Automated Monitoring of CORSnet-NSW using the Bernese Software

Joel HAASDYK, Craig ROBERTS and Volker JANSSEN, Australia

SUMMARY

Global Navigation Satellite System (GNSS) observations are increasingly used for a wide range of applications, and networks of Continuously Operating Reference Stations (CORS) are being rapidly installed to provide centimetre-level relative positioning. It is becoming increasingly important to determine and report on the quality control of these installations. This is necessary for legal traceability of data and measurements as well as for long-term stability studies of station coordinates.

This paper presents the automation of high-precision daily coordinate solutions of stations in CORSnet-NSW, using the *Bernese* software. CORSnet-NSW is a rapidly expanding network of CORS stations separated by significant distances (up to 275 km in remote regions) in the state of New South Wales, Australia. Coordinates are obtained in ITRF2005 and transformed into GDA94. The ongoing analysis of these coordinates can reveal: 1) Site specific velocities of a network at higher densities than those provided by the IGS network, 2) A medium density sampling of the local distortions present in the GDA94 datum and the distortions in ellipsoidal heights derived from the Australian Height Datum 1971 (AHD71) and AUSGeoid98, and 3) Trends in site coordinates revealing local ground deformation.

GPS data collected over a short period (60 days) in 2009 is sufficient to calculate station coordinates at millimetre-level precision, and velocities with 2-4 mm/yr precision that agree with expected tectonic motions. Significant differences are shown to exist between the coordinates of CORSnet-NSW stations obtained from the *Bernese* solution and their published GDA94 and ellipsoidal height coordinates at the 0.2 m and 0.3 m levels horizontally and vertically, respectively. The published coordinates are calculated from local tie-surveys and retain local distortions in GDA94 and AHD71 for the benefit of local users.

Network-RTK error modelling methods, legal traceability via national 'Regulation 13' position certification, and overlapping CORS networks will soon require station coordinates in a more homogeneous datum, such as ITRF. Ever-increasing GNSS accuracy will highlight the local distortions present in GDA94 and AHD71/AUSGeoid98 and cause possible confusion for users. For these reasons, the time has come to review and renew the national horizontal and vertical datums.

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   1/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

Automated Monitoring of CORSnet-NSW using the Bernese Software

Joel HAASDYK, Craig ROBERTS and Volker JANSSEN, Australia

1. INTRODUCTION

Global Navigation Satellite System (GNSS) observations, such as those utilising the Global Positioning System (GPS), are increasingly used for a wide range of applications, including geodesy, deformation monitoring, precision agriculture and cadastral surveying (e.g. Roberts et al., 2007; Zhang et al., 2007). To achieve the required accuracies for these applications, differential positioning techniques are often employed. By simultaneously observing the same satellites at two or more stations, these methods can eliminate or mitigate the spatially correlated biases that are experienced by multiple receivers (e.g. atmospheric delays and satellite orbit errors). However, this procedure is restricted to baselines of only several tens of kilometres if centimetre-level positioning is required (e.g. Rizos et al., 2003; Roberts et al., 2004).

As a result, there is a trend towards densification of permanent GNSS receivers. Networks of Continuously Operating Reference Stations (CORS) are being rapidly installed in Australia. In addition to the existing fundamental Australian Regional GPS Network (ARGN) (GA, 2009b), a national GNSS network consisting of 100 CORS is currently being established as part of the AuScope (2009) project. Several state jurisdictions are also building and expanding their networks, e.g. GPSnet in Victoria (Land Victoria, 2010) and CORSnet-NSW in New South Wales (LPMA, 2010). It is clearly evident that CORS networks are becoming the fundamental control of future geodetic datums, including, e.g., the anticipated new realisation of the Geocentric Datum of Australia (GDA201x).

CORSnet-NSW (White et al., 2009; Janssen et al., 2010) is a rapidly expanding network of CORS stations separated by significant distances (up to 275 km in remote regions) in the state of New South Wales, Australia. At the time of data collection, this network was composed of 23 stations (Figure 1). State-wide coverage is planned for no later than 2013 with at least 70 stations, including 10 to AuScope (2009) specifications.

As the accuracy of differential positioning is directly dependant on the accuracy of the reference station coordinates, it is becoming increasingly important to setup and report on the quality control of these permanent GNSS reference stations. This is necessary for legal traceability of data and measurements (Hale et al., 2007), and long-term stability studies of station coordinates. Scientific studies, such as ground deformation and sea-level monitoring can also profit from such long-term observation records.

This paper presents the automation of high-precision daily coordinate solutions of stations in CORSnet-NSW, using the *Bernese* software (Dach et al., 2007). Coordinates are obtained in the International Terrestrial Reference Frame 2005 (ITRF2005) (Altamimi et al., 2007) and transformed into the Geocentric Datum of Australia 1994 (GDA94) (ICSM, 2009). The reader is referred to Janssen (2009a) for a review of the coordinate systems, datums and

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   2/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

associated transformations used in the Australian context. The ongoing analysis of these coordinates can reveal: 1) Site specific velocities of a network at higher densities than those provided by the IGS network, allowing comparisons with existing plate models, 2) A medium density sampling of the local distortions present in the GDA94 datum and the distortions in ellipsoidal heights derived from the Australian Height Datum 1971 (AHD71) and AUSGeoid98 (Featherstone et al., 2001), and 3) Trends in site coordinates which can reveal local ground deformation.
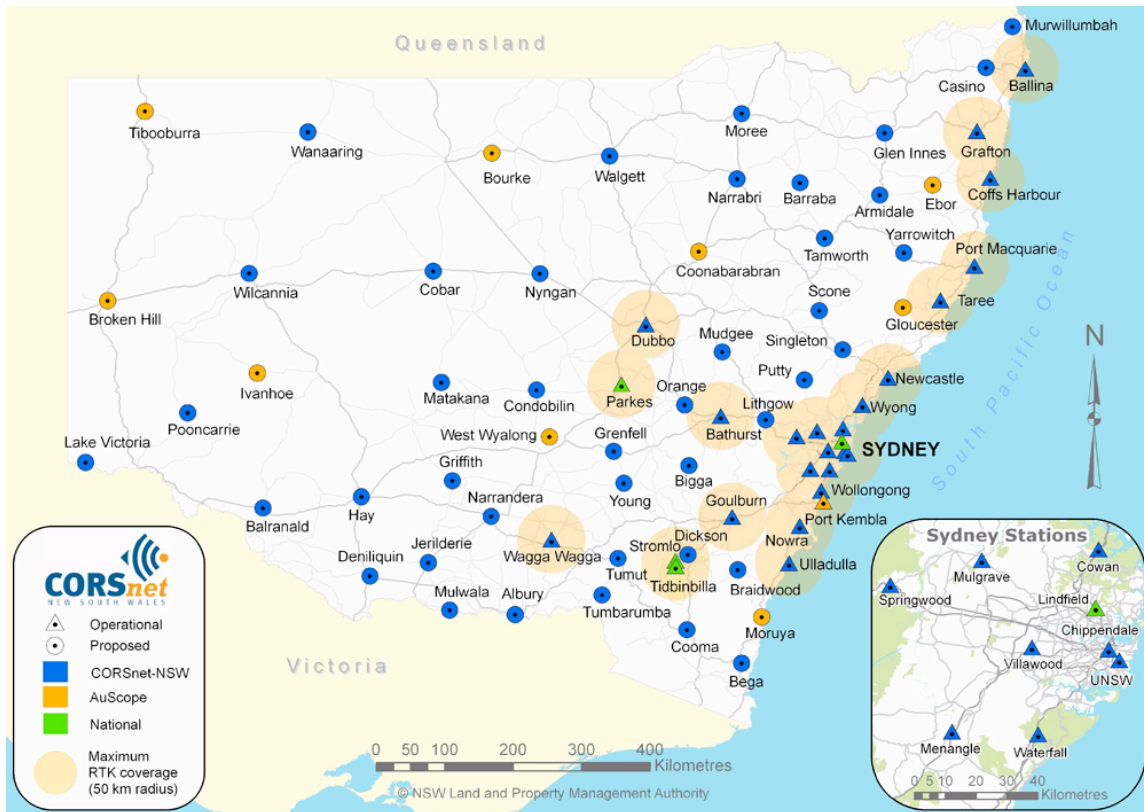
Figure 1: CORSnet-NSW network coverage as of July 2009, showing existing stations as triangles, while proposed sites are indicated by circles.

GPS data collected over a short period (60 days) in 2009 is sufficient to calculate station coordinates at millimetre-level precision, and velocities with 2-4 mm/yr precision that agree with expected tectonic motions. Significant differences are shown to exist between the coordinates of CORSnet-NSW stations obtained from the *Bernese* solution and their published GDA94 and ellipsoidal height coordinates (LPMA, 2009) at the 0.2 m and 0.3 m levels horizontally and vertically, respectively. Previous studies have shown that the CORS station coordinates in the state of Victoria have similar distortions (up to 0.18 m) between published GDA94 and observed ITRF coordinates (Brown et al., 2002; Ramm and Hale, 2004).

Ideally, CORS station coordinates should be referenced directly to the Australian Fiducial Network (AFN), the nation's fundamental geodetic network (GA, 2009b) so that there is good

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

3/19

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

agreement with the national framework. However, the published coordinates are currently calculated from local tie-surveys and retain local distortions in GDA94 for the benefit of local users. It should be noted that all vertical comparisons in this study are between ellipsoidal heights. Observed GDA94 ellipsoidal heights are derived from the GPS observations, while expected (published) ellipsoidal heights are derived from the local AHD71 orthometric heights and geoid undulation values obtained from AUSGeoid98 (Featherstone et al., 2001). Therefore any distortions noted in the height component could be due to contributions from either the height datum or the geoid model.

As more users gain access to increasing GNSS accuracy, these local distortions in the national horizontal datum and vertical datum/geoid model will become a significant issue. AUSPOS, Geoscience Australia's online GPS processing service (GA, 2009a), currently provides coordinates accurate to 20 mm horizontally and 50 mm in elevation relative to the Australian Regional GPS Network (ARGN) – the successor of the AFN – with as little as two hours of static, dual frequency data. Confusion and misunderstanding can occur when the coordinates from these GNSS observations do not match the lower-order ground marks that were typically coordinated using traditional surveying methods (Brown et al., 2002; Ramm and Hale, 2004).

Similarly, the expansion of state based networks will soon require a seamless integration of various CORS networks across state and territory borders. One option is to distort the highly consistent CORS network observations to match the local ground control of each state, thereby sacrificing the much higher quality of the GNSS observations. However, a more practical solution would be to renew the state and national datums and consider the adoption of a datum fully consistent with the international standard, ITRF.

2. DATA SOURCES

The period of data analysis for this study covers 60 days in 2009, from 20 April to 18 June inclusive (days 110 to 169). Only GPS observations have been considered. RINEX data for 23 CORSnet-NSW stations were gathered directly from RTCM data streams over the internet using the BNC NTRIP client ('Networked Transport of RTCM via Internet Protocol'; BKG, 2010). It should be noted that the station TARE (located in Taree, NSW) was only commissioned 8 days before the end of this study. As a result, coordinates but not site velocities have been determined for TARE. RINEX data for 4 ARGN stations (PARK, STR1, SYDN and TID1) were gathered as daily files from Geoscience Australia (via ftp from ftp://ftp.ga.gov.au).

Post-processed precise satellite orbits, earth orientation data, and satellite clock offset information were sourced from the International GNSS Service (via ftp from ftp://igscb.jpl.nasa.gov/igscb/product). These were provided in SP3, ERP and CLK files, respectively, which were renamed with extensions PRE, IEP and CLK to match *Bernese* conventions. Further post-processed files such as atmospheric modelling and differential code bias files were obtained from the University of Bern (via ftp from ftp://ftp.unibe.ch/aiub/CODE) as daily ION files and monthly P1P2.DCB and P1C1.DCB files. Ocean tide loading coefficients were sourced from Chalmers (2009) using all default parameters.

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   4/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

Official station coordinates for the CORSnet-NSW sites were obtained as curvilinear GDA94 coordinates (latitude and longitude), ellipsoidal heights from AHD71 plus AUSGeoid98 geoid undulation values, as well as Map Grid of Australia 1994 (MGA94) grid coordinates (Easting, Northing and zone number) as published by the NSW Land and Property Management Authority (LPMA, 2009), and converted to Cartesian coordinates using the MATLAB 'lla2ecef' function (Constell, 2009). These coordinates were initially transformed to ITRF2000 and then the datum and reference epoch of ITRF2005(2000.0) using transformation parameters of Geoscience Australia and the ITRF (e.g. Dawson and Steed, 2004; IGN, 2009; Janssen, 2009a). It should be noted that this 2-step procedure was necessary because published direct transformation parameters between GDA94 and ITRF2005(2000.0) were not available at the time of this study. Reference site velocities were determined using the ITRF plate model (Altamimi et al., 2007; Stanaway and Roberts, 2009).

Official ARGN station coordinates were obtained in ITRF2005, and propagated if necessary, to the reference epoch at 2000.0 using site velocities as determined above. PARK, SYDN, and TID1 station coordinates were sourced from GA (2009c) and STR1 station coordinates from IERS (2005). Table 1 lists the official coordinates of all stations included in this study.

Table 1: Published MGA94 coordinates of CORSnet-NSW and ARGN stations utilised in this study (ellipsoidal heights derived from AHD71 and AUSGeoid98, assumed to be equivalent to GDA94)

Station	Easting (m)	Northing (m)	MGA Zone	GDA94 Ell. Height (m)	AHD Height (m)	Data Source
BALL	555010.083	6805989.971	56	44.390	6.991	LPMA (2009)
BATH	738680.563	6298128.342	55	756.887	731.468	LPMA (2009)
CHIP	333655.811	6248928.975	56	55.944	33.267	LPMA (2009)
COFF	513301.218	6647949.825	56	46.559	13.158	LPMA (2009)
CWAN	330343.334	6281392.869	56	218.203	194.380	LPMA (2009)
DBBO	650926.495	6430796.248	55	297.909	272.700	LPMA (2009)
GFTN	493508.567	6715225.999	56	59.098	23.814	LPMA (2009)
GLBN	748763.452	6150683.972	55	678.959	657.190	LPMA (2009)
GONG	306923.584	6188470.403	56	75.833	54.863	LPMA (2009)
MENA	291928.752	6221563.054	56	111.452	88.965	LPMA (2009)
MGRV	298805.016	6277143.343	56	45.357	21.265	LPMA (2009)
NEWC	384557.597	6355842.776	56	53.122	27.169	LPMA (2009)
NWRA	281077.492	6138337.574	56	46.612	26.737	LPMA (2009)
PARK (ARGN)	618139.977	6348139.000	55	397.470	n/a	GA (2009c)
PMAC	490279.099	6519200.107	56	43.856	13.635	LPMA (2009)
SPWD	274216.919	6268603.638	56	399.625	375.337	LPMA (2009)
STR1 (ARGN)	682726.015	6090110.666	55	800.017	n/a	IERS (2005)
SYDN (ARGN)	328742.550	6260601.368	56	85.668	n/a	GA (2009c)
TARE	449304.031	6469169.858	56	44.958	15.635	LPMA (2009)
TID1 (ARGN)	679807.853	6080884.469	55	665.426	n/a	GA (2009c)
ULLA	269706.176	6083865.092	56	63.114	45.110	LPMA (2009)
UNSW	336547.289	6245564.235	56	86.993	64.465	LPMA (2009)
VLWD	312919.842	6249236.650	56	42.738	19.862	LPMA (2009)
WFAL	315117.362	6221146.451	56	251.663	229.726	LPMA (2009)
WGGA	533654.929	6115007.737	55	216.067	201.270	LPMA (2009)

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

5/19

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

WYNG	353238.245	6316280.736	56	58.034	33.182	LPMA (2009)

The Cartesian coordinates held fixed during *Bernese* processing are listed in Table 2. It should be noted that two of the fixed stations, BATH* and PARK* have their coordinates determined from the mean of the 60 daily Bernese PPP determined from these data, with an RMS of 3 mm. These are named with an asterisk to distinguish them from the official published coordinates for these stations. The coordinates for PARK* were determined by PPP because this ARGN station was flagged by the Bernese Network process as having coordinates inconsistent with the rest of the network. Subsequent discussions with GA (Dawson, 2010, pers. comm.) confirmed that coordinates computed by GA match those determined via *Bernese* in this study. Coordinates for BATH* were determined by PPP because an additional fixed station was required outside of the Sydney Basin in order to allow a study of subsidence of those stations within the Sydney Basin relative to the rest of the state.

Table 2: *Bernese* network solution fixed stations and Cartesian coordinates in ITRF2005(2000.0).

Station	X (m)	Y (m)	Z (m)	Data Source
BATH*	-4594792.278	2699284.263	-3494245.764	PPP solution mean
PARK*	-4554254.484	2816652.474	-3454060.625	PPP solution mean
PARK (ARGN)	-4554254.507	2816652.496	-3454060.631	GA (2009c)
STR1 (ARGN)	-4467102.470	2683039.473	-3666949.669	IERS (2005)
SYDN (ARGN)	-4648240.160	2560636.484	-3526318.707	GA (2009c)
TID1 (ARGN)	-4460996.240	2682557.083	-3674443.558	GA (2009c)

Note: PPP solutions for fixed stations BATH* and PARK* were obtained as the mean of the *Bernese* PPP solution for these stations over days 110 to 169 (2009), propagated to 2000.0 using the ITRF plate model (Altamimi et al., 2007; Stanaway and Roberts, 2009).

3. ANALYSIS SOFTWARE AND METHODOLOGY

3.1 Software

Bernese is a high performance, high accuracy, and highly flexible GPS/GLONASS post-processing package (Dach et al., 2007). Typical users include scientists for research and education, national survey agencies responsible for high-accuracy GNSS surveys (e.g. first order networks), and agencies responsible for the maintenance of CORS networks.

The *Bernese* software is particularly well suited for automatic processing of permanent networks, both large and small, combining different receiver types. It can handle very long baselines in excess of 2000 km, and can generate a minimally constrained network. *Bernese* is very flexible and can be used to solve for parameters such as satellite orbits and atmospheric delay values, or can accept high precision pre-calculated information or models for these parameters, such as those produced by IGS (2009).

The *Bernese* software was updated to the latest international datum, IGS05 (Ferland, 2006), and absolute Antenna Phase Centre Variation (APCV) models as per instructions provided

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   6/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

with the software (Dach et al., 2007). Note that IGS products and *Bernese* output in IGS05 are considered to be nominally identical to ITRF2005: The IGS05 is based on GPS-only observations of the ITRF stations, and takes absolute APCV models into account. The IGS05 frame is aligned via a Helmert transformation to the ITRF2005, which fully preserves the reference ITRF datum in orientation, translation and scale, but without any internal distortions (Ray et al., 2004; Kouba, 2009). For the purposes of this study, *Bernese* output will therefore be treated as ITRF2005.
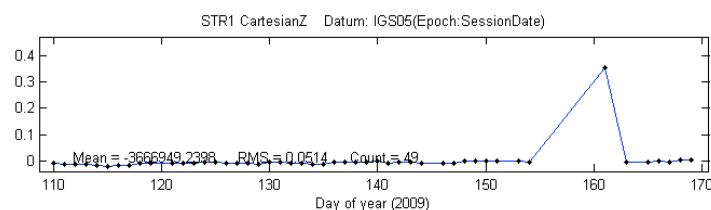
MATLAB was employed for coordinate transformations, analysis of the coordinate output from *Bernese*, and the generation of charts to help visualise results. The PERL scripting language was used to automate the acquisition and processing of data by *Bernese* and MATLAB, and the archiving and reporting of results. PERL was chosen because *Bernese* accepts instructions and runs its own internal scripts in PERL (Dach et al., 2007).

3.2 Methodology

After gathering the required GPS data, *Bernese* was used to calculate a daily coordinate solution for each station using the Precise Point Positioning routine 'PPP.PCF'. These apriori coordinates were used as input to the *Bernese* Network Solution routine 'RNX2SNX.PCF' to calculate a network solution. Details about these processing routines are available in Dach et al. (2007). All default processing parameters were accepted. Stations that were fixed for the network solution are BATH*, PARK*, STR1, SYDN and TID1 (see Table 2).

The output coordinates (in IGS05, nominally ITRF2005) from the *Bernese* analysis are collated by PERL scripting into station-specific coordinate series with one solution per day. These coordinate series are input into MATLAB where each daily solution is propagated to a common reference epoch at 2000.0 using the Euler Pole Parameters of the ITRF2005 plate model (Altamimi et al., 2007; Stanaway and Roberts, 2009). These ITRF2005(2000.0) coordinates are transformed into a daily coordinate series in ITRF2000 and then GDA94 and MGA94 using transformation parameters given in Dawson and Steed (2004), IGN (2009) and Janssen (2009a). As previously mentioned, this 2-step transformation is employed because there are currently no published direct transformation parameters between ITRF2005 and GDA94 available. Statistics for each coordinate component (in each of ITRF2005, GDA94 and MGA94) are automatically determined.

It should be noted that outlier detection and omission is currently not included in this automated processing routine, and data were manually removed only in cases where a discrepancy was obvious (Figure 2). This outlier at STR1 was caused by a short duration of observations (<<24 hours) on one GPS day as the station came back online after maintenance.

Figure 2: STR1 (Mt. Stromlo) PPP solution time series, clearly including an outlier.

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   7/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

The trend in each coordinate is determined by linear regression. This trend represents the absolute station velocity if the daily coordinate series is given in the current epoch, and represents local deformation if the daily coordinate series is first propagated back to a common reference epoch, i.e. removing the effects of tectonic plate motion.

For each station, a plot of the coordinate time series can be produced for many reference frames. Figure 3 shows two examples for BALL, i.e. ITRF2005 Cartesian coordinates and Universal Transverse Mercator (UTM) grid coordinates at the current epoch. The separation of horizontal and vertical components allows a more intuitive interpretation of the site motion and demonstrates the lower precision of the vertical coordinate component, as expected.
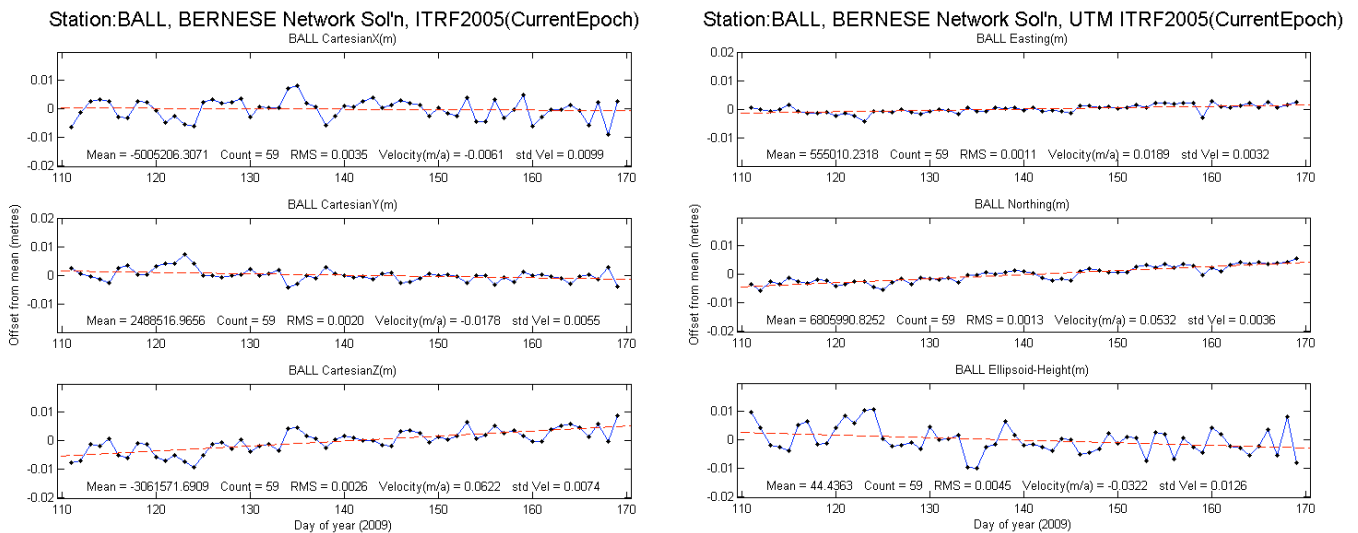
Figure 3: Coordinate time-series for BALL (Ballina, NSW), *Bernese* Network Solution. For each coordinate component, mean, RMS and station velocity (dashed red line) are shown.

4. RESULTS

4.1 Observed Station Coordinates

The *Bernese* Network Solution for each of the CORSnet-NSW stations, stated in MGA94 grid coordinates, is shown in Table 3.

Table 3: *Bernese* Network Solution for MGA94 station coordinates with RMS.

Station	Easting (m)	Easting RMS (m)	Northing (m)	Northing RMS (m)	GDA94 Ell. Height (m)	Ell. Height RMS (m)	MGA Zone
BALL	555009.883	0.0011	6805990.015	0.0013	44.524	0.0045	56
BATH	738680.544	0.0010	6298128.349	0.0008	756.622	0.0020	55
CHIP	333655.791	0.0012	6248929.001	0.0010	55.898	0.0029	56
COFF	513301.101	0.0010	6647949.865	0.0012	46.576	0.0051	56
CWAN	330343.321	0.0009	6281392.912	0.0013	218.097	0.0041	56
DBBO	650926.529	0.0009	6430796.215	0.0008	297.654	0.0027	55

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

8/19

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

GFTN	493508.511	0.0010	6715225.987	0.0009	59.189	0.0040	56
GLBN	748763.455	0.0010	6150683.940	0.0010	678.725	0.0023	55
GONG	306923.584	0.0013	6188470.386	0.0015	75.794	0.0049	56
MENA	291928.736	0.0009	6221563.080	0.0011	111.429	0.0049	56
MGRV	298804.997	0.0010	6277143.361	0.0010	45.238	0.0034	56
NEWC	384557.518	0.0009	6355842.790	0.0012	52.952	0.0040	56
NWRA	281077.482	0.0008	6138337.580	0.0010	46.573	0.0029	56
PARK	618139.979	0.0007	6348138.981	0.0009	397.436	0.0022	55
SPWD	274216.900	0.0010	6268603.663	0.0010	399.506	0.0031	56
STR1	682726.017	0.0012	6090110.672	0.0008	800.021	0.0032	55
SYDN	328742.549	0.0008	6260601.377	0.0007	85.672	0.0029	56
TARE	449303.897	0.0003	6469169.884	0.0006	44.876	0.0038	56
TID1	679807.856	0.0013	6080884.474	0.0010	665.423	0.0025	55
UNSW	336547.269	0.0013	6245564.259	0.0010	86.977	0.0043	56
VLWD	312919.830	0.0011	6249236.670	0.0009	42.675	0.0041	56
WFAL	315117.349	0.0011	6221146.480	0.0010	251.652	0.0033	56
WGGA	533654.914	0.0012	6115007.720	0.0010	215.984	0.0031	55

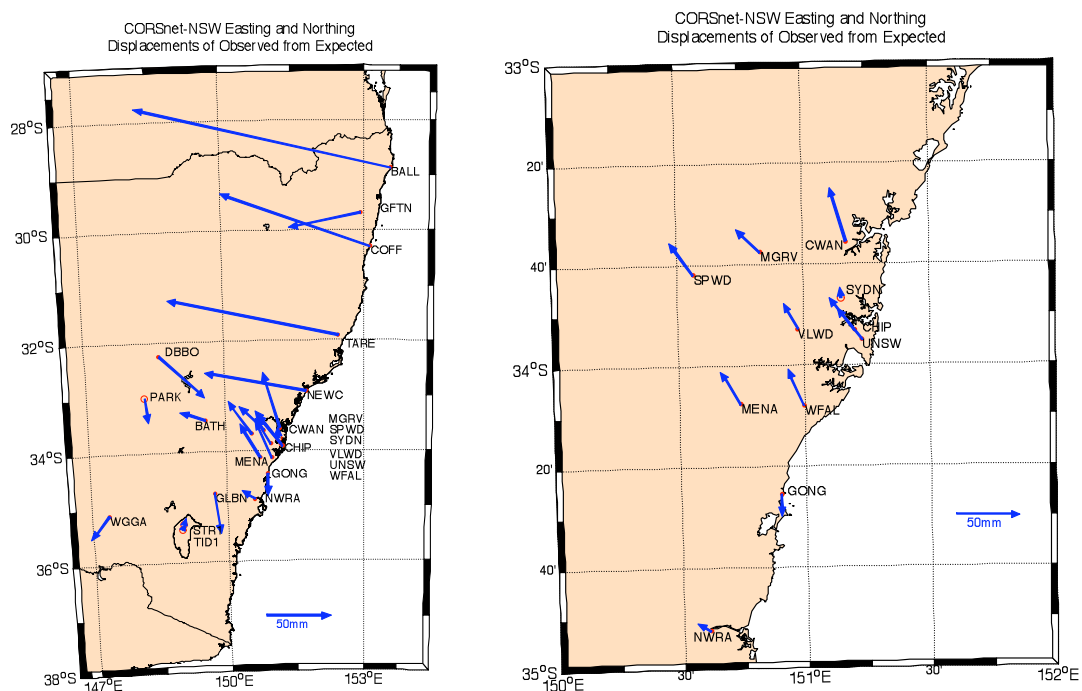## 4.2 Comparison between Observed and Expected Coordinates

The observed MGA94 station coordinates (Table 3) differ from the expected (i.e. published) coordinates (Table 1). The true bearing and distance of each horizontal displacement from the expected is calculated, taking into account grid convergence and scale (ICSM, 2009). The differences are shown in Table 4.

Table 4: Difference of observed station coordinates from expected (published) coordinates (MGA94).

Station	Difference in Easting (m)	Difference in Northing (m)	Difference in Ell. Height (m)	Observed Ground Displacement (m)	Observed Bearing from TRUE north (deg)
BALL	-0.2002	0.0444	0.1335	0.205	282.232
BATH	-0.0193	0.0073	-0.2648	0.021	289.304
CHIP	-0.0203	0.0256	-0.0464	0.033	322.590
COFF	-0.1171	0.0402	0.0166	0.124	288.877
CWAN	-0.0132	0.0427	-0.1056	0.045	343.834
DBBO	0.0343	-0.0335	-0.2546	0.048	133.469
GFTN	-0.0556	-0.0116	0.0906	0.057	258.248
GLBN	0.0034	-0.0318	-0.2336	0.032	172.347
GONG	0.0003	-0.0169	-0.0394	0.017	180.171
MENA	-0.0162	0.0257	-0.0227	0.030	329.041
MGRV	-0.0192	0.0179	-0.1195	0.026	314.195
NEWC	-0.0794	0.0138	-0.1696	0.081	280.531

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   9/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

NWRA	-0.0105	0.0062	-0.0386	0.012	301.931
PARK	0.0020	-0.0195	-0.0343	0.020	173.338
SPWD	-0.0187	0.0252	-0.1186	0.031	324.774
STR1	0.0016	0.0055	0.0033	0.006	15.058
SYDN	-0.0009	0.0086	0.0038	0.009	355.054
TARE	-0.1336	0.0262	-0.0818	0.136	281.379
TID1	0.0025	0.0049	-0.0032	0.006	25.884
UNSW	-0.0200	0.0243	-0.0159	0.032	321.531
VLWD	-0.0119	0.0197	-0.0629	0.023	329.993
WFAL	-0.0129	0.0286	-0.0111	0.031	336.848
WGGA	-0.0149	-0.0175	-0.0827	0.023	220.200

Since the coordinate precision from this 60-day campaign is better than 2 mm horizontally and 5 mm in the vertical (see Table 3), almost every one of these differences is statistically significant. Assuming these GPS observations are more accurate than the original densification surveys which coordinated the local survey marks, this suggests significant local distortions in the underlying datums, i.e. GDA94 (up to 200 mm) and AHD71/AUSGeoid98 (up to 270 mm). The displacement vectors of all observed stations are most easily visualised on a map (Figures 4 and 5).

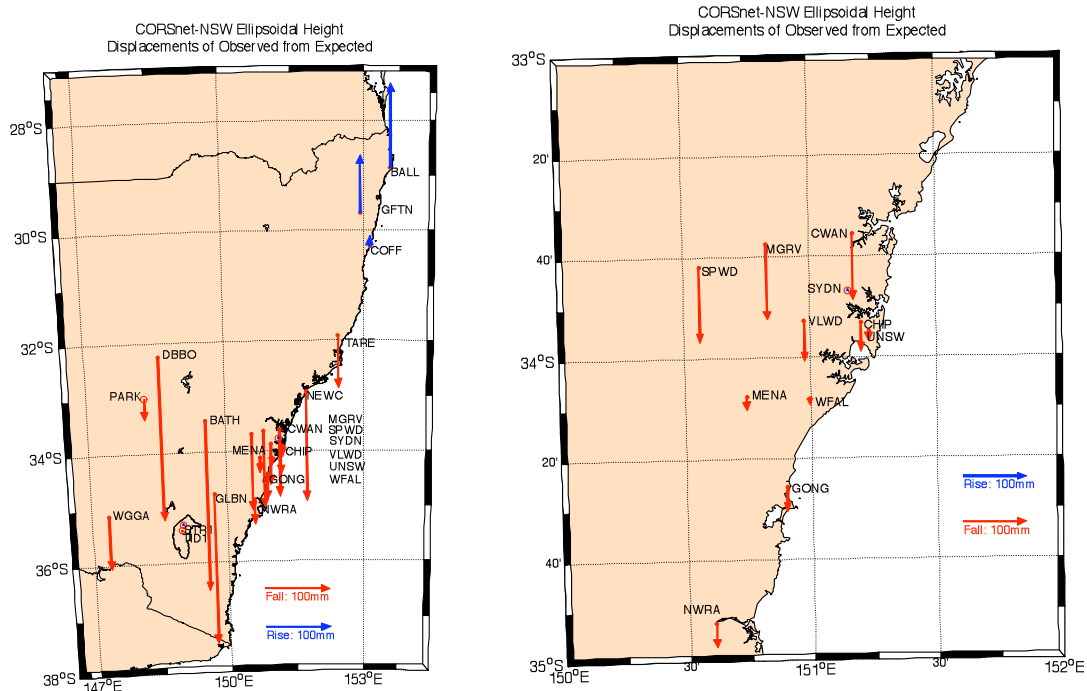**Figure 4: Horizontal displacement vectors of observed minus expected coordinates.**

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

Figure 5: Vertical displacement vectors of observed minus expected coordinates.

4.3 Tectonic Motion

The absolute site velocity of each station (horizontal and vertical) can be determined by converting each daily ITRF2005 solution to Easting, Northing and Ellipsoidal height components without first propagating to a common reference epoch (Table 5). The horizontal velocity vectors are graphically illustrated in Figure 6, clearly indicating the relatively uniform effect of tectonic motion in the study area.

Table 5: *Bernese* Network Solution: Station velocities in ITRF2005(current epoch).

Station	Velocity Easting (m/yr)	Velocity Easting STD (m/yr)	Velocity Northing (m/yr)	Velocity Northing STD (m/yr)	Velocity Ell. Height (m/yr)	Velocity Height STD (m/yr)
BALL	0.0189	0.0032	0.0532	0.0036	-0.0322	0.0126
BATH	0.0202	0.0029	0.0505	0.0023	0.0085	0.0057
CHIP	0.0123	0.0036	0.0557	0.0029	0.0121	0.0086
COFF	0.0147	0.0029	0.0469	0.0032	0.0027	0.0143
CWAN	0.0145	0.0025	0.0551	0.0037	0.0155	0.0120
DBBO	0.0192	0.0026	0.0494	0.0023	-0.0170	0.0076
GFTN	0.0116	0.0029	0.0528	0.0027	-0.0247	0.0111
GLBN	0.0260	0.0027	0.0477	0.0028	-0.0131	0.0063
GONG	0.0203	0.0037	0.0560	0.0042	0.0078	0.0138
MENA	0.0172	0.0026	0.0590	0.0031	-0.0156	0.0144

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

11/19

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

|						
MGRV	0.0064	0.0028	0.0517	0.0029	0.0006	0.0100
NEWC	0.0191	0.0025	0.0537	0.0034	0.0085	0.0114
NWRA	0.0186	0.0023	0.0521	0.0027	0.0200	0.0082
PARK	0.0259	0.0019	0.0605	0.0024	-0.0103	0.0065
SPWD	0.0146	0.0028	0.0505	0.0027	-0.0029	0.0088
STR1	0.0102	0.0039	0.0516	0.0025	-0.0097	0.0099
SYDN	0.0172	0.0022	0.0517	0.0021	0.0052	0.0083
TARE	n/a	n/a	n/a	n/a	n/a	n/a
TID1	0.0198	0.0041	0.0554	0.0031	0.0191	0.0082
UNSW	0.0157	0.0037	0.0469	0.0029	-0.0037	0.0122
VLWD	0.0169	0.0032	0.0593	0.0026	0.0074	0.0119
WFAL	0.0153	0.0031	0.0514	0.0031	0.0099	0.0096
WGGA	0.0217	0.0033	0.0535	0.0029	-0.0057	0.0087
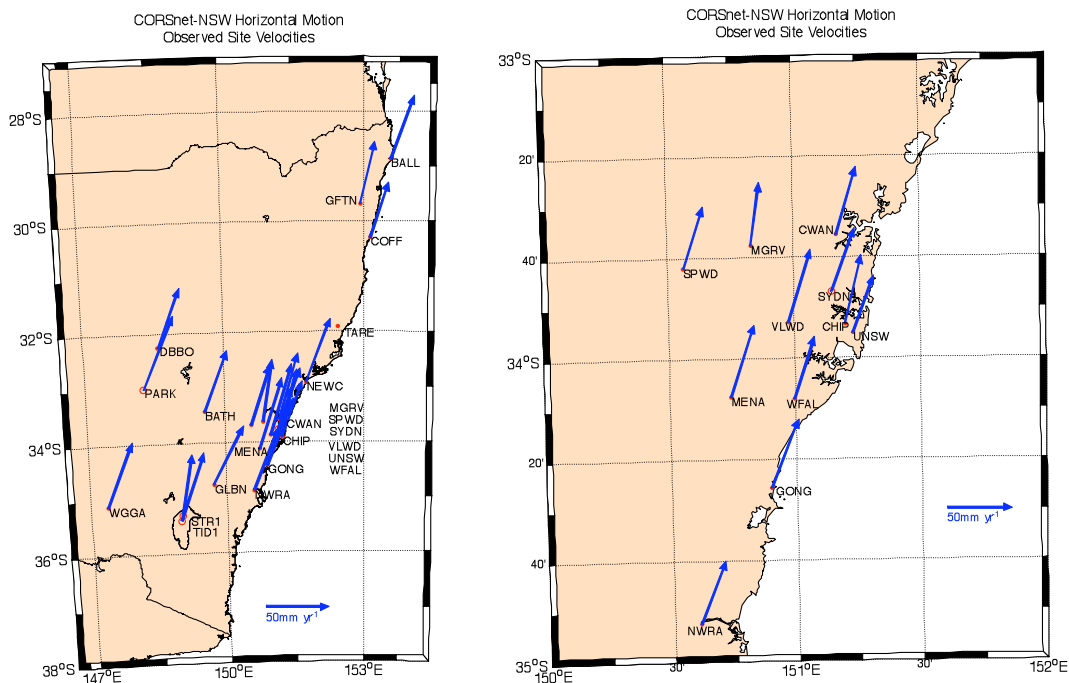
Figure 6: Horizontal site velocity vectors.

4.4 Local Station Deformation (Tectonic Motion Removed)

One important aspect of quality control lies in the monitoring for local deformation, such as subsidence. After propagating each daily solution in the ITRF2005 to a common reference epoch (here 2000.0) and transforming to MGA94, we can test for any significant change in the individual coordinate components. For our purposes, Ellipsoidal Height velocity will give a good approximation of vertical subsidence motion.

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

12/19

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

Table 6 shows the residual station velocities (i.e. deformation) after tectonic motion is removed. A simple t-test can reveal if any of these observed velocities are statistically significant. Highlighted in red is a single station, MGRV, which has a local velocity significantly different than zero at the 95% confidence level. The same result is obtained if the SYDN station is not held fixed in the *Bernese* network solution, which tests for subsidence in the Sydney Basin (data not shown).

Table 6: MGA94 residual station velocities (i.e. site deformation).

Station	Velocity Easting (m/yr)	Velocity Easting STD (m/yr)	Velocity Northing (m/yr)	Velocity Northing STD (m/yr)	Velocity Ell. Height (m/yr)	Velocity Height STD (m/yr)
BALL	-0.0017	0.0032	0.0003	0.0036	-0.0321	0.0126
BATH	-0.0002	0.0029	-0.0036	0.0023	0.0086	0.0057
CHIP	-0.0046	0.0036	0.0014	0.0029	0.0123	0.0086
COFF	-0.0049	0.0029	-0.0062	0.0032	0.0028	0.0143
CWAN	-0.0027	0.0025	0.0009	0.0037	0.0157	0.0120
DBBO	-0.0020	0.0026	-0.0053	0.0023	-0.0168	0.0076
GFTN	-0.0084	0.0029	-0.0004	0.0027	-0.0245	0.0111
GLBN	0.0064	0.0027	-0.0064	0.0028	-0.0129	0.0063
GONG	0.0037	0.0037	0.0016	0.0042	0.0080	0.0138
MENA	0.0004	0.0026	0.0044	0.0031	-0.0154	0.0144
MGRV	-0.0107	0.0028	-0.0028	0.0029	0.0008	0.0100
NEWC	0.0014	0.0025	-0.0002	0.0034	0.0087	0.0114
NWRA	0.0024	0.0023	-0.0025	0.0027	0.0201	0.0082
PARK	0.0052	0.0019	0.0056	0.0024	-0.0101	0.0065
SPWD	-0.0025	0.0028	-0.0041	0.0027	-0.0028	0.0088
STR1	-0.0090	0.0039	-0.0029	0.0025	-0.0095	0.0099
SYDN	0.0002	0.0022	-0.0026	0.0021	0.0054	0.0083
TARE	n/a	n/a	n/a	n/a	n/a	n/a
TID1	0.0014	0.0038	0.0013	0.0030	0.0176	0.0073
UNSW	-0.0013	0.0037	-0.0073	0.0029	-0.0035	0.0122
VLWD	-0.0001	0.0032	0.0049	0.0026	0.0076	0.0119
WFAL	-0.0015	0.0031	-0.0030	0.0031	0.0100	0.0096
WGGA	0.0023	0.0033	-0.0019	0.0029	-0.0056	0.0087

5. DISCUSSION

The results obtained from this automated *Bernese* processing were highly consistent. Station coordinates have been determined with a precision of 1-2 mm horizontally and 2-5 mm vertically (Table 3), and any significant and sustained change above this magnitude would be flagged for further investigation. Station velocities (Tables 5 and 6) have been determined with a precision of 2-4 mm/yr horizontally and 7-15 mm/yr in the height component.

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   13/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

Table 4 and Figure 4 show the difference in the horizontal component between the observed station coordinates and the expected (local) station coordinates. It is apparent from these figures that the displacements observed at these 23 stations are not randomly distributed across the state of NSW. Rather, there is a systematic bias towards the west in the North Coast area (approx. 120 mm at 280°), a north-westerly bias in the Sydney Basin (approx. 30 mm at 330°) and a smaller southerly bias (approx. 15 mm at 150°) in the south-eastern part of the state. A similar pattern can be seen in the vertical component (Figure 5). The North Coast shows a rise (approx. 80 mm) when compared to expected (local) coordinates, the Sydney Basin shows a fall (approx. 40 mm) (predominantly at its northern extent), and regional stations such as DBBO, BATH, GLBN and WGGA show larger falls (approx. 210 mm).

These biases are to be expected, as it is known that the method of realising the GDA94 datum by sequential adjustment down to the lower-order control has left centimetre level biases in the local ground control when compared to coordinates derived directly from the AFN (Brown et al., 2002). As previously mentioned, the expected ellipsoidal height component was determined from both AHD71 and the most current geoid model, AUSGeoid98. Therefore biases in either data source could cause the distortions observed in ellipsoidal heights. It will be interesting to see how the improved new AUSGeoid09, due for imminent publication, will affect these results.

Table 5 and Figure 6 demonstrate the ability of the presented automated analysis to observe the actual tectonic motion of these CORS stations at the millimetre-level horizontally and the centimetre-level vertically. These data show the relative agreement in station motions, i.e. 56 ± 4 mm/yr to the NNE. The horizontal coordinate velocities agree, using a simple t-test at a 95% confidence interval, when compared to expected values for tectonic motion determined from the ITRF2005 plate model. The vertical velocities, although measured at large magnitudes of up to 30 mm/yr, also have large standard deviations, and are not significantly different to zero motion. Obviously, the velocity estimates determined with this automated process can be improved with longer observation time series.

In addition to sudden changes in coordinates, it is important to elucidate any local, slow-scale, long-term changes in CORS station coordinates that can be determined after the dominating tectonic motion effect has been removed. Such changes in the horizontal component are not expected in this context as the Australian continent resides on a rigid part of the Australian Plate with intraplate deformation expected to be less than 2 mm/yr (Tregoning, 2003). Slow vertical displacements can be caused, for instance, by ground subsidence, isostatic rebound, and other geological processes. Of particular interest is the subsidence observed over the Sydney Basin by Ng et al. (2009) using InSAR techniques, amounting to an average value of 5 mm/yr and a maximum of 9 mm/yr in the Eastern Suburbs, possibly due to water extraction.

It is important to note that state-wide CORS networks such as GPSnet (Victoria) and CORSnet-NSW are not expected to deliver data of the highest geodetic quality, and are therefore not built to the same monument specifications as the AuScope network, which utilises concrete pillars on solid bedrock (Janssen, 2009b). On the contrary, CORS antennas are commonly mounted in positions that take advantage of existing infrastructure in regards to

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   14/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

land ownership, available power supply and convenient communication links. For example, in CORSnet-NSW some GNSS antennas are mounted on metal poles on state-rail property, or on the top of multi-storey buildings.

CORS monument stability is an issue that has been previously raised, and it is reasonable to assume that antennas on these sites may exhibit less stability and be subject to more multipath and interference than those mounted on geodetic pillars. However, research indicates that the year-to-year and day-to-day movement of such non-geodetic grade monuments is less than 10 mm (e.g. Penna et al., 2005; Zhang et al., 2005). Shorter time periods such as hourly or diurnally have also been studied to investigate the effects of sudden wind, or significant heat change. Yousufi et al. (2006) found that sub-daily movements of such monuments in Victoria's GPSnet, even in the face of extreme meteorological events, are below the threshold of detectable movement by *Bernese*. Similarly, the results of this study show no significant difference in the repeatability of daily solutions between the types of antenna mounts at the observed stations (data not shown).

At the time of this study, most of the existing CORSnet-NSW stations were located within the eastern part of the state. As CORSnet-NSW continues to expand in order to provide state-wide coverage, we will obtain additional data offering a more comprehensive picture of the local distortions across the state.

6. CONCLUSION

Although the automation of GNSS CORS network processing is not novel, this is the first implementation of an automated monitoring system for the CORSnet-NSW network. We have shown that the *Bernese* software is capable of deriving and visualising coordinates with mm-level precision and utilised these for quality control purposes of the station installations.

Coordinates have been determined with a precision of 1-2 mm horizontally and 2-5 mm vertically, and any sustained change above this magnitude can be observed and flagged. Station velocities have been determined with a precision of 2-4 mm/yr horizontally and 7-15 mm/yr in the height component. Velocity estimates can be improved with a longer observation time series.

As evident from the results of this study, even with the small number of sites (23) investigated, we have determined significant, systematic distortions in the national GDA94 datum and ellipsoidal heights determined from AHD71 and AUSGeoid98 by comparing observed GNSS coordinates with the expected station coordinates based on local tie-surveys. At the CORSnet-NSW stations, these local distortions (or displacements) are up to 0.2 m in the horizontal component and 0.3 m in height.

As CORSnet-NSW migrates towards the provision of Network-RTK services, where GNSS observation errors are modelled between stations, it will become necessary to consider updating the underlying datum to one that is more consistent with GNSS observations, such as the ITRF. For a reliable Network-RTK service to be possible, reference station coordinates must have a homogenous accuracy of better than 15 mm (Ramm and Hale, 2004). Such

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I 15/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

datum improvements would in turn assist with the seamless integration of various CORS networks across state and territory borders, a necessity for applications that regularly cross borders such as LiDAR, major construction projects and geodetic land surveying.

In any case, for the purposes of supporting legal traceability, for a CORS station to act as a National Positional Standard, the official station coordinates cannot be issued in local coordinates (i.e. based on local tie-surveys). Instead a 'Regulation 13' certificate must be issued with coordinates that are rigorously connected to the AFN, and sufficiently stable (Hale et al., 2007).

Brown et al. (2002) assert that as more satellite observations are used in the official realisation of the datum, we will move towards a datum that is more consistently linked with the AFN. As CORS networks continue to expand across the continent, these new stations will help to create an improved realisation of GDA to an absolute accuracy that is anticipated to be better than 2 cm (Hale and Ramm, 2007). Faced with ever-increasing GNSS accuracy and the potential for confusion as users compare GNSS results with outdated realisations of local coordinates, the time has come to review and renew the national horizontal and vertical datums.

REFERENCES

Altamimi, Z., Collilieux, X., Legrand, J., Garayt, B. and Boucher, C. (2007) ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and earth orientation parameters, *Journal of Geophysical Research*, 112, B09401, doi:10.1029/2007JB004949.

AuScope (2009) AuScope – An organisation for a national earth science infrastructure program, http://www.auscope.org.au/ (accessed Jan 2010).

BKG (2010) NTRIP: Networked Transport of RTCM via Internet Protocol, Bundesamt für Kartographie und Geodäsie, http://igs.bkg.bund.de/ntrip/ntriphomepage (accessed Jan 2010).

Brown, N., Kealy, A., Millner, J., Ramm, P. and Williamson, I. (2002) Quality control and integrity monitoring of the Victorian GPS reference station network, Proceedings of XXII FIG International Congress, Washington, DC, 19-26 April, 13pp.

Chalmers (2009) Free ocean tide loading provider, http://www.oso.chalmers.se/~loading/ (accessed Jan 2010).

Constell (2009) MATLAB: Constell GNSS toolbox, http://www.constell.org/ (accessed Jan 2010).

Dach, R., Hugentobler, U., Fridez, P. and Meindl, M. (2007) Bernese GPS Software Version 5.0, Astronomical Institute, University of Bern.

Dawson, J. and Steed, J. (2004) International Terrestrial Reference Frame (ITRF) to GDA94 coordinate transformations, http://www.ga.gov.au/image_cache/GA3795.pdf (accessed Jan 2010).

Featherstone, W.E., Kirby, J.F., Kearsley, A.H.W., Gilliland, J.R., Johnston, G.M., Steed, J., Forsberg, R. and Sideris, M.G. (2001) The AUSGeoid98 geoid model of Australia: Data treatment, computations and comparisons with GPS-levelling data, *Journal of Geodesy*, 75(5-6), 313-330.

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   16/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

Ferland, R. (2006) IGSMAIL-5447: Proposed IGS05 realization, 19 Oct 2006.

GA (2009a) AUSPOS – Online GPS Processing Service, http://www.ga.gov.au/geodesy/sgc/wwwgps/ (accessed Jan 2010).

GA (2009b) Australian Regional GPS Network, http://www.ga.gov.au/geodesy/argn/ (accessed Jan 2010).

GA (2009c) National Geospatial Reference System, http://www.ga.gov.au/ngrs/ (accessed Jan 2010).

Hale, M. and Ramm, P. (2007) GPSnet – Current and future developments in GNSS CORS network management and service delivery, Proceedings of SSC2007, Hobart, Australia, 14-18 May, 142-151.

Hale, M., Ramm, P. and Wallace, J. (2007) Legal positions and Victoria's GPSnet, Proceedings of SSC2007, Hobart, Australia, 14-18 May, 163-176.

ICSM (2009) Geocentric Datum of Australia technical manual, version 2.3, http://www.icsm.gov.au/gda/gdatm/gdav2.3.pdf (accessed Jan 2010).

IERS (2005) ITRF2005 station positions at epoch 2000.0 and velocities, http://itrf.ensg.ign.fr/ITRF_solutions/2005/doc/ITRF2005_GPS.SSC.txt (accessed Jan 2010).

IGN (2009) Transformation parameters from ITRF2005 to ITRF2000, http://itrf.ensg.ign.fr/ITRF_solutions/2005/tp_05-00.php (accessed Jan 2010).

IGS (2009) International GNSS Service, http://igscb.jpl.nasa.gov/ (accessed Jan 2010).

Janssen, V. (2009a) Understanding coordinate systems, datums and transformations in Australia, Proceedings of SSC2009, 28 Sep - 2 Oct, Adelaide, Australia, 697-715.

Janssen, V. (2009b) Precision rules! How to establish an AusCORS site, *Position Magazine*, 44, 64-66.

Janssen, V., White, A. and Yan, T. (2010) CORSnet-NSW: Towards state-wide CORS infrastructure for New South Wales, Australia, Proceedings of XXIV FIG International Congress 2010, Sydney, Australia, 11-16 April, 14pp.

Kouba, J. (2009) A guide to using International GNSS Service (IGS) products, http://igscb.jpl.nasa.gov/components/usage.html (accessed Jan 2010).

Land Victoria (2010) GPSnet, http://www.land.vic.gov.au/GPSnet (accessed Jan 2010).

LPMA (2009).CORSnet-NSW station summary, version 10 Sep 2009, http://sydnet.lands.nsw.gov.au/gsp/sydnet/StnSummary.pdf (accessed Oct 2009).

LPMA (2010) CORSnet-NSW, http://corsnet.lpma.nsw.gov.au/ (accessed Jan 2010).

Ng, A.H-M., Chang, H-C., Zhang, K., Ge, L. and Rizos, C. (2009) Land subsidence monitoring in Australia and China using satellite interferometry, in Sideris, M.G. (Ed.) *Observing Our Changing Earth*, IAG Symposia, Vol. 133, Springer, 743-750.

Penna, N., Lo, J., Luton, G. (2005) Geodetic Analysis of Land Victoria's GPSnet, *Journal of Spatial Science*, 50 (1), 45-57.

Ramm, P. and Hale, M. (2004) Realisation of the geodetic datum in Victoria, Proceedings of GNSS 2004, Sydney, Australia, 6-8 December, 14pp.

Ray, J., Dong, D. and Altamimi, Z. (2004) IGS reference frames: Status and future improvements, *GPS Solutions*, 8(4), 251-266.

Rizos, C., Yan, T., Omar, S., Musa, T. and Kinlyside, D. (2003) Implementing network-RTK: The SydNET CORS infrastructure, Proceedings of SatNav 2003, Melbourne, Australia, 22-25 July, 12pp.

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   17/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

Roberts, C., McElroy, S., Kinlyside, D., Yan, T., Jones, G., Allison, S., Hendro, F. and Hoffman, S. (2007) Centimetres across Sydney: First results from the SydNET CORS network, Proceedings of SSC2007, Hobart, Australia, 14-18 May, 152-161.

Roberts, C., Zhang, K., Rizos, C., Kealy, A., Ge, L., Ramm, P., Hale, M., Kinlyside, D. and Harcombe, P. (2004) Improved atmospheric modelling for large scale high-precision positioning based on GNSS CORS networks in Australia, *Journal of Global Positioning Systems*, 3 (1-2), 218-225.

Stanaway, R. and Roberts, C. (2009) A simplified parameter transformation model from ITRF2005 to any static geocentric datum (e.g. GDA94), Proceedings of IGNSS2009, Surfers Paradise, Australia, 1-3 December, 15pp.

Tregoning, P. (2003) Is the Australian Plate deforming? A space geodetic perspective, *Geological Society of America Special Papers*, 372, 41-48.

White, A., Yan, T., Janssen, V. and Yates, K. (2009) CORSnet-NSW: Delivering a state-of-the-art CORS network for New South Wales, Proceedings of IGNSS2009, Surfers Paradise, Australia, 1-3 December, 7pp.

Yousufi, S.H., Asmussen, H., Zhang, K. and Ramm, P. (2006) Temporal variation of the Victorian GPSnet base stations, Proceedings of IGNSS 2006, Surfers Paradise, Australia, 17-21 July, 15pp.

Zhang, K., Hu, Y., Liu, G. Deakin, R. Wu, F. (2005) Deformation monitoring and analysis using Victorian regional CORS data, *Journal of Global Positioning Systems*, 4 (1-2), 129-138.

Zhang, K., Wu, F., Wu, S., Rizos, C., Lim, S., Roberts, C., Ge, L. and Kealy, A. (2007) The latest development of a state-wide GNSS network-based RTK system in Australia, Proceedings of ION GNSS 2007, Fort Worth, Texas, 25-28 September, 699-707.

BIOGRAPHICAL NOTES

Joel Haasdyk is a recent graduate from the University of New South Wales, and the recipient of the New South Wales Surveyor General Scholarship. Previously involved in biological research and publication at the micro-level, Joel has changed focus to analysis on the macro-scale with a focus on GNSS and earth-monitoring. He is currently employed at the NSW Land and Property Management Authority in Bathurst, Australia to assist with the establishment of the expanding CORSnet-NSW network and the automated monitoring of this infrastructure using the *Bernese* software.

Craig Roberts is a Senior Lecturer in Surveying/GPS/Geodesy at the University of New South Wales (UNSW), Sydney, Australia. He holds a Bachelor of Surveying from the University of South Australia and a PhD in GPS for volcano monitoring from UNSW. He has worked as a private surveyor in Adelaide, a Geodetic Engineer at UNAVCO, USA involved with GPS for geodynamic studies in Nepal, Ethiopia, Argentina and Indonesia, a Geodetic Engineer at the GeoForschungsZentrum, Germany and lectured at RMIT University, Melbourne. His current research interests involve leveraging CORS infrastructure for practical application to surveying and spatial information.

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   18/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010

Volker Janssen is a GNSS Surveyor (CORS Network) in the Survey Infrastructure and Geodesy branch at the NSW Land and Property Management Authority in Bathurst, Australia. He holds a Dipl.-Ing. (MSc) in Surveying from the University of Bonn, Germany, and a PhD in GPS for deformation monitoring from the University of New South Wales (UNSW). He worked as an assistant lecturer at UNSW and as graduate surveyor in Sydney before being a Lecturer in Surveying and Spatial Sciences at the University of Tasmania between 2004 and 2009. Volker's research interests are in the fields of geodesy and geodynamics, with an emphasis on GPS/GNSS studies and CORS networks.

CONTACTS

Joel Haasdyk
Survey Infrastructure & Geodesy
NSW Land and Property Management Authority
346 Panorama Avenue
Bathurst NSW 2795
AUSTRALIA
Tel. +61 2 6332 8485
Fax +61 2 6332 8479
Email: Joel.Haasdyk@lpma.nsw.gov.au
Web site: www.lpma.nsw.gov.au

Dr Craig Roberts
School of Surveying and Spatial Information Systems
The University of New South Wales
Sydney NSW 2052
AUSTRALIA
Tel. +61-2-9385 4464
Fax +61-2-9313 7493
Email: c.roberts@unsw.edu.au
Web site: www.gmat.unsw.edu.au

Dr Volker Janssen
Survey Infrastructure & Geodesy
NSW Land and Property Management Authority
346 Panorama Avenue
Bathurst NSW 2795
AUSTRALIA
Tel. +61-2-6332 8426
Fax +61-2-6332 8479
Email: Volker.Janssen@lpma.nsw.gov.au
Web site: www.lpma.nsw.gov.au

FS 1H – GNSS CORS Networks – Positioning Infrastructure, Analysis and Applications I   19/19
Joel Haasdyk, Craig Roberts and Volker Janssen
Automated Monitoring of CORSnet-NSW using the Bernese Software

FIG Congress 2010
Facing the Challenges – Building the Capacity
Sydney, Australia, 11-16 April 2010