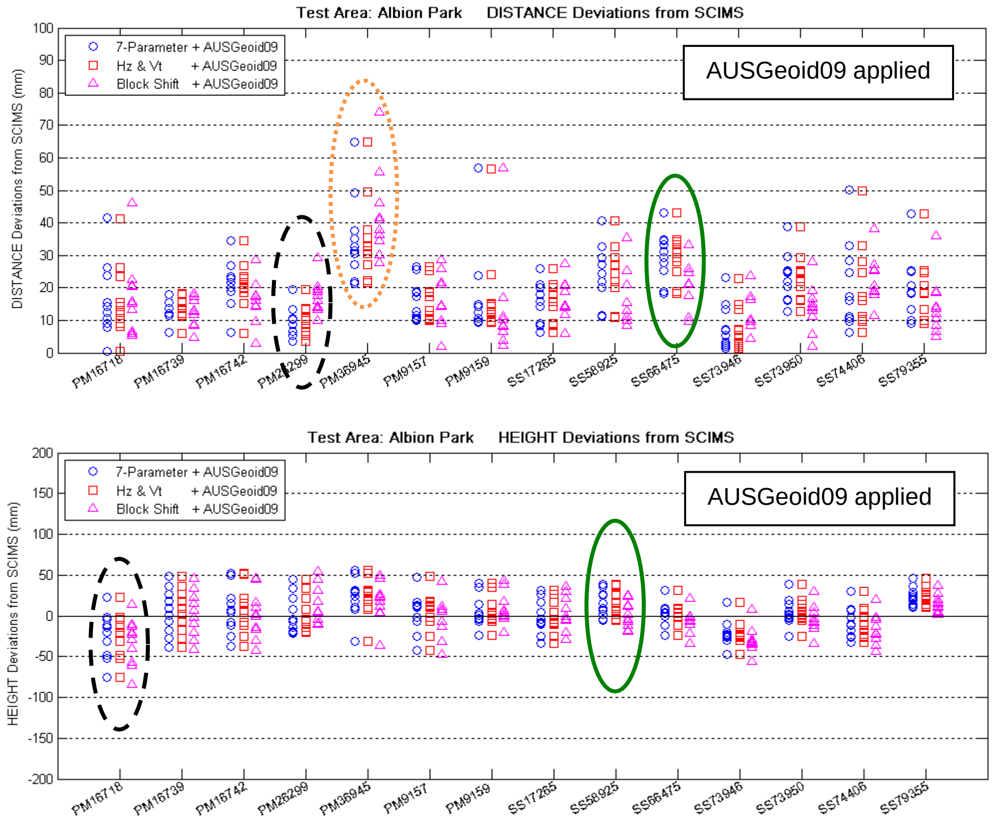


Figure 4: Horizontal and vertical NRTK accuracy vs. SCIMS in Albion Park, using different site transformation methods (AUSGeoid09 applied).

It can be seen in Figure 4 that the 7-parameter transformation and the hz & vt transformation (blue circles and red squares, respectively) yield essentially identical results in both horizontal position and height. At several marks, the block shift transformation (magenta triangles) provides slightly better agreement with SCIMS (e.g. SS66475 in the horizontal and SS58925 in the vertical component, circled with solid green). At other marks, the block shift performs slightly worse (e.g. PM26299 in the horizontal and PM16718 in the vertical component, circled with dashed black). The remaining study areas showed comparable results.

Cases where a consistent offset from the official SCIMS coordinates persists regardless of the site transformation employed (e.g. PM36945, circled in dotted orange in Figure 4) indicate a possible issue with the published SCIMS coordinates, e.g. due to mark movement, and show that poor control can be identified with redundant observations.

In order to investigate the effect of ignoring AUSGeoid09 in the site transformation process, the above analysis was repeated without the use of AUSGeoid09 (Figure 5). As expected, the results for the horizontal component are almost identical for all three transformation methods when compared to those results obtained with AUSGeoid09 (see Figure 4). 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 test area.

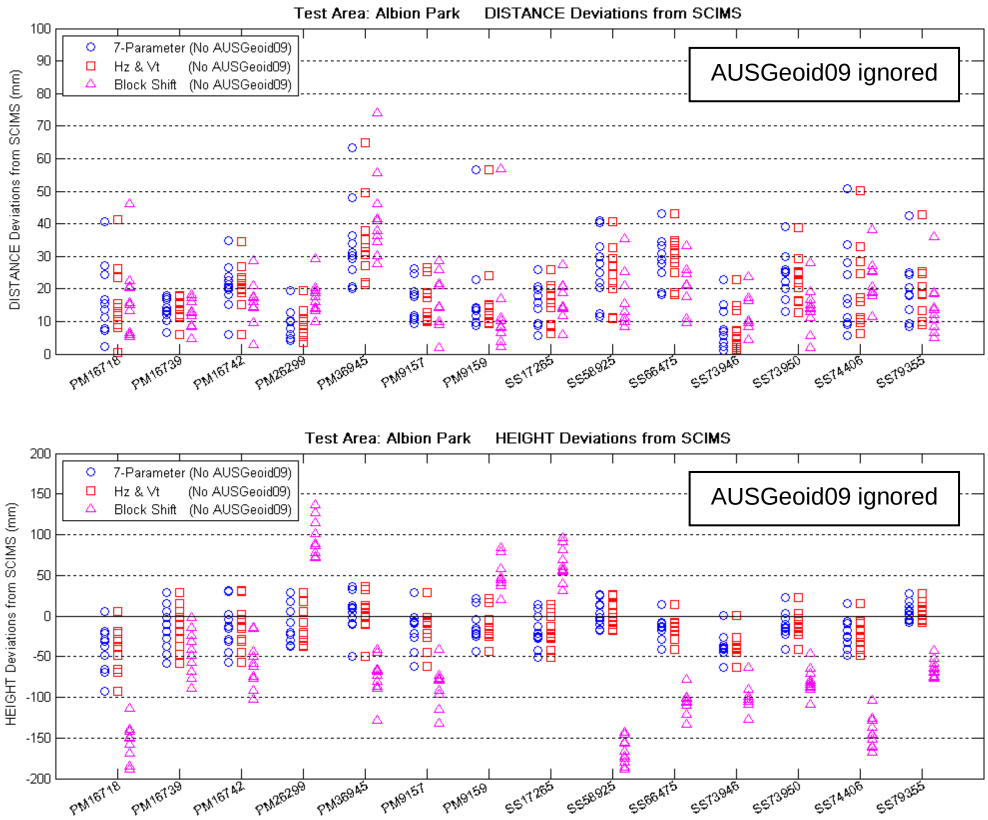


Figure 5: Horizontal and vertical NRTK accuracy vs. SCIMS in Albion Park, using different site transformation methods (AUSGeoid09 ignored).

It should be noted that the negative effect of ignoring AUSGeoid09 in the site transformation is less pronounced in smaller areas with a much smaller variation in N values. For instance, while the Albion Park area exhibits a relatively large change of 555 mm in AUSGeoid09 values (see Figure 1), the change amounts to only 29 mm in the Woodburn area (see Figure 3). In order to illustrate the effect of these N value variations, Table 1 lists the agreement with SCIMS across the two test areas, obtained with the different transformation methods. The average agreement with SCIMS is quantified by the Root Mean Square (RMS) of the difference between observed and expected coordinates for the horizontal and vertical coordinate components. A low RMS indicates a better agreement with SCIMS. In this case, these RMS values were calculated across all occupations (10 rounds) on all test points (11-15) in the test area, and then averaged across the seven unique site transformations observed. Since good agreement was found between the repeated site transformations in each test area, these *averaged* RMS values are representative of the full dataset collected.

Table 1: Agreement with SCIMS, in distance and height, quantified by the average Root Mean Square (RMS) in millimetres for three transformation methods (with and without applying AUSGeoid09).

RMS Distance Test Area	7-Parameter (AUSGeoid09)	7-Parameter (no geoid)	Hz & Vt (AUSGeoid09)	Hz & Vt (no geoid)	Block Shift (AUSGeoid09)	Block Shift (no geoid)
Albion Park	22.0	21.8	22.0	22.0	21.1	21.1
Woodburn	20.2	20.2	20.2	20.2	19.7	19.7

RMS Height Test Area	7-Parameter (AUSGeoid09)	7-Parameter (no geoid)	Hz & Vt (AUSGeoid09)	Hz & Vt (no geoid)	Block Shift (AUSGeoid09)	Block Shift (no geoid)
Albion Park	26.9	28.7	26.9	28.7	26.0	99.9
Woodburn	51.2	51.2	51.2	51.2	50.6	51.5

As highlighted in Table 1, the performance of the block shift transformation in Albion Park deteriorates significantly (by a factor of 3.8 in height) if AUSGeoid09 is ignored. On the other hand, excluding AUSGeoid09 from the block shift transformation in Woodburn has only minor consequences (~1 mm). This can be explained by the inability of the block shift to account for significant changes in N values across the test area unless a geoid model is applied.

The information collated in Table 1 also demonstrates that the 7-parameter transformation and the hz & vt transformation are almost indistinguishable, confirming what has already been shown visually in Figures 4 and 5. As expected, ignoring AUSGeoid09 in the hz & vt and the block shift transformations does not affect the horizontal component at all because in both cases position is decoupled from height. In regards to the vertical component, the hz & vt transformation follows the pattern of the 7-parameter transformation, i.e. the RMS worsens slightly if AUSGeoid09 is not included in the process.

While the omission of a geoid model in the 7-parameter transformation can produce acceptable results in some cases (Janssen and Haasdyk, 2011c), it is advised and best practice to use AUSGeoid09 for all transformation methods. Applying AUSGeoid09 is essential if a block shift transformation is employed, or if the geoid surface is not a simple plane over the area in question.

4.2 Repeatability of Site Transformation Parameters

The repeatability of the transformation parameters calculated during a site transformation was investigated by inspecting the parameters obtained from the seven site transformations performed in each test area. As a representative example, Tables 2-4 list the parameters obtained for the 7-parameter, hz & vt and block shift transformations in the Albion Park test area. AUSGeoid09 was applied in all cases.

Table 2: Repeatability of site transformation parameters for the 7-parameter transformation in Albion Park (AUSGeoid09 applied).

7-Parameter	Shift dX (m)	Shift dY (m)	Shift dZ (m)	Rotation X (”)	Rotation Y (”)	Rotation Z (”)	Scale (ppm)
1st	44.728	-40.965	-53.333	-2.35	-1.55	-0.34	2.9127
2nd	7.202	-10.529	18.863	-0.59	0.67	-0.35	3.1447
3rd	60.849	2.340	-51.489	-1.10	-2.05	-1.21	2.1597
4th	16.844	-32.599	-10.344	-1.39	-0.18	0.02	3.0416
5th	15.515	-1.527	0.574	-0.57	0.04	-0.60	1.8962
6th	7.033	5.390	5.125	-0.12	0.15	-0.44	0.9024
7th	29.095	-33.331	-33.859	-1.39	-1.13	0.13	2.3879

Table 3: Repeatability of site transformation parameters for the hz & vt transformation in Albion Park (AUSGeoid09 applied). The rotation is applied around the centroid of the test area.

Hz & Vt	Shift dE (m)	Shift dN (m)	Rotation (”)	Scale Factor	Shift dH (m)
1st	-0.032	-0.004	1.30	2.900	-0.036
2nd	-0.034	0.004	0.90	3.152	-0.047
3rd	-0.032	0.007	0.60	2.156	-0.036
4th	-0.032	0.002	0.90	3.039	-0.044
5th	-0.031	-0.001	0.80	1.900	-0.031
6th	-0.023	-0.002	0.40	0.910	-0.038
7th	-0.033	0.008	0.50	2.381	-0.045

Table 4: Repeatability of site transformation parameters for the block shift transformation in Albion Park (AUSGeoid09 applied).

Block Shift	Shift dE (m)	Shift dN (m)	Shift dH (m)
1st	-0.032	-0.004	-0.037
2nd	-0.033	0.004	-0.048
3rd	-0.032	0.007	-0.037
4th	-0.032	0.002	-0.044
5th	-0.030	-0.001	-0.032
6th	-0.023	-0.002	-0.039
7th	-0.033	0.008	-0.046

It is evident that the parameters describing the 7-parameter transformation are not intuitive as they refer to Cartesian coordinate axes, with an origin at the centre of the Earth. All of the seven parameters show considerable variation between repeated site transformations (e.g. several 10s of metres in the translation parameters *dX*, *dY* and *dZ*). The parameters for the hz & vt and block shift transformation methods are more intuitive because they refer to grid coordinates, separating horizontal and vertical coordinate components.

In the hz & vt transformation, the shifts in Easting and Northing are comparable across the seven individual site transformations (±5 mm), while the Height shift shows more variation between repeats (±10 mm). The Height shift parameter is determined based on the average shift of the sloped plane correcting for the difference between the GNSS-derived and the AHD71 heights at the control points. In this case the slope is insignificant, but it should be emphasised that the slope quickly becomes significant if AUSGeoid09 is ignored in the site transformation (data not shown). In addition, there are noticeable variations in rotation and scale for individual site transformations, and no attempt was made to determine if these parameters were actually statistically significant.

The block shift parameters are virtually identical (±1 mm) to the shift parameters from the hz & vt transformation. Consequently, the Easting and Northing shifts are very similar across the seven individual site transformations (±5 mm), while the Height shift shows a little more variation than the horizontal parameters (±10 mm).

It should also be noted that, while individual transformation parameters may change significantly between repeat site transformations (as with the 7-parameter method), the effects on the transformed coordinates of the test points are generally small (at the cm-level, see section 4.3). However, it is important to note that this statement is only valid if it is assumed that no local distortion and no change in CORS coordinates and/or SCIMS coordinates has taken place between repeats. It is strongly advised against using a site transformation in practice that was calculated a considerable time before the survey takes place. As mentioned earlier, it is GNSS good practice to perform (or confirm) a site transformation at the start of every real-time survey.

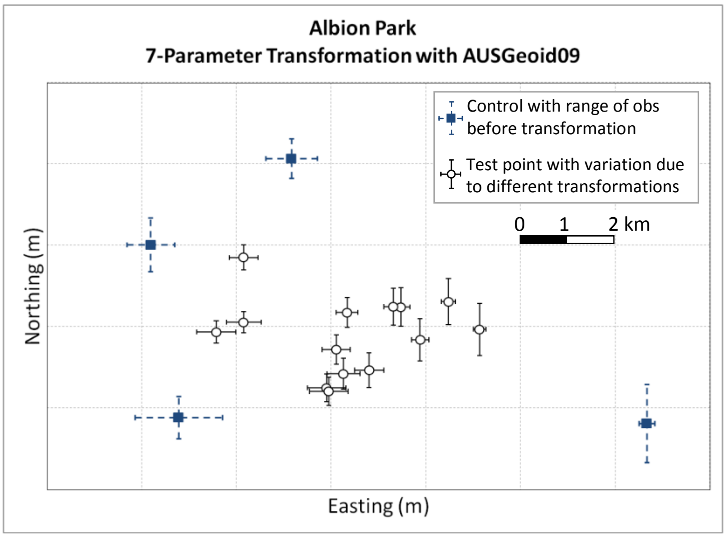
4.3 Effect of Site Transformation Geometry

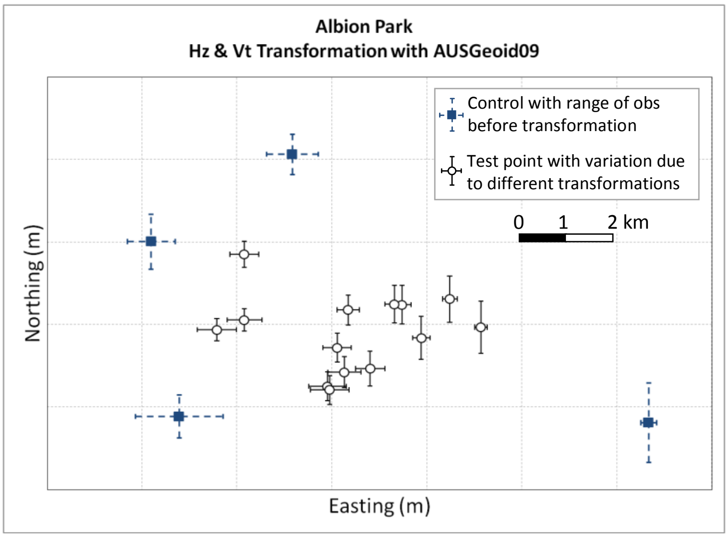
In the 7-parameter and hz & vt transformations (but not the block shift), the scale and rotation parameters effectively allow the observations to be stretched and skewed to fit the existing control. As a consequence, the transformation geometry (i.e. the relative distribution of the common points used to calculate the transformation parameters) has an effect on the output coordinate repeatability/quality. Obviously, the quality of the GNSS observations (and the SCIMS coordinates) on the control marks also affects the coordinate output (rubbish-in-rubbish-out principle). Since the same observations were used to compute 7-parameter, hz & vt and block shift transformations, this section focuses on the effect of the site transformation itself on the quality and variability of output coordinates for the test points.

The variability in the transformed test point coordinates, solely due to the adoption of a new site transformation, was investigated across all seven test areas. As an example, Figure 6 illustrates this behaviour in regards to the horizontal position for the three transformation methods investigated in the Albion Park test area. 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 (i.e. raw point observations, 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. It should be noted that this analysis focuses on the relative effect on the test points depending on the geometry of the control points, i.e. the absolute values are of no interest in this context.

In Figure 6 it can be seen that the 7-parameter and hz & vt transformations introduce variability in the transformed coordinates depending on the relative geometry of the control and test points, as well as the quality of the observations at the control points. 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 rotated to accommodate any errors at this control point, and the test points in the vicinity exhibit the same behaviour. It should be noted that extrapolated points would suffer even more significant variation.

Similarly, test points located in the south-western corner of the test area are affected more by the higher variation in Easting at the south-western control point. The 7-parameter and hz & vt transformation methods 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 these errors into extra parameters.





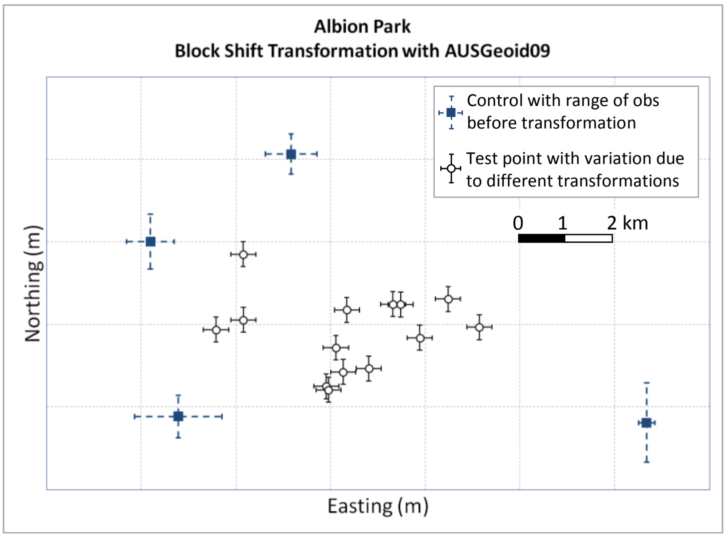


Figure 6: Variability of horizontal output coordinates at each test point (single occupation), solely due to the geometry and observation variability of the control points, for different site transformation methods in Albion Park (AUSGeoid09 applied). All 'error' bars are scaled by 50,000.

In contrast, the effect of the block shift is uniform across all test points, and is generally of a smaller range (better precision) than the 7-parameter and hz & vt transformations. Notably, the variation in transformed coordinates at the test points is independent of the geometry of the control points, and is the same for all test points in the transformation area. In practice, this means that a new block shift transformation will change all existing observations by exactly the same amount. Also, the observations are not scaled or skewed to fit the control, i.e. the block shift transformation does not 'hide' any errors in the control nearly as effectively as the other transformation methods, but can instead can be used to identify these errors, as shown in section 4.4.

Table 5 quantifies the variability in test point coordinates due to the site transformation for Albion Park by specifying the range (i.e. summation of the absolute minimum and maximum differences from the official SCIMS coordinates) and the RMS (i.e. average agreement with SCIMS) for the Easting, Northing and Height components. The results confirm that the 7-parameter and hz & vt transformations provide almost identical results, which are outperformed by the block shift.

Table 5: Average variability in test point coordinates solely due to the variation in transformation parameters for the Albion Park test area (AUSGeoid09 applied). All values are in millimetres.

Transformation Method	Range Easting	Range Northing	Range Height	RMS Easting	RMS Northing	RMS Height
7-Parameter	11.2	16.3	25.4	3.5	5.1	8.4
Hz & Vt	11.3	16.3	25.4	3.5	5.1	8.3
Block Shift	10.6	12.1	16.0	3.4	4.2	5.3

The remaining test areas exhibit a very similar pattern. In all cases, the average range of the block shift is slightly better (up to 5 mm and 10 mm smaller in the horizontal and vertical components respectively), while the average RMS is generally the same or slightly better (by 1 mm horizontally and 2 mm vertically), compared to the other two transformation methods. This confirms that the effect of the variability amongst the individual site transformations is larger for the 7-parameter and hz & vt transformations when compared to the block shift, i.e. the transformed test points will generally not change as much when applying a new block shift rather than a new 7-parameter or hz & vt transformation.

4.4 Identification of Outliers at Control Marks using the Block Shift Method

The block shift transformation is able to identify (and not 'hide') control marks (or observations at those marks) that do not fit with other nearby control, by highlighting any observations with significant residuals. In contrast, the 7-parameter and hz & vt transformations are able to employ additional scale and rotation parameters to fit the observations to the control marks (see section 4.3). With the limited (or minimum) number of control points often used to determine the transformation, finding errors in observations or control coordinates can be more difficult (or impossible) with the 7-parameter and hz & vt methods.

GNSS rover software generally reports the residuals of the site transformation calculation in Easting, Northing and Height (calculated from the difference between transformed and expected control point coordinates) to help the user identify outliers. In the Albion Park test area (Figure 1), it was found that all residuals for the 7-parameter and hz & vt transformations passed our performance criteria (25 mm in Easting and Northing, and 50 mm in Height) and the largest residual was 27 mm in the Height of PM26298. In contrast, the largest residual for the block shift was 54 mm (in the Northing of PM73889), and all seven block shift transformations showed a consistent disagreement at this control mark with average residuals of 38 mm in Northing. It should be noted that PM73889 is the south-eastern point discussed in section 4.3, which was shown to have a large effect on the 7-parameter and hz & vt transformations. Although this control mark is still within A1 specifications, it should be used with caution in the transformation and extra or alternative control marks should be employed in the area if possible. Only the block shift transformation method was able to highlight this issue.

In a similar fashion, a poor observation on a control mark, e.g. due to multipath or centring errors, would be highlighted by the block shift and hidden by the 7-parameter and hz & vt transformations. Of course, this study only employed a single observation at each control point to calculate each site transformation, while it is recommended best practice to always use two or more observations to achieve redundancy and enable outlier detection.

In general, it was also identified that the residuals of a block shift transformation are always larger than those of the other two transformation methods. It is the responsibility of the GNSS user to determine what is 'fit for purpose' when determining the agreement of observations to the existing control. However, while the residuals at the control marks may be larger for the block shift, the average agreement of the transformed test point coordinates with SCIMS remains much the same for all transformation methods (see section 4.5).

4.5 Effect of Site Transformation Methods on Transformed Coordinates in Practice

This section investigates the effect of the different site transformation methods on the transformed coordinates in practice, following the initial assessment presented in section 4.1. Since the 7-parameter and hz & vt transformations have been shown to produce near-identical results, the remainder of this analysis is limited to the comparison of the most rigorous transformation (i.e. 7-parameter transformation) and the simplest transformation (i.e. block shift). AUSGeoid09 is applied in all cases. In order to assess the effect on the transformed test point coordinates in practice, the agreement with SCIMS was investigated in each of the seven test areas. This agreement was quantified by the average RMS in horizontal position (i.e. distance from SCIMS position) and height, incorporating all test point occupations *and* the seven unique site transformations observed for each method. It should be noted that one site transformation in the Cessnock test area exceeded accuracy specifications and was therefore removed from the analysis.

Figure 7 summarises the performance of the 7-parameter and block shift transformations in each test area, reducing the information gathered from the extensive fieldwork undertaken to a few RMS values. It can be seen that both transformations generally provide comparable results in the horizontal position (within about a millimetre). In regards to heights, the RMS is generally slightly better (lower by 1-2 mm) when the block shift is used, with one exception in the Woolgoolga test area where the 7-parameter transformation performs better by almost 2 millimetres. The RMS values reported here are somewhat exaggerated, because each unique transformation is based on a single observation at each control point. As recommended, at least two observations should be included at each control mark to improve the precision of the transformation and consequently the agreement with SCIMS.

Considering the context of this study, this shows that there is hardly any difference between the three transformation methods in practice, provided AUSGeoid09 is applied to take variations in AUSGeoid09 across the survey area into account. However, as demonstrated in the earlier sections, the block shift has advantages over the 7-parameter and hz & vt transformations such as easier outlier detection and greater versatility when faced with limited control or separate horizontal and vertical control.

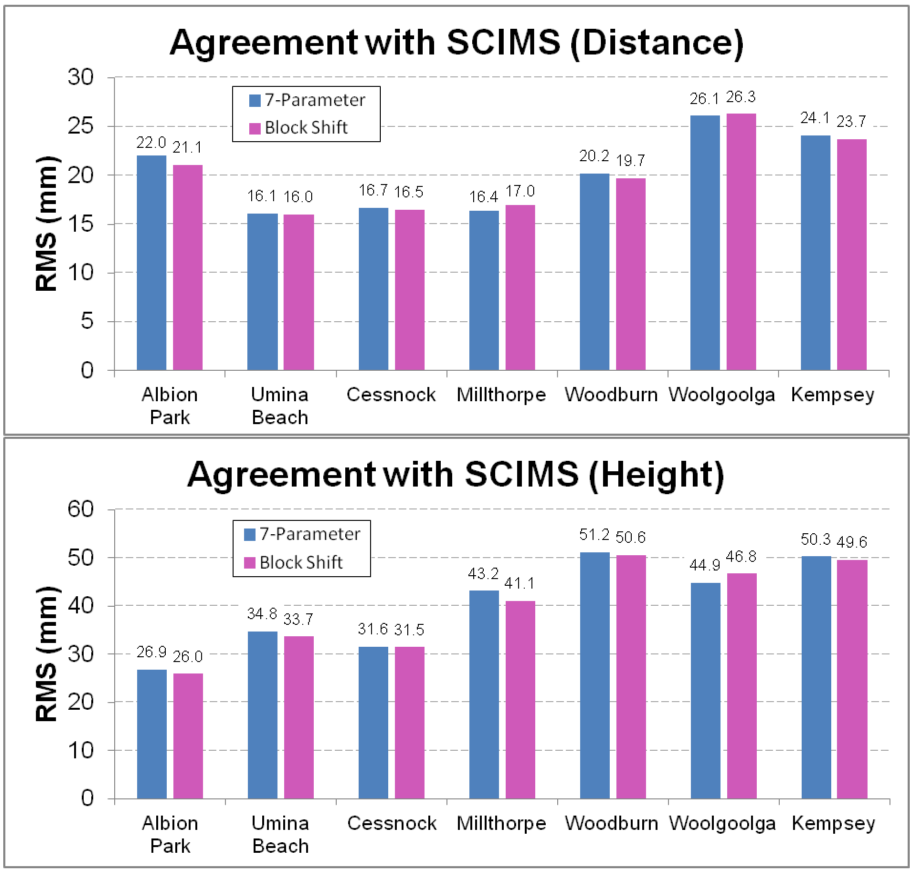


Figure 7: Agreement with SCIMS, quantified by the average Root Mean Square (RMS) in millimetres for 7-parameter and block shift transformations (applying AUSGeoid09) in each test area.

It is important to complete a site transformation even in areas where there appears to be little disagreement between GDA94(2010) and GDA94(1997). In the test areas investigated in this study, applying no site transformation always resulted in poorer agreement with SCIMS, by 30% to 800% (data not shown). Performing a site transformation is always GNSS good practice to verify the fit of observation with local control at the time of the survey.

5 CONCLUDING REMARKS

In order to use CORSnet-NSW real-time positioning services in concert with local SCIMS marks in New South Wales, a site transformation is required. An extensive dataset consisting of 2,200 occupations in seven study areas distributed across eastern NSW has been analysed to investigate the effect of applying different site transformation methods. Comparisons were made between a 7-parameter transformation, a 4-parameter horizontal transformation plus separate height shift (here termed “hz & vt”) and a simple block shift.

It was found that a block shift in Easting, Northing and Height is sufficient to transform NRTK or RTK observations onto local SCIMS control for surveys requiring centimetre-level accuracy, provided AUSGeoid09 is applied. At a practical level, it is generally not required to solve for scale and rotation parameters since, by definition, GDA94(2010) and GDA94(1997) share the same ellipsoid and coordinate axes.

Compared to the more complex 7-parameter transformation, the block shift returns similar or better agreement with SCIMS in the test areas investigated (up to 12 km across) and has a number of additional benefits. By using a block shift, transformation parameters are more intuitive, outliers in control (observations or SCIMS values) 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.

The block shift transformation method also has the great benefit of allowing the user to employ the same site transformation methodology whether control is sparse or in ample supply. In fact, if there is only a single control mark in the area, it is perfectly valid to create a transformation using that single control mark in order to achieve coordinates consistent with local control.

The GNSS rover equipment employed may not provide a specific menu tool to perform a block shift transformation. However, generally an option comparable to the separate hz & vt transformation is available. By manually defining certain parameters (i.e. setting the rotation and scale parameters to zero) and setting the height model to simple averaging, it is possible to turn the hz & vt transformation into a simple block shift for use with any number of control marks.

Regardless of the site transformation method employed, the quality of the site transformation is always dependent on the number and even distribution of the common points utilised, and the quality of the GNSS observations. It is strongly recommended to follow GNSS best practice and observe a minimum of three known control marks of sufficient quality *immediately surrounding* (and, if present, within) the survey area to calculate the transformation parameters. The nearest existing control marks should be used, i.e. the network should not ignore or span existing local control. Every mark (including existing control) in the NRTK/RTK survey should be observed at least twice to provide redundancy, thereby lowering the risk of outliers in the control point observations flowing into the calculation of site transformation parameters. The latest AUSGeoid product (currently AUSGeoid09) should be used as part of the site transformation – this is essential if the block shift method is employed.

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