Comparison of Community and Commercial DGPS Correction Sources in Tasmania, Australia

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Abstract

Differential Global Positioning System (DGPS) observations are utilised for a wide range of applications. Users take their accuracy requirements into consideration when selecting from available observables, either in real-time or in post-processed mode. These accuracy requirements range from metres to millimetres and are closely linked to economic considerations, since the cost of the necessary hardware varies significantly. This study investigates and compares several pseudo-range data sources available in Tasmania, Australia, either at a cost or free of charge. The quality of the differential data and correction sources is assessed by determining accuracy relative to the State's primary geodetic control network as a function of distance from reference receivers. Datum differences are routinely overlooked by practitioners utilising code measurements, hence we quantify how this affects the accuracy achievable with real-time pseudo-range based DGPS services. Simple coordinate shifts are proposed to effectively consider these datum differences in practice for sub-metre pseudo-range DGPS positioning in Tasmania. A comparison to the accuracy achievable with available carrier phase based correction data sources is also presented.

1 Introduction

Global Navigation Satellite System (GNSS) technology has become an integral part of a wide variety of industries such as agriculture, commercial shipping, forestry and emergency management. It is recognised that relative or differential GNSS techniques improve accuracies to levels required for more exact applications, such as land and engineering surveying and precise Geographic Information System (GIS) data capture (El-Rabbany, 2006). Various organisations around the world have set up the means to provide GNSS users with reference station data or differential corrections, either at a cost or free of charge, enabling users to acquire higher quality positions without the need for a second GNSS unit. Correction services vary greatly and can be utilised for single frequency pseudo-range, single frequency carrier phase or dual frequency carrier phase measurements. Data can be delivered in real-time by radio, telephone, internet or satellite broadcast, or reference station data files can be downloaded for post-processing at a later stage. Along with the rest of the world, Tasmania has developed the need for correction services and consequently private and public organisations have attempted to meet the needs of the local spatial community. Services are continuing to emerge around Australia, while existing services are being densified (i.e. Victoria's GPSnet) or extended to provide state-wide coverage in the future, e.g. Queensland's SunPOZ covering Brisbane and surrounds, NSW's SydNET covering the greater Sydney area and Western Australia's GPS Network Perth.

This study analyses the quality of Tasmania's commercial and community (free of charge) Global Positioning System (GPS) data sources. Data collected at a range of known class A (1st order) points across the State are used to compare the data sources in terms of the coordinate quality they provide. Of additional interest to practitioners are the effects of often ignored datum transformations on pseudo-range based differential GPS positioning.

2 Correction Sources available in Tasmania

Several continuously operating reference stations (CORS) are operating in Tasmania, providing a range of GPS data or correction sources. GPS reference station data are either made available in post-processing mode to differentially correct the user data post survey or are converted to real-time corrections that can be immediately applied in the field, provided the user is equipped with the required hardware. In this paper, we refer to both as correction sources. The type of differential GPS corrections varies considerably, incorporating the use of a single post-processed reference station, a single (code-based) real-time reference station correction, and a real-time Wide Area Differential GPS (WADGPS) correction. Practitioners are able to choose a particular method or service based on the accuracy specifications, productivity considerations and whether positions are required in real-time.

Geoscience Australia (GA) is the federal government organisation responsible for managing the Australian geospatial infrastructure, including the Australian Fiducial Network (AFN) and the Australian Regional GPS Network (ARGN). In Tasmania, this includes a continuously operating, high-quality, geodetic dual frequency GPS receiver near Cambridge (Hob2). Additional sites in Burnie, Liawenee and Spring Bay are currently being established as part of the National Collaborative Research Infrastructure Strategy (NCRIS) initiative (AuScope, 2006) and are expected to be operational by the end of 2008. GPS data collected at 1-second intervals are stored in RINEX format at 15-minute epochs on a ‘high rate’ file transfer protocol (FTP) website and are available at no cost. In addition, 30-second RINEX data are routinely available, e.g. via the GA website or from the Scripps Orbit and Permanent Array Centre (SOPAC) through a fully automated process to be utilised by commercial software packages such as Trimble Pathfinder Office or Leica GeoOffice. GA also provides the free AUSPOS online GPS processing service, generating high quality positions for static dual frequency data generally collected at 30-second intervals, for observation sessions of more than one hour (AUSPOS, 2008).

Commercial provider Ultimate Positioning operates two dual frequency GNSS reference stations in Hobart and Launceston (Ultimate Positioning, 2008). RINEX data are available for each site, at 5-second and 1-second collection rates, via individual restricted-access FTP websites. A real-time correction data stream is also available, currently restricted to Trimble users, via NTRIP (Networked Transport of RTCM via Internet Protocol) access but has not been utilised in this study.

The Hobart Port Authority maintains a ‘ProXR Community Base Station’ at Franklin Wharf. Single frequency GPS data (code and carrier phase) are collected at 5-second epochs and stored in 1-hour Trimble standard storage format (.ssf) files on the Hobart Port Authority website (http://www.tasports.com.au/infrastructure/gps.html). The data are available through a subscription or a casual usage fee.

The Australian Maritime Safety Authority (AMSA) operates a real-time single reference station DGPS correction service to improve GPS coordinates for commercial shipping in selected areas of the Australian coast. The real-time network consists of 16 individual reference stations, referenced to the WGS84 (NIMA, 2004). Corrections are transmitted on a different frequency for each reference station, ranging from 285 to 325 kHz (AMSA, 2007a). Figure 1 shows an approximate coverage map, illustrating a likelihood of receiving the Crib Point correction in Northern Tasmania.

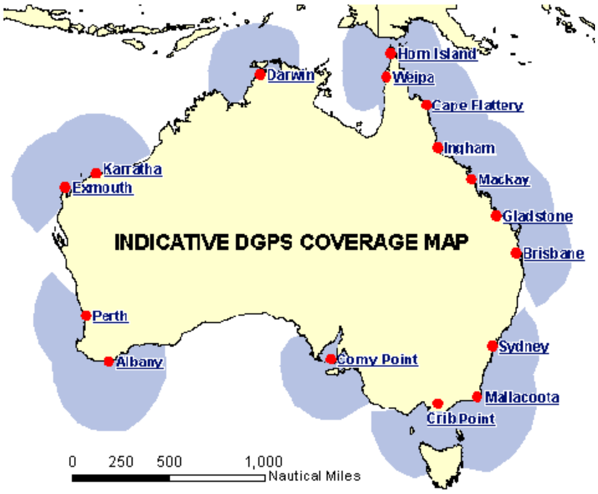

Figure 1: Coverage map of AMSA's DGPS service (AMSA, 2007a)

DGPS coverage generally reaches further over open water than inland, and 1-metre accuracy is achievable at each transmitter, with accuracy degrading by about one metre per 150 km away from the base station, although smaller degradation rates of 0.2 m per 100 km have been shown (Monteiro et al., 2005). Monitoring of AMSA's operational reference stations indicates that an accuracy of 2-4 m can be expected by a typical maritime DGPS receiver (AMSA, 2007a). The maritime reference stations compute the size and rate of range errors to each individual satellite, based on the known coordinates of the antenna and satellite. The corrections to these errors are then transmitted to the minimum shift keying (MSK) beacon, which is part of the GPS receiver, and applied to each range measured by the rover antenna.

Fugro's commercially available OmniSTAR virtual base station (VBS) service provides a real-time WADGPS correction, which is based on around 100 reference stations and allows more than 90% coverage worldwide (OmniSTAR, 2004). The VBS service is a measurement-domain WADGPS, which computes corrections for each GPS satellite based on data collected across a network of reference stations, rather than corrections based on only a single reference station as is the case for the AMSA service. These corrections are then transmitted to a geostationary communications satellite, which broadcasts the corrections over the network coverage area on an L-band frequency (El-Rabbany, 2006). A compatible receiver must therefore be an OmniSTAR-enabled unit, which can be set to a given satellite's frequency.

OmniSTAR's code-based WADGPS VBS technology provides sub-metre accuracy at 95% confidence for applications such as agriculture, GIS data capture and photogrammetry (OmniSTAR, 2004). For more precise applications, a dual frequency GPS augmentation service at decimetre-level accuracy is provided. It has been shown that this OmniSTAR-HP (high performance) service offers positioning accuracies of 10 cm and 15 cm in the horizontal and vertical components (95% confidence), respectively (Lapucha et al., 2004). Since January 2007, all corrections are calculated in the International Terrestrial Reference Frame 2005 (ITRF2005), i.e. the user positions will also be given with respect to this datum. Figure 2 shows the coverage area of OmniSTAR's Australian satellite, the reference stations involved and the distances from Hobart to each reference station within a 2000 km radius. This study utilises the VBS service provided by OmniSTAR.

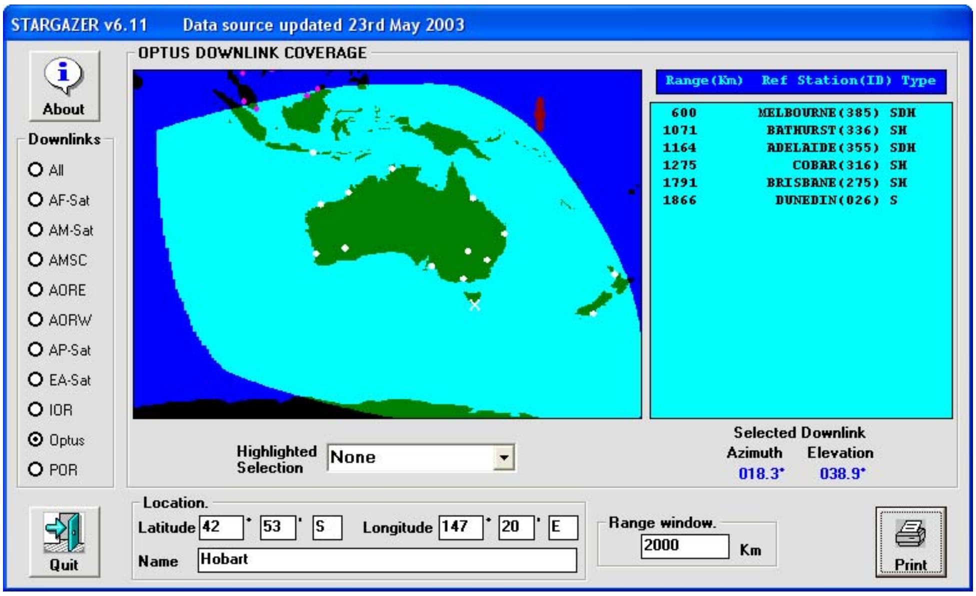

Figure 2: Coverage of OmniSTAR's Australian satellite and reference stations involved, visualised using the Stargazer software (OmniSTAR, 2008)

3 Datum Considerations

The ITRF is the most precise earth-centred earth-fixed terrestrial datum currently available, realised by an extensive global network of accurate coordinates based on the Geodetic Reference System 1980 (GRS80) ellipsoid and derived from geodetic observations using GPS, Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Lunar Laser Ranging (LLR) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). The ITRF is a dynamic datum and changes according to temporal variations of coordinates and their velocities due to the effects of crustal motion, earth orientation, polar motion and other geophysical phenomena such as earthquakes and volcanic activity (Bock, 1998). ITRF is now sufficiently refined to ensure that the change between successive realisations is in the order of 1-2 cm. Transformation parameters between the current ITRF2005 (Altamimi et al., 2007) and previous realisations are available from the ITRF website (http://itrf.ensg.ign.fr/trans_para.php).

The World Geodetic System 1984 (WGS84) datum was developed for the United States Defense Mapping Agency (DMA), later named NIMA (National Imagery and Mapping Agency) and now called NGA (National Geospatial-Intelligence Agency), and is the nominal datum used by GPS (NIMA, 2004). It is based on the WGS84 ellipsoid which only exhibits a small difference in the flattening parameter compared to the GRS80 and therefore both ellipsoids can be assumed identical for most practical purposes. The WGS84 datum has been refined several times to be closely aligned with the ITRF in order to prevent degradation of the GPS broadcast ephemerides due to plate tectonics. The latest refinement, known as WGS84 (G1150), was implemented in GPS week 1150 (20 January 2002) based on 15 days of GPS data collected during February 2001 at six Air Force monitoring stations, 11 NIMA stations and several additional global tracking stations. After this alignment with the ITRF2000, it was shown that the WGS84 coincides with the ITRF within a few centimetres at the global level (Merrigan et al., 2002). For all mapping and charting purposes with accuracy requirements at the 10 cm level, the WGS84 and the most current ITRF can therefore be assumed identical (NIMA, 2004). However, it should be noted that the level of agreement worsens as the time gap between WGS84 (G1150) and the latest realisation of ITRF grows.

The Australian geospatial infrastructure is currently referenced to the Geocentric Datum of Australia 1994 (GDA94), a fixed datum adopted by the Intergovernmental Committee on Surveying and Mapping (ICSM) that does not account for tectonic motion (ICSM, 2002). The GDA94 was defined in the ITRF92 datum at epoch 1994.0 (1 January 1994) and has since been assumed fixed (i.e. stationary). Due to the drift of the Australian continent (~ 7 cm to the north-north-east per year), the difference between absolute ITRF/WGS84 coordinates and GDA94 coordinates increases over time. For differential GPS applications within Australia this is not an issue, as both ends of a baseline move at the same rate. For most practical applications with an accuracy requirement of only a metre, it has previously been assumed that absolute GDA94 coordinates can be considered the same as ITRF/WGS84 (Steed & Luton, 2000). However, this assumption will soon cease to be valid since the effect of tectonic motion since 1994.0 will amount to about 1 metre in 2008. For applications where an accuracy of better than a metre is required, the difference needs to be taken into account via a standard 7-parameter similarity transformation (consisting of 3 origin shifts, 3 rotations and 1 scale change) from either WGS84 or the most recent ITRF to GDA94. Transformation parameters are regularly calculated from the known GDA94 and continually updated ITRF positions of the ARGN (Dawson & Steed, 2004).

This study therefore accommodates three different datums (GDA94, WGS84 and ITRF2005), all producing slightly different coordinates for a given point. The usual situation faced by Australian GNSS users is to relate GPS-derived positions to other spatial or mapping products given in the GDA94. Both the AMSA and OmniSTAR real-time correction service providers make recommendations to users in regards to datum transformations (AMSA, 2007a, 2007b; OmniSTAR, 2005). In practice however, when accuracies at the metre-level are required, all three datums are generally considered to be the same and datum transformations are not applied by practitioners. This study shows that this assumption is not valid.

4 Methodology

4.1 Control Network

The performance of the different correction sources was assessed by comparing derived coordinates against nine State Permanent Marks (SPMs), evenly distributed across Tasmania, with coordinates given in the GDA94. Only class A (1st order) control marks were considered in order to provide the best available ground truth. Class A marks are established by the Department of Primary Industries and Water (DPIW) as part of state geodetic surveys, and the 1st order classification stipulates that a 95% confidence interval of 22 mm applies (horizontally).

In Australia, vertical control coordinates are referenced to the Australian Height Datum (AHD). The majority of class A marks used in this study were coordinated to a 3rd order height component, i.e. with a 95% confidence interval of 50 mm. While this accuracy is sufficient for comparison with DGPS-derived heights, it should be noted that the quality of the GPS height analysis will be reduced by any inaccuracies in the AUSGeoid98 geoid model (Featherstone et al., 2001) which is utilised to convert GPS-derived ellipsoidal heights to orthometric AHD heights. However, since the vertical component is a lot less critical for most DGPS applications, this study mainly concentrates on the horizontal component.

All SPMs adopted were easily accessible, free of triangulation beacons and located in a multipath-free environment. All marks were stainless steel pins in bedrock, with the exception of ST1087 and ST1116, which were several-metre long steel rods. Figure 3 shows the location of the control marks used in this study.

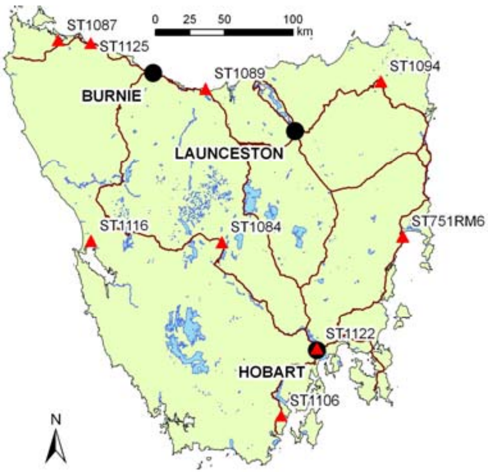

Figure 3: Location of control marks adopted (map created from data provided by Geoscience Australia)

4.2 Equipment

Trimble's Pathfinder Pro XRS L1 carrier smoothed DGPS unit with integrated MSK radio beacon was used for the collection of pseudo-range (C/A code) data. This unit was chosen as it has the capacity to receive and apply both the OmniSTAR real-time corrections on the L1 frequency and AMSA's real-time radio-based corrections. A Trimble Recon handheld computer was used as a data collector, via the TerraSync software.

In order to allow a comparison with carrier phase based positioning performance using single and dual frequency processing over relatively long distances, carrier phase data were collected using a Leica System 300 dual frequency GPS receiver, which included a Leica AT202 antenna (with ground plane).

4.3 Data Acquisition

GPS data were collected between 7-10 March and 21-23 March 2008. The equipment was used in static mode with the antenna attached to a calibrated tribrach on a tripod. At each of the nine control sites the Trimble Pro XRS antenna was positioned over the SPM. The following standard settings were used during code data collection: 15° elevation mask, 1-second sampling rate, and maximum PDOP of 4. Data were collected in 40-minute (i.e. 2400-epoch) periods for each available real-time correction source as well as uncorrected data. OmniSTAR's satellite-based VRS service was available at all sites, while AMSA's single reference station transmission was available at all sites with the exception of ST1106 at Dover (the most southerly site visited). Dual frequency carrier phase data were then collected using the Leica AT202 antenna set up over the same SPM for 1 hour (i.e. 3600 epochs), again using standard settings. Typical satellite geometry conditions were encountered during data collection, i.e. the number of GPS satellites varied between 6 and 8 at all sites and PDOP values generally ranged between 2 and 4. Unfortunately, logistical considerations prevented simultaneous data collection at the control points. However, the satellite constellations encountered were deemed similar enough for the purposes of this study. In order to investigate the performance of post-processed DGPS, data were also obtained from the four reference stations Hob2, Hobart Port, Ult. Hobart and Ult. Launceston.

4.4 Processing the Code Data

Code data were processed using the Trimble Pathfinder Office version 4.00 software. In addition to utilising the real-time DGPS services provided by AMSA and OmniSTAR, field data were differentially corrected against the files collated from each of the four reference stations. The Differential Correction Wizard was used with the following standard settings: standard pseudo-range processing only, corrected only output, unfiltered data processing, data collection filters as stated above, and no re-correction of real-time corrected positions. It should be noted that the software interpolated the 5-second data from the Hobart Port reference station in order to produce positions at 1-second epochs for the rover sites, which is likely to have caused slight reductions in coordinate quality.

Following the correction process for each site using each correction method, the resulting positions were automatically projected into Universal Transverse Mercator (UTM) grid coordinates to generate time series of grid coordinates and their 99% 'precisions' (confidence intervals) as determined by the software. Since all code processing was completed using a single software package, the precision values serve as a good statistic for relative comparison. The analysis of the vertical component was based on AHD heights.

4.5 Processing the Carrier Phase Data

For surveying applications, carrier phase processing is required in order to meet the higher accuracy constraints. For comparison, carrier phase processing was performed based on available stand-alone reference stations. It is well known that recommended observation durations are dependent on baseline length, number of available satellites, equipment used and the positioning accuracy required. This study briefly compares alternatives for the processing of static data collected for a period of one hour.

Carrier phase data were processed with the Leica GeoOffice version 6.0 software using the L1 only, L1+L2, and L3 (ionosphere free) strategies. The coordinates of the three reference stations used (Hob2, Ult. Hobart and Ult. Launceston) were all given in the GDA94 and standard processing parameter settings were applied.

5 Results and Analysis

Pseudo-range results obtained using the different correction sources were compared, in both the horizontal and vertical components, to assess the achievable accuracy and precision. The analysis was extended to investigate accuracy and precision as a function of baseline length. In addition, carrier phase processing techniques were investigated in order to assess what level of accuracy can be achieved with currently available reference station infrastructure.

5.1 Comparison of Code Correction Sources

Accuracy. The accuracies of the results based on the different reference sources were determined by comparing the coordinate results to the survey control supplied by the SPMs. It should be noted that post-processed positions based on the reference stations Hob2, Ult. Hobart, Ult. Launceston and Hobart Port were obtained in the GDA94, corresponding directly to the datum of the SPMs. However, positions obtained through the AMSA and OmniSTAR real-time services were referenced to the ITRF/WGS84. As mentioned earlier, this study aims to determine whether these positions can be considered equivalent to GDA94 positions within accuracy specifications. Table 1 lists the (unsigned) accuracies obtained for the correction sources investigated.

Table 1. Accuracies produced by code correction sources

Correction Source	Mean Horizontal Accuracy (m)	Mean Vertical Accuracy (m)
Ult. Launceston	0.105 ± 0.059	0.331 ± 0.166
Ult. Hobart	0.162 ± 0.081	0.240 ± 0.282
Hobart Port	0.261 ± 0.094	0.355 ± 0.402
Hob2	0.277 ± 0.113	0.321 ± 0.303
AMSA	0.702 ± 0.206	0.299 ± 0.386
OmniSTAR	0.888 ± 0.194	0.425 ± 0.579
Uncorrected	0.992 ± 0.297	2.259 ± 1.708

The mean accuracy was calculated across all nine control sites to assess the likely accuracy state-wide. The standard deviation represents the deviation of accuracy values across the nine control sites. The uncorrected coordinate time series was generated by single-epoch, pseudo-range based single point positioning. It should be noted that the vertical accuracy is based on the comparison of AHD heights, obtained by applying the AUSGeoid98 within the software. Figure 4a ranks the correction sources from most to least accurate, based on the horizontal component. Error bars are included for both components but not always visible.

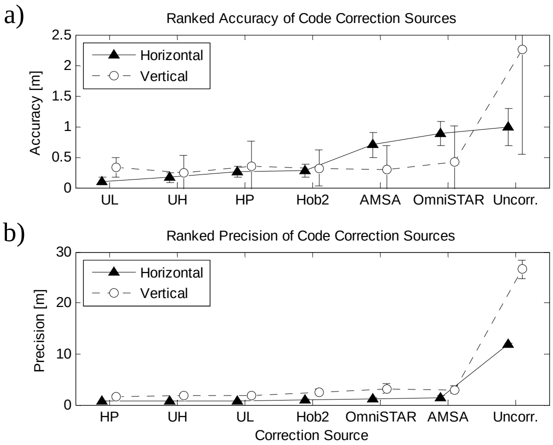

Figure 4: Ranked code correction sources: (a) accuracy and (b) precision estimates (HP = Hobart Port, UH = Ult. Hobart, UL = Ult. Launceston)

The accuracy statistics are similar for all post-processed reference station providers, producing mean accuracies of less than ±0.5 m in both components, which suggests that all provide sufficient accuracies to meet the differential pseudo-range needs of users (usually <1 m). Ultimate Positioning's reference station at Launceston provides slightly more accurate results in the horizontal component, which can possibly be attributed to its more central location within the control network. In regards to the two real-time sources, it is noticeable that the horizontal accuracy is comparable to that of uncorrected observations, while the vertical accuracy is at the same level as the post-processed sources and of a significantly higher standard than the horizontal component thus indicating the anticipated datum discrepancy.

In spite of ignoring datum differences, AMSA positions meet accuracy specifications (2-4 m). However, at times OmniSTAR positions fall just outside their more stringent specifications (<1 m), indicating that datum transformations need to be taken into account at this accuracy level.

Precision. The 99% precision estimates obtained for each reference station provider are software generated values, calculated using an algorithm that takes into account factors such as DOP values, number of satellites and receiver type. These estimates indicate that the position is within the stated distance of the most likely value with 99% probability and are sufficient for direct comparison in a relative sense. The values listed in Table 2 were calculated as the mean across all nine control sites. Figure 4b ranks the correction sources from most to least precise, based on the horizontal component.

Table 2. Precisions produced by code correction sources

Correction Source	Mean Horizontal Precision (m)	Mean Vertical Precision (m)
Hobart Port	0.653 ± 0.117	1.628 ± 0.391
Ult. Hobart	0.705 ± 0.117	1.792 ± 0.401
Ult. Launceston	0.714 ± 0.069	1.846 ± 0.188
Hob2	1.047 ± 0.114	2.551 ± 0.459
OmniSTAR	1.268 ± 0.189	3.170 ± 1.014
AMSA	1.418 ± 0.312	2.990 ± 0.833
Uncorrected	11.883 ± 0.171	26.616 ± 1.794

As expected, precisions for uncorrected data are poor, and the small standard deviation value suggests that this is the case across all control sites. The post-processed reference station sources produce similar results, indicating that precisions at the 1-metre level are achievable in the horizontal component with 99% confidence. Interestingly, the Hob2 results do not quite match the quality of the other sources, and it is noticeable that the real-time services show lower precisions than the post-processed correction sources.

Distance from reference source. This study encompassed GPS data collected at sites evenly distributed across Tasmania, with baseline lengths ranging from 1 km to 295 km. As expected, a degradation of coordinate quality with increasing distance from the reference station is clearly visible (Figure 5).

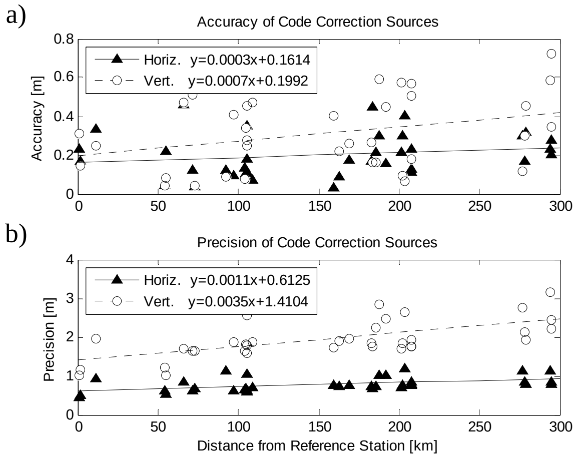

Figure 5: Degradation of position quality with increasing baseline length: (a) accuracy and (b) precision estimates based on post-processed correction sources

The linear trends determined based on the post-processed correction sources suggest that accuracy decreases by about 0.03 m and 0.07 m every 100 km away from the reference station in the horizontal and vertical component, respectively. Precision decreases by about 0.11 m in the horizontal and 0.35 m in the vertical component for every 100 km away from the correction source. The increasing uncertainty is mainly caused by the increasing effects of the ionosphere and the reduced effectiveness of the corrections to model these effects over longer baselines. It should be noted that statistically the linear regressions did not fit the data very well, documented by R^2 values of 0.35 and below (a value of 1.0 would indicate a perfect fit). This can be explained by the relatively small sample size and the fact that the nine state control marks were not occupied at the same time.

5.2 Carrier Phase Processing

If positions are required at or below the few-decimetre accuracy level, and post-processing is feasible, practitioners can utilise carrier phase GPS processing as an alternative. For comparison, the positions of the nine state control marks were determined utilising each of three reference stations (Hob2, Ult. Hobart and Ult. Launceston) and three different processing techniques: L1 only, L1+L2, and L3 (ionosphere free).

The effects of ionospheric disturbances generally limit L1 processing to shorter baselines and hinder ambiguity resolution over distances greater than 20 km (Hofmann-Wellenhof et al., 2001). Over longer distances it is therefore recommended to use the ionosphere free linear combination to eliminate most of the effect, however the resulting signal is noisier and the integer nature of the ambiguities may be lost depending on the ambiguity resolution strategy applied. Due to these disadvantages, the L3 processing technique is not recommended for baselines less than 20 km (El-Rabbany, 2006).

As expected, ambiguity resolution proved to be difficult at times since observation periods lasted only one hour and baseline lengths reached up to 295 km. The results confirm prior knowledge and are therefore not presented in detail here. It is evident that L1 solutions are suitable for short distances but perform poorly over longer baselines due to their inability to effectively account for ionospheric effects. On the other hand, L3 solutions are well suited for longer baselines but perform poorly over shorter distances because the attempt to model ionospheric variations over shorter baselines over-complicates actual conditions due to the high spatial correlation present. Since most baselines in this study exceed 50 km, the L3 technique generally provided the best results, i.e. higher accuracy and lower accuracy degradation over increasing distances. The results suggest that existing reference station infrastructure in Tasmania is currently able to provide positioning accuracies at the decimetre level state-wide based on post-processing of carrier phase data with observation sessions lasting one hour under typical conditions, provided ambiguity resolution is successful. However, it is well known that ambiguity resolution is often difficult to accomplish with limited data over long baselines.

Seven of the control sites used in this study were processed by Geoscience Australia's AUSPOS online service for comparison. The remaining two sites had to be excluded because slightly less than the minimum 60 minutes of data required by AUSPOS processing were collected at these sites. Accuracies of 0.07 ± 0.05 m and 0.17 ± 0.11 m were achieved in the horizontal and vertical component, respectively, showing that AUSPOS is able to deliver sub-decimetre horizontal accuracy across Tasmania for dual frequency observation periods of 1 hour.

While the Tasmanian spatial infrastructure will be improved with the establishment of three additional reference stations as part of the NCRIS strategy, thereby reducing the distances to available reference stations, accuracies required for surveying applications (1-2 cm) are very unlikely to be achievable with limited data without a further densification of the state network or the use of more sophisticated processing strategies utilising scientific GPS processing software.

6 Importance of Datum Transformations

Real-time GPS positioning is becoming increasingly popular for productivity gains and time-critical applications. The horizontal accuracies obtained with the OmniSTAR and AMSA real-time services appear to be inferior to the post-processed pseudo-range solutions. The relatively good precisions and height accuracies suggest that the difference in datums significantly reduced horizontal accuracies, at times seemingly to a level below specifications. This section discusses the importance of considering datum transformations if sub-metre pseudo-range positioning is required.

6.1 OmniSTAR

OmniSTAR reference station coordinates are based on the ITRF2005 and as such the corrected coordinates determined in the field are also referenced to ITRF2005 and not GDA94 (OmniSTAR, 2005). As previously mentioned, the ITRF2005 is a dynamic datum with an epoch attributed to its coordinates. OmniSTAR updates its reference station coordinates on a 6-monthly basis for realignment with the ITRF2005 by setting the coordinates to what they will be three months into the future (midpoint of the 6-month period, i.e. 1 April and 1 October). This ensures that the coordinates will only be incorrect by a maximum of three months or ~18 mm due to tectonic motion (OmniSTAR, 2005). Given the approximate movement of the Australian continent at 0.07 m/yr and the 14-year period since the GDA94 was fixed to the ITRF, the separation between the two datums is expected to approach 1 m in 2008. OmniSTAR (2005) informs its users that a similarity transformation is necessary in order to transform its positions from ITRF into GDA94 and frequently publishes the parameters required. Alternatively, these transformation parameters can easily be obtained from Dawson & Steed (2004) by applying the given rates to obtain parameters for the appropriate observation epoch.

Since the OmniSTAR correction service operates in real-time, field work reliant on it must be carried out in the ITRF or be transformed in real-time to GDA94 in order to fit with state control marks. In practice, it is generally preferred to calculate the difference in grid coordinates between ITRF and GDA94 to enable the implementation of a constant offset in real-time processing, e.g. within the Pathfinder GPS equipment. A Microsoft Excel spreadsheet was created based on spreadsheets contained in the GDA Technical Manual in order to recalculate coordinate shifts on a 6-monthly basis for pseudo-range applications with higher accuracy requirements (at the few-decimetre level). We calculated coordinate shifts that can be applied in Tasmania to minimise the datum error without the need for an integrated 7-parameter transformation (Table 3).

Table 3. Recommended datum shifts from ITRF2000/2005 to GDA94 grid coordinates in Tasmania

Period	Epoch	Easting (m)	Northing (m)
Jan – Jun 2008	2008.25	-0.247	-0.779
Jul – Dec 2008	2008.75	-0.255	-0.807
Jan – Jun 2009	2009.25	-0.262	-0.834
Jul – Dec 2009	2009.75	-0.270	-0.862
Jan – Jun 2010	2010.25	-0.278	-0.890
Jul – Dec 2010	2010.75	-0.286	-0.918

These datum shifts were calculated by transforming the coordinates of an arbitrary point, located in the centre of Tasmania, from ITRF2000 to GDA94 according to Dawson & Steed (2004). The resulting shifts were checked against coordinates around Tasmania, and it was established that differences in the shift vector across the State remain below 2 cm. The datum shifts are applicable to both ITRF2000 and ITRF2005 positions in Tasmania since the difference between these two frames introduces a positional error of less than 2 cm in the time period considered. It can therefore be assumed that the values listed in Table 3 are accurate to about 5 cm at the epoch stated.

It should be noted that these offset parameters should ideally be updated on a 6-monthly basis to coincide with OmniSTAR's datum updates. Applying the datum shifts for epoch 2008.25 to the data in this study improved the horizontal accuracy of the OmniSTAR service to 0.256 ± 0.112 m, which is well within the OmniSTAR specifications. This clearly shows that it is essential to consider the difference between datums if accuracies at the sub-metre level are sought. If this datum shift is ignored, users will need to expect that the specified accuracy level cannot be met.

6.2 AMSA

The AMSA DGPS reference station at Crib Point has been coordinated in the ITRF2000 (equivalent to WGS84) with an accuracy of 0.1 m (AMSA, 2007b) and as such the real-time corrections also produce ITRF/WGS84 coordinates at the roving receiver. This study found that the AMSA-corrected horizontal coordinates had an accuracy of 0.702 ± 0.206 m when compared to state survey control marks. This infers that the corrected coordinates of all nine sites were displaced by a similar amount, suggesting the datum difference was noticeable, although the error introduced was still within the provider's accuracy specifications of ±2-4 m. In order to improve accuracy when comparing AMSA-corrected DGPS positions against GDA94 coordinates, AMSA (2007b) recommends the ITRF2000 to GDA94 transformation described by Dawson & Steed (2004). Hence, the datum shifts listed in Table 3 can also be applied to the AMSA service. Applying the datum shifts for epoch 2008.25 to the data in this study improved the horizontal accuracy of the AMSA service to 0.251 ± 0.161 m, a value almost identical to the OmniSTAR results for the dataset analysed here. This clearly shows that accuracies significantly better than the specifications can be achieved by applying a simple coordinate shift between the datums. However, it should be noted that AMSA, contrary to OmniSTAR, does not guarantee sub-metre accuracies.

7 Concluding Remarks

This study compared differential pseudo-range and carrier phase reference sources provided by existing CORS sites in Tasmania. The accuracies and precisions of these providers were assessed against the State's primary geodetic control network and trends in regards to the distance between reference and rover receiver were determined. The importance of applying datum transformations if sub-metre accuracies are required was demonstrated.

In regards to pseudo-range correction sources, only a relatively small difference was found across the State between the post-processed solutions utilising a single reference station. Accuracies produced by these reference sources were all well below 0.5 m, easily meeting the accuracy specifications generally adopted for differential pseudo-range positioning (<1 m). It should be noted that commercial services guarantee data availability while community services do not. Linear trends in the degradation of accuracy and precision with respect to distance from the reference station were determined and showed that horizontal accuracies and precisions decrease by approximately 0.03 m and 0.11 m every 100 km. This suggests that remote areas of Tasmania up to few hundred kilometres from a reference source can obtain coordinates of sub-metre accuracy using any of the currently available reference stations. If real-time positions are required, both the OmniSTAR and AMSA services can be utilised, with accuracy specifications of sub-metre and 2-4 m, respectively. Both services have been shown to deliver accuracies at the few-decimetre level in Tasmania if datum transformations are applied. While ignoring datum shifts between the ITRF/WGS84 and GDA94 is acceptable in regards to meeting AMSA accuracy specifications, it will have a significant impact on OmniSTAR results, causing accuracy specifications to be exceeded at times.

Analysis of post-processed carrier phase processing results confirmed several aspects of carrier phase GPS processing. Single frequency data is suited for short baselines where ionospheric variation is highly correlated. Over longer baselines, the ionosphere free (L3) linear combination should be utilised due to its ability to greatly reduce the ionospheric effects between receivers. However, L3 processing is not suited for shorter baselines, due to its attempt to model an ionospheric effect that is highly correlated spatially. This study also demonstrated that AUSPOS can deliver sub-decimetre horizontal accuracy for observation periods of 1 hour under typical conditions.

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