Post-earthquake accuracy and precision assessment of NZGD2000

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Introduction

This paper assesses the accuracy and precision of the Land Information New Zealand (LINZ) PositioNZ sites, which underlie New Zealand's geodetic infrastructure and have, over the last decade, been affected by several significant earthquakes. We do this by estimating the coordinate precision (standard deviation) and accuracy (root mean square error (rms)) at approximately one year intervals from 2014 to 2020. The coordinates for all (mainland) PositioNZ sites have been computed as part of a student assignment (Paper SURV301, Survey Methods 2, School of Surveying) using the LINZ online post processing service, PositioNZ-PP (see below). Over this period of time, and taking into account the disruptive effects of both the Christchurch and Kaikōura earthquake events, we find that there is a general improvement in both the coordinate precision and accuracy. However, the largest sources of coordinate error are from uplift and subsidence which are currently assumed, by the deformation model, to be zero; slow slip events (SSEs), and post-seismic deformation. The deformation model itself implicitly assumes zero vertical motion, the model only has horizontal motions. Assuming that there is no vertical land motion will result in accumulated coordinate error. This has implications for our understanding of sea level rise, coastal communities and

local authority planning. Ignoring SSEs will result in small, but not necessarily insignificant positioning bias while the post-seismic deformation following the Kaikōura 2016 event (and potentially future events), will result in accumulated coordinate error at the decimetre level over time periods of years to decades.

This paper briefly describes the background of the New Zealand Geodetic Datum 2000 (NZGD2000), including crustal deformation; the online positioning service; PositioNZ-PP, provided by LINZ, and the NZGD2000 Deformation Model (NDM). We describe the precision and accuracy assessment of the PositioNZ sites and show that the horizontal and vertical repeatability (precision) is consistently better than ±10 mm. The horizontal accuracy is now better than ±10 mm (range ±3–388 mm) and the vertical accuracy is at the ±10 mm (range ±2–289 mm) level. The LINZ coordinate accuracy standard (LINZG25706, LINZ (2010)) specifies the horizontal and vertical network accuracy for Order 0 (National Reference Frame) sites is better than 0.05 m (95% confidence level). On average, a total of 2 and 11 sites in the horizontal and vertical components respectively have calculated accuracies that are greater than (i.e. do not conform), to the LINZ coordinate accuracy specification each year.

A Brief History of NZGD2000

The current geodetic datum, New Zealand Geodetic Datum 2000 (NZGD2000), was implemented over 20 years ago. Although an understanding of earth deformation in New Zealand at the plate tectonic level was well documented (e.g. Bevin et al., 1984), the first static GPS data observed in 1989 showed that deformation and distortion of the previous horizontal datum, NZGD1949 (Lee 1978), had resulted in the accumulation of over five metres of movement (Bevin and Hall, 1995). Grant (1995) promoted the idea that earth deformation needed to be modelled and incorporated into the geodetic infrastructure in order to manage the cadastral and topographic datasets (Blick et al., 2003). Subsequently, the limitations and requirements of the new datum were recognised (Blick and Rowe, 1997) and options for managing crustal dynamics were developed (Grant and Blick, 1998). The complexities of crustal deformation, largely due to plate tectonic motion and seismic events, but to a lesser extent volcanic and large-scale landslide activity, also needed to be addressed in order to maintain datum accuracy for a wide variety of national spatial data applications. From a technical and geodetic perspective, the implementation of NZGD2000 was straightforward, but Blick and Grant (2010) outlined the need to manage both horizontal and vertical deformation on an ongoing basis. Today, using GNSS technologies and continuous GNSS sites (e.g. PositioNZ and cGNSS (Continuously Operating GNSS) services),

it is a straightforward process to generate accurate, three dimensional positions, anywhere in New Zealand. What is more challenging is accommodating—and thereby maintaining the accuracy of the deformation model—of periodic and transient effects that result from seismic, volcanic, and landslide deformation.

Crustal Deformation

In contrast to NZGD1949, where the coordinates of the 1st Order trigonometric stations remained unchanged for nearly five decades, it was clear that relative deformation across the country would need to be accounted for in a new datum (Blick, 2003). Beavan and Haines (2001) developed the first nationwide velocity field for New Zealand that implemented the concepts of dynamic and semi-dynamic datums. In principle, this allows the position of any point in the country to be determined for any time if one knows the point's reference coordinate and its velocity:

$$X(t) = X(t_0) + V_X (t - t_0) \tag{1}$$

where $X(t)$ is the position at time t, V_X is the secular velocity and $X(t_0)$ is the position at a reference epoch t_0 e.g. 2000.0. This allows sites with different long term linear (otherwise referred to as, secular) motion to move at different rates thereby allowing for crustal deformation across the Australian/Pacific plate boundary. For most day-to-day survey operations that tend to be localised (e.g. topographical, engineering, cadastral), large scale nationwide deformation is not critical. However, with modern survey technology e.g. GNSS and the ability to measure to distant trigs (albeit GNSS base stations) over 100 kms away, it has become necessary to correct for the effects of ongoing deformation. Examples of applications include NetworkRTK (Denys 2017; Denys et al. 2017), online processing engines e.g. PositioNZ-PP, Precise Point Positioning (PPP) as well as any global or national geospatial datasets where positioning data has been recorded in terms of a geocentric datum.

Over time, a number of limitations of NZGD2000 have been identified (Beavan and Blick, 2007; Blick et al, 2009). In the New Zealand context, in addition to ongoing secular plate tectonic motion, earth deformation also results from earthquakes, slow slip events, and volcanic activity. It becomes necessary to have the ability to survey, record and account for the deformation in order to maintain the accuracy of the geodetic infrastructure (Blick, 2005). Because of the complex deformation experienced in New Zealand, the deformation cannot adequately be modelled as a simple velocity field (Equation 1), and additional short term deformation (e.g. earthquakes, slow

slip events), and longer term deformation (post-seismic deformation) need to also be accounted for e.g. Denys and Pearson (2015, 2016).

PositioNZ-PP Positioning

PositioNZ-PP generates the three-dimensional coordinate of a point in a specific realisation of the International Terrestrial Reference Frame (ITRF—e.g. ITRF2008). Since the ITRF is a dynamic coordinate frame, the coordinate epoch is the current date of the observational data, referred to the instantaneous or observational epoch. The coordinate transformation from ITRF2008 to NZGD2000 is a two-step process; namely

> (1) a 14 parameter Helmert coordinate frame transformation from ITRF2008 to ITRF1996 (the coordinate frame upon which NZGD2000 is aligned) at the epoch of observation (Donnelly et al., 2014);
> (2) followed by the application of the National Deformation Model (NDM) from the current date to the reference epoch 2000.0 (i.e. 1/1/2000) that accounts for plate motion and other deformation effects since 2000.0.

The transformation is summarised as a Helmert 14 parameter transformation for the epoch of observation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^{ITRF1996} = \begin{bmatrix} T_X \\ T_Y \\ T_Z \end{bmatrix} + \left(1 + \Delta\mu\right) \begin{bmatrix} 1 & +\theta_Z & -\theta_Y \\ -\theta_Z & 1 & +\theta_X \\ +\theta_Y & -\theta_X & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^{ITRF2008} \tag{2}$$

where the transformation parameters for epoch, t, and reference epoch, t_0 = 2000.0, are given by

$$x(t) = x(t_0) + \dot{x}(t - t_0) \tag{3}$$

The ITRF1996 cartesian coordinates given by Equation (2) are transformed to topocentric (projection) coordinates and the NDM applied using Equation (1) (LINZ 2017).[1]

NZGD2000 Deformation Model

Integral to the PositioNZ-PP coordinate calculation, is the NZGD2000 Deformation Model (NDM) that transforms the calculated position from the epoch of observation to the NZGD2000 (epoch 2000.0). The model is based

on the long term secular velocity as originally computed by Beavan and Haines (2001) and updated in 2013 (Crook and Donnelly, 2013; Crook et al., 2016). The concept of dynamic or semi-dynamic datums, proposed by Grant (1995), Grant and Blick (1998), is a practical approach for dealing with a continuously deforming plate boundary margin. However, from time to time the plate boundary undergoes seismic events that can potentially cause three effects: (1) abrupt, up to ~10 metre position changes due to an earthquake event (coseismic displacement), (2) slowly evolving post-earthquake relaxation that results in transient position changes on time scales of days to decades (postseismic deformation) and (3) small centimetre level periodic displacements that occur semi-regularly at multi-year intervals (Slow Slip Events—SSE).

To maintain the integrity of the geodetic infrastructure, LINZ recognised the complex nature of the deformation caused by earthquakes and other seismic events needed to be taken into account (Blick et al., 2009). Jordan (2006) introduced the concept of a Localised Deformation Model (LDM) or deformation patch that models a deformation event for a given time period and with defined spatial limits. The LDM is then incorporated into the NDM to refine the deformation spatially and temporally. A first attempt to create a LDM used a dislocation model of the 2003 Secretary Island Mw 7.2 earthquake (Jordan et al., 2007). While the effect of the earthquake was limited to the Fiordland region, the LDM demonstrated that the spatial distribution of the deformation caused by a large earthquake could be accurately modelled based on a relatively small number of survey marks.

Deformation patches have subsequently been developed by LINZ following major earthquake events (see Table 2). For example, the Dusky Sound 2009 earthquake (Winefield et al., 2010), the Christchurch 2010-2011 sequence (Crook et al., 2013), Cook Straight 2013 and Kaikōura 2016 events. In practice, the concept of a reverse patch (Crook et al., 2013) is nearly always applied. The modelled coseimsic displacements are applied to all affected NZGD2000 coordinates at epoch 2000 to correct for the earthquake (coseismic) deformation. The long term secular motion (Equation 1) is then applied in "reverse" to recompute the NZGD2000 (epoch 2000.0) coordinate from the current date back in time to the NZGD2000 reference epoch, 2000.0. In other words, a new NZGD2000 (epoch 2000.0) coordinate is determined as *if the earthquake event did not occur!*

Assessment of the PositioNZ Precision and Accuracy

As a School of Surveying class assignment,[2] PositioNZ rinex data has been downloaded each year since 2013 from the LINZ archive[3] and processed using the PositioNZ-PP online engine.[4] Each student was allocated a block of six

days for 5-6 PositioNZ sites from the previous 12 month period. The Receiver Independent Exchange (RINEX) data files are uploaded (individually or in batches) to PositioNZ-PP plus an email address in order to receive and download the PositioNZ-PP processing results. Each year this generates a set of ~1300–1900 site positions (approximately 50 students x 6 sites x days) covering all mainland PositioNZ sites at arbitrary times over the previous 12 month period. In the initial years, the sheer quantity of data files would overload the LINZ processing server(s). Over time the LINZ systems have improved, and the failure rate reduced such that it is now not a significant issue.

Precision and accuracy estimates are determined for the sites and tracked over the seven year period. We tabulate the descriptive statistics for all years (2014 – 2020, Table 1), but exclude the 2017 data from the graphical plots (Figure 1 and Figure 2) since, at the time, LINZ had not updated the geodetic database coordinates or NDM to account for the Kaikōura 2016 earthquake event. As the earthquake significantly affected all PositioNZ sites in the upper South Island and lower North Island, the precision and accuracy estimates are adversely affected.

To determine the position repeatability or precision, we compute the circular horizontal[5] and linear vertical coordinate standard deviation, $\left(\sigma_{Hz}, \sigma_{Vt}\right)$, for each PositioNZ site for each block of ~6 days for which

$$\sigma_{Hz} = \sqrt{\frac{\sum\left[\left(E_i - \hat{E}\right)^2 + \left(N_i - \hat{N}\right)^2\right]}{n-1}} \; and \; \sigma_{Vt} = \sqrt{\frac{\sum\left(H_i - \hat{H}\right)^2}{n-1}} \qquad (4)$$

where E_i, N_i, H_i are the computed topocentric coordinates and $\hat{E}, \hat{N}, \hat{H}$ coordinates for each block of *site* positions (the mean of 6 daily positions). Table 1 reports the mean standard deviation, $\left(\hat{\sigma}_{Hz}, \hat{\sigma}_{Vt}\right)$ for each year. Note that the horizontal standard deviation is interpreted as the precision about the mean horizontal coordinate, $\hat{E}, \hat{N}$.

In a similar manner, the positional accuracy is determined with respect to each PositionNZ site's official coordinate by computing the circular horizontal and linear vertical root mean square error, (rms_{Hz}, rms_{Vt}), for which

$$rms_{Hz} = \sqrt{\frac{\sum\left[\left(E_i - E_{LINZ}\right)^2 + \left(N_i - N_{LINZ}\right)^2\right]}{n}} \; and \; rms_{Vt} = \sqrt{\frac{\sum\left(H_i - H_{LINZ}\right)^2}{n}} \qquad (5)$$

where E_{LINZ}, N_{LINZ}, H_{LINZ} are the LINZ official geodetic topocentric coordinates for each site and n is the total number of computed positions for each year and site. The root mean square error is normally used as a comparison against the true or known value of a higher accuracy quantity e.g. coordinate. In the case of the current study, the coordinates used by PositioNZ-PP for the PositioNZ sites are determined using position time series analyses as described in Pearson et al., (2013a, b, 2015a, b), and not the official LINZ values (i.e. E_{LINZ},N_{LINZ}, H_{LINZ}). Because the same GPS/GNSS data is used in in establishing official LINZ NZGD2000 coordinates as well as the position time series for each PositioNZ site, it is not strictly an independent assessment. However, ignoring that the same data is used for both the PositioNZ coordinates and PositioNZ-PP calculations, and since the LINZ coordinates are the authoritative values used in New Zealand, it is the sensible choice for the "known" coordinates to compare against. Table 1 reports the mean *rms* for each year together with the minimum and maximum *rms* values.

PositioNZ coordinates are periodically updated as a result of national geodetic adjustments that are required to maintain the geodetic infrastructure, but also in response to major seismic events e.g. the Christchurch 2010-2011 sequence (Kaiser et al., 2012) and Kaikōura 2016 (Hamling et al., 2017). Table 2 summarises key PositioNZ position changes and updates. The known coordinates used for the calculation given in Table 1 are therefore the most recent official coordinates for each year, downloaded from the geodetic database.

The network accuracy, for both the horizontal and vertical PositioNZ sites (Order 0, Tier A), is given in the LINZ (2010) fact sheet as ±0.05m at the 95% confidence level. Using the *rms* as an estimate of the network accuracy equates to the maximum horizontal error (HE) and vertical error (VE) for a position of HE_{68} = ± 29mm and VE_{68} = ± 26mm respectively (68% confidence level). Table 1 reports the number of sites that exceed these limits, (i.e.HE_{68} VE_{68}), out of the total of 32–37 sites used in each year's analysis.

For the majority of PositioNZ sites and excluding 2017, the horizontal accuracy is satisfactory with an average *rms* of approximately ±10 mm and only a few (<5) sites exceed the LINZ maximum HE. Clearly the 9 sites where HE_{68} > ± 29mm in 2017 is due to the Kaikōura 2016 earthquake. Compared to the horizontal accuracy, the average vertical *rms* is greater than ±10 mm, while the number of sites exceeding the maximum VE, with VE_{68} > ± 26mm is consistently over 7 (average >10) and does not appear to be improving.

***Table 1**: The horizontal and vertical mean standard deviation (precision) and the mean, minumum and maximum root mean square error (rms) (accuracy) for PositioNZ sites, 2014-2020. The number of sites that exceed the maximum horizontal error (HE_{68} = ±29 mm, 68% CI) and vertical error (VE_{68} = ±26 mm, 68% CI) are computed using the LINZG25706 standard (LINZ 2010). For each year, the total number of sites and observations (n) is given on the RHS.*

	Precision (mm)		Horizontal Accuracy (mm)		HE_{68}	Vertical Accuracy (mm)		VE_{68}	Total	
Year	$\hat{\sigma}_{Hz}$	$\hat{\sigma}_{Vt}$	$r\hat{m}s_{Hz}$	min / max	Sites >29 mm	$r\hat{m}s_{Vt}$	min / max	Sites >26 mm	Sites	n
2014	3	5	16	5 / 41	4	34	4 / 148	25	32	1276
2015	3	6	7	3 / 20	0	12	5 / 26	9	34	1438
2016	3	6	5	2 / 13	0	8	2 / 23	7	35	1697
2017	18	14	27	3 / 388	9	18	3 / 289	10	37	1822
2018	6	8	11	3 / 61	5	11	3 / 44	11	37	1592
2019	3	6	6	2 / 35	2	9	3 / 25	8	36	1841
2020	4	8	8	3 /42	1	10	5 / 35	10	36	1914
mean	6	8	11		3	15		11	total	11580
mean[1]	4	7	9		2	14		12	total	9758

[1] Mean value excluding 2017 due to the Kaikoura 2016 earthquake

Table 2: Sequence of PositioNZ coordinate upgrades (LINZ 2018)

Date	Description	NMD version
28-Jul-1999	NZGD2000 Development Project, secular velocity model	20000101
14-Dec-2013	Geodetic patch including signficant earthquakes 2003-2011	20130801
12-Dec-2014	Geodetic patch for the 2013 Cook Strait and Lake Grassmere earthquakes	20140201
17-Dec-2015	PositioNZ Coordinate update, includes Auckland and Antipodes Islands	20150101
30-Jun-2016	Geodetic patch for the February 2016 Christchurch earthquake,	20160701
14-Jan-2018	National Geodetic Adjustment NZGD2000 update. Geodetic patch for the 2016 Kaikoura earthquake	20171201
25-Oct-2018	Update geodetic patch for the Kaikoura earthquake	20180701

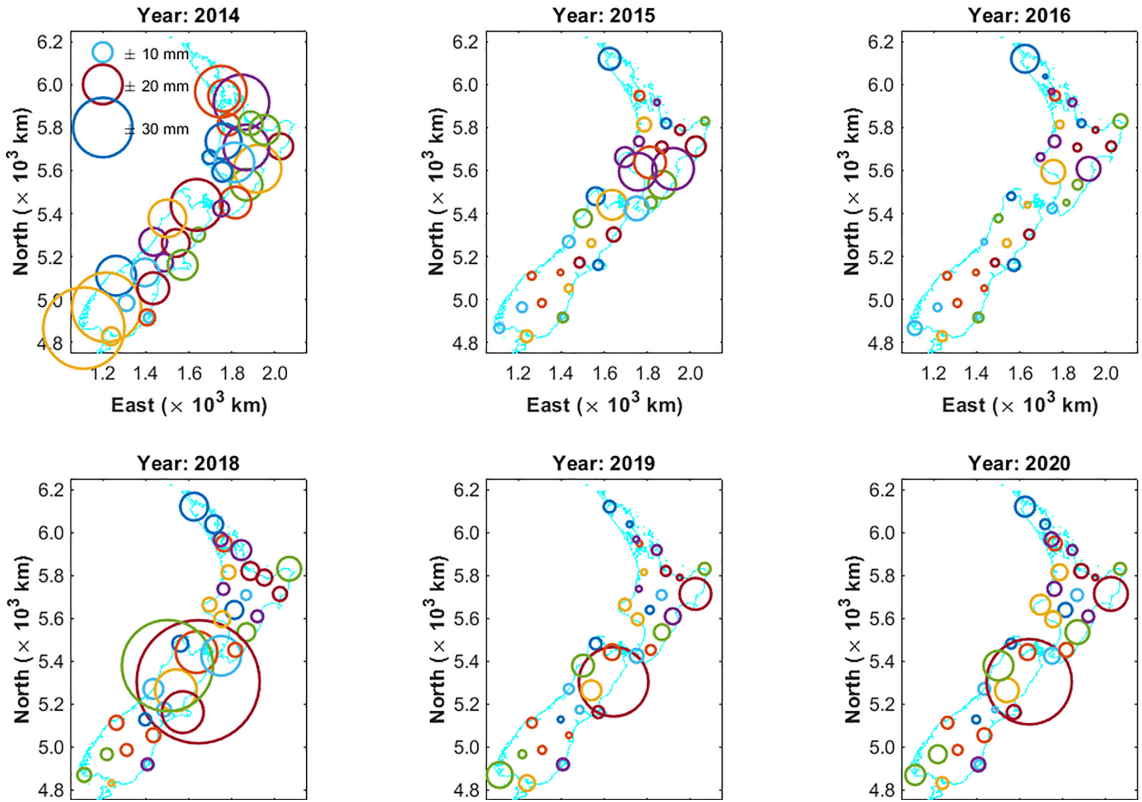

Figure 1: Mean horizontal accuracy (rms) for PositioNZ sites 2014-2016, 2018-2020. The plot for 2017, following the Kaikoura 2016 earthquake, is excluded since the coordinate error is unrepresentatively large (see 2017, Table 1). LINZ subsequently recomputed and updated the official coordinates, which have been used from 2018.

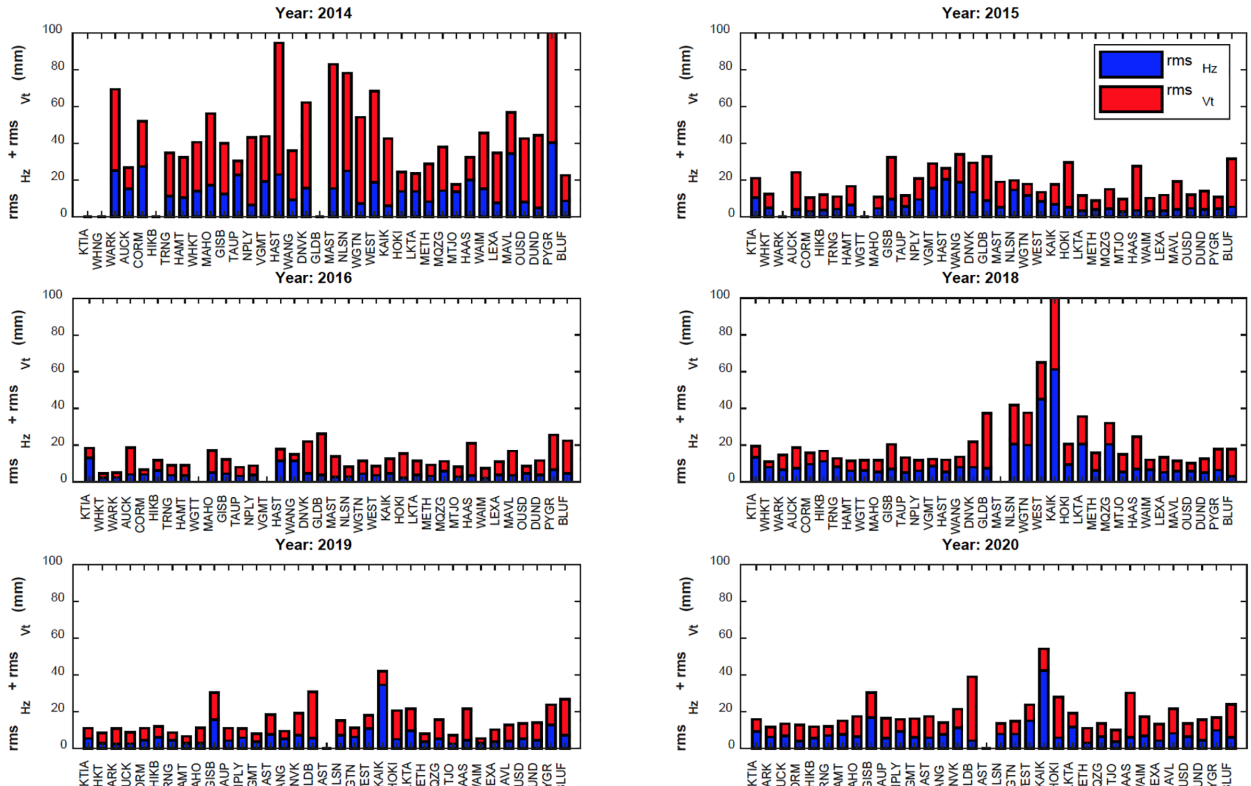

Figure 2: Combined rms_{Hz} and rms_{Vt} for each PositioNZ sites 2014–2016, 2018–2020. The plot for 2017, following the Kaikoura 2016 earthquake, is excluded since the coordinate error is unrepresentatively large (see 2017, Table 1). The PositioNZ sites are order approximately by latitude from the North (left) to the South (right).

Interpretation

Except for 2017, the site repeatability estimates are largely consistent over the seven year period, 2014-2020 (Table 1). The elevated standard deviations in 2017 (× 2–5) is not unexpected since the Kaikōura earthquake impacted all sites throughout New Zealand. The upper South Island and lower North Island underwent both horizontal and vertical deformation of up to approximately the 10 metre level (Hamling et al., 2017). Clearly, the earthquake deformation created significant relative positional changes between PositioNZ sites, resulting in a decrease in precision for approximately one year following the earthquake event. As the PositionNZ sites had moved physically, compared to the authoritative coordinates, the PositioNZ-PP processing introduced bias to the baseline vectors used to determine the positions of the site(s) being processed.

In terms of accuracy, compared to 2014, the December 2014 PositioNZ coordinate update (Table 2) made a significant impact with an approximately 60% improvement in both the horizontal and vertical accuracy (Table 1, Figure 1 and Figure 2). In 2014, the vertical accuracy is particular poor with rms_{Vt} = ± 34mm, which is nearly double the 2017 rms value, and with more than 75% (25/32) sites exceeding the maximum vertical error specification of VE_{68} = ± 26mm. The most uniformly high accuracy across the whole of the geodetic network is achieved in 2016 (sub-centimetre level: rms_{Hz} = ± 5mm, rms_{Vt} = ± 8mm), as well as having the least number of PositionNZ sites that exceed the maximum horizontal and vertical error limits with 5 and 7 sites respectively (total 35 sites). This is clearly seen in Figure 1 and Figure 2.

The three years, 2018–2020, show consistently the ongoing elevated network error levels where the sites in the Kaikōura region continue to dominate. A horizontal accuracy improvement of 45% following the October 2018 PositioNZ update can be seen visually in Figure 1 , although there is no discernible improvement in the vertical accuracy (Table 1). Overall, the mean horizontal and vertical accuracy following the national geodetic adjustment and reverse patch update (January 2018) appears to be at the one centimetre level or slightly better.

The effects of the Kaikōura earthquake clearly continue to bias the sites, KAIK, LKTA, GLDB and WEST, where the horizontal *rms* > ± 10mm (Figure 2). In fact, the horizontal rms at these sites increased in 2020 suggesting that the effect of on-going Kaikōura postseismic deformation is significant and the error is likely to become larger in the future. Notably the vertical rms for these sites and others in the upper South Island tend to be at the rms_{Vt} ~ ± 10mm or larger and are generally less than the horizontal rms suggesting that vertical post earthquake deformation has stabilised while the horizontal deformation

has not. The post-seismic deformation since January 2018 has not been included in the current NDM.

Two other sites on the east coast of the North Island, GISB and DNVK, also have horizontal and vertical rms values > ± 10mm, which is due to the slow slip events (SSE) caused by the East Coast subduction zone.

Discussion

Updating New Zealand's geodetic infrastructure, upon which all other spatial data sets are based (e.g. cadastral, topographic maps, hydrographic charts), has clearly been achieved following the major earthquake events that have occurred in the South Island over the last two decades. What has not been achieved is adequate modelling of non-linear deformation (Denys and Pearson, 2015, 2016) and ongoing post-seismic deformation e.g. Denys et al. (2019). The current NDM does not include deformation caused by subsidence and uplift (the vertical component) (Pearson and Denys, 2015), slow slip events (SSEs) and post-seismic deformation.

Vertical deformation: New Zealand's global position on the boundary between the Australian and Pacific plates means that there is significant vertical deformation as well as horizontal deformation. For example, the subduction of the Pacific plate under the Australian plate along the east coast of the North Island, Kāpiti Coast and upper South Island results in ongoing subsidence of up to 10 mm/yr (Fadil et al., 2013). Further south, Bevan et al. (2010) showed that the central Southern Alps are uplifting by 5–6 mm/yr. In addition, other geophysical processes also contribute to vertical instability. For example, modelling by Riva et al. (2017) shows that the loss of ice in the Southern Alps due to a warming climate has a small but consistent impact on the solid earth throughout the whole of New Zealand. The whole of the North Island is subsiding >0.35 mm/yr (35 mm/ century), the South Island slightly less at 0.3 mm/yr (Denys et al., 2020) while the central Southern Alps is uplifting at 0.8 mm/yr. The lack of vertical velocities in the (NDM) will cause a bias between (GNSS measured) ellipsoid heights measured at different epochs. The lack of vertical velocities is probably the most serious deficiency in the NDM as the bias will accumulate with time.

Slow Slip Events: New Zealand is subject to non-linear deformation associated with slow slip events (SSEs). These typically cause periodic 10-20 mm position changes along the central east coast of the North Island and up to 50 mm along the Kāpiti Coast. This level of regional deformation is not incorporated in the NZGD2000 deformation model. Since the NDM velocities are determined using a linear model, the effect is averaged across multiple SSEs, resulting in the true position of the point being systematically

displaced from the SSEs, resulting in the true position of the point being systematically displaced from the modelled position by an amount dependent on where the SSE cycle happens to be at the time in question. This is similar to a cyclic error but does not have a regular sine curve periodicity.) As a result, coordinates determined at different times for points located in areas subject to SSEs will have a potential bias in both the horizontal and vertical directions. However, since the SSEs are quasi periodic, the bias is limited to plus or minus half the typical amplitude of the SSEs i.e. typically ~ 10 – 20 mm. For the PositioNZ site, HAST (Hasting, Figure 3), the SSE results in a significant eastward shift of ~100 mm, a small southward shift of 10 mm and 50 mm of vertical uplift over 18.5 years.

Post-seismic deformation: Unmodelled post-seismic relaxation is a third source of bias. The NDM does not currently include post-seismic relaxation models, instead, it includes a series of temporary velocity changes or ramps that approximates the post-seismic deformation. However, for the Kaikōura earthquake, the ramp functions terminate at 14 Feb 2017. As a result, the ongoing post-seismic deformation since this time is not corrected by the NDM and will bias the NZGD2000 coordinates when transformed to epoch 2000.0 (NZGD2000). As an example, we plot the position time series in Figure 4 (East, North, Height components) for the GeoNet station CMBL (Cape Campbell, located near the northern trace of the Kaikōura earthquake) with the date 14 Feb 2017 marked as a vertical line. Up until this date, the post-seismic displacements amounts to 0.03-0.05 m. Clearly the post-seismic deformation has continued and has now resulted in (May 2021) displacements of over 0.1 m and 0.15 m in the horizontal and vertical components respectively.

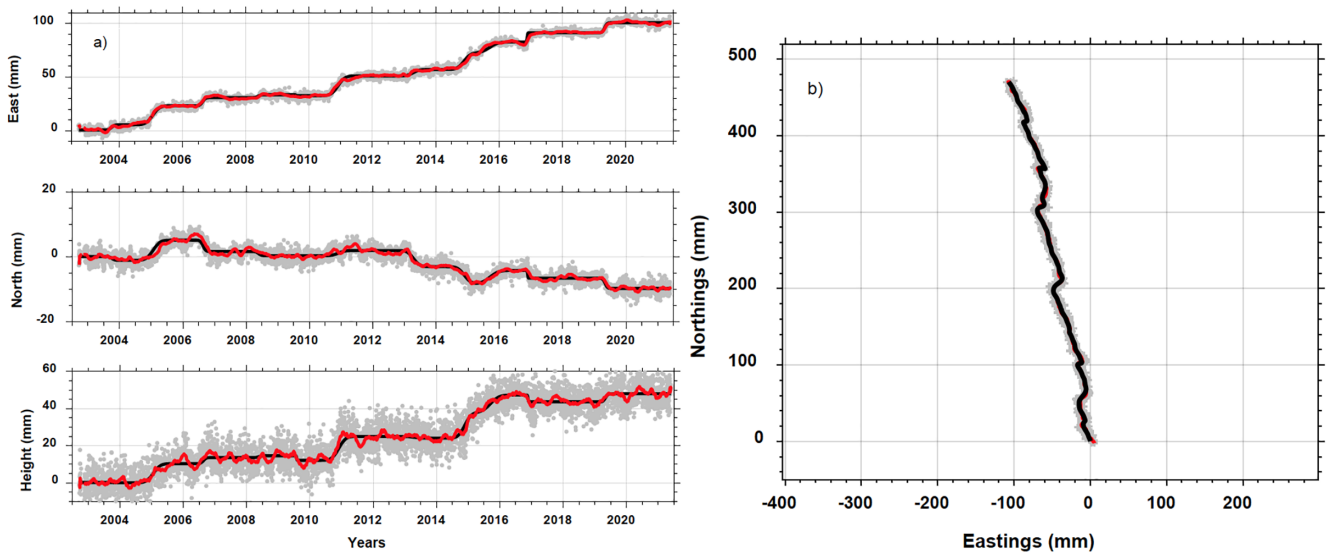

Figure 3: The PositioNZ station HAST (Hasting) showing the semi-regular SSEs for the East, North and Height time series components (a) and as a horizontal plot (b). The accumlated motion over 18.5 years is over 0.1 m east, 0.01 south and 0.05 m up.

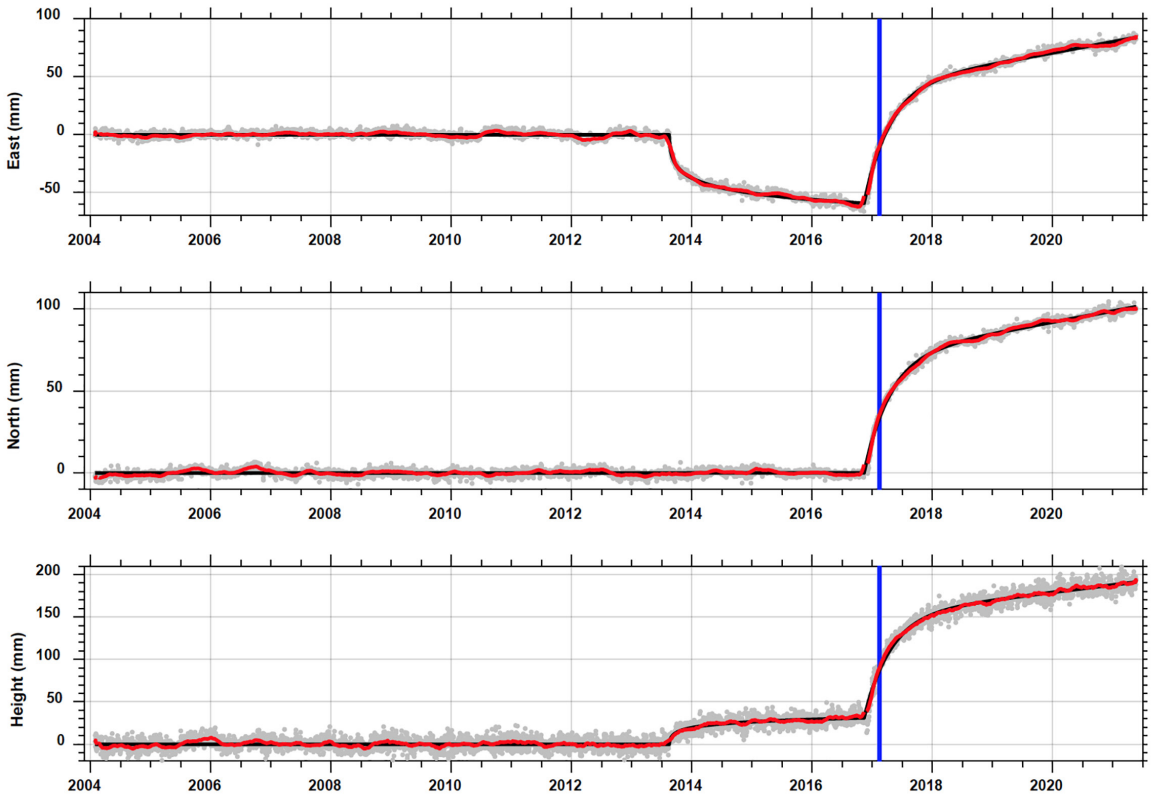

Figure 4 Position time series for GeoNet station CMBL (Cape Campbell) showing the combined post-seismic deformation from the Grassmere/Cook Strait earthquakes (2013.6) and the Kaikoura earthquake (2016.8). The coseismic displacements are not shown, (-1 – 2.5 m level). For the Kaikoura event, the ongoing post-seismic deformation exceeds 0.1 m in the horizontal components and 0.15 m in the vertical component. The date 14 Februray 2017 is shown as a vertical blue line.

Summary

Over the seven year period 2014 – 2020, and ignoring the immediate effect following the 2016 Kaikōura earthquake, the estimated PositioNZ site repeatability is a consistent ±4 mm and ±7 mm for the horizontal and vertical precision respectively. Site accuracy is approximately double the site precision at ±9 mm and ±14 mm for the horizontal and vertical components respectively. The least accurate sites are typically ±20 – 40 mm. The number of sites that exceed the LINZG25706 standard (LINZ 2010) for the maximum horizontal error is less than five (2018) and less than 11 (2018) for the maximum vertical error. For the seven year period the number of sites that exceeded the maximum horizontal error has been or is decreasing to zero while the maximum vertical error is consistently in the order of 10 sites.

New Zealand's tectonic setting means that the country is actively deforming as a result of plate boundary processes. While the relative deformation is regular and largely secular in nature, seismic activity results in significant displacements (coseismic deformation) as well as ongoing postseismic relaxation and SSEs. It is these three geophysical phenomena
that degrade New Zealand's geodetic infrastructure and are currently impacting the overall geodetic accuracy of the network. Clearly, LINZ's geodetic network upgrades following significant earthquake events has improved the horizontal accuracy, although sites closest to the Kaikōura region are still affected by on-going post-seismic relaxation. Throughout the country, vertical accuracy remains consistently less accurate, which in part can be attributed to an assumed zero vertical land motion in the NDM.

It is imperative that the geodetic infrastructure is maintained to a regular standard in order to underpin the topographic, cadastral and bathymetric datasets as well as the most remote sensing technologies, which are based on a geocentric coordinate frame. While many of the geodetic biases are small, it is the incremental effects that gradually distorts the geodetic infrastructure over time. Vertical deformation; SSEs, and post seismic deformation should be included in the NDM in order to maintain the accuracy of the geodetic infrastructure.

Notes

[1] We note that the deformation model does not include vertical velocities which happen to be quite high especially along the east coast of the North Island. Other parts of LINZ do incorporate vertical change such as PositioNZ processing. Hence when we do a PositioNZ-PP solution the coordinates we assume for the PositioNZ stations are corrected for vertical motion to give an accurate current position but when we project these to epoch 2000.0 we ignore the vertical component.

[2] Paper SURV301 (Survey Methods 2), School of Surveying, University of Otago

[3] www.linz.govt.nz/data/geodetic-services/positionz/rinex-data-archive

[4] www.linz.govt.nz/data/geodetic-services/positionz/positionz-post-processing-service

[5] Circular horizontal standard deviation is a circle with a radius computed from the square root of the sum of east and north variances

References

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